Learning, development and plasticity

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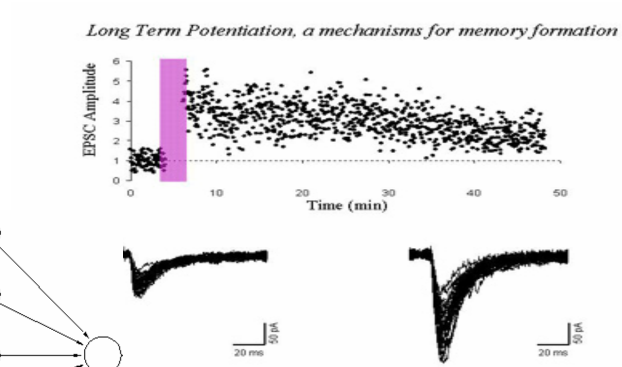
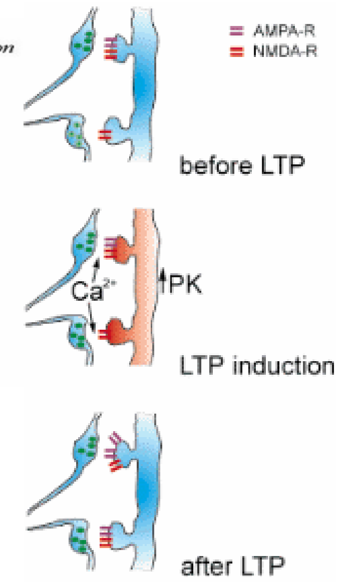
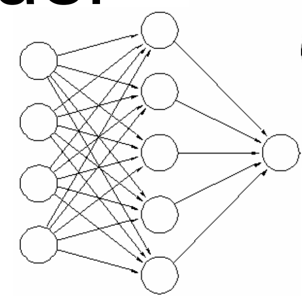
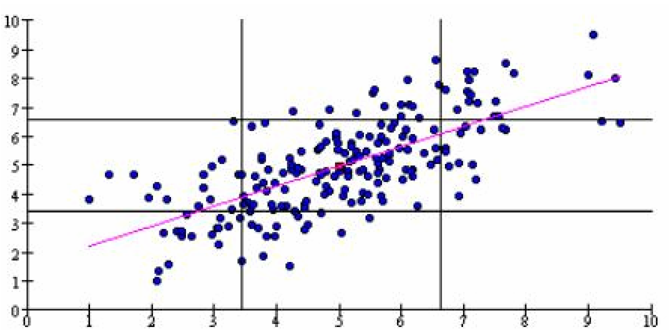
Can we develop an integrated theory of learning, in computational, behavioral and neural terms?

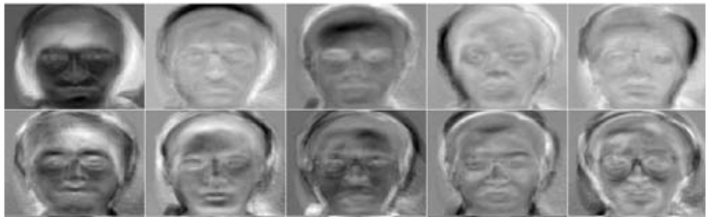
- The “standard model”











Supervised

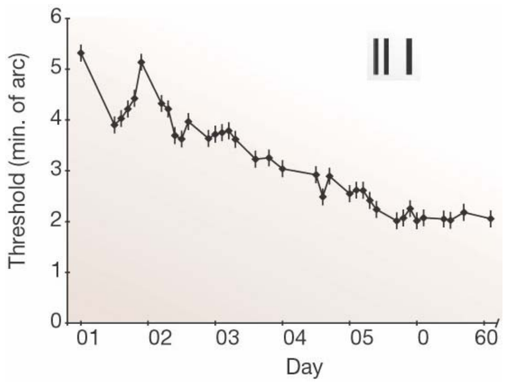
$$E = \frac{1}{2}\sum_{t=1}^{n}(y_t - w \cdot x_t)^2$$

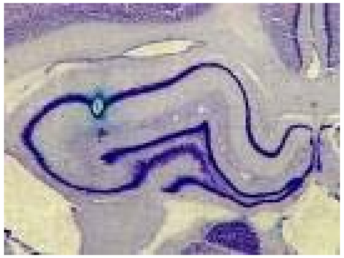
$$\Delta w \propto -\frac{\partial E}{\partial w} = \sum_{t=1}^{n}(y_t - w \cdot x_t)\, x_t$$

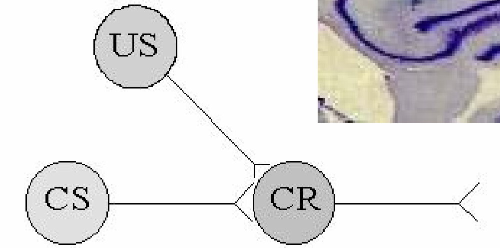
Unsupervised

$$E = \frac{1}{2}\sum_{t=1}^{n} y_t^{\,2} = \frac{1}{2}\sum_{t=1}^{n}(w \cdot x_t)^2$$

$$\Delta w \propto -\frac{\partial E}{\partial w} = \sum_{t=1}^{n} y_t \cdot x_t$$

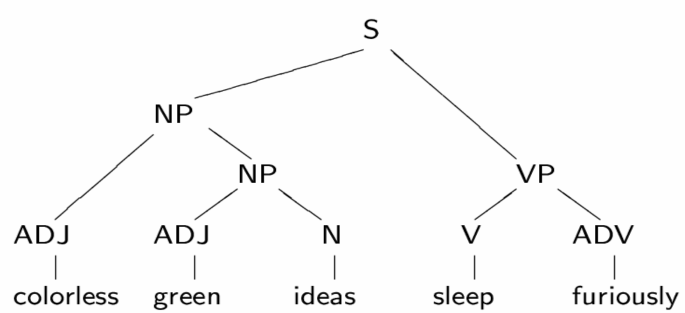


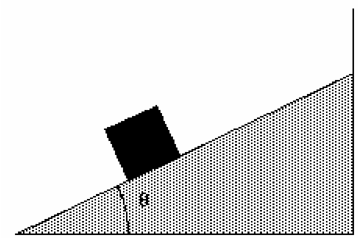


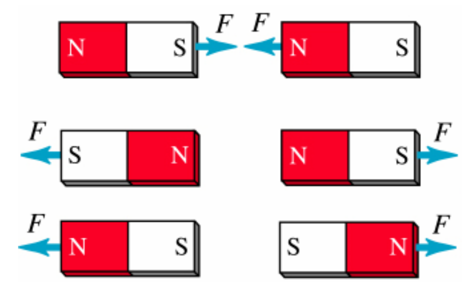


<u>Fig 1.1:</u> **Hebbian Synapse** neuro-modulators work across the synapse between the facilitator and motor neuron.

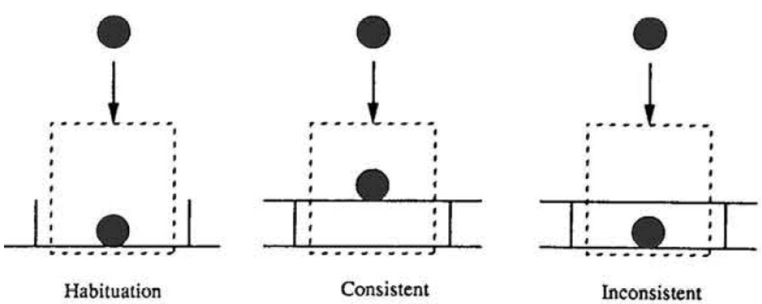
The really hard problems

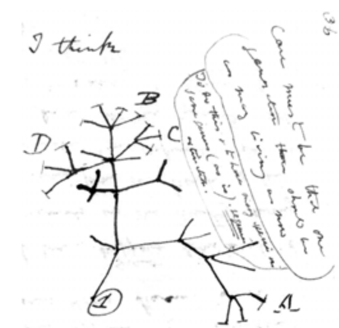


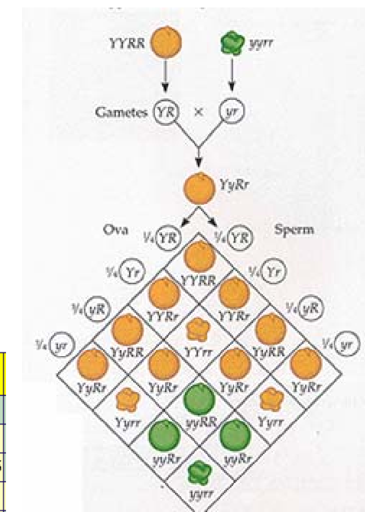


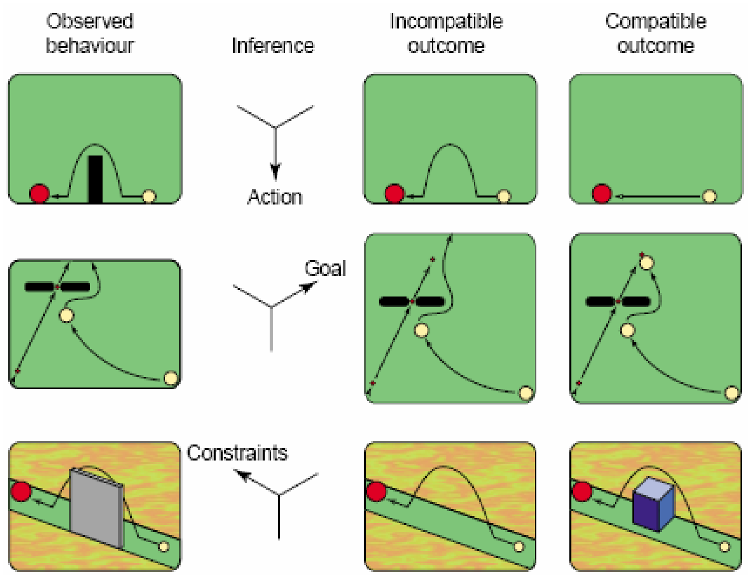


$$F = m\,a$$









Group Period	I	II	III	IV	V	VI	VII
1	H=1						
2	Li=7	Be=9.4	B=11	C=12	N=14	O=16	F=19
3	Na=23	Mg=24	Al=27.3	Si=28	P=31	S=32	Cl=35.5
4	K=39	Ca=40	?=44	Ti=48	V=51	Cr=52	Mn=55
5	Cu=63	Zn=65	?=68	?=72	As=75	Se=78	Br=80
6	Rb=85	Sr=87	?Yt=88	Zr=90	Nb=94	Mo=96	?=100
7	Ag=108	Cd=112	In=113	Sn=118	Sb=122	Te=125	J=127

Two cultures

"Nature"
Innate structured representations
Grounded in cognition

versus

"Nurture"
Statistical learning, plasticity
Grounded in the brain

Recent causes for optimism

- New models from machine learning, AI
  - Structured statistical models

    Probabilities defined over structured representations: graphs, causal networks, grammars, predicate logic.
  - Multilevel (hierarchical) statistical models

    Inference at multiple levels of abstraction and multiple timescales.
  - Flexible statistical models

    Hypothesis spaces grow as new data are encountered.
- New technologies
  - "Supercomputers" on the desktop, grid computing
  - Life-size datasets for modeling cognitive development
  - Mainstream functional MRI

“Universal Grammar”

P(grammar | UG)

Grammar

P(phrase structure | grammar)

Phrase structure

P(utterance | phrase structure)

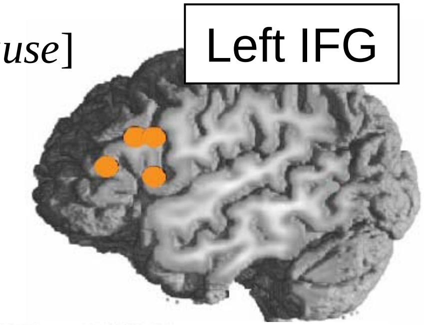
Utterance

P(speech | utterance)

Speech signal

Hierarchical phrase structure grammars (e.g., CFG, HPSG, TAG)

$$S \rightarrow NP\ VP$$
$$NP \rightarrow Det\ [Adj]\ Noun\ [RelClause]$$
$$RelClause \rightarrow [Rel]\ NP\ V$$
$$VP \rightarrow VP\ NP$$
$$VP \rightarrow Verb$$



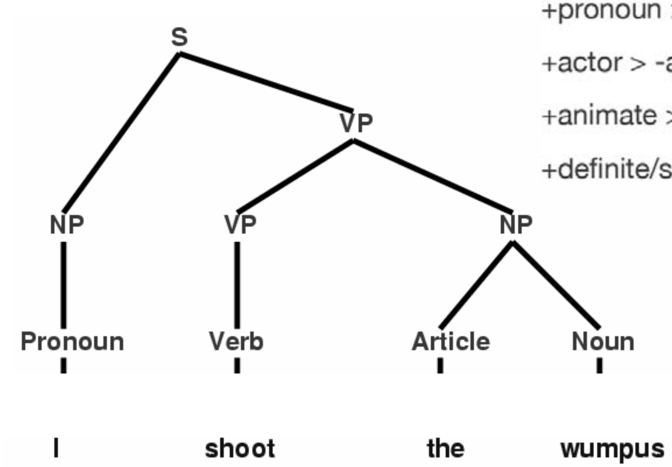
+subject > -subject

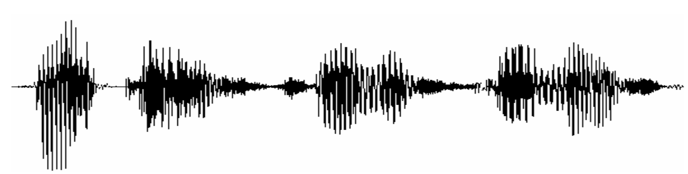
+pronoun > -pronoun

+actor > -actor

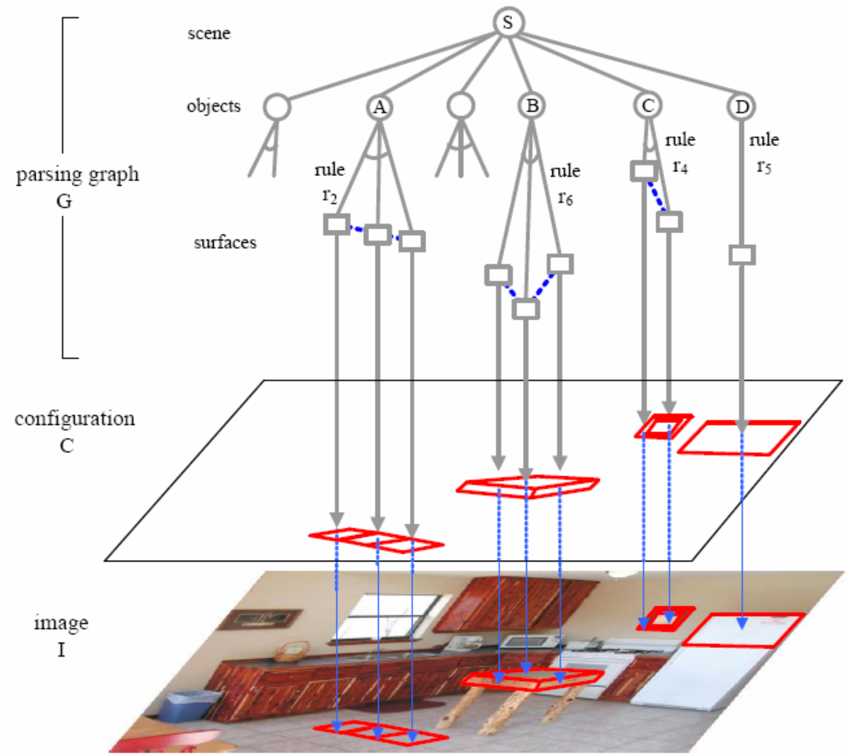
+animate > -animate

+definite/specific > -definite/specific



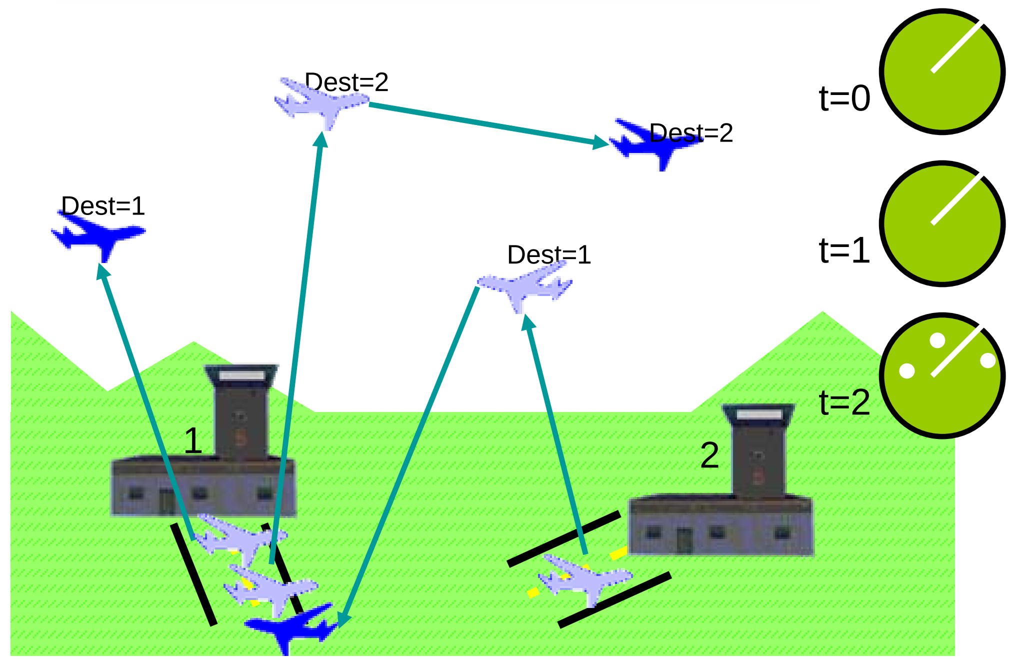


Probabilistic scene parsing

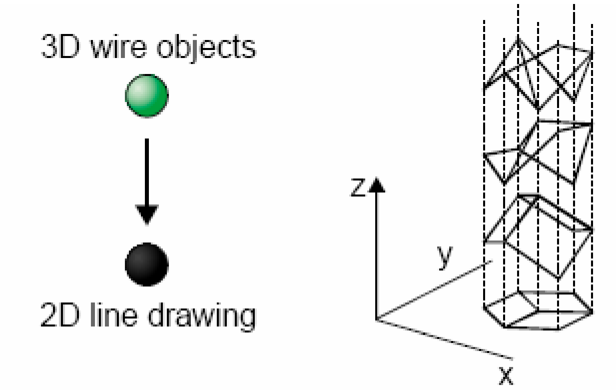


```
type Aircraft;  type Blip;

random R6Vector State(Aircraft, NaturalNum);
random R3Vector ApparentPos(Blip);

nonrandom NaturalNum Pred(NaturalNum) = Predecessor;

generating Aircraft Source(Blip);
generating NaturalNum Time(Blip);

#Aircraft ~ NumAircraftDistrib();

State(a, t)
  if t = 0 then ~ InitState()
  else ~ StateTransition(State(a, Pred(t)));

#Blip: (Source, Time) -> (a, t)
  ~ DetectionDistrib(State(a, t));

#Blip: (BlipTime) -> (t)
  ~ NumFalseAlarmsDistrib();

ApparentPos(r)
  if (BlipSource(r) = null) then ~ FalseAlarmDistrib()
  else ~ ObsDistrib(State(Source(r), Time(r)));
```

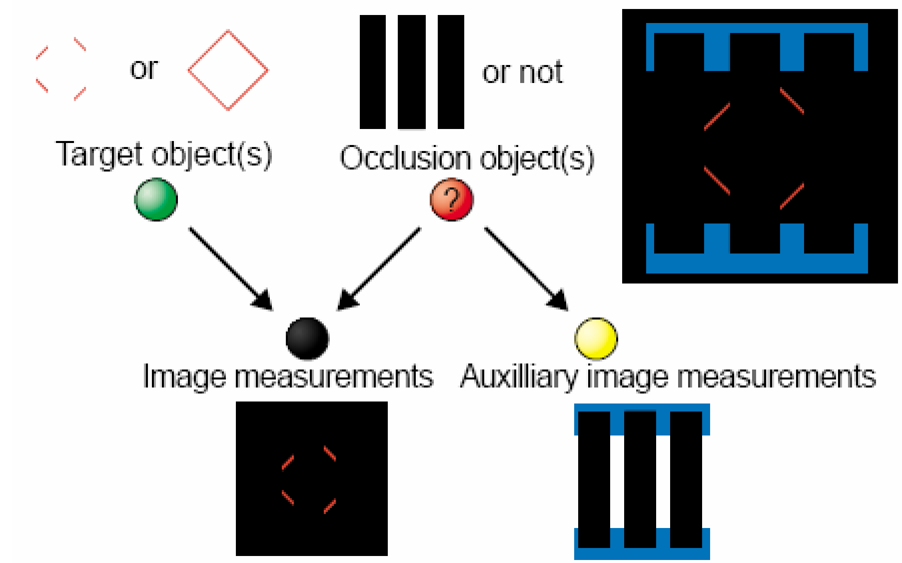
BLOG
(Bayesian
Logic)



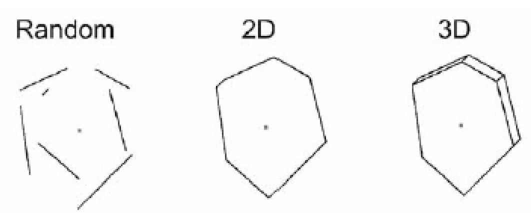
Probabilistic scene parsing

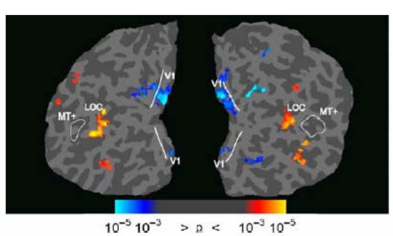


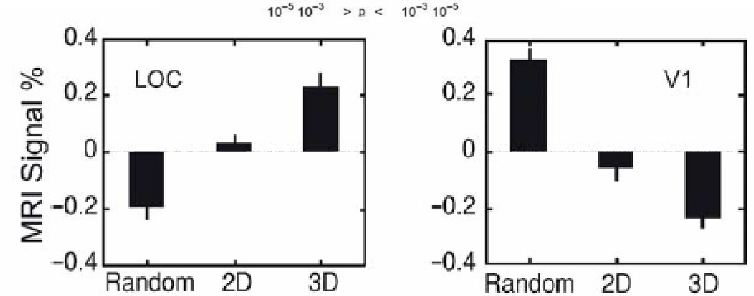
Basic Bayes

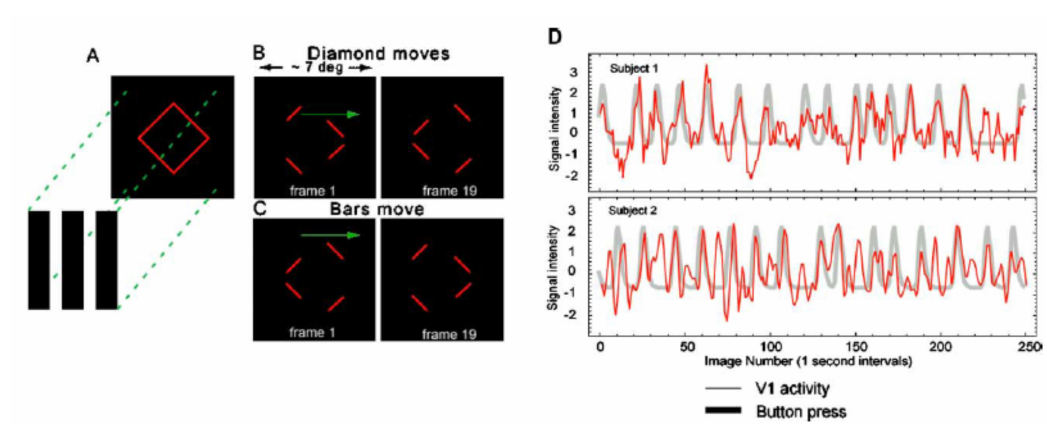


Perceptual "Explaining Away"









Learning domain structures

F: form

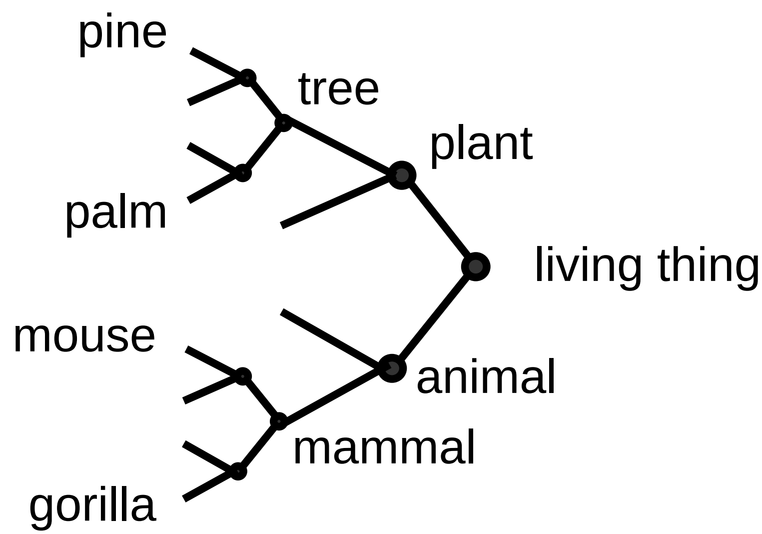
P(structure | form)

S: structure

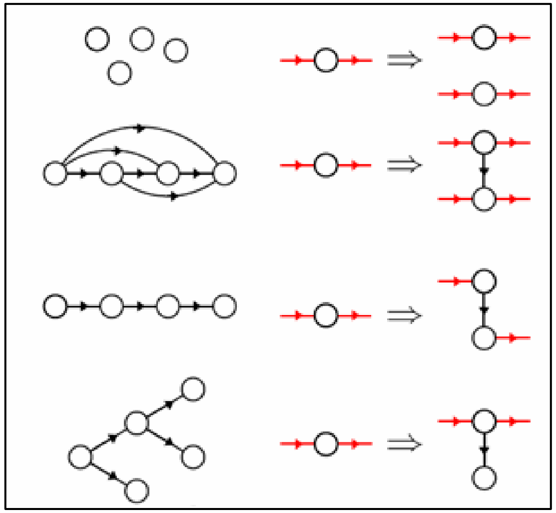
P(data | structure)

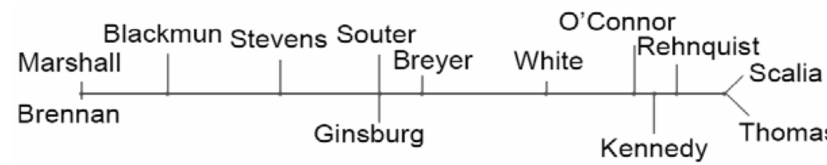
D: data

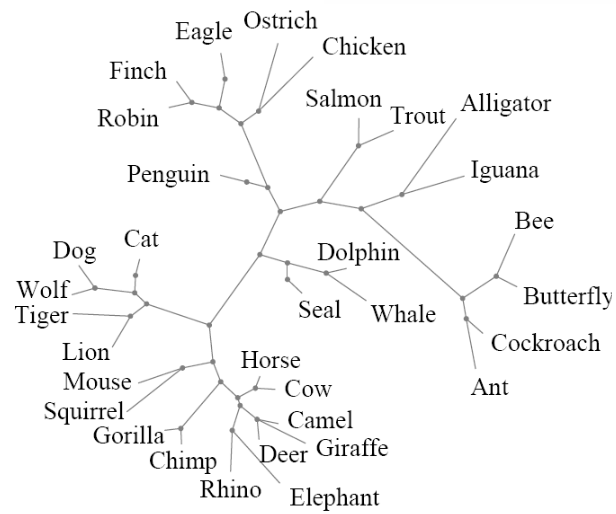
Tree with objects at leaf nodes

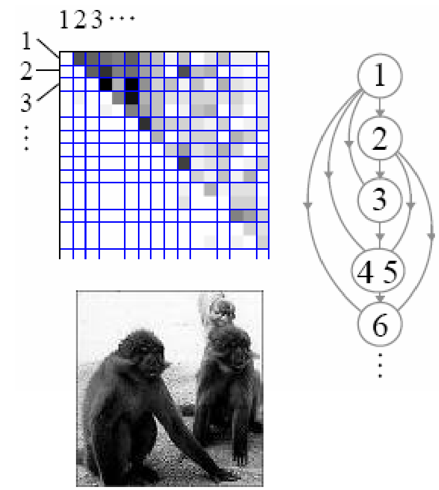


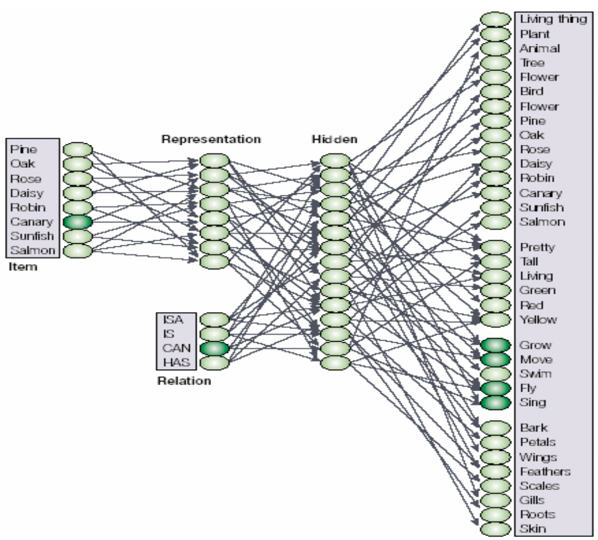
Learning domain structures

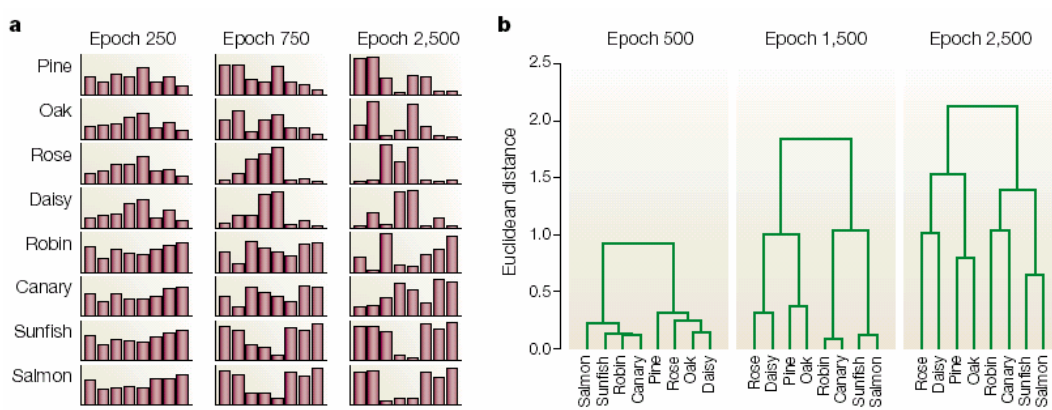












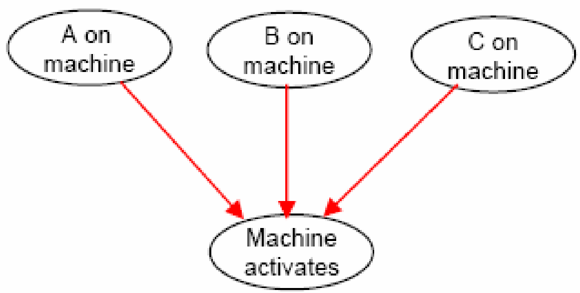
Learning causal theories

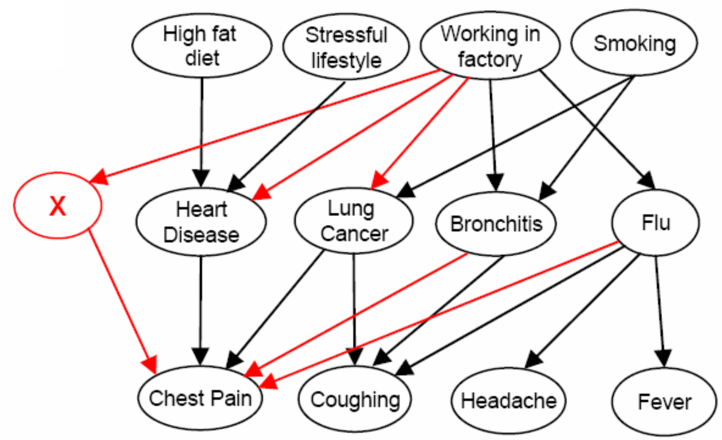
Abstract Principles

Objects can activate Machines
Activation requires contact
Machines are (near) deterministic

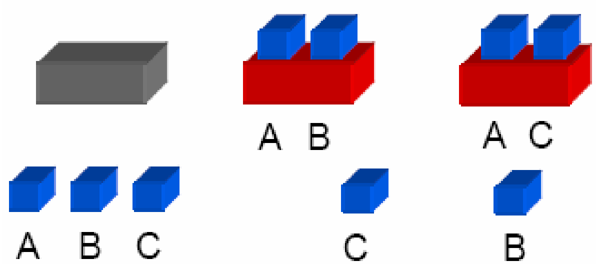
Classes: {R, D, S} (Risks, Diseases, Symptoms)
Causal laws: R → D, D → S

Structure



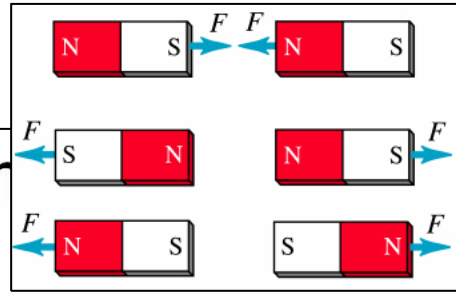


Data

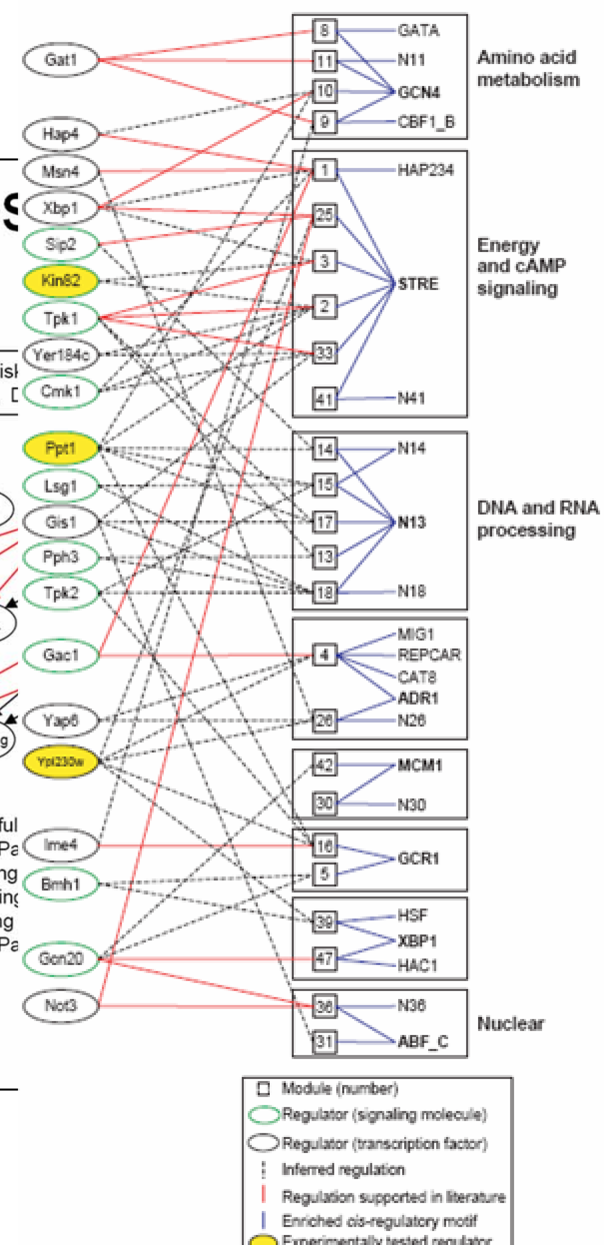


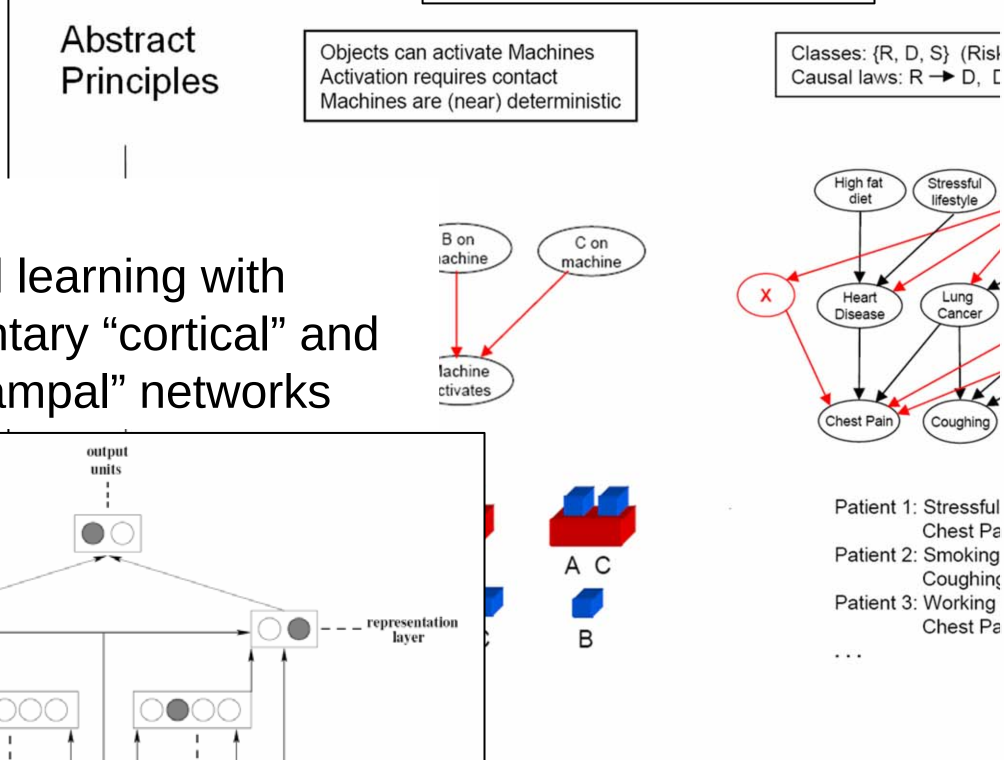
Patient 1: Stressful lifestyle
Chest Pain
Patient 2: Smoking
Coughing
Patient 3: Working in factory
Chest Pain
. . .

Learning the laws of magnetism

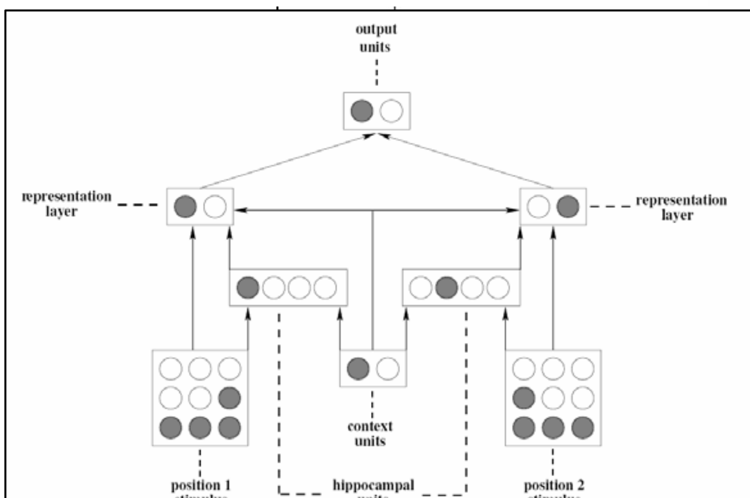


Learning regulatory modules in genetics

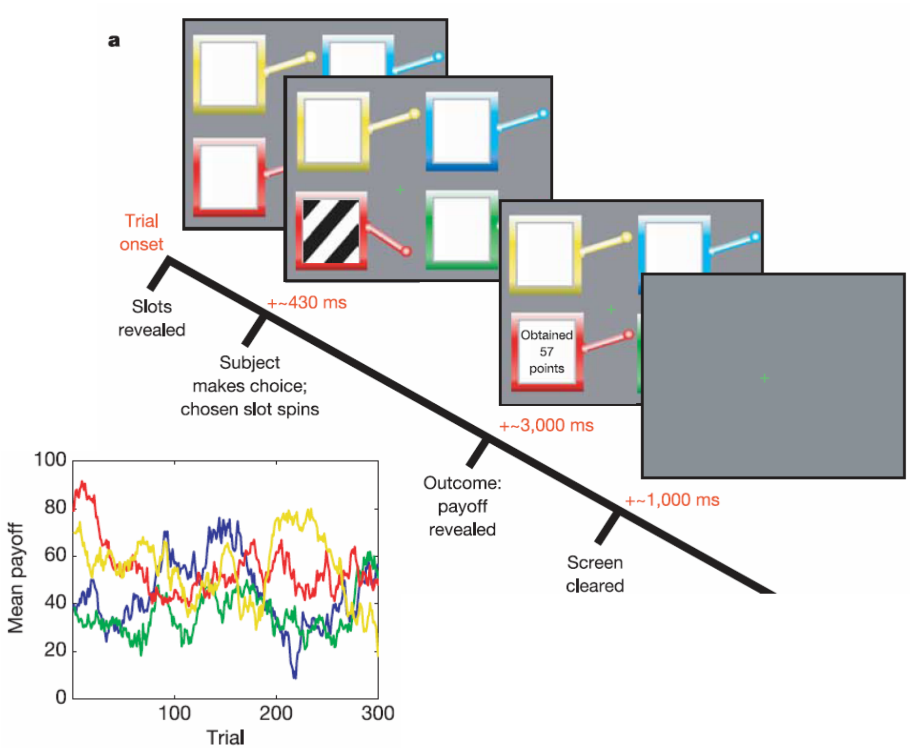


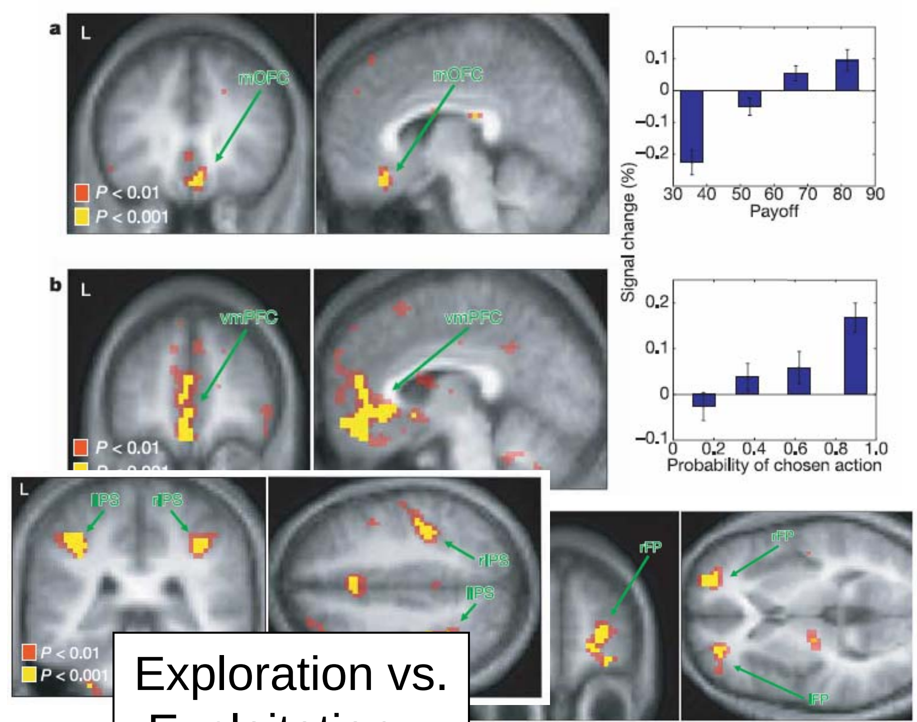


Causal learning with complementary “cortical” and “hippocampal” networks

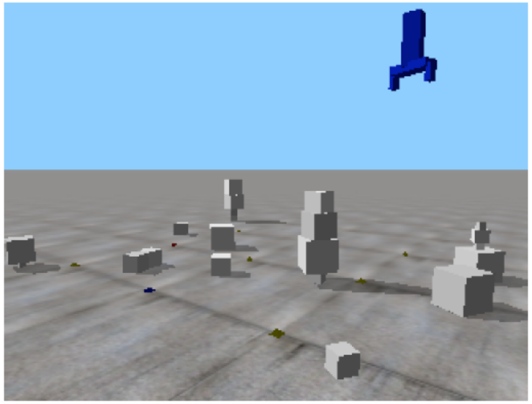


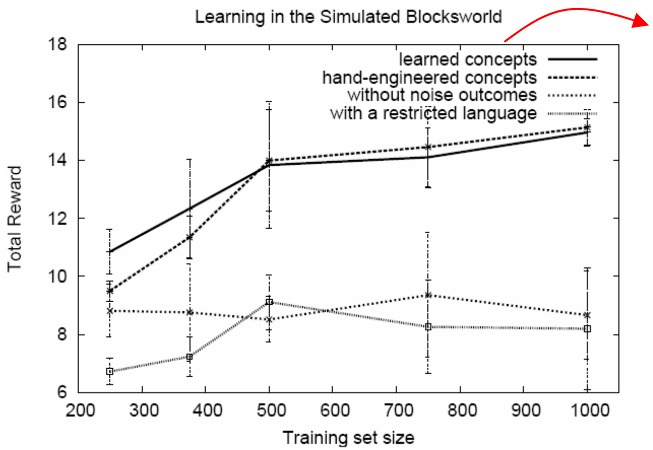
Learning to act





Exploration vs. Exploitation





Concepts learned:
Clear,
Inhand
Topstack
Above
Height
…

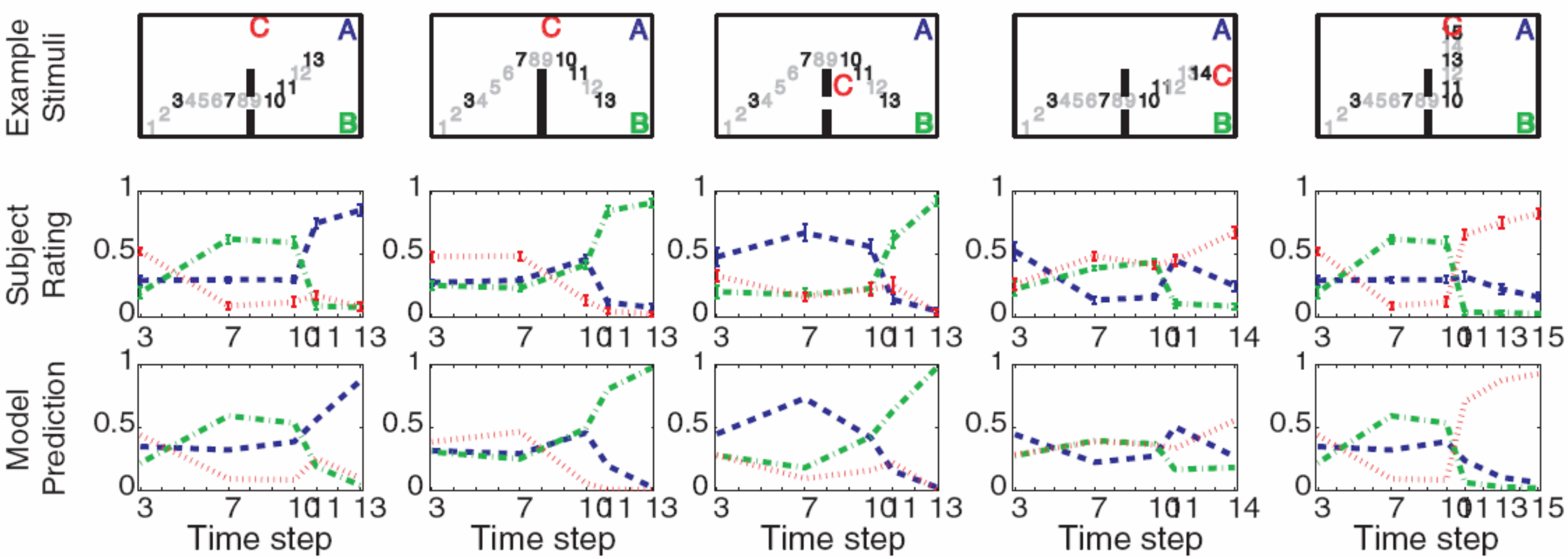
Understanding actions: goal inference

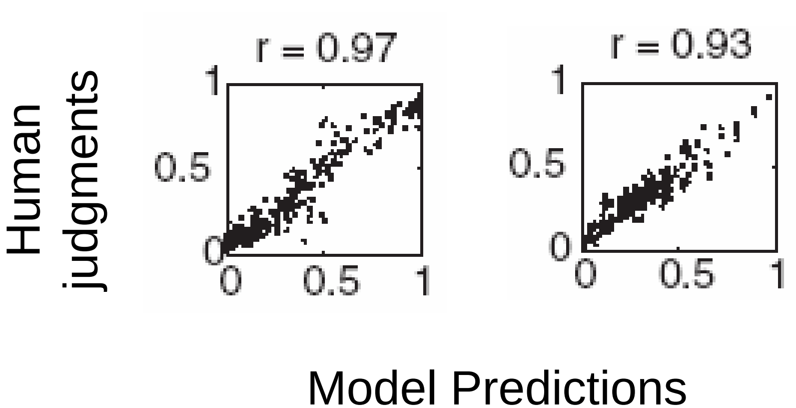
Constraints   Goals

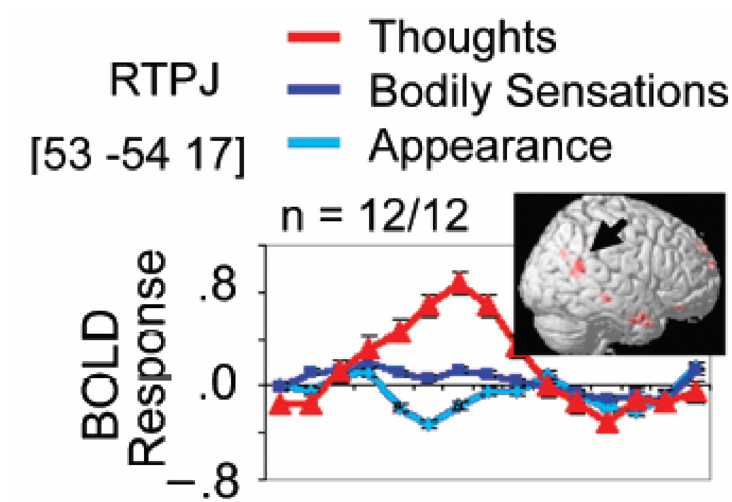
Rational planning
(PO)MDP

↓

Actions







The grand challenge