1 graphBAM class

1.1 Introduction

The graphBAM class has been created as a more efficient replacement for the graphAM class in the graph package. The adjacency matrix in the graphBAM class is represented as a bit array using a raw vector. This significantly reduces the memory occupied by graphs having a large number of nodes. The bit vector representation also provides advantages in terms of performing operations such as intersection or union of graphs.

We first load the graph package which provides the class definition and methods for the graphBAM class.

> library(graph)

One of the arguments df to the graphBAM constructor is a data.frame containing three columns: "from", "to" and "weight", each row in the data.frame representing an edge in the graph. The from and to columns can be character vectors or factors, while the weight column must be a numeric vector. The argument nodes are calculated from the unique names in the from and to columns of the data.frame. The argument edgeMode should be a character vector, either "directed" or "undirected" indicating whether the graph represented should be directed or undirected respectively.

1.2 A simple graph represented using graphBAM class

We proceed to represent a simple graph using the graphBAM class. Our example is a directed graph representing airlines flying between different cities. In this example, cities represent the nodes of the graph and each edge represents a flight from an originating city (from) to the destination city (to). The weight represents the fare for flying between the from and to cities.

> df <- data.frame(from = c("SEA", "SFO", "SEA", "LAX", "SEA"),
+ to = c("SFO", "LAX", "LAX", "SEA", "DEN"),
+ weight = c( 90, 96, 124, 115, 259))
> g <- graphBAM(df, edgemode = "directed")
> g

A graphBAM graph with directed edges
Number of Nodes = 4
Number of Edges = 5

The cities (nodes) included in our graph object as well as the stored fares(weight) can be obtained using the nodes and edgeWeights methods respectively.

> nodes(g)
Additional nodes or edges can be added to our graph using the `addNode` and `addEdge` methods. For our example, we first add a new city "IAH" to our graph. We then add a flight connection between "DEN" and "IAH" having a fare of $120.

```r
> g <- addNode("IAH", g)
> g <- addEdge(from = "DEN", to = "IAH", graph = g, weight = 120)
> g
```

A graphBAM graph with directed edges
Number of Nodes = 5
Number of Edges = 6

Similarly edges and nodes can be removed from the graph using the `removeNode` and `removeEdge` methods respectively. We proceed to remove the flight connection from "DEN" to "IAH" and subsequently the node "IAH".

```r
> g <- removeEdge(from = "DEN", to = "IAH", g)
> g <- removeNode(node = "IAH", g)
> g
```

A graphBAM graph with directed edges
Number of Nodes = 4
Number of Edges = 5

We can create a subgraph with only the cities "DEN", "LAX" and "SEA" using the `subGraph` method.

```r
> g <- subGraph(snodes = c("DEN", "LAX", "SEA"), g)
> g
```

A graphBAM graph with directed edges
Number of Nodes = 3
Number of Edges = 3

We can extract the from-to relationships for our graph using the `extractFromTo` method.

```r
> extractFromTo(g)
from to weight
1 SEA DEN 259
2 SEA LAX 124
3 LAX SEA 115
```
1.3 Mice gene interaction data for brain tissue (SAGE data)

The C57BL/6J and C3H/HeJ mouse strains exhibit different cardiovascular and metabolic phenotypes on the hyperlipidemic apolipoprotein E (ApoE) null background. The interaction data for the genes from adipose, brain, liver and muscle tissue samples from male and female mice were studied. This interaction data for the various genes is included in the graph package as a list of data.frames containing information for from-gene, to-gene and the strength of interaction weight for each of the tissues studied.

We proceed to load the data for male and female mice.

```r
> data("esetsFemale")
> data("esetsMale")
```

We are interested in studying the interaction data for the genes in the brain tissue for male and female mice and hence proceed to represent this data as directed graphs using graphBAM objects for male and female mice.

```r
> dfMale <- esetsMale[["brain"]]
> dfFemale <- esetsFemale[["brain"]]
> head(dfMale)

```

<table>
<thead>
<tr>
<th>from</th>
<th>to</th>
<th>weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>10024402938</td>
<td>10024393150</td>
<td>0.835</td>
</tr>
<tr>
<td>10024415240</td>
<td>10024393156</td>
<td>0.667</td>
</tr>
<tr>
<td>10024403128</td>
<td>10024393162</td>
<td>0.312</td>
</tr>
<tr>
<td>10024409968</td>
<td>10024393162</td>
<td>0.482</td>
</tr>
<tr>
<td>10024393260</td>
<td>10024393163</td>
<td>0.997</td>
</tr>
<tr>
<td>10024394731</td>
<td>10024393165</td>
<td>0.714</td>
</tr>
</tbody>
</table>
```

```r
> male <- graphBAM(dfMale, edgemode = "directed")
> female <- graphBAM(dfFemale, edgemode = "directed")
```

We are interested in pathways that are common to both male and female graphs for the brain tissue and hence proceed to perform a graph intersection operation using the graphIntersect method. Since edges can have different values of the weight attribute, we would like the result to have the sum of the weight attribute in the male and female graphs. We pass in sum as the function for handling weights to the edgeFun argument. The edgeFun argument should be passed a list of named functions corresponding to the edge attributes to be handled during the intersection process.

```r
> intrsct <- graphIntersect(male, female, edgeFun=list(weight = sum))
> intrsct

A graphBAM graph with directed edges
Number of Nodes = 2117
Number of Edges = 473
```

If node attributes were present in the graphBAM objects, a list of named function could be passed as input to the graphIntersect method for handling them during the intersection process.

We proceed to remove edges from the graphBAM result we just calculated with a weight attribute less than a numeric value of 0.8 using the removeEdgesByWeight method.

```r
> resWt <- removeEdgesByWeight(intrsct, lessThan = 1.5)
```
Once we have narrowed down to the edges that we are interested in, we would like to change the color attribute for these edges in our original graphBAM objects for the male and female graphs to "red". Before an attribute can be added, we have to set its default value using the edgedataDefaults method. For our example, we set the default value for the color attribute to white.

We first obtain the from-to relationship for the resWt graph using the extractFromTo method and then make use of the edgeData method to update the "color" edge attribute.

```r
> ftSub <- extractFromTo(resWt)
> edgeDataDefaults(male, attr = "color") <- "white"
> edgeDataDefaults(female, attr = "color") <- "white"
> edgeData(male, from = as.character(ftSub[,"from"]),
+ to = as.character(ftSub[,"to"]), attr = "color") <- "red"
> edgeData(female, from = as.character(ftSub[,"from"]),
+ to = as.character(ftSub[,"to"]), attr = "color") <- "red"
```

2 MultiGraphs

2.1 Introduction

The MultiGraph class can be used to represent graphs that share a single node set and have one or more edge sets, each edge set representing a different type of interaction between the nodes. An edgeSet object can be described as representing the relationship between a set of from-nodes and to-nodes which can either be directed or undirected. A numeric value (weight) indicates the strength of interaction between the connected edges.

Self loops are permitted in the MultiGraph class representation (i.e. the from-node is the same as the to-node). The MultiGraph class supports the handling of arbitrary node and edge attributes. These attributes are stored separately from the edge weights to facilitate efficient edge weight computation.

We shall load the graph and RBGL packages that we will be using. We will then create a MultiGraph object and then spend some time examining some of the different functions that can be applied to MultiGraph objects.

```r
> library(graph)
> library(RBGL)
```

2.2 A simple MultiGraph example

We proceed to construct a MultiGraph object with directed edgeSets to represent the flight connections of airlines Alaska, Delta, United and American that fly between the cities Baltimore, Denver, Houston, Los Angeles, Seattle and San Francisco. For our example, the cities represent the nodes of the MultiGraph and we have one edgeSet each for the airlines. Each edgeSet represents the flight connections from an originating city(from) to the destination city(to). The weight represents the fare for flying between the from and to cities.

For each airline, we proceed to create a data.frame containing the originating city, the destination city and the fare.

```r
> ft1 <- data.frame(  
+   from = c("SEA", "SFO", "SEA", "LAX", "SEA"),
+   to = c("SFO", "LAX", "LAX", "SEA", "DEN"),
+   weight = c(90, 96, 124, 115, 259))
> ft2 <- data.frame(  
+   from = c("SEA", "SFO", "SEA", "LAX", "SEA", "DEN", "SEA", "IAH", "DEN"),
+   to = c("SFO", "LAX", "LAX", "SEA", "DEN", "SEA", "IAH", "DEN"),
  ...
These data frames are then passed to `MultiGraph` class constructor as a named list, each member of the list being a `data.frame` for an airline. A logical vector passed to the `directed` argument of the `MultiGraph` constructor indicates whether the `MultiGraph` to be created should have directed or undirected edge sets.

```
> esets <- list(Alaska = ft1, United = ft2, Delta = ft3, American = ft4)
> mg <- MultiGraph(esets, directed = TRUE)
> mg
```

```
MultiGraph with 6 nodes and 4 edge sets

<table>
<thead>
<tr>
<th>edge_set</th>
<th>directed</th>
<th>edge_count</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alaska</td>
<td>TRUE</td>
<td>5</td>
</tr>
<tr>
<td>United</td>
<td>TRUE</td>
<td>9</td>
</tr>
<tr>
<td>Delta</td>
<td>TRUE</td>
<td>10</td>
</tr>
<tr>
<td>American</td>
<td>TRUE</td>
<td>7</td>
</tr>
</tbody>
</table>
```

The nodes (cities) of the `MultiGraph` object can be obtained by using the `nodes` method.

```
> nodes(mg)
[1] "BWI" "DEN" "IAH" "LAX" "SEA" "SFO"
```

To find the fares for all the flights that originate from SEA for the Delta airline, we can use the `mgEdgeData` method.

```
> mgEdgeData(mg, "Delta", from = "SEA", attr = "weight")
$'SEA|DEN'
[1] 281
$'SEA|IAH'
[1] 282
$'SEA|LAX'
[1] 156
$'SEA|SFO'
[1] 237
```

We proceed to add some node attributes to the `MultiGraph` using the `nodeData` method. Before node attributes can be added, we have to set a default value for each node attribute using the `nodeDataDefault` method. For our example, we would like to set a default value of square for the node attribute shape.

We would like to set the node attribute "shape" for Seattle to the value "triangle" and that for the cities that connect with Seattle to the value "circle".
nodeDataDefaults(mg, attr="shape") <- "square"
nodeData(mg, n = c("SEA", "DEN", "IAH", "LAX", "SFO"), attr = "shape") <-
  c("triangle", "circle", "circle", "circle", "circle")

The node attribute shape for cities we have not specifically assigned a value (such as BWI) gets
assigned the default value of "square".

nodeData(mg, attr = "shape")

$BWI
[1] "square"

$DEN
[1] "circle"

$IAH
[1] "circle"

$LAX
[1] "circle"

$SEA
[1] "triangle"

$SFO
[1] "circle"

We then update the edge attribute color for the Delta airline flights that connect with Seattle to
"green". For the remaining Delta flights that connect to other destination in the MultiGraph, we would
like to assign a default color of "red".

Before edge attributes can be added to the MultiGraph, their default values must be set using
the mgEdgeDataDefaults method. Subsequently, the mgEdgeData<- method can be used to update
specific edge attributes.

mgEdgeDataDefaults(mg, "Delta", attr = "color") <- "red"
mgEdgeData(mg, "Delta", from = c("SEA", "SEA", "SEA", "SEA"),
  to = c("DEN", "IAH", "LAX", "SFO"), attr = "color") <- "green"
mgEdgeData(mg, "Delta", attr = "color")

$'DEN|BWI'
[1] "red"

$'IAH|DEN'
[1] "red"

$'SEA|DEN'
[1] "green"

$'DEN|IAH'
[1] "red"

$'SEA|IAH'
We are only interested in studying the fares for the airlines Alaska, United and Delta and hence would like to create a smaller *MultiGraph* object containing edge sets for only these airlines. This can be achieved using the `subsetEdgeSets` method.

```r
> g <- subsetEdgeSets(mg, edgeSets = c("Alaska", "United", "Delta"))
```

We proceed to find out the lowest fares for Alaska, United and Delta along the routes common to them. To do this, we make use of the `edgeSetIntersect0` method which computes the intersection of all the edgesets in a MultiGraph. While computing the intersection of edge sets, we are interesting in retaining the lowest fares in cases where different airlines flying along a route have different fares. To do this, we pass in a named list containing the `weight` function that calculates the minimum of the fares as the input to the `edgeSetIntersect0` method. (The user has the option of specifying any function for appropriate handling of edge attributes).

```r
> edgeFun <- list( weight = min)
> gInt <- edgeSetIntersect0(g, edgeFun = edgeFun)
> gInt

MultiGraph with 6 nodes and 1 edge sets

```

The edge set by the `edgeSetIntersect0` operation is named by concatenating the names of the edgeSets passed as input to the function.

```r
> mgEdgeData(gInt, "Alaska_United_Delta", attr = "weight")
```

```r
$`SEA|DEN`
[1] 259

$`SEA|LAX`
[1] 110

$`SFO|LAX`
[1] 65
```
2.3 MultiGraph representation of mice gene interaction data. (SAGE)

The C57BL/6J and C3H/HeJ mouse strains exhibit different cardiovascular and metabolic phenotypes on the hyperlipidemic apolipoprotein E (Apoe) null background. The interaction data for the genes from adipose, brain, liver and muscle tissue samples from male and female mice were studied. This interaction data for the various genes is included in the graph package as a list of data.frames containing information for from-gene, to-gene and the strength of interaction weight for each of the tissues studied.

We proceed to load the data for male and female mice.

```r
> data("esetsFemale")
> data("esetsMale")
> names(esetsFemale)
[1] "adipose" "brain" "liver" "muscle"

> head(esetsFemale$brain)

from   to   weight
1 10024404688 10024393150 0.853
2 10024406215 10024393156 0.513
3 10024411796 10024393163 1.000
4 10024415608 10024393167 0.727
5 10024399302 10024393196 0.342
6 10024399912 10024393196 0.555
```

The esetsFemale and esetsMale objects are a named list of data frames corresponding to the data obtained from adipose, brain, liver and muscle tissues for the male and female mice that were studied. Each data frame has a from, to and a weight column corresponding to the from and to genes that were studied and weight representing the strength of interaction of the corresponding genes.

We proceed to create MultiGraph objects for the male and female data sets by making use of the MultiGraph constructor, which directly accepts a named list of data frames as the input and returns a MultiGraph with edgeSets corresponding to the names of the data frames.

```r
> female <- MultiGraph(edgeSets = esetsFemale, directed = TRUE)
> male <- MultiGraph(edgeSets = esetsMale, directed = TRUE)
> male

MultiGraph with 7081 nodes and 4 edge sets
edge_set directed edge_count
adipose   TRUE  1601
brain     TRUE  2749
liver     TRUE  3690
muscle    TRUE  3000
```

We then select a particular gene of interest in this network and proceed to identify its neighboring genes connected to this gene in terms of the maximum sum of weights along the path that connects the genes for the brain edge set.

We are interested in the gene "10024416717" and the sum of the weights along the path that connects this gene to the other genes for the brain tissue. Since the algorithms in the RBGL package that we will use to find the edges that are connected to the gene "10024416717" do not work directly with MultiGraph objects, we proceed to create graphBAM objects from the male and female edge sets for the brain tissue.

MultiGraph objects can be converted to a named list of graphBAM objects using the graphBAM method.

```r
> maleBrain <- extractGraphBAM(male, "brain")[['brain']]
> maleBrain

A graphBAM graph with directed edges
Number of Nodes = 7081
Number of Edges = 2749

> femaleBrain <- extractGraphBAM(female, "brain")[['brain']]

We then identify the genes connected to gene "10024416717" as well as the sum of the weights along the path that connect the identified genes using the function bellman.ford.sp function from the RBGL package.

```r
> maleWt <- bellman.ford.sp(maleBrain, start = c("10024416717"))$distance
> maleWt <- maleWt[maleWt != Inf & maleWt != 0]
> maleWt

10024409301 10024409745
0.636 1.389

> femaleWt <- bellman.ford.sp(femaleBrain, start = c("10024416717"))$distance
> femaleWt <- femaleWt[femaleWt != Inf & femaleWt != 0]
> femaleWt

10024393904 10024409503
0.789 0.866
```

For the subset of genes we identified, we proceed to add node attributes to our original MultiGraph objects for the male and female data. The node "10024416717" and all its connected nodes are assigned a color attribute "red" while the rest of the nodes are assigned a color attribute of "gray".

```r
> nodeDataDefaults(male, attr = "color") <- "gray"
> nodeData(male, n = c("10024416717", names(maleWt)), attr = "color") <- c("red")
> nodeDataDefaults(female, attr = "color") <- "gray"
> nodeData(female, n = c("10024416717", names(femaleWt)), attr = "color") <- c("red")
```
Our `MultiGraph` objects now contain the required node attributes for the subset of genes that we have narrowed our selection to.

For the `MultiGraph` objects for male and female, we are also interested in the genes that are common to both `MultiGraphs`. This can be calculated using the `graphIntersect` method.

```r
> resInt <- graphIntersect(male, female)
> resInt

MultiGraph with 5699 nodes and 4 edge sets
  edge_set directed edge_count
  adipose   TRUE   88
  brain     TRUE  473
  liver     TRUE  455
  muscle    TRUE  370
```

The operations we have dealt with so far only deal with manipulation of `MultiGraph` objects. Additional functions will need to be implemented for the visualization of the `MultiGraph` objects.