Learning with infinite relational models

Charles Kemp, MIT

Josh Tenenbaum, MIT

Tom Griffiths, Brown U.

What we want to understand

- Structure of belief networks
- Structure of social networks
- Their interactions
  - Beliefs about social systems
  - How social systems govern the development of belief systems

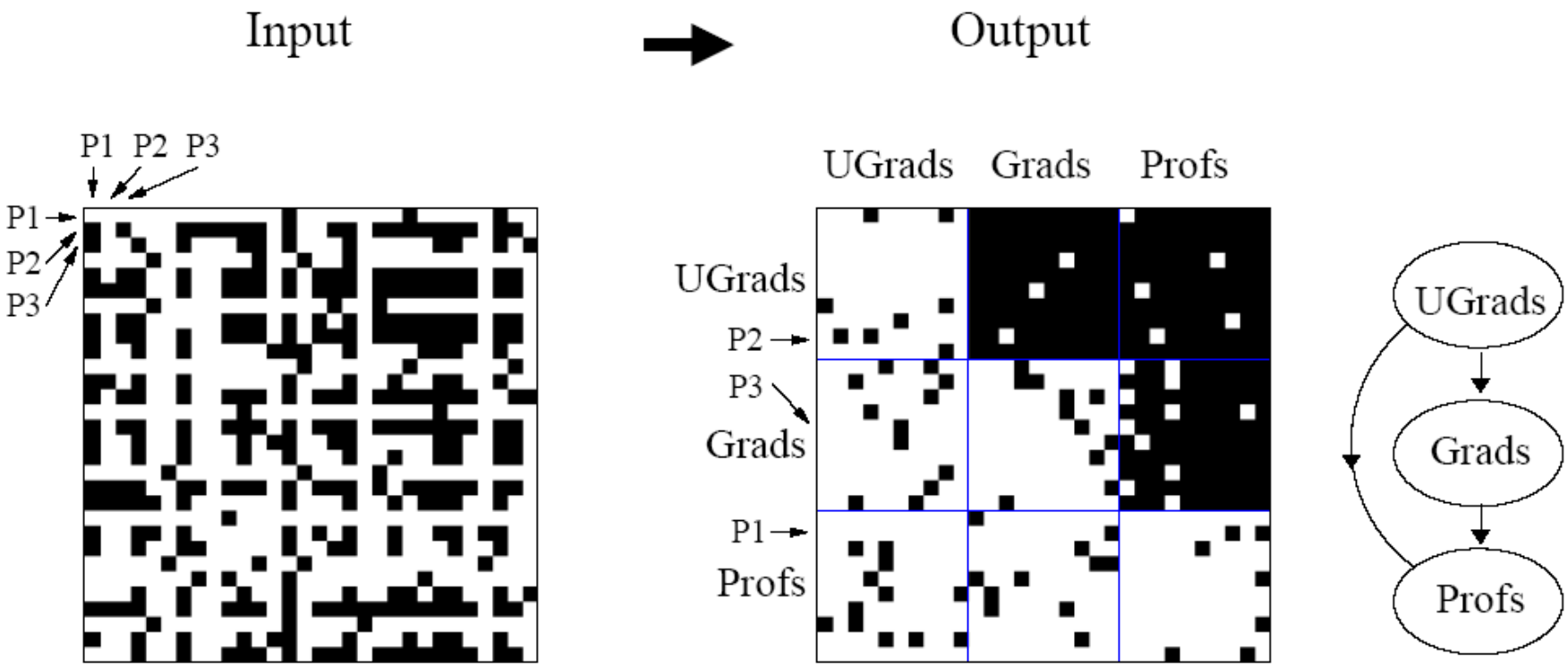
A common motif

Network structure is based on (i) a division of nodes into classes (categories, groups), and (ii) regularities about how nodes in different classes tend to be connected to each other.

A computational framework for learning relational systems

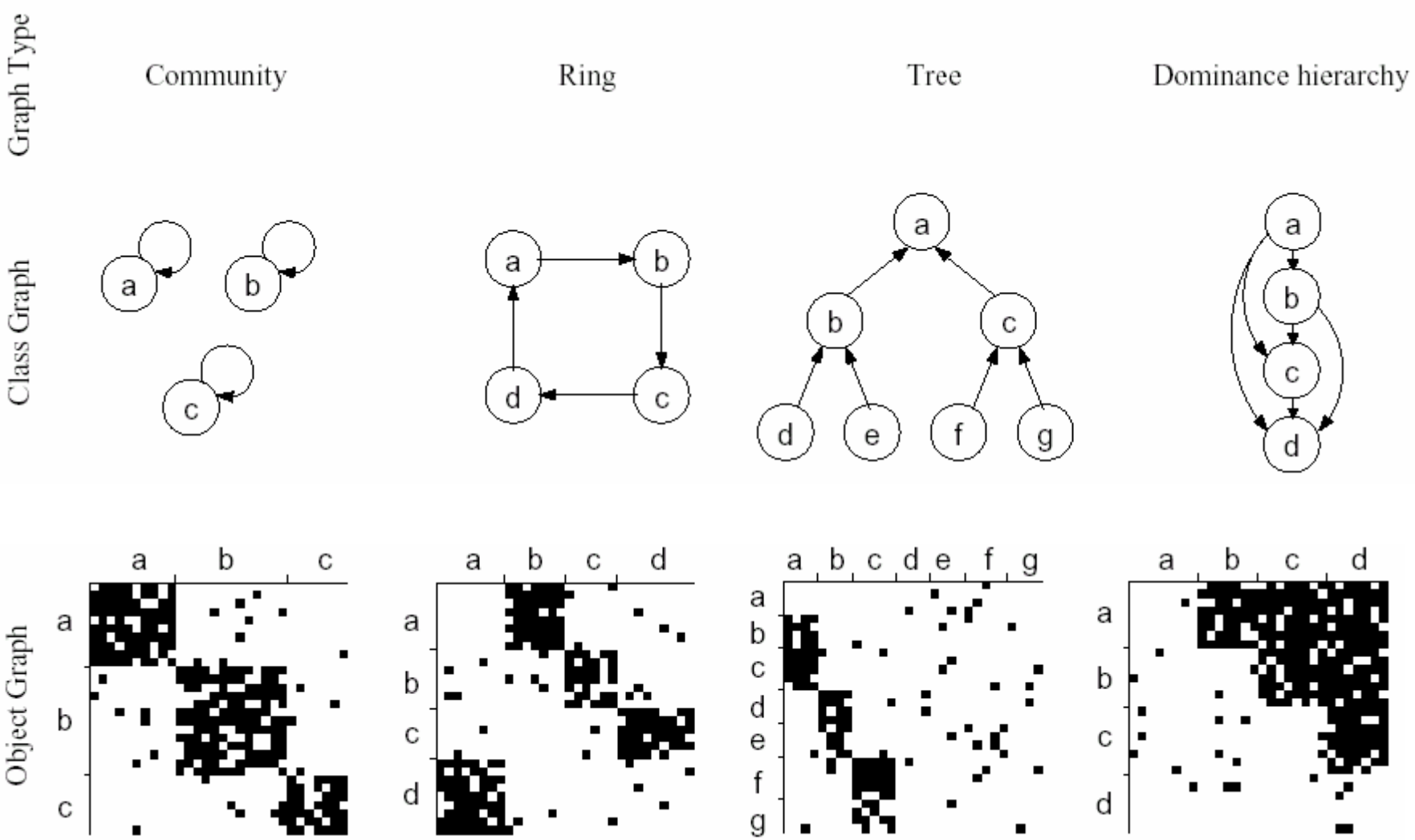
- Input
  - Data on how specific nodes (objects, people) relate to each other.
- Output
  - Which nodes cluster together (including number of classes).
  - How nodes in different classes are likely to be connected.
- Target applications
  - Exploratory analysis and predictive modeling of sparsely observed, real-world belief networks or social networks.
  - Modeling how people learn and modify belief networks on the basis of experience.

Learning relational systems

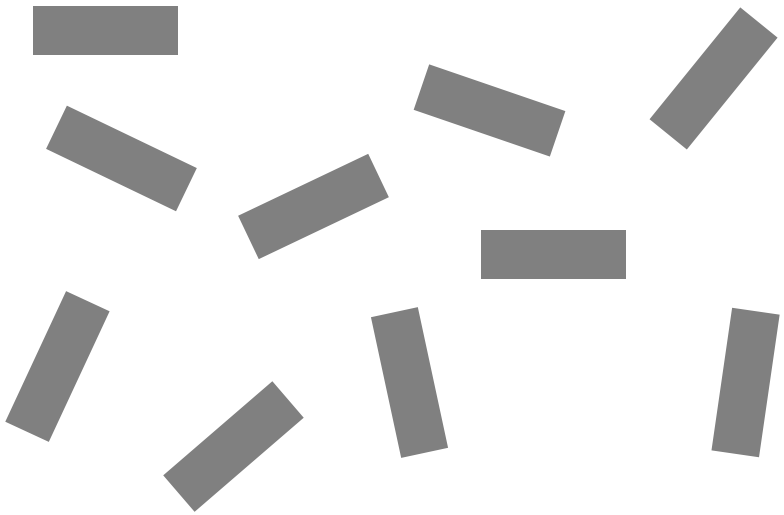


"*x* defers to *y*"

Different kinds of relational systems



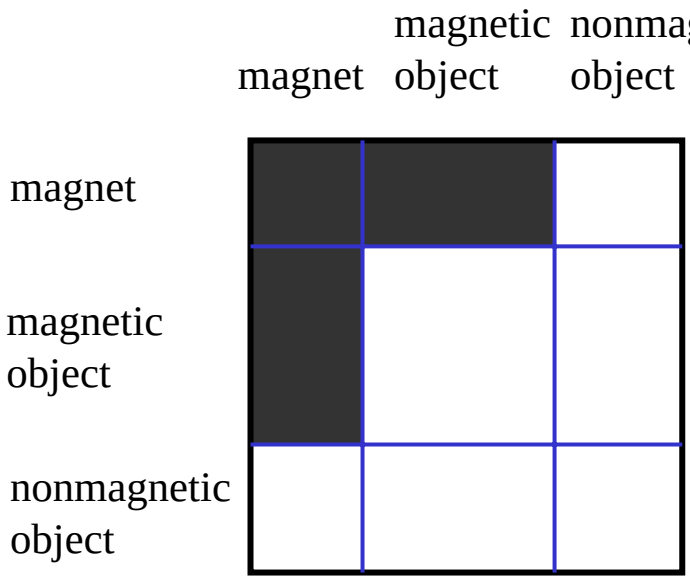
Learning relational systems



Learning relational systems

A theory:

- Classes
  - *magnet*
  - *magnetic object*
  - *nonmagnetic object*
- Relational regularities
  - *magnets* interact with each other.
  - *magnets* and *magnetic objects* interact.
  - *magnetic objects* do not interact with each other.
  - *nonmagnetic objects* interact with nothing.



"*x* interacts with *y*"

Infinite relational model (IRM)

$$z \sim \mathrm{CRP}(\alpha)$$

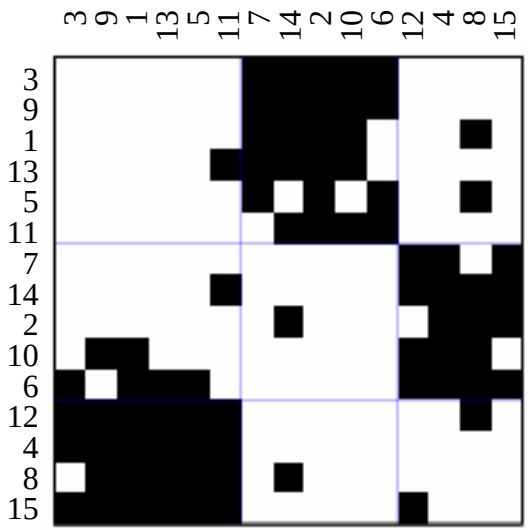
$$\eta_{ij} \sim \mathrm{Beta}(\beta, \beta)$$

0.1	0.9	0.1
0.1	0.1	0.9
0.9	0.1	0.1

3 9 1
13 5
11

7 14 2
10 6

12 4
8 15



$$P(O_{ij} = 1 | z_i, z_j) = \eta_{ij}$$

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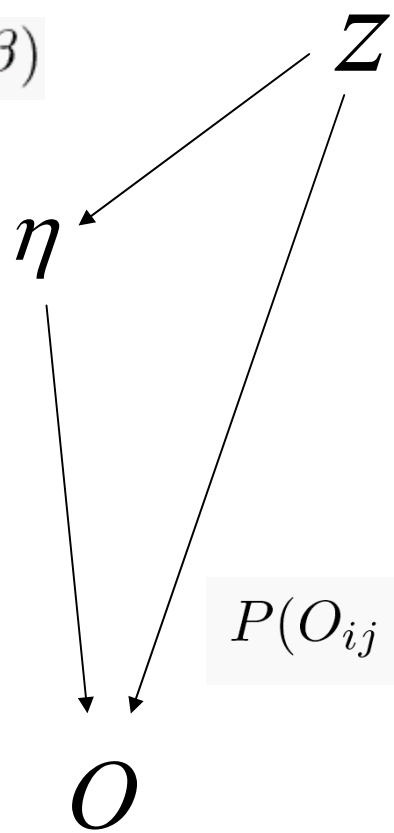
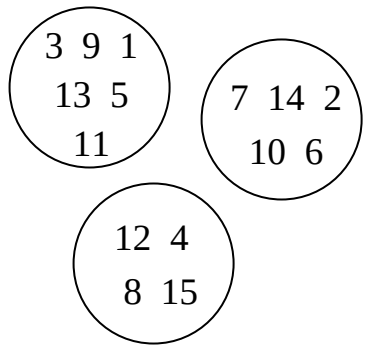
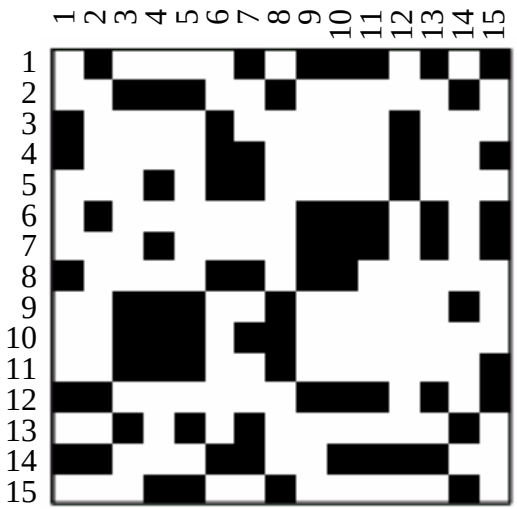






$$P(O_{ij} = 1 | z_i, z_j) = \eta_{ij}$$

Generating η and z

- Independent symmetric beta priors on η:

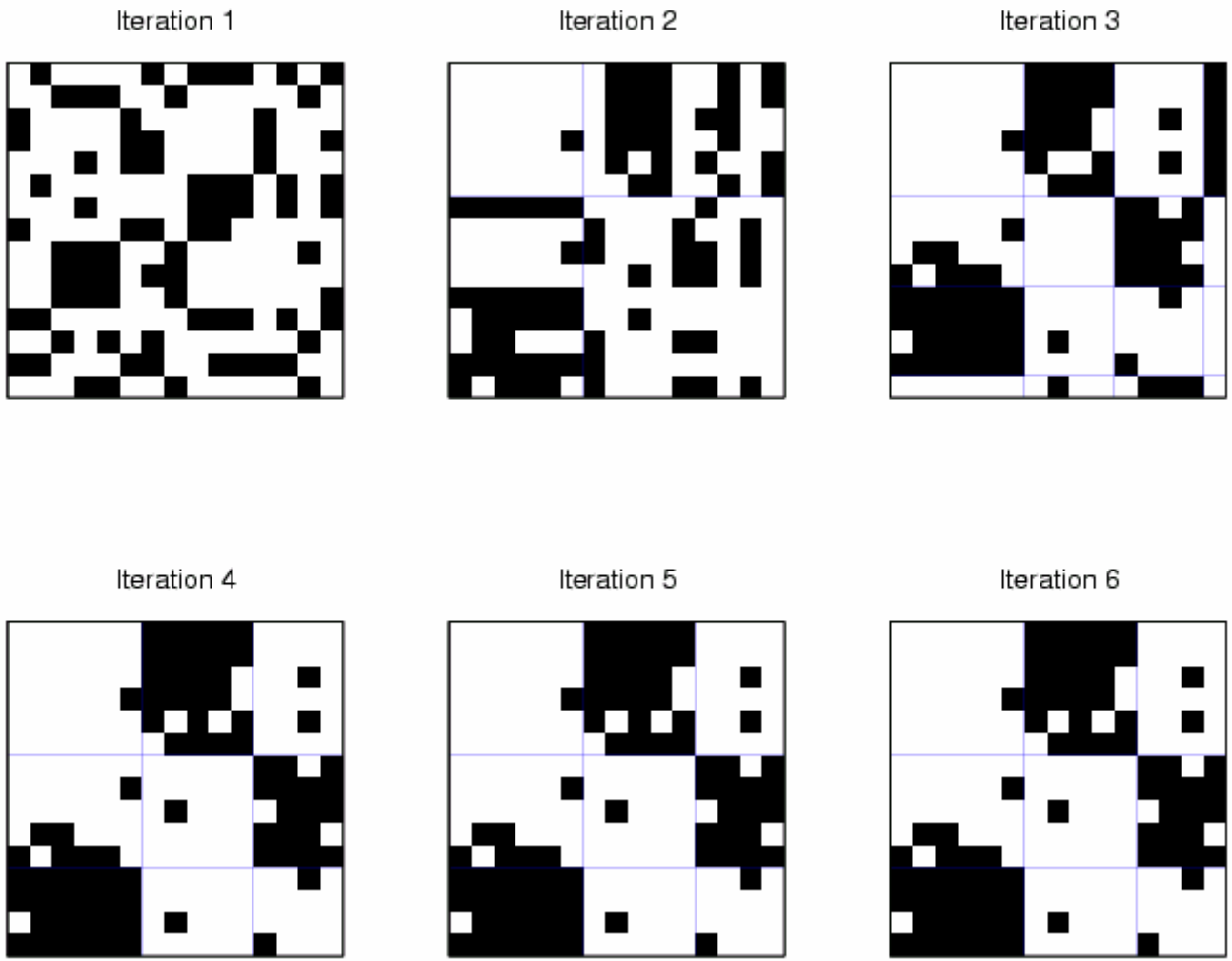
$$\eta_{ij} \sim \text{Beta}(\beta, \beta)$$

- Chinese Restaurant Process over z:

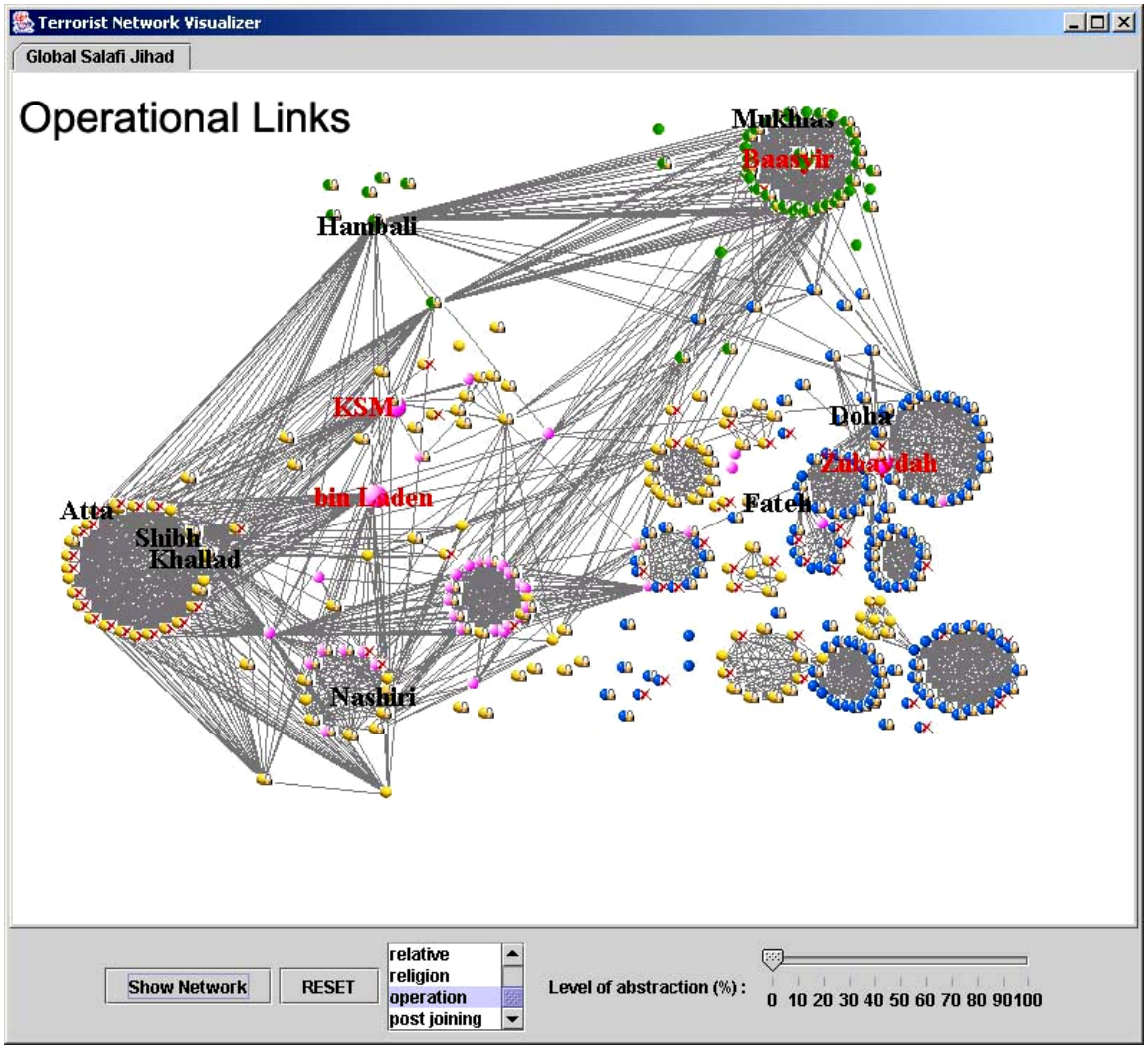
$$P(z_n = C \mid z_1, \ldots, z_{n-1}) = \begin{cases} \dfrac{n_C}{n+\alpha} & n_C > 0 \\ \dfrac{\alpha}{n+\alpha} & C \text{ is a new class} \end{cases}$$

- Goal:
  - Infer $p(z, \eta \mid O)$
  - Infer $p(z \mid O)$ (integrating out η to reduce space of unknowns)

Global-local search process

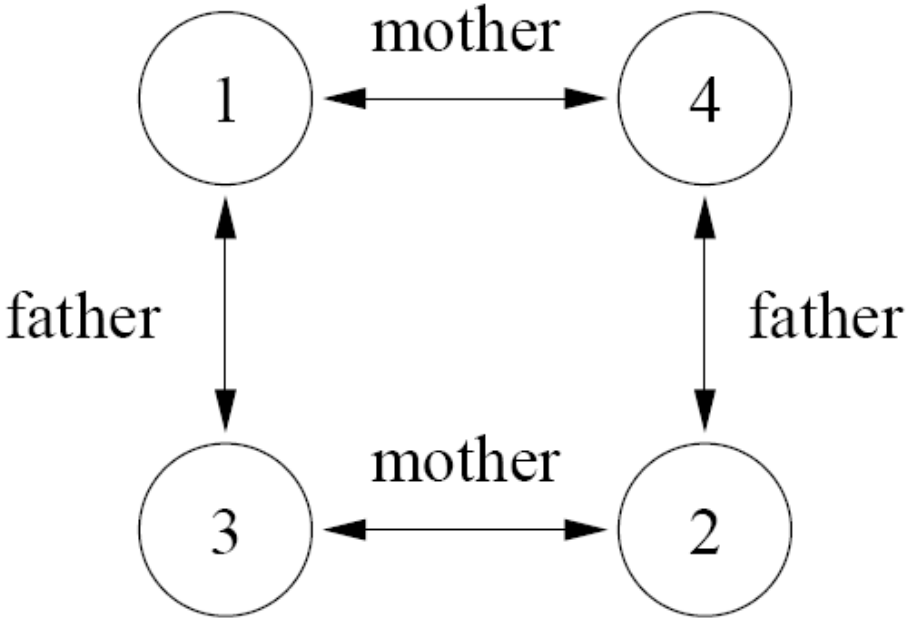


Learning social networks



Global terror networks
(Atran, Sageman, et al.)

Learning social networks

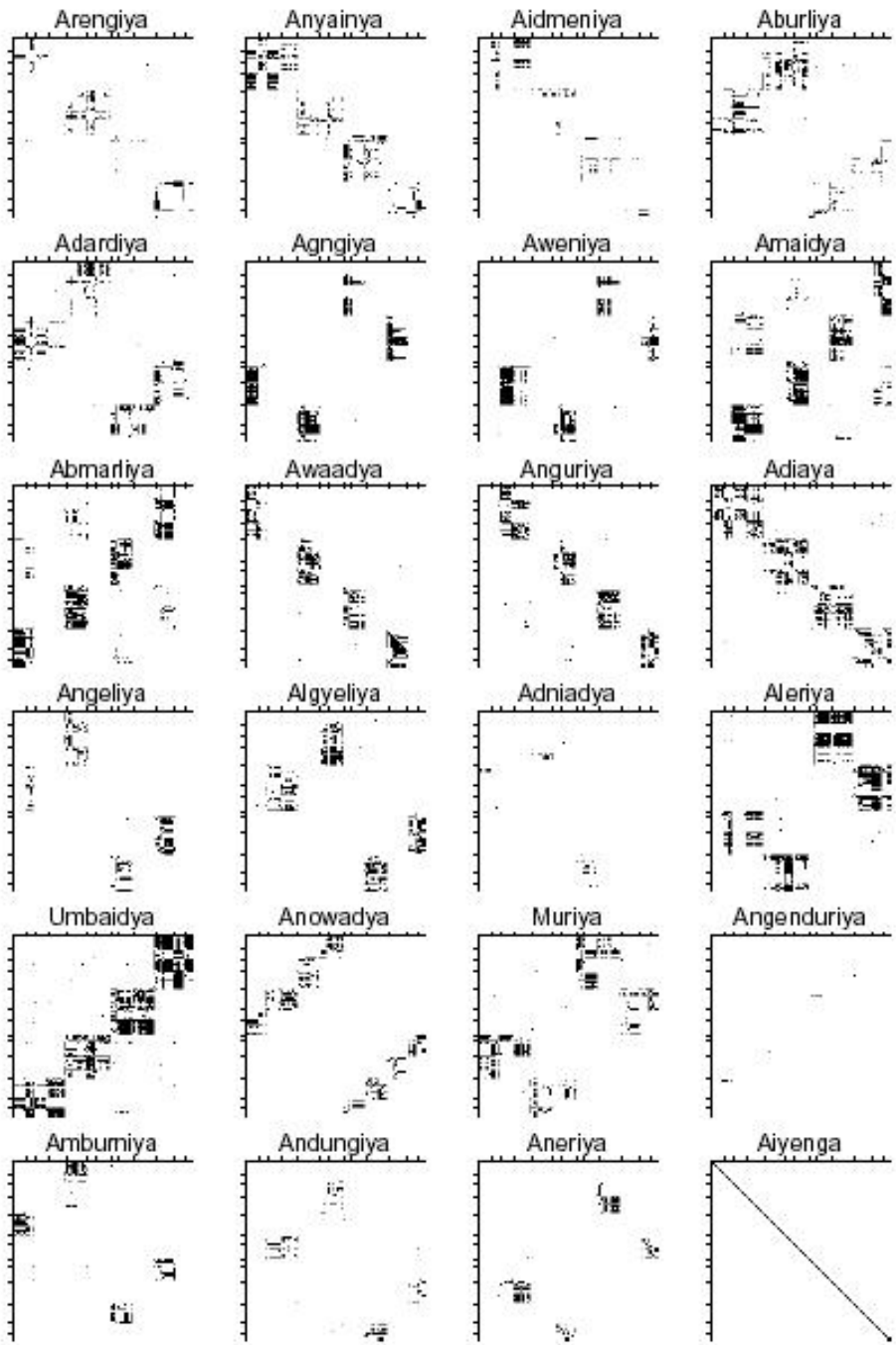


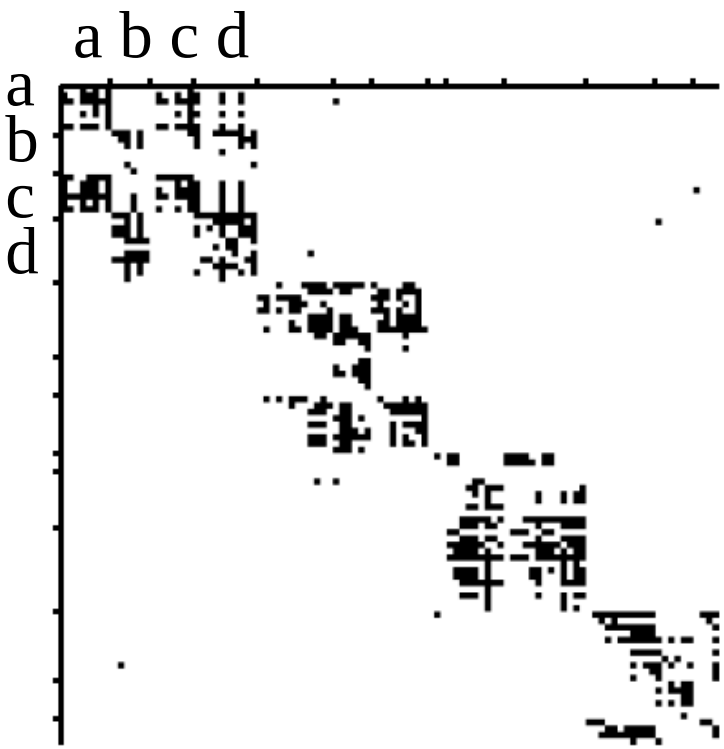
Alyawarra tribe
(Central Australia)

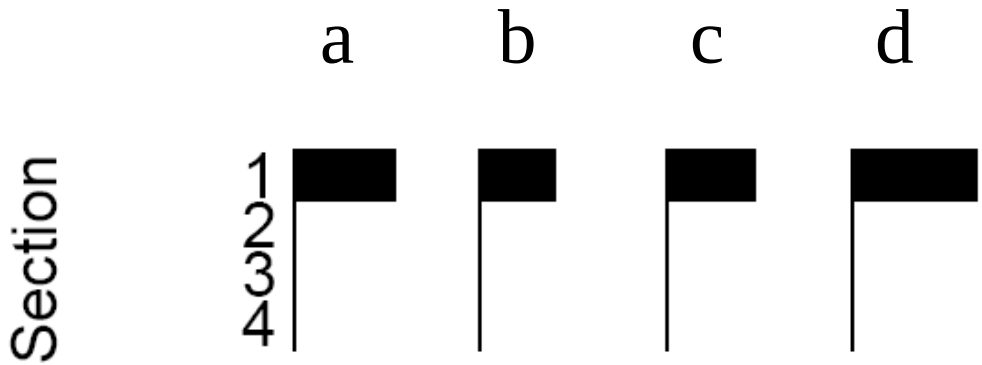
Learning social networks

- Data collected by Denham (1973)
- 104 members of Alyawarra tribe in central Australia
- 27 relational terms supplied by participants
- 3 attributes (not used in learning model)
  - kinship class
  - sex
  - age

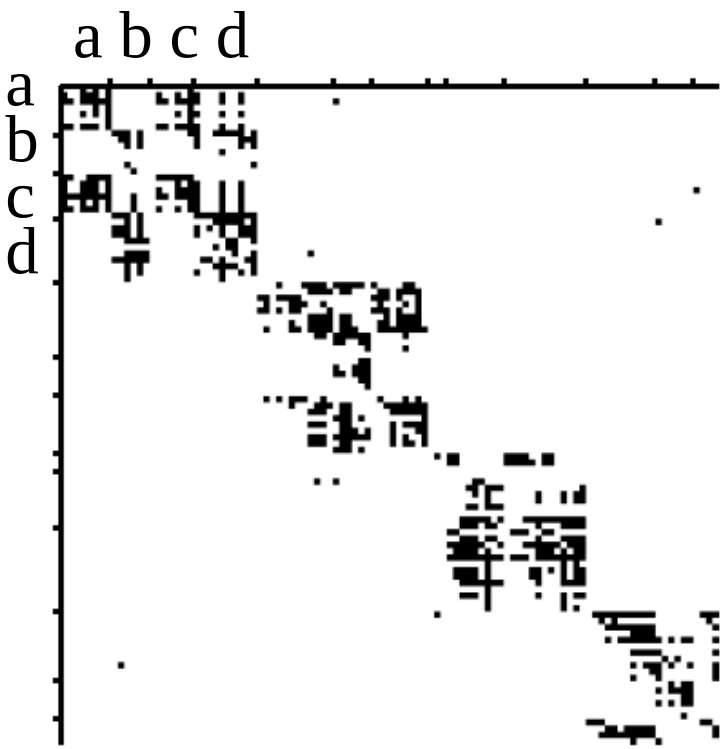
Clusters are defined simultaneously over all kinship relations:

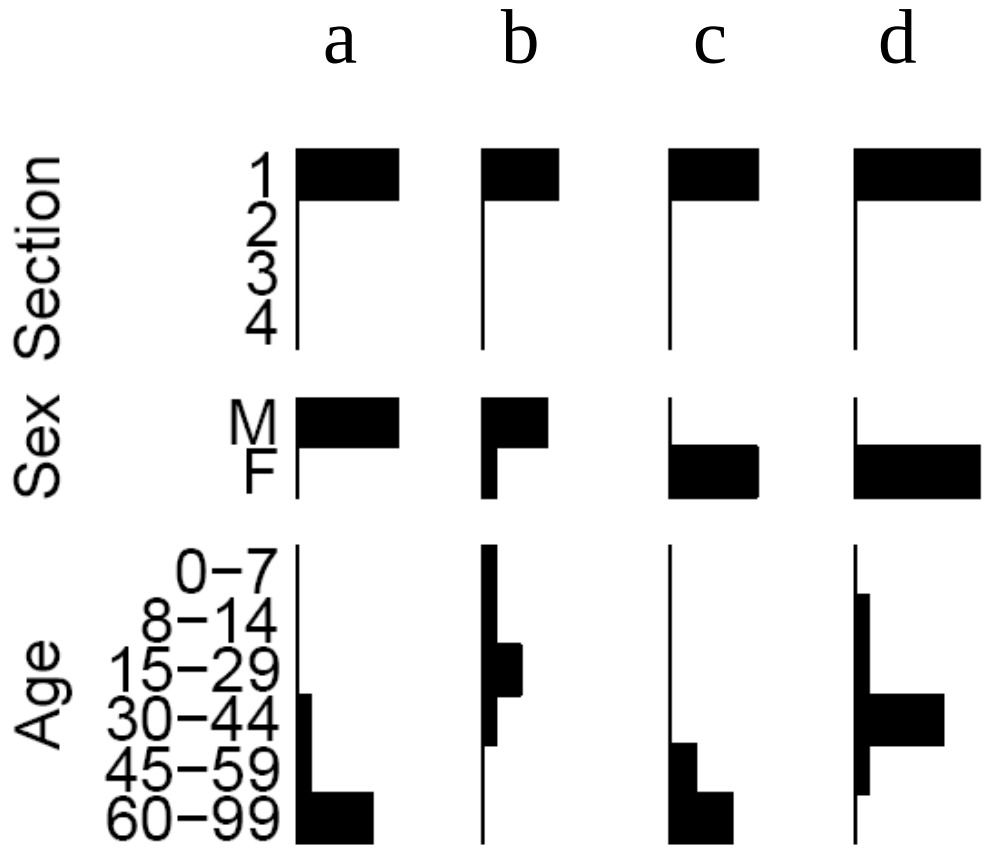




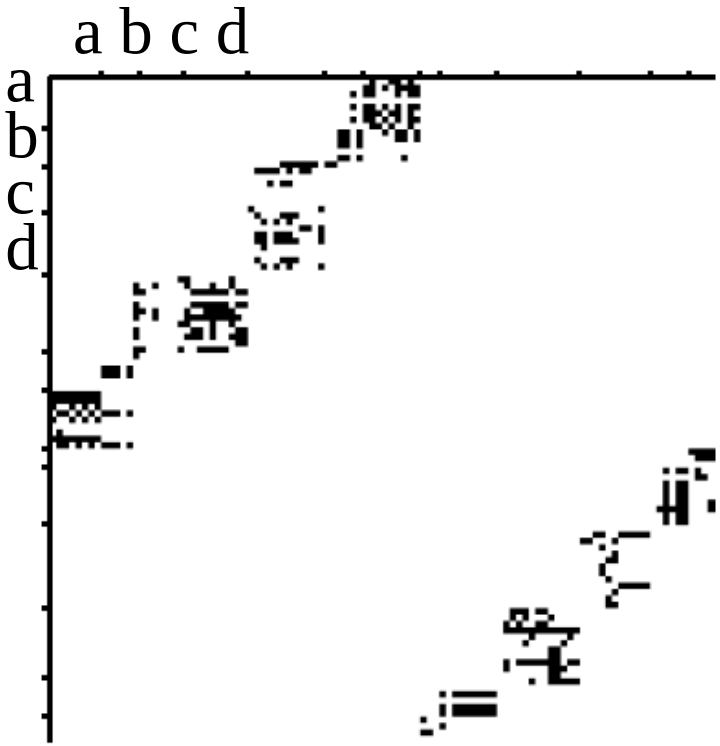


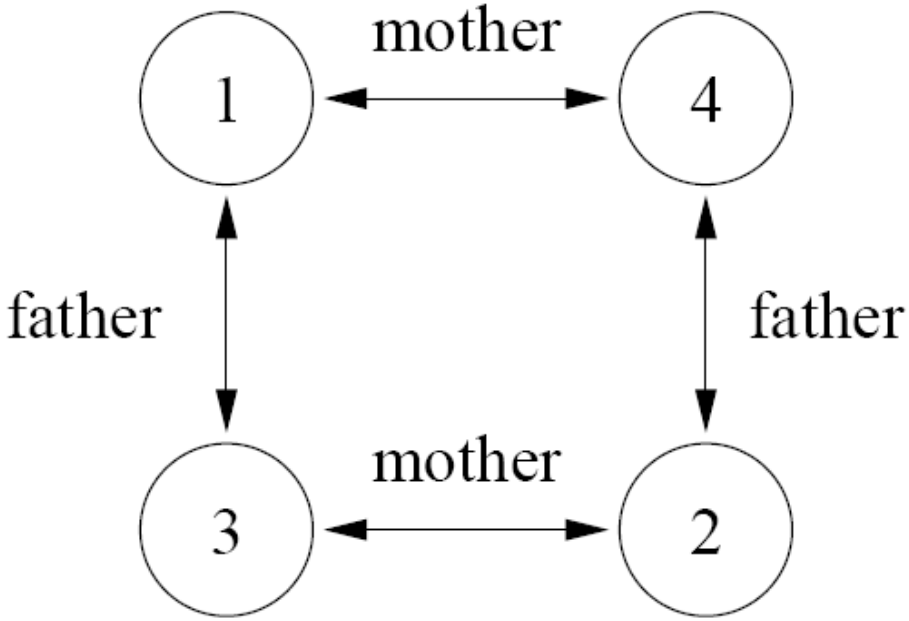
Adiadya


a b c d
a
b
c
d


a
b
c
d
Section
1
2
3
4
Sex
M
F
Age
0−7
8−14
15−29
30−44
45−59
60−99

Adiadya



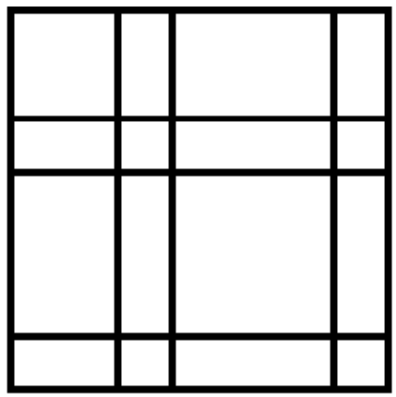


Anowadya

Academic communities

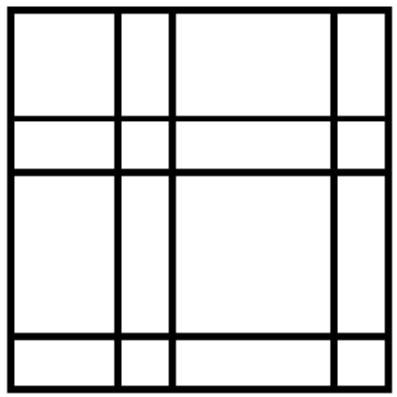
Documents

Documents

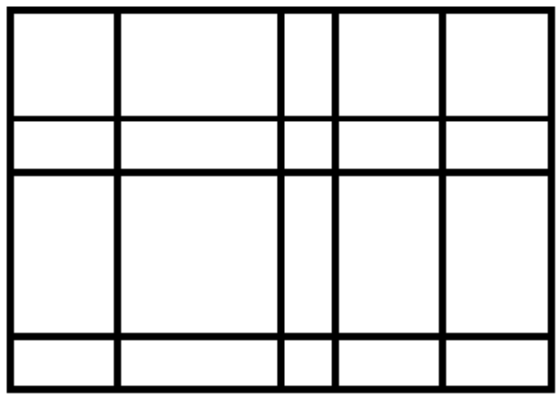


Academic communities

Documents



Words



Academic communities

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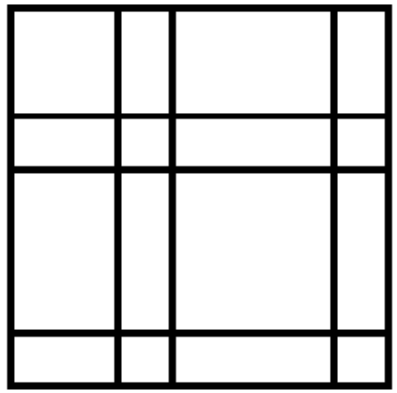
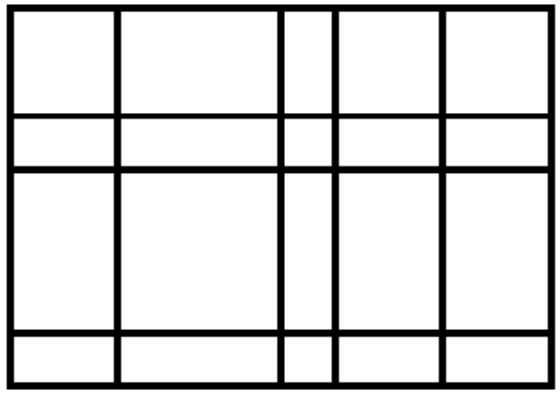
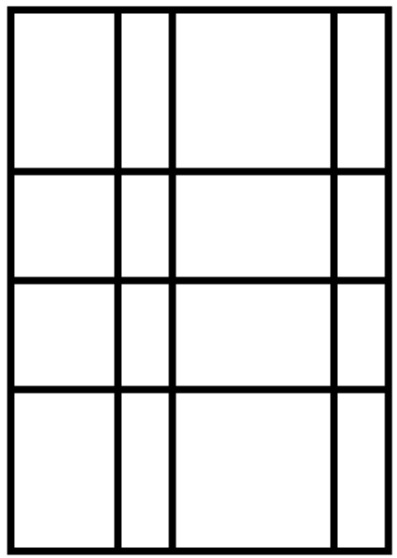
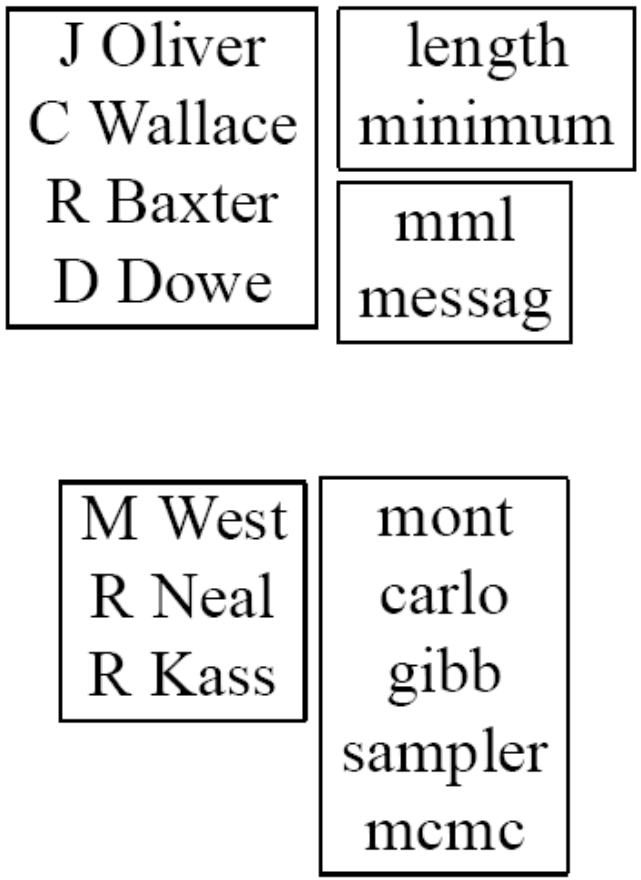




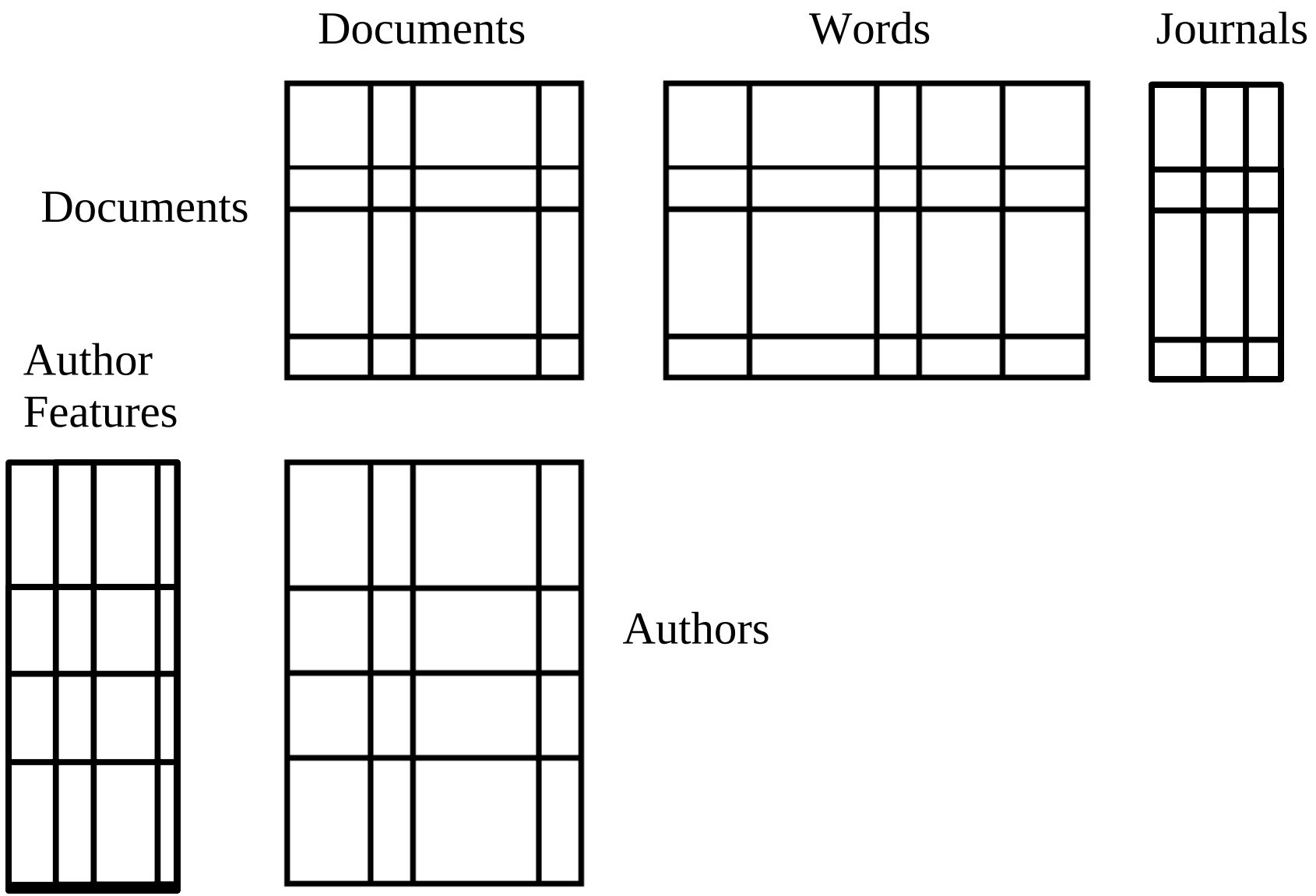
Authors



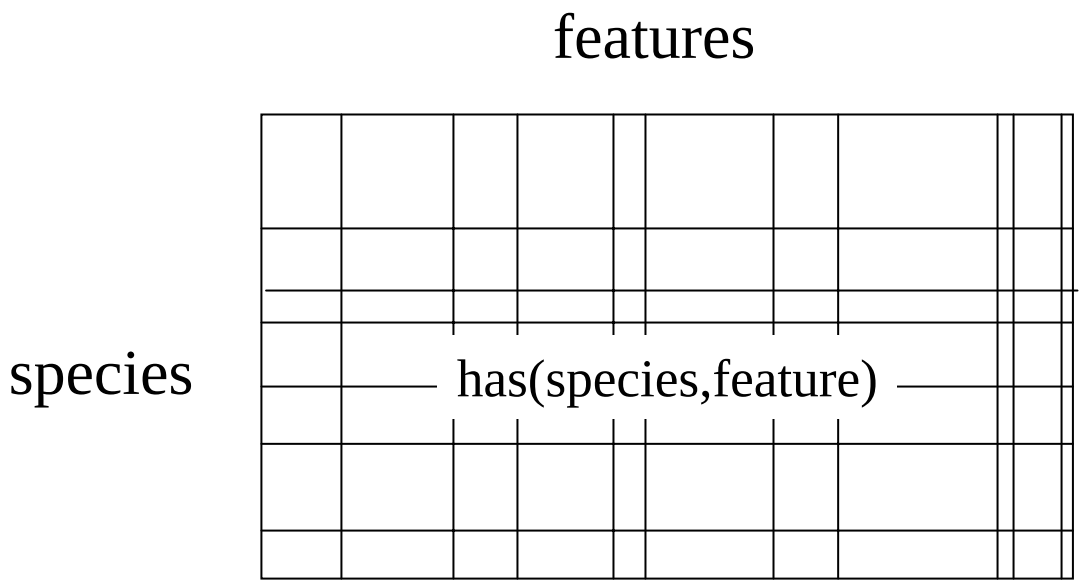
Example: machine learning papers



Academic communities



Learning belief networks: Joint clustering of entities & attributes

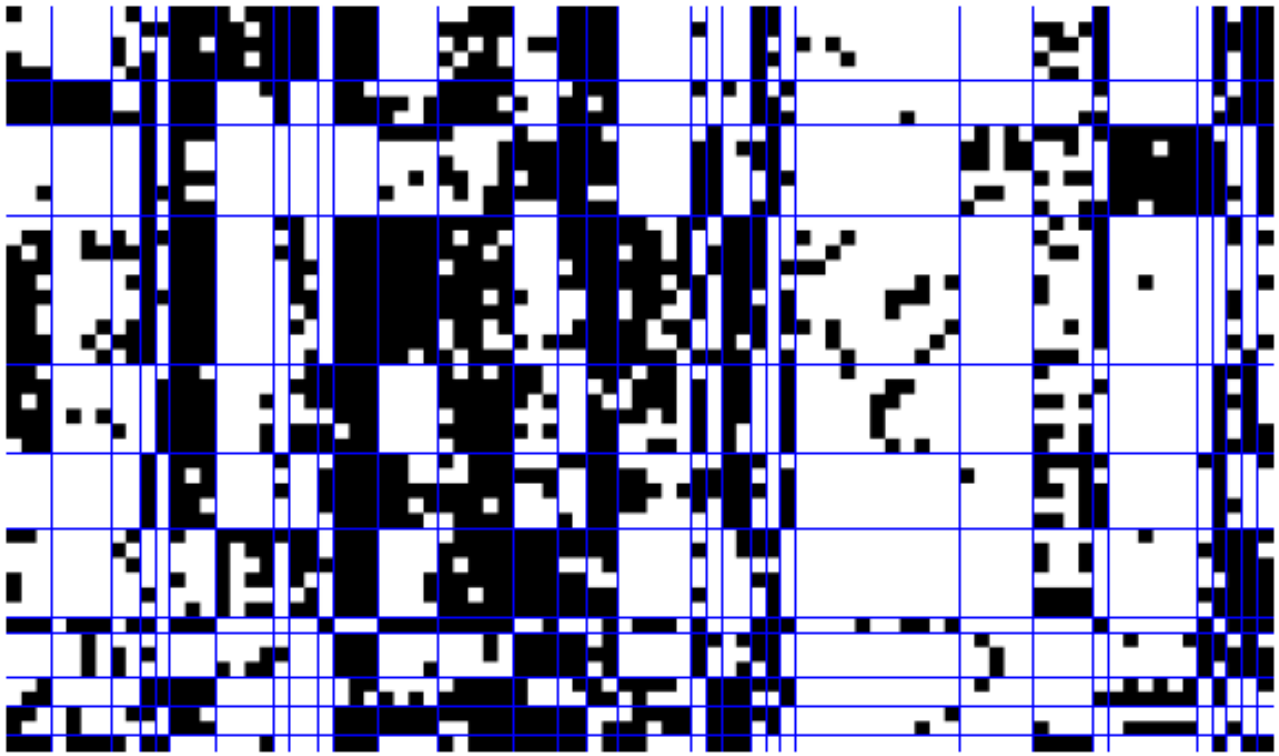


- 48 animals: {antelope, beaver, bat, chihuahua ...}
- 85 attributes: {swims, nocturnal, smart, tough skin...}

Animals

Attributes

- 48 animals: {antelope, beaver, bat, chihuahua ...}
- 85 attributes: {swims, nocturnal, smart, tough skin...}



Animals

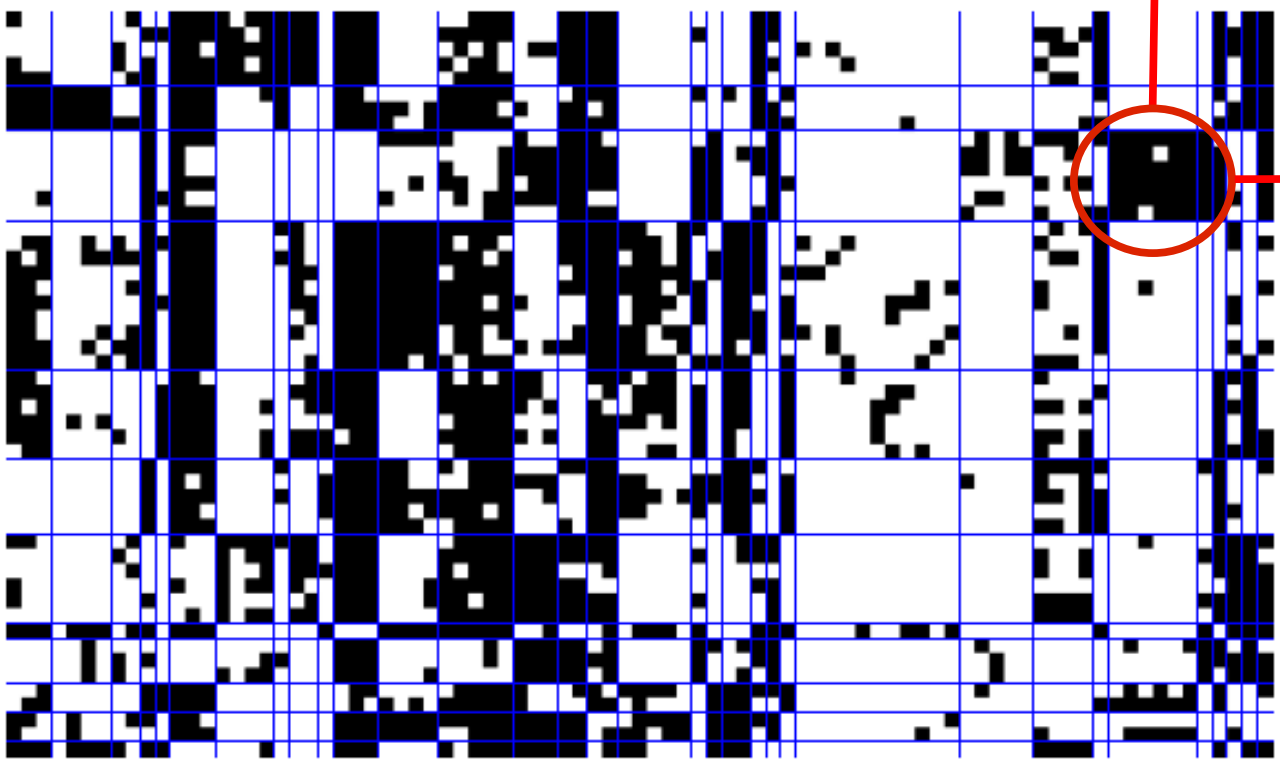
Attributes

Species clusters

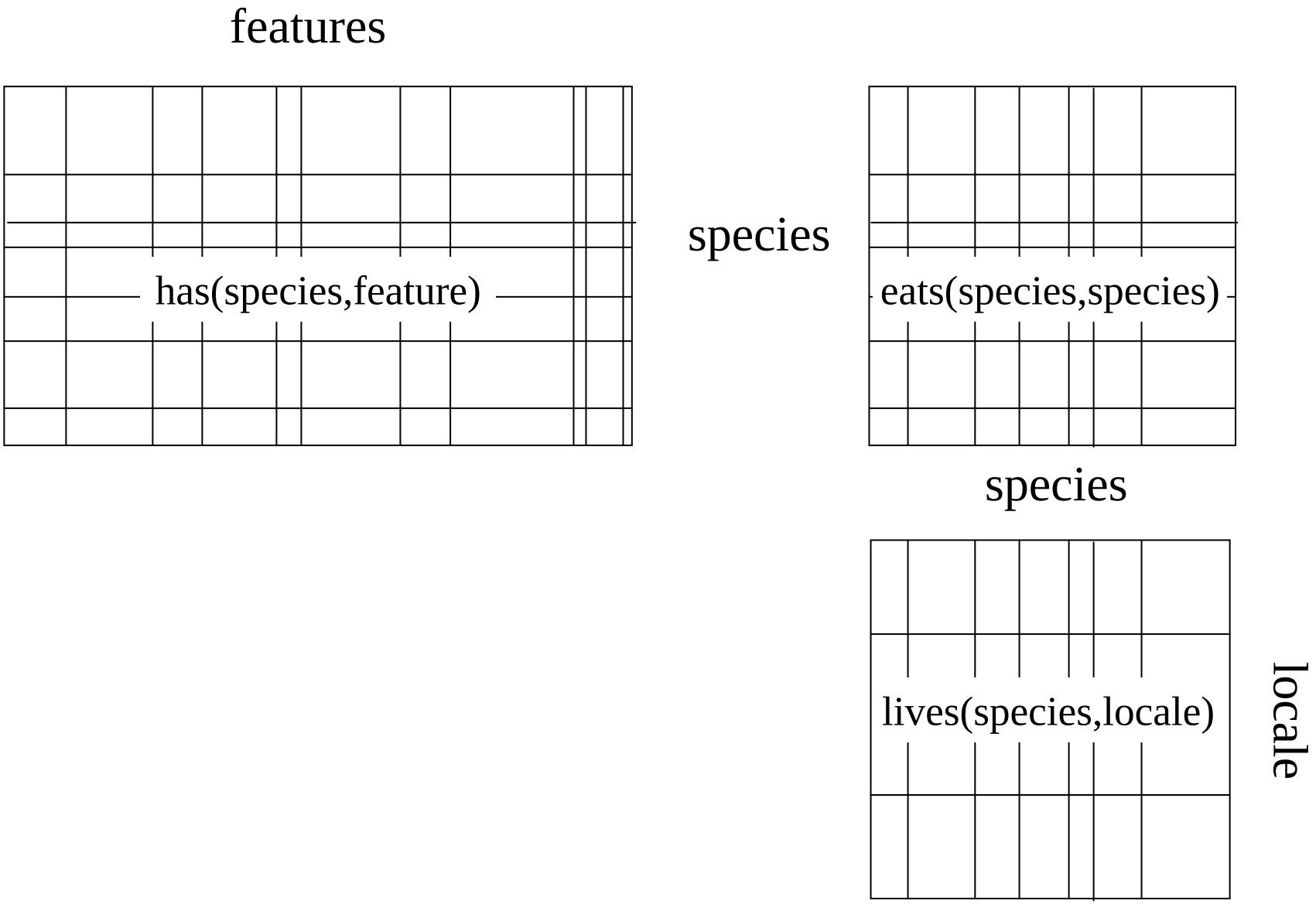
- antelope, horse, giraffe, zebra, deer
- chimp, monkey, gorilla
- killer whale, humpback whale, blue whale, walrus, dolphin, seal
- hippopotamus, elephant, rhinoceros
- dalmatian, persian cat, siamese cat, chihuahua, collie

Attribute clusters

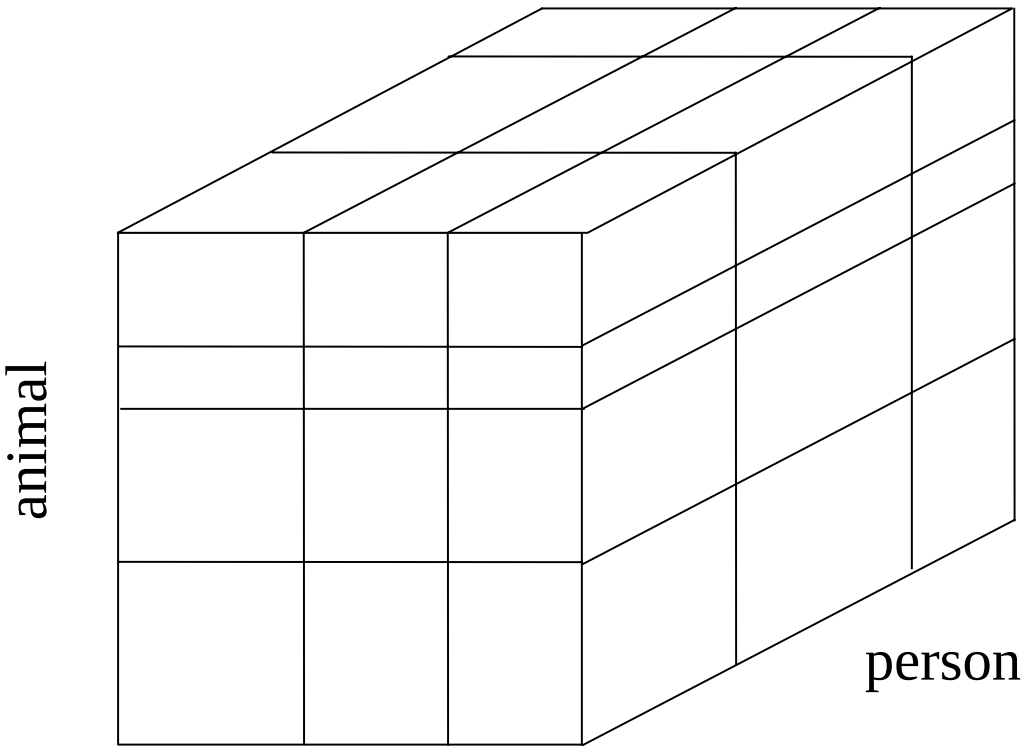
- hooves, long neck, horns, grazer
- hands, bipedal, tree, jungle
- flippers, swims, arctic, ocean, coastal, water
- fast, active, agility
- pads, claws, nocturnal, stalker, hibernate
- walks, quadrapedal, ground


Flippers
Swims
Arctic
Coastal
Ocean
Water
Killer Whale
Blue Whale
Humpback
Seal
Walrus
Dolphin
Animals
Attributes

Ecological knowledge

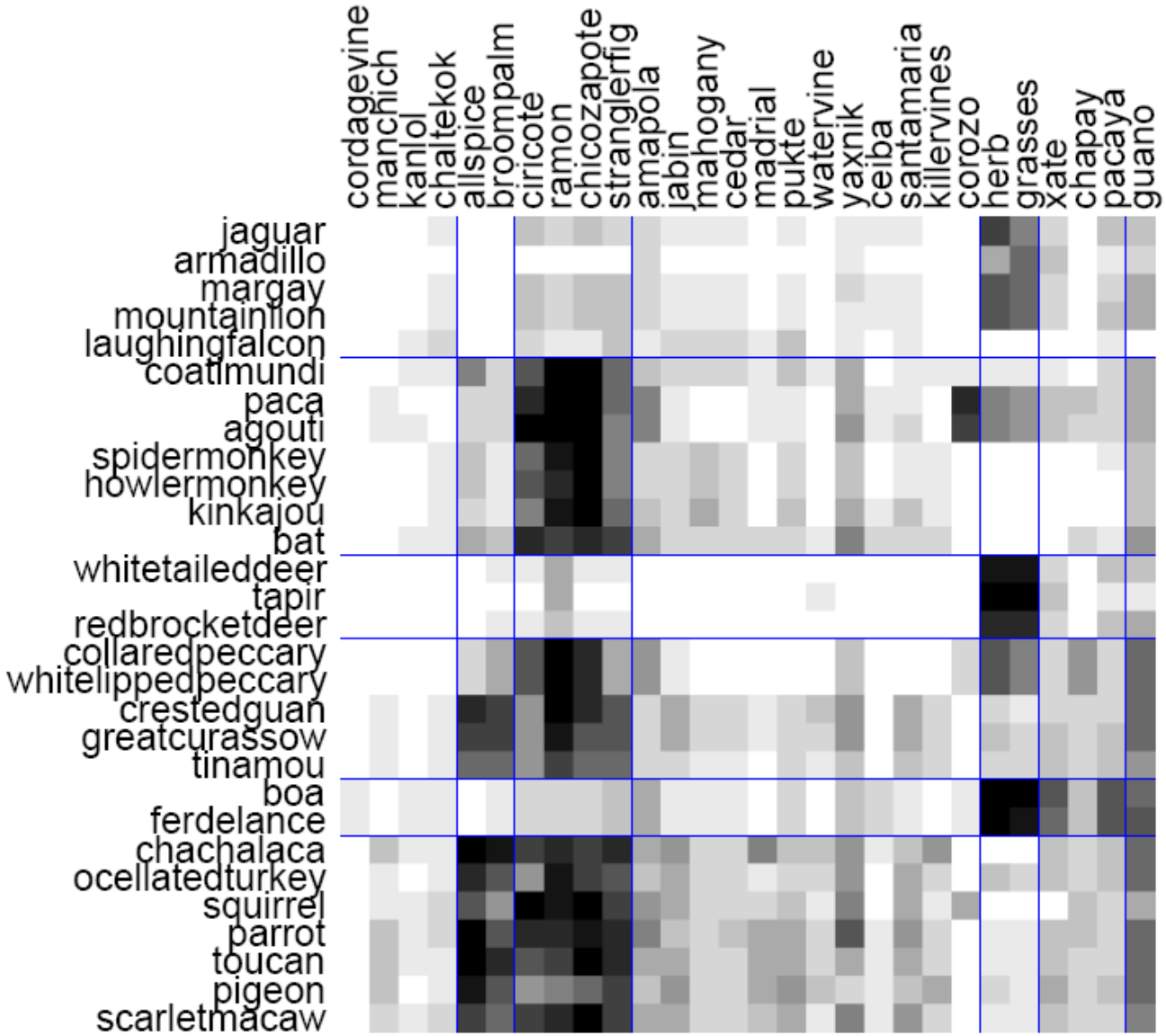


Joint modeling of belief systems and social systems

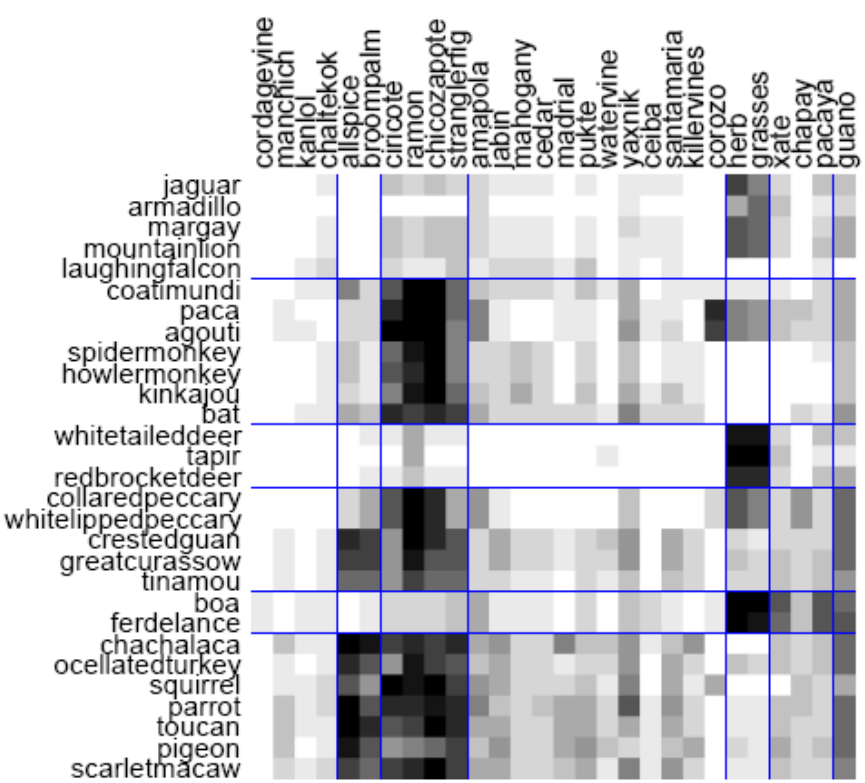


helps(plant,animal,person judging)

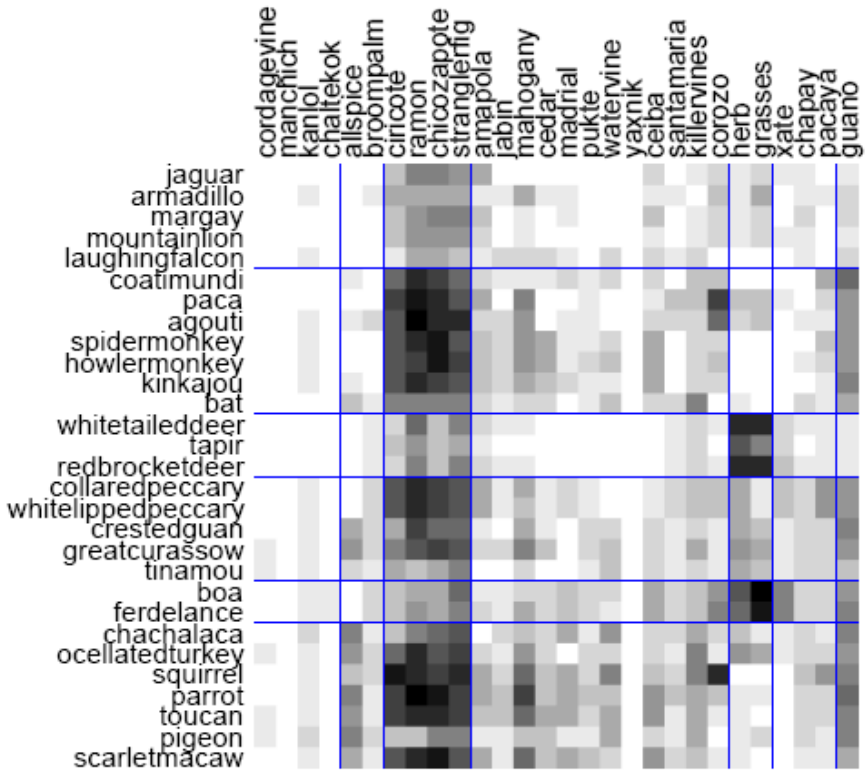
Data from Atran and Medin

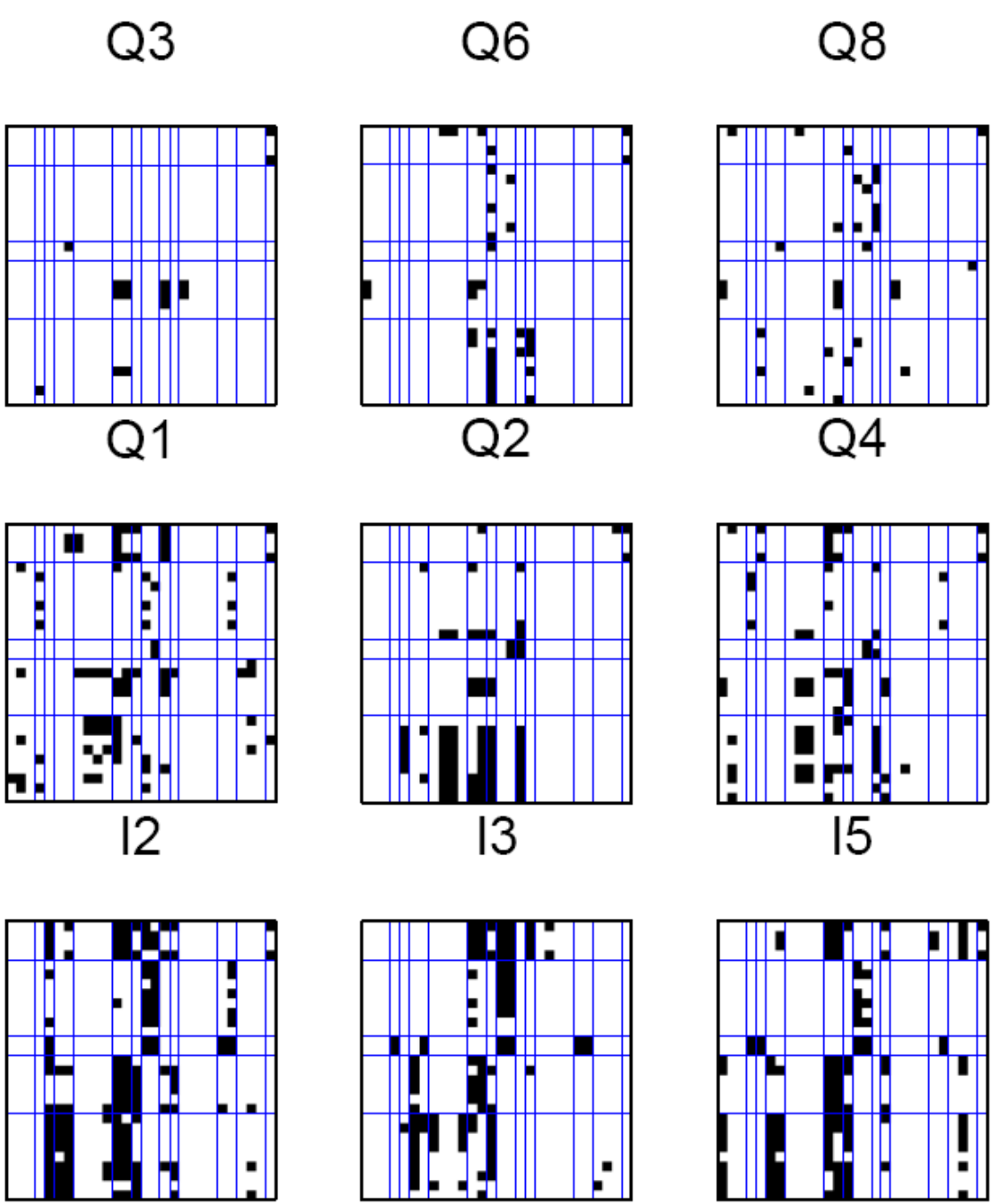

cordagevine
manchich
kanlol
chaltekok
allspice
broompalm
ciricote
ramon
chicozapote
stranglerfig
amapola
jabin
mahogany
cedar
madrial
pukte
watervine
yaxnik
ceiba
santamaria
killervines
corozo
herb
grasses
xate
chapay
pacaya
guano
jaguar
armadillo
margay
mountainlion
laughingfalcon
coatimundi
paca
agouti
spidermonkey
howlermonkey
kinkajou
bat
whitetaileddeer
tapir
redbrocketdeer
collaredpeccary
whitelippedpeccary
crestedguan
greatcurassow
tinamou
boa
ferdelance
chachalaca
ocellatedturkey
squirrel
parrot
toucan
pigeon
scarletmacaw

Itza

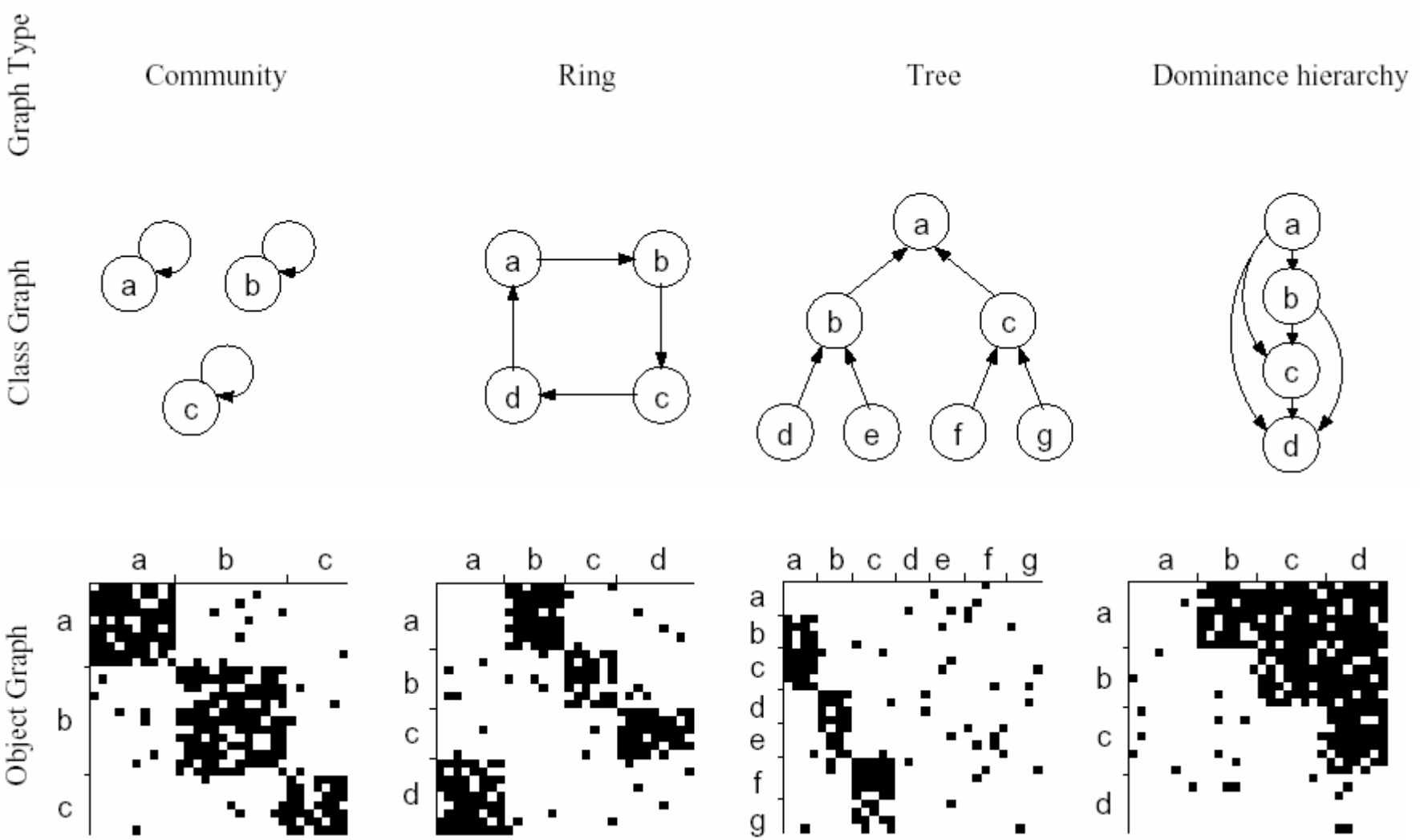


Ladinos

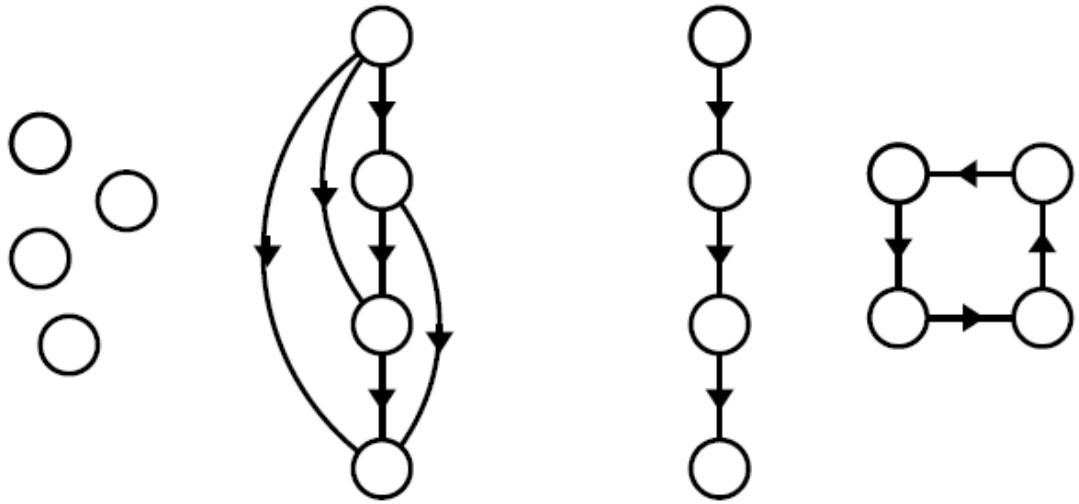



Q3
Q6
Q8
Q1
Q2
Q4
I2
I3
I5

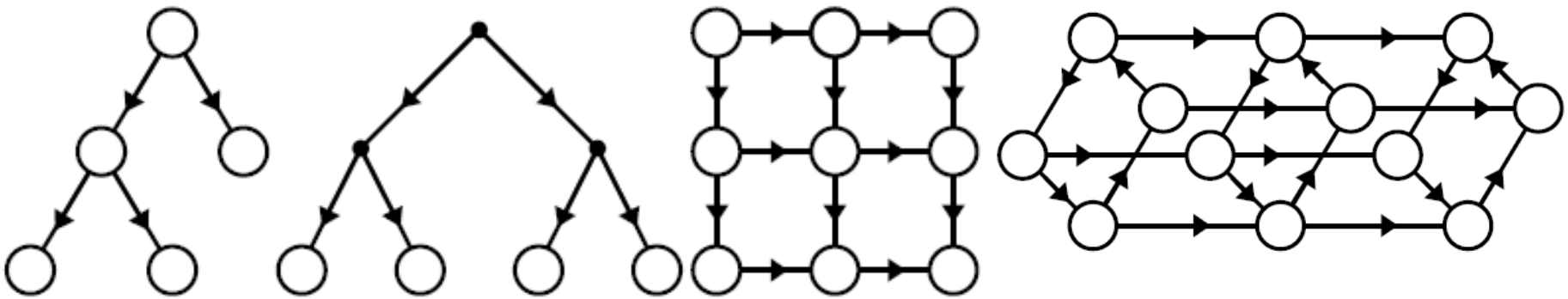
Towards richer models



Structural forms



Partition Order Chain Ring

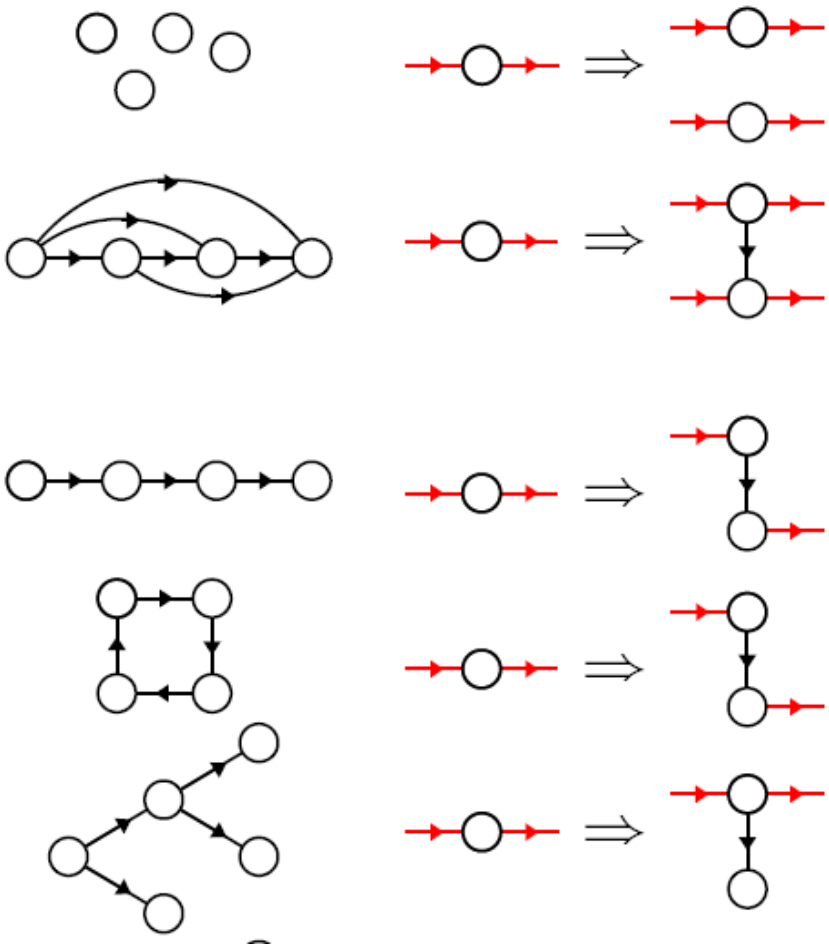


Hierarchy Tree Grid Cylinder

Probabilistic graph grammars

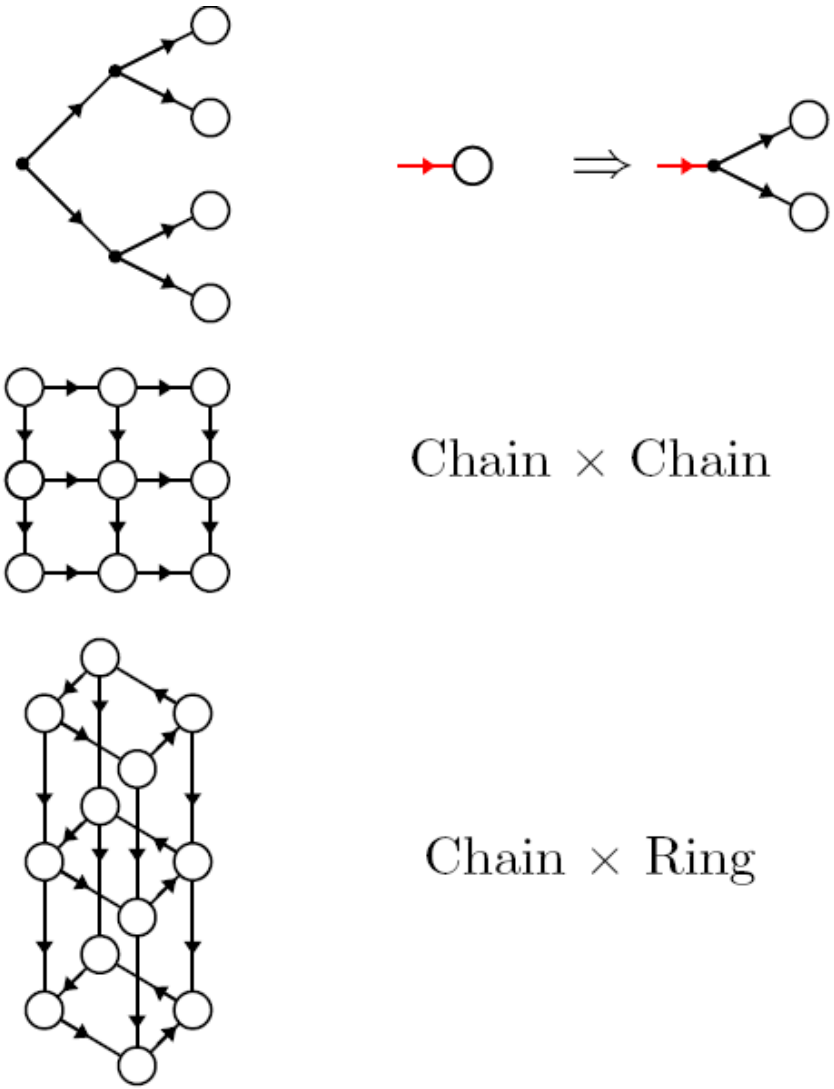
Form

Process



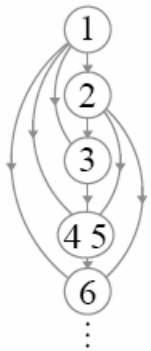
Form

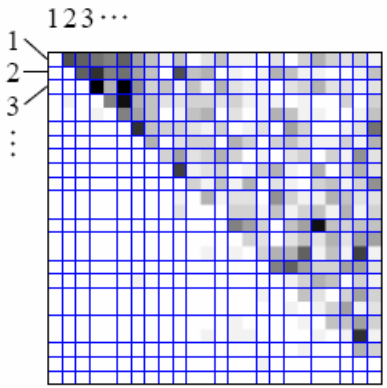
Process



Learning structural forms

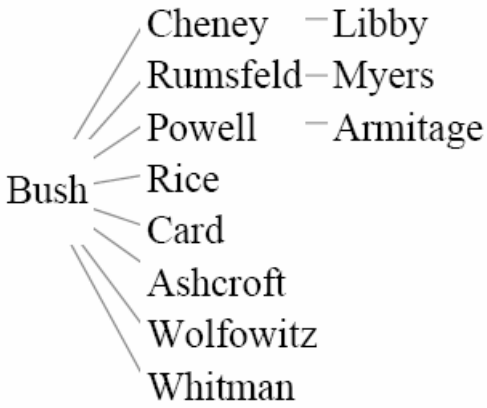
Dominance hierarchy

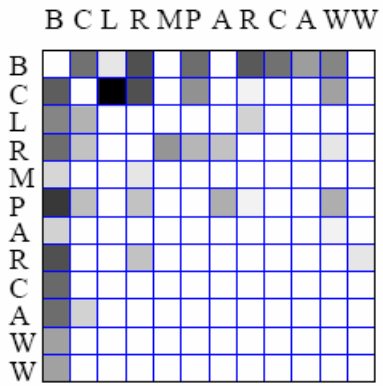




Primate troop
"beats"

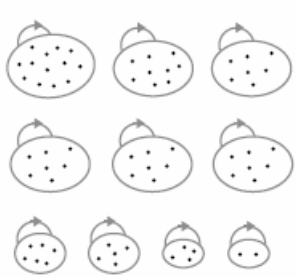
Tree

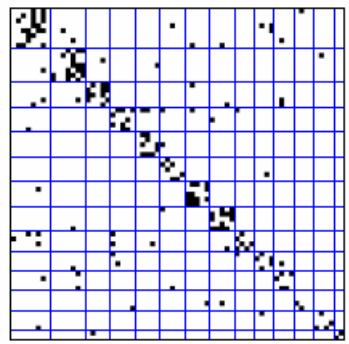




Bush administration
"told"

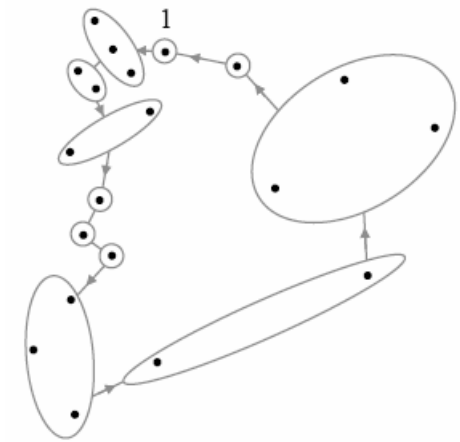
Cliques

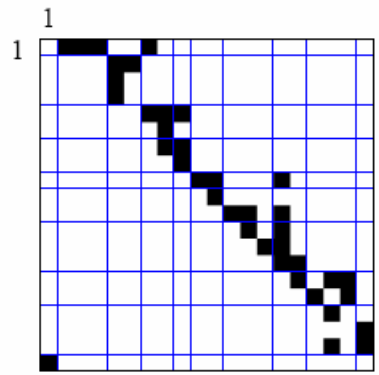




Prison inmates
"likes"

Ring





New Guinea islands
"trades with"

Conclusions

- A probabilistic model for unsupervised learning of relational systems of concepts.
  - Belief networks
  - Social networks
  - Joint networks of beliefs and social structures
- Useful for both cognitive modeling and exploratory data analysis.
  - Allows arbitrary collection of types and relations
  - Automatically discovers appropriate complexity

Future directions

- Richer representations of network structure
- Richer interactions between social networks and belief networks
- Modeling of network evolution and development
- Scalable online learning
- Testing behavioral predictions in learning experiments