Knowledge Representation

Lecture 1: Introduction

Patrick Koopmann, Atefeh Keshavarzi Zafarghandi, Andreas Sauter

October 30, 2023

Meet the Lecturers

Patrick Koopmann

- PhD in Manchester, PostDoc in Oxford, Dresden
- Assistant Professor
- Expert in Description Logics

Atefeh Keshavarzi Zafarghandi

- PhD in Groningen
- Post Doctoral Researcher
- Expert in Argumentation Theory

Andreas Sauter

- PhD-Student
- Expert in Reinforcement Learning

Meet the TAs

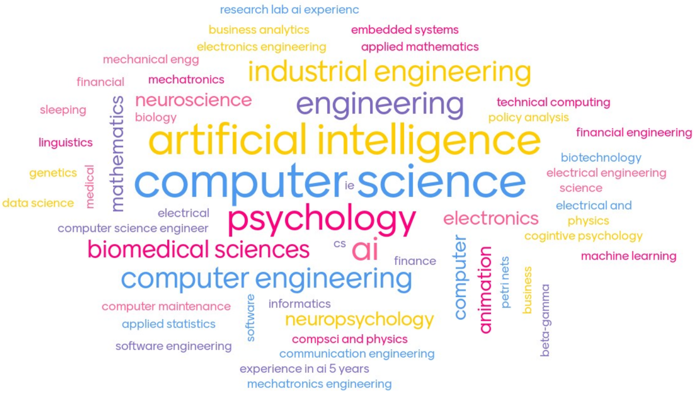
Kuhu Sinha

Andrzei Szczpura

And who are you?

What did you do your Bachelor in?

114 responses



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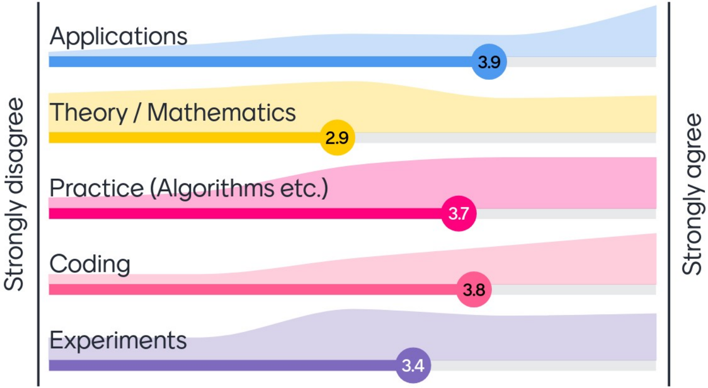
What do you enjoy?



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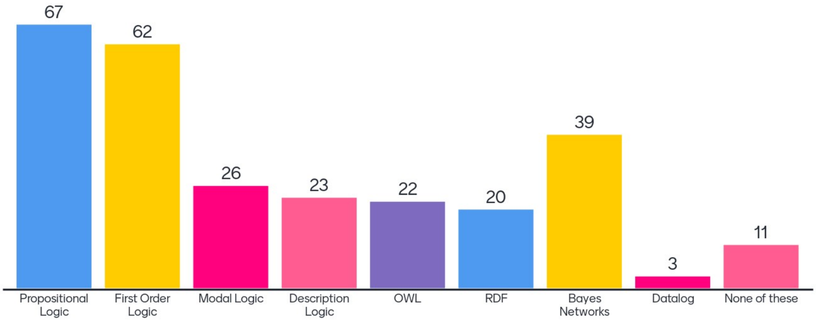
84

Which of these formalisms do you already know?



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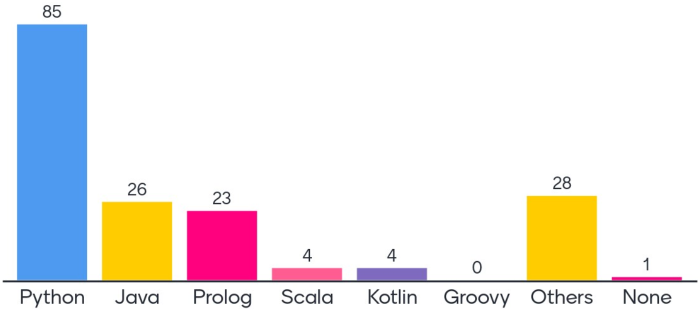
82

Which programming languages can you use?



Nice to meet you!

Overview of Today

- Course Practicalities
- What is Knowledge Representation?
- Overview of the rest of the lecture

Course Practicalities

- 6 Weeks @ up to 3 Lectures
- Three Topics from KR:
  - Description Logics (me)
  - Argumentation Theory (Atefeh Zafarghandi)
  - Probabilistic Graphical Models (Andreas Sauter)

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- Working groups: Weeks 2, 4, 7 $\Longrightarrow$ exam training

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- Working groups: Weeks 2, 4, 7 $\Longrightarrow$ exam training
- Practical Work:
  - Week 1: Nothing
  - Week 2–4: Project 1 on description logics
  - Week 5: peer review reports for Project 1
  - Week 5–7: Project 2 on argumentation
  - Week 8: Exam
  - Week 8: peer review reports for Project 2

Course Practicalities

- Two projects
  1. Description Logics
  2. Argumentation
- Work in groups of 3
- Judged by peer reviewing and us
- Q&A's next to lectures
  - Support sessions for research projects
- Final Score: 25% for each project, 50% for the exam

Building the Groups

- Groups of 3
  - Challenges
    - larger group, more difficult to manage
    - not all of you work on all skill-sets
  - Opportunities
    - (closer) contact with more people
    - get in contact with new people
- Different teams for each project
- Randomly distributed groups

Course Practicalities

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  - No panic
  - Usually two lectures (Monday+Friday)
  - This week a "bonus lecture" on classical logic
  - Every two weeks a Q&A session
  - Additional Q&As if needed

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- *"I attended KR before."*
  - If you already finished a project in a previous iteration of this course, you can reuse its result
  - You can decide which project to skip, and we will use the result from the previous time
  - You can even skip both projects
  - But careful: The KR lecture is quite different this time. For exam preparation, I strongly advise to follow the lecture and working groups

Course Practicalities: Communication

Communication:

- You find further information on the Canvas page, such as about suggested reading material
- I will also use Canvas to make announcements
- There is a slack group for asking questions about the course — find it also on canvas

Knowledge Representation

Two Types of Intelligence

What do you see on this picture?

(a) A cat
(b) An apple

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Why?

Two Types of Intelligence

Are you currently attending a Masters lecture that is part of the AI Masters program?

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Why?

Two Types of Intelligence

Are you currently attending a Masters lecture that is part of the AI Masters program?

Why?

1. You are a Master student in AI at the VU
2. KR is a mandatory course for AI Master students at the VU
3. The course is currently happening
4. Nothing prevented me from attending the course

One relevant part of human intelligence

- depends on explicitly known facts (we have learned or can access)
- derives implicit knowledge through reasoning
- can be (mostly) justified based on the above two

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In artificial intelligence, this part corresponds to symbolic AI,
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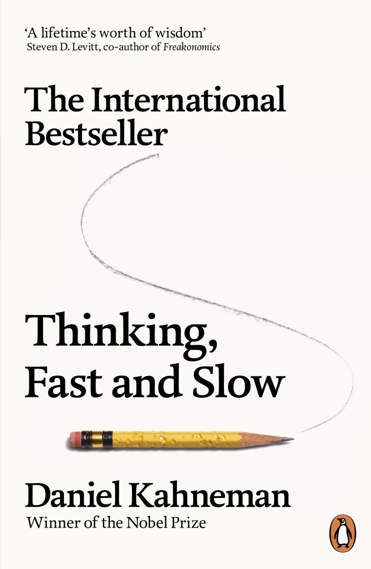
This is not all of human intelligence (for example, we also have intuitions).
Similarly, symbolic AI and knowledge representation are not all there is in AI.

Two Types of Intelligence



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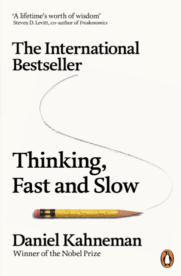


Kahnemann distinguishes two systems of thinking:

- System 1: fast, intuitive, and emotional
- System 2: slower, more deliberative, more logical

Two Types of Intelligence

These systems correspond to two fundamentally different branches of AI:

- Data-Centric / Statistical AI:
  - Machine Learning
  - Deep Neural Networks
  - Large Language Models
- Symbolic AI:
  - Logical reasoning
  - Explicit knowledge
  - Transparent inferencing

Two Types of Intelligence

. . . with different applications:

- Data-Centric / Statistical AI:
  - Pattern Recognition (images, sound, shapes)
  - Motor skills (robotics)
  - Text/image generation

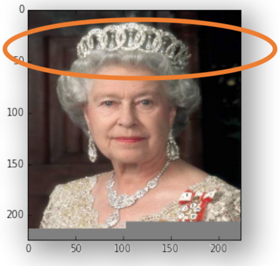
- Symbolic AI:
  - Planning (autonomous space missions)
  - Reasoning (diagnosis, design, decision support)
  - Search engines

Thinking Fast without Thinking Slow

Class: 793

Label: n04209133 (shower cap)

Certainty: 99.7%



Other Limitations of Data-Centric Methods

`Bing, what is Patrick Koopmann's Lecture about?`

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Patrick Koopmann is an assistant professor in the Knowledge in AI group at
the Vrije Universiteit Amsterdam.  His lecture is about his research
interests, which are in knowledge representation, automated reasoning and
theoretical computer science, more specifically on description logics and
related logical formalisms.  He will talk about some of the problems and
techniques he investigates, such as explainability, abduction, learning,
modularization, query answering, and extensions of description logics.  He
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(No panic, the lecture will not be about all of these things.)

Strengths and Weaknesses

1. Construction of Knowledge
   - Data-centric techniques rely on large sets of training data
     - GPT-3: 45 Terabytes of text
     - DeepFace (face recognition by facebook): 4.4 million images
     - AlphaGo (defeated the human world champion in Go): 30 million human expert moves

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     - you can build a usable knowledge base by yourself

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   - On the other hand, human effort tends to be larger
     - we need to formalize the knowledge
   - Example: SNOMED CT
     - medical knowledge base used by many national health systems
     - over 300,000 definitions
     - 55 years of effort (started as SNOP in 1965)
     - around 10,000 updates every year

Strengths and Weaknesses

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2. Scalability
   - Data-centric AI: more data is better

Strengths and Weaknesses

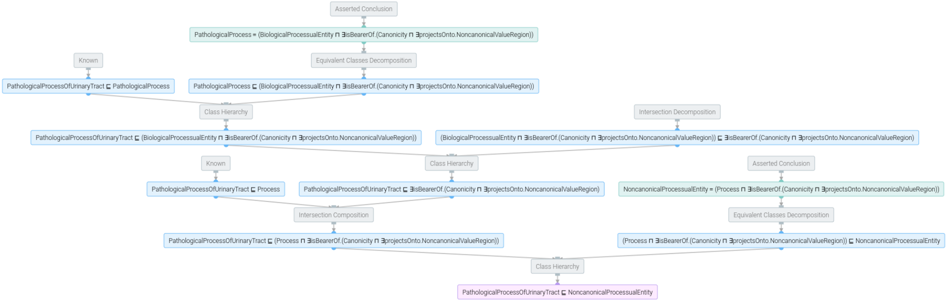
1. Construction of Knowledge
2. Scalability
   - Data-centric AI: more data is better
   - KR: more knowledge makes it harder
     - computational effort
     - higher chances of bugs

Strengths and Weaknesses

1. Construction of Knowledge
2. Scalability
3. Explainability / Transparency
   - data-centric: challenging

Strengths and Weaknesses

1. Construction of Knowledge
2. Scalability
3. Explainability / Transparency
   - data-centric: challenging
   - Knowledge representation: in a way “explainable by design”



Which is Best?

- It is not a competition
- Different types of AI are used for different purposes
- Use KR if
  - you have the knowledge
  - you have the resources to formalize it
  - you need trust, transparency and precision
- In the future, combined systems will likely gain importance (neuro-symbolic AI)

What is Knowledge Representation?

What is Knowledge Representation?

Let's start with some examples!

KR Formalisms You Might Know: Logics

Logics are the classical KR formalism:

Propositional logic: $(a \vee b) \leftrightarrow \neg c$

First order logic: $\forall x : \exists y : (R(x, y) \rightarrow y)$

Modal logics: $a \rightarrow \Diamond(b \vee \Box c)$

Description logics: $\mathit{Student} \sqsubseteq \exists \mathit{studiesAt}.\mathit{University}$

KR Formalisms You Might Know: Prolog and Friends

```
connected(living_room, corridor).
connected(bedroom, corridor).
connected(entrance, corridor).
connected(kitchen, living_room).
connected(bedroom, balcony).
```

```
reachable(X,Y) :- connected(X,Y).
reachable(X,Y) :- connected(Y,X).
reachable(X,Y) :- reachable(X,Z),
                  reachable(Z,Y).
```

```
?- connected(X,Y).
X = living_room, Y = corridor ;
X = bedroom, Y = corridor ;
X = entrance, Y = corridor ;
X = kitchen, Y = living_room ;
X = bedroom, Y = balcony.
```

KR Formalisms You Might Know: Prolog and friends

Prolog:

- A declarative, logic-based programming language
- Most popular system, SWI-Prolog, developed at VU
- Integrates KR and programming

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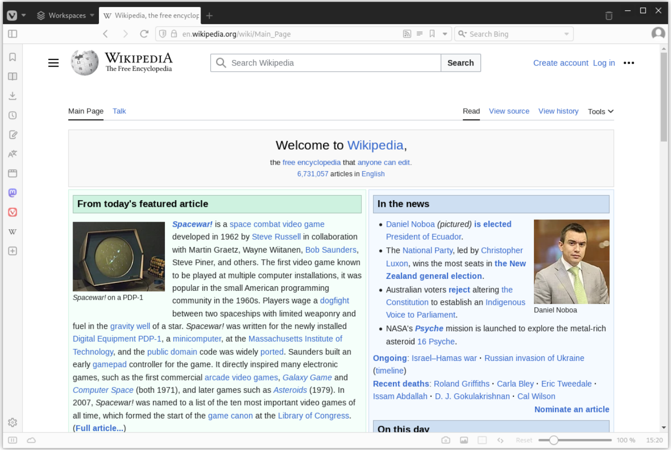
Other relevant rule-based formalisms:

- Datalog
- Answer Set Programming (ASP)
- Tuple-Generating Dependencies (TGDs)

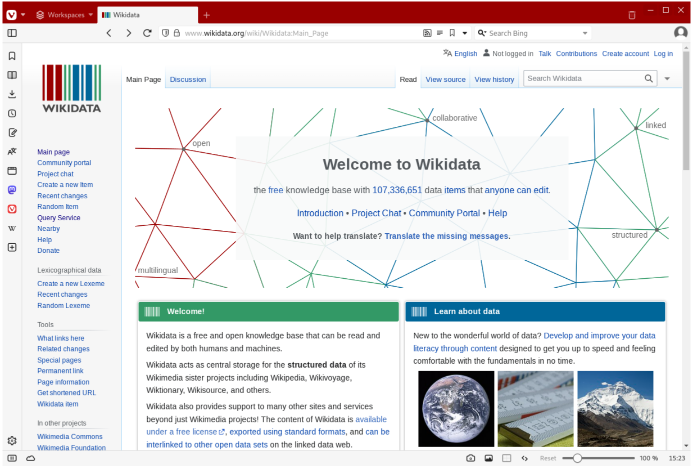
KR Formalisms You Might Know: Knowledge Graphs / Wikidata

You all know Wikipedia:



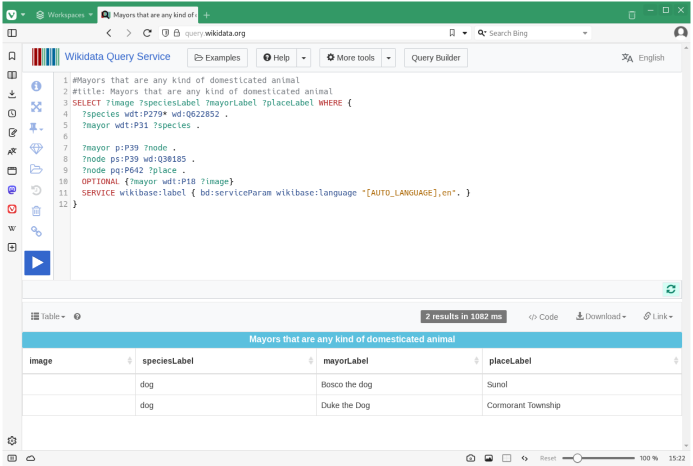
KR Formalisms You Might Know: Knowledge Graphs / Wikidata

Do you also know Wikidata?



KR Formalisms You Might Know: Knowledge Graphs / Wikidata

Query: Which mayors are domesticated animals?



KR Formalisms You Might Know: Knowledge Graphs / Wikidata

Query: Which mayors are domesticated animals?

Wikidata Query Service

```
#Mayors that are any kind of domesticated animal
#title: Mayors that are any kind of domesticated animal
SELECT ?image ?speciesLabel ?mayorLabel ?placeLabel WHERE {
  ?species wdt:P279* wd:Q622852 .
  ?mayor wdt:P31 ?species .

  ?mayor p:P39 ?node .
  ?node ps:P39 wd:Q30185 .
  ?node pq:P642 ?place .
  OPTIONAL {?mayor wdt:P18 ?image}
  SERVICE wikibase:label { bd:serviceParam wikibase:language "[AUTO_LANGUAGE],en". }
}
```

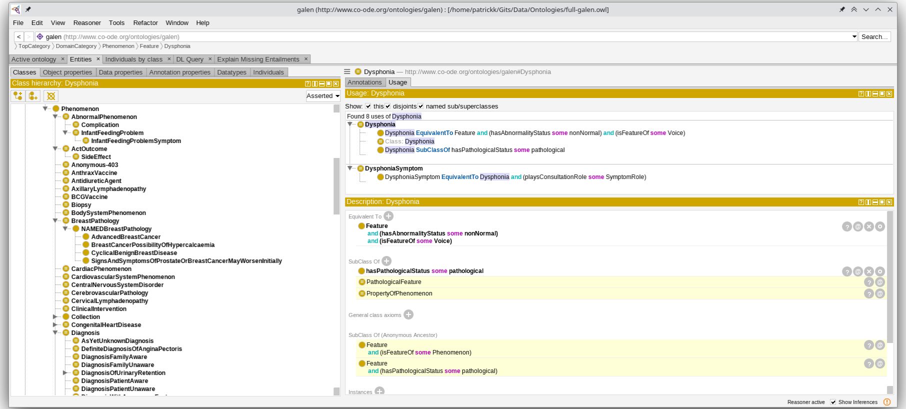
2 results in 1082 ms

Mayors that are any kind of domesticated animal

image	speciesLabel	mayorLabel	placeLabel
	dog	Bosco the dog	Sunol
	dog	Duke the Dog	Cormorant Township

More on knowledge graphs in Ilaria Tiddy's lecture "KR on the Web", P4

KR Formalisms You Might Know: OWL Ontologies



“Digital dictionaries”, covered in Part 1 of this lecture

Zoom in on Propositional Logic

Propositional logic is an example of a simple KR

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- Propositional variables abstract atoms of information
  - a: Tom comes to the VU.

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  - d: It is sunny.

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- Operators allow to build complex formulas
  1. $d \rightarrow \neg e$
  2. $a \leftrightarrow (b \vee c)$
  3. $(e \vee f) \rightarrow \neg b$
  4. $(d \wedge \neg f) \rightarrow b$
  5. $g \rightarrow \neg c$
  6. $e \wedge \neg g$

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  5. $g \to \neg c$
  6. $e \wedge \neg g$
- A clear semantics defines what these formulas mean
- Automated reasoning can be used to infer implicit information
  - *Does Tom come to the VU?*

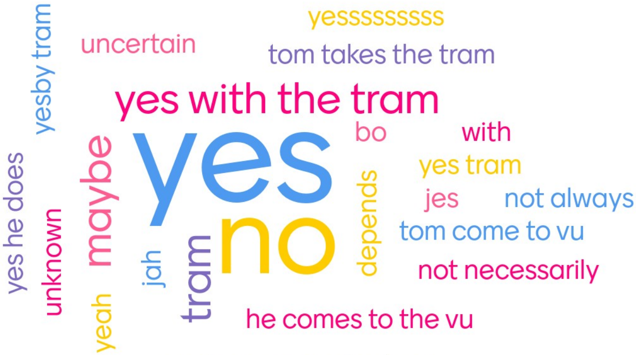
Example in Natural Language

- When it is sunny, it is not raining.
- Tom comes to the VU if and only if he takes the bike or the tram.
- If it is raining or the bike is broken, Tom does not take the bike.
- If it is sunny and the bike is not broken, Tom takes the bike.
- If the tram company is on strike, then Tom takes does not take the tram.
- It rains and the tram company is not on strike.

Does Tom come to the VU?

Does Tom come to the VU?

94 responses



3

91

Example in Natural Language

Correct answer:

- We don't know!
- But if he comes, he takes the tram.

Propositional Logic

Very simple - is this relevant at all?

- SAT: deciding satisfiability of propositional formulas
  - Our example: Knowledge + Toms comes/does not come to the VU.
- A lot of problems (not only from symbolic AI) can be reduced to SAT
- But: for modern symbolic AI-systems, direct applications of SAT are not so common.

What is a Knowledge Representation?

What is a Knowledge Representation?

after [Davis, Shrobe and Szolovits, 1993]:

1. Surrogate
2. Expression of ontological commitment
3. Theory of intelligent reasoning
4. Medium of efficient computation
5. Medium of human expression

1. KR as Surrogate

Knowledge representations are surrogates:

- represent external objects
- abstractions
- necessarily simplified
- in certain aspects necessarily wrong

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Propositional logic:

- Atomic propositions — no inner structure
- Everything is true or false

2. KR as Expression of Ontological Commitment

Knowledge representations express an ontological commitment

- Focus on some part of the world we are interested in
- Where *do* we want to be precise?
- What do we see, and how do we see it?

3. KR as Theory of Intelligent Reasoning

Knowledge representations provide a theory of intelligent reasoning

- How to deduce *implicit information*
- What can be deduced? What should be deduced?

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Databases satisfy Aspects 1 and 2 of KRs, but not necessarily Aspect 3: beyond querying, there is not much intelligence.

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- What can be deduced? What should be deduced?

Propositional logic:

- Clearly defined semantics based on truth tables

p	q	$\neg p$	$p \vee q$	$p \wedge q$
false	false	true	false	false
false	true	true	true	false
true	false	false	true	false
true	true	false	true	true

3. KR as Theory of Intelligent Reasoning

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Propositional logic:

- Clearly defined semantics based on truth tables
- Typical reasoning problems:
  - satisfiability — is there a satisfying truth assignment?
  - implication — what follows from my knowledge?

p	q	$\neg p$	$p \vee q$	$p \wedge q$
false	**false**	**true**	**false**	**false**
false	**true**	**true**	**true**	**false**
true	**false**	**false**	**true**	**false**
true	**true**	**false**	**true**	**true**

3. KR as Theory of Intelligent Reasoning

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Propositional logic:

- Clearly defined semantics based on truth tables
- Typical reasoning problems:
  - satisfiability — is there a satisfying truth assignment?
  - implication — what follows from my knowledge?
- Less typical, but relevant reasoning problems:
  - Find a minimal unsatisifable subset
    - explanation, diagnosis
  - Find a minimal satisfying assignment
    - minimize true propositions
    - useful for optimization

p	q	$\neg p$	$p \vee q$	$p \wedge q$
false	false	true	false	false
false	true	true	true	false
true	false	false	true	false
true	true	false	true	true

4. KR as Medium for Efficient Computation

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  - However: highly optimized SAT solvers!

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First-order logic is more expressive, but only semi-decidable

- There cannot be an algorithm that can answer all queries

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In Part I, we will learn about description logics, which are decidable fragments of first-order logic, some of which have even better complexity that propositional logic.

5. KR as Medium of Human Expression

Finally, knowledge representations are a medium of human expression

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- OWL Manchester Syntax:
  `takes some (Course and (location value VU)) SubClassOf VUStudent`

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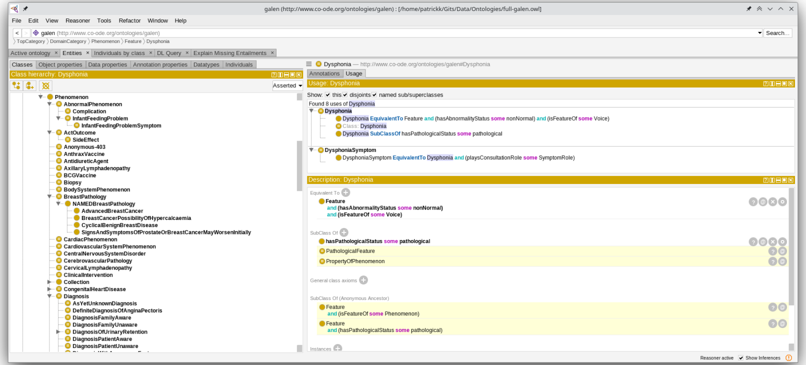

Knowledge Engineering

Knowledge Engineering is about putting KR into practice:

1. Determining the requirements of the KR system
2. Selecting the right KR formalism for the application
3. Eliciting and formalizing the domain knowledge
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Towards Point 2, we will learn about different KR formalisms in this lecture.

Classical Logics

Logics are the classical KR formalism:

$$(\mathrm{Rain} \vee \mathrm{Storm} \vee \neg\mathrm{Sun}) \rightarrow \mathrm{BadWeather}$$

$$\forall x : (\mathit{Student}(x) \rightarrow \exists y : (\mathit{studiesAt}(x, y) \wedge \mathit{University}(y)))$$

Tomorrow, we will refresh our knowledge on it.

The Rest of the Lecture

From here, we will go in the following directions:

- Add expressivity without the mess of first-order logic
  - Description Logics
  - Decidable, efficient for desired reasoning problems
  - Optimized representation language
  - *"Every VU student studies at the VU."*

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  - Non-monotonic reasoning and argumentation
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- Drop certainty assumption
  - Probabilistic Graphical Models
  - Probabilistic information
  - *"It is going to rain tomorrow."*