The IDP System: What and why?

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ARTIFICIAL
INTELLIGENCE
RESEARCH GROUP

Based on presentations of Marc Denecker

1. Introduction

2. Separating Knowledge from Problem: The KB Paradigm

3. FO(·), Informal Semantics and Inductive Definitions

4. Demo: IDP for Blocks World

5. Outlook

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WHAT IS THE IDP SYSTEM?

- A Constraint Programming System
  (lazy clause generation solver)
- An Answer Set Solving System
  (ASP competitions, inductive definitions)
- A theorem prover
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- None (or all) of the above:
  A knowledge base system

SOME DRIVING PRINCIPLES BEHIND IDP

- The Knowledge Base Paradigm: Knowledge and Problem should be separated
- Clear and precise Informal Semantics
- Focus on domain experts (rather than modelling experts)
  (limited core language, symmetry, function detection, grounding techniques, definitional structure)

SEPARATING KNOWLEDGE FROM PROBLEMS

One issue that fragments computational logic more than anything else:

the reasoning/inference task

STATE OF THE ART

- For every type of reasoning task, a new logic (or more than one):
  - Classical first order logic (FO):
    deduction
  - Deductive Databases (SQL, Datalog):
    query answering & other database operations
  - Answer set Programming (ASP):
    answer set computation
  - Abductive Logic Programming:
    abduction
  - Constraint Programming (CP):
    constraint solving
  - Planning languages PDDL :
    planning
  - Temporal logics :
    model checking
  - . . .

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Depending on the task to be solved, we need a different system and a different logic to represent this proposition.

Is declarative knowledge not independent of the task (and hence, of a specific form of inference) ?

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We use knowledge to solve a problem by applying the appropriate form of *inference*.

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$$\forall x \forall y (G(x, y) \Rightarrow Col(x) \neq Col(y))$$

- How to solve a graph coloring problem in FO?
- What kind of inference do we need to apply to this formula to solve this problem?

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- Form of inference needed here:

model generation/expansion

Shouldn’t it be possible to solve multiple types of tasks using the same language?

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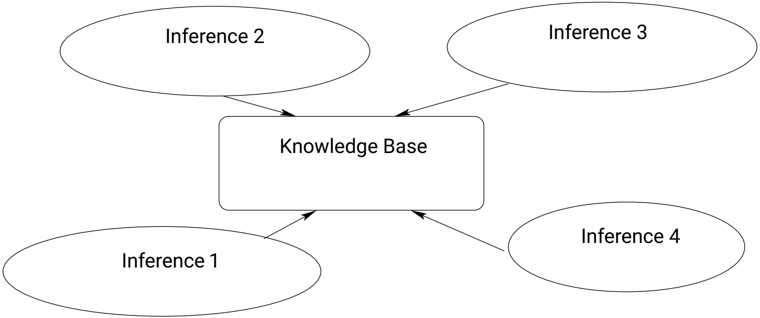

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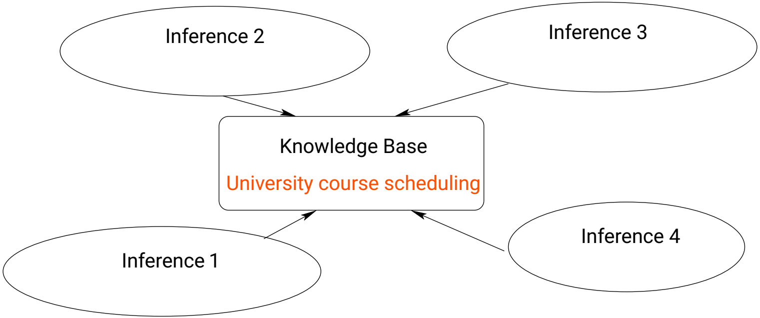

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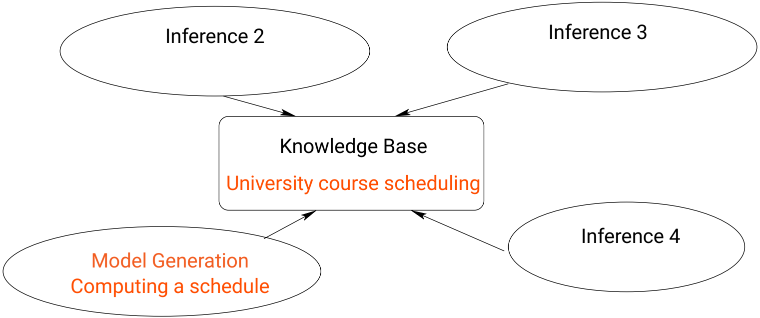

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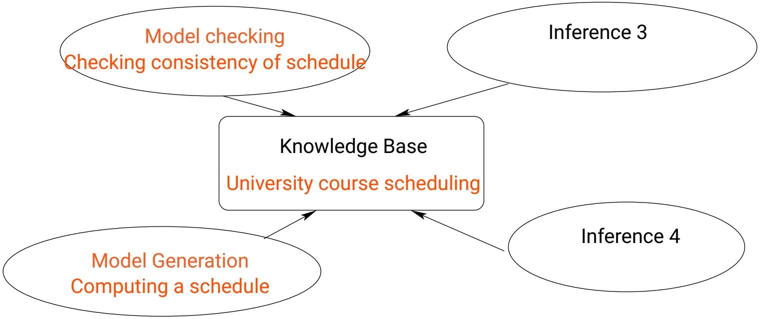

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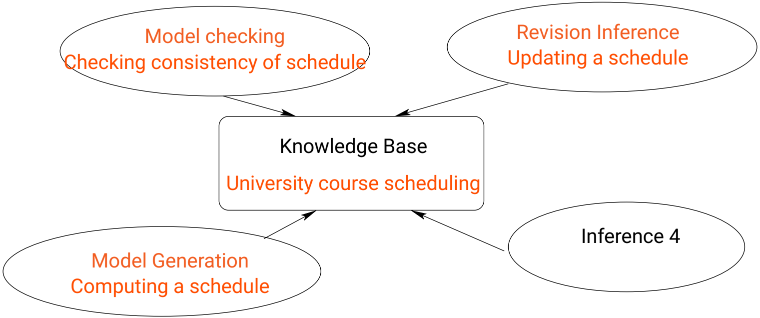

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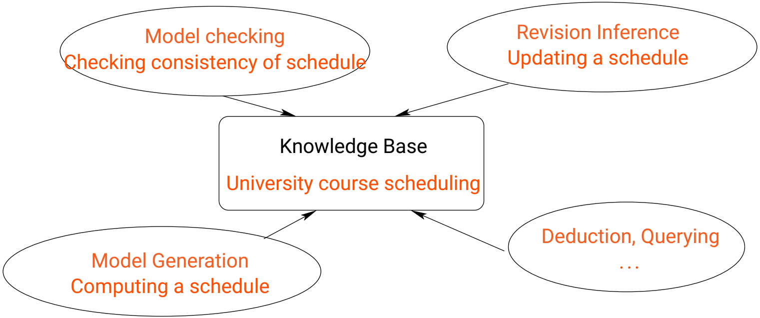

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- Equiped with different forms of inference:
  - Model generation: Computing a schedule
  - Model checking: Verifying consistency of a schedule
  - Update and Revision: Updating a given schedule
  - Deduction for verification of the KB
    Querying of defined predicates, ...

THE FO(·)-KBS PROJECT

- On the logical level: FO(·)
  - Study “knowledge” by principled development of expressive KR languages
  - Clear informal semantics
  - Expressive language, rich enough so that the information, relevant to solve a problem CAN be represented.
  - Model-theoretic semantics, in the Tarskian style.
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(FO($\cdot$)= family of extensions of FO)

THE FO(·)-KBS PROJECT

- On the application level:
  - Towards a typology of tasks and computational problems in terms of (the same) logic and inference.
  - Eagerly searching for novel ways of using declarative specifications to solve problems.

THE FO(·)-KBS PROJECT

- On the inference level:
  - Building solvers for various forms of inference for FO(·)
  - Integrating various solving techniques from various declarative programming paradigms in one Knowledge Base System.
    (In IDP3, with the Lua scripting language)

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WHY FO AS A FOUNDATION ?

FO: the language that failed in the seventies?

- Too expressive for building “practical” systems?
  - Undecidability
  - Expressivity/Efficiency trade-off

- FO is not suitable for describing common sense knowledge?
  - Nonmonotonic reasoning

- FO as a language is too difficult for practical use?
  - E.g., quantifiers

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  $$\forall x(Human(x) \Rightarrow Man(x) \vee Woman(x))$$

  means

  All humans are men or women

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- Model semantics as a way to formalize meaning.

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(2) But FO is not enough for practical KR.

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- Such forms of inference have apparently many applications than deduction.

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In a knowledge-centered logic, we must accept that some sort of problems are untractable or undecidable, while other problems are solvable.

- That is life, that is how knowledge is.
- We still hope to be able to solve many problems.

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  - Coinductive Definitions

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  - Modal operators

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  - Modal operators
  - Higher Order logic
  - ...

The FO(·) language framework

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SOME PROTOTYPICAL INDUCTIVE DEFINITIONS.

The two most common forms of ID's.

Monotone induction

The transitive closure T_G of a graph G is defined inductively:

- $(x, y) \in T_G$ if $(x, y) \in G$;
- $(x, y) \in T_G$ if for some vertex z, $(x, z), (z, y) \in T_G$.

Induction over well-founded order

We define $\mathfrak{A} \models \varphi$ by induction on the structure of φ

- $\mathfrak{A} \models q$ if $q \in \mathfrak{A}$;
- $\mathfrak{A} \models \alpha \wedge \beta$ if $\mathfrak{A} \models \alpha$ and $\mathfrak{A} \models \beta$;
- $\mathfrak{A} \models \neg\alpha$ if $\mathfrak{A} \not\models \alpha$ (i.e., if not $\mathfrak{A} \models \alpha$);

PROPERTIES OF INFORMAL ID'S

- Linguistically, a set of informal rules (with negation)
- Semantically, two principles:
  - Non-constructively, the least set closed under rule application
  - Constructively, the set obtained by iterated rule application.
- These two principles coincide – Tarski!

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- These two principles coincide – Tarski!
- Only for monotone definitions!

INFORMAL (INDUCTIVE) DEFINITIONS (ID´S)

- Definitions in mathematics: a special sort of knowledge:
  - of mathematical precision
  - broadly used
  - intuitively well understood
  - but not scientifically well-understood

ADDING ID'S TO FO

- Inductive definitions frequently occur in KR and formal specifications
- ID's cannot be expressed in FO in general.
  - Compactness theorem

$\Rightarrow$ It is necessary to extend FO with them.

FO(ID) (DENECKER 2000, DENECKER& TERNOVSKA 2008)

An FO(ID) theory:

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Example:

$$\left\{ \begin{array}{l} \forall x \forall y (R(x,y) \leftarrow G(x,y)) \\ \forall x \forall y (R(x,y) \leftarrow \exists z (G(x,z) \land R(z,y))) \end{array} \right\}$$
$$\forall x \forall y R(x,y)$$

expresses that ...

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Claim (KR 2014)

Rules under well-founded semantics provide a uniform formalism for expressing the most common forms of definitions.

FO(ID) AS A RULE FORMALISM

- Many rule-based formalisms
  - Logic Programming
  - Datalog
  - Answer Set Programming
  - Description logics with rules
  - Abductive Logic Programming
  - Business rule systems
- FO(ID) overlaps with many of them and provides two precise, well-understood declarative sorts of rules
  - Material implications, definitional rules

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SMALL DEMONSTRATION

Block's World Application

- Blocks can either be on the table or stacked
- Robot (arm) can grab a block to move it (and later put it down)
- Entire stacks can be moved
- If too large a stack is picked up, it falls down (on the table)

BLOCK'S WORLD VOCABULARY

Types

- Time points (discrete time)
- Objects (including table

Discrete time (functions)

- Start point
- Successor

Relations

- Fluents (On, Holds)
- Actions (Take, Put)
- Derived Fluents (Above, Fall)

BLOCK'S WORLD THEORIES

Some different theories

- Theory describing the temporal domain
- Goal theory (for planning)
- Invariant theory (to prove)

BLOCK'S WORLD DEMO

Let's look at

- IDP Syntax
- Language Features (Definitions, aggregates, . . .)
- Different inference methods
- Lua programming environment

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FUTURE

- IDP3 (as demonstrated) no longer actively maintained
- New version coming
  - MinisatID replaced by Z3
  - Lua replaced by python
  - Strong focus on extensibility of the language

MAIN PUBLICATIONS

- IDP:

  B. De Cat, B. Bogaerts, M. Bruynooghe, G. Janssens and M. Denecker Predicate Logic as a Modeling Language: The IDP System. Chapter in Declarative Logic Programming: Theory, Systems, and Applications, p. 279-323, 2018.

- The KBS-paradigm:

  Denecker, Marc; Vennekens, Joost. Building a knowledge base system for an integration of logic programming and classical logic, ICLP 2008

- The logic FO(ID):

  Denecker, Marc; Ternovska, Eugenia. A logic of nonmonotone inductive definitions, ACM Transactions on Computational Logic, volume 9, issue 2, 2008.

- The well-founded semantics works well for IDs:

  Marc Denecker, Joost Vennekens: The Well-Founded Semantics Is the Principle of Inductive Definition, Revisited. KR 2014