Mobile robots control architectures

Programming your robot

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Mobile robots control architectures

Question of the day

- How to write robotic software?
- How to connect sensors and actuators?

General set-up

Availible components

- Sensors & actuators
- External state
- Internal state
- Abstractly defined goals

The program logic should

- Handle all of this
- Be robust – in a static or dynamic environment
- Be modular & Extensible
- Be intelligent

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Outline

“Think hard, then act.”

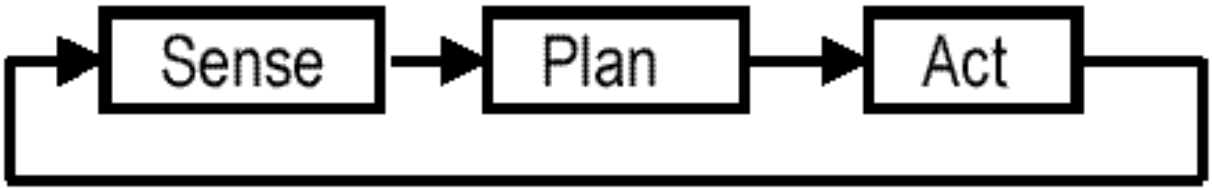

Image source: http://www.cs.brown.edu/~tld/courses/cs148/02/architectures.html

Deliberative architectures

- Also known as “Sense-(Model-)Plan-Act”
- Popular in early robotics (from 1960)
- Sequential architecture

Deliberative architectures: Main idea

Deliberative Control: Idea

- ...is a process of manipulating explicit representations of the world
- Essential: the planning process
- Required: Knowledge about the state of the world and plan

Deliberative architectures: Example

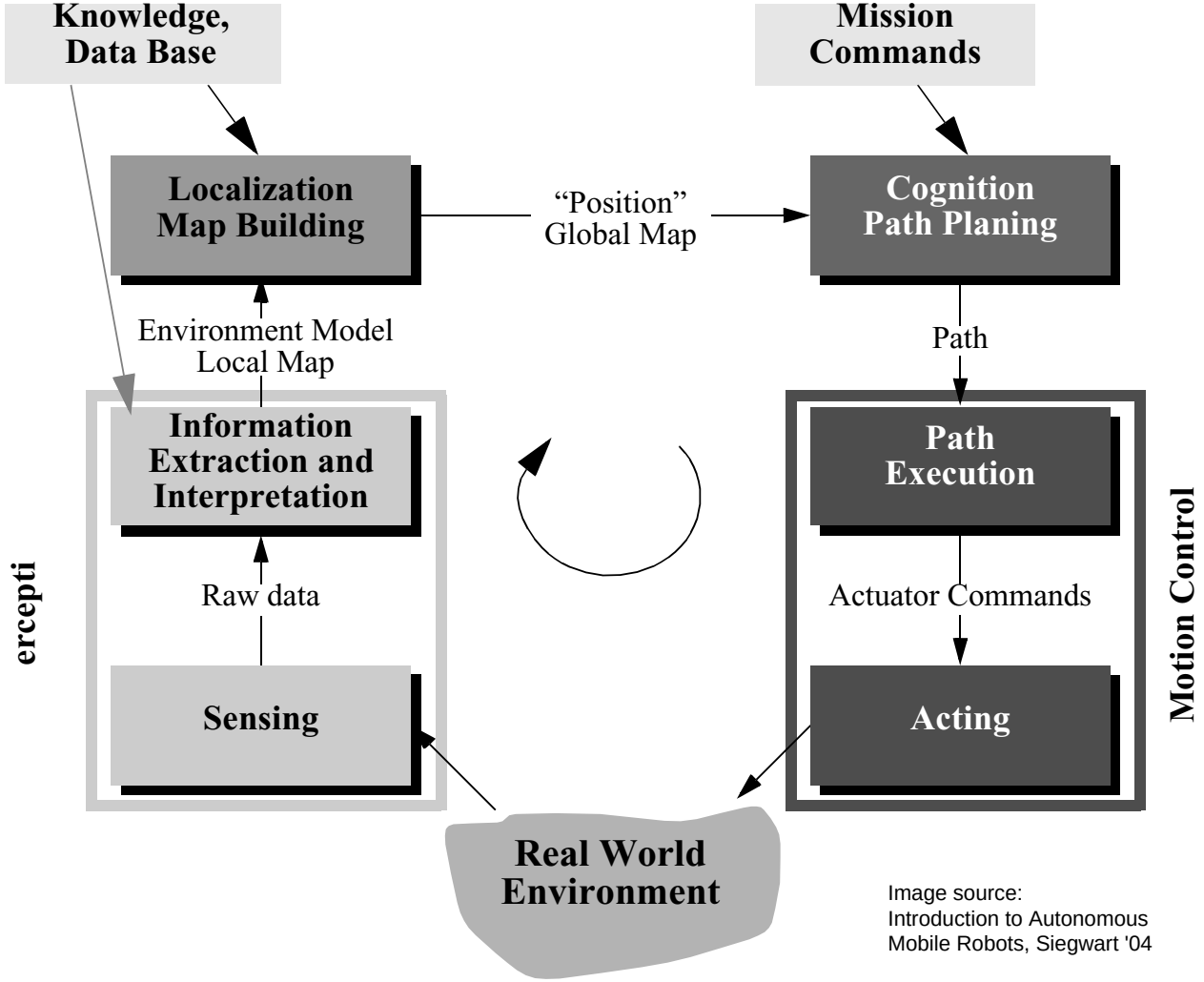

Image source:
Introduction to Autonomous Mobile Robots, Siegwart '04

Deliberative architectures: Characteristics

Advantages

- Straight-forward
- High-level intelligence is possible
- Useful in a static environment

Disadvantages

- Slow reacting to unexpected events
- Unusable in a highly dynamic environment

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“Don’t think, react.”

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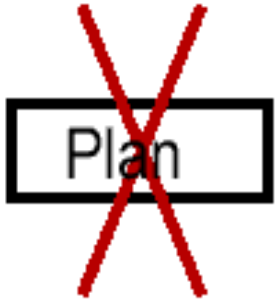


Reactive architectures

- Popular since 1980
- Highly parallel architectures
- Basic idea: No memory, almost no states, just use reflexes

Reactive architectures: Idea

Basic principles

- Tight sensing-action coupling (▷as in animal reflexes)
- No explicit world modelling
- Pre-computed sensors⟶motors function
- Small, asynchronous components

Generic reactive architecture

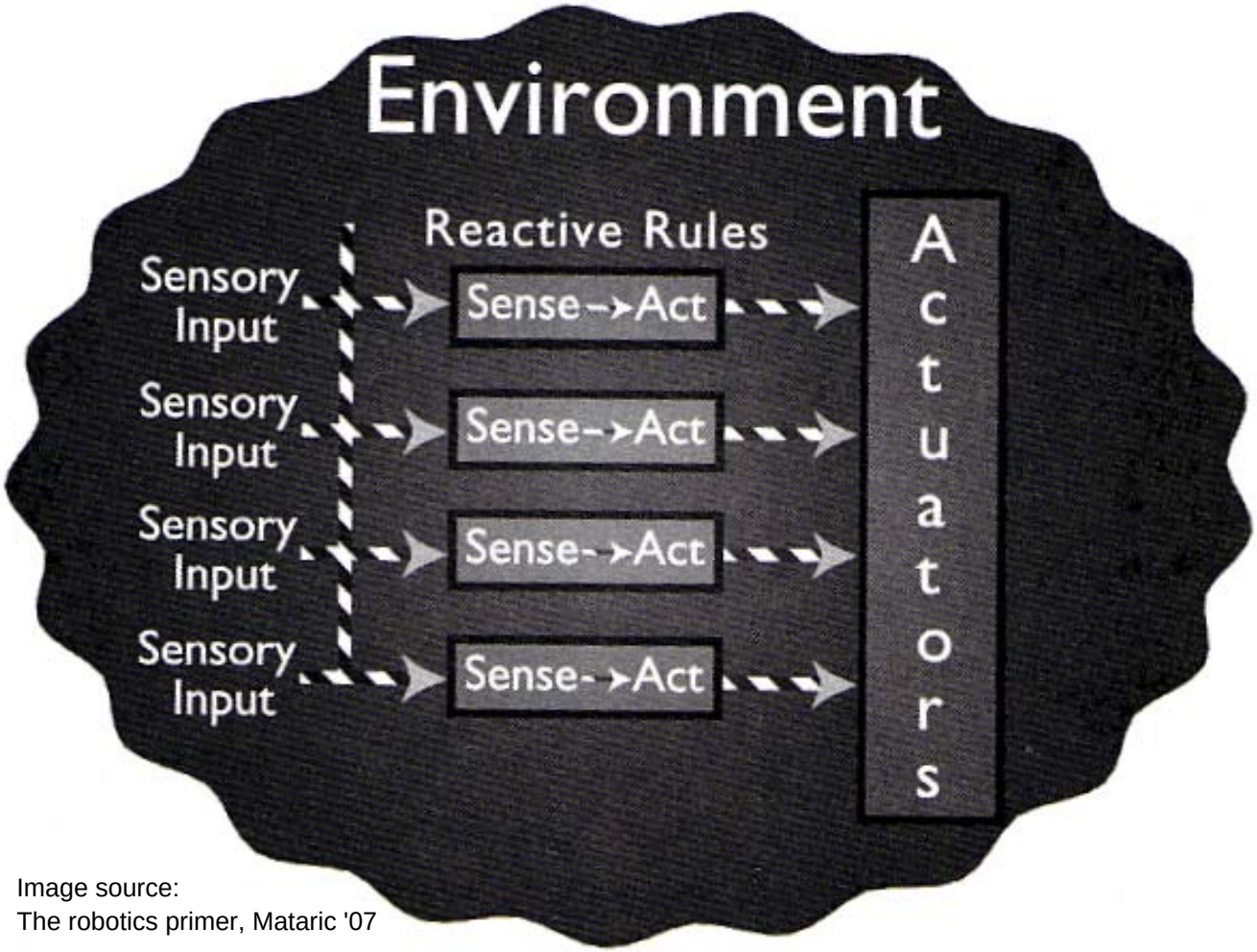


Image source:
The robotics primer, Mataric '07

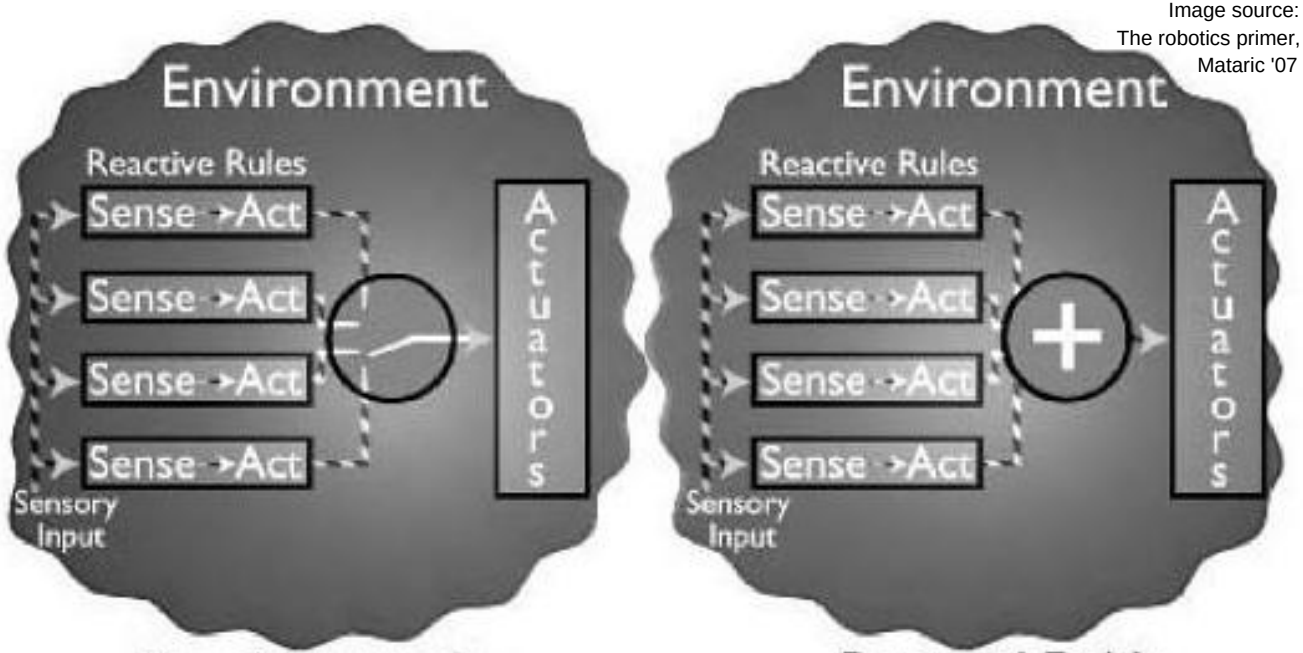
Reactive architectures: Example

Example rules & actions

- "If nothing is in front of you, move forward"
- "Start a counter. After 30 seconds turn randomly left/right 30 degrees"
- "If sonar nr. 42 is in a safe-zone, turn right"
- "If you are in front of a soda can and the arm is not extended yet, extend it"
- "If you are in front of the can ant the arm is extended, close the gripper"

Reactive architectures: Combining rules

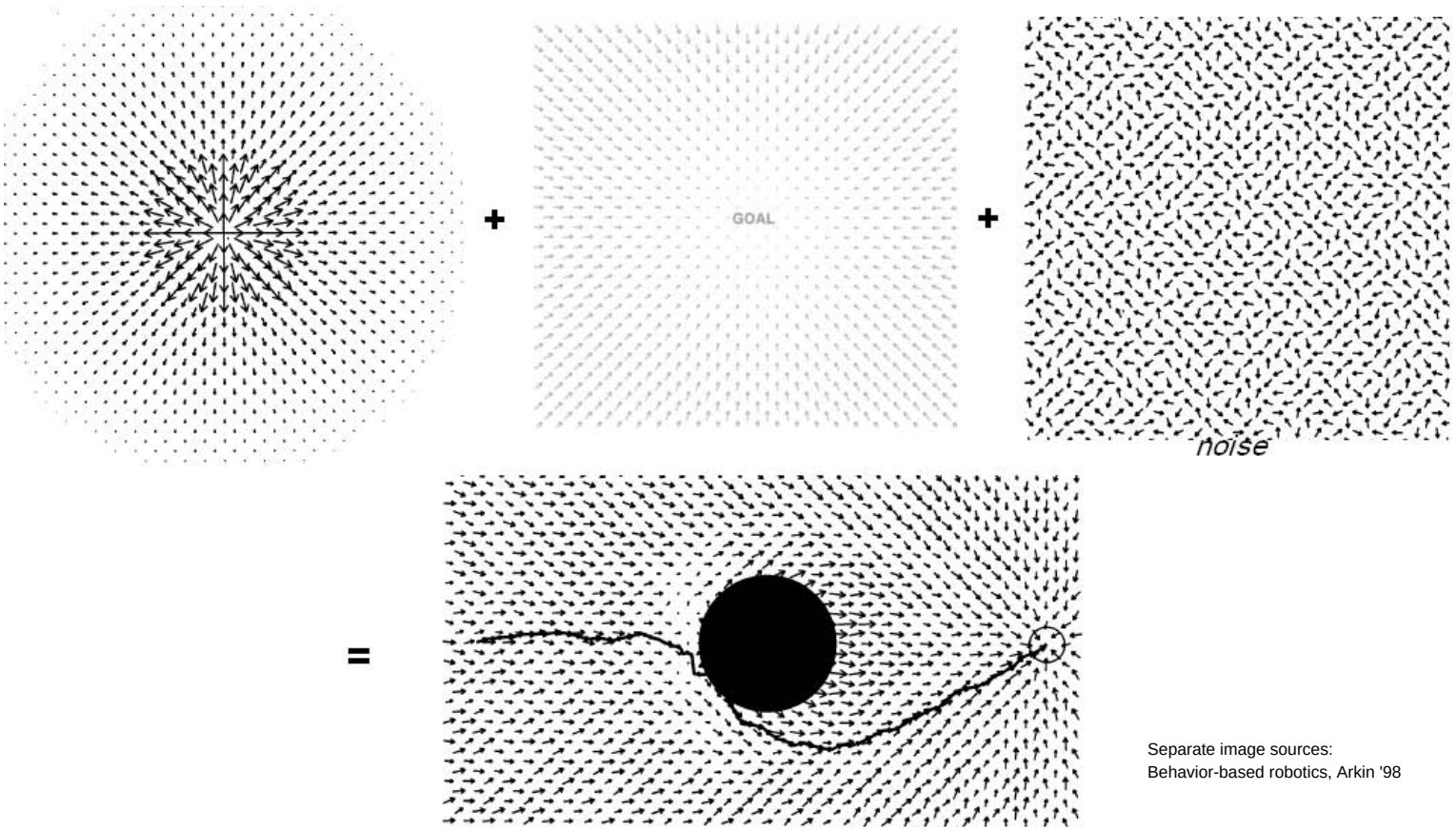
Image source:
The robotics primer,
Mataric '07



Fixed Heirarchy
Dynamic Heirarchy
Decision Theory
Probability

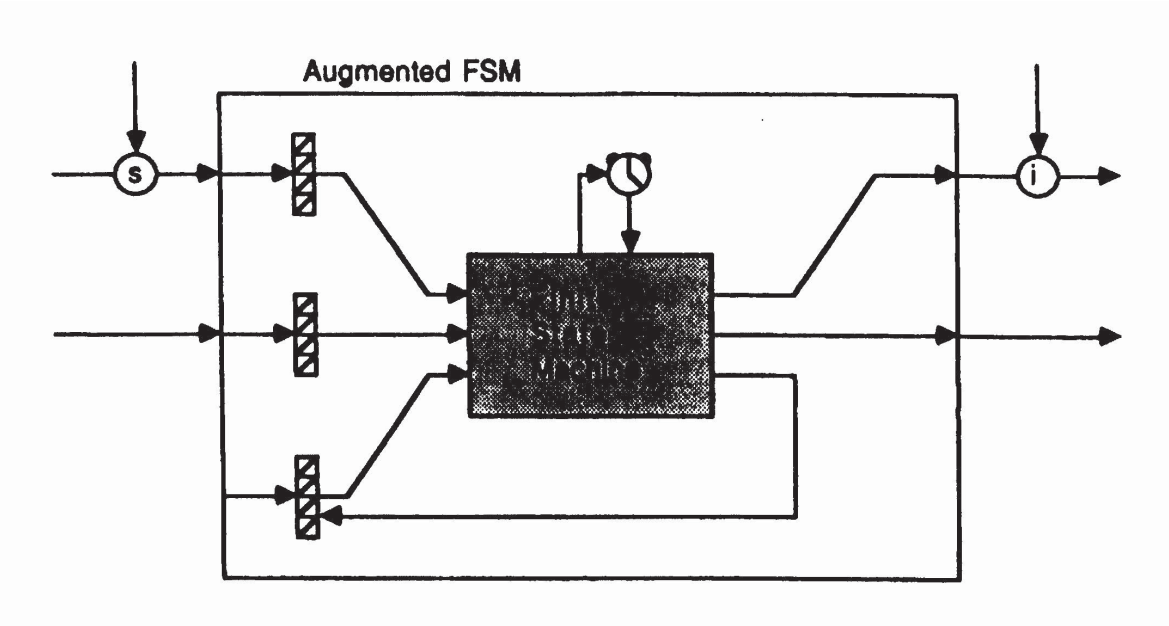
Potential Fields
Fuzzy Logic
Dynamical Systems
Motor Schemas

Reactive architectures: Motor schema example



Separate image sources:
Behavior-based robotics, Arkin '98

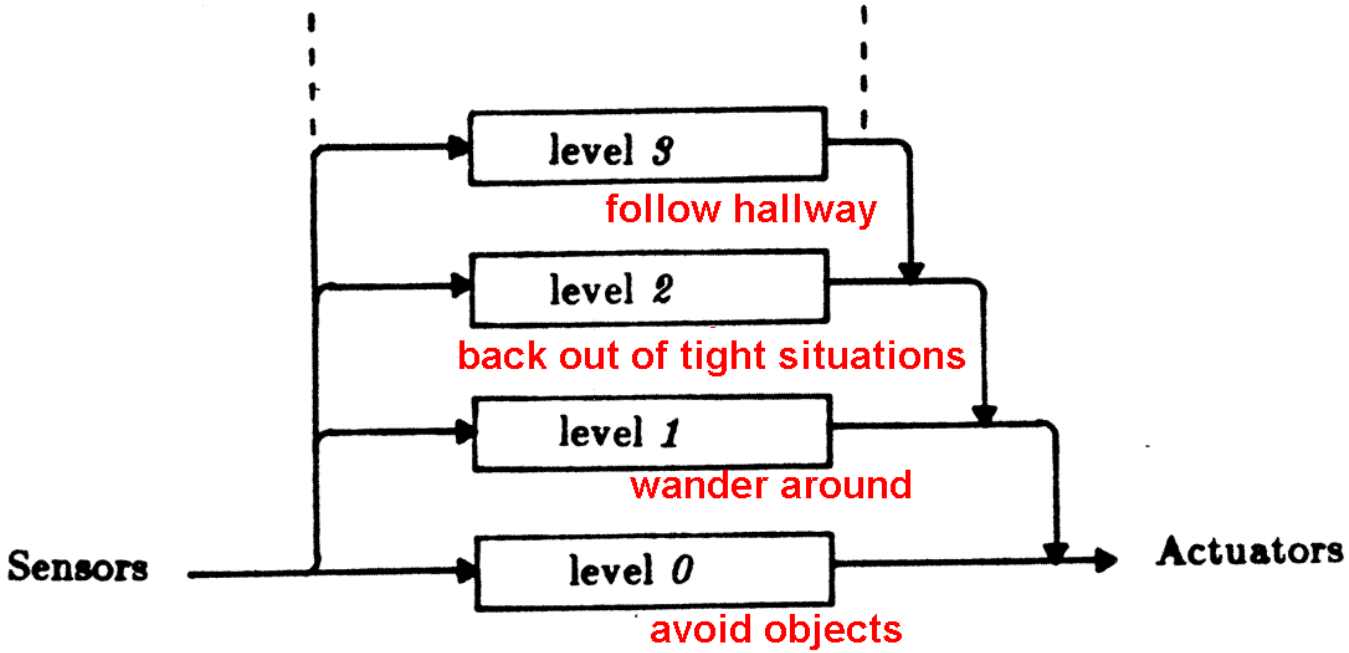
Subsumption architecture



Structure of one reactive element

- Element = final state machine + simple transforming function
- Inputs can be suppressed and outputs can be inhibited

Subsumption architecture



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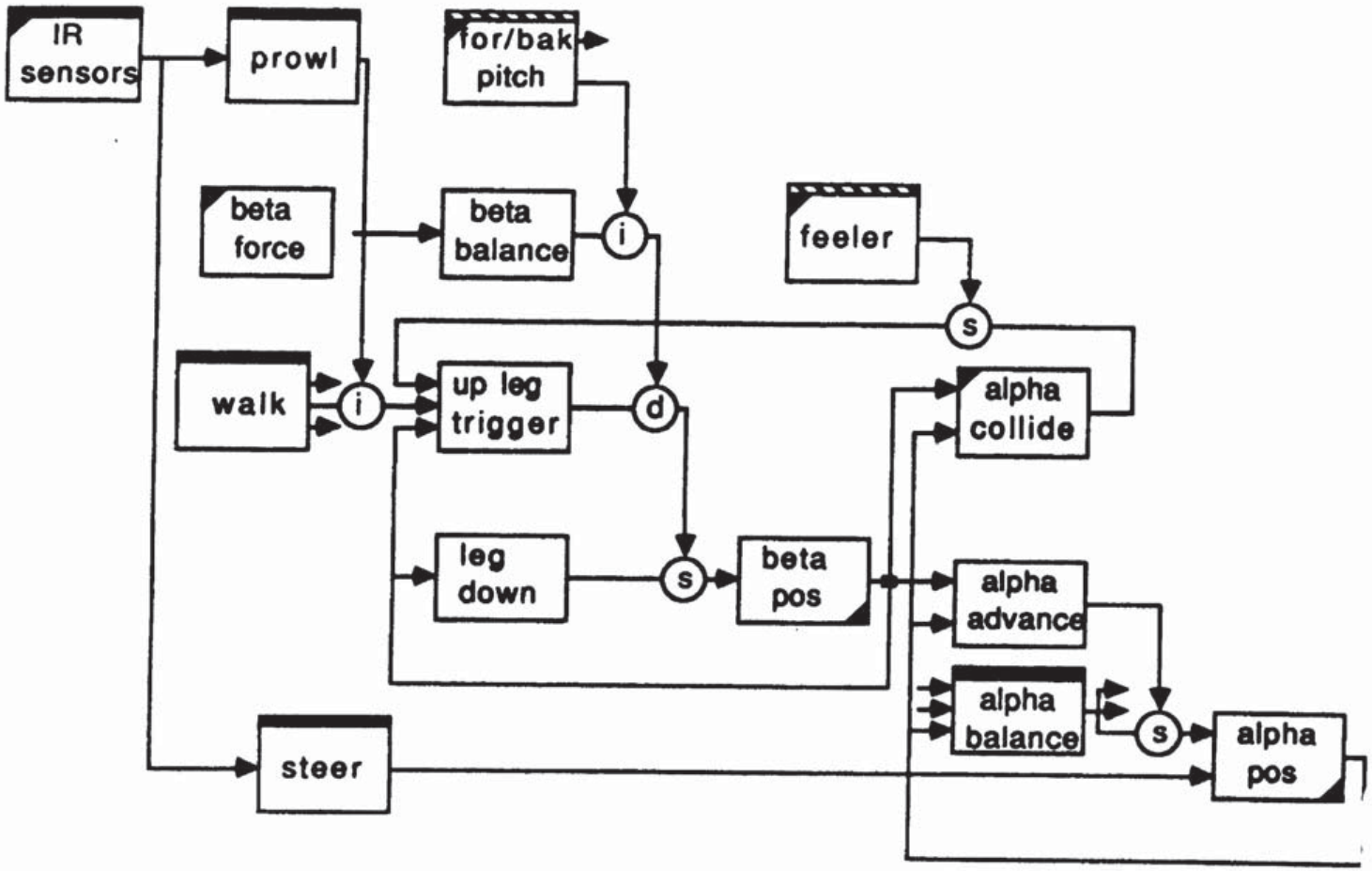
Combinations of elements with layers

- Hierarchical layering is used.

Subsumption architeture: Six-legged robot example



Reactive architectures: Characteristics

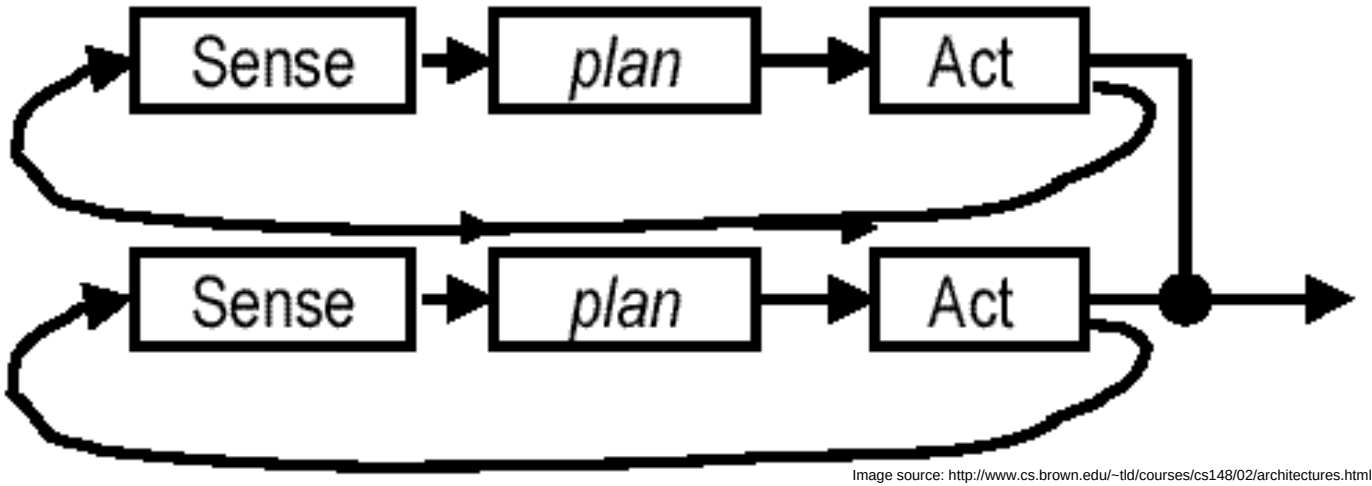
Advantages

- Simplicity and robustness possible
- Timely responses in dynamic, unstructured worlds will be produced
- Never out of date
- Subsumption architecture: testing is relatively easy

Disadvantages

- Intelligent behavior is difficult to implement
- Robot will not be able to learn
- Sequencing is difficult

“Think the way you act.”



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Behavior-based architectures

- Can be seen as enhancement of reactive architectures
- Highly modular
- Reminds me of multi agent systems

Behavior-based control architectures – Characteristics

Behavior-based control

- Reactive systems with memory
- Consists of so-called "behavior"-modules
- Task-oriented decomposition
- Highly parallel system
- Information is not centralized
- Alternative to hybrid systems (see later)

Behaviors: definition and classification

Behaviors...

- ...can be more complex than actions
- ...achieve or maintain goals
- ...are time-extended
- ...can take inputs from actions and other behaviors and
- ...send outputs to effectors and other behaviors
- ...can be added at runtime
- ...have to be on compatible time-scales

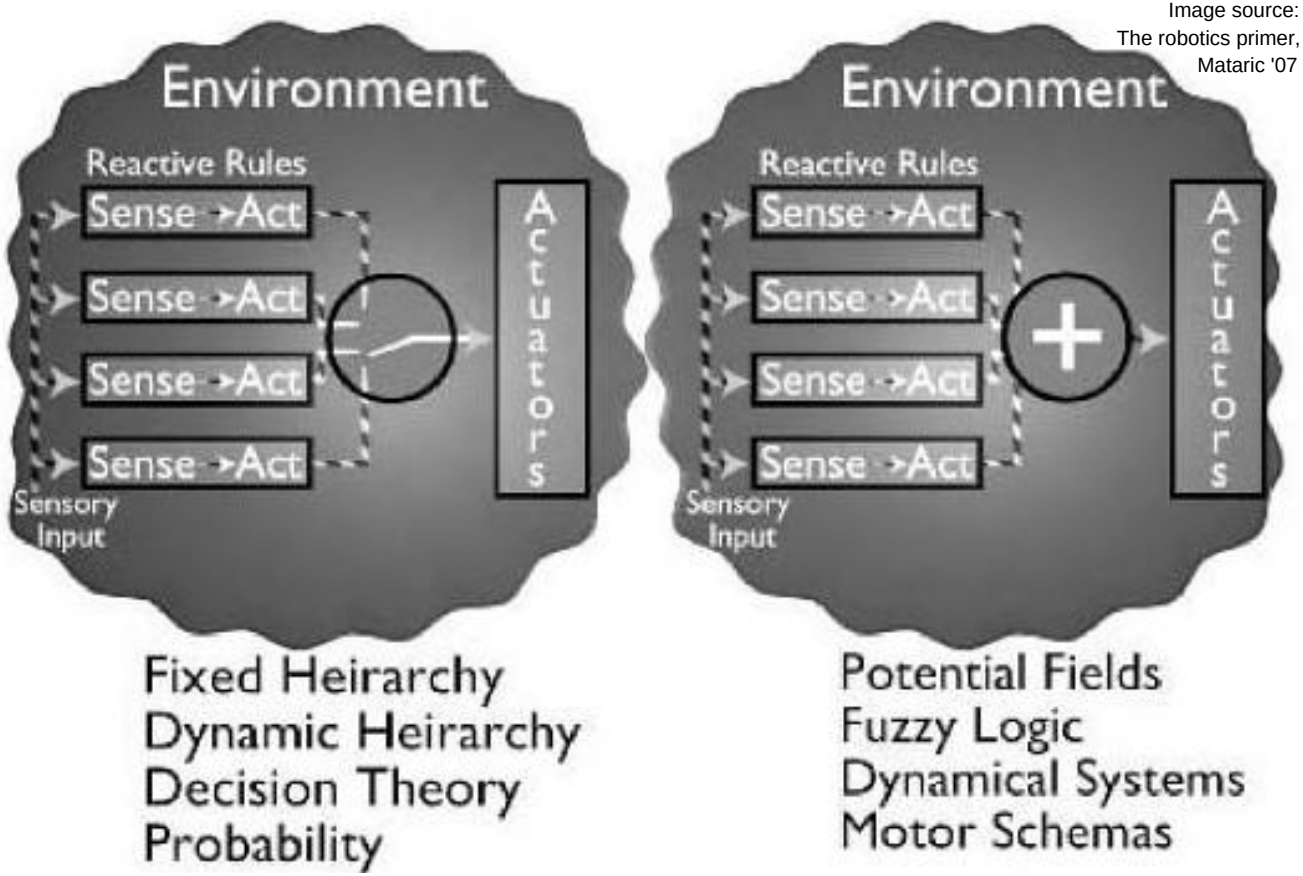
Behaviors: Some examples

Example behaviors...

- "Do not collide with anyting"
- "Regulary recharge battery"
- "Go to the opposite edge of the room"
- "Construct a partial map and associate it with this room"
- ...

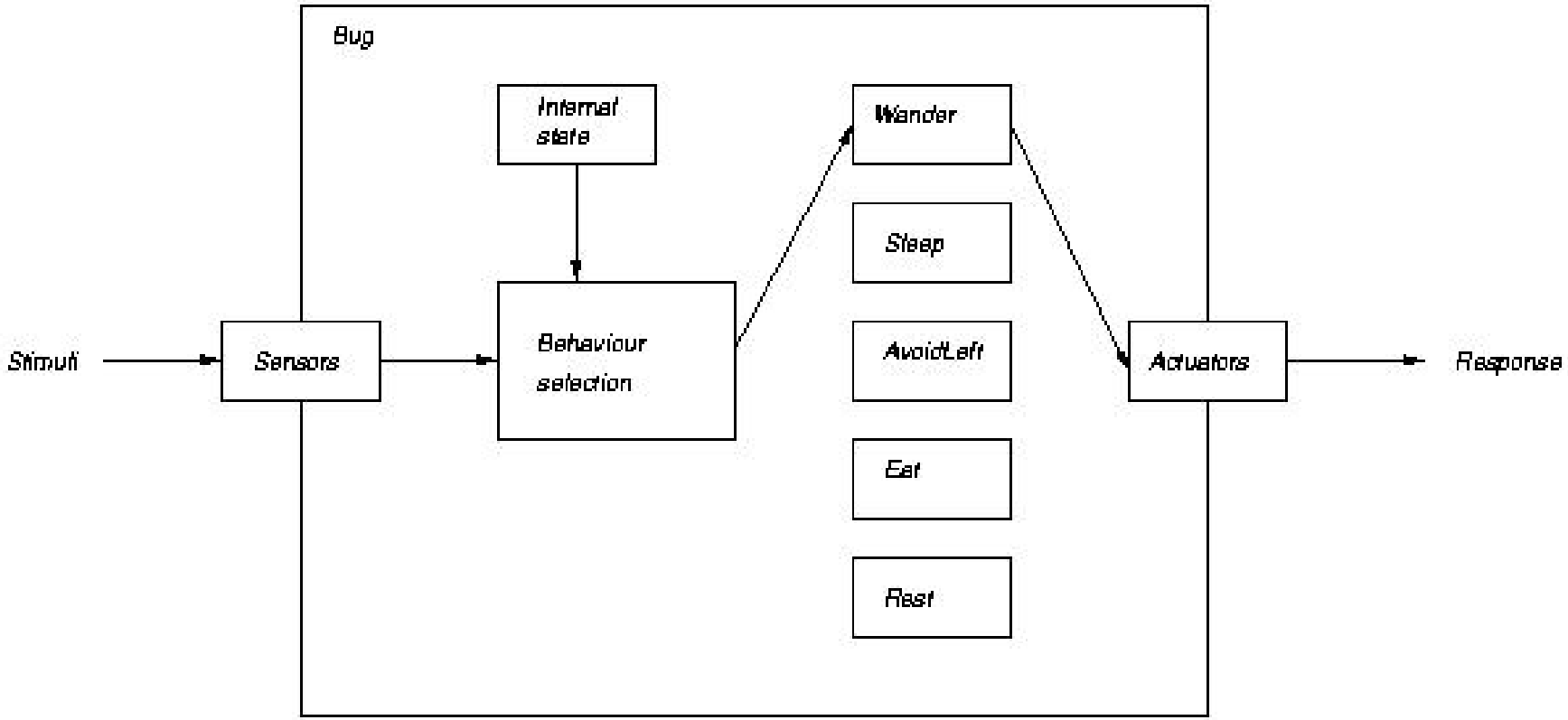
Behavior assembly

Image source:
The robotics primer,
Mataric '07



Behavior-based control architectures – an example

Image Source: http://legolab.daimi.au.dk/Projects/JungleCube.dir/Chapter.html



Behavior-based control architectures – Characteristics

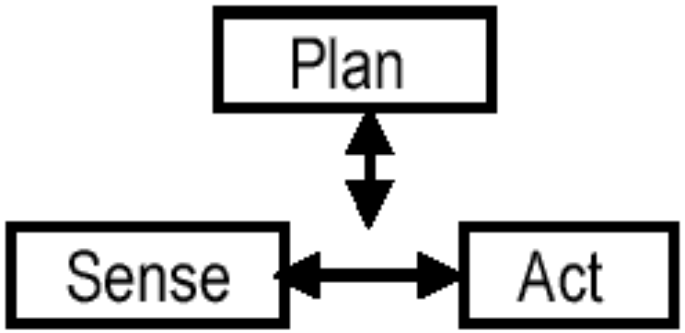
Advantages

- Fast real-time responses
- Modularity
- Possible to handle complex tasks

Disadvantages

- A difficult-to-comprehend approach
- Design could result in too many modules

“Think and act independently, in parallel.”



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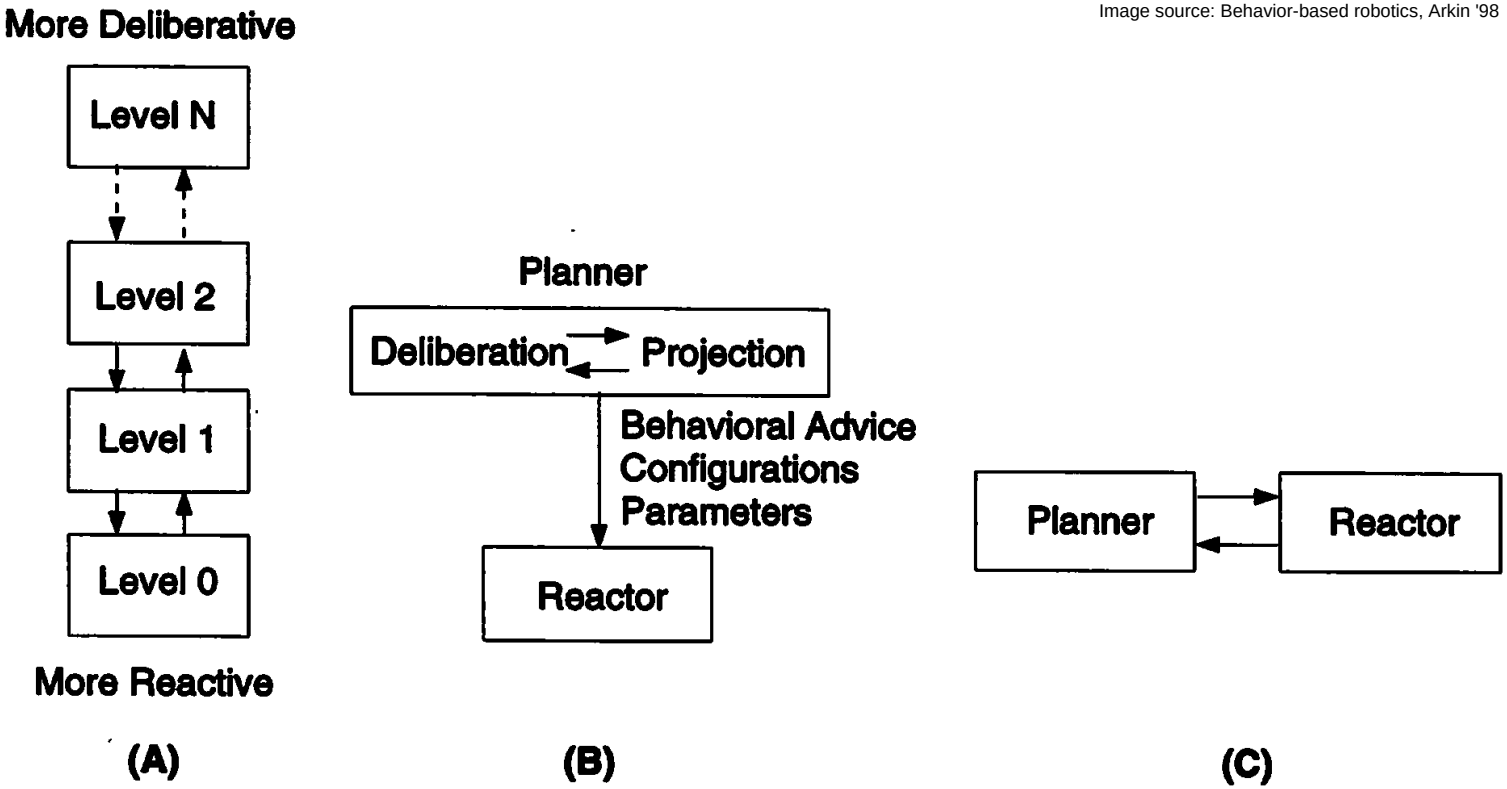
Hybrid architectures

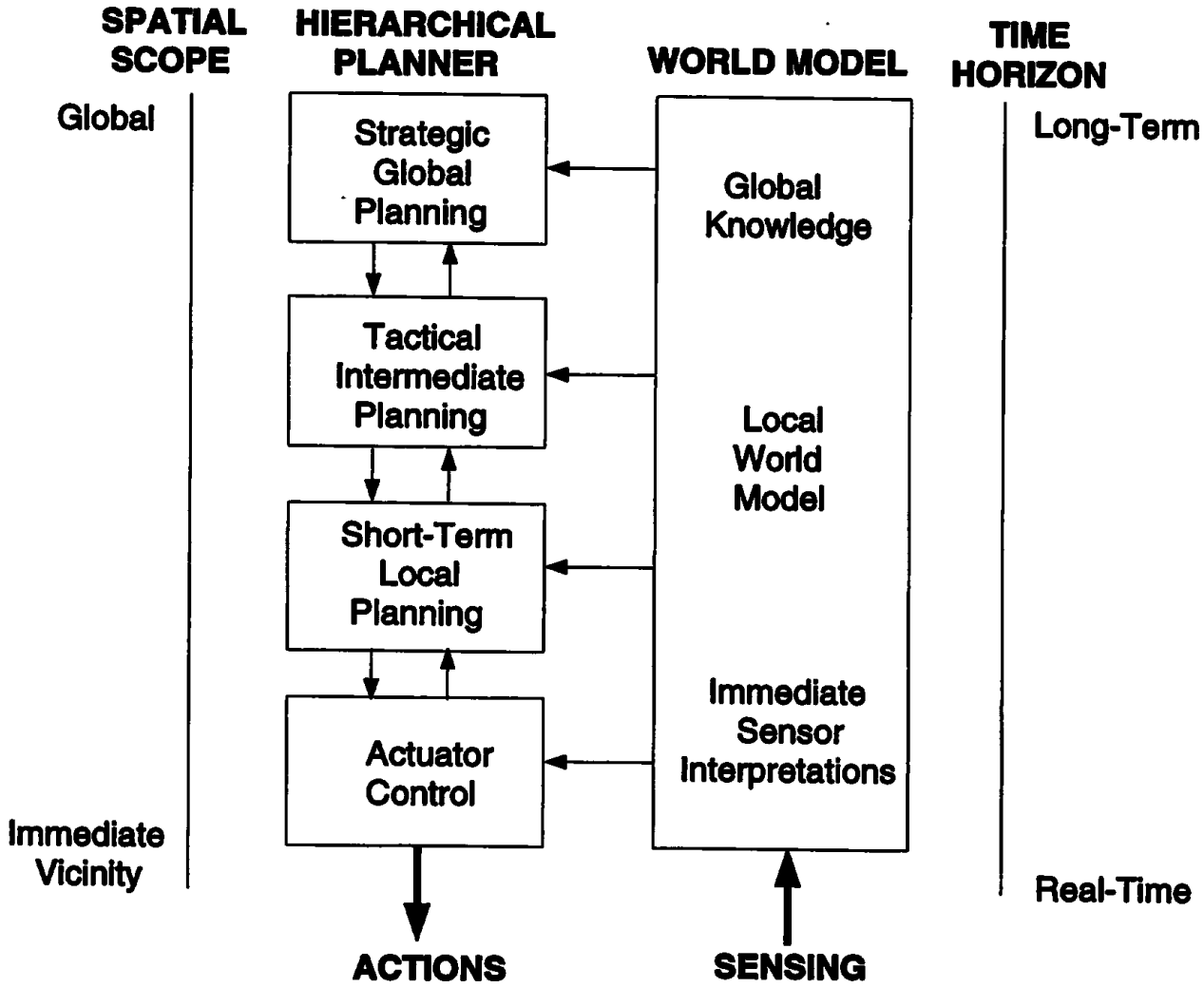
- Trying to combine deliberative and reactive controls

Hybrid architectures: possible three-layer systems

Image source: Behavior-based robotics, Arkin '98



Hybrid architectures: Zoomin (A)



Hybrid architectures: Zoomin (B)

Communication Strategies

- Selection
- Advising
- Adaption
- Postponing
- Configuration

Hybrid architectures: Characteristics

Hybrid architectures

- ...try to combine both deliberative and reactive architectures
- There are many quite different attempts to do so.

Advantages

- Both intelligence, learning and fast reaction are possible at the same time

Disadvantages

- It's hard to design a good middle layer.

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Even more architectures

Some design ideas...

- Force control
  - ...as opposed to position control
- Agent-based architectures
  - Defined protocols between agents
  - Agent $\equiv$ Coordination(Agent$_1$, Agent$_2$, ..., Agent$_i$)

Outline

Summary & Conclusion

Summary & Conclusion

- A control structure is essential.
- There exist 4 basic ones:
  - Deliberative
  - Reactive
  - Hybrid
  - Behavior-based
- ... as well as many specificities of them.
- The choice isn't always easy.

Further reading

Introduction to robotic and architectures

- Matarić, The robotics primer, MIT Press, 2007
- Siegwart et al., Introduction to autonomous mobile robots, The MIT Press, 2004
- Arkin, Behavior-based robotics, MIT Press, 1998

Subsumption architecture well explained

- Brooks, A Robot that Walks; Emergent Behaviors from a Carefully Evolved Network, A. I. Memo 1091, February 1989

More Literature

- Van Breemen, Agent-Based Multi-Controller Systems - A design framework for complex control problems, Twente University Press, 2001
- *Hybrid & multiagent systems: There is a big number of papers availible showing custom realizations of such systems, but there is almost no literature to cover the basic principles. However, Siegwart'04 and Arkin'98 cover hybrid systems.*

Thank you for your attention!