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Elements of Hybrid Control in Autonomous Systems and Cognitics

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2. Benefits of hybrid approach and cognitics
3. Defining new terms in cognitive ontology context
4. Generic schemes for cognition and control
5. Conclusion

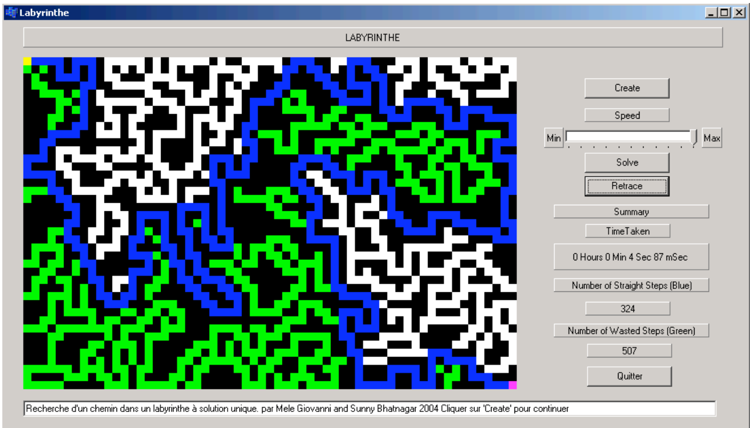
1. Introduction 1 of 3

- Intelligent autonomous systems, and robots improve their ability towards mission goals that humans assign to them.
- Control for such systems should hybridize the best current theories and practices
- Four components have proven particularly crucial:
  - *AI*. Dramatic achievements proving some mathematical theorems or playing chess
  - *Situated automata*. Modeling and world representations could be avoided if machines can immediately perceive the world and react
  - *Closed-loop control*. Control based on feedback: whole corpus of contributions, for example, fast and accurate positioning of minute magnetic heads on dense hard disks; successful travel of space rockets towards precise targets at astronomical distances.
  - *Computer infrastructure and networks*. Computer sciences and engineering, as well as novel 1-1 or network-based communication possibilities also contribute to control.

1. Introduction 2 of 3

- **However, significant limitations remain:**
  - ***AI*. For AI, huge difficulty of representing, in general, objects and processes.**
  - ***Situated automata*. Constraint to "here and now" ; no past nor future world can be perceived so directly, neither alternate nor remote locations can be sensed, to say nothing of hypothetical, virtual worlds..**
  - ***Real-world systems* always suffer from delays, which are crucial for closed-loop systems behavior and performance (stability, speed, accuracy, and cost.).**
- **This paper aims to contribute to pushing those limitations farther away.**

1. Introduction 3 of 3



Navigation in random mazes (walls are black, path is initially white) by a reactive mobile system without memory: situated automaton.

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2. Benefits of hybrid approaches and cognitics

2.1 Quantitative cognitics
2.2 Hybrid approaches
2.3 Ingenuity, chance and/or time

2.1 Quantitative cognitics 1 of 4

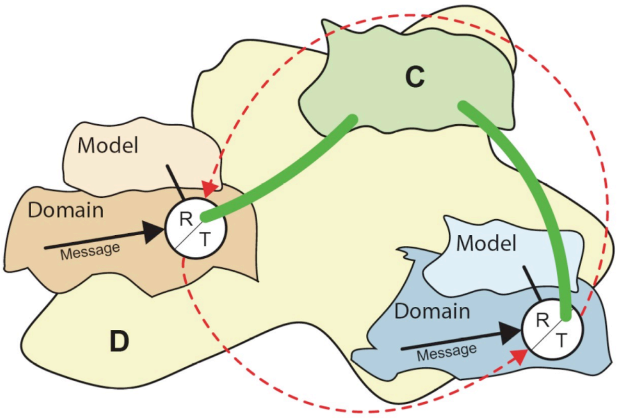
- Quantitative cognitics and MSC have proven useful in precisely defining knowledge, complexity, expertise, learning, etc., in quantitatively assessing them, and in drawing conclusions from our experiences with them.
- Some examples :

  1. Estimating a quantity of intelligence (unit : lin/s/bit)
  2. Assessing the ratio of complexity between a given domain of reality and a corresponding model of it.
  3. Noticing many intelligent man-made artifacts; in particular current ordinary computers, capable of learning, e.g. with the cache paradigm.

2.1 Quantitative cognitics 2 of 4

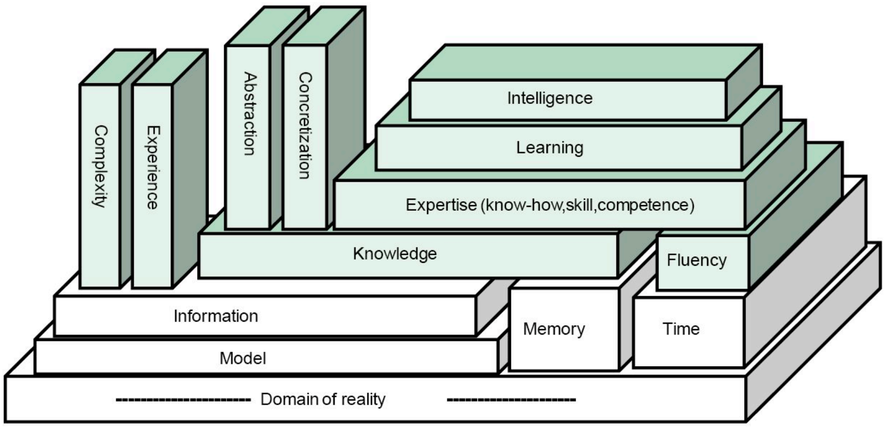
- The definitions provided in the MSC ontology are not claimed to be true (they describe an infinitesimal part of reality), but just useful; in particular, they are useful in engineering, in autonomous systems, providing the ability to take the right steps towards mission goals.
- The cognitics perspective provides a sound basis for assessing and complementing classical AI and reactive architectures, as well as control, computer and software bases.
- Opportunity to raise interest in the perspective offered by MSC. Furthermore, in Part 3, new terms added to the ontology.

2.1 Quantitative cognitics 3 of 4



•In the **MSC** framework, autonomous systems can be represented as **behavioral** systems (e.g., individuals or groups, on the left), and on the basis of **information** and **time**.

2.1 Quantitative cognitics 4 of 4



• **With MSC, the main cognitive entities can be quantitatively estimated**

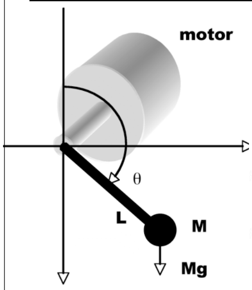
2.2 Hybrid approaches 1 of 7

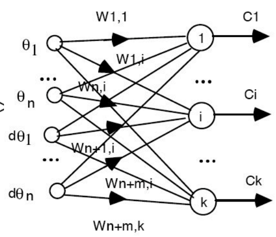
Four hybrid cases considered :

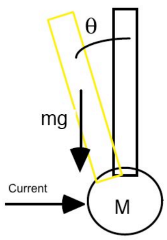
- **AI-Cognitics,**
- **Control-AI,**
- **Reactive systems (RS)-Cognitics,**
- **AI-Computer technologies.**

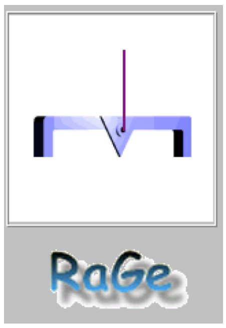
First: examples

2.2 Hybrid approaches 2 of 7









HEIG-VD examples **Many physical processes like the motorized inverted pendulum can be successfully controlled, using classical approaches as well as typical AI systems (fuzzy logic, neural networks) or mixed type systems, such as controllers synthesized with genetic algorithm paradigms.**

2.2 Hybrid approaches 3 of 7

- *AI-cognitics* . Most relevant definitions include the following:
  - A- Turing's definition (anthropocentric and culturally oriented),
  - B- Social and epistemic definitions,
  - C- common implicit definition: "suicidal" to AI; intelligence is "that very cognitive property that specifically discriminates humans from machines,"
  - D- in the MSC model, intelligence is the specific property of cognitive systems that are capable of learning
- Except for case C, the definitions provided in the MSC ontology for cognitics are not necessarily incompatible with definitions above.
- Benefit from MSC in AI : rigorous and encouraging assessment of numerous existing intelligent systems.
- A hybrid view is particularly natural here

2.2 Hybrid approaches 4 of 7

Control-AI. Control processes sometimes need to rely on some feedback components; there an effective management of delays is critical.

For years, compensation for some delays, typically in practice by a prediction strategy based on signal derivatives.

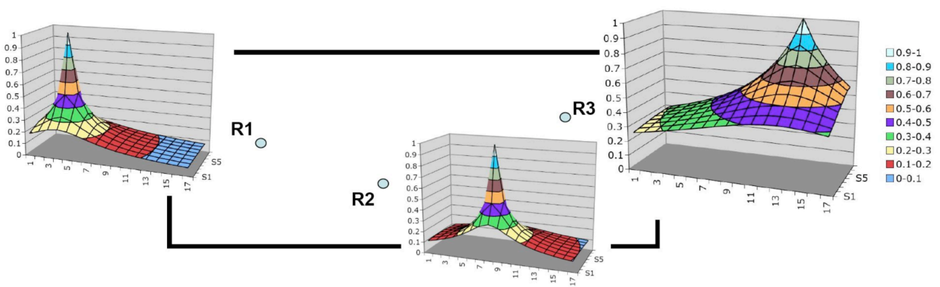
Now in hybrid terms, many new possibilities arise when AI used in control systems as a mean to improve predictions, to automate novel applications, such as for robots cooperating with humans in cognitively demanding applications

2.2 Hybrid approaches 5 of 7

RS-Cognitics. **Agents in MSC theory similar to those in reactive systems or situated automata: all involve essentially behavioral elementary components**

A hybrid strategy may thus be useful, as RS will keep things simple where possible, while approaches advocated in cognitics can address factors beyond just the immediate signals emanating from the environment

2.2 Hybrid approaches 6 of 7



Example : a hybrid approach merges the control power of multiple classical controllers (R1, R2, R3), each individually and optimally tuned in key configurations, with the paradigm typical of fuzzy logic controllers, by which dynamic weights and interpolation functions ensure the smooth transitions in physical space (here, 2D) of the respective controller contributions.

2.2 Hybrid approaches 7 of 7

***AI-Computer technologies*. In one sense, computer technologies obviously bring a lot to AI : practically all cognitive systems today are implemented on computers (e.g., simulation of neurons, generations of evolving populations, virtual ants, etc.).**

Progress in microelectronics, software technologies, communication and network engineering => the processing of large amounts of complexity, knowledge, expertise, learning and other core cognitive properties is nowadays routine.

Yet a quantitative approach quickly proves that cognitive processes can yet be much more powerful than such tools and techniques! Example : the accurate estimation of "Pi," i.e., 3.14... Boosting computer technology would yield a mere additional *10 digits* while (human) ingenuity has added about *200 millions digits* in the past two decades!

2.3 Ingenuity, chance and/or time 1 of 2

Cognition for strong innovation?

- **Necessary for managing complexity (today, a huge number of artificial cognitive systems routinely run successful operations and deliver information that is physically impossible to be stored a priori)**
- **Not sufficient: how to create new models and novel cognitive systems? quantum leaps? Tempting to think of yet another cognitive property, ingenuity? But a cognitive process immediately embedded in a specific domain of *reality* calls for infinite amounts of incoming information, thus of knowledge and expertise.**

2.3 Ingenuity, chance and/or time 2 of 2

- In fact, there *is* a powerful possible source for strong innovation: chance.
- In the MSC model, random processes are capable of generating infinite amounts of unpredictable information, and thus feature infinite amounts of knowledge in their domain.
- Thus, ingenuity is a regular cognitive process that evaluates and keeps selecting models or cognitive systems. Re basic paradigm in AI: trial and error.
- Chance takes time; here cognition (experts) helps (focus, keeping track of improvements, and possibly tuning-up contingent solutions).

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3. Defining new terms in cognitive ontology context 1 of 8

- **Hybrid approaches bring attention to multiple interesting concepts. Some of them, such as learning, are central for cognitics and have already been listed and defined in the MSC ontology. Some other ones are new here:** ***control, reactive control, deliberation, top-down and bottom-up approaches*****. And other entities, including those mentioned above, including** ***ingenuity*** **and** ***chance*****, or still others, such as** ***creativity*** **should all be discussed in the MSC framework or from the MSC perspective .**

3. Defining new terms in cognitive ontology context 2 of 8

Control**. Control is a process that delivers commands to a system so as to reach some specific goal.**
Generally speaking, "control" and "commands" imply power, forces and/or other physical entities. Here only the information aspects are considered. Thus, in the MSC model a control unit or agent is just a regular cognitive system, which, like any other one, is fully described by its input – output information flows ("behavior") and time; all derived cognitive entities (knowledge, expertise, complexity, etc.) are equally applicable here.

3. Defining new terms in cognitive ontology context 3 of 8

***Reactive control and other control types*.**
- Reactive control is a control in which some particular kind of input information is relevant. A still more specific type of control, a subset of reactive control, is called closed-loop control, in which some input information entering the control system results more or less directly from the commands issued to the system being controlled ("feedback").
- The opposite is proactive control, in which information is transmitted as "feed-forward", "open-loop" information toward the system being controlled.
- When integrated in complex systems, control units may simultaneously feature multiple control types, depending on the subsystems and functions considered.

3. Defining new terms in cognitive ontology context 4 of 8

***Deliberation*. Root : Roman scales by which weights were measured. "which side of the scale is lower", maps directly to the "if" statement, to Boolean, On/Off, and reactive control systems. From the MSC perspective: deliberation is the regular operation of cognitive systems, fully described by input – output information flows ("behavior") and time; all derived cognitive entities (knowledge, expertise, complexity, etc.) are equally applicable.**
"Decision making" or "data processing" may also be considered as synonyms for deliberation. No new concept and units required.

Top-down approach 1 of 5

A top-down approach implicitly refers to a hierarchical pyramid.

In the MSC model, there is no such exact notion of higher or lower levels (top-bottom).

In MSC, three notions primarily relate to interaction between agents and thus also overlap with the concept of top-down approach:

- "input–output" information flows,

- "abstraction–concretization" processes,

- "integral systems versus more elementary subsystems"

Top-down approach 2 of 5

- "Input–output" information flows,

The distinction and complementary aspects of input–output flows are obvious, and apply symmetrically for each of the two communicating elements; yet if the information does flow in a single direction, then one element is necessarily a pure transmitter and the other one a pure receiver. Schematically, top-level elements transmit information, and bottom elements receive it. Examples in the internal control hierarchy of a cooperating robot could be A. the control of stepper motors, or B. the synthesis of speech.

Top-down approach 3 of 5

- "Abstraction–concretization" processes

Abstraction is the property of cognitive agents that generate less information than they receive; conversely, concretization generates more information .

In general, top-down organization calls for concretization.

Examples : A. a higher-level, coordination level for motion control); B. a speech synthesis unit.

High performance cognitive approaches often rely, in some steps, on opposite strategies, e.g., temporarily trading degrees of abstraction for improvements in fluency. Ex. hash tables.

Top-down approach 4 of 5

- "integral systems versus more elementary subsystems"

As mentioned above, the MSC model is equally applicable at all granularity scales. This means that if a system is analyzed as a set of subunits, for each subunit the same scheme is applicable; similarly, if several cognitive systems are considered in an integrated, synthetic way, the resulting "meta-system" can also be represented with the same scheme.

Top-down approach 5 of 5

The notion of hierarchy is therefore "orthogonal", or independent to granularity scales (by analogy, notice social hierarchies in general not apparent in the infrastructure, human individuals; communication and transportation networks; or the usual objects in a program). Another challenge is the mesh aspect of interconnections; instead of a simple, unidirectional level axis (implicit in a top-down structure), what is useful in such contexts is the consideration of multiple dimensions, with parallelism and nested loops. The MSC model supports these views.

3. Defining new terms in cognitive ontology context 5 of 8

- ***Bottom-up approaches***. The discussion in the previous paragraph, §Top-down, is applicable here mutatis mutandis. In particular, the bottom-up organization in general calls for abstraction.
- Examples of such bottom-up, high abstraction cognitive processes for a cooperating robot include
  - A. vision and laser-based localization, and SLAM, and
  - B. Speech recognition.

3. Defining new terms in cognitive ontology context 6 of 8

Creativity: **Particular kind of *knowledge* (unit: lin), that features a *concretization* index higher than 1.**

•Knowledge and concretization have already been formally defined in the MSC ontology. The specificity of a creative system is thus simply to ensure that there be actually some concretization, i.e., that more (pertinent, domain-relevant) information is generated by the system than the system itself receives. Creativity is a very common feature of cognitive systems. Here are two examples: building a family house, for an architect; or generating a navigation path from the living room to the fridge, for a domestic service robot.

Ingenuity 1 of 2

Ingenuity: **particular kind of *knowledge* (measuring unit: lin), i.e., knowledge in a specific *domain*, which contains reality as the input space and information about novel, improved cognitive system(s) (e.g., better knowledge, better expertise, better intelligence, better abstraction, etc.) as the output space.**

• The specificity of the domain is of a contingent nature, in the same way as knowing a language contains the instances of knowing French or knowing English.

Ingenuity 2 of 2

Ingenuity is the most desirable and prestigious element in MSC concepts relating to the generation of information:

- **expression (just generating any sort of information),**
- **knowledge (expressing correct information),**
- **expertise (doing it correctly and quickly),**
- **intelligence (able to increase expertise),**
- **creativity (knowledge with a concretization index higher than 1),**
- **ingenuity (a kind of meta-intelligence by which the cognitive system itself is reengineered so as to yield a quantum improvement in its expertise) .**

3. Defining new terms in cognitive ontology context 7 of 8

Chance: kind of *knowledge* (measuring unit: lin), i.e., knowledge in a specific *domain*; the domain contains no input space but an output space consisting of totally unpredictable information.

• Chance is knowledge, and as such already defined in MSC; in quantitative terms, in as much as the information delivered is purely stochastic, of potentially unlimited size, the quantity of knowledge here is infinite!

• To engineer chance, pragmatic solutions include *approaching* chance with finite resources (e.g., pseudo random generators) and "*redirecting*" information generated by an external, natural, source of random information (chance).

3. Defining new terms in cognitive ontology context 8 of 8

Conclusions about new concepts in MSC.

- **The core elements of MSC model offer a strong basis for cognitive theories and are quite universal; re. electronic circuits made from very few basic blocks (resistor, diodes, etc.).**
- **There are a wealth of other concepts debated in the world of cognition and cognitics, which can be formally defined, as derivatives and sometimes simply special cases of existing, well-defined, core concepts (domain, model, information, knowledge, expertise, etc.).**

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4. Generic schemes for cognition and control 1 of

Five generic schemes for the control of systems, from more established ones to more recent and ambitious ones, where hybrid control as well as automated cognition, i.e., cognitics, play critical roles. Classical elements are listed here along with other, original ones, thus allowing for a more complete perspective.

4. Generic schemes for cognition and control 2 of

4.1 Reactive systems

4.2 Cognition for the virtual exploration of inaccessible dimensions and parameter regions

4.3 About learning

4.4 Limited relevance of external versus internal discrimination and consequence on estimation of autonomy

4.5 Chance, and statistical redundancy as antidotes to random factors

4.1 Reactive systems 1 of 2

- **Many control systems are effective, on the basis of what is known a priori.**
- **Yet when unknown disturbances, necessity to adopt another scheme: feedback scheme from the systems being controlled.**
- **In subsumption architecture schemes, an additional benefit of going reactive is to avoid the problem of modeling, which a priori knowledge typically implies.**
- **In such circumstances, i.e., considering reactive systems, the primary concern is the relative agility**

4.1 Reactive systems 2 of 2

T : controller decision time and communication delays
τ : time constant of system to be controlled

Relative agility of controller: (τ/T)

4.2 Cognition for the virtual exploration of inaccessible dimensions & parameters 1 of 5

- **In the context of control and automation, cognition supports modeling and may help in several regards for reactive and open-loop systems:**
  - **Time**
  - **Localization**
  - **Other dimensions**

4.2 Cognition for the virtual exploration of inaccessible dimensions & parameters 2 of 5

- ***Time*. A good knowledge of the controlled system allows for forecasting its behavior, and by this token, a cognitic controller may in principle compensate for some or all control loop delays. This paradigm commonly allows for improvements in effective agility, and consequently commonly brings significant improvements in performance.**

4.2 Cognition for the virtual exploration of inaccessible dimensions & parameters 3 of 5

- ***Localization***. In a subsumption scheme, a robot sensor is located at any given time in a single place. If at the same time, similar estimates of the sensor would be useful at other locations for control purposes, then a hybrid strategy, with modeling, and more generally a cognitic approach, can help.

4.2 Cognition for the virtual exploration of inaccessible dimensions & parameters 4 of 5

- ***Other dimensions***. The power of cognitics not bound to extrapolation in time and space.
- On the contrary of situated automata, cognition can extend estimation possibilities in domains out of physical reach.
- In principle quite universal and may prove similarly useful in other physical dimensions.
- Example: weight parameter for ABB robots and "Grasp" instruction=>dynamics.

4.2 Cognition for the virtual exploration of inaccessible dimensions & parameters 5 of 5

Our domestic robots (here, RH4-Y in Robocup world competition, Graz'09) consist in complex systems, classical controllers (PLC, elaborated servo-controllers), computer and processors (tablet PC, etc.) and software solutions (Windows Linux), as well

as novel components, our multi-agent, real-time and simulation environment (Piaget), multiple cognitive capabilities such as sensing distances in 3D, recognizing scenes, gestures and speech, locating objects, learning new tasks and topologies, and generating coordinated motions and trajectories as well as producing their own speech and graphics, following humans and handling objects (re. numerous videos at http://rahe.populus.ch).

4.3 About learning 1 of 2

- Learning capability *seems* very important (core of the definition of intelligence in the MSC model).

  What is ultimately useful is expertise: the ability to do things correctly and quickly.
  - Expertise may gradually result from time-consuming learning phases, acquired by each agent individually, through its own experience.
  - Expertise may also result from some engineering with encapsulated learning. Directly reused, with minimal delays. Expertise may even suddenly result from novel ideas and ad hoc design, without any learning at all.
- In all cases, what is finally desirable is expertise.

4.3 About learning 2 of 2

- Example 1: human skills. Search for confirmed expert or young trainee?
- Example 2: cognitics. For multiplying two floating numbers, a circuit at peak expertise level, or in-progress learning system in the multiplication domain?
- Domain not stationary enough for the reuse of existing expertise? learning required? Contradictory requirements!: learning is obviously impossible without some stationarity of the related cognitive domain.

4.4 External versus internal discrimination and autonomy

- One common question relates to the degree of autonomy: Examples : 1. Neural network learning according to Hebb's law requires a set of examples given by a tutor. 2. Elementary controller where target values and possibly feed-forward contributions are given by external agents. 3. Consider a robot following a guide; this requires a guide.
- The development of new concepts and systems usually requires an incremental approach. Similarly, an analytical approach calls for considering, at a given time, only a fraction of the possible overall systems.
- In cases above, the current focus leaves some components as external complements: systems must are non-autonomous. However, as developments progress, or the analytical scheme moves attention, complements become internal to a larger system, and the latter may rightfully be recognized as autonomous.

4.5 Chance, and statistical redundancy as antidotes to random factors

- Our guts detect ingenuity in numerous cases (re e.g. Archimedes's fluid mechanics, Newton's gravity law, or Beethoven's symphonies).
- Yet the quantitative approach in MSC context, is still undecided as relates to ingenuity (re. Section 3).
In quantitative cognitics, a rational explanation for what looks like ingenuity lies in the nature of the following process: the cognitive universality of chance randomly generates novel, revolutionary, finite-size models. Then experts optimize them with the help of tools and techniques.
- Random nature of source and exceptional nature of occurrence of adequate models => long time usually required for invention.
- Redundancy in search for a model, and good expertise levels of resources improve the probability of success.

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5. Conclusion

Intelligent systems and robots are progressing: AI, situated automata approach, closed-loop control, computer infrastructure and networks. Nevertheless limitations remain.
Cognitics and hybrid approaches offer multiple benefits:
- MSC model has been developed, a sound basis for assessing and complementing the various current solutions.
-Hybrid approaches integrate specific advantages offered by classical AI (predict phenomena), control (compensate for disturbances), reactive systems (embed in reality so as to simplify representation), cognitics (the move toward quantitative and automated systems in more of the cognitive world) and computer technologies (implement on digital processors, with the best of software methods).
-Hybrid approaches, inevitably bring together analog notions that collide. Notions like deliberation, control, reactive systems or top-down approaches are therefore newly discussed from the MSC perspective, while others, in particular creativity, ingenuity and chance, are added to the MSC ontology.

5. Conclusion

Generic schemes have been presented : classical control, reactive systems, very usefully complemented by AI, and more generally cognitive approaches: closed-loop control is critically sensitive to time aspects (relative agility), reactive systems essentially restricted to "here and now", while cognition can compensate for delays and estimate entities in virtually all regions of high dimensionality spaces; intuitively, learning (and intelligence) often appear to be important while in fact *expertise* has typically proven to be the decisive cognitive property in the MSC context; the difference between external versus internal discrimination is often more a matter of time, or a single step in an ongoing process of development, then a fundamental difference; finally, an expert process harnessing chance is a more rational source for radical innovation than a hard-to-define, intuitive notion of ingenuity.

Thanks for the attention!

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References

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Appendix

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