CYFS nebraska center for research
children youth families & schools

research methodology series

Characterizing Changing Classifications: Practical Illustrations of Latent Transition Analysis (LTA)

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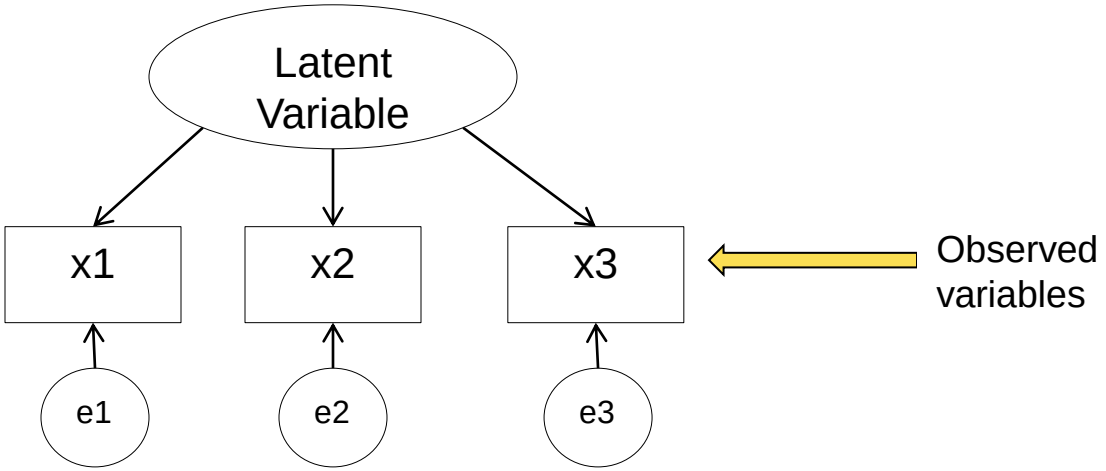
Overview

- Introduction to Latent Transition Analysis (LTA)
  - Classification of latent variable models
  - LTA model
  - Markov model as a special case of LTA model
- Model selection and parameter estimates in LTA
  - Model selection
  - Parameter estimates
  - Statistical packages available
- Demonstration of LTA
  - Exploration of change in psychological status
  - Exploration of change in reading proficiency designation
- Discussion
  - Summary
  - Issues

Introduction to LTA
- Classification of latent variable models

- In factor analysis, a covariance matrix is analyzed statistically in order to shed light on the underlying latent structure
  - For example, latent variable with three observed variables as indicators



- When the type of latent variable is categorical, the latent variable model is called latent class or latent profile model
- Their longitudinal version is called *latent transition analysis* (LTA) model

Introduction to LTA
- Classification of latent variable models

- Both latent and observed variables can be either categorical or continuous, which differentiates between latent variable models (Collins & Lanza, 2011)

		Latent Variables	
		Continuous	Categorical
Indicators	continuous	Factor analysis (FA)	Latent profile analysis (LPA)
	categorical	Item response theory (IRT)	Latent class analysis (LCA)

  - It is often more difficult to determine whether the latent variable is categorical or continuous, compared to indicators
  - In practice, the applied researcher should consider whether a continuous or categorical operationalization of the construct is more relevant to the research questions at hand

Introduction to LTA
- Classification of latent variable models

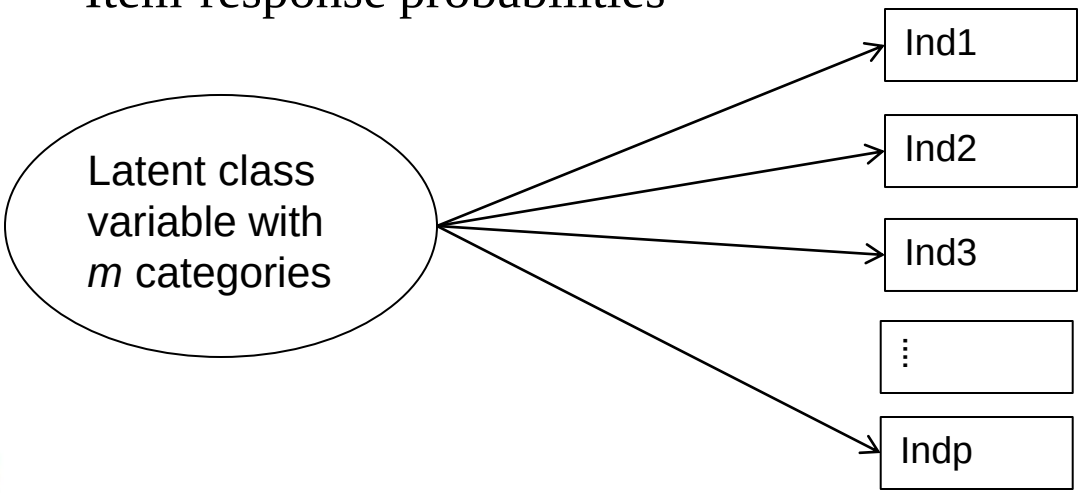
- Both latent and observed variables can be either categorical or continuous, which differentiates between latent variable models (Collins & Lanza, 2011)

		Latent Variables	
		Continuous	Categorical
Indicators	continuous	Factor analysis (FA)	Latent profile analysis (LPA)
	categorical	Item response theory (IRT)	**Latent class analysis (LCA)**

- **Latent class analysis (LCA) and its longitudinal version, latent transition analysis (LTA), are today's foci.**

Introduction to LTA
- Latent Transition Analysis (LTA)

- Latent class analysis (LCA)
  - Classifying individuals into latent classes based on observed categorical indicators
  - Latent classes are mutually exclusive and exhaustive
  - True class membership is unknown
- Outcomes of LCA
  - Latent class membership probabilities – latent prevalence
  - Item-response probabilities



Introduction to LTA
- Latent Transition Analysis (LTA)

- One of primary goal in longitudinal data analysis is to understand the *change* over time

- Modeling change over time
  - For continuous latent variable

    Change: Slope → Latent growth model
  - For categorical latent variable

    Change: *Movement between time points* → Latent transition analysis

		Time (t+1)	
		LC1	LC2
Time t	LC1	*p11*	*p12*
	LC2	*p21*	*p22*

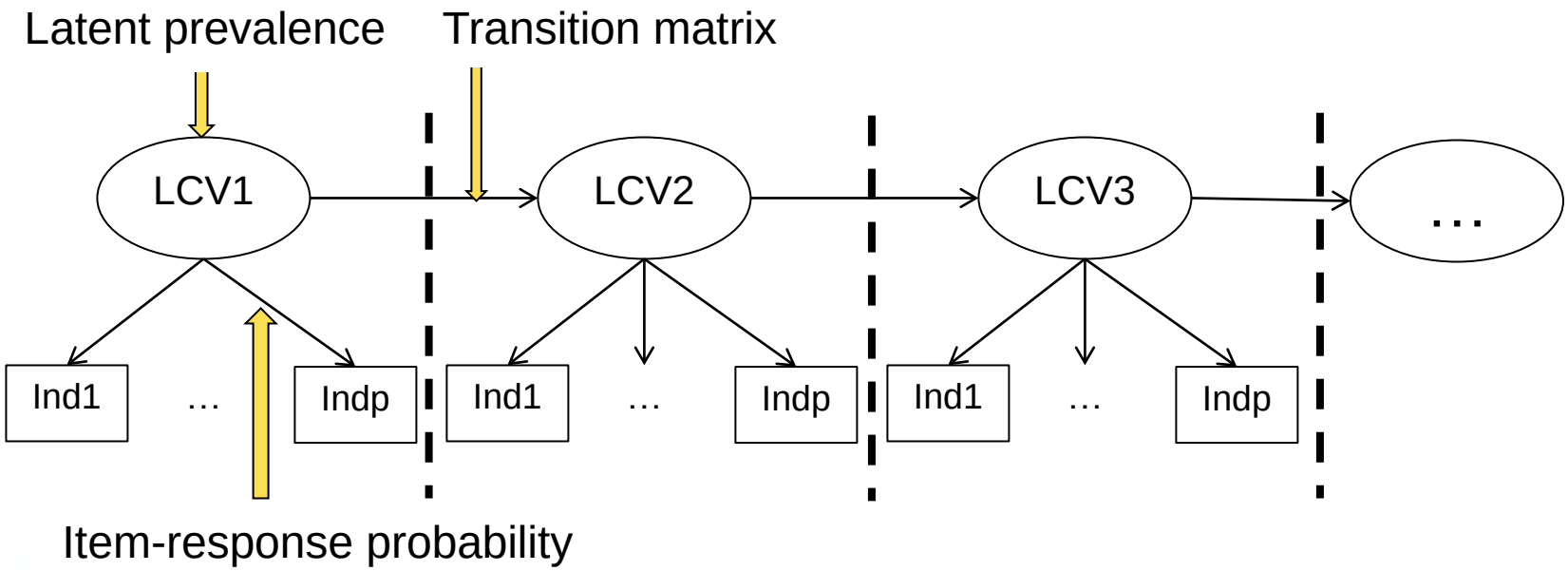
Note: *P*s are transition probabilities, i.e., *p12* is the probability of changing latent class 1 at Time t to latent class 2 at Time (t+1)

Introduction to LTA
- Latent transition analysis (LTA)

- Latent transition analysis (LTA)
  - LTA is a longitudinal extension of latent class models and enables the investigator to model a dynamic, or changing, latent variables
  - Some development can be represented as movement among latent class membership
  - Different people may take different paths

Introduction to LTA
- Latent transition analysis (LTA)

- Outcomes of LTA
  - Latent class membership probabilities – latent prevalence
  - Item-response probabilities
  - Transition matrix – Change of latent class membership over time



where the latent class variable has m categories

Introduction to LTA
- Markov model as a special case of LTA model

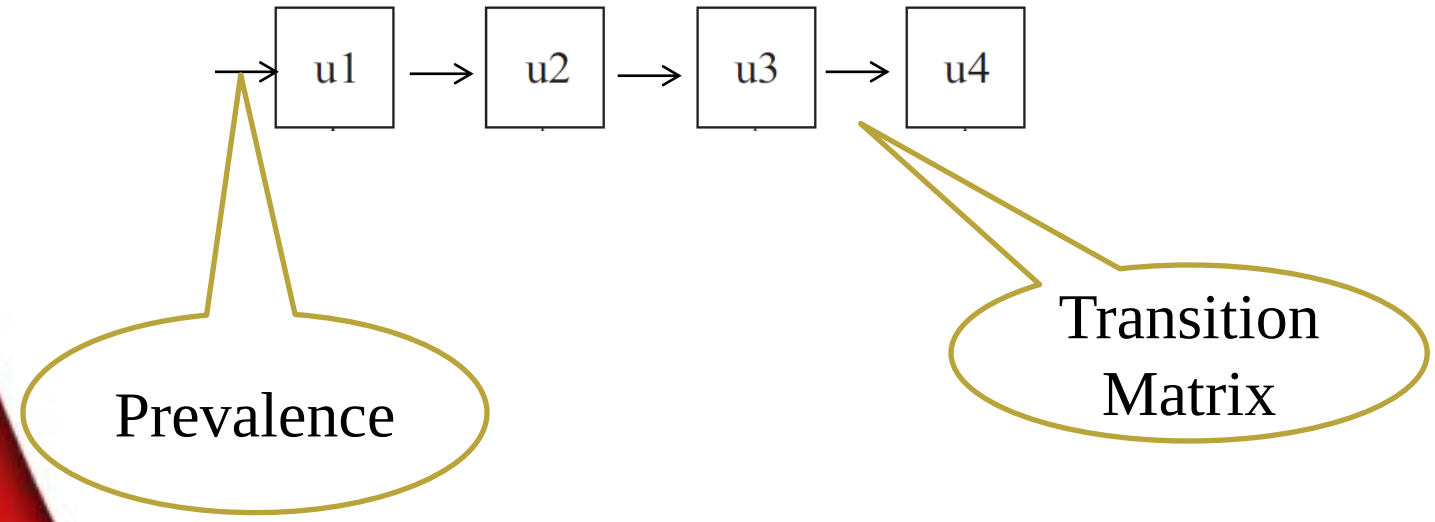
- A special case of Latent Transition Model
  - One item at each time point only
  - The item is categorical

- Data
  - Many individuals are measured repeatedly at a limited number of occasions (one measure at each occasion)

(Time Series Analysis: A few individuals are measured repeatedly at many occasions)

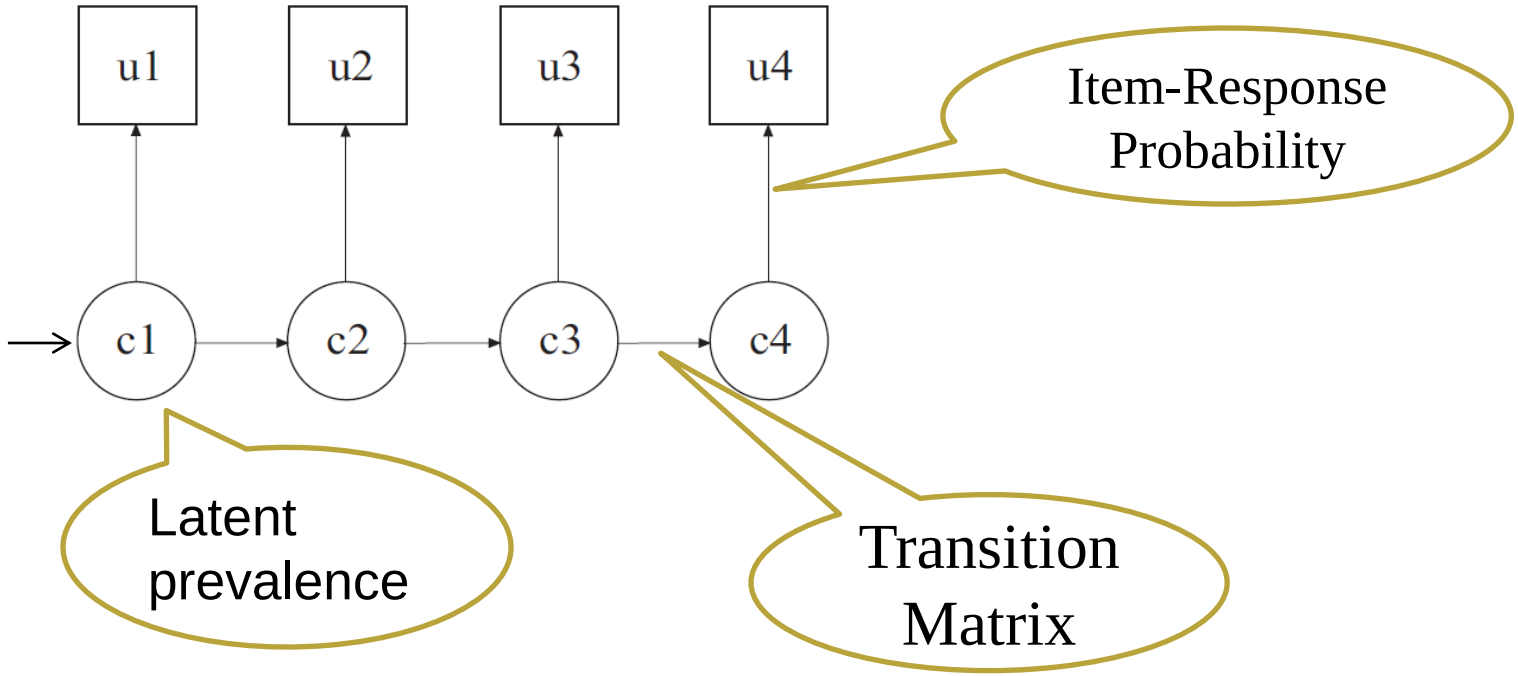
Introduction to LTA
- Markov model as a special case of LTA model

- Manifest (Simple) Markov model
  - Measurement is assumed to be perfect
  - Example, “Do you have a job right now (Y/N)?”
  - May be realistic for some types of variables (e.g. disease, employment status) but unlikely to describe educational assessment results



Introduction to LTA
- Markov model as a special case of LTA model

- Latent Markov Model
  - Measurement is not perfect
  - For example, “Do the students meet the reading proficiency standard?”
  - Parameters consist of three components



Model selection and parameter estimates in LTA
- Model selection

- Estimation methods
  - Expectation-maximization (EM) algorithm
    - Full-Information Maximum Likelihood (FIML)
  - Bayesian method

- Estimation of LTA is based on response patterns in the contingency table based on the number of items
  - Example: The case of 8 dichotomized items over 3 time points provides a contingency table consisting of 16,777,216 cells

$$W = (2^8)^3 = 16{,}777{,}216$$

Model selection and parameter estimates in LTA
- Model selection

- Contingency table at Time 1

Response pattern	Item 1	Item 2	Item3	Item 4	Item 5	Item 6	Item 7	Item 8
Pattern 1	No	No	No	No	No	No	No	No
Pattern 2	No	No	No	No	No	No	No	Yes
Pattern 3	No	No	No	No	No	No	Yes	No
Pattern 4	No	No	No	No	No	No	Yes	Yes
Pattern 5	No	No	No	No	No	Yes	No	No
Pattern 6	No	No	No	No	No	Yes	No	Yes
Pattern 7	No	No	No	No	No	Yes	Yes	No
Pattern 8	No	No	No	No	No	Yes	Yes	Yes
⋮								
Pattern 253	Yes	Yes	Yes	Yes	Yes	Yes	No	No
Pattern 254	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes
Pattern 255	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
Pattern 256	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Model selection and parameter estimates in LTA
- Model selection

- Contingency table at Time 1 and Time 2

Response pattern	Item 1	Item 2	Item3	Item 4	Item 5	Item 6	Item 7	Item 8
Pattern 1	Pattern 1	No	No	No	No	No	No	No	No
Pattern 2	Pattern 2	No	No	No	No	No	No	No	Yes
Pattern 3	Pattern 3	No	No	No	No	No	No	Yes	No
Pattern 4	Pattern 4	No	No	No	No	No	No	Yes	Yes
Pattern 5	Pattern 5	No	No	No	No	No	Yes	No	No
Pattern 6	Pattern 6	No	No	No	No	No	Yes	No	Yes
Pattern 7	Pattern 7	No	No	No	No	No	Yes	Yes	No
Pattern 8	Pattern 8	No	No	No	No	No	Yes	Yes	Yes
⋮	⋮								
Pattern 253	Pattern 253	Yes	Yes	Yes	Yes	Yes	Yes	No	No
Pattern 254	Pattern 254	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes
Pattern 255	Pattern 255	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
Pattern 256	Pattern 256	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Model selection and parameter estimates in LTA
- Model selection

- Contingency table at Time 1, Time 2, and Time 3

Response pattern	Item 1	Item 2	Item3	Item 4	Item 5	Item 6	Item 7	Item 8
Pattern 1								
Pattern 2								
Pattern 3								
Pattern 4								
Pattern 5								
Pattern 6								
Pattern 7								
Pattern 8								
⋮								
Pattern 253								
Pattern 254								
Pattern 255								
Pattern 256								

Response pattern	Item 1	Item 2	Item3	Item 4	Item 5	Item 6	Item 7	Item 8
Pattern 1								
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Pattern 256								

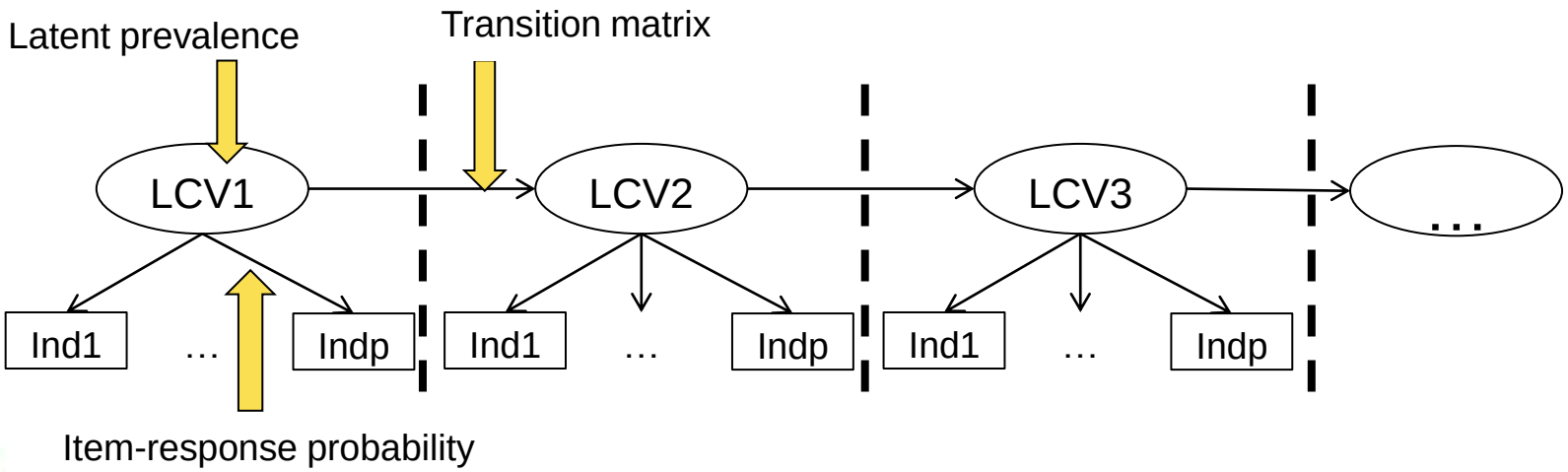
Response pattern	Item 1	Item 2	Item3	Item 4	Item 5	Item 6	Item 7	Item 8
Pattern 1	No	No	No	No	No	No	No	No
Pattern 2	No	No	No	No	No	No	No	Yes
Pattern 3	No	No	No	No	No	No	Yes	No
Pattern 4	No	No	No	No	No	No	Yes	Yes
Pattern 5	No	No	No	No	No	Yes	No	No
Pattern 6	No	No	No	No	No	Yes	No	Yes
Pattern 7	No	No	No	No	No	Yes	Yes	No
Pattern 8	No	No	No	No	No	Yes	Yes	Yes
⋮								
Pattern 253	Yes	Yes	Yes	Yes	Yes	Yes	No	No
Pattern 254	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes
Pattern 255	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
Pattern 256	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Model selection and parameter estimates in LTA
- Model selection

- Model fit to select the number of latent classes
  - Likelihood ratio statistics (G^2; Agresti, 1990)
    - Reflects how well a latent class/transition model fits observed data
      - The null hypothesis is that the model test is adequate
      - A p-value for the G^2 can be obtained by comparing the G^2 test statistics to the reference chi-square distribution
      - $df = W - P - 1$
  - Information criteria: smaller is better
    - $AIC = G^2 + 2P$
    - $BIC = G^2 + [\log(N)]P$
    - Where P is a number of parameters and N is a sample size

Model selection and parameter estimates in LTA
- Parameters in LTA

- Parameters in LTA
  - Latent prevalence (Delta estimates, Δ)
    - Prevalence in Time 1 is only estimated and prevalence in later time is computed by the result in Time 1 and transition matrices
  - Item-response probabilities (Rho estimates, ρ)
    - Usually fixed over time, assuming the measurement invariance
  - Transition matrices consisting of transition probabilities (Tau estimates, τ)



Model selection and parameter estimates in LTA
- Statistical packages available

- SAS Proc LTA* (http://methodology.psu.edu/)

- *Free software*
  - *l*EM (http://spitswww.uvt.nl/~vermunt/)
  - WinLTA (http://methodology.psu.edu/)
  - R packages (https://www.msu.edu/~chunghw/downloads.html)
    - CAT_LVM
    - CAT_LVM_BAYESIAN

- *Commercial software packages*
  - Mplus* (http://www.statmodel.com/)
  - Latent Gold (http://www.statisticalinnovations.com/)

Note: (*) indicates statistical packages used in this study

Demonstration of LTA

- Example 1: Exploration of change in psychological status (Self-esteem) using *Latent Transition Analysis*

This photo was captured from Google image at 3/28/2012

Demonstration of LTA
- Exploration of change in psychological status

- Data
  - Pacific-Rim Bullying measure (PRBm; Konishi et al., 2009)
    - Administered in School Experiences across Cultures: An International Study
  - General self-esteem from Self-description Questionnaire-I (SDQ-I; Marsh, 1988)
    - Eight items with 4 Likert type response
    - Original Likert type items were transformed by dichotomizing the responses (yes or no) because of distribution problem and missing data
  - Participants were 1180 students
    - From 5th to 9th grade at the fall of 2005 attending nine schools
    - Due to students' transitions, the number of schools increased to 22 over three semesters
    - 1173 at fall of 2005; 1114 at spring of 2006; 999 at fall of 2006

Demonstration of LTA
- Exploration of change in psychological status

- Research Questions
  1. Are there distinct subgroups of students within the sample that exhibit particular patterns of self-esteem?
  2. Is there change between latent classes membership across time?
  3. If so, how can this change be characterized?
  4. If an individual is in a particular latent class at Time t, what is the probability that the individual will be in that latent class at Time (t+1), and what is the probability that the individual will be in a different latent class?

Demonstration of LTA
- Exploration of change in psychological status

- Marginal Response Proportions

Item	Time 1 (Fall, 2005)		Time 2 (Spring, 2006)		Time 3 (Fall, 2006)	
	Obs.	Yes	Obs. N	Yes	Obs. N	Yes
I do lots of important things	1172	0.869	1112	0.881	996	0.875
In general, I like being the way I am	1172	0.923	1112	0.929	995	0.935
Overall, I have a lot to be proud of	1169	0.915	1110	0.825	994	0.927
I can do things as well as most other people	1171	0.917	1112	0.915	994	0.931
Other people think I am a good person	1169	0.944	1109	0.949	995	0.956
A lot of things about me are good	1171	0.942	1109	0.944	995	0.946
I am as good as most other people	1170	0.927	1109	0.913	993	0.929
When I do something, I do it well	1171	0.924	1113	0.936	996	0.945

Demonstration of LTA
- Exploration of change in psychological status

- LTA was conducted by SAS Proc LTA and its syntax is given below:

```
PROC LTA data=gss10;
      Title ‘General Self esteem in PRBm with 3 times, 3 statues';
      NSTATUS 3;
      NTIMES 3;
      ITEMS pr4t1 pr5t1 pr6t1 pr7t1 pr8t1 pr9t1 pr10t1 pr11t1
            pr4t2 pr5t2 pr6t2 pr7t2 pr8t2 pr9t2 pr10t2 pr11t2
            pr4t3 pr5t3 pr6t3 pr7t3 pr8t3 pr9t3 pr10t3 pr11t3;
      CATEGORIES 2 2 2 2 2 2 2 2;
      measurement times;
      seed 741620;
Run;
```

Demonstration of LTA
- Exploration of change in psychological status

- LTA was conducted by SAS Proc LTA and its syntax is given below:

Need to specify the number of latent classes and time points

```
PROC LTA data=gss10;
    Title 'General Self esteem in PRBm with 3 times, 3 statues';
    NSTATUS 3;
    NTIMES 3;
    ITEMS pr4t1 pr5t1 pr6t1 pr7t1 pr8t1 pr9t1 pr10t1 pr11t1
          pr4t2 pr5t2 pr6t2 pr7t2 pr8t2 pr9t2 pr10t2 pr11t2
          pr4t3 pr5t3 pr6t3 pr7t3 pr8t3 pr9t3 pr10t3 pr11t3;
    CATEGORIES 2 2 2 2 2 2 2 2;
    measurement times;
    seed 741620;
Run;
```

Demonstration of LTA
- Exploration of change in psychological status

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          pr4t2 pr5t2 pr6t2 pr7t2 pr8t2 pr9t2 pr10t2 pr11t2
          pr4t3 pr5t3 pr6t3 pr7t3 pr8t3 pr9t3 pr10t3 pr11t3;
    CATEGORIES 2 2 2 2 2 2 2 2;
    measurement times;
    seed 741620;
Run;
```

Data format as subject by variables

Demonstration of LTA
- Exploration of change in psychological status

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            pr4t2 pr5t2 pr6t2 pr7t2 pr8t2 pr9t2 pr10t2 pr11t2
            pr4t3 pr5t3 pr6t3 pr7t3 pr8t3 pr9t3 pr10t3 pr11t3;
      CATEGORIES 2 2 2 2 2 2 2 2;
      measurement times;
      seed 741620;
Run;
```

Number of response categories

Demonstration of LTA
- Exploration of change in psychological status

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```
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      NSTATUS 3;
      NTIMES 3;
      ITEMS pr4t1 pr5t1 pr6t1 pr7t1 pr8t1 pr9t1 pr10t1 pr11t1
            pr4t2 pr5t2 pr6t2 pr7t2 pr8t2 pr9t2 pr10t2 pr11t2
            pr4t3 pr5t3 pr6t3 pr7t3 pr8t3 pr9t3 pr10t3 pr11t3;
      CATEGORIES 2 2 2 2 2 2 2 2;
      measurement times;
      seed 741620;
Run;
```

Fixing item-response probabilities across time points

Demonstration of LTA
- Exploration of change in psychological status

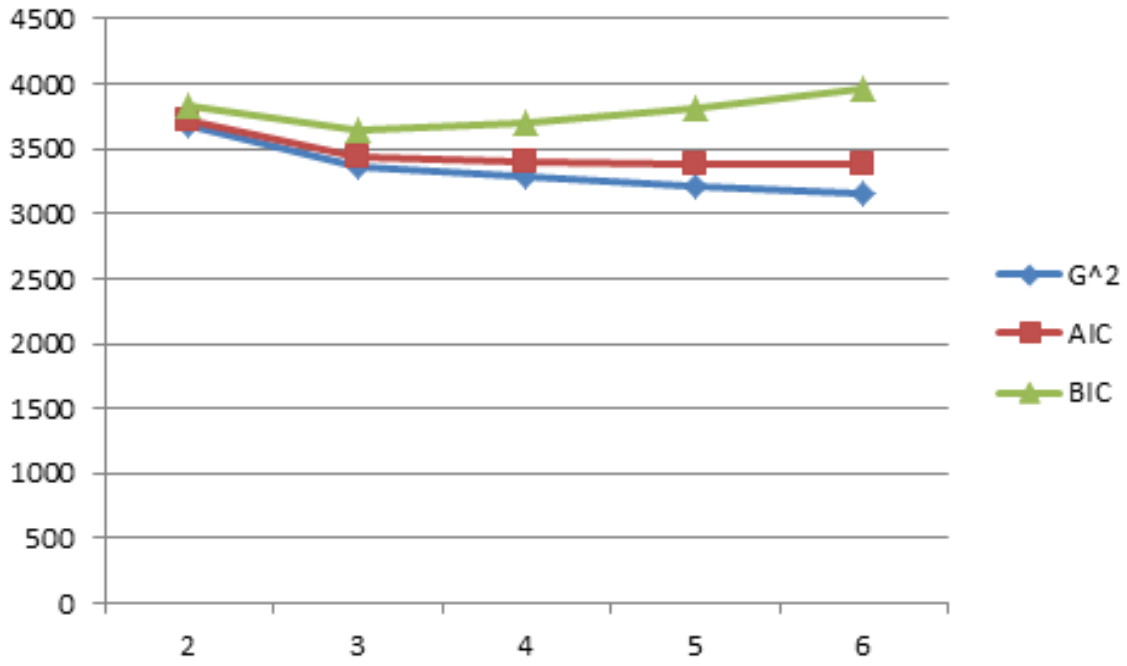
- Result of LTA on General Self-esteem with # = 2 to 6

Number of Latent Statues	Model fit				
	G^2*	df	AIC	BIC	Log-likelighood
2	3677.89	16777194	3719.89	3826.43	-5420.31
3	3366.72	16777177	3442.72	3635.51	-5264.73
4	3285.81	16777156	3403.81	3703.13	-5224.27
5	3213.79	16777131	3381.79	3807.94	5188.26
6	3162.63	16777102	3388.63	3961.9	-5162.68

  - Since df is too big, it is not suggested to use G^2statistics
  - AIC result indicates that five latent class model is adequate while BIC result indicates that three latent class model is adequate

Demonstration of LTA
- Exploration of change in psychological status

- Result of LTA on General Self-esteem over different latent statues from 2 to 6

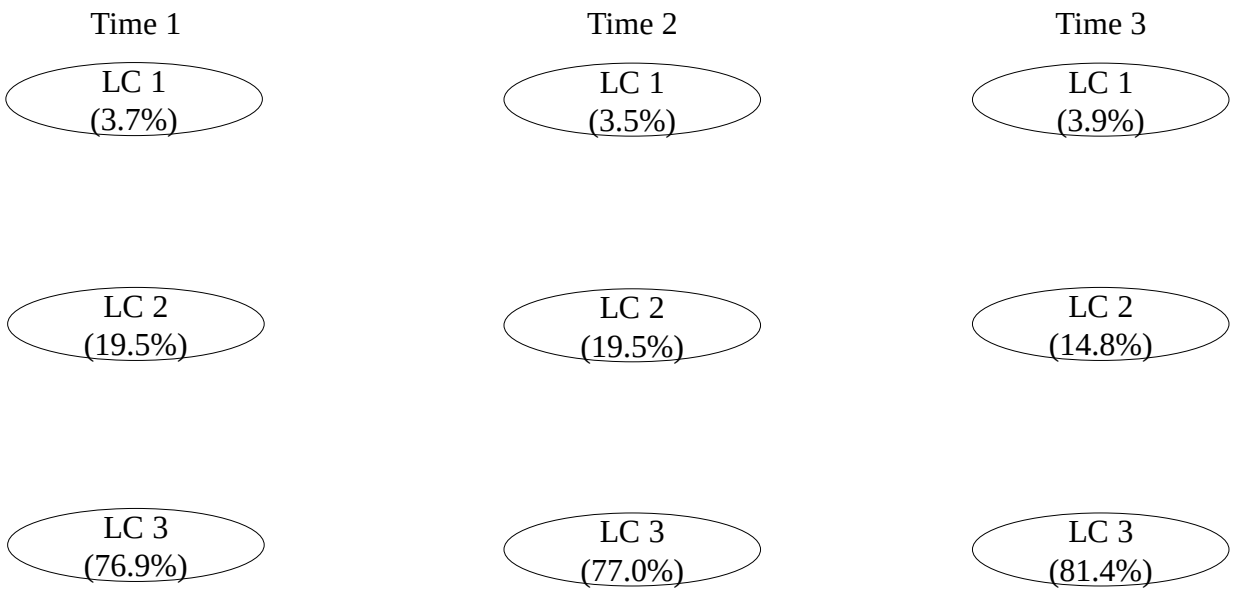


- Latent transition model with three latent statues was selected.

Demonstration of LTA
- Exploration of change in psychological status

- Latent class prevalence over three time points

	Latent class prevalence		
Time	Latent class 1	Latent class 2	Latent class3
Fall, 2005	3.7%	19.5%	76.9%
Spring, 2006	3.5%	19.5%	77.0%
Fall, 2006	3.9%	14.8%	81.4%



Demonstration of LTA
- Exploration of change in psychological status

- Item-response probabilities for yes

Item	Latent class 1	Latent class 2	Latent class3
I do lots of important things	29.6%	66.2%	94.9%
In general, I like being the way I am	30.0%	78.9%	98.9%
Overall, I have a lot to be proud of	16.3%	76.4%	99.0%
I can do things as well as most other people	38.6%	70.7%	99.3%
Other people think I am a good person	43.7%	83.9%	99.7%
A lot of things about me are good	13.1%	85.9%	100%
I am as good as most other people	23.4%	74.7%	99.4%
When I do something, I do it well	33.1%	79.0%	99.4%

  - Latent class 3 – High Self-esteem (HSE)
  - Latent class 2 – Positive Self-esteem (PSE)
  - Latent class 1 – Low Self-esteem (LSE)

Demonstration of LTA
- Exploration of change in psychological status

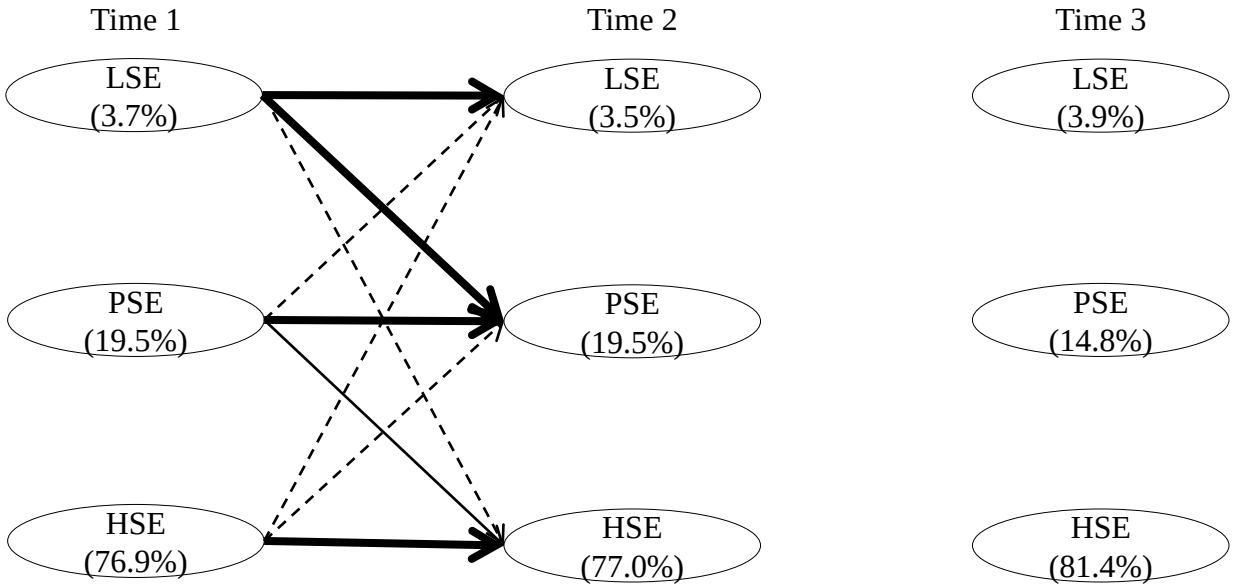
- Latent transition matrix from fall of 2005 to spring of 2006

	Transition probabilities		
Time 1\Time 2	LSE	PSE	HSE
LSE	43.87%	43.86%	12.3%
PSE	6.3%	68.9%	24.8%
HSE	0.8%	5.8%	93.4%

--> < 20%

→ 20% < 40%

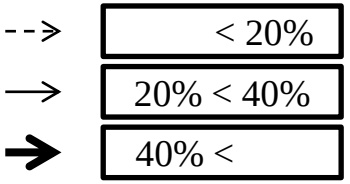
➔ 40% <

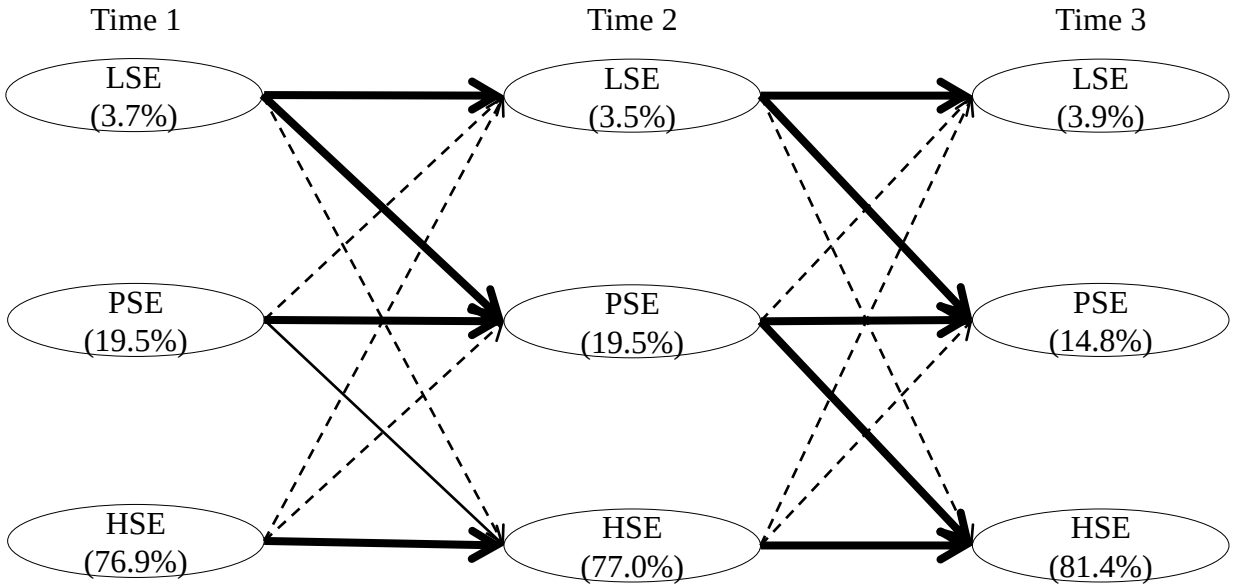


Demonstration of LTA
- Exploration of change in psychological status

- Latent transition matrix from spring of 2006 to fall of 2006

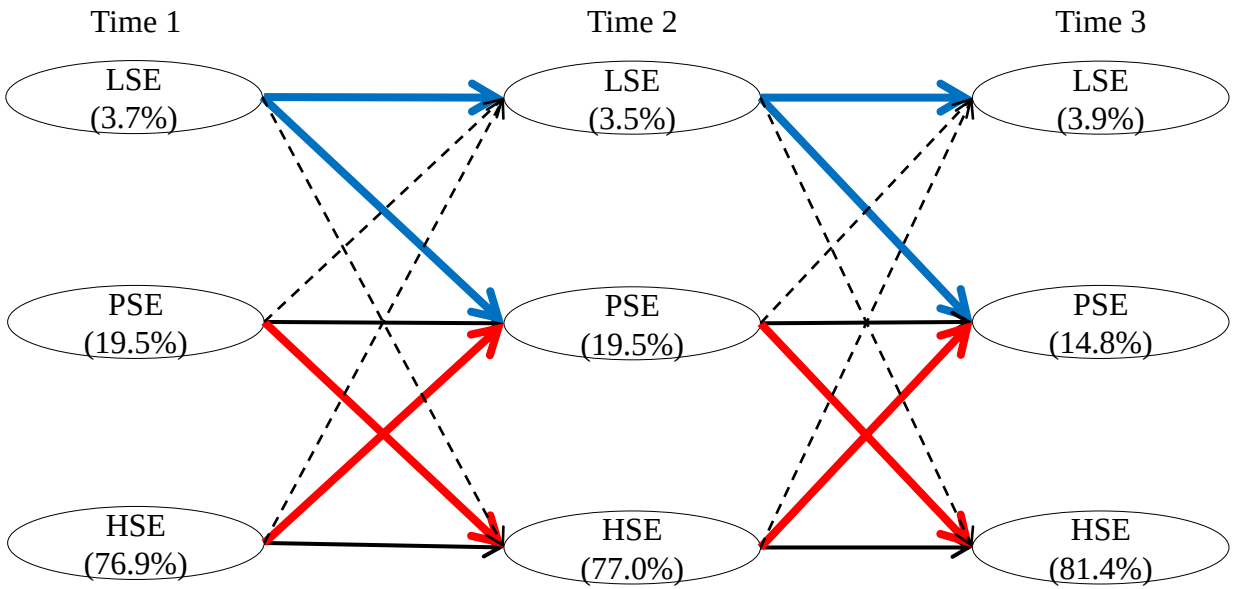
	Transition probabilities		
Time 2\Time 3	LSE	PSE	HSE
LSE	43.6%	44.0%	12.4%
PSE	8.3%	50.4%	41.3%
HSE	0.9%	4.5%	94.6%





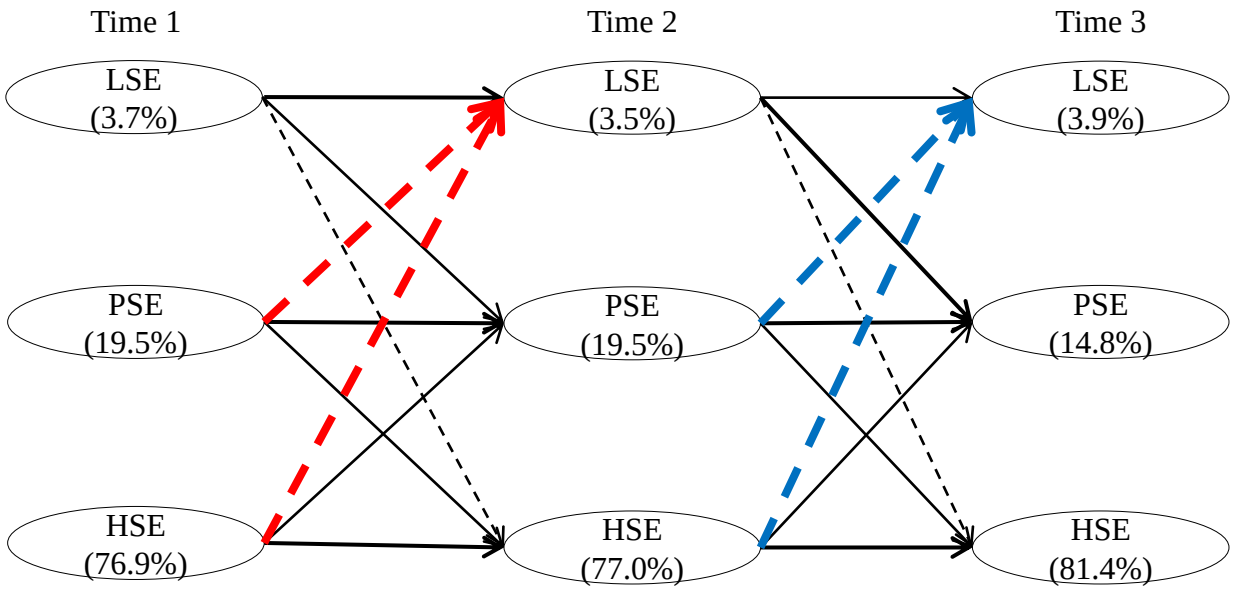
Demonstration of LTA
- Exploration of change in psychological status

- **Discussion 1: Based on the numbers of students changing latent class membership over time**
- Many students fluctuate between PSE and HSE.
  - For example, 52 and 57 student move from HSE to PSE and from PSE to HSE, respectively, at 1st transition. 38 and 90 students move from HSE to PSE and from PSE to HSE, respectively, at 2nd transition.
- LSE group has high mobility rate to PSE and HSE



Demonstration of LTA
- Exploration of change in psychological status

- **Discussion 2: In some situations, transitions to LSE from higher SE level might be interested**
  - 14 and 8 students from PSE and HSE, respectively at 1st transition
  - 18 and 8 students from PSE and HSE, respectively at 2nd transition
- It might be helpful to understand these movements if we further investigate students' characteristics



Demonstration of LTA

- Example 2: Exploration of change in reading proficiency designation (DIBELS) using *Markov Model*

This photo was captured from Google image at 3/28/2012

Demonstration of LTA
- Exploration of change in reading proficiency designation

- Measures of DIBELS Oral Reading Fluency
- Four time points
- 2 categories at each occasion:
  - High Risk (Category 1), Low Risk (Category 2)
- Research Question:
  - How do students progress in oral reading fluency over time?
  - Or how do they change at Risk status?

Demonstration of LTA
- Exploration of change in reading proficiency designation

- Inspection of the data
  - Change from time 1 to time 2

		Time 2	
		High	Low
Time 1	High	155	35
	Low	11	148

  - We could check from time 2 to time 3, and from time 3 to time 4, too.

Demonstration of LTA
- Exploration of change in reading proficiency designation

- All the patterns

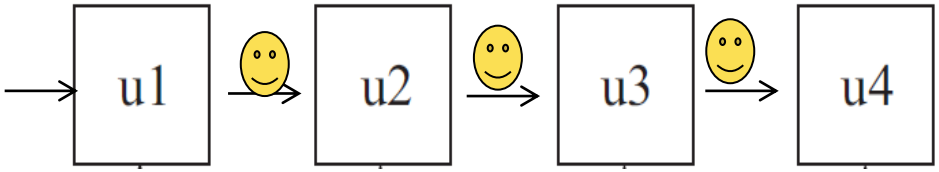
time 1	time 2	time 3	time 4	Frequency
High	High	High	High	141
High	High	High	Low	5
High	High	Low	High	6
High	High	Low	Low	3
High	Low	High	High	7
High	Low	High	Low	5
High	Low	Low	High	14
High	Low	Low	Low	9
Low	High	High	High	6
Low	High	Low	High	1
Low	High	Low	Low	4
Low	Low	High	High	6
Low	Low	High	Low	5
Low	Low	Low	High	13
Low	Low	Low	Low	124

Demonstration of LTA
- Exploration of change in reading proficiency designation

- Two models are fitted for illustration purpose
  - Model 1: Manifest Markov Model
  - Model 2: Latent Markov Model
  - We could fit more models…

Demonstration of LTA
- Exploration of change in reading proficiency designation

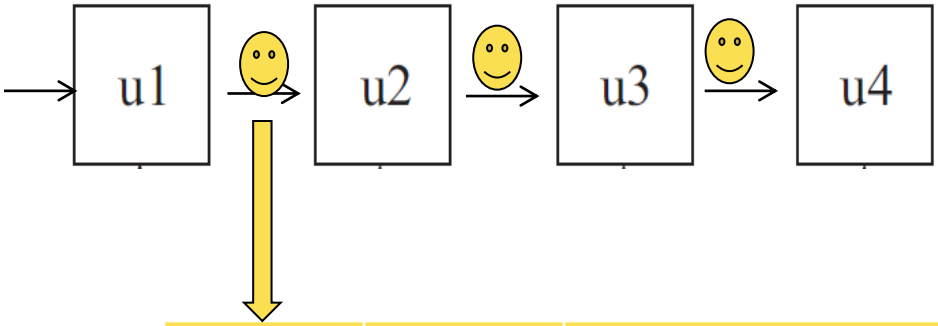
- Model 1: Manifest Markov Model
  - There is no measurement error, or the measure is perfect
  - Stationary, this is not necessary



Demonstration of LTA
- Exploration of change in reading proficiency designation

- Results

- Model 1: Manifest Markov Model-Transition matrix



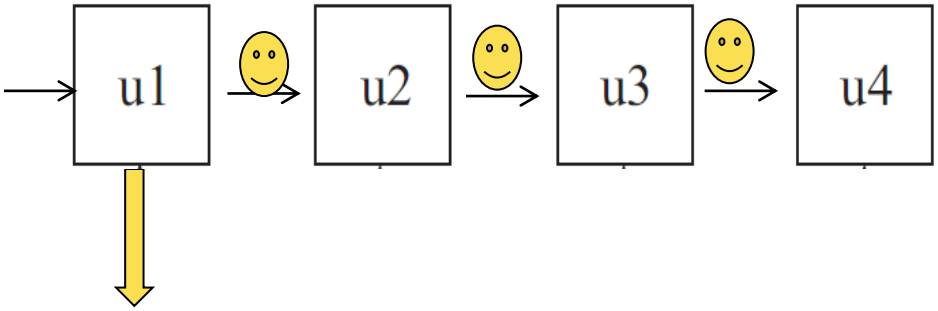
		C2	
		High	Low
C1	High	86.8%	13.2%
	Low	12.1%	87.9%

Transition Matrix

Demonstration of LTA
- Exploration of change in reading proficiency designation

- Results

- Model 1: Manifest Markov Model--prevalence

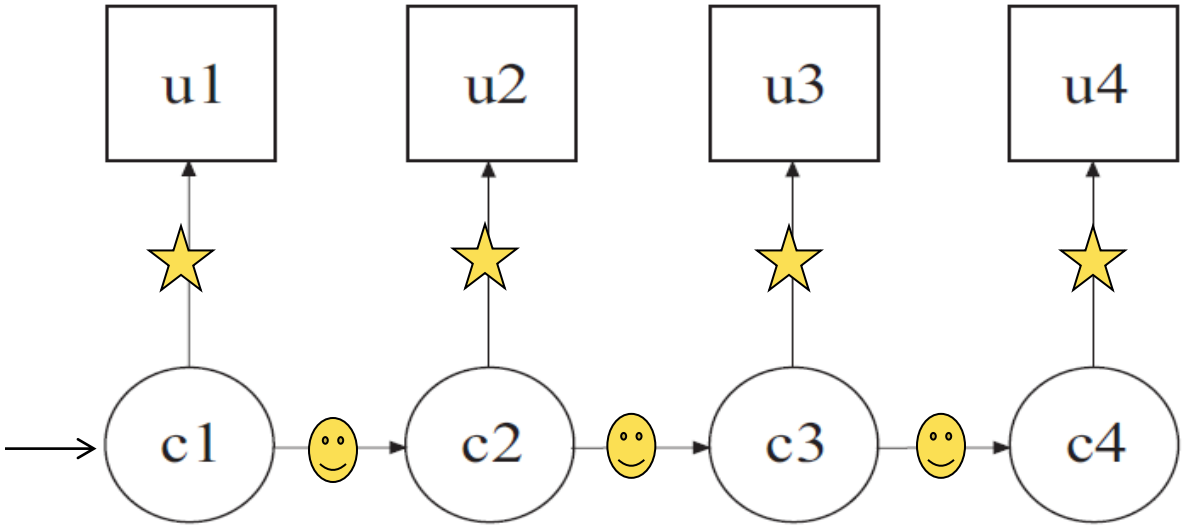


u1	
High	45.6%
Low	54.4%

prevalence

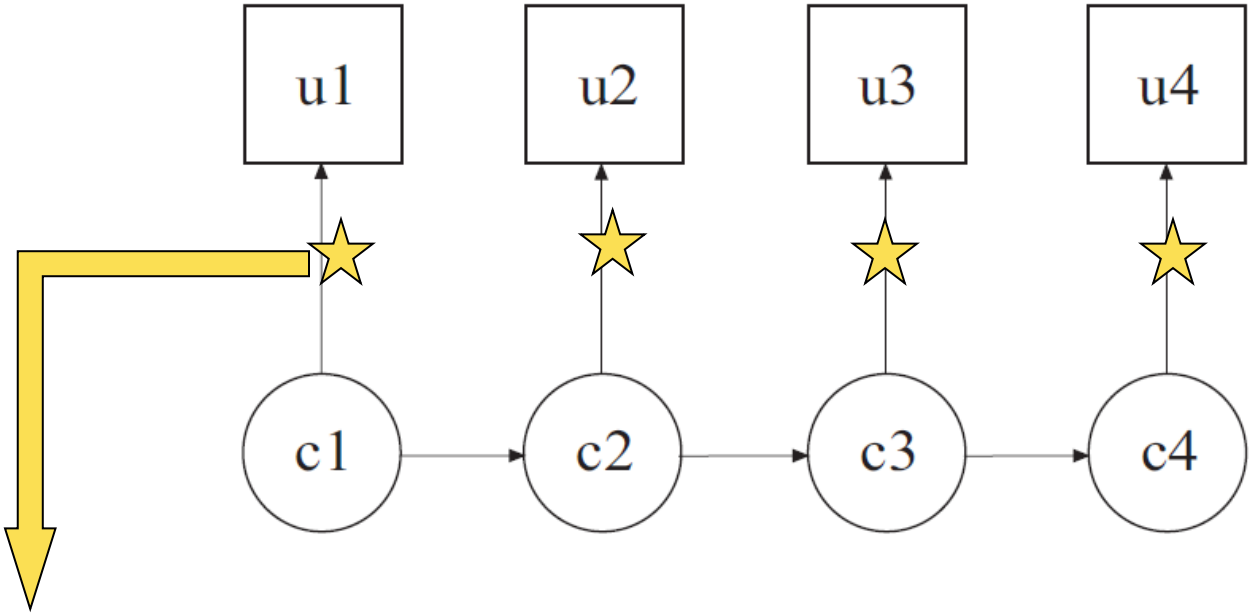
Demonstration of LTA
- Exploration of change in reading proficiency designation

- Model 2: Latent Markov model
  - Measure is not perfect
  - The transition matrixes are fixed to be equal across time points;
  - The item-response probabilities are fixed to be equal at different time points, too.
  - It is not necessary to do so though.



Demonstration of LTA
- Exploration of change in reading proficiency designation

- Results
  - Model 2: Latent Markov Model

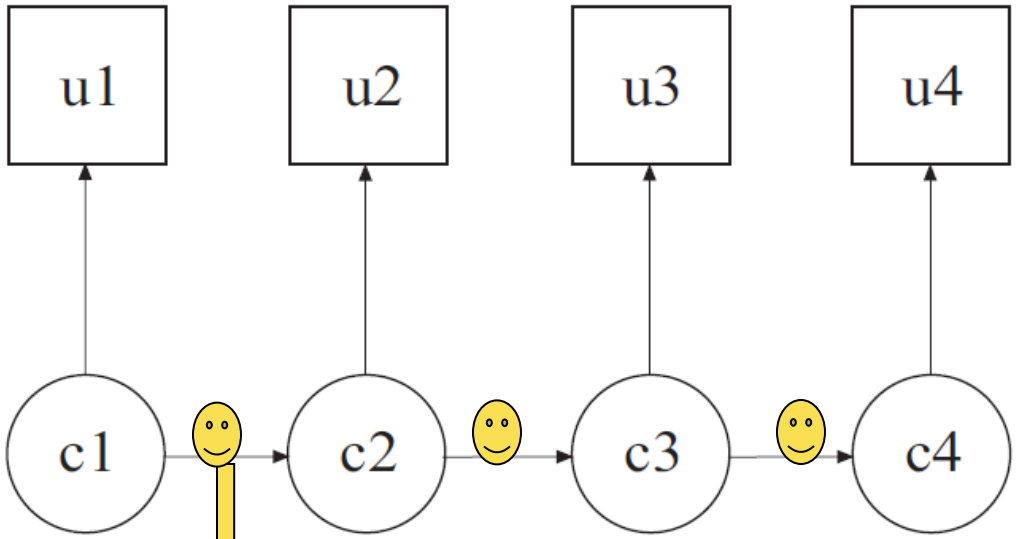


		U1	
		High	Low
C1	1	96.4%	3.6%
	2	8.7%	91.3%

Item-Response probabilities

Demonstration of LTA
- Exploration of change in reading proficiency designation

- Results
  - Model 2: Latent Markov Model

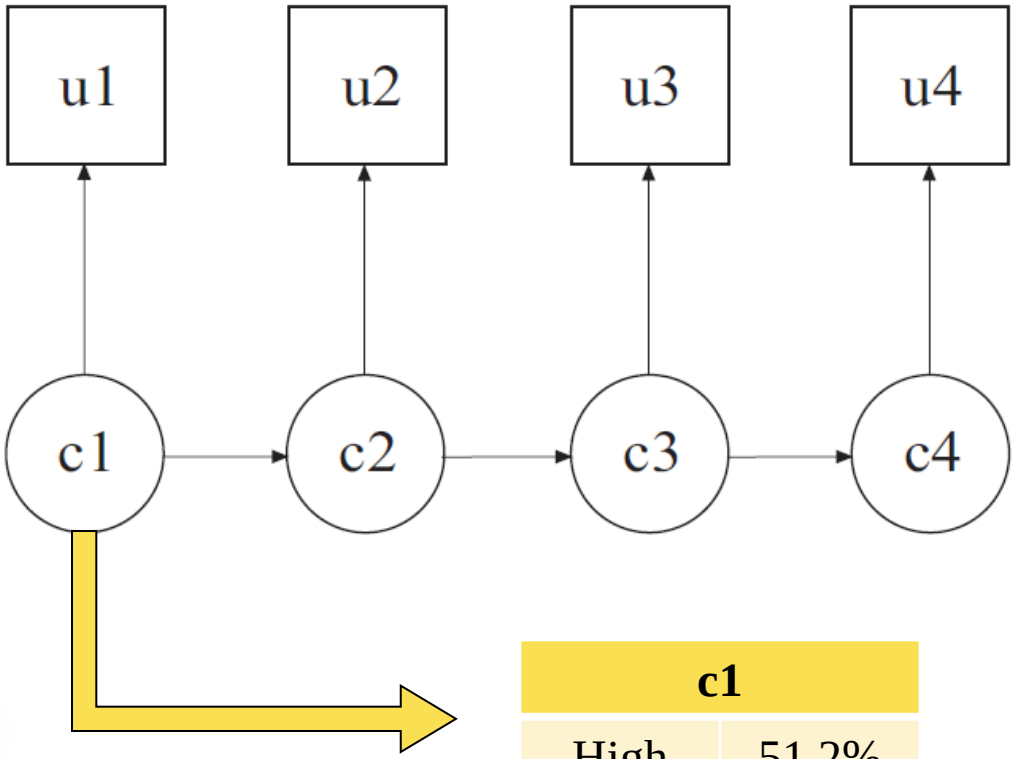


		C2	
		High	Low
C1	High	97%	3%
	Low	2%	98%

Transition Matrix

Demonstration of LTA
- Exploration of change in reading proficiency designation

- Results
  - Model 2: Latent Markov Model



Latent prevalence

c1	
High	51.2%
Low	48.8%

Discussion
- Summary

- Wrap-up
  - LTA provides latent class membership as well as its transition over time
  - Parameters in LTA were estimated by MLE based on the response patterns
  - Its results can be interpreted in various ways

- LTA can be extended with
  - Multiple group analysis
  - Analysis with covariates

Discussion
- Issues

- Issues in LTA
  - Weak in or lack of model comparison tools
  - Sample size (the larger, the better)
    - **N=349 for LTA ← Oral reading proficiency data**
    - N=469 for LCA
    - **N=1,180 for LTA ← Self-esteem data**
    - N=1,265 for LTA
    - N=2,061 for LTA
    - N=2,065 for LCA
    - N=2,087 for LCA
    - N=2,937 for LTA
    - N=13,840 for LCA

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Thank you!

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Syntaxes are available at
http://quantitativemethods.wordpress.com

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