Presentazione Corso

- Corso da 6 crediti (48 ore)
- Orario di Ricevimento: Mercoledì, 15:30-17:30
- e-mail: alberto.finzi@unina.it
- Pagina-web: http://wpage.unina.it/alberto.finzi/didattica/SGRB/
- Orario:
  - Martedì 14:00 16:00 (H4)
  - Giovedì 11:00 13:00 (C11)

Obiettivi del Corso

- Completa il corso di Sistemi per il Governo di Robot (Modulo A):
  - Robotica Probabilistica:
    - metodi statistici in robotica
  - Robotica Mobile:
    - navigazione, localizzazione, mapping, esplorazione, pianificazione di percorso, etc.
  - Architetture Ibride:
    - Sistemi per il monitoraggio, l'esecuzione, la pianificazione delle attività
  - Architetture Cognitive:
    - Architetture Cognitive, Modellazione Cognitiva, Robotica Cognitiva
  - Interazione Uomo-Robot:
    - Architetture e modalità di interazione, interazione multimodale, iniziativa mista, fattori umani, etc.

Materiale Didattico

- Slides, papers, on-line references
- Murphy R.R. - Introduction to AI robotics - MIT Press
- Probabilistic Robotics, Sebastian Thrun, Wolfram Burgard and Dieter Fox, MIT Press

Esame

- Modalità di accertamento del profitto:
  - Presentazione e discussione papers
  - Progetto
  - Presentazione e discussione progetto

- **Autonomous:**
  - Greek: Automaton (auto + matos)
    - auto: self
    - matos: thinking, animated, willing

- **Robots:**
  - Czech: Robota (work) and robotnik (worker)
  - Karel Čapek in his play R.U.R. (Rossum's Universal Robots), published in 1920
  - “Robotics” by Isaac Asimov in science fiction short-story "Liar!“ (three Laws of Robotics), 1941

self-willed … but task-oriented

1948 Norbert Wiener formulated the principles of cybernetics

Wiener, Cybernetics

- Studied regulatory systems and their application to control (antiaircraft gun)

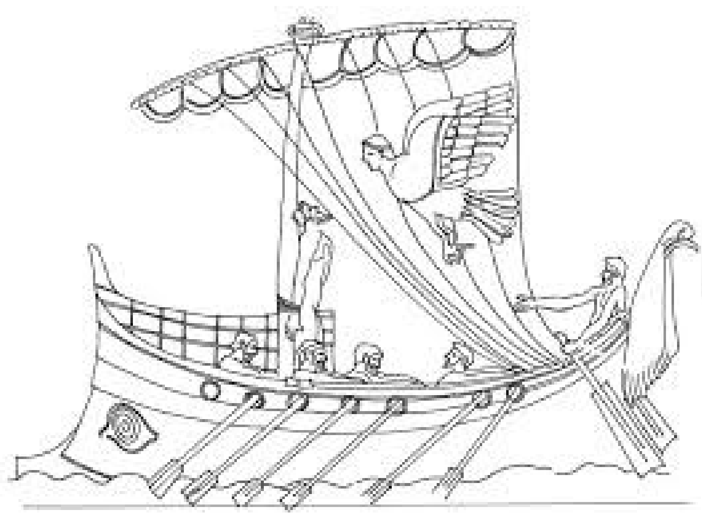
- "it has long been clear to me that the modern ultra-rapid computing machine was in principle an ideal central nervous system to an apparatus for automatic control; and its input and output need not be in the form of numbers or diagrams, but might very well be, respectively, the readings of artificial sensors such as photoelectric cells or thermometers, and the performance of motors or solenoids".

[Electronics, 1949]

1961, first digitally programmable robot (Unimate)

Cybernetics

- “the scientific study of control and communication in the animal and the machine”
- From greek κυβερνητική (kybernetike) "governance", κυβερνάω (kybernao), "to steer, navigate or govern", κυβέρνησις (kybernesis), "government", κυβερνήτης (kybernetes), governor or the captain

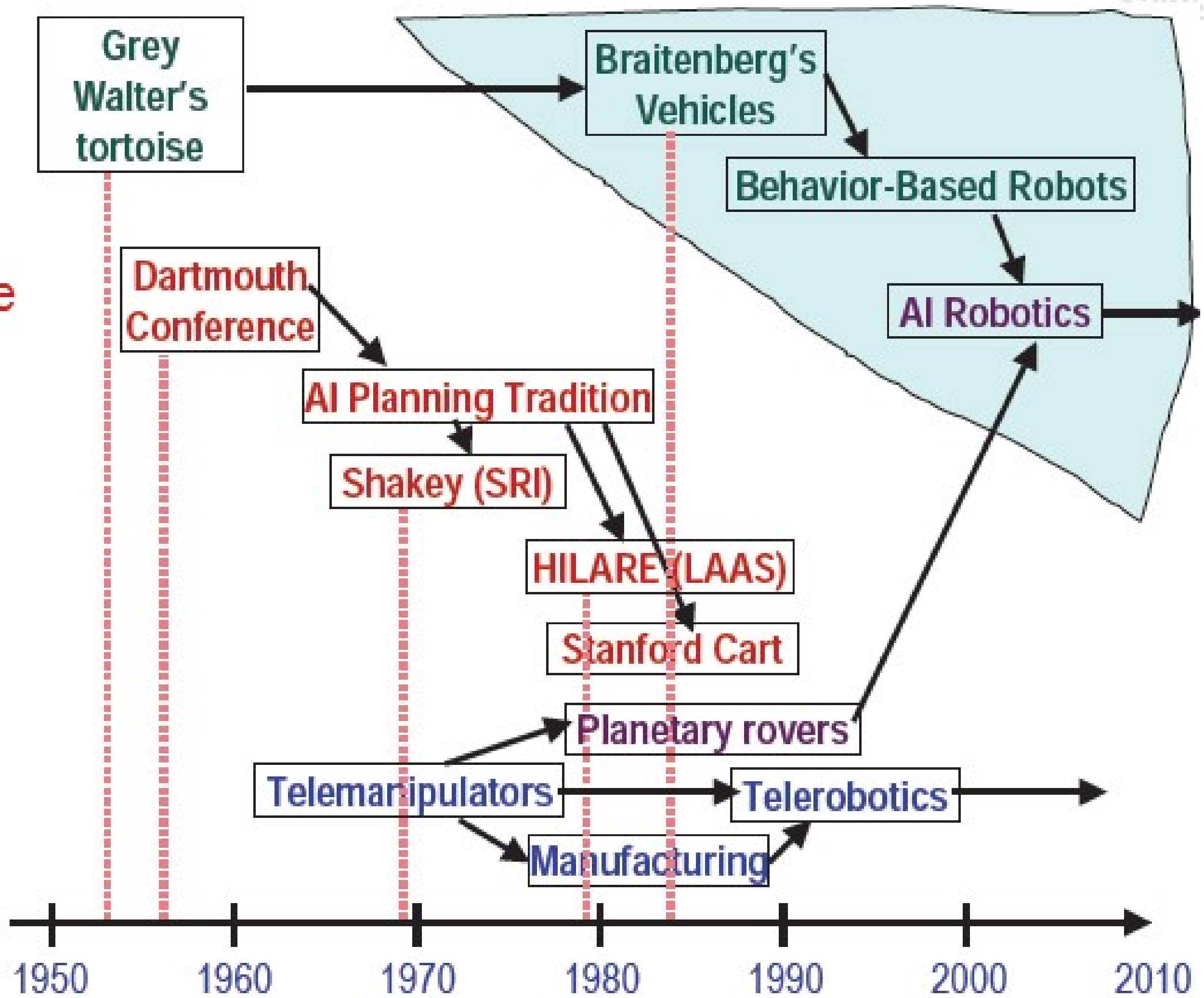


- High-Level Control (Governance)
- Low-Level Control (Control)

- Several levels:
  - Deliberative
  - Executive
  - Behavior-based
  - Sensorimotor
  - Feedback

Autonomous Robots

- Cybernetics
- Artificial Intelligence
- Robotics



- Cognitive Architectures
  - Unified Theory of Cognition [Newell 1990]

- Cognitive Robotics
  - Embodied AI
    - Robots able to perceive, reason, learn, deliberate, plan, act, interact, etc.
  - Autonomous Robots and Cognitive Architectures
    - Robotics, cognitive framework, cognitive models, computational models

Autonomous Robots

Autonomous robots: robots that can perform desired tasks in unstructured environments without continuous human guidance

- Industrial robots (fixed-base) are fast, accurate, ripetitive … but limited in work space;

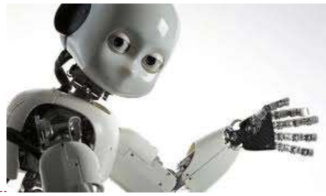
- To operate in the real world, robots must be able to cope with:
  - large,
  - unstructured,
  - dynamic,
  - uncertain,
  - partially observable environments
  - populated
  - …

- Autonomous Systems:
  - Field Robotics:
    - Agricultural, exploration, search and rescue, etc.
  - Service Robotics:
    - Domestic, logistic, health, etc.
  - Social Robotics:
    - Assistive, entertainment, etc.









Autonomous Robots

1. **Teleoperation**. A human operator controls each movement, each machine actuator change is specified by the operator

2. **Supervisory**. A human specifies general moves or position changes and the machine decides specific movements of its actuators

3. **Task-level autonomy**. The operator specifies only the task and the robot manages itself to complete it

4. **Full autonomy**. The machine will create and complete all its tasks without human interaction.

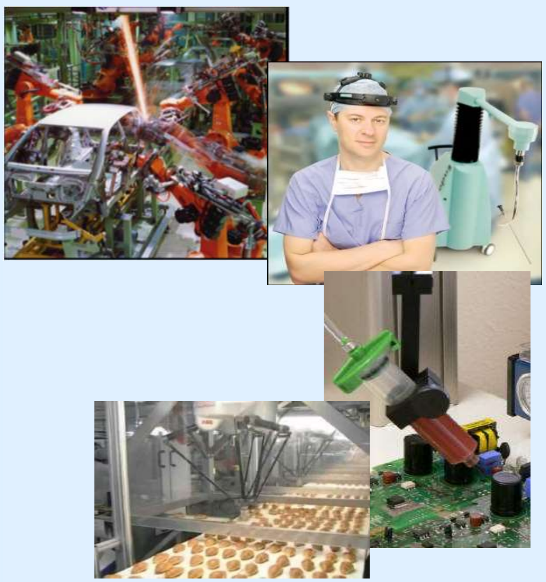
Autonomous Robots

- **Taskability**: ability to achieve multiple tasks described at an abstract level.
- **Autonomy**: ability to carry out actions by itself
  - **Adaptability:** modify own behavior according to current goal and execution context as perceived.
  - **Reactivity**: take into account situations and events with time bounds compatible with the correct and efficient achievement of goals and with environment dynamics.
- **Consistent behavior**: reactions to events guided by the objectives of the task (not "pure reflex").
- **Robustness/dependability**: ability to cope with failures and critical environmental changes.
- **Reconfigurability and evolvability**: possibility to add (or "grow") new components and abilities. Scalability, **open-endedness**, ease of development.

Autonomous Robots

Structured, controlled

Industrial



Manufacturing
Mining
Surgery

Unstructured, unmanned, autonomous

Field

Aerospace
Underwater
Rescue

Unstructured, proactive, interactive

Service

Home
Entertainment
Health care

- Automotive:
  - Driveless car
    - Mapping, localization, vision/LiDAR-based detection, avoidance, path planning, navigation, decision making, etc.

  - Assisted Driving
    - Autopilot, cruise control, vision-based detection, avoidance, alerting, HMI, etc.

- Search & Rescue Robotics:
  - Robotic system designed for searching and rescuing people
  - Urban (earthquake, dangerous places, etc.), not Urban (sea, mountains, harsh terrains, etc.)
  - Robots:
    - Ground
    - Aerial
    - Marine
    - …

Interazione Uomo-Robot per il Soccorso Alpino

- Squadra di droni per il soccorso alpino





Robot terrestri ed aerei per supportare le attività delle squadre di soccorso

Un soccorritore è il comandante "busy genius" e impartisce ordini ai robot con commandi brevi e veloci, sia con gesti che con voce

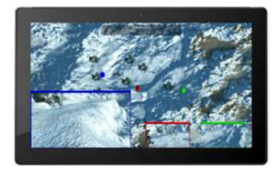
Interazione Uomo-Robot per il Soccorso Alpino

Interazione Uomo-Robot per il Soccorso Alpino

- Squadra di droni per il soccorso alpino







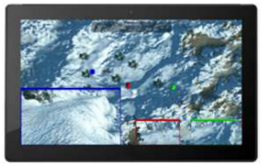


Interazione Uomo-Robot per il Soccorso Alpino

- Squadra di droni per il soccorso alpino

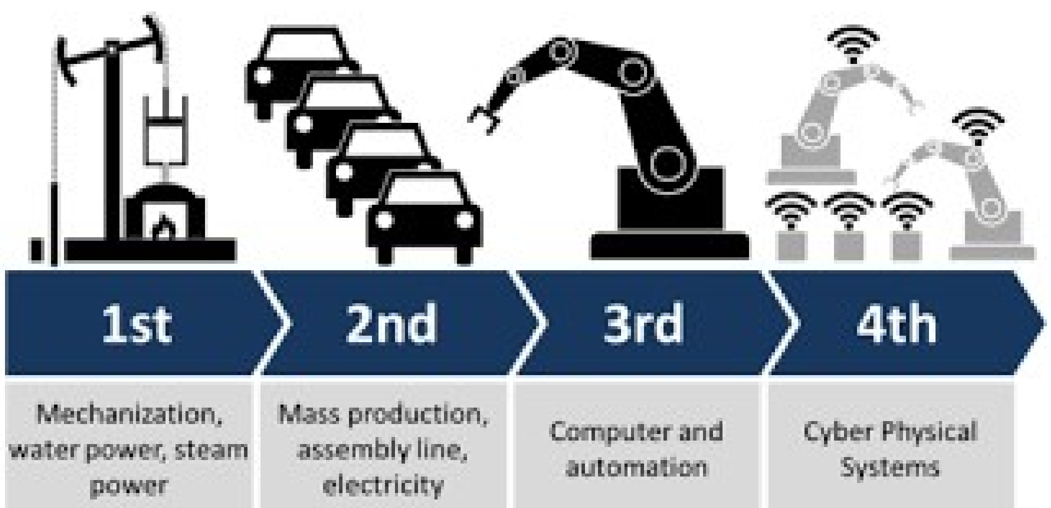




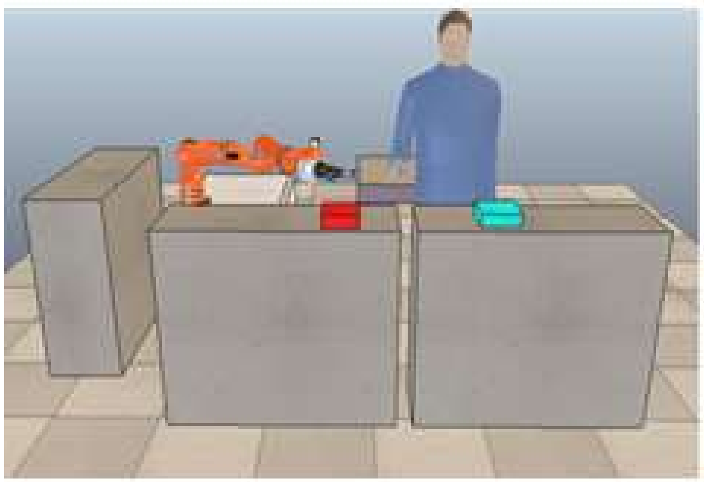


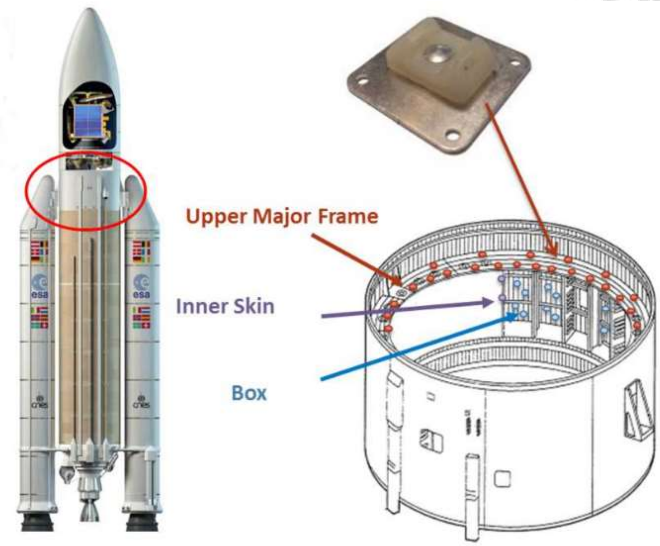
- Robot co-worker (Cobot, Industry 4.0)
  - Smart production, advanced manufacturing solutions
  - Customization of products, flexibilized mass-production



Interazione Uomo-Robot in Contesto Industriale

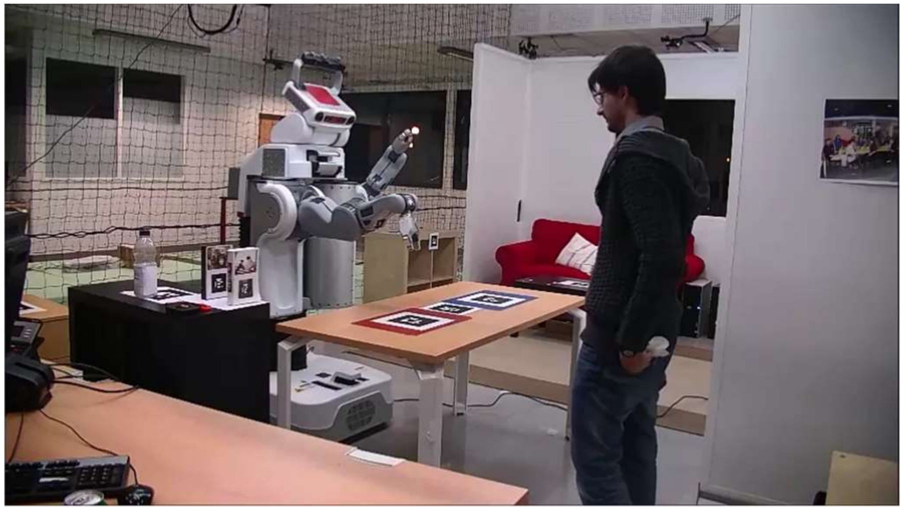
- Contesto Industriale:
  - Robot co-worker
  - Ariane 5 Launcher



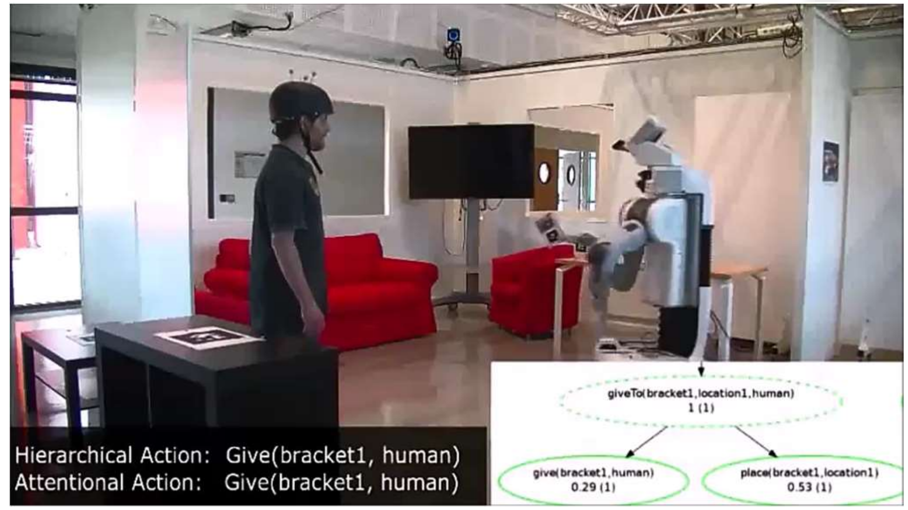


- Compiti di Installazione:
  - L'uomo ed il robot collaborano nell'installazione.
  - Il robot porta material ed indica dove posizionarlo.

Autonomous Robots



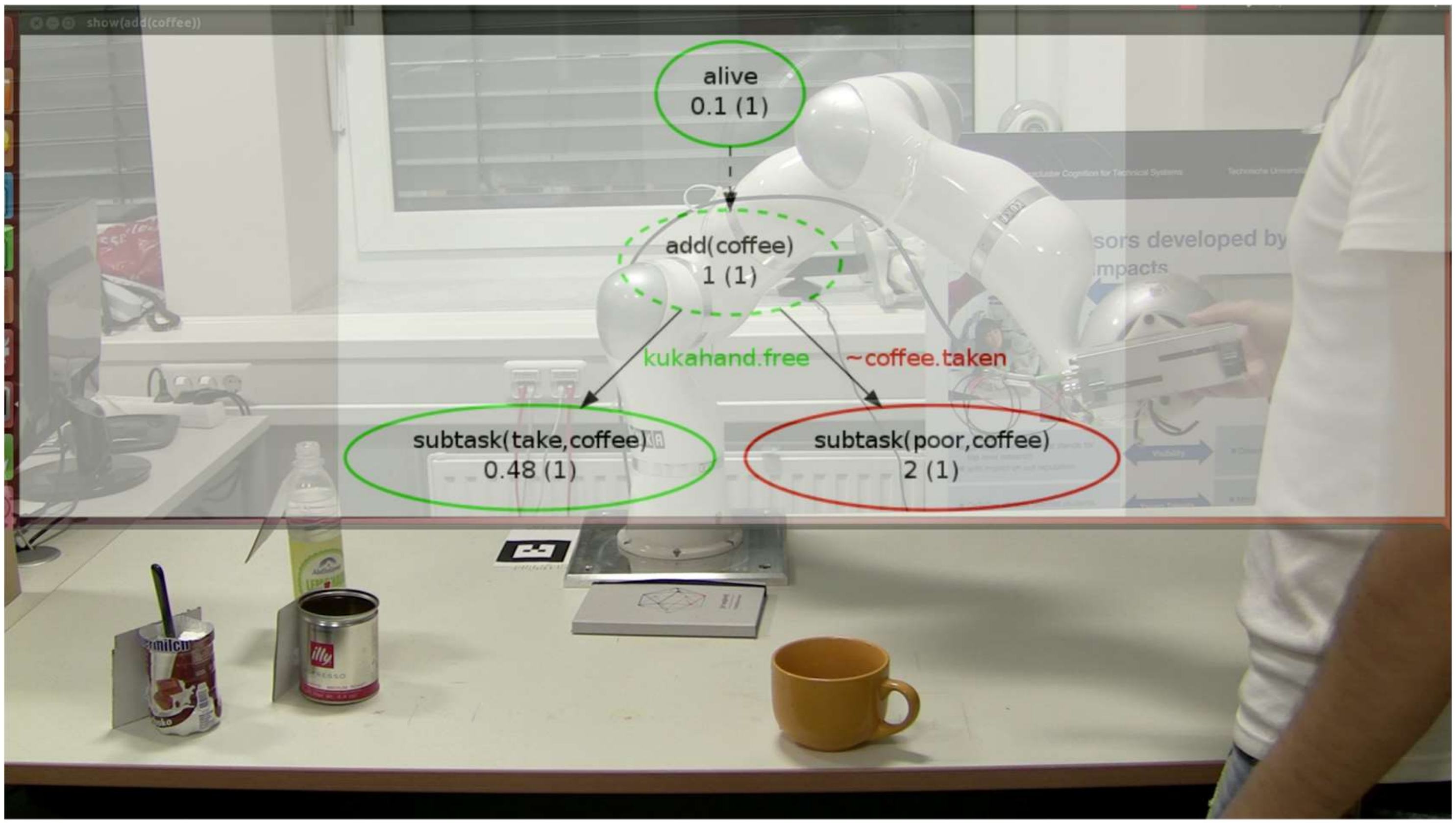
Multimodal Interaction



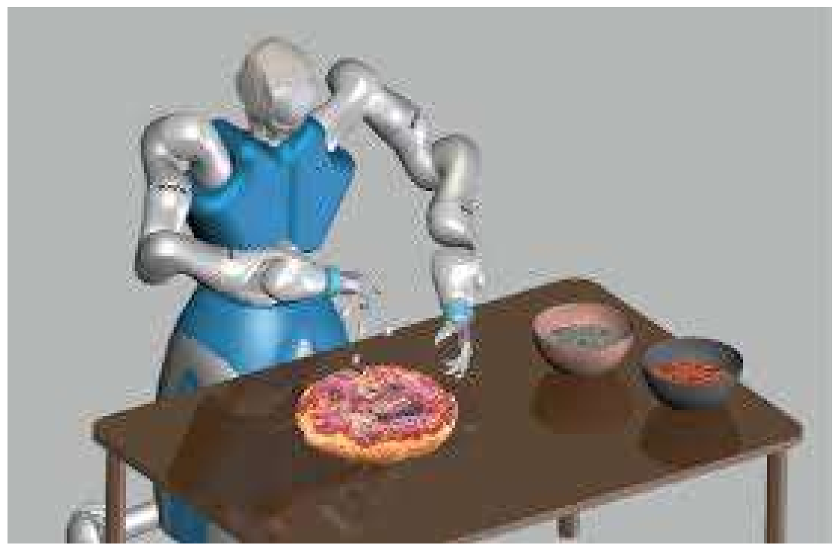
Unexpected Events

- Robot co-worker
  - Human monitoring
  - Intention recognition
  - Cognitive/physical interaction
  - Flexible and interactive task execution
  - Multimodal comunication and dialogue
  - Cooperative task execution
  - Turn taking
  - Mixed-initiative planning and execution
  - Plan/task/action recovery/repair
  - Task teaching
  - Learning by demonstration

- Multimodal interaction and learning by demonstration



- RObotic DYnamic MANipulation
  - Unified framework for dynamic manipulation of non-prehensile non-rigid or deformable objects (ERC, PI Prof. Bruno Siciliano)



Autonomous Robots

- Robots will allow a smarter shelf refilling
- **R**obotics **E**nabling **F**ully-**I**ntegrated **L**ogistics **L**ines for **S**upermarkets — **REFILLS** (H2020 PI Prof. Bruno Siciliano)

Trends in Robotics Research

Classical Robotics (mid-70's)
- exact models
- no sensing necessary

Reactive Paradigm (mid-80's)
- no models
- relies heavily on good sensing

Hybrids (since 90's)
- model-based at higher levels
- reactive at lower levels

Probabilistic Robotics (since mid-90's)
- seamless integration of models and sensing
- inaccurate models, inaccurate sensors

Autonomous Robots: Paradigms

- Classic Robotics (AI '70):
  - Model-based (representation = world), symbolic, no sensing, only reasoning
- Reactive Robotics (Ethology '80):
  - No models (world is the model), reactive: sense-act (insects-like)
- Hybrid Architectures (Agents '90):
  - Model-based (rep. abstract, but fine) + reactive (3T architectures)
- Probabilistic Robotics (Mobile Robotics '90):
  - Approximate/probabilistic models (rep. != world), actuators not reliable, sensors not accurate;
  - Sensors/Actuators models tight integration.

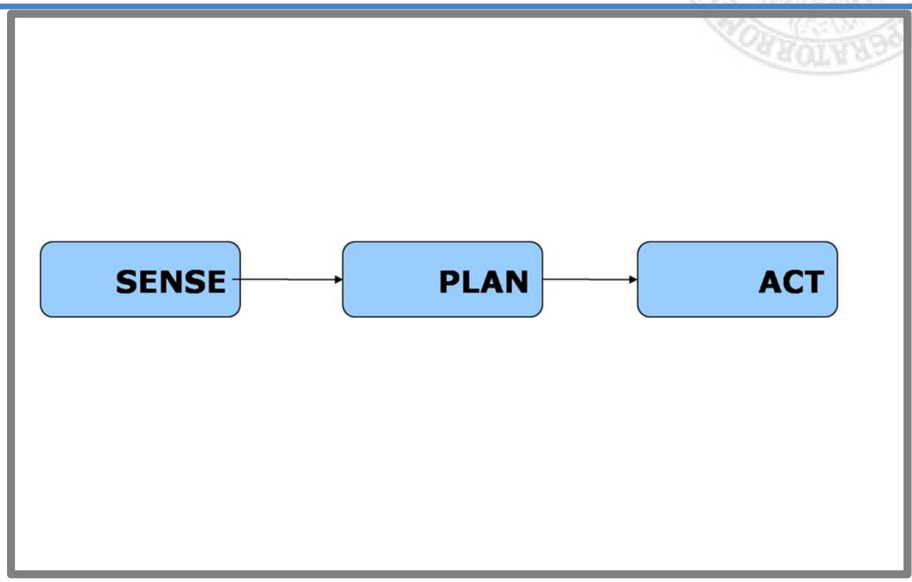
Autonomous Robots: Paradigms

Hierarchical Architecture

Knowledge Representation and formal
reasoning (logic+deductive)

Closed World:
- Complete model of the environment
- Deterministic, Symbolic, Observable

Functional decomposition of the activities
[Shakey 1969]

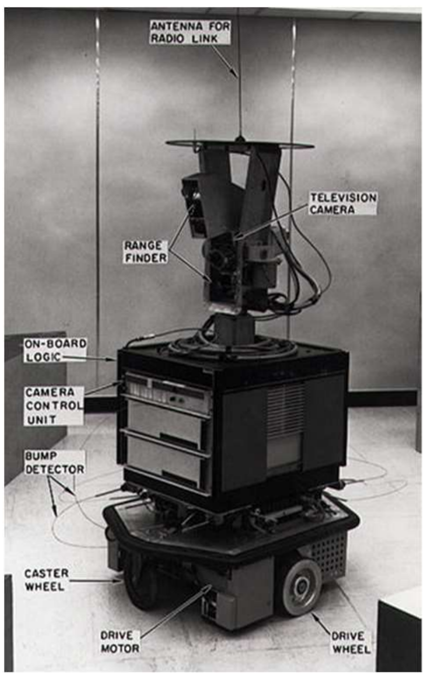


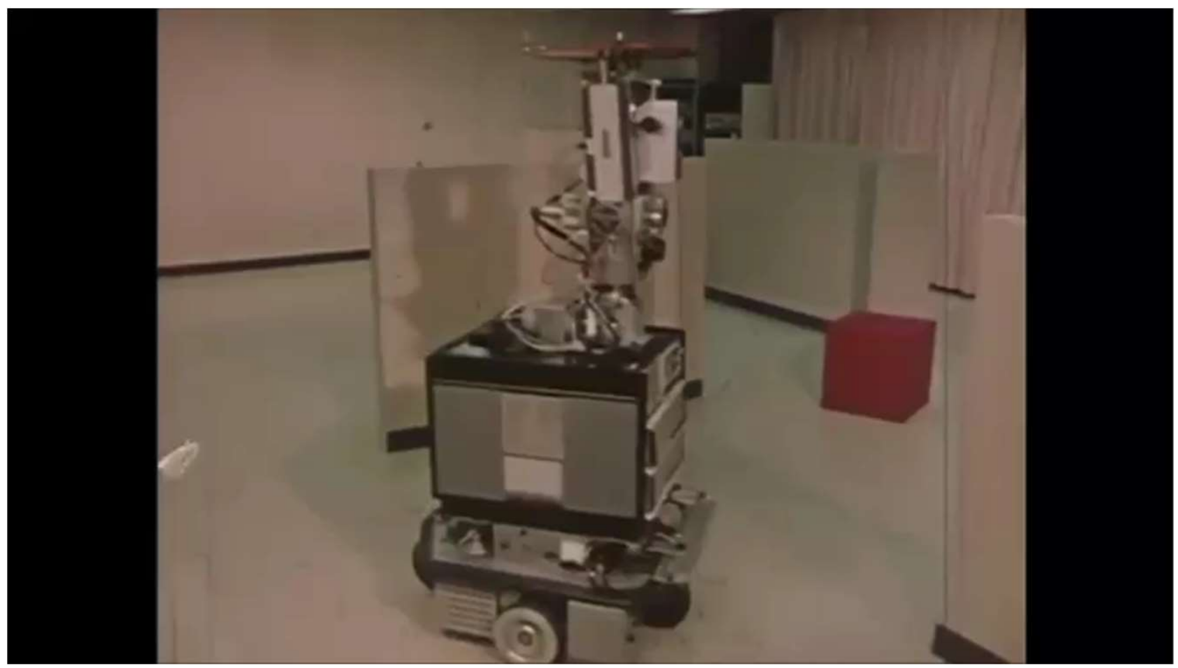
Classical Control Schema

Stanford AI Laboratory / CMU (Moravec)

- Robotics & Artificial Intelligence
  - Intelligent behavior
  - Representation, Reasoning, Planning, etc.
  - Shakey the robot (1966-72), Stanford Cart (1971-80)

Paradigma:
Sense
Plan
Act





Classical Paradigm

Hierarchical Architecture

Knowledge Representation and formal reasoning (logic+deductive)

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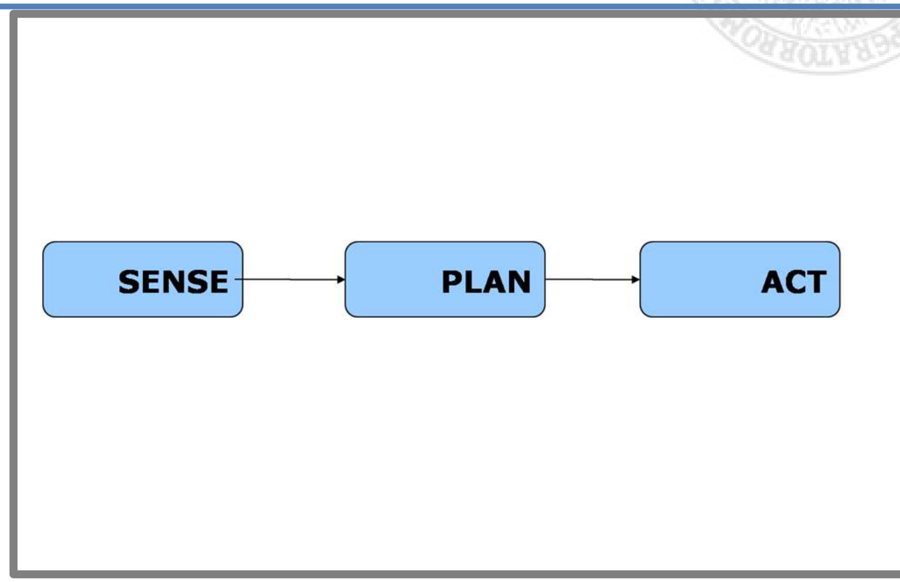
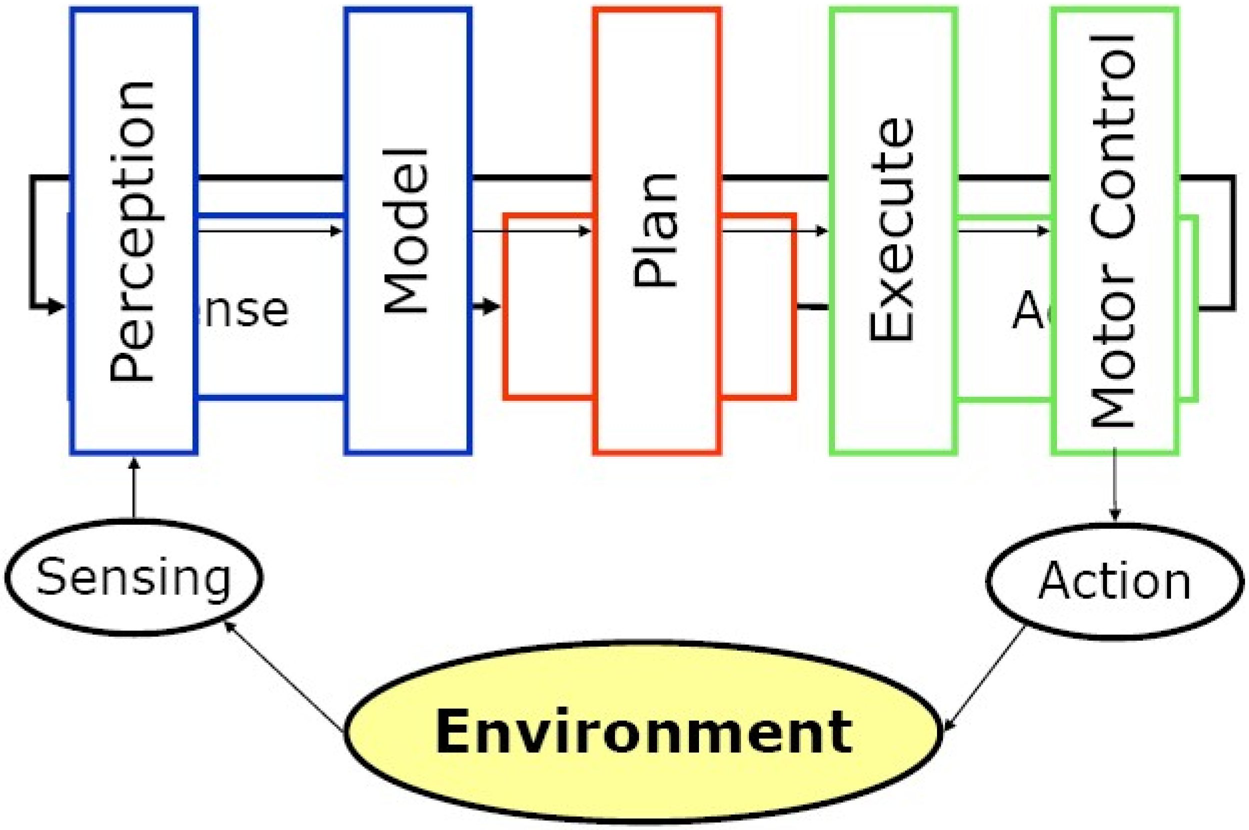
Functional decomposition of the activities [Shakey 1969]



Classical Control Schema

Stanford AI Laboratory / CMU (Moravec)

Classical Paradigm as Horizontal/Functional Decomposition



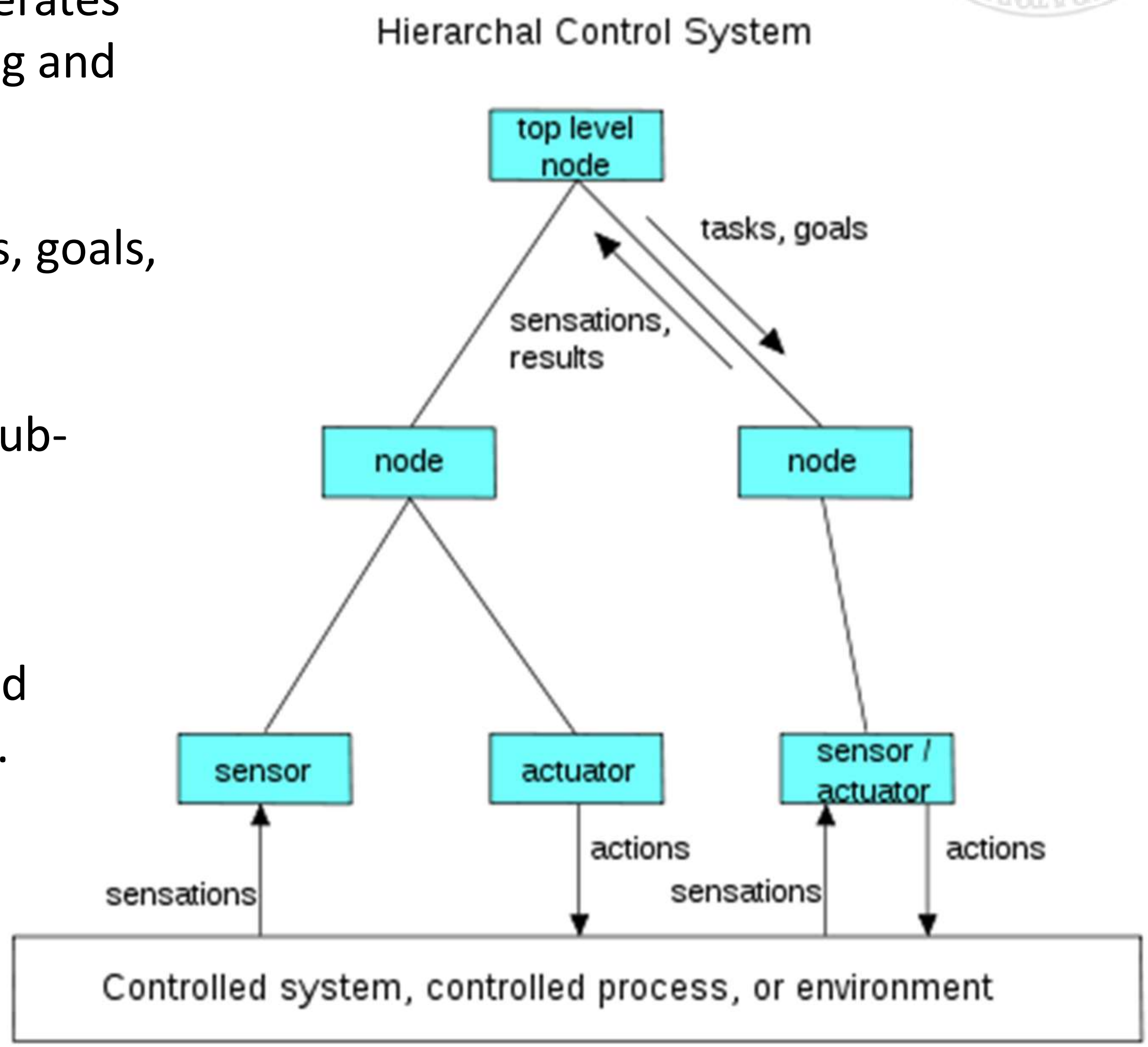
Hierarchical Paradigm

Each higher layer of the tree operates with a longer interval of planning and execution time

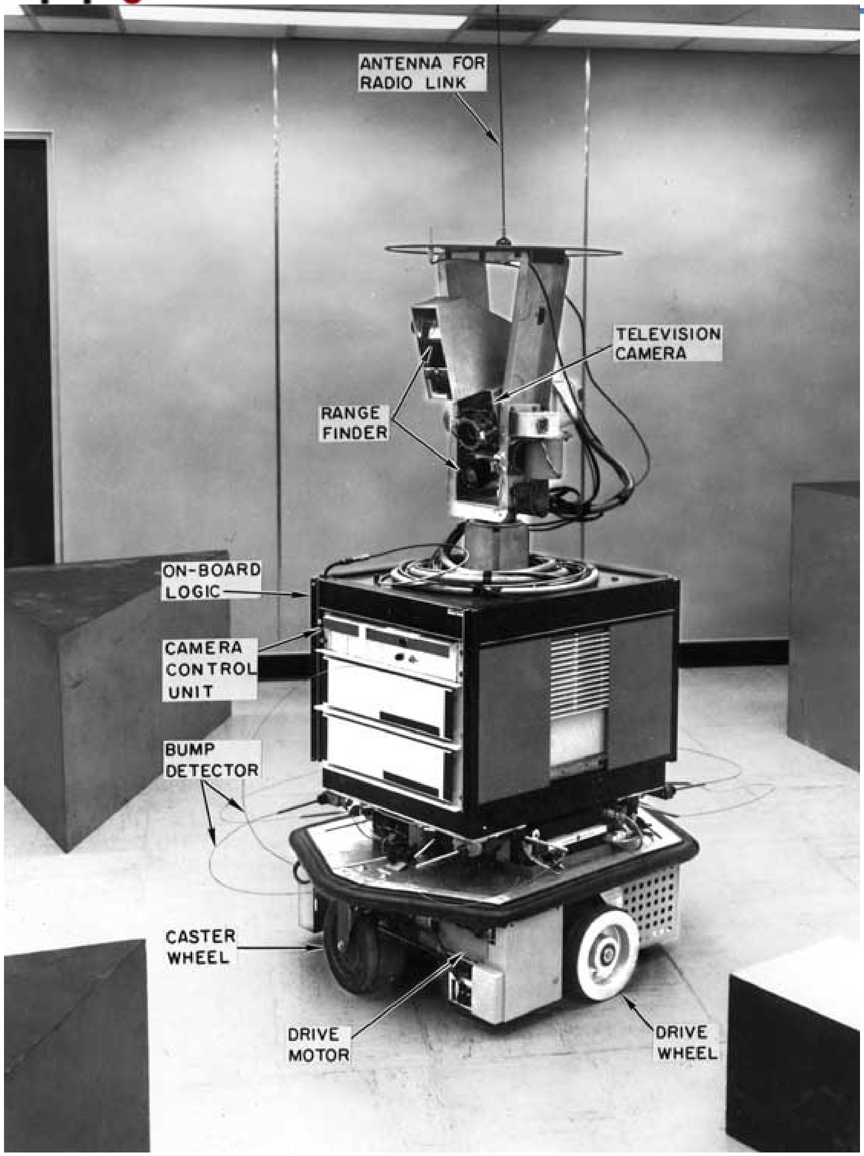
The lower layers have local tasks, goals, and sensations

The lowest, reactive layers are sub-symbolic.

The higher layers are capable of reasoning from an abstract world model and performing planning.

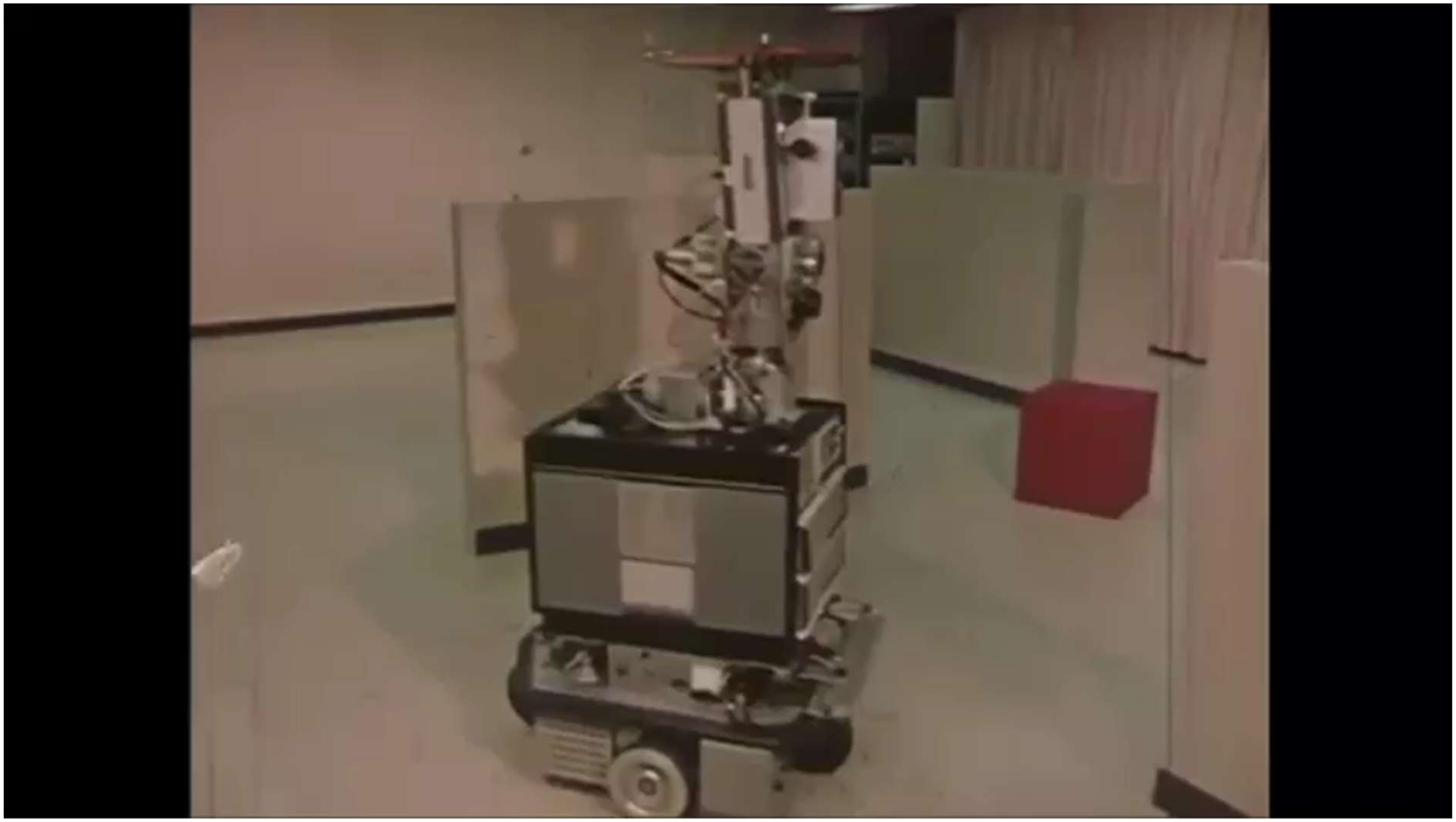


1970-Shakey the robot

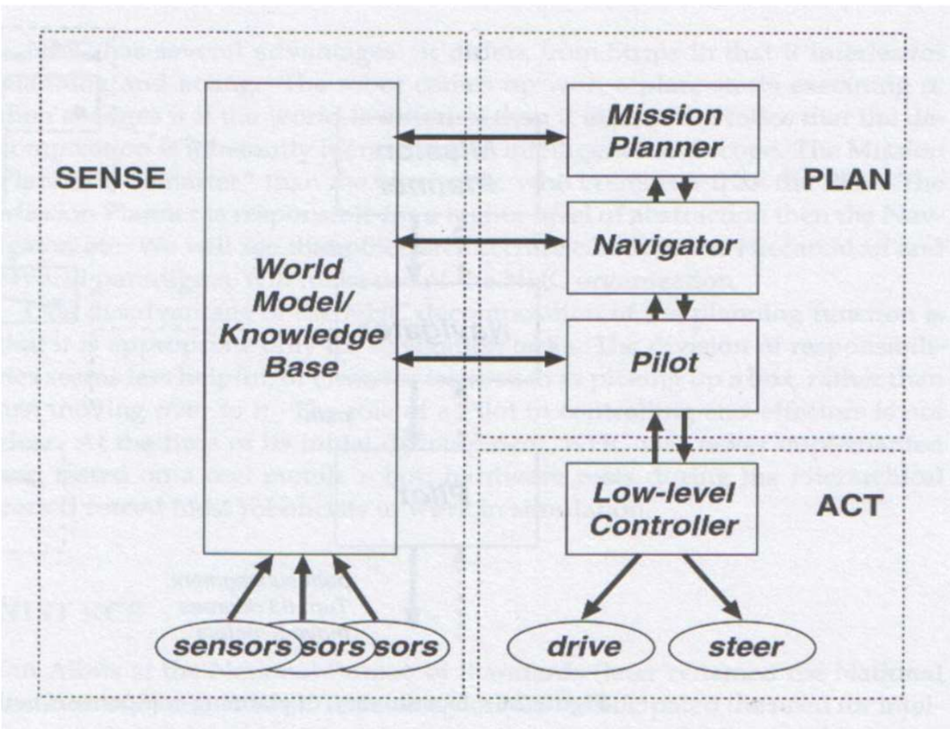


- Remote controlled by a computer.
- Reasoning program fed with very selective spatial data.
- Weak edge-based processing of camera and laser range measurements.
- Generated Plans involving moving from place to place and pushing blocks to achieve a goal.

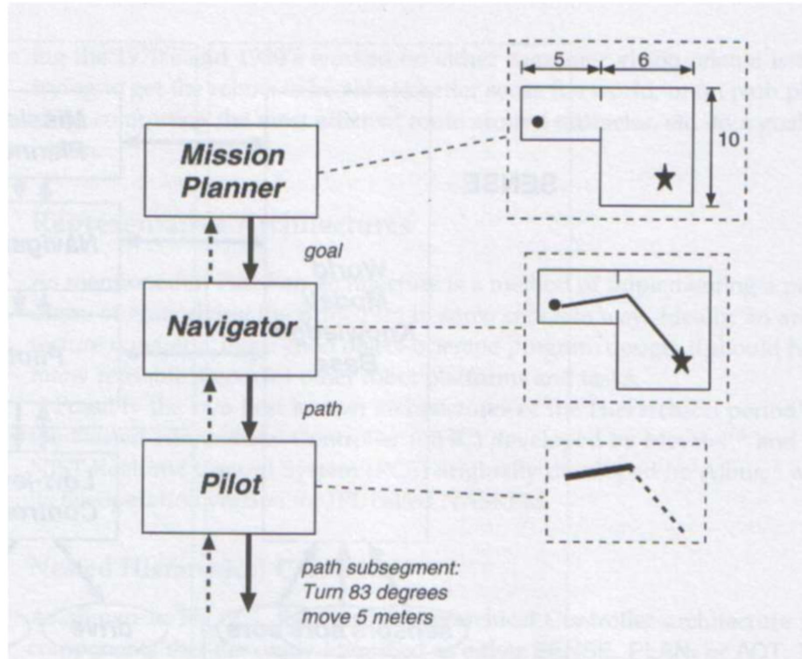
- Shakey the robot



Nested Hierarchical Controller (NHC), Meystel (1990). SENSE-PLAN-ACT cycle:



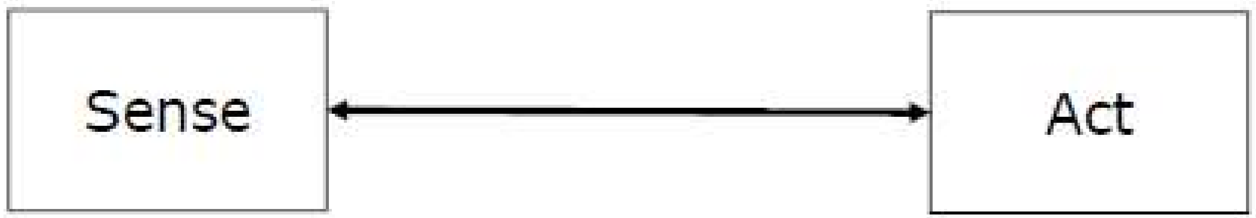
Nested Hierarchical Controller.



Examination of planning components in the NHC architecture.

DIE
TI.

Reactive / Behavior-based Paradigm



- No models: The world is its own, best model
- Easy successes, but also limitations
- Investigate biological systems

Reactive Paradigm

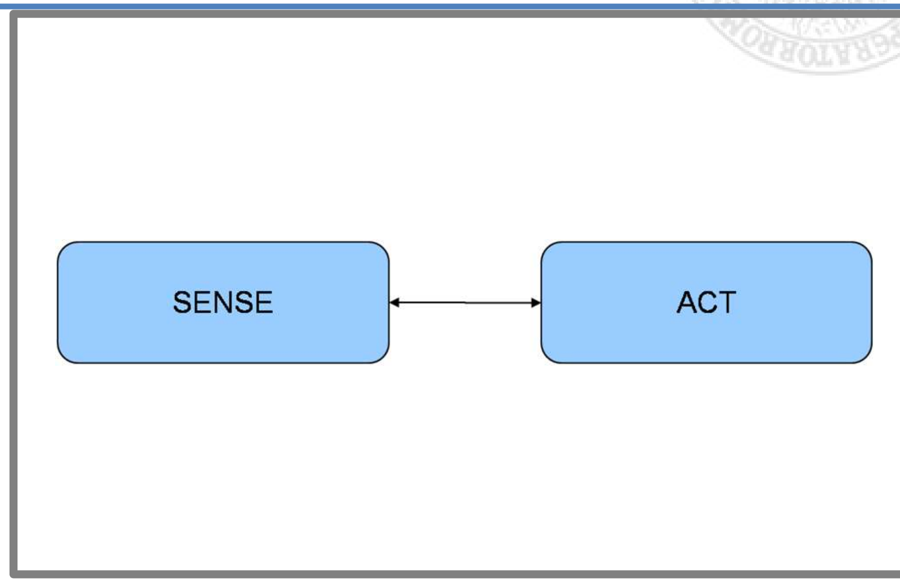
- Situated:
  interacting with the env.

- No Memory, no model:
  memory and model are the
  external world (stigmergic)

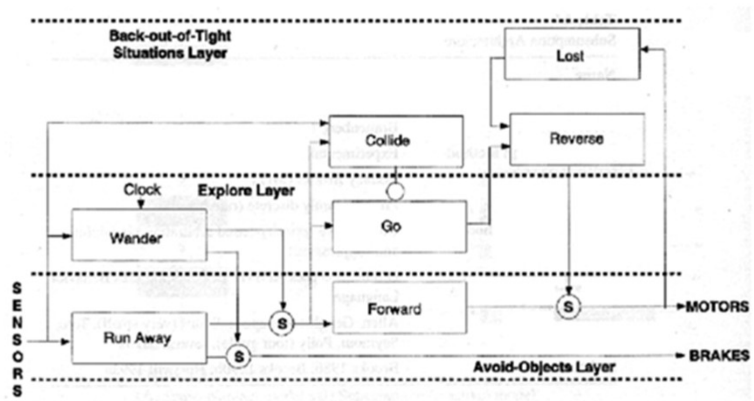
- Behavior-based:
  sense e act coupled and
  associated with the behavior (Fixed Action Patterns)

  - Subsumption Architecture
    [Brooks 1986]

  - Potential Fields



Sense-Act Paradigm



Reactive Paradigm

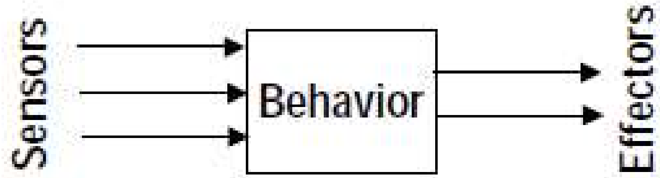
- Ethology: The study of animal behavior in natural conditions

- "Founding fathers" of ethology: Konrad Lorenz and Niko Tinbergen (Nobel prize winners in 1973)
  - They studied:
    - Individual animal behaviors
    - How animals acquire behaviors
    - How animals select or coordinate groups of behaviors

Lorenz

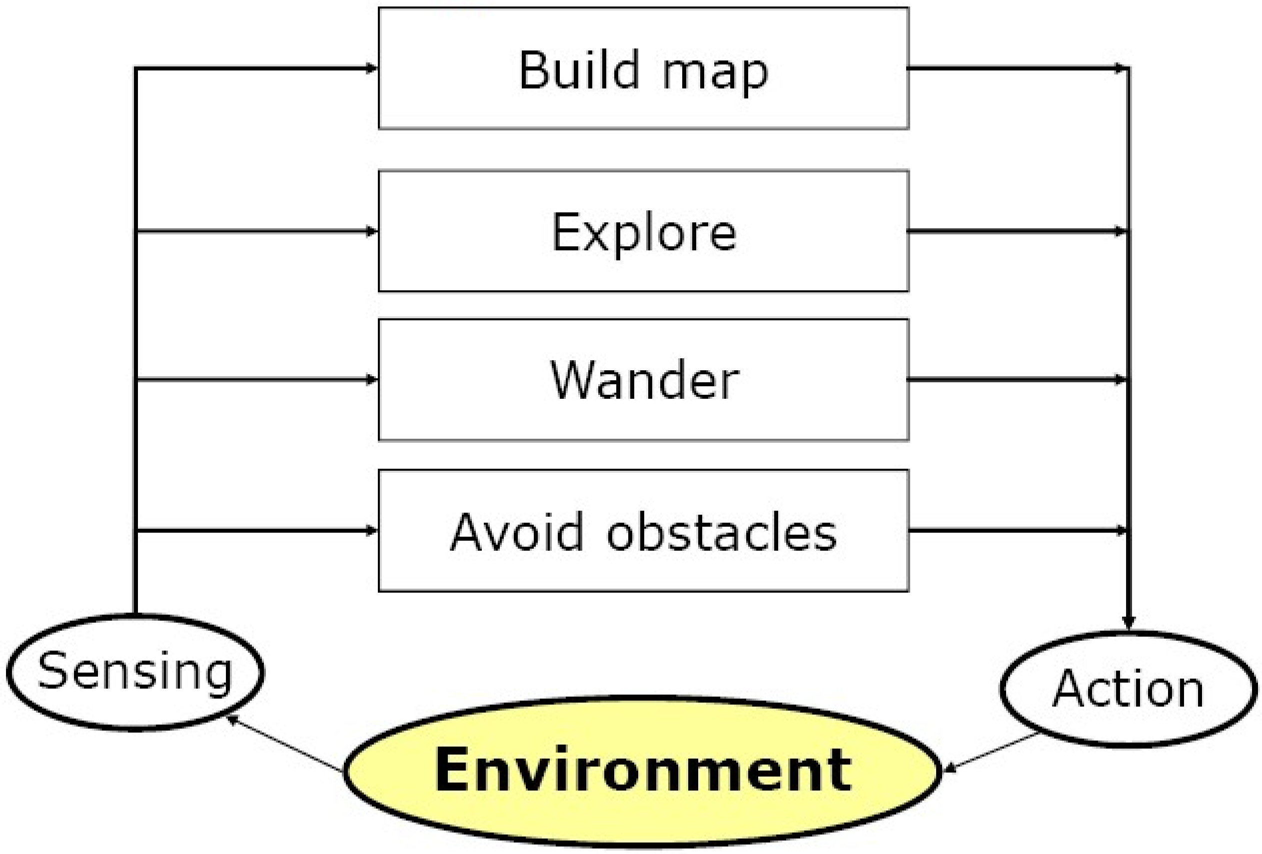
DIE
TI.

- Behavior: Mapping of sensory inputs to a pattern of motor actions that are used to achieve a task



- Three broad categories of behaviors:
  - Reflexive behaviors:
    - Stimulus-response
    - Hard-wired for fast response
    - Example: (physical) knee-jerk reaction
  - Reactive behaviors:
    - Learned
    - "Compiled down" to be executed without conscious thought
    - Examples: "muscle memory" – playing piano, riding bicycle, running, etc.
  - Conscious behaviors:
    - Require deliberative thought
    - Examples: writing computer code, completing your tax returns, etc.

Reactive Paradigm as Vertical Decomposition



Characteristics of Reactive Paradigm

- Situated agent, robot is integral part of the world.
- No memory, controlled by what is happening in the world.
- Tight coupling between perception and action via behaviors.
- Only local, behavior-specific sensing is permitted (ego-centric representation).

Behaviors

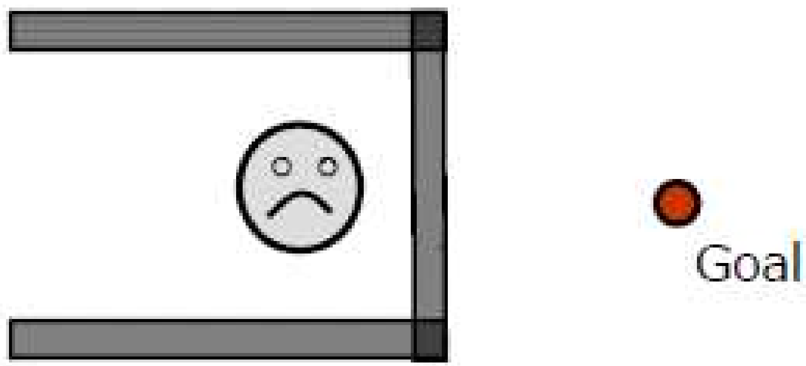
- ... are a direct mapping of sensory inputs to a pattern of motor actions that are then used to achieve a task.
- ... serve as the basic building block for robotics actions, and the overall behavior of the robot is emergent.
- ... support good software design principles due to modularity.

Subsumption Architecture

- Introduced by Rodney Brooks '86.
- Behaviors are networks of sensing and acting modules (augmented finite state machines AFSM).
- Modules are grouped into layers of competence.
- Layers can subsume lower layers.
- No internal state!

Characteristics of Potential Fields

- Suffer from local minima

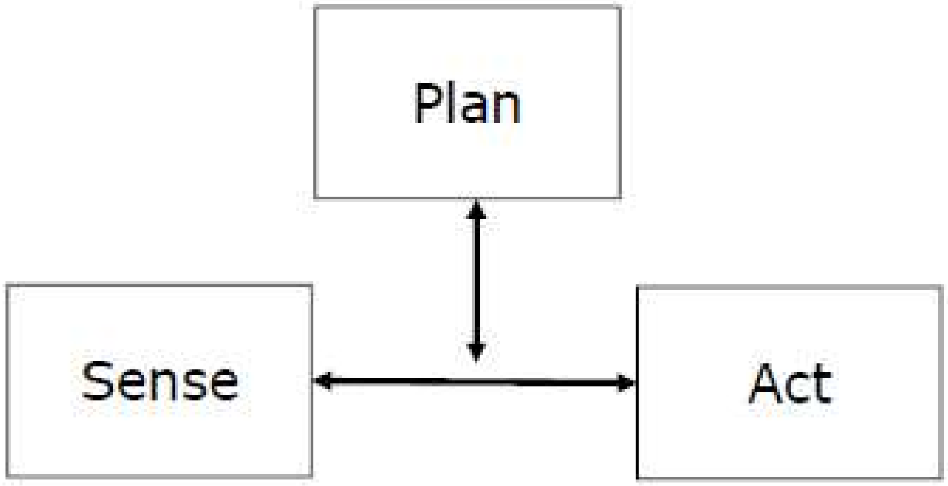


  - Backtracking
  - Random motion to escape local minimum
  - Procedural planner s.a. wall following
  - Increase potential of visited regions
  - Avoid local minima by harmonic functions

Reactive Paradigm

- Representations?
- Good software engineering principles?
- Easy to program?
- Robustness?
- Scalability?

Hybrid Deliberative/reactive Paradigm



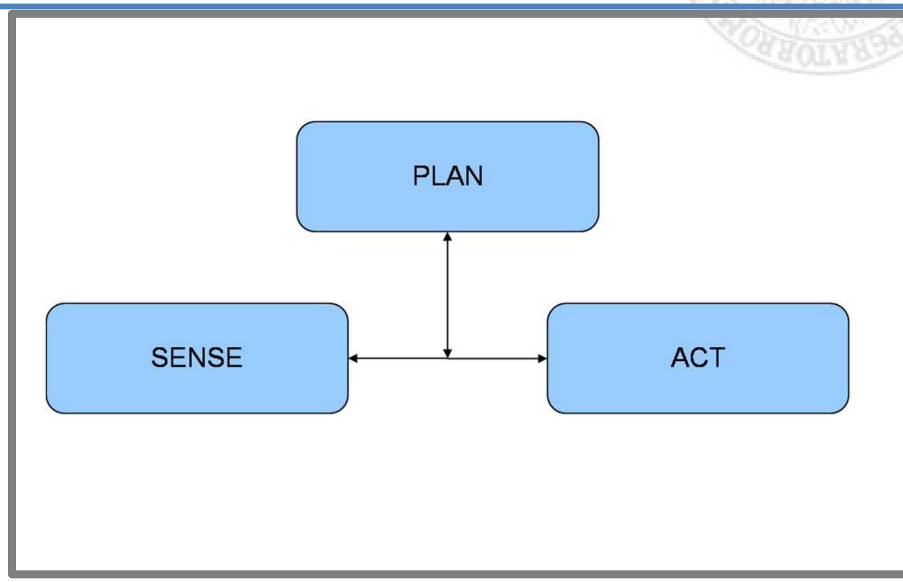
- Combines advantages of previous paradigms
  - World model used for planning
  - Closed loop, reactive control

Hybrid Paradigm

- It combines the two paradigms (3T [Gat 1996, Bonasso et. al 1998])
  - Model-based planning and reasoning
  - Reactive at the low-level control

E.g. ATLANTIS [Gat 1996]:

- Control Layer,
- Sequencing Layer,
- Deliberative Layer.



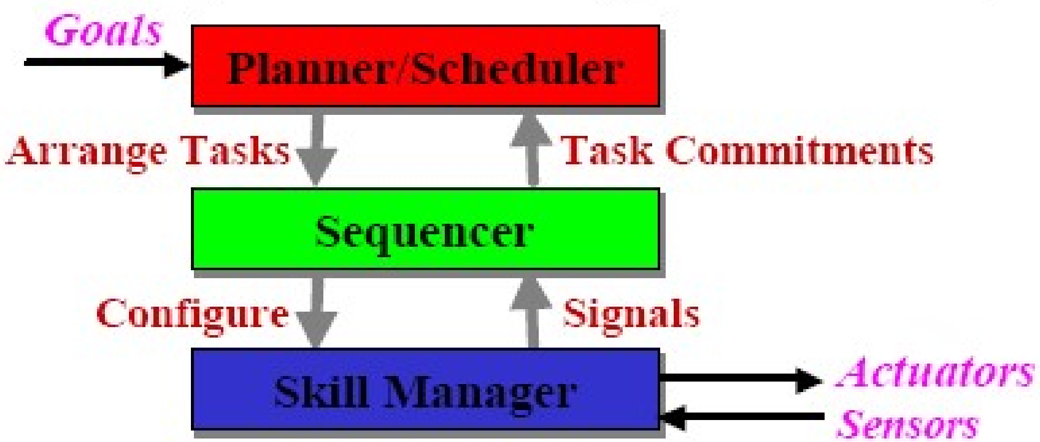
Sense-Act + Plan

3 Layered Architectures

- Deliberative layer:
  plan, reasoning, deliberation
- Esecutive layer:
  execution monitoring, scheduling, sequencing, dispatching, recovery, synchronization, etc.
- Functional layer:
  specialized controllers, perceptive systems, sensory-motor loops, reactive behaviors

3T Architecture: ATLANTIS

- Explicit Separation of Planning, Sequencing, and Control
  - Upper layers provide *control flow* for lower layers
  - Lower layers provide *status* (state change) and *synchronization* (success/failure) for upper layers
- Heterogeneous Architecture
  - Each layer utilizes algorithms tuned for its particular role
  - Each layer has a representation to support its reasoning

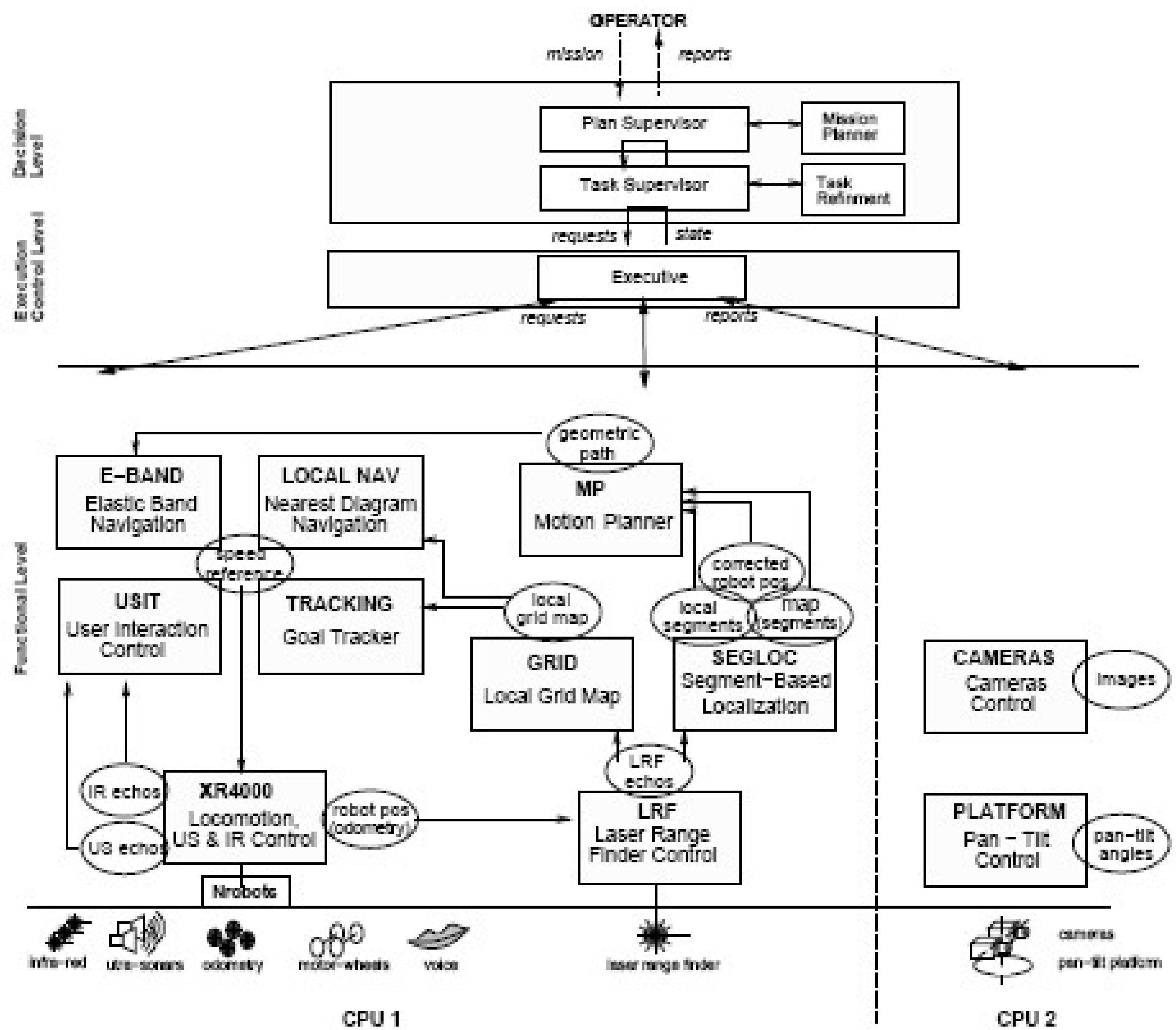


• LAAS architecture:

Three Layers:

1. Deliberative (temporal planner)
2. Executive (PRS)
3. Functional (GENOME)

Rover Control

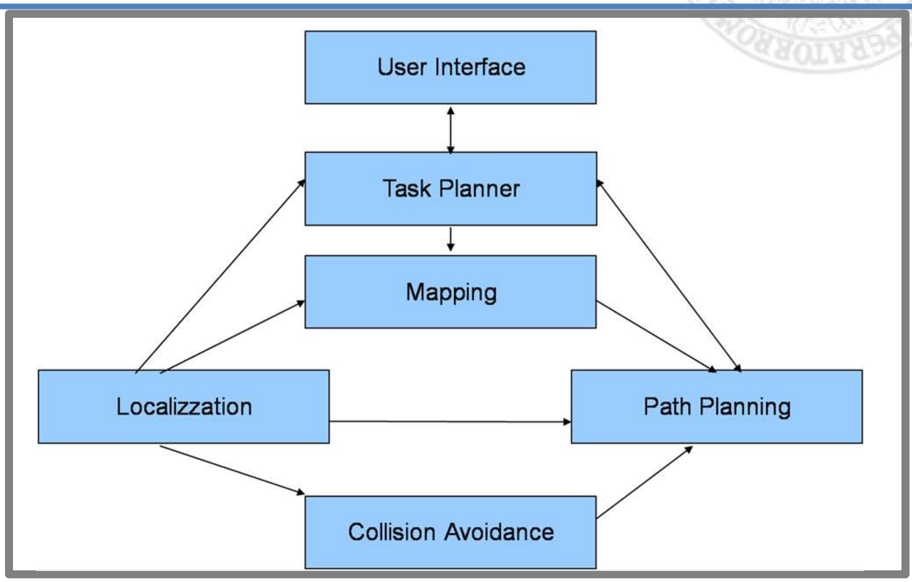


RHINO Architecture

Robotic tour guide - Bonn Science museum (1995); MINERVA – Atlanta (1998)

3T mobile robot:

1. Functional:
   Mapping, Localizzation, Obstacle Avoidance
2. Executive:
   Sequencer, monitor
3. Deliberative:
   Task Planner (tour planner)



RHINO Architetture

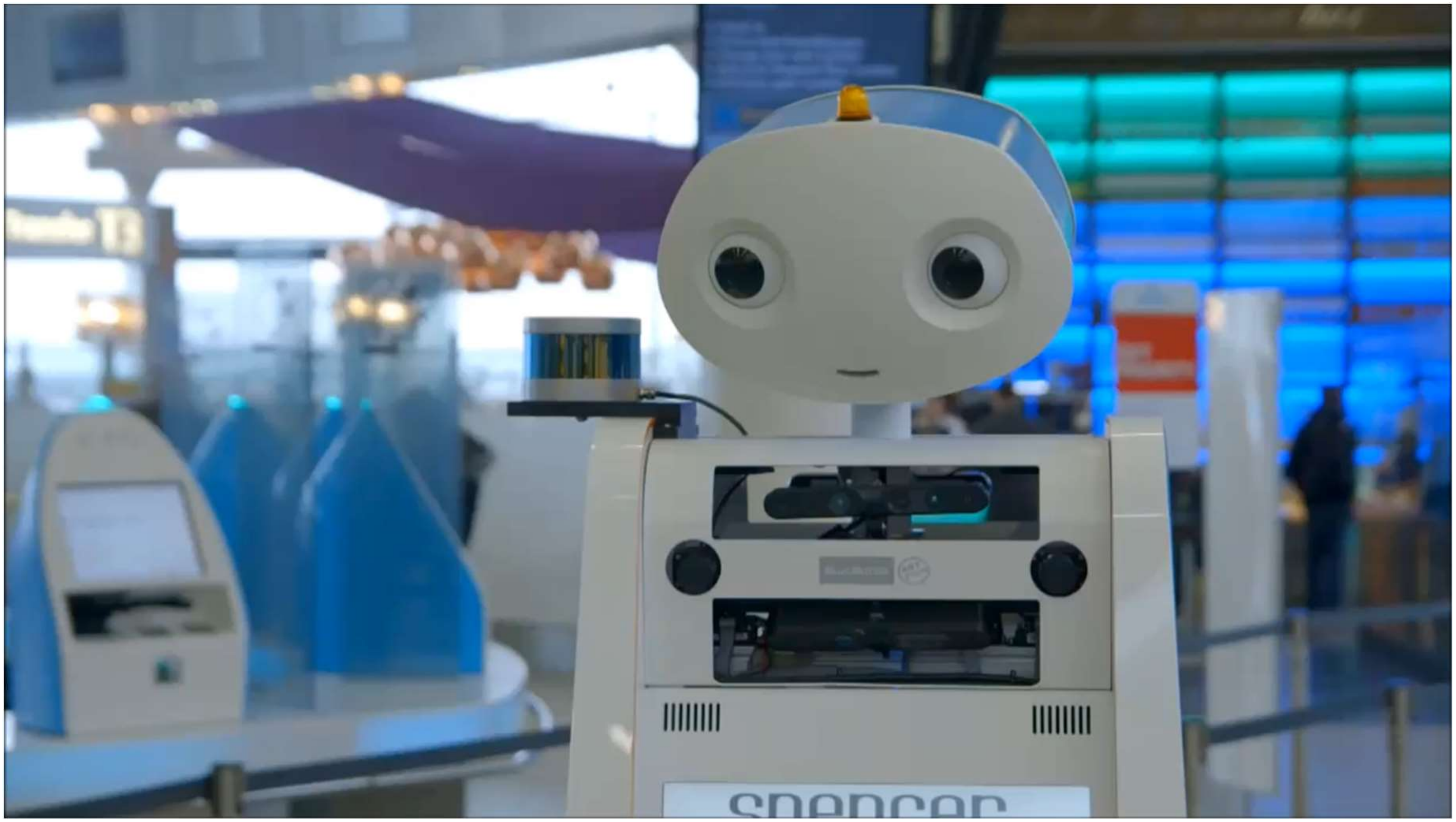
Rhino, 1997

Minerva, 1998

MINERVA

Spencer

- Social Robot in populated environments

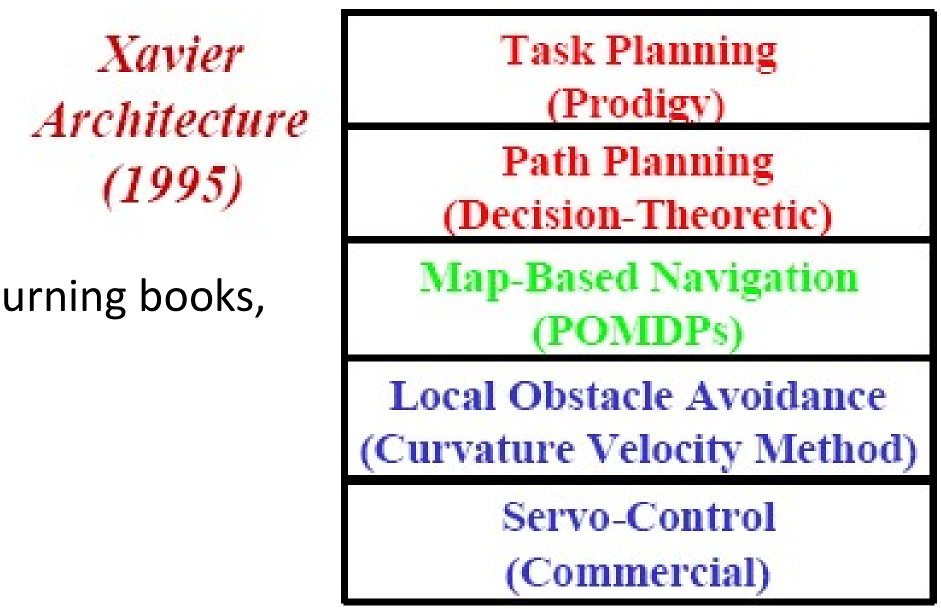


Social situation-aware perception and action for cognitive robots (SPENCER) FP7

Xavier Architecture (1995)

-Low-level control: high resolution, high frequency

-High-level control: low resolution (abstract), low frequency

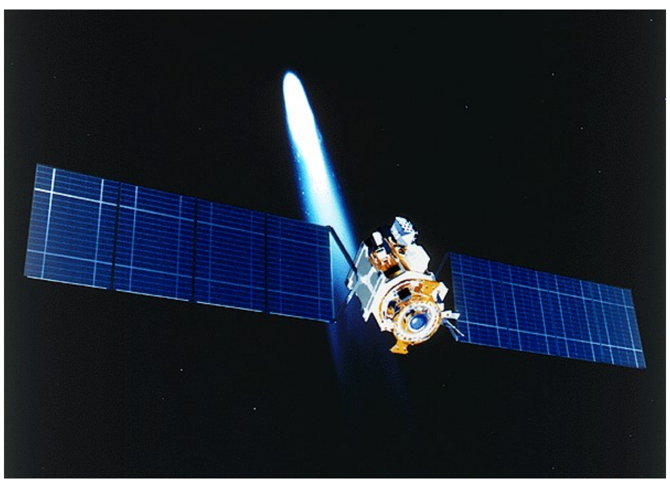


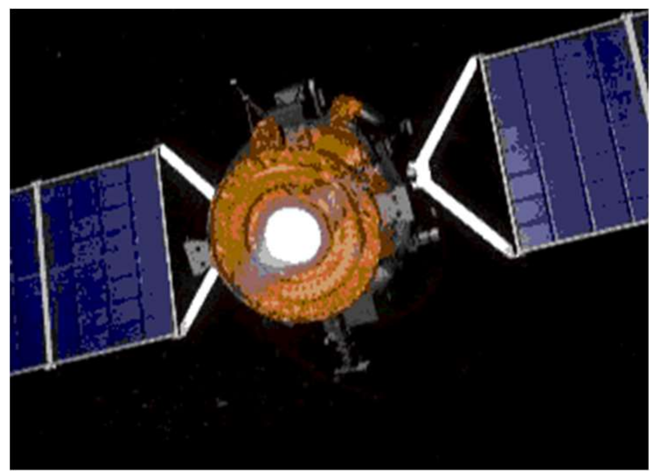
Office delivery robot:
picking up and delivering mail or faxes, returning books, getting coffee.

The layers are independent,
always active

DS1 (Remote Agent)

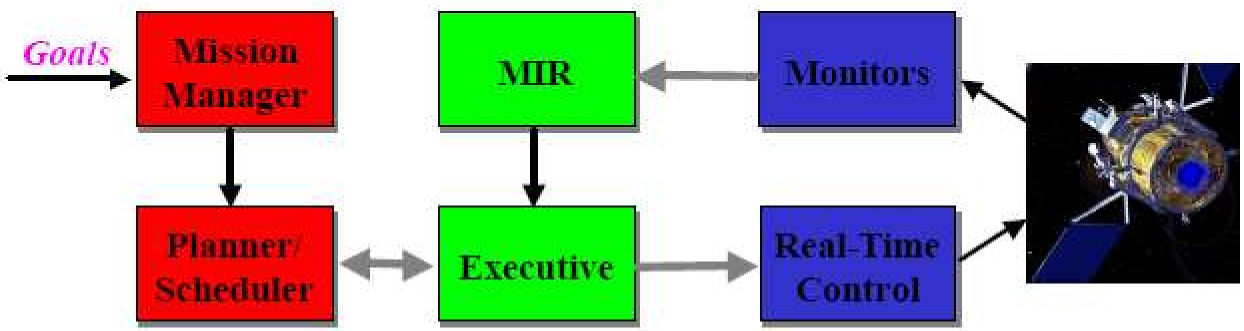
- Mission: testing new technologies for the New Millennium Program (and observe Borrelly comet)
- First autonomous spacecraft
- Planner and smart executive system (RAX: Remote Agent Experiment).
- Planning, scheduling, adaptive execution, diagnosis, recovery.



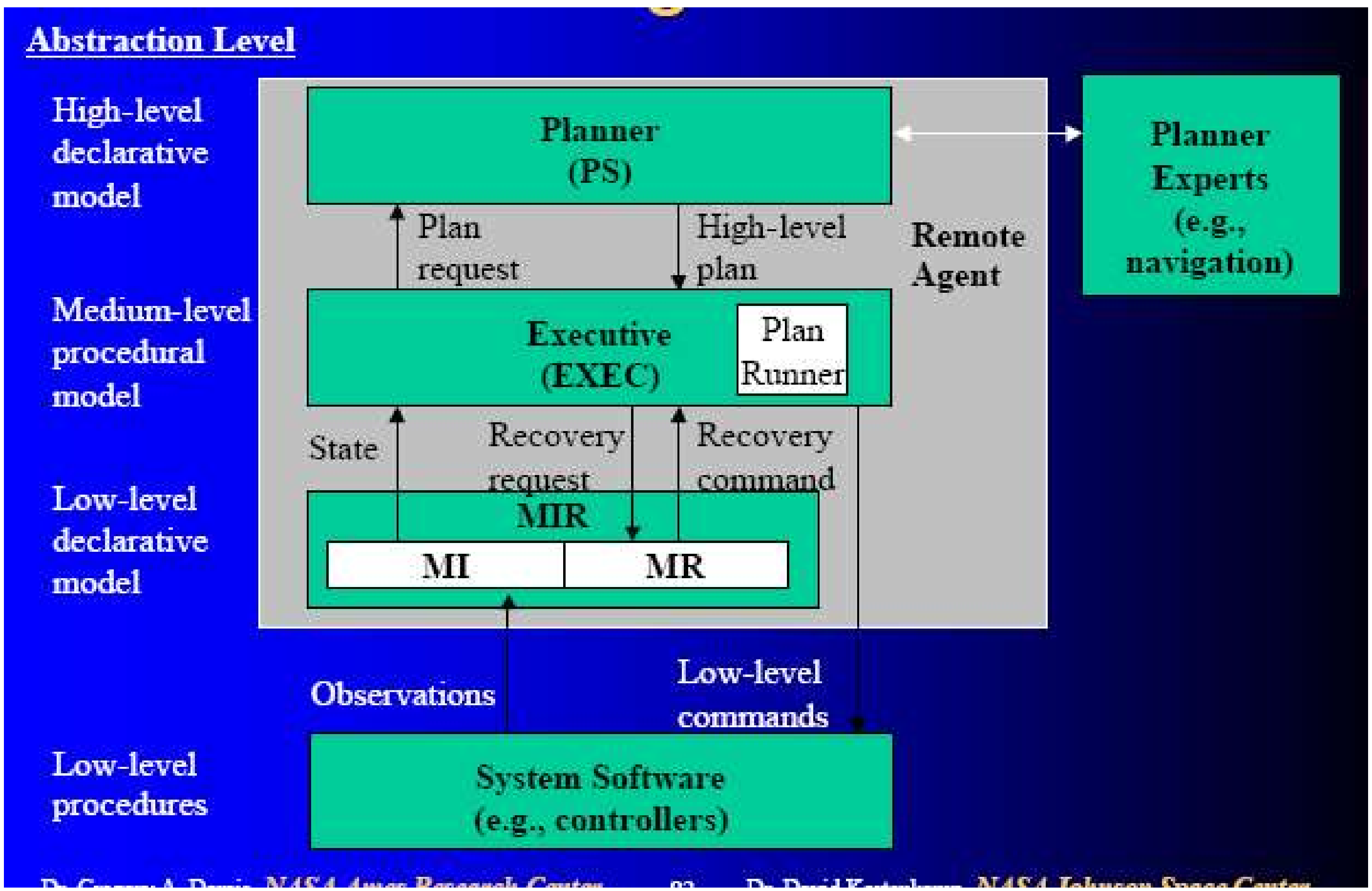


3T: REX

- Remote Agent:
  - -Three Layers:
    - -Mission Manager, Temporal planning and scheduling
    - -Execution Monitoring/Dispatching, Mode Identification (Diagnosis) and Recovery (MIR)
    - -Reflex control, sense (real-time)



3T: REX



Abstraction Level
High-level declarative model
Medium-level procedural model
Low-level declarative model
Low-level procedures
Planner (PS)
Plan request
High-level plan
Remote Agent
Planner Experts (e.g., navigation)
Executive (EXEC)
Plan Runner
State
Recovery request
Recovery command
MIR
MI
MR
Observations
Low-level commands
System Software (e.g., controllers)

3T Architectures

Problems with 3T:
Modular architectures but …

- Heterogeneous (different models)
- Abstraction level == control level:
  - HL abstract deliberation (task and mission planning)
  - LL reaction (implicit model, no flexible)
- Interaction deliberative-reactive?
  - Plan-Exec interaction
  - Replanning
  - Several exec-monitor-control loops
- Ad hoc executive system (when too complex, only sequencer and dispatcher)

Executive Layer: the key stone

- Forms a Bridge Between Planning and Behaviors
  - Discrete vs. continuous control
  - Symbolic vs. numeric representations
  - Real-time considerations
- Basic Roles
  - Decompose task into subtasks and dispatch tasks
  - Monitor execution for contingencies and opportunities
  - Reschedule tasks (or schedule new tasks) upon failure
- Differences Between Approaches
  - Methods for distributing functionality
  - Representation of domain and control knowledge
  - **RAP** (Firby); **TCA/TDL** (Simmons); ESL (Gat); PRS (Georgeoff)

Cognitive Architectures

- Field Robotics : Autonomous robot and flexible behavior
- Social Robotics : Interaction, Interpretation, Continous learning

Robotic Architetture as Cognitive Architectures:

Additional capabilities:
- Sensor fusion
- Reasoning
- Deliberation
- Learning

- Perception/Recognition and Perception/Action
- Attention and Executive Control
- Sensory-motor coordination (synergies)
- Motivations, emotions
- Human-robot interaction
- Incremental Learning (developmental robotics)

Cognitive Architectures: ACT-R (1993)

Cognitive Plausability:
Testing cognition theories

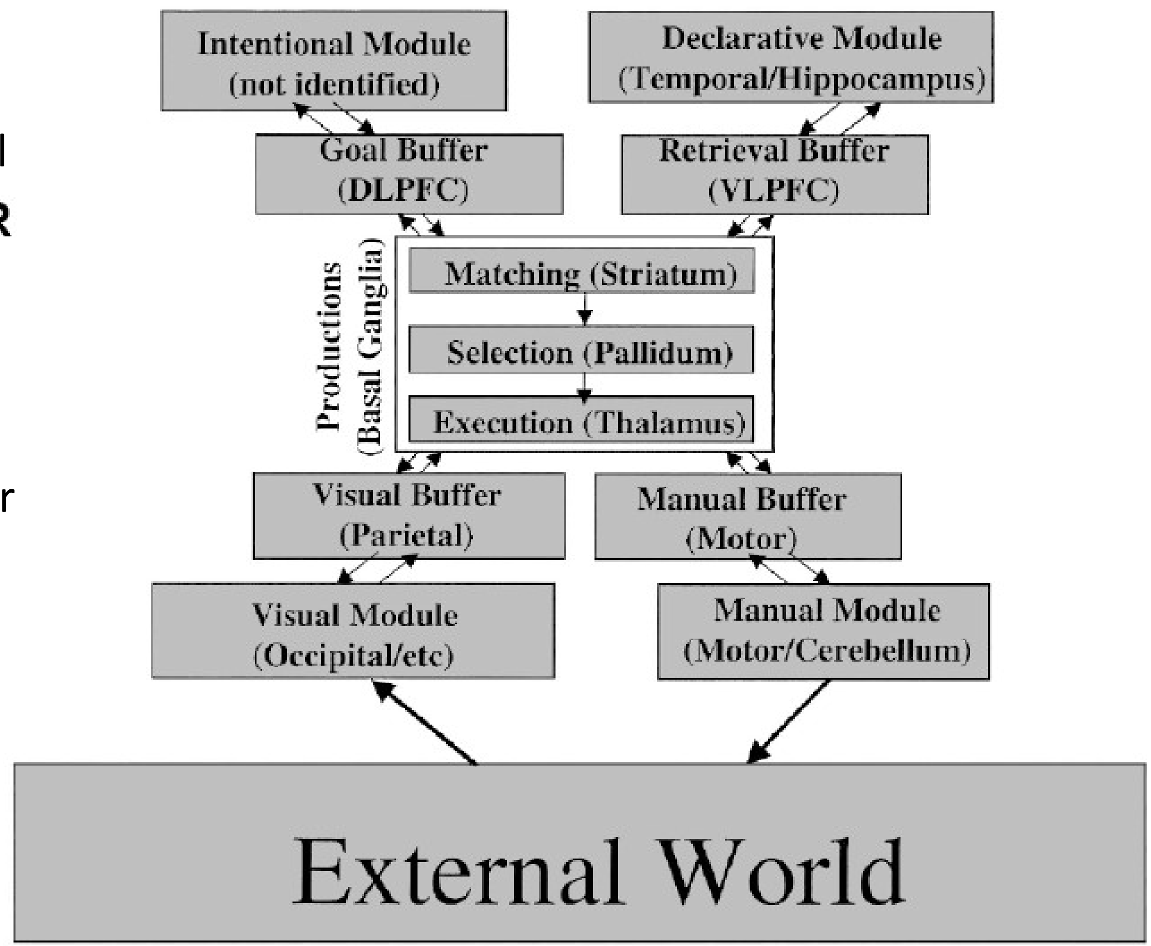
Embodied Agent: used to control robots

Two memories: procedural and associative

The pattern matcher searches for a production that matches the current state of the buffers

ACT-R cognition as a succession of production firings.

ACT-R



Prime Architetture Cognitive: SOAR (1987)

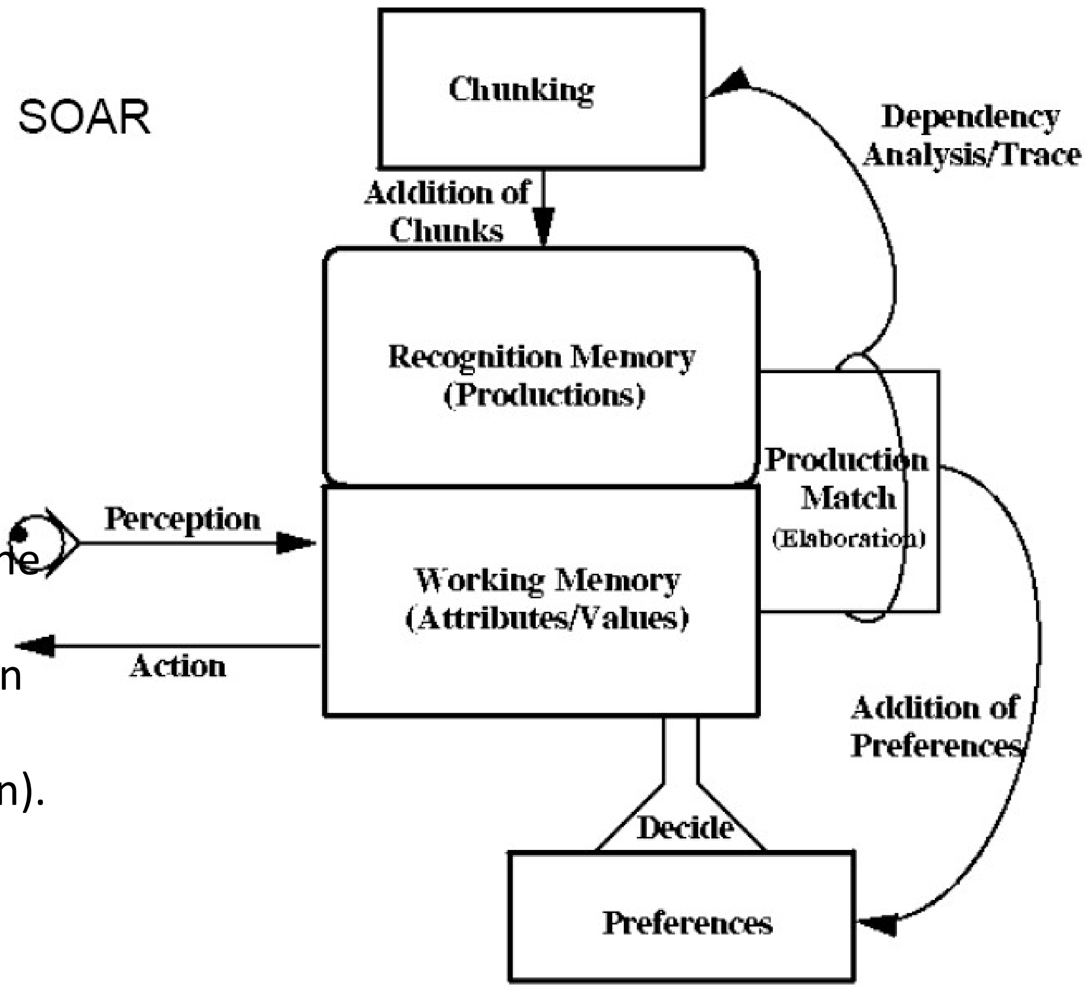
Cognitive plausability:

Production rules and goal-oriented tasks

Soar based on a production system: explicit production rules to govern its behavior

Decision cycle: elaboration phase (knowledge bearing the problem are brought to working mem) and a decision procedure (preferences to decide the action to be taken).

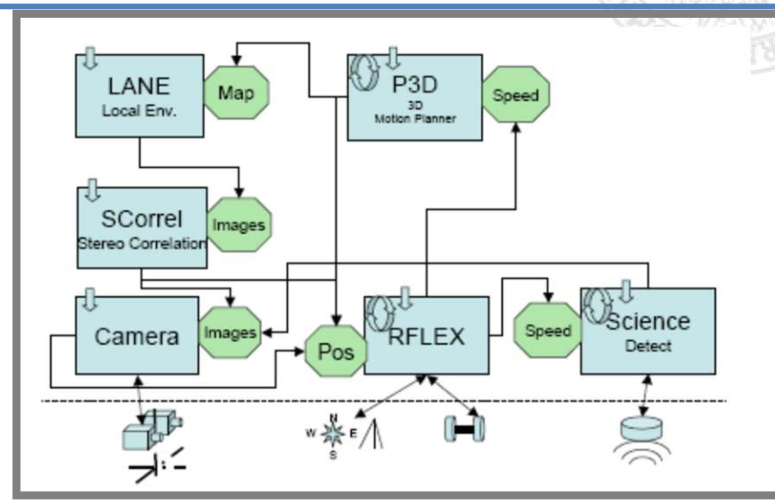
SOAR



Functional

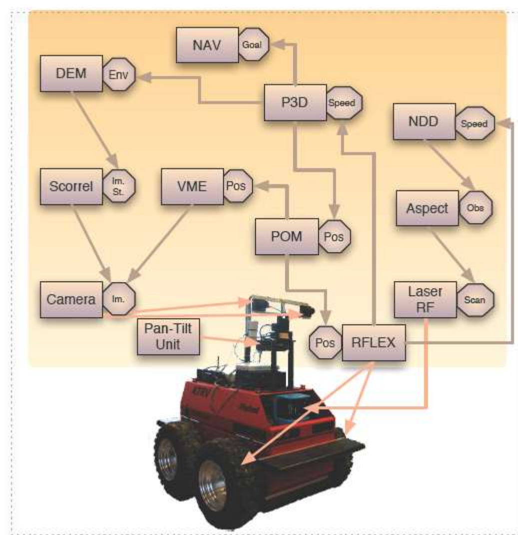
Functionalities

- Avoidance
- Mapping
- Localization
- Navigation
- Perception/recognition object,situation,place,...
- Object manipulation
- Visual perception
- Human-robot interaction
- ...



Esempio: GENOME functional layer

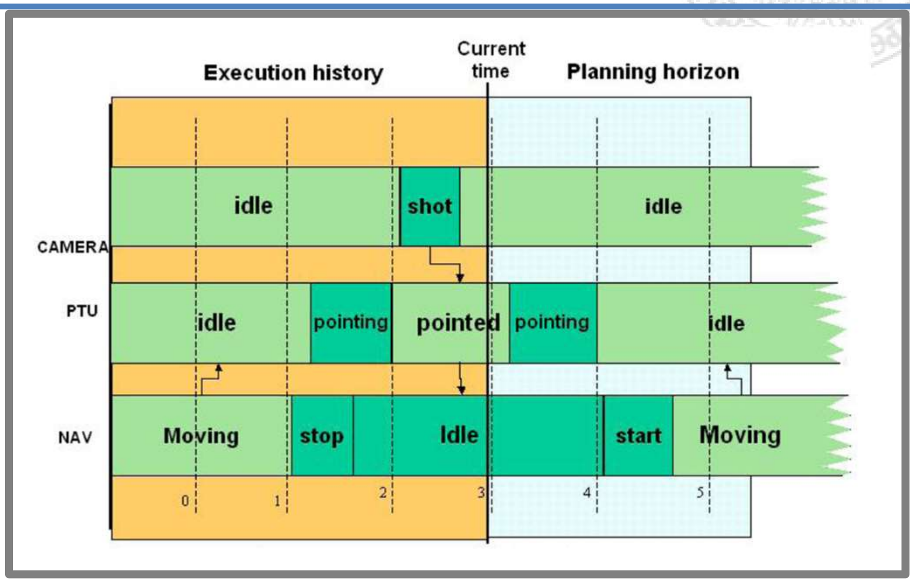
Livello funzionale in



Deliberative layer

Meccanismi di decisione:

- Task planning
- Reactive/Dynamic Planning
- Path Planning
- Temporal, dynamic reasoning,etc.
- Decision Making



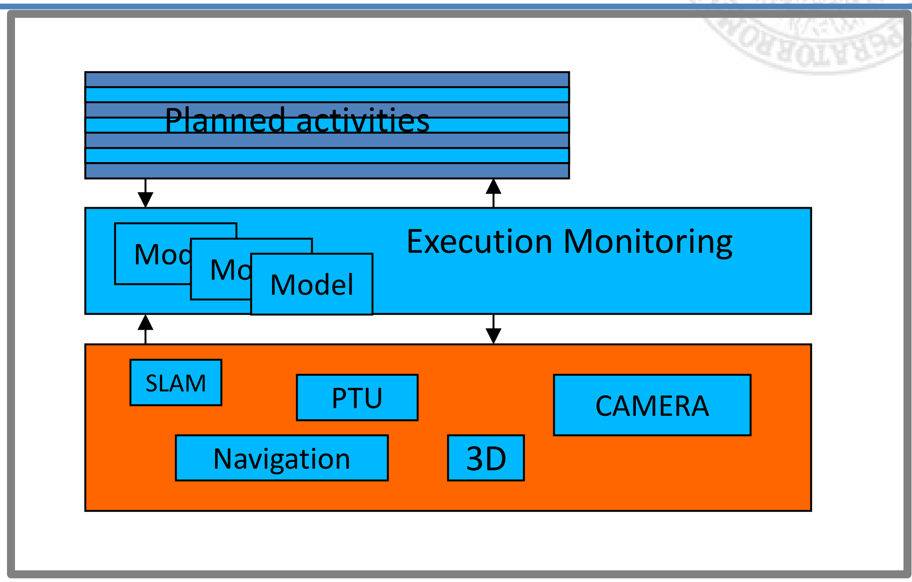
Esempio: Timeline-based Planning

- Environment models (maps, constraints, cause-effects, dynamics, etc.)
- Robot Models (sensor/actuator)
- Decision Models (utility, costs etc.)
- Interaction Models (HRI)

Executive Layer

Between functional and deliberative:

- Sensory-motor coordination
- Deliberative-reactive coordination
- Execution monitoring
- Error detection, diagnosis and recover
- Adapt/Rapair/Replanning



Issues

Functional, Deliberative and Executive layers

- Functional layer:

Mobile robotics and probabilistic robotics (mapping e localizzation, navigation, exploration, etc.).
Bayesian models, bayesian filters

- Executive layer:

Execution monitoring and dynamic planning; cognitive control and attentional systems.
Temporal models, automata, cognitive models etc.

- Deliberative layer:

Planning and scheduling; planning and execution; decision theoric planning; reinforcement learning.
Temporal models, markov models, etc..

Tools

- Laboratorio PRISMA, PRISCA,
- Centro ICAROS