Washington University in St. Louis
James McKelvey School of Engineering

Idiographic Personality Gaussian Process for Psychological Assessment

Yehu Chen, Muchen Xi,
Joshua Jackson, Jacob Montgomery, Roman Garnett

NeurIPS 2024

Outline

Problem statement

- Personality and Big Five
- On-going debate and challenges

Proposed method

- Data and setup
- Idiographic personality Gaussian Process

Main results

- Existing cross-sectional data for Big Five validation
- A novel longitudinal data for idiographic personalities

Outline

Problem statement

- Personality and Big Five
- On-going debate and challenges

Proposed method

- Data and setup
- Idiographic personality Gaussian Process

Main results

- Existing cross-sectional data for Big Five validation
- A novel longitudinal data for idiographic personalities

Personality with Big Five

Broad dimensions

OPENNESS CONSCIENCTIOUS EXTRAVERSION AGREEABLENESS NEUROTICISM

Personality with Big Five

Broad dimensions

OPENNESS CONSCIENCTIOUS EXTRAVERSION AGREEABLENESS NEUROTICISM

Relation to political/socioeconomic outcomes

- Political disposition/party identification (Mondak et al. 2008, Gerber et al. 2010, etc)
- Schooling, wages and longevity (Borghans et al. 2008)
- Risky financial behavior (Brown et al. 2014)

But…

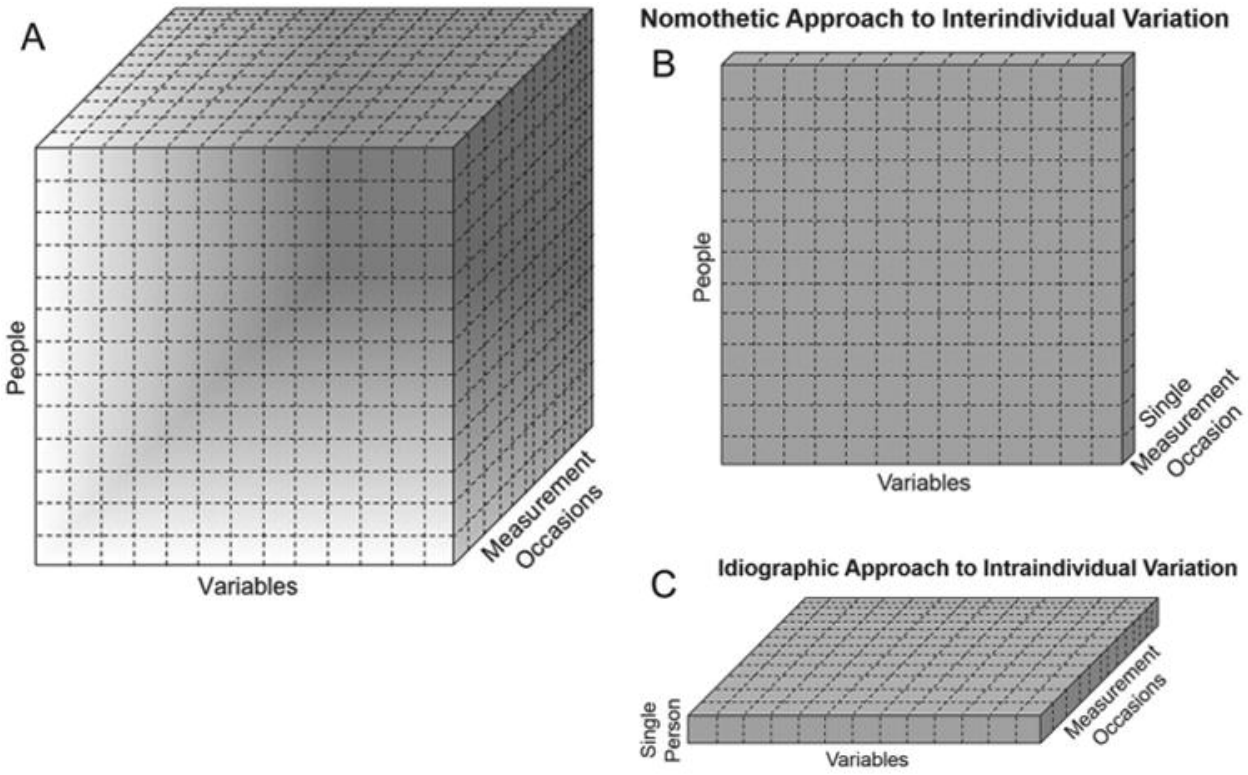
There are still debates in psychology on how to study personality.

- Do people have common or unique personality structure under different environment?
- E.g. many causes may lead to depression; students behave differently studying vs not
- Debate: developing general principles (nomothetic) or understanding individuals within their unique contexts (idiographic)

But...

Psychologists lack both data and method to address this debate.

- Current taxonomies developed on cross-sectional rather than longitudinal data
- No existing psychometric models allow both common structure and individual deviation



Beltz, Adriene M., et al. Bridging the nomothetic and idiographic approaches to the analysis of clinical data. Assessment 23.4 (2016): 447-458.

But...

Building idiographic model is challenging.

- Related phenomenon differ in biological causes (Borsboom et al. 2003, Molenaar 2004)

But...

Building idiographic model is challenging.

- Related phenomenon differ in biological causes (Borsboom et al. 2003, Molenaar 2004)

- Balance between inter- and intra-individual variation (Beltz et al. 2017)

But…

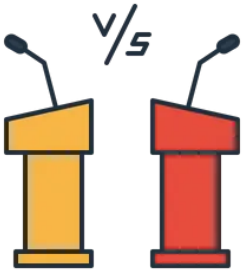
Building idiographic model is challenging.

- Related phenomenon differ in biological causes (Borsboom et al. 2003, Molenaar 2004)

- Balance between inter- and intra-individual variation (Beltz et al. 2017)

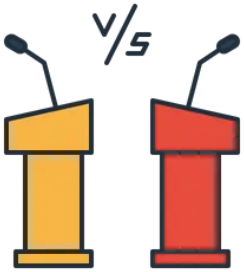
- Intrinsic evolution of psychological process (Vallacher et al. 2015)

Research Questions



RQ1.
A long-lasting psychological debate: do psychological features like personality share a common structure across population (*nomothetic*), vary uniquely for individuals (*idiographic*), or include both shared structure and individuals deviations?

Research Questions



RQ1.
A long-lasting psychological debate: do psychological features like personality share a common structure across population (*nomothetic*), vary uniquely for individuals (*idiographic*), or include both shared structure and individuals deviations?

RQ2.
Could we build a new psychometric measurement model with intra-individual/temporal variation, and contribute to this debate using a novel longitudinal dataset?

Outline

Problem statement

- Personality and Big Five
- On-going debate and challenges

Proposed method

- Data and setup
- Idiographic personality Gaussian Process

Main results

- Existing cross-sectional data for Big Five validation
- A novel longitudinal data for idiographic personalities

Setup

Our collected data

- 93 students answering 45 questions over 6-week periods
  - I see myself as someone who: is talkative/worries a lot/has little creativity, etc
  - Emotion: angry/surprised/excited, etc
  - Situation: was studying/interacted with friends/was listening to music, etc
  - DIAMONDS: work has to be done(duty)/deep thinking is required(intellect), etc

Setup

Our collected data

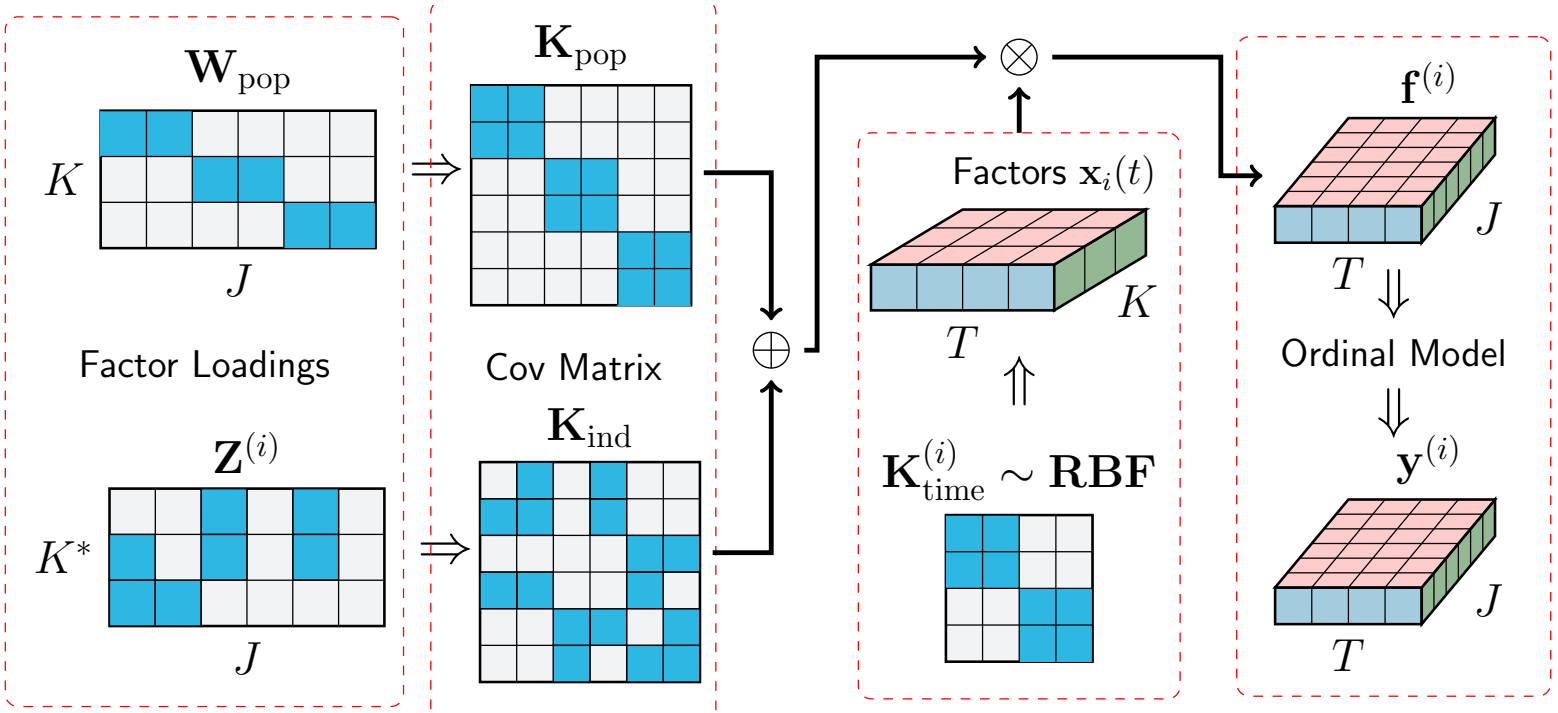
- 93 students answering 45 questions over 6-week periods
  - I see myself as someone who: is talkative/worries a lot/has little creativity, etc
  - Emotion: angry/surprised/excited, etc
  - Situation: was studying/interacted with friends/was listening to music, etc
  - DIAMONDS: work has to be done(duty)/deep thinking is required(intellect), etc

Notations

- $y_{ijt} \in \{1,...,C\}$: Likert response ranging from strongly disagree to strongly agree
- Latent variable $f_j^{(i)}(t) = \mathbf{w}_j^T \mathbf{x}_i(t)$ with factor structures in item response theory
- $\mathbf{x}_i(t)$: unit-level latent traits of length K (e.g. K=5 in Big Five) for unit i and time t
- $\mathbf{w}_j$: item-level population loading of length K for question j
- $\mathbf{Z}^{(i)}$: unit-specific low-rank idiographic component for unit i with length J

Proposed Model

Idiographic Personality Gaussian Process

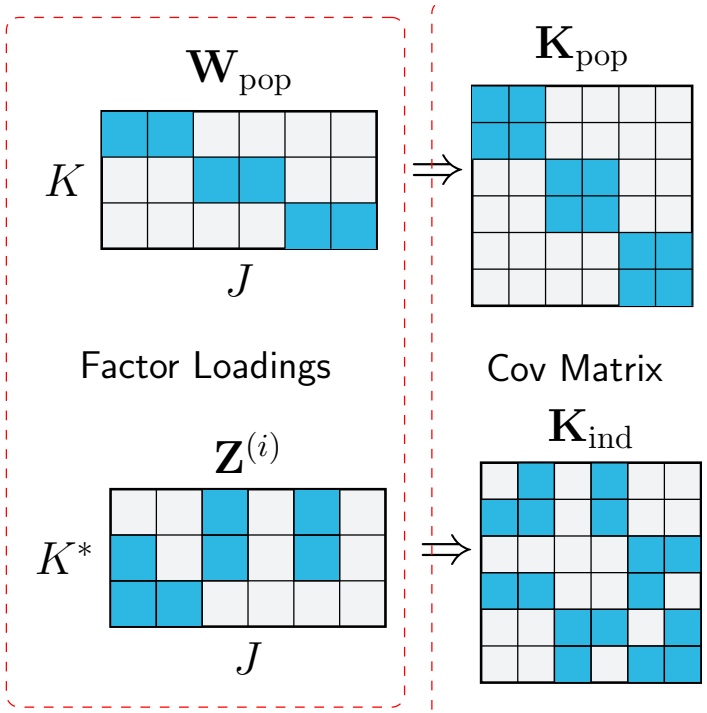


- Question-level covariance with nomothetic $\mathbf{w}_j$ and idiographic component $\mathbf{Z}^{(i)}$
- Linear model of coregionalization for $\mathbf{x}_i(t)$
- Ordinal probit likelihood for Likert response $y_{ijt} \in \{1,...,C\}$

Proposed Model

Nomothetic model

- K is latent dimension and J is number of questions
- Full covariance for unit i at time t is $J \times J$
- $\mathbf{W}_{\text{pop}}$ is $K \times J$ shared interpersonal loading matrix
- Nomothetic cov: $\mathbf{K}_{\text{pop}} = \mathbf{W}_{\text{pop}}^T \mathbf{W}_{\text{pop}}$



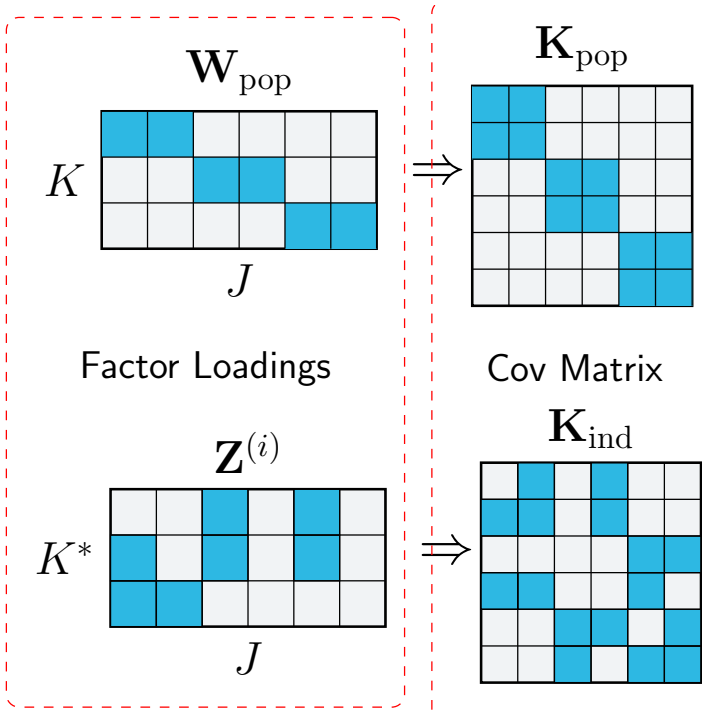
Proposed Model

Nomothetic model

- K is latent dimension and J is number of questions
- Full covariance for unit i at time t is $J \times J$
- $\mathbf{W}_{\text{pop}}$ is $K \times J$ shared interpersonal loading matrix
- Nomothetic cov: $\mathbf{K}_{\text{pop}} = \mathbf{W}_{\text{pop}}^T \mathbf{W}_{\text{pop}}$

Idiographic model

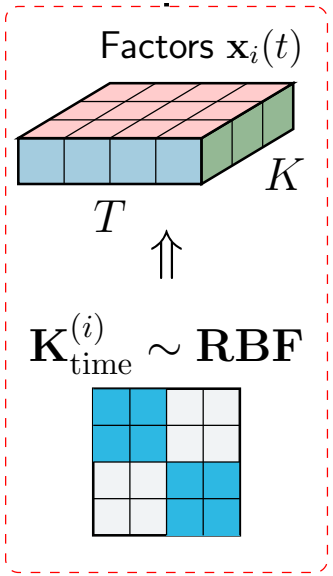
- $\mathbf{Z}^{(i)}$ is the $K^* \times J$ unit-specific low-rank idiographic component independent of $\mathbf{W}_{\text{pop}}$
- Idiographic cov: $\mathbf{K}^{(i)} = \mathbf{W}_{\text{pop}}^T \mathbf{W}_{\text{pop}} + \mathbf{Z}^{(i)T} \mathbf{Z}^{(i)}$
- Rank-1 approximation $K^* = 1$



Proposed Model

Linear model of coregionalization for $\mathbf{x}_i(t)$

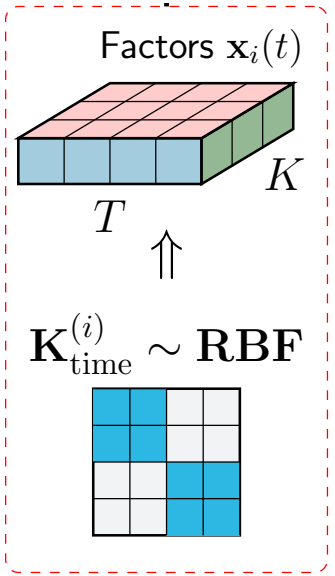
- Gaussian process prior $\mathbf{x}_i(t) \sim \text{GP}(0, K^{(i)}_{\text{time}})$ on the temporal evolution of latent traits
- $K^{(i)}_{\text{time}}$: RBF kernel with unit-specific bandwidth ℓ_i



Proposed Model

Linear model of coregionalization for $\mathbf{x}_i(t)$

- Gaussian process prior $\mathbf{x}_i(t) \sim \text{GP}(0, K^{(i)}_{\text{time}})$ on the temporal evolution of latent traits
- $K^{(i)}_{\text{time}}$: RBF kernel with unit-specific bandwidth ℓ_i



Multitask Gaussian Process

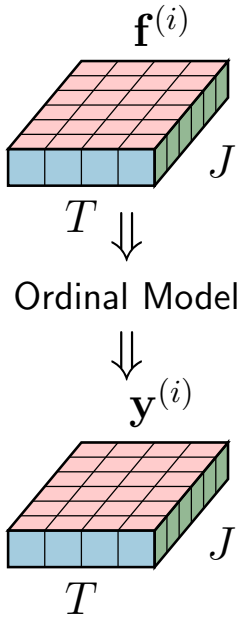
- $\mathbf{f}^{(i)}_j = [\mathbf{f_j}^{(i)}(1), \ldots, \mathbf{f_j}^{(i)}(T)]^T \sim \text{N}(0, \mathbf{w}_j^T \mathbf{w}_j K^{(i)}_{\text{time}})$ collects responses for unit i question j for all T periods
- $\mathbf{f}^{(i)} = [\mathbf{f_1}^{(i)}, \ldots, \mathbf{f_J}^{(i)}]^T$: the flattened $JT \times 1$ vector for unit i of all J questions and T periods with Kronecker product

$$\mathbf{f}^{(i)} \sim \text{GP}\left(\begin{bmatrix} \mathbf{0} \\ \vdots \\ \mathbf{0} \end{bmatrix}, \begin{bmatrix} \mathbf{w}_1^T \mathbf{w}_1 \mathbf{K}^{(i)}_{\text{time}} & \cdots & \mathbf{w}_1^T \mathbf{w}_J \mathbf{K}^{(i)}_{\text{time}} \\ \vdots & \ddots & \vdots \\ \mathbf{w}_J^T \mathbf{w}_1 \mathbf{K}^{(i)}_{\text{time}} & \cdots & \mathbf{w}_J^T \mathbf{w}_J \mathbf{K}^{(i)}_{\text{time}} \end{bmatrix} \right) \quad \Leftrightarrow \quad \mathbf{f}^{(i)} \sim \text{GP}\left(\mathbf{0}, \mathbf{W}^T \mathbf{W} \otimes \mathbf{K}^{(i)}_{\text{time}}\right)$$

Proposed Model

Ordinal probit for Likert response y_{ijt}

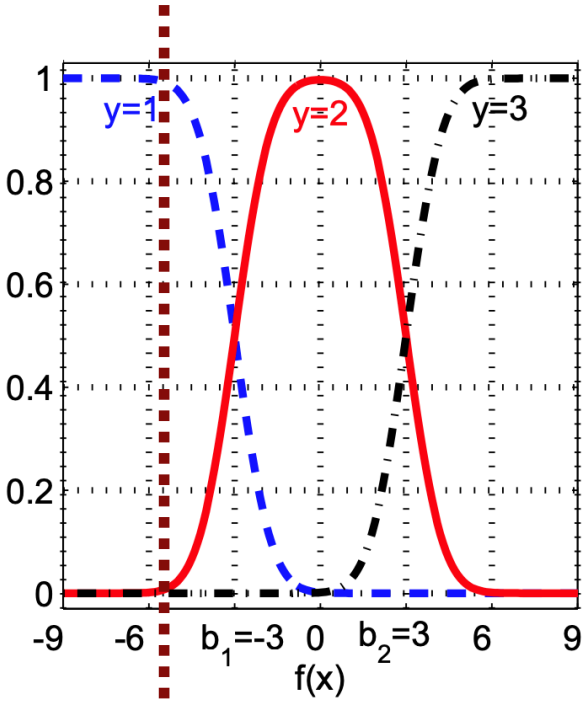
- $p\left(y = c \mid f = \mathbf{w}_j^T \mathbf{x}_i(t)\right) = \Phi(b_c - f) - \Phi(b_{c-1} - f)$ with normal CDF $\Phi(\cdot)$
- $b_0, \ldots, b_C$: threshold parameters to ensure probability simplex

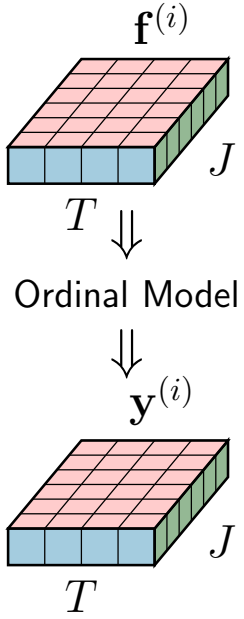


Proposed Model

Ordinal probit for Likert response y_{ijt}

- $p\left(y = c \mid f = \mathbf{w}_j^T \mathbf{x}_i(t)\right) = \Phi(b_c - f) - \Phi(b_{c-1} - f)$ with normal CDF $\Phi(\cdot)$
- $b_0, \ldots, b_C$: threshold parameters to ensure probability simplex



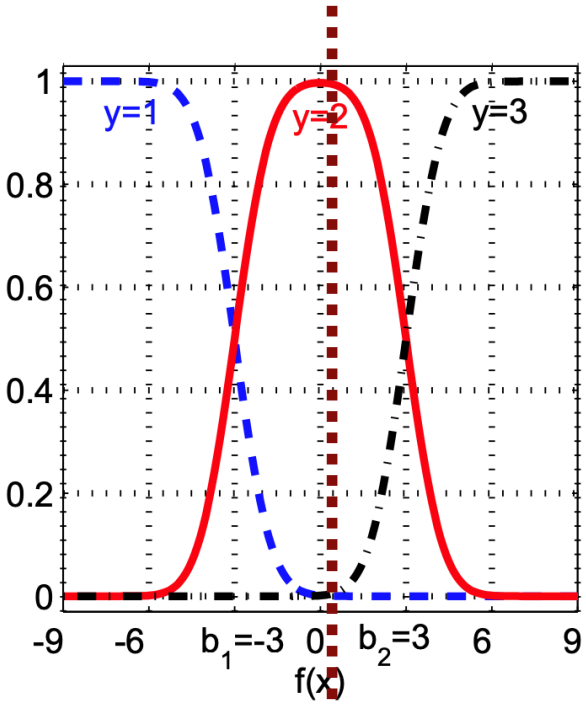


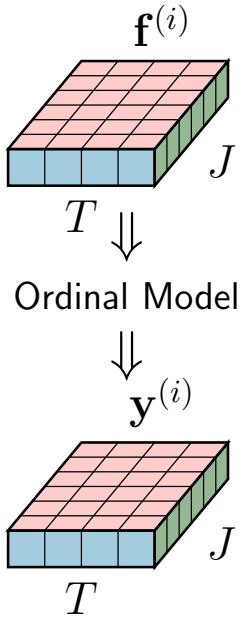
$$p(y = 1 \mid f = -6) \approx 1$$

Proposed Model

Ordinal probit for Likert response y_{ijt}

- $p\left(y = c \mid f = \mathbf{w}_j^T \mathbf{x}_i(t)\right) = \Phi(b_c - f) - \Phi(b_{c-1} - f)$ with normal CDF $\Phi(\cdot)$
- $b_0, \ldots, b_C$: threshold parameters to ensure probability simplex



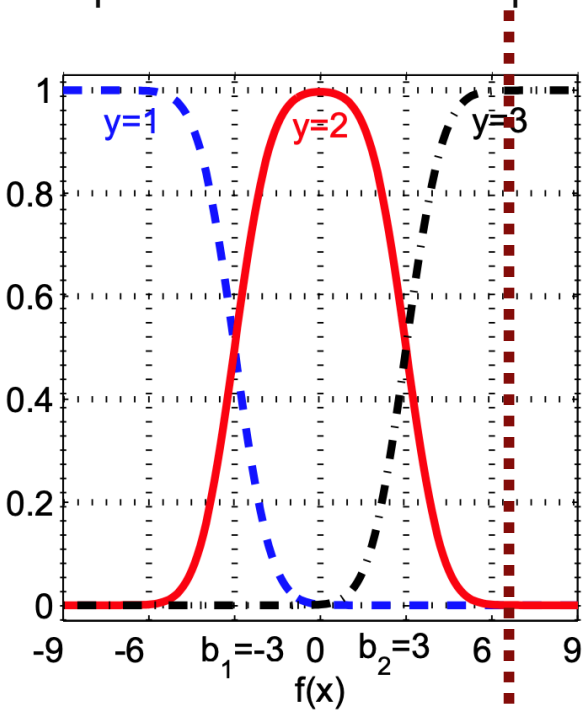


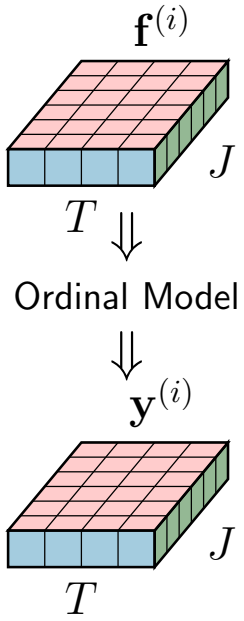
$$p(y = 2 \mid f = 0) \approx 1$$

Proposed Model

Ordinal probit for Likert response y_{ijt}

- $p\left(y = c \mid f = \mathbf{w}_j^T \mathbf{x}_i(t)\right) = \Phi(b_c - f) - \Phi(b_{c-1} - f)$ with normal CDF $\Phi(\cdot)$
- $b_0, \ldots, b_C$: threshold parameters to ensure probability simplex



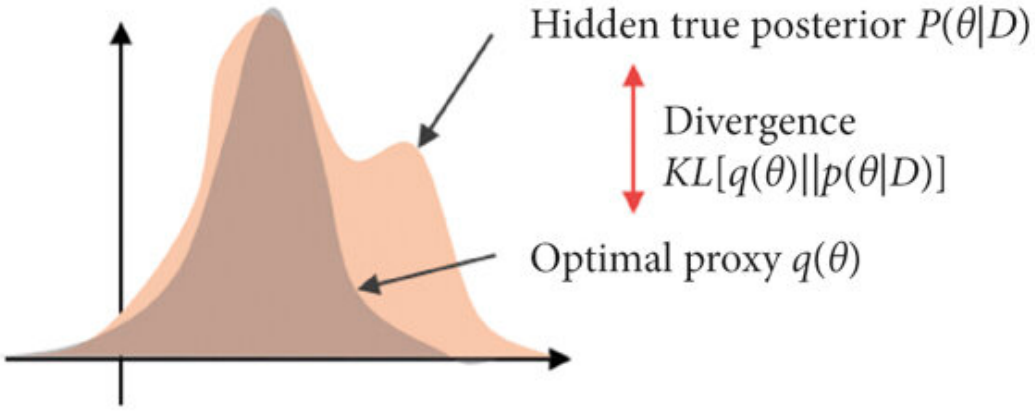


$$p(y = 3 \mid f = 6) \approx 1$$

Proposed Model

Variational inference

- Model evidence $p(\mathbf{y}) = \int p(\mathbf{y}, \mathbf{w})\, d\mathbf{w} = \int p(\mathbf{y} \mid \mathbf{w}) p(\mathbf{w})\, d\mathbf{w}$ not always tractable
- Approximate $p(\mathbf{w} \mid \mathbf{y})$ with a simpler distribution $q_\phi(\mathbf{w})$
- Maximize Evidence Lower Bound $\mathbb{E}_{q_\phi(\mathbf{w})}\left[\log p(\mathbf{y}, \mathbf{w})\right] - \mathbb{E}_{q_\phi(\mathbf{w})}\left[\log q_\phi(\mathbf{w})\right]$
- Off-the-shelf SVI + optimizer in GPyTorch



Outline

Problem statement

- Personality and Big Five
- On-going debate and challenges

Proposed method

- Data and setup
- Idiographic personality Gaussian Process

Main results

- Existing cross-sectional data for Big Five validation
- A novel longitudinal data for idiographic personalities

Data

Study 1: existing cross-sectional data (Soto 2017)

- Life outcomes of personality replication (LOOPR)
- 3,459 participants on Qualtrics answering 60 questions from the Big Five Inventory (BFI) but in one assessment, resulting in 207,540 responses
- Apply quota sampling to ensure sample diversity

Data

Study 1: existing cross-sectional data (Soto 2017)

- Life outcomes of personality replication (LOOPR)
- 3,459 participants on Qualtrics answering 60 questions from the Big Five Inventory (BFI) but in one assessment, resulting in 207,540 responses
- Apply quota sampling to ensure sample diversity

Study 2: novel longitudinal-sectional data (Chen et al. 2024)

- 93 participants with 94 assessments per student on average (automated reminder to participants)
- Answer 45 questions from the next Big Five Inventory (BFI-2), resulting in 603,420 responses in total
- Focused on student sub-population, but also applied quota sampling

Results: Study 1

i. IPGP improves model evidence and response prediction

	ACC ↑					LL / N ↑				
MODEL	$K=1$	$K=2$	$K=3$	$K=4$	$K=5$	$K=1$	$K=2$	$K=3$	$K=4$	$K=5$
PCA	0.106	0.099	0.123	0.217	0.192	−1.957	−1.990	−2.009	−2.036	−2.051
GRM	0.238	0.107	0.178	0.113	0.146	−1.838	−1.832	−1.814	−1.838	−1.841
GPCM	0.213	0.156	0.186	0.159	0.163	−1.754	−1.761	−1.764	−1.750	−1.756
SRM	0.243	0.134	0.179	0.125	0.155	−1.784	−1.784	−1.783	−1.780	−1.767
GPDM	0.268	0.272	0.266	0.268	0.263	−2.155	−2.158	−2.158	−2.159	−2.158
DSEM	0.188	0.114	0.110	0.105	0.104	−1.997	−1.960	−1.908	−1.845	−1.775
IPGP	**0.322**	**0.319**	***0.323***	**0.318**	**0.318**	**−1.478**	**−1.477**	**−1.477**	**−1.477**	***−1.476***

Baselines

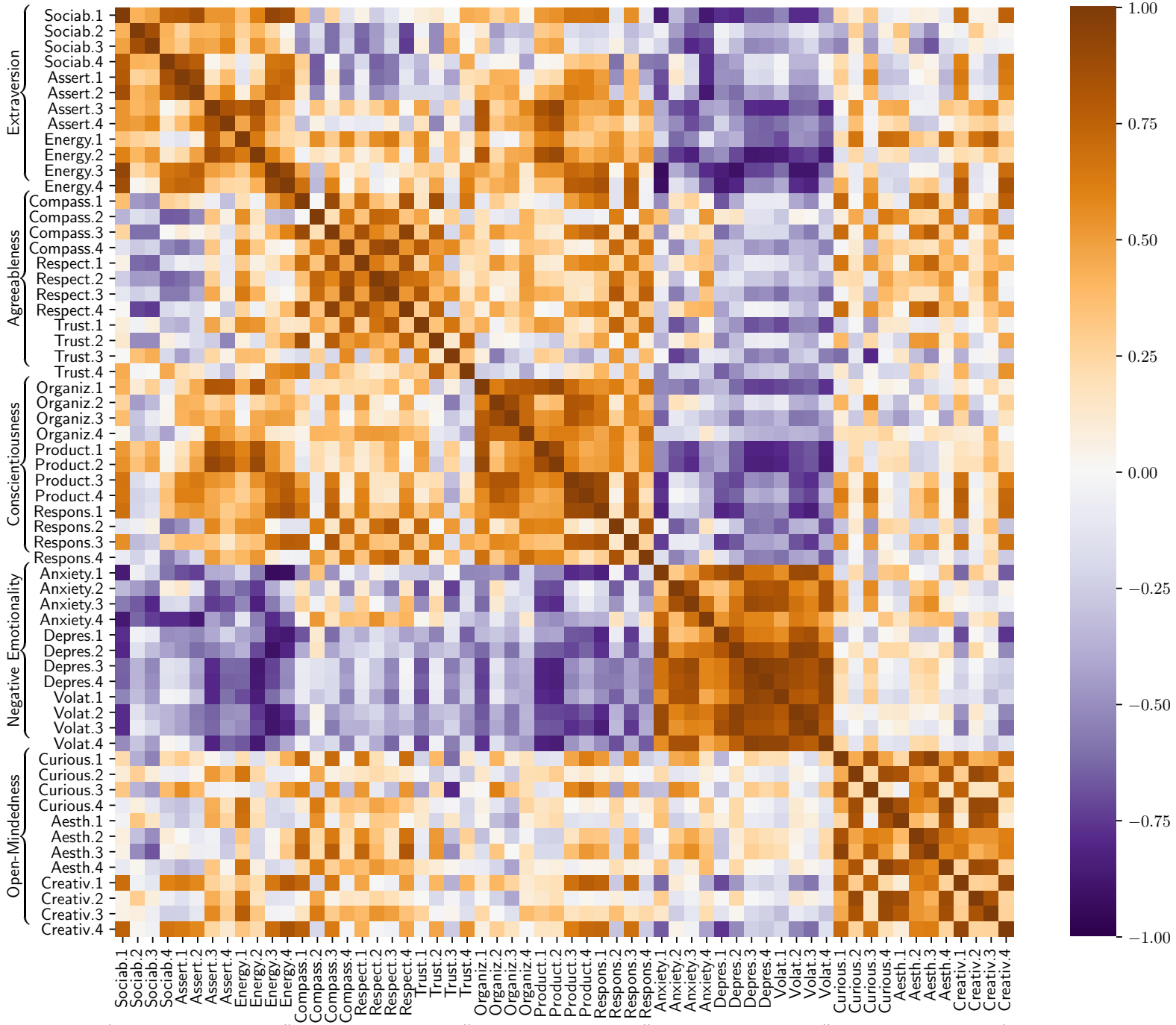
- PCA: raw factor analysis with principal component analysis, no latent space
- Item response models: graded response model (GRM), generalized partial credit (GPCM), sequential response model (SRM)
- Gaussian process dynamic model (GPDM)
- (Dynamic) structural equation (DSEM)

Results: Study 1

ii. Explorative factor analysis verifies Big Five theory

RANK	1	2	3	4	5	6	7	8	9	10
LL/N ↑	−1.478	−1.477	−1.477	−1.477	**−1.476**	−1.477	−1.477	−1.477	−1.478	−1.477
BIC ($\times 10^{11}$) ↓	1.2736	1.2726	1.2728	1.2726	**1.2722**	1.2725	1.2726	1.2732	1.2732	1.2724

$$BIC = k\ln(n) - 2\ln(L)$$


Extraversion
Sociab.1
Sociab.2
Sociab.3
Sociab.4
Assert.1
Assert.2
Assert.3
Assert.4
Energy.1
Energy.2
Energy.3
Energy.4
Agreeableness
Compass.1
Compass.2
Compass.3
Compass.4
Respect.1
Respect.2
Respect.3
Respect.4
Trust.1
Trust.2
Trust.3
Trust.4
Conscientiousness
Organiz.1
Organiz.2
Organiz.3
Organiz.4
Product.1
Product.2
Product.3
Product.4
Respons.1
Respons.2
Respons.3
Respons.4
Negative Emotionality
Anxiety.1
Anxiety.2
Anxiety.3
Anxiety.4
Depres.1
Depres.2
Depres.3
Depres.4
Volat.1
Volat.2
Volat.3
Volat.4
Open-Mindedness
Curious.1
Curious.2
Curious.3
Curious.4
Aesth.1
Aesth.2
Aesth.3
Aesth.4
Creativ.1
Creativ.2
Creativ.3
Creativ.4
1.00
0.75
0.50
0.25
0.00
−0.25
−0.50
−0.75
−1.00

Results: Study 2

i. Idiographic model is favored to nomothetic model in likelihood ratio test.

	ACC	LL/N
GRM	0.210	−2.266
GPCM	0.288	−1.516
SRM	0.260	−1.927
GPDM	0.382	−3.865
DSEM	0.226	−1.399
TVAR	0.382	−1.546
IPGP-NOM	0.403	−1.410
IPGP	**0.417**	**−1.369**

$$\log\left(\frac{P(M_{\text{idio}} \mid D)}{P(M_{\text{nom}} \mid D)}\right) = 1.06 \times 10^4$$

Results: Study 2

i. Idiographic model is favored to nomothetic model in likelihood ratio test.

	ACC	LL/N
GRM	0.210	−2.266
GPCM	0.288	−1.516
SRM	0.260	−1.927
GPDM	0.382	−3.865
DSEM	0.226	−1.399
TVAR	0.382	−1.546
IPGP-NOM	0.403	−1.410
IPGP	**0.417**	**−1.369**

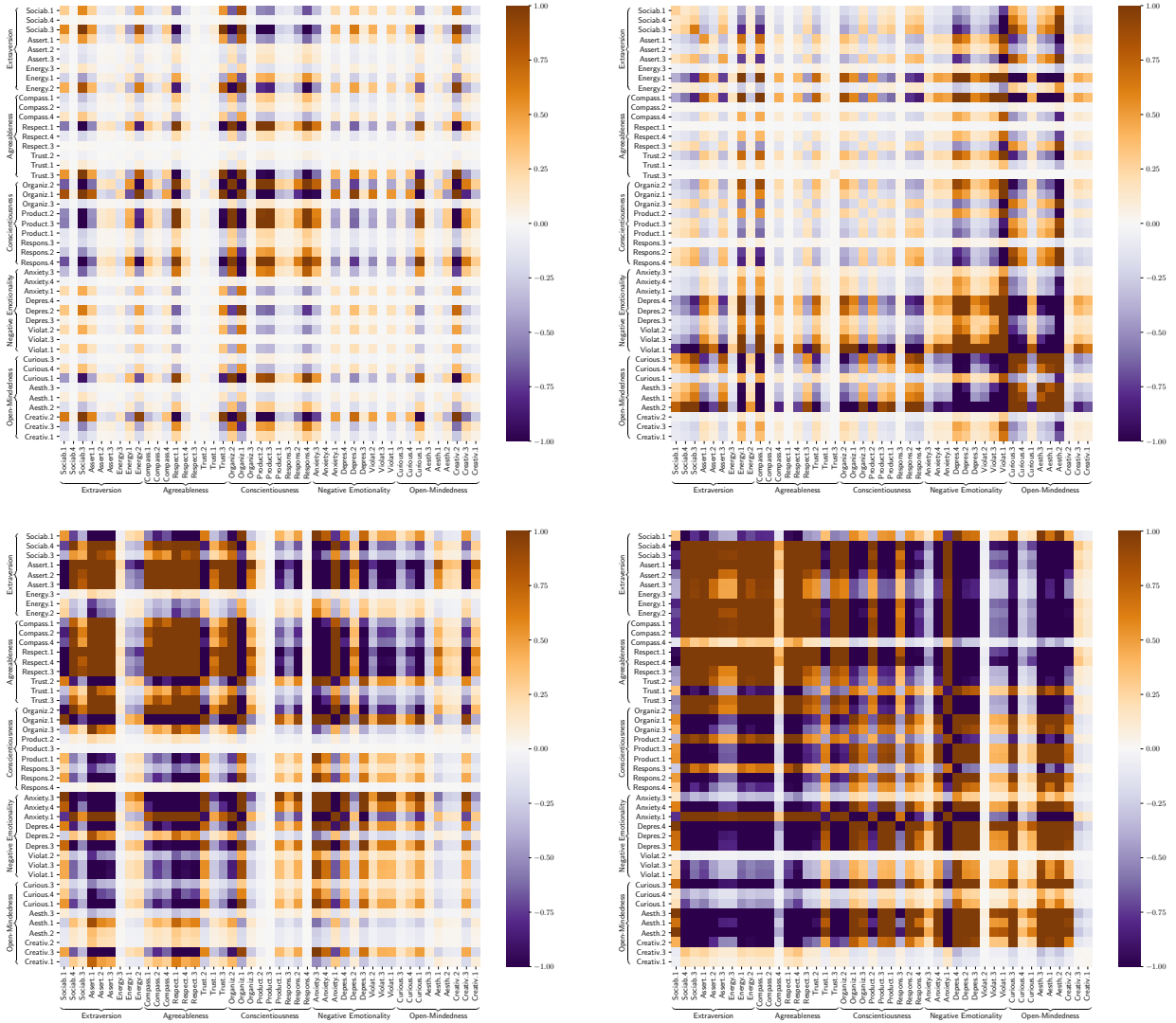
$$\log\left(\frac{P(M_{\text{idio}} \mid D)}{P(M_{\text{nom}} \mid D)}\right) = 1.06 \times 10^4$$

RQ1.

Answer: Psychological features include both shared structure and individuals deviations.

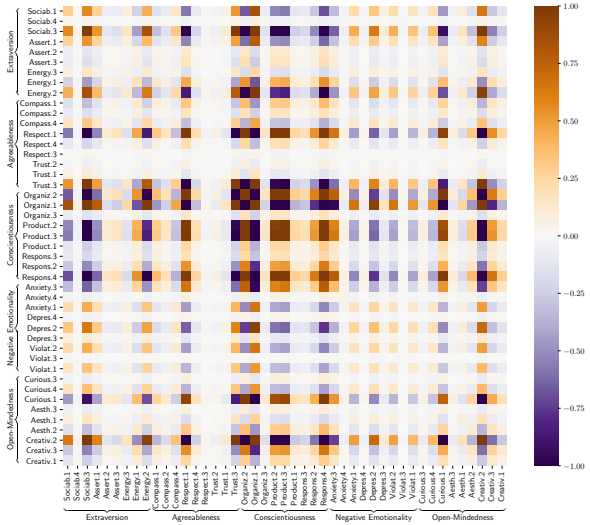
IPGP-NOM	0.403	−1.410
IPGP	**0.417**	**−1.369**

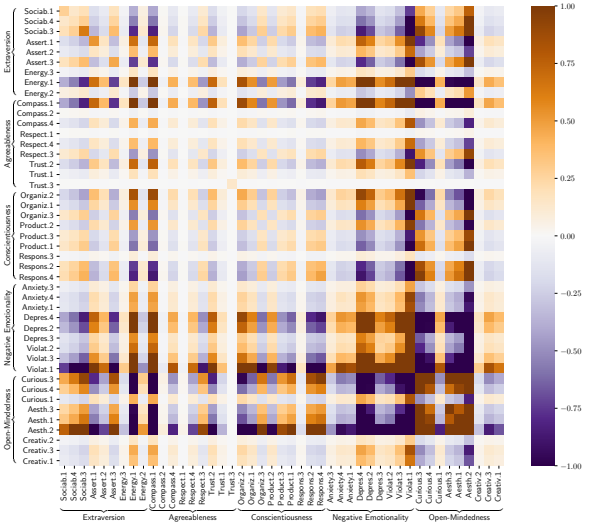
$$\log\left(\frac{P(M_{\text{idio}} \mid D)}{P(M_{\text{nom}} \mid D)}\right) = 1.06 \times 10^4$$



IPGP-NOM	0.403	−1.410
IPGP	**0.417**	**−1.369**

$$\log\left(\frac{P(M_{\text{idio}} \mid D)}{P(M_{\text{nom}} \mid D)}\right) = 1.06 \times 10^4$$



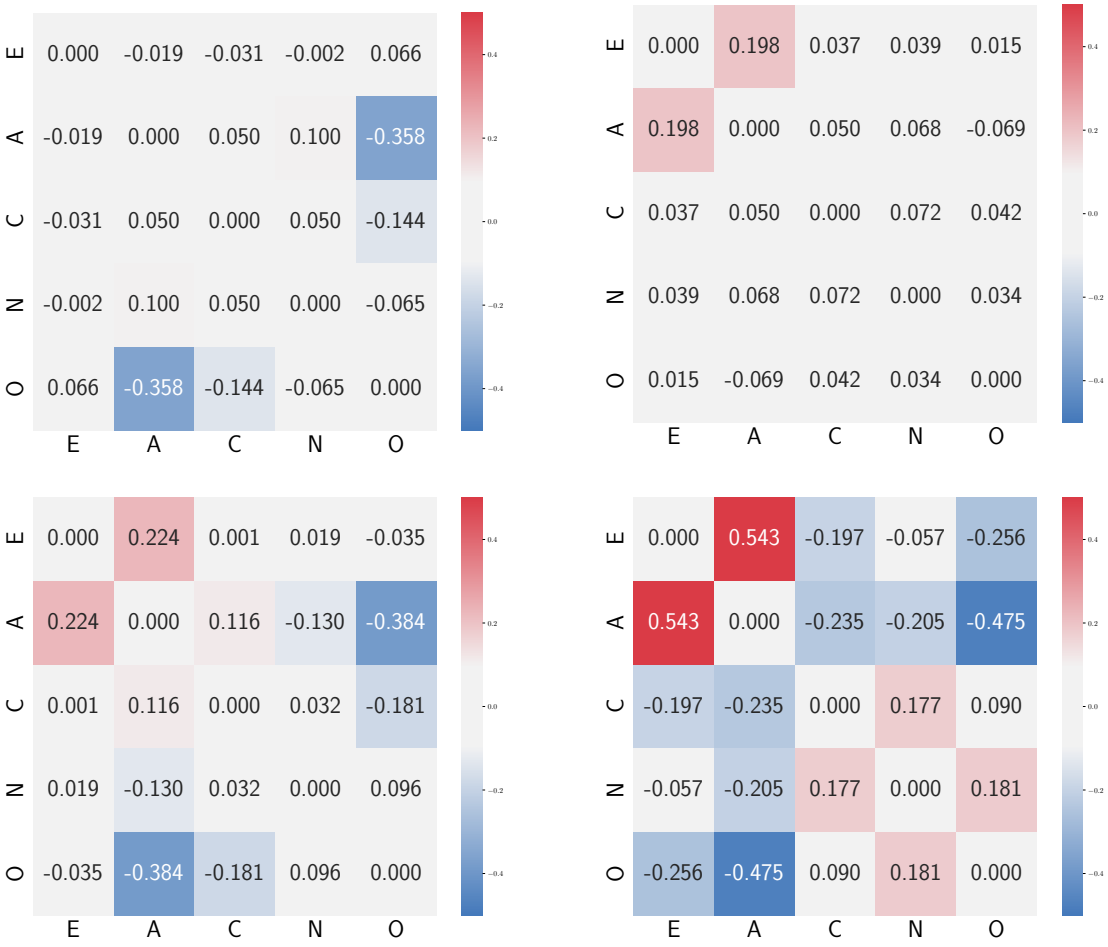


RQ2.

Answer: Our new measurement model is able to identify intra-individual variation.

Results: Study 2

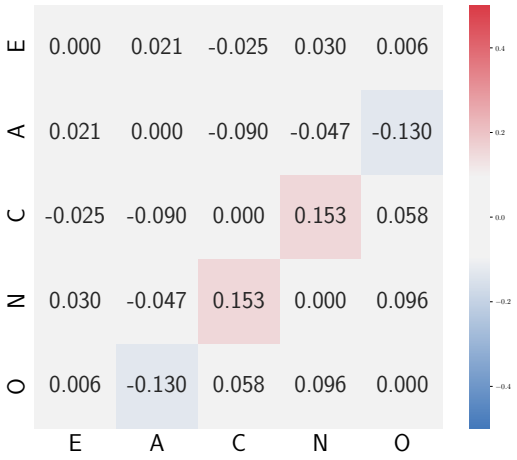
ii. Idiographic model identifies unique clusters of personality covariance.



Results: Study 2

iii. Inter-trait correlation can be explained by contexts.

Averaged inter-trait correlation matrix



Residual corr of studying vs not

Takeaway

- **New measurement model of idiographic personality Gaussian Process to address the idiographic and nomothetic debate**

- **Collect a novel longitudinal dataset with fidelity and predictive accuracy**

- **Open new revenues for future research on psychology measurement with environment and context**

Thank you!

Project Code

github.com/yahoochen97/GP-Idiographic-Measurement

Funding

2023 Seed Grant of Transdisciplinary Institute in Applied Data Sciences at Washington University in St Louis

National Science Foundation IIS–1845434