

1 Galant Programmer Documentation

Animation programmers can write algorithms in notation that resembles textbook pseudocode in files that have a `.alg` extension. The animation examples have used procedural syntax for function calls, as in, for example, `setWeight(v,0)`. Java (object oriented) syntax can also be used: `v.setWeight(0)`. A key advantage of Galant is that a seasoned Java programmer can not only use the Java syntax but can also augment Galant algorithms with arbitrary Java classes defined externally, using `import` statements. All Galant code is effectively Java, either natively, or via macro preprocessing.

The text panel provides a crude editor for algorithms (as well as GraphML descriptions of graphs); its limited capabilities make it useful primarily for fine tuning and error correction. The first author uses emacs in Java mode to edit algorithms offline, for example, not a major inconvenience – it is easy to reload algorithms when they are modified without exiting Galant. The Galant editor is also useful in that it provides syntax highlighting of Galant functions and macros.

The source code for an algorithm begins with any number (including none) of global variable declarations and function definitions. This is followed by the code for the algorithm itself, starting with the keyword `algorithm`. A *code block* is a sequence of statements, each terminated by a semicolon, just as in Java. The main algorithm has the form

```
algorithm {
    code block
}
```

Declarations of global variables are also like those of Java:

```
type variable_name;
```

or

```
type [] variable_name;
```

to declare an array of the given type. All variables must be initialized either within a function definition or in the algorithm. The Java incantation

```
type variable_name = new type[ size ]
```

is used to initialize an array with *size* elements initialized to `null` or `0`. Arrays use 0-based indexing: the largest index is *size* – 1. Detailed information about function declarations is in Section 1.2.1 below.

Central to the Galant API is the `graph` object: currently all other parts of the API refer to it. The components of a graph are declared to be of type `Node` or `Edge` and can be accessed/modified via a variety of functions/methods. When an observer or explorer interacts with the animation they move either forward or backward one step at a time. All aspects of the graph API therefore refer to the current *state of the graph*, the set of states behaving as a stack. API calls that change the state of a node or an edge automatically generate a next step, but the programmer can override this using a `beginStep()` and `endStep()` pair. For example, the beginning of our implementation of Dijkstra's algorithm looks like

```
beginStep();
for_nodes(node) {
    setWeight(node, INFINITY);
    nodePQ.add(node);
}
endStep();
```

Without the `beginStep/endStep` override, this initialization would require the observer to click through multiple steps (one for each node) before getting to the interesting part of the animation.

Functions and macros for the graph as a whole are shown in Table 1, while Table 2 lists some algorithm functions not related to any aspect of a graph.

The nodes and edges, of type `Node` and `Edge`, respectively, are subtypes/extensions of `GraphElement`.

| | |
|---|--|
| List(Node) getNodes() NodeList getNodes() | returns a list of the nodes of the graph; type NodeList is built into Galant and essentially equivalent to the Java List(Node) ; see Table 6 |
| List(Edge) edges() EdgeList edges() | returns a list of edges of the graph; return type EdgeList is analogous to NodeList |
| for_nodes(v) { <i>code block</i> } | equivalent to <code>for (Node v : nodes()) { <i>code block</i> }</code> ; the statements are executed for each node v |
| for_edges(e) { <i>code block</i> } | analogous to for_nodes |
| Integer numberOfNodes() | returns the number of nodes |
| Integer numberOfEdges() | returns the number of edges |
| int id(Node v), int id(Edge e) | returns the unique identifier of v or e |
| int nodeIds(), int edgeIds() | returns the largest node/edge identifier plus one; useful when an array is to be indexed using node/edge identifiers, since these are not necessarily contiguous |
| source(Edge e), target(Edge e) | returns the source/target of edge e , sometimes called the (arrow) tail/head or source/destination |
| Integer degree(Node v) Integer indegree(Node v) Integer outdegree(Node v) | the number of edges incident on v , total, incoming and outgoing; if the graph is undirected, the outdegree is the same as the degree |
| EdgeList edges(Node v) EdgeList inEdges(Node v) EdgeList outEdges(Node v) | returns a list of v 's incident, incoming or outgoing edges, respectively; outgoing edges are the same as incident edges if the graph is undirected |
| Node otherEnd(Edge e, Node v) Node otherEnd(Node v, Edge e) | returns the node opposite v on edge e ; if v is the source otherEnd returns the target and vice-versa |
| NodeList neighbors(Node v) | returns a list of nodes adjacent to v |
| for_adjacent(v, e, w) { <i>code block</i> } for_incoming(v, e, w) { <i>code block</i> } for_outgoing(v, e, w) { <i>code block</i> } | for_adjacent executes the code block for each edge e incident on v , where w is otherEnd(e,v) ; v must already be declared but e and w are declared by the macro; the other two are analogous for incoming and outgoing edges |
| getStartNode() | returns the first node in the list of nodes, typically the one with smallest id; used by algorithms that require a start node |
| isDirected() | returns true if the graph is directed |
| setDirected(boolean directed) | makes the graph directed or undirected depending on whether directed is true or false, respectively |
| Node addNode() Node addNode(Integer x, Integer y) | returns a new node and adds it to the list of nodes; the id is the smallest integer not currently in use as an id; attributes such as weight, label and position are absent and must be set explicitly by appropriate method calls; the second version puts the node at position (x,y), where x and y are pixel coordinates. |
| addEdge(Node source, Node target) addEdge(int sourceId, int targetId) | adds an edge from the source to the target (source and target are interchangeable when graph is undirected); the second variation specifies id's of the nodes to be connected; as in the case of adding a node, the edge is added to the list of edges and its weight and label are absent |
| deleteNode(Node v) | removes node v and its incident edges from the graph |
| deleteEdge(Edge e) | removes edge e from the graph |

Table 1: Functions and macros that apply to the structure of a graph.

| | |
|---|---|
| <code>print(String s)</code> | prints <code>s</code> on the console; useful for debugging |
| <code>display(String s)</code> | writes the string <code>s</code> at the top of the window |
| <code>String getMessage()</code> | returns the message currently displayed on the message banner |
| <code>error(String s)</code> | prints <code>s</code> on the console with a stack trace; also displays <code>s</code> in popup window with an option to view the stack trace; the algorithm terminates and the user can choose whether to terminate Galant entirely or continue interacting |
| <code>beginStep(), endStep()</code> | any actions between a <code>beginStep()</code> and an <code>endStep()</code> take place atomically, i.e., all in a single “step forward” action by the user |
| <code>Node getNode(String message)</code> | pops up a window with the given message and prompts the user to enter the identifier of a node, which is returned; if no node with that id exists, an error popup is displayed and the user is prompted again |
| <code>Edge getEdge(String message)</code> | pops up a window with the given message and prompts the user to enter the identifiers of two nodes, the endpoints of an edge, which is returned; if either id has no corresponding node or the two nodes are not connect by an edge (in the right direction if the graph is directed), an error popup is displayed and the user is prompted again |
| <code>Node getNode(String p, NodeSet s, String e)</code> <code>Edge getEdge(String p, EdgeSet s, String e)</code> | variations of <code>getNode</code> and <code>getEdge</code> ; here <code>p</code> is the prompt, <code>s</code> is the set from which the node or edge must be chosen and <code>e</code> an error message if the node/edge does not belong to the specified set; useful when wanting to specify an adjacent node or an outgoing edge |
| <code>String getString(String message)</code> <code>Integer getInteger(String message)</code> <code>Double getReal(String message)</code> | analogous to <code>getNode</code> and <code>getEdge</code> ; allow algorithm to engage in dialog with the user |
| <code>Integer integer(String s)</code> <code>Double real(String s)</code> | performs conversion from a string to an integer/double; useful when parsing labels that represent numbers |
| <code>windowWidth(), windowHeight()</code> | current width and height of the window, in case the algorithm wants to rescale the graph |

Table 2: Utility functions.

Arbitrary attributes can be assigned to each graph element. In the GraphML file these show up as, for example,

```
<node attribute_1="value_1" ... attribute_k="value_k" />
```

Each node and edge has a unique integer id. The id's are assigned consecutively as nodes/edges are created; they may not be altered. The id of a node or edge can be accessed via the `id()` function. Often, as is the case with the depth-first search algorithm, it makes sense to use arrays indexed by node or edge id's. Since graphs may be generated externally and/or have undergone deletions of nodes or edges, the id's are not always contiguous. The functions `nodeIds()` and `edgeIds()` return the size of an array large enough to accommodate the appropriate id's as indexes. So code such as

```
Integer myArray[] = new Integer[nodeIds()];
for_nodes(v) { myArray[id(v)] = 1; }
}
```

is immune to array out of bounds errors.

1.1 Node and edge methods

Nodes and edges have 'getters' and 'setters' for a variety of attributes, i.e.,

```
seta(<a's type> x)
```

and

<a's type> geta(), where *a* is the name of an attribute such as `Color`, `Label` or `Weight`. A more convenient way to access these standard attributes omits the prefix `get` and uses procedural syntax: `color(x)` is a synonym for `x.getColor()`, for example. Procedural syntax for the setters is also available: `setColor(x,c)` is a synonym for `x.setColor(c)`. In the special cases of color and label it is possible to omit the `set` (since it reads naturally): `color(x,c)` instead of `setColor(x,c)`.

1.1.1 Logical attributes: functions and macros

Nodes. From a node's point of view we would like information about the adjacent nodes and incident edges. The relevant *methods* require the use of Java generics, but macros are provided to simplify graph API access. The macros, which have equivalents in GDR, are:

- `for_adjacent(x, e, y){ code block }` executes the statements in the code block for each edge incident on *x*. The statements can refer to *x*, or *e*, the current incident edge, or *y*, the other endpoint of *e*. The macro assumes that *x* has already been declared as `Node` but *e* and *y* are declared automatically.
- `for_outgoing(Node x, Edge e, Node y){ code block }` behaves like `for_adjacent` except that, when the graph is directed, it iterates only over the edges whose source is *x* (it still iterates over all the edges when the graph is undirected).
- `for_incoming(Node x, Edge e, Node y){ code block }` behaves like `for_adjacent` except that, when the graph is directed, it iterates only over the edges whose sink is *x* (it still iterates over all the edges when the graph is undirected).

The actual API methods hiding behind these macros are (these are Node methods):

- `List<Edge> getIncidentEdges()` returns a list of all edges incident to this node, both incoming and outgoing.
- `List<Edge> getOutgoingEdges()` returns a list of edges directed away from this node (all incident edges if the graph is undirected).
- `List<Edge> getIncomingEdges()` returns a list of edges directed toward this node (all incident edges if the graph is undirected).
- `Node travel(Edge e)` returns the other endpoint of *e*.

The above all use Java syntax, as in `v.travel(e)`. The following are node-related functions with procedural syntax.

- `degree(v)`, `indegree(v)` and `outdegree(v)` return the appropriate integers.

- `otherEnd(v, e)`, where `v` is a node and `e` is an edge returns node `w` such that `e` connects `v` and `w`; the programmer can also say `otherEnd(e, v)` in case she forgets the order of the arguments.
- `neighbors(v)` returns a list of the nodes adjacent to node `v`.

Edges. The logical attributes of an edge are its source and target (destination).

- `setSourceNode(Node)` and `Node getSourceNode()`
- `setTargetNode(Node)` and `Node getTargetNode()`
- `getOtherEndPoint(Node u)` returns `v` where this edge is either `uv` or `vu`.

Graph Elements. Nodes and edges both have a mechanism for setting (and getting) arbitrary attributes of type `Integer`, `String`, and `Double`. the relevant methods are

`setIntegerAttribute(String key, Integer value)`

to associate an integer value with a node and

`Integer getIntegerAttribute(String key)`

to retrieve it. `String` and `Double` attributes work the same way as integer attributes. These are useful when an algorithm requires arbitrary information to be associated with nodes and/or edges. The user-defined attributes may differ from one node or edge to the next. For example, some nodes may have a `depth` attribute while others do not.

1.1.2 Geometric attributes

Currently, the only geometric attributes are the positions of the nodes. Unlike GDR, the edges in Galant are all straight lines and the positions of their labels are fixed. The relevant methods for nodes – using procedural syntax – are `int getX(Node)`, `int getY(Node)` and `Point getPosition(Node)` for the ‘getters’. To set a position, one should use

`setPosition(Node, Point)`

or

`setPosition(Node, int, int)`.

Once a node has an established position, it is possible to change only one coordinate using `setX(Node, int)` or `setY(Node, int)`. Object-oriented variants of all of these, e.g., `v.setX(100)`, are also available.

Ordinarily the user can move nodes during algorithm execution and the resulting positions persist after execution terminates. For some algorithms, such as sorting, the algorithm itself needs to move nodes. It is desirable then to keep the user from moving nodes. The declaration `movesNodes()` at the beginning of an algorithm accomplishes this.

1.1.3 Display attributes

Each node and edge has both a (double) weight and a label. The weight is also a logical attribute in that it is used implicitly as a key for sorting and priority queues. The label is simply text and may be interpreted however the programmer chooses. The conversion functions `integer(String)` and `real(String)` – see Table 2 – provide a convenient mechanism for treating labels as objects of class `Integer` or `Double`, respectively. The argument of `setLabel` and its relatives – see below – is not the expected `String` but `Object`; any type of object that has a Java `toString` method will work – numbers have to be of type `Integer` or `Double` rather than `int` or `double` since the latter are not objects in Java.¹ So conversion between string labels and numbers works both ways.

Aside from the setters and getters: `setWeight(double)`, `Double getWeight()`, `setLabel(Object)` and `String getLabel()`, the programmer can also manipulate and test for the absence of weights/labels using `clearWeight()` and `boolean hasWeight()`, and the corresponding methods for labels. The procedural variants in this case are `setWeight(Node, double)`, `Double weight(Node)`,² `label(Node, Object)`,³

¹ Galant functions return objects, `Integer` or `Double`, when return values are numbers for this reason.

² The *get* is omitted here for more natural syntax.

³ A natural syntax that resembles English. However, `setLabel(Node, Object)` is also allowed.

| | |
|---------|-------------|
| RED | = "#ff0000" |
| BLUE | = "#00ff00" |
| GREEN | = "#0000ff" |
| YELLOW | = "#ffff00" |
| MAGENTA | = "#ff00ff" |
| CYAN | = "#00ffff" |
| TEAL | = "#009999" |
| VIOLET | = "#9900cc" |
| ORANGE | = "#ff8000" |
| GRAY | = "#808080" |
| BLACK | = "#000000" |
| WHITE | = "#ffffff" |

Table 3: Predefined color constants.

and `String label(Node)`

Nodes can either be plain, highlighted (selected), marked (visited) or both highlighted and marked. Being highlighted alters the the boundary (color and thickness) of a node (as controlled by the implementation), while being marked affects the fill color. Edges can be plain or selected, with thickness and color modified in the latter case.

The relevant methods are (here `Element` refers to either a `Node` or an `Edge`):

- `highlight(Element)`, `unhighlight(Element)` and `Boolean isHighlighted(Element)`
- correspondingly, `setSelected(true)`, `setSelected(false)`, and `boolean isSelected()`
- `mark(Node)`, `unmark(Node)` and `Boolean isMarked(Node)`, equivalently `Boolean marked(Node)`.

Although the specific colors for displaying the outlines of nodes or the lines representing edges are predetermined for plain and highlighted nodes/edges, the animation implementation can modify these colors, thus allowing for many different kinds of highlighting. The `getColor` and `setColor` methods and their procedural variants have `String` arguments in the RGB format `#RRGGBB`; for example, the string `#0000ff` is blue. The predefined color constants are listed in Table 3.

Of the attributes listed above, weight, label, color and position can be accessed and modified by the user as well as the program. In all cases, modifications by execution of the animation are ephemeral – the graph returns to its original state after execution. The user can save the mid-execution state of the graph: select the **Export** option on the file menu of the *graph* window.

A summary of functions relevant to node and edge attributes (their procedural versions) is given in Table 4.

1.1.4 Global access for individual node/edge attributes and graph attributes

It is sometimes useful to access or manipulate attributes of nodes and edges globally. For example, an algorithm might want to hide node weights entirely because they are not relevant or hide them initially and reveal them for individual nodes as the algorithm progresses. These functionalities can be accomplished by `hideNodeWeights` or `hideAllNodeWeights`, respectively. A summary of these capabilities is given in Table 5.

1.2 Additional programmer information

A Galant algorithm/program is executed as a method within a Java class. In order to shield the Galant programmer from Java idiosyncrasies, some features have been added.

| | |
|--|--|
| <code>id(<i>element</i>)</code> | returns the unique identifier of the node or edge |
| <code>source(Edge e), target(Edge e)</code> | returns the source/target of edge <i>e</i> , sometimes called the (arrow) tail/head or source/destination |
| <code>mark(Node v), unmark(Node v)</code> | shades the interior of a node or undoes that |
| <code>Boolean marked(Node v)</code> | returns <code>true</code> if the node is marked |
| <code>highlight(<i>element</i>), unhighlight(<i>element</i>)</code> | makes the node or edge highlighted, i.e., thickens the border or line and makes it red / undoes the highlighting |
| <code>Boolean highlighted(<i>element</i>)</code> | returns <code>true</code> if the node or edge is highlighted |
| <code>select(<i>element</i>), deselect(<i>element</i>)</code> <code>selected(<i>element</i>)</code> | synonyms for <code>highlight</code> , <code>unhighlight</code> and <code>highlighted</code> |
| <code>Double weight(<i>element</i>)</code> <code>setWeight(<i>element</i>, double weight)</code> | get/set the weight of the element |
| <code>showWeight(<i>element</i>), hideWeight(<i>element</i>)</code> <code>Boolean weightIsVisible(<i>element</i>)</code> <code>Boolean weightIsHidden(<i>element</i>)</code> | make the weight of the element visible/invisible, query their visibility; weights of the element type have to be globally visible – see Table 5 – for <code>showWeight</code> to have an effect |
| <code>String label(<i>element</i>)</code> <code>label(<i>element</i>, Object obj)</code> | get/set the label of the element, the <code>Object</code> argument allows an object of any other type to be converted to a (<code>String</code>) label, as long as there is a <code>toString</code> method, which is true of all major classes (you have to be careful, for example, to use <code>Integer</code> instead of <code>int</code>) |
| <code>showLabel(<i>element</i>), hideLabel(<i>element</i>)</code> <code>Boolean labelIsVisible(<i>element</i>)</code> <code>Boolean labelIsHidden(<i>element</i>)</code> | analogous to the corresponding weight functions |
| <code>hide(<i>element</i>), show(<i>element</i>)</code> <code>Boolean hidden(<i>element</i>)</code> <code>Boolean visible(<i>element</i>)</code> | makes nodes/edges disappear/reappear and tests whether they are visible or hidden; useful when an algorithm (logically) deletes objects, but they need to be revealed again upon completion |
| <code>String color(<i>element</i>)</code> <code>color(<i>element</i>, String c)</code> <code>uncolor(<i>element</i>)</code> | get/set/remove the color of the border of a node or line representing an edge; colors are encoded as strings of the form “#RRBBGG”, the RR, BB and GG being hexadecimal numbers representing the red, blue and green components of the color, respectively; see Table 3 for a list of predefined colors; when an element has no color, the line is thinner and black |
| <code>boolean set(<i>element</i>, String key, <type> value)</code> | sets an arbitrary attribute, <code>key</code> , of the element to have a value of a given type, where the type is one of <code>Integer</code> , <code>Double</code> , <code>Boolean</code> or <code>String</code> ; in the special case of <code>Boolean</code> the third argument may be omitted and defaults to <code>true</code> ; so <code>set(v, “attr”)</code> is equivalent to <code>set(v, “attr”, true)</code> ; returns <code>true</code> if the element already has a value for the given attribute, <code>false</code> otherwise |
| <code>boolean clear(<i>element</i>, String key)</code> | removes the attribute <code>key</code> from the element; if the <code>key</code> refers to a <code>Boolean</code> attribute, this is logically equivalent to making it <code>false</code> |
| <code><type> get<type>(<i>element</i>, String key)</code> <code>Boolean is(<i>element</i>, String key)</code> | returns the value associated with <code>key</code> or <code>null</code> if the graph has no value of the given type for <code>key</code> , i.e., if no <code>set(String key, <type> value)</code> has occurred; in the special case of a <code>Boolean</code> attribute, the second formulation may be used; the object-oriented syntax, such as <code>e.is(“inTree”)</code> , sometimes reads more naturally |

Table 4: Functions that query and manipulate attributes of individual nodes and edges. Here, *element* refers to either a `Node` or an `Edge`, both the type and the formal parameter.

| | |
|--|---|
| Boolean nodeLabelsAreVisible() Boolean edgeLabelsAreVisible() Boolean nodeWeightsAreVisible() Boolean edgeWeightsAreVisible() | returns true if node/edge labels/weights are <i>globally</i> visible, the default state, which can be altered by <code>hideNodeLabels()</code> , etc., defined below |
| hideNodeLabels(), hideEdgeLabels() hideNodeWeights(), hideEdgeWeights() | hides all node/edge labels/weights; typically used at the beginning of an algorithm to hide unnecessary information; labels and weights are shown by default |
| showNodeLabels(), showEdgeLabels() showNodeWeights(), showEdgeWeights() | undoes the hiding of labels/weights |
| hideAllNodeLabels() hideAllEdgeLabels() hideAllNodeWeights() hideAllEdgeWeights() | hides all node/edge labels/weights even if they are visible globally by default or by <code>showNodeLabels()</code> , etc., or for individual nodes and edges; in order for the label or weight of a node/edge to be displayed, labels/weights must be visible globally and its label/weight must be visible; initially, all labels/weights are visible, both globally and for individual nodes/edges; these functions are used to hide information so that it can be revealed subsequently, one node or edge at a time |
| showAllNodeLabels() showAllEdgeLabels() showAllNodeWeights() showAllEdgeWeights() | makes all individual node/edge weights/labels visible if they are globally visible by default or via <code>showNodeLabels()</code> , etc.; this undoes the effect of <code>hideAllNodeLabels()</code> , etc., and of any individual hiding of labels/weights |
| clearNodeLabels(), clearEdgeLabels() clearNodeWeights(), clearEdgeWeights() | gets rid of all node/edge labels/weights; this not only makes them invisible, but also erases whatever values they have |
| showNodes(), showEdges() | undo any hiding of nodes/edges that has taken place during the algorithm |
| clearNodeMarks() clearNodeHighlighting() clearEdgeHighlighting() | unmarks all nodes, unhighlights all nodes/edges, respectively |
| clearNodeLabels() clearNodeWeights() clearEdgeLabels() clearEdgeWeights() | erases labels/weights of all nodes/edges; useful if an algorithm needs to start with a clean slate with respect to any of these attributes |
| clearAllNode(String attribute) clearAllEdge(String attribute) | erases values of the given attribute from all nodes/edges, a generalization of <code>clearNodeLabels</code> , etc. |
| boolean set(String attribute, <i><type></i> value) | sets an arbitrary attribute of the graph to have a value of a given type, where the type is one of <code>Integer</code> , <code>Double</code> , <code>Boolean</code> or <code>String</code> ; in the special case of <code>Boolean</code> the second argument may be omitted and defaults to <code>true</code> ; so <code>set("attr")</code> is equivalent to <code>set("attr",true)</code> ; returns true if the graph already has a value for the given attribute, false otherwise |
| <i><type></i> get <i><type></i> (String attribute) Boolean is(String attribute) | returns the value associated with <code>attribute</code> or <code>null</code> if the graph has no value of the given type for <code>attribute</code> , i.e., if no <code>set(String attribute, <type> value)</code> has occurred; in the special case of a <code>Boolean</code> attribute, the second formulation may be used |
| clearAllNode(String attribute) clearAllEdge(String attribute) | erases the value of the given attribute for all nodes/edges |

Table 5: Functions that query and manipulate graph node and edge attributes globally, i.e., for all nodes or edges at once. Also included are functions that deal with graph attributes.

1.2.1 Definition of Functions/Methods

A programmer can define arbitrary functions (methods) using the construct

```
function [return_type] name ( parameters ) {
    code block
}
```

The behavior is like that of a Java method. So, for example,

```
function int plus( int a, int b ) {
    return a + b;
}
```

is equivalent to

```
static int plus( int a, int b ) {
    return a + b;
}
```

The *return_type* is optional. If it is missing, the function behaves like a `void` method in Java. An example is the recursive

```
function visit( Node v ) { code }
```

The conversion of functions into Java methods when Galant code is compiled is complex and may result in indecipherable error messages.

1.2.2 Data Structures

Galant provides some standard data structures for nodes and edges automatically. These are described in detail in Table 6. Data structures use object-oriented syntax. For example, to add a node `v` to a `NodeList` `L`, the appropriate syntax is `L.add(v)`. Most data structure operations are as efficient as one might expect. A notable exception is `decreaseKey` for priority queues. The operation `pq.decreaseKey(v,k)` does `pq.remove(v)` followed by `pq.add(v)`. The new key is implicit – it is the weight of the element. In practice, assuming `pq` is a `NodePriorityQueue`, `v` is a `Node` and `k` is a `Double`, the sequence would be

```
setWeight(v, k);
pq.decreaseKey(v,k);
```

which would translate to

```
setWeight(v, k);
pq.remove(v);
pq.add(v)
```

As pointed out above, the weight of a node or edge is used for priority in a priority queue or for sorting. The programmer can change this default by redefining the Java `compareTo()` method, but this requires finesse and Java expertise.

NodeList and EdgeList: lists of nodes or edges, respectively. We use *list* as shorthand for either **NodeList** *L* or **EdgeList** *L*, *type* for either **Node** or **Edge** and *element* for **Node** *v* or **Edge** *e*.

| | |
|--------------------------------------|--|
| <i>type</i> <code>first(list)</code> | returns the first element of this list |
| <code>add(element, list)</code> | adds the element to the end of the list; along with <code>first</code> we get the effect of a queue |
| <code>remove(element, list)</code> | removes the first occurrence of the element from the list |
| <code>sort(list)</code> | use the weights of the nodes/edges to sort the list <i>L</i> ; sort is actually a macro that invokes Java <code>Collections.sort(L)</code> ; this means that <i>L</i> can be any collection (list, stack, queue, set) of comparable elements |

NodeQueue and EdgeQueue: queues of nodes or edges, respectively. Same conventions as for lists.

| | |
|------------------------------------|--|
| <code>void enqueue(element)</code> | adds the element to the rear of the queue |
| <i>type</i> <code>dequeue()</code> | returns and removes the element at the front of the queue; returns <code>null</code> if the queue is empty |
| <i>type</i> <code>remove()</code> | returns and removes the element at the front of the queue; throws an exception if the queue is empty |
| <i>type</i> <code>element()</code> | returns the element at the front of the queue without removing it; throws an exception if the queue is empty |
| <i>type</i> <code>peek()</code> | returns the element at the front of the queue without removing it; returns <code>null</code> if the queue is empty |
| <code>size()</code> | returns the number of elements in the queue |
| <code>isEmpty()</code> | returns <code>true</code> if the queue is empty |

NodeStack and EdgeStack: stacks of nodes or edges, respectively.

| | |
|--|--|
| <code>void push(element)</code> | adds the element to the top of the stack |
| <i>type</i> <code>pop()</code> | returns and removes the element at the top of the stack; throws an exception if the stack is empty |
| <i>type</i> <code>peek()</code> | returns the element at the top of the stack without removing it; returns <code>null</code> if the stack is empty |
| <code>size()</code> , <code>isEmpty()</code> | analogous to the corresponding queue methods |

NodePriorityQueue and EdgePriorityQueue: priority queues of nodes or edges, respectively.

| | |
|--|---|
| <code>void add(element)</code> | adds the element to the priority queue; the priority is defined to be its weight – see Section 1.1.3 |
| <i>type</i> <code>removeMin()</code> | returns and removes the element with minimum weight; returns <code>null</code> if the queue is empty |
| <code>boolean remove(element)</code> | removes the element; returns <code>true</code> if it is present, <code>false</code> otherwise |
| <code>void decreaseKey(element, double key)</code> | changes the weight of the element to the new key and reorganizes the priority queue appropriately; since this is accomplished by removing and reinserting the object, i.e., inefficiently, this method can also be used to increase the key |
| <code>size()</code> , <code>isEmpty()</code> | analogous to the corresponding queue methods |

NodeSet and EdgeSet: sets of nodes or edges, respectively.

| | |
|--|--|
| <code>boolean add(element)</code> | adds the element to the set; returns <code>true</code> if the element was a new addition, <code>false</code> otherwise |
| <code>boolean remove(element)</code> | removes the element returns <code>true</code> if the element was present, <code>false</code> otherwise |
| <code>boolean contains(element)</code> | returns <code>true</code> if the element is in the set |
| <code>size()</code> , <code>isEmpty()</code> | analogous to the corresponding methods for other data structures |

Table 6: Built-in data structures and their methods. These methods use object-oriented syntax: $\langle structure \rangle . \langle method \rangle (\langle arguments \rangle)$ and are created using, e.g., `NodeQueue Q = new NodeQueue();` the new operator in Java.