Evaluating Intelligence:
A Computational Semiotics Perspective

Ricardo R. Gudwin,
Department of Computer Engineering and Industrial Automation - DCA
Faculty of Electrical and Computer Engineering - FEEC
State University of Campinas - UNICAMP - Brasil
gudwin@dca.fee.unicamp.br

ABSTRACT

The purpose of this paper is to discuss methods for evaluating the intelligence of intelligent systems by means of Computational Semiotics concepts. Instead of looking at the system as a black box and testing its behavior, the process described in this paper focus on architectural details of structures, organizations, processes and algorithms used in the construction of the intelligent system, evaluating the impact of using these elements in the overall intelligent behavior exhibited by the system. It proposes then an "insider" type of metrics that, coupled to "outsider" metrics, we hope will be important for the determination of general metrics of intelligence in intelligent systems.

1. Introduction

Intelligent systems, in a very open and imprecise definition, are systems that, in some sense, are able to exhibit a behavior considered to be intelligent. Despite the fact that this definition is far from satisfying, the notion of intelligent system is one of the most widespread in the contemporary computer world no matter what is the domain of application, or which discipline we use for analysis of this domain. Intelligent systems usually have perception, knowledge, decision making capabilities and in many cases, actuators to follow the decisions. Intelligent systems are expected to work, and work well, in many different environments. Their property of intelligence allows them to maximize the probability of success even if full knowledge of the situation is not available. Functioning of intelligent systems cannot be considered separately from the environment and the concrete situation including the goal.

Over the past 50 years, numerous disciplines related to intelligence, like the information and cognitive sciences, have achieved fundamental breakthroughs that will radically alter our vision of the architecture of existing systems we repute to be intelligent, as much as will help us on the design and control of the intelligent systems of the future.

One of the questions that remains open, though, is: How are we able to measure the "intelligence" of intelligent systems ? How can we evaluate the "intelligence" a system is equipped with ? This question has bothered psychologists since a long time ago without a definitive answer. IQ tests showed to be inappropriate. Howard Gardner's theory of multiple intelligences [1] illustrates how intelligence may manifest itself in many different forms and aspects. Are we able to use that as a cue for measuring system's intelligence as well ? What would be appropriate metrics for measuring the intelligence of systems ?

We should also be concerned if we need to evaluate the system's intelligence from an outside perspective (e.g. considering it as a black box and analyzing its behavior) or from an inside perspective (e.g. analyzing its architecture and identifying structures, organizations, processes and algorithms that should be used as metrics of its intelligence).

The purpose of this paper is to discuss methods for evaluating the intelligence of intelligent systems by means of a Computational Semiotics perspective. Instead of looking at the system as a black box and testing its behavior, the process described in this paper focus on architectural details of structures, organizations, processes and algorithms used in the construction of the intelligent system, evaluating the impact of using these elements in the overall intelligent behavior exhibited by the system. It proposes then an "insider" type of metrics that, coupled to "outsider" metrics, we hope will be important for the determination of general metrics of intelligence in intelligent systems.

The metrics described in this paper will serve to a double purpose. They will allow the analysis of "already running" systems, by looking at the system architecture with a semiotic perspective, performing an identification of the semiotic processes happening within it and with that making predictions on the amount of intelligence it is capable of producing. The second purpose of the metrics presented here is directed on the sense of being "guidelines" for the synthesis of new intelligent systems. They will serve as an aid for the project and construction of intelligent systems, allowing the system designer to arbitrarily choose the amount of intelligence he is specifying for the system being constructed.

The main approach used to generate these metrics is directed to the identification of the architecture being utilized and the different types of signs and sign processes occurring in the given architecture. Attached to this approach there is the philosophical statement that beyond the architecture, the level of intelligence of a system is directly associated to the number of different types of signs the system is able to handle in its architecture. In this sense, the determination of the different types of signs involved in the architecture, besides the architecture by itself, will lead to an evaluation of the overall intelligence of the system.

Of course, this kind of analysis is only an analysis of the "potential" intelligence a system is able to perform. They must be complimented with "outsider" metrics of intelligence in order to measure the "general" intelligence a system is able to produce. But such an "insider" analysis is very important, because it will state the limits of a given architecture. In other words, we can not expect that a given architecture, tied by a certain use of signs and sign-processes, have better performance than it is able to do. The metrics described in this paper, will allow, thus the determination exactly of the "limits" of a given architecture, as much as making suggestions on how to overcome such limitations with extensions and add-ons to the architecture.

2. A Semiotic Definition of Intelligence

Before we proceed in our objective, it will be necessary, though, to put aside our current view of intelligence, and make a journey to the past and do some reflections on what exactly was the meaning of the term “intelligence”, as Peirce [2] has stated it.

For Peirce, the definition of intelligence is very clear and very well stated, opposite to our current efforts in defining it. In order to understand it, we may recover some philosophical background from the time of Peirce. Aristotle has studied the process of “causation”, and has identified two main types of causation: the efficient causation and the final causation. The difference among them is that the first one is a purely mechanical act of causation, and the second one is a purposeful act of causation, i.e., it has some sort of finality or purpose ruling its behavior. Peirce, studying Aristotle efficient and final causations, stated that what Aristotle calls an efficient causation is an instance of what he calls a process of secondness, i.e., a purelly mechanical and non-intelligent act. In the same sense, final causations are instances of what Peirce calls a process of thirdness, i.e. purposeful or intelligent mediated act. Briefly speaking, the difference between a secondness and a thirdness process is the introduction of intelligence mediating the causative act. Peirce’s notion of thirdness is regarded to the process of mediation, i.e. a third element mediating the relation between the other two. In the sense of causal relations, the first is the cause, the second is the effect, and third is the intelligence, which drives the process of turning the cause into effect. But this still does not define what is intelligence, in Peirce’s sense, despite giving us a clue. For fully understand the meaning of intelligence, in terms of Peirce, it is necessary first to get the Peircean view of what is “Mind”. Peirce has a very broad definition of mind. For Peirce, mind is any sort of system or module, which is able to measure the achievement of a purpose (goal or objective). So, this clearly includes the human mind, but also includes any kind of device that is able to provide such a measuring. Now, we are able to proceed and define intelligence, in a Peircean sense. For Peirce, for some act to be intelligent, there should be some “Mind” behind it, and it is also necessary that the measuring provided by this mind is used to mediate some act, in order to let the system follow its purpose, i.e., meet its objectives. Just this ! So, what is the definition of intelligence, in Peirce’s sense ?

Intelligence, (according to Peirce), is the ability of something (system, device, being) to evaluate the achievement of a purpose, and use this evaluation to drive its further behavior in order to let the purpose to realize. So, for a system to be intelligent there should be the following conditions:

- There should be a purpose to be followed (goal)
- There should be a way of dynamically measuring the achievement of this purpose. Peirce calls whatever is performing this measure as “Mind”
- This measuring should be used in order to drive a behavior that will make the purpose to realize

It is interesting, by this time, to introduce Albus’ definition of intelligence [3]:

“Intelligence is a faculty of the system that provides an ability of a system to act appropriately in an uncertain environment, where appropriate action is that which increases the probability of success, and success is the achievement of behavioral sub-goals that support the system's ultimate goal.”

This definition is very close to Peirce’s definition. It presupposes a goal and it presupposes the system is also able to act in a way to achieve this goal. The only difference is that Albus’ definition doesn’t impose the necessity to have a measuring of how much this goal is being achieved. This may appear like a very small difference, but it is not. It is a crucial difference. In order to understand this difference we need to go back again to the time of Peirce and to the theme of mechanical x intelligent behavior. There was a great debate regarding how to evaluate if some act was purposeful or not. Peirce uses a very illustrative example: the warrior and the dragon. Suppose that the warrior throws a rock and this rock hits the dragon’s eye. Now, suppose two hypotheses to describe this course of actions. In the first one, the warrior just threw the rock away, and incidentally, it hit the dragon’s eye. In the second one, the warrior had a clear intention to hit the dragon’s eye, and when he threw the rock, and it further hit the dragon’s eye, he just achieved his earlier purpose. If the first hypothesis is true, we had an efficient cause (non-intelligent behavior), but if the second hypothesis is true, it was a final cause (intelligent behavior). Then, we have a problem. How to distinguish, from an external observer’s point of view, if a given course of action followed the first or the second scenario ? This is the same as asking if it was an intelligent or a non-intelligent action. If we are able to do some abstractions, we will see that this is exactly the picture of current science when trying to evaluate (or either, to measure) the intelligence of a given working system. We cannot afford a complete and definitive answer to this question, if it is stated simply like that. We are only able to make hypotheses, and take conclusions, assuming those hypotheses are true. For the dragon’s example, it is impossible to say, decisively, what happened. So, this is impossible to decide if it was an intelligent or a non-intelligent action. If we take Albus' definition of intelligence, it will let us assume that we **are** able to evaluate the intelligence of a system, only by means of an external observer point of view. This assumption will lead us to a state of indeterminacy where we will have only imprecise and non-conclusive ways of performing those measuring. If we take Peirce's definition, we will see that it is impossible to evaluate conclusively the intelligence of a system, only by an external point of view. In order to be effective in this evaluation, we need to have access to the internals of the system, and check if the achievement of the goal is being measured and used to drive its behavior. Maybe, this explains why we still didn't achieved until now a good way of evaluating the intelligence of a system.

But, if we now assume Peirce's definition of intelligence, we will have problems from a different nature. For Peirce, an act is intelligent or it is not. There are not multiple degrees of intelligence. If the system acts purposefully, it is intelligent. If not, it is not. In this sense, any type of feedback enabled control system, like a thermostat, is as intelligent as a human being, for example. They both comply with the requirements for intelligence. So, how to re-state the problem of measuring different degrees of intelligence, assuming that a human being is "more intelligent" than a thermostat ?

Maybe, the answer is in the notion of goal. A thermostat has a unique and simple goal: to force a measured temperature to follow a reference. A human being has a multiple and complex networked linked set of goals.

Our common understanding of intelligence (which is opposed to Peirce's one) will certainly suggest that an intelligent system should be able to cope with multiple types of goals. Goals may be precisely defined or vague. They may be cooperative or contradictory. They may require many preliminary steps or a few. They may be achieved by the system alone or only through cooperation with other systems. So, before trying to measure the intelligence of a system by itself, we may first start studying the complexity of the goals we are intending for the system. Other alternative is to try to classify the behavior of a system in different categories, and exploit the possibilities of each one. Of course, this approach will not lead us to a definitive measure of intelligence, but will give us a clue. We will follow this approach, remembering that the analysis of complexity of goals is a requirement to be worked in the future.

3. Intelligent Systems Architectures

We can classify intelligent system by means of its architecture. For this purpose, we propose a set of 6 different architecture categories, based on the reference model of Albus [3]:

1. Reflexive Intelligent System
2. Behavioral Intelligent System
3. Planner Intelligent System
4. Emotional Intelligent System
5. Communicative Intelligent System
6. Semiotic Intelligent System

3.1. Reflexive Intelligent System

This architecture can be seen in figure 1. The main characteristic of this architecture is its stateless unique process of perception-action, which mimics a pure reflex. The action is a direct function of sensor inputs. The function f(x) can be whatever (a set of condition-action rules – fuzzy or binaries, a neural network or a simple mathematical function).

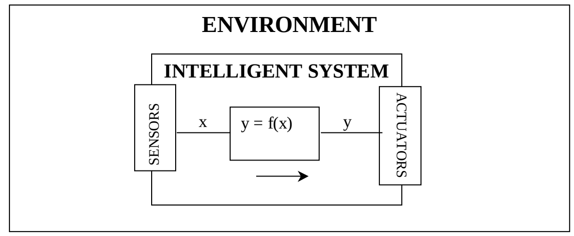

Figure 1 – The Reflexive Intelligent System

To ensure that the system will reach the goals, we need to choose function f(x) with some methodology that warranties that. In other words, the goals are always implicit on the choice of function f(x). The design of f(x) can be done by many different means:

- Heuristics
  - Heuristic algorithm (implicit knowledge)
  - Knowledge based (fuzzy logic) – explicit knowledge
- Learning
  - Inductive (neural networks)
  - Evolutive (genetic algorithms)
- By means of an optimization algorithm (parameter finding)
- By means of search mechanisms

3.2. Behavioral Intelligent System

This architecture can be seen in figure 2.

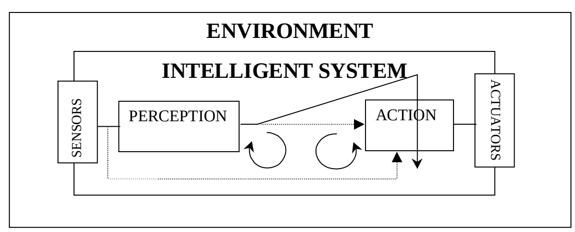

Figure 2 – TheBehavioral Intelligent System

The main characteristic of this architecture is the independence of perception and action, running in different threads or modules. Action is an independent process, controlled by the perception module, which chooses one among different types of behavior previously determined. A typical example of such an architecture is given by Brooks [4]. Usually, there is a pre-defined set of behaviors, which are selected depending on a given perception. In a more elaborate version of this architecture, we may have a fusion of different behaviors, again, monitored by the perception. Despite its simplicity, this type of architecture can generate a very sophisticated general behavior. Unfortunately, there are severe constraints in its applicability. Because the system also doesn't know explicitly its objectives, we can not have a warranty that the goals will be met. It also depends on an adequate specification of the set of available behaviors. These behaviors may (or may not) be different types of reflexive mechanisms, with the constraint that only one of these mechanisms will be on in a given time.

3.3. Planner Intelligent System

The planner intelligent system can be viewed in figure 3 below.

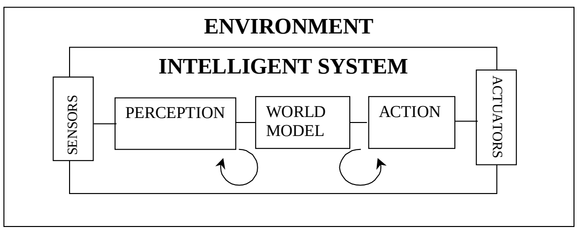

Figure 3 – The Planner Intelligent System

Again, a main characteristic of the Planner Intelligent System is that the processes of perception and action are independent to each other. But the great evolution in this architecture is the inclusion of a World Model. The action is not generated directly by the perception, but there is a mechanism for behavior generation. The World Model works like a de-coupling module between perception and action. It can be known "a priori", i.e. it may be included by the system designer, or it can be learnt by letting the system interact with the environment. In the first case, the perception mechanism only situates the system within the environment. In the second case, the perception mechanism learns the parts that constitute the world and further situate the agent within the known world.

Details in the model may include parts of the world, the physics of the world (how to interact dynamically with it), the history of the world, i.e., an episodic model (episodic memory) of past and present situation of objects of the world.

The action module will use the world model to elaborate predictions on how the world will behave regarding possible actions, and will generate a plan of actions for the system. This plan is a set of actions to be taken by the system, and may contain multiple horizons of actuation. There should be a plan generator, which tries different plans and choose the best one among them.

The behavior generation module will use the prediction generator to determine the results for different plans given by the plan generator. The best plan will be effectively executed.

The plans can be rated in three categories. In the first one, the goals are not achieved. In the second one, the goal is achieved but not in an optimal sense. In the third category, the goals are achieved in an optimal sense. In order to evaluate a given plan, it is important, so, to have a utility measure. This measure gives a score to a plan, which more than simply saying if a goal is achieved, it evaluates how well this goal is being achieved. This utility measure allows for the selection of plans when there are multiple plans meeting the goals, but with different performances.

In some situations, there should be the case to make a re-planning. This may happens, e.g., when, during the execution of a previous plan, this plan shows inadequate for some reason. This may happen, e.g., due to changes in the world model, either because the world has changed or because our knowledge about the world has changed. In this case, the old plan becomes obsolete. It may be not meeting the goals anymore, or it may see a decrease of its quality. In this case, what should be done ? The system must abort the plan execution and re-initiate the planning process.

3.4. Emotional Intelligent System

The emotional intelligent system is shown in figure 4 below.

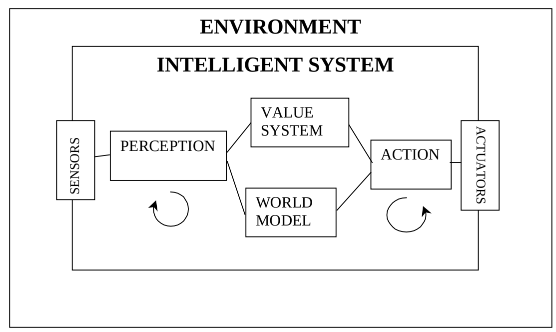

Figure 4 – The Emotional Intelligent System

In some cases, a single utility function can be an insufficient measure for the planner intelligent system. In this case, a full value system should be designed, in order to adequately evaluate the convenience and usefulness of plans. This value system is exactly what we are calling here the emotional system.

We understand emotions as internal evaluations of different natures, which measures if the system goals are being achieved. We use, then, those emotions in order to influence in the planning of future actions. These emotions can be used as internal values, but they may also be externalized by means of characteristic behaviors of the system. This is what happens, e.g., with human emotions, that are externalized by means of involuntary muscle actions. These emotions can also be used as means of communication between different intelligent system.

Emotions can be of different natures. We may have fear, which is an evaluation that something is dangerous and will lead the system to not meet the goals. We may have desire, which means that something should be surely included into the plans. We may have pain, which is a measure that something has damaged the system in some sense. We may have joy, which means that the system is evaluating that the goals are being reached and we may have many other types of emotions. All of them will be in some sense linked to an evaluation of how the goals are being or will be reached. These emotions can be regarding the actual state of the system, or future planned states.

3.5. Communicative Intelligent System

We may see the communicative intelligent systems in figure 5 below.

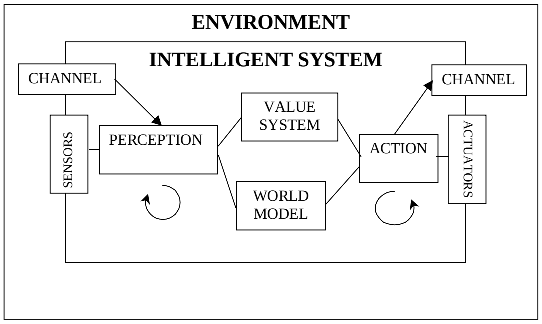

Figure 5 – The Communicative Intelligent System

The communicative intelligent system has as its main characteristic a direct channel of communication with other systems like it or with human supervisors. We presume that in order to be operational, the communicative intelligent system should also include a value system module, being so an evolution of the emotional intelligent system. But this is not a requirement. We may see communicative intelligent systems without a value system. In this case, it will be a direct evolution of a planner intelligent system.

In order to be effective, this intelligent system (or intelligent agent), should be equipped with an agent communication language, responsible for encoding the communicative act associated to the messages dispatched and received by the system. Common examples of such languages are the KQML (Knowledge Query and Manipulation Language) [5] and the FIPA language (Federation for the Intelligent Physical Agents) [6].

Intelligent systems using this type of architecture usually comprise what we call multi-agent systems. In this case, there will be multiple systems running in a same environment, and each system will be specialized in a given task. Two main approaches are possible in order to coordinate the agents. In the first one, called the central coordination scheme, there will be one agent or external module that will act as a coordinator, giving orders to the other agents, which will be the workers. In the second approach, called the distributed coordination, there will be a relationship of cooperation and collaboration among the agents. The agents may assume attitudes of cooperation and collaboration, depending on where they are and what agents are in their neighborhood. This type of approach leads to what is called sometimes an emergent behavior. The agents may be all equal or different among themselves. In some cases, the agents are equal, but they assume different behavioral roles, depending on the situation.

3.6. Semiotic Intelligent Systems

The semiotic intelligent system is illustrated in figure 6. The semiotic intelligent system is an evolution of the communicative intelligent system. In the same way as the communicative intelligent system, it will communicate with other intelligent systems around the environment. The great difference, in this case, is that the semiotic intelligent system does not need an exclusive communication channel anymore. It is able to use the own environment as a communication channel. This communication will be due to the production and interpretation of signs, which are collected and dropped from the environment. It is clear, in this case, that due to its semiotic abilities, the semiotic intelligent system must have a more sophisticated mechanism for perception and action. The perception mechanism should be able to fully interpret different kinds of signs existing on the environment. In the same way it should be able to produce different types of signs, which means that it should need a more sophisticated action mechanism, that is able to take care of this explicit sign production.

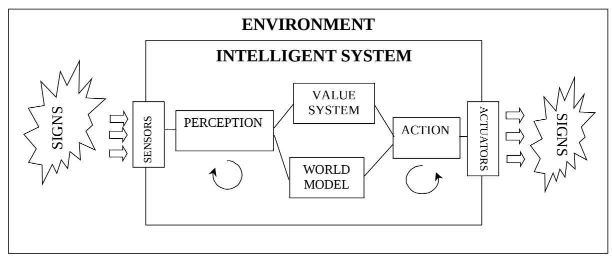

Figure 6 – The Semiotic Intelligent System

4. Types of Signs and Knowledge Units

In previous works [7,8,9], we presented a classification for different types of knowledge, which would be represented by different types of signs. They are summarized in figure 7, and we will be using them on next section, in order to create our metric for intelligence. This classification of knowledge start from the most basic types of knowledge, that is the sensorial knowledge, building up different categories used to represent different types of phenomena from the world. So, we start with sensations (which are the most basic types of phenomena we are able to perceive), pass through objects and entities (which are abstractions we build out of our sensations), plus the meaning of verbs and further occurrences on the environment (which are the representation for the dynamics of the environment), until reaching linguistic propositions, arguments and mechanisms of reasoning. We claim that as many different types of those a system is able to handle, more intelligent it should be. This is because this hierarchy of types of knowledge starts to become more and more difficult to handle, as we proceed. But, the types of signs, by themselves, are not able, as a whole, to determine a single measuring of intelligence. They should be mixed with the chosen architecture, in order to give us a good estimation for the system intelligence.

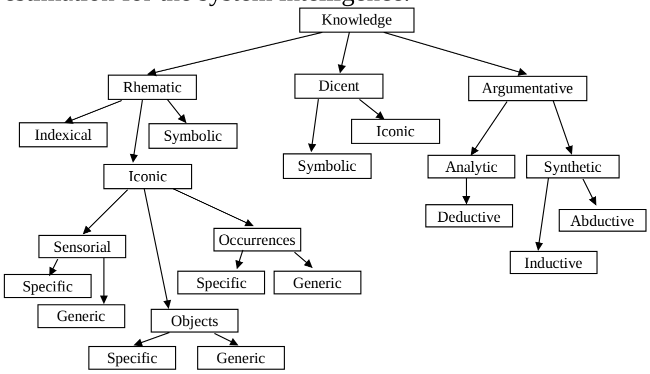

Figure 7 – A Hierarchy of Types of Knowledge

5. Setting up a Measure of Intelligence

Now that we settled up the different architectures and presented the different types of knowledge a system is able to process, we are able to describe our metric of intelligence.

This metric is a very preliminary one, and very naïve, either. We are proposing it as a starting point to foster further discussions on the theme.

Our first argument in section 2 was that following Peirce's concept of intelligence, it was impossible to create a metric to evaluate intelligence (because following Peirce, a system either is intelligent or is not). We then enlarged Peirce's view of intelligence, including into it the complexity of goals a system is able to cope with. We somewhat postponed the goal complexity issue, and as an alternative decided to classify a system among different architectures, which will be suitable to different levels of goal complexity. This classification was evolutive, where each new classification was an evolution of a previous one. So, our first item of evaluation for a system will be its architecture. We numbered the types of architectures from 1 to 6. Implicitly, we are so considering that an architecture of type 2 has a greater potential for intelligence if compared to an architecture of type 1 and so on for the other architectures. We then presented the classification of different types of knowledge, and argued that we considered that a system able to handle more different types of knowledge will be considered to be more intelligent. So, now, what we propose as our metric for intelligence, is a classification pair (X,Y), where X is the type of architecture, following the list of architectures in section 3, and Y is the number of different types of signs a given system is able to handle, according to section 4. So, a metric of (3,4) means that the system uses a planning architecture and is able to handle 4 different types of knowledge, according to figure 7. What do we pretend with this metric ? We want to say that instead having a linear measure for intelligence, maybe it is more adequate to have a lattice. So, when comparing a system with a metric (3,8) and other with (4,1), we will not be able to say precisely if the one with (4,1) is more intelligent than the one with (3,8). But, we surely will be able to say that one with a metric (6,8) is certainly more intelligent than one with (1,1).

6. Conclusions

The metric we proposed is a very preliminary one, and there are many aspects on it that should be criticized. Certainly, there are many other aspects that are important in order to consider for evaluating the intelligent of a system.

Our purpose here was to state, though, some important points:

- The architecture of a system is certainly very important when trying to measure its intelligence
- The number of different types of signs a given architecture is able to handle is also very important

Our metric, despite its simplicity, can give us some very important clues on how considering this topic of measuring intelligence, from an "insider" point of view. More elaborated metrics should now compliment this one, enlarging it with the goal complexity issue that we consciously postponed.

7. References

[1] H. Gardner – "Frames of the Mind – The Theory of Multiple Intelligences", Basic Books, 1993 2nd edition.

[2] Peirce C.S. - *Collected Papers of Charles Sanders Peirce* - vols I to VI - edited by Charles Hartshorne and Paul Weiss - Belknap Press of Harvard University Press - Cambridge, Massachussets, 2nd printing, 1960.

[3] J.S. Albus, "Outline for a Theory of Intelligence" - *IEEE Transactions on Systems, Man and Cybernetics*, vol. 21, n. 3, May/June 1991.

[4] R.A. Brooks,- "Intelligence Without Reason" in *Proceedings of the Twelfth International Conference on Artificial Intelligence*, Vol. 1 (1991) 569-595.

[5] T. Finin – "DRAFT Specification of the KQML Agent-Communication Language plus example agent policies and architectures" - The DARPA Knowledge Sharing Initiative, External Interfaces Working Group – available in http://www.cs.umbc.edu/kqml/kqmlspec/spec.html

[6] FIPA Specifications – available at http://www.fipa.org/spec/index.html

[7] R.R. Gudwin, - *Contribuições ao Estudo Matemático de Sistemas Inteligentes* – PhD Thesis - DCA-FEEC-UNICAMP, Maio 1996 (in portuguese)

[8] R. Gudwin, F. Gomide – "An Approach to Computational Semiotics" – Proceedings of the Intelligent Systems and Semiotics ISAS'97 Conference – NIST - Gaithersburg, 1997.

[9] R. Gonçalves, R. Gudwin – "Semiotic Oriented Autonomous Intelligent Systems Engineering" – Proceedings of Intelligent Systems and Semiotics ISAS'98 Conference – NIST,Gaithersburg, USA, 1998, pp. 700-705.