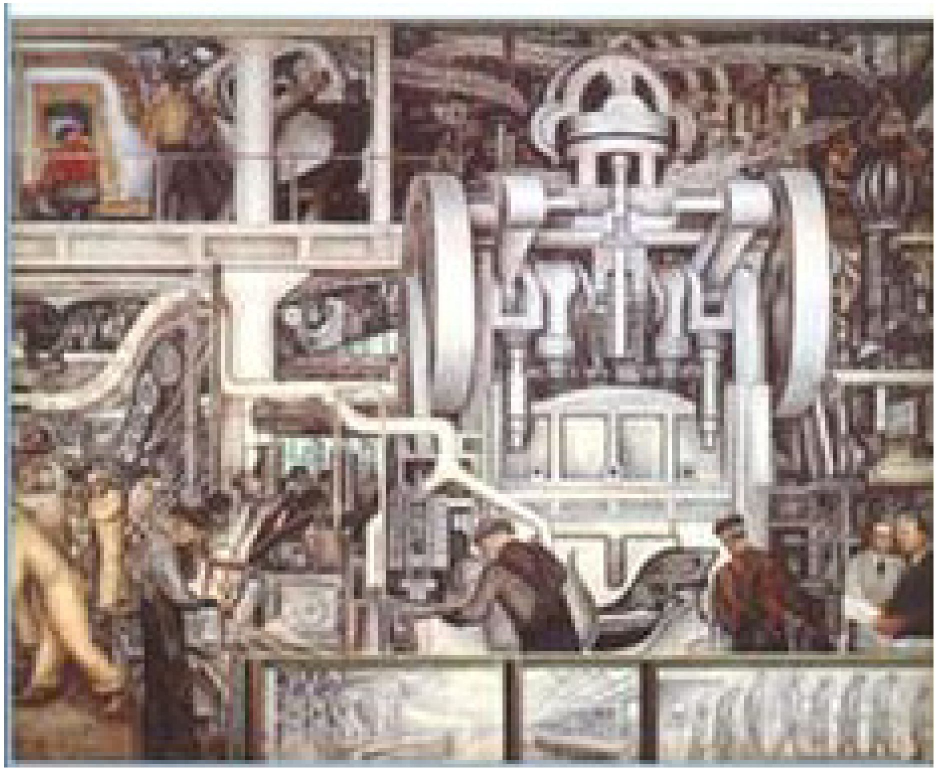
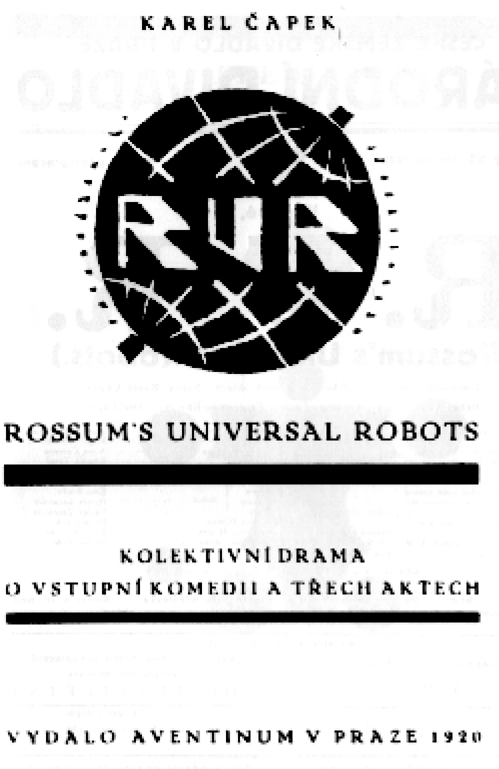
Introduction to Robotics

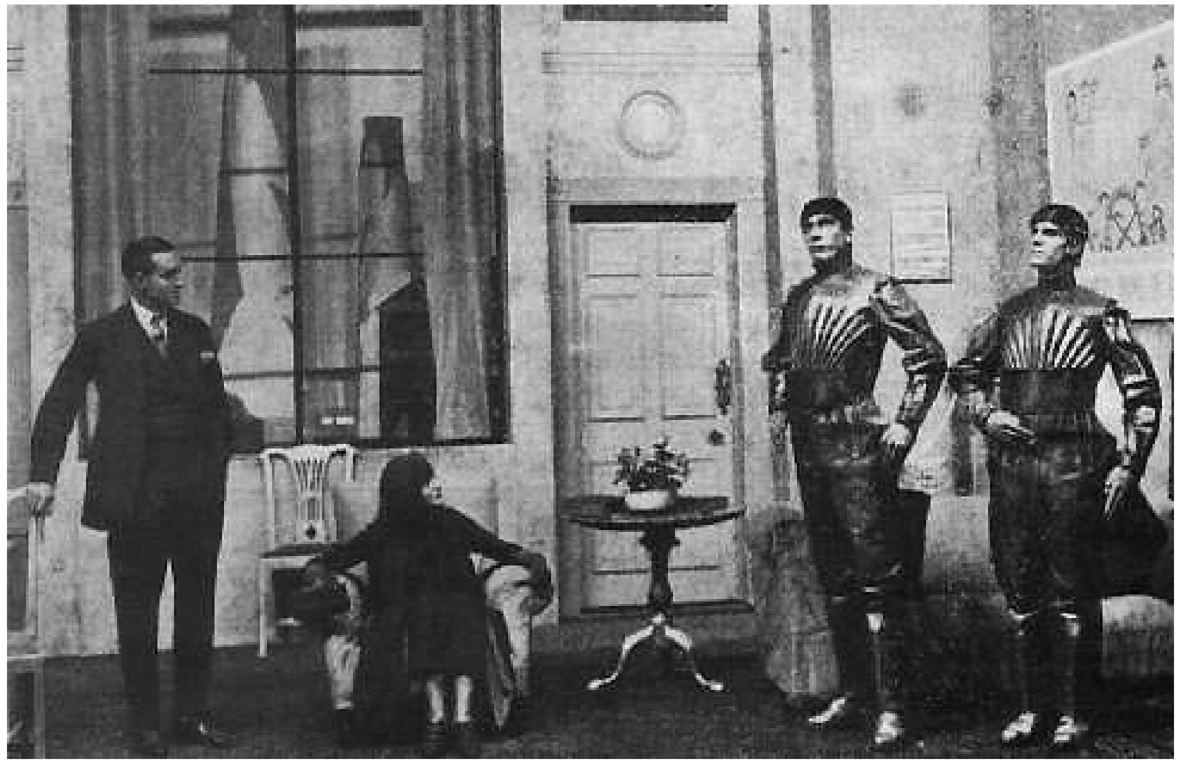


A Modern Approach

Arnoud Visser

The Robot



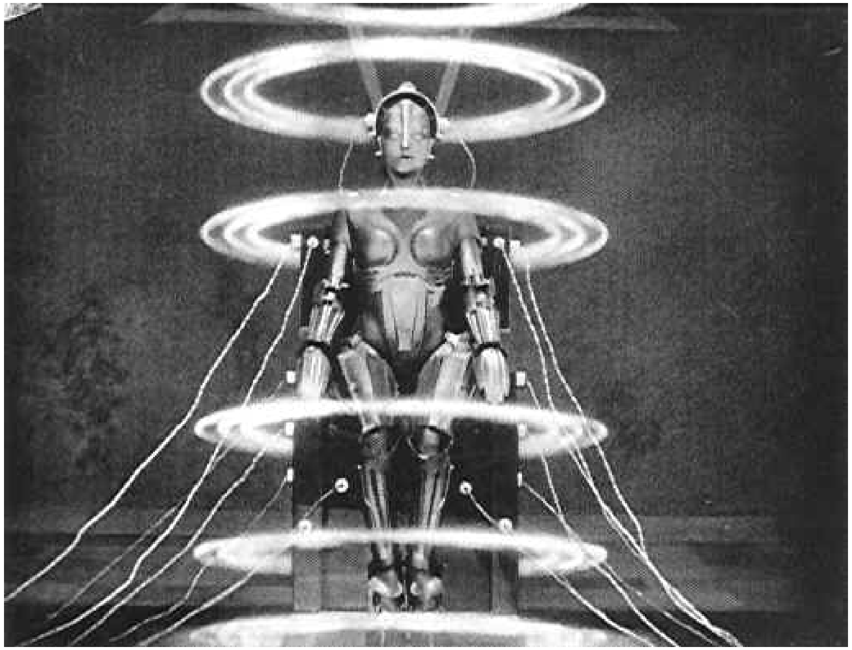


The word *robot* was introduced in 1920 in a play by Karel Capek called R.U.R

AIMA p. 939

The Robot

A robot is an artificial worker, which can replace a human worker.

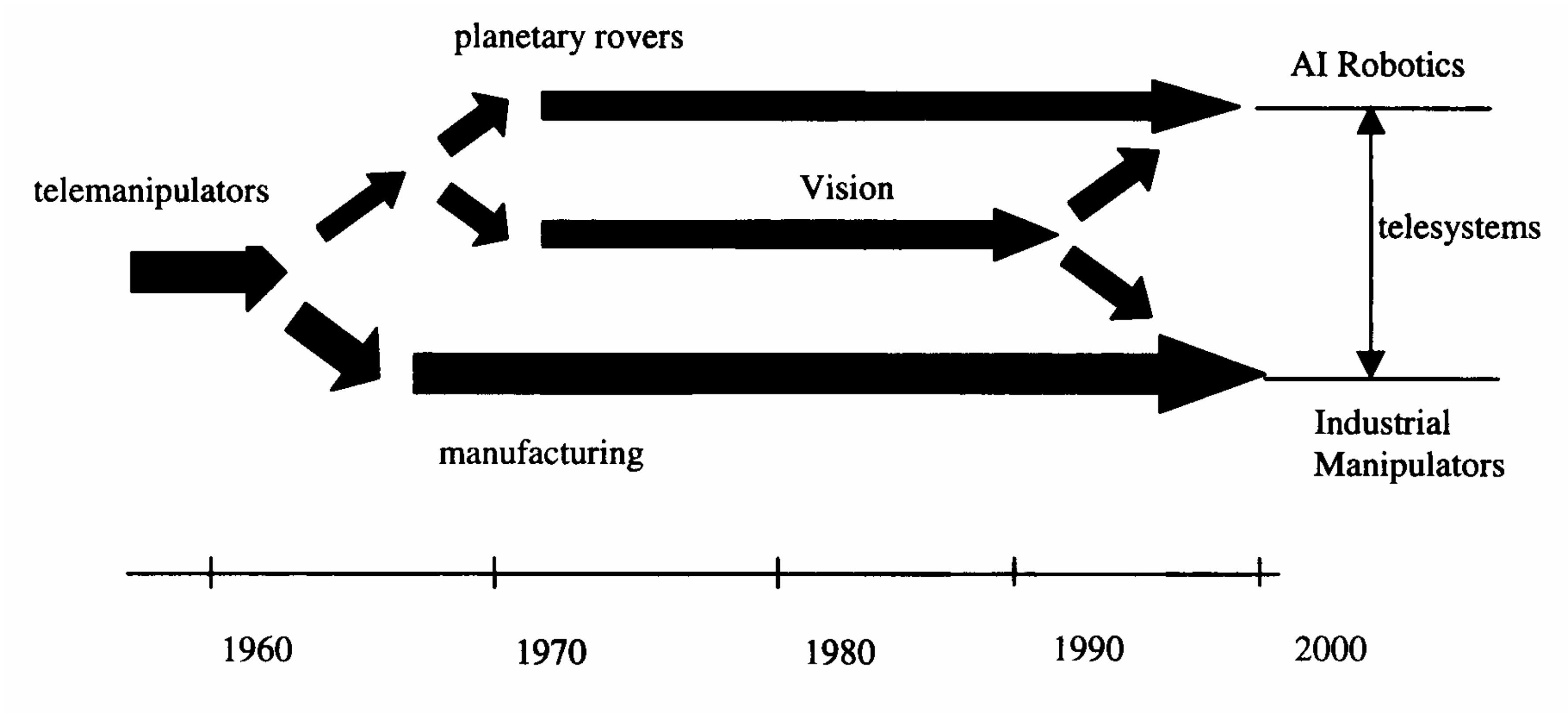


Industrial Robots

- Industrial robots have replaced many human workers for tasks which are:
  - high repetitive
  - well structured
  - i.e. factory jobs

AIMA p. 935

Robotic Evolution



AIMA p. 901

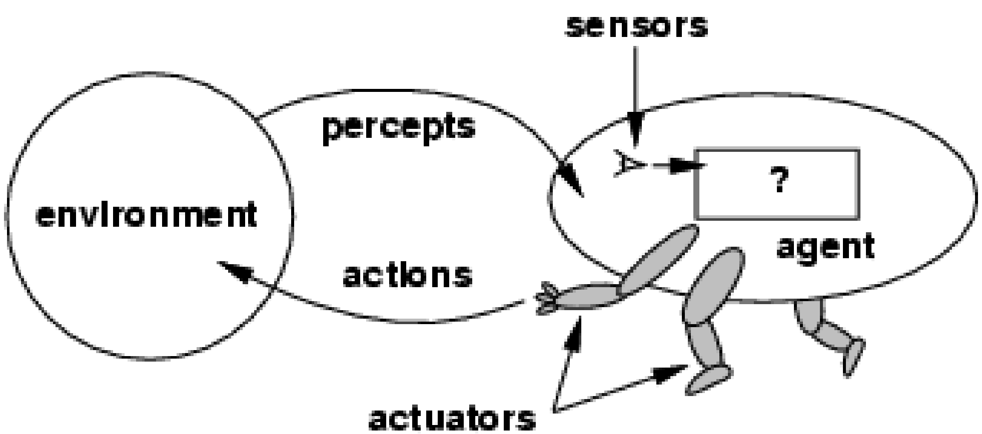
AI Robots

AI Robots are physically situated *agents* with:

- Knowledge representation
- Learning
- Planning and problem solving
- Search and Inference
- Vision
- Understanding natural language

AIMA p. 902

Physical situated agent



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

† Russell & Norvig, 'Artificial Intelligence – A modern approach', Prentice Hall, 2003

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The physical grounding hypothesis

‘To build an intelligent system it is necessary to have its representations grounded in the physical world.’

i.e.:

‘The world is its own best model;
its always exactly up to date and
contains always every detail there is to know.’ †

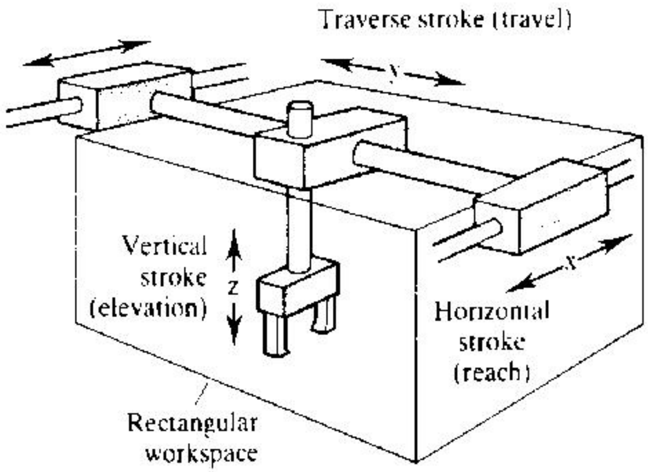
† Rodney A. Brooks, ‘Elephants Don’t Play Chess’, Robotics and Autonomous System *6* (1990).

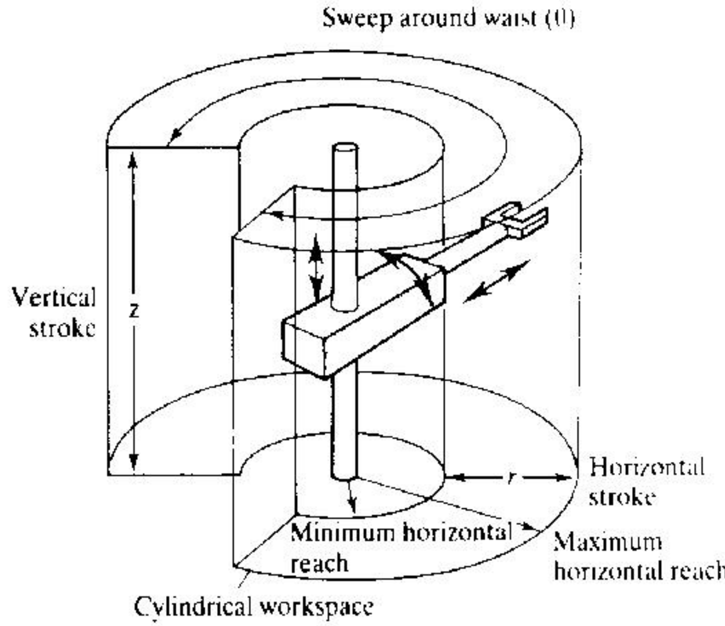
Introduction to
Classical Robotics

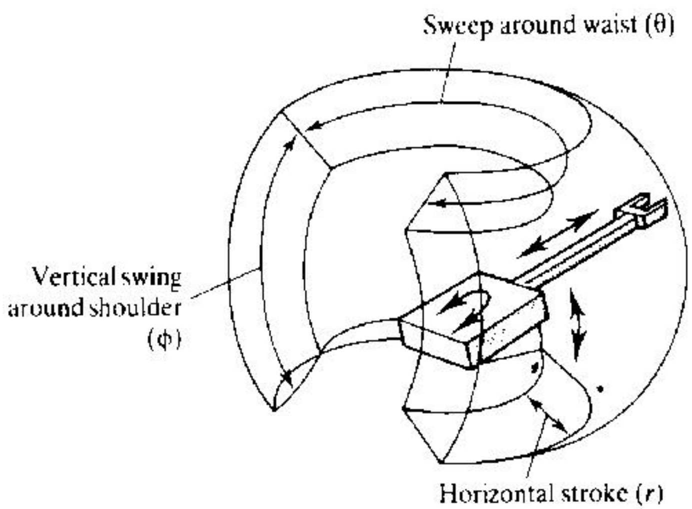
Model based

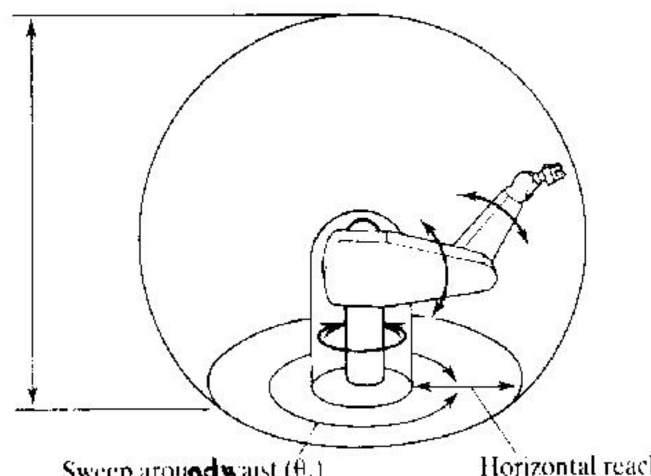
† Summary of material covered by Leo Dorst's syllabus
'An Introduction to Robotics', Universiteit van Amsterdam, 2001.

Robot arms

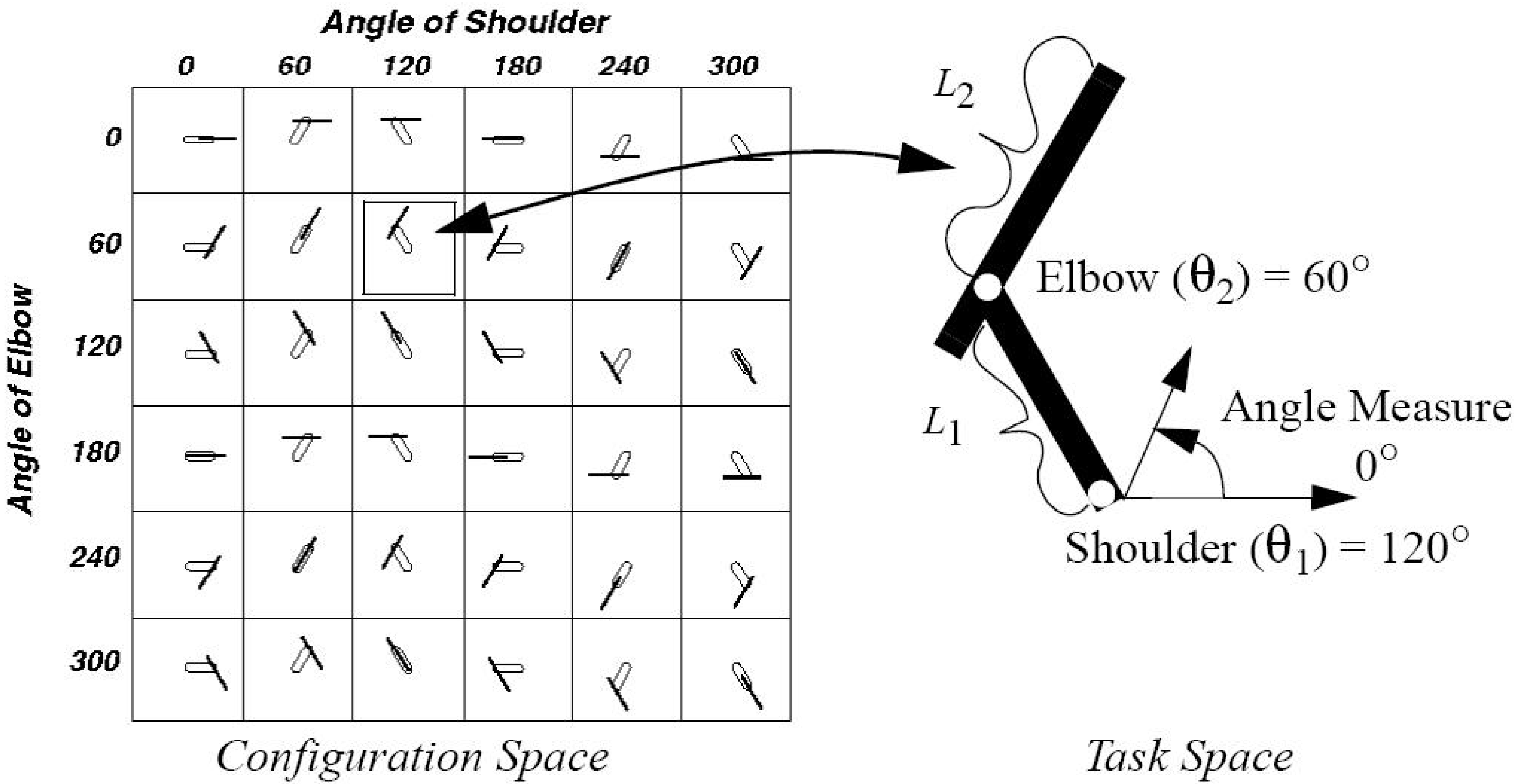

Traverse stroke (travel)
y
Vertical
stroke
(elevation)
z
x
Horizontal
stroke
(reach)
Rectangular
workspace


Sweep around waist (θ)
Vertical
stroke
z
r
Horizontal
stroke
Minimum horizontal
reach
Maximum
horizontal reach
Cylindrical workspace

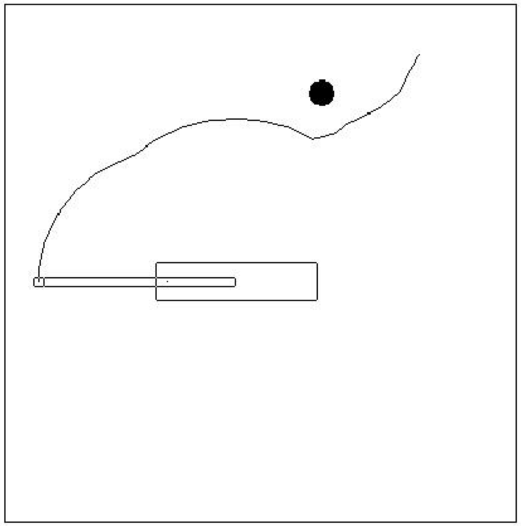

Sweep around waist (θ)
Vertical swing
around shoulder
(ϕ)
Horizontal stroke (r)

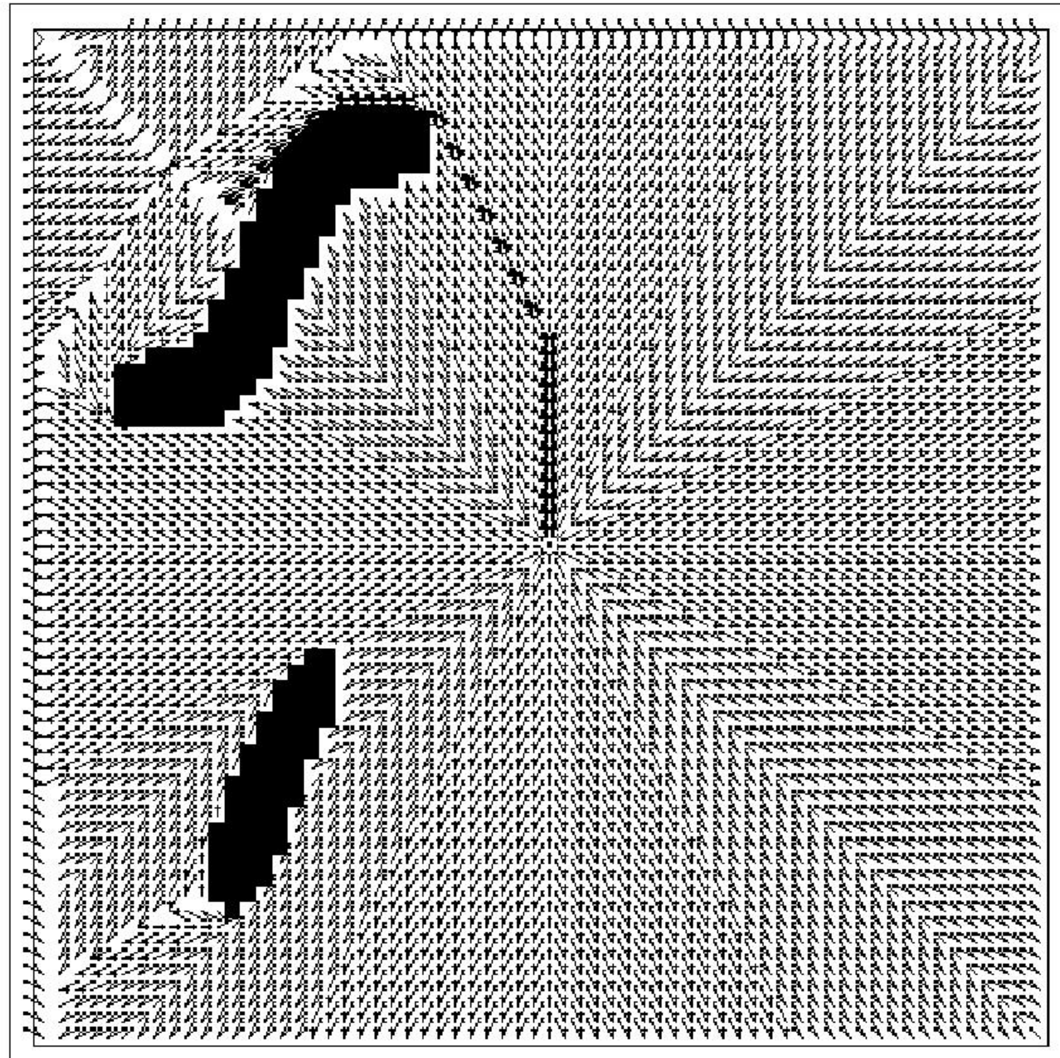

Sweep around waist (θ1)
Horizontal reach

Controllable Degrees of Freedom



Planning to move





- Cell decomposition

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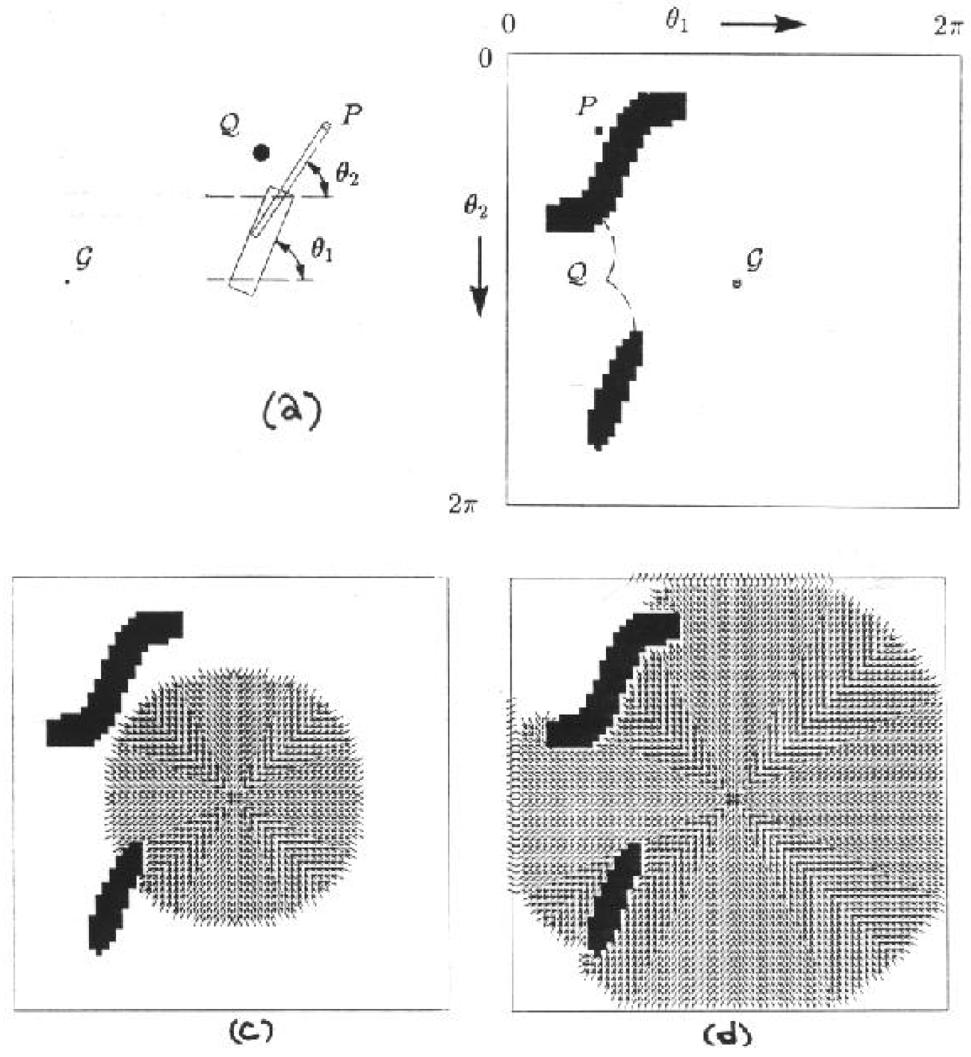
Several cost models possible



- Value Iteration

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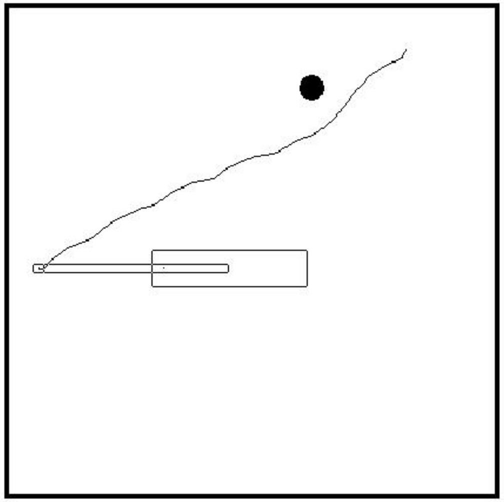
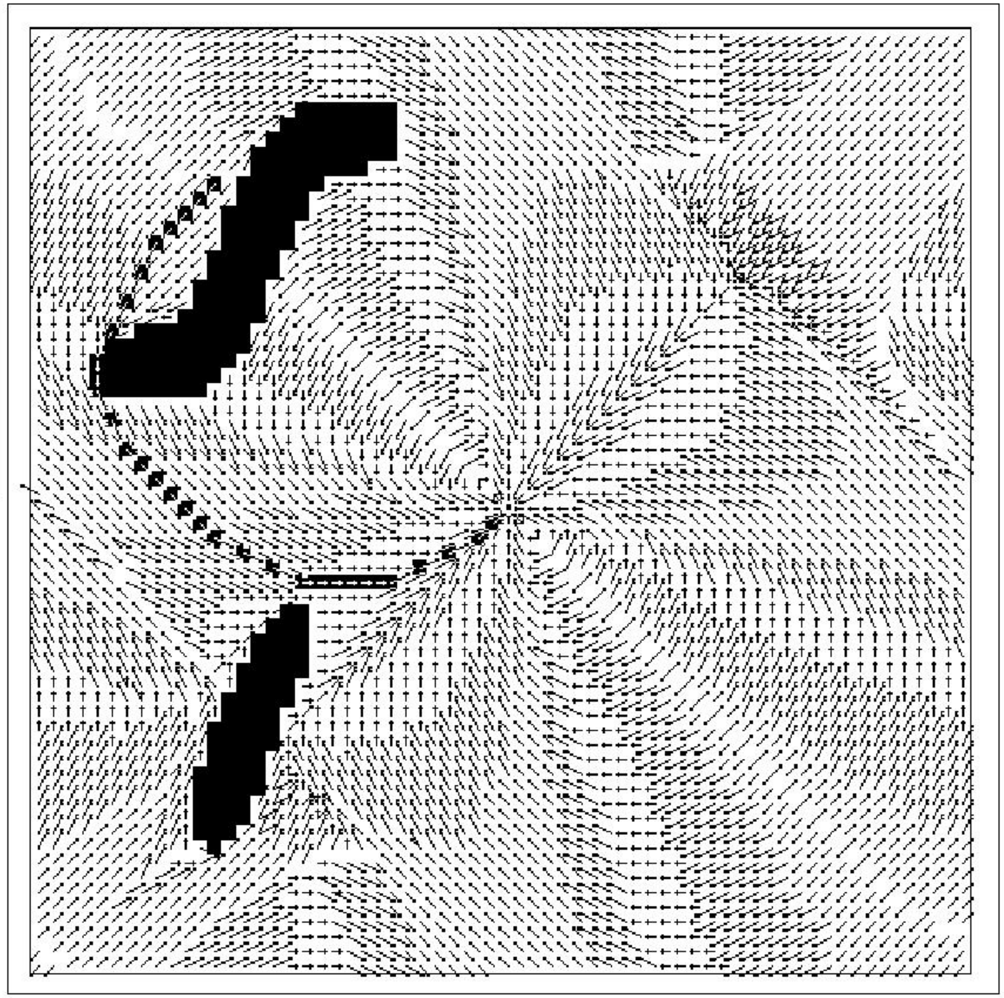
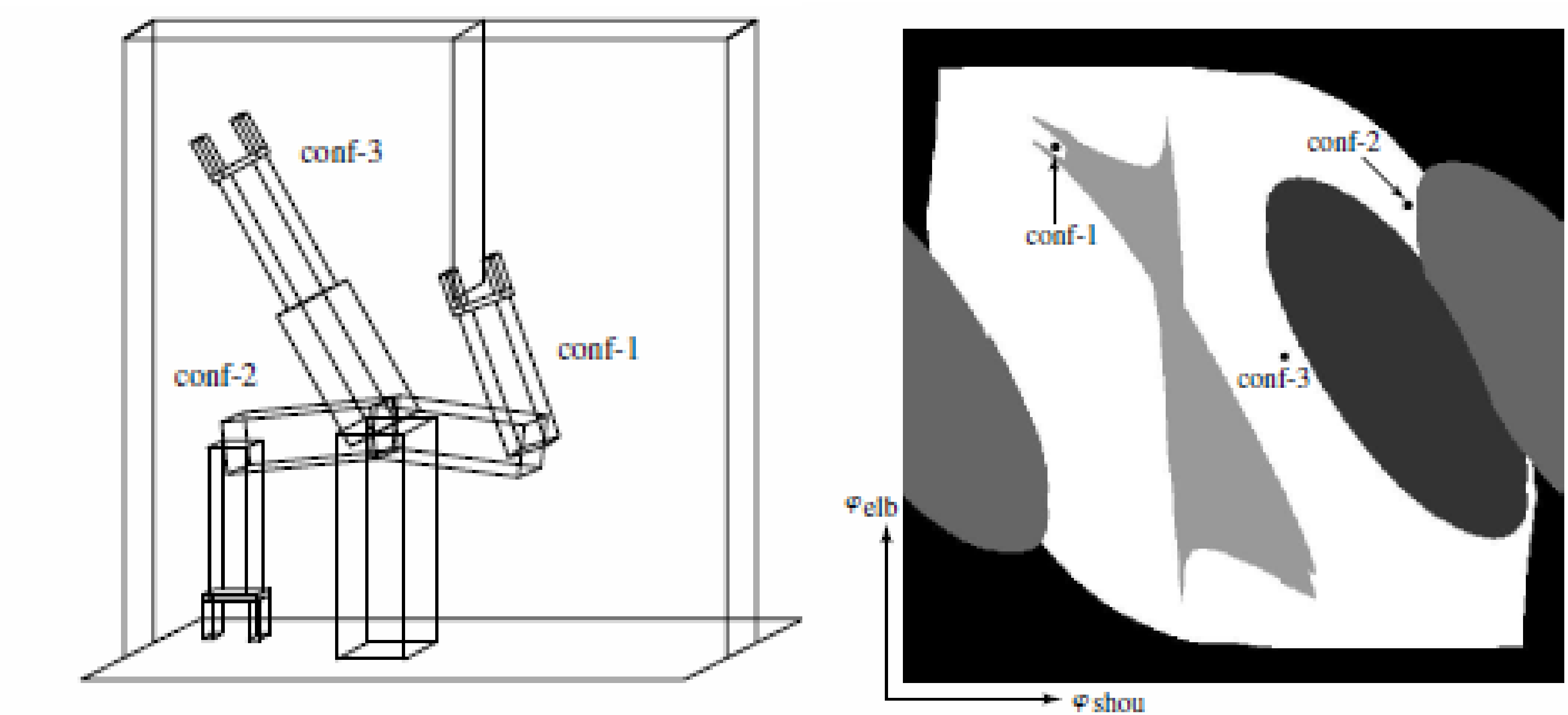
Minimal movement of hand





Same configuration, more obstacles



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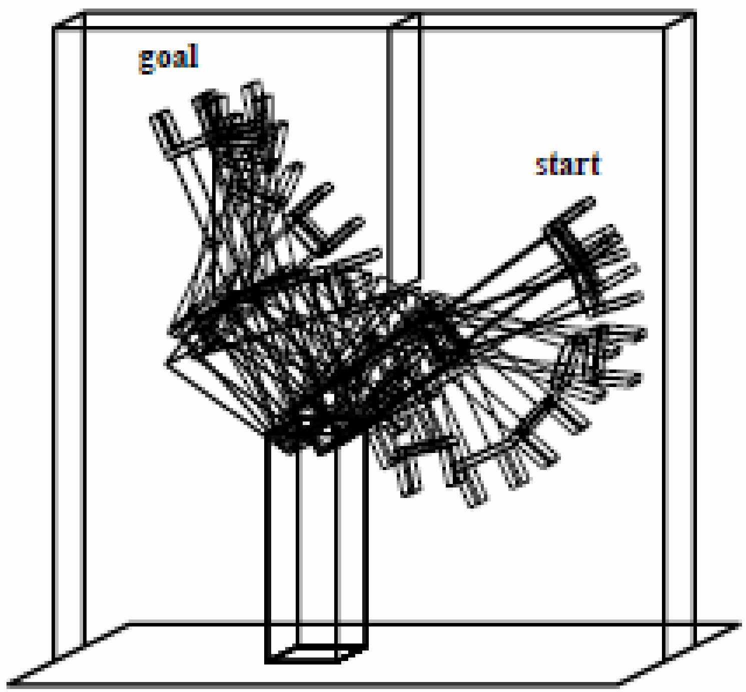
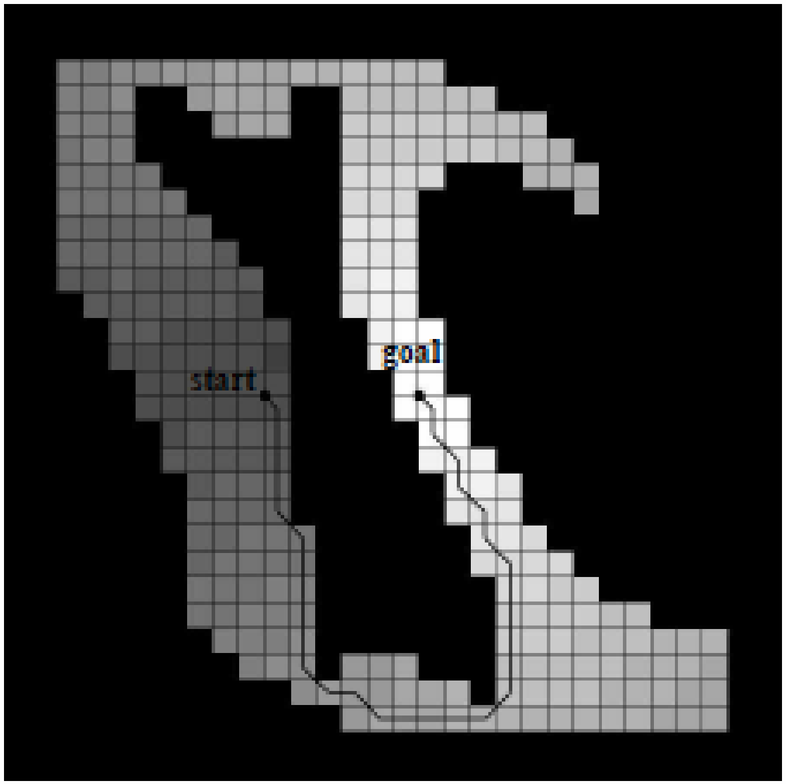
Mixed cells

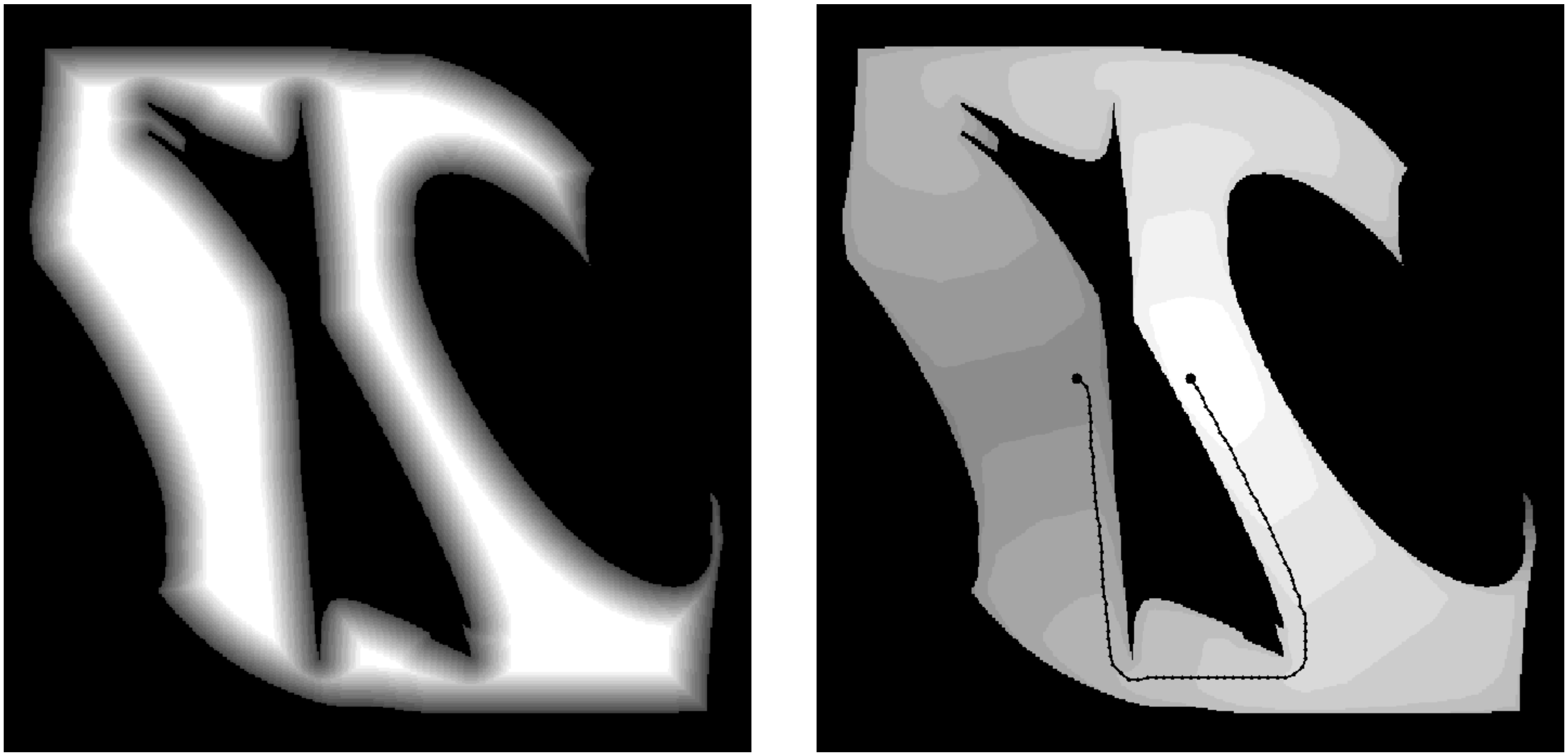




- Discretization Error

AIMA p. 920

Potential Field



- Other cost function!

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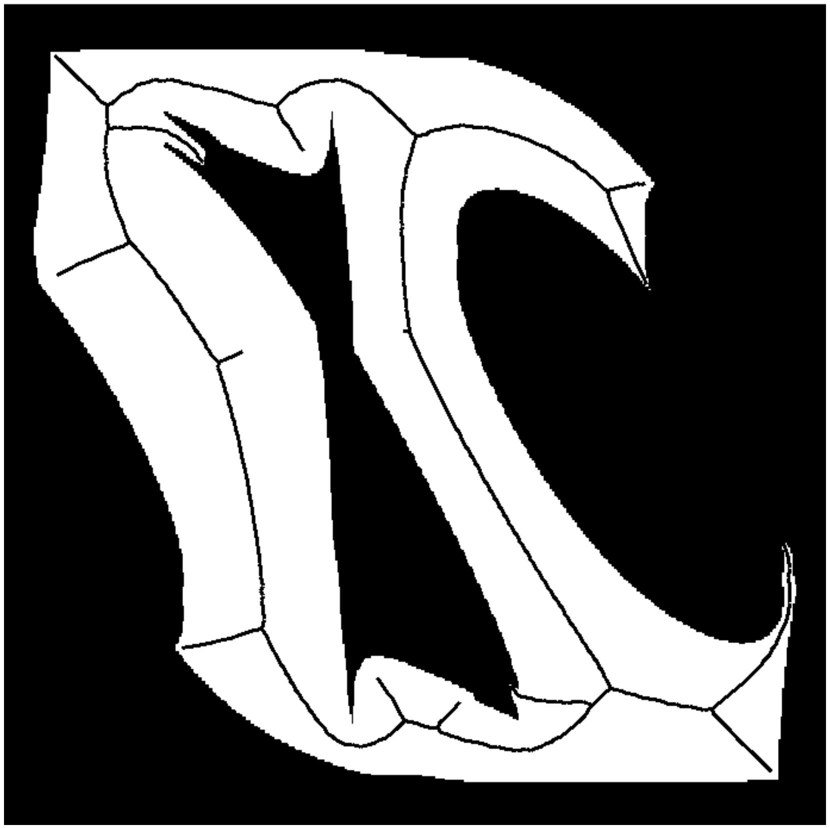
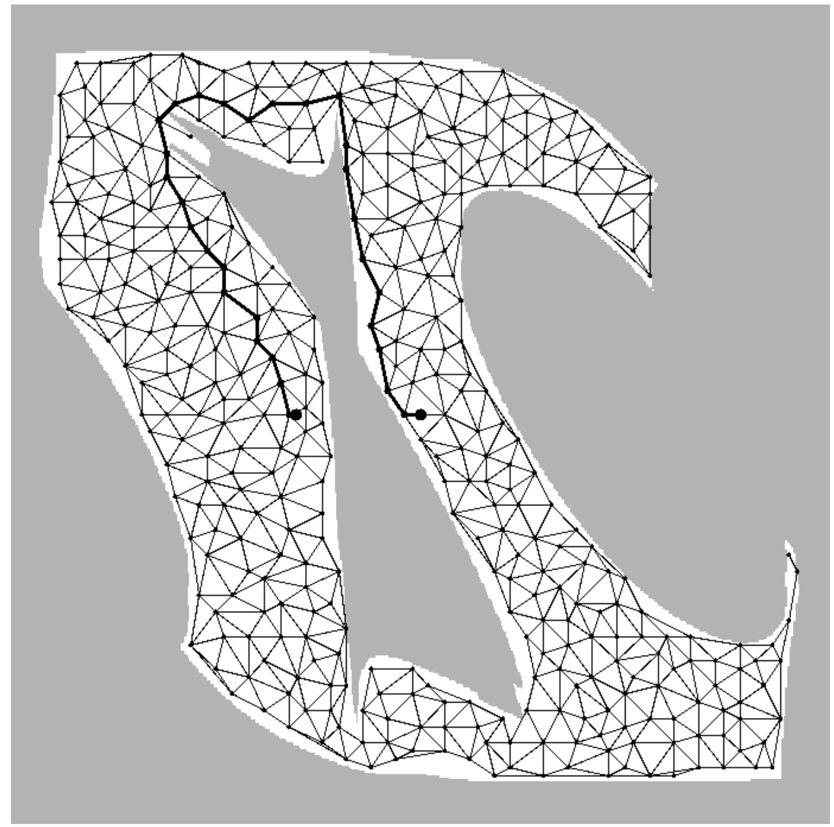
Skeleton Methods





- Other representation of free space

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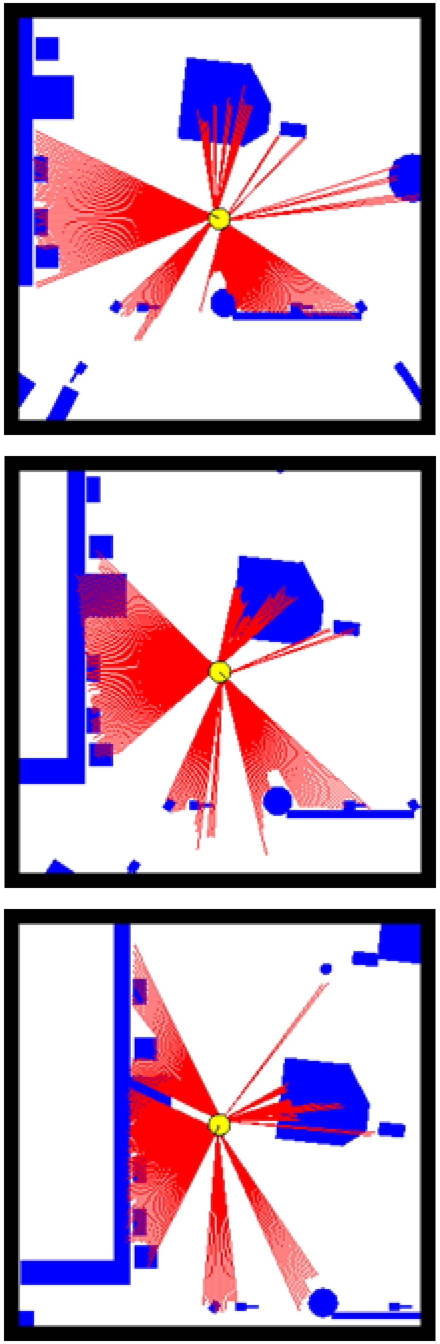

Sensors

Range finders:
sonar (land, underwater), laser range finder, radar (aircraft), tactile sensors, GPS

Imaging sensors:
cameras (visual, infrared)

Proprioceptive sensors:
shaft decoders (joints, wheels), inertial sensors, force sensors, torque sensors

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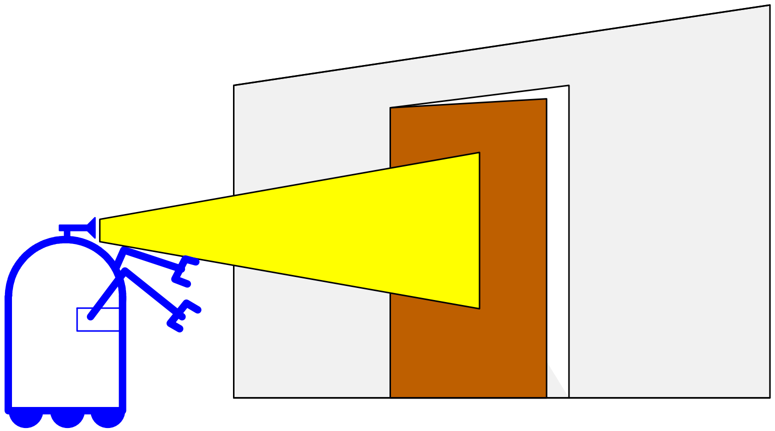
Uncertainty

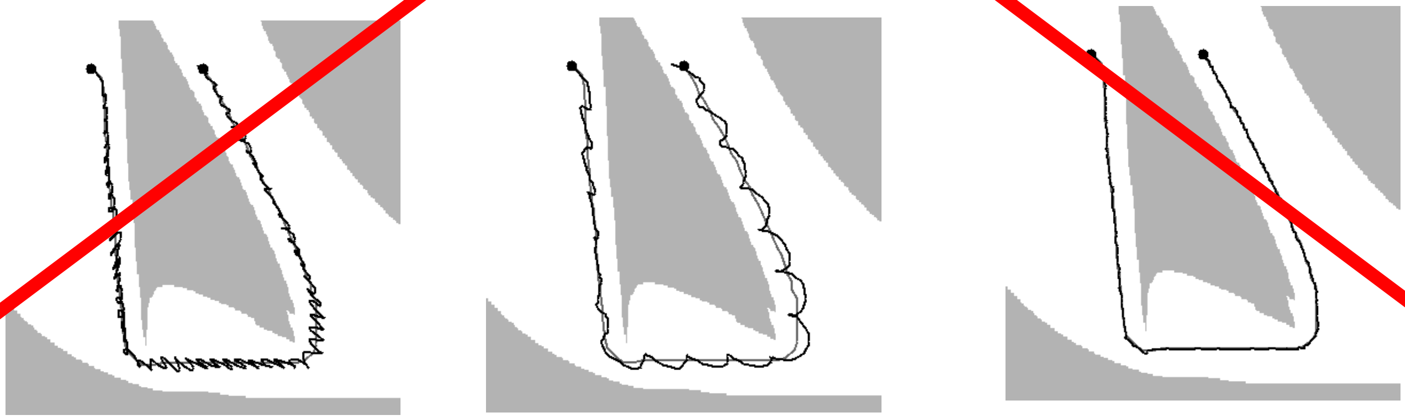
- Both uncertainty in observations and in movements
- Reasoning over time and uncertainty
- States, transitions, observations & beliefs
- Causal versus Diagnostic Reasoning



- P(seems open | is open)
  versus
  P(is open | seems open)

25.3 Robotic Perception

25.5 Planning uncertain movements



AIMA 907-916

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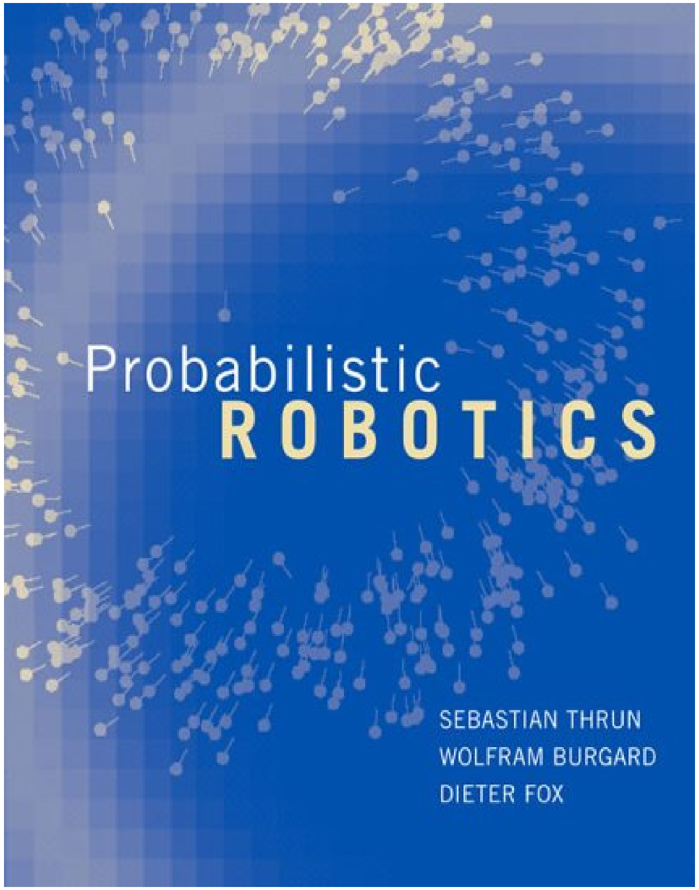
Probabilistic Robotics†



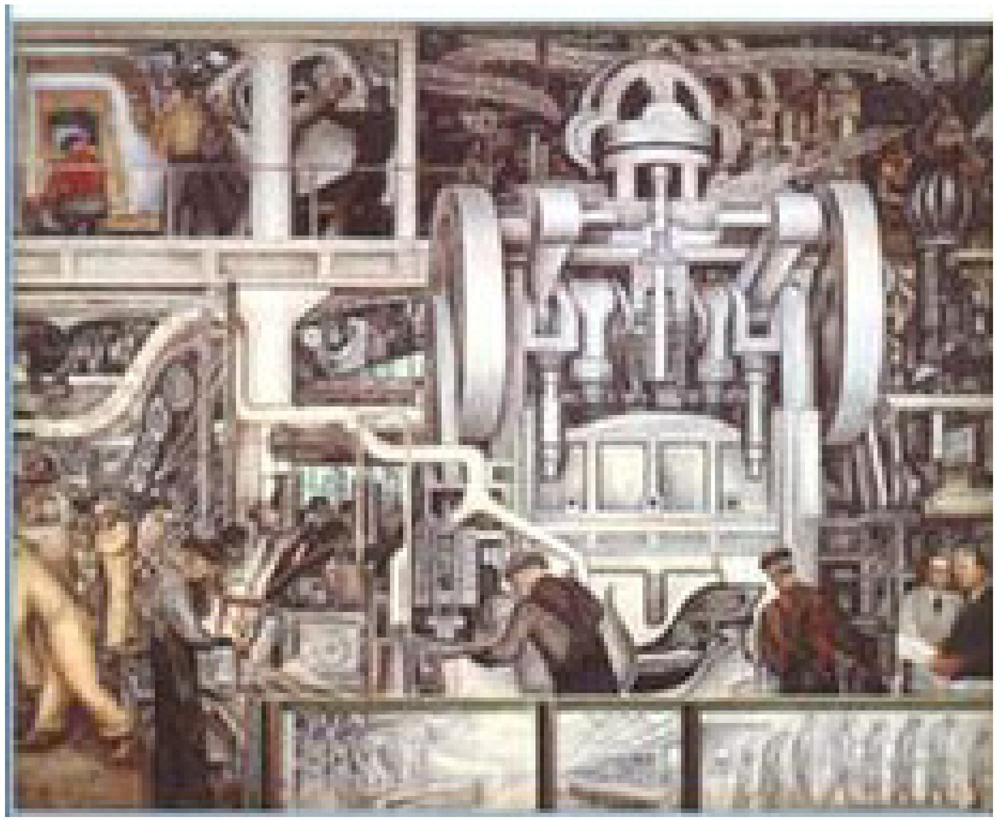
† S. Thrun, W. Burgard, D. Fox, ‘Probabilistic Robotics’, MIT Press, 2005

Robotic Paradigms

1976 — 1986	**Model-Based Robotics** • Full model, no sensor data • Focus on motion planning
1986 — 1996	**Behavior-Based Robotics** • No model, entirely data-driven • Focus on environment feedback
1996 — 2006	**Probabilistic Robotics** • Uncertain model, noisy data • Integration of data and model

† Sebastian Thrun '1996-2006 Autonomous Robots', 50 years Artificial Intelligence Symposium, Bremen.

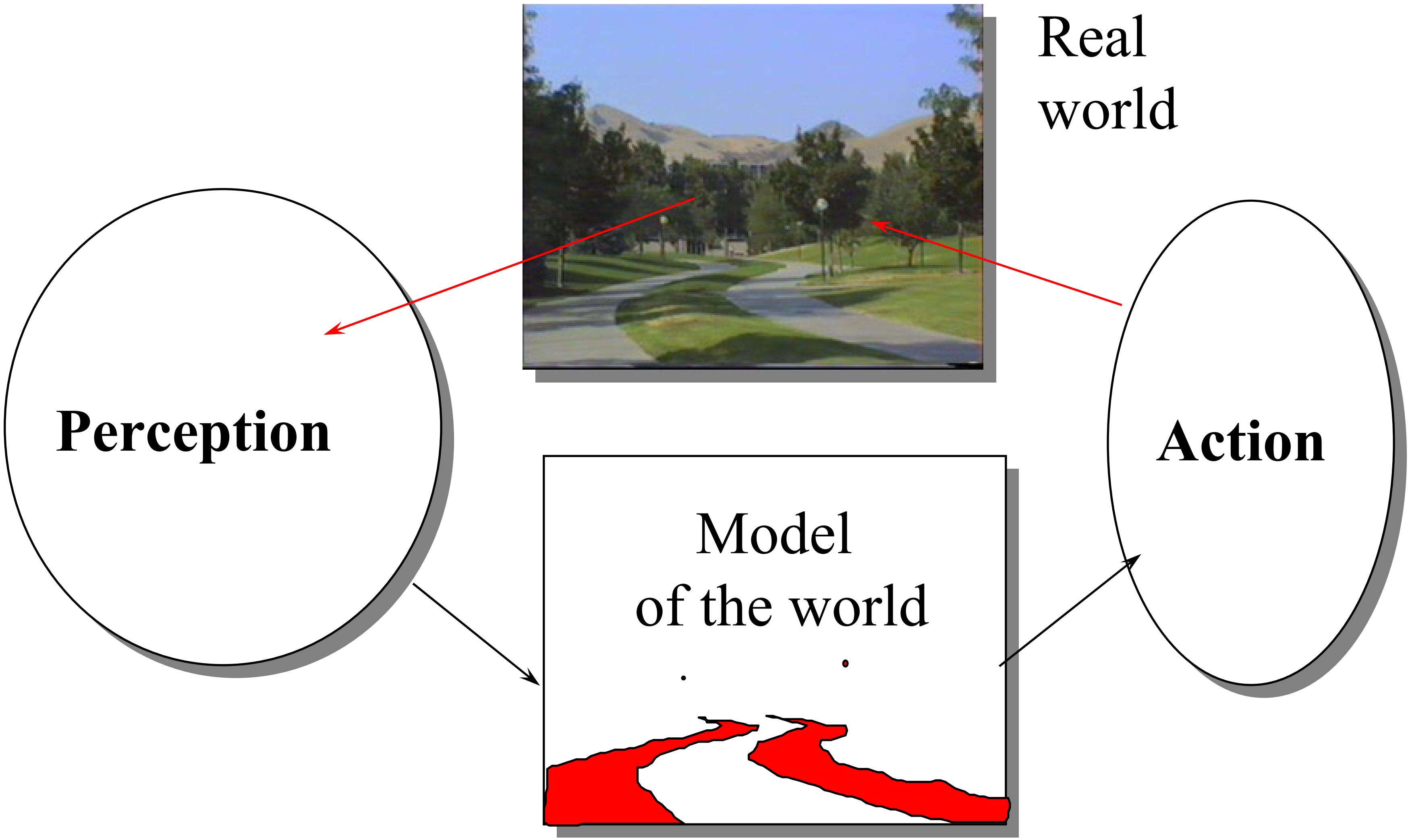
Introduction to
AI Robotics



Behavior Based

† Summary of Leo Dorst's course material belonging to Robin Murphy's book 'Introduction to AI Robotics', MIT Press, 2000.

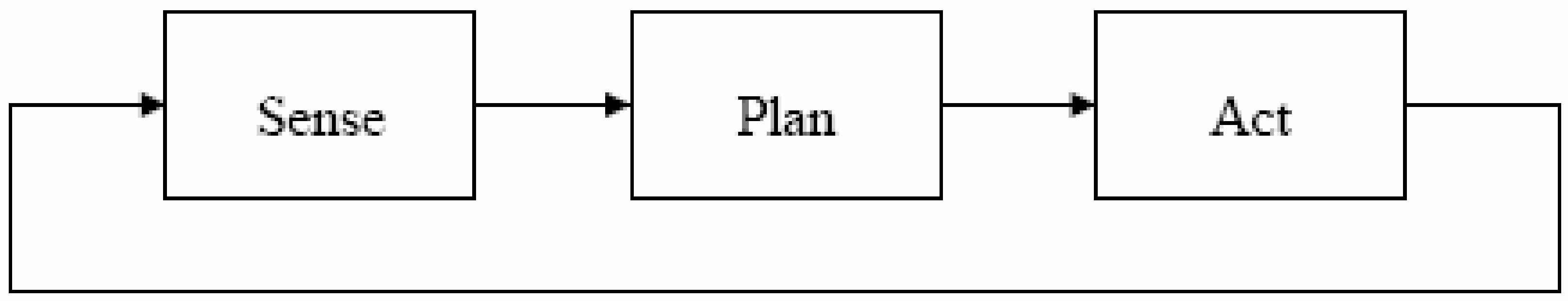
Perception - Action Cycle



Sense-Plan-Act

- Sense
  - "Translate" physical properties to electrical (digital) signals.
  - Sensor: Input of the system
- Plan
  - Attempt to solve a problem (with a purpose)
  - Needs (complete) model of the world
- Act
  - "Translate" electrical (digital) signals to other physical properties.
  - Actuator: Output of the system

Hierarchical approach



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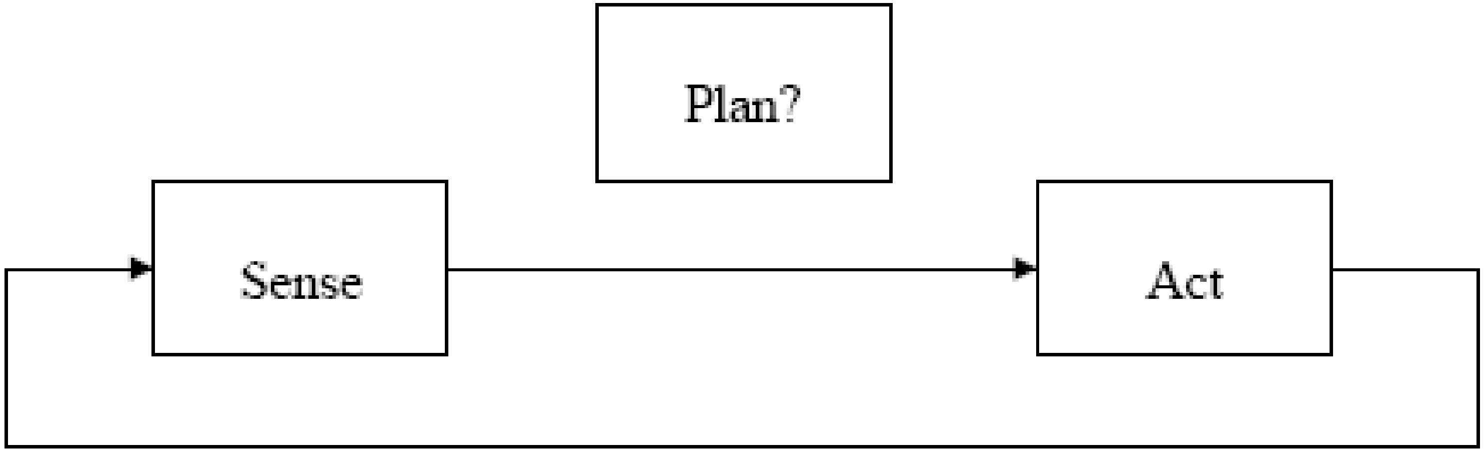
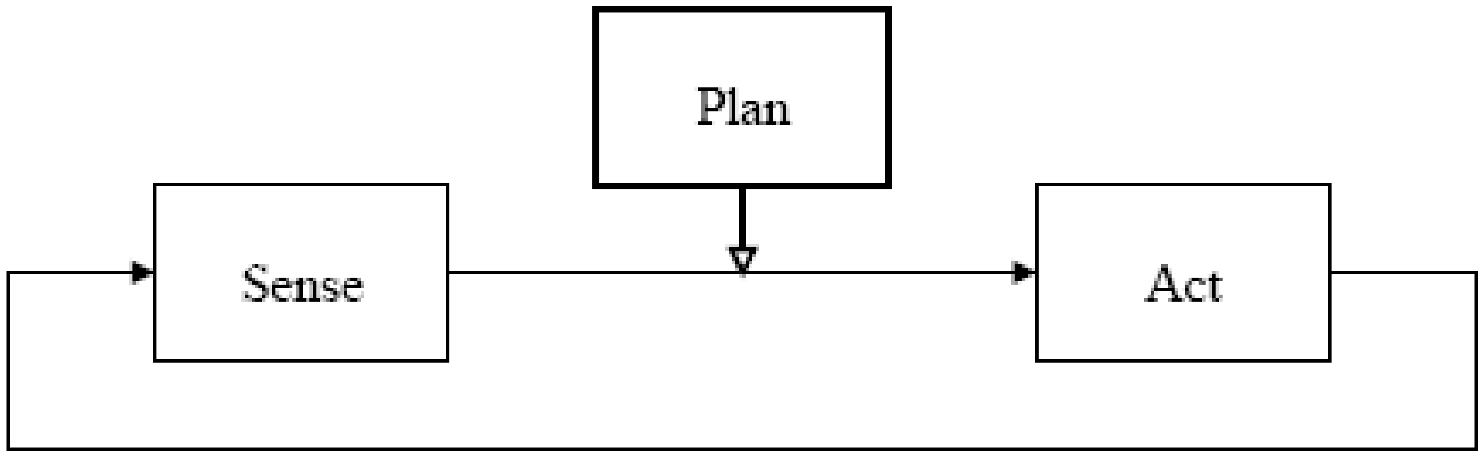
Reactive Approach



AIMA p. 932-933

Hybrid / deliberative approach



- Planning is making decisions autonomously!

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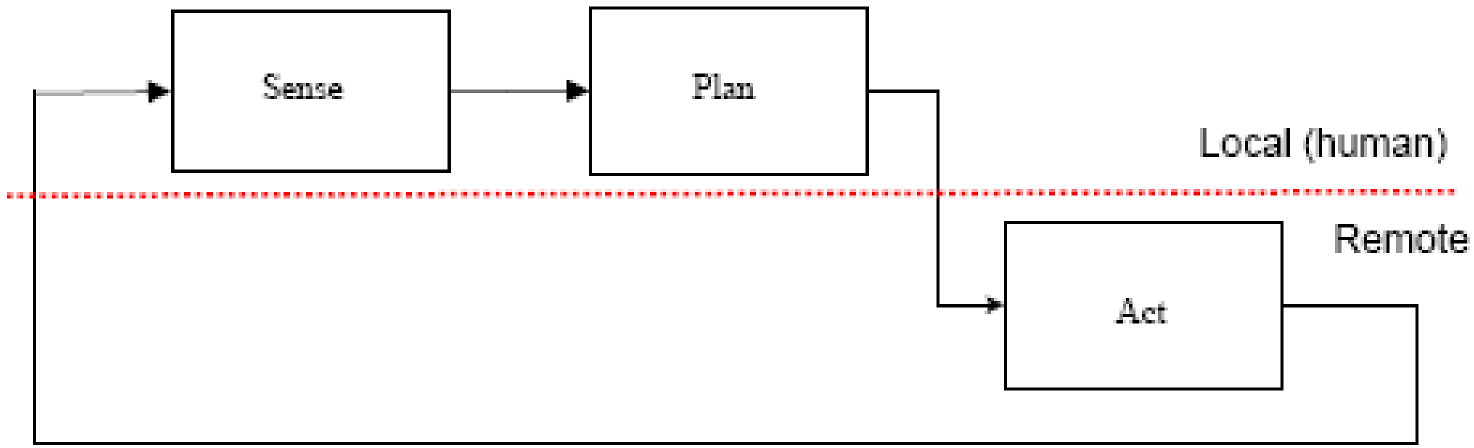
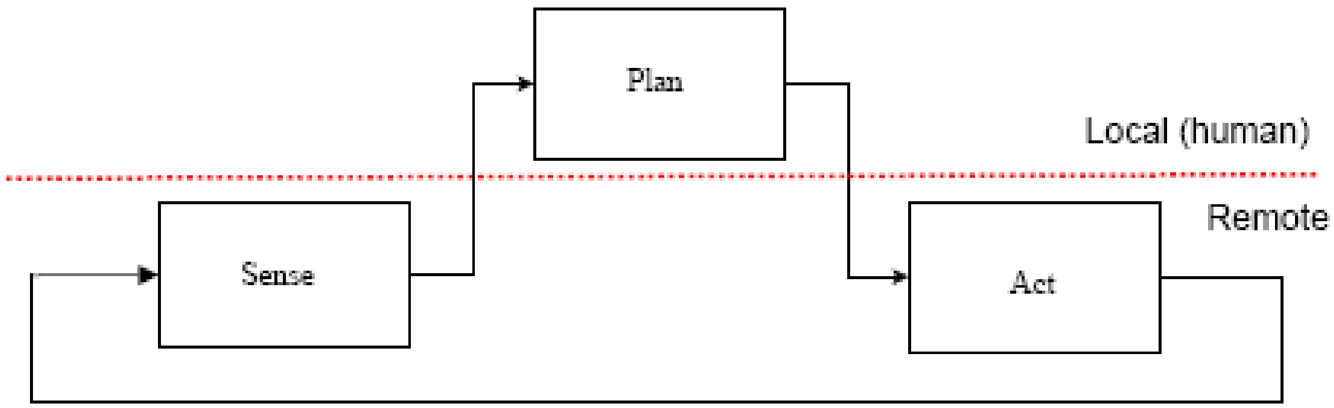
Remote Control



- you control the robot
- you can view the robot and its relationship to the environment
- *operator isn't removed from scene, not very safe*

Example: Bomb squad

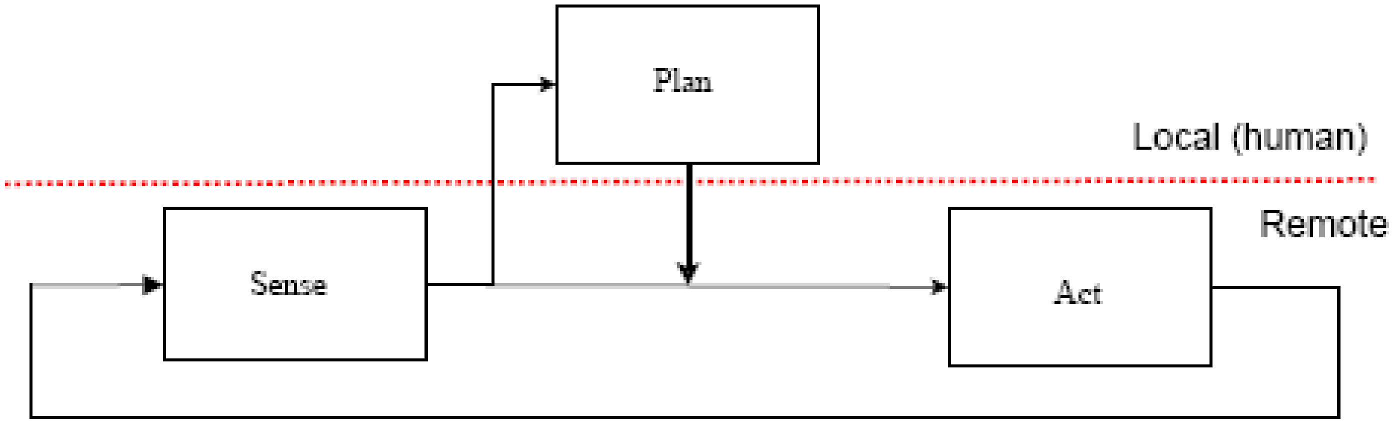
Teleoperation



- you control the robot
- you can only view the environment through the robot's eyes
- *don't have to figure out AI*
- Depending on display: Telepresence

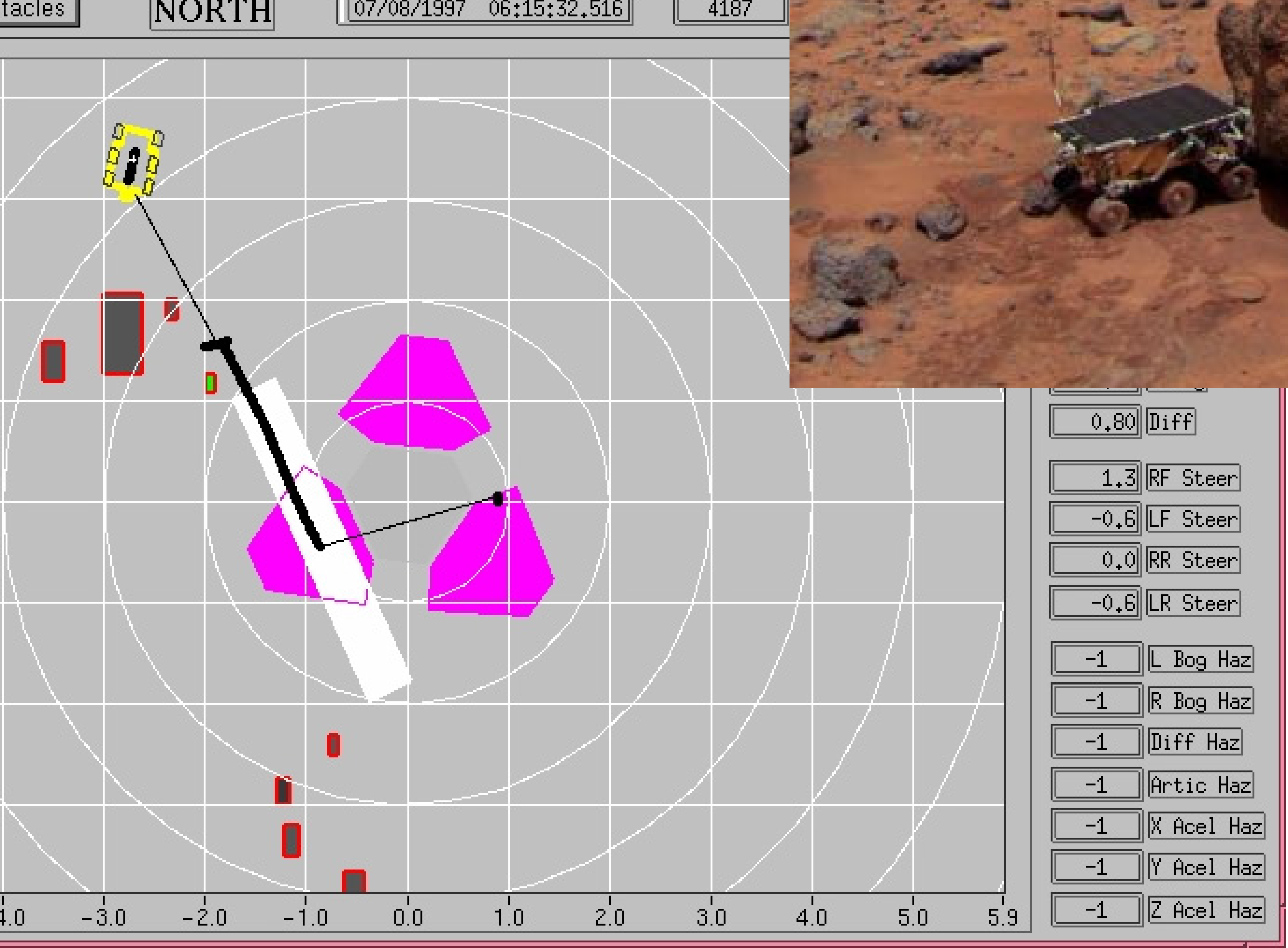
Example: Micro Aerial Vehicle

semi-autonomy



- human is involved, but routine or "safe" portions of the task are handled autonomously by the robot
- Shared Control/ Guarded Control
  - human initiates action, interacts with remote by adding perceptual inputs or feedback, and interrupts execution as needed
  - robot may "protect" itself by not bumping into things
- Traded Control
  - human initiates action, does not interact
- *human doesn't have to do everything*

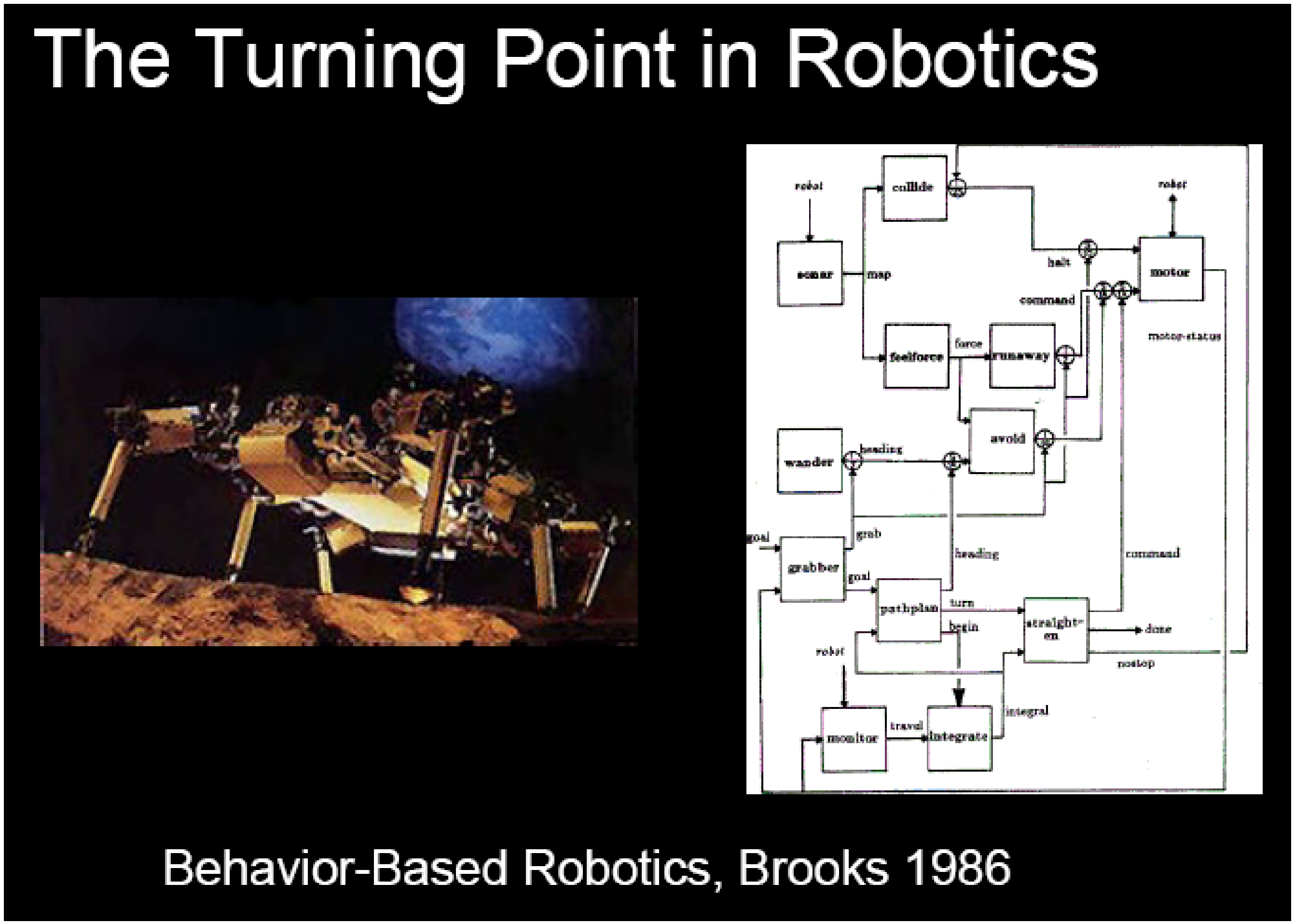
Example: semi-autonomy



Autonomy in Robotics

- Use Robots
  - when humans cannot or do not want do do it
- In Teleoperations
  - humans do not act, but are needed all the time
  - cognitive fatigue, high comms bandwidth, long delays, and many:one human to robot ratios
- Semi-autonomy
  - tries to reduce fatigue, bandwidth by delegating portions of the task to robot
  - human only acts when needed

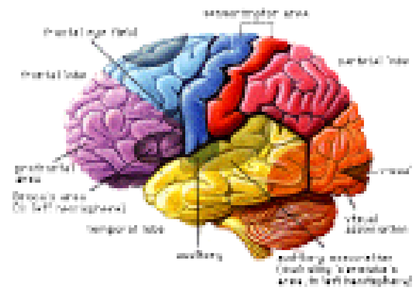
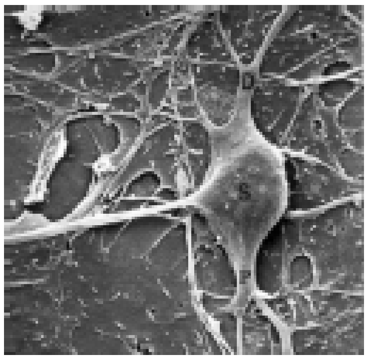
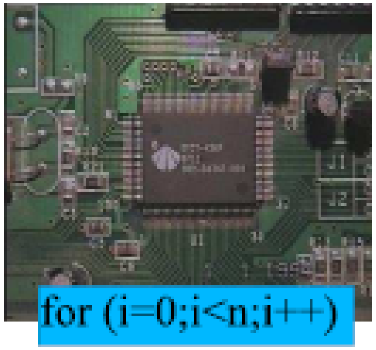
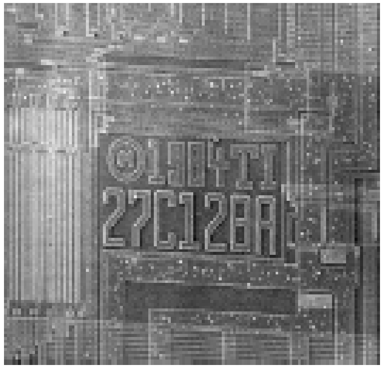
Behavior-based approach



† Sebastian Thrun '1996-2006 Autonomous Robots', 50 years Artificial Intelligence Symposium, Bremen.

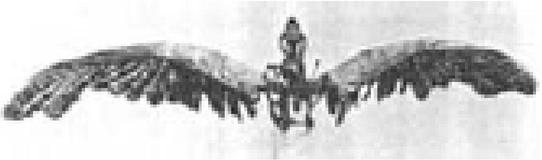
AIMA p. 932-933

Bio-inspired

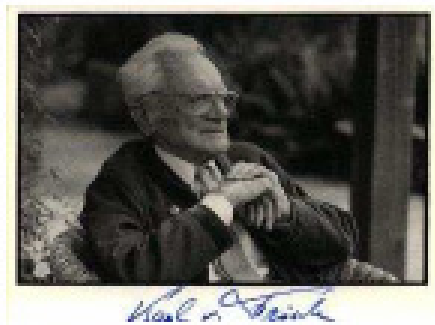
Level 1: What is the phenomena?	Level 2: How is it represented?	Level 3: How is it implemented?
		
		

Why look at biology?

- No world model (so no frame problem)
  - "The world is its own best representation" [Gibson]
- Proof of principle
  - It is possible
- Copying the "organization"
  - Shows how it can be done

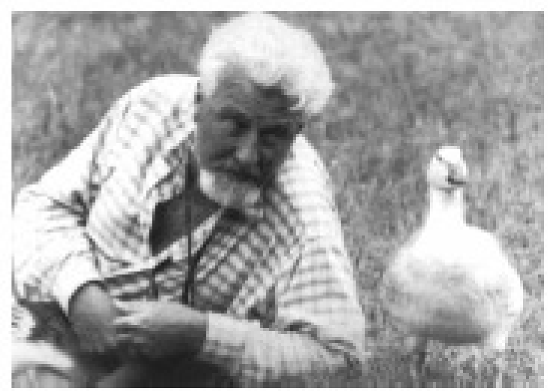




Ethology: Coordination and Control of Behaviors



1973 Nobel Prize for Physiology or Medicine:

- Karl Von Frisch, Konrad Lorenz and Nikolaas Tinbergen



Behaviors

Types of behaviors

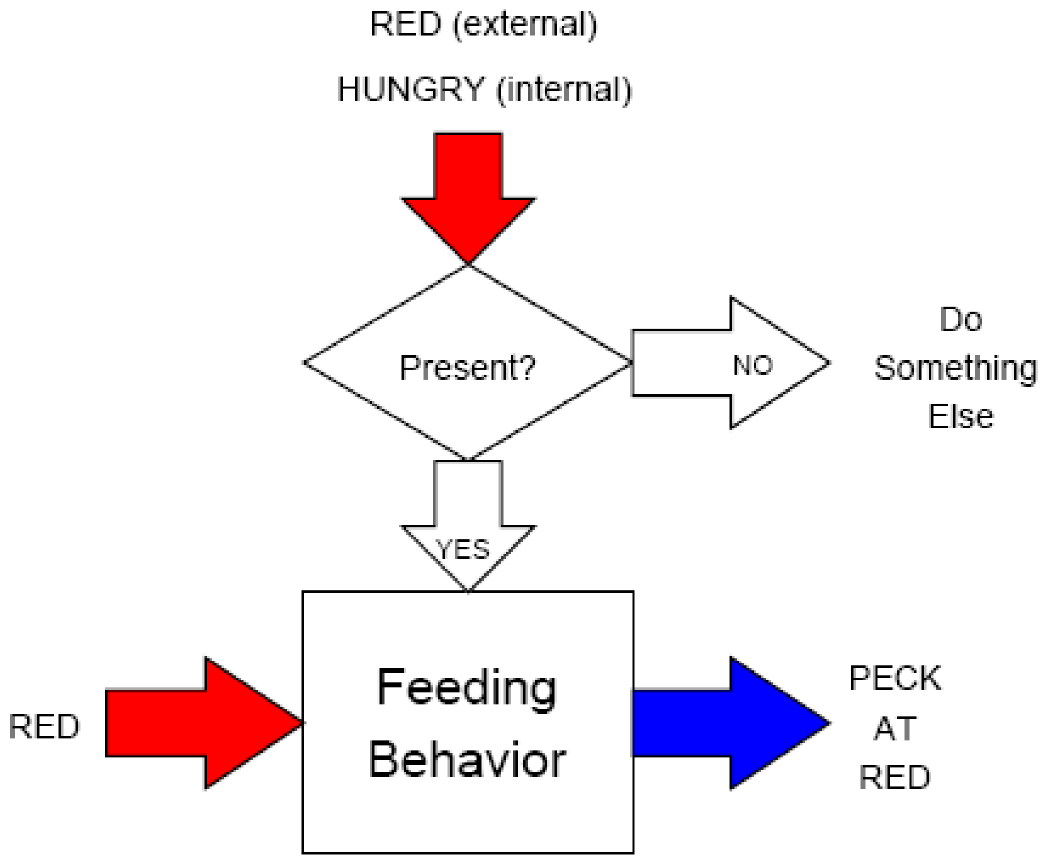
- Reflexive
  - stimulus-response, often abbreviated S-R
- Reactive
  - learned or "muscle memory"
- Conscious
  - deliberately stringing together

Warning: In robotics "reactive behavior" often means purely reflexive, and reactive behaviors are refered to as "skills".

Example of reflexive behavior

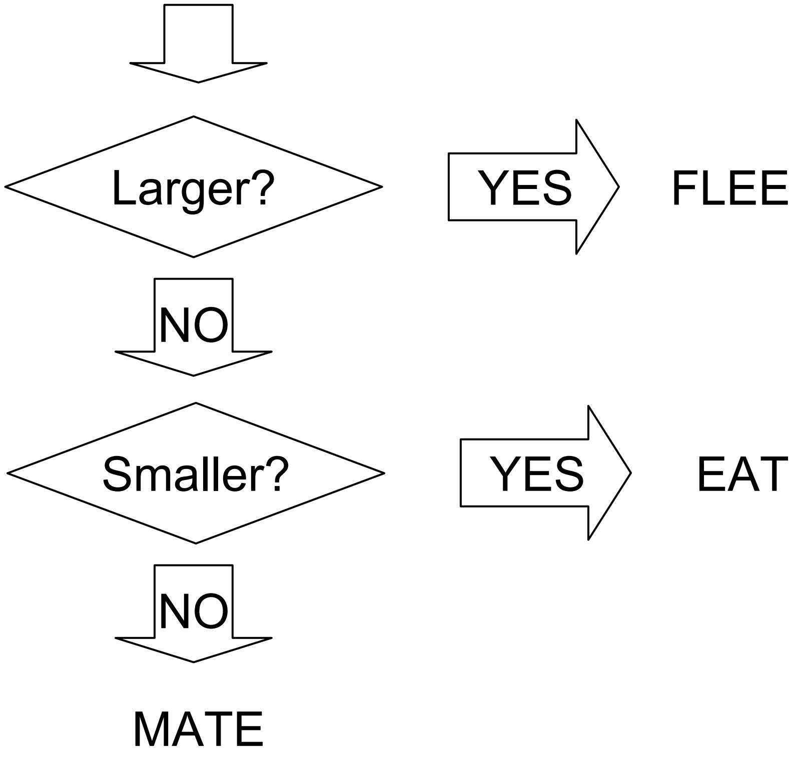
- Arctic terns live in the Arctic (black, white, gray environment, some grass) but adults have a red spot on beak
- When hungry, baby pecks at parent's beak, who regurgitates food for baby to eat
- How does it know its parent?
  - It doesn't! It just goes for the largest red spot in its field of view (e.g., ethology student)
  - Only red thing should be an adult tern
  - Closer = large red

Feeding behavior



Behavior of Life

OTHER LIVING THING (external)



General principles

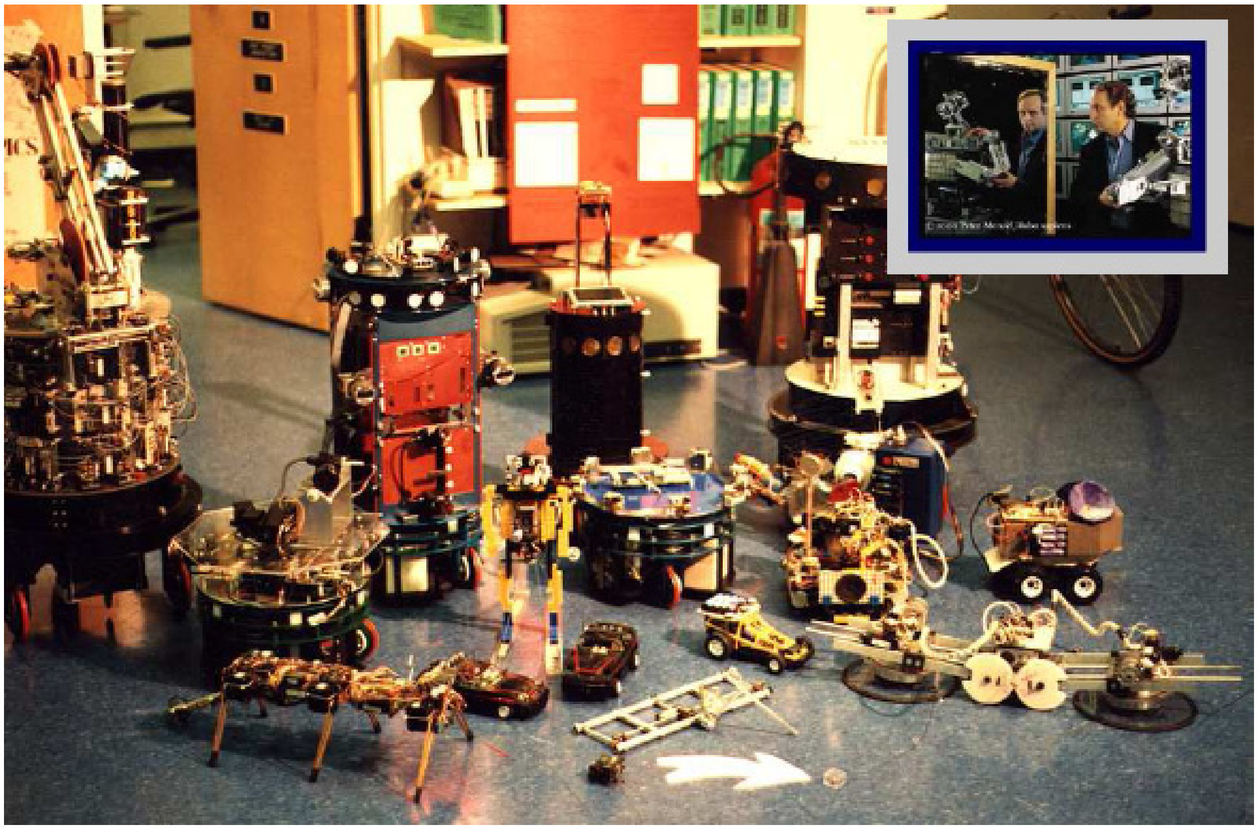
Ethology

- All animals possess a set of behaviors
- Releasers for these behaviors rely on both internal state and external stimulus
- Perception is filtered; perceive what is relevant to the task
- Some behaviors and associated perception do not require explicit knowledge representation

Robotics

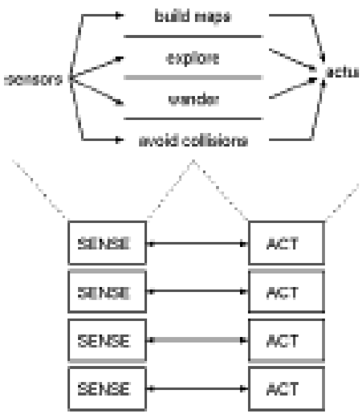
- Individual robots must survive, not species
- Must be able to predict emergent behaviors
- Not clear how to learn quickly
- Robots need more alternative perceptual schemas since poorer understanding of the environment

Subsumption architecture
(Brooks 1986)

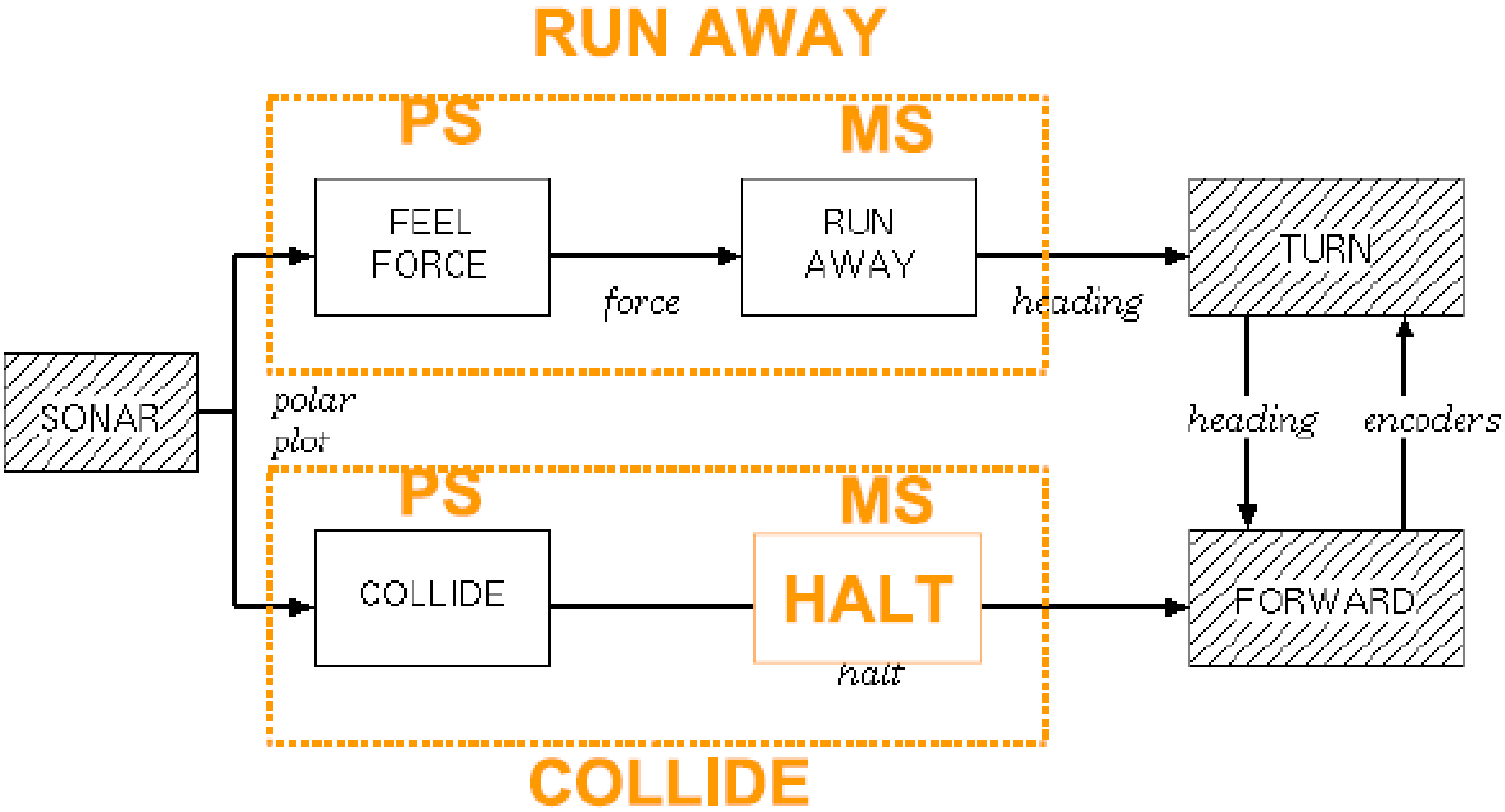


Subsumption philosophy

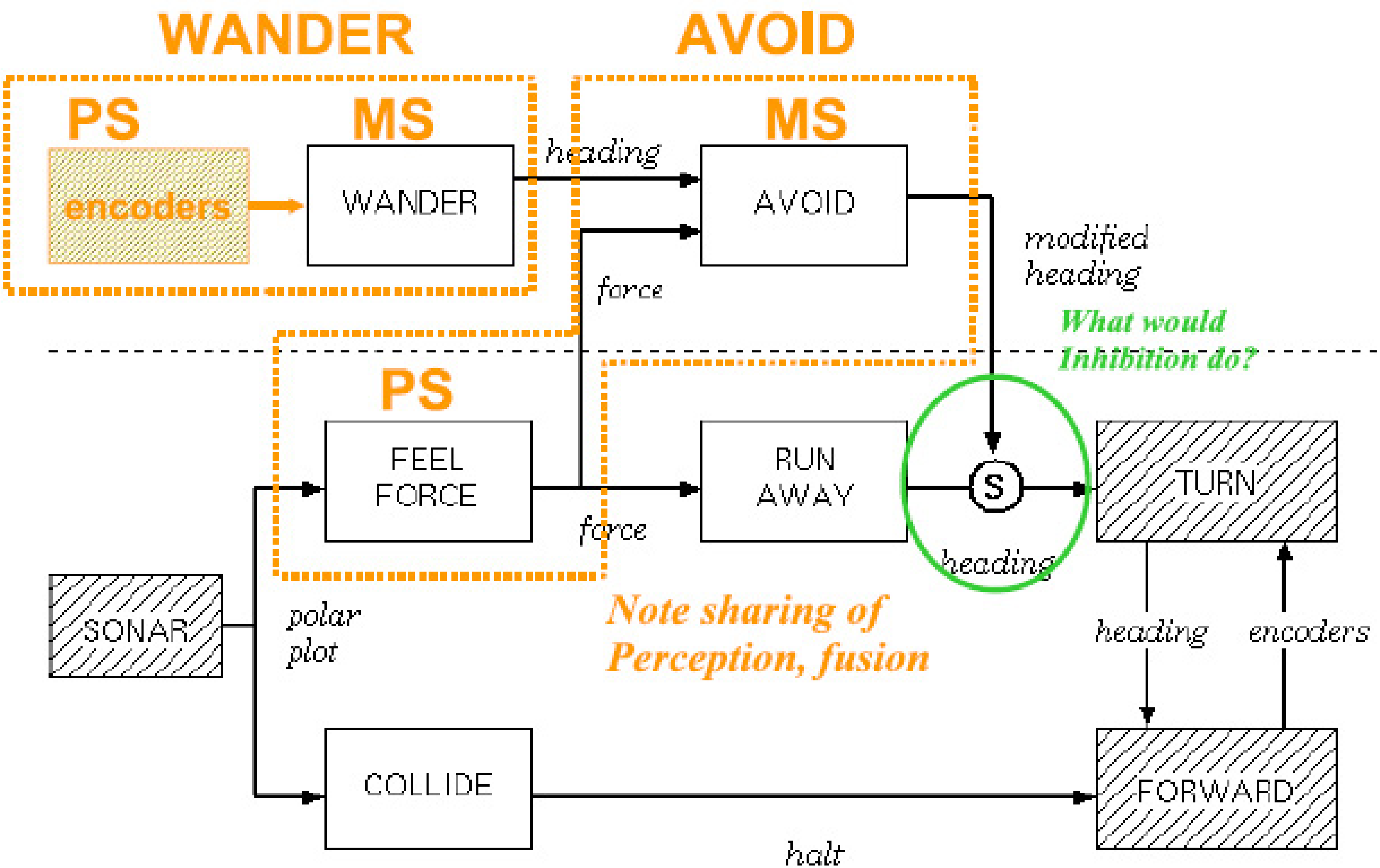
- Modules should be grouped into layers of competence
- Modules in a higher lever can override or subsume behaviors in the next lower level
  - Suppression: substitute input going to a module
  - Inhibit: turn off output from a module
- No internal state in the sense of a local, persistent representation similar to a world model.
- Architecture should be taskable: accomplished by a higher level turning on/off lower layers



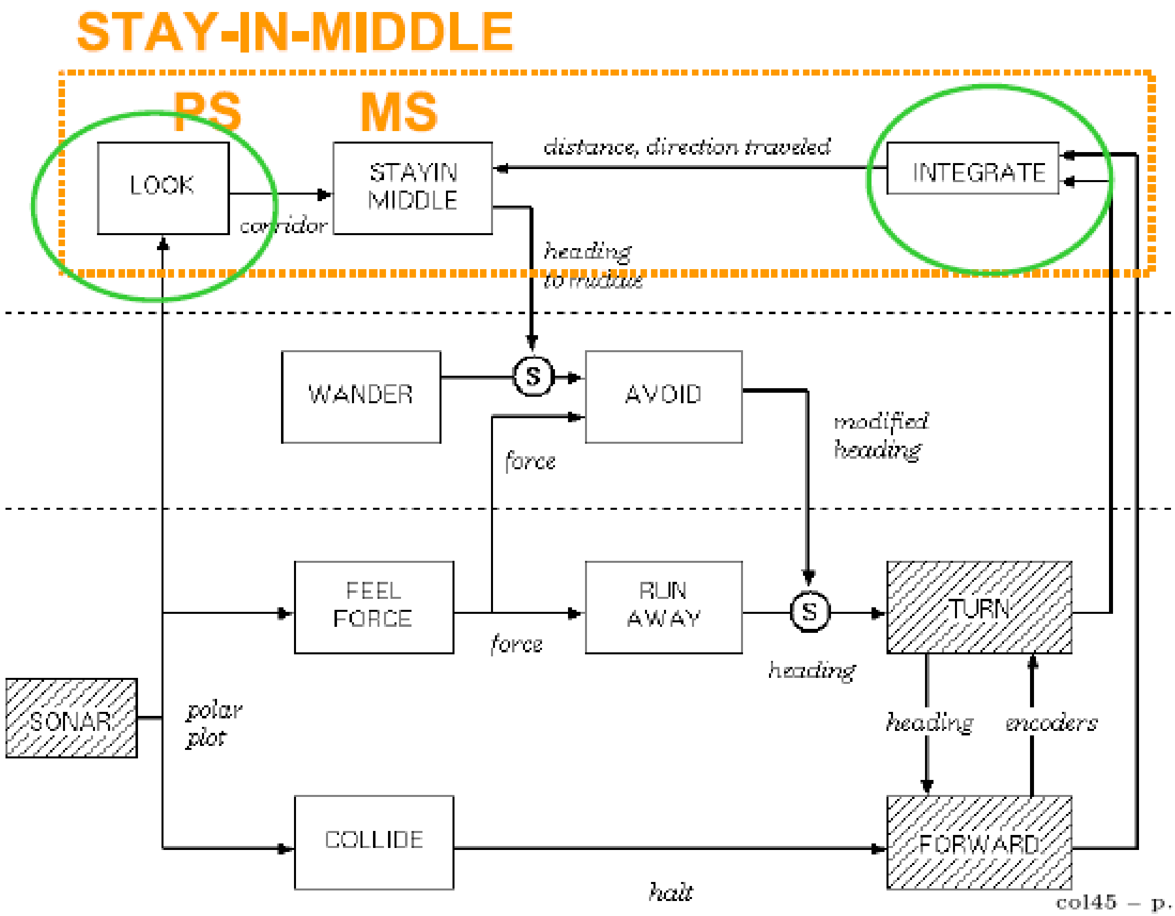
Level 0: avoid collision



Level 1: wander

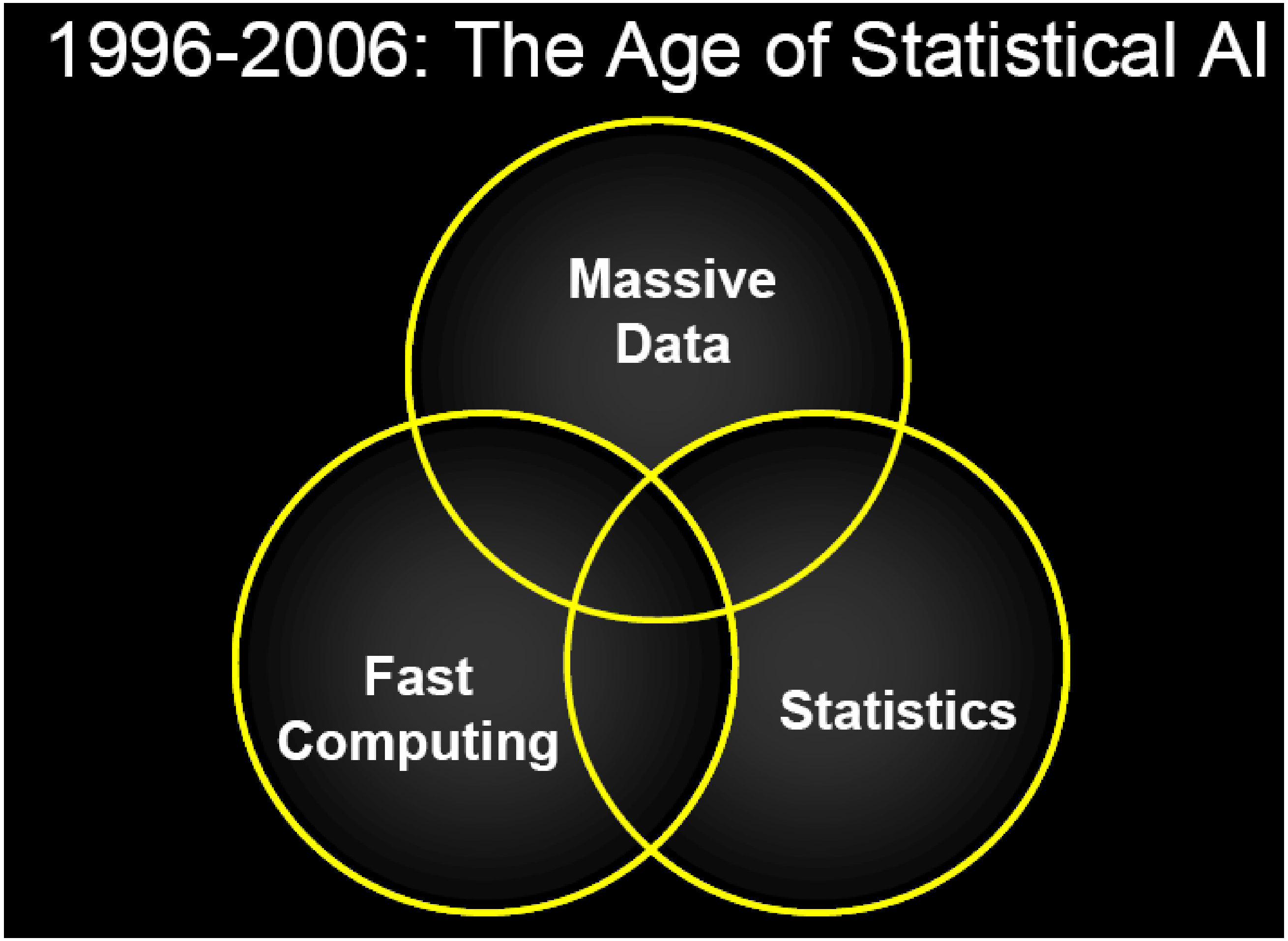


Level 2: follow corridor



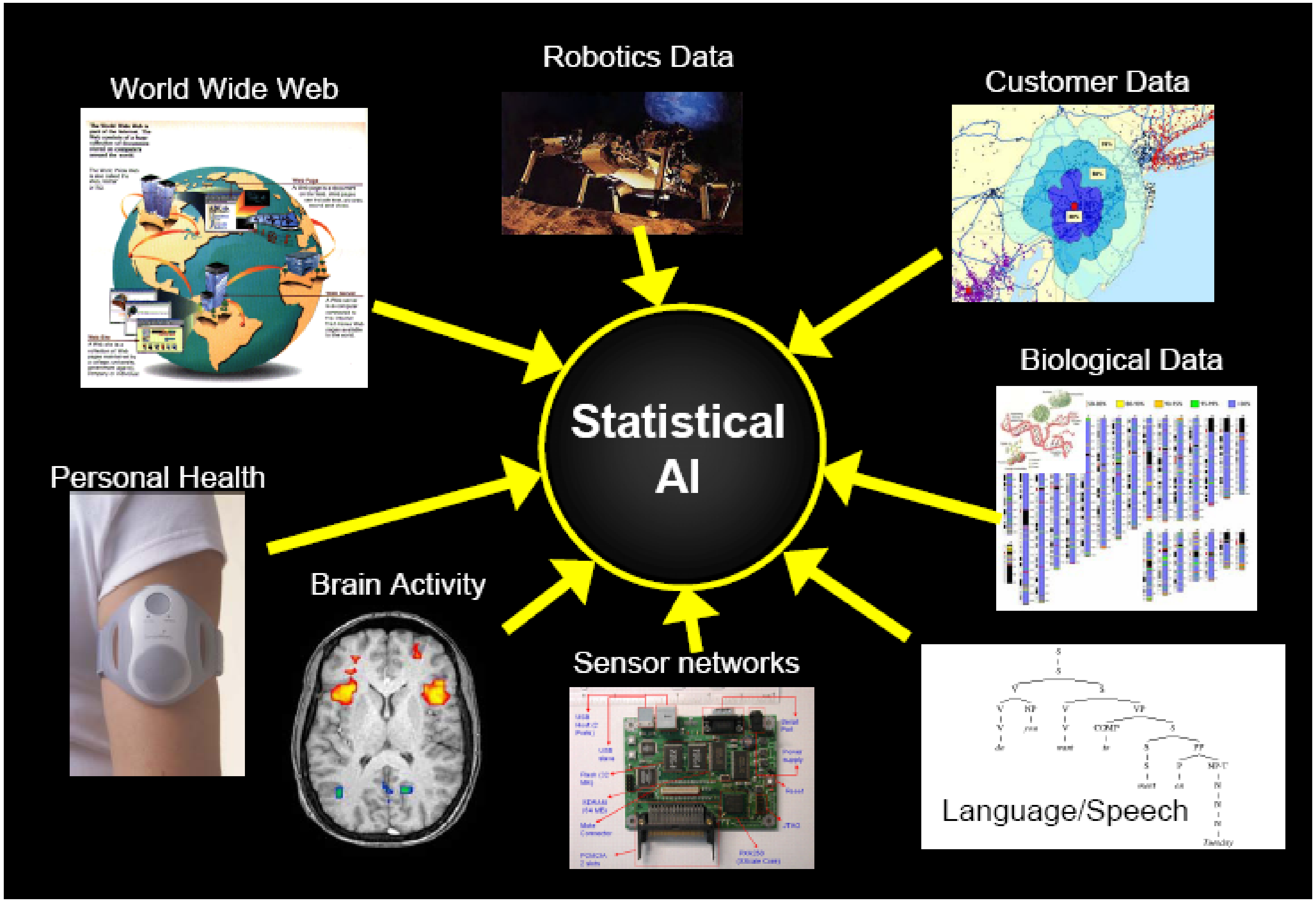
The result: Finite State Automata

FSM is a simplification of the world



† Sebastian Thrun '1996-2006 Autonomous Robots', 50 years Artificial Intelligence Symposium, Bremen.

Searching for correlations in data



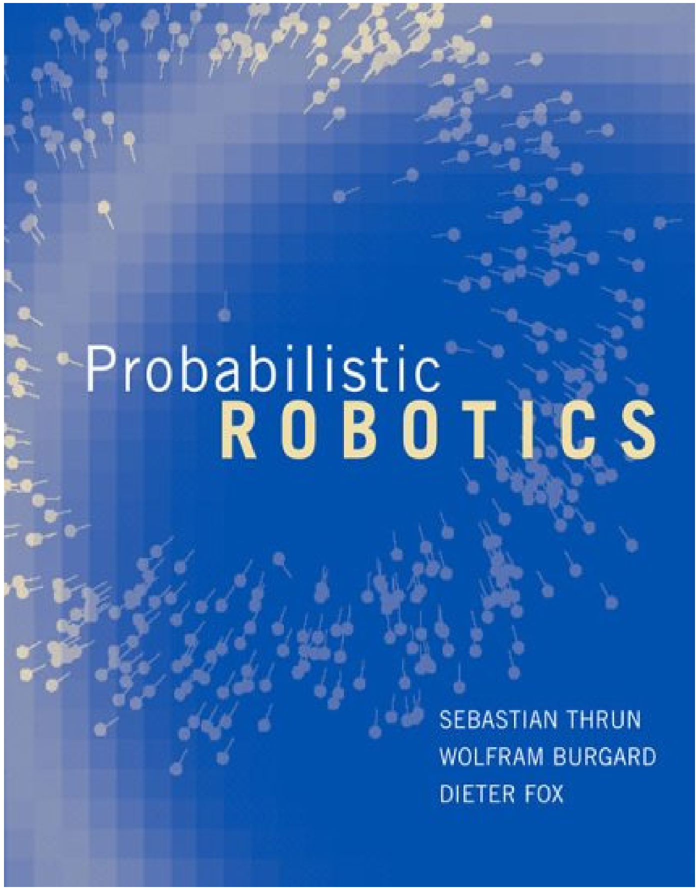
† Sebastian Thrun '1996-2006 Autonomous Robots', 50 years Artificial Intelligence Symposium, Bremen.

Spatial Knowledge in Robotics†

- Localization (current location)
  Where am I?
- Mapping (past locations)
  Where have I been?
- Exploration (future locations)
  Where am I going?

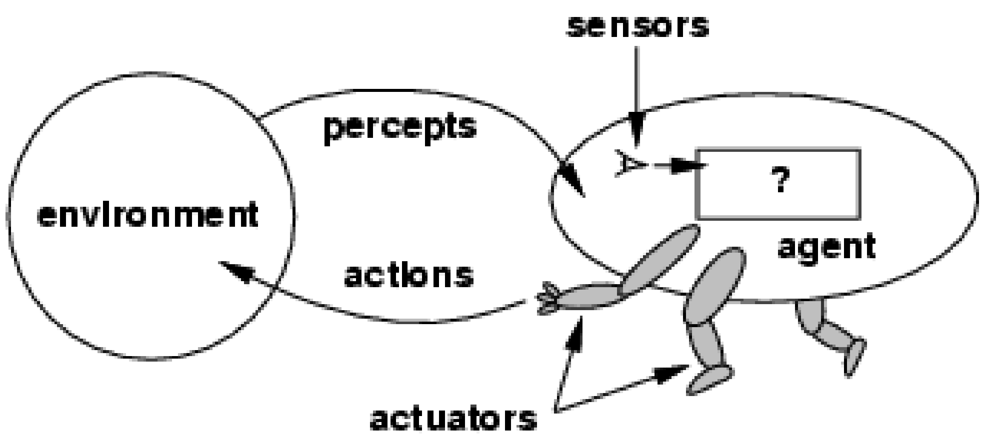
† Robin R. Murphy, 'Introduction to AI Robotics', MIT Press, 2000

Probabilistic Robotics†



† S. Thrun, W. Burgard, D. Fox, 'Probabilistic Robotics', MIT Press, 2005

Physical situated agent



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

† Russell & Norvig, 'Artificial Intelligence – A modern approach', Prentice Hall, 2003

Theory of multiple intelligences

- linguistic,
- logical-mathematical,
- <u>spatial</u>,
- <u>bodily-kinesthetic</u>,
- <u>naturalistic</u>,
- musical,
- interpersonal,
- intrapersonal. †

† Howard Gardner, ‘Multiple Intelligences’, BasicBooks, New York (2006).

Anthropic principle

To replace a human worker,
a robot needs the equivalent of:

- Human knowledge
- Human rational
- Human perception
- Human actuators
- Human communication

Human actuators

† Asimo, Honda’s Humanoid robot, Commercial 2006

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Robotics plays a central role in AI

- Integration platform for many areas of AI
- Benchmark platform for progress in AI
- Embodiment is a prerequisite for intelligence
- Future of AI is projected on robotics†

† 50 years Artificial Intelligence Symposium, Bremen.

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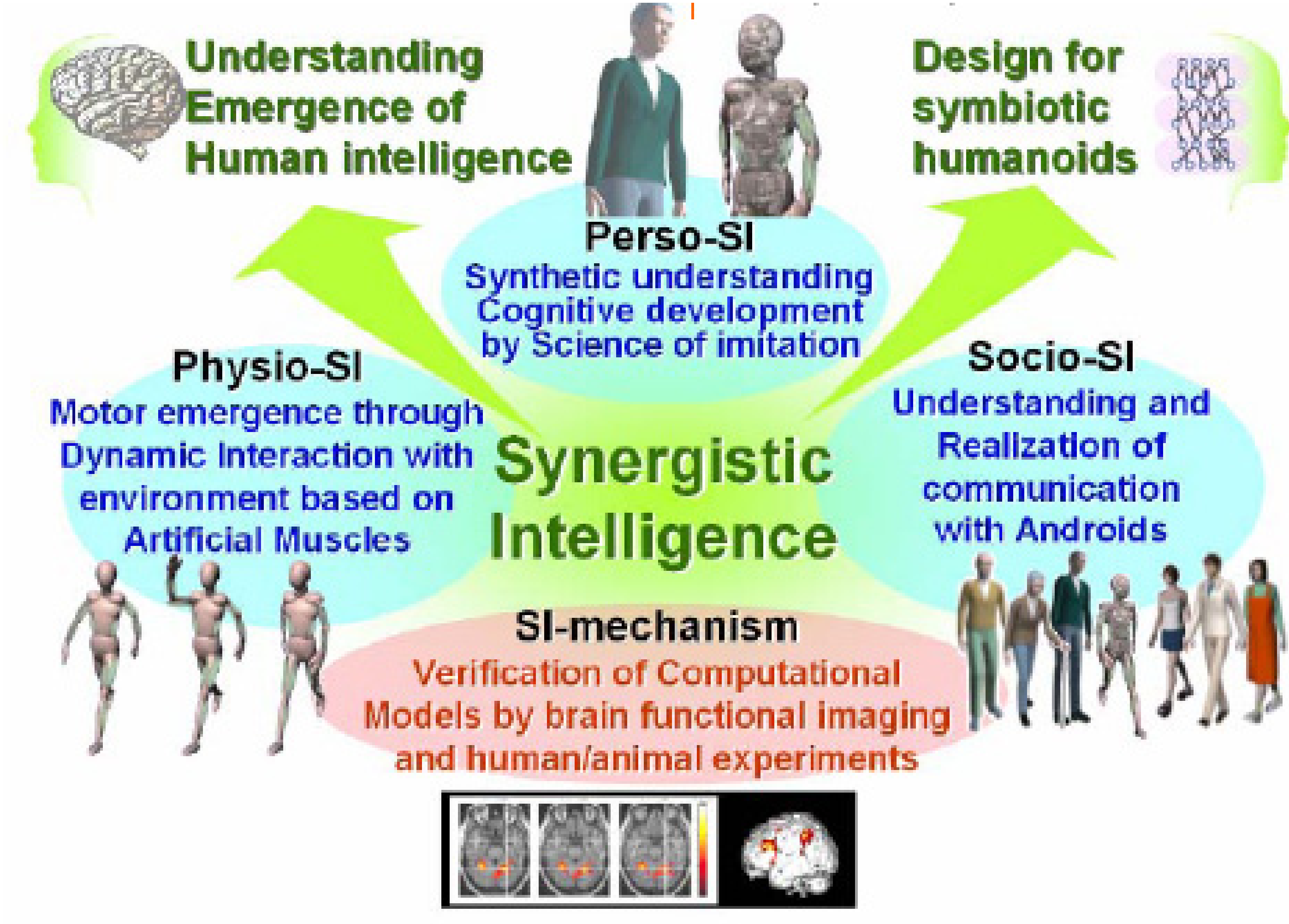
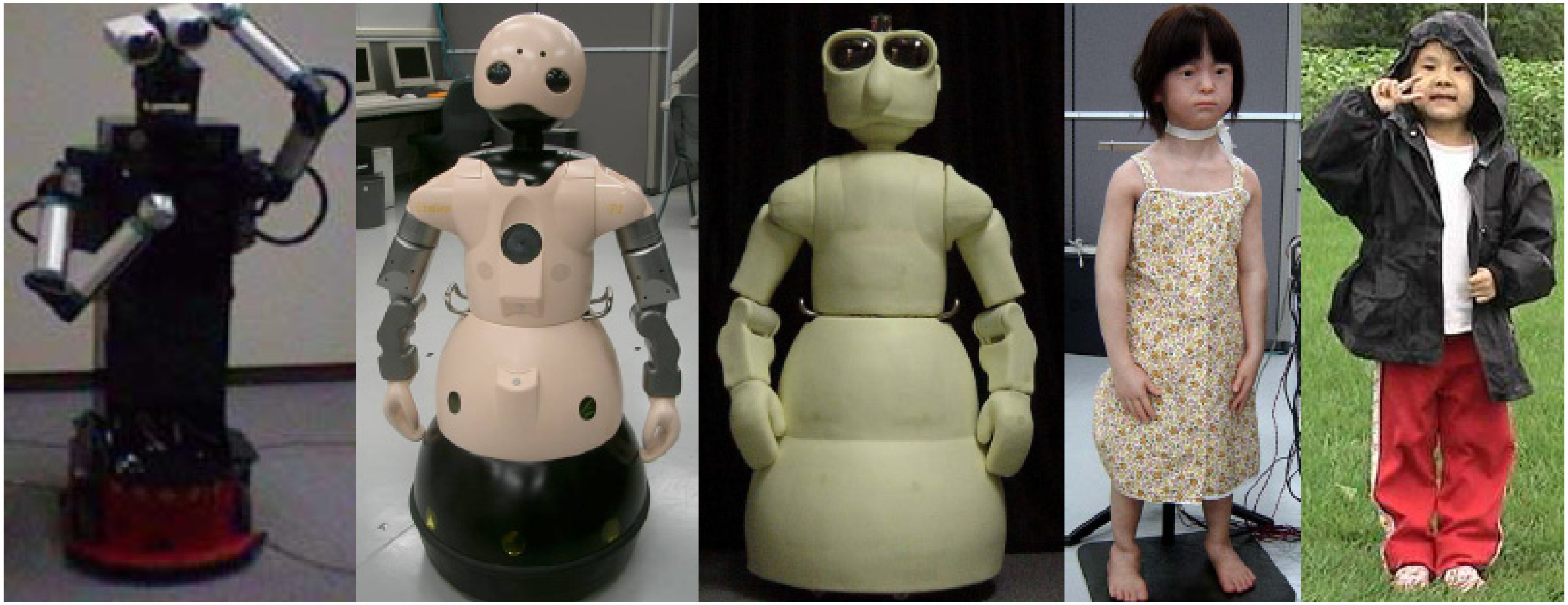
Synergistic Intelligence

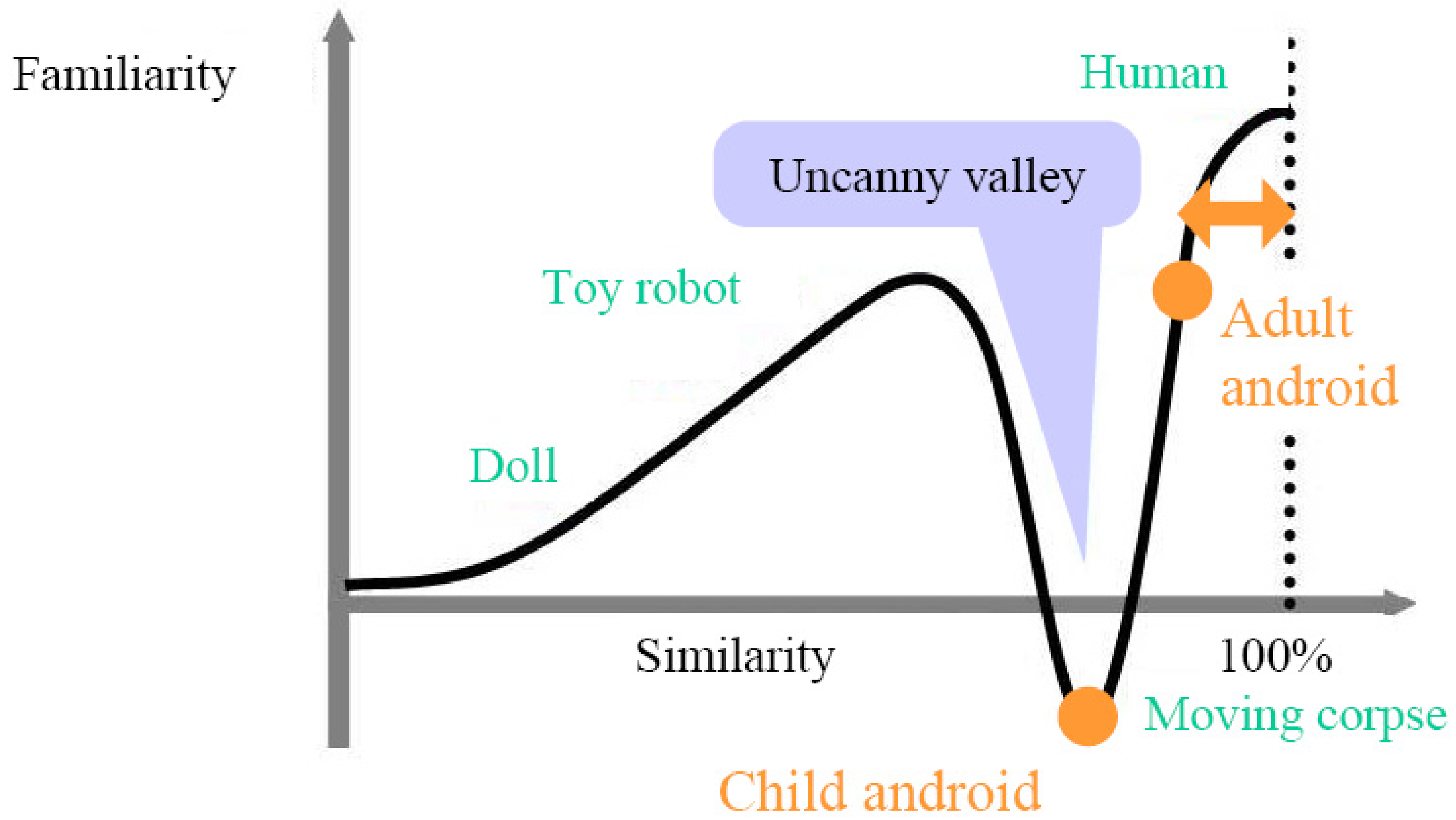


† Hiroshi Ishiguro '2006-2056 Projects and Vision in Robotics', 50 years Artificial Intelligence Symposium, Bremen.

Developments humanoids go fast



Uncanny valley [Mori et al. ’97]



Ishiguro’s Androids

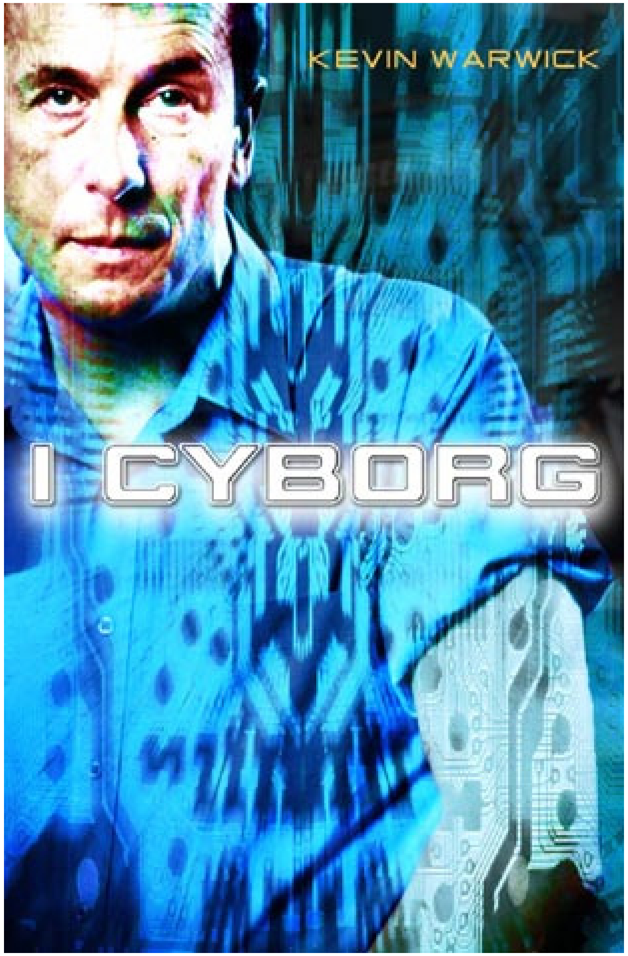
- Child (Repliqee R1)

- Adult (Repliqee Q2)

- Ishiguro (Gemenoid)

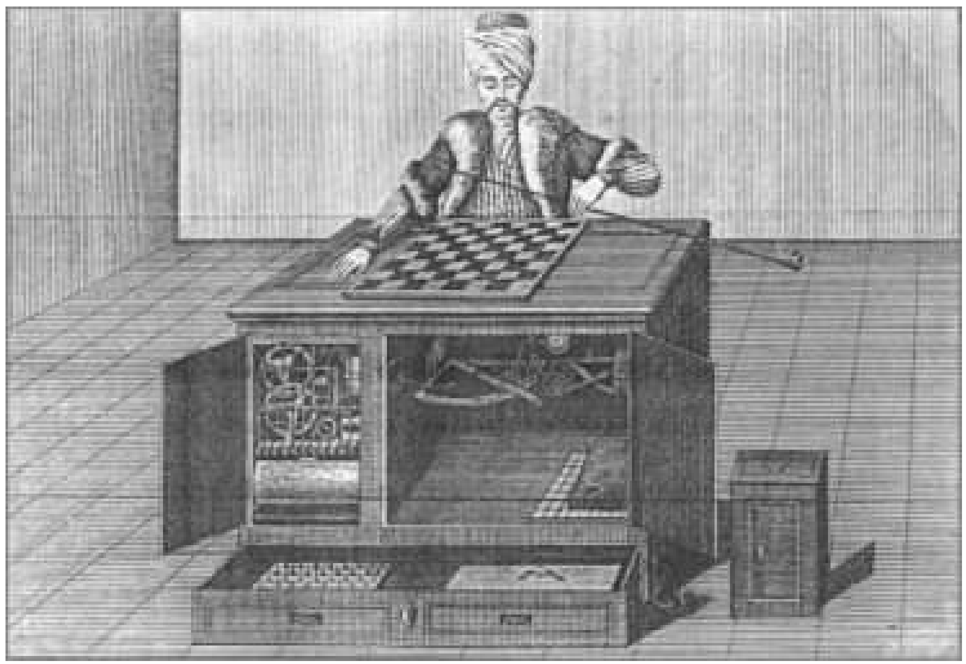
Cybernetics

- Can we use technology to upgrade humans?
- Can we use organic brains in robots?



Conclusion

- Robotics plays a central role in AI
- Embodiment is a prerequisite for intelligence



The chess-playing Turk defeated Napoleon in 1769