PSYCH 252
STANFORD
MARCH 15, 2021

CHANGING HOW WE DO MEASUREMENT:
CHALLENGING CLASSICAL TEST THEORY

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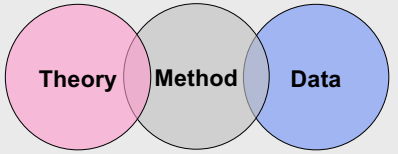
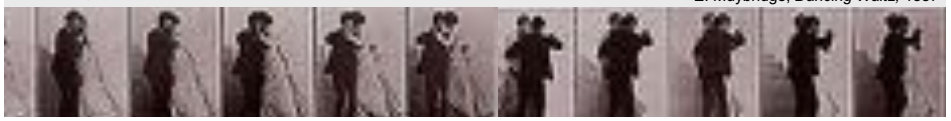
Theory, Method & Data

Aligning, developing, and adapting theoretical perspectives, contemporary methods, and longitudinal data to the study of "biopsychosociocultural" phenomena.

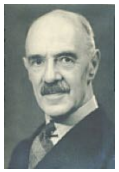


J. Wohlwill, 1991

E. Muybridge, *Dancing Waltz,* 1887



100+ years of Factor Analysis



- Beginnings: Spearman (1904)
  - "One factor theory of intelligence"

- Early Years and Transformations: C. Burt, L.L. Thurstone, H. Kaiser, R. B. Cattell, etc.
  - Methods for factor extraction
  - The number of factors
  - The meaning of factors
  - Factor rotation methods

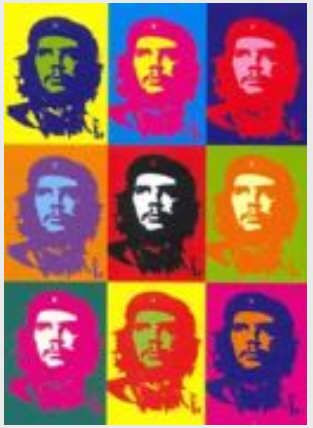
- A Revolution: Joreskog (1970s)
  - Confirmatory Factor Analysis and SEM

M. Duchamp, *Fountain*, 1917

… broaden the meaning of what "art" is and what art can be …

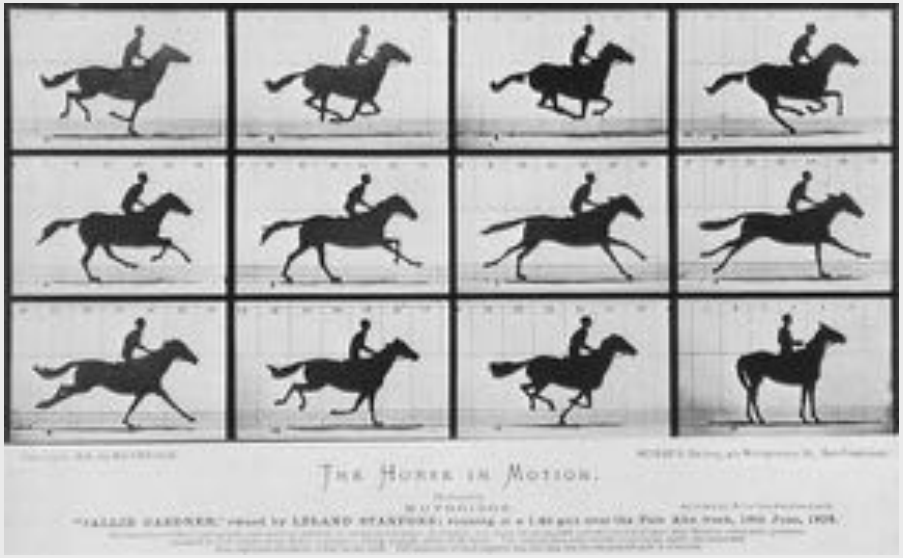
DaDa

Design And Data Analysis

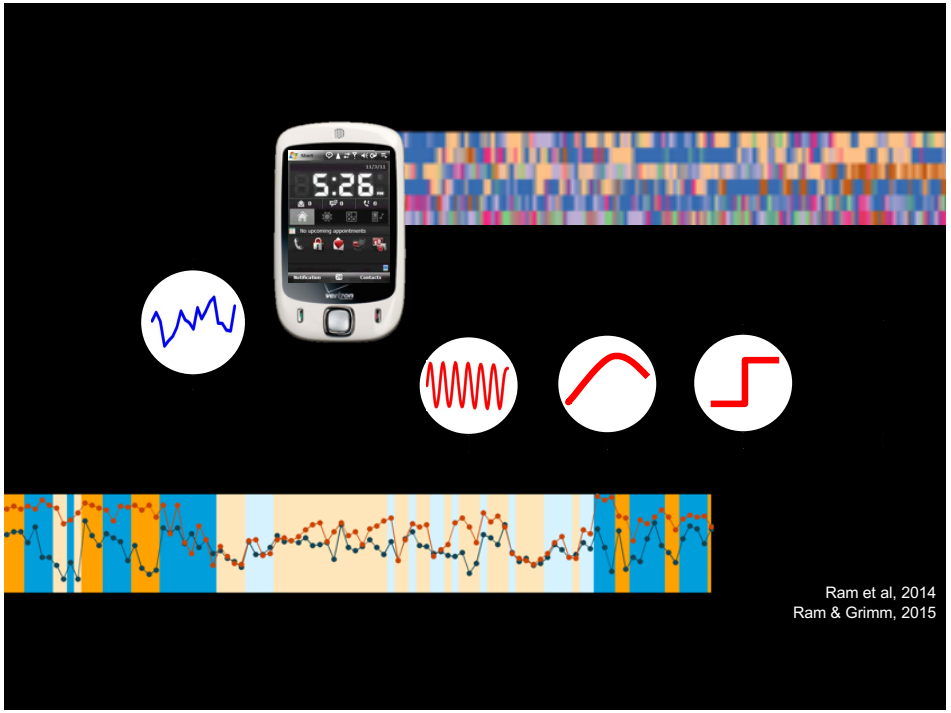


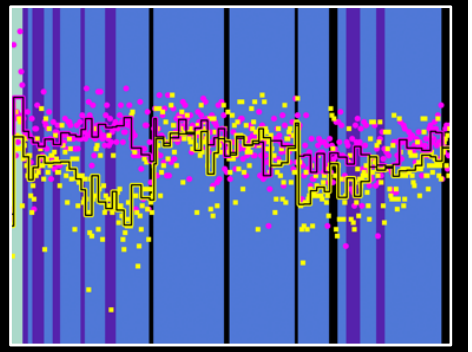
A. Warhol, *Che Guevara*, 1962

Movement, Change, Development, Dynamics



G. Muybridge, *The Horse in Motion*, 1878





https://playingthearchive.com

Experience Sampling

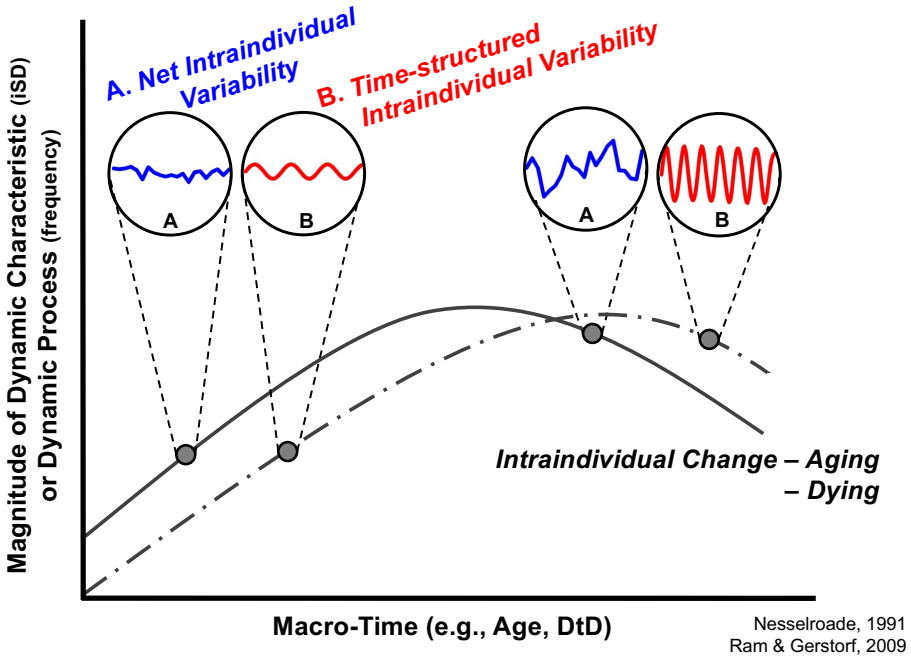
Daily Diary, Ecological Momentary Assessment, Ambulatory Assessment …

Bolger et al., 2003; Shiffman et al., 2008

1. Data collected in ***real-world environments***, as individuals go about their daily lives,
   – Benefit: **Generalization to individuals' real lives –**

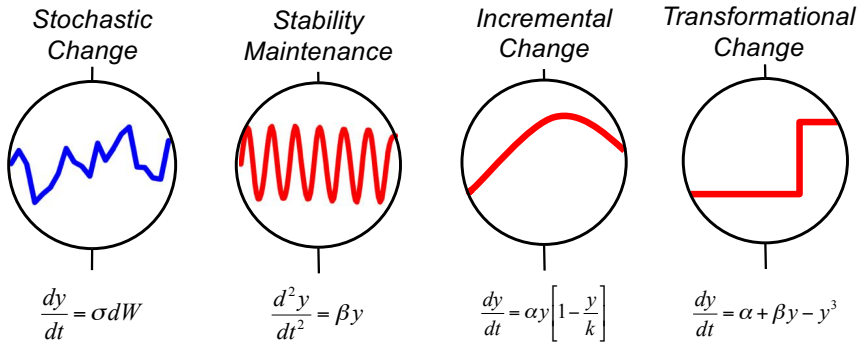
2. Assessment of individuals' ***current or recent state***,
   – Benefit: **Reduction of error or bias associated with retrospective reporting –**

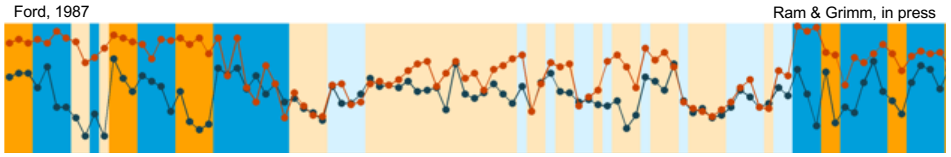
3. Individuals complete ***multiple assessments***
   - Sampling scheme: interval, momentary, random interval, fixed interval, event-contingent
     – see Bolger & Laurenceau, 2013; Ram & Reeves, 2018
   – Benefit: **Study of intraindividual variability –**



Studying Change Processes

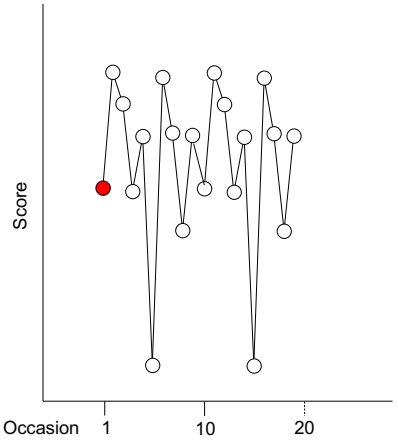
Longitudinal Design and Analysis

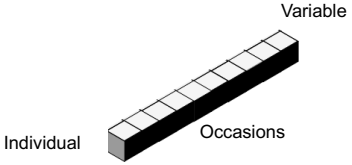




Multiple Occasions of Measurement

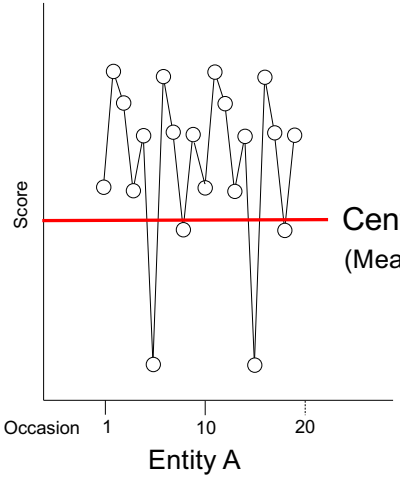
Intraindividual Variability (IIV)





Multiple Occasions of Measurement

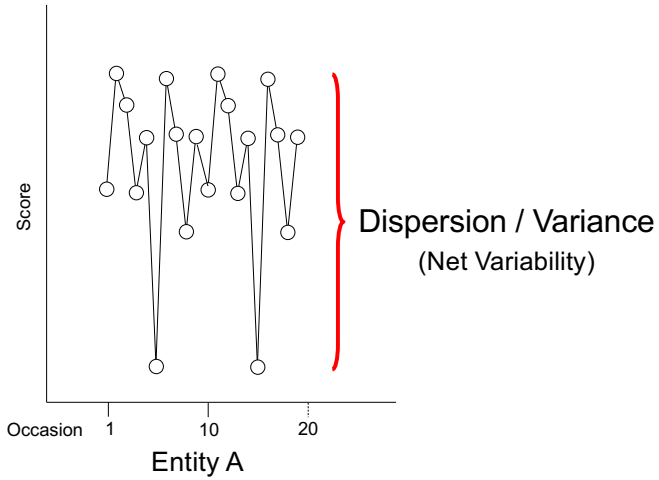
Measures of Central Tendency



Central Tendency
(Mean, Median, etc.)

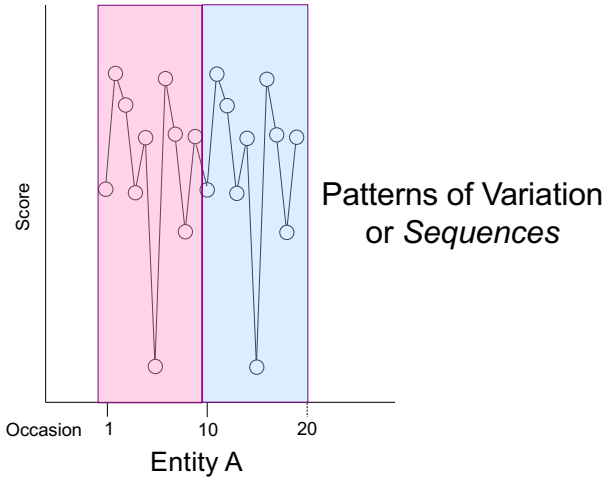
Multiple Occasions of Measurement

Measures of 'Dispersion'

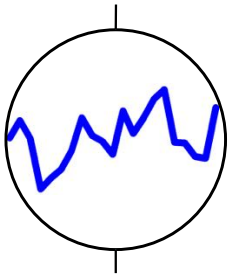


Multiple Occasions of Measurement

Modeling 'Systematicity'



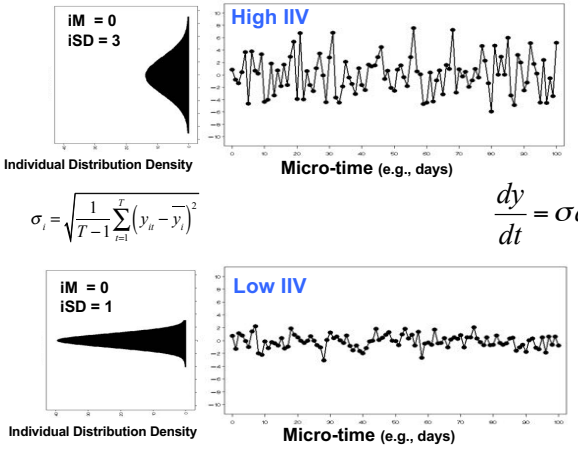
Net Intraindividual Variability



- *Dynamic Characteristics*
  - *– Capacities or potentials for change*
- *Quantity of variability*
  - "spontaneous variability" – those changes that do not show any systematic trends over time (i.e., the ordering of occasions is immaterial) (Fiske & Rice, 1955)
  - *– Measures of Dispersion:*
    - Quantifying how many observations in the data are distributed across various categories?

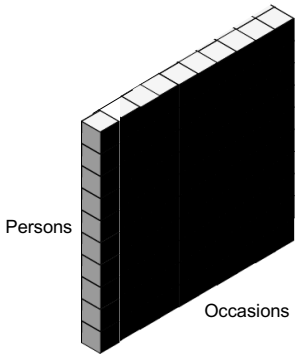
Intraindividual Variability

Variability, Lability, Plasticity, Flexibility, Complexity, Diversity, …



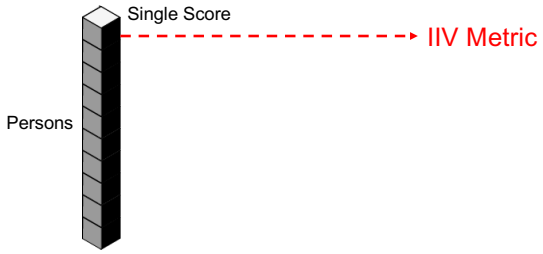
Fiske & Rice, 1955
Nesselroade, 1991; Ram & Gerstorf, 2009

Compressing Multiple-Occasions into Single Score



Compressing Multiple-Occasions into Single Score

A Single Assessment of Variability



→ Interindividual Differences

Theories of Intraindividual Variation

- *What is "intraindividual variability"?*

  – *As a "differences" characteristic*
    - Marker of impending decline or low functionality
      (Rowe & Kahn, 1985, 1997)
    - … impending increase or high functionality
      (Eid & Diener, 1999; Seigler, 1994)

    - Predictive of other interindividual differences
      – Temperament (Fox & Porgess, 1985)
      – Mortality (Deary & Der, 2005)

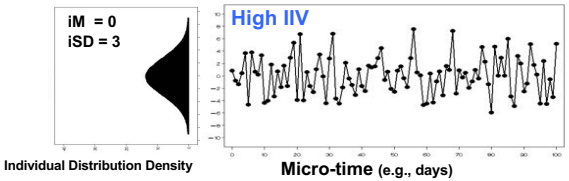
      – Intraindividual variability in other characteristics?

IIV Across the Life Span

- Infants
  – intraindividual variability in infants' heart rate ~ later differences in temperament (Fox & Porges, 1985; Kagan, 1994)
- Children
  – intraindividual variability in performance ~ impending cognitive developmental transitions (Siegler, 1994)
- Adults
  – Intraindividual variability in self-esteem (i.e., self-esteem lability) ~ depression proneness (Butler et al., 1994)
- Older adults
  – Intraindividual variability in internality beliefs ~ mortality some five years later (Eizenman et al., 1997)

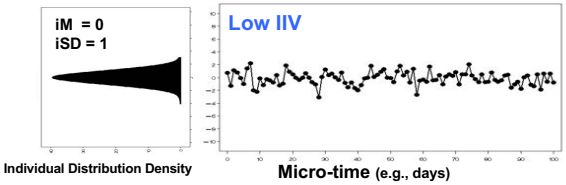
Individual Differences in IIV

Variability, Lability, Plasticity, Flexibility, Complexity, Diversity, …



$$\sigma_i = \sqrt{\frac{1}{T-1}\sum_{t=1}^{T}\left(y_{it} - \bar{y}_i\right)^2}$$

$$\frac{dy}{dt} = \sigma dW$$

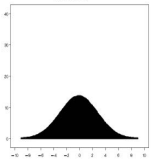


Fiske & Rice, 1955
Nesselroade, 1991; Ram & Gerstorf, 2009

Interindividual Differences in IIV

A 2-step Approach

1. *Measurement of a Construct*
   - Each individuals' ensemble of repeated measures are summarized as a single score
     - iMean, iMedian, iSD, iRange, iSkew, iEntropy …
   - Dynamic characteristics
     - Within-person world



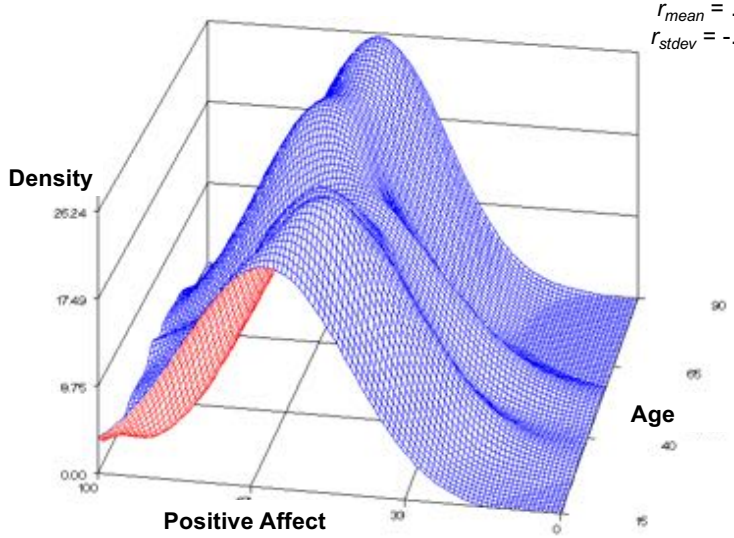
2. *Relations among Constructs*
   - Use the IIV scores in an analysis of individual differences
     - ANOVA, Correlation, Regression, SEM, …
   - IIV as a predictor, correlate, outcome …
     - Between-person world

Ram & Gerstorf, 2009

Intraindividual Variation in Positive Affect

Distribution (iMean, iSD) ***as a Function of Age***

r_{mean} = .10, p = .21
r_{stdev} = -.35, p < .01

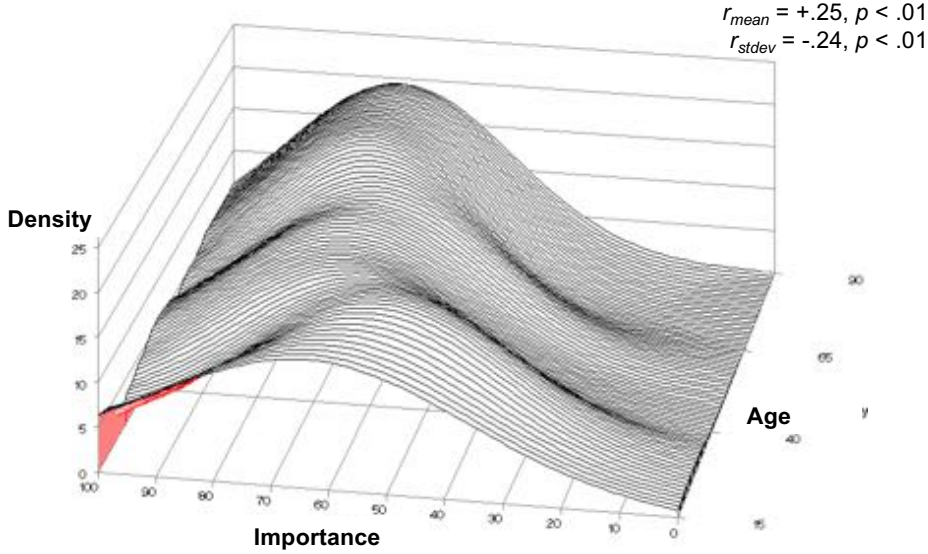


Motivational Shifts with Age

SocioEmotional SelectivityTheory

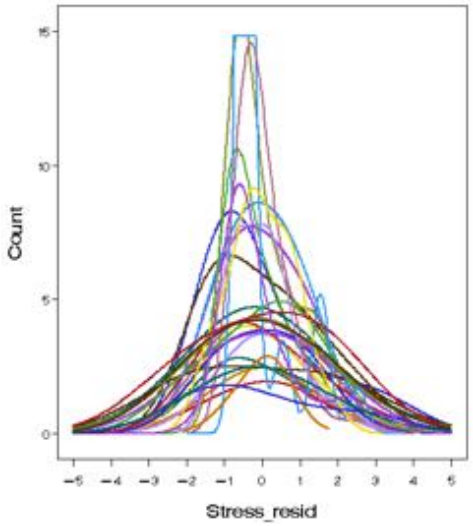
"How IMPORTANT was this interaction for you?"

r_{mean} = +.25, p < .01
r_{stdev} = -.24, p < .01



Intraindividual Density Distributions

Univariate



- *Describing Distributions*
  - *iMean*
  - *iVariance (iSD)*
  - *iSkew*
  - *iKurtosis*
  - *Formal distributions*
    - *normal, maximum value, minimum value, exponential, etc.*
  - *Kernel distributions*

Collection of Distributions

Distributions as an Interindividual Differences Factor

Is the IIV distribution related to other variables, X_i ??

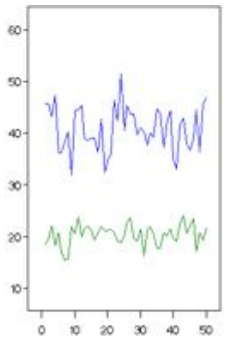
Net Intraindividual Variability

- Measures of IIV…
  - Intraindividual Standard Deviation (*iSD*)
    - Preponderant
  - Lots of other measures of 'dispersion'
    - Coefficient of Variation
    - Signal-to-Noise Ratio
    - Range
    - Mean Square of Successive Differences
    - Probability of Acute Change
    - Auto-correlation
    - Turbulence
    - Relative Variation
  - "Feature Extraction …"

Coefficient of Variation (iCV)

- Ratio of standard deviation to mean
  - Allows comparison of variation of populations that have significantly different means
    - Note: not useful when mean is near 0

$$cv_i = \frac{\sigma_i}{\mu_i}$$



σ_i = 4, μ_i = 40 **cv_i = 0.1**

σ_i = 2, μ_i = 20 **cv_i = 0.1**

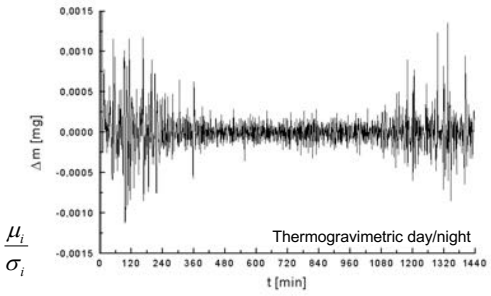
Stock Market

Signal to Noise Ratio (iSNR)

- Ratio of meaningful information to background noise
  - Often useful for measures of change **Δ**

$$SNR_i = \frac{P_{signal}}{P_{noise}}$$

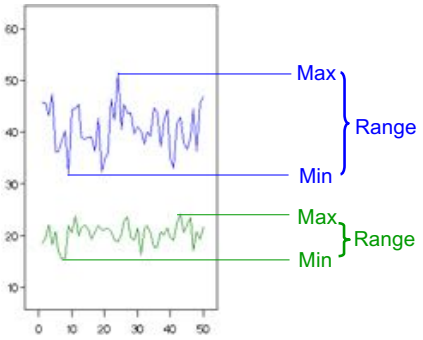
$$SNR_i = \frac{\mu_i}{\sigma_i}$$

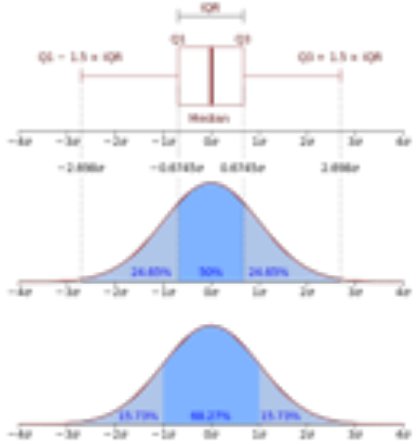


Geoscience

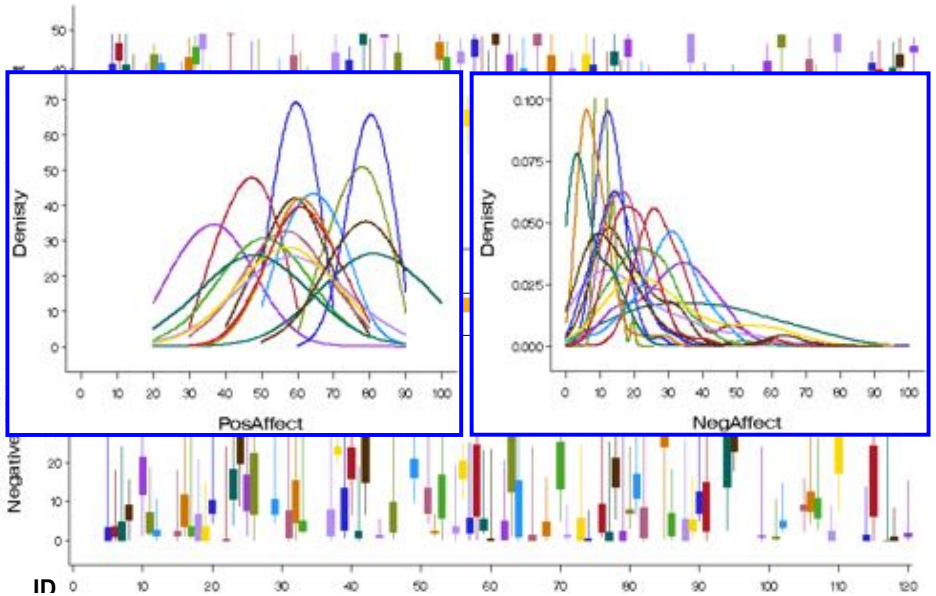
iRange

- Max & Min Scores
- (Max – Min) = Range
- Interquartile Range (IQR)
- Other theoretically interesting possibilities …



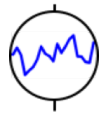


Distributions as a Typology of Processes



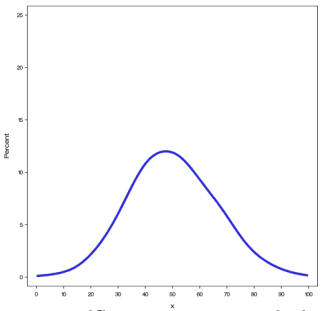
Dynamic Outputs

Person-Specific Density Distributions

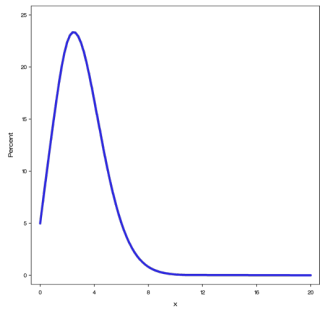


– Differential dynamics inferred from distributional shape

Output of *Gaussian Process*



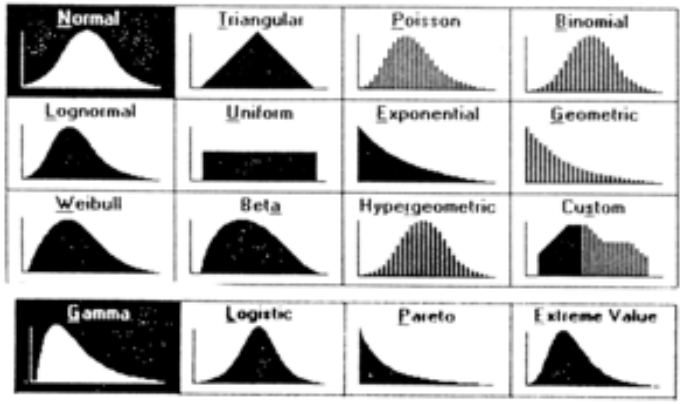
Output of *Poisson Process*

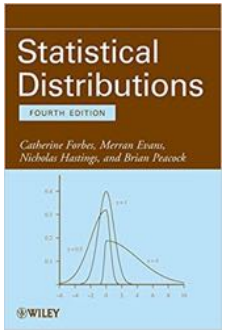


- Person-specific nonparametric kernel density curves/surfaces
- **Top-down** or **bottom-up classification** into a typology of distributions

Distributions as a Typology of Processes

- What is the shape of the **within-person** distribution?





http://www.snipview.com/q/Probability_distributions

Distributions as a Typology of Processes

- Describing IIV using parameters of a formal distribution
  - *qualitative and/or quantitative differences*

Poisson

$$P(Y_i = y_i|\mathbf{x}_i) = \frac{e^{-\mu_i}\mu_i^{y_i}}{y_i!}, \quad y_i = 0, 1, 2, \ldots$$

Zero-Inflated Poisson (ZIP)

$$\Pr(Y_{di} = 0) = \phi_{di} + (1 - \phi_{di})\exp(-\lambda_{di}),$$

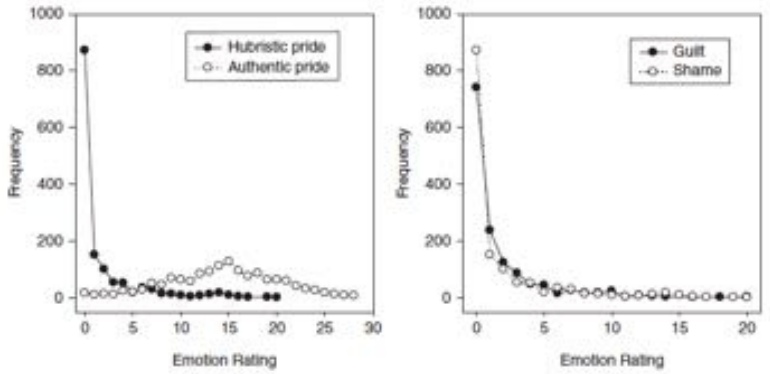
$$\Pr(Y_{di} = y_{di}) = (1 - \phi_{di})\frac{\lambda_{di}^{y_{di}}\exp(-\lambda_{di})}{y_{di}!}, \quad y = 1, 2, \ldots, \tag{6}$$

where ϕ_{di} is the probability of remaining in the zero (non-activated) state (with $0 < \phi_{di} < 1$), $1 - \phi_{di}$ is the probability of moving into an activated state, and λ_{di} governs the intensity of the emotion when it is activated.

Conroy, Ram, Pincus, Rebar, 2014

Distributions as a Typology of Processes

- What is the shape of the distribution?
  - Gaussian / skewed
  - Poisson, ZIP, ZINB, NB hurdle, …



Conroy, Ram, Pincus, Rebar, 2014

Distributions as a Typology of Processes

- Which distribution to choose?
  - Theoretical vs. Empirical choice
    - Testing the relative fit of various distributions

Variable	Fit index	Normal (Gaussian)	ZIP	ZINB	Negative binomial hurdle
Authentic pride	AIC	8465.01	9482.00	8610.48	8610.82
	BIC	8480.76	9492.49	8631.47	8631.81
Hubristic pride	AIC	6284.21	5186.48	3821.41	4153.47
	BIC	6299.95	5196.98	3842.39	4174.46
Shame	AIC	6590.65	5487.40	4458.08	4640.08
	BIC	6606.40	5497.90	4479.08	4661.08
Guilt	AIC	7311.78	6342.31	5305.40	5439.70
	BIC	7327.53	6352.81	5326.40	5460.70

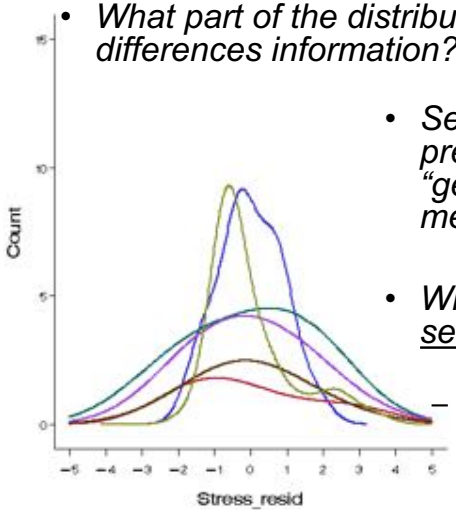
Note: AIC, Akaike Information Criteria; BIC, Bayes Information Criteria.

Conroy, Ram, Pincus, Rebar, 2014

Intraindividual Density Distributions

Univariate

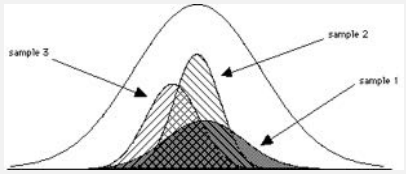
- *What part of the distribution holds interindividial differences information?*
  - *Selecting distribution requires a precise conception of the "generating or selection mechanisms"*
  - *What are possible generating or selection mechanisms?*
    - *Structural affordances or constraints*
      - *Notion of a filter or sieve*

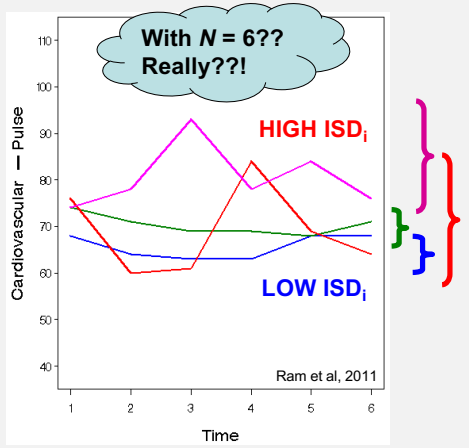


Importance of Number of Repeated Measures

Reliability of 1st, 2nd, 3rd, 4th Statistical Moments

- # of observations needed to characterize a distribution





- SD is only half as reliable as the mean
- Implications for examining interindividual differences in *iSD, iSkew, iKurtosis, …*

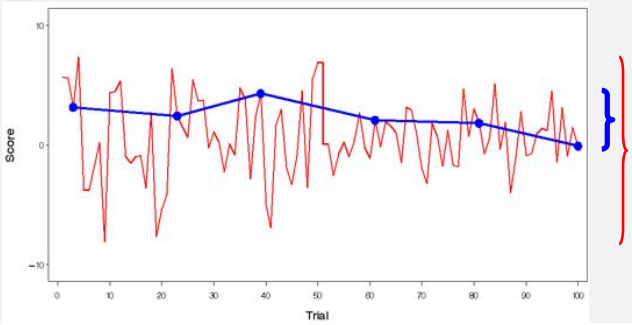
https://psychology.illinoisstate.edu/jccutti/psych240/chpt7.html

Importance of Time Scale

$$ISD_i = \sigma_i = \sqrt{\frac{1}{T-1}\sum_{t=1}^{T}\left(y_{it} - \overline{y}_i\right)^2}$$

What is ***T*** *(occasions)* ?

– *Net Intraindividual Variability* across *Trials, Days, or Weeks*?



Assumption

- Calculation of all of the above metrics assume that the ensemble of repeated measures obtained from an individual are … independently and identically distributed (*i.i.d*)
  - *Order of the observations (t-1, t, t+1) is immaterial*
  - *Observations can be "shuffled"*
  - *Principles of random sampling*
    - Influence on study design (signal-contingent)
  - → A bit of *dissonance* when working with repeated measures – What about the interdependence?

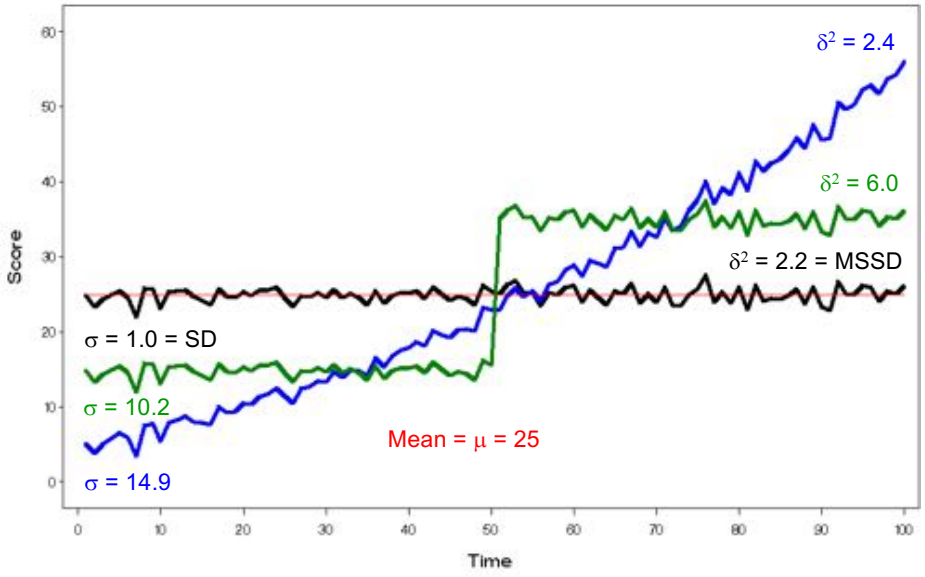
Mean Square Successive Differences (iMSSD)

$$\delta_i^2 = \frac{1}{T-1}\sum_{t=1}^{T}\left(y_{i(t+1)} - y_{i(t)}\right)^2$$

$$\sqrt{\delta_i^2} \approx 2\sigma_i$$

- "There are cases, however, where the standard deviation may be held constant, but the mean varies from one observation to the next. … It is for this purpose that the mean square successive difference is suggested" (von Neumann et al., 1941)

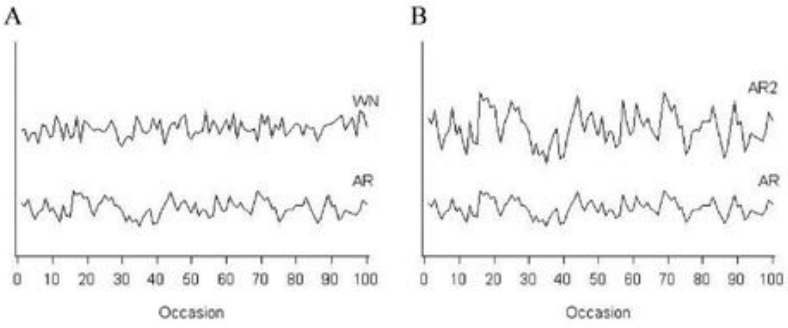
Mean Square Successive Differences (MSSD)



Auto-Regression

- Variability (in Δy)
- Temporal Dependency

"Roughness"
"Spikyness"
"Persistency"
"Inertia"



Measures of Instability/Variability

- Autocorrelation:
  - an index of how well scores at (i+h)th occasions correlate with ith occasions

$$\mathrm{ACORR}(h) = \frac{\hat{\gamma}(h)}{\hat{\gamma}(0)} = \frac{\sum_{i=1}^{N-h}(x_{i+h} - \bar{x})(x_i - \bar{x})}{\sum_{i=1}^{N}(x_i - \bar{x})^2},$$

- The magnitude of the ***persistency*** of states between measurement points over the same time interval (elsewhere referred to as ***inertia***, Kuppens et al)
  - does not reflect extremity or degree of amplitude of fluctuations

Probability of Acute Change

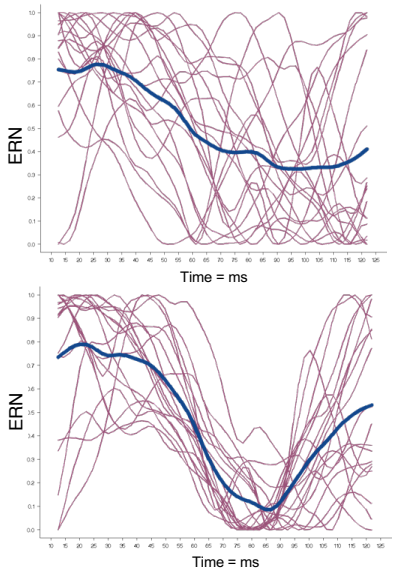
- Probability of Acute Change (PAC): **"Spikyness" "Fragility" "Instability"**

$$\mathrm{PAC} = \frac{1}{N-1}\sum_{i=1}^{N-1} \mathrm{AC}_{i+1}, \qquad (5)$$

where $\mathrm{AC}_{i+1} = 1$, if $x_{i+1} - x_i \geq c$; c = a predetermined cut point; and $\mathrm{AC}_{i+1} = 0$, otherwise. The cut point, c, can be determined theoretically or statistically by researchers and should be the same across all individuals if comparisons across individuals are to be made.[4]

Temporal Intraindividual Variability

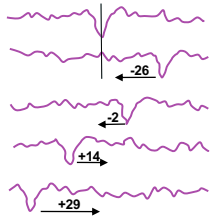
Feature Definition – *Attention Monitoring & Neural Timing*



Reconsider Variability on y_t as Variability on t_t

Shifting the conception of variability from *dy* to *dt*

Temporal alignment of repeated signals
(Woody, 1967)



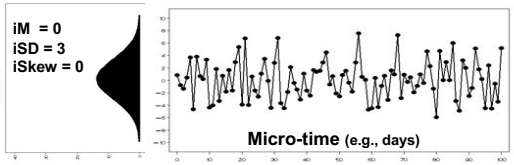
(Fz-theta)

Age-related changes in temporal variability

Dupuis, Ram, Willner, Karalunas, Segalowitz, & Gatzke-Kopp, 2015

Categorical Intensive Longitudinal Data

- Intraindividual Distributions (IIV)
  1. *Central Tendency*
  2. *Dispersion*
  3. *Skew*



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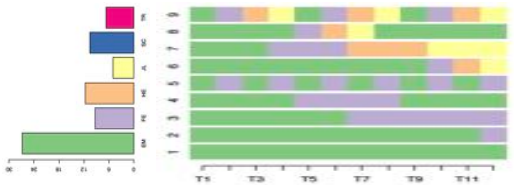
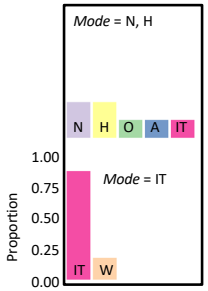


Categorical Intensive Longitudinal Data

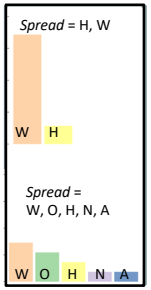
6 Metrics of Categorical IIV

- Categorical Intraindividual Distributions (IIV)
  1. *Central Tendency*
  2. ***Dispersion***
  3. *Skew*

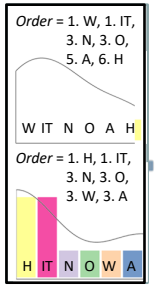
1. Dominance/Mode



2. Diversity/Spread



3. Rarity/Order



Koffer, Ram & Almeida (2018)

Categorical IIV - Entropy

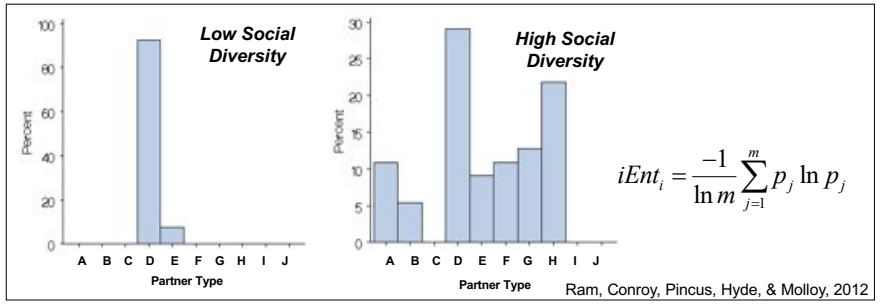
- Degree of 'disorder' or 'uncertainty' in a system
  - How observations in the data set are distributed across various categories (Shannon, 1948)

m = 4	A	B	C	D
p_j	--	--	1.0	--

***Entropy* = 0.0**

m = 4	A	B	C	D
p_j	.25	.25	.25	.25

***Entropy* = 1.0**



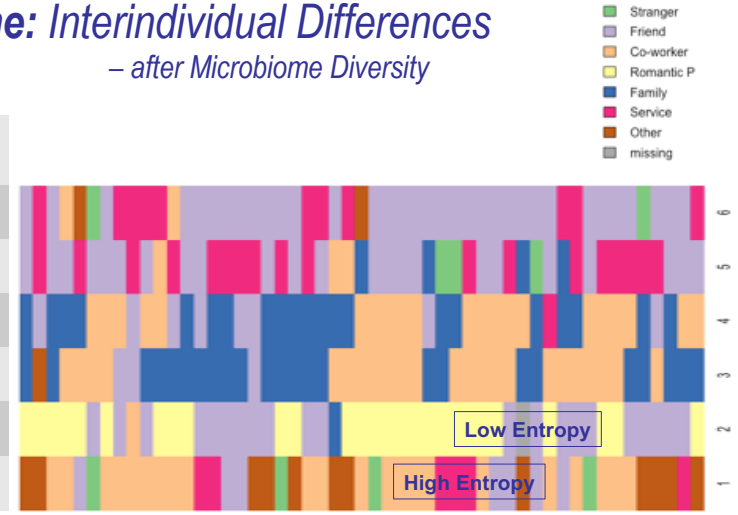
$$iEnt_i = \frac{-1}{\ln m}\sum_{j=1}^{m} p_j \ln p_j$$

Ram, Conroy, Pincus, Hyde, & Molloy, 2012

Socio-ome: Interindividual Differences

– after Microbiome Diversity

Type Turb.	Type Entropy
20.3	0.51
29.9	0.65
23.8	0.56
16.9	0.49
19.5	0.44
28.3	0.73



- *Diversity of Social Interaction Types:*
  - **Entropy**
  - **Turbulence**

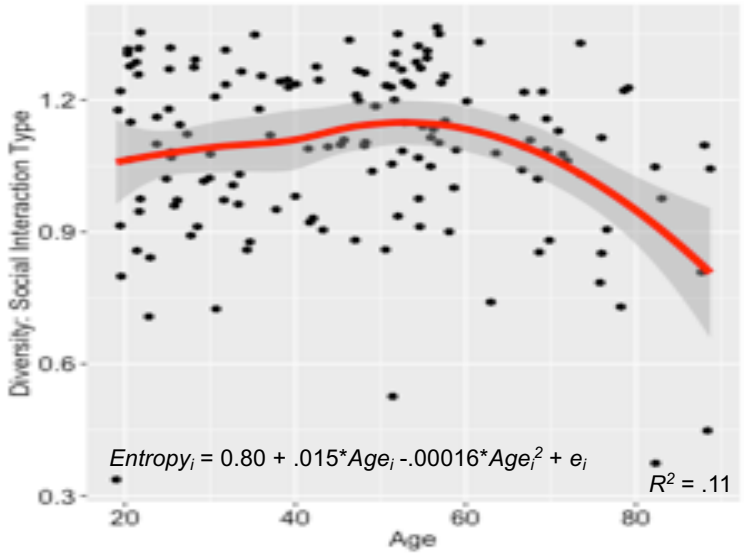
$$h(\pi_1, \ldots, \pi_s) = -\sum_{i=1}^{s} \pi_i \log \pi_i$$

$$T(x) = \log_2\left(\phi(x)\frac{s^2_{t,max}(x)+1}{s^2_t(x)+1}\right)$$

Shannon, 1948; Elzinga, 2006

Diversity of Socio-ome across Adulthood

Lower Type Diversity in Older-adult Quartile

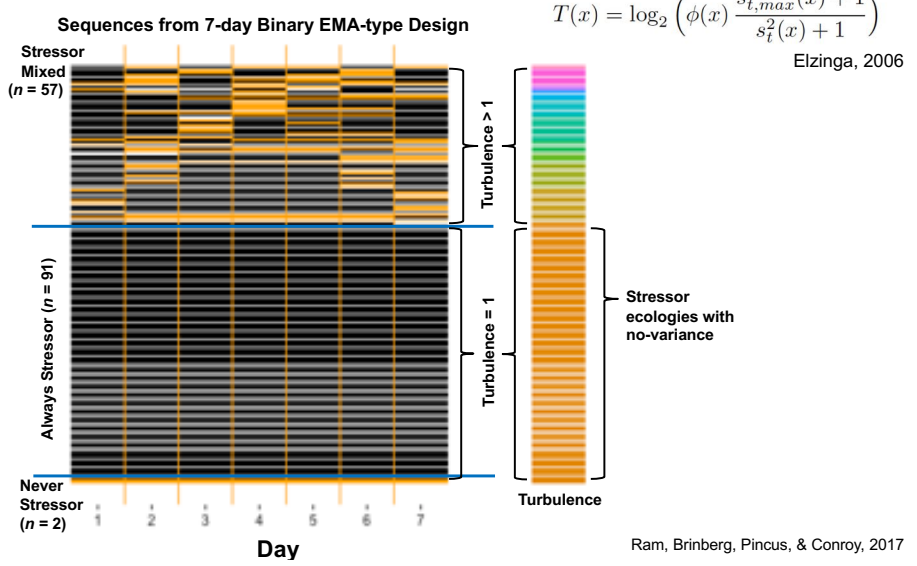


Stressor Turbulence: Interindividual Differences

– after Oceanography - ***Temporal Regularity***

$$T(x) = \log_2\left(\phi(x)\frac{s^2_{t,max}(x)+1}{s^2_t(x)+1}\right)$$

Elzinga, 2006

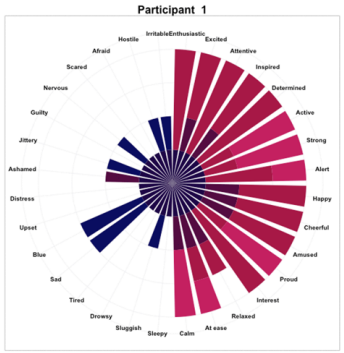


Ram, Brinberg, Pincus, & Conroy, 2017

Emodiversity: *Interindividual Differences*

– after Ecological Diversity

– Distribution of quantity and intensity experience of many discrete emotions



Low Diversity

High Diversity

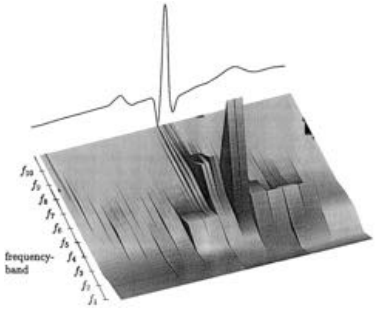
Benson, Ram, Almeida, Zautra & Ong (2018)

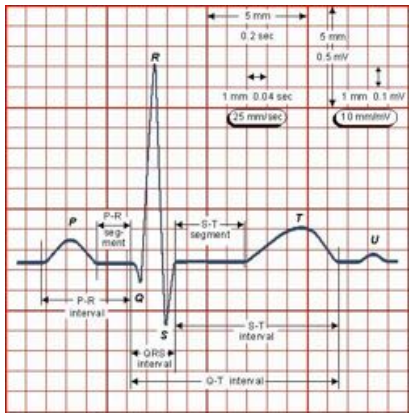
Generalizing … Feature Extraction

Terminology from Computer Science

1234567890

- Heart Beat





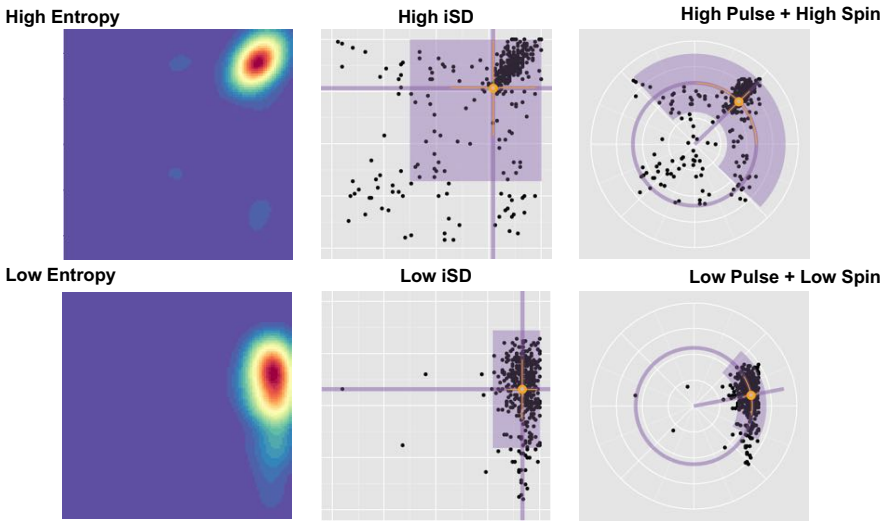
Many Measures of Intraindividual Variability

- There are sooo many possibilities!!!
  - **Feature extraction from Time Series**
  - **R package: tsfeaturex**
    - **Nelson Roque**
    - **https://github.com/nelsonroque/tsfeaturex**

BIVARIATE INTRAINDIVIDUAL VARIABILITY

Bivariate Intraindividual Variability

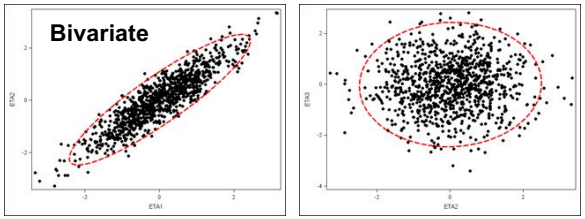
(Emo-) Variability, Lability, Flexibility, Pulse, Spin, Diversity, …



Fiske & Rice, 1955; Moskowitz & Zuroff, 2004; Ram et al., 2017; Shannon, 1948

Intraindividual Covariation

iCorr



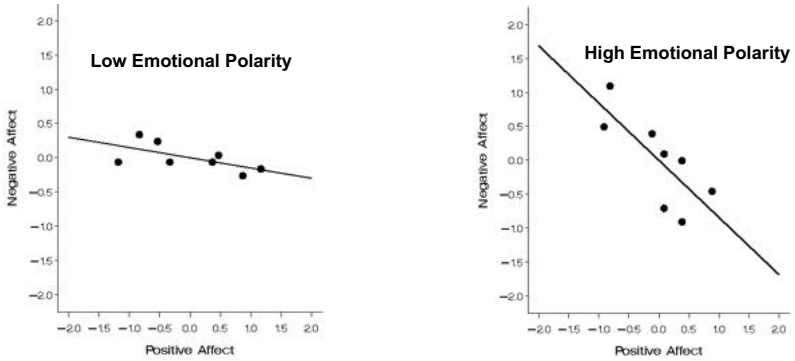
$$r_{xyi} = \frac{1}{T-1}\sum_{t=1}^{T}\left(\frac{x_{it}-\mu_{xi}}{\sigma_{xi}}\right)\left(\frac{y_{it}-\mu_{yi}}{\sigma_{yi}}\right)$$

- **Poignancy, emotional polarity, affect synchrony**
  - (Carstensen et al., 2000; Zautra et al., 2005)
- **Behavioral Signatures, If…then contingencies**
  - (Mischel & Shoda, 1985)

Intraindividual Covariation

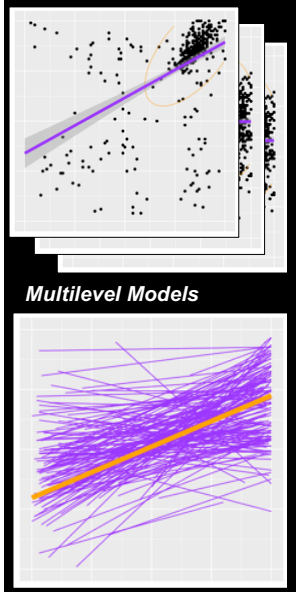
iReg

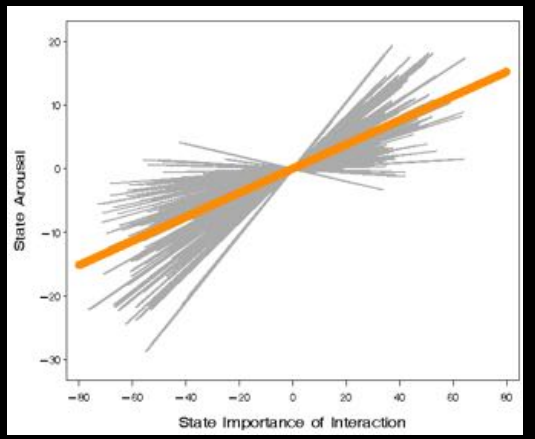
$$y_{ti} = \beta_{xyi}x_{ti} + e_{ti}$$



Intraindividual Covariation

iReg → Multilevel Model

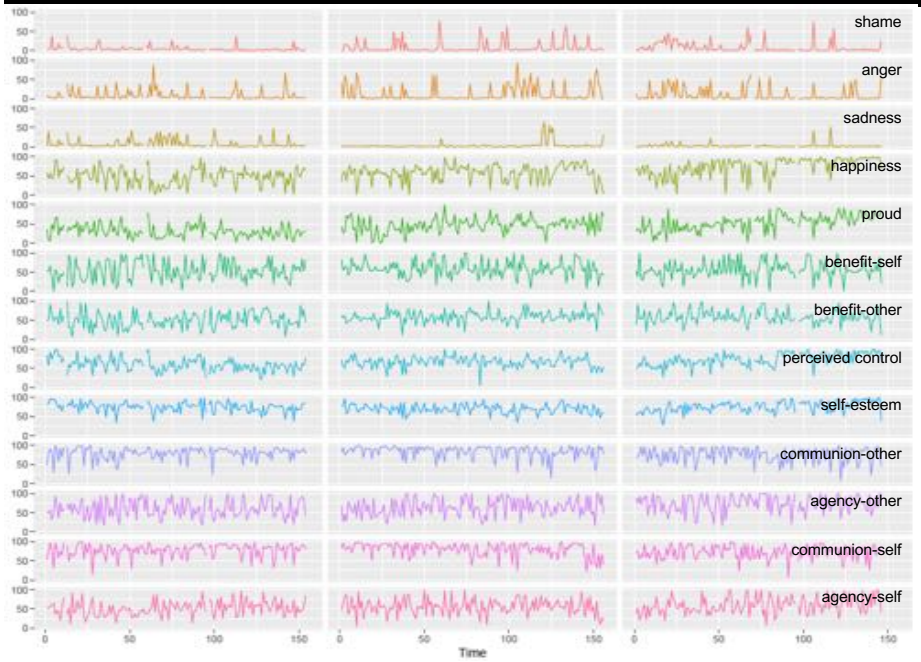




Vogel, et al, 2017, *Emotion*

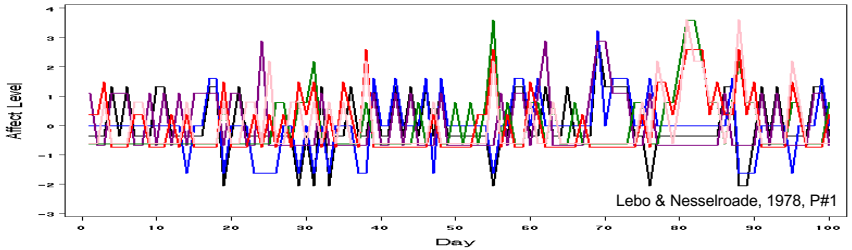
MULTI-VARIATE INTRAINDIVIDUAL VARIABILITY

High-Dimensional Continuous Data



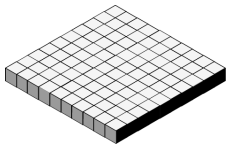
Multivariate Intraindividual Variability

(Multiple Variables x Multiple Occasions for One Person)



Intraindividual Correlation Matrix

	$Active_t$	$Lively_t$	$Peppy_t$	$Slugg_t$	$Tired_t$	$Weary_t$
$Active_t$	1.00					
$Lively_t$	.64	1.00				
$Peppy_t$	.56	.41	1.00			
$Sluggish_t$	-.48	-.35	-.42	1.00		
$Tired_t$	-.47	-.42	-.47	.72	1.00	
$Weary_t$	-.43	-.43	-.44	.64	.83	1.00



Multivariate Intraindividual Variability

Determinant, Frobenius Norm

	$Active_t$	$Lively_t$	$Peppy_t$	$Slugg_t$	$Tired_t$	$Weary_t$
$Active_t$	1.00					
$Lively_t$	.64	1.00				
$Peppy_t$	.56	.41	1.00			
$Sluggish_t$	-.48	-.35	-.42	1.00		
$Tired_t$	-.47	-.42	-.47	.72	1.00	
$Weary_t$	-.43	-.43	-.44	.64	.83	1.00

Det = 0.038
$Norm_F$ = 3.80

- Quantify matrix as a single number?
  - Determinant of a matrix
    - measure of generalized variance (i.e., combined variance of each variable minus covariance between the variables)

$$\begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix}$$

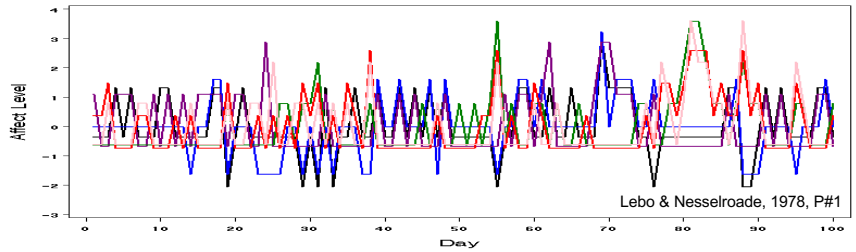
$$|\mathbf{A}| = a_{11}a_{22} - a_{21}a_{12}$$

  - (Frobenius) Norm of a matrix
    - Often used to quantify distance between matrices

$$Norm(\mathbf{A}) = \sqrt{\sum_{i=1}^{N}\sum_{j=1}^{n} a_{ij}^2}$$

Factor Structure

Factor Structure



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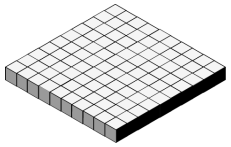
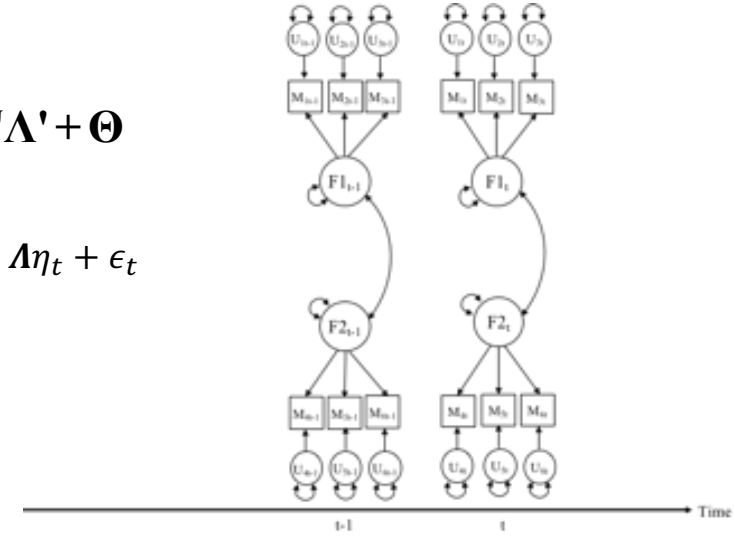


Multivariate Intraindividual Covariation

P-Technique Factor Analysis

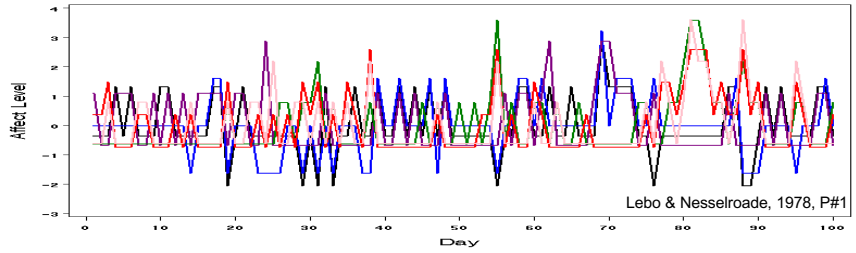
$$\Sigma = \Lambda\Psi\Lambda' + \Theta$$

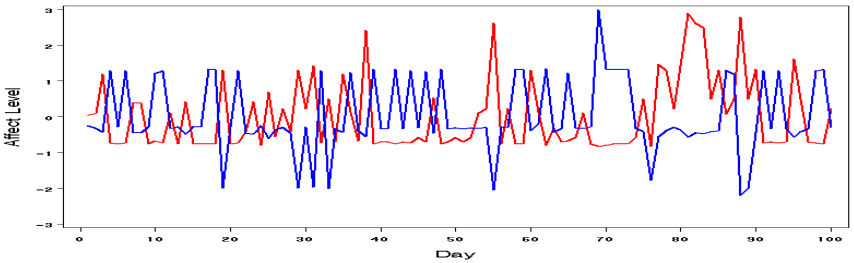
$$y_t = \Lambda\eta_t + \epsilon_t$$



Brose & Ram, 2012

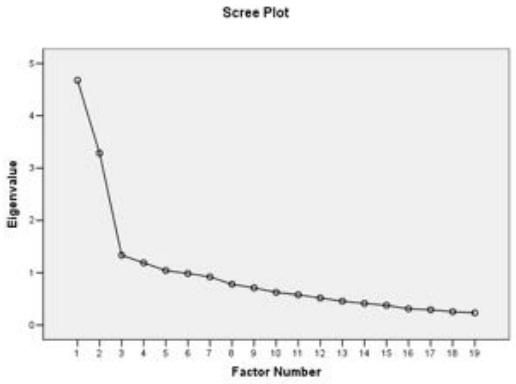
Latent Structure & P-Factor Scores





Determining Number of Factors

Scree Test, Eigenvalues > 1 (Kaiser Rule)

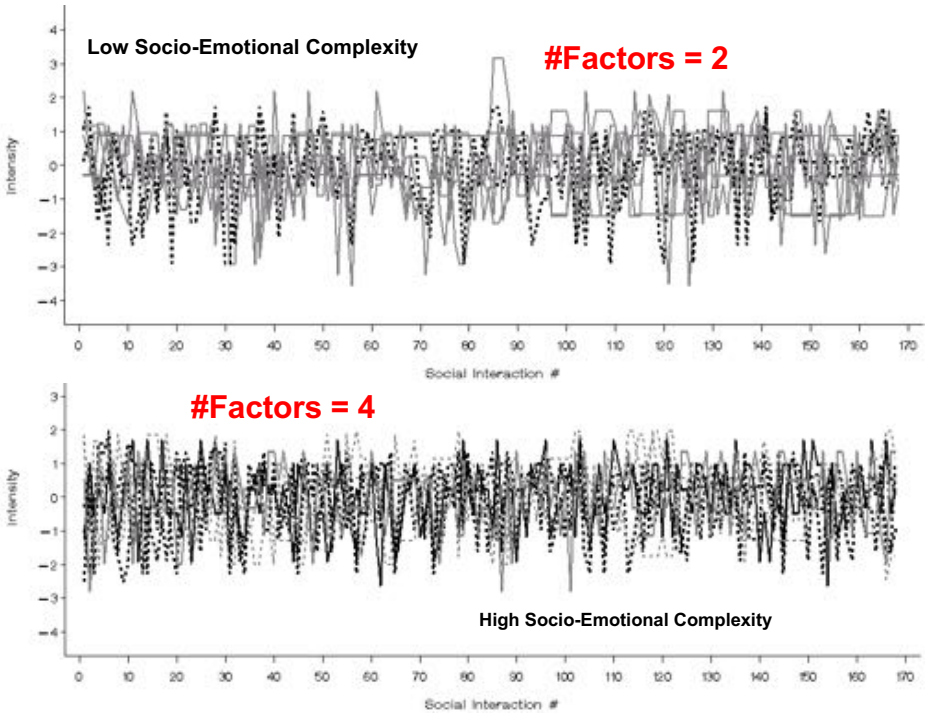


Total Variance Explained

Factor	Initial Eigenvalues			Rotation
	Total	% of Variance	Cumulative %	Total
1	4.678	24.621	24.621	3.359
2	3.287	17.299	41.919	2.408
3	1.335	7.027	48.946	3.143
4	1.190	6.261	55.207	1.952
5	1.043	5.490	60.697	2.965
6	.987	5.194	65.891	
7	.921	4.850	70.741	
8	.780	4.107	74.848	
9	.712	3.746	78.594	
10	.627	3.298	81.892	
11	.579	3.047	84.939	
12	.518	2.727	87.666	
13	.458	2.408	90.073	
14	.414	2.177	92.250	
15	.378	1.991	94.241	
16	.311	1.638	95.879	
17	.293	1.544	97.423	
18	.255	1.340	98.764	
19	.235	1.236	100.000	

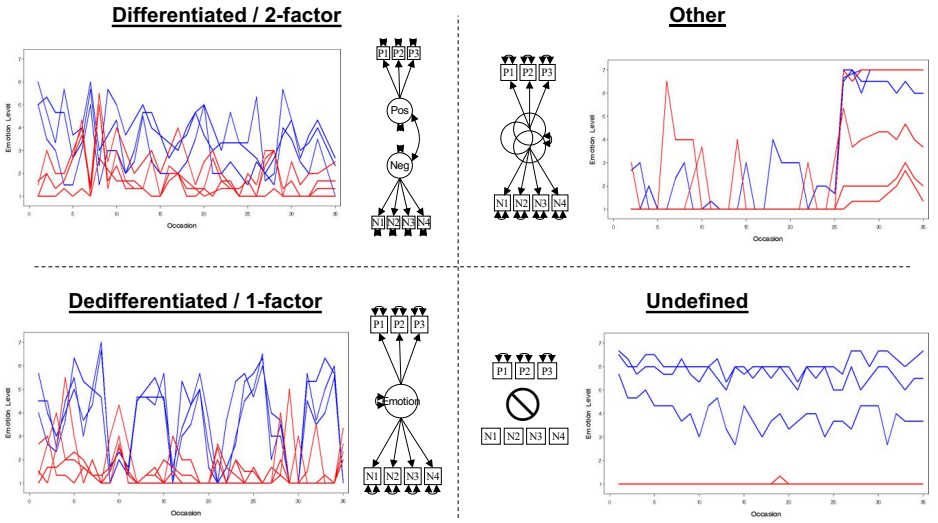
Extraction Method: Principal Axis Factoring.

a. When factors are correlated, sums of squared loadings cannot be added to obtain a total variance.



Multivariate Intraindividual Covariation

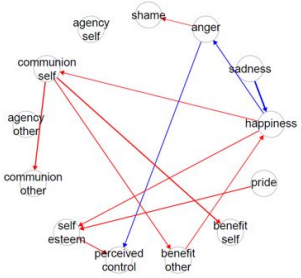
Interindividual Differences in P-Technique Factor Structures



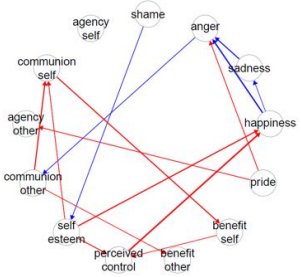
Ram, Carstensen, & Nesselroade, 2006

Multivariate Intraindividual Variability

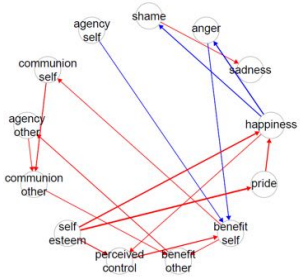
Differences in Person-specific Network Structures



Density .07 (10 edges)
Centralization .19
Clustering .12 (triangles)



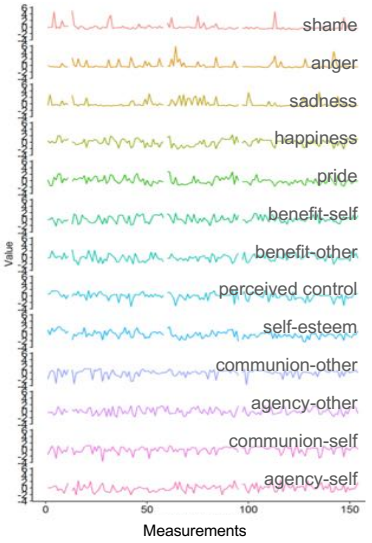
Density .10 (13 edges)
Centralization .17
Clustering .20 (triangles)

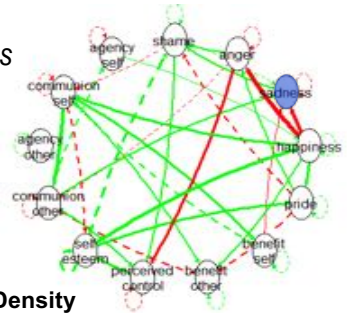


Density .11 (16 edges)
Centralization .15
Clustering .24 (triangles)

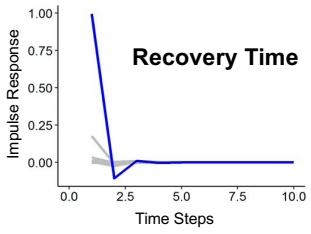
Person-Specific Network

Describing High-dimensional Dynamic Systems





Network Density



Yang et al., 2018

Interindividual Differences in IIV

A 2-step Approach

1. *Measurement of a Construct*
   - Each individuals' ensemble of repeated measures are summarized as a single score
     - iMean, iMedian, iSD, iRange, iSkew, iEntropy …
   - Dynamic characteristics
     - Within-person world

BE CREATIVE!
Invent new constructs

2. *Relations among Constructs*
   - Use the IIV scores in an analysis of individual differences
     - ANOVA, Correlation, Regression, SEM, …
   - IIV as a predictor, correlate, outcome …
     - Between-person world

Ram & Gerstorf, 2009