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 (E4)
  - Mercoledì 14:00 16:00 (E4)

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

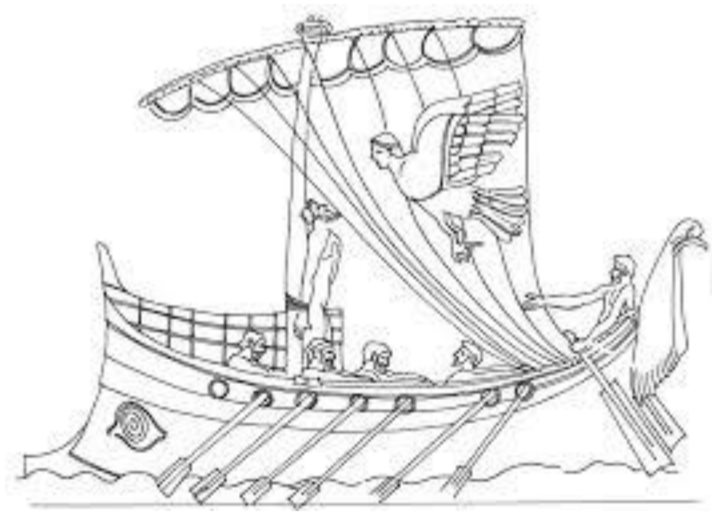
- **Autonomous:**
  - Greek: Automaton (auto + matos)
    - auto: self
    - matos: thinking, animated, willing

- **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

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

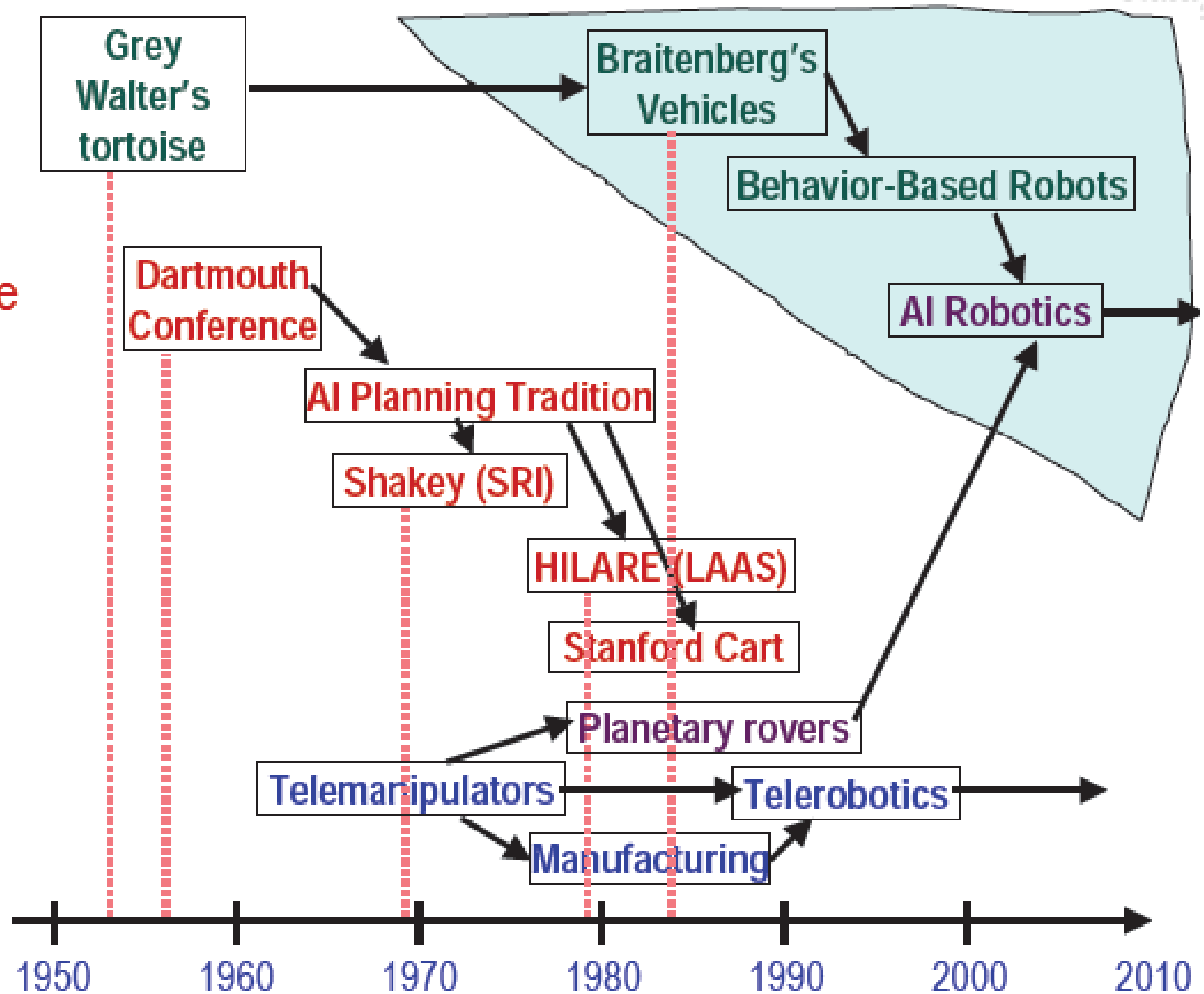


- High-Level Control (Governance)
- Low-Level Control (Control)

- 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
  - …

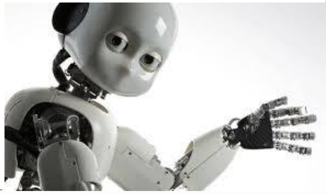
Autonomous Robots

- 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.

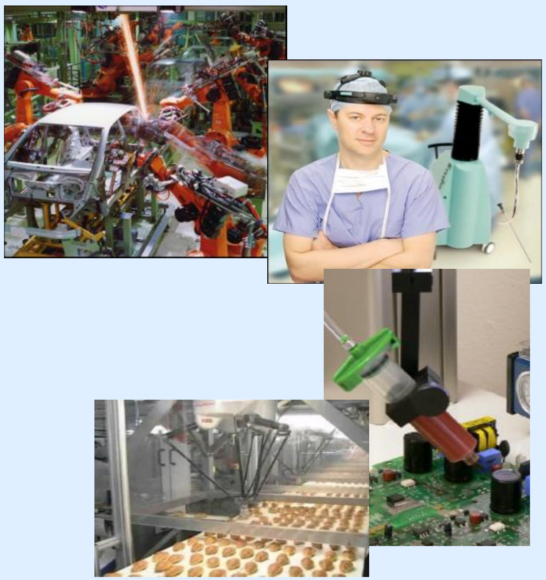
Autonomous Robots

Structured, controlled

Unstructured, unmanned, autonomous

Unstructured, proactive, interactive

Industrial



Manufacturing
Mining
Surgery

Field

Aerospace
Underwater
Rescue

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



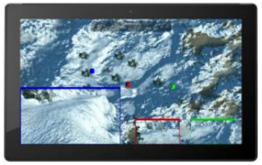

Interazione Uomo-Robot per il Soccorso Alpino

Interazione Uomo-Robot per il Soccorso Alpino

- Squadra di droni per il soccorso alpino









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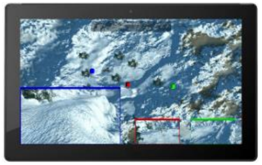
Interazione Uomo-Robot per il Soccorso Alpino

- Squadra di droni per il soccorso alpino



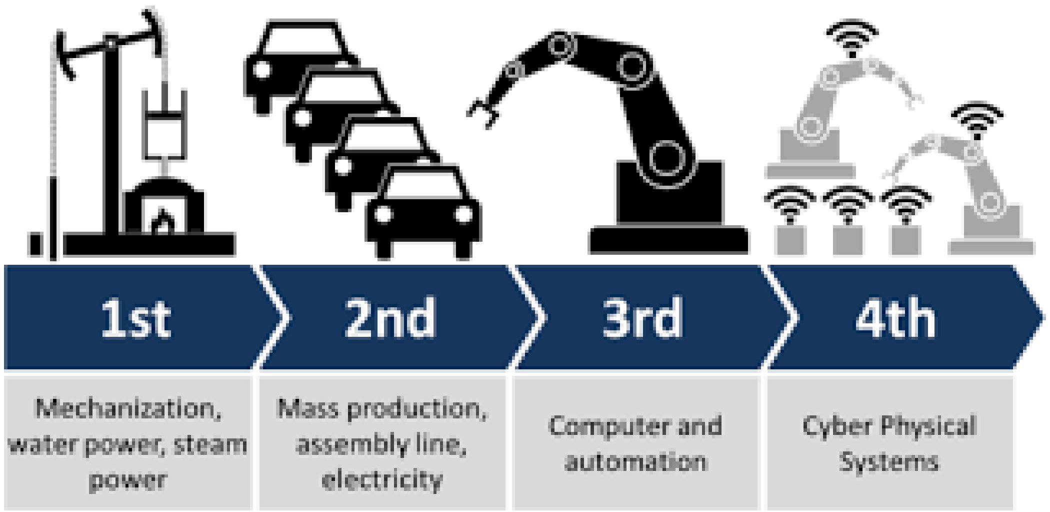




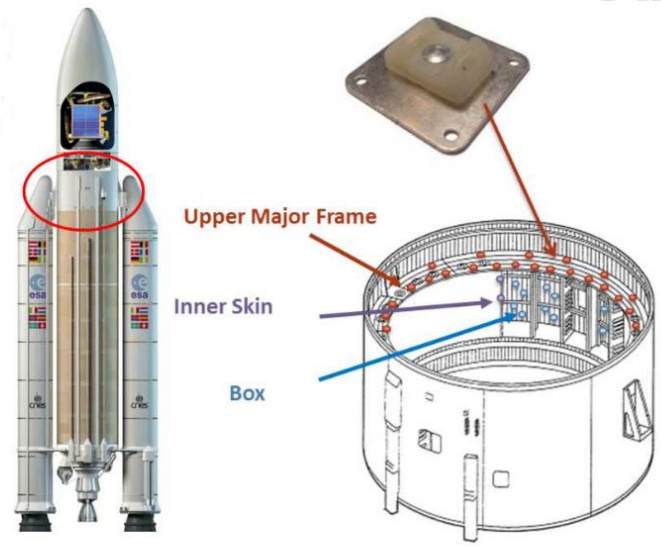
Autonomous Robots

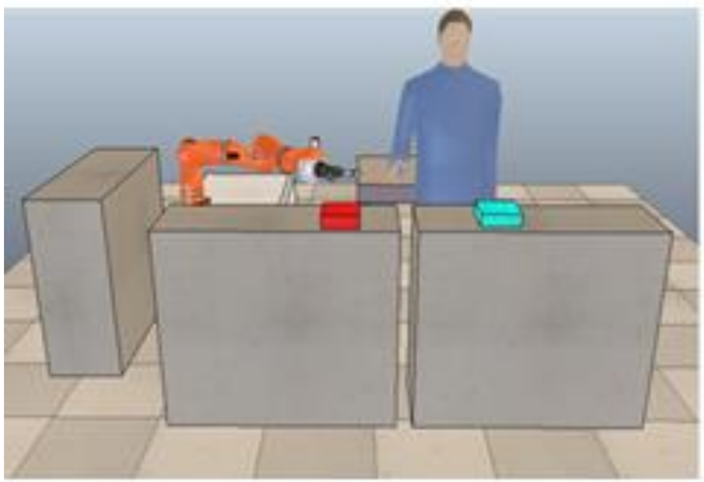
- Robot co-worker (Cobot, Industry 4.0)
  - Smart production, advanced manufacturing solutions
  - Customization of products, flexibilized mass-production



Interazione Uomo-Robot in Contesto Industriale

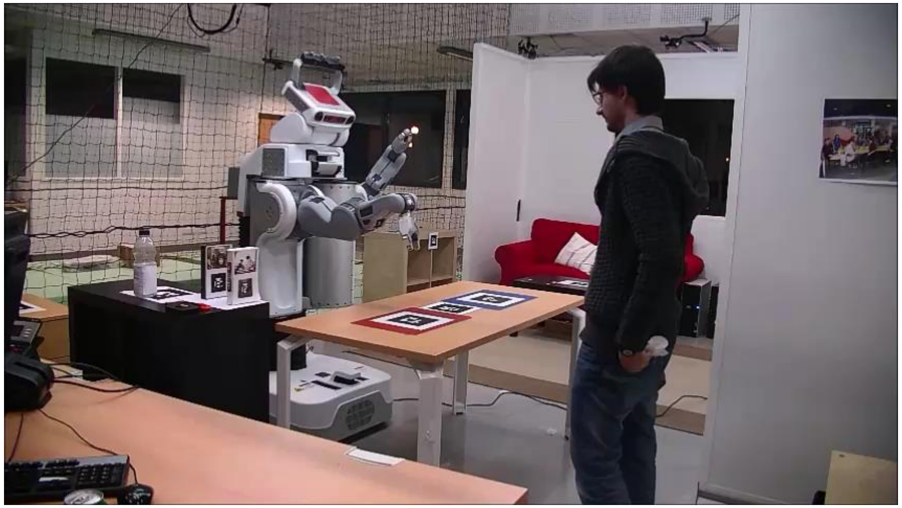
- Contesto Industriale:
  - Robot co-worker
  - Ariane 5 Launcher



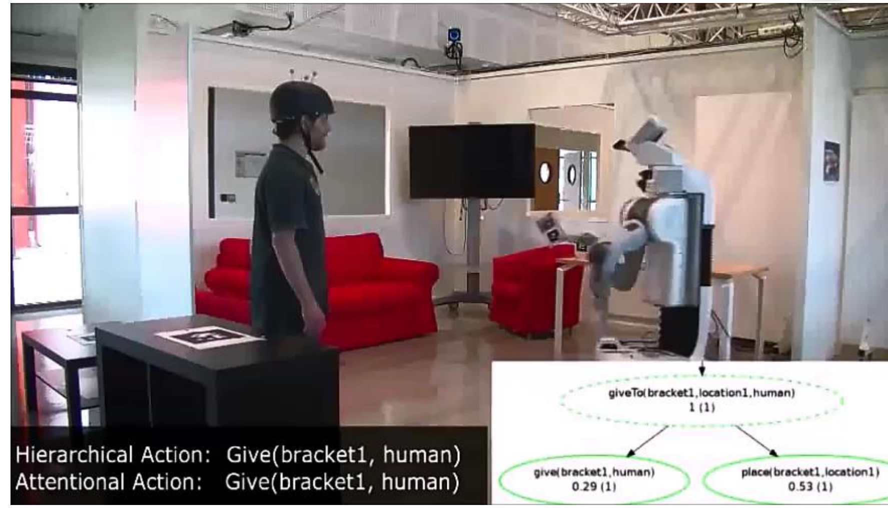


- Compiti di Installazione:
  - L'uomo ed il robot collaborano nell'installazione.
  - Il robot porta material ed indica dove posizionarlo.

Autonomous Robots



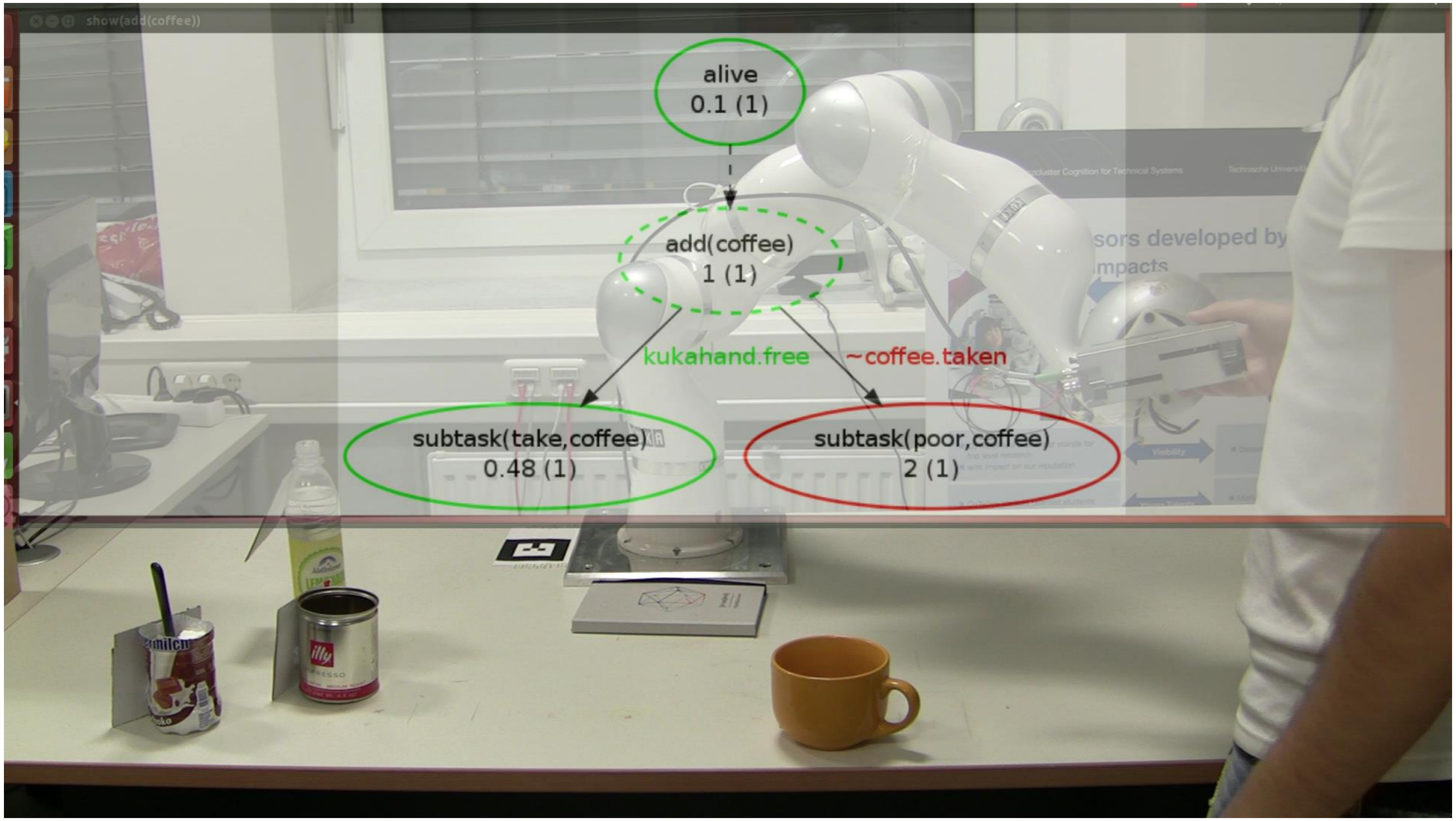
Multimodal Interaction



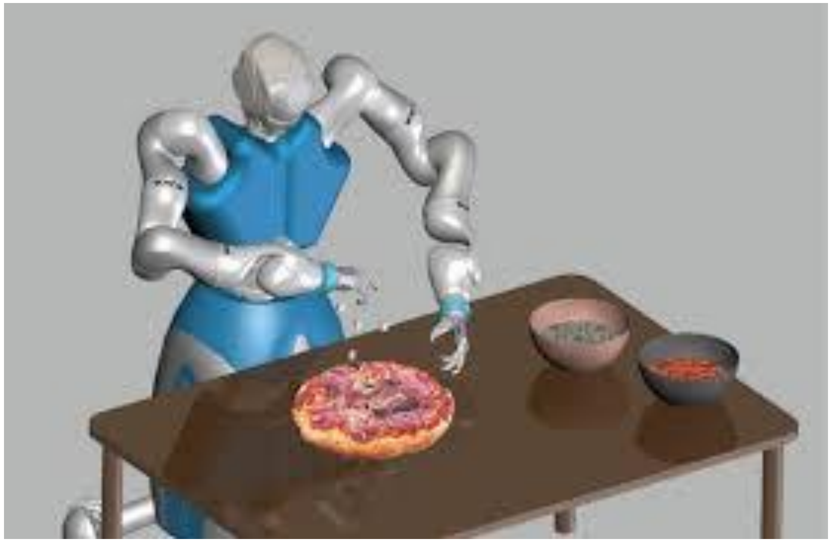
Unexpected Events

- 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.

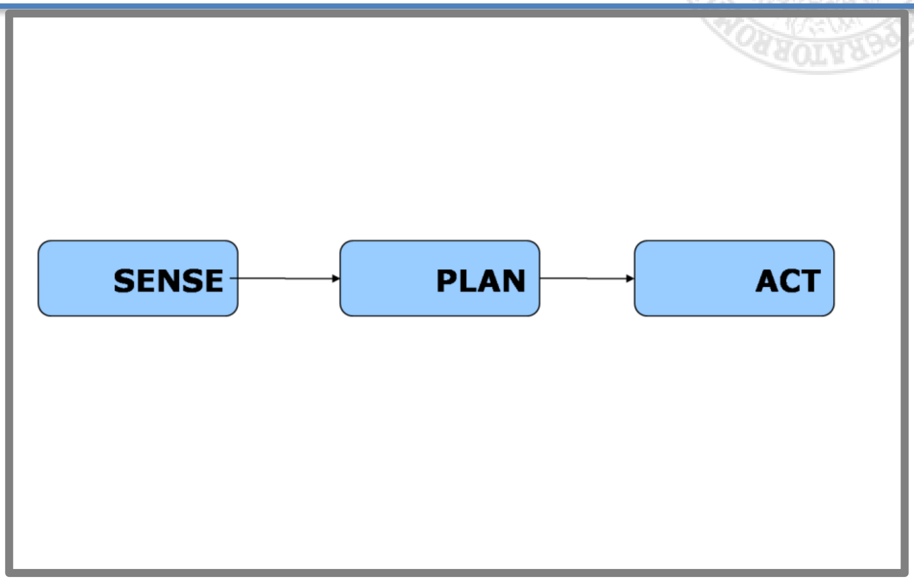
Autonomous Robots: Paradigms

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)

Classical Paradigm

Hierarchical Architecture

Knowledge Representation and formal reasoning (logic+deductive)

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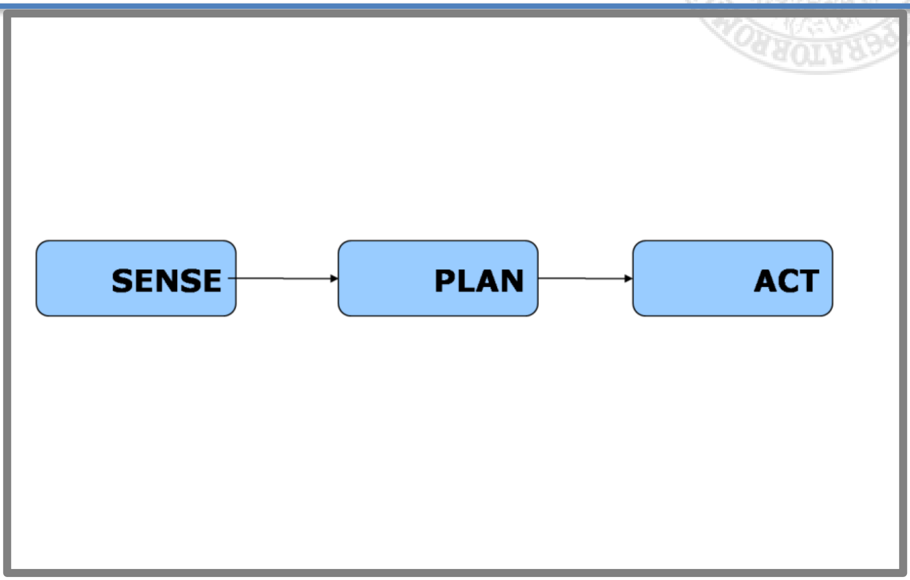
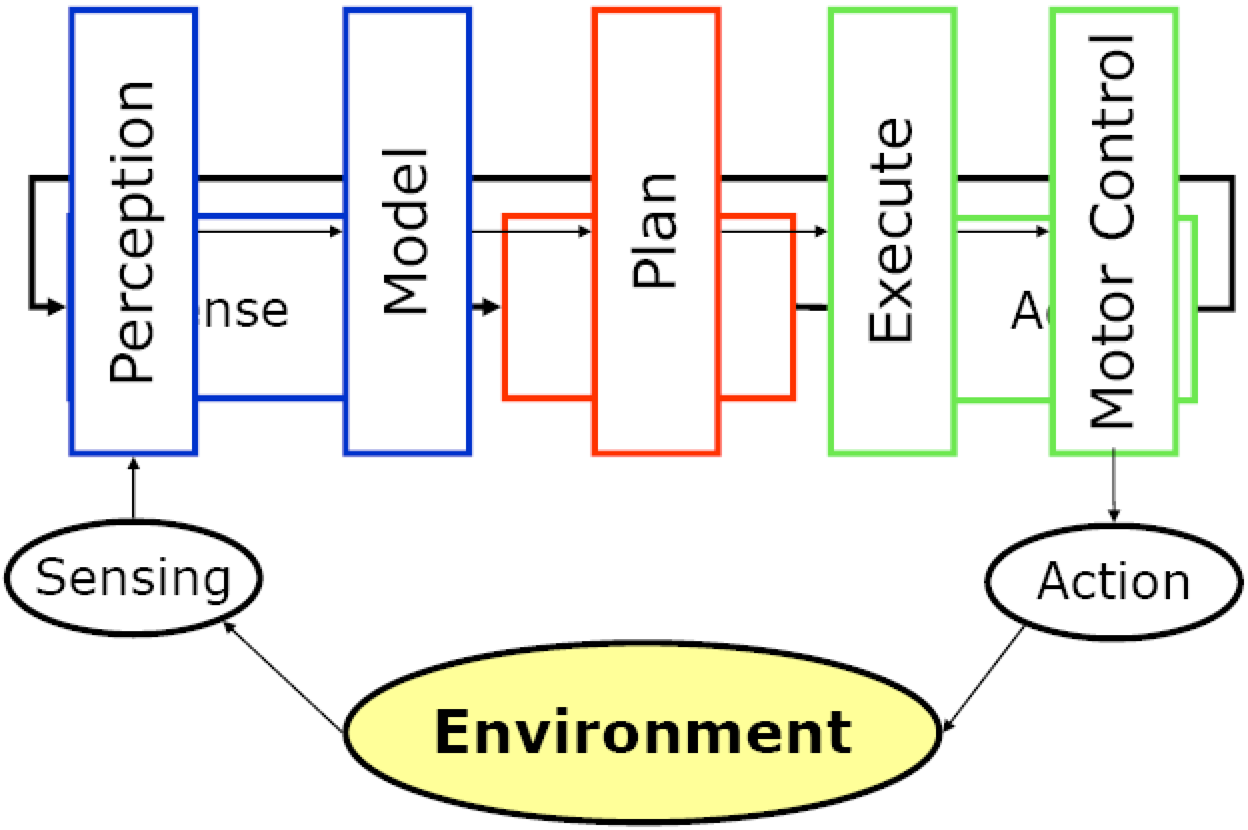


Classical Control Schema

Stanford AI Laboratory / CMU (Moravec)

Classical Paradigm as Horizontal/Functional Decomposition



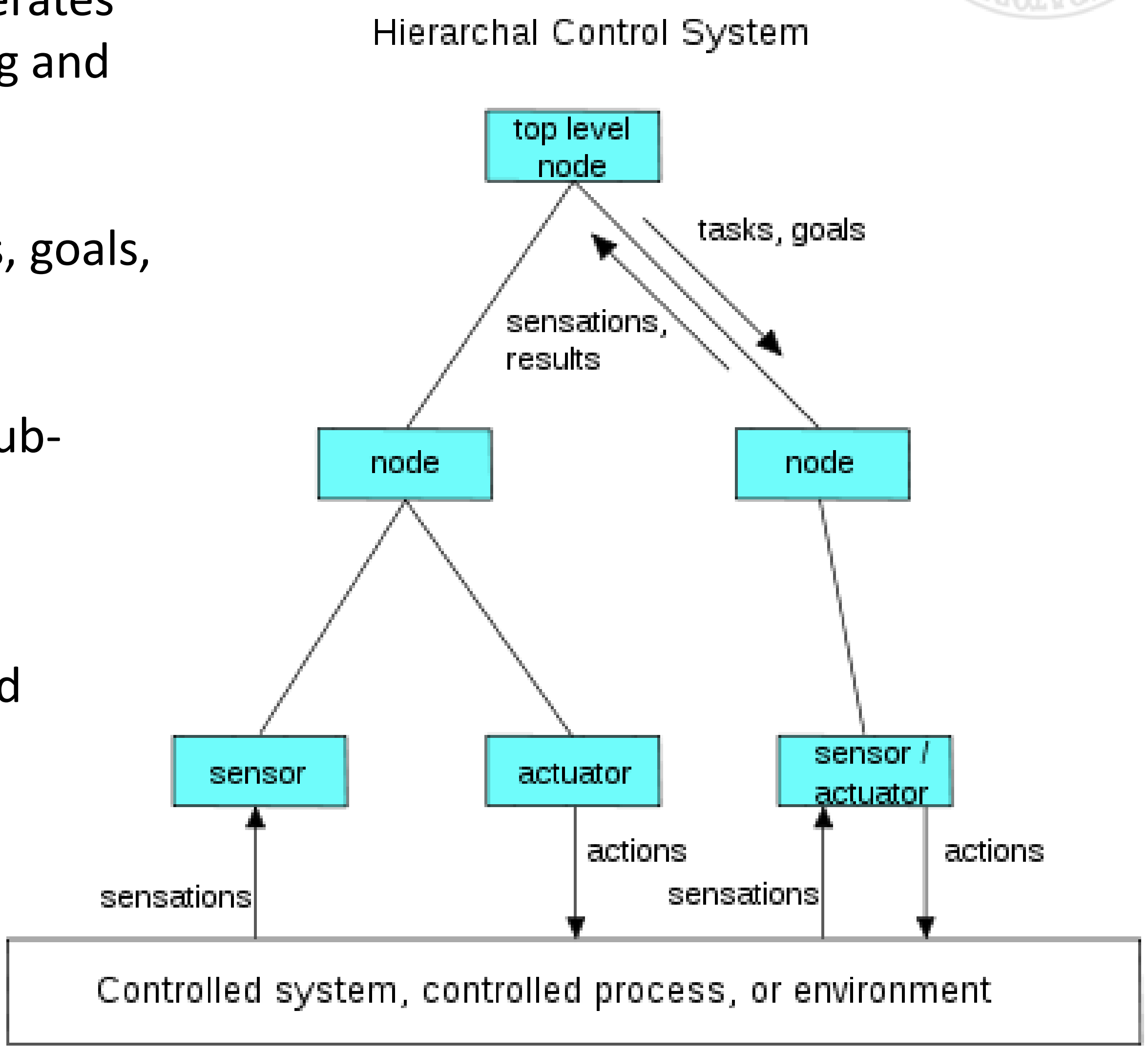
Hierarchical Paradigm

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

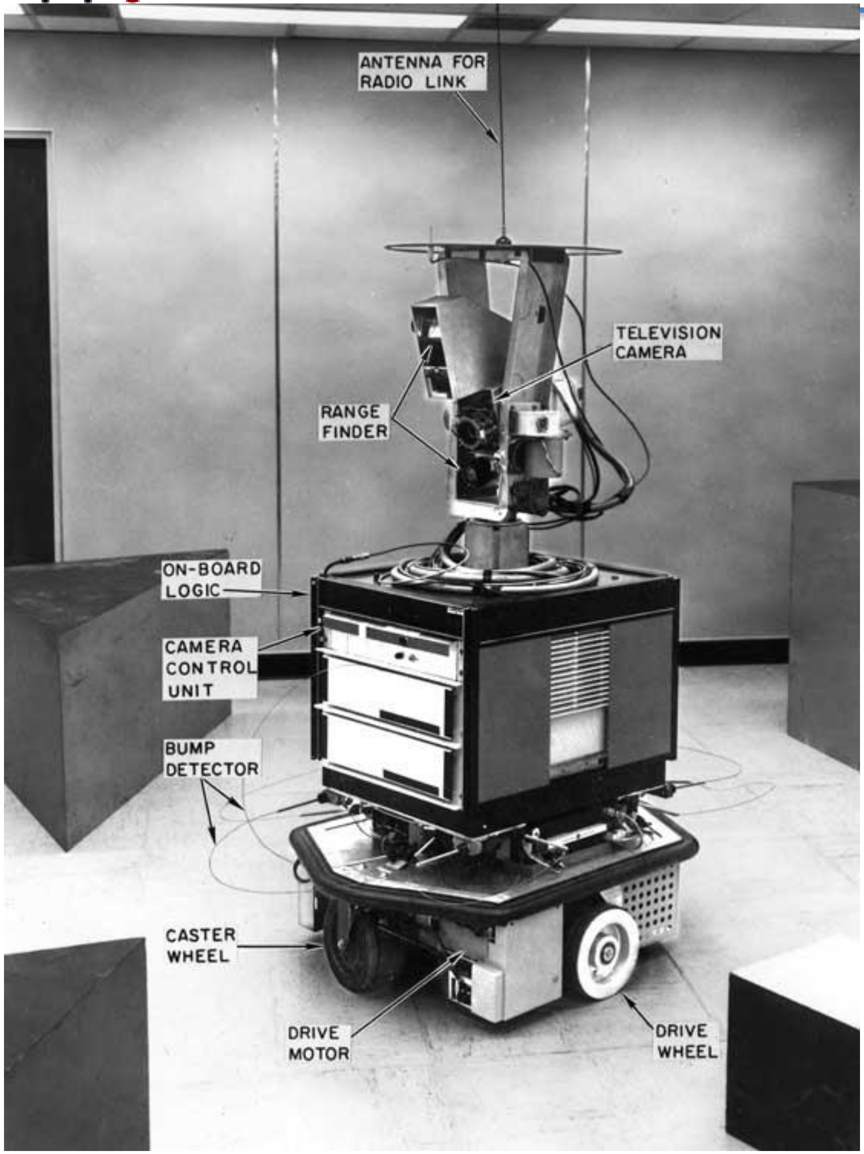
The lower layers have local tasks, goals, and sensations

The lowest, reactive layers are sub-symbolic.

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

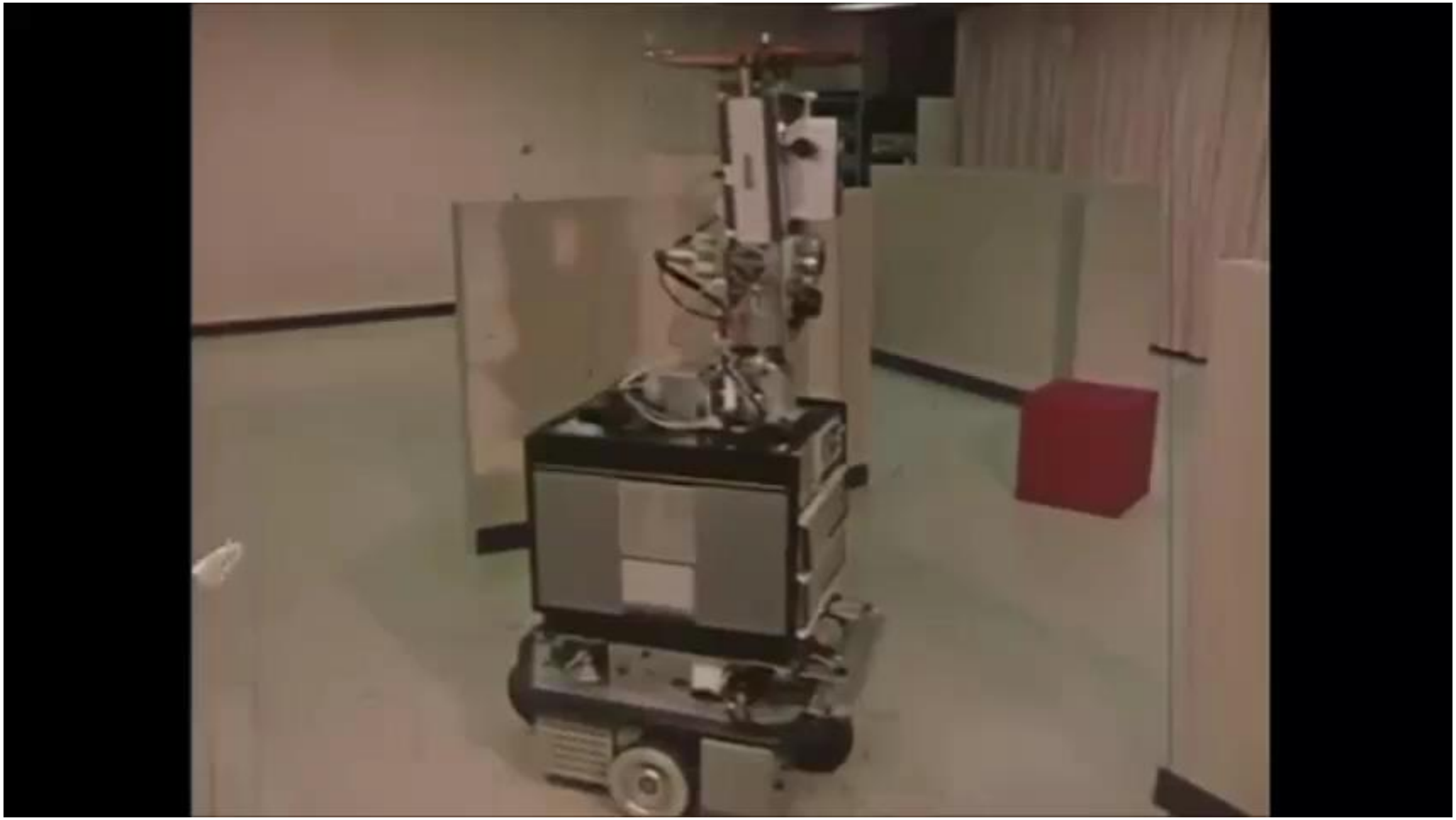


1970-Shakey the robot



- 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



Reactive / Behavior-based Paradigm

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

Reactive Paradigm

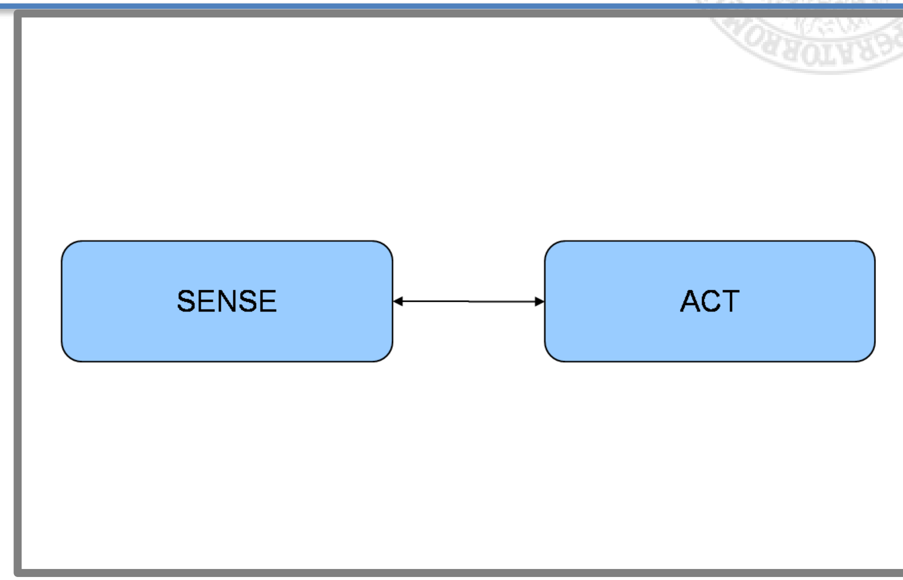
- Situated:
  interacting with the env.

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

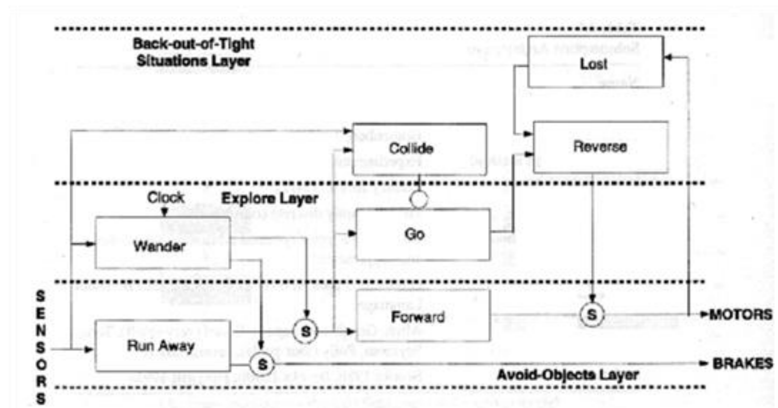
- Behavior-based:
  sense e act coupled and
  associated with the behavior (Fixed
  Action Patterns)

  - Subsumption Architecture
    [Brooks 1986]

  - Potential Fields



Sense-Act Paradigm



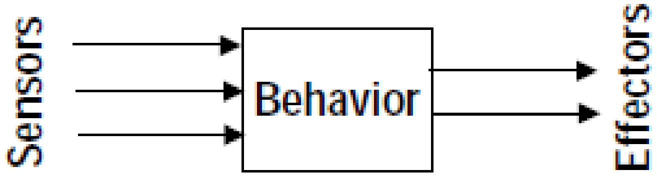
Reactive Paradigm

- 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

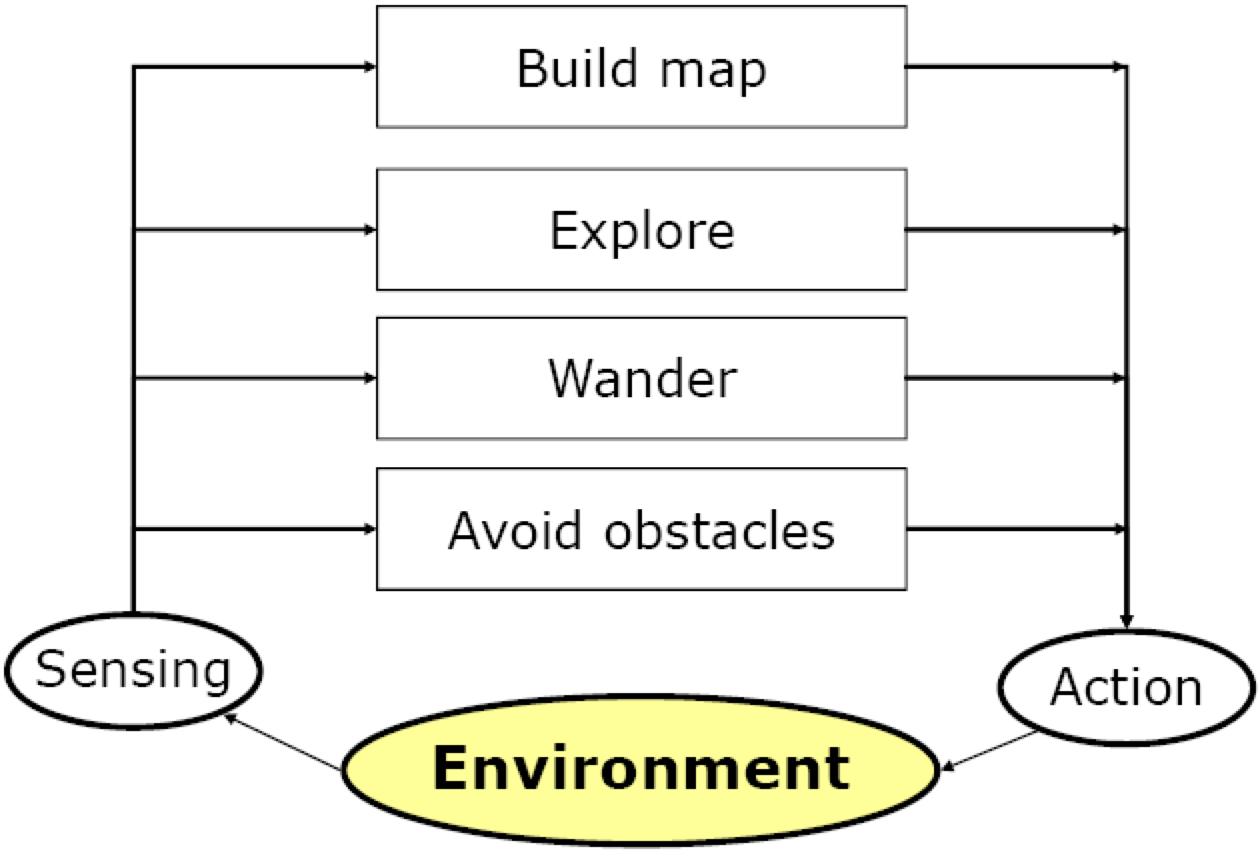
Lorenz

- 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).

DIETI

Behaviors

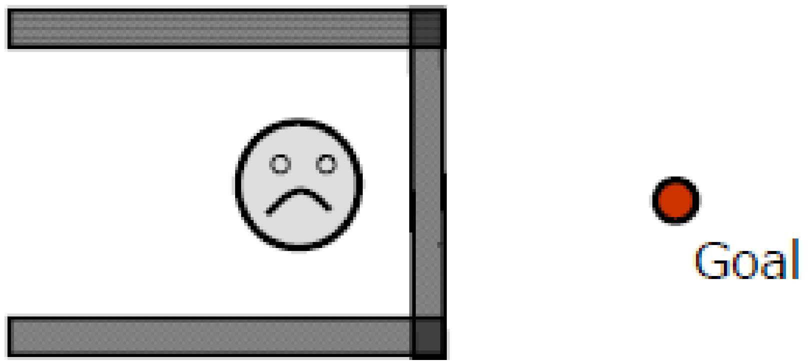
- … are a direct mapping of sensory inputs to a pattern of motor actions that are then used to achieve a task.
- … serve as the basic building block for robotics actions, and the overall behavior of the robot is emergent.
- … support good software design principles due to modularity.

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

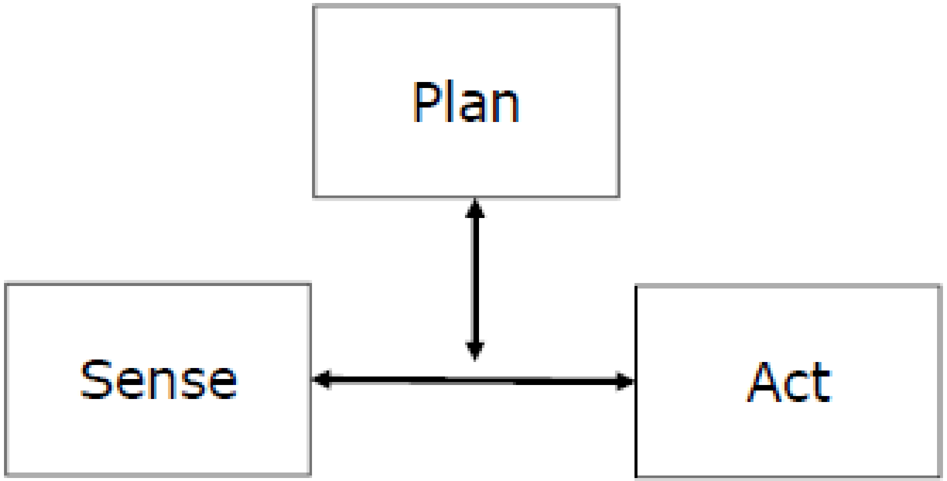


  - Backtracking
  - Random motion to escape local minimum
  - Procedural planner s.a. wall following
  - Increase potential of visited regions
  - Avoid local minima by harmonic functions

Reactive Paradigm

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

Hybrid Deliberative/reactive Paradigm



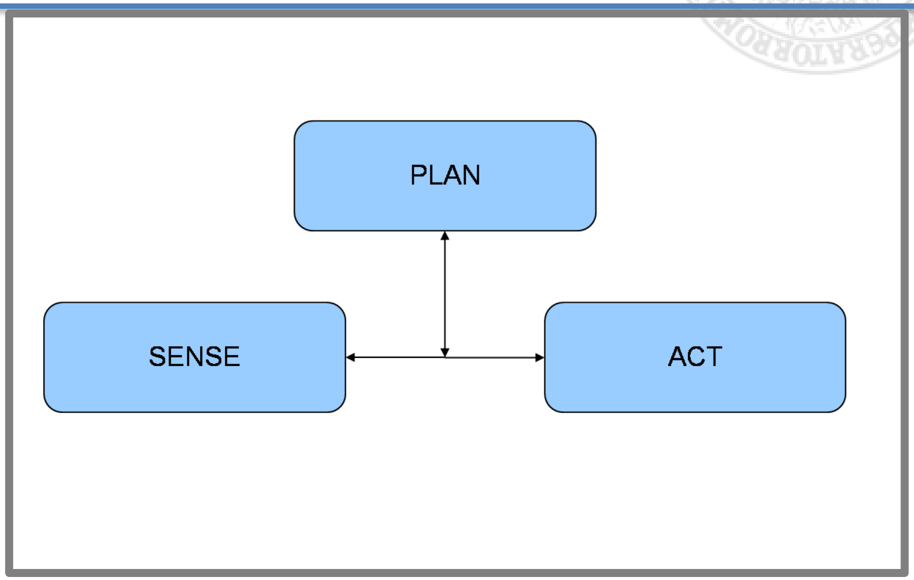
- Combines advantages of previous paradigms
  - World model used for planning
  - Closed loop, reactive control

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.



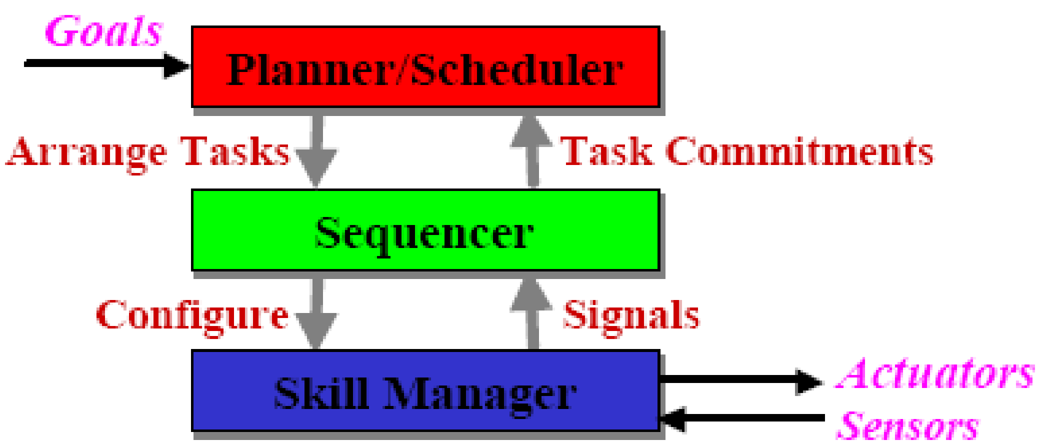
Sense-Act + Plan

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



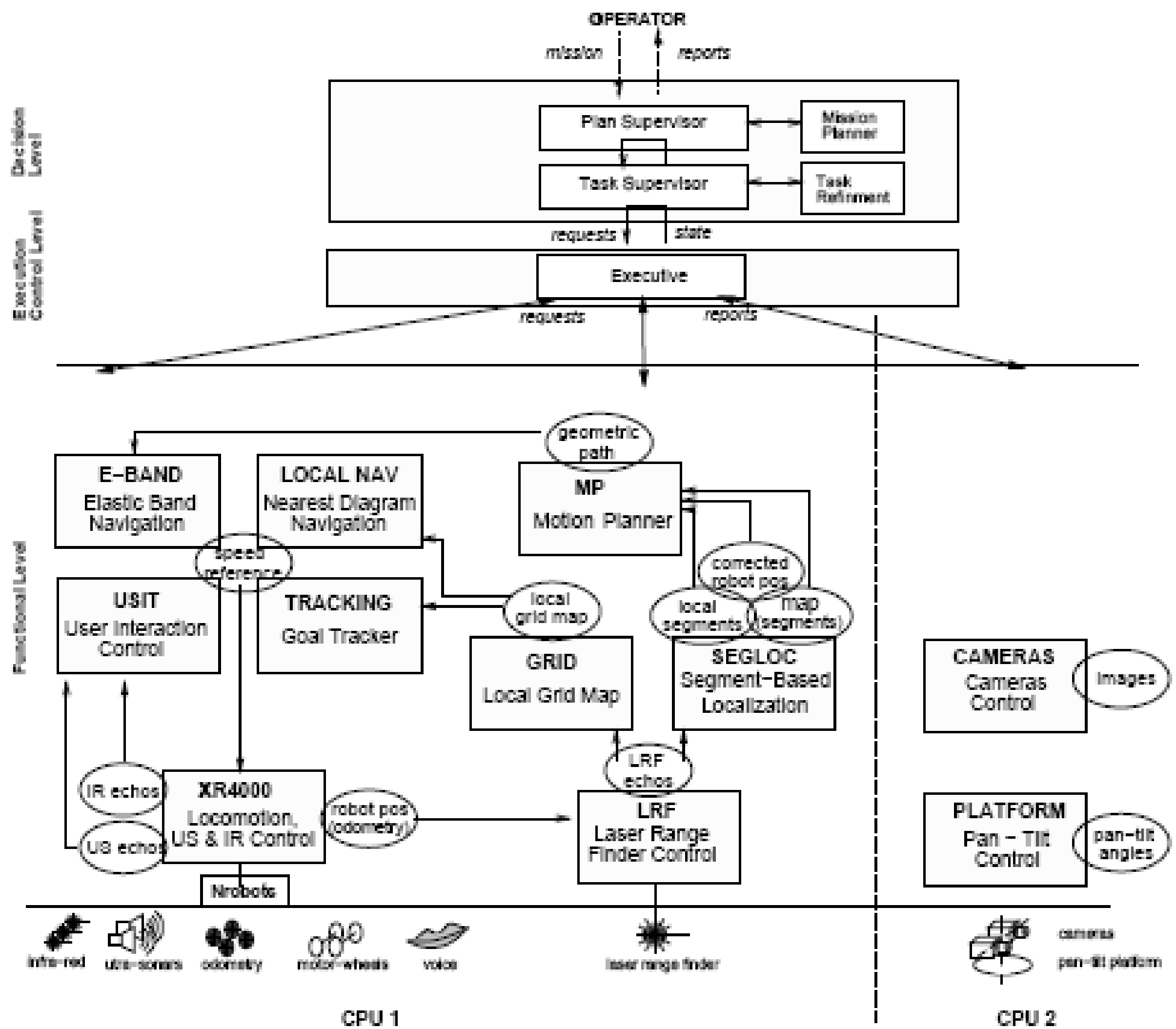
3T Architecture

- LAAS architecture:

Three Layers:

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

Rover Control

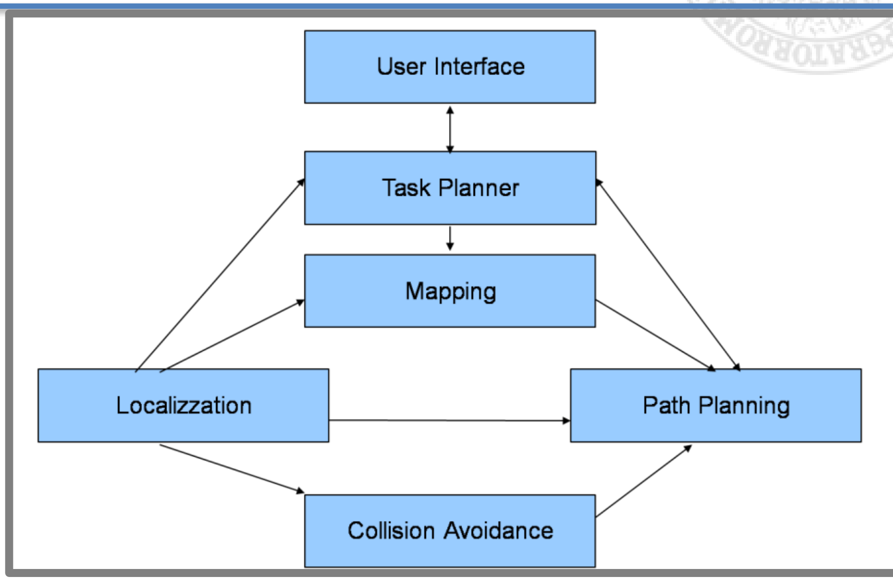


RHINO Architecture

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)



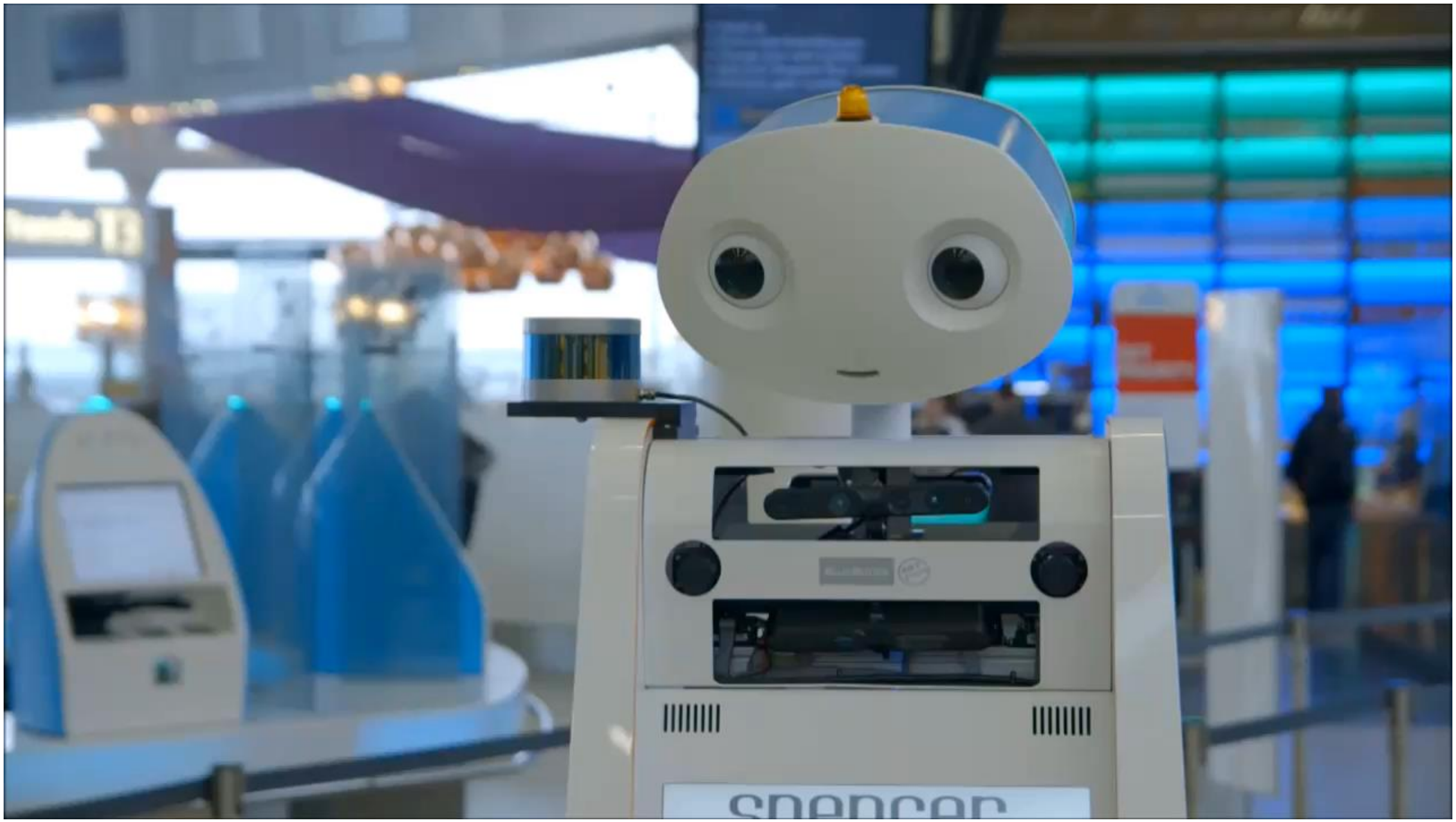
RHINO Architetture

Rhino, 1997

Minerva, 1998


The Minerva Experience

- Social Robot in populated environments



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

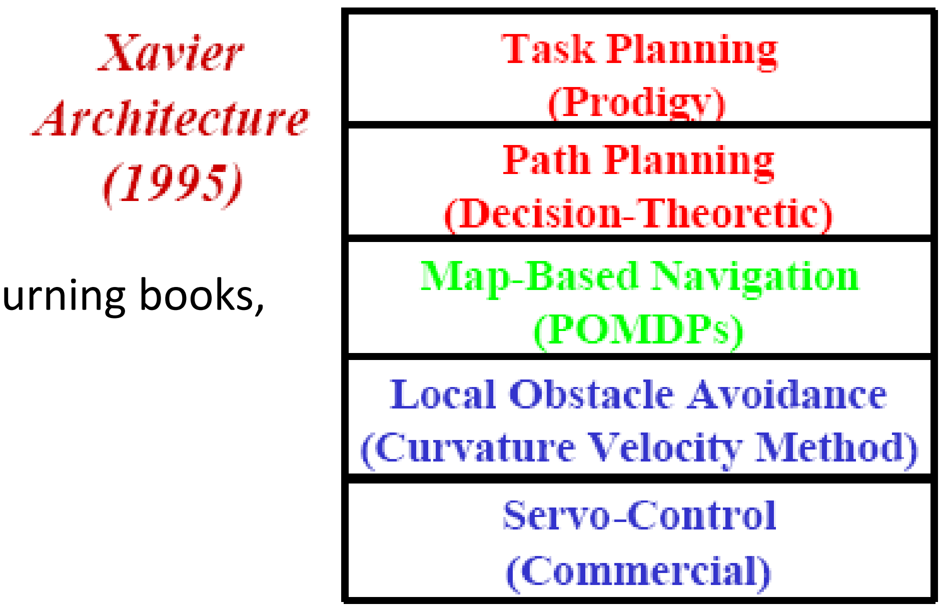
Xavier Architecture (1995)

-Low-level control: high resolution, high frequency

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

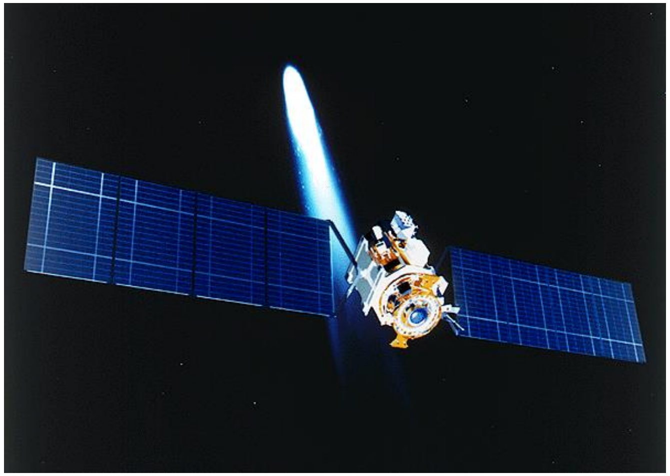
Office delivery robot:
picking up and delivering mail or faxes, returning books, getting coffee.

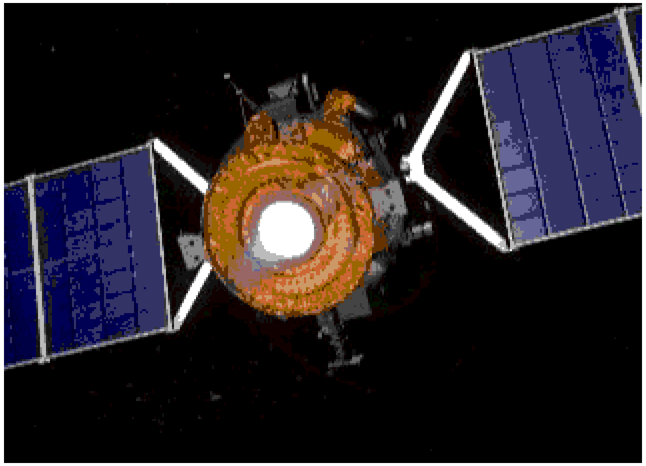
The layers are independent,
always active



DS1 (Remote Agent)

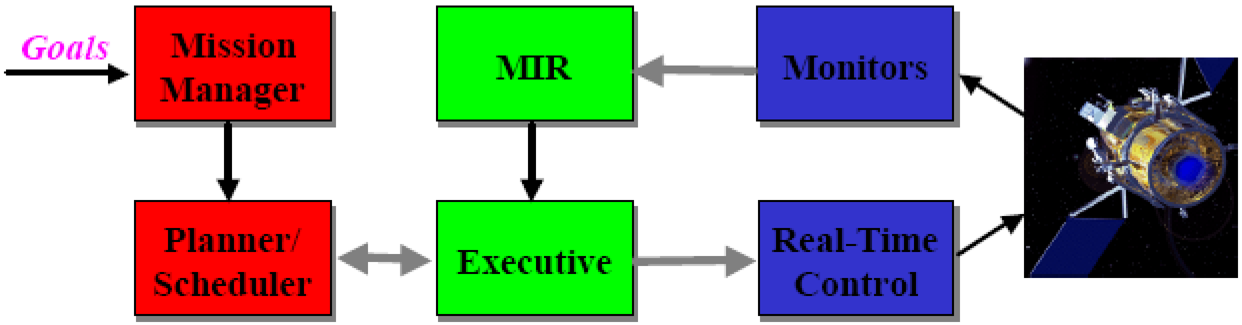
- Mission: testing new technologies for the New Millennium Program (and observe Borrelly comet)
- First autonomous spacecraft
- Planner and smart executive system (RAX: Remote Agent Experiment).
- Planning, scheduling, adaptive execution, diagnosis, recovery.



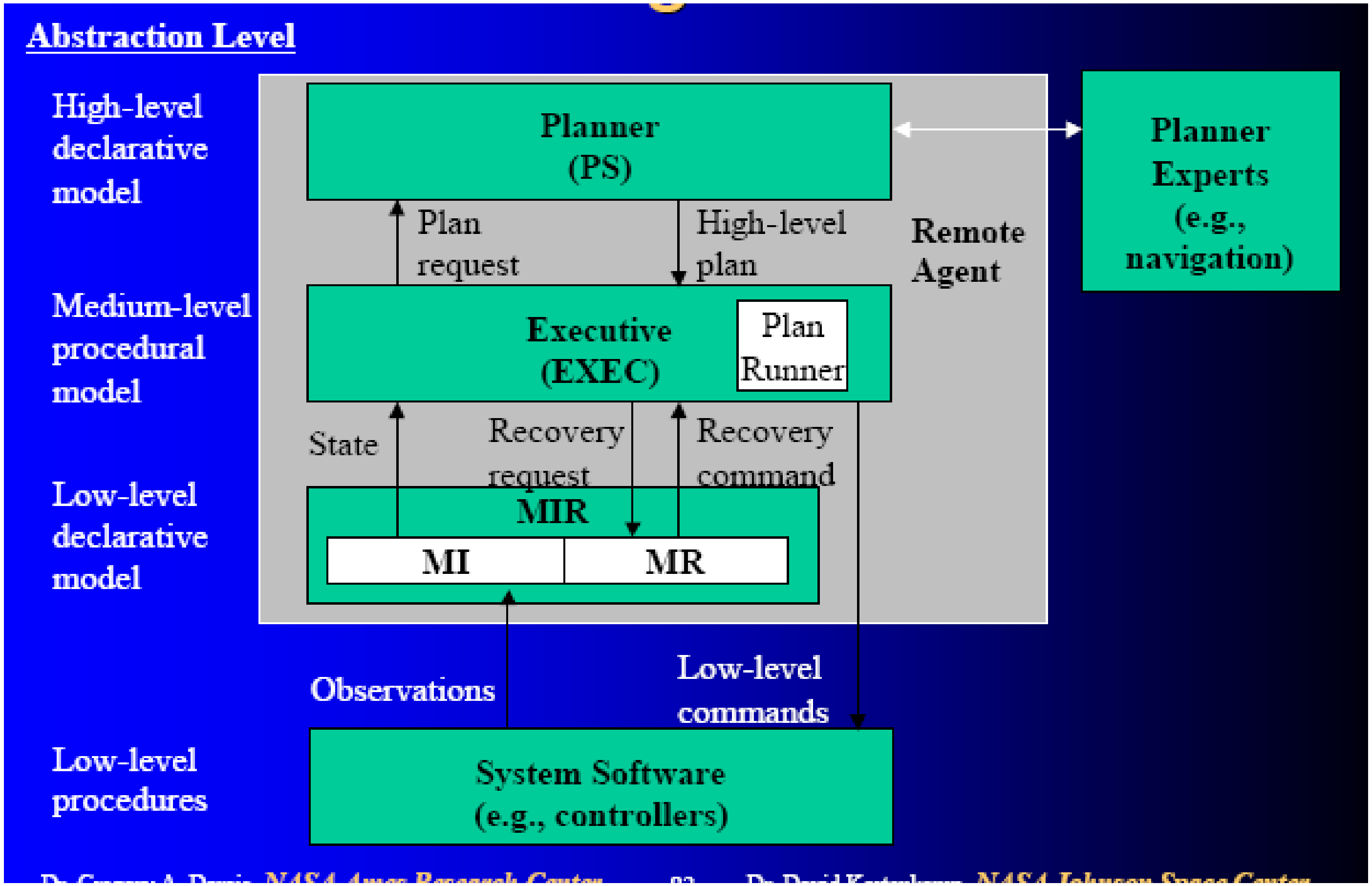


3T: REX

- 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)

- 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

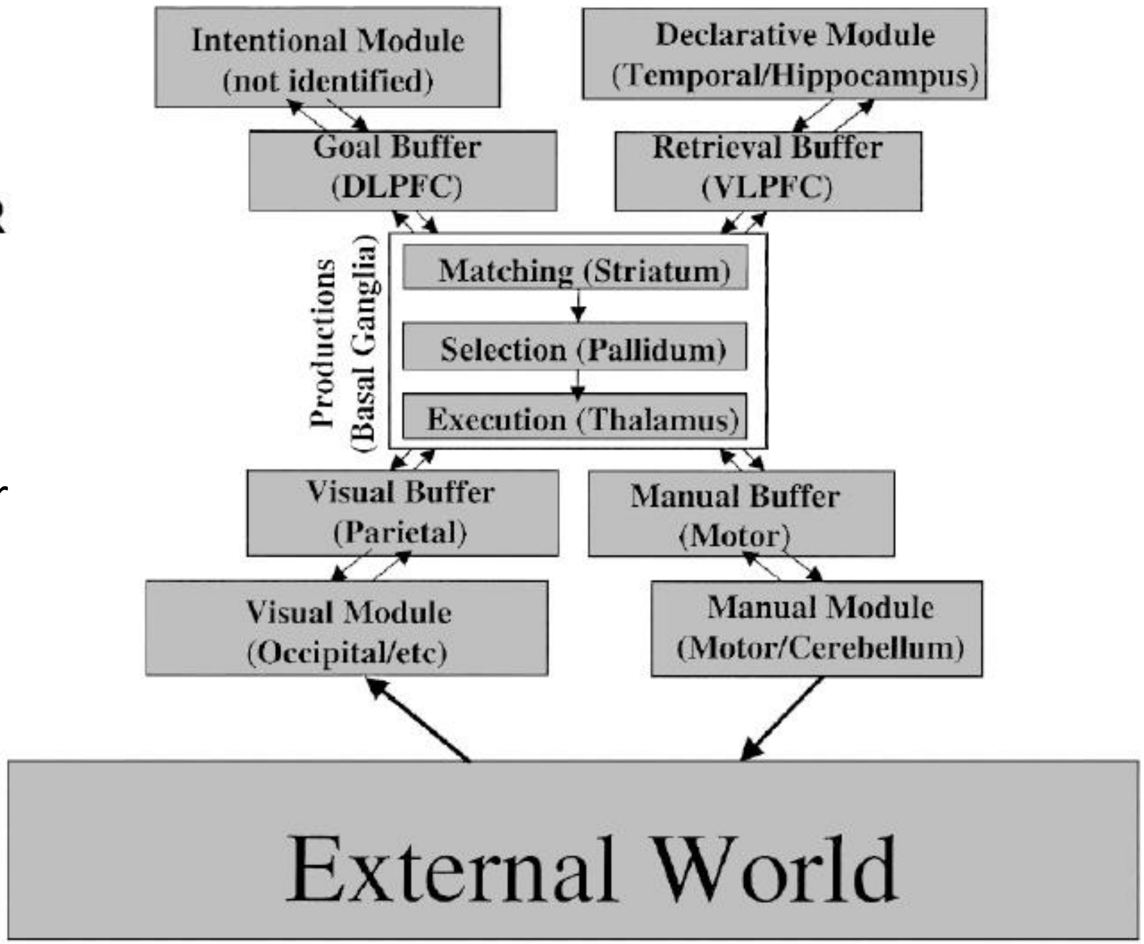
Embodied Agent: used to control robots

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



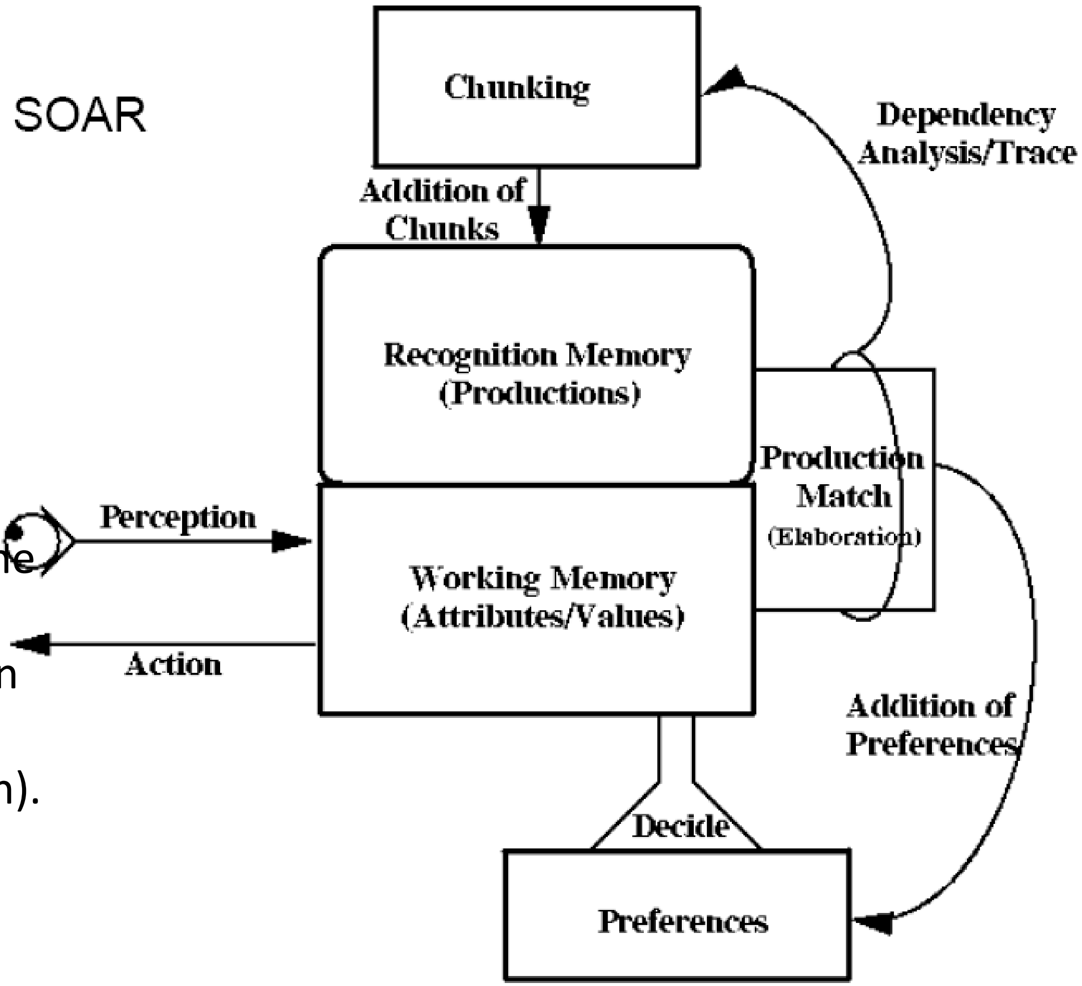
Prime Architetture Cognitive: SOAR (1987)

Cognitive plausability:

Production rules and goal-oriented tasks

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

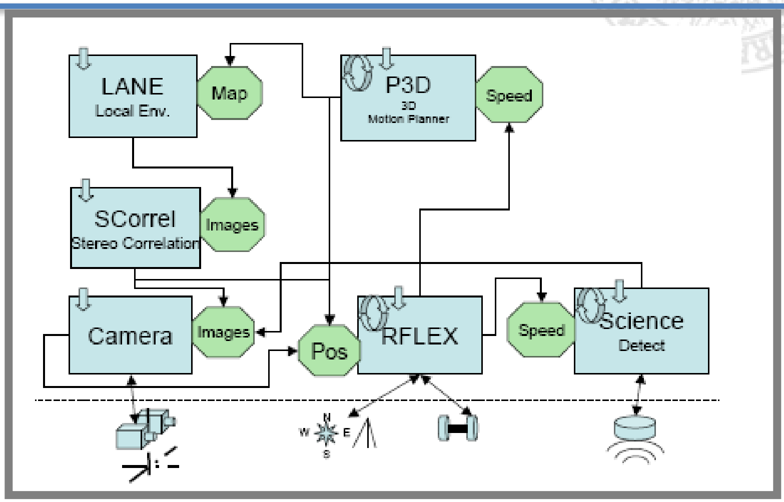
Decision cycle: elaboration phase (knowledge bearing the problem are brought to working mem) and a decision procedure (preferences to decide the action to be taken).



Functional

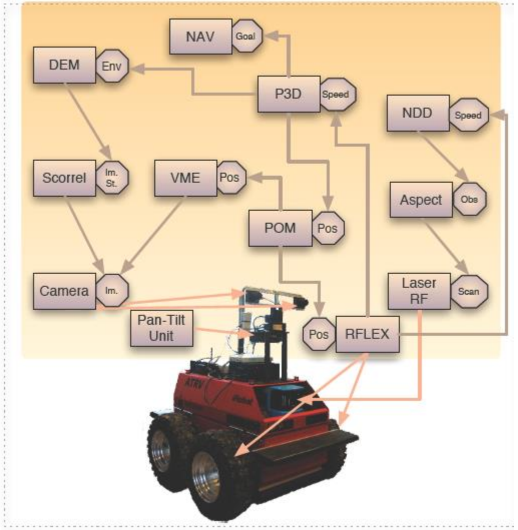
Functionalities

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



Esempio: GENOME functional layer

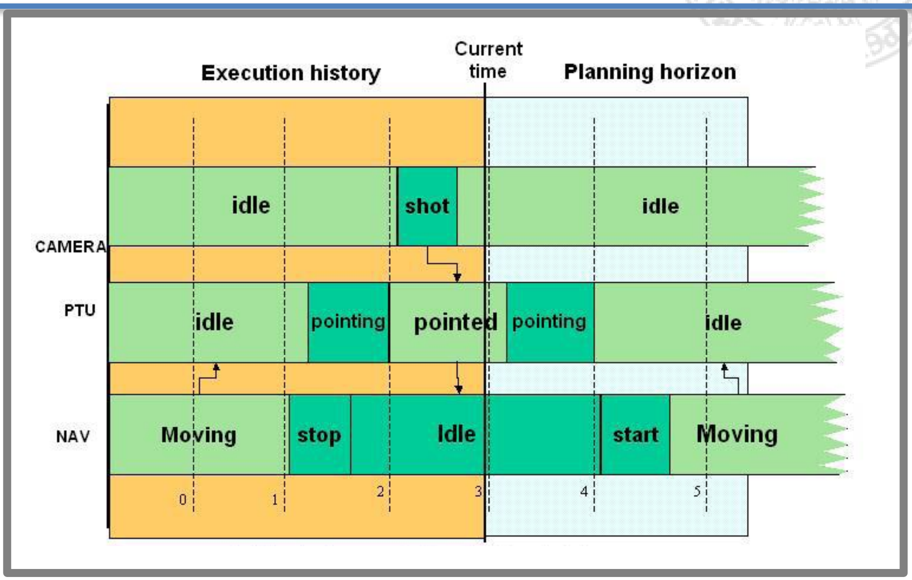
Livello funzionale in



Deliberative layer

Meccanismi di decisione:

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



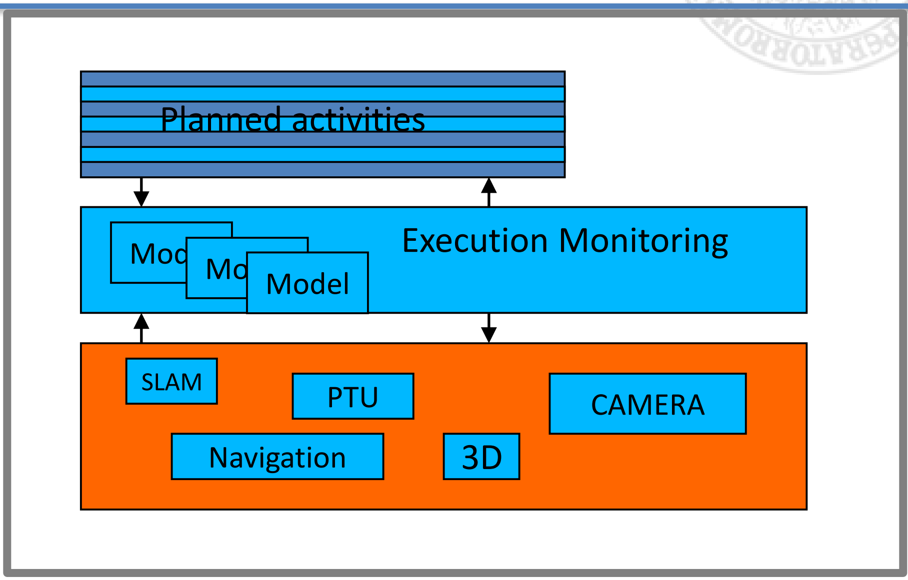
Esempio: Timeline-based Planning

- 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



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.

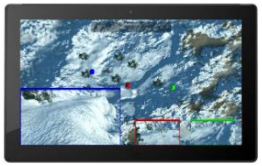
Temporal models, automata, cognitive models etc.

- Deliberative layer:

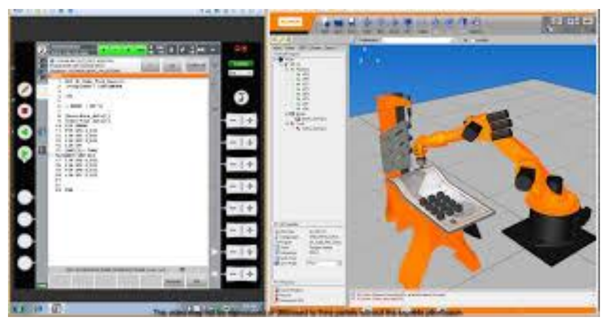
Planning and scheduling; planning and execution; decision theoric planning; reinforcement learning.

Temporal models, markov models, etc..

- Laboratorio PRISMA, PRISCA,
- Centro ICAROS



- Strumenti software



Proposta di Progetto

- Algoritmi di Ricerca Bayesiana in ambiente alpini
  - Progettazione ed implementazione di algoritmi di ricerca multiagenti per identificazione di vittime statiche/mobili
  - Possibili strumenti: Unity 3D, ROS, Path Planning, Bayesian Search Theory
  - Tematiche:
    - Simulazione ambiente
    - Modellazione dei robot
    - Algoritmi di ricerca
    - Simulazione della missione

Proposta di Progetti

- Sistema di riconoscimento delle attività dagli oggetti manipolati:
  - Riconoscimento attività e decisione con piani condivisi
  - Possibili strumenti: V-Rep, ROS, SCFG
  - Tematiche:
    - Simulazione del comportamento dell'Operatore
    - Simulazione del sensore
    - Interpretazione del comportamento dell'operatore a partire dalla sequenza di oggetti manipolati

Proposta di Progetti

- Interazione Uomo-Robot con interazione fisica:
  - Riconoscimento attività e decisione con piani condivisi
  - Possibili strumenti: V-Rep, ROS, (+ RGD-B e/o Oculus)
  - Tematiche:
    - Simulazione del comportamento del Robot
    - Simulazione del comportamento dell'Operatore
    - Simulazione del contatto
    - Interpretazione contestualizzata del contatto
    - Dialogo non verbale

- Pianificazione ed Esecuzione in ROS
  - Test di sistemi in ROS per pianificazione ed esecuzione
  - Strumenti: V-Rep, ROS, moduli esecutivi esterni
  - Tematiche:
    - ROSPLAN
    - BDI e Pianificazione gerarchica (CogniTao)
    - Continual Planning (e.g. GOLOG)
    - ACT-R, etc.

Proposta di Progetti

- Sistema di attenzione visiva in ambiente simulato:
  - Progettazione ed implementazione di un sistema di attenzionale visiva in ambiente simulato
  - Possibili strumenti: V-Rep, ROS
  - Tematiche:
    - Simulazione dei sensori
    - Modelli di salienza
    - Modelli attenzione top-down
    - Simulazione del robot e/o dell’operatore in compiti condivisi

Proposta di Progetti

- Sistema di teleoperazione con feedback aptico e visivo:
  - Progettazione ed implementazione di sistema di guida mixed-initiative con feedback aptico
  - Possibili strumenti: V-Rep, ROS,
  - Hardware: Oculus, haptic joystick, robot manipulator
  - Tematiche:
    - Simulazione del robot
    - Simulazione di mapping, localizzazione planning
    - Simulazione del sistema con ritorno aptico

- Multi-robot path-planning
  - Progettazione di un sistema per pianificare percorsi per più robots evitando le autocollisioni
  - Approccio: path-planning probabilistico
  - Metodo: simulazione