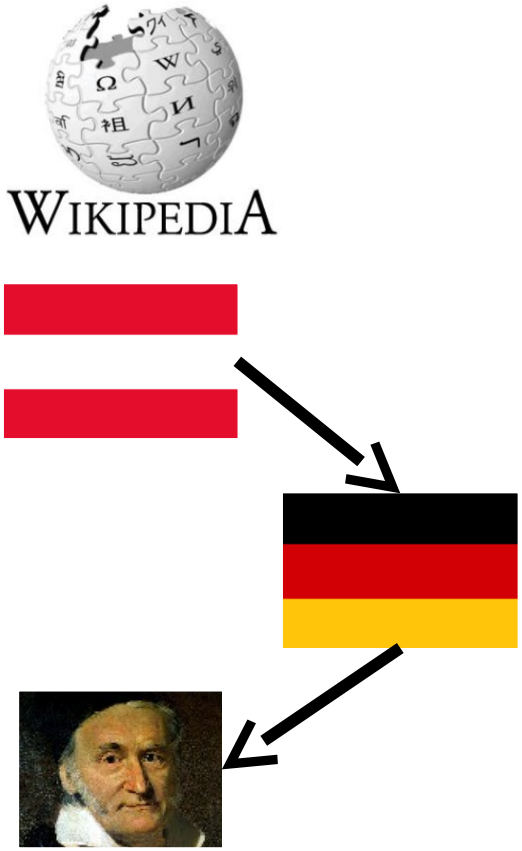
Part 4

Comparing Hypotheses about Sequential Data

Example: Human Navigation

- Humans prefer to navigate…
  - H1: over semantically similar websites
  - H2: via self-loops (e.g., refreshing)
  - H3: by using the structural link network
  - H4: by preferring similar categories
  - H5: by utilizing structural properties
  - H6: by information scent



[West et al. IJCAI 2009], [Singer et al. IJSWIS 2013],
[West & Leskovec WWW 2012], [Chi et al. CHI 2001]

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What is the relative plausibility of these hypotheses given data?

[West et al. IJCAI 2009], [Singer et al. IJSWIS 2013],
[West & Leskovec WWW 2012], [Chi et al. CHI 2001]

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HypTrails
[Singer et al. WWW 2015]

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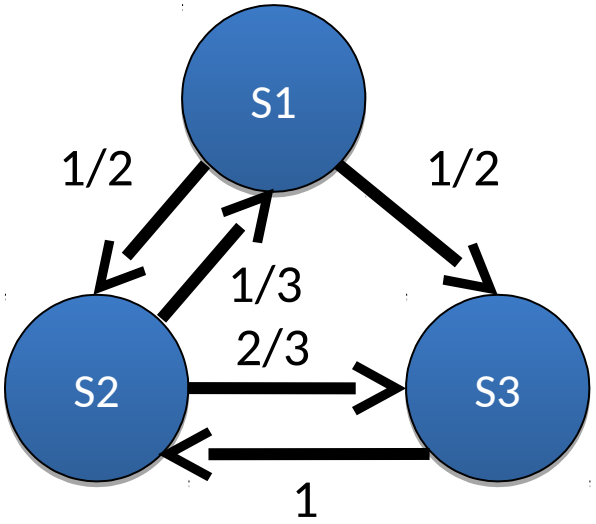
HypTrails in a nutshell

- Goal: Express and compare hypotheses about sequences in a coherent research approach
- Method:
  - First-order Markov chain model
  - Bayesian inference
- Idea:
  - Incorporate hypotheses as priors
  - Utilize sensitivity of marginal likelihood on the prior
- Outcome: Partial ordering of hypotheses

Structure of HypTrails

Structure of HypTrails

MC Model

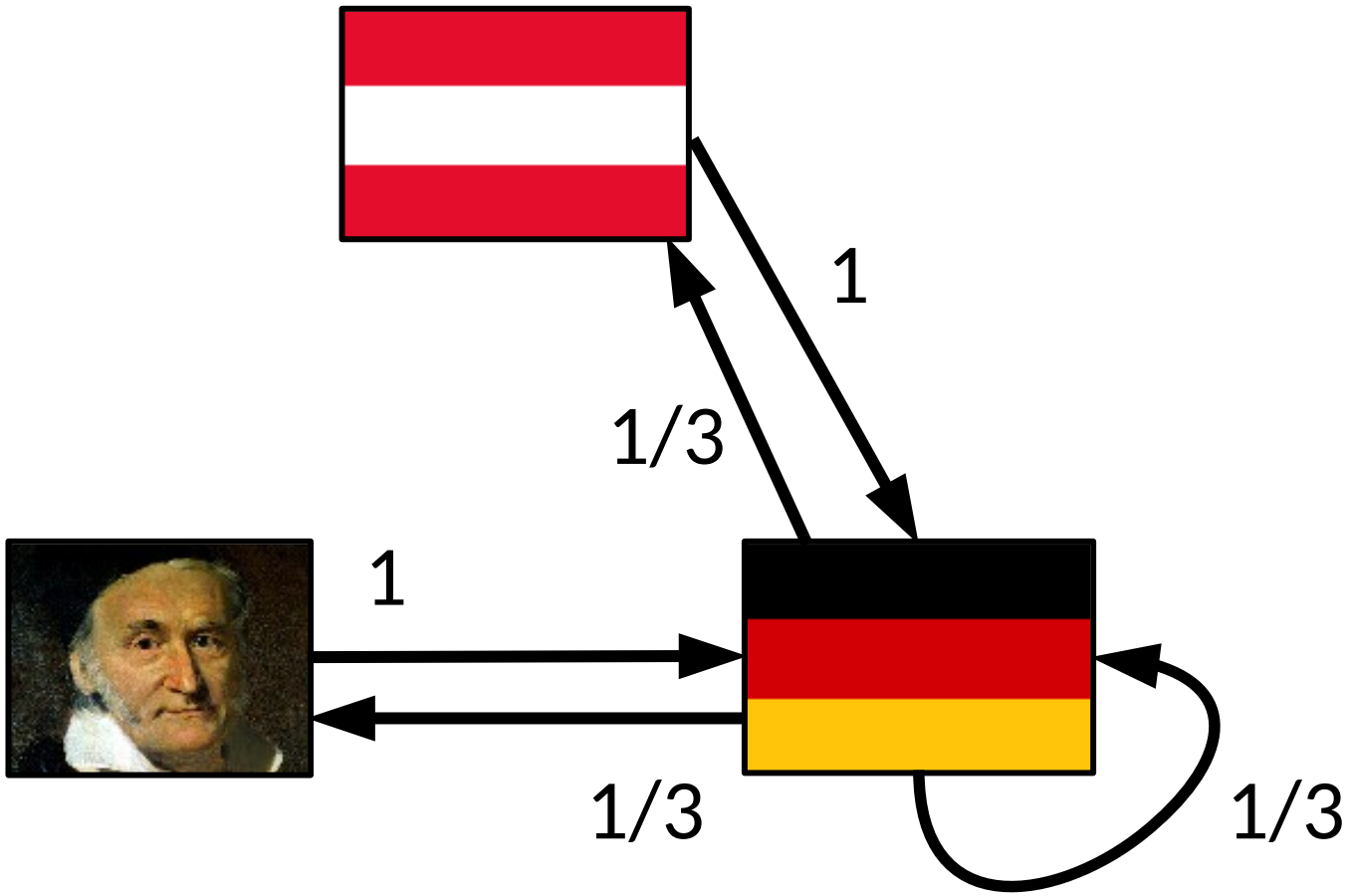


How to express hypotheses?

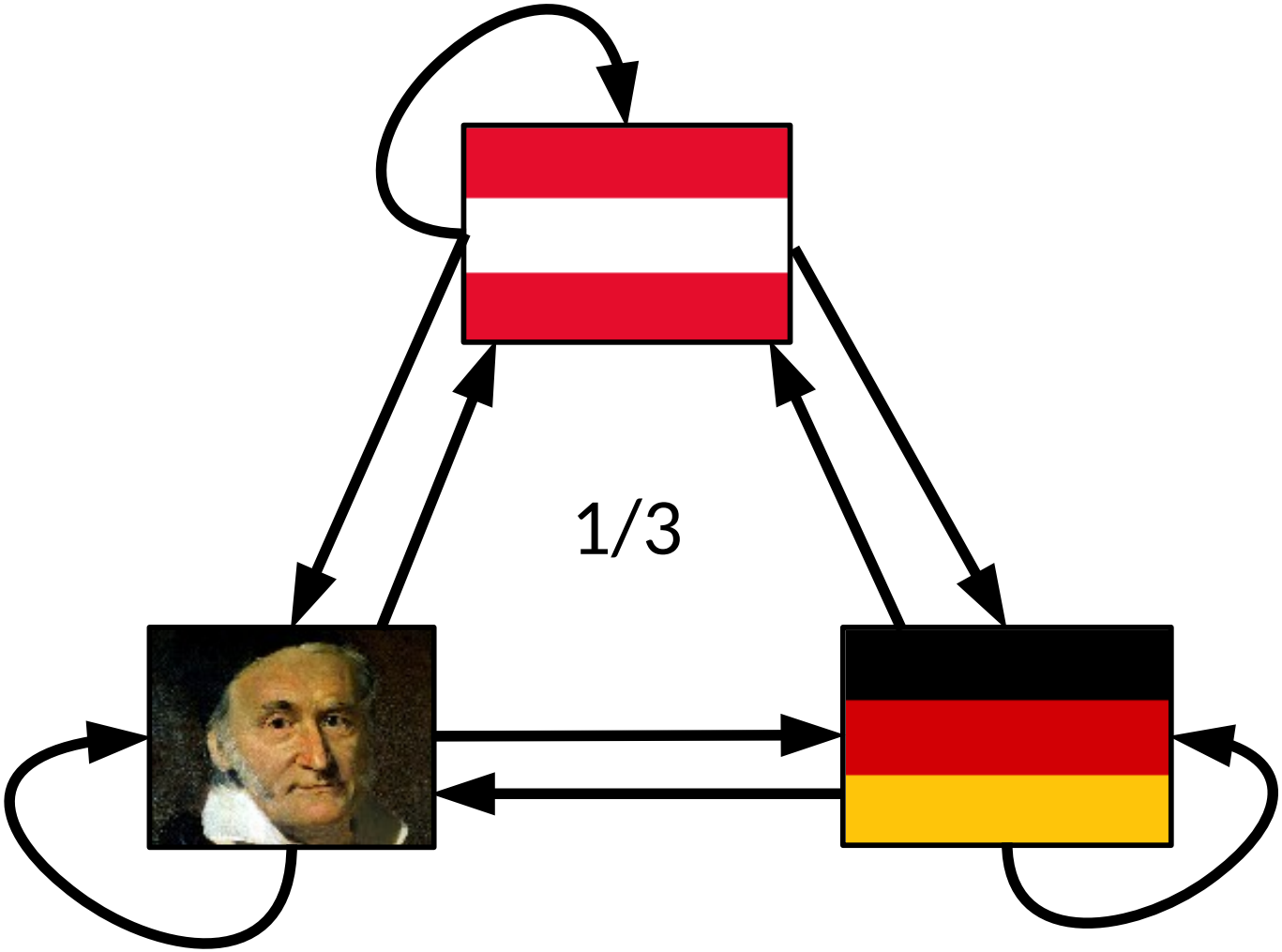
How to express hypotheses?

As assumptions in parameters of Markov Chain model.

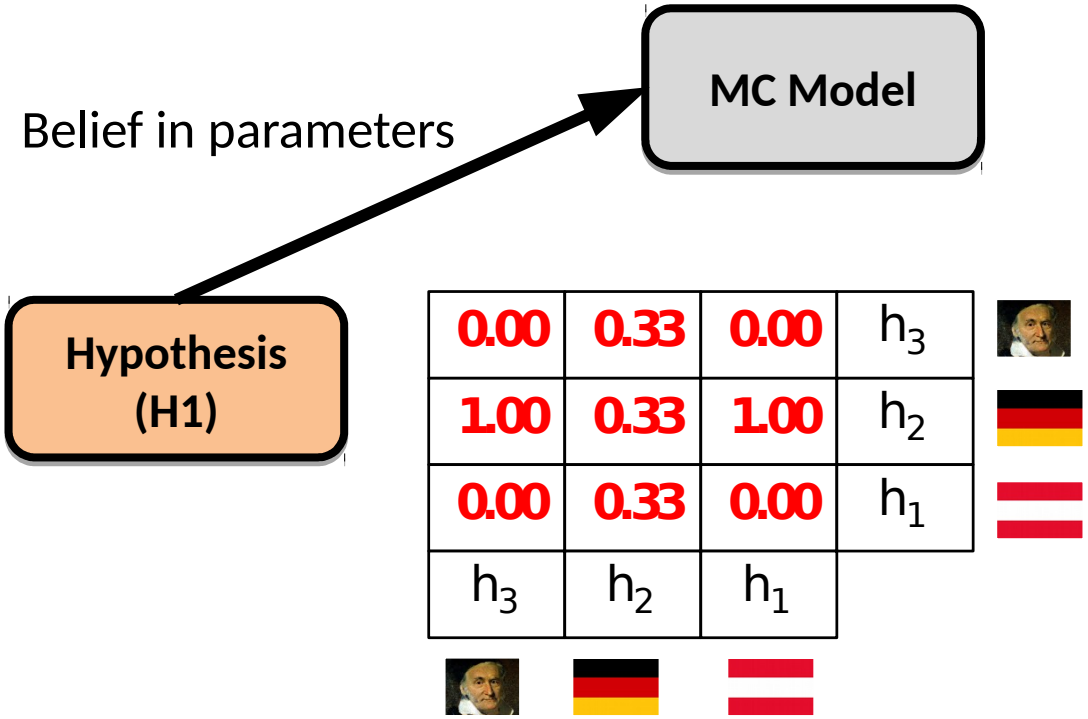
Structural hypothesis



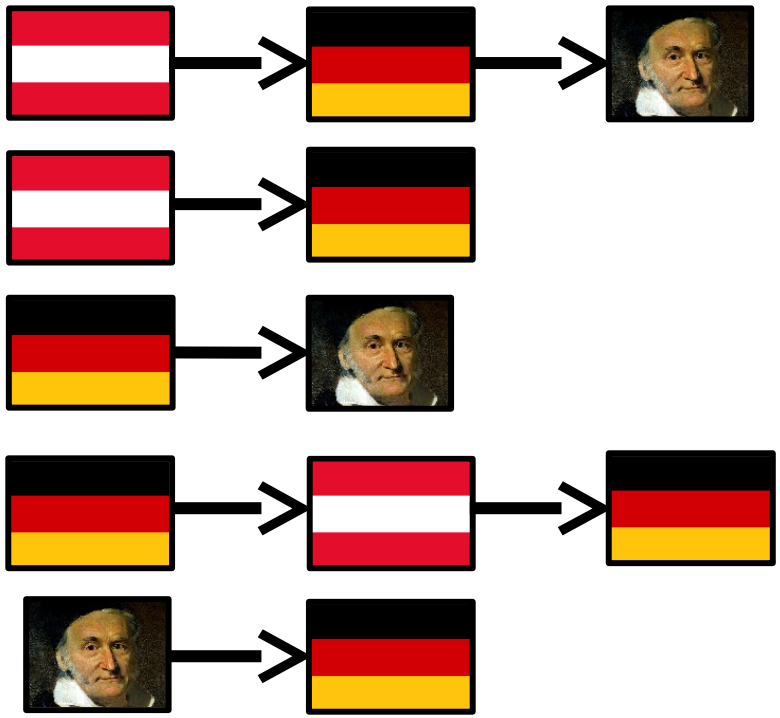
Uniform hypothesis

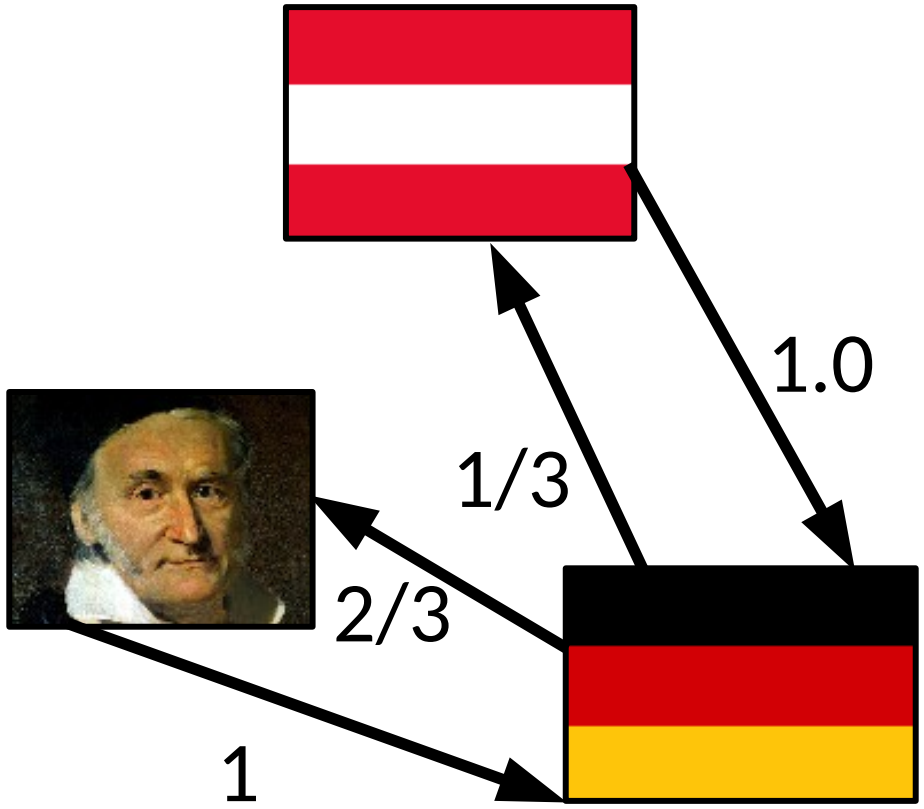


Structure of HypTrails



Empirical observations





Which hypothesis is the most plausible one?

Bayesian model comparison: marginal likelihood

$$\overbrace{P(D|M)}^{\text{marginal likelihood}} = \int \overbrace{P(D|\theta, M)}^{\text{likelihood}} \overbrace{P(\theta|M)}^{\text{prior}} d\theta$$

Bayesian model comparison: marginal likelihood

Probability of parameters before observing data

$$\overbrace{P(D|H)}^{\text{marginal likelihood}} = \int \overbrace{P(D|\theta)}^{\text{likelihood}} \overbrace{P(\theta|H)}^{\text{prior}} d\theta$$

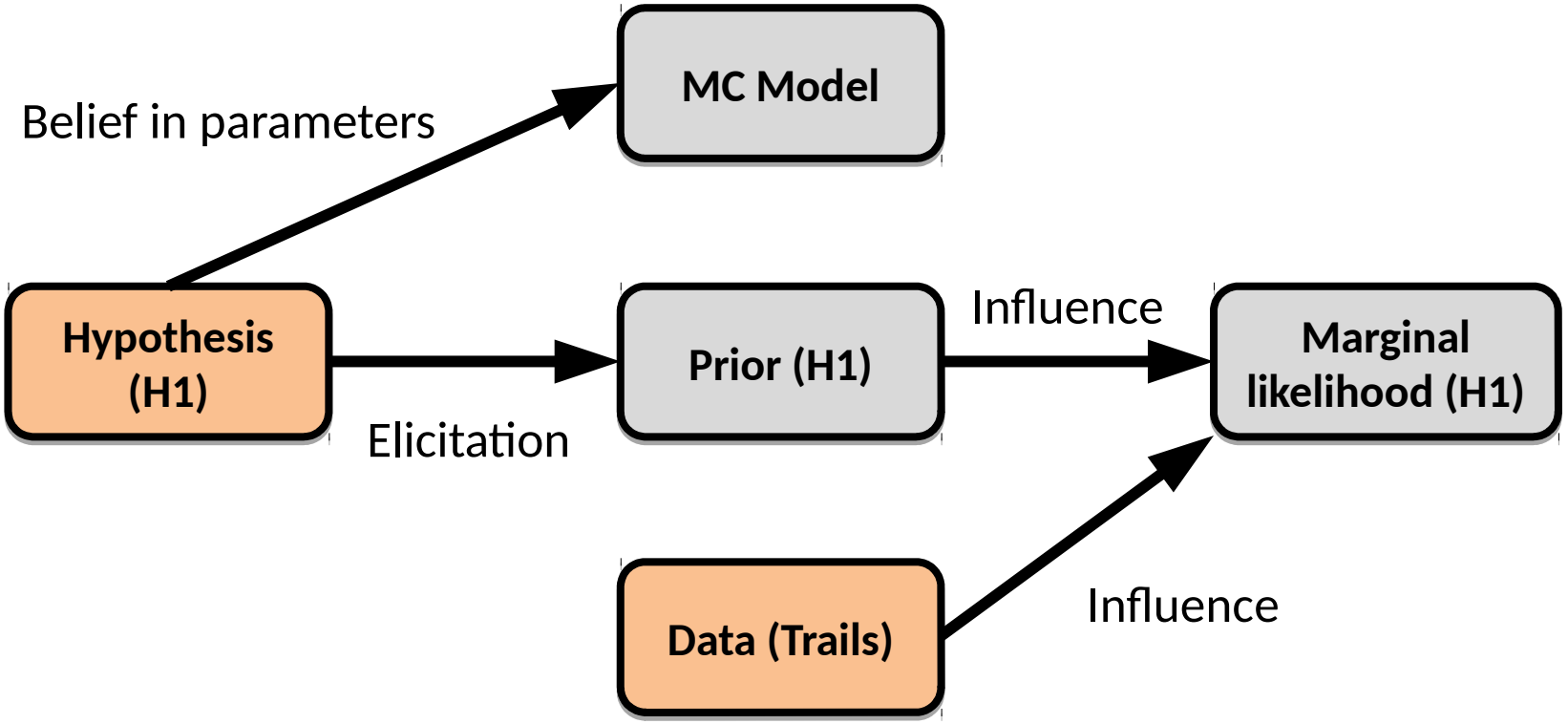
Bayesian model comparison: marginal likelihood

Probability of parameters before observing data

$$\overbrace{P(D|H)}^{\text{marginal likelihood}} = \int \overbrace{P(D|\theta)}^{\text{likelihood}} \overbrace{P(\theta|H)}^{\text{prior}} d\theta$$

Hypothesis

Structure of HypTrails



How to elicit priors from expressed hypotheses?

Conjugate Dirichlet prior

- Hyperparameters: pseudo counts

Conjugate Dirichlet prior

- Hyperparameters: pseudo counts

$$\begin{bmatrix} p_{1,1} & p_{1,2} & \dots & p_{1,j} \\ p_{2,1} & p_{2,2} & \dots & p_{2,j} \\ \dots & \dots & \dots & \dots \\ p_{i,1} & p_{i,2} & \dots & p_{i,j} \end{bmatrix} \Rightarrow \begin{bmatrix} \alpha_{1,1} & \alpha_{1,2} & \dots & \alpha_{1,j} \\ \alpha_{2,1} & \alpha_{2,2} & \dots & \alpha_{2,j} \\ \dots & \dots & \dots & \dots \\ \alpha_{i,1} & \alpha_{i,2} & \dots & \alpha_{i,j} \end{bmatrix}$$

Hypothesis parameters

Dirichlet hyperparameters

Elicitation

- Multiply row-normalized hypothesis matrix with concentration parameter k
- Higher k → stronger belief
- Additional proto-prior

$$\begin{bmatrix} p_{1,1} & p_{1,2} & \dots & p_{1,j} \\ p_{2,1} & p_{2,2} & \dots & p_{2,j} \\ \dots & \dots & \dots & \dots \\ p_{i,1} & p_{i,2} & \dots & p_{i,j} \end{bmatrix} \cdot k \Rightarrow \begin{bmatrix} \alpha_{1,1} & \alpha_{1,2} & \dots & \alpha_{1,j} \\ \alpha_{2,1} & \alpha_{2,2} & \dots & \alpha_{2,j} \\ \dots & \dots & \dots & \dots \\ \alpha_{i,1} & \alpha_{i,2} & \dots & \alpha_{i,j} \end{bmatrix}$$

Hypothesis parameters

Dirichlet hyperparameters

2 state example: Beta prior

Hypothesis: $[0.7, 0.3]$

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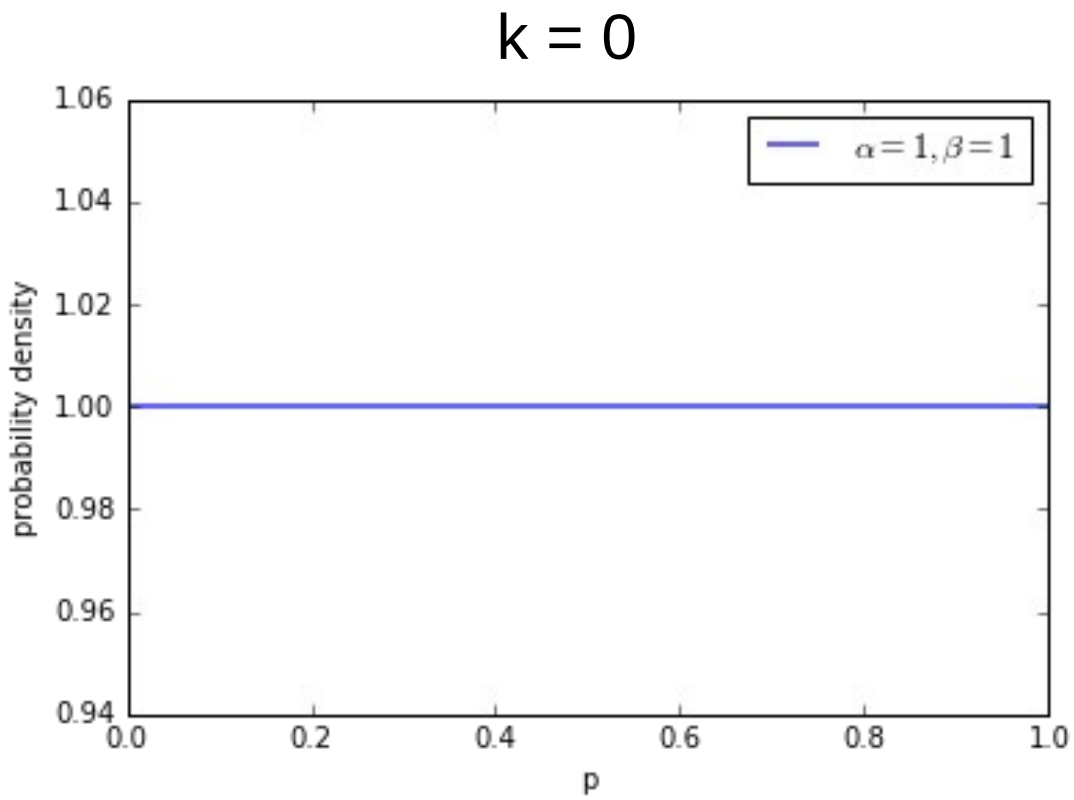
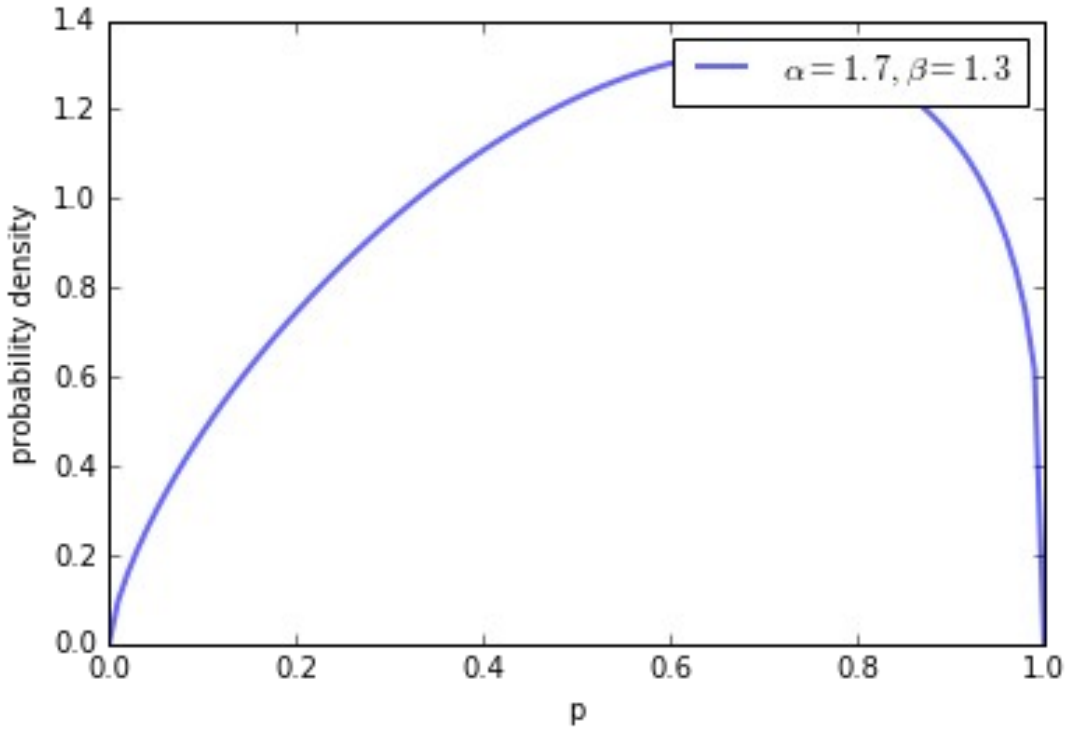


2 state example: Beta prior

Hypothesis: $[0.7, 0.3]$

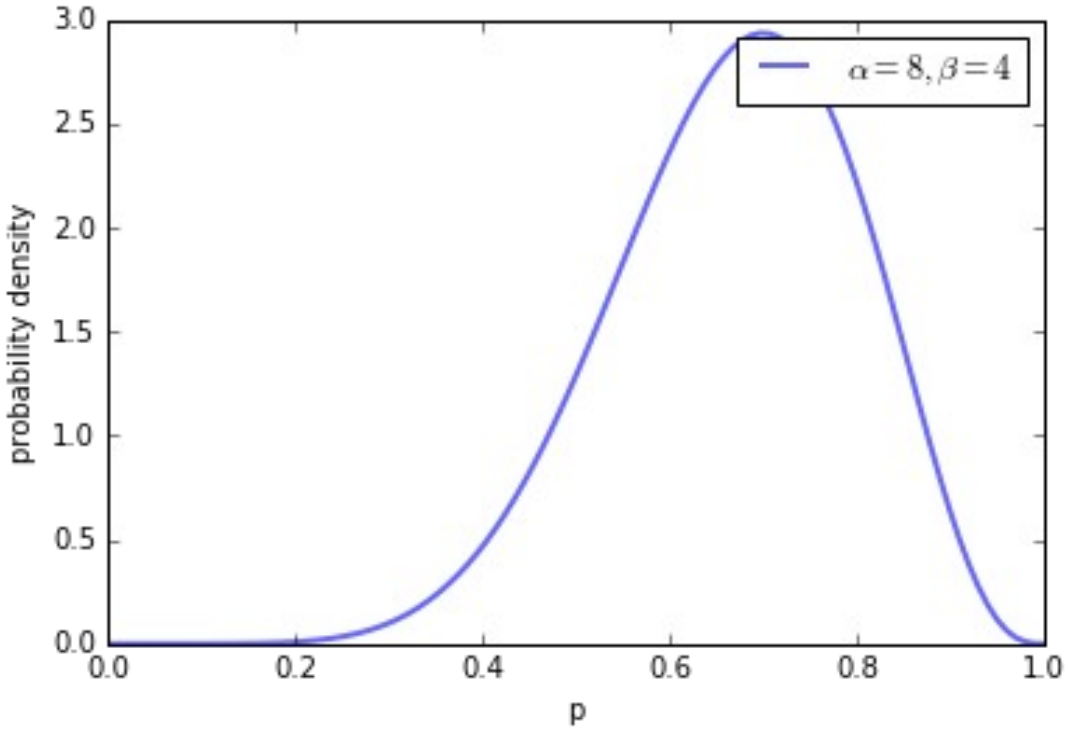
k = 1



2 state example: Beta prior

Hypothesis: $[0.7, 0.3]$

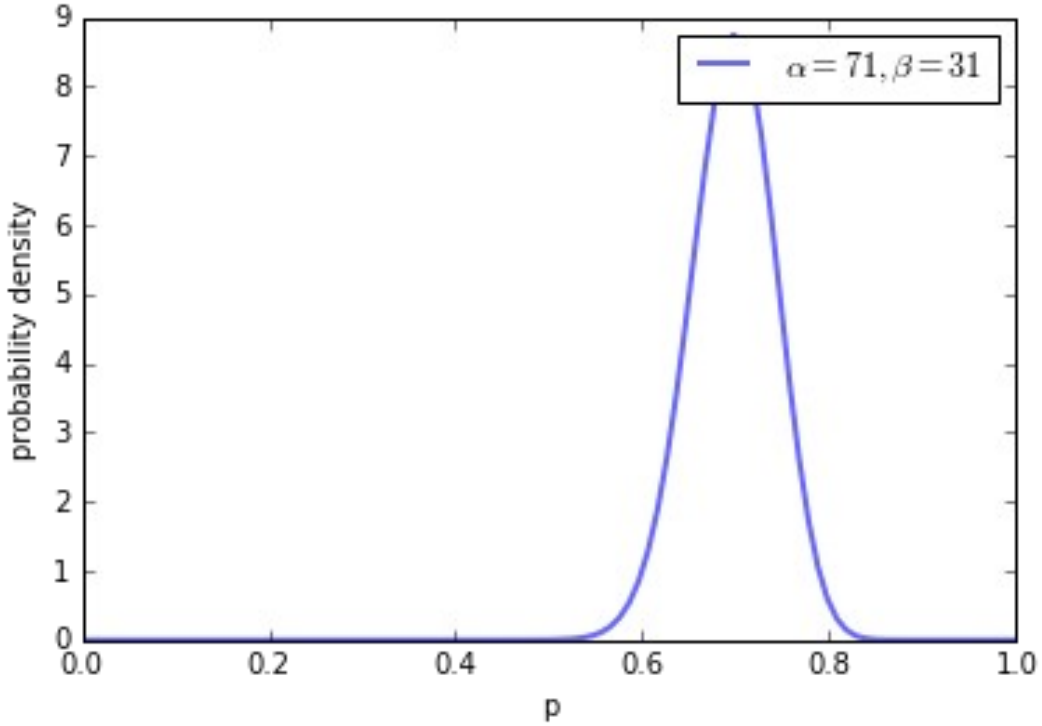
k = 10



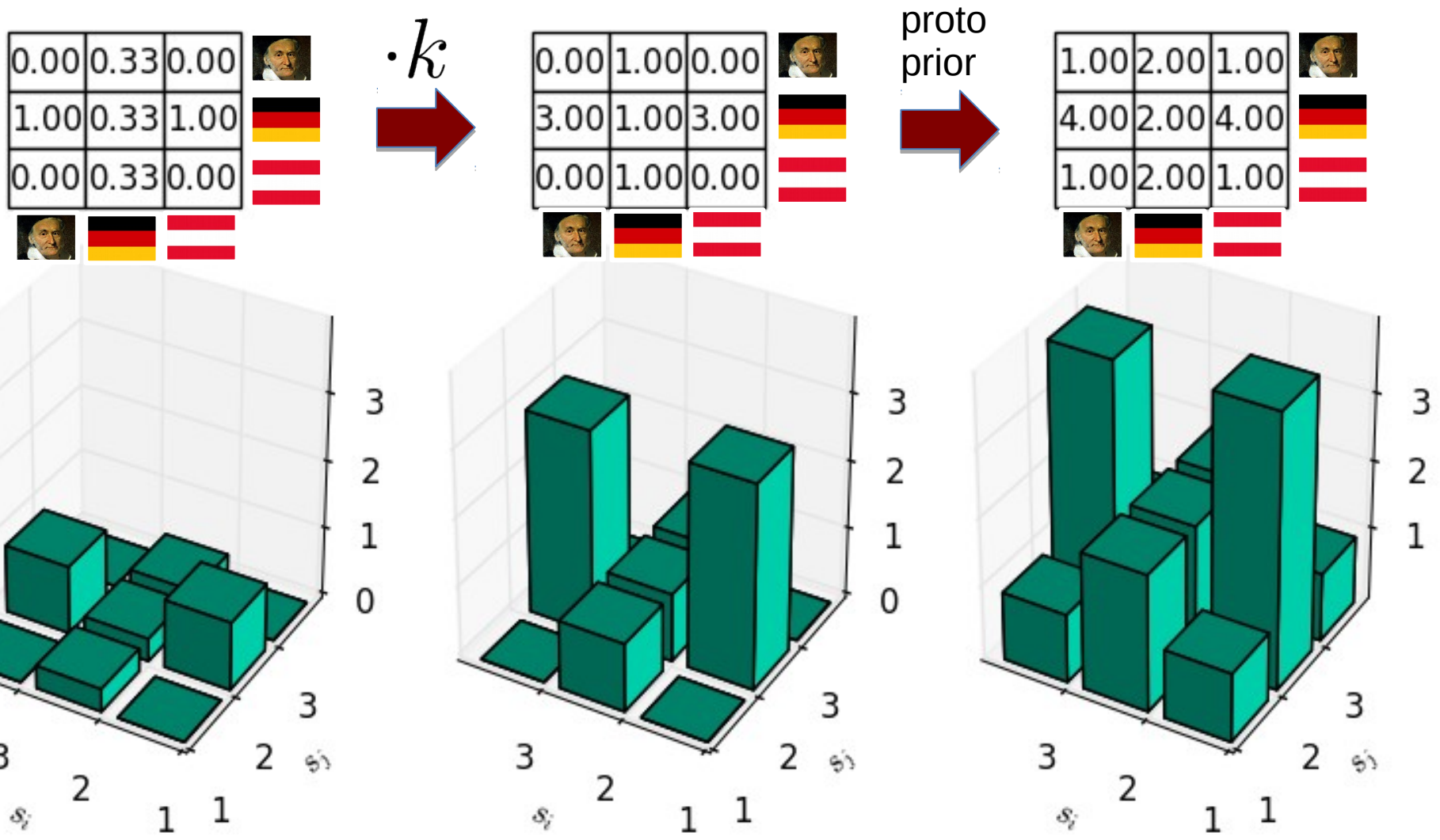
2 state example: Beta prior

Hypothesis: $[0.7, 0.3]$

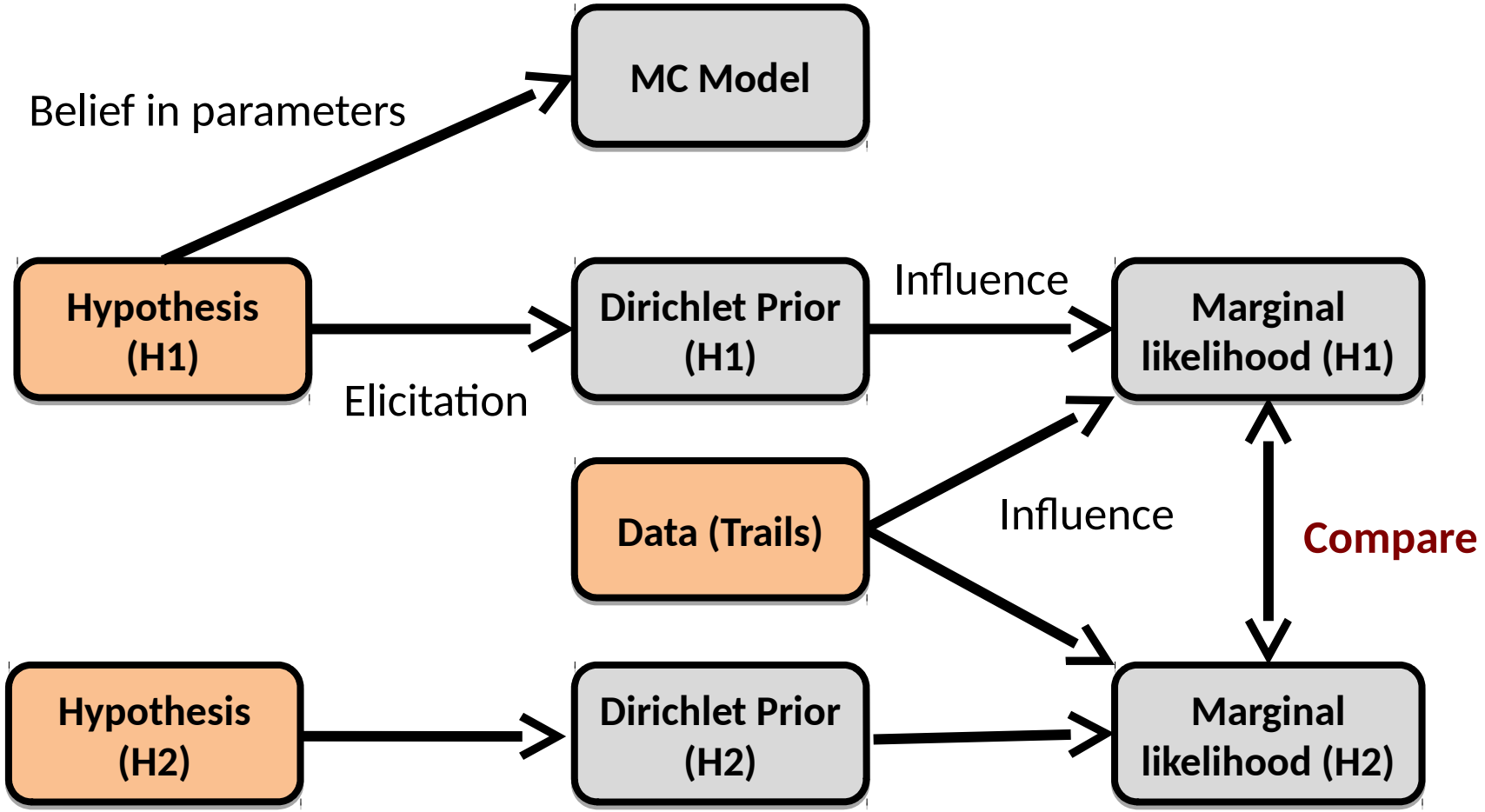
k = 100



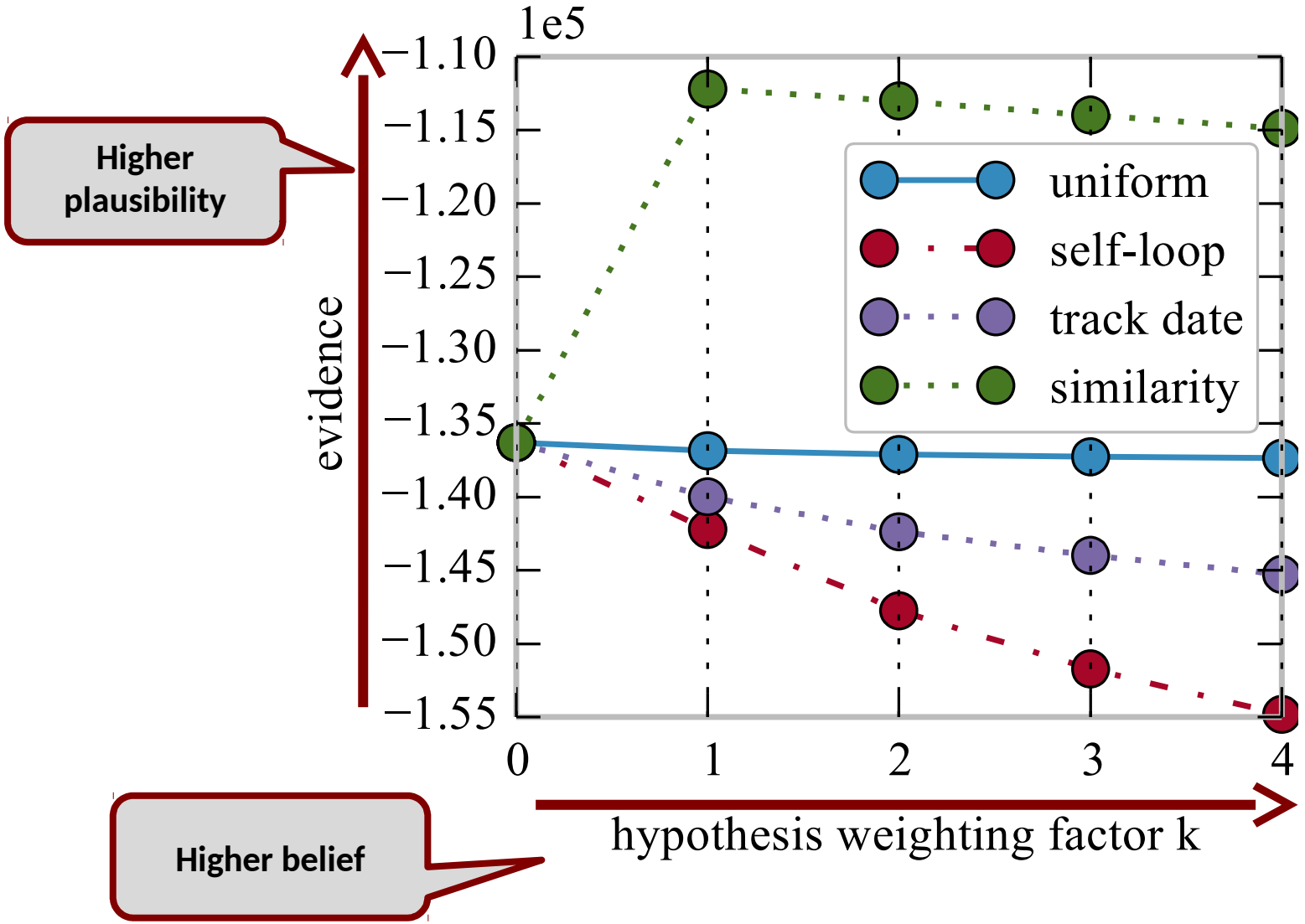
Example: Structural hypothesis



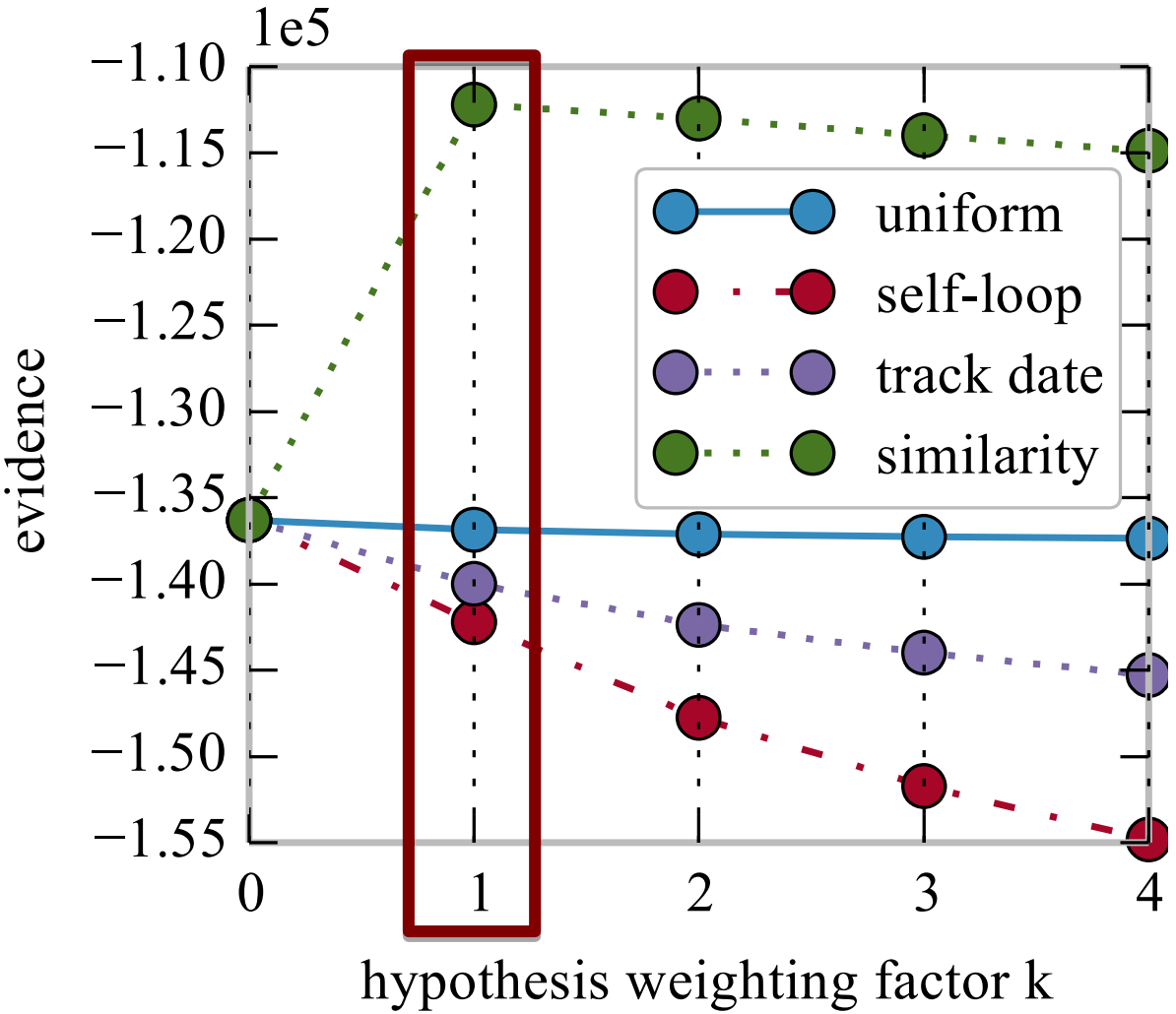
Structure of HypTrails



Example result: Last.fm



Example result: Last.fm



Hands-on jupyter notebook

Further applications

- Ontology engineering – edit sequences
  [Walk et al. ISWC 2015]
- Real-world navigational trails
  - Flickr [Becker et al. SocialCom 2015]
  - Taxi data [Espín-Noboa et al. WWW 2016]
  - Car data [Atzmüller et al. WWW 2016]
- Wikipedia co-editing patterns
  [Samoilenko et al. 2016]

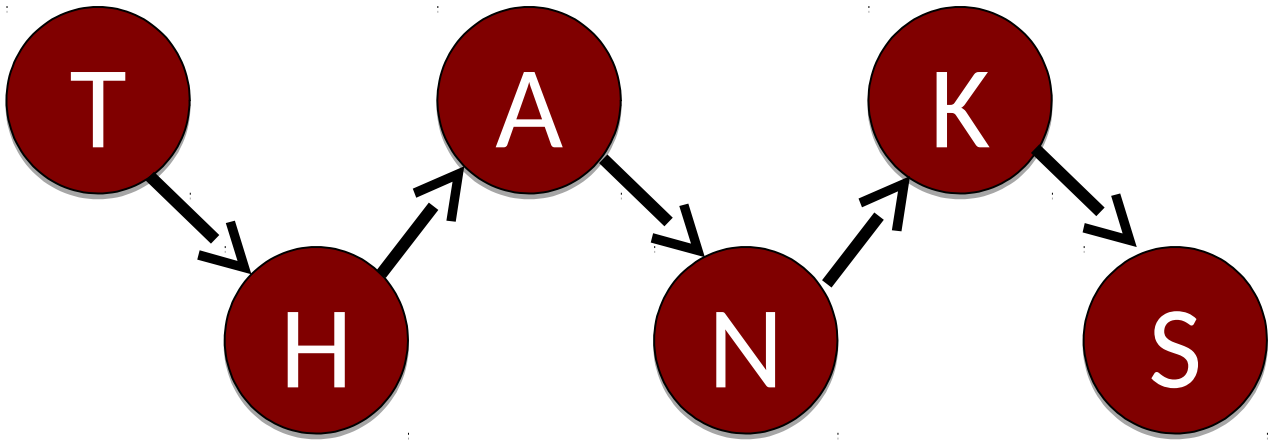
Methodological extensions

- Detect and model heterogeneity in data
- Higher-order Markov chain models
- Adaption for other models

What have we learned?

- Comparing hypotheses about sequential data
- Bayesian approach: HypTrails
- Applications

Questions?



for your attention!

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