

# Package ‘nem’

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**Title** (Dynamic) Nested Effects Models and Deterministic Effects  
Propagation Networks to reconstruct phenotypic hierarchies

**Version** 2.56.0

**Author** Holger Froehlich, Florian Markowetz, Achim Tresch, Theresa Niederberger, Christian Bender, Matthias Maneck, Claudio Lottaz, Tim Beissbarth

**Description** The package 'nem' allows to reconstruct features of pathways from the nested structure of perturbation effects. It takes as input (1.) a set of pathway components, which were perturbed, and (2.) phenotypic readout of these perturbations (e.g. gene expression, protein expression). The output is a directed graph representing the phenotypic hierarchy.

**Reference** Froehlich H, Beissbarth T, Tresch A, Kostka D, Jacob J, Spang R, Markowetz F: Analyzing gene perturbation screens with nested effects models in R and bioconductor, *Bioinformatics*, 2008, 24:2549-50.

**Maintainer** Holger Froehlich <froehlich@bit.uni-bonn.de>

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**Enhances** doMC, snow, parallel

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BFSlevel

*Build (generalized) hierarchy by Breath-First Search*

---

**Description**

BFSlevel builds a (generalized) hierarchy by Breath-First Search as described in (Yu and Gerstein, 2006)

**Usage**

BFSlevel(g, verbose=TRUE)

**Arguments**

g graphNEL object  
 verbose Default: TRUE

**Details**

Haiyuan Yu and Mark Gerstein: Genomic analysis of the hierarchical structure of regulatory networks, PNAS 103(40):14724-14731, 2006

**Value**

level vector of levels for each node

**Author(s)**

Florian Markowetz

**Examples**

```
## bla
```

---

BoutrosRNAi2002

*RNAi data on Drosophila innate immune response*

---

**Description**

Data from a study on innate immune response in *Drosophila* (Boutros et al, 2002). Selectively removing signaling components by RNAi blocked induction of all, or only parts, of the transcriptional response to LPS. The nested structure of perturbation effects allows to reconstruct a branching in the Imd pathway.

**Usage**

```
data(BoutrosRNAi2002)
```

**Format**

BoutrosRNAiExpression: data matrix: 14010 x 16\ BoutrosRNAiDiscrete: binary matrix: 68 x 16\ BoutrosRNAiDens: data matrix: 68 x 4\ BoutrosRNAiLods: data matrix: 68 x 4\ BoutrosRNAiLogFC: data matrix: 68 x 4

**Details**

The dataset consists of 16 Affymetrix-microarrays: 4 replicates of control experiments without LPS and without RNAi (negative controls), 4 replicates of expression profiling after stimulation with LPS but without RNAi (positive controls), and 2 replicates each of expression profiling after applying LPS and silencing one of the four candidate genes tak, key, rel, and mkk4/hep.

BoutrosRNAiExpression: For preprocessing we performed normalization on probe level using a variance stabilizing transformation (Huber et al, 2002), and probe set summarization using a median polish fit of an additive model (Irizarry et al, 2003).

BoutrosRNAiDiscrete: contains only the 68 genes more than two-fold up-regulated between negative and positive controls. The continuous expression values are discretized to 1 (effect: closer to negative controls) and 0 (no effect: closer to positive controls).

BoutrosRNAiDens: log  $p$ -value density matrix for the 68 genes with more than two-fold up-regulated between negative and positive controls.

BoutrosRNAiLods: B-value matrix for the 68 genes with more than two-fold up-regulated between negative and positive controls.

BoutrosRNAiLogFC: matrix with log fold changes

## References

Boutros M, Agaisse H, Perrimon N, Sequential activation of signaling pathways during innate immune responses in *Drosophila*. *Developmental Cell*. 3(5):711-722, 2002

## See Also

[nem.discretize](#)

## Examples

```
data("BoutrosRNAi2002")
dim(BoutrosRNAiExpression)
dim(BoutrosRNAiDiscrete)
```

---

```
closest.transitive.greedy
```

*Find transitively closed graph most similar to the given one*

---

## Description

First, from the original graph  $\Phi$  spurious edges are pruned via `prune.graph`. Then the new graph  $\Phi'$  is transitively closed. Afterwards, the algorithm successively introduces new edges minimizing the distance to the original graph (defined as  $\sum_{ij} |\Phi_{ij} - \Phi'_{ij}|$ ) most. After each edge addition the graph is transitively closed again.

## Usage

```
closest.transitive.greedy(Phi, verbose=TRUE)
```

## Arguments

Phi	adjacency matrix
verbose	do you want to see progress statements printed or not? Default: TRUE

## Value

adjacency matrix

## Author(s)

Holger Froehlich

**See Also**

[prune.graph](#), [transitive.closure](#), [transitive.reduction](#)

---

enumerate.models	<i>Exhaustive enumeration of models</i>
------------------	---

---

**Description**

The function `enumerate.models` is used to create the model space for inference by exhaustive enumeration. It computes a list of all transitively closed directed graphs on a given number of nodes.

**Usage**

```
enumerate.models(x, name=NULL, trans.close=TRUE, verbose=TRUE)
```

**Arguments**

<code>x</code>	either the number of nodes or a vector of node names.
<code>name</code>	optionally the nodenames, if they are not provided in <code>x</code>
<code>trans.close</code>	should graphs be transitively closed?
<code>verbose</code>	if TRUE outputs number of (unique) models. Default: TRUE

**Details**

The model space of Nested Effects Models consists of all transitively closed directed graphs. The function `enumerate.models` creates them in three steps: (1.) build all directed graphs on `x` (or `length(x)`) nodes, (2.) transitively close each one of them, and (3.) remove redundant models to yield a unique set. So far, enumeration is limited to up to 5 nodes.

I'm aware that this is inefficient! It would be very desirable to enumerate the models directly (i.e. without creating all directed graphs as an intermediate step).

**Value**

a list of models. Each entry is a transitively closed adjacency matrix with unit main diagonal.

**Author(s)**

Florian Markowetz

**See Also**

[nem](#)

**Examples**

```
enumerate.models(2)
enumerate.models(c("Anna", "Bert"))
```

---

generateNetwork      *Random networks and data sampling*

---

### Description

1. Random network generation; 2. sampling of data from a given network topology

### Usage

```
sampleRndNetwork(Sgenes, scaleFree=TRUE, gamma=2.5, maxOutDegree=length(Sgenes), maxInDegree=length(Sgenes))
```

```
sampleData(Phi, m, prob=NULL, uninformative=0, type="binary", replicates=4, typeI.err=0.05, typeII.err=0.05)
```

### Arguments

Sgenes	character vector of S-genes
scaleFree	should the network topology be scale free?
gamma	for scale free networks: out-degrees of nodes are sampled from $\frac{1}{Z} * (0 : \text{maxOutDegree})^{-\gamma}$ , where Z is a normalization factor
maxOutDegree	maximal out-degree of nodes
maxInDegree	maximal in-degree of nodes prior to transitive closure
trans.close	Should the transitive closure of the graph be returned? Default: TRUE
DAG	Should only DAGs be sampled? Default: FALSE
Phi	adjacency matrix
m	number of E-genes to sample
prob	probability for each S-gene to get an E-gene attached
uninformative	additional number of uninformative E-genes, i.e. E-genes carrying no information about the nested structure
type	"binary" = binary data; "density" = log 'p-value' densities sampled from beta-uniform mixture model; "lodds" = log odds sampled from two normal distributions
replicates	number of replicate measurements to simulate for binary data
typeI.err	simulated type I error for binary data
typeII.err	simulated type II error for binary data
alpha	parameter for $Beta(\alpha, 1)$ distribution: one parameter per S-gene
beta	parameter for $Beta(1, \beta)$ distribution: one parameter per S-gene
lambda	mixing coefficients for beta-uniform mixture model of the form: $\lambda_1 + \lambda_2 * Beta(\alpha, 1) + \lambda_3 * Beta(1, \beta)$ . There is a vector of 3 mixing coefficients per model and one model per S-gene.
meansH1	normal distribution means of log odds ratios under the hypothesis of expecting an effect: one mean per S-gene
meansH0	normal distribution means of log odds ratios under the null hypothesis: one mean per S-gene
sdsH1	normal distribution standard deviations of log odds values under the hypothesis of expecting an effect: one sd per S-gene
sdsH0	normal distribution standard deviations of log odds values under the null hypothesis: one sd per S-gene

**Details**

Random networks are generated as follows: For each S-gene  $S_k$  we randomly choose the number  $o$  of outgoing edges between 0 and `maxOutDegree`. This is either done uniform randomly or, if scale free networks are created, according to a power law distribution specified by `gamma`. We then select  $o$  S-genes having at most `maxInDegree` ingoing edge and connected  $S_k$  to them.

The function `sampleData` samples data from a given network topology as follows: We first attach E-genes to S-genes according to the probabilities `prob` (default: uniform). We then simulate knock-downs of the individual S-genes. For those E-genes, where no effects are expected, values are sampled from a null distribution, otherwise from an alternative distribution. In the simplest case we only sample binary data, where 1 indicates an effect and 0 no effect. Alternatively, we can sample log "p-value" densities according to a beta-uniform mixture model, where the null distribution is uniform and the alternative a mixture of two beta distributions. A third possibility is to sample log odds ratios, where alternative and null distribution are both normal.

**Value**

For `sampleRndNetwork` an adjacency matrix, for `sampleData` a data matrix, for `sampleData.BN` a data matrix and a linking of effects to signals.

**Author(s)**

Holger Froehlich, Cordula Zeller

**See Also**

[getDensityMatrix](#)

**Examples**

```
Phi = sampleRndNetwork(paste("S",1:5,sep=""))
D = sampleData(Phi, 100, type="density")$D
if(require(Rgraphviz)){
  plot(as(transitive.reduction(Phi),"graphNEL"), main="original graph")
  x11()
  plot.nem(nem(D, control=set.default.parameters(unique(colnames(D)), type="CONTmLLBayes")), transitiveRedu
}
```

---

`getDensityMatrix`

*Calculate density matrix from raw p-value matrix*

---

**Description**

Fit a 3 component BUM model to each column of a raw p-value matrix.

**Usage**

```
getDensityMatrix(Porig, dirname=NULL, startab=c(0.3,10), startlam=c(0.6,0.1,0.3), tol=1e-4)
```

**Arguments**

Porig	matrix of raw p-values
dirname	name of a directory to save histograms and QQ-plots to. If dirname=NULL, then the plots are made to the screen, and after each fit the user is asked to press a key in order to continue.
startab	start values for alpha and beta parameter
startlam	start values for mixing coefficients
tol	convergence tolerance: If the absolute likelihood ratio -1 becomes smaller than this value, then the EM algorithm is supposed to be converged.

**Details**

The BUM density model consists of 3 components:  $f(x) = \lambda_1 + \lambda_2 * dbeta(x, \alpha, 1) + \lambda_3 * dbeta(x, 1, \beta)$ . The mixing coefficients and the parameters alpha and beta are fitted together via an EM algorithm.

**Value**

log-density matrix of same dimensions as Porig: The log-densities can be interpreted as log signal-to-noise ratios. A value > 0 means higher signal than noise, and a value < 0 a higher noise than signal.

**Note**

Note the difference to the previous package version: the LOG-density is returned now!

**Author(s)**

Holger Froehlich

---

getRelevantEGenes      *Automatic selection of most relevant effect reporters*

---

**Description**

1. A-priori filtering of effect reporters/E-genes: Select effect reporters, which show a pattern of differential expression across experiments that is expected to be non-random. 2. Automated effect reporters subset selection: Select those effect reporters, which have the highest likelihood under the given network hypothesis.

**Usage**

```
filterEGenes(Porig, D, Padj=NULL, ntop=100, fpr=0.05, adjmethod="bonferroni", cutoff=0.05)

getRelevantEGenes(Phi, D, control, nGenes=min(10*nrow(Phi), nrow(D)))
```



**Arguments**

	For method filterEGenes:
	matrix of raw p-values, typically from the complete array
<code>Orig</code>	data matrix. Columns correspond to the nodes in the silencing scheme. Rows are effect reporters.
<code>Padj</code>	matrix of false positive rates. If not, provided Benjamini-Hochbergs method for false positive rate computation is used.
<code>ntop</code>	number of top genes to consider from each knock-down experiment
<code>fpr</code>	significance cutoff for the FDR
<code>adjmethod</code>	adjustment method for pattern p-values
<code>cutoff</code>	significance cutoff for patterns
	For method getRelevantEGenes:
<code>Phi</code>	adjacency matrix with unit main diagonal
<code>control</code>	list of parameters: see <code>set.default.parameters</code>
<code>nEgenes</code>	no. of E-genes to select

**Details**

The method `filterEGenes` performs an a-priori filtering of the complete microarray. It determines how often E-genes are expected to be differentially expressed across experiments just randomly. According to this only E-genes are chosen, which show a pattern of differential expression more often than can be expected by chance.

The method `getRelevantEGenes` looks for the E-genes, which have the highest likelihood under the given network hypothesis. In case of the scoring type "CONTmLLBayes" these are all E-genes which have a positive contribution to the total log-likelihood. In case of type "CONTmLLMAP" all E-genes not assigned to the "null" S-gene are returned. This involves the prior probability `delta/no. S-genes` for leaving out an E-gene. For all other cases ("CONTmLL", "FULLmLL", "mLL") the `nEgenes` E-genes with the highest likelihood under the given network hypothesis are returned.

**Value**

<code>I</code>	index of selected E-genes
<code>dat</code>	subset of original data according to <code>I</code>
<code>patterns</code>	significant patterns
<code>nobserved</code>	no. of cases per observed pattern
<code>selected</code>	selected E-genes
<code>mLL</code>	marginal likelihood of a phenotypic hierarchy
<code>pos</code>	posterior distribution of effect positions in the hierarchy
<code>mappos</code>	Maximum a posteriori estimate of effect positions
<code>LLperGene</code>	likelihood per selected E-gene

**Author(s)**

Holger Froehlich

**See Also**

[nem](#), [score](#), [mLL](#), [FULLmLL](#)

**Examples**

```
# Drosophila RNAi and Microarray Data from Boutros et al, 2002
data("BoutrosRNAi2002")
D <- BoutrosRNAiDiscrete[,9:16]

# enumerate all possible models for 4 genes
Sgenes = unique(colnames(D))
models <- enumerate.models(Sgenes)

getRelevantEGenes(models[[64]], D, control=set.default.parameters(Sgenes, para=c(.13,.05), type="mLL"))
```

infer.edge.type

*Infer regulation direction for each edge***Description**

The method infers edge types (up-regulation, down-regulation) for a given nem model. Direct approach: For an edge a->b the method looks, whether b is up- or down-regulated in a knock-down of a.

Indirect approach: For an edge a->b the method looks at the fraction of E-genes attached to b (including b itself), which are up- or down-regulated in a knock-down of a. If significantly more genes are down-regulated than up-regulated, the edge a->b is assumed to be an activation. Likewise, if significantly more genes are up-regulated than down-regulated, a->b is assumed to be an inhibition. If there is no significant difference in up- and down-regulated edges, a->b does not have a specified type.

**Usage**

```
infer.edge.type(x, logFC, alpha=0.05, adj.method="BY", method=c("direct", "indirect"))
```

**Arguments**

x	nem object
logFC	matrix with fold changes. The rownames of this matrix should correspond to the rownames of the data matrix, which was used to infer the nem model.
alpha	p-value cutoff
adj.method	multiple testing correction method. Default: Benjamini-Yekutieli
method	default: "direct"

**Details**

Significance in case of the indirect method is calculated using a two-tailed binomial test with null hypothesis  $p=0.5$ .

**Value**

Modified nem object. Each edge in the nem graph now has a "weight" and a "label" attribute. The label attribute corresponds to the original value in the adjacency matrix. The weight attribute encodes up- and down-regulation in the following way: value 2 means up-regulation, value -1 down-regulation and value 1 an unknown effect.

**Author(s)**

Holger Froehlich

**See Also**

[binom.test](#)

**Examples**

```
data("BoutrosRNAi2002")
D <- BoutrosRNAiDiscrete[,9:16]
result = nem(D, control=set.default.parameters(unique(colnames(D)), para=c(0.13,0.05)))
resEdgeInf = infer.edge.type(result, BoutrosRNAiLogFC)
if(require(Rgraphviz))
  plot.nem(resEdgeInf)
```

---

internal

*internal functions*

---

**Description**

internal functions: do not call these functions directly.

**Usage**

various

**Arguments**

various

**Value**

various

**Author(s)**

Holger Froehlich

---

Ivanova2006RNAiTimeSeries

*Perturbation Time Series*

---

## Description

The dataset consists of time series microarray measurements (only 1 replicate, 6 time points) for RNAi knock-downs of each of the six genes Nanog, Oct4, Sox2, Esrrb, Tbx3, and Tc11 in mouse embryonic stem cells.

## Usage

```
data(Ivanova2006RNAiTimeSeries)
```

## Format

dat: 8 x 122 x 6 array of discretized time series data for E-genes showing a  $\text{abs}(\log\text{FC}) > 1$  in at least one time point (see Anchang et al., 2009).

## Details

Mouse embryonic stem cells (ESCs) were grown in the presence of leukemia inhibitory factor (LIF), thus retaining their undifferentiated self-renewing state (positive controls). Differentiation associated changes in gene expression were measured by replacing LIF with retinoic acid (RA), thus inducing differentiation of stem cells (negative controls). RNAi silencing of the 6 afore mentioned genes was done in (LIF+, RA-) cell cultures to investigate their potential for induced cell differentiation. Microarray expression measurements at 6 - 7 time points in one-day intervals were taken for the two controls (positive and negative) and the six RNAi assays. The dataset by Ivanova et al. (2006) was measured once on Affymetrix MOE430A and once on MOE430B chips. The authors normalized both datasets via the MAS 5.0 software (Hubbell et al., 2002). Here, only the Affymetrix MOE430A chip series is included.

## References

Ivanova, N., Dobrin, R., Lu, R., Kotenko, I., Levorse, J., DeCoste, C., Schafer, X., Lun, Y., and Lemischka, I. R. (2006). Dissecting self-renewal in stem cells with RNA interference. *Nature*, 442(7102):533-538.

Anchang, B., Sadeh, M. J., Jacob, J., Tresch, A., Vlad, M. O., Oefner, P. J., and Spang, R. (2009). Modeling the temporal interplay of molecular signaling and gene expression by using dynamic nested effects models. *Proceedings of the National Academy of Sciences of the United States of America*, 106(16):6447-52.

## See Also

[Ivanova2006RNAiTimeSeries](#)

## Examples

```
data("Ivanova2006RNAiTimeSeries")
dim(dat)
```

---

local.model.prior	<i>Computes a prior to be used for edge-wise model inference</i>
-------------------	--

---

### Description

The function `pairwise.posterior` infers a phenotypic hierarchy edge by edge by choosing between four models (unconnected, subset, superset, undistinguishable). For each edge, `local.model.prior` computes a prior distribution over the four models. It can be used to ensure sparsity of the graph and high confidence in results.

### Usage

```
local.model.prior(size,n,bias)
```

### Arguments

size	expected number of edges in the graph.
n	number of perturbed genes in the dataset, number of nodes in the graph
bias	the factor by which the double-headed edge is preferred over the single-headed edges

### Details

A graph on  $n$  nodes has  $N=n*(n-1)/2$  possible directed edges (one- or bi-directional). If each edge occurs with probability  $p$ , we expect to see  $Np$  edges in the graph. The function `local.model.prior` takes the number of genes ( $n$ ) and the expected number of edges (`size`) as an input and computes a prior distribution for edge occurrence: no edge with probability  $size/N$ , and the probability for edge existence being split over the three edge models with a bias towards the conservative double-headed model specified by `bias`. To ensure sparsity, the `size` should be chosen small compared to the number of possible edges.

### Value

a distribution over four states: a vector of four positive real numbers summing to one

### Author(s)

Florian Markowetz

### See Also

[pairwise.posterior](#), [nem](#)

### Examples

```
# uniform over the 3 edge models
local.model.prior(4,4,1)
# bias towards <->
local.model.prior(4,4,2)
```

---

nem *Nested Effects Models - main function*

---

## Description

The main function to perform model learning from data

## Usage

```
nem(D, inference="nem.greedy", models=NULL, control=set.default.parameters(setdiff(unique(colnames(D)), "id")))

## S3 method for class 'nem'
print(x, ...)
```

## Arguments

D	data matrix with experiments in the columns (binary or continuous)
inference	search to use exhaustive enumeration, triples for triple-based inference, pairwise for the pairwise heuristic, ModuleNetwork for the module based inference proposed in Fröhlich et al. 2008, ModuleNetwork.orig for the module based inference proposed in Fröhlich et al. 2007, nem.greedy for greedy hillclimbing, nem.greedyMAP for alternating MAP optimization using log odds or log p-value densities, mc.eminem for EM based inference using log odds or log p-value densities, BN.greedy, BN.exhaustive for a conventional Bayesian Network treatment using binomial or normal distribution assumptions, dynoNEM for MCMC based inference from time series data, mc.eminem for EM based inference
models	a list of adjacency matrices for model search. If NULL, an exhaustive enumeration of all possible models is performed.
control	list of parameters: see set.default.parameters
verbose	do you want to see progression statements? Default: TRUE
x	nem object
...	other arguments to pass

## Details

If parameter  $P_m \neq \text{NULL}$  and parameter  $\lambda = 0$ , a Bayesian approach to include prior knowledge is used. Alternatively, the regularization parameter  $\lambda$  can be tuned in a model selection step via the function `nemModelSelection` using the BIC criterion. If automated subset selection of effect reporters is used (default), the regularization parameter  $\delta$  can be tuned via the BIC model selection criterion. Per default it is fixed to  $1 / (\text{no. S-genes} + 1)$ .

The function `plot.nem` plots the inferred phenotypic hierarchy as a directed graph, the likelihood distribution of the models (only for exhaustive search) or the posterior position of the effected genes.

## Value

graph	inferred directed S-gene graph (graphNEL object)
mLL	log posterior marginal likelihood of model(s)
pos	posterior over effect positions

mappos	MAP estimate of effect positions
selected	selected E-gene subset
LLperGene	likelihood per selected E-gene
avg	in case of MCMC: posterior mean S-gene graph (edge weighted adjacency matrix)
control	hyperparameter as in function call

For inference = "mc.eminem" the following additional values are returned:

local.maxima	local maxima of the EM procedure
graphs.sampled	sampled graphs
EB	samples of the empirical Bayes prior
acc_list	list that indicates whether the corresponding sampled S-gene graph has been accepted (new local maximum (1), same local maximum (0)) or rejected(-1) in the MCMC sampling process - length(acc_list)=mcmc.nsamples + mcmc.nburnin

### Author(s)

Holger Froehlich, Florian Markowetz

### References

- Markowetz, F.; Bloch, J. & Spang, R., Non-transcriptional Pathway Features Reconstructed from Secondary Effects of RNA interference. *Bioinformatics*, 2005, 21, 4026 - 4032\
- Markowetz, F.; Kostka, D.; Troyanskaya, O. & Spang, R., Nested Effects Models for High-dimensional Phenotyping Screens. *Bioinformatics*, 2007, 23, i305 - i312\
- Fröhlich, H.; Fellmann, M.; Sultmann, H.; Poustka, A. & Beissbarth, T. Large Scale Statistical Inference of Signaling Pathways from RNAi and Microarray Data. *BMC Bioinformatics*, 2007, 8, 386\
- Fröhlich, H.; Fellmann, M.; Sultmann, H.; Poustka, A. & Beissbarth, T. Estimating Large Scale Signaling Networks through Nested Effect Models with Intervention Effects from Microarray Data. *Bioinformatics*, 2008, 24, 2650-2656\
- Tresch, A. & Markowetz, F., Structure Learning in Nested Effects Models *Statistical Applications in Genetics and Molecular Biology*, 2008, 7\
- Zeller, C.; Fröhlich, H. & Tresch, A., A Bayesian Network View on Nested Effects Models *EURASIP Journal on Bioinformatics and Systems Biology*, 2009, 195272\
- Fröhlich, H.; Tresch, A. & Beissbarth, T., Nested Effects Models for Learning Signaling Networks from Perturbation Data. *Biometrical Journal*, 2009, 2, 304 - 323\
- Fröhlich, H.; Sahin, Ö.; Arlt, D.; Bender, C. & Beissbarth, T. Deterministic Effects Propagation Networks for Reconstructing Protein Signaling Networks from Multiple Interventions. *BMC Bioinformatics*, 2009, 10, 322\
- Fröhlich, H.; Praveen, P. & Tresch, A., Fast and Efficient Dynamic Nested Effects Models. *Bioinformatics*, 2011, 27, 238-244\
- Niederberger, T.; Etzold, S.; Lidschreiber, M.; Maier, K.; Martin, D.; Fröhlich, H.; Cramer, P.; Tresch, A., MC Eminent Maps the Interaction Landscape of the Mediator, *PLoS Comp. Biol.*, 8(6): e1002568, 2012.

**See Also**

[set.default.parameters](#), [nemModelSelection](#), [nem.jackknife](#), [nem.bootstrap](#), [nem.consensus](#), [local.model.prior](#), [plot.nem](#)

**Examples**

```
data("BoutrosRNAi2002")
D <- BoutrosRNAiDiscrete[,9:16]
control = set.default.parameters(unique(colnames(D)), para=c(0.13, 0.05))
res1 <- nem(D,inference="search", control=control)
res2 <- nem(D,inference="pairwise", control=control)
res3 <- nem(D,inference="triples", control=control)
res4 <- nem(D,inference="ModuleNetwork", control=control)
res5 <- nem(D,inference="nem.greedy", control=control)
res6 = nem(BoutrosRNAiLods, inference="nem.greedyMAP", control=control)

par(mfrow=c(2,3))
plot.nem(res1,main="exhaustive search")
plot.nem(res2,main="pairs")
plot.nem(res3,main="triples")
plot.nem(res4,main="module network")
plot.nem(res5,main="greedy hillclimber")
plot.nem(res6,main="alternating MAP optimization")
```

---

nem.bootstrap

*Bootstrapping for nested effect models*

---

**Description**

Performs bootstrapping (resampling with replacement) on effect reporters to assess the statistical stability of networks

**Usage**

```
nem.bootstrap(D, thresh=0.5, nboot=1000,inference="nem.greedy",models=NULL,control=set.default.p

## S3 method for class 'nem.bootstrap'
print(x, ...)
```

**Arguments**

D	data matrix with experiments in the columns (binary or continuous)
thresh	only edges appearing with a higher frequency than "thresh" are returned
nboot	number of bootstrap samples desired
inference	search to use exhaustive enumeration, triples for triple-based inference, pairwise for the pairwise heuristic, ModuleNetwork for the module based inference, nem.greedy for greedy hillclimbing, nem.greedyMAP for alternating MAP optimization using log odds or log p-value densities
models	a list of adjacency matrices for model search. If NULL, an exhaustive enumeration of all possible models is performed.



control	list of parameters: see <code>set.default.parameters</code>
verbose	do you want to see progression statements? Default: TRUE
x	nem object
...	other arguments to pass

### Details

Calls `nem` or `nemModelSelection` internally, depending on whether or not `lambda` is a vector and `Pm != NULL`. For DEPNS a stratified bootstrap is carried out, where strata are defined on each replicate group for each time point.

### Value

nem object with edge weights being the bootstrap probabilities

### Author(s)

Holger Froehlich

### See Also

[nem.jackknife](#), [nem.consensus](#), [nem.calcSignificance](#), [nem](#)

### Examples

```
## Not run:
  data("BoutrosRNAi2002")
  D <- BoutrosRNAiDiscrete[,9:16]
  nem.bootstrap(D, control=set.default.parameters(unique(colnames(D)), para=c(0.13,0.05)))

## End(Not run)
```

---

nem.calcSignificance *Statistical significance of network hypotheses*

---

### Description

Assess statistical significance of a network hypothesis by comparing it to a null hypothesis.

### Usage

```
nem.calcSignificance(D, x, N=1000, which.test=c("permutation", "rand.net", "rand.modify"), seed=1
```

### Arguments

D	data matrix with experiments in the columns (binary or continuous)
x	nem object
N	number of random networks to sample
which.test	type of significance test to conduct (see details)
seed	random seed
mc.cores	number of cores to be used on a multicore processor

## Details

Given data,  $N$  random network hypotheses from a null distribution are drawn as follows: For each S-gene  $S_k$  we randomly choose a number  $o$  of outgoing edges between 0 and 3. We then select  $o$  S-genes having at most 1 ingoing edge, connected  $S_k$  to them and transitively closed the graph. For all random network hypotheses it is counted, how often their likelihood is bigger than that of the given network. This yields an exact p-value.

Another way of assessing the statistical significance of the network hypothesis is to draw random permutations of the node labels. Note that in this case the node degree distribution is the same as in the given network. Again, we can obtain an exact p-value by counting, how often the likelihood of the permuted network is bigger than that of the given network.

Finally, comparison to randomly perturbed networks (insertion, deletion or reversion of 1 edge) yields an exact p-value describing the stability of the network. For dynoNEMs network modification operations are edge weight increase, decrease and swap.

## Value

For "random" network: p-value of the network according to the null hypothesis that it is random. For permuted network: p-value of the network according to the null hypothesis that a network with permuted node labels is at least as good. For perturbed / modified network: p-value of the network according to the null hypothesis a randomly perturbed network is at least as good.

## Author(s)

Holger Froehlich

## See Also

[nem.consensus](#), [nem.jackknife](#), [nem.bootstrap](#), [nem](#)

## Examples

```
## Not run:
  data("BoutrosRNAi2002")
  D <- BoutrosRNAiDiscrete[,9:16]
  res = nem(D, control=set.default.parameters(unique(colnames(D)), para=c(0.13,0.05))) # get best network
  nem.calcSignificance(D,res) # assess its statistical significance

## End(Not run)
```

---

nem.consensus

*Statistically stabile nested effects models*

---

## Description

Performs bootstrapping (resampling with replacement) on E-genes and jackknife on S-genes to assess the statistical stability of networks. Only edges appearing with a higher frequency than a predescribed threshold in both procedures are regarded as statistical stable and appear in the so-called consensus network.

**Usage**

```
nem.consensus(D, thresh=0.5, nboot=1000, inference="nem.greedy", models=NULL, control=set.default.pa
```

```
## S3 method for class 'nem.consensus'
print(x, ...)
```

**Arguments**

D	data matrix with experiments in the columns (binary or continuous)
thresh	only edges appearing with a higher frequency than "thresh" in both, bootstrap and jackknife procedure, are regarded as statistically stable and trust worthy
nboot	number of bootstrap samples desired
inference	search to use exhaustive enumeration, triples for triple-based inference, pairwise for the pairwise heuristic, ModuleNetwork for the module based inference, nem.greedy for greedy hillclimbing, nem.greedyMAP for alternating MAP optimization using log odds or log p-value densities
models	a list of adjacency matrices for model search. If NULL, an exhaustive enumeration of all possible models is performed.
control	list of parameters: see set.default.parameters
verbose	do you want to see progression statements? Default: TRUE
x	nem object
...	other arguments to pass

**Details**

Calls [nem](#) or [nemModelSelection](#) internally, depending on whether or not lambda is a vector and Pm != NULL.

**Value**

consensus network (nem object)

**Author(s)**

Holger Froehlich

**See Also**

[nem.bootstrap](#), [nem.jackknife](#), [nem.calcSignificance](#), [nem](#)

**Examples**

```
## Not run:
data("BoutrosRNAi2002")
D <- BoutrosRNAiDiscrete[,9:16]
nem.consensus(D, control=set.default.parameters(unique(colnames(D)), para=c(0.13,0.05)))

## End(Not run)
```

---

nem.cont.preprocess     *Calculate classification probabilities of perturbation data according to control experiments*

---

### Description

Calculates probabilities of data to define effects of interventions with respect to wildtype/control measurements

### Usage

```
nem.cont.preprocess(D,neg.control=NULL,pos.control=NULL,nfold=2, influencefactor=NULL, empPval=.
```

### Arguments

D	matrix with experiments as columns and effect reporters as rows
neg.control	either indices of columns in D or a matrix with the same number of rows as D
pos.control	either indices of columns in D or a matrix with the same number of rows as D
nfold	fold-change between neg. and pos. controls for selecting effect reporters. Default: 2
influencefactor	factor multiplied onto the probabilities, so that all negative control genes are treated as influenced, usually automatically determined
empPval	empirical p-value cutoff for effects if only one control is available
verbose	Default: TRUE

### Details

Determines the empirical distributions of the controls and calculates the probabilities of perturbation data to belong to the control distribution(s).

### Value

dat	data matrix
pos	positive controls [in the two-controls setting]
neg	negative controls [in the two-controls setting]
sel	effect reporters selected [in the two-controls setting]
prob.influenced	probability of a reporter to be influenced
influencefactor	factor multiplied onto the probabilities, so that all negative control genes are treated as influenced

### Note

preliminary! will be developed to be more generally applicable

### Author(s)

Florian Markowetz

**References**

Markowitz F, Bloch J, Spang R, Non-transcriptional pathway features reconstructed from secondary effects of RNA interference, *Bioinformatics*, 2005

**See Also**

[BoutrosRNAi2002](#)

**Examples**

```
data("BoutrosRNAi2002")
preprocessed <- nem.cont.preprocess(BoutrosRNAiExpression,neg.control=1:4,pos.control=5:8)
```

---

nem.discretize	<i>Discretize perturbation data according to control experiments</i>
----------------	--

---

**Description**

discretizes raw data to define effects of interventions with respect to wildtype/control measurements

**Usage**

```
nem.discretize(D,neg.control=NULL,pos.control=NULL,nfold=2,cutoff=0:10/10, pCounts=20, empPval=.
```

**Arguments**

D	matrix with experiments as columns and effect reporters as rows
neg.control	either indices of columns in D or a matrix with the same number of rows as D
pos.control	either indices of columns in D or a matrix with the same number of rows as D
nfold	fold-change between neg. and pos. controls for selecting effect reporters. Default: 2
cutoff	a (vector of) cutoff value(s) weighting the pos. controls versus the neg. controls. Default: 0:10/10
pCounts	pseudo-counts to guard against unreasonable low error estimates
empPval	empirical p-value cutoff for effects if only one control is available
verbose	Default: TRUE

**Details**

Chooses cutoff such that separation between negative and positive controls becomes optimal.

**Value**

dat	discretized data matrix
pos	discretized positive controls [in the two-controls setting]
neg	discretized negative controls [in the two-controls setting]
sel	effect reporters selected [in the two-controls setting]
cutoff	error rates for different cutoff values [in the two-controls setting]
para	estimated error rates [in the two-controls setting]

**Note**

preliminary! will be developed to be more generally applicable

**Author(s)**

Florian Markowetz

**References**

Markowetz F, Bloch J, Spang R, Non-transcriptional pathway features reconstructed from secondary effects of RNA interference, *Bioinformatics*, 2005

**See Also**

[BoutrosRNAi2002](#)

**Examples**

```
# discretize Boutros data as in
# Markowetz et al, 2005
data("BoutrosRNAi2002")
disc <- nem.discretize(BoutrosRNAiExpression,neg.control=1:4,pos.control=5:8,cutoff=.7)
stopifnot(disc$dat==BoutrosRNAiDiscrete[,9:16])
```

---

nem.jackknife

*Jackknife for nested effect models*

---

**Description**

Assesses the statistical stability of a network via a jackknife procedure: Each S-gene is left out once and the network reconstructed on the remaining ones. The relative frequency of each edge to appear in n-1 jackknife samples is returned.

**Usage**

```
nem.jackknife(D, thresh=0.5, inference="nem.greedy",models=NULL,control=set.default.parameters(u

## S3 method for class 'nem.jackknife'
print(x, ...)
```

**Arguments**

D	data matrix with experiments in the columns (binary or continuous)
thresh	only edges appearing with a higher frequency than "thresh" are returned
inference	search to use exhaustive enumeration, triples for triple-based inference, pairwise for the pairwise heuristic, ModuleNetwork for the module based inference, nem.greedy for greedy hillclimbing, nem.greedyMAP for alternating MAP optimization using log odds or log p-value densities
models	a list of adjacency matrices for model search. If NULL, an exhaustive enumeration of all possible models is performed.
control	list of parameters: see set.default.parameters

verbose	do you want to see progression statements? Default: TRUE
x	nem object
...	other arguments to pass

**Details**

Calls `nem` or `nemModelSelection` internally, depending on whether or not parameter `lambda` is a vector and parameter `Pm` != NULL.

**Value**

nem object with edge weights being the jackknife probabilities

**Author(s)**

Holger Froehlich

**See Also**

[nem.bootstrap](#), [nem.consensus](#), [nem](#), [nemModelSelection](#)

**Examples**

```
## Not run:
  data("BoutrosRNAi2002")
  D <- BoutrosRNAiDiscrete[,9:16]
  nem.jackknife(D, control=set.default.parameters(unique(colnames(D)), para=c(0.13,0.05)))

## End(Not run)
```

---

nemModelSelection	<i>Model selection for nested effect models</i>
-------------------	---

---

**Description**

Infers models with different regularization constants, compares them via the BIC or AIC criterion and returns the highest scoring one

**Usage**

```
nemModelSelection(lambdas,D,inference="nem.greedy",models=NULL,control=set.default.parameters(un
```

**Arguments**

lambdas	vector of regularization constants
D	data matrix with experiments in the columns (binary or continuous)
inference	search to use exhaustive enumeration, triples for triple-based inference, pairwise for the pairwise heuristic, ModuleNetwork for the module based inference, nem.greedy for greedy hillclimbing, nem.greedyMAP for alternating MAP optimization using log odds or log p-value densities

models	a list of adjacency matrices for model search. If NULL, an exhaustive enumeration of all possible models is performed.
control	list of parameters: see <code>set.default.parameters</code>
verbose	do you want to see progression statements? Default: TRUE
...	other arguments to pass to function <code>nem</code> or <code>network.AIC</code>

### Details

`nemModelSelection` internally calls `nem` to infer a model with a given regularization constant. The comparison between models is based on the BIC or AIC criterion, depending on the parameters passed to `network.AIC`.

### Value

`nem` object

### Author(s)

Holger Froehlich

### See Also

[set.default.parameters](#), [nem](#), [network.AIC](#)

### Examples

```
data("BoutrosRNAi2002")
D <- BoutrosRNAiDiscrete[,9:16]
hyper = set.default.parameters(unique(colnames(D)), para=c(0.13, 0.05), Pm=diag(4))
res <- nemModelSelection(c(0.1,1,10), D, control=hyper)

plot.nem(res,main="highest scoring model")
```

---

network.AIC

*AIC/BIC criterion for network graph*

---

### Description

Calculate AIC/BIC for a given network graph (should be transitively closed). The number of free parameters equals the number of unknown edges in the network graph.

### Usage

```
network.AIC(network,Pm=NULL,k=length(nodes(network$graph)),verbose=TRUE)
```

### Arguments

network	a <code>nem</code> object (e.g. 'pairwise')
Pm	prior over models (n x n matrix). If NULL, then a matrix of 0s is assumed
k	penalty per parameter in the AIC/BIC calculation. k = 2 for classical AIC
verbose	print out the result



**Details**

For  $k = \log(n)$  the BIC (Schwarz criterion) is computed. Usually this function is not called directly but from `nemModelSelection`

**Value**

AIC/BIC value

**Author(s)**

Holger Froehlich

**See Also**

[nemModelSelection](#)

**Examples**

```
data("BoutrosRNAi2002")
D = BoutrosRNAiDiscrete[,9:16]
control = set.default.parameters(unique(colnames(D)), para=c(0.13,0.05))
res1 <- nem(D, control=control)
network.AIC(res1)
control$lambda=100 # enforce sparsity
res2 <- nem(D,control=control)
network.AIC(res2)
```

---

NiederbergerMediator2012

*Expression measurements upon perturbation of Mediator subunits*

---

**Description**

This dataset combines expression data from 4 gene perturbation studies in *S. cerevisiae*, including the perturbations of the 9 Mediator subunits Med2, Med7 (N-terminus), Med7 (C-terminus), Med10, Med15, Med19, Med20, Med21 and Med31. Med10 and Med21 have been combined due to indistinguishable results.

**Usage**

```
data(NiederbergerMediator2012)
```

**Format**

NiederbergerMediatorLods: data matrix(log-odds ratios): 2578 x 8 NiederbergerMediatorLogFC: data matrix(log2 fold-changes): 2578 x 8 NiederbergerMediatorPVals: data matrix(p-values): 2578 x 8

## Details

The data has been preprocessed using the R/Bioconductor package limma. The results have been filtered as follows: The original data contains a double-knockout Med7N/Med31, which can't be assessed by EMINEM and has thus been removed. Analysis of the data revealed genes showing batch-specific effects, they have been excluded from further analysis. Finally, genes that do not react to any perturbation have been removed since they do not contain additional information. For a more detailed description of the individual studies and datasets as well as further information on data processing and results, please refer to Niederberger et al, 2012. The raw data is available on Array Express (accession number [provided upon publication]).

NiederbergerMediatorLods: the log-odds ratios NiederbergerMediatorLogFC: the log2 fold-changes NiederbergerMediatorPVals: the corresponding p-values

## References

Niederberger T., Etzold S., Lidschreiber M., Maier K.C., Martin D.E., Fr"o hlich H., Cramer P., Tresch A., MC EMINEM Maps the Interaction Landscape of the Mediator. PLoS Computational Biology, 8(6): e1002568, 2012-

## Examples

```
data(NiederbergerMediator2012)
dim(NiederbergerMediatorLods)
dim(NiederbergerMediatorLogFC)
dim(NiederbergerMediatorPVals)
```

---

plot.nem

*plot nested effect model*

---

## Description

plot graph of nested effects model, the marginal likelihood distribution or the posterior position of the effected genes

## Usage

```
## S3 method for class 'nem'
plot(x, what="graph", remove.singletons=FALSE, PDF=FALSE, filename="nemplot.pdf", thresh=0, trans
```

## Arguments

x	nem object to plot
what	(i), "graph", (ii) "mLL" = likelihood distribution, (iii) "pos" = posterior position of effected genes
remove.singletons	remove unconnected nodes from the graph plot
PDF	output as PDF-file
filename	filename of PDF-file
thresh	if x has a real valued adjacency matrix (weight matrix), don't plot edges with  weight  <= thresh

transitiveReduction	plot a transitively reduced graph
plot.probs	plot edge weights/probabilities. If regulation directions have been inferred (see <code>infer.edge.type</code> ), upregulated edges are drawn red and downregulated edges blue. Edges, where no clear direction could be inferred, are drawn in black.
SCC	plot the strongly connected components graph
D	Visualize the nested subset structure of the dataset via <code>plotEffects</code> along with the graph and show the linking of E-genes to S-genes in the dataset. Should only be used for small networks. Default: Just plot the graph
draw.lines	If the nested subset structure is shown, should additionally lines connecting S-genes and their associated E-genes be drawn? <b>WARNING:</b> For larger datasets than e.g. 5 S-genes this most probably does not work, because the nested subset structure picture then partially overlaps with the graph picture. Default: Do not draw these lines
palette	color palette to use: either 'BlueRed' (default) or 'Grey'
...	other arguments to be passed to the Rgraphviz plot function or to the graphics 'image' function.

**Value**

none

**Author(s)**

Florian Markowetz, Holger Froehlich

**See Also**[nem](#), [plotEffects](#), [infer.edge.type](#)

---

`plotEffects`*Plots data according to a phenotypic hierarchy*

---

**Description**

`plotEffects` visualizes the subset structure in the data by reordering rows and columns according to the topological order given by a phenotypic hierarchy.

**Usage**

```
plotEffects(D, nem, border=TRUE, legend=TRUE, order=NULL, orderSCC=TRUE, palette="BlueRed", ...)
```

**Arguments**

D	data matrix
nem	phenotypic hierarchy (object of class 'score' or 'pairwise')
border	draw red lines to indicate gene-specific effect reporters. Default: TRUE
legend	plot a legend. Default: TRUE

order	pre-define an order of the S-genes instead of the topological order to visualize the subset structure. Default: Use topological order.
orderSCC	Is the pre-defined order given on strongly connected components rather than on individual nodes?
palette	color palette to use: either 'BlueRed' (default) or 'Grey'
...	additional parameters for the graphics function 'image'

**Details**

The experiments in the columns are reordered according to the topological order given by a phenotypic hierarchy. The effect reporters in the rows are grouped together by their position in the hierarchy. The groups are then arranged by topological order. Within each group the rows are hierarchically clustered.

**Value**

ordering of the E-genes according to the hierarchy (vector of indices)

**Note**

This function was formerly named `plot.effects`. This naming is not possible any more, since S3 classes were used for the function `plot.nem`.

**Author(s)**

Florian Markowetz, Holger Froehlich

**Examples**

```
data("BoutrosRNAi2002")
D <- BoutrosRNAiDiscrete[,9:16]
res <- nem(D,control=set.default.parameters(unique(colnames(D)), para=c(.13,.05))
if(require(Rgraphviz))
plotEffects(D,res)
```

---

`prior.EgeneAttach.EB` *Initialize E-gene attachment prior for empirical Bayes*

---

**Description**

This function computes an initial prior for the attachment of E-genes based on observed log-pvalue densities or log-odds ratios. This prior can then be updated within an empirical Bayes procedure (MC.EMiNEM).

**Usage**

```
prior.EgeneAttach.EB(ratioMat)
```

**Arguments**

`ratioMat` data matrix with experiments in the columns (log-odds ratios or log-pvalue densities)

**Value**

$|E\text{-genes}| \times (|S\text{-genes}| + 1)$  matrix with prior E-gene attachment probabilities. The last column denotes the virtual 'null' S-gene, which is there to filter E-genes that have no obvious attachment to any of the real S-genes.

**Author(s)**

Theresa Niederberger, Holger Froehlich

**References**

Niederberger, T.; Etzold, S.; Lidschreiber, M; Maier, K.; Martin, D.; Froehlich, H.; Cramer, P.; Tresch, A., MC EMINEM Maps the Interaction Landscape of the Mediator, PLoS Comp. Biol., 2012, submitted.

**See Also**

[set.default.parameters](#), [nem](#)

**Examples**

```
# only for test purposes
data("BoutrosRNAi2002")
D <- BoutrosRNAiDens
control = set.default.parameters(unique(colnames(D)), Pe=prior.EgeneAttach.EB(D), mcmc.nsamples=100, mcmc)
res <- nem(D, inference="mc.eminem", control=control)
if(require(Rgraphviz))
  plot(res)
```

---

prune.graph

*Prunes spurious edges in a phenotypic hierarchy*

---

**Description**

A heuristic to prune spurious edges in a phenotypic hierarchy

**Usage**

```
prune.graph(g, cutIN=NULL, cutOUT=NULL, quant=.95, verbose=TRUE)
```

**Arguments**

<code>g</code>	an adjacency matrix or a 'graphNEL' object
<code>cutIN</code>	minimum number of missing in-edges required to cut all in-edges. Default
<code>cutOUT</code>	minimum number of missing out-edges required to cut all out-edges
<code>quant</code>	if 'cutIN' or 'cutOUT' are not assigned, a quantile 'quant' of the distribution of missing in- or out-edges for all nodes is used
<code>verbose</code>	Default: TRUE

**Details**

`prune.graph` provides a heuristic approach to prune surrious edges. `prune.graph` compares the input graph to its transitive closure, and counts for each node how many incoming and outgoing edges are missing. If the number is bigger than a user-defined cutoff, all incoming (outgoing) edges are removed.

**Value**

<code>graph</code>	the pruned phenotypic hierarchy (a 'graphNEL' object)
<code>removed</code>	number of removed edges
<code>missing.in</code>	number of missing in-edges for each node
<code>missing.out</code>	number of missing out-edges for each node

**Author(s)**

Florian Markowetz

**Examples**

```
# a transitively closed core with two spurious edges
g <- matrix(0,5,5)
g[1,2] <- 1
g[2,c(3,4)] <- 1
g[3,4] <- 1
g[4,5] <- 1
dimnames(g) <- list(LETTERS[1:5],LETTERS[1:5])
g <- as(g,"graphNEL")

# prune graph
gP <- prune.graph(g)

# plot
if(require(Rgraphviz)){
  par(mfrow=c(1,2))
  plot(g,main="two spurious edges")
  plot(gP$graph,main="pruned")
}
```

---

quicknem

*Quick run of Nested Effects Models inference*

---

**Description**

Interface to learn NEM models from data

**Usage**

```
quicknem(D, type="CONTmLLDens", inference="nem.greedy", controls.name=NULL, contrasts=NULL, normalize
```

**Arguments**

D	ExpressionSet object or data matrix with raw or normalized expression data.
type	Parameter estimation, either mLL, FULLmLL, CONTmLL, CONTmLLBayes, CONTmLLMAP, depn.
inference	search to use exhaustive enumeration, triples for triple-based inference, pairwise for the pairwise heuristic, ModuleNetwork for the module based inference, nem.greedy for greedy hillclimbing, nem.greedyMAP for alternating MAP optimization using log odds or log p-value densities
controls.name	Pattern to search for in the columnnames of D. Defines which columns in D should be regarded as controls.
contrasts	String defining the contrasts to estimate via limma
normalize	boolean value, should quantile normalization be performed
cutoff	P-value cutoff for differential expression using adjusted p.values from limma.
DIR	Directory name, where additional informative plots should be stored. Created if not present.
plot	Should the inferred network be plotted?
bootstrap	Integer defining the number of bootstrapping samples to be performed. Defaults to 0.
...	other arguments to pass

**Details**

Wrapper function for call of nem inference. Extracts differential genes for given contrasts and infers a NEM - graph for the given inference type.

**D** Is either an ExpressionSet Object or a matrix/data.frame containing the expression values from the siRNA knockdown experiments. If an ExpressionSet, the data is extracted via `exprs(ExpressionSet)`. The knockdowns must be in the columns, the measured effect genes in the rows of the expression matrix.

**type** mLL or FULLmLL or CONTmLL or CONTmLLBayes or CONTmLLMAP or depn. CONTmLLDens and CONTmLLRatio are identical to CONTmLLBayes and CONTmLLMAP and are still supported for compatibility reasons. mLL and FULLmLL are used for binary data (see `BoutrosRNAiDiscrete`) and CONTmLL for a matrix of effect probabilities. CONTmLLBayes and CONTmLLMAP are used, if log-odds ratios, p-value densities or any other model specifies effect likelihoods. CONTmLLBayes refers to an inference scheme, were the linking positions of effect reporters to network nodes are integrated out, and CONTmLLMAP to an inference scheme, were a MAP estimate for the linking positions is calculated. depn indicates Deterministic Effects Propagation Networks (DEPNs).

**inference** Type of network reconstruction. search enumerates all possible networks. Set to triples, pairwise, ModuleNetwork, nem.greedy or nem.greedyMAP for heuristic search of the network.

**controls.name** Defines a pattern to search for in the column names of D, which describes the control experiments. Each remaining experiment is then compared via limma to these controls by defining the appropriate contrasts. If NULL, then controls.name must be given, except for using type="depn", where neither controls.name nor contrasts needs to be defined.

**contrasts** Defines the contrasts of interest that should be used for the limma analysis. If NULL, then controls.name must be given, except for using type="depn", where neither controls.name nor contrasts needs to be defined.

**DIR** In case of type="CONTmLLDens" or type="CONTmLLBayes" some additional plots for the BUM model fits are created and stored here.

**Value**

graph	the inferred directed graph (graphNEL object)
mLL	log posterior marginal likelihood of final model
pos	posterior over effect positions
mappos	MAP estimate of effect positions
selected	selected E-gene subset
LLperGene	likelihood per selected E-gene
control	hyperparameter as in function call
bootstrap	Integer number defining how many bootstrap samples should be drawn. If 0, no bootstrapping will be performed. Else, <code>nem.bootstrap</code> will be called internally.

**Author(s)**

Christian Bender, Holger Froehlich, Florian Markowetz

**See Also**

[nem](#), [set.default.parameters](#), [nemModelSelection](#), [nem.jackknife](#), [nem.bootstrap](#), [nem.consensus](#), [local.model.prior](#), [plot.nem](#)

**Examples**

```
## Not run:
data(BoutrosRNAi2002)
exps <- colnames(BoutrosRNAiExpression)
res <- quicknem(BoutrosRNAiExpression,controls="control")
res <- quicknem(BoutrosRNAiExpression,controls="control",type="CONTmLLRatio")
res <- quicknem(BoutrosRNAiExpression,controls="control",type="CONTmLLRatio",inference="ModuleNetwork")
contrasts <- c("rel-control","rel-LPS","key-control","key-LPS","tak-control","tak-LPS","mkk4hep-control","m
res <- quicknem(BoutrosRNAiExpression,contrasts=contrasts)

data(SahinRNAi2008)
dat <- dat.unnormalized #[,sample(1:17,5)]
res <- quicknem(dat,type="depn")

## End(Not run)
```

---

SahinRNAi2008

*Combinatorial Protein Knockdowns in the ERBB Signaling Pathway*

---

**Description**

Sixteen RNAi knockdowns (including 3 double knockdowns) of proteins in the ERBB signaling pathway of trastuzumab resistant breast cancer cells were conducted. Reverse Phase Protein Array (RPPA) measurements for 10 signaling intermediates are available before and after EGF stimulation with 4 technical and 3 biological replicates.

**Usage**

```
data(SahinRNAi2008)
```



## Format

dat.unnormalized: 408 x 17 matrix (rows = RPPA measurements for (16 KOs + MOCK) x 4 technical x 3 biological replicates, columns = 10 antibodies + 6 proteins without measurements + time) dat.normalized: 408 x 17 matrix (measurements from technical and biological replicates are quantile normalized for each RNAi experiment) map.int2node: list with names being interventions (=names of dat.normalized) and entries being node names (=column names of dat.normalized)

## Details

The cells were lysed on ice by scraping the cells in M-PER lysis buffer (Pierce, Rockford, IL) containing protease inhibitor Complete Mini (Roche, Basel), anti-phosphatase PhosSTOP (Roche, Basel), 10 mM NaF and 1mM Na4VO3. Protein concentrations were determined with a BCA Protein Assay Reagent Kit (Pierce, Rockford, IL). Lysates were mixed 1:2 with 2 times Protein Arraying Buffer (Whatman, Brentfort, UK) to obtain a final protein concentration of 1.5 µg/µL. Briefly, these lysates were printed onto nitrocellulose coated ONCYTE-slides (Grace Bio Labs, Bend, USA) using a non-contact piezo spotter, sciFlexarrayer S5 (Scienion, Berlin, Germany). After primary and near-infrared (NIR)-dye labeled secondary antibodies applied, spots were analysed using an Odyssey scanner (LI-COR, Lincoln, USA) and signal intensities were quantified using Odyssey 2.0 software (For detailed information and an antibody list, see Sahin et al., 2008). Since no antibody against MEK1 was available, we measured protein expression of pERK1/2, which is downstream of MEK1.

## References

Oezguer Sahin, Holger Froehlich, Christian Loebke, Ulrike Korf, Sara Burmester, Meher Majety, Jens Mattern, Ingo Schupp, Claudine Chaouiya, Denis Thieffry, Annemarie Poustka, Stefan Wiemann, Tim Beissbarth, Dorit Arlt, Modeling ERBB receptor-regulated G1/S transition to find novel targets for de novo trastuzumab resistance, BMC Systems Biology, 2008

## See Also

[BoutrosRNAi2002](#)

## Examples

```
data("SahinRNAi2008")
dim(dat.normalized)
dim(dat.unnormalized)
```

---

SCCgraph

*Combines Strongly Connected Components into single nodes*

---

## Description

SCCgraph is used to identify all nodes which are not distinguishable given the data.

## Usage

```
SCCgraph(x, name=TRUE, nlength=20)
```

**Arguments**

x	graphNEL object or an adjacency matrix
name	Concatenate all names of summarized nodes, if TRUE, or number nodes, if FALSE. Default: TRUE
nlength	maximum length of names

**Details**

A graph inferred by either `nem` or `nemModelSelection` may have cycles if some phenotypic profiles are not distinguishable. The function `SCCgraph` identifies cycles in the graph (the strongly connected components) and summarizes them in a single node. The resulting graph is then acyclic.

**Value**

graph	a graphNEL object with connected components of the input graph summarized into single nodes
scc	a list mapping SCCs to nodes
which.scc	a vector mapping nodes to SCCs

**Author(s)**

Florian Markowetz, Holger Froehlich

**See Also**

[nem](#), [transitive.reduction](#)

**Examples**

```
data("BoutrosRNAi2002")
D <- BoutrosRNAiDiscrete[,9:16]
res <- nem(D,control=set.default.parameters(unique(colnames(D)), para=c(.13,.05))
#
sccg <- SCCgraph(res$graph,name=TRUE)
#
par(mfrow=c(1,2))
if(require(Rgraphviz)){
  plot.nem(res, main="inferred from data")
  plot(sccg$graph, main="condensed (rel,key)")
}
```

---

set.default.parameters

*Get/set hyperparameters*

---

**Description**

Allows to set and retrieve various hyperparameters for different inference methods.

**Usage**

```
set.default.parameters(Sgenes, ...)
```

**Arguments**

**Sgenes** character vector of S-gene identifiers  
 ... parameters to set (see details)

**Details**

Since version 2.5.4 functions in the nem package do not have any more a large amount of individual parameters. Instead there is just one hyperparameter, which is passed to all functions. Parameter values with the hyperparameter can be set with this function.

**type** mLL or FULLmLL or CONTmLL or CONTmLLBayes or CONTmLLMAP or deprn. CONTmLLDens and CONTmLLRatio are identical to CONTmLLBayes and CONTmLLMAP and are still supported for compatibility reasons. mLL and FULLmLL are used for binary data (see BoutrosRNAiDiscrete) and CONTmLL for a matrix of effect probabilities. CONTmLLBayes and CONTmLLMAP are used, if log-odds ratios, p-value densities or any other model specifies effect likelihoods. CONTmLLBayes refers to an inference scheme, were the linking positions of effect reporters to network nodes are integrated out, and CONTmLLMAP to an inference scheme, were a MAP estimate for the linking positions is calculated. deprn indicates Deterministic Effects Propagation Networks (DEPNs).

**para** vector of length two: false positive rate and false negative rate for binary data. Used by mLL

**hyperpara** vector of length four: used by FULLmLL() for binary data

**Pe** prior of effect reporter positions in the phenotypic hierarchy (same dimension as D). Not used type deprn. Default: NULL

**Pm** prior over models (n x n matrix). Default: NULL

**Pm.frac\_edges** expected fraction of edges in the true S-gene graph

**Pmlocal** local model prior for pairwise and triple learning. For pairwise learning generated by local.model.prior according to arguments local.prior.size and local.prior.bias

**local.prior.size** prior expected number of edges in the graph (for pairwise learning). Default: no. nodes

**local.prior.bias** bias towards double-headed edges. Default: 1 (no bias; for pairwise learning)

**triples.thrsh** threshold for model averaging to combine triple models for each edge. Default: 0.5

**lambda** regularization parameter to incorporate prior assumptions. May also be a vector of possible values, if nemModelSelection is used, Default: 0 (no regularization)

**delta** regularization parameter for automated subset selection of effect reporters. If no E-gene selection is wanted, set delta to 0. Default: 1/(no. S-genes + 1)

**selEGenes.method** If "regularization", E-gene selection is performed by introducing a "null" S-gene to which E-genes are attached with probability delta/(no. S-genes + 1). If "iterative" and selEGenes=TRUE, getRelevantEGenes is called and a new model is trained on the selected E-genes. The process is then repeated until convergence. Default: "regularization"

**selEGenes** Tune parameter delta for automated selection of E-genes. Default: FALSE. NOTE: Since version > 2.18.0 E-gene selection is now performed per default by using the regularization mechanism with parameter delta. If no E-gene selection is wanted, set delta to 0.

**trans.close** Should always transitive closed graphs be computed? Default: TRUE. NOTE: This has only an impact for type nem.greedyMAP and deprn. Default: TRUE

**backward.elimination** For module networks and greedy hillclimbing inference: Try to eliminate edges increasing the likelihood. Works only, if trans.close=FALSE. Default: FALSE

- mode** For Bayesian network inference and DEPNs: binary\_ML: effects come from a binomial distribution - ML learning of parameters (Bayesian networks only); binary\_Bayesian: effects come from a binomial distribution - Bayesian learning of parameters (Bayesian networks only); continuous\_ML: effects come from a normal distribution - ML learning of parameters; continuous\_Bayesian: effects come from a normal distribution - Bayesian learning of parameters.
- nu.intervention, lambda.intervention** For depn: For any perturbed node we suppose the unknown mean  $\mu$  given its unknown variance  $\sigma^2$  to be drawn from  $N(\text{nu.intervention}, \sigma^2/\text{lambda.intervention})$ . Default: nu.intervention=0.6, lambda.intervention=4
- nu.no\\_intervention, lambda.no\\_intervention** The same parameters for unperturbed nodes. Default: nu.no\\_intervention=0.95, lambda.no\\_intervention=4
- df.intervention, scale.intervention** For depn: The unknown variance  $\sigma^2$  for perturbed nodes is supposed to be drawn from  $\text{Inv-}\chi^2(\text{df.intervention}, \text{scale.intervention})$ . Default: df.intervention=4.4, scale.intervention=4.4
- df.no\\_intervention, scale.no\\_intervention** The same parameters for unperturbed nodes. Default: df.no\\_intervention=4.4, scale.no\\_intervention=0.023
- map** For depn: Mapping of interventions to network nodes. The format is a named list of strings with names being the interventions and entries being the network nodes. Default: Entries and names are the network nodes.
- outputdir** Directory where to put diagnostic plots. Default: folder "QualityControl" in current working directory
- debug** Print out or plot diagnostic information. Default: FALSE
- mc.cores** number of cores to be used on a multicore processor. Default: 8
- mcmc.nsamples** Number of MCMC samples to take. Default: 1e6
- mcmc.nburnin** Number of additional samples for burnin phase. Default: 1e6
- mcmc.seed** random seed. Default: 1234
- mcmc.hyperprior** Parameter for exponential distribution hyperprior for regularization parameter  $1/\lambda$ . Default: 1
- eminem.maxsteps** Maximum number of iterations for the EM algorithm (MC.EMINEM). Default: 1000
- eminem.sdVal** positive number, between 1 and  $\text{ncol}(D) * (\text{ncol}(D) - 1)$ : number of edges to change in one MCMC step; see paper for the author's choice. Default: 1
- eminem.changeHfreq** positive number, mcmc.nsamples must be a multiple: the Empirical Bayes step is performed every <changeHfreq> steps (see paper for the author's choice); set  $\geq$  mcmc.nsamples (or leave to default) to exclude this step. Default: NULL
- prob.cutoff** Only edges with probability  $>$  prob.cutoff are assumed to be present. Default: 0.5

### Value

A list containing all parameters described above.

### Author(s)

Holger Froehlich

## References

- Markowetz, F.; Bloch, J. & Spang, R., Non-transcriptional Pathway Features Reconstructed from Secondary Effects of RNA interference. *Bioinformatics*, 2005, 21, 4026 - 4032\
- Markowetz, F.; Kostka, D.; Troyanskaya, O. & Spang, R., Nested Effects Models for High-dimensional Phenotyping Screens. *Bioinformatics*, 2007, 23, i305 - i312\
- Fröhlich, H.; Fellmann, M.; Sultmann, H.; Poustka, A. & Beissbarth, T. Large Scale Statistical Inference of Signaling Pathways from RNAi and Microarray Data. *BMC Bioinformatics*, 2007, 8, 386\
- Fröhlich, H.; Fellmann, M.; Sultmann, H.; Poustka, A. & Beissbarth, T. Estimating Large Scale Signaling Networks through Nested Effect Models with Intervention Effects from Microarray Data. *Bioinformatics*, 2008, 24, 2650-2656\
- Tresch, A. & Markowetz, F., Structure Learning in Nested Effects Models *Statistical Applications in Genetics and Molecular Biology*, 2008, 7\
- Zeller, C.; Fröhlich, H. & Tresch, A., A Bayesian Network View on Nested Effects Models *EURASIP Journal on Bioinformatics and Systems Biology*, 2009, 195272\
- Fröhlich, H.; Tresch, A. & Beissbarth, T., Nested Effects Models for Learning Signaling Networks from Perturbation Data. *Biometrical Journal*, 2009, 2, 304 - 323\
- Fröhlich, H.; Sahin, V.O.; Arlt, D.; Bender, C. & Beissbarth, T. Deterministic Effects Propagation Networks for Reconstructing Protein Signaling Networks from Multiple Interventions. *BMC Bioinformatics*, 2009, 10, 322\
- Fröhlich, H.; Praveen, P. & Tresch, A., Fast and Efficient Dynamic Nested Effects Models. *Bioinformatics*, 2011, 27, 238-244\
- Niederberger, T.; Etzold, S.; Lidschreiber, M; Maier, K.; Martin, D.; Fröhlich, H.; Cramer, P.; Tresch, A., MC Eminem Maps the Interaction Landscape of the Mediator, *PLoS Comp. Biol.*, 2012, submitted.

## Examples

```
control = set.default.parameters(LETTERS[1:5], type="CONTmLLBayes", selGenes=TRUE) # set inference type and
```

---

```
sim.intervention          Simulate interventions in a Nested Effects Model
```

---

## Description

Simulates a knock-down of a list of network nodes and returns the network nodes and effect reporters, where effects are expected.

## Usage

```
sim.intervention(x, int, T=1)
```

## Arguments

x	nem object
int	a character vector of nodes in the network
T	number of time steps to be simulated (only for dynoNEMs)

**Value**

list with two slots:

`Sgenes.effectuated`

effectuated network nodes (by intervention)

`Egenes.effectuated`

most likely effectuated downstream effect reporters (by intervention)

`Egenes.effectuated.prob`

probability of each reporter to be effectuated by the respective intervention experiment.

**Author(s)**

Holger Froehlich

**Examples**

```
data("BoutrosRNAi2002")
D <- BoutrosRNAiDiscrete[,9:16]
res = nem(D, control=set.default.parameters(unique(colnames(D)), para=c(0.13,0.05)))
sim.intervention(res, "rel") # simulate knock-down of rel
```

---

subsets

*Subsets*

---

**Description**

subsets

**Usage**

```
subsets(n, r, v = 1:n, set = TRUE)
```

**Arguments**

n	bli
r	bla
v	blo
set	blu

**Details**

taken from the programmers corner of some R-News issue by Dennis

**Value**

n	bli
r	bla
v	blo

**Author(s)**

Dennis Kostka

**Examples**

## bla

---

transitive.closure     *Computes the transitive closure of a directed graph*


---

**Description**

Computes the transitive closure of a graph. Introduces a direct edge whenever there is a path between two nodes in a digraph.

**Usage**

```
transitive.closure(g, mat=FALSE, loops=TRUE)
```

**Arguments**

<code>g</code>	graphNEL object or adjacency matrix.
<code>mat</code>	convert result to adjacency matrix.
<code>loops</code>	Add loops from each node to itself?

**Details**

This function calculates the transitive closure of a given graph. We use the matrix exponential to find the transitive closure.

**Value**

returns a graphNEL object or adjacency matrix

**Author(s)**

Florian Markowetz

**See Also**

[transitive.reduction](#)

**Examples**

```
V <- LETTERS[1:3]
edL <- list(A=list(edges="B"),B=list(edges="C"),C=list(edges=NULL))
g <- new("graphNEL",nodes=V,edgeL=edL,edgemode="directed")
gc <- transitive.closure(g,loops=FALSE)

if(require(Rgraphviz)){
  par(mfrow=c(1,2))
  plot(g,main="NOT transitively closed")
  plot(gc,main="transitively closed")
}
```

transitive.projections

*Computes the transitive approximation of a directed graph*

---

### Description

Computes the transitive approximation of a graph. The transitive approximation of a graph is a graph that is "almost" transitively closed and has minimal distance to the input graph.

### Usage

```
transitive.projections(adjmat)
```

### Arguments

adjmat            graphNEL object or adjacency matrix.

### Value

returns adjacency matrices and having minimal graph distance to the input graph matrix

### Author(s)

Juby Jacob

### See Also

[transitive.projections](#)

---

transitive.reduction    *Computes the transitive reduction of a graph*

---

### Description

transitive.reduction removes direct edges, which can be explained by another path in the graph. Regulation directions inferred via infer.edge.type are taken into account.

### Usage

```
transitive.reduction(g)
```

### Arguments

g                    adjacency matrix

### Details

transitive.reduction uses a modification of the classical algorithm from the Sedgewick book for computing transitive closures. The so-called "transitive reduction" is neither necessarily unique (only for DAGs) nor minimal in the number of edges (this could be improved).



**Value**

returns an adjacency matrix with shortcuts removed

**Author(s)**

Holger Froehlich

**References**

R. Sedgewick, Algorithms, Pearson, 2002.

**See Also**

[transitive.closure](#), [infer.edge.type](#)

**Examples**

```
V <- LETTERS[1:3]
edL <- list(A=list(edges=c("B", "C")),B=list(edges="C"),C=list(edges=NULL))
gc <- new("graphNEL",nodes=V,edgeL=edL,edgemode="directed")
g <- transitive.reduction(gc)

if(require(Rgraphviz)){
  par(mfrow=c(1,2))
  plot(gc,main="shortcut A->C")
  plot(as(g,"graphNEL"),main="shortcut removed")
}
```

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