Languages and software architectures for safe robotics

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Plan

- Introduction to robotics and telerobotics
- Robotic architectures
- Languages and programming systems for robotics
- Dependability of robotic applications

Introduction to robotics and telerobotics

- Robotics history
- Definitions and overview
- Application domains
- Non autonomous robotics
- Mobile robotics
- Submarine robotics
- Entertainment robotics
- Some useful terms

Origin of words robot and robotics

- Robot:
  - Comes from theatre piece R.U.R. (Rossum's Universal Robots) produced and written by Czechoslovak Karel Capek (1890-1938).
  - In Czechoslovakia, « Robota » means « forced labor».
- Robotics:
  - Comes from fiction science.
  - Appeared for the first time in a news written by Isaac Asimov, « Runaround » (1942) that is now part of a collection entitled « I, Robot ».

Robotics history

- 1779: Kemplen's chess player automaton (human hidden inside).
- The success of the first industrial robot namely a die casting machine, did not generate an immediate acceptance. Numerous manufacturing responsible were considering robotics as fiction science.
- Years 1940 : manipulator arm of nuclear material.
- 1954: master/slave tele manipulator with electric motorization.

Robotics history

- 1956 : beginning of the serious development of robotics with the happy addition of numeric command toolbox and semi-conductors electronics.
- Years 65-70: beginning of mobile robotics (Shakey robot, …).
- 1971: forming of Japan Industrial Robotics Association (JIRA).
- 1975 : the United States create their own industrial robotics association.
- Years 80-90: Rise of mobile robotics (crawler robots, wheeled robots, legged robots).

Robotics history

- 1990 : development of tele manipulators with effort feedback arm. Robotics industry is worth 3 million dollars. It is 70% controlled by Japan.
- Years 90-2000: cleaning robots, intervention submarine robots, airship pilots (Alpha).
- 1998: Industrial Robotics represents 4,2 billions dollars according to the I.F.R. (Institute of Federation of Research).
- Nowadays, even if a lot of work can be done by mute, deaf or blind robots, sensorial aspects are more and more put in front: vision, relocalization, trajectory following, strength sensors, etc. These components give to the robot a minimum of intelligence.

Robotics projects history

Period	Year	Motivations and programs	Projects
BEGINNING	1965	Experimentation support for AI research	CART (Stanford, USA, 66) SHAKEY (SRI, USA, 68) JASON (Berkeley, USA,70)
STAGNATION	1970		MARS ROVER (NASA,USA)
	1975		
NEW IMPULSION	1980	Support for research in AI + Evolution of technologies + Perspectives of applications	HILARE (Toulouse, 78) VESA (Rennes) YAMABICO (Tsukuba, Japon,78) MEL-DEIC (Japon, 1981) CMU-ROVER (USA,1981)
	1985	Versailles Summit « Advanced Robotics » RAM Program (France) JUPITER Program (Japon) Program driven by NSF (USA) Projects within EUREKA (Europe)	Projects at MIT (USA) Stanford (USA) SRI (USA) INRIA (France) …..

Definitions and overview

- Robotics : discipline targeting tasks automation with the help of complex systems, called robots, combining mechanics, electronics, automatics and computer science.
- 2 main approaches :
  - Autonomous: the robot replaces completely the human in its tasks.
  - Non autonomous: the robot is integrated into a whole where the human has an active place.
- Main advantages : increase productivity, intervention in hostile environment.

Application domains

- Microsurgery, telemedicine.
- Rational agriculture.
- Nuclear.
- Spatial exploration.
- Entertainment.
- Military domain : mines destruction, information gathering,….
- Submarine recognition.
- Pipeline building assistance, …

Non autonomous robotics

- Frequent terminology : teleoperation, Computer Aided teleoperation, telerobotics.
- *Teleoperation* : robot designed as a mean enabling the extension of human intervention capabilities.
- *Classical teleoperation* : master arm driven by the operator + slave arm which reproduces the movement of the master arm.
- Computer Aided Teleoperation: Introduction of a computer between the operator and the robot.

Mobile robot

- Characterized, in comparison to static manufacturing robot, by a greater quantitative and qualitative complexity of the environment.
- Main problematic : environment understanding.
- 2 main classes :
  - Legged mobile robots : mechanics and command aspects.
  - Wheeled mobile robots : AI aspects.

Underwater robotics

- Some definitions
- State of the art of the main underwater vehicles
- Autonomy: fields of technological investigation
- Diversity of architectures of the underwater robots

Definitions in underwater robotics

- U.U.V.: Unmanned Underwater Vehicle (Generic Term used to indicate all the uninhabited vehicles moving in the hydrosphere).
- R.O.V.: Remote Operated Vehicle.
- A.U.V.: Autonomous Underwater Vehicle.
- S.U.V. : Supervised Unmanned vehicle.
- U.S.V. :Unmanned Surface Vehicle

State of the art of the main underwater vehicles

- Vehicles towed for the cartography
- R.O.V:
  - Maturity guided by the offshore.
  - 2 categories: observation, work.
- Unattached vehicles.

Vehicles towed for the cartography

- Vehicles towed without propulsion but sometimes with active stabilization.
- Current activity is very important in cartography and environment surveys.
- Realization in small series.
- Use : bathymetry, imagery, magnetism, seismic.
- Producers: Klein, Ultra, Egerton, TMS, …
- Specific systems for deep seabed: SCAMPI IFREMER, SAR IFREMER, ARGO WHOI.

Tele – operated vehicles: R.O.V

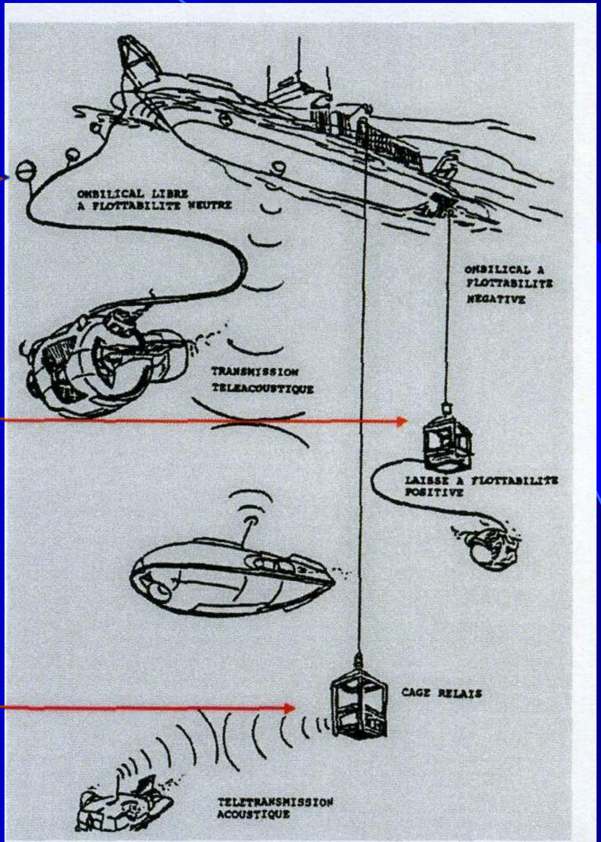
- Technological and industrial maturity for small and medium seabed.
- Numerous models available.
- Producers: Perry Tritech, Benthos, Deep Ocean, ISE, …
- Users : businessmen of underwater works (ex: Coflexip / Sténa, Racal, Subsea).
- Implementation:
  - Free umbilical.
  - Relay cage and cables
  - Relay cage, cable and acoustical communication.

R.O.V: implementation

Free umbilical

Relay cage and cable

Relay cage, cable and
acoustic communication



P. Baraona - un aspect de la robotique sous-marine - Revue Française de Mécanique N° 1987 - 4

R.O.V: generality

- Observation ROV:
  - Small and mobile.
  - Equipped with electrical actuators.
  - Sometimes with small manipulators.
  - Use: assistance lighting ROVs of heavy dockyard, divers, uninhabited vehicles.
- Working ROV:
  - Heavy vehicles: till 15 tons.
  - Equipped of loud hydraulic actuators.
  - Powerful hydraulic manipulators.
  - Generally, use of cage to limit the influence of the movements of the sea on the cable directly linked up in ROV => heaviness of use and action ray reduced.
  - Use: manipulations on offshore structures.

The unattached vehicles

- Heirs in the behavior of the inhabited submarines.
- No physical link between the vehicle and the supervisor.
- Own source of embedded energy.
- Autonomy at piloting and navigation levels.
- Diversity of forms, of characteristics and of performances.
- Transition from a «search of market» in the nineties to an explosion of request in the field of the offshore in the 2000s.
- Appearance in industrial, military and scientific domains.

The unattached vehicles

- 2 categories:
  - Preprogrammed: mission managed by a non-reactive robot, programmed beforehand by an operator. These vehicles are *ordinarily called A.U.V.*
  - Tele-supervised / tele-programmed through an acoustical transmission from an operator site on surface, by taking into account transmission delays caused by acoustical waves. Are *ordinarily called S.U.V.*
- Current use: surveillance, recognition of sites and collection of data.

Autonomy: fields of technological investigation

- Energy autonomy:
  - Optimization of the resources of energy and of optimum hydrodynamic and hydro mechanical conception.
  - The use of "conventional" rechargeable batteries (lead-acid accumulators, Ni-Cd), corresponds to the majority of current applications.
- Decision-making autonomy:
  - Architectures of mission programming.
  - Research of security of functioning, automatic identification of breakdowns: technical maturity seems attained today for the preprogrammed vehicles having a decision-making level reduced to few automata (of obstacle avoidance, transition to security mode on dysfunction).
  - Improvement of integrated navigation systems.

Diversity of architectures of the underwater robots

	Engin à câble	Engin libre
Structure ouverte	 Quest : ROV électrique d'Alstom avec télémanipulateurs hydrauliques	 Sirène : engin libre téléopéré par acoustique SUV de l'Ifremer
Structure optimisée pour le déplacement	 PAP : engin de chasse aux minesfiloguidé de la société ECA, téléopéré par fibre optique	 PTEROA : engin optimisé pour le planning hydrodynamique, surveillance et suivi de câbles sous-marins, Université de Tokyo

Robotics of entertainment

- 2 aspects: educational, emotional
- Emotional robotics: based on two types of interactions:
  - Physical interaction with the systems of virtual reality: a human being equipped with sensors and with actuators is going to move in a simulated environment and will receive in return sensations by means of actuators.
  - Influence on feelings by the displacement of mechanical structures (Furby, Omron, Sony pet robot, etc.) in such a way that their behaviors bear of emotion according to the context.

Robotics of entertainment

- 2 types of systems of educational entertainment: Simulation systems, real Systems:
- Simulation systems
  - Allow the user, by means of game, to investigate the dynamic evolution of complex systems: study of the virtual animals and their evolution.
  - Examples: Virtual fish Tank, software Creatures.
- Real systems:
  - Come from building games allowing the user to construct its robot and to endow it with functionality.
  - Examples: Lego Mindstorms, Kit-robot

Robotics of entertainment

- Emerges and evolves nowadays at high-speed:
  - Existing technological solutions are as high as its expectations (autonomy, density and performance of robots).
  - The media coverage or the sharing of information via modern communication media act as true catalysts.
- The public now links unknowingly a life semblance as soon as a robot evolves in an autonomous way.
- Example: infatuation carried in 1990s to Tamagotchi.

Robotics competitions

- Places of experimentation of entertainment robotics.
- Examples of competitions:
  - Climb of rope.
  - Soccer match.
  - Sumo fight.
  - Struggle against fire.
  - Exploration.
- The robot must be capable mechanically of answering the need, but especially, he must use an infallible strategy to put its rivals in failure.

Some useful terms

- *Third generation robots*: sensing capabilities, important decision making capabilities, possibility to modify significantly the course of its action when unexpected events occur.
- *Decision making* : completing an action at a non explicitly preprogrammed time after evaluation of a global situation.
- *Planning*:
  - Generate a plan, i.e. a sequence of actions (some may be parallel), in order to reach a given goal expressed as a state of the world.
  - Planners use a world model, a set of possible actions of the robot and must perform some inference activity.
- *Navigation*: using spatial models for the understanding of space structure and planning and execution of the path. It is the heart of mobility function.
- *Guiding*: Control of the mobile robot for the following of a predefined path.

Some useful terms

- *Control of execution*: control of the actions of the robot in the real world to execute the plan. This requires specific decision-making capability, management of the robot system, use of sensors to control actions, and correction of plan in case of failure.
- *Perception*: acquisition of data relating to environment or to state of the robot through passive or active devices such as a camera, a laser, ultrasounds sensors, tactile or force sensors, optic encoder, etc. for the modelling of the world or the control of actions.

Robotics architectures

- First robots:
  - typically 1 thing at the same time: observe first, then construct a map, then build a path, then move.
  - No resource sharing nor control flow to be treated.
  - Constructed by a single person: potential architectural aspects manageable in the head of the designer.

  => these robots had no real architecture.
- Today's robots:
  - Several sensors (sonars, video, etc.) and different way of treating every sensor.
  - Several tasks often performed in parallel: displacement, perception, possible communication with distant controllers and sensors.
  - Constructed by a significant number of persons and different institutions.

  => Growing desire of standardization, of possibility of reuse of components on several robots, of common sets of specifications.

  => Necessity of architectures robotics.

Robotics architectures

- Goal : Structure developments into abstraction levels.
- No architecture fulfills all tasks.
- Different tasks have different criteria that lead to different architectures.
- 4 main classes :
  - *Centralized* (Examples : STRIPS, Blackboard)
  - *Hierarchical* (Examples : NASREM, LIFIA architecture, …),
  - *Behavioral* (Examples : Subsumption, DAMN),
  - *Hybrid* (Examples : ControlShell, LAAS Architecture, ORCCAD).

Centralized architectures

- Inspired by Artificial Intelligence and organized around decision-making processes and a symbolic state of the world and the robot
- Main flaw: all assume that the world is easy to model.
- Adapted when the system models the world well enough and the world obeys his or her models and the system can retrieve information for inclusion in the heart of central planning.
- First applications in this category: STRIPS, SHAKEY Planning System.

Centralized architecture examples

- STRIPS:
  - Implementation of the means-ends method proposed by Newell and Simon in 1963.
  - Recursive decomposition method of goals into a series of primitives executable by the robot.
  - Assume that the planner has modeled every useful aspect of the environment and that the environment does not change during the execution of the plan.
  - None of these assumptions remain true in the real world.
- Modern approaches are more flexible than STRIPS :
  - Blackboard: accumulates data on the world and makes immediate decisions based on both a priori variable goals and a changing world.

Centralized architecture examples

- Architectures have been proposed that allow for goal changes and error recovery (Georgeff and Lansky, 1986)..
- There are architectures that “learn”, that is, adapting their internal models in a variety of ways: chunking (Laird et al , 1987), case based reasoning (Carbonell and Veloso, 1988).

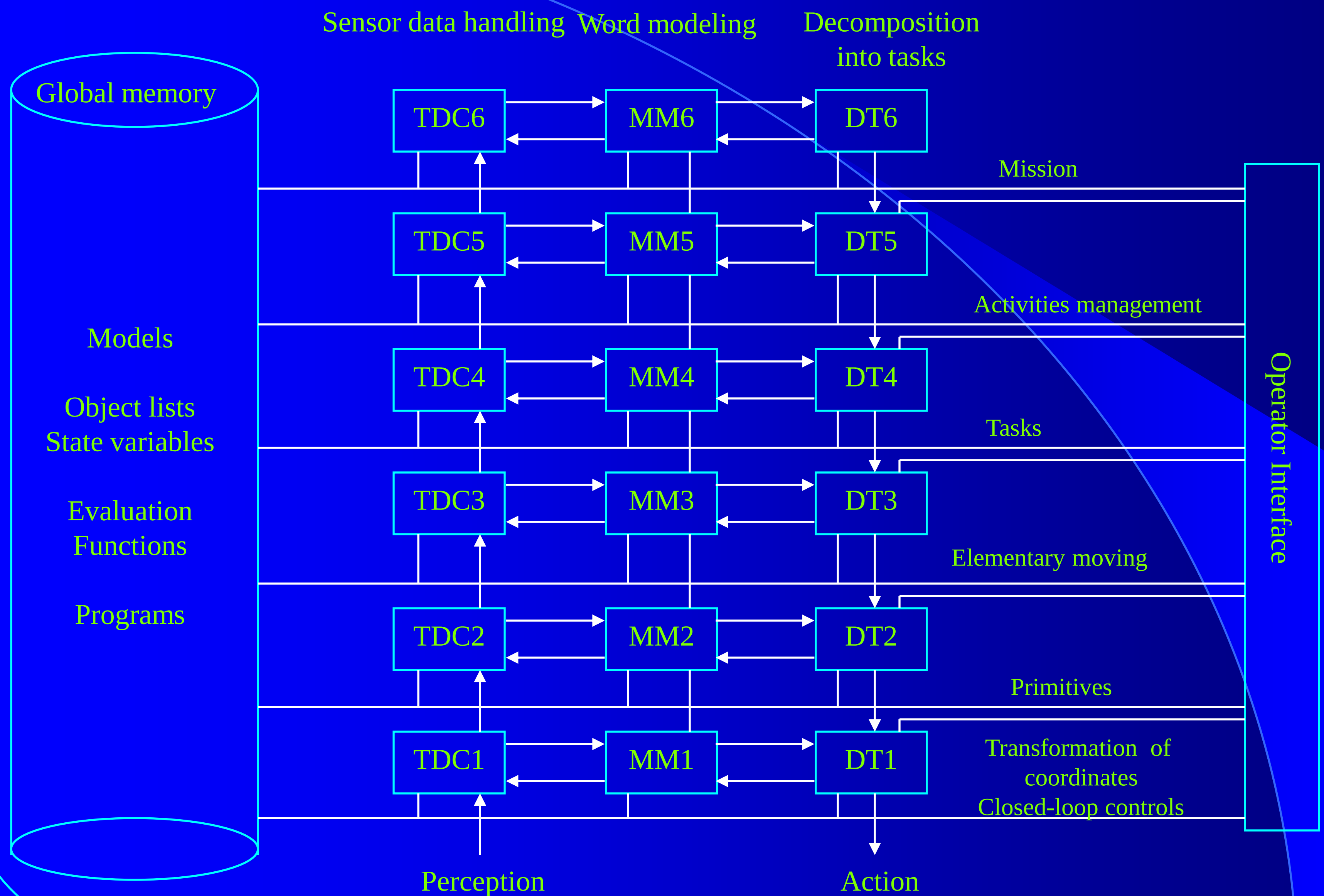
Hierarchical architectures

- Decompose programming of robotic applications into increasingly abstract levels with less and less important debits:
  - At the top: Mission objectives and plans processed in the order of once a day.
  - At the very bottom: control loops interacting with the sensors and effectors of the order of once per ms.
  - Each layer generates commands at its own level of abstraction to lower levels.
  - The lower levels do their best to " go into detail "Commands, perform them and return the results to higher levels.
- Realization of a high precision with predictive models of the world (e.g. vehicle paint, etc.).
- Drawbacks: low reactivity.

The NASREM architecture

- The most typical example of hierarchical architectures.
- Originally conceived as an architectural standard for telerobotics (Albus et al ., 1987).

NASREM architecture

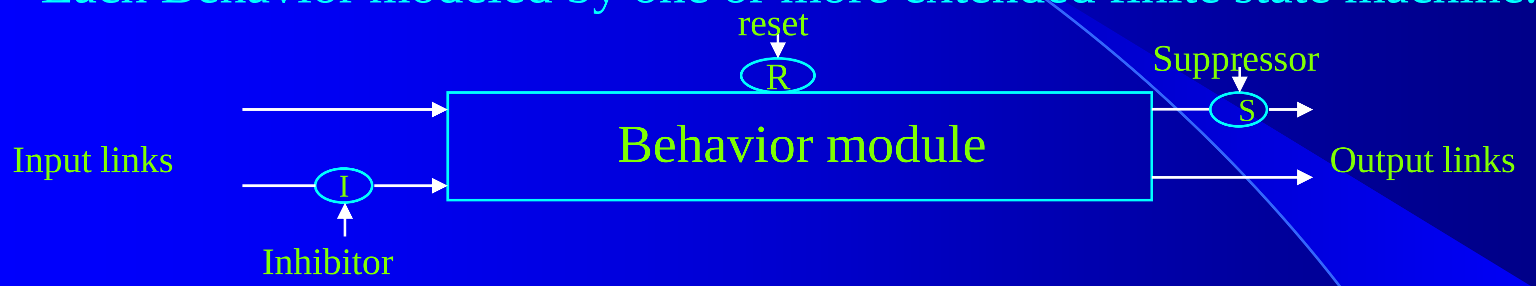


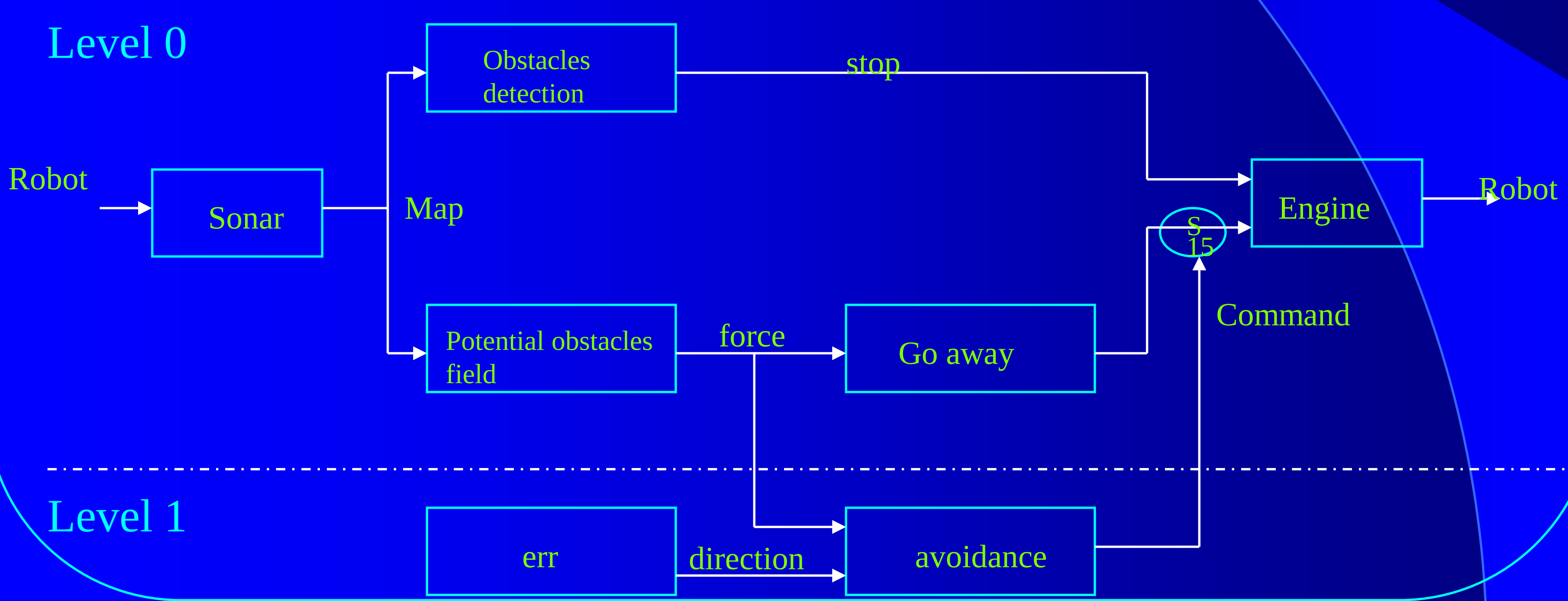
Behavioral architectures

- From the observation of animal behavior.
- Based on the following assumption: a complex and evolved behavior of a robot can emerge from the simultaneous combination of elementary behaviors.
- Adapted for tasks that must be carried out in an unpredictable and dynamic world.
- Good reactivity.
- Have proven themselves in mobile robotics.
- Drawback : rarely go beyond the navigation (difficulty of ensuring the stability of the law of complex controls, e.g. for manipulator arms).

Subsumption architecture

- Initiating architecture of behavioral architectures.
- Created by Brooks in the 80's
- Rejects the usefulness of a central model of the world.
- Each Behavior modeled by one or more extended finite state machine.





DAMN architecture

- Variant of Brooks' works.
- Proposed by Rosenblatt (Rosenblatt, 1997).
- No real hierarchy of modules.
- Sensors command obtained by fusion of commands produced by the modules.

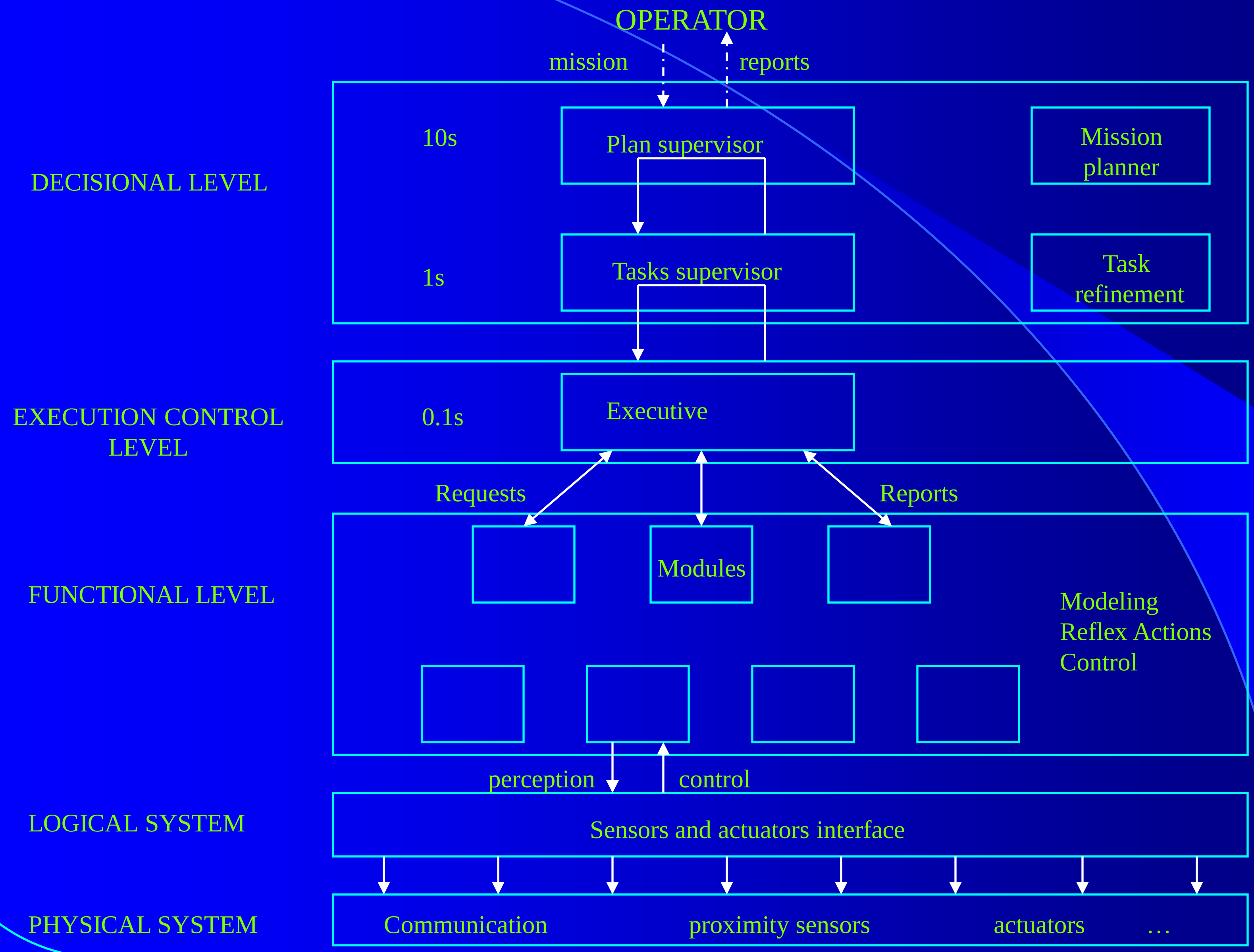
Hybrid architectures

- Goal : combine reactive capabilities of behavioral architectures and reasoning capabilities of hierarchical architectures.
- Examples :
  - LAAS architecture.
  - ORCCAD architecture.

LAAS Architecture

- Structured in 3 levels:
  - Functional :
    - Includes the robot's action and perception abilities.
    - Organized around communicating modules.
  - Executive: control and coordination of the execution of the activities proposed by the functional layer, according to a task to be carried out ordered by the decision-making level.
  - Decisional: product plans and lists of actions to perform based on a given target, while remaining responsive to reports of execution of the lower levels.

LAAS architecture



ORCCAD architecture

- Methodology of robotic application programming based on the “control-command” approach.
- Graphic programming of basic command actions , called TASKS-ROBOTS, in block diagram form.
- Focus on application dependability :
  - Rigorous real-time execution of command laws.
  - Use of the ESTEREL synchronous language for specifying the control part.
  - Use of formal verification tools for the application control parts.
- Several execution platforms : VxWorks, Solaris, etc.

ORCCAD architecture

Robot Procedure

Command modes change

Actions : Robot tasks

Data flow
+
Logical behavior