

Structural Equation Modeling with R using lavaan

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What is SEM?

- AKA:
 - ▶ Simultaneous Equations
 - ▶ Covariance Structure Analysis
 - ▶ Path Analysis
 - ▶ Confirmatory Factor Analysis (CFA)

SEM in R

- There are (at least) four packages that fit SEM models in R
 - ▶ lavaan, OpenMx, sem, and lava

lavaan

a free open-source, but commercial-quality package for latent variable modeling.

- From `lavaan.org`

- lavaan is extensively tested and updated
 - ▶ Bugs are quickly reported and corrected
- To install lavaan:

```
install.packages("lavaan")
```

- Features

- ▶ Full support for mean structures and multiple groups
- ▶ Several estimators available (including ML, GLS, WLS...)
- ▶ Standard and robust standard errors and test statistics (bootstrapping too!)
- ▶ Missing data handling through FIML
- ▶ Linear and non-linear inequality constraints
- ▶ Support for categorical data (and mixture of binary, ordered and continuous observed variables)

lavaan syntax

- lavaan specifies relationships based on a path diagram
 - ▶ Every arrow in the path diagram is a line of syntax in lavaan
- lavaan syntax uses a few different operators to specify relationships between variables
 - ▶ `=~` is used for factor loadings
 - ★ `energetic =~ active`
 - ▶ `~~` is used for variance and covariances
 - ★ `active ~~ active`
 - ▶ `~` is used for regressions
 - ▶ `*` is used to fix a parameter to a specific value
 - ★ `energetic ~~ 1*energetic`

lavaan syntax

- Users can also specify models with code from other software and fit them with lavaan
 - ▶ `plus2lavaan` (in the `lavaan` package)
 - ▶ `lisrel2lavaan` (in the `semTools` package)
 - ▶ Onyx (graphical user interface)

lavaan: Example

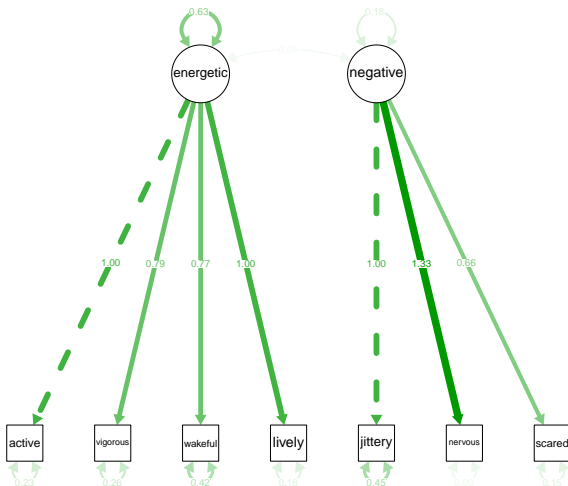
- Two factor CFA based on the msq data (from the psych package)

```
mod <- '  
energetic =~ active + vigorous + wakeful + lively  
negative =~ jittery + nervous + scared  
'  
  
fit <- cfa(mod, data = msq)
```


lavaan: Example

By default lavaan uses a marker variable method of scale setting

```
semPaths(fit, "est", nCharNodes = 0)
```

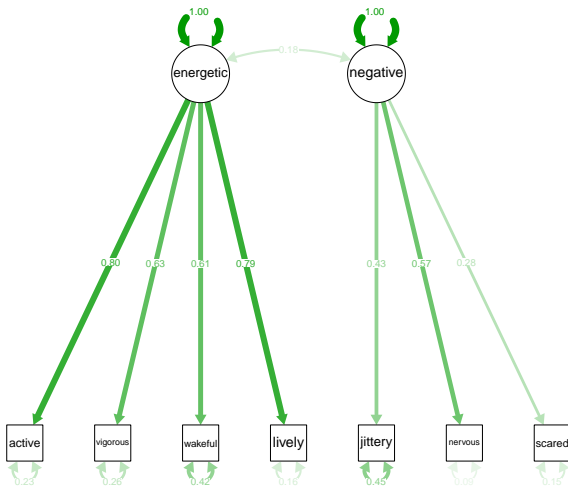


lavaan: Example

```
fit1 <- cfa(mod, data = msq, std.lv = TRUE)
```

- The std.lv option will use a fixed factor method of identification

lavaan: Example



lavaan: Example

- Model results can be inspected with summary, nested models can be compared with anova

Estimator	ML
Minimum Function Test Statistic	354.351
Degrees of freedom	13
P-value (Chi-square)	0.000

User model versus baseline model:

Comparative Fit Index (CFI)	0.969
Tucker-Lewis Index (TLI)	0.950

Loglikelihood and Information Criteria:

Loglikelihood user model (H0)	-25561.582
Loglikelihood unrestricted model (H1)	-25384.406

lavaan: Example

Number of free parameters	15
Akaike (AIC)	51153.164
Bayesian (BIC)	51246.989
Sample-size adjusted Bayesian (BIC)	51199.326

Root Mean Square Error of Approximation:

RMSEA	0.083
90 Percent Confidence Interval	0.075 0.090
P-value RMSEA \leq 0.05	0.000

Standardized Root Mean Square Residual:

SRMR	0.076
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lavaan: Example

	Estimate	Std.err	Z-value	P(> z)
Latent variables:				
energetic =~				
active	0.796	0.012	63.720	0.000
vigorous	0.632	0.011	55.166	0.000
wakeful	0.615	0.013	46.630	0.000
lively	0.792	0.012	67.459	0.000
negative =~				
jittery	0.429	0.014	29.904	0.000
nervous	0.571	0.013	42.769	0.000
scared	0.282	0.009	32.220	0.000
Covariances:				
energetic ~~				
negative	0.181	0.018	9.853	0.000

lavaan: Example Multiple Groups

- Two factor CFA based on the msq data (from the psych package)
 - ▶ Compare the msq with the revised msq

```
mod <- '  
energetic =~ active + vigorous + wakeful + lively  
negative =~ jittery + nervous + scared  
'  
  
fitg <- cfa(mod, data = msq, group = "scale")
```

lavaan: Example Multiple Groups

- Parameters can be constrained with group.equal option

```
fitgW <- cfa(mod, data = msq, group = "scale",  
             group.equal = "loadings")
```

```
anova(fitg, fitgW)
```

```
## Chi Square Difference Test
```

```
##
```

```
##           Df    AIC    BIC   Chisq Chisq diff Df diff Pr(>Chisq)
```

```
## fitg      26 51105 51381 380.75
```

```
## fitgW     31 51111 51355 396.41      15.657      5    0.007895 *
```

```
## ---
```

```
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```


lavaan: Example Multiple Groups

- Or invariance testing can be conducted using the `measurementInvariance` function
 - ▶ In the `semTools` package

```
measurementInvariance(mod, data = msq, group = "scale")
```

lavaan: Example Multiple Groups

Model 1: configural invariance:

chisq	df	pvalue	cfi	rmsea	bic
380.753	26.000	0.000	0.968	0.084	51380.620

Model 2: weak invariance (equal loadings):

chisq	df	pvalue	cfi	rmsea	bic
396.410	31.000	0.000	0.967	0.078	51355.002

[Model 1 versus model 2]

delta.chisq	delta.df	delta.p.value	delta.cfi
15.657	5.000	0.008	0.001

Model 3: strong invariance (equal loadings + intercepts):

chisq	df	pvalue	cfi	rmsea	bic
403.573	36.000	0.000	0.967	0.073	51320.889

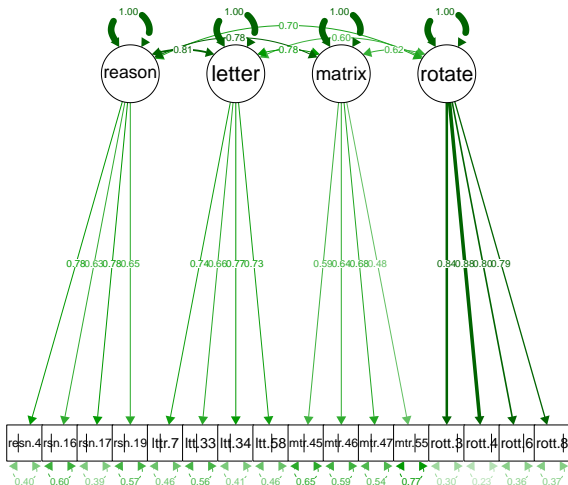
[Model 1 versus model 3]

lavaan: Example Categorical Indicators

- Two factor CFA based on the ability data (from the psych package)

```
modCat <- '  
reason =~ reason.4 + reason.16 + reason.17 + reason.19  
letter =~ letter.7 + letter.33 + letter.34 + letter.58  
matrix =~ matrix.45 + matrix.46 + matrix.47 + matrix.55  
rotate =~ rotate.3 + rotate.4 + rotate.6 + rotate.8  
'  
  
fitCat <- cfa(modCat, data = ability, std.lv = TRUE,  
              ordered = names(ability))
```

lavaan: Example Categorical Indicators



lavaan: Extensions

- There are many packages providing additional functionality to lavaan:
 - ▶ semPlot - Path diagrams for lavaan (used to make the above plots)
 - ▶ semTools - useful functions for SEM in R
 - ★ Includes functions for latent interactions, multiple imputation and more
 - ▶ simsem - simulation package for SEM
 - ▶ lavaan.survey - apply survey weights, clustering corrections and other corrections for lavaan models
 - ▶ Onyx - graphical user interface for SEM
(<http://onyx.brandmaier.de/>)

lavaan: Resources

- The lavaan website is extremely helpful (<http://lavaan.org>)
 - ▶ It include a tutorial in lavaan
 - ▶ Links to examples from popular SEM books in lavaan
 - ▶ Link to a discussion board about lavaan

Thank you!

- Questions?
- email: schoemanna@ecu.edu
- Slides and code: <https://sites.google.com/site/alexandermschoemann/supplementarymaterials>