DCMs in Practice

Section 3

ECPE Example Data Set

This data was used in:
Burke, Templin & Henson (2008);
Templin & Hoffman (in press);
Templin & Bradshaw (under review).

ECPE

- Examination for the Certificate of Proficiency in English (ECPE)
  - Grammar section
- The ECPE is a test developed and scored by the English Language Institute of the University of Michigan
- The ECPE was developed to measure advanced English ability in respondents for which English is not their first language
- Analysis is for the grammar section of the test
  - 40 multiple choice items (28 items used in analysis)
    - 10 were non-operational
    - 2 had difficulties greater than 0.9

ECPE-like Item

- An example written to resemble an item in the Grammar section of the ECPE is:
  - I have always _____ snow.
    - to enjoy
    - enjoyed
    - enjoying
    - to enjoyed

Examinees

- A total of 2922 examinees are used to analyze the 2003-2004 ECPE Grammar section
  - The average age of examinees was approximately 23 years old
  - Approximately 50% spoke Portuguese and an additional 31% of the examinees spoke Spanish as a first language

Attributes Measured

- Three attributes measured representing knowledge of:
  - Morphosyntactic rules
  - Cohesive rules
  - Lexical rules
- Q-matrix characteristics
  - 19 items measuring only one attribute (simple structure)
  - 9 items measuring two attributes
  - 0 items measuring all three attributes

item	a1	a2	a3
1	1	1	0
2	0	1	0
3	1	0	1
4	0	0	1
5	0	0	1
6	0	0	1
7	1	0	1
8	0	1	0
9	0	0	1
10	1	0	0
11	1	0	1
12	1	0	1
13	1	0	0
14	1	0	0
15	0	0	1
16	1	0	1
17	0	1	1
18	0	0	1
19	0	0	1
20	1	0	1
21	1	0	1
22	0	0	1
23	0	1	0
24	0	1	0
25	1	0	0
26	0	0	1
27	1	0	0
28	0	0	1

ECPE Data Analysis
Model A: Full LCDM

Mplus Files

- Input Files
  - lcdmnhecpe.in
    - Mplus input file
  - ecpedata.dat
    - Your data
- Output Files
  - lcdmnhecpe.out
    - Mplus output file
  - lcdm_Examinees.dat
    - Examinee classifications

SAS Macro for Estimating the LCDM

You can download this from
http://projects.coe.uga.edu/jtemplin/teaching/dcm/dcm12ncme/

SAS Macro

- In SAS_MACRO folder:
- LCDM_Mplus2.sas
  - Creates Mplus syntax
  - Parses results into SAS output files
    - Useful for viewing/reporting results
- ECPEexample.sas
  - You actually run this file
  - Edit lines 23 -82 for your input information
  - You change this file when you want to change the model being run

Edit this part of ECPEexample.SAS

```
*******************************************************************************
**********              MACRO VARIABLE DEFINITIONS:                  ********
**********      USER NEEDS TO CHANGE THESE VALUES PER ANALYSIS       ********
*******************************************************************************;

* Defining needed macro variables as global;
%GLOBAL macroloc filesave filename saslibname Qname dataname IDname
        itemstem itemlist numitem ordervar maxitemorder
        attstem attcat numatt numclass structon structorder loosen processors;

* Location of original data files - CHANGE ALL OF THEM;
* Permanent SAS library;                  LIBNAME folder      "C:\Users\bradshlp\Desktop\ECPE_Class6\SAS_MACRO";
* Path to SAS macro file;                 %LET macroloc=       C:\Users\bradshlp\Desktop\ECPE_Class6\SAS_MACRO;
* Path to import/export files from;       %LET filesave=       C:\Users\bradshlp\Desktop\ECPE_Class6\SAS_MACRO;

* Name prefix for files to be created;    %LET filename =     ECPE_saturated;
* Name of SAS library files are stored in; %LET saslibname=   work;
* Name of SAS dataset for Q matrix;       %LET Qname=         ECPEq;
* Name of SAS dataset with original data; %LET dataname=     ECPEdata_saturated;

* Name of person ID variable (required);  %LET IDname=        ID;
* Item stem in Q matrix (cant be "item"); %LET itemstem=      x;
* List of items to be modeled;            %LET itemlist=      x1-x28;
* Total number of items;                  %LET numitem=       28;
* Variable for order of item model;       %LET ordervar=      itemorder;
* Max order of interaction in item model; %LET maxitemorder=  3;

* Attribute stem in Q matrix;             %LET attstem=       attribute;
* Number of categories for attributes;    %LET attcat =       2; * currently only set to 2;
* Total number of attributes;             %LET numatt=        3;
* Number of total classes (2^A);          %LET numclass=      8;
* Use structural model(0=N,1=Y);          %LET structon=      1;
* Order of interaction in structural model; %LET structorder= 3;

* Loosen congergence criteria (0=N,1=Y)?; %LET loosen=        0;
* Number of processors available for Mplus; %LET processors=  4;
*******************************************************************************;
```


ECPEexample.SAS

Comments in code are self-explanatory on many
For others:

- Itemorder
  - You set this in the next section for each item
- Attstem
  - Name for attributes (i.e., Attribute 1 vs. Att 1 vs. A1)
- Attcat = 2 for dichotomous attributes (e.g., mastery vs non-mastery)
- Structon
  - 1 produces code for the log-linear structural model
  - 0 runs the log-linear model in the background as default, but doesn't give you the structural parameters
- Convergence criteria
  - Zero leaves it at Mplus' default
- Processors available
  - Check the computer you're on

Edit this Part of ECPEexample.SAS

- Input Q-matrix
- Fill in the appropriate values in yellow under DATALINES;
- The last column is the highest interaction term for the item

```
* Import Q-matrix into SAS;
DATA &saslibname..&Qname.;
INPUT &itemstem. attribute1-attribute3 &ordervar.;
DATALINES;
1   1   1   0   2
2   0   1   0   1
3   1   0   1   2
4   0   0   1   1
5   0   0   1   1
6   0   0   1   1
7   1   0   1   2
8   0   1   0   1
9   0   0   1   1
10  1   0   0   1
11  1   0   1   2
12  1   0   1   2
13  1   0   0   1
14  1   0   0   1
15  0   0   1   1
16  1   0   1   2
17  0   1   1   2
18  0   0   1   1
19  0   0   1   1
20  1   0   1   2
21  1   0   1   2
22  0   0   1   1
23  0   1   0   1
24  0   1   0   1
25  1   0   0   1
26  0   0   1   1
27  1   0   0   1
28  0   0   1   1
; RUN;
```

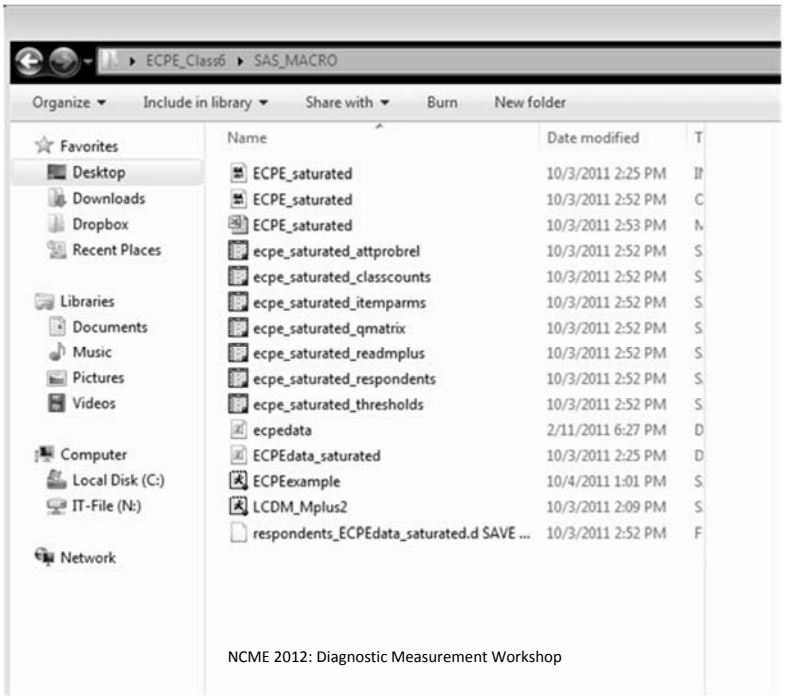
Edit this Part of ECPEexample.SAS

- Change this to your datafile name

```
* Import original data into SAS dataset;
DATA &saslibname..&dataname.;
    INFILE "&filesave.\ecpedata.dat" TRUNCOVER;
    INPUT &IDname. &itemlist.;
RUN;
```

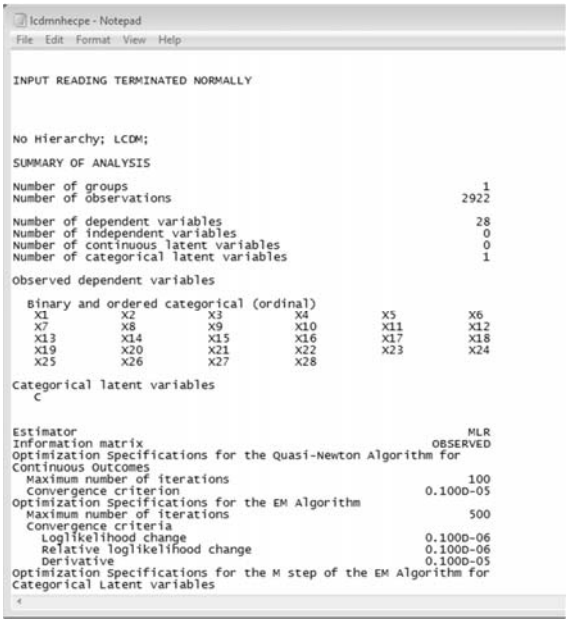
Output Files from SAS Macro

- More on these later today



Did it run?

- It will yell at you if it didn't
- Or not give you standard errors for your parameters



First Things First

- Before we look at parameter estimates in the output, we would want to look at the model-data fit
  - More on this in Section 5
  - Skip for now
- This sections will focus on the estimated parameters
  - Item parameter estimates
  - Examinee classifications

Mplus Output: Item Parameter Estimates

	Parameter Estimate	SE	Estimate /SE	p
New/Additional Parameters				
G_11	-3.539	0.867	-4.080	0.000
G_12	-3.228	1.378	-2.343	0.019
G_13	-0.846	0.219	-3.867	0.000
G_212	3.439	1.899	1.811	0.070
G_213	1.577	1.062	1.485	0.138
G_223	3.534	1.268	2.787	0.005
G_3123	-0.797	2.076	-0.384	0.701
L1_0	0.835	0.085	9.781	0.000
L1_11	0.000	0.000	100.000	0.000
L1_12	0.600	0.240	2.500	0.012
L1_212	1.222	0.304	4.021	0.000
L2_0	1.037	0.089	11.634	0.000
L2_12	1.247	0.155	8.058	0.000
		0.088	-3.873	0.000
		0.887	0.843	0.399
		0.134	2.576	0.010
		0.909	0.589	0.556
		0.084	-1.658	0.097
		0.108	15.633	0.000
		0.095	11.347	0.000
		0.162	12.414	0.000
		0.086	10.097	0.000
		0.136	12.458	0.000
L7_0	-0.106	0.094	-1.124	0.261
L7_11	2.855	0.208	13.720	0.000
L7_13	0.952	0.144	6.601	0.000
L7_213	-0.952	0.144	-6.601	0.000
L8_0	1.482	0.104	14.210	0.000
L8_12	1.922	0.249	7.713	0.000
L9_0	0.119	0.077	1.538	0.124
L9_13	1.195	0.103	11.616	0.000
L10_0	0.055	0.067	0.815	0.415
L10_11	2.050	0.151	13.583	0.000
L11_0	-0.039	0.084	-0.467	0.640
L11_11	0.818	0.791	1.034	0.301
L11_13	0.961	0.143	6.727	0.000
L11_213	0.777	0.831	0.934	0.350
L12_0	-1.769	0.116	-15.282	0.000
L12_11	0.000	0.000	100.000	0.000
L13_0	0.660	0.062	10.693	0.000
L13_11	1.630	0.159	10.283	0.000
L14_0	0.176	0.057	3.083	0.002
L14_11	1.368	0.124	11.038	0.000
L15_0	0.996	0.098	10.179	0.000
L15_13	2.114	0.160	13.241	0.000
L16_0	-0.105	0.094	-1.117	0.264
L16_11	2.343	2.451	0.956	0.339
L16_13	0.892	0.143	6.259	0.000
L16_213	-0.866	2.452	-0.353	0.724
L17_0	1.354	0.119	11.350	0.000
L17_12	0.767	1.618	0.474	0.636
L17_13	0.596	0.317	1.878	0.060
L17_223	0.076	1.721	0.044	0.965
L18_0	0.926	0.089	10.421	0.000
L18_13	1.389	0.126	10.987	0.000
L19_0	-0.195	0.092	-2.105	0.035
L19_13	1.848	0.110	16.723	0.000
L20_0	-1.389	0.113	-12.286	0.000
L20_11	0.243	1.137	0.214	0.831
L20_13	0.908	0.159	5.716	0.000
L20_213	1.410	1.163	1.212	0.225
L21_0	0.164	0.092	1.784	0.075
L21_11	1.053	0.761	1.383	0.167
L21_13	1.130	0.148	7.658	0.000
L21_213	0.042	0.803	0.053	0.958
L22_0	-0.872	0.109	-7.984	0.000
L22_13	2.245	0.116	19.282	0.000
L23_0	0.665	0.099	6.683	0.000
L23_12	2.071	0.189	10.968	0.000
L24_0	-0.673	0.100	-6.717	0.000
L24_12	1.522	0.121	12.578	0.000
L25_0	0.092	0.053	1.740	0.082
L25_11	1.136	0.123	9.265	0.000
L26_0	0.164	0.078	2.101	0.036
L26_13	1.119	0.101	11.074	0.000
L27_0	-0.887	0.071	-12.443	0.000
L27_11	1.713	0.108	15.831	0.000
L28_0	0.568	0.093	6.106	0.000
L28_13	1.745	0.126	13.882	0.000

$\lambda_{i,0}$ =Li_0
$\lambda_{i,1(1)}$ =Li_11
$\lambda_{i,1(2)}$ =Li_12
$\lambda_{i,2(12)}$ =Li_212

Parameter Interpretation

- To demonstrate parameter interpretation, let's look at Item 7
  - Attributes measured:
    - Morphosyntactic rules (Attribute 1)
    - Lexical rules (Attribute 3)
- Parameter estimates:

Parameter	Estimate	SE	p-value
$\lambda_{7,0}$	-0.106	0.094	0.264
$\lambda_{7,1,(1)}$	2.855	0.208	0.000
$\lambda_{7,1,(3)}$	0.952	0.144	0.000
$\lambda_{7,2,(1,3)}$	-0.952	0.144	0.000

LCDM Intercepts

- Estimated Intercept: -0.106 (0.095)
- Indicates the logit of a correct response for a non-master of all attributes
  - Here, non-masters have an average probability of a correct response: exp(-0.106)/1+exp(-0.106) = 0.47
- Hypothesis test is not important
  - Tests whether non-masters have a probability of a correct response of 0.5
- Problematic when very high
  - Difficult to identify other parameters
  - Indicates issues with test, Q-matrix, or attributes

Higher Order Model Parameters

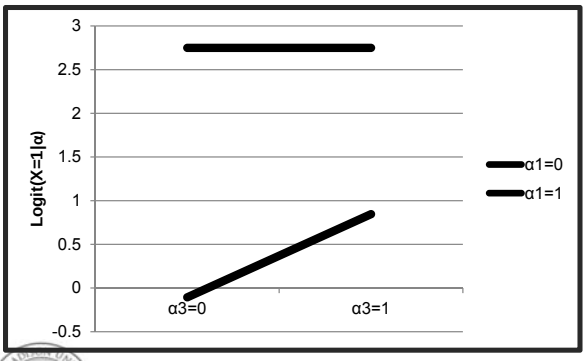
- Interpretation of main effects and interactions proceeds sequentially:
- If interactions are present:
  - Examine highest level of interaction
    - If significantly different from zero, leave in model
    - If not, term can be omitted
- If interactions are not present:
  - Examine how far main effect is from zero

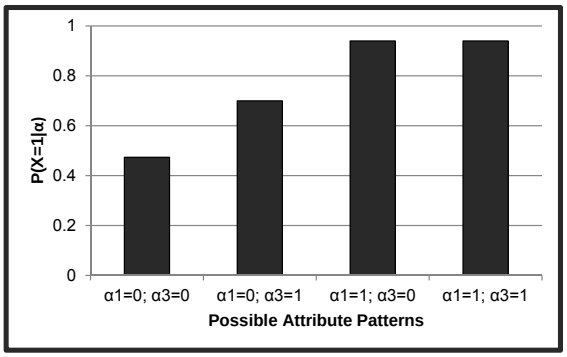
Examining Interaction Parameters

- 2-way interaction parameter: -0.952 (0.144)
- P-value for parameter was small (0.000)
  - Indicates parameter is significantly different from zero
  - Candidate to leave in model
- Value indicates that there is an under-additive effect of mastering both attributes
  - Means mastery of one attribute is sufficient to have high chance to get item correct

More on Interactions

- Interaction pattern for this item indicates that mastery morphosyntatic rules is key to answering correctly
  - Mastery of lexical rules helps, but not above that of mastery of morphosyntatic rules
  - For why this is the case, stay tuned…





Other Interactions

- Significant interactions?

New/Additional Parameters

G_11	-3.539	0.867	-4.080	0.000
G_12	-3.228	1.378	-2.343	0.019
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L1_212	1.222	0.304	4.021	0.000
L2_0	1.037	0.089	11.634	0.000
L2_12	1.247	0.155	8.058	0.000
L3_0	-0.340	0.088	-3.873	0.000
L3_11	0.748	0.887	0.843	0.399
L3_13	0.346	0.134	2.576	0.010
L3_213	0.535	0.909	0.589	0.556
L4_0	-0.139	0.084	-1.658	0.097
L4_13	1.691	0.108	15.633	0.000
L5_0	1.082	0.095	11.347	0.000
L5_13	2.015	0.162	12.414	0.000
L6_0	0.865	0.086	10.097	0.000
L6_13	1.692	0.136	12.458	0.000
L7_0	-0.106	0.094	-1.124	0.261
L7_11	2.855	0.208	13.720	0.000
L7_13	0.952	0.144	6.601	0.000
L7_213	-0.952	0.144	-6.601	0.000
L8_0	1.482	0.104	14.210	0.000
L8_12	1.922	0.249	7.713	0.000
L9_0	0.119	0.077	1.538	0.124
L9_13	1.195	0.103	11.616	0.000
L10_0	0.055	0.067	0.815	0.415
L10_11	2.050	0.151	13.583	0.000
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L11_213	0.777	0.831	0.934	0.350
L12_0	-1.769	0.116	-15.282	0.000
L12_11	0.000	0.000	100.000	0.000
L12_13	1.290	0.171	7.558	0.000
L12_213	1.515	0.146	10.339	0.000
L13_0	0.660	0.062	10.693	0.000
L13_11	1.630	0.159	10.283	0.000
L14_0	0.176	0.057	3.083	0.002
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L20_0	-1.389	0.113	-12.286	0.000
L20_11	0.243	1.137	0.214	0.831
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L27_0	-0.887	0.071	-12.443	0.000
L27_11	1.713	0.108	15.831	0.000
L28_0	0.568	0.093	6.106	0.000
L28_13	1.745	0.126	13.882	0.000

SAS Output of Item Parameters

VIEWTABLE: TMP1.lcdmecpe_itemparms

	parm	item	x	order	Atts	itemEst	itemSE	itemZ	itemP	itemorder	itematt1	itematt2	itematt3
1	L1_0	1	1	0	0	0.84	0.09	9.78	0	2	1	1	0
2	L1_11	1	1	1	1	0	0	100	0	2	1	1	0
3	L1_12	1	1	1	2	0.6	0.24	2.5	0.01	2	1	1	0
4	L1_212	1	1	2	12	1.22	0.3	4.02	0	2	1	1	0
5	L2_0	2	2	0	0	1.04	0.09	11.6	0	1	0	1	0
6	L2_12	2	2	1	2	1.25	0.16	8.06	0	1	0	1	0
7	L3_0	3	3	0	0	-.34	0.09	-3.8	0	2	1	0	1
8	L3_11	3	3	1	1	0.75	0.92	0.81	0.42	2	1	0	1
9	L3_13	3	3	1	3	0.35	0.14	2.56	0.01	2	1	0	1
10	L3_213	3	3	2	13	0.54	0.94	0.57	0.57	2	1	0	1
11	L4_0	4	4	0	0	-.14	0.08	-1.7	0.1	1	0	0	1
12	L4_13	4	4	1	3	1.69	0.11	15.6	0	1	0	0	1
13	L5_0	5	5	0	0	1.08	0.1	11.3	0	1	0	0	1
14	L5_13	5	5	1	3	2.02	0.16	12.4	0	1	0	0	1
15	L6_0	6	6	0	0	0.87	0.09	10.1	0	1	0	0	1
16	L6_13	6	6	1	3	1.69	0.14	12.5	0	1	0	0	1
17	L7_0	7	7	0	0	-.11	0.1	-1.1	0.26	2	1	0	1
18	L7_11	7	7	1	1	2.86	0.21	13.7	0	2	1	0	1
19	L7_13	7	7	1	3	0.95	0.14	6.59	0	2	1	0	1
20	L7_213	7	7	2	13	-.95	0.14	-6.6	0	2	1	0	1

Other Interactions

- Of 9 interaction parameters, 3 were significantly different from zero
  - Candidates to be removed from model
- Of the 6 items with non-significant interactions 3 had small main effects on one attribute (Item 3, 12 & 20)
  - Attribute not highly related to item response
  - Indicates that Q-matrix ***may*** be incorrect
    - Have to re-fit with new Q-matrix and compare model fit

Interpreting Main Effects

- When significant interactions are present, main effects cannot be easily interpreted
  - Sometimes called conditional main effects
  - Need to know *combination* of attributes mastered to fully describe item response function
- Main effects in LCDM cannot be tested for significance
  - Lower bound is zero (for monotonicity)
  - p-values are inaccurate as they approach zero
  - Use practical significance
    - How much of an increase in probability for mastery of attribute is meaningful?
  - Or estimate the model with and without the main effect to compare fit

Item 7 Lexical Main Effect (Att 3)

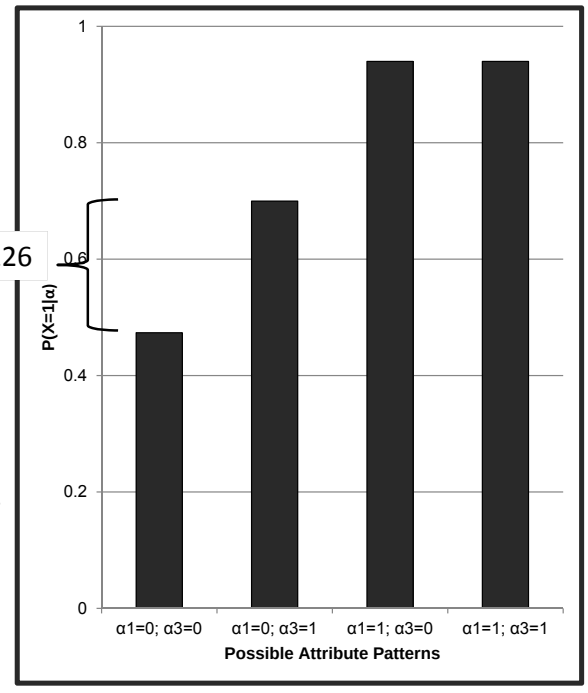
- Because of the significant interaction, interpretation is conditional

Parameter	Estimate	SE	p-value
$\lambda_{7,0}$	-0.106	0.094	0.264
$\lambda_{7,1,(1)}$	2.855	0.208	0.000
$\lambda_{7,1,(3)}$	0.952	0.144	0.000
$\lambda_{7,2,(1,3)}$	-0.952	0.144	0.000

- When Morphosyntactic Rules have not been mastered:

  Lexical main effect : $\lambda_{7,1,(1)} = 0.952$

  - Respondents who have mastered Lexical Rules have an increase in logit of 0.952 over respondents who are non-masters
  - Respondents who have mastered Lexical Rules have an increase in probability of .226 over respondents who are non-masters

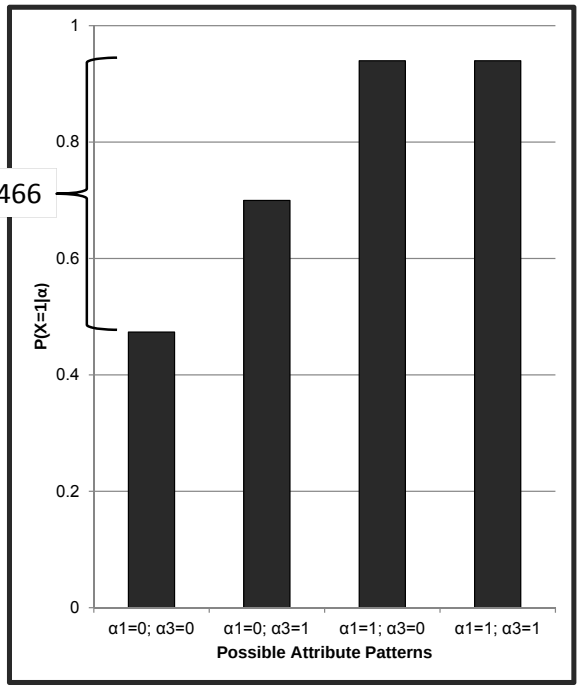


Item 7 Morphosyntactic Main Effect (Att 1)

- Because of the significant interaction, interpretation is conditional

Parameter	Estimate	SE	p-value
$\lambda_{7,0}$	-0.106	0.094	0.264
$\lambda_{7,1,(1)}$	2.855	0.208	0.000
$\lambda_{7,1,(3)}$	0.952	0.144	0.000
$\lambda_{7,2,(1,3)}$	-0.952	0.144	0.000

- When Lexical Rules have not been mastered:
  - Morphosyntactic main effect:
    $\lambda_{7,1,(3)} = 2.855$
  - Respondents who have mastered Morphosyntactic Rules have an increase in logit of 2.855 over respondents who are non-masters
  - Respondents who have mastered Morphosyntactic Rules have an increase in probability of 0.466 over respondents who are non-masters



Note about Thresholds

- Notice item parameters sum to give us (negative) thresholds
- Item 1 parameters

L1_0	0.835	0.085	9.781	0.000
L1_11	0.000	0.000	100.000	0.000
L1_12	0.600	0.240	2.500	0.012
L1_212	1.222	0.304	4.021	0.000

- For class 5 [100], they have a threshold of -.835
  - Sum of intercept (.835) + main effect for attribute 1 (0)

Latent Class 5

Thresholds

X1$1	-0.835	0.085	-9.781	0.000
X2$1	-1.037	0.089	-11.634	0.000
X3$1	-0.408	0.847	-0.481	0.630
X4$1	0.139	0.084	1.658	0.097

- For class 7 [110], they have a threshold of -2.657
  - Sum of intercept (.835) + main effect for attribute 1 (0) + main effect for attribute 2 (.600) + interaction (1.222)

Latent Class 7

Thresholds

X1$1	-2.657	0.199	-13.320	0.000
X2$1	-2.284	0.126	-18.091	0.000
X3$1	-0.408	0.847	-0.481	0.630
X4$1	0.139	0.084	1.658	0.097

Examinee Classifications

- Proportion of Examinees in each Class
- **Mplus output** **SAS Output**

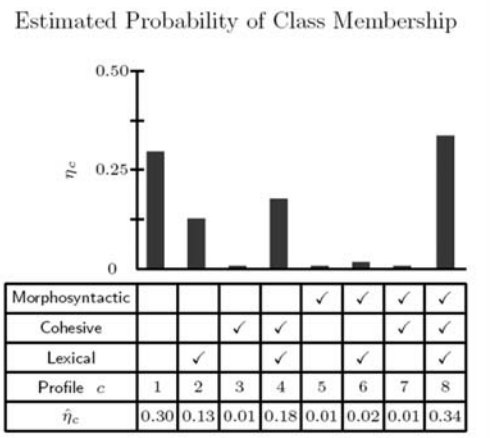
```
FINAL CLASS COUNTS AND PROPORTIONS FOR THE LATENT CLASSES
BASED ON THE ESTIMATED MODEL

   Latent
   Classes

      1        878.76337          0.30074
      2        376.91360          0.12899
      3         34.82821          0.01192
      4        511.56508          0.17507
      5         25.53224          0.00874
      6         53.03095          0.01815
      7         31.51259          0.01078
      8       1009.85397          0.34560
```

VMP1.lcdmecpe_classcounts

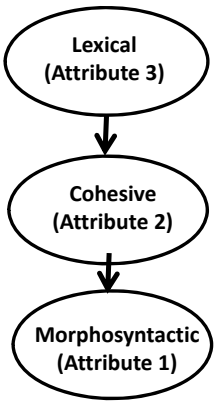
class	estcount	estprop	classatt1	classatt2	classatt3
1	878.76795	0.30074	0	0	0
2	376.91412	0.12899	0	0	1
3	34.82871	0.01192	0	1	0
4	511.56557	0.17507	0	1	1
5	25.53098	0.00874	1	0	0
6	53.03071	0.01815	1	0	1
7	31.51112	0.01078			

- Many examinees are in 4 classes:
  - Class 1 (30.07%)
  - Class 2 (12.9%)
  - Class 4 (17.5%)
  - Class 8 (34.5%)
- Few examinees are in Classes 3, 5, 6, & 7

Attribute Pattern Probabilities



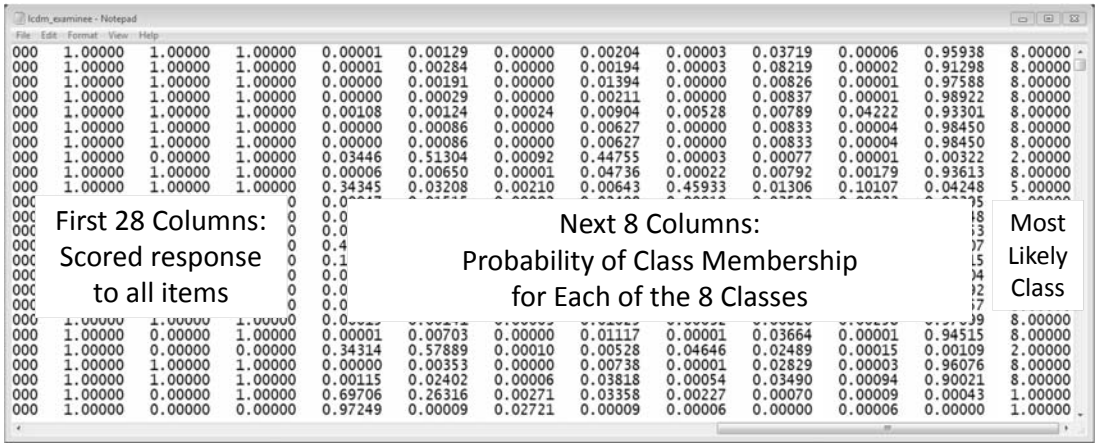
Morphosyntactic					✓	✓	✓	✓
Cohesive			✓	✓			✓	✓
Lexical		✓		✓		✓		✓
Profile c	1	2	3	4	5	6	7	8
$\hat{\eta}_c$	0.30	0.13	0.01	0.18	0.01	0.02	0.01	0.34



- Base-rate pattern of profiles mastered in sample indicates an **attribute hierarchy**
  - Lexical
  - Cohesive
  - Morphosyntatic
- Suggests information about second-language acquisition
- If we saw this hierarchy, we could impose and then test the hierarchy using the hierarchical DCM (HDCM; Templin & Bradshaw, under review)

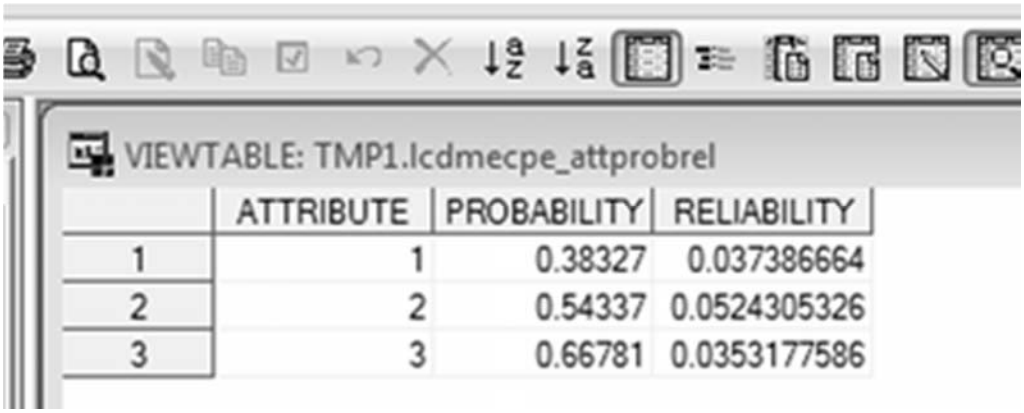
Examinee Classifications

- Examinee-level classifications
- Lcdm_examinee.dat
  - Output file



Marginal Attribute Mastery

- From Macro Out files



VIEWTABLE: TMP1.lcdmecpe_attprobrel

	ATTRIBUTE	PROBABILITY	RELIABILITY
1	1	0.38327	0.037386664
2	2	0.54337	0.0524305326
3	3	0.66781	0.0353177586

- Calculate these by summing across relevant classes
  - Demonstrated in Section 4

Example Respondent Estimates

- Respondent estimates are probabilities of mastery for each attribute
- Shown for 5 example respondents
  - Test score given to provide comparison

Respondent	Total Score	Morphosyntactic	Cohesive	Lexical
1	26	**1.00**	**0.96**	**1.00**
10	23	**0.62**	0.15	0.10
14	15	0.00	0.00	**0.54**
29	25	**0.56**	0.08	**0.95**
33	13	0.21	0.18	0.02

General Modeling Tips

- High-level interactions are difficult to estimate in most samples
  - More than 2-way interactions may not be possible
- Modeling strategy:
  - Try all interactions
    - If model does not converge, limit to only 2-way interactions
  - Remove non-significant interactions from model
  - If all interactions and main effects for an attribute are close to zero:
    - Try removing entry for attribute in Q-matrix

Concluding Remarks

Section 3

Wrap-Up and Take-Home Points

- Session 3 demonstrated a potential use of DCMs
- Applications of DCMs are rare
  - Tests aren't designed to measure categorical attributes
    - Item information is different in DCMs
  - Users haven't had access to software
    - Previously, most applications use software built by researchers
      - MCMC in Fortran or WinBugs
      - MML in Fortran
    - Now, researchers can use Mplus

Notes on Usefulness of DCMs

- Full utility of DCMs cannot be understood unless applications become more frequent
  - For now, have to use sub-optimal data and problems
  - Future applications coming soon
    - Mathematical reasoning test (NSF funded)
    - Assessment of readiness for first grade in kindergartners
- Funding opportunities exist and seem to review well
  - Educational Measurement: NSF (DR-K12); IES (Goals 2 and 5)
  - Psychological Measurement: NIH (NIMH; NIDA; NIA;…)
- Industry seems interested
  - ETS/College Board/ACT/Measurement Inc.