

NAME

Graph

SYNOPSIS

use Graph;

use Graph qw(:all);

DESCRIPTION

Graph class provides the following methods:

new, AddCycle, AddEdge, AddEdges, AddPath, AddVertex, AddVertices, ClearCycles, Copy, CopyEdgesProperties, CopyVerticesAndEdges, CopyVerticesProperties, DeleteCycle, DeleteEdge, DeleteEdgeProperties, DeleteEdgeProperty, DeleteEdges, DeleteEdgesProperties, DeleteEdgesProperty, DeleteGraphProperties, DeleteGraphProperty, DeletePath, DeleteVertex, DeleteVertexProperties, DeleteVertexProperty, DeleteVertices, DeleteVerticesProperty, DetectCycles, GetAdjacencyMatrix, GetAdmittanceMatrix, GetAllPaths, GetAllPathsStartingAt, GetAllPathsStartingAtWithLength, GetAllPathsStartingAtWithLengthUpto, GetAllPathsWithLength, GetAllPathsWithLengthUpto, GetCircumference, GetConnectedComponentsVertices, GetCycles, GetCyclesWithEvenSize, GetCyclesWithOddSize, GetCyclesWithSize, GetCyclesWithSizeGreaterThan, GetCyclesWithSizeLessThan, GetDegree, GetDegreeMatrix, GetDistanceMatrix, GetEdgeCycles, GetEdgeCyclesWithEvenSize, GetEdgeCyclesWithOddSize, GetEdgeCyclesWithSize, GetEdgeCyclesWithSizeGreaterThan, GetEdgeCyclesWithSizeLessThan, GetEdgeProperties, GetEdgeProperty, GetEdges, GetEdgesProperty, GetFusedAndNonFusedCycles, GetGirth, GetGraphProperties, GetGraphProperty, GetIncidenceMatrix, GetIsolatedVertices, GetKirchhoffMatrix, GetLaplacianMatrix, GetLargestCycle, GetLargestEdgeCycle, GetLargestVertexCycle, GetLeafVertices, GetMaximumDegree, GetMinimumDegree, GetNeighborhoodVertices, GetNeighborhoodVerticesWithRadiusUpto, GetNeighborhoodVerticesWithSuccessors, GetNeighborhoodVerticesWithSuccessorsAndRadiusUpto, GetNeighbors, GetNormalizedLaplacianMatrix, GetNumOfCycles, GetNumOfCyclesWithEvenSize, GetNumOfCyclesWithOddSize, GetNumOfCyclesWithSize, GetNumOfCyclesWithSizeGreaterThan, GetNumOfCyclesWithSizeLessThan, GetNumOfEdgeCycles, GetNumOfEdgeCyclesWithEvenSize, GetNumOfEdgeCyclesWithOddSize, GetNumOfEdgeCyclesWithSize, GetNumOfEdgeCyclesWithSizeGreaterThan, GetNumOfEdgeCyclesWithSizeLessThan, GetNumOfVertexCycles, GetNumOfVertexCyclesWithEvenSize, GetNumOfVertexCyclesWithOddSize, GetNumOfVertexCyclesWithSize, GetNumOfVertexCyclesWithSizeGreaterThan, GetNumOfVertexCyclesWithSizeLessThan, GetPaths, GetPathsBetween, GetPathsStartingAt, GetPathsStartingAtWithLength, GetPathsStartingAtWithLengthUpto, GetPathsWithLength, GetPathsWithLengthUpto, GetSiedelAdjacencyMatrix, GetSizeOfLargestCycle, GetSizeOfLargestEdgeCycle, GetSizeOfLargestVertexCycle, GetSizeOfSmallestCycle, GetSizeOfSmallestEdgeCycle, GetSizeOfSmallestVertexCycle, GetSmallestCycle, GetSmallestEdgeCycle, GetSmallestVertexCycle, GetTopologicallySortedVertices, GetVertex, GetVertexCycles, GetVertexCyclesWithEvenSize, GetVertexCyclesWithOddSize, GetVertexCyclesWithSize, GetVertexCyclesWithSizeGreaterThan, GetVertexCyclesWithSizeLessThan, GetVertexProperties, GetVertexProperty, GetVertexWithLargestDegree, GetVertexWithSmallestDegree, GetVertices, GetVerticesProperty, GetVerticesWithDegreeLessThan, HasCycle, HasEdge, HasEdgeProperty, HasEdges, HasFusedCycles, HasGraphProperty, HasPath, HasVertex, HasVertexProperty, HasVertices, IsAcyclic, IsAcyclicEdge, IsAcyclicVertex, IsCyclic, IsCyclicEdge, IsCyclicVertex, IsGraph, IsIsolatedVertex, IsLeafVertex, IsUnicyclic, IsUnicyclicEdge, IsUnicyclicVertex, SetActiveCyclicPaths, SetEdgeProperties, SetEdgeProperty, SetEdgesProperty, SetGraphProperties, SetGraphProperty, SetVertexProperties, SetVertexProperty, SetVerticesProperty, StringifyEdgesProperties, StringifyGraph, StringifyGraphProperties, StringifyProperties, StringifyVerticesAndEdges, StringifyVerticesProperties, UpdateEdgeProperty, UpdateVertexProperty

METHODS

new

```
$NewGraph = new Graph([@VertexIDs]);
```

Using specified *Graph VertexIDs*, new method creates a new Graph object and returns newly created Graph object.

Examples:

```
$Graph = new Graph();
$Graph = new Graph(@VertexIDs);
```

AddCycle

```
$Graph->AddCycle(@VertexIDs);
```

Adds edges between successive pair of *VertexIDs* including an additional edge from the last to first vertex ID to complete the cycle to *Graph* and returns *Graph*.

AddEdge

```
$Graph->AddEdge($VertexID1, $VertexID2);
```

Adds an edge between *VertexID1* and *VertexID2* in a *Graph* and returns *Graph*.

AddEdges

```
$Graph->AddEdges(@VertexIDs);
```

Adds edges between successive pair of *VertexIDs* in a *Graph* and returns *Graph*.

AddPath

```
$Graph->AddPath(@VertexIDs);
```

Adds edges between successive pair of *VertexIDs* in a *Graph* and returns *Graph*.

AddVertex

```
$Graph->AddVertex($VertexID);
```

Adds *VertexID* to *Graph* and returns *Graph*.

AddVertices

```
$Graph->AddVertices(@VertexIDs);
```

Adds vertices using *VertexIDs* to *Graph* and returns *Graph*.

ClearCycles

```
$Graph->ClearCycles();
```

Delete all cycle properties assigned to graph, vertices, and edges by *DetectCycles* method.

Copy

```
$NewGraph = $Graph->Copy();
```

Copies *Graph* and its associated data using *Storable::dclone* and returns a new *Graph* object.

CopyEdgesProperties

```
$OtherGraph = $Graph->CopyEdgesProperties($OtherGraph);
```

Copies all properties associated with edges from *Graph* to *\$OtherGraph* and returns *OtherGraph*.

CopyVerticesAndEdges

```
$OtherGraph = $Graph->CopyVerticesAndEdges($OtherGraph);
```

Copies all vertices and edges from *Graph* to *\$OtherGraph* and returns *OtherGraph*.

CopyVerticesProperties

```
$OtherGraph = $Graph->CopyVerticesProperties($OtherGraph);
```

Copies all properties associated with vertices from *Graph* to *\$OtherGraph* and returns *OtherGraph*.

DeleteCycle

```
$Graph->DeleteCycle(@VertexIDs);
```

Deletes edges between successive pair of *VertexIDs* including an additional edge from the last to first vertex ID to complete the cycle to *Graph* and returns *Graph*.

DeleteEdge

```
$Graph->DeleteEdge($VertexID1, $VertexID2);
```

Deletes an edge between *VertexID1* and *VertexID2* in a *Graph* and returns *Graph*.

DeleteEdgeProperties

```
$Graph->DeleteEdgeProperties($VertexID1, $VertexID2);
```

Deletes all properties associated with edge between *VertexID1* and *VertexID2* in a *Graph* and returns *Graph*.

DeleteEdgeProperty

```
$Graph->DeleteEdgeProperty($PropertyName, $VertexID1, $VertexID2);
```

Deletes *PropertyName* associated with edge between *VertexID1* and *VertexID2* in a *Graph* and returns *Graph*.

DeleteEdges

```
$Graph->DeleteEdges(@VertexIDs);
```

Deletes edges between successive pair of *VertexIDs* and returns *Graph*.

DeleteEdgesProperties

```
$Graph->DeleteEdgesProperties(@VertexIDs);
```

Deletes all properties associated with edges between successive pair of *VertexIDs* and returns *Graph*.

DeleteEdgesProperty

```
$Graph->DeleteEdgesProperty($PropertyName, @VertexIDs);
```

Deletes *PropertyName* associated with edges between successive pair of *VertexIDs* and returns *Graph*.

DeleteGraphProperties

```
$Graph->DeleteGraphProperties();
```

Deletes all properties associated as graph not including properties associated to vertices or edges and returns *Graph*.

DeleteGraphProperty

```
$Graph->DeleteGraphProperty($PropertyName);
```

Deletes a *PropertyName* associated as graph property and returns *Graph*.

DeletePath

```
$Graph->DeletePath(@VertexIDs);
```

Deletes edges between successive pair of *VertexIDs* in a *Graph* and returns *Graph*.

DeleteVertex

```
$Graph->DeleteVertex($VertexID);
```

Deletes *VertexID* to *Graph* and returns *Graph*.

DeleteVertexProperties

```
$Graph->DeleteVertexProperties($VertexID);
```

Deletes all properties associated with *VertexID* and returns *Graph*.

DeleteVertexProperty

```
$Graph->DeleteVertexProperty($PropertyName, $VertexID);
```

Deletes a *PropertyName* associated with *VertexID* and returns *Graph*.

DeleteVertices

```
$Graph->DeleteVertices(@VertexIDs);
```

Deletes vertices specified in *VertexIDs* and returns *Graph*.

DeleteVerticesProperty

```
$Graph->DeleteVerticesProperty($PropertyName, @VertexIDs);
```

Deletes a *PropertyName* associated with *VertexIDs* and returns *Graph*.

DetectCycles

```
$Graph->DetectCycles();
```

Detect cycles using CyclesDetection class and associate found cycles to *Graph* object as graph

properties: *ActiveCyclicPaths*, *AllCyclicPaths*, *IndependentCyclicPaths*.

Notes:

- . CyclesDetection class detects all cycles in the graph and filters them to find independent cycles.
- . All cycles related methods in the graph operate on *ActiveCyclicPaths*. By default, active cyclic paths correspond to *IndependentCyclicPaths*. This behavior can be changed using *SetActiveCyclicPaths* method.

GetAdjacencyMatrix

```
$GraphMatrix = $Graph->GetAdjacencyMatrix();
```

Returns adjacency matrix for *Graph* as a *GraphMatrix* object with row and column indices corresponding to graph vertices returned by *GetVertices* method.

For a simple graph G with n vertices, the adjacency matrix for G is a n x n square matrix and its elements M_{ij} are:

- . 0 if $i = j$
- . 1 if $i \neq j$ and vertex V_i is adjacent to vertex V_j
- . 0 if $i \neq j$ and vertex V_i is not adjacent to vertex V_j

GetAdmittanceMatrix

```
$GraphMatrix = $Graph->GetAdmittanceMatrix();
```

Returns admittance matrix for *Graph* as a *GraphMatrix* object with row and column indices corresponding to graph vertices returned by *GetVertices* method.

For a simple graph G with n vertices, the adjacency matrix for G is a n x n square matrix and its elements M_{ij} are:

- . 0 if $i = j$
- . 1 if $i \neq j$ and vertex V_i is adjacent to vertex V_j
- . 0 if $i \neq j$ and vertex V_i is not adjacent to vertex V_j

GetAllPaths

```
$PathsRef = $Graph->GetAllPaths([$AllowCycles]);
```

Returns a reference to an array containing *Path* objects corresponding to all possible lengths starting from each vertex in graph with sharing of edges in paths traversed. By default, cycles are included in paths. A path containing a cycle is terminated at a vertex completing the cycle. Duplicate paths are not removed.

GetAllPathsStartingAt

```
@Paths = $Graph->GetAllPathsStartingAt($StartVertexID,
    [$AllowCycles]);
```

Returns an array of *Path* objects starting from a *StartVertexID* of any length with sharing of edges in paths traversed. By default, cycles are included in paths. A path containing a cycle is terminated at a vertex completing the cycle.

GetAllPathsStartingAtWithLength

```
@Paths = $Graph->GetAllPathsStartingAtWithLength($StartVertexID,
    $Length, [$AllowCycles]);
```

Returns an array of *Path* objects starting from a *StartVertexID* of specified *Length* with sharing of edges in paths traversed. By default, cycles are included in paths. A path containing a cycle is terminated at a vertex completing the cycle.

GetAllPathsStartingAtWithLengthUpto

```
@Paths = $Graph->GetAllPathsStartingAtWithLengthUpto($StartVertexID,
    $Length, [$AllowCycles]);
```

Returns an array of *Path* objects starting from a *StartVertexID* with length upto a *Length* with sharing of edges in paths traversed. By default, cycles are included in paths. A path containing a cycle is terminated at a vertex completing the cycle.

GetAllPathsWithLength

```
$PathsRef = $Graph->GetAllPathsWithLength($Length,  
[ $AllowCycles]);
```

Returns a reference to an array containing *Path* objects corresponding to paths with *Length* starting from each vertex in graph with sharing of edges in paths traversed. By default, cycles are included in paths. A path containing a cycle is terminated at a vertex completing the cycle. Duplicate paths are not removed.

GetAllPathsWithLengthUpto

```
$PathsRef = $Graph->GetAllPathsWithLengthUpto($Length,  
[ $AllowCycles]);
```

Returns a reference to an array containing *Path* objects corresponding to paths up to specified *Length* starting from each vertex in graph with sharing of edges in paths traversed. By default, cycles are included in paths. A path containing a cycle is terminated at a vertex completing the cycle. Duplicate paths are not removed.

GetCircumference

```
$Circumference = $Graph->GetCircumference();
```

Returns size of largest cycle in a *Graph*

GetConnectedComponentsVertices

```
@ConnectedComponents = $Graph->GetConnectedComponentsVertices();
```

Returns an array *ConnectedComponents* containing references to arrays with vertex IDs for each component sorted in order of their decreasing size.

GetCycles

```
@CyclicPaths = $Graph->GetCycles();
```

Returns an array *CyclicPaths* containing *Path* objects corresponding to cycles in a *Graph*.

GetCyclesWithEvenSize

```
@CyclicPaths = $Graph->GetCyclesWithEvenSize();
```

Returns an array *CyclicPaths* containing *Path* objects corresponding to cycles with even size in a *Graph*.

GetCyclesWithOddSize

```
@CyclicPaths = $Graph->GetCyclesWithOddSize();
```

Returns an array *CyclicPaths* containing *Path* objects corresponding to cycles with odd size in a *Graph*.

GetCyclesWithSize

```
@CyclicPaths = $Graph->GetCyclesWithSize($CycleSize);
```

Returns an array *CyclicPaths* containing *Path* objects corresponding to cycles with *CycleSize* in a *Graph*.

GetCyclesWithSizeGreaterThan

```
@CyclicPaths = $Graph->GetCyclesWithSizeGreaterThan($CycleSize);
```

Returns an array *CyclicPaths* containing *Path* objects corresponding to cycles with size greater than *CycleSize* in a *Graph*.

GetCyclesWithSizeLessThan

```
@CyclicPaths = $Graph->GetCyclesWithSizeLessThan($CycleSize);
```

Returns an array *CyclicPaths* containing *Path* objects corresponding to cycles with size less than *CycleSize* in a *Graph*.

GetDegree

```
$Degree = $Graph->GetDegree($VertexID);
```

Returns Degree for *VertexID* in a *Graph* corresponding to sum of in and out vertex degree values.

GetDegreeMatrix

```
$GraphMatrix = $Graph->GetDegreeMatrix();
```

Returns degree matrix for *Graph* as a *GraphMatrix* object with row and column indices corresponding to graph vertices returned by GetVertices method.

For a simple graph G with n vertices, the degree matrix for G is a n x n square matrix and its elements M_{ij} are:

```
. deg(Vi)    if i == j and deg(Vi) is the degree of vertex Vi
. 0          otherwise
```

GetDistanceMatrix

```
$GraphMatrix = $Graph->GetDistanceMatrix();
```

Returns distance matrix for *Graph* as a *GraphMatrix* object with row and column indices corresponding to graph vertices returned by GetVertices method.

For a simple graph G with n vertices, the distance matrix for G is a n x n square matrix and its elements M_{ij} are:

```
. 0          if i == j
. d          if i != j and d is the shortest distance between vertex Vi and vertex Vj
```

In the final matrix, value of constant BigNumber defined in Constants.pm module corresponds to vertices with no edges.

GetEdgeCycles

```
@CyclicPaths = $Graph->GetEdgeCycles($VertexID1, $VertexID2);
```

Returns an array *CyclicPaths* containing *Path* objects corresponding to all cycles containing edge between *VertexID1* and *VertexID2* in a *Graph*.

GetEdgeCyclesWithEvenSize

```
@CyclicPaths = $Graph->GetEdgeCyclesWithEvenSize($VertexID1,
$VertexID2);
```

Returns an array *CyclicPaths* containing *Path* objects corresponding to cycles with even size containing edge between *VertexID1* and *VertexID2* in a *Graph*.

GetEdgeCyclesWithOddSize

```
@CyclicPaths = $Graph->GetEdgeCyclesWithOddSize($VertexID1,
$VertexID2);
```

Returns an array *CyclicPaths* containing *Path* objects corresponding to cycles with odd size containing edge between *VertexID1* and *VertexID2* in a *Graph*.

GetEdgeCyclesWithSize

```
@CyclicPaths = $Graph->GetEdgeCyclesWithSize($VertexID1, $VertexID2,
$CycleSize);
```

Returns an array *CyclicPaths* containing *Path* objects corresponding to cycles with size *CycleSize* containing edge between *VertexID1* and *VertexID2* in a *Graph*.

GetEdgeCyclesWithSizeGreaterThan

```
@CyclicPaths = $Graph->GetEdgeCyclesWithSizeGreaterThan($VertexID1,
$VertexID2, $CycleSize);
```

Returns an array *CyclicPaths* containing *Path* objects corresponding to cycles with size greater than *CycleSize* containing edge between *VertexID1* and *VertexID2* in a *Graph*.

GetEdgeCyclesWithSizeLessThan

```
@CyclicPaths = $Graph->GetEdgeCyclesWithSizeLessThan($VertexID1,
$VertexID2, $CycleSize);
```

Returns an array *CyclicPaths* containing *Path* objects corresponding to cycles with size less than *CycleSize* containing edge between *VertexID1* and *VertexID2*.

GetEdgeProperties

```
%EdgeProperties = $Graph->GetEdgeProperties($VertexID1, $VertexID2);
```

Returns a hash *EdgeProperties* containing all *PropertyName* and *PropertyValue* pairs associated with an edge between *VertexID1* and *VertexID2* in a *Graph*.

GetEdgeProperty

```
$Value = $Graph->GetEdgeProperty($PropertyName, $VertexID1, $VertexID2);
```

Returns value of *PropertyName* associated with an edge between *VertexID1* and *VertexID2* in a *Graph*.

GetEdges

```
@EdgeVertexIDs = $Graph->GetEdges($VertexID);
$NumOfEdges = $Graph->GetEdges($VertexID);
```

Returns an array *EdgeVertexIDs* with successive pair of IDs corresponding to edges involving *VertexID* or number of edges for *VertexID* in a *Graph*.

GetEdgesProperty

```
@PropertyValues = $Graph->GetEdgesProperty($PropertyName, @VertexIDs);
```

Returns an array *PropertyValues* containing property values corresponding to *PropertyName* associated with edges between successive pair of *VertexIDs*.

GetFusedAndNonFusedCycles

```
($FusedCycleSetsRef, $NonFusedCyclesRef) =
    $Graph->GetFusedAndNonFusedCycles();
```

Returns references to arrays *FusedCycleSetsRef* and *NonFusedCyclesRef* containing references to arrays of cyclic *Path* objects corresponding to fuses and non-fused cyclic paths.

GetGirth

```
$Girth = $Graph->GetGirth();
```

Returns size of smallest cycle in a *Graph*.

GetGraphProperties

```
%GraphProperties = $Graph->GetGraphProperties();
```

Returns a hash *EdgeProperties* containing all *PropertyName* and *PropertyValue* pairs associated with graph in a *Graph*.

GetGraphProperty

```
$PropertyValue = $Graph->GetGraphProperty($PropertyName);
```

Returns value of *PropertyName* associated with graph in a *Graph*.

GetIncidenceMatrix

```
$GraphMatrix = $Graph->GetIncidenceMatrix();
```

Returns incidence matrix for *Graph* as a *GraphMatrix* object with row and column indices corresponding to graph vertices returned by *GetVertices* method.

For a simple graph *G* with *n* vertices and *e* edges, the incidence matrix for *G* is a *n x e* matrix its elements *M_{ij}* are:

```
. 1    if vertex Vi and the edge Ej are incident; in other words, Vi and Ej are
related
. 0    otherwise
```

GetIsolatedVertices

```
@VertexIDs = $Graph->GetIsolatedVertices();
```

Returns an array *VertexIDs* containing vertices without any edges in *Graph*.

GetKirchhoffMatrix

```
$GraphMatrix = $Graph->GetKirchhoffMatrix();
```

Returns Kirchhoff matrix for *Graph* as a *GraphMatrix* object with row and column indices corresponding to graph vertices returned by GetVertices method.

KirchhoffMatrix is another name for LaplacianMatrix.

GetLaplacianMatrix

```
$GraphMatrix = $Graph->GetLaplacianMatrix();
```

Returns Laplacian matrix for *Graph* as a *GraphMatrix* object with row and column indices corresponding to graph vertices returned by GetVertices method.

For a simple graph G with n vertices, the Laplacian matrix for G is a n x n square matrix and its elements M_{ij} are:

```
. deg(Vi)    if i == j and deg(Vi) is the degree of vertex Vi
. -1         if i != j and vertex Vi is adjacent to vertex Vj
. 0          otherwise
```

GetLargestCycle

```
$CyclicPath = $Graph->GetLargestCycle();
```

Returns a cyclic *Path* object corresponding to largest cycle in a *Graph*.

GetLargestEdgeCycle

```
$CyclicPath = $Graph->GetLargestEdgeCycle($VertexID1, $VertexID2);
```

Returns a cyclic *Path* object corresponding to largest cycle containing edge between *VertexID1* and *VertexID2* in a *Graph*.

GetLargestVertexCycle

```
$CyclicPath = $Graph->GetLargestVertexCycle($VertexID);
```

Returns a cyclic *Path* object corresponding to largest cycle containing *VertexID* in a *Graph*.

GetLeafVertices

```
@VertexIDs = $Graph->GetLeafVertices();
```

Returns an array *VertexIDs* containing vertices with degree of 1 in a *Graph*.

GetMaximumDegree

```
$Degree = $Graph->GetMaximumDegree();
```

Returns value of maximum vertex degree in a *Graph*.

GetMinimumDegree

```
$Degree = $Graph->GetMinimumDegree();
```

Returns value of minimum vertex degree in a *Graph*.

GetNeighborhoodVertices

```
@VertexNeighborhoods = GetNeighborhoodVertices($StartVertexID);
```

Returns an array *VertexNeighborhoods* containing references to arrays corresponding to neighborhood vertices around a specified *StartVertexID* at all possible radii levels.

GetNeighborhoodVerticesWithRadiusUpto

```
@VertexNeighborhoods = GetNeighborhoodVerticesWithRadiusUpto(
    $StartVertexID, $Radius);
```

Returns an array *VertexNeighborhoods* containing references to arrays corresponding to neighborhood vertices around a specified *StartVertexID* upto specified *Radius* levels.

GetNeighborhoodVerticesWithSuccessors

```
@VertexNeighborhoods = GetNeighborhoodVerticesWithSuccessors(
    $StartVertexID);
```

Returns vertex neighborhoods around a specified *StartVertexID*, along with their successor connected vertices, collected at all neighborhood radii as an array *VertexNeighborhoods* containing references to

arrays with first value corresponding to vertex ID and second value as reference to an array containing its successor connected vertices.

For a neighborhood vertex at each radius level, the successor connected vertices correspond to the neighborhood vertices at the next radius level. Consequently, the neighborhood vertices at the last radius level don't contain any successor vertices which fall outside the range of specified radius.

GetNeighborhoodVerticesWithSuccessorsAndRadiusUpto

```
@VertexNeighborhoods = GetNeighborhoodVerticesWithSuccessors(
    $StartVertexID, $Radius);
```

Returns vertex neighborhoods around a specified *StartVertexID*, along with their successor connected vertices, collected with in a specified *Radius* as an array *VertexNeighborhoods* containing references to arrays with first value corresponding to vertex ID and second value as reference to a list containing its successor connected vertices.

For a neighborhood vertex at each radius level, the successor connected vertices correspond to the neighborhood vertices at the next radius level. Consequently, the neighborhood vertices at the last radius level don't contain any successor vertices which fall outside the range of specified radius.

GetNeighbors

```
@VertexIDs = $Graph->GetNeighbors($VertexID);
$NumOfNeighbors = $Graph->GetNeighbors($VertexID);
```

Returns an array *VertexIDs* containing vertices connected to *VertexID* of number of neighbors of a *VertexID* in a *Graph*.

GetNormalizedLaplacianMatrix

```
$GraphMatrix = $Graph->GetNormalizedLaplacianMatrix();
```

Returns normalized Laplacian matrix for *Graph* as a *GraphMatrix* object with row and column indices corresponding to graph vertices returned by *GetVertices* method.

For a simple graph *G* with *n* vertices, the normalized Laplacian matrix *L* for *G* is a *n* x *n* square matrix and its elements *L_{ij}* are:

```
. 1          if i == j and deg(Vi) != 0
. -1/SQRT(deg(Vi) * deg(Vj)) if i != j and vertex Vi is adjacent to vertex Vj
. 0          otherwise
```

GetNumOfCycles

```
$NumOfCycles = $Graph->GetNumOfCycles();
```

Returns number of cycles in a *Graph*.

GetNumOfCyclesWithEvenSize

```
$NumOfCycles = $Graph->GetNumOfCyclesWithEvenSize();
```

Returns number of cycles with even size in a *Graph*.

GetNumOfCyclesWithOddSize

```
$NumOfCycles = $Graph->GetNumOfCyclesWithOddSize();
```

Returns number of cycles with odd size in a *Graph*.

GetNumOfCyclesWithSize

```
$NumOfCycles = $Graph->GetNumOfCyclesWithSize($CycleSize);
```

Returns number of cycles with *CyclesSize* in a *Graph*.

GetNumOfCyclesWithSizeGreaterThan

```
$NumOfCycles = $Graph->GetNumOfCyclesWithSizeGreaterThan(
    $CycleSize);
```

Returns number of cycles with size greater than *CyclesSize* in a *Graph*.

GetNumOfCyclesWithSizeLessThan

```
$NumOfCycles = $Graph->GetNumOfCyclesWithSizeLessThan($CycleSize);
```

Returns number of cycles with size less than *CyclesSize* in a *Graph*.

GetNumOfEdgeCycles

```
$NumOfCycles = $Graph->GetNumOfEdgeCycles($VertexID1, $VertexID2);
```

Returns number of cycles containing edge between *VertexID1* and *VertexID2* in a *Graph*.

GetNumOfEdgeCyclesWithEvenSize

```
$NumOfCycles = $Graph->GetNumOfEdgeCyclesWithEvenSize($VertexID1, $VertexID2);
```

Returns number of cycles containing edge between *VertexID1* and *VertexID2* with even size in a *Graph*.

GetNumOfEdgeCyclesWithOddSize

```
$NumOfCycles = $Graph->GetNumOfEdgeCyclesWithOddSize($VertexID1, $VertexID2);
```

Returns number of cycles containing edge between *VertexID1* and *VertexID2* with odd size in a *Graph*.

GetNumOfEdgeCyclesWithSize

```
$NumOfCycles = $Graph->GetNumOfEdgeCyclesWithSize($VertexID1, $VertexID2, $CycleSize);
```

Returns number of cycles containing edge between *VertexID1* and *VertexID2* with *CycleSize* size in a *Graph*.

GetNumOfEdgeCyclesWithSizeGreaterThan

```
$NumOfCycles = $Graph->GetNumOfEdgeCyclesWithSizeGreaterThan($VertexID1, $VertexID2, $CycleSize);
```

Returns number of cycles containing edge between *VertexID1* and *VertexID2* with size greater than *CycleSize* size in a *Graph*.

GetNumOfEdgeCyclesWithSizeLessThan

```
$NumOfCycles = $Graph->GetNumOfEdgeCyclesWithSizeLessThan($VertexID1, $VertexID2, $CycleSize);
```

Returns number of cycles containing edge between *VertexID1* and *VertexID2* with size less than *CycleSize* size in a *Graph*.

GetNumOfVertexCycles

```
$NumOfCycles = $Graph->GetNumOfVertexCycles($VertexID);
```

Returns number of cycles containing *VertexID* in a *Graph*.

GetNumOfVertexCyclesWithEvenSize

```
$NumOfCycles = $Graph->GetNumOfVertexCyclesWithEvenSize($VertexID);
```

Returns number of cycles containing *VertexID* with even size in a *Graph*.

GetNumOfVertexCyclesWithOddSize

```
$NumOfCycles = $Graph->GetNumOfVertexCyclesWithOddSize($VertexID);
```

Returns number of cycles containing *VertexID* with odd size in a *Graph*.

GetNumOfVertexCyclesWithSize

```
$NumOfCycles = $Graph->GetNumOfVertexCyclesWithSize($VertexID);
```

Returns number of cycles containing *VertexID* with even size in a *Graph*.

GetNumOfVertexCyclesWithSizeGreaterThan

```
$NumOfCycles = $Graph->GetNumOfVertexCyclesWithSizeGreaterThan($VertexID, $CycleSize);
```

Returns number of cycles containing *VertexID* with size greater than *CycleSize* in a *Graph*.

GetNumOfVertexCyclesWithSizeLessThan

```
$NumOfCycles = $Graph->GetNumOfVertexCyclesWithSizeLessThan(
    $VertexID, $CycleSize);
```

Returns number of cycles containing *VertexID* with size less than *CycleSize* in a *Graph*.

GetPaths

```
$PathsRefs = $Graph->GetPaths([$AllowCycles]);
```

Returns a reference to an array of *Path* objects corresponding to paths of all possible lengths starting from each vertex with no sharing of edges in paths traversed. By default, cycles are included in paths. A path containing a cycle is terminated at a vertex completing the cycle.

GetPathsBetween

```
@Paths = $Graph->GetPathsBetween($StartVertexID, $EndVertexID);
```

Returns an arrays of *Path* objects list of paths between *StartVertexID* and *EndVertexID*. For cyclic graphs, the list contains may contain more than one *Path* object.

GetPathsStartingAt

```
@Paths = $Graph->GetPathsStartingAt($StartVertexID, [$AllowCycles]);
```

Returns an array of *Path* objects corresponding to all possible lengths starting from a specified *StartVertexID* with no sharing of edges in paths traversed. By default, cycles are included in paths. A path containing a cycle is terminated at a vertex completing the cycle.

GetPathsStartingAtWithLength

```
@Paths = $Graph->StartingAtWithLength($StartVertexID, $Length,
    $AllowCycles);
```

Returns an array of *Path* objects corresponding to all paths starting from a specified *StartVertexID* with length *Length* and no sharing of edges in paths traversed. By default, cycles are included in paths. A path containing a cycle is terminated at a vertex completing the cycle.

GetPathsStartingAtWithLengthUpto

```
@Paths = $Graph->StartingAtWithLengthUpto($StartVertexID, $Length,
    $AllowCycles);
```

Returns an array of *Path* objects corresponding to all paths starting from a specified *StartVertexID* with length upto *Length* and no sharing of edges in paths traversed. By default, cycles are included in paths. A path containing a cycle is terminated at a vertex completing the cycle.

GetPathsWithLength

```
@Paths = $Graph->GetPathsWithLength($Length, $AllowCycles);
```

Returns an array of *Path* objects corresponding to to paths starting from each vertex in graph with specified <Length> and no sharing of edges in paths traversed. By default, cycles are included in paths. A path containing a cycle is terminated at a vertex completing the cycle.

GetPathsWithLengthUpto

```
@Paths = $Graph->GetPathsWithLengthUpto($Length, $AllowCycles);
```

Returns an array of *Path* objects corresponding to to paths starting from each vertex in graph with length upto specified *Length* and no sharing of edges in paths traversed. By default, cycles are included in paths. A path containing a cycle is terminated at a vertex completing the cycle.

GetSiedelAdjacencyMatrix

```
$GraphMatrix = $Graph->GetSiedelAdjacencyMatrix();
```

Returns Siedel admittance matrix for *Graph* as a *GraphMatrix* object with row and column indices corresponding to graph vertices returned by *GetVertices* method.

For a simple graph G with n vertices, the Siedal adjacency matrix for G is a n x n square matrix and its elements *Mij* are:

```
. 0    if i == j
. -1   if i != j and vertex Vi is adjacent to vertex Vj
. 1    if i != j and vertex Vi is not adjacent to vertex Vj
```

GetSizeOfLargestCycle

```
$Size = $Graph->GetSizeOfLargestCycle();
```

Returns size of the largest cycle in a *Graph*.

GetSizeOfLargestEdgeCycle

```
$Size = $Graph->GetSizeOfLargestEdgeCycle($VertexID1, $VertexID2);
```

Returns size of the largest cycle containing edge between *VertexID1* and *VertexID2* in a *Graph*.

GetSizeOfLargestVertexCycle

```
$Size = $Graph->GetSizeOfLargestVertexCycle($VertexID);
```

Returns size of the largest cycle containing *VertexID* in a *Graph*.

GetSizeOfSmallestCycle

```
$Size = $Graph->GetSizeOfSmallestCycle();
```

Returns size of the smallest cycle in a *Graph*.

GetSizeOfSmallestEdgeCycle

```
$Size = $Graph->GetSizeOfSmallestEdgeCycle($VertexID1, $VertexID2);
```

Returns size of the smallest cycle containing edge between *VertexID1* and *VertexID2* in a *Graph*.

GetSizeOfSmallestVertexCycle

```
$Size = $Graph->GetSizeOfSmallestVertexCycle($VertexID);
```

Returns size of the smallest cycle containing *VertexID* in a *Graph*.

GetSmallestCycle

```
$CyclicPath = $Graph->GetSmallestCycle();
```

Returns a cyclic *Path* object corresponding to smallest cycle in a *Graph*.

GetSmallestEdgeCycle

```
$CyclicPath = $Graph->GetSmallestEdgeCycle($VertexID1, $VertexID2);
```

Returns a cyclic *Path* object corresponding to smallest cycle containing edge between *VertexID1* and *VertexID2* in a *Graph*.

GetSmallestVertexCycle

```
$CyclicPath = $Graph->GetSmallestVertexCycle($VertexID);
```

Returns a cyclic *Path* object corresponding to smallest cycle containing *VertexID* in a *Graph*.

GetTopologicallySortedVertices

```
@VertexIDs = $Graph->GetTopologicallySortedVertices(
    [$RootVertexID]);
```

Returns an array of *VertexIDs* sorted topologically starting from a specified *RootVertexID* or from an arbitrary vertex ID.

GetVertex

```
$VertexValue = $Graph->GetVertex($VertexID);
```

Returns vertex value for *VertexID* in a *Graph*. Vertex IDs and values are equivalent in the current implementation of Graph.

GetVertexCycles

```
@CyclicPaths = $Graph->GetVertexCycles($VertexID);
```

Returns an array *CyclicPaths* containing *Path* objects corresponding to all cycles containing *VertexID* in a *Graph*.

GetVertexCyclesWithEvenSize

```
@CyclicPaths = $Graph->GetVertexCyclesWithEvenSize($VertexID);
```

Returns an array *CyclicPaths* containing *Path* objects corresponding to cycles with even size containing *VertexID* in a *Graph*.

GetVertexCyclesWithOddSize

```
@CyclicPaths = $Graph->GetVertexCyclesWithOddSize($VertexID);
```

Returns an array *CyclicPaths* containing *Path* objects corresponding to cycles with odd size containing *VertexID* in a *Graph*.

GetVertexCyclesWithSize

```
@CyclicPaths = $Graph->GetVertexCyclesWithSize($VertexID,  
$CycleSize);
```

Returns an array *CyclicPaths* containing *Path* objects corresponding to cycles with size *CycleSize* containing *VertexID* in a *Graph*.

GetVertexCyclesWithSizeGreaterThan

```
@CyclicPaths = $Graph->GetVertexCyclesWithSizeGreaterThan($VertexID,  
$CycleSize);
```

Returns an array *CyclicPaths* containing *Path* objects corresponding to cycles with size greater than *CycleSize* containing *VertexID* in a *Graph*.

GetVertexCyclesWithSizeLessThan

```
@CyclicPaths = $Graph->GetVertexCyclesWithSizeLessThan($VertexID,  
$CycleSize);
```

Returns an array *CyclicPaths* containing *Path* objects corresponding to cycles with size less than *CycleSize* containing *VertexID* in a *Graph*.

GetVertexProperties

```
%VertexProperties = $Graph->GetVertexProperties($VertexID);
```

Returns a hash *VertexProperties* containing all *PropertyName* and *PropertyValue* pairs associated with a *VertexID* in a *Graph*.

GetVertexProperty

```
$Value = $Graph->GetVertexProperty($PropertyName, $VertexID);
```

Returns value of *PropertyName* associated with a *VertexID* in a *Graph*.

GetVertexWithLargestDegree

```
$VertexID = $Graph->GetVertexWithLargestDegree();
```

Returns *VertexID* with largest degree in a *Graph*.

GetVertexWithSmallestDegree

```
$VertexID = $Graph->GetVertexWithSmallestDegree();
```

Returns *VertexID* with smallest degree in a *Graph*.

GetVertices

```
@VertexIDs = $Graph->GetVertices();  
$VertexCount = $Graph->GetVertices();
```

Returns an array of *VertexIDs* corresponding to all vertices in a *Graph*; in a scalar context, number of vertices is returned.

GetVerticesProperty

```
@PropertyValues = $Graph->GetVerticesProperty($PropertyName, @VertexIDs);
```

Returns an array *PropertyValues* containing property values corresponding to *PropertyName* associated with *VertexIDs* in a *Graph*.

GetVerticesWithDegreeLessThan

```
@VertexIDs = $Graph->GetVerticesWithDegreeLessThan($Degree);
```

Returns an array of *VertexIDs* containing vertices with degree less than *Degree* in a *Graph*.

HasCycle

```
$Status = $Graph->HasCycle(@VertexIDs);
```

Returns 1 or 0 based on whether edges between successive pair of *VertexIDs* including an additional edge from the last to first vertex ID exists in a *Graph*.

HasEdge

```
$Status = $Graph->HasEdge($VertexID1, $VertexID2);
```

Returns 1 or 0 based on whether an edge between *VertexID1* and *VertexID2* exist in a *Graph*.

HasEdgeProperty

```
$Status = $Graph->HasEdgeProperty($PropertyName, $VertexID1,
    $VertexID2);
```

Returns 1 or 0 based on whether *PropertyName* has already been associated with an edge between *VertexID1* and *VertexID2* in a *Graph*.

HasEdges

```
@EdgesStatus = $Graph->HasEdges(@VertexIDs);
$FoundEdgesCount = $Graph->HasEdges(@VertexIDs);
```

Returns an array *EdgesStatus* containing 1s and 0s corresponding to whether edges between successive pairs of *VertexIDs* exist in a *Graph*. In a scalar context, number of edges found is returned.

HasFusedCycles

```
$Status = $Graph->HasFusedCycles();
```

Returns 1 or 0 based on whether any fused cycles exist in a *Graph*.

HasGraphProperty

```
$Status = $Graph->HasGraphProperty($PropertyName);
```

Returns 1 or 0 based on whether *PropertyName* has already been associated as a graph property as opposed to vertex or edge property in a *Graph*.

HasPath

```
$Status = $Graph->HasPath(@VertexIDs);
```

Returns 1 or 0 based on whether edges between all successive pairs of *VertexIDs* exist in a *Graph*.

HasVertex

```
$Status = $Graph->HasVertex($VertexID);
```

Returns 1 or 0 based on whether *VertexID* exists in a *Graph*.

HasVertexProperty

```
$Status = $Graph->HasGraphProperty($HasVertexProperty, $VertexID);
```

Returns 1 or 0 based on whether *PropertyName* has already been associated with *VertexID* in a *Graph*.

HasVertices

```
@VerticesStatus = $Graph->HasVertices(@VertexIDs);
$VerticesFoundCount = $Graph->HasVertices(@VertexIDs);
```

Returns an array containing 1s and 0s corresponding to whether *VertexIDs* exist in a *Graph*. In a scalar context, number of vertices found is returned.

IsAcyclic

```
$Status = $Graph->IsAcyclic();
```

Returns 0 or 1 based on whether a cycle exist in a *Graph*.

IsAcyclicEdge

```
$Status = $Graph->IsAcyclicEdge($VertexID1, $VertexID2);
```

Returns 0 or 1 based on whether a cycle containing an edge between *VertexID1* and *VertexID2* exists in a *Graph*.

IsAcyclicVertex

```
$Status = $Graph->IsAcyclicVertex($VertexID1);
```

Returns 0 or 1 based on whether a cycle containing a *VertexID* exists in a *Graph*.

IsCyclic

```
$Status = $Graph->IsCyclic();
```

Returns 1 or 0 based on whether a cycle exist in a *Graph*.

IsCyclicEdge

```
$Status = $Graph->IsCyclicEdge($VertexID1, $VertexID2);
```

Returns 1 or 0 based on whether a cycle containing an edge between *VertexID1* and *VertexID2* exists in a *Graph*.

IsCyclicVertex

```
$Status = $Graph->IsCyclicVertex($VertexID1);
```

Returns 1 or 0 based on whether a cycle containing a *VertexID* exists in a *Graph*.

IsGraph

```
$Status = Graph::IsGraph($Object);
```

Returns 1 or 0 based on whether *Object* is a Graph object.

IsIsolatedVertex

```
$Status = $Graph->IsIsolatedVertex($VertexID);
```

Returns 1 or 0 based on whether *VertexID* is an isolated vertex in a *Graph*. A vertex with zero as its degree value is considered an isolated vertex.

IsLeafVertex

```
$Status = $Graph->IsLeafVertex($VertexID);
```

Returns 1 or 0 based on whether *VertexID* is an isolated vertex in a *Graph*. A vertex with one as its degree value is considered an isolated vertex.

IsUnicyclic

```
$Status = $Graph->IsUnicyclic();
```

Returns 1 or 0 based on whether only one cycle is present in a *Graph*.

IsUnicyclicEdge

```
$Status = $Graph->IsUnicyclicEdge($VertexID1, $VertexID2);
```

Returns 1 or 0 based on whether only one cycle contains the edge between *VertexID1* and *VertexID2* in a *Graph*.

IsUnicyclicVertex

```
$Status = $Graph->IsUnicyclicVertex($VertexID);
```

Returns 1 or 0 based on whether only one cycle contains *VertexID* in a *Graph*.

SetActiveCyclicPaths

```
$Graph->SetActiveCyclicPaths($CyclicPathsType);
```

Sets the type of cyclic paths to use during all methods related to cycles and returns *Graph*. Possible values for cyclic paths: *Independent* or *All*.

SetEdgeProperties

```
$Graph->SetEdgeProperties($VertexID1, $VertexID2, @NamesAndValues);
```

Associates property names and values corresponding to successive pairs of values in *NamesAndValues* to an edge between *VertexID1* and *VertexID2* in a *Graph* and returns *Graph*.

SetEdgeProperty

```
$Graph->SetEdgeProperty($Name, $Value, $VertexID1, $VertexID2);
```

Associates property *Name* and *Value* to an edge between *VertexID1* and *VertexID2* in a *Graph* and returns *Graph*.

SetEdgesProperty

```
$Graph->SetEdgesProperty($Name, @ValuesAndVertexIDs);
```

Associates a same property *Name* but different *Values* for different edges specified using triplets of *PropertyValue*, *\$VertexID1*, *\$VertexID2* via *ValuesAndVertexIDs* in a *graph*.

SetGraphProperties

```
$Graph->SetGraphProperties(%NamesAndValues);
```

Associates property names and values *NamesAndValues* hash to graph as opposed to vertex or edge and returns *Graph*.

SetGraphProperty

```
$Graph->SetGraphProperty($Name, $Value);
```

Associates property *Name* and *Value* to graph as opposed to vertex or edge and returns *Graph*.

SetVertexProperties

```
$Graph->SetVertexProperties($VertexID, @NamesAndValues);
```

Associates property names and values corresponding to successive pairs of values in *NamesAndValues* to *VertexID* in a *Graph* and returns *Graph*.

SetVertexProperty

```
$Graph->SetVertexProperty($Name, $Value, $VertexID);
```

Associates property *Name* and *Value* to *VertexID* in a *Graph* and returns *Graph*.

SetVerticesProperty

```
$Graph->SetVerticesProperty($Name, @ValuesAndVertexIDs);
```

Associates a same property *Name* but different *Values* for different vertices specified using doublets of *PropertyValue*, *\$VertexID* via *ValuesAndVertexIDs* in a *graph*.

StringifyEdgesProperties

```
$String = $Graph->StringifyEdgesProperties();
```

Returns a string containing information about properties associated with all edges in a *Graph* object.

StringifyGraph

```
$String = $Graph->StringifyGraph();
```

Returns a string containing information about *Graph* object.

StringifyGraphProperties

```
$String = $Graph->StringifyGraphProperties();
```

Returns a string containing information about properties associated with graph as opposed to vertex. or an edge in a *Graph* object

StringifyProperties

```
$String = $Graph->StringifyProperties();
```

Returns a string containing information about properties associated with graph, vertices, and edges in a

Graph object.

StringifyVerticesAndEdges

```
$String = $Graph->StringifyVerticesAndEdges();
```

Returns a string containing information about vertices and edges in a *Graph* object.

StringifyVerticesProperties

```
$String = $Graph->StringifyVerticesProperties();
```

Returns a string containing information about properties associated with vertices a *Graph* object.

UpdateEdgeProperty

```
$Graph->UpdateEdgeProperty($Name, $Value, $VertexID1, $VertexID2);
```

Updates property *Value* for *Name* associated with an edge between *VertexID1* and *VertexID1* and returns *Graph*.

UpdateVertexProperty

```
$Graph->UpdateVertexProperty($Name, $Value, $VertexID);
```

Updates property *Value* for *Name* associated with *VertexID* and returns *Graph*.

AUTHOR

Manish Sud <msud@san.rr.com>

SEE ALSO

CyclesDetection.pm, Path.pm, PathGraph.pm, PathsTraversal.pm

COPYRIGHT

Copyright (C) 2019 Manish Sud. All rights reserved.

This file is part of MayaChemTools.

MayaChemTools is free software; you can redistribute it and/or modify it under the terms of the GNU Lesser General Public License as published by the Free Software Foundation; either version 3 of the License, or (at your option) any later version.