Quantitative Data Analysis: A Companion for Accounting and Information Systems Research

Teaching Materials

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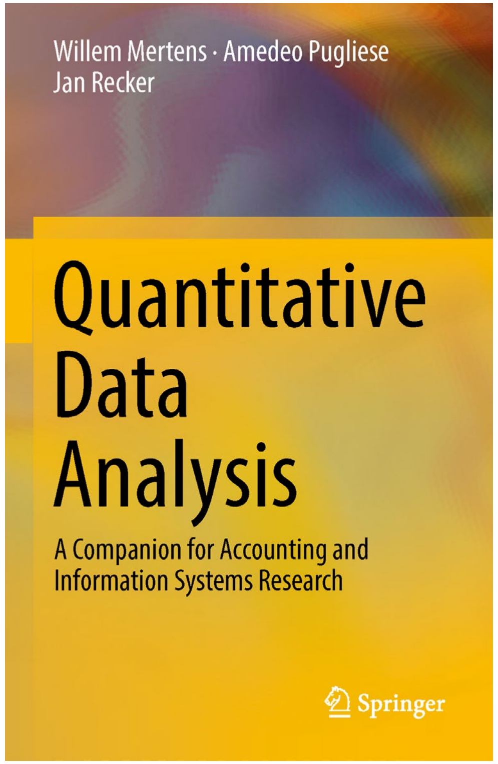
What these materials are about

Offering a guide through the essential steps required in quantitative data analysis

1. Introduction
2. Comparing Differences Across Groups
3. Assessing (Innocuous) Relationships
4. Models with Latent Concepts and Multiple Relationships: Structural Equation Modeling
5. **Nested Data and Multilevel Models: Hierarchical Linear Modeling**
6. Analyzing Longitudinal and Panel Data
7. Causality: Endogeneity Biases and Possible Remedies
8. How to Start Analyzing, Test Assumptions and Deal with that Pesky p-Value
9. Keeping Track and Staying Sane



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Part 5:
Hierarchical Linear Modeling

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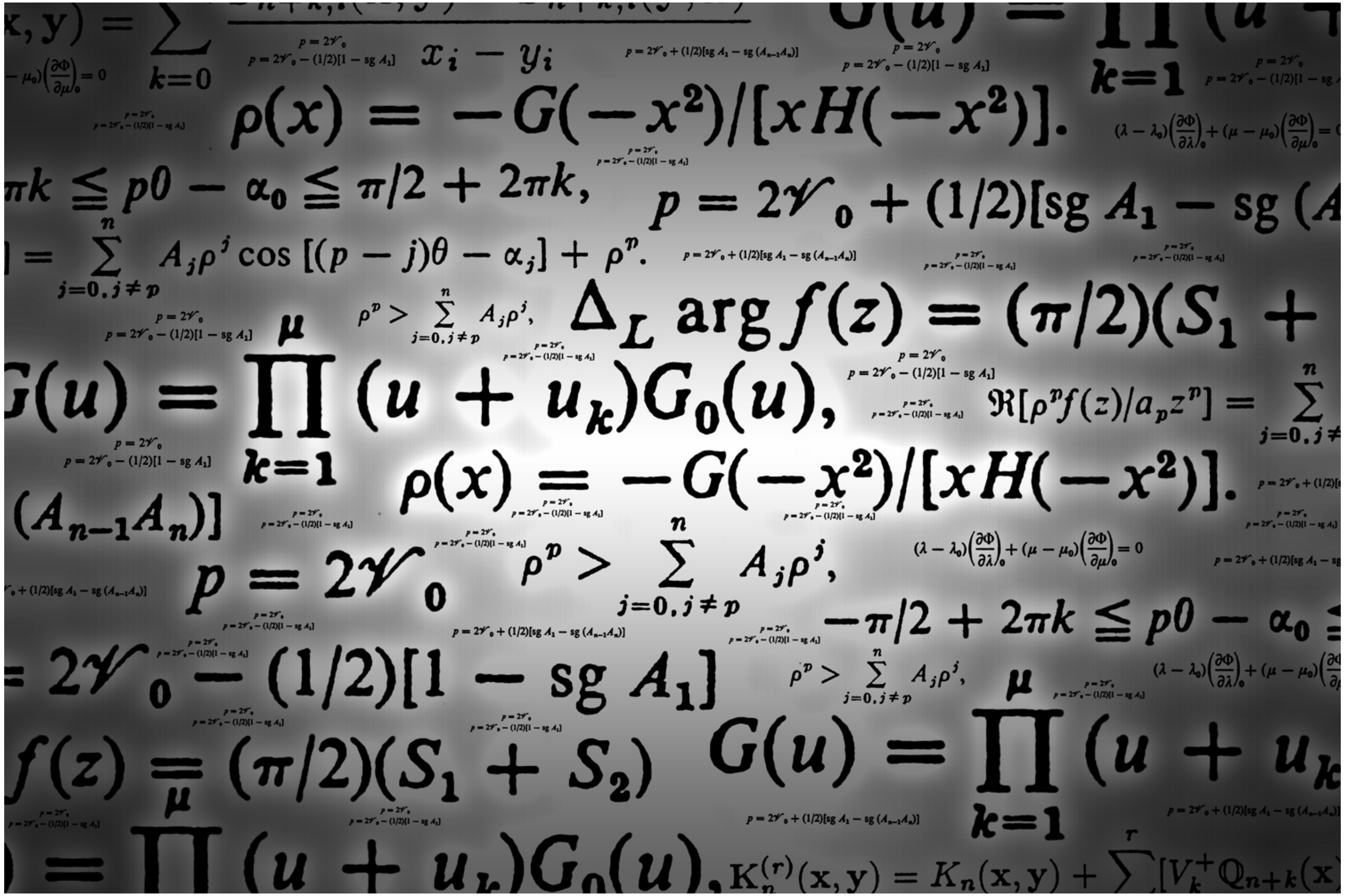
Agenda

1. Theoretical background
   - Multilevel research
   - Assumptions, agreement and reliability
   - Building the measurement model
   - (Multilevel) regressions and Random Coefficient Modeling

2. Demonstration using HLM7
   - Importing data
   - Specifying the model
   - Interpreting results

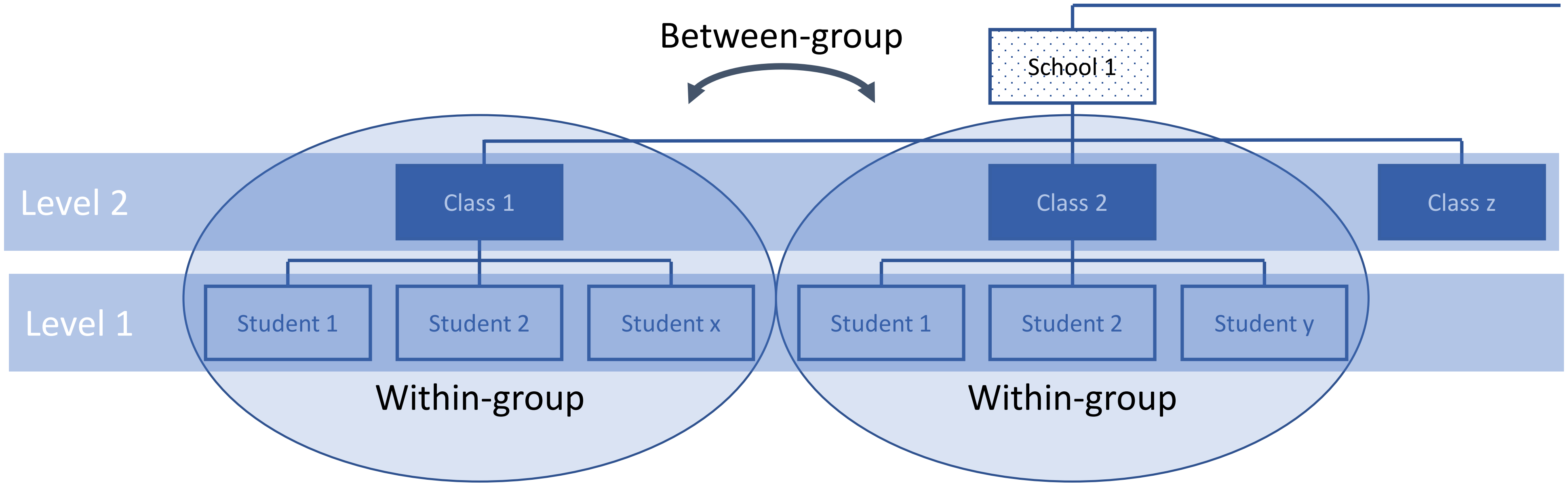
THEORETICAL BACKGROUND



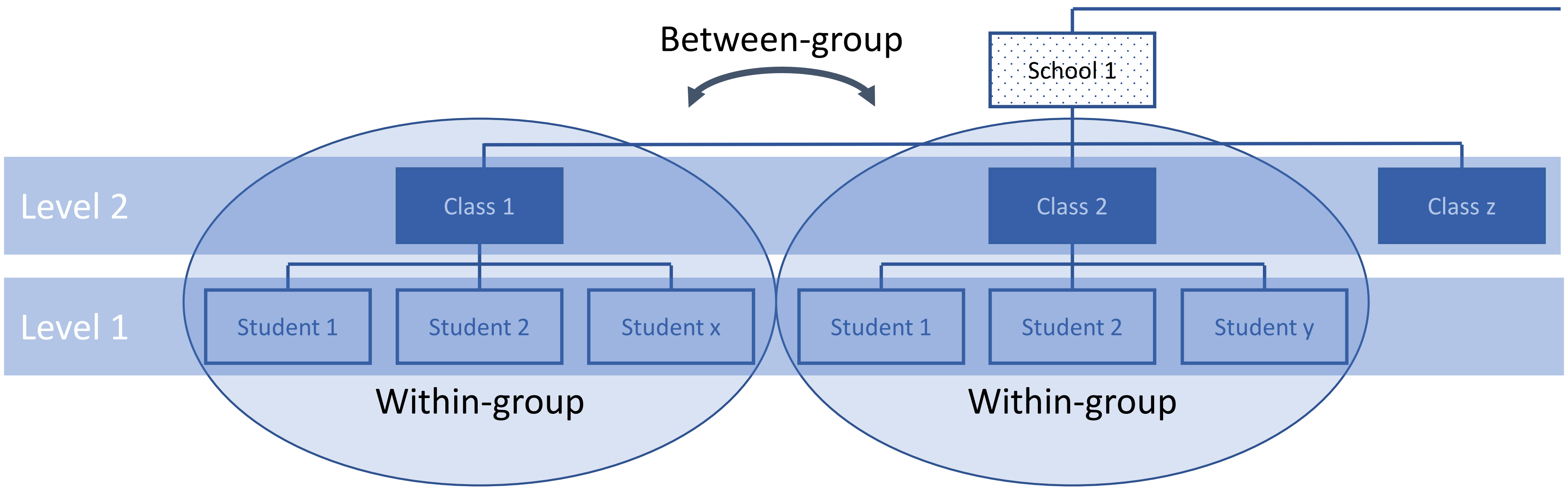
Multilevel research: what is it?

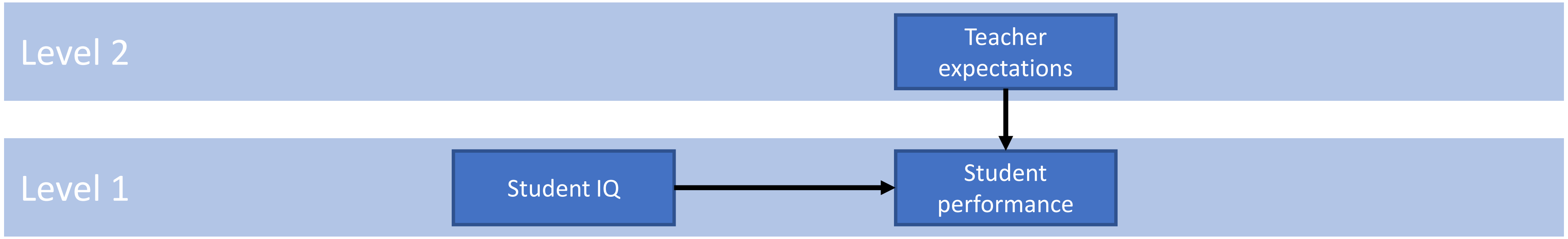
- Effect of group membership on individual outcomes
  --> Top-down

- E.g. effect of IQ (level 1), teacher expectations (level 2) on student performance



Multilevel research: what is it?





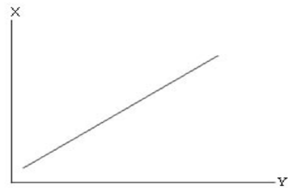
Multilevel research: traditional approaches

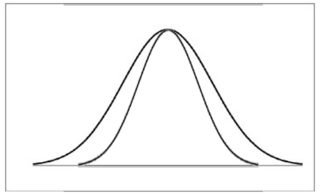
- Aggregate individual-level variables
  - X Individual variance is lost (IQ)
  - X Effects get inflated because of the loss of variance
- Assign group-level variables to individuals
  - X Violation of ‘independence of observations’ (correlated error terms)

==> Hierarchical Linear Modeling

Assumptions, agreement and reliability (1)

- Assumptions that apply for regression
  - (Reliable and valid measurement model)
  - Linearity
  - Normality
  - Independence
  - Homoscedasticity (homogeneity of variance)





- However:
  - Independence and homoscedasticity only within-group
  - Additional assumptions when using peer-ratings (e.g. students rate teacher)

a. Inter-rater consistency
b. Reliability of group means
c. Inter-rater agreement

Assumptions, agreement and reliability (2)

a. Inter-rater consistency: Intraclass Correlation (1) (ICC(1))

- ICC(1) = $\tau_{00} / (\tau_{00} + \sigma^2)$
  - τ_{00} = between-group variance
  - σ^2 = within-group variance
    - ➢ Part of variance that is explained by between-group variance (i.e. by group membership)

- From ANOVA: ICC(1) = $\frac{\mathrm{MSB} - \mathrm{MSW}}{\mathrm{MSB} + [(\mathrm{k}-1) * \mathrm{MSW}]}$
  - MSB = between-group mean square
  - MSW = within-group mean square
  - k = within-group size

(Bliese, 2000)

Assumptions, agreement and reliability (3)

b. Reliability of group means: Intraclass Correlation (2) (ICC(2))

- From ANOVA: ICC(2) = $\frac{\mathrm{MSB} - \mathrm{MSW}}{\mathrm{MSB}}$
  - MSB = between-group mean square
  - MSW = within-group mean square
    - ➢ Part of between group variance that is not explained by within-group variance

(Bliese, 2000)

Assumptions, agreement and reliability (4)

c. Within-group inter-rater agreement: r^*_{wg}

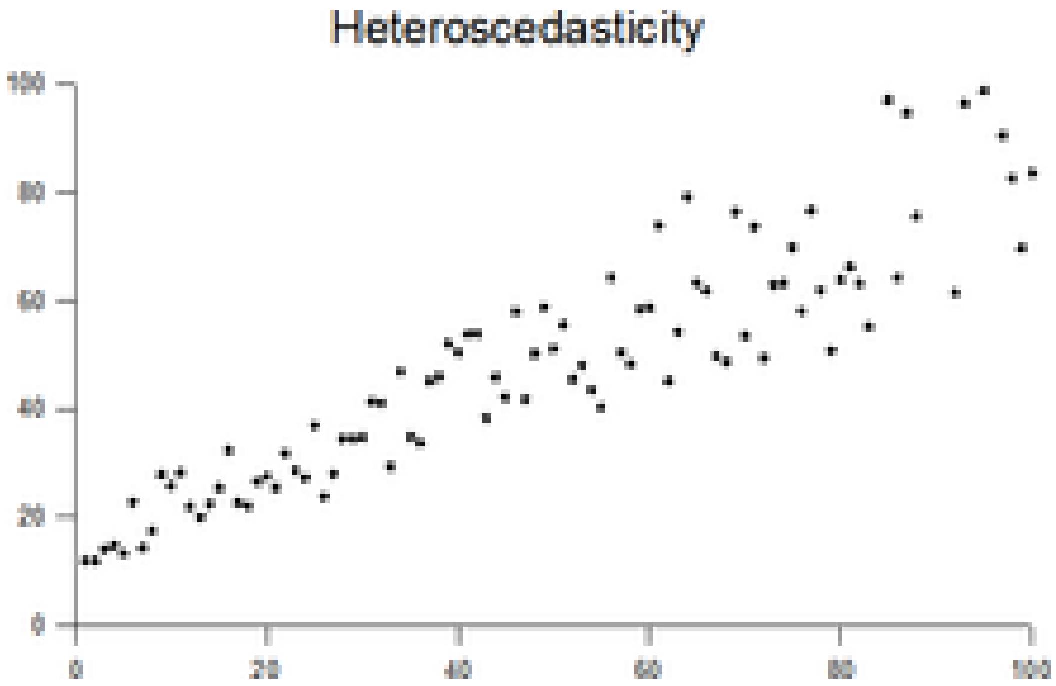
- $r^*_{wg} = 1 - \frac{\bar{\sigma}_x^2}{\sigma_{EU}^2}$
  - $\bar{\sigma}_x^2$ = average within-group variance
  - σ_{EU}^2 = variance under uniform distribution = $(A^2 - 1)/12$ with A = number of response categories

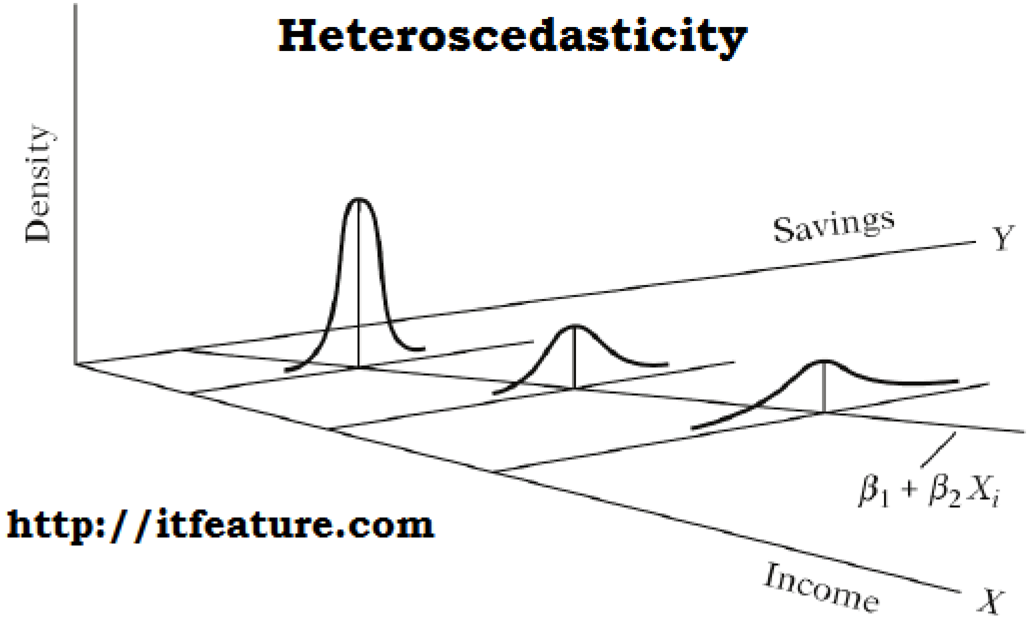
➢ Ratio of average within-group variance per estimated variance without groups

(Lindell, Brandt, & Whitney, 1999)

Recap: Homoscedasticity / Homogeneity of Variance

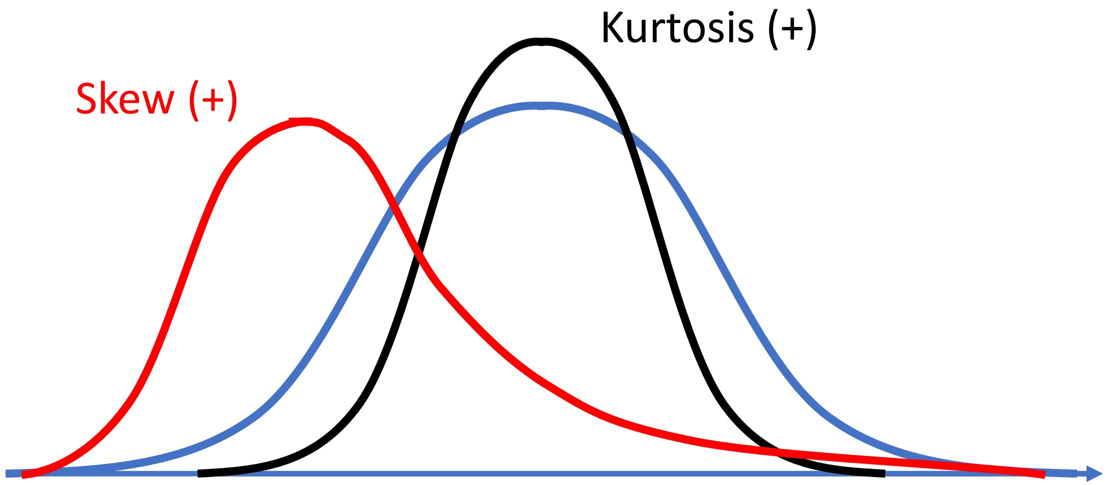
- Two variables (e.g. regression): spread of errors/residuals is equal across different values of *x*

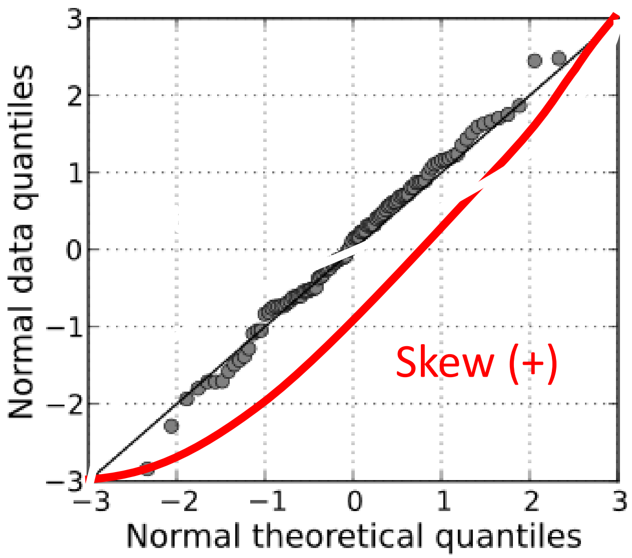




Recap: Normality

- In many statistical tests
  - Sampling distribution is normally distributed
    --> test normality of sample
    - Visually testing normality of (sub-)sample data
      - Histograms (see slide 10)
      - Q-Q plots: theoretical vs. actual quantiles





"Normal normal qq" by Skbkekas - Wikipedia

Recap: Normality

- Statistical tests for normality of (sub-)sample data
  - Compute descriptives including skew and kurtosis
  - Convert skew and kurtosis to *z*-scores, e.g.:

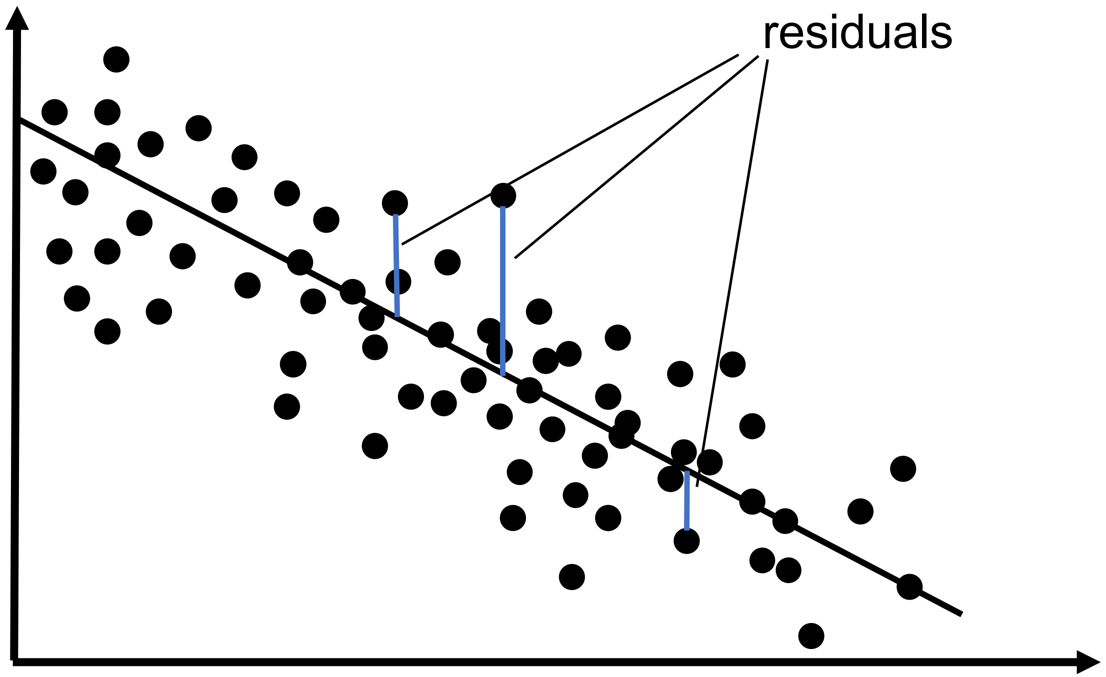
$$z_{skewness} = \frac{skewness - 0}{SE_{skewness}} \Rightarrow \frac{|\,skewness\,|}{SE_{skewness}} \quad \text{must be} \leq 1.96$$

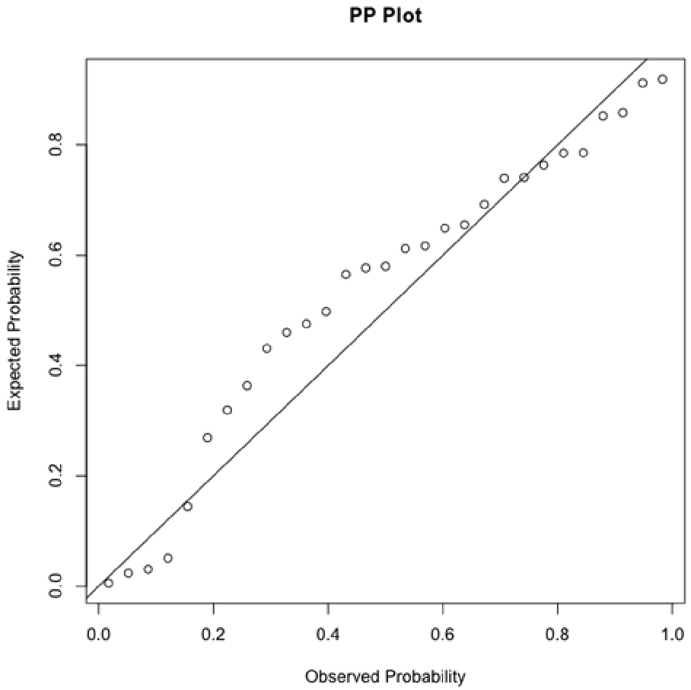
Increase to 2.58 in larger samples and do not use in very large samples ($n > 200$)

  - Shapiro-Wilk test: significant ($p < .05$) when NOT normal

Recap: Normality

- In regression-based models
  - Errors/residuals, not indicators need to be normally distributed
  - Same visual principles as Q-Q plot apply





Please note: in this case, both graphs do not represent the same data

What if assumptions are violated?

- Correct data
  - Exclude outliers
  - Transform data, e.g.:
    - Log-, square root and reciprocal (1/x) transformations shorten the right tale (i.e. correct positive skew)
    - The same transformations applied to the reverse score (score – highest score + 1) correct for negative skew

The same transformation has to be applied to variables that are compared directly

- Turn to tests that are robust against violations or to non-parametric tests, e.g.
  - Mann–Whitney U for group comparisons
  - Kendall's tau for dependence between two variables

Building the measurement model

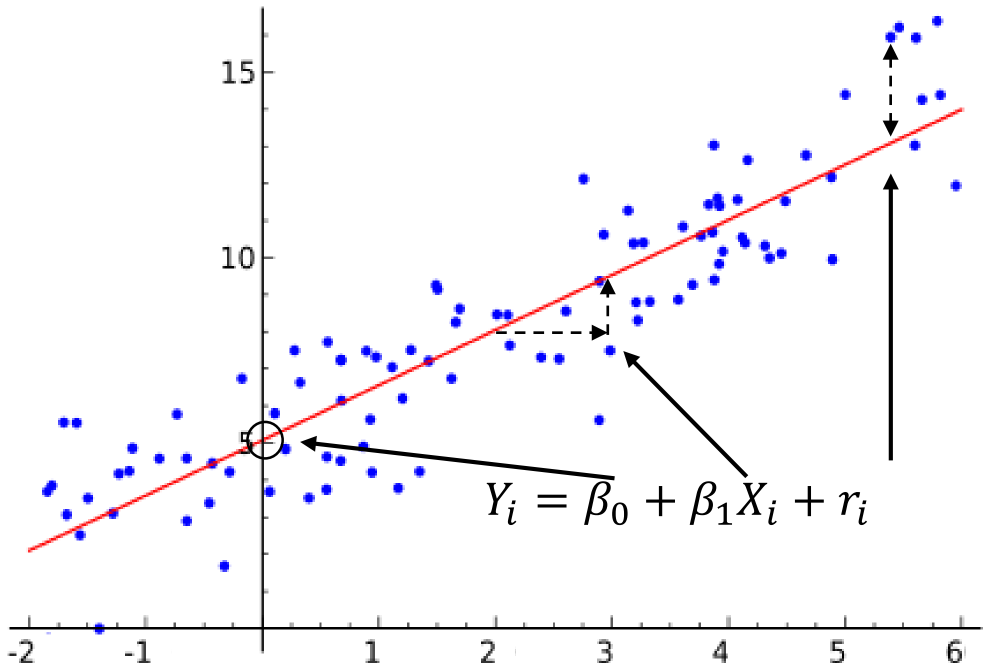
- For individual-level variables (IQ)
  - Classical approach to creating and evaluating scales (e.g., CFA, Cronbach's Alpha)
- For group-level variables (teacher expectations)
  - Test for consistency, reliability of group means, agreement based on individual-level items
  - Aggregate items to the group level (average)
  - Create and evaluate scale based on aggregated items

For alternatives see: Peterson, M. F., & Castro, S. L. (2006). Measurement metrics at aggregate levels of analysis: Implications for organization culture research and the GLOBE project. *The Leadership Quarterly, 17*, 506-521.

(Peterson and Castro, 2006)

(Multilevel) regressions

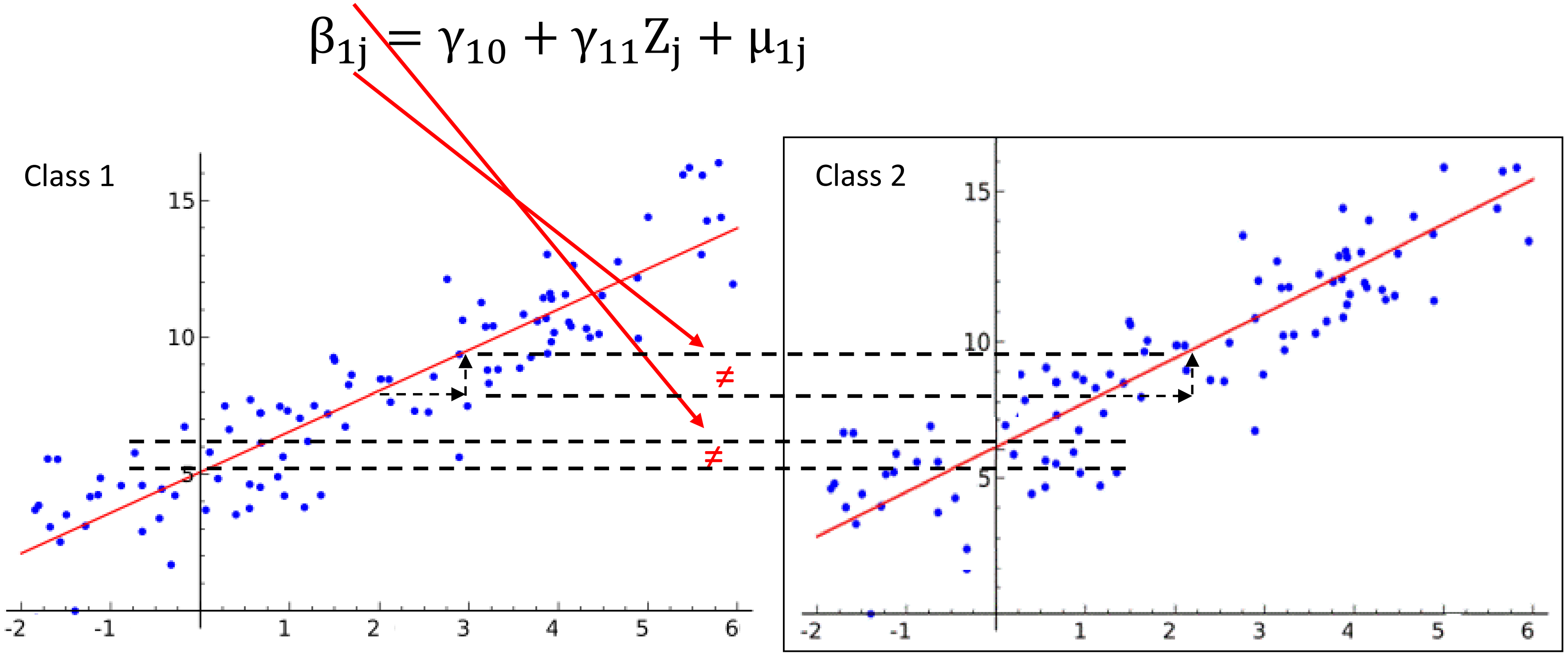
- Classical linear regression



(Multilevel) regressions

- Hierarchical Linear Model
  - Level 1: $Y_i = \beta_{0j} + \beta_{1j}X_{ij} + r_i$
  - Level 2: $\beta_{0j} = \gamma_{00} + \gamma_{01}Z_j + \mu_{0j}$

    $\beta_{1j} = \gamma_{10} + \gamma_{11}Z_j + \mu_{1j}$



(Multilevel) regression / HLM / Random Coefficient Modeling

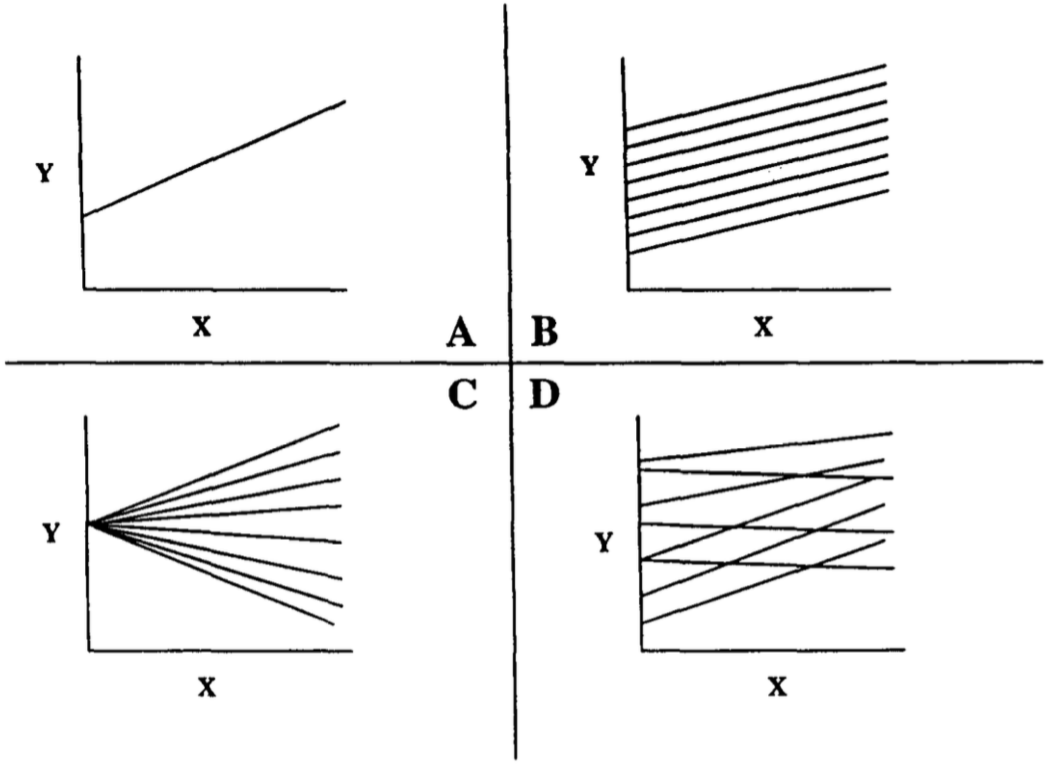
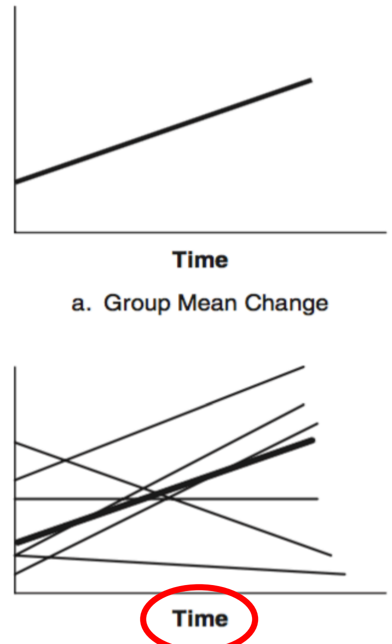


Figure 1. Four possible patterns for intercepts and slopes when level-1 models are estimated separately for each group.

Cross-sectional

Differences Between Group Mean Change and Intraunit Change



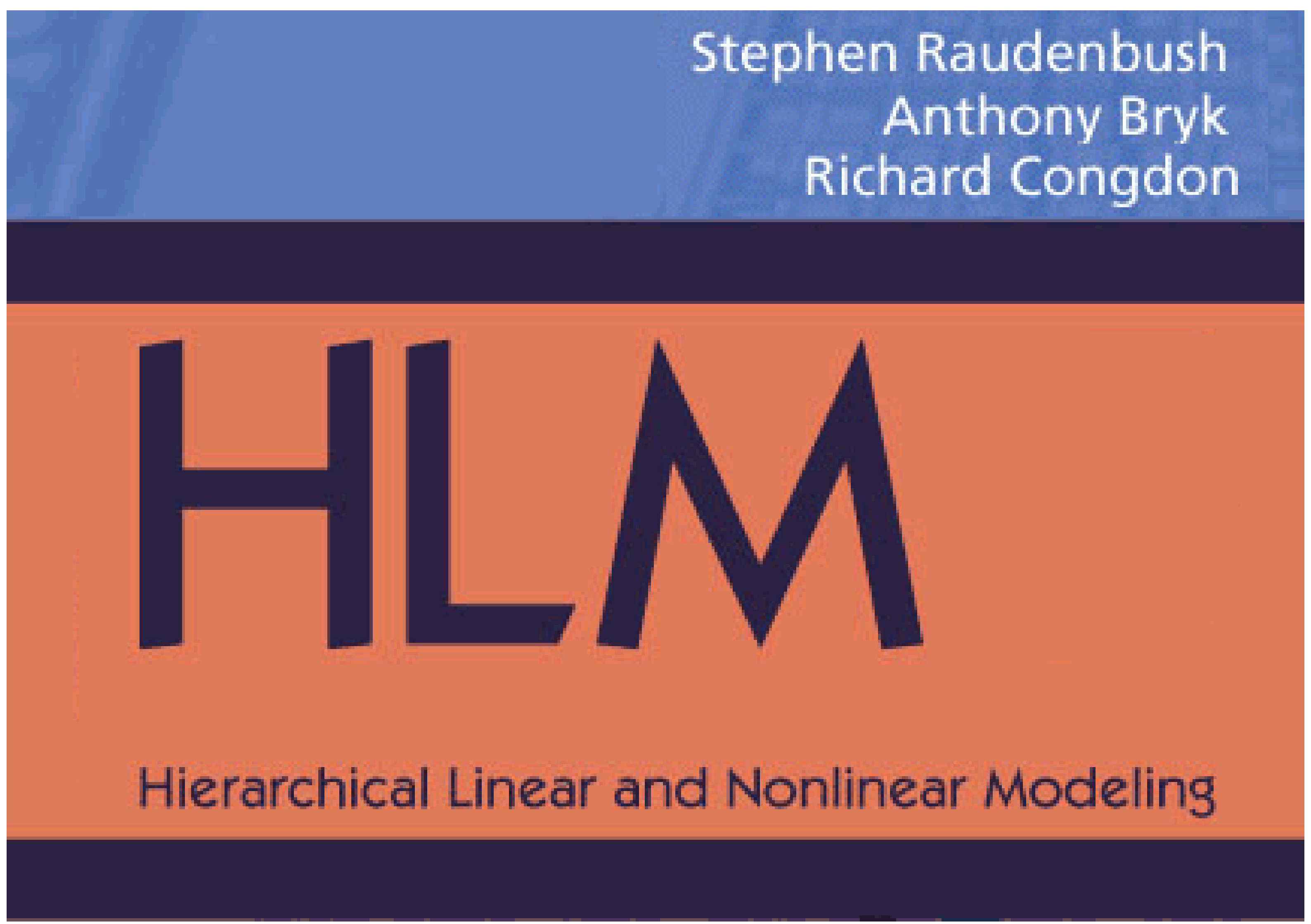
b. Interunit Differences in Intraunit Change (the bold line represents the overall mean change, smaller lines represent change for each observation)

Longitudinal

Different types of models

- Hierarchical linear models
  - 2 Levels
  - More levels
  - E.g. student performance per class (per school)
- Hierarchical multivariate linear models
  - 2 or more levels
  - Multiple outcome variables
  - E.g. student performance per class over time
- Cross-classified multilevel models (see Leckie 2013)
  - 2 or more levels
  - Units can belong to multiple groups
  - E.g. student performance per class and neighbourhood

APPLICATION



Import data (the easy way)

- Make level 1 and level 2 file
  - Level 1: each student is one row (case)
  - Level 2: each class/teacher is one row (case)

Recap: Structuring data

- One row per case, one variable per column

Student	Age	Class	IQ	Performance	…
1	19	1	95	5.9	…
2	53	1	93	6.3	…
3	27	2	105	6.5	…
4	2	107	…	4.7	
…	…	…	…	…	…

- Depends on unit of analysis (e.g. person)

Structuring data

- Multilevel data: split into level 1 and level 2

Level 1

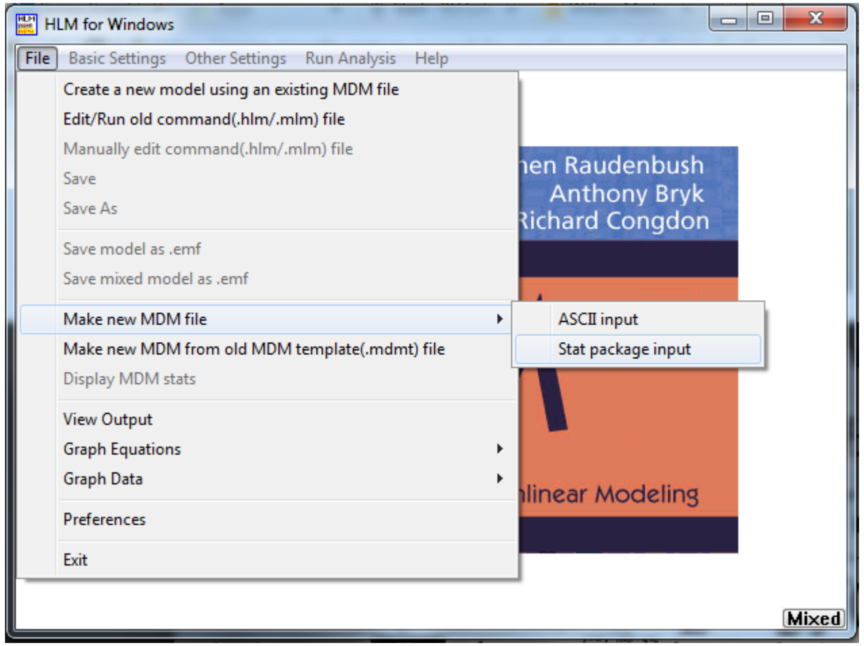
Student	Class	IQ	Performance	…
1	1	95	5.9	…
2	1	93	6.3	…
3	2	105	6.5	…
4	2	107	4.7	…
5	2	118	5.4	…
6	2	79	5.5	…
…	…	…	…	…

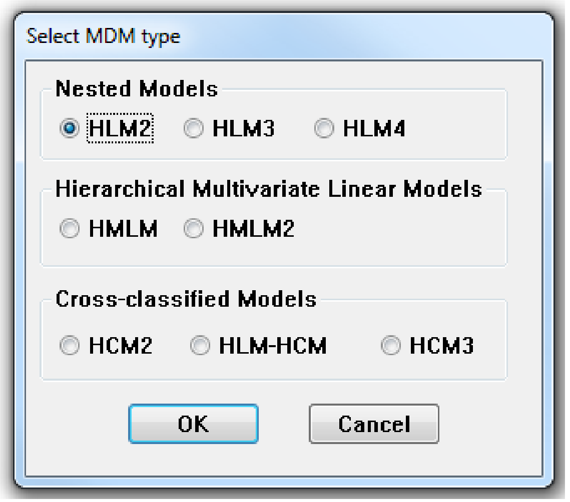
Level 2

Class	Expectation	…
1	7	…
2	5	…
3	4	…
…	…	…

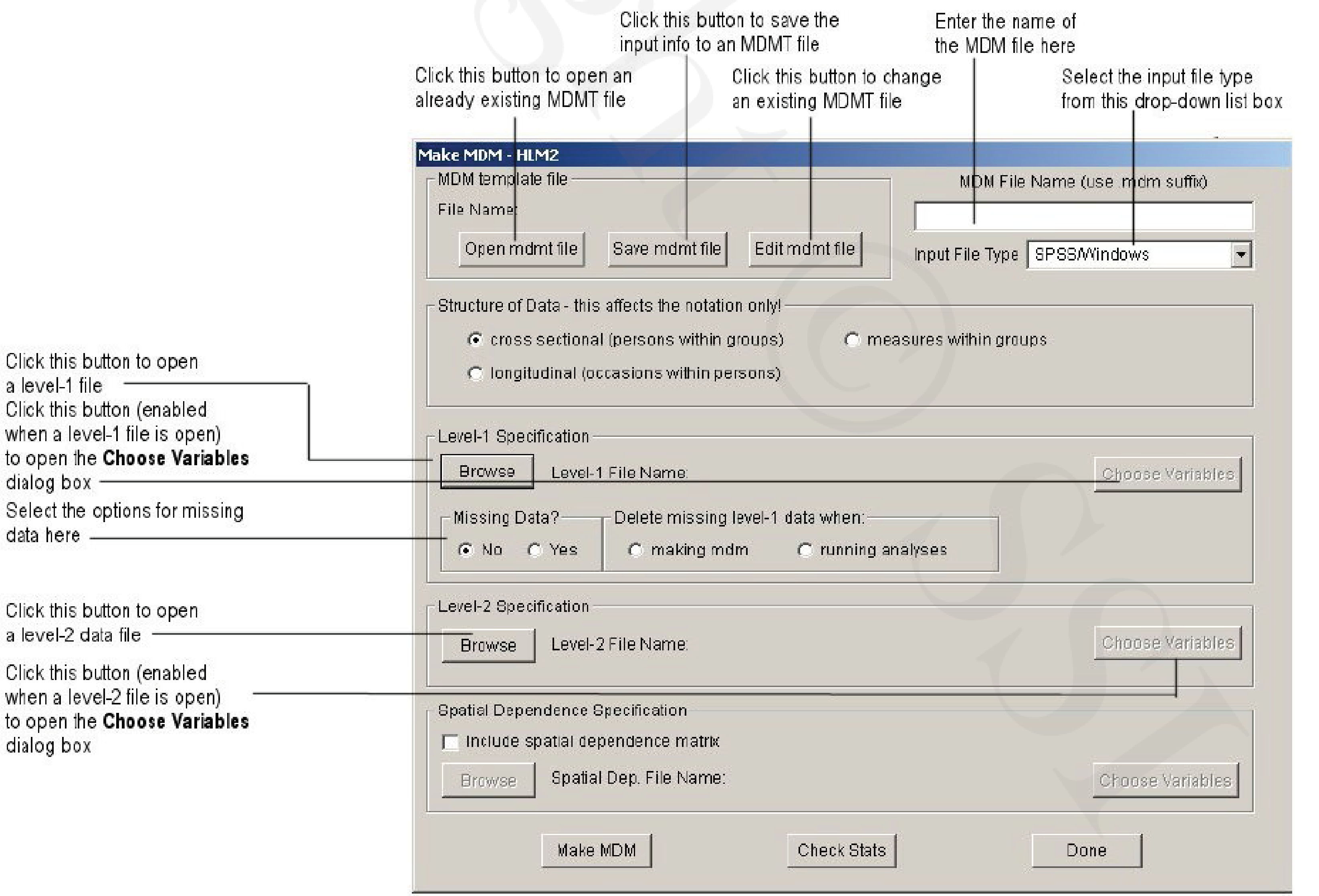
Import data (the easy way)

- Make level 1 and level 2 file
  - Level 1: each student is one row (case)
  - Level 2: each class/teacher is one row (case)
- Build Multivariate Data Matrix (MDM)

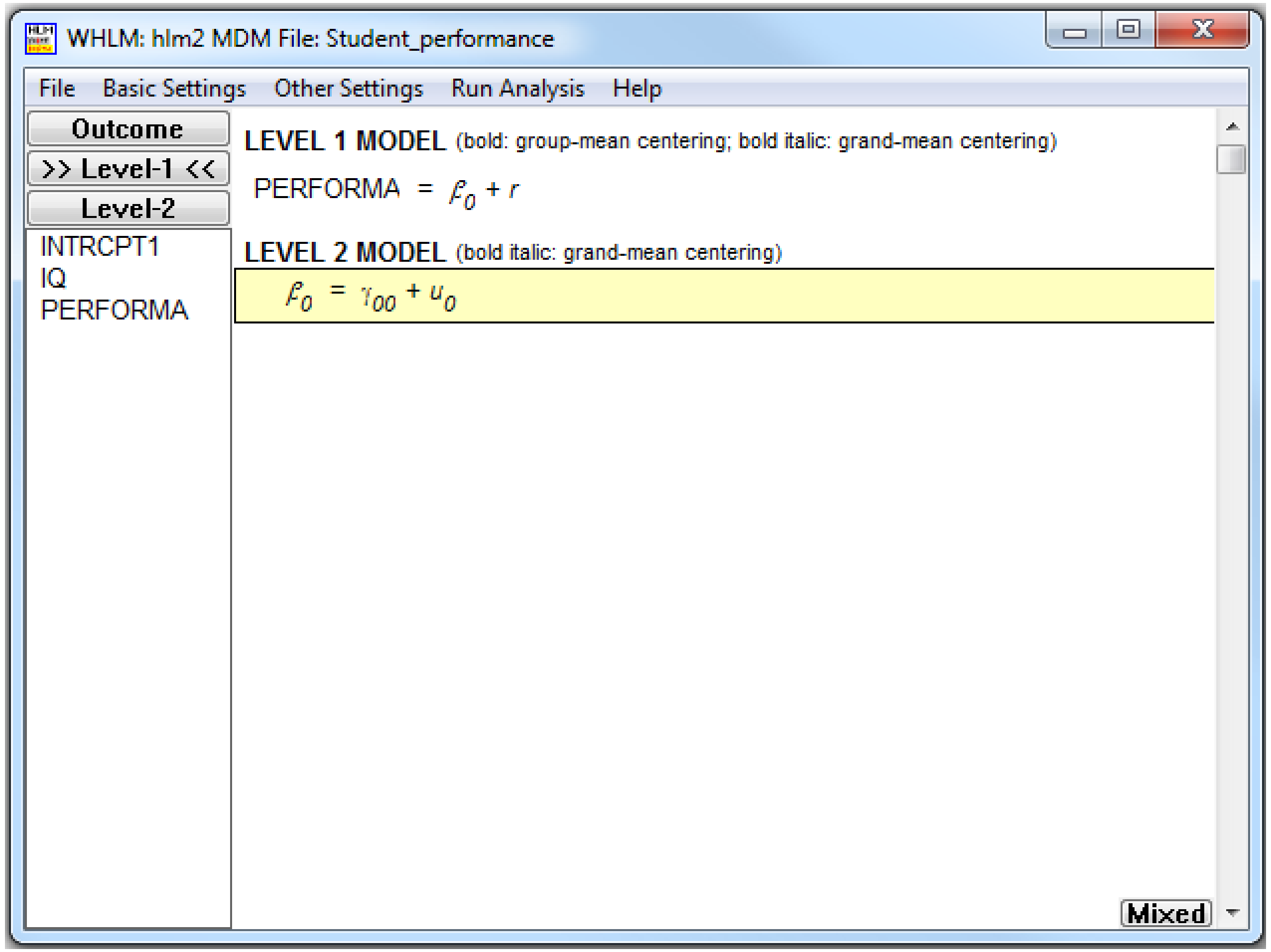




Import data (the easy way)



Specifying the model



Specifying the model

- Mean centring
  - RAW: original score
  - Group: individual score minus group mean
    - Does not control for between-group variance in level 1 variables when testing level 2 variables
  - Grand: individual score minus total sample mean
    - Yields intercepts and slope parameters that are easier to interpret
      - Overall average becomes reference point
      - E.g. if I have average intelligence, my group membership will have γ_{00} influence on my performance

Interpreting the results

- Based on basic model = one-way ANOVA
  - "reliability estimate" = ICC(1)
  - "final estimation of variance component" tests significance of between-group variance

$\sigma^2 = 1.33760$

τ
INTRCPT1, β_0 0.11949

Random level-1 coefficient	Reliability estimate
INTRCPT1, β_0	0.260

Final estimation of variance components

Random Effect	Standard Deviation	Variance Component	*d.f.*	χ^2	*p*-value
INTRCPT1, u_0	0.34567	0.11949	143	195.88435	0.002
level-1, r	1.15655	1.33760			

- Robust *SE* means robust against violations of assumptions --> if non-robust *SE* and robust *SE* differ you should check assumptions
  - Residual plots like with regression
  - Other assumptions: see Raudenbush and Bryk (2002)

- Coefficient for intercept level 2 (γ_{00}) = average performance

Interpreting the results

- More advanced model

LEVEL 1 MODEL (bold: group-mean centering; bold italic: grand-mean centering)

PERFORMA = $\beta_0 + \beta_1(\mathbf{IQ}) + r$

LEVEL 2 MODEL (bold italic: grand-mean centering)

$\beta_0 = \gamma_{00} + \gamma_{01}(\boldsymbol{EXPECTAT}) + u_0$

$\beta_1 = \gamma_{10} + u_1$

  - Coefficient is similar to regression
  - Coefficient is different from 0 when *t*-ratio is significant

Final estimation of fixed effects:

Fixed Effect	Coefficient	Standard error	*t*-ratio	Approx. *d.f.*	*p*-value
For INTRCPT1, β_0					
INTRCPT2, γ_{00}	6.025300	0.053885	111.818	142	<0.001
EXPECTAT, γ_{01}	0.272556	0.077423	3.520	142	<0.001
For IQ slope, β_1					
INTRCPT2, γ_{10}	0.302148	0.065899	4.585	439	<0.001

Final estimation of fixed effects (with robust standard errors)

Fixed Effect	Coefficient	Standard error	*t*-ratio	Approx. *d.f.*	*p*-value
For INTRCPT1, β_0					
INTRCPT2, γ_{00}	6.025300	0.053689	112.226	142	<0.001
EXPECTAT, γ_{01}	0.272556	0.081977	3.325	142	0.001
For IQ slope, β_1					
INTRCPT2, γ_{10}	0.302148	0.084492	3.576	439	<0.001

Test for multilevel mediation

- (Unrealistic) example: teacher expectations --> IQ --> student performance
  - Step 1: level 1 model: $PERF_{ij} = \beta_{0j} + r_{ij}$;
    level 2 model: $\beta_{0j} = \gamma_{00} + \gamma_{01} * EXPECT_{ij} + u_{0j}$
  - Step 2: level 1 model: $PERF_{ij} = \beta_{0j} + \beta_{1j} * IQ_{ij} + r_{ij}$
    level 2 model: $\beta_{0j} = \gamma_{00} + \gamma_{01} * EXPECT_{ij} + u_{0j}$
  - Step 3: level 1 model: $IQ_{ij} = \beta_{0j} + r_{ij}$
    level 2 model: $\beta_{0j} = \gamma_{00} + \gamma_{01} * EXPECT_{ij} + u_{0j}$
  - Step 4: Interpret coefficients
    - Coefficient of EXPECT not significant in Step 3? No mediation
    - Coefficient of EXPECT equal in step 1 and 2? No mediation
    - Coefficient of EXPECT significant in Step 1 and step 3, but not in step 2? Full mediation
    - Coefficient of EXPECT significant in all steps, but lower in step 2 than 1? Partial mediation

Krull and MacKinnon (1999, 2001)

  - If full mediation: Level 1: $PERF_{ij} = \beta_{0j} + \beta_{1j} * IQ_{ij} + r_{ij}$
    Level 2: $\beta_{0j} = \gamma_{00} + u_{0j}$
    $\beta_{1j} = \gamma_{10} + \gamma_{11} * EXPECT_{j} + u_{1j}$

References

Referred to in slides

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Key resources

- K. J. Klein & S. W. J. Kozlowski (2000), Multi-level theory, research and methods in organizations: Foundations, extensions, and new directions. San Francisco, CA: Jossey-Bass
- S. W. Raudenbush and A. S. Bryk (2002), Hierarchical Linear Models: Applications and data analysis methods. Thousand Oaks, CA: Sage Publications, Inc.
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- Software: http://www.ssicentral.com/hlm/resources.html
- Leckie, G. (2013). Cross-Classified Multilevel Models - Concepts. LEMMA VLE Module 12, 1-60. http://www.bristol.ac.uk/cmm/learning/course.html

End of Part 5

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