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lavaanExtra: Convenience Functions for Package *lavaan*

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Summary

{lavaanExtra} is an R package that offers an alternative and vector-based syntax to the package {lavaan}, as well as other convenience functions such as naming paths and defining indirect effects automatically. It also offers convenience formatting optimized for publication and script sharing workflows.

Statement of need

{lavaan} (Rosseel, 2012) is a very popular R package for structural equation modeling (SEM). The package relies on specific operators to define latent variables, regressions, covariances, indirect effects, and so on. However, some individuals (e.g., beginners to R and {lavaan})—or in some cases power users—may prefer not having to specify the operators themselves, or would like to see some steps automatized, such as generating the {lavaan} model layout or defining indirect effects. Furthermore, for researchers, it can be relatively difficult to extract relevant statistical outputs in the form of tables and figures that are suitable for scientific publication.

{lavaanExtra} does mainly two things to address these issues. First, it offers an alternative, code-efficient flexible modular syntax that allows automatizing certain steps, such as defining indirect effects in certain scenarios or the desired structure of a SEM model to be plotted (however, note that {lavaan} is also compatible with a modular approach). Second, it facilitates the analysis-to-publication workflow by providing publication-ready tables and figures following the style requirements of the American Psychological Association (APA).

Usage

There is a single function at the center of the proposed alternative syntax, `write_lavaan()`. The idea behind `write_lavaan()` is to define individual components (regressions, covariances, latent variables, etc.), provide them to the function, and have it write the `lavaan` model, so the user does not have to worry about making typos in the specific symbols required for each aspect of the model.

There are several benefits to this approach. Some `lavaan` models can become very large. By defining the entire model every time, such as is typical with {lavaan} users, not only do we break the DRY (Don't Repeat Yourself) principle, but our scripts can also become long and unwieldy. This problem gets worse in the scenario where we want to compare several variations of the same general model. `write_lavaan()` allows the user to reuse code components, say, only the latent variables, for future models.

This aspect also allows better control over the user's code. If the user makes a mistake in one of, say, five SEM models definition, the user will have to change it at all five places within the script. With `write_lavaan()`, users only need to define the reusable component the first time, or until they need to change that component again.

The vector-based approach also allows the use of functions to define components. For example, if all scale items are named consistently, say `x1` to `x50`, one can use `paste0("x", 1:50)` instead of typing all the items by hand and risk making mistakes. However, note that reusable components through functions is also compatible with {lavaan}.

Another issue with `lavaan` models is the readability of the code defining the model. One can go to lengths to make it pretty, but not everyone does, and many people do not use the same strategies to organize the information of the model definition. With `write_lavaan()`, not only is the model information standardized, but it is also neatly divided into clear and useful categories.

Finally, for beginners, it can be difficult to remember the correct `lavaan` symbols for each specific operation. `write_lavaan()` uses familiar names to convert the information to the correct symbols. Even for people familiar with `lavaan` syntax, this approach can save time. The function also offers the possibility to define the named paths automatically with clear and intuitive names.

I provide a simple Confirmatory Factor Analysis (CFA) example below using the `HolzingerSwineford1939` dataset (Holzinger & Swineford, 1939). The dataset contains the mental ability test scores of children. In this example, we want to define the latent variables `visual` (visual perception ability), `textual` (reading and writing ability), and `speed` (processing speed ability), which are defined by items 1 to 9, respectively. We can then use the `cat()` function on the resulting object (of type character) to read it in the traditional way and make sure we have not made any mistake.

```
library(lavaanExtra)

x <- paste0("x", 1:9)
latent <- list(
  visual = x[1:3],
  textual = x[4:6],
  speed = x[7:9]
)

model.cfa <- write_lavaan(latent = latent)
cat(model.cfa)
```

```
## ##################################################
## # [-----Latent variables (measurement model)-----]
##
## visual =~ x1 + x2 + x3
## textual =~ x4 + x5 + x6
## speed =~ x7 + x8 + x9
```

Should we want to use these latent variables in a full SEM model, we do not need to define the latent variables again, only the new components. In the example below, I add regressions, covariances, and indirect effects to the model. Two of our latent variables (`textual` and `speed`) are now predicted by our mediating variable, `visual`. In turn, `visual` is now predicted by our independent variables, `grade` (the students' grade) and `ageyr` (the students' age, in years).

With the `lavaanExtra` syntax, when defining our lists of components, we can think of the `=` sign as "predicted by", a bit like `~` for regression. There is an exception to this for the `indirect` object, which also allows specifying our variables directly instead. When such is the case, `write_lavaan()` will define all indirect paths automatically.

```
DV <- c("textual", "speed")
```

```r
M <- "visual"
IV <- c("grade", "ageyr")

mediation <- list(speed = M, textual = M, visual = IV)
regression <- list(speed = IV, textual = IV)
covariance <- list(speed = "textual", ageyr = "grade", x4 = x[5:6])
indirect <- list(IV = IV, M = M, DV = DV)

model.sem <- write_lavaan(mediation = mediation,
                          regression = regression,
                          covariance = covariance,
                          indirect = indirect,
                          latent = latent,
                          label = TRUE)
cat(model.sem)
```

```
## ##################################################
## # [-----Latent variables (measurement model)-----]
##
## visual =~ x1 + x2 + x3
## textual =~ x4 + x5 + x6
## speed =~ x7 + x8 + x9
##
## ##################################################
## # [-----------Mediations (named paths)-----------]
##
## speed ~ visual_speed*visual
## textual ~ visual_textual*visual
## visual ~ grade_visual*grade + ageyr_visual*ageyr
##
## ##################################################
## # [---------Regressions (Direct effects)---------]
##
## speed ~ grade + ageyr
## textual ~ grade + ageyr
##
## ##################################################
## # [------------------Covariances-----------------]
##
## speed ~~ textual
## ageyr ~~ grade
## x4 ~~ x5 + x6
##
## ##################################################
## # [--------Mediations (indirect effects)---------]
##
## grade_visual_textual := grade_visual * visual_textual
## grade_visual_speed := grade_visual * visual_speed
## ageyr_visual_textual := ageyr_visual * visual_textual
## ageyr_visual_speed := ageyr_visual * visual_speed
```

Tables

The `nice_fit()` function extracts only some of the most popular fit indices and organize them such that it is easy to compare models. There is an option to format the table as an APA {flextable} (Gohel & Skintzos, 2023), through the {rempsyc} package (Thériault, 2022), using option `nice_table = TRUE`. This `flextable` object can then be easily exported to Microsoft Word. Below we fit our two earlier models and feed them to `nice_fit()` as a named list:

```
library(lavaan)
fit.cfa <- cfa(model.cfa, data = HolzingerSwineford1939)
fit.sem <- sem(model.sem, data = HolzingerSwineford1939)

list.mods <- list(`CFA model` = fit.cfa, `SEM model` = fit.sem)
fit_table <- nice_fit(list.mods, nice_table = TRUE)
```

```
fit_table
```

Model	χ^2	*df*	χ^2/df	*p*	CFI	TLI	RMSEA [90% CI]	SRMR	AIC	BIC
CFA model	85.31	24	3.55	< .001	.93	.90	.09 [.07, .11]	.06	7,517.49	7,595.34
SEM model	114.20	34	3.36	< .001	.93	.88	.09 [.07, .11]	.05	8,640.07	8,758.59
Suggested soft cutoffs[a]	**—**	**—**	**< 2 or 3**	**> .05**	**≥ .95**	**≥ .95**	**< .05 [.00, .08]**	**≤ .08**	**Smaller**	**Smaller**

[a]Based on Schreiber (2017), Table 3.

The table can then be saved to word simply using `flextable::save_as_docx()` on the resulting `flextable` object.

```
flextable::save_as_docx(fit_table, path = "fit_table.docx")
```

It will also render to PDF in an `rmarkdown` document with `output: pdf_document`, but using `latex_engine: xelatex` is necessary when including Unicode symbols in tables like with the `nice_fit()` function.

It is similarly possible to prepare APA tables in Word or other formats with the regression coefficients (`lavaan_reg()`), covariances (`lavaan_cov()`), correlations (`lavaan_cor()`), variances (`lavaan_var()`), or user-defined parameters like for indirect effects (`lavaan_defined()`). For example, for indirect effects:

```
lavaan_defined(fit.sem, lhs_name = "Indirect Effect", nice_table = TRUE)
```

Indirect Effect	Paths	*SE*	*Z*	*p*	*b*	95% CI (*b*)	*b**	95% CI (*b**)
grade → visual → textual	grade_visual*visual_textual	0.08	3.35	.001***	0.28	[0.11, 0.44]	0.13	[0.05, 0.20]
grade → visual → textual	grade_visual*visual_speed	0.06	3.05	.002**	0.17	[0.06, 0.28]	0.13	[0.05, 0.21]
grade → visual → textual	ageyr_visual*visual_textual	0.03	-2.47	.014*	-0.08	[-0.15, -0.02]	-0.08	[-0.14, -0.02]
grade → visual → textual	ageyr_visual*visual_speed	0.02	-2.34	.019*	-0.05	[-0.10, -0.01]	-0.08	[-0.15, -0.02]

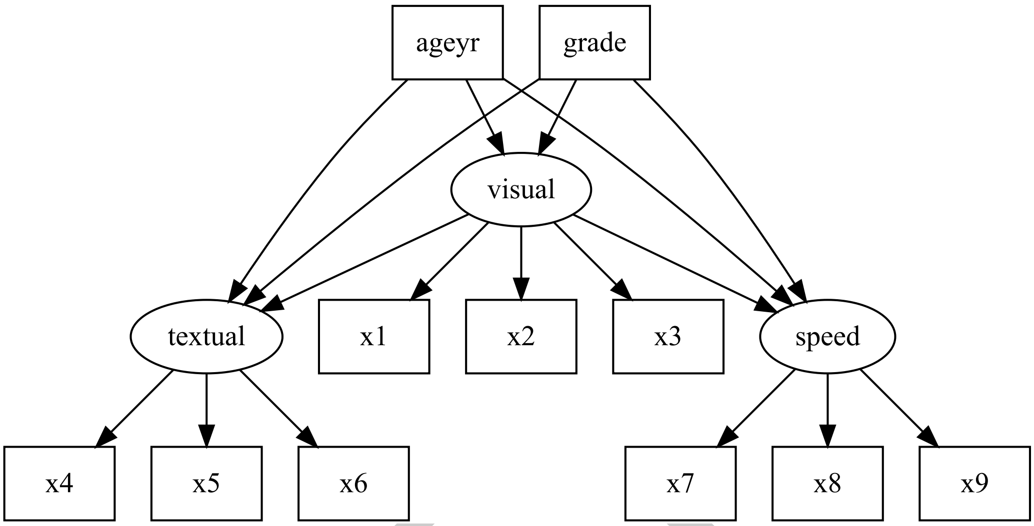
Figures

There are several packages designed to plot SEM models, but few that people consider satisfying or sufficiently good for publication by default. There are two packages that stand out however, {lavaanPlot} (Lishinski, 2021) and {tidySEM} (van Lissa, 2023b). Yet, even for those excellent packages, most people do not view them as publication-ready or at least optimized in the best possible way.

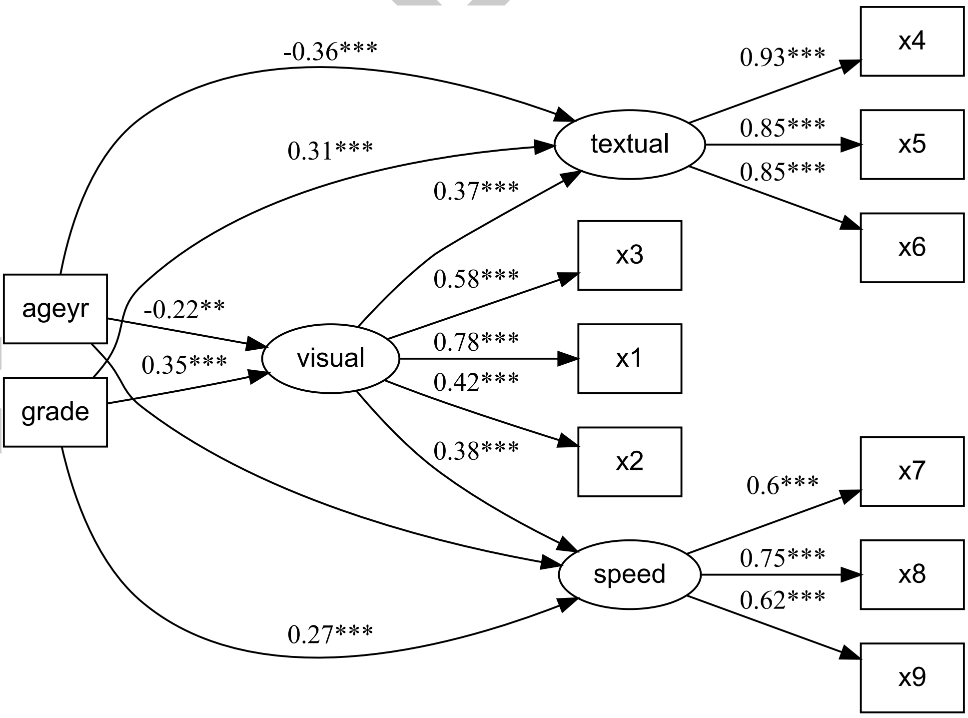
The Journal of Open Source Software

This is what nice_lavaanPlot and nice_tidySEM aim to correct. Let's compare the default lavaanPlot() and nice_lavaanPlot() outputs side-by-side for demonstration purposes.

```r
lavaanPlot::lavaanPlot(model = fit.sem)
```




```r
nice_lavaanPlot(fit.sem)
```



For reference, nice_lavaaPlot() is a simple wrapper around lavaanPlot::lavaanPlot() and an identical figure can be obtained using only lavaanPlot with the following code:

```r
lavaanPlot::lavaanPlot(
    model = fit.sem,
    node_options = list(shape = "box", fontname = "Helvetica"),
    coefs = TRUE,
    stand = TRUE,
    stars = c("regress", "latent", "covs"),
    graph_options = c(rankdir = "LR"),
```

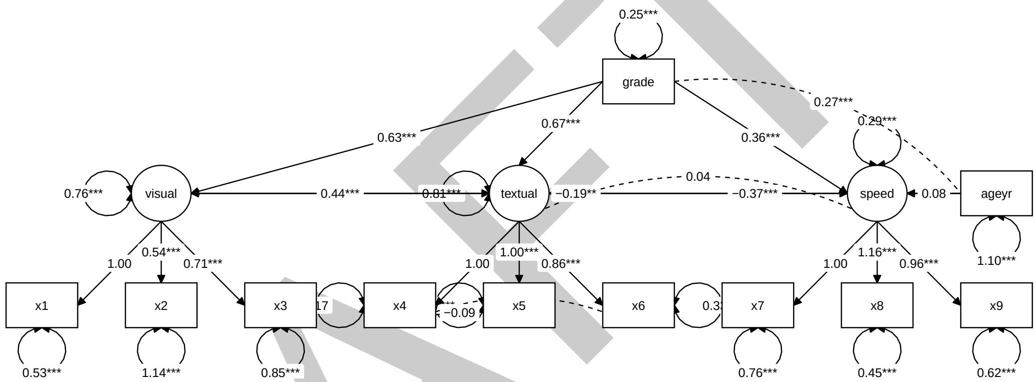
```
  sig = .05
)
```

As these figures demonstrate, `nice_lavaanPlot()` has several elements frequently requested by researchers (especially in psychology): (a) a horizontal, rather than vertical, layout; (b) the coefficients appear by default (but only significant ones); (c) significance stars; and (d) the use of a sans serif font (as required by APA style for figures).

Even so, `nice_lavaanPlot` is not perfectly optimal for publication, for example for the use of curved lines, which many researchers dislike. Nonetheless, it will still yield excellent and satisfying results for a quick and easy check.

The best option for publication then is `nice_tidySEM`. Let's first look at the default output of the base `tidySEM::graph_sem()` for reference.

```
tidySEM::graph_sem(fit.sem)
```

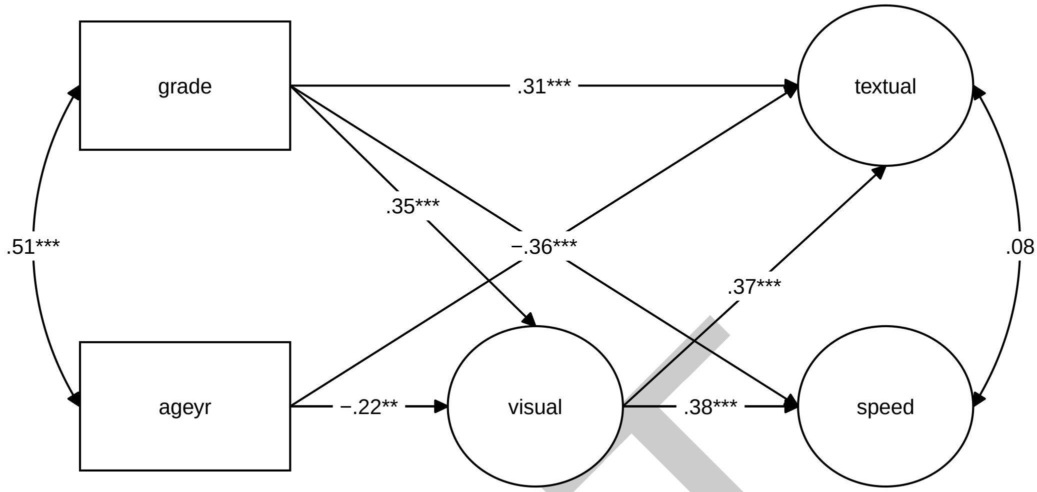


The author of the {tidySEM} package notes that

> This uses a default layout, provided by the `igraph` package. However, the node placement is not very aesthetically pleasing. One of the areas where tidySEM really excels is customization. (van Lissa, 2023a)

In this sense, most of the time, both `tidySEM` and `nice_tidySEM` will need a layout in order to yield the best result. One of the benefits of `nice_tidySEM` is that when our model is simply made of three "levels": independent variables, mediators, and dependent variables (e.g., for a path analysis, or if we do not want to draw the items for a full SEM), it is possible to automatically specify a proper layout by simply feeding it the `indirect` object that we created earlier.

```
nice_tidySEM(fit.sem, layout = indirect)
```



For reference, below I provide the code necessary to reproduce this figure using the `tidySEM` package only.

```
library(tidySEM)

mylayout <- data.frame(
  IV = c("grade", "ageyr"),
  M = c("", "visual"),
  DV = c("textual", "speed")
)
p <- prepare_graph(fit.sem, layout = mylayout)
p <- hide_var(p)
x <- p$edges$est_sig_std
x <- sub("^0", "", x)
x <- sub("^-0", "-", x)
p$edges$label <- x
p$edges$linetype <- 1
p$edges$arrow <- ifelse(p$edges$arrow == "none", "both", p$edges$arrow)
plot(p)
```

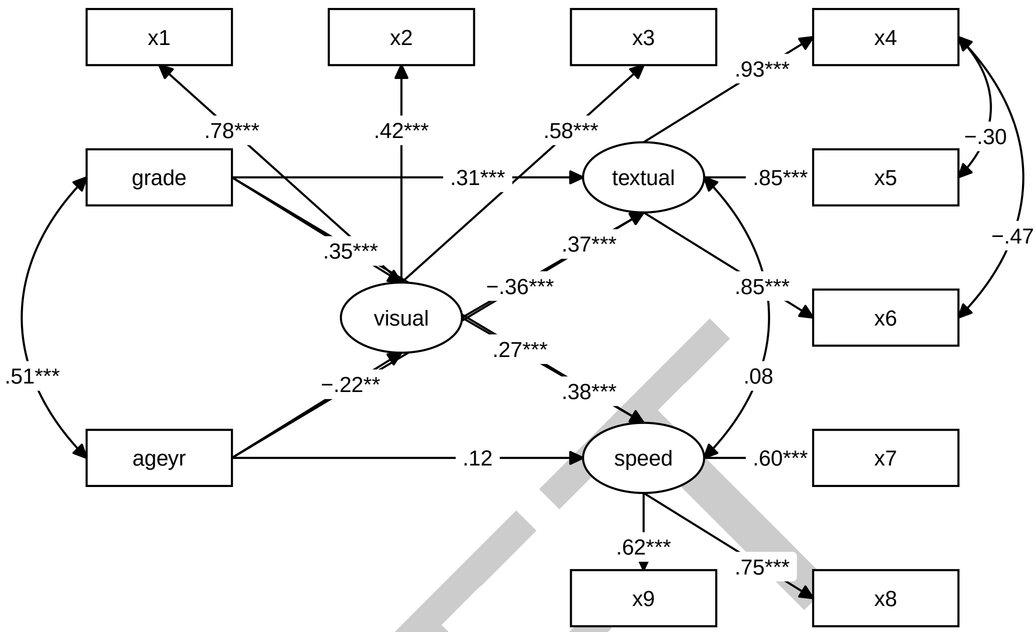
For the time being, `nice_tidySEM` only supports this three-level automatic layout, but designs with more levels are in the works. In the meantime, when the model is more complex (or that we want to include items), it is necessary to specify the layout manually using a matrix or data frame, which allows fine-grained control over the generated figure.

```
mylayout <- data.frame(
  IV = c("x1", "grade", "", "ageyr", ""),
  M = c("x2", "", "visual", "", ""),
  DV = c("x3", "textual", "", "speed", "x9"),
  DV.items = c(paste0("x", 4:8)))
as.matrix(mylayout)
```

```
##      IV      M        DV        DV.items
## [1,] "x1"    "x2"     "x3"      "x4"
## [2,] "grade" ""       "textual" "x5"
## [3,] ""      "visual" ""        "x6"
## [4,] "ageyr" ""       "speed"   "x7"
## [5,] ""      ""       "x9"      "x8"
```

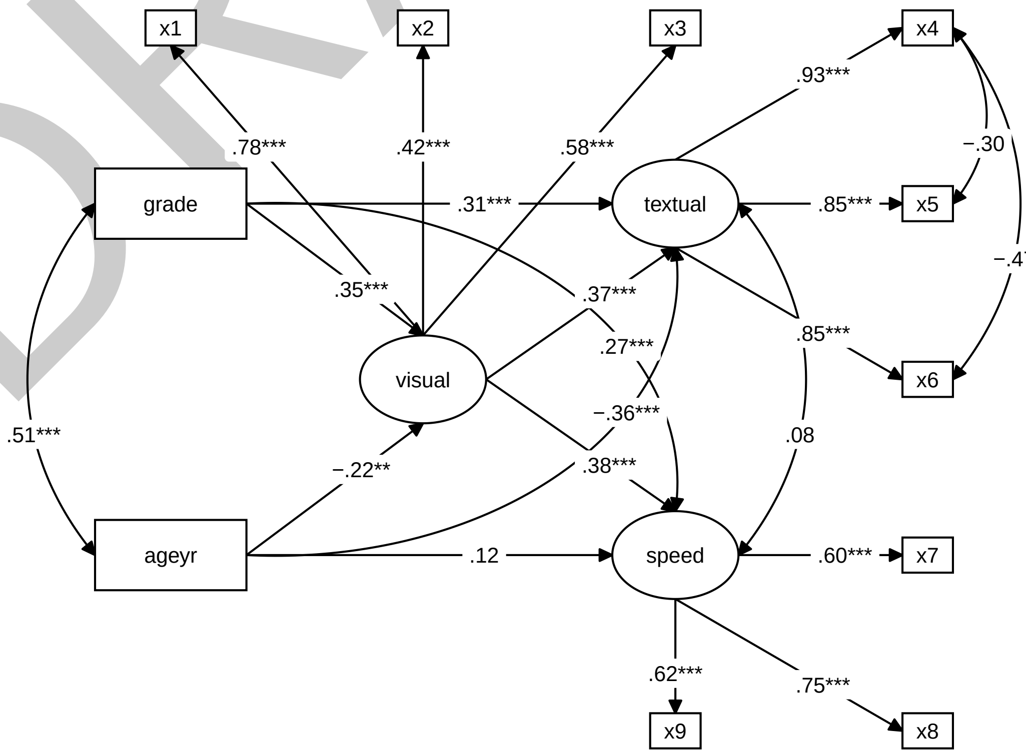
```
nice_tidySEM(fit.sem, layout = mylayout, label_location = 0.70)
```

The Journal of Open Source Software



If the figure is still not sufficiently satisfying, it is possible to store the output as a `tidy_sem` object (by using `plot = FALSE`), which can then be modified according to regular `tidySEM` syntax. This can be useful to fine-tune and finalize the figure.

```
x <- nice_tidySEM(fit.sem, layout = mylayout, label_location = 0.65,
                  reduce_items = c(x = 0.4, y = 0.2), plot = FALSE)
from <- x$edges$from
to <- x$edges$to
x$edges[from == "grade" & to == "speed", "curvature"] <- 40
x$edges[from == "ageyr" & to == "textual", "curvature"] <- -40
plot(x)
```



The resulting figure can be saved using ggplot2::ggsave() (Wickham, 2016):

```
ggplot2::ggsave("my_semPlot.pdf", width = 8, height = 6)
```

For reference, below I provide the code necessary to reproduce this figure using the tidySEM package only.

```
library(tidySEM)

p <- prepare_graph(fit.sem, layout = mylayout)
p <- edit_graph(p, { label_location <- 0.65 })
p <- hide_var(p)
x <- p$edges$est_sig_std
x <- sub("^0", "", x)
x <- sub("^-0", "-", x)
p$edges$label <- x
items <- p$edges[p$edges$op == "=~", "rhs"]
i <- p$nodes$name %in% items
p$nodes[i, ]$node_xmin <- p$nodes[i, ]$node_xmin + 0.4
p$nodes[i, ]$node_xmax <- p$nodes[i, ]$node_xmax - 0.4
p$nodes[i, ]$node_ymin <- p$nodes[i, ]$node_ymin + 0.2
p$nodes[i, ]$node_ymax <- p$nodes[i, ]$node_ymax - 0.2
p$edges$linetype <- 1
p$edges$arrow <- ifelse(p$edges$arrow == "none", "both", p$edges$arrow)
from <- p$edges$from
to <- p$edges$to
p$edges[from == "grade" & to == "speed", "curvature"] <- 40
p$edges[from == "ageyr" & to == "textual", "curvature"] <- -40
plot(p)
```

Other differences between {tidySEM} and nice_tidySEM() are that: (a) the latter displays standardized coefficients by default (but unstandardized coefficients can be specified with est_std = FALSE), (b) if using standardized coefficients, the leading zero is omitted (as preferred by many researchers); (c) does not plot the variances by default, (d) uses full double-headed arrows instead of dashed lines with no arrows for covariances, (e) has further arguments for easy customization (e.g., reduce_items), and (f) allows defining an automatic layout in specific cases (as described earlier).

Finally, the base function, tidySEM::graph_sem(), is difficult to customize in depth. For the aesthetics of nice_tidySEM(), for example, we need to rely instead on the {tidySEM}'s prepare_graph(), edit_graph(), and numerous conditional formatting functions. In contrast to nice_tidySEM(), these tidySEM functions act more like a grammar of SEM plotting, akin to the popular grammar of graphics, {ggplot2} (Wickham, 2016). This provides great flexibility, but for the occasional user, also comes with an additional burden, as users may for example need to skim through almost 400 undocumented functions, should they want to conditionally edit the resulting tidy_sem object.

Availability

The {lavaanExtra} package is licensed under the MIT License. It is available on CRAN, and can be installed using install.packages("lavaanExtra"). The full tutorial website can be accessed at: https://lavaanExtra.remi-theriault.com/. All code is open-source and hosted on GitHub, and bugs can be reported at https://github.com/rempsyc/lavaanExtra/issues/.

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