Contributions to Standards and Common Platforms in Robotics; Prerequisites for Quantitative Cognitics

Jean-Daniel Dessimoz[1]

[1] HESSO // Western Switzerland University of Applied Sciences, ,
HEIG-VD // School of Management and Engineering,
CH-1400 Yverdon-les-Bains, Switzerland
Jean-Daniel.Dessimoz@heig-vd.ch

Abstract. Robocup seems to raise the need of developing cooperatively standards and common platforms. There exists however a whole spectrum of classic ways by which cooperation can be done worldwide and in more universal domains. Robocup turns out to be on the forefront of merging robotics and AI, moreover integrating Human-Machine cooperative interactions, as in "at-Home" league. For this area, quantitative cognitics is a key domain in terms of providing standards for the estimation and comparison of cognitive performances. While core concepts have been published elsewhere, it is useful here to complement them by revisiting some of the support notions, as some of the properties of the latter are not known well enough, and yet affect all subsequent cognitive entities. Information is model-based, very perishable, and highly subjective; modeling is a necessity between cognitive world and reality; models are, but infinitesimal exceptions, totally incomplete. Yet they may be useful for specific goals.

Keywords: Standardization, knowledge, cognition, cognitics, ontology, information, model, memory.

1 Introduction

Robotics and AI research have made a lot of progress, so that many application fields are now being considered. Required functionalities of robots are varied and complex.

In order to handle such situations, activities of standardizations and platform developments should be performed by researchers and developers, so that reasonable levels of predictability and efficiency are reached, and consequently the considered applications really materialize. A special area of interest for us is the progress in cooperative robotics and human interaction in domestic environment [1,2].

A special area of contribution for us includes AI and more widely, cognitive sciences, or "cognitics" when cognitive processes are automated. In the same way as it is easy to guess whether a human being can jump over the wall when we know the height of the wall, it is very useful to have a metric, quantitative approach in the cognitive world as well. Publications of core concepts in this regard have already been made (e.g. [3-5]), and especially a recent integrated work, in French though [6],

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mostly under the name of “MCS” theory, like “Model for Cognitive Sciences”. MCS includes an ontological approach, in the fundamental meaning of the word. It is not just a computer world with coherent internal definitions and relationships among concepts, but aims at describing the very nature of things; in this theory it is also shown how limited any description may be, and how to cope with these limitations. MCS is more than a glossary or a lexicon as it gives not only definitions, but also metric units and associated estimation formulas, ultimately reaching into the real world. MCS theory is strongly based on the concept of information, originally defined by Claude Shannon [7]. It appears however that this classic basis, information, as well as older concepts yet, namely “model” and “memory” require to be discussed from a cognition perspective, because some underestimated yet crucial features of those classic concepts are inherited by subsequent cognitive entities, such as complexity, knowledge, expertise or intelligence.

The current paper contributes to progress in standardization for robotics and AI in several ways. Section 2 sketches a broad spectrum of the general ways by which best solutions can diffuse. Section 3 introduces quantitative cognitics. Then sections 4 to 6 focus on very specific contributions, successively on the definitions of information, model and memory. A good understanding of these classical notions constitutes a necessary pre-requisite for a good understanding the MCS system of definitions and metric procedures, which is built on them. The MCS theory allows for a quantitative estimation of performance for existing cognitive systems as well as for quantitative requirements of new cognitive applications. This is very precious, in particular in the context of smart robotic applications. In order to underline critical properties of classical notions, four elements of theory (“theorems”) are given below, under the subtitles of “Principles”.

2 A spectrum of approaches for standards and common platforms in robotics

When considering standardization of activities in robotics, many very different ways to proceed exist. Some are classical, others more revolutionary ; sometimes it is also possible to reuse sub-domains, standardized on their own ; this section concludes with a synthesis.

2.1 Classical approaches

Mankind has always tried to reach for some efficiency, to let people contribute where they prove most capable, and to avoid losing resources in “reinventing the wheel”.

COTS. The oldest way to reach for some efficiency has been to let people exchange their goods, which has progressively lead to market economy and COTS – commercial, off-the-shelf products and services. By definition, commodities are

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standard goods and services, which consequently can be efficiently supplied by market economy processes.

Publications. The basic approach adopted in university and education contexts, in order to turn good novel solutions into standard procedures and platforms is to rely on conferences and libraries, on textbooks and publications.

Patents. Even in the most competitive fields, on the market, patents have been introduced not so much to guarantee a monopolistic situation for inventors, which last for little time in historical perspective. Patents are in principle there in order that new solutions be well documented so as to let production in practice be replicated or even extended by all possible producers in a reasonably short time.

2.2 Free software and the like

Recent years have brought a lot of new opportunities for users, and this, to a large extent, with the help of interconnected networks; in particular free software and wikis.

Free software. For many years now the concept of free software, in its multiple variants, has been established, which aims at making it as easy as possible for people to reuse and improve software solutions developed by others.

Wikis. Cooperative tools are also present by which, individual contributions are easily merged into collective environments immediately available for all group members, such as wikis (re the ongoing example of Robocup-at-Home).

2.3 Other standards related to robotics

Robotic systems typically include many components. It is therefore not surprising that they can benefit from standards developed for goals different from their own. Overlapping with robotics, kinematics, motion control, embedded and communication systems, portable computers, AI or smart sensors are common examples of domains where progress can be shared with non-robotic applications.

2.4 Synthesis

Reuse has opposite aspects. In some contexts efficiency is very good; in some others, costs may be prohibitive. Similarly, optimal funding and sharing mechanisms depend on circumstances, can be very diverse, with some hard cases to solve. All these different schemes may simultaneously apply to different, specific Robocup contexts.

Efficiency. We have seen above a number of ways to make use of existing, standard solutions. So to a very large extent, research and development efforts in that regards

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can be avoided. At most, costs may be incurred because some of those efforts need be replicated for education purpose.

Cost considerations. But the human beings keep striving to do yet better than ever before. How to proceed? Cost considerations often limit what can be done in several ways. The most frustrating cases may be when solutions could be provided by others, but at costs or conditions locally unbearable. Another situation is where directions look technically promising but resources would be required to move ahead, which cannot be afforded.

Funding, sharing, and community efforts. For long-term efforts, typically, public resources are allocated and results are public; at the other extreme, short-term efforts may be private, and temporarily kept secret but soon here again efforts should be shared, with possibly IPR and patent protection for some time. In between, current solutions are not obvious, and it might be where community developments by multiple, coordinated groups, in the direction of common test cases may be the most beneficial (re. the case of "at-Home" league).

3 Quantitative cognitics

This section reports on cognitics – automated cognition. Automation requires clear definitions and, beyond usual dictionaries, lexicons and glossaries, a proper metric system. A recent publication in French [6] gives a good integrated presentation of the domain. In English however, publication has been a little scattered so far. The reader may already refer to various other contexts [3-5 are good starting points] for core definitions, or for extensions into a few specific application areas. A synthesis in English is only in the plan so far. Nevertheless, what experience shows now as probably the most significant complementary components to publish, are given in the following sections, 4 to 6. What follows in this section reports especially on introductory considerations, rationale for the development of the theory and on careful reviewing of pre-requisites.

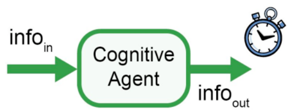

Fig. 1. *Framework for cognition*. The framework for cognition in MCS theory includes, in addition to cognitive agents or systems, information flows and time considerations.

Mankind has invented an ever-increasing variety of tools and methods, thereby growing in number, living longer, and exploring an ever-larger part of our universe.

Schematically, and for long, two kinds of progress have been made, quite independently from each other, relating in one case the intangible world of ideas, and in the other one, the world of physical objects. Only the human beings seemed to have the ability to establish a link between these two worlds, in particular with speech, writing and drawing, possibly sculpture and architecture.

During twentieth century, the revolution of long-distance communications has been accompanied by the formal expression of a first connecting channel between physical

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world and intangible world: information. It was essential to establish a well-defined correspondence between ideas to communicate and physical objects supporting messages, and this has been done.

Today, a new stage opens in front of us, where man-made systems can not only commute, often with much ease, between physical world and world of ideas; but moreover, it is even possible for such systems to process ideas on their own; to draw conclusions, to induce precedents, to abstract or on the contrary to concretize. Here is the field of cognitics, i.e. of automated management of cognitive activities, which, traditionally, were typically, or even exclusively, reserved for the human beings.

In order to progress in cognitics, it is timely to define essential concepts for this field, in a rigorous way, as well as to establish an appropriate metric system. This is what the current theory does, entitled “MCS”, initials of « Model for Cognitive Sciences » (re. figure 1, 2 and [3-5]). Understanding should be made easier by an initial survey of the main development stages of this theory, as well as the more detailed presentation of main MCS features; the latter items though can only be found in French yet [6].

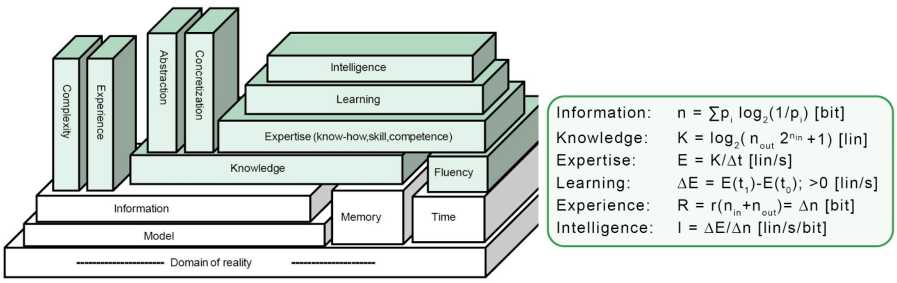

Fig. 2. *Main cognitive entities in MCS theory*. Important cognitive concepts, defined in MCS theory, are colored in green(*left*). They are based on a few classic entities. Information, model and memory, though classic, need a discussion from a cognitive perspective; which follows.

But before reaching in the vast plains of cognitics, it is necessary to cross two classic passes, curiously much more difficult to ride over that it a priori seemed to me. Numerous discussions with varied interlocutors convinced me that to cross well these preliminary passes turns out a necessary condition to appreciate then with comfort and without reserve the proposed new landscape. Thus the next two sections accompany again readers who wish it on the supposedly known, or even very well known, grounds, of information and model.

4 Revisiting the concept of information

Definitions:

Information is what allows the cognitive system, CS, that receives it, to build up and update the representation he/she/it maintains for oneself, of a certain cognitive domain, i.e. his/her/its ad hoc model. Intuitively, it could be said that "information shapes up opinion".

Information is conveyed by messages. The quantity of information conveyed by a message has been defined by correspondence in a probability. Essentially, it is related to the instantaneous expectation the CS has of incoming message.

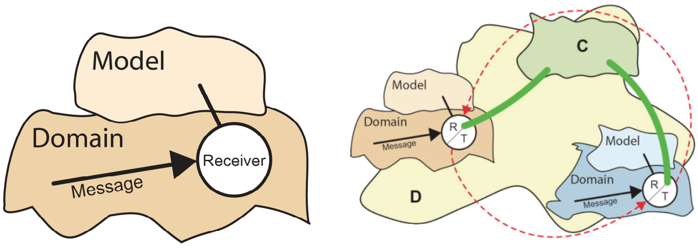

Fig. 3. *Information*. Information, conveyed by messages, allows the receiver to shape up his/her/its opinion, i.e. internal model, simplified representation of (some domains) of real world (*left*). At group level, a similar scheme may support the notion of culture: common aspects of multiple individual models (*right*).

When messages can be perfectly forecast, information quantity is nil. If instead, messages are very unexpected, a large quantity of information is received.

The fundamental function, which defines the quantity of information in a message, Q, dates back to the middle of twentieth century, and was provided by Claude Shannon.

A message that is totally predictable does not carry any information. On the contrary, a much unexpected message surprises. A low probability actually corresponds to a lot of information. The mathematical function which describes this phenomenon, it is first the inverse of probability of occurrence of the message[1]:

$$Q = f(1/p) \ . \quad (1)$$

Besides, it looks adequate that if several messages occur, their respective information quantities add up. Now if considerations remain at the level of probabilities, the appropriate operation is multiplication: for example if two independent signals have individual probabilities of occurrence of one third, one ninth denotes the chance that both of them occur simultaneously. In order to keep using simple additions, logarithms are required:

$$Q = \log_2\left(\frac{1}{p}\right) \text{[bit]} \ . \quad (2)$$

In Equation 2, the unit is the « Bit », contraction of « BInary digiT », referring to the base « 2 » selected for logarithm evaluation[re. note2].

[1] The fundamental definition is expressed, like here, for the case of discrete (discontinuous) messages. But in fact this is not really a limit, as pathways exist in order to extent it to other cases, such as notably, continuous signals.

[2] In theory, logarithms with bases 10 and « e » have also been used, thus leading to « dit » and « nit » units. But in practice these variants are not widespread.

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It can be observed that the formula gives well a nil amount of information (zero bit) for the case of messages that can be totally forecast (probability equal to one).

Comments:
The classic definition of information is well established, and there is no question here to modify it. Nevertheless, or even on the contrary, it is appropriate to well understand two of its essential properties : perishable and subjective characters.

Principle 1 – Information is immediately perishable

Proof:
Equation 2 defines the quantity of information conveyed by a message on the basis of its probability of occurrence, as estimated *before reception*, by receiver..

It can be observed that the formula gives well a nil amount of information (zero bit) for the case of messages that can be totally forecast (probability equal to one). Now messages precisely have as function, and therefore typically as effect, to change this probability. Upon receiving, what was previously just a probability for receiver then transforms into certainty. *A posteriori probability* for received message amounts to « 1 ». Equation 2 gives zero bit in these new circumstances. The message is now well known and does not contain information any longer.

Discussion:
Consider, as an example, a cognitive domain corresponding to the single, random, toss of a coin. Before receiving, two messages are possible: heads or tails. They are usually expected each with a probability of ½. After message arrival however, respective probabilities change, the probability for one message (for example "heads") becoming 1, and for the other message, zero. For this unique toss, it is useless to repeat the message. Equation 2 indeed gives a quantity of information amounting to 1 bit for the initial message, the 0 bit for all possibly repeated messages.

It is important to well understand this peculiarity of information, for this contrasts with respect to experience gained with other metric units, in physical world: repeating the estimation of a weight, of a length, or of a time gives in principle always the same result, in kilograms, meters, or seconds. Repeating the same message in the same circumstances by contrast bring no information any longer; 0 bit are contained in repeated messages.

Here are some informal examples where the time-varying character of information plays a particularly obvious role:

- In practice, the same newspaper in not read twice by the same person.
- It is usually badly judged to tell the end of the movie to friends if they are precisely about to go and watch it.
- It is hard to prepare collectively and to deliver a surprise for a person at a given point in the future.
- Stock exchanges operations are forbidden for insiders.

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Principle 2 – Information is essentially subjective

Proof:
Equation 2 gives the quantity of information in a message. It can be seen there that it contains the occurrence probability as estimated by receiver. Information has therefore a character essentially subjective.

Discussion:
The objective property of received messages is not guaranteed at all by basis equation. Intuitively however, people tend to believe in such an objective character, especially for the two following reasons:

- In simple technical domains, such as those for which the theory of information has first been developed, models are standardized, rigidly defined, in conformity for emitters and receivers, in the framework of coherent systems.
- In general, all members of a group have gained, in life, experiences to a large extent similar, and therefore tend to develop a certain uniformity of their respective models.

And yet the very same message may simultaneously have as many different probabilities as there are different receivers.

For example in the domain of tossing a coin, let us consider two very different receivers. One of them typically estimates the a priori probability of "heads" state to be one half. On the contrary, the second one is a joker who has provided the coin, a special coin stamped on both side as "heads". For the latter player, the probability of receiving the "heads" message is already a priori amounting to one, one hundred percent. In such a situation the message ("heads") conveys 1 bit of information to the first receiver and 0 bit to the second receiver.

It is useful to take well into account the critical role of receiver. Even if often in practice information seems to have a very objective property, for example when referring to measuring units or very common objects, there exits a whole spectrum of situations, which sometimes also reach far towards the other extreme, for example to so-called modern art objects or even Rorschach inkblot tests.

5 The notion of "model"

Definitions:
A model is a simplified representation of reality; typically elaborated in order to reach a certain goal. Sometimes correspondence with reality is not a strong constraint and it is then question, by extension, of the representation of other, virtual worlds.

The correspondence between model and reality defines the notion of sense, or meaning.

In as much as a model allows for reaching a certain goal, it can be qualified as good for this goal.

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Principle 3 – Information requires the notion of model

Proof:
The very definition of information requires the notions of message, and associated probability, quantitatively estimated in a representation appropriate for the receiver (re. Equation 2). This set of elements (messages, probabilities, appropriate representation) de facto constitutes a model (re. also Figure 3).

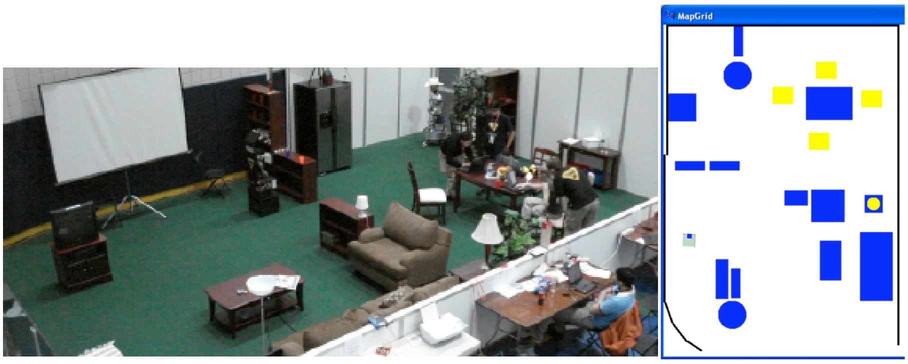

Fig. 4. *Model or reality*. There is always a huge difference between a real object and any model adopted to describe it Nor the picture (*left*) nor the map (*right*) are close to exhaustively describing the "Home" of Robocup congress in Atlanta 2007.

Discussion:
Temptation is constant for human beings to establish a direct bridge between cognitive world and reality. But this is practically impossible. Some philosophers as well known as Socrates, Kant or Hegel are especially representative of efforts made to formalize this problem and to propose solutions. Socrates is forced to notice that the reach of our perceptions typically limit themselves as shadows and reflections on cave walls; Kant postulates the existence of categories already established for the human mind in prerequisite in any perception; and for Hegel the importance of representations is such as these constitute the main part of our world, going as far as rejecting reality, of which we can in the extreme case even doubt any existence.

In our approach, similarly, it might be desirable to apply the metric technique defined for information estimation directly to reality, but this is impossible. We shall come back on this point later on, in the discussion of Principle 4. For the time being, let's just live with Principle 3.

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Principle 4 – Subject to a goal reached in similar ways, the preferred model is the most false

Proof:
The essential quality expected from a model is that it allows for reaching a certain goal. In this sense, it is good. Now, if the goal can be reached in a similar way with a simpler model, i.e. with a model that can be described with less information, the latter model is generally considered as preferable. In order to get simpler, a model must ignore some aspects, becoming then less complete with respect to reality. And if a model is more incomplete, it must be globally seen as more false. Thus, subject to a goal being reached in a similar way, the preferred model is possibly the most false.

Discussion:
It is a classic statement that theories should be simple (re. notably the "law of parsimony" or "Occam's razor"), and this is surely an attractive quality for a model. But in this formulation, the extent by which reality is abstracted, respectively ignored, remains hidden. Einstein with his word "Everything should be made as simple as possible, but not simpler" raises a little the veil on the risk of abstracting too much from reality. The difficulty grows if several goals are considered: a model adequately simple for one goal turns out too simple for another goal. Unfortunately in all cases huge amounts of reality are filtered out, and therefore, as George Box puts it: "Essentially, all models are wrong, but some are useful" . The present Principle , and more generally, the approach aiming at a quantitative estimation of cognitive entities, push this statement yet further: in substance yes, there can be useful and good qualities in the process of doing simple, but it should also be noted that in terms of correspondence to reality, models remain always *extremely* lacunary, incomplete.

It is sometimes stated that a specific quality of experts is that they know how to very selectively focus their attention on critical domain dimensions, thus knowing how to ignore all other aspects, which make the situation confusing for beginners.

A common mistake is to think that a model could have some qualities of truth, a capability to represent reality at the same time in a compact and exhaustive way; that it could retain without any loss the "quintessence" of the reality it represents. When a quantitative estimation is attempted, force is to notice that this is impossible.

No matter how constrained and restricted a domain of reality is delineated, an infinite amount of information remains necessary for exhaustive description of this domain. In practice only very limited aspects can be perceived. This is for example true for Robocup « Home» (Fig. 4). Let's take another example, the famous *painting* of Magritte « Ceci n'est pas une pipe - This is not a pipe ». Even if the question is to describe a certain cubic millimeter of the fire region of the corresponding real pipe, the necessary quantity of information for this goal explodes : what are the wooden fibers, are there preserving agents in the material, where does the wood come from, is it covered by any insurance, have the workers who produced the pipe been treated ethically ? etc.

In practice, to answer those questions and others, models are used : depending on current goal, it is one very particular aspect of reality which is retained, or another, as exclusively as possible. So the pipe will be well described by an order number for the accounting department ; by visibility information and possibly a normalized color code for pictorial rendering ; by information about bad taste for the pipe smoker; etc. Briefly expressed, the principle could read “The better model, the more false”!

Fig. 5.. *Good and false*. Models are “false”; e.g. France is often called after its shape: hexagon (*left*). But they can be good for a goal: as a red jack “attracts” metal bowls in petanque game (*right*), a goal is a prerequisite for elaborating good models.

For practical interest, it should be insisted once more on the necessity to be always very clear with respect to circumstances: target domain, adopted model, and selected goal. Jesuits have long been used to modestly limit themselves to “hic et nunc”, here and now; recent management methods in software engineering, “extreme programming”, similarly require that specifications be met as strictly as possible, i.e. without any “bonus” in terms of more search for universal solutions, which are by principle considered as impossible to reach. For example if it is question of the weight of a person, different domains might be considered, and clarification should be performed: is this while wearing clothes ? in the morning at wake-up time ? on Earth or on planet Mars ? Consider another example, the message delivering a phone number : does it directly state the number (e.g. +12 345 6789) or does it give the number indirectly (e.g. « it’s John’s phone number »). In quantitative cognitics, it appears that some of these various domains may very strongly differ from other ones.

6 Memory

Definition:
A memory is a support, the essential property of which is the preservation of information through time.

Discussion:
Memory deserves a particular comment. It is schematically represented on figure 2. As a physical support for long term, e.g. standing stones, memory does not present a big interest from a cognitive point of view. Simply, what is expected in this regard is just a long lasting stability of the physical support. By definition, what is expected is to be able later on to get back exactly what has been written in a first phase; in this sense predictability is total; the amount of generated information is nil.

From another point of view, observing a microelectronic memory device shows the important role of addressing circuits, as well as of the circuits responsible of writing and reading. Generally, in as much as the notion of memory would include those processes (addressing, writing and reading), one or several rather complex cognitive systems would then be implied. For example, it would no longer be question of a standing stone alone, but also the human being who had shaped it up. For a library, it would be question not only of a collection of books on shelves, but also of the

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librarian capable first to adequately go and file information, and then later on, on demand, to search and find it back.

In MCS theory, the property of (unlimited) permanence is essential for memory. This property however does not seem to deserve much developments here. Besides, the processes of addressing, writing and reading, can be considered separately, per se, just as any other cognitive process.

7 Conclusion

Robocup could help developing cooperatively standards and common platforms. There exists however a whole spectrum of classic ways by which cooperation can be done worldwide and in more universal domains. Robocup turns out to be on the forefront of merging robotics and AI, moreover integrating Human-Machine cooperative interactions, as in the “at-Home” league. For this area, quantitative cognitics is a key domain in terms of providing standards for the estimation and comparison of cognitive performances. A theory for core cognitive concepts has been published but it has been found that a better understanding of classical support notions would be useful. Therefore the paper has brought a complementary revisit of support notions, more specifically of some of their properties that are usually not known well enough, yet affecting all cognitive entities, built on them. Information is model-based, very perishable, and highly subjective; modeling is a necessity between cognition and reality; models are, but infinitesimal exceptions, totally incomplete. Yet they may be useful for specific goals.

References

1. Tijn van der Zant and Thomas Wisspeintner, « RoboCup X: A proposal for a new league where RoboCup goes real world » In: Itsuki Noda et al.(Eds.) RoboCup-2005: Robot Soccer World Cup IX, Lecture Notes in Artificial Intelligence, Springer, 2006 ,7pp
2. Jean-Daniel Dessimoz, Pierre-François Gauthey, "RH3-Y – Toward A Cooperating Robot for Home Applications", Robocup-at-Home League, Proceedings Robocup08 Symposium and World Competition, Suzhou, China, 14-20 July 2008
3. Jean-Daniel Dessimoz, Pierre-François Gauthey and Carl Kjeldsen, "Ontology for Cognitics, Closed-Loop Agility Constraint , and Case Study in Embedded Autonomous Systems – a Mobile Robot with Industrial-Grade Components", Proc. Conf. INDIN '06 on Industrial Informatics, IEEE, Singapore, Aug.14-17, 2006, pp6
4. Jean-Daniel Dessimoz and Pierre-François Gauthey, "Quantitative Cognitics and Agility Requirements in the Design of Cooperating Autonomous Robots", Proc. Eurobot Conference 2008, Heidelberg, Germany,22-24 May 2008, ISBN: 978-80-7378-042-5
5. Cognitics.org, http://cognitique.populus.ch .
6. Jean-Daniel Dessimoz, «La Cognitique - Définitions et métrique pour les sciences cognitives et la cognition automatisée”, Editions Roboptics, Yverdon-les-Bains, Switzerland, ISBN 978-2-9700629-0-5,
7. Claude Elwood Shannon: *coll. papers*, ed. by N.J.A. Sloane, A. D. Wyner, Piscataway, NJ, IEEE Press, (1993)

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