

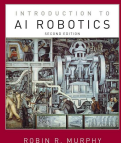
4b

System Architectures

Can you make the “architecture”
of AI for robots more tangible?

What are the subsystems in
a system architecture?

I know a technical architecture
depends on the implementation,
but what goes into a technical
architecture?



<http://brrism.blogspot.com/2010/07/brrism11-edemocracyopen-datasocial.html>

© 2019 Robin Murphy Introduction to AI Robotics 2nd Edition (MIT Press 2019)

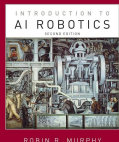


4b

Specific Learning Objectives

Objectives
Review
Systems
- 5 Subsystems
- Paradigms
- Hierarchical
- Reactive
- Hybrid
Technical Arch
- evaluating

- Be able to relate the functions in the canonical operational architecture to the 5 common subsystems
- Classify a systems architecture as being either hierarchical, reactive, or hybrid deliberative/reactive based on 1) the relationship of the 3 AI robot primitives and 2) sensing handling
- Be able to draw the Hybrid Deliberative/Reactive System Architecture

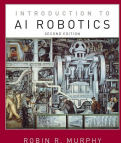


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Systems Architectures: Outline

- Review
- 3 ways of generally organizing systems
 - 5 common subsystems
 - Why those 5? A historical evolution of Hierarchical, Reactive, Hybrid Deliberative/Reactive
 - Contributions to canonical system architecture
- A little about technical architectures (technical)
- Summary

Objectives
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- evaluating

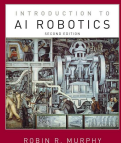


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Recall: Types of architectures *[Levis, George Mason University]*

Objectives
Review
Systems
- 5 Subsystems
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- Hybrid
Technical Arch
- evaluating

- **operational architecture:** describes what the systems does, not how it does it
- **systems architecture:** describes how a system works in terms of major subsystems
- **technical architecture:** implementation details, language



4b

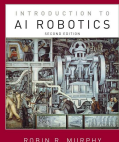
Types of architectures

Class will focus on these levels

- **operational architecture:** describes what the systems does, not how it does it
- **systems architecture:** describes how a system works in terms of major subsystems
- **technical architecture:** implementation details, language

And the algorithms used at this level

Objectives
Review
System Arch
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Technical Arch
- evaluating



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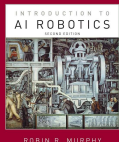
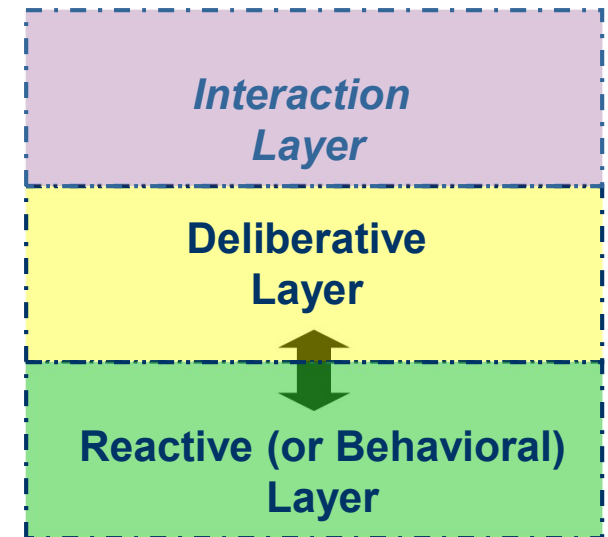
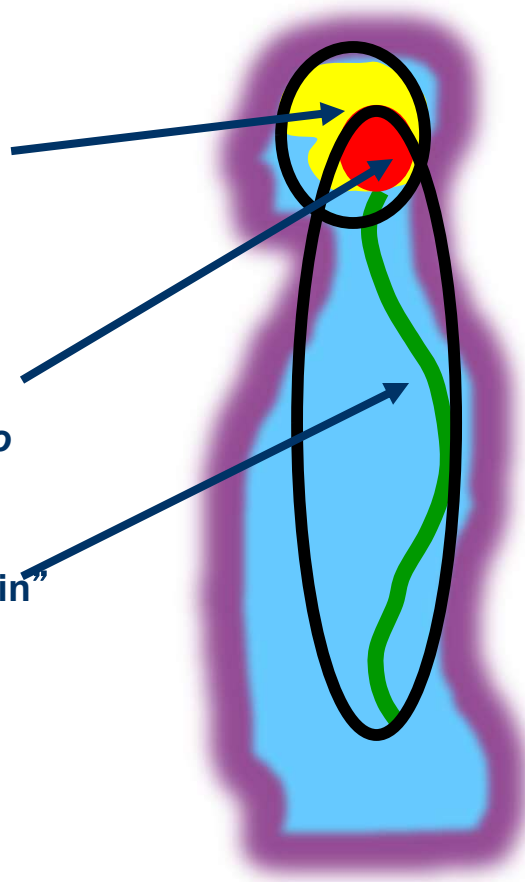
The Most Abstract Canonical Operational Architecture

Objectives
Review
System Arch
- 5 Subsystems
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Technical Arch
- evaluating

“Upper brain” or cortex
*Reasoning over symbols
(information) about goals*

“Middle brain”
*Converting sensor data into
symbols (information)*

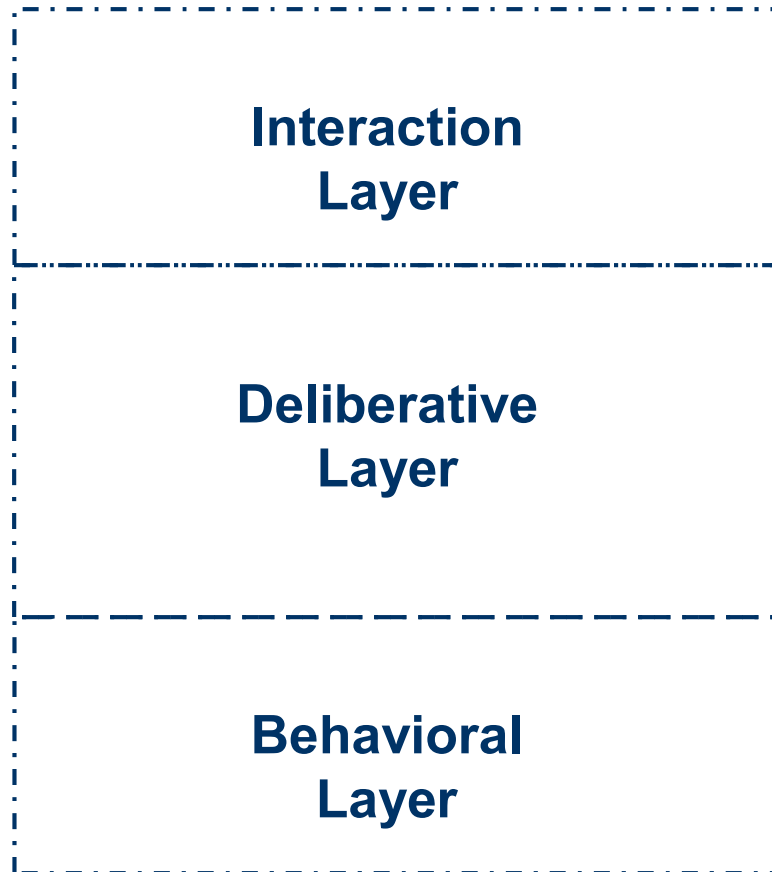
Spinal Cord and “lower brain”
Skills and responses



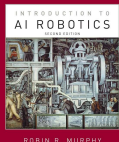
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The Most Abstract Canonical Operational Architecture

Objectives
Review
System Arch
- 5 Subsystems
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- Reactive
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- evaluating



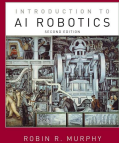
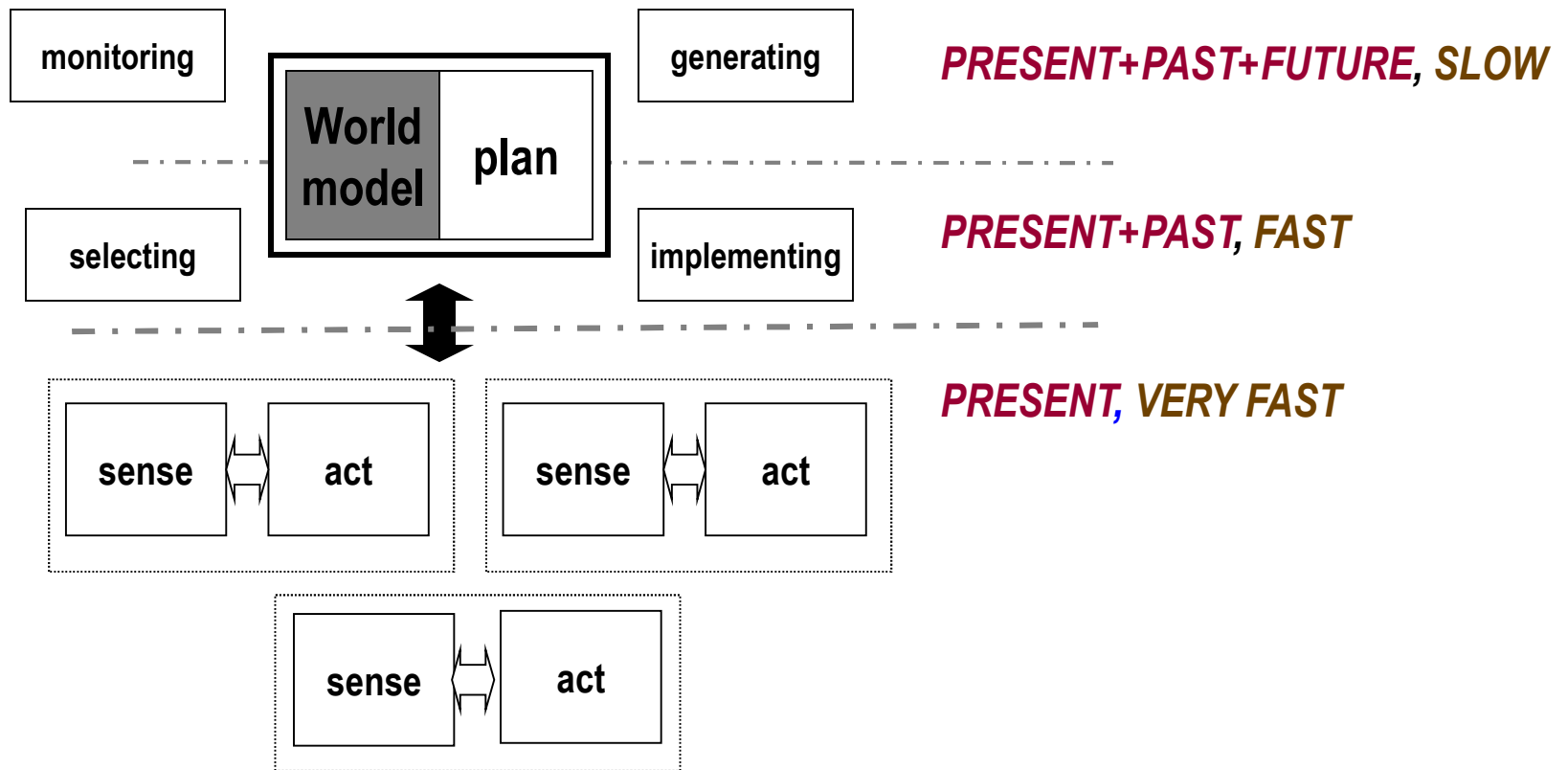
- Each layer has a different style of program organization
- Not concerned with details of interaction layer



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More Tangible Canonical Operational Architecture

Objectives
Review
System Arch
- 5 Subsystems
- Paradigms
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- Reactive
- Hybrid
Technical Arch
- evaluating

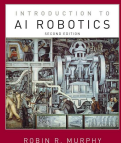


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Four deliberative functions:

- **Generating**
 - Generating plans which corresponds to planning, reasoning, and problem solving in AI
- **Selecting**
 - Selecting specific resources to accomplish the plan, which corresponds to planning, resource allocation, and knowledge representation of capabilities in AI
- **Implementing**
 - Implementing the plan, which corresponds to execution
- **Monitoring**
 - Monitoring the execution of the plan to determine if it is meeting the goal, learning what is normal, and anticipating potential failures, which corresponds to planning and reasoning in AI

Objectives
Review
System Arch
- 5 Subsystems
- Paradigms
- Hierarchical
- Reactive
- Hybrid
Technical Arch
- evaluating



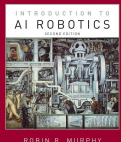
4b

Types of architectures *[Levis, George Mason University]*

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- 5 S
- Pa
-Hiera
-Reactive
-Hybrid
Technical Arch
- evaluating



- **operational architecture:** describes what the systems does, not how it does it
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- **technical architecture:** implementation details, language

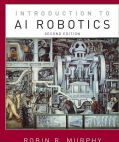


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System Architectures Provide...

- “right” subsystems
 - Focus on good software engineering
 - Modular (**object-oriented**)
 - Abstraction and cohesion
- Libraries of algorithms and data structures within a subsystem
 - Can pick from library to fit a specific niche
- Platform neutral

Objectives
Review
System Arch
- 5 Subsystems
- Paradigms
- Hierarchical
- Reactive
- Hybrid
Technical Arch
- evaluating

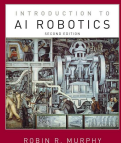


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Generally Accepted Subsystems (or Objects)

Objectives
Review
System Arch
- 5 Subsystems
- Paradigms
- Hierarchical
- Reactive
- Hybrid
Technical Arch
- evaluating

- **Planning** (Generating mission, Implementing, Selecting, Monitoring)
- **Navigation** (Generating)
 - Planning about navigational goals, path planning
- **Cartographer, World Model, World Map** (World Model)
 - Everything to do with world models and planning over maps
- **Motor Schemas, Behaviors** (executing motor commands)
- **Perception, Sensing, Perceptual Schemas** (executing sensor input)



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Generally Accepted Subsystems (or Objects)

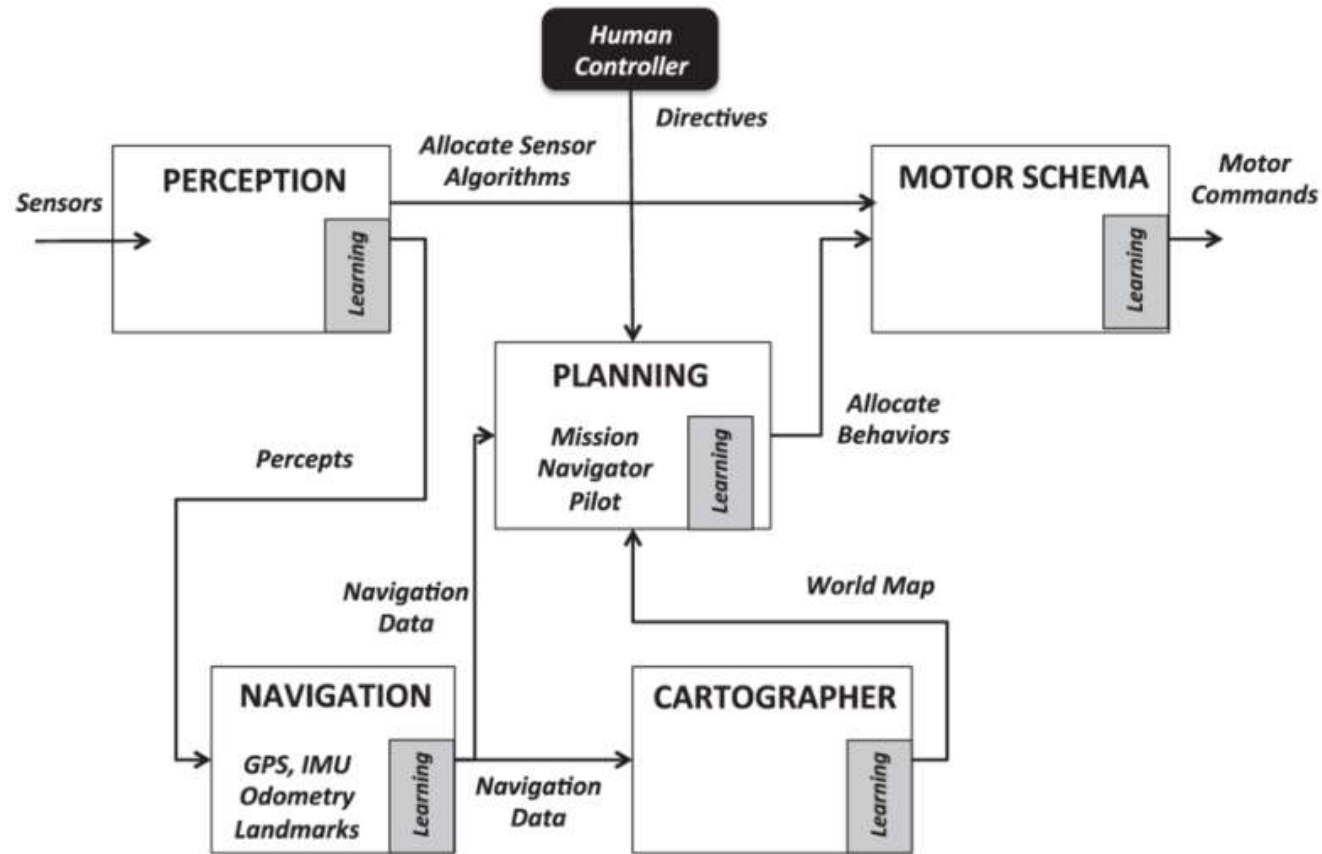
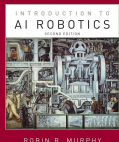


Figure 4.6 The five common subsystems in intelligent robotics, adapted from Technology Development for Army Unmanned Ground Vehicles.¹⁵⁸

Objectives
Review
System Arch
- 5 Subsystems
- Paradigms
- Hierarchical
- Reactive
- Hybrid
Technical Arch
- evaluating

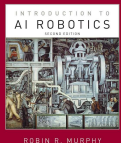


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Describing Systems Architectures in AI Robotics

Objectives
Review
System Arch
- 5 Subsystems
- **Paradigms**
- Hierarchical
- Reactive
- Hybrid
Technical Arch
- evaluating

- Subsystems can be thought of in terms of **2 attributes**
 1. (relationship) How **3 building blocks, or *robot primitives***, are arranged
 2. (content) How sensing is handled
- This leads to **3 *paradigms*** of system architectures for AI robotics
 - Hierarchical
 - Reactive
 - Hybrid Deliberative/Reactive



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Recall: AI Primitives within an Agent

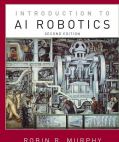
SENSE

PLAN

ACT

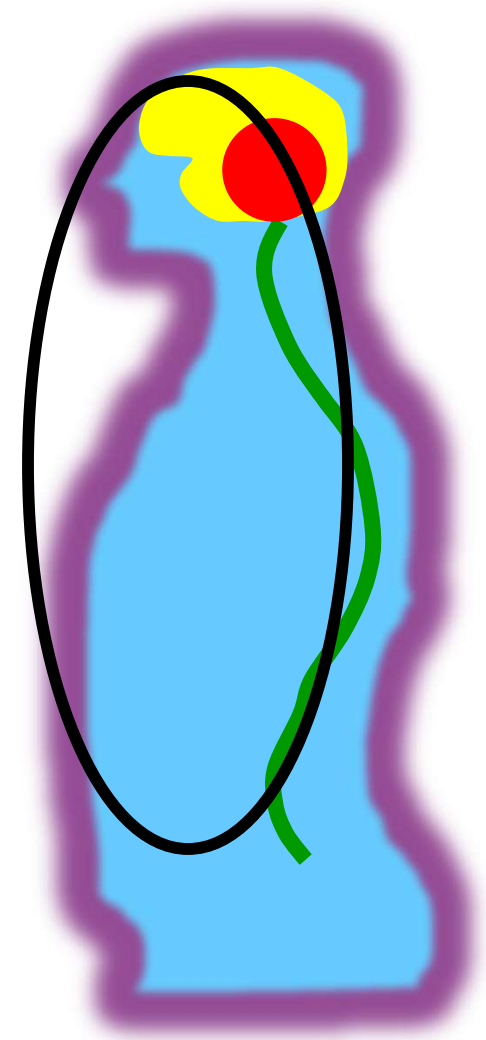
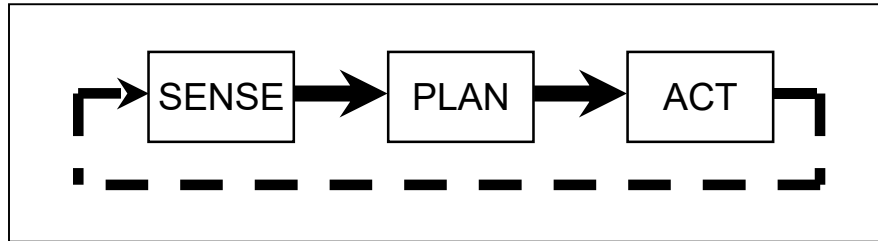
LEARN

Objectives
Review
System Arch
- 5 Subsystems
- **Paradigms**
- Hierarchical
- Reactive
- Hybrid
Technical Arch
- evaluating

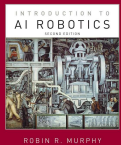


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Hierarchical (1967)



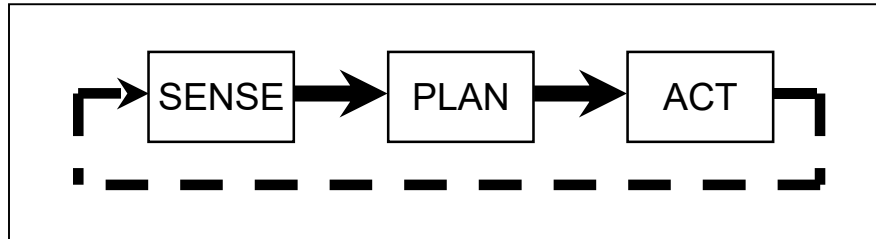
Objectives
Review
System Arch
- 5 Subsystems
- Paradigms
- Hierarchical
- Reactive
- Hybrid
Technical Arch
- evaluating



4b

Hierarchical (1967)

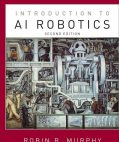
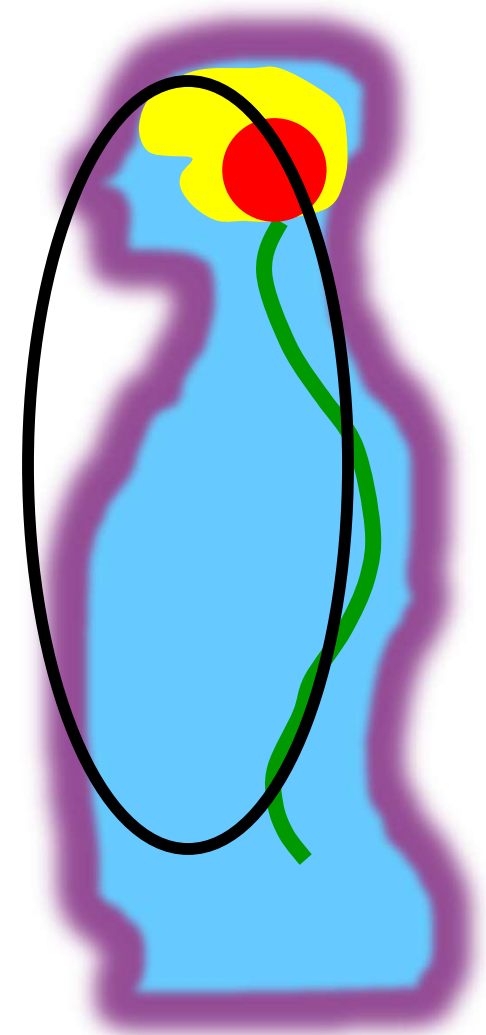
Objectives
Review
System Arch
- 5 Subsystems
- Paradigms
- Hierarchical
- Reactive
- Hybrid
Technical Arch
- evaluating



Control people hated
because didn't "close the
loop"

AI people hated because
monolithic

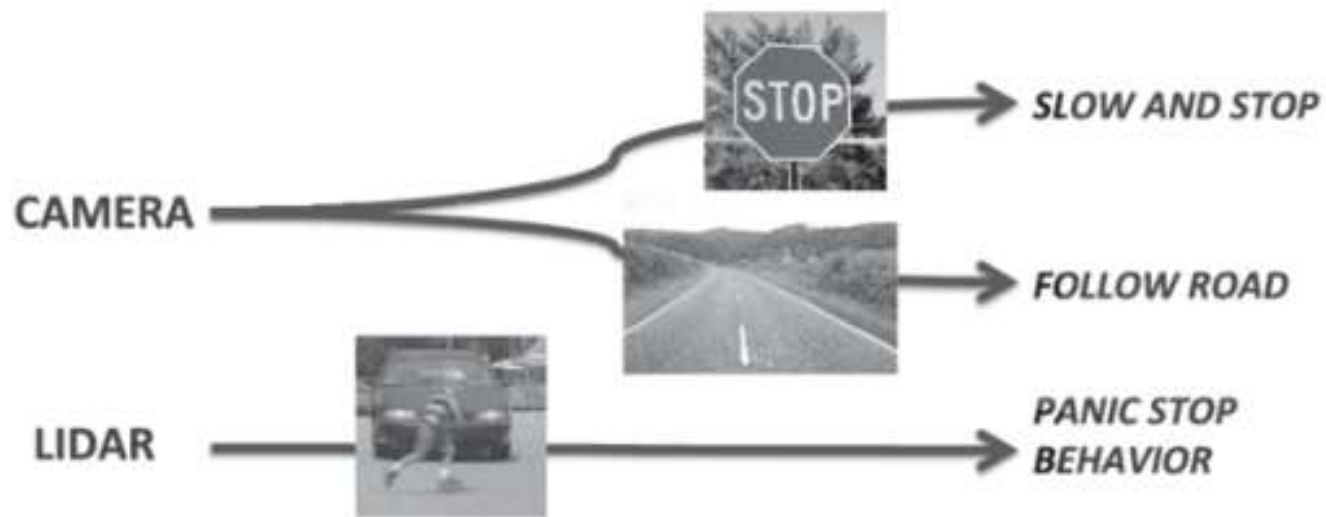
Users hated because very
slow



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Sensing Route (1)

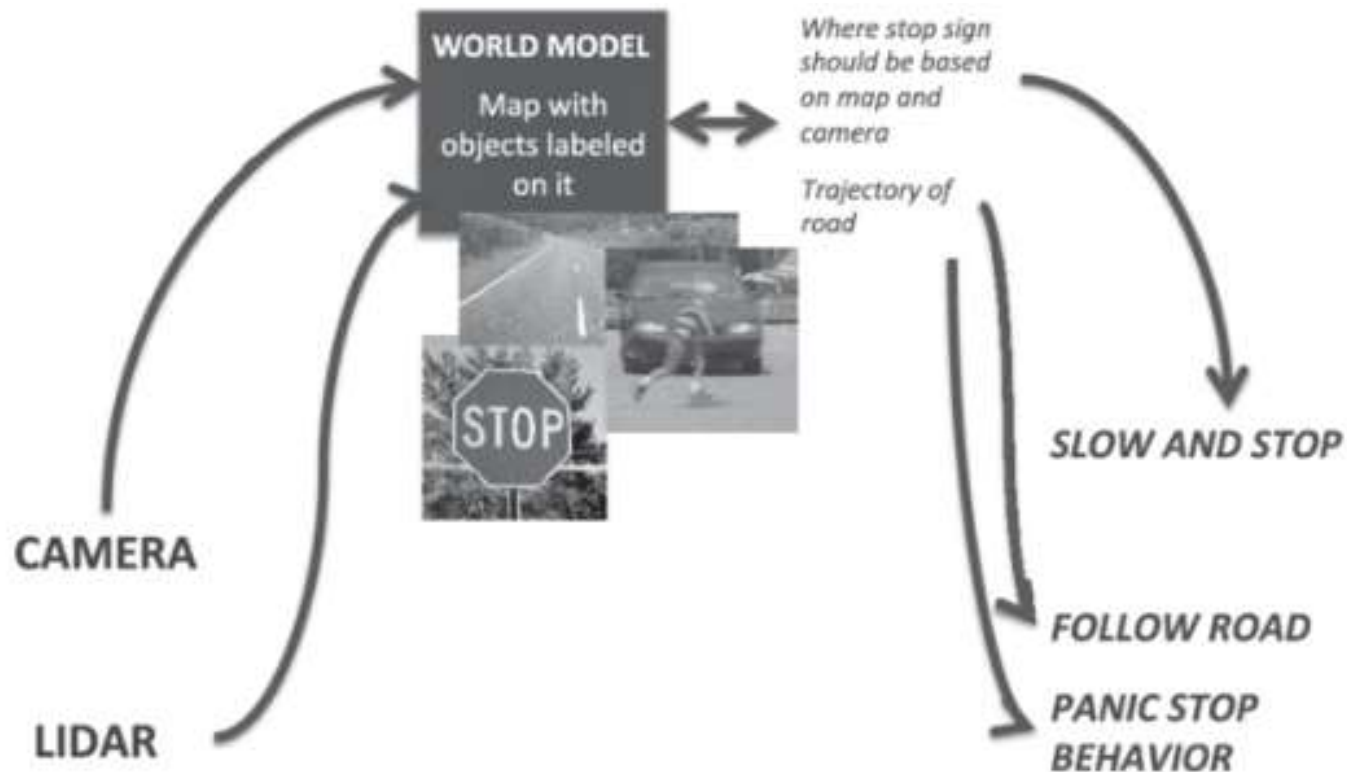
- **Local:** The sensor data go directly to the behavior or function using the sensor data



4b

Sensing Route (2)

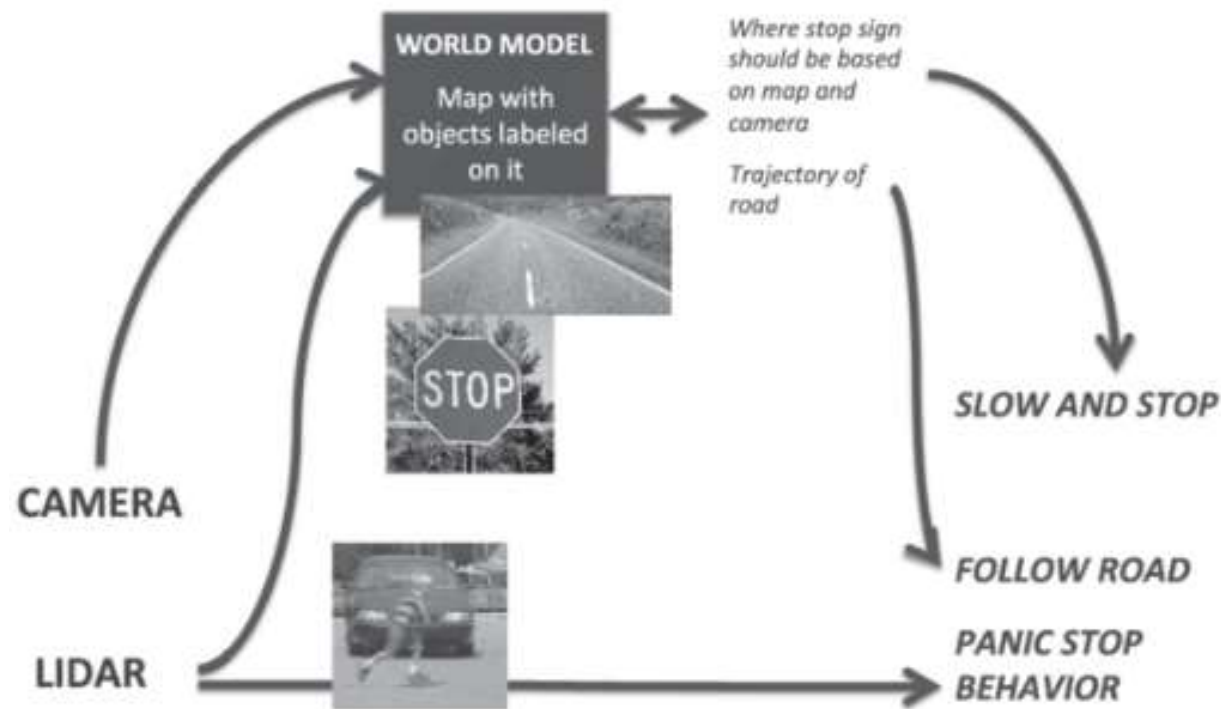
- **Global:** All the sensor data are transmitted to a function that transforms and fuses the data into a global World Model or unified data structure



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Sensing Route (3)

- **Hybrid:** A combination, where the same data from a sensor may go to one or more functions that perform local transformations and to a global sensing function

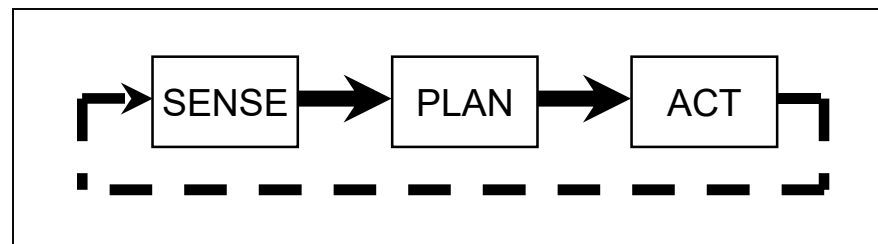


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Hierarchical Paradigm for Systems Architectures

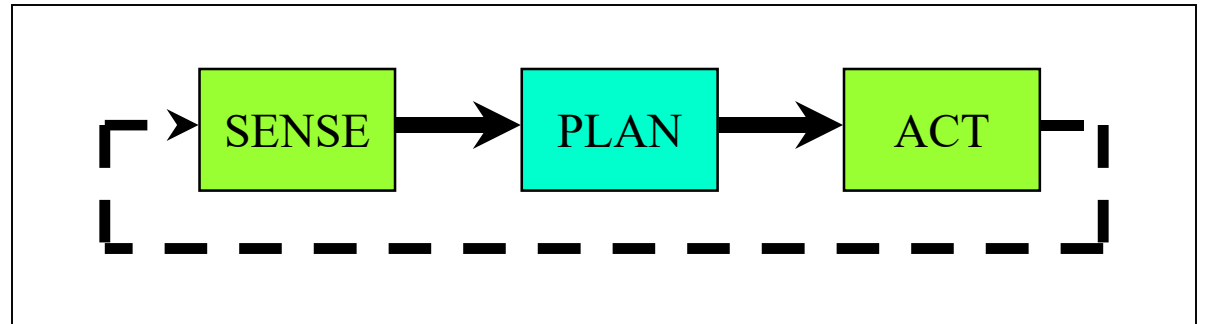
Objectives
Review
System Arch
- 5 Subsystems
- Paradigms
- Hierarchical
- Reactive
- Hybrid
Technical Arch
- evaluating

- Hierarchies are a natural way to organize functionality
- If the priorities and goals are clear, they can be computationally efficient because they can reduce computation by specifying the frame and defining a closed world
- Hierarchical systems are used for implementations where the mission or application is well-understood and further additions of capabilities or major upgrades are not expected



4b

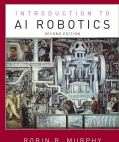
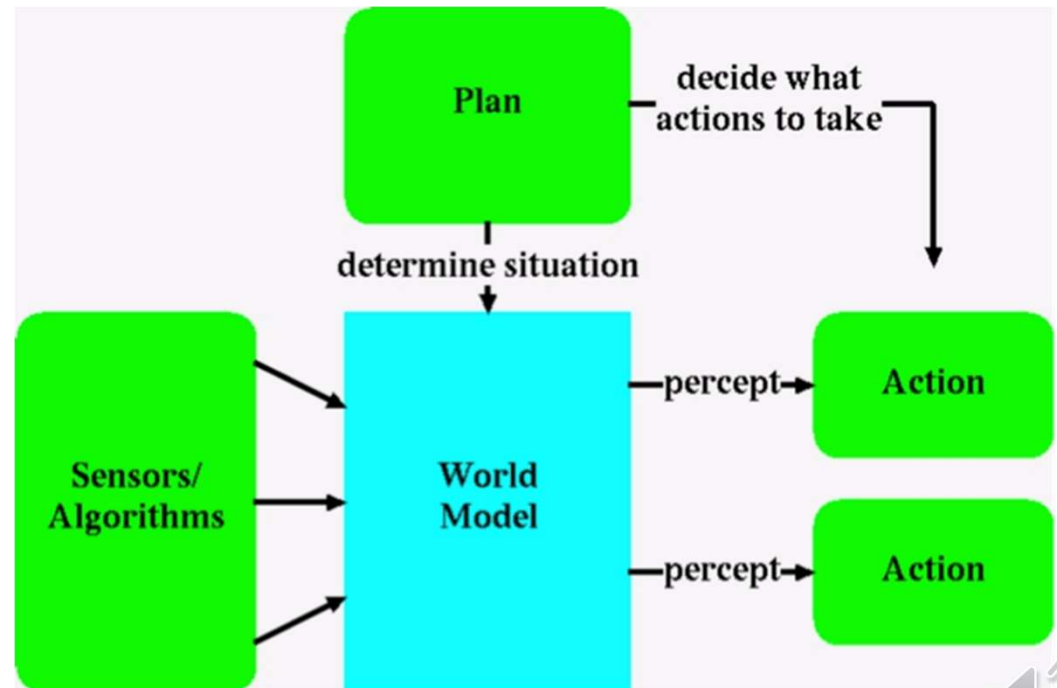
Hierarchical Paradigm: Sensing is Centralized (global)



World model is a fused global data structure.

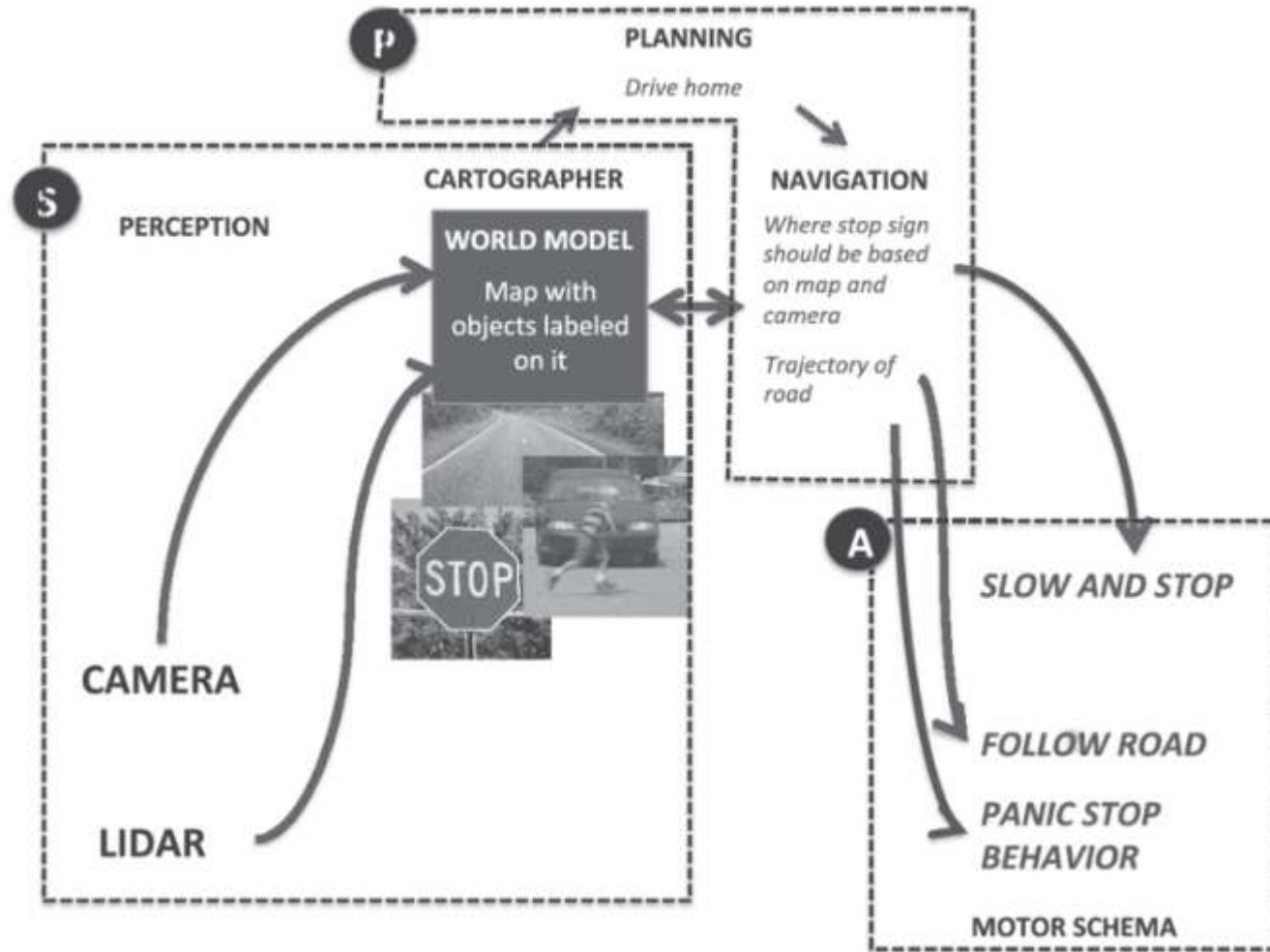
It combines:

1. A priori representation
2. Sensed info
3. Cognitive understanding



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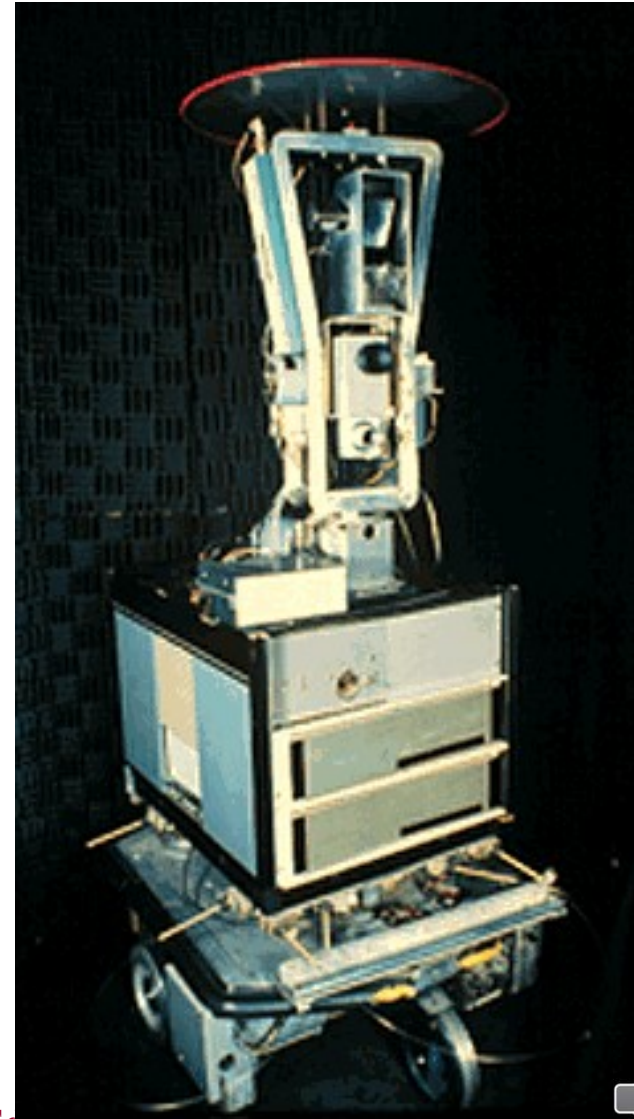
Example of a Hierarchical Systems Architecture for a driverless car



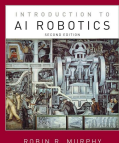
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Shakey

- First AI robot
- Built by SRI (Stanford Research Institute) for DARPA 1967-9
- Used **Strips** as main algorithm for controlling what to do



Objectives
Review
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- evaluating

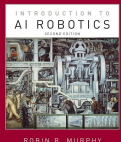


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Hierarchical Paradigm: Notable Systems Architectures

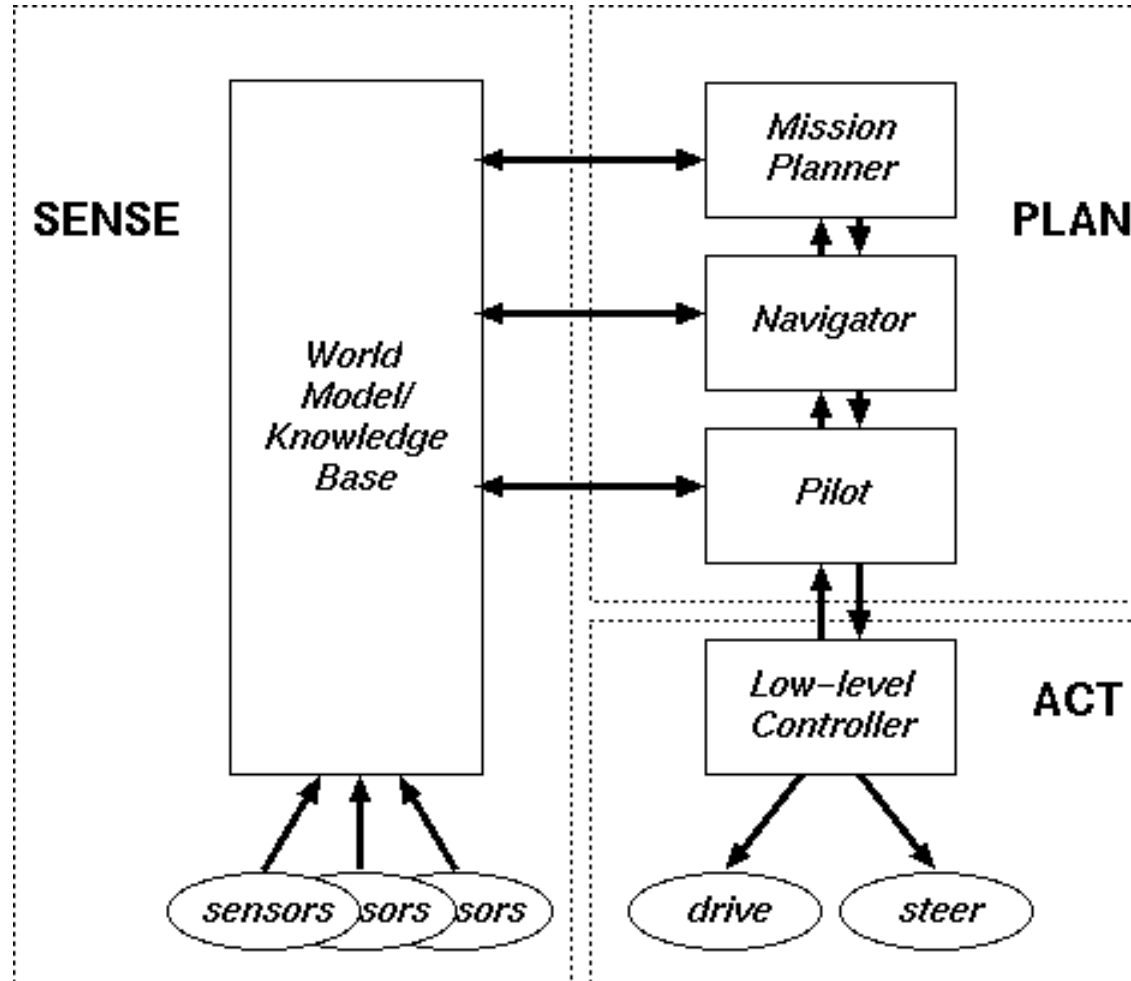
- STRIPS/GPS (*Nilsson*)
 - Not used anymore, but did spawn planning industry
 - Shakey
- **Nested Hierarchical Controller** or NHC (*Mystel*)
 - Mostly theoretical, oriented towards navigation
 - Divided into subsystems: *mission planner, navigator, pilot, world model, low-level controllers*

Objectives
Review
System Arch
- 5 Subsystems
- Paradigms
- Hierarchical
- Reactive
- Hybrid
Technical Arch
- evaluating

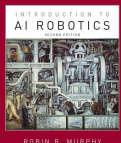


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Nested Hierarchical Controller (Meystel)



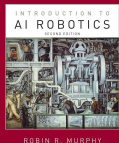
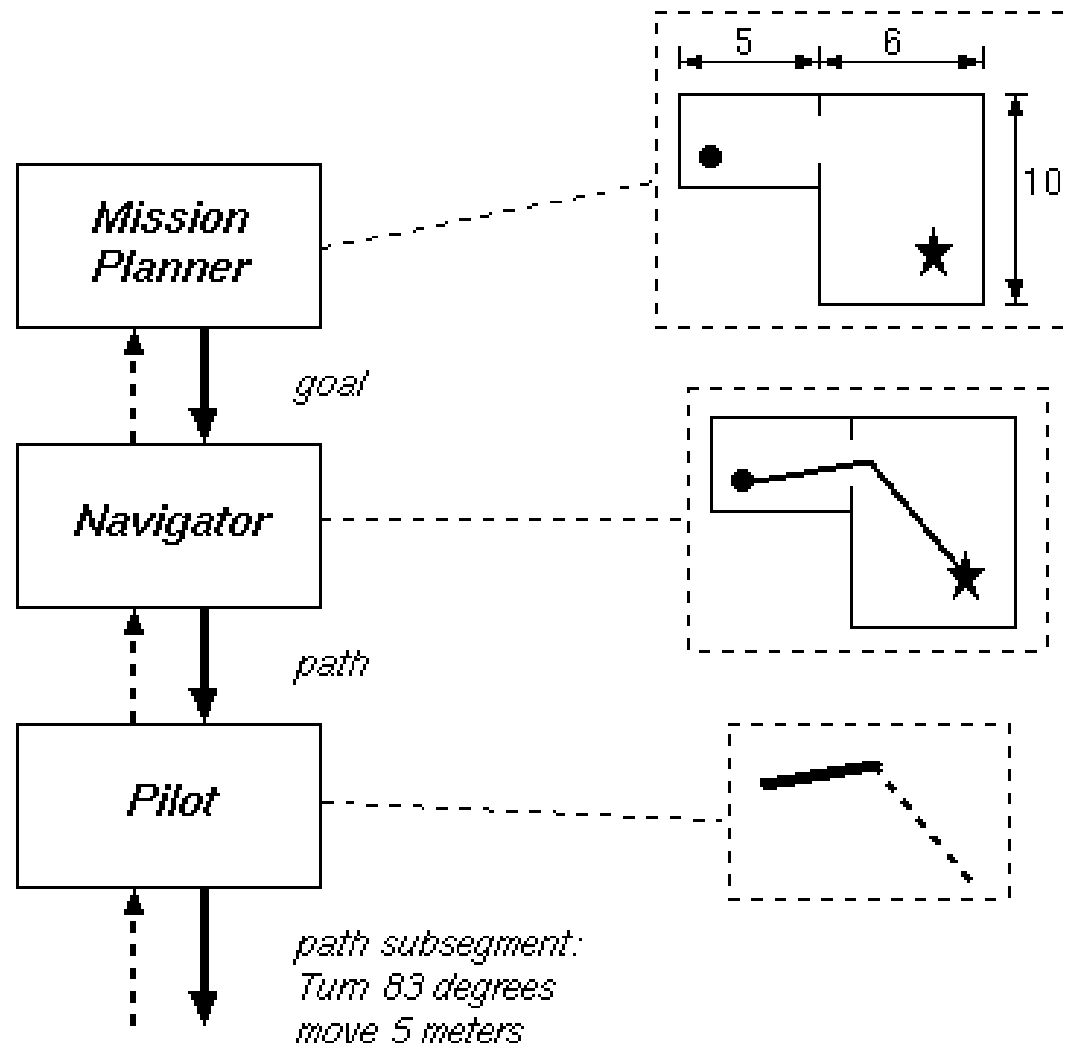
Objectives
Review
System Arch
- 5 Subsystems
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- Reactive
- Hybrid
Technical Arch
- evaluating



4b

NHC Planner

- Objectives
- Review
- System Arch
- 5 Subsystems
- Paradigms
- Hierarchical
- Reactive
- Hybrid
- Technical Arch
- evaluating

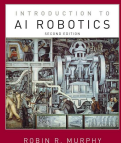


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Disadvantages of Hierarchical Systems Architectures

- While hierarchies have advantages, relying on a *world model* creates problems
 - Bottleneck on processing, particularly for control
 - Alternative is to create layers or hierarchies within the world model to match other subsystems (Kaebling, Simmons)
 - World model requires extensive representation which leads to two major problems:
 - Operates under the *closed world assumption*
 - *Frame problem*
 - Correctly identifying what is unchanging in the world, and thus does not require constant updating, thereby reducing computation.
- In practice, implementations are planning-centric

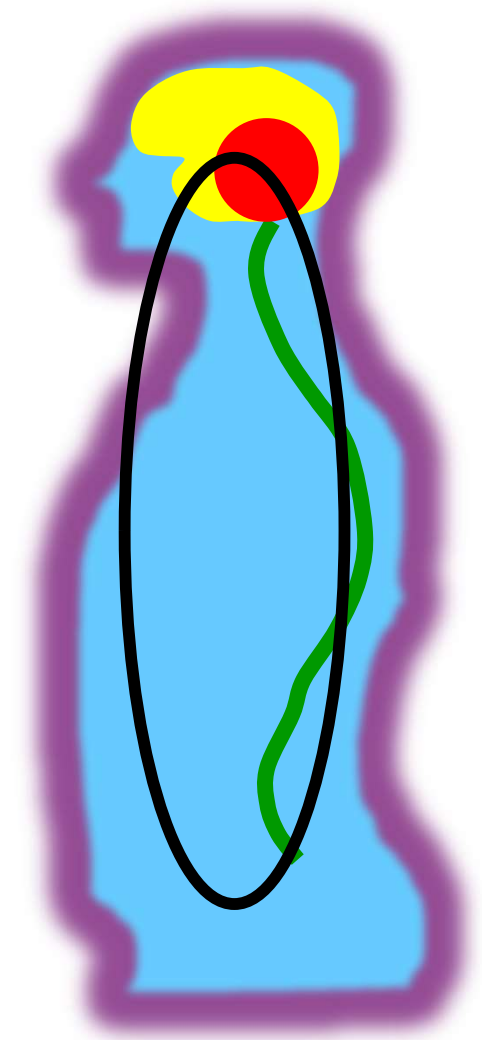
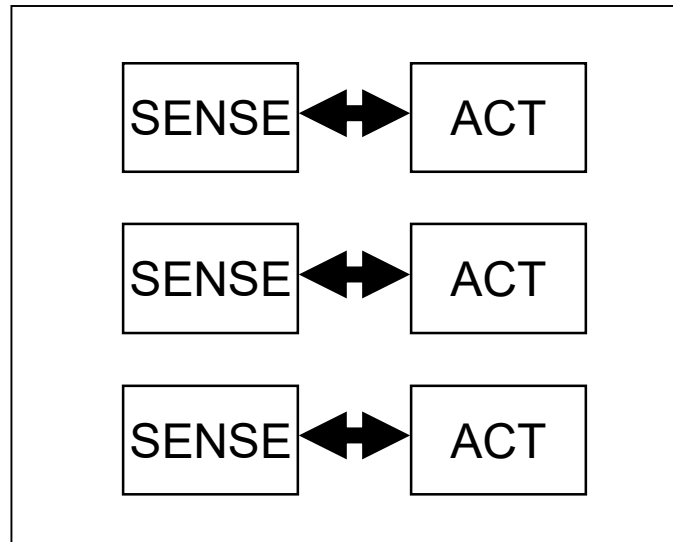
Objectives
Review
System Arch
- 5 Subsystems
- Paradigms
- Hierarchical
- Reactive
- Hybrid
Technical Arch
- evaluating
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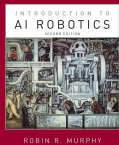
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Reactive (1986)

~~PLAN~~



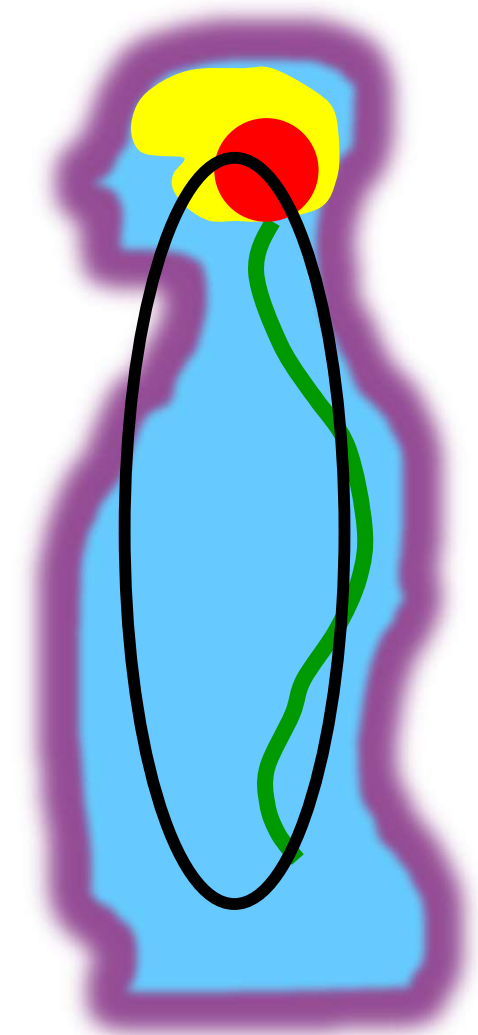
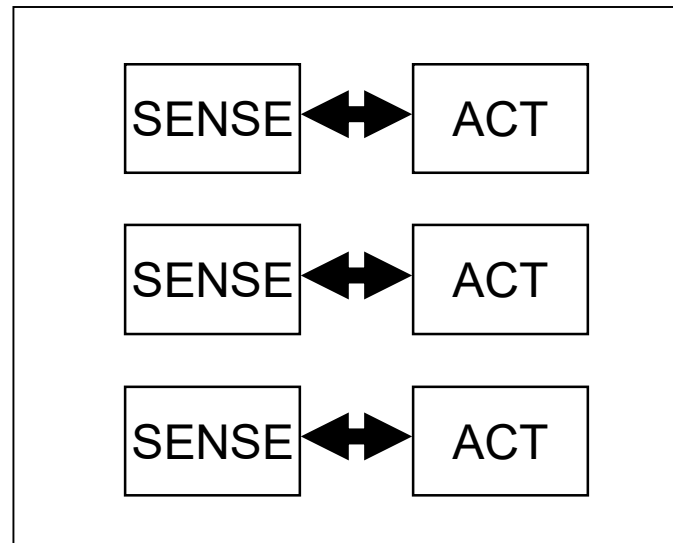
- Objectives
- Review
- System Arch
- 5 Subsystems
- Paradigms
- Hierarchical
- **Reactive**
- Hybrid
- Technical Arch
- evaluating



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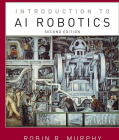
Reactive (1986)

~~PLAN~~



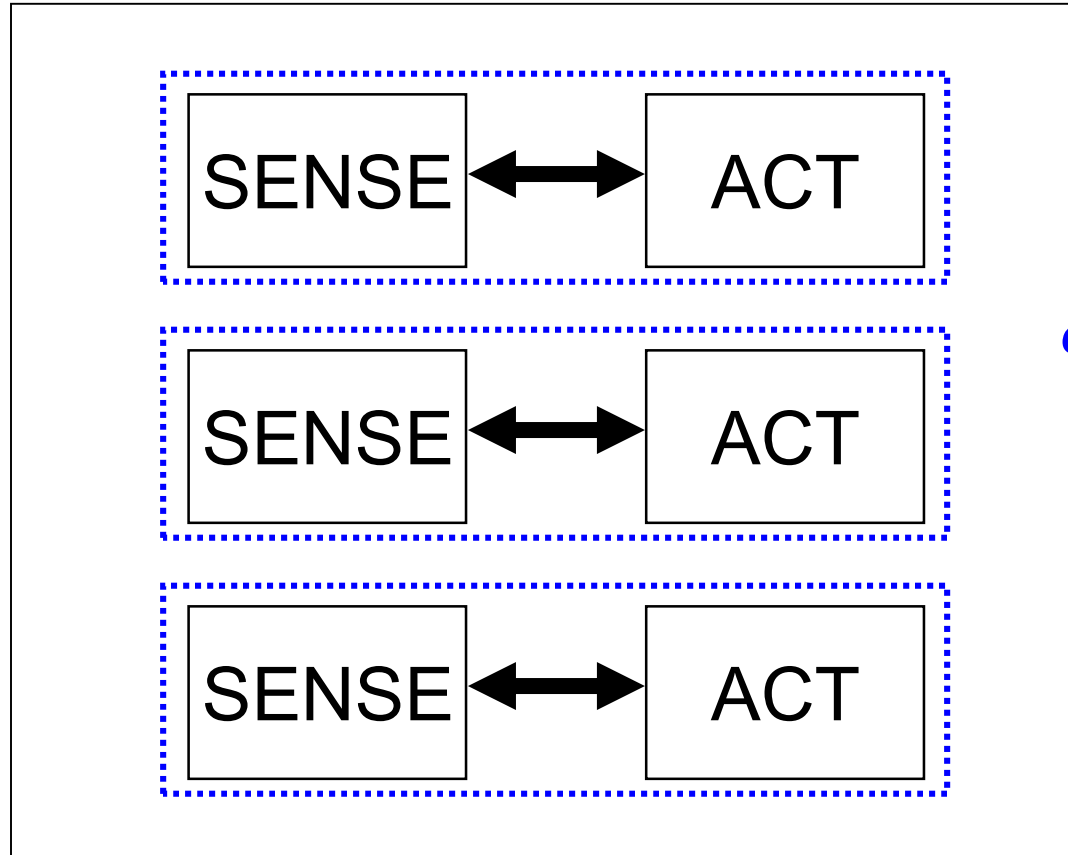
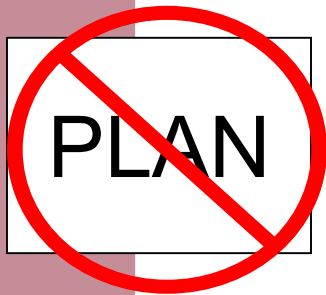
Users loved it because it worked
AI people loved it, but wanted to put
PLAN back in
Control people hated it because
couldn't rigorously prove it worked

Objectives
Review
System Arch
- 5 Subsystems
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- Reactive
- Hybrid
Technical Arch
- evaluating



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Reactive Paradigm: Two primitives grouped into concurrent behaviors

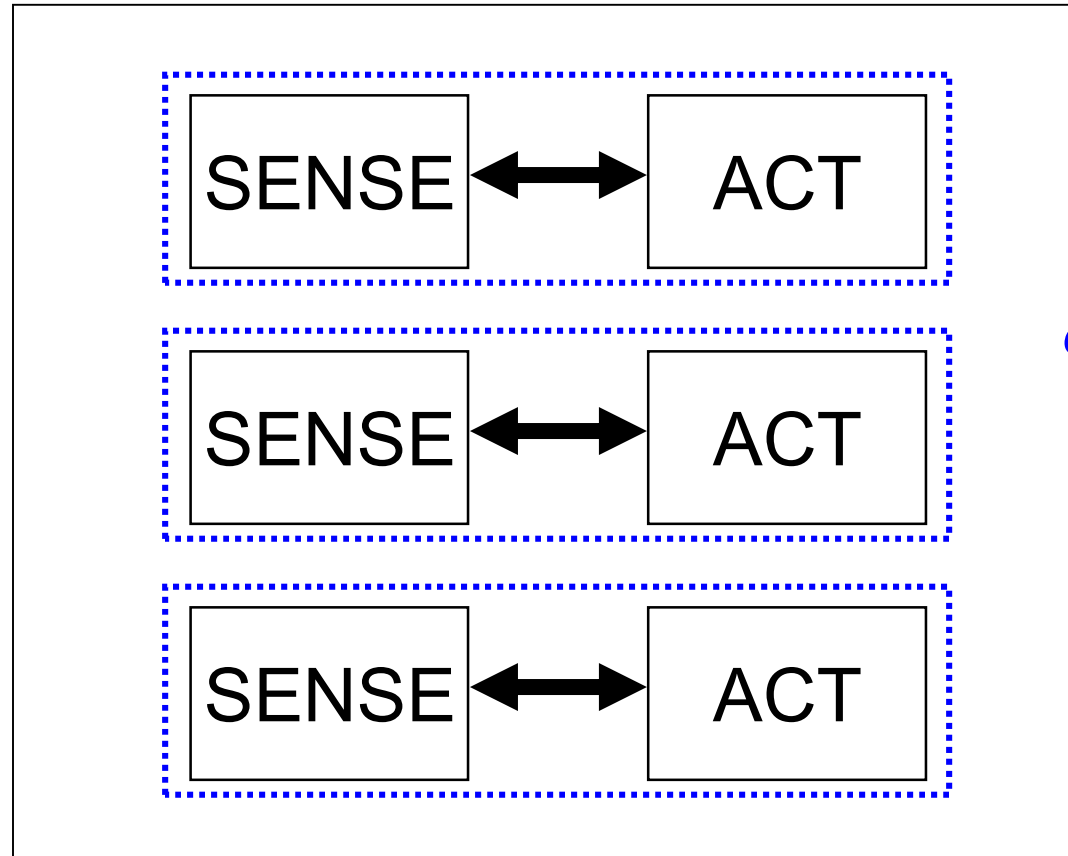


SENSE-ACT couplings are "behaviors"

Behaviors are independent, run in parallel, output is emergent

4b

Reactive Paradigm: Sensing is behavior specific (local)

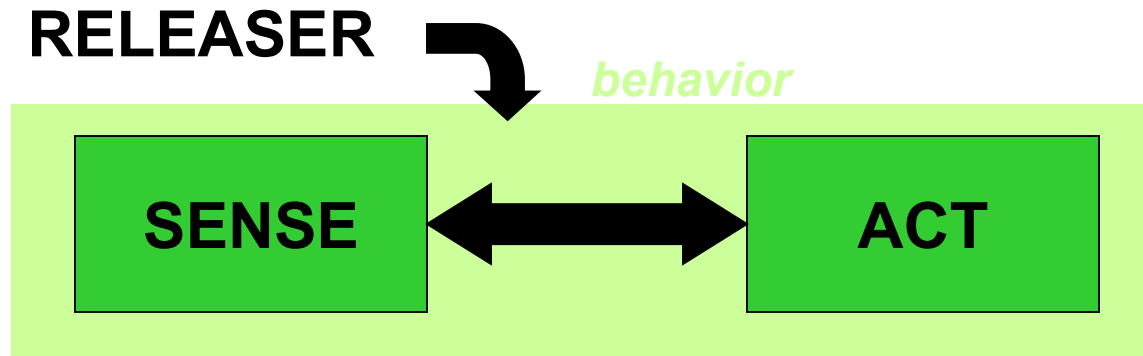


*SENSE-ACT
couplings are
“behaviors”*

*Behaviors are independent,
run in parallel, output is emergent*

4b

Reactive Robots



Objectives
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System Arch
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- evaluating

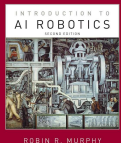
- Behaviors (independent processes), released by perceptual or internal events (state)
- No world models or long term memory
- Highly modular, generic
- Overall behavior *emerges*

4b

Reactive Paradigm: Notable Systems Architectures

- **Subsumption** (*Brooks*)
 - No subsystems, just layers of competence
- **AuRA** (Arkin)
 - **Potential field implementation**
- *Will cover in great detail later*

Objectives
Review
System Arch
- 5 Subsystems
- **Paradigms**
- Hierarchical
- **Reactive**
- Hybrid
Technical Arch
- evaluating



4b

What can you do without planning?

Objectives
Review
System Arch
- 5 Subsystems
- **Paradigms**
- Hierarchical
- **Reactive**
- Hybrid
Technical Arch
- evaluating

- Behaviors?
- Random
- Avoid
 - Avoid(bump=obstacle)
 - Avoid(wire=boundary)
- Stop
 - Stop(tilt=ON)
- All active

Robomow



4b

Hybrid Deliberative/Reactive (1990)

- Objectives
- Review
- System Arch**
- 5 Subsystems
- **Paradigms**
- Hierarchical
- Reactive
- **Hybrid**
- Technical Arch
- evaluating

