

# Package ‘sem’

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**Title** Structural Equation Models

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**Depends** R (>= 1.6.0), stats

**Suggests** boot

**Description** This package contains functions for fitting general linear structural equation models (with observed and unobserved variables) by the method of maximum likelihood using the RAM approach, and for fitting structural equations in observed-variable models by two-stage least squares.

**License** GPL (>= 2)

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boot.sem	<i>Bootstrap a Structural Equation Model</i>
----------	--

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## Description

Bootstraps a structural equation model in an `sem` object (as returned by the `sem` function).

## Usage

```
boot.sem(data, model, R=100, cov=cov, ...)

## S3 method for class 'bootsem':
print(x, digits=getOption("digits"), ...)

## S3 method for class 'bootsem':
summary(object,
         type=c("perc", "bca", "norm", "basic", "none"), level=0.95, ...)
```

## Arguments

<code>data</code>	a data frame containing the data to which the model was fit; note that the original observations are required, not just the covariance matrix of the observed variables in the model.
<code>model</code>	an <code>sem</code> object, produced by the <code>sem</code> function.
<code>R</code>	the number of bootstrap replications; the default is 100, which should be enough for computing standard errors, but not confidence intervals (except for the normal-theory intervals).
<code>cov</code>	a function to compute the input covariance matrix; the default is <code>cov</code> . Use <code>cor</code> if the model is fit to the correlation matrix. The function <code>hetcor</code> in the <code>polycor</code> package will compute product-moment, polychoric, and polyserial correlations among mixed continuous and ordinal variables (see the example below for an illustration).
<code>x, object</code>	an object of class <code>bootsem</code> .
<code>digits</code>	controls the number of digits to print.
<code>type</code>	type of bootstrapped confidence intervals to compute; the default is "perc" (percentile); see <code>boot.ci</code> for details.

level            level for confidence intervals; default is 0.95.  
 ...            in `boot.sem`, arguments to be passed to `sem`; otherwise ignored.

### Details

`boot.sem` implements the nonparametric bootstrap, assuming an independent random sample. Convergence failures in the bootstrap resamples are discarded (and a warning printed); 10 consecutive convergence failures result in an error. You can use the `boot` function in the `boot` package for more complex sampling schemes and additional options.

Bootstrapping is implemented by resampling the observations in `data`, recalculating the input covariance matrix with `cov` and refitting the model with `sem`, using the parameter estimates from the original sample as start-values.

**Warning:** the bootstrapping process can be very time-consuming.

### Value

`boot.sem` returns an object of class `bootsem`, which inherits from class `boot`, supported by the `boot` package. The returned object contains the following components:

<code>t0</code>	the estimated parameters in the model fit to the original data set.
<code>t</code>	a matrix containing the bootstrapped estimates, one bootstrap replication per row.
<code>data</code>	the data frame containing the data to which the model was fit.
<code>seed</code>	the value of <code>.Random.seed</code> when <code>boot.sem</code> was called.
<code>statistic</code>	the function used to produce the bootstrap replications; this is always the local function <code>refit</code> from <code>boot.sem</code> .
<code>sim</code>	always set to "ordinary"; see the documentation for the <code>boot</code> function.
<code>stype</code>	always set to "i"; see the documentation for the <code>boot</code> function.
<code>call</code>	the call of the <code>boot.sem</code> function.
<code>strata</code>	always a vector of ones.

### Author(s)

John Fox <jfox@mcmaster.ca>

### References

Davison, A. C., and Hinkley, D. V. (1997) *Bootstrap Methods and their Application*. Cambridge.  
 Efron, B., and Tibshirani, R. J. (1993) *An Introduction to the Bootstrap*. Chapman and Hall.

### See Also

[boot](#), [sem](#)

**Examples**

```

## Not run:

# A simple confirmatory factor-analysis model using polychoric correlations.
# The polycor package is required for the hetcor function.

library(polycor)

# The following function returns correlations computed by hetcor,
# and is used for the bootstrapping.

hcor <- function(data) hetcor(data, std.err=FALSE)$correlations

model.cnes <- specify.model()
F -> MBSA2, lam1, NA
F -> MBSA7, lam2, NA
F -> MBSA8, lam3, NA
F -> MBSA9, lam4, NA
F <-> F, NA, 1
MBSA2 <-> MBSA2, the1, NA
MBSA7 <-> MBSA7, the2, NA
MBSA8 <-> MBSA8, the3, NA
MBSA9 <-> MBSA9, the4, NA

data(CNES)
R.cnes <- hcor(CNES)

sem.cnes <- sem(model.cnes, R.cnes, N=1529)
summary(sem.cnes)

# Note: this can take a couple of minutes:

system.time(boot.cnes <- boot.sem(CNES, sem.cnes, R=100, cov=hcor), gcFirst=TRUE)
summary(boot.cnes, type="norm")
# cf., standard errors to those computed by summary(sem.cnes)

## End(Not run)

```

---

CNES

---

*Variables from the 1997 Canadian National Election Study*


---

**Description**

These variables are from the mailback questionnaire to the 1997 Canadian National Election Study, and are intended to tap attitude towards “traditional values.”

**Usage**

```
data(CNES)
```

**Format**

A data frame with 1529 observations on the following 4 variables.

**MBSA2** an ordered factor with levels `StronglyDisagree` `Disagree` `Agree` `StronglyAgree`, in response to the statement, “We should be more tolerant of people who choose to live according to their own standards, even if they are very different from our own.”

**MBSA7** an ordered factor with levels `StronglyDisagree` `Disagree` `Agree` `StronglyAgree`, in response to the statement, “Newer lifestyles are contributing to the breakdown of our society.”

**MBSA8** an ordered factor with levels `StronglyDisagree` `Disagree` `Agree` `StronglyAgree`, in response to the statement, “The world is always changing and we should adapt our view of moral behaviour to these changes.”

**MBSA9** an ordered factor with levels `StronglyDisagree` `Disagree` `Agree` `StronglyAgree`, in response to the statement, “This country would have many fewer problems if there were more emphasis on traditional family values.”

**Source**

York University Institute for Social Research.

---

fscores

*Factor Scores for Latent Variables*

---

**Description**

Calculate factor scores or factor-score coefficients for the latent variables in a structural-equation model.

**Usage**

```
fscores(model, ...)

## S3 method for class 'sem':
fscores(model, data, center = TRUE, scale = FALSE, ...)
```

**Arguments**

<code>model</code>	an object of class "sem", produced by the <code>sem</code> function.
<code>data</code>	an optional numeric data frame or matrix containing the observed variables in the model; if present, the estimated factor scores are returned; if absent, the factor-score <i>coefficients</i> are returned.
<code>center</code>	if TRUE, the default, the means of the observed variables are subtracted prior to computing factor scores. One would normally use this option if the model is estimated from a covariance or correlation matrix among the observed variables.

`scale` if TRUE, the possibly centered variables are divided by their room-mean-squares; the default is FALSE. One would normally use this option if the model is estimated from a correlation matrix among the observed variables. Centering and scaling are performed by the `scale` function.

`...` arguments to pass down.

### Details

Factor-score coefficients are computed by the “regression” method as  $B = C^{-1}C^*$ , where  $C$  is the model-implied covariance or moment matrix among the observed variables and  $C^*$  is the matrix of model-implied covariances or moments between the observed and latent variables.

### Value

Either a matrix of estimated factor scores (if the `data` argument is supplied) or a matrix of factor-score coefficients (otherwise).

### Author(s)

John Fox (jfox@mcmaster.ca)

### References

Bollen, K. A. (1989) *Structural Equations With Latent Variables*. Wiley.

### See Also

[sem](#), [scale](#)

### Examples

```
## Not run:

S.wh <- read.moments(names=c('Anomia67','Powerless67','Anomia71',
                             'Powerless71','Education','SEI'))

 11.834
  6.947   9.364
  6.819   5.091  12.532
  4.783   5.028   7.495   9.986
 -3.839  -3.889  -3.841  -3.625   9.610
-21.899 -18.831 -21.748 -18.775  35.522  450.288

# This model in the SAS manual for PROC CALIS

model.wh.1 <- specify.model()
  Alienation67 -> Anomia67,      NA,      1
  Alienation67 -> Powerless67,  NA,      0.833
  Alienation71 -> Anomia71,     NA,      1
  Alienation71 -> Powerless71,  NA,      0.833
  SES          -> Education,    NA,      1
  SES          -> SEI,          lamb,    NA
```

```

SES          -> Alienation67, gam1, NA
Alienation67 -> Alienation71, beta, NA
SES          -> Alienation71, gam2, NA
Anomia67     <-> Anomia67, the1, NA
Anomia71     <-> Anomia71, the1, NA
Powerless67  <-> Powerless67, the2, NA
Powerless71  <-> Powerless71, the2, NA
Education    <-> Education, the3, NA
SEI          <-> SEI, the4, NA
Anomia67     <-> Anomia71, the5, NA
Powerless67  <-> Powerless71, the5, NA
Alienation67 <-> Alienation67, psi1, NA
Alienation71 <-> Alienation71, psi2, NA
SES          <-> SES, phi, NA

```

```
sem.wh.1 <- sem(model.wh.1, S.wh, 932)
```

```
fscores(sem.wh.1)
```

```

##          Alienation67 Alienation71          SES
## Anomia67      0.413112363  0.048268330 -0.05212632
## Powerless67  0.345402079  0.040014780 -0.04355578
## Anomia71     0.052663484  0.430618716 -0.03999218
## Powerless71  0.043704122  0.360044434 -0.03339943
## Education   -0.074921670 -0.063969383  0.50571037
## SEI         -0.004638977 -0.003960837  0.03131242

## End(Not run)

```

---

Klein

*Klein's Data on the U. S. Economy*

---

### Description

Data for Klein's (1950) simple econometric model of the U. S. economy.  
The `Klein` data frame has 22 rows and 10 columns.

### Usage

```
data(Klein)
```

### Format

This data frame contains the following columns:

**Year** 1921–1941  
**C** consumption.  
**P** private profits.

**Wp** private wages.  
**I** investment.  
**K.lag** capital stock, lagged one year.  
**X** equilibrium demand.  
**Wg** government wages.  
**G** government non-wage spending.  
**T** indirect business taxes and net exports.

### Source

Greene, W. H. (1993) *Econometric Analysis, Second Edition*. Macmillan.

### References

Klein, L. (1950) *Economic Fluctuations in the United States 1921–1941*. Wiley.

### Examples

```
data(Klein)

Klein$P.lag <- c(NA, Klein$P[-22])
Klein$X.lag <- c(NA, Klein$X[-22])

summary(tsls(C ~ P + P.lag + I(Wp + Wg),
  instruments=~1 + G + T + Wg + I(Year - 1931) + K.lag + P.lag + X.lag,
  data=Klein))

summary(tsls(I ~ P + P.lag + K.lag,
  instruments=~1 + G + T + Wg + I(Year - 1931) + K.lag + P.lag + X.lag,
  data=Klein))

summary(tsls(Wp ~ X + X.lag + I(Year - 1931),
  instruments=~1 + G + T + Wg + I(Year - 1931) + K.lag + P.lag + X.lag,
  data=Klein))
```

---

Kmenta

*Partly Artificial Data on the U. S. Economy*

---

### Description

These are partly contrived data from Kmenta (1986), constructed to illustrate estimation of a simultaneous-equation model.

The `Kmenta` data frame has 20 rows and 5 columns.

### Usage

```
data(Kmenta)
```

**Format**

This data frame contains the following columns:

**Q** food consumption per capita.

**P** ratio of food prices to general consumer prices.

**D** disposable income in constant dollars.

**F** ratio of preceding year's prices received by farmers to general consumer prices.

**A** time in years.

**Details**

The exogenous variables D, F, and A are based on real data; the endogenous variables P and Q were generated by simulation.

**Source**

Kmenta, J. (1986) *Elements of Econometrics, Second Edition*, Macmillan.

**Examples**

```
data(Kmenta)
```

---

```
mod.indices
```

*Modification Indices for Structural Equation Models*

---

**Description**

mod.indices calculates modification indices (score tests) and estimated parameter changes for the fixed and constrained parameters in a structural equation model. [Warning: This is a preliminary version: the computed values are a bit off the correct values.]

**Usage**

```
mod.indices(model, ...)

## S3 method for class 'sem':
mod.indices(model, ...)

## S3 method for class 'sem.modind':
print(x, n.largest=5, ...)

## S3 method for class 'sem.modind':
summary(object, round=2,
         print.matrices=c("both", "par.change", "mod.indices"), ...)
```

**Arguments**

model	an object of class <code>sem</code> , produced by the <code>sem</code> function.
object, x	an object of class <code>sem.modind</code> , produced by the <code>mod.indices</code> function.
n.largest	number of modification indices to print in each of the $A$ and $P$ matrices of the RAM model.
round	number of places to the right of the decimal point in printing modification indices.
print.matrices	which matrices to print: estimated changes in the fixed parameters, modification indices, or both (the default).
...	arguments to be passed down.

**Details**

Modification indices are one-df chi-square score statistics for the fixed and constrained parameters in a structural equation model. They may be regarded as an estimate of the improvement in the likelihood-ratio chi-square statistic for the model if the corresponding parameter is respecified as a free parameter. The `mod.indices` function also estimates the change in the value of a fixed or constrained parameter if the parameter is respecified as free. When several parameters are set equal, modification indices and estimated changes are given for all but the first. Modification indices and estimated parameter changes for currently free parameters are given as NA.

The method employed is described in Saris, Satorra, and Sorbom (1987) and Sorbom (1989).

**Value**

`mod.indices` returns an object of class `sem.modind` with the following elements:

<code>mod.A</code>	modification indices for the elements of the $A$ matrix.
<code>mod.P</code>	modification indices for the elements of the $P$ matrix.
<code>par.A</code>	estimated parameter changes for the elements of the $A$ matrix.
<code>par.P</code>	estimated parameter changes for the elements of the $P$ matrix.

**Author(s)**

John Fox (jfox@mcmaster.ca)

**References**

Sarris, W. E., Satorra, A., and Sorbom, D. (1987) The detection and correction of specification errors in structural equation models. Pp. 105–129 in Clogg, C. C. (ed.), *Sociological Methodology 1987*. American Sociological Association.

Sorbom, D. (1989) Model modification. *Psychometrika* **54**, 371–384.

**See Also**

[sem](#)

**Examples**

```

# This example is adapted from the SAS manual

S.wh <- read.moments(names=c('Anomia67','Powerless67','Anomia71',
                             'Powerless71','Education','SEI'))

11.834
 6.947   9.364
 6.819   5.091  12.532
 4.783   5.028   7.495   9.986
-3.839  -3.889  -3.841  -3.625   9.610
-21.899 -18.831 -21.748 -18.775  35.522  450.288

model.wh <- specify.model()
  Alienation67 -> Anomia67,      NA, 1
  Alienation67 -> Powerless67,   NA, 0.833
  Alienation71 -> Anomia71,      NA, 1
  Alienation71 -> Powerless71,   NA, 0.833
  SES          -> Education,     NA, 1
  SES          -> SEI,           lamb, NA
  SES          -> Alienation67,  gam1, NA
  Alienation67 -> Alienation71,  beta, NA
  SES          -> Alienation71,  gam2, NA
  Anomia67     <-> Anomia67,      the1, NA
  Anomia71     <-> Anomia71,      the1, NA
  Powerless67  <-> Powerless67,   the2, NA
  Powerless71  <-> Powerless71,   the2, NA
  Education    <-> Education,     the3, NA
  SEI          <-> SEI,           the4, NA
  Anomia67     <-> Anomia71,      the5, NA
  Powerless67  <-> Powerless71,   the5, NA
  Alienation67 <-> Alienation67,  psi1, NA
  Alienation71 <-> Alienation71,  psi2, NA
  SES          <-> SES,           phi, NA

sem.wh <- sem(model.wh, S.wh, 932)
mod.indices(sem.wh)

##      5 largest modification indices, A matrix:
## Powerless67:Education   Anomia67:Education
##                4.8736                3.8027
##      Powerless67:SES Education:Powerless67
##                2.7608                2.4619
##      Anomia67:SES
##                2.3122
##
##      5 largest modification indices, P matrix:
## Education:Powerless67   Education:Anomia67
##                6.4028                4.5398
##      SES:Powerless67      SES:Anomia67
##                2.7608                2.3122
##      SEI:Powerless67
##                1.3185

```

---

 path.diagram

 Draw Path Diagram
 

---

## Description

path.diagram creates a description of the path diagram for a structural-equation-model object to be processed by the graph-drawing program *dot*, which can be called automatically; see Koutsofios and North (2002) and <http://www.graphviz.org/>. To obtain graphics output directly, the *dot* program must be on the system search path.

## Usage

```
path.diagram(model, ...)
```

```
## S3 method for class 'sem':
```

```
path.diagram(model, file, min.rank = NULL, max.rank = NULL,
  same.rank = NULL, variables = model$var.names, parameters = rownames(model$
  ignore.double = TRUE, edge.labels = c("names", "values", "both"),
  size = c(8, 8), node.font = c("Helvetica", 14),
  edge.font = c("Helvetica", 10), rank.direction = c("LR", "TB"),
  digits = 2, standardize = FALSE, output.type=c("graphics", "dot"),
  graphics.fmt="pdf", dot.options=NULL, ...)
```

## Arguments

model	a structural-equation-model object produced by sem.
...	arguments to be passed down to path.diagram.sem.
file	a file name, given <i>without</i> an extension, to which to write the <i>dot</i> description of the path diagram and, by default, to use that to draw a graph of the model; if not specified, the <i>dot</i> description is written to standard output (normally the R Console). Note that by default (see the output.type argument below), <i>two</i> files are written: a ".dot" file and a graphics file of type specified by the graphics.fmt argument (below); file may include a path specification.
min.rank	a character string listing names of variables to be assigned minimum rank (order) in the graph; the names should be separated by commas.
max.rank	a character string listing names of variables to be assigned maximum rank in the graph; the names should be separated by commas.
same.rank	a character string or vector of character strings of variables to be assigned equivalent rank in the graph; names in each string should be separated by commas.
variables	variable names; defaults to the variable names in model. If specified, the variable names should be in the same order as in model.
parameters	parameter names; defaults to the parameter names in model. If specified, the parameter names should be in the same order as in model.

```

ignore.double      if TRUE, the default, double-headed arrows, representing variances and covari-
                   ances, are not graphed.
edge.labels        "names" to label arrows with parameter names; "values" to label arrows
                   with parameter estimates, or "both".
size               the size of the graph, in inches.
node.font          font name and point-size for printing variable names.
edge.font          font name and point-size for printing arrow names or values.
rank.direction     draw graph left-to-right, "LR", the default, or top-to-bottom, "TB".
digits            number of digits after the decimal point (default, 2) to which to round parameter
                   estimates.
standardize        if TRUE, display standardized coefficients; default is FALSE.
output.type        if "graphics", the default, both a ".dot" file and a graphics file will be cre-
                   ated.
graphics.fmt       a graphics format recognized by the dot program; the default is "pdf"; graphics.fmt
                   is also used for the extension of the graphics file that is created.
dot.options        options to be passed to the dot program, given as a character string.

```

**Value**

NULL: path.diagram is used for its side-effect, producing a graph description of the model.

**Author(s)**

John Fox (jfox@mcmaster.ca), Adam Kramer, and Michael Friendly

**References**

Koutsofios, E., and North, S. C. (2002) Drawing graphs with *dot*. <http://www.graphviz.org/Documentation/dotguide.pdf>.

**See Also**

[sem](#)

**Examples**

```

## Not run:
# The Duncan, Haller, and Portes Peer-Influences Model

R.DHP <- read.moments(diag=FALSE, names=c('ROccAsp', 'REdAsp', 'FOccAsp',
                                         'FEdAsp', 'RParAsp', 'RIQ', 'RSES', 'FSES', 'FIQ', 'FParAsp'))

.6247
.3269 .3669
.4216 .3275 .6404
.2137 .2742 .1124 .0839
.4105 .4043 .2903 .2598 .1839

```

```

.3240 .4047 .3054 .2786 .0489 .2220
.2930 .2407 .4105 .3607 .0186 .1861 .2707
.2995 .2863 .5191 .5007 .0782 .3355 .2302 .2950
.0760 .0702 .2784 .1988 .1147 .1021 .0931 -.0438 .2087

model.dhp <- specify.model()
  RParAsp -> RGenAsp, gam11, NA
  RIQ      -> RGenAsp, gam12, NA
  RSES     -> RGenAsp, gam13, NA
  FSES     -> RGenAsp, gam14, NA
  RSES     -> FGenAsp, gam23, NA
  FSES     -> FGenAsp, gam24, NA
  FIQ      -> FGenAsp, gam25, NA
  FParAsp -> FGenAsp, gam26, NA
  FGenAsp -> RGenAsp, beta12, NA
  RGenAsp -> FGenAsp, beta21, NA
  RGenAsp -> ROccAsp, NA, 1
  RGenAsp -> REdAsp, lam21, NA
  FGenAsp -> FOccAsp, NA, 1
  FGenAsp -> FEdAsp, lam42, NA
  RGenAsp <-> RGenAsp, ps11, NA
  FGenAsp <-> FGenAsp, ps22, NA
  RGenAsp <-> FGenAsp, ps12, NA
  ROccAsp <-> ROccAsp, theta1, NA
  REdAsp  <-> REdAsp, theta2, NA
  FOccAsp <-> FOccAsp, theta3, NA
  FEdAsp  <-> FEdAsp, theta4, NA

sem.dhp <- sem(model.dhp, R.DHP, 329,
  fixed.x=c('RParAsp', 'RIQ', 'RSES', 'FSES', 'FIQ', 'FParAsp'))

path.diagram(sem.dhp, min.rank='RIQ, RSES, RParAsp, FParAsp, FSES, FIQ',
  max.rank='ROccAsp, REdAsp, FEdAsp, FOccAsp')

## digraph "sem.dhp" {
## rankdir=LR;
## size="8,8";
## node [fontname="Helvetica" fontsize=14 shape=box];
## edge [fontname="Helvetica" fontsize=10];
## center=1;
## {rank=min "RIQ" "RSES" "RParAsp" "FParAsp" "FSES" "FIQ"}
## {rank=max "ROccAsp" "REdAsp" "FEdAsp" "FOccAsp"}
## "RGenAsp" [shape=ellipse]
## "FGenAsp" [shape=ellipse]
## "RParAsp" -> "RGenAsp" [label="gam11"];
## "RIQ" -> "RGenAsp" [label="gam12"];
## "RSES" -> "RGenAsp" [label="gam13"];
## "FSES" -> "RGenAsp" [label="gam14"];
## "RSES" -> "FGenAsp" [label="gam23"];
## "FSES" -> "FGenAsp" [label="gam24"];
## "FIQ" -> "FGenAsp" [label="gam25"];
## "FParAsp" -> "FGenAsp" [label="gam26"];
## "FGenAsp" -> "RGenAsp" [label="beta12"];

```

```
## "RGenAsp" -> "FGenAsp" [label="beta21"];
## "RGenAsp" -> "ROccAsp" [label=""];
## "RGenAsp" -> "REdAsp" [label="lam21"];
## "FGenAsp" -> "FOccAsp" [label=""];
## "FGenAsp" -> "FEdAsp" [label="lam42"];
## }
## End(Not run)
```

---

ram

*RAM Matrix for a Structural-Equation Model*


---

## Description

Print the labelled RAM definition matrix for a structural-equation model fit by `sem`.

## Usage

```
ram(object, digits=5, startvalues=FALSE)
```

## Arguments

<code>object</code>	an object of class <code>sem</code> returned by the <code>sem</code> function.
<code>digits</code>	number of digits for printed output.
<code>startvalues</code>	if TRUE, start values for parameters are printed; otherwise, the parameter estimates are printed; the default is FALSE.

## Value

A data frame containing the labelled RAM definition matrix, which is normally just printed.

## Author(s)

John Fox <jfox@mcmaster.ca>

## See Also

[sem](#)

## Examples

```
# ----- assumes that Duncan, Haller and Portes peer-influences model
# ----- has been fit and is in sem.dhp

## Not run:
ram(sem.dhp)

## heads to from parameter estimate arrow
## 1 1 11 0 1.000000 ROccAsp <--- RGenAsp
```

```

## lam21      1  2  11      1  1.062673  REdAsp <--- RGenAsp
##           1  3  12      0  1.000000  FOccAsp <--- FGenAsp
## lam42      1  4  12      2  0.929732  FEdAsp <--- FGenAsp
## gam11      1 11   5      3  0.161220  RGenAsp <--- RParAsp
## gam12      1 11   6      4  0.249647      RGenAsp <--- RIQ
## gam13      1 11   7      5  0.218402      RGenAsp <--- RSES
## gam14      1 11   8      6  0.071836      RGenAsp <--- FSES
## gam23      1 12   7      7  0.061879      FGenAsp <--- RSES
## gam24      1 12   8      8  0.228863      FGenAsp <--- FSES
## gam25      1 12   9      9  0.349030      FGenAsp <--- FIQ
## gam26      1 12  10     10  0.159529  FGenAsp <--- FParAsp
## beta12     1 11  12     11  0.184245  RGenAsp <--- FGenAsp
## beta21     1 12  11     12  0.235502  FGenAsp <--- RGenAsp
## theta1     2  1   1     13  0.412143  ROccAsp <--> ROccAsp
## theta2     2  2   2     14  0.336146      REdAsp <--> REdAsp
## theta3     2  3   3     15  0.311197  FOccAsp <--> FOccAsp
## theta4     2  4   4     16  0.404601      FEdAsp <--> FEdAsp
## psi11      2 11  11     17  0.280987  RGenAsp <--> RGenAsp
## psi22      2 12  12     18  0.263832  FGenAsp <--> FGenAsp
## psi12      2 11  12     19 -0.022620  RGenAsp <--> FGenAsp
##           2  5   5      0  1.000000  RParAsp <--> RParAsp
##           2  6   5      0  0.183900      RIQ <--> RParAsp
##           2  6   6      0  1.000000      RIQ <--> RIQ
##           2  7   5      0  0.048900      RSES <--> RParAsp
##           2  7   6      0  0.222000      RSES <--> RIQ
##           2  7   7      0  1.000000      RSES <--> RSES
##           2  8   5      0  0.018600      FSES <--> RParAsp
##           2  8   6      0  0.186100      FSES <--> RIQ
##           2  8   7      0  0.270700      FSES <--> RSES
##           2  8   8      0  1.000000      FSES <--> FSES
##           2  9   5      0  0.078200      FIQ <--> RParAsp
##           2  9   6      0  0.335500      FIQ <--> RIQ
##           2  9   7      0  0.230200      FIQ <--> RSES
##           2  9   8      0  0.295000      FIQ <--> FSES
##           2  9   9      0  1.000000      FIQ <--> FIQ
##           2 10   5      0  0.114700  FParAsp <--> RParAsp
##           2 10   6      0  0.102100      FParAsp <--> RIQ
##           2 10   7      0  0.093100      FParAsp <--> RSES
##           2 10   8      0 -0.043800      FParAsp <--> FSES
##           2 10   9      0  0.208700      FParAsp <--> FIQ
##           2 10  10     0  1.000000  FParAsp <--> FParAsp
## End(Not run)

```

raw.moments

*Compute Raw Moments Matrix***Description**

Computes the “uncorrected” sum-of-squares-and-products matrix divided by the number of observations.

**Usage**

```

raw.moments(object, ...)

## S3 method for class 'formula':
raw.moments(formula, data, subset, na.action,
             contrasts = NULL, ...)

## Default S3 method:
raw.moments(object, ...)

cov2raw(cov, mean, N, sd)

## S3 method for class 'rawmoments':
print(x, ...)

```

**Arguments**

<code>object</code>	a one-sided model formula or an object coercible to a numeric matrix.
<code>formula</code>	a one-sided model formula specifying the model matrix for which raw moments are to be computed; note that a constant is included if it is not explicitly suppressed by putting <code>-1</code> in the formula.
<code>data</code>	an optional data frame containing the variables in the formula. By default the variables are taken from the environment from which <code>raw.moments</code> is called.
<code>subset</code>	an optional vector specifying a subset of observations to be used in computing moments.
<code>na.action</code>	a function that indicates what should happen when the data contain NAs. The default is set by the <code>na.action</code> option.
<code>contrasts</code>	an optional list. See the <code>contrasts.arg</code> of <code>model.matrix.default</code>
<code>cov</code>	a covariance or correlation matrix.
<code>mean</code>	a vector of means.
<code>N</code>	the number of observations on which the covariances or correlations are based.
<code>sd</code>	an optional vector of standard deviations, to be given if <code>cov</code> is a correlation matrix.
<code>x</code>	an object of class <code>rawmoments</code> to print.
<code>...</code>	arguments passed down.

**Value**

`raw.moments` and `cov2raw` return an object of class `rawmoments`, which is simply a matrix with an attribute "N" that contains the number of observations on which the moments are based.

**Author(s)**

John Fox (jfox@mcmaster.ca)

**See Also**[sem](#)**Examples**

```

data(Kmenta)
raw.moments(cbind(1, Kmenta))
raw.moments(~ Q + P + D + F + A, data=Kmenta)

Cov <- with(Kmenta, cov(cbind(Q, P, D, F, A)))
cov2raw(Cov, colMeans(Kmenta), nrow(Kmenta))

```

---

read.moments	<i>Input a Covariance, Correlation, or Raw Moment Matrix</i>
--------------	--

---

**Description**

This functions makes it simpler to input covariance, correlation, and raw-moment matrices to be analyzed by the [sem](#) function. The matrix is input in lower-triangular form on as many lines as is convenient, omitting the above-diagonal elements. The elements on the diagonal may also optionally be omitted, in which case they are taken to be 1.

**Usage**

```

read.moments(file = "", diag = TRUE,
             names = as.character(paste("X", 1:n, sep = "")))

```

**Arguments**

file	The (quoted) file from which to read the model specification, including the path to the file if it is not in the current directory. If "" (the default), then the specification is read from the standard input stream, and is terminated by a blank line.
diag	If TRUE (the default), then the input matrix includes diagonal elements.
names	a character vector containing the names of the variables, to label the rows and columns of the moment matrix.

**Value**

Returns a lower-triangular matrix (i.e., with zeroes above the main diagonal) suitable for input to [sem](#).

**Author(s)**

John Fox <jfox@mcmaster.ca>

**See Also**[sem](#)**Examples**

```
## Not run:
R.DHP <- read.moments(diag=FALSE, names=c("ROccAsp", "REdAsp", "FOccAsp",
    "FEdAsp", "RParAsp", "RIQ", "RSES", "FSES", "FIQ", "FParAsp"))
.6247
.3269 .3669
.4216 .3275 .6404
.2137 .2742 .1124 .0839
.4105 .4043 .2903 .2598 .1839
.3240 .4047 .3054 .2786 .0489 .2220
.2930 .2407 .4105 .3607 .0186 .1861 .2707
.2995 .2863 .5191 .5007 .0782 .3355 .2302 .2950
.0760 .0702 .2784 .1988 .1147 .1021 .0931 -.0438 .2087

R.DHP

## End(Not run)
```

residuals.sem

*Residual Covariances for a Structural Equation Model***Description**

These functions compute residual covariances, variance-standardized residual covariances, and normalized residual covariances for the observed variables in a structural-equation model fit by `sem`.

**Usage**

```
## S3 method for class 'sem':
residuals(object, ...)

standardized.residuals(object, ...)

## S3 method for class 'sem':
standardized.residuals(object, ...)

normalized.residuals(object, ...)

## S3 method for class 'sem':
normalized.residuals(object, ...)
```

**Arguments**

`object` an object of class `sem` returned by the `sem` function.  
`...` not for the user.

## Details

Residuals are defined as  $S - C$ , where  $S$  is the sample covariance matrix of the observed variables and  $C$  is the model-reproduced covariance matrix. The *standardized* residual covariance for a pair of variables divides the residual covariance by the product of the sample standard deviations of the two variables,  $(s_{ij} - c_{ij})/(s_{ii}s_{jj})^{1/2}$ . The *normalized* residual is given by

$$\frac{s_{ij} - c_{ij}}{[(c_{ii}c_{jj} - c_{ij}^2)/N^*]^{1/2}}$$

where  $N^*$  is the number of observations minus one if the model is fit to a covariance matrix, or the number of observations if it is fit to a raw moment matrix.

## Value

Each function returns a matrix of residuals.

## Author(s)

John Fox (jfox@mcmaster.ca)

## References

Bollen, K. A. (1989) *Structural Equations With Latent Variables*. Wiley.

## See Also

[sem](#)

## Examples

```
## Not run:
# ----- assumes that Duncan, Haller and Portes peer-influences model
# ----- has been fit and is in sem.dhp.1

residuals(sem.dhp.1)

##           ROccAsp      REdAsp      FOccAsp      FEdAsp
## ROccAsp  4.156103e-07 -2.896368e-07 -2.866110e-02  9.102874e-02
## REdAsp   -2.896368e-07 -1.541581e-06 -1.094841e-02 -2.379215e-02
## FOccAsp  -2.866110e-02 -1.094841e-02 -3.740356e-06 -9.564103e-07
##
## . . .
##
##           FIQ      FParAsp
## ROccAsp  3.467853e-02 -3.187309e-02
## REdAsp   4.878970e-03 -4.443480e-02
## FOccAsp  -7.354686e-03  2.488120e-02
## FEdAsp   1.124604e-02 -3.690078e-02
## RParAsp  2.775558e-17  5.551115e-17
## RIQ      2.220446e-16  6.938894e-17
## RSES     0.000000e+00 -1.387779e-17
```

```
##      FSES      1.110223e-16 -2.775558e-17
##      FIQ       4.440892e-16  1.110223e-16
##      FParAsp  1.110223e-16  4.440892e-16
```

normalized.residuals(sem.dhp.1)

```
##      ROccAsp      REdAsp      FOccAsp      FEdAsp
##      ROccAsp  5.330519e-06 -4.455587e-06 -4.898232e-01  1.567678e+00
##      REdAsp   -4.455587e-06 -1.977191e-05 -1.857670e-01 -4.071582e-01
##      FOccAsp -4.898232e-01 -1.857670e-01 -4.797271e-05 -1.460881e-05
##
##      . . .
##
##      FIQ      FParAsp
##      ROccAsp  6.080514e-01 -5.747909e-01
##      REdAsp   8.518738e-02 -8.007295e-01
##      FOccAsp -1.180429e-01  4.374639e-01
##      FEdAsp   1.832159e-01 -6.514685e-01
##      RParAsp  5.019082e-16  1.000322e-15
##      RIQ      3.818356e-15  1.252092e-15
##      RSES     0.000000e+00 -2.506364e-16
##      FSES     1.931472e-15 -5.029583e-16
##      FIQ      5.695780e-15  1.971289e-15
##      FParAsp  1.971289e-15  5.695780e-15
```

standardized.residuals(sem.dhp.1)

```
##      ROccAsp      REdAsp      FOccAsp      FEdAsp
##      ROccAsp  4.156103e-07 -2.896368e-07 -2.866110e-02  9.102874e-02
##      REdAsp   -2.896368e-07 -1.541581e-06 -1.094841e-02 -2.379215e-02
##      FOccAsp -2.866110e-02 -1.094841e-02 -3.740356e-06 -9.564103e-07
##
##      . . .
##
##      FIQ      FParAsp
##      ROccAsp  3.467853e-02 -3.187309e-02
##      REdAsp   4.878970e-03 -4.443480e-02
##      FOccAsp -7.354686e-03  2.488120e-02
##      FEdAsp   1.124604e-02 -3.690078e-02
##      RParAsp  2.775558e-17  5.551115e-17
##      RIQ      2.220446e-16  6.938894e-17
##      RSES     0.000000e+00 -1.387779e-17
##      FSES     1.110223e-16 -2.775558e-17
##      FIQ      4.440892e-16  1.110223e-16
##      FParAsp  1.110223e-16  4.440892e-16
##      End(Not run)
```

## Description

`sem` fits general structural equation models (with both observed and unobserved variables) by the method of maximum likelihood, assuming multinormal errors. Observed variables are also called *indicators* or *manifest variables*; unobserved variables are also called *factors* or *latent variables*. Normally, the generic function (`sem`) would be used.

## Usage

```
sem(ram, ...)

## S3 method for class 'mod':
sem(ram, S, N, obs.variables=rownames(S), fixed.x=NULL, debug=FALSE, ...)

## Default S3 method:
sem(ram, S, N, param.names = paste("Param", 1:t, sep = ""),
    var.names = paste("V", 1:m, sep = ""), fixed.x = NULL, raw=FALSE,
    debug = FALSE, analytic.gradient = TRUE, warn = FALSE, maxiter = 500,
    par.size=c('ones', 'startvalues'), refit=TRUE, start.tol=1E-6, ...)

startvalues(S, ram, debug = FALSE, tol=1E-6)

## S3 method for class 'sem':
print(x, ...)

## S3 method for class 'sem':
summary(object, digits=5, conf.level=0.9, ...)

## S3 method for class 'sem':
deviance(object, ...)

## S3 method for class 'sem':
df.residual(object, ...)

## S3 method for class 'sem':
anova(object, model.2, ...)

## S3 method for class 'sem':
coef(object, ...)

## S3 method for class 'sem':
vcov(object, ...)
```

## Arguments

`ram` RAM specification, which is a simple encoding of the path diagram for the model. The `ram` matrix may be given either in symbolic form (as a `mod` object, as returned by the `specify.model` function, or as a character matrix), invoking `sem.mod`, which calls `sem.default` after setting up the model,

or (less conveniently) in numeric form, invoking `sem.default` directly (see **Details** below).

<code>S</code>	covariance matrix among observed variables; may be input as a symmetric matrix, or as a lower- or upper-triangular matrix. <code>S</code> may also be a raw (i.e., “un-corrected”) moment matrix — that is, a sum-of-squares-and-products matrix divided by <code>N</code> . This form of input is useful for fitting models with intercepts, in which case the moment matrix should include the mean square and cross-products for a unit variable all of whose entries are 1; of course, the raw mean square for the unit variable is 1. Raw-moment matrices may be computed by <code>raw.moments</code> . If the <code>ram</code> argument is given in symbolic form, then the observed-variable covariance or raw-moment matrix may contain variables that do not appear in the model, in which case a warning is printed.
<code>N</code>	number of observations on which the covariance matrix is based.
<code>obs.variables</code>	names of observed variables, by default taken from the row names of the covariance matrix <code>S</code> .
<code>fixed.x</code>	names (if the <code>ram</code> matrix is given in symbolic form) or indices (if it is in numeric form) of fixed exogenous variables. Specifying these obviates the necessity of having to fix the variances and covariances among these variables (and produces correct degrees of freedom for the model chisquare).
<code>raw</code>	TRUE if <code>S</code> is a raw moment matrix, as opposed to a covariance matrix; the default is FALSE.
<code>debug</code>	if TRUE, some information is printed to help you debug the symbolic model specification; for example, if a variable name is misspelled, <code>sem</code> will assume that the variable is a (new) latent variable. The default is FALSE.
<code>...</code>	arguments to be passed down, including from <code>sem.default</code> to the <code>nlm</code> optimizer.
<code>param.names</code>	names of the $t$ free parameters, given in their numerical order; default names are <code>Param1, ..., Paramt</code> . Note: Should not be specified when the <code>ram</code> matrix is given in symbolic form.
<code>var.names</code>	names of the $m$ entries of the $v$ vector (typically the observed and latent variables — see below), given in their numerical order; default names are <code>Var1, ..., Var m</code> . Note: Should not be specified when the <code>ram</code> matrix is given in symbolic form.
<code>analytic.gradient</code>	if TRUE (the default), then analytic first derivatives are used in the maximization of the likelihood; otherwise numeric derivatives are used.
<code>warn</code>	if TRUE, warnings produced by the optimization function will be printed. This should generally not be necessary, since <code>sem</code> prints its own warning, and saves information about convergence. The default is FALSE.
<code>maxiter</code>	the maximum number of iterations for the optimization performed by the <code>nlm</code> function, to be passed to it via its <code>iterlim</code> argument.
<code>par.size</code>	the anticipated size of the free parameters; if <code>"ones"</code> , a vector of ones is used; if <code>"startvalues"</code> , taken from the start values. You can try changing this argument if you encounter convergence problems. The default is <code>"startvalues"</code>

	if the largest input variance is at least 100 times the smallest, and "ones" otherwise.
<code>refit</code>	if TRUE (the default), attempt to refit the model eliminating apparently aliased parameters if under-identification is detected.
<code>start.tol</code> , <code>tol</code>	if the magnitude of an automatic start value is less than <code>start.tol</code> , then it is set to <code>start.tol</code> ; defaults to 1E-6.
<code>object</code> , <code>x</code>	an object of class <code>sem</code> returned by the <code>sem</code> function.
<code>digits</code>	number of digits for printed output.
<code>conf.level</code>	level for confidence interval for the RMSEA index (default is .9).
<code>model.2</code>	an object of class <code>sem</code> returned by the <code>sem</code> function, to be compared by a likelihood-ratio test to <code>object</code> ; the two models must be fit to the same data.

## Details

The model is set up using RAM (“reticular action model” – don’t ask!) notation – a simple format for specifying general structural equation models by coding the “arrows” in the path diagram for the model (see, e.g., McArdle and McDonald, 1984).

The variables in the  $v$  vector in the model (typically, the observed and unobserved variables, but not error variables) are numbered from 1 to  $m$ . the RAM matrix contains one row for each (free or constrained) parameter of the model, and may be specified either in symbolic format or in numeric format.

A symbolic `ram` matrix consists of three columns, as follows:

- 1. Arrow specification:** This is a simple formula, of the form "A -> B" or, equivalently, "B <- A" for a regression coefficient (i.e., a single-headed or directional arrow); "A <-> A" for a variance or "A <-> B" for a covariance (i.e., a double-headed or bidirectional arrow). Here, A and B are variable names in the model. If a name does not correspond to an observed variable, then it is assumed to be a latent variable. Spaces can appear freely in an arrow specification, and there can be any number of hyphens in the arrows, including zero: Thus, e.g., "A->B", "A -> B", and "A>B" are all legitimate and equivalent.
- 2. Parameter name:** The name of the regression coefficient, variance, or covariance specified by the arrow. Assigning the same name to two or more arrows results in an equality constraint. Specifying the parameter name as NA produces a fixed parameter.
- 3. Value:** start value for a free parameter or value of a fixed parameter. If given as NA, `sem` will compute the start value.

It is simplest to construct the RAM matrix with the `specify.model` function, which returns an object of class `mod`. This process is illustrated in the examples below.

A numeric `ram` matrix consists of five columns, as follows:

- 1. Number of arrow heads:** 1 (directed arrow) or 2 (covariance).
- 2. Arrow to:** index of the variable at the head of a directional arrow, or at one end of a bidirectional arrow. Observed variables should be assigned the numbers 1 to  $n$ , where  $n$  is the number of rows/columns in the covariance matrix  $S$ , with the indices corresponding to the variables’ positions in  $S$ . Variable indices above  $n$  represent latent variables.

3. **Arrow from:** the index of the variable at the tail of a directional arrow, or at the other end of a bidirectional arrow.
4. **Parameter number:** free parameters are numbered from 1 to  $t$ , but do not necessarily appear in consecutive order. Fixed parameters are given the number 0. Equality constraints are specified by assigning two or more parameters the same number.
5. **Value:** start value for a free parameter, or value of a fixed parameter. If given as NA, the program will compute a start value, by a slight modification of the method described by McDonald and Hartmann (1992). *Note:* In some circumstances, some start values are selected randomly; this might produce small differences in the parameter estimates when the program is rerun.

sem fits the model by calling the `nlm` optimizer to minimize the negative log-likelihood for the model. If `nlm` fails to converge, a warning message is printed.

The RAM formulation of the general structural equation model is given by the basic equation

$$v = Av + u$$

where  $v$  and  $u$  are vectors of random variables (observed or unobserved), and the parameter matrix  $A$  contains regression coefficients, symbolized by single-headed arrows in a path diagram. Another parameter matrix,

$$P = E(uu')$$

contains covariances among the elements of  $u$  (assuming that the elements of  $u$  have zero means). Usually  $v$  contains endogenous and exogenous observed and unobserved variables, but not error variables (see the examples below).

The `startvalues` function may be called directly, but is usually called by `sem.default`.

The `sem` methods for the generic functions `deviance` and `df.residual` functions return, respectively, minus twice the difference in the log-likelihoods for the fitted model and a saturated model, and the degrees of freedom associated with the deviance.

## Value

`sem` returns an object of class `sem`, with the following elements:

<code>ram</code>	RAM matrix, including any rows generated for covariances among fixed exogenous variables; column 5 includes computed start values.
<code>coeff</code>	estimates of free parameters.
<code>criterion</code>	fitting criterion — minus twice the difference in the log-likelihood between the fitted model and a saturated model, divided by $N - 1$ (or $N$ if the model is fit to a raw moment matrix).
<code>cov</code>	estimated asymptotic covariance matrix of parameter estimates.
<code>S</code>	observed covariance matrix.
<code>J</code>	RAM selection matrix, $J$ , which picks out observed variables.
<code>C</code>	model-reproduced covariance matrix.
<code>A</code>	RAM $A$ matrix.
<code>P</code>	RAM $P$ matrix.
<code>n.fix</code>	number of fixed exogenous variables.

<code>n</code>	number of observed variables.
<code>N</code>	number of observations.
<code>m</code>	number of variables (observed plus unobserved).
<code>t</code>	number of free parameters.
<code>par.posn</code>	indices of free parameters.
<code>var.names</code>	vector of variable names.
<code>observed</code>	indices of observed variables.
<code>convergence</code>	convergence code returned by <code>nlm</code> (a code $> 2$ indicates a problem).
<code>iterations</code>	number of iterations performed.
<code>raw</code>	TRUE if the model is fit to a raw moment matrix, FALSE otherwise.
<code>chisqNull</code>	Unless the model is fit to a raw moment matrix, the chisquare value associated with a null model in which all of the observed variables are uncorrelated.

### Warning

A common error is to fail to specify variance or covariance terms in the model, which are denoted by double-headed arrows,  $\langle - \rangle$ .

In general, every observed or latent variable in the model should be associated with a variance or error variance. This may be a free parameter to estimate or a fixed constant (as in the case of a latent exogenous variable for which you wish to fix the variance, e.g., to 1). Again in general, there will be an *error variance* associated with each endogenous variable in the model (i.e., each variable to which at least one single-headed arrow points — including observed indicators of latent variables), and a *variance* associated with each exogenous variable (i.e., each variable that appears only at the tail of single-headed arrows, never at the head).

To my knowledge, the only *apparent* exception to this rule is for observed variables that are declared to be fixed exogenous variables. In this case, the program generates the necessary (fixed-constant) variances and covariances automatically.

If there are missing variances, a warning message will be printed, and estimation will almost surely fail in some manner. Missing variances might well indicate that there are missing covariances too, but it is not possible to deduce this in a mechanical manner.

### Author(s)

John Fox ([jfox@mcmaster.ca](mailto:jfox@mcmaster.ca))

### References

- Fox, J. (2006) Structural equation modeling with the sem package in R. *Structural Equation Modeling* **13**:465–486.
- Bollen, K. A. (1989) *Structural Equations With Latent Variables*. Wiley.
- Bollen, K. A. and Long, J. S. (eds.) *Testing Structural Equation Models*, Sage.
- McArdle, J. J. and Epstein, D. (1987) Latent growth curves within developmental structural equation models. *Child Development* **58**, 110–133.

McArdle, J. J. and McDonald, R. P. (1984) Some algebraic properties of the reticular action model. *British Journal of Mathematical and Statistical Psychology* **37**, 234–251.

McDonald, R. P. and Hartmann, W. M. (1992) A procedure for obtaining initial values of parameters in the RAM model. *Multivariate Behavioral Research* **27**, 57–76.

Raftery, A. E. (1993) Bayesian model selection in structural equation models. In Bollen, K. A. and Long, J. S. (eds.) *Testing Structural Equation Models*, Sage.

Raftery, A. E. (1995) Bayesian model selection in social research (with discussion). *Sociological Methodology* **25**, 111–196,

### See Also

[raw.moments](#), [nlm](#)

### Examples

```
# Note: These examples can't be run via example() because the default file
# argument of specify.model() and read.moments() requires that the model
# specification and covariances, correlations, or raw moments be entered
# at the command prompt. The examples can be copied and run in the R console,
# however. See ?specify.model and ?read.moments for further information.

## Not run:

# ----- Duncan, Haller and Portes peer-influences model -----
# A nonrecursive SEM with unobserved endogenous variables and fixed exogenous variables

R.DHP <- read.moments(diag=FALSE, names=c("ROccAsp", "REdAsp", "FOccAsp",
    "FEdAsp", "RParAsp", "RIQ", "RSES", "FSES", "FIQ", "FParAsp"))
    .6247
    .3269 .3669
    .4216 .3275 .6404
    .2137 .2742 .1124 .0839
    .4105 .4043 .2903 .2598 .1839
    .3240 .4047 .3054 .2786 .0489 .2220
    .2930 .2407 .4105 .3607 .0186 .1861 .2707
    .2995 .2863 .5191 .5007 .0782 .3355 .2302 .2950
    .0760 .0702 .2784 .1988 .1147 .1021 .0931 -.0438 .2087

# Fit the model using a symbolic ram specification

model.dhp <- specify.model()
  RParAsp -> RGenAsp, gam11, NA
  RIQ      -> RGenAsp, gam12, NA
  RSES     -> RGenAsp, gam13, NA
  FSES     -> RGenAsp, gam14, NA
  RSES     -> FGenAsp, gam23, NA
  FSES     -> FGenAsp, gam24, NA
  FIQ      -> FGenAsp, gam25, NA
  FParAsp -> FGenAsp, gam26, NA
  FGenAsp -> RGenAsp, beta12, NA
```

```

RGenAsp -> FGenAsp, beta21, NA
RGenAsp -> ROccAsp, NA, 1
RGenAsp -> REdAsp, lam21, NA
FGenAsp -> FOccAsp, NA, 1
FGenAsp -> FEdAsp, lam42, NA
RGenAsp <-> RGenAsp, ps11, NA
FGenAsp <-> FGenAsp, ps22, NA
RGenAsp <-> FGenAsp, ps12, NA
ROccAsp <-> ROccAsp, theta1, NA
REdAsp <-> REdAsp, theta2, NA
FOccAsp <-> FOccAsp, theta3, NA
FEdAsp <-> FEdAsp, theta4, NA

```

```

sem.dhp.1 <- sem(model.dhp, R.DHP, 329,
  fixed.x=c('RParAsp', 'RIQ', 'RSES', 'FSES', 'FIQ', 'FParAsp'))

```

```

summary(sem.dhp.1)

```

```

##      Model Chisquare = 26.697   Df = 15 Pr(>Chisq) = 0.031302
##      Chisquare (null model) = 872   Df = 45
##      Goodness-of-fit index = 0.98439
##      Adjusted goodness-of-fit index = 0.94275
##      RMSEA index = 0.048759   90 % CI: (0.014517, 0.07831)
##      Bentler-Bonnett NFI = 0.96938
##      Tucker-Lewis NNFI = 0.95757
##      Bentler CFI = 0.98586
##      SRMR = 0.020204
##      BIC = -60.244
##
##      Normalized Residuals
##      Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##      -0.7990 -0.1180  0.0000 -0.0120  0.0397  1.5700
##
##      Parameter Estimates
##      Estimate Std Error z value Pr(>|z|)
##      gam11    0.161224 0.038487  4.1890 2.8019e-05 RGenAsp <---- RParAsp
##      gam12    0.249653 0.044580  5.6001 2.1428e-08 RGenAsp <---- RIQ
##      gam13    0.218404 0.043476  5.0235 5.0730e-07 RGenAsp <---- RSES
##      gam14    0.071843 0.050335  1.4273 1.5350e-01 RGenAsp <---- FSES
##      gam23    0.061894 0.051738  1.1963 2.3158e-01 FGenAsp <---- RSES
##      gam24    0.228868 0.044495  5.1437 2.6938e-07 FGenAsp <---- FSES
##      gam25    0.349039 0.044551  7.8346 4.6629e-15 FGenAsp <---- FIQ
##      gam26    0.159535 0.040129  3.9755 7.0224e-05 FGenAsp <---- FParAsp
##      beta12   0.184226 0.096207  1.9149 5.5506e-02 RGenAsp <---- FGenAsp
##      beta21   0.235458 0.119742  1.9664 4.9255e-02 FGenAsp <---- RGenAsp
##      lam21    1.062674 0.091967 11.5549 0.0000e+00 REdAsp <---- RGenAsp
##      lam42    0.929727 0.071152 13.0668 0.0000e+00 FEdAsp <---- FGenAsp
##      ps11     0.280987 0.046311  6.0674 1.2999e-09 RGenAsp <--> RGenAsp
##      ps22     0.263836 0.044902  5.8759 4.2067e-09 FGenAsp <--> FGenAsp
##      ps12    -0.022601 0.051649 -0.4376 6.6168e-01 FGenAsp <--> RGenAsp
##      theta1   0.412145 0.052211  7.8939 2.8866e-15 ROccAsp <--> ROccAsp
##      theta2   0.336148 0.053323  6.3040 2.9003e-10 REdAsp <--> REdAsp
##      theta3   0.311194 0.046665  6.6687 2.5800e-11 FOccAsp <--> FOccAsp

```

```

##      theta4  0.404604  0.046733   8.6578  0.0000e+00  FEdAsp <--> FEdAsp
##
##      Iterations = 28

# Fit the model using a numerical ram specification

ram.dhp <- matrix(c(
#           heads   to     from   param  start
           1,      1,     11,     0,     1,
           1,      2,     11,     1,     NA, # lam21
           1,      3,     12,     0,     1,
           1,      4,     12,     2,     NA, # lam42
           1,     11,      5,     3,     NA, # gam11
           1,     11,      6,     4,     NA, # gam12
           1,     11,      7,     5,     NA, # gam13
           1,     11,      8,     6,     NA, # gam14
           1,     12,      7,     7,     NA, # gam23
           1,     12,      8,     8,     NA, # gam24
           1,     12,      9,     9,     NA, # gam25
           1,     12,     10,    10,     NA, # gam26
           1,     11,     12,    11,     NA, # beta12
           1,     12,     11,    12,     NA, # beta21
           2,      1,      1,    13,     NA, # theta1
           2,      2,      2,    14,     NA, # theta2
           2,      3,      3,    15,     NA, # theta3
           2,      4,      4,    16,     NA, # theta4
           2,     11,     11,    17,     NA, # psi11
           2,     12,     12,    18,     NA, # psi22
           2,     11,     12,    19,     NA, # psi12
           ), ncol=5, byrow=TRUE)

params.dhp <- c('lam21', 'lam42', 'gam11', 'gam12', 'gam13', 'gam14',
               'gam23', 'gam24', 'gam25', 'gam26',
               'beta12', 'beta21', 'theta1', 'theta2', 'theta3', 'theta4',
               'psi11', 'psi22', 'psi12')

vars.dhp <- c('ROccAsp', 'REdAsp', 'FOccAsp', 'FEdAsp', 'RParAsp', 'RIQ',
             'RSES', 'FSES', 'FIQ', 'FParAsp', 'RGenAsp', 'FGenAsp')

sem.dhp.2 <- sem(ram.dhp, R.DHP, 329, params.dhp, vars.dhp, fixed.x=5:10)

summary(sem.dhp.2)

##      Model Chisquare = 26.697   Df = 15 Pr(>Chisq) = 0.031302
##      Chisquare (null model) = 872   Df = 45
##      Goodness-of-fit index = 0.98439
##      Adjusted goodness-of-fit index = 0.94275
##      RMSEA index = 0.048759   90 % CI: (0.014517, 0.07831)
##      Bentler-Bonnett NFI = 0.96938
##      Tucker-Lewis NNFI = 0.95757
##      Bentler CFI = 0.98586
##      SRMR = 0.020204
##      BIC = -60.244

```

```

##
##      Normalized Residuals
##      Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##      -0.7990 -0.1180  0.0000 -0.0120  0.0397  1.5700
##
##      Parameter Estimates
##      Estimate Std Error z value Pr(>|z|)
##      lam21    1.062674 0.091967  11.5549 0.0000e+00 REdAsp <--- RGenAsp
##      lam42    0.929727 0.071152  13.0668 0.0000e+00 FEdAsp <--- FGenAsp
##      gam11    0.161224 0.038487   4.1890 2.8019e-05 RGenAsp <--- RParAsp
##      gam12    0.249653 0.044580   5.6001 2.1428e-08 RGenAsp <--- RIQ
##      gam13    0.218404 0.043476   5.0235 5.0730e-07 RGenAsp <--- RSES
##      gam14    0.071843 0.050335   1.4273 1.5350e-01 RGenAsp <--- FSES
##      gam23    0.061894 0.051738   1.1963 2.3158e-01 FGenAsp <--- RSES
##      gam24    0.228868 0.044495   5.1437 2.6938e-07 FGenAsp <--- FSES
##      gam25    0.349039 0.044551   7.8346 4.6629e-15 FGenAsp <--- FIQ
##      gam26    0.159535 0.040129   3.9755 7.0224e-05 FGenAsp <--- FParAsp
##      beta12   0.184226 0.096207   1.9149 5.5506e-02 RGenAsp <--- FGenAsp
##      beta21   0.235458 0.119742   1.9664 4.9255e-02 FGenAsp <--- RGenAsp
##      theta1   0.412145 0.052211   7.8939 2.8866e-15 ROccAsp <--> ROccAsp
##      theta2   0.336148 0.053323   6.3040 2.9003e-10 REdAsp <--> REdAsp
##      theta3   0.311194 0.046665   6.6687 2.5800e-11 FOccAsp <--> FOccAsp
##      theta4   0.404604 0.046733   8.6578 0.0000e+00 FEdAsp <--> FEdAsp
##      psi11    0.280987 0.046311   6.0674 1.2999e-09 RGenAsp <--> RGenAsp
##      psi22    0.263836 0.044902   5.8759 4.2067e-09 FGenAsp <--> FGenAsp
##      psi12   -0.022601 0.051649  -0.4376 6.6168e-01 RGenAsp <--> FGenAsp

##      Iterations = 28

# ----- Wheaton et al. alienation data -----

S.wh <- read.moments(names=c('Anomia67','Powerless67','Anomia71',
                             'Powerless71','Education','SEI'))

  11.834
   6.947   9.364
   6.819   5.091  12.532
   4.783   5.028   7.495   9.986
  -3.839  -3.889  -3.841  -3.625   9.610
 -21.899 -18.831 -21.748 -18.775  35.522  450.288

# This is the model in the SAS manual for PROC CALIS: A Recursive SEM with
# latent endogenous and exogenous variables.
# Curiously, both factor loadings for two of the latent variables are fixed.

model.wh.1 <- specify.model()
  Alienation67 -> Anomia67,      NA,      1
  Alienation67 -> Powerless67,  NA,      0.833
  Alienation71 -> Anomia71,     NA,      1
  Alienation71 -> Powerless71,  NA,      0.833
  SES          -> Education,    NA,      1
  SES          -> SEI,          lamb,    NA
  SES          -> Alienation67, gam1,    NA

```

```

Alienation67  -> Alienation71,  beta,  NA
SES           -> Alienation71,  gam2,  NA
Anomia67      <-> Anomia67,      the1,  NA
Anomia71      <-> Anomia71,      the1,  NA
Powerless67   <-> Powerless67,  the2,  NA
Powerless71   <-> Powerless71,  the2,  NA
Education     <-> Education,    the3,  NA
SEI           <-> SEI,          the4,  NA
Anomia67      <-> Anomia71,      the5,  NA
Powerless67   <-> Powerless71,  the5,  NA
Alienation67  <-> Alienation67,  psi1,  NA
Alienation71  <-> Alienation71,  psi2,  NA
SES           <-> SES,          phi,   NA

```

```
sem.wh.1 <- sem(model.wh.1, S.wh, 932)
```

```
summary(sem.wh.1)
```

```

##      Model Chisquare = 13.485   Df = 9 Pr(>Chisq) = 0.14186
##      Chisquare (null model) = 2131.4   Df = 15
##      Goodness-of-fit index = 0.99527
##      Adjusted goodness-of-fit index = 0.98896
##      RMSEA index = 0.023136   90 % CI: (NA, 0.046997)
##      Bentler-Bonnett NFI = 0.99367
##      Tucker-Lewis NNFI = 0.99647
##      Bentler CFI = 0.99788
##      SRMR = 0.014998
##      BIC = -48.051
##
##      Normalized Residuals
##      Min. 1st Qu. Median Mean 3rd Qu. Max.
##      -1.26000 -0.13100 0.00014 -0.02870 0.11400 0.87400
##
##      Parameter Estimates
##      Estimate Std Error z value Pr(>|z|)
##      lamb 5.36880 0.433982 12.3710 0.0000e+00 SEI <--- SES
##      gam1 -0.62994 0.056128 -11.2233 0.0000e+00 Alienation67 <--- SES
##      beta 0.59312 0.046820 12.6680 0.0000e+00 Alienation71 <--- Alienation67
##      gam2 -0.24086 0.055202 -4.3632 1.2817e-05 Alienation71 <--- SES
##      the1 3.60787 0.200589 17.9864 0.0000e+00 Anomia67 <--> Anomia67
##      the2 3.59494 0.165234 21.7567 0.0000e+00 Powerless67 <--> Powerless67
##      the3 2.99366 0.498972 5.9996 1.9774e-09 Education <--> Education
##      the4 259.57583 18.321121 14.1681 0.0000e+00 SEI <--> SEI
##      the5 0.90579 0.121710 7.4422 9.9032e-14 Anomia71 <--> Anomia67
##      psi1 5.67050 0.422906 13.4084 0.0000e+00 Alienation67 <--> Alienation67
##      psi2 4.51481 0.334993 13.4773 0.0000e+00 Alienation71 <--> Alienation71
##      phi 6.61632 0.639506 10.3460 0.0000e+00 SES <--> SES
##
##      Iterations = 78

# The same model, but treating one loading for each latent variable as free
# (and equal to each other).

```

```

model.wh.2 <- specify.model()
  Alienation67 -> Anomia67,      NA,      1
  Alienation67 -> Powerless67,   lamby,   NA
  Alienation71 -> Anomia71,      NA,      1
  Alienation71 -> Powerless71,   lamby,   NA
  SES          -> Education,     NA,      1
  SES          -> SEI,           lambx,   NA
  SES          -> Alienation67,  gam1,   NA
  Alienation67 -> Alienation71,  beta,   NA
  SES          -> Alienation71,  gam2,   NA
  Anomia67     <-> Anomia67,     the1,   NA
  Anomia71     <-> Anomia71,     the1,   NA
  Powerless67  <-> Powerless67,  the2,   NA
  Powerless71  <-> Powerless71,  the2,   NA
  Education    <-> Education,    the3,   NA
  SEI          <-> SEI,          the4,   NA
  Anomia67     <-> Anomia71,     the5,   NA
  Powerless67  <-> Powerless71,  the5,   NA
  Alienation67 <-> Alienation67,  psi1,   NA
  Alienation71 <-> Alienation71,  psi2,   NA
  SES          <-> SES,          phi,    NA

sem.wh.2 <- sem(model.wh.2, S.wh, 932)

summary(sem.wh.2)

##      Model Chisquare = 12.673   Df = 8 Pr(>Chisq) = 0.12360
##      Chisquare (null model) = 2131.4   Df = 15
##      Goodness-of-fit index = 0.99553
##      Adjusted goodness-of-fit index = 0.98828
##      RMSEA index = 0.025049   90 % CI: (NA, 0.04985)
##      Bentler-Bonnett NFI = 0.99405
##      Tucker-Lewis NNFI = 0.99586
##      Bentler CFI = 0.9978
##      SRMR = 0.012981
##      BIC = -42.026
##
##      Normalized Residuals
##      Min.    1st Qu.    Median      Mean    3rd Qu.    Max.
## -0.997000 -0.140000  0.000295 -0.028800  0.100000  0.759000
##
##      Parameter Estimates
##      Estimate Std Error z value Pr(>|z|)
## lamby  0.86261  0.033383  25.8402 0.0000e+00 Powerless67 <--- Alienation67
## lamby  5.35302  0.432591  12.3743 0.0000e+00 SEI <--- SES
## gam1   -0.62129  0.056142 -11.0663 0.0000e+00 Alienation67 <--- SES
## beta   0.59428  0.047040  12.6335 0.0000e+00 Alienation71 <--- Alienation67
## gam2  -0.23580  0.054684  -4.3121 1.6173e-05 Alienation71 <--- SES
## the1   3.74499  0.249823  14.9906 0.0000e+00 Anomia67 <--> Anomia67
## the2   3.49378  0.200754  17.4033 0.0000e+00 Powerless67 <--> Powerless67
## the3   2.97409  0.499661   5.9522 2.6456e-09 Education <--> Education
## the4  260.13252 18.298141  14.2163 0.0000e+00 SEI <--> SEI

```

```

##      the5      0.90377  0.121818   7.4190 1.1791e-13 Anomia71 <--> Anomia67
##      psi1      5.47380  0.464073  11.7951 0.0000e+00 Alienation67 <--> Alienation67
##      psi2      4.36410  0.362722  12.0315 0.0000e+00 Alienation71 <--> Alienation71
##      phi       6.63576  0.640425  10.3615 0.0000e+00 SES <--> SES
##
##      Iterations = 79
##

# Compare the two models by a likelihood-ratio test:

anova(sem.wh.1, sem.wh.2)

##      LR Test for Difference Between Models
##
##      Model Df Model Chisq Df LR Chisq Pr(>Chisq)
##      Model 1      9      13.4851
##      Model 2      8      12.6731  1  0.8119      0.3676

# ----- Thurstone data -----
# Second-order confirmatory factor analysis, from the SAS manual for PROC CALIS

R.thur <- read.moments(diag=FALSE, names=c('Sentences','Vocabulary',
      'Sent.Completion','First.Letters','4.Letter.Words','Suffixes',
      'Letter.Series','Pedigrees', 'Letter.Group'))

.828
.776 .779
.439 .493 .46
.432 .464 .425 .674
.447 .489 .443 .59 .541
.447 .432 .401 .381 .402 .288
.541 .537 .534 .35 .367 .32 .555
.38 .358 .359 .424 .446 .325 .598 .452

model.thur <- specify.model()
F1 -> Sentences, lam11, NA
F1 -> Vocabulary, lam21, NA
F1 -> Sent.Completion, lam31, NA
F2 -> First.Letters, lam41, NA
F2 -> 4.Letter.Words, lam52, NA
F2 -> Suffixes, lam62, NA
F3 -> Letter.Series, lam73, NA
F3 -> Pedigrees, lam83, NA
F3 -> Letter.Group, lam93, NA
F4 -> F1, gam1, NA
F4 -> F2, gam2, NA
F4 -> F3, gam3, NA
Sentences <-> Sentences, th1, NA
Vocabulary <-> Vocabulary, th2, NA
Sent.Completion <-> Sent.Completion, th3, NA
First.Letters <-> First.Letters, th4, NA
4.Letter.Words <-> 4.Letter.Words, th5, NA
Suffixes <-> Suffixes, th6, NA
Letter.Series <-> Letter.Series, th7, NA

```

```

Pedigrees <-> Pedigrees,          th8,  NA
Letter.Group <-> Letter.Group,    th9,  NA
F1 <-> F1,                          NA,   1
F2 <-> F2,                          NA,   1
F3 <-> F3,                          NA,   1
F4 <-> F4,                          NA,   1

```

```
sem.thur <- sem(model.thur, R.thur, 213)
```

```
summary(sem.thur)
```

```

##      Model Chisquare = 38.196   Df = 24 Pr(>Chisq) = 0.033101
##      Chisquare (null model) = 1101.9   Df = 36
##      Goodness-of-fit index = 0.95957
##      Adjusted goodness-of-fit index = 0.9242
##      RMSEA index = 0.052822   90 % CI: (0.015262, 0.083067)
##      Bentler-Bonnett NFI = 0.96534
##      Tucker-Lewis NNFI = 0.98002
##      Bentler CFI = 0.98668
##      SRMR = 0.043595
##      BIC = -90.475
##
##      Normalized Residuals
##      Min.   1st Qu.   Median     Mean   3rd Qu.     Max.
## -9.72e-01 -4.16e-01 -4.20e-07  4.01e-02  9.39e-02  1.63e+00
##
##      Parameter Estimates
##      Estimate Std Error z value Pr(>|z|)
## lam11 0.51512  0.064964  7.9293 2.2204e-15 Sentences <--- F1
## lam21 0.52031  0.065162  7.9849 1.3323e-15 Vocabulary <--- F1
## lam31 0.48743  0.062422  7.8087 5.7732e-15 Sent.Completion <--- F1
## lam41 0.52112  0.063137  8.2538 2.2204e-16 First.Letters <--- F2
## lam52 0.49707  0.059673  8.3298 0.0000e+00 4.Letter.Words <--- F2
## lam62 0.43806  0.056479  7.7562 8.6597e-15 Suffixes <--- F2
## lam73 0.45244  0.071371  6.3392 2.3100e-10 Letter.Series <--- F3
## lam83 0.41729  0.061037  6.8367 8.1020e-12 Pedigrees <--- F3
## lam93 0.40763  0.064524  6.3175 2.6584e-10 Letter.Group <--- F3
## gam1  1.44381  0.264173  5.4654 4.6184e-08 F1 <--- F4
## gam2  1.25383  0.216597  5.7888 7.0907e-09 F2 <--- F4
## gam3  1.40655  0.279331  5.0354 4.7681e-07 F3 <--- F4
## th1   0.18150  0.028400  6.3907 1.6517e-10 Sentences <--> Sentences
## th2   0.16493  0.027797  5.9334 2.9678e-09 Vocabulary <--> Vocabulary
## th3   0.26713  0.033468  7.9816 1.5543e-15 Sent.Completion <--> Sent.Completion
## th4   0.30150  0.050686  5.9484 2.7073e-09 First.Letters <--> First.Letters
## th5   0.36450  0.052358  6.9617 3.3618e-12 4.Letter.Words <--> 4.Letter.Words
## th6   0.50642  0.059963  8.4455 0.0000e+00 Suffixes <--> Suffixes
## th7   0.39033  0.061599  6.3367 2.3474e-10 Letter.Series <--> Letter.Series
## th8   0.48137  0.065388  7.3618 1.8141e-13 Pedigrees <--> Pedigrees
## th9   0.50510  0.065227  7.7437 9.5479e-15 Letter.Group <--> Letter.Group
##
##      Iterations = 54
##

```

```

#----- Kerchoff/Kenney path analysis -----
# An observed-variable recursive SEM from the LISREL manual

R.kerch <- read.moments(diag=FALSE, names=c('Intelligence','Siblings',
      'FatherEd','FatherOcc','Grades','EducExp','OccupAsp'))

  -.100
  .277  -.152
  .250  -.108  .611
  .572  -.105  .294  .248
  .489  -.213  .446  .410  .597
  .335  -.153  .303  .331  .478  .651

model.kerch <- specify.model()
  Intelligence -> Grades,      gam51,      NA
  Siblings -> Grades,         gam52,      NA
  FatherEd -> Grades,         gam53,      NA
  FatherOcc -> Grades,        gam54,      NA
  Intelligence -> EducExp,    gam61,      NA
  Siblings -> EducExp,        gam62,      NA
  FatherEd -> EducExp,        gam63,      NA
  FatherOcc -> EducExp,       gam64,      NA
  Grades -> EducExp,          beta65,     NA
  Intelligence -> OccupAsp,   gam71,      NA
  Siblings -> OccupAsp,       gam72,      NA
  FatherEd -> OccupAsp,       gam73,      NA
  FatherOcc -> OccupAsp,      gam74,      NA
  Grades -> OccupAsp,         beta75,     NA
  EducExp -> OccupAsp,        beta76,     NA
  Grades <-> Grades,          psi5,       NA
  EducExp <-> EducExp,        psi6,       NA
  OccupAsp <-> OccupAsp,     psi7,       NA

sem.kerch <- sem(model.kerch, R.kerch, 737, fixed.x=c('Intelligence','Siblings',
  'FatherEd','FatherOcc'))

summary(sem.kerch)

##      Model Chisquare = 3.2685e-13   Df = 0 Pr(>Chisq) = NA
##      Chisquare (null model) = 1664.3   Df = 21
##      Goodness-of-fit index = 1
##      BIC = 3.2685e-13
##
##      Normalized Residuals
##      Min.    1st Qu.    Median      Mean    3rd Qu.    Max.
## -4.28e-15  0.00e+00  0.00e+00  7.62e-16  1.47e-15  5.17e-15
##
##      Parameter Estimates
##      Estimate Std Error z value Pr(>|z|)
##      gam51    0.525902 0.031182 16.86530 0.0000e+00 Grades <--- Intelligence
##      gam52   -0.029942 0.030149 -0.99314 3.2064e-01 Grades <--- Siblings
##      gam53    0.118966 0.038259  3.10951 1.8740e-03 Grades <--- FatherEd
##      gam54    0.040603 0.037785  1.07456 2.8257e-01 Grades <--- FatherOcc

```

```
##      gam61    0.160270 0.032710    4.89979 9.5940e-07 EducExp <--- Intelligence
##      gam62   -0.111779 0.026876   -4.15899 3.1966e-05 EducExp <--- Siblings
##      gam63    0.172719 0.034306    5.03461 4.7882e-07 EducExp <--- FatherEd
##      gam64    0.151852 0.033688    4.50758 6.5571e-06 EducExp <--- FatherOcc
##      beta65   0.405150 0.032838   12.33799 0.0000e+00 EducExp <--- Grades
##      gam71   -0.039405 0.034500   -1.14215 2.5339e-01 OccupAsp <--- Intelligence
##      gam72   -0.018825 0.028222   -0.66700 5.0477e-01 OccupAsp <--- Siblings
##      gam73   -0.041333 0.036216   -1.14126 2.5376e-01 OccupAsp <--- FatherEd
##      gam74    0.099577 0.035446    2.80924 4.9658e-03 OccupAsp <--- FatherOcc
##      beta75   0.157912 0.037443    4.21738 2.4716e-05 OccupAsp <--- Grades
##      beta76   0.549593 0.038260   14.36486 0.0000e+00 OccupAsp <--- EducExp
##      psi5     0.650995 0.033946   19.17743 0.0000e+00 Grades <--> Grades
##      psi6     0.516652 0.026943   19.17590 0.0000e+00 EducExp <--> EducExp
##      psi7     0.556617 0.029026   19.17644 0.0000e+00 OccupAsp <--> OccupAsp
##
##      Iterations = 0
```

```
#----- McCardle/Epstein latent-growth-curve model -----
# This model, from McCardle and Epstein (1987, p.118), illustrates the use of a
# raw moment matrix to fit a model with an intercept. (The example was suggested
# by Mike Stoolmiller.)
```

```
M.McCardle <- read.moments(names=c('WISC1', 'WISC2', 'WISC3', 'WISC4', 'UNIT'))
365.661
503.175      719.905
675.656      958.479      1303.392
890.680     1265.846     1712.475     2278.257
18.034       25.819       35.255       46.593       1.000
```

```
mod.McCardle <- specify.model()
C -> WISC1, NA, 6.07
C -> WISC2, B2, NA
C -> WISC3, B3, NA
C -> WISC4, B4, NA
UNIT -> C, Mc, NA
C <-> C, Vc, NA,
WISC1 <-> WISC1, Vd, NA
WISC2 <-> WISC2, Vd, NA
WISC3 <-> WISC3, Vd, NA
WISC4 <-> WISC4, Vd, NA
```

```
sem.McCardle <- sem(mod.McCardle, M.McCardle, 204, fixed.x="UNIT", raw=TRUE)
summary(sem.McCardle)
```

```
##      Model fit to raw moment matrix.
##
##      Model Chisquare = 83.791    Df = 8 Pr(>Chisq) = 8.4377e-15
##      BIC = 41.246
##
##      Normalized Residuals
##      Min. 1st Qu. Median Mean 3rd Qu. Max.
##      -0.15300 -0.01840 0.00132 -0.00576 0.02400 0.07760
##
```

```
##      Parameter Estimates
##      Estimate Std Error z value Pr(>|z|)
##      B2  8.61354 0.135438 63.5976 0      WISC2 <--- C
##      B3 11.64054 0.168854 68.9387 0      WISC3 <--- C
##      B4 15.40323 0.213071 72.2916 0      WISC4 <--- C
##      Mc  3.01763 0.060690 49.7219 0      C <--- UNIT
##      Vc  0.44343 0.047704  9.2955 0      C <--> C
##      Vd 11.78832 0.674060 17.4885 0      WISC1 <--> WISC1
##
##      Iterations = 37

## End(Not run)
```

specify.model

*Specify a Structural Equation Model*

## Description

Create the RAM specification of a structural equation model.

## Usage

```
specify.model(file = "")

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

## Arguments

file	The (quoted) file from which to read the model specification, including the path to the file if it is not in the current directory. If "" (the default), then the specification is read from the standard input stream, and is terminated by a blank line.
x	An object of class mod to print, as produced by specify.model.
...	Ignored.

## Details

Each line of the RAM specification consists of three (unquoted) entries, separated by commas:

- Arrow specification:** This is a simple formula, of the form  $A \rightarrow B$  or, equivalently,  $B \leftarrow A$  for a regression coefficient (i.e., a single-headed or directional arrow);  $A \leftrightarrow A$  for a variance or  $A \leftrightarrow B$  for a covariance (i.e., a double-headed or bidirectional arrow). Here,  $A$  and  $B$  are variable names in the model. If a name does not correspond to an observed variable, then it is assumed to be a latent variable. Spaces can appear freely in an arrow specification, and there can be any number of hyphens in the arrows, including zero: Thus, e.g.,  $A \rightarrow B$ ,  $A \rightarrow B$ , and  $A > B$  are all legitimate and equivalent.

- 2. Parameter name:** The name of the regression coefficient, variance, or covariance specified by the arrow. Assigning the same name to two or more arrows results in an equality constraint. Specifying the parameter name as NA produces a fixed parameter.
- 3. Value:** start value for a free parameter or value of a fixed parameter. If given as NA, `sem` will compute the start value.

Lines may end in a comment following #.

See [sem](#) for further details on model specification.

### Value

An object of class `mod`, suitable as input for [sem](#).

### Author(s)

John Fox ([jfox@mcmaster.ca](mailto:jfox@mcmaster.ca))

### See Also

[sem](#)

### Examples

```
## Not run:
model.dhp <- specify.model()
RParAsp -> RGenAsp, gam11, NA
RIQ     -> RGenAsp, gam12, NA
RSES    -> RGenAsp, gam13, NA
FSES    -> RGenAsp, gam14, NA
RSES    -> FGenAsp, gam23, NA
FSES    -> FGenAsp, gam24, NA
FIQ     -> FGenAsp, gam25, NA
FParAsp -> FGenAsp, gam26, NA
FGenAsp -> RGenAsp, beta12, NA
RGenAsp -> FGenAsp, beta21, NA
RGenAsp -> ROccAsp, NA, 1
RGenAsp -> REdAsp, lam21, NA
FGenAsp -> FOccAsp, NA, 1
FGenAsp -> FEdAsp, lam42, NA
RGenAsp <-> RGenAsp, ps11, NA
FGenAsp <-> FGenAsp, ps22, NA
RGenAsp <-> FGenAsp, ps12, NA
ROccAsp <-> ROccAsp, theta1, NA
REdAsp  <-> REdAsp, theta2, NA
FOccAsp <-> FOccAsp, theta3, NA
FEdAsp  <-> FEdAsp, theta4, NA

model.dhp
## End(Not run)
```

---

`standardized.coefficients`*Standardized Coefficients for Structural Equation Models*

---

**Description**

These functions calculate standardized regression coefficients for structural equation models. The function `std.coef` is simply an abbreviation for `standardized.coefficients`.

**Usage**

```
standardized.coefficients(object, digits = 5, oneheaded=TRUE, twoheaded=TRUE)
std.coef(...)
```

**Arguments**

<code>object</code>	an object of class <code>sem</code> returned by the <code>sem</code> function.
<code>digits</code>	number of digits for printed output.
<code>oneheaded</code>	standardize path coefficients? Default is <code>TRUE</code> .
<code>twoheaded</code>	standardize variances and covariances? Default is <code>TRUE</code> .
<code>...</code>	arguments to pass to <code>standardized.coefficients</code> .

**Value**

Returns a data frame with the standardized coefficients, labelled both by parameter names and by arrows in the path diagram for the model.

**Author(s)**

John Fox ([jfox@mcmaster.ca](mailto:jfox@mcmaster.ca)) and Adam Kramer

**References**

Bollen, K. A. (1989) *Structural Equations With Latent Variables*. Wiley.

**See Also**

[sem](#)

**Examples**

```

# ----- assumes that Duncan, Haller and Portes peer-influences model
# ----- has been fit and is in sem.dhp.1
## Not run:
standardized.coefficients(sem.dhp.1)

##          Std. Estimate
          Std. Estimate
## 1  gam11  0.210278    RGenAsp <--- RParAsp
## 2  gam12  0.325612    RGenAsp <--- RIQ
## 3  gam13  0.284855    RGenAsp <--- RSES
## 4  gam14  0.093702    RGenAsp <--- FSES
## 5  gam23  0.074576    FGenAsp <--- RSES
## 6  gam24  0.275763    FGenAsp <--- FSES
## 7  gam25  0.420558    FGenAsp <--- FIQ
## 8  gam26  0.192224    FGenAsp <--- FParAsp
## 9  beta12 0.199418    RGenAsp <--- FGenAsp
## 10 beta21 0.217521    FGenAsp <--- RGenAsp
## 11          0.766717    ROccAsp <--- RGenAsp
## 12 lam21  0.814771    REdAsp <--- RGenAsp
## 13          0.829943    FOccAsp <--- FGenAsp
## 14 lam42  0.771619    FEdAsp <--- FGenAsp
## 15 ps11   0.477987    RGenAsp <--> RGenAsp
## 16 ps22   0.383036    FGenAsp <--> FGenAsp
## 17 ps12  -0.035518    FGenAsp <--> RGenAsp
## 18 theta1 0.412144    ROccAsp <--> ROccAsp
## 19 theta2 0.336148    REdAsp <--> REdAsp
## 20 theta3 0.311194    FOccAsp <--> FOccAsp
## 21 theta4 0.404603    FEdAsp <--> FEdAsp
## 22          1.000000    RParAsp <--> RParAsp
## 23          0.183900    RIQ <--> RParAsp
## 24          1.000000    RIQ <--> RIQ
## 25          0.048900    RSES <--> RParAsp
## 26          0.222000    RSES <--> RIQ
## 27          1.000000    RSES <--> RSES
## 28          0.018600    FSES <--> RParAsp
## 29          0.186100    FSES <--> RIQ
## 30          0.270700    FSES <--> RSES
## 31          1.000000    FSES <--> FSES
## 32          0.078200    FIQ <--> RParAsp
## 33          0.335500    FIQ <--> RIQ
## 34          0.230200    FIQ <--> RSES
## 35          0.295000    FIQ <--> FSES
## 36          1.000000    FIQ <--> FIQ
## 37          0.114700    FParAsp <--> RParAsp
## 38          0.102100    FParAsp <--> RIQ
## 39          0.093100    FParAsp <--> RSES
## 40          -0.043800    FParAsp <--> FSES
## 41          0.208700    FParAsp <--> FIQ
## 42          1.000000    FParAsp <--> FParAsp
## End(Not run)

```

---

 tsls

*Two-Stage Least Squares*


---

## Description

Fits an equation in a structural-equation model by two-stage least squares. This is equivalent to direct instrumental-variables estimation when the number of instruments is equal to the number of predictors.

## Usage

```
tsls(y, ...)
## S3 method for class 'formula':
tsls(formula, instruments, data, subset, na.action, contrasts=NULL, ...)
## Default S3 method:
tsls(y, X, Z, names=NULL, ...)

## S3 method for class 'tsls':
print(x, ...)
## S3 method for class 'tsls':
summary(object, digits=4, ...)
## S3 method for class 'tsls':
anova(object, model.2, s2, dfe, ...)

## S3 method for class 'tsls':
fitted(object, ...)
## S3 method for class 'tsls':
residuals(object, ...)
## S3 method for class 'tsls':
coef(object, ...)
## S3 method for class 'tsls':
vcov(object, ...)
```

## Arguments

<code>formula</code>	model formula for structural equation to be estimated; a regression constant is implied if not explicitly omitted.
<code>instruments</code>	one-sided model formula specifying instrumental variables.
<code>data</code>	an optional data frame containing the variables in the model. By default the variables are taken from the environment from which <code>tsls</code> is called.
<code>subset</code>	an optional vector specifying a subset of observations to be used in fitting the model.
<code>na.action</code>	a function that indicates what should happen when the data contain NAs. The default is set by the <code>na.action</code> option.
<code>contrasts</code>	an optional list. See the <code>contrasts.arg</code> of <code>model.matrix.default</code> .

<code>y</code>	Response-variable vector.
<code>X</code>	Matrix of predictors, including a constant (if one is in the model).
<code>Z</code>	Matrix of instrumental variables, including a constant (if one is in the model).
<code>names</code>	optional character vector of names for the columns of the <code>X</code> matrix.
<code>x, object, model.2</code>	objects of class <code>tsls</code> returned by <code>tsls.formula</code> , containing nested models to be compared by an incremental $F$ -test. One model should be nested in the other; the order of models is immaterial.
<code>s2</code>	an optional estimate of error variance for the denominator of the $F$ -test. If missing, the error-variance estimate is taken from the larger model.
<code>dfe</code>	optional error degrees of freedom, to be specified when an estimate of error variance is given.
<code>digits</code>	number of digits for summary output.
<code>...</code>	arguments to be passed down.

### Value

`tsls.formula` returns an object of class `tsls`, with the following components:

<code>n</code>	number of observations.
<code>p</code>	number of parameters.
<code>coefficients</code>	parameter estimates.
<code>V</code>	estimated covariance matrix of coefficients.
<code>s</code>	residual standard error.
<code>residuals</code>	vector of residuals.
<code>response</code>	vector of response values.
<code>X</code>	model matrix.
<code>Z</code>	instrumental-variables matrix.
<code>response.name</code>	name of response variable, or expression evaluating to response.
<code>formula</code>	model formula.
<code>instruments</code>	one-sided formula for instrumental variables.

### Author(s)

John Fox (jfox@mcmaster.ca)

### References

- Fox, J. (1979) Simultaneous equation models and two-stage least-squares. In Schuessler, K. F. (ed.) *Sociological Methodology 1979*, Jossey-Bass.
- Greene, W. H. (1993) *Econometric Analysis, Second Edition*, Macmillan.

**See Also**[sem](#)**Examples**

```

data(Kmenta)
summary(tsls(Q ~ P + D, ~ D + F + A, data=Kmenta)) # demand equation

## 2SLS Estimates
##
## Model Formula: Q ~ P + D
##
## Instruments: ~D + F + A
##
## Residuals:
##      Min.   1st Qu.   Median     Mean   3rd Qu.     Max.
## -3.43e+00 -1.24e+00 -1.89e-01 -2.49e-13  1.58e+00  2.49e+00
##
##           Estimate Std. Error t value Pr(>|t|)
## (Intercept)  94.6333    7.92084  11.947 1.076e-09
## P            -0.2436    0.09648  -2.524 2.183e-02
## D             0.3140    0.04694   6.689 3.811e-06
##
## Residual standard error: 1.9663 on 17 degrees of freedom

summary(tsls(Q ~ P + F + A, ~ D + F + A, data=Kmenta)) # supply equation

## 2SLS Estimates
##
## Model Formula: Q ~ P + F + A
##
## Instruments: ~D + F + A
##
## Residuals:
##      Min.   1st Qu.   Median     Mean   3rd Qu.     Max.
## -4.87e+00 -1.26e+00  6.42e-01 -5.64e-12  1.47e+00  3.49e+00
##
##           Estimate Std. Error t value Pr(>|t|)
## (Intercept)  49.5324   12.01053   4.124 7.954e-04
## P             0.2401    0.09993   2.402 2.878e-02
## F             0.2556    0.04725   5.410 5.785e-05
## A             0.2529    0.09966   2.538 2.193e-02
##
## Residual standard error: 2.4576 on 16 degrees of freedom

anova(tsls(Q ~ P + F + A, ~ D + F + A, data=Kmenta),
      tsls(Q ~ 1, ~ D + F + A, data=Kmenta))
##
## Analysis of Variance
##
## Model 1: Q ~ P + F + A Instruments: ~D + F + A
## Model 2: Q ~ 1 Instruments: ~D + F + A

```

```
##
##           Res.Df      RSS Df Sum of Sq      F      Pr(>F)
## Model 1         16  96.633
## Model 2         19 268.114   3   171.481  9.4643 0.0007834 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

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