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Is a Robot That Can Autonomously Play Soccer Intelligent?

J.-D. Dessimoz, P.-F. Gauthey, P. Roulin

Hesso/Eivd - West Switzerland University of Applied Sciences
1400 Yverdon-les-Bains, Switzerland, Jean-Daniel.Dessimoz@eivd.ch

Abstract. 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; intelligence is 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 and computers. Autonomy implies self support and is mostly considered here for energy and decision-making domains. Games and soccer playing have been recognized as stimulating testbeds for new concepts in IAS field. We at eivd have designed various systems in the past for robotic competitions. Diego^3 for instance has been competing in official, reduced-sized soccer tournaments. In the same way as any model is valid only for some bounded domain of reality, all associated cognitive properties, including the one of intelligence are similarly limited. But within this boundary, and specifically soccer-playing according to European robot cup rules, interesting conclusions can be drawn. In practice what counts ultimately is not to be intelligent, i.e. able to learn but to be expert, i.e. to do right and fast; for the case of intelligence, we found Diego^3 intelligent enough in competition, but comparatively more limited for inter-match strategy adaptation. The successor, Arthur, was made more intelligent by the design of our Piaget interpreter.

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].

Schematically, common approaches for assessing the value of concepts and theories can be grouped in two categories. The first one tends to work "from inside" and focuses on the proof of coherence and validity of each candidate with respect to some proposed assumptions; the other one works "from outside" and tends to confront candidates to standard tasks. It is in this type of approaches that we find benchmarks, games, and soccer competition. [13-17].

In our industrial societies, games are generally viewed at best as entertaining but very seldom as really useful. Yet in our context it is so, and even doubly the case: participants get some training in using classical techniques (e. g. [18, 19]), and results can rather directly be transposed into economically relevant contexts (e.g. [20-23]).

The paper is organized as follows. Part 2 briefly presents fundamentals in cognition theory. Part 3 describes the context of test tasks, notably soccer-playing. and then Part 4 shows in more details a platform developed in our group, which has been at one stage competing in soccer tournament.

On this basis, an answer is finally provided for the challenging question expressed in title.

2. Basics for Intelligence and Autonomy

Before assessing whether or how much a robot is intelligent, one cannot escape giving a clear definition of what is intelligence. Related classical works have been referenced above.

In a concise and coherent way, the reader finds again, in what follows, core definitions and metrics for cognition. 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.

In the next paragraph (§2.2) the case is further commented for the concept of autonomy. Finally (§2.3), 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.

2.1 Assessing information, knowledge and other 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. Let's see these concepts in more details (for a more extensive discussion on various aspects, see [9-12, or 22]).

2.1.1 Information

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. 1). Information is conveyed by "messages". In formal terms, it essentially describes 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.

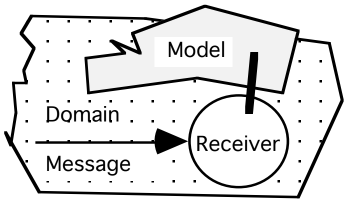	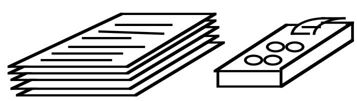
Fig. 1. Context for information	**Fig. 2**. Example: Information (left) can often be generated by cognitive systems (right); sometimes in potentially huge quantitites

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.

2.1.2 Knowledge

"Knowledge" 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. And the latter is the set of all possible input-output associations:

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

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.*

2.1.3 Expertise

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.

$$E = K f$$

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*.

2.1.4 Other cognitive properties

In a similar way, other cognitive concepts have been unambiguously defined: learning (positive variations in expertise amounts), experience (amount of information received about a domain), intelligence (rate of learning as a function of experience), 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), etc.

2.2. Case for autonomy

Autonomy is the property of a system that can exist and act by itself, i. e. independently of all other resources. Reality being very complex, the meaning of autonomy must always be restricted to some specific domains, in practice. For our context, autonomy has many different aspects. It corresponds to decision and energy aspects. It is also bounded in time on a certain time interval. In cognitive terms, autonomy must be treated differently during competition phases or training phases.

2.3 The concept of "model" revisited

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 analyzis 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.

3. Applications

As stated in §2.3, the quality of a model is primarily defined by the means it provides to reach a goal. The applications described below provide well defined goals, to which alternative systems can be confronted, and in which their various merits can be revealed.

Our applications feature some aspects maybe unexpected. Autonomy is made more difficult, for energy and decision properties, by two constraints : platform size and volume are limited. Intelligence is required with a new twist: time is limited for action (match duration) and much learning (competitors must adapt strategies, i.e. must "teach" their robots) must be done during the short time interval during matches, thereby setting serious requirements on robots in terms of intelligence.

Three categories of applications follow. The first one relates to soccer, and the following one get more general, addressing other games (§3.2) or industrial applications (§3.3) .

3.1. Soccer-playing and Diego[3]

Soccer is a type of sport which is increasingly practiced and well-known, at international level. It is recognized of good value because of the type of ludic, ecological, non-violent and cooperative characteristics it features. Active autonomous systems in this world should be able to move in time and space. Therefore, robots are likely candidates for trials. Therefore a variety of groups have set rules that combine both worlds: soccer competitions for robots.

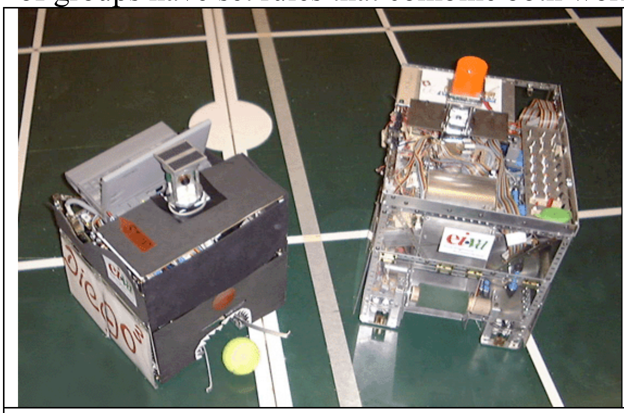

Fig. 3 Intelligent autonomous robots: Diego[3] and Arthur

Fig. 4 Experiment with non-contact vehicle tracking in Serpentine

Worldwide, quite a few competitions are organized nowadays, and currently the most elaborate contest relating to soccer with robots, simulated or real, may be Robocup, organized in the context of IJCAI. Here is a short quotation of [14]; "The most prominent feature of RoboCup is that it provides the researchers with the opportunity to demonstrate their research results as a kind of competition in a dynamically changing hostile environment, defined as the international standard game definition, in which the gamut of intelligent robotics research issues are naturally involved. ... Currently, we have four kinds of leagues: the real robot small, middle, and four legged ones, and the simulation league. While the practical issues have been mainly attacked in the real robot leagues, the more strategic issues in multi-agent environments have been focused in the simulation league, such as teamwork among agents, agent modeling, and multi-agent learning.".

French organizers have set-up very meaningful and successful robot competitions for soon 10 years, and in 1997/98, they adopted a soccer type of tournament. Playground was 2x3m in size; balls where of tennis type and laid in 8 predefined spots; match duration was 1.5 minute; goal were .5 m. wide, and 1 single on/off action could be transmitted once from human competitors, during match For several years, the competition was open, at final stages, to other European countries. For this reason, the same competition was held in various other European countries, incuding, for our part, Switzerland, where our robot, Diego^3, finished number 3 of a group of 6.

3.2. Other games and Arthur

Strategically, the French and European committees have decided to change each year the type of game, so as to open better chances for new groups to enter competition .

The French and European Robot Cup is an entertaining, scientific and technical challenge proposed to young students of universities and colleges of engineering, gathered in clubs or within study projects, as well as to independant clubs.

Participants must design and realize a robot that complies with contest rules and competition spirit, and which is able to participate in matches (qualification).

As mentioned above, for the French and European Robot Cup soccer was competition theme in 97/98. The year 98/99 featured Middle-age castle-type tower attacks (our robot can be watched passing very successfully the European qualification stage, on QuickTime/video record [24]; it was for a short while called "Excalibur" and then definitely referred to as "Arthur" - name inspired by King Arthur). In 99/Y2K, balloon piercing, in a hill and valley environment is the target application (see [13] for detailed Y2K competition description).

Worldwide, similar initiatives having a broader scope than relating to soccer are numerous. An interesting example can be found in [16]: Super Mechano System (SMS) is a research project supported by the Japanese Ministry of Education, Sciences, Sports and Culture, started in 1997 at Tokyo Institute of Technology. It aims at establishing a new discipline by the autonomous, functional integration of advanced technologies in mechanisms, structures and control in order to attain higher performance for a given objective.

3.3. Industrial applications and significance for economy

For teams ready to consider regularly updated game rules, changing objective is easy in order to address immediately directly relevant themes in industrial context or more generally for ensuring some impact on society. An obvious shift is the one translating many of the techniques used in playing robots towards AGV. For our case, another interesting example can be found in our Serpentine project [22, 23].

Intelligence is the ability to learn, i. e. to respond with improving expertise to new contextual conditions. In the specific case of Serpentine, this quality is ensured in several ways. For example, the system globally adapts with high flexibility to passenger demand. Inductive sensor processing relies on pattern recognition techniques. The steering and speed controller involves a sophisticated vehicle and process modeling. Collisions are avoided even in the case of many types of sudden, non predictable moving obstacles in front of vehicle.

More generally, so-called intelligent systems usually also appear to rely on complex modeling (R. Brooks's animats are probably the best known exceptions). In this sense the Serpentine project has also given us the opportunity to design complete 3-D animated sequences, with a virtual articulated Serpentine vehicle moving along self generated, kinematically correct clothoidal paths, and with realistic rendering (texture or orthonized/deparallaxed picture mapping for houses, windscreen transparency, slightly cloudy virtual sky, etc.) through the Swiss city of Yverdon-les-Bains.

4. EIVD Platform for IAS study

In our group, a platform has been designed for participation in robot competition, initially as a teaching project. But very fast, task-related requirements has forced us to innovate and to transfer onto our platform the best developments and techniques, tapping partly into some of our research project results but also in international contributions.

4.1. Main functions and components

Table 1 presents a summary of major functions and components of Diego^3 or Arthur.

Current design includes a LAN, distributed axis controllers, and DC motors, as an alternative to PC controlled stepper motors.

4.2. Specific decision processes and rating

Table 2 presents some key decision processes for our IAS, automated techniques for cognition, along with some rating of achieved performance..

Table 1 Main functions and components

perception (sensors)	tactile micro-switches, electro-optic elements and fibers, video camera
action (actuators)	motors for ball picking, ball shooting, obstacle ejection, relays for mechanical action or electrical power switching
energy	20 min. battery packs, 16 bar air pressure tank; associated regulators and voltage converters
decision	(Portable) PC
mobility	Stepper motors, gear-works and wheels; passive 2-D wheels or low-friction pad
platform and container	machined basis and standard kit elements
internal communi-cations	connectors, bus's, (bidirectionnal) multiplexers and selectors, serial and parallel links
external communi-cations	keyboard, screen, radio link and controller, LED's, switches (push-buttons), light sources

Table 2 Main functions and components

axis coordination (3 axes: locomotion and camera)
direct and inverse kinematics (non-holonomic motion)
transformation matrices and calculus (numerous frames)
motion laws (trapezoidal speed profile)
trajectory control (tracking, 150cm/s speed max, 200cm/s2 acc. max, emergency braking)
vision for position estimation (1% accuracy, 0.01 s total acquisition and processing time)
teleoperation (5 channel radio link for tele-manipulation)
elaborate software engineering approach (database-inspired structures, strict coherence between real world and internal representation for objects and processes).
Subsumption components (collision avoidance, ball picking, line-following, ball supply, canon shooting, etc.)
mouse support (more than 50 click actions on screen)
color graphics (color encoded state representation)
real-time (multiple time scales, 10 micros-1s)
file support (DOS, Windows 95)
other physical properties and mechanical action (15-20 kg, 30-40cm diameter, ballistic shooting of tennis balls at 5 meters, 2 finger extensions and pushing motions)

For larger applications a very flexible solution for communication with non connected computer has been implemented, using herzian Ethernet link (e. g. [22]). We do not need it much for systems behaving autonomously. But for development phases, such a communication channel is very useful.

5. Multitasking environment and Piaget interpreter

Our robots benefit from multitasking approaches and can interpret a specialized language.

5.1 Multitasking environment

A multi-task kernel has been designed, which is very efficient, *switching contexts* (pc’s, stacks, etc.) like for some old TI computers, rather then pushing/pulling registers. For design efficiency and portability, this is implemented in Pascal, like for the early Macintosh operating systems. In our application, about 20 tasks are used, and extremely fast processing is achieved: One microsecond time is used per task slot in average, and this is the total time for switching *and* computing!

5.2 Piaget Interpreter

During strict competition time, when robots are autonomous, an interpreter is not very meaningful. But in practice these phases are short and rare in comparison to development, debugging and strategy adaptation times. The latter point is critical: the team must be able to communicate very efficiently with robots between matches, in order to adapt strategies to what is seen from other team behavior. For this reason an interpreter has been designed, which immediately decodes a specialized language matching our applications: soccer playing, castle destroying, balloon piercing… It interprets numerous keywords referring to robot properties and structure. No less than 50 orders can be interpreted, many of them implying procedural calls to parallel tasks (see Table 3). A meta-call paradigm allows for subroutine calling and returning, with time scales much longer than task-switching time boundaries (e.g. several seconds).

Input partly comes from mouse, keyboard or files; but in most cases similar functions can also been defined at programming level. Because of the cognitive aspects of robot tasks, and because motion in space plays here an important part, we have called our interpreter and environment "Piaget", in credit to Jean Piaget the well-known constructive psychology scientist.

Table 3 Some high-level instructions in Piaget (some also have shortcuts, to be interpreted)

Keyword (originally in French)	Description
GoFetchBall (RightBehind)	In order to execute this order, the system computes in real time a trajectory, with rotation and linear trajectory, from current location to a new location such that robot grasping tool is on nominal target position of the specified ball on the playground; it ensures a trapezoidal speed motion law with individual control of motor steps; it coordinates camera rotation; and it starts grasp motor action.
Sleep (time)	The task skips its turn until time has elapsed
MoveRight(R, Angle)	The robot moves on a circular path of R radius, for Angle degree
ShootAtTower(Center)	Feeds gun if necessary, reorients robot depending on current location and specified tower, finally releases air pressure if ball is ready.
ChooseBridgeVisually	Captures a picture, analyzes opponent's location, and chooses the bridge to cross so as to minimize the risk of collision
CrossTheBridge	Moves ahead, tracking bridge path with optic sensors; stops when the other side is reached

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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. Autonomy implies self support and is mostly considered here for energy and decision-making domains. Games and soccer playing have been recognized as stimulating test-beds for new concepts in IAS field. They provide clear goals, which force teams to balance expertise in a large number of subfields, and point at critical shortcomings.

At Eivd, various systems have been designed for robotic competitions. Diego[3] for instance has been competing in official, reduced-sized soccer tournaments. Within the specific boundary of soccer-playing, according to French and European robot cup rules, interesting conclusions can be drawn. In practice what counts ultimately is not to be intelligent, i.e. able to learn but to be expert, i.e. to do right and fast; for the case of intelligence, we found Diego[3] intelligent enough in competition, but comparatively more limited for inter-match strategy adaptation. The successor, Arthur, was made more intelligent by the design of our Piaget interpreter.

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