

1 The GraphBLAS C API Specification †:

2 Version 2.1

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Chapter 1

Introduction

The GraphBLAS standard defines a set of matrix and vector operations based on semiring algebraic structures. These operations can be used to express a wide range of graph algorithms. This document defines the C binding to the GraphBLAS standard. We refer to this as the *GraphBLAS C API* (Application Programming Interface).

The GraphBLAS C API is built on a collection of objects exposed to the C programmer as opaque data types. Functions that manipulate these objects are referred to as *methods*. These methods fully define the interface to GraphBLAS objects to create or destroy them, modify their contents, and copy the contents of opaque objects into non-opaque objects; the contents of which are under direct control of the programmer.

The GraphBLAS C API is designed to work with C99 (ISO/IEC 9899:199) extended with *static type-based* and *number of parameters-based* function polymorphism, and language extensions on par with the `_Generic` construct from C11 (ISO/IEC 9899:2011). Furthermore, the standard assumes programs using the GraphBLAS C API will execute on hardware that supports floating point arithmetic such as that defined by the IEEE 754 (IEEE 754-2008) standard.

The GraphBLAS C API assumes programs will run on a system that supports acquire-release memory orders. This is needed to support the memory models required for multithreaded execution as described in section 2.5.2.

Implementations of the GraphBLAS C API will target a wide range of platforms. We expect cases will arise where it will be prohibitive for a platform to support a particular type or a specific parameter for a method defined by the GraphBLAS C API. We want to encourage implementors to support the GraphBLAS C API even when such cases arise. Hence, an implementation may still call itself “conformant” as long as the following conditions hold.

- Every method and operation from chapter 4 is supported for the vast majority of cases.
- Any cases not supported must be documented as an implementation-defined feature of the GraphBLAS implementation. Unsupported cases must be caught as an API error (section 2.6) with the parameter `GrB_NOT_IMPLEMENTED` returned by the associated method call.
- It is permissible to omit the corresponding nonpolymorphic methods from chapter 5 when it

301 is not possible to express the signature of that method.

302 The number of allowed omitted cases is vague by design. We cannot anticipate the features of target
303 platforms, on the market today or in the future, that might cause problems for the GraphBLAS
304 specification. It is our expectation, however, that such omitted cases would be a minuscule fraction
305 of the total combination of methods, types, and parameters defined by the GraphBLAS C API
306 specification.

307 The remainder of this document is organized as follows:

- 308 • Chapter 2: Basic Concepts
- 309 • Chapter 3: Objects
- 310 • Chapter 4: Methods
- 311 • Chapter 5: Nonpolymorphic interface
- 312 • Appendix A: Revision history
- 313 • Appendix B: Non-opaque data format definitions
- 314 • Appendix C: Examples

315 Chapter 2

316 Basic concepts

317 The GraphBLAS C API is used to construct graph algorithms expressed “in the language of linear
318 algebra.” Graphs are expressed as matrices, and the operations over these matrices are generalized
319 through the use of a semiring algebraic structure.

320 In this chapter, we will define the basic concepts used to define the GraphBLAS C API. We provide
321 the following elements:

- 322 • Glossary of terms and notation used in this document.
- 323 • Algebraic structures and associated arithmetic foundations of the API.
- 324 • Functions that appear in the GraphBLAS algebraic structures and how they are managed.
- 325 • Domains of elements in the GraphBLAS.
- 326 • Indices, index arrays, scalar arrays, and external matrix formats used to expose the contents
327 of GraphBLAS objects.
- 328 • The GraphBLAS opaque objects.
- 329 • The execution and error models implied by the GraphBLAS C specification.
- 330 • Enumerations used by the API and their values.

331 2.1 Glossary

332 2.1.1 GraphBLAS API basic definitions

- 333 • *application*: A program that calls methods from the GraphBLAS C API to solve a problem.
- 334 • *GraphBLAS C API*: The application programming interface that fully defines the types,
335 objects, literals, and other elements of the C binding to the GraphBLAS.

- 336 • *function*: Refers to a named group of statements in the C programming language. Methods,
337 operators, and user-defined functions are typically implemented as C functions. When refer-
338 ring to the code programmers write, as opposed to the role of functions as an element of the
339 GraphBLAS, they may be referred to as such.
- 340 • *method*: A function defined in the GraphBLAS C API that manipulates GraphBLAS objects
341 or other opaque features of the implementation of the GraphBLAS API.
- 342 • *operator*: A function that performs an operation on the elements stored in GraphBLAS
343 matrices and vectors.
- 344 • *GraphBLAS operation*: A mathematical operation defined in the GraphBLAS mathematical
345 specification. These operations (not to be confused with *operators*) typically act on matrices
346 and vectors with elements defined in terms of an algebraic semiring.

347 2.1.2 GraphBLAS objects and their structure

- 348 • *non-opaque datatype*: Any datatype that exposes its internal structure and can be manipu-
349 lated directly by the user.
- 350 • *opaque datatype*: Any datatype that hides its internal structure and can be manipulated
351 only through an API.
- 352 • *GraphBLAS object*: An instance of an *opaque datatype* defined by the *GraphBLAS C API*
353 that is manipulated only through the GraphBLAS API. There are four kinds of GraphBLAS
354 opaque objects: *domains* (i.e., types), *algebraic objects* (operators, monoids and semirings),
355 *collections* (scalars, vectors, matrices and masks), and descriptors.
- 356 • *handle*: A variable that holds a reference to an instance of one of the GraphBLAS opaque
357 objects. The value of this variable holds a reference to a GraphBLAS object but not the
358 contents of the object itself. Hence, assigning a value to another variable copies the reference
359 to the GraphBLAS object of one handle but not the contents of the object.
- 360 • *domain*: The set of valid values for the elements stored in a GraphBLAS *collection* or
361 operated on by a GraphBLAS *operator*. Note that some GraphBLAS objects involve functions
362 that map values from one or more input domains onto values in an output domain. These
363 GraphBLAS objects would have multiple domains.
- 364 • *collection*: An opaque GraphBLAS object that holds a number of elements from a specified
365 *domain*. Because these objects are based on an opaque datatype, an implementation of the
366 GraphBLAS C API has the flexibility to optimize the data structures for a particular platform.
367 GraphBLAS objects are often implemented as sparse data structures, meaning only the subset
368 of the elements that have values are stored.
- 369 • *implied zero*: Any element that has a valid index (or indices) in a GraphBLAS vector or
370 matrix but is not explicitly identified in the list of elements of that vector or matrix. From a
371 mathematical perspective, an *implied zero* is treated as having the value of the zero element of
372 the relevant monoid or semiring. However, GraphBLAS operations are purposefully defined

373 using set notation in such a way that it makes it unnecessary to reason about implied zeros.
374 Therefore, this concept is not used in the definition of GraphBLAS methods and operators.

375 • *mask*: An internal GraphBLAS object used to control how values are stored in a method's
376 output object. The mask exists only inside a method; hence, it is called an *internal opaque*
377 *object*. A mask is formed from the elements of a collection object (vector or matrix) input as
378 a mask parameter to a method. GraphBLAS allows two types of masks:

379 1. In the default case, an element of the mask exists for each element that exists in the
380 input collection object when the value of that element, when cast to a Boolean type,
381 evaluates to `true`.

382 2. In the *structure only* case, masks have structure but no values. The input collection
383 describes a structure whereby an element of the mask exists for each element stored in
384 the input collection regardless of its value.

385 • *complement*: The *complement* of a GraphBLAS mask, M , is another mask, M' , where the
386 elements of M' are those elements from M that *do not* exist.

387 2.1.3 Algebraic structures used in the GraphBLAS

388 • *associative operator*: In an expression where a binary operator is used two or more times
389 consecutively, that operator is *associative* if the result does not change regardless of the way
390 operations are grouped (without changing their order). In other words, in a sequence of binary
391 operations using the same associative operator, the legal placement of parenthesis does not
392 change the value resulting from the sequence operations. Operators that are associative over
393 infinitely precise numbers (e.g., real numbers) are not strictly associative when applied to
394 numbers with finite precision (e.g., floating point numbers). Such non-associativity results,
395 for example, from roundoff errors or from the fact some numbers can not be represented
396 exactly as floating point numbers. In the GraphBLAS specification, as is common practice
397 in computing, we refer to operators as *associative* when their mathematical definition over
398 infinitely precise numbers is associative even when they are only approximately associative
399 when applied to finite precision numbers.

400 No GraphBLAS method will imply a predefined grouping over any associative operators.
401 Implementations of the GraphBLAS are encouraged to exploit associativity to optimize per-
402 formance of any GraphBLAS method with this requirement. This holds even if the definition
403 of the GraphBLAS method implies a fixed order for the associative operations.

404 • *commutative operator*: In an expression where a binary operator is used (usually two or more
405 times consecutively), that operator is *commutative* if the result does not change regardless of
406 the order the inputs are operated on.

407 No GraphBLAS method will imply a predefined ordering over any commutative operators.
408 Implementations of the GraphBLAS are encouraged to exploit commutativity to optimize per-
409 formance of any GraphBLAS method with this requirement. This holds even if the definition
410 of the GraphBLAS method implies a fixed order for the commutative operations.

- 411 • *GraphBLAS operators*: Binary or unary operators that act on elements of GraphBLAS ob-
412 jects. *GraphBLAS operators* are used to express algebraic structures used in the GraphBLAS
413 such as monoids and semirings. They are also used as arguments to several GraphBLAS meth-
414 ods. There are two types of *GraphBLAS operators*: (1) predefined operators found in Table 3.5
415 and (2) user-defined operators created using `GrB_UnaryOp_new()` or `GrB_BinaryOp_new()`
416 (see Section 4.2.2).
- 417 • *monoid*: An algebraic structure consisting of one domain, an associative binary operator,
418 and the identity of that operator. There are two types of GraphBLAS monoids: (1) predefined
419 monoids found in Table 3.7 and (2) user-defined monoids created using `GrB_Monoid_new()`
420 (see Section 4.2.2).
- 421 • *semiring*: An algebraic structure consisting of a set of allowed values (the *domain*), a
422 commutative and associative binary operator called addition, a binary operator called mul-
423 tiplication (where multiplication distributes over addition), and identities over addition (0)
424 and multiplication (1). The additive identity is an annihilator over multiplication.
- 425 • *GraphBLAS semiring*: is allowed to diverge from the mathematically rigorous definition of
426 a *semiring* since certain combinations of domains, operators, and identity elements are useful
427 in graph algorithms even when they do not strictly match the mathematical definition of a
428 semiring. There are two types of *GraphBLAS semirings*: (1) predefined semirings found in
429 Tables 3.8 and 3.9, and (2) user-defined semirings created using `GrB_Semiring_new()` (see
430 Section 4.2.2).
- 431 • *index unary operator*: A variation of the unary operator that operates on elements of
432 GraphBLAS vectors and matrices along with the index values representing their location in
433 the objects. There are predefined index unary operators found in Table 3.6), and user-defined
434 operators created using `GrB_IndexUnaryOp_new` (see Section 4.2.2).

435 2.1.4 The execution of an application using the GraphBLAS C API

- 436 • *program order*: The order of the GraphBLAS method calls in a thread, as defined by the
437 text of the program.
- 438 • *host programming environment*: The GraphBLAS specification defines an API. The functions
439 from the API appear in a program. This program is written using a programming language
440 and execution environment defined outside of the GraphBLAS. We refer to this programming
441 environment as the “host programming environment”.
- 442 • *execution time*: time expended while executing instructions defined by a program. This
443 term is specifically used in this specification in the context of computations carried out on
444 behalf of a call to a GraphBLAS method.
- 445 • *sequence*: A GraphBLAS application uniquely defines a directed acyclic graph (DAG) of
446 GraphBLAS method calls based on their program order. At any point in a program, the
447 state of any GraphBLAS object is defined by a subgraph of that DAG. An ordered collection
448 of GraphBLAS method calls in program order that defines that subgraph for a particular
449 object is the *sequence* for that object.

- 450 • *complete*: A GraphBLAS object is complete when it can be used in a happens-before relation-
 451 ship with a method call that reads the variable on another thread. This concept is used when
 452 reasoning about memory orders in multithreaded programs. A GraphBLAS object defined on
 453 one thread that is complete can be safely used as an IN or INOUT argument in a method-call
 454 on a second thread assuming the method calls are correctly synchronized so the definition on
 455 the first thread *happens-before* it is used on the second thread. In blocking-mode, an object is
 456 complete after a GraphBLAS method call that writes to that object returns. In nonblocking-
 457 mode, an object is complete after a call to the `GrB_wait()` method with the `GrB_COMPLETE`
 458 parameter.

- 459 • *materialize*: A GraphBLAS object is materialized when it is (1) complete, (2) the compu-
 460 tations defined by the sequence that define the object have finished (either fully or stopped
 461 at an error) and will not consume any additional computational resources, and (3) any errors
 462 associated with that sequence are available to be read according to the GraphBLAS error
 463 model. A GraphBLAS object that is never loaded into a non-opaque data structure may
 464 potentially never be materialized. This might happen, for example, if the operations associ-
 465 ated with the object are fused or otherwise changed by the runtime system that supports the
 466 implementation of the GraphBLAS C API. An object can be materialized by a call to the
 467 `materialize` mode of the `GrB_wait()` method.

- 468 • *context*: An instance of the GraphBLAS C API implementation as seen by an application.
 469 An application can have only one context between the start and end of the application. A
 470 context begins with the first thread that calls `GrB_init()` and ends with the first thread to
 471 call `GrB_finalize()`. It is an error for `GrB_init()` or `GrB_finalize()` to be called more than one
 472 time within an application. The context is used to constrain the behavior of an instance of
 473 the GraphBLAS C API implementation and support various execution strategies. Currently,
 474 the only supported constraints on a context pertain to the mode of program execution.

- 475 • *program execution mode*: Defines how a GraphBLAS sequence executes, and is associated
 476 with the *context* of a GraphBLAS C API implementation. It is set by an application with
 477 its call to `GrB_init()` to one of two possible states. In *blocking mode*, GraphBLAS methods
 478 return after the computations complete and any output objects have been materialized. In
 479 *nonblocking mode*, a method may return once the arguments are tested as consistent with
 480 the method (i.e., there are no API errors), and potentially before any computation has taken
 481 place.

482 2.1.5 GraphBLAS methods: behaviors and error conditions

- 483 • *implementation-defined behavior*: Behavior that must be documented by the implementation
 484 and is allowed to vary among different compliant implementations.

- 485 • *undefined behavior*: Behavior that is not specified by the GraphBLAS C API. A conforming
 486 implementation is free to choose results delivered from a method whose behavior is undefined.

- 487 • *thread-safe*: Consider a function called from multiple threads with arguments that do not
 488 overlap in memory (i.e. the argument lists do not share memory). If the function is *thread-safe*

489 then it will behave the same when executed concurrently by multiple threads or sequentially
490 on a single thread.

491 • *dimension compatible*: GraphBLAS objects (matrices and vectors) that are passed as param-
492 eters to a GraphBLAS method are dimension (or shape) compatible if they have the correct
493 number of dimensions and sizes for each dimension to satisfy the rules of the mathematical def-
494 inition of the operation associated with the method. If any *dimension compatibility* rule above
495 is violated, execution of the GraphBLAS method ends and the GrB_DIMENSION_MISMATCH
496 error is returned.

497 • *domain compatible*: Two domains for which values from one domain can be cast to values in
498 the other domain as per the rules of the C language. In particular, domains from Table 3.2
499 are all compatible with each other, and a domain from a user-defined type is only compatible
500 with itself. If any *domain compatibility* rule above is violated, execution of the GraphBLAS
501 method ends and the GrB_DOMAIN_MISMATCH error is returned.

Notation	Description
$D_{out}, D_{in}, D_{in_1}, D_{in_2}$	Refers to output and input domains of various GraphBLAS operators.
$\mathbf{D}_{out}(*), \mathbf{D}_{in}(*),$ $\mathbf{D}_{in_1}(*), \mathbf{D}_{in_2}(*)$	Evaluates to output and input domains of GraphBLAS operators (usually a unary or binary operator, or semiring).
$\mathbf{D}(*)$	Evaluates to the (only) domain of a GraphBLAS object (usually a monoid, vector, or matrix).
f	An arbitrary unary function, usually a component of a unary operator.
$\mathbf{f}(F_u)$	Evaluates to the unary function contained in the unary operator given as the argument.
\odot	An arbitrary binary function, usually a component of a binary operator.
$\odot(*)$	Evaluates to the binary function contained in the binary operator or monoid given as the argument.
\otimes	Multiplicative binary operator of a semiring.
\oplus	Additive binary operator of a semiring.
$\otimes(S)$	Evaluates to the multiplicative binary operator of the semiring given as the argument.
$\oplus(S)$	Evaluates to the additive binary operator of the semiring given as the argument.
$\mathbf{0}(*)$	The identity of a monoid, or the additive identity of a GraphBLAS semiring.
$\mathbf{L}(*)$	The contents (all stored values) of the vector or matrix GraphBLAS objects. For a vector, it is the set of (index, value) pairs, and for a matrix it is the set of (row, col, value) triples.
503 $\mathbf{v}(i)$ or v_i	The i^{th} element of the vector \mathbf{v} .
$\mathbf{size}(\mathbf{v})$	The size of the vector \mathbf{v} .
$\mathbf{ind}(\mathbf{v})$	The set of indices corresponding to the stored values of the vector \mathbf{v} .
$\mathbf{nrows}(\mathbf{A})$	The number of rows in the \mathbf{A} .
$\mathbf{ncols}(\mathbf{A})$	The number of columns in the \mathbf{A} .
$\mathbf{indrow}(\mathbf{A})$	The set of row indices corresponding to rows in \mathbf{A} that have stored values.
$\mathbf{indcol}(\mathbf{A})$	The set of column indices corresponding to columns in \mathbf{A} that have stored values.
$\mathbf{ind}(\mathbf{A})$	The set of (i, j) indices corresponding to the stored values of the matrix.
$\mathbf{A}(i, j)$ or A_{ij}	The element of \mathbf{A} with row index i and column index j .
$\mathbf{A}(:, j)$	The j^{th} column of matrix \mathbf{A} .
$\mathbf{A}(i, :)$	The i^{th} row of matrix \mathbf{A} .
\mathbf{A}^T	The transpose of matrix \mathbf{A} .
$\neg\mathbf{M}$	The complement of \mathbf{M} .
$\mathbf{s}(\mathbf{M})$	The structure of \mathbf{M} .
$\tilde{\mathbf{t}}$	A temporary object created by the GraphBLAS implementation.
$\langle type \rangle$	A method argument type that is <code>void *</code> or one of the types from Table 3.2.
<code>GrB_ALL</code>	A method argument literal to indicate that all indices of an input array should be used.
<code>GrB_Type</code>	A method argument type that is either a user defined type or one of the types from Table 3.2.
<code>GrB_Object</code>	A method argument type referencing any of the GraphBLAS object types.
<code>GrB_NULL</code>	The GraphBLAS NULL.

2.3 Mathematical foundations

Graphs can be represented in terms of matrices. The values stored in these matrices correspond to attributes (often weights) of edges in the graph.¹ Likewise, information about vertices in a graph are stored in vectors. The set of valid values that can be stored in either matrices or vectors is referred to as their domain. Matrices are usually sparse because the lack of an edge between two vertices means that nothing is stored at the corresponding location in the matrix. Vectors may be sparse or dense, or they may start out sparse and become dense as algorithms traverse the graphs.

Operations defined by the GraphBLAS C API specification operate on these matrices and vectors to carry out graph algorithms. These GraphBLAS operations are defined in terms of GraphBLAS semiring algebraic structures. Modifying the underlying semiring changes the result of an operation to support a wide range of graph algorithms. Inside a given algorithm, it is often beneficial to change the GraphBLAS semiring that applies to an operation on a matrix. This has two implications for the C binding of the GraphBLAS API.

First, it means that we define a separate object for the semiring to pass into methods. Since in many cases the full semiring is not required, we also support passing monoids or even binary operators, which means the semiring is implied rather than explicitly stated.

Second, the ability to change semirings impacts the meaning of the *implied zero* in a sparse representation of a matrix or vector. This element in real arithmetic is zero, which is the identity of the *addition* operator and the annihilator of the *multiplication* operator. As the semiring changes, this implied zero changes to the identity of the *addition* operator and the annihilator (if present) of the *multiplication* operator for the new semiring. Nothing changes regarding what is stored in the sparse matrix or vector, but the implied zeros within them change with respect to a particular operation. In all cases, the nature of the implied zero does not matter since the GraphBLAS C API requires that implementations treat them as nonexistent elements of the matrix or vector.

As with matrices and vectors, GraphBLAS semirings have domains associated with their inputs and outputs. The semirings in the GraphBLAS C API are defined with two domains associated with the input operands and one domain associated with output. When used in the GraphBLAS C API these domains may not match the domains of the matrices and vectors supplied in the operations. In this case, only valid *domain compatible* casting is supported by the API.

The mathematical formalism for graph operations in the language of linear algebra often assumes that we can operate in the field of real numbers. However, the GraphBLAS C binding is designed for implementation on computers, which by necessity have a finite number of bits to represent numbers. Therefore, we require a conforming implementation to use floating point numbers such as those defined by the IEEE-754 standard (both single- and double-precision) wherever real numbers need to be represented. The practical implications of these finite precision numbers is that the result of a sequence of computations may vary from one execution to the next as the grouping of operands (because of associativity) within the operations changes. While techniques are known to reduce these effects, we do not require or even expect an implementation to use them as they may add

¹More information on the mathematical foundations can be found in the following paper: J. Kepner, P. Aaltonen, D. Bader, A. Buluç, F. Franchetti, J. Gilbert, D. Hutchison, M. Kumar, A. Lumsdaine, H. Meyerhenke, S. McMillan, J. Moreira, J. Owens, C. Yang, M. Zalewski, and T. Mattson. 2016, September. Mathematical foundations of the GraphBLAS. In *2016 IEEE High Performance Extreme Computing Conference (HPEC)* (pp. 1-9). IEEE.

Table 2.1: Types of GraphBLAS opaque objects.

GrB_Object types	Description
GrB_Type	Scalar type.
GrB_UnaryOp	Unary operator.
GrB_IndexUnaryOp	Unary operator, that operates on a single value and its location index values.
GrB_BinaryOp	Binary operator.
GrB_Monoid	Monoid algebraic structure.
GrB_Semiring	A GraphBLAS semiring algebraic structure.
GrB_Scalar	One element; could be empty.
GrB_Vector	One-dimensional collection of elements; can be sparse.
GrB_Matrix	Two-dimensional collection of elements; typically sparse.
GrB_Descriptor	Descriptor object, used to modify behavior of methods (specifically GraphBLAS operations).

542 considerable overhead. In most cases, these roundoff errors are not significant. When they are
 543 significant, the problem itself is ill-conditioned and needs to be reformulated.

544 2.4 GraphBLAS opaque objects

545 Objects defined in the GraphBLAS standard include types (the domains of elements), collections
 546 of elements (matrices, vectors, and scalars), operators on those elements (unary, index unary, and
 547 binary operators), algebraic structures (semirings and monoids), and descriptors. GraphBLAS
 548 objects are defined as opaque types; that is, they are managed, manipulated, and accessed solely
 549 through the GraphBLAS application programming interface. This gives an implementation of the
 550 GraphBLAS C specification flexibility to optimize objects for different scenarios or to meet the
 551 needs of different hardware platforms.

552 A GraphBLAS opaque object is accessed through its *handle*. A handle is a variable that references
 553 an instance of one of the types from Table 2.1. An implementation of the GraphBLAS specification
 554 has a great deal of flexibility in how these handles are implemented. All that is required is that the
 555 handle corresponds to a type defined in the C language that supports assignment and comparison
 556 for equality. The GraphBLAS specification defines a literal `GrB_INVALID_HANDLE` that is valid
 557 for each type. Using the logical equality operator from C, it must be possible to compare a handle
 558 to `GrB_INVALID_HANDLE` to verify that a handle is valid.

559 Every GraphBLAS object has a *lifetime*, which consists of the sequence of instructions executed
 560 in program order between the *creation* and the *destruction* of the object. The GraphBLAS C API
 561 predefines a number of these objects which are created when the GraphBLAS context is initialized
 562 by a call to `GrB_init` and are destroyed when the GraphBLAS context is terminated by a call to
 563 `GrB_finalize`.

564 An application using the GraphBLAS API can create additional objects by declaring variables of the
 565 appropriate type from Table 2.1 for the objects it will use. Before use, the object must be initialized

566 with a call call to one of the object’s respective *constructor* methods. Each kind of object has at
567 least one explicit constructor method of the form `GrB*_new` where ‘*’ is replaced with the type
568 of object (e.g., `GrB_Semiring_new`). Note that some objects, especially collections, have additional
569 constructor methods such as duplication, import, or deserialization. Objects explicitly created by
570 a call to a constructor should be destroyed by a call to `GrB_free`. The behavior of a program that
571 calls `GrB_free` on a pre-defined object is undefined.

572 These constructor and destructor methods are the only methods that change the value of a handle.
573 Hence, objects changed by these methods are passed into the method as pointers. In all other
574 cases, handles are not changed by the method and are passed by value. For example, even when
575 multiplying matrices, while the contents of the output product matrix changes, the handle for that
576 matrix is unchanged.

577 Several GraphBLAS constructor methods take other objects as input arguments and use these
578 objects to create a new object. For all these methods, the lifetime of the created object must
579 end strictly before the lifetime of any dependent input objects. For example, a vector constructor
580 `GrB_Vector_new` takes a `GrB_Type` object as input. That type object must not be destroyed until
581 after the created vector is destroyed. Similarly, a `GrB_Semiring_new` method takes a monoid and
582 a binary operator as inputs. Neither of these can be destroyed until after the created semiring is
583 destroyed.

584 Note that some constructor methods like `GrB_Vector_dup` and `GrB_Matrix_dup` behave differently.
585 In these cases, the input vector or matrix can be destroyed as soon as the call returns. However,
586 the original type object used to create the input vector or matrix cannot be destroyed until after
587 the vector or matrix created by `GrB_Vector_dup` or `GrB_Matrix_dup` is destroyed. This behavior
588 must hold for any chain of duplicating constructors.

589 Programmers using GraphBLAS handles must be careful to distinguish between a handle and the
590 object manipulated through a handle. For example, a program may declare two GraphBLAS objects
591 of the same type, initialize one, and then assign it to the other variable. That assignment, however,
592 only assigns the handle to the variable. It does not create a copy of that variable (to do that,
593 one would need to use the appropriate duplication method). If later the object is freed by calling
594 `GrB_free` with the first variable, the object is destroyed and the second variable is left referencing
595 an object that no longer exists (a so-called “dangling handle”).

596 In addition to opaque objects manipulated through handles, the GraphBLAS C API defines an
597 additional opaque object as an internal object; that is, the object is never exposed as a variable
598 within an application. This opaque object is the mask used to control which computed values can
599 be stored in the output operand of a *GraphBLAS operation*. Masks are described in Section 3.5.4.

600 2.5 Execution model

601 A program using the GraphBLAS C API is called a GraphBLAS application. The application con-
602 structs GraphBLAS objects, manipulates them to implement a graph algorithm, and then extracts
603 values from the GraphBLAS objects to produce the results for that algorithm. Functions defined
604 within the GraphBLAS C API that manipulate GraphBLAS objects are called *methods*. If the
605 method corresponds to one of the operations defined in the GraphBLAS mathematical specifica-

606 tion, we refer to the method as an *operation*.

607 The GraphBLAS application specifies an ordered collection of GraphBLAS method calls defined
608 by the order they appear in the text of the program (the *program order*). These define a directed
609 acyclic graph (DAG) where nodes are GraphBLAS method calls and edges are dependencies between
610 method calls.

611 Each method call in the DAG uniquely and unambiguously defines the output GraphBLAS objects
612 as long as there are no execution errors that put objects in an invalid state (see Section 2.6). An
613 ordered collection of method calls, a subgraph of the overall DAG for an application, defines the
614 state of a GraphBLAS object at any point in a program. This ordered collection is the *sequence*
615 for that object.

616 Since the GraphBLAS execution is defined in terms of a DAG and the GraphBLAS objects are
617 opaque, the semantics of the GraphBLAS specification affords an implementation considerable
618 flexibility to optimize performance. A GraphBLAS implementation can defer execution of nodes in
619 the DAG, fuse nodes, or even replace whole subgraphs within the DAG to optimize performance.
620 We discuss this topic further in section 2.5.1 when we describe *blocking* and *non-blocking* execution
621 modes.

622 A correct GraphBLAS application must be *race-free*. This means that the DAG produced by an
623 application and the results produced by execution of that DAG must be the same regardless of
624 how the threads are scheduled for execution. It is the application programmer's responsibility to
625 control memory orders and establish the required synchronized-with relationships to assure race-free
626 execution of a multi-threaded GraphBLAS application. Writing race-free GraphBLAS applications
627 is discussed further in Section 2.5.2.

628 2.5.1 Execution modes

629 The execution of the DAG defined by a GraphBLAS application depends on the *execution mode* of
630 the GraphBLAS program. There are two modes: *blocking* and *nonblocking*.

- 631 • *blocking*: In blocking mode, each method finishes the GraphBLAS operation defined by the
632 method and all output GraphBLAS objects are *materialized* before proceeding to the next
633 statement. Even mechanisms that break the opaqueness of the GraphBLAS objects (e.g.,
634 performance monitors, debuggers, memory dumps) will observe that the operation has fin-
635 ished.
- 636 • *nonblocking*: In nonblocking mode, each method may return once the input arguments have
637 been inspected and verified to define a well formed GraphBLAS operation. (That is, there
638 are no API errors; see Section 2.6.) The GraphBLAS method may not have finished, but the
639 output object is ready to be used by the next GraphBLAS method call. If needed, a call to
640 GrB_wait with GrB_COMPLETE or GrB_MATERIALIZE can be used to force the sequence
641 for a GraphBLAS object (obj) to finish its execution.

642 The *execution mode* is defined in the GraphBLAS C API when the context of the library invoca-
643 tion is defined. This occurs once before any GraphBLAS methods are called with a call to the

644 GrB_init() function. This function takes a single argument of type GrB_Mode with values shown
645 in Table 3.1(a).

646 An application executing in nonblocking mode is not required to return immediately after input
647 arguments have been verified. A conforming implementation of the GraphBLAS C API running
648 in nonblocking mode may choose to execute *as if* in blocking mode. A sequence of operations
649 in nonblocking mode where every GraphBLAS operation with output object `obj` is followed by a
650 GrB_wait(obj, GrB_MATERIALIZE) call is equivalent to the same sequence in blocking mode with
651 GrB_wait(obj, GrB_MATERIALIZE) calls removed.

652 Nonblocking mode allows for any execution strategy that satisfies the mathematical definition of
653 the sequence. The methods can be placed into a queue and deferred. They can be chained together
654 and fused (e.g., replacing a chained pair of matrix products with a matrix triple product). Lazy
655 evaluation, greedy evaluation, and asynchronous execution are all valid as long as the final result
656 agrees with the mathematical definition provided by the sequence of GraphBLAS method calls
657 appearing in program order.

658 Blocking mode forces an implementation to carry out precisely the GraphBLAS operations defined
659 by the methods and to complete each and every method call individually. It is valuable for debug-
660 ging or in cases where an external tool such as a debugger needs to evaluate the state of memory
661 during a sequence of operations.

662 In a sequence of operations free of execution errors, and with input objects that are well-conditioned,
663 the results from blocking and nonblocking modes should be identical outside of effects due to
664 roundoff errors associated with floating point arithmetic. Due to the great flexibility afforded to an
665 implementation when using nonblocking mode, we expect execution of a sequence in nonblocking
666 mode to potentially complete execution in less time.

667 It is important to note that, processing of nonopaque objects is never deferred in GraphBLAS.
668 That is, methods that consume nonopaque objects (e.g., GrB_Matrix_build(), Section 4.2.5.9) and
669 methods that produce nonopaque objects (e.g., GrB_Matrix_extractTuples(), Section 4.2.5.13) al-
670 ways finish consuming or producing those nonopaque objects before returning regardless of the
671 execution mode.

672 Finally, after all GraphBLAS method calls have been made, the context is terminated with a call
673 to GrB_finalize(). In the current version of the GraphBLAS C API, the context can be set only
674 once in the execution of a program. That is, after GrB_finalize() is called, a subsequent call to
675 GrB_init() is not allowed.

676 2.5.2 Multi-threaded execution

677 The GraphBLAS C API is designed to work with applications that utilize multiple threads executing
678 within a shared address space. This specification does not define how threads are created, managed
679 and synchronized. We expect the host programming environment to provide those services.

680 A conformant implementation of the GraphBLAS must be *thread safe*. A GraphBLAS library
681 is thread safe when independent method calls (i.e., GraphBLAS objects are not shared between
682 method calls) from multiple threads in a race-free program return the same results as would follow

683 from their sequential execution in some interleaved order. This is a common requirement in software
684 libraries.

685 Thread safety applies to the behavior of multiple independent threads. In the more general case
686 for multithreading, threads are not independent; they share variables and mix read and write
687 operations to those variables across threads. A memory consistency model defines which values
688 can be returned when reading an object shared between two or more threads. The GraphBLAS
689 specification does not define its own memory consistency model. Instead the specification defines
690 what must be done by a programmer calling GraphBLAS methods and by the implementor of a
691 GraphBLAS library so an implementation of the GraphBLAS specification can work correctly with
692 the memory consistency model for the host environment.

693 A memory consistency model is defined in terms of happens-before relations between methods in
694 different threads. The defining case is a method that writes to an object on one thread that is
695 read (i.e., used as an IN or INOUT argument) in a GraphBLAS method on a different thread. The
696 following steps must occur between the different threads.

- 697 • A sequence of GraphBLAS methods results in the definition of the GraphBLAS object.
- 698 • The GraphBLAS object is put into a state of completion by a call to `GrB_wait()` with the
699 `GrB_COMPLETE` parameter (see Table 3.1(b)). A GraphBLAS object is said to be *complete*
700 when it can be safely used as an IN or INOUT argument in a GraphBLAS method call from
701 a different thread.
- 702 • Completion happens before a synchronized-with relation that executes with *at least* a release
703 memory order.
- 704 • A synchronized-with relation on the other thread executes with *at least* an acquire memory
705 order.
- 706 • This synchronized-with relation happens-before the GraphBLAS method that reads the graph-
707 BLAS object.

708 We use the phrase *at least* when talking about the memory orders to indicate that a stronger
709 memory order such as *sequential consistency* can be used in place of the acquire-release order.

710 A program that violates these rules contains a data race. That is, its reads and writes are unordered
711 across threads making the final value of a variable undefined. A program that contains a data race
712 is invalid and the results of that program are undefined. We note that multi-threaded execution is
713 compatible with both blocking and non-blocking modes of execution.

714 Completion is the central concept that allows GraphBLAS objects to be used in happens-before
715 relations between threads. In earlier versions of GraphBLAS (1.X) completion was implied by
716 any operation that produced non-opaque values from a GraphBLAS object. These operations are
717 summarized in Table 2.2). In GraphBLAS 2.0, these methods no longer imply completion. This
718 change was made since there are cases where the non-opaque value is needed but the object from
719 which it is computed is not. We want implementations of the GraphBLAS to be able to exploit
720 this case and not form the opaque object when that object is not needed.

Table 2.2: Methods that extract values from a GraphBLAS object forced completion of the operations contributing to that particular object in GraphBLAS 1.X. In GraphBLAS 2.X, these methods *do not* force completion.

Method	Section
GrB_Vector_nvals	4.2.4.6
GrB_Vector_extractElement	4.2.4.10
GrB_Vector_extractTuples	4.2.4.11
GrB_Matrix_nvals	4.2.5.8
GrB_Matrix_extractElement	4.2.5.12
GrB_Matrix_extractTuples	4.2.5.13
GrB_reduce (vector-scalar value variant)	4.3.10.2
GrB_reduce (matrix-scalar value variant)	4.3.10.3

721 2.6 Error model

722 All GraphBLAS methods return a value of type GrB_Info (an enum) to provide information available
 723 to the system at the time the method returns. The returned value will be one of the defined values
 724 shown in Table 3.16. The return values fall into three groups: informational, API errors, and
 725 execution errors. While API and execution errors take on negative values, informational return
 726 values listed in Table 3.16(a) are non-negative and include GrB_SUCCESS (a value of 0) and
 727 GrB_NO_VALUE.

728 An API error (listed in Table 3.16(b)) means that a GraphBLAS method was called with parameters
 729 that violate the rules for that method. These errors are restricted to those that can be determined
 730 by inspecting the dimensions and domains of GraphBLAS objects, GraphBLAS operators, or the
 731 values of scalar parameters fixed at the time a method is called. API errors are deterministic and
 732 consistent across platforms and implementations. API errors are never deferred, even in nonblocking
 733 mode. That is, if a method is called in a manner that would generate an API error, it always
 734 returns with the appropriate API error value. If a GraphBLAS method returns with an API error,
 735 it is guaranteed that none of the arguments to the method (or any other program data) have
 736 been modified. The informational return value, GrB_NO_VALUE, is also deterministic and never
 737 deferred in nonblocking mode.

738 Execution errors (listed in Table 3.16(c)) indicate that something went wrong during the execution
 739 of a legal GraphBLAS method invocation. Their occurrence may depend on specifics of the exe-
 740 cution environment and data values being manipulated. This does not mean that execution errors
 741 are the fault of the GraphBLAS implementation. For example, a memory leak could arise from
 742 an error in an application’s source code (a “program error”), but it may manifest itself in different
 743 points of a program’s execution (or not at all) depending on the platform, problem size, or what
 744 else is running at that time. Index out-of-bounds errors, for example, always indicate a program
 745 error.

746 If a GraphBLAS method returns with any execution error other than GrB_PANIC, it is guaranteed
 747 that the state of any argument used as input-only is unmodified. Output arguments may be left in
 748 an invalid state, and their use downstream in the program flow may cause additional errors. If a

749 GraphBLAS method returns with a `GrB_PANIC` execution error, no guarantees can be made about
750 the state of any program data.

751 In nonblocking mode, execution errors can be deferred. A return value of `GrB_SUCCESS` only
752 guarantees that there are no API errors in the method invocation. If an execution error value is
753 returned by a method with output object `obj` in nonblocking mode, it indicates that an error was
754 found during execution of any of the pending operations on `obj`, up to and including the `GrB_wait()`
755 method (Section 4.2.8) call that completes those pending operations. When possible, that return
756 value will provide information concerning the cause of the error.

757 As discussed in Section 4.2.8, a `GrB_wait(obj)` on a specific GraphBLAS object `obj` completes all
758 pending operations on that object. No additional errors on the methods that precede the call to
759 `GrB_wait` and have `obj` as an `OUT` or `INOUT` argument can be reported. From a GraphBLAS
760 perspective, those methods are *complete*. Details on the guaranteed state of objects after a call to
761 `GrB_wait` can be found in Section 4.2.8.

762 After a call to any GraphBLAS method that modifies an opaque object, the program can re-
763 trieve additional error information (beyond the error code returned by the method) though a call
764 to the function `GrB_error()`, passing the method's output object as described in Section 4.2.9.
765 The function returns a pointer to a NULL-terminated string, and the contents of that string are
766 implementation-dependent. In particular, a null string (not a NULL pointer) is always a valid error
767 string. `GrB_error()` is a thread-safe function, in the sense that multiple threads can call it simul-
768 taneously and each will get its own error string back, referring to the object passed as an input
769 argument.

770 Chapter 3

771 Objects

772 In this chapter, all of the enumerations, literals, data types, and predefined opaque objects defined
773 in the GraphBLAS API are presented. Enumeration literals in GraphBLAS are assigned specific
774 values to ensure compatibility between different runtime library implementations. The chapter
775 starts by defining the enumerations that are used by the `init()` and `wait()` methods. Then a num-
776 ber of transparent (i.e., non-opaque) types that are used for interfacing with external data are
777 defined. Sections that follow describe the various types of opaque objects in GraphBLAS: types
778 (or *domains*), algebraic objects, collections and descriptors. Each of these sections also lists the
779 predefined instances of each opaque type that are required by the API. This chapter concludes with
780 a section on the definition for `GrB_Info` enumeration that is used as the return type of all methods.

781 3.1 Enumerations for `init()` and `wait()`

782 Table 3.1 lists the enumerations and the corresponding values used in the `GrB_init()` method to set
783 the execution mode and in the `GrB_wait()` method for completing or materializing opaque objects.

784 3.2 Indices, index arrays, and scalar arrays

785 In order to interface with third-party software (i.e., software other than an implementation of the
786 GraphBLAS), operations such as `GrB_Matrix_build` (Section 4.2.5.9) and `GrB_Matrix_extractTuples`
787 (Section 4.2.5.13) must specify how the data should be laid out in non-opaque data structures. To
788 this end we explicitly define the types for indices and the arrays used by these operations.

789 For indices a `typedef` is used to give a GraphBLAS name to a concrete type. We define it as follows:

```
790     typedef uint64_t GrB_Index;
```

791 The range of valid values for a variable of type `GrB_Index` is `[0, GrB_INDEX_MAX]` where the
792 largest index value permissible is defined with a macro, `GrB_INDEX_MAX`. For example:

793 `#define GrB_INDEX_MAX ((GrB_Index) 0xffffffffffffffff);`

794 An implementation is required to define and document this value.

795 An index array is a pointer to a set of `GrB_Index` values that are stored in a contiguous block of
796 memory (i.e., `GrB_Index*`). Likewise, a scalar array is a pointer to a contiguous block of memory
797 storing a number of scalar values as specified by the user. Some GraphBLAS operations (e.g.,
798 `GrB_assign`) include an input parameter with the type of an index array. This input index array
799 selects a subset of elements from a GraphBLAS vector or matrix object to be used in the operation.
800 In these cases, the literal `GrB_ALL` can be used in place of the index array input parameter to
801 indicate that all indices of the associated GraphBLAS vector or matrix object should be used. An
802 implementation of the GraphBLAS C API has considerable freedom in terms of how `GrB_ALL`
803 is defined. Since `GrB_ALL` is used as an argument for an array parameter, it must use a type
804 consistent with a pointer. `GrB_ALL` must also have a non-null value to distinguish it from the
805 erroneous case of passing a `NULL` pointer as an array.

806 3.3 Types (domains)

807 In GraphBLAS, domains correspond to the valid values for types from the host language (in our
808 case, the C programming language). GraphBLAS defines a number of operators that take elements
809 from one or more domains and produce elements of a (possibly) different domain. GraphBLAS
810 also defines three kinds of collections: matrices, vectors and scalars. For any given collection, the
811 elements of the collection belong to a *domain*, which is the set of valid values for the elements. For
812 any variable or object V in GraphBLAS we denote as $\mathbf{D}(V)$ the domain of V , that is, the set of
813 possible values that elements of V can take.

Table 3.1: Enumeration literals and corresponding values input to various GraphBLAS methods.

(a) `GrB_Mode` execution modes for the `GrB_init` method.

Symbol	Value	Description
<code>GrB_NONBLOCKING</code>	0	Specifies the nonblocking mode context.
<code>GrB_BLOCKING</code>	1	Specifies the blocking mode context.

(b) `GrB_WaitMode` wait modes for the `GrB_wait` method.

Symbol	Value	Description
<code>GrB_COMPLETE</code>	0	The object is in a state where it can be used in a happens-before relation so that multithreaded programs can be properly synchronized.
<code>GrB_MATERIALIZE</code>	1	The object is <i>complete</i> , and in addition, all computation of the object is finished and any error information is available.

Table 3.2: Predefined GrB_Type values, and the corresponding GraphBLAS domain suffixes, C type (for scalar parameters), and domains for GraphBLAS. The domain suffixes are used in place of I , F , and T in Tables 3.5, 3.6, 3.7, 3.8, and 3.9).

GrB_Type	GrB_Type_Code	Suffix	C type	Domain
-	GrB_UDT_CODE=0	UDT	-	-
GrB_BOOL	GrB_BOOL_CODE=1	BOOL	bool	{false, true}
GrB_INT8	GrB_INT8_CODE=2	INT8	int8_t	$\mathbb{Z} \cap [-2^7, 2^7)$
GrB_UINT8	GrB_UINT8_CODE=3	UINT8	uint8_t	$\mathbb{Z} \cap [0, 2^8)$
GrB_INT16	GrB_INT16_CODE=4	INT16	int16_t	$\mathbb{Z} \cap [-2^{15}, 2^{15})$
GrB_UINT16	GrB_UINT16_CODE=5	UINT16	uint16_t	$\mathbb{Z} \cap [0, 2^{16})$
GrB_INT32	GrB_INT32_CODE=6	INT32	int32_t	$\mathbb{Z} \cap [-2^{31}, 2^{31})$
GrB_UINT32	GrB_UINT32_CODE=7	UINT32	uint32_t	$\mathbb{Z} \cap [0, 2^{32})$
GrB_INT64	GrB_INT64_CODE=8	INT64	int64_t	$\mathbb{Z} \cap [-2^{63}, 2^{63})$
GrB_UINT64	GrB_UINT64_CODE=9	UINT64	uint64_t	$\mathbb{Z} \cap [0, 2^{64})$
GrB_FP32	GrB_FP32_CODE=10	FP32	float	IEEE 754 binary32
GrB_FP64	GrB_FP64_CODE=11	FP64	double	IEEE 754 binary64

814 The domains for elements that can be stored in collections and operated on through GraphBLAS
815 methods are defined by GraphBLAS objects called GrB_Type. The predefined types and cor-
816 responding domains used in the GraphBLAS C API are shown in Table 3.2. The Boolean type
817 (bool) is defined in `stdbool.h`, the integral types (`int8_t`, `uint8_t`, `int16_t`, `uint16_t`, `int32_t`,
818 `uint32_t`, `int64_t`, `uint64_t`) are defined in `stdint.h`, and the floating-point types (`float`,
819 `double`) are native to the language and platform and in most cases defined by the IEEE-754
820 standard. UDT stands for user-defined type and is the type code returned for all objects which use
821 a non-predefined type. Implementations which add new types should start their GrB_Type_Codes
822 at 100 to avoid possible conflicts with built-in types which may be added in the future.

823 3.4 Algebraic objects, operators and associated functions

824 GraphBLAS operators operate on elements stored in GraphBLAS collections. A *binary operator*
825 is a function that maps two input values to one output value. A *unary operator* is a function that
826 maps one input value to one output value. Binary operators are defined over two input domains
827 and produce an output from a (possibly different) third domain. Unary operators are specified over
828 one input domain and produce an output from a (possibly different) second domain.

829 In addition to the operators that operate on stored values, GraphBLAS also supports *index unary*
830 *operators* that maps a stored value and the indices of its position in the matrix or vector to an
831 output value. That output value can be used in the index unary operator variants of `apply` (§ 4.3.8)
832 to compute a new stored value, or be used in the `select` operation (§ 4.3.9) to determine if the stored
833 input value should be kept or annihilated.

834 Some GraphBLAS operations require a monoid or semiring. A monoid contains an associative

Table 3.3: Operator input for relevant GraphBLAS operations. The semiring add and times are shown if applicable.

Operation	Operator input
mxm, mxv, vxm	semiring
eWiseAdd	binary operator monoid semiring (add)
eWiseMult	binary operator monoid semiring (times)
reduce (to vector or GrB_Scalar)	binary operator monoid
reduce (to scalar value)	monoid
apply	unary operator binary operator with scalar index unary operator
select	index unary operator
kroncker	binary operator monoid semiring
dup argument (build methods)	binary operator
accum argument (various methods)	binary operator

835 binary operator where the input and output domains are the same. The monoid also includes an
 836 identity value of the operator. The semiring consists of a binary operator – referred to as the
 837 “times” operator – with up to three different domains (two inputs and one output) and a monoid
 838 – referred to as the “plus” operator – that is also commutative. Furthermore, the domain of the
 839 monoid must be the same as the output domain of the “times” operator.

840 The GraphBLAS *algebraic objects* operators, monoids, and semirings are presented in this section.
 841 These objects can be used as input arguments to various GraphBLAS operations, as shown in
 842 Table 3.3. The specific rules for each algebraic object are explained in the respective sections of
 843 those objects. A summary of the properties and recipes for building these GraphBLAS algebraic
 844 objects is presented in Table 3.4.

845 A number of predefined operators are specified by the GraphBLAS C API. They are presented
 846 in tables in their respective subsections below. Each of these operators is defined to operate on
 847 specific GraphBLAS types and therefore, this type is built into the name of the object as a suffix.
 848 These suffixes and the corresponding predefined GrB_Type objects that are listed in Table 3.2.

849 3.4.1 Operators

850 A GraphBLAS *unary operator* $F_u = \langle D_{out}, D_{in}, f \rangle$ is defined by two domains, D_{out} and D_{in} , and
 851 an operation $f : D_{in} \rightarrow D_{out}$. For a given GraphBLAS unary operator $F_u = \langle D_{out}, D_{in}, f \rangle$, we

Table 3.4: Properties and recipes for building GraphBLAS algebraic objects: unary operator, binary operator, monoid, and semiring (composed of operations *add* and *times*).

(a) Properties of algebraic objects.

Object	Must be commutative	Must be associative	Identity must exist	Number of domains
Unary operator	n/a	n/a	n/a	2
Binary operator	no	no	no	3
Monoid	no	yes	yes	1
Reduction add	yes	yes	yes (see Note 1)	1
Semiring add	yes	yes	yes	1
Semiring times	no	no	no	3 (see Note 2)

(b) Recipes for algebraic objects.

Object	Recipe	Number of domains
Unary operator	Function pointer	2
Binary operator	Function pointer	3
Monoid	Associative binary operator with identity	1
Semiring	Commutative monoid + binary operator	3

Note 1: Some high-performance GraphBLAS implementations may require an identity to perform reductions to sparse objects such as GraphBLAS vectors and scalars. According to the descriptions of the corresponding GraphBLAS operations, however, this identity is mathematically not necessary. There are API signatures to support both.

Note 2: The output domain of the semiring times must be same as the domain of the semiring's add monoid. This ensures three domains for a semiring rather than four.

852 define $\mathbf{D}_{out}(F_u) = D_{out}$, $\mathbf{D}_{in}(F_u) = D_{in}$, and $\mathbf{f}(F_u) = f$.

853 A GraphBLAS *binary operator* $F_b = \langle D_{out}, D_{in_1}, D_{in_2}, \odot \rangle$ is defined by three domains, D_{out} , D_{in_1} ,
854 D_{in_2} , and an operation $\odot : D_{in_1} \times D_{in_2} \rightarrow D_{out}$. For a given GraphBLAS binary operator $F_b =$
855 $\langle D_{out}, D_{in_1}, D_{in_2}, \odot \rangle$, we define $\mathbf{D}_{out}(F_b) = D_{out}$, $\mathbf{D}_{in_1}(F_b) = D_{in_1}$, $\mathbf{D}_{in_2}(F_b) = D_{in_2}$, and $\odot(F_b) =$
856 \odot . Note that \odot could be used in place of either \oplus or \otimes in other methods and operations.

857 A GraphBLAS *index unary operator* $F_i = \langle D_{out}, D_{in_1}, \mathbf{D}(\text{GrB_Index}), D_{in_2}, f_i \rangle$ is defined by three
858 domains, D_{out} , D_{in_1} , D_{in_2} , the domain of GraphBLAS indices, and an operation $f_i : D_{in_1} \times I_{U64}^2 \times$
859 $D_{in_2} \rightarrow D_{out}$ (where I_{U64} corresponds to the domain of a `GrB_Index`). For a given GraphBLAS
860 index operator F_i , we define $\mathbf{D}_{out}(F_i) = D_{out}$, $\mathbf{D}_{in_1}(F_i) = D_{in_1}$, $\mathbf{D}_{in_2}(F_i) = D_{in_2}$, and $\mathbf{f}(F_i) = f_i$.

861 User-defined operators can be created with calls to `GrB_UnaryOp_new`, `GrB_BinaryOp_new`, and
862 `GrB_IndexUnaryOp_new`, respectively. See Section 4.2.2 for information on these methods. The
863 GraphBLAS C API predefines a number of these operators. These are listed in Tables 3.5 and 3.6.
864 Note that most entries in these tables represent a “family” of predefined operators for a set of
865 different types represented by the T , I , or F in their names. For example, the multiplicative
866 inverse (`GrB_MINV_F`) function is only defined for floating-point types ($F = \text{FP32}$ or FP64). The
867 division (`GrB_DIV_T`) function is defined for all types, but only if $y \neq 0$ for integral and floating
868 point types and $y \neq \text{false}$ for the Boolean type.

Table 3.5: Predefined unary and binary operators for GraphBLAS in C. The T can be any suffix from Table 3.2, I can be any integer suffix from Table 3.2, and F can be any floating-point suffix from Table 3.2.

Operator type	GraphBLAS identifier	Domains	Description	
GrB_UnaryOp	GrB_IDENTITY_ T	$T \rightarrow T$	$f(x) = x,$	identity
GrB_UnaryOp	GrB_ABS_ T	$T \rightarrow T$	$f(x) = x ,$	absolute value
GrB_UnaryOp	GrB_AINV_ T	$T \rightarrow T$	$f(x) = -x,$	additive inverse
GrB_UnaryOp	GrB_MINV_ F	$F \rightarrow F$	$f(x) = \frac{1}{x},$	multiplicative inverse
GrB_UnaryOp	GrB_LNOT	$\text{bool} \rightarrow \text{bool}$	$f(x) = \neg x,$	logical inverse
GrB_UnaryOp	GrB_BNOT_ I	$I \rightarrow I$	$f(x) = \sim x,$	bitwise complement
GrB_BinaryOp	GrB_LOR	$\text{bool} \times \text{bool} \rightarrow \text{bool}$	$f(x, y) = x \vee y,$	logical OR
GrB_BinaryOp	GrB_LAND	$\text{bool} \times \text{bool} \rightarrow \text{bool}$	$f(x, y) = x \wedge y,$	logical AND
GrB_BinaryOp	GrB_LXOR	$\text{bool} \times \text{bool} \rightarrow \text{bool}$	$f(x, y) = x \oplus y,$	logical XOR
GrB_BinaryOp	GrB_LXNOR	$\text{bool} \times \text{bool} \rightarrow \text{bool}$	$f(x, y) = \overline{x \oplus y},$	logical XNOR
GrB_BinaryOp	GrB_BOR_ I	$I \times I \rightarrow I$	$f(x, y) = x y,$	bitwise OR
GrB_BinaryOp	GrB_BAND_ I	$I \times I \rightarrow I$	$f(x, y) = x \& y,$	bitwise AND
GrB_BinaryOp	GrB_BXOR_ I	$I \times I \rightarrow I$	$f(x, y) = x \hat{\ } y,$	bitwise XOR
GrB_BinaryOp	GrB_BXNOR_ I	$I \times I \rightarrow I$	$f(x, y) = \overline{x \hat{\ } y},$	bitwise XNOR
GrB_BinaryOp	GrB_EQ_ T	$T \times T \rightarrow \text{bool}$	$f(x, y) = (x == y)$	equal
GrB_BinaryOp	GrB_NE_ T	$T \times T \rightarrow \text{bool}$	$f(x, y) = (x \neq y)$	not equal
GrB_BinaryOp	GrB_GT_ T	$T \times T \rightarrow \text{bool}$	$f(x, y) = (x > y)$	greater than
GrB_BinaryOp	GrB_LT_ T	$T \times T \rightarrow \text{bool}$	$f(x, y) = (x < y)$	less than
GrB_BinaryOp	GrB_GE_ T	$T \times T \rightarrow \text{bool}$	$f(x, y) = (x \geq y)$	greater than or equal
GrB_BinaryOp	GrB_LE_ T	$T \times T \rightarrow \text{bool}$	$f(x, y) = (x \leq y)$	less than or equal
GrB_BinaryOp	GrB_ONEB_ T	$T \times T \rightarrow T$	$f(x, y) = 1,$	1 (cast to T)
GrB_BinaryOp	GrB_FIRST_ T	$T \times T \rightarrow T$	$f(x, y) = x,$	first argument
GrB_BinaryOp	GrB_SECOND_ T	$T \times T \rightarrow T$	$f(x, y) = y,$	second argument
GrB_BinaryOp	GrB_MIN_ T	$T \times T \rightarrow T$	$f(x, y) = (x < y) ? x : y,$	minimum
GrB_BinaryOp	GrB_MAX_ T	$T \times T \rightarrow T$	$f(x, y) = (x > y) ? x : y,$	maximum
GrB_BinaryOp	GrB_PLUS_ T	$T \times T \rightarrow T$	$f(x, y) = x + y,$	addition
GrB_BinaryOp	GrB_MINUS_ T	$T \times T \rightarrow T$	$f(x, y) = x - y,$	subtraction
GrB_BinaryOp	GrB_TIMES_ T	$T \times T \rightarrow T$	$f(x, y) = xy,$	multiplication
GrB_BinaryOp	GrB_DIV_ T	$T \times T \rightarrow T$	$f(x, y) = \frac{x}{y},$	division

Table 3.6: Predefined index unary operators for GraphBLAS in C. The T can be any suffix from Table 3.2. I_{U64} refers to the unsigned 64-bit, GrB_Index, integer type, I_{32} refers to the signed, 32-bit integer type, and I_{64} refers to signed, 64-bit integer type. The parameters, u_i or A_{ij} , are the stored values from the containers where the i and j parameters are set to the row and column indices corresponding to the location of the stored value. When operating on vectors, j will be passed with a zero value. Finally, s is an additional scalar value used in the operators. The expressions in the “Description” column are to be treated as mathematical specifications. That is, for the index arithmetic functions in the first two groups below, each one of i , j , and s is interpreted as an integer number in the set \mathbb{Z} . Functions are evaluated using arithmetic in \mathbb{Z} , producing a result value that is also in \mathbb{Z} . The result value is converted to the output type according to the rules of the C language. In particular, if the value cannot be represented as a signed 32- or 64-bit integer type, the output is implementation defined. Any deviations from this ideal behavior, including limitations on the values of i , j , and s , or possible overflow and underflow conditions, must be defined by the implementation.

Operator type Type	GraphBLAS identifier	Domains (– is don’t care)				Description
		A, u	i, j	s	result	
GrB_IndexUnaryOp	GrB_ROWINDEX_ $I_{32/64}$	–	I_{U64}	$I_{32/64}$	$I_{32/64}$	$f(A_{ij}, i, j, s) = (i + s)$, replace with its row index (+ s)
GrB_IndexUnaryOp	GrB_COLINDEX_ $I_{32/64}$	–	I_{U64}	$I_{32/64}$	$I_{32/64}$	$f(u_i, i, 0, s) = (i + s)$ $f(A_{ij}, i, j, s) = (j + s)$ replace with its column index (+ s)
GrB_IndexUnaryOp	GrB_DIAGINDEX_ $I_{32/64}$	–	I_{U64}	$I_{32/64}$	$I_{32/64}$	$f(A_{ij}, i, j, s) = (j - i + s)$ replace with its diagonal index (+ s)
GrB_IndexUnaryOp	GrB_TRIL	–	I_{U64}	I_{64}	bool	$f(A_{ij}, i, j, s) = (j \leq i + s)$ triangle on or below diagonal s
GrB_IndexUnaryOp	GrB_TRIU	–	I_{U64}	I_{64}	bool	$f(A_{ij}, i, j, s) = (j \geq i + s)$ triangle on or above diagonal s
GrB_IndexUnaryOp	GrB_DIAG	–	I_{U64}	I_{64}	bool	$f(A_{ij}, i, j, s) = (j == i + s)$ diagonal s
GrB_IndexUnaryOp	GrB_OFFDIAG	–	I_{U64}	I_{64}	bool	$f(A_{ij}, i, j, s) = (j \neq i + s)$ all but diagonal s
GrB_IndexUnaryOp	GrB_COLLE	–	I_{U64}	I_{64}	bool	$f(A_{ij}, i, j, s) = (j \leq s)$ columns less or equal to s
GrB_IndexUnaryOp	GrB_COLGT	–	I_{U64}	I_{64}	bool	$f(A_{ij}, i, j, s) = (j > s)$ columns greater than s
GrB_IndexUnaryOp	GrB_ROWLE	–	I_{U64}	I_{64}	bool	$f(A_{ij}, i, j, s) = (i \leq s)$, rows less or equal to s
GrB_IndexUnaryOp	GrB_ROWGT	–	I_{U64}	I_{64}	bool	$f(u_i, i, 0, s) = (i \leq s)$ $f(A_{ij}, i, j, s) = (i > s)$, rows greater than s
GrB_IndexUnaryOp	GrB_VALUEEQ_ T	T	–	T	bool	$f(A_{ij}, i, j, s) = (A_{ij} == s)$, elements equal to value s
GrB_IndexUnaryOp	GrB_VALUENE_ T	T	–	T	bool	$f(u_i, i, 0, s) = (u_i == s)$ $f(A_{ij}, i, j, s) = (A_{ij} \neq s)$, elements not equal to value s
GrB_IndexUnaryOp	GrB_VALUELT_ T	T	–	T	bool	$f(u_i, i, 0, s) = (u_i \neq s)$ $f(A_{ij}, i, j, s) = (A_{ij} < s)$, elements less than value s
GrB_IndexUnaryOp	GrB_VALUELE_ T	T	–	T	bool	$f(u_i, i, 0, s) = (u_i < s)$ $f(A_{ij}, i, j, s) = (A_{ij} \leq s)$, elements less or equal to value s
GrB_IndexUnaryOp	GrB_VALUEGT_ T	T	–	T	bool	$f(u_i, i, 0, s) = (u_i \leq s)$ $f(A_{ij}, i, j, s) = (A_{ij} > s)$, elements greater than value s
GrB_IndexUnaryOp	GrB_VALUEGE_ T	T	–	T	bool	$f(u_i, i, 0, s) = (u_i > s)$ $f(A_{ij}, i, j, s) = (A_{ij} \geq s)$, elements greater or equal to value s
		T	–	T	bool	$f(u_i, i, 0, s) = (u_i \geq s)$

869 3.4.2 Monoids

870 A GraphBLAS *monoid* $M = \langle D, \odot, 0 \rangle$ is defined by a single domain D , an *associative*¹ operation
871 $\odot : D \times D \rightarrow D$, and an identity element $0 \in D$. For a given GraphBLAS monoid $M = \langle D, \odot, 0 \rangle$
872 we define $\mathbf{D}(M) = D$, $\odot(M) = \odot$, and $\mathbf{0}(M) = 0$. A GraphBLAS monoid is equivalent to the
873 conventional *monoid* algebraic structure.

874 Let $F = \langle D, D, D, \odot \rangle$ be an associative GraphBLAS binary operator with identity element $0 \in D$.
875 Then $M = \langle F, 0 \rangle = \langle D, \odot, 0 \rangle$ is a GraphBLAS monoid. If \odot is commutative, then M is said to be
876 a *commutative monoid*. If a monoid M is created using an operator \odot that is not associative, the
877 outcome of GraphBLAS operations using such a monoid is undefined.

878 User-defined monoids can be created with calls to `GrB_Monoid_new` (see Section 4.2.2). The
879 GraphBLAS C API predefines a number of monoids that are listed in Table 3.7. Predefined
880 monoids are named `GrB_op_MONOID_T`, where *op* is the name of the predefined GraphBLAS
881 operator used as the associative binary operation of the monoid and T is the domain (type) of the
882 monoid.

883 3.4.3 Semirings

884 A GraphBLAS *semiring* $S = \langle D_{out}, D_{in_1}, D_{in_2}, \oplus, \otimes, 0 \rangle$ is defined by three domains D_{out} , D_{in_1} , and
885 D_{in_2} ; an *associative*¹ and commutative additive operation $\oplus : D_{out} \times D_{out} \rightarrow D_{out}$; a multiplicative
886 operation $\otimes : D_{in_1} \times D_{in_2} \rightarrow D_{out}$; and an identity element $0 \in D_{out}$. For a given GraphBLAS
887 semiring $S = \langle D_{out}, D_{in_1}, D_{in_2}, \oplus, \otimes, 0 \rangle$ we define $\mathbf{D}_{in_1}(S) = D_{in_1}$, $\mathbf{D}_{in_2}(S) = D_{in_2}$, $\mathbf{D}_{out}(S) =$
888 D_{out} , $\oplus(S) = \oplus$, $\otimes(S) = \otimes$, and $\mathbf{0}(S) = 0$.

889 Let $F = \langle D_{out}, D_{in_1}, D_{in_2}, \otimes \rangle$ be an operator and let $A = \langle D_{out}, \oplus, 0 \rangle$ be a commutative monoid,
890 then $S = \langle A, F \rangle = \langle D_{out}, D_{in_1}, D_{in_2}, \oplus, \otimes, 0 \rangle$ is a semiring.

891 In a GraphBLAS semiring, the multiplicative operator does not have to distribute over the additive
892 operator. This is unlike the conventional *semiring* algebraic structure.

893 Note: There must be one GraphBLAS monoid in every semiring which serves as the semiring's
894 additive operator and specifies the same domain for its inputs and output parameters. If this
895 monoid is not a commutative monoid, the outcome of GraphBLAS operations using the semiring
896 is undefined.

897 A UML diagram of the conceptual hierarchy of object classes in GraphBLAS algebra (binary
898 operators, monoids, and semirings) is shown in Figure 3.1.

899 User-defined semirings can be created with calls to `GrB_Semiring_new` (see Section 4.2.2). A list of
900 predefined true semirings and convenience semirings can be found in Tables 3.8 and 3.9, respectively.
901 Predefined semirings are named `GrB_add_mul_SEMIRING_T`, where *add* is the semiring additive
902 operation, *mul* is the semiring multiplicative operation and T is the domain (type) of the semiring.

¹It is expected that implementations of the GraphBLAS will utilize floating point arithmetic such as that defined in the IEEE-754 standard even though floating point arithmetic is not strictly associative.

Table 3.7: Predefined monoids for GraphBLAS in C. Maximum and minimum values for the various integral types are defined in `stdint.h`. Floating-point infinities are defined in `math.h`. The x in `UINT x` or `INT x` can be one of 8, 16, 32, or 64; whereas in `FP x` , it can be 32 or 64.

GraphBLAS identifier	Domains, T ($T \times T \rightarrow T$)	Identity	Description
GrB_PLUS_MONOID_ T	UINT x	0	addition
	INT x	0	
	FP x	0	
GrB_TIMES_MONOID_ T	UINT x	1	multiplication
	INT x	1	
	FP x	1	
GrB_MIN_MONOID_ T	UINT x	UINT x _MAX	minimum
	INT x	INT x _MAX	
	FP x	INFINITY	
GrB_MAX_MONOID_ T	UINT x	0	maximum
	INT x	INT x _MIN	
	FP x	-INFINITY	
GrB_LOR_MONOID_BOOL	BOOL	false	logical OR
GrB_LAND_MONOID_BOOL	BOOL	true	logical AND
GrB_LXOR_MONOID_BOOL	BOOL	false	logical XOR (not equal)
GrB_LXNOR_MONOID_BOOL	BOOL	true	logical XNOR (equal)

Table 3.8: Predefined true semirings for GraphBLAS in C where the additive identity is the multiplicative annihilator. The x can be one of 8, 16, 32, or 64 in $UINTx$ or $INTx$, and can be 32 or 64 in FPx .

GraphBLAS identifier	Domains, T ($T \times T \rightarrow T$)	+ identity \times annihilator	Description
GrB_PLUS_TIMES_SEMIRING_ T	$UINTx$ $INTx$ FPx	0 0 0	arithmetic semiring
GrB_MIN_PLUS_SEMIRING_ T	$UINTx$ $INTx$ FPx	$UINTx_MAX$ $INTx_MAX$ INFINITY	min-plus semiring
GrB_MAX_PLUS_SEMIRING_ T	$INTx$ FPx	$INTx_MIN$ -INFINITY	max-plus semiring
GrB_MIN_TIMES_SEMIRING_ T	$UINTx$	$UINTx_MAX$	min-times semiring
GrB_MIN_MAX_SEMIRING_ T	$UINTx$ $INTx$ FPx	$UINTx_MAX$ $INTx_MAX$ INFINITY	min-max semiring
GrB_MAX_MIN_SEMIRING_ T	$UINTx$ $INTx$ FPx	0 $INTx_MIN$ -INFINITY	max-min semiring
GrB_MAX_TIMES_SEMIRING_ T	$UINTx$	0	max-times semiring
GrB_PLUS_MIN_SEMIRING_ T	$UINTx$	0	plus-min semiring
GrB_LOR_LAND_SEMIRING_BOOL	BOOL	false	Logical semiring
GrB_LAND_LOR_SEMIRING_BOOL	BOOL	true	"and-or" semiring
GrB_LXOR_LAND_SEMIRING_BOOL	BOOL	false	same as NE_LAND
GrB_LXNOR_LOR_SEMIRING_BOOL	BOOL	true	same as EQ_LOR

Table 3.9: Other useful predefined semirings for GraphBLAS in C that don't have a multiplicative annihilator. The x can be one of 8, 16, 32, or 64 in $UINTx$ or $INTx$, and can be 32 or 64 in FPx .

GraphBLAS identifier	Domains, T ($T \times T \rightarrow T$)	+ identity	Description
GrB_MAX_PLUS_SEMIRING_ T	$UINTx$	0	max-plus semiring
GrB_MIN_TIMES_SEMIRING_ T	$INTx$	$INTx_MAX$	min-times semiring
	FPx	$INFINITY$	
GrB_MAX_TIMES_SEMIRING_ T	$INTx$	$INTx_MIN$	max-times semiring
	FPx	$-INFINITY$	
GrB_PLUS_MIN_SEMIRING_ T	$INTx$	0	plus-min semiring
	FPx	0	
GrB_MIN_FIRST_SEMIRING_ T	$UINTx$	$UINTx_MAX$	min-select first semiring
	$INTx$	$INTx_MAX$	
	FPx	$INFINITY$	
GrB_MIN_SECOND_SEMIRING_ T	$UINTx$	$UINTx_MAX$	min-select second semiring
	$INTx$	$INTx_MAX$	
	FPx	$INFINITY$	
GrB_MAX_FIRST_SEMIRING_ T	$UINTx$	0	max-select first semiring
	$INTx$	$INTx_MIN$	
	FPx	$-INFINITY$	
GrB_MAX_SECOND_SEMIRING_ T	$UINTx$	0	max-select second semiring
	$INTx$	$INTx_MIN$	
	FPx	$-INFINITY$	

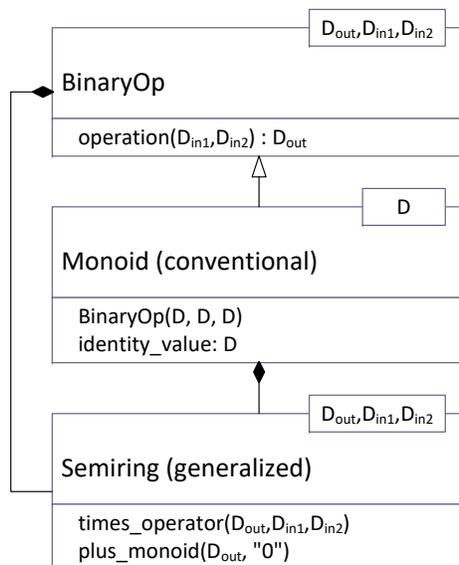


Figure 3.1: Hierarchy of algebraic object classes in GraphBLAS. GraphBLAS semirings consist of a conventional monoid with one domain for the addition function, and a binary operator with three domains for the multiplication function.

903 3.5 Collections

904 3.5.1 Scalars

905 A *GraphBLAS scalar*, $s = \langle D, \{\sigma\} \rangle$, is defined by a domain D , and a set of zero or one *scalar value*,
 906 σ , where $\sigma \in D$. We define $\mathbf{size}(s) = 1$ (constant), and $\mathbf{L}(s) = \{\sigma\}$. The set $\mathbf{L}(s)$ is called the
 907 *contents* of the GraphBLAS scalar s . We also define $\mathbf{D}(s) = D$. Finally, $\mathbf{val}(s)$ is a reference to
 908 the scalar value, σ , if the GraphBLAS scalar is not empty, and is undefined otherwise.

909 3.5.2 Vectors

910 A vector $\mathbf{v} = \langle D, N, \{(i, v_i)\} \rangle$ is defined by a domain D , a size $N > 0$, and a set of tuples (i, v_i)
 911 where $0 \leq i < N$ and $v_i \in D$. A particular value of i can appear at most once in \mathbf{v} . We define
 912 $\mathbf{size}(\mathbf{v}) = N$ and $\mathbf{L}(\mathbf{v}) = \{(i, v_i)\}$. The set $\mathbf{L}(\mathbf{v})$ is called the *content* of vector \mathbf{v} . We also define
 913 the set $\mathbf{ind}(\mathbf{v}) = \{i : (i, v_i) \in \mathbf{L}(\mathbf{v})\}$ (called the *structure* of \mathbf{v}), and $\mathbf{D}(\mathbf{v}) = D$. For a vector \mathbf{v} ,
 914 $\mathbf{v}(i)$ is a reference to v_i if $(i, v_i) \in \mathbf{L}(\mathbf{v})$ and is undefined otherwise.

915 **3.5.3 Matrices**

916 A matrix $\mathbf{A} = \langle D, M, N, \{(i, j, A_{ij})\} \rangle$ is defined by a domain D , its number of rows $M > 0$, its
 917 number of columns $N > 0$, and a set of tuples (i, j, A_{ij}) where $0 \leq i < M$, $0 \leq j < N$, and
 918 $A_{ij} \in D$. A particular pair of values i, j can appear at most once in \mathbf{A} . We define $\mathbf{ncols}(\mathbf{A}) = N$,
 919 $\mathbf{nrows}(\mathbf{A}) = M$, and $\mathbf{L}(\mathbf{A}) = \{(i, j, A_{ij})\}$. The set $\mathbf{L}(\mathbf{A})$ is called the *content* of matrix \mathbf{A} . We also
 920 define the sets $\mathbf{indrow}(\mathbf{A}) = \{i : \exists(i, j, A_{ij}) \in \mathbf{A}\}$ and $\mathbf{indcol}(\mathbf{A}) = \{j : \exists(i, j, A_{ij}) \in \mathbf{A}\}$. (These
 921 are the sets of nonempty rows and columns of \mathbf{A} , respectively.) The *structure* of matrix \mathbf{A} is the
 922 set $\mathbf{ind}(\mathbf{A}) = \{(i, j) : (i, j, A_{ij}) \in \mathbf{L}(\mathbf{A})\}$, and $\mathbf{D}(\mathbf{A}) = D$. For a matrix \mathbf{A} , $\mathbf{A}(i, j)$ is a reference to
 923 A_{ij} if $(i, j, A_{ij}) \in \mathbf{L}(\mathbf{A})$ and is undefined otherwise.

924 If \mathbf{A} is a matrix and $0 \leq j < N$, then $\mathbf{A}(:, j) = \langle D, M, \{(i, A_{ij}) : (i, j, A_{ij}) \in \mathbf{L}(\mathbf{A})\} \rangle$ is a
 925 vector called the j -th *column* of \mathbf{A} . Correspondingly, if \mathbf{A} is a matrix and $0 \leq i < M$, then
 926 $\mathbf{A}(i, :) = \langle D, N, \{(j, A_{ij}) : (i, j, A_{ij}) \in \mathbf{L}(\mathbf{A})\} \rangle$ is a vector called the i -th *row* of \mathbf{A} .

927 Given a matrix $\mathbf{A} = \langle D, M, N, \{(i, j, A_{ij})\} \rangle$, its *transpose* is another matrix $\mathbf{A}^T = \langle D, N, M, \{(j, i, A_{ij}) : (i, j, A_{ij}) \in \mathbf{L}(\mathbf{A})\} \rangle$.

929 **3.5.3.1 External matrix formats**

930 The specification also supports the export and import of matrices to/from a number of commonly
 931 used formats, such as COO, CSR, and CSC formats. When importing or exporting a matrix to or
 932 from a GraphBLAS object using `GrB_Matrix_import` (§ 4.2.5.17) or `GrB_Matrix_export` (§ 4.2.5.16),
 933 it is necessary to specify the data format for the matrix data external to GraphBLAS, which is
 934 being imported from or exported to. This non-opaque data format is specified using an argument of
 935 enumeration type `GrB_Format` that is used to indicate one of a number of predefined formats. The
 936 predefined values of `GrB_Format` are specified in Table 3.10. A precise definition of the non-opaque
 937 data formats can be found in Appendix B.

Table 3.10: `GrB_Format` enumeration literals and corresponding values for matrix import and export methods.

Symbol	Value	Description
<code>GrB_CSR_FORMAT</code>	0	Specifies the compressed sparse row matrix format.
<code>GrB_CSC_FORMAT</code>	1	Specifies the compressed sparse column matrix format.
<code>GrB_COO_FORMAT</code>	2	Specifies the sparse coordinate matrix format.

938 **3.5.4 Masks**

939 The GraphBLAS C API defines an opaque object called a *mask*. The mask is used to control how
 940 computed values are stored in the output from a method. The mask is an *internal* opaque object;
 941 that is, it is never exposed as a variable within an application.

942 The mask is formed from input objects to the method that uses the mask. For example, a Graph-
 943 BLAS method may be called with a matrix as the mask parameter. The internal mask object is

944 constructed from the input matrix in one of two ways. In the default case, an element of the mask
 945 is created for each tuple that exists in the matrix for which the value of the tuple cast to Boolean
 946 evaluates to `true`. Alternatively, the user can specify *structure*-only behavior where an element of
 947 the mask is created for each tuple that exists in the matrix *regardless* of the value stored in the
 948 input matrix.

949 The internal mask object can be either a one- or a two-dimensional construct. One- and two-
 950 dimensional masks, described more formally below, are similar to vectors and matrices, respectively,
 951 except that they have structure (indices) but no values. When needed, a value is implied for the
 952 elements of a mask with an implied value of `true` for elements that exist and an implied value
 953 of `false` for elements that do not exist (i.e., the locations of the mask that do not have a stored
 954 value imply a value of `false`). Hence, even though a mask does not contain any values, it can be
 955 considered to imply values from a Boolean domain.

956 A one-dimensional mask $\mathbf{m} = \langle N, \{i\} \rangle$ is defined by its number of elements $N > 0$, and a set
 957 $\mathbf{ind}(\mathbf{m})$ of indices $\{i\}$ where $0 \leq i < N$. A particular value of i can appear at most once in \mathbf{m} . We
 958 define $\mathbf{size}(\mathbf{m}) = N$. The set $\mathbf{ind}(\mathbf{m})$ is called the *structure* of mask \mathbf{m} .

959 A two-dimensional mask $\mathbf{M} = \langle M, N, \{(i, j)\} \rangle$ is defined by its number of rows $M > 0$, its number
 960 of columns $N > 0$, and a set $\mathbf{ind}(\mathbf{M})$ of tuples (i, j) where $0 \leq i < M, 0 \leq j < N$. A particular pair
 961 of values i, j can appear at most once in \mathbf{M} . We define $\mathbf{ncols}(\mathbf{M}) = N$, and $\mathbf{nrows}(\mathbf{M}) = M$. We
 962 also define the sets $\mathbf{indrow}(\mathbf{M}) = \{i : \exists(i, j) \in \mathbf{ind}(\mathbf{M})\}$ and $\mathbf{indcol}(\mathbf{M}) = \{j : \exists(i, j) \in \mathbf{ind}(\mathbf{M})\}$.
 963 These are the sets of nonempty rows and columns of \mathbf{M} , respectively. The set $\mathbf{ind}(\mathbf{M})$ is called the
 964 *structure* of mask \mathbf{M} .

965 One common operation on masks is the *complement*. For a one-dimensional mask \mathbf{m} this is denoted
 966 as $\neg\mathbf{m}$. For a two-dimensional mask \mathbf{M} , this is denoted as $\neg\mathbf{M}$. The complement of a one-
 967 dimensional mask \mathbf{m} is defined as $\mathbf{ind}(\neg\mathbf{m}) = \{i : 0 \leq i < N, i \notin \mathbf{ind}(\mathbf{m})\}$. It is the set of all
 968 possible indices that do not appear in \mathbf{m} . The complement of a two-dimensional mask \mathbf{M} is defined
 969 as the set $\mathbf{ind}(\neg\mathbf{M}) = \{(i, j) : 0 \leq i < M, 0 \leq j < N, (i, j) \notin \mathbf{ind}(\mathbf{M})\}$. It is the set of all possible
 970 indices that do not appear in \mathbf{M} .

971 3.6 Descriptors

972 Descriptors are used to modify the behavior of a GraphBLAS method. When present in the
 973 signature of a method, they appear as the last argument in the method. Descriptors specify how
 974 the other input arguments corresponding to GraphBLAS collections – vectors, matrices, and masks
 975 – should be processed (modified) before the main operation of a method is performed. A complete
 976 list of what descriptors are capable of are presented in this section.

977 The descriptor is a lightweight object. It is composed of (*field*, *value*) pairs where the *field* selects
 978 one of the GraphBLAS objects from the argument list of a method and the *value* defines the
 979 indicated modification associated with that object. For example, a descriptor may specify that a
 980 particular input matrix needs to be transposed or that a mask needs to be complemented (defined
 981 in Section 3.5.4) before using it in the operation.

982 For the purpose of constructing descriptors, the arguments of a method that can be modified

983 are identified by specific field names. The output parameter (typically the first parameter in a
984 GraphBLAS method) is indicated by the field name, `GrB_OUTP`. The mask is indicated by the
985 `GrB_MASK` field name. The input parameters corresponding to the input vectors and matrices are
986 indicated by `GrB_INP0` and `GrB_INP1` in the order they appear in the signature of the GraphBLAS
987 method. The descriptor is an opaque object and hence we do not define how objects of this type
988 should be implemented. When referring to *(field, value)* pairs for a descriptor, however, we often use
989 the informal notation `desc[GrB_Desc_Field].GrB_Desc_Value` without implying that a descriptor is
990 to be implemented as an array of structures (in fact, field values can be used in conjunction with
991 multiple values that are composable). We summarize all types, field names, and values used with
992 descriptors in Table 3.11.

993 In the definitions of the GraphBLAS methods, we often refer to the *default behavior* of a method
994 with respect to the action of a descriptor. If a descriptor is not provided or if the value associated
995 with a particular field in a descriptor is not set, the default behavior of a GraphBLAS method is
996 defined as follows:

- 997 • Input matrices are not transposed.
- 998 • The mask is used, as is, without complementing, and stored values are examined to determine
999 whether they evaluate to `true` or `false`.
- 1000 • Values of the output object that are not directly modified by the operation are preserved.

1001 GraphBLAS specifies all of the valid combinations of (field, value) pairs as predefined descriptors.
1002 Their identifiers and the corresponding set of (field, value) pairs for that identifier are shown in
1003 Table 3.12.

1004 3.7 Fields

1005 All GraphBLAS objects and library implementations contain fields similar to those in descriptors.
1006 These fields provide information to users and let users set runtime parameters or hints. Users query
1007 or set these fields for any GraphBLAS object through `GrB_get` and `GrB_set` methods. The library
1008 implementation itself also contains several *(field, value)* pairs, which provide defaults to object level
1009 fields, and implementation information such as the version number or implementation name.

1010 The required *(field, value)* pairs available for each object are defined in Table 3.13. Implementations
1011 may add their own custom `GrB_Field` enum values to extend the behavior of objects and methods.
1012 A field must always be readable, but in many cases may not be writable. Such read-only fields
1013 might contain static, compile-time information such as `GrB_API_VER`, while others are determined
1014 by other operations, such as `GrB_BLOCKING_MODE` which is determined by `GrB_Init`.

1015 `GrB_INVALID_VALUE` must be returned when attempting to write to fields which are read only.

1016 The `GrB_Field` enumeration is defined by the values in Table 3.13. Selected values are described in
1017 Table 3.14.

Table 3.11: Descriptors are GraphBLAS objects passed as arguments to GraphBLAS operations to modify other GraphBLAS objects in the operation’s argument list. A descriptor, `desc`, has one or more (*field, value*) pairs indicated as `desc[GrB_Desc_Field].GrB_Desc_Value`. In this table, we define all types and literals used with descriptors.

(a) Types used with GraphBLAS descriptors.

Type	Description
<code>GrB_Descriptor</code>	Type of a GraphBLAS descriptor object.
<code>GrB_Desc_Field</code>	The descriptor field enumeration.
<code>GrB_Desc_Value</code>	The descriptor value enumeration.

(b) Descriptor field names of type `GrB_Desc_Field` enumeration and corresponding values.

Field Name	Value	Description
<code>GrB_OUTP</code>	0	Field name for the output GraphBLAS object.
<code>GrB_MASK</code>	1	Field name for the mask GraphBLAS object.
<code>GrB_INP0</code>	2	Field name for the first input GraphBLAS object.
<code>GrB_INP1</code>	3	Field name for the second input GraphBLAS object.

(c) Descriptor field values of type `GrB_Desc_Value` enumeration and corresponding values.

Value Name	Value	Description
<code>GrB_DEFAULT</code>	0	The default (unset) value for each field.
<code>GrB_REPLACE</code>	1	Clear the output object before assigning computed values.
<code>GrB_COMP</code>	2	Use the complement of the associated object. When combined with <code>GrB_STRUCTURE</code> , the complement of the structure of the associated object is used without evaluating the values stored.
<code>GrB_TRAN</code>	3	Use the transpose of the associated object.
<code>GrB_STRUCTURE</code>	4	The write mask is constructed from the structure (pattern of stored values) of the associated object. The stored values are not examined.
<code>GrB_COMP_STRUCTURE</code>	6	Shorthand for both <code>GrB_COMP</code> and <code>GrB_STRUCTURE</code> .

Table 3.12: Predefined GraphBLAS descriptors. The list includes all possible descriptors, according to the current standard. Columns list the possible fields and entries list the value(s) associated with those fields for a given descriptor.

Identifier	GrB_OUTP	GrB_MASK	GrB_INP0	GrB_INP1
GrB_NULL	–	–	–	–
GrB_DESC_T1	–	–	–	GrB_TRAN
GrB_DESC_T0	–	–	GrB_TRAN	–
GrB_DESC_T0T1	–	–	GrB_TRAN	GrB_TRAN
GrB_DESC_C	–	GrB_COMP	–	–
GrB_DESC_S	–	GrB_STRUCTURE	–	–
GrB_DESC_CT1	–	GrB_COMP	–	GrB_TRAN
GrB_DESC_ST1	–	GrB_STRUCTURE	–	GrB_TRAN
GrB_DESC_CT0	–	GrB_COMP	GrB_TRAN	–
GrB_DESC_ST0	–	GrB_STRUCTURE	GrB_TRAN	–
GrB_DESC_CT0T1	–	GrB_COMP	GrB_TRAN	GrB_TRAN
GrB_DESC_ST0T1	–	GrB_STRUCTURE	GrB_TRAN	GrB_TRAN
GrB_DESC_SC	–	GrB_STRUCTURE, GrB_COMP	–	–
GrB_DESC_SCT1	–	GrB_STRUCTURE, GrB_COMP	–	GrB_TRAN
GrB_DESC_SCT0	–	GrB_STRUCTURE, GrB_COMP	GrB_TRAN	–
GrB_DESC_SCT0T1	–	GrB_STRUCTURE, GrB_COMP	GrB_TRAN	GrB_TRAN
GrB_DESC_R	GrB_REPLACE	–	–	–
GrB_DESC_RT1	GrB_REPLACE	–	–	GrB_TRAN
GrB_DESC_RT0	GrB_REPLACE	–	GrB_TRAN	–
GrB_DESC_RT0T1	GrB_REPLACE	–	GrB_TRAN	GrB_TRAN
GrB_DESC_RC	GrB_REPLACE	GrB_COMP	–	–
GrB_DESC_RS	GrB_REPLACE	GrB_STRUCTURE	–	–
GrB_DESC_RCT1	GrB_REPLACE	GrB_COMP	–	GrB_TRAN
GrB_DESC_RST1	GrB_REPLACE	GrB_STRUCTURE	–	GrB_TRAN
GrB_DESC_RCT0	GrB_REPLACE	GrB_COMP	GrB_TRAN	–
GrB_DESC_RST0	GrB_REPLACE	GrB_STRUCTURE	GrB_TRAN	–
GrB_DESC_RCT0T1	GrB_REPLACE	GrB_COMP	GrB_TRAN	GrB_TRAN
GrB_DESC_RST0T1	GrB_REPLACE	GrB_STRUCTURE	GrB_TRAN	GrB_TRAN
GrB_DESC_RSC	GrB_REPLACE	GrB_STRUCTURE, GrB_COMP	–	–
GrB_DESC_RSCT1	GrB_REPLACE	GrB_STRUCTURE, GrB_COMP	–	GrB_TRAN
GrB_DESC_RSCT0	GrB_REPLACE	GrB_STRUCTURE, GrB_COMP	GrB_TRAN	–
GrB_DESC_RSCT0T1	GrB_REPLACE	GrB_STRUCTURE, GrB_COMP	GrB_TRAN	GrB_TRAN

1018 **3.7.1 Input Types**

1019 Allowable types used in `GrB_get` and `GrB_set` are `INT32`, `GrB_Scalar`, `char*`, `void*`, and `SIZE`. Each
1020 `GrB_Field` is associated with exactly one of these types as defined in Table 3.13. Implementations
1021 that add additional `GrB_Fields` must document the type associated with each `GrB_Field`.

1022 **3.7.1.1 INT32**

1023 `INT32` types use a 32-bit signed integer type. This can be used both for numeric values as well as
1024 enumerated C types. Enumerated types must specify the numeric value for each enum, and the
1025 value specified must fit within the allowable 32-bit signed integer range.

1026 **3.7.1.2 GrB_Scalar**

1027 When calling `GrB_get`, the user must provide an already initialized `GrB_Scalar` object to which
1028 the implementation will write a value of the correct element type. When calling `GrB_set`, the
1029 `GrB_Scalar` must not be empty, otherwise a `GrB_EMPTY_OBJECT` error is raised.

1030 **3.7.1.3 String (char*)**

1031 When the input to `GrB_set` is a `char*`, the input array is a null terminated string. The GraphBLAS
1032 implementation must copy this array into internal data structures. Using `GrB_get` for strings
1033 requires two calls. First, call `GrB_get` with the field and object, but pass `size_t*` as the value
1034 argument. The implementation will return the size of the string buffer that the user must create.
1035 Second, call `GrB_get` with the field and object, this time passing a pointer to the newly created
1036 string buffer. The GraphBLAS implementation will write to this buffer, including a trailing null
1037 terminator. The size returned in the first call will include enough bytes for the null terminator.

1038 **3.7.1.4 void***

1039 When the input to `GrB_set` is a `void*`, an extra `size_t` argument is passed to indicate the size of the
1040 buffer. The GraphBLAS implementation must copy this many bytes from the buffer into internal
1041 data structures. Similar to reading strings, `GrB_get` must be called twice for `void*`. The first call
1042 passes `size_t*` to find the required buffer size. The user must create a buffer and then pass the
1043 pointer to `GrB_get`. The implementation will write to this buffer. No standard specification or
1044 protocol is required for the contents of `void*`. It is meant to be a mechanism to allow full freedom
1045 for GraphBLAS implementations with needs that cannot be handled using `INT32`, `GrB_Scalar`, or
1046 `Strings`.

1047 **3.7.1.5 SIZE**

1048 `SIZE` types use a `size_t` type. Normally, `SIZE` is used in conjunction with `char*` and `void*` to indicate
1049 the buffer size. However, it can also be used when the actual return type is `size_t`, as is the case

1050 for the size of a Type.

1051 3.7.2 Hints

1052 Several fields are *hints* (marked H in Table 3.13). Hints are used to represent intended use cases
1053 or best guesses but do not determine strict behavior. When `GrB_set` is called with a hint, the
1054 GraphBLAS implementation should return `GrB_SUCCESS`, but is free to use or ignore the hint.
1055 When `GrB_get` is called, the implementation should return a best guess of the correct answer. If
1056 there is no clear answer, the implementation should return `GrB_UNKNOWN`.

1057 3.7.3 GrB_NAME

1058 The `GrB_NAME` field is a special case regarding writability. All user-defined objects have a
1059 `GrB_NAME` field which defaults to an empty string. Collections and `GrB_Descriptors` may have
1060 their `GrB_NAME` set at any time. User-defined algebraic objects and `GrB_Types` may only have
1061 their `GrB_NAME` set once to a globally unique value. Attempting to set this field after it has
1062 already been set will return a `GrB_ALREADY_SET` error code.

1063 Built-in algebraic objects and `GrB_Types` have names which can be read but not written to. The
1064 name returned will be the string form of the `GrB_Type` listed in Table 3.2 or the GraphBLAS
1065 identifier listed in Tables 3.5, 3.6, 3.7, 3.8, and 3.9. For example, the name of `GrB_BOOL` type
1066 is "`GrB_BOOL`" (8 characters) and the name of `GrB_MIN_FP64` binary op is "`GrB_MIN_FP64`" (12
1067 characters).

1068 The `GrB_NAME` of the global context is read-only and returns the name of the library implemen-
1069 tation.

Table 3.13: Field values of type GrB_Field enumeration, corresponding types, and the objects which must implement that GrB_Field. Collection refers to GrB_Matrix, GrB_Vector, and GrB_Scalar, Algebraic refers to Operators, Monoids, and Semirings, Type refers to GrB_Type, and Global refers to the GrB_Global context. All fields may be read, some may be written (denoted by W), and some are hints (denoted by H) which may be ignored by the implementation. For * see 3.7

Field Name	W	H	Value	Implementing Objects	Type
GrB_OUTP_FIELD	W	—	0	GrB_Descriptor	INT32 (GrB_Desc_Value)
GrB_MASK_FIELD	W	—	1	GrB_Descriptor	INT32 (GrB_Desc_Value)
GrB_INP0_FIELD	W	—	2	GrB_Descriptor	INT32 (GrB_Desc_Value)
GrB_INP1_FIELD	W	—	3	GrB_Descriptor	INT32 (GrB_Desc_Value)
GrB_NAME	*		10	Global, Collection, Algebraic, Type	Null terminated char*
GrB_LIBRARY_VER_MAJOR	—	—	11	Global	INT32
GrB_LIBRARY_VER_MINOR	—	—	12	Global	INT32
GrB_LIBRARY_VER_PATCH	—	—	13	Global	INT32
GrB_API_VER_MAJOR	—	—	14	Global	INT32
GrB_API_VER_MINOR	—	—	15	Global	INT32
GrB_API_VER_PATCH	—	—	16	Global	INT32
GrB_BLOCKING_MODE	—	—	17	Global	INT32 (GrB_Mode)
GrB_STORAGE_ORIENTATION_HINT	W	H	100	Global, Collection	INT32 (GrB_Orientation)
GrB_EL_TYPE_CODE	—	—	102	Collection, Type	INT32 (GrB_Type_Code)
GrB_INP0_TYPE_CODE	—	—	103	Algebraic	INT32 (GrB_Type_Code)
GrB_INP1_TYPE_CODE	—	—	104	Algebraic	INT32 (GrB_Type_Code)
GrB_OUTP_TYPE_CODE	—	—	105	Algebraic	INT32 (GrB_Type_Code)
GrB_EL_TYPE_STRING	—	—	106	Collection, Type	Null terminated char*
GrB_INP0_TYPE_STRING	—	—	107	Algebraic	Null terminated char*
GrB_INP1_TYPE_STRING	—	—	108	Algebraic	Null terminated char*
GrB_OUTP_TYPE_STRING	—	—	109	Algebraic	Null terminated char*
GrB_SIZE	—	—	110	Type	SIZE

Table 3.14: Descriptions of select *field, value* pairs listed in Table 3.13

Field Name	Description
GrB_NAME	The name of any GraphBLAS object, or the name of the library implementation.
GrB_BLOCKING_MODE	The blocking mode as set by GrB_init
GrB_STORAGE_ORIENTATION_HINT	Hint to the library that a collection is best stored in a row (lexicographic) or column (colexicographic) major format.
GrB_EL_TYPE_(CODE STRING)	The element type of a collection.
GrB_INP0_TYPE_(CODE STRING)	The type of the first argument to an operator. Returns GrB_NO_VALUE for Semirings and IndexUnaryOps which depend only on the index.
GrB_INP1_TYPE_(CODE STRING)	The type of the second argument to an operator. Returns GrB_NO_VALUE for Semirings, UnaryOps, and IndexUnaryOps which depend only on the index.
GrB_OUTP_TYPE_(CODE STRING)	The type of the output of an operator.
GrB_SIZE	The size of the GrB_Type.

1070 3.8 GrB_Info return values

1071 All GraphBLAS methods return a GrB_Info enumeration value. The three types of return codes
 1072 (informational, API error, and execution error) and their corresponding values are listed in Ta-
 1073 ble 3.16.

Table 3.15: Enumerations not defined elsewhere in the documents and used when getting or setting fields are defined in the following tables.

(a) Field values of type GrB_Orientation.

Value Name	Value	Description
GrB_ROWMAJOR	0	The majority of iteration over the object will be row-wise.
GrB_COLMAJOR	1	The majority of iteration over the object will be column-wise.
GrB_BOTH	2	Iteration may occur with equal frequency in both directions.
GrB_UNKNOWN	3	No indication is given or is unknown.

Table 3.16: Enumeration literals and corresponding values returned by GraphBLAS methods and operations.

(a) Informational return values

Symbol	Value	Description
GrB_SUCCESS	0	The method/operation completed successfully (blocking mode), or encountered no API errors (non-blocking mode).
GrB_NO_VALUE	1	A location in a matrix or vector is being accessed that has no stored value at the specified location.

(b) API errors

Symbol	Value	Description
GrB_UNINITIALIZED_OBJECT	-1	The GrB_Type object has not been initialized by a call to GrB_Type_new
GrB_NULL_POINTER	-2	A NULL is passed for a pointer parameter.
GrB_INVALID_VALUE	-3	Miscellaneous incorrect values.
GrB_INVALID_INDEX	-4	Indices passed are larger than dimensions of the matrix or vector being accessed.
GrB_DOMAIN_MISMATCH	-5	A mismatch between domains of collections and operations when user-defined domains are in use.
GrB_DIMENSION_MISMATCH	-6	Operations on matrices and vectors with incompatible dimensions.
GrB_OUTPUT_NOT_EMPTY	-7	An attempt was made to build a matrix or vector using an output object that already contains valid tuples (elements).
GrB_NOT_IMPLEMENTED	-8	An attempt was made to call a GraphBLAS method for a combination of input parameters that is not supported by a particular implementation.
GrB_ALREADY_SET	-9	An attempt was made to write to a field which may only be written to once.

(c) Execution errors

Symbol	Value	Description
GrB_PANIC	-101	Unknown internal error.
GrB_OUT_OF_MEMORY	-102	Not enough memory for operations.
GrB_INSUFFICIENT_SPACE	-103	The array provided is not large enough to hold output.
GrB_INVALID_OBJECT	-104	One of the opaque GraphBLAS objects (input or output) is in an invalid state caused by a previous execution error.
GrB_INDEX_OUT_OF_BOUNDS	-105	Reference to a vector or matrix element that is outside the defined dimensions of the object.
GrB_EMPTY_OBJECT	-106	One of the opaque GraphBLAS objects does not have a stored value.

1074 Chapter 4

1075 Methods

1076 This chapter defines the behavior of all the methods in the GraphBLAS C API. All methods can
1077 be declared for use in programs by including the `GraphBLAS.h` header file.

1078 We would like to emphasize that no GraphBLAS method will imply a predefined order over any
1079 associative operators. Implementations of the GraphBLAS are encouraged to exploit associativity
1080 to optimize performance of any GraphBLAS method. This holds even if the definition of the
1081 GraphBLAS method implies a fixed order for the associative operations.

1082 4.1 Context methods

1083 The methods in this section set up and tear down the GraphBLAS context within which all Graph-
1084 BLAS methods must be executed. The initialization of this context also includes the specification
1085 of which execution mode is to be used.

1086 4.1.1 `init`: Initialize a GraphBLAS context

1087 Creates and initializes a GraphBLAS C API context.

1088 C Syntax

```
1089     GrB_Info GrB_init(GrB_Mode mode);
```

1090 Parameters

1091 mode Mode for the GraphBLAS context. Must be either `GrB_BLOCKING` or `GrB_NONBLOCKING`.

1092 **Return Values**

1093 `GrB_SUCCESS` operation completed successfully.

1094 `GrB_PANIC` unknown internal error.

1095 `GrB_INVALID_VALUE` invalid mode specified, or method called multiple times.

1096 **Description**

1097 The `init` method creates and initializes a GraphBLAS C API context. The argument to `GrB_init`
1098 defines the mode for the context. The two available modes are:

- 1099 • `GrB_BLOCKING`: In this mode, each method in a sequence returns after its computations have
1100 completed and output arguments are available to subsequent statements in an application.
1101 When executing in `GrB_BLOCKING` mode, the methods execute in program order.
- 1102 • `GrB_NONBLOCKING`: In this mode, methods in a sequence may return after arguments in
1103 the method have been tested for dimension and domain compatibility within the method
1104 but potentially before their computations complete. Output arguments are available to sub-
1105 sequent GraphBLAS methods in an application. When executing in `GrB_NONBLOCKING`
1106 mode, the methods in a sequence may execute in any order that preserves the mathematical
1107 result defined by the sequence.

1108 An application can only create one context per execution instance. An application may only call
1109 `GrB_init` once. Calling `GrB_init` more than once results in undefined behavior.

1110 **4.1.2 finalize: Finalize a GraphBLAS context**

1111 Terminates and frees any internal resources created to support the GraphBLAS C API context.

1112 **C Syntax**

```
1113 GrB_Info GrB_finalize();
```

1114 **Return Values**

1115 `GrB_SUCCESS` operation completed successfully.

1116 `GrB_PANIC` unknown internal error.

1117 **Description**

1118 The `finalize` method terminates and frees any internal resources created to support the GraphBLAS
1119 C API context. `GrB_finalize` may only be called after a context has been initialized by calling
1120 `GrB_init`, or else undefined behavior occurs. After `GrB_finalize` has been called to finalize a Graph-
1121 BLAS context, calls to any GraphBLAS methods, including `GrB_finalize`, will result in undefined
1122 behavior.

1123 **4.1.3 getVersion: Get the version number of the standard.**

1124 Query the library for the version number of the standard that this library implements.

1125 **C Syntax**

```
1126         GrB_Info GrB_getVersion(unsigned int *version,  
1127                               unsigned int *subversion);
```

1128 **Parameters**

1129 `version` (OUT) On successful return will hold the value of the major version number.

1130 `subversion` (OUT) On successful return will hold the value of the subversion number.

1131 **Return Values**

1132 `GrB_SUCCESS` operation completed successfully.

1133 `GrB_PANIC` unknown internal error.

1134 **Description**

1135 The `getVersion` method is used to query the major and minor version number of the GraphBLAS
1136 C API specification that the library implements at runtime. To support compile time queries the
1137 following two macros shall also be defined by the library.

```
1138         #define GRB_VERSION      2  
1139         #define GRB_SUBVERSION  0
```

1140 **4.2 Object methods**

1141 This section describes methods that setup and operate on GraphBLAS opaque objects but are not
1142 part of the the GraphBLAS math specification.

1143 4.2.1 Get and Set methods

1144 The methods in this section query and, optionally, set internal fields of GraphBLAS objects.

1145 4.2.1.1 get: Query the value of a field for an object

1146 Get the content of a field for an existing GraphBLAS object.

1147 C Syntax

```
1148     GrB_Info GrB_get(GrB_<OBJ> obj, <type> value, GrB_Field field);
```

1149 Parameters

1150 obj (IN) An existing, valid GraphBLAS object (collection, operation, type) which is
1151 being queried. To indicate the global context, the constant `GrB_Global` is used.

1152 value (OUT) A pointer to or `GrB_Scalar` containing a value whose type is dependent on
1153 field which will be filled with the current value of the field. `type` may be `int32_t*`,
1154 `size_t*`, `GrB_Scalar`, `char*` or `void*`.

1155 field (IN) The field being queried.

1156 Return Value

1157 `GrB_SUCCESS` The method completed successfully.

1158 `GrB_PANIC` unknown internal error.

1159 `GrB_OUT_OF_MEMORY` not enough memory available for operation.

1160 `GrB_UNINITIALIZED_OBJECT` the value parameter is `GrB_Scalar` and has not been initialized by
1161 a call to the appropriate `new` method.

1162 `GrB_INVALID_VALUE` invalid value type provided for the field or invalid field.

1163 Description

1164 This method queries a field of an existing GraphBLAS object. The type of the argument is uniquely
1165 determined by field. For the case of `char*` and `void*`, the value can be replaced with `size_t*` to get
1166 the required buffer size to hold the response. Fields marked as hints in Table 3.13 will return a
1167 hint on how best to use the object.

1168 **4.2.1.2 set: Set a field for an object**

1169 Set the content of a field for an existing GraphBLAS object.

1170 **C Syntax**

```
1171 GrB_Info GrB_set(GrB_<OBJ> obj, <type> value, GrB_Field field);  
1172 GrB_Info GrB_set(GrB_<OBJ> obj, void *value, GrB_Field field, size_t voidSize);
```

1173 **Parameters**

1174 obj (IN) The GraphBLAS object which is having its field set. To indi-
1175 cate the global context, the constant GrB_Global is used.

1176 value (IN) A value whose type is dependent on field. type may be a
1177 int32_t, GrB_Scalar, char* or void*.

1178 field (IN) The field being set.

1179 voidSize (IN) The size of the void* buffer. Note that a size is not needed for
1180 char* because the string is assumed null-terminated.

1181 **Return Values**

1182 GrB_SUCCESS The method completed successfully.

1183 GrB_PANIC unknown internal error.

1184 GrB_OUT_OF_MEMORY not enough memory available for operation.

1185 GrB_UNINITIALIZED_OBJECT the GrB_Scalar parameter has not been initialized by a call to the
1186 appropriate new method.

1187 GrB_INVALID_VALUE invalid value set on the field, invalid field, or field is read-only.

1188 GrB_ALREADY_SET this field has already been set, and may only be set once.

1189 **Description**

1190 This method sets a field of obj or the Global context to a new value.

1191 4.2.2 Algebra methods

1192 4.2.2.1 Type_new: Construct a new GraphBLAS (user-defined) type

1193 Creates a new user-defined GraphBLAS type. This type can then be used to create new operators,
1194 monoids, semirings, vectors and matrices.

1195 C Syntax

```
1196         GrB_Info GrB_Type_new(GrB_Type  *utype,  
1197                             size_t     sizeof(ctype));
```

1198 Parameters

1199 utype (INOUT) On successful return, contains a handle to the newly created user-defined
1200 GraphBLAS type object.

1201 ctype (IN) A C type that defines the new GraphBLAS user-defined type.

1202 Return Values

1203 GrB_SUCCESS operation completed successfully.

1204 GrB_PANIC unknown internal error.

1205 GrB_OUT_OF_MEMORY not enough memory available for operation.

1206 GrB_NULL_POINTER utype pointer is NULL.

1207 Description

1208 Given a C type ctype, the Type_new method returns in utype a handle to a new GraphBLAS type
1209 that is equivalent to the C type. Variables of this ctype must be a struct, union, or fixed-size array.
1210 In particular, given two variables, src and dst, of type ctype, the following operation must be a
1211 valid way to copy the contents of src to dst:

```
1212         memcpy(&dst, &src, sizeof(ctype))
```

1213 A new, user-defined type utype should be destroyed with a call to GrB_free(utype) when no longer
1214 needed.

1215 It is not an error to call this method more than once on the same variable; however, the handle to
1216 the previously created object will be overwritten.

1217 **4.2.2.2 UnaryOp_new: Construct a new GraphBLAS unary operator**

1218 Initializes a new GraphBLAS unary operator with a specified user-defined function and its types
1219 (domains).

1220 **C Syntax**

```
1221     GrB_Info GrB_UnaryOp_new(GrB_UnaryOp *unary_op,  
1222                             void          (*unary_func)(void*, const void*),  
1223                             GrB_Type      d_out,  
1224                             GrB_Type      d_in);
```

1225 **Parameters**

1226 unary_op (INOUT) On successful return, contains a handle to the newly created GraphBLAS
1227 unary operator object.

1228 unary_func (IN) a pointer to a user-defined function that takes one input parameter of d_in's
1229 type and returns a value of d_out's type, both passed as void pointers. Specifically
1230 the signature of the function is expected to be of the form:

```
1231         void func(void *out, const void *in);  
1232
```

1233 d_out (IN) The GrB_Type of the return value of the unary operator being created. Should
1234 be one of the predefined GraphBLAS types in Table 3.2, or a user-defined Graph-
1235 BLAS type.

1236 d_in (IN) The GrB_Type of the input argument of the unary operator being created.
1237 Should be one of the predefined GraphBLAS types in Table 3.2, or a user-defined
1238 GraphBLAS type.

1239 **Return Values**

1240 GrB_SUCCESS operation completed successfully.

1241 GrB_PANIC unknown internal error.

1242 GrB_OUT_OF_MEMORY not enough memory available for operation.

1243 GrB_UNINITIALIZED_OBJECT any GrB_Type parameter (for user-defined types) has not been ini-
1244 tialized by a call to GrB_Type_new.

1245 GrB_NULL_POINTER unary_op or unary_func pointers are NULL.

1246 **Description**

1247 The `UnaryOp_new` method creates a new GraphBLAS unary operator

1248 $f_u = \langle \mathbf{D}(d_out), \mathbf{D}(d_in), unary_func \rangle$

1249 and returns a handle to it in `unary_op`.

1250 The implementation of `unary_func` must be such that it works even if the `d_out` and `d_in` arguments
1251 are aliased. In other words, for all invocations of the function:

1252 `unary_func(out, in);`

1253 the value of `out` must be the same as if the following code was executed:

```
1254     D(d_in) *tmp = malloc(sizeof(D(d_in)));  
1255     memcpy(tmp, in, sizeof(D(d_in)));  
1256     unary_func(out, tmp);  
1257     free(tmp);
```

1258 It is not an error to call this method more than once on the same variable; however, the handle to
1259 the previously created object will be overwritten.

1260 **4.2.2.3 BinaryOp_new: Construct a new GraphBLAS binary operator**

1261 Initializes a new GraphBLAS binary operator with a specified user-defined function and its types
1262 (domains).

1263 **C Syntax**

```
1264     GrB_Info GrB_BinaryOp_new(GrB_BinaryOp *binary_op,  
1265                             void          (*binary_func)(void*,  
1266                                                         const void*,  
1267                                                         const void*),  
1268                             GrB_Type      d_out,  
1269                             GrB_Type      d_in1,  
1270                             GrB_Type      d_in2);
```

1271 **Parameters**

1272 `binary_op` (INOUT) On successful return, contains a handle to the newly created GraphBLAS
1273 binary operator object.

1274 `binary_func` (IN) A pointer to a user-defined function that takes two input parameters of types
1275 `d_in1` and `d_in2` and returns a value of type `d_out`, all passed as void pointers.
1276 Specifically the signature of the function is expected to be of the form:

```
1277         void func(void *out, const void *in1, const void *in2);  
1278
```

1279 `d_out` (IN) The `GrB_Type` of the return value of the binary operator being created. Should
1280 be one of the predefined GraphBLAS types in Table 3.2, or a user-defined Graph-
1281 BLAS type.

1282 `d_in1` (IN) The `GrB_Type` of the left hand argument of the binary operator being created.
1283 Should be one of the predefined GraphBLAS types in Table 3.2, or a user-defined
1284 GraphBLAS type.

1285 `d_in2` (IN) The `GrB_Type` of the right hand argument of the binary operator being cre-
1286 ated. Should be one of the predefined GraphBLAS types in Table 3.2, or a user-
1287 defined GraphBLAS type.

1288 Return Values

1289 `GrB_SUCCESS` operation completed successfully.

1290 `GrB_PANIC` unknown internal error.

1291 `GrB_OUT_OF_MEMORY` not enough memory available for operation.

1292 `GrB_UNINITIALIZED_OBJECT` the `GrB_Type` (for user-defined types) has not been initialized by a
1293 call to `GrB_Type_new`.

1294 `GrB_NULL_POINTER` `binary_op` or `binary_func` pointer is NULL.

1295 Description

1296 The `BinaryOp_new` methods creates a new GraphBLAS binary operator

```
1297      $f_b = \langle \mathbf{D}(d\_out), \mathbf{D}(d\_in1), \mathbf{D}(d\_in2), binary\_func \rangle$ 
```

1298 and returns a handle to it in `binary_op`.

1299 The implementation of `binary_func` must be such that it works even if any of the `d_out`, `d_in1`, and
1300 `d_in2` arguments are aliased to each other. In other words, for all invocations of the function:

```
1301     binary_func(out, in1, in2);
```

1302 the value of `out` must be the same as if the following code was executed:

```

1303     D(d_in1) *tmp1 = malloc(sizeof(D(d_in1)));
1304     D(d_in2) *tmp2 = malloc(sizeof(D(d_in2)));
1305     memcpy(tmp1,in1,sizeof(D(d_in1)));
1306     memcpy(tmp2,in2,sizeof(D(d_in2)));
1307     binary_func(out,tmp1,tmp2);
1308     free(tmp2);
1309     free(tmp1);

```

1310 It is not an error to call this method more than once on the same variable; however, the handle to
1311 the previously created object will be overwritten.

1312 4.2.2.4 Monoid_new: Construct a new GraphBLAS monoid

1313 Creates a new monoid with specified binary operator and identity value.

1314 C Syntax

```

1315     GrB_Info GrB_Monoid_new(GrB_Monoid *monoid,
1316                           GrB_BinaryOp binary_op,
1317                           <type>      identity);

```

1318 Parameters

1319 **monoid** (INOUT) On successful return, contains a handle to the newly created GraphBLAS
1320 monoid object.

1321 **binary_op** (IN) An existing GraphBLAS associative binary operator whose input and output
1322 types are the same.

1323 **identity** (IN) The value of the identity element of the monoid. Must be the same type as
1324 the type used by the **binary_op** operator.

1325 Return Values

1326 **GrB_SUCCESS** operation completed successfully.

1327 **GrB_PANIC** unknown internal error.

1328 **GrB_OUT_OF_MEMORY** not enough memory available for operation.

1329 **GrB_UNINITIALIZED_OBJECT** the **GrB_BinaryOp** (for user-defined operators) has not been initial-
1330 ized by a call to **GrB_BinaryOp_new**.

1331 **GrB_NULL_POINTER** monoid pointer is NULL.

1332 **GrB_DOMAIN_MISMATCH** all three argument types of the binary operator and the type of the
1333 identity value are not the same.

1334 **Description**

1335 The `Monoid_new` method creates a new monoid $M = \langle \mathbf{D}(\text{binary_op}), \text{binary_op}, \text{identity} \rangle$ and re-
1336 turns a handle to it in `monoid`.

1337 If `binary_op` is not associative, the results of GraphBLAS operations that require associativity of
1338 this monoid will be undefined.

1339 It is not an error to call this method more than once on the same variable; however, the handle to
1340 the previously created object will be overwritten.

1341 **4.2.2.5 Semiring_new: Construct a new GraphBLAS semiring**

1342 Creates a new semiring with specified domain, operators, and elements.

1343 **C Syntax**

```
1344         GrB_Info GrB_Semiring_new(GrB_Semiring *semiring,  
1345                                 GrB_Monoid   add_op,  
1346                                 GrB_BinaryOp  mul_op);
```

1347 **Parameters**

1348 `semiring` (INOUT) On successful return, contains a handle to the newly created GraphBLAS
1349 `semiring`.

1350 `add_op` (IN) An existing GraphBLAS commutative monoid that specifies the addition op-
1351 erator and its identity.

1352 `mul_op` (IN) An existing GraphBLAS binary operator that specifies the semiring's multi-
1353 plication operator. In addition, `mul_op`'s output domain, $\mathbf{D}_{out}(\text{mul_op})$, must be
1354 the same as the `add_op`'s domain $\mathbf{D}(\text{add_op})$.

1355 **Return Values**

1356 `GrB_SUCCESS` operation completed successfully.

1357 `GrB_PANIC` unknown internal error.

1358 `GrB_OUT_OF_MEMORY` not enough memory available for this method to complete.

1359 `GrB_UNINITIALIZED_OBJECT` the `add_op` (for user-define monoids) object has not been initialized
1360 with a call to `GrB_Monoid_new` or the `mul_op` (for user-defined
1361 operators) object has not been not been initialized by a call to
1362 `GrB_BinaryOp_new`.

1363 GrB_NULL_POINTER semiring pointer is NULL.

1364 GrB_DOMAIN_MISMATCH the output domain of mul_op does not match the domain of the
1365 add_op monoid.

1366 Description

1367 The Semiring_new method creates a new semiring:

1368 $S = \langle \mathbf{D}_{out}(\text{mul_op}), \mathbf{D}_{in_1}(\text{mul_op}), \mathbf{D}_{in_2}(\text{mul_op}), \text{add_op}, \text{mul_op}, \mathbf{0}(\text{add_op}) \rangle$

1369 and returns a handle to it in semiring. Note that $\mathbf{D}_{out}(\text{mul_op})$ must be the same as $\mathbf{D}(\text{add_op})$.

1370 If add_op is not commutative, then GraphBLAS operations using this semiring will be undefined.

1371 It is not an error to call this method more than once on the same variable; however, the handle to
1372 the previously created object will be overwritten.

1373 4.2.2.6 IndexUnaryOp_new: Construct a new GraphBLAS index unary operator

1374 Initializes a new GraphBLAS index unary operator with a specified user-defined function and its
1375 types (domains).

1376 C Syntax

```
1377 GrB_Info GrB_IndexUnaryOp_new(GrB_IndexUnaryOp *index_unary_op,  
1378                               void (*index_unary_func)(void*,  
1379                                                         const void*,  
1380                                                         GrB_Index,  
1381                                                         GrB_Index,  
1382                                                         const void*),  
1383                               GrB_Type d_out,  
1384                               GrB_Type d_in1,  
1385                               GrB_Type d_in2);
```

1386 Parameters

1387 index_unary_op (INOUT) On successful return, contains a handle to the newly created Graph-
1388 BLAS index unary operator object.

1389 index_unary_func (IN) A pointer to a user-defined function that takes input parameters of types
1390 d_in1, GrB_Index, GrB_Index and d_in2 and returns a value of type d_out. Ex-
1391 cept for the GrB_Index parameters, all are passed as void pointers. Specifically
1392 the signature of the function is expected to be of the form:

```

1393         void func(void      *out,
1394                  const void *in1,
1395                  GrB_Index  row_index,
1396                  GrB_Index  col_index,
1397                  const void *in2);
1398

```

1399 **d_out** (IN) The GrB_Type of the return value of the index unary operator being created.
1400 Should be one of the predefined GraphBLAS types in Table 3.2, or a user-defined
1401 GraphBLAS type.

1402 **d_in1** (IN) The GrB_Type of the first input argument of the index unary operator being
1403 created and corresponds to the stored values of the GrB_Vector or GrB_Matrix
1404 being operated on. Should be one of the predefined GraphBLAS types in Ta-
1405 ble 3.2, or a user-defined GraphBLAS type.

1406 **d_in2** (IN) The GrB_Type of the last input argument of the index unary operator be-
1407 ing created and corresponds to a scalar provided by the GraphBLAS operation
1408 that uses this operator. Should be one of the predefined GraphBLAS types in
1409 Table 3.2, or a user-defined GraphBLAS type.

1410 Return Values

1411 GrB_SUCCESS operation completed successfully.

1412 GrB_PANIC unknown internal error.

1413 GrB_OUT_OF_MEMORY not enough memory available for operation.

1414 GrB_UNINITIALIZED_OBJECT the GrB_Type (for user-defined types) has not been initialized by a
1415 call to GrB_Type_new.

1416 GrB_NULL_POINTER index_unary_op or index_unary_func pointer is NULL.

1417 Description

1418 The IndexUnaryOp_new methods creates a new GraphBLAS index unary operator

1419 $f_i = \langle \mathbf{D}(d_out), \mathbf{D}(d_in1), \mathbf{D}(GrB_Index), \mathbf{D}(GrB_Index), \mathbf{D}(d_in2), index_unary_func) \rangle$

1420 and returns a handle to it in index_unary_op.

1421 The implementation of index_unary_func must be such that it works even if any of the d_out,
1422 d_in1, and d_in2 arguments are aliased to each other. In other words, for all invocations of the
1423 function:

```

1424 index_unary_func(out, in1, row_index, col_index, n, in2);

```

1425 the value of out must be the same as if the following code was executed (shown here for matrices):

```
1426     GrB_Index row_index = ...;
1427     GrB_Index col_index = ...;
1428     D(d_in1) *tmp1 = malloc(sizeof(D(d_in1)));
1429     D(d_in2) *tmp2 = malloc(sizeof(D(d_in2)));
1430     memcpy(tmp1,in1,sizeof(D(d_in1)));
1431     memcpy(tmp2,in2,sizeof(D(d_in2)));
1432     index_unary_func(out,tmp1,row_index,col_index,tmp2);
1433     free(tmp2);
1434     free(tmp1);
```

1435 It is not an error to call this method more than once on the same variable; however, the handle to
1436 the previously created object will be overwritten.

1437 4.2.3 Scalar methods

1438 4.2.3.1 Scalar_new: Construct a new scalar

1439 Creates a new empty scalar with specified domain.

1440 C Syntax

```
1441     GrB_Info GrB_Scalar_new(GrB_Scalar *s,
1442                             GrB_Type    d);
```

1443 Parameters

1444 s (INOUT) On successful return, contains a handle to the newly created GraphBLAS
1445 scalar.

1446 d (IN) The type corresponding to the domain of the scalar being created. Can be
1447 one of the predefined GraphBLAS types in Table 3.2, or an existing user-defined
1448 GraphBLAS type.

1449 Return Values

1450 GrB_SUCCESS In blocking mode, the operation completed successfully. In non-
1451 blocking mode, this indicates that the API checks for the input
1452 arguments passed successfully. Either way, output scalar s is ready
1453 to be used in the next method of the sequence.

1454 GrB_PANIC Unknown internal error.

1455 GrB_INVALID_OBJECT This is returned in any execution mode whenever one of the opaque
1456 GraphBLAS objects (input or output) is in an invalid state caused
1457 by a previous execution error. Call GrB_error() to access any error
1458 messages generated by the implementation.

1459 GrB_OUT_OF_MEMORY Not enough memory available for operation.

1460 GrB_UNINITIALIZED_OBJECT The GrB_Type object has not been initialized by a call to GrB_Type_new
1461 (needed for user-defined types).

1462 GrB_NULL_POINTER The s pointer is NULL.

1463 **Description**

1464 Creates a new GraphBLAS scalar s of domain $\mathbf{D}(d)$ and empty $\mathbf{L}(s)$. The method returns a handle
1465 to the new scalar in s .

1466 It is not an error to call this method more than once on the same variable; however, the handle to
1467 the previously created object will be overwritten.

1468 **4.2.3.2 Scalar_dup: Construct a copy of a GraphBLAS scalar**

1469 Creates a new scalar with the same domain and contents as another scalar.

1470 **C Syntax**

```
1471           GrB_Info GrB_Scalar_dup(GrB_Scalar        *t,  
1472                                    const GrB_Scalar  s);
```

1473 **Parameters**

1474 t (INOUT) On successful return, contains a handle to the newly created GraphBLAS
1475 scalar.

1476 s (IN) The GraphBLAS scalar to be duplicated.

1477 **Return Values**

1478 GrB_SUCCESS In blocking mode, the operation completed successfully. In non-
1479 blocking mode, this indicates that the API checks for the input
1480 arguments passed successfully. Either way, output scalar t is ready
1481 to be used in the next method of the sequence.

1482 GrB_PANIC Unknown internal error.

1483 GrB_INVALID_OBJECT This is returned in any execution mode whenever one of the opaque
1484 GraphBLAS objects (input or output) is in an invalid state caused
1485 by a previous execution error. Call GrB_error() to access any error
1486 messages generated by the implementation.

1487 GrB_OUT_OF_MEMORY Not enough memory available for operation.

1488 GrB_UNINITIALIZED_OBJECT The GraphBLAS scalar, *s*, has not been initialized by a call to
1489 Scalar_new or Scalar_dup.

1490 GrB_NULL_POINTER The *t* pointer is NULL.

1491 Description

1492 Creates a new scalar *t* of domain $\mathbf{D}(s)$ and contents $\mathbf{L}(s)$. The method returns a handle to the new
1493 scalar in *t*.

1494 It is not an error to call this method more than once with the same output variable; however, the
1495 handle to the previously created object will be overwritten.

1496 4.2.3.3 Scalar_clear: Clear/remove a stored value from a scalar

1497 Removes the stored value from a scalar.

1498 C Syntax

```
1499           GrB_Info GrB_Scalar_clear(GrB_Scalar s);
```

1500 Parameters

1501 *s* (INOUT) An existing GraphBLAS scalar to clear.

1502 Return Values

1503 GrB_SUCCESS In blocking mode, the operation completed successfully. In non-
1504 blocking mode, this indicates that the API checks for the input
1505 arguments passed successfully. Either way, output scalar *s* is ready
1506 to be used in the next method of the sequence.

1507 GrB_PANIC Unknown internal error.

1508 GrB_INVALID_OBJECT This is returned in any execution mode whenever one of the opaque
1509 GraphBLAS objects (input or output) is in an invalid state caused
1510 by a previous execution error. Call GrB_error() to access any error
1511 messages generated by the implementation.

1512 GrB_OUT_OF_MEMORY Not enough memory available for operation.

1513 GrB_UNINITIALIZED_OBJECT The GraphBLAS scalar, *s*, has not been initialized by a call to
1514 Scalar_new or Scalar_dup.

1515 **Description**

1516 Removes the stored value from an existing scalar. After the call, **L(s)** is empty. The size of the
1517 scalar does not change.

1518 **4.2.3.4 Scalar_nvals: Number of stored elements in a scalar**

1519 Retrieve the number of stored elements in a scalar (either zero or one).

1520 **C Syntax**

```
1521        GrB_Info GrB_Scalar_nvals(GrB_Index        *nvals,  
1522                                                    const GrB_Scalar s);
```

1523 **Parameters**

1524 *nvals* (OUT) On successful return, this is set to the number of stored elements in the
1525 scalar (zero or one).

1526 *s* (IN) An existing GraphBLAS scalar being queried.

1527 **Return Values**

1528 GrB_SUCCESS In blocking or non-blocking mode, the operation completed suc-
1529 cessfully and the value of *nvals* has been set.

1530 GrB_PANIC Unknown internal error.

1531 GrB_INVALID_OBJECT This is returned in any execution mode whenever one of the opaque
1532 GraphBLAS objects (input or output) is in an invalid state caused
1533 by a previous execution error. Call GrB_error() to access any error
1534 messages generated by the implementation.

1535 GrB_OUT_OF_MEMORY Not enough memory available for operation.

1536 GrB_UNINITIALIZED_OBJECT The GraphBLAS scalar, *s*, has not been initialized by a call to
1537 Scalar_new or Scalar_dup.

1538 GrB_NULL_POINTER The *nvals* pointer is NULL.

1539 **Description**

1540 Return `nvals(s)` in `nvals`. This is the number of stored elements in scalar `s`, which is the size of
1541 `L(s)`, and can only be either zero or one (see Section 3.5.1).

1542 **4.2.3.5 Scalar_setElement: Set the single element in a scalar**

1543 Set the single element of a scalar to a given value.

1544 **C Syntax**

```
1545         GrB_Info GrB_Scalar_setElement(GrB_Scalar  s,  
1546                                     <type>      val);
```

1547 **Parameters**

1548 `s` (INOUT) An existing GraphBLAS scalar for which the element is to be assigned.

1549 `val` (IN) Scalar value to assign. The type must be compatible with the domain of `s`.

1550 **Return Values**

1551 `GrB_SUCCESS` In blocking mode, the operation completed successfully. In non-
1552 blocking mode, this indicates that the compatibility tests on in-
1553 dex/dimensions and domains for the input arguments passed suc-
1554 cessfully. Either way, the output scalar `s` is ready to be used in the
1555 next method of the sequence.

1556 `GrB_PANIC` Unknown internal error.

1557 `GrB_INVALID_OBJECT` This is returned in any execution mode whenever one of the opaque
1558 GraphBLAS objects (input or output) is in an invalid state caused
1559 by a previous execution error. Call `GrB_error()` to access any error
1560 messages generated by the implementation.

1561 `GrB_OUT_OF_MEMORY` Not enough memory available for operation.

1562 `GrB_UNINITIALIZED_OBJECT` The GraphBLAS scalar, `s`, has not been initialized by a call to
1563 `Scalar_new` or `Scalar_dup`.

1564 `GrB_DOMAIN_MISMATCH` The domains of `s` and `val` are incompatible.

1565 **Description**

1566 First, `val` and output GraphBLAS scalar are tested for domain compatibility as follows: $\mathbf{D}(\text{val})$ must
1567 be compatible with $\mathbf{D}(s)$. Two domains are compatible with each other if values from one domain
1568 can be cast to values in the other domain as per the rules of the C language. In particular, domains
1569 from Table 3.2 are all compatible with each other. A domain from a user-defined type is only com-
1570 patible with itself. If any compatibility rule above is violated, execution of `GrB_Scalar_setElement`
1571 ends and the domain mismatch error listed above is returned.

1572 We are now ready to carry out the assignment `val`; that is:

1573
$$s(0) = \text{val}$$

1574 If `s` already had a stored value, it will be overwritten; otherwise, the new value is stored in `s`.

1575 In `GrB_BLOCKING` mode, the method exits with return value `GrB_SUCCESS` and the new contents
1576 of `s` is as defined above and fully computed. In `GrB_NONBLOCKING` mode, the method exits with
1577 return value `GrB_SUCCESS` and the new content of scalar `s` is as defined above but may not be
1578 fully computed; however, it can be used in the next GraphBLAS method call in a sequence.

1579 **4.2.3.6 Scalar_extractElement: Extract a single element from a scalar.**

1580 Assign a non-opaque scalar with the value of the element stored in a GraphBLAS scalar.

1581 **C Syntax**

```
1582     GrB_Info GrB_Scalar_extractElement(<type>          *val,  
1583                                     const GrB_Scalar s);
```

1584 **Parameters**

1585 `val` (INOUT) Pointer to a non-opaque scalar of type that is compatible with the domain
1586 of scalar `s`. On successful return, `val` holds the result of the operation, and any
1587 previous value in `val` is overwritten.

1588 `s` (IN) The GraphBLAS scalar from which an element is extracted.

1589 **Return Values**

1590 `GrB_SUCCESS` In blocking or non-blocking mode, the operation completed suc-
1591 cessfully. This indicates that the compatibility tests on dimensions
1592 and domains for the input arguments passed successfully, and the
1593 output scalar, `val`, has been computed and is ready to be used in
1594 the next method of the sequence.

1595 `GrB_PANIC` Unknown internal error.

1626 **Parameters**

- 1627 **v** (INOUT) On successful return, contains a handle to the newly created GraphBLAS
1628 vector.
- 1629 **d** (IN) The type corresponding to the domain of the vector being created. Can be
1630 one of the predefined GraphBLAS types in Table 3.2, or an existing user-defined
1631 GraphBLAS type.
- 1632 **nsiz**e (IN) The size of the vector being created.

1633 **Return Values**

- 1634 **GrB_SUCCESS** In blocking mode, the operation completed successfully. In non-
1635 blocking mode, this indicates that the API checks for the input
1636 arguments passed successfully. Either way, output vector **v** is ready
1637 to be used in the next method of the sequence.
- 1638 **GrB_PANIC** Unknown internal error.
- 1639 **GrB_INVALID_OBJECT** This is returned in any execution mode whenever one of the opaque
1640 GraphBLAS objects (input or output) is in an invalid state caused
1641 by a previous execution error. Call **GrB_error()** to access any error
1642 messages generated by the implementation.
- 1643 **GrB_OUT_OF_MEMORY** Not enough memory available for operation.
- 1644 **GrB_UNINITIALIZED_OBJECT** The **GrB_Type** object has not been initialized by a call to **GrB_Type_new**
1645 (needed for user-defined types).
- 1646 **GrB_NULL_POINTER** The **v** pointer is NULL.
- 1647 **GrB_INVALID_VALUE** **nsiz**e is zero or outside the range of the type **GrB_Index**.

1648 **Description**

- 1649 Creates a new vector **v** of domain **D(d)**, size **nsiz**e, and empty **L(v)**. The method returns a handle
1650 to the new vector in **v**.
- 1651 It is not an error to call this method more than once on the same variable; however, the handle to
1652 the previously created object will be overwritten.

1653 **4.2.4.2 Vector_dup: Construct a copy of a GraphBLAS vector**

- 1654 Creates a new vector with the same domain, size, and contents as another vector.

1655 **C Syntax**

```
1656         GrB_Info GrB_Vector_dup(GrB_Vector      *w,  
1657                               const GrB_Vector u);
```

1658 **Parameters**

1659 **w** (INOUT) On successful return, contains a handle to the newly created GraphBLAS
1660 vector.

1661 **u** (IN) The GraphBLAS vector to be duplicated.

1662 **Return Values**

1663 **GrB_SUCCESS** In blocking mode, the operation completed successfully. In non-
1664 blocking mode, this indicates that the API checks for the input
1665 arguments passed successfully. Either way, output vector **w** is ready
1666 to be used in the next method of the sequence.

1667 **GrB_PANIC** Unknown internal error.

1668 **GrB_INVALID_OBJECT** This is returned in any execution mode whenever one of the opaque
1669 GraphBLAS objects (input or output) is in an invalid state caused
1670 by a previous execution error. Call **GrB_error()** to access any error
1671 messages generated by the implementation.

1672 **GrB_OUT_OF_MEMORY** Not enough memory available for operation.

1673 **GrB_UNINITIALIZED_OBJECT** The GraphBLAS vector, **u**, has not been initialized by a call to
1674 **Vector_new** or **Vector_dup**.

1675 **GrB_NULL_POINTER** The **w** pointer is NULL.

1676 **Description**

1677 Creates a new vector **w** of domain **D(u)**, size **size(u)**, and contents **L(u)**. The method returns a
1678 handle to the new vector in **w**.

1679 It is not an error to call this method more than once on the same variable; however, the handle to
1680 the previously created object will be overwritten.

1681 **4.2.4.3 Vector_resize: Resize a vector**

1682 Changes the size of an existing vector.

1683 **C Syntax**

```
1684         GrB_Info GrB_Vector_resize(GrB_Vector  w,  
1685                                   GrB_Index   nsize);
```

1686 **Parameters**

1687 `w` (INOUT) An existing Vector object that is being resized.

1688 `nsize` (IN) The new size of the vector. It can be smaller or larger than the current size.

1689 **Return Values**

1690 `GrB_SUCCESS` In blocking mode, the operation completed successfully. In non-
1691 blocking mode, this indicates that the API checks for the input
1692 arguments passed successfully. Either way, output vector `w` is ready
1693 to be used in the next method of the sequence.

1694 `GrB_PANIC` Unknown internal error.

1695 `GrB_INVALID_OBJECT` This is returned in any execution mode whenever one of the opaque
1696 GraphBLAS objects (input or output) is in an invalid state caused
1697 by a previous execution error. Call `GrB_error()` to access any error
1698 messages generated by the implementation.

1699 `GrB_OUT_OF_MEMORY` Not enough memory available for operation.

1700 `GrB_NULL_POINTER` The `w` pointer is NULL.

1701 `GrB_INVALID_VALUE` `nsize` is zero or outside the range of the type `GrB_Index`.

1702 **Description**

1703 Changes the size of `w` to `nsize`. The domain $\mathbf{D}(w)$ of vector `w` remains the same. The contents $\mathbf{L}(w)$
1704 are modified as described below.

1705 Let $w = \langle \mathbf{D}(w), N, \mathbf{L}(w) \rangle$ when the method is called. When the method returns, $w = \langle \mathbf{D}(w), nsize, \mathbf{L}'(w) \rangle$
1706 where $\mathbf{L}'(w) = \{(i, w_i) : (i, w_i) \in \mathbf{L}(w) \wedge (i < nsize)\}$. That is, all elements of `w` with index greater
1707 than or equal to the new vector size (`nsize`) are dropped.

1708 **4.2.4.4 Vector_clear: Clear a vector**

1709 Removes all the elements (tuples) from a vector.

1710 **C Syntax**

1711 `GrB_Info GrB_Vector_clear(GrB_Vector v);`

1712 **Parameters**

1713 `v` (INOUT) An existing GraphBLAS vector to clear.

1714 **Return Values**

1715 `GrB_SUCCESS` In blocking mode, the operation completed successfully. In non-
1716 blocking mode, this indicates that the API checks for the input
1717 arguments passed successfully. Either way, output vector `v` is ready
1718 to be used in the next method of the sequence.

1719 `GrB_PANIC` Unknown internal error.

1720 `GrB_INVALID_OBJECT` This is returned in any execution mode whenever one of the opaque
1721 GraphBLAS objects (input or output) is in an invalid state caused
1722 by a previous execution error. Call `GrB_error()` to access any error
1723 messages generated by the implementation.

1724 `GrB_OUT_OF_MEMORY` Not enough memory available for operation.

1725 `GrB_UNINITIALIZED_OBJECT` The GraphBLAS vector, `v`, has not been initialized by a call to
1726 `Vector_new` or `Vector_dup`.

1727 **Description**

1728 Removes all elements (tuples) from an existing vector. After the call to `GrB_Vector_clear(v)`,
1729 $L(v) = \emptyset$. The size of the vector does not change.

1730 **4.2.4.5 Vector_size: Size of a vector**

1731 Retrieve the size of a vector.

1732 **C Syntax**

1733 `GrB_Info GrB_Vector_size(GrB_Index *nsize,`
1734 `const GrB_Vector v);`

1735 **Parameters**

1736 `nsz` (OUT) On successful return, is set to the size of the vector.

1737 `v` (IN) An existing GraphBLAS vector being queried.

1738 **Return Values**

1739 `GrB_SUCCESS` In blocking or non-blocking mode, the operation completed suc-
1740 cessfully and the value of `nsz` has been set.

1741 `GrB_PANIC` Unknown internal error.

1742 `GrB_INVALID_OBJECT` This is returned in any execution mode whenever one of the opaque
1743 GraphBLAS objects (input or output) is in an invalid state caused
1744 by a previous execution error. Call `GrB_error()` to access any error
1745 messages generated by the implementation.

1746 `GrB_UNINITIALIZED_OBJECT` The GraphBLAS vector, `v`, has not been initialized by a call to
1747 `Vector_new` or `Vector_dup`.

1748 `GrB_NULL_POINTER` `nsz` pointer is NULL.

1749 **Description**

1750 Return `size(v)` in `nsz`.

1751 **4.2.4.6 Vector_nvals: Number of stored elements in a vector**

1752 Retrieve the number of stored elements (tuples) in a vector.

1753 **C Syntax**

```
1754            GrB_Info GrB_Vector_nvals(GrB_Index            *nvals,  
1755                                                            const GrB_Vector v);
```

1756 **Parameters**

1757 `nvals` (OUT) On successful return, this is set to the number of stored elements (tuples)
1758 in the vector.

1759 `v` (IN) An existing GraphBLAS vector being queried.

1760 **Return Values**

1761 GrB_SUCCESS In blocking or non-blocking mode, the operation completed suc-
1762 cessfully and the value of `nvals` has been set.

1763 GrB_PANIC Unknown internal error.

1764 GrB_INVALID_OBJECT This is returned in any execution mode whenever one of the opaque
1765 GraphBLAS objects (input or output) is in an invalid state caused
1766 by a previous execution error. Call `GrB_error()` to access any error
1767 messages generated by the implementation.

1768 GrB_OUT_OF_MEMORY Not enough memory available for operation.

1769 GrB_UNINITIALIZED_OBJECT The GraphBLAS vector, `v`, has not been initialized by a call to
1770 `Vector_new` or `Vector_dup`.

1771 GrB_NULL_POINTER The `nvals` pointer is NULL.

1772 **Description**

1773 Return `nvals(v)` in `nvals`. This is the number of stored elements in vector `v`, which is the size of
1774 `L(v)` (see Section 3.5.2).

1775 **4.2.4.7 Vector_build: Store elements from tuples into a vector**

1776 **C Syntax**

```
1777           GrB_Info GrB_Vector_build(GrB_Vector            w,  
1778                                    const GrB_Index        *indices,  
1779                                    const <type>           *values,  
1780                                    GrB_Index               n,  
1781                                    const GrB_BinaryOp     dup);
```

1782 **Parameters**

1783 w (INOUT) An existing Vector object to store the result.

1784 indices (IN) Pointer to an array of indices.

1785 values (IN) Pointer to an array of scalars of a type that is compatible with the domain of
1786 vector `w`.

1787 n (IN) The number of entries contained in each array (the same for indices and values).

1788 **dup** (IN) An associative and commutative binary operator to apply when duplicate
 1789 values for the same location are present in the input arrays. All three domains of
 1790 **dup** must be the same; hence $dup = \langle D_{dup}, D_{dup}, D_{dup}, \oplus \rangle$. If **dup** is **GrB_NULL**,
 1791 then duplicate locations will result in an error.

1792 Return Values

1793 **GrB_SUCCESS** In blocking mode, the operation completed successfully. In non-
 1794 blocking mode, this indicates that the API checks for the input
 1795 arguments passed successfully. Either way, output vector **w** is
 1796 ready to be used in the next method of the sequence.

1797 **GrB_PANIC** Unknown internal error.

1798 **GrB_INVALID_OBJECT** This is returned in any execution mode whenever one of the
 1799 opaque GraphBLAS objects (input or output) is in an invalid
 1800 state caused by a previous execution error. Call **GrB_error()** to
 1801 access any error messages generated by the implementation.

1802 **GrB_OUT_OF_MEMORY** Not enough memory available for operation.

1803 **GrB_UNINITIALIZED_OBJECT** Either **w** has not been initialized by a call to **GrB_Vector_new**
 1804 or by **GrB_Vector_dup**, or **dup** has not been initialized by a call
 1805 to **GrB_BinaryOp_new**.

1806 **GrB_NULL_POINTER** indices or values pointer is **NULL**.

1807 **GrB_INDEX_OUT_OF_BOUNDS** A value in indices is outside the allowed range for **w**.

1808 **GrB_DOMAIN_MISMATCH** Either the domains of the GraphBLAS binary operator **dup** are
 1809 not all the same, or the domains of **values** and **w** are incompatible
 1810 with each other or D_{dup} .

1811 **GrB_OUTPUT_NOT_EMPTY** Output vector **w** already contains valid tuples (elements). In
 1812 other words, **GrB_Vector_nvals(C)** returns a positive value.

1813 **GrB_INVALID_VALUE** indices contains a duplicate location and **dup** is **GrB_NULL**.

1814 Description

1815 If **dup** is not **GrB_NULL**, an internal vector $\tilde{\mathbf{w}} = \langle D_{dup}, \mathbf{size}(\mathbf{w}), \emptyset \rangle$ is created, which only differs
 1816 from **w** in its domain; otherwise, $\tilde{\mathbf{w}} = \langle \mathbf{D}(\mathbf{w}), \mathbf{size}(\mathbf{w}), \emptyset \rangle$.

1817 Each tuple $\{\text{indices}[k], \text{values}[k]\}$, where $0 \leq k < n$, is a contribution to the output in the form of

$$1818 \quad \tilde{\mathbf{w}}(\text{indices}[k]) = \begin{cases} (D_{dup}) \text{values}[k] & \text{if } \mathbf{dup} \neq \mathbf{GrB_NULL} \\ (\mathbf{D}(\mathbf{w})) \text{values}[k] & \text{otherwise.} \end{cases}$$

1819 If multiple values for the same location are present in the input arrays and `dup` is not `GrB_NULL`,
 1820 `dup` is used to reduce the values before assignment into $\tilde{\mathbf{w}}$ as follows:

$$1821 \quad \tilde{\mathbf{w}}_i = \bigoplus_{k: \text{indices}[k]=i} (D_{dup}) \text{values}[k],$$

1822 where \oplus is the `dup` binary operator. Finally, the resulting $\tilde{\mathbf{w}}$ is copied into `w` via typecasting its
 1823 values to `D(w)` if necessary. If \oplus is not associative or not commutative, the result is undefined.

1824 The nonopaque input arrays, `indices` and `values`, must be at least as large as `n`.

1825 It is an error to call this function on an output object with existing elements. In other words,
 1826 `GrB_Vector_nvals(w)` should evaluate to zero prior to calling this function.

1827 After `GrB_Vector_build` returns, it is safe for a programmer to modify or delete the arrays `indices`
 1828 or `values`.

1829 4.2.4.8 Vector_setElement: Set a single element in a vector

1830 Set one element of a vector to a given value.

1831 C Syntax

```
1832 // scalar value
1833 GrB_Info GrB_Vector_setElement(GrB_Vector      w,
1834                               <type>        val,
1835                               GrB_Index       index);
1836
1837 // GraphBLAS scalar
1838 GrB_Info GrB_Vector_setElement(GrB_Vector      w,
1839                               const GrB_Scalar s,
1840                               GrB_Index       index);
```

1841 Parameters

1842 `w` (INOUT) An existing GraphBLAS vector for which an element is to be assigned.

1843 `val` or `s` (IN) Scalar assign. Its domain (type) must be compatible with the domain of `w`.

1844 `index` (IN) The location of the element to be assigned.

1845 Return Values

1846 `GrB_SUCCESS` In blocking mode, the operation completed successfully. In non-
 1847 blocking mode, this indicates that the compatibility tests on in-
 1848 dex/dimensions and domains for the input arguments passed suc-

1849 cessfully. Either way, the output vector w is ready to be used in
1850 the next method of the sequence.

1851 `GrB_PANIC` Unknown internal error.

1852 `GrB_INVALID_OBJECT` This is returned in any execution mode whenever one of the opaque
1853 GraphBLAS objects (input or output) is in an invalid state caused
1854 by a previous execution error. Call `GrB_error()` to access any error
1855 messages generated by the implementation.

1856 `GrB_OUT_OF_MEMORY` Not enough memory available for operation.

1857 `GrB_UNINITIALIZED_OBJECT` The GraphBLAS vector, w , or GraphBLAS scalar, s , has not been
1858 initialized by a call to a respective constructor.

1859 `GrB_INVALID_INDEX` index specifies a location that is outside the dimensions of w .

1860 `GrB_DOMAIN_MISMATCH` The domains of the vector and the scalar are incompatible.

1861 Description

1862 First, the scalar and output vector are tested for domain compatibility as follows: $\mathbf{D}(\text{val})$ or $\mathbf{D}(s)$
1863 must be compatible with $\mathbf{D}(w)$. Two domains are compatible with each other if values from
1864 one domain can be cast to values in the other domain as per the rules of the C language. In
1865 particular, domains from Table 3.2 are all compatible with each other. A domain from a user-
1866 defined type is only compatible with itself. If any compatibility rule above is violated, execution of
1867 `GrB_Vector_setElement` ends and the domain mismatch error listed above is returned.

1868 Then, the index parameter is checked for a valid value where the following condition must hold:

$$1869 \quad 0 \leq \text{index} < \text{size}(w)$$

1870 If this condition is violated, execution of `GrB_Vector_setElement` ends and the invalid index error
1871 listed above is returned.

1872 We are now ready to carry out the assignment; that is:

$$1873 \quad w(\text{index}) = \begin{cases} \mathbf{L}(s), & \text{GraphBLAS scalar.} \\ \text{val}, & \text{otherwise.} \end{cases}$$

1874 In the case of a transparent scalar or if $\mathbf{L}(s)$ is not empty, then a value will be stored at the
1875 specified location in w , overwriting any value that may have been stored there before. In the case
1876 of a GraphBLAS scalar, if $\mathbf{L}(s)$ is empty, then any value stored at the specified location in w will
1877 be removed.

1878 In `GrB_BLOCKING` mode, the method exits with return value `GrB_SUCCESS` and the new contents
1879 of w is as defined above and fully computed. In `GrB_NONBLOCKING` mode, the method exits with
1880 return value `GrB_SUCCESS` and the new contents of vector w is as defined above but may not be
1881 fully computed; however, it can be used in the next GraphBLAS method call in a sequence.

1882 **4.2.4.9 Vector_removeElement: Remove an element from a vector**

1883 Remove (annihilate) one stored element from a vector.

1884 **C Syntax**

```
1885         GrB_Info GrB_Vector_removeElement(GrB_Vector  w,  
1886                                         GrB_Index   index);
```

1887 **Parameters**

1888 w (INOUT) An existing GraphBLAS vector from which an element is to be removed.

1889 index (IN) The location of the element to be removed.

1890 **Return Values**

1891 GrB_SUCCESS In blocking mode, the operation completed successfully. In non-
1892 blocking mode, this indicates that the compatibility tests on in-
1893 dex/dimensions and domains for the input arguments passed suc-
1894 cessfully. Either way, the output vector w is ready to be used in
1895 the next method of the sequence.

1896 GrB_PANIC Unknown internal error.

1897 GrB_INVALID_OBJECT This is returned in any execution mode whenever one of the opaque
1898 GraphBLAS objects (input or output) is in an invalid state caused
1899 by a previous execution error. Call GrB_error() to access any error
1900 messages generated by the implementation.

1901 GrB_OUT_OF_MEMORY Not enough memory available for operation.

1902 GrB_UNINITIALIZED_OBJECT The GraphBLAS vector, w, has not been initialized by a call to
1903 Vector_new or Vector_dup.

1904 GrB_INVALID_INDEX index specifies a location that is outside the dimensions of w.

1905 **Description**

1906 First, the index parameter is checked for a valid value where the following condition must hold:

$$1907 \quad 0 \leq \text{index} < \text{size}(w)$$

1908 If this condition is violated, execution of GrB_Vector_removeElement ends and the invalid index
1909 error listed above is returned.

1910 We are now ready to carry out the removal of a value that may be stored at the location specified
1911 by `index`. If a value does not exist at the specified location in `w`, no error is reported and the
1912 operation has no effect on the state of `w`. In either case, the following will be true on return from
1913 the method: `index` \notin `ind(w)`.

1914 In `GrB_BLOCKING` mode, the method exits with return value `GrB_SUCCESS` and the new contents
1915 of `w` is as defined above and fully computed. In `GrB_NONBLOCKING` mode, the method exits with
1916 return value `GrB_SUCCESS` and the new content of vector `w` is as defined above but may not be
1917 fully computed; however, it can be used in the next GraphBLAS method call in a sequence.

1918 4.2.4.10 `Vector_extractElement`: Extract a single element from a vector.

1919 Extract one element of a vector into a scalar.

1920 C Syntax

```
1921 // scalar value
1922 GrB_Info GrB_Vector_extractElement(<type>          *val,
1923                                   const GrB_Vector u,
1924                                   GrB_Index        index);
1925
1926 // GraphBLAS scalar
1927 GrB_Info GrB_Vector_extractElement(GrB_Scalar      s,
1928                                   const GrB_Vector u,
1929                                   GrB_Index        index);
```

1930 Parameters

1931 `val` or `s` (INOUT) An existing scalar of whose domain is compatible with the domain of vector
1932 `u`. On successful return, this scalar holds the result of the extract. Any previous
1933 value stored in `val` or `s` is overwritten.

1934 `u` (IN) The GraphBLAS vector from which an element is extracted.

1935 `index` (IN) The location in `u` to extract.

1936 Return Values

1937 `GrB_SUCCESS` In blocking or non-blocking mode, the operation completed suc-
1938 cessfully. This indicates that the compatibility tests on dimensions
1939 and domains for the input arguments passed successfully, and the
1940 output scalar, `val` or `s`, has been computed and is ready to be used
1941 in the next method of the sequence.

1942 GrB_NO_VALUE When using the transparent scalar, `val`, this is returned when there
1943 is no stored value at specified location.

1944 GrB_PANIC Unknown internal error.

1945 GrB_INVALID_OBJECT This is returned in any execution mode whenever one of the opaque
1946 GraphBLAS objects (input or output) is in an invalid state caused
1947 by a previous execution error. Call `GrB_error()` to access any error
1948 messages generated by the implementation.

1949 GrB_OUT_OF_MEMORY Not enough memory available for operation.

1950 GrB_UNINITIALIZED_OBJECT The GraphBLAS vector, `u`, or scalar, `s`, has not been initialized by
1951 a call to a corresponding constructor.

1952 GrB_NULL_POINTER `val` pointer is NULL.

1953 GrB_INVALID_INDEX `index` specifies a location that is outside the dimensions of `w`.

1954 GrB_DOMAIN_MISMATCH The domains of the vector and scalar are incompatible.

1955 **Description**

1956 First, the scalar and input vector are tested for domain compatibility as follows: $\mathbf{D}(\text{val})$ or $\mathbf{D}(s)$
1957 must be compatible with $\mathbf{D}(u)$. Two domains are compatible with each other if values from
1958 one domain can be cast to values in the other domain as per the rules of the C language. In
1959 particular, domains from Table 3.2 are all compatible with each other. A domain from a user-
1960 defined type is only compatible with itself. If any compatibility rule above is violated, execution of
1961 `GrB_Vector_extractElement` ends and the domain mismatch error listed above is returned.

1962 Then, the `index` parameter is checked for a valid value where the following condition must hold:

1963
$$0 \leq \text{index} < \text{size}(u)$$

1964 If this condition is violated, execution of `GrB_Vector_extractElement` ends and the invalid index
1965 error listed above is returned.

1966 We are now ready to carry out the extract into the output scalar; that is:

1967
$$\left. \begin{array}{l} \mathbf{L}(s) \\ \text{val} \end{array} \right\} = u(\text{index})$$

1968 If $\text{index} \in \mathbf{ind}(u)$, then the corresponding value from `u` is copied into `s` or `val` with casting as
1969 necessary. If $\text{index} \notin \mathbf{ind}(u)$, then one of the follow occurs depending on output scalar type:

- 1970 • The GraphBLAS scalar, `s`, is cleared and `GrB_SUCCESS` is returned.
- 1971 • The non-opaque scalar, `val`, is unchanged, and `GrB_NO_VALUE` is returned.

1972 When using the non-opaque scalar variant (`val`) in both `GrB_BLOCKING` mode `GrB_NONBLOCKING`
1973 mode, the new contents of `val` are as defined above if the method exits with return value `GrB_SUCCESS`
1974 or `GrB_NO_VALUE`.

1975 When using the GraphBLAS scalar variant (`s`) with a `GrB_SUCCESS` return value, the method
1976 exits and the new contents of `s` is as defined above and fully computed in `GrB_BLOCKING` mode.
1977 In `GrB_NONBLOCKING` mode, the new contents of `s` is as defined above but may not be fully
1978 computed; however, it can be used in the next GraphBLAS method call in a sequence.

1979 4.2.4.11 `Vector_extractTuples`: Extract tuples from a vector

1980 Extract the contents of a GraphBLAS vector into non-opaque data structures.

1981 C Syntax

```
1982     GrB_Info GrB_Vector_extractTuples(GrB_Index      *indices,  
1983                                     <type>         *values,  
1984                                     GrB_Index      *n,  
1985                                     const GrB_Vector v);  
1986
```

1987 `indices` (OUT) Pointer to an array of indices that is large enough to hold all of the stored
1988 values' indices.

1989 `values` (OUT) Pointer to an array of scalars of a type that is large enough to hold all of
1990 the stored values whose type is compatible with `D(v)`.

1991 `n` (INOUT) Pointer to a value indicating (on input) the number of elements the
1992 `values` and `indices` arrays can hold. Upon return, it will contain the number of
1993 values written to the arrays.

1994 `v` (IN) An existing GraphBLAS vector.

1995 Return Values

1996 `GrB_SUCCESS` In blocking or non-blocking mode, the operation completed suc-
1997 cessfully. This indicates that the compatibility tests on the input
1998 argument passed successfully, and the output arrays, `indices` and
1999 `values`, have been computed.

2000 `GrB_PANIC` Unknown internal error.

2001 `GrB_INVALID_OBJECT` This is returned in any execution mode whenever one of the opaque
2002 GraphBLAS objects (input or output) is in an invalid state caused
2003 by a previous execution error. Call `GrB_error()` to access any error
2004 messages generated by the implementation.

2005 GrB_OUT_OF_MEMORY Not enough memory available for operation.

2006 GrB_INSUFFICIENT_SPACE Not enough space in indices and values (as indicated by the n parameter) to hold all of the tuples that will be extracted.

2007

2008 GrB_UNINITIALIZED_OBJECT The GraphBLAS vector, v, has not been initialized by a call to Vector_new or Vector_dup.

2009

2010 GrB_NULL_POINTER indices, values, or n pointer is NULL.

2011 GrB_DOMAIN_MISMATCH The domains of the v vector or values array are incompatible with one another.

2012

2013 Description

2014 This method will extract all the tuples from the GraphBLAS vector v. The values associated with those tuples are placed in the values array and the indices are placed in the indices array. Both indices and values must be pre-allocated by the user to have enough space to hold at least GrB_Vector_nvals(v) elements before calling this function.

2015

2016

2017

2018 Upon return of this function, n will be set to the number of values (and indices) copied. Also, the entries of indices are unique, but not necessarily sorted. Each tuple (i, v_i) in v is unzipped and copied into a distinct kth location in output vectors:

2019

2020

$$\{\text{indices}[k], \text{values}[k]\} \leftarrow (i, v_i),$$

2021 where $0 \leq k < \text{GrB_Vector_nvals}(v)$. No gaps in output vectors are allowed; that is, if indices[k] and values[k] exist upon return, so does indices[j] and values[j] for all j such that $0 \leq j < k$.

2022

2023 Note that if the value in n on input is less than the number of values contained in the vector v, then a GrB_INSUFFICIENT_SPACE error is returned because it is undefined which subset of values would be extracted otherwise.

2024

2025

2026 In both GrB_BLOCKING mode GrB_NONBLOCKING mode if the method exits with return value GrB_SUCCESS, the new contents of the arrays indices and values are as defined above.

2027

2028 4.2.5 Matrix methods

2029 4.2.5.1 Matrix_new: Construct new matrix

2030 Creates a new matrix with specified domain and dimensions.

2031 C Syntax

```
2032        GrB_Info GrB_Matrix_new(GrB_Matrix *A,
2033                                GrB_Type     d,
```


2064 **4.2.5.2 Matrix_dup: Construct a copy of a GraphBLAS matrix**

2065 Creates a new matrix with the same domain, dimensions, and contents as another matrix.

2066 **C Syntax**

```
2067         GrB_Info GrB_Matrix_dup(GrB_Matrix      *C,  
2068                               const GrB_Matrix A);
```

2069 **Parameters**

2070 C (INOUT) On successful return, contains a handle to the newly created GraphBLAS
2071 matrix.

2072 A (IN) The GraphBLAS matrix to be duplicated.

2073 **Return Values**

2074 GrB_SUCCESS In blocking mode, the operation completed successfully. In non-
2075 blocking mode, this indicates that the API checks for the input
2076 arguments passed successfully. Either way, output matrix C is ready
2077 to be used in the next method of the sequence.

2078 GrB_PANIC Unknown internal error.

2079 GrB_INVALID_OBJECT This is returned in any execution mode whenever one of the opaque
2080 GraphBLAS objects (input or output) is in an invalid state caused
2081 by a previous execution error. Call GrB_error() to access any error
2082 messages generated by the implementation.

2083 GrB_OUT_OF_MEMORY Not enough memory available for operation.

2084 GrB_UNINITIALIZED_OBJECT The GraphBLAS matrix, A, has not been initialized by a call to
2085 any matrix constructor.

2086 GrB_NULL_POINTER The C pointer is NULL.

2087 **Description**

2088 Creates a new matrix **C** of domain **D(A)**, size **nrows(A) × ncols(A)**, and contents **L(A)**. It returns
2089 a handle to it in **C**.

2090 It is not an error to call this method more than once on the same variable; however, the handle to
2091 the previously created object will be overwritten.

2092 **4.2.5.3 Matrix_diag: Construct a diagonal GraphBLAS matrix**

2093 Creates a new matrix with the same domain and contents as a `GrB_Vector`, and square dimensions
2094 appropriate for placing the contents of the vector along the specified diagonal of the matrix.

2095 **C Syntax**

```
2096         GrB_Info GrB_Matrix_diag(GrB_Matrix      *C,  
2097                                 const GrB_Vector v,  
2098                                 int64_t         k);
```

2099 **Parameters**

2100 `C` (INOUT) On successful return, contains a handle to the newly created GraphBLAS
2101 matrix. The matrix is square with each dimension equal to $\text{size}(v) + |k|$.

2102 `v` (IN) The GraphBLAS vector whose contents will be copied to the diagonal of the
2103 matrix.

2104 `k` (IN) The diagonal to which the vector is assigned. $k = 0$ represents the main
2105 diagonal, $k > 0$ is above the main diagonal, and $k < 0$ is below.

2106 **Return Values**

2107 `GrB_SUCCESS` In blocking mode, the operation completed successfully. In non-
2108 blocking mode, this indicates that the API checks for the input
2109 arguments passed successfully. Either way, output matrix `C` is ready
2110 to be used in the next method of the sequence.

2111 `GrB_PANIC` Unknown internal error.

2112 `GrB_INVALID_OBJECT` This is returned in any execution mode whenever one of the opaque
2113 GraphBLAS objects (input or output) is in an invalid state caused
2114 by a previous execution error. Call `GrB_error()` to access any error
2115 messages generated by the implementation.

2116 `GrB_OUT_OF_MEMORY` Not enough memory available for the operation.

2117 `GrB_UNINITIALIZED_OBJECT` The GraphBLAS vector, `v`, has not been initialized by a call to
2118 `Vector_new` or `Vector_dup`.

2119 `GrB_NULL_POINTER` The `C` pointer is `NULL`.

2120 **Description**

2121 Creates a new matrix **C** of domain **D(v)**, size $(\mathbf{size}(v) + |k|) \times (\mathbf{size}(v) + |k|)$, and contents

$$\begin{aligned} 2122 \quad \mathbf{L}(C) &= \{(i, i + k, v_i) : (i, v_i) \in \mathbf{L}(v)\} \text{ if } k \geq 0 \text{ or} \\ 2123 \quad \mathbf{L}(C) &= \{(i - k, i, v_i) : (i, v_i) \in \mathbf{L}(v)\} \text{ if } k < 0. \end{aligned}$$

2124 It returns a handle to it in **C**. It is not an error to call this method more than once on the same
2125 variable; however, the handle to the previously created object will be overwritten.

2126 **4.2.5.4 Matrix_resize: Resize a matrix**

2127 Changes the dimensions of an existing matrix.

2128 **C Syntax**

```
2129     GrB_Info GrB_Matrix_resize(GrB_Matrix  C,  
2130                               GrB_Index   nrows,  
2131                               GrB_Index   ncols);
```

2132 **Parameters**

2133 **C** (INOUT) An existing Matrix object that is being resized.

2134 **nrows** (IN) The new number of rows of the matrix. It can be smaller or larger than the
2135 current number of rows.

2136 **ncols** (IN) The new number of columns of the matrix. It can be smaller or larger than
2137 the current number of columns.

2138 **Return Values**

2139 **GrB_SUCCESS** In blocking mode, the operation completed successfully. In non-
2140 blocking mode, this indicates that the API checks for the input
2141 arguments passed successfully. Either way, output matrix **C** is ready
2142 to be used in the next method of the sequence.

2143 **GrB_PANIC** Unknown internal error.

2144 **GrB_INVALID_OBJECT** This is returned in any execution mode whenever one of the opaque
2145 GraphBLAS objects (input or output) is in an invalid state caused
2146 by a previous execution error. Call **GrB_error()** to access any error
2147 messages generated by the implementation.

2148 **GrB_OUT_OF_MEMORY** Not enough memory available for operation.

2149 GrB_NULL_POINTER The C pointer is NULL.

2150 GrB_INVALID_VALUE nrows or ncols is zero or outside the range of the type GrB_Index.

2151 **Description**

2152 Changes the number of rows and columns of C to nrows and ncols, respectively. The domain $\mathbf{D}(C)$
2153 of matrix C remains the same. The contents $\mathbf{L}(C)$ are modified as described below.

2154 Let $C = \langle \mathbf{D}(C), M, N, \mathbf{L}(C) \rangle$ when the method is called. When the method returns C is modified
2155 to $C = \langle \mathbf{D}(C), \text{nrows}, \text{ncols}, \mathbf{L}'(C) \rangle$ where $\mathbf{L}'(C) = \{(i, j, C_{ij}) : (i, j, C_{ij}) \in \mathbf{L}(C) \wedge (i < \text{nrows}) \wedge (j < \text{ncols})\}$. That is, all elements of C with row index greater than or equal to nrows or column index
2156 greater than or equal to ncols are dropped.
2157

2158 **4.2.5.5 Matrix_clear: Clear a matrix**

2159 Removes all elements (tuples) from a matrix.

2160 **C Syntax**

2161 GrB_Info GrB_Matrix_clear(GrB_Matrix A);

2162 **Parameters**

2163 A (IN) An existing GraphBLAS matrix to clear.

2164 **Return Values**

2165 GrB_SUCCESS In blocking mode, the operation completed successfully. In non-
2166 blocking mode, this indicates that the API checks for the input
2167 arguments passed successfully. Either way, output matrix A is ready
2168 to be used in the next method of the sequence.

2169 GrB_PANIC Unknown internal error.

2170 GrB_INVALID_OBJECT This is returned in any execution mode whenever one of the opaque
2171 GraphBLAS objects (input or output) is in an invalid state caused
2172 by a previous execution error. Call GrB_error() to access any error
2173 messages generated by the implementation.

2174 GrB_OUT_OF_MEMORY Not enough memory available for operation.

2175 GrB_UNINITIALIZED_OBJECT The GraphBLAS matrix, A, has not been initialized by a call to
2176 any matrix constructor.

2177 **Description**

2178 Removes all elements (tuples) from an existing matrix. After the call to `GrB_Matrix_clear(A)`,
2179 $\mathbf{L}(\mathbf{A}) = \emptyset$. The dimensions of the matrix do not change.

2180 **4.2.5.6 Matrix_nrows: Number of rows in a matrix**

2181 Retrieve the number of rows in a matrix.

2182 **C Syntax**

```
2183         GrB_Info GrB_Matrix_nrows(GrB_Index      *nrows,  
2184                                 const GrB_Matrix A);
```

2185 **Parameters**

2186 nrows (OUT) On successful return, contains the number of rows in the matrix.

2187 A (IN) An existing GraphBLAS matrix being queried.

2188 **Return Values**

2189 GrB_SUCCESS In blocking or non-blocking mode, the operation completed suc-
2190 cessfully and the value of `nrows` has been set.

2191 GrB_PANIC Unknown internal error.

2192 GrB_INVALID_OBJECT This is returned in any execution mode whenever one of the opaque
2193 GraphBLAS objects (input or output) is in an invalid state caused
2194 by a previous execution error. Call `GrB_error()` to access any error
2195 messages generated by the implementation.

2196 GrB_UNINITIALIZED_OBJECT The GraphBLAS matrix, `A`, has not been initialized by a call to
2197 any matrix constructor.

2198 GrB_NULL_POINTER `nrows` pointer is NULL.

2199 **Description**

2200 Return `nrows(A)` in `nrows` (the number of rows).

2201 **4.2.5.7 Matrix_ncols: Number of columns in a matrix**

2202 Retrieve the number of columns in a matrix.

2203 **C Syntax**

```
2204         GrB_Info GrB_Matrix_ncols(GrB_Index      *ncols,  
2205                                 const GrB_Matrix A);
```

2206 **Parameters**

2207 ncols (OUT) On successful return, contains the number of columns in the matrix.

2208 A (IN) An existing GraphBLAS matrix being queried.

2209 **Return Values**

2210 GrB_SUCCESS In blocking or non-blocking mode, the operation completed suc-
2211 cessfully and the value of ncols has been set.

2212 GrB_PANIC Unknown internal error.

2213 GrB_INVALID_OBJECT This is returned in any execution mode whenever one of the opaque
2214 GraphBLAS objects (input or output) is in an invalid state caused
2215 by a previous execution error. Call GrB_error() to access any error
2216 messages generated by the implementation.

2217 GrB_UNINITIALIZED_OBJECT The GraphBLAS matrix, A, has not been initialized by a call to
2218 any matrix constructor.

2219 GrB_NULL_POINTER ncols pointer is NULL.

2220 **Description**

2221 Return `ncols(A)` in `ncols` (the number of columns).

2222 **4.2.5.8 Matrix_nvals: Number of stored elements in a matrix**

2223 Retrieve the number of stored elements (tuples) in a matrix.

2224 **C Syntax**

```
2225         GrB_Info GrB_Matrix_nvals(GrB_Index      *nvals,  
2226                                 const GrB_Matrix A);
```

2227 **Parameters**

2228 nvals (OUT) On successful return, contains the number of stored elements (tuples) in
2229 the matrix.

2230 A (IN) An existing GraphBLAS matrix being queried.

2231 **Return Values**

2232 GrB_SUCCESS In blocking or non-blocking mode, the operation completed suc-
2233 cessfully and the value of nvals has been set.

2234 GrB_PANIC Unknown internal error.

2235 GrB_INVALID_OBJECT This is returned in any execution mode whenever one of the opaque
2236 GraphBLAS objects (input or output) is in an invalid state caused
2237 by a previous execution error. Call GrB_error() to access any error
2238 messages generated by the implementation.

2239 GrB_OUT_OF_MEMORY Not enough memory available for operation.

2240 GrB_UNINITIALIZED_OBJECT The GraphBLAS matrix, A, has not been initialized by a call to
2241 any matrix constructor.

2242 GrB_NULL_POINTER The nvals pointer is NULL.

2243 **Description**

2244 Return nvals(A) in nvals. This is the number of tuples stored in matrix A, which is the size of
2245 L(A) (see Section 3.5.3).

2246 **4.2.5.9 Matrix_build: Store elements from tuples into a matrix**

2247 **C Syntax**

```
GrB_Info GrB_Matrix_build(GrB_Matrix      C,
                          const GrB_Index *row_indices,
                          const GrB_Index *col_indices,
                          const <type>  *values,
                          GrB_Index      n,
                          const GrB_BinaryOp dup);
```

2248 **Parameters**

2249 C (INOUT) An existing Matrix object to store the result.

2250 `row_indices` (IN) Pointer to an array of row indices.

2251 `col_indices` (IN) Pointer to an array of column indices.

2252 `values` (IN) Pointer to an array of scalars of a type that is compatible with the domain of
2253 matrix, `C`.

2254 `n` (IN) The number of entries contained in each array (the same for `row_indices`,
2255 `col_indices`, and `values`).

2256 `dup` (IN) An associative and commutative binary operator to apply when duplicate
2257 values for the same location are present in the input arrays. All three domains of
2258 `dup` must be the same; hence $dup = \langle D_{dup}, D_{dup}, D_{dup}, \oplus \rangle$. If `dup` is `GrB_NULL`,
2259 then duplicate locations will result in an error.

2260 Return Values

2261 `GrB_SUCCESS` In blocking mode, the operation completed successfully. In non-
2262 blocking mode, this indicates that the API checks for the input
2263 arguments passed successfully. Either way, output matrix `C` is
2264 ready to be used in the next method of the sequence.

2265 `GrB_PANIC` Unknown internal error.

2266 `GrB_INVALID_OBJECT` This is returned in any execution mode whenever one of the
2267 opaque GraphBLAS objects (input or output) is in an invalid
2268 state caused by a previous execution error. Call `GrB_error()` to
2269 access any error messages generated by the implementation.

2270 `GrB_OUT_OF_MEMORY` Not enough memory available for operation.

2271 `GrB_UNINITIALIZED_OBJECT` Either `C` has not been initialized by a call to any matrix construc-
2272 tor, or `dup` has not been initialized by a call to `GrB_BinaryOp_new`.

2273 `GrB_NULL_POINTER` `row_indices`, `col_indices` or `values` pointer is `NULL`.

2274 `GrB_INDEX_OUT_OF_BOUNDS` A value in `row_indices` or `col_indices` is outside the allowed range
2275 for `C`.

2276 `GrB_DOMAIN_MISMATCH` Either the domains of the GraphBLAS binary operator `dup` are
2277 not all the same, or the domains of `values` and `C` are incompatible
2278 with each other or D_{dup} .

2279 `GrB_OUTPUT_NOT_EMPTY` Output matrix `C` already contains valid tuples (elements). In
2280 other words, `GrB_Matrix_nvals(C)` returns a positive value.

2281 `GrB_INVALID_VALUE` `indices` contains a duplicate location and `dup` is `GrB_NULL`.

2282 **Description**

2283 If `dup` is not `GrB_NULL`, an internal matrix $\tilde{\mathbf{C}} = \langle D_{dup}, \mathbf{nrows}(\mathbf{C}), \mathbf{ncols}(\mathbf{C}), \emptyset \rangle$ is created, which
2284 only differs from \mathbf{C} in its domain; otherwise, $\tilde{\mathbf{C}} = \langle \mathbf{D}(\mathbf{C}), \mathbf{nrows}(\mathbf{C}), \mathbf{ncols}(\mathbf{C}), \emptyset \rangle$.

2285 Each tuple $\{\text{row_indices}[k], \text{col_indices}[k], \text{values}[k]\}$, where $0 \leq k < n$, is a contribution to the
2286 output in the form of

$$2287 \quad \tilde{\mathbf{C}}(\text{row_indices}[k], \text{col_indices}[k]) = \begin{cases} (D_{dup}) \text{ values}[k] & \text{if } \text{dup} \neq \text{GrB_NULL} \\ (\mathbf{D}(\mathbf{C})) \text{ values}[k] & \text{otherwise.} \end{cases}$$

2288 If multiple values for the same location are present in the input arrays and `dup` is not `GrB_NULL`,
2289 `dup` is used to reduce the values before assignment into $\tilde{\mathbf{C}}$ as follows:

$$2290 \quad \tilde{\mathbf{C}}_{ij} = \bigoplus_{k: \text{row_indices}[k]=i \wedge \text{col_indices}[k]=j} (D_{dup}) \text{ values}[k],$$

2291 where \oplus is the `dup` binary operator. Finally, the resulting $\tilde{\mathbf{C}}$ is copied into \mathbf{C} via typecasting its
2292 values to $\mathbf{D}(\mathbf{C})$ if necessary. If \oplus is not associative or not commutative, the result is undefined.

2293 The nonopaque input arrays `row_indices`, `col_indices`, and `values` must be at least as large as `n`.

2294 It is an error to call this function on an output object with existing elements. In other words,
2295 `GrB_Matrix_nvals(C)` should evaluate to zero prior to calling this function.

2296 After `GrB_Matrix_build` returns, it is safe for a programmer to modify or delete the arrays `row_indices`,
2297 `col_indices`, or `values`.

2298 **4.2.5.10 Matrix_setElement: Set a single element in matrix**

2299 Set one element of a matrix to a given value.

2300 **C Syntax**

```
2301 // scalar value
2302 GrB_Info GrB_Matrix_setElement(GrB_Matrix      C,
2303                               <type>         val,
2304                               GrB_Index       row_index,
2305                               GrB_Index       col_index);
2306
2307 // GraphBLAS scalar
2308 GrB_Info GrB_Matrix_setElement(GrB_Matrix      C,
2309                               const GrB_Scalar s,
2310                               GrB_Index       row_index,
2311                               GrB_Index       col_index);
```

2312 **Parameters**

- 2313 C (INOUT) An existing GraphBLAS matrix for which an element is to be assigned.
- 2314 val or s (IN) Scalar to assign. Its domain (type) must be compatible with the domain of
2315 C.
- 2316 row_index (IN) Row index of element to be assigned
- 2317 col_index (IN) Column index of element to be assigned

2318 **Return Values**

- 2319 GrB_SUCCESS In blocking mode, the operation completed successfully. In non-
2320 blocking mode, this indicates that the compatibility tests on in-
2321 dex/dimensions and domains for the input arguments passed suc-
2322 cessfully. Either way, the output matrix C is ready to be used in
2323 the next method of the sequence.
- 2324 GrB_PANIC Unknown internal error.
- 2325 GrB_INVALID_OBJECT This is returned in any execution mode whenever one of the opaque
2326 GraphBLAS objects (input or output) is in an invalid state caused
2327 by a previous execution error. Call GrB_error() to access any error
2328 messages generated by the implementation.
- 2329 GrB_OUT_OF_MEMORY Not enough memory available for operation.
- 2330 GrB_UNINITIALIZED_OBJECT The GraphBLAS matrix, A, or GraphBLAS scalar, s, has not been
2331 initialized by a call to a respective constructor.
- 2332 GrB_INVALID_INDEX row_index or col_index is outside the allowable range (i.e., not less
2333 than **nrows**(C) or **ncols**(C), respectively).
- 2334 GrB_DOMAIN_MISMATCH The domains of the matrix and the scalar are incompatible.

2335 **Description**

2336 First, the scalar and output matrix are tested for domain compatibility as follows: **D**(val) or
2337 **D**(s) must be compatible with **D**(C). Two domains are compatible with each other if values from
2338 one domain can be cast to values in the other domain as per the rules of the C language. In
2339 particular, domains from Table 3.2 are all compatible with each other. A domain from a user-
2340 defined type is only compatible with itself. If any compatibility rule above is violated, execution of
2341 GrB_Matrix_setElement ends and the domain mismatch error listed above is returned.

2342 Then, both index parameters are checked for valid values where following conditions must hold:

2343
$$0 \leq \text{row_index} < \mathbf{nrows}(C),$$

$$0 \leq \text{col_index} < \mathbf{ncols}(C)$$

2344 If either of these conditions is violated, execution of `GrB_Matrix_setElement` ends and the invalid
2345 index error listed above is returned.

2346 We are now ready to carry out the assignment; that is:

$$2347 \quad C(\text{row_index}, \text{col_index}) = \begin{cases} \mathbf{L}(s), & \text{GraphBLAS scalar.} \\ \text{val}, & \text{otherwise.} \end{cases}$$

2348 In the case of a transparent scalar or if $\mathbf{L}(s)$ is not empty, then a value will be stored at the
2349 specified location in C , overwriting any value that may have been stored there before. In the case
2350 of a GraphBLAS scalar and if $\mathbf{L}(s)$ is empty, then any value stored at the specified location in C
2351 will be removed.

2352 In `GrB_BLOCKING` mode, the method exits with return value `GrB_SUCCESS` and the new contents
2353 of C is as defined above and fully computed. In `GrB_NONBLOCKING` mode, the method exits with
2354 return value `GrB_SUCCESS` and the new content of vector C is as defined above but may not be
2355 fully computed; however, it can be used in the next GraphBLAS method call in a sequence.

2356 **4.2.5.11 Matrix_removeElement: Remove an element from a matrix**

2357 Remove (annihilate) one stored element from a matrix.

2358 **C Syntax**

```
2359     GrB_Info GrB_Matrix_removeElement(GrB_Matrix  C,  
2360                                     GrB_Index   row_index,  
2361                                     GrB_Index   col_index);
```

2362 **Parameters**

2363 C (INOUT) An existing GraphBLAS matrix from which an element is to be removed.

2364 `row_index` (IN) Row index of element to be removed

2365 `col_index` (IN) Column index of element to be removed

2366 **Return Values**

2367 `GrB_SUCCESS` In blocking mode, the operation completed successfully. In non-
2368 blocking mode, this indicates that the compatibility tests on in-
2369 dex/dimensions and domains for the input arguments passed suc-
2370 cessfully. Either way, the output matrix C is ready to be used in
2371 the next method of the sequence.

2372 `GrB_PANIC` Unknown internal error.

2373 GrB_INVALID_OBJECT This is returned in any execution mode whenever one of the opaque
2374 GraphBLAS objects (input or output) is in an invalid state caused
2375 by a previous execution error. Call GrB_error() to access any error
2376 messages generated by the implementation.

2377 GrB_OUT_OF_MEMORY Not enough memory available for operation.

2378 GrB_UNINITIALIZED_OBJECT The GraphBLAS matrix, C, has not been initialized by a call to
2379 any matrix constructor.

2380 GrB_INVALID_INDEX row_index or col_index is outside the allowable range (i.e., not less
2381 than nrows(C) or ncols(C), respectively).

2382 Description

2383 First, both index parameters are checked for valid values where following conditions must hold:

$$\begin{aligned} 2384 \quad & 0 \leq \text{row_index} < \text{nrows}(\text{C}), \\ & 0 \leq \text{col_index} < \text{ncols}(\text{C}) \end{aligned}$$

2385 If either of these conditions is violated, execution of GrB_Matrix_removeElement ends and the
2386 invalid index error listed above is returned.

2387 We are now ready to carry out the removal of a value that may be stored at the location specified by
2388 (row_index, col_index). If a value does not exist at the specified location in C, no error is reported
2389 and the operation has no effect on the state of C. In either case, the following will be true on return
2390 from this method: (row_index, col_index) \notin ind(C)

2391 In GrB_BLOCKING mode, the method exits with return value GrB_SUCCESS and the new contents
2392 of C is as defined above and fully computed. In GrB_NONBLOCKING mode, the method exits with
2393 return value GrB_SUCCESS and the new content of vector C is as defined above but may not be
2394 fully computed; however, it can be used in the next GraphBLAS method call in a sequence.

2395 4.2.5.12 Matrix_extractElement: Extract a single element from a matrix

2396 Extract one element of a matrix into a scalar.

2397 C Syntax

```
2398 // scalar value
2399 GrB_Info GrB_Matrix_extractElement(<type>          *val,
2400                                   const GrB_Matrix A,
2401                                   GrB_Index        row_index,
2402                                   GrB_Index        col_index);
2403
2404 // GraphBLAS scalar
```

```

2405     GrB_Info GrB_Matrix_extractElement(GrB_Scalar      s,
2406                                     const GrB_Matrix A,
2407                                     GrB_Index        row_index,
2408                                     GrB_Index        col_index);
2409

```

2410 Parameters

2411 `val` or `s` (INOUT) An existing scalar whose domain is compatible with the domain of matrix
2412 `A`. On successful return, this scalar holds the result of the extract. Any previous
2413 value stored in `val` or `s` is overwritten.

2414 `A` (IN) The GraphBLAS matrix from which an element is extracted.

2415 `row_index` (IN) The row index of location in `A` to extract.

2416 `col_index` (IN) The column index of location in `A` to extract.

2417 Return Values

2418 `GrB_SUCCESS` In blocking or non-blocking mode, the operation completed suc-
2419 cessfully. This indicates that the compatibility tests on dimensions
2420 and domains for the input arguments passed successfully, and the
2421 output scalar, `val` or `s`, has been computed and is ready to be used
2422 in the next method of the sequence.

2423 `GrB_NO_VALUE` When using the transparent scalar, `val`, this is returned when there
2424 is no stored value at specified location.

2425 `GrB_PANIC` Unknown internal error.

2426 `GrB_INVALID_OBJECT` This is returned in any execution mode whenever one of the opaque
2427 GraphBLAS objects (input or output) is in an invalid state caused
2428 by a previous execution error. Call `GrB_error()` to access any error
2429 messages generated by the implementation.

2430 `GrB_OUT_OF_MEMORY` Not enough memory available for operation.

2431 `GrB_UNINITIALIZED_OBJECT` The GraphBLAS matrix, `A`, or scalar, `s`, has not been initialized by
2432 a call to a corresponding constructor.

2433 `GrB_NULL_POINTER` `val` pointer is NULL.

2434 `GrB_INVALID_INDEX` `row_index` or `col_index` is outside the allowable range (i.e. less than
2435 zero or greater than or equal to `nrows(A)` or `ncols(A)`, respec-
2436 tively).

2437 `GrB_DOMAIN_MISMATCH` The domains of the matrix and scalar are incompatible.

2438 **Description**

2439 First, the scalar and input matrix are tested for domain compatibility as follows: $\mathbf{D}(\text{val})$ or $\mathbf{D}(s)$
2440 must be compatible with $\mathbf{D}(A)$. Two domains are compatible with each other if values from
2441 one domain can be cast to values in the other domain as per the rules of the C language. In
2442 particular, domains from Table 3.2 are all compatible with each other. A domain from a user-
2443 defined type is only compatible with itself. If any compatibility rule above is violated, execution of
2444 `GrB_Matrix_extractElement` ends and the domain mismatch error listed above is returned.

2445 Then, both index parameters are checked for valid values where following conditions must hold:

$$\begin{aligned} 2446 \quad & 0 \leq \text{row_index} < \mathbf{nrows}(A), \\ & 0 \leq \text{col_index} < \mathbf{ncols}(A) \end{aligned}$$

2447 If either condition is violated, execution of `GrB_Matrix_extractElement` ends and the invalid index
2448 error listed above is returned.

2449 We are now ready to carry out the extract into the output scalar; that is,

$$2450 \quad \left. \begin{array}{l} \mathbf{L}(s) \\ \text{val} \end{array} \right\} = A(\text{row_index}, \text{col_index})$$

2451 If $(\text{row_index}, \text{col_index}) \in \mathbf{ind}(A)$, then the corresponding value from A is copied into s or val
2452 with casting as necessary. If $(\text{row_index}, \text{col_index}) \notin \mathbf{ind}(A)$, then one of the follow occurs
2453 depending on output scalar type:

- 2454 • The GraphBLAS scalar, s , is cleared and `GrB_SUCCESS` is returned.
- 2455 • The non-opaque scalar, val , is unchanged, and `GrB_NO_VALUE` is returned.

2456 When using the non-opaque scalar variant (val) in both `GrB_BLOCKING` mode `GrB_NONBLOCKING`
2457 mode, the new contents of val are as defined above if the method exits with return value `GrB_SUCCESS`
2458 or `GrB_NO_VALUE`.

2459 When using the GraphBLAS scalar variant (s) with a `GrB_SUCCESS` return value, the method
2460 exits and the new contents of s is as defined above and fully computed in `GrB_BLOCKING` mode.
2461 In `GrB_NONBLOCKING` mode, the new contents of s is as defined above but may not be fully
2462 computed; however, it can be used in the next GraphBLAS method call in a sequence.

2463 **4.2.5.13 Matrix_extractTuples: Extract tuples from a matrix**

2464 Extract the contents of a GraphBLAS matrix into non-opaque data structures.

2465 **C Syntax**

```
2466     GrB_Info GrB_Matrix_extractTuples(GrB_Index      *row_indices,  
2467                                     GrB_Index      *col_indices,
```

```

2468                                     <type>           *values,
2469                                     GrB_Index        *n,
2470                                     const GrB_Matrix  A);

```

2471 Parameters

2472 `row_indices` (OUT) Pointer to an array of row indices that is large enough to hold all of the
2473 row indices.

2474 `col_indices` (OUT) Pointer to an array of column indices that is large enough to hold all of the
2475 column indices.

2476 `values` (OUT) Pointer to an array of scalars of a type that is large enough to hold all of
2477 the stored values whose type is compatible with $\mathbf{D}(\mathbf{A})$.

2478 `n` (INOUT) Pointer to a value indicating (in input) the number of elements the `values`,
2479 `row_indices`, and `col_indices` arrays can hold. Upon return, it will contain the
2480 number of values written to the arrays.

2481 `A` (IN) An existing GraphBLAS matrix.

2482 Return Values

2483 `GrB_SUCCESS` In blocking or non-blocking mode, the operation completed suc-
2484 cessfully. This indicates that the compatibility tests on the input
2485 argument passed successfully, and the output arrays, indices and
2486 values, have been computed.

2487 `GrB_PANIC` Unknown internal error.

2488 `GrB_INVALID_OBJECT` This is returned in any execution mode whenever one of the opaque
2489 GraphBLAS objects (input or output) is in an invalid state caused
2490 by a previous execution error. Call `GrB_error()` to access any error
2491 messages generated by the implementation.

2492 `GrB_OUT_OF_MEMORY` Not enough memory available for operation.

2493 `GrB_INSUFFICIENT_SPACE` Not enough space in `row_indices`, `col_indices`, and `values` (as indi-
2494 cated by the `n` parameter) to hold all of the tuples that will be
2495 extracted.

2496 `GrB_UNINITIALIZED_OBJECT` The GraphBLAS matrix, `A`, has not been initialized by a call to
2497 any matrix constructor.

2498 `GrB_NULL_POINTER` `row_indices`, `col_indices`, `values` or `n` pointer is NULL.

2499 `GrB_DOMAIN_MISMATCH` The domains of the `A` matrix and `values` array are incompatible
2500 with one another.

2501 **Description**

2502 This method will extract all the tuples from the GraphBLAS matrix **A**. The values associated with
2503 those tuples are placed in the **values** array, the column indices are placed in the **col_indices** array,
2504 and the row indices are placed in the **row_indices** array. These output arrays are pre-allocated by
2505 the user before calling this function such that each output array has enough space to hold at least
2506 **GrB_Matrix_nvals(A)** elements.

2507 Upon return of this function, a pair of $\{\text{row_indices}[k], \text{col_indices}[k]\}$ are unique for every valid
2508 k , but they are not required to be sorted in any particular order. Each tuple (i, j, A_{ij}) in **A** is
2509 unzipped and copied into a distinct k th location in output vectors:

$$\{\text{row_indices}[k], \text{col_indices}[k], \text{values}[k]\} \leftarrow (i, j, A_{ij}),$$

2510 where $0 \leq k < \text{GrB_Matrix_nvals}(v)$. No gaps in output vectors are allowed; that is, if **row_indices**[k],
2511 **col_indices**[k] and **values**[k] exist upon return, so does **row_indices**[j], **col_indices**[j] and **values**[j] for
2512 all j such that $0 \leq j < k$.

2513 Note that if the value in **n** on input is less than the number of values contained in the matrix **A**,
2514 then a **GrB_INSUFFICIENT_SPACE** error is returned since it is undefined which subset of values
2515 would be extracted.

2516 In both **GrB_BLOCKING** mode **GrB_NONBLOCKING** mode if the method exits with return value
2517 **GrB_SUCCESS**, the new contents of the arrays **row_indices**, **col_indices** and **values** are as defined
2518 above.

2519 **4.2.5.14 Matrix_exportHint: Provide a hint as to which storage format might be most**
2520 **efficient for exporting a matrix**

2521 **C Syntax**

```
GrB_Info GrB_Matrix_exportHint(GrB_Format          *hint,  
                               GrB_Matrix         A);
```

2522 **Parameters**

2523 **hint** (OUT) Pointer to a value of type **GrB_Format**.

2524 **A** (IN) A GraphBLAS matrix object.

2525 **Return Values**

2526 **GrB_SUCCESS** In blocking or non-blocking mode, the operation completed suc-
2527 cessfully and the value of **hint** has been set.

2528 **GrB_PANIC** Unknown internal error.

2529 GrB_INVALID_OBJECT This is returned in any execution mode whenever one of the
2530 opaque GraphBLAS objects (input or output) is in an invalid
2531 state caused by a previous execution error. Call GrB_error() to
2532 access any error messages generated by the implementation.

2533 GrB_OUT_OF_MEMORY Not enough memory available for operation.

2534 GrB_UNINITIALIZED_OBJECT The GraphBLAS matrix, A, has not been initialized by a call to
2535 any matrix constructor.

2536 GrB_NULL_POINTER hint is NULL.

2537 GrB_NO_VALUE If the implementation does not have a preferred format, it may
2538 return the value GrB_NO_VALUE.

2539 Description

2540 Given a GraphBLAS matrix A, provide a hint as to which format might be most efficient for
2541 exporting the matrix A. GraphBLAS implementations might return the current storage format of
2542 the matrix, or the format to which it could most efficiently be exported. However, implementations
2543 are free to return any value for format defined in Section 3.5.3.1. Note that an implementation is
2544 free to refuse to provide a format hint, returning GrB_NO_VALUE.

2545 4.2.5.15 Matrix_exportSize: Return the array sizes necessary to export a GraphBLAS 2546 matrix object

2547 C Syntax

```
GrB_Info GrB_Matrix_exportSize(GrB_Index                   *n_indptr,  
                                  GrB_Index                   *n_indices,  
                                  GrB_Index                   *n_values,  
                                  GrB_Format                  format,  
                                  GrB_Matrix                  A);
```

2548 Parameters

2549 n_indptr (OUT) Pointer to a value of type GrB_Index.

2550 n_indices (OUT) Pointer to a value of type GrB_Index.

2551 n_values (OUT) Pointer to a value of type GrB_Index.

2552 format (IN) a value indicating the format in which the matrix will be exported, as defined
2553 in Section 3.5.3.1.

2554 A (IN) A GraphBLAS matrix object.

2555 Return Values

2556 GrB_SUCCESS In blocking mode or non-blocking mode, the operation completed successfully. This indicates that the API checks for the input arguments passed successfully, and the number of elements necessary for the export buffers have been written to `n_indptr`, `n_indices`, and `n_values`, respectively.

2561 GrB_PANIC Unknown internal error.

2562 GrB_INVALID_OBJECT This is returned in any execution mode whenever one of the opaque GraphBLAS objects (input or output) is in an invalid state caused by a previous execution error. Call `GrB_error()` to access any error messages generated by the implementation.

2566 GrB_OUT_OF_MEMORY Not enough memory available for operation.

2567 GrB_UNINITIALIZED_OBJECT The GraphBLAS Matrix, `A`, has not been initialized by a call to any matrix constructor.

2569 GrB_NULL_POINTER `n_indptr`, `n_indices`, or `n_values` is NULL.

2570 Description

2571 Given a matrix `A`, returns the required capacities of arrays `values`, `indptr`, and `indices` necessary to export the matrix in the format specified by `format`. The output values `n_values`, `n_indptr`, and `indices` will contain the corresponding sizes of the arrays (in number of elements) that must be allocated to hold the exported matrix. The argument `format` can be chosen arbitrarily by the user as one of the values defined in Section 3.5.3.1.

2576 4.2.5.16 Matrix_export: Export a GraphBLAS matrix to a pre-defined format

2577 C Syntax

```
GrB_Info GrB_Matrix_export(GrB_Index          *indptr,
                          GrB_Index          *indices,
                          <type>            *values,
                          GrB_Index          *n_indptr,
                          GrB_Index          *n_indices,
                          GrB_Index          *n_values,
                          GrB_Format         format,
                          GrB_Matrix        A);
```

2578 **Parameters**

- 2579 **indptr** (INOUT) Pointer to an array that will hold row or column offsets, or row indices, depending on the value of **format**. It must be large enough to hold at
2580 least **n_indptr** elements of type **GrB_Index**, where **n_indptr** was returned from
2581 **GrB_Matrix_exportSize()** method.
2582
- 2583 **indices** (INOUT) Pointer to an array that will hold row or column indices of the elements
2584 in **values**, depending on the value of **format**. It must be large enough to hold at
2585 least **n_indices** elements of type **GrB_Index**, where **n_indices** was returned from
2586 **GrB_Matrix_exportSize()** method.
- 2587 **values** (INOUT) Pointer to an array that will hold stored values. The type of element
2588 must match the type of the values stored in **A**. It must be large enough
2589 to hold at least **n_values** elements of that type, where **n_values** was returned from
2590 **GrB_Matrix_exportSize**.
- 2591 **n_indptr** (INOUT) Pointer to a value indicating (on input) the number of elements the **indptr**
2592 array can hold. Upon return, it will contain the number of elements written to the
2593 array.
- 2594 **n_indices** (INOUT) Pointer to a value indicating (on input) the number of elements the **indices**
2595 array can hold. Upon return, it will contain the number of elements written to the
2596 array.
- 2597 **n_values** (INOUT) Pointer to a value indicating (on input) the number of elements the **values**
2598 array can hold. Upon return, it will contain the number of elements written to the
2599 array.
- 2600 **format** (IN) a value indicating the format in which the matrix will be exported, as defined
2601 in Section 3.5.3.1.
- 2602 **A** (IN) A GraphBLAS matrix object.

2603 **Return Values**

- 2604 **GrB_SUCCESS** In blocking or non-blocking mode, the operation completed successfully. This indicates that the compatibility tests on the input
2605 argument passed successfully, and the output arrays, **indptr**, **indices** and **values**, have been computed.
2606
2607
- 2608 **GrB_PANIC** Unknown internal error.
- 2609 **GrB_INVALID_OBJECT** This is returned in any execution mode whenever one of the opaque GraphBLAS objects (input or output) is in an invalid
2610 state caused by a previous execution error. Call **GrB_error()** to
2611 access any error messages generated by the implementation.
2612
- 2613 **GrB_OUT_OF_MEMORY** Not enough memory available for operation.

2614 GrB_INSUFFICIENT_SPACE Not enough space in `indptr`, `indices`, and/or `values` (as indicated
2615 by the corresponding `n_*` parameter) to hold all of the corre-
2616 sponding elements that will be extracted.

2617 GrB_UNINITIALIZED_OBJECT The GraphBLAS matrix, `A`, has not been initialized by a call to
2618 any matrix constructor.

2619 GrB_NULL_POINTER `indptr`, `indices`, `values` `n_indptr`, `n_indices`, `n_values` pointer is
2620 NULL.

2621 GrB_DOMAIN_MISMATCH The domain of `A` does not match with the type of `values`.

2622 Description

2623 Given a matrix `A`, this method exports the contents of the matrix into one of the pre-defined
2624 `GrB_Format` formats from Section 3.5.3.1. The user-allocated arrays pointed to by `indptr`, `indices`,
2625 and `values` must be at least large enough to hold the corresponding number of elements returned
2626 by calling `GrB_Matrix_exportSize`. The value of `format` can be chosen arbitrarily, but a call to
2627 `GrB_Matrix_exportHint` may suggest a format that results in the most efficient export. Details
2628 of the contents of `indptr`, `indices`, and `values` corresponding to each supported format is given in
2629 Appendix B.

2630 4.2.5.17 Matrix_import: Import a matrix into a GraphBLAS object

2631 C Syntax

```

GrB_Info GrB_Matrix_import(GrB_Matrix      *A,
                          GrB_Type        d,
                          GrB_Index       nrows,
                          GrB_Index       ncols
                          const GrB_Index *indptr,
                          const GrB_Index *indices,
                          const <type>   *values,
                          GrB_Index       n_indptr,
                          GrB_Index       n_indices,
                          GrB_Index       n_values,
                          GrB_Format      format);

```

2632 Parameters

2633 `A` (INOUT) On a successful return, contains a handle to the newly created Graph-
2634 BLAS matrix.

2635 `d` (IN) The type corresponding to the domain of the matrix being created. Can be
2636 one of the predefined GraphBLAS types in Table 3.2, or an existing user-defined
2637 GraphBLAS type.

2638 `nrows` (IN) Integer value holding the number of rows in the matrix.

2639 `ncols` (IN) Integer value holding the number of columns in the matrix.

2640 `indptr` (IN) Pointer to an array of row or column offsets, or row indices, depending on the
2641 value of `format`.

2642 `indices` (IN) Pointer to an array row or column indices of the elements in `values`, depending
2643 on the value of `format`.

2644 `values` (IN) Pointer to an array of values. Type must match the type of `d`.

2645 `n_indptr` (IN) Integer value holding the number of elements in the array pointed to by `indptr`.

2646 `n_indices` (IN) Integer value holding the number of elements in the array pointed to by `indices`.

2647 `n_values` (IN) Integer value holding the number of elements in the array pointed to by `values`.

2648 `format` (IN) a value indicating the format of the matrix being imported, as defined in
2649 Section 3.5.3.1.

2650 **Return Values**

2651 `GrB_SUCCESS` In blocking mode, the operation completed successfully. In non-
2652 blocking mode, this indicates that the API checks for the input
2653 arguments passed successfully and the input arrays have been
2654 consumed. Either way, output matrix `A` is ready to be used in
2655 the next method of the sequence.

2656 `GrB_PANIC` Unknown internal error.

2657 `GrB_OUT_OF_MEMORY` Not enough memory available for operation.

2658 `GrB_UNINITIALIZED_OBJECT` The `GrB_Type` object has not been initialized by a call to `GrB_Type_new`
2659 (needed for user-defined types).

2660 `GrB_NULL_POINTER` `A`, `indptr`, `indices` or `values` pointer is `NULL`.

2661 `GrB_INDEX_OUT_OF_BOUNDS` A value in `indptr` or `indices` is outside the allowed range for indices
2662 in `A` and or the size of `values`, `n_values`, depending on the value
2663 of `format`.

2664 `GrB_INVALID_VALUE` `nrows` or `ncols` is zero or outside the range of the type `GrB_Index`.

2665 `GrB_DOMAIN_MISMATCH` The domain given in parameter `d` does not match the element
2666 type of `values`.

2667 **Description**

2668 Creates a new matrix **A** of domain **D**(d) and dimension `nrows × ncols`. The new GraphBLAS
2669 matrix will be filled with the contents of the matrix pointed to by `indptr`, and `indices`, and `values`.
2670 The method returns a handle to the new matrix in **A**. The structure of the data being imported is
2671 defined by `format`, which must be equal to one of the values defined in Section 3.5.3.1. Details of
2672 the contents of `indptr`, `indices` and `values` for each supported format is given in Appendix B.

2673 It is not an error to call this method more than once on the same output matrix; however, the
2674 handle to the previously created object will be overwritten.

2675 **4.2.5.18 Matrix_serializeSize: Compute the serialize buffer size**

2676 Compute the buffer size (in bytes) necessary to serialize a `GrB_Matrix` using `GrB_Matrix_serialize`.

2677 **C Syntax**

```
GrB_Info GrB_Matrix_serializeSize(GrB_Index *size,  
                                GrB_Matrix A);
```

2678 **Parameters**

2679 `size` (OUT) Pointer to `GrB_Index` value where size in bytes of serialized object will be
2680 written.

2681 `A` (IN) A GraphBLAS matrix object.

2682 **Return Values**

2683 `GrB_SUCCESS` The operation completed successfully and the value pointed to
2684 by `*size` has been computed and is ready to use.

2685 `GrB_PANIC` Unknown internal error.

2686 `GrB_OUT_OF_MEMORY` Not enough memory available for operation.

2687 `GrB_NULL_POINTER` `size` is NULL.

2688 **Description**

2689 Returns the size in bytes of the data buffer necessary to serialize the GraphBLAS matrix object **A**.
2690 Users may then allocate a buffer of `size` bytes to pass as a parameter to `GrB_Matrix_serialize`.

2691 **4.2.5.19 Matrix_serialize: Serialize a GraphBLAS matrix.**

2692 Serialize a GraphBLAS Matrix object into an opaque stream of bytes.

2693 **C Syntax**

```
GrB_Info GrB_Matrix_serialize(void      *serialized_data,  
                               GrB_Index *serialized_size,  
                               GrB_Matrix A);
```

2694 **Parameters**

2695 `serialized_data` (INOUT) Pointer to the preallocated buffer where the serialized matrix will be
2696 written.

2697 `serialized_size` (INOUT) On input, the size in bytes of the buffer pointed to by `serialized_data`.
2698 On output, the number of bytes written to `serialized_data`.

2699 `A` (IN) A GraphBLAS matrix object.

2700 **Return Values**

2701 `GrB_SUCCESS` In blocking or non-blocking mode, the operation completed suc-
2702 cessfully. This indicates that the compatibility tests on the in-
2703 put argument passed successfully, and the output buffer `serial-
2704 ized_data` and `serialized_size`, have been computed and are ready
2705 to use.

2706 `GrB_PANIC` Unknown internal error.

2707 `GrB_INVALID_OBJECT` This is returned in any execution mode whenever one of the
2708 opaque GraphBLAS objects (input or output) is in an invalid
2709 state caused by a previous execution error. Call `GrB_error()` to
2710 access any error messages generated by the implementation.

2711 `GrB_OUT_OF_MEMORY` Not enough memory available for operation.

2712 `GrB_NULL_POINTER` `serialized_data` or `serialize_size` is NULL.

2713 `GrB_UNINITIALIZED_OBJECT` The GraphBLAS matrix, `A`, has not been initialized by a call to
2714 any matrix constructor.

2715 `GrB_INSUFFICIENT_SPACE` The size of the buffer `serialized_data` (provided as an input `seri-
2716 alized_size`) was not large enough.

2717 **Description**

2718 Serializes a GraphBLAS matrix object to an opaque buffer. To guarantee successful execution,
2719 the size of the buffer pointed to by `serialized_data`, provided as an input by `serialized_size`, must
2720 be of at least the number of bytes returned from `GrB_Matrix_serializeSize`. The actual size of the
2721 serialized matrix written to `serialized_data` is provided upon completion as an output written to
2722 `serialized_size`.

2723 The contents of the serialized buffer are implementation defined. Thus, a serialized matrix created
2724 with one library implementation is not necessarily valid for deserialization with another implemen-
2725 tation.

2726 **4.2.5.20 Matrix_deserialize: Deserialize a GraphBLAS matrix.**

2727 Construct a new GraphBLAS matrix from a serialized object.

2728 **C Syntax**

```
GrB_Info GrB_Matrix_deserialize(GrB_Matrix *A,  
                                GrB_Type   d,  
                                const void *serialized_data,  
                                GrB_Index  serialized_size);
```

2729 **Parameters**

2730 `A` (INOUT) On a successful return, contains a handle to the newly created Graph-
2731 BLAS matrix.

2732 `d` (IN) the type of the matrix that was serialized in `serialized_data`.
2733 If `d` is `GrB_NULL`, the implementation must attempt to deserialize the matrix
2734 without a provided type object.

2735 `serialized_data` (IN) a pointer to a serialized GraphBLAS matrix created with `GrB_Matrix_serialize`.

2736 `serialized_size` (IN) the size of the buffer pointed to by `serialized_data` in bytes.

2737 **Return Values**

2738 `GrB_SUCCESS` In blocking mode, the operation completed successfully. In non-
2739 blocking mode, this indicates that the API checks for the input
2740 arguments passed successfully. Either way, output matrix `A` is
2741 ready to be used in the next method of the sequence.

2742 `GrB_PANIC` Unknown internal error.

2743 `GrB_INVALID_OBJECT` This is returned if `serialized_data` is invalid or corrupted.

2772 **Return Value**

2773 GrB_SUCCESS The method completed successfully.

2774 GrB_PANIC unknown internal error.

2775 GrB_OUT_OF_MEMORY not enough memory available for operation.

2776 GrB_NULL_POINTER desc pointer is NULL.

2777 **Description**

2778 Creates a new descriptor object and returns a handle to it in `desc`. A newly created descriptor can
2779 be populated by calls to `Descriptor_set`.

2780 It is not an error to call this method more than once on the same variable; however, the handle to
2781 the previously created object will be overwritten.

2782 **4.2.6.2 Descriptor_set: Set content of descriptor**

2783 Sets the content for a field for an existing descriptor.

2784 **C Syntax**

```
2785           GrB_Info GrB_Descriptor_set(GrB_Descriptor        desc,  
2786                                    GrB_Desc_Field        field,  
2787                                    GrB_Desc_Value        val);
```

2788 **Parameters**

2789 desc (IN) An existing GraphBLAS descriptor to be modified.

2790 field (IN) The field being set.

2791 val (IN) New value for the field being set.

2792 **Return Values**

2793 GrB_SUCCESS operation completed successfully.

2794 GrB_PANIC unknown internal error.

2795 GrB_OUT_OF_MEMORY not enough memory available for operation.

2796 GrB_UNINITIALIZED_OBJECT the desc parameter has not been initialized by a call to `new`.

2797 GrB_INVALID_VALUE invalid value set on the field, or invalid field.

2798 **Description**

2799 For a given descriptor, the `GrB_Descriptor_set` method can be called for each field in the descriptor
2800 to set the value associated with that field. Valid values for the `field` parameter include the following:

2801 `GrB_OUTP` refers to the output parameter (result) of the operation.

2802 `GrB_MASK` refers to the mask parameter of the operation.

2803 `GrB_INP0` refers to the first input parameters of the operation (matrices and vectors).

2804 `GrB_INP1` refers to the second input parameters of the operation (matrices and vectors).

2805 Valid values for the `val` parameter are:

2806 `GrB_STRUCTURE` Use only the structure of the stored values of the corresponding mask
2807 (`GrB_MASK`) parameter.

2808 `GrB_COMP` Use the complement of the corresponding mask (`GrB_MASK`) param-
2809 eter. When combined with `GrB_STRUCTURE`, the complement of the
2810 structure of the mask is used without evaluating the values stored.

2811 `GrB_TRAN` Use the transpose of the corresponding matrix parameter (valid for input
2812 matrix parameters only).

2813 `GrB_REPLACE` When assigning the masked values to the output matrix or vector, clear
2814 the matrix first (or clear the non-masked entries). The default behavior
2815 is to leave non-masked locations unchanged. Valid for the `GrB_OUTP`
2816 parameter only.

2817 Descriptor values can only be set, and once set, cannot be cleared. As, in the case of `GrB_MASK`,
2818 multiple values can be set and all will apply (for example, both `GrB_COMP` and `GrB_STRUCTURE`).
2819 A value for a given field may be set multiple times but will have no additional effect. Fields that
2820 have no values set result in their default behavior, as defined in Section 3.6.

2821 **4.2.7 free: Destroy an object and release its resources**

2822 Destroys a previously created GraphBLAS object and releases any resources associated with the
2823 object.

2824 **C Syntax**

2825 `GrB_Info GrB_free(<GrB_Object> *obj);`

2826 Parameters

2827 obj (INOUT) An existing GraphBLAS object to be destroyed. The object must have
2828 been created by an explicit call to a GraphBLAS constructor. It can be any of the
2829 opaque GraphBLAS objects such as matrix, vector, descriptor, semiring, monoid,
2830 binary op, unary op, or type. On successful completion of GrB_free, obj behaves
2831 as an uninitialized object.

2832 Return Values

2833 GrB_SUCCESS operation completed successfully

2834 GrB_PANIC unknown internal error. If this return value is encountered when
2835 in nonblocking mode, the error responsible for the panic condition
2836 could be from any method involved in the computation of the input
2837 object. The GrB_error() method should be called for additional
2838 information.

2839 Description

2840 GraphBLAS objects consume memory and other resources managed by the GraphBLAS runtime
2841 system. A call to GrB_free frees those resources so they are available for use by other GraphBLAS
2842 objects.

2843 The parameter passed into GrB_free is a handle referencing a GraphBLAS opaque object of a data
2844 type from Table 2.1. The object must have been created by an explicit call to a GraphBLAS con-
2845 structor. The behavior of a program that calls GrB_free on a pre-defined object is implementation
2846 defined.

2847 After the GrB_free method returns, the object referenced by the input handle is destroyed and the
2848 handle has the value GrB_INVALID_HANDLE. The handle can be used in subsequent GraphBLAS
2849 methods but only after the handle has been reinitialized with a call the the appropriate _new or
2850 _dup method.

2851 Note that unlike other GraphBLAS methods, calling GrB_free with an object with an invalid handle
2852 is legal. The system may attempt to free resources that might be associated with that object, if
2853 possible, and return normally.

2854 When using GrB_free it is possible to create a dangling reference to an object. This would occur
2855 when a handle is assigned to a second variable of the same opaque type. This creates two handles
2856 that reference the same object. If GrB_free is called with one of the variables, the object is destroyed
2857 and the handle associated with the other variable no longer references a valid object. This is not an
2858 error condition that the implementation of the GraphBLAS API can be expected to catch, hence
2859 programmers must take care to prevent this situation from occurring.

2860 **4.2.8 wait: Return once an object is either *complete* or *materialized***

2861 Wait until method calls in a sequence put an object into a state of *completion* or *materialization*.

2862 **C Syntax**

2863 `GrB_Info GrB_wait(GrB_Object obj, GrB_WaitMode mode);`

2864 **Parameters**

2865 `obj` (INOUT) An existing GraphBLAS object. The object must have been created by an
2866 explicit call to a GraphBLAS constructor. Can be any of the opaque GraphBLAS
2867 objects such as matrix, vector, descriptor, semiring, monoid, binary op, unary op,
2868 or type. On successful return of `GrB_wait`, the `obj` can be safely read from another
2869 thread (completion) or all computing to produce `obj` by all GraphBLAS operations
2870 in its sequence have finished (materialization).

2871 `mode` (IN) Set's the mode for `GrB_wait` for whether it is waiting for `obj` to be in the
2872 state of *completion* or *materialization*. Acceptable values are `GrB_COMPLETE` or
2873 `GrB_MATERIALIZE`.

2874 **Return values**

2875 `GrB_SUCCESS` operation completed successfully.

2876 `GrB_INDEX_OUT_OF_BOUNDS` an index out-of-bounds execution error happened during com-
2877 pletion of pending operations.

2878 `GrB_OUT_OF_MEMORY` and out-of-memory execution error happened during completion
2879 of pending operations.

2880 `GrB_UNINITIALIZED_OBJECT` object has not been initialized by a call to the respective `*_new`,
2881 or other constructor, method.

2882 `GrB_PANIC` unknown internal error.

2883 `GrB_INVALID_VALUE` method called with a `GrB_WaitMode` other than `GrB_COMPLETE`
2884 `GrB_MATERIALIZE`.

2885 **Description**

2886 On successful return from `GrB_wait()`, the input object, `obj` is in one of two states depending on
2887 the mode of `GrB_wait`:

- 2888 • *complete*: `obj` can be used in a happens-before relation, so in a properly synchronized program
2889 it can be safely used as an IN or INOUT parameter in a GraphBLAS method call from another
2890 thread. This result occurs when the mode parameter is set to `GrB_COMPLETE`.
- 2891 • *materialized*: `obj` is *complete*, but in addition, no further computing will be carried out on
2892 behalf of `obj` and error information is available. This result occurs when the mode parameter
2893 is set to `GrB_MATERIALIZE`.

2894 Since in blocking mode OUT or INOUT parameters to any method call are materialized upon return,
2895 `GrB_wait(obj,mode)` has no effect when called in blocking mode.

2896 In non-blocking mode, the status of any pending method calls, other than those associated with pro-
2897 ducing the *complete* or *materialized* state of `obj`, are not impacted by the call to `GrB_wait(obj,mode)`.
2898 Methods in the sequence for `obj`, however, most likely would be impacted by a call to `GrB_wait(obj,mode)`;
2899 especially in the case of the *materialized* mode for which any computing on behalf of `obj` must be
2900 finished prior to the return from `GrB_wait(obj,mode)`.

2901 4.2.9 error: Retrieve an error string

2902 Retrieve an error-message about any errors encountered during the processing associated with an
2903 object.

2904 C Syntax

```
2905         GrB_Info GrB_error(const char          **error,
2906                           const GrB_Object    obj);
```

2907 Parameters

2908 `error` (OUT) A pointer to a null-terminated string. The contents of the string are im-
2909 plementation defined.

2910 `obj` (IN) An existing GraphBLAS object. The object must have been created by an
2911 explicit call to a GraphBLAS constructor. Can be any of the opaque GraphBLAS
2912 objects such as matrix, vector, descriptor, semiring, monoid, binary op, unary op,
2913 or type.

2914 Return value

2915 `GrB_SUCCESS` operation completed successfully.

2916 `GrB_UNINITIALIZED_OBJECT` object has not been initialized by a call to the respective `*_new`,
2917 or other constructor, method.

2918 `GrB_PANIC` unknown internal error.

2919 **Description**

2920 This method retrieves a message related to any errors that were encountered during the last Graph-
2921 BLAS method that had the opaque GraphBLAS object, `obj`, as an OUT or INOUT parameter.
2922 The function returns a pointer to a null-terminated string and the contents of that string are
2923 implementation-dependent. In particular, a null string (not a NULL pointer) is always a valid error
2924 string. The string that is returned is owned by `obj` and will be valid until the next time `obj` is
2925 used as an OUT or INOUT parameter or the object is freed by a call to `GrB_free(obj)`. This is a
2926 thread-safe function. It can be safely called by multiple threads for the same object in a race-free
2927 program.

2928 **4.3 GraphBLAS operations**

2929 The GraphBLAS operations are defined in the GraphBLAS math specification and summarized in
2930 Table 4.1. In addition to methods that implement these fundamental GraphBLAS operations, we
2931 support a number of variants that have been found to be especially useful in algorithm development.
2932 A flowchart of the overall behavior of a GraphBLAS operation is shown in Figure 4.1.

2933 **Domains and Casting**

2934 A GraphBLAS operation is only valid when the domains of the GraphBLAS objects are mathemat-
2935 ically consistent. The C programming language defines implicit casts between built-in data types.
2936 For example, floats, doubles, and ints can be freely mixed according to the rules defined for implicit
2937 casts. It is the responsibility of the user to assure that these casts are appropriate for the algorithm
2938 in question. For example, a cast to int implies truncation of a floating point type. Depending on
2939 the operation, this truncation error could lead to erroneous results. Furthermore, casting a wider
2940 type onto a narrower type can lead to overflow errors. The GraphBLAS operations do not attempt
2941 to protect a user from these sorts of errors.

2942 When user-define types are involved, however, GraphBLAS requires strict equivalence between
2943 types and no casting is supported. If GraphBLAS detects these mismatches, it will return a
2944 domain mismatch error.

2945 **Dimensions and Transposes**

2946 GraphBLAS operations also make assumptions about the numbers of dimensions and the sizes of
2947 vectors and matrices in an operation. An operation will test these sizes and report an error if they
2948 are not *shape compatible*. For example, when multiplying two matrices, $\mathbf{C} = \mathbf{A} \times \mathbf{B}$, the number
2949 of rows of \mathbf{C} must equal the number of rows of \mathbf{A} , the number of columns of \mathbf{A} must match the
2950 number of rows of \mathbf{B} , and the number of columns of \mathbf{C} must match the number of columns of \mathbf{B} .
2951 This is the behavior expected given the mathematical definition of the operations.

2952 For most of the GraphBLAS operations involving matrices, an optional descriptor can modify the
2953 matrix associated with an input GraphBLAS matrix object. For example, if an input matrix is an

Table 4.1: A mathematical notation for the fundamental GraphBLAS operations supported in this specification. Input matrices \mathbf{A} and \mathbf{B} may be optionally transposed (not shown). Use of an optional accumulate with existing values in the output object is indicated with \odot . Use of optional write masks and replace flags are indicated as $\mathbf{C}\langle\mathbf{M}, r\rangle$ when applied to the output matrix, \mathbf{C} . The mask controls which values resulting from the operation on the right-hand side are written into the output object (complement and structure flags are not shown). The “replace” option, indicated by specifying the r flag, means that all values in the output object are removed prior to assignment. If “replace” is not specified, only the values/locations computed on the right-hand side and allowed by the mask will be written to the output (“merge” mode).

Operation Name	Mathematical Notation	
mxm	$\mathbf{C}\langle\mathbf{M}, r\rangle$	$= \mathbf{C} \odot \mathbf{A} \oplus . \otimes \mathbf{B}$
mxv	$\mathbf{w}\langle\mathbf{m}, r\rangle$	$= \mathbf{w} \odot \mathbf{A} \oplus . \otimes \mathbf{u}$
vxm	$\mathbf{w}^T\langle\mathbf{m}^T, r\rangle$	$= \mathbf{w}^T \odot \mathbf{u}^T \oplus . \otimes \mathbf{A}$
eWiseMult	$\mathbf{C}\langle\mathbf{M}, r\rangle$	$= \mathbf{C} \odot \mathbf{A} \otimes \mathbf{B}$
	$\mathbf{w}\langle\mathbf{m}, r\rangle$	$= \mathbf{w} \odot \mathbf{u} \otimes \mathbf{v}$
eWiseAdd	$\mathbf{C}\langle\mathbf{M}, r\rangle$	$= \mathbf{C} \odot \mathbf{A} \oplus \mathbf{B}$
	$\mathbf{w}\langle\mathbf{m}, r\rangle$	$= \mathbf{w} \odot \mathbf{u} \oplus \mathbf{v}$
extract	$\mathbf{C}\langle\mathbf{M}, r\rangle$	$= \mathbf{C} \odot \mathbf{A}(i, j)$
	$\mathbf{w}\langle\mathbf{m}, r\rangle$	$= \mathbf{w} \odot \mathbf{u}(i)$
assign	$\mathbf{C}\langle\mathbf{M}, r\rangle(i, j)$	$= \mathbf{C}(i, j) \odot \mathbf{A}$
	$\mathbf{w}\langle\mathbf{m}, r\rangle(i)$	$= \mathbf{w}(i) \odot \mathbf{u}$
reduce (row)	$\mathbf{w}\langle\mathbf{m}, r\rangle$	$= \mathbf{w} \odot [\oplus_j \mathbf{A}(:, j)]$
reduce (scalar)	s	$= s \odot [\oplus_{i,j} \mathbf{A}(i, j)]$
	s	$= s \odot [\oplus_i \mathbf{u}(i)]$
apply	$\mathbf{C}\langle\mathbf{M}, r\rangle$	$= \mathbf{C} \odot f_u(\mathbf{A})$
	$\mathbf{w}\langle\mathbf{m}, r\rangle$	$= \mathbf{w} \odot f_u(\mathbf{u})$
apply(indexop)	$\mathbf{C}\langle\mathbf{M}, r\rangle$	$= \mathbf{C} \odot f_i(\mathbf{A}, \text{ind}(\mathbf{A}), s)$
	$\mathbf{w}\langle\mathbf{m}, r\rangle$	$= \mathbf{w} \odot f_i(\mathbf{u}, \text{ind}(\mathbf{u}), s)$
select	$\mathbf{C}\langle\mathbf{M}, r\rangle$	$= \mathbf{C} \odot \mathbf{A}\langle f_i(\mathbf{A}, \text{ind}(\mathbf{A}), s) \rangle$
	$\mathbf{w}\langle\mathbf{m}, r\rangle$	$= \mathbf{w} \odot \mathbf{u}\langle f_i(\mathbf{u}, \text{ind}(\mathbf{u}), s) \rangle$
transpose	$\mathbf{C}\langle\mathbf{M}, r\rangle$	$= \mathbf{C} \odot \mathbf{A}^T$
kroncker	$\mathbf{C}\langle\mathbf{M}, r\rangle$	$= \mathbf{C} \odot \mathbf{A} \otimes \mathbf{B}$

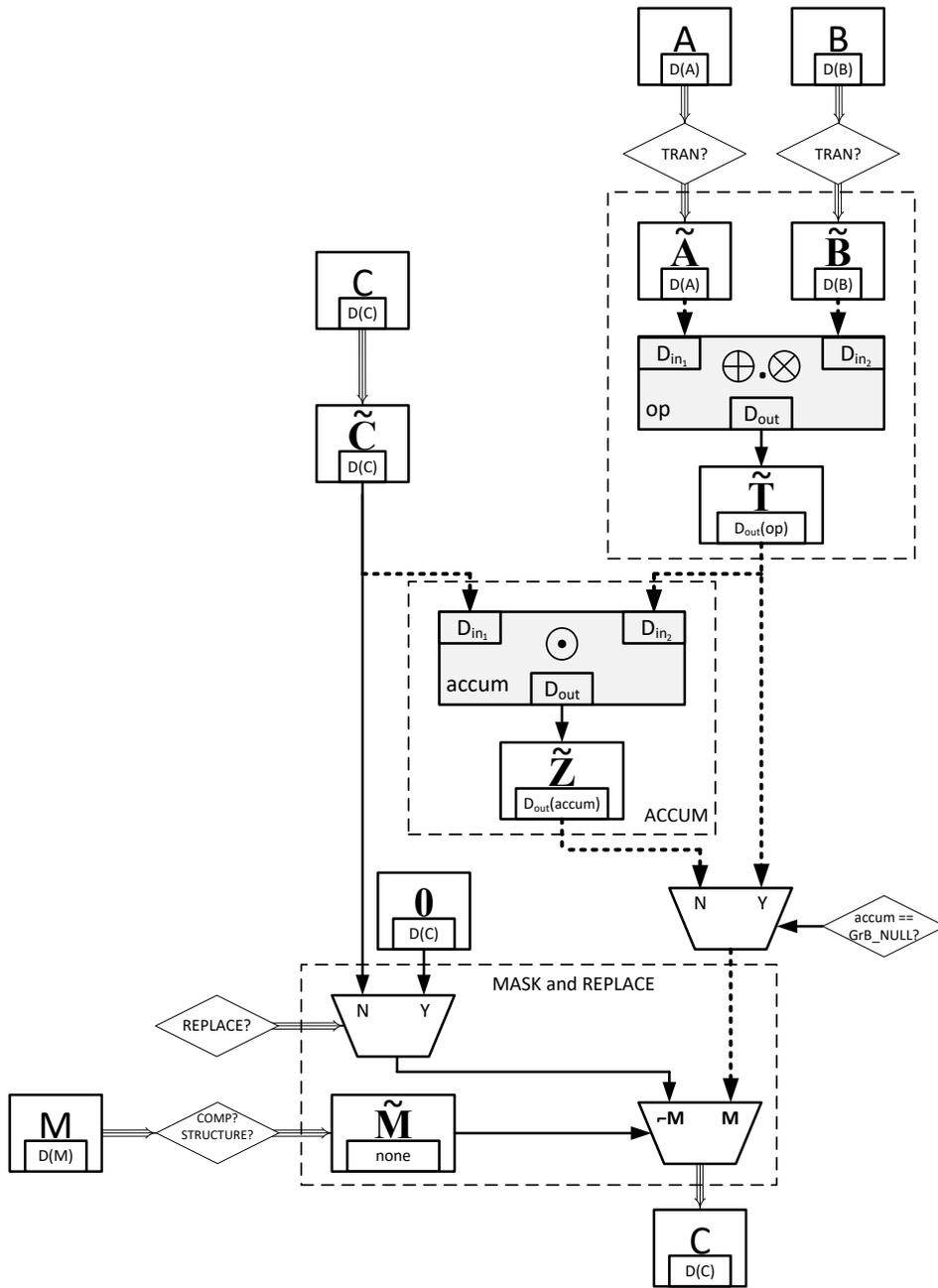


Figure 4.1: Flowchart for the GraphBLAS operations. Although shown specifically for the mxm operation, many elements are common to all operations: such as the “ACCUM” and “MASK and REPLACE” blocks. The triple arrows (\Rightarrow) denote where “as if copy” takes place (including both collections and descriptor settings). The bold, dotted arrows indicate where casting may occur between different domains.

2954 argument to a GraphBLAS operation and the associated descriptor indicates the transpose option,
 2955 then the operation occurs as if on the transposed matrix. In this case, the relationships between
 2956 the sizes in each dimension shift in the mathematically expected way.

2957 **Masks: Structure-only, Complement, and Replace**

2958 When a GraphBLAS operation supports the use of an optional mask, that mask is specified through
 2959 a GraphBLAS vector (for one-dimensional masks) or a GraphBLAS matrix (for two-dimensional
 2960 masks). When a mask is used and the `GrB_STRUCTURE` descriptor value is not set, it is applied
 2961 to the result from the operation wherever the stored values in the mask evaluate to true. If the
 2962 `GrB_STRUCTURE` descriptor is set, the mask is applied to the result from the operation wherever the
 2963 mask as a stored value (regardless of that value). Wherever the mask is applied, the result from
 2964 the operation is either assigned to the provided output matrix/vector or, if a binary accumulation
 2965 operation is provided, the result is accumulated into the corresponding elements of the provided
 2966 output matrix/vector.

2967 Given a GraphBLAS vector $\mathbf{v} = \langle D, N, \{(i, v_i)\} \rangle$, a one-dimensional mask is derived for use in the
 2968 operation as follows:

$$2969 \quad \mathbf{m} = \begin{cases} \langle N, \{\mathbf{ind}(\mathbf{v})\} \rangle, & \text{if } \text{GrB_STRUCTURE} \text{ is specified,} \\ \langle N, \{i : (\text{bool})v_i = \text{true}\} \rangle, & \text{otherwise} \end{cases}$$

2970 where $(\text{bool})v_i$ denotes casting the value v_i to a Boolean value (true or false). Likewise, given a
 2971 GraphBLAS matrix $\mathbf{A} = \langle D, M, N, \{(i, j, A_{ij})\} \rangle$, a two-dimensional mask is derived for use in the
 2972 operation as follows:

$$2973 \quad \mathbf{M} = \begin{cases} \langle M, N, \{\mathbf{ind}(\mathbf{A})\} \rangle, & \text{if } \text{GrB_STRUCTURE} \text{ is specified,} \\ \langle M, N, \{(i, j) : (\text{bool})A_{ij} = \text{true}\} \rangle, & \text{otherwise} \end{cases}$$

2974 where $(\text{bool})A_{ij}$ denotes casting the value A_{ij} to a Boolean value. (true or false)

2975 In both the one- and two-dimensional cases, the mask may also have a subsequent complement
 2976 operation applied (*Section 3.5.4*) as specified in the descriptor, before a final mask is generated for
 2977 use in the operation.

2978 When the descriptor of an operation with a mask has specified that the `GrB_REPLACE` value is
 2979 to be applied to the output (`GrB_OUTP`), then anywhere the mask is not true, the corresponding
 2980 location in the output is cleared.

2981 **Invalid and uninitialized objects**

2982 Upon entering a GraphBLAS operation, the first step is a check that all objects are valid and ini-
 2983 tialized. (Optional parameters can be set to `GrB_NULL`, which always counts as a valid object.) An
 2984 invalid object is one that could not be computed due to a previous execution error. An uninitialized
 2985 object is one that has not yet been created by a corresponding `new` or `dup` method. Appropriate
 2986 error codes are returned if an object is not initialized (`GrB_UNINITIALIZED_OBJECT`) or invalid
 2987 (`GrB_INVALID_OBJECT`).

2988 To support the detection of as many cases of uninitialized objects as possible, it is strongly rec-
2989 ommended to initialize all GraphBLAS objects to the predefined value GrB_INVALID_HANDLE at
2990 the point of their declaration, as shown in the following examples:

```
2991         GrB_Type          type = GrB_INVALID_HANDLE;  
2992         GrB_Semiring      semiring = GrB_INVALID_HANDLE;  
2993         GrB_Matrix        matrix = GrB_INVALID_HANDLE;
```

2994 Compliance

2995 We follow a *prescriptive* approach to the definition of the semantics of GraphBLAS operations.
2996 That is, for each operation we give a recipe for producing its outcome. Any implementation that
2997 produces the same outcome, and follows the GraphBLAS execution model (Section 2.5) and error
2998 model (Section 2.6) is a conforming implementation.

2999 4.3.1 mxm: Matrix-matrix multiply

3000 Multiplies a matrix with another matrix on a semiring. The result is a matrix.

3001 C Syntax

```
3002         GrB_Info GrB_mxm(GrB_Matrix          C,  
3003                         const GrB_Matrix    Mask,  
3004                         const GrB_BinaryOp   accum,  
3005                         const GrB_Semiring   op,  
3006                         const GrB_Matrix    A,  
3007                         const GrB_Matrix    B,  
3008                         const GrB_Descriptor desc);
```

3009 Parameters

3010 **C** (INOUT) An existing GraphBLAS matrix. On input, the matrix provides values
3011 that may be accumulated with the result of the matrix product. On output, the
3012 matrix holds the results of the operation.

3013 **Mask** (IN) An optional “write” mask that controls which results from this operation are
3014 stored into the output matrix C. The mask dimensions must match those of the
3015 matrix C. If the GrB_STRUCTURE descriptor is *not* set for the mask, the domain
3016 of the Mask matrix must be of type `bool` or any of the predefined “built-in” types
3017 in Table 3.2. If the default mask is desired (i.e., a mask that is all true with the
3018 dimensions of C), GrB_NULL should be specified.

3019 **accum** (IN) An optional binary operator used for accumulating entries into existing **C**
 3020 entries. If assignment rather than accumulation is desired, **GrB_NULL** should be
 3021 specified.

3022 **op** (IN) The semiring used in the matrix-matrix multiply.

3023 **A** (IN) The GraphBLAS matrix holding the values for the left-hand matrix in the
 3024 multiplication.

3025 **B** (IN) The GraphBLAS matrix holding the values for the right-hand matrix in the
 3026 multiplication.

3027 **desc** (IN) An optional operation descriptor. If a *default* descriptor is desired, **GrB_NULL**
 3028 should be specified. Non-default field/value pairs are listed as follows:
 3029

Param	Field	Value	Description
C	GrB_OUTP	GrB_REPLACE	Output matrix C is cleared (all elements removed) before the result is stored in it.
Mask	GrB_MASK	GrB_STRUCTURE	The write mask is constructed from the structure (pattern of stored values) of the input Mask matrix. The stored values are not examined.
Mask	GrB_MASK	GrB_COMP	Use the complement of Mask .
A	GrB_INP0	GrB_TRAN	Use transpose of A for the operation.
B	GrB_INP1	GrB_TRAN	Use transpose of B for the operation.

3031 **Return Values**

3032 **GrB_SUCCESS** In blocking mode, the operation completed successfully. In non-
 3033 blocking mode, this indicates that the compatibility tests on di-
 3034 mensions and domains for the input arguments passed successfully.
 3035 Either way, output matrix **C** is ready to be used in the next method
 3036 of the sequence.

3037 **GrB_PANIC** Unknown internal error.

3038 **GrB_INVALID_OBJECT** This is returned in any execution mode whenever one of the opaque
 3039 GraphBLAS objects (input or output) is in an invalid state caused
 3040 by a previous execution error. Call **GrB_error()** to access any error
 3041 messages generated by the implementation.

3042 **GrB_OUT_OF_MEMORY** Not enough memory available for the operation.

3043 **GrB_UNINITIALIZED_OBJECT** One or more of the GraphBLAS objects has not been initialized by
 3044 a call to **new** (or **Matrix_dup** for matrix parameters).

3045 **GrB_DIMENSION_MISMATCH** Mask and/or matrix dimensions are incompatible.

3046 GrB_DOMAIN_MISMATCH The domains of the various matrices are incompatible with the
 3047 corresponding domains of the semiring or accumulation operator,
 3048 or the mask's domain is not compatible with `bool` (in the case where
 3049 `desc[GrB_MASK].GrB_STRUCTURE` is not set).

3050 Description

3051 GrB_mxm computes the matrix product $C = A \oplus . \otimes B$ or, if an optional binary accumulation operator
 3052 (\odot) is provided, $C = C \odot (A \oplus . \otimes B)$ (where matrices A and B can be optionally transposed).
 3053 Logically, this operation occurs in three steps:

3054 **Setup** The internal matrices and mask used in the computation are formed and their domains
 3055 and dimensions are tested for compatibility.

3056 **Compute** The indicated computations are carried out.

3057 **Output** The result is written into the output matrix, possibly under control of a mask.

3058 Up to four argument matrices are used in the GrB_mxm operation:

- 3059 1. $C = \langle \mathbf{D}(C), \mathbf{nrows}(C), \mathbf{ncols}(C), \mathbf{L}(C) = \{(i, j, C_{ij})\} \rangle$
- 3060 2. $\text{Mask} = \langle \mathbf{D}(\text{Mask}), \mathbf{nrows}(\text{Mask}), \mathbf{ncols}(\text{Mask}), \mathbf{L}(\text{Mask}) = \{(i, j, M_{ij})\} \rangle$ (optional)
- 3061 3. $A = \langle \mathbf{D}(A), \mathbf{nrows}(A), \mathbf{ncols}(A), \mathbf{L}(A) = \{(i, j, A_{ij})\} \rangle$
- 3062 4. $B = \langle \mathbf{D}(B), \mathbf{nrows}(B), \mathbf{ncols}(B), \mathbf{L}(B) = \{(i, j, B_{ij})\} \rangle$

3063 The argument matrices, the semiring, and the accumulation operator (if provided) are tested for
 3064 domain compatibility as follows:

- 3065 1. If `Mask` is not `GrB_NULL`, and `desc[GrB_MASK].GrB_STRUCTURE` is not set, then $\mathbf{D}(\text{Mask})$
 3066 must be from one of the pre-defined types of Table 3.2.
- 3067 2. $\mathbf{D}(A)$ must be compatible with $\mathbf{D}_{in_1}(\text{op})$ of the semiring.
- 3068 3. $\mathbf{D}(B)$ must be compatible with $\mathbf{D}_{in_2}(\text{op})$ of the semiring.
- 3069 4. $\mathbf{D}(C)$ must be compatible with $\mathbf{D}_{out}(\text{op})$ of the semiring.
- 3070 5. If `accum` is not `GrB_NULL`, then $\mathbf{D}(C)$ must be compatible with $\mathbf{D}_{in_1}(\text{accum})$ and $\mathbf{D}_{out}(\text{accum})$
 3071 of the accumulation operator and $\mathbf{D}_{out}(\text{op})$ of the semiring must be compatible with $\mathbf{D}_{in_2}(\text{accum})$
 3072 of the accumulation operator.

3073 Two domains are compatible with each other if values from one domain can be cast to values in
 3074 the other domain as per the rules of the C language. In particular, domains from Table 3.2 are
 3075 all compatible with each other. A domain from a user-defined type is only compatible with itself.

3076 If any compatibility rule above is violated, execution of `GrB_mxm` ends and the domain mismatch
3077 error listed above is returned.

3078 From the argument matrices, the internal matrices and mask used in the computation are formed
3079 (\leftarrow denotes copy):

- 3080 1. Matrix $\tilde{\mathbf{C}} \leftarrow \mathbf{C}$.
- 3081 2. Two-dimensional mask, $\tilde{\mathbf{M}}$, is computed from argument `Mask` as follows:
 - 3082 (a) If `Mask = GrB_NULL`, then $\tilde{\mathbf{M}} = \langle \mathbf{nrows}(\mathbf{C}), \mathbf{ncols}(\mathbf{C}), \{(i, j), \forall i, j : 0 \leq i < \mathbf{nrows}(\mathbf{C}), 0 \leq$
3083 $j < \mathbf{ncols}(\mathbf{C})\} \rangle$.
 - 3084 (b) If `Mask \neq GrB_NULL`,
 - 3085 i. If `desc[GrB_MASK].GrB_STRUCTURE` is set, then $\tilde{\mathbf{M}} = \langle \mathbf{nrows}(\mathbf{Mask}), \mathbf{ncols}(\mathbf{Mask}), \{(i, j) :$
3086 $(i, j) \in \mathbf{ind}(\mathbf{Mask})\} \rangle$,
 - 3087 ii. Otherwise, $\tilde{\mathbf{M}} = \langle \mathbf{nrows}(\mathbf{Mask}), \mathbf{ncols}(\mathbf{Mask}),$
3088 $\{(i, j) : (i, j) \in \mathbf{ind}(\mathbf{Mask}) \wedge (\mathbf{bool})\mathbf{Mask}(i, j) = \mathbf{true}\} \rangle$.
 - 3089 (c) If `desc[GrB_MASK].GrB_COMP` is set, then $\tilde{\mathbf{M}} \leftarrow \neg\tilde{\mathbf{M}}$.
- 3090 3. Matrix $\tilde{\mathbf{A}} \leftarrow \mathbf{desc}[\mathbf{GrB_INP0}].\mathbf{GrB_TRAN} ? \mathbf{A}^T : \mathbf{A}$.
- 3091 4. Matrix $\tilde{\mathbf{B}} \leftarrow \mathbf{desc}[\mathbf{GrB_INP1}].\mathbf{GrB_TRAN} ? \mathbf{B}^T : \mathbf{B}$.

3092 The internal matrices and masks are checked for dimension compatibility. The following conditions
3093 must hold:

- 3094 1. $\mathbf{nrows}(\tilde{\mathbf{C}}) = \mathbf{nrows}(\tilde{\mathbf{M}})$.
- 3095 2. $\mathbf{ncols}(\tilde{\mathbf{C}}) = \mathbf{ncols}(\tilde{\mathbf{M}})$.
- 3096 3. $\mathbf{nrows}(\tilde{\mathbf{C}}) = \mathbf{nrows}(\tilde{\mathbf{A}})$.
- 3097 4. $\mathbf{ncols}(\tilde{\mathbf{C}}) = \mathbf{ncols}(\tilde{\mathbf{B}})$.
- 3098 5. $\mathbf{ncols}(\tilde{\mathbf{A}}) = \mathbf{nrows}(\tilde{\mathbf{B}})$.

3099 If any compatibility rule above is violated, execution of `GrB_mxm` ends and the dimension mismatch
3100 error listed above is returned.

3101 From this point forward, in `GrB_NONBLOCKING` mode, the method can optionally exit with
3102 `GrB_SUCCESS` return code and defer any computation and/or execution error codes.

3103 We are now ready to carry out the matrix multiplication and any additional associated operations.
3104 We describe this in terms of two intermediate matrices:

- 3105 • $\tilde{\mathbf{T}}$: The matrix holding the product of matrices $\tilde{\mathbf{A}}$ and $\tilde{\mathbf{B}}$.
- 3106 • $\tilde{\mathbf{Z}}$: The matrix holding the result after application of the (optional) accumulation operator.

3107 The intermediate matrix $\tilde{\mathbf{T}} = \langle \mathbf{D}_{out}(\text{op}), \mathbf{nrows}(\tilde{\mathbf{A}}), \mathbf{ncols}(\tilde{\mathbf{B}}), \{(i, j, T_{ij}) : \mathbf{ind}(\tilde{\mathbf{A}}(i, :)) \cap \mathbf{ind}(\tilde{\mathbf{B}}(:$
3108 $, j)) \neq \emptyset\}$ is created. The value of each of its elements is computed by

$$3109 \quad T_{ij} = \bigoplus_{k \in \mathbf{ind}(\tilde{\mathbf{A}}(i, :)) \cap \mathbf{ind}(\tilde{\mathbf{B}}(:, j))} (\tilde{\mathbf{A}}(i, k) \otimes \tilde{\mathbf{B}}(k, j)),$$

3110 where \oplus and \otimes are the additive and multiplicative operators of semiring op , respectively.

3111 The intermediate matrix $\tilde{\mathbf{Z}}$ is created as follows, using what is called a *standard matrix accumulate*:

- 3112 • If `accum = GrB_NULL`, then $\tilde{\mathbf{Z}} = \tilde{\mathbf{T}}$.
- 3113 • If `accum` is a binary operator, then $\tilde{\mathbf{Z}}$ is defined as

$$3114 \quad \tilde{\mathbf{Z}} = \langle \mathbf{D}_{out}(\text{accum}), \mathbf{nrows}(\tilde{\mathbf{C}}), \mathbf{ncols}(\tilde{\mathbf{C}}), \{(i, j, Z_{ij}) \forall (i, j) \in \mathbf{ind}(\tilde{\mathbf{C}}) \cup \mathbf{ind}(\tilde{\mathbf{T}})\}\rangle.$$

3115 The values of the elements of $\tilde{\mathbf{Z}}$ are computed based on the relationships between the sets of
3116 indices in $\tilde{\mathbf{C}}$ and $\tilde{\mathbf{T}}$.

$$3117 \quad Z_{ij} = \tilde{\mathbf{C}}(i, j) \odot \tilde{\mathbf{T}}(i, j), \text{ if } (i, j) \in (\mathbf{ind}(\tilde{\mathbf{T}}) \cap \mathbf{ind}(\tilde{\mathbf{C}})),$$

$$3118 \quad Z_{ij} = \tilde{\mathbf{C}}(i, j), \text{ if } (i, j) \in (\mathbf{ind}(\tilde{\mathbf{C}}) - (\mathbf{ind}(\tilde{\mathbf{T}}) \cap \mathbf{ind}(\tilde{\mathbf{C}}))),$$

$$3119 \quad Z_{ij} = \tilde{\mathbf{T}}(i, j), \text{ if } (i, j) \in (\mathbf{ind}(\tilde{\mathbf{T}}) - (\mathbf{ind}(\tilde{\mathbf{T}}) \cap \mathbf{ind}(\tilde{\mathbf{C}}))),$$

3122 where $\odot = \odot(\text{accum})$, and the difference operator refers to set difference.

3123 Finally, the set of output values that make up matrix $\tilde{\mathbf{Z}}$ are written into the final result matrix \mathbf{C} ,
3124 using what is called a *standard matrix mask and replace*. This is carried out under control of the
3125 mask which acts as a “write mask”.

- 3126 • If `desc[GrB_OUTP].GrB_REPLACE` is set, then any values in \mathbf{C} on input to this operation are
3127 deleted and the content of the new output matrix, \mathbf{C} , is defined as,

$$3128 \quad \mathbf{L}(\mathbf{C}) = \{(i, j, Z_{ij}) : (i, j) \in (\mathbf{ind}(\tilde{\mathbf{Z}}) \cap \mathbf{ind}(\tilde{\mathbf{M}}))\}.$$

- 3129 • If `desc[GrB_OUTP].GrB_REPLACE` is not set, the elements of $\tilde{\mathbf{Z}}$ indicated by the mask are
3130 copied into the result matrix, \mathbf{C} , and elements of \mathbf{C} that fall outside the set indicated by the
3131 mask are unchanged:

$$3132 \quad \mathbf{L}(\mathbf{C}) = \{(i, j, C_{ij}) : (i, j) \in (\mathbf{ind}(\mathbf{C}) \cap \mathbf{ind}(\neg \tilde{\mathbf{M}}))\} \cup \{(i, j, Z_{ij}) : (i, j) \in (\mathbf{ind}(\tilde{\mathbf{Z}}) \cap \mathbf{ind}(\tilde{\mathbf{M}}))\}.$$

3133 In `GrB_BLOCKING` mode, the method exits with return value `GrB_SUCCESS` and the new content
3134 of matrix \mathbf{C} is as defined above and fully computed. In `GrB_NONBLOCKING` mode, the method
3135 exits with return value `GrB_SUCCESS` and the new content of matrix \mathbf{C} is as defined above but
3136 may not be fully computed. However, it can be used in the next GraphBLAS method call in a
3137 sequence.

3138 4.3.2 vxm: Vector-matrix multiply

3139 Multiplies a (row) vector with a matrix on an semiring. The result is a vector.

3140 C Syntax

```
3141     GrB_Info GrB_vxm(GrB_Vector      w,  
3142                   const GrB_Vector  mask,  
3143                   const GrB_BinaryOp accum,  
3144                   const GrB_Semiring op,  
3145                   const GrB_Vector  u,  
3146                   const GrB_Matrix  A,  
3147                   const GrB_Descriptor desc);
```

3148 Parameters

3149 **w** (INOUT) An existing GraphBLAS vector. On input, the vector provides values
3150 that may be accumulated with the result of the vector-matrix product. On output,
3151 this vector holds the results of the operation.

3152 **mask** (IN) An optional “write” mask that controls which results from this operation are
3153 stored into the output vector **w**. The mask dimensions must match those of the
3154 vector **w**. If the `GrB_STRUCTURE` descriptor is *not* set for the mask, the domain
3155 of the mask vector must be of type `bool` or any of the predefined “built-in” types
3156 in Table 3.2. If the default mask is desired (i.e., a mask that is all true with the
3157 dimensions of **w**), `GrB_NULL` should be specified.

3158 **accum** (IN) An optional binary operator used for accumulating entries into existing **w**
3159 entries. If assignment rather than accumulation is desired, `GrB_NULL` should be
3160 specified.

3161 **op** (IN) Semiring used in the vector-matrix multiply.

3162 **u** (IN) The GraphBLAS vector holding the values for the left-hand vector in the
3163 multiplication.

3164 **A** (IN) The GraphBLAS matrix holding the values for the right-hand matrix in the
3165 multiplication.

3166 **desc** (IN) An optional operation descriptor. If a *default* descriptor is desired, `GrB_NULL`
3167 should be specified. Non-default field/value pairs are listed as follows:
3168

Param	Field	Value	Description
w	GrB_OUTP	GrB_REPLACE	Output vector w is cleared (all elements removed) before the result is stored in it.
mask	GrB_MASK	GrB_STRUCTURE	The write mask is constructed from the structure (pattern of stored values) of the input mask vector. The stored values are not examined.
mask	GrB_MASK	GrB_COMP	Use the complement of mask.
A	GrB_INP1	GrB_TRAN	Use transpose of A for the operation.

3169

3170 Return Values

3171 GrB_SUCCESS In blocking mode, the operation completed successfully. In non-
3172 blocking mode, this indicates that the compatibility tests on di-
3173 mensions and domains for the input arguments passed successfully.
3174 Either way, output vector w is ready to be used in the next method
3175 of the sequence.

3176 GrB_PANIC Unknown internal error.

3177 GrB_INVALID_OBJECT This is returned in any execution mode whenever one of the opaque
3178 GraphBLAS objects (input or output) is in an invalid state caused
3179 by a previous execution error. Call GrB_error() to access any error
3180 messages generated by the implementation.

3181 GrB_OUT_OF_MEMORY Not enough memory available for the operation.

3182 GrB_UNINITIALIZED_OBJECT One or more of the GraphBLAS objects has not been initialized by
3183 a call to new (or dup for matrix or vector parameters).

3184 GrB_DIMENSION_MISMATCH Mask, vector, and/or matrix dimensions are incompatible.

3185 GrB_DOMAIN_MISMATCH The domains of the various vectors/matrices are incompatible with
3186 the corresponding domains of the semiring or accumulation opera-
3187 tor, or the mask's domain is not compatible with bool (in the case
3188 where desc[GrB_MASK].GrB_STRUCTURE is not set).

3189 Description

3190 GrB_vxm computes the vector-matrix product $w^T = u^T \oplus . \otimes A$, or, if an optional binary accu-
3191 mulation operator (\odot) is provided, $w^T = w^T \odot (u^T \oplus . \otimes A)$ (where matrix A can be optionally
3192 transposed). Logically, this operation occurs in three steps:

3193 **Setup** The internal vectors, matrices and mask used in the computation are formed and their
3194 domains/dimensions are tested for compatibility.

3195 **Compute** The indicated computations are carried out.

3196 **Output** The result is written into the output vector, possibly under control of a mask.

3197 Up to four argument vectors or matrices are used in the GrB_vxm operation:

- 3198 1. $\mathbf{w} = \langle \mathbf{D}(\mathbf{w}), \mathbf{size}(\mathbf{w}), \mathbf{L}(\mathbf{w}) = \{(i, w_i)\} \rangle$
- 3199 2. $\mathbf{mask} = \langle \mathbf{D}(\mathbf{mask}), \mathbf{size}(\mathbf{mask}), \mathbf{L}(\mathbf{mask}) = \{(i, m_i)\} \rangle$ (optional)
- 3200 3. $\mathbf{u} = \langle \mathbf{D}(\mathbf{u}), \mathbf{size}(\mathbf{u}), \mathbf{L}(\mathbf{u}) = \{(i, u_i)\} \rangle$
- 3201 4. $\mathbf{A} = \langle \mathbf{D}(\mathbf{A}), \mathbf{nrows}(\mathbf{A}), \mathbf{ncols}(\mathbf{A}), \mathbf{L}(\mathbf{A}) = \{(i, j, A_{ij})\} \rangle$

3202 The argument matrices, vectors, the semiring, and the accumulation operator (if provided) are
3203 tested for domain compatibility as follows:

- 3204 1. If \mathbf{mask} is not GrB_NULL, and desc[GrB_MASK].GrB_STRUCTURE is not set, then $\mathbf{D}(\mathbf{mask})$
3205 must be from one of the pre-defined types of Table 3.2.
- 3206 2. $\mathbf{D}(\mathbf{u})$ must be compatible with $\mathbf{D}_{in_1}(\mathbf{op})$ of the semiring.
- 3207 3. $\mathbf{D}(\mathbf{A})$ must be compatible with $\mathbf{D}_{in_2}(\mathbf{op})$ of the semiring.
- 3208 4. $\mathbf{D}(\mathbf{w})$ must be compatible with $\mathbf{D}_{out}(\mathbf{op})$ of the semiring.
- 3209 5. If \mathbf{accum} is not GrB_NULL, then $\mathbf{D}(\mathbf{w})$ must be compatible with $\mathbf{D}_{in_1}(\mathbf{accum})$ and $\mathbf{D}_{out}(\mathbf{accum})$
3210 of the accumulation operator and $\mathbf{D}_{out}(\mathbf{op})$ of the semiring must be compatible with $\mathbf{D}_{in_2}(\mathbf{accum})$
3211 of the accumulation operator.

3212 Two domains are compatible with each other if values from one domain can be cast to values in
3213 the other domain as per the rules of the C language. In particular, domains from Table 3.2 are
3214 all compatible with each other. A domain from a user-defined type is only compatible with itself.
3215 If any compatibility rule above is violated, execution of GrB_vxm ends and the domain mismatch
3216 error listed above is returned.

3217 From the argument vectors and matrices, the internal matrices and mask used in the computation
3218 are formed (\leftarrow denotes copy):

- 3219 1. Vector $\tilde{\mathbf{w}} \leftarrow \mathbf{w}$.
- 3220 2. One-dimensional mask, $\tilde{\mathbf{m}}$, is computed from argument \mathbf{mask} as follows:
 - 3221 (a) If $\mathbf{mask} = \text{GrB_NULL}$, then $\tilde{\mathbf{m}} = \langle \mathbf{size}(\mathbf{w}), \{i, \forall i : 0 \leq i < \mathbf{size}(\mathbf{w})\} \rangle$.
 - 3222 (b) If $\mathbf{mask} \neq \text{GrB_NULL}$,
 - 3223 i. If desc[GrB_MASK].GrB_STRUCTURE is set, then $\tilde{\mathbf{m}} = \langle \mathbf{size}(\mathbf{mask}), \{i : i \in \mathbf{ind}(\mathbf{mask})\} \rangle$,
 - 3224 ii. Otherwise, $\tilde{\mathbf{m}} = \langle \mathbf{size}(\mathbf{mask}), \{i : i \in \mathbf{ind}(\mathbf{mask}) \wedge (\mathbf{bool})\mathbf{mask}(i) = \text{true}\} \rangle$.
 - 3225 (c) If desc[GrB_MASK].GrB_COMP is set, then $\tilde{\mathbf{m}} \leftarrow \neg \tilde{\mathbf{m}}$.
- 3226 3. Vector $\tilde{\mathbf{u}} \leftarrow \mathbf{u}$.

3227 4. Matrix $\tilde{\mathbf{A}} \leftarrow \text{desc}[\text{GrB_INP1}].\text{GrB_TRAN} ? \mathbf{A}^T : \mathbf{A}$.

3228 The internal matrices and masks are checked for shape compatibility. The following conditions
3229 must hold:

3230 1. $\text{size}(\tilde{\mathbf{w}}) = \text{size}(\tilde{\mathbf{m}})$.

3231 2. $\text{size}(\tilde{\mathbf{w}}) = \text{ncols}(\tilde{\mathbf{A}})$.

3232 3. $\text{size}(\tilde{\mathbf{u}}) = \text{nrows}(\tilde{\mathbf{A}})$.

3233 If any compatibility rule above is violated, execution of `GrB_vxm` ends and the dimension mismatch
3234 error listed above is returned.

3235 From this point forward, in `GrB_NONBLOCKING` mode, the method can optionally exit with
3236 `GrB_SUCCESS` return code and defer any computation and/or execution error codes.

3237 We are now ready to carry out the vector-matrix multiplication and any additional associated
3238 operations. We describe this in terms of two intermediate vectors:

- 3239 • $\tilde{\mathbf{t}}$: The vector holding the product of vector $\tilde{\mathbf{u}}^T$ and matrix $\tilde{\mathbf{A}}$.
- 3240 • $\tilde{\mathbf{z}}$: The vector holding the result after application of the (optional) accumulation operator.

3241 The intermediate vector $\tilde{\mathbf{t}} = \langle \mathbf{D}_{out}(\text{op}), \text{ncols}(\tilde{\mathbf{A}}), \{(j, t_j) : \text{ind}(\tilde{\mathbf{u}}) \cap \text{ind}(\tilde{\mathbf{A}}(:, j)) \neq \emptyset\} \rangle$ is created.
3242 The value of each of its elements is computed by

$$3243 \quad t_j = \bigoplus_{k \in \text{ind}(\tilde{\mathbf{u}}) \cap \text{ind}(\tilde{\mathbf{A}}(:, j))} (\tilde{\mathbf{u}}(k) \otimes \tilde{\mathbf{A}}(k, j)),$$

3244 where \oplus and \otimes are the additive and multiplicative operators of semiring `op`, respectively.

3245 The intermediate vector $\tilde{\mathbf{z}}$ is created as follows, using what is called a *standard vector accumulate*:

- 3246 • If `accum = GrB_NULL`, then $\tilde{\mathbf{z}} = \tilde{\mathbf{t}}$.
- 3247 • If `accum` is a binary operator, then $\tilde{\mathbf{z}}$ is defined as

$$3248 \quad \tilde{\mathbf{z}} = \langle \mathbf{D}_{out}(\text{accum}), \text{size}(\tilde{\mathbf{w}}), \{(i, z_i) \mid \forall i \in \text{ind}(\tilde{\mathbf{w}}) \cup \text{ind}(\tilde{\mathbf{t}})\} \rangle.$$

3249 The values of the elements of $\tilde{\mathbf{z}}$ are computed based on the relationships between the sets of
3250 indices in $\tilde{\mathbf{w}}$ and $\tilde{\mathbf{t}}$.

$$\begin{aligned} 3251 \quad z_i &= \tilde{\mathbf{w}}(i) \odot \tilde{\mathbf{t}}(i), \text{ if } i \in (\text{ind}(\tilde{\mathbf{t}}) \cap \text{ind}(\tilde{\mathbf{w}})), \\ 3252 \quad z_i &= \tilde{\mathbf{w}}(i), \text{ if } i \in (\text{ind}(\tilde{\mathbf{w}}) - (\text{ind}(\tilde{\mathbf{t}}) \cap \text{ind}(\tilde{\mathbf{w}}))), \\ 3253 \quad z_i &= \tilde{\mathbf{t}}(i), \text{ if } i \in (\text{ind}(\tilde{\mathbf{t}}) - (\text{ind}(\tilde{\mathbf{t}}) \cap \text{ind}(\tilde{\mathbf{w}}))), \\ 3254 \quad z_i &= \tilde{\mathbf{t}}(i), \text{ if } i \in (\text{ind}(\tilde{\mathbf{t}}) - (\text{ind}(\tilde{\mathbf{t}}) \cap \text{ind}(\tilde{\mathbf{w}}))), \\ 3255 \end{aligned}$$

3256 where $\odot = \odot(\text{accum})$, and the difference operator refers to set difference.

3257 Finally, the set of output values that make up vector $\tilde{\mathbf{z}}$ are written into the final result vector \mathbf{w} ,
 3258 using what is called a *standard vector mask and replace*. This is carried out under control of the
 3259 mask which acts as a “write mask”.

- 3260 • If desc[GrB_OUTP].GrB_REPLACE is set, then any values in \mathbf{w} on input to this operation are
 3261 deleted and the content of the new output vector, \mathbf{w} , is defined as,

$$3262 \quad \mathbf{L}(\mathbf{w}) = \{(i, z_i) : i \in (\mathbf{ind}(\tilde{\mathbf{z}}) \cap \mathbf{ind}(\tilde{\mathbf{m}}))\}.$$

- 3263 • If desc[GrB_OUTP].GrB_REPLACE is not set, the elements of $\tilde{\mathbf{z}}$ indicated by the mask are
 3264 copied into the result vector, \mathbf{w} , and elements of \mathbf{w} that fall outside the set indicated by the
 3265 mask are unchanged:

$$3266 \quad \mathbf{L}(\mathbf{w}) = \{(i, w_i) : i \in (\mathbf{ind}(\mathbf{w}) \cap \mathbf{ind}(\neg\tilde{\mathbf{m}}))\} \cup \{(i, z_i) : i \in (\mathbf{ind}(\tilde{\mathbf{z}}) \cap \mathbf{ind}(\tilde{\mathbf{m}}))\}.$$

3267 In GrB_BLOCKING mode, the method exits with return value GrB_SUCCESS and the new content
 3268 of vector \mathbf{w} is as defined above and fully computed. In GrB_NONBLOCKING mode, the method
 3269 exits with return value GrB_SUCCESS and the new content of vector \mathbf{w} is as defined above but
 3270 may not be fully computed. However, it can be used in the next GraphBLAS method call in a
 3271 sequence.

3272 4.3.3 mxv: Matrix-vector multiply

3273 Multiplies a matrix by a vector on a semiring. The result is a vector.

3274 C Syntax

```
3275     GrB_Info GrB_mxv(GrB_Vector      w,
3276                   const GrB_Vector  mask,
3277                   const GrB_BinaryOp accum,
3278                   const GrB_Semiring op,
3279                   const GrB_Matrix  A,
3280                   const GrB_Vector  u,
3281                   const GrB_Descriptor desc);
```

3282 Parameters

3283 \mathbf{w} (INOUT) An existing GraphBLAS vector. On input, the vector provides values
 3284 that may be accumulated with the result of the matrix-vector product. On output,
 3285 this vector holds the results of the operation.

3286 \mathbf{mask} (IN) An optional “write” mask that controls which results from this operation are
 3287 stored into the output vector \mathbf{w} . The mask dimensions must match those of the
 3288 vector \mathbf{w} . If the GrB_STRUCTURE descriptor is *not* set for the mask, the domain

3289 of the mask vector must be of type `bool` or any of the predefined “built-in” types
 3290 in Table 3.2. If the default mask is desired (i.e., a mask that is all true with the
 3291 dimensions of `w`), `GrB_NULL` should be specified.

3292 `accum` (IN) An optional binary operator used for accumulating entries into existing `w`
 3293 entries. If assignment rather than accumulation is desired, `GrB_NULL` should be
 3294 specified.

3295 `op` (IN) Semiring used in the vector-matrix multiply.

3296 `A` (IN) The GraphBLAS matrix holding the values for the left-hand matrix in the
 3297 multiplication.

3298 `u` (IN) The GraphBLAS vector holding the values for the right-hand vector in the
 3299 multiplication.

3300 `desc` (IN) An optional operation descriptor. If a *default* descriptor is desired, `GrB_NULL`
 3301 should be specified. Non-default field/value pairs are listed as follows:

3302

Param	Field	Value	Description
<code>w</code>	<code>GrB_OUTP</code>	<code>GrB_REPLACE</code>	Output vector <code>w</code> is cleared (all elements removed) before the result is stored in it.
<code>mask</code>	<code>GrB_MASK</code>	<code>GrB_STRUCTURE</code>	The write mask is constructed from the structure (pattern of stored values) of the input <code>mask</code> vector. The stored values are not examined.
<code>mask</code>	<code>GrB_MASK</code>	<code>GrB_COMP</code>	Use the complement of <code>mask</code> .
<code>A</code>	<code>GrB_INP0</code>	<code>GrB_TRAN</code>	Use transpose of <code>A</code> for the operation.

3303

3304 Return Values

3305 `GrB_SUCCESS` In blocking mode, the operation completed successfully. In non-
 3306 blocking mode, this indicates that the compatibility tests on di-
 3307 mensions and domains for the input arguments passed successfully.
 3308 Either way, output vector `w` is ready to be used in the next method
 3309 of the sequence.

3310 `GrB_PANIC` Unknown internal error.

3311 `GrB_INVALID_OBJECT` This is returned in any execution mode whenever one of the opaque
 3312 GraphBLAS objects (input or output) is in an invalid state caused
 3313 by a previous execution error. Call `GrB_error()` to access any error
 3314 messages generated by the implementation.

3315 `GrB_OUT_OF_MEMORY` Not enough memory available for the operation.

3316 `GrB_UNINITIALIZED_OBJECT` One or more of the GraphBLAS objects has not been initialized by
 3317 a call to `new` (or `dup` for matrix or vector parameters).

3318 GrB_DIMENSION_MISMATCH Mask, vector, and/or matrix dimensions are incompatible.

3319 GrB_DOMAIN_MISMATCH The domains of the various vectors/matrices are incompatible with
3320 the corresponding domains of the semiring or accumulation opera-
3321 tor, or the mask's domain is not compatible with `bool` (in the case
3322 where `desc[GrB_MASK].GrB_STRUCTURE` is not set).

3323 Description

3324 GrB_mvx computes the matrix-vector product $\mathbf{w} = \mathbf{A} \oplus . \otimes \mathbf{u}$, or, if an optional binary accumulation
3325 operator (\odot) is provided, $\mathbf{w} = \mathbf{w} \odot (\mathbf{A} \oplus . \otimes \mathbf{u})$ (where matrix \mathbf{A} can be optionally transposed).
3326 Logically, this operation occurs in three steps:

3327 **Setup** The internal vectors, matrices and mask used in the computation are formed and their
3328 domains/dimensions are tested for compatibility.

3329 **Compute** The indicated computations are carried out.

3330 **Output** The result is written into the output vector, possibly under control of a mask.

3331 Up to four argument vectors or matrices are used in the GrB_mvx operation:

- 3332 1. $\mathbf{w} = \langle \mathbf{D}(\mathbf{w}), \mathbf{size}(\mathbf{w}), \mathbf{L}(\mathbf{w}) = \{(i, w_i)\} \rangle$
- 3333 2. $\mathbf{mask} = \langle \mathbf{D}(\mathbf{mask}), \mathbf{size}(\mathbf{mask}), \mathbf{L}(\mathbf{mask}) = \{(i, m_i)\} \rangle$ (optional)
- 3334 3. $\mathbf{A} = \langle \mathbf{D}(\mathbf{A}), \mathbf{nrows}(\mathbf{A}), \mathbf{ncols}(\mathbf{A}), \mathbf{L}(\mathbf{A}) = \{(i, j, A_{ij})\} \rangle$
- 3335 4. $\mathbf{u} = \langle \mathbf{D}(\mathbf{u}), \mathbf{size}(\mathbf{u}), \mathbf{L}(\mathbf{u}) = \{(i, u_i)\} \rangle$

3336 The argument matrices, vectors, the semiring, and the accumulation operator (if provided) are
3337 tested for domain compatibility as follows:

- 3338 1. If `mask` is not `GrB_NULL`, and `desc[GrB_MASK].GrB_STRUCTURE` is not set, then $\mathbf{D}(\mathbf{mask})$
3339 must be from one of the pre-defined types of Table 3.2.
- 3340 2. $\mathbf{D}(\mathbf{A})$ must be compatible with $\mathbf{D}_{in_1}(\mathbf{op})$ of the semiring.
- 3341 3. $\mathbf{D}(\mathbf{u})$ must be compatible with $\mathbf{D}_{in_2}(\mathbf{op})$ of the semiring.
- 3342 4. $\mathbf{D}(\mathbf{w})$ must be compatible with $\mathbf{D}_{out}(\mathbf{op})$ of the semiring.
- 3343 5. If `accum` is not `GrB_NULL`, then $\mathbf{D}(\mathbf{w})$ must be compatible with $\mathbf{D}_{in_1}(\mathbf{accum})$ and $\mathbf{D}_{out}(\mathbf{accum})$
3344 of the accumulation operator and $\mathbf{D}_{out}(\mathbf{op})$ of the semiring must be compatible with $\mathbf{D}_{in_2}(\mathbf{accum})$
3345 of the accumulation operator.

3346 Two domains are compatible with each other if values from one domain can be cast to values in
 3347 the other domain as per the rules of the C language. In particular, domains from Table 3.2 are
 3348 all compatible with each other. A domain from a user-defined type is only compatible with itself.
 3349 If any compatibility rule above is violated, execution of `GrB_m xv` ends and the domain mismatch
 3350 error listed above is returned.

3351 From the argument vectors and matrices, the internal matrices and mask used in the computation
 3352 are formed (\leftarrow denotes copy):

- 3353 1. Vector $\tilde{\mathbf{w}} \leftarrow \mathbf{w}$.
- 3354 2. One-dimensional mask, $\tilde{\mathbf{m}}$, is computed from argument `mask` as follows:
 - 3355 (a) If `mask = GrB_NULL`, then $\tilde{\mathbf{m}} = \langle \mathbf{size}(\mathbf{w}), \{i, \forall i : 0 \leq i < \mathbf{size}(\mathbf{w})\} \rangle$.
 - 3356 (b) If `mask \neq GrB_NULL`,
 - 3357 i. If `desc[GrB_MASK].GrB_STRUCTURE` is set, then $\tilde{\mathbf{m}} = \langle \mathbf{size}(\mathbf{mask}), \{i : i \in \mathbf{ind}(\mathbf{mask})\} \rangle$,
 - 3358 ii. Otherwise, $\tilde{\mathbf{m}} = \langle \mathbf{size}(\mathbf{mask}), \{i : i \in \mathbf{ind}(\mathbf{mask}) \wedge (\mathbf{bool})\mathbf{mask}(i) = \mathbf{true}\} \rangle$.
 - 3359 (c) If `desc[GrB_MASK].GrB_COMP` is set, then $\tilde{\mathbf{m}} \leftarrow \neg \tilde{\mathbf{m}}$.
- 3360 3. Matrix $\tilde{\mathbf{A}} \leftarrow \mathbf{desc}[\mathbf{GrB_INP0}].\mathbf{GrB_TRAN} ? \mathbf{A}^T : \mathbf{A}$.
- 3361 4. Vector $\tilde{\mathbf{u}} \leftarrow \mathbf{u}$.

3362 The internal matrices and masks are checked for shape compatibility. The following conditions
 3363 must hold:

- 3364 1. $\mathbf{size}(\tilde{\mathbf{w}}) = \mathbf{size}(\tilde{\mathbf{m}})$.
- 3365 2. $\mathbf{size}(\tilde{\mathbf{w}}) = \mathbf{nrows}(\tilde{\mathbf{A}})$.
- 3366 3. $\mathbf{size}(\tilde{\mathbf{u}}) = \mathbf{ncols}(\tilde{\mathbf{A}})$.

3367 If any compatibility rule above is violated, execution of `GrB_m xv` ends and the dimension mismatch
 3368 error listed above is returned.

3369 From this point forward, in `GrB_NONBLOCKING` mode, the method can optionally exit with
 3370 `GrB_SUCCESS` return code and defer any computation and/or execution error codes.

3371 We are now ready to carry out the matrix-vector multiplication and any additional associated
 3372 operations. We describe this in terms of two intermediate vectors:

- 3373 • $\tilde{\mathbf{t}}$: The vector holding the product of matrix $\tilde{\mathbf{A}}$ and vector $\tilde{\mathbf{u}}$.
- 3374 • $\tilde{\mathbf{z}}$: The vector holding the result after application of the (optional) accumulation operator.

3375 The intermediate vector $\tilde{\mathbf{t}} = \langle \mathbf{D}_{out}(\mathbf{op}), \mathbf{nrows}(\tilde{\mathbf{A}}), \{(i, t_i) : \mathbf{ind}(\tilde{\mathbf{A}}(i, :)) \cap \mathbf{ind}(\tilde{\mathbf{u}}) \neq \emptyset\} \rangle$ is created.
 3376 The value of each of its elements is computed by

$$3377 \quad t_i = \bigoplus_{k \in \mathbf{ind}(\tilde{\mathbf{A}}(i, :)) \cap \mathbf{ind}(\tilde{\mathbf{u}})} (\tilde{\mathbf{A}}(i, k) \otimes \tilde{\mathbf{u}}(k)),$$

3378 where \oplus and \otimes are the additive and multiplicative operators of semiring op , respectively.

3379 The intermediate vector $\tilde{\mathbf{z}}$ is created as follows, using what is called a *standard vector accumulate*:

- 3380 • If `accum = GrB_NULL`, then $\tilde{\mathbf{z}} = \tilde{\mathbf{t}}$.
- 3381 • If `accum` is a binary operator, then $\tilde{\mathbf{z}}$ is defined as

$$3382 \quad \tilde{\mathbf{z}} = \langle \mathbf{D}_{out}(\text{accum}), \text{size}(\tilde{\mathbf{w}}), \{(i, z_i) \mid \forall i \in \mathbf{ind}(\tilde{\mathbf{w}}) \cup \mathbf{ind}(\tilde{\mathbf{t}})\} \rangle.$$

3383 The values of the elements of $\tilde{\mathbf{z}}$ are computed based on the relationships between the sets of
 3384 indices in $\tilde{\mathbf{w}}$ and $\tilde{\mathbf{t}}$.

$$3385 \quad z_i = \tilde{\mathbf{w}}(i) \odot \tilde{\mathbf{t}}(i), \text{ if } i \in (\mathbf{ind}(\tilde{\mathbf{t}}) \cap \mathbf{ind}(\tilde{\mathbf{w}})),$$

$$3386 \quad z_i = \tilde{\mathbf{w}}(i), \text{ if } i \in (\mathbf{ind}(\tilde{\mathbf{w}}) - (\mathbf{ind}(\tilde{\mathbf{t}}) \cap \mathbf{ind}(\tilde{\mathbf{w}}))),$$

$$3387 \quad z_i = \tilde{\mathbf{t}}(i), \text{ if } i \in (\mathbf{ind}(\tilde{\mathbf{t}}) - (\mathbf{ind}(\tilde{\mathbf{t}}) \cap \mathbf{ind}(\tilde{\mathbf{w}}))),$$

3388 where $\odot = \odot(\text{accum})$, and the difference operator refers to set difference.

3391 Finally, the set of output values that make up vector $\tilde{\mathbf{z}}$ are written into the final result vector \mathbf{w} ,
 3392 using what is called a *standard vector mask and replace*. This is carried out under control of the
 3393 mask which acts as a “write mask”.

- 3394 • If `desc[GrB_OUTP].GrB_REPLACE` is set, then any values in \mathbf{w} on input to this operation are
 3395 deleted and the content of the new output vector, \mathbf{w} , is defined as,

$$3396 \quad \mathbf{L}(\mathbf{w}) = \{(i, z_i) : i \in (\mathbf{ind}(\tilde{\mathbf{z}}) \cap \mathbf{ind}(\tilde{\mathbf{m}}))\}.$$

- 3397 • If `desc[GrB_OUTP].GrB_REPLACE` is not set, the elements of $\tilde{\mathbf{z}}$ indicated by the mask are
 3398 copied into the result vector, \mathbf{w} , and elements of \mathbf{w} that fall outside the set indicated by the
 3399 mask are unchanged:

$$3400 \quad \mathbf{L}(\mathbf{w}) = \{(i, w_i) : i \in (\mathbf{ind}(\mathbf{w}) \cap \mathbf{ind}(\neg\tilde{\mathbf{m}}))\} \cup \{(i, z_i) : i \in (\mathbf{ind}(\tilde{\mathbf{z}}) \cap \mathbf{ind}(\tilde{\mathbf{m}}))\}.$$

3401 In `GrB_BLOCKING` mode, the method exits with return value `GrB_SUCCESS` and the new content
 3402 of vector \mathbf{w} is as defined above and fully computed. In `GrB_NONBLOCKING` mode, the method
 3403 exits with return value `GrB_SUCCESS` and the new content of vector \mathbf{w} is as defined above but
 3404 may not be fully computed. However, it can be used in the next GraphBLAS method call in a
 3405 sequence.

3406 4.3.4 eWiseMult: Element-wise multiplication

3407 **Note:** The difference between `eWiseAdd` and `eWiseMult` is not about the element-wise operation
 3408 but how the index sets are treated. `eWiseAdd` returns an object whose indices are the “union” of
 3409 the indices of the inputs whereas `eWiseMult` returns an object whose indices are the “intersection”
 3410 of the indices of the inputs. In both cases, the passed semiring, monoid, or operator operates on
 3411 the set of values from the resulting index set.

3412 4.3.4.1 eWiseMult: Vector variant

3413 Perform element-wise (general) multiplication on the intersection of elements of two vectors, pro-
3414 ducing a third vector as result.

3415 C Syntax

```
3416     GrB_Info GrB_eWiseMult(GrB_Vector      w,  
3417                          const GrB_Vector  mask,  
3418                          const GrB_BinaryOp accum,  
3419                          const GrB_Semiring op,  
3420                          const GrB_Vector  u,  
3421                          const GrB_Vector  v,  
3422                          const GrB_Descriptor desc);  
3423  
3424     GrB_Info GrB_eWiseMult(GrB_Vector      w,  
3425                          const GrB_Vector  mask,  
3426                          const GrB_BinaryOp accum,  
3427                          const GrB_Monoid  op,  
3428                          const GrB_Vector  u,  
3429                          const GrB_Vector  v,  
3430                          const GrB_Descriptor desc);  
3431  
3432     GrB_Info GrB_eWiseMult(GrB_Vector      w,  
3433                          const GrB_Vector  mask,  
3434                          const GrB_BinaryOp accum,  
3435                          const GrB_BinaryOp op,  
3436                          const GrB_Vector  u,  
3437                          const GrB_Vector  v,  
3438                          const GrB_Descriptor desc);
```

3439 Parameters

3440 **w** (INOUT) An existing GraphBLAS vector. On input, the vector provides values
3441 that may be accumulated with the result of the element-wise operation. On output,
3442 this vector holds the results of the operation.

3443 **mask** (IN) An optional “write” mask that controls which results from this operation are
3444 stored into the output vector **w**. The mask dimensions must match those of the
3445 vector **w**. If the **GrB_STRUCTURE** descriptor is *not* set for the mask, the domain
3446 of the mask vector must be of type **bool** or any of the predefined “built-in” types
3447 in Table 3.2. If the default mask is desired (i.e., a mask that is all true with the
3448 dimensions of **w**), **GrB_NULL** should be specified.

3449 **accum** (IN) An optional binary operator used for accumulating entries into existing **w**

3450 entries. If assignment rather than accumulation is desired, GrB_NULL should be
 3451 specified.

3452 **op** (IN) The semiring, monoid, or binary operator used in the element-wise “product”
 3453 operation. Depending on which type is passed, the following defines the binary
 3454 operator, $F_b = \langle \mathbf{D}_{out}(\text{op}), \mathbf{D}_{in_1}(\text{op}), \mathbf{D}_{in_2}(\text{op}), \otimes \rangle$, used:

3455 BinaryOp: $F_b = \langle \mathbf{D}_{out}(\text{op}), \mathbf{D}_{in_1}(\text{op}), \mathbf{D}_{in_2}(\text{op}), \odot(\text{op}) \rangle$.

3456 Monoid: $F_b = \langle \mathbf{D}(\text{op}), \mathbf{D}(\text{op}), \mathbf{D}(\text{op}), \odot(\text{op}) \rangle$; the identity element is ig-
 3457 nored.

3458 Semiring: $F_b = \langle \mathbf{D}_{out}(\text{op}), \mathbf{D}_{in_1}(\text{op}), \mathbf{D}_{in_2}(\text{op}), \otimes(\text{op}) \rangle$; the additive monoid
 3459 is ignored.

3460 **u** (IN) The GraphBLAS vector holding the values for the left-hand vector in the
 3461 operation.

3462 **v** (IN) The GraphBLAS vector holding the values for the right-hand vector in the
 3463 operation.

3464 **desc** (IN) An optional operation descriptor. If a *default* descriptor is desired, GrB_NULL
 3465 should be specified. Non-default field/value pairs are listed as follows:
 3466

Param	Field	Value	Description
w	GrB_OUTP	GrB_REPLACE	Output vector w is cleared (all elements removed) before the result is stored in it.
mask	GrB_MASK	GrB_STRUCTURE	The write mask is constructed from the structure (pattern of stored values) of the input mask vector. The stored values are not examined.
mask	GrB_MASK	GrB_COMP	Use the complement of mask.

3468 Return Values

3469 GrB_SUCCESS In blocking mode, the operation completed successfully. In non-
 3470 blocking mode, this indicates that the compatibility tests on di-
 3471 mensions and domains for the input arguments passed successfully.
 3472 Either way, output vector w is ready to be used in the next method
 3473 of the sequence.

3474 GrB_PANIC Unknown internal error.

3475 GrB_INVALID_OBJECT This is returned in any execution mode whenever one of the opaque
 3476 GraphBLAS objects (input or output) is in an invalid state caused
 3477 by a previous execution error. Call GrB_error() to access any error
 3478 messages generated by the implementation.

3479 GrB_OUT_OF_MEMORY Not enough memory available for the operation.

3480 GrB_UNINITIALIZED_OBJECT One or more of the GraphBLAS objects has not been initialized by
3481 a call to new (or dup for vector parameters).

3482 GrB_DIMENSION_MISMATCH Mask or vector dimensions are incompatible.

3483 GrB_DOMAIN_MISMATCH The domains of the various vectors are incompatible with the cor-
3484 responding domains of the binary operator (op) or accumulation
3485 operator, or the mask's domain is not compatible with bool (in the
3486 case where desc[GrB_MASK].GrB_STRUCTURE is not set).

3487 Description

3488 This variant of GrB_eWiseMult computes the element-wise “product” of two GraphBLAS vectors:
3489 $\mathbf{w} = \mathbf{u} \otimes \mathbf{v}$, or, if an optional binary accumulation operator (\odot) is provided, $\mathbf{w} = \mathbf{w} \odot (\mathbf{u} \otimes \mathbf{v})$.
3490 Logically, this operation occurs in three steps:

3491 **Setup** The internal vectors and mask used in the computation are formed and their domains
3492 and dimensions are tested for compatibility.

3493 **Compute** The indicated computations are carried out.

3494 **Output** The result is written into the output vector, possibly under control of a mask.

3495 Up to four argument vectors are used in the GrB_eWiseMult operation:

- 3496 1. $\mathbf{w} = \langle \mathbf{D}(\mathbf{w}), \mathbf{size}(\mathbf{w}), \mathbf{L}(\mathbf{w}) = \{(i, w_i)\} \rangle$
- 3497 2. $\mathbf{mask} = \langle \mathbf{D}(\mathbf{mask}), \mathbf{size}(\mathbf{mask}), \mathbf{L}(\mathbf{mask}) = \{(i, m_i)\} \rangle$ (optional)
- 3498 3. $\mathbf{u} = \langle \mathbf{D}(\mathbf{u}), \mathbf{size}(\mathbf{u}), \mathbf{L}(\mathbf{u}) = \{(i, u_i)\} \rangle$
- 3499 4. $\mathbf{v} = \langle \mathbf{D}(\mathbf{v}), \mathbf{size}(\mathbf{v}), \mathbf{L}(\mathbf{v}) = \{(i, v_i)\} \rangle$

3500 The argument vectors, the “product” operator (op), and the accumulation operator (if provided)
3501 are tested for domain compatibility as follows:

- 3502 1. If mask is not GrB_NULL, and desc[GrB_MASK].GrB_STRUCTURE is not set, then $\mathbf{D}(\mathbf{mask})$
3503 must be from one of the pre-defined types of Table 3.2.
- 3504 2. $\mathbf{D}(\mathbf{u})$ must be compatible with $\mathbf{D}_{in_1}(\mathbf{op})$.
- 3505 3. $\mathbf{D}(\mathbf{v})$ must be compatible with $\mathbf{D}_{in_2}(\mathbf{op})$.
- 3506 4. $\mathbf{D}(\mathbf{w})$ must be compatible with $\mathbf{D}_{out}(\mathbf{op})$.
- 3507 5. If accum is not GrB_NULL, then $\mathbf{D}(\mathbf{w})$ must be compatible with $\mathbf{D}_{in_1}(\mathbf{accum})$ and $\mathbf{D}_{out}(\mathbf{accum})$
3508 of the accumulation operator and $\mathbf{D}_{out}(\mathbf{op})$ of op must be compatible with $\mathbf{D}_{in_2}(\mathbf{accum})$ of
3509 the accumulation operator.

3510 Two domains are compatible with each other if values from one domain can be cast to values in
 3511 the other domain as per the rules of the C language. In particular, domains from Table 3.2 are all
 3512 compatible with each other. A domain from a user-defined type is only compatible with itself. If any
 3513 compatibility rule above is violated, execution of `GrB_eWiseMult` ends and the domain mismatch
 3514 error listed above is returned.

3515 From the argument vectors, the internal vectors and mask used in the computation are formed (\leftarrow
 3516 denotes copy):

- 3517 1. Vector $\tilde{\mathbf{w}} \leftarrow \mathbf{w}$.
- 3518 2. One-dimensional mask, $\tilde{\mathbf{m}}$, is computed from argument `mask` as follows:
 - 3519 (a) If `mask = GrB_NULL`, then $\tilde{\mathbf{m}} = \langle \mathbf{size}(\mathbf{w}), \{i, \forall i : 0 \leq i < \mathbf{size}(\mathbf{w})\} \rangle$.
 - 3520 (b) If `mask \neq GrB_NULL`,
 - 3521 i. If `desc[GrB_MASK].GrB_STRUCTURE` is set, then $\tilde{\mathbf{m}} = \langle \mathbf{size}(\mathbf{mask}), \{i : i \in \mathbf{ind}(\mathbf{mask})\} \rangle$,
 - 3522 ii. Otherwise, $\tilde{\mathbf{m}} = \langle \mathbf{size}(\mathbf{mask}), \{i : i \in \mathbf{ind}(\mathbf{mask}) \wedge (\mathbf{bool})\mathbf{mask}(i) = \mathbf{true}\} \rangle$.
 - 3523 (c) If `desc[GrB_MASK].GrB_COMP` is set, then $\tilde{\mathbf{m}} \leftarrow \neg \tilde{\mathbf{m}}$.
- 3524 3. Vector $\tilde{\mathbf{u}} \leftarrow \mathbf{u}$.
- 3525 4. Vector $\tilde{\mathbf{v}} \leftarrow \mathbf{v}$.

3526 The internal vectors and mask are checked for dimension compatibility. The following conditions
 3527 must hold:

- 3528 1. $\mathbf{size}(\tilde{\mathbf{w}}) = \mathbf{size}(\tilde{\mathbf{m}}) = \mathbf{size}(\tilde{\mathbf{u}}) = \mathbf{size}(\tilde{\mathbf{v}})$.

3529 If any compatibility rule above is violated, execution of `GrB_eWiseMult` ends and the dimension
 3530 mismatch error listed above is returned.

3531 From this point forward, in `GrB_NONBLOCKING` mode, the method can optionally exit with
 3532 `GrB_SUCCESS` return code and defer any computation and/or execution error codes.

3533 We are now ready to carry out the element-wise “product” and any additional associated operations.
 3534 We describe this in terms of two intermediate vectors:

- 3535 • $\tilde{\mathbf{t}}$: The vector holding the element-wise “product” of $\tilde{\mathbf{u}}$ and vector $\tilde{\mathbf{v}}$.
- 3536 • $\tilde{\mathbf{z}}$: The vector holding the result after application of the (optional) accumulation operator.

3537 The intermediate vector $\tilde{\mathbf{t}} = \langle \mathbf{D}_{out}(\mathbf{op}), \mathbf{size}(\tilde{\mathbf{u}}), \{(i, t_i) : \mathbf{ind}(\tilde{\mathbf{u}}) \cap \mathbf{ind}(\tilde{\mathbf{v}}) \neq \emptyset\} \rangle$ is created. The
 3538 value of each of its elements is computed by:

$$3539 \quad t_i = (\tilde{\mathbf{u}}(i) \otimes \tilde{\mathbf{v}}(i)), \forall i \in (\mathbf{ind}(\tilde{\mathbf{u}}) \cap \mathbf{ind}(\tilde{\mathbf{v}}))$$

3540 The intermediate vector $\tilde{\mathbf{z}}$ is created as follows, using what is called a *standard vector accumulate*:

3541 • If `accum = GrB_NULL`, then $\tilde{\mathbf{z}} = \tilde{\mathbf{t}}$.

3542 • If `accum` is a binary operator, then $\tilde{\mathbf{z}}$ is defined as

3543
$$\tilde{\mathbf{z}} = \langle \mathbf{D}_{out}(\text{accum}), \text{size}(\tilde{\mathbf{w}}), \{(i, z_i) \mid \forall i \in \mathbf{ind}(\tilde{\mathbf{w}}) \cup \mathbf{ind}(\tilde{\mathbf{t}})\} \rangle.$$

3544 The values of the elements of $\tilde{\mathbf{z}}$ are computed based on the relationships between the sets of
3545 indices in $\tilde{\mathbf{w}}$ and $\tilde{\mathbf{t}}$.

3546
$$z_i = \tilde{\mathbf{w}}(i) \odot \tilde{\mathbf{t}}(i), \text{ if } i \in (\mathbf{ind}(\tilde{\mathbf{t}}) \cap \mathbf{ind}(\tilde{\mathbf{w}})),$$

3547

3548
$$z_i = \tilde{\mathbf{w}}(i), \text{ if } i \in (\mathbf{ind}(\tilde{\mathbf{w}}) - (\mathbf{ind}(\tilde{\mathbf{t}}) \cap \mathbf{ind}(\tilde{\mathbf{w}}))),$$

3549

3550
$$z_i = \tilde{\mathbf{t}}(i), \text{ if } i \in (\mathbf{ind}(\tilde{\mathbf{t}}) - (\mathbf{ind}(\tilde{\mathbf{t}}) \cap \mathbf{ind}(\tilde{\mathbf{w}}))),$$

3551 where $\odot = \odot(\text{accum})$, and the difference operator refers to set difference.

3552 Finally, the set of output values that make up vector $\tilde{\mathbf{z}}$ are written into the final result vector \mathbf{w} ,
3553 using what is called a *standard vector mask and replace*. This is carried out under control of the
3554 mask which acts as a “write mask”.

3555 • If `desc[GrB_OUTP].GrB_REPLACE` is set, then any values in \mathbf{w} on input to this operation are
3556 deleted and the content of the new output vector, \mathbf{w} , is defined as,

3557
$$\mathbf{L}(\mathbf{w}) = \{(i, z_i) : i \in (\mathbf{ind}(\tilde{\mathbf{z}}) \cap \mathbf{ind}(\tilde{\mathbf{m}}))\}.$$

3558 • If `desc[GrB_OUTP].GrB_REPLACE` is not set, the elements of $\tilde{\mathbf{z}}$ indicated by the mask are
3559 copied into the result vector, \mathbf{w} , and elements of \mathbf{w} that fall outside the set indicated by the
3560 mask are unchanged:

3561
$$\mathbf{L}(\mathbf{w}) = \{(i, w_i) : i \in (\mathbf{ind}(\mathbf{w}) \cap \mathbf{ind}(\neg\tilde{\mathbf{m}}))\} \cup \{(i, z_i) : i \in (\mathbf{ind}(\tilde{\mathbf{z}}) \cap \mathbf{ind}(\tilde{\mathbf{m}}))\}.$$

3562 In `GrB_BLOCKING` mode, the method exits with return value `GrB_SUCCESS` and the new content
3563 of vector \mathbf{w} is as defined above and fully computed. In `GrB_NONBLOCKING` mode, the method
3564 exits with return value `GrB_SUCCESS` and the new content of vector \mathbf{w} is as defined above but
3565 may not be fully computed. However, it can be used in the next GraphBLAS method call in a
3566 sequence.

3567 4.3.4.2 eWiseMult: Matrix variant

3568 Perform element-wise (general) multiplication on the intersection of elements of two matrices, pro-
3569 ducing a third matrix as result.

3570 C Syntax

```

3571     GrB_Info GrB_eWiseMult(GrB_Matrix      C,
3572                          const GrB_Matrix Mask,
3573                          const GrB_BinaryOp accum,
3574                          const GrB_Semiring op,
3575                          const GrB_Matrix  A,
3576                          const GrB_Matrix  B,
3577                          const GrB_Descriptor desc);
3578
3579     GrB_Info GrB_eWiseMult(GrB_Matrix      C,
3580                          const GrB_Matrix Mask,
3581                          const GrB_BinaryOp accum,
3582                          const GrB_Monoid  op,
3583                          const GrB_Matrix  A,
3584                          const GrB_Matrix  B,
3585                          const GrB_Descriptor desc);
3586
3587     GrB_Info GrB_eWiseMult(GrB_Matrix      C,
3588                          const GrB_Matrix Mask,
3589                          const GrB_BinaryOp accum,
3590                          const GrB_BinaryOp op,
3591                          const GrB_Matrix  A,
3592                          const GrB_Matrix  B,
3593                          const GrB_Descriptor desc);

```

3594 Parameters

3595 **C** (INOUT) An existing GraphBLAS matrix. On input, the matrix provides values
3596 that may be accumulated with the result of the element-wise operation. On output,
3597 the matrix holds the results of the operation.

3598 **Mask** (IN) An optional “write” mask that controls which results from this operation are
3599 stored into the output matrix C. The mask dimensions must match those of the
3600 matrix C. If the GrB_STRUCTURE descriptor is *not* set for the mask, the domain
3601 of the Mask matrix must be of type bool or any of the predefined “built-in” types
3602 in Table 3.2. If the default mask is desired (i.e., a mask that is all true with the
3603 dimensions of C), GrB_NULL should be specified.

3604 **accum** (IN) An optional binary operator used for accumulating entries into existing C
3605 entries. If assignment rather than accumulation is desired, GrB_NULL should be
3606 specified.

3607 **op** (IN) The semiring, monoid, or binary operator used in the element-wise “product”
3608 operation. Depending on which type is passed, the following defines the binary
3609 operator, $F_b = \langle \mathbf{D}_{out}(\text{op}), \mathbf{D}_{in_1}(\text{op}), \mathbf{D}_{in_2}(\text{op}), \otimes \rangle$, used:

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BinaryOp: $F_b = \langle \mathbf{D}_{out}(\text{op}), \mathbf{D}_{in_1}(\text{op}), \mathbf{D}_{in_2}(\text{op}), \odot(\text{op}) \rangle$.

Monoid: $F_b = \langle \mathbf{D}(\text{op}), \mathbf{D}(\text{op}), \mathbf{D}(\text{op}), \odot(\text{op}) \rangle$; the identity element is ignored.

Semiring: $F_b = \langle \mathbf{D}_{out}(\text{op}), \mathbf{D}_{in_1}(\text{op}), \mathbf{D}_{in_2}(\text{op}), \otimes(\text{op}) \rangle$; the additive monoid is ignored.

A (IN) The GraphBLAS matrix holding the values for the left-hand matrix in the operation.

B (IN) The GraphBLAS matrix holding the values for the right-hand matrix in the operation.

desc (IN) An optional operation descriptor. If a *default* descriptor is desired, GrB_NULL should be specified. Non-default field/value pairs are listed as follows:

Param	Field	Value	Description
C	GrB_OUTP	GrB_REPLACE	Output matrix C is cleared (all elements removed) before the result is stored in it.
Mask	GrB_MASK	GrB_STRUCTURE	The write mask is constructed from the structure (pattern of stored values) of the input Mask matrix. The stored values are not examined.
Mask	GrB_MASK	GrB_COMP	Use the complement of Mask.
A	GrB_INP0	GrB_TRAN	Use transpose of A for the operation.
B	GrB_INP1	GrB_TRAN	Use transpose of B for the operation.

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3623 Return Values

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GrB_SUCCESS In blocking mode, the operation completed successfully. In non-blocking mode, this indicates that the compatibility tests on dimensions and domains for the input arguments passed successfully. Either way, output matrix C is ready to be used in the next method of the sequence.

3629

GrB_PANIC Unknown internal error.

3630
3631
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GrB_INVALID_OBJECT This is returned in any execution mode whenever one of the opaque GraphBLAS objects (input or output) is in an invalid state caused by a previous execution error. Call GrB_error() to access any error messages generated by the implementation.

3634

GrB_OUT_OF_MEMORY Not enough memory available for the operation.

3635
3636

GrB_UNINITIALIZED_OBJECT One or more of the GraphBLAS objects has not been initialized by a call to new (or Matrix_dup for matrix parameters).

3637

GrB_DIMENSION_MISMATCH Mask and/or matrix dimensions are incompatible.

3638 GrB_DOMAIN_MISMATCH The domains of the various matrices are incompatible with the
 3639 corresponding domains of the binary operator (`op`) or accumulation
 3640 operator, or the mask's domain is not compatible with `bool` (in the
 3641 case where `desc[GrB_MASK].GrB_STRUCTURE` is not set).

3642 Description

3643 This variant of `GrB_eWiseMult` computes the element-wise “product” of two GraphBLAS matrices:
 3644 $C = A \otimes B$, or, if an optional binary accumulation operator (\odot) is provided, $C = C \odot (A \otimes B)$.
 3645 Logically, this operation occurs in three steps:

3646 **Setup** The internal matrices and mask used in the computation are formed and their domains
 3647 and dimensions are tested for compatibility.

3648 **Compute** The indicated computations are carried out.

3649 **Output** The result is written into the output matrix, possibly under control of a mask.

3650 Up to four argument matrices are used in the `GrB_eWiseMult` operation:

- 3651 1. $C = \langle \mathbf{D}(C), \mathbf{nrows}(C), \mathbf{ncols}(C), \mathbf{L}(C) = \{(i, j, C_{ij})\} \rangle$
- 3652 2. $\text{Mask} = \langle \mathbf{D}(\text{Mask}), \mathbf{nrows}(\text{Mask}), \mathbf{ncols}(\text{Mask}), \mathbf{L}(\text{Mask}) = \{(i, j, M_{ij})\} \rangle$ (optional)
- 3653 3. $A = \langle \mathbf{D}(A), \mathbf{nrows}(A), \mathbf{ncols}(A), \mathbf{L}(A) = \{(i, j, A_{ij})\} \rangle$
- 3654 4. $B = \langle \mathbf{D}(B), \mathbf{nrows}(B), \mathbf{ncols}(B), \mathbf{L}(B) = \{(i, j, B_{ij})\} \rangle$

3655 The argument matrices, the “product” operator (`op`), and the accumulation operator (if provided)
 3656 are tested for domain compatibility as follows:

- 3657 1. If `Mask` is not `GrB_NULL`, and `desc[GrB_MASK].GrB_STRUCTURE` is not set, then $\mathbf{D}(\text{Mask})$
 3658 must be from one of the pre-defined types of Table 3.2.
- 3659 2. $\mathbf{D}(A)$ must be compatible with $\mathbf{D}_{in_1}(\text{op})$.
- 3660 3. $\mathbf{D}(B)$ must be compatible with $\mathbf{D}_{in_2}(\text{op})$.
- 3661 4. $\mathbf{D}(C)$ must be compatible with $\mathbf{D}_{out}(\text{op})$.
- 3662 5. If `accum` is not `GrB_NULL`, then $\mathbf{D}(C)$ must be compatible with $\mathbf{D}_{in_1}(\text{accum})$ and $\mathbf{D}_{out}(\text{accum})$
 3663 of the accumulation operator and $\mathbf{D}_{out}(\text{op})$ of `op` must be compatible with $\mathbf{D}_{in_2}(\text{accum})$ of
 3664 the accumulation operator.

3665 Two domains are compatible with each other if values from one domain can be cast to values in
 3666 the other domain as per the rules of the C language. In particular, domains from Table 3.2 are all
 3667 compatible with each other. A domain from a user-defined type is only compatible with itself. If any

3668 compatibility rule above is violated, execution of `GrB_eWiseMult` ends and the domain mismatch
 3669 error listed above is returned.

3670 From the argument matrices, the internal matrices and mask used in the computation are formed
 3671 (\leftarrow denotes copy):

- 3672 1. Matrix $\tilde{\mathbf{C}} \leftarrow \mathbf{C}$.
- 3673 2. Two-dimensional mask, $\tilde{\mathbf{M}}$, is computed from argument `Mask` as follows:
 - 3674 (a) If `Mask = GrB_NULL`, then $\tilde{\mathbf{M}} = \langle \mathbf{nrows}(\mathbf{C}), \mathbf{ncols}(\mathbf{C}), \{(i, j), \forall i, j : 0 \leq i < \mathbf{nrows}(\mathbf{C}), 0 \leq$
 3675 $j < \mathbf{ncols}(\mathbf{C})\} \rangle$.
 - 3676 (b) If `Mask \neq GrB_NULL`,
 - 3677 i. If `desc[GrB_MASK].GrB_STRUCTURE` is set, then $\tilde{\mathbf{M}} = \langle \mathbf{nrows}(\mathbf{Mask}), \mathbf{ncols}(\mathbf{Mask}), \{(i, j) :$
 3678 $(i, j) \in \mathbf{ind}(\mathbf{Mask})\} \rangle$,
 - 3679 ii. Otherwise, $\tilde{\mathbf{M}} = \langle \mathbf{nrows}(\mathbf{Mask}), \mathbf{ncols}(\mathbf{Mask}),$
 3680 $\{(i, j) : (i, j) \in \mathbf{ind}(\mathbf{Mask}) \wedge (\mathbf{bool})\mathbf{Mask}(i, j) = \mathbf{true}\} \rangle$.
 - 3681 (c) If `desc[GrB_MASK].GrB_COMP` is set, then $\tilde{\mathbf{M}} \leftarrow \neg \tilde{\mathbf{M}}$.
- 3682 3. Matrix $\tilde{\mathbf{A}} \leftarrow \mathbf{desc}[\mathbf{GrB_INP0}].\mathbf{GrB_TRAN} ? \mathbf{A}^T : \mathbf{A}$.
- 3683 4. Matrix $\tilde{\mathbf{B}} \leftarrow \mathbf{desc}[\mathbf{GrB_INP1}].\mathbf{GrB_TRAN} ? \mathbf{B}^T : \mathbf{B}$.

3684 The internal matrices and masks are checked for dimension compatibility. The following conditions
 3685 must hold:

- 3686 1. $\mathbf{nrows}(\tilde{\mathbf{C}}) = \mathbf{nrows}(\tilde{\mathbf{M}}) = \mathbf{nrows}(\tilde{\mathbf{A}}) = \mathbf{nrows}(\tilde{\mathbf{B}})$.
- 3687 2. $\mathbf{ncols}(\tilde{\mathbf{C}}) = \mathbf{ncols}(\tilde{\mathbf{M}}) = \mathbf{ncols}(\tilde{\mathbf{A}}) = \mathbf{ncols}(\tilde{\mathbf{B}})$.

3688 If any compatibility rule above is violated, execution of `GrB_eWiseMult` ends and the dimension
 3689 mismatch error listed above is returned.

3690 From this point forward, in `GrB_NONBLOCKING` mode, the method can optionally exit with
 3691 `GrB_SUCCESS` return code and defer any computation and/or execution error codes.

3692 We are now ready to carry out the element-wise “product” and any additional associated operations.
 3693 We describe this in terms of two intermediate matrices:

- 3694 • $\tilde{\mathbf{T}}$: The matrix holding the element-wise product of $\tilde{\mathbf{A}}$ and $\tilde{\mathbf{B}}$.
- 3695 • $\tilde{\mathbf{Z}}$: The matrix holding the result after application of the (optional) accumulation operator.

3696 The intermediate matrix $\tilde{\mathbf{T}} = \langle \mathbf{D}_{out}(\mathbf{op}), \mathbf{nrows}(\tilde{\mathbf{A}}), \mathbf{ncols}(\tilde{\mathbf{A}}), \{(i, j, T_{ij}) : \mathbf{ind}(\tilde{\mathbf{A}}) \cap \mathbf{ind}(\tilde{\mathbf{B}}) \neq \emptyset\} \rangle$
 3697 is created. The value of each of its elements is computed by

$$3698 \quad T_{ij} = (\tilde{\mathbf{A}}(i, j) \otimes \tilde{\mathbf{B}}(i, j)), \forall (i, j) \in \mathbf{ind}(\tilde{\mathbf{A}}) \cap \mathbf{ind}(\tilde{\mathbf{B}})$$

3699 The intermediate matrix $\tilde{\mathbf{Z}}$ is created as follows, using what is called a *standard matrix accumulate*:

- 3700 • If `accum = GrB_NULL`, then $\tilde{\mathbf{Z}} = \tilde{\mathbf{T}}$.
- 3701 • If `accum` is a binary operator, then $\tilde{\mathbf{Z}}$ is defined as

$$3702 \quad \tilde{\mathbf{Z}} = \langle \mathbf{D}_{out}(\text{accum}), \mathbf{nrows}(\tilde{\mathbf{C}}), \mathbf{ncols}(\tilde{\mathbf{C}}), \{(i, j, Z_{ij}) \mid \forall (i, j) \in \mathbf{ind}(\tilde{\mathbf{C}}) \cup \mathbf{ind}(\tilde{\mathbf{T}})\} \rangle.$$

3703 The values of the elements of $\tilde{\mathbf{Z}}$ are computed based on the relationships between the sets of
 3704 indices in $\tilde{\mathbf{C}}$ and $\tilde{\mathbf{T}}$.

$$3705 \quad Z_{ij} = \tilde{\mathbf{C}}(i, j) \odot \tilde{\mathbf{T}}(i, j), \text{ if } (i, j) \in (\mathbf{ind}(\tilde{\mathbf{T}}) \cap \mathbf{ind}(\tilde{\mathbf{C}})),$$

$$3706 \quad Z_{ij} = \tilde{\mathbf{C}}(i, j), \text{ if } (i, j) \in (\mathbf{ind}(\tilde{\mathbf{C}}) - (\mathbf{ind}(\tilde{\mathbf{T}}) \cap \mathbf{ind}(\tilde{\mathbf{C}}))),$$

$$3707 \quad Z_{ij} = \tilde{\mathbf{T}}(i, j), \text{ if } (i, j) \in (\mathbf{ind}(\tilde{\mathbf{T}}) - (\mathbf{ind}(\tilde{\mathbf{T}}) \cap \mathbf{ind}(\tilde{\mathbf{C}}))),$$

3710 where $\odot = \odot(\text{accum})$, and the difference operator refers to set difference.

3711 Finally, the set of output values that make up matrix $\tilde{\mathbf{Z}}$ are written into the final result matrix \mathbf{C} ,
 3712 using what is called a *standard matrix mask and replace*. This is carried out under control of the
 3713 mask which acts as a “write mask”.

- 3714 • If `desc[GrB_OUTP].GrB_REPLACE` is set, then any values in \mathbf{C} on input to this operation are
 3715 deleted and the content of the new output matrix, \mathbf{C} , is defined as,

$$3716 \quad \mathbf{L}(\mathbf{C}) = \{(i, j, Z_{ij}) : (i, j) \in (\mathbf{ind}(\tilde{\mathbf{Z}}) \cap \mathbf{ind}(\tilde{\mathbf{M}}))\}.$$

- 3717 • If `desc[GrB_OUTP].GrB_REPLACE` is not set, the elements of $\tilde{\mathbf{Z}}$ indicated by the mask are
 3718 copied into the result matrix, \mathbf{C} , and elements of \mathbf{C} that fall outside the set indicated by the
 3719 mask are unchanged:

$$3720 \quad \mathbf{L}(\mathbf{C}) = \{(i, j, C_{ij}) : (i, j) \in (\mathbf{ind}(\mathbf{C}) \cap \mathbf{ind}(\neg\tilde{\mathbf{M}}))\} \cup \{(i, j, Z_{ij}) : (i, j) \in (\mathbf{ind}(\tilde{\mathbf{Z}}) \cap \mathbf{ind}(\tilde{\mathbf{M}}))\}.$$

3721 In `GrB_BLOCKING` mode, the method exits with return value `GrB_SUCCESS` and the new content
 3722 of matrix \mathbf{C} is as defined above and fully computed. In `GrB_NONBLOCKING` mode, the method
 3723 exits with return value `GrB_SUCCESS` and the new content of matrix \mathbf{C} is as defined above but
 3724 may not be fully computed. However, it can be used in the next GraphBLAS method call in a
 3725 sequence.

3726 4.3.5 eWiseAdd: Element-wise addition

3727 **Note:** The difference between `eWiseAdd` and `eWiseMult` is not about the element-wise operation
 3728 but how the index sets are treated. `eWiseAdd` returns an object whose indices are the “union” of
 3729 the indices of the inputs whereas `eWiseMult` returns an object whose indices are the “intersection”
 3730 of the indices of the inputs. In both cases, the passed semiring, monoid, or operator operates on
 3731 the set of values from the resulting index set.

3732 4.3.5.1 eWiseAdd: Vector variant

3733 Perform element-wise (general) addition on the elements of two vectors, producing a third vector
3734 as result.

3735 C Syntax

```
3736     GrB_Info GrB_eWiseAdd(GrB_Vector      w,  
3737                          const GrB_Vector  mask,  
3738                          const GrB_BinaryOp accum,  
3739                          const GrB_Semiring op,  
3740                          const GrB_Vector  u,  
3741                          const GrB_Vector  v,  
3742                          const GrB_Descriptor desc);  
3743  
3744     GrB_Info GrB_eWiseAdd(GrB_Vector      w,  
3745                          const GrB_Vector  mask,  
3746                          const GrB_BinaryOp accum,  
3747                          const GrB_Monoid  op,  
3748                          const GrB_Vector  u,  
3749                          const GrB_Vector  v,  
3750                          const GrB_Descriptor desc);  
3751  
3752     GrB_Info GrB_eWiseAdd(GrB_Vector      w,  
3753                          const GrB_Vector  mask,  
3754                          const GrB_BinaryOp accum,  
3755                          const GrB_BinaryOp op,  
3756                          const GrB_Vector  u,  
3757                          const GrB_Vector  v,  
3758                          const GrB_Descriptor desc);
```

3759 Parameters

3760 **w** (INOUT) An existing GraphBLAS vector. On input, the vector provides values
3761 that may be accumulated with the result of the element-wise operation. On output,
3762 this vector holds the results of the operation.

3763 **mask** (IN) An optional “write” mask that controls which results from this operation are
3764 stored into the output vector **w**. The mask dimensions must match those of the
3765 vector **w**. If the `GrB_STRUCTURE` descriptor is *not* set for the mask, the domain
3766 of the mask vector must be of type `bool` or any of the predefined “built-in” types
3767 in Table 3.2. If the default mask is desired (i.e., a mask that is all true with the
3768 dimensions of **w**), `GrB_NULL` should be specified.

3769 **accum** (IN) An optional binary operator used for accumulating entries into existing **w**

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entries. If assignment rather than accumulation is desired, GrB_NULL should be specified.

op (IN) The semiring, monoid, or binary operator used in the element-wise “sum” operation. Depending on which type is passed, the following defines the binary operator, $F_b = \langle \mathbf{D}_{out}(\text{op}), \mathbf{D}_{in_1}(\text{op}), \mathbf{D}_{in_2}(\text{op}), \oplus \rangle$, used:

BinaryOp: $F_b = \langle \mathbf{D}_{out}(\text{op}), \mathbf{D}_{in_1}(\text{op}), \mathbf{D}_{in_2}(\text{op}), \odot(\text{op}) \rangle$.

Monoid: $F_b = \langle \mathbf{D}(\text{op}), \mathbf{D}(\text{op}), \mathbf{D}(\text{op}), \odot(\text{op}) \rangle$; the identity element is ignored.

Semiring: $F_b = \langle \mathbf{D}_{out}(\text{op}), \mathbf{D}_{in_1}(\text{op}), \mathbf{D}_{in_2}(\text{op}), \oplus(\text{op}) \rangle$; the multiplicative binary op and additive identity are ignored.

u (IN) The GraphBLAS vector holding the values for the left-hand vector in the operation.

v (IN) The GraphBLAS vector holding the values for the right-hand vector in the operation.

desc (IN) An optional operation descriptor. If a *default* descriptor is desired, GrB_NULL should be specified. Non-default field/value pairs are listed as follows:

Param	Field	Value	Description
w	GrB_OUTP	GrB_REPLACE	Output vector w is cleared (all elements removed) before the result is stored in it.
mask	GrB_MASK	GrB_STRUCTURE	The write mask is constructed from the structure (pattern of stored values) of the input mask vector. The stored values are not examined.
mask	GrB_MASK	GrB_COMP	Use the complement of mask.

3787

3788 Return Values

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3793

GrB_SUCCESS In blocking mode, the operation completed successfully. In non-blocking mode, this indicates that the compatibility tests on dimensions and domains for the input arguments passed successfully. Either way, output vector w is ready to be used in the next method of the sequence.

3794

GrB_PANIC Unknown internal error.

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3798

GrB_INVALID_OBJECT This is returned in any execution mode whenever one of the opaque GraphBLAS objects (input or output) is in an invalid state caused by a previous execution error. Call GrB_error() to access any error messages generated by the implementation.

3799

GrB_OUT_OF_MEMORY Not enough memory available for the operation.

3800 GrB_UNINITIALIZED_OBJECT One or more of the GraphBLAS objects has not been initialized by
3801 a call to `new` (or `dup` for vector parameters).

3802 GrB_DIMENSION_MISMATCH Mask or vector dimensions are incompatible.

3803 GrB_DOMAIN_MISMATCH The domains of the various vectors are incompatible with the cor-
3804 responding domains of the binary operator (`op`) or accumulation
3805 operator, or the mask's domain is not compatible with `bool` (in the
3806 case where `desc[GrB_MASK].GrB_STRUCTURE` is not set).

3807 Description

3808 This variant of `GrB_eWiseAdd` computes the element-wise “sum” of two GraphBLAS vectors: $\mathbf{w} =$
3809 $\mathbf{u} \oplus \mathbf{v}$, or, if an optional binary accumulation operator (\odot) is provided, $\mathbf{w} = \mathbf{w} \odot (\mathbf{u} \oplus \mathbf{v})$. Logically,
3810 this operation occurs in three steps:

3811 **Setup** The internal vectors and mask used in the computation are formed and their domains
3812 and dimensions are tested for compatibility.

3813 **Compute** The indicated computations are carried out.

3814 **Output** The result is written into the output vector, possibly under control of a mask.

3815 Up to four argument vectors are used in the `GrB_eWiseAdd` operation:

- 3816 1. $\mathbf{w} = \langle \mathbf{D}(\mathbf{w}), \mathbf{size}(\mathbf{w}), \mathbf{L}(\mathbf{w}) = \{(i, w_i)\} \rangle$
- 3817 2. $\mathbf{mask} = \langle \mathbf{D}(\mathbf{mask}), \mathbf{size}(\mathbf{mask}), \mathbf{L}(\mathbf{mask}) = \{(i, m_i)\} \rangle$ (optional)
- 3818 3. $\mathbf{u} = \langle \mathbf{D}(\mathbf{u}), \mathbf{size}(\mathbf{u}), \mathbf{L}(\mathbf{u}) = \{(i, u_i)\} \rangle$
- 3819 4. $\mathbf{v} = \langle \mathbf{D}(\mathbf{v}), \mathbf{size}(\mathbf{v}), \mathbf{L}(\mathbf{v}) = \{(i, v_i)\} \rangle$

3820 The argument vectors, the “sum” operator (`op`), and the accumulation operator (if provided) are
3821 tested for domain compatibility as follows:

- 3822 1. If `mask` is not `GrB_NULL`, and `desc[GrB_MASK].GrB_STRUCTURE` is not set, then $\mathbf{D}(\mathbf{mask})$
3823 must be from one of the pre-defined types of Table 3.2.
- 3824 2. $\mathbf{D}(\mathbf{u})$ must be compatible with $\mathbf{D}_{in_1}(\mathbf{op})$.
- 3825 3. $\mathbf{D}(\mathbf{v})$ must be compatible with $\mathbf{D}_{in_2}(\mathbf{op})$.
- 3826 4. $\mathbf{D}(\mathbf{w})$ must be compatible with $\mathbf{D}_{out}(\mathbf{op})$.
- 3827 5. $\mathbf{D}(\mathbf{u})$ and $\mathbf{D}(\mathbf{v})$ must be compatible with $\mathbf{D}_{out}(\mathbf{op})$.
- 3828 6. If `accum` is not `GrB_NULL`, then $\mathbf{D}(\mathbf{w})$ must be compatible with $\mathbf{D}_{in_1}(\mathbf{accum})$ and $\mathbf{D}_{out}(\mathbf{accum})$
3829 of the accumulation operator and $\mathbf{D}_{out}(\mathbf{op})$ of `op` must be compatible with $\mathbf{D}_{in_2}(\mathbf{accum})$ of
3830 the accumulation operator.

3831 Two domains are compatible with each other if values from one domain can be cast to values in
 3832 the other domain as per the rules of the C language. In particular, domains from Table 3.2 are all
 3833 compatible with each other. A domain from a user-defined type is only compatible with itself. If
 3834 any compatibility rule above is violated, execution of `GrB_eWiseAdd` ends and the domain mismatch
 3835 error listed above is returned.

3836 From the argument vectors, the internal vectors and mask used in the computation are formed (\leftarrow
 3837 denotes copy):

- 3838 1. Vector $\tilde{\mathbf{w}} \leftarrow \mathbf{w}$.
- 3839 2. One-dimensional mask, $\tilde{\mathbf{m}}$, is computed from argument `mask` as follows:
 - 3840 (a) If `mask = GrB_NULL`, then $\tilde{\mathbf{m}} = \langle \mathbf{size}(\mathbf{w}), \{i, \forall i : 0 \leq i < \mathbf{size}(\mathbf{w})\} \rangle$.
 - 3841 (b) If `mask \neq GrB_NULL`,
 - 3842 i. If `desc[GrB_MASK].GrB_STRUCTURE` is set, then $\tilde{\mathbf{m}} = \langle \mathbf{size}(\mathbf{mask}), \{i : i \in \mathbf{ind}(\mathbf{mask})\} \rangle$,
 - 3843 ii. Otherwise, $\tilde{\mathbf{m}} = \langle \mathbf{size}(\mathbf{mask}), \{i : i \in \mathbf{ind}(\mathbf{mask}) \wedge (\mathbf{bool})\mathbf{mask}(i) = \mathbf{true}\} \rangle$.
 - 3844 (c) If `desc[GrB_MASK].GrB_COMP` is set, then $\tilde{\mathbf{m}} \leftarrow \neg \tilde{\mathbf{m}}$.
- 3845 3. Vector $\tilde{\mathbf{u}} \leftarrow \mathbf{u}$.
- 3846 4. Vector $\tilde{\mathbf{v}} \leftarrow \mathbf{v}$.

3847 The internal vectors and mask are checked for dimension compatibility. The following conditions
 3848 must hold:

- 3849 1. $\mathbf{size}(\tilde{\mathbf{w}}) = \mathbf{size}(\tilde{\mathbf{m}}) = \mathbf{size}(\tilde{\mathbf{u}}) = \mathbf{size}(\tilde{\mathbf{v}})$.

3850 If any compatibility rule above is violated, execution of `GrB_eWiseAdd` ends and the dimension
 3851 mismatch error listed above is returned.

3852 From this point forward, in `GrB_NONBLOCKING` mode, the method can optionally exit with
 3853 `GrB_SUCCESS` return code and defer any computation and/or execution error codes.

3854 We are now ready to carry out the element-wise “sum” and any additional associated operations.
 3855 We describe this in terms of two intermediate vectors:

- 3856 • $\tilde{\mathbf{t}}$: The vector holding the element-wise “sum” of $\tilde{\mathbf{u}}$ and vector $\tilde{\mathbf{v}}$.
- 3857 • $\tilde{\mathbf{z}}$: The vector holding the result after application of the (optional) accumulation operator.

3858 The intermediate vector $\tilde{\mathbf{t}} = \langle \mathbf{D}_{out}(\mathbf{op}), \mathbf{size}(\tilde{\mathbf{u}}), \{(i, t_i) : \mathbf{ind}(\tilde{\mathbf{u}}) \cup \mathbf{ind}(\tilde{\mathbf{v}}) \neq \emptyset\} \rangle$ is created. The
 3859 value of each of its elements is computed by:

$$3860 \quad t_i = (\tilde{\mathbf{u}}(i) \oplus \tilde{\mathbf{v}}(i)), \forall i \in (\mathbf{ind}(\tilde{\mathbf{u}}) \cap \mathbf{ind}(\tilde{\mathbf{v}}))$$

$$3861 \quad t_i = \tilde{\mathbf{u}}(i), \forall i \in (\mathbf{ind}(\tilde{\mathbf{u}}) - (\mathbf{ind}(\tilde{\mathbf{u}}) \cap \mathbf{ind}(\tilde{\mathbf{v}})))$$

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$$t_i = \tilde{\mathbf{v}}(i), \forall i \in (\mathbf{ind}(\tilde{\mathbf{v}}) - (\mathbf{ind}(\tilde{\mathbf{u}}) \cap \mathbf{ind}(\tilde{\mathbf{v}})))$$

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where the difference operator in the previous expressions refers to set difference.

3866

The intermediate vector $\tilde{\mathbf{z}}$ is created as follows, using what is called a *standard vector accumulate*:

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- If `accum = GrB_NULL`, then $\tilde{\mathbf{z}} = \tilde{\mathbf{t}}$.

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- If `accum` is a binary operator, then $\tilde{\mathbf{z}}$ is defined as

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$$\tilde{\mathbf{z}} = \langle \mathbf{D}_{out}(\mathbf{accum}), \mathbf{size}(\tilde{\mathbf{w}}), \{(i, z_i) \mid \forall i \in \mathbf{ind}(\tilde{\mathbf{w}}) \cup \mathbf{ind}(\tilde{\mathbf{t}})\} \rangle.$$

3870

The values of the elements of $\tilde{\mathbf{z}}$ are computed based on the relationships between the sets of indices in $\tilde{\mathbf{w}}$ and $\tilde{\mathbf{t}}$.

3871

$$z_i = \tilde{\mathbf{w}}(i) \odot \tilde{\mathbf{t}}(i), \text{ if } i \in (\mathbf{ind}(\tilde{\mathbf{t}}) \cap \mathbf{ind}(\tilde{\mathbf{w}})),$$

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3873

$$z_i = \tilde{\mathbf{w}}(i), \text{ if } i \in (\mathbf{ind}(\tilde{\mathbf{w}}) - (\mathbf{ind}(\tilde{\mathbf{t}}) \cap \mathbf{ind}(\tilde{\mathbf{w}}))),$$

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$$z_i = \tilde{\mathbf{t}}(i), \text{ if } i \in (\mathbf{ind}(\tilde{\mathbf{t}}) - (\mathbf{ind}(\tilde{\mathbf{t}}) \cap \mathbf{ind}(\tilde{\mathbf{w}}))),$$

3877

where $\odot = \odot(\mathbf{accum})$, and the difference operator refers to set difference.

3878

Finally, the set of output values that make up vector $\tilde{\mathbf{z}}$ are written into the final result vector \mathbf{w} , using what is called a *standard vector mask and replace*. This is carried out under control of the mask which acts as a “write mask”.

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- If `desc[GrB_OUTP].GrB_REPLACE` is set, then any values in \mathbf{w} on input to this operation are deleted and the content of the new output vector, \mathbf{w} , is defined as,

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$$\mathbf{L}(\mathbf{w}) = \{(i, z_i) : i \in (\mathbf{ind}(\tilde{\mathbf{z}}) \cap \mathbf{ind}(\tilde{\mathbf{m}}))\}.$$

3884

- If `desc[GrB_OUTP].GrB_REPLACE` is not set, the elements of $\tilde{\mathbf{z}}$ indicated by the mask are copied into the result vector, \mathbf{w} , and elements of \mathbf{w} that fall outside the set indicated by the mask are unchanged:

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$$\mathbf{L}(\mathbf{w}) = \{(i, w_i) : i \in (\mathbf{ind}(\mathbf{w}) \cap \mathbf{ind}(\neg\tilde{\mathbf{m}}))\} \cup \{(i, z_i) : i \in (\mathbf{ind}(\tilde{\mathbf{z}}) \cap \mathbf{ind}(\tilde{\mathbf{m}}))\}.$$

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In `GrB_BLOCKING` mode, the method exits with return value `GrB_SUCCESS` and the new content of vector \mathbf{w} is as defined above and fully computed. In `GrB_NONBLOCKING` mode, the method exits with return value `GrB_SUCCESS` and the new content of vector \mathbf{w} is as defined above but may not be fully computed. However, it can be used in the next GraphBLAS method call in a sequence.

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4.3.5.2 eWiseAdd: Matrix variant

3894

Perform element-wise (general) addition on the elements of two matrices, producing a third matrix as result.

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3896 C Syntax

```
3897     GrB_Info GrB_eWiseAdd(GrB_Matrix      C,  
3898                          const GrB_Matrix Mask,  
3899                          const GrB_BinaryOp accum,  
3900                          const GrB_Semiring op,  
3901                          const GrB_Matrix A,  
3902                          const GrB_Matrix B,  
3903                          const GrB_Descriptor desc);  
3904  
3905     GrB_Info GrB_eWiseAdd(GrB_Matrix      C,  
3906                          const GrB_Matrix Mask,  
3907                          const GrB_BinaryOp accum,  
3908                          const GrB_Monoid op,  
3909                          const GrB_Matrix A,  
3910                          const GrB_Matrix B,  
3911                          const GrB_Descriptor desc);  
3912  
3913     GrB_Info GrB_eWiseAdd(GrB_Matrix      C,  
3914                          const GrB_Matrix Mask,  
3915                          const GrB_BinaryOp accum,  
3916                          const GrB_BinaryOp op,  
3917                          const GrB_Matrix A,  
3918                          const GrB_Matrix B,  
3919                          const GrB_Descriptor desc);
```

3920 Parameters

3921 **C** (INOUT) An existing GraphBLAS matrix. On input, the matrix provides values
3922 that may be accumulated with the result of the element-wise operation. On output,
3923 the matrix holds the results of the operation.

3924 **Mask** (IN) An optional “write” mask that controls which results from this operation are
3925 stored into the output matrix C. The mask dimensions must match those of the
3926 matrix C. If the GrB_STRUCTURE descriptor is *not* set for the mask, the domain
3927 of the Mask matrix must be of type bool or any of the predefined “built-in” types
3928 in Table 3.2. If the default mask is desired (i.e., a mask that is all true with the
3929 dimensions of C), GrB_NULL should be specified.

3930 **accum** (IN) An optional binary operator used for accumulating entries into existing C
3931 entries. If assignment rather than accumulation is desired, GrB_NULL should be
3932 specified.

3933 **op** (IN) The semiring, monoid, or binary operator used in the element-wise “sum”
3934 operation. Depending on which type is passed, the following defines the binary
3935 operator, $F_b = \langle \mathbf{D}_{out}(\text{op}), \mathbf{D}_{in_1}(\text{op}), \mathbf{D}_{in_2}(\text{op}), \oplus \rangle$, used:

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BinaryOp: $F_b = \langle \mathbf{D}_{out}(\text{op}), \mathbf{D}_{in_1}(\text{op}), \mathbf{D}_{in_2}(\text{op}), \odot(\text{op}) \rangle$.

Monoid: $F_b = \langle \mathbf{D}(\text{op}), \mathbf{D}(\text{op}), \mathbf{D}(\text{op}), \odot(\text{op}) \rangle$; the identity element is ignored.

Semiring: $F_b = \langle \mathbf{D}_{out}(\text{op}), \mathbf{D}_{in_1}(\text{op}), \mathbf{D}_{in_2}(\text{op}), \oplus(\text{op}) \rangle$; the multiplicative binary op and additive identity are ignored.

A (IN) The GraphBLAS matrix holding the values for the left-hand matrix in the operation.

B (IN) The GraphBLAS matrix holding the values for the right-hand matrix in the operation.

desc (IN) An optional operation descriptor. If a *default* descriptor is desired, GrB_NULL should be specified. Non-default field/value pairs are listed as follows:

Param	Field	Value	Description
C	GrB_OUTP	GrB_REPLACE	Output matrix C is cleared (all elements removed) before the result is stored in it.
Mask	GrB_MASK	GrB_STRUCTURE	The write mask is constructed from the structure (pattern of stored values) of the input Mask matrix. The stored values are not examined.
Mask	GrB_MASK	GrB_COMP	Use the complement of Mask.
A	GrB_INP0	GrB_TRAN	Use transpose of A for the operation.
B	GrB_INP1	GrB_TRAN	Use transpose of B for the operation.

3948

3949 Return Values

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GrB_SUCCESS In blocking mode, the operation completed successfully. In non-blocking mode, this indicates that the compatibility tests on dimensions and domains for the input arguments passed successfully. Either way, output matrix C is ready to be used in the next method of the sequence.

GrB_PANIC Unknown internal error.

GrB_INVALID_OBJECT This is returned in any execution mode whenever one of the opaque GraphBLAS objects (input or output) is in an invalid state caused by a previous execution error. Call GrB_error() to access any error messages generated by the implementation.

GrB_OUT_OF_MEMORY Not enough memory available for the operation.

GrB_UNINITIALIZED_OBJECT One or more of the GraphBLAS objects has not been initialized by a call to new (or Matrix_dup for matrix parameters).

GrB_DIMENSION_MISMATCH Mask and/or matrix dimensions are incompatible.

3964 GrB_DOMAIN_MISMATCH The domains of the various matrices are incompatible with the
 3965 corresponding domains of the binary operator (\oplus) or accumulation
 3966 operator, or the mask's domain is not compatible with `bool` (in the
 3967 case where `desc[GrB_MASK].GrB_STRUCTURE` is not set).

3968 Description

3969 This variant of `GrB_eWiseAdd` computes the element-wise “sum” of two GraphBLAS matrices:
 3970 $C = A \oplus B$, or, if an optional binary accumulation operator (\odot) is provided, $C = C \odot (A \oplus B)$.
 3971 Logically, this operation occurs in three steps:

3972 **Setup** The internal matrices and mask used in the computation are formed and their domains
 3973 and dimensions are tested for compatibility.

3974 **Compute** The indicated computations are carried out.

3975 **Output** The result is written into the output matrix, possibly under control of a mask.

3976 Up to four argument matrices are used in the `GrB_eWiseAdd` operation:

- 3977 1. $C = \langle \mathbf{D}(C), \mathbf{nrows}(C), \mathbf{ncols}(C), \mathbf{L}(C) = \{(i, j, C_{ij})\} \rangle$
- 3978 2. $\text{Mask} = \langle \mathbf{D}(\text{Mask}), \mathbf{nrows}(\text{Mask}), \mathbf{ncols}(\text{Mask}), \mathbf{L}(\text{Mask}) = \{(i, j, M_{ij})\} \rangle$ (optional)
- 3979 3. $A = \langle \mathbf{D}(A), \mathbf{nrows}(A), \mathbf{ncols}(A), \mathbf{L}(A) = \{(i, j, A_{ij})\} \rangle$
- 3980 4. $B = \langle \mathbf{D}(B), \mathbf{nrows}(B), \mathbf{ncols}(B), \mathbf{L}(B) = \{(i, j, B_{ij})\} \rangle$

3981 The argument matrices, the “sum” operator (\oplus), and the accumulation operator (if provided) are
 3982 tested for domain compatibility as follows:

- 3983 1. If `Mask` is not `GrB_NULL`, and `desc[GrB_MASK].GrB_STRUCTURE` is not set, then $\mathbf{D}(\text{Mask})$
 3984 must be from one of the pre-defined types of Table 3.2.
- 3985 2. $\mathbf{D}(A)$ must be compatible with $\mathbf{D}_{in_1}(\oplus)$.
- 3986 3. $\mathbf{D}(B)$ must be compatible with $\mathbf{D}_{in_2}(\oplus)$.
- 3987 4. $\mathbf{D}(C)$ must be compatible with $\mathbf{D}_{out}(\oplus)$.
- 3988 5. $\mathbf{D}(A)$ and $\mathbf{D}(B)$ must be compatible with $\mathbf{D}_{out}(\oplus)$.
- 3989 6. If `accum` is not `GrB_NULL`, then $\mathbf{D}(C)$ must be compatible with $\mathbf{D}_{in_1}(\text{accum})$ and $\mathbf{D}_{out}(\text{accum})$
 3990 of the accumulation operator and $\mathbf{D}_{out}(\oplus)$ of \oplus must be compatible with $\mathbf{D}_{in_2}(\text{accum})$ of
 3991 the accumulation operator.

3992 Two domains are compatible with each other if values from one domain can be cast to values in
 3993 the other domain as per the rules of the C language. In particular, domains from Table 3.2 are all
 3994 compatible with each other. A domain from a user-defined type is only compatible with itself. If
 3995 any compatibility rule above is violated, execution of `GrB_eWiseAdd` ends and the domain mismatch
 3996 error listed above is returned.

3997 From the argument matrices, the internal matrices and mask used in the computation are formed
 3998 (\leftarrow denotes copy):

- 3999 1. Matrix $\tilde{\mathbf{C}} \leftarrow \mathbf{C}$.
- 4000 2. Two-dimensional mask, $\tilde{\mathbf{M}}$, is computed from argument `Mask` as follows:
 - 4001 (a) If `Mask = GrB_NULL`, then $\tilde{\mathbf{M}} = \langle \mathbf{nrows}(\mathbf{C}), \mathbf{ncols}(\mathbf{C}), \{(i, j), \forall i, j : 0 \leq i < \mathbf{nrows}(\mathbf{C}), 0 \leq$
 4002 $j < \mathbf{ncols}(\mathbf{C})\} \rangle$.
 - 4003 (b) If `Mask \neq GrB_NULL`,
 - 4004 i. If `desc[GrB_MASK].GrB_STRUCTURE` is set, then $\tilde{\mathbf{M}} = \langle \mathbf{nrows}(\mathbf{Mask}), \mathbf{ncols}(\mathbf{Mask}), \{(i, j) :$
 4005 $(i, j) \in \mathbf{ind}(\mathbf{Mask})\} \rangle$,
 - 4006 ii. Otherwise, $\tilde{\mathbf{M}} = \langle \mathbf{nrows}(\mathbf{Mask}), \mathbf{ncols}(\mathbf{Mask}),$
 4007 $\{(i, j) : (i, j) \in \mathbf{ind}(\mathbf{Mask}) \wedge (\mathbf{bool})\mathbf{Mask}(i, j) = \mathbf{true}\} \rangle$.
 - 4008 (c) If `desc[GrB_MASK].GrB_COMP` is set, then $\tilde{\mathbf{M}} \leftarrow \neg \tilde{\mathbf{M}}$.
- 4009 3. Matrix $\tilde{\mathbf{A}} \leftarrow \mathbf{desc}[\mathbf{GrB_INP0}].\mathbf{GrB_TRAN} ? \mathbf{A}^T : \mathbf{A}$.
- 4010 4. Matrix $\tilde{\mathbf{B}} \leftarrow \mathbf{desc}[\mathbf{GrB_INP1}].\mathbf{GrB_TRAN} ? \mathbf{B}^T : \mathbf{B}$.

4011 The internal matrices and masks are checked for dimension compatibility. The following conditions
 4012 must hold:

- 4013 1. $\mathbf{nrows}(\tilde{\mathbf{C}}) = \mathbf{nrows}(\tilde{\mathbf{M}}) = \mathbf{nrows}(\tilde{\mathbf{A}}) = \mathbf{nrows}(\tilde{\mathbf{B}})$.
- 4014 2. $\mathbf{ncols}(\tilde{\mathbf{C}}) = \mathbf{ncols}(\tilde{\mathbf{M}}) = \mathbf{ncols}(\tilde{\mathbf{A}}) = \mathbf{ncols}(\tilde{\mathbf{B}})$.

4015 If any compatibility rule above is violated, execution of `GrB_eWiseAdd` ends and the dimension
 4016 mismatch error listed above is returned.

4017 From this point forward, in `GrB_NONBLOCKING` mode, the method can optionally exit with
 4018 `GrB_SUCCESS` return code and defer any computation and/or execution error codes.

4019 We are now ready to carry out the element-wise “sum” and any additional associated operations.
 4020 We describe this in terms of two intermediate matrices:

- 4021 • $\tilde{\mathbf{T}}$: The matrix holding the element-wise sum of $\tilde{\mathbf{A}}$ and $\tilde{\mathbf{B}}$.
- 4022 • $\tilde{\mathbf{Z}}$: The matrix holding the result after application of the (optional) accumulation operator.

4023 The intermediate matrix $\tilde{\mathbf{T}} = \langle \mathbf{D}_{out}(\text{op}), \mathbf{nrows}(\tilde{\mathbf{A}}), \mathbf{ncols}(\tilde{\mathbf{A}}), \{(i, j, T_{ij}) : \mathbf{ind}(\tilde{\mathbf{A}}) \cup \mathbf{ind}(\tilde{\mathbf{B}}) \neq \emptyset\} \rangle$
 4024 is created. The value of each of its elements is computed by

$$4025 \quad T_{ij} = (\tilde{\mathbf{A}}(i, j) \oplus \tilde{\mathbf{B}}(i, j)), \forall (i, j) \in \mathbf{ind}(\tilde{\mathbf{A}}) \cap \mathbf{ind}(\tilde{\mathbf{B}})$$

$$4026 \quad T_{ij} = \tilde{\mathbf{A}}(i, j), \forall (i, j) \in (\mathbf{ind}(\tilde{\mathbf{A}}) - (\mathbf{ind}(\tilde{\mathbf{A}}) \cap \mathbf{ind}(\tilde{\mathbf{B}})))$$

$$4027 \quad T_{ij} = \tilde{\mathbf{B}}(i, j), \forall (i, j) \in (\mathbf{ind}(\tilde{\mathbf{B}}) - (\mathbf{ind}(\tilde{\mathbf{A}}) \cap \mathbf{ind}(\tilde{\mathbf{B}})))$$

4030 where the difference operator in the previous expressions refers to set difference.

4031 The intermediate matrix $\tilde{\mathbf{Z}}$ is created as follows, using what is called a *standard matrix accumulate*:

- 4032 • If `accum = GrB_NULL`, then $\tilde{\mathbf{Z}} = \tilde{\mathbf{T}}$.
- 4033 • If `accum` is a binary operator, then $\tilde{\mathbf{Z}}$ is defined as

$$4034 \quad \tilde{\mathbf{Z}} = \langle \mathbf{D}_{out}(\text{accum}), \mathbf{nrows}(\tilde{\mathbf{C}}), \mathbf{ncols}(\tilde{\mathbf{C}}), \{(i, j, Z_{ij}) \mid \forall (i, j) \in \mathbf{ind}(\tilde{\mathbf{C}}) \cup \mathbf{ind}(\tilde{\mathbf{T}})\} \rangle.$$

4035 The values of the elements of $\tilde{\mathbf{Z}}$ are computed based on the relationships between the sets of
 4036 indices in $\tilde{\mathbf{C}}$ and $\tilde{\mathbf{T}}$.

$$4037 \quad Z_{ij} = \tilde{\mathbf{C}}(i, j) \odot \tilde{\mathbf{T}}(i, j), \text{ if } (i, j) \in (\mathbf{ind}(\tilde{\mathbf{T}}) \cap \mathbf{ind}(\tilde{\mathbf{C}})),$$

$$4038 \quad Z_{ij} = \tilde{\mathbf{C}}(i, j), \text{ if } (i, j) \in (\mathbf{ind}(\tilde{\mathbf{C}}) - (\mathbf{ind}(\tilde{\mathbf{T}}) \cap \mathbf{ind}(\tilde{\mathbf{C}}))),$$

$$4039 \quad Z_{ij} = \tilde{\mathbf{T}}(i, j), \text{ if } (i, j) \in (\mathbf{ind}(\tilde{\mathbf{T}}) - (\mathbf{ind}(\tilde{\mathbf{T}}) \cap \mathbf{ind}(\tilde{\mathbf{C}}))),$$

4042 where $\odot = \odot(\text{accum})$, and the difference operator refers to set difference.

4043 Finally, the set of output values that make up matrix $\tilde{\mathbf{Z}}$ are written into the final result matrix \mathbf{C} ,
 4044 using what is called a *standard matrix mask and replace*. This is carried out under control of the
 4045 mask which acts as a “write mask”.

- 4046 • If `desc[GrB_OUTP].GrB_REPLACE` is set, then any values in \mathbf{C} on input to this operation are
 4047 deleted and the content of the new output matrix, \mathbf{C} , is defined as,

$$4048 \quad \mathbf{L}(\mathbf{C}) = \{(i, j, Z_{ij}) : (i, j) \in (\mathbf{ind}(\tilde{\mathbf{Z}}) \cap \mathbf{ind}(\tilde{\mathbf{M}}))\}.$$

- 4049 • If `desc[GrB_OUTP].GrB_REPLACE` is not set, the elements of $\tilde{\mathbf{Z}}$ indicated by the mask are
 4050 copied into the result matrix, \mathbf{C} , and elements of \mathbf{C} that fall outside the set indicated by the
 4051 mask are unchanged:

$$4052 \quad \mathbf{L}(\mathbf{C}) = \{(i, j, C_{ij}) : (i, j) \in (\mathbf{ind}(\mathbf{C}) \cap \mathbf{ind}(\neg\tilde{\mathbf{M}}))\} \cup \{(i, j, Z_{ij}) : (i, j) \in (\mathbf{ind}(\tilde{\mathbf{Z}}) \cap \mathbf{ind}(\tilde{\mathbf{M}}))\}.$$

4053 In `GrB_BLOCKING` mode, the method exits with return value `GrB_SUCCESS` and the new content
 4054 of matrix \mathbf{C} is as defined above and fully computed. In `GrB_NONBLOCKING` mode, the method
 4055 exits with return value `GrB_SUCCESS` and the new content of matrix \mathbf{C} is as defined above but
 4056 may not be fully computed. However, it can be used in the next GraphBLAS method call in a
 4057 sequence.

4058 **4.3.6 extract: Selecting sub-graphs**

4059 Extract a subset of a matrix or vector.

4060 **4.3.6.1 extract: Standard vector variant**

4061 Extract a sub-vector from a larger vector as specified by a set of indices. The result is a vector
4062 whose size is equal to the number of indices.

4063 **C Syntax**

```
4064         GrB_Info GrB_extract(GrB_Vector          w,  
4065                             const GrB_Vector    mask,  
4066                             const GrB_BinaryOp   accum,  
4067                             const GrB_Vector    u,  
4068                             const GrB_Index     *indices,  
4069                             GrB_Index          nindices,  
4070                             const GrB_Descriptor desc);
```

4071 **Parameters**

4072 **w** (INOUT) An existing GraphBLAS vector. On input, the vector provides values
4073 that may be accumulated with the result of the extract operation. On output, this
4074 vector holds the results of the operation.

4075 **mask** (IN) An optional “write” mask that controls which results from this operation are
4076 stored into the output vector **w**. The mask dimensions must match those of the
4077 vector **w**. If the **GrB_STRUCTURE** descriptor is *not* set for the mask, the domain
4078 of the **mask** vector must be of type **bool** or any of the predefined “built-in” types
4079 in Table 3.2. If the default mask is desired (i.e., a mask that is all true with the
4080 dimensions of **w**), **GrB_NULL** should be specified.

4081 **accum** (IN) An optional binary operator used for accumulating entries into existing **w**
4082 entries. If assignment rather than accumulation is desired, **GrB_NULL** should be
4083 specified.

4084 **u** (IN) The GraphBLAS vector from which the subset is extracted.

4085 **indices** (IN) Pointer to the ordered set (array) of indices corresponding to the locations of
4086 elements from **u** that are extracted. If all elements of **u** are to be extracted in order
4087 from 0 to **nindices** – 1, then **GrB_ALL** should be specified. Regardless of execution
4088 mode and return value, this array may be manipulated by the caller after this
4089 operation returns without affecting any deferred computations for this operation.

4090 **nindices** (IN) The number of values in **indices** array. Must be equal to **size(w)**.

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`desc` (IN) An optional operation descriptor. If a *default* descriptor is desired, `GrB_NULL` should be specified. Non-default field/value pairs are listed as follows:

4094

Param	Field	Value	Description
<code>w</code>	<code>GrB_OUTP</code>	<code>GrB_REPLACE</code>	Output vector <code>w</code> is cleared (all elements removed) before the result is stored in it.
<code>mask</code>	<code>GrB_MASK</code>	<code>GrB_STRUCTURE</code>	The write mask is constructed from the structure (pattern of stored values) of the input <code>mask</code> vector. The stored values are not examined.
<code>mask</code>	<code>GrB_MASK</code>	<code>GrB_COMP</code>	Use the complement of <code>mask</code> .

4095 Return Values

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`GrB_SUCCESS` In blocking mode, the operation completed successfully. In non-blocking mode, this indicates that the compatibility tests on dimensions and domains for the input arguments passed successfully. Either way, output vector `w` is ready to be used in the next method of the sequence.

4101

`GrB_PANIC` Unknown internal error.

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4103
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4105

`GrB_INVALID_OBJECT` This is returned in any execution mode whenever one of the opaque GraphBLAS objects (input or output) is in an invalid state caused by a previous execution error. Call `GrB_error()` to access any error messages generated by the implementation.

4106

`GrB_OUT_OF_MEMORY` Not enough memory available for operation.

4107
4108

`GrB_UNINITIALIZED_OBJECT` One or more of the GraphBLAS objects has not been initialized by a call to `new` (or `dup` for vector parameters).

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4110

`GrB_INDEX_OUT_OF_BOUNDS` A value in `indices` is greater than or equal to `size(u)`. In non-blocking mode, this error can be deferred.

4111

`GrB_DIMENSION_MISMATCH` `mask` and `w` dimensions are incompatible, or `nindices` \neq `size(w)`.

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4113
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4115

`GrB_DOMAIN_MISMATCH` The domains of the various vectors are incompatible with each other or the corresponding domains of the accumulation operator, or the mask's domain is not compatible with `bool` (in the case where `desc[GrB_MASK].GrB_STRUCTURE` is not set).

4116

`GrB_NULL_POINTER` Argument `row_indices` is a NULL pointer.

4117 Description

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This variant of `GrB_extract` computes the result of extracting a subset of locations from a GraphBLAS vector in a specific order: `w = u(indices)`; or, if an optional binary accumulation operator

4120 (\odot) is provided, $w = w \odot u(\text{indices})$. More explicitly:

$$\begin{aligned} 4121 \quad w(i) &= u(\text{indices}[i]), \forall i : 0 \leq i < \text{nindices}, \text{ or} \\ w(i) &= w(i) \odot u(\text{indices}[i]), \forall i : 0 \leq i < \text{nindices} \end{aligned}$$

4122 Logically, this operation occurs in three steps:

4123 **Setup** The internal vectors and mask used in the computation are formed and their domains
4124 and dimensions are tested for compatibility.

4125 **Compute** The indicated computations are carried out.

4126 **Output** The result is written into the output vector, possibly under control of a mask.

4127 Up to three argument vectors are used in this `GrB_extract` operation:

- 4128 1. $w = \langle \mathbf{D}(w), \mathbf{size}(w), \mathbf{L}(w) = \{(i, w_i)\} \rangle$
- 4129 2. $\text{mask} = \langle \mathbf{D}(\text{mask}), \mathbf{size}(\text{mask}), \mathbf{L}(\text{mask}) = \{(i, m_i)\} \rangle$ (optional)
- 4130 3. $u = \langle \mathbf{D}(u), \mathbf{size}(u), \mathbf{L}(u) = \{(i, u_i)\} \rangle$

4131 The argument vectors and the accumulation operator (if provided) are tested for domain compati-
4132 bility as follows:

- 4133 1. If `mask` is not `GrB_NULL`, and `desc[GrB_MASK].GrB_STRUCTURE` is not set, then $\mathbf{D}(\text{mask})$
4134 must be from one of the pre-defined types of Table 3.2.
- 4135 2. $\mathbf{D}(w)$ must be compatible with $\mathbf{D}(u)$.
- 4136 3. If `accum` is not `GrB_NULL`, then $\mathbf{D}(w)$ must be compatible with $\mathbf{D}_{in_1}(\text{accum})$ and $\mathbf{D}_{out}(\text{accum})$
4137 of the accumulation operator and $\mathbf{D}(u)$ must be compatible with $\mathbf{D}_{in_2}(\text{accum})$ of the accu-
4138 mulation operator.

4139 Two domains are compatible with each other if values from one domain can be cast to values in
4140 the other domain as per the rules of the C language. In particular, domains from Table 3.2 are all
4141 compatible with each other. A domain from a user-defined type is only compatible with itself. If
4142 any compatibility rule above is violated, execution of `GrB_extract` ends and the domain mismatch
4143 error listed above is returned.

4144 From the arguments, the internal vectors, mask, and index array used in the computation are
4145 formed (\leftarrow denotes copy):

- 4146 1. Vector $\tilde{w} \leftarrow w$.
- 4147 2. One-dimensional mask, \tilde{m} , is computed from argument `mask` as follows:
 - 4148 (a) If `mask = GrB_NULL`, then $\tilde{m} = \langle \mathbf{size}(w), \{i, \forall i : 0 \leq i < \mathbf{size}(w)\} \rangle$.

- 4149 (b) If $\text{mask} \neq \text{GrB_NULL}$,
- 4150 i. If $\text{desc}[\text{GrB_MASK}].\text{GrB_STRUCTURE}$ is set, then $\widetilde{\mathbf{m}} = \langle \text{size}(\text{mask}), \{i : i \in \mathbf{ind}(\text{mask})\} \rangle$,
- 4151 ii. Otherwise, $\widetilde{\mathbf{m}} = \langle \text{size}(\text{mask}), \{i : i \in \mathbf{ind}(\text{mask}) \wedge (\text{bool})\text{mask}(i) = \text{true}\} \rangle$.
- 4152 (c) If $\text{desc}[\text{GrB_MASK}].\text{GrB_COMP}$ is set, then $\widetilde{\mathbf{m}} \leftarrow \neg\widetilde{\mathbf{m}}$.
- 4153 3. Vector $\widetilde{\mathbf{u}} \leftarrow \mathbf{u}$.
- 4154 4. The internal index array, $\widetilde{\mathbf{I}}$, is computed from argument indices as follows:
- 4155 (a) If $\text{indices} = \text{GrB_ALL}$, then $\widetilde{\mathbf{I}}[i] = i, \forall i : 0 \leq i < \text{nindices}$.
- 4156 (b) Otherwise, $\widetilde{\mathbf{I}}[i] = \text{indices}[i], \forall i : 0 \leq i < \text{nindices}$.

4157 The internal vectors and mask are checked for dimension compatibility. The following conditions
4158 must hold:

- 4159 1. $\text{size}(\widetilde{\mathbf{w}}) = \text{size}(\widetilde{\mathbf{m}})$
- 4160 2. $\text{nindices} = \text{size}(\widetilde{\mathbf{w}})$.

4161 If any compatibility rule above is violated, execution of `GrB_extract` ends and the dimension mis-
4162 match error listed above is returned.

4163 From this point forward, in `GrB_NONBLOCKING` mode, the method can optionally exit with
4164 `GrB_SUCCESS` return code and defer any computation and/or execution error codes.

4165 We are now ready to carry out the extract and any additional associated operations. We describe
4166 this in terms of two intermediate vectors:

- 4167 • $\widetilde{\mathbf{t}}$: The vector holding the extraction from $\widetilde{\mathbf{u}}$ in their destination locations relative to $\widetilde{\mathbf{w}}$.
- 4168 • $\widetilde{\mathbf{z}}$: The vector holding the result after application of the (optional) accumulation operator.

4169 The intermediate vector, $\widetilde{\mathbf{t}}$, is created as follows:

$$4170 \quad \widetilde{\mathbf{t}} = \langle \mathbf{D}(\mathbf{u}), \text{size}(\widetilde{\mathbf{w}}), \{(i, \widetilde{\mathbf{u}}[\widetilde{\mathbf{I}}[i]]) \mid \forall i, 0 \leq i < \text{nindices} : \widetilde{\mathbf{I}}[i] \in \mathbf{ind}(\widetilde{\mathbf{u}})\} \rangle.$$

4171 At this point, if any value in $\widetilde{\mathbf{I}}$ is not in the valid range of indices for vector $\widetilde{\mathbf{u}}$, the execution of
4172 `GrB_extract` ends and the index-out-of-bounds error listed above is generated. In `GrB_NONBLOCKING`
4173 mode, the error can be deferred until a sequence-terminating `GrB_wait()` is called. Regardless, the
4174 result vector, \mathbf{w} , is invalid from this point forward in the sequence.

4175 The intermediate vector $\widetilde{\mathbf{z}}$ is created as follows, using what is called a *standard vector accumulate*:

- 4176 • If $\text{accum} = \text{GrB_NULL}$, then $\widetilde{\mathbf{z}} = \widetilde{\mathbf{t}}$.
- 4177 • If accum is a binary operator, then $\widetilde{\mathbf{z}}$ is defined as

$$4178 \quad \widetilde{\mathbf{z}} = \langle \mathbf{D}_{out}(\text{accum}), \text{size}(\widetilde{\mathbf{w}}), \{(i, z_i) \mid \forall i \in \mathbf{ind}(\widetilde{\mathbf{w}}) \cup \mathbf{ind}(\widetilde{\mathbf{t}})\} \rangle.$$

4179 The values of the elements of $\tilde{\mathbf{z}}$ are computed based on the relationships between the sets of
 4180 indices in $\tilde{\mathbf{w}}$ and $\tilde{\mathbf{t}}$.

$$\begin{aligned}
 4181 \quad z_i &= \tilde{\mathbf{w}}(i) \odot \tilde{\mathbf{t}}(i), \text{ if } i \in (\mathbf{ind}(\tilde{\mathbf{t}}) \cap \mathbf{ind}(\tilde{\mathbf{w}})), \\
 4182 \\
 4183 \quad z_i &= \tilde{\mathbf{w}}(i), \text{ if } i \in (\mathbf{ind}(\tilde{\mathbf{w}}) - (\mathbf{ind}(\tilde{\mathbf{t}}) \cap \mathbf{ind}(\tilde{\mathbf{w}}))), \\
 4184 \\
 4185 \quad z_i &= \tilde{\mathbf{t}}(i), \text{ if } i \in (\mathbf{ind}(\tilde{\mathbf{t}}) - (\mathbf{ind}(\tilde{\mathbf{t}}) \cap \mathbf{ind}(\tilde{\mathbf{w}}))),
 \end{aligned}$$

4186 where $\odot = \odot(\text{accum})$, and the difference operator refers to set difference.

4187 Finally, the set of output values that make up vector $\tilde{\mathbf{z}}$ are written into the final result vector \mathbf{w} ,
 4188 using what is called a *standard vector mask and replace*. This is carried out under control of the
 4189 mask which acts as a “write mask”.

- 4190 • If desc[GrB_OUTP].GrB_REPLACE is set, then any values in \mathbf{w} on input to this operation are
 4191 deleted and the content of the new output vector, \mathbf{w} , is defined as,

$$4192 \quad \mathbf{L}(\mathbf{w}) = \{(i, z_i) : i \in (\mathbf{ind}(\tilde{\mathbf{z}}) \cap \mathbf{ind}(\tilde{\mathbf{m}}))\}.$$

- 4193 • If desc[GrB_OUTP].GrB_REPLACE is not set, the elements of $\tilde{\mathbf{z}}$ indicated by the mask are
 4194 copied into the result vector, \mathbf{w} , and elements of \mathbf{w} that fall outside the set indicated by the
 4195 mask are unchanged:

$$4196 \quad \mathbf{L}(\mathbf{w}) = \{(i, w_i) : i \in (\mathbf{ind}(\mathbf{w}) \cap \mathbf{ind}(\neg\tilde{\mathbf{m}}))\} \cup \{(i, z_i) : i \in (\mathbf{ind}(\tilde{\mathbf{z}}) \cap \mathbf{ind}(\tilde{\mathbf{m}}))\}.$$

4197 In GrB_BLOCKING mode, the method exits with return value GrB_SUCCESS and the new content
 4198 of vector \mathbf{w} is as defined above and fully computed. In GrB_NONBLOCKING mode, the method
 4199 exits with return value GrB_SUCCESS and the new content of vector \mathbf{w} is as defined above but
 4200 may not be fully computed. However, it can be used in the next GraphBLAS method call in a
 4201 sequence.

4202 4.3.6.2 extract: Standard matrix variant

4203 Extract a sub-matrix from a larger matrix as specified by a set of row indices and a set of column
 4204 indices. The result is a matrix whose size is equal to size of the sets of indices.

4205 C Syntax

```

4206     GrB_Info GrB_extract(GrB_Matrix      C,
4207                         const GrB_Matrix Mask,
4208                         const GrB_BinaryOp accum,
4209                         const GrB_Matrix A,
4210                         const GrB_Index *row_indices,
4211                         GrB_Index      nrows,
4212                         const GrB_Index *col_indices,
4213                         GrB_Index      ncols,
4214                         const GrB_Descriptor desc);
  
```

4215 **Parameters**

4216 C (INOUT) An existing GraphBLAS matrix. On input, the matrix provides values
 4217 that may be accumulated with the result of the extract operation. On output, the
 4218 matrix holds the results of the operation.

4219 Mask (IN) An optional “write” mask that controls which results from this operation are
 4220 stored into the output matrix C. The mask dimensions must match those of the
 4221 matrix C. If the GrB_STRUCTURE descriptor is *not* set for the mask, the domain
 4222 of the Mask matrix must be of type bool or any of the predefined “built-in” types
 4223 in Table 3.2. If the default mask is desired (i.e., a mask that is all true with the
 4224 dimensions of C), GrB_NULL should be specified.

4225 accum (IN) An optional binary operator used for accumulating entries into existing C
 4226 entries. If assignment rather than accumulation is desired, GrB_NULL should be
 4227 specified.

4228 A (IN) The GraphBLAS matrix from which the subset is extracted.

4229 row_indices (IN) Pointer to the ordered set (array) of indices corresponding to the rows of A
 4230 from which elements are extracted. If elements in all rows of A are to be extracted
 4231 in order, GrB_ALL should be specified. Regardless of execution mode and return
 4232 value, this array may be manipulated by the caller after this operation returns
 4233 without affecting any deferred computations for this operation.

4234 nrows (IN) The number of values in the row_indices array. Must be equal to **nrows(C)**.

4235 col_indices (IN) Pointer to the ordered set (array) of indices corresponding to the columns
 4236 of A from which elements are extracted. If elements in all columns of A are to
 4237 be extracted in order, then GrB_ALL should be specified. Regardless of execution
 4238 mode and return value, this array may be manipulated by the caller after this
 4239 operation returns without affecting any deferred computations for this operation.

4240 ncols (IN) The number of values in the col_indices array. Must be equal to **ncols(C)**.

4241 desc (IN) An optional operation descriptor. If a *default* descriptor is desired, GrB_NULL
 4242 should be specified. Non-default field/value pairs are listed as follows:
 4243

Param	Field	Value	Description
C	GrB_OUTP	GrB_REPLACE	Output matrix C is cleared (all elements removed) before the result is stored in it.
Mask	GrB_MASK	GrB_STRUCTURE	The write mask is constructed from the structure (pattern of stored values) of the input Mask matrix. The stored values are not examined.
Mask	GrB_MASK	GrB_COMP	Use the complement of Mask.
A	GrB_INP0	GrB_TRAN	Use transpose of A for the operation.

4244

4245 Return Values

- 4246 GrB_SUCCESS In blocking mode, the operation completed successfully. In non-
4247 blocking mode, this indicates that the compatibility tests on
4248 dimensions and domains for the input arguments passed suc-
4249 cessfully. Either way, output matrix C is ready to be used in the
4250 next method of the sequence.
- 4251 GrB_PANIC Unknown internal error.
- 4252 GrB_INVALID_OBJECT This is returned in any execution mode whenever one of the
4253 opaque GraphBLAS objects (input or output) is in an invalid
4254 state caused by a previous execution error. Call GrB_error() to
4255 access any error messages generated by the implementation.
- 4256 GrB_OUT_OF_MEMORY Not enough memory available for the operation.
- 4257 GrB_UNINITIALIZED_OBJECT One or more of the GraphBLAS objects has not been initialized
4258 by a call to new (or Matrix_dup for matrix parameters).
- 4259 GrB_INDEX_OUT_OF_BOUNDS A value in row_indices is greater than or equal to nrows(A), or
4260 a value in col_indices is greater than or equal to ncols(A). In
4261 non-blocking mode, this error can be deferred.
- 4262 GrB_DIMENSION_MISMATCH Mask and C dimensions are incompatible, nrow \neq nrow(C), or
4263 ncol \neq ncol(C).
- 4264 GrB_DOMAIN_MISMATCH The domains of the various matrices are incompatible with each
4265 other or the corresponding domains of the accumulation oper-
4266 ator, or the mask's domain is not compatible with bool (in the
4267 case where desc[GrB_MASK].GrB_STRUCTURE is not set).
- 4268 GrB_NULL_POINTER Either argument row_indices is a NULL pointer, argument col_indices
4269 is a NULL pointer, or both.

4270 Description

4271 This variant of GrB_extract computes the result of extracting a subset of locations from specified
4272 rows and columns of a GraphBLAS matrix in a specific order: $C = A(\text{row_indices}, \text{col_indices})$; or,
4273 if an optional binary accumulation operator (\odot) is provided, $C = C \odot A(\text{row_indices}, \text{col_indices})$.
4274 More explicitly (not accounting for an optional transpose of A):

$$4275 \quad C(i, j) = \quad A(\text{row_indices}[i], \text{col_indices}[j]) \quad \forall i, j : 0 \leq i < \text{nrows}, 0 \leq j < \text{ncols}, \text{ or}$$
$$C(i, j) = C(i, j) \odot A(\text{row_indices}[i], \text{col_indices}[j]) \quad \forall i, j : 0 \leq i < \text{nrows}, 0 \leq j < \text{ncols}$$

4276 Logically, this operation occurs in three steps:

4277 **Setup** The internal matrices and mask used in the computation are formed and their domains
4278 and dimensions are tested for compatibility.

4279 **Compute** The indicated computations are carried out.

4280 **Output** The result is written into the output matrix, possibly under control of a mask.

4281 Up to three argument matrices are used in the `GrB_extract` operation:

- 4282 1. $C = \langle \mathbf{D}(C), \mathbf{nrows}(C), \mathbf{ncols}(C), \mathbf{L}(C) = \{(i, j, C_{ij})\} \rangle$
- 4283 2. $\text{Mask} = \langle \mathbf{D}(\text{Mask}), \mathbf{nrows}(\text{Mask}), \mathbf{ncols}(\text{Mask}), \mathbf{L}(\text{Mask}) = \{(i, j, M_{ij})\} \rangle$ (optional)
- 4284 3. $A = \langle \mathbf{D}(A), \mathbf{nrows}(A), \mathbf{ncols}(A), \mathbf{L}(A) = \{(i, j, A_{ij})\} \rangle$

4285 The argument matrices and the accumulation operator (if provided) are tested for domain compat-
4286 ibility as follows:

- 4287 1. If `Mask` is not `GrB_NULL`, and `desc[GrB_MASK].GrB_STRUCTURE` is not set, then $\mathbf{D}(\text{Mask})$
4288 must be from one of the pre-defined types of Table 3.2.
- 4289 2. $\mathbf{D}(C)$ must be compatible with $\mathbf{D}(A)$.
- 4290 3. If `accum` is not `GrB_NULL`, then $\mathbf{D}(C)$ must be compatible with $\mathbf{D}_{in_1}(\text{accum})$ and $\mathbf{D}_{out}(\text{accum})$
4291 of the accumulation operator and $\mathbf{D}(A)$ must be compatible with $\mathbf{D}_{in_2}(\text{accum})$ of the accu-
4292 mulation operator.

4293 Two domains are compatible with each other if values from one domain can be cast to values in
4294 the other domain as per the rules of the C language. In particular, domains from Table 3.2 are all
4295 compatible with each other. A domain from a user-defined type is only compatible with itself. If
4296 any compatibility rule above is violated, execution of `GrB_extract` ends and the domain mismatch
4297 error listed above is returned.

4298 From the arguments, the internal matrices, `mask`, and index arrays used in the computation are
4299 formed (\leftarrow denotes copy):

- 4300 1. Matrix $\tilde{C} \leftarrow C$.
- 4301 2. Two-dimensional mask, \tilde{M} , is computed from argument `Mask` as follows:
 - 4302 (a) If `Mask` = `GrB_NULL`, then $\tilde{M} = \langle \mathbf{nrows}(C), \mathbf{ncols}(C), \{(i, j), \forall i, j : 0 \leq i < \mathbf{nrows}(C), 0 \leq$
4303 $j < \mathbf{ncols}(C)\} \rangle$.
 - 4304 (b) If `Mask` \neq `GrB_NULL`,
 - 4305 i. If `desc[GrB_MASK].GrB_STRUCTURE` is set, then $\tilde{M} = \langle \mathbf{nrows}(\text{Mask}), \mathbf{ncols}(\text{Mask}), \{(i, j) :$
4306 $(i, j) \in \mathbf{ind}(\text{Mask})\} \rangle$,
 - 4307 ii. Otherwise, $\tilde{M} = \langle \mathbf{nrows}(\text{Mask}), \mathbf{ncols}(\text{Mask}),$
4308 $\{(i, j) : (i, j) \in \mathbf{ind}(\text{Mask}) \wedge (\text{bool})\text{Mask}(i, j) = \text{true}\} \rangle$.
 - 4309 (c) If `desc[GrB_MASK].GrB_COMP` is set, then $\tilde{M} \leftarrow \neg \tilde{M}$.
- 4310 3. Matrix $\tilde{A} \leftarrow \text{desc}[\text{GrB_INP0}].\text{GrB_TRAN} ? A^T : A$.

- 4311 4. The internal row index array, $\tilde{\mathbf{I}}$, is computed from argument `row_indices` as follows:
- 4312 (a) If `row_indices = GrB_ALL`, then $\tilde{\mathbf{I}}[i] = i, \forall i : 0 \leq i < \text{nrows}$.
- 4313 (b) Otherwise, $\tilde{\mathbf{I}}[i] = \text{row_indices}[i], \forall i : 0 \leq i < \text{nrows}$.
- 4314 5. The internal column index array, $\tilde{\mathbf{J}}$, is computed from argument `col_indices` as follows:
- 4315 (a) If `col_indices = GrB_ALL`, then $\tilde{\mathbf{J}}[j] = j, \forall j : 0 \leq j < \text{ncols}$.
- 4316 (b) Otherwise, $\tilde{\mathbf{J}}[j] = \text{col_indices}[j], \forall j : 0 \leq j < \text{ncols}$.

4317 The internal matrices and mask are checked for dimension compatibility. The following conditions
4318 must hold:

- 4319 1. $\text{nrows}(\tilde{\mathbf{C}}) = \text{nrows}(\tilde{\mathbf{M}})$.
- 4320 2. $\text{ncols}(\tilde{\mathbf{C}}) = \text{ncols}(\tilde{\mathbf{M}})$.
- 4321 3. $\text{nrows}(\tilde{\mathbf{C}}) = \text{nrows}$.
- 4322 4. $\text{ncols}(\tilde{\mathbf{C}}) = \text{ncols}$.

4323 If any compatibility rule above is violated, execution of `GrB_extract` ends and the dimension mis-
4324 match error listed above is returned.

4325 From this point forward, in `GrB_NONBLOCKING` mode, the method can optionally exit with
4326 `GrB_SUCCESS` return code and defer any computation and/or execution error codes.

4327 We are now ready to carry out the extract and any additional associated operations. We describe
4328 this in terms of two intermediate matrices:

- 4329 • $\tilde{\mathbf{T}}$: The matrix holding the extraction from $\tilde{\mathbf{A}}$.
- 4330 • $\tilde{\mathbf{Z}}$: The matrix holding the result after application of the (optional) accumulation operator.

4331 The intermediate matrix, $\tilde{\mathbf{T}}$, is created as follows:

4332
$$\tilde{\mathbf{T}} = \langle \mathbf{D}(\mathbf{A}), \text{nrows}(\tilde{\mathbf{C}}), \text{ncols}(\tilde{\mathbf{C}}), \{ (i, j, \tilde{\mathbf{A}}(\tilde{\mathbf{I}}[i], \tilde{\mathbf{J}}[j])) \mid \forall (i, j), 0 \leq i < \text{nrows}, 0 \leq j < \text{ncols} : (\tilde{\mathbf{I}}[i], \tilde{\mathbf{J}}[j]) \in \text{ind}(\tilde{\mathbf{A}}) \} \rangle.$$

4333 At this point, if any value in the $\tilde{\mathbf{I}}$ array is not in the range $[0, \text{nrows}(\tilde{\mathbf{A}}))$ or any value in the $\tilde{\mathbf{J}}$
4334 array is not in the range $[0, \text{ncols}(\tilde{\mathbf{A}}))$, the execution of `GrB_extract` ends and the index out-of-
4335 bounds error listed above is generated. In `GrB_NONBLOCKING` mode, the error can be deferred
4336 until a sequence-terminating `GrB_wait()` is called. Regardless, the result matrix \mathbf{C} is invalid from
4337 this point forward in the sequence.

4338 The intermediate matrix $\tilde{\mathbf{Z}}$ is created as follows, using what is called a *standard matrix accumulate*:

- 4339 • If `accum = GrB_NULL`, then $\tilde{\mathbf{Z}} = \tilde{\mathbf{T}}$.

4340 • If `accum` is a binary operator, then $\tilde{\mathbf{Z}}$ is defined as

$$4341 \quad \tilde{\mathbf{Z}} = \langle \mathbf{D}_{out}(\text{accum}), \mathbf{nrows}(\tilde{\mathbf{C}}), \mathbf{ncols}(\tilde{\mathbf{C}}), \{(i, j, Z_{ij}) \mid \forall (i, j) \in \mathbf{ind}(\tilde{\mathbf{C}}) \cup \mathbf{ind}(\tilde{\mathbf{T}})\} \rangle.$$

4342 The values of the elements of $\tilde{\mathbf{Z}}$ are computed based on the relationships between the sets of
4343 indices in $\tilde{\mathbf{C}}$ and $\tilde{\mathbf{T}}$.

$$4344 \quad Z_{ij} = \tilde{\mathbf{C}}(i, j) \odot \tilde{\mathbf{T}}(i, j), \text{ if } (i, j) \in (\mathbf{ind}(\tilde{\mathbf{T}}) \cap \mathbf{ind}(\tilde{\mathbf{C}})),$$

$$4345 \quad Z_{ij} = \tilde{\mathbf{C}}(i, j), \text{ if } (i, j) \in (\mathbf{ind}(\tilde{\mathbf{C}}) - (\mathbf{ind}(\tilde{\mathbf{T}}) \cap \mathbf{ind}(\tilde{\mathbf{C}}))),$$

$$4346 \quad Z_{ij} = \tilde{\mathbf{T}}(i, j), \text{ if } (i, j) \in (\mathbf{ind}(\tilde{\mathbf{T}}) - (\mathbf{ind}(\tilde{\mathbf{T}}) \cap \mathbf{ind}(\tilde{\mathbf{C}}))),$$

4347 where $\odot = \odot(\text{accum})$, and the difference operator refers to set difference.

4350 Finally, the set of output values that make up matrix $\tilde{\mathbf{Z}}$ are written into the final result matrix \mathbf{C} ,
4351 using what is called a *standard matrix mask and replace*. This is carried out under control of the
4352 mask which acts as a “write mask”.

4353 • If `desc[GrB_OUTP].GrB_REPLACE` is set, then any values in \mathbf{C} on input to this operation are
4354 deleted and the content of the new output matrix, \mathbf{C} , is defined as,

$$4355 \quad \mathbf{L}(\mathbf{C}) = \{(i, j, Z_{ij}) : (i, j) \in (\mathbf{ind}(\tilde{\mathbf{Z}}) \cap \mathbf{ind}(\tilde{\mathbf{M}}))\}.$$

4356 • If `desc[GrB_OUTP].GrB_REPLACE` is not set, the elements of $\tilde{\mathbf{Z}}$ indicated by the mask are
4357 copied into the result matrix, \mathbf{C} , and elements of \mathbf{C} that fall outside the set indicated by the
4358 mask are unchanged:

$$4359 \quad \mathbf{L}(\mathbf{C}) = \{(i, j, C_{ij}) : (i, j) \in (\mathbf{ind}(\mathbf{C}) \cap \mathbf{ind}(\neg\tilde{\mathbf{M}}))\} \cup \{(i, j, Z_{ij}) : (i, j) \in (\mathbf{ind}(\tilde{\mathbf{Z}}) \cap \mathbf{ind}(\tilde{\mathbf{M}}))\}.$$

4360 In `GrB_BLOCKING` mode, the method exits with return value `GrB_SUCCESS` and the new content
4361 of matrix \mathbf{C} is as defined above and fully computed. In `GrB_NONBLOCKING` mode, the method
4362 exits with return value `GrB_SUCCESS` and the new content of matrix \mathbf{C} is as defined above but
4363 may not be fully computed. However, it can be used in the next GraphBLAS method call in a
4364 sequence.

4365 4.3.6.3 extract: Column (and row) variant

4366 Extract from one column of a matrix into a vector. Note that with the transpose descriptor for the
4367 source matrix, elements of an arbitrary row of the matrix can be extracted with this function as
4368 well.

4369 C Syntax

```
4370         GrB_Info GrB_extract(GrB_Vector          w,  
4371                             const GrB_Vector    mask,  
4372                             const GrB_BinaryOp    accum,  
4373                             const GrB_Matrix     A,  
4374                             const GrB_Index      *row_indices,  
4375                             GrB_Index          nrows,  
4376                             GrB_Index          col_index,  
4377                             const GrB_Descriptor  desc);
```

4378 Parameters

4379 **w** (INOUT) An existing GraphBLAS vector. On input, the vector provides values
4380 that may be accumulated with the result of the extract operation. On output, this
4381 vector holds the results of the operation.

4382 **mask** (IN) An optional “write” mask that controls which results from this operation are
4383 stored into the output vector **w**. The mask dimensions must match those of the
4384 vector **w**. If the **GrB_STRUCTURE** descriptor is *not* set for the mask, the domain
4385 of the **mask** vector must be of type **bool** or any of the predefined “built-in” types
4386 in Table 3.2. If the default mask is desired (i.e., a mask that is all true with the
4387 dimensions of **w**), **GrB_NULL** should be specified.

4388 **accum** (IN) An optional binary operator used for accumulating entries into existing **w**
4389 entries. If assignment rather than accumulation is desired, **GrB_NULL** should be
4390 specified.

4391 **A** (IN) The GraphBLAS matrix from which the column subset is extracted.

4392 **row_indices** (IN) Pointer to the ordered set (array) of indices corresponding to the locations
4393 within the specified column of **A** from which elements are extracted. If elements in
4394 all rows of **A** are to be extracted in order, **GrB_ALL** should be specified. Regardless
4395 of execution mode and return value, this array may be manipulated by the caller
4396 after this operation returns without affecting any deferred computations for this
4397 operation.

4398 **nrows** (IN) The number of indices in the **row_indices** array. Must be equal to **size(w)**.

4399 **col_index** (IN) The index of the column of **A** from which to extract values. It must be in the
4400 range $[0, \mathbf{ncols}(A))$.

4401 **desc** (IN) An optional operation descriptor. If a *default* descriptor is desired, **GrB_NULL**
4402 should be specified. Non-default field/value pairs are listed as follows:
4403

Param	Field	Value	Description
w	GrB_OUTP	GrB_REPLACE	Output vector w is cleared (all elements removed) before the result is stored in it.
mask	GrB_MASK	GrB_STRUCTURE	The write mask is constructed from the structure (pattern of stored values) of the input mask vector. The stored values are not examined.
mask	GrB_MASK	GrB_COMP	Use the complement of mask.
A	GrB_INP0	GrB_TRAN	Use transpose of A for the operation.

4404

4405 Return Values

4406

GrB_SUCCESS In blocking mode, the operation completed successfully. In non-blocking mode, this indicates that the compatibility tests on dimensions and domains for the input arguments passed successfully. Either way, output vector w is ready to be used in the next method of the sequence.

4407

4408

4409

4410

4411

GrB_PANIC Unknown internal error.

4412

GrB_INVALID_OBJECT This is returned in any execution mode whenever one of the opaque GraphBLAS objects (input or output) is in an invalid state caused by a previous execution error. Call GrB_error() to access any error messages generated by the implementation.

4413

4414

4415

4416

GrB_OUT_OF_MEMORY Not enough memory available for operation.

4417

GrB_UNINITIALIZED_OBJECT One or more of the GraphBLAS objects has not been initialized by a call to new (or dup for vector or matrix parameters).

4418

4419

GrB_INVALID_INDEX col_index is outside the allowable range (i.e., greater than ncols(A)).

4420

GrB_INDEX_OUT_OF_BOUNDS A value in row_indices is greater than or equal to nrows(A). In non-blocking mode, this error can be deferred.

4421

4422

GrB_DIMENSION_MISMATCH mask and w dimensions are incompatible, or nrows \neq size(w).

4423

GrB_DOMAIN_MISMATCH The domains of the vector or matrix are incompatible with each other or the corresponding domains of the accumulation operator, or the mask's domain is not compatible with bool (in the case where desc[GrB_MASK].GrB_STRUCTURE is not set).

4424

4425

4426

4427

GrB_NULL_POINTER Argument row_indices is a NULL pointer.

4428 Description

4429

This variant of GrB_extract computes the result of extracting a subset of locations (in a specific order) from a specified column of a GraphBLAS matrix: $w = A(:, col_index)(row_indices)$; or, if

4430

4431 an optional binary accumulation operator (\odot) is provided, $w = w \odot A(:, \text{col_index})(\text{row_indices})$.
 4432 More explicitly:

$$4433 \quad w(i) = A(\text{row_indices}[i], \text{col_index}) \quad \forall i : 0 \leq i < \text{nrows}, \quad \text{or}$$

$$4434 \quad w(i) = w(i) \odot A(\text{row_indices}[i], \text{col_index}) \quad \forall i : 0 \leq i < \text{nrows}$$

4434 Logically, this operation occurs in three steps:

4435 **Setup** The internal matrices, vectors, and mask used in the computation are formed and their
 4436 domains and dimensions are tested for compatibility.

4437 **Compute** The indicated computations are carried out.

4438 **Output** The result is written into the output vector, possibly under control of a mask.

4439 Up to three argument vectors and matrices are used in this `GrB_extract` operation:

- 4440 1. $w = \langle \mathbf{D}(w), \mathbf{size}(w), \mathbf{L}(w) = \{(i, w_i)\} \rangle$
- 4441 2. $\text{mask} = \langle \mathbf{D}(\text{mask}), \mathbf{size}(\text{mask}), \mathbf{L}(\text{mask}) = \{(i, m_i)\} \rangle$ (optional)
- 4442 3. $A = \langle \mathbf{D}(A), \mathbf{nrows}(A), \mathbf{ncols}(A), \mathbf{L}(A) = \{(i, j, A_{ij})\} \rangle$

4443 The argument vectors, matrix and the accumulation operator (if provided) are tested for domain
 4444 compatibility as follows:

- 4445 1. If `mask` is not `GrB_NULL`, and `desc[GrB_MASK].GrB_STRUCTURE` is not set, then $\mathbf{D}(\text{mask})$
 4446 must be from one of the pre-defined types of Table 3.2.
- 4447 2. $\mathbf{D}(w)$ must be compatible with $\mathbf{D}(A)$.
- 4448 3. If `accum` is not `GrB_NULL`, then $\mathbf{D}(w)$ must be compatible with $\mathbf{D}_{in_1}(\text{accum})$ and $\mathbf{D}_{out}(\text{accum})$
 4449 of the accumulation operator and $\mathbf{D}(A)$ must be compatible with $\mathbf{D}_{in_2}(\text{accum})$ of the accu-
 4450 mulation operator.

4451 Two domains are compatible with each other if values from one domain can be cast to values in
 4452 the other domain as per the rules of the C language. In particular, domains from Table 3.2 are all
 4453 compatible with each other. A domain from a user-defined type is only compatible with itself. If
 4454 any compatibility rule above is violated, execution of `GrB_extract` ends and the domain mismatch
 4455 error listed above is returned.

4456 From the arguments, the internal vector, matrix, mask, and index array used in the computation
 4457 are formed (\leftarrow denotes copy):

- 4458 1. Vector $\tilde{w} \leftarrow w$.
- 4459 2. One-dimensional mask, \tilde{m} , is computed from argument `mask` as follows:
 4460 (a) If `mask = GrB_NULL`, then $\tilde{m} = \langle \mathbf{size}(w), \{i, \forall i : 0 \leq i < \mathbf{size}(w)\} \rangle$.

- 4461 (b) If $\text{mask} \neq \text{GrB_NULL}$,
- 4462 i. If $\text{desc}[\text{GrB_MASK}].\text{GrB_STRUCTURE}$ is set, then $\tilde{\mathbf{m}} = \langle \text{size}(\text{mask}), \{i : i \in \mathbf{ind}(\text{mask})\} \rangle$,
- 4463 ii. Otherwise, $\tilde{\mathbf{m}} = \langle \text{size}(\text{mask}), \{i : i \in \mathbf{ind}(\text{mask}) \wedge (\text{bool})\text{mask}(i) = \text{true}\} \rangle$.
- 4464 (c) If $\text{desc}[\text{GrB_MASK}].\text{GrB_COMP}$ is set, then $\tilde{\mathbf{m}} \leftarrow \neg\tilde{\mathbf{m}}$.
- 4465 3. Matrix $\tilde{\mathbf{A}} \leftarrow \text{desc}[\text{GrB_INP0}].\text{GrB_TRAN} ? \mathbf{A}^T : \mathbf{A}$.
- 4466 4. The internal row index array, $\tilde{\mathbf{I}}$, is computed from argument `row_indices` as follows:
- 4467 (a) If `indices = GrB_ALL`, then $\tilde{\mathbf{I}}[i] = i, \forall i : 0 \leq i < \text{nrows}$.
- 4468 (b) Otherwise, $\tilde{\mathbf{I}}[i] = \text{indices}[i], \forall i : 0 \leq i < \text{nrows}$.

4469 The internal vector, `mask`, and index array are checked for dimension compatibility. The following
4470 conditions must hold:

- 4471 1. $\text{size}(\tilde{\mathbf{w}}) = \text{size}(\tilde{\mathbf{m}})$
- 4472 2. $\text{size}(\tilde{\mathbf{w}}) = \text{nrows}$.

4473 If any compatibility rule above is violated, execution of `GrB_extract` ends and the dimension mis-
4474 match error listed above is returned.

4475 The `col_index` parameter is checked for a valid value. The following condition must hold:

- 4476 1. $0 \leq \text{col_index} < \text{ncols}(\mathbf{A})$

4477 If the rule above is violated, execution of `GrB_extract` ends and the invalid index error listed above
4478 is returned.

4479 From this point forward, in `GrB_NONBLOCKING` mode, the method can optionally exit with
4480 `GrB_SUCCESS` return code and defer any computation and/or execution error codes.

4481 We are now ready to carry out the extract and any additional associated operations. We describe
4482 this in terms of two intermediate vectors:

- 4483 • $\tilde{\mathbf{t}}$: The vector holding the extraction from a column of $\tilde{\mathbf{A}}$.
- 4484 • $\tilde{\mathbf{z}}$: The vector holding the result after application of the (optional) accumulation operator.

4485 The intermediate vector, $\tilde{\mathbf{t}}$, is created as follows:

4486
$$\tilde{\mathbf{t}} = \langle \mathbf{D}(\mathbf{A}), \text{nrows}, \{(i, \tilde{\mathbf{A}}(\tilde{\mathbf{I}}[i], \text{col_index})) \mid \forall i, 0 \leq i < \text{nrows} : (\tilde{\mathbf{I}}[i], \text{col_index}) \in \mathbf{ind}(\tilde{\mathbf{A}})\} \rangle.$$

4487 At this point, if any value in $\tilde{\mathbf{I}}$ is not in the range $[0, \text{nrows}(\tilde{\mathbf{A}}))$, the execution of `GrB_extract`
4488 ends and the index-out-of-bounds error listed above is generated. In `GrB_NONBLOCKING` mode,
4489 the error can be deferred until a sequence-terminating `GrB_wait()` is called. Regardless, the result
4490 vector, `w`, is invalid from this point forward in the sequence.

4491 The intermediate vector $\tilde{\mathbf{z}}$ is created as follows, using what is called a *standard vector accumulate*:

- 4492 • If `accum = GrB_NULL`, then $\tilde{\mathbf{z}} = \tilde{\mathbf{t}}$.
- 4493 • If `accum` is a binary operator, then $\tilde{\mathbf{z}}$ is defined as

$$4494 \quad \tilde{\mathbf{z}} = \langle \mathbf{D}_{out}(\text{accum}), \text{size}(\tilde{\mathbf{w}}), \{(i, z_i) \mid i \in \mathbf{ind}(\tilde{\mathbf{w}}) \cup \mathbf{ind}(\tilde{\mathbf{t}})\} \rangle.$$

4495 The values of the elements of $\tilde{\mathbf{z}}$ are computed based on the relationships between the sets of
 4496 indices in $\tilde{\mathbf{w}}$ and $\tilde{\mathbf{t}}$.

$$4497 \quad z_i = \tilde{\mathbf{w}}(i) \odot \tilde{\mathbf{t}}(i), \text{ if } i \in (\mathbf{ind}(\tilde{\mathbf{t}}) \cap \mathbf{ind}(\tilde{\mathbf{w}})),$$

$$4498 \quad z_i = \tilde{\mathbf{w}}(i), \text{ if } i \in (\mathbf{ind}(\tilde{\mathbf{w}}) - (\mathbf{ind}(\tilde{\mathbf{t}}) \cap \mathbf{ind}(\tilde{\mathbf{w}}))),$$

$$4499 \quad z_i = \tilde{\mathbf{t}}(i), \text{ if } i \in (\mathbf{ind}(\tilde{\mathbf{t}}) - (\mathbf{ind}(\tilde{\mathbf{t}}) \cap \mathbf{ind}(\tilde{\mathbf{w}}))),$$

4500 where $\odot = \odot(\text{accum})$, and the difference operator refers to set difference.

4503 Finally, the set of output values that make up vector $\tilde{\mathbf{z}}$ are written into the final result vector \mathbf{w} ,
 4504 using what is called a *standard vector mask and replace*. This is carried out under control of the
 4505 mask which acts as a “write mask”.

- 4506 • If `desc[GrB_OUTP].GrB_REPLACE` is set, then any values in \mathbf{w} on input to this operation are
 4507 deleted and the content of the new output vector, \mathbf{w} , is defined as,

$$4508 \quad \mathbf{L}(\mathbf{w}) = \{(i, z_i) : i \in (\mathbf{ind}(\tilde{\mathbf{z}}) \cap \mathbf{ind}(\tilde{\mathbf{m}}))\}.$$

- 4509 • If `desc[GrB_OUTP].GrB_REPLACE` is not set, the elements of $\tilde{\mathbf{z}}$ indicated by the mask are
 4510 copied into the result vector, \mathbf{w} , and elements of \mathbf{w} that fall outside the set indicated by the
 4511 mask are unchanged:

$$4512 \quad \mathbf{L}(\mathbf{w}) = \{(i, w_i) : i \in (\mathbf{ind}(\mathbf{w}) \cap \mathbf{ind}(\neg\tilde{\mathbf{m}}))\} \cup \{(i, z_i) : i \in (\mathbf{ind}(\tilde{\mathbf{z}}) \cap \mathbf{ind}(\tilde{\mathbf{m}}))\}.$$

4513 In `GrB_BLOCKING` mode, the method exits with return value `GrB_SUCCESS` and the new content
 4514 of vector \mathbf{w} is as defined above and fully computed. In `GrB_NONBLOCKING` mode, the method
 4515 exits with return value `GrB_SUCCESS` and the new content of vector \mathbf{w} is as defined above but
 4516 may not be fully computed. However, it can be used in the next GraphBLAS method call in a
 4517 sequence.

4518 4.3.7 assign: Modifying sub-graphs

4519 Assign the contents of a subset of a matrix or vector.

4520 4.3.7.1 assign: Standard vector variant

4521 Assign values from one GraphBLAS vector to a subset of a vector as specified by a set of indices.
 4522 The size of the input vector is the same size as the index array provided.

4523 C Syntax

```
4524         GrB_Info GrB_assign(GrB_Vector      w,  
4525                             const GrB_Vector  mask,  
4526                             const GrB_BinaryOp accum,  
4527                             const GrB_Vector  u,  
4528                             const GrB_Index   *indices,  
4529                             GrB_Index       nindices,  
4530                             const GrB_Descriptor desc);
```

4531 Parameters

4532 **w** (INOUT) An existing GraphBLAS vector. On input, the vector provides values
4533 that may be accumulated with the result of the assign operation. On output, this
4534 vector holds the results of the operation.

4535 **mask** (IN) An optional “write” mask that controls which results from this operation are
4536 stored into the output vector **w**. The mask dimensions must match those of the
4537 vector **w**. If the `GrB_STRUCTURE` descriptor is *not* set for the mask, the domain
4538 of the **mask** vector must be of type `bool` or any of the predefined “built-in” types
4539 in Table 3.2. If the default mask is desired (i.e., a mask that is all true with the
4540 dimensions of **w**), `GrB_NULL` should be specified.

4541 **accum** (IN) An optional binary operator used for accumulating entries into existing **w**
4542 entries. If assignment rather than accumulation is desired, `GrB_NULL` should be
4543 specified.

4544 **u** (IN) The GraphBLAS vector whose contents are assigned to a subset of **w**.

4545 **indices** (IN) Pointer to the ordered set (array) of indices corresponding to the locations in
4546 **w** that are to be assigned. If all elements of **w** are to be assigned in order from 0
4547 to `nindices - 1`, then `GrB_ALL` should be specified. Regardless of execution mode
4548 and return value, this array may be manipulated by the caller after this operation
4549 returns without affecting any deferred computations for this operation. If this
4550 array contains duplicate values, it implies in assignment of more than one value to
4551 the same location which leads to undefined results.

4552 **nindices** (IN) The number of values in **indices** array. Must be equal to `size(u)`.

4553 **desc** (IN) An optional operation descriptor. If a *default* descriptor is desired, `GrB_NULL`
4554 should be specified. Non-default field/value pairs are listed as follows:
4555

Param	Field	Value	Description
w	GrB_OUTP	GrB_REPLACE	Output vector w is cleared (all elements removed) before the result is stored in it.
mask	GrB_MASK	GrB_STRUCTURE	The write mask is constructed from the structure (pattern of stored values) of the input mask vector. The stored values are not examined.
mask	GrB_MASK	GrB_COMP	Use the complement of mask.

4556

4557 Return Values

4558 GrB_SUCCESS In blocking mode, the operation completed successfully. In non-
4559 blocking mode, this indicates that the compatibility tests on
4560 dimensions and domains for the input arguments passed suc-
4561 cessfully. Either way, output vector w is ready to be used in the
4562 next method of the sequence.

4563 GrB_PANIC Unknown internal error.

4564 GrB_INVALID_OBJECT This is returned in any execution mode whenever one of the
4565 opaque GraphBLAS objects (input or output) is in an invalid
4566 state caused by a previous execution error. Call GrB_error() to
4567 access any error messages generated by the implementation.

4568 GrB_OUT_OF_MEMORY Not enough memory available for operation.

4569 GrB_UNINITIALIZED_OBJECT One or more of the GraphBLAS objects has not been initialized
4570 by a call to new (or dup for vector parameters).

4571 GrB_INDEX_OUT_OF_BOUNDS A value in indices is greater than or equal to size(w). In non-
4572 blocking mode, this can be reported as an execution error.

4573 GrB_DIMENSION_MISMATCH mask and w dimensions are incompatible, or nindices \neq size(u).

4574 GrB_DOMAIN_MISMATCH The domains of the various vectors are incompatible with each
4575 other or the corresponding domains of the accumulation oper-
4576 ator, or the mask's domain is not compatible with bool (in the
4577 case where desc[GrB_MASK].GrB_STRUCTURE is not set).

4578 GrB_NULL_POINTER Argument indices is a NULL pointer.

4579 Description

4580 This variant of GrB_assign computes the result of assigning elements from a source GraphBLAS
4581 vector to a destination GraphBLAS vector in a specific order: $w(\text{indices}) = u$; or, if an optional
4582 binary accumulation operator (\odot) is provided, $w(\text{indices}) = w(\text{indices}) \odot u$. More explicitly:

$$4583 \quad w(\text{indices}[i]) = \quad \quad \quad u(i), \forall i : 0 \leq i < n\text{indices}, \quad \text{or}$$

$$w(\text{indices}[i]) = w(\text{indices}[i]) \odot u(i), \forall i : 0 \leq i < n\text{indices}.$$

4584 Logically, this operation occurs in three steps:

4585 **Setup** The internal vectors and mask used in the computation are formed and their domains
4586 and dimensions are tested for compatibility.

4587 **Compute** The indicated computations are carried out.

4588 **Output** The result is written into the output vector, possibly under control of a mask.

4589 Up to three argument vectors are used in the GrB_assign operation:

- 4590 1. $\mathbf{w} = \langle \mathbf{D}(\mathbf{w}), \mathbf{size}(\mathbf{w}), \mathbf{L}(\mathbf{w}) = \{(i, w_i)\} \rangle$
- 4591 2. $\mathbf{mask} = \langle \mathbf{D}(\mathbf{mask}), \mathbf{size}(\mathbf{mask}), \mathbf{L}(\mathbf{mask}) = \{(i, m_i)\} \rangle$ (optional)
- 4592 3. $\mathbf{u} = \langle \mathbf{D}(\mathbf{u}), \mathbf{size}(\mathbf{u}), \mathbf{L}(\mathbf{u}) = \{(i, u_i)\} \rangle$

4593 The argument vectors and the accumulation operator (if provided) are tested for domain compati-
4594 bility as follows:

- 4595 1. If \mathbf{mask} is not GrB_NULL, and $\text{desc}[\text{GrB_MASK}].\text{GrB_STRUCTURE}$ is not set, then $\mathbf{D}(\mathbf{mask})$
4596 must be from one of the pre-defined types of Table 3.2.
- 4597 2. $\mathbf{D}(\mathbf{w})$ must be compatible with $\mathbf{D}(\mathbf{u})$.
- 4598 3. If \mathbf{accum} is not GrB_NULL, then $\mathbf{D}(\mathbf{w})$ must be compatible with $\mathbf{D}_{in_1}(\mathbf{accum})$ and $\mathbf{D}_{out}(\mathbf{accum})$
4599 of the accumulation operator and $\mathbf{D}(\mathbf{u})$ must be compatible with $\mathbf{D}_{in_2}(\mathbf{accum})$ of the accu-
4600 mulation operator.

4601 Two domains are compatible with each other if values from one domain can be cast to values in
4602 the other domain as per the rules of the C language. In particular, domains from Table 3.2 are all
4603 compatible with each other. A domain from a user-defined type is only compatible with itself. If
4604 any compatibility rule above is violated, execution of GrB_assign ends and the domain mismatch
4605 error listed above is returned.

4606 From the arguments, the internal vectors, mask and index array used in the computation are formed
4607 (\leftarrow denotes copy):

- 4608 1. Vector $\tilde{\mathbf{w}} \leftarrow \mathbf{w}$.
- 4609 2. One-dimensional mask, $\tilde{\mathbf{m}}$, is computed from argument \mathbf{mask} as follows:
 - 4610 (a) If $\mathbf{mask} = \text{GrB_NULL}$, then $\tilde{\mathbf{m}} = \langle \mathbf{size}(\mathbf{w}), \{i, \forall i : 0 \leq i < \mathbf{size}(\mathbf{w})\} \rangle$.
 - 4611 (b) If $\mathbf{mask} \neq \text{GrB_NULL}$,
 - 4612 i. If $\text{desc}[\text{GrB_MASK}].\text{GrB_STRUCTURE}$ is set, then $\tilde{\mathbf{m}} = \langle \mathbf{size}(\mathbf{mask}), \{i : i \in \mathbf{ind}(\mathbf{mask})\} \rangle$,
 - 4613 ii. Otherwise, $\tilde{\mathbf{m}} = \langle \mathbf{size}(\mathbf{mask}), \{i : i \in \mathbf{ind}(\mathbf{mask}) \wedge (\text{bool})\mathbf{mask}(i) = \text{true}\} \rangle$.
 - 4614 (c) If $\text{desc}[\text{GrB_MASK}].\text{GrB_COMP}$ is set, then $\tilde{\mathbf{m}} \leftarrow \neg \tilde{\mathbf{m}}$.

4615

3. Vector $\tilde{\mathbf{u}} \leftarrow \mathbf{u}$.

4616

4. The internal index array, $\tilde{\mathbf{I}}$, is computed from argument indices as follows:

4617

(a) If `indices = GrB_ALL`, then $\tilde{\mathbf{I}}[i] = i, \forall i : 0 \leq i < \text{nindices}$.

4618

(b) Otherwise, $\tilde{\mathbf{I}}[i] = \text{indices}[i], \forall i : 0 \leq i < \text{nindices}$.

4619

The internal vector and mask are checked for dimension compatibility. The following conditions must hold:

4620

4621

1. $\text{size}(\tilde{\mathbf{w}}) = \text{size}(\tilde{\mathbf{m}})$

4622

2. $\text{nindices} = \text{size}(\tilde{\mathbf{u}})$.

4623

If any compatibility rule above is violated, execution of `GrB_assign` ends and the dimension mismatch error listed above is returned.

4624

4625

From this point forward, in `GrB_NONBLOCKING` mode, the method can optionally exit with `GrB_SUCCESS` return code and defer any computation and/or execution error codes.

4626

4627

We are now ready to carry out the assign and any additional associated operations. We describe this in terms of two intermediate vectors:

4628

4629

- $\tilde{\mathbf{t}}$: The vector holding the elements from $\tilde{\mathbf{u}}$ in their destination locations relative to $\tilde{\mathbf{w}}$.

4630

- $\tilde{\mathbf{z}}$: The vector holding the result after application of the (optional) accumulation operator.

4631

The intermediate vector, $\tilde{\mathbf{t}}$, is created as follows:

4632

$$\tilde{\mathbf{t}} = \langle \mathbf{D}(\mathbf{u}), \text{size}(\tilde{\mathbf{w}}), \{(\tilde{\mathbf{I}}[i], \tilde{\mathbf{u}}(i)) \mid \forall i, 0 \leq i < \text{nindices} : i \in \text{ind}(\tilde{\mathbf{u}})\} \rangle.$$

4633

At this point, if any value of $\tilde{\mathbf{I}}[i]$ is outside the valid range of indices for vector $\tilde{\mathbf{w}}$, computation ends and the method returns the index-out-of-bounds error listed above. In `GrB_NONBLOCKING` mode, the error can be deferred until a sequence-terminating `GrB_wait()` is called. Regardless, the result vector, \mathbf{w} , is invalid from this point forward in the sequence.

4634

4635

4636

4637

The intermediate vector $\tilde{\mathbf{z}}$ is created as follows:

4638

- If `accum = GrB_NULL`, then $\tilde{\mathbf{z}}$ is defined as

4639

$$\tilde{\mathbf{z}} = \langle \mathbf{D}(\mathbf{w}), \text{size}(\tilde{\mathbf{w}}), \{(i, z_i), \forall i \in (\text{ind}(\tilde{\mathbf{w}}) - (\{\tilde{\mathbf{I}}[k], \forall k\} \cap \text{ind}(\tilde{\mathbf{w}}))) \cup \text{ind}(\tilde{\mathbf{t}})\} \rangle.$$

4640

The above expression defines the structure of vector $\tilde{\mathbf{z}}$ as follows: We start with the structure of $\tilde{\mathbf{w}}$ ($\text{ind}(\tilde{\mathbf{w}})$) and remove from it all the indices of $\tilde{\mathbf{w}}$ that are in the set of indices being assigned ($\{\tilde{\mathbf{I}}[k], \forall k\} \cap \text{ind}(\tilde{\mathbf{w}})$). Finally, we add the structure of $\tilde{\mathbf{t}}$ ($\text{ind}(\tilde{\mathbf{t}})$).

4641

4642

4643

The values of the elements of $\tilde{\mathbf{z}}$ are computed based on the relationships between the sets of indices in $\tilde{\mathbf{w}}$ and $\tilde{\mathbf{t}}$.

4644

4645

$$z_i = \tilde{\mathbf{w}}(i), \text{ if } i \in (\text{ind}(\tilde{\mathbf{w}}) - (\{\tilde{\mathbf{I}}[k], \forall k\} \cap \text{ind}(\tilde{\mathbf{w}}))),$$

4646

$$z_i = \tilde{\mathbf{t}}(i), \text{ if } i \in \text{ind}(\tilde{\mathbf{t}}),$$

4647

4648

where the difference operator refers to set difference.

4649 • If `accum` is a binary operator, then $\tilde{\mathbf{z}}$ is defined as

$$4650 \quad \langle \mathbf{D}_{out}(\text{accum}), \text{size}(\tilde{\mathbf{w}}), \{(i, z_i) \mid \forall i \in \mathbf{ind}(\tilde{\mathbf{w}}) \cup \mathbf{ind}(\tilde{\mathbf{t}})\} \rangle.$$

4651 The values of the elements of $\tilde{\mathbf{z}}$ are computed based on the relationships between the sets of
 4652 indices in $\tilde{\mathbf{w}}$ and $\tilde{\mathbf{t}}$.

$$4653 \quad z_i = \tilde{\mathbf{w}}(i) \odot \tilde{\mathbf{t}}(i), \text{ if } i \in (\mathbf{ind}(\tilde{\mathbf{t}}) \cap \mathbf{ind}(\tilde{\mathbf{w}})),$$

$$4654 \quad z_i = \tilde{\mathbf{w}}(i), \text{ if } i \in (\mathbf{ind}(\tilde{\mathbf{w}}) - (\mathbf{ind}(\tilde{\mathbf{t}}) \cap \mathbf{ind}(\tilde{\mathbf{w}}))),$$

$$4655 \quad z_i = \tilde{\mathbf{t}}(i), \text{ if } i \in (\mathbf{ind}(\tilde{\mathbf{t}}) - (\mathbf{ind}(\tilde{\mathbf{t}}) \cap \mathbf{ind}(\tilde{\mathbf{w}}))),$$

4656 where $\odot = \odot(\text{accum})$, and the difference operator refers to set difference.

4659 Finally, the set of output values that make up vector $\tilde{\mathbf{z}}$ are written into the final result vector \mathbf{w} ,
 4660 using what is called a *standard vector mask and replace*. This is carried out under control of the
 4661 mask which acts as a “write mask”.

4662 • If `desc[GrB_OUTP].GrB_REPLACE` is set, then any values in \mathbf{w} on input to this operation are
 4663 deleted and the content of the new output vector, \mathbf{w} , is defined as,

$$4664 \quad \mathbf{L}(\mathbf{w}) = \{(i, z_i) : i \in (\mathbf{ind}(\tilde{\mathbf{z}}) \cap \mathbf{ind}(\tilde{\mathbf{m}}))\}.$$

4665 • If `desc[GrB_OUTP].GrB_REPLACE` is not set, the elements of $\tilde{\mathbf{z}}$ indicated by the mask are
 4666 copied into the result vector, \mathbf{w} , and elements of \mathbf{w} that fall outside the set indicated by the
 4667 mask are unchanged:

$$4668 \quad \mathbf{L}(\mathbf{w}) = \{(i, w_i) : i \in (\mathbf{ind}(\mathbf{w}) \cap \mathbf{ind}(\neg\tilde{\mathbf{m}}))\} \cup \{(i, z_i) : i \in (\mathbf{ind}(\tilde{\mathbf{z}}) \cap \mathbf{ind}(\tilde{\mathbf{m}}))\}.$$

4669 In `GrB_BLOCKING` mode, the method exits with return value `GrB_SUCCESS` and the new content
 4670 of vector \mathbf{w} is as defined above and fully computed. In `GrB_NONBLOCKING` mode, the method
 4671 exits with return value `GrB_SUCCESS` and the new content of vector \mathbf{w} is as defined above but
 4672 may not be fully computed. However, it can be used in the next GraphBLAS method call in a
 4673 sequence.

4674 4.3.7.2 `assign`: Standard matrix variant

4675 Assign values from one GraphBLAS matrix to a subset of a matrix as specified by a set of indices.
 4676 The dimensions of the input matrix are the same size as the row and column index arrays provided.

4677 C Syntax

```
4678     GrB_Info GrB_assign(GrB_Matrix      C,
4679                       const GrB_Matrix Mask,
4680                       const GrB_BinaryOp accum,
4681                       const GrB_Matrix A,
```

```

4682         const GrB_Index      *row_indices,
4683         GrB_Index            nrows,
4684         const GrB_Index      *col_indices,
4685         GrB_Index            ncols,
4686         const GrB_Descriptor desc);

```

4687 Parameters

4688 **C** (INOUT) An existing GraphBLAS matrix. On input, the matrix provides values
4689 that may be accumulated with the result of the assign operation. On output, the
4690 matrix holds the results of the operation.

4691 **Mask** (IN) An optional “write” mask that controls which results from this operation are
4692 stored into the output matrix **C**. The mask dimensions must match those of the
4693 matrix **C**. If the **GrB_STRUCTURE** descriptor is *not* set for the mask, the domain
4694 of the **Mask** matrix must be of type **bool** or any of the predefined “built-in” types
4695 in Table 3.2. If the default mask is desired (i.e., a mask that is all **true** with the
4696 dimensions of **C**), **GrB_NULL** should be specified.

4697 **accum** (IN) An optional binary operator used for accumulating entries into existing **C**
4698 entries. If assignment rather than accumulation is desired, **GrB_NULL** should be
4699 specified.

4700 **A** (IN) The GraphBLAS matrix whose contents are assigned to a subset of **C**.

4701 **row_indices** (IN) Pointer to the ordered set (array) of indices corresponding to the rows of **C**
4702 that are assigned. If all rows of **C** are to be assigned in order from 0 to **nrows** – 1,
4703 then **GrB_ALL** can be specified. Regardless of execution mode and return value,
4704 this array may be manipulated by the caller after this operation returns without
4705 affecting any deferred computations for this operation. If this array contains du-
4706 plicate values, it implies assignment of more than one value to the same location
4707 which leads to undefined results.

4708 **nrows** (IN) The number of values in the **row_indices** array. Must be equal to **nrows(A)**
4709 if **A** is not transposed, or equal to **ncols(A)** if **A** is transposed.

4710 **col_indices** (IN) Pointer to the ordered set (array) of indices corresponding to the columns
4711 of **C** that are assigned. If all columns of **C** are to be assigned in order from 0
4712 to **ncols** – 1, then **GrB_ALL** should be specified. Regardless of execution mode
4713 and return value, this array may be manipulated by the caller after this operation
4714 returns without affecting any deferred computations for this operation. If this
4715 array contains duplicate values, it implies assignment of more than one value to
4716 the same location which leads to undefined results.

4717 **ncols** (IN) The number of values in **col_indices** array. Must be equal to **ncols(A)** if **A** is
4718 not transposed, or equal to **nrows(A)** if **A** is transposed.

4719
4720
4721

desc (IN) An optional operation descriptor. If a *default* descriptor is desired, GrB_NULL should be specified. Non-default field/value pairs are listed as follows:

Param	Field	Value	Description
C	GrB_OUTP	GrB_REPLACE	Output matrix C is cleared (all elements removed) before the result is stored in it.
Mask	GrB_MASK	GrB_STRUCTURE	The write mask is constructed from the structure (pattern of stored values) of the input Mask matrix. The stored values are not examined.
Mask	GrB_MASK	GrB_COMP	Use the complement of Mask.
A	GrB_INP0	GrB_TRAN	Use transpose of A for the operation.

4722

4723 Return Values

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4726
4727
4728

GrB_SUCCESS In blocking mode, the operation completed successfully. In non-blocking mode, this indicates that the compatibility tests on dimensions and domains for the input arguments passed successfully. Either way, output matrix C is ready to be used in the next method of the sequence.

4729

GrB_PANIC Unknown internal error.

4730
4731
4732
4733

GrB_INVALID_OBJECT This is returned in any execution mode whenever one of the opaque GraphBLAS objects (input or output) is in an invalid state caused by a previous execution error. Call GrB_error() to access any error messages generated by the implementation.

4734

GrB_OUT_OF_MEMORY Not enough memory available for the operation.

4735
4736

GrB_UNINITIALIZED_OBJECT One or more of the GraphBLAS objects has not been initialized by a call to new (or Matrix_dup for matrix parameters).

4737
4738
4739

GrB_INDEX_OUT_OF_BOUNDS A value in row_indices is greater than or equal to nrows(C), or a value in col_indices is greater than or equal to ncols(C). In non-blocking mode, this can be reported as an execution error.

4740
4741

GrB_DIMENSION_MISMATCH Mask and C dimensions are incompatible, nrows \neq nrows(A), or ncols \neq ncols(A).

4742
4743
4744
4745

GrB_DOMAIN_MISMATCH The domains of the various matrices are incompatible with each other or the corresponding domains of the accumulation operator, or the mask's domain is not compatible with bool (in the case where desc[GrB_MASK].GrB_STRUCTURE is not set).

4746
4747

GrB_NULL_POINTER Either argument row_indices is a NULL pointer, argument col_indices is a NULL pointer, or both.

4748 **Description**

4749 This variant of `GrB_assign` computes the result of assigning the contents of `A` to a subset of rows
 4750 and columns in `C` in a specified order: $C(\text{row_indices}, \text{col_indices}) = A$; or, if an optional binary
 4751 accumulation operator (\odot) is provided, $C(\text{row_indices}, \text{col_indices}) = C(\text{row_indices}, \text{col_indices}) \odot$
 4752 `A`. More explicitly (not accounting for an optional transpose of `A`):

$$\begin{aligned} & C(\text{row_indices}[i], \text{col_indices}[j]) = A(i, j), \quad \forall i, j : 0 \leq i < \text{nrows}, 0 \leq j < \text{ncols}, \text{ or} \\ 4753 & C(\text{row_indices}[i], \text{col_indices}[j]) = C(\text{row_indices}[i], \text{col_indices}[j]) \odot A(i, j), \\ & \quad \forall (i, j) : 0 \leq i < \text{nrows}, 0 \leq j < \text{ncols} \end{aligned}$$

4754 Logically, this operation occurs in three steps:

4755 Setup The internal matrices and mask used in the computation are formed and their domains
 4756 and dimensions are tested for compatibility.

4757 Compute The indicated computations are carried out.

4758 Output The result is written into the output matrix, possibly under control of a mask.

4759 Up to three argument matrices are used in the `GrB_assign` operation:

- 4760 1. `C` = $\langle \mathbf{D}(C), \mathbf{nrows}(C), \mathbf{ncols}(C), \mathbf{L}(C) = \{(i, j, C_{ij})\} \rangle$
- 4761 2. `Mask` = $\langle \mathbf{D}(\text{Mask}), \mathbf{nrows}(\text{Mask}), \mathbf{ncols}(\text{Mask}), \mathbf{L}(\text{Mask}) = \{(i, j, M_{ij})\} \rangle$ (optional)
- 4762 3. `A` = $\langle \mathbf{D}(A), \mathbf{nrows}(A), \mathbf{ncols}(A), \mathbf{L}(A) = \{(i, j, A_{ij})\} \rangle$

4763 The argument matrices and the accumulation operator (if provided) are tested for domain compat-
 4764 ibility as follows:

- 4765 1. If `Mask` is not `GrB_NULL`, and `desc[GrB_MASK].GrB_STRUCTURE` is not set, then $\mathbf{D}(\text{Mask})$
 4766 must be from one of the pre-defined types of Table 3.2.
- 4767 2. $\mathbf{D}(C)$ must be compatible with $\mathbf{D}(A)$.
- 4768 3. If `accum` is not `GrB_NULL`, then $\mathbf{D}(C)$ must be compatible with $\mathbf{D}_{in_1}(\text{accum})$ and $\mathbf{D}_{out}(\text{accum})$
 4769 of the accumulation operator and $\mathbf{D}(A)$ must be compatible with $\mathbf{D}_{in_2}(\text{accum})$ of the accu-
 4770 mulation operator.

4771 Two domains are compatible with each other if values from one domain can be cast to values in
 4772 the other domain as per the rules of the C language. In particular, domains from Table 3.2 are all
 4773 compatible with each other. A domain from a user-defined type is only compatible with itself. If
 4774 any compatibility rule above is violated, execution of `GrB_assign` ends and the domain mismatch
 4775 error listed above is returned.

4776 From the arguments, the internal matrices, mask, and index arrays used in the computation are
 4777 formed (\leftarrow denotes copy):

- 4778 1. Matrix $\tilde{\mathbf{C}} \leftarrow \mathbf{C}$.
- 4779 2. Two-dimensional mask $\tilde{\mathbf{M}}$ is computed from argument `Mask` as follows:
- 4780 (a) If `Mask = GrB_NULL`, then $\tilde{\mathbf{M}} = \langle \mathbf{nrows}(\mathbf{C}), \mathbf{ncols}(\mathbf{C}), \{(i, j), \forall i, j : 0 \leq i < \mathbf{nrows}(\mathbf{C}), 0 \leq$
4781 $j < \mathbf{ncols}(\mathbf{C})\} \rangle$.
- 4782 (b) If `Mask \neq GrB_NULL`,
- 4783 i. If `desc[GrB_MASK].GrB_STRUCTURE` is set, then $\tilde{\mathbf{M}} = \langle \mathbf{nrows}(\mathbf{Mask}), \mathbf{ncols}(\mathbf{Mask}), \{(i, j) :$
4784 $(i, j) \in \mathbf{ind}(\mathbf{Mask})\} \rangle$,
- 4785 ii. Otherwise, $\tilde{\mathbf{M}} = \langle \mathbf{nrows}(\mathbf{Mask}), \mathbf{ncols}(\mathbf{Mask}),$
4786 $\{(i, j) : (i, j) \in \mathbf{ind}(\mathbf{Mask}) \wedge (\mathbf{bool})\mathbf{Mask}(i, j) = \mathbf{true}\} \rangle$.
- 4787 (c) If `desc[GrB_MASK].GrB_COMP` is set, then $\tilde{\mathbf{M}} \leftarrow \neg \tilde{\mathbf{M}}$.
- 4788 3. Matrix $\tilde{\mathbf{A}} \leftarrow \mathbf{desc}[\mathbf{GrB_INP0}].\mathbf{GrB_TRAN} ? \mathbf{A}^T : \mathbf{A}$.
- 4789 4. The internal row index array, $\tilde{\mathbf{I}}$, is computed from argument `row_indices` as follows:
- 4790 (a) If `row_indices = GrB_ALL`, then $\tilde{\mathbf{I}}[i] = i, \forall i : 0 \leq i < \mathbf{nrows}$.
- 4791 (b) Otherwise, $\tilde{\mathbf{I}}[i] = \mathbf{row_indices}[i], \forall i : 0 \leq i < \mathbf{nrows}$.
- 4792 5. The internal column index array, $\tilde{\mathbf{J}}$, is computed from argument `col_indices` as follows:
- 4793 (a) If `col_indices = GrB_ALL`, then $\tilde{\mathbf{J}}[j] = j, \forall j : 0 \leq j < \mathbf{ncols}$.
- 4794 (b) Otherwise, $\tilde{\mathbf{J}}[j] = \mathbf{col_indices}[j], \forall j : 0 \leq j < \mathbf{ncols}$.

4795 The internal matrices and mask are checked for dimension compatibility. The following conditions
4796 must hold:

- 4797 1. $\mathbf{nrows}(\tilde{\mathbf{C}}) = \mathbf{nrows}(\tilde{\mathbf{M}})$.
- 4798 2. $\mathbf{ncols}(\tilde{\mathbf{C}}) = \mathbf{ncols}(\tilde{\mathbf{M}})$.
- 4799 3. $\mathbf{nrows}(\tilde{\mathbf{A}}) = \mathbf{nrows}$.
- 4800 4. $\mathbf{ncols}(\tilde{\mathbf{A}}) = \mathbf{ncols}$.

4801 If any compatibility rule above is violated, execution of `GrB_assign` ends and the dimension mis-
4802 match error listed above is returned.

4803 From this point forward, in `GrB_NONBLOCKING` mode, the method can optionally exit with
4804 `GrB_SUCCESS` return code and defer any computation and/or execution error codes.

4805 We are now ready to carry out the assign and any additional associated operations. We describe
4806 this in terms of two intermediate vectors:

- 4807 • $\tilde{\mathbf{T}}$: The matrix holding the contents from $\tilde{\mathbf{A}}$ in their destination locations relative to $\tilde{\mathbf{C}}$.
- 4808 • $\tilde{\mathbf{Z}}$: The matrix holding the result after application of the (optional) accumulation operator.

4809 The intermediate matrix, $\tilde{\mathbf{T}}$, is created as follows:

$$4810 \quad \tilde{\mathbf{T}} = \langle \mathbf{D}(\mathbf{A}), \mathbf{nrows}(\tilde{\mathbf{C}}), \mathbf{ncols}(\tilde{\mathbf{C}}), \\ \{(\tilde{\mathbf{I}}[i], \tilde{\mathbf{J}}[j], \tilde{\mathbf{A}}(i, j)) \forall (i, j), 0 \leq i < \mathbf{nrows}, 0 \leq j < \mathbf{ncols} : (i, j) \in \mathbf{ind}(\tilde{\mathbf{A}})\} \rangle.$$

4811 At this point, if any value in the $\tilde{\mathbf{I}}$ array is not in the range $[0, \mathbf{nrows}(\tilde{\mathbf{C}}))$ or any value in the
 4812 $\tilde{\mathbf{J}}$ array is not in the range $[0, \mathbf{ncols}(\tilde{\mathbf{C}}))$, the execution of `GrB_assign` ends and the index out-of-
 4813 bounds error listed above is generated. In `GrB_NONBLOCKING` mode, the error can be deferred
 4814 until a sequence-terminating `GrB_wait()` is called. Regardless, the result matrix \mathbf{C} is invalid from
 4815 this point forward in the sequence.

4816 The intermediate matrix $\tilde{\mathbf{Z}}$ is created as follows:

- 4817 • If `accum = GrB_NULL`, then $\tilde{\mathbf{Z}}$ is defined as

$$4818 \quad \tilde{\mathbf{Z}} = \langle \mathbf{D}(\mathbf{C}), \mathbf{nrows}(\tilde{\mathbf{C}}), \mathbf{ncols}(\tilde{\mathbf{C}}), \\ 4819 \quad \{(i, j, Z_{ij}) \forall (i, j) \in (\mathbf{ind}(\tilde{\mathbf{C}}) - (\{(\tilde{\mathbf{I}}[k], \tilde{\mathbf{J}}[l]), \forall k, l\} \cap \mathbf{ind}(\tilde{\mathbf{C}}))) \cup \mathbf{ind}(\tilde{\mathbf{T}})\} \rangle.$$

4820 The above expression defines the structure of matrix $\tilde{\mathbf{Z}}$ as follows: We start with the structure
 4821 of $\tilde{\mathbf{C}}$ ($\mathbf{ind}(\tilde{\mathbf{C}})$) and remove from it all the indices of $\tilde{\mathbf{C}}$ that are in the set of indices being
 4822 assigned ($\{(\tilde{\mathbf{I}}[k], \tilde{\mathbf{J}}[l]), \forall k, l\} \cap \mathbf{ind}(\tilde{\mathbf{C}})$). Finally, we add the structure of $\tilde{\mathbf{T}}$ ($\mathbf{ind}(\tilde{\mathbf{T}})$).

4823 The values of the elements of $\tilde{\mathbf{Z}}$ are computed based on the relationships between the sets of
 4824 indices in $\tilde{\mathbf{C}}$ and $\tilde{\mathbf{T}}$.

$$4825 \quad Z_{ij} = \tilde{\mathbf{C}}(i, j), \text{ if } (i, j) \in (\mathbf{ind}(\tilde{\mathbf{C}}) - (\{(\tilde{\mathbf{I}}[k], \tilde{\mathbf{J}}[l]), \forall k, l\} \cap \mathbf{ind}(\tilde{\mathbf{C}}))), \\ 4826 \\ 4827 \quad Z_{ij} = \tilde{\mathbf{T}}(i, j), \text{ if } (i, j) \in \mathbf{ind}(\tilde{\mathbf{T}}),$$

4828 where the difference operator refers to set difference.

- 4829 • If `accum` is a binary operator, then $\tilde{\mathbf{Z}}$ is defined as

$$4830 \quad \langle \mathbf{D}_{out}(\mathbf{accum}), \mathbf{nrows}(\tilde{\mathbf{C}}), \mathbf{ncols}(\tilde{\mathbf{C}}), \{(i, j, Z_{ij}) \forall (i, j) \in \mathbf{ind}(\tilde{\mathbf{C}}) \cup \mathbf{ind}(\tilde{\mathbf{T}})\} \rangle.$$

4831 The values of the elements of $\tilde{\mathbf{Z}}$ are computed based on the relationships between the sets of
 4832 indices in $\tilde{\mathbf{C}}$ and $\tilde{\mathbf{T}}$.

$$4833 \quad Z_{ij} = \tilde{\mathbf{C}}(i, j) \odot \tilde{\mathbf{T}}(i, j), \text{ if } (i, j) \in (\mathbf{ind}(\tilde{\mathbf{T}}) \cap \mathbf{ind}(\tilde{\mathbf{C}})), \\ 4834 \\ 4835 \quad Z_{ij} = \tilde{\mathbf{C}}(i, j), \text{ if } (i, j) \in (\mathbf{ind}(\tilde{\mathbf{C}}) - (\mathbf{ind}(\tilde{\mathbf{T}}) \cap \mathbf{ind}(\tilde{\mathbf{C}}))), \\ 4836 \\ 4837 \quad Z_{ij} = \tilde{\mathbf{T}}(i, j), \text{ if } (i, j) \in (\mathbf{ind}(\tilde{\mathbf{T}}) - (\mathbf{ind}(\tilde{\mathbf{T}}) \cap \mathbf{ind}(\tilde{\mathbf{C}}))),$$

4838 where $\odot = \odot(\mathbf{accum})$, and the difference operator refers to set difference.

4839 Finally, the set of output values that make up matrix $\tilde{\mathbf{Z}}$ are written into the final result matrix \mathbf{C} ,
 4840 using what is called a *standard matrix mask and replace*. This is carried out under control of the
 4841 mask which acts as a “write mask”.

- If desc[GrB_OUTP].GrB_REPLACE is set, then any values in C on input to this operation are deleted and the content of the new output matrix, C, is defined as,

$$\mathbf{L}(\mathbf{C}) = \{(i, j, Z_{ij}) : (i, j) \in (\mathbf{ind}(\tilde{\mathbf{Z}}) \cap \mathbf{ind}(\tilde{\mathbf{M}}))\}.$$

- If desc[GrB_OUTP].GrB_REPLACE is not set, the elements of $\tilde{\mathbf{Z}}$ indicated by the mask are copied into the result matrix, C, and elements of C that fall outside the set indicated by the mask are unchanged:

$$\mathbf{L}(\mathbf{C}) = \{(i, j, C_{ij}) : (i, j) \in (\mathbf{ind}(\mathbf{C}) \cap \mathbf{ind}(\neg\tilde{\mathbf{M}}))\} \cup \{(i, j, Z_{ij}) : (i, j) \in (\mathbf{ind}(\tilde{\mathbf{Z}}) \cap \mathbf{ind}(\tilde{\mathbf{M}}))\}.$$

In GrB_BLOCKING mode, the method exits with return value GrB_SUCCESS and the new content of matrix C is as defined above and fully computed. In GrB_NONBLOCKING mode, the method exits with return value GrB_SUCCESS and the new content of matrix C is as defined above but may not be fully computed. However, it can be used in the next GraphBLAS method call in a sequence.

4.3.7.3 assign: Column variant

Assign the contents a vector to a subset of elements in one column of a matrix. Note that since the output cannot be transposed, a different variant of assign is provided to assign to a row of a matrix.

C Syntax

```
GrB_Info GrB_assign(GrB_Matrix      C,
                   const GrB_Vector  mask,
                   const GrB_BinaryOp accum,
                   const GrB_Vector  u,
                   const GrB_Index   *row_indices,
                   GrB_Index         nrows,
                   GrB_Index         col_index,
                   const GrB_Descriptor desc);
```

Parameters

C (INOUT) An existing GraphBLAS matrix. On input, the matrix provides values that may be accumulated with the result of the assign operation. On output, this matrix holds the results of the operation.

mask (IN) An optional “write” mask that controls which results from this operation are stored into the specified column of the output matrix C. The mask dimensions must match those of a single column of the matrix C. If the GrB_STRUCTURE descriptor is *not* set for the mask, the domain of the Mask matrix must be of type

4875 bool or any of the predefined “built-in” types in Table 3.2. If the default mask
 4876 is desired (i.e., a mask that is all true with the dimensions of a column of C),
 4877 GrB_NULL should be specified.

4878 **accum** (IN) An optional binary operator used for accumulating entries into existing C
 4879 entries. If assignment rather than accumulation is desired, GrB_NULL should be
 4880 specified.

4881 **u** (IN) The GraphBLAS vector whose contents are assigned to (a subset of) a column
 4882 of C.

4883 **row_indices** (IN) Pointer to the ordered set (array) of indices corresponding to the locations in
 4884 the specified column of C that are to be assigned. If all elements of the column
 4885 in C are to be assigned in order from index 0 to `nrows - 1`, then GrB_ALL should
 4886 be specified. Regardless of execution mode and return value, this array may be
 4887 manipulated by the caller after this operation returns without affecting any de-
 4888 ferred computations for this operation. If this array contains duplicate values, it
 4889 implies in assignment of more than one value to the same location which leads to
 4890 undefined results.

4891 **nrows** (IN) The number of values in `row_indices` array. Must be equal to `size(u)`.

4892 **col_index** (IN) The index of the column in C to assign. Must be in the range `[0, ncols(C))`.

4893 **desc** (IN) An optional operation descriptor. If a *default* descriptor is desired, GrB_NULL
 4894 should be specified. Non-default field/value pairs are listed as follows:

4895

Param	Field	Value	Description
C	GrB_OUTP	GrB_REPLACE	Output column in C is cleared (all elements removed) before result is stored in it.
mask	GrB_MASK	GrB_STRUCTURE	The write mask is constructed from the structure (pattern of stored values) of the input <code>mask</code> vector. The stored values are not examined.
mask	GrB_MASK	GrB_COMP	Use the complement of mask.

4897 **Return Values**

4898 GrB_SUCCESS In blocking mode, the operation completed successfully. In non-
 4899 blocking mode, this indicates that the compatibility tests on
 4900 dimensions and domains for the input arguments passed suc-
 4901 cessfully. Either way, output matrix C is ready to be used in the
 4902 next method of the sequence.

4903 GrB_PANIC Unknown internal error.

4904 GrB_INVALID_OBJECT This is returned in any execution mode whenever one of the
4905 opaque GraphBLAS objects (input or output) is in an invalid
4906 state caused by a previous execution error. Call GrB_error() to
4907 access any error messages generated by the implementation.

4908 GrB_OUT_OF_MEMORY Not enough memory available for operation.

4909 GrB_UNINITIALIZED_OBJECT One or more of the GraphBLAS objects has not been initialized
4910 by a call to new (or dup for vector or matrix parameters).

4911 GrB_INVALID_INDEX col_index is outside the allowable range (i.e., greater than ncols(C)).

4912 GrB_INDEX_OUT_OF_BOUNDS A value in row_indices is greater than or equal to nrows(C). In
4913 non-blocking mode, this can be reported as an execution error.

4914 GrB_DIMENSION_MISMATCH mask size and number of rows in C are not the same, or nrows \neq
4915 size(u).

4916 GrB_DOMAIN_MISMATCH The domains of the matrix and vector are incompatible with
4917 each other or the corresponding domains of the accumulation
4918 operator, or the mask's domain is not compatible with bool (in
4919 the case where desc[GrB_MASK].GrB_STRUCTURE is not set).

4920 GrB_NULL_POINTER Argument row_indices is a NULL pointer.

4921 Description

4922 This variant of GrB_assign computes the result of assigning a subset of locations in a column of a
4923 GraphBLAS matrix (in a specific order) from the contents of a GraphBLAS vector:
4924 $C(:, \text{col_index}) = u$; or, if an optional binary accumulation operator (\odot) is provided, $C(:, \text{col_index}) =$
4925 $C(:, \text{col_index}) \odot u$. Taking order of row_indices into account, it is more explicitly written as:

$$4926 \quad C(\text{row_indices}[i], \text{col_index}) = u(i), \forall i : 0 \leq i < \text{nrows}, \text{ or}$$

$$C(\text{row_indices}[i], \text{col_index}) = C(\text{row_indices}[i], \text{col_index}) \odot u(i), \forall i : 0 \leq i < \text{nrows}.$$

4927 Logically, this operation occurs in three steps:

4928 **Setup** The internal matrices, vectors and mask used in the computation are formed and their
4929 domains and dimensions are tested for compatibility.

4930 **Compute** The indicated computations are carried out.

4931 **Output** The result is written into the output matrix, possibly under control of a mask.

4932 Up to three argument vectors and matrices are used in this GrB_assign operation:

- 4933 1. $C = \langle \mathbf{D}(C), \text{nrows}(C), \text{ncols}(C), \mathbf{L}(C) = \{(i, j, C_{ij})\} \rangle$
- 4934 2. $\text{mask} = \langle \mathbf{D}(\text{mask}), \text{size}(\text{mask}), \mathbf{L}(\text{mask}) = \{(i, m_i)\} \rangle$ (optional)

4935 3. $\mathbf{u} = \langle \mathbf{D}(\mathbf{u}), \mathbf{size}(\mathbf{u}), \mathbf{L}(\mathbf{u}) = \{(i, u_i)\} \rangle$

4936 The argument vectors, matrix, and the accumulation operator (if provided) are tested for domain
4937 compatibility as follows:

4938 1. If `mask` is not `GrB_NULL`, and `desc[GrB_MASK].GrB_STRUCTURE` is not set, then $\mathbf{D}(\text{mask})$
4939 must be from one of the pre-defined types of Table 3.2.

4940 2. $\mathbf{D}(\mathbf{C})$ must be compatible with $\mathbf{D}(\mathbf{u})$.

4941 3. If `accum` is not `GrB_NULL`, then $\mathbf{D}(\mathbf{C})$ must be compatible with $\mathbf{D}_{in_1}(\text{accum})$ and $\mathbf{D}_{out}(\text{accum})$
4942 of the accumulation operator and $\mathbf{D}(\mathbf{u})$ must be compatible with $\mathbf{D}_{in_2}(\text{accum})$ of the accu-
4943 mulation operator.

4944 Two domains are compatible with each other if values from one domain can be cast to values in
4945 the other domain as per the rules of the C language. In particular, domains from Table 3.2 are all
4946 compatible with each other. A domain from a user-defined type is only compatible with itself. If
4947 any compatibility rule above is violated, execution of `GrB_assign` ends and the domain mismatch
4948 error listed above is returned.

4949 The `col_index` parameter is checked for a valid value. The following condition must hold:

4950 1. $0 \leq \text{col_index} < \mathbf{ncols}(\mathbf{C})$

4951 If the rule above is violated, execution of `GrB_assign` ends and the invalid index error listed above
4952 is returned.

4953 From the arguments, the internal vectors, `mask`, and index array used in the computation are
4954 formed (\leftarrow denotes copy):

4955 1. The vector, $\tilde{\mathbf{c}}$, is extracted from a column of \mathbf{C} as follows:

4956
$$\tilde{\mathbf{c}} = \langle \mathbf{D}(\mathbf{C}), \mathbf{nrows}(\mathbf{C}), \{(i, C_{ij}) \mid \forall i : 0 \leq i < \mathbf{nrows}(\mathbf{C}), j = \text{col_index}, (i, j) \in \mathbf{ind}(\mathbf{C})\} \rangle$$

4957 2. One-dimensional mask, $\tilde{\mathbf{m}}$, is computed from argument `mask` as follows:

4958 (a) If `mask` = `GrB_NULL`, then $\tilde{\mathbf{m}} = \langle \mathbf{nrows}(\mathbf{C}), \{i, \forall i : 0 \leq i < \mathbf{nrows}(\mathbf{C})\} \rangle$.

4959 (b) If `mask` \neq `GrB_NULL`,

4960 i. If `desc[GrB_MASK].GrB_STRUCTURE` is set, then $\tilde{\mathbf{m}} = \langle \mathbf{size}(\text{mask}), \{i : i \in \mathbf{ind}(\text{mask})\} \rangle$,

4961 ii. Otherwise, $\tilde{\mathbf{m}} = \langle \mathbf{size}(\text{mask}), \{i : i \in \mathbf{ind}(\text{mask}) \wedge (\text{bool})\text{mask}(i) = \text{true}\} \rangle$.

4962 (c) If `desc[GrB_MASK].GrB_COMP` is set, then $\tilde{\mathbf{m}} \leftarrow \neg \tilde{\mathbf{m}}$.

4963 3. Vector $\tilde{\mathbf{u}} \leftarrow \mathbf{u}$.

4964 4. The internal row index array, $\tilde{\mathbf{I}}$, is computed from argument `row_indices` as follows:

4965 (a) If `row_indices` = `GrB_ALL`, then $\tilde{\mathbf{I}}[i] = i, \forall i : 0 \leq i < \mathbf{nrows}$.

4966 (b) Otherwise, $\tilde{\mathbf{I}}[i] = \text{row_indices}[i]$, $\forall i : 0 \leq i < \text{nrows}$.

4967 The internal vectors, matrices, and masks are checked for dimension compatibility. The following
4968 conditions must hold:

- 4969 1. $\text{size}(\tilde{\mathbf{c}}) = \text{size}(\tilde{\mathbf{m}})$
- 4970 2. $\text{nrows} = \text{size}(\tilde{\mathbf{u}})$.

4971 If any compatibility rule above is violated, execution of `GrB_assign` ends and the dimension mis-
4972 match error listed above is returned.

4973 From this point forward, in `GrB_NONBLOCKING` mode, the method can optionally exit with
4974 `GrB_SUCCESS` return code and defer any computation and/or execution error codes.

4975 We are now ready to carry out the assign and any additional associated operations. We describe
4976 this in terms of two intermediate vectors:

- 4977 • $\tilde{\mathbf{t}}$: The vector holding the elements from $\tilde{\mathbf{u}}$ in their destination locations relative to $\tilde{\mathbf{c}}$.
- 4978 • $\tilde{\mathbf{z}}$: The vector holding the result after application of the (optional) accumulation operator.

4979 The intermediate vector, $\tilde{\mathbf{t}}$, is created as follows:

$$4980 \quad \tilde{\mathbf{t}} = \langle \mathbf{D}(\mathbf{u}), \text{size}(\tilde{\mathbf{c}}), \{(\tilde{\mathbf{I}}[i], \tilde{\mathbf{u}}(i)) \mid \forall i, 0 \leq i < \text{nrows} : i \in \text{ind}(\tilde{\mathbf{u}})\} \rangle.$$

4981 At this point, if any value of $\tilde{\mathbf{I}}[i]$ is outside the valid range of indices for vector $\tilde{\mathbf{c}}$, computation
4982 ends and the method returns the index out-of-bounds error listed above. In `GrB_NONBLOCKING`
4983 mode, the error can be deferred until a sequence-terminating `GrB_wait()` is called. Regardless, the
4984 result matrix, \mathbf{C} , is invalid from this point forward in the sequence.

4985 The intermediate vector $\tilde{\mathbf{z}}$ is created as follows:

- 4986 • If `accum = GrB_NULL`, then $\tilde{\mathbf{z}}$ is defined as

$$4987 \quad \tilde{\mathbf{z}} = \langle \mathbf{D}(\mathbf{C}), \text{size}(\tilde{\mathbf{c}}), \{(i, z_i), \forall i \in (\text{ind}(\tilde{\mathbf{c}}) - (\{\tilde{\mathbf{I}}[k], \forall k\} \cap \text{ind}(\tilde{\mathbf{c}}))) \cup \text{ind}(\tilde{\mathbf{t}})\} \rangle.$$

4988 The above expression defines the structure of vector $\tilde{\mathbf{z}}$ as follows: We start with the structure
4989 of $\tilde{\mathbf{c}}$ ($\text{ind}(\tilde{\mathbf{c}})$) and remove from it all the indices of $\tilde{\mathbf{c}}$ that are in the set of indices being
4990 assigned ($\{\tilde{\mathbf{I}}[k], \forall k\} \cap \text{ind}(\tilde{\mathbf{c}})$). Finally, we add the structure of $\tilde{\mathbf{t}}$ ($\text{ind}(\tilde{\mathbf{t}})$).

4991 The values of the elements of $\tilde{\mathbf{z}}$ are computed based on the relationships between the sets of
4992 indices in $\tilde{\mathbf{c}}$ and $\tilde{\mathbf{t}}$.

$$4993 \quad z_i = \tilde{\mathbf{c}}(i), \text{ if } i \in (\text{ind}(\tilde{\mathbf{c}}) - (\{\tilde{\mathbf{I}}[k], \forall k\} \cap \text{ind}(\tilde{\mathbf{c}}))),$$

$$4994 \quad z_i = \tilde{\mathbf{t}}(i), \text{ if } i \in \text{ind}(\tilde{\mathbf{t}}),$$

4996 where the difference operator refers to set difference.

4997 • If `accum` is a binary operator, then $\tilde{\mathbf{z}}$ is defined as

$$4998 \quad \langle \mathbf{D}_{out}(\text{accum}), \text{size}(\tilde{\mathbf{c}}), \{(i, z_i) \mid i \in \mathbf{ind}(\tilde{\mathbf{c}}) \cup \mathbf{ind}(\tilde{\mathbf{t}})\} \rangle.$$

4999 The values of the elements of $\tilde{\mathbf{z}}$ are computed based on the relationships between the sets of
5000 indices in $\tilde{\mathbf{w}}$ and $\tilde{\mathbf{t}}$.

$$5001 \quad z_i = \tilde{\mathbf{c}}(i) \odot \tilde{\mathbf{t}}(i), \text{ if } i \in (\mathbf{ind}(\tilde{\mathbf{t}}) \cap \mathbf{ind}(\tilde{\mathbf{c}})),$$

$$5002 \quad z_i = \tilde{\mathbf{c}}(i), \text{ if } i \in (\mathbf{ind}(\tilde{\mathbf{c}}) - (\mathbf{ind}(\tilde{\mathbf{t}}) \cap \mathbf{ind}(\tilde{\mathbf{c}}))),$$

$$5003 \quad z_i = \tilde{\mathbf{t}}(i), \text{ if } i \in (\mathbf{ind}(\tilde{\mathbf{t}}) - (\mathbf{ind}(\tilde{\mathbf{t}}) \cap \mathbf{ind}(\tilde{\mathbf{c}}))),$$

5006 where $\odot = \odot(\text{accum})$, and the difference operator refers to set difference.

5007 Finally, the set of output values that make up the $\tilde{\mathbf{z}}$ vector are written into the column of the final
5008 result matrix, $\mathbf{C}(:, \text{col_index})$. This is carried out under control of the mask which acts as a “write
5009 mask”.

5010 • If `desc[GrB_OUTP].GrB_REPLACE` is set, then any values in $\mathbf{C}(:, \text{col_index})$ on input to this
5011 operation are deleted and the new contents of the column is given by:

$$5012 \quad \mathbf{L}(\mathbf{C}) = \{(i, j, C_{ij}) : j \neq \text{col_index}\} \cup \{(i, \text{col_index}, z_i) : i \in (\mathbf{ind}(\tilde{\mathbf{z}}) \cap \mathbf{ind}(\tilde{\mathbf{m}}))\}.$$

5013 • If `desc[GrB_OUTP].GrB_REPLACE` is not set, the elements of $\tilde{\mathbf{z}}$ indicated by the mask are
5014 copied into the column of the final result matrix, $\mathbf{C}(:, \text{col_index})$, and elements of this column
5015 that fall outside the set indicated by the mask are unchanged:

$$5016 \quad \mathbf{L}(\mathbf{C}) = \{(i, j, C_{ij}) : j \neq \text{col_index}\} \cup$$

$$5017 \quad \{(i, \text{col_index}, \tilde{\mathbf{c}}(i)) : i \in (\mathbf{ind}(\tilde{\mathbf{c}}) \cap \mathbf{ind}(\neg \tilde{\mathbf{m}}))\} \cup$$

$$5018 \quad \{(i, \text{col_index}, z_i) : i \in (\mathbf{ind}(\tilde{\mathbf{z}}) \cap \mathbf{ind}(\tilde{\mathbf{m}}))\}.$$

5019 In `GrB_BLOCKING` mode, the method exits with return value `GrB_SUCCESS` and the new content
5020 of vector \mathbf{w} is as defined above and fully computed. In `GrB_NONBLOCKING` mode, the method
5021 exits with return value `GrB_SUCCESS` and the new content of vector \mathbf{w} is as defined above but may
5022 not be fully computed; however, it can be used in the next GraphBLAS method call in a sequence.

5023 4.3.7.4 `assign`: Row variant

5024 Assign the contents a vector to a subset of elements in one row of a matrix. Note that since the
5025 output cannot be transposed, a different variant of `assign` is provided to assign to a column of a
5026 matrix.

5027 C Syntax

```
5028         GrB_Info GrB_assign(GrB_Matrix      C,  
5029                             const GrB_Vector  mask,  
5030                             const GrB_BinaryOp accum,  
5031                             const GrB_Vector  u,  
5032                             GrB_Index       row_index,  
5033                             const GrB_Index  *col_indices,  
5034                             GrB_Index       ncols,  
5035                             const GrB_Descriptor desc);
```

5036 Parameters

5037 **C** (INOUT) An existing GraphBLAS Matrix. On input, the matrix provides values
5038 that may be accumulated with the result of the assign operation. On output, this
5039 matrix holds the results of the operation.

5040 **mask** (IN) An optional “write” mask that controls which results from this operation are
5041 stored into the specified row of the output matrix **C**. The mask dimensions must
5042 match those of a single row of the matrix **C**. If the **GrB_STRUCTURE** descriptor
5043 is *not* set for the mask, the domain of the **Mask** matrix must be of type **bool** or
5044 any of the predefined “built-in” types in Table 3.2. If the default mask is desired
5045 (i.e., a mask that is all **true** with the dimensions of a row of **C**), **GrB_NULL** should
5046 be specified.

5047 **accum** (IN) An optional binary operator used for accumulating entries into existing **C**
5048 entries. If assignment rather than accumulation is desired, **GrB_NULL** should be
5049 specified.

5050 **u** (IN) The GraphBLAS vector whose contents are assigned to (a subset of) a row of
5051 **C**.

5052 **row_index** (IN) The index of the row in **C** to assign. Must be in the range $[0, \mathbf{nrows}(\mathbf{C})]$.

5053 **col_indices** (IN) Pointer to the ordered set (array) of indices corresponding to the locations in
5054 the specified row of **C** that are to be assigned. If all elements of the row in **C** are to
5055 be assigned in order from index 0 to $\mathbf{ncols} - 1$, then **GrB_ALL** should be specified.
5056 Regardless of execution mode and return value, this array may be manipulated by
5057 the caller after this operation returns without affecting any deferred computations
5058 for this operation. If this array contains duplicate values, it implies in assignment
5059 of more than one value to the same location which leads to undefined results.

5060 **ncols** (IN) The number of values in **col_indices** array. Must be equal to **size(u)**.

5061 **desc** (IN) An optional operation descriptor. If a *default* descriptor is desired, **GrB_NULL**
5062 should be specified. Non-default field/value pairs are listed as follows:
5063

Param	Field	Value	Description
C	GrB_OUTP	GrB_REPLACE	Output row in C is cleared (all elements removed) before result is stored in it.
mask	GrB_MASK	GrB_STRUCTURE	The write mask is constructed from the structure (pattern of stored values) of the input <code>mask</code> vector. The stored values are not examined.
mask	GrB_MASK	GrB_COMP	Use the complement of <code>mask</code> .

5064

5065 Return Values

5066

`GrB_SUCCESS` In blocking mode, the operation completed successfully. In non-blocking mode, this indicates that the compatibility tests on dimensions and domains for the input arguments passed successfully. Either way, output matrix C is ready to be used in the next method of the sequence.

5067

5068

5069

5070

5071

`GrB_PANIC` Unknown internal error.

5072

`GrB_INVALID_OBJECT` This is returned in any execution mode whenever one of the opaque GraphBLAS objects (input or output) is in an invalid state caused by a previous execution error. Call `GrB_error()` to access any error messages generated by the implementation.

5073

5074

5075

5076

`GrB_OUT_OF_MEMORY` Not enough memory available for operation.

5077

`GrB_UNINITIALIZED_OBJECT` One or more of the GraphBLAS objects has not been initialized by a call to `new` (or `dup` for vector or matrix parameters).

5078

5079

`GrB_INVALID_INDEX` `row_index` is outside the allowable range (i.e., greater than `nrows(C)`).

5080

`GrB_INDEX_OUT_OF_BOUNDS` A value in `col_indices` is greater than or equal to `ncols(C)`. In non-blocking mode, this can be reported as an execution error.

5081

5082

`GrB_DIMENSION_MISMATCH` `mask` size and number of columns in C are not the same, or `ncols` \neq `size(u)`.

5083

5084

`GrB_DOMAIN_MISMATCH` The domains of the matrix and vector are incompatible with each other or the corresponding domains of the accumulation operator, or the mask's domain is not compatible with `bool` (in the case where `desc[GrB_MASK].GrB_STRUCTURE` is not set).

5085

5086

5087

5088

`GrB_NULL_POINTER` Argument `col_indices` is a NULL pointer.

5089 Description

5090

This variant of `GrB_assign` computes the result of assigning a subset of locations in a row of a GraphBLAS matrix (in a specific order) from the contents of a GraphBLAS vector:

5091

5092 $C(\text{row_index}, :) = u$; or, if an optional binary accumulation operator (\odot) is provided, $C(\text{row_index}, :$
5093 $) = C(\text{row_index}, :) \odot u$. Taking order of `col_indices` into account it is more explicitly written as:

$$5094 \quad C(\text{row_index}, \text{col_indices}[j]) = u(j), \forall j : 0 \leq j < \text{ncols}, \text{ or}$$

$$C(\text{row_index}, \text{col_indices}[j]) = C(\text{row_index}, \text{col_indices}[j]) \odot u(j), \forall j : 0 \leq j < \text{ncols}$$

5095 Logically, this operation occurs in three steps:

5096 **Setup** The internal matrices, vectors and mask used in the computation are formed and their
5097 domains and dimensions are tested for compatibility.

5098 **Compute** The indicated computations are carried out.

5099 **Output** The result is written into the output matrix, possibly under control of a mask.

5100 Up to three argument vectors and matrices are used in this `GrB_assign` operation:

- 5101 1. $C = \langle \mathbf{D}(C), \mathbf{nrows}(C), \mathbf{ncols}(C), \mathbf{L}(C) = \{(i, j, C_{ij})\} \rangle$
- 5102 2. $\text{mask} = \langle \mathbf{D}(\text{mask}), \mathbf{size}(\text{mask}), \mathbf{L}(\text{mask}) = \{(i, m_i)\} \rangle$ (optional)
- 5103 3. $u = \langle \mathbf{D}(u), \mathbf{size}(u), \mathbf{L}(u) = \{(i, u_i)\} \rangle$

5104 The argument vectors, matrix, and the accumulation operator (if provided) are tested for domain
5105 compatibility as follows:

- 5106 1. If `mask` is not `GrB_NULL`, and `desc[GrB_MASK].GrB_STRUCTURE` is not set, then $\mathbf{D}(\text{mask})$
5107 must be from one of the pre-defined types of Table 3.2.
- 5108 2. $\mathbf{D}(C)$ must be compatible with $\mathbf{D}(u)$.
- 5109 3. If `accum` is not `GrB_NULL`, then $\mathbf{D}(C)$ must be compatible with $\mathbf{D}_{in_1}(\text{accum})$ and $\mathbf{D}_{out}(\text{accum})$
5110 of the accumulation operator and $\mathbf{D}(u)$ must be compatible with $\mathbf{D}_{in_2}(\text{accum})$ of the accu-
5111 mulation operator.

5112 Two domains are compatible with each other if values from one domain can be cast to values in
5113 the other domain as per the rules of the C language. In particular, domains from Table 3.2 are all
5114 compatible with each other. A domain from a user-defined type is only compatible with itself. If
5115 any compatibility rule above is violated, execution of `GrB_assign` ends and the domain mismatch
5116 error listed above is returned.

5117 The `row_index` parameter is checked for a valid value. The following condition must hold:

- 5118 1. $0 \leq \text{row_index} < \mathbf{nrows}(C)$

5119 If the rule above is violated, execution of `GrB_assign` ends and the invalid index error listed above
5120 is returned.

5121 From the arguments, the internal vectors, mask, and index array used in the computation are
5122 formed (\leftarrow denotes copy):

5123 1. The vector, $\tilde{\mathbf{c}}$, is extracted from a row of \mathbf{C} as follows:

$$5124 \quad \tilde{\mathbf{c}} = \langle \mathbf{D}(\mathbf{C}), \mathbf{ncols}(\mathbf{C}), \{(j, C_{ij}) \mid \forall j : 0 \leq j < \mathbf{ncols}(\mathbf{C}), i = \text{row_index}, (i, j) \in \mathbf{ind}(\mathbf{C})\} \rangle$$

5125 2. One-dimensional mask, $\tilde{\mathbf{m}}$, is computed from argument `mask` as follows:

5126 (a) If `mask = GrB_NULL`, then $\tilde{\mathbf{m}} = \langle \mathbf{ncols}(\mathbf{C}), \{i, \forall i : 0 \leq i < \mathbf{ncols}(\mathbf{C})\} \rangle$.

5127 (b) If `mask \neq GrB_NULL`,

5128 i. If `desc[GrB_MASK].GrB_STRUCTURE` is set, then $\tilde{\mathbf{m}} = \langle \mathbf{size}(\text{mask}), \{i : i \in \mathbf{ind}(\text{mask})\} \rangle$,

5129 ii. Otherwise, $\tilde{\mathbf{m}} = \langle \mathbf{size}(\text{mask}), \{i : i \in \mathbf{ind}(\text{mask}) \wedge (\text{bool})\text{mask}(i) = \text{true}\} \rangle$.

5130 (c) If `desc[GrB_MASK].GrB_COMP` is set, then $\tilde{\mathbf{m}} \leftarrow \neg \tilde{\mathbf{m}}$.

5131 3. Vector $\tilde{\mathbf{u}} \leftarrow \mathbf{u}$.

5132 4. The internal column index array, $\tilde{\mathbf{J}}$, is computed from argument `col_indices` as follows:

5133 (a) If `col_indices = GrB_ALL`, then $\tilde{\mathbf{J}}[j] = j, \forall j : 0 \leq j < \mathbf{ncols}$.

5134 (b) Otherwise, $\tilde{\mathbf{J}}[j] = \text{col_indices}[j], \forall j : 0 \leq j < \mathbf{ncols}$.

5135 The internal vectors, matrices, and masks are checked for dimension compatibility. The following
5136 conditions must hold:

5137 1. $\mathbf{size}(\tilde{\mathbf{c}}) = \mathbf{size}(\tilde{\mathbf{m}})$

5138 2. $\mathbf{ncols} = \mathbf{size}(\tilde{\mathbf{u}})$.

5139 If any compatibility rule above is violated, execution of `GrB_assign` ends and the dimension mis-
5140 match error listed above is returned.

5141 From this point forward, in `GrB_NONBLOCKING` mode, the method can optionally exit with
5142 `GrB_SUCCESS` return code and defer any computation and/or execution error codes.

5143 We are now ready to carry out the assign and any additional associated operations. We describe
5144 this in terms of two intermediate vectors:

5145 • $\tilde{\mathbf{t}}$: The vector holding the elements from $\tilde{\mathbf{u}}$ in their destination locations relative to $\tilde{\mathbf{c}}$.

5146 • $\tilde{\mathbf{z}}$: The vector holding the result after application of the (optional) accumulation operator.

5147 The intermediate vector, $\tilde{\mathbf{t}}$, is created as follows:

$$5148 \quad \tilde{\mathbf{t}} = \langle \mathbf{D}(\mathbf{u}), \mathbf{size}(\tilde{\mathbf{c}}), \{(\tilde{\mathbf{J}}[j], \tilde{\mathbf{u}}(j)) \mid \forall j, 0 \leq j < \mathbf{ncols} : j \in \mathbf{ind}(\tilde{\mathbf{u}})\} \rangle.$$

5149 At this point, if any value of $\tilde{\mathbf{J}}[j]$ is outside the valid range of indices for vector $\tilde{\mathbf{c}}$, computation
5150 ends and the method returns the index out-of-bounds error listed above. In `GrB_NONBLOCKING`
5151 mode, the error can be deferred until a sequence-terminating `GrB_wait()` is called. Regardless, the
5152 result matrix, \mathbf{C} , is invalid from this point forward in the sequence.

5153 The intermediate vector $\tilde{\mathbf{z}}$ is created as follows:

5154 • If `accum = GrB_NULL`, then $\tilde{\mathbf{z}}$ is defined as

$$5155 \quad \tilde{\mathbf{z}} = \langle \mathbf{D}(\mathbf{C}), \mathbf{size}(\tilde{\mathbf{c}}), \{(i, z_i), \forall i \in (\mathbf{ind}(\tilde{\mathbf{c}}) - (\{\tilde{\mathbf{I}}[k], \forall k\} \cap \mathbf{ind}(\tilde{\mathbf{c}}))) \cup \mathbf{ind}(\tilde{\mathbf{t}})\} \rangle.$$

5156 The above expression defines the structure of vector $\tilde{\mathbf{z}}$ as follows: We start with the structure
5157 of $\tilde{\mathbf{c}}$ ($\mathbf{ind}(\tilde{\mathbf{c}})$) and remove from it all the indices of $\tilde{\mathbf{c}}$ that are in the set of indices being
5158 assigned ($\{\tilde{\mathbf{I}}[k], \forall k\} \cap \mathbf{ind}(\tilde{\mathbf{c}})$). Finally, we add the structure of $\tilde{\mathbf{t}}$ ($\mathbf{ind}(\tilde{\mathbf{t}})$).

5159 The values of the elements of $\tilde{\mathbf{z}}$ are computed based on the relationships between the sets of
5160 indices in $\tilde{\mathbf{c}}$ and $\tilde{\mathbf{t}}$.

$$5161 \quad z_i = \tilde{\mathbf{c}}(i), \text{ if } i \in (\mathbf{ind}(\tilde{\mathbf{c}}) - (\{\tilde{\mathbf{I}}[k], \forall k\} \cap \mathbf{ind}(\tilde{\mathbf{c}}))),$$

$$5162 \quad z_i = \tilde{\mathbf{t}}(i), \text{ if } i \in \mathbf{ind}(\tilde{\mathbf{t}}),$$

5164 where the difference operator refers to set difference.

5165 • If `accum` is a binary operator, then $\tilde{\mathbf{z}}$ is defined as

$$5166 \quad \langle \mathbf{D}_{out}(\mathbf{accum}), \mathbf{size}(\tilde{\mathbf{c}}), \{(j, z_j) \mid j \in \mathbf{ind}(\tilde{\mathbf{c}}) \cup \mathbf{ind}(\tilde{\mathbf{t}})\} \rangle.$$

5167 The values of the elements of $\tilde{\mathbf{z}}$ are computed based on the relationships between the sets of
5168 indices in $\tilde{\mathbf{w}}$ and $\tilde{\mathbf{t}}$.

$$5169 \quad z_j = \tilde{\mathbf{c}}(j) \odot \tilde{\mathbf{t}}(j), \text{ if } j \in (\mathbf{ind}(\tilde{\mathbf{t}}) \cap \mathbf{ind}(\tilde{\mathbf{c}})),$$

$$5170 \quad z_j = \tilde{\mathbf{c}}(j), \text{ if } j \in (\mathbf{ind}(\tilde{\mathbf{c}}) - (\mathbf{ind}(\tilde{\mathbf{t}}) \cap \mathbf{ind}(\tilde{\mathbf{c}}))),$$

$$5171 \quad z_j = \tilde{\mathbf{t}}(j), \text{ if } j \in (\mathbf{ind}(\tilde{\mathbf{t}}) - (\mathbf{ind}(\tilde{\mathbf{t}}) \cap \mathbf{ind}(\tilde{\mathbf{c}}))),$$

5172 where $\odot = \odot(\mathbf{accum})$, and the difference operator refers to set difference.

5173 Finally, the set of output values that make up the $\tilde{\mathbf{z}}$ vector are written into the column of the final
5174 result matrix, $\mathbf{C}(\text{row_index}, :)$. This is carried out under control of the mask which acts as a “write
5175 mask”.

5176 • If `desc[GrB_OUTP].GrB_REPLACE` is set, then any values in $\mathbf{C}(\text{row_index}, :)$ on input to this
5177 operation are deleted and the new contents of the column is given by:

$$5180 \quad \mathbf{L}(\mathbf{C}) = \{(i, j, C_{ij}) : i \neq \text{row_index}\} \cup \{(\text{row_index}, j, z_j) : j \in (\mathbf{ind}(\tilde{\mathbf{z}}) \cap \mathbf{ind}(\tilde{\mathbf{m}}))\}.$$

5181 • If `desc[GrB_OUTP].GrB_REPLACE` is not set, the elements of $\tilde{\mathbf{z}}$ indicated by the mask are
5182 copied into the column of the final result matrix, $\mathbf{C}(\text{row_index}, :)$, and elements of this column
5183 that fall outside the set indicated by the mask are unchanged:

$$5184 \quad \mathbf{L}(\mathbf{C}) = \{(i, j, C_{ij}) : i \neq \text{row_index}\} \cup$$

$$5185 \quad \{(\text{row_index}, j, \tilde{\mathbf{c}}(j)) : j \in (\mathbf{ind}(\tilde{\mathbf{c}}) \cap \mathbf{ind}(\neg \tilde{\mathbf{m}}))\} \cup$$

$$5186 \quad \{(\text{row_index}, j, z_j) : j \in (\mathbf{ind}(\tilde{\mathbf{z}}) \cap \mathbf{ind}(\tilde{\mathbf{m}}))\}.$$

5187 In `GrB_BLOCKING` mode, the method exits with return value `GrB_SUCCESS` and the new content
5188 of vector \mathbf{w} is as defined above and fully computed. In `GrB_NONBLOCKING` mode, the method
5189 exits with return value `GrB_SUCCESS` and the new content of vector \mathbf{w} is as defined above but may
5190 not be fully computed; however, it can be used in the next GraphBLAS method call in a sequence.

5191 4.3.7.5 assign: Constant vector variant

5192 Assign the same value to a specified subset of vector elements. With the use of GrB_ALL, the entire
5193 destination vector can be filled with the constant.

5194 C Syntax

```
5195     GrB_Info GrB_assign(GrB_Vector      w,  
5196                       const GrB_Vector mask,  
5197                       const GrB_BinaryOp accum,  
5198                       <type>         val,  
5199                       const GrB_Index  *indices,  
5200                       GrB_Index        nindices,  
5201                       const GrB_Descriptor desc);
```

```
5202     GrB_Info GrB_assign(GrB_Vector      w,  
5203                       const GrB_Vector mask,  
5204                       const GrB_BinaryOp accum,  
5205                       const GrB_Scalar  s,  
5206                       const GrB_Index  *indices,  
5207                       GrB_Index        nindices,  
5208                       const GrB_Descriptor desc);
```

5209 Parameters

5210 **w** (INOUT) An existing GraphBLAS vector. On input, the vector provides values
5211 that may be accumulated with the result of the assign operation. On output, this
5212 vector holds the results of the operation.

5213 **mask** (IN) An optional “write” mask that controls which results from this operation are
5214 stored into the output vector **w**. The mask dimensions must match those of the
5215 vector **w**. If the GrB_STRUCTURE descriptor is *not* set for the mask, the domain
5216 of the mask vector must be of type `bool` or any of the predefined “built-in” types
5217 in Table 3.2. If the default mask is desired (i.e., a mask that is all true with the
5218 dimensions of **w**), GrB_NULL should be specified.

5219 **accum** (IN) An optional binary operator used for accumulating entries into existing **w**
5220 entries. If assignment rather than accumulation is desired, GrB_NULL should be
5221 specified.

5222 **val** (IN) Scalar value to assign to (a subset of) **w**.

5223 **s** (IN) Scalar value to assign to (a subset of) **w**.

5224 **indices** (IN) Pointer to the ordered set (array) of indices corresponding to the locations in
5225 **w** that are to be assigned. If all elements of **w** are to be assigned in order from 0

5226 to `nindices - 1`, then `GrB_ALL` should be specified. Regardless of execution mode
 5227 and return value, this array may be manipulated by the caller after this operation
 5228 returns without affecting any deferred computations for this operation. In this
 5229 variant, the specific order of the values in the array has no effect on the result.
 5230 Unlike other variants, if there are duplicated values in this array the result is still
 5231 defined.

5232 `nindices` (IN) The number of values in `indices` array. Must be in the range: $[0, \text{size}(w)]$. If
 5233 `nindices` is zero, the operation becomes a NO-OP.

5234 `desc` (IN) An optional operation descriptor. If a *default* descriptor is desired, `GrB_NULL`
 5235 should be specified. Non-default field/value pairs are listed as follows:
 5236

Param	Field	Value	Description
<code>w</code>	<code>GrB_OUTP</code>	<code>GrB_REPLACE</code>	Output vector <code>w</code> is cleared (all elements removed) before the result is stored in it.
<code>mask</code>	<code>GrB_MASK</code>	<code>GrB_STRUCTURE</code>	The write mask is constructed from the structure (pattern of stored values) of the input <code>mask</code> vector. The stored values are not examined.
<code>mask</code>	<code>GrB_MASK</code>	<code>GrB_COMP</code>	Use the complement of <code>mask</code> .

5238 Return Values

5239 `GrB_SUCCESS` In blocking mode, the operation completed successfully. In non-
 5240 blocking mode, this indicates that the compatibility tests on
 5241 dimensions and domains for the input arguments passed suc-
 5242 cessfully. Either way, output vector `w` is ready to be used in the
 5243 next method of the sequence.

5244 `GrB_PANIC` Unknown internal error.

5245 `GrB_INVALID_OBJECT` This is returned in any execution mode whenever one of the
 5246 opaque GraphBLAS objects (input or output) is in an invalid
 5247 state caused by a previous execution error. Call `GrB_error()` to
 5248 access any error messages generated by the implementation.

5249 `GrB_OUT_OF_MEMORY` Not enough memory available for operation.

5250 `GrB_UNINITIALIZED_OBJECT` One or more of the GraphBLAS objects has not been initialized
 5251 by a call to `new` (or `dup` for vector parameters).

5252 `GrB_INDEX_OUT_OF_BOUNDS` A value in `indices` is greater than or equal to `size(w)`. In non-
 5253 blocking mode, this can be reported as an execution error.

5254 `GrB_DIMENSION_MISMATCH` `mask` and `w` dimensions are incompatible, or `nindices` is not less
 5255 than `size(w)`.

5256 GrB_DOMAIN_MISMATCH The domains of the vector and scalar are incompatible with each
 5257 other or the corresponding domains of the accumulation oper-
 5258 ator, or the mask's domain is not compatible with bool (in the
 5259 case where desc[GrB_MASK].GrB_STRUCTURE is not set).

5260 GrB_NULL_POINTER Argument indices is a NULL pointer.

5261 Description

5262 This variant of GrB_assign computes the result of assigning a constant scalar value – either val or
 5263 s – to locations in a destination GraphBLAS vector. Either $w(\text{indices}) = \text{val}$ or $w(\text{indices}) = s$ is
 5264 performed. If an optional binary accumulation operator (\odot) is provided, then either $w(\text{indices}) =$
 5265 $w(\text{indices}) \odot \text{val}$ or $w(\text{indices}) = w(\text{indices}) \odot s$ is performed. More explicitly, if a non-opaque value
 5266 val is provided:

$$5267 \quad w(\text{indices}[i]) = \text{val}, \forall i : 0 \leq i < n_{\text{indices}}, \text{ or}$$

$$5267 \quad w(\text{indices}[i]) = w(\text{indices}[i]) \odot \text{val}, \forall i : 0 \leq i < n_{\text{indices}}.$$

5268 Correspondingly, if a GrB_Scalar s is provided:

$$5269 \quad w(\text{indices}[i]) = s, \forall i : 0 \leq i < n_{\text{indices}}, \text{ or}$$

$$5269 \quad w(\text{indices}[i]) = w(\text{indices}[i]) \odot s, \forall i : 0 \leq i < n_{\text{indices}}.$$

5270 Logically, this operation occurs in three steps:

5271 **Setup** The internal vectors and mask used in the computation are formed and their domains
 5272 and dimensions are tested for compatibility.

5273 **Compute** The indicated computations are carried out.

5274 **Output** The result is written into the output vector, possibly under control of a mask.

5275 Up to two argument vectors are used in the GrB_assign operation:

- 5276 1. $w = \langle \mathbf{D}(w), \mathbf{size}(w), \mathbf{L}(w) = \{(i, w_i)\} \rangle$
- 5277 2. $\text{mask} = \langle \mathbf{D}(\text{mask}), \mathbf{size}(\text{mask}), \mathbf{L}(\text{mask}) = \{(i, m_i)\} \rangle$ (optional)

5278 The argument scalar, vectors, and the accumulation operator (if provided) are tested for domain
 5279 compatibility as follows:

- 5280 1. If mask is not GrB_NULL, and desc[GrB_MASK].GrB_STRUCTURE is not set, then $\mathbf{D}(\text{mask})$
 5281 must be from one of the pre-defined types of Table 3.2.
- 5282 2. $\mathbf{D}(w)$ must be compatible with either $\mathbf{D}(\text{val})$ or $\mathbf{D}(s)$, depending on the signature of the
 5283 method.
- 5284 3. If accum is not GrB_NULL, then $\mathbf{D}(w)$ must be compatible with $\mathbf{D}_{in_1}(\text{accum})$ and $\mathbf{D}_{out}(\text{accum})$
 5285 of the accumulation operator.

5286 4. If `accum` is not `GrB_NULL`, then either $\mathbf{D}(\text{val})$ or $\mathbf{D}(s)$, depending on the signature of the
 5287 method, must be compatible with $\mathbf{D}_{in_2}(\text{accum})$ of the accumulation operator.

5288 Two domains are compatible with each other if values from one domain can be cast to values in
 5289 the other domain as per the rules of the C language. In particular, domains from Table 3.2 are all
 5290 compatible with each other. A domain from a user-defined type is only compatible with itself. If
 5291 any compatibility rule above is violated, execution of `GrB_assign` ends and the domain mismatch
 5292 error listed above is returned.

5293 From the arguments, the internal vectors, mask and index array used in the computation are formed
 5294 (\leftarrow denotes copy):

- 5295 1. Vector $\tilde{\mathbf{w}} \leftarrow \mathbf{w}$.
- 5296 2. One-dimensional mask, $\tilde{\mathbf{m}}$, is computed from argument `mask` as follows:
 - 5297 (a) If `mask = GrB_NULL`, then $\tilde{\mathbf{m}} = \langle \mathbf{size}(\mathbf{w}), \{i, \forall i : 0 \leq i < \mathbf{size}(\mathbf{w})\} \rangle$.
 - 5298 (b) If `mask \neq GrB_NULL`,
 - 5299 i. If `desc[GrB_MASK].GrB_STRUCTURE` is set, then $\tilde{\mathbf{m}} = \langle \mathbf{size}(\text{mask}), \{i : i \in \mathbf{ind}(\text{mask})\} \rangle$,
 - 5300 ii. Otherwise, $\tilde{\mathbf{m}} = \langle \mathbf{size}(\text{mask}), \{i : i \in \mathbf{ind}(\text{mask}) \wedge (\text{bool})\text{mask}(i) = \text{true}\} \rangle$.
 - 5301 (c) If `desc[GrB_MASK].GrB_COMP` is set, then $\tilde{\mathbf{m}} \leftarrow \neg \tilde{\mathbf{m}}$.
- 5302 3. Scalar $\tilde{s} \leftarrow s$ (`GrB_Scalar` version only).
- 5303 4. The internal index array, $\tilde{\mathbf{I}}$, is computed from argument `indices` as follows:
 - 5304 (a) If `indices = GrB_ALL`, then $\tilde{\mathbf{I}}[i] = i, \forall i : 0 \leq i < \mathbf{nindices}$.
 - 5305 (b) Otherwise, $\tilde{\mathbf{I}}[i] = \text{indices}[i], \forall i : 0 \leq i < \mathbf{nindices}$.

5306 The internal vector and mask are checked for dimension compatibility. The following conditions
 5307 must hold:

- 5308 1. $\mathbf{size}(\tilde{\mathbf{w}}) = \mathbf{size}(\tilde{\mathbf{m}})$
- 5309 2. $0 \leq \mathbf{nindices} \leq \mathbf{size}(\tilde{\mathbf{w}})$.

5310 If any compatibility rule above is violated, execution of `GrB_assign` ends and the dimension mis-
 5311 match error listed above is returned.

5312 From this point forward, in `GrB_NONBLOCKING` mode, the method can optionally exit with
 5313 `GrB_SUCCESS` return code and defer any computation and/or execution error codes.

5314 We are now ready to carry out the assign and any additional associated operations. We describe
 5315 this in terms of two intermediate vectors:

- 5316 • $\tilde{\mathbf{t}}$: The vector holding the copies of the scalar, either `val` or \tilde{s} , in their destination locations
 5317 relative to $\tilde{\mathbf{w}}$.

5318 • $\tilde{\mathbf{z}}$: The vector holding the result after application of the (optional) accumulation operator.

5319 The intermediate vector, $\tilde{\mathbf{t}}$, is created as follows. If a non-opaque scalar val is provided:

5320
$$\tilde{\mathbf{t}} = \langle \mathbf{D}(\text{val}), \mathbf{size}(\tilde{\mathbf{w}}), \{(\tilde{\mathbf{I}}[i], \text{val}) \mid \forall i, 0 \leq i < \text{nindices}\} \rangle.$$

5321 Correspondingly, if a non-empty `GrB_Scalar` \tilde{s} is provided (i.e., $\mathbf{size}(\tilde{s}) = 1$):

5322
$$\tilde{\mathbf{t}} = \langle \mathbf{D}(\tilde{s}), \mathbf{size}(\tilde{\mathbf{w}}), \{(\tilde{\mathbf{I}}[i], \mathbf{val}(\tilde{s})) \mid \forall i, 0 \leq i < \text{nindices}\} \rangle.$$

5323 Finally, if an empty `GrB_Scalar` \tilde{s} is provided (i.e., $\mathbf{size}(\tilde{s}) = 0$):

5324
$$\tilde{\mathbf{t}} = \langle \mathbf{D}(\tilde{s}), \mathbf{size}(\tilde{\mathbf{w}}), \emptyset \rangle.$$

5325 If $\tilde{\mathbf{I}}$ is empty, this operation results in an empty vector, $\tilde{\mathbf{t}}$. Otherwise, if any value in the $\tilde{\mathbf{I}}$ array
 5326 is not in the range $[0, \mathbf{size}(\tilde{\mathbf{w}}))$, the execution of `GrB_assign` ends and the index out-of-bounds
 5327 error listed above is generated. In `GrB_NONBLOCKING` mode, the error can be deferred until a
 5328 sequence-terminating `GrB_wait()` is called. Regardless, the result vector, \mathbf{w} , is invalid from this
 5329 point forward in the sequence.

5330 The intermediate vector $\tilde{\mathbf{z}}$ is created as follows:

5331 • If `accum = GrB_NULL`, then $\tilde{\mathbf{z}}$ is defined as

5332
$$\tilde{\mathbf{z}} = \langle \mathbf{D}(\mathbf{w}), \mathbf{size}(\tilde{\mathbf{w}}), \{(i, z_i), \forall i \in (\mathbf{ind}(\tilde{\mathbf{w}}) - (\{\tilde{\mathbf{I}}[k], \forall k\} \cap \mathbf{ind}(\tilde{\mathbf{w}}))) \cup \mathbf{ind}(\tilde{\mathbf{t}})\} \rangle.$$

5333 The above expression defines the structure of vector $\tilde{\mathbf{z}}$ as follows: We start with the structure
 5334 of $\tilde{\mathbf{w}}$ ($\mathbf{ind}(\tilde{\mathbf{w}})$) and remove from it all the indices of $\tilde{\mathbf{w}}$ that are in the set of indices being
 5335 assigned ($\{\tilde{\mathbf{I}}[k], \forall k\} \cap \mathbf{ind}(\tilde{\mathbf{w}})$). Finally, we add the structure of $\tilde{\mathbf{t}}$ ($\mathbf{ind}(\tilde{\mathbf{t}})$).

5336 The values of the elements of $\tilde{\mathbf{z}}$ are computed based on the relationships between the sets of
 5337 indices in $\tilde{\mathbf{w}}$ and $\tilde{\mathbf{t}}$.

5338
$$z_i = \tilde{\mathbf{w}}(i), \text{ if } i \in (\mathbf{ind}(\tilde{\mathbf{w}}) - (\{\tilde{\mathbf{I}}[k], \forall k\} \cap \mathbf{ind}(\tilde{\mathbf{w}}))),$$

 5339
$$z_i = \tilde{\mathbf{t}}(i), \text{ if } i \in \mathbf{ind}(\tilde{\mathbf{t}}),$$

 5340

5341 where the difference operator refers to set difference. We note that in this case of assigning
 5342 a constant, $\{\tilde{\mathbf{I}}[k], \forall k\}$ and $\mathbf{ind}(\tilde{\mathbf{t}})$ are identical.

5343 • If `accum` is a binary operator, then $\tilde{\mathbf{z}}$ is defined as

5344
$$\langle \mathbf{D}_{out}(\text{accum}), \mathbf{size}(\tilde{\mathbf{w}}), \{(i, z_i) \mid \forall i \in \mathbf{ind}(\tilde{\mathbf{w}}) \cup \mathbf{ind}(\tilde{\mathbf{t}})\} \rangle.$$

5345 The values of the elements of $\tilde{\mathbf{z}}$ are computed based on the relationships between the sets of
 5346 indices in $\tilde{\mathbf{w}}$ and $\tilde{\mathbf{t}}$.

5347
$$z_i = \tilde{\mathbf{w}}(i) \odot \tilde{\mathbf{t}}(i), \text{ if } i \in (\mathbf{ind}(\tilde{\mathbf{t}}) \cap \mathbf{ind}(\tilde{\mathbf{w}})),$$

 5348
$$z_i = \tilde{\mathbf{w}}(i), \text{ if } i \in (\mathbf{ind}(\tilde{\mathbf{w}}) - (\mathbf{ind}(\tilde{\mathbf{t}}) \cap \mathbf{ind}(\tilde{\mathbf{w}}))),$$

 5349
$$z_i = \tilde{\mathbf{t}}(i), \text{ if } i \in (\mathbf{ind}(\tilde{\mathbf{t}}) - (\mathbf{ind}(\tilde{\mathbf{t}}) \cap \mathbf{ind}(\tilde{\mathbf{w}}))),$$

 5350

5352 where $\odot = \odot(\text{accum})$, and the difference operator refers to set difference.

5353 Finally, the set of output values that make up vector $\tilde{\mathbf{z}}$ are written into the final result vector \mathbf{w} ,
 5354 using what is called a *standard vector mask and replace*. This is carried out under control of the
 5355 mask which acts as a “write mask”.

- 5356 • If desc[GrB_OUTP].GrB_REPLACE is set, then any values in \mathbf{w} on input to this operation are
 5357 deleted and the content of the new output vector, \mathbf{w} , is defined as,

$$5358 \quad \mathbf{L}(\mathbf{w}) = \{(i, z_i) : i \in (\mathbf{ind}(\tilde{\mathbf{z}}) \cap \mathbf{ind}(\tilde{\mathbf{m}}))\}.$$

- 5359 • If desc[GrB_OUTP].GrB_REPLACE is not set, the elements of $\tilde{\mathbf{z}}$ indicated by the mask are
 5360 copied into the result vector, \mathbf{w} , and elements of \mathbf{w} that fall outside the set indicated by the
 5361 mask are unchanged:

$$5362 \quad \mathbf{L}(\mathbf{w}) = \{(i, w_i) : i \in (\mathbf{ind}(\mathbf{w}) \cap \mathbf{ind}(\neg\tilde{\mathbf{m}}))\} \cup \{(i, z_i) : i \in (\mathbf{ind}(\tilde{\mathbf{z}}) \cap \mathbf{ind}(\tilde{\mathbf{m}}))\}.$$

5363 In GrB_BLOCKING mode, the method exits with return value GrB_SUCCESS and the new content
 5364 of vector \mathbf{w} is as defined above and fully computed. In GrB_NONBLOCKING mode, the method
 5365 exits with return value GrB_SUCCESS and the new content of vector \mathbf{w} is as defined above but
 5366 may not be fully computed. However, it can be used in the next GraphBLAS method call in a
 5367 sequence.

5368 4.3.7.6 assign: Constant matrix variant

5369 Assign the same value to a specified subset of matrix elements. With the use of GrB_ALL, the
 5370 entire destination matrix can be filled with the constant.

5371 C Syntax

```
5372     GrB_Info GrB_assign(GrB_Matrix      C,
5373                       const GrB_Matrix Mask,
5374                       const GrB_BinaryOp accum,
5375                       <type>          val,
5376                       const GrB_Index  *row_indices,
5377                       GrB_Index        nrows,
5378                       const GrB_Index  *col_indices,
5379                       GrB_Index        ncols,
5380                       const GrB_Descriptor desc);
```

```
5381     GrB_Info GrB_assign(GrB_Matrix      C,
5382                       const GrB_Matrix Mask,
5383                       const GrB_BinaryOp accum,
5384                       const GrB_Scalar  s,
5385                       const GrB_Index  *row_indices,
5386                       GrB_Index        nrows,
```

```

5387         const GrB_Index      *col_indices,
5388         GrB_Index            ncols,
5389         const GrB_Descriptor desc);

```

5390 Parameters

5391 **C** (INOUT) An existing GraphBLAS matrix. On input, the matrix provides values
5392 that may be accumulated with the result of the assign operation. On output, the
5393 matrix holds the results of the operation.

5394 **Mask** (IN) An optional “write” mask that controls which results from this operation are
5395 stored into the output matrix **C**. The mask dimensions must match those of the
5396 matrix **C**. If the **GrB_STRUCTURE** descriptor is *not* set for the mask, the domain
5397 of the **Mask** matrix must be of type **bool** or any of the predefined “built-in” types
5398 in Table 3.2. If the default mask is desired (i.e., a mask that is all true with the
5399 dimensions of **C**), **GrB_NULL** should be specified.

5400 **accum** (IN) An optional binary operator used for accumulating entries into existing **C**
5401 entries. If assignment rather than accumulation is desired, **GrB_NULL** should be
5402 specified.

5403 **val** (IN) Scalar value to assign to (a subset of) **C**.

5404 **s** (IN) Scalar value to assign to (a subset of) **C**.

5405 **row_indices** (IN) Pointer to the ordered set (array) of indices corresponding to the rows of **C**
5406 that are assigned. If all rows of **C** are to be assigned in order from 0 to **nrows** - 1,
5407 then **GrB_ALL** can be specified. Regardless of execution mode and return value,
5408 this array may be manipulated by the caller after this operation returns without
5409 affecting any deferred computations for this operation. Unlike other variants, if
5410 there are duplicated values in this array the result is still defined.

5411 **nrows** (IN) The number of values in **row_indices** array. Must be in the range: [0, **nrows**(**C**)].
5412 If **nrows** is zero, the operation becomes a NO-OP.

5413 **col_indices** (IN) Pointer to the ordered set (array) of indices corresponding to the columns of **C**
5414 that are assigned. If all columns of **C** are to be assigned in order from 0 to **ncols** - 1,
5415 then **GrB_ALL** should be specified. Regardless of execution mode and return value,
5416 this array may be manipulated by the caller after this operation returns without
5417 affecting any deferred computations for this operation. Unlike other variants, if
5418 there are duplicated values in this array the result is still defined.

5419 **ncols** (IN) The number of values in **col_indices** array. Must be in the range: [0, **ncols**(**C**)].
5420 If **ncols** is zero, the operation becomes a NO-OP.

5421 **desc** (IN) An optional operation descriptor. If a *default* descriptor is desired, **GrB_NULL**
5422 should be specified. Non-default field/value pairs are listed as follows:
5423

Param	Field	Value	Description
C	GrB_OUTP	GrB_REPLACE	Output matrix C is cleared (all elements removed) before the result is stored in it.
Mask	GrB_MASK	GrB_STRUCTURE	The write mask is constructed from the structure (pattern of stored values) of the input Mask matrix. The stored values are not examined.
Mask	GrB_MASK	GrB_COMP	Use the complement of Mask.

5424

5425 Return Values

5426 GrB_SUCCESS In blocking mode, the operation completed successfully. In non-
5427 blocking mode, this indicates that the compatibility tests on
5428 dimensions and domains for the input arguments passed suc-
5429 cessfully. Either way, output matrix C is ready to be used in the
5430 next method of the sequence.

5431 GrB_PANIC Unknown internal error.

5432 GrB_INVALID_OBJECT This is returned in any execution mode whenever one of the
5433 opaque GraphBLAS objects (input or output) is in an invalid
5434 state caused by a previous execution error. Call GrB_error() to
5435 access any error messages generated by the implementation.

5436 GrB_OUT_OF_MEMORY Not enough memory available for the operation.

5437 GrB_UNINITIALIZED_OBJECT One or more of the GraphBLAS objects has not been initialized
5438 by a call to new (or dup for vector parameters).

5439 GrB_INDEX_OUT_OF_BOUNDS A value in row_indices is greater than or equal to nrows(C), or
5440 a value in col_indices is greater than or equal to ncols(C). In
5441 non-blocking mode, this can be reported as an execution error.

5442 GrB_DIMENSION_MISMATCH Mask and C dimensions are incompatible, nrows is not less than
5443 nrows(C), or ncols is not less than ncols(C).

5444 GrB_DOMAIN_MISMATCH The domains of the matrix and scalar are incompatible with
5445 each other or the corresponding domains of the accumulation
5446 operator, or the mask's domain is not compatible with bool (in
5447 the case where desc[GrB_MASK].GrB_STRUCTURE is not set).

5448 GrB_NULL_POINTER Either argument row_indices is a NULL pointer, argument col_indices
5449 is a NULL pointer, or both.

5450 Description

5451 This variant of GrB_assign computes the result of assigning a constant scalar value – either val or
5452 s – to locations in a destination GraphBLAS matrix: Either $C(\text{row_indices}, \text{col_indices}) = \text{val}$

5453 or $C(\text{row_indices}, \text{col_indices}) = s$ is performed. If an optional binary accumulation operator
 5454 (\odot) is provided, then either $C(\text{row_indices}, \text{col_indices}) = C(\text{row_indices}, \text{col_indices}) \odot \text{val}$ or
 5455 $C(\text{row_indices}, \text{col_indices}) = C(\text{row_indices}, \text{col_indices}) \odot s$ is performed. More explicitly, if a
 5456 non-opaque value val is provided:

$$\begin{aligned} & C(\text{row_indices}[i], \text{col_indices}[j]) = \text{val}, \text{ or} \\ 5457 & C(\text{row_indices}[i], \text{col_indices}[j]) = C(\text{row_indices}[i], \text{col_indices}[j]) \odot \text{val} \\ & \quad \forall (i, j) : 0 \leq i < \text{nrows}, 0 \leq j < \text{ncols} \end{aligned}$$

5458 Correspondingly, if a `GrB_Scalar` s is provided:

$$\begin{aligned} & C(\text{row_indices}[i], \text{col_indices}[j]) = s, \text{ or} \\ 5459 & C(\text{row_indices}[i], \text{col_indices}[j]) = C(\text{row_indices}[i], \text{col_indices}[j]) \odot s \\ & \quad \forall (i, j) : 0 \leq i < \text{nrows}, 0 \leq j < \text{ncols} \end{aligned}$$

5460 Logically, this operation occurs in three steps:

5461 Setup The internal vectors and mask used in the computation are formed and their domains
 5462 and dimensions are tested for compatibility.

5463 Compute The indicated computations are carried out.

5464 Output The result is written into the output matrix, possibly under control of a mask.

5465 Up to two argument matrices are used in the `GrB_assign` operation:

- 5466 1. $C = \langle \mathbf{D}(C), \mathbf{nrows}(C), \mathbf{ncols}(C), \mathbf{L}(C) = \{(i, j, C_{ij})\} \rangle$
- 5467 2. $\text{Mask} = \langle \mathbf{D}(\text{Mask}), \mathbf{nrows}(\text{Mask}), \mathbf{ncols}(\text{Mask}), \mathbf{L}(\text{Mask}) = \{(i, j, M_{ij})\} \rangle$ (optional)

5468 The argument scalar, matrices, and the accumulation operator (if provided) are tested for domain
 5469 compatibility as follows:

- 5470 1. If `Mask` is not `GrB_NULL`, and `desc[GrB_MASK].GrB_STRUCTURE` is not set, then $\mathbf{D}(\text{Mask})$
 5471 must be from one of the pre-defined types of Table 3.2.
- 5472 2. $\mathbf{D}(C)$ must be compatible with either $\mathbf{D}(\text{val})$ or $\mathbf{D}(s)$, depending on the signature of the
 5473 method.
- 5474 3. If `accum` is not `GrB_NULL`, then $\mathbf{D}(C)$ must be compatible with $\mathbf{D}_{in_1}(\text{accum})$ and $\mathbf{D}_{out}(\text{accum})$
 5475 of the accumulation operator.
- 5476 4. If `accum` is not `GrB_NULL`, then either $\mathbf{D}(\text{val})$ or $\mathbf{D}(s)$, depending on the signature of the
 5477 method, must be compatible with $\mathbf{D}_{in_2}(\text{accum})$ of the accumulation operator.

5478 Two domains are compatible with each other if values from one domain can be cast to values in
 5479 the other domain as per the rules of the C language. In particular, domains from Table 3.2 are all
 5480 compatible with each other. A domain from a user-defined type is only compatible with itself. If
 5481 any compatibility rule above is violated, execution of GrB_assign ends and the domain mismatch
 5482 error listed above is returned.

5483 From the arguments, the internal matrices, index arrays, and mask used in the computation are
 5484 formed (\leftarrow denotes copy):

- 5485 1. Matrix $\tilde{\mathbf{C}} \leftarrow \mathbf{C}$.
- 5486 2. Two-dimensional mask $\tilde{\mathbf{M}}$ is computed from argument Mask as follows:
 - 5487 (a) If Mask = GrB_NULL, then $\tilde{\mathbf{M}} = \langle \mathbf{nrows}(\mathbf{C}), \mathbf{ncols}(\mathbf{C}), \{(i, j), \forall i, j : 0 \leq i < \mathbf{nrows}(\mathbf{C}), 0 \leq$
 5488 $j < \mathbf{ncols}(\mathbf{C})\} \rangle$.
 - 5489 (b) If Mask \neq GrB_NULL,
 - 5490 i. If desc[GrB_MASK].GrB_STRUCTURE is set, then $\tilde{\mathbf{M}} = \langle \mathbf{nrows}(\text{Mask}), \mathbf{ncols}(\text{Mask}), \{(i, j) :$
 5491 $(i, j) \in \mathbf{ind}(\text{Mask})\} \rangle$,
 - 5492 ii. Otherwise, $\tilde{\mathbf{M}} = \langle \mathbf{nrows}(\text{Mask}), \mathbf{ncols}(\text{Mask}),$
 5493 $\{(i, j) : (i, j) \in \mathbf{ind}(\text{Mask}) \wedge (\text{bool})\text{Mask}(i, j) = \text{true}\} \rangle$.
 - 5494 (c) If desc[GrB_MASK].GrB_COMP is set, then $\tilde{\mathbf{M}} \leftarrow \neg\tilde{\mathbf{M}}$.
- 5495 3. Scalar $\tilde{s} \leftarrow s$ (GrB_Scalar version only).
- 5496 4. The internal row index array, $\tilde{\mathbf{I}}$, is computed from argument row_indices as follows:
 - 5497 (a) If row_indices = GrB_ALL, then $\tilde{\mathbf{I}}[i] = i, \forall i : 0 \leq i < \mathbf{nrows}$.
 - 5498 (b) Otherwise, $\tilde{\mathbf{I}}[i] = \text{row_indices}[i], \forall i : 0 \leq i < \mathbf{nrows}$.
- 5499 5. The internal column index array, $\tilde{\mathbf{J}}$, is computed from argument col_indices as follows:
 - 5500 (a) If col_indices = GrB_ALL, then $\tilde{\mathbf{J}}[j] = j, \forall j : 0 \leq j < \mathbf{ncols}$.
 - 5501 (b) Otherwise, $\tilde{\mathbf{J}}[j] = \text{col_indices}[j], \forall j : 0 \leq j < \mathbf{ncols}$.

5502 The internal matrix and mask are checked for dimension compatibility. The following conditions
 5503 must hold:

- 5504 1. $\mathbf{nrows}(\tilde{\mathbf{C}}) = \mathbf{nrows}(\tilde{\mathbf{M}})$.
- 5505 2. $\mathbf{ncols}(\tilde{\mathbf{C}}) = \mathbf{ncols}(\tilde{\mathbf{M}})$.
- 5506 3. $0 \leq \mathbf{nrows} \leq \mathbf{nrows}(\tilde{\mathbf{C}})$.
- 5507 4. $0 \leq \mathbf{ncols} \leq \mathbf{ncols}(\tilde{\mathbf{C}})$.

5508 If any compatibility rule above is violated, execution of GrB_assign ends and the dimension mis-
 5509 match error listed above is returned.

5510 From this point forward, in GrB_NONBLOCKING mode, the method can optionally exit with
 5511 GrB_SUCCESS return code and defer any computation and/or execution error codes.

5512 We are now ready to carry out the assign and any additional associated operations. We describe
 5513 this in terms of two intermediate matrices:

- 5514 • $\tilde{\mathbf{T}}$: The matrix holding the copies of the scalar, either val or \tilde{s} , in their destination locations
 5515 relative to $\tilde{\mathbf{C}}$.
- 5516 • $\tilde{\mathbf{Z}}$: The matrix holding the result after application of the (optional) accumulation operator.

5517 The intermediate matrix, $\tilde{\mathbf{T}}$, is created as follows. If a non-opaque scalar val is provided:

$$5518 \quad \tilde{\mathbf{T}} = \langle \mathbf{D}(\text{val}), \mathbf{nrows}(\tilde{\mathbf{C}}), \mathbf{ncols}(\tilde{\mathbf{C}}), \\ \{(\tilde{\mathbf{I}}[i], \tilde{\mathbf{J}}[j], \text{val}) \mid \forall (i, j), 0 \leq i < \mathbf{nrows}, 0 \leq j < \mathbf{ncols}\} \rangle.$$

5519 Correspondingly, if a non-empty GrB_Scalar \tilde{s} is provided (i.e., $\mathbf{size}(\tilde{s}) = 1$):

$$5520 \quad \tilde{\mathbf{T}} = \langle \mathbf{D}(\tilde{s}), \mathbf{nrows}(\tilde{\mathbf{C}}), \mathbf{ncols}(\tilde{\mathbf{C}}), \\ \{(\tilde{\mathbf{I}}[i], \tilde{\mathbf{J}}[j], \text{val}(\tilde{s})) \mid \forall (i, j), 0 \leq i < \mathbf{nrows}, 0 \leq j < \mathbf{ncols}\} \rangle.$$

5521 Finally, if an empty GrB_Scalar \tilde{s} is provided (i.e., $\mathbf{size}(\tilde{s}) = 0$):

$$5522 \quad \tilde{\mathbf{T}} = \langle \mathbf{D}(\tilde{s}), \mathbf{nrows}(\tilde{\mathbf{C}}), \mathbf{ncols}(\tilde{\mathbf{C}}), \emptyset \rangle.$$

5523 If either $\tilde{\mathbf{I}}$ or $\tilde{\mathbf{J}}$ is empty, this operation results in an empty matrix, $\tilde{\mathbf{T}}$. Otherwise, if any value
 5524 in the $\tilde{\mathbf{I}}$ array is not in the range $[0, \mathbf{nrows}(\tilde{\mathbf{C}}))$ or any value in the $\tilde{\mathbf{J}}$ array is not in the range
 5525 $[0, \mathbf{ncols}(\tilde{\mathbf{C}}))$, the execution of GrB_assign ends and the index out-of-bounds error listed above is
 5526 generated. In GrB_NONBLOCKING mode, the error can be deferred until a sequence-terminating
 5527 GrB_wait() is called. Regardless, the result matrix \mathbf{C} is invalid from this point forward in the
 5528 sequence.

5529 The intermediate matrix $\tilde{\mathbf{Z}}$ is created as follows:

- 5530 • If $\text{accum} = \text{GrB_NULL}$, then $\tilde{\mathbf{Z}}$ is defined as

$$5531 \quad \tilde{\mathbf{Z}} = \langle \mathbf{D}(\mathbf{C}), \mathbf{nrows}(\tilde{\mathbf{C}}), \mathbf{ncols}(\tilde{\mathbf{C}}), \\ 5532 \quad \{(i, j, Z_{ij}) \mid \forall (i, j) \in (\mathbf{ind}(\tilde{\mathbf{C}}) - (\{(\tilde{\mathbf{I}}[k], \tilde{\mathbf{J}}[l]), \forall k, l\} \cap \mathbf{ind}(\tilde{\mathbf{C}}))) \cup \mathbf{ind}(\tilde{\mathbf{T}})\} \rangle.$$

5533 The above expression defines the structure of matrix $\tilde{\mathbf{Z}}$ as follows: We start with the structure
 5534 of $\tilde{\mathbf{C}}$ ($\mathbf{ind}(\tilde{\mathbf{C}})$) and remove from it all the indices of $\tilde{\mathbf{C}}$ that are in the set of indices being
 5535 assigned ($\{(\tilde{\mathbf{I}}[k], \tilde{\mathbf{J}}[l]), \forall k, l\} \cap \mathbf{ind}(\tilde{\mathbf{C}})$). Finally, we add the structure of $\tilde{\mathbf{T}}$ ($\mathbf{ind}(\tilde{\mathbf{T}})$).

5536 The values of the elements of $\tilde{\mathbf{Z}}$ are computed based on the relationships between the sets of
 5537 indices in $\tilde{\mathbf{C}}$ and $\tilde{\mathbf{T}}$.

$$5538 \quad Z_{ij} = \tilde{\mathbf{C}}(i, j), \text{ if } (i, j) \in (\mathbf{ind}(\tilde{\mathbf{C}}) - (\{(\tilde{\mathbf{I}}[k], \tilde{\mathbf{J}}[l]), \forall k, l\} \cap \mathbf{ind}(\tilde{\mathbf{C}}))), \\ 5539 \\ 5540 \quad Z_{ij} = \tilde{\mathbf{T}}(i, j), \text{ if } (i, j) \in \mathbf{ind}(\tilde{\mathbf{T}}),$$

5541 where the difference operator refers to set difference. We note that, in this particular case of
 5542 assigning a constant to a matrix, the sets $\{(\tilde{\mathbf{I}}[k], \tilde{\mathbf{J}}[l]), \forall k, l\}$ and $\mathbf{ind}(\tilde{\mathbf{T}})$ are identical.

5543 • If `accum` is a binary operator, then $\tilde{\mathbf{Z}}$ is defined as

$$5544 \quad \langle \mathbf{D}_{out}(\text{accum}), \text{nrows}(\tilde{\mathbf{C}}), \text{ncols}(\tilde{\mathbf{C}}), \{(i, j, Z_{ij}) \mid \forall (i, j) \in \text{ind}(\tilde{\mathbf{C}}) \cup \text{ind}(\tilde{\mathbf{T}})\} \rangle.$$

5545 The values of the elements of $\tilde{\mathbf{Z}}$ are computed based on the relationships between the sets of
5546 indices in $\tilde{\mathbf{C}}$ and $\tilde{\mathbf{T}}$.

$$5547 \quad Z_{ij} = \tilde{\mathbf{C}}(i, j) \odot \tilde{\mathbf{T}}(i, j), \text{ if } (i, j) \in (\text{ind}(\tilde{\mathbf{T}}) \cap \text{ind}(\tilde{\mathbf{C}})),$$

5548

$$5549 \quad Z_{ij} = \tilde{\mathbf{C}}(i, j), \text{ if } (i, j) \in (\text{ind}(\tilde{\mathbf{C}}) - (\text{ind}(\tilde{\mathbf{T}}) \cap \text{ind}(\tilde{\mathbf{C}}))),$$

5550

$$5551 \quad Z_{ij} = \tilde{\mathbf{T}}(i, j), \text{ if } (i, j) \in (\text{ind}(\tilde{\mathbf{T}}) - (\text{ind}(\tilde{\mathbf{T}}) \cap \text{ind}(\tilde{\mathbf{C}}))),$$

5552 where $\odot = \odot(\text{accum})$, and the difference operator refers to set difference.

5553 Finally, the set of output values that make up matrix $\tilde{\mathbf{Z}}$ are written into the final result matrix \mathbf{C} ,
5554 using what is called a *standard matrix mask and replace*. This is carried out under control of the
5555 mask which acts as a “write mask”.

5556 • If `desc[GrB_OUTP].GrB_REPLACE` is set, then any values in \mathbf{C} on input to this operation are
5557 deleted and the content of the new output matrix, \mathbf{C} , is defined as,

$$5558 \quad \mathbf{L}(\mathbf{C}) = \{(i, j, Z_{ij}) : (i, j) \in (\text{ind}(\tilde{\mathbf{Z}}) \cap \text{ind}(\tilde{\mathbf{M}}))\}.$$

5559 • If `desc[GrB_OUTP].GrB_REPLACE` is not set, the elements of $\tilde{\mathbf{Z}}$ indicated by the mask are
5560 copied into the result matrix, \mathbf{C} , and elements of \mathbf{C} that fall outside the set indicated by the
5561 mask are unchanged:

$$5562 \quad \mathbf{L}(\mathbf{C}) = \{(i, j, C_{ij}) : (i, j) \in (\text{ind}(\mathbf{C}) \cap \text{ind}(\neg \tilde{\mathbf{M}}))\} \cup \{(i, j, Z_{ij}) : (i, j) \in (\text{ind}(\tilde{\mathbf{Z}}) \cap \text{ind}(\tilde{\mathbf{M}}))\}.$$

5563 In `GrB_BLOCKING` mode, the method exits with return value `GrB_SUCCESS` and the new content
5564 of matrix \mathbf{C} is as defined above and fully computed. In `GrB_NONBLOCKING` mode, the method
5565 exits with return value `GrB_SUCCESS` and the new content of matrix \mathbf{C} is as defined above but
5566 may not be fully computed. However, it can be used in the next GraphBLAS method call in a
5567 sequence.

5568 4.3.8 apply: Apply a function to the elements of an object

5569 Computes the transformation of the values of the elements of a vector or a matrix using a unary
5570 function, or a binary function where one argument is bound to a scalar.

5571 4.3.8.1 apply: Vector variant

5572 Computes the transformation of the values of the elements of a vector using a unary function.

5573 **C Syntax**

```

5574         GrB_Info GrB_apply(GrB_Vector          w,
5575                             const GrB_Vector    mask,
5576                             const GrB_BinaryOp   accum,
5577                             const GrB_UnaryOp    op,
5578                             const GrB_Vector    u,
5579                             const GrB_Descriptor desc);

```

5580 **Parameters**

5581 **w** (INOUT) An existing GraphBLAS vector. On input, the vector provides values
5582 that may be accumulated with the result of the apply operation. On output, this
5583 vector holds the results of the operation.

5584 **mask** (IN) An optional “write” mask that controls which results from this operation are
5585 stored into the output vector *w*. The mask dimensions must match those of the
5586 vector *w*. If the `GrB_STRUCTURE` descriptor is *not* set for the mask, the domain
5587 of the mask vector must be of type `bool` or any of the predefined “built-in” types
5588 in Table 3.2. If the default mask is desired (i.e., a mask that is all true with the
5589 dimensions of *w*), `GrB_NULL` should be specified.

5590 **accum** (IN) An optional binary operator used for accumulating entries into existing *w*
5591 entries. If assignment rather than accumulation is desired, `GrB_NULL` should be
5592 specified.

5593 **op** (IN) A unary operator applied to each element of input vector *u*.

5594 **u** (IN) The GraphBLAS vector to which the unary function is applied.

5595 **desc** (IN) An optional operation descriptor. If a *default* descriptor is desired, `GrB_NULL`
5596 should be specified. Non-default field/value pairs are listed as follows:

5597

Param	Field	Value	Description
<i>w</i>	<code>GrB_OUTP</code>	<code>GrB_REPLACE</code>	Output vector <i>w</i> is cleared (all elements removed) before the result is stored in it.
<i>mask</i>	<code>GrB_MASK</code>	<code>GrB_STRUCTURE</code>	The write mask is constructed from the structure (pattern of stored values) of the input <i>mask</i> vector. The stored values are not examined.
<i>mask</i>	<code>GrB_MASK</code>	<code>GrB_COMP</code>	Use the complement of <i>mask</i> .

5598

5599 **Return Values**

5600 **GrB_SUCCESS** In blocking mode, the operation completed successfully. In non-
5601 blocking mode, this indicates that the compatibility tests on di-
5602 mensions and domains for the input arguments passed successfully.

5603 Either way, output vector w is ready to be used in the next method
5604 of the sequence.

5605 GrB_PANIC Unknown internal error.

5606 GrB_INVALID_OBJECT This is returned in any execution mode whenever one of the opaque
5607 GraphBLAS objects (input or output) is in an invalid state caused
5608 by a previous execution error. Call `GrB_error()` to access any error
5609 messages generated by the implementation.

5610 GrB_OUT_OF_MEMORY Not enough memory available for operation.

5611 GrB_UNINITIALIZED_OBJECT One or more of the GraphBLAS objects has not been initialized by
5612 a call to `new` (or `dup` for vector parameters).

5613 GrB_DIMENSION_MISMATCH `mask`, `w` and/or `u` dimensions are incompatible.

5614 GrB_DOMAIN_MISMATCH The domains of the various vectors are incompatible with the corre-
5615 sponding domains of the accumulation operator or unary function,
5616 or the mask's domain is not compatible with `bool` (in the case where
5617 `desc[GrB_MASK].GrB_STRUCTURE` is not set).

5618 Description

5619 This variant of `GrB_apply` computes the result of applying a unary function to the elements of a
5620 GraphBLAS vector: $w = f(u)$; or, if an optional binary accumulation operator (\odot) is provided,
5621 $w = w \odot f(u)$.

5622 Logically, this operation occurs in three steps:

5623 **Setup** The internal vectors and mask used in the computation are formed and their domains
5624 and dimensions are tested for compatibility.

5625 **Compute** The indicated computations are carried out.

5626 **Output** The result is written into the output vector, possibly under control of a mask.

5627 Up to three argument vectors are used in this `GrB_apply` operation:

5628 1. $w = \langle \mathbf{D}(w), \mathbf{size}(w), \mathbf{L}(w) = \{(i, w_i)\} \rangle$

5629 2. $mask = \langle \mathbf{D}(mask), \mathbf{size}(mask), \mathbf{L}(mask) = \{(i, m_i)\} \rangle$ (optional)

5630 3. $u = \langle \mathbf{D}(u), \mathbf{size}(u), \mathbf{L}(u) = \{(i, u_i)\} \rangle$

5631 The argument vectors, unary operator and the accumulation operator (if provided) are tested for
5632 domain compatibility as follows:

- 5633 1. If `mask` is not `GrB_NULL`, and `desc[GrB_MASK].GrB_STRUCTURE` is not set, then $\mathbf{D}(\text{mask})$
5634 must be from one of the pre-defined types of Table 3.2.
- 5635 2. $\mathbf{D}(\mathbf{w})$ must be compatible with $\mathbf{D}_{out}(\text{op})$ of the unary operator.
- 5636 3. If `accum` is not `GrB_NULL`, then $\mathbf{D}(\mathbf{w})$ must be compatible with $\mathbf{D}_{in_1}(\text{accum})$ and $\mathbf{D}_{out}(\text{accum})$
5637 of the accumulation operator and $\mathbf{D}_{out}(\text{op})$ of the unary operator must be compatible with
5638 $\mathbf{D}_{in_2}(\text{accum})$ of the accumulation operator.
- 5639 4. $\mathbf{D}(\mathbf{u})$ must be compatible with $\mathbf{D}_{in}(\text{op})$.

5640 Two domains are compatible with each other if values from one domain can be cast to values in
5641 the other domain as per the rules of the C language. In particular, domains from Table 3.2 are all
5642 compatible with each other. A domain from a user-defined type is only compatible with itself. If
5643 any compatibility rule above is violated, execution of `GrB_apply` ends and the domain mismatch
5644 error listed above is returned.

5645 From the argument vectors, the internal vectors and mask used in the computation are formed (\leftarrow
5646 denotes copy):

- 5647 1. Vector $\tilde{\mathbf{w}} \leftarrow \mathbf{w}$.
- 5648 2. One-dimensional mask, $\tilde{\mathbf{m}}$, is computed from argument `mask` as follows:
- 5649 (a) If `mask = GrB_NULL`, then $\tilde{\mathbf{m}} = \langle \text{size}(\mathbf{w}), \{i, \forall i : 0 \leq i < \text{size}(\mathbf{w})\} \rangle$.
- 5650 (b) If `mask \neq GrB_NULL`,
- 5651 i. If `desc[GrB_MASK].GrB_STRUCTURE` is set, then $\tilde{\mathbf{m}} = \langle \text{size}(\text{mask}), \{i : i \in \text{ind}(\text{mask})\} \rangle$,
- 5652 ii. Otherwise, $\tilde{\mathbf{m}} = \langle \text{size}(\text{mask}), \{i : i \in \text{ind}(\text{mask}) \wedge (\text{bool})\text{mask}(i) = \text{true}\} \rangle$.
- 5653 (c) If `desc[GrB_MASK].GrB_COMP` is set, then $\tilde{\mathbf{m}} \leftarrow \neg \tilde{\mathbf{m}}$.
- 5654 3. Vector $\tilde{\mathbf{u}} \leftarrow \mathbf{u}$.

5655 The internal vectors and masks are checked for dimension compatibility. The following conditions
5656 must hold:

- 5657 1. $\text{size}(\tilde{\mathbf{w}}) = \text{size}(\tilde{\mathbf{m}})$
- 5658 2. $\text{size}(\tilde{\mathbf{u}}) = \text{size}(\tilde{\mathbf{w}})$.

5659 If any compatibility rule above is violated, execution of `GrB_apply` ends and the dimension mismatch
5660 error listed above is returned.

5661 From this point forward, in `GrB_NONBLOCKING` mode, the method can optionally exit with
5662 `GrB_SUCCESS` return code and defer any computation and/or execution error codes.

5663 We are now ready to carry out the apply and any additional associated operations. We describe
5664 this in terms of two intermediate vectors:

- 5665 • $\tilde{\mathbf{t}}$: The vector holding the result from applying the unary operator to the input vector $\tilde{\mathbf{u}}$.
- 5666 • $\tilde{\mathbf{z}}$: The vector holding the result after application of the (optional) accumulation operator.

5667 The intermediate vector, $\tilde{\mathbf{t}}$, is created as follows:

$$5668 \quad \tilde{\mathbf{t}} = \langle \mathbf{D}_{out}(\text{op}), \text{size}(\tilde{\mathbf{u}}), \{(i, f(\tilde{\mathbf{u}}(i))) \mid \forall i \in \mathbf{ind}(\tilde{\mathbf{u}})\} \rangle,$$

5669 where $f = \mathbf{f}(\text{op})$.

5670 The intermediate vector $\tilde{\mathbf{z}}$ is created as follows, using what is called a *standard vector accumulate*:

- 5671 • If `accum = GrB_NULL`, then $\tilde{\mathbf{z}} = \tilde{\mathbf{t}}$.
- 5672 • If `accum` is a binary operator, then $\tilde{\mathbf{z}}$ is defined as

$$5673 \quad \tilde{\mathbf{z}} = \langle \mathbf{D}_{out}(\text{accum}), \text{size}(\tilde{\mathbf{w}}), \{(i, z_i) \mid \forall i \in \mathbf{ind}(\tilde{\mathbf{w}}) \cup \mathbf{ind}(\tilde{\mathbf{t}})\} \rangle.$$

5674 The values of the elements of $\tilde{\mathbf{z}}$ are computed based on the relationships between the sets of
5675 indices in $\tilde{\mathbf{w}}$ and $\tilde{\mathbf{t}}$.

$$5676 \quad z_i = \tilde{\mathbf{w}}(i) \odot \tilde{\mathbf{t}}(i), \text{ if } i \in (\mathbf{ind}(\tilde{\mathbf{t}}) \cap \mathbf{ind}(\tilde{\mathbf{w}})),$$

$$5677 \quad z_i = \tilde{\mathbf{w}}(i), \text{ if } i \in (\mathbf{ind}(\tilde{\mathbf{w}}) - (\mathbf{ind}(\tilde{\mathbf{t}}) \cap \mathbf{ind}(\tilde{\mathbf{w}}))),$$

$$5678 \quad z_i = \tilde{\mathbf{t}}(i), \text{ if } i \in (\mathbf{ind}(\tilde{\mathbf{t}}) - (\mathbf{ind}(\tilde{\mathbf{t}}) \cap \mathbf{ind}(\tilde{\mathbf{w}}))),$$

$$5679$$

$$5680$$

5681 where $\odot = \odot(\text{accum})$, and the difference operator refers to set difference.

5682 Finally, the set of output values that make up vector $\tilde{\mathbf{z}}$ are written into the final result vector \mathbf{w} ,
5683 using what is called a *standard vector mask and replace*. This is carried out under control of the
5684 mask which acts as a “write mask”.

- 5685 • If `desc[GrB_OUTP].GrB_REPLACE` is set, then any values in \mathbf{w} on input to this operation are
5686 deleted and the content of the new output vector, \mathbf{w} , is defined as,

$$5687 \quad \mathbf{L}(\mathbf{w}) = \{(i, z_i) : i \in (\mathbf{ind}(\tilde{\mathbf{z}}) \cap \mathbf{ind}(\tilde{\mathbf{m}}))\}.$$

- 5688 • If `desc[GrB_OUTP].GrB_REPLACE` is not set, the elements of $\tilde{\mathbf{z}}$ indicated by the mask are
5689 copied into the result vector, \mathbf{w} , and elements of \mathbf{w} that fall outside the set indicated by the
5690 mask are unchanged:

$$5691 \quad \mathbf{L}(\mathbf{w}) = \{(i, w_i) : i \in (\mathbf{ind}(\mathbf{w}) \cap \mathbf{ind}(\neg \tilde{\mathbf{m}}))\} \cup \{(i, z_i) : i \in (\mathbf{ind}(\tilde{\mathbf{z}}) \cap \mathbf{ind}(\tilde{\mathbf{m}}))\}.$$

5692 In `GrB_BLOCKING` mode, the method exits with return value `GrB_SUCCESS` and the new content
5693 of vector \mathbf{w} is as defined above and fully computed. In `GrB_NONBLOCKING` mode, the method
5694 exits with return value `GrB_SUCCESS` and the new content of vector \mathbf{w} is as defined above but
5695 may not be fully computed. However, it can be used in the next GraphBLAS method call in a
5696 sequence.

5697 **4.3.8.2 apply: Matrix variant**

5698 Computes the transformation of the values of the elements of a matrix using a unary function.

5699 **C Syntax**

```

5700     GrB_Info GrB_apply(GrB_Matrix      C,
5701                       const GrB_Matrix Mask,
5702                       const GrB_BinaryOp accum,
5703                       const GrB_UnaryOp op,
5704                       const GrB_Matrix  A,
5705                       const GrB_Descriptor desc);

```

5706 **Parameters**

5707 **C (INOUT)** An existing GraphBLAS matrix. On input, the matrix provides values
5708 that may be accumulated with the result of the apply operation. On output, the
5709 matrix holds the results of the operation.

5710 **Mask (IN)** An optional “write” mask that controls which results from this operation are
5711 stored into the output matrix C. The mask dimensions must match those of the
5712 matrix C. If the GrB_STRUCTURE descriptor is *not* set for the mask, the domain
5713 of the Mask matrix must be of type bool or any of the predefined “built-in” types
5714 in Table 3.2. If the default mask is desired (i.e., a mask that is all true with the
5715 dimensions of C), GrB_NULL should be specified.

5716 **accum (IN)** An optional binary operator used for accumulating entries into existing C
5717 entries. If assignment rather than accumulation is desired, GrB_NULL should be
5718 specified.

5719 **op (IN)** A unary operator applied to each element of input matrix A.

5720 **A (IN)** The GraphBLAS matrix to which the unary function is applied.

5721 **desc (IN)** An optional operation descriptor. If a *default* descriptor is desired, GrB_NULL
5722 should be specified. Non-default field/value pairs are listed as follows:
5723

Param	Field	Value	Description
C	GrB_OUTP	GrB_REPLACE	Output matrix C is cleared (all elements removed) before the result is stored in it.
Mask	GrB_MASK	GrB_STRUCTURE	The write mask is constructed from the structure (pattern of stored values) of the input Mask matrix. The stored values are not examined.
Mask	GrB_MASK	GrB_COMP	Use the complement of Mask.
A	GrB_INP0	GrB_TRAN	Use transpose of A for the operation.

5724

5725 Return Values

5726 GrB_SUCCESS In blocking mode, the operation completed successfully. In non-
5727 blocking mode, this indicates that the compatibility tests on
5728 dimensions and domains for the input arguments passed suc-
5729 cessfully. Either way, output matrix C is ready to be used in the
5730 next method of the sequence.

5731 GrB_PANIC Unknown internal error.

5732 GrB_INVALID_OBJECT This is returned in any execution mode whenever one of the
5733 opaque GraphBLAS objects (input or output) is in an invalid
5734 state caused by a previous execution error. Call GrB_error() to
5735 access any error messages generated by the implementation.

5736 GrB_OUT_OF_MEMORY Not enough memory available for the operation.

5737 GrB_UNINITIALIZED_OBJECT One or more of the GraphBLAS objects has not been initialized
5738 by a call to new (or Matrix_dup for matrix parameters).

5739 GrB_DIMENSION_MISMATCH Mask and C dimensions are incompatible, nrows \neq nrows(C), or
5740 ncols \neq ncols(C).

5741 GrB_DOMAIN_MISMATCH The domains of the various matrices are incompatible with the
5742 corresponding domains of the accumulation operator or unary
5743 function, or the mask's domain is not compatible with bool (in
5744 the case where desc[GrB_MASK].GrB_STRUCTURE is not set).

5745 Description

5746 This variant of GrB_apply computes the result of applying a unary function to the elements of a
5747 GraphBLAS matrix: $C = f(A)$; or, if an optional binary accumulation operator (\odot) is provided,
5748 $C = C \odot f(A)$.

5749 Logically, this operation occurs in three steps:

5750 **Setup** The internal matrices and mask used in the computation are formed and their domains
5751 and dimensions are tested for compatibility.

5752 **Compute** The indicated computations are carried out.

5753 **Output** The result is written into the output matrix, possibly under control of a mask.

5754 Up to three argument matrices are used in the GrB_apply operation:

- 5755 1. $C = \langle \mathbf{D}(C), \mathbf{nrows}(C), \mathbf{ncols}(C), \mathbf{L}(C) = \{(i, j, C_{ij})\} \rangle$
- 5756 2. $\text{Mask} = \langle \mathbf{D}(\text{Mask}), \mathbf{nrows}(\text{Mask}), \mathbf{ncols}(\text{Mask}), \mathbf{L}(\text{Mask}) = \{(i, j, M_{ij})\} \rangle$ (optional)

5757 3. $\mathbf{A} = \langle \mathbf{D}(\mathbf{A}), \mathbf{nrows}(\mathbf{A}), \mathbf{ncols}(\mathbf{A}), \mathbf{L}(\mathbf{A}) = \{(i, j, A_{ij})\} \rangle$

5758 The argument matrices, unary operator and the accumulation operator (if provided) are tested for
5759 domain compatibility as follows:

5760 1. If `Mask` is not `GrB_NULL`, and `desc[GrB_MASK].GrB_STRUCTURE` is not set, then $\mathbf{D}(\text{Mask})$
5761 must be from one of the pre-defined types of Table 3.2.

5762 2. $\mathbf{D}(\mathbf{C})$ must be compatible with $\mathbf{D}_{out}(\text{op})$ of the unary operator.

5763 3. If `accum` is not `GrB_NULL`, then $\mathbf{D}(\mathbf{C})$ must be compatible with $\mathbf{D}_{in_1}(\text{accum})$ and $\mathbf{D}_{out}(\text{accum})$
5764 of the accumulation operator and $\mathbf{D}_{out}(\text{op})$ of the unary operator must be compatible with
5765 $\mathbf{D}_{in_2}(\text{accum})$ of the accumulation operator.

5766 4. $\mathbf{D}(\mathbf{A})$ must be compatible with $\mathbf{D}_{in}(\text{op})$ of the unary operator.

5767 Two domains are compatible with each other if values from one domain can be cast to values in
5768 the other domain as per the rules of the C language. In particular, domains from Table 3.2 are all
5769 compatible with each other. A domain from a user-defined type is only compatible with itself. If
5770 any compatibility rule above is violated, execution of `GrB_apply` ends and the domain mismatch
5771 error listed above is returned.

5772 From the argument matrices, the internal matrices, `mask`, and index arrays used in the computation
5773 are formed (\leftarrow denotes copy):

5774 1. Matrix $\tilde{\mathbf{C}} \leftarrow \mathbf{C}$.

5775 2. Two-dimensional mask, $\tilde{\mathbf{M}}$, is computed from argument `Mask` as follows:

5776 (a) If `Mask = GrB_NULL`, then $\tilde{\mathbf{M}} = \langle \mathbf{nrows}(\mathbf{C}), \mathbf{ncols}(\mathbf{C}), \{(i, j), \forall i, j : 0 \leq i < \mathbf{nrows}(\mathbf{C}), 0 \leq$
5777 $j < \mathbf{ncols}(\mathbf{C})\} \rangle$.

5778 (b) If `Mask \neq GrB_NULL`,

5779 i. If `desc[GrB_MASK].GrB_STRUCTURE` is set, then $\tilde{\mathbf{M}} = \langle \mathbf{nrows}(\text{Mask}), \mathbf{ncols}(\text{Mask}), \{(i, j) :$
5780 $(i, j) \in \mathbf{ind}(\text{Mask})\} \rangle$,

5781 ii. Otherwise, $\tilde{\mathbf{M}} = \langle \mathbf{nrows}(\text{Mask}), \mathbf{ncols}(\text{Mask}),$
5782 $\{(i, j) : (i, j) \in \mathbf{ind}(\text{Mask}) \wedge (\text{bool})\text{Mask}(i, j) = \text{true}\} \rangle$.

5783 (c) If `desc[GrB_MASK].GrB_COMP` is set, then $\tilde{\mathbf{M}} \leftarrow \neg \tilde{\mathbf{M}}$.

5784 3. Matrix $\tilde{\mathbf{A}} \leftarrow \text{desc}[\text{GrB_INP0}].\text{GrB_TRAN} ? \mathbf{A}^T : \mathbf{A}$.

5785 The internal matrices and mask are checked for dimension compatibility. The following conditions
5786 must hold:

5787 1. $\mathbf{nrows}(\tilde{\mathbf{C}}) = \mathbf{nrows}(\tilde{\mathbf{M}})$.

5788 2. $\mathbf{ncols}(\tilde{\mathbf{C}}) = \mathbf{ncols}(\tilde{\mathbf{M}})$.

5789 3. $\mathbf{nrows}(\tilde{\mathbf{C}}) = \mathbf{nrows}(\tilde{\mathbf{A}})$.

5790 4. $\mathbf{ncols}(\tilde{\mathbf{C}}) = \mathbf{ncols}(\tilde{\mathbf{A}})$.

5791 If any compatibility rule above is violated, execution of `GrB_apply` ends and the dimension mismatch
5792 error listed above is returned.

5793 From this point forward, in `GrB_NONBLOCKING` mode, the method can optionally exit with
5794 `GrB_SUCCESS` return code and defer any computation and/or execution error codes.

5795 We are now ready to carry out the apply and any additional associated operations. We describe
5796 this in terms of two intermediate matrices:

- 5797 • $\tilde{\mathbf{T}}$: The matrix holding the result from applying the unary operator to the input matrix $\tilde{\mathbf{A}}$.
- 5798 • $\tilde{\mathbf{Z}}$: The matrix holding the result after application of the (optional) accumulation operator.

5799 The intermediate matrix, $\tilde{\mathbf{T}}$, is created as follows:

$$5800 \quad \tilde{\mathbf{T}} = \langle \mathbf{D}_{out}(\mathbf{op}), \mathbf{nrows}(\tilde{\mathbf{C}}), \mathbf{ncols}(\tilde{\mathbf{C}}), \{(i, j, f(\tilde{\mathbf{A}}(i, j))) \mid \forall (i, j) \in \mathbf{ind}(\tilde{\mathbf{A}})\} \rangle,$$

5801 where $f = \mathbf{f}(\mathbf{op})$.

5802 The intermediate matrix $\tilde{\mathbf{Z}}$ is created as follows, using what is called a *standard matrix accumulate*:

- 5803 • If `accum = GrB_NULL`, then $\tilde{\mathbf{Z}} = \tilde{\mathbf{T}}$.
- 5804 • If `accum` is a binary operator, then $\tilde{\mathbf{Z}}$ is defined as

$$5805 \quad \tilde{\mathbf{Z}} = \langle \mathbf{D}_{out}(\mathbf{accum}), \mathbf{nrows}(\tilde{\mathbf{C}}), \mathbf{ncols}(\tilde{\mathbf{C}}), \{(i, j, Z_{ij}) \mid \forall (i, j) \in \mathbf{ind}(\tilde{\mathbf{C}}) \cup \mathbf{ind}(\tilde{\mathbf{T}})\} \rangle.$$

5806 The values of the elements of $\tilde{\mathbf{Z}}$ are computed based on the relationships between the sets of
5807 indices in $\tilde{\mathbf{C}}$ and $\tilde{\mathbf{T}}$.

$$5808 \quad Z_{ij} = \tilde{\mathbf{C}}(i, j) \odot \tilde{\mathbf{T}}(i, j), \text{ if } (i, j) \in (\mathbf{ind}(\tilde{\mathbf{T}}) \cap \mathbf{ind}(\tilde{\mathbf{C}})),$$

$$5809 \quad Z_{ij} = \tilde{\mathbf{C}}(i, j), \text{ if } (i, j) \in (\mathbf{ind}(\tilde{\mathbf{C}}) - (\mathbf{ind}(\tilde{\mathbf{T}}) \cap \mathbf{ind}(\tilde{\mathbf{C}}))),$$

$$5810 \quad Z_{ij} = \tilde{\mathbf{T}}(i, j), \text{ if } (i, j) \in (\mathbf{ind}(\tilde{\mathbf{T}}) - (\mathbf{ind}(\tilde{\mathbf{T}}) \cap \mathbf{ind}(\tilde{\mathbf{C}}))),$$

$$5811 \quad Z_{ij} = \tilde{\mathbf{T}}(i, j), \text{ if } (i, j) \in (\mathbf{ind}(\tilde{\mathbf{T}}) - (\mathbf{ind}(\tilde{\mathbf{T}}) \cap \mathbf{ind}(\tilde{\mathbf{C}}))),$$

$$5812 \quad Z_{ij} = \tilde{\mathbf{T}}(i, j), \text{ if } (i, j) \in (\mathbf{ind}(\tilde{\mathbf{T}}) - (\mathbf{ind}(\tilde{\mathbf{T}}) \cap \mathbf{ind}(\tilde{\mathbf{C}}))),$$

5813 where $\odot = \odot(\mathbf{accum})$, and the difference operator refers to set difference.

5814 Finally, the set of output values that make up matrix $\tilde{\mathbf{Z}}$ are written into the final result matrix \mathbf{C} ,
5815 using what is called a *standard matrix mask and replace*. This is carried out under control of the
5816 mask which acts as a “write mask”.

- 5817 • If `desc[GrB_OUTP].GrB_REPLACE` is set, then any values in \mathbf{C} on input to this operation are
5818 deleted and the content of the new output matrix, \mathbf{C} , is defined as,

$$5819 \quad \mathbf{L}(\mathbf{C}) = \{(i, j, Z_{ij}) : (i, j) \in (\mathbf{ind}(\tilde{\mathbf{Z}}) \cap \mathbf{ind}(\tilde{\mathbf{M}}))\}.$$

- If desc[GrB_OUTP].GrB_REPLACE is not set, the elements of $\tilde{\mathbf{Z}}$ indicated by the mask are copied into the result matrix, C, and elements of C that fall outside the set indicated by the mask are unchanged:

$$\mathbf{L}(\mathbf{C}) = \{(i, j, C_{ij}) : (i, j) \in (\mathbf{ind}(\mathbf{C}) \cap \mathbf{ind}(\neg\tilde{\mathbf{M}}))\} \cup \{(i, j, Z_{ij}) : (i, j) \in (\mathbf{ind}(\tilde{\mathbf{Z}}) \cap \mathbf{ind}(\tilde{\mathbf{M}}))\}.$$

In GrB_BLOCKING mode, the method exits with return value GrB_SUCCESS and the new content of matrix C is as defined above and fully computed. In GrB_NONBLOCKING mode, the method exits with return value GrB_SUCCESS and the new content of matrix C is as defined above but may not be fully computed. However, it can be used in the next GraphBLAS method call in a sequence.

4.3.8.3 apply: Vector-BinaryOp variants

Computes the transformation of the values of the stored elements of a vector using a binary operator and a scalar value. In the *bind-first* variant, the specified scalar value is passed as the first argument to the binary operator and stored elements of the vector are passed as the second argument. In the *bind-second* variant, the elements of the vector are passed as the first argument and the specified scalar value is passed as the second argument. The scalar can be passed either as a non-opaque variable or as a GrB_Scalar object.

C Syntax

```

5837 // bind-first + scalar value
5838 GrB_Info GrB_apply(GrB_Vector          w,
5839                  const GrB_Vector      mask,
5840                  const GrB_BinaryOp    accum,
5841                  const GrB_BinaryOp    op,
5842                  <type>                val,
5843                  const GrB_Vector      u,
5844                  const GrB_Descriptor   desc);

5845 // bind-first + GraphBLAS scalar
5846 GrB_Info GrB_apply(GrB_Vector          w,
5847                  const GrB_Vector      mask,
5848                  const GrB_BinaryOp    accum,
5849                  const GrB_BinaryOp    op,
5850                  const GrB_Scalar      s,
5851                  const GrB_Vector      u,
5852                  const GrB_Descriptor   desc);

5853 // bind-second + scalar value
5854 GrB_Info GrB_apply(GrB_Vector          w,
5855                  const GrB_Vector      mask,
```

```

5856         const GrB_BinaryOp    accum,
5857         const GrB_BinaryOp    op,
5858         const GrB_Vector      u,
5859         <type>                val,
5860         const GrB_Descriptor  desc);

5861 // bind-second + GraphBLAS scalar
5862 GrB_Info GrB_apply(GrB_Vector      w,
5863                  const GrB_Vector  mask,
5864                  const GrB_BinaryOp accum,
5865                  const GrB_BinaryOp op,
5866                  const GrB_Vector  u,
5867                  const GrB_Scalar  s,
5868                  const GrB_Descriptor desc);

```

5869 Parameters

- 5870 **w** (INOUT) An existing GraphBLAS vector. On input, the vector provides values
5871 that may be accumulated with the result of the apply operation. On output, this
5872 vector holds the results of the operation.
- 5873 **mask** (IN) An optional “write” mask that controls which results from this operation are
5874 stored into the output vector *w*. The mask dimensions must match those of the
5875 vector *w*. If the `GrB_STRUCTURE` descriptor is *not* set for the mask, the domain
5876 of the mask vector must be of type `bool` or any of the predefined “built-in” types
5877 in Table 3.2. If the default mask is desired (i.e., a mask that is all true with the
5878 dimensions of *w*), `GrB_NULL` should be specified.
- 5879 **accum** (IN) An optional binary operator used for accumulating entries into existing *w*
5880 entries. If assignment rather than accumulation is desired, `GrB_NULL` should be
5881 specified.
- 5882 **op** (IN) A binary operator applied to each element of input vector, *u*, and the scalar
5883 value, *val*.
- 5884 **u** (IN) The GraphBLAS vector whose elements are passed to the binary operator as
5885 the right-hand (second) argument in the *bind-first* variant, or the left-hand (first)
5886 argument in the *bind-second* variant.
- 5887 **val** (IN) Scalar value that is passed to the binary operator as the left-hand (first)
5888 argument in the *bind-first* variant, or the right-hand (second) argument in the
5889 *bind-second* variant.
- 5890 **s** (IN) A GraphBLAS scalar that is passed to the binary operator as the left-hand
5891 (first) argument in the *bind-first* variant, or the right-hand (second) argument in
5892 the *bind-second* variant. It must not be empty.

5893
5894
5895

desc (IN) An optional operation descriptor. If a *default* descriptor is desired, GrB_NULL should be specified. Non-default field/value pairs are listed as follows:

Param	Field	Value	Description
w	GrB_OUTP	GrB_REPLACE	Output vector w is cleared (all elements removed) before the result is stored in it.
mask	GrB_MASK	GrB_STRUCTURE	The write mask is constructed from the structure (pattern of stored values) of the input mask vector. The stored values are not examined.
mask	GrB_MASK	GrB_COMP	Use the complement of mask.

5896

5897 Return Values

5898
5899
5900
5901
5902

GrB_SUCCESS In blocking mode, the operation completed successfully. In non-blocking mode, this indicates that the compatibility tests on dimensions and domains for the input arguments passed successfully. Either way, output vector w is ready to be used in the next method of the sequence.

5903

GrB_PANIC Unknown internal error.

5904
5905
5906
5907

GrB_INVALID_OBJECT This is returned in any execution mode whenever one of the opaque GraphBLAS objects (input or output) is in an invalid state caused by a previous execution error. Call GrB_error() to access any error messages generated by the implementation.

5908

GrB_OUT_OF_MEMORY Not enough memory available for operation.

5909
5910

GrB_UNINITIALIZED_OBJECT One or more of the GraphBLAS objects has not been initialized by a call to new (or dup for vector parameters).

5911

GrB_DIMENSION_MISMATCH mask, w and/or u dimensions are incompatible.

5912
5913
5914
5915

GrB_DOMAIN_MISMATCH The domains of the various vectors and scalar are incompatible with the corresponding domains of the binary operator or accumulation operator, or the mask's domain is not compatible with bool (in the case where desc[GrB_MASK].GrB_STRUCTURE is not set).

5916
5917

GrB_EMPTY_OBJECT The GrB_Scalar s used in the call is empty (nvals(s) = 0) and therefore a value cannot be passed to the binary operator.

5918 Description

5919
5920

This variant of GrB_apply computes the result of applying a binary operator to the elements of a GraphBLAS vector each composed with a scalar constant, either val or s:

5921 bind-first: $w = f(\text{val}, u)$ or $w = f(s, u)$

5922 bind-second: $w = f(u, \text{val})$ or $w = f(u, s)$,

5923 or if an optional binary accumulation operator (\odot) is provided:

5924 bind-first: $w = w \odot f(\text{val}, u)$ or $w = w \odot f(s, u)$

5925 bind-second: $w = w \odot f(u, \text{val})$ or $w = w \odot f(u, s)$.

5926 Logically, this operation occurs in three steps:

5927 **Setup** The internal vectors and mask used in the computation are formed and their domains
5928 and dimensions are tested for compatibility.

5929 **Compute** The indicated computations are carried out.

5930 **Output** The result is written into the output vector, possibly under control of a mask.

5931 Up to three argument vectors are used in this GrB_apply operation:

5932 1. $w = \langle \mathbf{D}(w), \mathbf{size}(w), \mathbf{L}(w) = \{(i, w_i)\} \rangle$

5933 2. $\text{mask} = \langle \mathbf{D}(\text{mask}), \mathbf{size}(\text{mask}), \mathbf{L}(\text{mask}) = \{(i, m_i)\} \rangle$ (optional)

5934 3. $u = \langle \mathbf{D}(u), \mathbf{size}(u), \mathbf{L}(u) = \{(i, u_i)\} \rangle$

5935 The argument scalar, vectors, binary operator and the accumulation operator (if provided) are
5936 tested for domain compatibility as follows:

5937 1. If **mask** is not GrB_NULL, and desc[GrB_MASK].GrB_STRUCTURE is not set, then $\mathbf{D}(\text{mask})$
5938 must be from one of the pre-defined types of Table 3.2.

5939 2. $\mathbf{D}(w)$ must be compatible with $\mathbf{D}_{out}(\text{op})$ of the binary operator.

5940 3. If **accum** is not GrB_NULL, then $\mathbf{D}(w)$ must be compatible with $\mathbf{D}_{in_1}(\text{accum})$ and $\mathbf{D}_{out}(\text{accum})$
5941 of the accumulation operator and $\mathbf{D}_{out}(\text{op})$ of the binary operator must be compatible with
5942 $\mathbf{D}_{in_2}(\text{accum})$ of the accumulation operator.

5943 4. $\mathbf{D}(u)$ must be compatible with $\mathbf{D}_{in_1}(\text{op})$ of the binary operator.

5944 5. If bind-first:

5945 (a) $\mathbf{D}(u)$ must be compatible with $\mathbf{D}_{in_2}(\text{op})$ of the binary operator.

5946 (b) If the non-opaque scalar **val** is provided, then $\mathbf{D}(\text{val})$ must be compatible with $\mathbf{D}_{in_1}(\text{op})$
5947 of the binary operator.

5948 (c) If the GrB_Scalar **s** is provided, then $\mathbf{D}(s)$ must be compatible with $\mathbf{D}_{in_1}(\text{op})$ of the
5949 binary operator.

- 5950 6. If bind-second:
- 5951 (a) $\mathbf{D}(\mathbf{u})$ must be compatible with $\mathbf{D}_{in_1}(\mathbf{op})$ of the binary operator.
- 5952 (b) If the non-opaque scalar \mathbf{val} is provided, then $\mathbf{D}(\mathbf{val})$ must be compatible with $\mathbf{D}_{in_2}(\mathbf{op})$
- 5953 of the binary operator.
- 5954 (c) If the `GrB_Scalar` \mathbf{s} is provided, then $\mathbf{D}(\mathbf{s})$ must be compatible with $\mathbf{D}_{in_2}(\mathbf{op})$ of the
- 5955 binary operator.

5956 Two domains are compatible with each other if values from one domain can be cast to values in

5957 the other domain as per the rules of the C language. In particular, domains from Table 3.2 are all

5958 compatible with each other. A domain from a user-defined type is only compatible with itself. If

5959 any compatibility rule above is violated, execution of `GrB_apply` ends and the domain mismatch

5960 error listed above is returned.

5961 From the argument vectors, the internal vectors and mask used in the computation are formed (\leftarrow

5962 denotes copy):

- 5963 1. Vector $\tilde{\mathbf{w}} \leftarrow \mathbf{w}$.
- 5964 2. One-dimensional mask, $\tilde{\mathbf{m}}$, is computed from argument `mask` as follows:
- 5965 (a) If `mask = GrB_NULL`, then $\tilde{\mathbf{m}} = \langle \mathbf{size}(\mathbf{w}), \{i, \forall i : 0 \leq i < \mathbf{size}(\mathbf{w})\} \rangle$.
- 5966 (b) If `mask \neq GrB_NULL`,
- 5967 i. If `desc[GrB_MASK].GrB_STRUCTURE` is set, then $\tilde{\mathbf{m}} = \langle \mathbf{size}(\mathbf{mask}), \{i : i \in \mathbf{ind}(\mathbf{mask})\} \rangle$,
- 5968 ii. Otherwise, $\tilde{\mathbf{m}} = \langle \mathbf{size}(\mathbf{mask}), \{i : i \in \mathbf{ind}(\mathbf{mask}) \wedge (\mathbf{bool})\mathbf{mask}(i) = \mathbf{true}\} \rangle$.
- 5969 (c) If `desc[GrB_MASK].GrB_COMP` is set, then $\tilde{\mathbf{m}} \leftarrow \neg \tilde{\mathbf{m}}$.
- 5970 3. Vector $\tilde{\mathbf{u}} \leftarrow \mathbf{u}$.
- 5971 4. Scalar $\tilde{\mathbf{s}} \leftarrow \mathbf{s}$ (`GraphBLAS` scalar case).

5972 The internal vectors and masks are checked for dimension compatibility. The following conditions

5973 must hold:

- 5974 1. $\mathbf{size}(\tilde{\mathbf{w}}) = \mathbf{size}(\tilde{\mathbf{m}})$
- 5975 2. $\mathbf{size}(\tilde{\mathbf{u}}) = \mathbf{size}(\tilde{\mathbf{w}})$.

5976 If any compatibility rule above is violated, execution of `GrB_apply` ends and the dimension mismatch

5977 error listed above is returned.

5978 From this point forward, in `GrB_NONBLOCKING` mode, the method can optionally exit with

5979 `GrB_SUCCESS` return code and defer any computation and/or execution error codes.

5980 If an empty `GrB_Scalar` $\tilde{\mathbf{s}}$ is provided ($\mathbf{nvals}(\tilde{\mathbf{s}}) = 0$), the method returns with code `GrB_EMPTY_OBJECT`.

5981 If a non-empty `GrB_Scalar`, $\tilde{\mathbf{s}}$, is provided (i.e., $\mathbf{nvals}(\tilde{\mathbf{s}}) = 1$), we then create an internal variable

5982 `val` with the same domain as $\tilde{\mathbf{s}}$ and set `val = val($\tilde{\mathbf{s}}$)`.

5983 We are now ready to carry out the apply and any additional associated operations. We describe

5984 this in terms of two intermediate vectors:

- 5985 • $\tilde{\mathbf{t}}$: The vector holding the result from applying the binary operator to the input vector $\tilde{\mathbf{u}}$.
- 5986 • $\tilde{\mathbf{z}}$: The vector holding the result after application of the (optional) accumulation operator.

5987 The intermediate vector, $\tilde{\mathbf{t}}$, is created as one of the following:

$$5988 \quad \text{bind-first:} \quad \tilde{\mathbf{t}} = \langle \mathbf{D}_{out}(\text{op}), \mathbf{size}(\tilde{\mathbf{u}}), \{(i, f(\text{val}, \tilde{\mathbf{u}}(i))) \forall i \in \mathbf{ind}(\tilde{\mathbf{u}})\} \rangle,$$

$$5989 \quad \text{bind-second:} \quad \tilde{\mathbf{t}} = \langle \mathbf{D}_{out}(\text{op}), \mathbf{size}(\tilde{\mathbf{u}}), \{(i, f(\tilde{\mathbf{u}}(i), \text{val})) \forall i \in \mathbf{ind}(\tilde{\mathbf{u}})\} \rangle,$$

5990 where $f = \mathbf{f}(\text{op})$.

5991 The intermediate vector $\tilde{\mathbf{z}}$ is created as follows, using what is called a *standard vector accumulate*:

- 5992 • If `accum = GrB_NULL`, then $\tilde{\mathbf{z}} = \tilde{\mathbf{t}}$.
- 5993 • If `accum` is a binary operator, then $\tilde{\mathbf{z}}$ is defined as

$$5994 \quad \tilde{\mathbf{z}} = \langle \mathbf{D}_{out}(\text{accum}), \mathbf{size}(\tilde{\mathbf{w}}), \{(i, z_i) \mid \forall i \in \mathbf{ind}(\tilde{\mathbf{w}}) \cup \mathbf{ind}(\tilde{\mathbf{t}})\} \rangle.$$

5995 The values of the elements of $\tilde{\mathbf{z}}$ are computed based on the relationships between the sets of
5996 indices in $\tilde{\mathbf{w}}$ and $\tilde{\mathbf{t}}$.

$$5997 \quad z_i = \tilde{\mathbf{w}}(i) \odot \tilde{\mathbf{t}}(i), \text{ if } i \in (\mathbf{ind}(\tilde{\mathbf{t}}) \cap \mathbf{ind}(\tilde{\mathbf{w}})),$$

$$5998$$

$$5999 \quad z_i = \tilde{\mathbf{w}}(i), \text{ if } i \in (\mathbf{ind}(\tilde{\mathbf{w}}) - (\mathbf{ind}(\tilde{\mathbf{t}}) \cap \mathbf{ind}(\tilde{\mathbf{w}}))),$$

$$6000$$

$$6001 \quad z_i = \tilde{\mathbf{t}}(i), \text{ if } i \in (\mathbf{ind}(\tilde{\mathbf{t}}) - (\mathbf{ind}(\tilde{\mathbf{t}}) \cap \mathbf{ind}(\tilde{\mathbf{w}}))),$$

6002 where $\odot = \odot(\text{accum})$, and the difference operator refers to set difference.

6003 Finally, the set of output values that make up vector $\tilde{\mathbf{z}}$ are written into the final result vector \mathbf{w} ,
6004 using what is called a *standard vector mask and replace*. This is carried out under control of the
6005 mask which acts as a “write mask”.

- 6006 • If `desc[GrB_OUTP].GrB_REPLACE` is set, then any values in \mathbf{w} on input to this operation are
6007 deleted and the content of the new output vector, \mathbf{w} , is defined as,

$$6008 \quad \mathbf{L}(\mathbf{w}) = \{(i, z_i) : i \in (\mathbf{ind}(\tilde{\mathbf{z}}) \cap \mathbf{ind}(\tilde{\mathbf{m}}))\}.$$

- 6009 • If `desc[GrB_OUTP].GrB_REPLACE` is not set, the elements of $\tilde{\mathbf{z}}$ indicated by the mask are
6010 copied into the result vector, \mathbf{w} , and elements of \mathbf{w} that fall outside the set indicated by the
6011 mask are unchanged:

$$6012 \quad \mathbf{L}(\mathbf{w}) = \{(i, w_i) : i \in (\mathbf{ind}(\mathbf{w}) \cap \mathbf{ind}(\neg\tilde{\mathbf{m}}))\} \cup \{(i, z_i) : i \in (\mathbf{ind}(\tilde{\mathbf{z}}) \cap \mathbf{ind}(\tilde{\mathbf{m}}))\}.$$

6013 In `GrB_BLOCKING` mode, the method exits with return value `GrB_SUCCESS` and the new content
6014 of vector \mathbf{w} is as defined above and fully computed. In `GrB_NONBLOCKING` mode, the method
6015 exits with return value `GrB_SUCCESS` and the new content of vector \mathbf{w} is as defined above but
6016 may not be fully computed. However, it can be used in the next GraphBLAS method call in a
6017 sequence.

6018 4.3.8.4 apply: Matrix-BinaryOp variants

6019 Computes the transformation of the values of the stored elements of a matrix using a binary
6020 operator and a scalar value. In the *bind-first* variant, the specified scalar value is passed as the
6021 first argument to the binary operator and stored elements of the matrix are passed as the second
6022 argument. In the *bind-second* variant, the elements of the matrix are passed as the first argument
6023 and the specified scalar value is passed as the second argument. The scalar can be passed either as
6024 a non-opaque variable or as a GrB_Scalar object.

6025 C Syntax

```
6026 // bind-first + scalar value
6027 GrB_Info GrB_apply(GrB_Matrix      C,
6028                   const GrB_Matrix Mask,
6029                   const GrB_BinaryOp accum,
6030                   const GrB_BinaryOp op,
6031                   <type>          val,
6032                   const GrB_Matrix A,
6033                   const GrB_Descriptor desc);
```

```
6034 // bind-first + GraphBLAS scalar
6035 GrB_Info GrB_apply(GrB_Matrix      C,
6036                   const GrB_Matrix Mask,
6037                   const GrB_BinaryOp accum,
6038                   const GrB_BinaryOp op,
6039                   const GrB_Scalar s,
6040                   const GrB_Matrix A,
6041                   const GrB_Descriptor desc);
```

```
6042 // bind-second + scalar value
6043 GrB_Info GrB_apply(GrB_Matrix      C,
6044                   const GrB_Matrix Mask,
6045                   const GrB_BinaryOp accum,
6046                   const GrB_BinaryOp op,
6047                   const GrB_Matrix A,
6048                   <type>          val,
6049                   const GrB_Descriptor desc);
```

```
6050 // bind-second + GraphBLAS scalar
6051 GrB_Info GrB_apply(GrB_Matrix      C,
6052                   const GrB_Matrix Mask,
6053                   const GrB_BinaryOp accum,
6054                   const GrB_BinaryOp op,
6055                   const GrB_Matrix A,
```

```
6056         const GrB_Scalar      s,  
6057         const GrB_Descriptor desc);
```

6058 Parameters

6059 **C** (INOUT) An existing GraphBLAS matrix. On input, the matrix provides values
6060 that may be accumulated with the result of the apply operation. On output, the
6061 matrix holds the results of the operation.

6062 **Mask** (IN) An optional “write” mask that controls which results from this operation are
6063 stored into the output matrix C. The mask dimensions must match those of the
6064 matrix C. If the GrB_STRUCTURE descriptor is *not* set for the mask, the domain
6065 of the Mask matrix must be of type `bool` or any of the predefined “built-in” types
6066 in Table 3.2. If the default mask is desired (i.e., a mask that is all true with the
6067 dimensions of C), GrB_NULL should be specified.

6068 **accum** (IN) An optional binary operator used for accumulating entries into existing C
6069 entries. If assignment rather than accumulation is desired, GrB_NULL should be
6070 specified.

6071 **op** (IN) A binary operator applied to each element of input matrix, A, with the element
6072 of the input matrix used as the left-hand argument, and the scalar value, val, used
6073 as the right-hand argument.

6074 **A** (IN) The GraphBLAS matrix whose elements are passed to the binary operator as
6075 the right-hand (second) argument in the *bind-first* variant, or the left-hand (first)
6076 argument in the *bind-second* variant.

6077 **val** (IN) Scalar value that is passed to the binary operator as the left-hand (first)
6078 argument in the *bind-first* variant, or the right-hand (second) argument in the
6079 *bind-second* variant.

6080 **s** (IN) GraphBLAS scalar value that is passed to the binary operator as the left-hand
6081 (first) argument in the *bind-first* variant, or the right-hand (second) argument in
6082 the *bind-second* variant. It must not be empty.

6083 **desc** (IN) An optional operation descriptor. If a *default* descriptor is desired, GrB_NULL
6084 should be specified. Non-default field/value pairs are listed as follows:
6085

Param	Field	Value	Description
C	GrB_OUTP	GrB_REPLACE	Output matrix C is cleared (all elements removed) before the result is stored in it.
Mask	GrB_MASK	GrB_STRUCTURE	The write mask is constructed from the structure (pattern of stored values) of the input Mask matrix. The stored values are not examined.
Mask	GrB_MASK	GrB_COMP	Use the complement of Mask.
A	GrB_INP0	GrB_TRAN	Use transpose of A for the operation (<i>bind-second</i> variant only).
A	GrB_INP1	GrB_TRAN	Use transpose of A for the operation (<i>bind-first</i> variant only).

6086

6087 Return Values

6088 GrB_SUCCESS In blocking mode, the operation completed successfully. In non-
6089 blocking mode, this indicates that the compatibility tests on
6090 dimensions and domains for the input arguments passed suc-
6091 cessfully. Either way, output matrix C is ready to be used in the
6092 next method of the sequence.

6093 GrB_PANIC Unknown internal error.

6094 GrB_INVALID_OBJECT This is returned in any execution mode whenever one of the
6095 opaque GraphBLAS objects (input or output) is in an invalid
6096 state caused by a previous execution error. Call GrB_error() to
6097 access any error messages generated by the implementation.

6098 GrB_OUT_OF_MEMORY Not enough memory available for the operation.

6099 GrB_UNINITIALIZED_OBJECT One or more of the GraphBLAS objects has not been initialized
6100 by a call to new (or Matrix_dup for matrix parameters).

6101 GrB_INDEX_OUT_OF_BOUNDS A value in row_indices is greater than or equal to nrows(A), or
6102 a value in col_indices is greater than or equal to ncols(A). In
6103 non-blocking mode, this can be reported as an execution error.

6104 GrB_DIMENSION_MISMATCH Mask and C dimensions are incompatible, nrow \neq nrow(C), or
6105 ncol \neq ncol(C).

6106 GrB_DOMAIN_MISMATCH The domains of the various matrices and scalar are incompatible
6107 with the corresponding domains of the binary operator or accu-
6108 mulation operator, or the mask's domain is not compatible with
6109 bool (in the case where desc[GrB_MASK].GrB_STRUCTURE is
6110 not set).

6111 GrB_EMPTY_OBJECT The GrB_Scalar s used in the call is empty (nvals(s) = 0) and
6112 therefore a value cannot be passed to the binary operator.

6113 **Description**

6114 This variant of `GrB_apply` computes the result of applying a binary operator to the elements of a
6115 GraphBLAS matrix each composed with a scalar constant, `val` or `s`:

6116 bind-first: $C = f(\text{val}, A)$ or $C = f(s, A)$

6117 bind-second: $C = f(A, \text{val})$ or $C = f(A, s)$,

6118 or if an optional binary accumulation operator (\odot) is provided:

6119 bind-first: $C = C \odot f(\text{val}, A)$ or $C = C \odot f(s, A)$

6120 bind-second: $C = C \odot f(A, \text{val})$ or $C = C \odot f(A, s)$.

6121 Logically, this operation occurs in three steps:

6122 **Setup** The internal matrices and mask used in the computation are formed and their domains
6123 and dimensions are tested for compatibility.

6124 **Compute** The indicated computations are carried out.

6125 **Output** The result is written into the output matrix, possibly under control of a mask.

6126 Up to three argument matrices are used in the `GrB_apply` operation:

6127 1. $C = \langle \mathbf{D}(C), \mathbf{nrows}(C), \mathbf{ncols}(C), \mathbf{L}(C) = \{(i, j, C_{ij})\} \rangle$

6128 2. $\text{Mask} = \langle \mathbf{D}(\text{Mask}), \mathbf{nrows}(\text{Mask}), \mathbf{ncols}(\text{Mask}), \mathbf{L}(\text{Mask}) = \{(i, j, M_{ij})\} \rangle$ (optional)

6129 3. $A = \langle \mathbf{D}(A), \mathbf{nrows}(A), \mathbf{ncols}(A), \mathbf{L}(A) = \{(i, j, A_{ij})\} \rangle$

6130 The argument scalar, matrices, binary operator and the accumulation operator (if provided) are
6131 tested for domain compatibility as follows:

6132 1. If `Mask` is not `GrB_NULL`, and `desc[GrB_MASK].GrB_STRUCTURE` is not set, then $\mathbf{D}(\text{Mask})$
6133 must be from one of the pre-defined types of Table 3.2.

6134 2. $\mathbf{D}(C)$ must be compatible with $\mathbf{D}_{out}(\text{op})$ of the binary operator.

6135 3. If `accum` is not `GrB_NULL`, then $\mathbf{D}(C)$ must be compatible with $\mathbf{D}_{in_1}(\text{accum})$ and $\mathbf{D}_{out}(\text{accum})$
6136 of the accumulation operator and $\mathbf{D}_{out}(\text{op})$ of the binary operator must be compatible with
6137 $\mathbf{D}_{in_2}(\text{accum})$ of the accumulation operator.

6138 4. $\mathbf{D}(A)$ must be compatible with $\mathbf{D}_{in_1}(\text{op})$ of the binary operator.

6139 5. If bind-first:

6140 (a) $\mathbf{D}(A)$ must be compatible with $\mathbf{D}_{in_2}(\text{op})$ of the binary operator.

6141 (b) If the non-opaque scalar val is provided, then $\mathbf{D}(\text{val})$ must be compatible with $\mathbf{D}_{in_1}(\text{op})$
 6142 of the binary operator.

6143 (c) If the `GrB_Scalar` s is provided, then $\mathbf{D}(s)$ must be compatible with $\mathbf{D}_{in_1}(\text{op})$ of the
 6144 binary operator.

6145 6. If `bind-second`:

6146 (a) $\mathbf{D}(A)$ must be compatible with $\mathbf{D}_{in_1}(\text{op})$ of the binary operator.

6147 (b) If the non-opaque scalar val is provided, then $\mathbf{D}(\text{val})$ must be compatible with $\mathbf{D}_{in_2}(\text{op})$
 6148 of the binary operator.

6149 (c) If the `GrB_Scalar` s is provided, then $\mathbf{D}(s)$ must be compatible with $\mathbf{D}_{in_2}(\text{op})$ of the
 6150 binary operator.

6151 Two domains are compatible with each other if values from one domain can be cast to values in
 6152 the other domain as per the rules of the C language. In particular, domains from Table 3.2 are all
 6153 compatible with each other. A domain from a user-defined type is only compatible with itself. If
 6154 any compatibility rule above is violated, execution of `GrB_apply` ends and the domain mismatch
 6155 error listed above is returned.

6156 From the argument matrices, the internal matrices, `mask`, and index arrays used in the computation
 6157 are formed (\leftarrow denotes copy):

6158 1. Matrix $\tilde{\mathbf{C}} \leftarrow C$.

6159 2. Two-dimensional mask, $\tilde{\mathbf{M}}$, is computed from argument `Mask` as follows:

6160 (a) If `Mask = GrB_NULL`, then $\tilde{\mathbf{M}} = \langle \mathbf{nrows}(C), \mathbf{ncols}(C), \{(i, j), \forall i, j : 0 \leq i < \mathbf{nrows}(C), 0 \leq$
 6161 $j < \mathbf{ncols}(C)\} \rangle$.

6162 (b) If `Mask \neq GrB_NULL`,

6163 i. If `desc[GrB_MASK].GrB_STRUCTURE` is set, then $\tilde{\mathbf{M}} = \langle \mathbf{nrows}(\text{Mask}), \mathbf{ncols}(\text{Mask}), \{(i, j) :$
 6164 $(i, j) \in \mathbf{ind}(\text{Mask})\} \rangle$,

6165 ii. Otherwise, $\tilde{\mathbf{M}} = \langle \mathbf{nrows}(\text{Mask}), \mathbf{ncols}(\text{Mask}),$
 6166 $\{(i, j) : (i, j) \in \mathbf{ind}(\text{Mask}) \wedge (\text{bool})\text{Mask}(i, j) = \text{true}\} \rangle$.

6167 (c) If `desc[GrB_MASK].GrB_COMP` is set, then $\tilde{\mathbf{M}} \leftarrow \neg \tilde{\mathbf{M}}$.

6168 3. Matrix $\tilde{\mathbf{A}}$ is computed from argument `A` as follows:

6169 `bind-first:` $\tilde{\mathbf{A}} \leftarrow \text{desc}[\text{GrB_INP1}].\text{GrB_TRAN} ? A^T : A$

6170 `bind-second:` $\tilde{\mathbf{A}} \leftarrow \text{desc}[\text{GrB_INP0}].\text{GrB_TRAN} ? A^T : A$

6171 4. Scalar $\tilde{s} \leftarrow s$ (`GraphBLAS` scalar case).

6172 The internal matrices and `mask` are checked for dimension compatibility. The following conditions
 6173 must hold:

6174 1. $\mathbf{nrows}(\tilde{\mathbf{C}}) = \mathbf{nrows}(\tilde{\mathbf{M}})$.

6175 2. $\mathbf{ncols}(\tilde{\mathbf{C}}) = \mathbf{ncols}(\tilde{\mathbf{M}})$.

6176 3. $\mathbf{nrows}(\tilde{\mathbf{C}}) = \mathbf{nrows}(\tilde{\mathbf{A}})$.

6177 4. $\mathbf{ncols}(\tilde{\mathbf{C}}) = \mathbf{ncols}(\tilde{\mathbf{A}})$.

6178 If any compatibility rule above is violated, execution of `GrB_apply` ends and the dimension mismatch
6179 error listed above is returned.

6180 From this point forward, in `GrB_NONBLOCKING` mode, the method can optionally exit with
6181 `GrB_SUCCESS` return code and defer any computation and/or execution error codes.

6182 If an empty `GrB_Scalar` \tilde{s} is provided ($\mathbf{nvals}(\tilde{s}) = 0$), the method returns with code `GrB_EMPTY_OBJECT`.

6183 If a non-empty `GrB_Scalar`, \tilde{s} , is provided (i.e., $\mathbf{nvals}(\tilde{s}) = 1$), we then create an internal variable
6184 `val` with the same domain as \tilde{s} and set `val = val(\tilde{s})`.

6185 We are now ready to carry out the apply and any additional associated operations. We describe
6186 this in terms of two intermediate matrices:

6187 • $\tilde{\mathbf{T}}$: The matrix holding the result from applying the binary operator to the input matrix $\tilde{\mathbf{A}}$.

6188 • $\tilde{\mathbf{Z}}$: The matrix holding the result after application of the (optional) accumulation operator.

6189 The intermediate matrix, $\tilde{\mathbf{T}}$, is created as one of the following:

6190 bind-first: $\tilde{\mathbf{T}} = \langle \mathbf{D}_{out}(\mathbf{op}), \mathbf{nrows}(\tilde{\mathbf{C}}), \mathbf{ncols}(\tilde{\mathbf{C}}), \{(i, j, f(\mathbf{val}, \tilde{\mathbf{A}}(i, j))) \mid (i, j) \in \mathbf{ind}(\tilde{\mathbf{A}})\} \rangle$,

6191 bind-second: $\tilde{\mathbf{T}} = \langle \mathbf{D}_{out}(\mathbf{op}), \mathbf{nrows}(\tilde{\mathbf{C}}), \mathbf{ncols}(\tilde{\mathbf{C}}), \{(i, j, f(\tilde{\mathbf{A}}(i, j), \mathbf{val})) \mid (i, j) \in \mathbf{ind}(\tilde{\mathbf{A}})\} \rangle$,

6192 where $f = \mathbf{f}(\mathbf{op})$.

6193 The intermediate matrix $\tilde{\mathbf{Z}}$ is created as follows, using what is called a *standard matrix accumulate*:

6194 • If `accum = GrB_NULL`, then $\tilde{\mathbf{Z}} = \tilde{\mathbf{T}}$.

6195 • If `accum` is a binary operator, then $\tilde{\mathbf{Z}}$ is defined as

6196
$$\tilde{\mathbf{Z}} = \langle \mathbf{D}_{out}(\mathbf{accum}), \mathbf{nrows}(\tilde{\mathbf{C}}), \mathbf{ncols}(\tilde{\mathbf{C}}), \{(i, j, Z_{ij}) \mid (i, j) \in \mathbf{ind}(\tilde{\mathbf{C}}) \cup \mathbf{ind}(\tilde{\mathbf{T}})\} \rangle$$
.

6197 The values of the elements of $\tilde{\mathbf{Z}}$ are computed based on the relationships between the sets of
6198 indices in $\tilde{\mathbf{C}}$ and $\tilde{\mathbf{T}}$.

6199
$$Z_{ij} = \tilde{\mathbf{C}}(i, j) \odot \tilde{\mathbf{T}}(i, j), \text{ if } (i, j) \in (\mathbf{ind}(\tilde{\mathbf{T}}) \cap \mathbf{ind}(\tilde{\mathbf{C}})),$$

6200
$$Z_{ij} = \tilde{\mathbf{C}}(i, j), \text{ if } (i, j) \in (\mathbf{ind}(\tilde{\mathbf{C}}) - (\mathbf{ind}(\tilde{\mathbf{T}}) \cap \mathbf{ind}(\tilde{\mathbf{C}}))),$$

6201
$$Z_{ij} = \tilde{\mathbf{T}}(i, j), \text{ if } (i, j) \in (\mathbf{ind}(\tilde{\mathbf{T}}) - (\mathbf{ind}(\tilde{\mathbf{T}}) \cap \mathbf{ind}(\tilde{\mathbf{C}}))),$$

6202 where $\odot = \odot(\mathbf{accum})$, and the difference operator refers to set difference.

6205 Finally, the set of output values that make up matrix $\tilde{\mathbf{Z}}$ are written into the final result matrix \mathbf{C} ,
 6206 using what is called a *standard matrix mask and replace*. This is carried out under control of the
 6207 mask which acts as a “write mask”.

- 6208 • If desc[GrB_OUTP].GrB_REPLACE is set, then any values in \mathbf{C} on input to this operation are
 6209 deleted and the content of the new output matrix, \mathbf{C} , is defined as,

$$6210 \quad \mathbf{L}(\mathbf{C}) = \{(i, j, Z_{ij}) : (i, j) \in (\mathbf{ind}(\tilde{\mathbf{Z}}) \cap \mathbf{ind}(\tilde{\mathbf{M}}))\}.$$

- 6211 • If desc[GrB_OUTP].GrB_REPLACE is not set, the elements of $\tilde{\mathbf{Z}}$ indicated by the mask are
 6212 copied into the result matrix, \mathbf{C} , and elements of \mathbf{C} that fall outside the set indicated by the
 6213 mask are unchanged:

$$6214 \quad \mathbf{L}(\mathbf{C}) = \{(i, j, C_{ij}) : (i, j) \in (\mathbf{ind}(\mathbf{C}) \cap \mathbf{ind}(\neg\tilde{\mathbf{M}}))\} \cup \{(i, j, Z_{ij}) : (i, j) \in (\mathbf{ind}(\tilde{\mathbf{Z}}) \cap \mathbf{ind}(\tilde{\mathbf{M}}))\}.$$

6215 In GrB_BLOCKING mode, the method exits with return value GrB_SUCCESS and the new content
 6216 of matrix \mathbf{C} is as defined above and fully computed. In GrB_NONBLOCKING mode, the method
 6217 exits with return value GrB_SUCCESS and the new content of matrix \mathbf{C} is as defined above but
 6218 may not be fully computed. However, it can be used in the next GraphBLAS method call in a
 6219 sequence.

6220 4.3.8.5 apply: Vector index unary operator variant

6221 Computes the transformation of the values of the stored elements of a vector using an index unary
 6222 operator that is a function of the stored value, its location indices, and an user provided scalar
 6223 value. The scalar can be passed either as a non-opaque variable or as a GrB_Scalar object.

6224 C Syntax

```
6225     GrB_Info GrB_apply(GrB_Vector      w,
6226                       const GrB_Vector mask,
6227                       const GrB_BinaryOp accum,
6228                       const GrB_IndexUnaryOp op,
6229                       const GrB_Vector u,
6230                       <type> val,
6231                       const GrB_Descriptor desc);
```

```
6232     GrB_Info GrB_apply(GrB_Vector      w,
6233                       const GrB_Vector mask,
6234                       const GrB_BinaryOp accum,
6235                       const GrB_IndexUnaryOp op,
6236                       const GrB_Vector u,
6237                       const GrB_Scalar s,
6238                       const GrB_Descriptor desc);
```

6239 **Parameters**

- 6240 **w** (INOUT) An existing GraphBLAS vector. On input, the vector provides values
 6241 that may be accumulated with the result of the apply operation. On output, this
 6242 vector holds the results of the operation.
- 6243 **mask** (IN) An optional “write” mask that controls which results from this operation are
 6244 stored into the output vector **w**. The mask dimensions must match those of the
 6245 vector **w**. If the **GrB_STRUCTURE** descriptor is *not* set for the mask, the domain
 6246 of the mask vector must be of type **bool** or any of the predefined “built-in” types
 6247 in Table 3.2. If the default mask is desired (i.e., a mask that is all **true** with the
 6248 dimensions of **w**), **GrB_NULL** should be specified.
- 6249 **accum** (IN) An optional binary operator used for accumulating entries into existing **w**
 6250 entries. If assignment rather than accumulation is desired, **GrB_NULL** should be
 6251 specified.
- 6252 **op** (IN) An index unary operator, $F_i = \langle D_{out}, D_{in_1}, \mathbf{D}(\mathbf{GrB_Index}), D_{in_2}, f_i \rangle$, applied
 6253 to each element stored in the input vector, **u**. It is a function of the stored element’s
 6254 value, its location index, and a user supplied scalar value (either **s** or **val**).
- 6255 **u** (IN) The GraphBLAS vector whose elements are passed to the index unary oper-
 6256 ator.
- 6257 **val** (IN) An additional scalar value that is passed to the index unary operator.
- 6258 **s** (IN) An additional GraphBLAS scalar that is passed to the index unary operator.
 6259 It must not be empty.
- 6260 **desc** (IN) An optional operation descriptor. If a *default* descriptor is desired, **GrB_NULL**
 6261 should be specified. Non-default field/value pairs are listed as follows:

6262

Param	Field	Value	Description
w	GrB_OUTP	GrB_REPLACE	Output vector w is cleared (all elements removed) before the result is stored in it.
mask	GrB_MASK	GrB_STRUCTURE	The write mask is constructed from the structure (pattern of stored values) of the input mask vector. The stored values are not examined.
mask	GrB_MASK	GrB_COMP	Use the complement of mask .

6263

6264 **Return Values**

- 6265 **GrB_SUCCESS** In blocking mode, the operation completed successfully. In non-
 6266 blocking mode, this indicates that the compatibility tests on di-
 6267 mensions and domains for the input arguments passed success-
 6268 fully. Either way, output vector **w** is ready to be used in the next
 6269 method of the sequence.

6270 GrB_PANIC Unknown internal error.

6271 GrB_INVALID_OBJECT This is returned in any execution mode whenever one of the
6272 opaque GraphBLAS objects (input or output) is in an invalid
6273 state caused by a previous execution error. Call GrB_error() to
6274 access any error messages generated by the implementation.

6275 GrB_OUT_OF_MEMORY Not enough memory available for operation.

6276 GrB_UNINITIALIZED_OBJECT One or more of the GraphBLAS objects has not been initialized
6277 by a call to new (or another constructor).

6278 GrB_DIMENSION_MISMATCH mask, w and/or u dimensions are incompatible.

6279 GrB_DOMAIN_MISMATCH The domains of the various vectors are incompatible with the cor-
6280 responding domains of the accumulation operator or index unary
6281 operator, or the mask's domain is not compatible with bool (in
6282 the case where desc[GrB_MASK].GrB_STRUCTURE is not set).

6283 GrB_EMPTY_OBJECT The GrB_Scalar s used in the call is empty ($\mathbf{nvals}(s) = 0$) and
6284 therefore a value cannot be passed to the index unary operator.

6285 Description

6286 This variant of GrB_apply computes the result of applying an index unary operator to the elements
6287 of a GraphBLAS vector each composed with the element's index and a scalar constant, val or s:

$$6288 \quad \mathbf{w} = f_i(\mathbf{u}, \mathbf{ind}(\mathbf{u}), 0, \text{val}) \text{ or } \mathbf{w} = f_i(\mathbf{u}, \mathbf{ind}(\mathbf{u}), 0, \mathbf{s}),$$

6289 or if an optional binary accumulation operator (\odot) is provided:

$$6290 \quad \mathbf{w} = \mathbf{w} \odot f_i(\mathbf{u}, \mathbf{ind}(\mathbf{u}), 0, \text{val}) \text{ or } \mathbf{w} = \mathbf{w} \odot f_i(\mathbf{u}, \mathbf{ind}(\mathbf{u}), 0, \mathbf{s}).$$

6291 Logically, this operation occurs in three steps:

6292 **Setup** The internal vectors and mask used in the computation are formed and their domains
6293 and dimensions are tested for compatibility.

6294 **Compute** The indicated computations are carried out.

6295 **Output** The result is written into the output vector, possibly under control of a mask.

6296 Up to three argument vectors are used in this GrB_apply operation:

- 6297 1. $\mathbf{w} = \langle \mathbf{D}(\mathbf{w}), \mathbf{size}(\mathbf{w}), \mathbf{L}(\mathbf{w}) = \{(i, w_i)\} \rangle$
- 6298 2. $\text{mask} = \langle \mathbf{D}(\text{mask}), \mathbf{size}(\text{mask}), \mathbf{L}(\text{mask}) = \{(i, m_i)\} \rangle$ (optional)

6299 3. $\mathbf{u} = \langle \mathbf{D}(\mathbf{u}), \mathbf{size}(\mathbf{u}), \mathbf{L}(\mathbf{u}) = \{(i, u_i)\} \rangle$

6300 The argument scalar, vectors, index unary operator and the accumulation operator (if provided)
6301 are tested for domain compatibility as follows:

6302 1. If `mask` is not `GrB_NULL`, and `desc[GrB_MASK].GrB_STRUCTURE` is not set, then $\mathbf{D}(\text{mask})$
6303 must be from one of the pre-defined types of Table 3.2.

6304 2. $\mathbf{D}(\mathbf{w})$ must be compatible with $\mathbf{D}_{out}(\text{op})$ of the index unary operator.

6305 3. If `accum` is not `GrB_NULL`, then $\mathbf{D}(\mathbf{w})$ must be compatible with $\mathbf{D}_{in_1}(\text{accum})$ and $\mathbf{D}_{out}(\text{accum})$
6306 of the accumulation operator and $\mathbf{D}_{out}(\text{op})$ of the index unary operator must be compatible
6307 with $\mathbf{D}_{in_2}(\text{accum})$ of the accumulation operator.

6308 4. $\mathbf{D}(\mathbf{u})$ must be compatible with $\mathbf{D}_{in_1}(\text{op})$ of the index unary operator.

6309 5. If the non-opaque scalar `val` is provided, then $\mathbf{D}(\text{val})$ must be compatible with $\mathbf{D}_{in_2}(\text{op})$ of
6310 the index unary operator.

6311 6. If the `GrB_Scalar` `s` is provided, then $\mathbf{D}(\text{s})$ must be compatible with $\mathbf{D}_{in_2}(\text{op})$ of the index
6312 unary operator.

6313 Two domains are compatible with each other if values from one domain can be cast to values in
6314 the other domain as per the rules of the C language. In particular, domains from Table 3.2 are all
6315 compatible with each other. A domain from a user-defined type is only compatible with itself. If
6316 any compatibility rule above is violated, execution of `GrB_apply` ends and the domain mismatch
6317 error listed above is returned.

6318 From the argument vectors, the internal vectors and mask used in the computation are formed (\leftarrow
6319 denotes copy):

6320 1. Vector $\tilde{\mathbf{w}} \leftarrow \mathbf{w}$.

6321 2. One-dimensional mask, $\tilde{\mathbf{m}}$, is computed from argument `mask` as follows:

6322 (a) If `mask = GrB_NULL`, then $\tilde{\mathbf{m}} = \langle \mathbf{size}(\mathbf{w}), \{i, \forall i : 0 \leq i < \mathbf{size}(\mathbf{w})\} \rangle$.

6323 (b) If `mask \neq GrB_NULL`,

6324 i. If `desc[GrB_MASK].GrB_STRUCTURE` is set, then $\tilde{\mathbf{m}} = \langle \mathbf{size}(\text{mask}), \{i : i \in \mathbf{ind}(\text{mask})\} \rangle$,

6325 ii. Otherwise, $\tilde{\mathbf{m}} = \langle \mathbf{size}(\text{mask}), \{i : i \in \mathbf{ind}(\text{mask}) \wedge (\text{bool})\text{mask}(i) = \text{true}\} \rangle$.

6326 (c) If `desc[GrB_MASK].GrB_COMP` is set, then $\tilde{\mathbf{m}} \leftarrow \neg \tilde{\mathbf{m}}$.

6327 3. Vector $\tilde{\mathbf{u}} \leftarrow \mathbf{u}$.

6328 4. Scalar $\tilde{s} \leftarrow \text{s}$ (GraphBLAS scalar case).

6329 The internal vectors and masks are checked for dimension compatibility. The following conditions
6330 must hold:

6331 1. $\mathbf{size}(\tilde{\mathbf{w}}) = \mathbf{size}(\tilde{\mathbf{m}})$

6332 2. $\mathbf{size}(\tilde{\mathbf{u}}) = \mathbf{size}(\tilde{\mathbf{w}})$.

6333 If any compatibility rule above is violated, execution of `GrB_apply` ends and the dimension mismatch
6334 error listed above is returned.

6335 From this point forward, in `GrB_NONBLOCKING` mode, the method can optionally exit with
6336 `GrB_SUCCESS` return code and defer any computation and/or execution error codes.

6337 If an empty `GrB_Scalar` \tilde{s} is provided ($\mathbf{nvals}(\tilde{s}) = 0$), the method returns with code `GrB_EMPTY_OBJECT`.

6338 If a non-empty `GrB_Scalar`, \tilde{s} , is provided ($\mathbf{nvals}(\tilde{s}) = 1$), we then create an internal variable `val`
6339 with the same domain as \tilde{s} and set `val = val(\tilde{s})`.

6340 We are now ready to carry out the apply and any additional associated operations. We describe
6341 this in terms of two intermediate vectors:

- 6342 • $\tilde{\mathbf{t}}$: The vector holding the result from applying the index unary operator to the input vector
6343 $\tilde{\mathbf{u}}$.
- 6344 • $\tilde{\mathbf{z}}$: The vector holding the result after application of the (optional) accumulation operator.

6345 The intermediate vector, $\tilde{\mathbf{t}}$, is created as follows:

$$6346 \quad \tilde{\mathbf{t}} = \langle \mathbf{D}_{out}(\mathbf{op}), \mathbf{size}(\tilde{\mathbf{u}}), \{(i, f_i(\tilde{\mathbf{u}}(i), [i], 0, \mathbf{val})) \mid \forall i \in \mathbf{ind}(\tilde{\mathbf{u}})\} \rangle,$$

6347 where $f_i = \mathbf{f}(\mathbf{op})$.

6348 The intermediate vector $\tilde{\mathbf{z}}$ is created as follows, using what is called a *standard vector accumulate*:

- 6349 • If `accum = GrB_NULL`, then $\tilde{\mathbf{z}} = \tilde{\mathbf{t}}$.
- 6350 • If `accum` is a binary operator, then $\tilde{\mathbf{z}}$ is defined as

$$6351 \quad \tilde{\mathbf{z}} = \langle \mathbf{D}_{out}(\mathbf{accum}), \mathbf{size}(\tilde{\mathbf{w}}), \{(i, z_i) \mid \forall i \in \mathbf{ind}(\tilde{\mathbf{w}}) \cup \mathbf{ind}(\tilde{\mathbf{t}})\} \rangle.$$

6352 The values of the elements of $\tilde{\mathbf{z}}$ are computed based on the relationships between the sets of
6353 indices in $\tilde{\mathbf{w}}$ and $\tilde{\mathbf{t}}$.

$$6354 \quad z_i = \tilde{\mathbf{w}}(i) \odot \tilde{\mathbf{t}}(i), \text{ if } i \in (\mathbf{ind}(\tilde{\mathbf{t}}) \cap \mathbf{ind}(\tilde{\mathbf{w}})),$$

$$6355 \quad z_i = \tilde{\mathbf{w}}(i), \text{ if } i \in (\mathbf{ind}(\tilde{\mathbf{w}}) - (\mathbf{ind}(\tilde{\mathbf{t}}) \cap \mathbf{ind}(\tilde{\mathbf{w}}))),$$

$$6356 \quad z_i = \tilde{\mathbf{t}}(i), \text{ if } i \in (\mathbf{ind}(\tilde{\mathbf{t}}) - (\mathbf{ind}(\tilde{\mathbf{t}}) \cap \mathbf{ind}(\tilde{\mathbf{w}}))),$$

6359 where $\odot = \odot(\mathbf{accum})$, and the difference operator refers to set difference.

6360 Finally, the set of output values that make up vector $\tilde{\mathbf{z}}$ are written into the final result vector `w`,
6361 using what is called a *standard vector mask and replace*. This is carried out under control of the
6362 mask which acts as a “write mask”.

- If desc[GrB_OUTP].GrB_REPLACE is set, then any values in w on input to this operation are deleted and the content of the new output vector, w, is defined as,

$$\mathbf{L}(\mathbf{w}) = \{(i, z_i) : i \in (\mathbf{ind}(\tilde{\mathbf{z}}) \cap \mathbf{ind}(\tilde{\mathbf{m}}))\}.$$

- If desc[GrB_OUTP].GrB_REPLACE is not set, the elements of $\tilde{\mathbf{z}}$ indicated by the mask are copied into the result vector, w, and elements of w that fall outside the set indicated by the mask are unchanged:

$$\mathbf{L}(\mathbf{w}) = \{(i, w_i) : i \in (\mathbf{ind}(\mathbf{w}) \cap \mathbf{ind}(\neg\tilde{\mathbf{m}}))\} \cup \{(i, z_i) : i \in (\mathbf{ind}(\tilde{\mathbf{z}}) \cap \mathbf{ind}(\tilde{\mathbf{m}}))\}.$$

In GrB_BLOCKING mode, the method exits with return value GrB_SUCCESS and the new content of vector w is as defined above and fully computed. In GrB_NONBLOCKING mode, the method exits with return value GrB_SUCCESS and the new content of vector w is as defined above but may not be fully computed. However, it can be used in the next GraphBLAS method call in a sequence.

4.3.8.6 apply: Matrix index unary operator variant

Computes the transformation of the values of the stored elements of a matrix using an index unary operator that is a function of the stored value, its location indices, and an user provided scalar value. The scalar can be passed either as a non-opaque variable or as a GrB_Scalar object.

C Syntax

```
GrB_Info GrB_apply(GrB_Matrix      C,
                  const GrB_Matrix  Mask,
                  const GrB_BinaryOp accum,
                  const GrB_IndexUnaryOp op,
                  const GrB_Matrix  A,
                  <type>           val,
                  const GrB_Descriptor desc);
```

```
GrB_Info GrB_apply(GrB_Matrix      C,
                  const GrB_Matrix  Mask,
                  const GrB_BinaryOp accum,
                  const GrB_IndexUnaryOp op,
                  const GrB_Matrix  A,
                  const GrB_Scalar  s,
                  const GrB_Descriptor desc);
```

Parameters

C (INOUT) An existing GraphBLAS matrix. On input, the matrix provides values that may be accumulated with the result of the apply operation. On output, the matrix holds the results of the operation.

6398 Mask (IN) An optional “write” mask that controls which results from this operation are
 6399 stored into the output matrix C. The mask dimensions must match those of the
 6400 matrix C. If the GrB_STRUCTURE descriptor is *not* set for the mask, the domain
 6401 of the Mask matrix must be of type `bool` or any of the predefined “built-in” types
 6402 in Table 3.2. If the default mask is desired (i.e., a mask that is all `true` with the
 6403 dimensions of C), GrB_NULL should be specified.

6404 accum (IN) An optional binary operator used for accumulating entries into existing C
 6405 entries. If assignment rather than accumulation is desired, GrB_NULL should be
 6406 specified.

6407 op (IN) An index unary operator, $F_i = \langle D_{out}, D_{in_1}, \mathbf{D}(\text{GrB_Index}), D_{in_2}, f_i \rangle$, applied
 6408 to each element stored in the input matrix, A. It is a function of the stored element’s
 6409 value, its row and column indices, and a user supplied scalar value (either `s` or `val`).

6410 A (IN) The GraphBLAS matrix whose elements are passed to the index unary oper-
 6411 ator.

6412 val (IN) An additional scalar value that is passed to the index unary operator.

6413 s (IN) An additional GraphBLAS scalar that is passed to the index unary operator.

6414 desc (IN) An optional operation descriptor. If a *default* descriptor is desired, GrB_NULL
 6415 should be specified. Non-default field/value pairs are listed as follows:

6416

Param	Field	Value	Description
C	GrB_OUTP	GrB_REPLACE	Output matrix C is cleared (all elements removed) before the result is stored in it.
Mask	GrB_MASK	GrB_STRUCTURE	The write mask is constructed from the structure (pattern of stored values) of the input Mask matrix. The stored values are not examined.
Mask	GrB_MASK	GrB_COMP	Use the complement of Mask.
A	GrB_INP0	GrB_TRAN	Use transpose of A for the operation.

6417

6418 Return Values

6419 GrB_SUCCESS In blocking mode, the operation completed successfully. In non-
 6420 blocking mode, this indicates that the compatibility tests on di-
 6421 mensions and domains for the input arguments passed successfully.
 6422 Either way, output matrix C is ready to be used in the next method
 6423 of the sequence.

6424 GrB_PANIC Unknown internal error.

6425 GrB_INVALID_OBJECT This is returned in any execution mode whenever one of the opaque
 6426 GraphBLAS objects (input or output) is in an invalid state caused

6427 by a previous execution error. Call `GrB_error()` to access any error
6428 messages generated by the implementation.

6429 **GrB_OUT_OF_MEMORY** Not enough memory available for operation.

6430 **GrB_UNINITIALIZED_OBJECT** One or more of the GraphBLAS objects has not been initialized by
6431 a call to `new` (or another constructor).

6432 **GrB_DIMENSION_MISMATCH** `mask`, `w` and/or `u` dimensions are incompatible.

6433 **GrB_DOMAIN_MISMATCH** The domains of the various matrices are incompatible with the
6434 corresponding domains of the accumulation operator or index unary
6435 operator, or the mask's domain is not compatible with `bool` (in the
6436 case where `desc[GrB_MASK].GrB_STRUCTURE` is not set).

6437 **GrB_EMPTY_OBJECT** The `GrB_Scalar s` used in the call is empty (`nvals(s) = 0`) and
6438 therefore a value cannot be passed to the index unary operator.

6439 **Description**

6440 This variant of `GrB_apply` computes the result of applying a index unary operator to the elements
6441 of a GraphBLAS matrix each composed with the elements `row` and `column` indices, and a scalar
6442 constant, `val` or `s`:

$$6443 \quad C = f_i(A, \mathbf{row}(\mathbf{ind}(A)), \mathbf{col}(\mathbf{ind}(A)), \mathit{val}) \text{ or } C = f_i(A, \mathbf{row}(\mathbf{ind}(A)), \mathbf{col}(\mathbf{ind}(A)), s),$$

6444 or if an optional binary accumulation operator (\odot) is provided:

$$6445 \quad C = C \odot f_i(A, \mathbf{row}(\mathbf{ind}(A)), \mathbf{col}(\mathbf{ind}(A)), \mathit{val}) \text{ or } C = C \odot f_i(A, \mathbf{row}(\mathbf{ind}(A)), \mathbf{col}(\mathbf{ind}(A)), s).$$

6446 Where the `row` and `col` functions extract the row and column indices from a list of two-dimensional
6447 indices, respectively.

6448 Logically, this operation occurs in three steps:

6449 **Setup** The internal matrices and mask used in the computation are formed and their domains
6450 and dimensions are tested for compatibility.

6451 **Compute** The indicated computations are carried out.

6452 **Output** The result is written into the output matrix, possibly under control of a mask.

6453 Up to three argument matrices are used in the `GrB_apply` operation:

6454 1. $C = \langle \mathbf{D}(C), \mathbf{nrows}(C), \mathbf{ncols}(C), \mathbf{L}(C) = \{(i, j, C_{ij})\} \rangle$

6455 2. $\text{Mask} = \langle \mathbf{D}(\text{Mask}), \mathbf{nrows}(\text{Mask}), \mathbf{ncols}(\text{Mask}), \mathbf{L}(\text{Mask}) = \{(i, j, M_{ij})\} \rangle$ (optional)

6456 3. $\mathbf{A} = \langle \mathbf{D}(\mathbf{A}), \mathbf{nrows}(\mathbf{A}), \mathbf{ncols}(\mathbf{A}), \mathbf{L}(\mathbf{A}) = \{(i, j, A_{ij})\} \rangle$

6457 The argument scalar, matrices, index unary operator and the accumulation operator (if provided)
6458 are tested for domain compatibility as follows:

- 6459 1. If `Mask` is not `GrB_NULL`, and `desc[GrB_MASK].GrB_STRUCTURE` is not set, then $\mathbf{D}(\text{Mask})$
6460 must be from one of the pre-defined types of Table 3.2.
- 6461 2. $\mathbf{D}(\mathbf{C})$ must be compatible with $\mathbf{D}_{out}(\text{op})$ of the index unary operator.
- 6462 3. If `accum` is not `GrB_NULL`, then $\mathbf{D}(\mathbf{C})$ must be compatible with $\mathbf{D}_{in_1}(\text{accum})$ and $\mathbf{D}_{out}(\text{accum})$
6463 of the accumulation operator and $\mathbf{D}_{out}(\text{op})$ of the index unary operator must be compatible
6464 with $\mathbf{D}_{in_2}(\text{accum})$ of the accumulation operator.
- 6465 4. $\mathbf{D}(\mathbf{A})$ must be compatible with $\mathbf{D}_{in_1}(\text{op})$ of the index unary operator.
- 6466 5. If the non-opaque scalar `val` is provided, then $\mathbf{D}(\text{val})$ must be compatible with $\mathbf{D}_{in_2}(\text{op})$ of
6467 the index unary operator.
- 6468 6. If the `GrB_Scalar` `s` is provided, then $\mathbf{D}(\text{s})$ must be compatible with $\mathbf{D}_{in_2}(\text{op})$ of the index
6469 unary operator.

6470 Two domains are compatible with each other if values from one domain can be cast to values in
6471 the other domain as per the rules of the C language. In particular, domains from Table 3.2 are all
6472 compatible with each other. A domain from a user-defined type is only compatible with itself. If
6473 any compatibility rule above is violated, execution of `GrB_apply` ends and the domain mismatch
6474 error listed above is returned.

6475 From the argument matrices, the internal matrices, `mask`, and index arrays used in the computation
6476 are formed (\leftarrow denotes copy):

- 6477 1. Matrix $\tilde{\mathbf{C}} \leftarrow \mathbf{C}$.
- 6478 2. Two-dimensional mask, $\tilde{\mathbf{M}}$, is computed from argument `Mask` as follows:
 - 6479 (a) If `Mask = GrB_NULL`, then $\tilde{\mathbf{M}} = \langle \mathbf{nrows}(\mathbf{C}), \mathbf{ncols}(\mathbf{C}), \{(i, j), \forall i, j : 0 \leq i < \mathbf{nrows}(\mathbf{C}), 0 \leq$
6480 $j < \mathbf{ncols}(\mathbf{C})\} \rangle$.
 - 6481 (b) If `Mask \neq GrB_NULL`,
 - 6482 i. If `desc[GrB_MASK].GrB_STRUCTURE` is set, then $\tilde{\mathbf{M}} = \langle \mathbf{nrows}(\text{Mask}), \mathbf{ncols}(\text{Mask}), \{(i, j) :$
6483 $(i, j) \in \mathbf{ind}(\text{Mask})\} \rangle$,
 - 6484 ii. Otherwise, $\tilde{\mathbf{M}} = \langle \mathbf{nrows}(\text{Mask}), \mathbf{ncols}(\text{Mask}),$
6485 $\{(i, j) : (i, j) \in \mathbf{ind}(\text{Mask}) \wedge (\text{bool})\text{Mask}(i, j) = \text{true}\} \rangle$.
 - 6486 (c) If `desc[GrB_MASK].GrB_COMP` is set, then $\tilde{\mathbf{M}} \leftarrow \neg \tilde{\mathbf{M}}$.
- 6487 3. Matrix $\tilde{\mathbf{A}}$ is computed from argument `A` as follows:
6488
$$\tilde{\mathbf{A}} \leftarrow \text{desc[GrB_INP0].GrB_TRAN} ? \mathbf{A}^T : \mathbf{A}$$
- 6489 4. Scalar $\tilde{s} \leftarrow s$ (GraphBLAS scalar case).

6490 The internal matrices and mask are checked for dimension compatibility. The following conditions
 6491 must hold:

- 6492 1. $\mathbf{nrows}(\tilde{\mathbf{C}}) = \mathbf{nrows}(\tilde{\mathbf{M}})$.
- 6493 2. $\mathbf{ncols}(\tilde{\mathbf{C}}) = \mathbf{ncols}(\tilde{\mathbf{M}})$.
- 6494 3. $\mathbf{nrows}(\tilde{\mathbf{C}}) = \mathbf{nrows}(\tilde{\mathbf{A}})$.
- 6495 4. $\mathbf{ncols}(\tilde{\mathbf{C}}) = \mathbf{ncols}(\tilde{\mathbf{A}})$.

6496 If any compatibility rule above is violated, execution of `GrB_apply` ends and the dimension mismatch
 6497 error listed above is returned.

6498 From this point forward, in `GrB_NONBLOCKING` mode, the method can optionally exit with
 6499 `GrB_SUCCESS` return code and defer any computation and/or execution error codes.

6500 If an empty `GrB_Scalar` \tilde{s} is provided ($\mathbf{nvals}(\tilde{s}) = 0$), the method returns with code `GrB_EMPTY_OBJECT`.
 6501 If a non-empty `GrB_Scalar`, \tilde{s} , is provided (i.e., $\mathbf{nvals}(\tilde{s}) = 1$), we then create an internal variable
 6502 `val` with the same domain as \tilde{s} and set `val = val(\tilde{s})`.

6503 We are now ready to carry out the apply and any additional associated operations. We describe
 6504 this in terms of two intermediate matrices:

- 6505 • $\tilde{\mathbf{T}}$: The matrix holding the result from applying the index unary operator to the input matrix
 6506 $\tilde{\mathbf{A}}$.
- 6507 • $\tilde{\mathbf{Z}}$: The matrix holding the result after application of the (optional) accumulation operator.

6508 The intermediate matrix, $\tilde{\mathbf{T}}$, is created as follows:

$$6509 \quad \tilde{\mathbf{T}} = \langle \mathbf{D}_{out}(\mathbf{op}), \mathbf{nrows}(\tilde{\mathbf{C}}), \mathbf{ncols}(\tilde{\mathbf{C}}), \{(i, j, f_i(\tilde{\mathbf{A}}(i, j), i, j, \mathbf{val})) \mid \forall (i, j) \in \mathbf{ind}(\tilde{\mathbf{A}})\} \rangle,$$

6510 where $f_i = \mathbf{f}(\mathbf{op})$.

6511 The intermediate matrix $\tilde{\mathbf{Z}}$ is created as follows, using what is called a *standard matrix accumulate*:

- 6512 • If `accum = GrB_NULL`, then $\tilde{\mathbf{Z}} = \tilde{\mathbf{T}}$.
- 6513 • If `accum` is a binary operator, then $\tilde{\mathbf{Z}}$ is defined as

$$6514 \quad \tilde{\mathbf{Z}} = \langle \mathbf{D}_{out}(\mathbf{accum}), \mathbf{nrows}(\tilde{\mathbf{C}}), \mathbf{ncols}(\tilde{\mathbf{C}}), \{(i, j, Z_{ij}) \mid \forall (i, j) \in \mathbf{ind}(\tilde{\mathbf{C}}) \cup \mathbf{ind}(\tilde{\mathbf{T}})\} \rangle.$$

6515 The values of the elements of $\tilde{\mathbf{Z}}$ are computed based on the relationships between the sets of
 6516 indices in $\tilde{\mathbf{C}}$ and $\tilde{\mathbf{T}}$.

$$6517 \quad Z_{ij} = \tilde{\mathbf{C}}(i, j) \odot \tilde{\mathbf{T}}(i, j), \text{ if } (i, j) \in (\mathbf{ind}(\tilde{\mathbf{T}}) \cap \mathbf{ind}(\tilde{\mathbf{C}})),$$

$$6518 \quad Z_{ij} = \tilde{\mathbf{C}}(i, j), \text{ if } (i, j) \in (\mathbf{ind}(\tilde{\mathbf{C}}) - (\mathbf{ind}(\tilde{\mathbf{T}}) \cap \mathbf{ind}(\tilde{\mathbf{C}}))),$$

$$6519 \quad Z_{ij} = \tilde{\mathbf{T}}(i, j), \text{ if } (i, j) \in (\mathbf{ind}(\tilde{\mathbf{T}}) - (\mathbf{ind}(\tilde{\mathbf{T}}) \cap \mathbf{ind}(\tilde{\mathbf{C}}))),$$

6520 where $\odot = \odot(\mathbf{accum})$, and the difference operator refers to set difference.

6523 Finally, the set of output values that make up matrix $\tilde{\mathbf{Z}}$ are written into the final result matrix \mathbf{C} ,
 6524 using what is called a *standard matrix mask and replace*. This is carried out under control of the
 6525 mask which acts as a “write mask”.

- 6526 • If desc[GrB_OUTP].GrB_REPLACE is set, then any values in \mathbf{C} on input to this operation are
 6527 deleted and the content of the new output matrix, \mathbf{C} , is defined as,

$$6528 \quad \mathbf{L}(\mathbf{C}) = \{(i, j, Z_{ij}) : (i, j) \in (\mathbf{ind}(\tilde{\mathbf{Z}}) \cap \mathbf{ind}(\tilde{\mathbf{M}}))\}.$$

- 6529 • If desc[GrB_OUTP].GrB_REPLACE is not set, the elements of $\tilde{\mathbf{Z}}$ indicated by the mask are
 6530 copied into the result matrix, \mathbf{C} , and elements of \mathbf{C} that fall outside the set indicated by the
 6531 mask are unchanged:

$$6532 \quad \mathbf{L}(\mathbf{C}) = \{(i, j, C_{ij}) : (i, j) \in (\mathbf{ind}(\mathbf{C}) \cap \mathbf{ind}(\neg\tilde{\mathbf{M}}))\} \cup \{(i, j, Z_{ij}) : (i, j) \in (\mathbf{ind}(\tilde{\mathbf{Z}}) \cap \mathbf{ind}(\tilde{\mathbf{M}}))\}.$$

6533 In GrB_BLOCKING mode, the method exits with return value GrB_SUCCESS and the new content
 6534 of matrix \mathbf{C} is as defined above and fully computed. In GrB_NONBLOCKING mode, the method
 6535 exits with return value GrB_SUCCESS and the new content of matrix \mathbf{C} is as defined above but
 6536 may not be fully computed. However, it can be used in the next GraphBLAS method call in a
 6537 sequence.

6538 4.3.9 select:

6539 Apply a select operator to the stored elements of an object to determine whether or not to keep
 6540 them.

6541 4.3.9.1 select: Vector variant

6542 Apply a select operator (an index unary operator) to the elements of a vector.

6543 C Syntax

```
6544 // scalar value variant
6545 GrB_Info GrB_select(GrB_Vector          w,
6546                   const GrB_Vector     mask,
6547                   const GrB_BinaryOp   accum,
6548                   const GrB_IndexUnaryOp op,
6549                   const GrB_Vector     u,
6550                   <type>               val,
6551                   const GrB_Descriptor  desc);
6552
6553 // GraphBLAS scalar variant
6554 GrB_Info GrB_select(GrB_Vector          w,
6555                   const GrB_Vector     mask,
```

```

6556         const GrB_BinaryOp      accum,
6557         const GrB_IndexUnaryOp  op,
6558         const GrB_Vector        u,
6559         const GrB_Scalar        s,
6560         const GrB_Descriptor    desc);
6561

```

6562 Parameters

6563 **w** (INOUT) An existing GraphBLAS vector. On input, the vector provides values
6564 that may be accumulated with the result of the select operation. On output, this
6565 vector holds the results of the operation.

6566 **mask** (IN) An optional “write” mask that controls which results from this operation are
6567 stored into the output vector **w**. The mask dimensions must match those of the
6568 vector **w**. If the `GrB_STRUCTURE` descriptor is *not* set for the mask, the domain
6569 of the mask vector must be of type `bool` or any of the predefined “built-in” types
6570 in Table 3.2. If the default mask is desired (i.e., a mask that is all true with the
6571 dimensions of **w**), `GrB_NULL` should be specified.

6572 **accum** (IN) An optional binary operator used for accumulating entries into existing **w**
6573 entries. If assignment rather than accumulation is desired, `GrB_NULL` should be
6574 specified.

6575 **op** (IN) An index unary operator, $F_i = \langle D_{out}, D_{in_1}, \mathbf{D}(\text{GrB_Index}), D_{in_2}, f_i \rangle$, applied
6576 to each element stored in the input vector, **u**. It is a function of the stored element’s
6577 value, its location index, and a user supplied scalar value (either **s** or **val**).

6578 **u** (IN) The GraphBLAS vector whose elements are passed to the index unary oper-
6579 ator.

6580 **val** (IN) An additional scalar value that is passed to the index unary operator.

6581 **s** (IN) An GraphBLAS scalar that is passed to the index unary operator. It must
6582 not be empty.

6583 **desc** (IN) An optional operation descriptor. If a *default* descriptor is desired, `GrB_NULL`
6584 should be specified. Non-default field/value pairs are listed as follows:

6585

Param	Field	Value	Description
w	<code>GrB_OUTP</code>	<code>GrB_REPLACE</code>	Output vector w is cleared (all elements removed) before the result is stored in it.
mask	<code>GrB_MASK</code>	<code>GrB_STRUCTURE</code>	The write mask is constructed from the structure (pattern of stored values) of the input mask vector. The stored values are not examined.
mask	<code>GrB_MASK</code>	<code>GrB_COMP</code>	Use the complement of mask .

6586

6587 Return Values

6588 GrB_SUCCESS In blocking mode, the operation completed successfully. In non-
6589 blocking mode, this indicates that the compatibility tests on di-
6590 mensions and domains for the input arguments passed success-
6591 fully. Either way, output vector w is ready to be used in the next
6592 method of the sequence.

6593 GrB_PANIC Unknown internal error.

6594 GrB_INVALID_OBJECT This is returned in any execution mode whenever one of the
6595 opaque GraphBLAS objects (input or output) is in an invalid
6596 state caused by a previous execution error. Call `GrB_error()` to
6597 access any error messages generated by the implementation.

6598 GrB_OUT_OF_MEMORY Not enough memory available for operation.

6599 GrB_UNINITIALIZED_OBJECT One or more of the GraphBLAS objects has not been initialized
6600 by a call to one of its constructors.

6601 GrB_DIMENSION_MISMATCH $mask$, w and/or u dimensions are incompatible.

6602 GrB_DOMAIN_MISMATCH The domains of the various vectors are incompatible with the cor-
6603 responding domains of the accumulation operator or index unary
6604 operator, or the mask's domain is not compatible with `bool` (in
6605 the case where `desc[GrB_MASK].GrB_STRUCTURE` is not set).

6606 GrB_EMPTY_OBJECT The `GrB_Scalar` s used in the call is empty ($nvals(s) = 0$) and
6607 therefore a value cannot be passed to the index unary operator.

6608 Description

6609 This variant of `GrB_select` computes the result of applying a index unary operator to select the
6610 elements of the input GraphBLAS vector. The operator takes, as input, the value of each stored
6611 element, along with the element's index and a scalar constant – either `val` or `s`. The corresponding
6612 element of the input vector is selected (kept) if the function evaluates to `true` when cast to `bool`.
6613 This acts like a functional mask on the input vector as follows:

$$6614 \quad w = u \langle f_i(u, \mathbf{ind}(u), 0, val) \rangle,$$

$$6615 \quad w = w \odot u \langle f_i(u, \mathbf{ind}(u), 0, val) \rangle.$$

6616 Correspondingly, if a `GrB_Scalar`, s , is provided:

$$6617 \quad w = u \langle f_i(u, \mathbf{ind}(u), 0, s) \rangle,$$

$$6618 \quad w = w \odot u \langle f_i(u, \mathbf{ind}(u), 0, s) \rangle.$$

6619 Logically, this operation occurs in three steps:

6620 **Setup** The internal vectors and mask used in the computation are formed and their domains
6621 and dimensions are tested for compatibility.

6622 **Compute** The indicated computations are carried out.

6623 **Output** The result is written into the output vector, possibly under control of a mask.

6624 Up to three argument vectors are used in this GrB_select operation:

- 6625 1. $\mathbf{w} = \langle \mathbf{D}(\mathbf{w}), \mathbf{size}(\mathbf{w}), \mathbf{L}(\mathbf{w}) = \{(i, w_i)\} \rangle$
- 6626 2. $\mathbf{mask} = \langle \mathbf{D}(\mathbf{mask}), \mathbf{size}(\mathbf{mask}), \mathbf{L}(\mathbf{mask}) = \{(i, m_i)\} \rangle$ (optional)
- 6627 3. $\mathbf{u} = \langle \mathbf{D}(\mathbf{u}), \mathbf{size}(\mathbf{u}), \mathbf{L}(\mathbf{u}) = \{(i, u_i)\} \rangle$

6628 The argument scalar, vectors, index unary operator and the accumulation operator (if provided)
6629 are tested for domain compatibility as follows:

- 6630 1. If `mask` is not `GrB_NULL`, and `desc[GrB_MASK].GrB_STRUCTURE` is not set, then $\mathbf{D}(\mathbf{mask})$
6631 must be from one of the pre-defined types of Table 3.2.
- 6632 2. $\mathbf{D}(\mathbf{w})$ must be compatible with $\mathbf{D}(\mathbf{u})$.
- 6633 3. If `accum` is not `GrB_NULL`, then $\mathbf{D}(\mathbf{w})$ must be compatible with $\mathbf{D}_{in_1}(\mathbf{accum})$ and $\mathbf{D}_{out}(\mathbf{accum})$
6634 of the accumulation operator and $\mathbf{D}(\mathbf{u})$ must be compatible with $\mathbf{D}_{in_2}(\mathbf{accum})$ of the accu-
6635 mulation operator.
- 6636 4. $\mathbf{D}_{out}(\mathbf{op})$ of the index unary operator must be from one of the pre-defined types of Table 3.2;
6637 i.e., castable to `bool`.
- 6638 5. $\mathbf{D}(\mathbf{u})$ must be compatible with $\mathbf{D}_{in_1}(\mathbf{op})$ of the index unary operator.
- 6639 6. $\mathbf{D}(\mathbf{val})$ or $\mathbf{D}(\mathbf{s})$, depending on the signature of the method, must be compatible with $\mathbf{D}_{in_2}(\mathbf{op})$
6640 of the index unary operator.

6641 Two domains are compatible with each other if values from one domain can be cast to values in
6642 the other domain as per the rules of the C language. In particular, domains from Table 3.2 are all
6643 compatible with each other. A domain from a user-defined type is only compatible with itself. If
6644 any compatibility rule above is violated, execution of `GrB_select` ends and the domain mismatch
6645 error listed above is returned.

6646 From the argument vectors, the internal vectors and mask used in the computation are formed (\leftarrow
6647 denotes copy):

- 6648 1. Vector $\tilde{\mathbf{w}} \leftarrow \mathbf{w}$.
- 6649 2. One-dimensional mask, $\tilde{\mathbf{m}}$, is computed from argument `mask` as follows:

- 6650 (a) If $\text{mask} = \text{GrB_NULL}$, then $\tilde{\mathbf{m}} = \langle \text{size}(\mathbf{w}), \{i, \forall i : 0 \leq i < \text{size}(\mathbf{w})\} \rangle$.
- 6651 (b) If $\text{mask} \neq \text{GrB_NULL}$,
- 6652 i. If $\text{desc}[\text{GrB_MASK}].\text{GrB_STRUCTURE}$ is set, then $\tilde{\mathbf{m}} = \langle \text{size}(\text{mask}), \{i : i \in \text{ind}(\text{mask})\} \rangle$,
- 6653 ii. Otherwise, $\tilde{\mathbf{m}} = \langle \text{size}(\text{mask}), \{i : i \in \text{ind}(\text{mask}) \wedge (\text{bool})\text{mask}(i) = \text{true}\} \rangle$.
- 6654 (c) If $\text{desc}[\text{GrB_MASK}].\text{GrB_COMP}$ is set, then $\tilde{\mathbf{m}} \leftarrow \neg\tilde{\mathbf{m}}$.
- 6655 3. Vector $\tilde{\mathbf{u}} \leftarrow \mathbf{u}$.
- 6656 4. Scalar $\tilde{s} \leftarrow s$ (GrB_Scalar version only).

6657 The internal vectors and masks are checked for dimension compatibility. The following conditions
6658 must hold:

- 6659 1. $\text{size}(\tilde{\mathbf{w}}) = \text{size}(\tilde{\mathbf{m}})$
- 6660 2. $\text{size}(\tilde{\mathbf{u}}) = \text{size}(\tilde{\mathbf{w}})$.

6661 If any compatibility rule above is violated, execution of `GrB_select` ends and the dimension mismatch
6662 error listed above is returned.

6663 From this point forward, in `GrB_NONBLOCKING` mode, the method can optionally exit with
6664 `GrB_SUCCESS` return code and defer any computation and/or execution error codes.

6665 If an empty `GrB_Scalar` \tilde{s} is provided (i.e., $\text{nvals}(\tilde{s}) = 0$), the method returns with code `GrB_EMPTY_OBJECT`.
6666 If a non-empty `GrB_Scalar`, \tilde{s} , is provided (i.e., $\text{nvals}(\tilde{s}) = 1$), we then create an internal variable
6667 `val` with the same domain as \tilde{s} and set $\text{val} = \text{val}(\tilde{s})$.

6668 We are now ready to carry out the `select` and any additional associated operations. We describe
6669 this in terms of two intermediate vectors:

- 6670 • $\tilde{\mathbf{t}}$: The vector holding the result from applying the index unary operator to the input vector
6671 $\tilde{\mathbf{u}}$.
- 6672 • $\tilde{\mathbf{z}}$: The vector holding the result after application of the (optional) accumulation operator.

6673 The intermediate vector, $\tilde{\mathbf{t}}$, is created as follows:

$$6674 \quad \tilde{\mathbf{t}} = \langle \mathbf{D}(\mathbf{u}), \text{size}(\tilde{\mathbf{u}}), \{(i, \tilde{\mathbf{u}}(i)), : i \in \text{ind}(\tilde{\mathbf{u}}) \wedge (\text{bool})f_i(\tilde{\mathbf{u}}(i), i, 0, \text{val}) = \text{true}\} \rangle,$$

6675 where $f_i = \mathbf{f}(\text{op})$.

6676 The intermediate vector $\tilde{\mathbf{z}}$ is created as follows, using what is called a *standard vector accumulate*:

- 6677 • If $\text{accum} = \text{GrB_NULL}$, then $\tilde{\mathbf{z}} = \tilde{\mathbf{t}}$.
- 6678 • If accum is a binary operator, then $\tilde{\mathbf{z}}$ is defined as

$$6679 \quad \tilde{\mathbf{z}} = \langle \mathbf{D}_{\text{out}}(\text{accum}), \text{size}(\tilde{\mathbf{w}}), \{(i, z_i) \forall i \in \text{ind}(\tilde{\mathbf{w}}) \cup \text{ind}(\tilde{\mathbf{t}})\} \rangle.$$

6680 The values of the elements of $\tilde{\mathbf{z}}$ are computed based on the relationships between the sets of
 6681 indices in $\tilde{\mathbf{w}}$ and $\tilde{\mathbf{t}}$.

$$\begin{aligned}
 6682 \quad z_i &= \tilde{\mathbf{w}}(i) \odot \tilde{\mathbf{t}}(i), \text{ if } i \in (\mathbf{ind}(\tilde{\mathbf{t}}) \cap \mathbf{ind}(\tilde{\mathbf{w}})), \\
 6683 \\
 6684 \quad z_i &= \tilde{\mathbf{w}}(i), \text{ if } i \in (\mathbf{ind}(\tilde{\mathbf{w}}) - (\mathbf{ind}(\tilde{\mathbf{t}}) \cap \mathbf{ind}(\tilde{\mathbf{w}}))), \\
 6685 \\
 6686 \quad z_i &= \tilde{\mathbf{t}}(i), \text{ if } i \in (\mathbf{ind}(\tilde{\mathbf{t}}) - (\mathbf{ind}(\tilde{\mathbf{t}}) \cap \mathbf{ind}(\tilde{\mathbf{w}}))),
 \end{aligned}$$

6687 where $\odot = \odot(\text{accum})$, and the difference operator refers to set difference.

6688 Finally, the set of output values that make up vector $\tilde{\mathbf{z}}$ are written into the final result vector \mathbf{w} ,
 6689 using what is called a *standard vector mask and replace*. This is carried out under control of the
 6690 mask which acts as a “write mask”.

- 6691 • If desc[GrB_OUTP].GrB_REPLACE is set, then any values in \mathbf{w} on input to this operation are
 6692 deleted and the content of the new output vector, \mathbf{w} , is defined as,

$$6693 \quad \mathbf{L}(\mathbf{w}) = \{(i, z_i) : i \in (\mathbf{ind}(\tilde{\mathbf{z}}) \cap \mathbf{ind}(\tilde{\mathbf{m}}))\}.$$

- 6694 • If desc[GrB_OUTP].GrB_REPLACE is not set, the elements of $\tilde{\mathbf{z}}$ indicated by the mask are
 6695 copied into the result vector, \mathbf{w} , and elements of \mathbf{w} that fall outside the set indicated by the
 6696 mask are unchanged:

$$6697 \quad \mathbf{L}(\mathbf{w}) = \{(i, w_i) : i \in (\mathbf{ind}(\mathbf{w}) \cap \mathbf{ind}(\neg\tilde{\mathbf{m}}))\} \cup \{(i, z_i) : i \in (\mathbf{ind}(\tilde{\mathbf{z}}) \cap \mathbf{ind}(\tilde{\mathbf{m}}))\}.$$

6698 In GrB_BLOCKING mode, the method exits with return value GrB_SUCCESS and the new content
 6699 of vector \mathbf{w} is as defined above and fully computed. In GrB_NONBLOCKING mode, the method
 6700 exits with return value GrB_SUCCESS and the new content of vector \mathbf{w} is as defined above but
 6701 may not be fully computed. However, it can be used in the next GraphBLAS method call in a
 6702 sequence.

6703 4.3.9.2 select: Matrix variant

6704 Apply a select operator (an index unary operator) to the elements of a matrix.

6705 C Syntax

```

6706 // scalar value variant
6707 GrB_Info GrB_select(GrB_Matrix          C,
6708                   const GrB_Matrix     Mask,
6709                   const GrB_BinaryOp   accum,
6710                   const GrB_IndexUnaryOp op,
6711                   const GrB_Matrix     A,
6712                   <type>               val,
6713                   const GrB_Descriptor  desc);
6714

```

```

6715 // GraphBLAS scalar variant
6716 GrB_Info GrB_select(GrB_Matrix          C,
6717                    const GrB_Matrix     Mask,
6718                    const GrB_BinaryOp   accum,
6719                    const GrB_IndexUnaryOp op,
6720                    const GrB_Matrix     A,
6721                    const GrB_Scalar     s,
6722                    const GrB_Descriptor  desc);

```

6723 Parameters

6724 **C** (INOUT) An existing GraphBLAS matrix. On input, the matrix provides values
6725 that may be accumulated with the result of the select operation. On output, the
6726 matrix holds the results of the operation.

6727 **Mask** (IN) An optional “write” mask that controls which results from this operation are
6728 stored into the output matrix **C**. The mask dimensions must match those of the
6729 matrix **C**. If the **GrB_STRUCTURE** descriptor is *not* set for the mask, the domain
6730 of the **Mask** matrix must be of type **bool** or any of the predefined “built-in” types
6731 in Table 3.2. If the default mask is desired (i.e., a mask that is all **true** with the
6732 dimensions of **C**), **GrB_NULL** should be specified.

6733 **accum** (IN) An optional binary operator used for accumulating entries into existing **C**
6734 entries. If assignment rather than accumulation is desired, **GrB_NULL** should be
6735 specified.

6736 **op** (IN) An index unary operator, $F_i = \langle D_{out}, D_{in_1}, \mathbf{D}(\mathbf{GrB_Index}), D_{in_2}, f_i \rangle$, applied
6737 to each element stored in the input matrix, **A**. It is a function of the stored element’s
6738 value, its row and column indices, and a user supplied scalar value (either **s** or **val**).

6739 **A** (IN) The GraphBLAS matrix whose elements are passed to the index unary oper-
6740 ator.

6741 **val** (IN) An additional scalar value that is passed to the index unary operator.

6742 **s** (IN) An GraphBLAS scalar that is passed to the index unary operator. It must
6743 not be empty.

6744 **desc** (IN) An optional operation descriptor. If a *default* descriptor is desired, **GrB_NULL**
6745 should be specified. Non-default field/value pairs are listed as follows:
6746

Param	Field	Value	Description
C	GrB_OUTP	GrB_REPLACE	Output matrix C is cleared (all elements removed) before the result is stored in it.
Mask	GrB_MASK	GrB_STRUCTURE	The write mask is constructed from the structure (pattern of stored values) of the input Mask matrix. The stored values are not examined.
Mask	GrB_MASK	GrB_COMP	Use the complement of Mask.
A	GrB_INP0	GrB_TRAN	Use transpose of A for the operation.

6747

6748 Return Values

6749 GrB_SUCCESS In blocking mode, the operation completed successfully. In non-
6750 blocking mode, this indicates that the compatibility tests on di-
6751 mensions and domains for the input arguments passed successfully.
6752 Either way, output matrix C is ready to be used in the next method
6753 of the sequence.

6754 GrB_PANIC Unknown internal error.

6755 GrB_INVALID_OBJECT This is returned in any execution mode whenever one of the opaque
6756 GraphBLAS objects (input or output) is in an invalid state caused
6757 by a previous execution error. Call GrB_error() to access any error
6758 messages generated by the implementation.

6759 GrB_OUT_OF_MEMORY Not enough memory available for operation.

6760 GrB_UNINITIALIZED_OBJECT One or more of the GraphBLAS objects has not been initialized by
6761 a call to one of its constructors.

6762 GrB_DIMENSION_MISMATCH Mask, C and/or A dimensions are incompatible.

6763 GrB_DOMAIN_MISMATCH The domains of the various matrices are incompatible with the
6764 corresponding domains of the accumulation operator or index unary
6765 operator, or the mask's domain is not compatible with bool (in the
6766 case where desc[GrB_MASK].GrB_STRUCTURE is not set).

6767 GrB_EMPTY_OBJECT The GrB_Scalar s used in the call is empty (**nvals(s) = 0**) and
6768 therefore a value cannot be passed to the index unary operator.

6769 Description

6770 This variant of GrB_select computes the result of applying a index unary operator to select the
6771 elements of the input GraphBLAS matrix. The operator takes, as input, the value of each stored
6772 element, along with the element's row and column indices and a scalar constant – from either **val**
6773 or **s**. The corresponding element of the input matrix is selected (kept) if the function evaluates
6774 to true when cast to bool. This acts like a functional mask on the input matrix as follows when
6775 specifying a transparent scalar value:

6776 $C = A\langle f_i(A, \mathbf{row}(\mathbf{ind}(A)), \mathbf{col}(\mathbf{ind}(A)), \mathbf{val}) \rangle$, or
6777 $C = C \odot A\langle f_i(A, \mathbf{row}(\mathbf{ind}(A)), \mathbf{col}(\mathbf{ind}(A)), \mathbf{val}) \rangle$.

6778 Correspondingly, if a GrB_Scalar, s , is provided:

6779 $C = A\langle f_i(A, \mathbf{row}(\mathbf{ind}(A)), \mathbf{col}(\mathbf{ind}(A)), s) \rangle$, or
6780 $C = C \odot A\langle f_i(A, \mathbf{row}(\mathbf{ind}(A)), \mathbf{col}(\mathbf{ind}(A)), s) \rangle$.

6781 Where the **row** and **col** functions extract the row and column indices from a list of two-dimensional
6782 indices, respectively.

6783 Logically, this operation occurs in three steps:

6784 **Setup** The internal matrices and mask used in the computation are formed and their domains
6785 and dimensions are tested for compatibility.

6786 **Compute** The indicated computations are carried out.

6787 **Output** The result is written into the output matrix, possibly under control of a mask.

6788 Up to three argument matrices are used in the GrB_select operation:

- 6789 1. $C = \langle \mathbf{D}(C), \mathbf{nrows}(C), \mathbf{ncols}(C), \mathbf{L}(C) = \{(i, j, C_{ij})\} \rangle$
- 6790 2. $\text{Mask} = \langle \mathbf{D}(\text{Mask}), \mathbf{nrows}(\text{Mask}), \mathbf{ncols}(\text{Mask}), \mathbf{L}(\text{Mask}) = \{(i, j, M_{ij})\} \rangle$ (optional)
- 6791 3. $A = \langle \mathbf{D}(A), \mathbf{nrows}(A), \mathbf{ncols}(A), \mathbf{L}(A) = \{(i, j, A_{ij})\} \rangle$

6792 The argument scalar, matrices, index unary operator and the accumulation operator (if provided)
6793 are tested for domain compatibility as follows:

- 6794 1. If Mask is not GrB_NULL, and desc[GrB_MASK].GrB_STRUCTURE is not set, then $\mathbf{D}(\text{Mask})$
6795 must be from one of the pre-defined types of Table 3.2.
- 6796 2. $\mathbf{D}(C)$ must be compatible with $\mathbf{D}(A)$.
- 6797 3. If accum is not GrB_NULL, then $\mathbf{D}(C)$ must be compatible with $\mathbf{D}_{in_1}(\text{accum})$ and $\mathbf{D}_{out}(\text{accum})$
6798 of the accumulation operator and $\mathbf{D}(A)$ must be compatible with $\mathbf{D}_{in_2}(\text{accum})$ of the accu-
6799 mulation operator.
- 6800 4. $\mathbf{D}_{out}(\text{op})$ of the index unary operator must be from one of the pre-defined types of Table 3.2;
6801 i.e., castable to bool.
- 6802 5. $\mathbf{D}(A)$ must be compatible with $\mathbf{D}_{in_1}(\text{op})$ of the index unary operator.
- 6803 6. $\mathbf{D}(\mathbf{val})$ or $\mathbf{D}(s)$, depending on the signature of the method, must be compatible with $\mathbf{D}_{in_2}(\text{op})$
6804 of the index unary operator.

6805 Two domains are compatible with each other if values from one domain can be cast to values in
6806 the other domain as per the rules of the C language. In particular, domains from Table 3.2 are all
6807 compatible with each other. A domain from a user-defined type is only compatible with itself. If
6808 any compatibility rule above is violated, execution of `GrB_select` ends and the domain mismatch
6809 error listed above is returned.

6810 From the argument matrices, the internal matrices, `mask`, and index arrays used in the computation
6811 are formed (\leftarrow denotes copy):

- 6812 1. Matrix $\tilde{\mathbf{C}} \leftarrow \mathbf{C}$.
- 6813 2. Two-dimensional mask, $\tilde{\mathbf{M}}$, is computed from argument `Mask` as follows:
 - 6814 (a) If `Mask = GrB_NULL`, then $\tilde{\mathbf{M}} = \langle \mathbf{nrows}(\mathbf{C}), \mathbf{ncols}(\mathbf{C}), \{(i, j), \forall i, j : 0 \leq i < \mathbf{nrows}(\mathbf{C}), 0 \leq$
6815 $j < \mathbf{ncols}(\mathbf{C})\} \rangle$.
 - 6816 (b) If `Mask \neq GrB_NULL`,
 - 6817 i. If `desc[GrB_MASK].GrB_STRUCTURE` is set, then $\tilde{\mathbf{M}} = \langle \mathbf{nrows}(\mathbf{Mask}), \mathbf{ncols}(\mathbf{Mask}), \{(i, j) :$
6818 $(i, j) \in \mathbf{ind}(\mathbf{Mask})\} \rangle$,
 - 6819 ii. Otherwise, $\tilde{\mathbf{M}} = \langle \mathbf{nrows}(\mathbf{Mask}), \mathbf{ncols}(\mathbf{Mask}),$
6820 $\{(i, j) : (i, j) \in \mathbf{ind}(\mathbf{Mask}) \wedge (\mathbf{bool})\mathbf{Mask}(i, j) = \mathbf{true}\} \rangle$.
 - 6821 (c) If `desc[GrB_MASK].GrB_COMP` is set, then $\tilde{\mathbf{M}} \leftarrow \neg \tilde{\mathbf{M}}$.
- 6822 3. Matrix $\tilde{\mathbf{A}}$ is computed from argument `A` as follows: $\tilde{\mathbf{A}} \leftarrow \mathbf{desc}[\mathbf{GrB_INP0}].\mathbf{GrB_TRAN} ? \mathbf{A}^T : \mathbf{A}$
- 6823 4. Scalar $\tilde{s} \leftarrow s$ (`GrB_Scalar` version only).

6824 The internal matrices and mask are checked for dimension compatibility. The following conditions
6825 must hold:

- 6826 1. $\mathbf{nrows}(\tilde{\mathbf{C}}) = \mathbf{nrows}(\tilde{\mathbf{M}})$.
- 6827 2. $\mathbf{ncols}(\tilde{\mathbf{C}}) = \mathbf{ncols}(\tilde{\mathbf{M}})$.
- 6828 3. $\mathbf{nrows}(\tilde{\mathbf{C}}) = \mathbf{nrows}(\tilde{\mathbf{A}})$.
- 6829 4. $\mathbf{ncols}(\tilde{\mathbf{C}}) = \mathbf{ncols}(\tilde{\mathbf{A}})$.

6830 If any compatibility rule above is violated, execution of `GrB_select` ends and the dimension mismatch
6831 error listed above is returned.

6832 From this point forward, in `GrB_NONBLOCKING` mode, the method can optionally exit with
6833 `GrB_SUCCESS` return code and defer any computation and/or execution error codes.

6834 If an empty `GrB_Scalar` \tilde{s} is provided (i.e., $\mathbf{nvals}(\tilde{s}) = 0$), the method returns with code `GrB_EMPTY_OBJECT`.
6835 If a non-empty `GrB_Scalar`, \tilde{s} , is provided (i.e., $\mathbf{nvals}(\tilde{s}) = 1$), we then create an internal variable
6836 `val` with the same domain as \tilde{s} and set `val = val(\tilde{s})`.

6837 We are now ready to carry out the `select` and any additional associated operations. We describe
6838 this in terms of two intermediate matrices:

- 6839 • $\tilde{\mathbf{T}}$: The matrix holding the result from applying the index unary operator to the input matrix
6840 $\tilde{\mathbf{A}}$.
- 6841 • $\tilde{\mathbf{Z}}$: The matrix holding the result after application of the (optional) accumulation operator.

6842 The intermediate matrix, $\tilde{\mathbf{T}}$, is created as follows:

$$6843 \quad \tilde{\mathbf{T}} = \langle \mathbf{D}(\mathbf{A}), \mathbf{nrows}(\tilde{\mathbf{A}}), \mathbf{ncols}(\tilde{\mathbf{A}}), \\ \{(i, j, \tilde{\mathbf{A}}(i, j) : i, j \in \mathbf{ind}(\tilde{\mathbf{A}}) \wedge (\mathbf{bool})f_i(\tilde{\mathbf{A}}(i, j), i, j, \mathbf{val}) = \mathbf{true})\},$$

6844 where $f_i = \mathbf{f}(\mathbf{op})$.

6845 The intermediate matrix $\tilde{\mathbf{Z}}$ is created as follows, using what is called a *standard matrix accumulate*:

- 6846 • If `accum = GrB_NULL`, then $\tilde{\mathbf{Z}} = \tilde{\mathbf{T}}$.
- 6847 • If `accum` is a binary operator, then $\tilde{\mathbf{Z}}$ is defined as

$$6848 \quad \tilde{\mathbf{Z}} = \langle \mathbf{D}_{out}(\mathbf{accum}), \mathbf{nrows}(\tilde{\mathbf{C}}), \mathbf{ncols}(\tilde{\mathbf{C}}), \{(i, j, Z_{ij}) \forall (i, j) \in \mathbf{ind}(\tilde{\mathbf{C}}) \cup \mathbf{ind}(\tilde{\mathbf{T}})\}\rangle.$$

6849 The values of the elements of $\tilde{\mathbf{Z}}$ are computed based on the relationships between the sets of
6850 indices in $\tilde{\mathbf{C}}$ and $\tilde{\mathbf{T}}$.

$$6851 \quad Z_{ij} = \tilde{\mathbf{C}}(i, j) \odot \tilde{\mathbf{T}}(i, j), \text{ if } (i, j) \in (\mathbf{ind}(\tilde{\mathbf{T}}) \cap \mathbf{ind}(\tilde{\mathbf{C}})), \\ 6852 \quad Z_{ij} = \tilde{\mathbf{C}}(i, j), \text{ if } (i, j) \in (\mathbf{ind}(\tilde{\mathbf{C}}) - (\mathbf{ind}(\tilde{\mathbf{T}}) \cap \mathbf{ind}(\tilde{\mathbf{C}}))), \\ 6853 \quad Z_{ij} = \tilde{\mathbf{T}}(i, j), \text{ if } (i, j) \in (\mathbf{ind}(\tilde{\mathbf{T}}) - (\mathbf{ind}(\tilde{\mathbf{T}}) \cap \mathbf{ind}(\tilde{\mathbf{C}}))), \\ 6854 \quad Z_{ij} = \tilde{\mathbf{T}}(i, j), \text{ if } (i, j) \in (\mathbf{ind}(\tilde{\mathbf{T}}) - (\mathbf{ind}(\tilde{\mathbf{T}}) \cap \mathbf{ind}(\tilde{\mathbf{C}}))), \\ 6855 \quad Z_{ij} = \tilde{\mathbf{T}}(i, j), \text{ if } (i, j) \in (\mathbf{ind}(\tilde{\mathbf{T}}) - (\mathbf{ind}(\tilde{\mathbf{T}}) \cap \mathbf{ind}(\tilde{\mathbf{C}}))),$$

6856 where $\odot = \odot(\mathbf{accum})$, and the difference operator refers to set difference.

6857 Finally, the set of output values that make up matrix $\tilde{\mathbf{Z}}$ are written into the final result matrix \mathbf{C} ,
6858 using what is called a *standard matrix mask and replace*. This is carried out under control of the
6859 mask which acts as a “write mask”.

- 6860 • If `desc[GrB_OUTP].GrB_REPLACE` is set, then any values in \mathbf{C} on input to this operation are
6861 deleted and the content of the new output matrix, \mathbf{C} , is defined as,

$$6862 \quad \mathbf{L}(\mathbf{C}) = \{(i, j, Z_{ij}) : (i, j) \in (\mathbf{ind}(\tilde{\mathbf{Z}}) \cap \mathbf{ind}(\tilde{\mathbf{M}}))\}.$$

- 6863 • If `desc[GrB_OUTP].GrB_REPLACE` is not set, the elements of $\tilde{\mathbf{Z}}$ indicated by the mask are
6864 copied into the result matrix, \mathbf{C} , and elements of \mathbf{C} that fall outside the set indicated by the
6865 mask are unchanged:

$$6866 \quad \mathbf{L}(\mathbf{C}) = \{(i, j, C_{ij}) : (i, j) \in (\mathbf{ind}(\mathbf{C}) \cap \mathbf{ind}(\neg\tilde{\mathbf{M}}))\} \cup \{(i, j, Z_{ij}) : (i, j) \in (\mathbf{ind}(\tilde{\mathbf{Z}}) \cap \mathbf{ind}(\tilde{\mathbf{M}}))\}.$$

6867 In `GrB_BLOCKING` mode, the method exits with return value `GrB_SUCCESS` and the new content
6868 of matrix \mathbf{C} is as defined above and fully computed. In `GrB_NONBLOCKING` mode, the method
6869 exits with return value `GrB_SUCCESS` and the new content of matrix \mathbf{C} is as defined above but
6870 may not be fully computed. However, it can be used in the next GraphBLAS method call in a
6871 sequence.

6872 **4.3.10 reduce: Perform a reduction across the elements of an object**

6873 Computes the reduction of the values of the elements of a vector or matrix.

6874 **4.3.10.1 reduce: Standard matrix to vector variant**

6875 This performs a reduction across rows of a matrix to produce a vector. If reduction down columns
6876 is desired, the input matrix should be transposed using the descriptor.

6877 **C Syntax**

```
6878     GrB_Info GrB_reduce(GrB_Vector      w,  
6879                       const GrB_Vector mask,  
6880                       const GrB_BinaryOp accum,  
6881                       const GrB_Monoid op,  
6882                       const GrB_Matrix A,  
6883                       const GrB_Descriptor desc);  
6884  
6885     GrB_Info GrB_reduce(GrB_Vector      w,  
6886                       const GrB_Vector mask,  
6887                       const GrB_BinaryOp accum,  
6888                       const GrB_BinaryOp op,  
6889                       const GrB_Matrix A,  
6890                       const GrB_Descriptor desc);
```

6891 **Parameters**

6892 **w** (INOUT) An existing GraphBLAS vector. On input, the vector provides values
6893 that may be accumulated with the result of the reduction operation. On output,
6894 this vector holds the results of the operation.

6895 **mask** (IN) An optional “write” mask that controls which results from this operation are
6896 stored into the output vector *w*. The mask dimensions must match those of the
6897 vector *w*. If the `GrB_STRUCTURE` descriptor is *not* set for the mask, the domain
6898 of the `mask` vector must be of type `bool` or any of the predefined “built-in” types
6899 in Table 3.2. If the default mask is desired (i.e., a mask that is all `true` with the
6900 dimensions of *w*), `GrB_NULL` should be specified.

6901 **accum** (IN) An optional binary operator used for accumulating entries into existing *w*
6902 entries. If assignment rather than accumulation is desired, `GrB_NULL` should be
6903 specified.

6904 **op** (IN) The monoid or binary operator used in the element-wise reduction operation.
6905 Depending on which type is passed, the following defines the binary operator with
6906 one domain, $F_b = \langle D, D, D, \oplus \rangle$, that is used:

6907

BinaryOp: $F_b = \langle \mathbf{D}_{out}(\text{op}), \mathbf{D}_{in_1}(\text{op}), \mathbf{D}_{in_2}(\text{op}), \odot(\text{op}) \rangle$.

6908

Monoid: $F_b = \langle \mathbf{D}(\text{op}), \mathbf{D}(\text{op}), \mathbf{D}(\text{op}), \odot(\text{op}) \rangle$, the identity element of the monoid is ignored.

6909

6910

If `op` is a `GrB_BinaryOp`, then all its domains must be the same. Furthermore, in both cases $\odot(\text{op})$ must be commutative and associative. Otherwise, the outcome of the operation is undefined.

6911

6912

6913

A (IN) The GraphBLAS matrix on which reduction will be performed.

6914

desc (IN) An optional operation descriptor. If a *default* descriptor is desired, `GrB_NULL` should be specified. Non-default field/value pairs are listed as follows:

6915

6916

Param	Field	Value	Description
w	GrB_OUTP	GrB_REPLACE	Output vector w is cleared (all elements removed) before the result is stored in it.
mask	GrB_MASK	GrB_STRUCTURE	The write mask is constructed from the structure (pattern of stored values) of the input mask vector. The stored values are not examined.
mask	GrB_MASK	GrB_COMP	Use the complement of mask.
A	GrB_INP0	GrB_TRAN	Use transpose of A for the operation.

6917

6918 Return Values

6919

GrB_SUCCESS In blocking mode, the operation completed successfully. In non-blocking mode, this indicates that the compatibility tests on dimensions and domains for the input arguments passed successfully. Either way, output vector w is ready to be used in the next method of the sequence.

6920

6921

6922

6923

6924

GrB_PANIC Unknown internal error.

6925

GrB_INVALID_OBJECT This is returned in any execution mode whenever one of the opaque GraphBLAS objects (input or output) is in an invalid state caused by a previous execution error. Call `GrB_error()` to access any error messages generated by the implementation.

6926

6927

6928

6929

GrB_OUT_OF_MEMORY Not enough memory available for the operation.

6930

GrB_UNINITIALIZED_OBJECT One or more of the GraphBLAS objects has not been initialized by a call to `new` (or `dup` for vector parameters).

6931

6932

GrB_DIMENSION_MISMATCH mask, w and/or u dimensions are incompatible.

6933

GrB_DOMAIN_MISMATCH Either the domains of the various vectors and matrices are incompatible with the corresponding domains of the accumulation operator or reduce function, or the domains of the GraphBLAS binary

6934

6935

6936 operator `op` are not all the same, or the mask's domain is not com-
 6937 patible with `bool` (in the case where `desc[GrB_MASK].GrB_STRUCTURE`
 6938 is not set).

6939 Description

6940 This variant of `GrB_reduce` computes the result of performing a reduction across each of the rows
 6941 of an input matrix: $w(i) = \bigoplus A(i, :)\forall i$; or, if an optional binary accumulation operator is provided,
 6942 $w(i) = w(i) \odot (\bigoplus A(i, :))\forall i$, where $\bigoplus = \odot(F_b)$ and $\odot = \odot(\text{accum})$.

6943 Logically, this operation occurs in three steps:

6944 **Setup** The internal vector, matrix and mask used in the computation are formed and their
 6945 domains and dimensions are tested for compatibility.

6946 **Compute** The indicated computations are carried out.

6947 **Output** The result is written into the output vector, possibly under control of a mask.

6948 Up to two vector and one matrix argument are used in this `GrB_reduce` operation:

- 6949 1. $w = \langle \mathbf{D}(w), \mathbf{size}(w), \mathbf{L}(w) = \{(i, w_i)\} \rangle$
- 6950 2. $\text{mask} = \langle \mathbf{D}(\text{mask}), \mathbf{size}(\text{mask}), \mathbf{L}(\text{mask}) = \{(i, m_i)\} \rangle$ (optional)
- 6951 3. $A = \langle \mathbf{D}(A), \mathbf{nrows}(A), \mathbf{ncols}(A), \mathbf{L}(A) = \{(i, j, A_{ij})\} \rangle$

6952 The argument vector, matrix, reduction operator and accumulation operator (if provided) are tested
 6953 for domain compatibility as follows:

- 6954 1. If `mask` is not `GrB_NULL`, and `desc[GrB_MASK].GrB_STRUCTURE` is not set, then $\mathbf{D}(\text{mask})$
 6955 must be from one of the pre-defined types of Table 3.2.
- 6956 2. $\mathbf{D}(w)$ must be compatible with the domain of the reduction binary operator, $\mathbf{D}(F_b)$.
- 6957 3. If `accum` is not `GrB_NULL`, then $\mathbf{D}(w)$ must be compatible with $\mathbf{D}_{in_1}(\text{accum})$ and $\mathbf{D}_{out}(\text{accum})$
 6958 of the accumulation operator and $\mathbf{D}(F_b)$, must be compatible with $\mathbf{D}_{in_2}(\text{accum})$ of the accu-
 6959 mulation operator.
- 6960 4. $\mathbf{D}(A)$ must be compatible with the domain of the binary reduction operator, $\mathbf{D}(F_b)$.

6961 Two domains are compatible with each other if values from one domain can be cast to values in
 6962 the other domain as per the rules of the C language. In particular, domains from Table 3.2 are all
 6963 compatible with each other. A domain from a user-defined type is only compatible with itself. If
 6964 any compatibility rule above is violated, execution of `GrB_reduce` ends and the domain mismatch
 6965 error listed above is returned.

6966 From the argument vectors, the internal vectors and mask used in the computation are formed (\leftarrow
 6967 denotes copy):

- 6968 1. Vector $\tilde{\mathbf{w}} \leftarrow \mathbf{w}$.
- 6969 2. One-dimensional mask, $\tilde{\mathbf{m}}$, is computed from argument `mask` as follows:
- 6970 (a) If `mask = GrB_NULL`, then $\tilde{\mathbf{m}} = \langle \mathbf{size}(\mathbf{w}), \{i, \forall i : 0 \leq i < \mathbf{size}(\mathbf{w})\} \rangle$.
- 6971 (b) If `mask \neq GrB_NULL`,
- 6972 i. If `desc[GrB_MASK].GrB_STRUCTURE` is set, then $\tilde{\mathbf{m}} = \langle \mathbf{size}(\mathbf{mask}), \{i : i \in \mathbf{ind}(\mathbf{mask})\} \rangle$,
- 6973 ii. Otherwise, $\tilde{\mathbf{m}} = \langle \mathbf{size}(\mathbf{mask}), \{i : i \in \mathbf{ind}(\mathbf{mask}) \wedge (\mathbf{bool})\mathbf{mask}(i) = \mathbf{true}\} \rangle$.
- 6974 (c) If `desc[GrB_MASK].GrB_COMP` is set, then $\tilde{\mathbf{m}} \leftarrow \neg \tilde{\mathbf{m}}$.
- 6975 3. Matrix $\tilde{\mathbf{A}} \leftarrow \mathbf{desc}[\mathbf{GrB_INP0}].\mathbf{GrB_TRAN} ? \mathbf{A}^T : \mathbf{A}$.

6976 The internal vectors and masks are checked for dimension compatibility. The following conditions
6977 must hold:

- 6978 1. $\mathbf{size}(\tilde{\mathbf{w}}) = \mathbf{size}(\tilde{\mathbf{m}})$
- 6979 2. $\mathbf{size}(\tilde{\mathbf{w}}) = \mathbf{nrows}(\tilde{\mathbf{A}})$.

6980 If any compatibility rule above is violated, execution of `GrB_reduce` ends and the dimension mis-
6981 match error listed above is returned.

6982 From this point forward, in `GrB_NONBLOCKING` mode, the method can optionally exit with
6983 `GrB_SUCCESS` return code and defer any computation and/or execution error codes.

6984 We carry out the reduce and any additional associated operations. We describe this in terms of
6985 two intermediate vectors:

- 6986 • $\tilde{\mathbf{t}}$: The vector holding the result from reducing along the rows of input matrix $\tilde{\mathbf{A}}$.
- 6987 • $\tilde{\mathbf{z}}$: The vector holding the result after application of the (optional) accumulation operator.

6988 The intermediate vector, $\tilde{\mathbf{t}}$, is created as follows:

$$6989 \quad \tilde{\mathbf{t}} = \langle \mathbf{D}(\mathbf{op}), \mathbf{size}(\tilde{\mathbf{w}}), \{(i, t_i) : \mathbf{ind}(\mathbf{A}(i, :)) \neq \emptyset\} \rangle.$$

6990 The value of each of its elements is computed by

$$6991 \quad t_i = \bigoplus_{j \in \mathbf{ind}(\tilde{\mathbf{A}}(i, :))} \tilde{\mathbf{A}}(i, j),$$

6992 where $\bigoplus = \odot(F_b)$.

6993 The intermediate vector $\tilde{\mathbf{z}}$ is created as follows, using what is called a *standard vector accumulate*:

- 6994 • If `accum = GrB_NULL`, then $\tilde{\mathbf{z}} = \tilde{\mathbf{t}}$.

6995 • If `accum` is a binary operator, then $\tilde{\mathbf{z}}$ is defined as

$$6996 \quad \tilde{\mathbf{z}} = \langle \mathbf{D}_{out}(\text{accum}), \text{size}(\tilde{\mathbf{w}}), \{(i, z_i) \mid \forall i \in \text{ind}(\tilde{\mathbf{w}}) \cup \text{ind}(\tilde{\mathbf{t}})\} \rangle.$$

6997 The values of the elements of $\tilde{\mathbf{z}}$ are computed based on the relationships between the sets of
6998 indices in $\tilde{\mathbf{w}}$ and $\tilde{\mathbf{t}}$.

$$6999 \quad z_i = \tilde{\mathbf{w}}(i) \odot \tilde{\mathbf{t}}(i), \text{ if } i \in (\text{ind}(\tilde{\mathbf{t}}) \cap \text{ind}(\tilde{\mathbf{w}})),$$

$$7000$$

$$7001 \quad z_i = \tilde{\mathbf{w}}(i), \text{ if } i \in (\text{ind}(\tilde{\mathbf{w}}) - (\text{ind}(\tilde{\mathbf{t}}) \cap \text{ind}(\tilde{\mathbf{w}}))),$$

$$7002$$

$$7003 \quad z_i = \tilde{\mathbf{t}}(i), \text{ if } i \in (\text{ind}(\tilde{\mathbf{t}}) - (\text{ind}(\tilde{\mathbf{t}}) \cap \text{ind}(\tilde{\mathbf{w}}))),$$

7004 where $\odot = \odot(\text{accum})$, and the difference operator refers to set difference.

7005 Finally, the set of output values that make up vector $\tilde{\mathbf{z}}$ are written into the final result vector \mathbf{w} ,
7006 using what is called a *standard vector mask and replace*. This is carried out under control of the
7007 mask which acts as a “write mask”.

7008 • If `desc[GrB_OUTP].GrB_REPLACE` is set, then any values in \mathbf{w} on input to this operation are
7009 deleted and the content of the new output vector, \mathbf{w} , is defined as,

$$7010 \quad \mathbf{L}(\mathbf{w}) = \{(i, z_i) : i \in (\text{ind}(\tilde{\mathbf{z}}) \cap \text{ind}(\tilde{\mathbf{m}}))\}.$$

7011 • If `desc[GrB_OUTP].GrB_REPLACE` is not set, the elements of $\tilde{\mathbf{z}}$ indicated by the mask are
7012 copied into the result vector, \mathbf{w} , and elements of \mathbf{w} that fall outside the set indicated by the
7013 mask are unchanged:

$$7014 \quad \mathbf{L}(\mathbf{w}) = \{(i, w_i) : i \in (\text{ind}(\mathbf{w}) \cap \text{ind}(\neg\tilde{\mathbf{m}}))\} \cup \{(i, z_i) : i \in (\text{ind}(\tilde{\mathbf{z}}) \cap \text{ind}(\tilde{\mathbf{m}}))\}.$$

7015 In `GrB_BLOCKING` mode, the method exits with return value `GrB_SUCCESS` and the new content
7016 of vector \mathbf{w} is as defined above and fully computed. In `GrB_NONBLOCKING` mode, the method
7017 exits with return value `GrB_SUCCESS` and the new content of vector \mathbf{w} is as defined above but
7018 may not be fully computed. However, it can be used in the next GraphBLAS method call in a
7019 sequence.

7020 4.3.10.2 reduce: Vector-scalar variant

7021 Reduce all stored values into a single scalar.

7022 C Syntax

```
7023 // scalar value + monoid (only)
7024 GrB_Info GrB_reduce(<type>          *val,
7025                      const GrB_BinaryOp accum,
7026                      const GrB_Monoid  op,
7027                      const GrB_Vector  u,
```

```

7028             const GrB_Descriptor desc);
7029
7030 // GraphBLAS Scalar + monoid
7031 GrB_Info GrB_reduce(GrB_Scalar      s,
7032                   const GrB_BinaryOp accum,
7033                   const GrB_Monoid  op,
7034                   const GrB_Vector  u,
7035                   const GrB_Descriptor desc);
7036
7037 // GraphBLAS Scalar + binary operator
7038 GrB_Info GrB_reduce(GrB_Scalar      s,
7039                   const GrB_BinaryOp accum,
7040                   const GrB_BinaryOp op,
7041                   const GrB_Vector  u,
7042                   const GrB_Descriptor desc);

```

7043 Parameters

7044 **val** or **s** (INOUT) Scalar to store final reduced value into. On input, the scalar provides
7045 a value that may be accumulated (optionally) with the result of the reduction
7046 operation. On output, this scalar holds the results of the operation.

7047 **accum** (IN) An optional binary operator used for accumulating entries into an exist-
7048 ing scalar (**s** or **val**) value. If assignment rather than accumulation is desired,
7049 **GrB_NULL** should be specified.

7050 **op** (IN) The monoid ($M = \langle D, \oplus, 0 \rangle$) or binary operator ($F_b = \langle D, D, D, \oplus \rangle$) used in
7051 the reduction operation. The \oplus operator must be commutative and associative;
7052 otherwise, the outcome of the operation is undefined.

7053 **u** (IN) The GraphBLAS vector on which reduction will be performed.

7054 **desc** (IN) An optional operation descriptor. If a *default* descriptor is desired, **GrB_NULL**
7055 should be specified. Non-default field/value pairs are listed as follows:

7057	Param	Field	Value	Description
------	-------	-------	-------	-------------

7058 *Note:* This argument is defined for consistency with the other GraphBLAS opera-
7059 tions. There are currently no non-default field/value pairs that can be set for this
7060 operation.

7061 Return Values

7062 **GrB_SUCCESS** In blocking or non-blocking mode, the operation completed suc-
7063 cessfully, and the output scalar (**s** or **val**) is ready to be used in the
7064 next method of the sequence.

7065 GrB_PANIC Unknown internal error.

7066 GrB_INVALID_OBJECT This is returned in any execution mode whenever one of the opaque
7067 GraphBLAS objects (input or output) is in an invalid state caused
7068 by a previous execution error. Call GrB_error() to access any error
7069 messages generated by the implementation.

7070 GrB_OUT_OF_MEMORY Not enough memory available for the operation.

7071 GrB_UNINITIALIZED_OBJECT One or more of the GraphBLAS objects has not been initialized by
7072 a call to a respective constructor.

7073 GrB_NULL_POINTER val pointer is NULL.

7074 GrB_DOMAIN_MISMATCH The domains of input and output arguments are incompatible with
7075 the corresponding domains of the accumulation operator, or reduce
7076 operator.

7077 **Description**

7078 This variant of GrB_reduce computes the result of performing a reduction across all of the stored
7079 elements of an input vector storing the result into either s or val. This corresponds to (shown here
7080 for the scalar value case only):

$$7081 \quad \text{val} = \begin{cases} \bigoplus_{i \in \text{ind}(\mathbf{u})} \mathbf{u}(i), & \text{or} \\ \text{val} \odot \left[\bigoplus_{i \in \text{ind}(\mathbf{u})} \mathbf{u}(i) \right], & \text{if the the optional accumulator is specified.} \end{cases}$$

7082 where $\bigoplus = \odot(\text{op})$ and $\odot = \odot(\text{accum})$.

7083 Logically, this operation occurs in three steps:

7084 **Setup** The internal vector used in the computation is formed and its domain is tested for
7085 compatibility.

7086 **Compute** The indicated computations are carried out.

7087 **Output** The result is written into the output scalar.

7088 One vector argument is used in this GrB_reduce operation:

- 7089 1. $\mathbf{u} = \langle \mathbf{D}(\mathbf{u}), \text{size}(\mathbf{u}), \mathbf{L}(\mathbf{u}) = \{(i, u_i)\} \rangle$

7090 The output scalar, argument vector, reduction operator and accumulation operator (if provided)
7091 are tested for domain compatibility as follows:

- 7092 1. If accum is GrB_NULL, then $\mathbf{D}(\text{val})$ or $\mathbf{D}(\text{s})$ must be compatible with $\mathbf{D}(\text{op})$ from M (or with
7093 $\mathbf{D}_{in_1}(\text{op})$ and $\mathbf{D}_{in_2}(\text{op})$ from F_b).

7094 2. If `accum` is not `GrB_NULL`, then $\mathbf{D}(\text{val})$ or $\mathbf{D}(\text{s})$ must be compatible with $\mathbf{D}_{in_1}(\text{accum})$ and
7095 $\mathbf{D}_{out}(\text{accum})$ of the accumulation operator, and $\mathbf{D}(\text{op})$ from M (or $\mathbf{D}_{out}(\text{op})$ from F_b) must
7096 be compatible with $\mathbf{D}_{in_2}(\text{accum})$ of the accumulation operator.

7097 3. $\mathbf{D}(\mathbf{u})$ must be compatible with $\mathbf{D}(\text{op})$ from M (or with $\mathbf{D}_{in_1}(\text{op})$ and $\mathbf{D}_{in_2}(\text{op})$ from F_b).

7098 Two domains are compatible with each other if values from one domain can be cast to values in
7099 the other domain as per the rules of the C language. In particular, domains from Table 3.2 are all
7100 compatible with each other. A domain from a user-defined type is only compatible with itself. If
7101 any compatibility rule above is violated, execution of `GrB_reduce` ends and the domain mismatch
7102 error listed above is returned.

7103 The number of values stored in the input, \mathbf{u} , is checked. If there are no stored values in \mathbf{u} , then one
7104 of the following occurs depending on the output variant:

$$7105 \quad \mathbf{L}(\mathbf{s}) = \begin{cases} \{\}, & \text{(cleared) if } \text{accum} = \text{GrB_NULL}, \\ \mathbf{L}(\mathbf{s}), & \text{(unchanged) otherwise,} \end{cases}$$

7106 OR

$$7107 \quad \text{val} = \begin{cases} \mathbf{0}(\text{op}), & \text{(cleared) if } \text{accum} = \text{GrB_NULL}, \\ \text{val} \odot \mathbf{0}(\text{op}), & \text{otherwise,} \end{cases}$$

7108 where $\mathbf{0}(\text{op})$ is the identity of the monoid. The operation returns immediately with `GrB_SUCCESS`.

7109 For all other cases, the internal vector and scalar used in the computation is formed (\leftarrow denotes
7110 copy):

7111 1. Vector $\tilde{\mathbf{u}} \leftarrow \mathbf{u}$.

7112 2. Scalar $\tilde{s} \leftarrow \mathbf{s}$ (GraphBLAS scalar case).

7113 We are now ready to carry out the reduction and any additional associated operations. An inter-
7114 mediate scalar result t is computed as follows:

$$7115 \quad t = \bigoplus_{i \in \text{ind}(\tilde{\mathbf{u}})} \tilde{\mathbf{u}}(i),$$

7116 where $\oplus = \odot(\text{op})$.

7117 The final reduction value is computed as follows:

$$7118 \quad \mathbf{L}(\mathbf{s}) \leftarrow \begin{cases} \{t\}, & \text{when } \text{accum} = \text{GrB_NULL} \text{ or } \tilde{s} \text{ is empty, or} \\ \{\text{val}(\tilde{s}) \odot t\}, & \text{otherwise;} \end{cases}$$

7119 OR

$$7120 \quad \text{val} \leftarrow \begin{cases} t, & \text{when } \text{accum} = \text{GrB_NULL, or} \\ \text{val} \odot t, & \text{otherwise;} \end{cases}$$

7121 In both GrB_BLOCKING and GrB_NONBLOCKING modes, the method exits with return value
7122 GrB_SUCCESS and the new contents of the output scalar is as defined above.

7123 4.3.10.3 reduce: Matrix-scalar variant

7124 Reduce all stored values into a single scalar.

7125 C Syntax

```
7126 // scalar value + monoid (only)
7127 GrB_Info GrB_reduce(<type>          *val,
7128                   const GrB_BinaryOp accum,
7129                   const GrB_Monoid  op,
7130                   const GrB_Matrix  A,
7131                   const GrB_Descriptor desc);
7132
7133 // GraphBLAS Scalar + monoid
7134 GrB_Info GrB_reduce(GrB_Scalar      s,
7135                   const GrB_BinaryOp accum,
7136                   const GrB_Monoid  op,
7137                   const GrB_Matrix  A,
7138                   const GrB_Descriptor desc);
7139
7140 // GraphBLAS Scalar + binary operator
7141 GrB_Info GrB_reduce(GrB_Scalar      s,
7142                   const GrB_BinaryOp accum,
7143                   const GrB_BinaryOp op,
7144                   const GrB_Matrix  A,
7145                   const GrB_Descriptor desc);
```

7146 Parameters

7147 **val** or **s** (INOUT) Scalar to store final reduced value into. On input, the scalar provides
7148 a value that may be accumulated (optionally) with the result of the reduction
7149 operation. On output, this scalar holds the results of the operation.

7150 **accum** (IN) An optional binary operator used for accumulating entries into existing (**s** or
7151 **val**) value. If assignment rather than accumulation is desired, GrB_NULL should
7152 be specified.

7153 **op** (IN) The monoid ($M = \langle D, \oplus, 0 \rangle$) or binary operator ($F_b = \langle D, D, D, \oplus \rangle$) used in
7154 the reduction operation. The \oplus operator must be commutative and associative;
7155 otherwise, the outcome of the operation is undefined.

7156 **A** (IN) The GraphBLAS matrix on which the reduction will be performed.

7157 desc (IN) An optional operation descriptor. If a *default* descriptor is desired, GrB_NULL
 7158 should be specified. Non-default field/value pairs are listed as follows:
 7159

7160	Param	Field	Value	Description
------	-------	-------	-------	-------------

7161 *Note:* This argument is defined for consistency with the other GraphBLAS opera-
 7162 tions. There are currently no non-default field/value pairs that can be set for this
 7163 operation.

7164 Return Values

7165 GrB_SUCCESS In blocking or non-blocking mode, the operation completed suc-
 7166 cessfully, and the output scalar (s or val) is ready to be used in the
 7167 next method of the sequence.

7168 GrB_PANIC Unknown internal error.

7169 GrB_INVALID_OBJECT This is returned in any execution mode whenever one of the opaque
 7170 GraphBLAS objects (input or output) is in an invalid state caused
 7171 by a previous execution error. Call GrB_error() to access any error
 7172 messages generated by the implementation.

7173 GrB_OUT_OF_MEMORY Not enough memory available for the operation.

7174 GrB_UNINITIALIZED_OBJECT One or more of the GraphBLAS objects has not been initialized by
 7175 a call to a respective constructor.

7176 GrB_NULL_POINTER val pointer is NULL.

7177 GrB_DOMAIN_MISMATCH The domains of input and output arguments are incompatible with
 7178 the corresponding domains of the accumulation operator, or reduce
 7179 operator.

7180 Description

7181 This variant of GrB_reduce computes the result of performing a reduction across all of the stored
 7182 elements of an input matrix storing the result into either s or val. This corresponds to (shown here
 7183 for the scalar value case only):

$$7184 \quad \text{val} = \begin{cases} \bigoplus_{(i,j) \in \text{ind}(\mathbf{A})} \mathbf{A}(i,j), & \text{or} \\ \text{val} \odot \left[\bigoplus_{(i,j) \in \text{ind}(\mathbf{A})} \mathbf{A}(i,j) \right], & \text{if the the optional accumulator is specified.} \end{cases}$$

7185 where $\bigoplus = \odot(\text{op})$ and $\odot = \odot(\text{accum})$.

7186 Logically, this operation occurs in three steps:

7187 **Setup** The internal matrix used in the computation is formed and its domain is tested for
 7188 compatibility.

7189 **Compute** The indicated computations are carried out.

7190 **Output** The result is written into the output scalar.

7191 One matrix argument is used in this GrB_reduce operation:

7192 1. $\mathbf{A} = \langle \mathbf{D}(\mathbf{A}), \mathbf{size}(\mathbf{A}), \mathbf{L}(\mathbf{A}) = \{(i, j, A_{i,j})\} \rangle$

7193 The output scalar, argument matrix, reduction operator and accumulation operator (if provided)
 7194 are tested for domain compatibility as follows:

7195 1. If `accum` is `GrB_NULL`, then $\mathbf{D}(\mathbf{val})$ or $\mathbf{D}(\mathbf{s})$ must be compatible with $\mathbf{D}(\mathbf{op})$ from M (or with
 7196 $\mathbf{D}_{in_1}(\mathbf{op})$ and $\mathbf{D}_{in_2}(\mathbf{op})$ from F_b).

7197 2. If `accum` is not `GrB_NULL`, then $\mathbf{D}(\mathbf{val})$ or $\mathbf{D}(\mathbf{s})$ must be compatible with $\mathbf{D}_{in_1}(\mathbf{accum})$ and
 7198 $\mathbf{D}_{out}(\mathbf{accum})$ of the accumulation operator, and $\mathbf{D}(\mathbf{op})$ from M (or $\mathbf{D}_{out}(\mathbf{op})$ from F_b) must
 7199 be compatible with $\mathbf{D}_{in_2}(\mathbf{accum})$ of the accumulation operator.

7200 3. $\mathbf{D}(\mathbf{A})$ must be compatible with $\mathbf{D}(\mathbf{op})$ from M (or with $\mathbf{D}_{in_1}(\mathbf{op})$ and $\mathbf{D}_{in_2}(\mathbf{op})$ from F_b).

7201 Two domains are compatible with each other if values from one domain can be cast to values in
 7202 the other domain as per the rules of the C language. In particular, domains from Table 3.2 are all
 7203 compatible with each other. A domain from a user-defined type is only compatible with itself. If
 7204 any compatibility rule above is violated, execution of `GrB_reduce` ends and the domain mismatch
 7205 error listed above is returned.

7206 The number of values stored in the input, \mathbf{A} , is checked. If there are no stored values in \mathbf{A} , then
 7207 one of the following occurs depending on the output variant:

$$7208 \quad \mathbf{L}(\mathbf{s}) = \begin{cases} \{\}, & \text{(cleared) if } \mathbf{accum} = \mathbf{GrB_NULL}, \\ \mathbf{L}(\mathbf{s}), & \text{(unchanged) otherwise,} \end{cases}$$

7209 or

$$7210 \quad \mathbf{val} = \begin{cases} \mathbf{0}(\mathbf{op}), & \text{(cleared) if } \mathbf{accum} = \mathbf{GrB_NULL}, \\ \mathbf{val} \odot \mathbf{0}(\mathbf{op}), & \text{otherwise,} \end{cases}$$

7211 where $\mathbf{0}(\mathbf{op})$ is the identity of the monoid. The operation returns immediately with `GrB_SUCCESS`.

7212 For all other cases, the internal matrix and scalar used in the computation is formed (\leftarrow denotes
 7213 copy):

7214 1. Matrix $\tilde{\mathbf{A}} \leftarrow \mathbf{A}$.

7215 2. Scalar $\tilde{s} \leftarrow \mathbf{s}$ (GraphBLAS scalar case).

7216 We are now ready to carry out the reduce and any additional associated operations. An intermediate
 7217 scalar result t is computed as follows:

$$7218 \quad t = \bigoplus_{(i,j) \in \text{ind}(\tilde{\mathbf{A}})} \tilde{\mathbf{A}}(i,j),$$

7219 where $\oplus = \odot(\text{op})$.

7220 The final reduction value is computed as follows:

$$7221 \quad \mathbf{L}(s) \leftarrow \begin{cases} \{t\}, & \text{when accum} = \text{GrB_NULL} \text{ or } \tilde{s} \text{ is empty, or} \\ \{\text{val}(\tilde{s}) \odot t\}, & \text{otherwise;} \end{cases}$$

7222 or

$$7223 \quad \text{val} \leftarrow \begin{cases} t, & \text{when accum} = \text{GrB_NULL, or} \\ \text{val} \odot t, & \text{otherwise;} \end{cases}$$

7224 In both GrB_BLOCKING and GrB_NONBLOCKING modes, the method exits with return value
 7225 GrB_SUCCESS and the new contents of the output scalar is as defined above.

7226 4.3.11 transpose: Transpose rows and columns of a matrix

7227 This version computes a new matrix that is the transpose of the source matrix.

7228 C Syntax

```
7229     GrB_Info GrB_transpose(GrB_Matrix      C,
7230                          const GrB_Matrix Mask,
7231                          const GrB_BinaryOp accum,
7232                          const GrB_Matrix  A,
7233                          const GrB_Descriptor desc);
```

7234 Parameters

7235 **C** (INOUT) An existing GraphBLAS matrix. On input, the matrix provides values
 7236 that may be accumulated with the result of the transpose operation. On output,
 7237 the matrix holds the results of the operation.

7238 **Mask** (IN) An optional “write” mask that controls which results from this operation are
 7239 stored into the output matrix C. The mask dimensions must match those of the
 7240 matrix C. If the GrB_STRUCTURE descriptor is *not* set for the mask, the domain
 7241 of the Mask matrix must be of type bool or any of the predefined “built-in” types
 7242 in Table 3.2. If the default mask is desired (i.e., a mask that is all true with the
 7243 dimensions of C), GrB_NULL should be specified.

7244 **accum** (IN) An optional binary operator used for accumulating entries into existing C
 7245 entries. If assignment rather than accumulation is desired, GrB_NULL should be
 7246 specified.

7247 **A** (IN) The GraphBLAS matrix on which transposition will be performed.

7248 **desc** (IN) An optional operation descriptor. If a *default* descriptor is desired, GrB_NULL
 7249 should be specified. Non-default field/value pairs are listed as follows:
 7250

Param	Field	Value	Description
C	GrB_OUTP	GrB_REPLACE	Output matrix C is cleared (all elements removed) before the result is stored in it.
Mask	GrB_MASK	GrB_STRUCTURE	The write mask is constructed from the structure (pattern of stored values) of the input Mask matrix. The stored values are not examined.
Mask	GrB_MASK	GrB_COMP	Use the complement of Mask.
A	GrB_INP0	GrB_TRAN	Use transpose of A for the operation.

7251

7252 Return Values

7253 **GrB_SUCCESS** In blocking mode, the operation completed successfully. In non-
 7254 blocking mode, this indicates that the compatibility tests on di-
 7255 mensions and domains for the input arguments passed successfully.
 7256 Either way, output matrix C is ready to be used in the next method
 7257 of the sequence.

7258 **GrB_PANIC** Unknown internal error.

7259 **GrB_INVALID_OBJECT** This is returned in any execution mode whenever one of the opaque
 7260 GraphBLAS objects (input or output) is in an invalid state caused
 7261 by a previous execution error. Call GrB_error() to access any error
 7262 messages generated by the implementation.

7263 **GrB_OUT_OF_MEMORY** Not enough memory available for the operation.

7264 **GrB_UNINITIALIZED_OBJECT** One or more of the GraphBLAS objects has not been initialized by
 7265 a call to new (or Matrix_dup for matrix parameters).

7266 **GrB_DIMENSION_MISMATCH** mask, C and/or A dimensions are incompatible.

7267 **GrB_DOMAIN_MISMATCH** The domains of the various matrices are incompatible with the cor-
 7268 responding domains of the accumulation operator, or the mask's do-
 7269 main is not compatible with bool (in the case where desc[GrB_MASK].GrB_STRUCT
 7270 is not set).

7271 **Description**

7272 GrB_transpose computes the result of performing a transpose of the input matrix: $C = A^T$; or, if an
7273 optional binary accumulation operator (\odot) is provided, $C = C \odot A^T$. We note that the input matrix
7274 A can itself be optionally transposed before the operation, which would cause either an assignment
7275 from A to C or an accumulation of A into C.

7276 Logically, this operation occurs in three steps:

7277 **Setup** The internal matrix and mask used in the computation are formed and their domains
7278 and dimensions are tested for compatibility.

7279 **Compute** The indicated computations are carried out.

7280 **Output** The result is written into the output matrix, possibly under control of a mask.

7281 Up to three matrix arguments are used in this GrB_transpose operation:

- 7282 1. $C = \langle \mathbf{D}(C), \mathbf{nrows}(C), \mathbf{ncols}(C), \mathbf{L}(C) = \{(i, j, C_{ij})\} \rangle$
- 7283 2. $\text{Mask} = \langle \mathbf{D}(\text{Mask}), \mathbf{nrows}(\text{Mask}), \mathbf{ncols}(\text{Mask}), \mathbf{L}(\text{Mask}) = \{(i, j, M_{ij})\} \rangle$ (optional)
- 7284 3. $A = \langle \mathbf{D}(A), \mathbf{nrows}(A), \mathbf{ncols}(A), \mathbf{L}(A) = \{(i, j, A_{ij})\} \rangle$

7285 The argument matrices and accumulation operator (if provided) are tested for domain compatibility
7286 as follows:

- 7287 1. If Mask is not GrB_NULL, and desc[GrB_MASK].GrB_STRUCTURE is not set, then $\mathbf{D}(\text{Mask})$
7288 must be from one of the pre-defined types of Table 3.2.
- 7289 2. $\mathbf{D}(C)$ must be compatible with $\mathbf{D}(A)$ of the input matrix.
- 7290 3. If accum is not GrB_NULL, then $\mathbf{D}(C)$ must be compatible with $\mathbf{D}_{in_1}(\text{accum})$ and $\mathbf{D}_{out}(\text{accum})$
7291 of the accumulation operator and $\mathbf{D}(A)$ of the input matrix must be compatible with $\mathbf{D}_{in_2}(\text{accum})$
7292 of the accumulation operator.

7293 Two domains are compatible with each other if values from one domain can be cast to values in
7294 the other domain as per the rules of the C language. In particular, domains from Table 3.2 are all
7295 compatible with each other. A domain from a user-defined type is only compatible with itself. If
7296 any compatibility rule above is violated, execution of GrB_transpose ends and the domain mismatch
7297 error listed above is returned.

7298 From the argument matrices, the internal matrices and mask used in the computation are formed
7299 (\leftarrow denotes copy):

- 7300 1. Matrix $\tilde{C} \leftarrow C$.
- 7301 2. Two-dimensional mask, \tilde{M} , is computed from argument Mask as follows:

- 7302 (a) If $\text{Mask} = \text{GrB_NULL}$, then $\widetilde{\mathbf{M}} = \langle \mathbf{nrows}(\mathbf{C}), \mathbf{ncols}(\mathbf{C}), \{(i, j), \forall i, j : 0 \leq i < \mathbf{nrows}(\mathbf{C}), 0 \leq$
7303 $j < \mathbf{ncols}(\mathbf{C})\}$.
- 7304 (b) If $\text{Mask} \neq \text{GrB_NULL}$,
- 7305 i. If $\text{desc}[\text{GrB_MASK}].\text{GrB_STRUCTURE}$ is set, then $\widetilde{\mathbf{M}} = \langle \mathbf{nrows}(\text{Mask}), \mathbf{ncols}(\text{Mask}), \{(i, j) :$
7306 $(i, j) \in \mathbf{ind}(\text{Mask})\}$,
- 7307 ii. Otherwise, $\widetilde{\mathbf{M}} = \langle \mathbf{nrows}(\text{Mask}), \mathbf{ncols}(\text{Mask}),$
7308 $\{(i, j) : (i, j) \in \mathbf{ind}(\text{Mask}) \wedge (\text{bool})\text{Mask}(i, j) = \text{true}\}$.
- 7309 (c) If $\text{desc}[\text{GrB_MASK}].\text{GrB_COMP}$ is set, then $\widetilde{\mathbf{M}} \leftarrow \neg\widetilde{\mathbf{M}}$.
- 7310 3. Matrix $\widetilde{\mathbf{A}} \leftarrow \text{desc}[\text{GrB_INP0}].\text{GrB_TRAN} ? \mathbf{A}^T : \mathbf{A}$.

7311 The internal matrices and masks are checked for dimension compatibility. The following conditions
7312 must hold:

- 7313 1. $\mathbf{nrows}(\widetilde{\mathbf{C}}) = \mathbf{nrows}(\widetilde{\mathbf{M}})$.
- 7314 2. $\mathbf{ncols}(\widetilde{\mathbf{C}}) = \mathbf{ncols}(\widetilde{\mathbf{M}})$.
- 7315 3. $\mathbf{nrows}(\widetilde{\mathbf{C}}) = \mathbf{ncols}(\widetilde{\mathbf{A}})$.
- 7316 4. $\mathbf{ncols}(\widetilde{\mathbf{C}}) = \mathbf{nrows}(\widetilde{\mathbf{A}})$.

7317 If any compatibility rule above is violated, execution of `GrB_transpose` ends and the dimension
7318 mismatch error listed above is returned.

7319 From this point forward, in `GrB_NONBLOCKING` mode, the method can optionally exit with
7320 `GrB_SUCCESS` return code and defer any computation and/or execution error codes.

7321 We are now ready to carry out the matrix transposition and any additional associated operations.
7322 We describe this in terms of two intermediate matrices:

- 7323 • $\widetilde{\mathbf{T}}$: The matrix holding the transpose of $\widetilde{\mathbf{A}}$.
- 7324 • $\widetilde{\mathbf{Z}}$: The matrix holding the result after application of the (optional) accumulation operator.

7325 The intermediate matrix

$$7326 \quad \widetilde{\mathbf{T}} = \langle \mathbf{D}(\mathbf{A}), \mathbf{ncols}(\widetilde{\mathbf{A}}), \mathbf{nrows}(\widetilde{\mathbf{A}}), \{(j, i, A_{ij}) \forall (i, j) \in \mathbf{ind}(\widetilde{\mathbf{A}})\} \rangle$$

7327 is created.

7328 The intermediate matrix $\widetilde{\mathbf{Z}}$ is created as follows, using what is called a *standard matrix accumulate*:

- 7329 • If $\text{accum} = \text{GrB_NULL}$, then $\widetilde{\mathbf{Z}} = \widetilde{\mathbf{T}}$.
- 7330 • If accum is a binary operator, then $\widetilde{\mathbf{Z}}$ is defined as

$$7331 \quad \widetilde{\mathbf{Z}} = \langle \mathbf{D}_{out}(\text{accum}), \mathbf{nrows}(\widetilde{\mathbf{C}}), \mathbf{ncols}(\widetilde{\mathbf{C}}), \{(i, j, Z_{ij}) \forall (i, j) \in \mathbf{ind}(\widetilde{\mathbf{C}}) \cup \mathbf{ind}(\widetilde{\mathbf{T}})\} \rangle.$$

7332 The values of the elements of $\tilde{\mathbf{Z}}$ are computed based on the relationships between the sets of
 7333 indices in $\tilde{\mathbf{C}}$ and $\tilde{\mathbf{T}}$.

$$\begin{aligned}
 7334 \quad Z_{ij} &= \tilde{\mathbf{C}}(i, j) \odot \tilde{\mathbf{T}}(i, j), \text{ if } (i, j) \in (\mathbf{ind}(\tilde{\mathbf{T}}) \cap \mathbf{ind}(\tilde{\mathbf{C}})), \\
 7335 \\
 7336 \quad Z_{ij} &= \tilde{\mathbf{C}}(i, j), \text{ if } (i, j) \in (\mathbf{ind}(\tilde{\mathbf{C}}) - (\mathbf{ind}(\tilde{\mathbf{T}}) \cap \mathbf{ind}(\tilde{\mathbf{C}}))), \\
 7337 \\
 7338 \quad Z_{ij} &= \tilde{\mathbf{T}}(i, j), \text{ if } (i, j) \in (\mathbf{ind}(\tilde{\mathbf{T}}) - (\mathbf{ind}(\tilde{\mathbf{T}}) \cap \mathbf{ind}(\tilde{\mathbf{C}}))),
 \end{aligned}$$

7339 where $\odot = \odot(\text{accum})$, and the difference operator refers to set difference.

7340 Finally, the set of output values that make up matrix $\tilde{\mathbf{Z}}$ are written into the final result matrix \mathbf{C} ,
 7341 using what is called a *standard matrix mask and replace*. This is carried out under control of the
 7342 mask which acts as a “write mask”.

- 7343 • If desc[GrB_OUTP].GrB_REPLACE is set, then any values in \mathbf{C} on input to this operation are
 7344 deleted and the content of the new output matrix, \mathbf{C} , is defined as,

$$7345 \quad \mathbf{L}(\mathbf{C}) = \{(i, j, Z_{ij}) : (i, j) \in (\mathbf{ind}(\tilde{\mathbf{Z}}) \cap \mathbf{ind}(\tilde{\mathbf{M}}))\}.$$

- 7346 • If desc[GrB_OUTP].GrB_REPLACE is not set, the elements of $\tilde{\mathbf{Z}}$ indicated by the mask are
 7347 copied into the result matrix, \mathbf{C} , and elements of \mathbf{C} that fall outside the set indicated by the
 7348 mask are unchanged:

$$7349 \quad \mathbf{L}(\mathbf{C}) = \{(i, j, C_{ij}) : (i, j) \in (\mathbf{ind}(\mathbf{C}) \cap \mathbf{ind}(\neg\tilde{\mathbf{M}}))\} \cup \{(i, j, Z_{ij}) : (i, j) \in (\mathbf{ind}(\tilde{\mathbf{Z}}) \cap \mathbf{ind}(\tilde{\mathbf{M}}))\}.$$

7350 In GrB_BLOCKING mode, the method exits with return value GrB_SUCCESS and the new content
 7351 of matrix \mathbf{C} is as defined above and fully computed. In GrB_NONBLOCKING mode, the method
 7352 exits with return value GrB_SUCCESS and the new content of matrix \mathbf{C} is as defined above but
 7353 may not be fully computed. However, it can be used in the next GraphBLAS method call in a
 7354 sequence.

7355 4.3.12 kronecker: Kronecker product of two matrices

7356 Computes the Kronecker product of two matrices. The result is a matrix.

7357 C Syntax

```

7358     GrB_Info GrB_kronecker(GrB_Matrix      C,
7359                          const GrB_Matrix  Mask,
7360                          const GrB_BinaryOp accum,
7361                          const GrB_Semiring op,
7362                          const GrB_Matrix  A,
7363                          const GrB_Matrix  B,
7364                          const GrB_Descriptor desc);
7365
  
```

```

7366     GrB_Info GrB_kronecker(GrB_Matrix      C,
7367                             const GrB_Matrix  Mask,
7368                             const GrB_BinaryOp accum,
7369                             const GrB_Monoid   op,
7370                             const GrB_Matrix  A,
7371                             const GrB_Matrix  B,
7372                             const GrB_Descriptor desc);
7373
7374     GrB_Info GrB_kronecker(GrB_Matrix      C,
7375                             const GrB_Matrix  Mask,
7376                             const GrB_BinaryOp accum,
7377                             const GrB_BinaryOp op,
7378                             const GrB_Matrix  A,
7379                             const GrB_Matrix  B,
7380                             const GrB_Descriptor desc);

```

7381 Parameters

7382 **C** (INOUT) An existing GraphBLAS matrix. On input, the matrix provides values
7383 that may be accumulated with the result of the Kronecker product. On output,
7384 the matrix holds the results of the operation.

7385 **Mask** (IN) An optional “write” mask that controls which results from this operation are
7386 stored into the output matrix C. The mask dimensions must match those of the
7387 matrix C. If the GrB_STRUCTURE descriptor is *not* set for the mask, the domain
7388 of the Mask matrix must be of type bool or any of the predefined “built-in” types
7389 in Table 3.2. If the default mask is desired (i.e., a mask that is all true with the
7390 dimensions of C), GrB_NULL should be specified.

7391 **accum** (IN) An optional binary operator used for accumulating entries into existing C
7392 entries. If assignment rather than accumulation is desired, GrB_NULL should be
7393 specified.

7394 **op** (IN) The semiring, monoid, or binary operator used in the element-wise “product”
7395 operation. Depending on which type is passed, the following defines the binary
7396 operator, $F_b = \langle \mathbf{D}_{out}(\text{op}), \mathbf{D}_{in_1}(\text{op}), \mathbf{D}_{in_2}(\text{op}), \otimes \rangle$, used:

7397 BinaryOp: $F_b = \langle \mathbf{D}_{out}(\text{op}), \mathbf{D}_{in_1}(\text{op}), \mathbf{D}_{in_2}(\text{op}), \odot(\text{op}) \rangle$.

7398 Monoid: $F_b = \langle \mathbf{D}(\text{op}), \mathbf{D}(\text{op}), \mathbf{D}(\text{op}), \odot(\text{op}) \rangle$; the identity element is ig-
7399 nored.

7400 Semiring: $F_b = \langle \mathbf{D}_{out}(\text{op}), \mathbf{D}_{in_1}(\text{op}), \mathbf{D}_{in_2}(\text{op}), \otimes(\text{op}) \rangle$; the additive monoid
7401 is ignored.

7402 **A** (IN) The GraphBLAS matrix holding the values for the left-hand matrix in the
7403 product.

7404 B (IN) The GraphBLAS matrix holding the values for the right-hand matrix in the
 7405 product.

7406 desc (IN) An optional operation descriptor. If a *default* descriptor is desired, GrB_NULL
 7407 should be specified. Non-default field/value pairs are listed as follows:
 7408

Param	Field	Value	Description
C	GrB_OUTP	GrB_REPLACE	Output matrix C is cleared (all elements removed) before the result is stored in it.
Mask	GrB_MASK	GrB_STRUCTURE	The write mask is constructed from the structure (pattern of stored values) of the input Mask matrix. The stored values are not examined.
Mask	GrB_MASK	GrB_COMP	Use the complement of Mask.
A	GrB_INP0	GrB_TRAN	Use transpose of A for the operation.
B	GrB_INP1	GrB_TRAN	Use transpose of B for the operation.

7409

7410 Return Values

7411 GrB_SUCCESS In blocking mode, the operation completed successfully. In non-
 7412 blocking mode, this indicates that the compatibility tests on di-
 7413 mensions and domains for the input arguments passed successfully.
 7414 Either way, output matrix C is ready to be used in the next method
 7415 of the sequence.

7416 GrB_PANIC Unknown internal error.

7417 GrB_INVALID_OBJECT This is returned in any execution mode whenever one of the opaque
 7418 GraphBLAS objects (input or output) is in an invalid state caused
 7419 by a previous execution error. Call GrB_error() to access any error
 7420 messages generated by the implementation.

7421 GrB_OUT_OF_MEMORY Not enough memory available for the operation.

7422 GrB_UNINITIALIZED_OBJECT One or more of the GraphBLAS objects has not been initialized by
 7423 a call to new (or Matrix_dup for matrix parameters).

7424 GrB_DIMENSION_MISMATCH Mask and/or matrix dimensions are incompatible.

7425 GrB_DOMAIN_MISMATCH The domains of the various matrices are incompatible with the
 7426 corresponding domains of the binary operator (op) or accumulation
 7427 operator, or the mask's domain is not compatible with bool (in the
 7428 case where desc[GrB_MASK].GrB_STRUCTURE is not set).

7429 Description

7430 GrB_kronecker computes the Kronecker product $C = A \otimes B$ or, if an optional binary accumulation
 7431 operator (\odot) is provided, $C = C \odot (A \otimes B)$ (where matrices A and B can be optionally transposed).

7432 The Kronecker product is defined as follows:

7433

$$7434 \quad \mathbf{C} = \mathbf{A} \otimes \mathbf{B} = \begin{bmatrix} A_{0,0} \otimes \mathbf{B} & A_{0,1} \otimes \mathbf{B} & \dots & A_{0,n_A-1} \otimes \mathbf{B} \\ A_{1,0} \otimes \mathbf{B} & A_{1,1} \otimes \mathbf{B} & \dots & A_{1,n_A-1} \otimes \mathbf{B} \\ \vdots & \vdots & \ddots & \vdots \\ A_{m_A-1,0} \otimes \mathbf{B} & A_{m_A-1,1} \otimes \mathbf{B} & \dots & A_{m_A-1,n_A-1} \otimes \mathbf{B} \end{bmatrix}$$

7435 where $\mathbf{A} : \mathbb{S}^{m_A \times n_A}$, $\mathbf{B} : \mathbb{S}^{m_B \times n_B}$, and $\mathbf{C} : \mathbb{S}^{m_A m_B \times n_A n_B}$. More explicitly, the elements of the
7436 Kronecker product are defined as

$$7437 \quad \mathbf{C}(i_A m_B + i_B, j_A n_B + j_B) = A_{i_A, j_A} \otimes B_{i_B, j_B},$$

7438 where \otimes is the multiplicative operator specified by the `op` parameter.

7439 Logically, this operation occurs in three steps:

7440 **Setup** The internal matrices and mask used in the computation are formed and their domains
7441 and dimensions are tested for compatibility.

7442 **Compute** The indicated computations are carried out.

7443 **Output** The result is written into the output matrix, possibly under control of a mask.

7444 Up to four argument matrices are used in the `GrB_kronecker` operation:

- 7445 1. $\mathbf{C} = \langle \mathbf{D}(\mathbf{C}), \mathbf{nrows}(\mathbf{C}), \mathbf{ncols}(\mathbf{C}), \mathbf{L}(\mathbf{C}) = \{(i, j, C_{ij})\} \rangle$
- 7446 2. $\text{Mask} = \langle \mathbf{D}(\text{Mask}), \mathbf{nrows}(\text{Mask}), \mathbf{ncols}(\text{Mask}), \mathbf{L}(\text{Mask}) = \{(i, j, M_{ij})\} \rangle$ (optional)
- 7447 3. $\mathbf{A} = \langle \mathbf{D}(\mathbf{A}), \mathbf{nrows}(\mathbf{A}), \mathbf{ncols}(\mathbf{A}), \mathbf{L}(\mathbf{A}) = \{(i, j, A_{ij})\} \rangle$
- 7448 4. $\mathbf{B} = \langle \mathbf{D}(\mathbf{B}), \mathbf{nrows}(\mathbf{B}), \mathbf{ncols}(\mathbf{B}), \mathbf{L}(\mathbf{B}) = \{(i, j, B_{ij})\} \rangle$

7449 The argument matrices, the "product" operator (`op`), and the accumulation operator (if provided)
7450 are tested for domain compatibility as follows:

- 7451 1. If `Mask` is not `GrB_NULL`, and `desc[GrB_MASK].GrB_STRUCTURE` is not set, then $\mathbf{D}(\text{Mask})$
7452 must be from one of the pre-defined types of Table 3.2.
- 7453 2. $\mathbf{D}(\mathbf{A})$ must be compatible with $\mathbf{D}_{in_1}(\text{op})$.
- 7454 3. $\mathbf{D}(\mathbf{B})$ must be compatible with $\mathbf{D}_{in_2}(\text{op})$.
- 7455 4. $\mathbf{D}(\mathbf{C})$ must be compatible with $\mathbf{D}_{out}(\text{op})$.
- 7456 5. If `accum` is not `GrB_NULL`, then $\mathbf{D}(\mathbf{C})$ must be compatible with $\mathbf{D}_{in_1}(\text{accum})$ and $\mathbf{D}_{out}(\text{accum})$
7457 of the accumulation operator and $\mathbf{D}_{out}(\text{op})$ of `op` must be compatible with $\mathbf{D}_{in_2}(\text{accum})$ of
7458 the accumulation operator.

7459 Two domains are compatible with each other if values from one domain can be cast to values in
7460 the other domain as per the rules of the C language. In particular, domains from Table 3.2 are all
7461 compatible with each other. A domain from a user-defined type is only compatible with itself. If
7462 any compatibility rule above is violated, execution of `GrB_kronecker` ends and the domain mismatch
7463 error listed above is returned.

7464 From the argument matrices, the internal matrices and mask used in the computation are formed
7465 (\leftarrow denotes copy):

- 7466 1. Matrix $\tilde{\mathbf{C}} \leftarrow \mathbf{C}$.
- 7467 2. Two-dimensional mask, $\tilde{\mathbf{M}}$, is computed from argument `Mask` as follows:
 - 7468 (a) If `Mask = GrB_NULL`, then $\tilde{\mathbf{M}} = \langle \mathbf{nrows}(\mathbf{C}), \mathbf{ncols}(\mathbf{C}), \{(i, j), \forall i, j : 0 \leq i < \mathbf{nrows}(\mathbf{C}), 0 \leq$
7469 $j < \mathbf{ncols}(\mathbf{C})\} \rangle$.
 - 7470 (b) If `Mask \neq GrB_NULL`,
 - 7471 i. If `desc[GrB_MASK].GrB_STRUCTURE` is set, then $\tilde{\mathbf{M}} = \langle \mathbf{nrows}(\mathbf{Mask}), \mathbf{ncols}(\mathbf{Mask}), \{(i, j) :$
7472 $(i, j) \in \mathbf{ind}(\mathbf{Mask})\} \rangle$,
 - 7473 ii. Otherwise, $\tilde{\mathbf{M}} = \langle \mathbf{nrows}(\mathbf{Mask}), \mathbf{ncols}(\mathbf{Mask}),$
7474 $\{(i, j) : (i, j) \in \mathbf{ind}(\mathbf{Mask}) \wedge (\mathbf{bool})\mathbf{Mask}(i, j) = \mathbf{true}\} \rangle$.
 - 7475 (c) If `desc[GrB_MASK].GrB_COMP` is set, then $\tilde{\mathbf{M}} \leftarrow \neg \tilde{\mathbf{M}}$.
- 7476 3. Matrix $\tilde{\mathbf{A}} \leftarrow \mathbf{desc}[\mathbf{GrB_INP0}].\mathbf{GrB_TRAN} ? \mathbf{A}^T : \mathbf{A}$.
- 7477 4. Matrix $\tilde{\mathbf{B}} \leftarrow \mathbf{desc}[\mathbf{GrB_INP1}].\mathbf{GrB_TRAN} ? \mathbf{B}^T : \mathbf{B}$.

7478 The internal matrices and masks are checked for dimension compatibility. The following conditions
7479 must hold:

- 7480 1. $\mathbf{nrows}(\tilde{\mathbf{C}}) = \mathbf{nrows}(\tilde{\mathbf{M}})$.
- 7481 2. $\mathbf{ncols}(\tilde{\mathbf{C}}) = \mathbf{ncols}(\tilde{\mathbf{M}})$.
- 7482 3. $\mathbf{nrows}(\tilde{\mathbf{C}}) = \mathbf{nrows}(\tilde{\mathbf{A}}) \cdot \mathbf{nrows}(\tilde{\mathbf{B}})$.
- 7483 4. $\mathbf{ncols}(\tilde{\mathbf{C}}) = \mathbf{ncols}(\tilde{\mathbf{A}}) \cdot \mathbf{ncols}(\tilde{\mathbf{B}})$.

7484 If any compatibility rule above is violated, execution of `GrB_kronecker` ends and the dimension
7485 mismatch error listed above is returned.

7486 From this point forward, in `GrB_NONBLOCKING` mode, the method can optionally exit with
7487 `GrB_SUCCESS` return code and defer any computation and/or execution error codes.

7488 We are now ready to carry out the Kronecker product and any additional associated operations.
7489 We describe this in terms of two intermediate matrices:

- 7490 • $\tilde{\mathbf{T}}$: The matrix holding the Kronecker product of matrices $\tilde{\mathbf{A}}$ and $\tilde{\mathbf{B}}$.
- 7491 • $\tilde{\mathbf{Z}}$: The matrix holding the result after application of the (optional) accumulation operator.

7492 The intermediate matrix $\tilde{\mathbf{T}} = \langle \mathbf{D}_{out}(\text{op}), \mathbf{nrows}(\tilde{\mathbf{A}}) \times \mathbf{nrows}(\tilde{\mathbf{B}}), \mathbf{ncols}(\tilde{\mathbf{A}}) \times \mathbf{ncols}(\tilde{\mathbf{B}}), \{(i, j, T_{ij}) \text{ where } i =$
7493 $i_A \cdot m_B + i_B, j = j_A \cdot n_B + j_B, \forall (i_A, j_A) = \mathbf{ind}(\tilde{\mathbf{A}}), (i_B, j_B) = \mathbf{ind}(\tilde{\mathbf{B}})\}$ is created. The value of
7494 each of its elements is computed by

$$7495 \quad T_{i_A \cdot m_B + i_B, j_A \cdot n_B + j_B} = \tilde{\mathbf{A}}(i_A, j_A) \otimes \tilde{\mathbf{B}}(i_B, j_B),$$

7496 where \otimes is the multiplicative operator specified by the `op` parameter.

7497 The intermediate matrix $\tilde{\mathbf{Z}}$ is created as follows, using what is called a *standard matrix accumulate*:

- 7498 • If `accum = GrB_NULL`, then $\tilde{\mathbf{Z}} = \tilde{\mathbf{T}}$.
- 7499 • If `accum` is a binary operator, then $\tilde{\mathbf{Z}}$ is defined as

$$7500 \quad \tilde{\mathbf{Z}} = \langle \mathbf{D}_{out}(\text{accum}), \mathbf{nrows}(\tilde{\mathbf{C}}), \mathbf{ncols}(\tilde{\mathbf{C}}), \{(i, j, Z_{ij}) \mid \forall (i, j) \in \mathbf{ind}(\tilde{\mathbf{C}}) \cup \mathbf{ind}(\tilde{\mathbf{T}})\}\rangle.$$

7501 The values of the elements of $\tilde{\mathbf{Z}}$ are computed based on the relationships between the sets of
7502 indices in $\tilde{\mathbf{C}}$ and $\tilde{\mathbf{T}}$.

$$7503 \quad Z_{ij} = \tilde{\mathbf{C}}(i, j) \odot \tilde{\mathbf{T}}(i, j), \text{ if } (i, j) \in (\mathbf{ind}(\tilde{\mathbf{T}}) \cap \mathbf{ind}(\tilde{\mathbf{C}})),$$

$$7504 \quad Z_{ij} = \tilde{\mathbf{C}}(i, j), \text{ if } (i, j) \in (\mathbf{ind}(\tilde{\mathbf{C}}) - (\mathbf{ind}(\tilde{\mathbf{T}}) \cap \mathbf{ind}(\tilde{\mathbf{C}}))),$$

$$7505 \quad Z_{ij} = \tilde{\mathbf{T}}(i, j), \text{ if } (i, j) \in (\mathbf{ind}(\tilde{\mathbf{T}}) - (\mathbf{ind}(\tilde{\mathbf{T}}) \cap \mathbf{ind}(\tilde{\mathbf{C}}))),$$

7506 where $\odot = \odot(\text{accum})$, and the difference operator refers to set difference.

7509 Finally, the set of output values that make up matrix $\tilde{\mathbf{Z}}$ are written into the final result matrix `C`,
7510 using what is called a *standard matrix mask and replace*. This is carried out under control of the
7511 mask which acts as a “write mask”.

- 7512 • If `desc[GrB_OUTP].GrB_REPLACE` is set, then any values in `C` on input to this operation are
7513 deleted and the content of the new output matrix, `C`, is defined as,

$$7514 \quad \mathbf{L}(\mathbf{C}) = \{(i, j, Z_{ij}) : (i, j) \in (\mathbf{ind}(\tilde{\mathbf{Z}}) \cap \mathbf{ind}(\tilde{\mathbf{M}}))\}.$$

- 7515 • If `desc[GrB_OUTP].GrB_REPLACE` is not set, the elements of $\tilde{\mathbf{Z}}$ indicated by the mask are
7516 copied into the result matrix, `C`, and elements of `C` that fall outside the set indicated by the
7517 mask are unchanged:

$$7518 \quad \mathbf{L}(\mathbf{C}) = \{(i, j, C_{ij}) : (i, j) \in (\mathbf{ind}(\mathbf{C}) \cap \mathbf{ind}(\neg \tilde{\mathbf{M}}))\} \cup \{(i, j, Z_{ij}) : (i, j) \in (\mathbf{ind}(\tilde{\mathbf{Z}}) \cap \mathbf{ind}(\tilde{\mathbf{M}}))\}.$$

7519 In `GrB_BLOCKING` mode, the method exits with return value `GrB_SUCCESS` and the new content
7520 of matrix `C` is as defined above and fully computed. In `GrB_NONBLOCKING` mode, the method
7521 exits with return value `GrB_SUCCESS` and the new content of matrix `C` is as defined above but
7522 may not be fully computed. However, it can be used in the next GraphBLAS method call in a
7523 sequence. `s`

7524 **Chapter 5**

7525 **Nonpolymorphic interface**

7526 Each polymorphic GraphBLAS method (those with multiple parameter signatures under the same
 7527 name) has a corresponding set of long-name forms that are specific to each parameter signature.
 7528 That is show in Tables 5.1 through 5.11.

Table 5.1: Long-name, nonpolymorphic form of GraphBLAS methods.

Polymorphic signature	Nonpolymorphic signature
GrB_Monoid_new(GrB_Monoid*,...,bool)	GrB_Monoid_new_BOOL(GrB_Monoid*,GrB_BinaryOp,bool)
GrB_Monoid_new(GrB_Monoid*,...,int8_t)	GrB_Monoid_new_INT8(GrB_Monoid*,GrB_BinaryOp,int8_t)
GrB_Monoid_new(GrB_Monoid*,...,uint8_t)	GrB_Monoid_new_UINT8(GrB_Monoid*,GrB_BinaryOp,uint8_t)
GrB_Monoid_new(GrB_Monoid*,...,int16_t)	GrB_Monoid_new_INT16(GrB_Monoid*,GrB_BinaryOp,int16_t)
GrB_Monoid_new(GrB_Monoid*,...,uint16_t)	GrB_Monoid_new_UINT16(GrB_Monoid*,GrB_BinaryOp,uint16_t)
GrB_Monoid_new(GrB_Monoid*,...,int32_t)	GrB_Monoid_new_INT32(GrB_Monoid*,GrB_BinaryOp,int32_t)
GrB_Monoid_new(GrB_Monoid*,...,uint32_t)	GrB_Monoid_new_UINT32(GrB_Monoid*,GrB_BinaryOp,uint32_t)
GrB_Monoid_new(GrB_Monoid*,...,int64_t)	GrB_Monoid_new_INT64(GrB_Monoid*,GrB_BinaryOp,int64_t)
GrB_Monoid_new(GrB_Monoid*,...,uint64_t)	GrB_Monoid_new_UINT64(GrB_Monoid*,GrB_BinaryOp,uint64_t)
GrB_Monoid_new(GrB_Monoid*,...,float)	GrB_Monoid_new_FP32(GrB_Monoid*,GrB_BinaryOp,float)
GrB_Monoid_new(GrB_Monoid*,...,double)	GrB_Monoid_new_FP64(GrB_Monoid*,GrB_BinaryOp,double)
GrB_Monoid_new(GrB_Monoid*,...,other)	GrB_Monoid_new_UDT(GrB_Monoid*,GrB_BinaryOp,void*)

Table 5.2: Long-name, nonpolymorphic form of GraphBLAS methods (continued).

Polymorphic signature	Nonpolymorphic signature
GrB_Scalar_setElement(..., bool,...)	GrB_Scalar_setElement_BOOL(..., bool,...)
GrB_Scalar_setElement(..., int8_t,...)	GrB_Scalar_setElement_INT8(..., int8_t,...)
GrB_Scalar_setElement(..., uint8_t,...)	GrB_Scalar_setElement_UINT8(..., uint8_t,...)
GrB_Scalar_setElement(..., int16_t,...)	GrB_Scalar_setElement_INT16(..., int16_t,...)
GrB_Scalar_setElement(..., uint16_t,...)	GrB_Scalar_setElement_UINT16(..., uint16_t,...)
GrB_Scalar_setElement(..., int32_t,...)	GrB_Scalar_setElement_INT32(..., int32_t,...)
GrB_Scalar_setElement(..., uint32_t,...)	GrB_Scalar_setElement_UINT32(..., uint32_t,...)
GrB_Scalar_setElement(..., int64_t,...)	GrB_Scalar_setElement_INT64(..., int64_t,...)
GrB_Scalar_setElement(..., uint64_t,...)	GrB_Scalar_setElement_UINT64(..., uint64_t,...)
GrB_Scalar_setElement(..., float,...)	GrB_Scalar_setElement_FP32(..., float,...)
GrB_Scalar_setElement(..., double,...)	GrB_Scalar_setElement_FP64(..., double,...)
GrB_Scalar_setElement(..., <i>other</i> ,...)	GrB_Scalar_setElement_UDT(..., const void*,...)
GrB_Scalar_extractElement(bool*,...)	GrB_Scalar_extractElement_BOOL(bool*,...)
GrB_Scalar_extractElement(int8_t*,...)	GrB_Scalar_extractElement_INT8(int8_t*,...)
GrB_Scalar_extractElement(uint8_t*,...)	GrB_Scalar_extractElement_UINT8(uint8_t*,...)
GrB_Scalar_extractElement(int16_t*,...)	GrB_Scalar_extractElement_INT16(int16_t*,...)
GrB_Scalar_extractElement(uint16_t*,...)	GrB_Scalar_extractElement_UINT16(uint16_t*,...)
GrB_Scalar_extractElement(int32_t*,...)	GrB_Scalar_extractElement_INT32(int32_t*,...)
GrB_Scalar_extractElement(uint32_t*,...)	GrB_Scalar_extractElement_UINT32(uint32_t*,...)
GrB_Scalar_extractElement(int64_t*,...)	GrB_Scalar_extractElement_INT64(int64_t*,...)
GrB_Scalar_extractElement(uint64_t*,...)	GrB_Scalar_extractElement_UINT64(uint64_t*,...)
GrB_Scalar_extractElement(float*,...)	GrB_Scalar_extractElement_FP32(float*,...)
GrB_Scalar_extractElement(double*,...)	GrB_Scalar_extractElement_FP64(double*,...)
GrB_Scalar_extractElement(<i>other</i> *,...)	GrB_Scalar_extractElement_UDT(void*,...)

Table 5.3: Long-name, nonpolymorphic form of GraphBLAS methods (continued).

Polymorphic signature	Nonpolymorphic signature
GrB_Vector_build(...,const bool*,...)	GrB_Vector_build_BOOL(...,const bool*,...)
GrB_Vector_build(...,const int8_t*,...)	GrB_Vector_build_INT8(...,const int8_t*,...)
GrB_Vector_build(...,const uint8_t*,...)	GrB_Vector_build_UINT8(...,const uint8_t*,...)
GrB_Vector_build(...,const int16_t*,...)	GrB_Vector_build_INT16(...,const int16_t*,...)
GrB_Vector_build(...,const uint16_t*,...)	GrB_Vector_build_UINT16(...,const uint16_t*,...)
GrB_Vector_build(...,const int32_t*,...)	GrB_Vector_build_INT32(...,const int32_t*,...)
GrB_Vector_build(...,const uint32_t*,...)	GrB_Vector_build_UINT32(...,const uint32_t*,...)
GrB_Vector_build(...,const int64_t*,...)	GrB_Vector_build_INT64(...,const int64_t*,...)
GrB_Vector_build(...,const uint64_t*,...)	GrB_Vector_build_UINT64(...,const uint64_t*,...)
GrB_Vector_build(...,const float*,...)	GrB_Vector_build_FP32(...,const float*,...)
GrB_Vector_build(...,const double*,...)	GrB_Vector_build_FP64(...,const double*,...)
GrB_Vector_build(...,const <i>other</i> *,...)	GrB_Vector_build_UDT(...,const void*,...)
GrB_Vector_setElement(...,GrB_Scalar,...)	GrB_Vector_setElement_Scalar(...,const GrB_Scalar,...)
GrB_Vector_setElement(...,bool,...)	GrB_Vector_setElement_BOOL(..., bool,...)
GrB_Vector_setElement(...,int8_t,...)	GrB_Vector_setElement_INT8(..., int8_t,...)
GrB_Vector_setElement(...,uint8_t,...)	GrB_Vector_setElement_UINT8(..., uint8_t,...)
GrB_Vector_setElement(...,int16_t,...)	GrB_Vector_setElement_INT16(..., int16_t,...)
GrB_Vector_setElement(...,uint16_t,...)	GrB_Vector_setElement_UINT16(..., uint16_t,...)
GrB_Vector_setElement(...,int32_t,...)	GrB_Vector_setElement_INT32(..., int32_t,...)
GrB_Vector_setElement(...,uint32_t,...)	GrB_Vector_setElement_UINT32(..., uint32_t,...)
GrB_Vector_setElement(...,int64_t,...)	GrB_Vector_setElement_INT64(..., int64_t,...)
GrB_Vector_setElement(...,uint64_t,...)	GrB_Vector_setElement_UINT64(..., uint64_t,...)
GrB_Vector_setElement(...,float,...)	GrB_Vector_setElement_FP32(..., float,...)
GrB_Vector_setElement(...,double,...)	GrB_Vector_setElement_FP64(..., double,...)
GrB_Vector_setElement(..., <i>other</i> ,...)	GrB_Vector_setElement_UDT(...,const void*,...)
GrB_Vector_extractElement(GrB_Scalar,...)	GrB_Vector_extractElement_Scalar(GrB_Scalar,...)
GrB_Vector_extractElement(bool*,...)	GrB_Vector_extractElement_BOOL(bool*,...)
GrB_Vector_extractElement(int8_t*,...)	GrB_Vector_extractElement_INT8(int8_t*,...)
GrB_Vector_extractElement(uint8_t*,...)	GrB_Vector_extractElement_UINT8(uint8_t*,...)
GrB_Vector_extractElement(int16_t*,...)	GrB_Vector_extractElement_INT16(int16_t*,...)
GrB_Vector_extractElement(uint16_t*,...)	GrB_Vector_extractElement_UINT16(uint16_t*,...)
GrB_Vector_extractElement(int32_t*,...)	GrB_Vector_extractElement_INT32(int32_t*,...)
GrB_Vector_extractElement(uint32_t*,...)	GrB_Vector_extractElement_UINT32(uint32_t*,...)
GrB_Vector_extractElement(int64_t*,...)	GrB_Vector_extractElement_INT64(int64_t*,...)
GrB_Vector_extractElement(uint64_t*,...)	GrB_Vector_extractElement_UINT64(uint64_t*,...)
GrB_Vector_extractElement(float*,...)	GrB_Vector_extractElement_FP32(float*,...)
GrB_Vector_extractElement(double*,...)	GrB_Vector_extractElement_FP64(double*,...)
GrB_Vector_extractElement(<i>other</i> *,...)	GrB_Vector_extractElement_UDT(void*,...)
GrB_Vector_extractTuples(...,bool*,...)	GrB_Vector_extractTuples_BOOL(..., bool*,...)
GrB_Vector_extractTuples(...,int8_t*,...)	GrB_Vector_extractTuples_INT8(..., int8_t*,...)
GrB_Vector_extractTuples(...,uint8_t*,...)	GrB_Vector_extractTuples_UINT8(..., uint8_t*,...)
GrB_Vector_extractTuples(...,int16_t*,...)	GrB_Vector_extractTuples_INT16(..., int16_t*,...)
GrB_Vector_extractTuples(...,uint16_t*,...)	GrB_Vector_extractTuples_UINT16(..., uint16_t*,...)
GrB_Vector_extractTuples(...,int32_t*,...)	GrB_Vector_extractTuples_INT32(..., int32_t*,...)
GrB_Vector_extractTuples(...,uint32_t*,...)	GrB_Vector_extractTuples_UINT32(..., uint32_t*,...)
GrB_Vector_extractTuples(...,int64_t*,...)	GrB_Vector_extractTuples_INT64(..., int64_t*,...)
GrB_Vector_extractTuples(...,uint64_t*,...)	GrB_Vector_extractTuples_UINT64(..., uint64_t*,...)
GrB_Vector_extractTuples(...,float*,...)	GrB_Vector_extractTuples_FP32(..., float*,...)
GrB_Vector_extractTuples(...,double*,...)	GrB_Vector_extractTuples_FP64(..., double*,...)
GrB_Vector_extractTuples(..., <i>other</i> *,...)	GrB_Vector_extractTuples_UDT(..., void*,...)

Table 5.4: Long-name, nonpolymorphic form of GraphBLAS methods (continued).

Polymorphic signature	Nonpolymorphic signature
GrB_Matrix_build(...,const bool*,...)	GrB_Matrix_build_BOOL(...,const bool*,...)
GrB_Matrix_build(...,const int8_t*,...)	GrB_Matrix_build_INT8(...,const int8_t*,...)
GrB_Matrix_build(...,const uint8_t*,...)	GrB_Matrix_build_UINT8(...,const uint8_t*,...)
GrB_Matrix_build(...,const int16_t*,...)	GrB_Matrix_build_INT16(...,const int16_t*,...)
GrB_Matrix_build(...,const uint16_t*,...)	GrB_Matrix_build_UINT16(...,const uint16_t*,...)
GrB_Matrix_build(...,const int32_t*,...)	GrB_Matrix_build_INT32(...,const int32_t*,...)
GrB_Matrix_build(...,const uint32_t*,...)	GrB_Matrix_build_UINT32(...,const uint32_t*,...)
GrB_Matrix_build(...,const int64_t*,...)	GrB_Matrix_build_INT64(...,const int64_t*,...)
GrB_Matrix_build(...,const uint64_t*,...)	GrB_Matrix_build_UINT64(...,const uint64_t*,...)
GrB_Matrix_build(...,const float*,...)	GrB_Matrix_build_FP32(...,const float*,...)
GrB_Matrix_build(...,const double*,...)	GrB_Matrix_build_FP64(...,const double*,...)
GrB_Matrix_build(...,const <i>other</i> *,...)	GrB_Matrix_build_UDT(...,const void*,...)
GrB_Matrix_setElement(...,GrB_Scalar,...)	GrB_Matrix_setElement_Scalar(...,const GrB_Scalar,...)
GrB_Matrix_setElement(...,bool,...)	GrB_Matrix_setElement_BOOL(..., bool,...)
GrB_Matrix_setElement(...,int8_t,...)	GrB_Matrix_setElement_INT8(..., int8_t,...)
GrB_Matrix_setElement(...,uint8_t,...)	GrB_Matrix_setElement_UINT8(..., uint8_t,...)
GrB_Matrix_setElement(...,int16_t,...)	GrB_Matrix_setElement_INT16(..., int16_t,...)
GrB_Matrix_setElement(...,uint16_t,...)	GrB_Matrix_setElement_UINT16(..., uint16_t,...)
GrB_Matrix_setElement(...,int32_t,...)	GrB_Matrix_setElement_INT32(..., int32_t,...)
GrB_Matrix_setElement(...,uint32_t,...)	GrB_Matrix_setElement_UINT32(..., uint32_t,...)
GrB_Matrix_setElement(...,int64_t,...)	GrB_Matrix_setElement_INT64(..., int64_t,...)
GrB_Matrix_setElement(...,uint64_t,...)	GrB_Matrix_setElement_UINT64(..., uint64_t,...)
GrB_Matrix_setElement(...,float,...)	GrB_Matrix_setElement_FP32(..., float,...)
GrB_Matrix_setElement(...,double,...)	GrB_Matrix_setElement_FP64(..., double,...)
GrB_Matrix_setElement(..., <i>other</i> ,...)	GrB_Matrix_setElement_UDT(...,const void*,...)
GrB_Matrix_extractElement(GrB_Scalar,...)	GrB_Matrix_extractElement_Scalar(GrB_Scalar,...)
GrB_Matrix_extractElement(bool*,...)	GrB_Matrix_extractElement_BOOL(bool*,...)
GrB_Matrix_extractElement(int8_t*,...)	GrB_Matrix_extractElement_INT8(int8_t*,...)
GrB_Matrix_extractElement(uint8_t*,...)	GrB_Matrix_extractElement_UINT8(uint8_t*,...)
GrB_Matrix_extractElement(int16_t*,...)	GrB_Matrix_extractElement_INT16(int16_t*,...)
GrB_Matrix_extractElement(uint16_t*,...)	GrB_Matrix_extractElement_UINT16(uint16_t*,...)
GrB_Matrix_extractElement(int32_t*,...)	GrB_Matrix_extractElement_INT32(int32_t*,...)
GrB_Matrix_extractElement(uint32_t*,...)	GrB_Matrix_extractElement_UINT32(uint32_t*,...)
GrB_Matrix_extractElement(int64_t*,...)	GrB_Matrix_extractElement_INT64(int64_t*,...)
GrB_Matrix_extractElement(uint64_t*,...)	GrB_Matrix_extractElement_UINT64(uint64_t*,...)
GrB_Matrix_extractElement(float*,...)	GrB_Matrix_extractElement_FP32(float*,...)
GrB_Matrix_extractElement(double*,...)	GrB_Matrix_extractElement_FP64(double*,...)
GrB_Matrix_extractElement(<i>other</i> ,...)	GrB_Matrix_extractElement_UDT(void*,...)
GrB_Matrix_extractTuples(..., bool*,...)	GrB_Matrix_extractTuples_BOOL(..., bool*,...)
GrB_Matrix_extractTuples(..., int8_t*,...)	GrB_Matrix_extractTuples_INT8(..., int8_t*,...)
GrB_Matrix_extractTuples(..., uint8_t*,...)	GrB_Matrix_extractTuples_UINT8(..., uint8_t*,...)
GrB_Matrix_extractTuples(..., int16_t*,...)	GrB_Matrix_extractTuples_INT16(..., int16_t*,...)
GrB_Matrix_extractTuples(..., uint16_t*,...)	GrB_Matrix_extractTuples_UINT16(..., uint16_t*,...)
GrB_Matrix_extractTuples(..., int32_t*,...)	GrB_Matrix_extractTuples_INT32(..., int32_t*,...)
GrB_Matrix_extractTuples(..., uint32_t*,...)	GrB_Matrix_extractTuples_UINT32(..., uint32_t*,...)
GrB_Matrix_extractTuples(..., int64_t*,...)	GrB_Matrix_extractTuples_INT64(..., int64_t*,...)
GrB_Matrix_extractTuples(..., uint64_t*,...)	GrB_Matrix_extractTuples_UINT64(..., uint64_t*,...)
GrB_Matrix_extractTuples(..., float*,...)	GrB_Matrix_extractTuples_FP32(..., float*,...)
GrB_Matrix_extractTuples(..., double*,...)	GrB_Matrix_extractTuples_FP64(..., double*,...)
GrB_Matrix_extractTuples(..., <i>other</i> *,...)	GrB_Matrix_extractTuples_UDT(..., void*,...)

Table 5.5: Long-name, nonpolymorphic form of GraphBLAS methods (continued).

Polymorphic signature	Nonpolymorphic signature
GrB_Matrix_import(...,const bool*,...)	GrB_Matrix_import_BOOL(...,const bool*,...)
GrB_Matrix_import(...,const int8_t*,...)	GrB_Matrix_import_INT8(...,const int8_t*,...)
GrB_Matrix_import(...,const uint8_t*,...)	GrB_Matrix_import_UINT8(...,const uint8_t*,...)
GrB_Matrix_import(...,const int16_t*,...)	GrB_Matrix_import_INT16(...,const int16_t*,...)
GrB_Matrix_import(...,const uint16_t*,...)	GrB_Matrix_import_UINT16(...,const uint16_t*,...)
GrB_Matrix_import(...,const int32_t*,...)	GrB_Matrix_import_INT32(...,const int32_t*,...)
GrB_Matrix_import(...,const uint32_t*,...)	GrB_Matrix_import_UINT32(...,const uint32_t*,...)
GrB_Matrix_import(...,const int64_t*,...)	GrB_Matrix_import_INT64(...,const int64_t*,...)
GrB_Matrix_import(...,const uint64_t*,...)	GrB_Matrix_import_UINT64(...,const uint64_t*,...)
GrB_Matrix_import(...,const float*,...)	GrB_Matrix_import_FP32(...,const float*,...)
GrB_Matrix_import(...,const double*,...)	GrB_Matrix_import_FP64(...,const double*,...)
GrB_Matrix_import(...,const other,...)	GrB_Matrix_import_UDT(...,const void*,...)
GrB_Matrix_export(...,bool*,...)	GrB_Matrix_export_BOOL(...,bool*,...)
GrB_Matrix_export(...,int8_t*,...)	GrB_Matrix_export_INT8(...,int8_t*,...)
GrB_Matrix_export(...,uint8_t*,...)	GrB_Matrix_export_UINT8(...,uint8_t*,...)
GrB_Matrix_export(...,int16_t*,...)	GrB_Matrix_export_INT16(...,int16_t*,...)
GrB_Matrix_export(...,uint16_t*,...)	GrB_Matrix_export_UINT16(...,uint16_t*,...)
GrB_Matrix_export(...,int32_t*,...)	GrB_Matrix_export_INT32(...,int32_t*,...)
GrB_Matrix_export(...,uint32_t*,...)	GrB_Matrix_export_UINT32(...,uint32_t*,...)
GrB_Matrix_export(...,int64_t*,...)	GrB_Matrix_export_INT64(...,int64_t*,...)
GrB_Matrix_export(...,uint64_t*,...)	GrB_Matrix_export_UINT64(...,uint64_t*,...)
GrB_Matrix_export(...,float*,...)	GrB_Matrix_export_FP32(...,float*,...)
GrB_Matrix_export(...,double*,...)	GrB_Matrix_export_FP64(...,double*,...)
GrB_Matrix_export(...,other,...)	GrB_Matrix_export_UDT(...,void*,...)
GrB_free(GrB_Type*)	GrB_Type_free(GrB_Type*)
GrB_free(GrB_UnaryOp*)	GrB_UnaryOp_free(GrB_UnaryOp*)
GrB_free(GrB_IndexUnaryOp*)	GrB_IndexUnaryOp_free(GrB_IndexUnaryOp*)
GrB_free(GrB_BinaryOp*)	GrB_BinaryOp_free(GrB_BinaryOp*)
GrB_free(GrB_Monoid*)	GrB_Monoid_free(GrB_Monoid*)
GrB_free(GrB_Semiring*)	GrB_Semiring_free(GrB_Semiring*)
GrB_free(GrB_Scalar*)	GrB_Scalar_free(GrB_Scalar*)
GrB_free(GrB_Vector*)	GrB_Vector_free(GrB_Vector*)
GrB_free(GrB_Matrix*)	GrB_Matrix_free(GrB_Matrix*)
GrB_free(GrB_Descriptor*)	GrB_Descriptor_free(GrB_Descriptor*)
GrB_wait(GrB_Type, GrB_WaitMode)	GrB_Type_wait(GrB_Type, GrB_WaitMode)
GrB_wait(GrB_UnaryOp, GrB_WaitMode)	GrB_UnaryOp_wait(GrB_UnaryOp, GrB_WaitMode)
GrB_wait(GrB_IndexUnaryOp, GrB_WaitMode)	GrB_IndexUnaryOp_wait(GrB_IndexUnaryOp, GrB_WaitMode)
GrB_wait(GrB_BinaryOp, GrB_WaitMode)	GrB_BinaryOp_wait(GrB_BinaryOp, GrB_WaitMode)
GrB_wait(GrB_Monoid, GrB_WaitMode)	GrB_Monoid_wait(GrB_Monoid, GrB_WaitMode)
GrB_wait(GrB_Semiring, GrB_WaitMode)	GrB_Semiring_wait(GrB_Semiring, GrB_WaitMode)
GrB_wait(GrB_Scalar, GrB_WaitMode)	GrB_Scalar_wait(GrB_Scalar, GrB_WaitMode)
GrB_wait(GrB_Vector, GrB_WaitMode)	GrB_Vector_wait(GrB_Vector, GrB_WaitMode)
GrB_wait(GrB_Matrix, GrB_WaitMode)	GrB_Matrix_wait(GrB_Matrix, GrB_WaitMode)
GrB_wait(GrB_Descriptor, GrB_WaitMode)	GrB_Descriptor_wait(GrB_Descriptor, GrB_WaitMode)
GrB_error(const char**, const GrB_Type)	GrB_Type_error(const char**, const GrB_Type)
GrB_error(const char**, const GrB_UnaryOp)	GrB_UnaryOp_error(const char**, const GrB_UnaryOp)
GrB_error(const char**, const GrB_IndexUnaryOp)	GrB_IndexUnaryOp_error(const char**, const GrB_IndexUnaryOp)
GrB_error(const char**, const GrB_BinaryOp)	GrB_BinaryOp_error(const char**, const GrB_BinaryOp)
GrB_error(const char**, const GrB_Monoid)	GrB_Monoid_error(const char**, const GrB_Monoid)
GrB_error(const char**, const GrB_Semiring)	GrB_Semiring_error(const char**, const GrB_Semiring)
GrB_error(const char**, const GrB_Scalar)	GrB_Scalar_error(const char**, const GrB_Scalar)
GrB_error(const char**, const GrB_Vector)	GrB_Vector_error(const char**, const GrB_Vector)
GrB_error(const char**, const GrB_Matrix)	GrB_Matrix_error(const char**, const GrB_Matrix)
GrB_error(const char**, const GrB_Descriptor)	GrB_Descriptor_error(const char**, const GrB_Descriptor)

Table 5.6: Long-name, nonpolymorphic form of GraphBLAS methods (continued).

Polymorphic signature	Nonpolymorphic signature
GrB_eWiseMult(GrB_Vector,...,GrB_Semiring,...)	GrB_Vector_eWiseMult_Semiring(GrB_Vector,...,GrB_Semiring,...)
GrB_eWiseMult(GrB_Vector,...,GrB_Monoid,...)	GrB_Vector_eWiseMult_Monoid(GrB_Vector,...,GrB_Monoid,...)
GrB_eWiseMult(GrB_Vector,...,GrB_BinaryOp,...)	GrB_Vector_eWiseMult_BinaryOp(GrB_Vector,...,GrB_BinaryOp,...)
GrB_eWiseMult(GrB_Matrix,...,GrB_Semiring,...)	GrB_Matrix_eWiseMult_Semiring(GrB_Matrix,...,GrB_Semiring,...)
GrB_eWiseMult(GrB_Matrix,...,GrB_Monoid,...)	GrB_Matrix_eWiseMult_Monoid(GrB_Matrix,...,GrB_Monoid,...)
GrB_eWiseMult(GrB_Matrix,...,GrB_BinaryOp,...)	GrB_Matrix_eWiseMult_BinaryOp(GrB_Matrix,...,GrB_BinaryOp,...)
GrB_eWiseAdd(GrB_Vector,...,GrB_Semiring,...)	GrB_Vector_eWiseAdd_Semiring(GrB_Vector,...,GrB_Semiring,...)
GrB_eWiseAdd(GrB_Vector,...,GrB_Monoid,...)	GrB_Vector_eWiseAdd_Monoid(GrB_Vector,...,GrB_Monoid,...)
GrB_eWiseAdd(GrB_Vector,...,GrB_BinaryOp,...)	GrB_Vector_eWiseAdd_BinaryOp(GrB_Vector,...,GrB_BinaryOp,...)
GrB_eWiseAdd(GrB_Matrix,...,GrB_Semiring,...)	GrB_Matrix_eWiseAdd_Semiring(GrB_Matrix,...,GrB_Semiring,...)
GrB_eWiseAdd(GrB_Matrix,...,GrB_Monoid,...)	GrB_Matrix_eWiseAdd_Monoid(GrB_Matrix,...,GrB_Monoid,...)
GrB_eWiseAdd(GrB_Matrix,...,GrB_BinaryOp,...)	GrB_Matrix_eWiseAdd_BinaryOp(GrB_Matrix,...,GrB_BinaryOp,...)
GrB_extract(GrB_Vector,...,GrB_Vector,...)	GrB_Vector_extract(GrB_Vector,...,GrB_Vector,...)
GrB_extract(GrB_Matrix,...,GrB_Matrix,...)	GrB_Matrix_extract(GrB_Matrix,...,GrB_Matrix,...)
GrB_extract(GrB_Vector,...,GrB_Matrix,...)	GrB_Col_extract(GrB_Vector,...,GrB_Matrix,...)
GrB_assign(GrB_Vector,...,GrB_Vector,...)	GrB_Vector_assign(GrB_Vector,...,GrB_Vector,...)
GrB_assign(GrB_Matrix,...,GrB_Matrix,...)	GrB_Matrix_assign(GrB_Matrix,...,GrB_Matrix,...)
GrB_assign(GrB_Matrix,...,GrB_Vector,const GrB_Index*,...)	GrB_Col_assign(GrB_Matrix,...,GrB_Vector,const GrB_Index*,...)
GrB_assign(GrB_Matrix,...,GrB_Vector,GrB_Index,...)	GrB_Row_assign(GrB_Matrix,...,GrB_Vector,GrB_Index,...)
GrB_assign(GrB_Vector,...,GrB_Scalar,...)	GrB_Vector_assign_Scalar(GrB_Vector,...,const GrB_Scalar,...)
GrB_assign(GrB_Vector,...,bool,...)	GrB_Vector_assign_BOOL(GrB_Vector,..., bool,...)
GrB_assign(GrB_Vector,...,int8_t,...)	GrB_Vector_assign_INT8(GrB_Vector,..., int8_t,...)
GrB_assign(GrB_Vector,...,uint8_t,...)	GrB_Vector_assign_UINT8(GrB_Vector,..., uint8_t,...)
GrB_assign(GrB_Vector,...,int16_t,...)	GrB_Vector_assign_INT16(GrB_Vector,..., int16_t,...)
GrB_assign(GrB_Vector,...,uint16_t,...)	GrB_Vector_assign_UINT16(GrB_Vector,..., uint16_t,...)
GrB_assign(GrB_Vector,...,int32_t,...)	GrB_Vector_assign_INT32(GrB_Vector,..., int32_t,...)
GrB_assign(GrB_Vector,...,uint32_t,...)	GrB_Vector_assign_UINT32(GrB_Vector,..., uint32_t,...)
GrB_assign(GrB_Vector,...,int64_t,...)	GrB_Vector_assign_INT64(GrB_Vector,..., int64_t,...)
GrB_assign(GrB_Vector,...,uint64_t,...)	GrB_Vector_assign_UINT64(GrB_Vector,..., uint64_t,...)
GrB_assign(GrB_Vector,...,float,...)	GrB_Vector_assign_FP32(GrB_Vector,..., float,...)
GrB_assign(GrB_Vector,...,double,...)	GrB_Vector_assign_FP64(GrB_Vector,..., double,...)
GrB_assign(GrB_Vector,...,other,...)	GrB_Vector_assign_UDT(GrB_Vector,...,const void*,...)
GrB_assign(GrB_Matrix,...,GrB_Scalar,...)	GrB_Matrix_assign_Scalar(GrB_Matrix,...,const GrB_Scalar,...)
GrB_assign(GrB_Matrix,...,bool,...)	GrB_Matrix_assign_BOOL(GrB_Matrix,..., bool,...)
GrB_assign(GrB_Matrix,...,int8_t,...)	GrB_Matrix_assign_INT8(GrB_Matrix,..., int8_t,...)
GrB_assign(GrB_Matrix,...,uint8_t,...)	GrB_Matrix_assign_UINT8(GrB_Matrix,..., uint8_t,...)
GrB_assign(GrB_Matrix,...,int16_t,...)	GrB_Matrix_assign_INT16(GrB_Matrix,..., int16_t,...)
GrB_assign(GrB_Matrix,...,uint16_t,...)	GrB_Matrix_assign_UINT16(GrB_Matrix,..., uint16_t,...)
GrB_assign(GrB_Matrix,...,int32_t,...)	GrB_Matrix_assign_INT32(GrB_Matrix,..., int32_t,...)
GrB_assign(GrB_Matrix,...,uint32_t,...)	GrB_Matrix_assign_UINT32(GrB_Matrix,..., uint32_t,...)
GrB_assign(GrB_Matrix,...,int64_t,...)	GrB_Matrix_assign_INT64(GrB_Matrix,..., int64_t,...)
GrB_assign(GrB_Matrix,...,uint64_t,...)	GrB_Matrix_assign_UINT64(GrB_Matrix,..., uint64_t,...)
GrB_assign(GrB_Matrix,...,float,...)	GrB_Matrix_assign_FP32(GrB_Matrix,..., float,...)
GrB_assign(GrB_Matrix,...,double,...)	GrB_Matrix_assign_FP64(GrB_Matrix,..., double,...)
GrB_assign(GrB_Matrix,...,other,...)	GrB_Matrix_assign_UDT(GrB_Matrix,...,const void*,...)

Table 5.7: Long-name, nonpolymorphic form of GraphBLAS methods (continued).

Polymorphic signature	Nonpolymorphic signature
GrB_apply(GrB_Vector,...,GrB_UnaryOp,GrB_Vector,...)	GrB_Vector_apply(GrB_Vector,...,GrB_UnaryOp,GrB_Vector,...)
GrB_apply(GrB_Matrix,...,GrB_UnaryOp,GrB_Matrix,...)	GrB_Matrix_apply(GrB_Matrix,...,GrB_UnaryOp,GrB_Matrix,...)
GrB_apply(GrB_Vector,...,GrB_BinaryOp,GrB_Scalar,GrB_Vector,...)	GrB_Vector_apply_BinaryOp1st_Scalar(GrB_Vector,...,GrB_BinaryOp,GrB_Scalar,GrB_Vector,...)
GrB_apply(GrB_Vector,...,GrB_BinaryOp,bool,GrB_Vector,...)	GrB_Vector_apply_BinaryOp1st_BOOL(GrB_Vector,...,GrB_BinaryOp,bool,GrB_Vector,...)
GrB_apply(GrB_Vector,...,GrB_BinaryOp,int8_t,GrB_Vector,...)	GrB_Vector_apply_BinaryOp1st_INT8(GrB_Vector,...,GrB_BinaryOp,int8_t,GrB_Vector,...)
GrB_apply(GrB_Vector,...,GrB_BinaryOp,uint8_t,GrB_Vector,...)	GrB_Vector_apply_BinaryOp1st_UINT8(GrB_Vector,...,GrB_BinaryOp,uint8_t,GrB_Vector,...)
GrB_apply(GrB_Vector,...,GrB_BinaryOp,int16_t,GrB_Vector,...)	GrB_Vector_apply_BinaryOp1st_INT16(GrB_Vector,...,GrB_BinaryOp,int16_t,GrB_Vector,...)
GrB_apply(GrB_Vector,...,GrB_BinaryOp,uint16_t,GrB_Vector,...)	GrB_Vector_apply_BinaryOp1st_UINT16(GrB_Vector,...,GrB_BinaryOp,uint16_t,GrB_Vector,...)
GrB_apply(GrB_Vector,...,GrB_BinaryOp,int32_t,GrB_Vector,...)	GrB_Vector_apply_BinaryOp1st_INT32(GrB_Vector,...,GrB_BinaryOp,int32_t,GrB_Vector,...)
GrB_apply(GrB_Vector,...,GrB_BinaryOp,uint32_t,GrB_Vector,...)	GrB_Vector_apply_BinaryOp1st_UINT32(GrB_Vector,...,GrB_BinaryOp,uint32_t,GrB_Vector,...)
GrB_apply(GrB_Vector,...,GrB_BinaryOp,int64_t,GrB_Vector,...)	GrB_Vector_apply_BinaryOp1st_INT64(GrB_Vector,...,GrB_BinaryOp,int64_t,GrB_Vector,...)
GrB_apply(GrB_Vector,...,GrB_BinaryOp,uint64_t,GrB_Vector,...)	GrB_Vector_apply_BinaryOp1st_UINT64(GrB_Vector,...,GrB_BinaryOp,uint64_t,GrB_Vector,...)
GrB_apply(GrB_Vector,...,GrB_BinaryOp,float,GrB_Vector,...)	GrB_Vector_apply_BinaryOp1st_FP32(GrB_Vector,...,GrB_BinaryOp,float,GrB_Vector,...)
GrB_apply(GrB_Vector,...,GrB_BinaryOp,double,GrB_Vector,...)	GrB_Vector_apply_BinaryOp1st_FP64(GrB_Vector,...,GrB_BinaryOp,double,GrB_Vector,...)
GrB_apply(GrB_Vector,...,GrB_BinaryOp, <i>other</i> ,GrB_Vector,...)	GrB_Vector_apply_BinaryOp1st_UDT(GrB_Vector,...,GrB_BinaryOp,const void*,GrB_Vector,...)
GrB_apply(GrB_Vector,...,GrB_BinaryOp,GrB_Vector,GrB_Scalar,...)	GrB_Vector_apply_BinaryOp2nd_Scalar(GrB_Vector,...,GrB_BinaryOp,GrB_Vector,GrB_Scalar,...)
GrB_apply(GrB_Vector,...,GrB_BinaryOp,GrB_Vector,bool,...)	GrB_Vector_apply_BinaryOp2nd_BOOL(GrB_Vector,...,GrB_BinaryOp,GrB_Vector,bool,...)
GrB_apply(GrB_Vector,...,GrB_BinaryOp,GrB_Vector,int8_t,...)	GrB_Vector_apply_BinaryOp2nd_INT8(GrB_Vector,...,GrB_BinaryOp,GrB_Vector,int8_t,...)
GrB_apply(GrB_Vector,...,GrB_BinaryOp,GrB_Vector,uint8_t,...)	GrB_Vector_apply_BinaryOp2nd_UINT8(GrB_Vector,...,GrB_BinaryOp,GrB_Vector,uint8_t,...)
GrB_apply(GrB_Vector,...,GrB_BinaryOp,GrB_Vector,int16_t,...)	GrB_Vector_apply_BinaryOp2nd_INT16(GrB_Vector,...,GrB_BinaryOp,GrB_Vector,int16_t,...)
GrB_apply(GrB_Vector,...,GrB_BinaryOp,GrB_Vector,uint16_t,...)	GrB_Vector_apply_BinaryOp2nd_UINT16(GrB_Vector,...,GrB_BinaryOp,GrB_Vector,uint16_t,...)
GrB_apply(GrB_Vector,...,GrB_BinaryOp,GrB_Vector,int32_t,...)	GrB_Vector_apply_BinaryOp2nd_INT32(GrB_Vector,...,GrB_BinaryOp,GrB_Vector,int32_t,...)
GrB_apply(GrB_Vector,...,GrB_BinaryOp,GrB_Vector,uint32_t,...)	GrB_Vector_apply_BinaryOp2nd_UINT32(GrB_Vector,...,GrB_BinaryOp,GrB_Vector,uint32_t,...)
GrB_apply(GrB_Vector,...,GrB_BinaryOp,GrB_Vector,int64_t,...)	GrB_Vector_apply_BinaryOp2nd_INT64(GrB_Vector,...,GrB_BinaryOp,GrB_Vector,int64_t,...)
GrB_apply(GrB_Vector,...,GrB_BinaryOp,GrB_Vector,uint64_t,...)	GrB_Vector_apply_BinaryOp2nd_UINT64(GrB_Vector,...,GrB_BinaryOp,GrB_Vector,uint64_t,...)
GrB_apply(GrB_Vector,...,GrB_BinaryOp,GrB_Vector,float,...)	GrB_Vector_apply_BinaryOp2nd_FP32(GrB_Vector,...,GrB_BinaryOp,GrB_Vector,float,...)
GrB_apply(GrB_Vector,...,GrB_BinaryOp,GrB_Vector,double,...)	GrB_Vector_apply_BinaryOp2nd_FP64(GrB_Vector,...,GrB_BinaryOp,GrB_Vector,double,...)
GrB_apply(GrB_Vector,...,GrB_BinaryOp,GrB_Vector, <i>other</i> ,...)	GrB_Vector_apply_BinaryOp2nd_UDT(GrB_Vector,...,GrB_BinaryOp,GrB_Vector,const void*,...)

Table 5.8: Long-name, nonpolymorphic form of GraphBLAS methods (continued).

Polymorphic signature	Nonpolymorphic signature
GrB_apply(GrB_Matrix,...,GrB_BinaryOp,GrB_Scalar,GrB_Matrix,...)	GrB_Matrix_apply_BinaryOp1st_Scalar(GrB_Matrix,...,GrB_BinaryOp,GrB_Scalar,GrB_Matrix,...)
GrB_apply(GrB_Matrix,...,GrB_BinaryOp,bool,GrB_Matrix,...)	GrB_Matrix_apply_BinaryOp1st_BOOL(GrB_Matrix,...,GrB_BinaryOp,bool,GrB_Matrix,...)
GrB_apply(GrB_Matrix,...,GrB_BinaryOp,int8_t,GrB_Matrix,...)	GrB_Matrix_apply_BinaryOp1st_INT8(GrB_Matrix,...,GrB_BinaryOp,int8_t,GrB_Matrix,...)
GrB_apply(GrB_Matrix,...,GrB_BinaryOp,uint8_t,GrB_Matrix,...)	GrB_Matrix_apply_BinaryOp1st_UINT8(GrB_Matrix,...,GrB_BinaryOp,uint8_t,GrB_Matrix,...)
GrB_apply(GrB_Matrix,...,GrB_BinaryOp,int16_t,GrB_Matrix,...)	GrB_Matrix_apply_BinaryOp1st_INT16(GrB_Matrix,...,GrB_BinaryOp,int16_t,GrB_Matrix,...)
GrB_apply(GrB_Matrix,...,GrB_BinaryOp,uint16_t,GrB_Matrix,...)	GrB_Matrix_apply_BinaryOp1st_UINT16(GrB_Matrix,...,GrB_BinaryOp,uint16_t,GrB_Matrix,...)
GrB_apply(GrB_Matrix,...,GrB_BinaryOp,int32_t,GrB_Matrix,...)	GrB_Matrix_apply_BinaryOp1st_INT32(GrB_Matrix,...,GrB_BinaryOp,int32_t,GrB_Matrix,...)
GrB_apply(GrB_Matrix,...,GrB_BinaryOp,uint32_t,GrB_Matrix,...)	GrB_Matrix_apply_BinaryOp1st_UINT32(GrB_Matrix,...,GrB_BinaryOp,uint32_t,GrB_Matrix,...)
GrB_apply(GrB_Matrix,...,GrB_BinaryOp,int64_t,GrB_Matrix,...)	GrB_Matrix_apply_BinaryOp1st_INT64(GrB_Matrix,...,GrB_BinaryOp,int64_t,GrB_Matrix,...)
GrB_apply(GrB_Matrix,...,GrB_BinaryOp,uint64_t,GrB_Matrix,...)	GrB_Matrix_apply_BinaryOp1st_UINT64(GrB_Matrix,...,GrB_BinaryOp,uint64_t,GrB_Matrix,...)
GrB_apply(GrB_Matrix,...,GrB_BinaryOp,float,GrB_Matrix,...)	GrB_Matrix_apply_BinaryOp1st_FP32(GrB_Matrix,...,GrB_BinaryOp,float,GrB_Matrix,...)
GrB_apply(GrB_Matrix,...,GrB_BinaryOp,double,GrB_Matrix,...)	GrB_Matrix_apply_BinaryOp1st_FP64(GrB_Matrix,...,GrB_BinaryOp,double,GrB_Matrix,...)
GrB_apply(GrB_Matrix,...,GrB_BinaryOp, <i>other</i> ,GrB_Matrix,...)	GrB_Matrix_apply_BinaryOp1st_UDT(GrB_Matrix,...,GrB_BinaryOp,const void*,GrB_Matrix,...)
GrB_apply(GrB_Matrix,...,GrB_BinaryOp,GrB_Matrix,GrB_Scalar,...)	GrB_Matrix_apply_BinaryOp2nd_Scalar(GrB_Matrix,...,GrB_BinaryOp,GrB_Matrix,GrB_Scalar,...)
GrB_apply(GrB_Matrix,...,GrB_BinaryOp,GrB_Matrix,bool,...)	GrB_Matrix_apply_BinaryOp2nd_BOOL(GrB_Matrix,...,GrB_BinaryOp,GrB_Matrix,bool,...)
GrB_apply(GrB_Matrix,...,GrB_BinaryOp,GrB_Matrix,int8_t,...)	GrB_Matrix_apply_BinaryOp2nd_INT8(GrB_Matrix,...,GrB_BinaryOp,GrB_Matrix,int8_t,...)
GrB_apply(GrB_Matrix,...,GrB_BinaryOp,GrB_Matrix,uint8_t,...)	GrB_Matrix_apply_BinaryOp2nd_UINT8(GrB_Matrix,...,GrB_BinaryOp,GrB_Matrix,uint8_t,...)
GrB_apply(GrB_Matrix,...,GrB_BinaryOp,GrB_Matrix,int16_t,...)	GrB_Matrix_apply_BinaryOp2nd_INT16(GrB_Matrix,...,GrB_BinaryOp,GrB_Matrix,int16_t,...)
GrB_apply(GrB_Matrix,...,GrB_BinaryOp,GrB_Matrix,uint16_t,...)	GrB_Matrix_apply_BinaryOp2nd_UINT16(GrB_Matrix,...,GrB_BinaryOp,GrB_Matrix,uint16_t,...)
GrB_apply(GrB_Matrix,...,GrB_BinaryOp,GrB_Matrix,int32_t,...)	GrB_Matrix_apply_BinaryOp2nd_INT32(GrB_Matrix,...,GrB_BinaryOp,GrB_Matrix,int32_t,...)
GrB_apply(GrB_Matrix,...,GrB_BinaryOp,GrB_Matrix,uint32_t,...)	GrB_Matrix_apply_BinaryOp2nd_UINT32(GrB_Matrix,...,GrB_BinaryOp,GrB_Matrix,uint32_t,...)
GrB_apply(GrB_Matrix,...,GrB_BinaryOp,GrB_Matrix,int64_t,...)	GrB_Matrix_apply_BinaryOp2nd_INT64(GrB_Matrix,...,GrB_BinaryOp,GrB_Matrix,int64_t,...)
GrB_apply(GrB_Matrix,...,GrB_BinaryOp,GrB_Matrix,uint64_t,...)	GrB_Matrix_apply_BinaryOp2nd_UINT64(GrB_Matrix,...,GrB_BinaryOp,GrB_Matrix,uint64_t,...)
GrB_apply(GrB_Matrix,...,GrB_BinaryOp,GrB_Matrix,float,...)	GrB_Matrix_apply_BinaryOp2nd_FP32(GrB_Matrix,...,GrB_BinaryOp,GrB_Matrix,float,...)
GrB_apply(GrB_Matrix,...,GrB_BinaryOp,GrB_Matrix,double,...)	GrB_Matrix_apply_BinaryOp2nd_FP64(GrB_Matrix,...,GrB_BinaryOp,GrB_Matrix,double,...)
GrB_apply(GrB_Matrix,...,GrB_BinaryOp,GrB_Matrix, <i>other</i> ,...)	GrB_Matrix_apply_BinaryOp2nd_UDT(GrB_Matrix,...,GrB_BinaryOp,GrB_Matrix,const void*,...)

Table 5.9: Long-name, nonpolymorphic form of GraphBLAS methods (continued).

Polymorphic signature	Nonpolymorphic signature
GrB_apply(GrB_Vector,...,GrB_IndexUnaryOp,GrB_Vector,GrB_Scalar,...)	GrB_Vector_apply_IndexOp_Scalar(GrB_Vector,...,GrB_IndexUnaryOp,GrB_Vector,GrB_Scalar,...)
GrB_apply(GrB_Vector,...,GrB_IndexUnaryOp,GrB_Vector,bool,...)	GrB_Vector_apply_IndexOp_BOOL(GrB_Vector,...,GrB_IndexUnaryOp,GrB_Vector,bool,...)
GrB_apply(GrB_Vector,...,GrB_IndexUnaryOp,GrB_Vector,int8_t,...)	GrB_Vector_apply_IndexOp_INT8(GrB_Vector,...,GrB_IndexUnaryOp,GrB_Vector,int8_t,...)
GrB_apply(GrB_Vector,...,GrB_IndexUnaryOp,GrB_Vector,uint8_t,...)	GrB_Vector_apply_IndexOp_UINT8(GrB_Vector,...,GrB_IndexUnaryOp,GrB_Vector,uint8_t,...)
GrB_apply(GrB_Vector,...,GrB_IndexUnaryOp,GrB_Vector,int16_t,...)	GrB_Vector_apply_IndexOp_INT16(GrB_Vector,...,GrB_IndexUnaryOp,GrB_Vector,int16_t,...)
GrB_apply(GrB_Vector,...,GrB_IndexUnaryOp,GrB_Vector,uint16_t,...)	GrB_Vector_apply_IndexOp_UINT16(GrB_Vector,...,GrB_IndexUnaryOp,GrB_Vector,uint16_t,...)
GrB_apply(GrB_Vector,...,GrB_IndexUnaryOp,GrB_Vector,int32_t,...)	GrB_Vector_apply_IndexOp_INT32(GrB_Vector,...,GrB_IndexUnaryOp,GrB_Vector,int32_t,...)
GrB_apply(GrB_Vector,...,GrB_IndexUnaryOp,GrB_Vector,uint32_t,...)	GrB_Vector_apply_IndexOp_UINT32(GrB_Vector,...,GrB_IndexUnaryOp,GrB_Vector,uint32_t,...)
GrB_apply(GrB_Vector,...,GrB_IndexUnaryOp,GrB_Vector,int64_t,...)	GrB_Vector_apply_IndexOp_INT64(GrB_Vector,...,GrB_IndexUnaryOp,GrB_Vector,int64_t,...)
GrB_apply(GrB_Vector,...,GrB_IndexUnaryOp,GrB_Vector,uint64_t,...)	GrB_Vector_apply_IndexOp_UINT64(GrB_Vector,...,GrB_IndexUnaryOp,GrB_Vector,uint64_t,...)
GrB_apply(GrB_Vector,...,GrB_IndexUnaryOp,GrB_Vector,float,...)	GrB_Vector_apply_IndexOp_FP32(GrB_Vector,...,GrB_IndexUnaryOp,GrB_Vector,float,...)
GrB_apply(GrB_Vector,...,GrB_IndexUnaryOp,GrB_Vector,double,...)	GrB_Vector_apply_IndexOp_FP64(GrB_Vector,...,GrB_IndexUnaryOp,GrB_Vector,double,...)
GrB_apply(GrB_Vector,...,GrB_IndexUnaryOp,GrB_Vector, <i>other</i> ,...)	GrB_Vector_apply_IndexOp_UDT(GrB_Vector,...,GrB_IndexUnaryOp,GrB_Vector,const void*,...)
GrB_apply(GrB_Matrix,...,GrB_IndexUnaryOp,GrB_Matrix,GrB_Scalar,...)	GrB_Matrix_apply_IndexOp_Scalar(GrB_Matrix,...,GrB_IndexUnaryOp,GrB_Matrix,GrB_Scalar,...)
GrB_apply(GrB_Matrix,...,GrB_IndexUnaryOp,GrB_Matrix,bool,...)	GrB_Matrix_apply_IndexOp_BOOL(GrB_Matrix,...,GrB_IndexUnaryOp,GrB_Matrix,bool,...)
GrB_apply(GrB_Matrix,...,GrB_IndexUnaryOp,GrB_Matrix,int8_t,...)	GrB_Matrix_apply_IndexOp_INT8(GrB_Matrix,...,GrB_IndexUnaryOp,GrB_Matrix,int8_t,...)
GrB_apply(GrB_Matrix,...,GrB_IndexUnaryOp,GrB_Matrix,uint8_t,...)	GrB_Matrix_apply_IndexOp_UINT8(GrB_Matrix,...,GrB_IndexUnaryOp,GrB_Matrix,uint8_t,...)
GrB_apply(GrB_Matrix,...,GrB_IndexUnaryOp,GrB_Matrix,int16_t,...)	GrB_Matrix_apply_IndexOp_INT16(GrB_Matrix,...,GrB_IndexUnaryOp,GrB_Matrix,int16_t,...)
GrB_apply(GrB_Matrix,...,GrB_IndexUnaryOp,GrB_Matrix,uint16_t,...)	GrB_Matrix_apply_IndexOp_UINT16(GrB_Matrix,...,GrB_IndexUnaryOp,GrB_Matrix,uint16_t,...)
GrB_apply(GrB_Matrix,...,GrB_IndexUnaryOp,GrB_Matrix,int32_t,...)	GrB_Matrix_apply_IndexOp_INT32(GrB_Matrix,...,GrB_IndexUnaryOp,GrB_Matrix,int32_t,...)
GrB_apply(GrB_Matrix,...,GrB_IndexUnaryOp,GrB_Matrix,uint32_t,...)	GrB_Matrix_apply_IndexOp_UINT32(GrB_Matrix,...,GrB_IndexUnaryOp,GrB_Matrix,uint32_t,...)
GrB_apply(GrB_Matrix,...,GrB_IndexUnaryOp,GrB_Matrix,int64_t,...)	GrB_Matrix_apply_IndexOp_INT64(GrB_Matrix,...,GrB_IndexUnaryOp,GrB_Matrix,int64_t,...)
GrB_apply(GrB_Matrix,...,GrB_IndexUnaryOp,GrB_Matrix,uint64_t,...)	GrB_Matrix_apply_IndexOp_UINT64(GrB_Matrix,...,GrB_IndexUnaryOp,GrB_Matrix,uint64_t,...)
GrB_apply(GrB_Matrix,...,GrB_IndexUnaryOp,GrB_Matrix,float,...)	GrB_Matrix_apply_IndexOp_FP32(GrB_Matrix,...,GrB_IndexUnaryOp,GrB_Matrix,float,...)
GrB_apply(GrB_Matrix,...,GrB_IndexUnaryOp,GrB_Matrix,double,...)	GrB_Matrix_apply_IndexOp_FP64(GrB_Matrix,...,GrB_IndexUnaryOp,GrB_Matrix,double,...)
GrB_apply(GrB_Matrix,...,GrB_IndexUnaryOp,GrB_Matrix, <i>other</i> ,...)	GrB_Matrix_apply_IndexOp_UDT(GrB_Matrix,...,GrB_IndexUnaryOp,GrB_Matrix,const void*,...)

Table 5.10: Long-name, nonpolymorphic form of GraphBLAS methods (continued).

Polymorphic signature	Nonpolymorphic signature
GrB_select(GrB_Vector,...,GrB_IndexUnaryOp,GrB_Vector,GrB_Scalar,...)	GrB_Vector_select_Scalar(GrB_Vector,...,GrB_IndexUnaryOp,GrB_Vector,GrB_Scalar,...)
GrB_select(GrB_Vector,...,GrB_IndexUnaryOp,GrB_Vector,bool,...)	GrB_Vector_select_BOOL(GrB_Vector,...,GrB_IndexUnaryOp,GrB_Vector,bool,...)
GrB_select(GrB_Vector,...,GrB_IndexUnaryOp,GrB_Vector,int8_t,...)	GrB_Vector_select_INT8(GrB_Vector,...,GrB_IndexUnaryOp,GrB_Vector,int8_t,...)
GrB_select(GrB_Vector,...,GrB_IndexUnaryOp,GrB_Vector,uint8_t,...)	GrB_Vector_select_UINT8(GrB_Vector,...,GrB_IndexUnaryOp,GrB_Vector,uint8_t,...)
GrB_select(GrB_Vector,...,GrB_IndexUnaryOp,GrB_Vector,int16_t,...)	GrB_Vector_select_INT16(GrB_Vector,...,GrB_IndexUnaryOp,GrB_Vector,int16_t,...)
GrB_select(GrB_Vector,...,GrB_IndexUnaryOp,GrB_Vector,uint16_t,...)	GrB_Vector_select_UINT16(GrB_Vector,...,GrB_IndexUnaryOp,GrB_Vector,uint16_t,...)
GrB_select(GrB_Vector,...,GrB_IndexUnaryOp,GrB_Vector,int32_t,...)	GrB_Vector_select_INT32(GrB_Vector,...,GrB_IndexUnaryOp,GrB_Vector,int32_t,...)
GrB_select(GrB_Vector,...,GrB_IndexUnaryOp,GrB_Vector,uint32_t,...)	GrB_Vector_select_UINT32(GrB_Vector,...,GrB_IndexUnaryOp,GrB_Vector,uint32_t,...)
GrB_select(GrB_Vector,...,GrB_IndexUnaryOp,GrB_Vector,int64_t,...)	GrB_Vector_select_INT64(GrB_Vector,...,GrB_IndexUnaryOp,GrB_Vector,int64_t,...)
GrB_select(GrB_Vector,...,GrB_IndexUnaryOp,GrB_Vector,uint64_t,...)	GrB_Vector_select_UINT64(GrB_Vector,...,GrB_IndexUnaryOp,GrB_Vector,uint64_t,...)
GrB_select(GrB_Vector,...,GrB_IndexUnaryOp,GrB_Vector,float,...)	GrB_Vector_select_FP32(GrB_Vector,...,GrB_IndexUnaryOp,GrB_Vector,float,...)
GrB_select(GrB_Vector,...,GrB_IndexUnaryOp,GrB_Vector,double,...)	GrB_Vector_select_FP64(GrB_Vector,...,GrB_IndexUnaryOp,GrB_Vector,double,...)
GrB_select(GrB_Vector,...,GrB_IndexUnaryOp,GrB_Vector,other,...)	GrB_Vector_select_UDT(GrB_Vector,...,GrB_IndexUnaryOp,GrB_Vector,const void*,...)
GrB_select(GrB_Matrix,...,GrB_IndexUnaryOp,GrB_Matrix,GrB_Scalar,...)	GrB_Matrix_select_Scalar(GrB_Matrix,...,GrB_IndexUnaryOp,GrB_Matrix,GrB_Scalar,...)
GrB_select(GrB_Matrix,...,GrB_IndexUnaryOp,GrB_Matrix,bool,...)	GrB_Matrix_select_BOOL(GrB_Matrix,...,GrB_IndexUnaryOp,GrB_Matrix,bool,...)
GrB_select(GrB_Matrix,...,GrB_IndexUnaryOp,GrB_Matrix,int8_t,...)	GrB_Matrix_select_INT8(GrB_Matrix,...,GrB_IndexUnaryOp,GrB_Matrix,int8_t,...)
GrB_select(GrB_Matrix,...,GrB_IndexUnaryOp,GrB_Matrix,uint8_t,...)	GrB_Matrix_select_UINT8(GrB_Matrix,...,GrB_IndexUnaryOp,GrB_Matrix,uint8_t,...)
GrB_select(GrB_Matrix,...,GrB_IndexUnaryOp,GrB_Matrix,int16_t,...)	GrB_Matrix_select_INT16(GrB_Matrix,...,GrB_IndexUnaryOp,GrB_Matrix,int16_t,...)
GrB_select(GrB_Matrix,...,GrB_IndexUnaryOp,GrB_Matrix,uint16_t,...)	GrB_Matrix_select_UINT16(GrB_Matrix,...,GrB_IndexUnaryOp,GrB_Matrix,uint16_t,...)
GrB_select(GrB_Matrix,...,GrB_IndexUnaryOp,GrB_Matrix,int32_t,...)	GrB_Matrix_select_INT32(GrB_Matrix,...,GrB_IndexUnaryOp,GrB_Matrix,int32_t,...)
GrB_select(GrB_Matrix,...,GrB_IndexUnaryOp,GrB_Matrix,uint32_t,...)	GrB_Matrix_select_UINT32(GrB_Matrix,...,GrB_IndexUnaryOp,GrB_Matrix,uint32_t,...)
GrB_select(GrB_Matrix,...,GrB_IndexUnaryOp,GrB_Matrix,int64_t,...)	GrB_Matrix_select_INT64(GrB_Matrix,...,GrB_IndexUnaryOp,GrB_Matrix,int64_t,...)
GrB_select(GrB_Matrix,...,GrB_IndexUnaryOp,GrB_Matrix,uint64_t,...)	GrB_Matrix_select_UINT64(GrB_Matrix,...,GrB_IndexUnaryOp,GrB_Matrix,uint64_t,...)
GrB_select(GrB_Matrix,...,GrB_IndexUnaryOp,GrB_Matrix,float,...)	GrB_Matrix_select_FP32(GrB_Matrix,...,GrB_IndexUnaryOp,GrB_Matrix,float,...)
GrB_select(GrB_Matrix,...,GrB_IndexUnaryOp,GrB_Matrix,double,...)	GrB_Matrix_select_FP64(GrB_Matrix,...,GrB_IndexUnaryOp,GrB_Matrix,double,...)
GrB_select(GrB_Matrix,...,GrB_IndexUnaryOp,GrB_Matrix,other,...)	GrB_Matrix_select_UDT(GrB_Matrix,...,GrB_IndexUnaryOp,GrB_Matrix,const void*,...)

Table 5.11: Long-name, nonpolymorphic form of GraphBLAS methods (continued).

Polymorphic signature	Nonpolymorphic signature
GrB_reduce(GrB_Vector,...,GrB_Monoid,...)	GrB_Matrix_reduce_Monoid(GrB_Vector,...,GrB_Monoid,...)
GrB_reduce(GrB_Vector,...,GrB_BinaryOp,...)	GrB_Matrix_reduce_BinaryOp(GrB_Vector,...,GrB_BinaryOp,...)
GrB_reduce(GrB_Scalar,...,GrB_Monoid,GrB_Vector,...)	GrB_Vector_reduce_Monoid_Scalar(GrB_Scalar,...,GrB_Vector,...)
GrB_reduce(GrB_Scalar,...,GrB_BinaryOp,GrB_Vector,...)	GrB_Vector_reduce_BinaryOp_Scalar(GrB_Scalar,...,GrB_Vector,...)
GrB_reduce(bool*,...,GrB_Vector,...)	GrB_Vector_reduce_BOOL(bool*,...,GrB_Vector,...)
GrB_reduce(int8_t*,...,GrB_Vector,...)	GrB_Vector_reduce_INT8(int8_t*,...,GrB_Vector,...)
GrB_reduce(uint8_t*,...,GrB_Vector,...)	GrB_Vector_reduce_UINT8(uint8_t*,...,GrB_Vector,...)
GrB_reduce(int16_t*,...,GrB_Vector,...)	GrB_Vector_reduce_INT16(int16_t*,...,GrB_Vector,...)
GrB_reduce(uint16_t*,...,GrB_Vector,...)	GrB_Vector_reduce_UINT16(uint16_t*,...,GrB_Vector,...)
GrB_reduce(int32_t*,...,GrB_Vector,...)	GrB_Vector_reduce_INT32(int32_t*,...,GrB_Vector,...)
GrB_reduce(uint32_t*,...,GrB_Vector,...)	GrB_Vector_reduce_UINT32(uint32_t*,...,GrB_Vector,...)
GrB_reduce(int64_t*,...,GrB_Vector,...)	GrB_Vector_reduce_INT64(int64_t*,...,GrB_Vector,...)
GrB_reduce(uint64_t*,...,GrB_Vector,...)	GrB_Vector_reduce_UINT64(uint64_t*,...,GrB_Vector,...)
GrB_reduce(float*,...,GrB_Vector,...)	GrB_Vector_reduce_FP32(float*,...,GrB_Vector,...)
GrB_reduce(double*,...,GrB_Vector,...)	GrB_Vector_reduce_FP64(double*,...,GrB_Vector,...)
GrB_reduce(<i>other</i> ,...,GrB_Vector,...)	GrB_Vector_reduce_UDT(void*,...,GrB_Vector,...)
GrB_reduce(GrB_Scalar,...,GrB_Monoid,GrB_Matrix,...)	GrB_Matrix_reduce_Monoid_Scalar(GrB_Scalar,...,GrB_Monoid,GrB_Matrix,...)
GrB_reduce(GrB_Scalar,...,GrB_BinaryOp,GrB_Matrix,...)	GrB_Matrix_reduce_BinaryOp_Scalar(GrB_Scalar,...,GrB_BinaryOp,GrB_Matrix,...)
GrB_reduce(bool*,...,GrB_Matrix,...)	GrB_Matrix_reduce_BOOL(bool*,...,GrB_Matrix,...)
GrB_reduce(int8_t*,...,GrB_Matrix,...)	GrB_Matrix_reduce_INT8(int8_t*,...,GrB_Matrix,...)
GrB_reduce(uint8_t*,...,GrB_Matrix,...)	GrB_Matrix_reduce_UINT8(uint8_t*,...,GrB_Matrix,...)
GrB_reduce(int16_t*,...,GrB_Matrix,...)	GrB_Matrix_reduce_INT16(int16_t*,...,GrB_Matrix,...)
GrB_reduce(uint16_t*,...,GrB_Matrix,...)	GrB_Matrix_reduce_UINT16(uint16_t*,...,GrB_Matrix,...)
GrB_reduce(int32_t*,...,GrB_Matrix,...)	GrB_Matrix_reduce_INT32(int32_t*,...,GrB_Matrix,...)
GrB_reduce(uint32_t*,...,GrB_Matrix,...)	GrB_Matrix_reduce_UINT32(uint32_t*,...,GrB_Matrix,...)
GrB_reduce(int64_t*,...,GrB_Matrix,...)	GrB_Matrix_reduce_INT64(int64_t*,...,GrB_Matrix,...)
GrB_reduce(uint64_t*,...,GrB_Matrix,...)	GrB_Matrix_reduce_UINT64(uint64_t*,...,GrB_Matrix,...)
GrB_reduce(float*,...,GrB_Matrix,...)	GrB_Matrix_reduce_FP32(float*,...,GrB_Matrix,...)
GrB_reduce(double*,...,GrB_Matrix,...)	GrB_Matrix_reduce_FP64(double*,...,GrB_Matrix,...)
GrB_reduce(<i>other</i> ,...,GrB_Matrix,...)	GrB_Matrix_reduce_UDT(void*,...,GrB_Matrix,...)
GrB_kronecker(GrB_Matrix,...,GrB_Semiring,...)	GrB_Matrix_kronecker_Semiring(GrB_Matrix,...,GrB_Semiring,...)
GrB_kronecker(GrB_Matrix,...,GrB_Monoid,...)	GrB_Matrix_kronecker_Monoid(GrB_Matrix,...,GrB_Monoid,...)
GrB_kronecker(GrB_Matrix,...,GrB_BinaryOp,...)	GrB_Matrix_kronecker_BinaryOp(GrB_Matrix,...,GrB_BinaryOp,...)

Table 5.12: Long-name, nonpolymorphic form of GraphBLAS methods (continued).

Polymorphic signature	Nonpolymorphic signature
GrB_get(GrB_Scalar,GrB_Scalar,GrB_Field)	GrB_Scalar_get_Scalar(GrB_Scalar,GrB_Scalar,GrB_Field)
GrB_get(GrB_Scalar,char*,GrB_Field)	GrB_Scalar_get_String(GrB_Scalar,char*,GrB_Field)
GrB_get(GrB_Scalar,int32_t*,GrB_Field)	GrB_Scalar_get_INT32(GrB_Scalar,int32_t*,GrB_Field)
GrB_get(GrB_Scalar,size_t*,GrB_Field)	GrB_Scalar_get_SIZE(GrB_Scalar,size_t*,GrB_Field)
GrB_get(GrB_Scalar,void*,GrB_Field)	GrB_Scalar_get_VOID(GrB_Scalar,void*,GrB_Field)
GrB_get(GrB_Vector,GrB_Scalar,GrB_Field)	GrB_Vector_get_Scalar(GrB_Vector,GrB_Scalar,GrB_Field)
GrB_get(GrB_Vector,char*,GrB_Field)	GrB_Vector_get_String(GrB_Vector,char*,GrB_Field)
GrB_get(GrB_Vector,int32_t*,GrB_Field)	GrB_Vector_get_INT32(GrB_Vector,int32_t*,GrB_Field)
GrB_get(GrB_Vector,size_t*,GrB_Field)	GrB_Vector_get_SIZE(GrB_Vector,size_t*,GrB_Field)
GrB_get(GrB_Vector,void*,GrB_Field)	GrB_Vector_get_VOID(GrB_Vector,void*,GrB_Field)
GrB_get(GrB_Matrix,GrB_Scalar,GrB_Field)	GrB_Matrix_get_Scalar(GrB_Matrix,GrB_Scalar,GrB_Field)
GrB_get(GrB_Matrix,char*,GrB_Field)	GrB_Matrix_get_String(GrB_Matrix,char*,GrB_Field)
GrB_get(GrB_Matrix,int32_t*,GrB_Field)	GrB_Matrix_get_INT32(GrB_Matrix,int32_t*,GrB_Field)
GrB_get(GrB_Matrix,size_t*,GrB_Field)	GrB_Matrix_get_SIZE(GrB_Matrix,size_t*,GrB_Field)
GrB_get(GrB_Matrix,void*,GrB_Field)	GrB_Matrix_get_VOID(GrB_Matrix,void*,GrB_Field)
GrB_get(GrB_UnaryOp,GrB_Scalar,GrB_Field)	GrB_UnaryOp_get_Scalar(GrB_UnaryOp,GrB_Scalar,GrB_Field)
GrB_get(GrB_UnaryOp,char*,GrB_Field)	GrB_UnaryOp_get_String(GrB_UnaryOp,char*,GrB_Field)
GrB_get(GrB_UnaryOp,int32_t*,GrB_Field)	GrB_UnaryOp_get_INT32(GrB_UnaryOp,int32_t*,GrB_Field)
GrB_get(GrB_UnaryOp,size_t*,GrB_Field)	GrB_UnaryOp_get_SIZE(GrB_UnaryOp,size_t*,GrB_Field)
GrB_get(GrB_UnaryOp,void*,GrB_Field)	GrB_UnaryOp_get_VOID(GrB_UnaryOp,void*,GrB_Field)
GrB_get(GrB_IndexUnaryOp,GrB_Scalar,GrB_Field)	GrB_IndexUnaryOp_get_Scalar(GrB_IndexUnaryOp,GrB_Scalar,GrB_Field)
GrB_get(GrB_IndexUnaryOp,char*,GrB_Field)	GrB_IndexUnaryOp_get_String(GrB_IndexUnaryOp,char*,GrB_Field)
GrB_get(GrB_IndexUnaryOp,int32_t*,GrB_Field)	GrB_IndexUnaryOp_get_INT32(GrB_IndexUnaryOp,int32_t*,GrB_Field)
GrB_get(GrB_IndexUnaryOp,size_t*,GrB_Field)	GrB_IndexUnaryOp_get_SIZE(GrB_IndexUnaryOp,size_t*,GrB_Field)
GrB_get(GrB_IndexUnaryOp,void*,GrB_Field)	GrB_IndexUnaryOp_get_VOID(GrB_IndexUnaryOp,void*,GrB_Field)
GrB_get(GrB_BinaryOp,GrB_Scalar,GrB_Field)	GrB_BinaryOp_get_Scalar(GrB_BinaryOp,GrB_Scalar,GrB_Field)
GrB_get(GrB_BinaryOp,char*,GrB_Field)	GrB_BinaryOp_get_String(GrB_BinaryOp,char*,GrB_Field)
GrB_get(GrB_BinaryOp,int32_t*,GrB_Field)	GrB_BinaryOp_get_INT32(GrB_BinaryOp,int32_t*,GrB_Field)
GrB_get(GrB_BinaryOp,size_t*,GrB_Field)	GrB_BinaryOp_get_SIZE(GrB_BinaryOp,size_t*,GrB_Field)
GrB_get(GrB_BinaryOp,void*,GrB_Field)	GrB_BinaryOp_get_VOID(GrB_BinaryOp,void*,GrB_Field)
GrB_get(GrB_Monoid,GrB_Scalar,GrB_Field)	GrB_Monoid_get_Scalar(GrB_Monoid,GrB_Scalar,GrB_Field)
GrB_get(GrB_Monoid,char*,GrB_Field)	GrB_Monoid_get_String(GrB_Monoid,char*,GrB_Field)
GrB_get(GrB_Monoid,int32_t*,GrB_Field)	GrB_Monoid_get_INT32(GrB_Monoid,int32_t*,GrB_Field)
GrB_get(GrB_Monoid,size_t*,GrB_Field)	GrB_Monoid_get_SIZE(GrB_Monoid,size_t*,GrB_Field)
GrB_get(GrB_Monoid,void*,GrB_Field)	GrB_Monoid_get_VOID(GrB_Monoid,void*,GrB_Field)
GrB_get(GrB_Semiring,GrB_Scalar,GrB_Field)	GrB_Semiring_get_Scalar(GrB_Semiring,GrB_Scalar,GrB_Field)
GrB_get(GrB_Semiring,char*,GrB_Field)	GrB_Semiring_get_String(GrB_Semiring,char*,GrB_Field)
GrB_get(GrB_Semiring,int32_t*,GrB_Field)	GrB_Semiring_get_INT32(GrB_Semiring,int32_t*,GrB_Field)
GrB_get(GrB_Semiring,size_t*,GrB_Field)	GrB_Semiring_get_SIZE(GrB_Semiring,size_t*,GrB_Field)
GrB_get(GrB_Semiring,void*,GrB_Field)	GrB_Semiring_get_VOID(GrB_Semiring,void*,GrB_Field)
GrB_get(GrB_Descriptor,GrB_Scalar,GrB_Field)	GrB_Descriptor_get_Scalar(GrB_Descriptor,GrB_Scalar,GrB_Field)
GrB_get(GrB_Descriptor,char*,GrB_Field)	GrB_Descriptor_get_String(GrB_Descriptor,char*,GrB_Field)
GrB_get(GrB_Descriptor,int32_t*,GrB_Field)	GrB_Descriptor_get_INT32(GrB_Descriptor,int32_t*,GrB_Field)
GrB_get(GrB_Descriptor,size_t*,GrB_Field)	GrB_Descriptor_get_SIZE(GrB_Descriptor,size_t*,GrB_Field)
GrB_get(GrB_Descriptor,void*,GrB_Field)	GrB_Descriptor_get_VOID(GrB_Descriptor,void*,GrB_Field)
GrB_get(GrB_Type,GrB_Scalar,GrB_Field)	GrB_Type_get_Scalar(GrB_Type,GrB_Scalar,GrB_Field)
GrB_get(GrB_Type,char*,GrB_Field)	GrB_Type_get_String(GrB_Type,char*,GrB_Field)
GrB_get(GrB_Type,int32_t*,GrB_Field)	GrB_Type_get_INT32(GrB_Type,int32_t*,GrB_Field)
GrB_get(GrB_Type,size_t*,GrB_Field)	GrB_Type_get_SIZE(GrB_Type,size_t*,GrB_Field)
GrB_get(GrB_Type,void*,GrB_Field)	GrB_Type_get_VOID(GrB_Type,void*,GrB_Field)
GrB_get(GrB_Global,GrB_Scalar,GrB_Field)	GrB_Global_get_Scalar(GrB_Global,GrB_Scalar,GrB_Field)
GrB_get(GrB_Global,char*,GrB_Field)	GrB_Global_get_String(GrB_Global,char*,GrB_Field)
GrB_get(GrB_Global,int32_t*,GrB_Field)	GrB_Global_get_INT32(GrB_Global,int32_t*,GrB_Field)
GrB_get(GrB_Global,size_t*,GrB_Field)	GrB_Global_get_SIZE(GrB_Global,size_t*,GrB_Field)
GrB_get(GrB_Global,void*,GrB_Field)	GrB_Global_get_VOID(GrB_Global,void*,GrB_Field)

Table 5.13: Long-name, nonpolymorphic form of GraphBLAS methods (continued).

Polymorphic signature	Nonpolymorphic signature
GrB_set(GrB_Scalar,GrB_Scalar,GrB_Field)	GrB_Scalar_set_Scalar(GrB_Scalar,GrB_Scalar,GrB_Field)
GrB_set(GrB_Scalar,char*,GrB_Field)	GrB_Scalar_set_String(GrB_Scalar,char*,GrB_Field)
GrB_set(GrB_Scalar,int32_t,GrB_Field)	GrB_Scalar_set_INT32(GrB_Scalar,int32_t,GrB_Field)
GrB_set(GrB_Scalar,void*,GrB_Field,size_t)	GrB_Scalar_set_VOID(GrB_Scalar,void*,GrB_Field,size_t)
GrB_set(GrB_Vector,GrB_Scalar,GrB_Field)	GrB_Vector_set_Scalar(GrB_Vector,GrB_Scalar,GrB_Field)
GrB_set(GrB_Vector,char*,GrB_Field)	GrB_Vector_set_String(GrB_Vector,char*,GrB_Field)
GrB_set(GrB_Vector,int32_t,GrB_Field)	GrB_Vector_set_INT32(GrB_Vector,int32_t,GrB_Field)
GrB_set(GrB_Vector,void*,GrB_Field,size_t)	GrB_Vector_set_VOID(GrB_Vector,void*,GrB_Field,size_t)
GrB_set(GrB_Matrix,GrB_Scalar,GrB_Field)	GrB_Matrix_set_Scalar(GrB_Matrix,GrB_Scalar,GrB_Field)
GrB_set(GrB_Matrix,char*,GrB_Field)	GrB_Matrix_set_String(GrB_Matrix,char*,GrB_Field)
GrB_set(GrB_Matrix,int32_t,GrB_Field)	GrB_Matrix_set_INT32(GrB_Matrix,int32_t,GrB_Field)
GrB_set(GrB_Matrix,void*,GrB_Field,size_t)	GrB_Matrix_set_VOID(GrB_Matrix,void*,GrB_Field,size_t)
GrB_set(GrB_UnaryOp,GrB_Scalar,GrB_Field)	GrB_UnaryOp_set_Scalar(GrB_UnaryOp,GrB_Scalar,GrB_Field)
GrB_set(GrB_UnaryOp,char*,GrB_Field)	GrB_UnaryOp_set_String(GrB_UnaryOp,char*,GrB_Field)
GrB_set(GrB_UnaryOp,int32_t,GrB_Field)	GrB_UnaryOp_set_INT32(GrB_UnaryOp,int32_t,GrB_Field)
GrB_set(GrB_UnaryOp,void*,GrB_Field,size_t)	GrB_UnaryOp_set_VOID(GrB_UnaryOp,void*,GrB_Field,size_t)
GrB_set(GrB_IndexUnaryOp,GrB_Scalar,GrB_Field)	GrB_IndexUnaryOp_set_Scalar(GrB_IndexUnaryOp,GrB_Scalar,GrB_Field)
GrB_set(GrB_IndexUnaryOp,char*,GrB_Field)	GrB_IndexUnaryOp_set_String(GrB_IndexUnaryOp,char*,GrB_Field)
GrB_set(GrB_IndexUnaryOp,int32_t,GrB_Field)	GrB_IndexUnaryOp_set_INT32(GrB_IndexUnaryOp,int32_t,GrB_Field)
GrB_set(GrB_IndexUnaryOp,void*,GrB_Field,size_t)	GrB_IndexUnaryOp_set_VOID(GrB_IndexUnaryOp,void*,GrB_Field,size_t)
GrB_set(GrB_BinaryOp,GrB_Scalar,GrB_Field)	GrB_BinaryOp_set_Scalar(GrB_BinaryOp,GrB_Scalar,GrB_Field)
GrB_set(GrB_BinaryOp,char*,GrB_Field)	GrB_BinaryOp_set_String(GrB_BinaryOp,char*,GrB_Field)
GrB_set(GrB_BinaryOp,int32_t,GrB_Field)	GrB_BinaryOp_set_INT32(GrB_BinaryOp,int32_t,GrB_Field)
GrB_set(GrB_BinaryOp,void*,GrB_Field,size_t)	GrB_BinaryOp_set_VOID(GrB_BinaryOp,void*,GrB_Field,size_t)
GrB_set(GrB_Monoid,GrB_Scalar,GrB_Field)	GrB_Monoid_set_Scalar(GrB_Monoid,GrB_Scalar,GrB_Field)
GrB_set(GrB_Monoid,char*,GrB_Field)	GrB_Monoid_set_String(GrB_Monoid,char*,GrB_Field)
GrB_set(GrB_Monoid,int32_t,GrB_Field)	GrB_Monoid_set_INT32(GrB_Monoid,int32_t,GrB_Field)
GrB_set(GrB_Monoid,void*,GrB_Field,size_t)	GrB_Monoid_set_VOID(GrB_Monoid,void*,GrB_Field,size_t)
GrB_set(GrB_Semiring,GrB_Scalar,GrB_Field)	GrB_Semiring_set_Scalar(GrB_Semiring,GrB_Scalar,GrB_Field)
GrB_set(GrB_Semiring,char*,GrB_Field)	GrB_Semiring_set_String(GrB_Semiring,char*,GrB_Field)
GrB_set(GrB_Semiring,int32_t,GrB_Field)	GrB_Semiring_set_INT32(GrB_Semiring,int32_t,GrB_Field)
GrB_set(GrB_Semiring,void*,GrB_Field,size_t)	GrB_Semiring_set_VOID(GrB_Semiring,void*,GrB_Field,size_t)
GrB_set(GrB_Descriptor,GrB_Scalar,GrB_Field)	GrB_Descriptor_set_Scalar(GrB_Descriptor,GrB_Scalar,GrB_Field)
GrB_set(GrB_Descriptor,char*,GrB_Field)	GrB_Descriptor_set_String(GrB_Descriptor,char*,GrB_Field)
GrB_set(GrB_Descriptor,int32_t,GrB_Field)	GrB_Descriptor_set_INT32(GrB_Descriptor,int32_t,GrB_Field)
GrB_set(GrB_Descriptor,void*,GrB_Field,size_t)	GrB_Descriptor_set_VOID(GrB_Descriptor,void*,GrB_Field,size_t)
GrB_set(GrB_Type,GrB_Scalar,GrB_Field)	GrB_Type_set_Scalar(GrB_Type,GrB_Scalar,GrB_Field)
GrB_set(GrB_Type,char*,GrB_Field)	GrB_Type_set_String(GrB_Type,char*,GrB_Field)
GrB_set(GrB_Type,int32_t,GrB_Field)	GrB_Type_set_INT32(GrB_Type,int32_t,GrB_Field)
GrB_set(GrB_Type,void*,GrB_Field,size_t)	GrB_Type_set_VOID(GrB_Type,void*,GrB_Field,size_t)
GrB_set(GrB_Global,GrB_Scalar,GrB_Field)	GrB_Global_set_Scalar(GrB_Global,GrB_Scalar,GrB_Field)
GrB_set(GrB_Global,char*,GrB_Field)	GrB_Global_set_String(GrB_Global,char*,GrB_Field)
GrB_set(GrB_Global,int32_t,GrB_Field)	GrB_Global_set_INT32(GrB_Global,int32_t,GrB_Field)
GrB_set(GrB_Global,void*,GrB_Field,size_t)	GrB_Global_set_VOID(GrB_Global,void*,GrB_Field,size_t)

7529 Appendix A

7530 Revision history

7531 Changes in 2.1.0 (Released: 22 December 2023):

- 7532 • (Issue BB-28, BB-27, BB-13, BB-7) We added a capability for meta-data associated with
7533 each GraphBLAS object and the library implementation (the global scope) as well. This
7534 was done through the new `GrB_get` and `GrB_set` methods with (field, value) pairs. We also
7535 needed a new error code for the case where an attempt is made to write to a write-once field,
7536 `GrB_ALREADY_SET`
- 7537 • (Issue BB-15, BB-14) The definition of meta-data on GraphBLAS objects added the ability
7538 to interact directly with the type system behind these objects. This required the addition of
7539 type codes (`GrB_Type_Code`) and the ability to manage the type system through strings.
- 7540 • We augmented the deserialization method so if passed a type parameter of `GrB_NULL` it will
7541 infer type information needed for deserialization of a GraphBLAS matrix.
- 7542 • We added new field values of type `GrB_Desc_Value` for use when working with Descriptors,
7543 `GrB_COMP_STRUCTURE` and `GrB_DEFAULT`.

7544 Changes in 2.0.1 (Released: 9 December 2022):

- 7545 • (Issue GH-69) Fix error in description of contents of matrix constructed from `GrB_Matrix_diag`.

7546 Changes in 2.0.0 (Released: 15 November 2021):

- 7547 • Reorganized Chapters 2 and 3: Chapter 2 contains prose regarding the basic concepts cap-
7548 tured in the API; Chapter 3 presents all of the enumerations, literals, data types, and prede-
7549 fined objects required by the API. Made short captions for the List of Tables.
- 7550 • (Issue BB-49, BB-50) Updated and corrected language regarding multithreading and comple-
7551 tion, and requirements regarding acquire-release memory orders. Methods that used to force
7552 complete no longer do.

- 7553 • (Issue BB-74, BB-9) Assigned integer values to all return codes as well as all enumerations
7554 in the API to ensure run-time compatibility between libraries.
- 7555 • (Issues BB-70, BB-67) Changed semantics and signature of `GrB_wait(obj, mode)`. Added wait
7556 modes for 'complete' or 'materialize' and removed `GrB_wait(void)`. **This breaks backward**
7557 **compatibility.**
- 7558 • (Issue GH-51) Removed deprecated `GrB_SCMP` literal from descriptor values. **This breaks**
7559 **backward compatibility.**
- 7560 • (Issues BB-8, BB-36) Added sparse `GrB_Scalar` object and its use in additional variants of
7561 `extract/setElement` methods, and `reduce`, `apply`, `assign` and `select` operations.
- 7562 • (Issues BB-34, GH-33, GH-45) Added new `select` operation that uses an index unary operator.
7563 Added new variants of `apply` that take an index unary operator (matrix and vector variants).
- 7564 • (Issues BB-68, BB-51) Added `serialize` and `deserialize` methods for matrices to/from imple-
7565 mentation defined formats.
- 7566 • (Issues BB-25, GH-42) Added `import` and `export` methods for matrices to/from API specified
7567 formats. Three formats have been specified: `CSC`, `CSR`, `COO`. Dense row and column formats
7568 have been deferred.
- 7569 • (Issue BB-75) Added matrix constructor to build a diagonal `GrB_Matrix` from a `GrB_Vector`.
- 7570 • (Issue BB-73) Allow `GrB_NULL` for `dup` operator in matrix and vector `build` methods. Return
7571 error if duplicate locations encountered.
- 7572 • (Issue BB-58) Added matrix and vector methods to remove (annihilate) elements.
- 7573 • (Issue BB-17) Added `GrB_ABS_T` (absolute value) unary operator.
- 7574 • (Issue GH-46) Adding `GrB_ONEB_T` binary operator that returns 1 cast to type `T` (not to
7575 be confused with the proposed unary operator).
- 7576 • (Issue GH-53) Added language about what constitutes a “conformant” implementation. Added
7577 `GrB_NOT_IMPLEMENTED` return value (API error) for API any combinations of inputs to
7578 a method that is not supported by the implementation.
- 7579 • Added `GrB_EMPTY_OBJECT` return value (execution error) that is used when an opaque
7580 object (currently only `GrB_Scalar`) is passed as an input that cannot be empty.
- 7581 • (Issue BB-45) Removed language about annihilators.
- 7582 • (Issue BB-69) Made names/symbols containing underscores searchable in PDF.
- 7583 • Updated a number algorithms in the appendix to use new operations and methods.
- 7584 • Numerous additions (some changes) to the non-polymorphic interface to track changes to the
7585 specification.
- 7586 • Typographical error in version macros was corrected. They are all caps: `GRB_VERSION` and
7587 `GRB_SUBVERSION`.

- 7588 • Typographical change to eWiseAdd Description to be consistent in order of set intersections.
- 7589 • Typographical errors in eWiseAdd: cut-and-paste errors from eWiseMult/set intersection
7590 fixed to read eWiseAdd/set union.
- 7591 • Typographical error (NEQ → NE) in Description of Table 3.8.

7592 Changes in 1.3.0 (Released: 25 September 2019):

- 7593 • (Issue BB-50) Changed definition of completion and added GrB_wait() that takes an opaque
7594 GraphBLAS object as an argument.
- 7595 • (Issue BB-39) Added GrB_kronecker operation.
- 7596 • (Issue BB-40) Added variants of the GrB_apply operation that take a binary function and a
7597 scalar.
- 7598 • (Issue BB-59) Changed specification about how reductions to scalar (GrB_reduce) are to be
7599 performed (to minimize dependence on monoid identity).
- 7600 • (Issue BB-24) Added methods to resize matrices and vectors (GrB_Matrix_resize and GrB_Vector_resize).
- 7601 • (Issue BB-47) Added methods to remove single elements from matrices and vectors (GrB_Matrix_removeElement
7602 and GrB_Vector_removeElement).
- 7603 • (Issue BB-41) Added GrB_STRUCTURE descriptor flag for masks (consider only the structure
7604 of the mask and not the values).
- 7605 • (Issue BB-64) Deprecated GrB_SCMP in favor of new GrB_COMP for descriptor values.
- 7606 • (Issue BB-46) Added predefined descriptors covering all possible combinations of field, value
7607 pairs.
- 7608 • Added unary operators: absolute value (GrB_ABS_T) and bitwise complement of integers
7609 (GrB_BNOT_I).
- 7610 • (Issues BB-42, BB-62) Added binary operators: Added boolean exclusive-nor (GrB_LXNOR)
7611 and bitwise logical operators on integers (GrB_BOR_I, GrB_BAND_I, GrB_BXOR_I, GrB_BXNOR_I).
- 7612 • (Issue BB-11) Added a set of predefined monoids and semirings.
- 7613 • (Issue BB-57) Updated all examples in the appendix to take advantage of new capabilities
7614 and predefined objects.
- 7615 • (Issue BB-43) Added parent-BFS example.
- 7616 • (Issue BB-1) Fixed bug in the non-batch betweenness centrality algorithm in Appendix C.4
7617 where source nodes were incorrectly assigned path counts.
- 7618 • (Issue BB-3) Added compile-time preprocessor defines and runtime method for querying the
7619 GraphBLAS API version being used.

- 7620 • (Issue BB-10) Clarified GrB_init() and GrB_finalize() errors.
- 7621 • (Issue BB-16) Clarified behavior of boolean and integer division. **Note that GrB_MINV for**
7622 **integer and boolean types was removed from this version of the spec.**
- 7623 • (Issue BB-19) Clarified aliasing in user-defined operators.
- 7624 • (Issue BB-20) Clarified language about behavior of GrB_free() with predefined objects (im-
7625 plementation defined)
- 7626 • (Issue BB-55) Clarified that multiplication does not have to distribute over addition in a
7627 GraphBLAS semiring.
- 7628 • (Issue BB-45) Removed unnecessary language about annihilators.
- 7629 • (Issue BB-61) Removed unnecessary language about implied zeros.
- 7630 • (Issue BB-60) Added disclaimer against overspecification.
- 7631 • Fixed miscellaneous typographical errors (such as $\otimes \oplus$).

7632 Changes in 1.2.0:

- 7633 • Removed "provisional" clause.

7634 Changes in 1.1.0:

- 7635 • Removed unnecessary const from nindices, nrows, and ncols parameters of both extract and
7636 assign operations.
- 7637 • Signature of GrB_UnaryOp_new changed: order of input parameters changed.
- 7638 • Signature of GrB_BinaryOp_new changed: order of input parameters changed.
- 7639 • Signature of GrB_Monoid_new changed: removal of domain argument which is now inferred
7640 from the domains of the binary operator provided.
- 7641 • Signature of GrB_Vector_extractTuples and GrB_Matrix_extractTuples to add an in/out ar-
7642 gument, n, which indicates the size of the output arrays provided (in terms of number of
7643 elements, not number of bytes). Added new execution error, GrB_INSUFFICIENT_SPACE
7644 which is returned when the capacities of the output arrays are insufficient to hold all of the
7645 tuples.
- 7646 • Changed GrB_Column_assign to GrB_Col_assign for consistency in non-polymorphic inter-
7647 face.
- 7648 • Added replace flag (z) notation to Table 4.1.
- 7649 • Updated the "Mathematical Description" of the assign operation in Table 4.1.
- 7650 • Added triangle counting example.

7651 • Added subsection headers for accumulate and mask/replace discussions in the Description
7652 sections of GraphBLAS operations when the respective text was the “standard” text (i.e.,
7653 identical in a majority of the operations).

7654 • Fixed typographical errors.

7655 Changes in 1.0.2:

7656 • Expanded the definitions of `Vector_build` and `Matrix_build` to conceptually use intermediate
7657 matrices and avoid casting issues in certain implementations.

7658 • Fixed the bug in the `GrB_assign` definition. Elements of the output object are no longer being
7659 erased outside the assigned area.

7660 • Changes non-polymorphic interface:

7661 – Renamed `GrB_Row_extract` to `GrB_Col_extract`.

7662 – Renamed `GrB_Vector_reduce_BinaryOp` to `GrB_Matrix_reduce_BinaryOp`.

7663 – Renamed `GrB_Vector_reduce_Monoid` to `GrB_Matrix_reduce_Monoid`.

7664 • Fixed the bugs with respect to isolated vertices in the Maximal Independent Set example.

7665 • Fixed numerous typographical errors.

7666 **Appendix B**

7667 **Non-opaque data format definitions**

7668 **B.1 GrB_Format: Specify the format for input/output of a Graph-**
7669 **BLAS matrix.**

7670 In this section, the non-opaque matrix formats specified by GrB_Format and used in matrix import
7671 and export methods are defined.

7672 **B.1.1 GrB_CSR_FORMAT**

7673 The GrB_CSR_FORMAT format indicates that a matrix will be imported or exported using the
7674 compressed sparse row (CSR) format. `indptr` is a pointer to an array of GrB_Index of size `nrows+1`
7675 elements, where the `i`'th index will contain the starting index in the `values` and `indices`
7676 corresponding to the `i`'th row of the matrix. `indices` is a pointer to an array of number of stored
7677 elements (each a GrB_Index), where each element contains the corresponding element's column
7678 index within a row of the matrix. `values` is a pointer to an array of number of stored elements (each
7679 the size of the scalar stored in the matrix) containing the corresponding value. The elements of
7680 each row are not required to be sorted by column index.

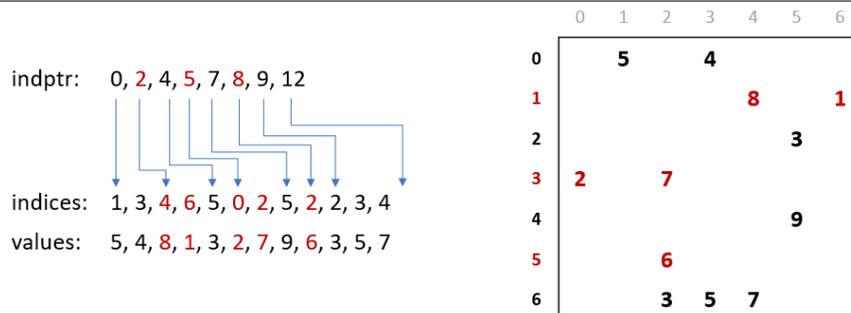


Figure B.1: Data layout for CSR format.

7681 **B.1.2 GrB_CSC_FORMAT**

7682 The GrB_CSC_FORMAT format indicates that a matrix will be imported or exported using the
 7683 compressed sparse column (CSC) format. `indptr` is a pointer to an array of `GrB_Index` of size
 7684 `ncols+1` elements, where the *i*'th index will contain the starting index in the `values` and `indices`
 7685 arrays corresponding to the *i*'th column of the matrix. `indices` is a pointer to an array of number of
 7686 stored elements (each a `GrB_Index`), where each element contains the corresponding element's row
 7687 index within a column of the matrix. `values` is a pointer to an array of number of stored elements
 7688 (each the size of the scalar stored in the matrix) containing the corresponding value. The elements
 7689 of each column are not required to be sorted by row index.

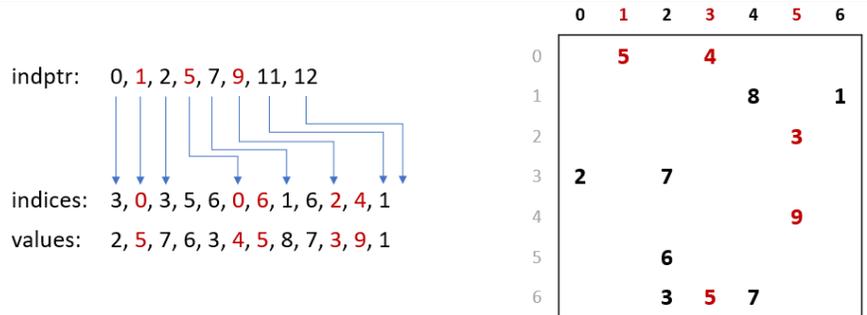


Figure B.2: Data layout for CSC format.

7690 **B.1.3 GrB_COO_FORMAT**

7691 The GrB_COO_FORMAT format indicates that a matrix will be imported or exported using the
 7692 coordinate list (COO) format. `indptr` is a pointer to an array of `GrB_Index` of size number of stored
 7693 elements, where each element contains the corresponding element's column index. `indices` will be a
 7694 pointer to an array of `GrB_Index` of size number of stored elements, where each element contains
 7695 the corresponding element's row index. `values` will be a pointer to an array of size number of stored
 7696 elements (each the size of the scalar stored in the matrix) containing the corresponding value.
 7697 Elements are not required to be sorted in any order.

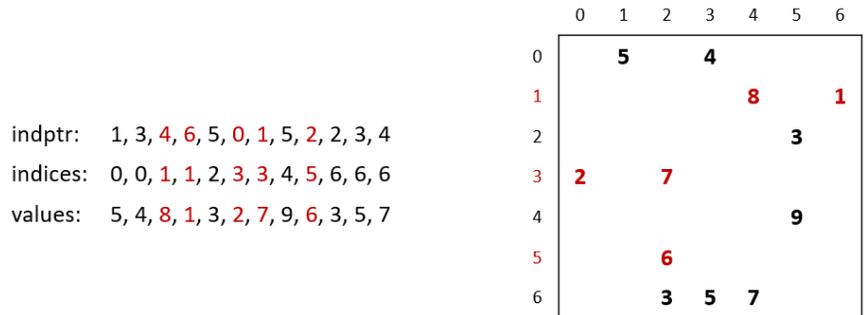


Figure B.3: Data layout for COO format.

7698 **Appendix C**

7699 **Examples**

C.1 Example: Level breadth-first search (BFS) in GraphBLAS

```

1 #include <stdlib.h>
2 #include <stdio.h>
3 #include <stdint.h>
4 #include <stdbool.h>
5 #include "GraphBLAS.h"
6
7 /*
8  * Given a boolean  $n \times n$  adjacency matrix  $A$  and a source vertex  $s$ , performs a BFS traversal
9  * of the graph and sets  $v[i]$  to the level in which vertex  $i$  is visited ( $v[s] == 1$ ).
10 * If  $i$  is not reachable from  $s$ , then  $v[i] = 0$ . (Vector  $v$  should be empty on input.)
11 */
12 GrB_Info BFS(GrB_Vector *v, GrB_Matrix A, GrB_Index s)
13 {
14     GrB_Index n;
15     GrB_Matrix_nrows(&n,A);           //  $n = \#$  of rows of  $A$ 
16
17     GrB_Vector_new(v,GrB_INT32,n);    // Vector<int32_t>  $v(n)$ 
18
19     GrB_Vector q;                    // vertices visited in each level
20     GrB_Vector_new(&q,GrB_BOOL,n);    // Vector<bool>  $q(n)$ 
21     GrB_Vector_setElement(q,(bool)true,s); //  $q[s] = \text{true}$ , false everywhere else
22
23     /*
24      * BFS traversal and label the vertices.
25      */
26     int32_t d = 0;                   //  $d =$  level in BFS traversal
27     bool succ = false;               //  $\text{succ} == \text{true}$  when some successor found
28     do {
29         ++d;                          // next level (start with 1)
30         GrB_assign(*v,q,GrB_NULL,d,GrB_ALL,n,GrB_NULL); //  $v[q] = d$ 
31         GrB_vxm(q,*v,GrB_NULL,GrB_LOR_LAND_SEMIRING_BOOL,
32             q,A,GrB_DESC_RC);         //  $q[!v] = q \parallel A$ ; finds all the
33                                     // unvisited successors from current  $q$ 
34         GrB_reduce(&succ,GrB_NULL,GrB_LOR_MONOID_BOOL,
35             q,GrB_NULL);              //  $\text{succ} = \parallel(q)$ 
36     } while (succ);                  // if there is no successor in  $q$ , we are done.
37
38     GrB_free(&q);                    //  $q$  vector no longer needed
39
40     return GrB_SUCCESS;
41 }

```

C.2 Example: Level BFS in GraphBLAS using apply

```

1 #include <stdlib.h>
2 #include <stdio.h>
3 #include <stdint.h>
4 #include <stdbool.h>
5 #include "GraphBLAS.h"
6
7 /*
8  * Given a boolean  $n \times n$  adjacency matrix  $A$  and a source vertex  $s$ , performs a BFS traversal
9  * of the graph and sets  $v[i]$  to the level in which vertex  $i$  is visited ( $v[s] == 1$ ).
10 * If  $i$  is not reachable from  $s$ , then  $v[i]$  does not have a stored element.
11 * Vector  $v$  should be uninitialized on input.
12 */
13 GrB_Info BFS(GrB_Vector *v, const GrB_Matrix A, GrB_Index s)
14 {
15     GrB_Index n;
16     GrB_Matrix_nrows(&n,A);           //  $n = \#$  of rows of  $A$ 
17
18     GrB_Vector_new(v,GrB_INT32,n);    // Vector<int32_t>  $v(n) = 0$ 
19
20     GrB_Vector q;                    // vertices visited in each level
21     GrB_Vector_new(&q,GrB_BOOL,n);    // Vector<bool>  $q(n) = false$ 
22     GrB_Vector_setElement(q,(bool)true,s); //  $q[s] = true$ , false everywhere else
23
24     /*
25      * BFS traversal and label the vertices.
26      */
27     int32_t level = 0;                // level = depth in BFS traversal
28     GrB_Index nvals;
29     do {
30         ++level;                      // next level (start with 1)
31         GrB_apply(*v,GrB_NULL,GrB_PLUS_INT32,
32                 GrB_SECOND_INT32,q,level,GrB_NULL); //  $v[q] = level$ 
33         GrB_vxm(q,*v,GrB_NULL,GrB_LOR_LAND_SEMIRING_BOOL,
34                q,A,GrB_DESC_RC);      //  $q[!v] = q \ || \ \&\& \ A$ ; finds all the
35                                     // unvisited successors from current  $q$ 
36         GrB_Vector_nvals(&nvals, q);
37     } while (nvals);                  // if there is no successor in  $q$ , we are done.
38
39     GrB_free(&q);                      //  $q$  vector no longer needed
40
41     return GrB_SUCCESS;
42 }

```

C.3 Example: Parent BFS in GraphBLAS

```
1 #include <stdlib.h>
2 #include <stdio.h>
3 #include <stdint.h>
4 #include <stdbool.h>
5 #include "GraphBLAS.h"
6
7 /*
8  * Given a binary  $n \times n$  adjacency matrix  $A$  and a source vertex  $s$ , performs a BFS
9  * traversal of the graph and sets  $parents[i]$  to the index of vertex  $i$ 's parent.
10 * The parent of the root vertex,  $s$ , will be set to itself ( $parents[s] = s$ ). If
11 * vertex  $i$  is not reachable from  $s$ ,  $parents[i]$  will not contain a stored value.
12 */
13 GrB_Info BFS(GrB_Vector *parents, const GrB_Matrix A, GrB_Index s)
14 {
15     GrB_Index N;
16     GrB_Matrix_nrows(&N, A);           //  $N = \#$  vertices
17
18     GrB_Vector_new(parents, GrB_UINT64, N);
19     GrB_Vector_setElement(*parents, s, s); //  $parents[s] = s$ 
20
21     GrB_Vector wavefront;
22     GrB_Vector_new(&wavefront, GrB_UINT64, N);
23     GrB_Vector_setElement(wavefront, 1UL, s); //  $wavefront[s] = 1$ 
24
25     /*
26      * BFS traversal and label the vertices.
27      */
28     GrB_Index nvals;
29     GrB_Vector_nvals(&nvals, wavefront);
30
31     while (nvals > 0)
32     {
33         // convert all stored values in wavefront to their 0-based index
34         GrB_apply(new(&wavefront), GrB_NULL, GrB_NULL, GrB_ROWINDEX_INT64,
35                 wavefront, 0UL, GrB_NULL);
36
37         // "FIRST" because left-multiplying wavefront rows. Masking out the parent
38         // list ensures wavefront values do not overwrite parents already stored.
39         GrB_vxm(wavefront, *parents, GrB_NULL, GrB_MIN_FIRST_SEMIRING_UINT64,
40                wavefront, A, GrB_DESC_RSC);
41
42         // Don't need to mask here since we did it in vxm. Merges new parents in
43         // current wavefront with existing parents:  $parents += wavefront$ 
44         GrB_apply(*parents, GrB_NULL, GrB_PLUS_UINT64,
45                 GrB_IDENTITY_UINT64, wavefront, GrB_NULL);
46
47         GrB_Vector_nvals(&nvals, wavefront);
48     }
49
50     GrB_free(&wavefront);
51
52     return GrB_SUCCESS;
53 }
```

C.4 Example: Betweenness centrality (BC) in GraphBLAS

```

1 #include <stdlib.h>
2 #include <stdio.h>
3 #include <stdint.h>
4 #include <stdbool.h>
5 #include "GraphBLAS.h"
6
7 /*
8  * Given a boolean  $n \times n$  adjacency matrix  $A$  and a source vertex  $s$ ,
9  * compute the BC-metric vector  $\delta$ , which should be empty on input.
10 */
11 GrB_Info BC(GrB_Vector *delta, GrB_Matrix A, GrB_Index s)
12 {
13     GrB_Index n;
14     GrB_Matrix_nrows(&n,A);           //  $n = \#$  of vertices in graph
15
16     GrB_Vector_new(delta,GrB_FP32,n); // Vector<float>  $\delta(n)$ 
17
18     GrB_Matrix sigma;                 // Matrix<int32_t>  $\sigma(n,n)$ 
19     GrB_Matrix_new(&sigma,GrB_INT32,n,n); //  $\sigma[d,k] = \#$  shortest paths to node  $k$  at level  $d$ 
20
21     GrB_Vector q;
22     GrB_Vector_new(&q,GrB_INT32,n);   // Vector<int32_t>  $q(n)$  of path counts
23     GrB_Vector_setElement(q,1,s);     //  $q[s] = 1$ 
24
25     GrB_Vector p;                     // Vector<int32_t>  $p(n)$  shortest path counts so far
26     GrB_Vector_dup(&p,q);             //  $p = q$ 
27
28     GrB_vxm(q,p,GrB_NULL,GrB_PLUS_TIMES_SEMIRING_INT32,
29             q,A,GrB_DESC_RC);        // get the first set of out neighbors
30
31     /*
32     * BFS phase
33     */
34     GrB_Index d = 0;                   // BFS level number
35     int32_t sum = 0;                   //  $\text{sum} == 0$  when BFS phase is complete
36
37     do {
38         GrB_assign(sigma,GrB_NULL,GrB_NULL,q,d,GrB_ALL,n,GrB_NULL); //  $\sigma[d,:] = q$ 
39         GrB_eWiseAdd(p,GrB_NULL,GrB_NULL,GrB_PLUS_INT32,p,q,GrB_NULL); // accum path counts on this level
40         GrB_vxm(q,p,GrB_NULL,GrB_PLUS_TIMES_SEMIRING_INT32,
41                q,A,GrB_DESC_RC);     //  $q = \#$  paths to nodes reachable
42                                     // from current level
43         GrB_reduce(&sum,GrB_NULL,GrB_PLUS_MONOID_INT32,q,GrB_NULL); // sum path counts at this level
44         ++d;
45     } while (sum);
46
47     /*
48     * BC computation phase
49     *  $(t1,t2,t3,t4)$  are temporary vectors
50     */
51     GrB_Vector t1; GrB_Vector_new(&t1,GrB_FP32,n);
52     GrB_Vector t2; GrB_Vector_new(&t2,GrB_FP32,n);
53     GrB_Vector t3; GrB_Vector_new(&t3,GrB_FP32,n);
54     GrB_Vector t4; GrB_Vector_new(&t4,GrB_FP32,n);
55
56     for(int i=d-1; i>0; i--)
57     {
58         GrB_assign(t1,GrB_NULL,GrB_NULL,1.0f,GrB_ALL,n,GrB_NULL); //  $t1 = 1 + \delta$ 
59         GrB_eWiseAdd(t1,GrB_NULL,GrB_NULL,GrB_PLUS_FP32,t1,*delta,GrB_NULL);
60         GrB_extract(t2,GrB_NULL,GrB_NULL,sigma,GrB_ALL,n,i,GrB_DESC_T0); //  $t2 = \sigma[i,:]$ 
61         GrB_eWiseMult(t2,GrB_NULL,GrB_NULL,GrB_DIV_FP32,t1,t2,GrB_NULL); //  $t2 = (1 + \delta) / \sigma[i,:]$ 
62         GrB_mxv(t3,GrB_NULL,GrB_NULL,GrB_PLUS_TIMES_SEMIRING_FP32,

```

```

63     A, t2, GrB_NULL);
64     GrB_extract(t4, GrB_NULL, GrB_NULL, sigma, GrB_ALL, n, i-1, GrB_DESC_T0); // t4 = sigma[i-1,:]
65     GrB_eWiseMult(t4, GrB_NULL, GrB_NULL, GrB_TIMES_FP32, t4, t3, GrB_NULL); // t4 = sigma[i-1,:]*t3
66     GrB_eWiseAdd(*delta, GrB_NULL, GrB_NULL, GrB_PLUS_FP32, *delta, t4, GrB_NULL); // accumulate into delta
67 }
68
69 GrB_free(&sigma);
70 GrB_free(&q); GrB_free(&p);
71 GrB_free(&t1); GrB_free(&t2); GrB_free(&t3); GrB_free(&t4);
72
73 return GrB_SUCCESS;
74 }

```

C.5 Example: Batched BC in GraphBLAS

```

1 #include <stdlib.h>
2 #include "GraphBLAS.h" // in addition to other required C headers
3
4 // Compute partial BC metric for a subset of source vertices, s, in graph A
5 GrB_Info BC_update(GrB_Vector *delta, GrB_Matrix A, GrB_Index *s, GrB_Index nsver)
6 {
7     GrB_Index n;
8     GrB_Matrix_nrows(&n, A); // n = # of vertices in graph
9     GrB_Vector_new(delta, GrB_FP32, n); // Vector<float> delta(n)
10
11 // index and value arrays needed to build numsp
12 GrB_Index *i_nsver = (GrB_Index*) malloc(sizeof(GrB_Index)*nsver);
13 int32_t *ones = (int32_t*) malloc(sizeof(int32_t)*nsver);
14 for(int i=0; i<nsver; ++i) {
15     i_nsver[i] = i;
16     ones[i] = 1;
17 }
18
19 // numsp: structure holds the number of shortest paths for each node and starting vertex
20 // discovered so far. Initialized to source vertices: numsp[s[i],i]=1, i=[0,nsver)
21 GrB_Matrix numsp;
22 GrB_Matrix_new(&numsp, GrB_INT32, n, nsver);
23 GrB_Matrix_build(numsp, s, i_nsver, ones, nsver, GrB_PLUS_INT32);
24 free(i_nsver); free(ones);
25
26 // frontier: Holds the current frontier where values are path counts.
27 // Initialized to out vertices of each source node in s.
28 GrB_Matrix frontier;
29 GrB_Matrix_new(&frontier, GrB_INT32, n, nsver);
30 GrB_extract(frontier, numsp, GrB_NULL, A, GrB_ALL, n, s, nsver, GrB_DESC_RCT0);
31
32 // sigma: stores frontier information for each level of BFS phase. The memory
33 // for an entry in sigmas is only allocated within the do-while loop if needed.
34 // n is an upper bound on diameter.
35 GrB_Matrix *sigmas = (GrB_Matrix*) malloc(sizeof(GrB_Matrix)*n);
36
37 int32_t d = 0; // BFS level number
38 GrB_Index nvals = 0; // nvals == 0 when BFS phase is complete
39
40 // ----- The BFS phase (forward sweep) -----
41 do {
42     // sigmas[d](:,s) = dth level frontier from source vertex s
43     GrB_Matrix_new(&(sigmas[d]), GrB_BOOL, n, nsver);
44
45     GrB_apply(sigmas[d], GrB_NULL, GrB_NULL,
46              GrB_IDENTITY_BOOL, frontier, GrB_NULL); // sigmas[d](:,:) = (Boolean) frontier
47     GrB_eWiseAdd(numsp, GrB_NULL, GrB_NULL, GrB_PLUS_INT32,
48                numsp, frontier, GrB_NULL); // numsp += frontier (accum path counts)
49     GrB_mxM(frontier, numsp, GrB_NULL, GrB_PLUS_TIMES_SEMIRING_INT32,
50             A, frontier, GrB_DESC_RCT0); // f<!numsp> = A' +.* f (update frontier)
51     GrB_Matrix_nvals(&nvals, frontier); // number of nodes in frontier at this level
52     d++;
53 } while (nvals);
54
55 // nspinv: the inverse of the number of shortest paths for each node and starting vertex.
56 GrB_Matrix nspinv;
57 GrB_Matrix_new(&nspinv, GrB_FP32, n, nsver);
58 GrB_apply(nspinv, GrB_NULL, GrB_NULL,
59          GrB_MINV_FP32, numsp, GrB_NULL); // nspinv = 1./numsp
60
61 // bcu: BC updates for each vertex for each starting vertex in s
62 GrB_Matrix bcu;

```

```

63 GrB_Matrix_new(&bcu, GrB_FP32, n, nsver);
64 GrB_assign(bcu, GrB_NULL, GrB_NULL,
65           1.0f, GrB_ALL, n, GrB_ALL, nsver, GrB_NULL); // filled with 1 to avoid sparsity issues
66
67 GrB_Matrix w; // temporary workspace matrix
68 GrB_Matrix_new(&w, GrB_FP32, n, nsver);
69
70 // ----- Tally phase (backward sweep) -----
71 for (int i=d-1; i>0; i--) {
72     GrB_eWiseMult(w, sigmas[i], GrB_NULL,
73                 GrB_TIMES_FP32, bcu, nspinv, GrB_DESC_R); // w<sigmas[i]>=(1 ./ nsp).*bcu
74
75     // add contributions by successors and mask with that BFS level's frontier
76     GrB_mxm(w, sigmas[i-1], GrB_NULL, GrB_PLUS_TIMES_SEMIRING_FP32,
77            A, w, GrB_DESC_R); // w<sigmas[i-1]> = (A +.* w)
78     GrB_eWiseMult(bcu, GrB_NULL, GrB_PLUS_FP32, GrB_TIMES_FP32,
79                 w, numsp, GrB_NULL); // bcu += w .* numsp
80 }
81
82 // row reduce bcu and subtract "nsver" from every entry to account
83 // for 1 extra value per bcu row element.
84 GrB_reduce(*delta, GrB_NULL, GrB_NULL, GrB_PLUS_FP32, bcu, GrB_NULL);
85 GrB_apply(*delta, GrB_NULL, GrB_NULL, GrB_MINUS_FP32, *delta, (float)nsver, GrB_NULL);
86
87 // Release resources
88 for (int i=0; i<d; i++) {
89     GrB_free(&(sigmas[i]));
90 }
91 free(sigmas);
92
93 GrB_free(&frontier); GrB_free(&numsp);
94 GrB_free(&nspinv); GrB_free(&bcu); GrB_free(&w);
95
96 return GrB_SUCCESS;
97 }

```

C.6 Example: Maximal independent set (MIS) in GraphBLAS

```

1 #include <stdlib.h>
2 #include <stdio.h>
3 #include <stdint.h>
4 #include <stdbool.h>
5 #include "GraphBLAS.h"
6
7 // Assign a random number to each element scaled by the inverse of the node's degree.
8 // This will increase the probability that low degree nodes are selected and larger
9 // sets are selected.
10 void setRandom(void *out, const void *in)
11 {
12     uint32_t degree = *(uint32_t*)in;
13     *(float*)out = (0.0001f + random()/(1. + 2.*degree)); // add 1 to prevent divide by zero
14 }
15
16 /*
17 * A variant of Luby's randomized algorithm [Luby 1985].
18 *
19 * Given a numeric n x n adjacency matrix A of an unweighted and undirected graph (where
20 * the value true represents an edge), compute a maximal set of independent vertices and
21 * return it in a boolean n-vector, 'iset' where set[i] == true implies vertex i is a member
22 * of the set (the iset vector should be uninitialized on input.)
23 */
24 GrB_Info MIS(GrB_Vector *iset, const GrB_Matrix A)
25 {
26     GrB_Index n;
27     GrB_Matrix_nrows(&n,A); // n = # of rows of A
28
29     GrB_Vector prob; // holds random probabilities for each node
30     GrB_Vector neighbor_max; // holds value of max neighbor probability
31     GrB_Vector new_members; // holds set of new members to iset
32     GrB_Vector new_neighbors; // holds set of new neighbors to new iset mbrs.
33     GrB_Vector candidates; // candidate members to iset
34
35     GrB_Vector_new(&prob,GrB_FP32,n);
36     GrB_Vector_new(&neighbor_max,GrB_FP32,n);
37     GrB_Vector_new(&new_members,GrB_BOOL,n);
38     GrB_Vector_new(&new_neighbors,GrB_BOOL,n);
39     GrB_Vector_new(&candidates,GrB_BOOL,n);
40     GrB_Vector_new(iset,GrB_BOOL,n); // Initialize independent set vector, bool
41
42     GrB_UnaryOp set_random;
43     GrB_UnaryOp_new(&set_random,setRandom,GrB_FP32,GrB_UINT32);
44
45     // compute the degree of each vertex.
46     GrB_Vector degrees;
47     GrB_Vector_new(&degrees,GrB_FP64,n);
48     GrB_reduce(degrees,GrB_NULL,GrB_NULL,GrB_PLUS_FP64,A,GrB_NULL);
49
50     // Isolated vertices are not candidates: candidates[degrees != 0] = true
51     GrB_assign(candidates,degrees,GrB_NULL,true,GrB_ALL,n,GrB_NULL);
52
53     // add all singletons to iset: iset[degree == 0] = 1
54     GrB_assign(*iset,degrees,GrB_NULL,true,GrB_ALL,n,GrB_DESC_RC);
55
56     // Iterate while there are candidates to check.
57     GrB_Index nvals;
58     GrB_Vector_nvals(&nvals,candidates);
59     while (nvals > 0) {
60         // compute a random probability scaled by inverse of degree
61         GrB_apply(prob,candidates,GrB_NULL,set_random,degrees,GrB_DESC_R);
62

```

```

63 // compute the max probability of all neighbors
64 GrB_m xv(neighbor_max , candidates , GrB_NULL, GrB_MAX_SECOND_SEMIRING_FP32, A, prob , GrB_DESC_R);
65
66 // select vertex if its probability is larger than all its active neighbors ,
67 // and apply a "masked no-op" to remove stored falses
68 GrB_eWiseAdd( new_members , GrB_NULL, GrB_NULL, GrB_GT_FP64, prob , neighbor_max , GrB_NULL);
69 GrB_apply( new_members , new_members , GrB_NULL, GrB_IDENTITY_BOOL, new_members , GrB_DESC_R);
70
71 // add new members to independent set .
72 GrB_eWiseAdd( *iset , GrB_NULL, GrB_NULL, GrB_LOR, *iset , new_members , GrB_NULL);
73
74 // remove new members from set of candidates  $c = c \& \text{!new}$ 
75 GrB_eWiseMult( candidates , new_members , GrB_NULL,
76               GrB_LAND, candidates , candidates , GrB_DESC_RC);
77
78 GrB_Vector_nvals(&nvals , candidates);
79 if ( nvals == 0) { break; } // early exit condition
80
81 // Neighbors of new members can also be removed from candidates
82 GrB_m xv( new_neighbors , candidates , GrB_NULL, GrB_LOR_LAND_SEMIRING_BOOL,
83          A, new_members , GrB_NULL);
84 GrB_eWiseMult( candidates , new_neighbors , GrB_NULL, GrB_LAND,
85               candidates , candidates , GrB_DESC_RC);
86
87 GrB_Vector_nvals(&nvals , candidates);
88 }
89
90 GrB_free(&neighbor_max); // free all objects "new'ed"
91 GrB_free(&new_members);
92 GrB_free(&new_neighbors);
93 GrB_free(&prob);
94 GrB_free(&candidates);
95 GrB_free(&set_random);
96 GrB_free(&degrees);
97
98 return GrB_SUCCESS;
99 }

```

C.7 Example: Counting triangles in GraphBLAS

```
1 #include <stdlib.h>
2 #include <stdio.h>
3 #include <stdint.h>
4 #include <stdbool.h>
5 #include "GraphBLAS.h"
6
7 /*
8  * Given an  $n \times n$  boolean adjacency matrix,  $A$ , of an undirected graph, computes
9  * the number of triangles in the graph.
10 */
11 uint64_t triangle_count(GrB_Matrix A)
12 {
13     GrB_Index n;
14     GrB_Matrix_nrows(&n, A);           //  $n = \#$  of vertices
15
16     //  $L: N \times N$ , lower-triangular, bool
17     GrB_Matrix L;
18     GrB_Matrix_new(&L, GrB_BOOL, n, n);
19     GrB_select(L, GrB_NULL, GrB_NULL, GrB_TRIL, A, 0UL, GrB_NULL);
20
21     GrB_Matrix C;
22     GrB_Matrix_new(&C, GrB_UINT64, n, n);
23
24     GrB_mxm(C, L, GrB_NULL, GrB_PLUS_TIMES_SEMIRING_UINT64, L, L, GrB_NULL); //  $\langle C \rangle = L + * L$ 
25
26     uint64_t count;
27     GrB_reduce(&count, GrB_NULL, GrB_PLUS_MONOID_UINT64, C, GrB_NULL); // 1-norm of  $C$ 
28
29     GrB_free(&C);
30     GrB_free(&L);
31
32     return count;
33 }
```