TDDC17

Seminar 1
Introduction to Artificial Intelligence
Some State of the Art Successes
Intelligent Agent Paradigm
Historical Precursors

Patrick Doherty
Dept of Computer and Information Science
Artificial Intelligence and Integrated Computer Systems Division

LINKÖPING UNIVERSITY

Course Contents

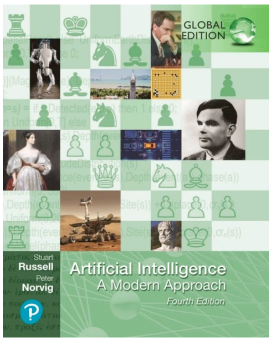
- **17 Föreläsningar (Seminars)**
  - (1) Introduction to AI [Doherty]
  - (2,3) Search [Doherty]
  - (4,5,6,7) Knowledge Representation [Doherty]
  - (8,9) Uncertain Knowledge and Reasoning [Doherty]
  - (10,11) Planning [Kvarnström]
  - (12,13,14) Machine Learning [Liu]
  - (15,16) Perception and Robotics [Wzorek], [Rudol]
  - (17) Course Summary/ Discussion [Doherty]
- **6 Labs**
  - Intelligent Agents
  - Search
  - Bayesian Networks
  - Planning
  - Machine Learning/RL
  - Machine Learning/DL
- **Reading**
  - Russell/Norvig Book (4th Ed, Global)
  - Additional Articles (2)
- **Exam**
  - Standard Written Exam
  - Completion of Labs

http://www.ida.liu.se/~TDDC17/index.en.shtml

https://liuonline.sharepoint.com/sites/Lisam_TDDC17_2021HT_CF

LINKÖPING UNIVERSITY

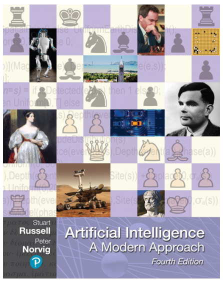
Course Book



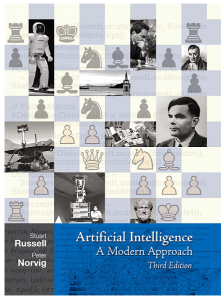
4th (Global) Edition recently accessible.
Can be purchased at LiU bookstore,
BOKAB has an E-Book edition also

Much more up-to-date than 3rd edition
New Chapters

Official course book



3rd Edition
Free copy on the web
(Not recommended)



LINKÖPING UNIVERSITY

What is Intelligence?

> It is only a word that people use to name those unknown processes with which our brains solve problems we call hard. [Marvin Minsky, MIT]

But if you learn the skill yourself or understand the mechanism behind a skill, you are suddenly less impressed!

Our working definitions of what intelligence is must necessarily change through the years. We deal with a moving target which makes it difficult to succinctly explain just what it is we target in AI.

LINKÖPING UNIVERSITY

The “Magic” Phase of AI Technology

“as soon as it works, no one calls it AI anymore.”

John McCarthy

LINKÖPING UNIVERSITY

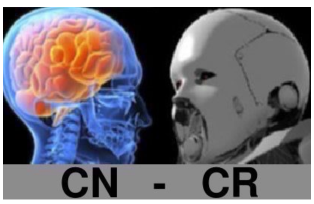
What is Artificial Intelligence?

<u>A Definition:</u>

“the scientific understanding of the mechanisms underlying <u>thought</u> and intelligent <u>behavior</u> and their embodiment in <u>machines</u>.” (AAAI)

<u>The Grand Goal:</u>

“a freely moving machine with the intellectual capabilities of a human being.” (Hans Moravec, CMU)

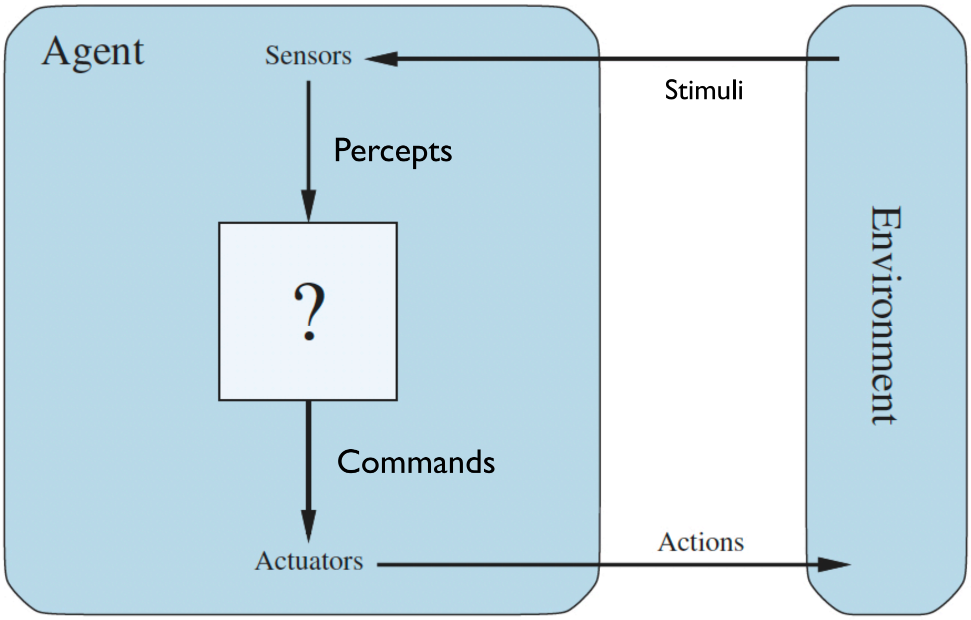


LINKÖPING UNIVERSITY

What is Artificial Intelligence? (Agent methodology)

An agent's **behavior** can be described formally as an **agent function** which maps any percept sequence to an action

An **agent program** implements an **agent function**



Agents interact with the environment through sensors and actuators

LINKÖPING UNIVERSITY

Some Perspectives on AI

	Empirical Sciences Fidelity to human performance **Human-Centered**	Mathematics/Engineering Ideal concept of Intelligence **Rationality-Centered**
Thought Processes Reasoning	Systems that think like humans	Systems that think rationally
	"The exciting new effort to make computers think. . .machines with minds, in the full and literal sense." (Haugeland, 1985) "[The automation of] activities that we associate with human thinking, activities such as decision-making, problem solving, learning..."(Bellman, 1978)	"The study of mental faculties through the use of computational models." (Charniak and McDermott, 1985) "The study of computations that make it possible to perceive, reason, and act." (Winston, 1992)
Behavior	Systems that act like humans	Systems that act rationally
	"The art of creating machines that perform functions that require intelligence when performed by people." (Kurzweil, 1990) "The study of how to make computers do things at which, at the moment, people are better." (Rich and Knight, 1991)	"Computational Intelligence is the study of the design of intelligent agents." (Poole et al., 1998) "AI . . . Is concerned with intelligent behavior in artifacts." (Nilsson, 1998)

LINKÖPING UNIVERSITY

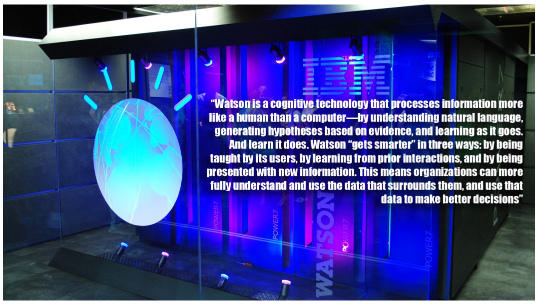
Different Views on AI

Artificial Narrow Intelligence (Weak AI)

AI that specialises in one area.

Computer Chess

IBM's WATSON

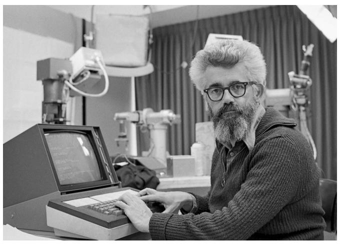


LINKÖPING UNIVERSITY

Different Views on AI

Artificial General Intelligence (Strong AI)

Smart as a human across the board



Human-level Intelligence
with common sense

"Human-level AI will be achieved, but new ideas are almost certainly needed, so a date cannot be reliably predicted—maybe five years, maybe five hundred years. I'd be inclined to bet on this 21st century."

"Overcoming the "brittleness" of present AI systems and reaching human-level AI requires programs that deal with the *common sense informatic situation*—in which the phenomena to be taken into account in achieving a goal are not fixed in advance."

LINKÖPING UNIVERSITY

Different Views on AI

Artificial Super Intelligence (ASI)

AI that surpasses humans.

Nick Bostrom

Let an ultraintelligent machine be defined as a machine that can far surpass all the intellectual activities of any man however clever. Since the design of machines is one of these intellectual activities, an ultraintelligent machine could design even better machines; there would then unquestionably be an "intelligence explosion", and the intelligence of man would be left far behind. Thus the first ultraintelligent machine is the last invention that man need ever make. — I. J. Good [1965]

We are on the edge of change comparable to the rise of human life on Earth. — Vernor Vinge [1993]

In his 2014 book Superintelligence: *Paths, Dangers, Strategies*, Bostrom reasoned that "the creation of a superintelligent being represents a possible means to the extinction of mankind". Bostrom argues that a computer with near human-level general intellectual ability could initiate an intelligence explosion on a digital time scale with the resultant rapid creation of something so powerful that it might deliberately or accidentally destroy human kind

LINKÖPING UNIVERSITY

Some State-of-the-art Achievements in Artificial Intelligence Research

LINKÖPING UNIVERSITY

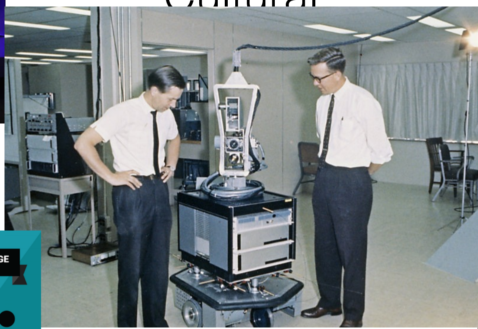
Historically: AI and Robotics

Artificial Intelligence
“Brains without Bodies”

Traditional Robotics
“Bodies without Brains”

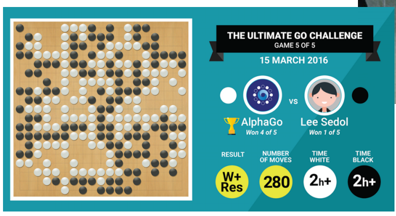
Watson - IBM

Cultural

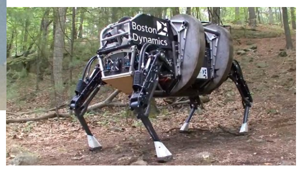


Stanford AI Lab
“Shakey”

ABB



Google Go-Deep Minds

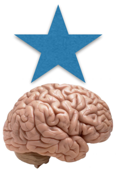


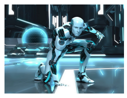
Big Dog

Now strong attempts at Integration

LINKÖPING UNIVERSITY

IBM’s WATSON

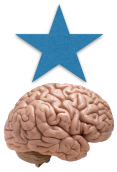


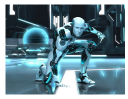


200 million pages of info/10 racks of 10 Power 750 servers

LINKÖPING UNIVERSITY

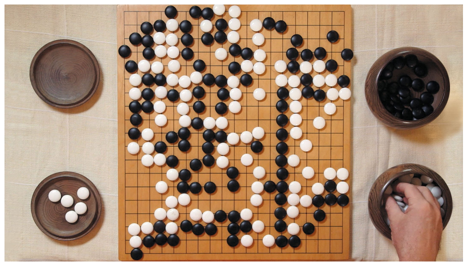
Google/Deep Minds Alpha Go





Monte-Carlo Tree search
Deep Learning
Extensive training using
both human, computer play

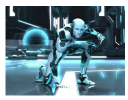
First computer Go program to
beat a human professional
Go player without handicaps
on a full-sized 19x19 board

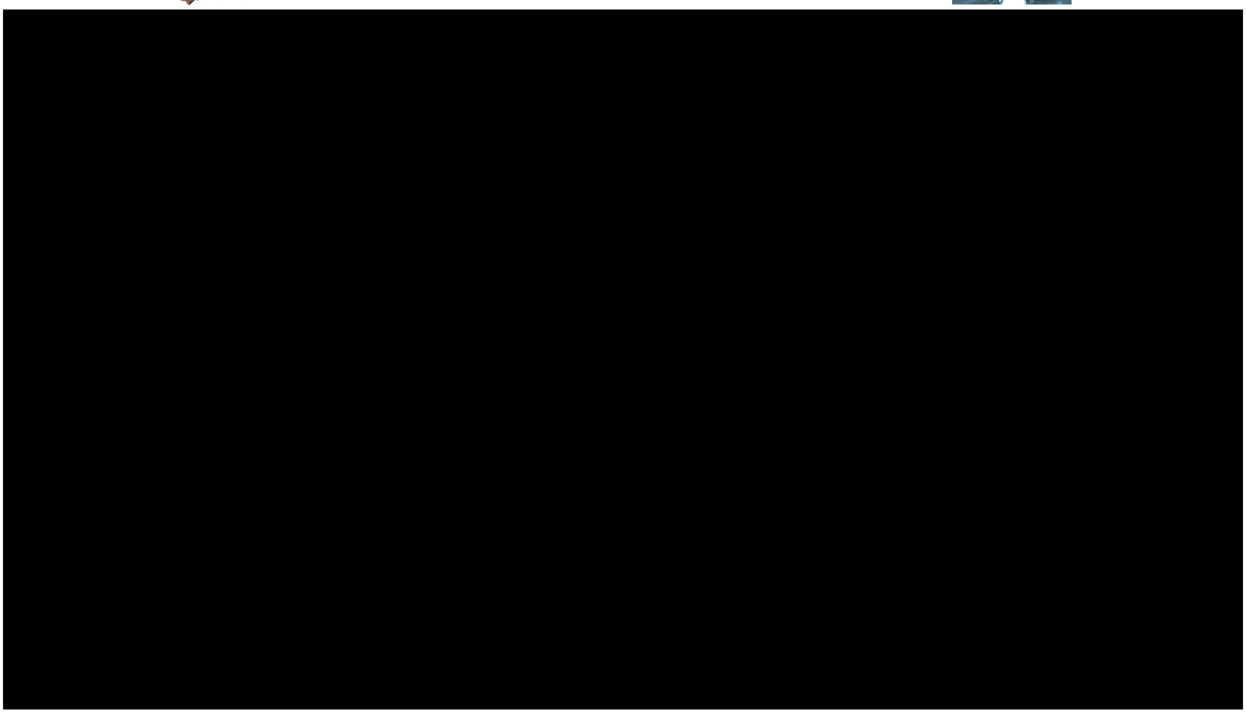


LINKÖPING UNIVERSITY

Kiva Systems - Smart Warehouse Logistics

Integration



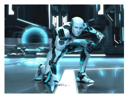


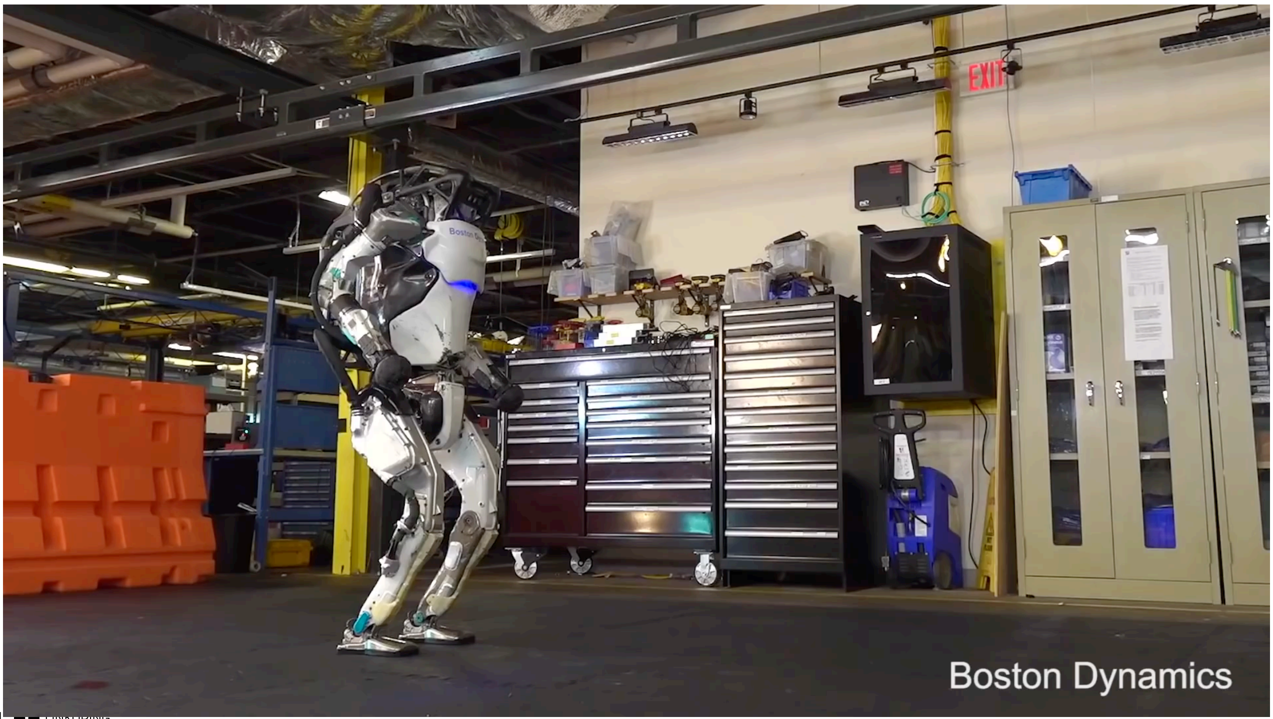
LINKÖPING UNIVERSITY

Purchased by Amazon in 2012: Now called Amazon Robotics

Robotics- Boston Dynamics: ATLAS & HANDLE

Integration





LINKÖPING UNIVERSITY

SPOTS got an Arm!

LINKÖPING UNIVERSITY

Deep Minds - Emergence of Locomotion

Integration

Simulation

LINKÖPING UNIVERSITY

1:26

The Intelligent Agent Paradigm

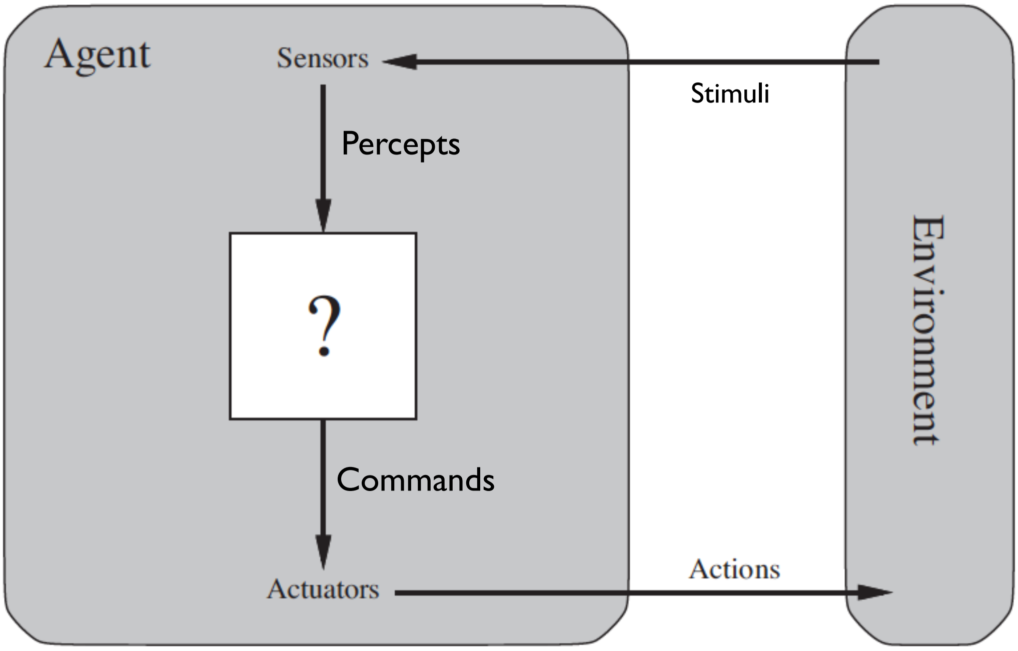
LINKÖPING UNIVERSITY

Intelligent Agents

An **agent** is anything that can be viewed as **perceiving** its **environment** through **sensors** and **acting** upon that environment through **actuators.**

An agent's **behavior** can be described formally as an **agent function** which maps any percept sequence to an action

An **agent program** implements an **agent function**



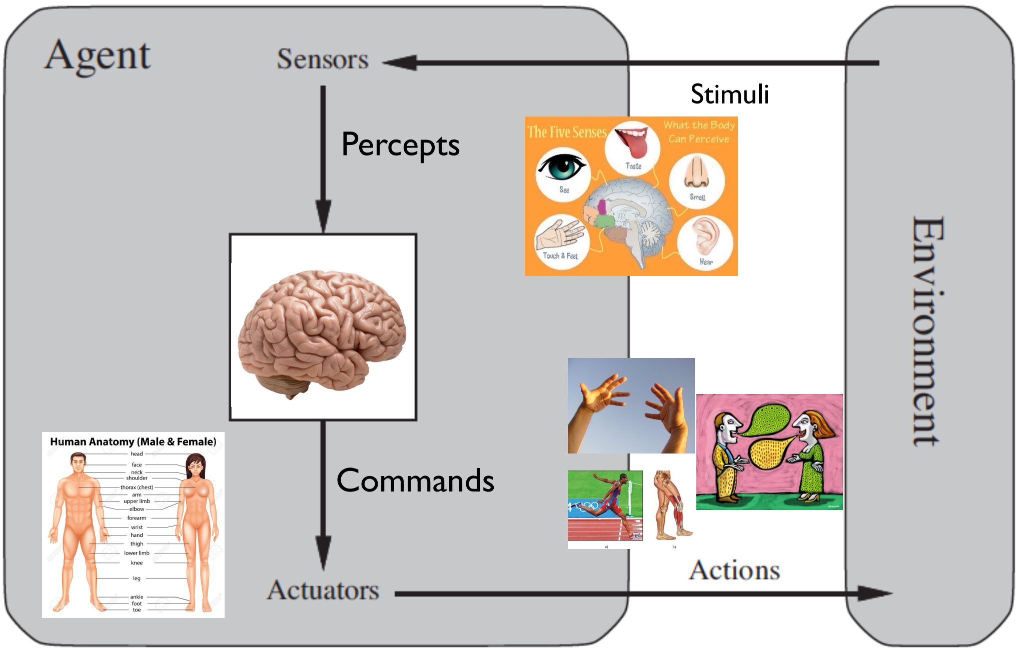
A **Rational Agent** is one that [does the right thing]() relative to an [external performance metric]()

LINKÖPING UNIVERSITY

Humans as Intelligent Agents

An agent's **behavior** can be described formally as an **agent function** which maps any percept sequence to an action

An **agent program** implements an **agent function**



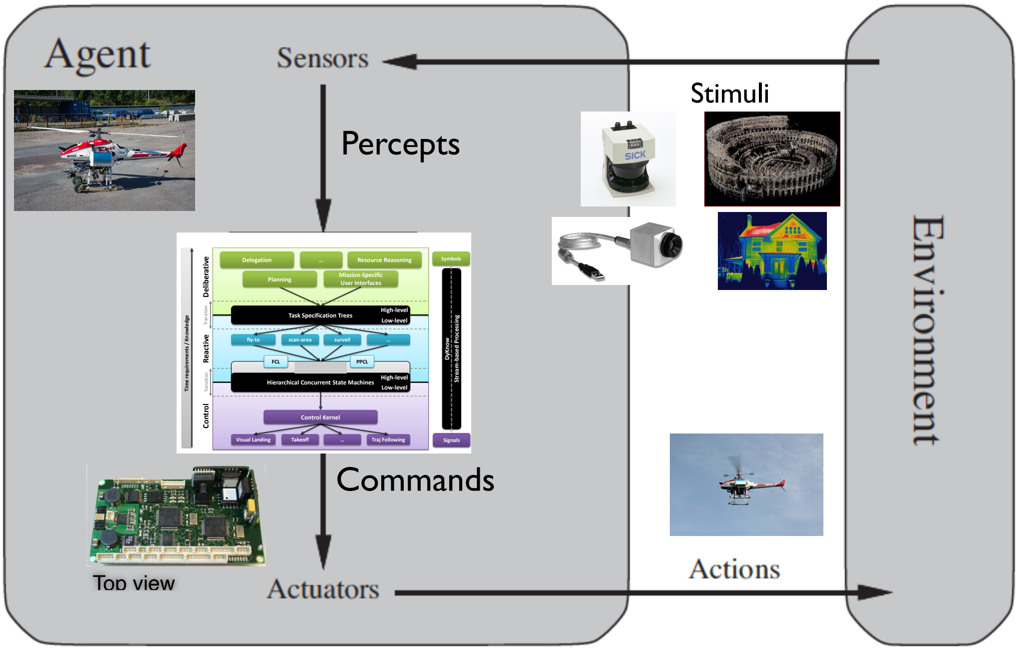
Agents interact with the environment through sensors and actuators

LINKÖPING UNIVERSITY

Robots as Intelligent Agents

An agent's **behavior** can be described formally as an **agent function** which maps any percept sequence to an action

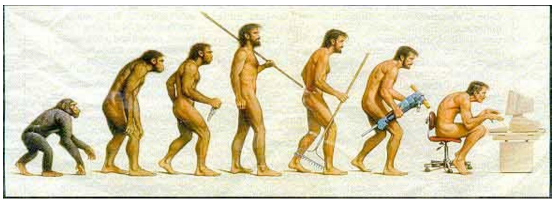
An **agent program** implements an **agent function**



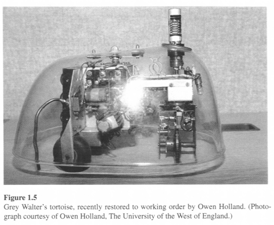
Agents interact with the environment through sensors and actuators

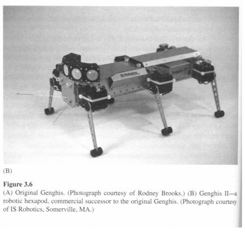
LINKÖPING UNIVERSITY

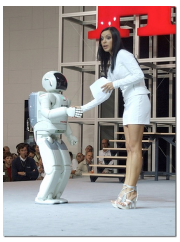
Intelligent Agent Paradigm

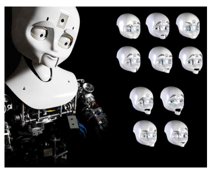


Evolutionary AI







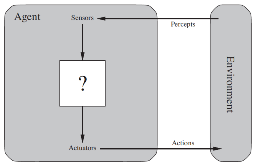


- Introduce a progression of agents (AI systems) each more complex than its predecessor
- Progression loosely follows milestones in evolution of animal species
- Incrementally introduces techniques for exploiting information about tasks **not** directly sensed

Good way to think about AI and to structure techniques, but the use of such techniques is not specific to the agent paradigm

LINKÖPING UNIVERSITY

Rationality



Rationality is dependent on:

- An agents percept sequence; everything the agent has perceived so far
- The embedding environment; what the agent knows about its environment
- An agent's capabilities; the actions the agent can perform.
- The external performance measure used to evaluate the agent's performance

Ideal Rational Agent is one that does the right thing!

For each possible percept sequence, an ideal rational agent should do whatever action is expected to maximize its performance measure, on the basis of the evidence provided by the percept sequence and whatever built-in knowledge the agent has.

LINKÖPING UNIVERSITY

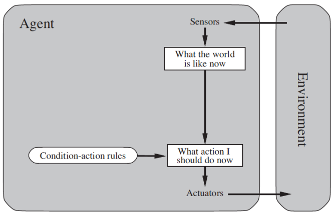
Character of the Task Environment

Influences the performance measurement

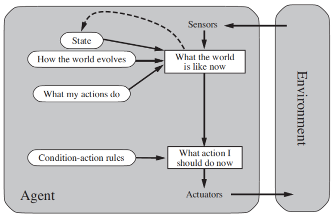
- Fully observable vs. Partially observable
  - An agent's sensory apparatus provides it with the *complete* state of the environment
- Deterministic vs. Stochastic
  - The next state of the environment is completely determined by the current state and the actions selected by the agents.
- Static vs. Dynamic
  - The environment remains unchanged while the agent is deliberating.
- Discrete vs. Continuous
  - There are a limited number of distinct, clearly defined percepts and actions.
  - States and time can be discrete or continuous.
- Episodic vs. Sequential
  - The agent's experience is divided into episodes suchs as ”perceiving and acting”. The quality of the action chosen is only dependent on the current episode (no prediction).
- Single Agent vs. Multi-agent
  - The environment contains one or more agents acting cooperatively or competitively.

LINKÖPING UNIVERSITY

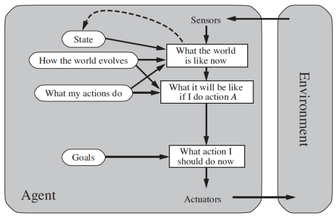
Agent Types



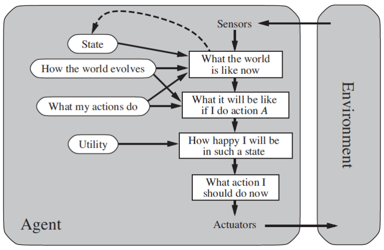
Simple reflex agent



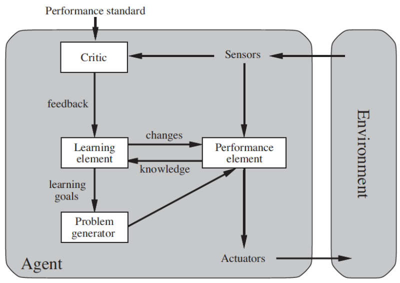
Model-based reflex agent



Goal-based agent



Utility-based agent



Learning agent

LINKÖPING UNIVERSITY

Labs: Environment Simulator

procedure RUN-ENVIRONMENT(*state*, UPDATE-FN, *agents*, *termination*)
  inputs: *state*, the initial state of the environment
    UPDATE-FN, function to modify the environment
    agents, a set of agents
    termination, a predicate to test when we are done

  repeat
    for each *agent* **in** *agents* **do**
Sense   Percept[*agent*] ← Get-Percept(*agent, state*)
    end
    for each *agent* **in** *agents* **do**
      ACTION[*agent*] ← PROGRAM[*agent*](PERCEPT[*agent*]) Think
    end
    state ← UPDATE-FN(*actions, agents, state*) Act
  until *termination*(*state*)

LINKÖPING UNIVERSITY

Vacuum Cleaner World

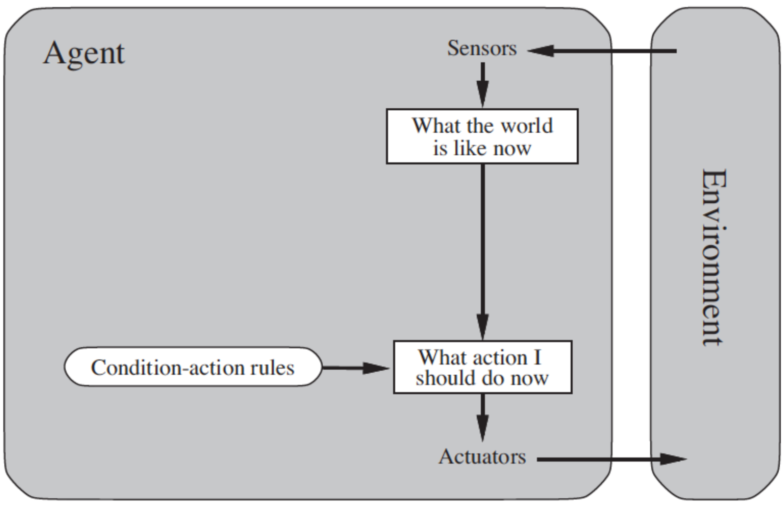
- Percepts – 3-element percept vector (1's or 0's)
  - Touch sensor : checks if you bumped into somthing
  - Photosensor: checks whether there is dirt or not
  - Infrared sensor: checks for home location.
- Actions – 5 actions
  - Go forward, turn right by 90 degrees, turn left by 90 degrees, suck up dirt, turn off.
- Goals – Clean up and go home
- Environment –
  - varied by room shape, dirt and furniture placement
  - Grid of squares with obstacles, dirt or free space

PEAS

Sensors
Actions
Environment
Performance

LINKÖPING UNIVERSITY

Simple Reflex Agent



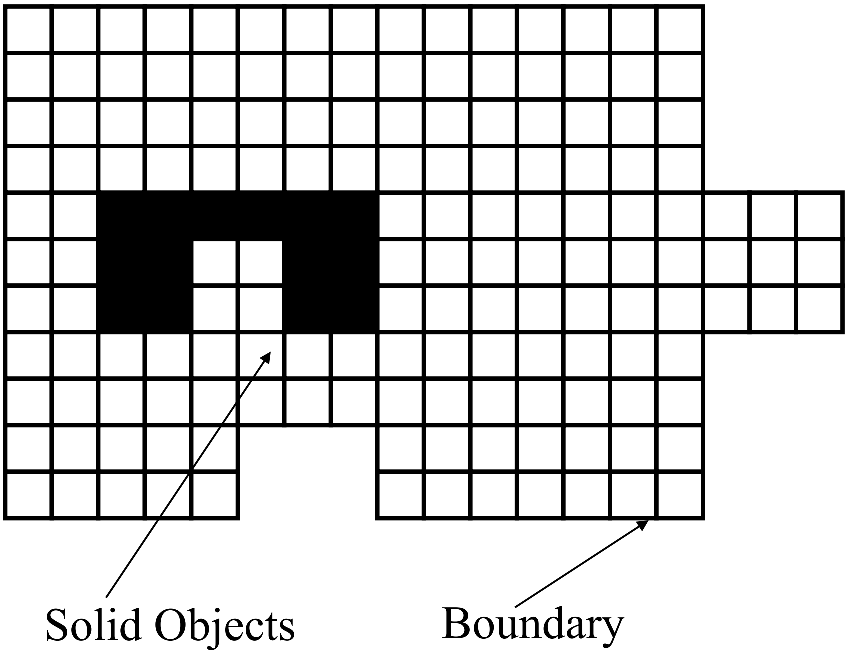
Stimulus-Response Agent

Let's build a simple reflex agent!

- Reacts to immediate stimuli in their environment
- No internal state
- Uses current state of the environment derived from sensory stimuli

LINKÖPING UNIVERSITY

Environment: 2D (3D) Grid Space World

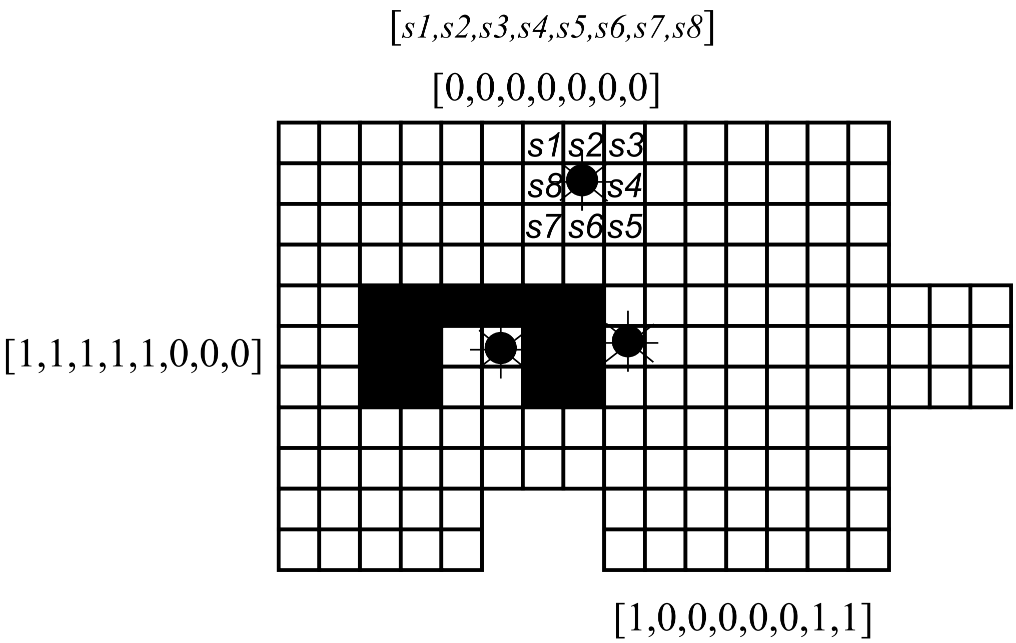


Constraint:
rule out tight spaces

LINKÖPING UNIVERSITY

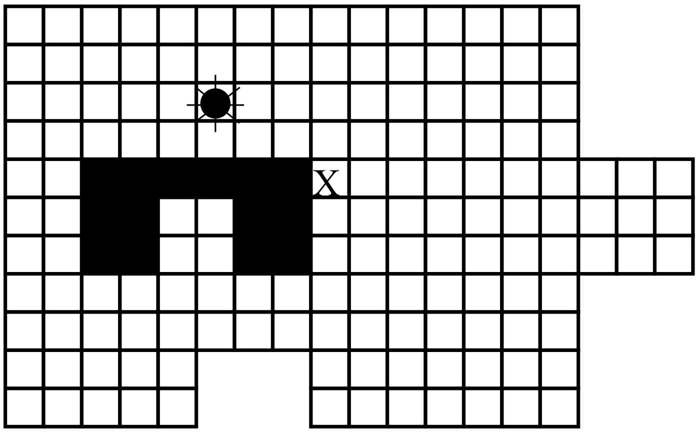
Robot Agent Sensor Capability

Free/obstructed Cells



LINKÖPING UNIVERSITY

Robot Agent Action Capability



- north *moves the robot one cell up in the grid*
- east *moves the robot one cell to the right*
- south *moves the robot one cell down*
- west *moves the robot one cell to the left*

If the robot can not move in a requested direction the action has no effect

Possible path to X:
east, east, east, south, south

LINKÖPING UNIVERSITY

Task Specification and Implementation

Given:
- the properties of the world the agent inhabits
- the agent's motor and sensory capabilities
- the task the agent is to perform:

Specify a function of the sensory inputs that selects actions appropriate for task achievement.

f: [s1,s2,s3,s4,s5,s6,s7,s8] --> {north, east, south, west}

256 possible inputs, 4 choices for output

4^{2^8} possible functions: $1{,}3 \times 10^{154}$

Number of atoms in the universe: 10^{78} - 10^{82}

LINKÖPING UNIVERSITY

Task Examples

Boundary Following

Go to a cell adjacent to a boundary or object and then follow that boundary along its perimeter forever.

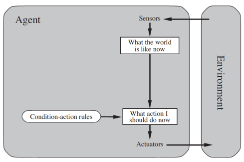
Durative Task: Never Ends

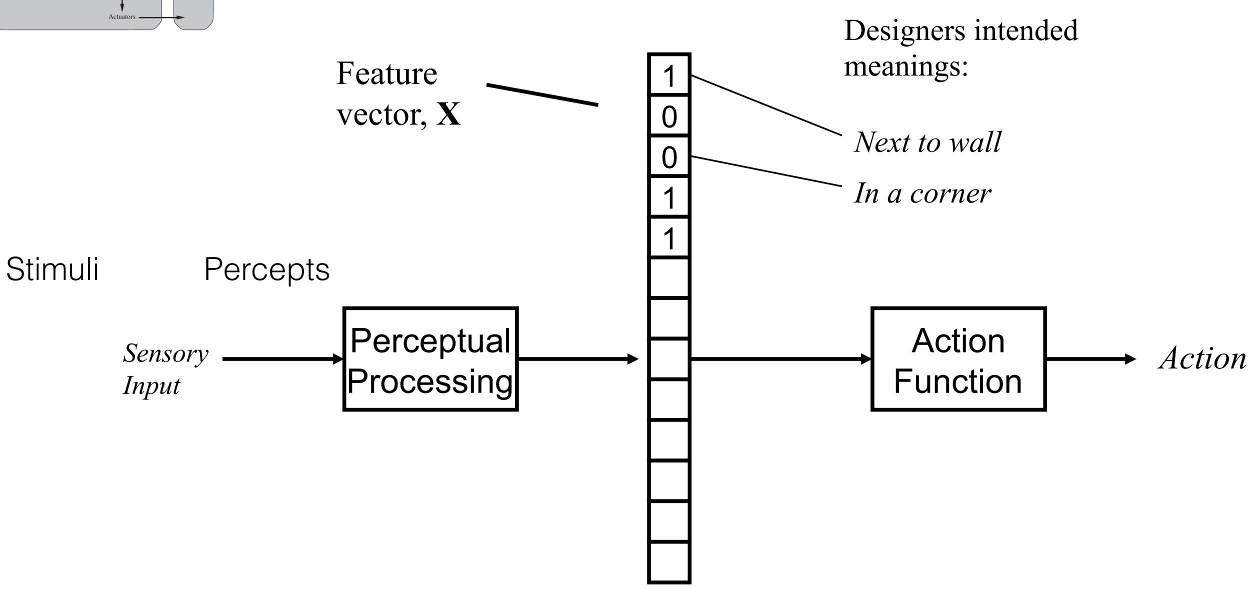
Foraging

- **Wander**: move through the world in search of an attractor
- **Acquire**: move toward the attractor when detected
- **Retrieve**: return the attractor to the home base once acquired

Goal-based Task: Cease activity after goal is achieved

Architecture: Perception and Action





Perception Processing Phase

- Produces a vector of features (x1, . . ., xi, . . ., xn) from the sensory input (s1, . . ., s8).

First level of abstraction: sensory to symbolic structure

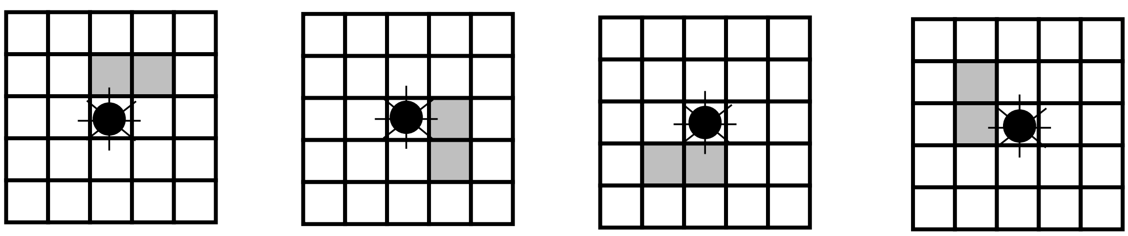
Features mean something to the designer of the artifact. It is debatable whether they mean something to the artifact, but the artifact will be causally effected by the setup (KR Hypothesis).

Feature Types

Numeric | *Non-Numeric*

Non-Numeric: *Boolean* | *Non-Boolean*

Features for Boundary Following



x1 *x2* *x3* *x4*

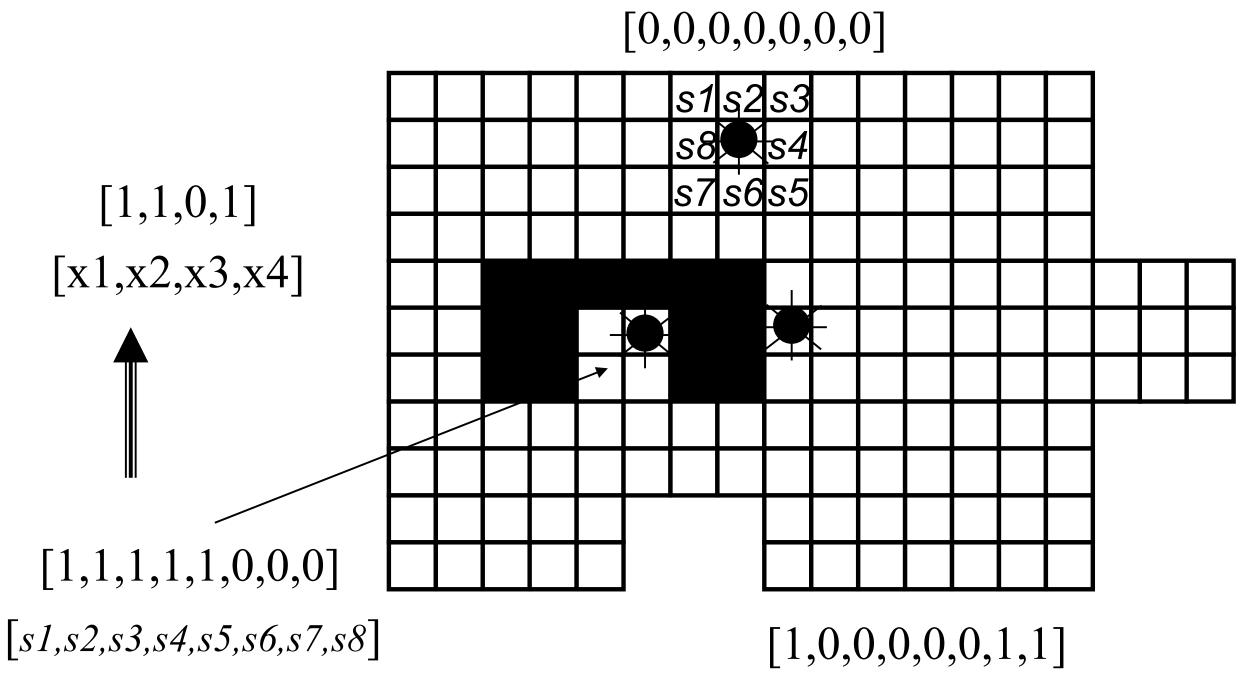
x1 = s2 + s3 | *x2 = s4 + s5* | *x3 = s6 + s7* | *x4 = s8 + s1*

No tight space condition:

Rule out any configuration where the the following boolean function equals 1

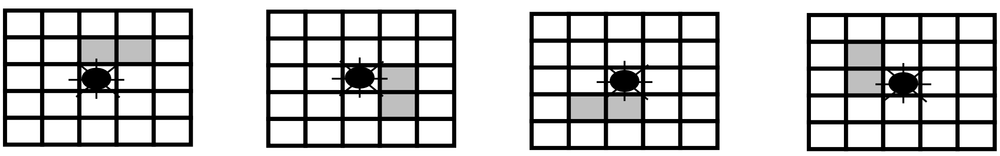
$$x1x2x3x4 + x1x3\overline{x2}\,\overline{x4} + x2x4\overline{x1}\,\overline{x3}$$

Robot Agent Feature Example



Action Function Phase

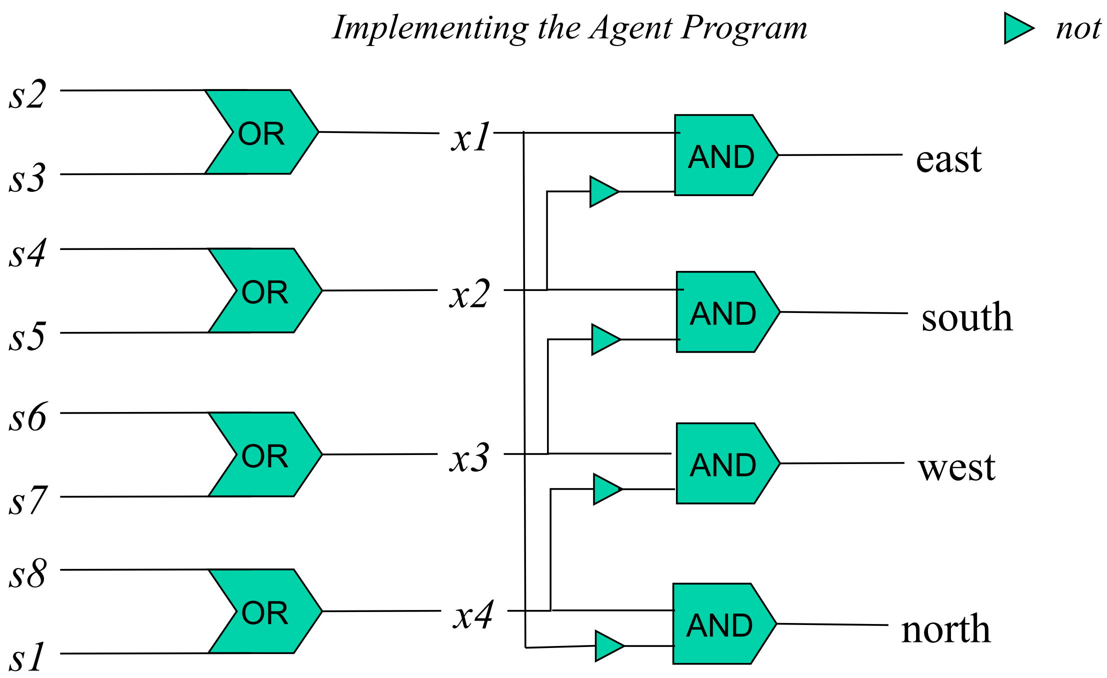
- Specify an *action function* which takes as input the feature vector and returns an action choice



x1	*x2*	*x3*	*x4*
$x1 = s2 + s3$	$x2 = s4 + s5$	$x3 = s6 + s7$	$x4 = s8 + s1$

if *x1*=1 and *x2*=0 then move **east**
if *x2*=1 and *x3*=0 then move **south**
if *x3*=1 and *x4*=0 then move **west**
if *x4*=1 and *x1*=0 then move **north**
if *x1*=0 and *x2*=0 and *x3*=0 and *x4*=0 then move **north**

Circuit Semantics & Boolean Combinations



Production Systems

- A convenient method for representing action functions is the use of *production systems*
- A production system consists of an <u>ordered</u> set of production rules with the following form:

$c_1 \longrightarrow a_1$

$c_2 \longrightarrow a_2$

$\vdots$

$c_i \longrightarrow a_i$

$\vdots$

$c_n \longrightarrow a_n$

$c_i \longrightarrow a_i$

condition — often a conjunction of literals

action — external action, call to another PS

The Boundary Following Task

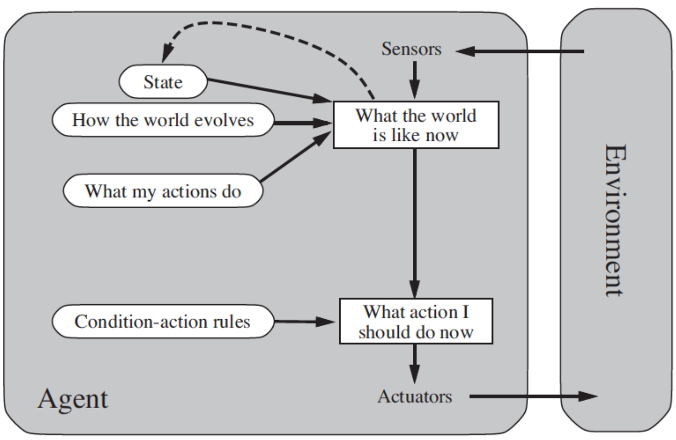
$$x_4\overline{x_1} \longrightarrow \text{north}$$
$$x_3\overline{x_4} \longrightarrow \text{west}$$
$$x_2\overline{x_3} \longrightarrow \text{south}$$
$$x_1\overline{x_2} \longrightarrow \text{east}$$
$$1 \longrightarrow \text{north}$$

- *Each condition is checked from the top down for the first that is true. Then its action is executed.*
- *The conditions are checked continuously.*

Implementing the Agent Program

LINKÖPING UNIVERSITY

Model-based Reflex Agent



State Machine Agent

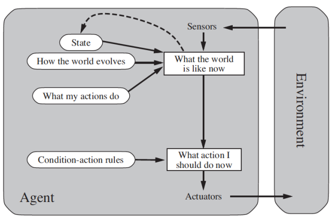
Reflex agent with internal state:
- Limited internal state (implies memory)
- Environmental state at t+1 is a function of:
  - the sensory input at t+1
  - the action taken at time t
  - the previous environmental state at t

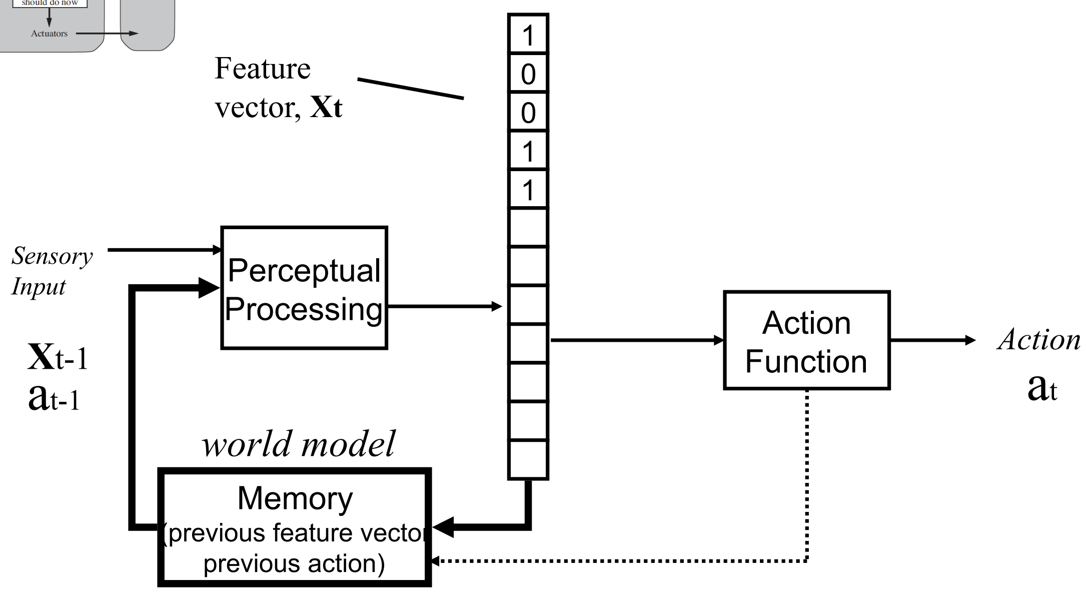
LINKÖPING UNIVERSITY

State Machine Agents

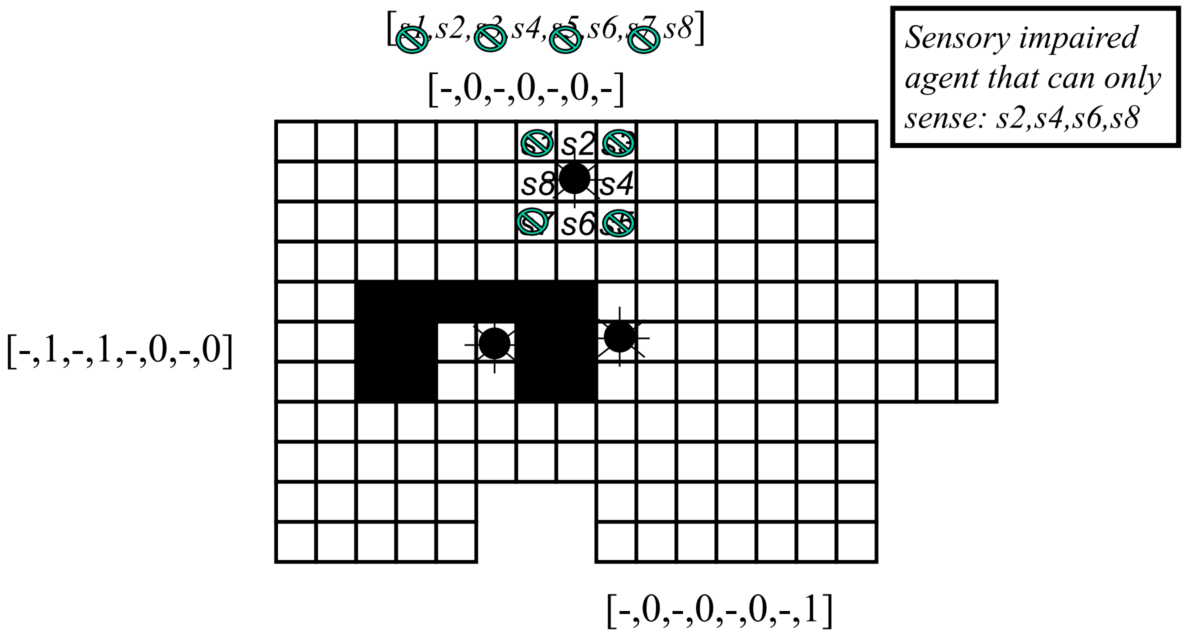
- If all important aspects of the environment relevant to a task can be sensed at the time the agent needs to know them
  - there is no reason to retain a model of the environment in memory
  - memoryless agents can achieve the task
  - In some sense, the world is the model!
- In general, sensory capabilities are almost always limited in some respect
  - one can compensate for this by using a stored model of the environment.
  - the agent can take account of previous sensory history (perhaps processed) to improve task achieving activity.
  - Can also perform tasks that memoryless agents cannot

Architecture: State Machine Agent





Robot Agent Sensor Capability (Revisited)



Boundary Following Task (Revisited)

Can use the world model to derive "hidden state"

[t]$w1$ = [t-1]$w2$ * [t-1]action= **east**

[t]$w3$ = [t-1]$w4$ * [t-1]action= **south**

[t]$w5$ = [t-1]$w6$ * [t-1]action= **west**

[t]$w7$ = [t-1]$w8$ * [t-1]action= **north**

[t]$w2$ = [t]$s2$

[t]$w4$ = [t]$s4$

[t]$w6$ = [t]$s6$

[t]$w8$ = [t]$s8$

4 sensory stimuli: *s2,s4,s6,s8*
8 features: *w1,w2,w3,w4,w5,w6,w7,w8*

Production System

$w2*\overline{w4}$	$\longrightarrow$	east
$w4*\overline{w6}$	$\longrightarrow$	south
$w6*\overline{w8}$	$\longrightarrow$	west
$w8*\overline{w2}$	$\longrightarrow$	north
$w1$	$\longrightarrow$	north
$w3$	$\longrightarrow$	east
$w5$	$\longrightarrow$	south
$w7$	$\longrightarrow$	west
1	$\longrightarrow$	north

Grey Walter’s Tortoise

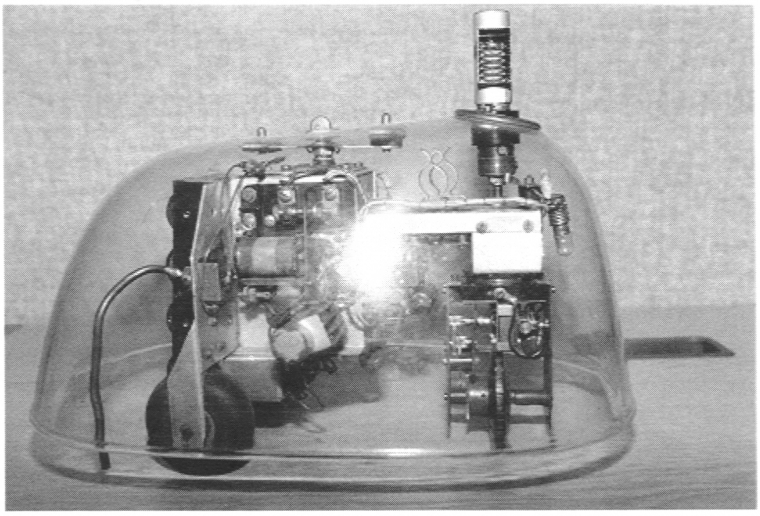


Figure 1.5
Grey Walter’s tortoise, recently restored to working order by Owen Holland. (Photograph courtesy of Owen Holland, The University of the West of England.)

Analog Device

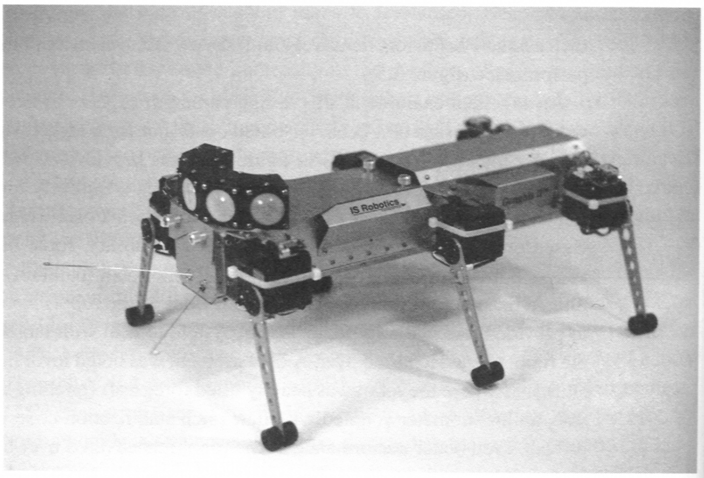
2 sensors:
- directional photcell
- bump contact sensor

2 actuators
2 nerve cells (vacuum tubes)

Skills:
- Seek weak light
- Avoid strong light
- turn and push (obstacle avoid.)
- Recharge battery

LINKÖPING UNIVERSITY

Gengis II: A Robot Hexapod



(B)

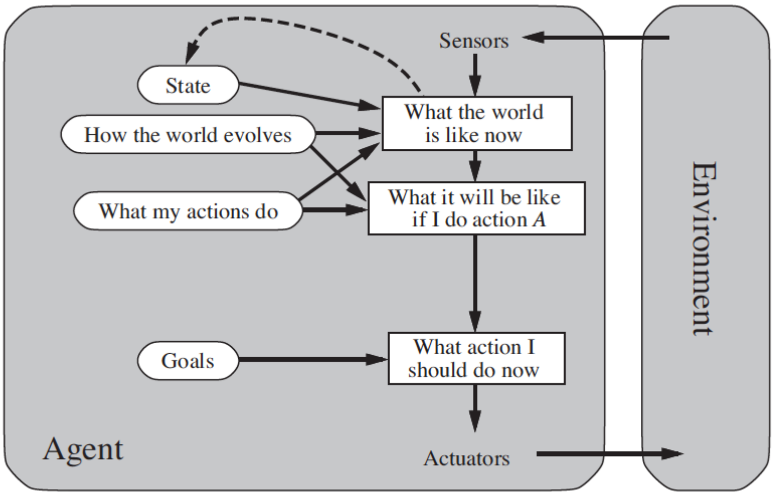
Figure 3.6
(A) Original Genghis. (Photograph courtesy of Rodney Brooks.) (B) Genghis II—a robotic hexapod, commercial successor to the original Genghis. (Photograph courtesy of IS Robotics, Somerville, MA.)

Brooks –
Subsumption-Based
Architectures.

Founded iRobot

LINKÖPING UNIVERSITY

A Goal-Based Agent



Planning and Reasoning Agents

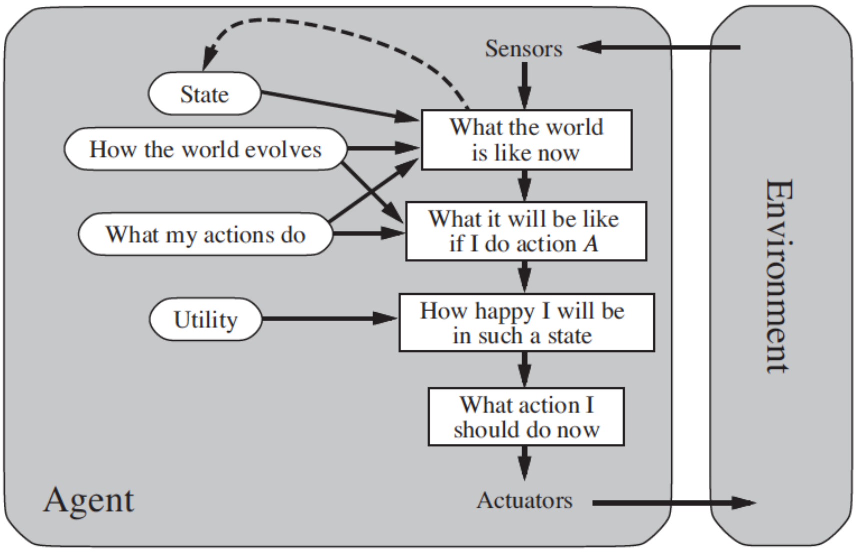
Major part of the course:
- Search
- Knowledge Representation & Reasoning
- Planning

Agents with Purpose!

Goal-based Agents:
- Rich internal state
- Can **anticipate** the effects of their actions
- Take those actions expected to lead toward achievement of goals
- Capable of **reasoning** and **deducing** properties of the world

LINKÖPING UNIVERSITY

Utility-based Agent



Decision Theory
+
Probabilities

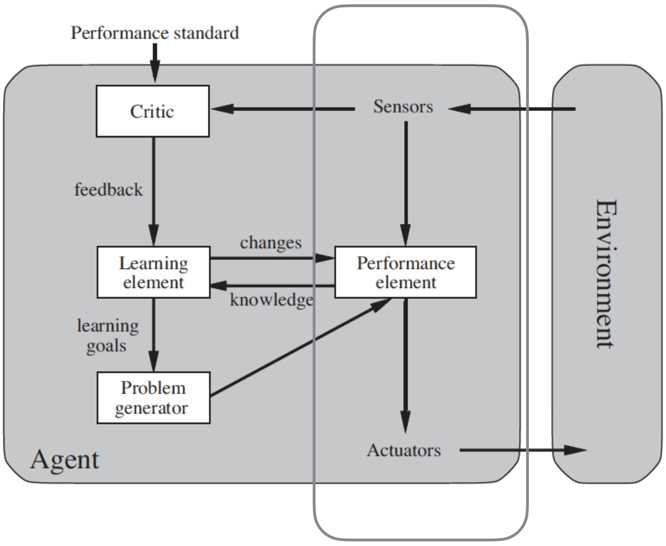
Maximizing Expected Utility of an action

Internalization of Performance measure

Utility-based Agent
- Use of utility function that maps state (or state sequences) into real numbers
- Permits more fine-grained reasoning about what can be achieved, what are the trade-offs, conflicting goals, etc.

LINKÖPING UNIVERSITY

Learning Agent



Previously the entire agent

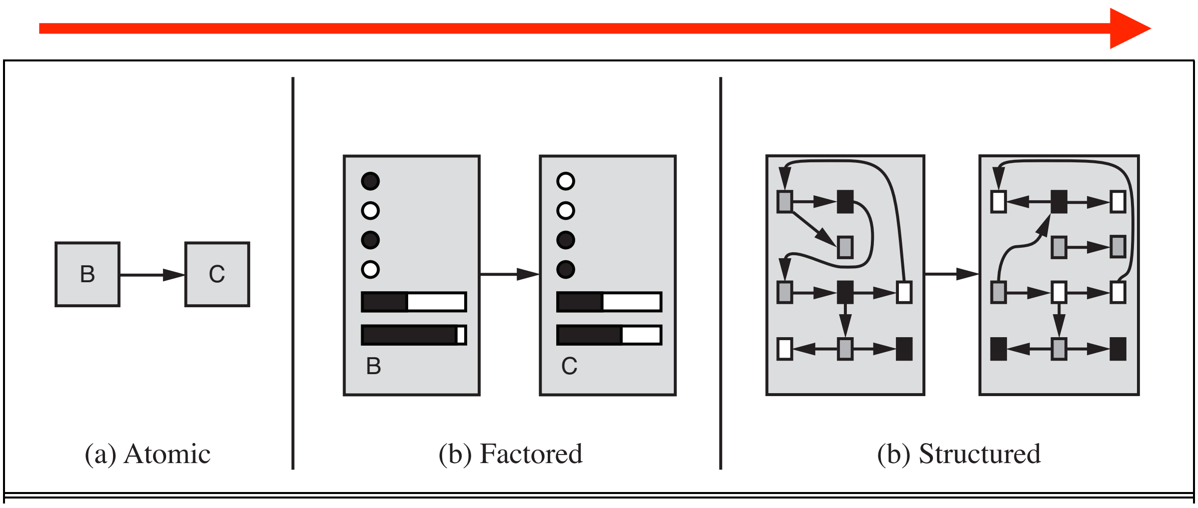
- Bayesian Learning
- Clustering
- Classification
- Reinforcement Learning
- NN/ Deep learning

Learning Agent:
- Has the ability to modify behavior for the better based on experience.
- It can learn new behaviors via exploration of new experiences

LINKÖPING UNIVERSITY

Representing Actions, Knowledge, Environment

Increasing Expressivity



(a) Atomic | (b) Factored | (b) Structured

Search
Game-playing
Hidden Markov Models
Markov Decision Processes

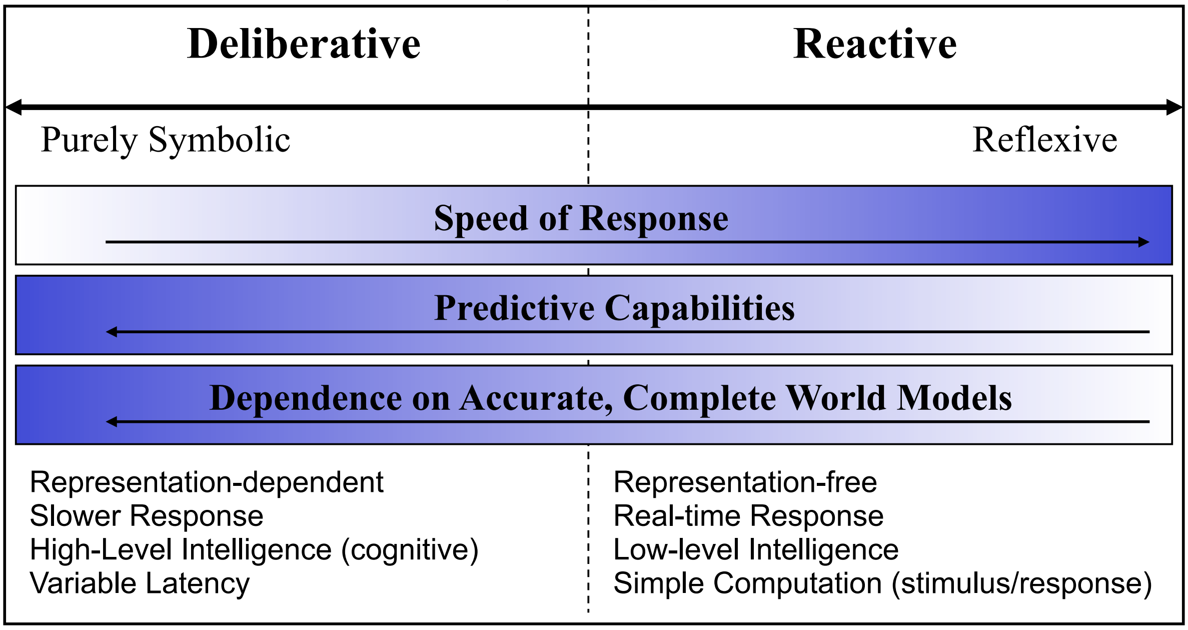
Constraint Satisfaction
Propositional Logic
Automated Planning
Bayesian Networks
Machine Learning

Relational Databases
1st-Order Logic
1st-Order Probability Models
Machine Learning

LINKÖPING UNIVERSITY

Trade-offs between Deliberation and Reaction

Robot Control System Spectrum (Arkin)



Thinking Fast and Slow (2011) - Daniel Kahneman

The book's central thesis is a dichotomy between two modes of thought:
"System 1" is fast, instinctive and emotional;
"System 2" is slower, more deliberative, and more logical.

LINKÖPING UNIVERSITY

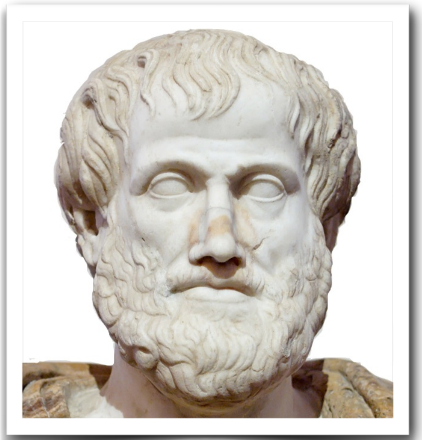
Historical Precursors to the Grand Idea of AI

Some Highlights

LINKÖPING UNIVERSITY

Socrates
Plato
Aristotle

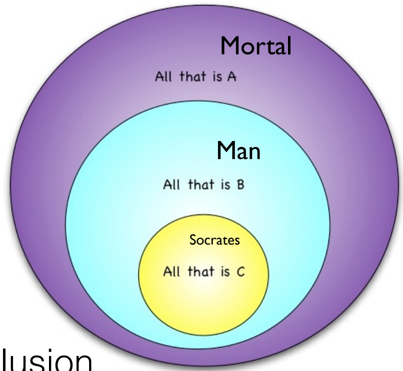
Aristotle (384-322 BC)



What is a good argument?

Syllogistic Reasoning

Syllogistic reasoning is a type of deductive argument. It involves trying to categorize objects by fitting them into contained circles. For instance, suppose we know that all the things matching category "B" fits completely inside the larger category of "A." That's our "major premise" or our first argument. Suppose we also can prove that all the things matching category "C" also fit inside the category of "B." That's our"minor premise" or our second argument. From these two statements, we can also conclude that all of "C" must fit in category "A" as well. We can see this if we chart it visually with three circles, like the drawing below.



All humans are mortal — Major Premise

Socrates is a human — Minor Premise

Socrates is mortal — Deductive Conclusion

Deduction

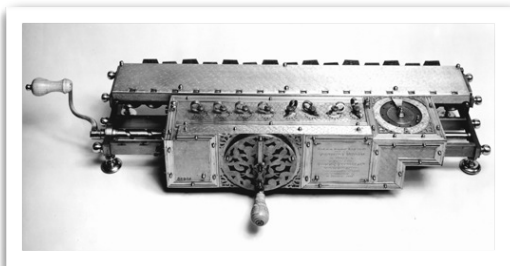
LINKÖPING UNIVERSITY

Leibniz (1646-1716)

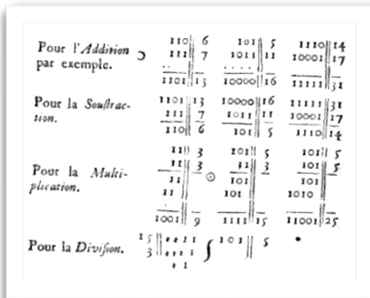
Let us Calculate!

Calculus Ratiocinator

- A universal artificial mathematical language
- All human knowledge could be represented in this language
- Calculational rules would reveal all logical relationships among these propositions
- Machines would be capable of carrying out such calculations



Addition
Subtraction
Multiplication
Square root extraction

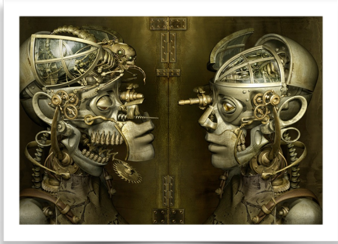


Binary Arithmetic

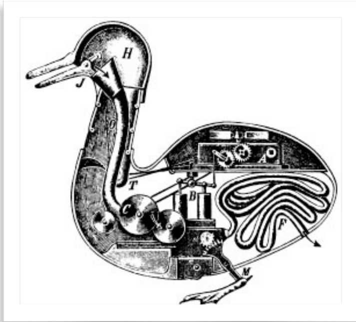
LINKÖPING UNIVERSITY

Automatons (1600 -)

Natural Laws are capable of producing complex behavior
Perhaps these laws govern human behavior?



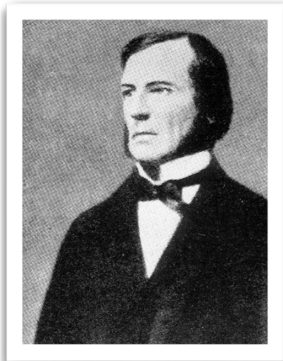
1772



Precursors to Robotics

LINKÖPING UNIVERSITY

Boole (1815 - 1864)



Turned “Logic” into Algebra

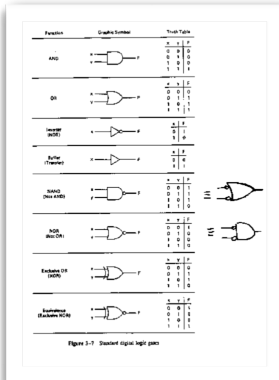
Classes and terms (thoughts) could be manipulated using algebraic rules resulting in valid inferences

Logical deduction could be developed as a branch of mathematics

$$a + 1 = 1$$
$$a \cdot 0 = 0$$
$$\left.\begin{array}{l} a + a = a \\ a \cdot a = a \end{array}\right\} \text{idempotence}$$
$$\left.\begin{array}{l} a \cdot (a + b) = a \\ a + (a \cdot b) = a \end{array}\right\} \text{absorption}$$
$$\left.\begin{array}{l} (a \cdot b) \cdot c = a \cdot (b \cdot c) \\ (a + b) + c = a + (b + c) \end{array}\right\} \text{associativité}$$

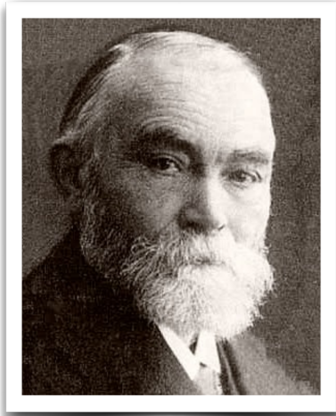
Subsumed Aristotle’s syllogisms
In essence Leibniz’ calculus rationator (lite)

Boolean Logic



LINKÖPING UNIVERSITY

Frege (1848 -1925)

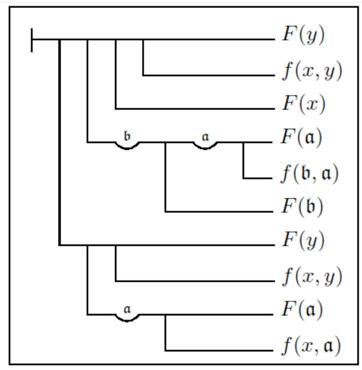


Begriffsschrift “Concept Script”

The 1st fully developed system of logic encompassing all of the deductive reasoning in ordinary mathematics.

- 1st example of formal artificial language with formal syntax
- logical inference as purely mechanical operations (rules of inference)

Intention was to show that all of mathematics could be based on logic! (Logicism)



Theorem 71 from *Begriffsschrift*

LINKÖPING UNIVERSITY

Russell’s Paradox

Frege’s arithmetic made use of sets of sets in the definition of number

defined recursively by 0 = {} (the empty set) and $n + 1 = n \cup \{n\}$

0 = {}, 1 = {0} = {{}},
2 = {0,1} = {{},{{}}}, 3 = {0,1,2} = {{},{{}},{{},{{}}}}

Russell showed that use of sets of sets can lead to contradiction

Ergo...the entire development of Frege was inconsistent!

- Extraordinary set: It is member of itself
- Ordinary set: It is not a member of itself

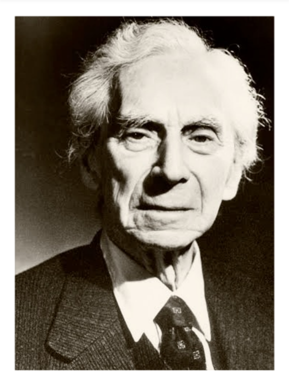
Take the set E of ordinary sets

Is E ordinary or extraordinary?

It must be one, but it is neither. A contradiction!

LINKÖPING UNIVERSITY

Russell (1872 - 1970)



Principia Mathematica (Russell & Whitehead)

An attempt to derive all mathematical truths from a well-defined set of axioms and inference rules in symbolic logic.

Dealt with the set-theoretical paradoxes in Frege's work through a theory of types

∗54·43. $\vdash :. \alpha, \beta \in 1 . \supset : \alpha \cap \beta = \Lambda . \equiv . \alpha \cup \beta \in 2$

Dem.

$\vdash . *54{\cdot}26 . \supset \vdash :. \alpha = \iota`x . \beta = \iota`y . \supset : \alpha \cup \beta \in 2 . \equiv . x \neq y .$

$[*51{\cdot}231] \qquad \equiv . \iota`x \cap \iota`y = \Lambda .$

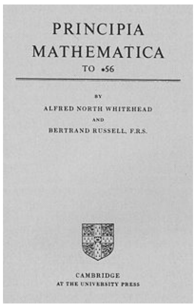
$[*13{\cdot}12] \qquad \equiv . \alpha \cap \beta = \Lambda \qquad (1)$

$\vdash . (1) . *11{\cdot}11{\cdot}35 . \supset$

$\vdash :. (\exists x, y) . \alpha = \iota`x . \beta = \iota`y . \supset : \alpha \cup \beta \in 2 . \equiv . \alpha \cap \beta = \Lambda \qquad (2)$

$\vdash . (2) . *11{\cdot}54 . *52{\cdot}1 . \supset \vdash .$ Prop

From this proposition it will follow, when arithmetical addition has been defined, that $1 + 1 = 2$.



Logicism

LINKÖPING UNIVERSITY

Hilbert (1862 - 1943)

1st Problem: Decide the truth of Cantor's Continum Hypothesis

2nd Problem: Establish the consistency of the axioms for the arithmetic of real numbers

24 problems for the 20th century

SUR LES

PROBLÈMES FUTURS DES MATHÉMATIQUES,

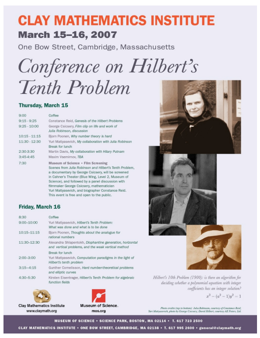
PAR M. DAVID HILBERT (Göttingen),

TRADUITE PAR M. L. LAUGEL (¹).

Qui ne soulèverait volontiers le voile qui nous cache l'avenir afin de jeter un coup d'œil sur les progrès de notre Science et les secrets de son développement ultérieur durant les siècles futurs? Dans ce champ si fécond et si vaste de la Science mathématique, quels seront les buts particuliers que tenteront d'atteindre les guides de la

Hilbert's lecture from the Paris Proceddings

23rd Problem: Does there exist an algorithm that can determine the truth or falsity of any logical proposition in a system of logic that is powerful enough to represent the natural numbers? (Entscheidungsproblem)



LINKÖPING UNIVERSITY

Hilbert's Program

Logic from the outside
Metamathematics

Consistency
Completeness
Decidability, etc

Only use Finitist Methods

Is 1st-order logic complete?
Is PA complete?

Logic from the inside
Formal axiomatic theories
Peano Arithmetic

Business as usual

LINKÖPING UNIVERSITY

Metamathematics

Syntax	Semantics
$\Delta \vdash \omega$	$\Delta \models \omega$
Inference	Entailment
Proof Theory	Model Theory

Soundness $\longrightarrow$ Not too strong

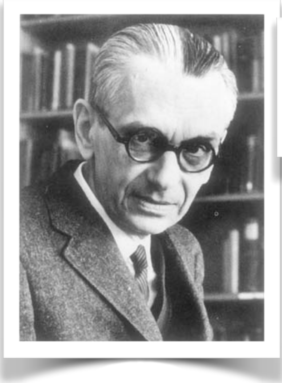
Completeness $\longleftarrow$ Strong enough

Consistency $\longleftrightarrow$ Correct

Can not infer both ω and its negation

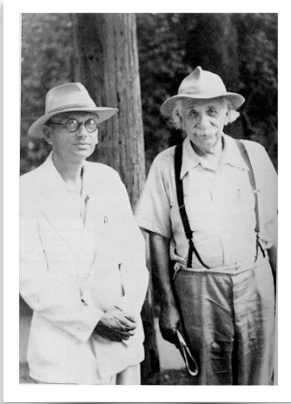
LINKÖPING UNIVERSITY

Gödel (1906 - 1978)



Showed the completeness of 1st-order logic in his PhD Thesis

Develop metamathematics inside a formal logical system by encoding propositions as numbers



The logic of PM (and consequently PA) is incomplete

There are true sentences not provable within the logical system

As part of his Incompleteness Theorem, Gödel translated the paradoxical statement:

"This statement cannot be proved"

into the pure mathematical statement:

$\sim(\exists r:\exists s: (P(r,s) \lor (s=g(sub\ (f_2(y))))))$

and used this to show there there are some mathematical statements which are true but which nevertheless cannot be proved.

Hilbert's 2nd Problem

As a consequence, the consistency of the mathematics of the real numbers can not be proven within any system as strong as PA

LINKÖPING UNIVERSITY

Gödel's Argument

Assume: Anything provable in PM is True

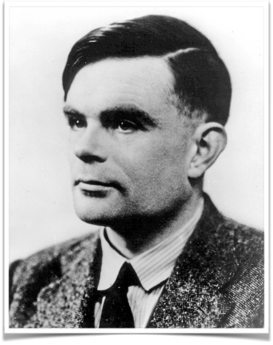
Self-referential: U is a proposition that states that "U is not provable in PM".

1. U is true: Suppose U were false. Then what it says would be false. So U would have to be provable, and therefore True (assumption). This contradicts the supposition that U is false.
2. U is not provable in PM: Since U is true, what it says must be true.
3. The negation of U is not provable in PM: Because U is true, its negation (that U is provable) must be false, and therefore the negation of U is not provable in PM.

U is a true (from the outside [1]) proposition, but an undecidable (from the inside [2,3]) proposition.

LINKÖPING UNIVERSITY

Turing (1912-1954)



Turing wanted to disprove the 23rd problem

23rd Problem: Does there exist an <u>algorithm</u> that can determine the truth or falsity of any logical proposition in a system of logic that is powerful enough to represent the natural numbers? (Entscheidungsproblem)

To do this, he had to come up with a formal characterization of the generic process underlying the computation of an algorithm

He then showed that there were functions that were not effectively computable including the Entscheidungsproblem!

As a byproduct he found a mathematical model of an all-purpose computing machine!

LINKÖPING UNIVERSITY

And… He also showed it limitations!

Effective Computability: Turing Machine

Example: with Alphabet $\{0, 1\}$

Given: a series of 1s on the tape (with head initially on the leftmost)

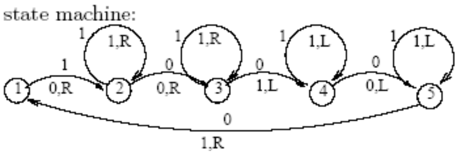
Computation: doubles the 1's with a 0 in between, i.e., "111" becomes "1110111".

The set of states is $\{s_1, s_2, s_3, s_4, s_5\}$ (s_1 start state)

actions:

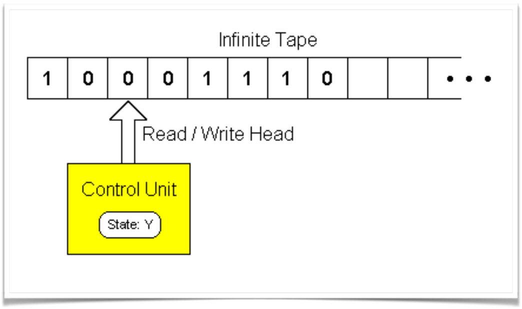
Old	Read	Wr.	Mv.	New	Old	Read	Wr.	Mv.	New
s_1	1	0	R	s_2	s_4	1	1	L	s_4
s_2	1	1	R	s_2	s_4	0	0	L	s_5
s_2	0	0	R	s_3	s_5	1	1	L	s_5
s_3	1	1	R	s_3	s_5	0	1	R	s_1
s_3	0	1	L	s_4					

state machine:



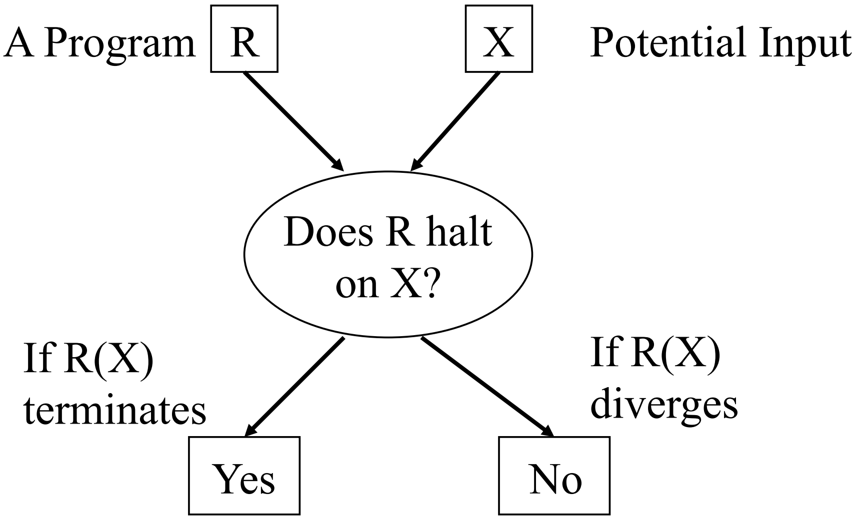
Claim: Any effective computation could be described as a Turing machine

- finite **alphabet** of symbols
- finite set of **states**
- infinite **tape** marked off with squares each of which is capable of carrying a single symbol
- mobile sensing-and-writing **head** that can travel along the tape one square at a time
- **state-transition diagram** containing the instructions that cause changes to take place at each step



LINKÖPING UNIVERSITY

An Unsolvable Problem



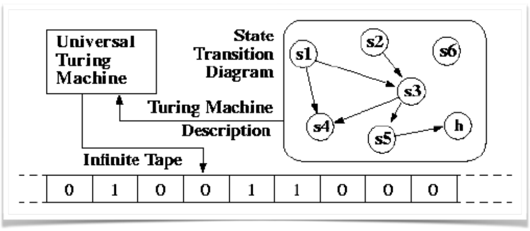
Halting Problem

There is no effective algorithm that, given an arbitrary program and arbitrary input can determine if the program will halt on the input

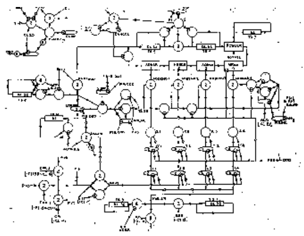
LINKÖPING UNIVERSITY

Universal Turing Machine

Formal mathematical abstraction of a [general computing device]

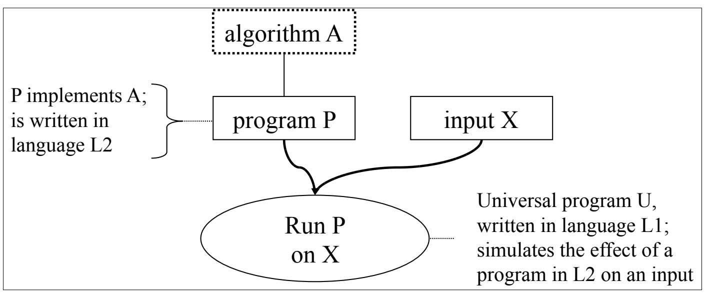


Interpreter for Turing Machines



Turing's Ace Computer

Functional Programming: Python, LISP



LISP: Eval
Programs as data

LINKÖPING UNIVERSITY

Church-Turing Thesis

Turing machines are capable of solving any effectively solvable algorithmic problem! Put differently, any algorithmic problem for which we can find an algorithm that can be programmed in some programming language, any language, running on some computer, any computer, even one that has not yet been built, and even one requiring unbounded amounts of time and memory space for ever larger inputs, is also solvable by a Turing machine!

Partial Recursive Functions: Gödel,Kleene
Lambda Calculus: Church
Post Production Systems: Post
Turing Machines: Turing
Unlimited Register Machines: Cutland

Scheme =
LISP=
Java=
Pascal=

Turing Machine

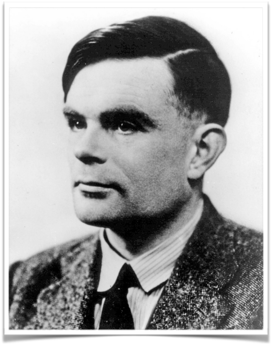
= C++
= JavaScript
= Ruby

LINKÖPING UNIVERSITY

Turing: Repercussions to AI

Turing focused on the human mechanical calculability on symbolic configurations. Consequently he imposed certain boundedness and locality conditions on Turing machines.

Turing did <u>not</u> show that mental procedures cannot go beyond mechanical procedures,



BUT

Turing did intend to show that the precise concept of Turing computability is intended to capture the <u>mechanical processes</u> that can be carried out by human beings.

LINKÖPING UNIVERSITY

Philosophical Repercussions: Mind-Body Problem

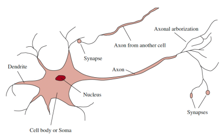
How can mind arise from nonMind?

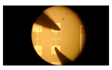
Materialism

Idealism

Mind as Machine

- Brain is physical (10's-100's billions of neurons)
- Neurons are biochemical machines
- In theory, one can make man-made machines which mimic the brains physical operations
- Intellectual capacities can be replicated





Synthetic brain comes a step closer with creation of artificial synapse (IBM)

Mind Beyond Machine

- Certain aspects of human thought and existence can not be understood as mechanical processes:

Consciousness

Emotion Feelings

Free Will

The circuit itself consists of highly-aligned carbon nanotubes that are grown on a quartz wafer, then transferred to a silicon substrate. It mimics an actual synapse insofar as the waveforms that are sent to it, and then successfully output from it, resemble biological waveforms in shape, relative amplitudes and durations.

LINKÖPING UNIVERSITY

Gödel: Repercussions to AI

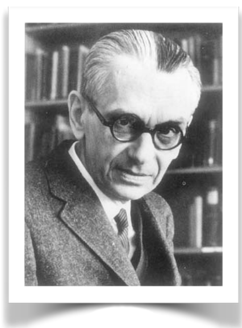
Gödel raised the question of whether the human mind was in all essentials equivalent to a computer (1951)

Without answering the question, he claimed both answers would be opposed to materialistic philosophy.

Yes

Incompleteness result shows that there are absolutely undecidable propositions about numbers that can never be proved by human beings

But this would also require a measure of idealistic philosophy just to make sense of a statement that assumes the objective existence of natural numbers with properties beyond those that a human being can ascertain.



No

If the human mind is not reducible to mechanism whereas the physical brain is reducible, it would follow that mind transcends physical reality, which is incompatible with materialism

Gödel swayed towards "No" in later life.

LINKÖPING UNIVERSITY

The Turing Test

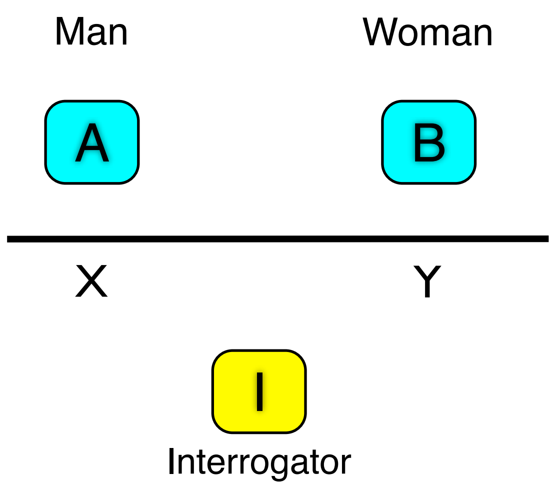
Computing Machinery and Intelligence - A. Turing (1953)

I propose to consider the question, "Can machines think?"

Since the meaning of both "machine" and "think" is ambiguous, Turing replaces the question by another.

Turing introduces a game called the "Imitation Game"

The Imitation Game



Goal: Determine which of the two is a man and which is a woman

A tries to make I make the wrong ID
B tries to make I make the right ID

What will happen when the machine takes the part of A in this game?

Will the interrogator decide wrongly as often when the game is played like this as when the game is played between a man and a woman?

Goal: Determine which of the two is a machine and which is a human

A tries to make I make the wrong ID
B tries to make I make the right ID

Winograd Schemas

A Winograd schema is a pair of sentences that differ in only one or two words and that contain an ambiguity that is resolved in opposite ways in the two sentences and requires <u>the use of world knowledge and reasoning</u> for its resolution.

The city councilmen refused the demonstrators a permit because <u>**they**</u> [feared] violence.

The city councilmen refused the demonstrators a permit because <u>**they**</u> [advocated] violence.

Commonsense Informatic Situation

LINKÖPING UNIVERSITY