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INSTITUTE FOR GLOBAL HEALTH, GENEVA

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ADVANCES IN ADDITIVE BAYESIAN NETWORK APPLIED TO OBSERVATIONAL SYSTEM EPIDEMIOLOGY DATASETS

- *Classical aim in epidemiology is to investigate relationship between covariate and ONE outcome*
- *Typically based on expert knowledge*

Issues:

- Multi-collinearity
- Dependence
- Confounders
- **Multivariate** versus **Multivariables**

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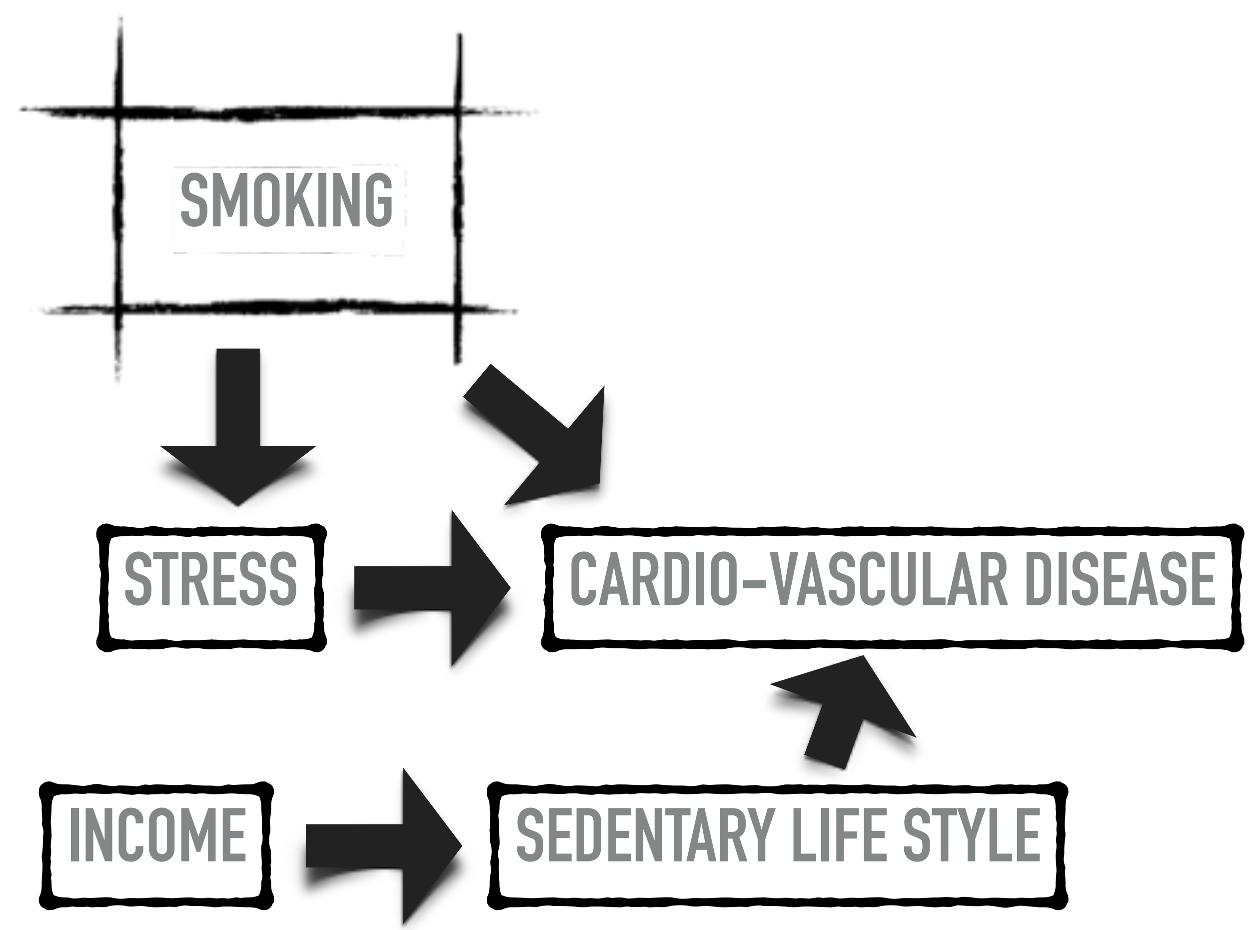
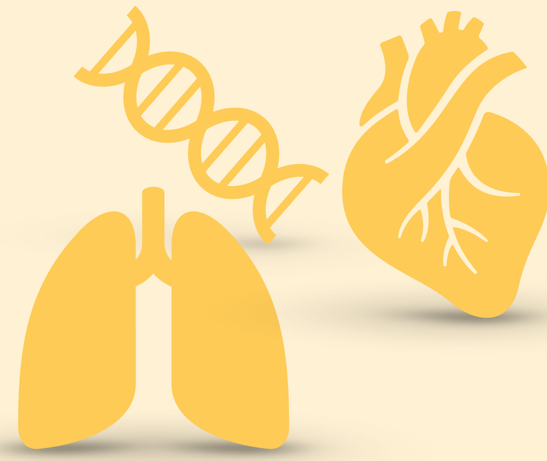


Enderlein and al. (1996)



DISEASE LEVEL

- Multiple outcomes/Scores
- Target variables for intervention
- Beginning of the coil of discovery

POPULATION LEVEL

- Demographic data
- Meta population information
- Cluster

ENVIRONMENT LEVEL

- External factors
- Ecology
- Living condition

Example

- **Metabolic syndrom**
- A clustering of 3/5 medical conditions

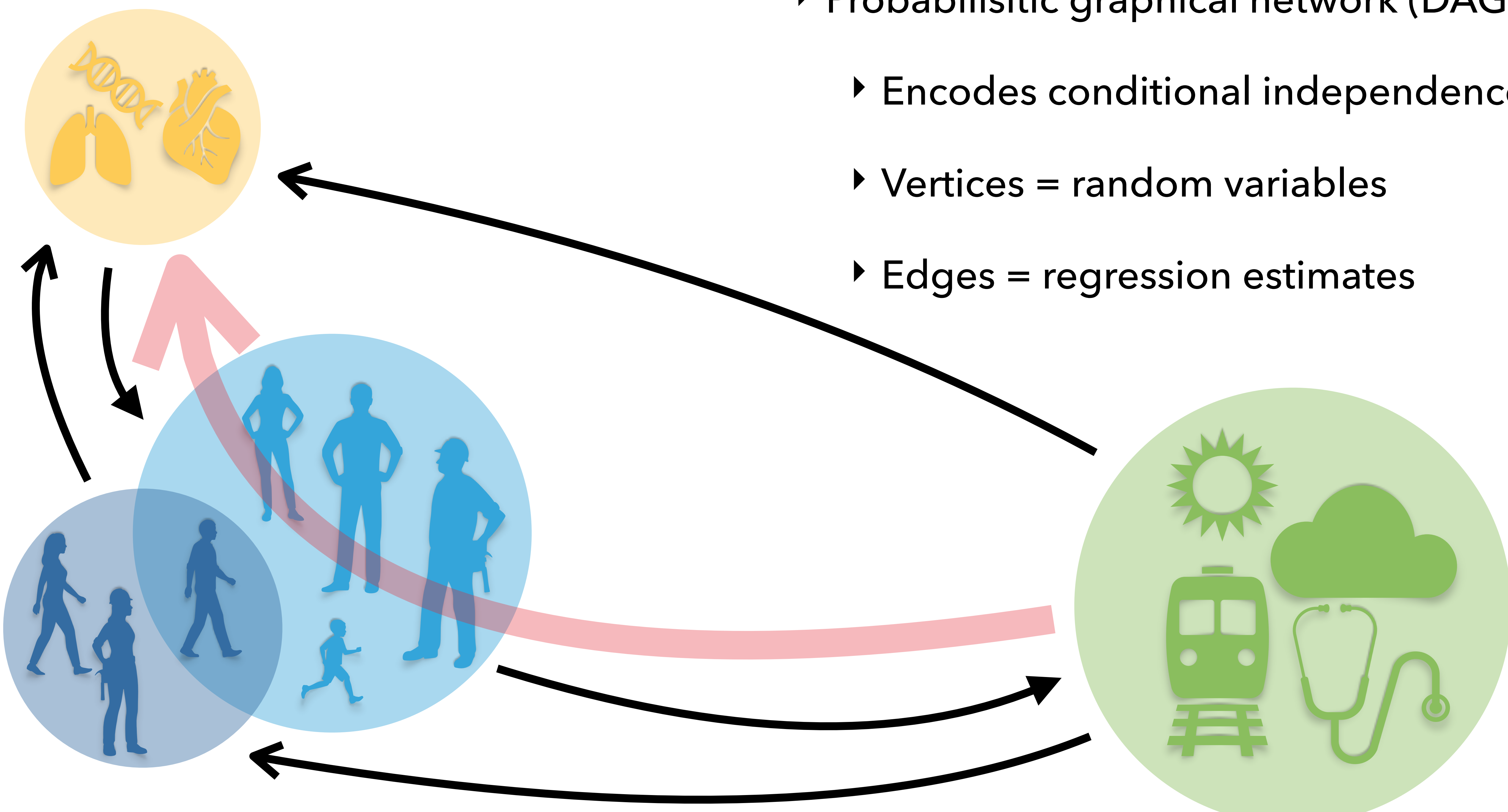
- Observational data
- Age, gender, …
- Random effect

- Weather condition
- Socio-economic condition
- Housing

Main purpose of ABN: Sort out **directly** associated versus **indirectly** associated, as they are not primary target for intervention

Bayesian Network

- Probabilisitic graphical network (DAG)
  - Encodes conditional independence
  - Vertices = random variables
  - Edges = regression estimates



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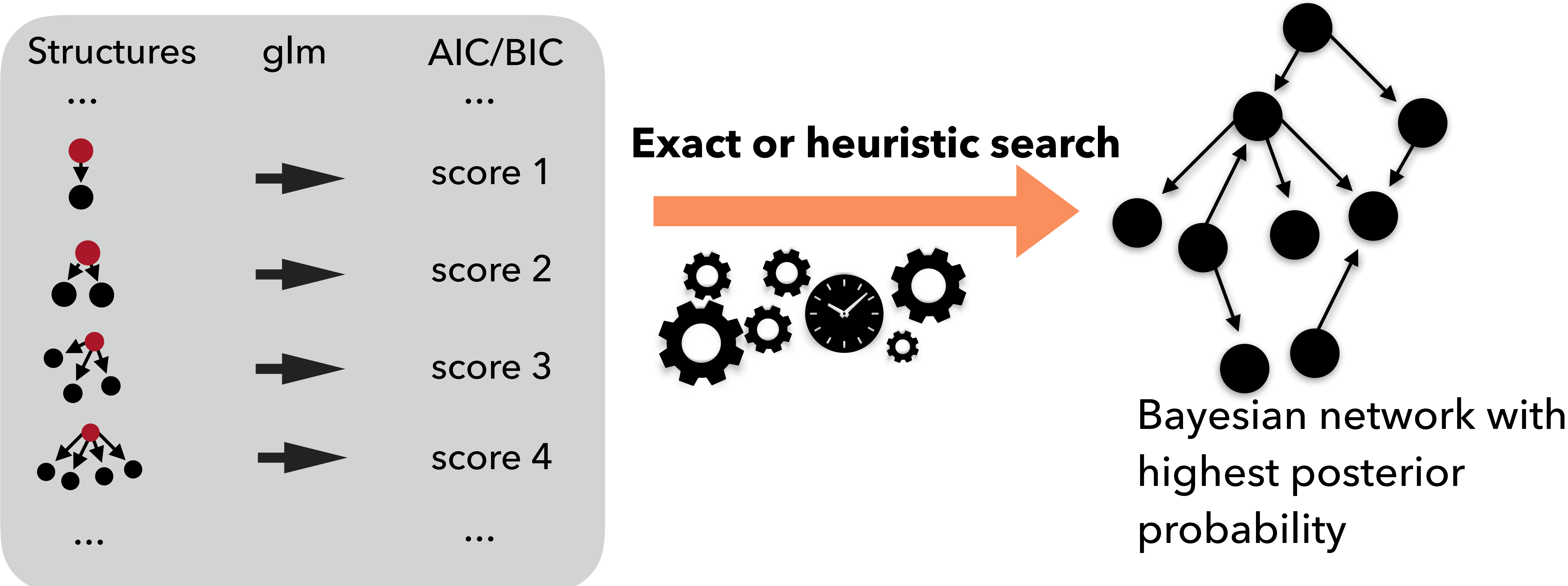
Search and score algorithm



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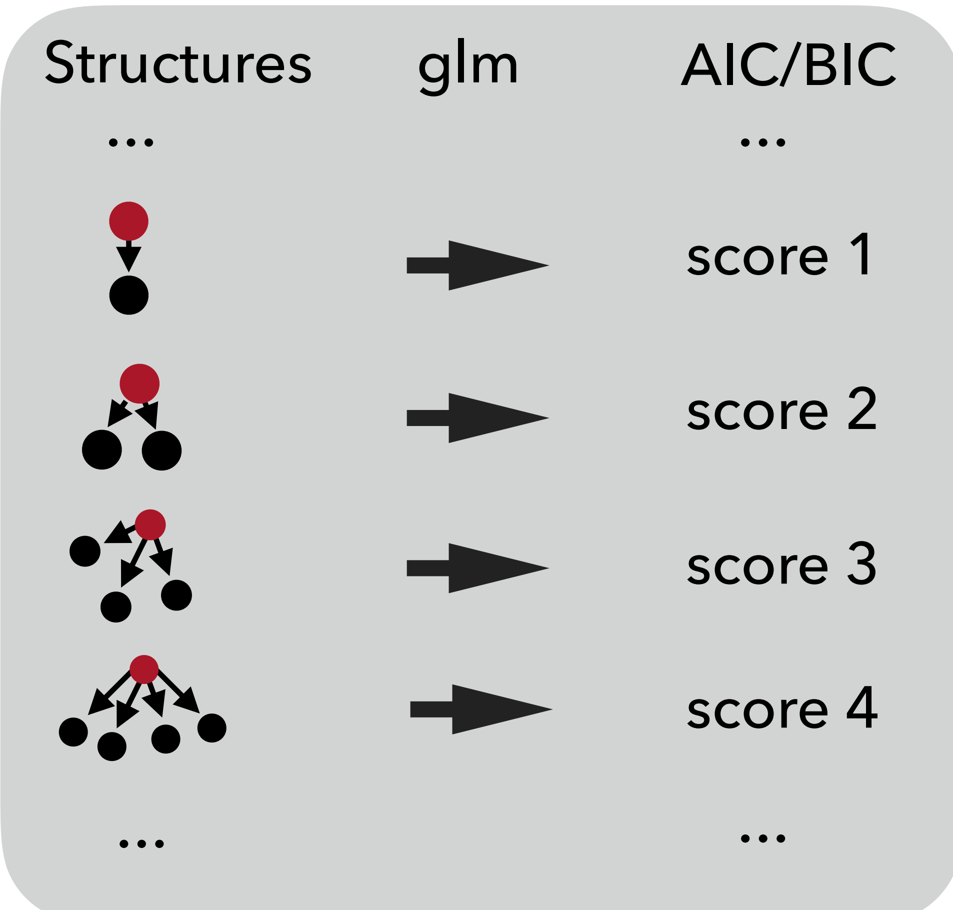
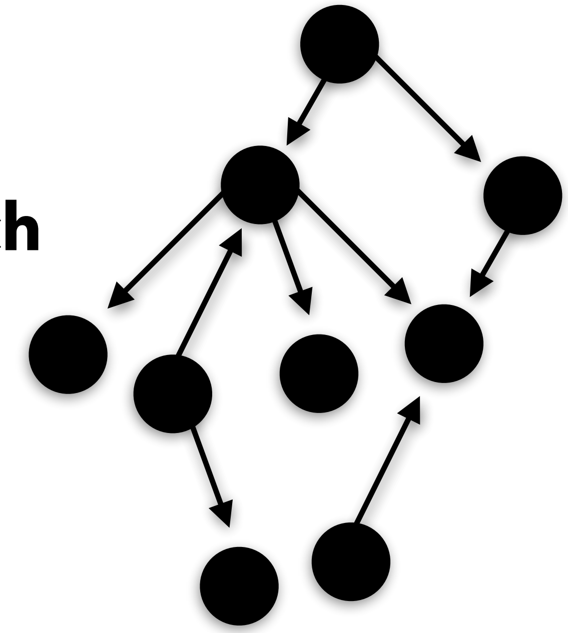


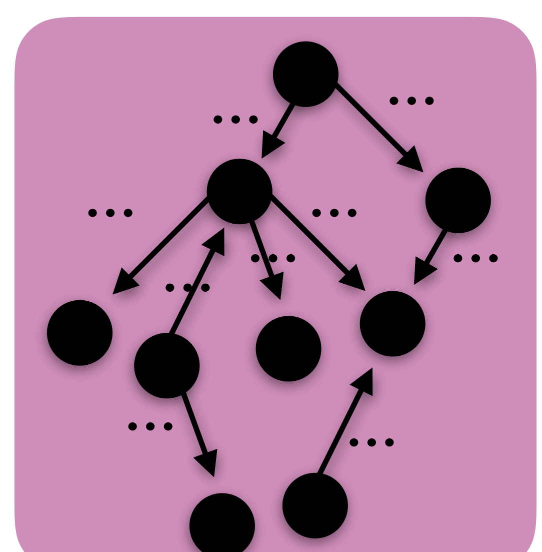
Exact or heuristic search



Bayesian network with highest posterior probability

Parameter estimation

- compute marginal posterior density
- regression estimate



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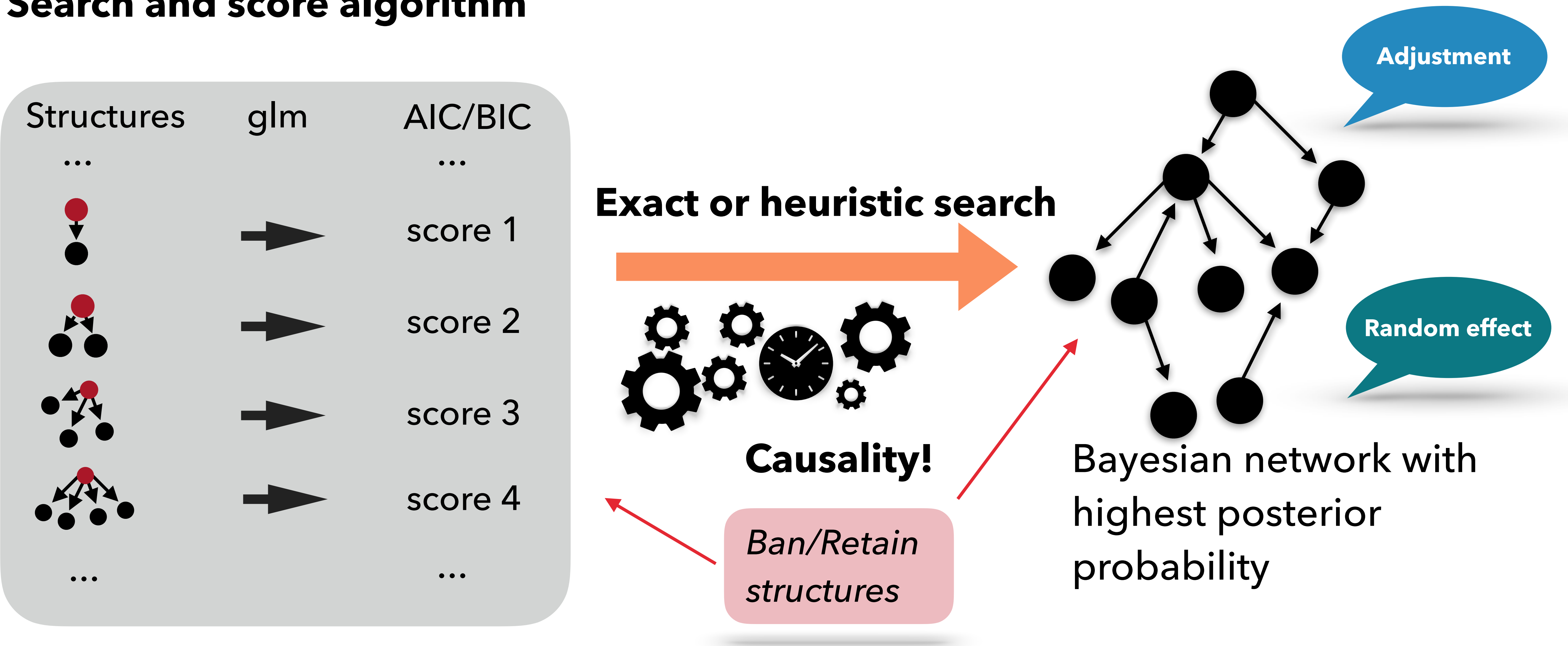

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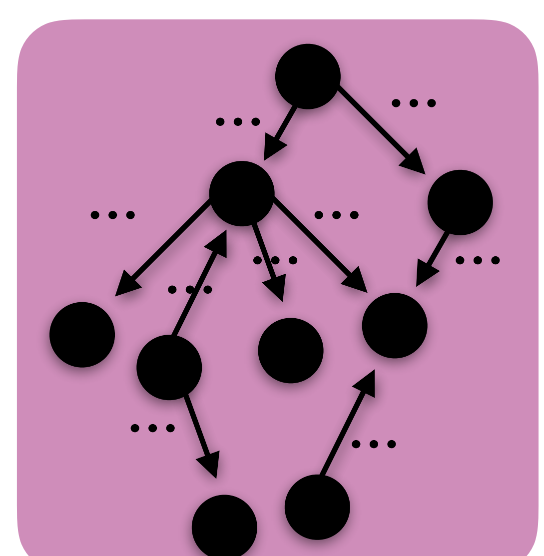
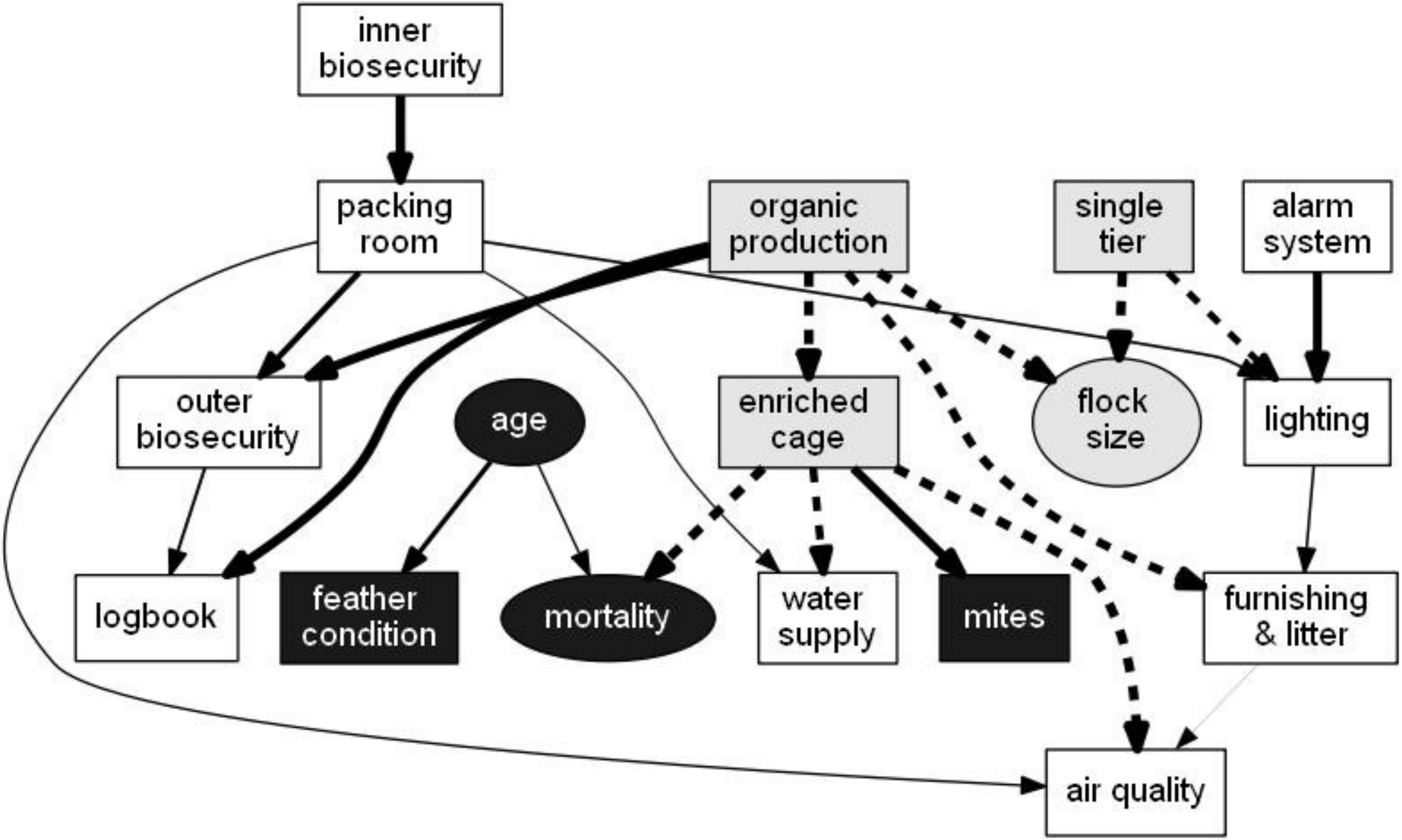


Using R

- *buildscorecache()*
- *mostprobable()*
- *fitabn()*



Arianna Comin et al (2017); Revealing the structure of the associations between housing system, facilities, management and welfare of commercial laying hens using Additive Bayesian networks

- Simple output
- Arc coefficients: easy to interpret
- Statistical guarantees

Current implementation

- Distributed as an R package (CRAN)
- Bayesian regression based on INLA (lm, logit and Poisson) with possibly **random effect**
- Most probable search (**exact search**) and Hill climber (heuristic approach)

(Very!) Near Future features

- Arc strength based on Mutual Information
  - Significance not p-value based
- GLM implementation (data separation, multinomial variable, adjustment)
  - Multiple scores: AIC, BIC, MDL

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System epidemiology

- Typically the set of possible variables is formidable
  - The classical approach for variable selection is based on prior scientific knowledge (29%)[1]
  - Change of estimate (18%)[1]
  - Stepwise model selection (16%)[1]
- No prior model
- Not one outcome experiment

varrank **Variable ranking for better time allocation**

- Variable ranking based on a set of variable of importance, distributed as an R package CRAN
- Model free. Based on information theory metrics
- Mixture of variables (continuous and discrete). Discretisation through rule/clustering
- Ranking of 100 variables with 100’000 observations in ~14 minutes! (forward greedy search)

[1] *Walter et al (2009)*

f_i candidate feature to be ranked

C set of variables of importance

$$\mathrm{H}(X) = \sum_{n=1}^{N} P(x_n) \log P(x_n)$$

S set of already selected variables

$$\mathrm{MI}(X;Y) = \sum_{n=1}^{N} \sum_{m=1}^{M} P(x_n; y_m) \log \frac{P(x_n; y_m)}{P(x_n)P(y_m)}$$

$$\mathrm{score}_i = \mathrm{MI}(f_i; \mathbf{C}) - \beta \sum_{F_s \in \mathbf{S}} \alpha(f_i, f_s, \mathbf{C})\ \mathrm{MI}(f_i; f_s)$$

Estévez and al. (2009)

$\beta = 1/|\mathbf{S}|$ and $\alpha(f_i, f_s, \mathbf{C}) = \dfrac{1}{\min(\mathrm{H}(f_i), \mathrm{H}(f_s))}$

f_i candidate feature to be ranked

C set of variables of importance

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$$\mathrm{H}(X) = \sum_{n=1}^{N} P(x_n) \log P(x_n)$$

Average amount of information of one RV

$$\mathrm{MI}(X;Y) = \sum_{n=1}^{N} \sum_{m=1}^{M} P(x_n; y_m) \log \frac{P(x_n; y_m)}{P(x_n)P(y_m)}$$

Mutual dependence between two RV

Greedy search

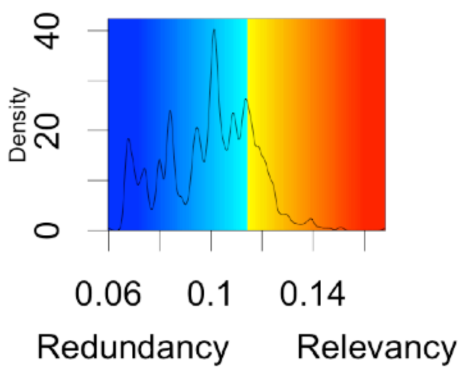
Forward - argmax

$$\mathrm{score}_i = \underbrace{\mathrm{MI}(f_i; \mathbf{C})}_{\text{Relevance}} - \beta \sum_{F_s \in \mathbf{S}} \underbrace{\alpha(f_i, f_s, \mathbf{C})}_{\text{Normalization}} \underbrace{\mathrm{MI}(f_i; f_s)}_{\text{Redundancy}}$$

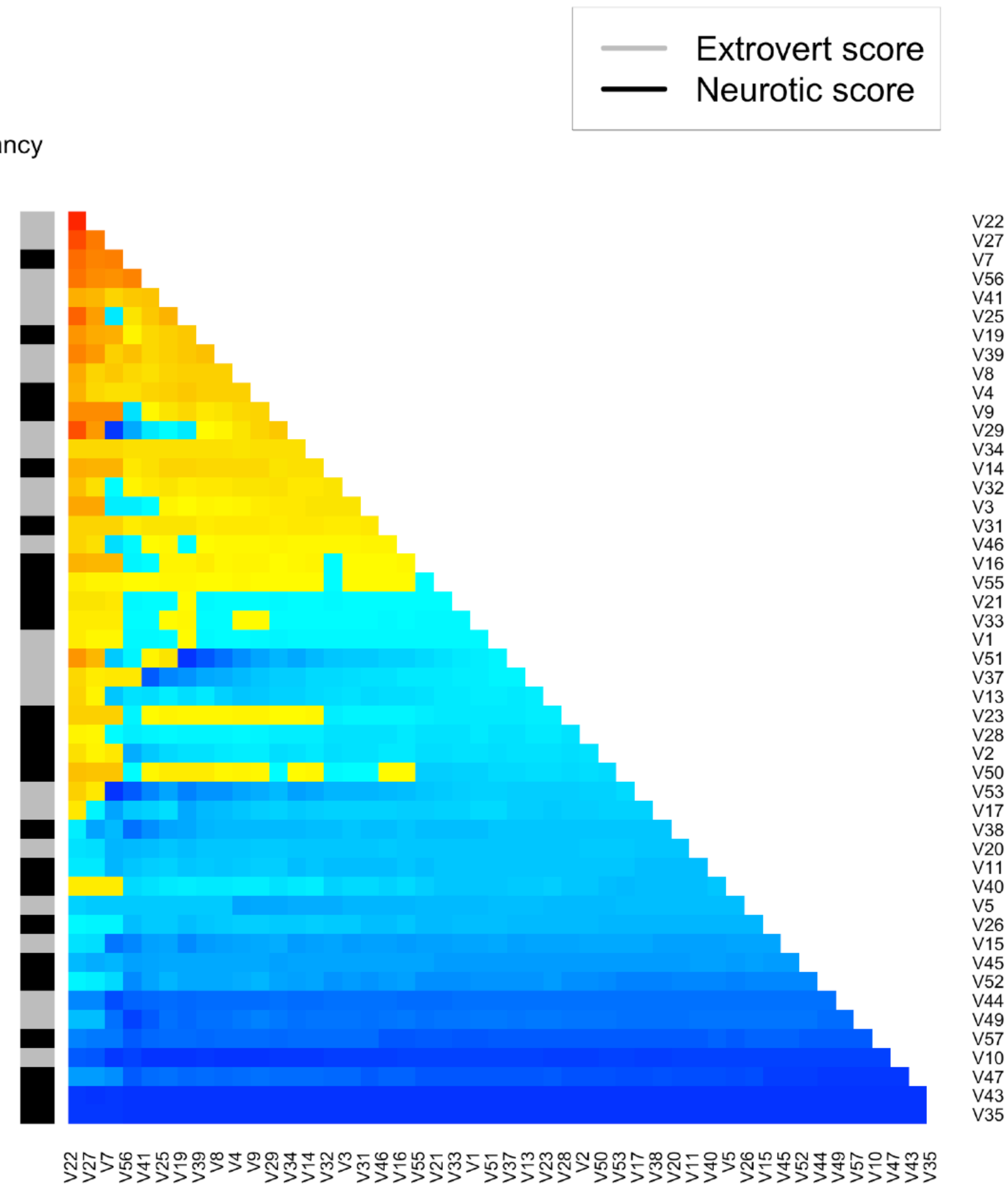
Estévez and al. (2009)

$$\beta = 1/|\mathbf{S}| \text{ and } \alpha(f_i, f_s, \mathbf{C}) = \frac{1}{\min(\mathrm{H}(f_i), \mathrm{H}(f_s))}$$

EYSENCK PERSONALITY INVENTORY

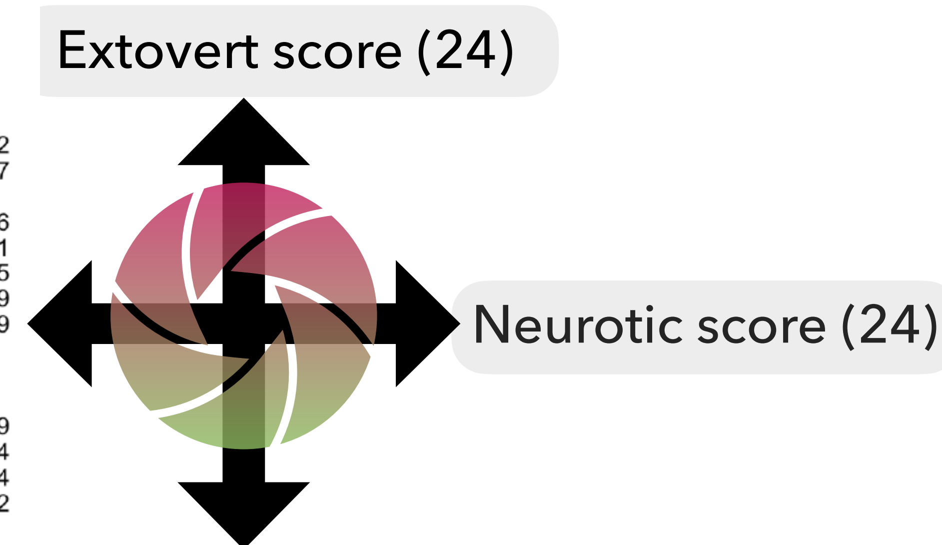


EPI: 3570 observations and 57 variables



Structure of EPI:

✓ Lie scale (9 responses)



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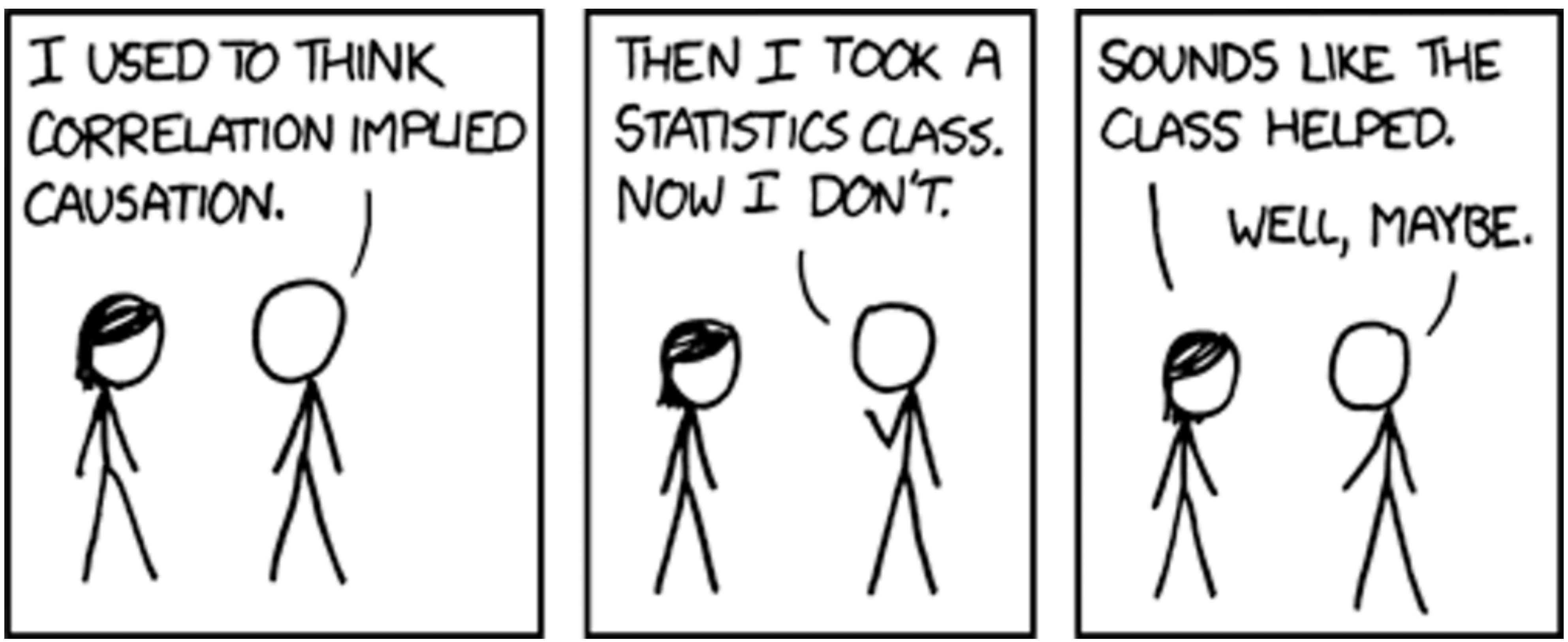
Looking forward for your questions, inputs or remarks …



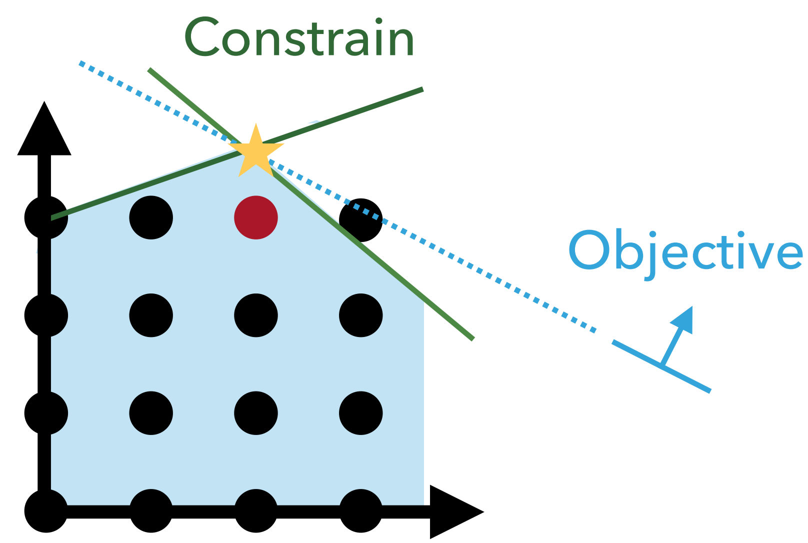
xkcd.com

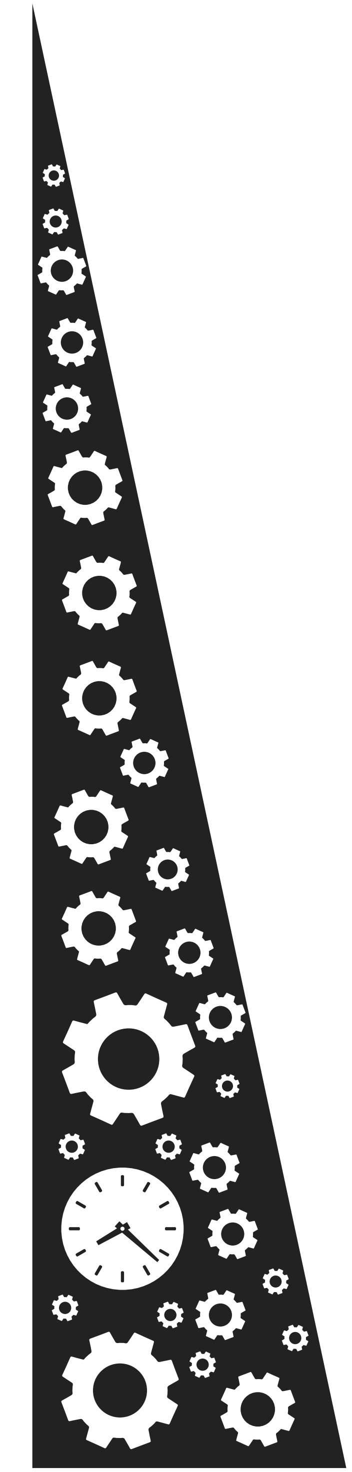
Backup slides

ABN FUTUR WORK

- Search algorithm based on Mutual Information
  - Penalized by χ^2 *(de Campos et al, 2006)*

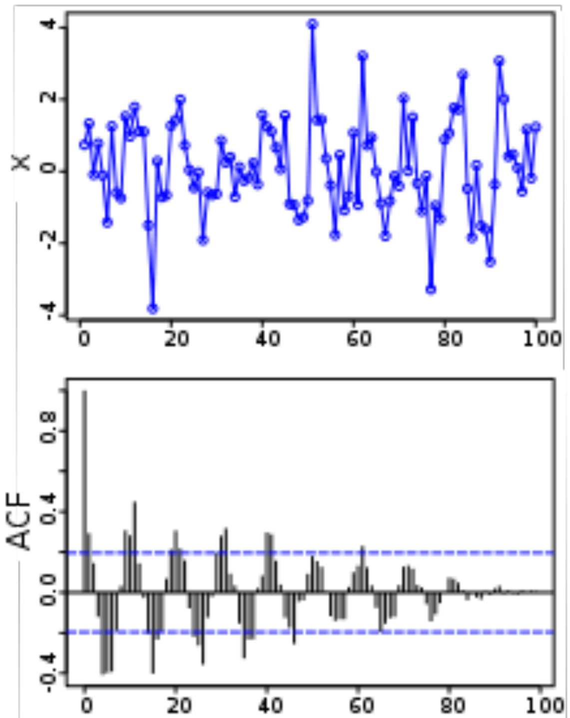
Increasing order of complexity!





- Algorithmic search implementation
  - Heuristic search/Hybrid search
  - Integer programming (*Cussens, 2012*)
- Bayesian regression work horse
  - Stan implementation
  - Diaconis-Ylvisaker conjugate priors (*Pittavino et al, 2016*)
- Causal belief: Informative prior structure *versus* incomplete synthetic observations

TSABN



Time series regression

- OLS estimates
- Goodness of fit metrics

Variance-Covariance

$$\begin{pmatrix} \sigma^2_{y_1} & \sigma_{y_1 y_2} & \cdots & \sigma_{y_1 y_n} \\ \sigma_{y_1 y_2} & \sigma^2_{y_2} & \cdots & \sigma_{y_2 y_n} \\ \vdots & \vdots & \ddots & \vdots \\ \sigma_{y_1 y_n} & \sigma_{y_2 y_n} & \cdots & \sigma^2_{y_n} \end{pmatrix}$$

tsabn as a time series extension of abn

- Extending ABN to correlated errors
- Several implemented scores: AIC, BIC, MDL
- Errors Autocorrelation: ARMA procedure with Autoregressive modelling
  - Kalman filter

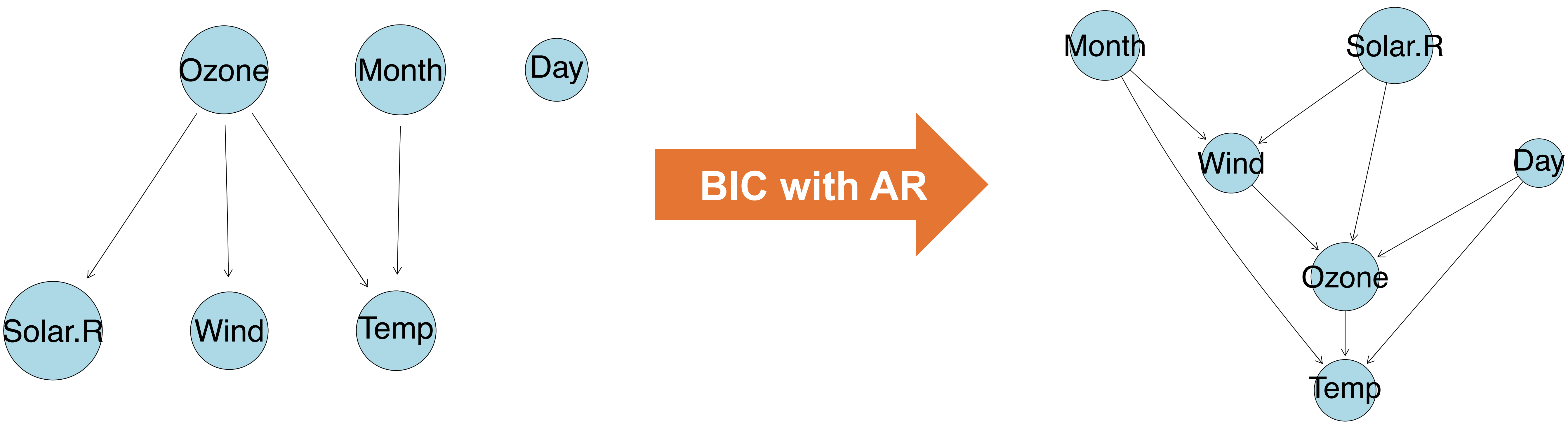
Future work

- Implementation of Granger causality score for BN learning

OZONE DATASET

Daily readings of the air quality values from May to September 1973

111 observations on 6 variables



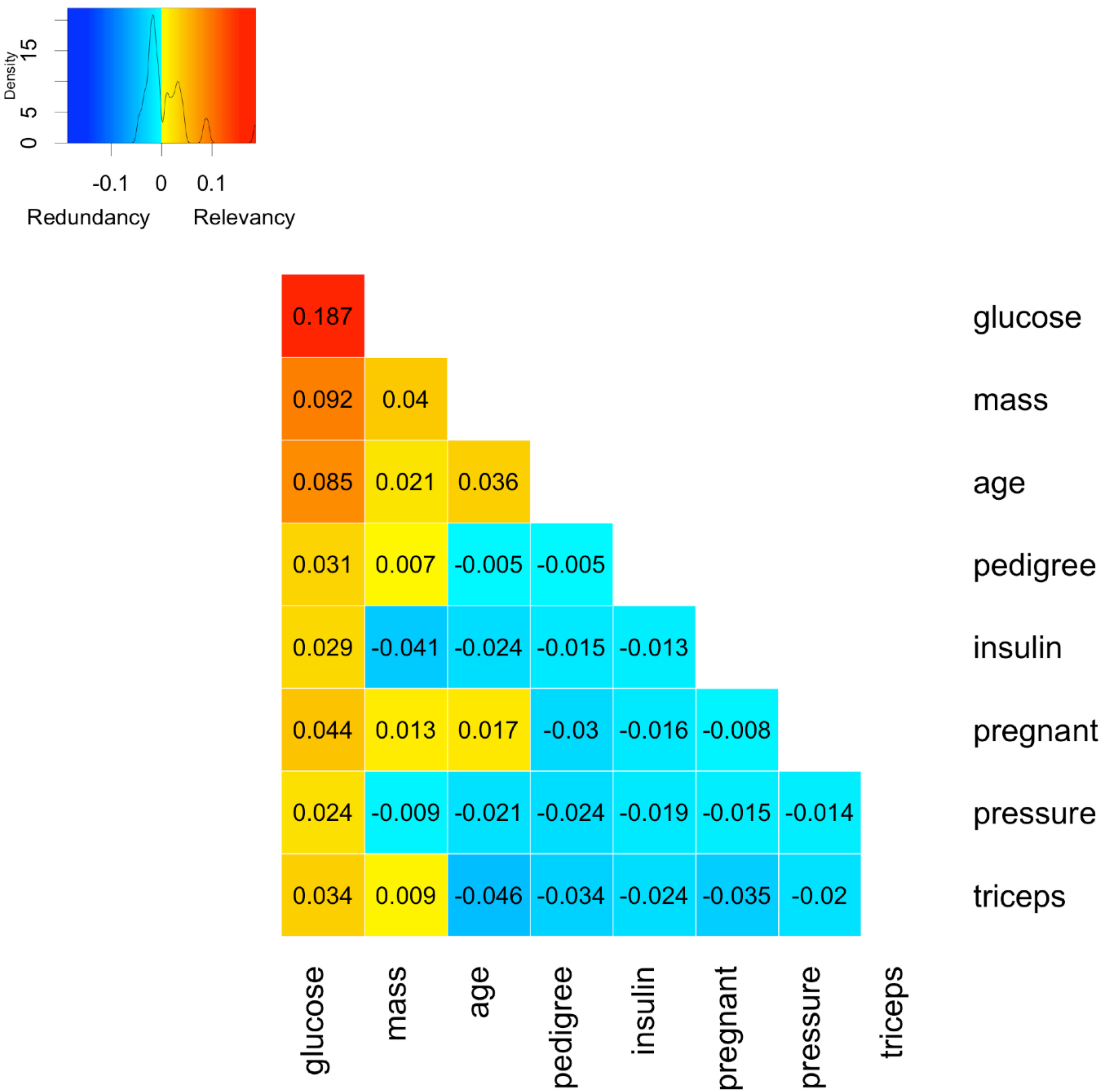
Future work:

Hourly readings of the PM2.5 and 6 other chemical compounds data of US embassy in Beijing with meteorological data from Beijing Capital International Airport from 2013 to 2017

DIABETE

Pima Indians Diabetes Database

768 observations on 9 variables



That is all folks!