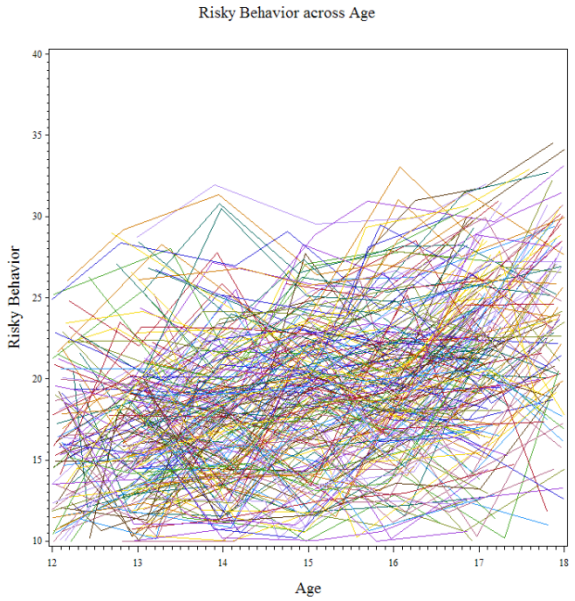
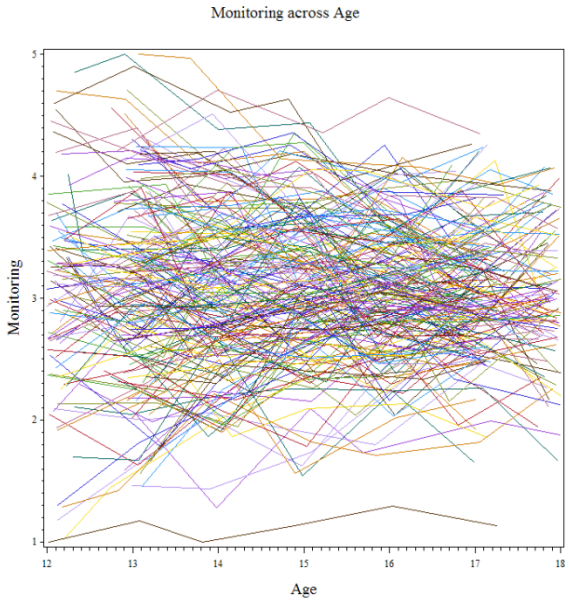
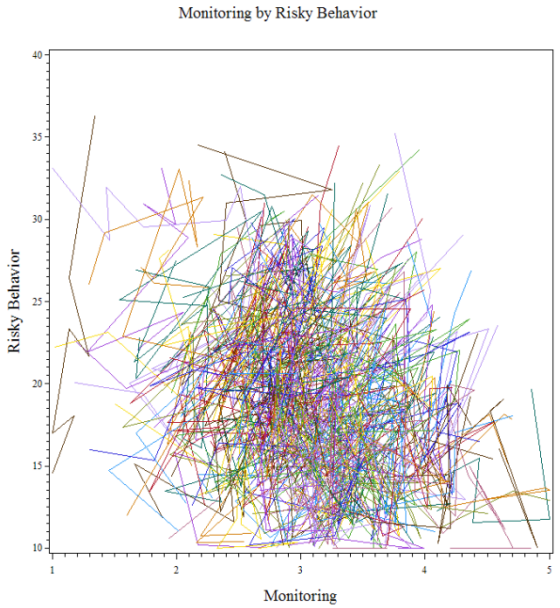
Example 9: Three Types of Multivariate Longitudinal Models: in SAS PROC MIXED, and Multivariate MLM ("Multilevel SEM") and Single-Level SEM in Mplus v. 8

These simulated data are from Hoffman (2015) chapter 9, and include 200 girls measured approximately annually from ages 12–18 (time 0 = age 18) on their risky behavior (the outcome, a sum ranging from 10 to 50) and the extent to which their mothers monitored their activities (the time-varying predictor, a mean ranging from 1 to 5, centered at 3). A time-invariant predictor of the conservativeness of mothers' attitudes about the smoking and drinking (a mean ranging from 1 to 5, centered at 4) was also collected at the age 12 occasion. Here are the individual growth trajectories for risky behavior and monitoring:







Undirected Multivariate Longitudinal Model

Level 1 :

$$y_{tid} = dvR\left[\beta_{0iR} + \beta_{1iR}\left(Age_{tiR} - 18\right) + \beta_{2iR}\left(Age_{tiR} - 18\right)^2 + e_{tiR}\right] +$$
$$dvM\left[\beta_{0iM} + \beta_{1iM}\left(Age_{tiM} - 18\right) + e_{tiM}\right]$$

Level 2 :

Risky Intercept: $\beta_{0iR} = \gamma_{00R} + \gamma_{01R}\left(Attitudes12_i - 4\right) + U_{0iR}$

Risky Age: $\beta_{1iR} = \gamma_{10R} + \gamma_{11R}\left(Attitudes12_i - 4\right) + U_{1iR}$

Risky Age^2: $\beta_{2iR} = \gamma_{20R}$

Monitor Intercept: $\beta_{0iM} = \gamma_{00M} + U_{0iM}$

Monitor Age: $\beta_{1iM} = \gamma_{10M} + U_{1iM}$

The best-fitting unconditional longitudinal models included fixed quadratic and random linear effects of age for risky behavior, but a random linear effect of age for monitoring (although the fixed linear age slope was nonsignificant). In addition, mother's attitudes significantly predicted the intercept and linear age slope for risky behavior, but did not significantly predict monitoring.

Chapter 9 began with person-mean-centering and baseline-centering of monitoring of a time-varying predictor of risky behavior. Both were shown to be inadequate because they do not properly distinguish the intercept, linear age slope, and residual variance contained in the monitoring predictor, each of which could potentially relate to those of risky behavior. So the purpose of this example is to demonstrate alternative software methods of estimating models of multivariate change so that you can decide what approach (software and syntax combination) will be most optimal for your own data.

Undirected Multivariate Longitudinal Model for Risky Behavior and Monitoring in SAS PROC MIXED, controlling risky behavior for time-invariant attitudes (Model 1):

```
* Stack longitudinal data into multivariate longitudinal;
DATA RiskyStacked2; SET RiskyStacked;
  DV="1risky  "; dvR=1; dvM=0; outcome=risky; OUTPUT;
  DV="2monitor"; dvR=0; dvM=1; outcome=mon3;  OUTPUT;
RUN;

TITLE1 "Multivariate Model at Age 18 = Time 0";
PROC MIXED DATA=work.RiskyStacked2 NOCLPRINT COVTEST IC
     NAMELEN=100 METHOD=ML;
CLASS FamilyID occasion DV;

MODEL outcome = dvR dvM dvR*agec18 dvM*agec18
                dvR*agec18*agec18 dvR*att4 dvR*att4*agec18
       / NOINT SOLUTION DDFM=Satterthwaite;

RANDOM dvR dvM dvR*agec18 dvM*agec18
      / G GCORR TYPE=UN SUBJECT=FamilyID;

REPEATED DV / R RCORR TYPE=UN SUBJECT=occasion*FamilyID;
RUN; TITLE1;

* Sending original longitudinal data to Mplus;
DATA Mplus; SET RiskyStacked;
agesq=agec18*agec18; mon3=monitor-3;
KEEP FamilyID occasion risky agec18 att4 mon3 agesq;
RUN;

* Export to .csv for use in Mplus;
PROC EXPORT DATA=work.Mplus
     OUTFILE= "&example.\Chapter9.csv"
     DBMS=CSV REPLACE; PUTNAMES=NO; RUN;
```

Mplus results start here: This is the same model as in SAS…

```
MODEL FIT INFORMATION
Number of Free Parameters                       20
Loglikelihood
          H0 Value                      -4392.253
Information Criteria

          Akaike (AIC)                   8824.506
          Bayesian (BIC)                 8929.390
          Sample-Size Adjusted BIC       8865.858
            (n* = (n + 2) / 24)
```

In Mplus, the same Model 1 using “multilevel SEM”:

```
TITLE:  Model 1: Multivariate Longitudinal Model as Multivariate MLM/SEM
DATA:   FILE = Chapter9.csv;   ! Syntax in same folder as data
VARIABLE:
! List of variables in data file
  NAMES = FamilyID occasion risky age18 att4 mon3 agesq;
! Variables to be analyzed in this model
  USEVARIABLE = age18 agesq att4 risky mon3;
  MISSING ARE ALL (-999);   ! Missing data identifier
! MLM options
  CLUSTER = FamilyID;       ! Level-2 ID
  BETWEEN = att4;           ! Observed ONLY level-2 predictors
  WITHIN  = age18 agesq;    ! Observed ONLY level-1 predictors

ANALYSIS:   TYPE = TWOLEVEL RANDOM; ESTIMATOR = ML;

MODEL:  ! R = risky behavior, M = monitoring
%WITHIN%
 Risky Mon3 (Rresvar Mresvar);   ! L1 R: Residual variances (labels)
 Rslp  | Risky ON age18;         ! Placeholder for R linear age slope
 Rquad | Risky ON agesq;         ! Placeholder for R quadratic age slope
 Mslp  | Mon3  ON age18;         ! Placeholder for M linear age slope
 Risky WITH Mon3 (ResCov);       ! L1 R: Residual covariance

%BETWEEN%
[Risky Mon3];                    ! Fixed intercepts
 Risky Mon3  (Rintvar Mintvar);  ! L2 G: Random intercept variances (labels)
[Rquad Rslp Mslp];               ! Fixed age slopes (as defined earlier)
 Rslp Mslp   (Rslpvar Mslpvar);  ! L2 G: Random linear age slope variances
 Rquad@0;                        ! No quadratic age slope variance

 Risky Rslp ON att4;             ! Att-> R int, linear age slope
 Risky WITH Rslp  (RIntSlp);     ! R Int-slope covariance (label)
 Mon3  WITH Mslp  (MIntSlp);     ! M Int-slope covariance (label)

 Risky WITH Mon3  (IntCov);      ! L2 G: Random intercept covariance
 Rslp  WITH Mslp  (SlpCov);      ! L2 G: Random linear age slope covariance
 Mon3  WITH Rslp  (Int2Slp);     ! L2 G: M int, R slope covariance
 Mslp  WITH Risky (Slp2Int);     ! L2 G: M slope, R int covariance

MODEL CONSTRAINT:  ! Like ESTIMATE in SAS, but can refer to any parameter

! Need to name each new created effect
NEW(ResCor IntCor SlpCor RIScor MIScor I2SCor S2ICor);

! Estimating correlations found in SAS RCORR and GCORR
  ResCor = ResCov  / (SQRT(Rresvar)*SQRT(Mresvar));
  IntCor = IntCov  / (SQRT(Rintvar)*SQRT(Mintvar));
  SlpCor = SlpCov  / (SQRT(Rslpvar)*SQRT(Mslpvar));
  RIScor = RIntSlp / (SQRT(Rintvar)*SQRT(Rslpvar));
  MIScor = MIntSlp / (SQRT(Mintvar)*SQRT(Mslpvar));
  I2Scor = Int2Slp / (SQRT(Mintvar)*SQRT(Rslpvar));
  S2Icor = Slp2Int / (SQRT(Mslpvar)*SQRT(Rintvar));
```

SAS Undirected Multivariate MLM Results:

Estimated R Matrix for PersonID*occasion 1 12

Row	Col1	Col2
1	8.3538	0.2874
2	0.2874	0.08077

Estimated R Correlation Matrix for PersonID*occasion 1 12

Row	Col1	Col2
1	1.0000	0.3499
2	**0.3499**	1.0000

Estimated G Matrix

Row	Effect	PersonID	Col1	Col2	Col3	Col4
1	dvR	1	18.0644	-0.8554	1.8829	0.04072
2	dvM	1	-0.8554	0.1953	-0.1064	-0.00047
3	dvR*agec18	1	1.8829	-0.1064	0.4883	-0.01815
4	dvM*agec18	1	0.04072	-0.00047	-0.01815	0.01049

Estimated G Correlation Matrix

Row	Effect	PersonID	Col1	Col2	Col3	Col4
1	dvR	1	1.0000	-0.4554	0.6340	0.09356
2	dvM	1	**-0.4554**	1.0000	-0.3446	-0.01043
3	dvR*agec18	1	**0.6340**	**-0.3446**	1.0000	-0.2537
4	dvM*agec18	1	**0.09356**	**-0.01043**	**-0.2537**	1.0000

Covariance Parameter Estimates

Cov Parm	Subject	Estimate	Standard Error	Z Value	Pr Z
UN(2,1)	FamilyID	-0.8554	0.1685	-5.08	<.0001
UN(3,1)	FamilyID	1.8829	0.3564	5.28	<.0001
UN(3,2)	FamilyID	-0.1064	0.03086	-3.45	0.0006
UN(4,1)	FamilyID	0.04072	0.03879	1.05	0.2939
UN(4,2)	FamilyID	-0.00047	0.004005	-0.12	0.9062
UN(4,3)	FamilyID	-0.01815	0.007344	-2.47	0.0135
UN(2,1)	FamilyID*occasion	0.2874	0.02753	10.44	<.0001

Information Criteria

Neg2LogLike	Parms	AIC	AICC	HQIC	BIC	CAIC
8784.5	20	8824.5	8824.8	8851.2	8890.5	8910.5

Solution for Fixed Effects

Effect	Estimate	Standard Error	DF	t Value	Pr > |t|
dvR	23.3138	0.3477	239	67.06	<.0001
dvM	0.06505	0.03412	200	1.91	0.0580
dvR*agec18	1.9743	0.1386	1185	14.25	<.0001
dvM*agec18	-0.00328	0.008176	200	-0.40	0.6884
dvR*agec18*agec18	0.1466	0.02058	1010	7.12	<.0001
dvR*Att4	-3.3328	0.5126	199	-6.50	<.0001
dvR*agec18*Att4	-0.5298	0.1025	199	-5.17	<.0001

Mplus results continue: This is the same model as in SAS…

	Estimate	S.E.	Est./S.E.	Two-Tailed P-Value
Within Level				
RISKY WITH				
MON3	0.287	0.028	10.441	0.000
Residual Variances				
MON3	0.081	0.004	22.354	0.000
RISKY	8.352	0.374	22.351	0.000
Between Level				
RSLP ON				
ATT4	-0.530	0.103	-5.161	0.000
RISKY ON				
ATT4	-3.333	0.514	-6.491	0.000
RISKY WITH				
RSLP	1.879	0.356	5.272	0.000
MON3 WITH				
MSLP	0.000	0.004	-0.118	0.906
RSLP	-0.106	0.031	-3.445	0.001
RSLP WITH				
MSLP	-0.018	0.007	-2.475	0.013
MSLP WITH				
RISKY	0.041	0.039	1.049	0.294
RISKY WITH				
MON3	-0.855	0.168	-5.076	0.000
Means				
MON3	0.065	0.034	1.907	0.057
RQUAD	0.147	0.021	7.117	0.000
MSLP	-0.003	0.008	-0.402	0.688
Intercepts				
RISKY	23.314	0.348	67.062	0.000
RSLP	1.974	0.138	14.255	0.000
Variances				
MON3	0.195	0.023	8.376	0.000
RQUAD	0.000	0.000	999.000	999.000
MSLP	0.010	0.001	7.803	0.000
Residual Variances				
RISKY	18.060	2.204	8.195	0.000
RSLP	0.485	0.080	6.071	0.000
New/Additional Parameters				
RESCOR	0.350	0.028	12.607	0.000
INTCOR	-0.455	0.074	-6.124	0.000
SLPCOR	-0.255	0.103	-2.480	0.013
RISCOR	0.635	0.057	11.087	0.000
MISCOR	-0.010	0.089	-0.117	0.906
I2SCOR	-0.346	0.095	-3.642	0.000
S2ICOR	0.094	0.087	1.071	0.284

Model 2: Directed Path Multivariate MLM as "Multilevel SEM" in Mplus: Monitor → Risky, from Hoffman (2015) Chapter 9

Level 1:

$$\text{Monitor}_{ti} = \beta_{0iM} + \beta_{1iM}\left(\text{Age}_{tiM} - 18\right) + e_{tiM}$$

$$\text{Risky}_{ti} = \beta_{0iR} + \beta_{1iR}\left(\text{Age}_{tiR} - 18\right) + \beta_{2iR}\left(\text{Age}_{tiR} - 18\right)^2 + \beta_{3iR}\left(\text{Monitor}_{ti}\right) + e_{tiR}$$

Level 2:

Monitor Intercept: $\beta_{0iM} = \gamma_{00M} + U_{0iM}$

Monitor Age: $\beta_{1iM} = \gamma_{10M} + U_{1iM}$

Risky Intercept: $\beta_{0iR} = \gamma_{00R} + \gamma_{01R}\left(\text{Attitudes12}_i - 4\right) + \gamma_{02R}\left(\beta_{0iM}\right) + \gamma_{03R}\left(\beta_{1iM}\right) + U_{0iR}$

Risky Age: $\beta_{1iR} = \gamma_{10R} + \gamma_{11R}\left(\text{Attitudes12}_i - 4\right) + \gamma_{12R}\left(\beta_{0iM}\right) + \gamma_{13R}\left(\beta_{1iM}\right) + U_{1iR}$

Risky Age^2: $\beta_{2iR} = \gamma_{20R}$

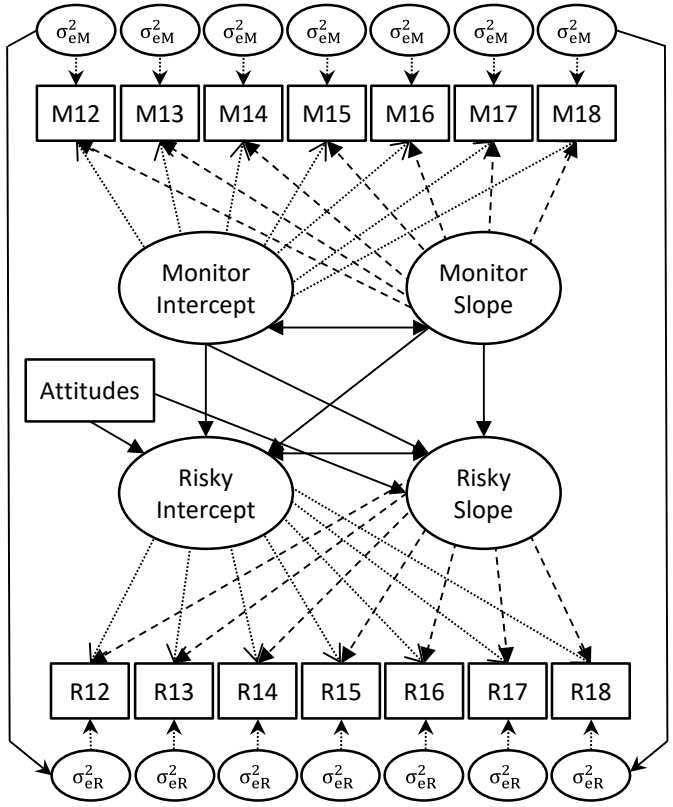
Risky WP Monitor: $\beta_{3iR} = \gamma_{30R}$

```
TITLE:  Model 2: Directed Path Multivariate Longitudinal Model as
        "Multilevel SEM" Using Placeholder
( DATA, VARIABLE, and ANALYSIS are the same as for Model 1 )
MODEL:  ! R = risky behavior, M = monitoring
%WITHIN%
 Risky Mon3 (Rresvar Mresvar);   ! L1 R: Residual variances (labels)
 Rslp  | Risky ON age18;         ! Placeholder for R linear age slope
 Rquad | Risky ON agesq;         ! Placeholder for R quadratic age slope
 Mslp  | Mon3  ON age18;         ! Placeholder for M linear age slope
 ! Regression between outcomes instead of covariance
 WPres | Risky ON Mon3;          ! Placeholder for L1 WP effect M->R

%BETWEEN%
[Risky Mon3];                    ! Fixed intercepts
 Risky Mon3  (Rintvar Mintvar);  ! L2 G: Random intercept variances
[Rquad Rslp Mslp];               ! Fixed age slopes (as defined earlier)
 Rslp Mslp   (Rslpvar Mslpvar);  ! L2 G: Random linear age slope variances
 Rquad@0;                        ! No quadratic age slope variance
 Risky Rslp ON att4;             ! Att-> R int, linear age slope
 Risky WITH Rslp  (RIntSlp);     ! R Int-slope covariance (label)
 Mon3  WITH Mslp  (MIntSlp);     ! M Int-slope covariance (label)

 ! Regressions between outcomes instead of covariances
 Risky ON Mon3 (IntCont);        ! Intercept contextual BP effect
 Rslp  ON Mslp (SlpCont);        ! Age slope contextual BP effect
 Rslp  ON Mon3 (Int2Slp);        ! M int -> R slope total BP effect
 Risky ON Mslp (Slp2Int);        ! M slope -> R int total BP effect
 [WPres] (ResEff);  ! Fixed effect for L1 WP M->R (as defined earlier)
  WPres@0;          ! No random L1 WP M->R effect variance

MODEL CONSTRAINT:  ! Like ESTIMATE in SAS, but can refer to any parameter
! Need to name each new created effect
NEW(BPIntEff BPSlpEff);
BPIntEff = ResEff + IntCont;    ! Total BP intercept effect
BPSlpEff = ResEff + SlpCont;    ! Total BP age slope effect
```

	Estimate	S.E.	Est./S.E.	Two-Tailed P-Value
Within Level				
Residual Variances				
RISKY	7.329	0.328	22.353	0.000
MON3	0.081	0.004	22.355	0.000
Between Level				
RSLP ON				
MSLP	**-5.316**	0.816	-6.517	0.000
RSLP ON				
ATT4	-0.530	0.103	-5.161	0.000
MON3	-0.548	0.160	-3.431	0.001
RISKY ON				
MSLP	3.685	3.494	1.055	0.292
RISKY ON				
ATT4	-3.333	0.514	-6.491	0.000
MON3	**-7.928**	0.861	-9.211	0.000
RISKY WITH				
RSLP	1.481	0.345	4.291	0.000
MON3 WITH				
MSLP	0.000	0.004	-0.118	0.906
Means				
MON3	0.065	0.034	1.906	0.057
RQUAD	0.147	0.021	7.117	0.000
MSLP	-0.003	0.008	-0.402	0.688
WPRES	**3.559**	**0.301**	**11.810**	**0.000**
Intercepts				
RISKY	23.610	0.333	70.898	0.000
RSLP	2.004	0.139	14.405	0.000
Variances				
MON3	0.195	0.023	8.376	0.000
RQUAD	0.000	0.000	999.000	999.000
MSLP	0.010	0.001	7.803	0.000
WPRES	0.000	0.000	999.000	999.000
Residual Variances				
RISKY	14.173	1.965	7.213	0.000
RSLP	0.394	0.082	4.787	0.000
New/Additional Parameters				
BPINTEFF	**-4.369**	**0.784**	**-5.574**	**0.000**
BPSLPEF	**-1.758**	**0.724**	**-2.428**	**0.015**

Let's see the same directed path multivariate MLM Model 2 as a Single-Level SEM:

```
TITLE:   Model 2: Directed Path Multivariate Longitudinal Model
         as Single-Level SEM
DATA:    FILE = Chapter9.csv;    ! Syntax in same folder as data
! Unstacking to multivariate format
DATA LONGTOWIDE:
! Names of old stacked former variables (without numbers)
  LONG = risky|mon|age;
! Names of new multivariate variables (that use numbers)
  WIDE = risky12-risky18|mon12-mon18|age12-age18;
! Variable with level-2 ID info
  IDVARIABLE = FamilyID;
! Old level-1 identifier
  REPETITION = age (12 13 14 15 16 17 18);

VARIABLE:
! List of variables in original data file
  NAMES = FamilyID occasion risky age18 att4 mon3 agesq;
! Variables to be analyzed in this model
  USEVARIABLE = att4 age12-age18 mon12-mon18 risky12-risky18;
  MISSING ARE ALL (-999);    ! Missing data identifier
  TSCORES = age12-age18;     ! Exact time indicator

ANALYSIS:    TYPE = RANDOM; ESTIMATOR = ML; MODEL = NOCOVARIANCES;
MODEL:  ! R = risky behavior, M = monitoring
[risky12-risky18@0 mon12-mon18@0]; ! All variable intercepts fixed to 0
 risky12-risky18 (Rresvar);       ! L1 R: R residual variances held equal
 mon12-mon18     (Mresvar);       ! L1 R: M residual variances held equal

! Risky behavior quadratic growth model using exact age as loadings
  Rint Rslp Rquad | risky12-risky18 AT age12-age18;
! Monitoring linear growth model using exact age as loadings
  Mint Mslp | mon12-mon18 AT age12-age18;
! Fixed growth effects for R and M
  [Rint Rslp Rquad Mint Mslp];
! L2 G: Random int and linear age slope variances, no quad age variance
  Rint Rslp Rquad@0 Mint Mslp;
! L2 G: Within-variable random int-slope covariances for R, M
  Rint WITH Rslp; Mint WITH Mslp;
! Attitudes --> risky int, linear slope
  Rint Rslp ON att4;

! Regressions between outcomes
  Rint ON Mint (IntCont);         ! Intercept contextual BP effect
  Rslp ON Mslp (SlpCont);         ! Age slope contextual BP effect
  Rslp ON Mint (Int2Slp);         ! M int -> R slope total BP effect
  Rint ON Mslp (Slp2Int);         ! M slope -> R int total BP effect

! Residual WP effect between same ages, held equal across age
  risky12-risky18 PON mon12-mon18 (ResEff);

MODEL CONSTRAINT:
NEW(BPIntEff BPSlpEff);
BPIntEff = ResEff + IntCont;    ! Total BP intercept effect
BPSlpEff = ResEff + SlpCont;    ! Total BP age slope effect
```



For balanced time, a growth model would use this instead:

```
Mint Mslp | mon12@-6 mon13@-5 mon14@-4 mon15@-3
            mon16@-2 mon17@-1 mon18@0;
```

Model 2 results for the same directed path multivariate MLM as a Single-Level SEM

MODEL FIT INFORMATION

Number of Free Parameters	20
Loglikelihood	
H0 Value	-4392.253
Information Criteria	
Akaike (AIC)	8824.506
Bayesian (BIC)	8890.472
Sample-Size Adjusted BIC (n* = (n + 2) / 24)	8827.110

MODEL RESULTS

	Estimate	S.E.	Est./S.E.	Two-Tailed P-Value
RINT ON				
MINT	-7.928	0.861	-9.211	0.000
MSLP	3.685	3.494	1.055	0.292
RSLP ON				
MSLP	-5.316	0.816	-6.517	0.000
MINT	-0.548	0.160	-3.431	0.001
RINT ON				
ATT4	-3.333	0.514	-6.491	0.000
RSLP ON				
ATT4	-0.530	0.103	-5.161	0.000
RISKY12 ON				
MON12	3.559	0.301	11.809	0.000
RISKY13 ON				
MON13	3.559	0.301	11.809	0.000
RISKY14 ON				
MON14	3.559	0.301	11.809	0.000
RISKY15 ON				
MON15	3.559	0.301	11.809	0.000
RISKY16 ON				
MON16	3.559	0.301	11.809	0.000
RISKY17 ON				
MON17	3.559	0.301	11.809	0.000
RISKY18 ON				
MON18	3.559	0.301	11.809	0.000
RINT WITH				
RSLP	1.481	0.345	4.291	0.000
MINT WITH				
MSLP	0.000	0.004	-0.118	0.906
Means				
RQUAD	0.147	0.021	7.117	0.000
MINT	0.065	0.034	1.906	0.057
MSLP	-0.003	0.008	-0.402	0.688
Intercepts				
MON12	0.000	0.000	999.000	999.000
MON13	0.000	0.000	999.000	999.000
MON14	0.000	0.000	999.000	999.000
MON15	0.000	0.000	999.000	999.000
MON16	0.000	0.000	999.000	999.000
MON17	0.000	0.000	999.000	999.000
MON18	0.000	0.000	999.000	999.000
RISKY12	0.000	0.000	999.000	999.000
RISKY13	0.000	0.000	999.000	999.000
RISKY14	0.000	0.000	999.000	999.000
RISKY15	0.000	0.000	999.000	999.000
RISKY16	0.000	0.000	999.000	999.000
RISKY17	0.000	0.000	999.000	999.000
RISKY18	0.000	0.000	999.000	999.000
RINT	23.610	0.333	70.898	0.000
RSLP	2.004	0.139	14.405	0.000
Variances				
RQUAD	0.000	0.000	999.000	999.000
MINT	0.195	0.023	8.376	0.000
MSLP	0.010	0.001	7.803	0.000
Residual Variances				
MON12	0.081	0.004	22.354	0.000
MON13	0.081	0.004	22.354	0.000
MON14	0.081	0.004	22.354	0.000
MON15	0.081	0.004	22.354	0.000
MON16	0.081	0.004	22.354	0.000
MON17	0.081	0.004	22.354	0.000
MON18	0.081	0.004	22.354	0.000
RISKY12	7.329	0.328	22.353	0.000
RISKY13	7.329	0.328	22.353	0.000
RISKY14	7.329	0.328	22.353	0.000
RISKY15	7.329	0.328	22.353	0.000
RISKY16	7.329	0.328	22.353	0.000
RISKY17	7.329	0.328	22.353	0.000
RISKY18	7.329	0.328	22.353	0.000
RINT	14.173	1.965	7.213	0.000
RSLP	0.394	0.082	4.787	0.000
New/Additional Parameters				
BPINTEFF	-4.369	0.784	-5.575	0.000
BPSLPEFF	-1.758	0.724	-2.429	0.015

By popular demand, here is an example of how to use "structured residuals" to fit cross-lag effects at level 1: Model 3, which switches to covariances at level 2 per convention when fitting these models (to be agnostic as to which comes first)

```
TITLE:  Model 3: Example of Structured Residuals to Fit Cross-Lag Effects
( DATA, VARIABLE, and ANALYSIS are the same as for Model 3 )
MODEL:  ! R = risky behavior, M = monitoring
[risky12-risky18@0 mon12-mon18@0]; ! All variable intercepts fixed to 0

! Risky behavior quadratic growth model using exact age as loadings
  Rint Rslp Rquad | risky12-risky18 AT age12-age18;
! Monitoring linear growth model using exact age as loadings
  Mint Mslp | mon12-mon18 AT age12-age18;
! Fixed growth effects for R and M
  [Rint Rslp Rquad Mint Mslp];
! L2 G: Random int and linear age slope variances, no quad age variance
  Rint Rslp Rquad@0 Mint Mslp;
! L2 G: Within-variable random int-slope covariances for R, M
  Rint WITH Rslp; Mint WITH Mslp;
! Attitudes --> risky int, linear slope
  Rint Rslp ON att4;
! L2 G: covariances for random intercepts and slopes across outcomes
  Rint Rslp WITH Mint Mslp;

! Define new latent factors for residuals at each occasion
  Frisky12 BY risky12@1;
  Frisky13 BY risky13@1;
  Frisky14 BY risky14@1;
  Frisky15 BY risky15@1;
  Frisky16 BY risky16@1;
  Frisky17 BY risky17@1;
  Frisky18 BY risky18@1;
  Fmon12 BY mon12@1;
  Fmon13 BY mon13@1;
  Fmon14 BY mon14@1;
  Fmon15 BY mon15@1;
  Fmon16 BY mon16@1;
  Fmon17 BY mon17@1;
  Fmon18 BY mon18@1;

! All factor means fixed to 0
  [Frisky12-Frisky18@0  Fmon12-Fmon18@0];

! Shut off old residual variances
  risky12-risky18@0 mon12-mon18@0;
! Hold new residual variances equal over time
  Frisky12-Frisky18 (Rresvar); ! L1 R: R residual variances held equal
  Fmon12-Fmon18     (Mresvar); ! L1 R: M residual variances held equal

! Factor residual WP effect between same ages, held equal across age
  Frisky12-Frisky18 PWITH Fmon12-Fmon18     (ResCov);

! Cross-lag WP effects predicting next age, held equal across age
  Frisky13-Frisky18 PON   Fmon12-Fmon17     (MR2RR);
  Fmon13-Fmon18     PON   Frisky12-Frisky17 (RR2MR);
```

```
MODEL FIT INFORMATION
Number of Free Parameters                       22

Loglikelihood
          H0 Value                      -4388.743

Information Criteria
          Akaike (AIC)                   8821.485
          Bayesian (BIC)                 8894.048
          Sample-Size Adjusted BIC       8824.350
            (n* = (n + 2) / 24)
```

MODEL RESULTS – Parameters fixed to 0 or 1 are omitted for brevity

	Estimate	S.E.	Est./S.E.	Two-Tailed P-Value
FRISKY13 ON				
FMON12	-0.255	0.373	-0.683	0.495
FRISKY14 ON				
FMON13	-0.255	0.373	-0.683	0.495
FRISKY15 ON				
FMON14	-0.255	0.373	-0.683	0.495
FRISKY16 ON				
FMON15	-0.255	0.373	-0.683	0.495
FRISKY17 ON				
FMON16	-0.255	0.373	-0.683	0.495
FRISKY18 ON				
FMON17	-0.255	0.373	-0.683	0.495
FMON13 ON				
FRISKY12	0.008	0.004	2.079	0.038
FMON14 ON				
FRISKY13	0.008	0.004	2.079	0.038
FMON15 ON				
FRISKY14	0.008	0.004	2.079	0.038
FMON16 ON				
FRISKY15	0.008	0.004	2.079	0.038
FMON17 ON				
FRISKY16	0.008	0.004	2.079	0.038
FMON18 ON				
FRISKY17	0.008	0.004	2.079	0.038
RINT ON				
ATT4	-3.331	0.514	-6.485	0.000
RSLP ON				
ATT4	-0.529	0.103	-5.153	0.000

RINT WITH				
RSLP	1.902	0.358	5.318	0.000
MINT	-0.883	0.171	-5.172	0.000
MSLP	0.033	0.039	0.852	0.394
MINT WITH				
MSLP	-0.001	0.004	-0.198	0.843
RSLP	-0.110	0.031	-3.525	0.000
RSLP WITH				
MSLP	-0.020	0.008	-2.638	0.008
FRISKY12 WITH				
FMON12	0.298	0.031	9.606	0.000
FRISKY13 WITH				
FMON13	0.298	0.031	9.606	0.000
FRISKY14 WITH				
FMON14	0.298	0.031	9.606	0.000
FRISKY15 WITH				
FMON15	0.298	0.031	9.606	0.000
FRISKY16 WITH				
FMON16	0.298	0.031	9.606	0.000
FRISKY17 WITH				
FMON17	0.298	0.031	9.606	0.000
FRISKY18 WITH				
FMON18	0.298	0.031	9.606	0.000

Means				
RQUAD	0.146	0.020	7.194	0.000
MINT	0.065	0.034	1.913	0.056
MSLP	-0.003	0.008	-0.388	0.698
Intercepts				
RINT	23.616	0.333	70.907	0.000
RSLP	2.001	0.137	14.658	0.000
Variances				
FRISKY12	8.301	0.379	21.890	0.000
FMON12	0.081	0.004	22.126	0.000
RQUAD	0.000	0.000	999.000	999.000
MINT	0.195	0.023	8.306	0.000
MSLP	0.010	0.001	7.676	0.000
Residual Variances				
FRISKY13	8.301	0.379	21.890	0.000
FRISKY14	8.301	0.379	21.890	0.000
FRISKY15	8.301	0.379	21.890	0.000
FRISKY16	8.301	0.379	21.890	0.000
FRISKY17	8.301	0.379	21.890	0.000
FRISKY18	8.301	0.379	21.890	0.000
FMON13	0.081	0.004	22.126	0.000
FMON14	0.081	0.004	22.126	0.000
FMON15	0.081	0.004	22.126	0.000
FMON16	0.081	0.004	22.126	0.000
FMON17	0.081	0.004	22.126	0.000
FMON18	0.081	0.004	22.126	0.000
RINT	14.078	2.003	7.030	0.000
RSLP	0.389	0.086	4.545	0.000

Btw, the same "structured residuals" approach could be used in Model 2, which would result in level-2 between instead of level-2 contextual effects between the intercepts and linear age slopes. The problem is that approach doesn't permit the level-1 within-person path to also have a random effect.