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EUROBOT CONFERENCE 2008

Ten Years of Experience with Eurobot ; Achievements, Lessons Learned and General Comments

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Ten Years of Experience with Eurobot ; Achievements, Lessons Learned and General Comments

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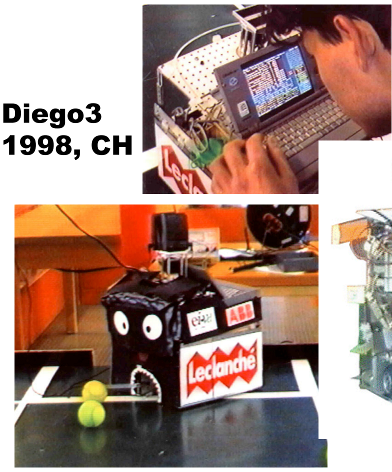
Content

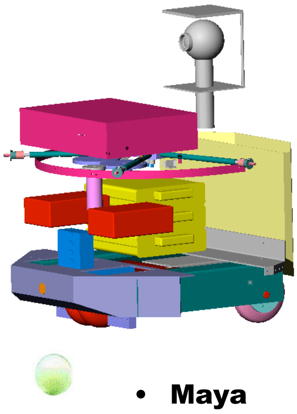
1. Introduction 1 of 3

- Our university and Eurobot, since 1998
- Movement launched before ('94), only within French boundaries.
- Many documents exist about Eurobot (TV in 15 countries, Euronews, E=M6 programs).
- European Community, Science and Society, sponsoring of Eurobot.

HEIG-VD Platforms for Eurobot

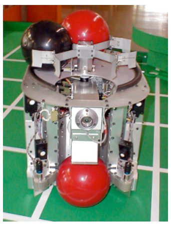
- **Diego3 1998, CH**





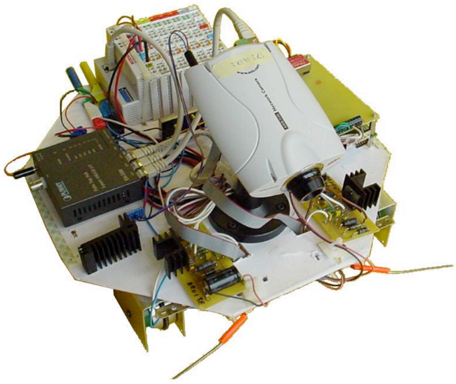
- **Arthur 1999, EU**
- **Maya 2000, EU**

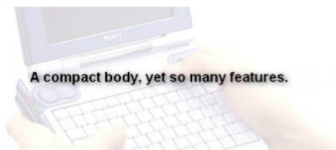
Alf 2001, EU

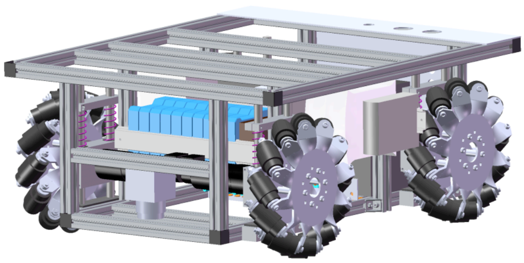


- **Hornuss 2003, CH**
- **PacMan 2002, EU**

HEIG-VD Platform - « NewOne »







1. Introduction 2 of 3

An excellent six minute description of Eurobot is available, with soundtrack in 6 different languages. It can be downloaded [1].

1. ***Description of Eurobot competitions***, **6 minutes, on DVD, Eurobot, oct. 2004. For download : http://lara.heig-vd.ch/publications/VideoWMProdEurobot2004SixMin/En/VTS011.VOB.zip ; or visit [8]**
8. **Our robots and Eurobot DVD : http://larae.populus.org/rub/4**

1. Introduction 3 of 3

- **Several international, large-scale robot-related initiatives, with different strong points:**
  - **FIRST, initiated in America, is probably the best for the very young (Lego League – market, socially oriented educational aspects, in particular also non-technical),**
  - **Robocup, initiated in Asia, maybe globally best profiled for academic research (senior leagues) and includes "applied, useful – no game" leagues (rescue, at-Home).**
  - **Eurobot is also unique in its kind: educational challenges and technological developments; it fosters design of hundreds of mostly dextrous and agile robots, always original (re. Ham radio).**
- **After 10 years of experience in Eurobot: perspectives; own; and shared?**

Content

2 Eurobot and ARY platform 1 of 2

- **Eurobot : totally new possibility** (for students, engineers and members of technical clubs)
  - –to work on a well defined problem,
  - –to compare their solutions to the solutions of peers,
  - –to disseminate their results to a large public.
- **Contrasting aspects:**
  - –very large autonomy left to the participants to solve the problem (every year a different task)
  - –some rules are strictly defined, including
    - - requirements for total autonomy,
    - - restricted volume,
    - - short play time (90 seconds),
    - - random components in task specifications (in addition to the unknown strategy of opposing robots on the common playground),
    - - effectiveness in real world (self motion, motion of objects),
    - - precise time when robots have to be ready for competitions.

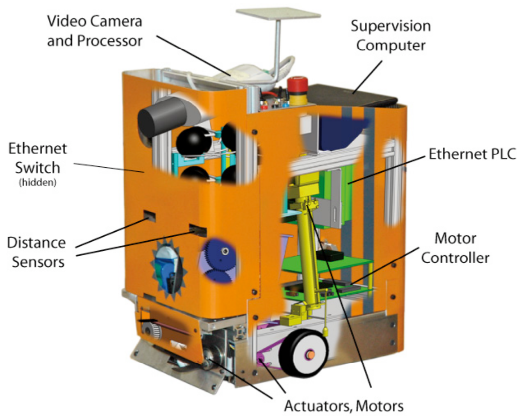
2 Eurobot and ARY platform 2 of 2

Eurobot strict requirements induce serious challenges in scientific and technical terms. The two main ones :

1. **design of a fully autonomous mechatronic system, active in physical space, specifically matching task properties: e.g. grasping, storing and shooting squash balls (ca. 3 cm diameter), or tennis balls, or rhythmic gymnastic balls (15 cm dia.), or soda PET bottles, or 1.5V batteries, or wooden pins with metallic insets, etc.;**
2. **design of a powerful programming environment, which allows for very fast adaptation of configurations and strategies.**

2.1 Necessity to design novel, specific, mechatronic systems in physical space 1 of 4

"Dude", with the help of another smaller robot, "Walter", was engaged in the bowling tournament of Eurobot. It could pick, store, and shoot squash balls in order to make its skittles fall; as well as to restore in an upright position the possibly fallen skittles of opponents



2.1 Necessity to design novel, specific, mechatronic systems in physical space 2 of 4

For our family of ARY robots:

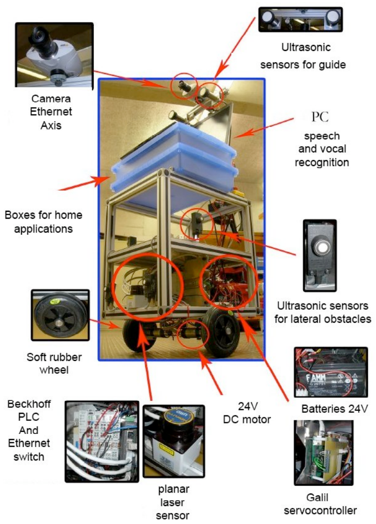
- attempt to ease the necessity to design novel, specific, mechatronic systems in physical space by using in as much as possible COTS elements

- unfortunately very little exists in *mechanical* terms, beyond bolts and screws, linear frame bars, and motor-gear-sensor assemblies

- worse : the necessity to pack a maximum of mechanical functions and components in a restricted volume.

2.1 Necessity to design novel, specific, mechatronic systems in physical space 3 of 4

"RH2-Y"(left) and "RH3-Y"(right), have been designed for "at-Home" applications and inherit many of the developments made for Eurobot. Additions: vocal dialogue, laser scanner (visible above), arm, hand, etc



2.1 Necessity to design novel, specific, mechatronic systems in physical space 4 of 4

- Many years ago, in a different context [10], we used to win a robot competition, essentially in two ways, similarly successful:
  - one was using a camera, a PC and an industrial robot,
  - the other one, provocatively for an AI context, was successful without any sensor nor digital processor!
- In fact not so different:
  - With usual programming: a few language primitives are progressively structured in larger, integrated procedures,
  - second case: a mechanical kit consists in small standard elements, joined in structures larger and larger, each ensuring by mechanical constraints that the required functions be enforced (moving, sorting, reorienting, lining-up, etc.).
- In Eurobot context, constraints of limited volume and very large changes in tasks-to-be-done really force teams, every year, to innovate, in order to successfully design new, efficient, mechatronic action systems.

2.2 Necessity to design a powerful programming environment 1 of 6

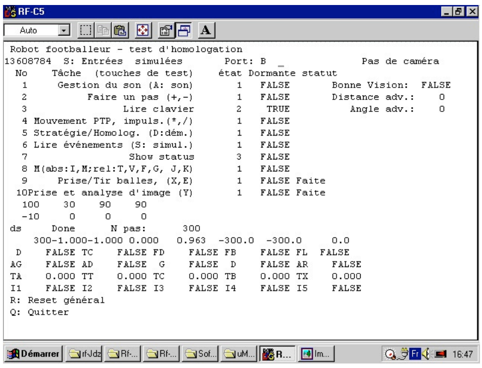
- Extensive possibilities in terms of simulation are helpful:
  - Eurobot participants face a very high degree of uncertainty.
  - Very fast changes are necessary during development and competition phases for reaching a certain level of excellence.
  - System development is made in such a way that typically, very little time is available after when robots are fully integrated
  - parallel engineering is required.
- For sophisticated programming, extensive simulation and man-machine interaction, PC technology was a good choice.
- For parallel programming and real-time control however, common tools were not appropriate. Our Piaget environment, including a very fast multitasking kernel and an application-oriented language.
- The second year, Piaget was adapted to include industrial robot types of instructions (a subset VAL instructions: move, appro, signal, inverse, tool, etc.). The reason was that when beginning with a new task (game), it is not known yet which sensors and actuators will be used, and which elements of strategy will be designed; thus to be able to handle programming as for a standard robot is an advantage during early phases.

2.2 Necessity to design a powerful programming environment 2 of 6

Piaget environment has remained remarkably constant, even though at implementation level, major changes have occurred:

- **moving from Pascal to C++,**
- **from DOS to Windows, and more importantly yet,**
- **from a conveniently centralized structure – the PC- with very high reactivity possibilities via standard parallel interface (ca. 1 microsecond per transaction) to a strongly distributed architecture, featuring Ethernet-TCP-IP communication standard (ca 0.1 s per transaction):**
  - **PC for supervision,**
  - **significant number of specialized subunits:**
    - **motion controllers,**
    - **PLC,**
    - **camera with embedded low-level processing unit,**
    - **etc..**

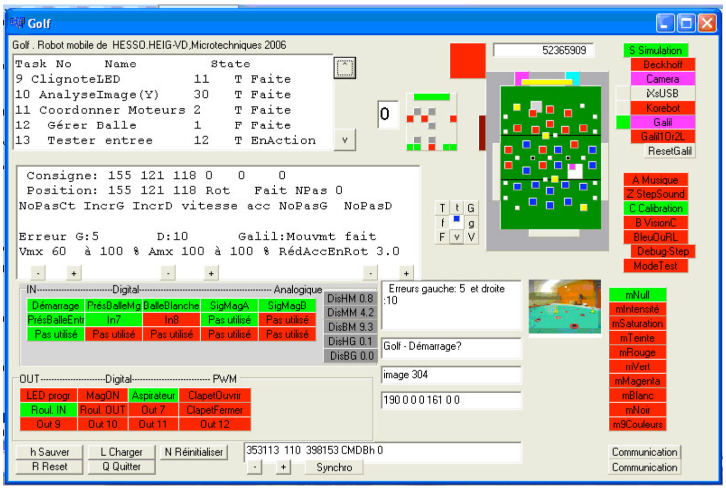
2.2 Necessity to design a powerful programming environment 3 of 6



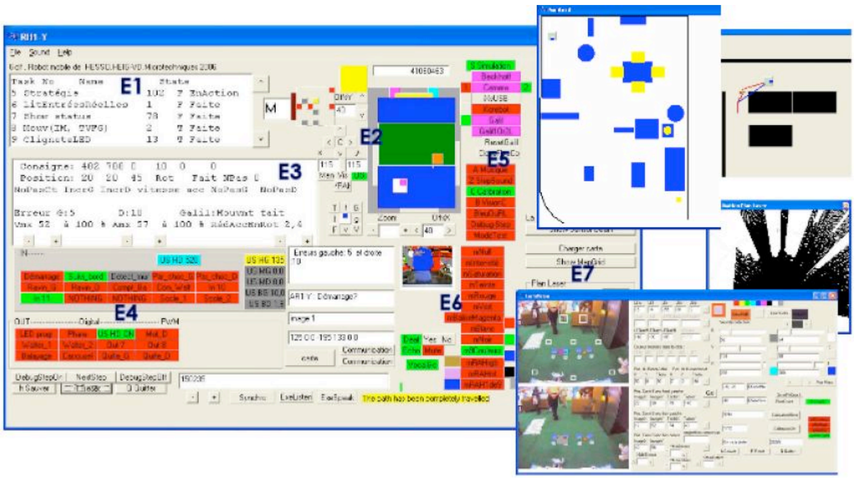
First versions of Piaget environment, on Diego3, 1998.

2.2 Necessity to design a powerful programming environment 4 of 6

Later versions of Piaget program-ming and control environ-ment, on Dark-18, 2006 .



2.2 Necessity to design a powerful programming environment 5 of 6



Current version of Piaget programming and control environment, on RH2-Y, 2007. In addition to main screen, 4 windows show a map of Atlanta “Robocup-at-Home” facility, virtual trajectories with detection of possible collisions, laser measured distances, and some vision processes for “CopyCat” test.

2.2 Necessity to design a powerful programming environment 6 of 6

- The main control panel allows to monitor
  - I/O states,
  - progress in all parallel tasks,
  - scenes,
  - distances,
  - and much more.
- It can also with immediate effect
  - change I/O states, especially in simulation mode for what concerns inputs,
  - trigger various sorts of motions;
  - a third category of actions allows for reconfiguration and parametrization of the robot, including the possibility to store the new configuration for later runs.

Content

3 Education and Research

For our experience, Eurobot has been useful both for education and research, and importantly, it has also proven effective in helping bridge the gap between education and research

- **3.1 Eurobot and education**
- **3.2 Research and innovation**

3.1 Eurobot and education 1 of 3

- **Before Eurobot:**
  - courses with a focus only on the areas of robotics generally found essential.
  - experiments in the lab were offered, with less short-term incentive than when competition context started to be considered.
- **Eurobot has forced a shake-up of course content:**
  - in priority urgent items. After such a first visit of course material, a second path was done, filling-up information which had been bypassed in the first turn.
  - More importantly, gaps in the classical training became apparent, and called for immediate action in terms of extended training/coaching, thereby fostering transfer from research to education.

3.1 Eurobot and education 1 of 3

- **From 1998 to 2005: enough time was allocated to robotics and automation, for a curriculum in microtechnology, so that 2 periods per week could be used to perform coaching for Eurobot**
  - **The advantage of this very good approach is, while a lot of initiative is anyway left to the students, that a careful coordination is possible with regular course and lab contents, in close synergy with curriculum requirements; and reciprocally, that students understand that such an experience is a necessity for their professional preparation.**
  - **Now, unfortunately, curriculum revisions in line with European bachelor and master recommendations (re. Bologna) have reduced the total amount of periods allocated to the program, forcing Eurobot preparation to be performed separately, in independent clubs.**

3.1 Eurobot and education 3 of 3

- **Unexpected, positive effect of Eurobot initiative:**
  - **has triggered interest in the whole educational line for our region, reaching, beyond universities and even technical and vocational schools, classes of secondary and even primary schools.**

    Of course, with adaptation of content, of roles for the students or even as themes and approaches (FIRST Lego Leagues, or even simply – but to a large scale – local school Cups).
  - **This has brought a lot of benefits in introducing the fun of science and technique to the youth and even to carry science more broadly, in the society at large.**

3.2 Research and innovation 1 of 2

- **Eurobot competitions call for “systems”:**
  - there are always finally one or several components that turn out critical.
  - they represent the limiting factors, and there is no way for improvement but to perform effective research on those items.
- **A key requirement : to design a flexible, multi-tasking/multi-agent, real-time kernel. To reach the top half of Eurobot score list, it is absolutely impossible to program the robot with a single programming thread; or to ignore (real) time-based constraints. Started from an old approach, made famous by Texas Instruments in the early 80’s: context-switching.**

3.2 Research and innovation 2 of 2

- **With progresses in microelectronics (high frequencies, large memory sizes) and in computer engineering (e.g. cache-memory mechanism), this has allowed us to have today, typically, our PC-based agents active, in average, every 2 microseconds (they start-work-and-leave within time slots of an average of about 100 nanoseconds. And this integrates the average time spent in all other Windows-tasks! With such a concept, priorities or interrupts do not need to be considered; polling is effective and makes task/agent synchronization a very simple thing to implement).**
- **In research, mostly two main challenges have been identified and solved beyond previous state of the art:**
  - quantitative assessment of cognitive properties (in automated systems: quantitative cognitics), and
  - ensuring a safe relative agility of decision-making resources, for all closed-control paths (stability of multi-agent systems)

Content

4 Science and Technique

4.1 AI versus software engineering
4.2 Active or "passive" control loops
4.3 Parallel port or Ethernet TCP-IP architectures
4.4 CC or brushless versus stepper motor
4.5 Other remarks

4.1 AI versus software engineering 1 of 2

- **Our laboratory, in the scope of industrial robotics and automation, has always been following progresses in artificial intelligence (and sometimes making contributions in this area as well).**
- **Experiments have been fully programmed for approaches typical of AI, such as below:**
  - **Genetic algorithm and natural selection process for control design (successful pole control)**
  - **Neural networks for successful pole control, using Hopfield model, Hebb law, and also Backpropagation**
  - **Fuzzy logic for successful pole control**
  - **Memoryless animats (re. R. Brooks's concept) for labyrinth search (deterministic) and collision-free navigation in labs (stochastic approach)**
  - **(Continues on next slide)**

4.1 AI versus software engineering 2 of 2

(continued)

- **Navigation algorithms with learning for collision-free navigation in labs,**
- **Tree search with forward and backward chaining, breadth-first and depth-first approach (Nokia-type puzzle),**
- **Eliza (in English and French),**
- **robotic handling of cubes on piles, using "expert-systems", i.e. declarative programming .**

- **Programming is now typically in C++; previously it has been done in Delphi, Pascal, Lisp, Basic, Prolog, "Personal Consultant Plus" environment, etc.**
- **Our main contribution for AI can probably found in quantitative cognitics. This technique clearly shows that for demanding cognitive tasks such as at Eurobot, all above AI methods cannot be used (at least not as the main driver) and on the contrary software engineering (or possibly logic-hardware based engineering; or even embedded approaches) provides far better possibilities.**

4.2 Active or “passive” control loops

- Feedback loops may have some value, even if not explicit and “digital”, but simply embedded in physical systems .
- For example the wheels of railway trains are commonly kept between rails without sensor nor computer, but just as a result of lateral forces and material elasticity (F=kx; F=ma).
- Similarly, a stepper motor will naturally deliver a corrective torque if disturbed from its nominal position, just as a DC-motor with encoder and digital controller would do.
- (Yet, slamming a robot against Eurobot table sides, as is often seen, though effective, is not so elegant for pose calibration)

4.3 Parallel port or Ethernet TCP-IP architectures

- Parallel ports are gone, and distributed architectures have novel merits.
- In early times, parallel ports were standard, even on very compact computers, and the OS allowed for fast and direct access to physical addresses, for user applications. Along with a lean OS, this could allow for a “total” programming of applications on the PC.
- Today, the parallel port is just not available, even not as an option on small systems. But Ethernet can be found everywhere. Similarly OS’s have evolved, offering on demand a really huge amount of interesting options.
- Cost :
  - poor reactivity of PC at outside events, in standard configurations;
  - Necessity of multi-agent architecture, with specialised resources for serving all fast processes (servo control etc.)

4.4 CC or brushless versus stepper motor 1 of 2

- **A question typically arises when starting a new robot : which motor technology is best for locomotion?**
- **Schematically speaking, CC or brushless motors can be considered here to be equivalent, and will be referred to as servoed motors. (Compared to CC motors, brushless motors have the potential of turning faster and lasting longer, but they are somewhat more complicated then DC motors to handle and should in principle not be required for Eurobot competitions).**
- **Stepper motors have a kind of Boolean behavior: if by design, steps cannot be forced (typically, the wheel slips on the floor before the motor misses steps), then they may be viewed as "perfect". Otherwise, they cannot be used.**

4.4 CC or brushless versus stepper motor 2 of 2

- **On the other hand, servoed motors seem always to work. But depending on control quality, best performances may be hard to reach, and in fact performances can degrade significantly, which may translate into important errors on trajectories.**
- **On former designs, we had typically stepper motors, with excellent performances and very simple, 2 bit interface with PC. Since we have switched to the distributed architecture, we have then been using DC motors, with dedicated controllers, interfaced with Ethernet TCP/IP. Servocontrol and trajectory laws (trapezoid speed curve) are specified by the supervisory PC, and implemented locally.**

4.5 Other remarks 1 of 5

Other remarks may be useful.

- ***Top-down or bottom-up approach (free-wheel sensors) for location estimation*.**
  - **We have nearly always used a top-down approach for the ego localization of robots.**
  - **Typically a 1 cm accuracy, i.e. on the order of 1/1000 could be achieved through a match.**
  - **Recalibration, with vision or laser sensor, have often been implemented, and sometimes been practiced during training phases, but**
    - **it is hard to be as accurate, and**
    - **it takes time and risks.**
  - **We have also tried the use of free-wheels,**
    - **may be necessary if motorized wheels slip significantly because of highly dynamic behavior,**
    - **but (in our case where motions are carefully parametrized,) integration of those 2 signals to estimate 3 coordinates in the plane is (comparatively) not accurate.**

4.5 Other remarks 2 of 5

- ***About quantitative cognitics*.**
  - **Cognitics is the science and techniques of automated cognition.**
  - **Found necessary to introduce a proper metric system for cognitive processes.**
    - **Take an analogy: can typical humans jump over a wall?**
      - » **Well, it depends on the height of the wall.**
      - » **Yes for 0.5 meter;**
      - » **No for a 5m high wall.**
    - **For cognitive tasks too, quantities matter;**
      - » **e.g. how complex is the task?**
      - » **How much knowledge does it require? etc.**
  - **We have therefore introduced units and mathematical equations for cognition, based on information and time, “bit” and “second” units; in particular “bit” for complexity, “lin” for knowledge, “lin/s” for expertise and learning.**

4.5 Other remarks 3 of 5

- ***Continuous versus PTP motion.***
  - **Newcomers typically have the feeling that motions should be ordered as preferably "long" and continuous, rather than "point-to-point", and incremental.**
  - **In fact it is possible, for the previous case, to have parallel agents watching for changes in circumstances and possibly requiring emergency stops and changes in motion plans.**
  - **But in practice,**
    - **this requires a good synchronization of several processes, which is never obvious, and**
    - **more importantly, this makes the programming of "next" actions extremely difficult: by this token,**
      - **a very large variety of situations may occur, and**
      - **to define practically what has to be done next, for each and all possible situations, may just turn out to be too difficult to be done.**

4.5 Other remarks 4 of 5

- ***Holonomic versus non-holonomic platform.***
  - **Moving in the plane requires 3 actuators to allow for "universal" immediate motions.**
  - **In our case, we usually use**
    - **2 motors and active wheels (very common approach),**
    - **"Amiguet '98" method to successively implement 3 virtual joints (θ1, d2, θ3), i.e., typically, straight-line motions;**
    - **sometimes we also implement circular interpolation (this is especially useful for leaving from very confined locations, i.e. to somehow simultaneously translate and turn).**
  - **If we relax the constraints for simplicity, volume, and cost, the holonomic approach may be interesting.**
    - **now in the process of designing a 4-motor-Mecchanum platform for our domestic robot,**
    - **this may help**
      - **for locomotion**
      - **for handling: the robot arm may so inherit from the 3 dof of the locomotion resource (total of 6 servoed axes: 4w+1s+1h).**

4.5 Other remarks 5 of 5

- Other interesting elements of experience could also be gained in other areas, notably in the following domains:
  - PLC versus PC or servocontrollers;
  - PC versus Integrated PC;
  - stereovision versus laser distance estimation;
  - single or multiple ultrasonic sensors (issues relating to perturbations);
  - similarity of information quantities in B&W versus color versus 3D images;
  - Amiguet's method versus splines, clothoids and other approaches (re. Serpentine) for trajectory generation;
  - dual need of teaching basics and offering tutorials versus incrementally communicating newest R&D results.
- re website or other publications.

Content

5. Conclusion 1 of 3

- After 10 years of Eurobot: a summary of knowledge and expertise gained so far is useful
- Eurobot has brought on the world scene,
  - typically for students in engineering schools and fans of technology, a
  - unique opportunity to design autonomous mobile robots,
  - most often with excellent agility and dexterity properties.
- Eurobot typically sets two major challenges:
  - design a fully autonomous mechatronic system; and
  - design a powerful programming and control environment for very numerous and fast adaptations.
- Here mechatronic systems require
  - a lot of original design, because of
    - requirements, yearly renewed, and
    - restricted volume allowed.

5. Conclusion 2 of 3

- As programming environment, we have created Piaget, which, for the final user is :
  - very simple,
  - effective, and
  - quite constant even though its implementation has changed a lot through the years, in terms of
    - implementation language,
    - operating system, and
    - control architecture.
- Education and research have both benefited from Eurobot initiative.
  - For education, in addition to the positive effect on students directly involved, Eurobot has contributed to a much larger impact on society, notably at schools and in training of the youth.
  - In research, improvements in quantitative cognitics, and considerations about the relative agility of multi-agents in control loops were important contributions to be fostered.

5. Conclusion 3 of 3

- **In terms of points and rank,**
  - **our goal has always been**
    - **to pass the homologation test,**
    - **so as to be able to actively participate in the event,**
    - **with a probability of 95%;**
  - **it turns out that until now**
    - **the team has constantly had a 100% success rate at homologation test,**
    - **both at national and European levels;**
    - **several cups have been obtained.**
- **In terms of organisation, advertising, with the involvement of TV channels, has been a key supporting ingredient. For the future, public support for edutainment and for public awareness in science and technology should be considered, along with education and private resources**
- **A decade of Eurobot experience has brought a number of other interesting elements.**

Thanks for your attention!

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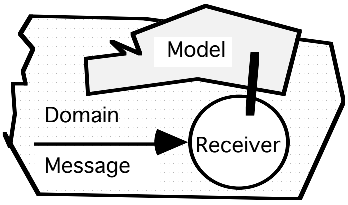
Fundamental definitions and units in MSC theory

- Concepts of "model" and information revisited *
- Assessing complexity, knowledge and other cognitive properties, in quantitative terms *

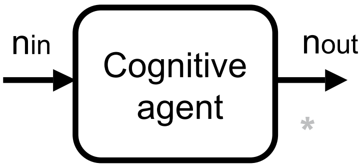
Model and information

- **Model : very simple representation of reality; very much incomplete; useful for specific applications and contexts.**
- **Information: what allows a receiving agent to create and update its model of a domain**



Main definitions and units in MCS

– **Information:** $n=\sum p_i \log_2(1/p_i)$ [bit]



– **Complexity of cognitive domain :** $L=n_{out}\, 2^{n_{in}}$ [bit]
– **Knowledge :** $K=\log_2(L+1)$ [lin]
– **Expertise :** $E=K/\Delta t$ [lin/s]
– **Learning :** $\Delta E=E(t_1)-E(t_0)$; >0 [lin/s]
– **Intelligence :** $I=\Delta E/\Delta n$ [lin/s/bit]

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