Knowledge Representation and Reasoning

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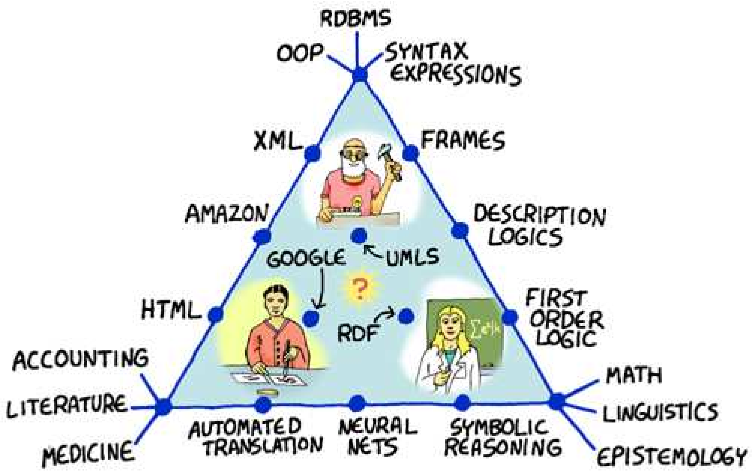


People involved

Lectures:

- Peter Lucas
- Martijn van Otterlo
- Arjen Hommersom

Practicals and tutorials:

- Wenyun Quan (w.quan@cs.ru.nl)
- Maarten van der Heijden (m.vanderheijden@gmail.com)
- Martijn van Otterlo (m.vanottterlo@donders.ru.nl)
- Arjen Hommersom (arjenh@cs.ru.nl)

Start practical: See blackboard/website

Course outline

Website: http://www.cs.ru.nl/~peterl/teaching/KeR

(1) Lectures:

- Theory of knowledge representation and reasoning; core of this formed by:
  - AI-style logics and probability theory
  - Nowadays you can even combine logic and probability theory

(2) Tutorials: do exercises

(3) Practical:

- Learn some programming in Prolog (the AI logic programming language)
- Develop reasoning systems in AIlog

Topics

- Refresh your memory on formal logic
  - this week: read “Logic and Resolution” (available on blackboard and website) – no lectures on 13th September!
  - 17th September: revision lecture on logic
  - 20th September: no lecture!
- Week 24th September: programming in Prolog and AILog
- Knowledge representation formalisms
- Model-based reasoning
- Reasoning with uncertainty and probabilistic logic
- Applications

Learning aims of the course

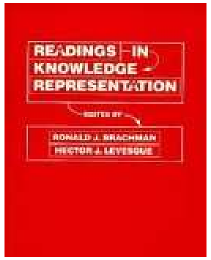
- Obtain insight into the development of knowledge systems, the use of problem solving methods, forms of knowledge representation, and model-based reasoning
- Gain knowledge about logical expressiveness of forms of knowledge representation and the use of probability theory in reasoning with uncertainty
- Being able to develop reasoning programs using Prolog and AILog
- Being able to understand core AI research as reflected in ECAI, IJCAI, AAAI

Reading and study material

- Slides and exercises
- Summarising lecture notes
- Practical manual
- Some material can be found in:
  S. Russell and P. Norvig, Artificial Intelligence: A Modern Approach, 2003 or 2009:
  - Part III Knowledge and Reasoning
    8 First-Order Logic
    9 Inference in First-Order Logic
    10 Knowledge Representation
  - Part V Uncertain Knowledge and Reasoning
    13 Uncertainty
    14 Probabilistic Reasoning

Further reading

- R.J. Brachman and H.J. Levesque, Readings in Knowledge Representation, Morgan Kaufmann, San Mateo, CA, 1985

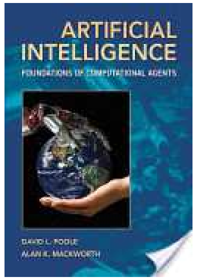


  - good collection of early KR papers

- F. van Harmelen, V. Lifschitz, and B. Porter, Handbook of Knowledge Representation, Elsevier, Amsterdam, 2008

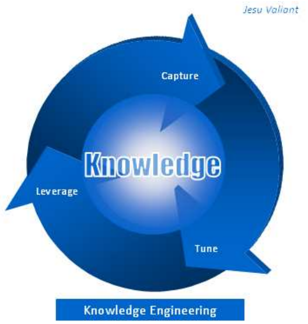
  - state of the art handbook on KR

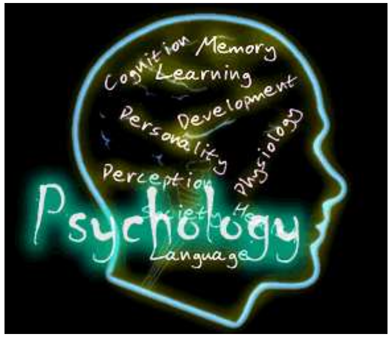
- D. Poole, Artificial Intelligence: Foundations of Computational Agents, Cambridge University Press, 2010



  - nice systematic and coherent approach to AI using logical and probabilistic reasoning (freely accessible)

Knowledge systems





knowledge engineering

machine learning

psychology

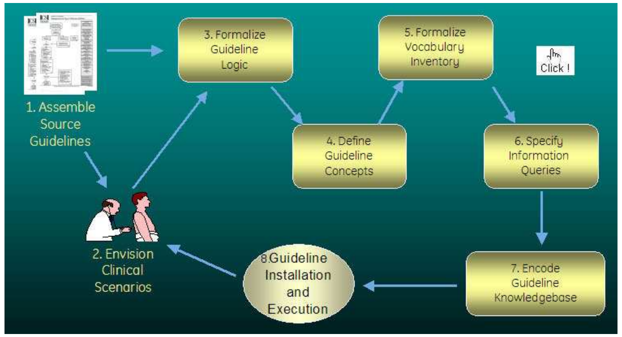
Knowledge system:
a system that is able to solve problems (diagnosis, trouble shooting, control a robot, planning of a task) using knowledge of the domain and given goals

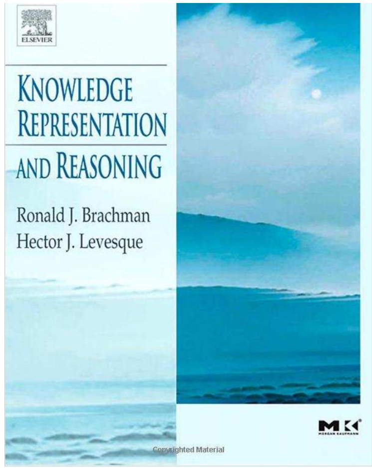
modelling

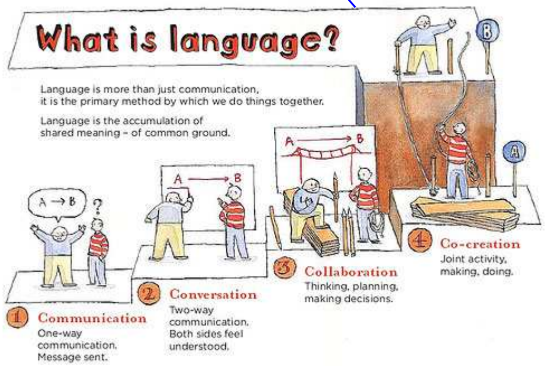
knowledge representation

reasoning

formal and natural language







Early knowledge systems

- Expert system: use of a *large* collection of symbolic expert knowledge to solve problems:
  - E.A. Feigenbaum, B.G. Buchanan, J. Lederberg – Heuristic DENDRAL (1965): contains knowledge from organic chemistry
  - E.H. Shortliffe: MYCIN (1974–1979) – diagnostics of infectious diseases
  - H.E. Pople, J.D. Myers: Internist-1 (1973-1982) – diagnosis in the big area of internal medicine
  - D. Lenat: Cyc (1984-) – representation of common sense knowledge

Modern knowledge systems

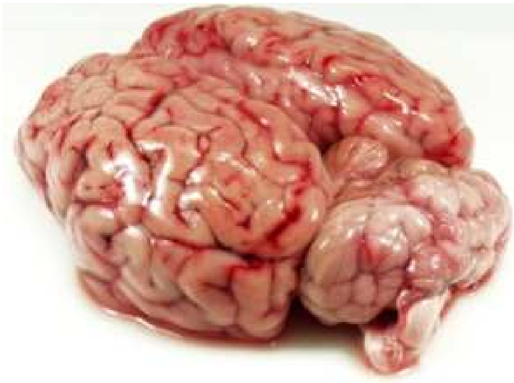
- Use of more sophisticated logical methods:
  - abductive reasoning (cause-effect reasoning and explaining observations), e.g., used in abductive diagnosis
  - use of functional models of behaviour, e.g., in consistency-based diagnosis

- Use of probabilistic and decision-theoretic methods:
  - Bayesian networks (to reason with uncertain knowledge)
  - augmented by decision theory (to allow making decision about appropriate actions)
  - Probabilistic logics

Knowledge: Implicit versus explicit

Two hypotheses:

(1) Human reasoning is hard to capture, and, thus, intricate implicit methods, such as neural networks, capture human reasoning best



(2) Human reasoning can be captured, although possibly incompletely. However, explicit representation is necessary for getting a grip on that knowledge (e.g., to be able to explain recommendations)

Choice: explicit knowledge

Knowledge representation hypothesis

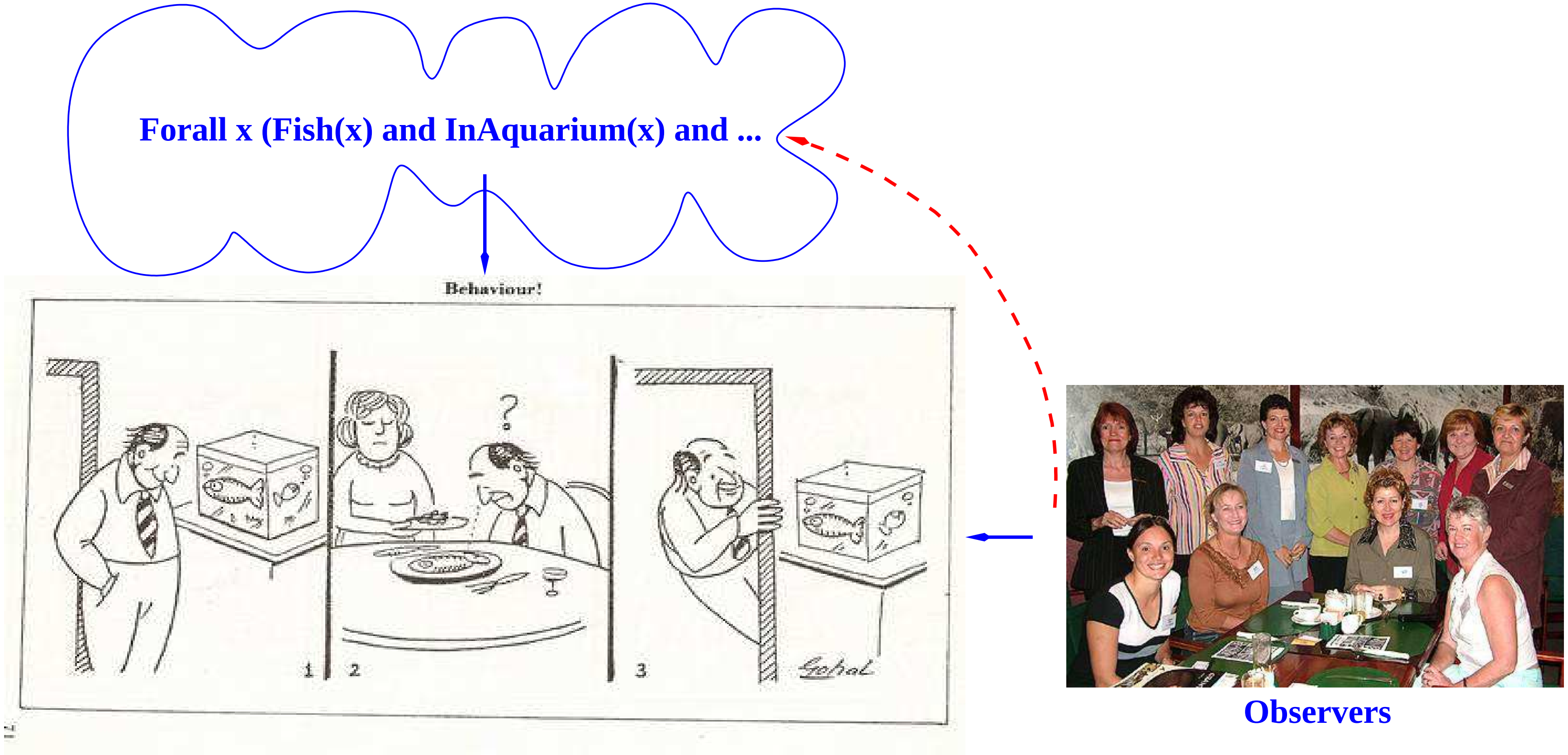
Brian Smith (1982):

Any mechanically embodied intelligent process will be comprised of structural ingredients that

(a) we as external observers naturally take to represent a propositional account of the knowledge that the overall process exhibits

(b) independent of such external semantical attribution, play a formal but causal and essential role in engendering the behaviour that manifests that knowledge

Knowledge representation hypothesis



- The observers will be able to build a knowledge theory based on what they observe
- The agent is driven in his behaviour by knowledge (although possibly different from that of the observers)

Formal knowledge representation

- Logic was originally developed as a language for mathematical reasoning
- Goal of knowledge representation different: represent semantic content of psychologically plausible memory models
- Need for semantics shared by most researchers in knowledge representation
- In time logic has become the dominant language as probability theory for uncertainty reasoning

Natural kinds

- Mathematical definitions: exact and complete.
  Example triangle: shape defined by three points that are not on a straight line and that are connected by lines

- Natural kinds: objects in the real word.
  'Definitions' of objects are often approximate and incomplete

  Example:

  $\forall x(\text{Human}(x) \rightarrow \text{Animal}(x))$
  $\forall x(\text{Human}(x) \rightarrow (\text{walks}(x) = \text{upright} \wedge \cdots \wedge \cdots))$

Role of representation system

- To manage beliefs expressed in the language
- More than just implementation of a (logical, probabilistic) calculus
- The symbolic representation cause the system to behave in a particular fashion

Thus,

> Any language with sufficient expressive power can be used

Language requirements

Levesque & Brachman (A fundamental tradeoff in knowledge representation and reasoning)

Emphasis on:

- What is represented $\equiv$ content $\Rightarrow$ knowledge level (rather than symbol level)
- Statements must be interpreted in relationship to other statements (otherwise no knowledge)
- This implies: language should have a truth theory
- Not a single language, but spectrum of languages (from simple, computationally tractable, to complex, computationally intractable)

Truth theory

- Knowledge base KB: what we know about the world
- Question: is the truth of statement φ implied by KB (note φ need not be included in KB)
- Notation:

$$\text{KB} \models \varphi$$

- In the form of inference = reasoning:

$$\text{KB} \vdash \varphi$$

or,

$$\vdash \text{KB} \rightarrow \varphi$$

($\text{KB} \rightarrow \varphi$ is a theorem) if we use logic, but many logics and other languages are still possible

Logics for knowledge representation

- First-order logic:
  - satisfiability: undecidable
  - when it is known that KB is unsatisfiable, then KB $\models \bot$ is decidable
- (Finite) propositional logic:
  - decidable, but NP complete
  - propositional Horn logic: model checking in polynomial time

    Horn formula: $(A_1 \wedge \cdots \wedge A_n) \rightarrow B$, with A_i and B positive literals

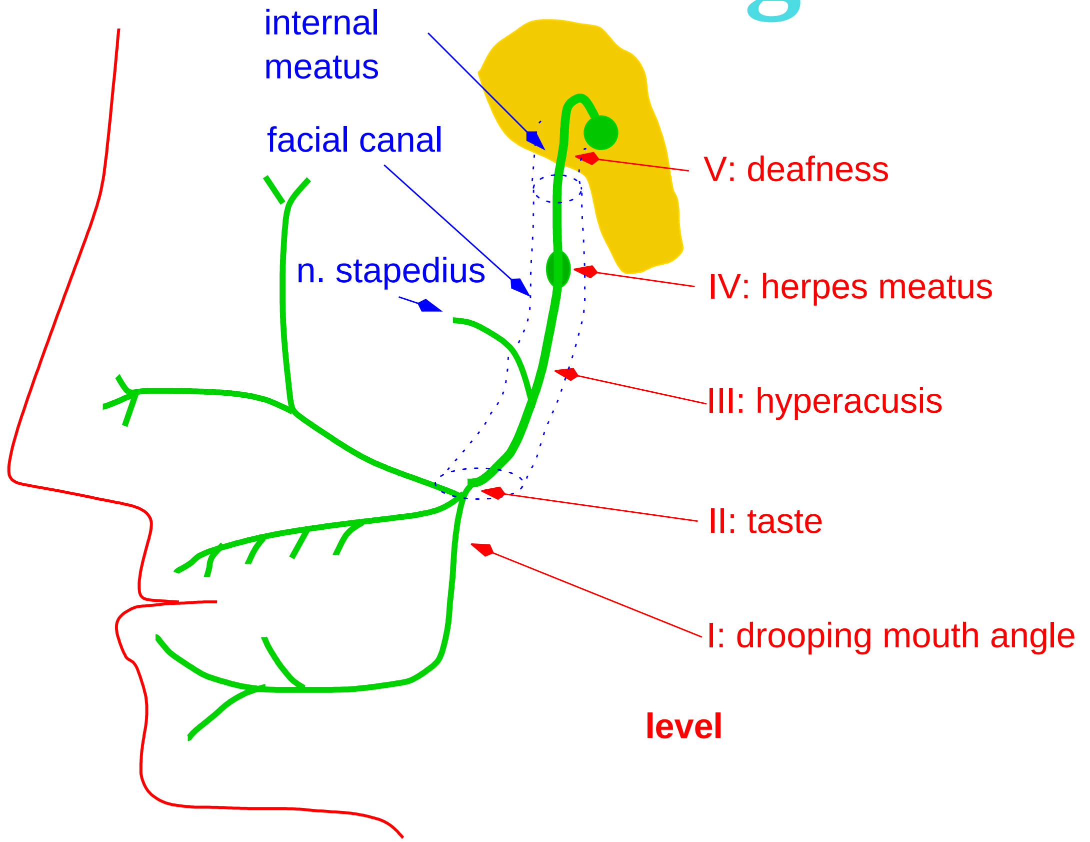
$\Rightarrow$ tradeoff between expressive power and computational complexity

Prolog

- Logical (programming) language with some restrictions, but based on first-order predicate logic
- One of the typical AI programming languages (other Lisp)
- Close relationship with knowledge representation and reasoning: AILog

```
in_mind([h,o,l,i,d,a,y]).
start :- write('Guess first letter'), read(X),
         in_mind([X|T]), write('OK. '), guess(T).
guess([]) :- write('The word is '),
             in_mind(W), write(W),!.
guess(L)  :- repeat, write('Next letter'), read(X),
             ((L=[X|T1], write('OK. '), guess(T1));
             (write('Fail. Try again!'), guess(L))).
```

Model-based reasoning



- Explicit representation of structure and function of systems (= model)
- Reasoning with this model to solve problems (e.g. diagnosis)

Reasoning with uncertainty

- Early: uncertainty attached to rule-based reasoning (ako uncertain reasoning with logical implications)
- 1990s: introduction of Bayesian/belief networks (causal networks with attached probability distributions)
- 1990s: extension to decision networks/influence diagrams (decision making under uncertainty)
- Recent: probabilistic logics (logic and probability theory integrated in an AI fashion)

Thus, after 30 years back to the early problem, which is now well understood

Pacemaker programming

display patient information

show settings

display histograms, counters, holters

provide treatment advice

enter patient data

change settings, perform tests

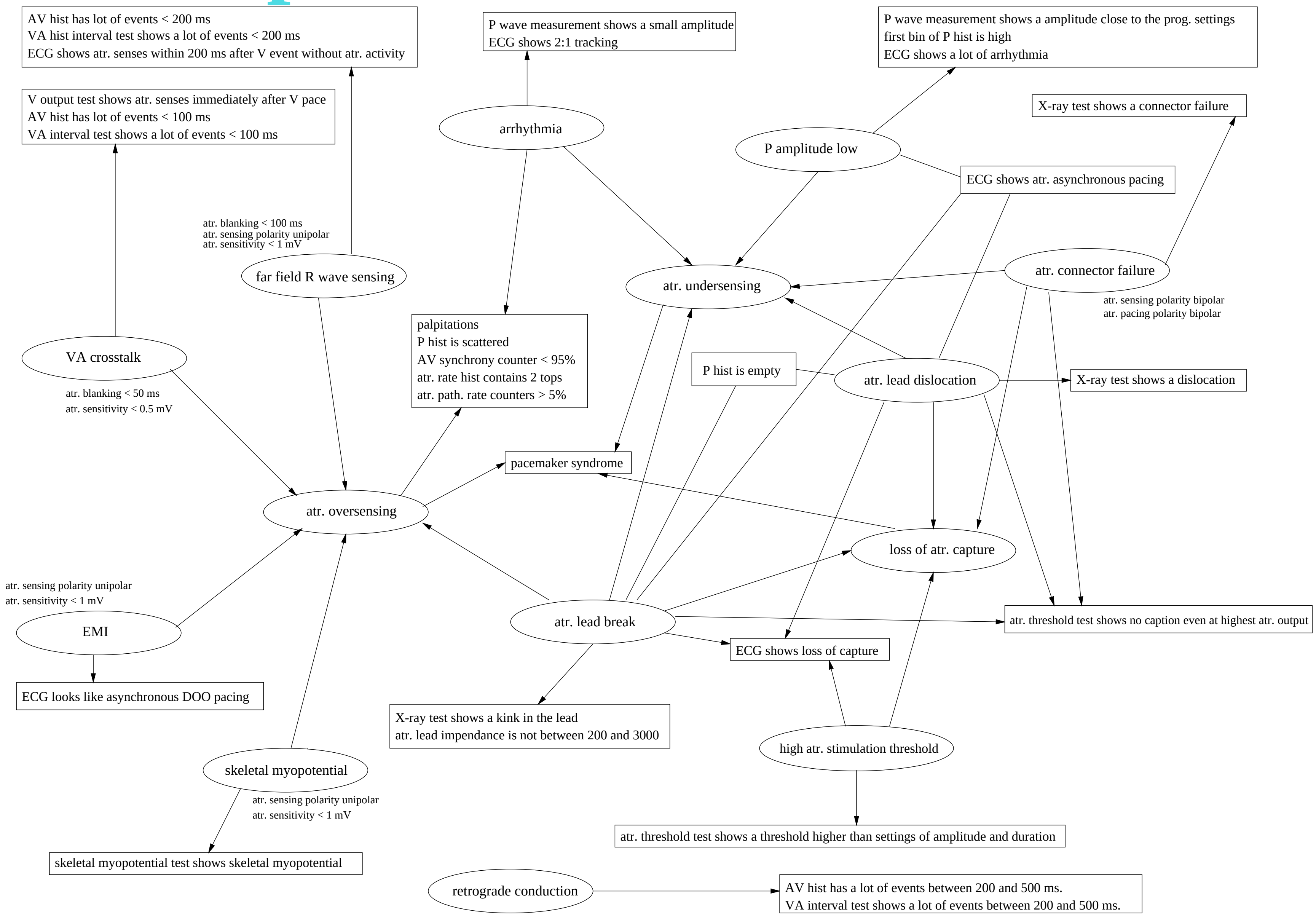
diagnostics

settings

reprogrammed settings

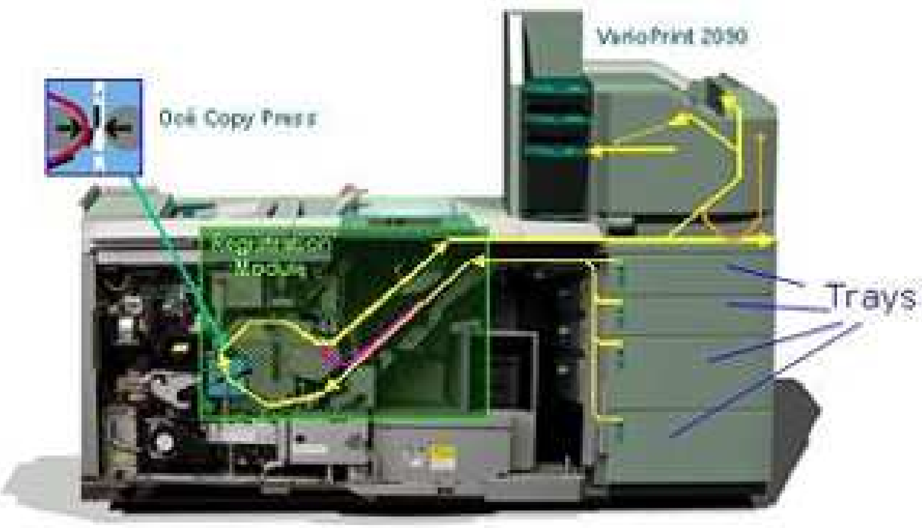
tests

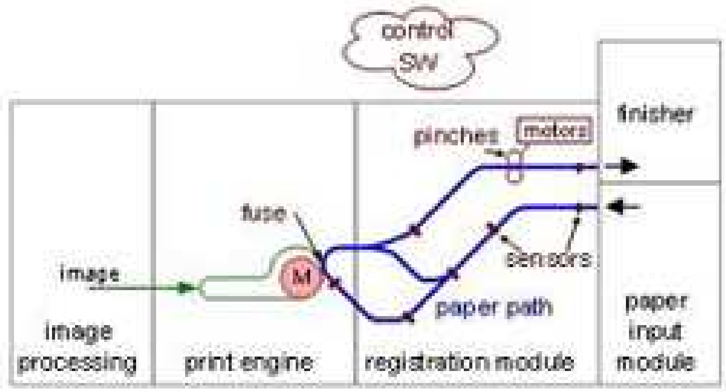
Causal pacemaker model



Smart production printers

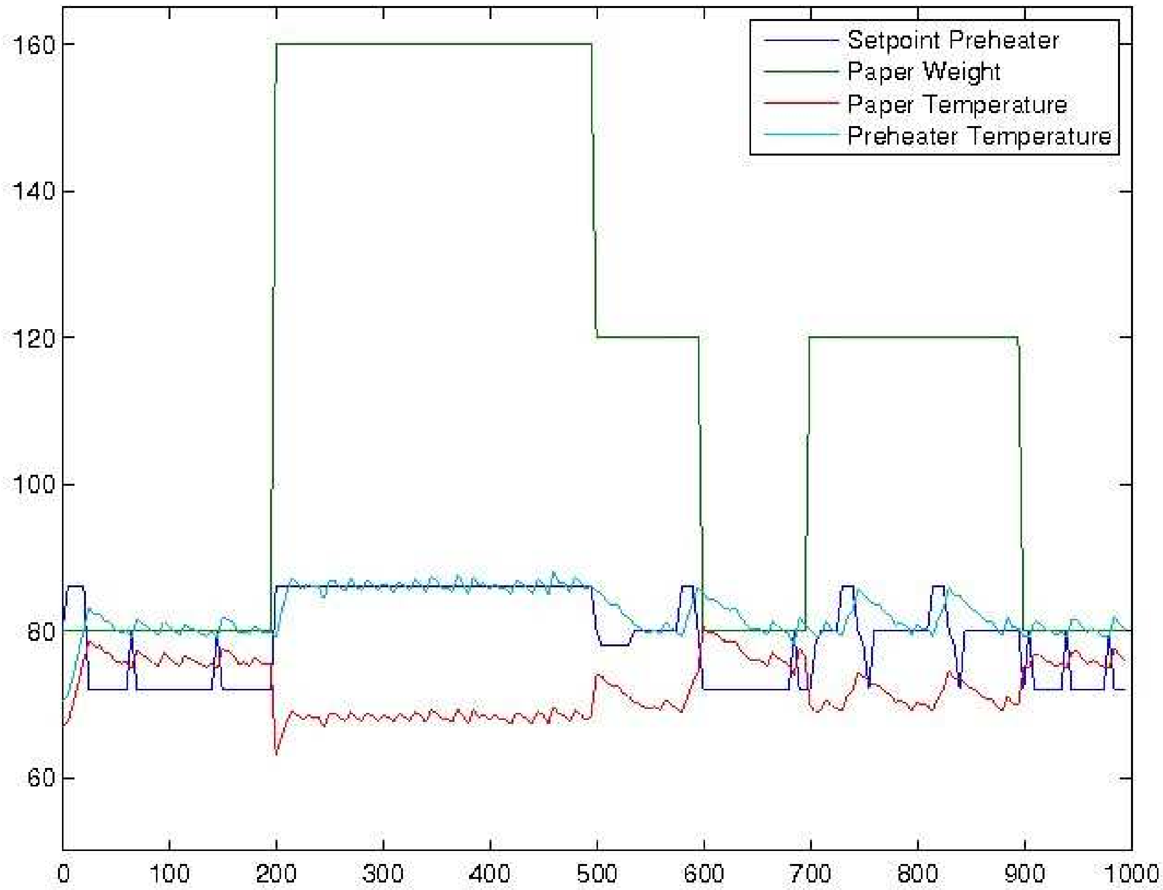
- project with Océ and Embedded Systems Institute
- model-based reasoning about behaviour of printers/copiers
- interpretation of sensor information
- adaptation to changing environment





Adaptive control

Avoid that paper temperature becomes lower than 66°C with 99% certainty:



Martijn

Connection to recent AI research

Conclusions

- Knowledge representation and reasoning defines the very core of AI
- Logic, probability theory and decision theory form its theoretical foundations
- The basis for building intelligent agents and applications
- Concepts form the basis of modern theories on human knowledge representation and reasoning and their complexity