Structural equation models (also referred to as "SEM models") have become very popular in the Social Sciences, especially in Psychology, Sociology, Education and, more recently, in Business and Public Administration and various applied health sciences (e.g., Nursing). A major feature in the development of structural equation models from the earlier causal ("path") models of the 1960s and 1970s is the conceptualization of latent variables. The terms, "unmeasured variable models" and "latent variable models" refer to types of structural equation models that explicitly incorporate measurement error into the estimation of structural equation parameters, and treat observed ("manifest") variables as indicators of underlying constructs rather than perfectly measured representations of these same constructs. These models are quite general, and subsume many of the multivariate techniques typically dealt with in lower-level courses, including regression models, factor analysis, analysis of variance/analysis of covariance, principal components analysis, and path modeling. More recently, SEM models have provided an approach to the estimation of parameters in growth curve models for longitudinal data (these can also be estimated in the multilevel model framework), and for an approach to the problem of the unbiased estimation of parameters in the presence of missing data.

In earlier usage, the models discussed in this course were, in the 1980s and early 1990s, often referred to as LISREL models. LISREL is now but one of the many computer programs now available to estimate SEM models; there are many others, including MPlus, AMOS, EQS, a set of SEM procedures distributed with R, a STATA procedure and a SAS procedure. In this course, we will emphasize MPlus, which is the most advanced of the SEM packages currently available, but we will also work with the sem procedure in STATA (which itself is highly popular in Social Science graduate schools) and to a lesser extent and as time permits, with the Lavaan package in R. AMOS, which is distributed by SPSS and which was -- at least until recently -- probably the second most popular SEM package in part because of its fairly intuitive interface, its ability to draw nice diagrams and the fact that many universities have SPSS site licenses, will not play a prominent role in the course, but those who are interested in learning how to use it can take part in a couple of optional “labs” outside of the regular class period (probably in the early evening). Participants who cannot attend these optional labs should still be able to follow the self-instructional guides that will be handed out (and thus teach themselves how to use the software). If there is interest on the part of participants, opportunities (self-instructional guides, a possible extra optional “lab” outside of regular class time) will be provided to learn how to program other SEM software.

After an introduction to SEM models in scalar terms, and an introduction to the extension of our models to simultaneous multiple-group estimation, we will briefly introduce the matrix-form representation of SEM models. Much of the early literature presents models using LISREL matrix notation (though this is no longer the norm), and some software (e.g., LISREL) is programmed primarily in matrix form. Next, we extend the models we have learned to models for means and intercepts, which are useful both for factor mean comparisons in the multiple-
group case and for longitudinal data analysis in the single (or multiple) group case. Towards the end of the course, we shall cover some more advanced topics, including estimation in the presence of missing data and growth curve models for longitudinal data. These topics both require a thorough understanding of models for means and intercepts, which are usually covered in week 3. If time permits, we will cover extensions to models with ordinal or binary indicators but continuous latent variables, and to models with categorical latent variables (also known as latent class models).

What sort of a background is required for this course? At the very least, individuals should have taken the I.C.P.S.R. Regression Analysis II workshop or its equivalent (note that this is a second level graduate regression course), or its equivalent. A thorough familiarity with regression models is absolutely essential. Taking the two courses simultaneously (this course and the Regression Analysis II: Linear Models course) is not recommended. A good understanding of the rudiments of matrix algebra will be needed for a small but important part of the class. I.C.P.S.R. offers a set of Matrix Algebra Lectures early in the second session; participants who have little exposure to matrix algebra should definitely attend these lectures. Individuals taking the course for formal credit or requiring a “grade letter” are warned that the absence of at least some introduction to matrix algebra could prove to be an impediment to achieving excellent grades. Some exposure to factor analysis will be helpful, since there are distinct parallels between some aspects of SEM modeling and factor analysis, but should not be considered essential.

Two I.C.P.S.R. courses which are available at different times in the summer of 2012 will complement the material covered in this course. The simultaneous equation models course covers many details in causal modeling which are deal with only in cursory fashion in the structural equation models course, and the longitudinal analysis course will be of interest to those intending to analyze panel data (which we cover from a different perspective in the last week and a half of the structural equation models course).

**Required and Recommended Readings:**

The major readings for this course can be found in a series of 15-30 page written course notes which will be posted on ICPSR “local” servers (in the Helen Newberry building) and on the “CTools” pages available via the web. These are exclusively for the use of ICPSR participants and are in PDF format, and can be downloaded. If there is interest, arrangements can be made to have these printed off and made available to class members for the cost of printing, but in recent years participants have found it more useful to simply download the material in electronic form.

While the course notes cover most of the material dealt with in the course, participants may wish to purchase copies of an additional text, since the ability to “triangulate” explanations is sometimes helpful in learning new techniques. The most useful of these will be:


This text is available at Ulrich’s bookstore.
The following texts cover some of the more advanced topics we deal with. A small number of copies has been ordered for the bookstore. These should not be considered essential, though participants who have a special interest in longitudinal data analysis may wish to obtain a copy of Bollen and Curran:


The following texts have not been ordered for the bookstore, but multiple copies should be available for borrowing at the ICPSR library in Helen Newberry. Again, these should not be considered essential:


Manuals for MPlus software should be available in the computer labs in Helen Newberry, but a PDF of the entire manual should be freely available from the MPlus web site ([www.statmodel.com](http://www.statmodel.com)). A special class handout will also be available in hard copy and PDF format. Manuals for the *sem* procedure in STATA should be available as part of STATA documentation available in the computer labs in Helen Newberry.

**Assignments and Exercises**

Most participants in this workshop do not attend for the purposes of obtaining formal course credit. For non-credit participants, it is important to complete as many of the computer exercises as possible; without practical experience working with software and writing up “results,” participants are not likely to be able to conduct research of their own using the methods discussed in the course. There will be five computer exercises throughout the course and three exercises not involving the use of computer software. Individuals taking the course for credit (or to receive a letter with a grade) will also be asked to write a take-home exam near the end of the course.

It is important that individuals who require a grade at the end of the course (taking the course for formal credit or would like ICPSR to write a letter indicating the grade that was received) identify themselves at the beginning of the course or mark “credit” or “grade” on their assignments. Assignments submitted by non-credit participants not requiring a grade are returned with comments and suggestions, but not with a grade.

Participants requiring a grade should ask for a copy of a “Grade Information” sheet which provides further information on the computation of formal grades for the course.
In the past, participants have asked if it would be possible to substitute any course requirements for a “major project” involving data that they are interested in working on. Unfortunately, the brevity of the summer program makes this alternative form impossible.

**Topic Outline:**

The relationship between sub headings and the daily lecture schedule is approximate, and will vary according to the amount of time devoted to particular topics (which itself varies from class to class given variables such as the level of background of class participants, questions asked in class, etc.). Readings do not always perfectly cover topics discussed in lectures (a # signifies that the match is particularly weak for a given reading); additional details can be found in the powerpoint slides posted for the class.

**Week 1**

a) Basics: manifest vs. latent variables; measurement error and its implications. Working with covariances. Limitations; relationship to OLS assumptions. Special cases and extensions. Orientation to the course. Software available for the estimation of SEM models. #Reading: Hoyle, chapter 1; #Schumacker and Lomax, chapter 3.

b) Path diagrams; Hypothesis testing (testable and non-testable hypotheses); covariance algebra for structural equation models; introduction to MPlus and STATA software  
   Reading: Class manuscript, chapters 1 & 2

c) Estimation; identification; interpreting results. Path model examples. Identification (the basics)  
   Reading: Class manuscript, chapter 3; #Schumacker and Lomax, chapter 4

d) Scaling and interpretation issues; constraints in SEM models; variances of latent variables; model fit and model improvement  
   Reading: Class manuscript, chapter 4; Hoyle chapter 5; Schumacker and Lomax, chapter 5

e) More on model fit and model improvement. As time permits: Problems and issues (convergence, negative variance estimates); start values; higher-order latent variables (“2nd order factor models”); the use of “phantom variables”; more on linear constraints.  
   Readings: class manuscript, chapter 5; #chapter 7 of Schumacker and Lomax for review and extensions.

**Week 2**

a) General linear parameter constraints; Multiple-group models (the 2-group case)  
   programming multi-group models in MPlus, STATA and R Readings: Class manuscript, chapter 8

b) Examples and issues; Multiple group models: the k group case; measurement equivalence, construct equation equivalence, other tests  
   Reading: Kaplan, chapter 4; Schumacker and Lomax, chapter 13 (sections 13.1 and 13.2 only).

c) More on multiple group models and parameter constraints; structural equation models in matrix terms. LISREL model notation Readings: Bollen, chapter 2.

d) Exercises and examples. SEM assumptions; performance of ML estimator under non-normality; transformations; writing up results from structural equation models.  
   Readings: #Schumacker and Lomax, chapter 11; Hoyle and Panter, chapter 9 in Hoyle.
e) Examples and exercises. Alternative parameterizations; reproduced covariances in matrix terms; An introduction to models for means and intercepts. Readings: #Class manuscript, chapter 9

Week 3

b) Exercises and examples (mean and intercept comparisons) Parallel and non-parallel slope models


d) Ordinal data, non-normal data: alternative estimators, scaled test statistics, bootstrapping (note: this presentation is within the general confines of models which assume that the underlying latent variables are continuous and that the manifest variables are at worse coarsely categorized continuous variables; see week 4 for models for categorical latent variables). Reading: West, Finch, Curran, chapter 4 in Hoyle.


Week 4


b) Growth curve models for multiple-indicator variables. Curve of factors and factor of curves models Reading: #Schumacker and Lomax, 16.2. Other readings TBA

c) Mixture models for categorical outcomes Reading: #Schumaker and Lomax, 15.2; #Kaplan, chapter 9.


If time permits, there will be a brief discussion of multi-level SEM models.