Deliberate Action in Robotics: A Perspective

Malik Ghallab

LAAS-CNRS

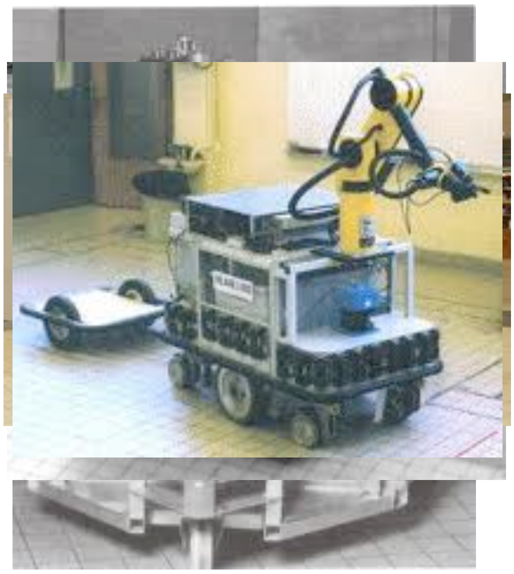
Aug. 2012

Robotics: a driving paradigm for AI

Pioneering AI projects

Shakey

Stanford Cart



Hilare

Outline

- Robotics: impressive multidisciplinary achievements
- Robotics: challenges for deliberation functions
  - Motivation for deliberation
  - Spectrum of deliberation functions
- Planning
- Acting
- Monitoring
- Observing
- Goal Reasoning
- Architecture
- Conclusion

Robotics: a wide multidisciplinary field

Impressive developments of

- Sensory motor functions
- Sophisticated platforms
- Achievements in particular in
  - Dynamic control
  - Motion planning and control
  - Simultaneous localization and mapping
  - Learning sensory motor functions
    by Reinforcement and/or Demonstration

Dynamic Control

5

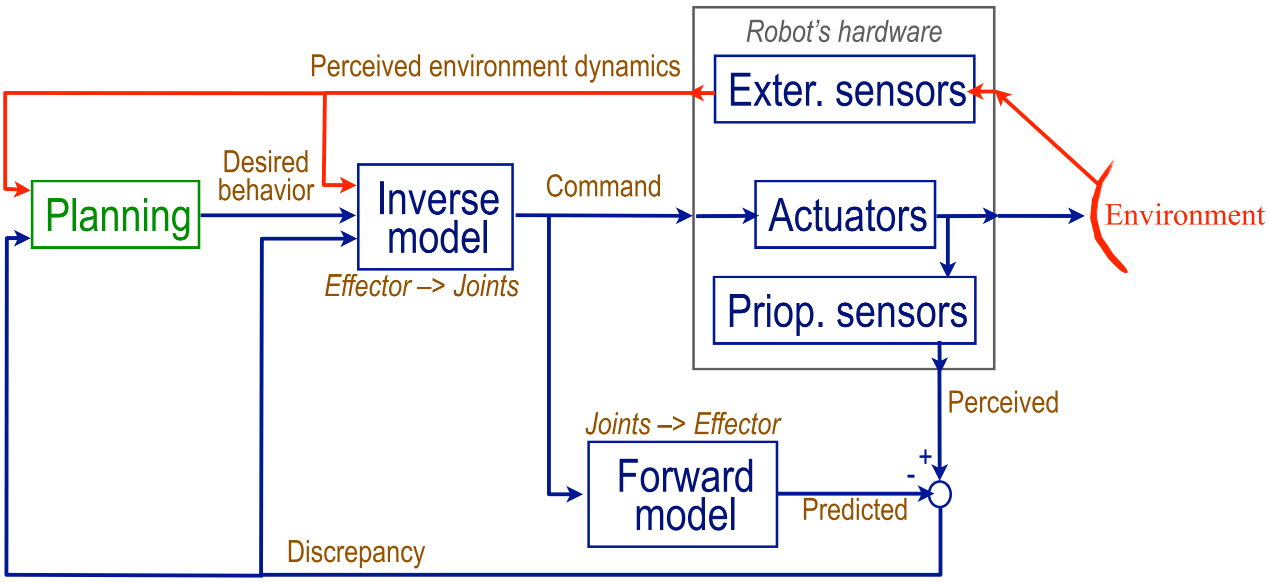
[DLR, Munich]

Dynamic Control

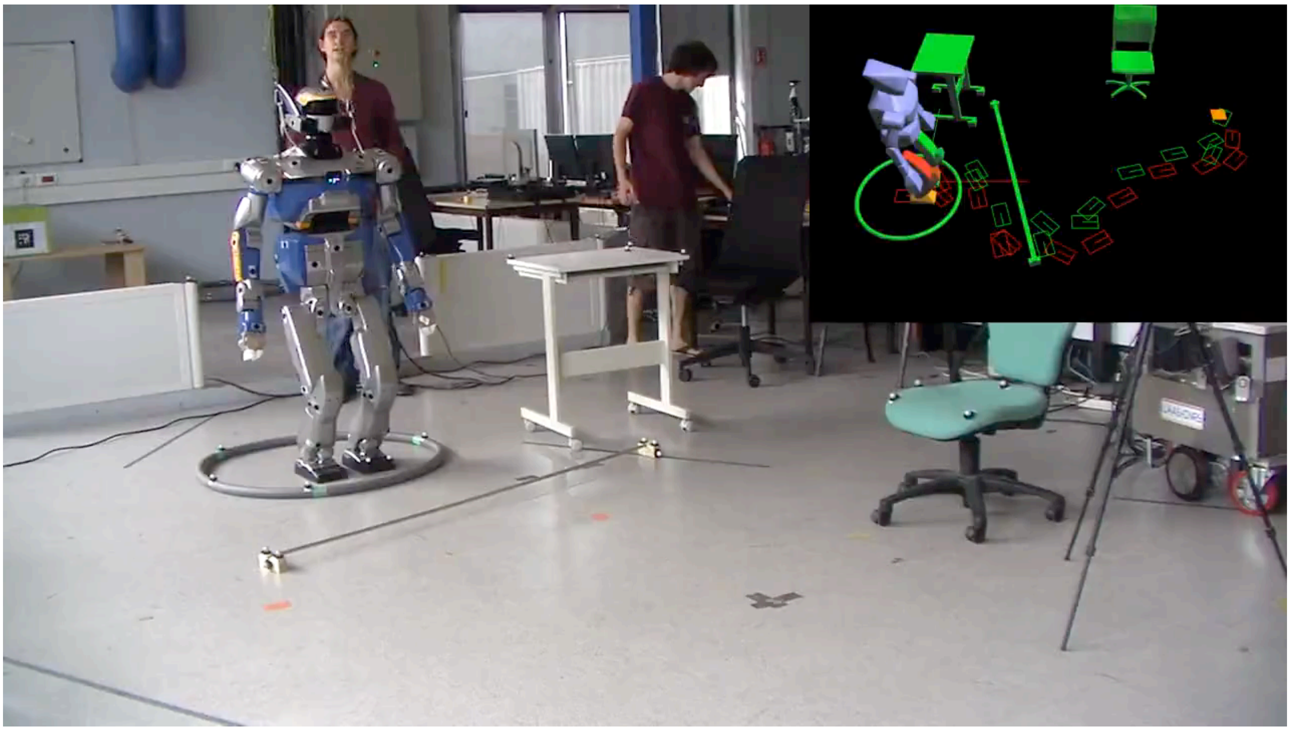
- Principles:

  Prediction $\qquad X_t, U_t \longrightarrow \hat{X}_{t+1}$

  Optimization $\qquad \hat{X}_{t+1}, X_{t+1} \longrightarrow U_{t+1}$

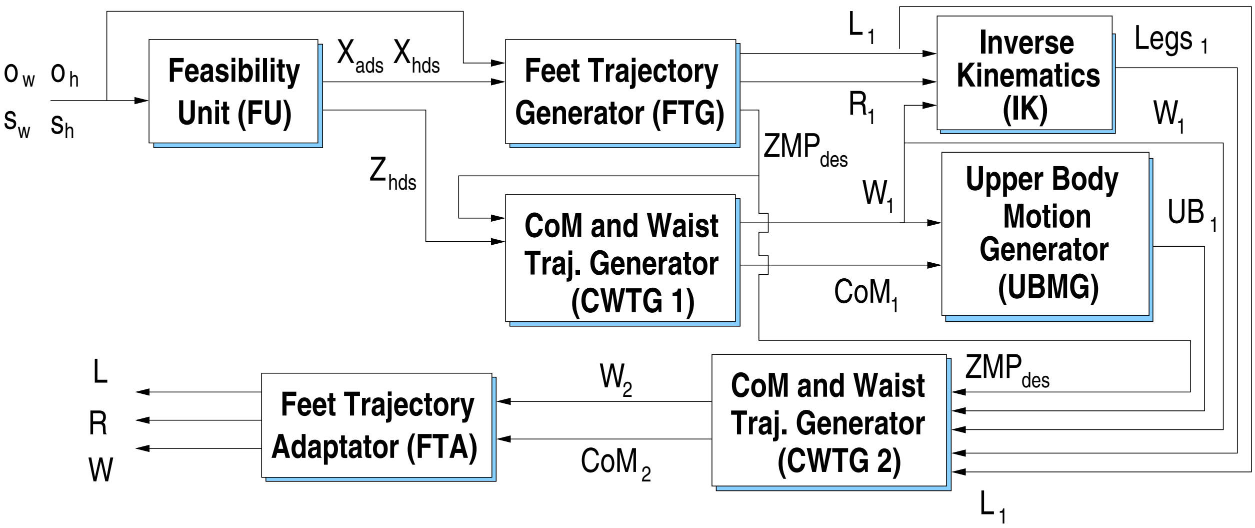


Dynamic Motion Planning



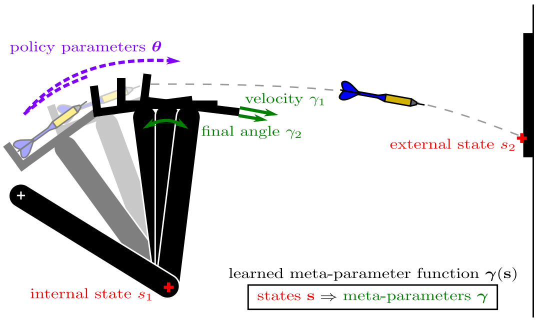
[LAAS, Toulouse]

Dynamic Motion Planning

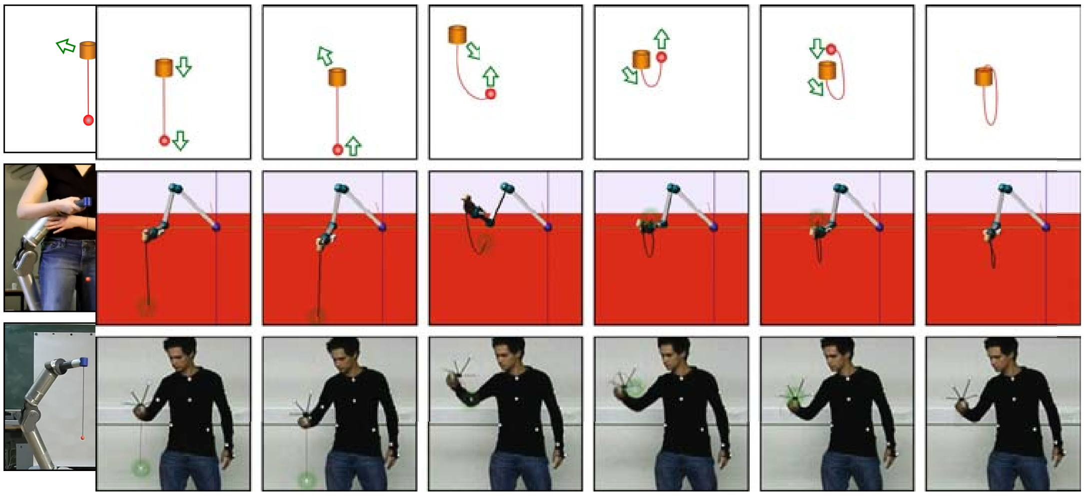


[Perrin & Stases, LAAS, Toulouse]

Reinforcement Learning of sensory motor functions



[MPI Bio-Cybernetics, Tübingen]



Helicopter Aerobatics Apprenticeship Learning

[U. Stanford]

Aerobatics Apprenticeship Learning

Simple linear rigid dynamic models of helicopter

- Learn dynamic models, *one for each type of maneuver*
  - Regression from teacher's demonstrations
  - Improvement by reinforcement learning in autonomous flight
- Learn reference trajectories, one for each aerobatic figure
  - *Expectation-Maximization* on teacher's demonstrations
  - Temporal alignment and optimization
- Learn controllers, one for each aerobatic figure
  - *Differential dynamic programming* continuous MDPs solved by iterative approximation of receding horizon LQR problems

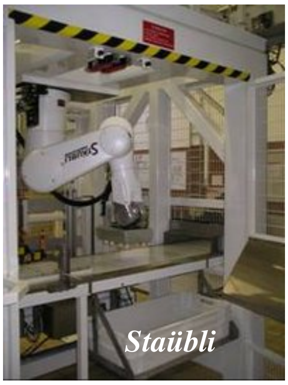
Outline

✓Robotics: impressive multidisciplinary achievements

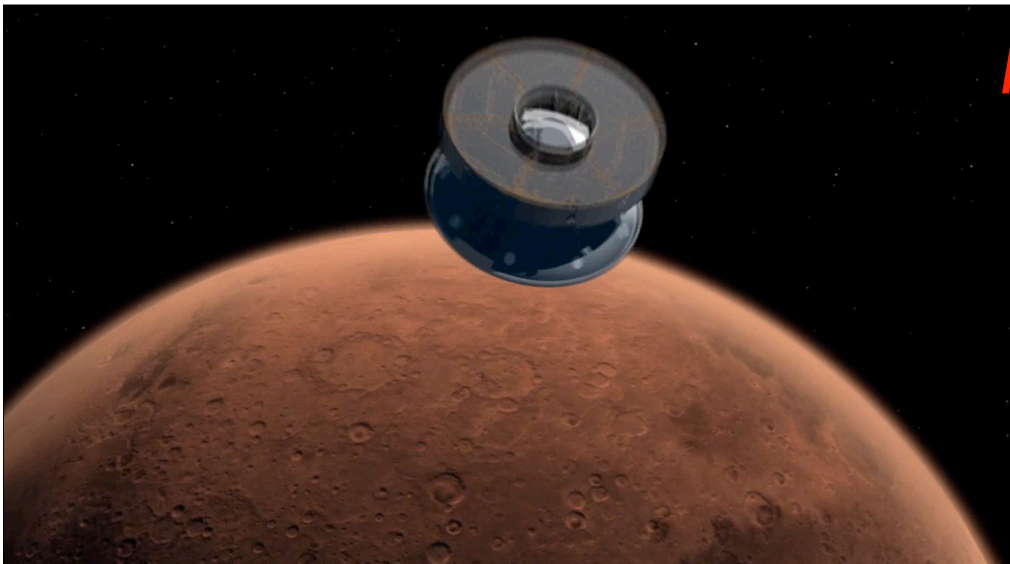
- Robotics: challenges for deliberation functions
  - Motivation for deliberation
  - Spectrum of deliberation functions
- Planning
- Acting
- Monitoring
- Observing
- Goal Reasoning
- Architecture
- Conclusion

Robotics: challenges for deliberation functions

- Characterization of a robotics demo
  - Type and variability of tasks and environments
  - Degree of autonomy
- Deliberation: not needed if there is
  - No variability
  - No autonomy



Motivations

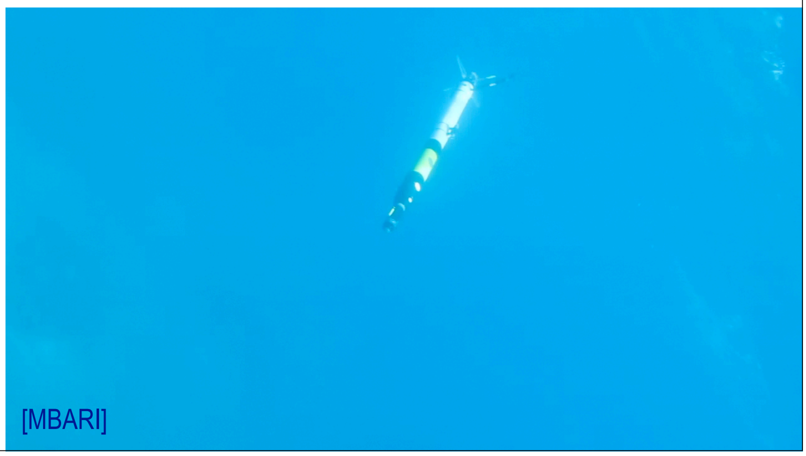


[Curiosity, Mars Space Lab, NASA/JPL]

- Complex mission: geology, atmosphere, climate, environment and bio-environment sciences
- Sophisticated instruments: micro, spectro & telescope, diffraction & radiation detection, soil sampling and analysis
- Extended motion and long range navigation

Motivations

- Mission
  - Navigate, map, explore, sample, analyze
  - Communicate, control instruments and resources
- Mission specification
  - Set of objectives, constraints and choice criteria
  - Not a set of executable commands

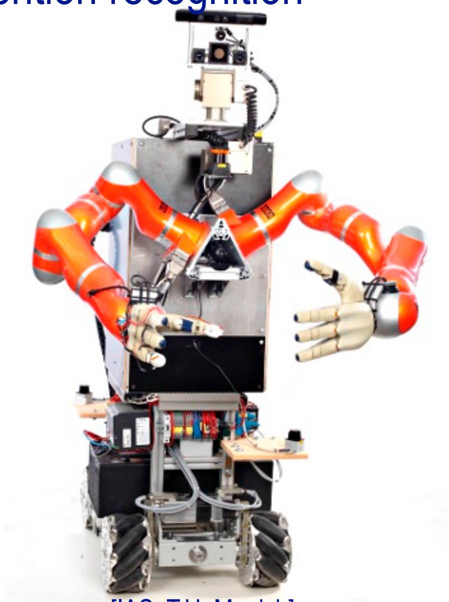


[MBARI]

Motivations

- Mission
  - Household services: maintain, sort, clean, cook, etc.
  - Support users, help, remind, monitor, etc.
- Interaction
  - Complex multimodal dialogue, plan and intention recognition
  - Cooperation in task achievement

[LAAS, Toulouse]

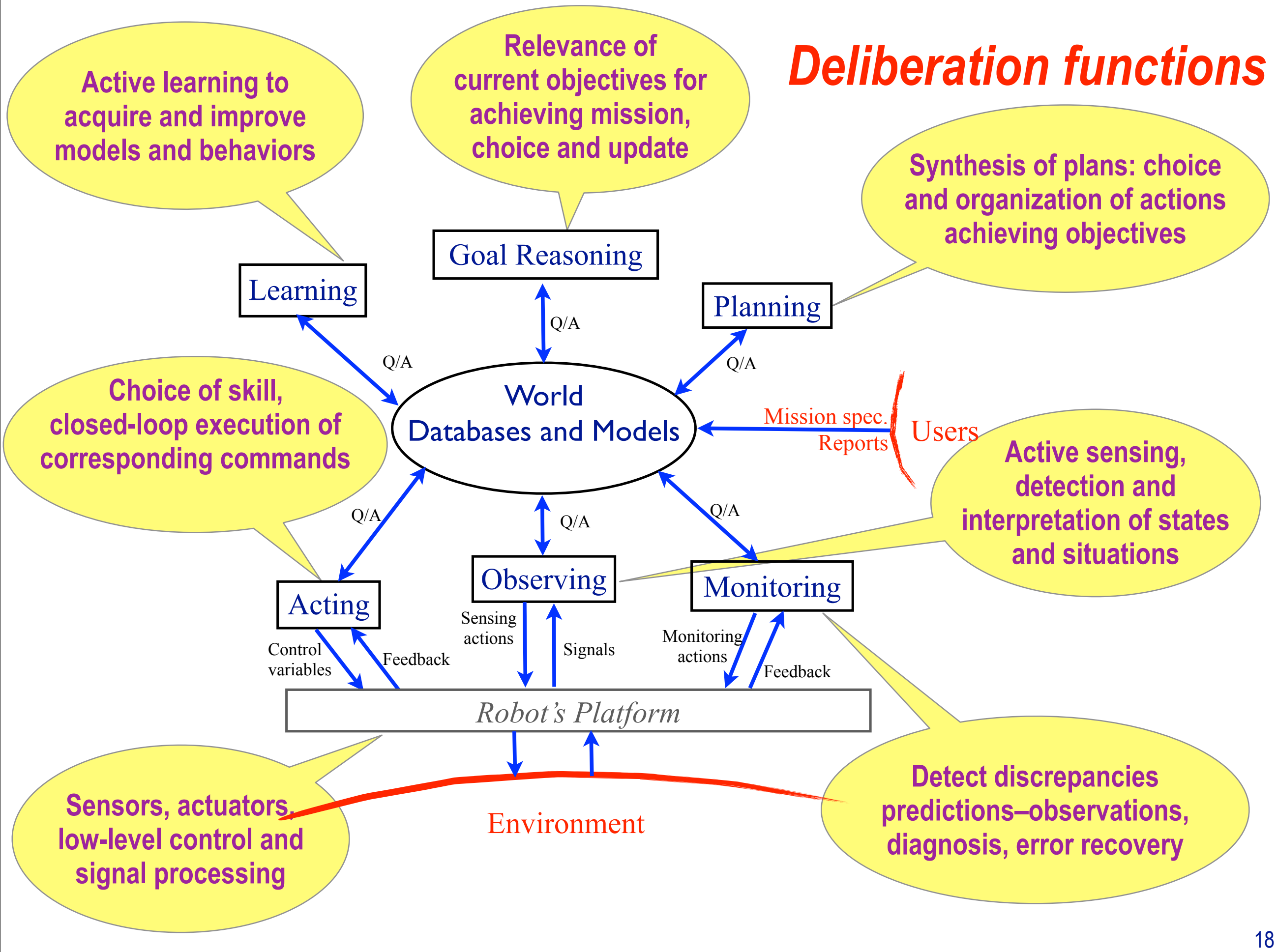


[IAS, T.U. Munich]

Deliberate action

- Purposeful action
  - Planned, intended to achieve some objectives
  - Pursued for the accomplishment of the robot's mission
- Computational gap between planning and control models
  => *Hierarchy of deliberation functions*
- Integrate action to sensory-motor platform and environment
  => *Diversity of deliberation functions*

Deliberation functions



Outline

✓Robotics: impressive multidisciplinary achievements

✓Robotics: challenges for deliberation functions

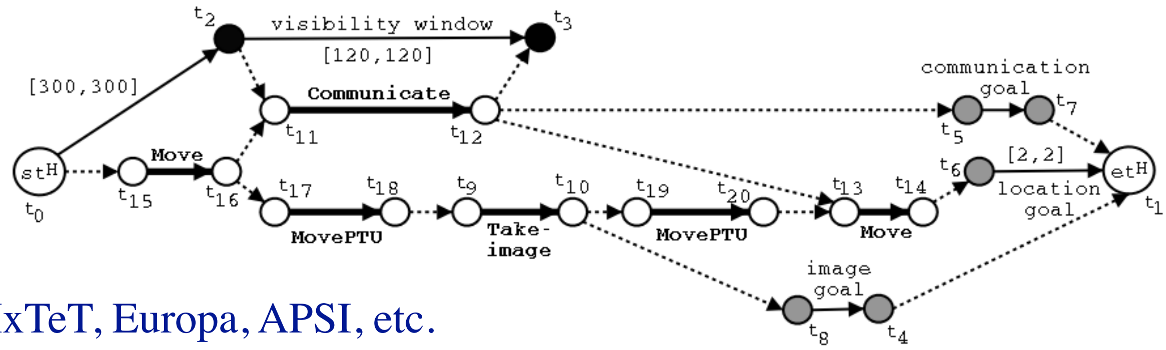
- Motivation for deliberation
- Spectrum of deliberation functions

- Planning
- Acting
- Monitoring
- Observing
- Goal Reasoning
- Architecture
- Conclusion

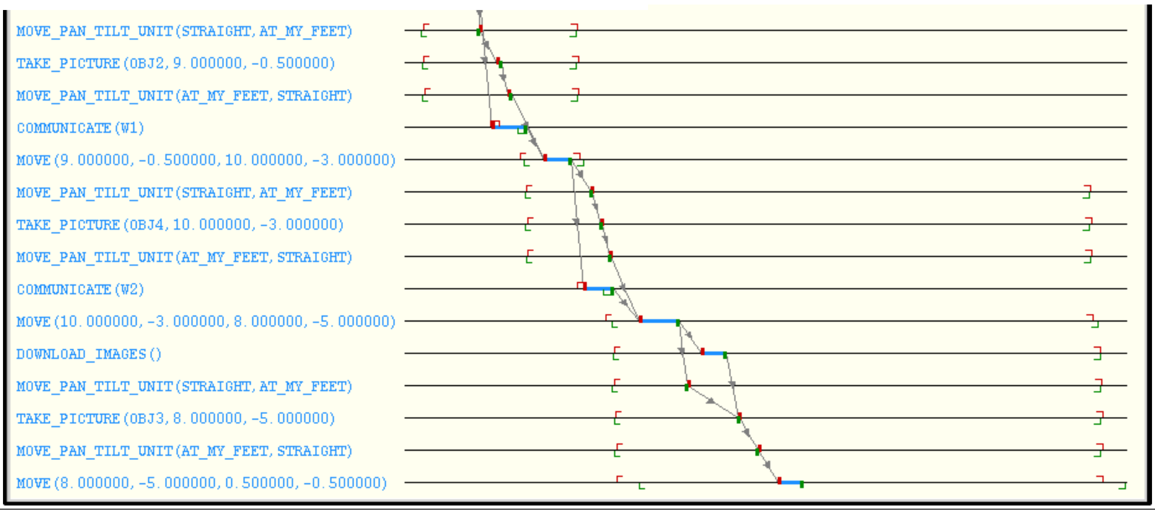
Planning for deliberate action

- Significant developments in automated planning
  - Several orders of magnitude in classical planning performances
  - Numerous extensions in representations & reasoning capabilities
- Research challenges
  - Integration of planning to acting and interacting
  - Integration of planning to sensing and observing
  - Concurrency of actions and exogenous events

Planning with timelines on state variables

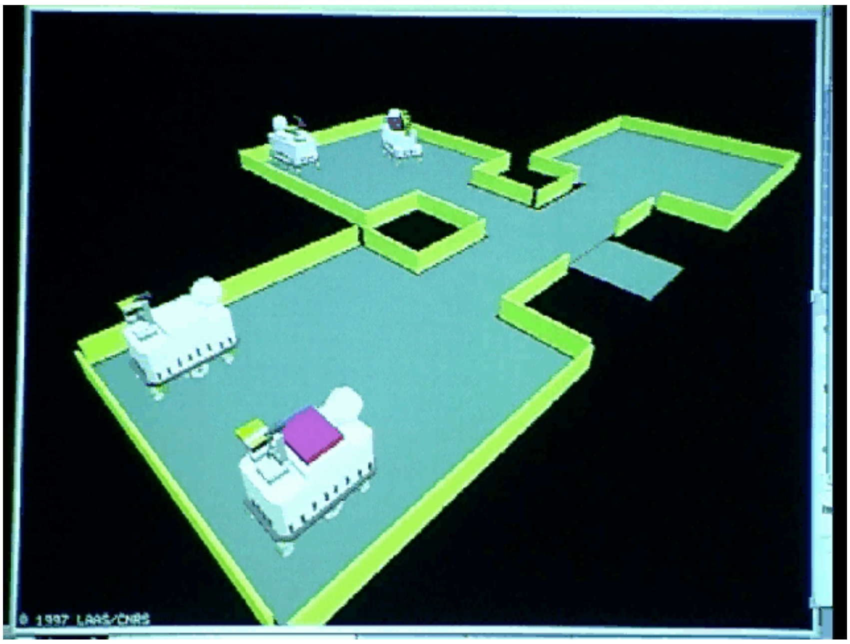


IxTeT, Europa, APSI, etc.



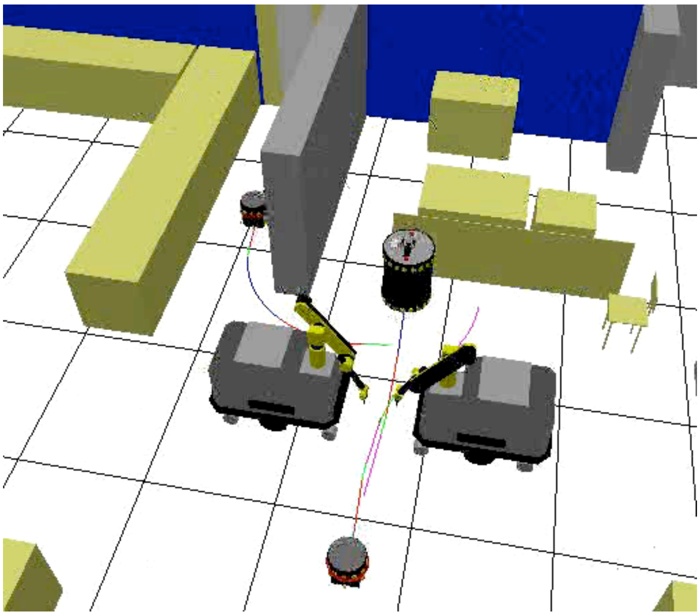
Multi-Robots Planning

- Distributed planning,
  coordination by ***plan merging*** over shared resources



[LAAS-CNRS]

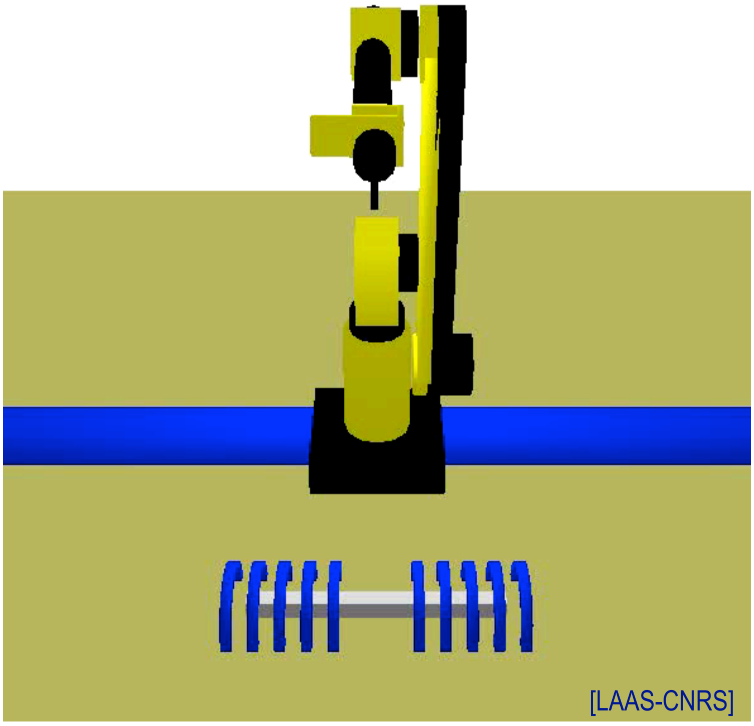
Multi-Robots Planning



[LAAS-CNRS]

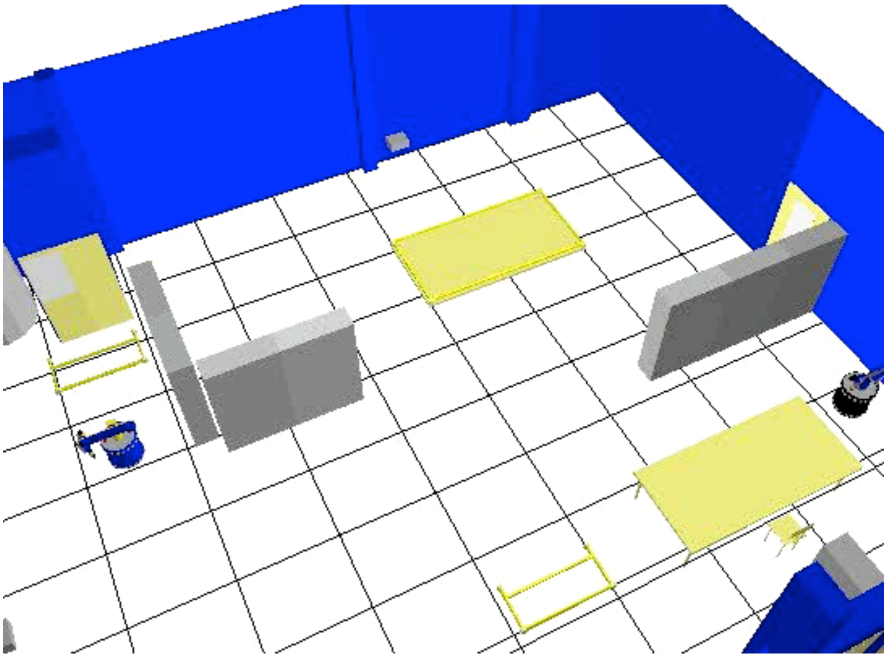
Manipulation planning

- Holding an object changes the configuration space
  => Composition: ***motion planning*** $\otimes$ ***task planning***



[LAAS-CNRS]

Multi-Robots Manipulation Planning



[LAAS-CNRS]

Outline

✓Robotics: impressive multidisciplinary achievements

✓Robotics: challenges for deliberation functions

- Motivation for deliberation
- Spectrum of deliberation functions

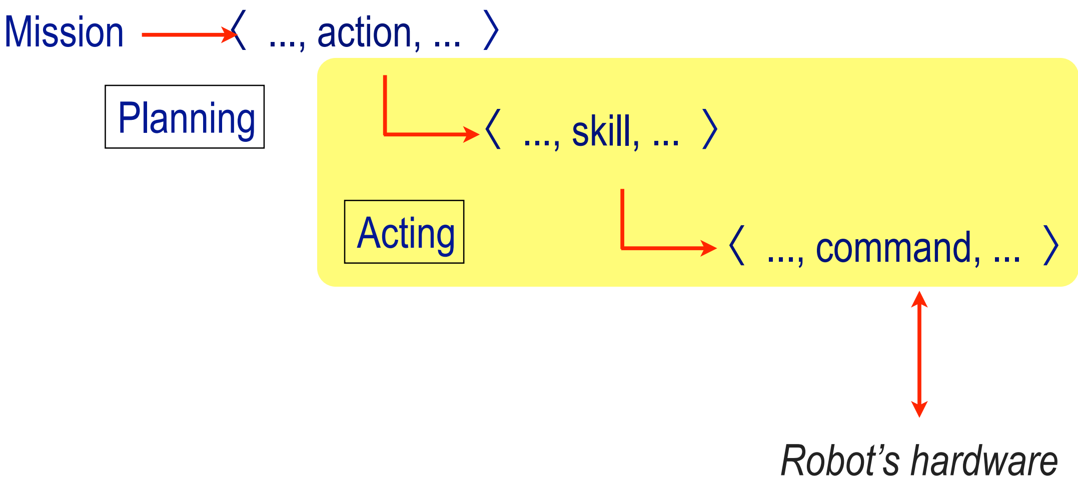
✓Planning

- Acting
- Monitoring
- Observing
- Goal Reasoning
- Architecture
- Conclusion

Integration of planning and acting

- About 20 plan steps
- Over a hundred sensory-motor commands

From abstract action to commands



Planning and acting

IxTeT-eXeC, IDEA, T-Rex, RMPL

Planning techniques in action refinement

Mission → ⟨ ..., action, ... ⟩

Planning

→ ⟨ ..., skill, ... ⟩

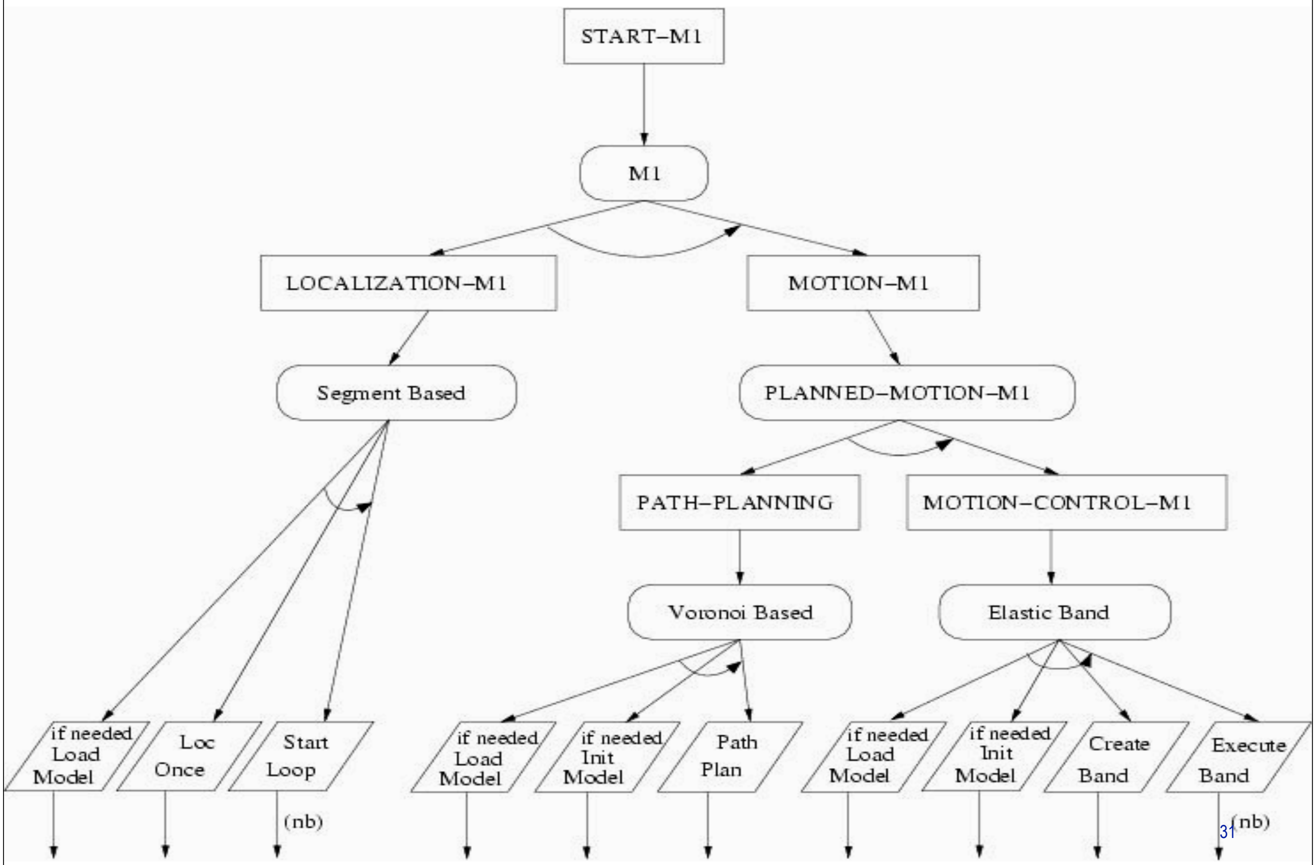
Acting

→ ⟨ ..., command, ... ⟩

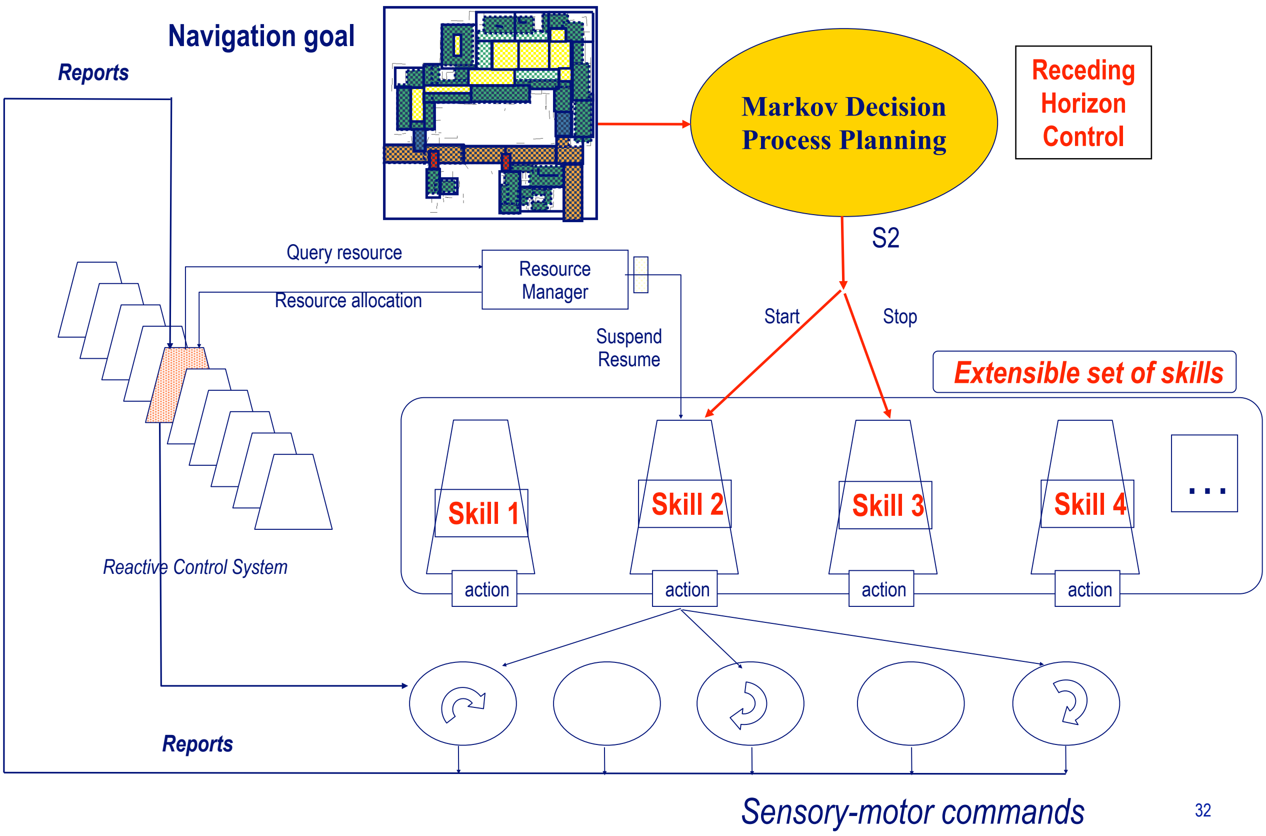
↕

Robot's hardware

Synthesis of skills achieving an action



Selection and switching between skills achieving an action

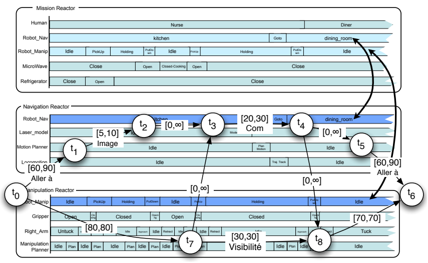


Navigation

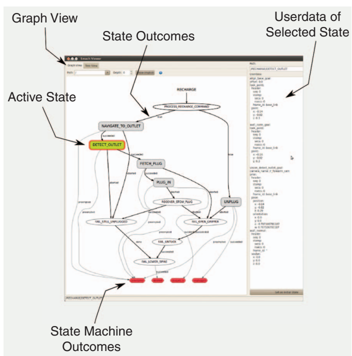
[LAAS, Toulouse]

Planning and Acting: approaches

- Temporal approaches
  IxTeT-eXeC, IDEA, T-ReX
  - CSP based
  - Dispatching, plan extension,revision
- Imperative approaches
  PRS, RAP, TDL, XFRM, etc.
  - Flexible
  - Hand-written
- State machine approaches
  PLEXIL, Smach, etc.
  - More open to V&V
  - Hand-written
- Stochastic approaches (MDP, DBN/DDN,)
  - Learned from experiences or from teaching



[T-Rex / IDEA]



[Smach (ROS)]

Outline

✓Robotics: impressive multidisciplinary achievements

✓Robotics: challenges for deliberation functions

- Motivation for deliberation
- Spectrum of deliberation functions

✓Planning

✓Acting

- Monitoring
- Observing
- Goal Reasoning
- Architecture
- Conclusion

Monitoring

- Role
  - Detect predictions - observations discrepancies
  - Explain and recognize
  - Repair
- Approaches
  - Hand-written skills to monitor applicability/maintenance conditions
  - Monitor plan invariants
  - Synthesize invariants from extended planning problems which guarantees the plan execution
  - Model checking execution traces with LTL
  - RMPL: Constraint Based Automata + Control programs
  - TALPlan: synthesize monitors for its plan

Temporal Action Logic for planning and monitoring

$$
\begin{aligned}
&[t,t']\textbf{fly-to}(uav,newx,newy) \rightsquigarrow \\
&\quad [t]\mathsf{fuel}(uav) > \mathsf{fuel\text{-}usage}(uav,\mathsf{x}(uav),\mathsf{y}(uav),newx,newy) \rightarrow \\
&\quad R([t+1]\ \mathsf{hovering}(uav) \hat{=} False) \wedge \\
&\quad R((t,t']\ \mathsf{x}(uav) \hat{=} newx \wedge \mathsf{y}(uav) \hat{=} newy \wedge \\
&\qquad\qquad \mathsf{fuel}(uav) \hat{=} value(t,\mathsf{fuel}(uav) - \\
&\qquad\qquad \mathsf{fuel\text{-}usage}(uav,\mathsf{x}(uav),\mathsf{y}(uav),newx,newy))) \wedge \\
&\quad t'-t = value(t,\mathsf{flight\text{-}time}(uav,\mathsf{x}(uav),\mathsf{y}(uav),newx,newy))
\end{aligned}
$$

TALPlan: order-sorted temporal logic for state-space planning

Monitoring integrated to TALPlan

- Predictions synthesized from *monitor formula* and planning knowledge while planning
  - At the action level
  - At the plan level : causal relations between actions

$$
\begin{aligned}
&\Box\, \forall uav.(\mathsf{power}(uav) > M \rightarrow \\
&\qquad \mathsf{power} < f \cdot M \ \mathsf{U}_{[0,\tau]}\ \Box_{[0,\tau']}\ \mathsf{power}(uav) \le M)
\end{aligned}
$$

- Surveillance of states and sequences *wrt* monitoring prediction with incremental *formula progression algorithm*
- Diagnosis of discrepancies
- Error recovery

Outline

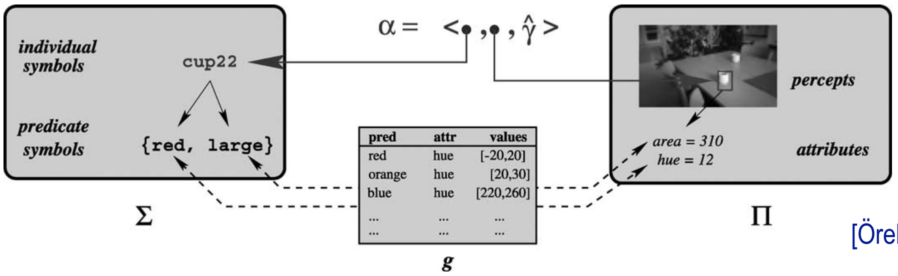
- ✓Robotics: impressive multidisciplinary achievements
- ✓Robotics: challenges for deliberation functions
  - Motivation for deliberation
  - Spectrum of deliberation functions
- ✓Planning
- ✓Acting
- ✓Monitoring
- Observing
- Goal Reasoning
- Architecture
- Conclusion

Observing

- Role
  - Process signals needed in closed loop servoing
  - Detect and structure environment features, recognize, categorize, link signals to symbols (anchoring)
  - Predict from sequences of events ongoing situations, plans and temporal chronicles
- Bottom-up to from signal to symbols
- Top-down to focus attention and trigger observation actions

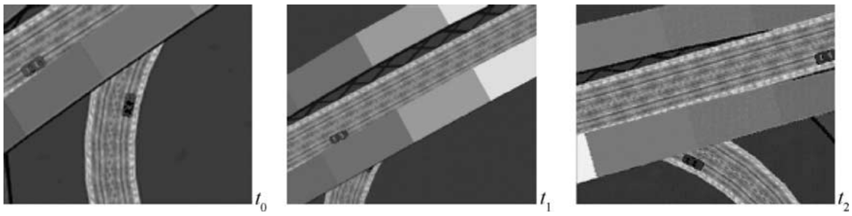
Observing

- Anchoring problem
  - Relate perceptual data and symbolic attribute corresponding to the same physical object



[Örebro Univ.]

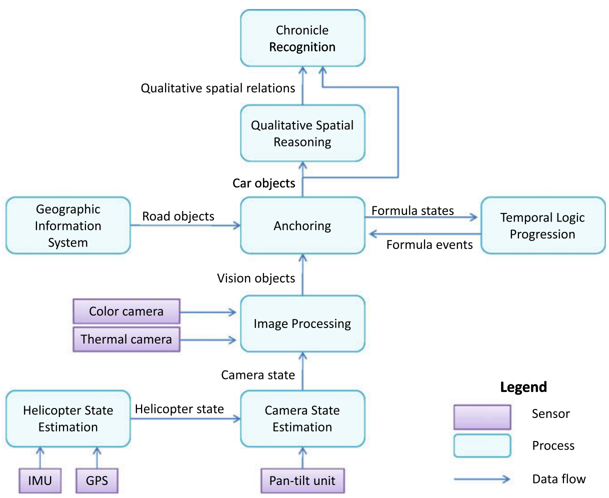
  - Track anchors overtime and refine/revise hypothesis



[Linköping Univ.]

Perception Engine

- Comprehensive and coherent approach for observing
- Data flow architecture
- Stream based formalism on perception processes:
  - primitive, refinement, configuration, mediation processes
  - policies over processes, temporal constraints
- Natural integration to planning and monitoring,
- Opens V&V perspectives



[Dyknow, Linköping U.]

Deliberation functions

[Linköping U.]

Outline

✓Robotics: impressive multidisciplinary achievements

✓Robotics: challenges for deliberation functions

- Motivation for deliberation
- Spectrum of deliberation functions

✓Planning

✓Acting

✓Monitoring

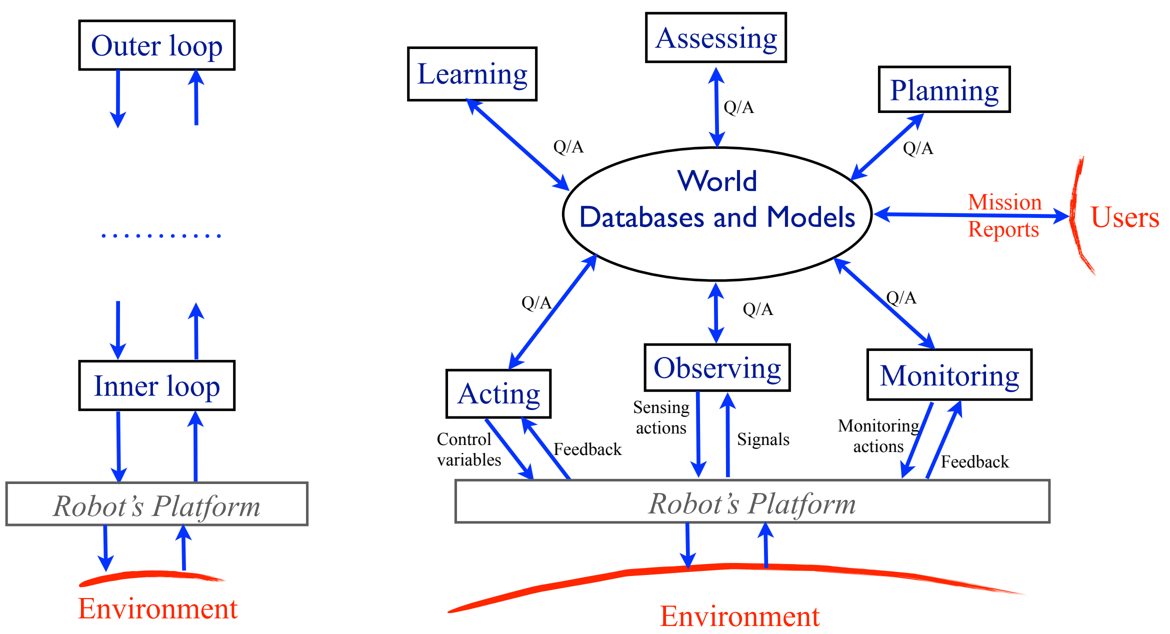
✓Observing

- Goal Reasoning
- Architecture
- Conclusion

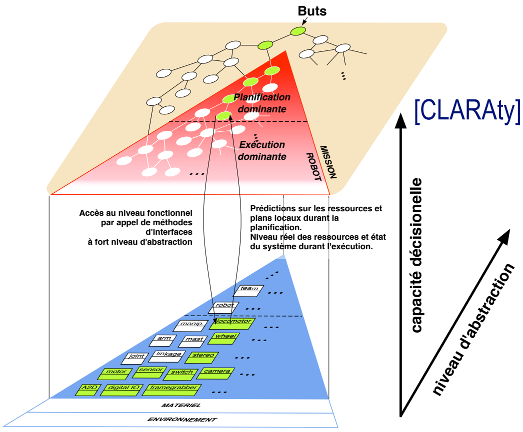
Goal Reasoning

- Goal Driven Autonomy (GDA), overall mission perspectives
- Higher level monitoring *wrt* objectives, criteria and constraints
- Discrepancy detector
- Explanation generator
- Goal generator to address new conditions
- Goal manager
  - Decision theory: tradeoff between conflicting goalls
  - Explicit choice
- Found in large systems (CPEF, DS1)
  Function often embedded in acting/monitoring/planning

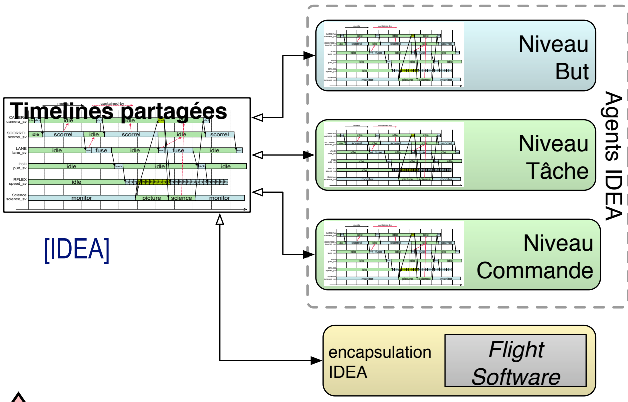
Deliberation functions



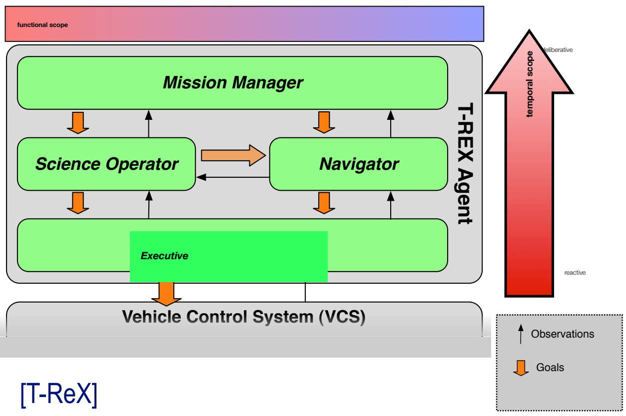
Architectures



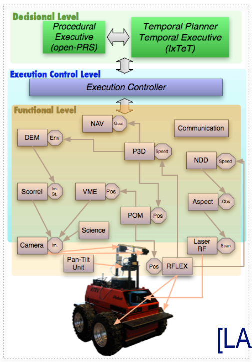
[CLARAty]



[IDEA]

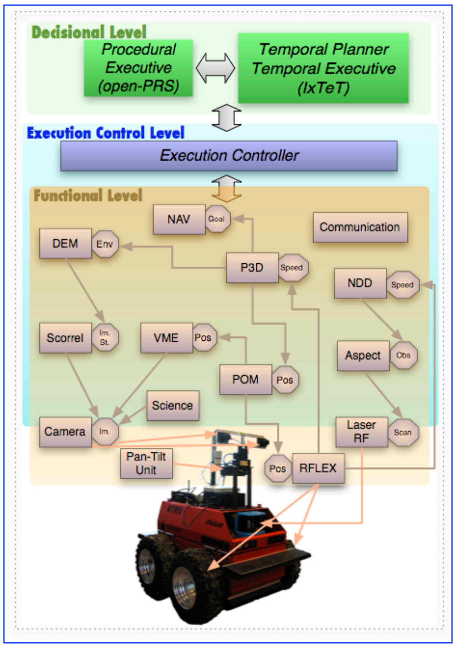


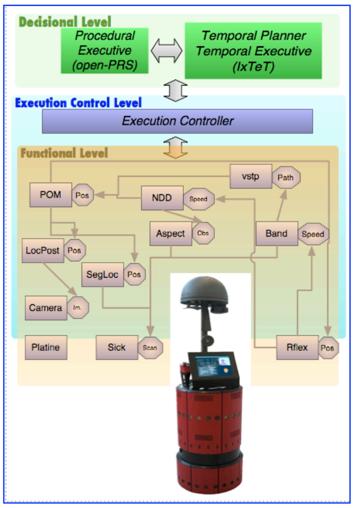
[T-ReX]

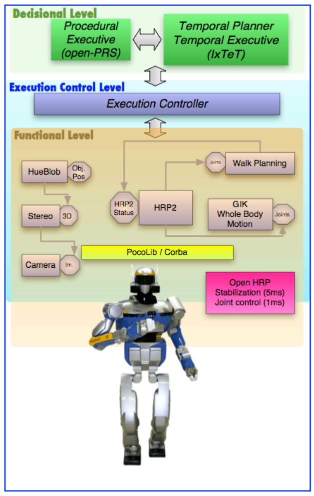


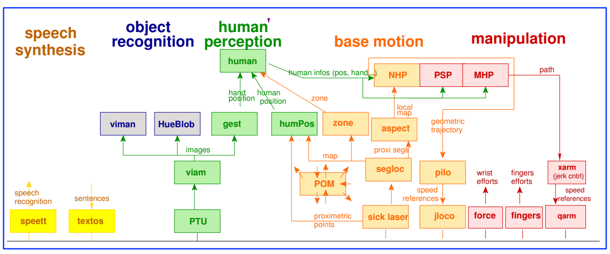
[LAAS]

Architectures









Outline

- ✓Robotics: impressive multidisciplinary achievements
- ✓Robotics: challenges for deliberation functions
  - Motivation for deliberation
  - Spectrum of deliberation functions
- ✓Planning
- ✓Acting
- ✓Monitoring
- ✓Observing
- ✓Goal Reasoning
- ✓Architecture
- Conclusion

Deliberation in robotics: key integrative challenge for AI

- Planning & Acting
- Observing the environment semantics
- Monitoring
- Goal reasoning
- Interacting
- Learning
  - Models of the robot and the environment
  - Categories
  - Functions, skills and behaviors
- Architecture
  - Specification
  - Robust adaptation

Acknowledgments

- LAAS, Toulouse
  - Felix Ingrand, Rachid Alami, Olivier Stasse
  - Benoit Morisset, Stéphane Cambon, Fabien Gravot, Severin Lemaignan
- Linköping U.: Patrick Doherty and colleagues
- DLR, Munich: Berthold Bäuml, Gerd Hirzinger
- TU Munich: Michael Beetz and colleagues
- MPI Biological Cybernetics, Tübingen: Jan Peters and colleagues
- Örebro U.: Alessandro Saffiotti
- Stanford U.: Peter Abbeel, Andrew Ng
- NASA AMES and JPL: David Smith, Vandi Verma, Jeremy Frank
- MBARI: Kanna Rajan