

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



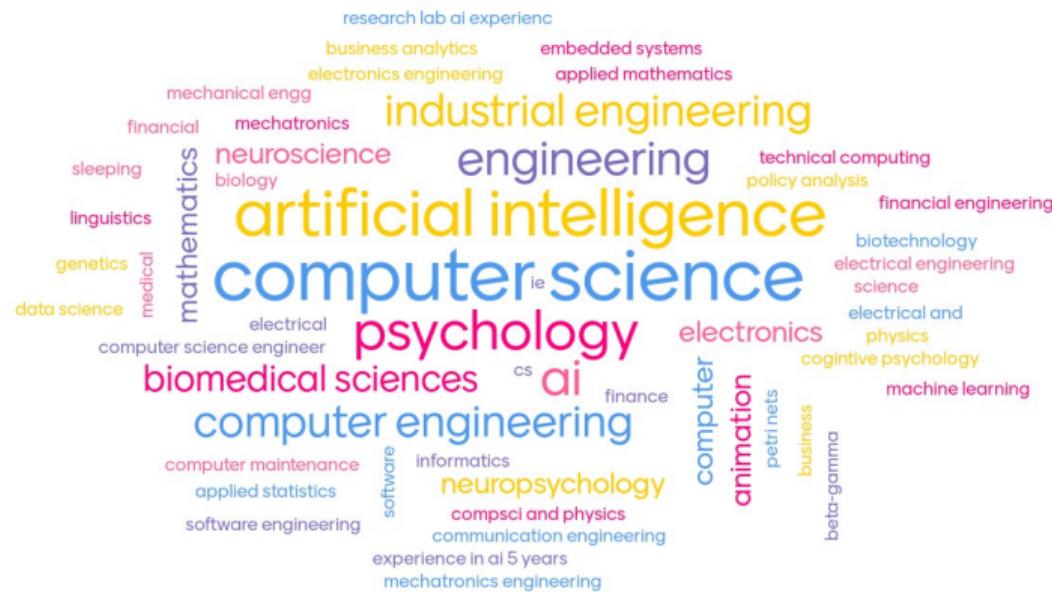
Andrzej Szczepura



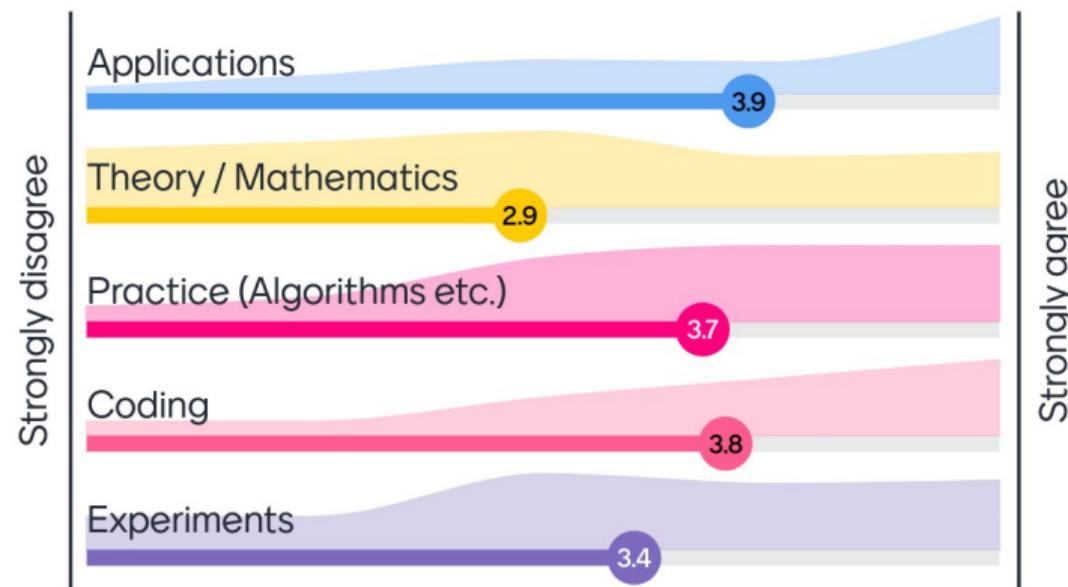
And who are you?

What did you do your Bachelor in?

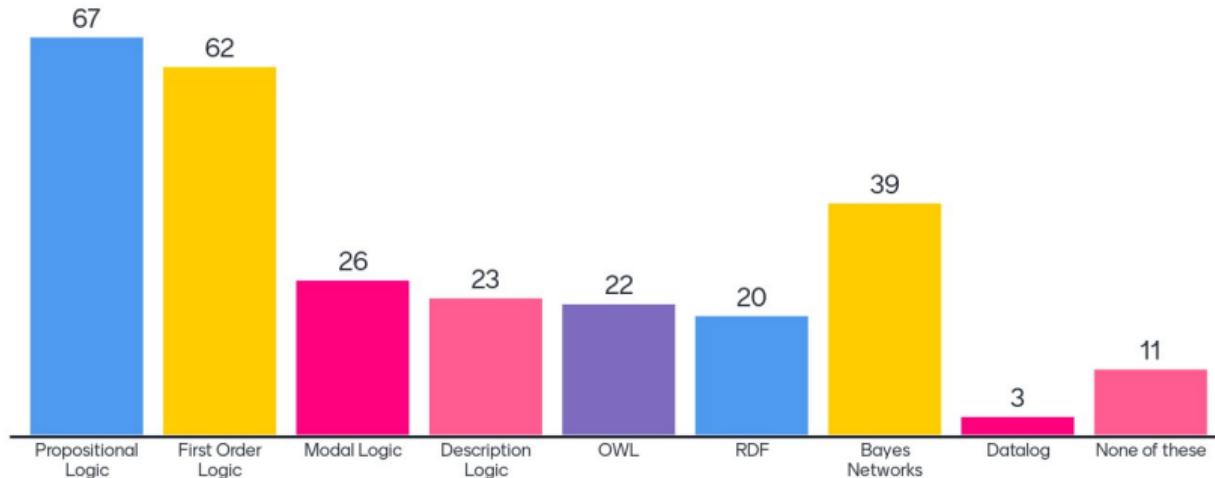
114 responses



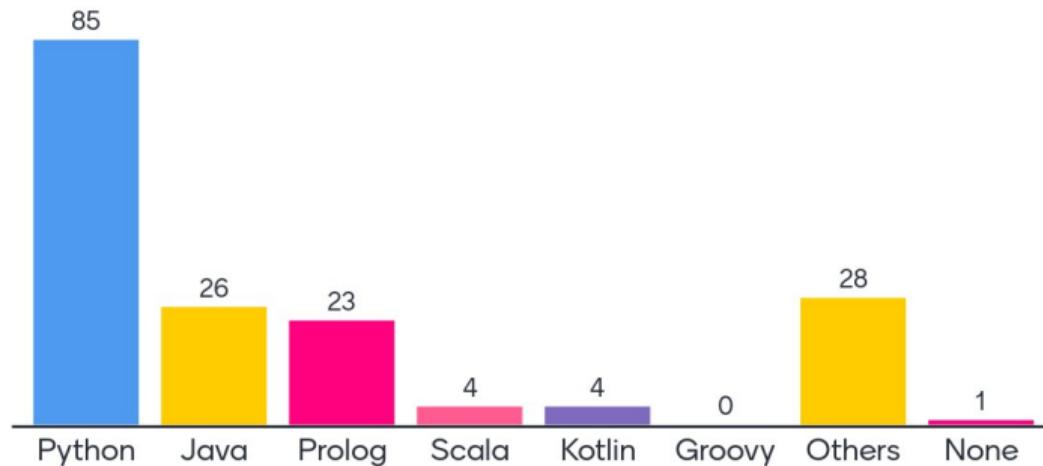
What do you enjoy?



Which of these formalisms do you already know?



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 \implies 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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 - ▶ Additional Q&As if needed
- ▶ “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

Two Types of Intelligence

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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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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

'A lifetime's worth of wisdom'
Steven D. Levitt, co-author of *Freakonomics*

The International Bestseller

Thinking, Fast and Slow

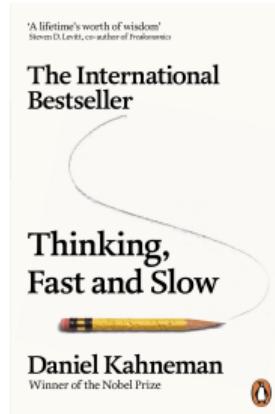


Daniel Kahneman

Winner of the Nobel Prize



Two Types of Intelligence



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:

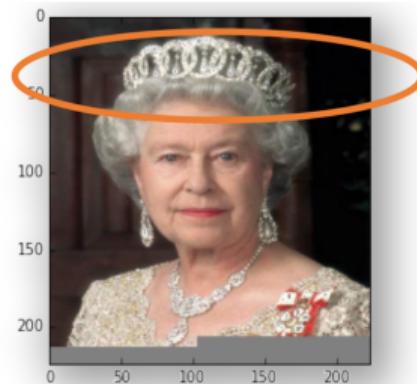
- ▶ Data-Centric / Statistical AI:
 - ▶ Pattern Recognition (images, sound, shapes)
 - ▶ Motor skills (robotics)
 - ▶ Text/image generation
- ▶ Symbolic AI:
 - ▶ Planning (autonomous space missions)
 - ▶ Reasoning (diagnosis, design, decision support)
 - ▶ Search engines

Thinking Fast without Thinking Slow

Class: 793

Label: n04209133 (shower cap)

Certainty: 99.7%



Other Limitations of Data-Centric Methods

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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 will also present some of the applications and tools he develops, such as graphical frontends for ontology editors and plugins for reasoning systems. His lecture is aimed at students and researchers who are interested in symbolic AI, semantic technologies, ontologies, and logic.

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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
- ▶ 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: $Student \sqsubseteq \exists studiesAt . University$

KR Formalisms You Might Know: Prolog and Friends

```
connected(living_room, corridor).      reachable(X,Y) :- connected(X,Y).
connected.bedroom, corridor).          reachable(X,Y) :- connected(Y,X).
connected(entrance, corridor).         reachable(X,Y) :- reachable(X,Z),
connected(kitchen, living_room).       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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Prolog:

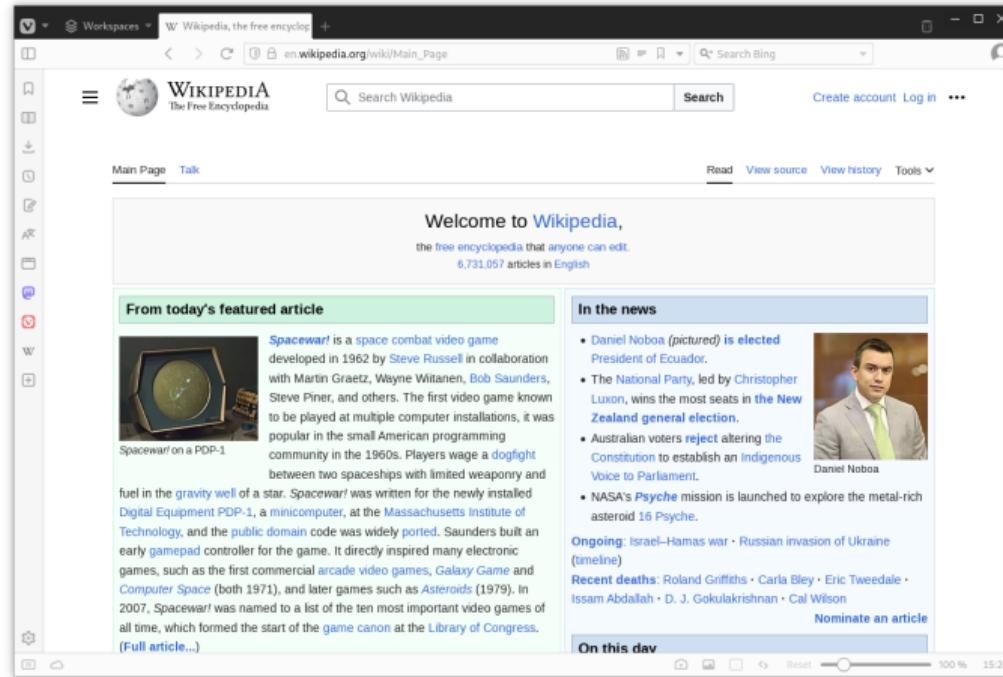
- ▶ A declarative, logic-based programming language
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Other relevant rule-based formalisms:

- ▶ 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**?

The screenshot shows the Wikidata main page (www.wikidata.org/wiki/Wikidata:Main_Page) with a prominent knowledge graph visualization in the center. The graph consists of several nodes connected by lines of different colors (red, green, blue) representing relationships. Nodes include 'open', 'multilingual', 'collaborative', 'linked', 'structured', and 'structured'. Below the graph, the text 'Welcome to Wikidata' and 'the free knowledge base with 107,336,651 data items that anyone can edit.' is displayed. At the bottom, there are two sections: 'Welcome!' and 'Learn about data', each with descriptive text and images.

Main page Discussion Main Page Read View source View history Search Wikidata

Welcome to Wikidata
the free knowledge base with 107,336,651 data items that anyone can edit.
Introduction • Project Chat • Community Portal • Help
Want to help translate? Translate the missing messages.

Welcome!
Wikidata is a free and open knowledge base that can be read and edited by both humans and machines.
Wikidata acts as central storage for the **structured data** of its Wikimedia sister projects including Wikipedia, Wikivoyage, Wiktionary, Wikisource, and others.
Wikidata also provides support to many other sites and services beyond just Wikimedia projects! The content of Wikidata is [available under a free license](#), [exported using standard formats](#), and can be interlinked to other open data sets on the linked data web.

Learn about data
New to the wonderful world of data? [Develop and improve your data literacy through content](#) designed to get you up to speed and feeling comfortable with the fundamentals in no time.

KR Formalisms You Might Know: Knowledge Graphs / Wikidata

Query: Which mayors are domesticated animals?

The screenshot shows the Wikidata Query Service interface. The query code is:

```
1 #Mayors that are any kind of domesticated animal
2 #title: Mayors that are any kind of domesticated animal
3 SELECT ?image ?speciesLabel ?mayorLabel ?placeLabel WHERE {
4   ?species wdt:P279* wd:Q622852 .
5   ?mayor wdt:P31 ?species .
6
7   ?mayor p:P39 ?node .
8   ?node ps:P39 wd:Q30185 .
9   ?node pq:P642 ?place .
10 OPTIONAL {?mayor wdt:P18 ?image}
11 SERVICE wikibase:label { bd:serviceParam wikibase:language "[AUTO_LANGUAGE],en" . }
12 }
```

The results table is titled "Mayors that are any kind of domesticated animal". It contains two rows:

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

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```

The results table shows 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

The screenshot shows the Galen ontology editor interface. The top menu bar includes File, Edit, View, Reasoner, Tools, Refactor, Window, and Help. The address bar indicates the URL is <http://www.co-ode.org/ontologies/galen>. The main window displays the 'Active ontology' section with tabs for Entities, Individuals by class, DL Query, and Explain Missing Entailments. The 'Class hierarchy: Dysphonia' tab is selected, showing a tree view of classes under the 'Phenomenon' category. The right side of the interface shows the asserted knowledge base, specifically for the 'Dysphonia' class, with asserted axioms such as 'Dysphonia EquivalentTo Feature and (hasAbnormalityStatus some nonNormal) and (isFeatureOf some Voice)' and 'Dysphonia SubClassOf hasPathologicalStatus some pathological'. Below this, there are sections for 'Description: Dysphonia' and 'General class axioms'. A status bar at the bottom right shows 'Reasoner active' and 'Show Inferences'.

“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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 - ▶ a : Tom comes to the VU.

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- ▶ c : Tom takes the tram.

Zoom in on Propositional Logic

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► Propositional variables abstract atoms of information

- *a*: Tom comes to the VU.
- *b*: Tom takes the bike.
- *c*: Tom takes the tram.
- *d*: It is sunny.

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- ▶ *e*: It is raining.

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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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- ▶ A clear semantics defines what these formulas mean
- ▶ Automated reasoning can be used to infer implicit information
 - ▶ Does Tom come to the VU?

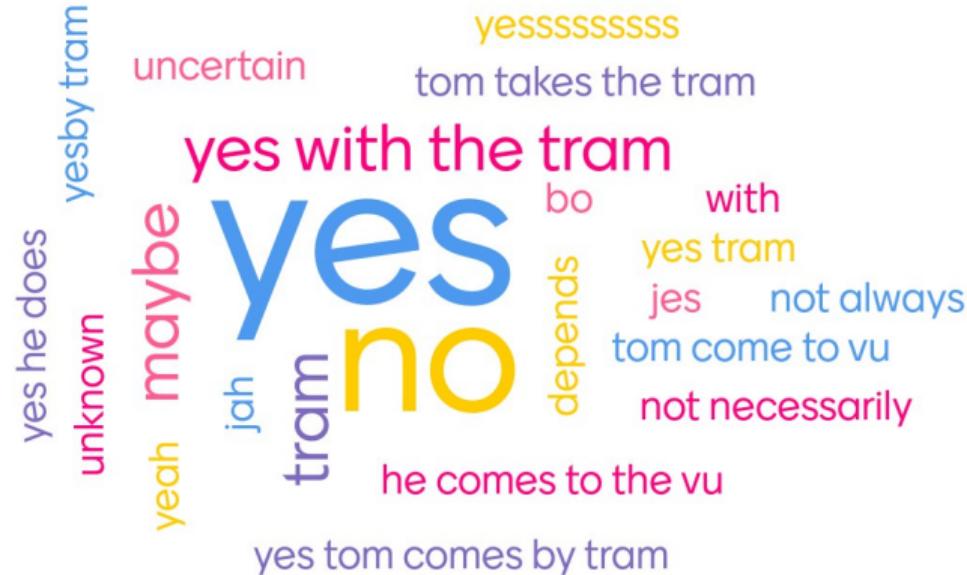
Example in Natural Language

- ▶ 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



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**:

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- ▶ abstractions
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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?

3. KR as Theory of Intelligent Reasoning

Knowledge representations provide a theory of intelligent reasoning

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- ▶ What can be deduced? What should be deduced?

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

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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
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- ▶ Less typical, but relevant reasoning problems:
 - ▶ Find a **minimal unsatisfiable subset**
 - ▶ explanation, diagnosis
 - ▶ Find a **minimal satisfying assignment**
 - ▶ minimize true propositions
 - ▶ useful for optimization

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 - ▶ Whether there is a polynomial-time algorithm relates to one of the big open problems in computer science
 - ▶ 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** than propositional logic.

5. KR as Medium of Human Expression

Finally, knowledge representations are a medium of **human expression**

- ▶ Humans produce, consume and work with representations
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Different representations:

- ▶ First order logic:

$$\forall x : ((\exists y : (\text{takes}(x, y) \wedge \text{Course}(y) \wedge \text{location}(y, \text{VU})) \rightarrow \text{VUStudent}(x))$$

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

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The screenshot shows the Galen ontology editor interface. The top menu bar includes File, Edit, Reasoner, Tools, Refactor, Window, and Help. The title bar indicates the current file is 'galen' at 'http://www.co-ode.org/ontologies/galen'. The left sidebar lists various ontological categories such as Phenomenon, AbnormalPhenomenon, Complication, InfarctFeedingProblem, InfarctFeedingProblemSymptom, SideEffect, Anonymouse-403, AnthraxVaccine, AnthraxVaccineAgent, AnthraxVaccinePathology, BCGVaccine, Biopsy, BodySystemPhenomenon, BreastsAndNipples, NAME000eastPathology, AdvancedBreastCancer, BreastCancerPossibilityOrHypercalcemia, CytologicallyProvenBreastDisease, SignificantlyImprovedOrPostponeOrBreastCancerMayWorsenInitially, CardiacPhenomenon, CardiovascularSystemPhenomenon, CentralNervousSystemBorder, CentralNervousSystemInflammation, CervicalLymphadenopathy, ClinicalIntervention, Collection, CoronaryHeartDisease, Diagnosis, AsYetUnknownDiagnosis, DefiniteDiagnosisOrMalignantPectoris, DiagnosisInitiallyKnown, DiagnosisPatientAware, DiagnosisOfVeryHighPriority, DiagnosisPatientUnaware, and DiagnosisUnaware.

The main workspace displays the 'Dysphonia' class definition. The 'Usage' tab is selected, showing the following asserted facts:

- Dysphonia — http://www.co-ode.org/ontologies/galen#Dysphonia
- Annotations, Usage
- Show: ✓ this ✓ dysphonia ✓ named sub/superclasses
- Find: Instances of Dysphonia
 - Dysphonia EquivalentTo Feature and (hasAbnormalityStatus some nonNormal) and (sFeatureOf some Voice)
 - Dysphonia SubClassOf hasPathologicalStatus some pathological
- DysphoniaSymptom
 - DysphoniaSymptom EquivalentTo Dysphonia and (playsConsultationRole some SymptomRole)

The 'Description' tab for the 'Dysphonia' class contains the following asserted facts:

- Equivalent To
 - Feature and (hasAbnormalityStatus some nonNormal) and (sFeatureOf some Voice)
- SubClass Of
 - hasPathologicalStatus some pathological
 - PathologicalFeature
 - PropertyAmenesison

The 'General class axioms' section contains the following asserted facts:

- SubClassOf (Dysphonia, Anomaly)
 - Feature and (sFeatureOf some Phenomenon)
 - Feature and (hasPathologicalStatus some pathological)

At the bottom right, there are buttons for 'Reasoner active' and 'Show Inferences'.

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:

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

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

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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- ▶ Drop **certainty** assumption
 - ▶ Probabilistic Graphical Models
 - ▶ Probabilistic information
 - ▶ "*It is going to rain tomorrow.*"