CSCI 561
Foundation for Artificial Intelligence

Welcome!

Today's Lectures

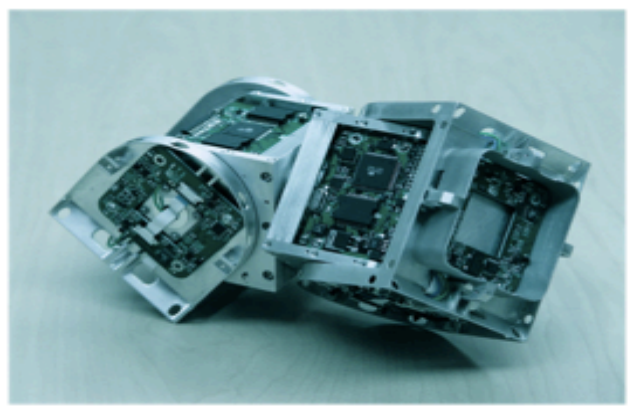
- Lecture 1: 6:40-7:55PM (Prof. Shen)
  - Introduction
    - Who are us? Who are you?
    - What will we learn and do this semester?
    - Course details: lectures, discussions, projects/hw, tests, grades, …
  - Overview of Artificial Intelligence
    - Intelligence, Agents, and Artificial Intelligence (how to test them?)
    - Agent Types and Rational Actions
- Break: 7:55-8:05
- Lecture 2: 8:05-9:20 (Prof. Tejada)
  - Search and Problem Solving
    - Complexity, and uninformed search methods

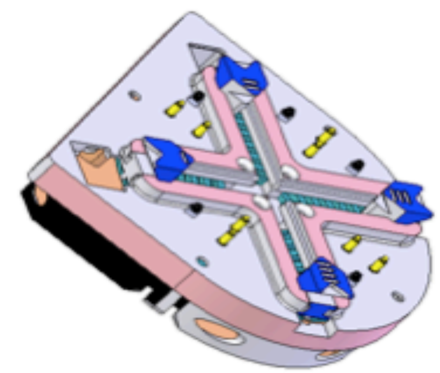
CS 561: Artificial Intelligence

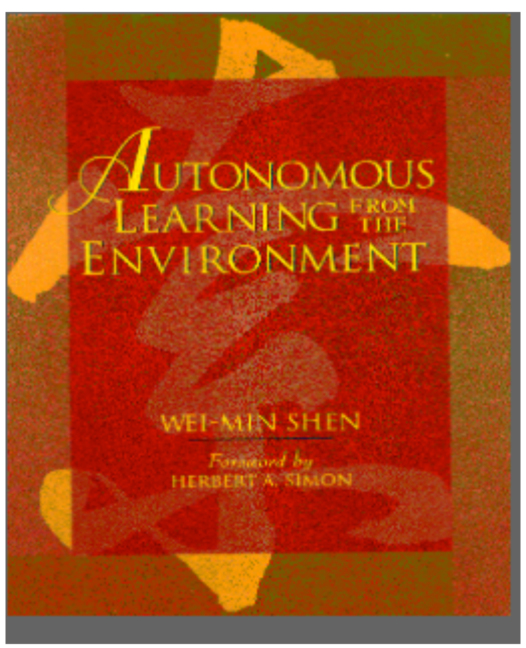
Instructors:	Profs. Wei-Min Shen (shen@isi.edu), Sheila Tejada (stejada@usc.edu) Ning Wang (nwang@ict.usc.edu)
TAs:	Chi-An Chen - chianc@usc.edu Daniel Link - dlink@usc.edu Thomas Collins – collins@usc.edu Ellizabeth Bondi - bondi@usc.edu Max Johnson - maxwelsj@usc.edu John Tran - jtran@isi.edu
Lectures:	M-W 17:00–18:20(SGM124); Tues. 18:40–21:20 (SGM-123)
Office hours:	TBA
Discussion:	Profs. Tejada & Wang

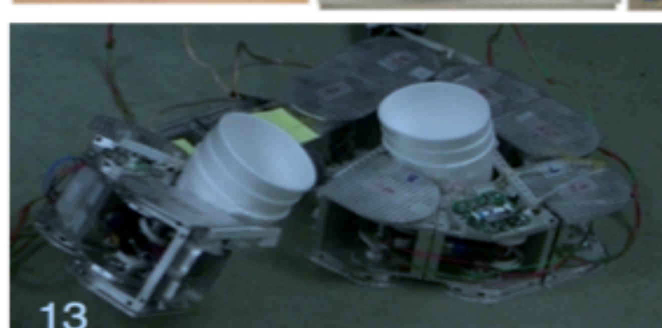
Textbook: [AIMA] Artificial Intelligence: A Modern Approach, by Russell & Norvig. (3rd ed)
Optional (ALFE): Autonomous Learning from the Environment by Shen

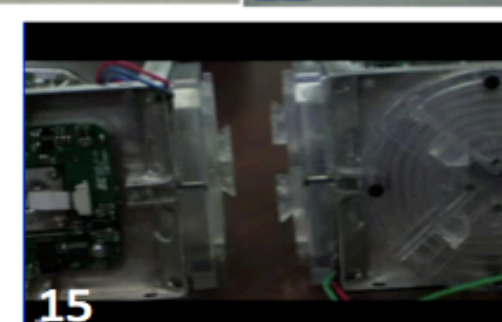
Prof Wei-Min Shen (http://www.isi.edu/robots)





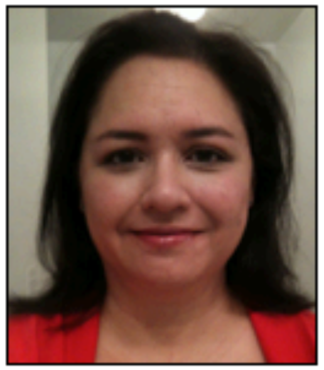






Prof Sheila Tejada (http://www-bcf.usc.edu/~stejada/)

USC University of Southern California



Dr. Sheila Tejada
Computer Science Department

Cool Robot Pix:

Office Hours:

Office: SAL 316
Hours:
CS561 Summer Syllabus
Check calendar for current schedule

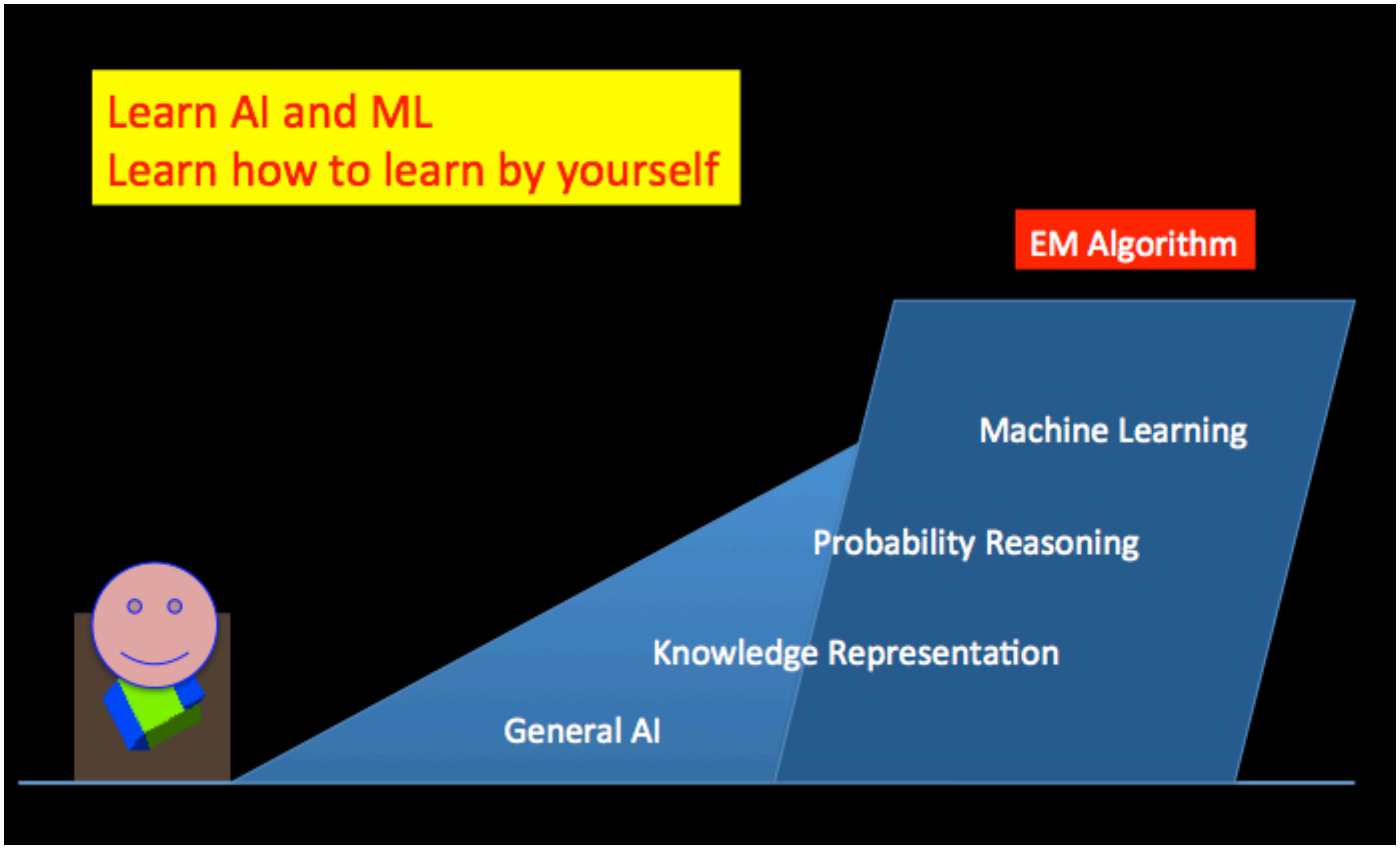
and by appointment

Teaching:

CSCI561 Foundations of Artificial Intelligence
CSCI 561 course website

Who Are You? What Will You Learn?

- Major: CS, EE, Others?
- Why you take this popular class? (Lucky you have a seat here ☺)
- What will you learn?



Tues: Prof Tejada: lectures 1-15; Prof Shen: lectures 16-30

Course Overview

Foundations of symbolic intelligent systems. Agents, search, problem solving, logic, representation, reasoning, symbolic programming, and robotics.

Prerequisites: CS 455x, i.e., programming principles, discrete mathematics for computing, software design and software engineering concepts. Good knowledge of C++ and STL, or Java, or Python needed for programming assignments.

Grading: 25% for midterm-1 +
25% for midterm-2 +
25% for final +
5% hw1, 10% hw2, 10% hw3

Note: Discussion sessions are important & will be tested.

CS 561: Artificial Intelligence

Grading:

Grading is absolute and according to the following scale:

>= 90 A+ (honorary – shows as A on transcript)
>= 80 A
>= 75 A-
>= 70 B+
>= 60 B
>= 55 B-
>= 50 C+
>= 40 C
>= 35 C-
< 35 F

Practical Issues

- **Class mailing list:** will be setup and annouced
- **Homeworks:** See class web page and syllabus. Homeworks are programming assignments.
  - Aug 29 – HW1 out   Topic: search
  - Sep 17 – HW1 due
  - Sep 26 – HW2 out   Topic: game playing or constraint satisfaction
  - Oct 15 – HW2 due
  - Oct 31 – HW3 out   Topic: logic reasoning and inference or neural networks
  - Nov 19 – HW3 due
- **Late homeworks:** you lose 20% of the homework's grade per 24-hour period that you are late. Beware, the penalty grows very fast: grade = points * (1 – n * 0.2) where n is the number of days late (n=0 if submitted on time, n=1 if submitted between 1 second and 24h late, etc).
- **Homework grading:** your hws will be graded by an A.I. agent (given to you in advance for testing) through the online system at **vocareum.com**.
- **Grade review / adjustment:** Requests will be considered up to 2 weeks after the grade is released. After that, it will be too late and requests for grading review will be denied.
- **Exams:**
  - Monday, September 24, 8:00pm – 9:50pm – midterm 1 (room TBA)
  - Monday, October 29, 8:00pm – 9:50pm – midterm 2 (room TBA)
  - Friday, November 26, 8:00am – 10:00am – final (room TBA)

More on Homeworks and Grading

- In each homework you will implement some algorithms from scratch.
- But our goal is to focus on A.I. algorithms, not on low-level programming. Hence I recommend C++/STL so that you can use the STL containers (queue, map, etc) instead of pointers and memory management. But the language you use is up to you.
- Code editing, compiling, testing: we will use www.vocareum.com which will be linked to desire2learn (this is in progress at this time).
- Vocareum supports several languages, there are choice of C, C++, C++11, Java, Python, etc. But you must use Python.

Discussion Sessions

- You must register for one lecture section (either M-W or Tues).

- You must register for one discussion section.

- You must also register for the Quiz section on Mondays.

There will not be a quiz every week. This slot is reserved so we can have the entire Class (M-W section + Tues section) take the exam at the same time. It will be used only for the two midterm exams.

Discussion	4:00-4:50pm	Thursday	35 of 35	Sheila Tejada	MHP B7B
Discussion	7:00-7:50pm	Wednesday	85 of 85	Sheila Tejada	OHE 132
Discussion	2:00-2:50pm	Friday	75 of 75	Ning Wang	ZHS 352
Discussion	1:00-1:50pm	Friday	72 of 75	Ning Wang	ZHS 352
Discussion	11:00-11:50am	Friday	75 of 75	Ning Wang	ZHS 352
Discussion	10:00-10:50am	Friday	75 of 75	Ning Wang	ZHS 352
Discussion	3:00-3:50pm	Thursday	30 of 28	Sheila Tejada	SOS B48
Discussion	8:00-8:50pm	Wednesday	84 of 85	Sheila Tejada	SLH 100
Quiz	8:00-9:50pm	Monday	531 of 600		OFFICE
Lecture	5:00-6:20pm	Mon, Wed	17 of 21	Sheila Tejada	DEN@Viterbi
Discussion	7:00-7:50pm	Wednesday	17 of 21	Sheila Tejada	DEN@Viterbi

- Discussion sections will
  - Provide more details, discussion and examples on complex topics
  - Run algorithms on more complex examples than during lectures
  - Relate lecture concepts to latest research topics
  - Showcase cool demos of recent A.I. achievements

Academic Integrity

- Familiarize yourself with the USC Academic Integrity guidelines.
- Violations of the Student Conduct Code will be filed with the Office of Student Judicial Affairs, and appropriate sanctions will be given.
- Homework assignments are to be solved **individually.**
- You are welcome to discuss class material in review groups, but do not discuss how to solve the homeworks.
- **Exams are closed-book with no questions allowed.**
- **Please read and understand:**

http://policy.usc.edu/student/scampus/
https://sjacs.usc.edu/students/

Academic Integrity

- **All students are responsible for reading and following the Student Conduct Code.** Note that the USC Student Conduct Code prohibits plagiarism.

- Some examples of what is not allowed by the conduct code: copying all or part of someone else's work (by hand or by looking at others' files, either secretly or if shown), and submitting it as your own; giving another student in the class a copy of your assignment solution; and consulting with another student during an exam. If you have questions about what is allowed, please discuss it with the instructor.

- Students who violate university standards of academic integrity are subject to disciplinary sanctions, including failure in the course and suspension from the university. Since dishonesty in any form harms the individual, other students, and the university, policies on academic integrity will be strictly enforced. Violations of the Student Conduct Code will be filed with the Office of Student Judicial Affairs.

USC
UNIVERSITY
OF SOUTHERN
CALIFORNIA

Division of Student Affairs

Student Judicial Affairs and Community Standards

October 5, 2007

[redacted]
Case #[redacted]
[redacted]
Los Angeles, CA [redacted]

Dear [redacted]

I have received a report from Professor Itti Engineering, concerning an alleged act of academic dishonesty which occurred in CSCI-561 (#30219) during the Fall Semester (20073).

Specifically, the complaint alleges that you violated Student Conduct Code §§:

11.12A Acquisition of term papers or other assignments from any source and the subsequent presentation of those materials as the student's own work, or providing term papers or assignments that another student submits as his/her own.

11.14B Unauthorized collaboration on a project, homework or other assignment. Collaboration between students will be considered unauthorized unless expressly part of the assignment in question or expressly permitted by the instructor.

11.15A Attempting to benefit from the work of another or attempting to hinder the work of another student.

11.15B Any act which may jeopardize another student's academic standing

11.15B Any act which may jeopardize another student's academic standing

11.21 Any act which gains or is intended to gain an unfair academic advantage may be considered an act of academic dishonesty.

The complaint concerns your assignment completed on or about September 26, 2007.

As a consequence of the complaint a review of the allegations is necessary. The guidelines for the review process (summary enclosed) can be found in the Student Conduct Code in the current *SCampus*. Please familiarize yourself with the standards and expectations concerning academic honesty prior to our meeting and the review. According to University policy, you will not be permitted to drop the course with a mark of 'W' (see enclosure).

Please contact the Office of Student Judicial Affairs and Community Standards at (213) 821-7373 to schedule a meeting with me and for a review of the matter. If you do not respond by **October 19, 2007,** an administrative hold may be placed on your record prohibiting further registration and enrollment transactions. A review also may be conducted in your absence should you choose not to respond.

Sincerely,

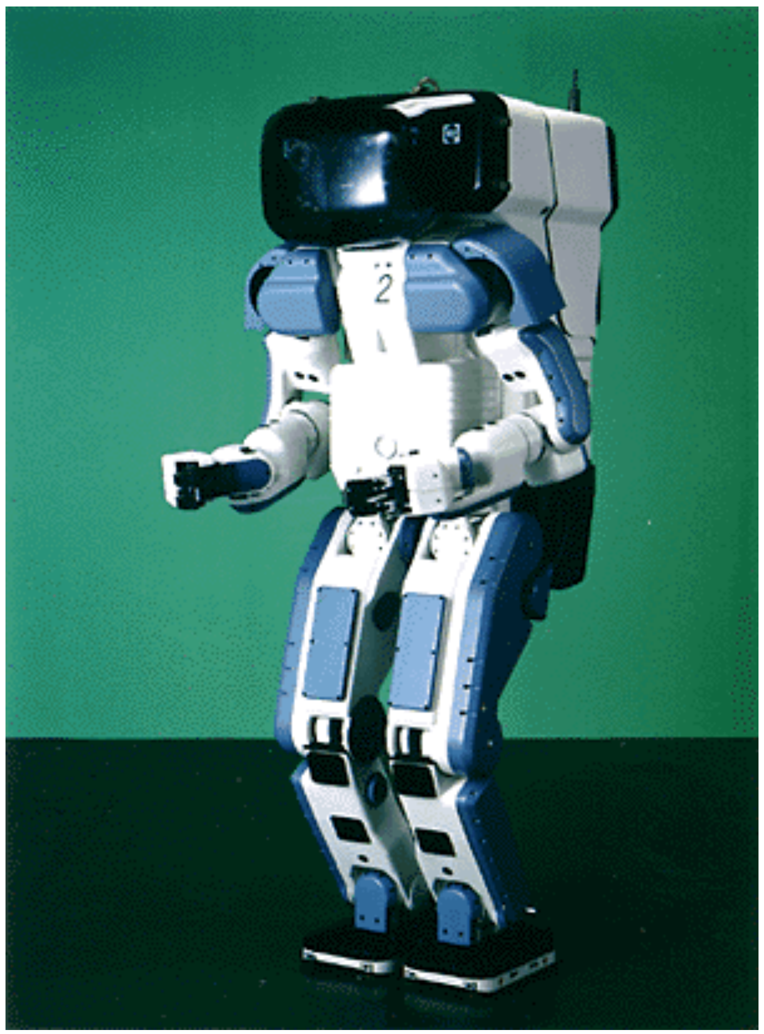
Raquel Torres-Retana
Director, Office of Student Judicial Affairs and Community Standards

University of
Southern California
Figueroa Building
Room 107
Los Angeles,
California 90089-1265
Tel: 213 821 7373
Fax: 213 740 7162

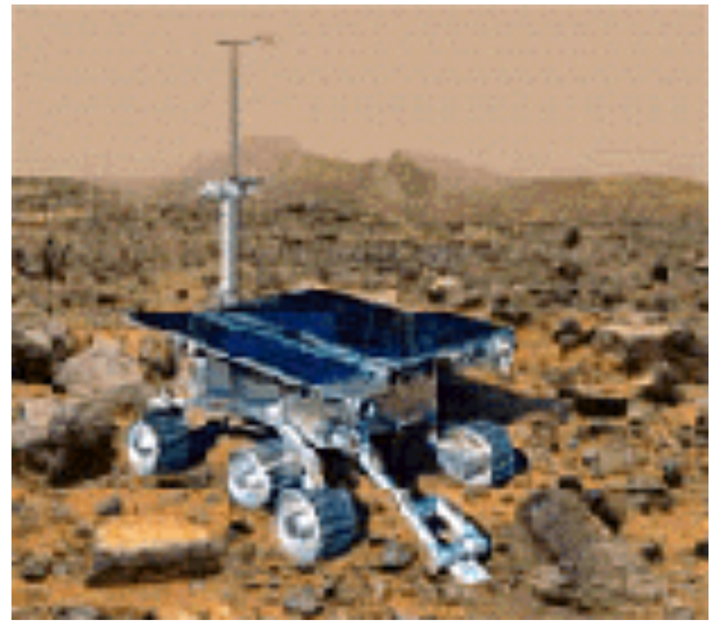
cc: Professor Laurent Itti
Kelly Goulis, Viterbi School of Engineering

Enclosures

Why Study AI?



Labor



Science

Google

YAHOO!

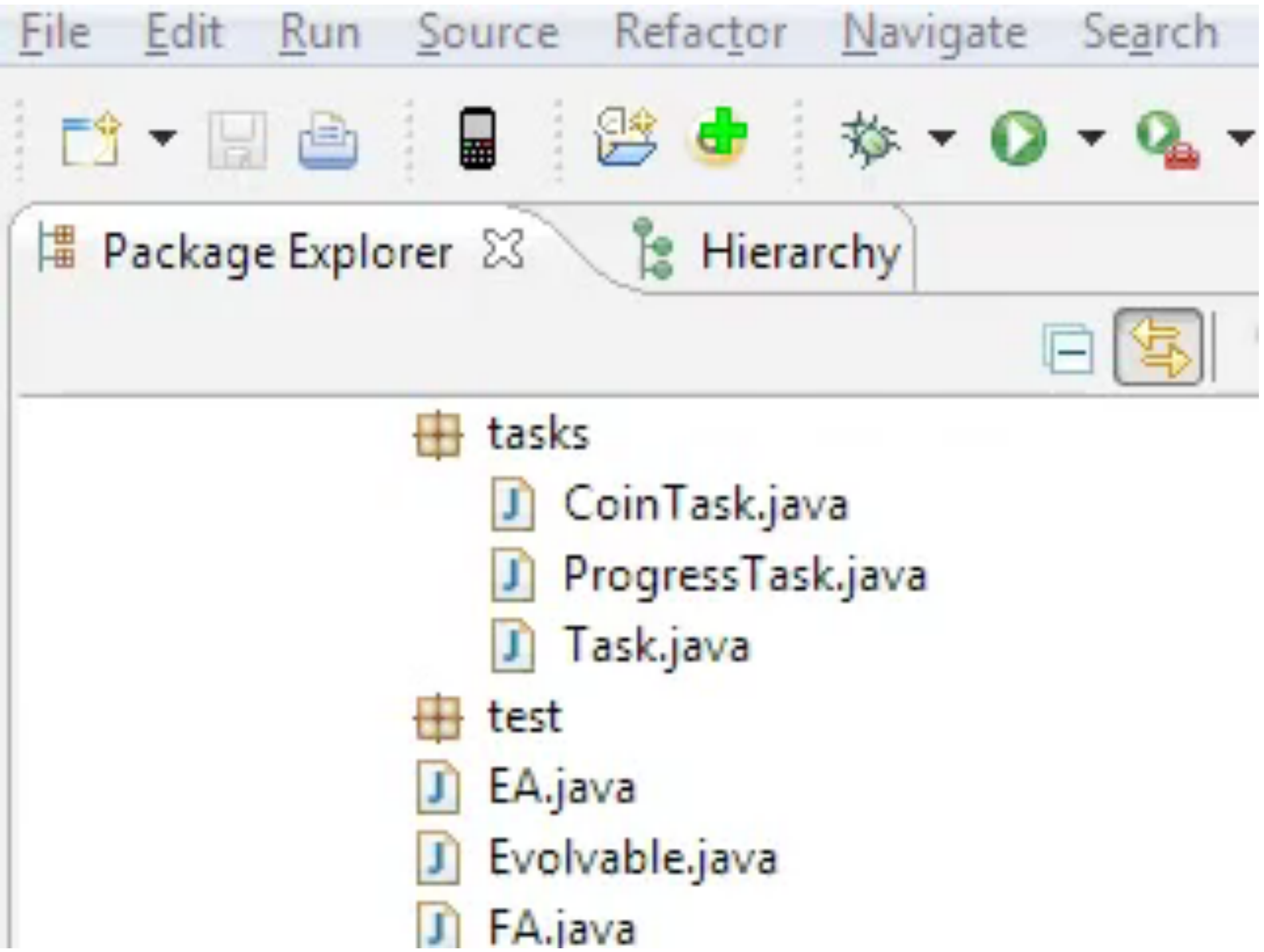
Search engines

Medicine / Diagnosis

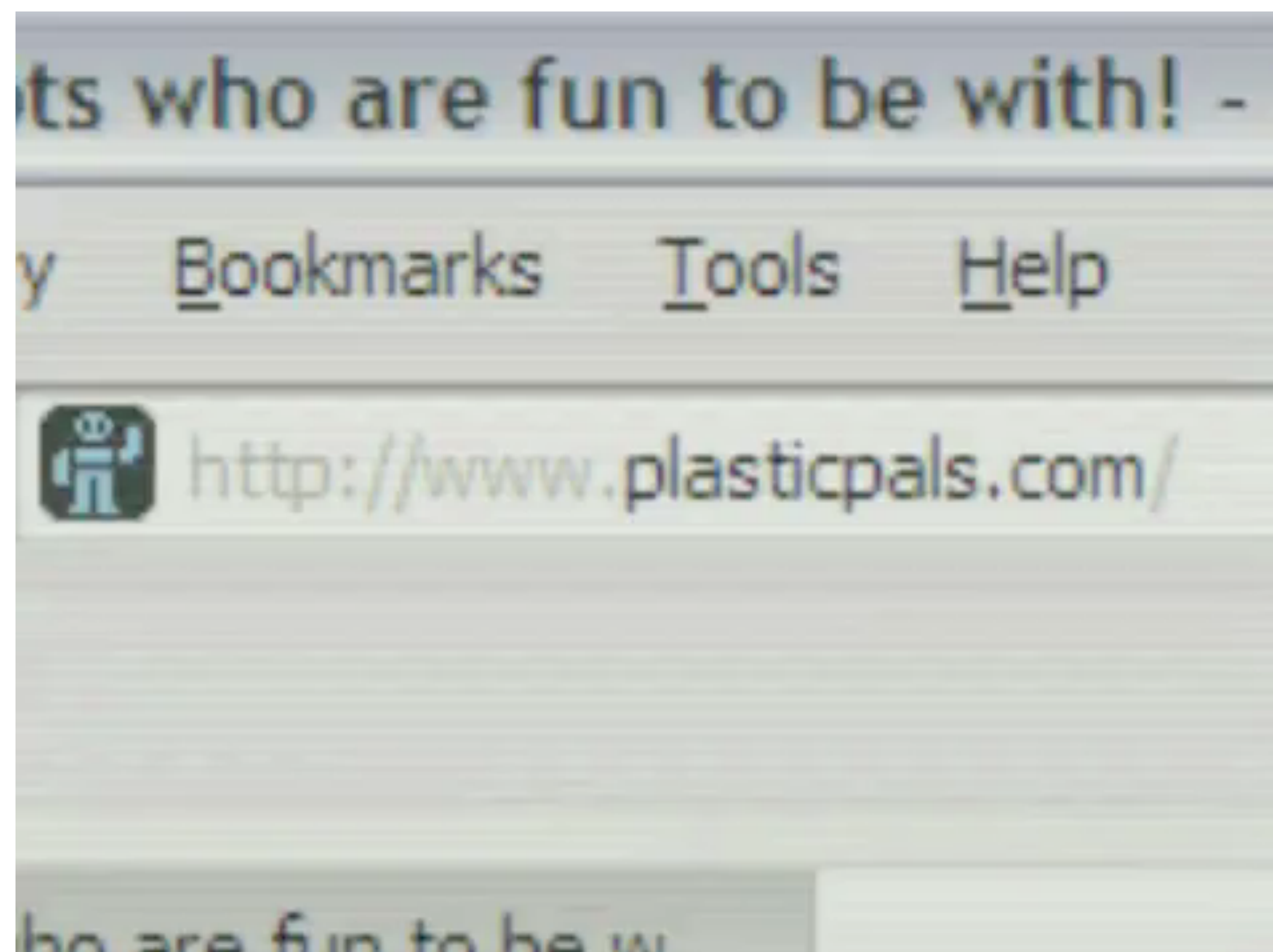
Appliances /
Internet of Things (IoT)

What else?

Why study AI?


File
Edit
Run
Source
Refactor
Navigate
Search
Package Explorer
Hierarchy
tasks
CoinTask.java
ProgressTask.java
Task.java
test
EA.java
Evolvable.java
FA.java


With whom would you like to speak?

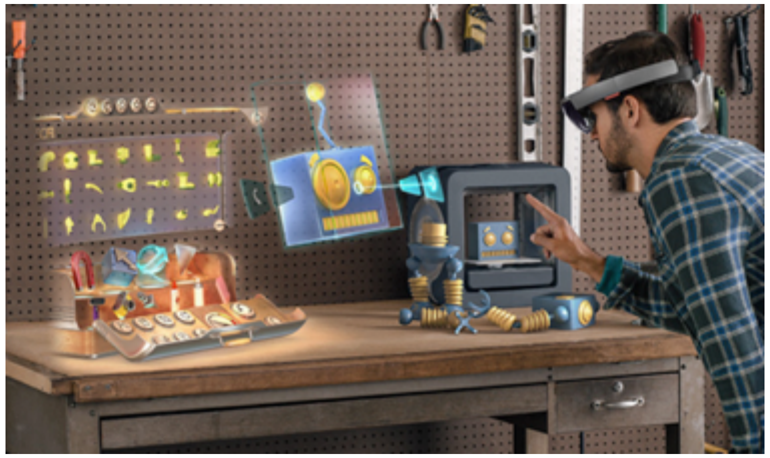

ts who are fun to be with! -
y
Bookmarks
Tools
Help
http://www.plasticpals.com/

DARPA Robotics Challenge


TEAM
KAIST
Biped Humanoid Robot DRC-Hubo

Wearable computing

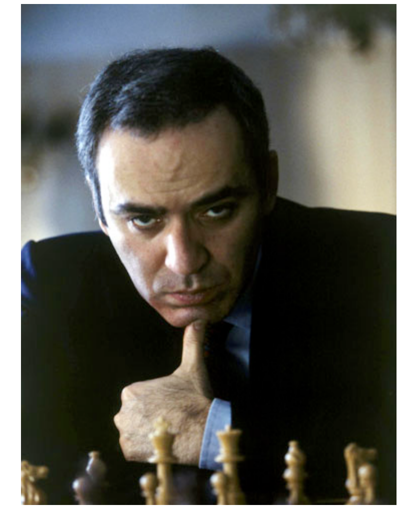
Google glass



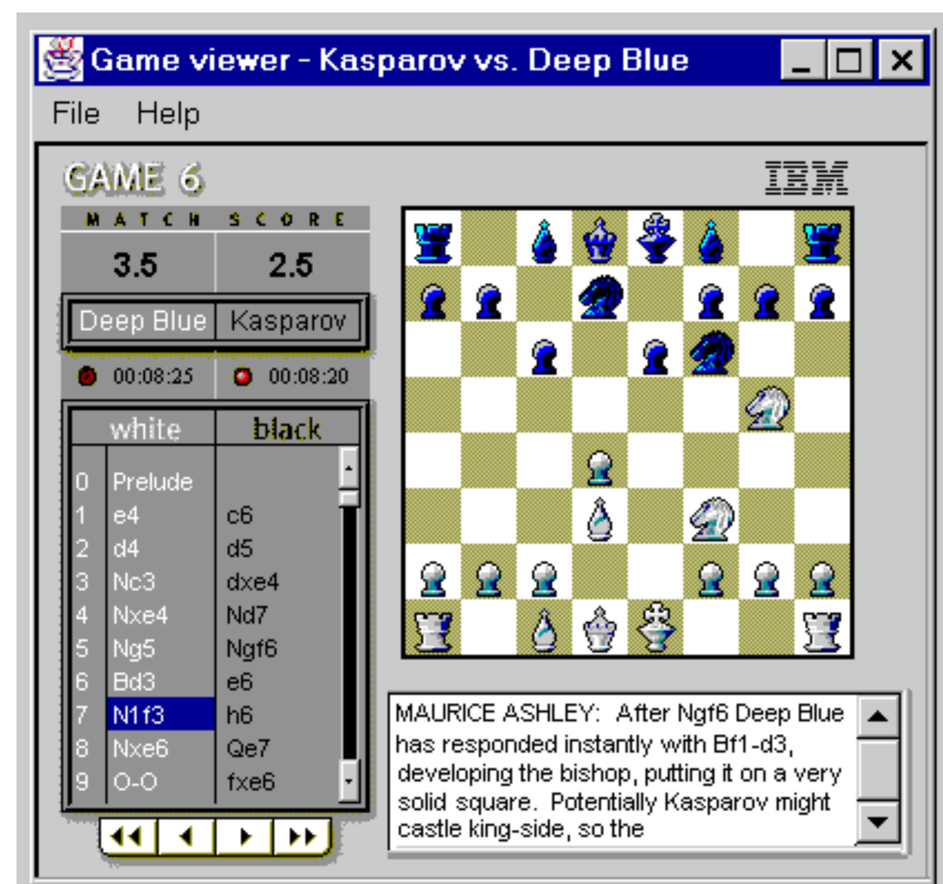
Microsoft Hololens

Zypad

Deep Blue

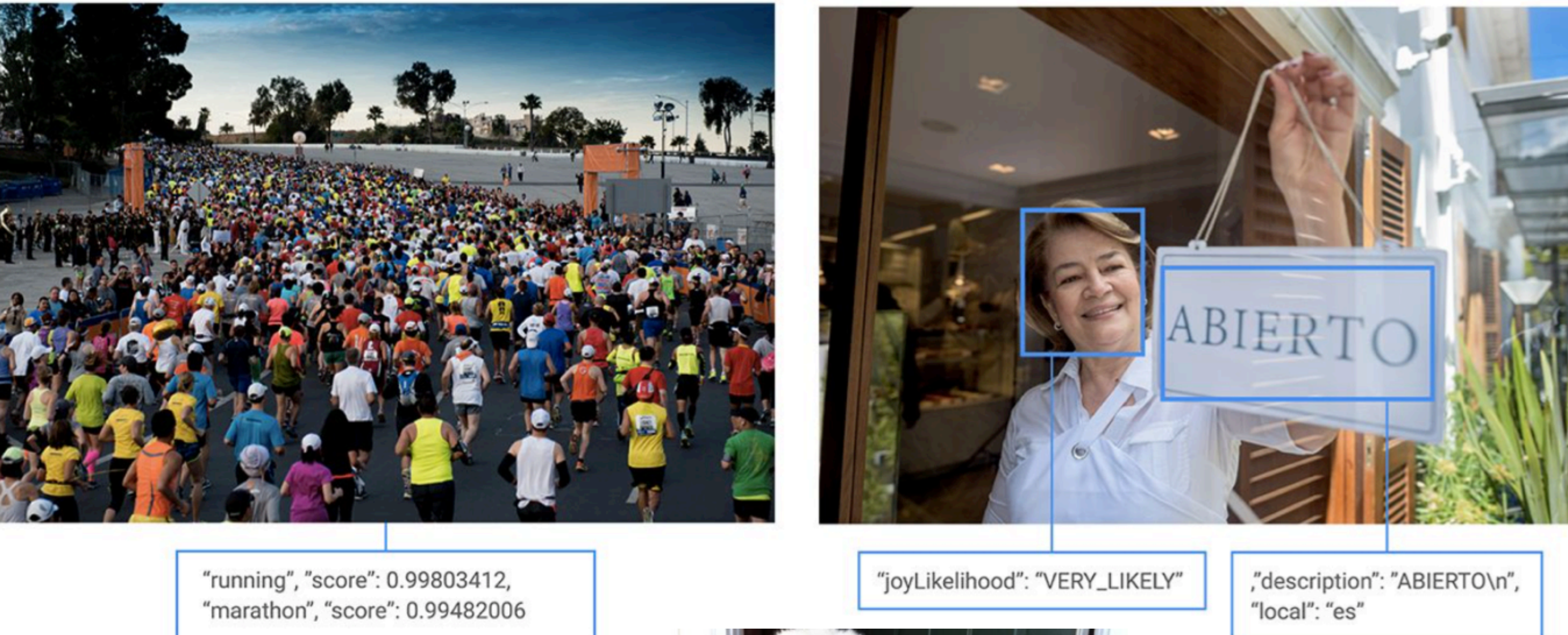


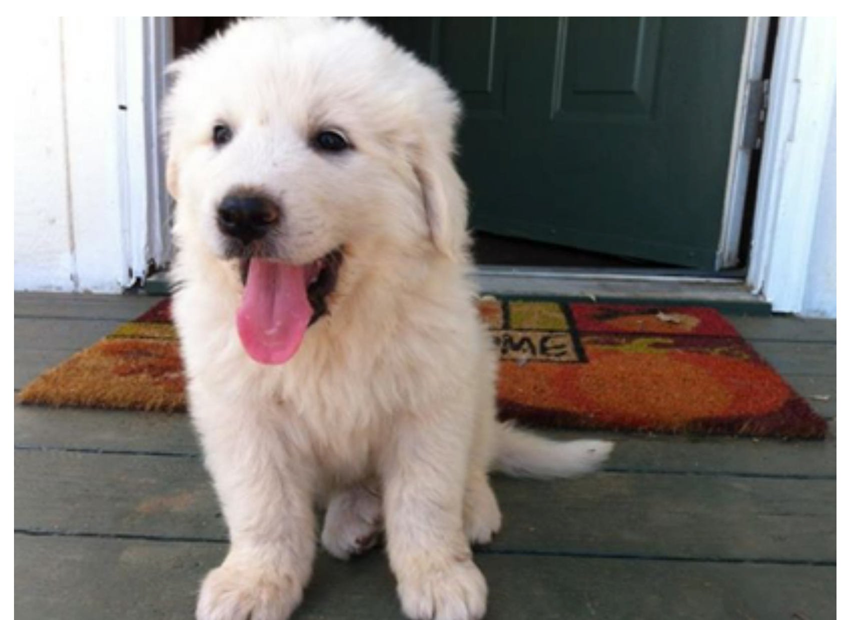
- In 1997 Deep Blue became the first machine to win a match against a reigning world chess champion (by 3.5-2.5)



Google DeepMind AlphaGO vs Human Champion (2017)

Google Cloud Vision APL:
https://cloud.google.com/vision/





What is AI?

Acting Humanly	Acting Rationally
The exciting new effort to make computers think … machines with minds, in the full and literal sense" (Haugeland 1985)	"The study of mental faculties through the use of computational models" (Charniak et al. 1985)
"The art of creating machines that perform functions that require intelligence when performed by people" (Kurzweil, 1990)	A field of study that seeks to explain and emulate intelligent behavior in terms of computational processes" (Schalkol, 1990)

Systems that think like humans	Systems that think rationally
Systems that act like humans	Systems that act rationally

Acting Rationally: The Rational Agent

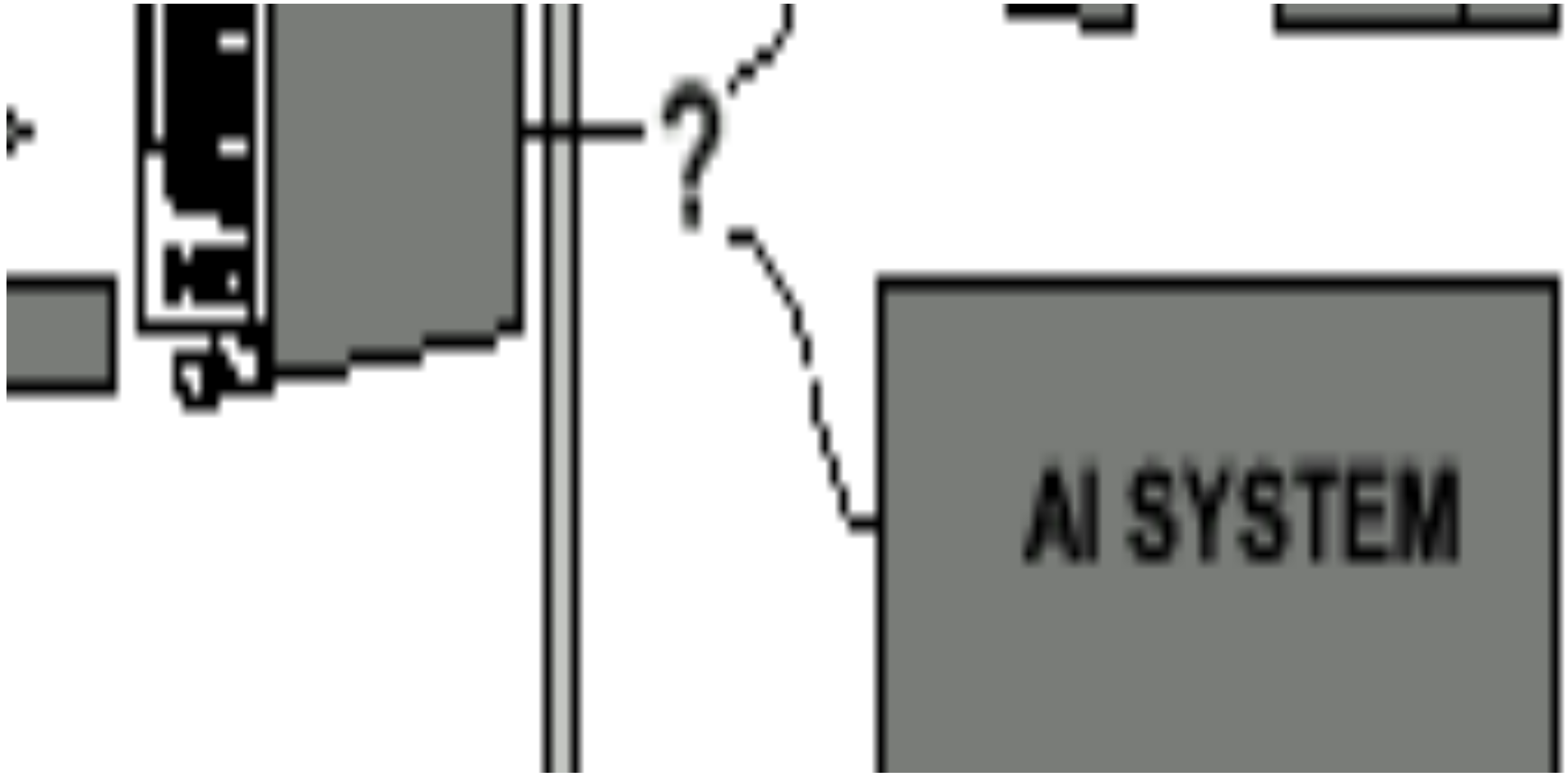
- Rational behavior: Doing the right thing!
- "The right thing"? That which is expected to maximize the expected return
- Provides the most general view of AI because it includes:
  - Correct inference ("Laws of thought")
  - Uncertainty handling
  - Resource limitation considerations (e.g., reflex vs. deliberation)
  - Cognitive skills (NLP, AR, knowledge representation, ML, etc.)
- Advantages:

  1)More general

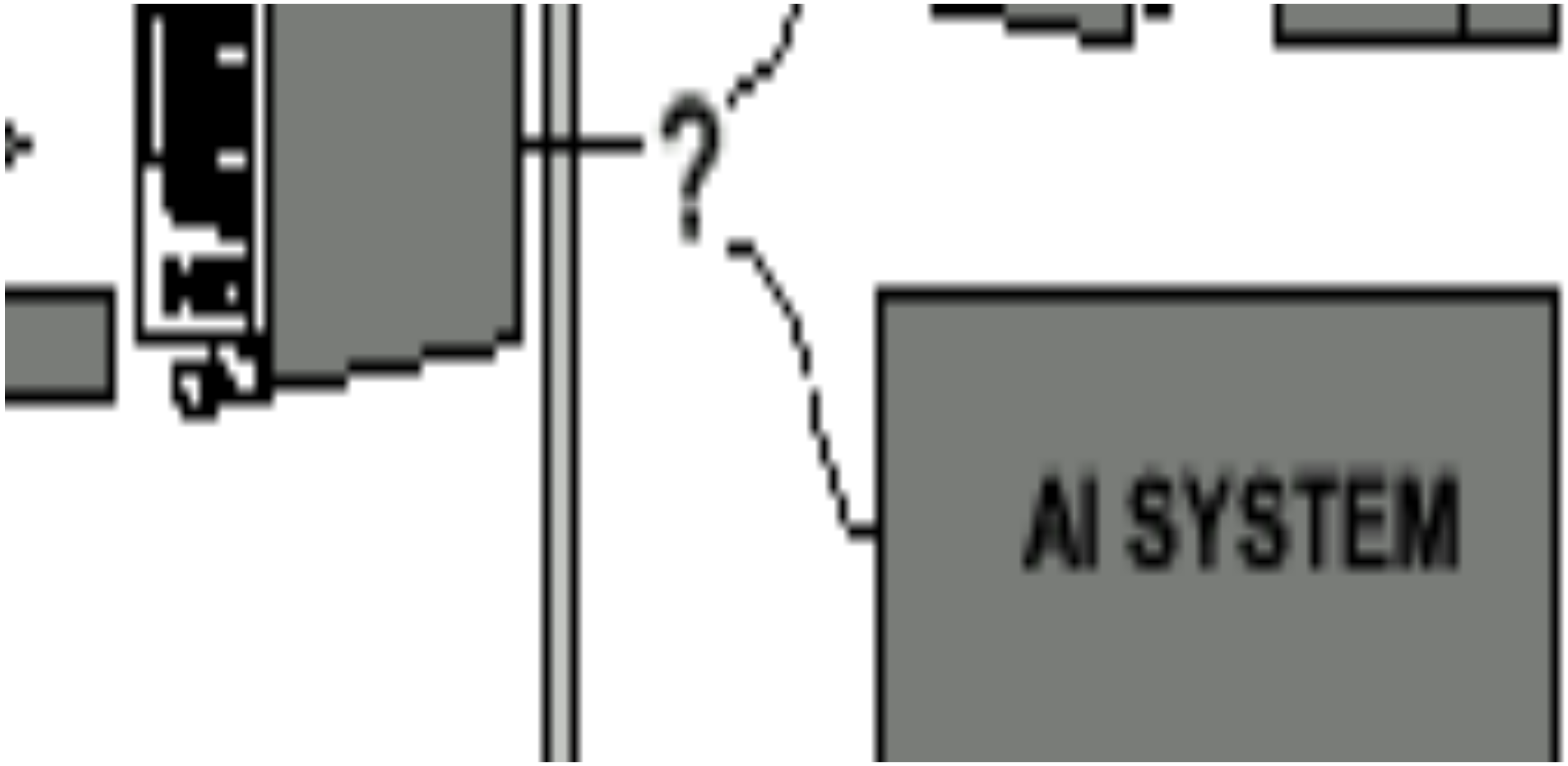
  2)Its goal of rationality is well defined

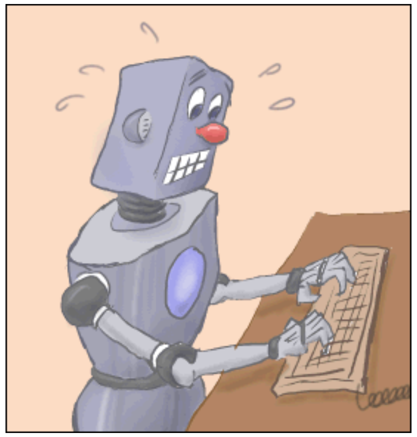
Acting Humanly: The Turing Test

- Alan Turing's 1950 article Computing Machinery and Intelligence discussed conditions for considering a machine to be intelligent
  - “Can machines think?” ←→ “Can machines behave intelligently?”
  - The Turing test (The Imitation Game): Operational definition of intelligence.



Acting Humanly: The Turing Test





- Computer needs to possess: Natural language processing, Knowledge representation, Automated reasoning, and Machine learning

- Are there any problems/limitations to the Turing Test?

Acting Humanly: The Full Turing Test

- Alan Turing's 1950 article Computing Machinery and Intelligence discussed conditions for considering a machine to be intelligent
  - “Can machines think?” ←→ “Can machines behave intelligently?”
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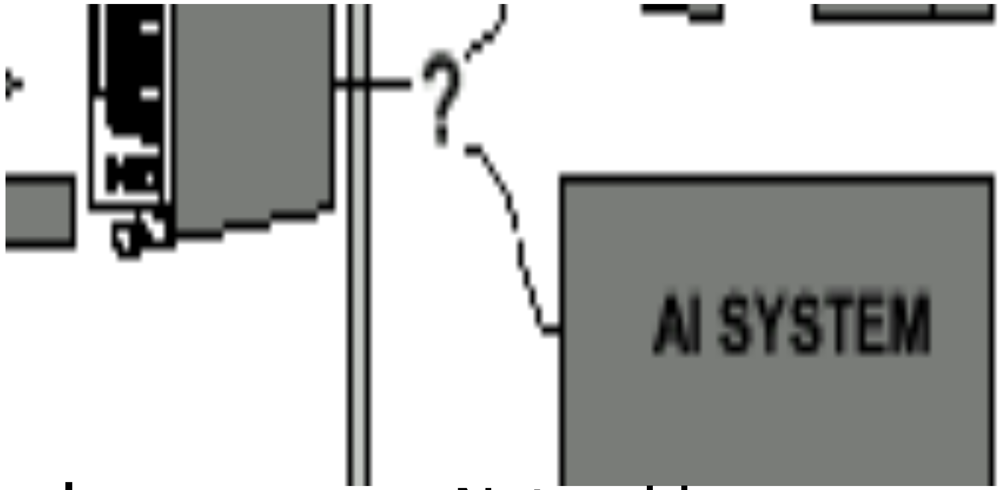
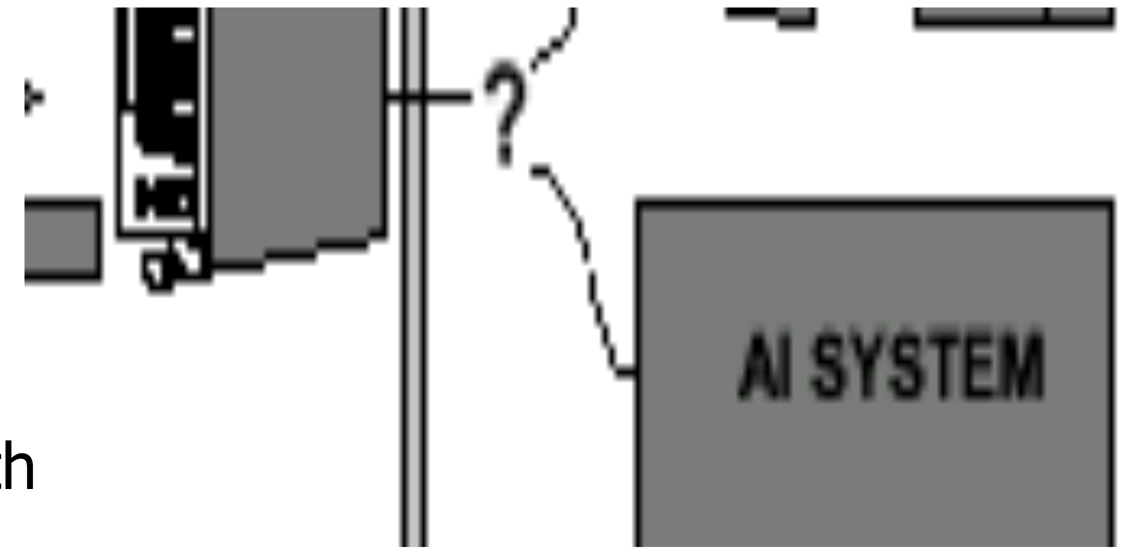


- Computer needs to possess: Natural language processing, Knowledge representation, Automated reasoning, and Machine learning
- Problem: 1) Turing test is not reproducible, constructive, and amenable to mathematic analysis. 2) What about physical interaction with interrogator and environment?
- Total Turing Test: Requires physical interaction and needs perception and actuation.

Acting Humanly: The Full Turing Test

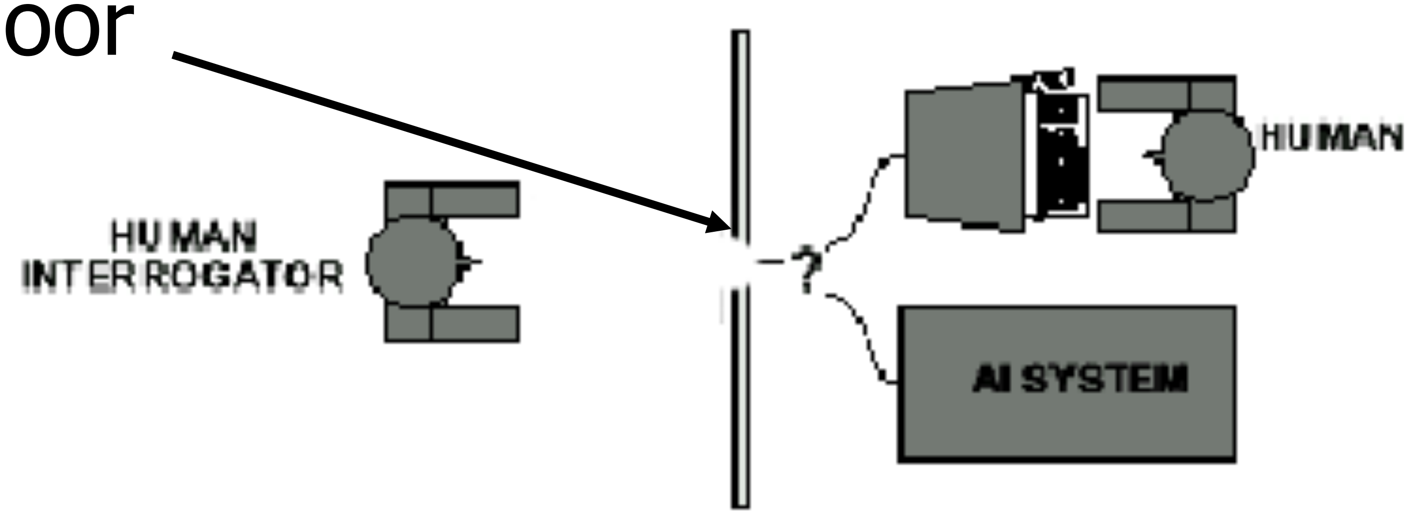


Problem:

1) Turing test is not reproducible, constructive, and amenable to mathematic analysis.

2) What about physical interaction with interrogator and environment?

Trap door



What a Computer Deeds to Pass a Turing Test?

- Natural language processing: to communicate with examiner.
- Knowledge representation: to store and retrieve information provided before or during interrogation.
- Automated reasoning: to use the stored information to answer questions and to draw new conclusions.
- Machine learning: to adapt to new circumstances and to detect and extrapolate patterns.

What a Computer Deeds to Pass a Turing Test?

- Natural language processing: to communicate with examiner.
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Core focus in this course

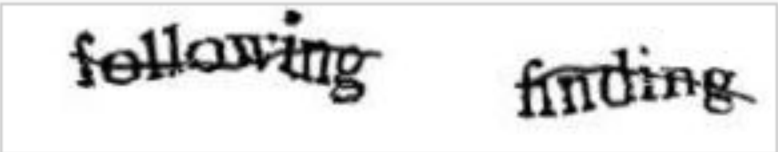
What a Computer Deeds to Pass a Turing Test?

- Vision (for Total Turing test): to recognize the examiner's actions and various objects presented by the examiner.
- Motor control (total test): to act upon objects as requested.
- Other senses (total test): such as audition, smell, touch, etc.

CAPTCHAs or “reverse Turing tests”

- Vision is a particularly difficult one for machines…
- Gave rise to “Completely Automated Public Turing test to tell Computers and Humans Apart” (CAPTCHA)

Early CAPTCHAs such as these, generated by the EZ-Gimpy program, were used on Yahoo!. However, technology was developed to read this type of CAPTCHA[1]



A modern CAPTCHA, rather than attempting to create a distorted background and high levels of warping on the text, might focus on making segmentation difficult by adding an angled line

Another way to make segmentation difficult is to crowd symbols together, as in Yahoo's current CAPTCHA format. This may occasionally present ambiguous challenges, as seen in the leftmost example, which could be read as "klopsh" or "kbpsh".

wikipedia

AI Prehistory

Philosophy	logic, methods of reaso
	mind as physical syster
	foundations of learning
Mathematics	formal representation a
	algorithms
	computation, (un)decic
	probability
Psychology	adaptation
	phenomena of percepti
	experimental technique
Linguistics	knowledge representati
	grammar
Neuroscience	physical substrate for r
Control theory	homeostatic systems, s

AI History

1943	McCulloch & Pitts: Boolean circuit model of brain
1950	Turing's "Computing Machinery and Intelligence"
1952–69	Look, Ma, no hands!
1950s	Early AI programs, including Samuel's checkers program, Newell & Simon's Logic Theorist, Gelernter's Geometry Engine
1956	Dartmouth meeting: "Artificial Intelligence" adopted
1965	Robinson's complete algorithm for logical reasoning
1966–74	AI discovers computational complexity Neural network research almost disappears
1969–79	Early development of knowledge-based systems
1980–88	Expert systems industry booms
1988–93	Expert systems industry busts: "AI Winter"
1985–95	Neural networks return to popularity
1988–	Resurgence of probabilistic and decision-theoretic methods Rapid increase in technical depth of mainstream AI "Nouvelle AI": ALife, GAs, soft computing

Professor Herbert A. Simon
Nobel Price Winner
A Founding Father of Artificial Intelligence

AI: The Current State of the Art

- Have the following been achieved by AI?
  - Pass the Turing test
  - World-class chess playing
  - Playing table tennis
  - Cross-country driving
  - Solving mathematical problems
  - Discovering and proving mathematical theories
  - Engaging in a meaningful conversation
  - Understanding spoken language
  - Observing and understanding human emotions
  - Expressing emotions
  - …

Computer AI passes Turing test in 'world first'

9 June 2014 | Technology

Eugene Goostman simulates a 13-year-old Ukrainian boy

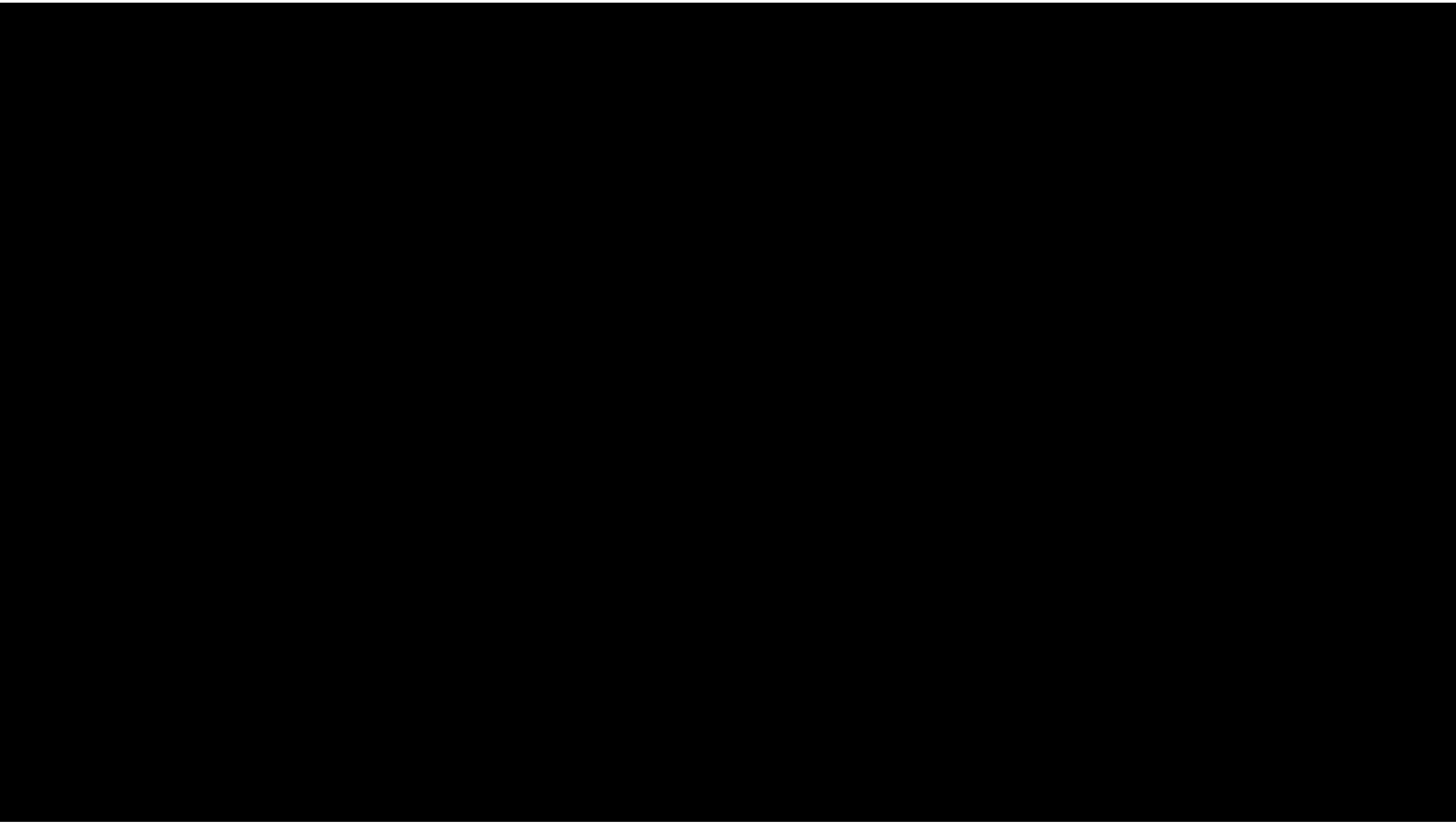
AI State of the Art

DARPA Urban Challenge (2007)

- "Autonomous vehicles that safely execute missions in a complex urban environment with moving traffic."
  - "The objective of this program is safe and correct autonomous driving capability in traffic at 20 mph."

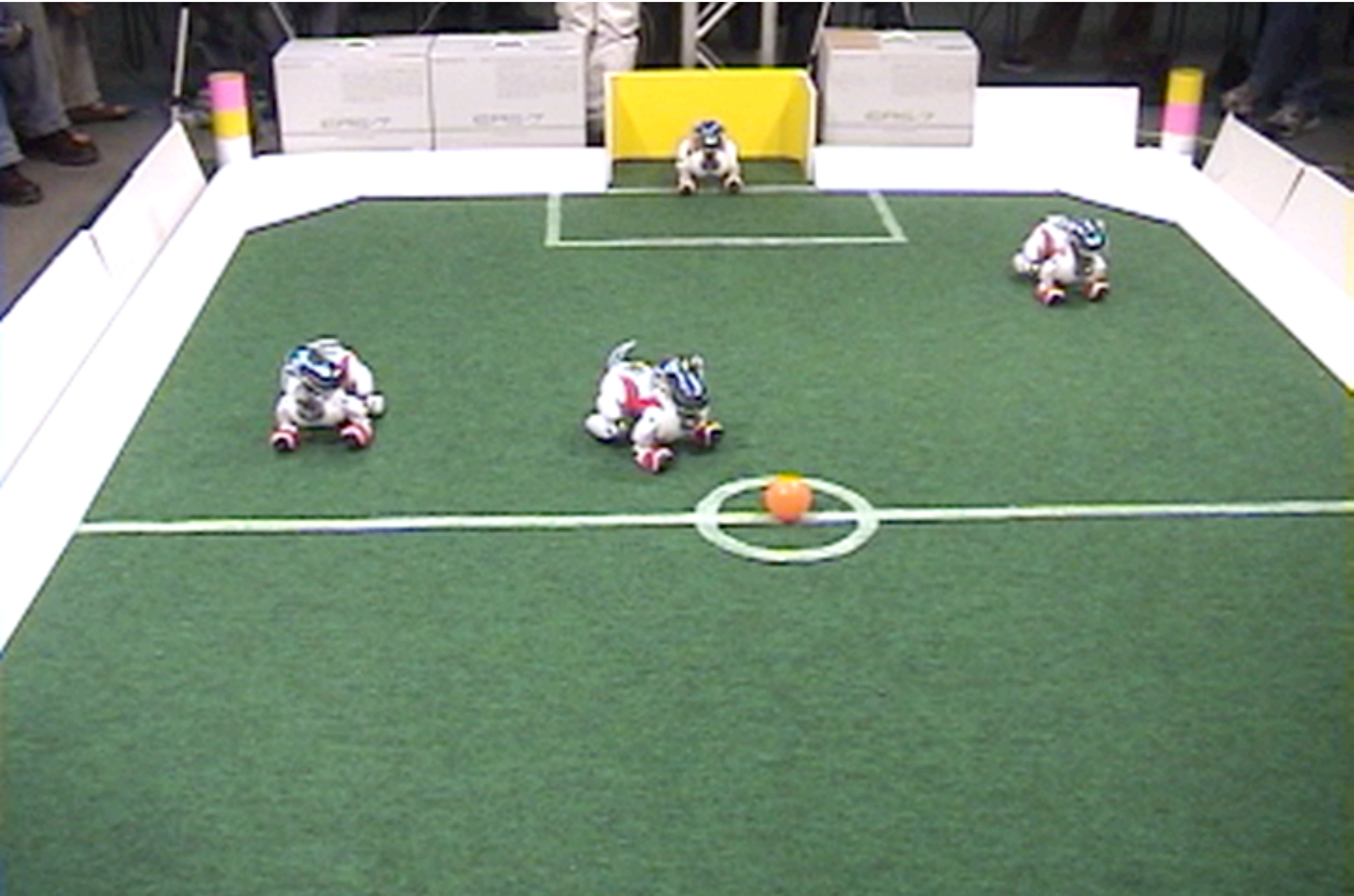
DARPA Urban Challenge (crossing desert)

Singing Robots (from Japan)



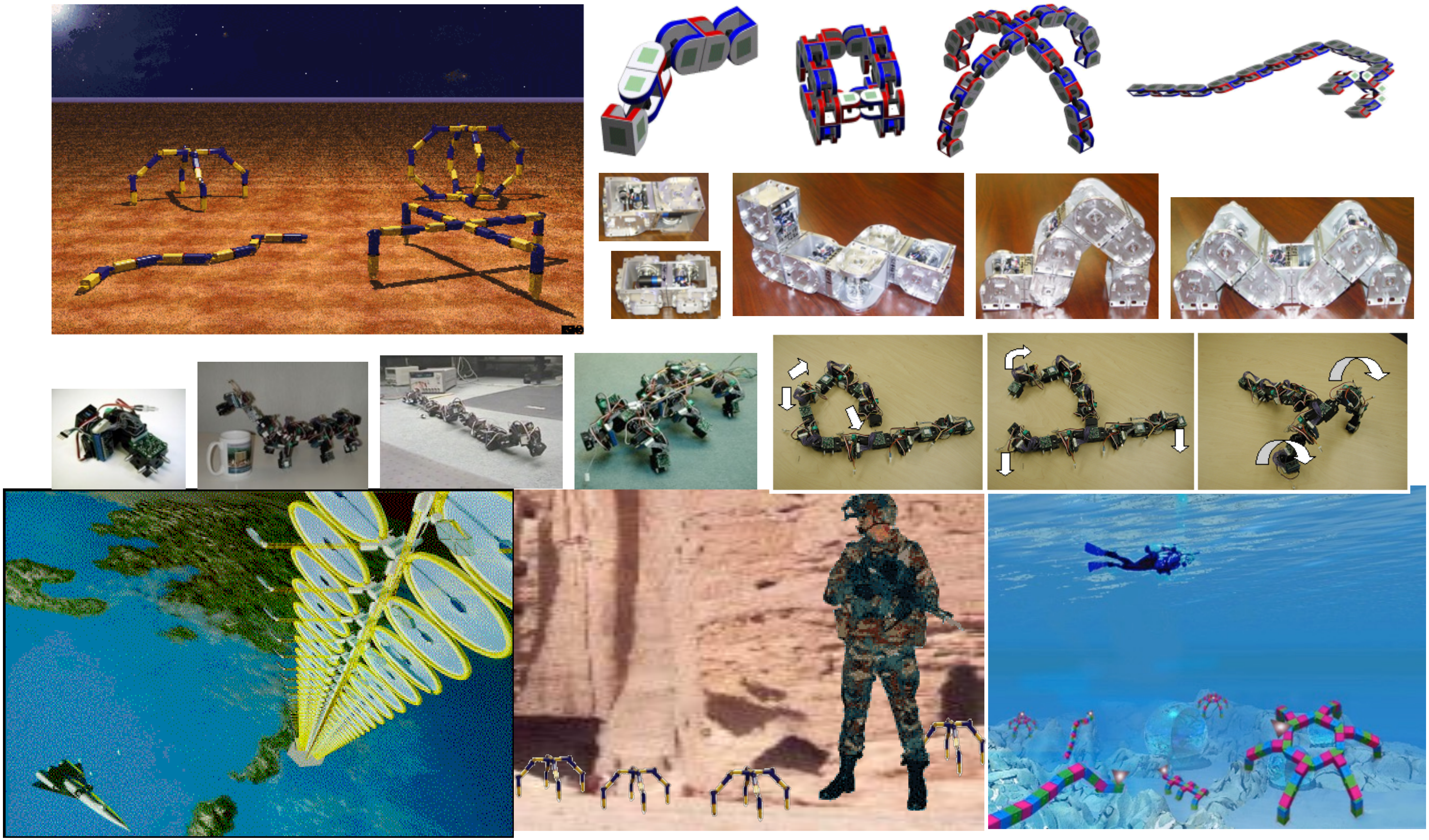
First RoboCup (1997, USC Dreamteam)


SONY



USC Self-Reconfigurable "SuperBot"

USC Self-Reconfigurable SuperBot



SuperBot Vision for Space

Modular, Multifunction, Self-Reconfiguration

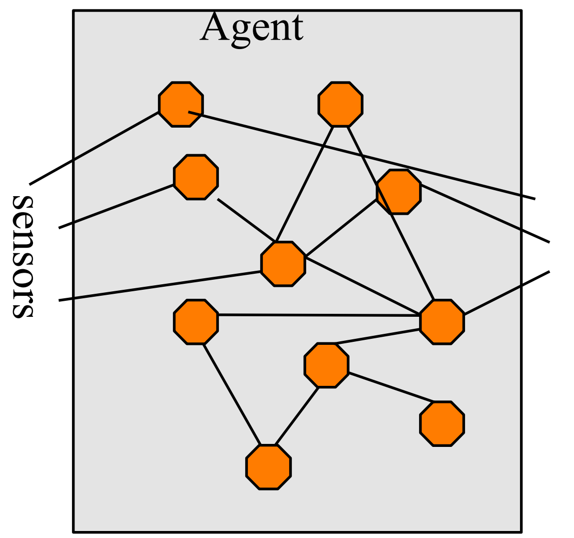
A Quick “Walk Through” of the Semester

(Please read this section by yourself too)

Course Overview

General Introduction

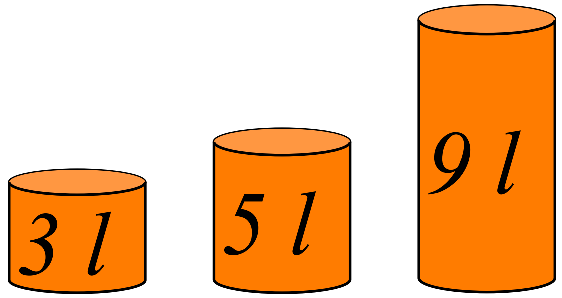
- **01-Introduction.** [AIMA Ch 1] Course Schedule. Homeworks, exams and grading. Course material, TAs and office hours. Why study AI? What is AI? The Turing test. Rationality. Branches of AI. Research disciplines connected to and at the foundation of AI. Brief history of AI. Challenges for the future. Overview of class syllabus.
  Intelligent Agents. [AIMA Ch 2] What is an intelligent agent? Examples. Doing the right thing (rational action). Performance measure. Autonomy. Environment and agent design. Structure of agents. Agent types. Reflex agents. Reactive agents. Reflex agents with state. Goal-based agents. Utility-based agents. Mobile agents. Information agents.



Course Overview (cont.)

How can we solve complex problems?

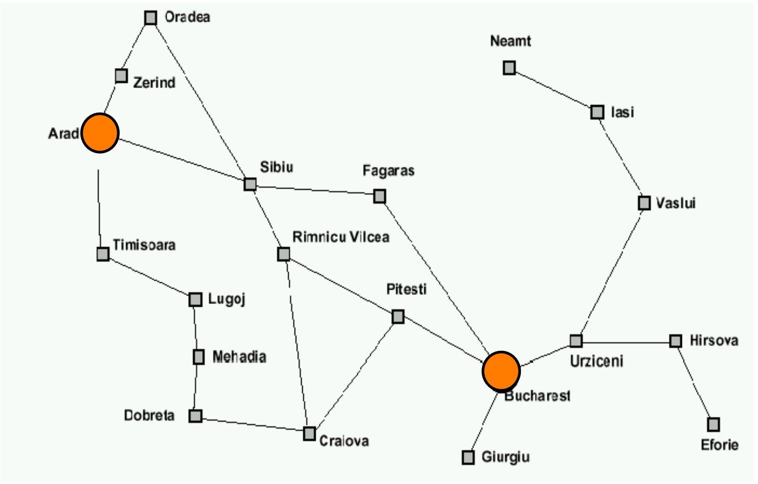
- **02-Problem solving and search.** [AIMA Ch 3] Example: measuring problem. Types of problems. More example problems. Basic idea behind search algorithms. Complexity. Combinatorial explosion and NP completeness. Polynomial hierarchy.



Using these 3 buckets, measure 7 liters of water.

- **03/04-Uninformed search.** [AIMA Ch 3] Depth-first. Breadth-first. Uniform-cost. Depth-limited. Iterative deepening. Examples. Properties.

- **05/06-Informed search.** [AIMA Ch 4] Best-first. A* search. Heuristics. Hill climbing. Problem of local extrema. Simulated annealing. Genetic algorithms.

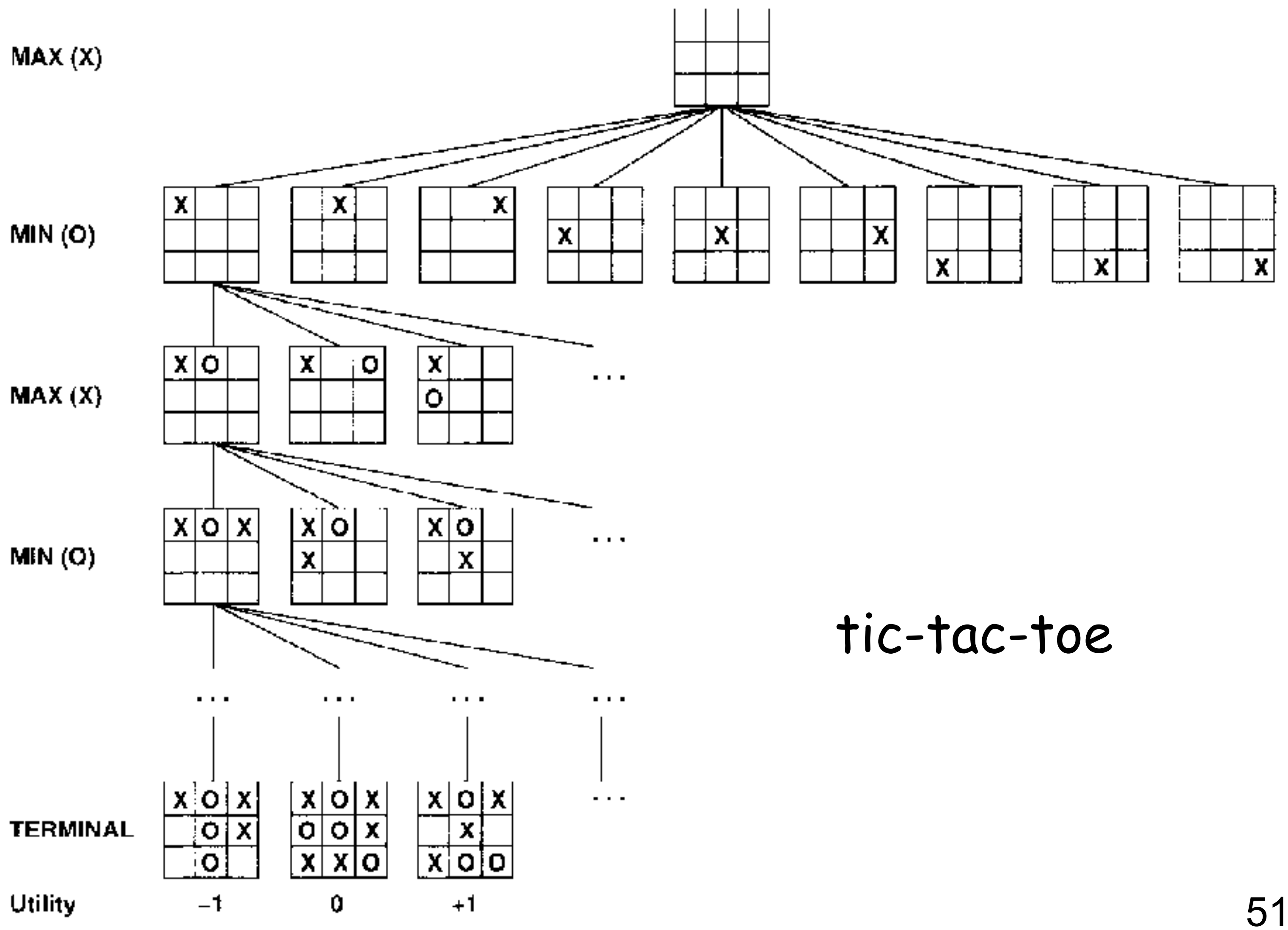


Traveling salesperson problem

Course Overview (cont.)

Practical applications of search.

- **07-Game playing.** [AIMA Ch 5] The minimax algorithm. Resource limitations. Aplha-beta pruning. Elements of chance and non-deterministic games.

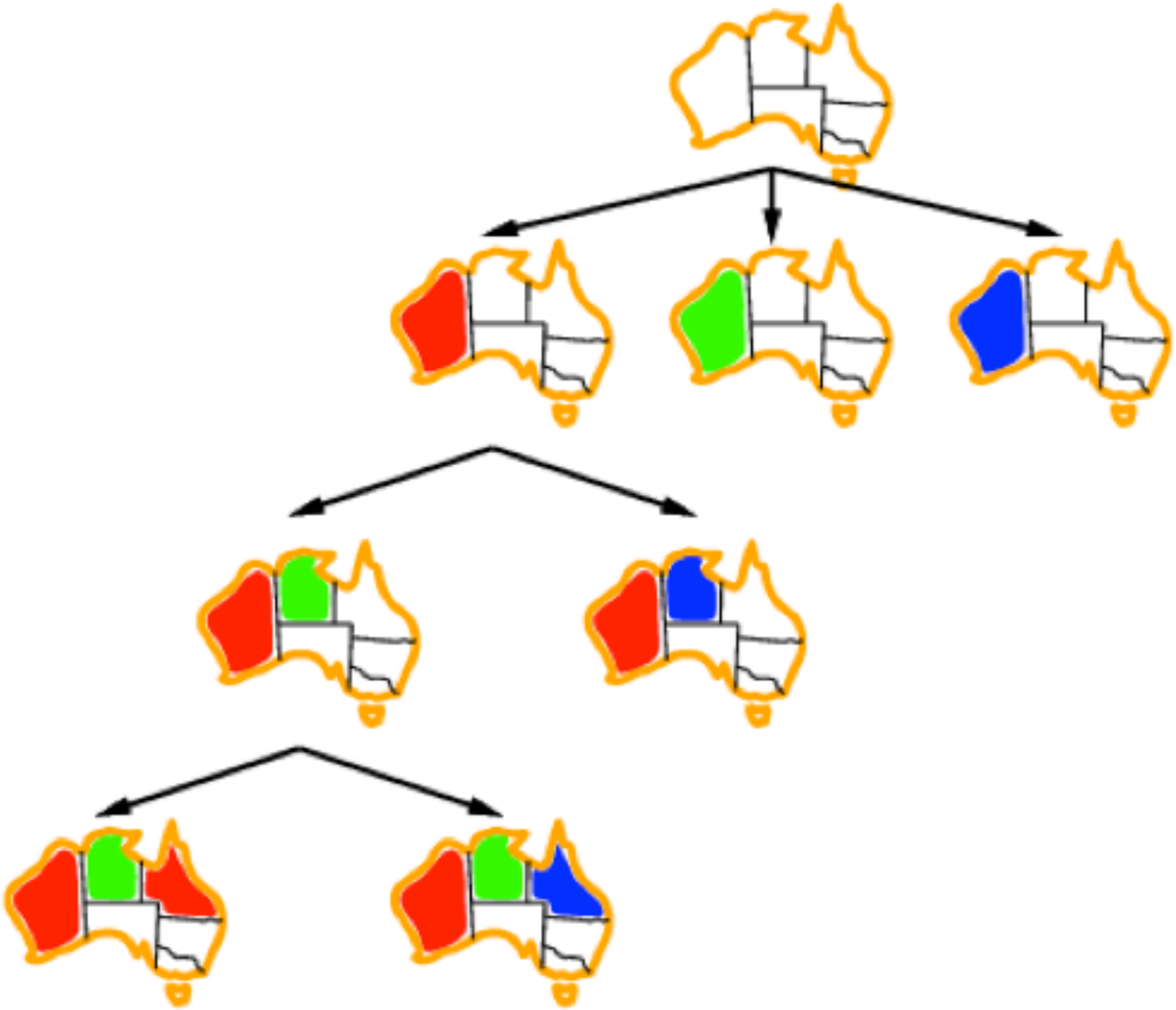


tic-tac-toe

Course Overview (cont.)

Search under constraints

- **08-Constraint satisfaction.** [AIMA Ch 6] Node, arc, path, and k-consistency. Backtracking search. Local search using min-conflicts.



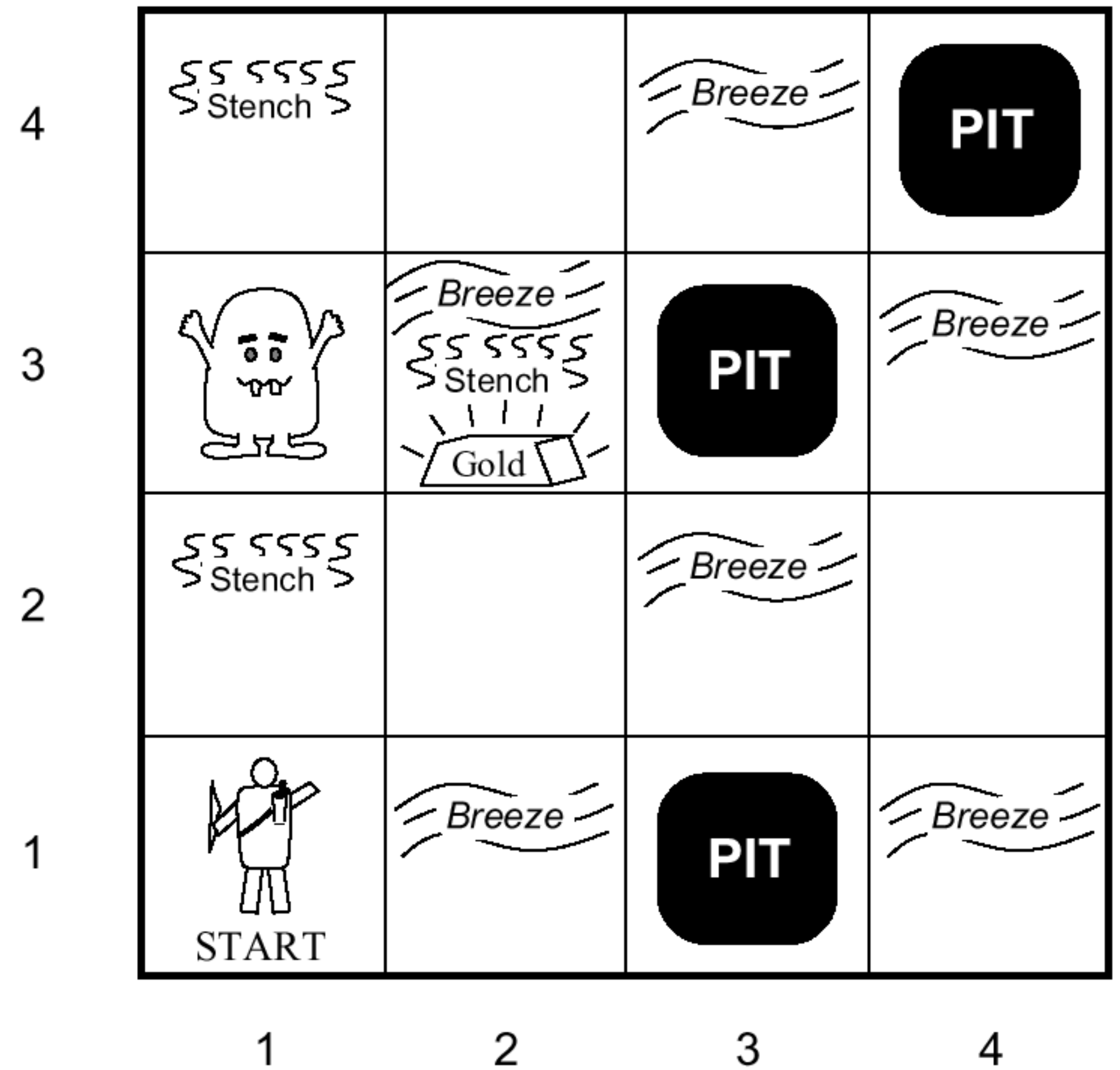
Map coloring

Course Overview (cont.)

Towards intelligent agents

- **9-Agents that reason logically 1.** [AIMA Ch 7] Knowledge-based agents. Logic and representation. Propositional (boolean) logic.

- **10-Agents that reason logically 2.** [AIMA Ch 7] Inference in propositional logic. Syntax. Semantics. Examples.



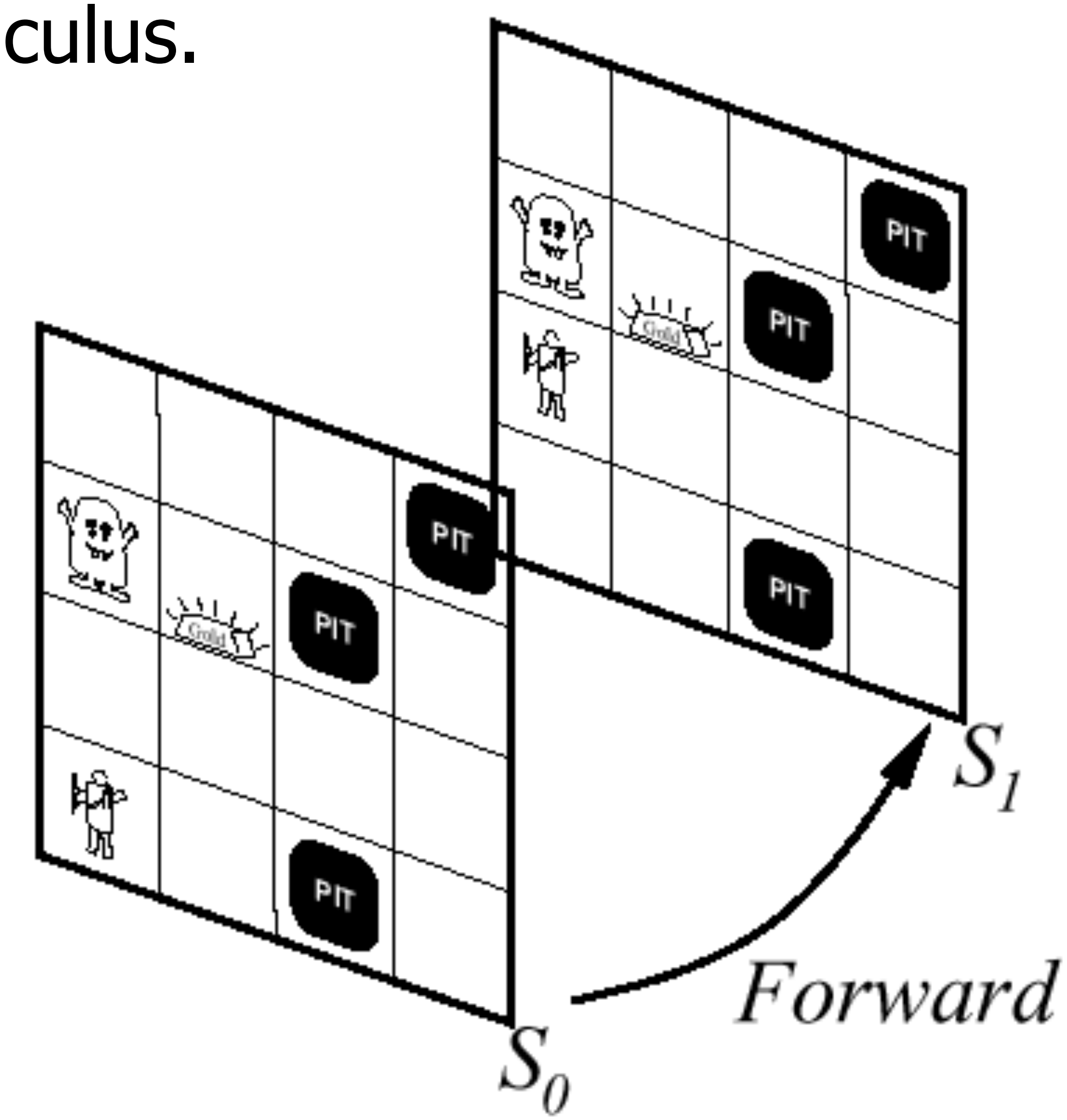
wumpus world

Course Overview (cont.)

Building knowledge-based agents: 1st Order Logic

- **11-First-order logic 1.** [AIMA Ch 8] Syntax. Semantics. Atomic sentences. Complex sentences. Quantifiers. Examples. FOL knowledge base. Situation calculus.

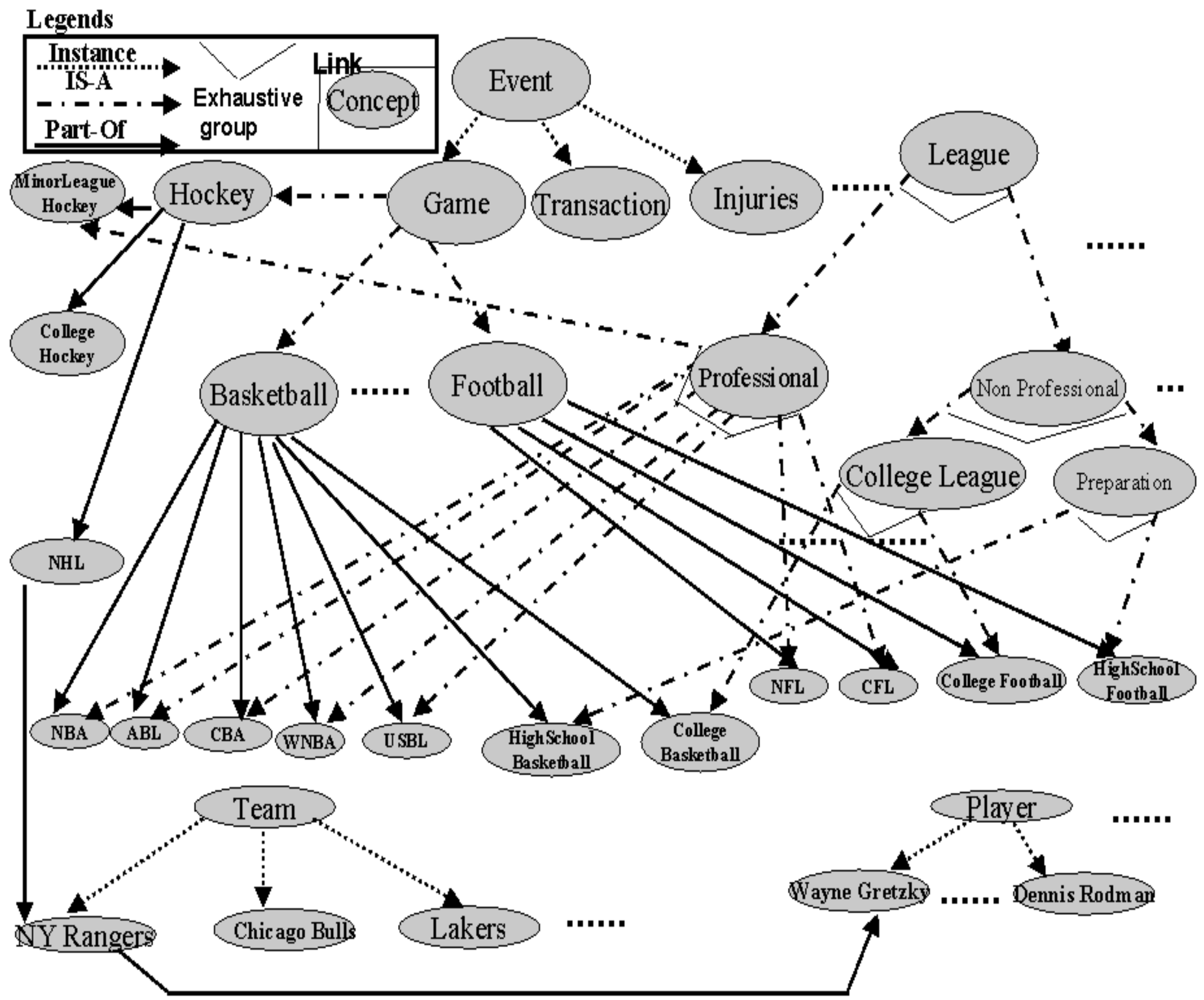
- **12-First-order logic 2.** [AIMA Ch 8] Describing actions. Planning. Action sequences.



Course Overview (cont.)

Representing and Organizing Knowledge

- **13-Building a knowledge base.** [AIMA Ch 12] Knowledge bases. Vocabulary and rules. Ontologies. Organizing knowledge.

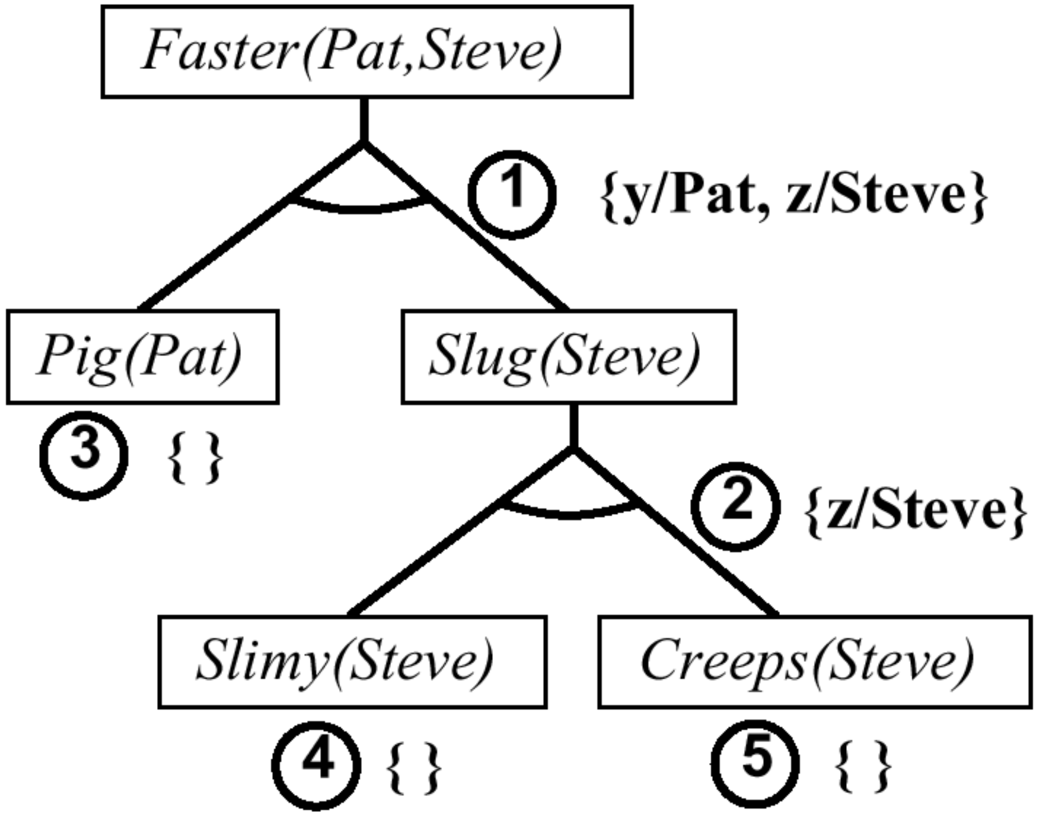


An ontology for the sports domain

Course Overview (cont.)

Reasoning Logically

- **14/15-Inference in first-order logic.** [AIMA Ch 9] Proofs. Unification. Generalized modus ponens. Forward and backward chaining.

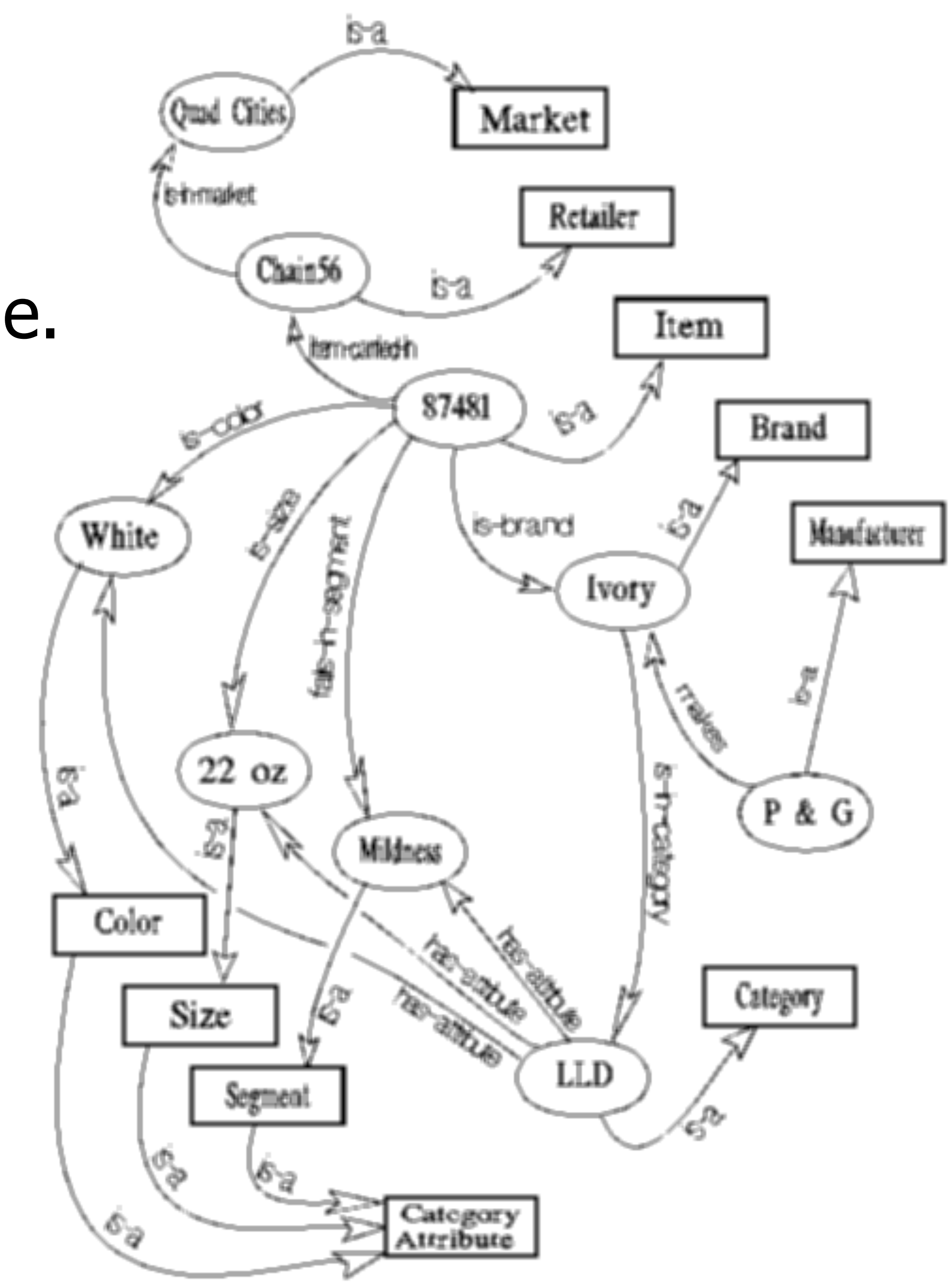


Example of backward chaining

Course Overview (cont.)

Examples of Logical Reasoning Systems

- **16-Logical reasoning systems.** [AIMA Ch 9] Indexing, retrieval and unification. The Prolog language. Theorem provers. Frame systems and semantic networks.

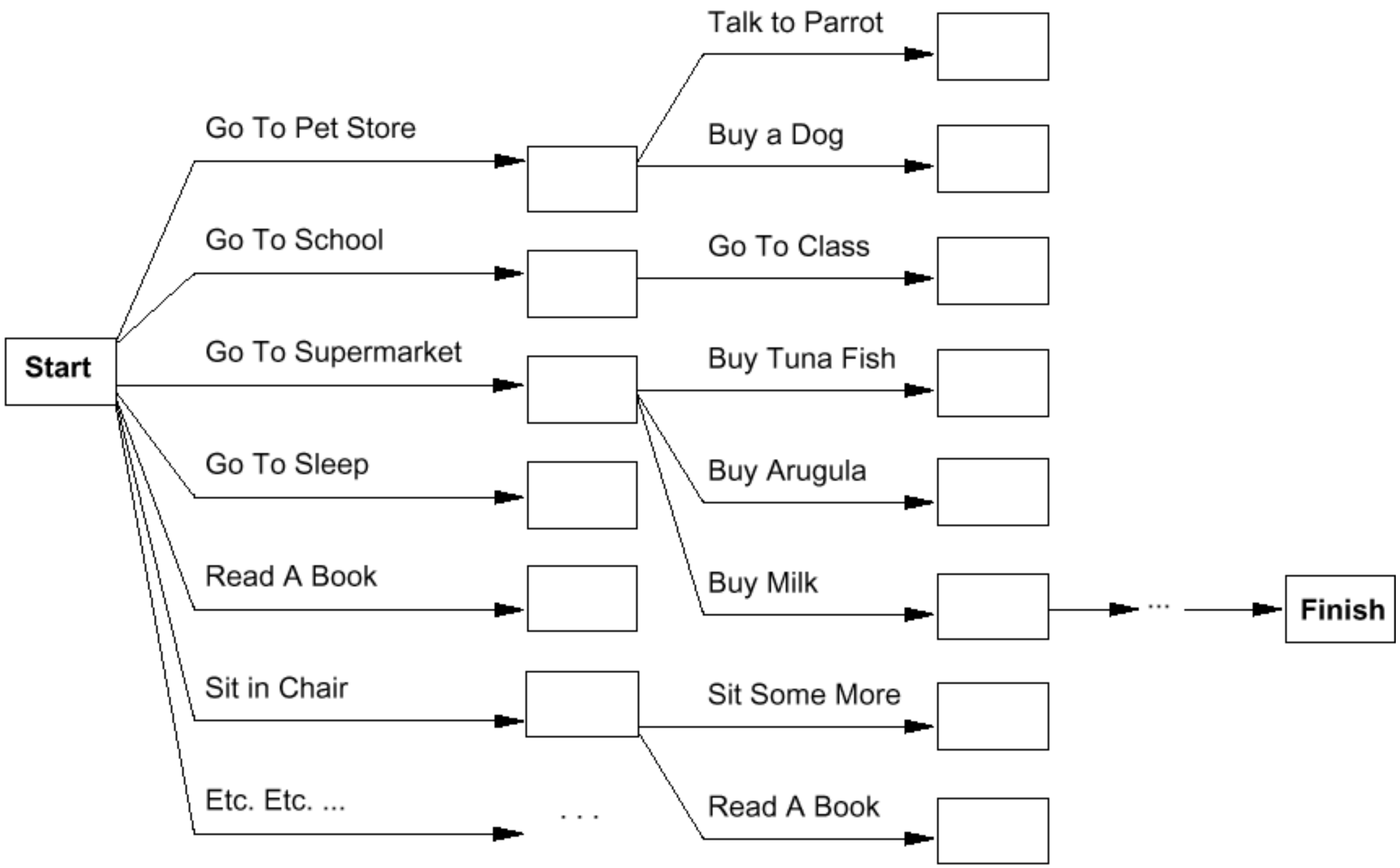


Semantic network used in an insight generator (Duke university)

Course Overview (cont.)

Systems that can Plan Future Behavior

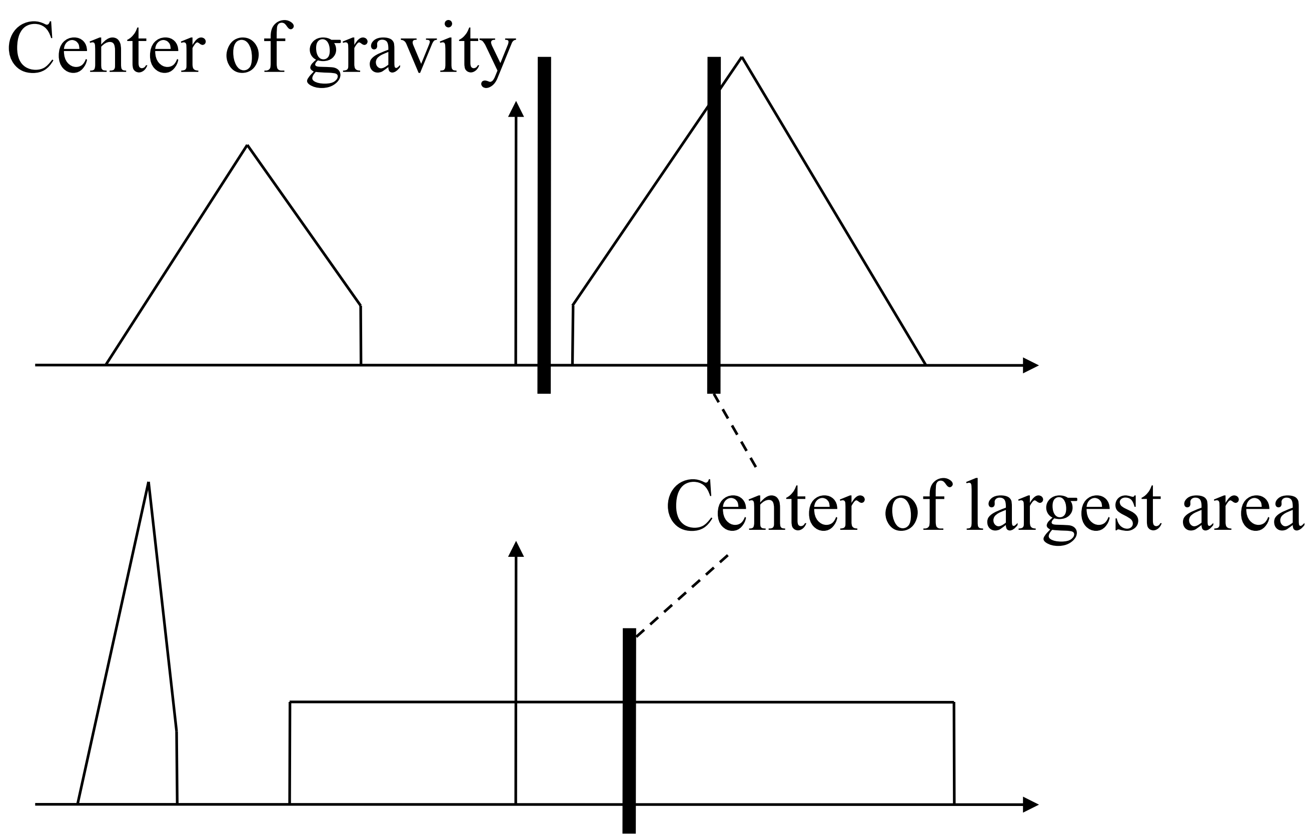
- **17-Planning.** [AIMA Ch 10] Definition and goals. Basic representations for planning. Situation space and plan space. Examples.



Course Overview (cont.)

Handling fuzziness, change, uncertainty.

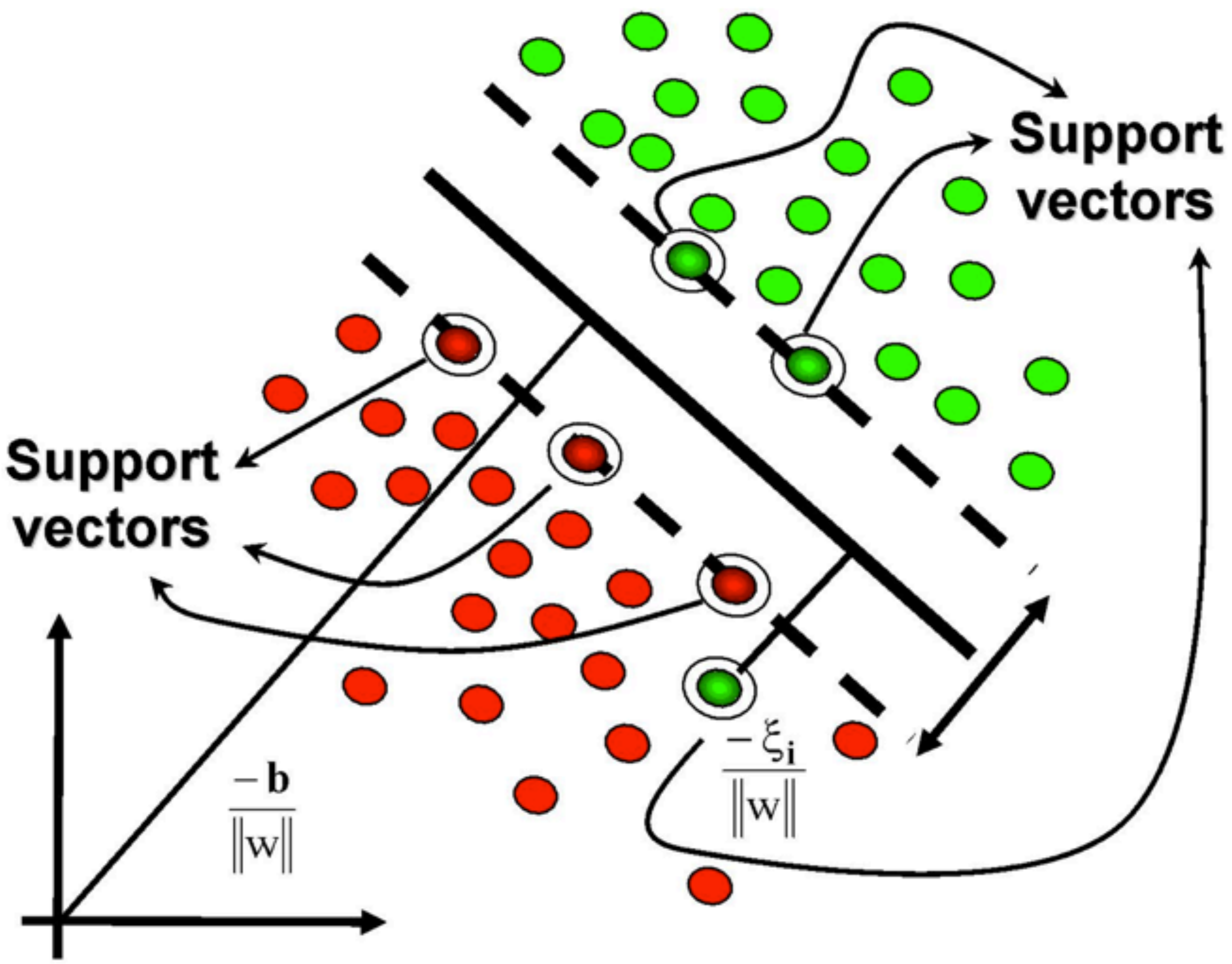
18-Fuzzy logic. [handout]. Fuzzy variables, fuzzy inference, aggregation, defuzzification.



Course Overview (cont.)

Handling fuzziness, change, uncertainty.

19-Learning from examples. [AIMA 18 + handout].
Supervised learning, learning decision trees, support vector machines.

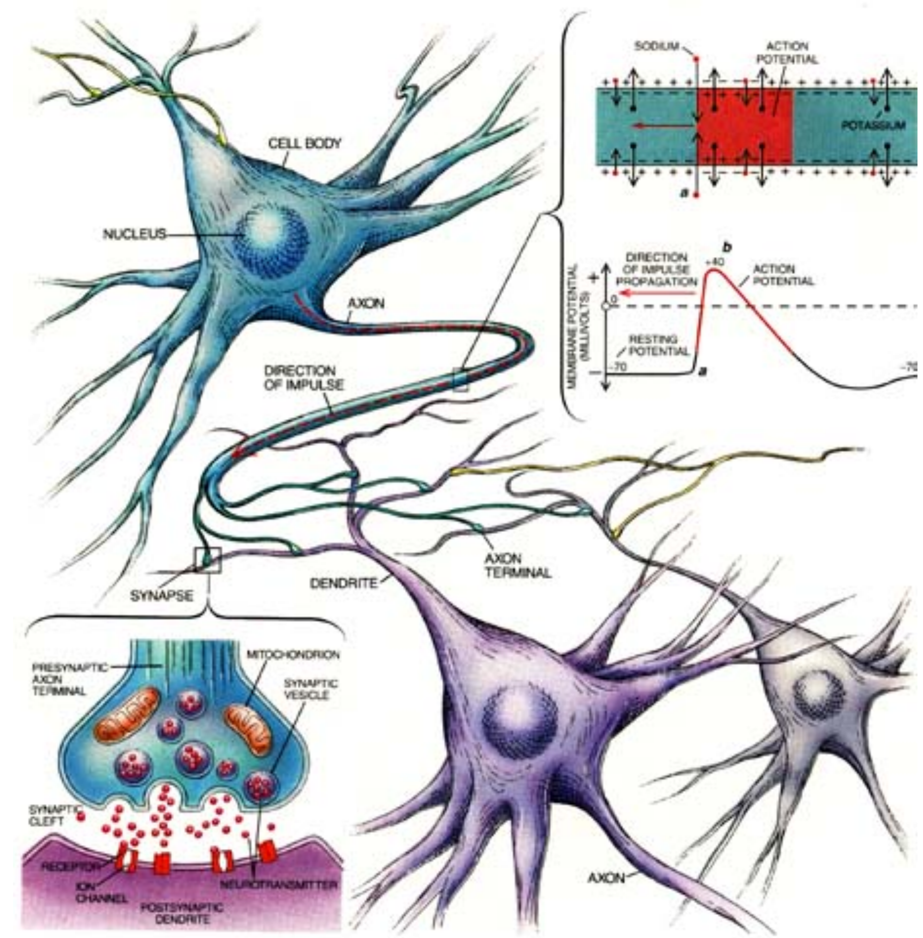


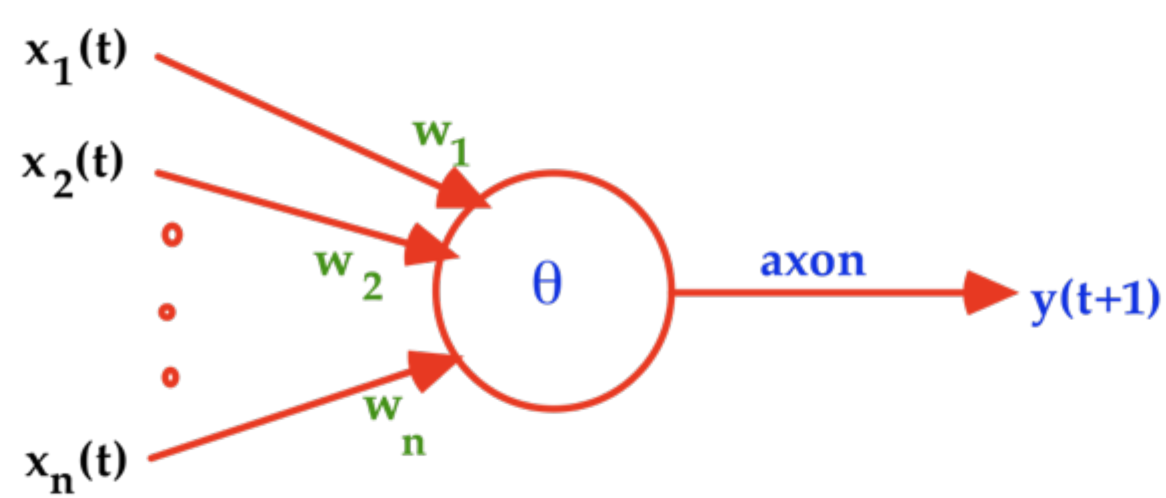
Course Overview (cont.)

Learning with Neural networks

- **20/21-Learning with Neural Networks.**

  [Handout + AIMA 18]
  Introduction to perceptrons, Hopfield networks, self-organizing feature maps. How to size a network? What can neural networks achieve? Advanced concepts – convnets, deep learning, stochastic gradient descent, dropout learning, autoencoders, applications and state of the art.





Course Overview (cont.)

Handling uncertainties and unexpected changes

- **22/23-Probabilistic reasoning.** [AIMA Ch 13, 14, 15] Reasoning under uncertainty – probabilities, conditional independence, Markov blanket, Bayes nets. Probabilistic reasoning in time. Hidden Markov Models, Kalman filters, dynamic Bayesian networks.

For assessing diagnostic probability from causal probability:

$$P(Cause|Effect) = \frac{P(Effect|Cause)P(Cause)}{P(Effect)}$$

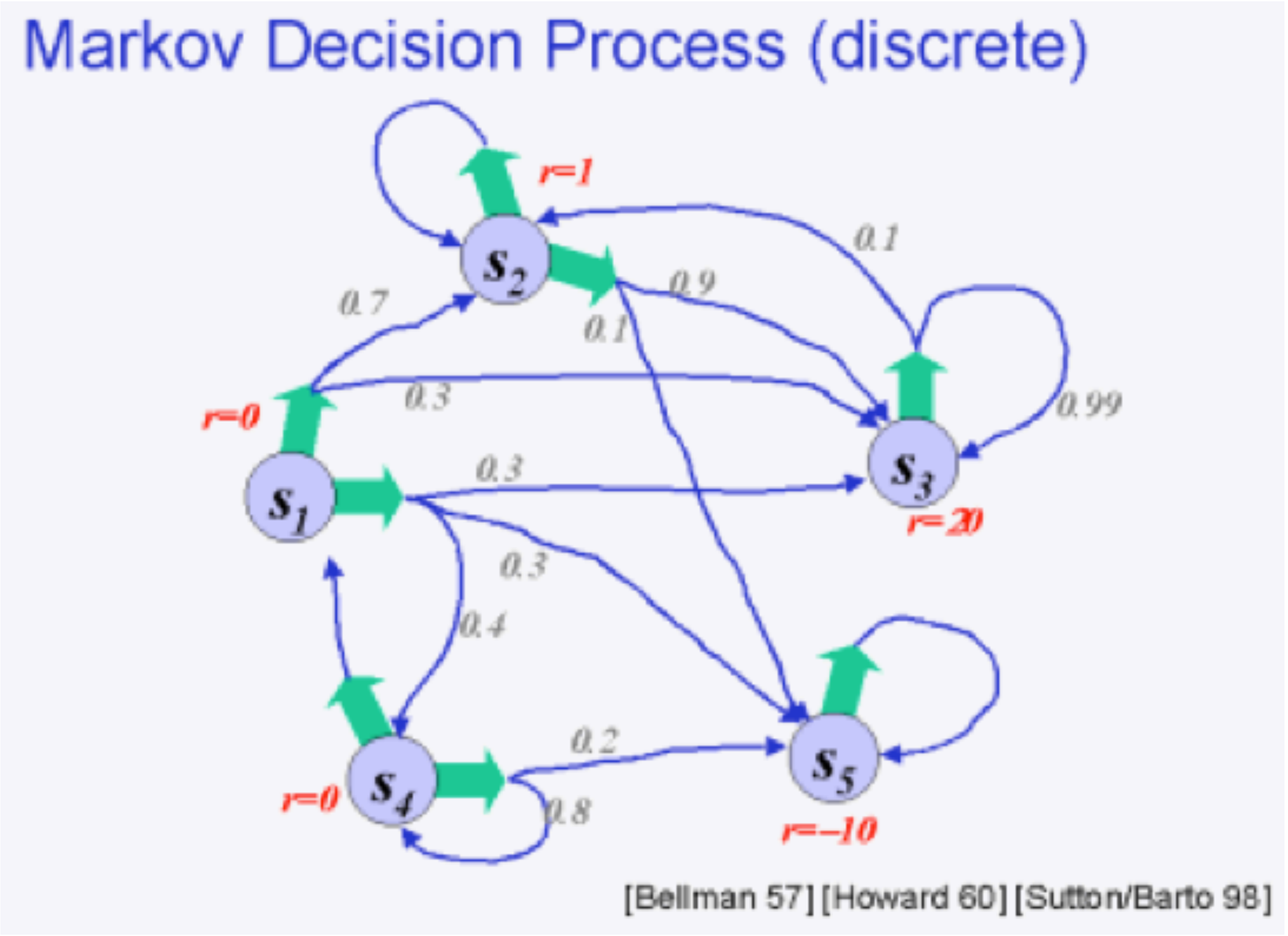
E.g., let M be meningitis, S be stiff neck:

$$P(M|S) = \frac{P(S|M)P(M)}{P(S)} = \frac{0.8 \times 0.0001}{0.1} = 0.0008$$

Course Overview (cont.)

Handling uncertainties and unexpected changes

- **24-Probabilistic decision making.** [AIMA 16, 17] – utility theory, decision networks, value iteration, policy iteration, Markov decision processes (MDP), partially-observable MDP (POMDP).

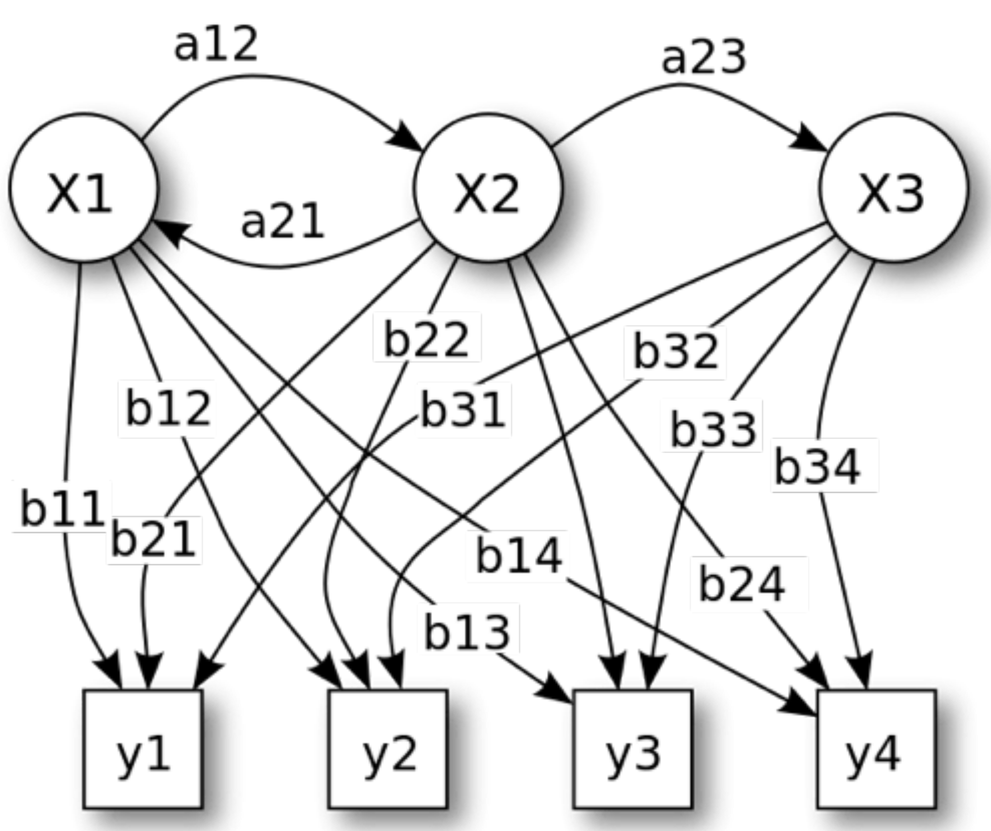


Course Overview (cont.)

Handling uncertainties and unexpected changes

- **25-Probabilistic reasoning over time.** [AIMA 15]

Temporal models, Hidden Markov Models, Kalman filters, Dynamic Bayesian Networks, Automata theory.

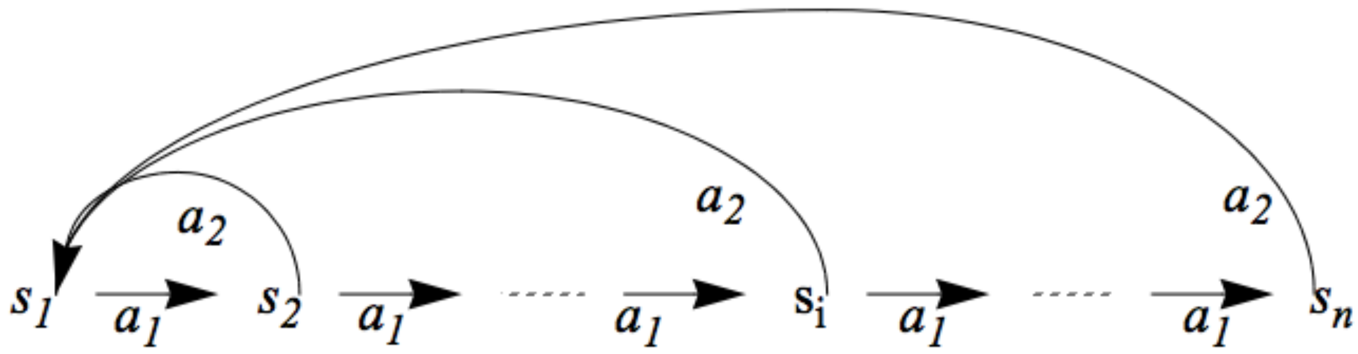


Course Overview (cont.)

Handling uncertainties and unexpected changes

- **26-Probability-based learning.** [AIMA 20-21]

Probabilistic Models, Naïve Bayes Models, EM algorithm, Reinforcement Learning.



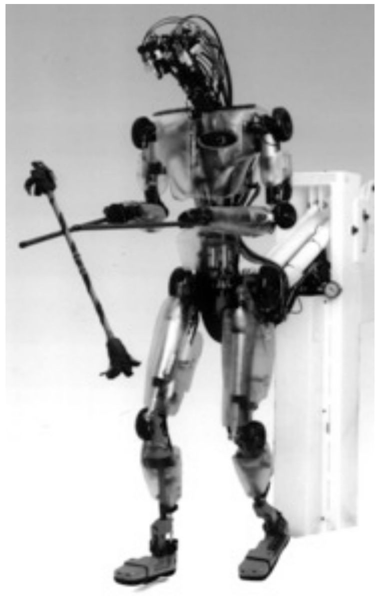
$$Q_{k+1}(s,a) \leftarrow \sum_{s'} T(s,a,s') \left[R(s,a,s') + \gamma \max_{a'} Q_k(s',a') \right]$$

Course Overview (cont.)

What challenges remain?

- **27-Natural language processing.** [AIMA Ch 22, 23] Language models, information retrieval, syntactic analysis, machine translation, speech recognition.

- **28-Towards intelligent machines.** [AIMA Ch 26, 27] The challenge of robots: with what we have learned, what hard problems remain to be solved? Different types of robots. Tasks that robots are for. Parts of robots. Architectures. Configuration spaces. Navigation and motion planning. Towards highly-capable robots. What have we learned. Where do we go from here?



Today's Concept: Defining Intelligent Agents

- Intelligent Agents (IA)
- Environment types
- IA Behavior
- IA Structure
- IA Types

What is an (Intelligent) Agent?

- An over-used, over-loaded, and misused term.

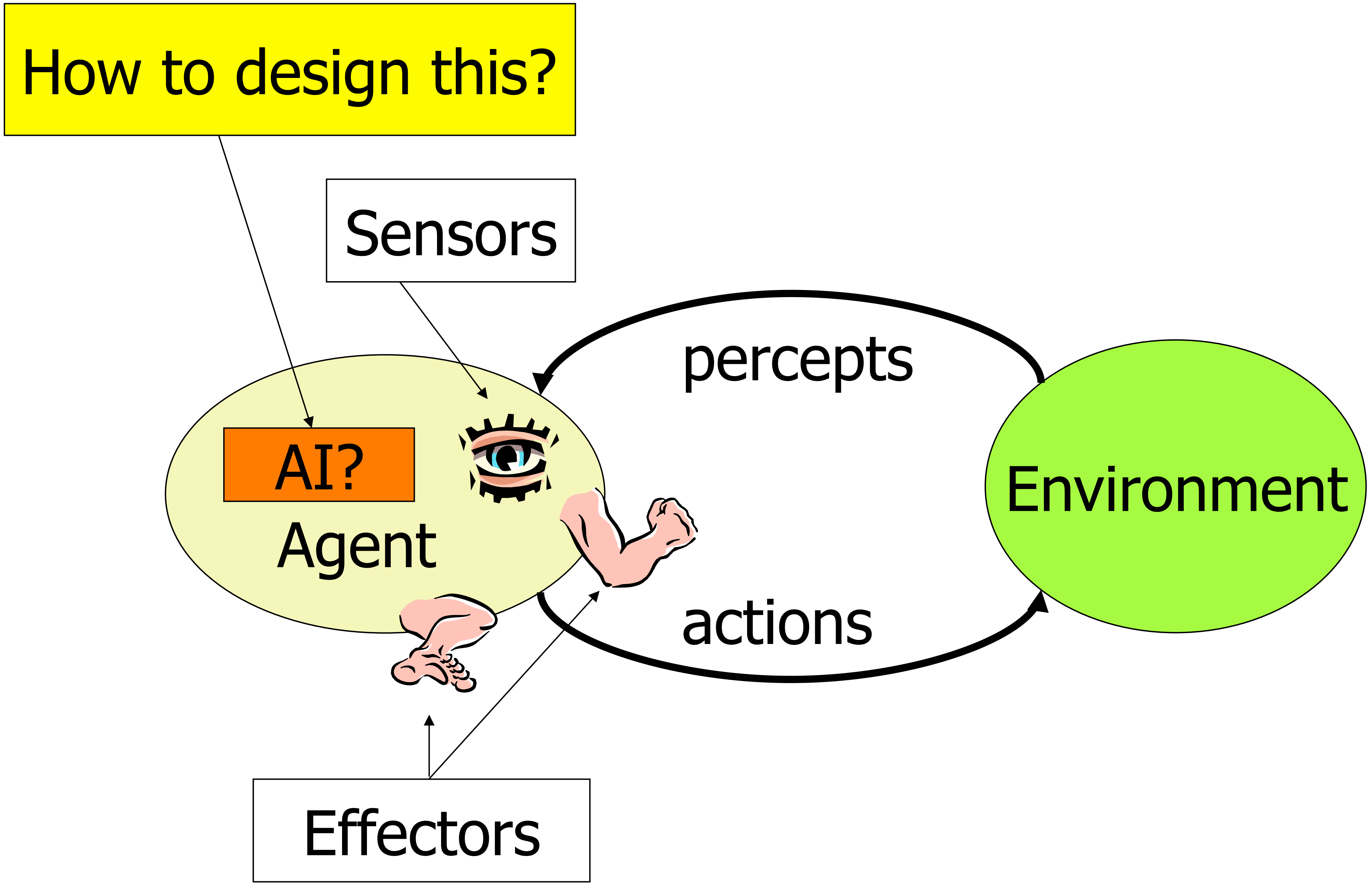
- Anything that can be *viewed as* **perceiving** its **environment** through **sensors** and **acting** upon that environment through its **effectors** to maximize progress towards its **goals**.

What is an (Intelligent) Agent?

- **PAGE** (Percepts, Actions, Goals, Environment)

- Task-specific & specialized: well-defined goals and environment
- The notion of an agent is meant to be a tool for analyzing systems,
  - It is not a different hardware or new programming languages

Rational Agents



A Windshield Wiper Agent

How do we design a agent that can wipe the windshields when needed?

- Goals?
- Percepts?
- Sensors?
- Effectors?
- Actions?
- Environment?

A Windshield Wiper Agent (Cont'd)

- Goals: Keep windshields clean & maintain visibility
- Percepts: Raining, Dirty
- Sensors: Camera (moist sensor)
- Effectors: Wipers (left, right, back)
- Actions: Off, Slow, Medium, Fast
- Environment: Inner city, freeways, highways, weather …

Interacting Agents (for Autonomous Driving)

Collision Avoidance Agent (CAA)
- Goals: Avoid running into obstacles
- Percepts ?
- Sensors?
- Effectors ?
- Actions ?
- Environment: Freeway

Lane Keeping Agent (LKA)
- Goals: Stay in current lane
- Percepts ?
- Sensors?
- Effectors ?
- Actions ?
- Environment: Freeway

Interacting Agents

Collision Avoidance Agent (CAA)
- Goals: Avoid running into obstacles
- Percepts: Obstacle distance, velocity, trajectory
- Sensors: Vision, proximity sensing
- Effectors: Steering Wheel, Accelerator, Brakes, Horn, Headlights
- Actions: Steer, speed up, brake, blow horn, signal (headlights)
- Environment: Freeway

Lane Keeping Agent (LKA)
- Goals: Stay in current lane
- Percepts: Lane center, lane boundaries
- Sensors: Vision
- Effectors: Steering Wheel, Accelerator, Brakes
- Actions: Steer, speed up, brake
- Environment: Freeway

Conflict Resolution by Action Selection Agents

- **Override:** CAA overrides LKA

- **Arbitrate:** if Obstacle is Close then CAA
  else LKA

- **Compromise:** Choose action that satisfies both agents

- Any combination of the above

- **Challenges:** Doing the right thing

The Right Thing = The Rational Action

- **Rational Action:** The action that maximizes the expected value of the performance measure given the percept sequence to date

  - Rational = Best ?
  - Rational = Optimal ?
  - Rational = Omniscience ?
  - Rational = Clairvoyant ?
  - Rational = Successful ?

The Right Thing = The Rational Action

- **Rational Action:** The action that maximizes the expected value of the performance measure <u>given the percept sequence to date</u>

  - Rational = Best — Yes, to the best of its knowledge
  - Rational = Optimal — Yes, to the best of its abilities (incl. its constraints)
  - Rational ≠ Omniscience
  - Rational ≠ Clairvoyant
  - Rational ≠ Successful

Behavior and Performance of Intelligent Agents

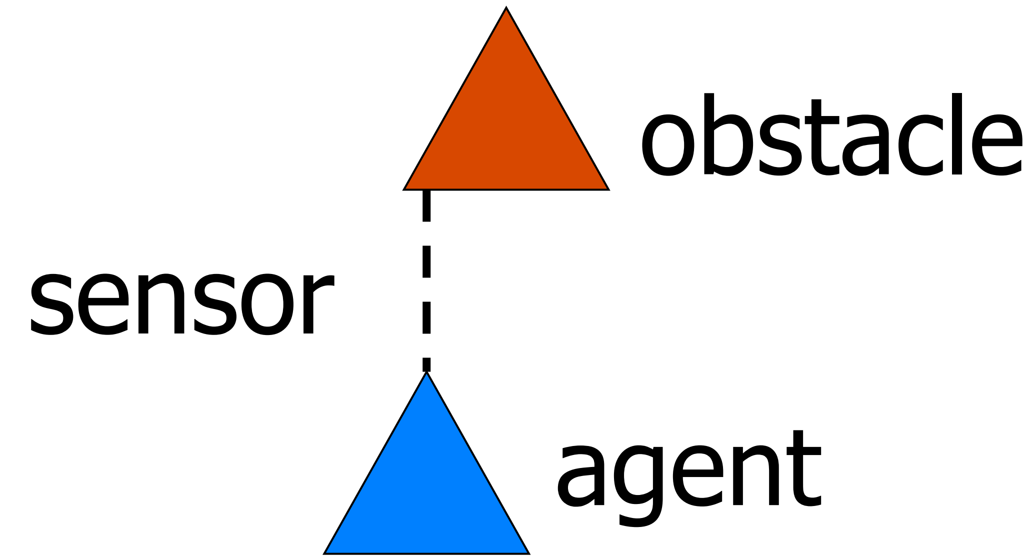
- **Perception** (sequence) to **Action Mapping:** $f : \mathcal{P}^* \rightarrow \mathcal{A}$
  - **Ideal mapping:** specifies which actions an agent ought to take at any point in time
  - **Implementation:** Look-Up-Table, Closed Form, Algorithm, etc.

- **Performance measure:** a *subjective* measure to characterize how successful an agent is (e.g., speed, power usage, accuracy, money, etc.)

- (degree of) **Autonomy:** to what extent is the agent able to make decisions and take actions on its own?

Implementation I: Look Up Table

Distance	Action
10	No action
5	Turn left 30 degrees
2	Stop



Implementation II: Closed Form

- Output (degree of rotation) = F(distance)
- E.g., F(d) = 10/d   (distance cannot be less than 1/10)

How is an Agent different from other software?

- Agents are **autonomous**, that is, they act on behalf of the user
- Agents contain some level of **intelligence**, from fixed rules to learning engines that allow them to adapt to changes in the environment
- Agents don't only act **reactively**, but sometimes also **proactively**
- Agents have **social ability**, that is, they communicate with the user, the system, and other agents as required
- Agents may also **cooperate** with other agents to carry out more complex tasks than they themselves can handle
- Agents may **migrate** from one system to another to access remote resources or even to meet other agents

Intelligent Agents/Robots

- Agent and Robot
  - What can it see, do, think, and learn?
  - What does it want?
    - "Fame & Fortune" ☺, goal, utility, solutions to problems
- Environment and world
  - What can be seen?
  - What can be changed?
  - Who else are there? (Obstacle and other agents)
- Cognitive Cycles

Cognitive Cycle

- Agent repeatedly decides what to do next
  - The *cognitive cycle* that repeats for agent lifetime

  - In humans, the cycle runs at ~50-100ms
    - This is minimum time to choose an action, but many such cycles can be combined to make harder choices
- On each cycle, agent can be considered to be computing a function for decision making

Two views of Agent Behavior

- View 1 (popular): The *agent is function* maps percept sequences to actions in the environment
  - **f1:** $\boxed{S^* \rightarrow A}$
  - *[Dirty] → WIPE*
  - *[Car <20′ away] → RUN*

- View 2 (deeper): The *agent is function* maps percept sequences & actions in the environment to a sequence of predictions
  - **f2** $\boxed{(S^*, A) \rightarrow P^*}$
  - *[Car <20′ away], STAY → HIT*
- Difference: **f2 knows what to do, as well as why**

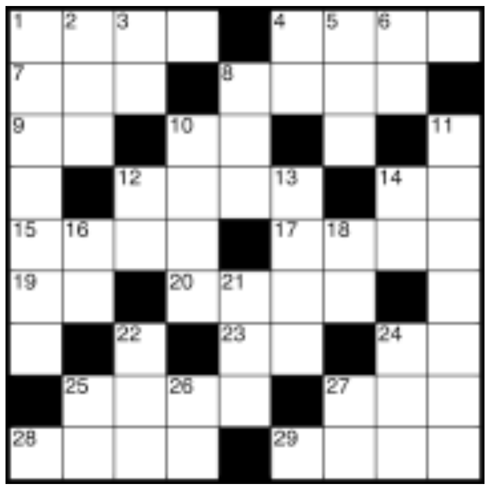
Rationality & Rational Agents

- What is rational at a given time depends on:
  - What has been seen? Percept sequence to date (sensors)
  - What can you do? Actions
  - What do you know? Prior environment knowledge
  - What do you want? Performance measure
    - Ideally objective, external, based on what is to be achieved
- A *rational agent* chooses whichever action maximizes the expected value of the performance measure given the percept sequence to date and the prior environment knowledge
- Most human beings have only bounded rationality
  - My story of playing irrational *Risk* with some kids

Environment Types

- However you define *environment*, its nature can dramatically impact the complexity of the required agent program as well as the difficulty of achieving goals in it
- Next few slides look at some key attributes of environments

Environment Types

	Crossword	Backgammon	Part-Picking Robot	Robot Taxi
Observable??				
Deterministic??				
Episodic??				
Static??				
Discrete??				
Single-agent??				

Environment Types

Fully vs. partially observable: an environment is fully observable when the sensors can detect all aspects that are *relevant* to the choice of action.

	Crossword	Backgammon	Part-Picking Robot	Robot Taxi
Observable??				
Deterministic??				
Episodic??				
Static??				
Discrete??				
Single-agent??				

Environment Types

Deterministic vs. stochastic: if the next environment state is completely determined by the current state and the executed action then the environment is deterministic

	Crossword	Backgammon	Part-Picking Robot	Robot Taxi
Observable??	FULL	FULL	PARTIAL	PARTIAL
Deterministic??				
Episodic??				
Static??				
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Single-agent??				

Environment Types

Deterministic vs. stochastic: if the next environment state is completely determined by the current state and the executed action then the environment is deterministic

	Crossword	Backgammon	Part-Picking Robot	Robot Taxi
Observable??	FULL	FULL	PARTIAL	PARTIAL
Deterministic??	YES	NO	NO	NO
Episodic??				
Static??				
Discrete??				
Single-agent??				

Environment Types

Episodic vs. sequential (Markov or not): In an episodic environment the agent's experience can be divided into atomic steps where the agent perceives and then performs a single action. The choice of action depends only on the episode itself, not on previous actions/episodes

	Crossword	Backgammon	Part-Picking Robot	Robot Taxi
Observable??	FULL	FULL	PARTIAL	PARTIAL
Deterministic??	YES	NO	NO	NO
Episodic??				
Static??				
Discrete??				
Single-agent??				

Environment Types

Static vs. dynamic: If the environment can change while the agent is choosing an action, the environment is dynamic

	Crossword	Backgammon	Part-Picking Robot	Robot Taxi
Observable??	FULL	FULL	PARTIAL	PARTIAL
Deterministic??	YES	NO	NO	NO
Episodic??	NO	NO	YES	NO
Static??				
Discrete??				
Single-agent??				

Environment Types

Static vs. dynamic: If the environment can change while the agent is choosing an action, the environment is dynamic

	Crossword	Backgammon	Part-Picking Robot	Robot Taxi
Observable??	FULL	FULL	PARTIAL	PARTIAL
Deterministic??	YES	NO	NO	NO
Episodic??	NO	NO	YES	NO
Static??	YES	YES	NO	NO
Discrete??				
Single-agent??				

Environment Types

Discrete vs. continuous: This distinction can be applied to the state of the environment, the way time is handled and to the percepts/actions of the agent

	Crossword	Backgammon	Part-Picking Robot	Robot Taxi
Observable??	FULL	FULL	PARTIAL	PARTIAL
Deterministic??	YES	NO	NO	NO
Episodic??	NO	NO	YES	NO
Static??	YES	YES	NO	NO
Discrete??				
Single-agent??				

Environment Types

Discrete vs. continuous: This distinction can be applied to the state of the environment, the way time is handled and to the percepts/actions of the agent

	Crossword	Backgammon	Part-Picking Robot	Robot Taxi
Observable??	FULL	FULL	PARTIAL	PARTIAL
Deterministic??	YES	NO	NO	NO
Episodic??	NO	NO	YES	NO
Static??	YES	YES	NO	NO
Discrete??	YES	YES	NO	NO
Single-agent??				

Environment Types

Single vs. multi-agent: Does the environment contain more than one agent whose behavior interacts in some relevant way?

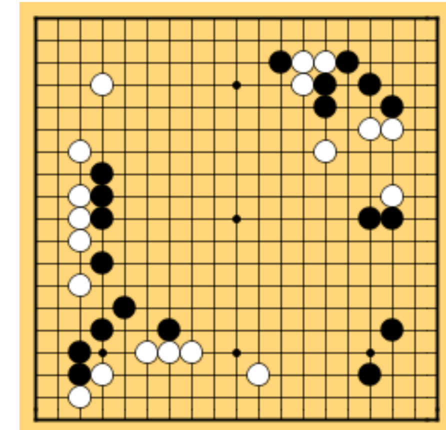
	Crossword	Backgammon	Part-Picking Robot	Robot Taxi
Observable??	FULL	FULL	PARTIAL	PARTIAL
Deterministic??	YES	NO	NO	NO
Episodic??	NO	NO	YES	NO
Static??	YES	YES	NO	NO
Discrete??	YES	YES	NO	NO
Single-agent??				

Environment Types

Single vs. multi-agent: Does the environment contain more than one agent whose behavior interacts in some relevant way?

	Crossword	Backgammon	Part-Picking Robot	Robot Taxi
Observable??	FULL	FULL	PARTIAL	PARTIAL
Deterministic??	YES	NO	NO	NO
Episodic??	NO	NO	YES	NO
Static??	YES	YES	NO	NO
Discrete??	YES	YES	NO	NO
Single-agent??	YES	NO	YES	NO

Environmental Difficulties

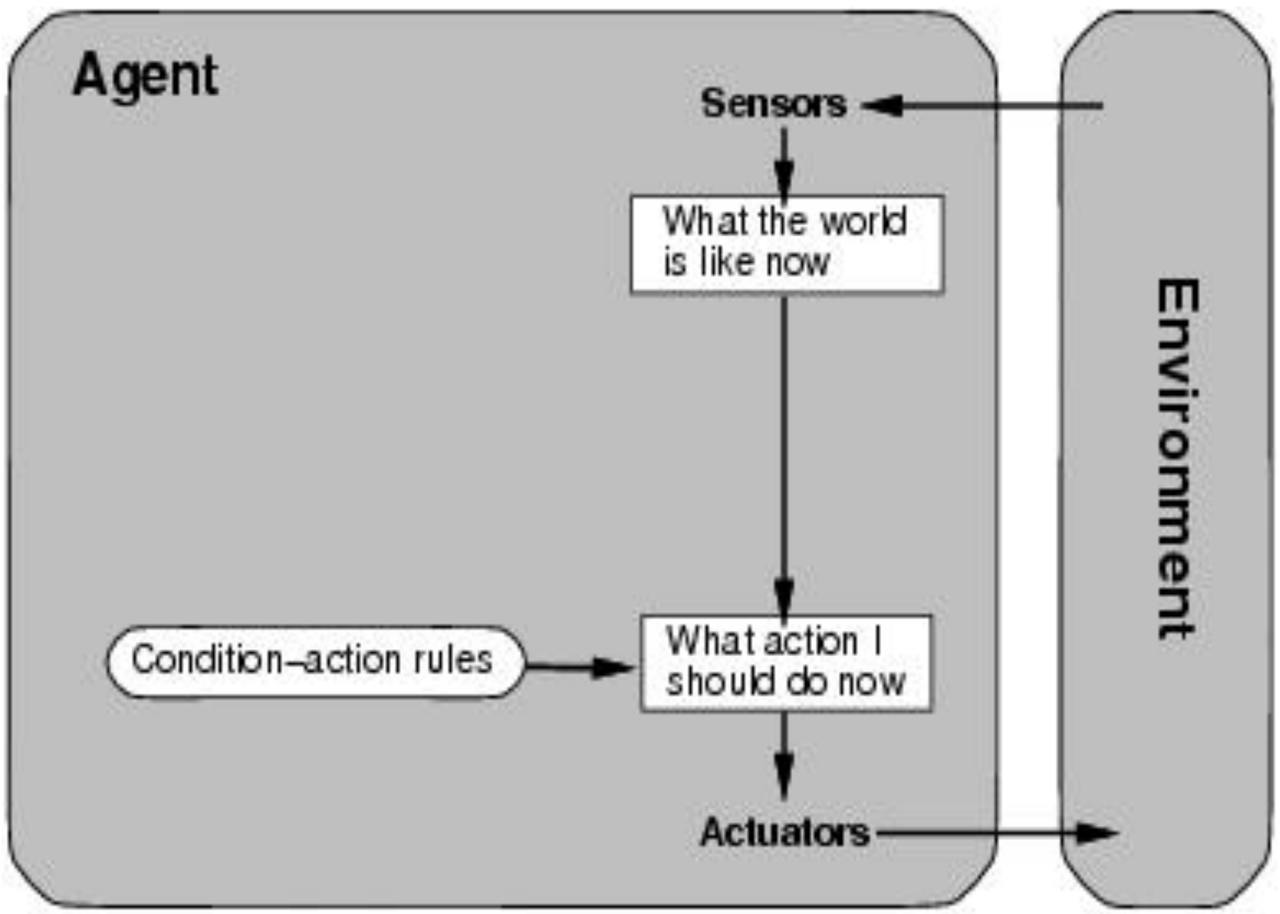


- The simplest environment is
  - Fully observable, deterministic, episodic, static, discrete and single-agent
- Real world situations are frequently
  - Partially observable, stochastic, sequential, dynamic, continuous and multi-agent
- Other factors that determine difficulty include
  - Difficulty of individual actions
    - E.g., Crosswords, part picking
  - Size/combinatorics of environment
    - E.g., The game of Go has $\sim 3^{19*19}$ (= $\sim 10^{172}$) states

Agent Types

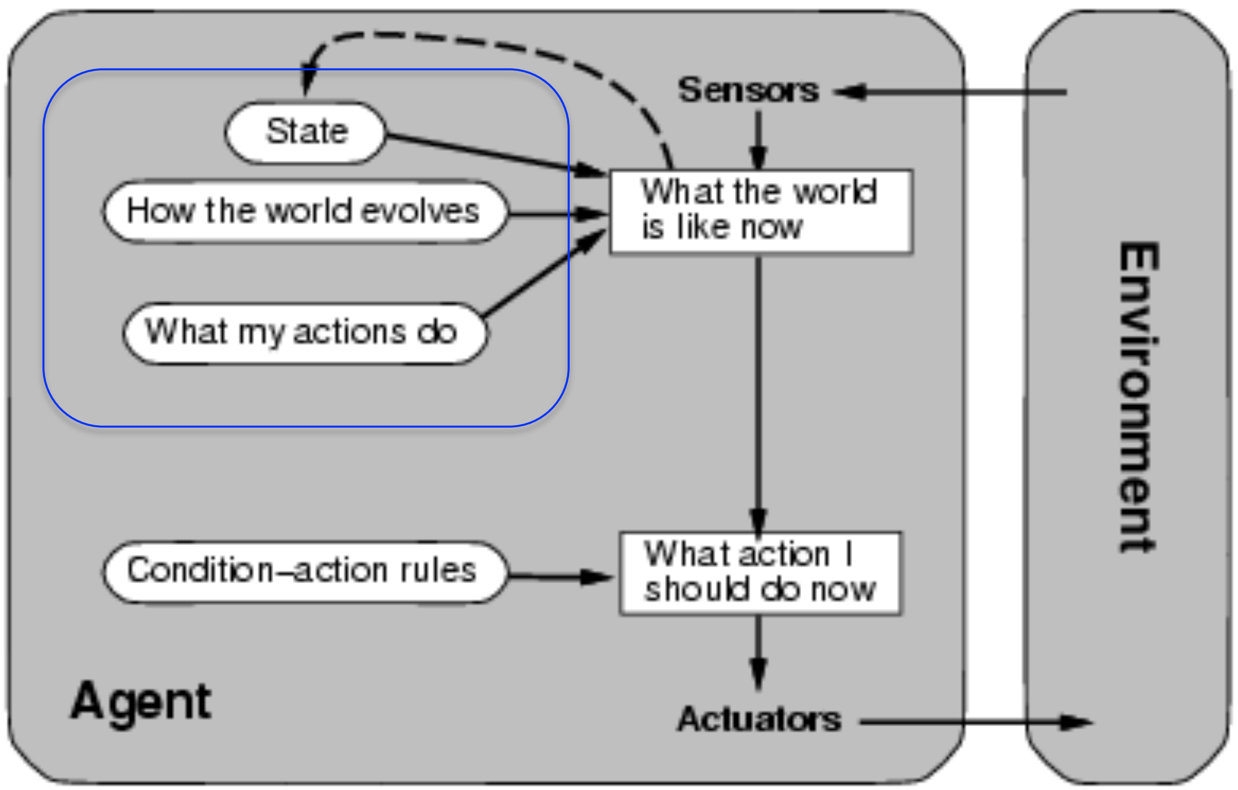
- Four basic kinds of agent programs will be discussed:
  - Simple reflex agents
  - Model-based reflex agents
  - Goal-based agents
  - Utility-based agents
- All can be turned into learning agents
- Two additional more complex variations
  - Hybrid agents
  - Reflective agents

Simple Reflex Agent



- Select action on the basis of *only the current* percept
- Large reduction in possible percept/action situations *(next slide)*
- May be implemented as *condition-action rules*
  - E.g., “If dirty then suck”

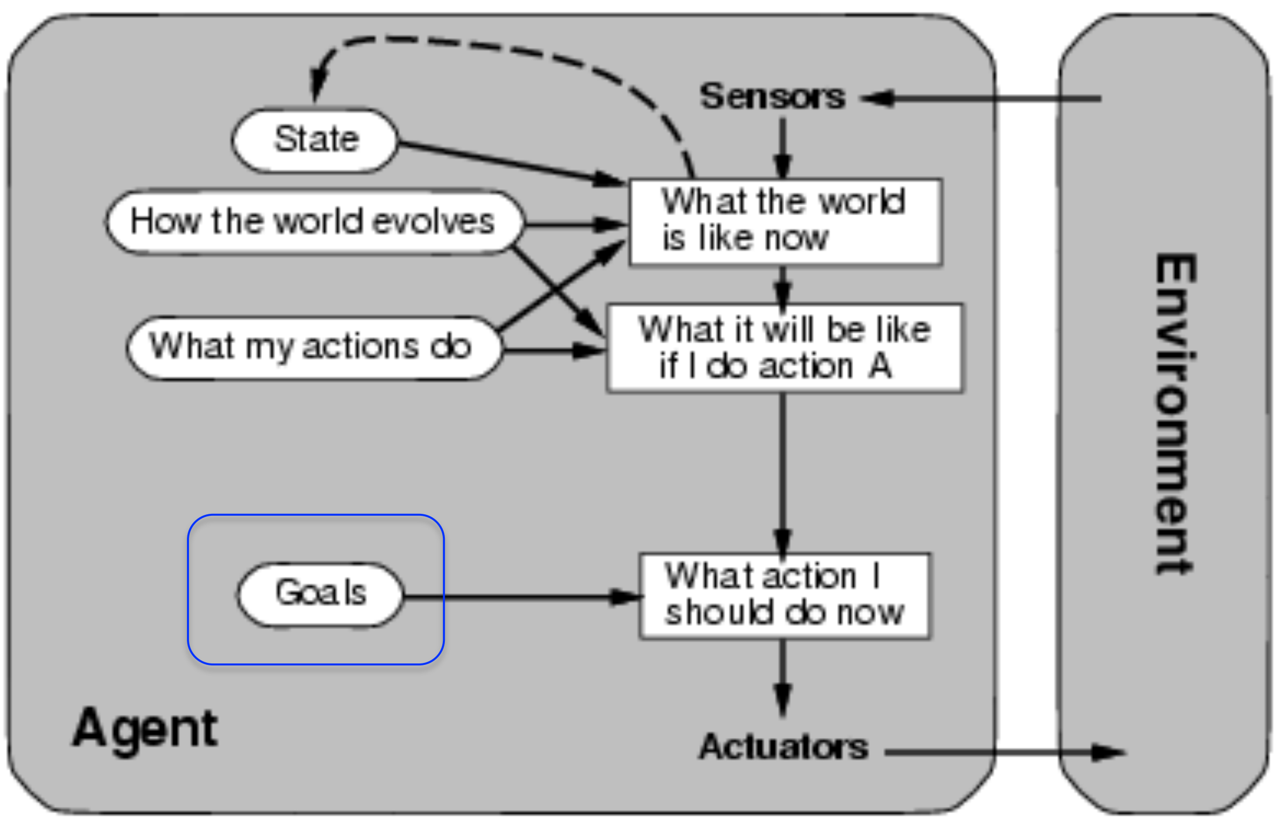
Model-Based Reflex Agent



- To tackle *partially observable* environments
  - Maintain internal state representing best estimate of current world situation
- Over time update state using world knowledge
  - How world changes
  - How actions affect world

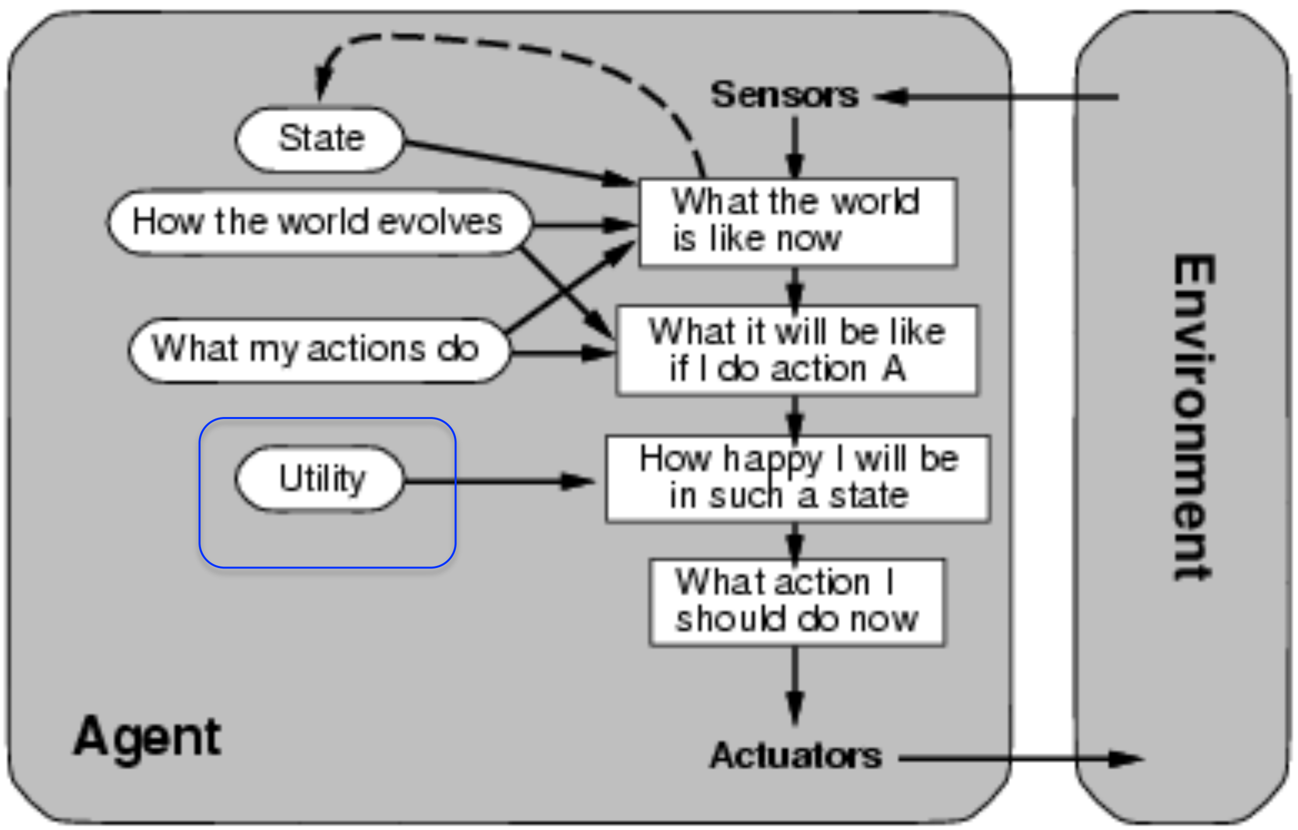
  ⇒ ***Model of World***

Goal-Based Agent



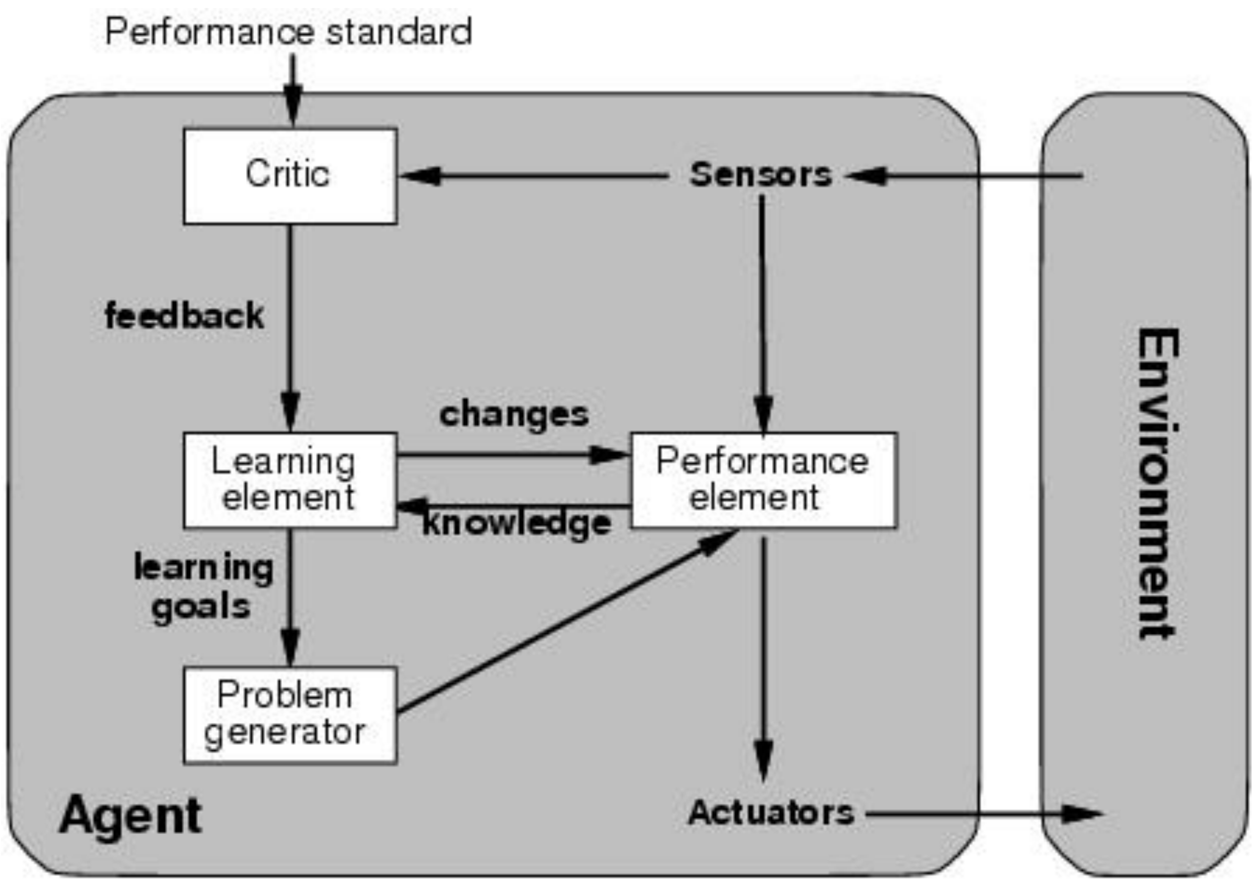
- Goals describe what agent wants
  - By changing goals, can change what agent does in same situation
- Combining models and goals enables determining which possible future paths could lead to goals
  - Typically investigated in **search**, **problem solving** and **planning** research

Utility-Based Agent



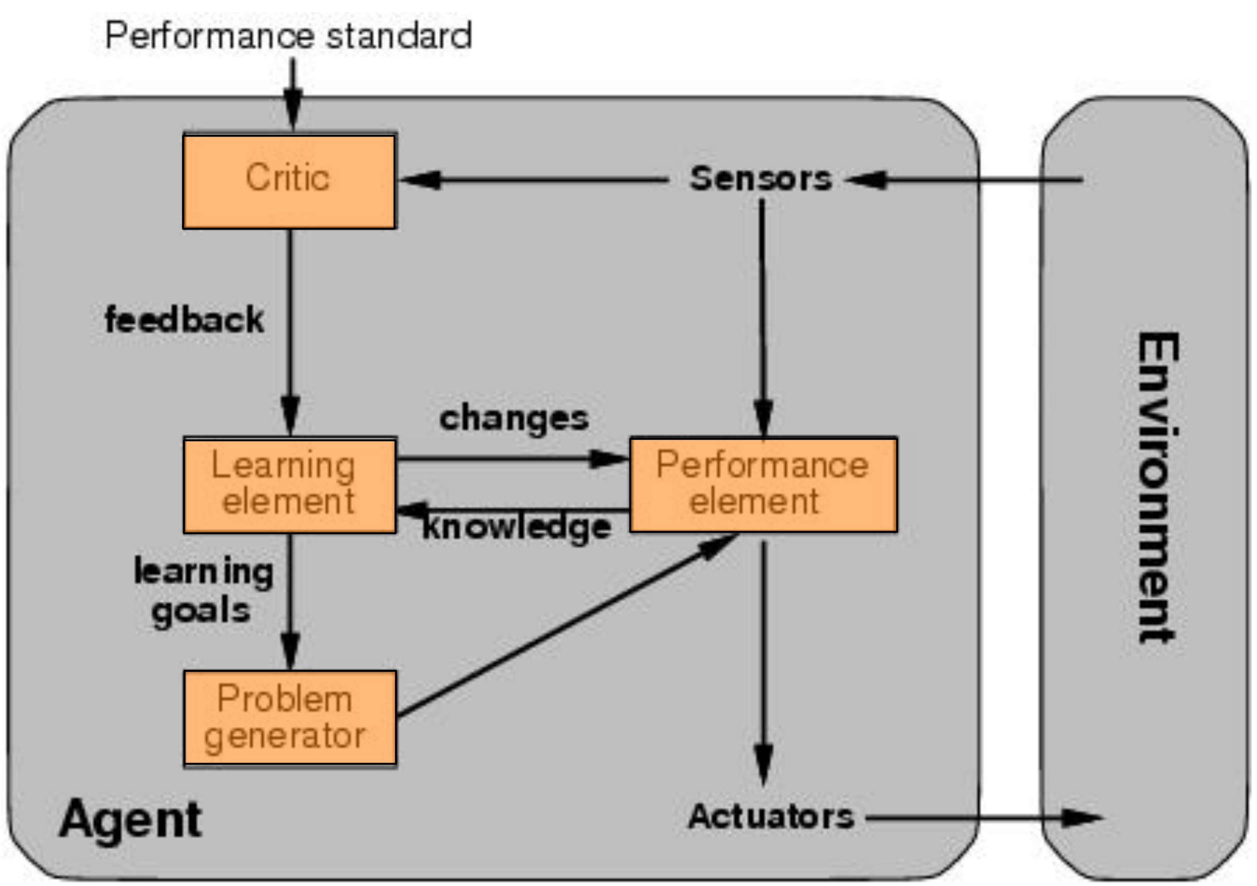
- Some goals can be solved in different ways
  - Some solutions may be "better" – have higher utility
- Utility function maps a (sequence of) state(s) onto a real number
  - Can think of goal achievement as 1 versus 0
- Can help in optimization or in arbitration among goals

Learning Agent



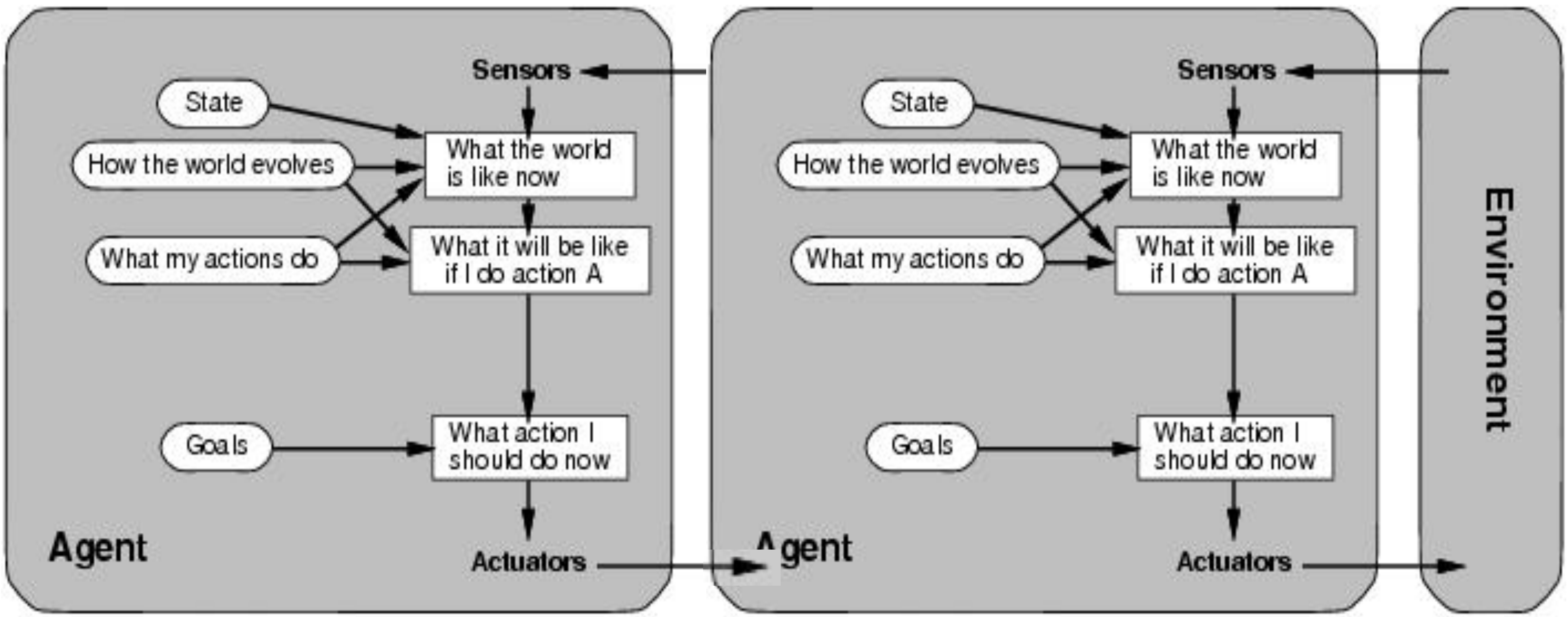
- All previous agent programs describe methods for selecting actions, yet they do not explain the origins of these programs
  - Learning programs can be used to do this
- Advantages
  - Robustness of the program in partially or totally unknown environments
  - Reduced programming effort
- Disadvantages
  - May do the unexpected in a disastrous manner

Nominal Structure of Learning Agent



- *Performance element*: selecting actions based on percepts
  - Corresponds to the previous agent programs
- *Learning element*: introduce improvements in performance element
- *Critic:* provides feedback on agent's performance based on fixed performance standard
- *Problem generator*: actively suggests actions that will lead to new and informative experiences
  - Exploration vs. exploitation

Self-Awareness Agent

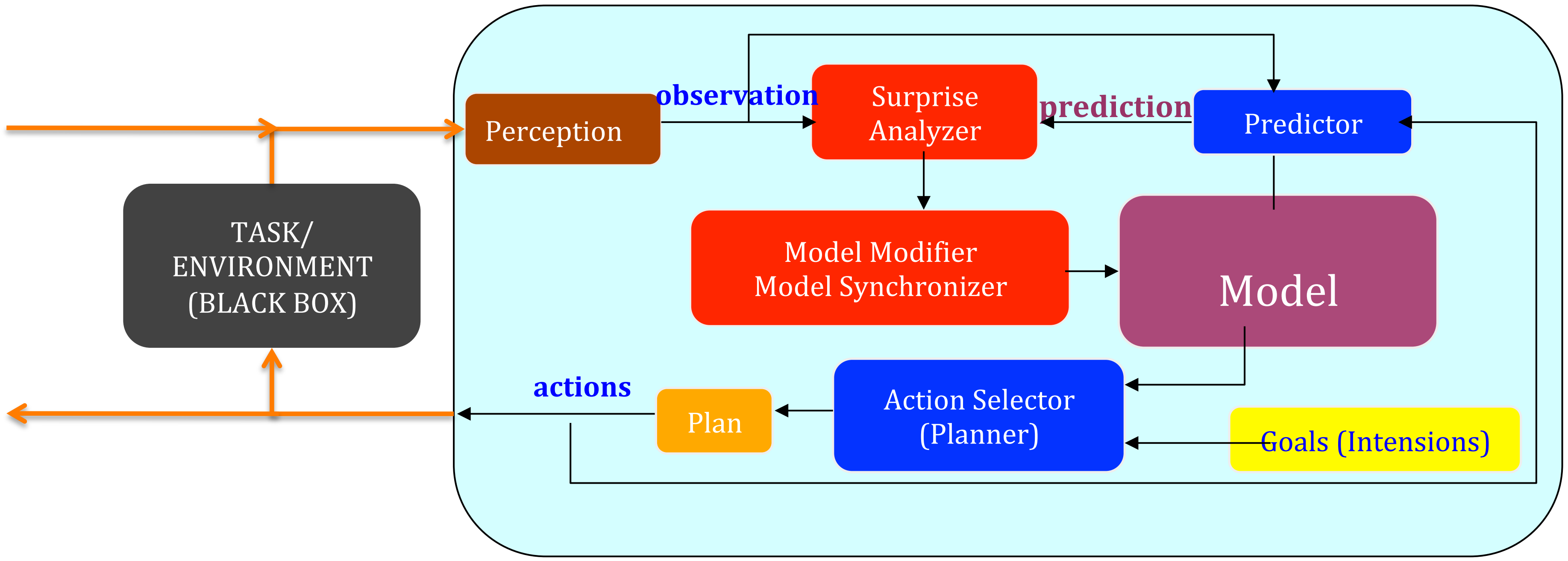


Related to self-awareness and meta-level processing

Adaptive Agents

- New Task → Learning → New Knowledge/Skill
  - No priori knowledge (e.g., baby swimming)
    - Don't-know-how → learning → know-how
- Recovery from unexpected failures or dynamics
  - Recover from unexpected (e.g., adult with inverted vision)
    - Know-how → Failures → learning → recovery

Surprise-Based Learning Agents

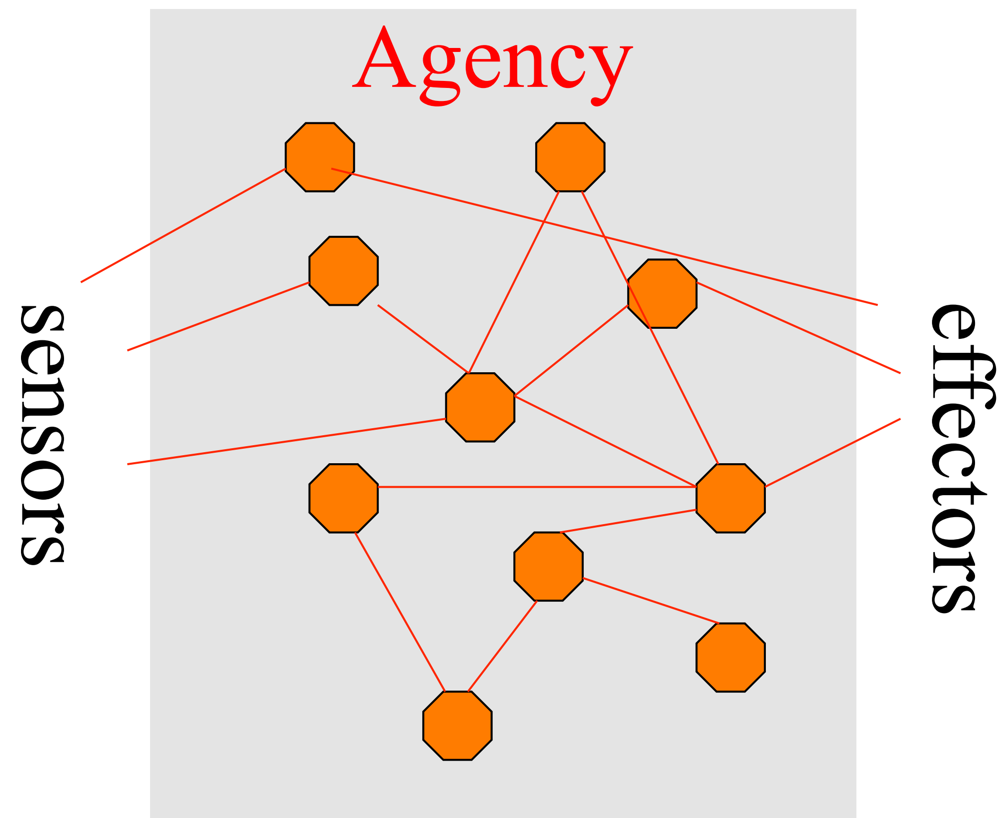


- The Learner continuously makes predictions, detects surprise, analyzes surprises, extracts critical information from surprises, and improves and use its action models

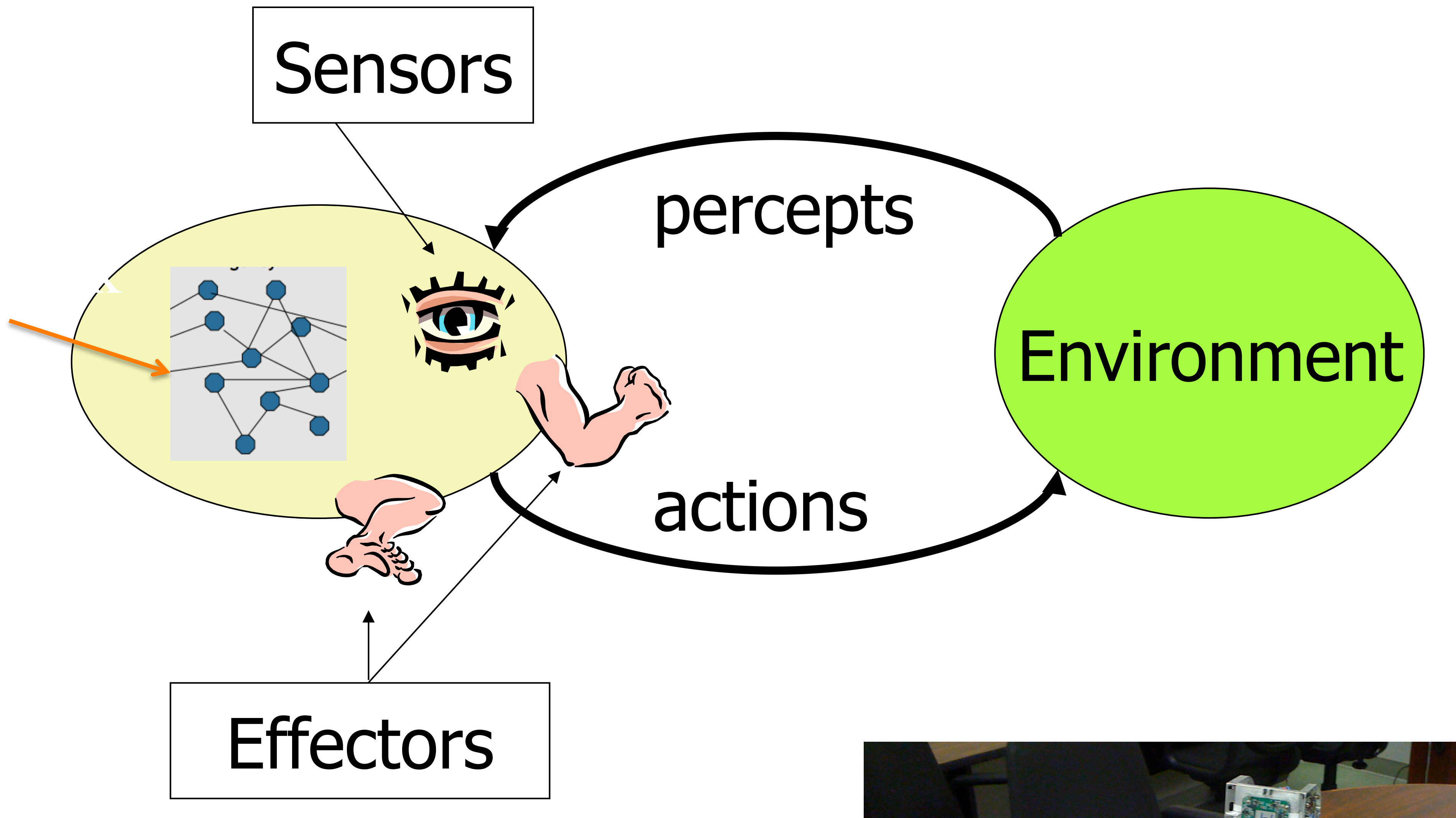
Surprise ==> Model ==> Prediction

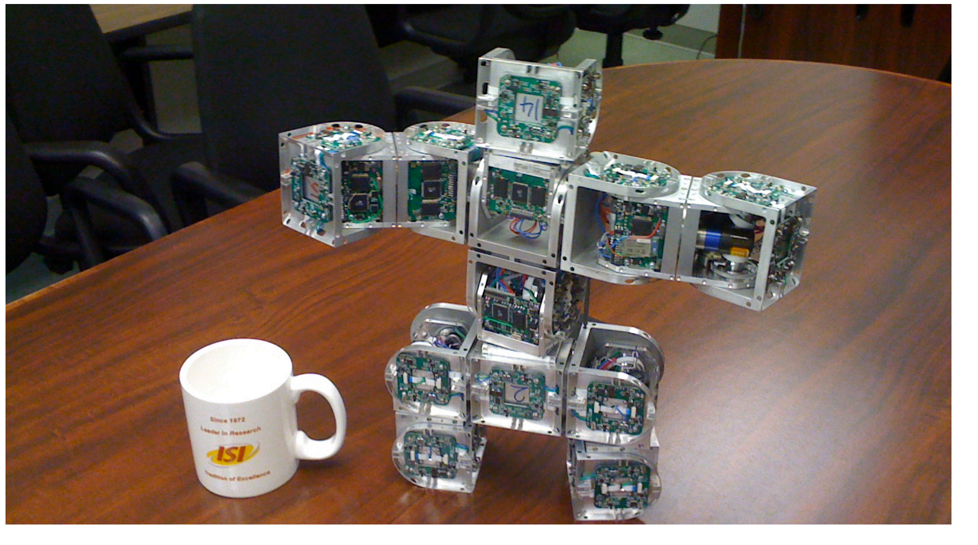
Real vs Artificial Intelligence

- **Real:** Human mind as network of thousands or millions of neural agents working in parallel.
- To produce artificial intelligence, this school holds, we should build systems that also contain many agents and systems for arbitrating among the agents' competing results.
- Distributed decision-making & control
- Challenges:
  - Action selection: What to do next?
  - Conflict resolution



Self-Reconfigurable Body/Mind

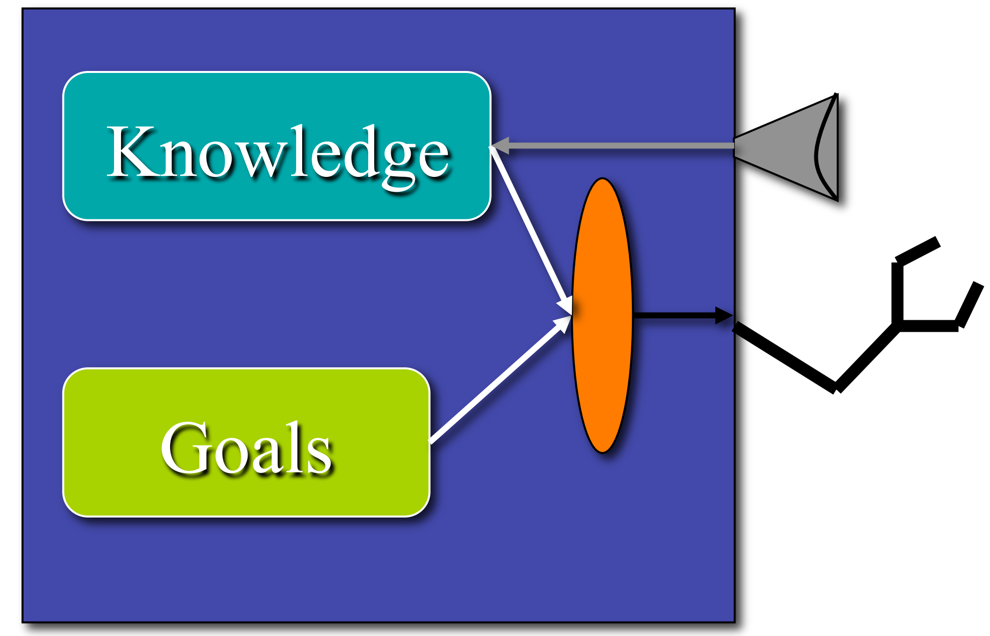




Mind: What behaviors should I do?

Body: What body should I become?

Other Views of Agent Types



- Knowledge
  - Fixed versus Flexible
    - Is new knowledge learned?
  - Covers past, present, future
    - Past: Percept Sequence (Table)
    - Present: What to do now (Reflex)
    - Future: Enables prediction (Model)
- Success(/Goals)
  - Fixed versus Flexible
    - Reflex (and MB) agents have fixed metrics of success
    - Goal/Utility based agents can change metric by task
  - Binary (goal) versus Graded (utility)

Hybrid Agents

- Many practical agents combine one or more of the basic types
- For example, robots that must perform complex tasks in real time frequently combine reflex and model-based agents
  - *Reactive:* Reflexes provide fast responses
  - *Deliberative:* Models and goals enable thinking about the future

Summary

- **Intelligent Agents:**
  - Anything that can be *viewed as* **perceiving** its **environment** through **sensors** and **acting** upon that environment through its **effectors** to maximize progress towards its **goals**.
  - PAGE (Percepts, Actions, Goals, Environment)
  - Described as a Perception (sequence) to Action Mapping: $f : \mathcal{P}^* \rightarrow \mathcal{A}$
  - Using look-up-table, closed form, etc.

- **Agent Types:** Reflex, state-based, goal-based, utility-based, learning

- **Rational Action:** The action that maximizes the expected value of the performance measure <u>given the percept sequence to date</u>

Interested in Research in Prof. Shen's Lab?