Example 6: Generalized Models for Binary Longitudinal Data
(complete syntax and output available for SAS and STATA electronically)

This example comes from real data collected over 12 days in 91 nursing home patients who were hospitalized. Day 0 is the first day of hospitalization. Each day an assessment as to the patient's level of delirium was conducted by hospital staff, in which 0 = no delirium, 1 = possible delirium, and 2 = full delirium. For the purposes of illustration, the 1 and 2 categories were collapsed to create a binary outcome of none vs. at least some delirium, with 37.25% = none and 62.75% = at least some delirium. SPSS does not estimate generalized multilevel levels using numeric integration, so only SAS and STATA are used for these binary models. We will first examine the pattern of change across days using polynomial models, and then see if cognitive status (as measured by MMSE centered at 16, SD = 7) predicts intercept and slope differences in probability of delirium.

Model 1: Empty Logistic Two-Level Model for None (0) vs. at least Some Delirium (1)

```
TITLE1 "SAS Empty Logistic Mixed Model";
TITLE2 "Logit Link, Binomial Response Distribution";
PROC GLIMMIX DATA=example6 NOCLPRINT NOITPRINT NAMELEN=100 GRADIENT METHOD=QUAD(QPOINTS=7);
      CLASS patient_ID;
      MODEL cam011 (DESCENDING) =  / SOLUTION LINK=LOGIT DIST=BINARY DDFM=BW;
      RANDOM INTERCEPT / TYPE=UN SUBJECT=patient_ID;
      ESTIMATE "Intercept" intercept 1 / ILINK;      * Get probability version;
      COVTEST "Need Random Intercept?"  0;
RUN; TITLE1; TITLE2;
```

The 0 value refers to the contents of the **G** matrix to hold to 0. Here, we hold the random intercept variance to 0.

```
 * STATA Empty Logistic Mixed Model, Logit Link, Binomial Response Distribution
xtmelogit cam011 ,  ||  PATIENT_ID:  ,   variance covariance(unstructured) intpoints(7),
estat ic, n(91)
```

SAS Output:

```
           Fit Statistics
-2 Log Likelihood             627.17
AIC  (smaller is better)      631.17
AICC (smaller is better)      631.19
BIC  (smaller is better)      636.19
CAIC (smaller is better)      638.19
HQIC (smaller is better)      633.19

             Covariance Parameter Estimates
Cov                                  Standard
Parm       Subject       Estimate       Error    Gradient
UN(1,1)    PATIENT_ID      1.5560      0.5078    9.623E-6   Random intercept variance

                         Solutions for Fixed Effects
                         Standard
Effect       Estimate       Error       DF     t Value     Pr > |t|     Gradient
Intercept      0.7410      0.1847       90        4.01       0.0001     0.000042

                                        Estimates
                                                                                Standard
                         Standard                                                  Error
Label        Estimate       Error       DF     t Value     Pr > |t|        Mean       Mean
Intercept      0.7410      0.1847       90        4.01       0.0001      0.6772    0.04037
```

Probability version

```
                        Tests of Covariance Parameters
                          Based on the Likelihood
Label                      DF     -2 Log Like      ChiSq     Pr > ChiSq     Note
Need Random Intercept?      1          673.50      46.34         <.0001     MI
MI: P-value based on a mixture of chi-squares.
```

Model 2: Adding a Fixed Linear Slope for Days Since Hospital Admission (0=Day Hospitalized)

```
TITLE3 "SAS Add Fixed Linear Slope for Day";
PROC GLIMMIX DATA=example6 NOCLPRINT NOITPRINT NAMELEN=100 GRADIENT METHOD=QUAD(QPOINTS=7);
      CLASS patient_ID;
      MODEL cam011 (DESCENDING) = day / SOLUTION LINK=LOGIT DIST=BINARY DDFM=BW;
      RANDOM INTERCEPT / TYPE=UN SUBJECT=patient_ID;
RUN; TITLE3;

 * STATA Add Fixed Linear Slope for Day
xtmelogit cam011 c.day,  || PATIENT_ID:  ,  ///
      variance covariance(unstructured) intpoints(7),
      estat ic, n(91),
      estimates store FixLin  // save for LRT
```

SAS Output:

Fit Statistics

-2 Log Likelihood	625.16
AIC (smaller is better)	631.16
AICC (smaller is better)	631.21
BIC (smaller is better)	638.69
CAIC (smaller is better)	641.69
HQIC (smaller is better)	634.20

Covariance Parameter Estimates

Cov Parm	Subject	Estimate	Standard Error	Gradient
UN(1,1)	PATIENT_ID	1.5869	0.5137	0.000025

Solutions for Fixed Effects

Effect	Estimate	Standard Error	DF	t Value	Pr > |t|	Gradient
Intercept	0.9553	0.2418	90	3.95	0.0002	6.434E-6
day	-0.05670	0.04014	418	-1.41	0.1585	-0.00002

Model 3: Adding a Random Linear Slope for Days Since Hospital Admission (0=Day Hospitalized)

```
TITLE3 "SAS Add Random Linear Slope for Day";
PROC GLIMMIX DATA=example6 NOCLPRINT NOITPRINT NAMELEN=100 GRADIENT METHOD=QUAD(QPOINTS=7);
      CLASS patient_ID;
      MODEL cam011 (DESCENDING) = day / SOLUTION LINK=LOGIT DIST=BINARY DDFM=BW;
      RANDOM INTERCEPT day / TYPE=UN SUBJECT=patient_ID;
      COVTEST "Need Random Linear Slope?"   . 0 0;
      COVTEST "Need Random Intercept?"      0 0 0;
RUN; TITLE3;

 * STATA Add Fixed Linear Slope for Day
xtmelogit cam011 c.day,  || PATIENT_ID: day ,  ///
      variance covariance(unstructured) intpoints(7),
      estimates store RandLin  // save for LRT
      lrtest RandLin FixLin    // test random linear
```

The . refers to the contents of the **G** matrix to estimate.

SAS Output:

Fit Statistics

-2 Log Likelihood	614.72
AIC (smaller is better)	624.72
AICC (smaller is better)	624.84
BIC (smaller is better)	637.27
CAIC (smaller is better)	642.27
HQIC (smaller is better)	629.78

Covariance Parameter Estimates

Cov Parm	Subject	Estimate	Standard Error	Gradient
UN(1,1)	PATIENT_ID	1.6729	1.0415	-0.00022
Random intercept variance				
UN(2,1)	PATIENT_ID	-0.2037	0.2209	-0.00257
Random intercept-linear covariance				
UN(2,2)	PATIENT_ID	0.1140	0.07322	-0.0072
Random linear slope variance				

Solutions for Fixed Effects

Effect	Estimate	Standard Error	DF	t Value	Pr > |t|	Gradient
Intercept	0.9485	0.2693	90	3.52	0.0007	0.00028
day	-0.06101	0.07079	418	-0.86	0.3892	0.000834

```
                         Tests of Covariance Parameters
                             Based on the Likelihood
Label                        DF     -2 Log Like      ChiSq     Pr > ChiSq     Note
Need Random Linear Slope?     2          625.16      10.44         0.0033     MI
Need Random Intercept?        3          672.67      57.95         <.0001     --
MI: P-value based on a mixture of chi-squares.  --: Standard test with unadjusted p-values.
```

Model 4: Adding a Fixed Quadratic Slope for Days Since Hospital Admission

```
TITLE3 "SAS Add Fixed Quadratic Slope for Day";
PROC GLIMMIX DATA=example6 NOCLPRINT NOITPRINT NAMELEN=100 GRADIENT METHOD=QUAD(QPOINTS=7);
      CLASS patient_ID;
      MODEL cam011 (DESCENDING) = day day*day / SOLUTION LINK=LOGIT DIST=BINARY DDFM=BW;
      RANDOM INTERCEPT day / TYPE=UN SUBJECT=patient_ID;
RUN; TITLE3;

 * STATA Add Fixed Quadratic Slope for Day
xtmelogit cam011 c.day c.daysq,  || PATIENT_ID: day ,  ///
      variance covariance(unstructured) intpoints(7),
      estat ic, n(91),
      estimates store FixQuad    // save for LRT
```

SAS Output:

```
          Fit Statistics
-2 Log Likelihood             614.58
AIC  (smaller is better)      626.58
AICC (smaller is better)      626.75
BIC  (smaller is better)      641.64
CAIC (smaller is better)      647.64
HQIC (smaller is better)      632.66
```

```
                 Covariance Parameter Estimates
Cov                                      Standard
Parm        Subject         Estimate        Error     Gradient
UN(1,1)     PATIENT_ID        1.7064       1.0538     -0.00012
UN(2,1)     PATIENT_ID       -0.2092       0.2219     0.000153
UN(2,2)     PATIENT_ID        0.1130      0.07273     0.002498
```

```
                         Solutions for Fixed Effects
                         Standard
Effect       Estimate       Error       DF     t Value     Pr > |t|     Gradient
Intercept      1.0263      0.3439       90        2.98       0.0037     0.000134
day           -0.1110      0.1522      417       -0.73       0.4664     -0.00162
day*day      0.005543     0.01492      417        0.37       0.7104      -0.0088
```

Model 5: Adding a Fixed Quadratic Slope for Days Since Hospital Admission

```
TITLE3 "SAS Add Fixed Quadratic Slope for Day";
PROC GLIMMIX DATA=example6 NOCLPRINT NOITPRINT NAMELEN=100 GRADIENT METHOD=QUAD(QPOINTS=7);
      CLASS patient_ID;
      MODEL cam011 (DESCENDING) = day day*day / SOLUTION LINK=LOGIT DIST=BINARY DDFM=BW;
      RANDOM INTERCEPT day day*day / TYPE=UN SUBJECT=patient_ID;
      COVTEST "Need Random Quadratic Slope?"  . . . 0 0 0;
      COVTEST "Need Random Linear Slope?"     . 0 0 0 0 0;
      COVTEST "Need Random Intercept?"        0 0 0 0 0 0;
RUN; TITLE3;

* STATA Add Random Quadratic Slope for Day - Won't Run!
 *xtmelogit cam011 c.day c.day#c.day,  || PATIENT_ID: day daysq,  ///
 *    variance covariance(unstructured) intpoints(7),
 *    estat ic, n(91),
 *    estimates store RandQuad   // save for LRT
 *    lrtest RandQuad FixQuad    // test random quadratic
```

SAS Output:

```
           Fit Statistics
-2 Log Likelihood              609.09
AIC  (smaller is better)       627.09
AICC (smaller is better)       627.45
BIC  (smaller is better)       649.68
CAIC (smaller is better)       658.68
HQIC (smaller is better)       636.20
```

```
              Covariance Parameter Estimates
Cov                                      Standard
Parm        Subject        Estimate         Error     Gradient
UN(1,1)     PATIENT_ID       6.3279        3.9098     -0.00001
UN(2,1)     PATIENT_ID      -2.2355        1.5151     -0.00007
UN(2,2)     PATIENT_ID       1.0617        0.6515     -0.00009
UN(3,1)     PATIENT_ID       0.1656        0.1241     -0.00012
UN(3,2)     PATIENT_ID     -0.07685       0.05332     -0.00335
UN(3,3)     PATIENT_ID     0.005829      0.004559     -0.03605
```

```
                          Solutions for Fixed Effects
                          Standard
Effect        Estimate       Error      DF    t Value    Pr > |t|    Gradient
Intercept       1.3593      0.5098      90       2.67      0.0091    0.000013
day            -0.2586      0.2339     417      -1.11      0.2695    0.000013
day*day        0.02003     0.02231     417       0.90      0.3698    -0.00022
```

```
                            Tests of Covariance Parameters
                               Based on the Likelihood
Label                              DF    -2 Log Like      ChiSq    Pr > ChiSq    Note
Need Random Quadratic Slope?        3         633.88      24.80        <.0001     --
Need Random Linear Slope?           5         624.79      15.71        0.0077     --
Need Random Intercept?              6         671.49      62.40        <.0001     --
--: Standard test with unadjusted p-values.
```

SAS got this wrong…! The −2ΔLL test for the random quadratic is n.s.

Model 6: Adding Effects of MMSE (Level-2 Predictor) on Intercept and Linear Slope

```
TITLE3 "SAS -- Adding Effects of MMSE on Intercept and Linear Slope";
PROC GLIMMIX DATA=example6 NOCLPRINT NOITPRINT NAMELEN=100 GRADIENT METHOD=QUAD(QPOINTS=7);
      CLASS patient_ID;
      MODEL cam011 (DESCENDING) = day mmse16 day*mmse16 / SOLUTION LINK=LOGIT DIST=BINARY DDFM=BW;
      RANDOM INTERCEPT day / TYPE=UN SUBJECT=patient_ID;
RUN; TITLE3;

* STATA Add Effects of MMSE on Intercept and Linear Slope
xtmelogit cam011 c.day c.mmse16 c.mmse16#c.day, ||  PATIENT_ID: day ,   ///
      variance covariance(unstructured) intpoints(7),
      estat ic, n(91)
```

SAS Output:

```
           Fit Statistics
-2 Log Likelihood              583.67
AIC  (smaller is better)       597.67
AICC (smaller is better)       597.90
BIC  (smaller is better)       615.25
CAIC (smaller is better)       622.25
HQIC (smaller is better)       604.77
```

```
              Covariance Parameter Estimates
Cov                                      Standard
Parm        Subject        Estimate         Error     Gradient
UN(1,1)     PATIENT_ID       1.2946        0.8896     0.000134
UN(2,1)     PATIENT_ID      -0.2450        0.2061     0.000937
UN(2,2)     PATIENT_ID       0.1044       0.06443     0.000276
```

```
                          Solutions for Fixed Effects
                           Standard
Effect         Estimate       Error      DF    t Value    Pr > |t|    Gradient
Intercept        0.8444      0.2592      89       3.26      0.0016     0.00035
day             -0.1128     0.07094     417      -1.59      0.1127    0.000623
mmse16         -0.07268     0.03975      89      -1.83      0.0708    -0.00145
day*mmse16     -0.02022     0.01167     417      -1.73      0.0838    -0.00819
```

There is a *linear* relationship between day and the *logit* of at least some delirium.
There is a *nonlinear* relationship between day and the *probility* of at least some delirium.