



Sundiata

Intelligence augmentée décisionnelle



# Réseaux bayésiens

Modélisation des **connaissances**,  
Apprentissage automatique à partir des **données**.



Breizh Data Day  
French Tech, Rennes  
Jeudi 19 octobre 2017

Emmanuel KEITA



Once upon a time...

# Decision



# Complexity

# Uncertainty

People are limited in their ability to integrate many different pieces of evidence. Computers are not.

Daphne Koller



WIRELESS

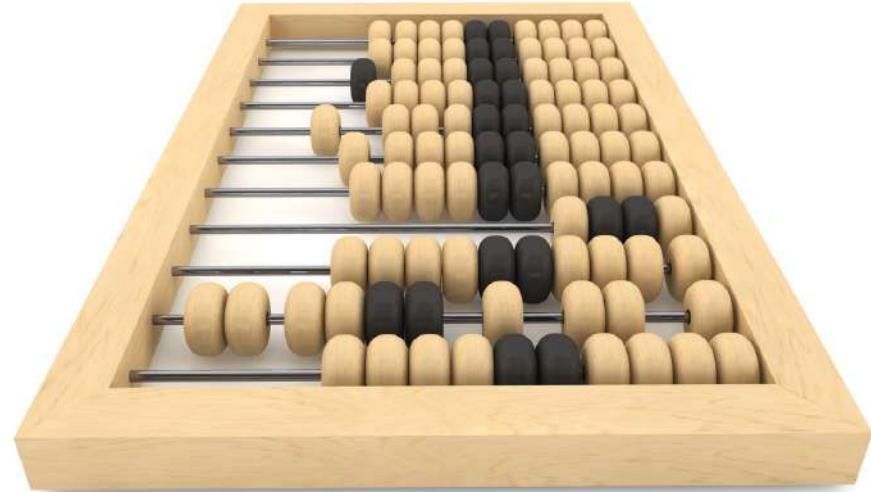
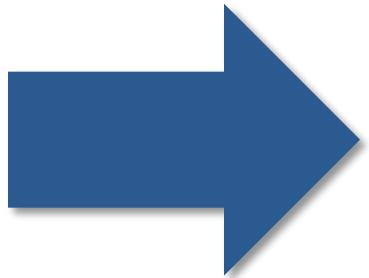
DAVID WEINBERGER BACKCHANNEL 04.18.17 08:22 PM

OUR MACHINES NOW HAVE KNOWLEDGE WE'LL  
NEVER UNDERSTAND

What?



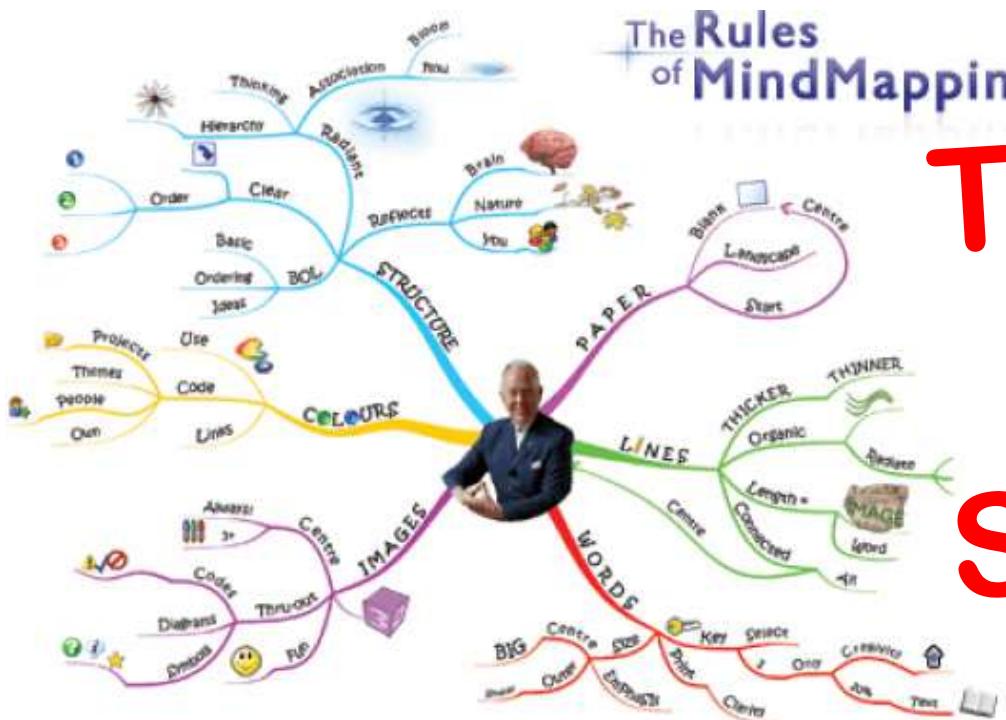
# Augmented Intelligence ?



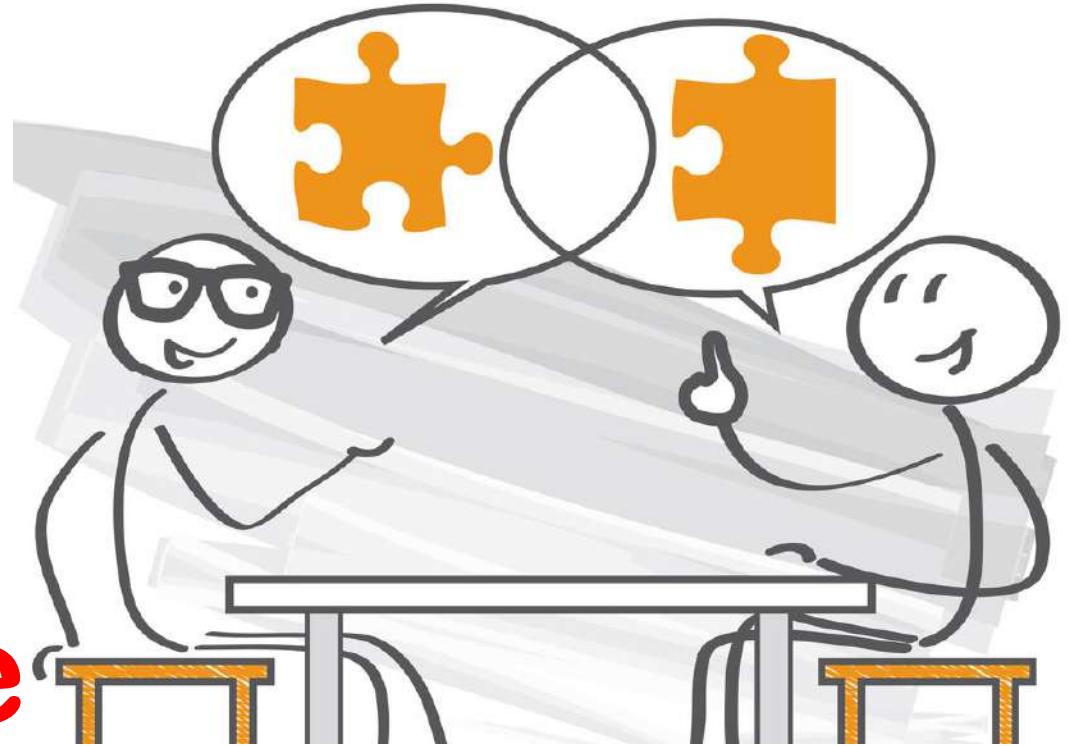
Artificial Intelligence  
solving a problem for you,  
as a “black box.”

Artificial Intelligence  
as a practical support for  
research and reasoning.

# Augmented Intelligence



Think  
&  
Share



# A Modeling Map

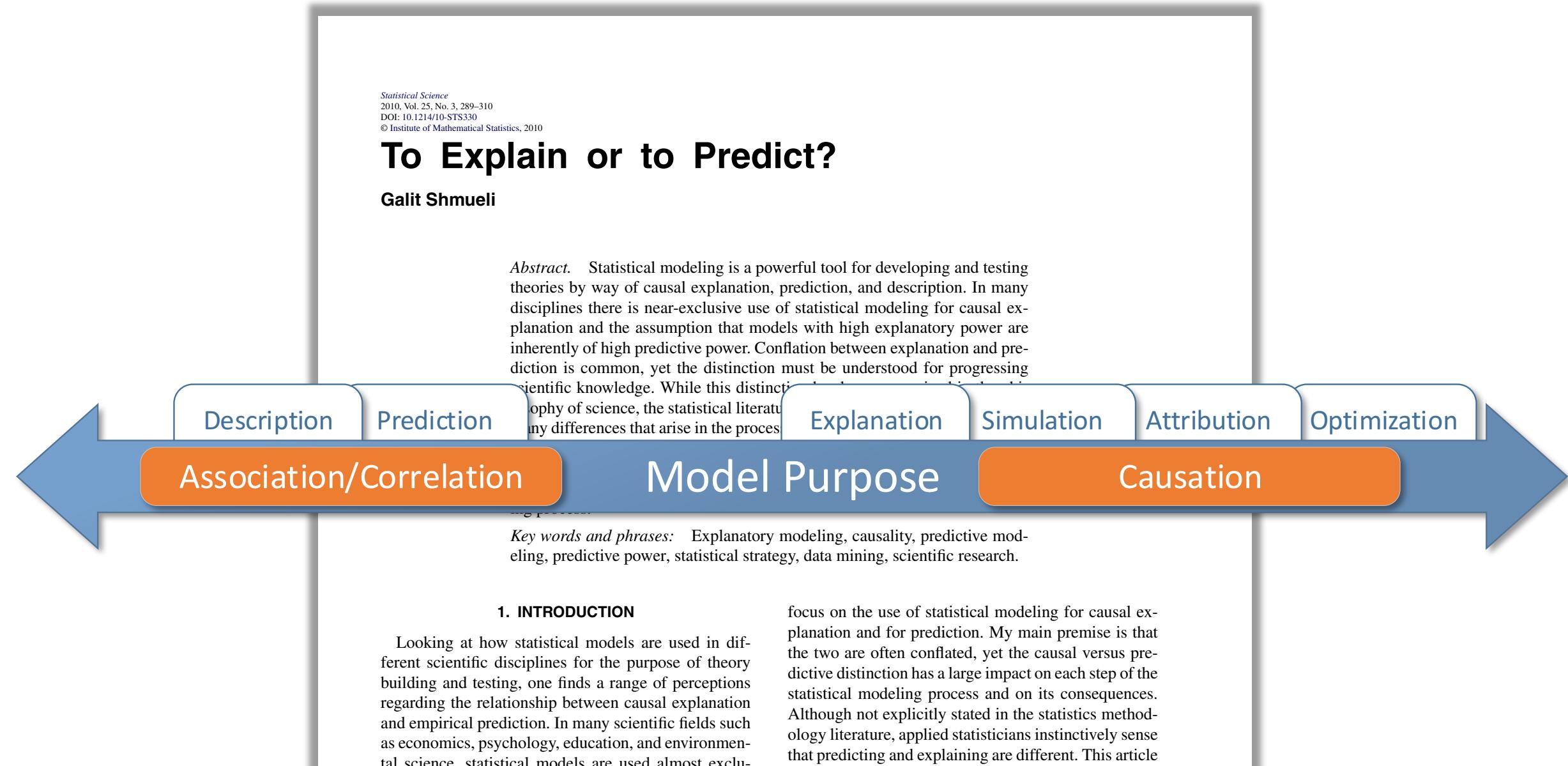
# A Map of Analytic Modeling

Y

All models are wrong but some are useful

X

# The Purpose of Models

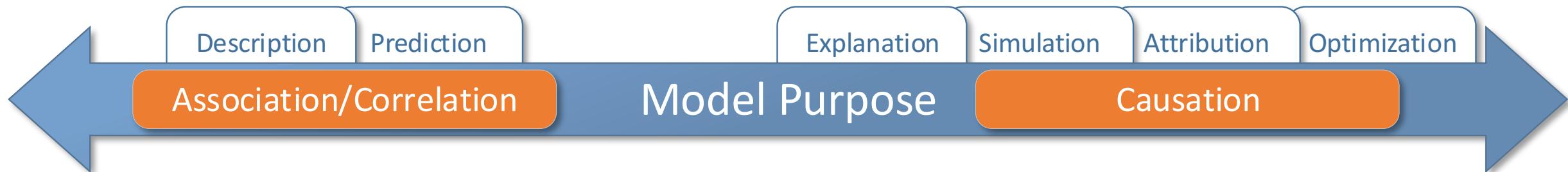


**Quelle est la probabilité qu'un client soit intéressé par mon nouveau produit ?**

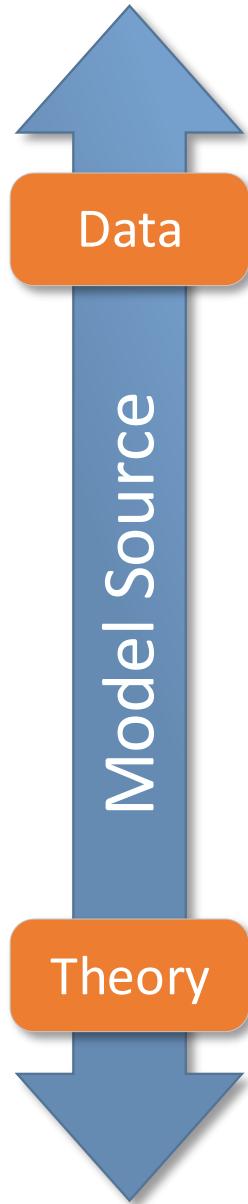
**Quelle est la probabilité que cette start-up fasse faillite ?**

**Quels sont les principaux leviers d'optimisation de mes ventes ?**

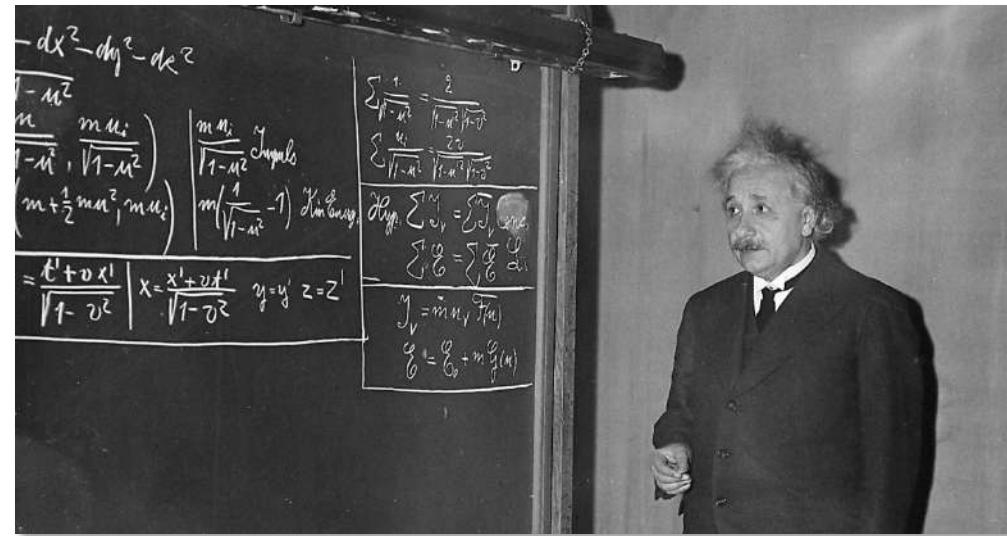
**Quels sont les effets réels de cette nouvelle molécule ?**



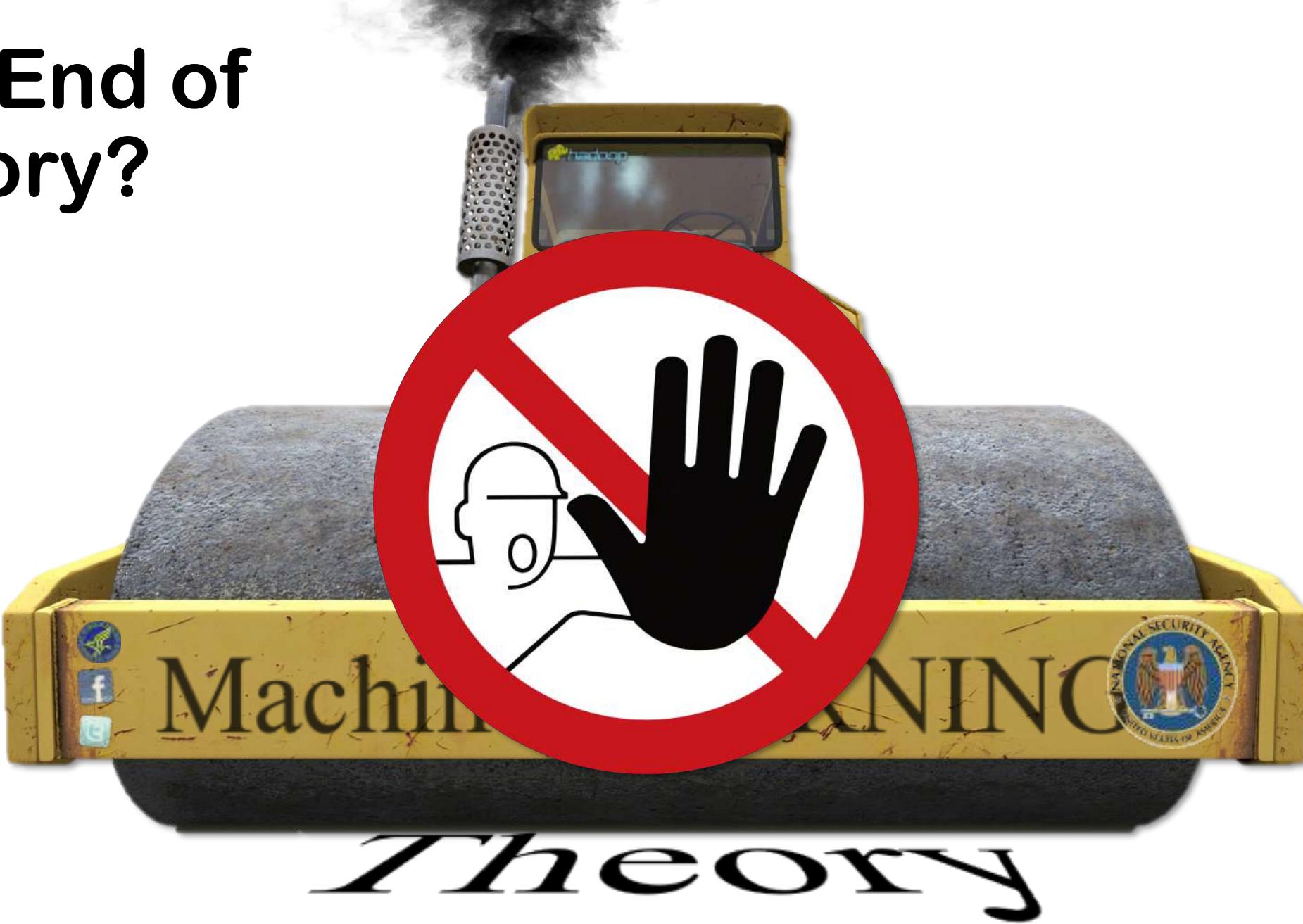
# Source of Models

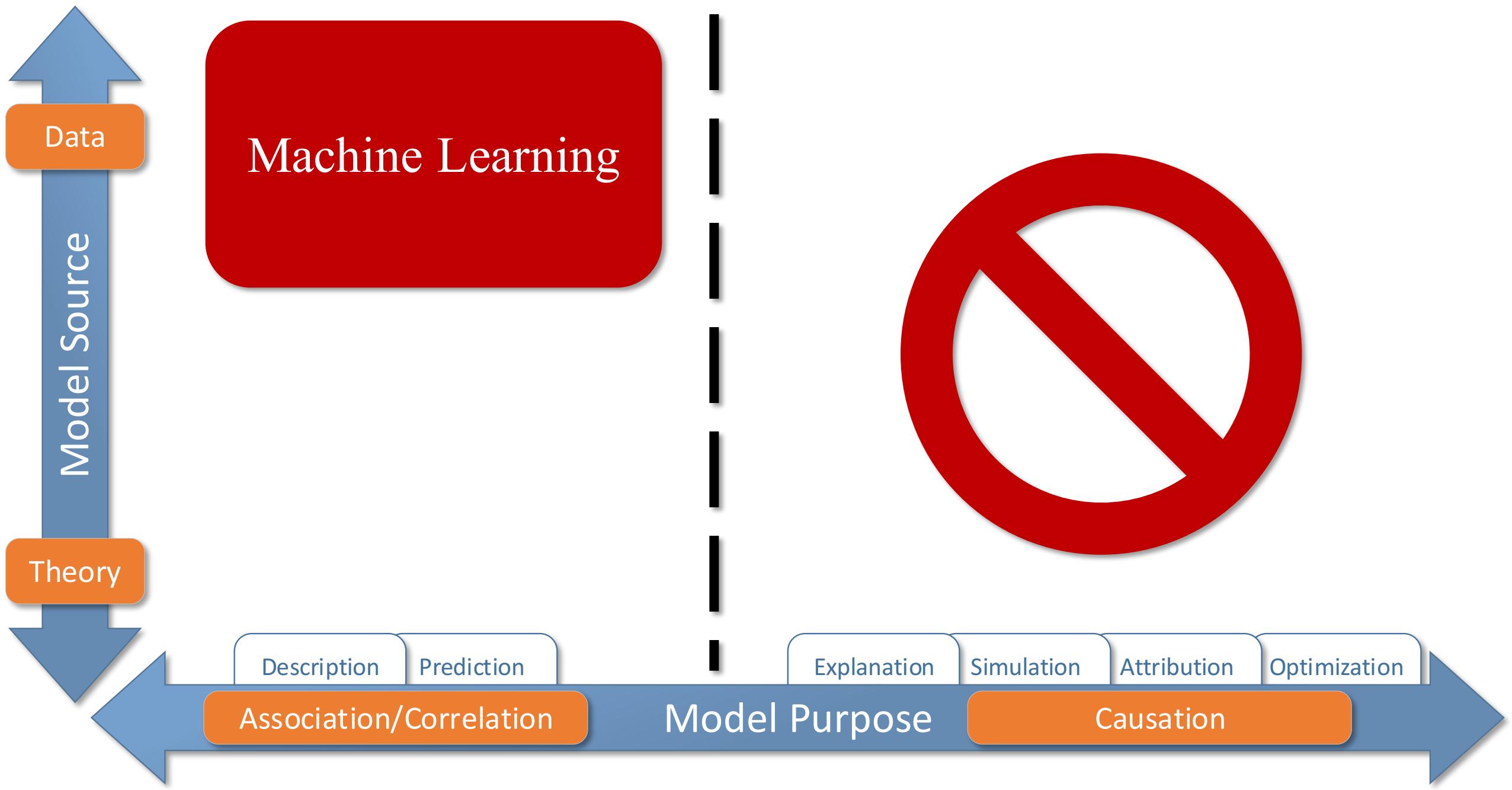


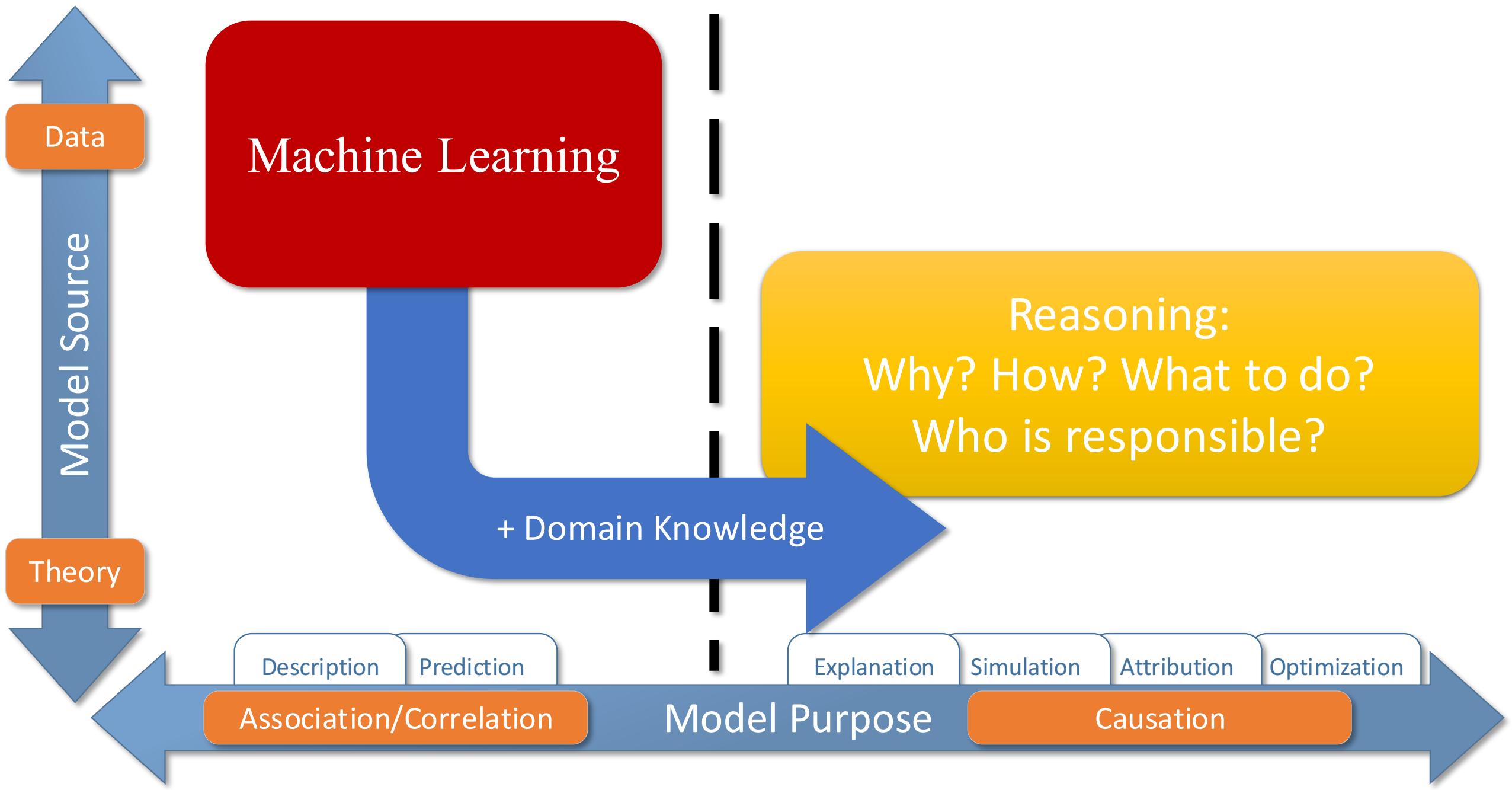
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120

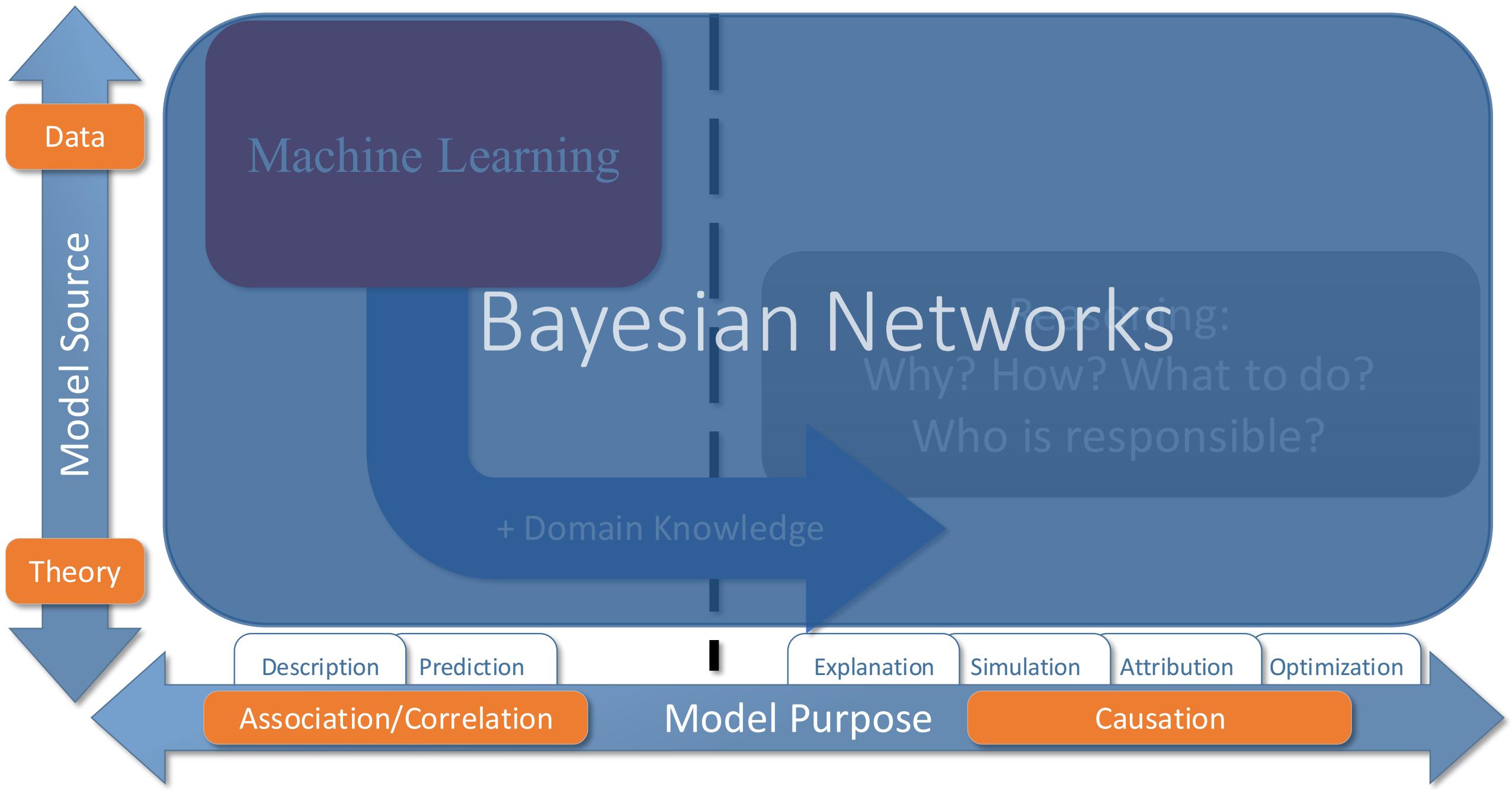


# The End of Theory?







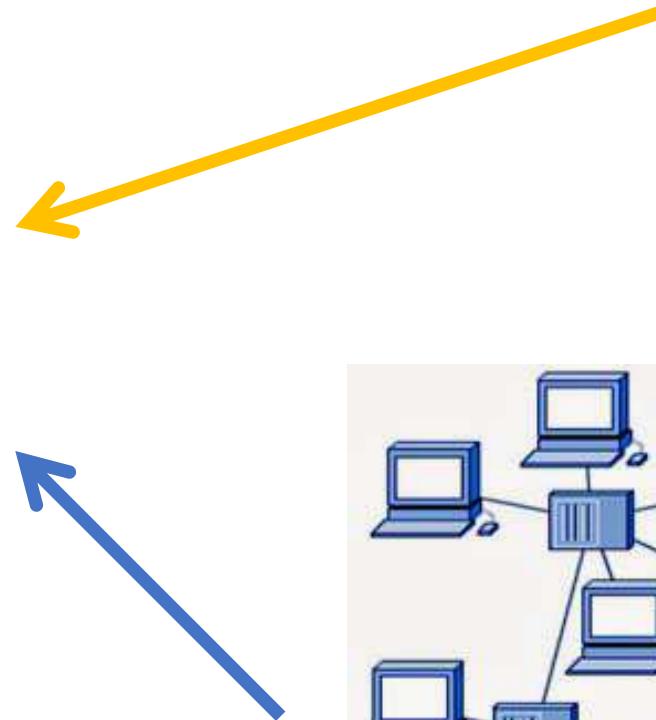
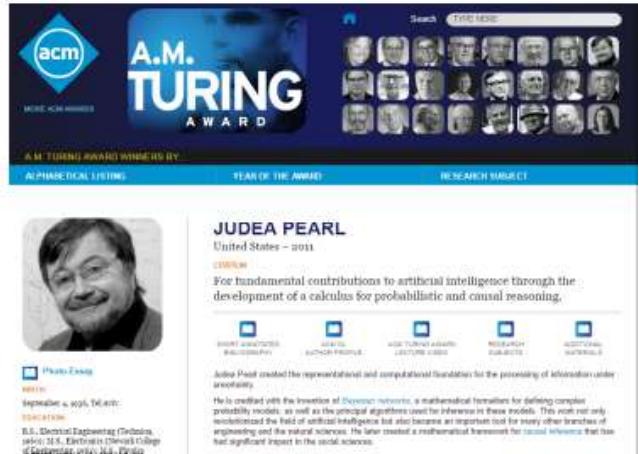


# Bayesian Networks

## Qualitative (DAGs) and Quantitative (discrete PD) representation of knowledge

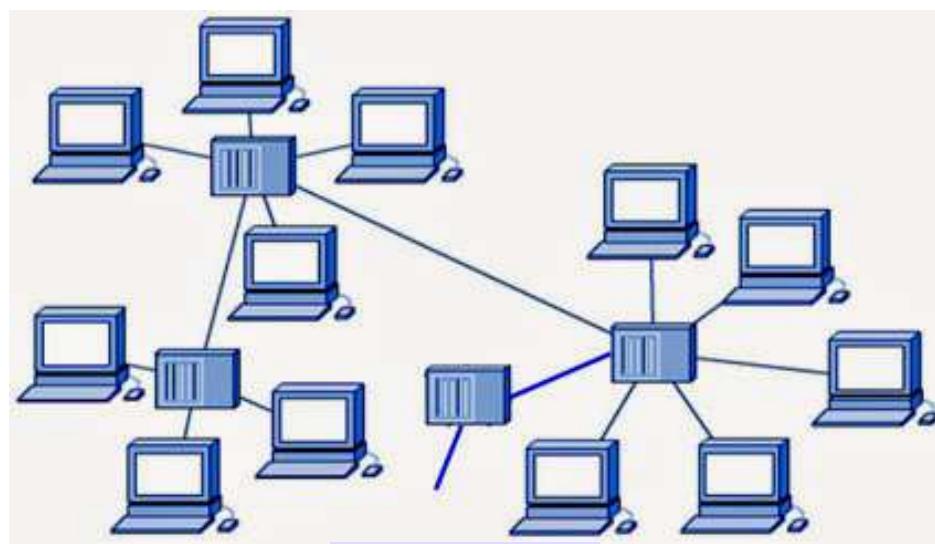
- ✓ Powerful Communication tool
- ✓ Easy knowledge modeling
- ✓ Inference engine
- ✓ Machine learning

# Bay... what?



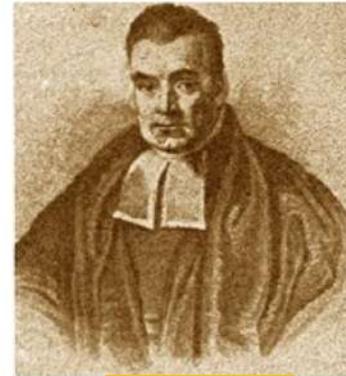
Bayesian Networks  
['Bay' + 'asian']

Réseaux bayésiens  
['Bye' + 'é' + 'zien']



A network

Rev. Thomas Bayes (1702-1761)



Bayes

- Rev. Thomas Bayes noted that sometimes the probability of a statistical hypothesis is given before event or evidence is observed (Prior); he showed how to compute the probability of the hypothesis after some observations are made (Posterior).
- Before Rev. Bayes, no one knew how to measure the probability of statistical hypotheses in the light of data. Only it was known as to how to reject a statistical hypothesis in the light of data.

# About Neural Networks

THE ALAN  
TURING  
INSTITUTE

## Deep Convolution Neworks

- The revival of neural networks: *Y. LeCun*

Hierarchical invariants  
Linearization

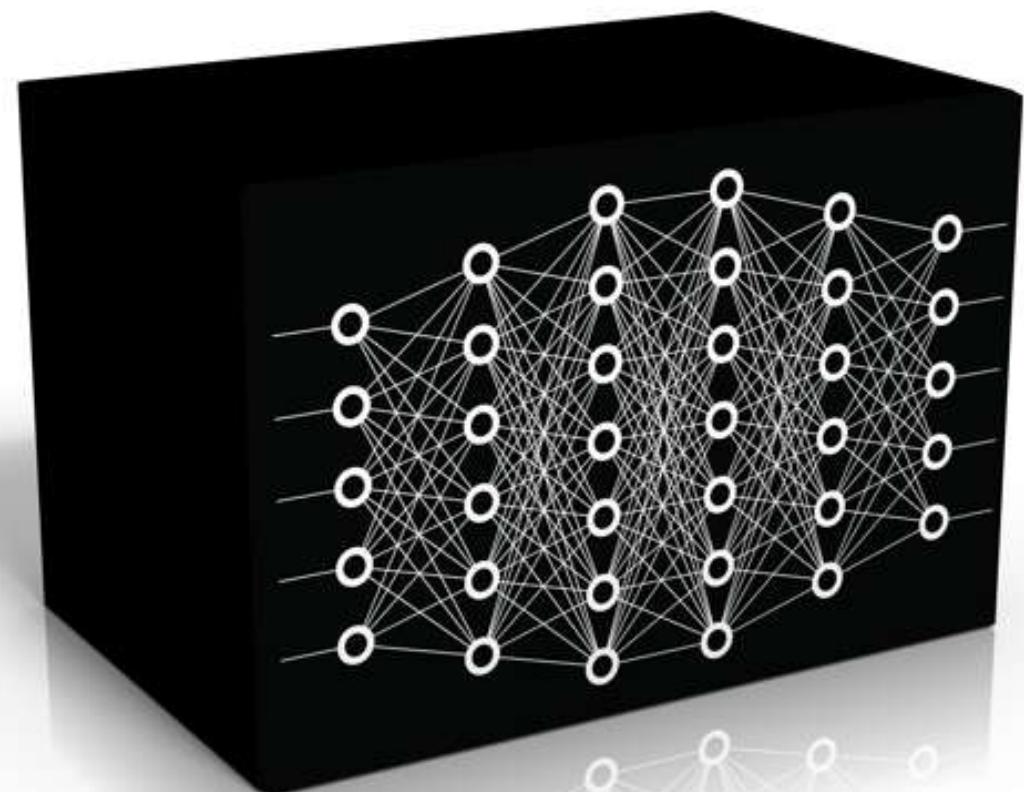
Optimize  $L_j$  with **architecture constraints**: over  $10^9$  parameters  
Exceptional results for *images, speech, language, bio-data...*

Why does it work so well ?



## UNDERSTANDING ?

<https://www.youtube.com/watch?v=nHXO43BqeQw>



- Trial and error testing can not guarantee reliability.

# About Bayesian Networks

Artificial Intelligence

Bayesian Networks



Research

The systematic investigation into and study of materials and sources in order to establish facts and reach new conclusions.

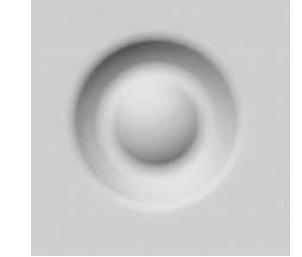
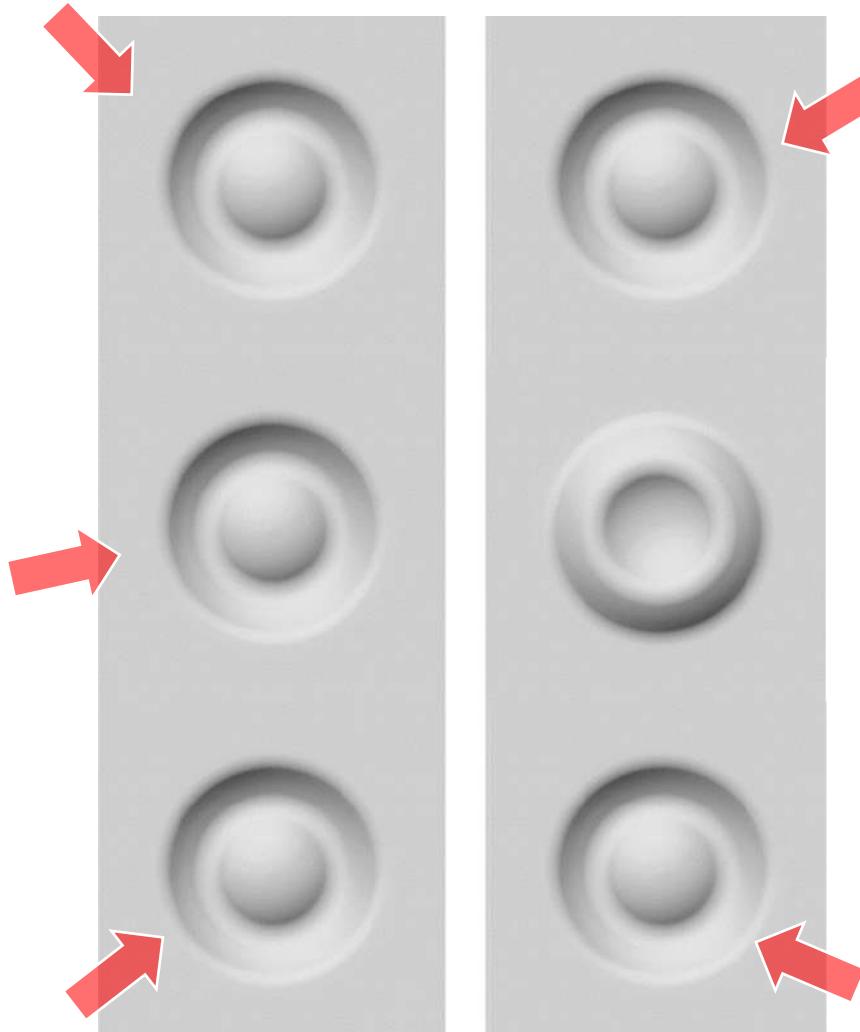
Reasoning

The process of forming conclusions, judgments, or inferences from facts or premises.

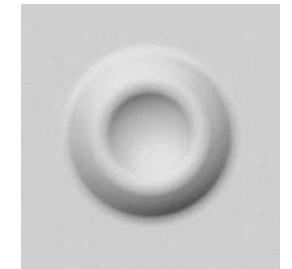
Analytic Modeling

# Strategic monitoring

Combien de boutons activables ?



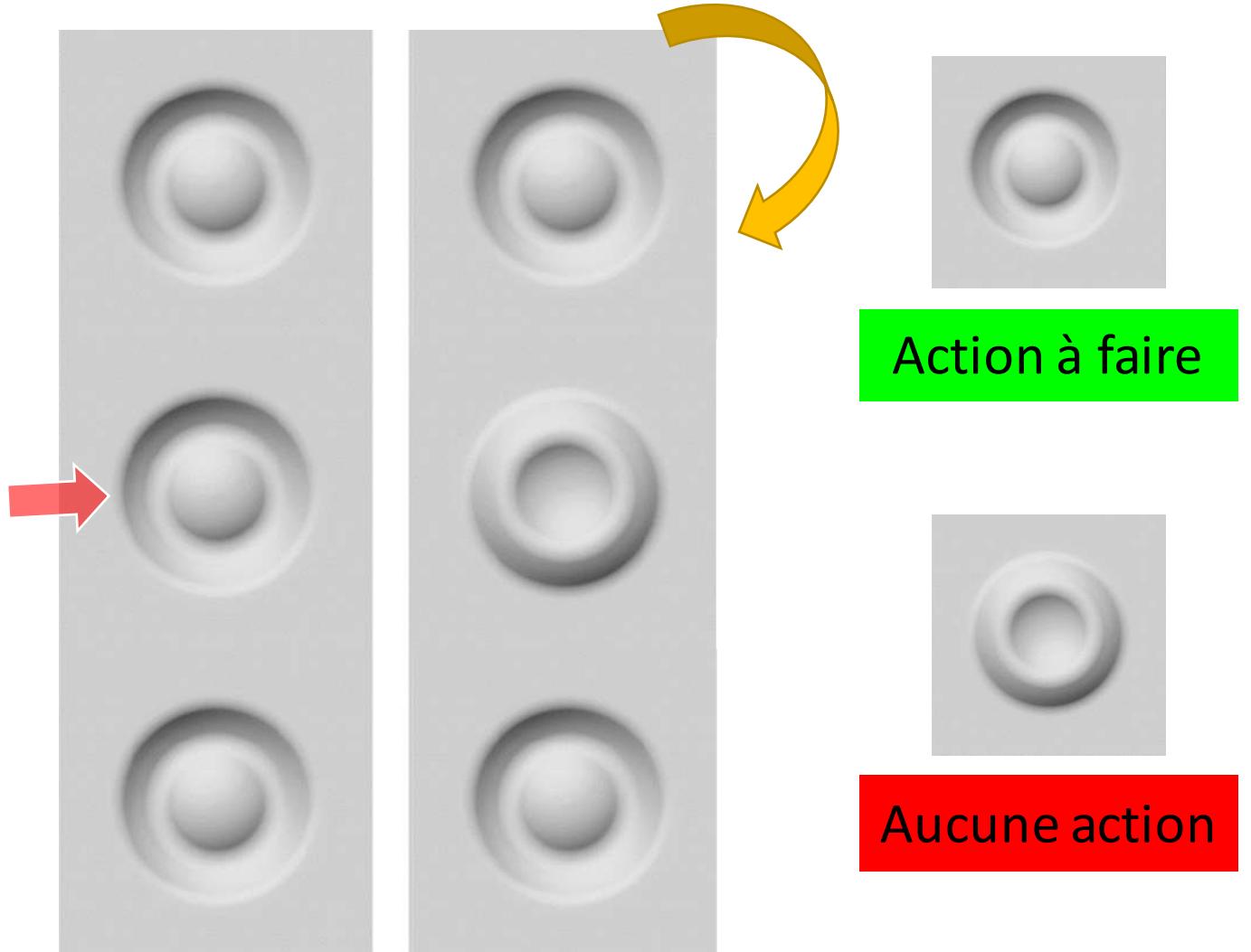
Action à faire

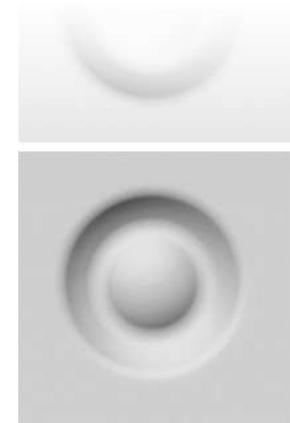
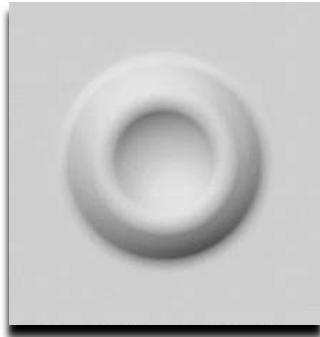
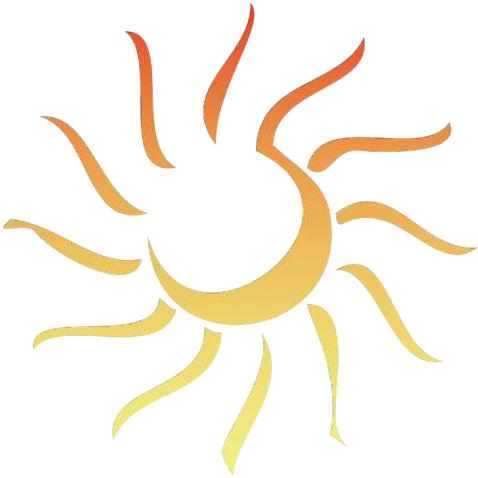


Aucune action

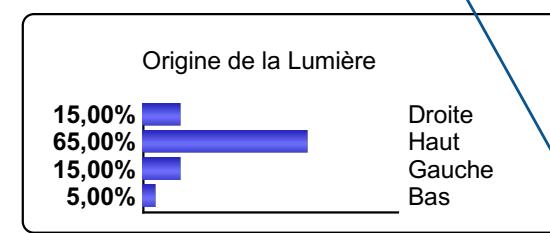
# Strategic monitoring

Combien de boutons activables ?

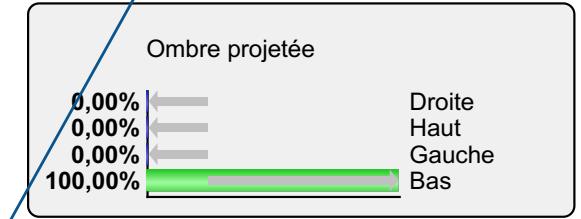




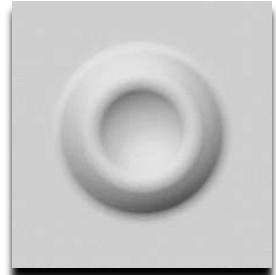
Origine  
de la  
Lumière



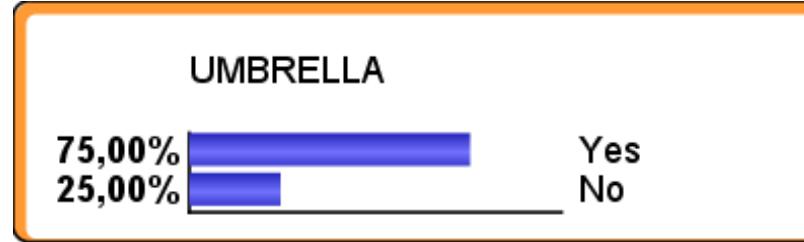
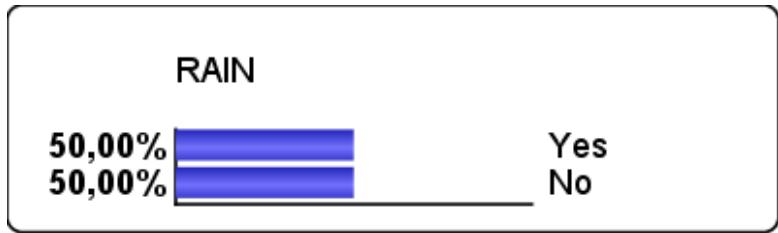
Ombre  
projétée



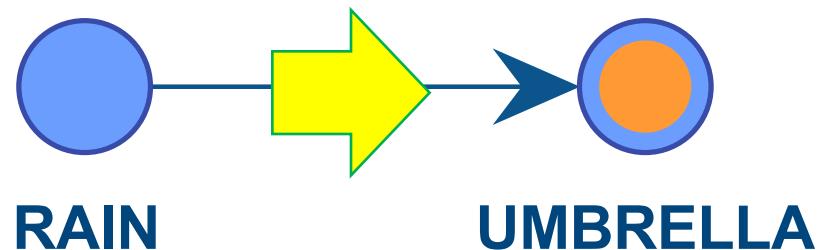
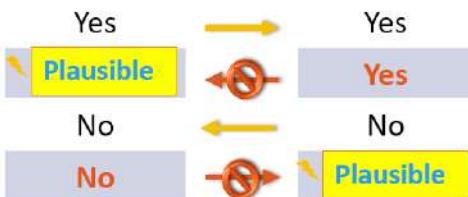
Relief



# Inference : representation and information



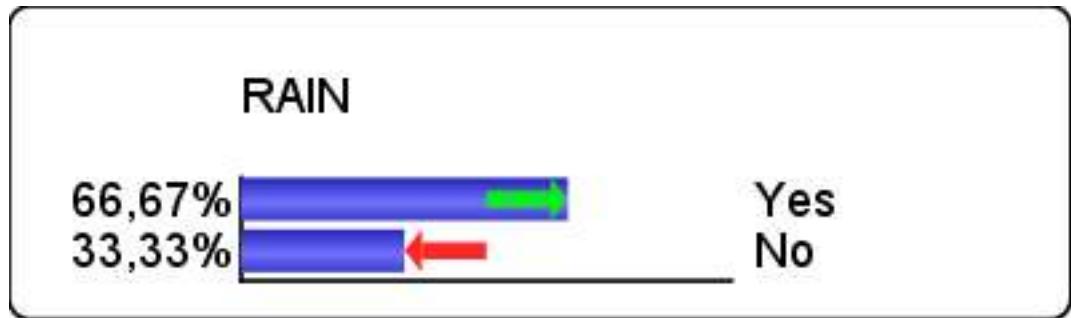
RAIN  $\iff$  UMBRELLA



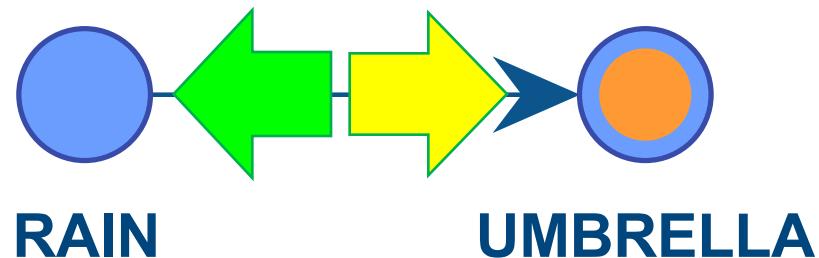
RAIN	
Yes	No
50%	50%

UMBRELLA		
	Yes	No
RAIN	Yes	100%
	No	50%
	75%	25%

# Inference : representation and information



Omnidirectional  
information flow



RAIN	
Yes	No
50%	50%

		UMBRELLA	
		Yes	No
RAIN	Yes	100%	0%
	No	50%	50%
		100%	0%

# Examples

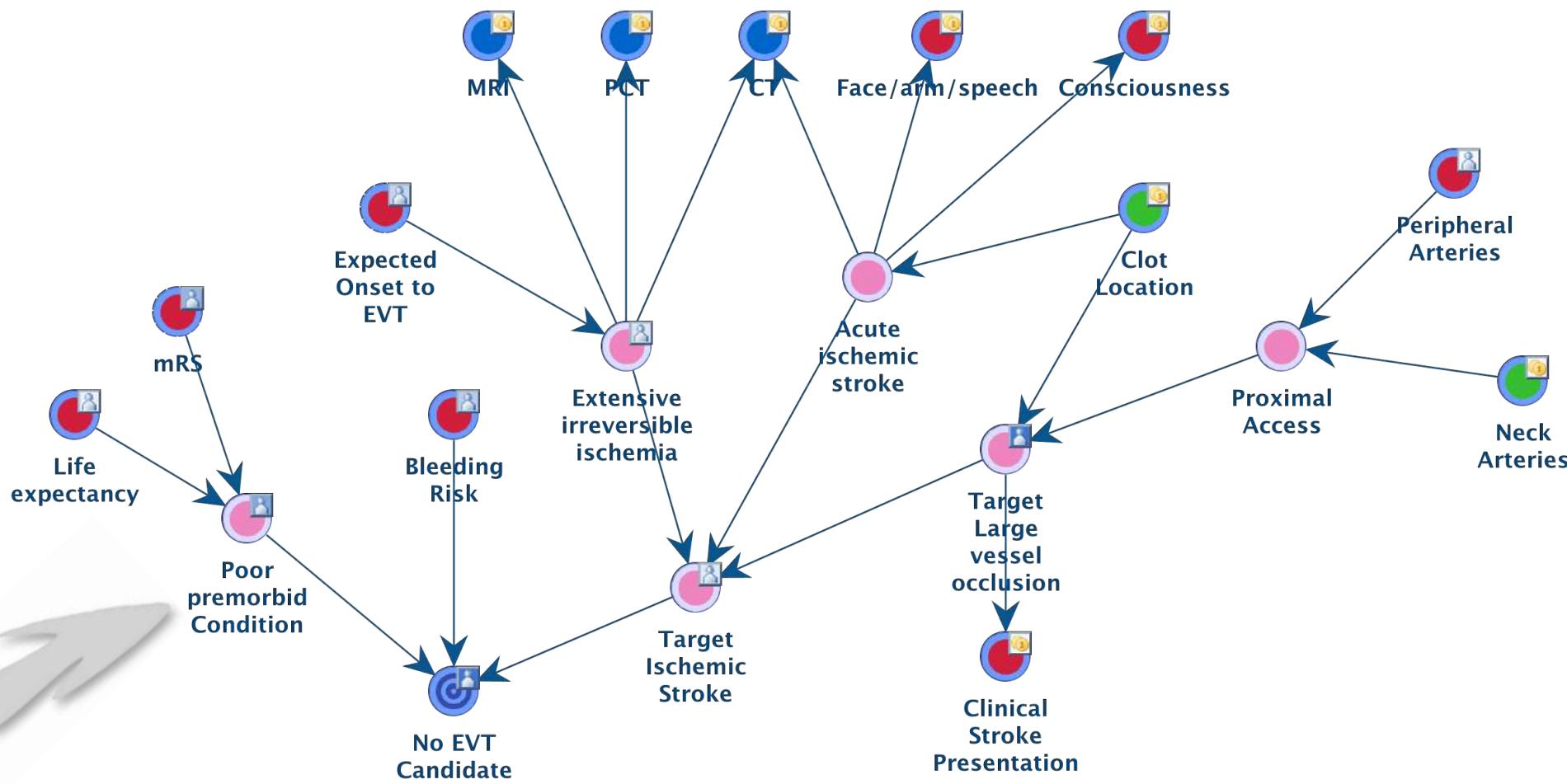
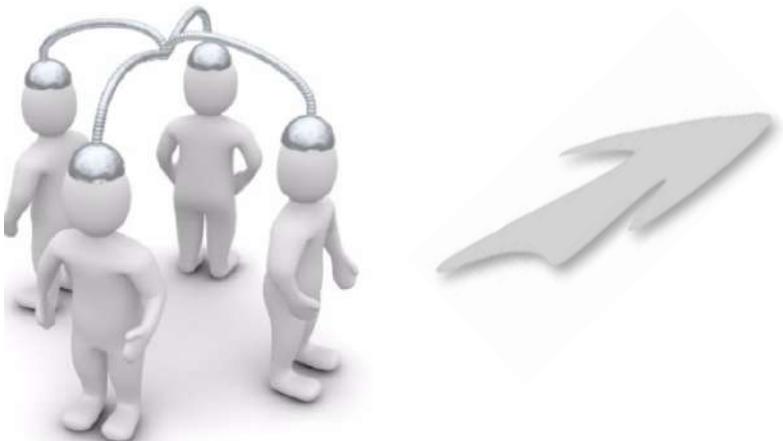
&

# Tools

# Knowledge Modeling : from expertise only



# Endovascular Therapy





**Stroke Model**

**Bayesia Adaptive Questionnaire** Target EVT\_02

Expected Onset to EVT

<input type="checkbox"/> Less than 6	<input type="checkbox"/> <= 3 months	<input type="checkbox"/> False	<input type="checkbox"/> No Clot
<input checked="" type="checkbox"/> Between 6 and 12	<input type="checkbox"/> > 3 months	<input type="checkbox"/> True	<input type="checkbox"/> Isolated Distal
<input type="checkbox"/> Observed	<input type="checkbox"/> Observed	<input type="checkbox"/> Observed	<input type="checkbox"/> Proximal

Life expectancy

<input type="checkbox"/> <= 3 months	<input type="checkbox"/> > 3 months	<input type="checkbox"/> False	<input type="checkbox"/> No Clot
<input type="checkbox"/> Observed	<input type="checkbox"/> Observed	<input type="checkbox"/> Observed	<input type="checkbox"/> Isolated Distal

Clinical Stroke Presentation

<input type="checkbox"/> False	<input type="checkbox"/> True	<input type="checkbox"/> Proximal
<input type="checkbox"/> Observed	<input type="checkbox"/> Observed	<input type="checkbox"/> Observed

Clot Location

<input type="checkbox"/> No Clot	<input type="checkbox"/> Multiple Distal	<input type="checkbox"/> Tandem (extra + proximal)
<input type="checkbox"/> Observed	<input type="checkbox"/> Observed	<input type="checkbox"/> Observed

No EVT Candidate

<input type="checkbox"/> False	<input type="checkbox"/> True
<span style="color: orange;">0.00% (0/0)</span>	<span style="color: green;">100% (1/1)</span>

Peripheral Arteries

<input type="checkbox"/> Relevant Disease	<input type="checkbox"/> False	<input type="checkbox"/> Acute Changes	<input type="checkbox"/> Negative
<input type="checkbox"/> Not Relevant Disease	<input type="checkbox"/> True	<input type="checkbox"/> No Acute Changes	<input type="checkbox"/> Positive
<input type="checkbox"/> Observed	<input type="checkbox"/> Observed	<input type="checkbox"/> Observed	<input type="checkbox"/> Observed

Consciousness

<input type="checkbox"/> False	<input type="checkbox"/> Acute Changes	<input type="checkbox"/> Negative
<input type="checkbox"/> True	<input type="checkbox"/> No Acute Changes	<input type="checkbox"/> Positive
<input type="checkbox"/> Observed	<input type="checkbox"/> Observed	<input type="checkbox"/> Observed

CT

<input type="checkbox"/> Acute Changes	<input type="checkbox"/> Negative
<input type="checkbox"/> No Acute Changes	<input type="checkbox"/> Positive
<input type="checkbox"/> Observed	<input type="checkbox"/> Observed

PCT

<input type="checkbox"/> Negative
<input type="checkbox"/> Positive
<input type="checkbox"/> Observed

MRI

<input type="checkbox"/> Negative
<input type="checkbox"/> Positive
<input type="checkbox"/> Observed

Neck Arteries

<input type="checkbox"/> Relevant Disease
<input type="checkbox"/> No Relevant Disease
<input type="checkbox"/> Observed

Bleeding Risk

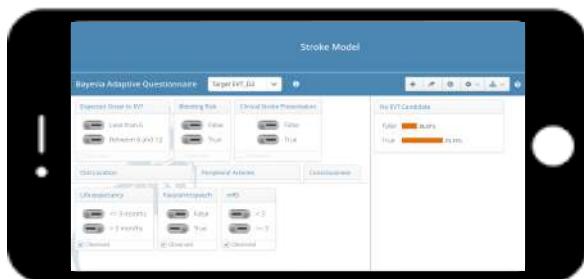
<input type="checkbox"/> False	<input type="checkbox"/> False	<input type="checkbox"/> < 3
<input type="checkbox"/> True	<input type="checkbox"/> True	<input type="checkbox"/> >= 3
<input type="checkbox"/> Observed	<input type="checkbox"/> Observed	<input type="checkbox"/> Observed

Facial/arm/speech

<input type="checkbox"/> False	<input type="checkbox"/> False	<input type="checkbox"/> < 3
<input type="checkbox"/> True	<input type="checkbox"/> True	<input type="checkbox"/> >= 3
<input type="checkbox"/> Observed	<input type="checkbox"/> Observed	<input type="checkbox"/> Observed

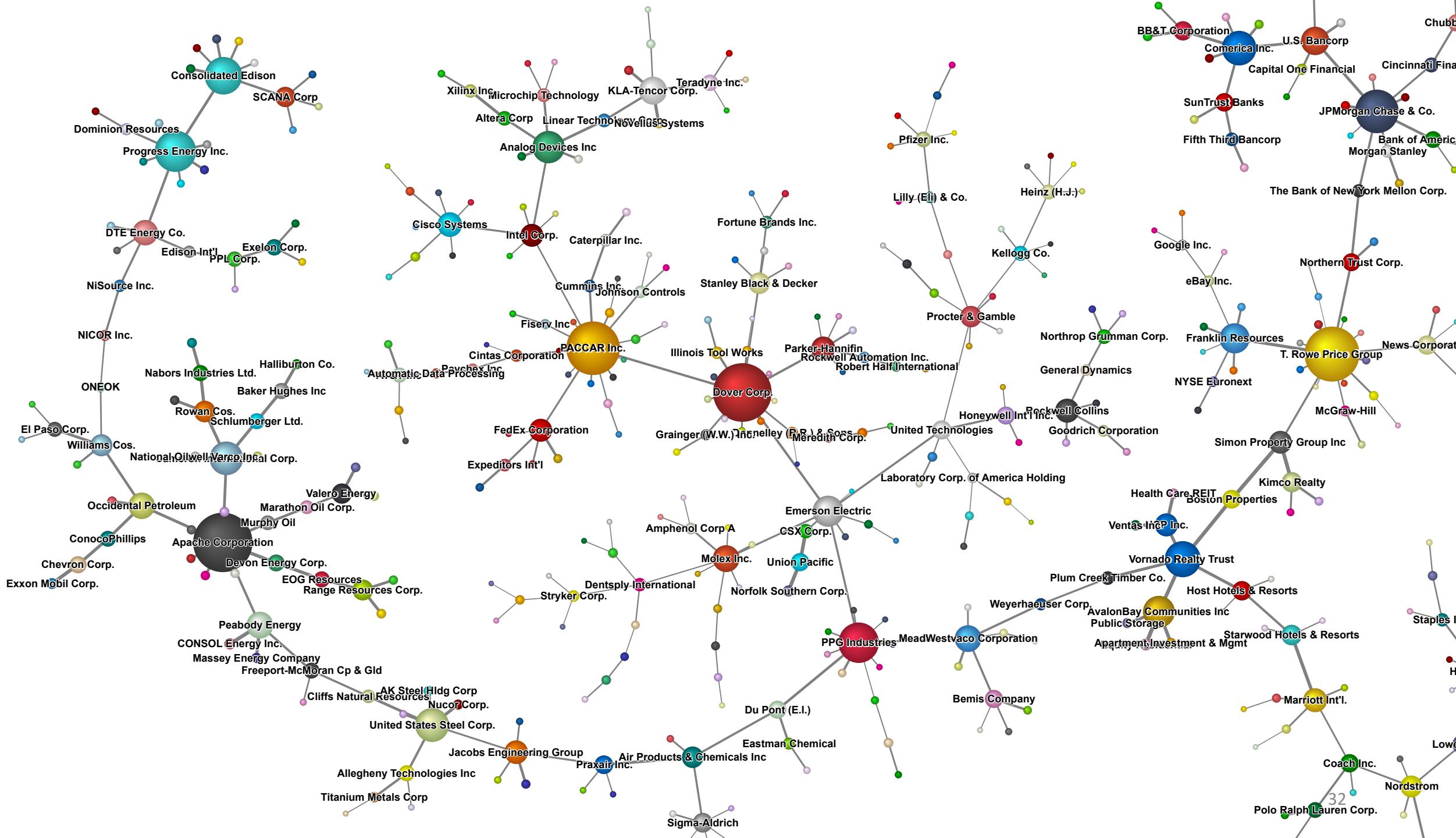
mRS

<input type="checkbox"/> < 3
<input type="checkbox"/> >= 3
<input type="checkbox"/> Observed



# Knowledge discovery : Unsupervised learning





# Information and model selection

**Node** → Entropy *Amount of uncertainty*  
→ 0 if no uncertainty /  $\log_2(\text{nb discretization})$  if uniform

$$H(X) = -\sum_{x \in X} P(x) \log_2 P(x)$$

**Arc** (2 nodes) → Mutual Information

*Gain of information on X by observing Y*  
→ useful to find best predictors for a target variable  
→ Advantage vs Pearson Correlation (non linearity)

$$I(X, Y) = H(X) - H(X | Y)$$

**Arc** (complete network) → Kullback-Liebler divergence

*Compares 2 joint probability distribution*  
→ Model selection ( $P$  initial network,  $Q$  initial network without the arc under study)

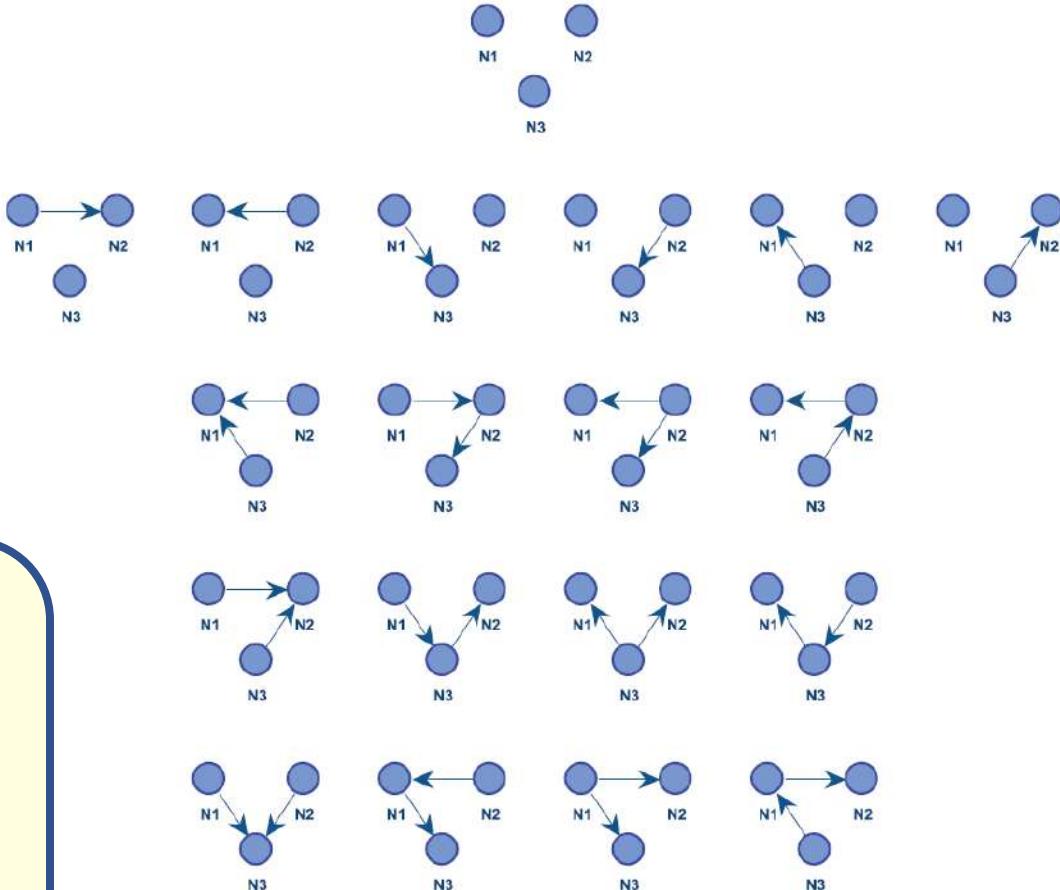
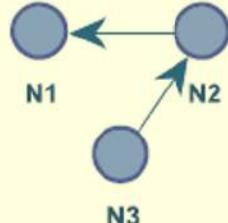
$$D_{KL}(P(X) \| Q(X)) = \sum_x P(X) \log_2 \frac{P(X)}{Q(X)},$$

# Information and model selection

## Learning complexity : Finding the optimal network

Number of Nodes	Number of Possible Networks
1	1
2	3
3	25
4	543
5	29281
6	$3.7815 \times 10^6$
7	$1.13878 \times 10^9$
8	$7.83702 \times 10^{11}$
9	$1.21344 \times 10^{15}$
10	$4.1751 \times 10^{18}$
...	...
47	$8.98454 \times 10^{376}$

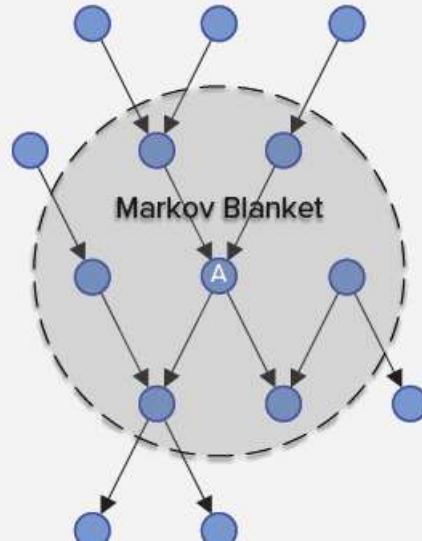
D-séparation by N2  
→ Indépendence according to N2



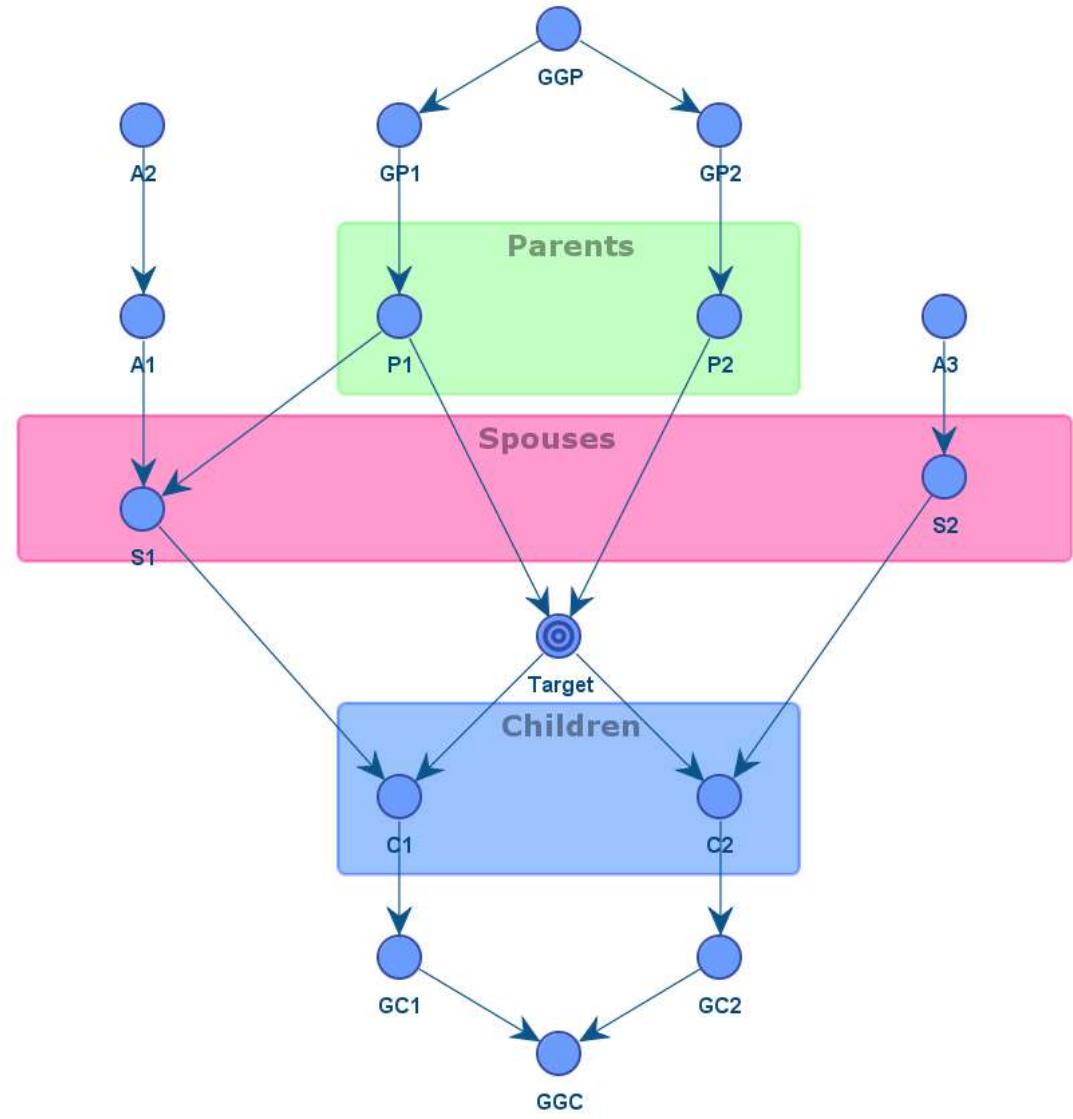
## Markov Blanket Definition

The Markov Blanket of a node  $A$  is the set of nodes composed of  $A$ 's parents, its children, and its children's other parents (=spouses). The Markov Blanket of the node  $A$  contains all the nodes that, if we know their states, i.e. we have hard evidence for these nodes, will shield the node  $A$  from the rest of the network, i.e. make  $A$  independent of all the other nodes given its Markov Blanket (Figure 6.12).

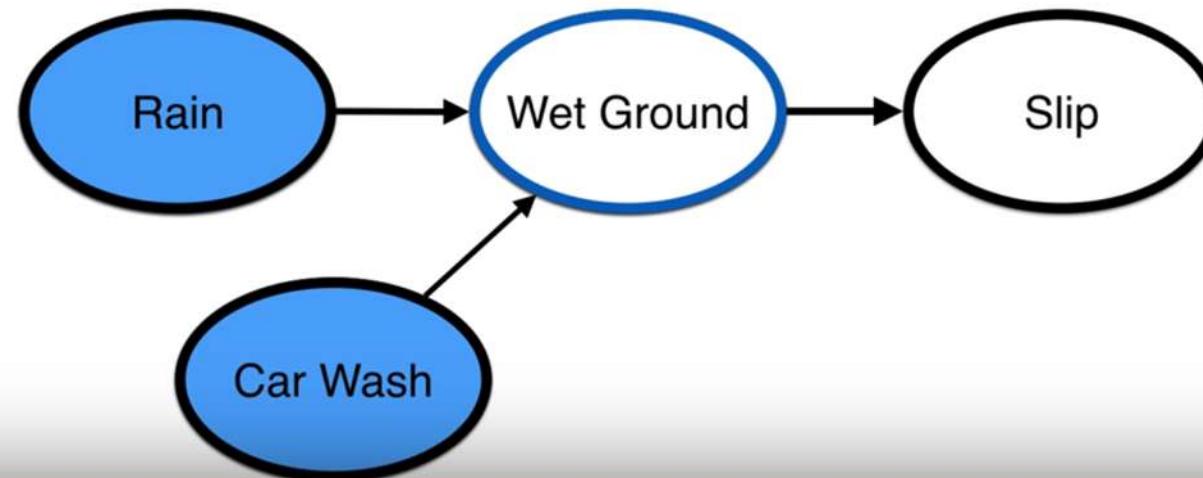
This means that the Markov Blanket of a node  $A$  is the only knowledge needed to predict the behavior of that node. Learning a Markov Blanket selects the most relevant predictor nodes, which is particularly helpful when there is a large number of variables in a dataset. As a result, this can serve as a highly-efficient variable selection method in preparation for other types of modeling, e.g. neural networks.



# Information and model selection

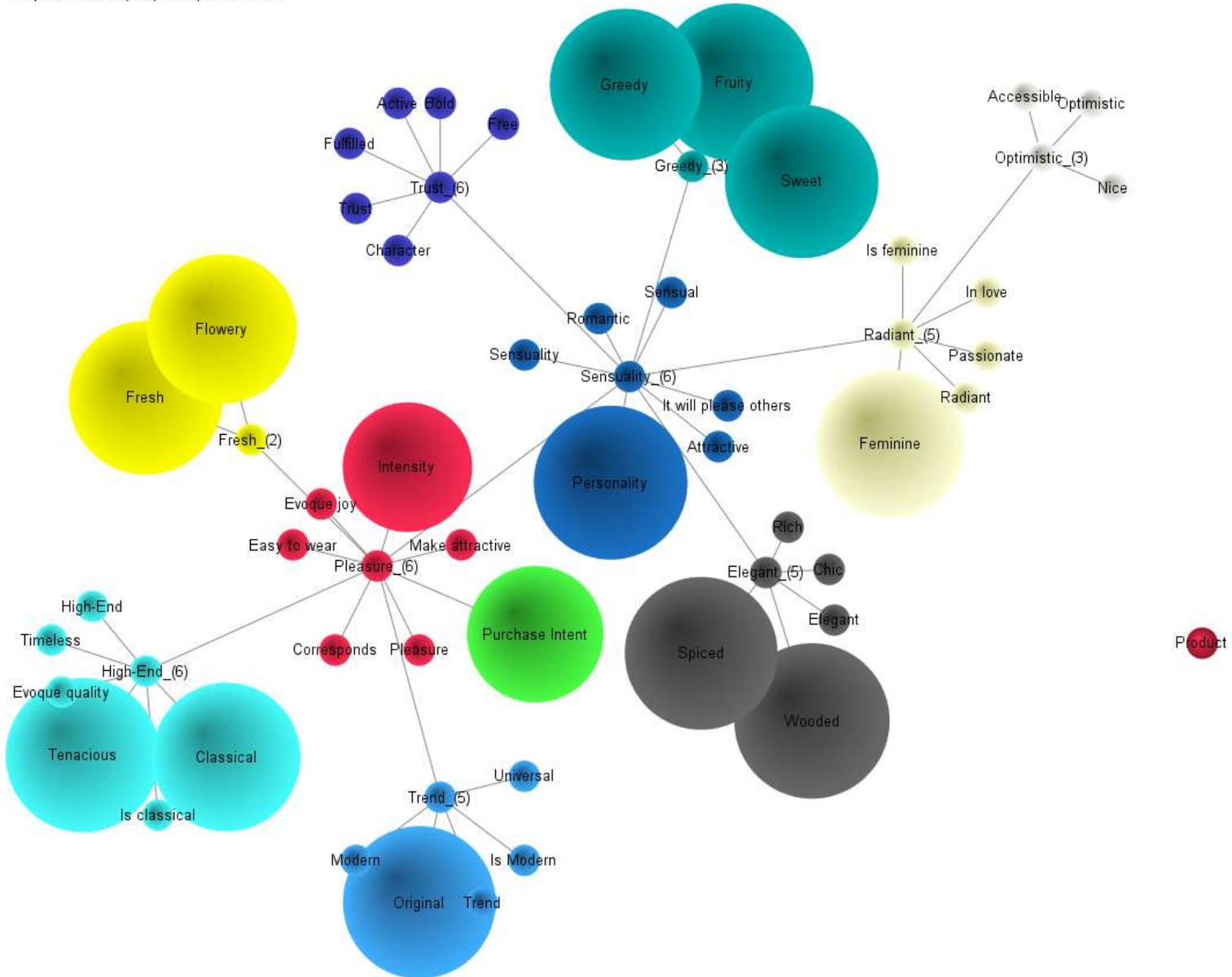


# Equation de la loi jointe

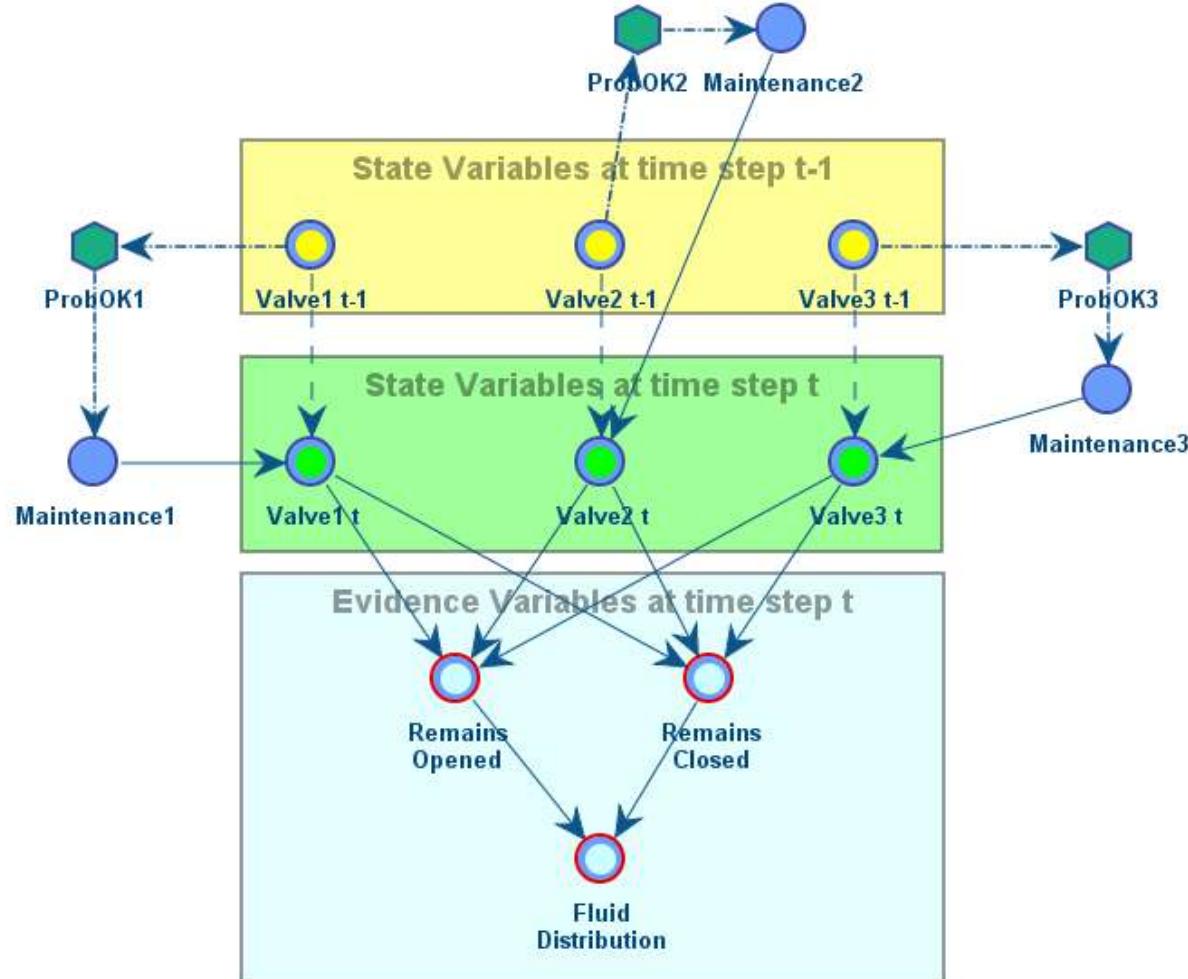
$$P(R, W, S, C) = P(R) P(C) P(W | C, R) P(S | W)$$
$$P(X | \text{Parents}(X))$$


# Probabilistic Structural Equation Modeling

Analyse des nœuds (taille) : Entropie normalisée

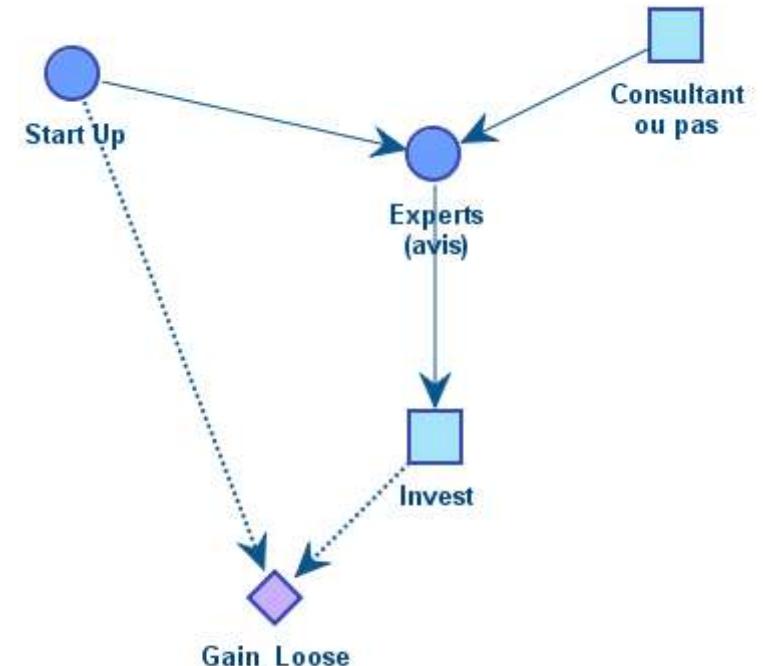
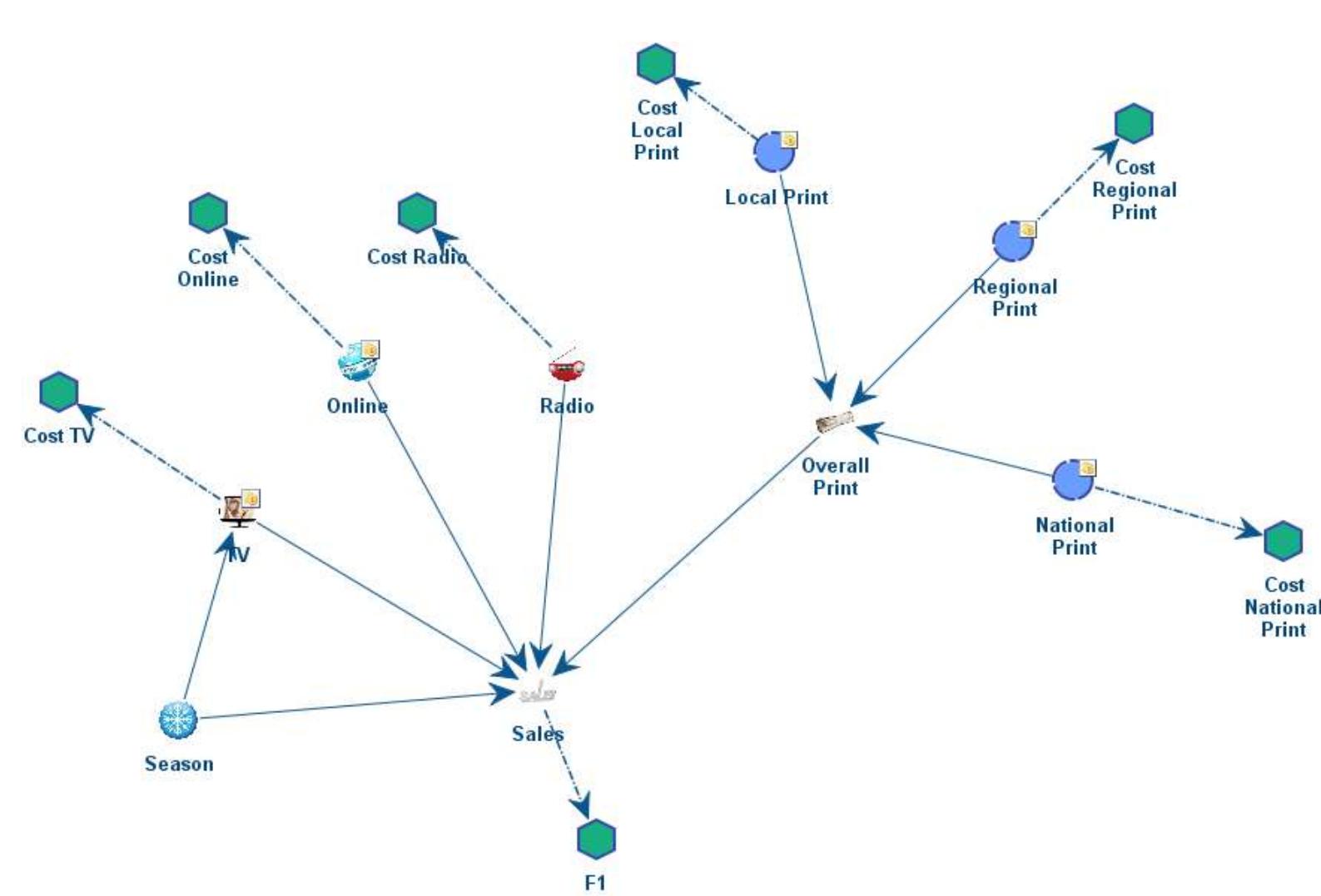


# Loop in a bayesian network : Time



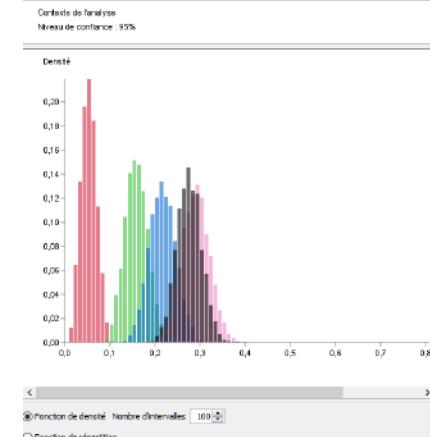
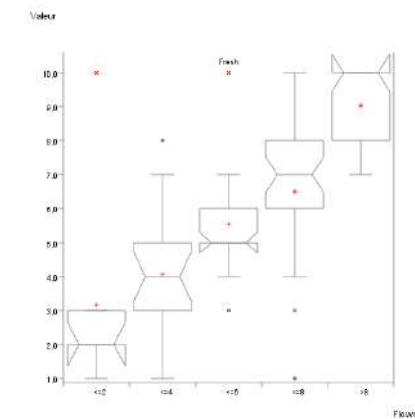
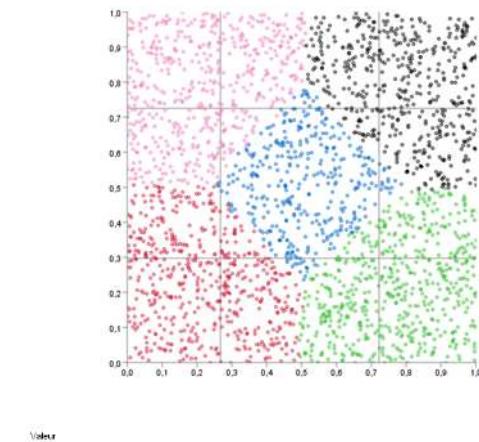
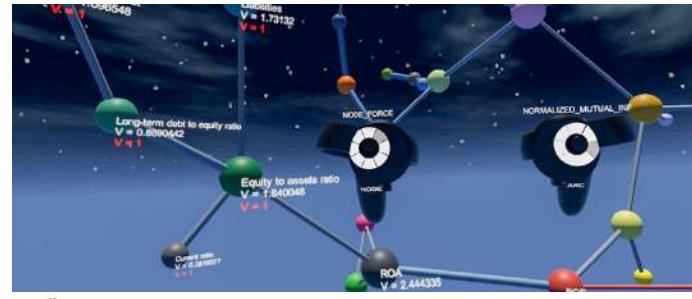
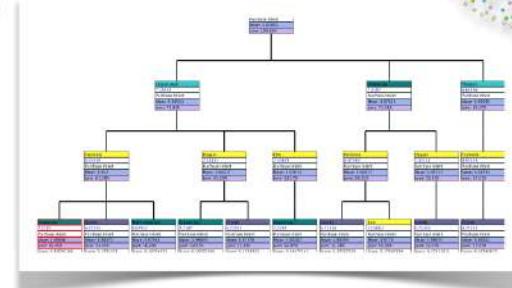
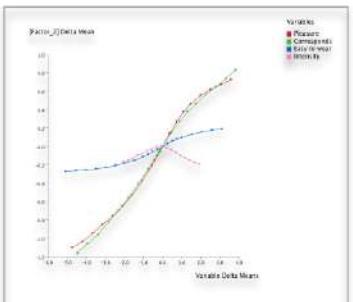
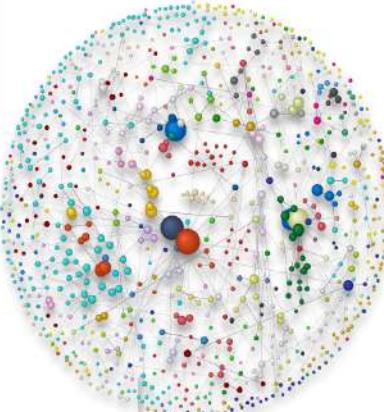
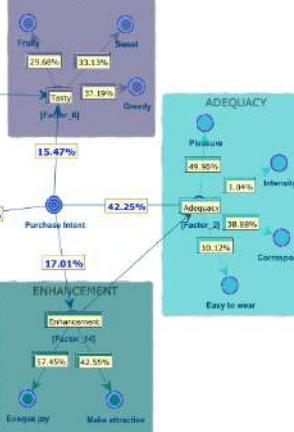
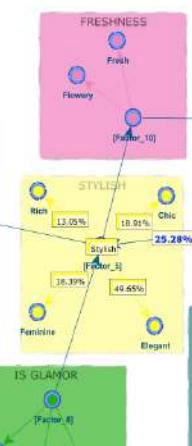
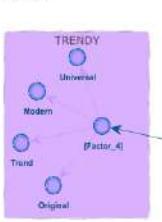
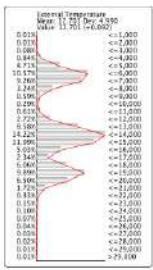
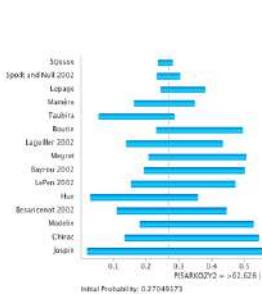
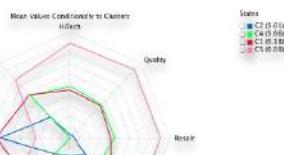
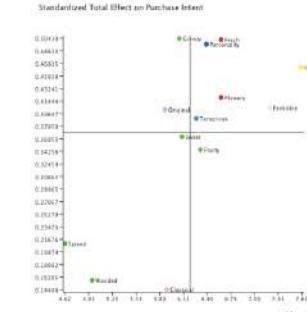
# Optimization : Costs,

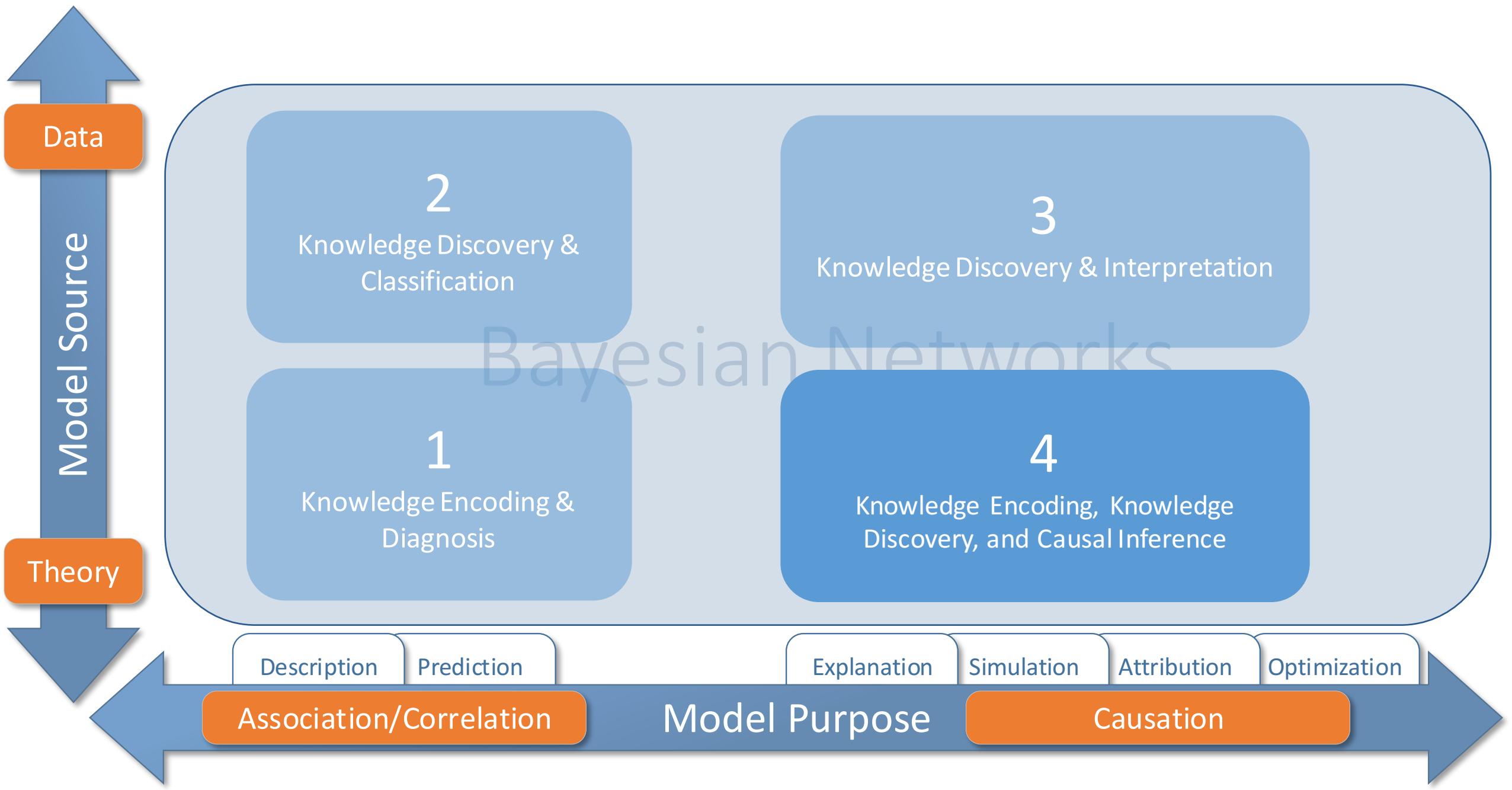
# Decision



# Some graphs

BAYESIALAB

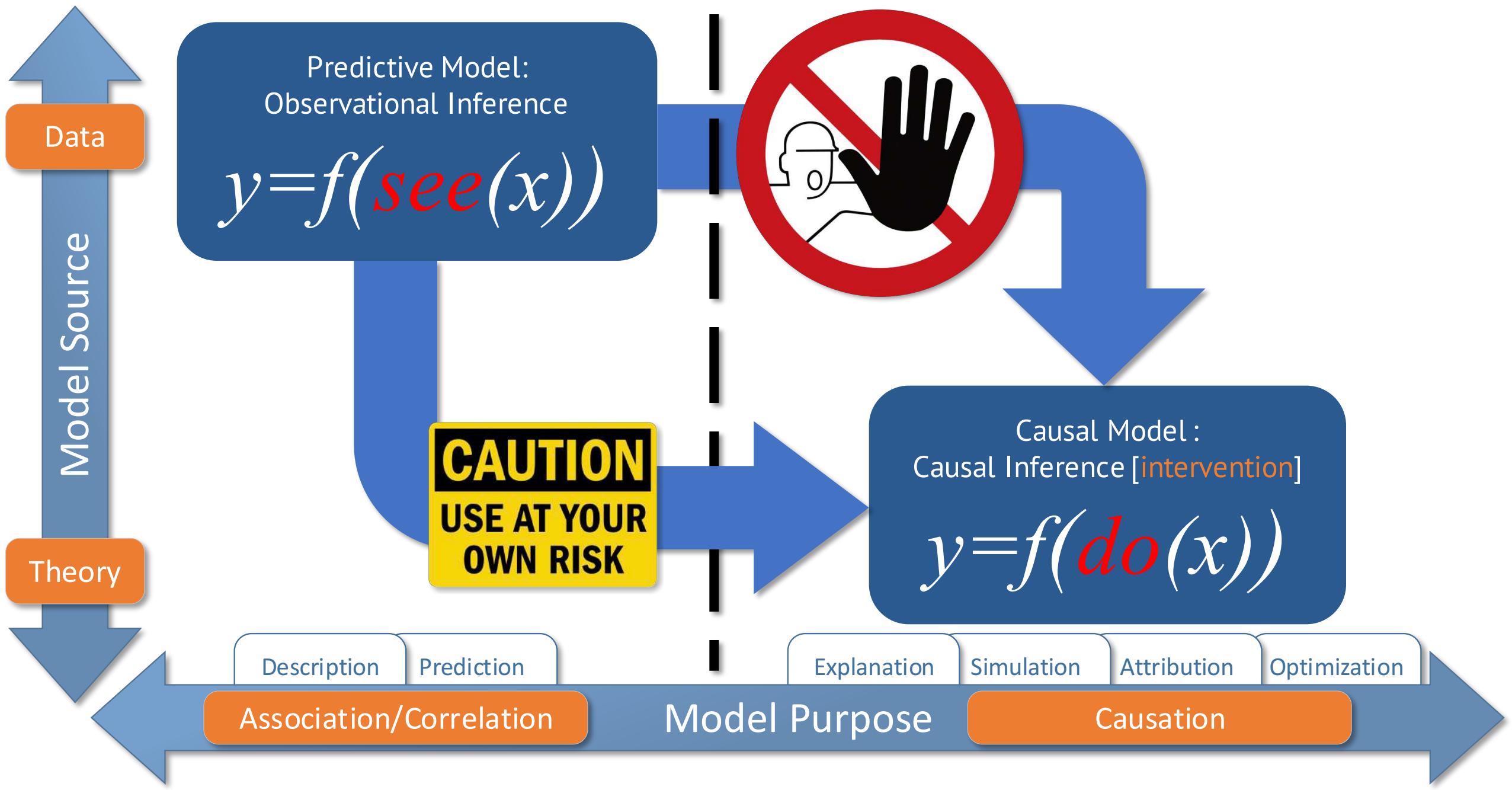




Correlation does not  
equal causation

for observational  
data

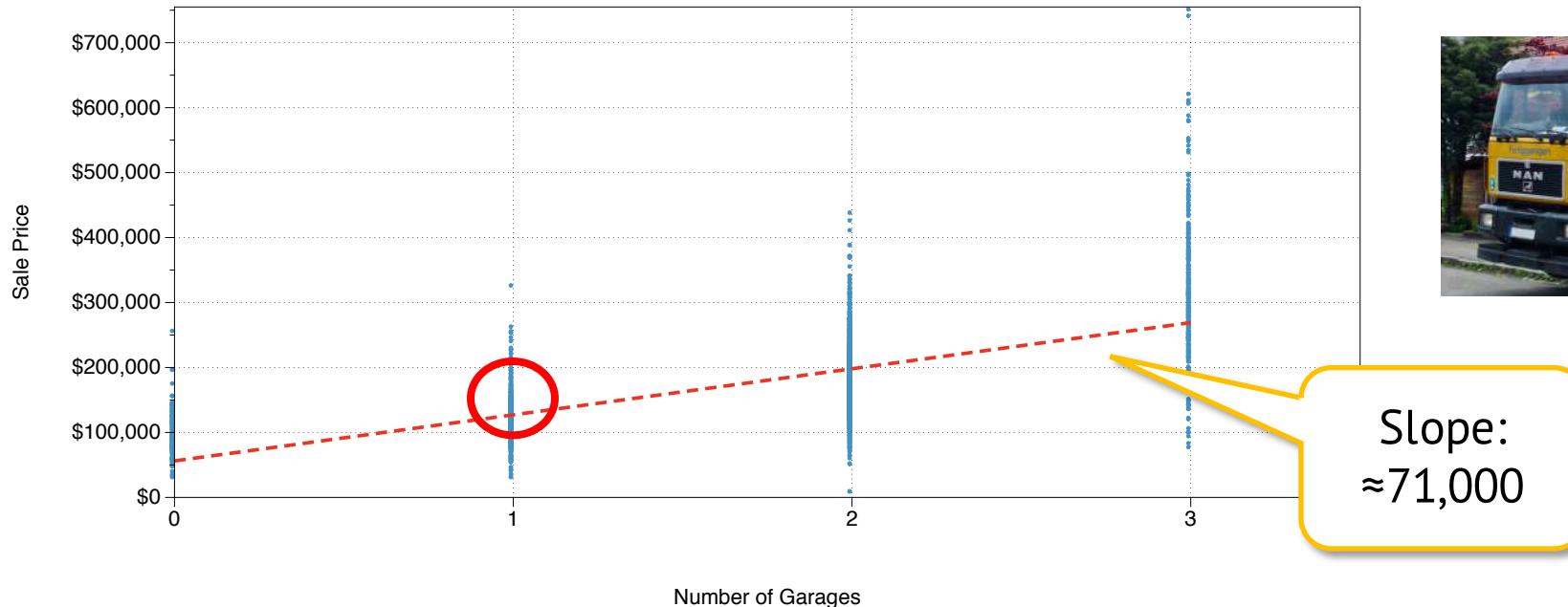




# Observational vs. Causal Inference

- Ames Dataset: Sale Prices of Single-Family Homes

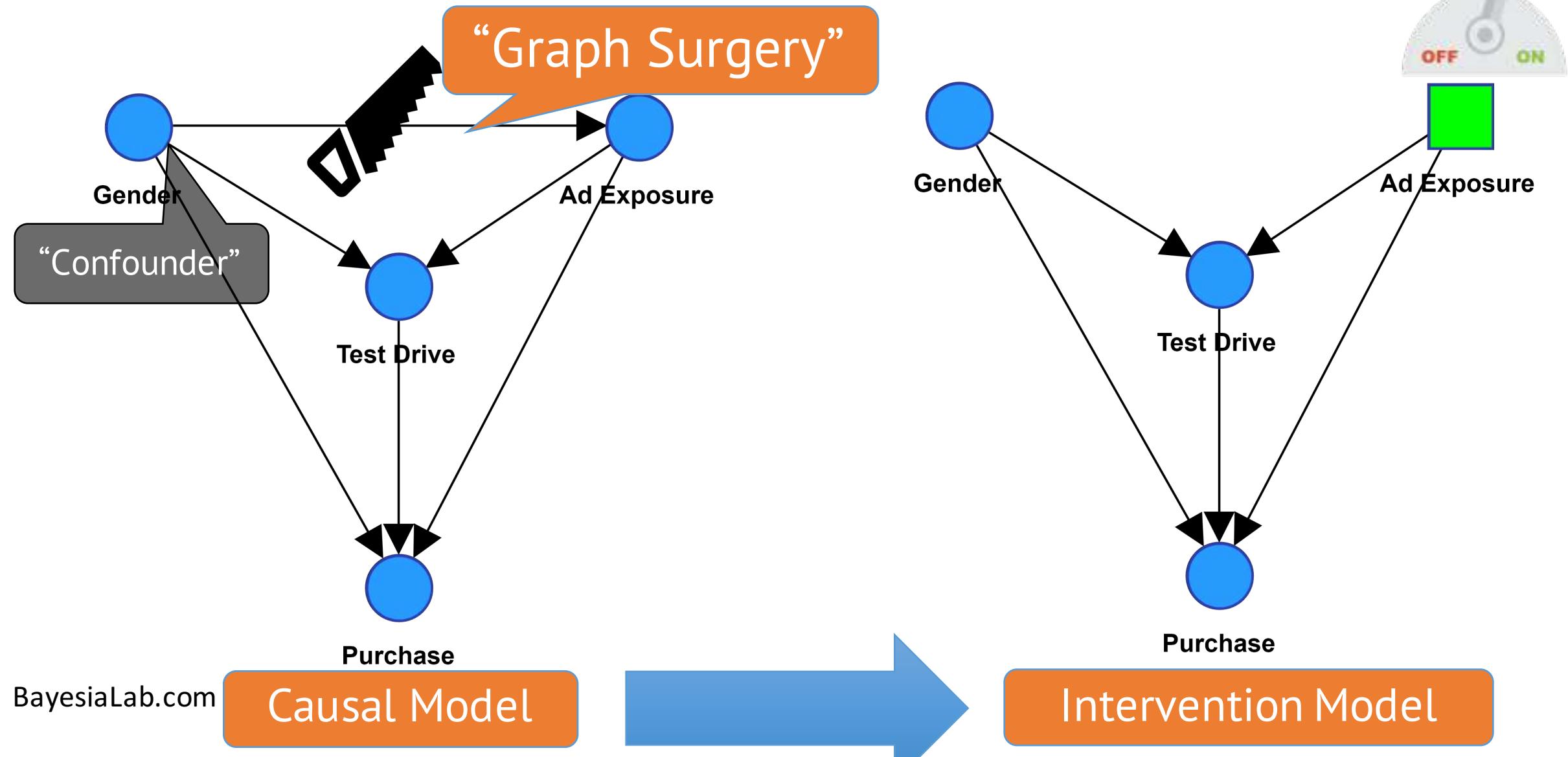
$$Price = \$56,157 + \$70,949 \times No. \text{ of Garages} + \varepsilon$$



Intervention

# Causal Inference?

- Simulating an Intervention

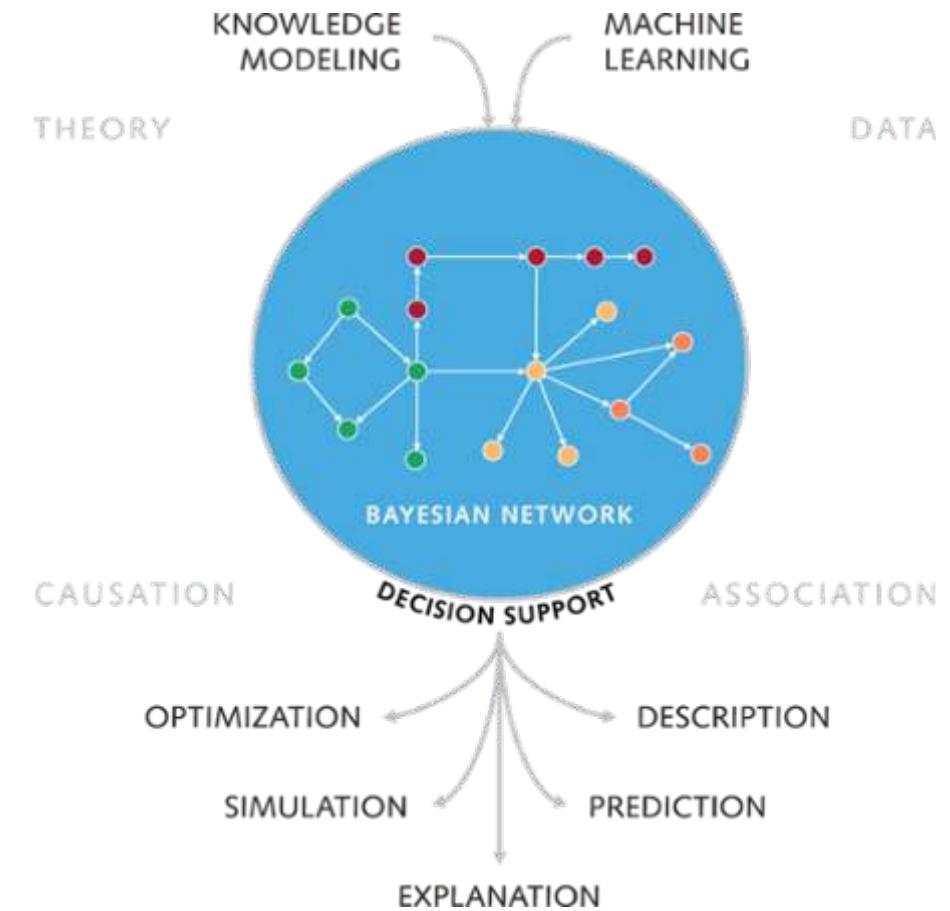


# Decision support

## Bayesian Networks

Qualitative (DAGs) and Quantitative  
(discrete PD) representation of knowledge

- ✓ Powerful Communication tool
- ✓ Easy knowledge modeling
- ✓ Inference engine
- ✓ Machine learning





## Calcul de scores



## Analyse de leviers d'optimization



Team Detroit



L'ORÉAL  
METRO

## Diagnostic et Dépannage



## Analyse des risques – Maintenance préventive



THALES



## Analyse opérationnelle



Booz | Allen | Hamilton



## Analyse de défauts – Optimisation de processus



ArcelorMittal



# Questions ?



emmanuel.keita@sundiata.  
fr



[linkedin.com/in/datavalue](https://linkedin.com/in/datavalue)

