

# Beyond Information Era : Cognition and Cognitics for Managing Complexity; the Case of "Enterprise", from a Holistic Perspective

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**Abstract.** Cognition and Cognitics provide the means to understand and manage complexity. The MSC Cognition theory sets the framework for the formal definition, the metric assessment, and the operationalization of core properties in intelligent systems; intelligence for example is defined as the property of systems that learn, is evaluated in lin/s/bit, and is implemented in a variety of physical structures, including biological neurones, mechanical systems, computers and organizations Cognitics is a domain wich includes the science of automated cognition, and related techniques. It deals with the operationalization of core cognitive properties in man-made systems (ACS – artificial cognitive systems). It is interesting here to do something not classic at all: to apply this approach to a context usually not related to cognitive systems: an Enterprise; furthermore, we adopt a holistic approach, not ignoring the double effect of Enterprise on its environment, and in return the one of environment on Enterprise.

Considering two sytems instead of one looks probably a simple thing to do. Indeed closing such a loop is common in control, leads to well-known dynamic patterns, but are often very hard to keep stable: systems typically oscillate, fade to a zero asymptotic value or diverge up to some saturation or rupture levels. The "life" phenomenon though proves that a different outcome is yet often possible: progressive and stable approach of some pre-selected goals, for significant periods of time. Another result of taking the holistic view is that reality appears seriously to exist beyond enterprise boundaries; it cannot be ignored, nor changed, which calls for cognitive performances usually much higher than what ACS can deliver today.

## 1. Introduction

Freedom is a core value of mankind. Its practice implies a certain control on what happens. To extend this control, many ways exist, and the one we advocate here is automation, i.e. the use of artificial systems for reaching goals assigned by humans. Leaving aside aspects of energy, and materials, we concentrate here on information processing.

Information processing is immediately understood. It is a concept that was most appropriate and sufficient for past decades, during which a straightforward encoding of basic phenomena was practiced. But today everyone is aware that we enter a new age. Beyond traditional information levels, complexity must be faced and handled. Complexity is the property of models or systems that require a huge amount of information to be exhaustively described. The solution for understanding and managing complexity is cognition. And the solution for artificially performing it, is found in cognitics, i.e. in the field of tools and techniques for automated cognitive processing. Good references relating to information, cognition and basic theories for intelligence can be found in [1- 12].

The presented Cognition theory is applicable to systems of all sizes; it may be useful for characterizing a simple neurone, but it can as well apply to much latger systems, such as a computer, a human brain or even a whole organization. We will apply it here at enterprise level; and from a holistic perspective, the world beyond traditional enterprise boudaries is also visible. This critically completes the overall system in which enterprises evolve, featuring notably

feedback and extra complexity. The latter point makes it worthwhile to discuss human capabilities, as only humans can typically cope with that type of cases.

The paper is essentially organized in four parts of uneven size. Section 2 briefly presents our cognition theory ; then cognitics are introduced ; the 4<sup>rd</sup> part analyses the case of enterprize viewed as a cognitive system (i.e. a system characterized in terms of knowledge, know-how, learning capabilities - re. e.g. entreprize agility -, etc.. And the 5<sup>th</sup> section extends enterprize scope in order to encompass its whole environment.

## 2. Cognition - a theory / Metrics for complexity, knowledge, intelligence, and other concepts

Let us review our theoretical framework (in previous publications, it has been refered to as MCS – a model for cognitive sciences)(See also fig.1 for an overview and structure of main concepts). After briefly presenting selected concepts, we get back to classics, especially to the notion of model, which MSC makes appear quite different from what people usually perceive. This section closes with a discussion about assessing human performances.

### 2.1 Cognitive properties, in quantitative terms

Cognitive systems essentially *process information*. Such systems can in particular be characterized by a certain quantity of knowledge and expertise. But other properties are often of interest as well.

In a concise and coherent way, the reader finds again, in what follows, core definitions and metrics for cognition (for a more extensive discussion on various aspects, see [9-12, 22, or 25-36]). Based on input and output information signals and flows, it is applicable to all kinds of cognitive systems, e.g. neurones, humans, electronic components or computers.

The properties mainly reviewed here are the following : information, complexity, knowledge, expertise, learninf nd intelligence. Other related concepts have been defined, as is shown on Fig. 1, or published in mentionned references.

*Information* is a well-defined concept, which has been scientifically introduced more than 50 years ago, particularly for communication engineering. It is presented here again, in a compatible way, but with a different focus, which makes its relevance in cognition context more evident.

"Information" is what allows a "receiver" to update her/his/its "model" (i.e. internal representation) of a given "domain" (i.e. restricted view of reality) (see fig. 2). Information is conveyed by "messages". In formal terms, information essentially corresponds to the property of non-predictability of a message. The unit is the "bit" or, as proposed more recently, the "Shannon".

$$n = \sum p_j \log_2 (1/p_j) \quad [\text{bit}]$$

where n represents the (average) amount of information delivered by a set of messages, each occurring with individual "probability"  $p_j$ .

Possible incoming messages and (instantaneous) associated probabilities are essential components of the model.

Even though in principle information quantities can always be assessed, in practice major obstacles are frequent (e.g. the telephone line is cut, newspapers may not be delivered in due time, appropriate statistics are not available, etc.). Nevertheless, no-one does, or would reasonably, question the usefulness of the theory of information.

Similarly, the quantitative estimation of all concepts derived from the one of information, such as those described below, may face some practical limits (and in particular, those resulting from uncertainties on information assessment), but this does not per se invalidate their definitions.

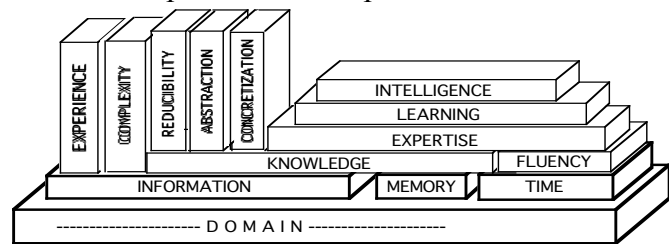
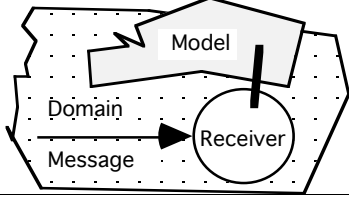



Fig. 1 Overview of relationship between MCS concepts. The lowest two levels consist in classical notions on which MSC concepts are built.

	
<p><b>Fig. 2.</b> Context for information</p>	<p><b>Fig. 3.</b> Example: Information (left) can often be generated by cognitive systems (right); sometimes in potentially huge quantities</p>

“Complexity” (L) is a key feature of a cognitive domain, or of a model; it describes its “size”. For exhaustive description, a conceptual immediate way to proceed is to list all possibilities, i. e. all possible input messages, and for each of them, all the corresponding output messages. Complexity is thus the size of the set of all possible such input-output associations:  $L = n_i 2^{n_o}$  [bit], where  $n_i$  and  $n_o$  are the average input and output information quantities.

“Knowledge” (K) is the property of a system which *generates* relevant output information either totally by itself or reactively to some incoming information. Fig.2 displays a simple example where a table of mathematical functions (i.e. static information quantities) can be replaced by the use of a pocket calculator (i.e. an artificial cognitive system).

Knowledge can only be assessed on a certain domain, and “relevance” means here that the outgoing information is indeed right, i. e. belongs to this domain.

Quantitatively, knowledge is measured as a function of domain size, i.e. complexity:

$$K = \log_2 (2^{n_i} * n_o + 1) \quad [\text{lin}]$$

where K denotes the quantity of knowledge,  $n_i$  is the amount of information entering the cognitive system, and  $n_o$ , the amount of outgoing information. The unit name, “lin”, results from contracting “Logarithm of INformation”.

In short, and loosely speaking, knowledge is the property of a system which *does it right*.

Systems featuring knowledge (i.e. cognitive systems) *do* require time to work. But the concept of knowledge does not quantitatively depend on it.

In order to characterize the performance of cognitive systems not only in terms of knowledge but also of processing time, it is useful to consider another concept, namely the one of “*expertise*”. Expertise is the property of cognitive systems which are knowledgeable and process information fast.

$$E = K f \quad [\text{lin/s}]$$

where E is the amount of expertise, and f the “*fluency*”, or processing speed, i.e. the inverse of average time delay between input and corresponding output information messages.

In short, expertise is the property of a system which *does it* (right and) *fast* (Common alternative words for expertise include know-how, skill or art).

In a similar way, other cognitive concepts have been unambiguously defined: *learning* (positive variations in expertise amounts, [lin/s]), *experience* (amount of information received about a domain [bit]), *intelligence* (rate of learning as a function of experience [lin/s/bit]), *abstraction* (ratio of incoming over outgoing information quantities), *concretization* (ratio of outgoing versus incoming information), *memory* (restrictive definition: permanence of information, and consequently, null direct contribution in terms of knowledge and expertise), complexity (quantity of information necessary to exhaustively describe a system or model, [bit]), etc.

## 2.2 The concept of “model” revisited

The concept of “model” is revisited. It has been implicitly assumed to be known until that point (re: commonsense), but it is worth to look at it again.

Surprisingly, even for scientists and engineers, the concept of “model” is not too clear. Applying cognition metrics to classical cases often causes a sequence of 2 states for the

observer. In the first state, the observer discovers amazing differences between equation results and intuitive assessment. And in a second phase, a thorough analysis convinces the observer of the rightness of equation results, thereby illuminating fundamentals. Thus it appears for example that astronomical numbers - traditionally found to be very large - appear very small indeed in comparison to cognition related quantities; or a very astounding result is the "paradox of models": the better it is (in the sense of being more simple, yet leading to the goal), the more wrong (in the sense that *simple* implies very *incomplete* with respect to reality)! Yet how many people still hope to capture the essence of reality in a simple model.

### 2.3 Rational versus intuitive/perceptive cognition

Applying MCS metrics to classical logic or predicate calculus shows that performance levels are typically very small there. Predicates typically convey less than 100 bit of information, and knowledge or expertise values are similarly small. In this context, we deal with more or less implicit models, which are rather simple. This is representative of rational cognitive processes, where an extensive coverage of the *modeled* domain is usually done: for all possible input configuration, there is a well defined corresponding output message.

But humans have other features. People can recognize a person at a glance, or catch the meaning of sentences pronounced in noisy environment. Managers often decide right and fast on the basis of their "gut-feeling".

Assessing intuitive or perceptive cognition performance levels is a challenge. Applying above equations, one gets astounding numbers. For example, recognizing a person on a picture of ordinary quality implies a knowledge quantity that can be rated to  $10^6$  lin at least (this is really huge - the *logarithm* of the quantity of information required for a comprehensive domain description!). If we base cognitive performance assessment on the perceptive channel capacity of humans, we get similar high numbers.

But obviously, continuing above examples, no one can recognize every person on pictures, nor understand all possible languages on Earth. In practice, for humans, the limiting factors are probably not set by basic (innate) perceptive or cognitive channels but rather by individual experience (past history). Thus above equations give here an upperbound, and for more accurate assessment, it is probably useful to refer additionally to psychometry specialists.

### 3. Cognitics

Cognition implies knowledge. And knowledge allows systems to elaborate, i. e. to generate pertinent information. This is qualitatively very different from just information processing. A good analogy in the world of physics could be the boundary between chemical processing and nuclear reactions; in chemical processing basic elements never vary in quantities, while in the second case this limit no longer holds.

In History, cognitive processes could not be handled by artefacts. But the recent decades have brought such progress in technology that this has very much changed. More and more ACS take over cognitive tasks previously performed by humans. Therefore a new discipline opens, which we propose to coin as cognitics, the field which includes the science and techniques of automated cognition.

While the operators of classical logic imply low cognitive levels, and arithmetic ones are somewhat higher, it appears for example, in cognitics, that addressing schemes are much more intensive. As another example, it is evident in cognitics that cache mechanisms are very effective operators for making ACS learn.

The main goal of cognitics is the automated management of complex systems.

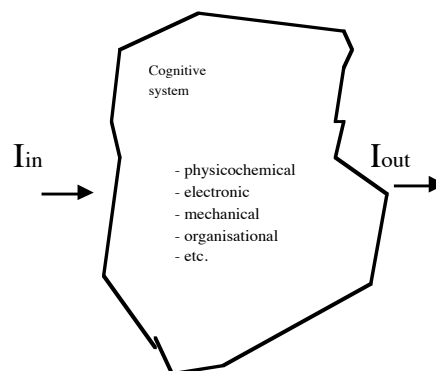
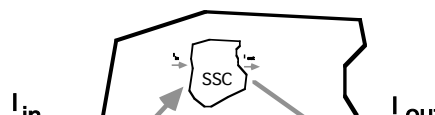


Fig. 4 Universality of implementation



As examples, here are a few processes, in enterprises, where cognitics are often at work today : clients get an initial contact through an electronic telephone agent (*phone mangement*), or through internet (*e-commerce portal*) ; manufactured goods are automatically checked for conformance (*visual quality control*) ; when distributed by surface mail, parcels are sorted by machines (*optical routing based on zip code*) ; the client prepares the payment with an ATM - *automated teller machines*. Further down the road, accompanying instructions may be done by *automatic abstract generators* or *language translators*.

Web access: 15 char. URL > 80-100 [lin]
E-commerce product ordering: 1000 articles and customer information: 50-100 [lin]
Visual quality control: 1-30 control areas > 50-100 [lin]
Mail sorting: 10000 addresses > 10-20 [lin]
Automatic Teller Machine: 10 <sup>10</sup> cards > 30-40 [lin]

Table 1. Estimation of knowledge levels for some typical ACS tasks (examples)

#### 4. Enterprise Modeling

MCS framework is readily applicable for enterprise modeling. The framework is universal in the sense that any type of physical implementation can be envisioned (fig. 4).

Enterprises being relatively large entities, one may gain in breaking down its structure and processes in smaller units. This system decomposition, analytical method, is immediately feasible in MCS, since higher level information flows may be viewed as an aggregation of lower level flows (see fig. 5).

In Enterprises, there is a clear trend towards increased structuring. Standard procedures and norms are encouraged. This is also a priority in quality management techniques. Thw result is that enterprises may be viewed in a somewhat "simple" way, and the correspondance between models and reality is relatively good. In other words, professionnals aim at reaching the "rational enterprise", and models cannot only be validly done but attempts are even made to operationalise it. e.g. to achieve the fully automated factory.

#### 5. Enterprise Modeling, from a holistic perspective

While in section 4, we adopted the classical analytical methodology, we look again at enterprises here from a holistic perspective (e.g. [37-40]. By this token, enterprises can no longer be viewed alone, isolated from their environment, like "in vitro".

Enterprises are merged in the real (and complex) world. People still attempt to make the external world interacting with enterprise simpler: structured networking, extended or virtual enterprises, ore more generally, there is an increasing number of community rules and international standards (re. communications, laws, UNO, Microsoft, etc.; see fig. 6). Nevertheless, from a holistic perspective, the fact cannot be ignored that enterprises are merged in real life, acting on a complex world, and being affected in return by an overwhelming quantity of factors. It appears that only the intuitive/perceptive components of human cognition, as discussed in §2.3, can cope with such situations.

#### Acknowledgments

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#### 6. Conclusion

Cognition theory, and cognitics, the corresponding domain for related automated techniques, provide the framework for the formal definition, the metric assessment, and the operationalization of intelligence.

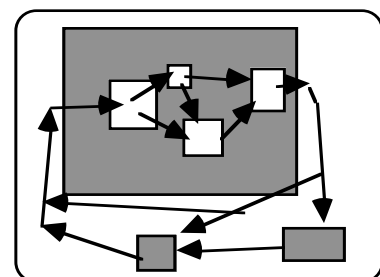


Fig. 6 From a holistic perspective, enterprises appear to merge in real world

Enterprises considered per se may be viewed as highly structured and therefore quite well described by "simple" models. But a holistic look at enterprises, taking into account the external world on which enterprises act, and from which they get their input, one cannot escape acknowledging the necessity to rely on humans, who are so far the only cognitive systems able to cope with world complexity, relying on their intuitive and perceptive cognition abilities.

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