

TDDE56: Knowledge Representation and Reasoning

Fredrik Heintz

Dept. of Computer Science, Linköping University

fredrik.heintz@liu.se

@FredrikHeintz

Knowledge Representation and Reasoning (KR&R)

- Knowledge representation and reasoning is a major sub-area of AI.
- *Intelligence can be understood by studying knowledge.*
- *Knowledge* is often defined as true justified belief in epistemology.
 - Declarative knowledge
 - Procedural knowledge
 - Heuristic knowledge
- *Representation* is a relationship between two domains, where the first is meant to “stand for” or take the place of the second.
- *Reasoning* is the formal manipulation of symbols representing knowledge to produce a new set of symbols representing new knowledge.

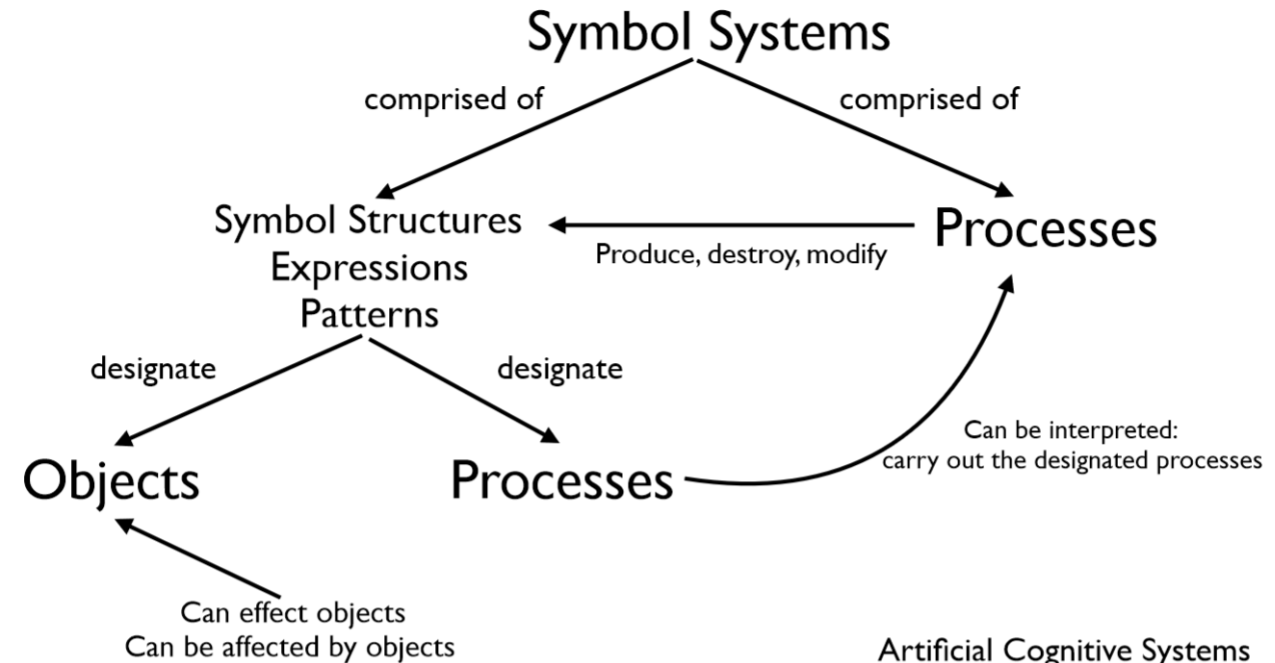
Deductive, Abductive, Inductive Reasoning

- **Deductive reasoning deals with certainty** and involves reasoning toward certain conclusions,
- **Inductive reasoning deals with probability** and involves reasoning toward likely conclusions based on data, and
- **Abductive reasoning deals with guesswork**, involves reasoning toward possible conclusions based on guesswork (a best guess), it is a type of reasoning that is used in formulating a hypothesis for further testing.

	Deductive	Inductive	Abductive
Major Premise	All Men are Mortal	Most Greeks Have Beards	Observation: That Man Has a Beard
Minor Premise	Socrates is a Man	Socrates is a Greek	Known Fact: Most Greeks Have Beards
Conclusion (Inference)	It is Certain that: Socrates is Mortal (this is logically certain given the premises; if all men are mortal, then Socrates being a man must be mortal. Here you can see that if a premise is false, deduction can produce false conclusions).	It is "likely" that: Socrates has a beard (given the premises, the conclusion can be assigned a likelihood; this argument isn't very compelling, but to explain that quality of induction here would be a rabbit hole).	Perhaps: This Man is Greek (a hypothesis based on an observation and a known fact; we can gather inductive evidence to test this hypothesis, for example by gathering more information about the origin of the man).

The Physical-Symbol System Hypothesis

- A physical-symbol system has the necessary and sufficient means for general intelligent action.
 - *Necessary*: any system exhibiting intelligence will prove upon analysis to be a physical symbol system.
 - *Sufficient*: any physical-symbol system of sufficient size can be organized further to exhibit general intelligence.



Artificial Cognitive Systems
David Vernon, MIT Press

Heuristic Search Hypothesis

- The solutions to problems are represented as symbol structures.
A physical-symbol system exercises its intelligence in problem solving by search – that is, by progressively modifying symbol structures until it produces a solution structure.

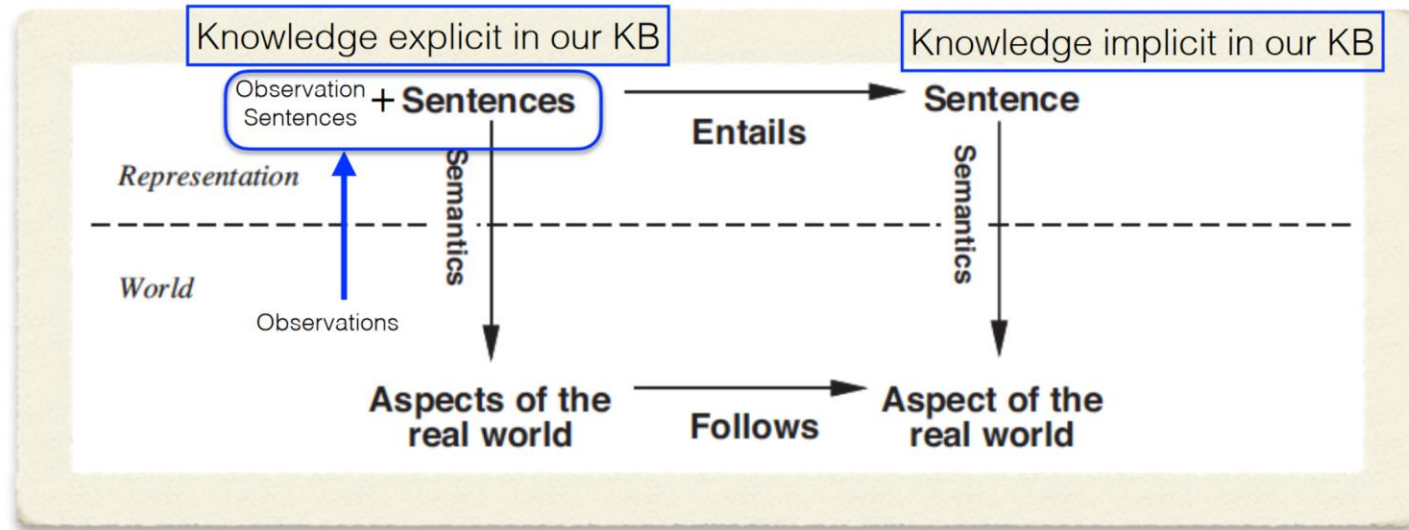
Knowledge Representation Hypothesis

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, and

b) independent of such external semantical attribution, play a formal but [causal](#) and essential [role](#) in engendering the behavior that manifests that knowledge. [\[Brian Smith, 1982\]](#)

Knowledge Representation and Logic



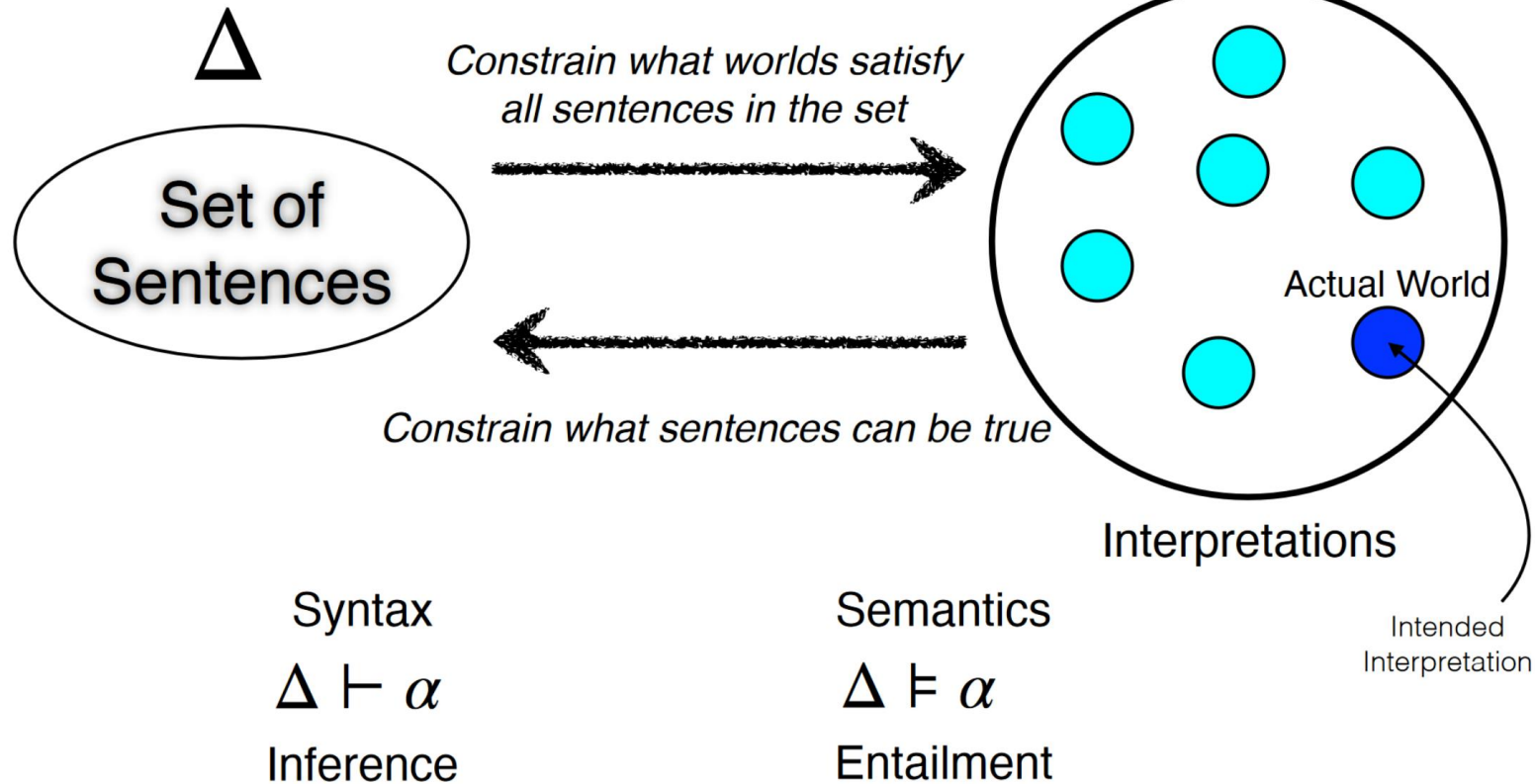
What is our representation language?
How is it grounded causally in the world?

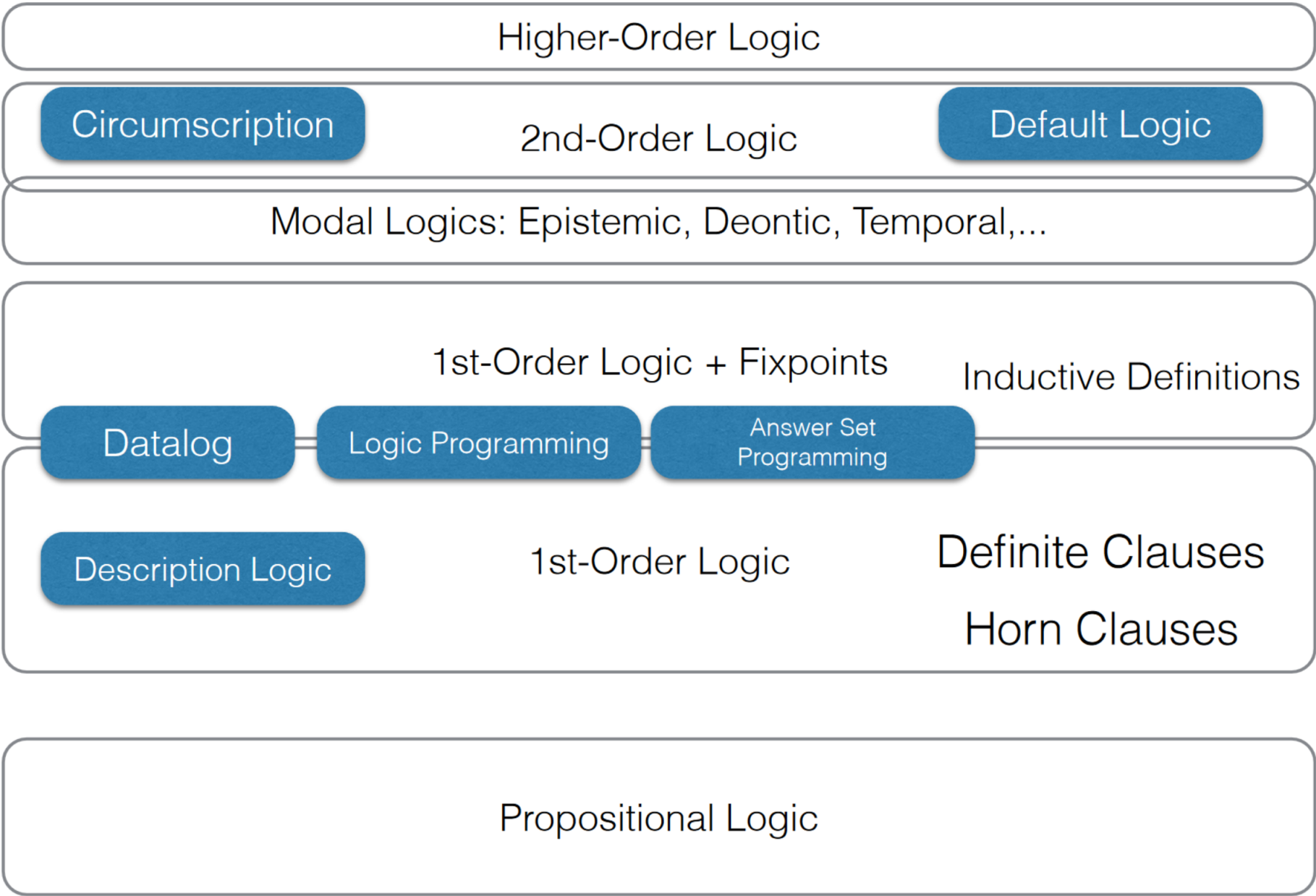
Truth preservation (soundness) guarantees fidelity of entailments to the world under the assumption that observation sentences (sensing) are correct, in addition to background knowledge in the KB.

Knowledge Representation and Logic

Knowledge Base

Possible Worlds





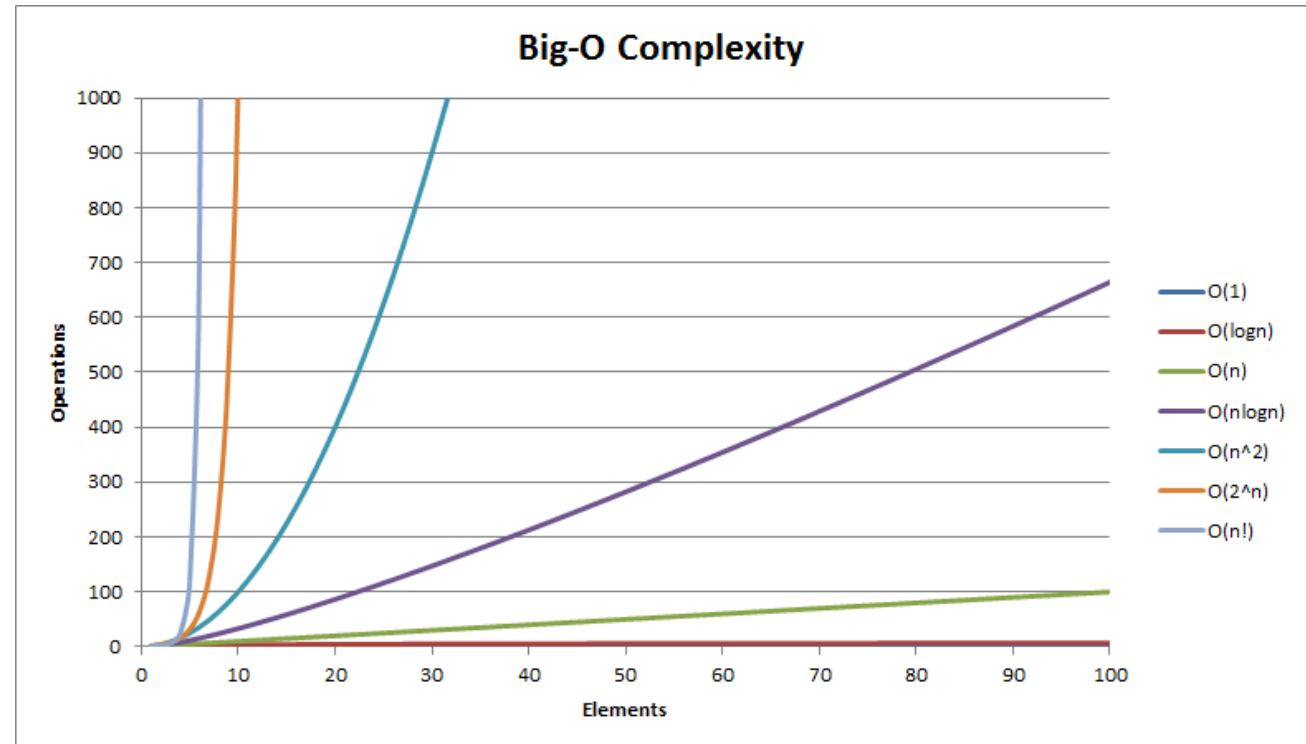
Language	Ontological Commitment (What exists in the world)	Epistemological Commitment (What an agent believes about facts)
Propositional Logic	facts	true/false/unknown
First-order Logic	facts, objects, relations	true/false/unknown
Temporal Logic	facts, objects, relations, times	true/false/unknown
Probability Theory	facts	degree of belief in $[0, 1]$
Fuzzy Logic	facts with degree of truth in $[0, 1]$	known interval value

Ontological Commitment - *what is assumed about the nature of reality*

Epistemological Commitment - *what is assumed about knowledge with respect to facts*

Efficiency and Representation

- Problems can be analyzed and it can be proved what is the most efficient solution.
- The choice of abstraction / representation affects the efficiency.



Graph Operations

Node / Edge Management	Storage	Add Vertex	Add Edge	Remove Vertex	Remove Edge	Query
Adjacency list	$O(V + E)$	$O(1)$	$O(1)$	$O(V + E)$	$O(E)$	$O(V)$
Incidence list	$O(V + E)$	$O(1)$	$O(1)$	$O(E)$	$O(E)$	$O(E)$
Adjacency matrix	$O(V ^2)$	$O(V ^2)$	$O(1)$	$O(V ^2)$	$O(1)$	$O(1)$
Incidence matrix	$O(V \cdot E)$	$O(V \cdot E)$	$O(V \cdot E)$	$O(V \cdot E)$	$O(V \cdot E)$	$O(E)$



Deductive, Abductive, Inductive Reasoning

- **Deductive reasoning deals with certainty** and involves reasoning toward certain conclusions,
- **Inductive reasoning deals with probability** and involves reasoning toward likely conclusions based on data, and
- **Abductive reasoning deals with guesswork**, involves reasoning toward possible conclusions based on guesswork (a best guess), it is a type of reasoning that is used in formulating a hypothesis for further testing.

	Deductive	Inductive	Abductive
Major Premise	All Men are Mortal	Most Greeks Have Beards	Observation: That Man Has a Beard
Minor Premise	Socrates is a Man	Socrates is a Greek	Known Fact: Most Greeks Have Beards
Conclusion (Inference)	It is Certain that: Socrates is Mortal (this is logically certain given the premises; if all men are mortal, then Socrates being a man must be mortal. Here you can see that if a premise is false, deduction can produce false conclusions).	It is "likely" that: Socrates has a beard (given the premises, the conclusion can be assigned a likelihood; this argument isn't very compelling, but to explain that quality of induction here would be a rabbit hole).	Perhaps: This Man is Greek (a hypothesis based on an observation and a known fact; we can gather inductive evidence to test this hypothesis, for example by gathering more information about the origin of the man).

Towards Integration of Paradigms

- Five core different communities including
 - Deep & Probabilistic Learning
 - Neuro-Symbolic Computation (NeSy)
 - Statistical Relational AI (StarAI)
 - Knowledge graphs for reasoning
 - Constraint Programming & Machine Learning

