

Knowledge Representation & Reasoning

EECS/MSAI 371

Irina Rabkina and Willie Wilson

Winter 2019

Introduction

Today

- Who we are
- Why we're here
- Why KR&R
- What's in store for the quarter
 - Including syllabus, tools, books, etc.

Who we are

- Instructors:
 - Irina Rabkina (irabkina@u.northwestern.edu)
 - Willie Wilson (jrw@northwestern.edu)
 - For best results, email us **both**
- Canvas
 - Homework assignments, readings, lecture notes
- Class Piazza page
 - piazza.com/northwestern/winter2019/eecs371

Why we're here

Why KR&R

- Today's Q/A systems are strongly limited by lack of understanding

Q: How much folic acid should an expectant mother take daily?

A: 360 tons

Q: What is the diameter of the Earth?

A: 14 ft.

Q: How many US states have a lottery?

A: 3,312

Examples drawn from TREC9 systems, which use word-level information retrieval and statistical information and heuristics to guess answers to questions based on a corpus of documents

On the other hand...

The image shows a Jeopardy! game board with three contestants: Ken, Watson, and Brad. The scores are \$2,000 for Ken, \$13,400 for Watson, and \$5,000 for Brad. The current question is about Albinism, Albino, and Porphyria. The board also displays the word 'THINK' and various international words for 'think'.

Contestant	Score
Ken	\$2,000
Watson	\$13,400
Brad	\$5,000

Category	Percentage
Albinism	98%
Albino	10%
Porphyria	7%


CBC

Classic Web Search: Low Precision



What is the history of unification?

About 5,320,000 results (0.43 seconds)

 **Everything**

 Images

 Videos

► [Bismarck and Unification: German History](#) ☆ 🔍

Here is the complete information about Bismarck and **unification** of Germany and also about German **history** - starting from the early times to medieval **history** ...

www.germanculture.com.ua/.../history/bl_bismarck_unification.htm - Cached - Similar



history of unification



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About 23,800,000 results (0.74 seconds)

It was a critical opportunity for the **unification** movement. In April 1860, separate insurrections began in Messina and Palermo in Sicily, both of which had demonstrated a **history** of opposing Neapolitan rule. ... On 14 May Garibaldi proclaimed himself dictator of Sicily, in the name of Victor Emmanuel.



[Italian unification - Wikipedia](#)

https://en.wikipedia.org/wiki/Italian_unification

About this result

Feedback

People also ask

What does unification mean in history?

What led to German unification?

How did Italy become unified?

Who united Italy?

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[Italian unification - Wikipedia](#)

https://en.wikipedia.org/wiki/Italian_unification ▼

It was a critical opportunity for the unification movement. In April 1860, separate insurrections began in Messina and Palermo in Sicily, both of which had demonstrated a **history** of opposing Neapolitan rule. ... On 14 May Garibaldi proclaimed himself dictator of Sicily, in the name of Victor Emmanuel.

[Five Days of Milan](#) · [Capture of Rome](#) · [Third Italian War of ...](#) · [Second Italian War](#)

Italian unification



Italian unification, or the Risorgimento, was the political and social movement that consolidated different states of the Italian peninsula into the single state of the Kingdom of Italy in the 19th century. [Wikipedia](#)

Period: 1815 – 1871

Location: [Italy](#)

Participants: [Kingdom of Sardinia](#), [Republic of San Marco](#), [MORE](#)

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[Franco-Pr... War](#)




[Brigandage in Southern Italy after...](#)

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What is the history of unification in logic?

About 796,000 results (0.23 seconds)

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► [Unification Theology](#) ☆ 🔍

As Dr. Lee has said, "**Unification** Thought begins with God in its **logical** ... Epistemology, Axiology, Ethics, the Theory of **History**, **Logic**, Pedagogy, ...

www.reverendsunmyungmoon.org/teach_read_unification_theology.html - [Cached](#) - [Similar](#)

[Unification types in logic \(Open Library\)](#) ☆ 🔍

Unification in logic is concerned with finding a substitution that transforms a formula into a theorem ... **History** Created November 16, 2008 · 5 revisions ...

openlibrary.org/books/OL22555458M/Unification_types_in_logic - [Cached](#)



history of unification in logic



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About 3,740,000 results (0.64 seconds)

Unification (computer science) - Wikipedia

[https://en.wikipedia.org/wiki/Unification_\(computer_science\)](https://en.wikipedia.org/wiki/Unification_(computer_science)) ▼

Application: **unification in logic programming**. The concept of **unification** is one of the main ideas behind **logic programming**, best known through the language Prolog. ... In many modern Prolog dialects and in first-order **logic**, a variable cannot be unified with a term that contains it; this is the so-called occurs check.

People also ask

What does unification mean in history?



What is unification in logic programming?



What is unification in Prolog?



How was Germany unified?




Feedback



What is the history of the unification algorithm?

About 219,000 results (0.29 seconds)

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[History of Algorithms and Algorithmics](#) ☆ 🔍

History of Algorithms and Algorithmics. The origin of the term comes from the ancients. The concept becomes more precise with the use of variables in ...

www.scriptol.com/programming/algorithm-history.php - Cached - Similar

[Algorithm - Wikipedia, the free encyclopedia](#) ☆ 🔍

6 Legal issues; 7 Etymology of the word **Algorithm**; 8 **History**: Development of the notion of "algorithm". 8.1 Discrete and distinguishable symbols ...

en.wikipedia.org/wiki/Algorithm - Cached - Similar

[History of Algorithms](#) ☆ 🔍

Beside the **history** of the name we will point out the methodological aspects of **algorithmic** work and the different programming techniques. ...

cs-exhibitions.uni-klu.ac.at/index.php?id=193 - Cached - Similar

[CiteULike: A Categorical Unification Algorithm](#) ☆ 🔍

by DE Rydeheard - Cited by 51 - Related articles

Tags. A Categorical **Unification Algorithm**. by: David E. Rydeheard, Rod M. Burstall ... X Posting **History**. X Export records. Always show this tags box ...

www.citeulike.org/user/spl/article/6980955 - Cached

[Principles of constraint programming - Google Books Result](#)

Krzysztof R. Apt - 2003 - Computers - 407 pages

In Robinson [1992] an interesting account of the **history of the unification algorithms** is provided. The Gauss-Jordan and the Gaussian Elimination algorithms ...

books.google.com/books?isbn=0521825830...

2014 Version



What is the history of the unification algorithm?

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About 7,770,000 results (0.49 seconds)

[\[PDF\] Unification theory - Computer Science](#)

www.cs.bu.edu/~snyder/publications/UnifChapter.pdf ▼

by F Baader - Cited by 601 - Related articles

analyzes **unification algorithms** that can be used in different contexts. ... then make some **historical** remarks on where unification was originally introduced,.

[Unification \(computer science\) - Wikipedia, the free encyclopedia](#)

[en.wikipedia.org/wiki/Unification_\(computer_science\)](http://en.wikipedia.org/wiki/Unification_(computer_science)) ▼

Jump to Particular **background** knowledge sets E - It is said that unification is decidable for a theory, if a **unification algorithm** has been devised for it that ...

[Anti-unification \(computer science\) - Wikipedia, the free encyclopedia](#)

[en.wikipedia.org/wiki/Anti-unification_\(computer_science\)](http://en.wikipedia.org/wiki/Anti-unification_(computer_science)) ▼

2016: Better still



What is the history of the unification algorithm?



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14,200,000 RESULTS Any time ▾

Unification (computer science) - Wikipedia, the free ...

https://en.wikipedia.org/wiki/Unification_algorithm ▾

This paper also lists preceding attempts to find an efficient syntactical **unification algorithm**, [11] [12] [13] [14] ...

Common formal definitions · Syntactic ... · Order-sorted **unification**

[PDF] **An Efficient Unification Algorithm - nsl.com**

www.nsl.com/misc/papers/martelli-montanari.pdf

An Efficient **Unification Algorithm** ALBERTO MARTELLI Consiglio Nazionale delle Ricerche and UGO ... **UNIFICATION AS THE SOLUTION OF A SET OF EQUATIONS:**

Unification -- from Wolfram MathWorld

mathworld.wolfram.com > ... > Logic > General Logic ▾

History and Terminology. Number Theory. ... The **unification algorithm** serves as a tool for the resolution principle. It is also a basis for term rewriting systems.

CiteSeerX — A Parallel Unification Algorithm

citeseerx.ist.psu.edu/viewdoc/summary?doi=10.1.1.56.1887 ▾

... Pradeep Teregowda): We define an abstract **unification algorithm** which can be ... **A Parallel Unification Algorithm** ... Version **History**; BibTeX

Anti-unification (computer science) - Wikipedia, the free ...

[https://en.wikipedia.org/wiki/Anti-unification_\(computer_science\)](https://en.wikipedia.org/wiki/Anti-unification_(computer_science)) ▾

Anti-unification is the process of constructing a generalization ... Fischer, Cornelia (May 1994), PAnTUDE – An **Anti-Unification Algorithm** for Expressing ...

Prerequisites · First-order ... · First-order anti ... · Higher-order anti ...



What is the history of the unification algorithm?

All Videos News Shopping Images More ▾ Search tools

About 510,000 results (0.61 seconds)

Unification (computer science) - Wikipedia, the free ...

[https://en.wikipedia.org/wiki/Unification_\(computer_science\)](https://en.wikipedia.org/wiki/Unification_(computer_science)) ▾ Wikipedia ▾

Jump to **A unification algorithm** - Robinson's 1965 **unification algorithm**. [show] ... The following faster algorithm originated from Martelli, Montanari (1982).

[PDF] **Unification theory - Computer Science**

www.cs.bu.edu/~snyder/publications/UnifChapter.pdf ▾ Boston University ▾

by F Baader - Cited by 718 - Related articles

analyzes **unification algorithms** that can be used in different contexts. ... then make some **historical** remarks on where unification was originally introduced,.

Unification -- from Wolfram MathWorld

mathworld.wolfram.com > ... > Logic > General Logic ▾ MathWorld ▾

A **unification algorithm** takes a set of expressions as its input. ... Web Resource, created by Eric W. Weisstein. <http://mathworld.wolfram.com/Unification.html> ...

[PDF] **An Efficient Unification Algorithm - MOSCOVA Project**

moscova.inria.fr/~levy/courses/X/IF/03/pi/.../martelli-montanari.pdf ▾

by A MARTELLI - 1982 - Cited by 1118 - Related articles

Resolution, however, is not the only application of the **unification algorithm**. With the above ordering, N_3 becomes a well-founded set, that is, a set where no.


Constraints in Computational Logics. Theory and ...


<https://books.google.com/books?isbn=3540454063>

Hubert Comon, Claude Marche, Ralf Treinen - 2003 - Computers

Such an algorithm either actually computes solutions of the E-unification ... and Its **History** Basically, the problem of combining E-unification algorithms can be ...

2019: Starting to get real answers




what is the history of the unification algorithm



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About 1,050,000 results (0.65 seconds)


In logic and computer science, **unification** is an algorithmic process of solving equations between symbolic expressions. ... A **unification algorithm** should compute for a given problem a complete, and minimal substitution set, that is, a set covering all its solutions, and containing no redundant members.





[Unification \(computer science\) - Wikipedia](https://en.wikipedia.org/wiki/Unification_(computer_science))
[https://en.wikipedia.org/wiki/Unification_\(computer_science\)](https://en.wikipedia.org/wiki/Unification_(computer_science))


 About this result  Feedback

People also ask

What does unification mean in history?



What is meant by unification of forces?

What was the unification of Germany?

What is unification in ancient Egypt?

Feedback


The big push: Answers, not Search





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About 33,700,000 results (0.81 seconds)


From Chicago, IL
To San Francisco, CA








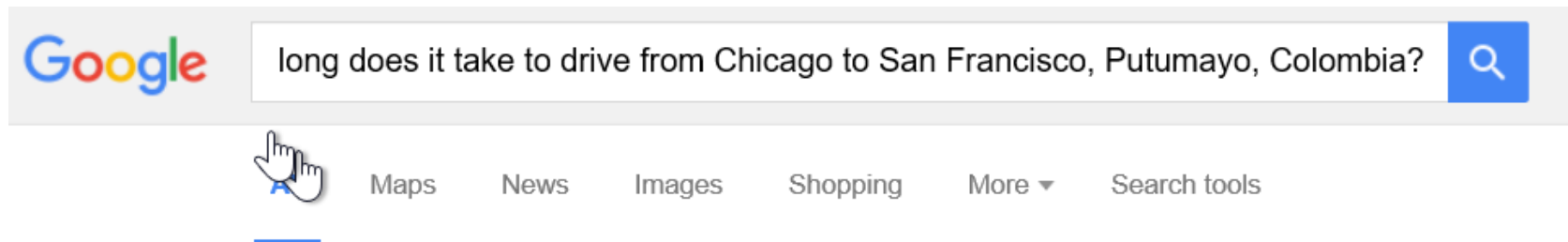




31 h (2,130.8 mi) via I-80 W


Directions

Harder than it looks



About 47,300 results (0.66 seconds)

'Jesus' Appears After Rockslide In Colombia - Huffington Post

www.huffingtonpost.com/.../jesus-rockslide-colombi... ▼ The Huffington Post ▼
Mar 25, 2015 - After a landslide last week in **San Francisco** in Putamayo, **Colombia** an ... rural de **San Francisco Putumayo**, dejo una imagen que se asemeja ...

Colombia flights - Lonely Planet

www.lonelyplanet.com/colombia/transport/getting.../flights ▼ Lonely Planet ▼
Cheapest flight to **Colombia** - search and compare **Colombia** flights and expert trip advice. ... Charter airlines also fly package tourists into Cartagena and **San Andrés**. ... Delta, www.delta.com, Bogotá/Atlanta, **Chicago** & New York/New Jersey (US) ... respectively), cross the land border and **take** another domestic flight to your ...
Missing: `francisco`

People Flock to See Jesus' Face on Hillside in Colombia ...

abcnews.go.com/International/people-flock-jesus-face...colombia/story?...
Mar 27, 2015 - ... **Chicago Chicago** · Philadelphia Philadelphia · **San Francisco** - Oakland - San Jose San ... People Flock to See Jesus' Face on Hillside in **Colombia** ... a hillside in the town of **San Francisco** in the Colombian province of **Putumayo**, according to ... Militia, Along With Bundy Family, **Take** Over Wildlife Refuge.

Andrew Moore

NAUGHTY DOG

THE LAST OF US



Non-player characters (NPCs)

- Hunters vs. Infected
 - Different stages of infection
- Different behaviors, sensory capabilities
 - Considerations: needs to not only work, but be intuitive for human player
 - One example: logical representations of sounds that (mostly) correspond to audio

Why KR&R, Part III

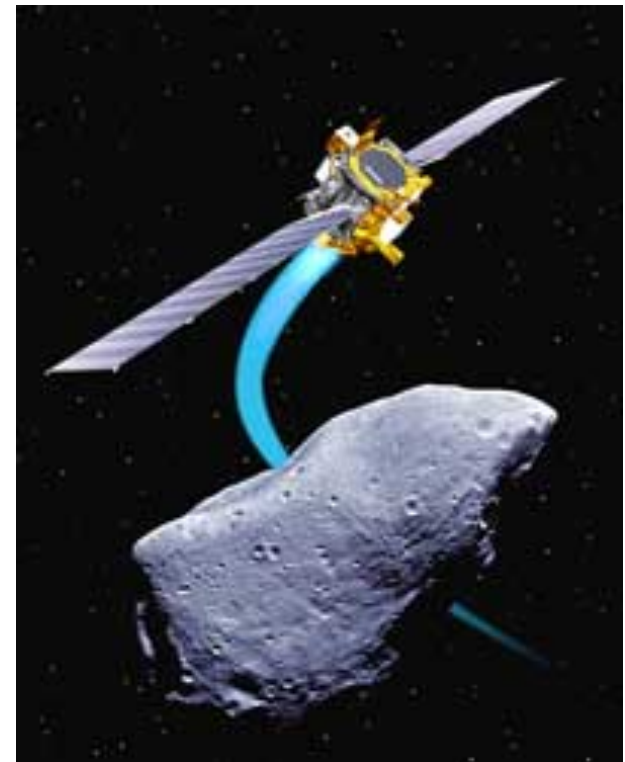
- Many real-world problems too complex for unaided human solution
 - Hardware/software verification, scheduling, optimization
 - Complex systems involve massive numbers of complex constraints
- Knowledge-rich systems routinely used in industry
 - Ascent Technologies: Schedules airport operations
 - Xerox: Automatic production of control software for copiers
 - Ford: Automatic failure modes and effects analysis
 - Logistics, robotic warehouses, data centers, ...

Why KR&R, Part IV

- Autonomous systems must understand the world around them



Stanford's robot Volkswagen Stanley, winning the DARPA Grand Challenge



NASA's Deep Space One, guided in part by Remote Agent, a model-based reasoning system

Why KR&R, Part V

- The Web was mostly a mass of text and images
- The Semantic Web is changing all of this
 - A web of data, that our machines understand
- Motivation for software assistants
 - Siri, Alexa, Cortana, Google Now, etc.
 - Goal: Conversational User Interfaces
 - Requires deeper understanding of people, contexts, etc.

As Government Shutdown Persists, Americans Feel the Bite



```
<meta data-rh="true" name="pubp_event_id" itemprop="identifier" content="pubp://event/9da37b528e2f4b46a34731694101e94c">
<meta data-rh="true" name="description" itemprop="description" content="Delayed mortgage applications, missed paychecks and stymied farmers are among the repercussions of a shutdown with no end in sight.">
<meta data-rh="true" name="image" itemprop="image" content="https://static01.nyt.com/images/2019/01/08/business/08dc-impact-1-print/08dc-impact-1-facebookJumbo.jpg">
<meta data-rh="true" name="byl" content="By Jim Tankersley, Matthew Goldstein and Glenn Thrush">
<meta data-rh="true" name="thumbnail" itemprop="thumbnailUrl" content="https://static01.nyt.com/images/2019/01/08/business/08dc-impact-1-print/08dc-impact-1-thumbStandard.jpg">
<meta data-rh="true" name="news_keywords" content="US Economy,Donald Trump,Closings,Federal Taxes,US Politics,Secret Service,IRS,Agriculture,Banking and Finance,Agriculture Department,Bureau of Alcohol, Tobacco, Firearms and Explosives,Commerce Department,Homeland Security,SEC,Civil service">
<meta data-rh="true" name="usageTerms" itemprop="usageTerms" content="http://www.nytimes.com/content/help/rights/sale/terms-of-sale.html">
<meta data-rh="true" name="pdate" content="20190107">
<meta data-rh="true" property="og:url" content="https://www.nytimes.com/2019/01/07/us/politics/government-shutdown-impact-effects.html">
<meta data-rh="true" property="og:type" content="article">
<meta data-rh="true" property="og:title" content="As Government Shutdown Persists, Americans Feel the Bite">
<meta data-rh="true" property="og:image" content="https://static01.nyt.com/images/2019/01/08/business/08dc-impact-1-print/08dc-impact-1-facebookJumbo.jpg">
<meta data-rh="true" property="og:description" content="Delayed mortgage applications, missed paychecks and stymied farmers are among the repercussions of a shutdown with no end in sight.">
<meta data-rh="true" property="twitter:url" content="https://www.nytimes.com/2019/01/07/us/politics/government-shutdown-impact-effects.html">
<meta data-rh="true" property="twitter:title" content="As Government Shutdown Persists, Americans Feel the Bite">
<meta data-rh="true" property="twitter:description" content="Delayed mortgage applications, missed paychecks and stymied farmers are among the repercussions of a shutdown with no end in sight.">
<meta data-rh="true" property="twitter:image" content="https://static01.nyt.com/images/2019/01/08/business/08dc-impact-1-print/08dc-impact-1-print-videoSixteenByNineJumbo1600-v2.jpg">
<meta data-rh="true" property="twitter:image:alt" content="Members of the Secret Service on Monday outside the White House. Virtually every
```

WASHINGTON — The impact of a partial government shutdown began to ripple across the economy as it stretched into Day 17, with mortgage applications delayed, public companies unable to get approval to raise capital and thousands of Secret Service agents expected to show up for work without pay.

Why KR&R, Part VI

- Crucial for cognitive science
 - i.e. understanding how people and other animals think
- Elements include:
 - Natural language understanding
 - Visual understanding
 - Reasoning, problem-solving, decision-making

What is Knowledge?

- Knowing how: riding a bicycle, typing
- Knowing emotionally: feelings towards another
- Knowing that: some state of affairs exists in a world
 - Cats like catnip.
 - Barack Obama was the 44th President of the U.S.
 - My name is Willie.

Representing Knowledge

- “Knowing that” requires *representation*
 - One thing standing for another
 - Names for entities
 - Relationships between entities



Holmes & Watson



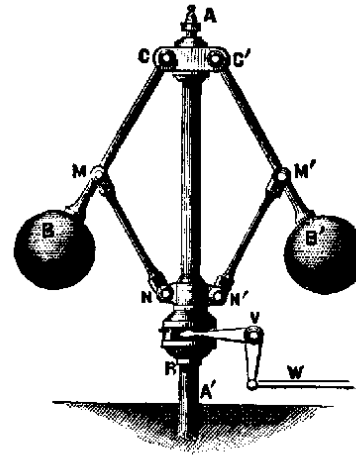
Love



Catnip

Kinds of Representation

- Numerical properties
- Words
 - “happiness”
- Sentences
 - “Happiness is a smoothly-running steam engine.”
- Symbolic expressions in a formal language



幸福

(implies

```
(and (isa ?BIRTH BirthEvent) (birthParent ?BIRTH ?MOTHER)
      (isa ?MOTHER Person) (spouse ?FATHER ?MOTHER))
```

```
(holdsIn (STIF ?BIRTH)
```

```
(feelsTowardsEvent ?FATHER ?BIRTH Happiness highAmountOf))))))
```

Potential Pitfalls

- “The thermostat knows that it is too cold”
- “The chess program wants to gain control of the center”
- *Intentional stance*: Attribute knowledge and intent to a system, whether or not it is actually inside it

Causally Central To Systems

- Payment not received on time: House gets foreclosed
 - So make sure the check is in the mail
- We believe this class meets every Tuesday and Thursday at 2pm
 - So we're here and ready to go
- Knowledge-based systems use explicit, symbolic representations to govern their behavior

What is Reasoning?

- Manipulation of representations to produce new information about the represented situation
- Analogy: Arithmetic
 - Inside computer: $1011+10 \rightarrow 1101$
 - Our interpretation: $11+2 \rightarrow 13$
- **(biologicalFather Mary John)
& (arg2Isa biologicalFather
MaleAnimal)
 \Rightarrow (isa John MaleAnimal)**

Why Reasoning?

- Good representations are not enough
 - Not everything that is true is explicitly encoded
- Normal programs: do action a if variable v has value n
 - Need to explicitly compute value of v
- Knowledge-based programs: do action a if the proposition p is satisfied
 - Satisfied = true in current context
 - Need to consider entire context

Why Reasoning? Cont'd

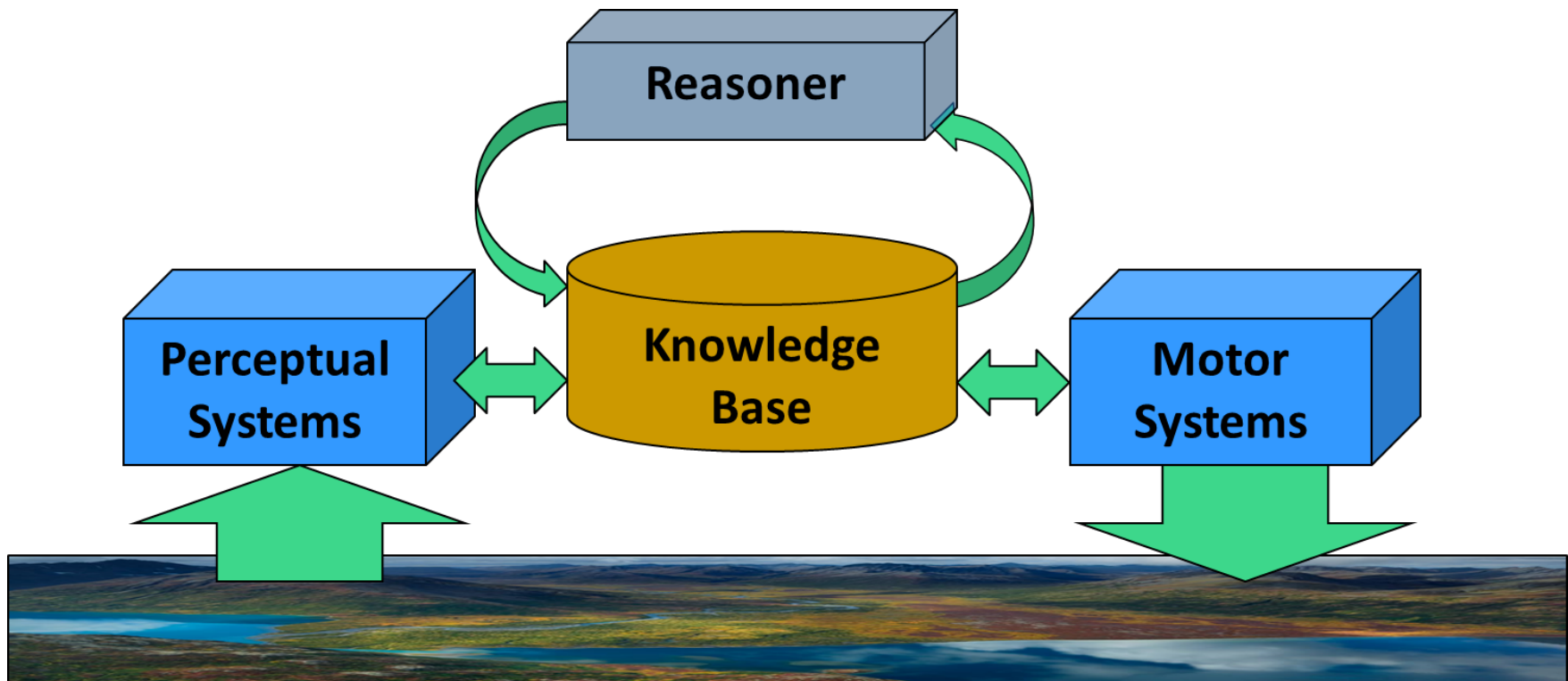
- Knowledge-based programs: do action a if the proposition p is satisfied
 - Satisfied = true in current context
 - Need to consider entire context
- Provides for more nuanced decisions
 - Example: Medicine m treats disease d . Patient p has been diagnosed with d .
 - Patient p is allergic to m .

Even Web Search Requires Reasoning Now

- Andrew Moore, Google, now Dean of the School of Computer Science at CMU

Knowledge-based Systems

- Contain symbolic representations of the world(s) they deal with
- Reason to figure out what to do



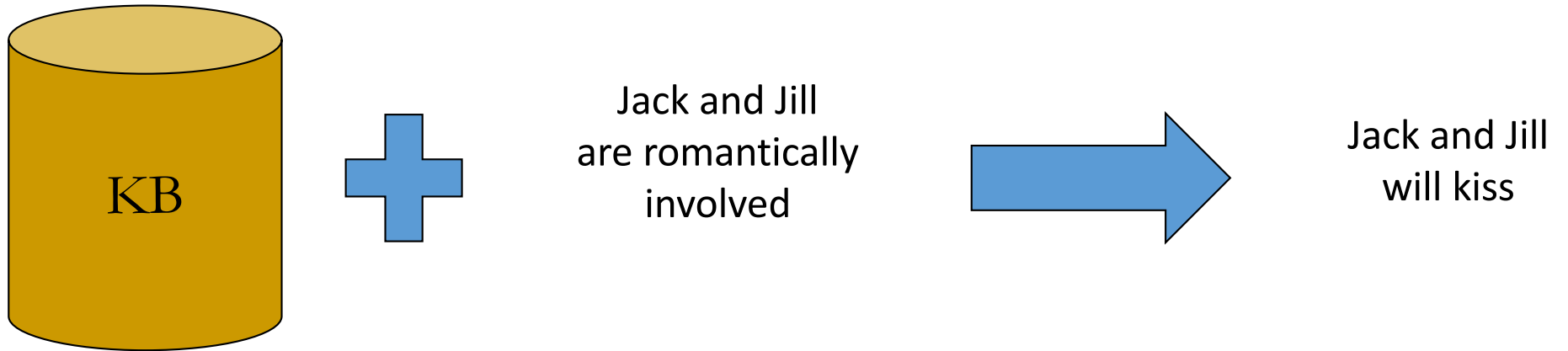
Reasoning vs. Procedures

- Reasoning operates over formal knowledge
- Procedures encode knowledge
 - Procedural knowledge = “knowing how to”
- Benefits of procedures:
 - Fast to execute
 - Requires few computational resources
- But:
 - Not good for explanation
 - Can be problematic when circumstances change

Advantages of Explicit KR

- More adaptable
 - Can add/remove facts, rather than reprogramming the entire system
 - Can add new concepts dynamically
- More flexible
 - Multiple uses: recognition, planning, instruction, etc.
- Provides explanation and rationale
 - Decisions based on explicit facts
- Supports learning

Model Theory



Properties of Formal Logics

- Soundness: If the formal system derives it and the assumptions are true, the conclusion is true.
- Completeness: If it is true in the world, it can be proven within the system.
- Efficiency: How much work does it take to derive something?
- Expressiveness: How much can one say in the system?

What You Will Get Out of This Course

- An understanding of formal logic
 - Precise framework for understanding representations
 - Characterizing expressiveness and tractability
- Familiarity with representations for core domains and experience in creating representations
 - Ontology for large-scale knowledge organization
 - Quantity, space, time, events, causality
 - Crafting representations for effective reasoning
- An understanding of semantic web ideas and technologies
- Hands-on experience!

How You Will Learn

- Textbooks
- Scholarly Articles
- Lectures
- Office hours
- Homeworks
- Tools
- Projects

Textbooks

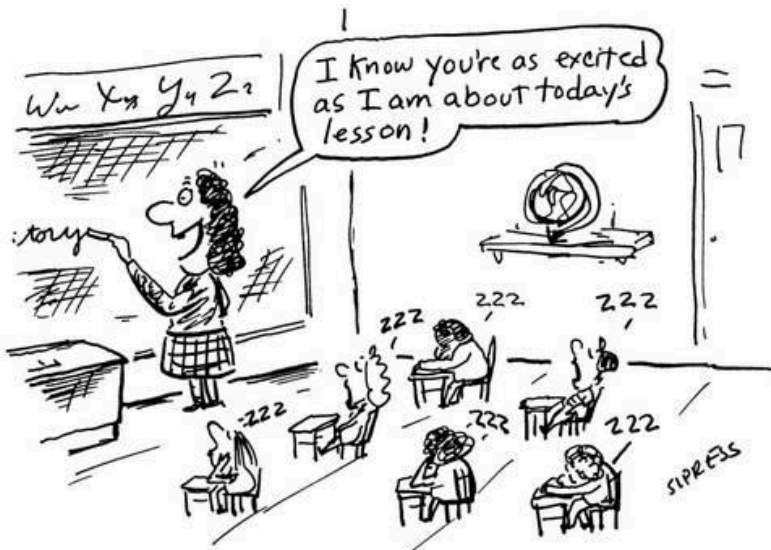
- Brachman, R. and Levesque, H. *Knowledge Representation and Reasoning*
 - Abbreviation: KRR
- Allemang, D. and Hendler, J. *Semantic Web for the Working Ontologist*, 2nd Edition
 - Abbreviation: SW2O
- First Reading: KRR Ch. 1&3

Scholarly Articles

- Papers or links posted on canvas

Lectures

- Class times and location
 - Tuesday & Thursday,
2 – 3:20 pm
 - Tech LR2
- Interactive lectures
 - Participation is key



Topics:

- Knowledge representation
 - First-order logic
 - Ontologies
- Reasoning
 - Resolution
 - Chaining
 - Analogy
 - Planning
- Semantic Web
- Domains
 - Physics
 - Language
 - Affordances
 - Morals

Office hours

- Still finalizing
 - Willie
 - Tues 5pm
 - Irina
 - Wed 10am
 - More coming soon
- Piazza
- Email (please email both of us)

Homeworks

- 5 assignments
 - Short
 - Basic practice in core concepts
 - Prepare you for your projects
- Due 1 week after being assigned
 - First HW will be assigned 1/10 and will be due 1/17
 - Posted and Submit via Canvas

Tools

- OpenCyc
- Companions
- CogSketch
- TopBraid

Projects

- Group projects (3-4 people)
- Topic of your choice
 - Ideally, something you are interested in (hobby, research, random curiosity, etc.)
- Deliverables:
 - Proposal
 - Updates
 - Presentation
 - Final report
 - With accompanying code, data, knowledge, etc.
- More details in a few weeks

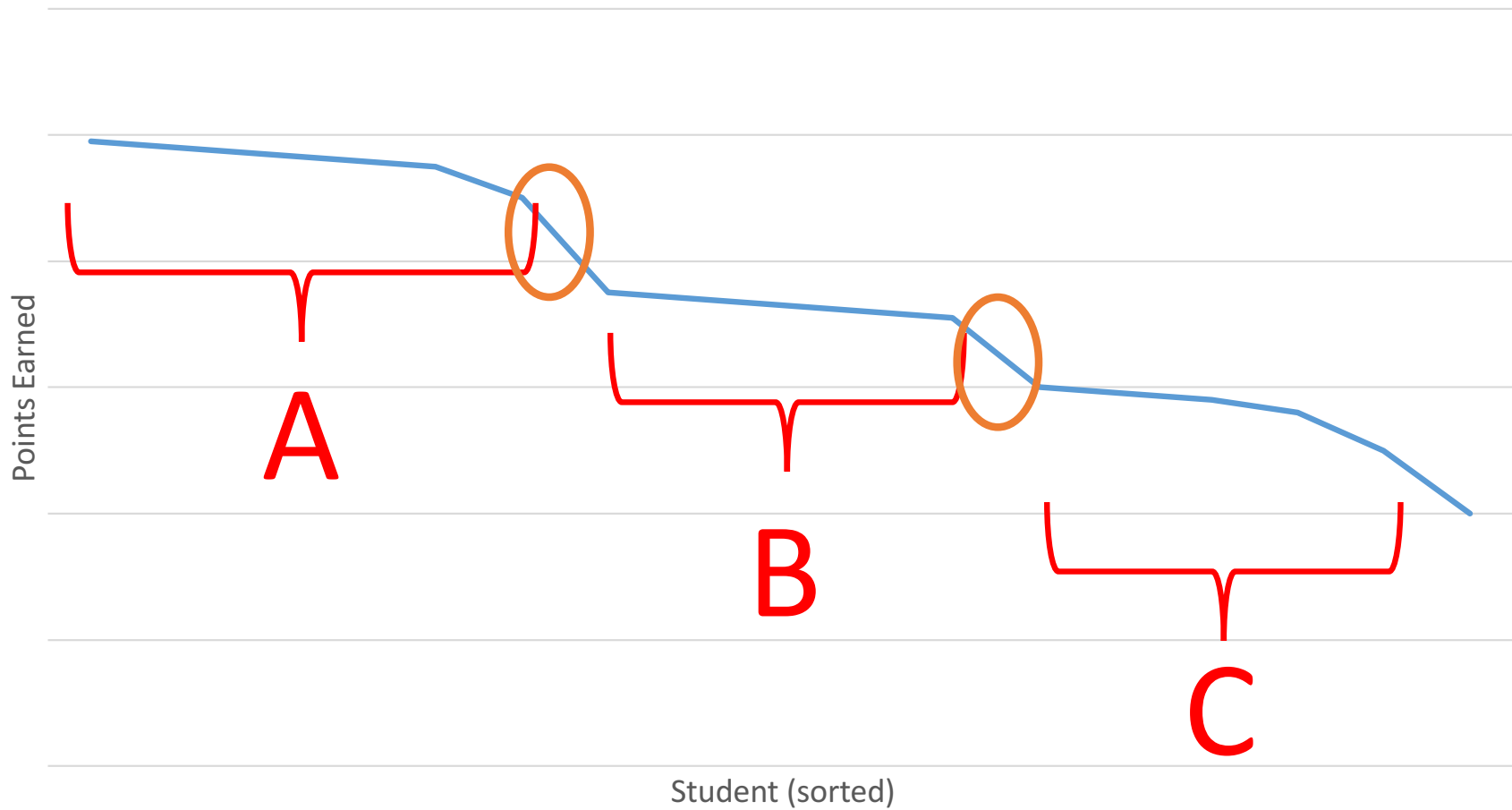
Academic Integrity

- Collaboration is important
 - Strongly encourage you to discuss course material
 - Share ideas
- Properly represent your work
 - Cite your sources and collaborators
 - HWs, projects, presentations

Grading

- All hands-on experience
- No exams!
- Breakdown
 - Participation: 15%
 - Homework: 25%
 - Project proposal: 10%
 - Project presentation: 20%
 - Final report: 30%

Final Grade Determination



Getting to know you

- Ungraded survey on Canvas
- Please complete today