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Knowledge Representation  
and  
Reasoning

CS227  
Spring 2011

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# Teaching Staff

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# Outline

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- Three Example Systems
  - Goals / Design of the course
  - Some Basic Definitions
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# Example Systems



- We will take a look at three implemented systems
  - Cognitive Assistant (SIRI)
  - Smart Textbook (Inquire)
  - Computational Knowledge Engine (Wolfram Alpha)
- For each system, we will look at
  - What knowledge must it represent?
  - What reasoning must it do?
  - What would it take to extend it?
  - Where does it fail?
  - How is it different from (current) Google?



# Cognitive Assistant SIRI

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- See Demo at: [http://www.youtube.com/watch?v=MpjpVAB06O4&feature=player\\_embedded](http://www.youtube.com/watch?v=MpjpVAB06O4&feature=player_embedded)
- What knowledge must it represent?
  - Restaurants, movies, events, reviews, ...
  - Location, tasks, web sources, ...
- What reasoning must it do?
  - Nearest location, date for tomorrow, AM vs PM, etc
- What would it take to extend it?
  - More sources, different sources,
- Where does it fail?
  - Completely different environment, completely different task
- Differences from Google
  - Dialog driven, task-oriented, location aware, ...



# Smart Textbook Inquire

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- What knowledge must it represent? (Demo in the class)
  - Concepts, definitions, relationships, descriptions
- What reasoning must it do?
  - Follow relationships, answer questions
- What would it take to extend it?
  - Must be customized to a new domain, must have methods for handling each kind of question
- Where does it fail?
  - Does not capture all the content in the book, limited forms of reasoning
- How is it different from Google?
  - Very specific domain targeted at a specific class of user situated in an educational context



# Wolfram Alpha

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- Try out examples at: <http://www.wolframalpha.com/examples/>
  - We will focus on the nutrition example
- What knowledge must it represent?
  - Different kinds of foods, their nutrition composition, caloric values
- What reasoning must it do?
  - Mathematical computations based on portions
- What would it take to extend it?
  - Add more data on foods and nutrition composition
- Where does it fail?
  - Does not know about recipes, how to combine foods, ...
- How is it different from Google?
  - Data driven as opposed to document driven, mathematical reasoning

# Goals of the Course

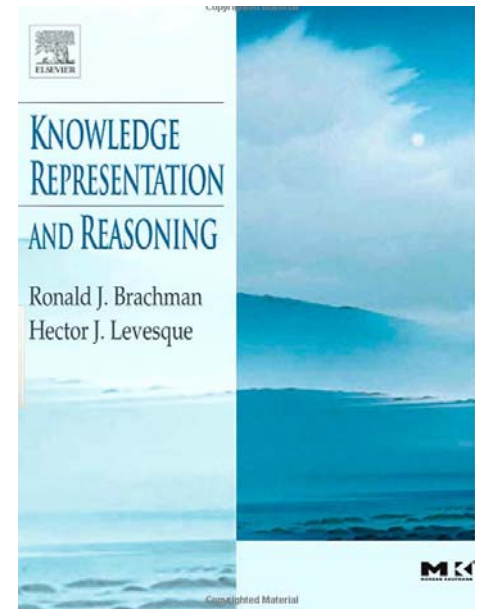
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- Introduction to techniques used to represent symbolic knowledge
  - Associated methods of automated reasoning
  - The three systems that we saw
    - use symbolic knowledge representation and reasoning
    - But, they also use non-symbolic methods
      - Non-symbolic methods are covered in other courses (CS228, CS229, ...)
  - This course would be better labeled as a course on Symbolic Representation and Reasoning
    - The non-symbolic representations are also knowledge representations but are not covered in this course
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# Design of the Course

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- Textbook:
  - Knowledge Representation & Reasoning by Brachman & Levesque (available online)
- Lectures
  - Tuesday and Thursday, 12:50-2:05, 300-300
- Grades
  - Four Assignments (40%), Mid-term (25%), Final (35%)
- Prerequisites
  - First order logic and Resolution (at the level of CS157)
    - There will be two tutorial sections to cover this material
    - The textbook chapters 2-4 provide adequate background
  - Discrete mathematics (data structures and algorithms)
  - A course in AI (knowledge of Lisp or Prolog)



# Design of the Course

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- Course website
    - <http://cs227.stanford.edu>
  - Topics:
    - Object-oriented representation, description logics, ontologies, logic programming, constraint programming, action representation and reasoning, abstraction/reformulation/approximation
  - Tests
    - Mid-term, Date: TBA
      - Will be held in the evening
      - Please let us know about any conflicts ASAP
    - Final, Date: TBA
  - Staff mailing list
    - [cs227-spr1011-staff@lists.stanford.edu](mailto:cs227-spr1011-staff@lists.stanford.edu)
  - Projects
    - Only with the approval of the instructor
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# Design of this Course

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- Will this course require programming?
    - We will work with several off-the-shelf representation and reasoning tools
    - We will not be writing any new tools from scratch
    - The focus will be on applying representation techniques to real world knowledge and using existing tools to reason with that knowledge
    - Minor programming may be needed for some assignments
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## Relationship to Other Courses

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- This course is a good follow up to
    - CS157: Computational Logic
    - CS221: Introduction to Artificial Intelligence
    - CS270: Modeling Bio-Medical Systems
  - This course is complementary to:
    - CS228: Probabilistic Graphical Models
  - This course can be followed by:
    - CS223: Rational Agency and Intelligent Interaction
    - CS224: Multi-agent systems
    - CS227B: General Game Playing
    - Application of techniques in your respective projects
    - Research opportunities in symbolic representation and reasoning
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# Mini Project

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- Represent a chapter from a Biology textbook and answer the questions at the back of the book
    - It is high school level knowledge and each of us should know it
      - Develop confidence in approaching any domain with the formal tools you will learn in this course
    - Primary focus on representation and reasoning
    - Provides natural progression:
      - one question, multiple questions, novel questions
      - Structured representations, inference rules, special purpose reasoners
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# Outline

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  - ✓ Goals / Design of the course
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# What is knowledge?

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Easier question: how do we talk about it?

We say “John knows that ...” and fill the blank with a proposition

- can be true / false, right / wrong

Contrast: “John fears that ...”

- same content, different attitude

Other forms of knowledge:

- know how, who, what, when, ...
- sensorimotor: typing, riding a bicycle
- affective: deep understanding

Belief: not necessarily true and/or held for appropriate reasons  
and weaker yet: “John suspects that ...”

Here: no distinction

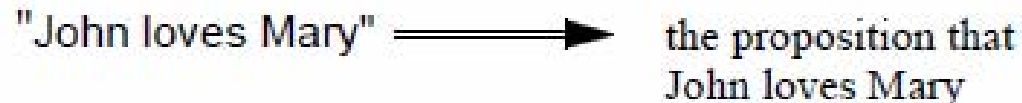
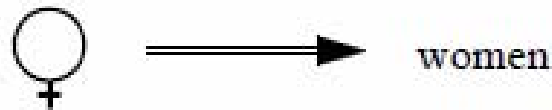
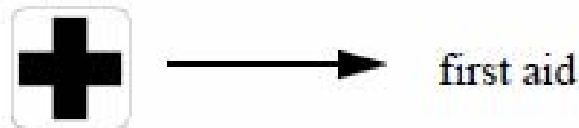
the main idea

taking the world to be one way and not another
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# What is representation?

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Symbols standing for things in the world



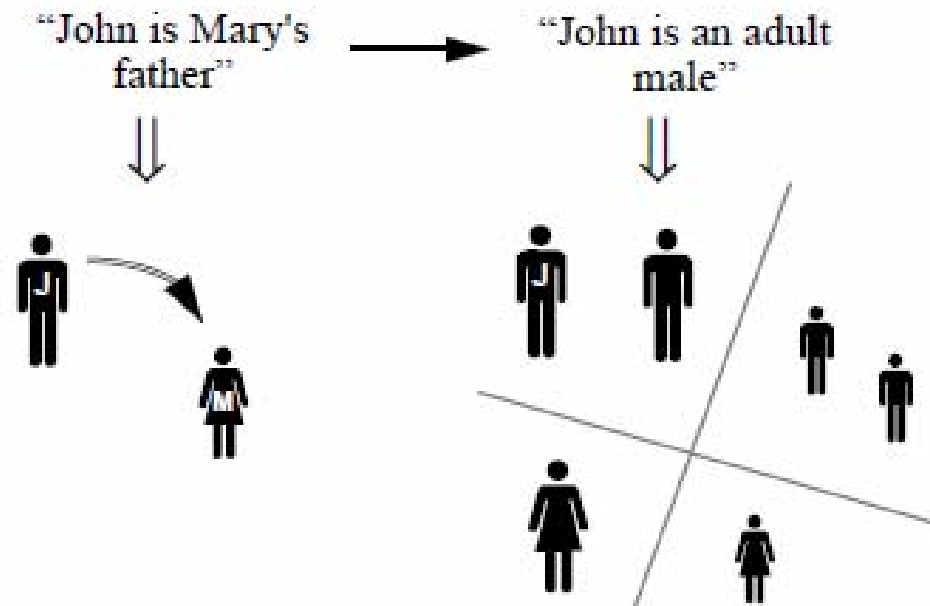
**Knowledge representation:**

symbolic encoding of propositions believed  
(by some agent)

# What is reasoning?

Manipulation of symbols encoding propositions to produce representations of new propositions

Analogy: arithmetic    "1011" + "10" → "1101"  
                                  ↓            ↓            ↓  
                                  eleven    two            thirteen



# Why KR&R?

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- KR Hypothesis (Brian Smith)
  - Any mechanically embodied intelligent process will be comprised of structural ingredients that
    - We as external observers naturally take to represent a propositional account of the knowledge that the overall process exhibits
    - Independent of such external semantic attribution, play a formal but causal and essential role in engendering the behavior that manifests that knowledge
- Two issues: existence of structures that
  - We can interpret
  - Determine how the system behaves

## Two examples

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Example 1

```
printColour(snow) :- !, write("It's white.").
printColour(grass) :- !, write("It's green.").
printColour(sky) :- !, write("It's yellow.").
printColour(X) :- write("Beats me.).
```

Example 2

```
printColour(X) :- colour(X,Y), !,
    write("It's "), write(Y), write(".").
printColour(X) :- write("Beats me.).
```

```
colour(snow,white).
colour(sky,yellow).
colour(X,Y) :- madeof(X,Z), colour(Z,Y).
madeof(grass,vegetation).
colour(vegetation,green).
```

Only the 2nd has a separate collection of symbolic structures à la KR Hypothesis

its knowledge base (or KB)

∴ a small knowledge-based system

# Benefits of Explicit Representation

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- We can add new tasks and easily make them depend on previous knowledge
    - Enumerating objects vs painting objects
  - Extend the existing behavior by adding new beliefs
    - Assert that canaries are yellow
  - Debug faulty behavior by locating the erroneous beliefs
    - By changing the color of sky we change any routine that uses that information
  - Explain and Justify the behavior of the system
    - The program did X because Y
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# Benefits of Reasoning

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- Given
    - Patient X allergic to medication M
    - Anyone allergic to medication M is also allergic to medication M'
  - Reasoning helps us derive
    - Patient X is allergic to medication M'
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# Entailment

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Sentences  $P_1, P_2, \dots, P_n$  entail sentence  $P$  iff the truth of  $P$  is implicit in the truth of  $P_1, P_2, \dots, P_n$ .

If the world is such that it satisfies the  $P_i$  then it must also satisfy  $P$ .

Applies to a variety of languages (languages with truth theories)

**Inference:** the process of calculating entailments

- sound: get only entailments
- complete: get all entailments

**Sometimes want unsound / incomplete reasoning**

for reasons to be discussed later

**Logic:** study of entailment relations

- languages
- truth conditions
- rules of inference

# Using logic

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## No universal language / semantics

- Why not English?
- Different tasks / worlds
- Different ways to carve up the world

## No universal reasoning scheme

- Geared to language
- Sometimes want “extralogical” reasoning

## Start with first-order predicate calculus (FOL)

- invented by philosopher Frege for the formalization of mathematics
- but will consider subsets / supersets and very different looking representation languages

# KR&R and AI

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- KR&R started as a field in the context of AI research
    - Need explicitly represented knowledge to achieve intelligent behavior
      - Expert systems, language understanding, ...
  - Many of the AI problems today heavily rely on statistical representation and reasoning
    - Speech understanding, vision, machine learning, natural language processing
      - For example, the recent Watson system relies on statistical methods but also uses some symbolic representation and reasoning
  - Some AI problems require symbolic representation and reasoning
    - Explanation, story generation
    - Planning, diagnosis
    - Abstraction, reformulation, approximation
    - Analogical reasoning
  - KR&R today has many applications outside AI
    - Bio-medicine, Engineering, Business and commerce, Databases, Software engineering, Education
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## Some Long-Term Problems that need Knowledge Representation

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- Read a chapter in a textbook and answer questions at the end of the chapter
  - Einstein in a box: The quality of reasoning that distinguishes an ordinary human from a top scientist
    - Answer the same questions as a national academy of science member
  - Learn how to repair a mobile robot and successfully demonstrate the capability by repairing one on Mars
  - Encyclopedia on Demand
    - Produce a 5000 word or less encyclopedia style article on a given subject by summarizing from the relevant information available on the web in less than 24 hours
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# Suggested Readings

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- Required Reading
    - Chapter 1 of Brachman & Levesque textbook
    - Chapters 2-4 if you do not have prior background in FOL
  - Optional Readings
    - Three Open Problems in AI. Raj Reddy. In the Journal of ACM, Vol 50, No. 1, 2003.
    - Some Challenges and Grand Challenges for Computational Intelligence. Edward A. Feigenbaum. In the Journal of ACM, Vol 50, No. 1, 2003.
    - Systems that Know What they're Doing. Ron Brachman. Intelligent Systems, Vol 17, no. 6, pp 67-71.
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