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An Open-source WYSIWYG Web Application for Drawing Path Diagrams of Structural Equation Models

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ABSTRACT

Structural equation modeling (SEM) is widely used in behavioral, social, and education research. Drawing publication-ready path diagrams for SEM is not a pleasant task with the existing software. The article introduces an open-source web-based graphical application, *semdiag*, for drawing WYSIWYG SEM path diagrams interactively. The application is an on-going project developed by the authors using JavaScript, and it can be used in major web browsers, both online and offline. Several examples are provided to demonstrate how to use the application.

KEYWORDS

JavaScript; structural equation modeling; path diagram; graphical interface

1. Motivation and Significance

Structural equation modeling (SEM) is a statistical technique that can be used to evaluate relations among observed and latent variables (Hoyle, 1995), where an observed variable can be measured directly but a latent variable has to be assessed indirectly using observed variables. The relations between two variables can be non-directional as correlation relationships or directional as predictive relationships (Hoyle, 1995; Kline, 2011). SEM generalizes many commonly used statistical models such as confirmatory factor models, path models, latent regression models, and growth curve models (Kline, 2011). Over the past few decades, the application of SEM has been rapidly growing in many disciplines (Kline, 2011; Nachtigall et al., 2003; Westland, 2015), especially in education (Khine, 2013), psychology (MacCallum & Austin, 2000), management (Shook et al., 2004), and marketing (Babin et al., 2008).

A variety of software packages were developed to conduct SEM analysis including commercial ones such as LISREL (Jöreskog & Sörbom, 2022), EQS (Bentler, 2020, 2006), AMOS (Arbuckle, 2021), and Mplus (Muthén & Muthén, 2017, 2021), as well as free ones such as Ωnyx (von Oertzen et al., 2015a, 2015b), R packages Lavaan (Rosseel, 2012; Rosseel et al., 2022), OpenMx (Boker et al., 2022), and sem (Fox et al., 2022). Some general-purpose statistical software products such as SAS and STATA also provide routines to perform SEM analysis. SEM almost always relies on representing models graphically as path diagrams for illustrating the theoretical models intuitively. For example, the software programs EQS (Bentler, 2020) and LISREL (Jöreskog & Sörbom, 2022) have options to graphically display path diagrams directly. Some programs such as the R package sem (Fox et al., 2022) can create syntax for external drawing software such as semPlot (Epskamp, 2015) to display path diagrams. There are also standard-alone programs to generate path diagrams such as LISPATH (Marcoulides & Papadopoulos, 1993) or for drawing path diagrams manually such as igraph (Csardi & Nepusz, 2006). Furthermore, some software programs such as AMOS (Arbuckle, 2021), Mplus (Muthén & Muthén, 2017) and Ωnyx (von Oertzen et al., 2015b) allow a SEM model to be specified in a graphical way by drawing its path diagram directly. Many of these tools, however, have limitations and can be difficult to use for customization of the path diagrams. For example, Ωnyx and SEM Builder in STATA can produce high-equality diagrams but are not open-source. The R package semPlot (Epskamp, 2015, 2022) provides a systematic way to plot path diagrams and is compatible with syntax from other software, but the diagram customization options can be limited.

The purpose of this study is to develop an open-source and user-friendly tool, *semdiag*, for drawing SEM path diagrams. The tool is a web application with the following features.

1. It is ready for use within a web browser either online or offline, and therefore does not require the installation of additional software.
2. It allows the creation of new path diagrams and easy modification of existing path diagrams through an interactive graphical interface, and the diagram is WYSIWYG (what you see is what you get).
3. It allows a user to save a working diagram to a local computer and load a saved diagram from the local computer.

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Ziqian Xu has equal contribution to the study as the first author.

4. It eases the diagram drawing process by automatically adding the default nodes and arrows.
5. The diagrams can be saved into SVG, PNG, PDF, and HTML formats and can be readily used in academic publications.
6. It is free and open-source, and accepts contribution from others through GitHub. New contributions can be directly and immediately applied.
7. It allows adding mathematical symbols and formulas on the diagrams through LATEX.

2. Framework of SEM Path Diagram

2.1. Components of SEM Path Diagram

A SEM path diagram consists of two types of graphical components: variables (nodes) and paths (edges).

2.1.1. Variables

Three types of variables are allowed in a SEM path diagram: observed, latent, and constant variables. We use a rectangle to represent an observed variable, an ellipse to denote a latent variable, and a triangle to indicate a constant. The constant is a special variable with the value of 1. It is used to indicate a mean or an intercept in the model. We will call the nodes by their respective geometric names (i.e., ellipse, triangle, and rectangle nodes) in this paper.

2.1.2. Paths

Two types of paths, a directed one and an undirected one, are allowed to define the relationship of the variables in a model or diagram. A directed path, represented by a one-way arrow, is used to indicate that one variable can predict another variable. In statistical language, it typically means a regression relationship. A directed path points from the predicting variable toward the outcome variable. More specifically in SEM, a directed path from an ellipse (a latent variable) to a rectangle (an observed variable) represents a factor loading; otherwise, it indicates a regression coefficient.

An undirected path is represented by a two-way arrow. If an undirected path connects two variables, it is the covariance between the two variables. In some cases, an undirected path can start from one variable and end on the same variable. Such a path can represent either a variance or a residual variance in a structural equation model. For a variable with such a path, if there is no directed path pointing to it, the path represents a variance, otherwise, a residual variance. Similar to the nodes, we will also call paths by their geometric names (i.e., one-way and two-way arrows) in this paper.

Both nodes and arrows can be labeled. For a node, we can label it using a mathematical symbol or the variable name from real-world data sets. For an arrow, we can label it using a coefficient name or a number denoting the value of a coefficient of a model.

2.2. Basic Rules for Drawing SEM Path Diagram

For efficiency and consistency with conventions of statistical modeling, the following rules are imposed by the *semdiag* application in constructing path diagrams. First, no more than one triangle node can be created in one diagram. Second, if connected with a triangle node, any one-way arrows can only start from the triangle node. Third, there can be either one one-way arrow or one two-way arrow between two rectangles or ellipses. Fourth, a two-way arrow is automatically created for a rectangle or ellipse node that is predicted by one or more other nodes. The arrow is also automatically removed when the involved node loses its predicting nodes. Finally, when a node is removed, all arrows connecting to it will be removed automatically. Note that the two-way arrow toward the same variable represents either the residual variance if the variable has predictors or the variance of the variable itself if it does not have any predictors.

3. Software Architecture

The *semdiag* interface is designed as an interactive web application. It consists of two main components. First, the nodes and arrows of the path diagrams are defined in the scalable vector graphics (SVG) format (Ferraiolo et al., 2000). Second, the client-side behavior is implemented using JavaScript to interact with the SVG graphs. Specifically, the library D3.js (Bostock, 2013; Myatt & Johnson, 2011) is applied to realize the data-driven SVG diagraming while the library jQuery (Resig et al., 2012) is used to create the dynamic dialogs. The file operations for saving and exporting diagrams are also completed with JavaScript. In particular, conversions with PDFs are done through the jsPDF and svg2pdf libraries (Hall, 2020; yWorks, 2019). Further, the software supports LATEX notations via the use of the MathJax library (American Mathematical Society, 2017; Cervone, 2012). As a web application, the interface can be used within a web browser on a computer, a tablet, a phone, or other devices that support modern web browsers. The web application is best supported by the Chrome web browser but also works in Microsoft Edge, Firefox, and Safari although features such as selecting multiple elements in the web application and saving the diagram to desired output formats can behave slightly differently depending on the browsers used.

4. Software Functionalities

The major functionalities of the interface include creating, editing, saving, and loading path diagrams, which are implemented through different buttons. A brief introduction of the functionalities is included in Table 1 (see also the left panel of Figure 1).

4.1. Create a New Diagram

A rectangle node or an ellipse node can be created by clicking their corresponding buttons in the interface. A new arrow

Table 1. Buttons and their functionalities in the interface.

Name	Button	Functionality
Open		Open a path diagram from a .diag file
New		Start a new path diagram
Save		Save a path diagram to a .diag file
SVG		Save a path diagram to a .svg file
PNG		Save a path diagram to a .png file
PDF		Save a path diagram to a .pdf file
HTML		Save a path diagram to a .html file
Render		Render LaTeX in a diagram
Rectangle		Draw a rectangle node
Ellipse		Draw an ellipse node
Triangle		Draw a triangle node
One-way		Draw a one-way arrow
Two-way		Draw a two-way arrow
Text		Add or edit texts or labels
Delete		Delete elements
Clone		Clone nodes
Black, Red, Blue, Green		Color nodes or arrows
Dotted		Change solid lines to dotted
Solid		Change dotted lines to solid
Hide Label, Show Label		Hide or show labels
Grid		Show or hide assistance grids of the canvas
Left, Right, Top, Bottom		Align nodes
Expand Width		Expand width to be the same as the largest node
Shrink Width		Shrink width to be the same as the smallest node
Expand Height		Expand height to be the same as the largest node
Shrink Height		Shrink height to be the same as the smallest node
Height		Adjust height
Width		Adjust width
Font Size		Adjust font size
Line Width		Adjust line width
Variance Size		Adjust variance arrow size
Rotate Variance		Rotate variance arrow direction
Move		Move elements

can be drawn by first selecting the start node, then clicking the arrow button ("One-way" or "Two-way" button), and finally clicking the end node. Another way to create an arrow is to first select the arrow, and then drag from the start node to the end node. Both the one-way and two-way arrows can be drawn in these ways. For the arrows representing variances, the start node and the end node are the same.

To create a triangle node, one needs to first select a rectangle or ellipse node and then click on the "Triangle" button. A one-way arrow will also be added automatically from

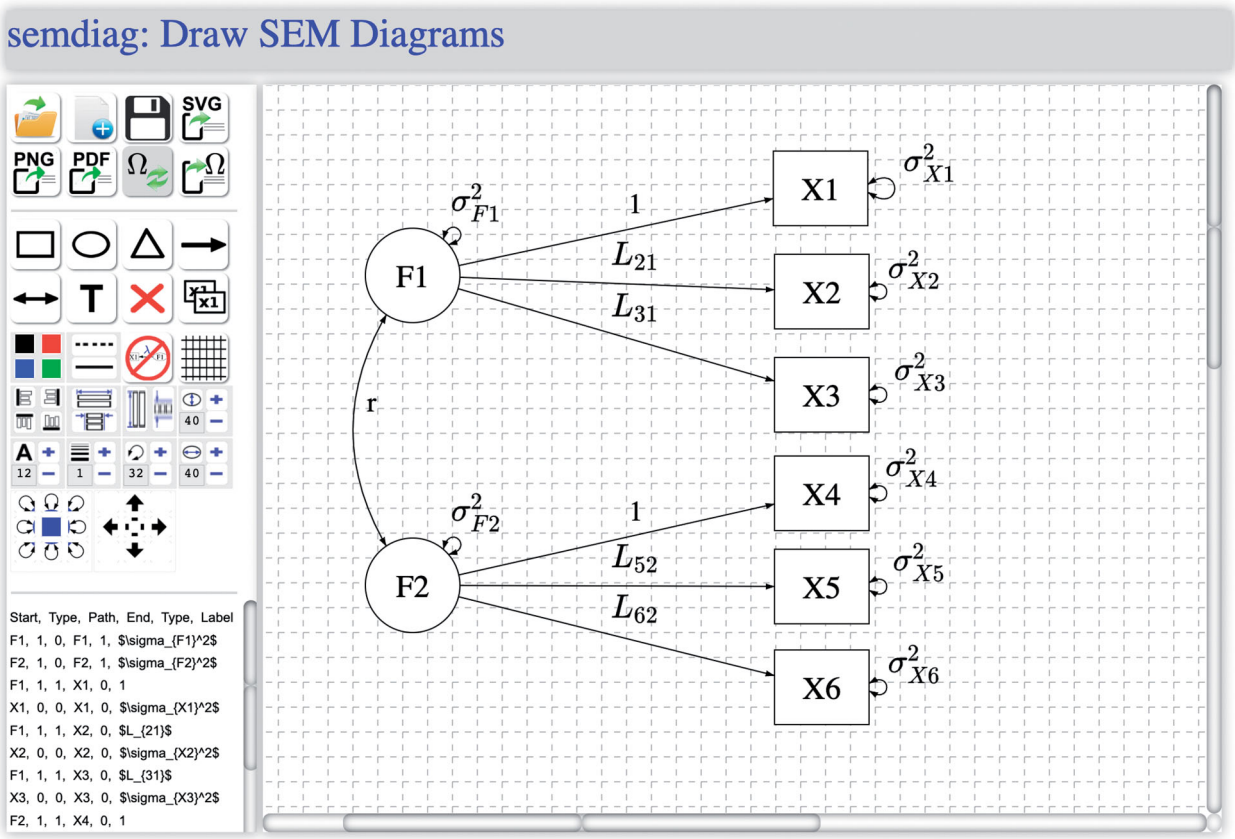

Figure 1. A factor model.

the triangle node to the node selected. There can only be one triangle node per diagram. However, additional arrows can be added between the triangle node and other ellipse or rectangle nodes.

Nodes and arrows can be duplicated easily. To duplicate one node, simply select it by clicking it and then click the "Clone" button. To copy and paste multiple nodes, one can select all the nodes as well as arrows then click the "Clone" button. There are two ways to select multiple elements in the diagram: One can directly drag over multiple elements or one can hold the "control" key and click on each element to be selected.

Both the nodes and arrows can be named. When first created, the nodes are labeled with default names whereas the arrows are unnamed. One can change them in a pop-up dialog by double clicking a node or an arrow. Another way is to first select the node or arrow and then click the "Text" button to bring up the dialog.

Text can be added anywhere in the diagram. To add a text box, first click the "Text" button and then click on the canvas where you want to put the text box. Mathematical equations can be defined in the text box using LATEX notations. For example, α will be rendered as α after clicking the "Render" button.

4.2. Edit an Existing Diagram

A node within a path diagram can be moved freely by dragging. To move multiple nodes and arrows, one can select the target elements and then drag them to a desired location. Nodes can also be moved using the "Move" buttons. The properties of a selected node or arrow can be modified by clicking the properties buttons such as "Color", "Font Size", and "Line Width." To delete a node or arrow, simply select it and then click the "Delete" button. The size of nodes can be adjusted using the "Width" and "Height" buttons. Labels on arrows can be turned on or off using the "Show Label" and" Hide Label" buttons. Line types of arrows and nodes can be toggled using the "Dotted" and "Solid" buttons.

If multiple nodes are selected, one can also align them using the "Left", "Right", "Top", and "Bottom" buttons. The "Expand Width" button can be used to expand the width of a group of selected nodes to be the same as the node with the largest width. The "Shrink Width", "Expand Height", and "Shrink Height" buttons work similarly.

After clicking on a variance or residual variance arrow, its location relative to the nodes can be rotated using the "Rotate Variance" buttons, in addition to dragging it using the mouse. The "Variance Size" button can be used to change sizes of the variance and residual variance arrows.

4.3. Save and Load a Diagram

By clicking the "Save" button, a path diagram will be saved to a file on the local computer as a text file. The extension name of the file is ".diag". The file can then be loaded for further edits by clicking the "Open" button. The saved diagram can be shared and opened on different computers in the *semdiag* application.

4.4. Generate Publication-ready Path Diagrams

The path diagram can be exported to a SVG graph, a PNG, an HTML, or a PDF using the "SVG", "PNG", "HTML", or "PDF" button. A dialog box is prompted for customizing the desired file name. Saving LATEX notations is currently only supported when saving the path diagrams to HTML files. If one needs to save the path diagram with mathematical symbols or equations to PDF, we recommend first saving the diagram into HTML and then printing the HTML to PDF.

5. Illustrative Examples

To illustrate how to use the web application for drawing path diagrams, we provide several examples here. Four path diagrams for popular SEM models are provided here. A Youtube video tutorial is available showing how to draw a path diagram in action (https://youtu.be/rSc4nbpWRh4).

5.1. A Factor Model

Figure 1 shows the path diagram of a factor model. There are two latent factors (variables) as portrayed by the two ellipse nodes labeled as $F1$ and $F2$. The 6 rectangle nodes represent the observed variables and are labeled as $X1$ to $X6$, respectively. The one-way arrows show the connection (factor loading) between the factors and the observed variables. Through the diagram, it is clear that $F1$ is measured by $X1$, $X2$, and $X3$, while $F2$ is measured by $X4$, $X5$, and $X6$. LATEX is also utilized for labeling parameters in this model. Labels can be added to arrows and nodes as well. The arrows such as the correlation between $F1$ and $F2$ can also be curved. Note that at the bottom left of the software panel, the corresponding start node name, type of element, whether the element is an arrow, end node name, and label given to the element are displayed for each element of the path diagram. This can be used in other SEM software for connecting our web application to the model estimation methods. All the labels can be hidden by clicking on the "Hide Label" button.

5.2. A Mediation Model

Figure 2 depicts a mediation model where the observed variable M in the rectangle node is a mediator. Both the predictor $F1$ and the outcome variable $F2$ are latent variables. In the diagram, a, b, and c represent the direct effects from $F1$ to M, M to $F2$, and $F1$ to $F2$, respectively. These labels can be used to create new parameters or calculate new effects. For example, the indirect effect from $F1$ to $F2$ can be constructed as $a \times b$, the multiplication of a and b. Arrows such as the direct effects among $F1$, $F2$, and M can be colored red, black, green, or blue.

5.3. A Latent Growth Model

Figure 3 is the path diagram of a latent growth curve model. In the model shown, the error variances on the outcome variables are constrained to be the same. Note that the label

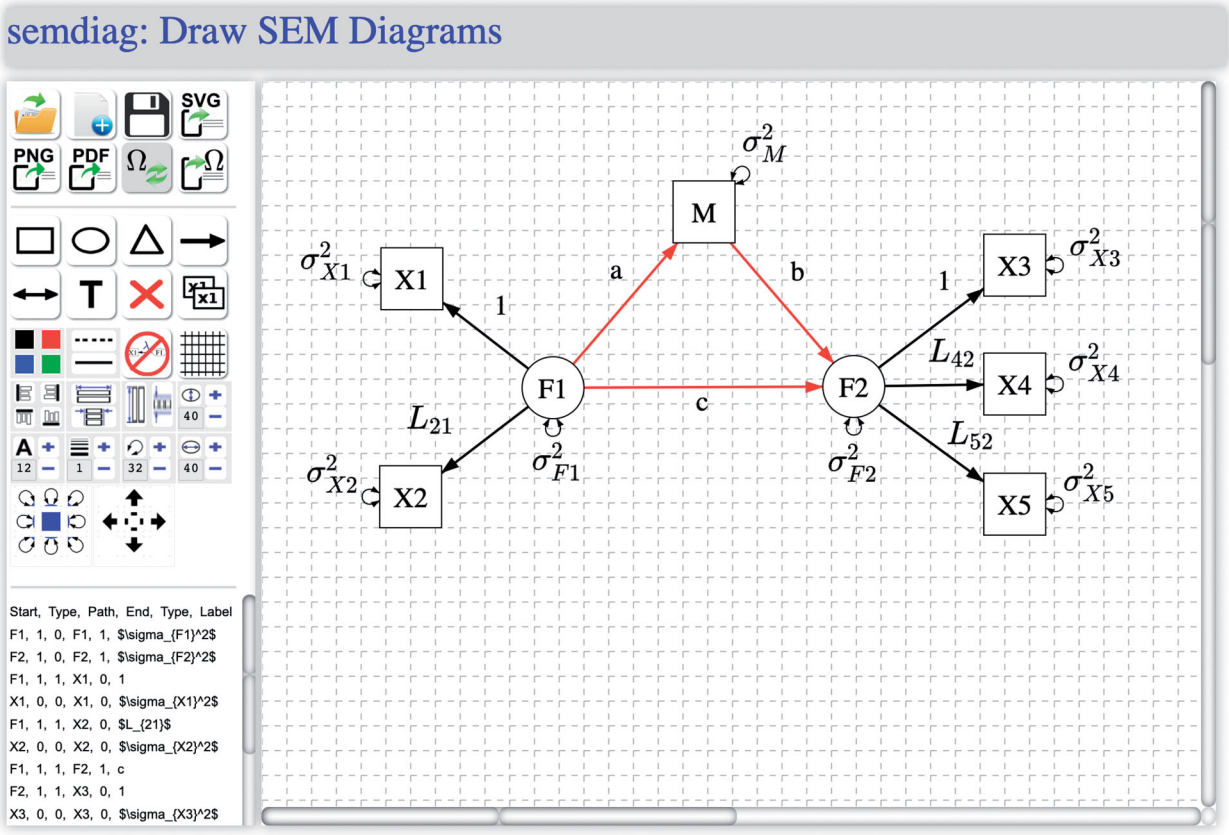

Figure 2. A mediation model.

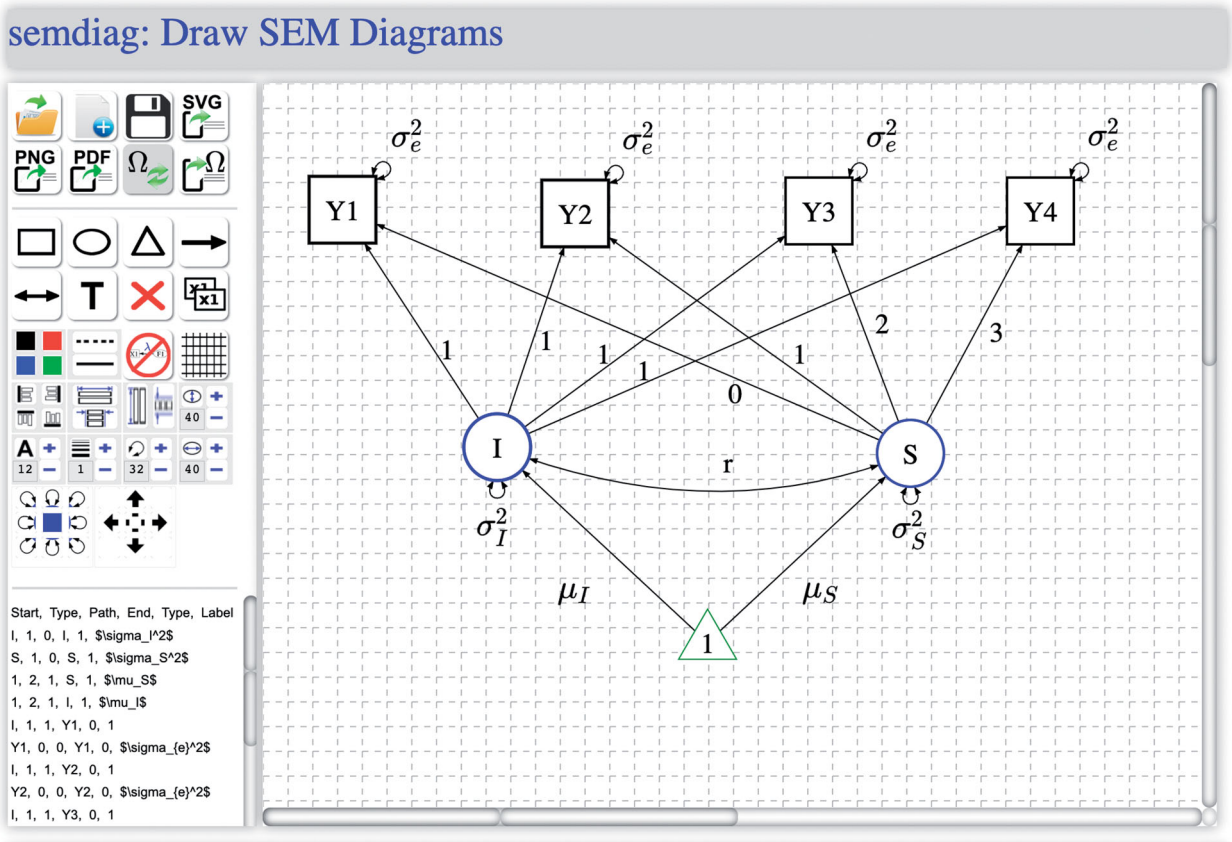

Figure 3. A latent growth model.

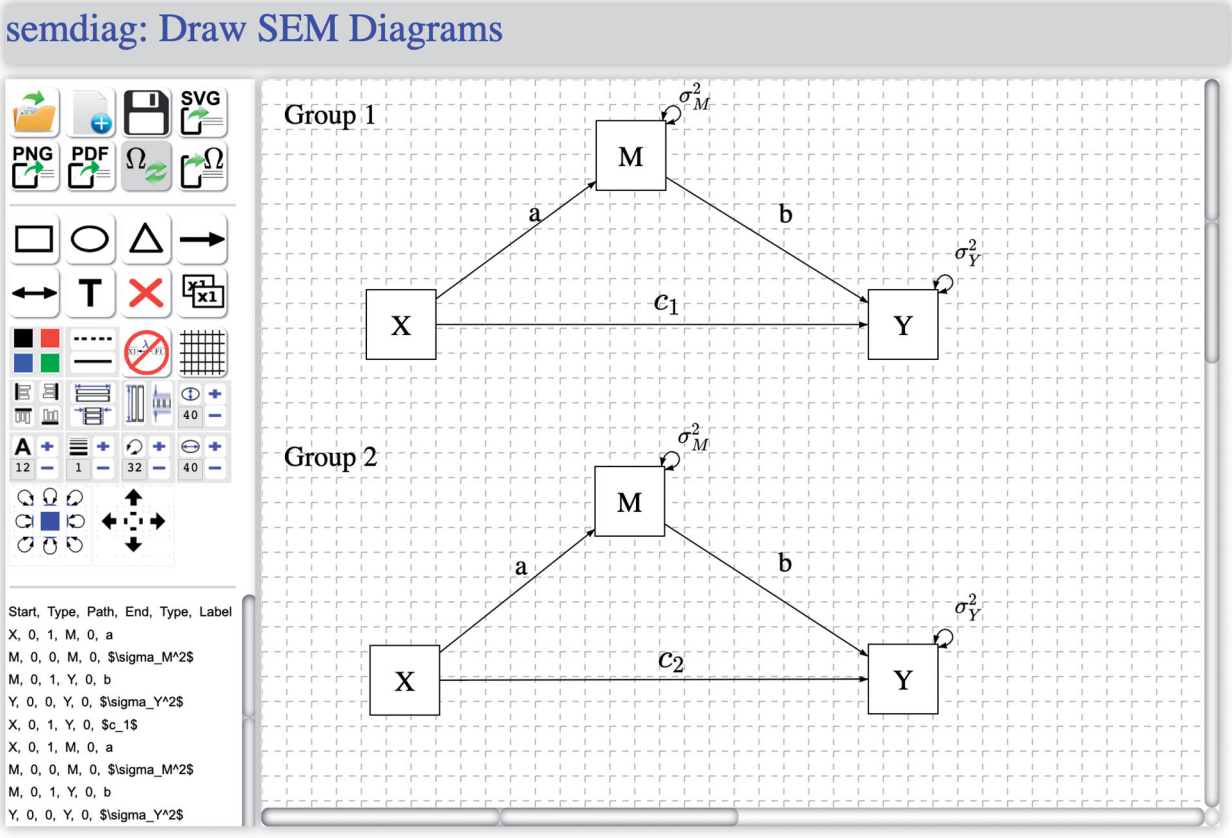

Figure 4. A multiple group model.

for an arrow can be a number. This typically means that the path takes a fixed value in the model. If the same labels are used for multiple arrows, it means the paths take the same value. In addition, different colors can be applied to nodes.

5.4. A Multiple Group Model

Figure 4 shows the path diagram of a two group mediation model. Each group consists of a predictor X, a mediator M, and an outcome Y. Whereas the mediation effects a and b are constrained to be the same across groups 1 and 2, the direct effects c_1 and c_2 are different across the two groups.

6. Discussion

In this study, we developed a web application for drawing SEM path diagrams. We showed how to use the web application through its interactive interface. Using the web application, a researcher can easily draw publication-ready path diagrams. Currently, the web application does not provide statistical analysis, and several functionalities behave slightly differently in different browsers. In the future, we hope to connect the web application with existing SEM software for statistical data analysis and upgrade the compatibility across browsers. More diagram customization options will also be added in the web application.

7. Software Information

The web application can be accessed online via https://semdiag.psychstat.org. The source code can be downloaded via the GitHub repository https://github.com/johnnyzhz/semdiag. The source code is also uploaded to Archive.org for download and permanent preservation (https://archive.org/download/semdiag/semdiag.zip).

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