International Conference on
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Singapore

ICIRA-09-D2-T1B

Cognition Dynamics; Time and Change Aspects in Quantitative Cognitics

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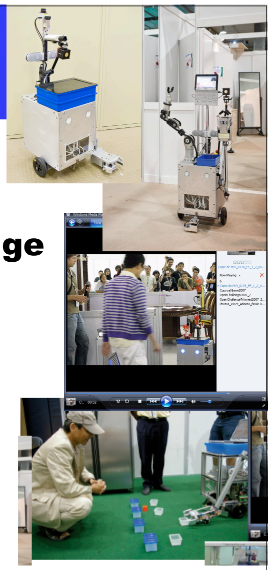

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- Cognition Dynamics -
Time and Change Aspects in Quantitative Cognitics

1. Introduction
2. Essential definitions in cognition and cognitics
3. New aspects in cognition dynamics
4. Examples
5. Conclusion

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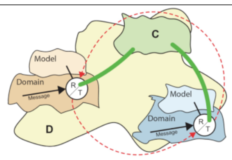
1. Introduction



Automation reaches where **cognitive abilities** are critical. Example: service robots, in particular help at home:

- self initiatives, cooperative behavior and, generally speaking, human-robot-interaction.
- league "at-Home" of the worldwide "Robocup" project:
  - practical experiments and
  - theoretical developments
  - forces stemming from all world horizons

Applications require technical excellence, and appropriate bases: **definitions and metric system** for machine-based cognition]. Quantitative aspects often proven critical. Ex.:

- 1. Mostly, signal processing techniques and software engineering approaches deliver much more performances than conventional AI methodologies;
- 2. shortcomings have been made more evident than in the past, even for concepts long established as models and information ;
- 3. another class of difficulties : traditionally rather too static view of matters, especially in cognition; phenomena involve time and changes, dynamics and evolution; again, it helps a lot to be quantitatively oriented.

- Cognition Dynamics -

Time and Change Aspects in Quantitative Cognitics

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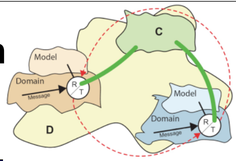
3. New aspects in cognition dynamics
4. Examples
5. Conclusion

2. Essential definitions in cognition and cognitics



2.1 Cognition domain and dynamics

2.2 Information and modeling

2.3 Basic time properties

$$K = \log_2(n_o \cdot 2^{n_i} + 1)$$

2.1 Cognition domain and dynamics

General views:

- **"in psychology and cognitive science cognition refers to an information processing view of an individual's psychological functions" . Etymology : cognoscere (Latin) i.e. "to know".**
- **"dynamics refers to time evolution of physical processes"; it may also refer to "forces and motions" of objects; original Greek form of (dynamics) means "power".**

In the paper: "cognition dynamics" :

- **coherent with these definitions;**
- **mapping into cognition, concepts derived from physical world (dynamics).**

"Cognitics": science and techniques of "automated", machine-based cognition.

With appropriate metric system, necessary for progress :"quantitative cognitics".

Knowledge:

- **cornerstone of this rigorous construction, refers to the roots of cognition ("to know");**
- **refers to the property of cognitive systems to deliver relevant (output) information.**
- **Quantitatively, K: function of two flows of information: input and output; unit : "lin".**

Complexity: property of requiring a large amount of information for description; unit: "bit"

Abstraction: property of yielding less information than receiving. Reciprocally: concretization

2.2 Information and modeling

Information has been defined in the middle of 20th century on the basis of a probability calculus; the unit for metric purpose is usually the "bit".

It turns out that in practice information cannot be estimated in finite terms directly on reality and always requires some modeling.

Models are always of relatively small complexity; nevertheless, specific models may be useful in order to reach pre-defined goals.

Historically, the information theory has been created for the field of machine communication. In this context, information involves relatively small amounts of information.

When moving to human context, more than before, reality is in background. As reality is infinitely complex, typically, two humans are schematically required: 1. one to select relevant goals, and 2. the other one to provide appropriate corresponding models (Setting-up the correspondence between model and reality establishes the meaning, and is sometimes referred to as the grounding problem). Between those two schematic humans, digital representations are possible, and as a matter of fact, they are now getting elaborated in very large quantities, contributing to a whole digital universe.

2.3 Basic time properties

As everyone would agree, "time is a component of a measuring system used to sequence events, to compare the durations of events and the intervals between them, and to quantify the motions of objects" [8]; it is measured in seconds.

The time constant of a system is usually understood as the time it takes for a system to essentially reach its asymptotic response state after a starting excitation.

Stationarity is the property of time-invariance.

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Time and Change Aspects in Quantitative Cognitics

1. Introduction
2. Essential definitions in cognition and cognitics
3. New aspects in cognition dynamics
4. Examples
5. Conclusion

3. New aspects in cognition dynamics

3.1 Order of stationarity
3.2 Time based difference between knowledge and expertise
3.3 Perishable quantities of complexity and knowledge
3.4 About expert paradoxes
3.5 Agility
3.6 Stability of automated processes
3.7 Time and change
3.8 Closed loop control, consequences on time properties, and autonomy
3.9 Driving causes for changes in general, consequences on time properties, and analogies in human psyche

3.1 Order of stationarity

Systems and processes may usually be viewed at various levels of abstraction. Depending on the level being considered, stationarity may strongly vary.

In general the lowest levels, more detailed, where no abstraction or very little abstraction is done, tend to vary more than higher levels.

For example, in learning systems, there is by definition no stationarity at lowest level, the level of elementary information flows, as improvements are under way; yet when considering more abstract levels, such as overall system architecture, or information processing paradigm, time invariance, i.e. stationarity typically applies.

There may also be significant variations in terms of time horizon; systems may be stationary for short term behavior and on the contrary not stationary on the long term.

All this can be accommodated with the concept of “domain”.

3.2 Time based difference between knowledge and expertise

Knowledge and expertise are probably the most essential entities in cognition. Time is qualitatively present in the concept of knowledge, and even more present, indeed quantitatively present, in the one of expertise.

The focus is set here on knowledge and expertise; nevertheless time and changes play also a role in some other cognitive concepts, such as, in particular, learning.

Consider here the intuitive definition for knowledge, i.e. the ability to ”do right”, to deliver the correct information. It is already clear that in principle knowledge is not *quantitatively* related to time. Referring to metric equations, time does not appear. Yet to process and deliver information however does imply time.

Now there are many cases in cognitive processes where time matters, or even is critical. “To do right and fast” is another quality than knowledge; it is the quality of experts. While the unit for knowledge is the “lin”, the unit for expertise (synonyms in natural language: skills, competences, know-how, etc.) is the lin per second, “lin/s”.

Re. B-Prize to be done

3.3 Perishable quantities of complexity and knowledge

Information is, by nature, subjective and perishable. Idem on derived cognitive properties:

- **Quantitatively, information is based on probability.**
- **Generally related to external circumstances (objective aspects), but in all cases primarily dependent on receiver's expectations (subjective aspects).**
- **And it is the very role of information to update receiver's model. Therefore expectations vary in time: a repeated message is in principle useless.**

Complexity is one of those cognitive concepts inheriting the features of information. For example a first explanation may require a lot of information. By definition, that explanation is complex. Yet it may be simply repeated: "Idem".

Similarly, a cognitive system may feature a large amount of knowledge, requiring in particular a large amount of incoming information. Yet as time goes, information flows may decrease, and consequently the instantaneous amount of knowledge will also decrease, as quantitatively shown by metric equations.

3.4 About expert paradoxes

The more humans know, the more they can learn?

- **Asymptotic limits often apply in physical world: Ex: compressing garbage, filling up a container,**
- **For cognition, true: subjective and perishable nature of information inherited by core cognitive concepts, e.g. complexity and knowledge. As people get more expert, the uncertain nature of incoming information, i.e. the quantity of incoming information tends to fade. Less complexity; less knowledge required for further processing.**

Experts are worse than beginners at forecasting?

- **Maybe yes, and maybe not. If experts are experts, this means that in principle they perform "right and fast".**
- **Now forecasting refers to future situations. Therefore a critical parameter is here stationarity:**
  - for phenomena that benefit from some order of stationarity, a proven expertise level will tend to be maintained through time.
  - Now, if on the contrary phenomena do not have an appropriate stationarity, it should not be, nor a surprise nor a paradox, that past expertise cannot be carried over through time. If cognitive domains are different in the past from in the future, it may even happen that at times a negative correlation develops.
- **Hazard may be an acceptable guide in domains that have never been explored before; this tends to radicalize the paradox under review.**

3.5 Agility

Cognitive systems have a real importance in as much as they are followed by actions. The latter is even more essential for control systems. A useful concept in this context is the one of agility.

Agility combines the notion of time with the one of action (both words, agility and action, share the same Latin root: agere, i.e. in current English to act, to do, to make). In natural language, agility has a connotation of referring to animal or human motions in space. This character may however be generalized by analogy to other forms of action.

Quantitatively, let us define agility of a system as the inverse of its time constant (re. §2.3), which implies 1/s as a unit.

3.6 Stability of automated processes

Closed-loop control (useful when unknown changes may happen) includes three classes of situations

1. very easy , and efficient, just by on-off control
2. tuning is more difficult yet performances are acceptable (fast, accurate, simple)
3. Failure; large errors, and possible unstability; ; structure must be changed, possibly with an hierarchical approach.

Extremely interesting indicator : ratio, Ar, of two agilities, the one of controller (including perception, decision, action and communication phases) versus the one of controlled load.

Here again, some time properties turn out to be a critical parameter or, at least, provide a critical indicator for successful system behavior in automation and cognitics domain.

T : controller decision time and communication delays

τ : time constant of system to be controlled

3.7 Time and change

Time is usually considered as a specific dimension of reality and is given its own unit (second, in the SI international unit system).

But other views may be useful. For example :

1. the ancient Greek Parmenides invites us to consider reality as a permanent whole without any dimensions at all (what is, is);

2. in this United Nations Year of Astronomy, it is particularly evident that yet another model of reality where time and space are dependent of each other may also have some merits (in astronomy distances are counted in years; and reciprocally far objects are old ones).

Here time is discussed in its interrelations with change.

- Intuitively, it appears that time can be defined in reference to change. For example a cycle of natural light change typically somehow defines a day long time duration.

- More rigorously, and quantitatively, a change is not sufficient per se to define time, and other factors need be expressed. Ex.:

1. a change in space by a speed factor,
2. a change in energy by a power factor,
3. a change in momentum by a force factor, or
4. a change in knowledge by an expertise factor.

This is particularly true in differential terms.

3.8 Closed loop control, consequences on time properties, and autonomy

In fact and ultimately, the own ("natural") time properties of a particular system may not always prove to be the relevant criteria for success. This is especially true in the context of perturbations and of control; and even more so in common practical cases where non-stationarities and non-linearities prevail.

Powerful systems are complex and are usually organized as a multiplicity of interconnected subsystems (e.g. hierarchies, cascades, parallel or distributed structures, etc.). In this context, it is regularly verified that an elementary system may behave with much improved time properties with the help of a dedicated, autonomous associated control system.

By this approach, far from representing absolute constraints, the natural time properties of an element may just be viewed as contingent features, which may drastically be improved at system level by appropriate design and engineering.

The paradigm of granting local autonomy is also very effective in improving the potential agility of control system in the closed loop.

3.9 Driving causes for changes in general, consequences on time properties, and analogies in human psyche

Time has been shown related by a power factor to a change in energy (re. § 3.7). Now energy is defined, in general, as the product of a driving cause by the corresponding effect. For example energy, in physics, may be estimated as the product 1. of a force by a distance, 2. of a voltage by some electric charges, or 3. pressure by a volume.

Notice that by the same token (energy is the product of a driving cause by the corresponding effect), since energy is the product of power by time, we could view power as a general cause for change, and time then becomes simply the corresponding effect!

For describing dynamics in human psyche, people have traditionally used analogies with the physical world: energetic person, powerful argument, etc.; a special place is given to mechanics, forces and motion: emotions and motivations are two words sharing the same Latin root: movere, to move.

Experience confirms that in the cognitive world as in the physical one, time is usually subjectively estimated as a function of changes; and that the factors linking changes to time are not always evaluated right; this principle leads sometimes to large errors in time estimation, especially when driving causes for changes are intense.

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4.1 Brief presentation of RH4-Y robot

4.2 Illustrative case study

4.1 Brief presentation of RH4-Y robot (1 of 3)

RH4-Y, version 4 of our cooperating robot for applications at home; replicating human motions and following a human, learning new tasks and locations, fetching and grasping objects (photos HEIG-VD / PFG)

4.1 Brief presentation of RH4-Y robot (2 of 3)

Developed since 2005 (or indirectly 1998), our RH-Y robot can move autonomously and interact cooperatively with humans in domestic context.

Hardware:

- platform mechanically driven in a classic way, i.e. with 2 active+1 wheels,
- arm and hand (plus also sometimes a 5 dof Katana arm),
- electrical system with batteries,
- a number of sensors (Axis color camera, Mesa-imaging 3D rangefinder, 2 Hokuyo planar laser rangefinders, a microphone)
- actuators (Maxon DC servomotors for wheels, arm, hand, lights, sound system),
- Fujitsu Siemens supervising computer,
- embedded system featuring essentially a
  - double star architecture, (Ethernet hub and USB hub),
  - distributed Galil and Fiveco processors for motion control,
  - Beckhoff BC9000 PLC.

4.1 Brief presentation of RH4-Y robot (3 of 3)

Software:

- key role is played by our Piaget language and environment:
  - four progressive levels of complexity for users,
  - extensive possibilities not only in programming and autonomous “run” modes but also in simulation, configuration, and interactive control modes.
  - Implementation code is mostly done in Borland C++ object-oriented language (previous and alternate implementation languages include Pascal, C and C#).
- Ancillary functions are provided by various commercially available drivers and codes specialized for our COTS pieces of equipment and for elementary word recognition (MS SAPI 4.4).
- Motion control typically develops at 4 complementary levels, of respective agilities ranking progressively from approximately 1 to 100’000 1/s:
  - programming and supervision, coordination, servo-control, and lowest level, encoder and motor management stage, including amplification and current limiting.
- Usually, position control is performed, and sometimes velocity control or force control laws are temporarily enacted.
- Details, illustrations and videos can be found on our website [9].

4.2 Illustrative case study

- *Service robots and cognitive tasks*
- *Quantitative aspects*
- *Modeling*
- *Grounding*
- *Information*
- *Complexity*
- *Knowledge*
- *Abstraction*
- *Time constant*
- *Stationarity*
- *Expertise*
- *Time-varying complexity and knowledge*
- *Expert paradoxes*
- *Agility*
- *Stability of automated processes*
- *Time and change interrelation*
- *Improving natural system time properties with control*
- *Driving causes for changes, time properties, and analogies in human psyche*

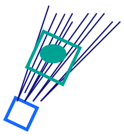
Service robots and cognitive tasks

- **In Robocup-at-Home league, the rulebook [e.g. 10] describes some representative tasks for a robot serving at home: "Follow a person" and move according to a few possible orders, "Navigate" autonomously through home towards vocally ordered locations, "Fetch and Carry" a specific object, recognize "Who is who" among a few persons, find some lost object, learn from gestures in a "CopyCat" fashion, etc., leaving in addition some blank slots where novel applications may be presented ("Open Challenge", "Demos" and "Finals").**

- **Depending on the considered year, variations on the mentioned themes may occur, e.g. for what is presented here as « Follow a person » there is in fact « Follow and Guide »(2007), « FastFollow »(2008), « Follow Me »(2009), and yet other titles for 2006 and 2010.**

Quantitative aspects

- **Quantitatively, the rules provide contrasting levels of explicitness; e.g. the "Who is who" (WiW) test was involving 5 persons in 2007, which is numerically very clear; but no value is given in terms of minimal difference between individuals. Obviously it would be much easier to distinguish 1. a small fat silent boy wearing black attire from a tall, noisy, slim boy wearing yellow, than 2. two monozygotic twins wearing and behaving the same.**



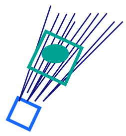
Modeling

- **Modeling who-is-who (WiW), with human intuition and expertise :**
  - **identify *goal*: to successfully perform the task**
  - **useful to break it in several subtasks: 1. to detect a person, 2. then to estimate a discriminating pattern, and 3. finally to recognize the latter by reference to previously learned references.**
  - **Let's concentrate on the first subtask – localization of a standing person:**
    - **sufficient to represent a human by the reflective nature of its chest, about 50cm wide, to the laser beam of a planar range finder mounted on robot,**
    - **in the vicinity, two 20cm or more empty spaces, one on each side**
    - **about 10 samples required, with accuracy in position of about 10cm in "width" and distance.**
    - **in addition, consider that the robot will walk around and that an elementary measurement would represent here the scanning of an area of about 1x1 m^2.**

Grounding

- **Rules are described digitally in a book available on the internet in a very adequate manner. Yet for establishing the official correspondence between rulebook representations and actual "homes" and real world circumstances, as in Bremen (2006), Atlanta (2007), Suzhou (2008), as well as surely in the future in Graz etc. further human contributions are/will be required, as typically: Referees, Technical and Organizing Committees, Execs, and Team Leader Meetings.**

Information



- **What is the *quantity of information* corresponding to an elementary measurement in the *domain* just described? The measurement consists in 10 samples which can each have one among 10 significantly different values (1 m with 10cm accuracy). Considering that samples are independent of each other and distances are all of equal *probability*, the quantity of information per measurement, Q, amounts to 33.2 bits.**

$$Q = N_{samples} \cdot \log_2(N_{values}) = 10 \cdot \log_2(10) = 33.2[bit]$$

Complexity

- **Two examples in estimation of complexity:**
  1. **The first one addresses the domain of the description of the WiW test. Considering that the description provided in the rulebook consists in 652 words, and that in average a word conveys 10 bit of information, the complexity of this description is of 6520 bit.**
  2. **Considering that the rulebook confines the persons to be recognized in a 4x4 m area of a home, i.e. 16 m², the complexity of the domain representing the location of persons, in accordance to above examples (re. § modeling, § information) amounts to 531.5 bits.**

Knowledge

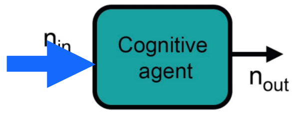
- **Consider the case of detecting the presence of a person in the cognitive domain introduced above (1 square meter of analyzed area, with coarse planar range estimation). As shown above, input information amounts to n_i=33.2 bit. The decision can be considered Boolean, and the probability of positive detection is of 5/16 (5 persons, with an individual area of about 1 square meter, out of a 16 square meter area; therefore the output information amounts to n_o=0.9 bit:**

$$n_o = \sum_{i=1}^{2} p_i \cdot \log_2(\frac{1}{p_i}) = 5/16 \cdot \log_2(16/5) + 11/16 \cdot \log_2(16/11) \cong 0.9 \quad [\text{bit}]$$

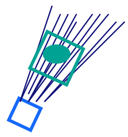
- **With these values, the necessary knowledge for locating a person in the domain of an elementary measurement amounts to K= 33 lin.**

$$K = \log_2\left(n_0 \cdot 2^{n_i} + 1\right) = \log_2\left(0.9 \cdot 2^{33.2} + 1\right) = 33.04 \qquad [\text{lin}]$$

Abstraction



- **In the current example, detecting a human in an elementary WiW test, the cognitive process features an abstraction index, i_A= 33.2/0.9, amounting to 37.**



Concretization

- **Imagine : a human detected at a distance of 1.5 m. The supervising stage calls for a forward motion of the robot by an amount of say 0.5 m. Consider, for simplification purpose here, just the cognitive task of the coordinating stage, moreover in its usual mode where feedback is restricted at higher and lower levels. On the input side, goal is given with a 1 cm accuracy, in a range of about 12m; acceleration, speed limit, and deceleration are given with a 1% accuracy, which amounts in total to n_i=30.2 bit :**

$$n_i = \log_2(1200) + 3 \cdot \log_2(100) \cong 30.2 \quad [\text{bit}]$$

- **On output side: targets computed for each of 2 wheels, at a rate of about 30 samples per second. Considering that the accuracy is also equivalent to the order of 1cm in a 12 m range, and assuming that the motion last for 1 second, output information amounts to n_o=614 bit:**

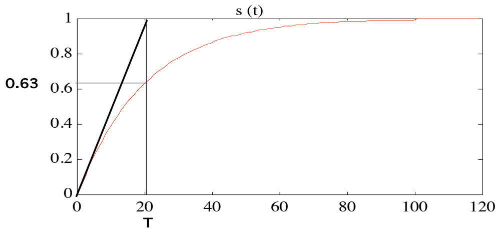
$$n_o = 2 \cdot 30 \cdot \log_2(1200) \cong 614 \quad [\text{bit}]$$

- **Under those assumptions, concretization index : i_C= 614/30.2, i.e. 20.3 .**

Time constant

1 In our motors, the time constant of coils is of about 1 millisecond. Imagine the following experiment: the (DC) motor is mechanically blocked; a voltage of 5V is applied (step signal), and the current is observed to climb towards an asymptotic value (say 2 A), which is reached within a 30% tolerance after 1 millisecond.

2 Classical example with 20 ms time constant:



Stationarity

Let's consider several cases:

1. Re. previous experiment (5V, 2A, etc.), after a short transient, all is stationary: applied voltage, measured current, coil under study.
2. Consider another case: the motor is let "free, without load", e.g. with the robot wheel off the ground. The 5V voltage supplied to the motor sets the latter into motion, and consequently the 5V voltage of the example is commuted on successive coils by commutator and brushes. From a single coil point of view, the supply is not stationary any longer; it consists in an alternating square signal, with a certain duty cycle (e.g. 2ms/0V ; 1ms/5V). At a more abstract level, the behavior may still be qualified of stationary, though in a different meaning: time-invariant velocity; time-invariant supply voltage and duty cycle.
3. Several levels of control higher, and even after integration of random perturbations and dialog components with the walker, there is still another order of stationarity which may qualify the paradigm of our robot, which dictates instantaneous changes in control modes (position, velocity, torque, recovery from errors, etc.), as in the current solution for "Follow Me" test

Expertise

- While knowledge does not quantitatively depend on time, expertise does. Consider again the cognitive domain of elementary human localization, as studied in above paragraph (re. § Knowledge). For this task, in our system, 0.1 second are necessary to acquire input information and the subsequent computation time is comparatively negligible. The quantity of expertise in this domain, E, amounts therefore to 330.4 lin/s

$$E = K / \Delta t = 33.04 / 0.1 = 330.4 \qquad \text{[lin/s]}$$

Time-varying complexity and knowledge

- As reminded above (re. §2.2 Information and modeling), information is a very perishable good, which has various consequences in cognitive domain. In the WiW test, humans are expected not to move. Therefore in this context the amounts of complexity and of required knowledge necessary for the detection of humans decreases very fast. It has been shown that initially 33.2 bit of information are required to describe the occupancy of 1 m^2 (re §Information); this is the initial value for the complexity of the description. Now we have also seen that the representation for occupancy after decision of the cognitive system consists only in 0.9 bit of information (re §Knowledge), which finally yields 33.04 lin of knowledge in the domain. This is true for the initial 0.1 s (re §Expertise). After that time, everything vanishes: input information drops to 0 bit, for the probability is "1" that identical messages repeat. Complexity drops to 0 bit ("no change"). It is the same for the output decision (probability=1 for same output) and reassessing the knowledge equation (Equ. 3) with n_i=0 bit and n_o=0 bit yields 0 lin as well.

Expert paradoxes

1. "The more experts know, the more they can learn": As seen in the previous paragraph, a WiW beginner would start with raw information, i.e. 33.2 bit of information (ranger data). Now an expert would immediately deduce the detected state, which amounts to only 0.9 bit of information (occupancy). This provides a simpler basis for further cognitive processes, such as searching for other areas and persons with corresponding amounts in terms of incoming information, knowledge, expertise; and learning.
2. "Experts are worse than beginners at forecasting". Consider again the elementary WiW detection of a person. If circumstances change, and the cognitive domain evolves for example because of a new rule introduced, whereby humans should stand sidewise in front of robots instead of facing them, the raw data of beginners would still provide a sound basis for the new task, while the expert "shortcut" just mentioned in the previous paragraph would become obsolete and would systematically fail to detect humans.

In the framework of current theory for quantitative cognitics, what used to appear as paradoxical, in fact turns out quite logical.

Agility

- It follows from above definitions (re § 3.5 Agility) and for the example case about time constants (re. § *Time constant*) that the agility of our motors is of 1000 1/s

Stability of automated processes (1 of 2)

Three examples taken in our application in the Robocup-at-Home "Follow a person" test:

1. Typically, for such an application there is a complex hierarchy of controls (levels A to E), which are briefly presented here:
   - -A. Linear and rotational motions as functions of walker position relative to robot (uppermost level, level 1; 2 parallel controls; multimode closed loop control -forward and rotational, proportional; reverse on/off; coordinated blocking, with recovery; etc.);
   - -B. MIMO stage, with inverse kinematics (level 2; 2 input and 2 output signals; parameterized gain matrix);
   - -C. Motion law stage (level 3; parameterized accelerations, 2 V-V controls);
   - -D. wheel velocity control (level 4; 2 PID closed loop control with encoder management);
   - -E. amplifier, current management (level 5, On/off closed loop control);

Stability of automated processes (2 of 2)

1. Relating to level E: In our robots, there has been a time where while apparently behaving normally, motors were hot. Signal observation made it clear that a 20kHz 24 V peak-to-peak wave was present in addition to normal command curve on motor lines. In fact this seems to be quite a common problem, and a standard solution consists in increasing the time constant of the load; this in practice is done by adding an inductance serially to the motor, in the drive circuit. The agility ratio, Ar is thus improved, and brings the system in the class 1 region, i.e. in stable state.

2: Relating to levels 4 and 1: In both cases, the agility ratio turns out to correspond to class 2 situations as defined in §3.6; in this class of situations, the main parameter is the proportional gain between tracking error and correction command, which in principle should be as high as possible without oscillation (if at higher levels a smooth motion is desired, this is typically ensured by other means, namely a specific motion low – re. level 3).

3: Beginners might imagine to control DC motors (e.g. time constant 1 ms) quite directly from supervising computer, even with the constraint of Ethernet TCP/IP protocol (time constant of about 0.1 s); these values yield an agility ratio Ar of 0.01, which corresponds to class 3, unstable systems; for a stable solution, modifications are required, additional resources are necessary, e.g. as further discussed below in § ***Improving natural system time properties with control.***

Time and change interrelation (1 of 2)

Generally speaking, a time duration can be estimated on the basis of a change in some other entity, in as much as a known conversion operator is available. Two examples follow:

1. Let us assign differently the role of unknown in the equation for elementary WiW subtask addressed above (re. § Expertise). In practice a time duration of 0.1s would correspond to waiting for a new decision about whether an elementary area is occupied or not, since knowledge amounts to 33.4 lin and expertise to 334 lin/s.

Time and change interrelation (2 of 2)

2. Changes in activity have the potential to describe time evolution.
For very high resolution, no standard clock was available on commonly available computers. Our Piaget programming environment therefore traditionally features an internal counter ("Ticks"), which is incremented every time that a full cycle of agent activity has been completed, i.e. all agents have used a single individual time slice. The purpose is to statistically estimate very small delays, freely selectable in the range from 1microsecond to 10 milliseconds. This is possible because our agents take in average very thin time slices (about 100 nanoseconds) for their individual subtasks. Conversion from activity change to time duration is made on the basis of a computer and configuration dependant calibration. While dynamic calibration has also been practiced in this application, a static calibration, stationary in the time horizon of a run-time session or more, is usually preferred.
(In current, C# development context, a 100 MHz system time basis is available and being used).

Improving natural system time properties with control (1 of 2)

1. **In the motor example presented above (re.§ *Time constant*), a 5V constant voltage was applied, and a 1 ms time constant had been measured on the current response, reaching 2A in asymptotic value. These performances per se are rather poor and would limit robot motions to low speed. Imagine now that you have a highly non-linear control system, which simply, with high agility, switches the supply voltage to + or – Vmax, depending on the target current (2A) being reached (closed loop current control). If Vmax is 50V, i.e. 10 times higher than the voltage in the previous example, the resulting, effective, new time constant will be 10 times shorter! In our robots, Vmax has usually a nominal value of 24 V; in the most recent platform, it is 48V.**

Improving natural system time properties with control (2 of 2)

2. **Our early robots could rely on PC parallel ports and DOS or early Windows OS, where access to physical addresses, either in memory or on IO ports were fast, simple, and standard. In such a context the real-time control of multiple stepper motors and even DC motors was possible even with implementation on supervising computer, with excellent possibility of integration of low-level or intermediary-level phenomena (smart handling of blocking situations, multi axes coordination in versatile modes), as agility was extraordinary high (10^6 1/s); in recent years, architecture has evolved – communication is now based on Ethernet or USB hubs - with a number of advantages (numerous services of OS and OS-compatible multiple sources, convenient mechanical and electrical connections with external devices), but also a sharp drop in agility (down to 10 1/s). While in the first case stable control could be achieved without extra resources, in the second case a hierarchy is required with an intermediary stage (incl. servo controllers and PLC) between former resources (between computer and DC motors, etc.), to which a certain level of autonomy is granted under normal circumstances**

(Of course some exceptions do exist, where under special conditions much better agilities are theoretically possible -re. « Real-time internet » -, but in as much as possible, standard solutions and conservative approaches should be preferred, which are compatible with the quoted value.)

Driving causes for changes, time properties, and analogies in human psyche

- Changes are not always correctly mapped into time duration, and errors can be particularly large when strong emotions occur.

1. Example of the first, "ordinary" case: during the development of one of our early robots, possibly because of the unusual situation which was involving small, microtechnological scale, hours have been wasted in an effort to correct a bug which in fact did not exist: the change of three rotations of an actuator was psychologically perceived as lasting much longer than the correct 0.8 second which had been programmed.
2. Example of the second, "emotionally laden" case: it has been reported that in emergency context such as an accident, because of unusual psychological turmoil occurring, time is temporarily perceived as being strongly shrunk or dilated.

- Cognition Dynamics -

Time and Change Aspects in Quantitative Cognitics

1. Introduction
2. Essential definitions in cognition and cognitics
3. New aspects in cognition dynamics
4. Examples
5. **Conclusion**

5. Conclusion (1 of 2)

Cognition, and automated cognition i.e. cognitics, have a theoretical framework, where core concepts have been formally defined, with metric units. Beyond intellectual exploration and cultural interest, this was also motivated by the goal to automate cognition.

First achievements make explicit and more evident than in the past the critical role, in cognitics, of time and change quantities, as well as of the coercive level of control actions, along with perturbations and system properties.

After a brief reminder of essential definitions, the paper has reported on cognition dynamics, describing and discussing a number of complementary aspects:

1. time and abstraction levels, which lead to various time properties and possibly specific orders of stationarity;
2. time based difference between knowledge and expertise;
3. critical role of time in estimation of information quantities, and thereby of complexity and knowledge quantities;

5. Conclusion (2 of 2)

4. explanation, straightforward in this context, of the apparent so-called “paradoxes of experts”, in learning and forecasting;
5. importance of time in automation as well, more specifically in loop control, where time properties of control path (including perception, decision and action phases) relatively to those of system behavior (here the system is the entity to be controlled) are critical for success;
6. time and change interrelations, with necessity, for quantitative estimation, of considering other factors as well;
7. possible changes of system time properties, in the context of closed loop control, whereby large differences may occur with respect to those in natural (open loop) status, depending on action and perturbation intensities, as well as on possible overall non-stationarities and non-linearities;
8. driving causes for changes, and classical analogies in the context of human psyche and cognition dynamics.

The paper illustrates discussions with concrete examples relating to Robocup-at-Home competition tests and applications.

Ack & Ref (1 of 2)

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