# CSCI 561
# Foundation for Artificial Intelligence

## Welcome!

Professor Wei-Min Shen

University of Southern California

# Lectures and Discussions

- Lectures: 5:00-7:20PM
  - Introduction
    - Who are us? Who are you?
    - What will we learn and do this semester?
    - Course details: lectures, discussions, homeworks, exams, grades, …
  - Overview of Artificial Intelligence, and Basics of Search
    - Intelligence, Agents, and Artificial Intelligence
    - Agent Types and Rational Actions
    - Problem Solving, Search Space and Algorithms
- Discussions: 7:30-8:20PM
  - What have AI accomplished?
  - How to measure intelligence?

# CS 561: Artificial Intelligence

Instructor: Professor Wei-Min Shen (wmshen@usc.edu)
Office Hours: after lectures (by email appointment)

TAs and CPs: Please see DEN and Piazza
Office Hours and Zooms: please see Piazza

Lectures: DEN WebEx, 5:00 – 7:20PM, **Wednesday**
Discussion: DEN WebEx, 7:30 – 8:20PM, **Wednesday**

This class will use **courses.uscden.net** (Desire2Learn, **D2L**)
- Up to date information, lecture notes, lecture videos
- Homework posting and submission information
- Grades, relevant dates, links, etc.

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

# CS 561: Artificial Intelligence

**Course overview:** foundations of symbolic intelligent systems. Agents, search, problem solving, logic, representation, reasoning, symbolic programming, machine learning, and robotics

**Prerequisites:** CS 455x, i.e., programming principles, discrete mathematics for computing, software design and software engineering concepts.
Good knowledge for (1) algorithm design, and (2) programming languages such as Python (preferred), and others (Java, C++ or C) are needed for homework

**Grading:**

20% for midterm-1 exam
20% for midterm-2 exam
30% for final exam
30% for 3 mandatory homework assignments

# 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:** has been setup on the D2L system and Piazza.
- **Homework:** See class web page on D2L, and they are take-home programming assignments
  - Week-2 – HW1 out — Topic: search or function optimization
  - Week-5 – HW1 due
  - Week-5 – HW2 out — Topic: game playing or constraint satisfaction
  - Week-11 – HW2 due
  - Week-11 – HW3 out — Topic: neural networks or logic reasoning/inference
  - Week-14 – HW3 due
- **Late homework:** 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 work 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 ignored.
- **Exams:**
  - Week-6 – midterm 1 (5-7PM, online)
  - Week-10 – midterm 2 (5-7PM, online)
  - Week-16 – final exam (5-7PM, online)

# Syllabus and Schedules

**5:00-7:20pm**
**7:30-8:20pm**

| Date | Topic | Reading |
|---|---|---|
| Week-1 8/24 | 1. Welcome – Introduction. Why study AI? What is AI? The Turing test. Rationality. Branches of AI. Brief history of AI. Challenges for the future. What is an intelligent agent? Doing the right thing (rational action)? Performance measures. Autonomy. Environment and agent. Types of agents. | AIMA 1, 2 (ALFE 1) |
| | 2. Problem Solving & Search – Types of problems. Example problems. Basic idea behind search algorithms. Complexity. Combinatorial explosion and NP completeness. Polynomial hierarchy. | AIMA 3 (ALFE 2, 6) |
| Week-2 8/31 | 3. Uninformed Search - Depth-first. Breadth-first. Uniform-cost. Depth-limited. Iterative deepening. Examples. Properties. | AIMA 3 HW1 out |
| | 4. Informed Search – Best-First, A* search, Heuristics, Hill climbing, Problem of local extrema, Simulated annealing, and Genetic Algorithms. | AIMA 3, 4 (ALFE 6) |
| Week-3 9/7 | 5. Constraint satisfaction. Node, arc, path, and k-consistency. Backtracking search. Local search using min-conflicts. | AIMA 6 |
| | 6. Game Playing - The minimax algorithm. Resource limitations. Alpha-beta pruning. Chance and non-deterministic games. | AIMA 5 |
| Week-4 9/14 | 7. Advanced Game Playing - Agent Interaction with environment and other agents.<br>8. Reinforcement Learning. | AIMA 21 ALFE 6.1 |
| Week-5 9/21 | 9. Agents that reason logically 1 – Knowledge-based agents. Logic and representation. Propositional (Boolean) logic. | AIMA 7 (ALFE 3) HW1 due |
| | 10. Agents that reason logically 2 – Inference in propositional logic. Syntax. Semantics. Examples. | AIMA 7 HW2 out |
| Week-6 9/28 | Midterm exam 1 (no make-up exam) | |

# Syllabus and Schedules

**5:00-7:20pm**
**7:30-8:20pm**

| | | |
|---|---|---|
| Week-7<br>10/5 | 11. First-order logic 1 – Syntax. Semantics. Atomic sentences. Complex sentences. Quantifiers. Examples. FOL knowledge base. Situation calculus. | AIMA 8,<br>AIMA 12 |
| | 12. First-order logic 2 – Describing actions. Planning. Action sequences. | AIMA 8 |
| Week-8<br>10/12 | 13. Inference in first-order logic – Proofs. Unification. Generalized modus ponens. Forward and backward chaining. | AIMA 9 |
| | 14. Continue Inference in first-order logic. Resolution. Proof by contradiction. | AIMA 9 |
| Week-9<br>10/19 | 15. Logical reasoning systems – Indexing, retrieval and unification. The Prolog language. Theorem provers. Frame systems and semantic networks. | AIMA 9 |
| | 16. Planning – Definition and goals. Basic representations for planning. Situation space and plan space. Examples. | AIMA 10<br>(ALFE 6) |
| Week-10<br>10/26 | Midterm exam 2 (no make-up exam) | HW2 due<br>HW3 out |

# Syllabus and Schedules

**5:00-7:20pm**
**7:30-8:20pm**

| | | |
|---|---|---|
| Week-11<br>11/2 | 17. Learning from examples – supervised learning, learning decision trees, support vector machines. | AIMA 18<br>Handout |
| | 18. Learning with neural networks – Perceptron, Hopfield networks. How to size a network? What can neural networks achieve? Deep learning and state of the art. | AIMA 18<br>Handout |
| Week-12<br>11/9 | 19. Reasoning under uncertainty – probabilities, conditional independence, Markov blanket, Bayes nets. | AIMA 13, 14 |
| | 20. Reasoning under uncertainty – Probabilistic inference, enumeration, variable elimination, approximate inference by stochastic simulation, Markov chain Monte Carlo, Gibbs sampling. | AIMA 14, 15<br>(ALFE 5) |
| Week-13<br>11/16 | 21. Probabilistic decision making – utility theory, decision networks, value iteration, policy iteration, Markov decision processes (MDP), partially observable MDP (POMDP). | AIMA 16, 17<br>(ALFE 5) |
| | 22. Probabilistic Reasoning over time: Temporal models, Hidden Markov Models, Kalman filters, Dynamic Bayesian Networks, Automata theory. | AIMA15<br>HW3 due |
| Week-14 | 11/23 Thanksgiving Break | |
| Week-15<br>11/30 | 23. Probability-Based Learning: Probabilistic Models, Naive Bayes Models, EM algorithm, Reinforcement Learning. | AIMA 20<br>(ALFE 5.10) |
| | 24. Towards intelligent machines – The challenge of robots: with what we have learned, what hard problems remain to be solved? Different types and architectures of robots. | AIMA 24,26-27<br>(ALFE 13) |
| Week-16 | 12/7 Final Exam 4:30-6:30PM (set by the University/School) (no make-up exam) | |

# More on Homework and Grading

- In each homework you will implement some algorithms from scratch by yourself

- But our goal is to focus on A.I. algorithms, not on low-level programming. Hence, we recommend Python (PREFERED), and others (Java, or 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 accessible for you
  - Please learn how to use the terminal window how to debug your code on Vocareum
- Vocareum supports many languages of your choice: Python (preferred), Java, C++, C++11, C, etc.
- Your program should take no command-line arguments. It should read a text file called "input.txt" that contains a problem definition, and write a file "output.txt" with your solution. For each homework, format for files input.txt and output.txt will be specified and examples will be given to you. Please follow the exact format or else the grading script will fail your code.
  - The grading will test your code on 40-50 test cases:
    - Create an input.txt file
    - Run your code
    - Compare output.txt created by your program with the correct one
  - If your outputs for all test cases are correct, you get **100** points
  - If one or more test case fails, you will get deductions based on the difficulty-level of the test cases

## Vocareum.com (subject to upgrades or changes)

gcc - 5.5
valgrind - 3.11
ar - 2.26.1
php - 7.0.32
python2 - 2.7.12
python3 - 3.5.2, 3.6.4 (preferred)
Java 1.8 - 1.8.0_191
perl - 5.22.1
make - 4.1

# Discussion Sections, TA Office Hours

- You must register the discussion section. Contents there will be tested in the exams

- 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

- TA/CourseProducer/Grader Office Hours
  - see announcements on DEN and Piazza
  - Please attend them, and we have ~20 excellent TAs/CPs for you

# Your Teaching Team This Semester

| | | |
|---|---|---|
| Alex Bisberg | When? | |
| | Where? | |
| Yilei Zeng | When? | |
| | Where? | |
| Kabir Juneja | When? | Mon |
| | Where? | http |
| Leela Surya Teja Mangamuri | When? | Frid |
| | Where? | http |
| Hitesh Pindikanti | When? | Tues |
| | Where? | http |
| Jincheng He | When? | Frid |
| | Where? | http |
| Chongjian Tang | When? | Thur |
| | Where? | http |
| Sam Griesemer | When? | |
| | Where? | |
| Ira Natu | When? | http |
| | Where? | Tue( |
| Maxyn Leitner | When? | http |
| | Where? | Mon |
| Divya Ravilla | When? | |
| | Where? | |

| | | |
|---|---|---|
| Raghav Mehta | When? | Thursday (7 PM - 8 PM)+ Friday (9 AM - 10 AM) |
| | Where? | https://usc.zoom.us/my/mehtaraghav?pwd=bXN3b3lwd09rSlVSRHRaVHFHUmZPdz09 |
| Gautam Pranjal | When? | Monday (9 AM -10 PM) + Wednesday (9 AM to 10 PM) |
| | Where? | https://usc.zoom.us/j/3042958534?pwd=enE5UWR3OS9XTlZPUHpPaW8zWTlsQT09 |
| Tanmay Subhash Dhaundiyal | When? | |
| | Where? | |
| Nirav Kishor Jain | When? | Thursday (10 AM - 11 AM)+ Friday (10 AM - 11 AM) |
| | Where? | https://usc.zoom.us/j/5742504759?pwd=d0tJbDlDb0srV3JSbFZ1YzhoSVRFZz09 |
| Vishrut Jetly | When? | |
| | Where? | |
| Yash Tejas Javeri | When? | Monday (7 PM - 8PM) + Thursday (7 PM - 8PM) |
| | Where? | https://usc.zoom.us/j/2623879607?pwd=M0wrcnQxV0VRaENEWDRyTHlDMWg0QT09 |
| Tarunbir Singh Gambhir | When? | |
| | Where? | |

# Piazza

- We will use www.piazza.com for questions and answers related to class material
- Please register by clicking the “Piazza” button on DEN (this is mandatory)

- Guidelines:
  - You may ask any question related to material covered in lectures, discussions, or exams
  - You may ask **clarification questions only** related to the homework definitions
  - You may **not** ask for advice on how to solve some aspect of a homework problem
  - You may **not** post code snippets related to homework problems
  - You may **not** post test cases or input/output examples related to homework problems
  - Please remember that homework assignments are to be solved strictly individually

# 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.

# Academic Integrity

USC
UNIVERSITY
OF SOUTHERN
CALIFORNIA

Division of
Student Affairs

Student Judicial
Affairs and
Community Standards

October 5, 2007

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

Dear M[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

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

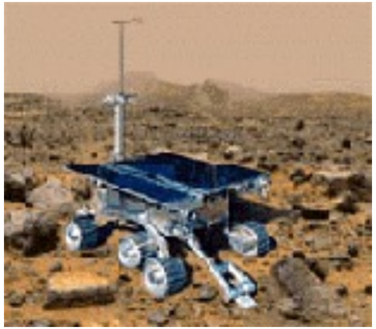
Enclosures

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

# GENERAL KNOWLEDGE OF ARTIFICIAL INTELLIGENCE (AI)

# Why Study AI?

Labor



Science

Search engines

Medicine /
Diagnosis


Appliances /
Internet of Things (IoT)

**What else?**

# What Could AI Do Now?

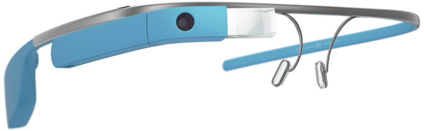


# DARPA Robotics Challenge

TEAM KAIST

Biped Humanoid Robot DRC-Hubo

Wearable computing



Google glass

Microsoft Hololens

Zypad

# HOW TO MEASURE “INTELLIGENCE” ?!

# What is AI? Two Basic Views

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**

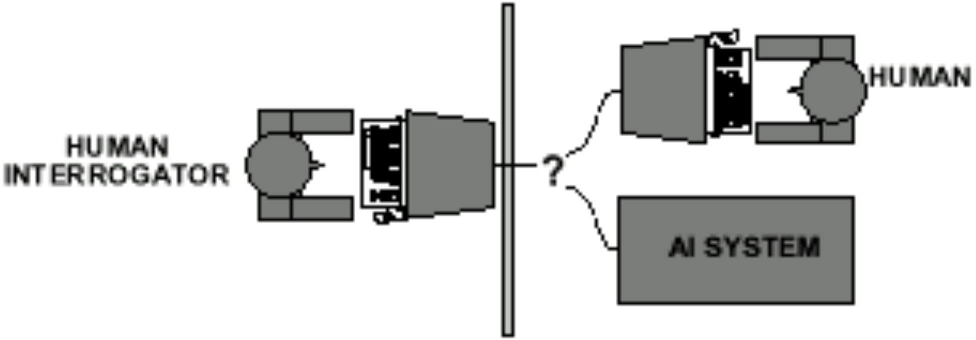
Systems that think **rationally**

Systems that act **like humans**

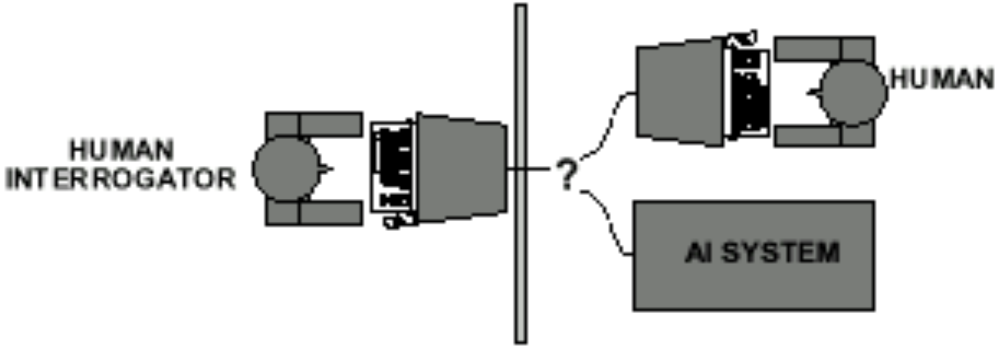
Systems that act **rationally**

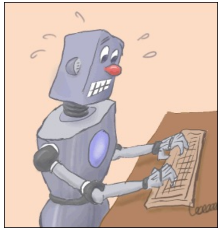
# Acting Humanly: The (basic) Turing Test

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



# Acting Humanly: The (basic) Turing Test



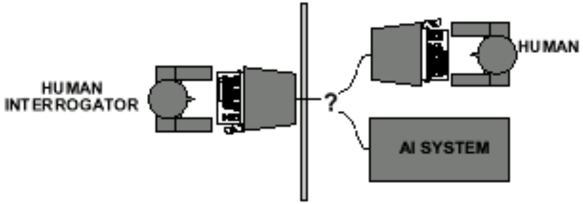



- Computer needs to possess: Natural language processing, Knowledge representation, Automated reasoning, and Machine learning

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

# Acting Humanly: The Full or Total 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.



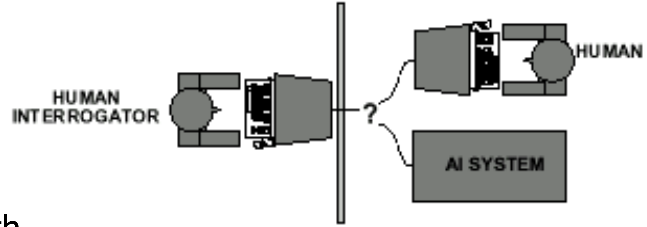

- Computer needs to possess: Natural language processing, Knowledge representation, Automated reasoning, and Machine learning
- Problem: 1) Turing test is not reproducible, constructive, and amenable to mathematic analysis. 2) What about physical interaction with interrogator and environment?
- Total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

# Acting Humanly: The Full Turing Test

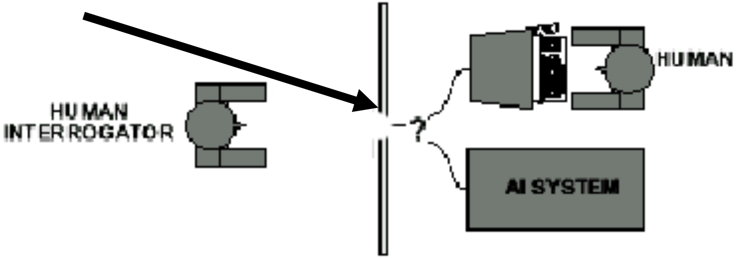
<u>Problem:</u>

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

2) What about physical interaction with interrogator and environment?




Trap door



## What would a computer need to pass the Basic 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 would a computer need to pass the Basic 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.

Core focus in this course

## What would a computer need to pass the Full/Total 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.

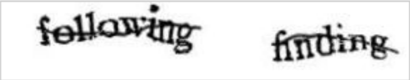
## CAPTCHAs or “Reverse Turing Tests”

- Vision is a particularly difficult one for machines…

- Gave rise to “Completely Automated Public Turing test to tell Computers and Humans Apart” (CAPTCHA)

wikipedia

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".

## Acting Rationally: The Rational Agent

- Another measurement of Intelligence (other than human-like)!
- 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.)
- <u>Advantages:</u>

  1) More general

  2) Its goal of rationality is well defined (you will learn that this semester)

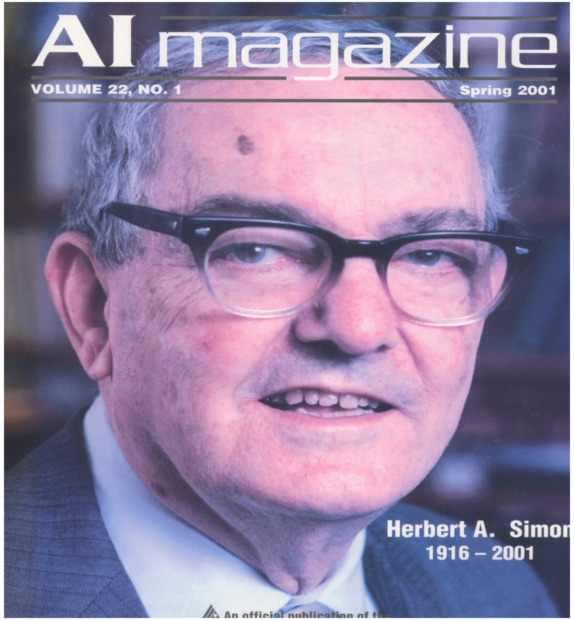
# AI Prehistory

| | |
|---|---|
| Philosophy | logic, methods of reasoning |
| | mind as physical system |
| | foundations of learning, language, rationality |
| Mathematics | formal representation and proof |
| | algorithms |
| | computation, (un)decidability, (in)tractability |
| | probability |
| Psychology | adaptation |
| | phenomena of perception and motor control |
| | experimental techniques (psychophysics, etc.) |
| Linguistics | knowledge representation |
| | grammar |
| Neuroscience | physical substrate for mental activity |
| Control theory | homeostatic systems, stability |
| | simple optimal agent designs |

# 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<br>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<br>Rapid increase in technical depth of mainstream AI<br>"Nouvelle AI": ALife, GAs, soft computing |

Today: you and me ☺




# Forecasting the Future or Shaping It?

October 19, 2000

Our task is not to *predict* the future; our task is to *design* a future for a sustainable and acceptable world, and then to devote our efforts to bringing that future about.

**Professor Herbert A. Simon**

Nobel Prize Laureate
A Founding Father of Artificial Intelligence

you

## AI State of the art

- Have the following been achieved by AI?
  - Pass the (basic) Turing test
  - World-class players for Chess and Go games
  - Playing table tennis
  - Autonomous 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
  - …

# AI State of the art

BBC | Sign in | News | Sport | Weather | Shop | Earth | Trav

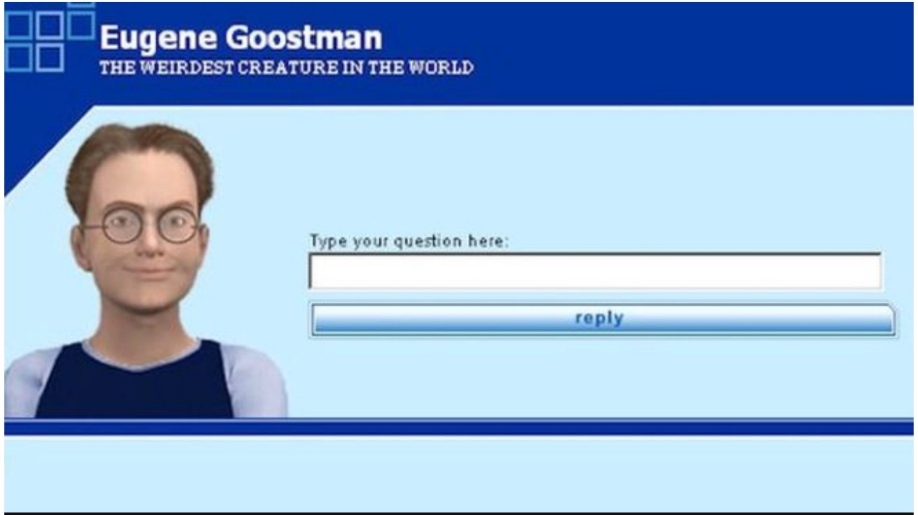
NEWS

Home | Video | World | UK | Business | Tech | Science | Magazine | Entertainment & Arts

Technology

## Computer AI passes Turing test in 'world first'

9 June 2014 | Technology




Eugene Goostman simulates a 13-year-old Ukrainian boy

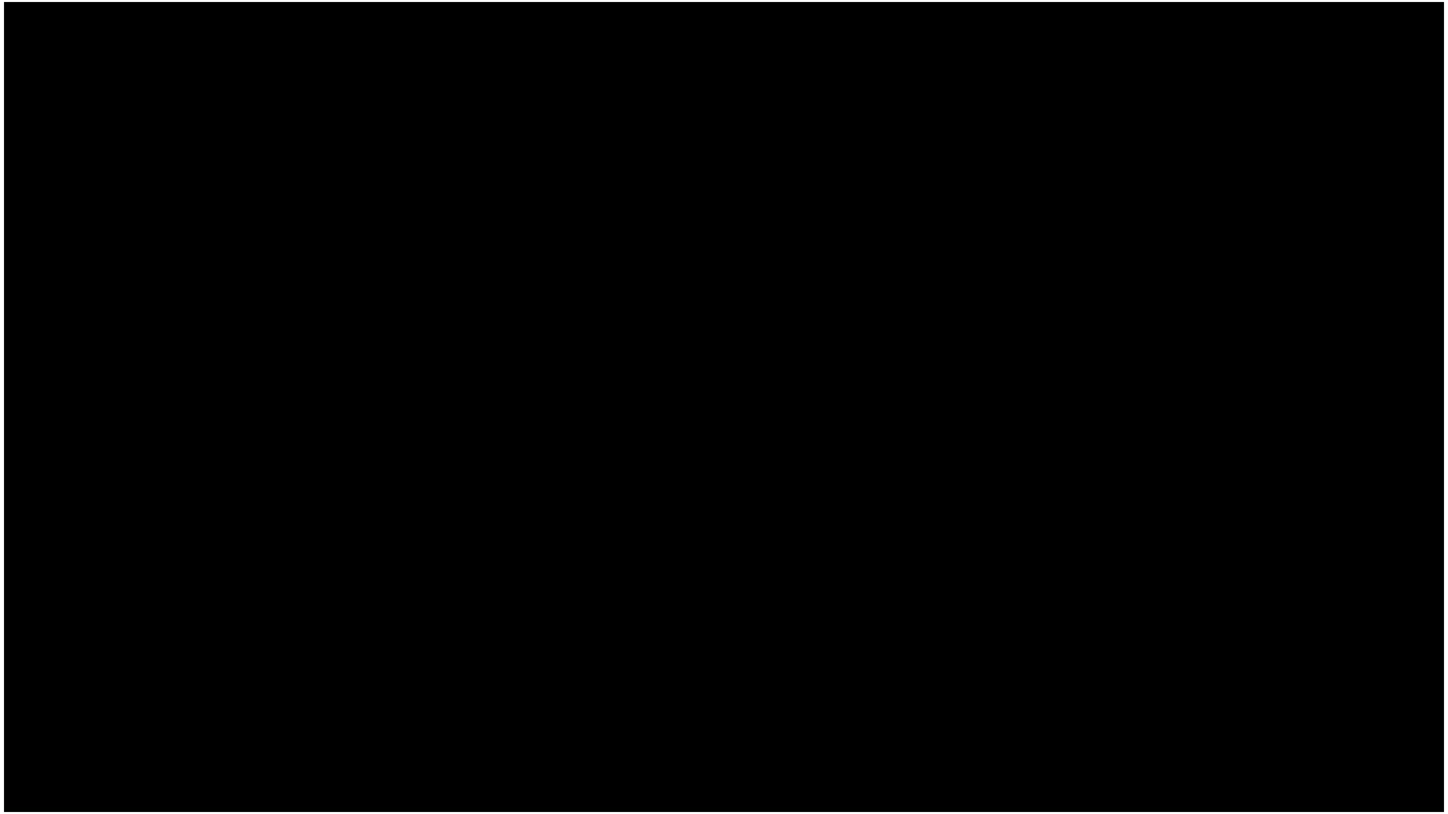

KBA
Google DeepMind
Challenge Match
8 - 15 March 2016
AlphaGo
Lee Sedol

# AI State of the Art ( a movie of robots play table tennis )

# AI State of the Art  (Self-Driving Cars)


BOSTON DYNAMICS

# AI State of the Art  (A female humanoid robot that sings)

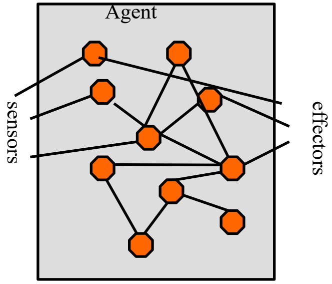


# CSCI-561 Course Overview

## 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.

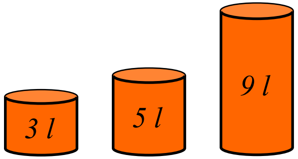
  **Intelligent Agents.** [AIMA Ch 2] What is an intelligent agent? Examples. Doing the right thing (rational action). Performance measure. Autonomy. Environment and agent design. Structure of agents. Agent types. Reflex agents. Reactive agents. Reflex agents with state. Goal-based agents. Utility-based agents. Mobile agents. Information agents.



# Course Overview (cont.)

## How can we solve complex problems?

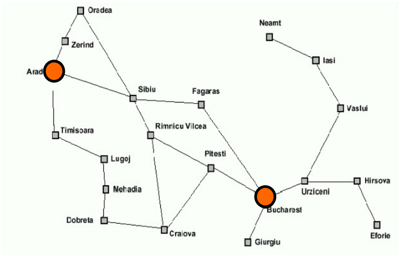
- **02-Problem solving and search.** [AIMA Ch 3] Example: measuring problem. Types of problems. More example problems. Basic idea behind search algorithms. Complexity. Combinatorial explosion and NP completeness. Polynomial hierarchy.




Using these 3 buckets, measure 7 liters of water.

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

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

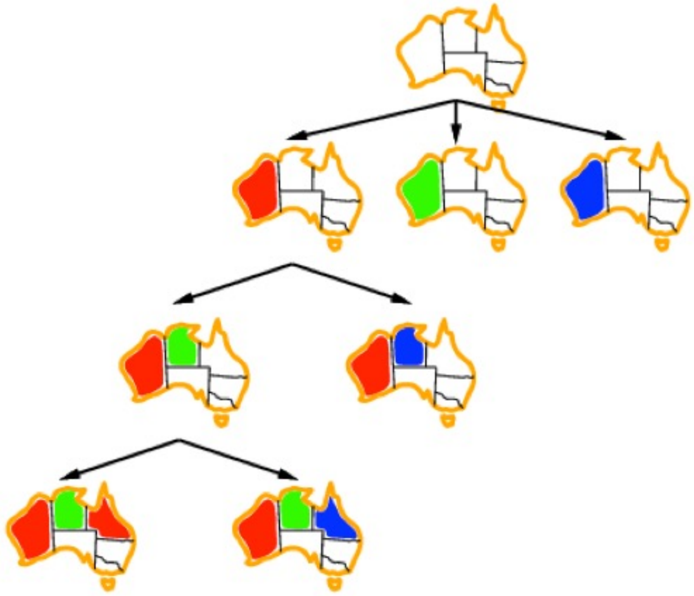



Traveling salesperson problem

## Course Overview (cont.)

### Search under constraints

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



Map coloring



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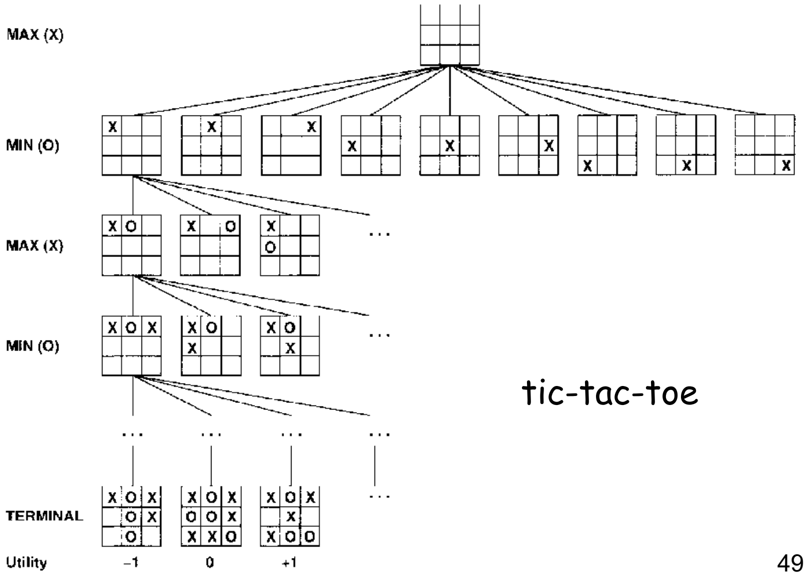
# Course Overview (cont.)

## Practical applications of search.

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

- **06-Advanced Game Playing** [AIMA Ch 16]
  - Reinforcement Q-Learning




tic-tac-toe



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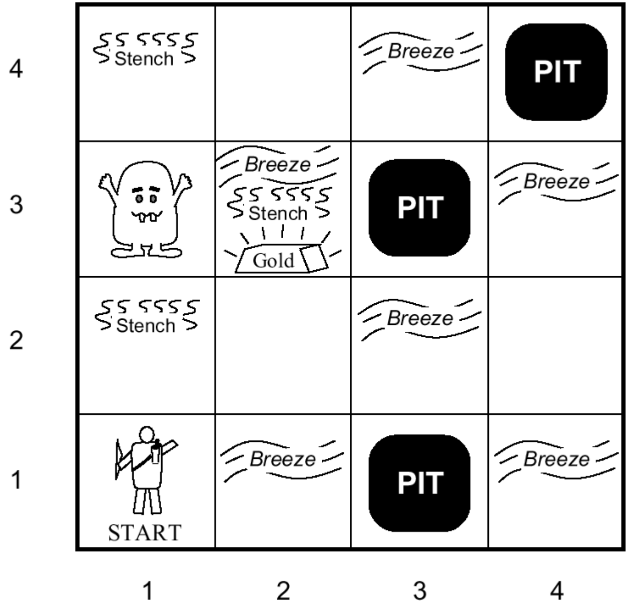
## Course Overview (cont.)

### 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.

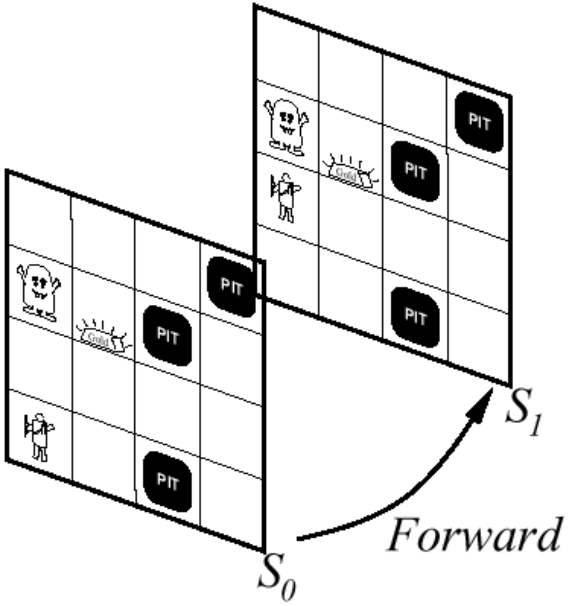



wumpus world

# Course Overview (cont.)

## Building knowledge-based agents: 1st Order Logic

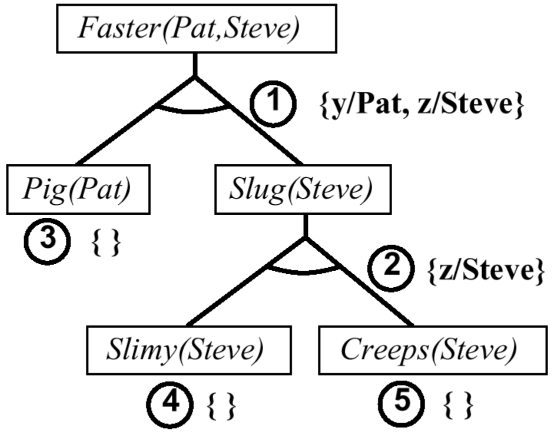
- **11-First-order logic 1.** [AIMA Ch 8] Syntax. Semantics. Atomic sentences. Complex sentences. Quantifiers. Examples. FOL knowledge base. Situation calculus.
- **12-First-order logic 2.** [AIMA Ch 8] Describing actions. Planning. Action sequences.



# Course Overview (cont.)

## Reasoning Logically

- **13/14-Inference in first-order logic.** [AIMA Ch 9] Proofs. Unification. Generalized modus ponens. Forward and backward chaining.

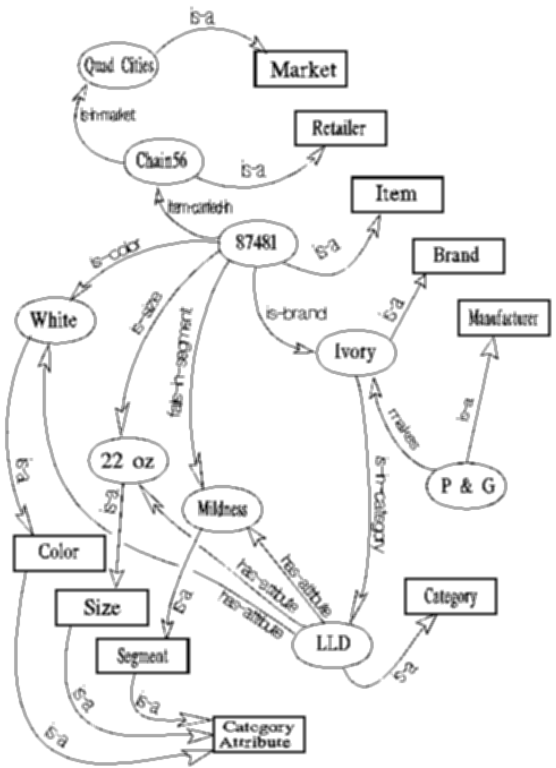



Example of backward chaining

Course Overview (cont.)

## Examples of Logical Reasoning Systems

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

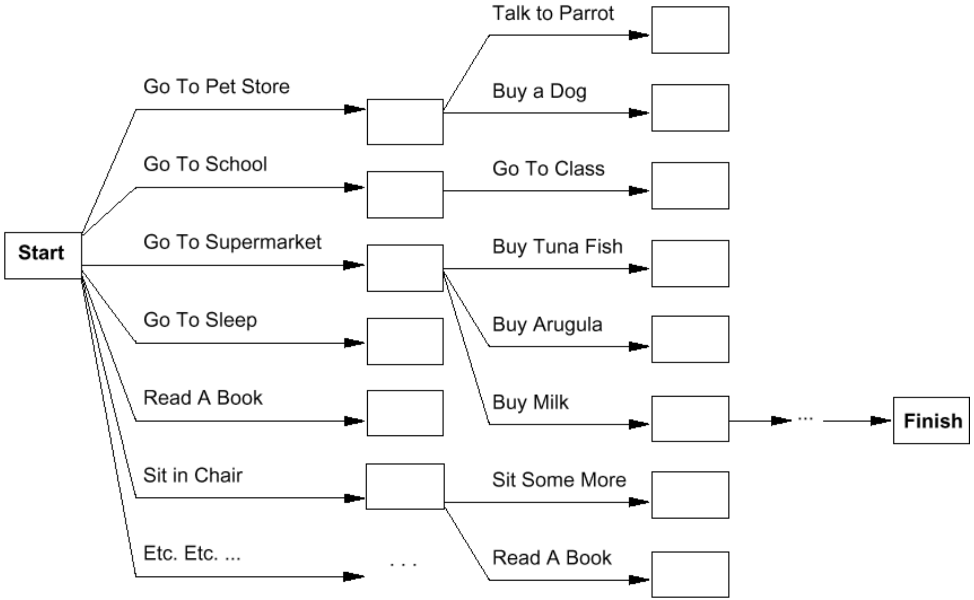



Semantic network used in an insight generator (Duke university)

## Course Overview (cont.)

### Systems that can Plan Future Behavior

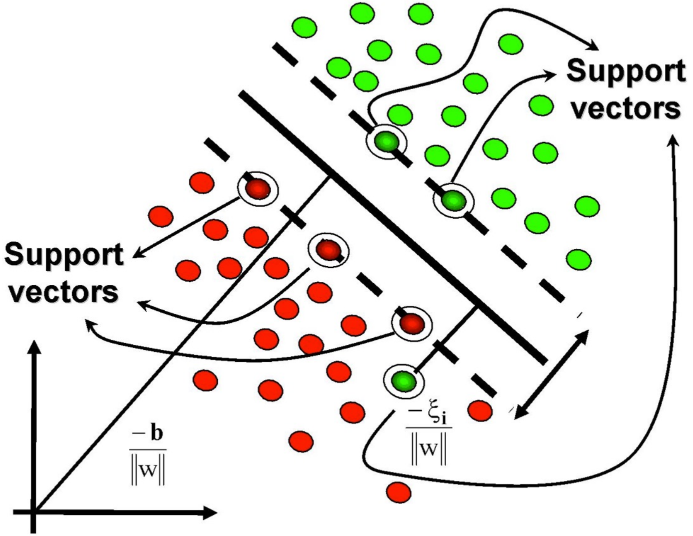
- **16-Planning.** [AIMA Ch 10] Definition and goals. Basic representations for planning. Situation space and plan space. Examples.



# Course Overview (cont.)

**Handling fuzziness, change, uncertainty.**

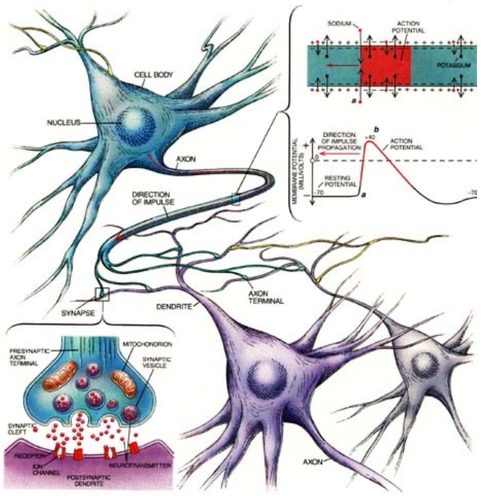
**18-Learning from examples.** [AIMA 18 + handout]. Supervised learning, learning decision trees, support vector machines.

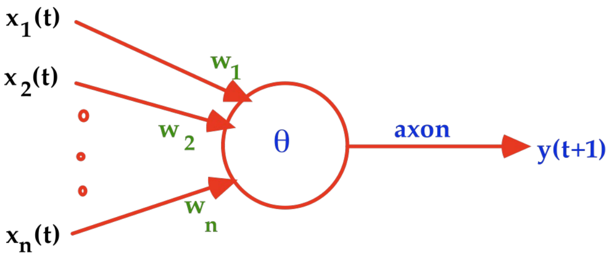


# Course Overview (cont.)

## Learning with Neural networks

- **19/20-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, fuzziness, and changes**

- **21/22-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:

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

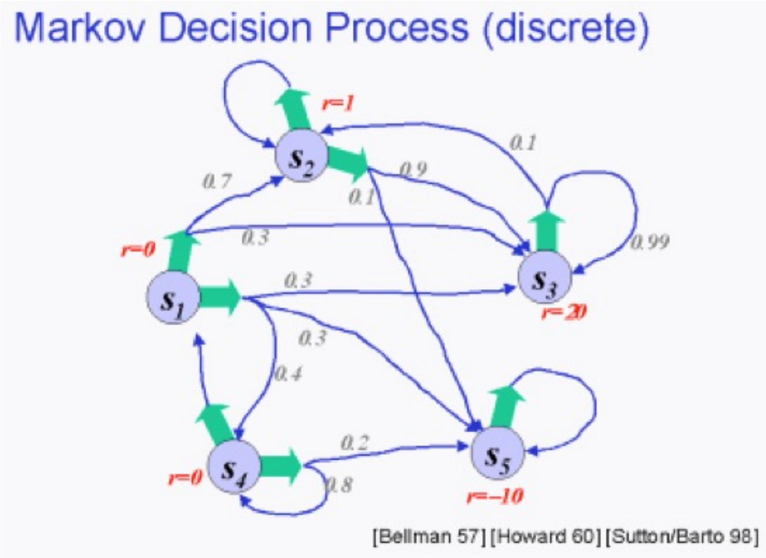
E.g., let $M$ be meningitis, $S$ be stiff neck:

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

# Course Overview (cont.)

## Handling uncertainties, fuzziness, and changes

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

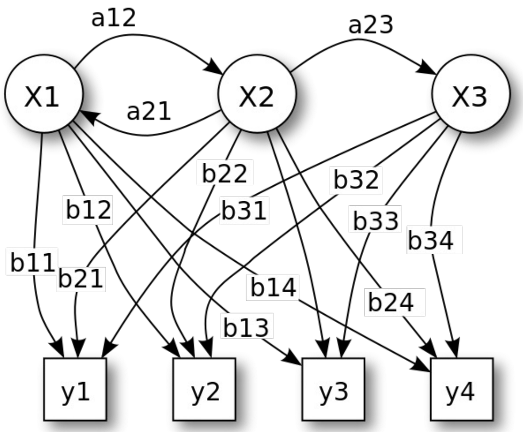


# Course Overview (cont.)

## Handling uncertainties, fuzziness, and changes

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

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

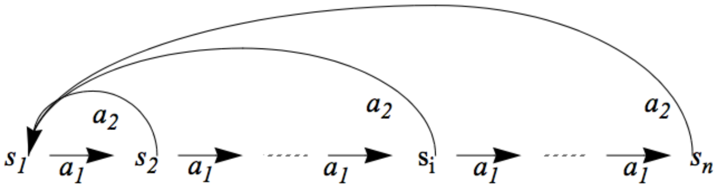


## Course Overview (cont.)

**Handling uncertainties, fuzziness, and changes**

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

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

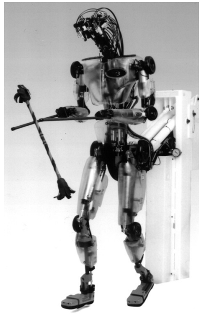



$$Q_{k+1}(s,a) \leftarrow \sum_{s'} T(s,a,s') \left[ R(s,a,s') + \gamma \max_{a'} Q_k(s',a') \right]$$

## Course Overview (cont.)

### What challenges remain?

- **26-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?



More from the Discussion Session later today

# INTELLIGENT AGENTS

## 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**.

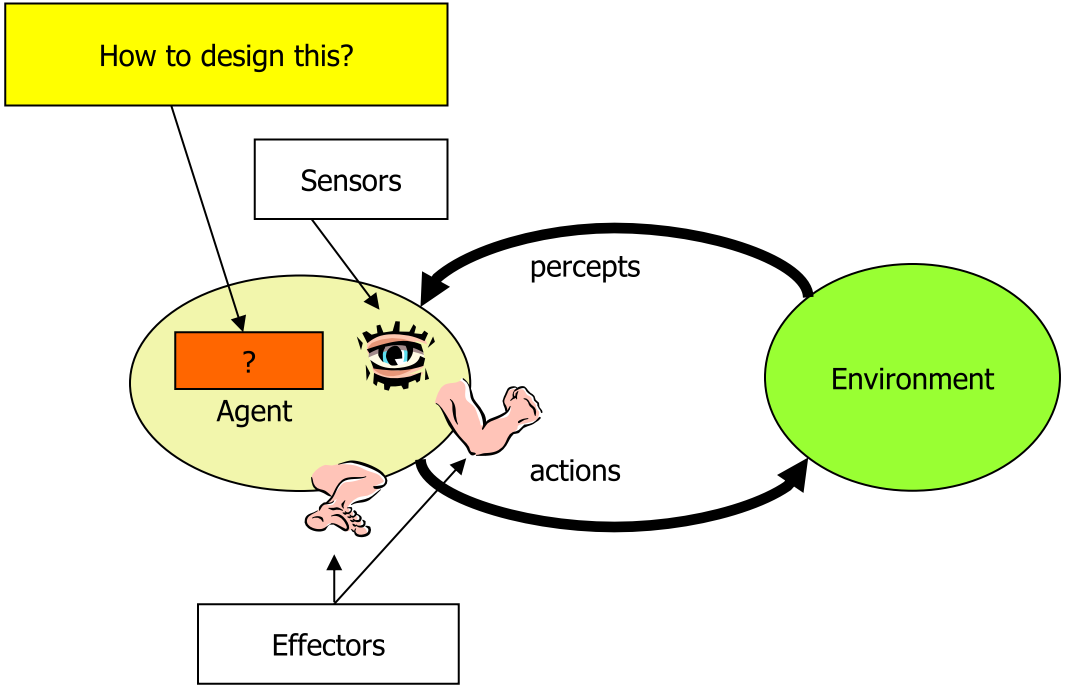
## What is an (Intelligent) Agent?

- **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

# Agent and Environment Interactions



## A Windshield Wiper Agent (Example)

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 …

# Interactions Among Agents

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

# Interactions Among 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 at the right time

## 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 (supernatural) ?
  - Rational = Successful ?

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

## Behavior and Performance of IAs

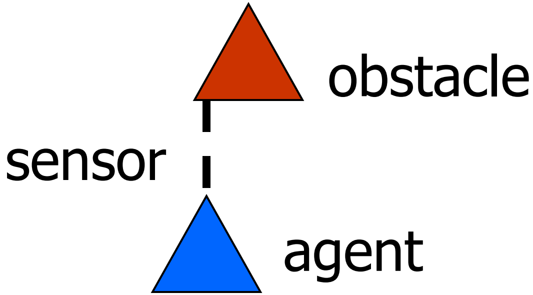
- **Perception** (sequence) **to Action Mapping:** $f: \mathcal{P}^* \rightarrow \mathcal{A}$
  - **Ideal mapping:** specifies which actions an agent ought to take at any point in time
  - **Implementation:** Look-Up-Table, Closed Form, Algorithm, etc.

- **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?

# “Look-Up-Table” Agent

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



# Closed Form

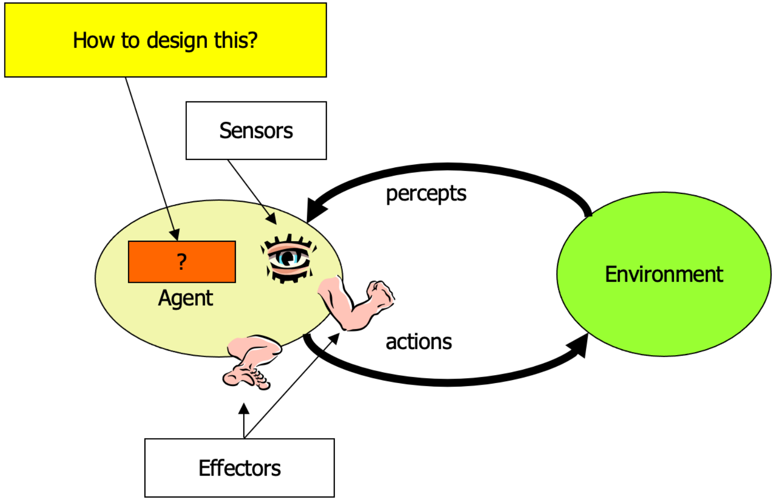
- Output (degree of rotation) = $F$(distance)
- E.g., $F$(d) = 10/d (distance cannot be less than 1/10)

# How is an Agent different from other software?

Is A/C Thermostats an Agent?
Is Zoom an agent?

- 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

# Types of Environments




- Characteristics
  - Accessible vs. Inaccessible
  - Deterministic vs. Nondeterministic
  - Episodic vs. Non-episodic
  - Hostile vs. Friendly
  - Static vs. Dynamic
  - Discrete vs. Continuous

## Environment Types

- Characteristics
  - Accessible (observable) vs. inaccessible (partial observable)
    - Accessible: sensors give access to **complete** state of the environment.
  - Deterministic vs. nondeterministic
    - Deterministic: the next state can be determined based on the current state and the action.
  - Episodic vs. non-episodic (Sequential)
    - Episode: each perceive and action pairs
    - In episodic environments, the quality of action does not depend on the previous episode and does not affect the next episode.
    - Example: Episodic: mail sorting system; non-episodic: chess

## Environment Types

- Characteristics
  - Hostile vs. friendly
  - Static vs. dynamic
    - Dynamic if the environment changes during deliberation
  - Discrete vs. continuous
    - Chess vs. driving

# Environment types

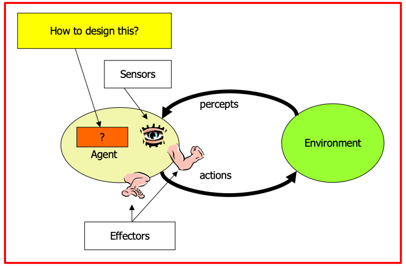
| Environment | Accessible | Deterministic | Episodic | Static | Discrete |
|---|---|---|---|---|---|
| Operating System | | | | | |
| Virtual Reality | | | | | |
| Office Environment | | | | | |
| Mars | | | | | |

## Environment types

| Environment | Accessible | Deterministic | Episodic | Static | Discrete |
|---|---|---|---|---|---|
| Operating System | Yes | Yes | No | No | Yes |
| Virtual Reality | Yes | Yes | Yes/no | No | Yes/no |
| Office Environment | No | No | No | No | No |
| Mars | No | Semi | No | Semi | No |

The environment types largely determine the agent design.

## Structure of Intelligent Agents




- **Agent** = architecture + program

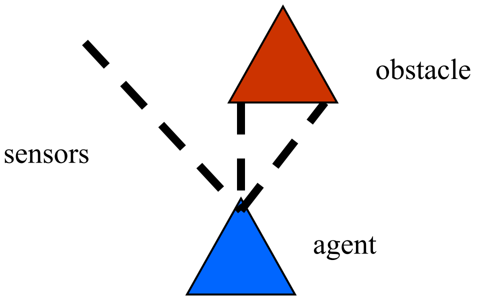
- **Agent Program:** the implementation of $f: \mathcal{P}^* \rightarrow \mathcal{A}$, the agent's perception-action mapping

```
function Skeleton-Agent(Percept) returns Action
        memory ← UpdateMemory(memory, Percept)
        Action ← ChooseBestAction(memory)
        memory ← UpdateMemory(memory, Action)
return Action
```

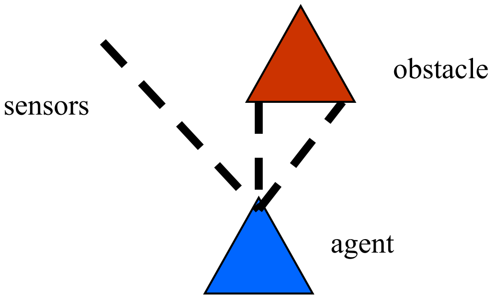
- **Architecture:** a device that can execute the agent program (e.g., general-purpose computer, specialized device, beobot, etc.)

# Using a look-up-table to encode $f : \mathcal{P}^* \rightarrow \mathcal{A}$

- **Example:** Collision Avoidance
  - Sensors: 3 proximity sensors
  - Effectors: Steering Wheel, Brakes
- How to generate?
- How large?
- How to select action?



# Using a look-up-table to encode $f : \mathcal{P}^* \to \mathcal{A}$




- Example: Collision Avoidance
  - Sensors: 3 proximity sensors
  - Effectors: Steering Wheel, Brakes
- How to generate: for each $p \in \mathcal{P}_l \times \mathcal{P}_m \times \mathcal{P}_r$ generate an appropriate action, $a \in \mathcal{S} \times \mathcal{B}$
- How large: size of table = # possible percepts times # possible actions = $|\mathcal{P}_l|\ |\mathcal{P}_m|\ |\mathcal{P}_r|\ |\mathcal{S}|\ |\mathcal{B}|$
  E.g., P = {close, medium, far}$^3$
  A = {left, straight, right} $\times$ {on, off}
  then size of table = 27 rows
- Total possible combinations (ways to fill table): 27*3*2=162
- How to select action? Search.

# TYPES OF AGENT

# Agent Types

- Reflex agents
- Reflex agents with internal states
- Goal-based agents
- Utility-based agents
- Learning agents

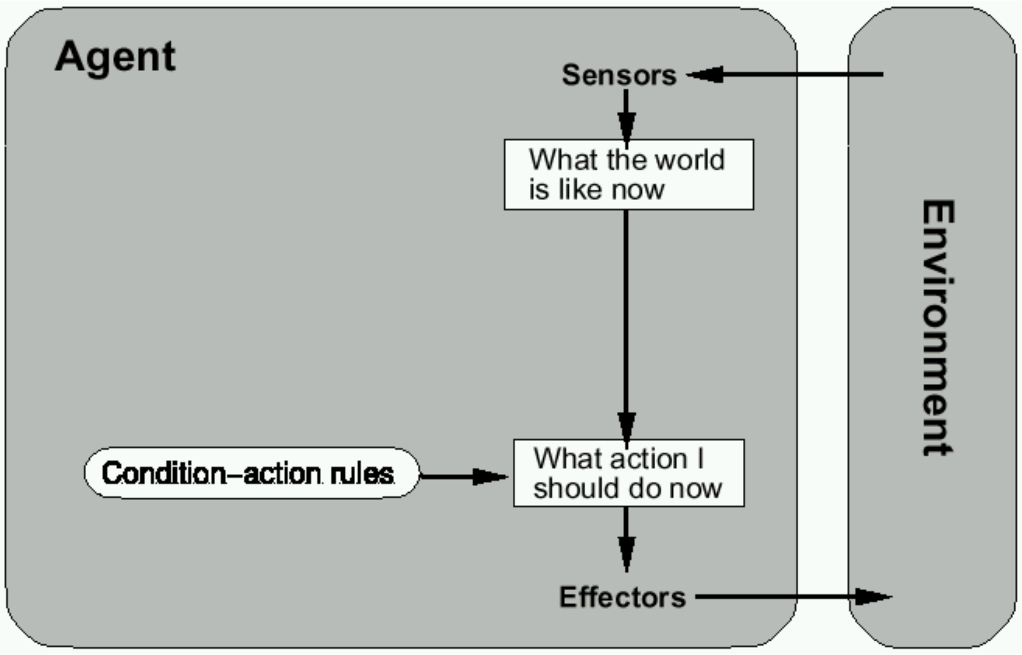
## Agent Types

- Reflex agents
  - Reactive: No memory
- Reflex agents with internal states
  - W/o previous state, may not be able to make decision
    - E.g. brake lights at night.
- Goal-based agents
  - Goal information needed to make decision

## Agent Types

- Utility-based agents
  - How well can the goal be achieved (degree of happiness)
  - What to do if there are conflicting goals?
    - Speed and safety
  - Which goal should be selected if several can be achieved?
- Learning agents
  - How can I adapt to the environment?
  - How can I learn from my mistakes?

# Reflex Agents

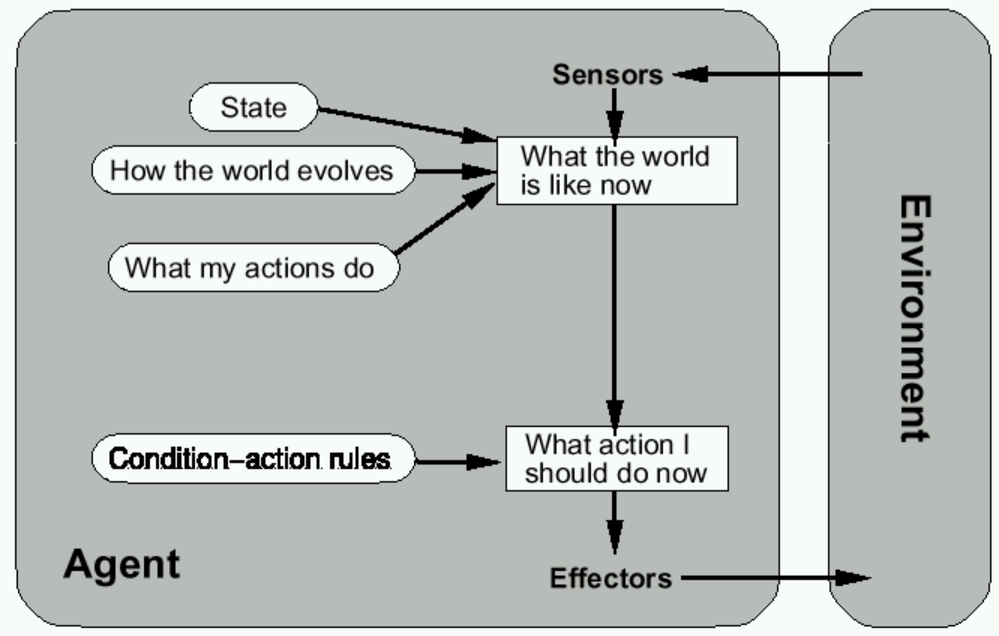


## Reactive Agents

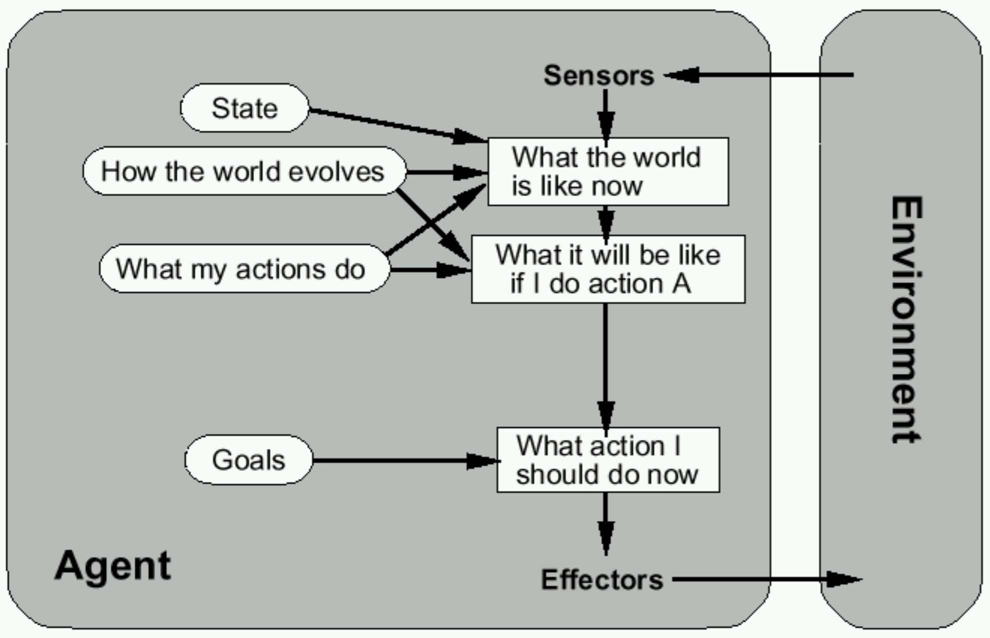
- Reactive agents do not have internal symbolic models.
- Act by stimulus-response to the current state of the environment.
- Each reactive agent is simple and interacts with others in a basic way.
- Complex patterns of behavior emerge from their interaction.

- **Benefits:** robustness, fast response time
- **Challenges:** scalability, how intelligent? how do you debug them?

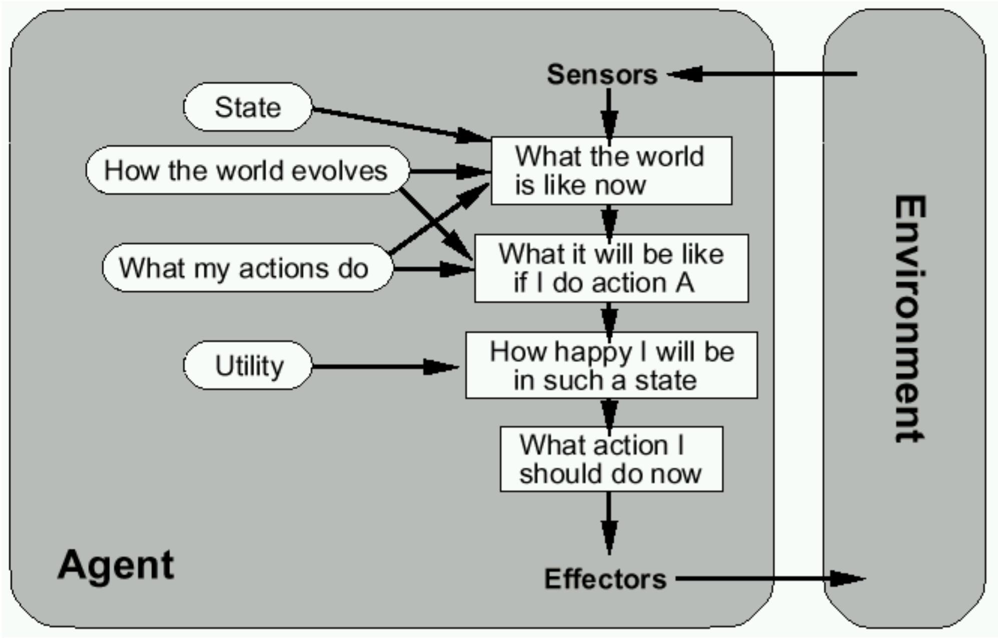
# Reflex Agents with Internal States



# Goal-Based Agents



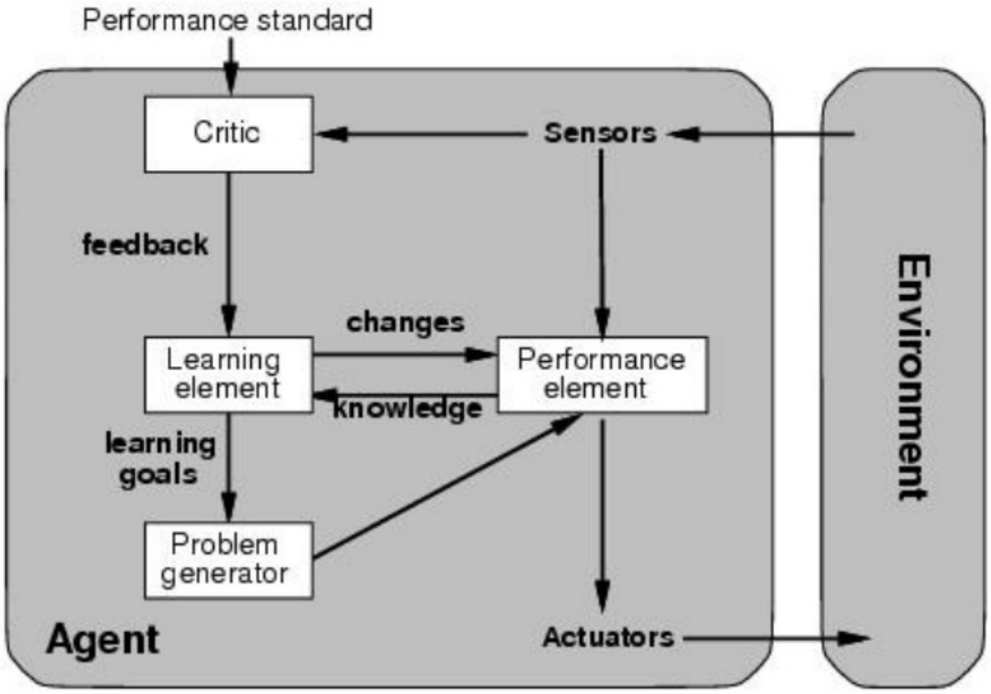
# Utility-Based Agents



# Learning Agents

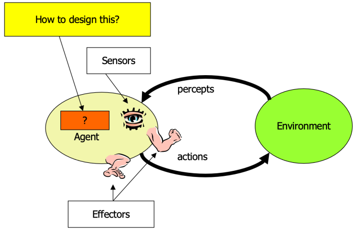
Critic: Determines outcomes of actions and gives feedback

Learning element: Takes feedback from critic and improves performance element




Problem generator: creates new experiences to promote learning

# Summary on Intelligent Agents




- **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>