Natural Emotions as Evidence of Continuous Assessment of Values, Threats and Opportunities in Humans, and Implementation of These Processes in Robots and Other Machines·

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Abstract

The design of better robots, notably capable of smart service for humans in private and public space, requires more integration of human capabilities in machines. This is also true for many more automated processes in our current, machine-based, automated world. Physical laws in natural sciences and the laws of logic have now been satisfactorily understood for some time, and numerous processes can be automated, notably with machines, electronics and computers. Now time has come to further address the laws of values. This is where emotions possibly occur, and often get expressed, in the case of humans. After briefly referring to a cognitive framework, this paper proposes a more comprehensive view of emotions than it is usually done. Instead of event-driven or episodic phenomena, the latter imply a permanent, recurring assessment of threats and opportunities, critical for ultimately ensuring survival. This value assessment process must actually set targets, and drives cognition accordingly, which notably often calls for specific, dynamical, changes in modelling strategies. Many practical difficulties appear; in human-centered approaches, even for essentially identical core cognitive concepts, different words are usually chosen, depending on the specific nature of cases, human or machine-related; thus unwanted differences in connotations may undermine the message, while typically these domain-related differences should not be taken as relevant here. In fact, emotion-related processes, when actually implemented in robots, can effectively replicate human behaviours. Finally, the paper describes some representative applications in real world and closes with a call for further discussions in CAID context.

1 Introduction

The design of better robots requires more integration of human capabilities in machines. The laws about physical nature have been satisfactorily understood for a long time, and machines have already been made accordingly, rather easily for this realm. Then understanding the laws of logic has also progressed, allowing for the automation of various cognitive processes, notably with electronics, computers, and networks. Now time has come to further address the laws of values. This is the context where emotions possibly occur, and are often effectively expressed, in the case of humans. As robots move in private and public space, and man-made systems interact with humans, a progress in the exploration of value-related processes becomes necessary, especially under the principles of universal design [Design.ncsu, 1997].

Emotion-related processes keep caring for permanently adapting behaviour to freely chosen goals and unavoidable circumstances; not only for a better life, but primarily for mere survival. This has already happened for ages in nature, implicitly; in theory, humans have also long paid a certain attention to topics relating to emotions, notably in social and medical contexts (re. in philosophy, education, business and economy, psychology, psychiatry, health in general, religion, language, art, etc.). Now, time has come to further study emotions in order to devise and design appropriate machine-based techniques, for support, improvement and large-scale deployment purpose (re. research in cognitics – automated cognition, including AI and computer engineering – and robotics). Notice the classical AI notions have progressively merged into the broader field of cognition, human or machine-based (e.g. [Lieto and Radicioni, 2016]).

Emotions, as etymology shows, and in coherence with classical views, relate to transitions, quitting one behavior for another, as a result of stimuli or other events. E.g., Ekman [1999] refers to the “appraisal of current *event*”.

Various extensions have been made, the former author being famous for his work in related facial expressions, and interorganismic influence. The latter point has been further developed in situationism (e.g. [Griffiths and Scarantino, 2005]). The instantaneous property of events has been somehow extended in the notion of episodes (e.g. [Weiss and Beal, 2005]).

Here a major extension addresses the *permanent processes* that keep agents monitoring reality, appraising risks (threats) and favorable circumstances (opportunities), consequently, occasionally, *triggering emotions* when significant changes in values are estimated, immediately, in real-time.

The paper is organized as follows: Section 2 introduces emotions, with a first reference to implicit, associated laws of values; it also develops the "hidden", continuous, underlying processes supporting occasional, emotional phenomena; Section 3 takes a more human-centered view and also relates to the H-R communication problem, which, which has become so important at the current stage of development of robots and machines in general: humans and robots cooperate in the real world, which necessarily involves emotional aspects, and implies a common culture and respective value assessments. Progress remains to be done in translating without betraying similar notions across the human-robot communication gap (re. Italian word "traduttore-traditore", "Traductor-traidor"; or the limits of digital, descriptive ontologies [Amoretti 2016]). Then Section 4 reports on brief representative applications, where laws of values are processed in order to ensure emotion-driven, smart human and robot group behaviour in real world. An example relates to a particular robot navigation task, in a building, under human-centered requirements, with additional considerations also for design phase in architectural context (re e.g. [Bhatt *et al.*, 2016] for more general aspects).

For the convenience of some readers, two appendices follow, providing a brief summary of elements published elsewhere in more details; they provide the necessary framework to formally and effectively support emotions; Appendix A revisits basics as this requirement appeared relatively late, out of necessity, and has led to new contributions; Appendix B presents a short summary of the Model for Cognitive Sciences (MCS), essentially behavioural.

2 Emotions and associated laws of values

Emotions are viewed quite differently now than even a few years ago. In this section, mention is first made about how emotions and the laws of values happened to impose themselves in the research field; this occurred in two phases, successively addressed below: initially rather at appearance level and in accordance to international trend; and more recently as a result of MCS theory development, in agreement with experimental validation, relating to a broader scope, including agent's environment, group issues and consequently values and ethics.

2.1 Emotions? Why?

How did emotions and the laws of values happen to impose themselves as research fields further to explore? Emotions made their way into our research domain in two mains steps, first as a tribute to on-going research in international community, and then later on, more fundamentally, along with laws of values, in order to drive cognition and effective, sustainable behaviour.

There is some continuity through the two phases; but not much, a radical change resulting in between, from the progress made in cognition theory (re. rigorous and metric approach ensured by MCS theory) and experimental validation in automated cognition - cognitics. Therefore the question in title is forwarded for more complete answers, both to next subsection, and later on also to Section 3, for the permanent underlying processes that possibly trigger occasional, emotional bursts.

2.2 Artificial Emotions – The first wave

In robotics, emotions have become a general subject of research very early, several decades ago (e.g. [Ekman 1978]). The general idea was first to give robots a more attractive look than traditional machines, in order to improve acceptance and empathy. Then attention has moved to communication aspects, with the concrete goal for machines to recognize human emotions.

Regarding our own work, several elements are worth mentioning.

In terms of look, a project was discussed where colleagues in art would provide some kind of "head" for our RH-Y robot, for participation in international robot competitions [Kitano *et al.*, 1997, van der Zant and Wisspeintner, 2007]. This collaboration could not cristallize and the alternative has been to use an Aldebaran-SoftBank Nao robot as a mediator between robot prototypes and humans: the look is attractive and completes what could already be done otherwise: vocal dialogue and other "machine"-based functions (omnidirectional platform motions, metallic arm handling, etc.)

Briefly said, in terms of fundamental research, while in literature emotions were mostly understood as states of mood primarily denoted by facial expressions, and the latter typically defined in a 2 or 3-D affect space (re. arousal, valence, stance), we found that machines and robots had many more ways and communication channels than (natural) voice and (face-related) vision, to synchronize their emotional state in a group (e.g. H-R), not the least being the mere functional, implicit appearance relating to operational status [Dessimoz and Gauthey, 2009 and rel. ref. Garcia-Rojas et al. 2009, Lim and Aylett 2007, Goris *et al.*, 2008, Petters *et al.*, 2017].

In those years, priority was more on formally clearing up essential aspects of cognition (e.g. what is, and how to measure knowledge? or expertise?), on revisiting basics (what is reality? what are the limits of modelling? what is time?) and, as will appear below, in next Section, a deeper attention for emotions had to be left for later on. From a purely cognitive perspective, emotions were then just associated with a particular domain of reality, for which universal core entities could similarly apply (e.g. knowledge, expertise, or time).

The title of current subsection includes "artificial" as a qualifier of emotions. It is time to draw attention to the ambiguous meaning of this term in natural language, which is particularly appropriately called upon here: in one sense, and for us, artificial is an antonym for natural, meaning "man-made", yet fully denotes true presence of all essential properties; and sometimes on the contrary, it means "fake".

2.3 Real Emotional Iceberg – Synchronously coping with threats and opportunities

Revisited, the concept of emotion has opened a whole world, of utmost importance. First, emotions were underestimated, or rather, largely left out of the focus of attention. But now consider these analogies: emotions are like smoke, they imply fire; or like the small visible part of an iceberg, emotions imply the existence of much more submerged material, i.e. permanent value assessment processes (appraisal). Let use develop this latter analogy.

First, evident as the tip of an iceberg, emotions in humans (i.e. natural emotions) appear as certain types of sudden changes in behaviour and activity, events or episodes; the etymology of the word confirms it: emotions set people into motion, typically away from their on-going behavioral mode (re. [Lewis and Short, 2017, Dessimoz, 2016a, Singer, 2016]).

Now the more interesting part in this phenomenon is the supporting, submerged part of the iceberg, the emotion-related permanent processes; the previous part, the one that schematically prepares and allow for triggering the possible occurrence of emotions. Emotional outbursts appear to schematically require three causes: 1. Constant synchronization with current circumstances, monitoring for status and changes, 2. Permanent estimation of convergence or deviation between status and goals [Dessimoz and Gauthey*,* 2009, Russell, 1997] and consequently 3. setting new current goals and consequently launching appropriate modelling strategies, cognitive developments, and actions (re. Fig.1).

1. Constant synchronization with current circumstances, monitoring status and changes. Cognition can extend into the infinite reaches of the imagination in humans' cognitive universe: it is generous of unlimited virtual possibilities, and, even if memories turn out to be mirages of the past and visions of future prove more or less illusory, all this does not necessarily matter. On the contrary, as shown in Appendix (§A.1 and §A.3), the *present moment is critical*, hosting all realities. Even cognition cannot develop without a real infrastructure; therefore reality constantly requires top priority of cognitive agent's attention for further survival. When changes occur, those changes should be detected without delay, and this should trigger new processes as presented in next point.

By the way notice that time showing devices, e.g. watches, are precious crutches for our emotions; these devices are safety tethers that connect us, synchronous, with reality, where everything is played in the moment, where it is vital, immediately, to slalom across threats and to gather opportunities [Mettraux, 2016].

2. Assessment of values, of convergence or deviation between status and goals. In MCS theory of cognition, good (and symmetrically, bad) have been defined as true (versus false), for logic laws relating to the ability of moving towards a corresponding goal. This is the axiomatic foundation for values in MCS theory (what is good-positive value, what is bad-negative value). In this sense opportunities can be associated to factors tilting results on the "good" side, i.e. tending to help the agent reach her goal -positive value, while threats tend to let her deviate from it - negative value. So in case of significant changes in current, perceived circumstances, the laws of values must be processed again and in case current goal gets out of reach or could be surpassed by others in optimality, adaptation should proceed, as described in next subsection.

In humans, it might be argued that no cognitive analysis would be required for value assessment, values being directly perceived, as immediate pains or pleasures. Nevertheless numerous examples show that such a direct connection is questionable. Obviously it is not applicable to highly abstract situations, like winning lottery or hearing about the risk of death by smoking. Thus if this direct perception were sometimes true, it would at most be restricted to low-level phenomena, like tasting salt or burning fingers. But even in such cases, experience often shows a gap as well: soldiers keeping shooting undisturbed, while having suddenly lost their own legs; or physicians practicing hypnosis, apparently decisively modulate pain by shifting agent's focus of attention.

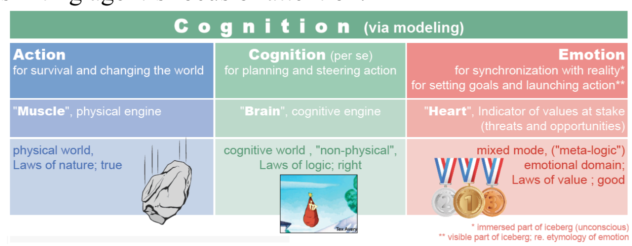

Figure 1. Emotions set goals for cognition, which steers action [updated from Dessimoz, 2015 & 2016a].

3. Appropriately setting new current goals, consequently triggering new cognitive efforts and launching corresponding actions. Here, depending on circumstances, a cascade of increasingly uncertain processes may develop. The simpler cases may simply call for immediately switching to another routine goal in a usual manner. More elaborate cases may require some new cognitive efforts, further exploration of reality, and possibly calling for collective and external help. But reality does not wait; so searching for more elaborate goal definitions also possibly requires meanwhile getting back to basic, traditionally safe situations, sustainable at least in immediate and short terms (fight, flee, lapse into a coma, etc.); this is of topmost importance for survival.

Changes in goal setting have dynamic consequences for cognition, first in terms of requirements for modelling, and second as processes for planning and launching appropriate actions.

3. H-R Dialogue - Translation and cultural mediation

Emotions deserve attention not only in order to be somehow implemented in machines but also in order that H-R communication develops well, and, more ambitiously yet, in order that mixed groups can be effectively established.

1. Emotions in machines – the translation issue. Natural emotions are evident in humans and theoretical definitions for emotions have been explicitly proposed as shown in previous sections (emotion[1] is a particular kind of expertise, i.e. the capability to do right and fast in a specific domain: to adapt behaviour in synchronization with reality, assessing values at stake, and consequently appropriately setting up new goals and launching corresponding actions). Such definitions can equally apply to humans, machines and robots. Thus, the translation in some sense is already made.

Nevertheless, translation remains difficult in general, and is particularly difficult here, as we get close to elements most specific of human nature.

As formally stated for speed elsewhere (re. §A.3 time and speed), a similar basic notion may be carried by many different concepts, each bringing some additional connotations e.g. describing the application domain rather than a different nature of speed itself (a quick search may easily yield 30 synonyms for speed, in English, such as agility, velocity, fluency, rate, frequency, to name a few).

For emotions as well, in a natural language like English, tens of words may relate, with different connotations, to the same basic idea of emotion as defined above, i.e. as change in behaviour resulting from synchronization with reality, assessment of values, and consequently appropriately setting new goals and launching corresponding actions (e.g. agitation, audaciousness, courage, enthusiasm, passion, etc.).

As mentioned above, with cognitive notions we get close to elements most specific of human nature, and thus humans often appear threatened in their uniqueness when the implementation of emotions in machines is considered; notably, most people today seem to have the gut feeling that intelligence is a cognitive property exclusively human (by this definition, AI could not be but an empty set!). Here this problem may become even more difficult to cope with, as emotions relate to values.

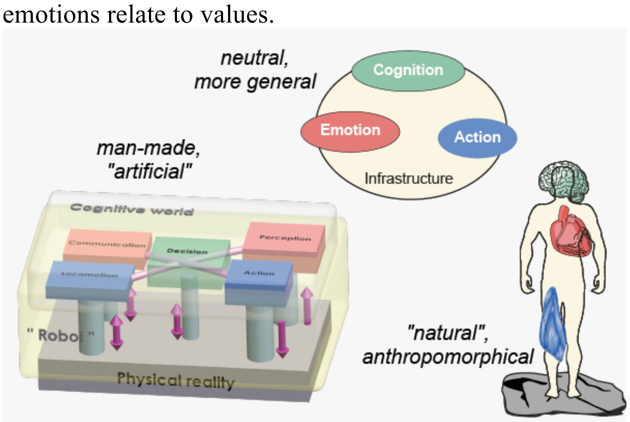

Figure 2. Examples of cognitive systems, operational in the real world. Standardization should avoid misleading connotations.

[1] Emotion shares with information and more generally other words ending with suffix ''-ation'' a certain ambiguity about the particular aspect of action it may relate to: process, instance, or product.

2. Emotions in groups – the common culture issue. From a cognitive perspective, for individual agents to merge into a group, it is necessary to have a communication channel and to share a common culture. For humans, this implies for example speaking the same language, and for machines, to have compatible codes and protocols. In H-R context, a common ground must be established, e.g. machines understanding some words of English and/or humans being ready to press a button.

For mutually understanding emotions, a lot can also be done without explicit agreement, just by observation, in the case of humans and machines, like e.g. for the case of humans of vastly different cultures.

In all cases, when available, some cultural mediation may help.

3. General approach for managing complexity and application in the case of emotions. Complexity is hard to deal with, and the usual strategy is to approach it gradually. Keywords in this type of methods include modelling, focus, hic et nunc, ad hoc, case-base reasoning. For practical management of emotions in H-R groups, some standardization is the most promising approach, focusing on addressed domain, and stripping away all connotations too specific for humans and machines like for road traffic signs or e.g. in the case of cognitive "agent" (re. Fig. 2).

Waiting for a standardization, an alternative way to avoid misunderstandings might rely on a dedicated translation scheme, as is routinely made for natural languages. In the same way an an interface or dialogue mode may refer to language L1, or L2, we may imagine a choice between human view and machine view (e.g. Fig. 2).

From human perspective, emotion is usual and somehow traditionnally understood in English. Now, it has been defined above (along with goodness and values), in a choice of concepts directly applicable also to machines and robots.

4. Application in the real world

Emotions and associated laws of values are not only conceptual notions. They can be implemented in machines, for effects in the real world. Three representative types of applications are illustrated below, the first one more basic, the second one reaching more abstract and complex levels, closer to what humans can "naturally" do, and the third one relating to a navigation task, with human constraints and some guidelines for architectural design processes. This Section closes with temporary conclusions and a call for further discussions in Cognition and AI for human-centered Design (CAID) workshop context.

1. Basic systems. The first examples shown here may shock the layperson, yet they allow by their simplicity an easy grasp of essential notions in the context of emotions and laws of values.

The most basic example of technological support for emotion-related processes is perhaps the alarm clock. It ensures accuracy in terms of synchronicity with the real-world. The law of value consists here in a single predicate: if current time "lays" before wake-up target time, W, stand still, otherwise ring! The device silently keeps monitoring time, then, when the moment comes, it switches goals and launches a noisy action. Notice that while alarm-clocks may look very mundane, nevertheless sleeping well and not missing planned activities after W point in time may be of very high value for the human who owns the clock.

Another key crutch for human emotions is the smoke detector: the device keeps tirelessly monitoring particle density in air, and when a significant level is detected, synchronously, an alarm is launched. Here also particle density may look mundane; nevertheless this translates into a risk of fire and therefore death for the humans served by this device.

Getting back to the time-base issue, an example involving robots may be quoted in the context of Eurobot robot competitions: round duration have always been set to 90 seconds. In early years, (human) team members. or referees, had to manually stop the machines with an ad hoc red button, at the specified moment. Then this operation has been transferred as a task to be autonomously done by robots, and an explicit rule of the game was introduced: failing to spontaneously stop after 90 second, a robot would loose the game.

In summary, we find already in these relatively simple[2] cases all the essential elements of emotions: synchronicity with the real world, assessment of value, and adaptation of current goals and launched actions.

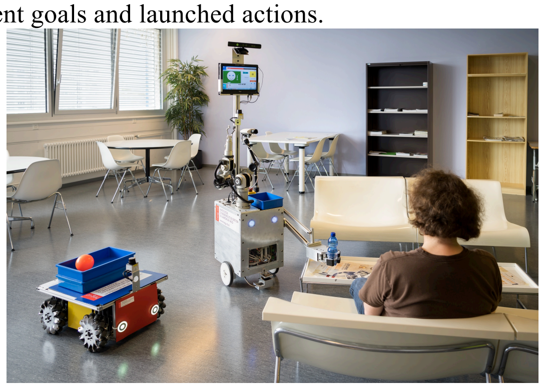

Figure 3. Original RH-Y and OP-Y robots, many times engaged in Robocup@Home competitions, shown here in a domestic task. The system is modular, featuring various configurations, all driven in Piaget environment

2. Robot group for domestic help. At world level, an effort to develop AI in the context of robots has led to the Robocup initiative [Kitano *et al.*, 1997]; initially, the focus was on playing soccer; later on, Robocup has introduced new leagues, extending scope to other applicative fields, notably domestic help [van der Zant and Wisspeintner, 2007]. Some robots participating to five editions and in that situation sometimes also involving a Nao robot as mediator between human and machines, could demonstrate their capabilities in many regards, e.g. communicating vocally with humans, synchronizing and following them without contact, locating and recognizing objects visually, "copycating" human motions in tasks involving kitchen goods, to name a few of the proven capabilities (re. Fig. 3).

Emotions have been implemented in this robot group, both in the consensual sense of §2.2, and also in the deeper sense involving laws of values, as defined in §2.3.

For example, in the former case, a graphic display may dynamically translate in usual facial codes (with displays similar to animated emoticons) the internal status of RH-Y robot; as another example, both robots feature colour headlights that may vary in a variety of manners according to internal conditions and circumstances.

During robot motions, several safety measures are enforced, In particular, obstacle detection and avoidance can be done, and additionally, a constant, low-level monitoring of torques on wheels is performed; consequently, some laws of values ensure that possible collisions are detected fast, at low force levels, that motion strategies are adapted, and that power gets selectively restricted in order to prevent casualties to humans.

In summary, it is clear that laws of values can be established and autonomously processed to ensure emotion-driven, smart behaviour in real world. In fact, emotion-related processes, when actually implemented in robots, can not only simulate human behaviors but can also even effectively replicate them. In practice, this notably means that beyond formal analysis, simulation may validate assumptions and theories. And the capability to implement emotion-related cognitive processes in machines opens the possibility to create a wealth of new resources helping humans.

3. Value-based navigation strategies and suggestions for architectural design. The third class of examples shown here most closely relates to CAID 2017 theme: a robot freely moves in our lab with a joint constraint of avoidance of physical collision in real world and avoidance of virtual obstacles, as defined by humans in order to restrict access to some a priori defined areas. The way the system works points at measures to recommend in architectural design phase.

As illustrated in Fig. 4, continuous monitoring and assessment of laws of values occasionally leads to emotions, i.e. quitting current behavior (here, schematically, moving ahead) for another one (here, schematically, rotating by a certain, partly random, angle).

A key difference in the two types of world involved – physical and virtual, is location estimation. In the former case, it is always quite noisy, reflecting the complexity of reality, while in the second one, it is typically noise-free. In the former case, solutions may be local, relative to close environment; in the latter case location estimation must be absolute, coherent with a priori definitions (re. maps – e.g. in CAD, or as in Fig.5). Thus for simulation purpose, artificial noise generation should not be neglected, for meaningful prediction of mobile behaviour, thereby

[2] Beware of an essential property of information, which is inherited here : its quantity vanishes upon reception (e.g. « idem » is sufficient to repeat a whole message). By this token, simplicity is by nature the quality of problems already solved. In fact, even devices as « simple » as alarm clocks have appeared rather recently in human evolution.

hopefully leading to appropriate corrective measures. In real world, some calibration means should always be provided.

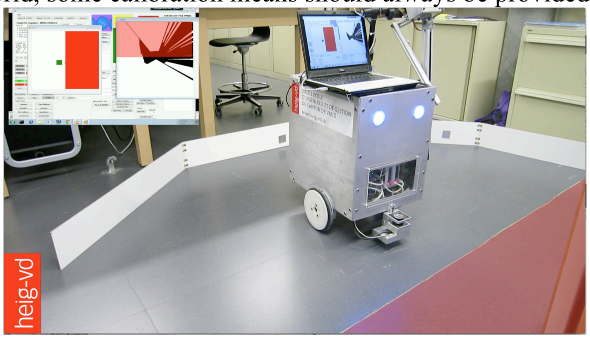

Figure 4. RH-Y robot navigates freely, assessing continuously threats, such as obstacles, to be perceived by LiDAR, or as forbidden areas (e.g. downwards staircases, pools) virtually and a priori defined by humans (shown here in red, graphically superimposed on original screens for reader's convenience). Notice also the gray squares on low walls – mirrors- conveniently made for calibration purpose.

Many approaches have been explored for indoor location. In particular, also visible in Fig. 4, a pragmatic approach in current state of the art, for cm range accuracy, consists in defining some calibration planes (e.g. 1m x 0.1m flat surface); with a 2D LiDAR, this retrieves two coordinates in the plane (e.g. x and phi), or even the third coordinate (y) with additional mirrors (thereby discontinuity in LiDAR signal, without discontinuity of surfaces). Thus most of common architectural items (walls, doors, furniture) naturally provide potential calibration planes; yet in some cases, it might be beneficial to provide additional ad hoc calibration structures for machine-based systems.

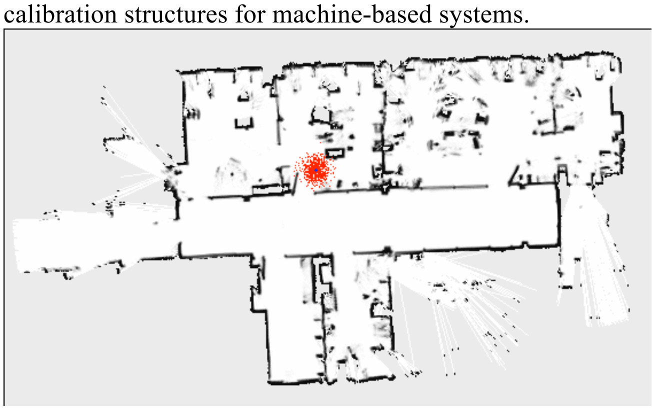

Figure 5. Example of a 2D map created using LiDAR data. The red blob represents the region where a robot is currently located in the map (ref. agv-iit-kgp.github,io, IIT Kharagpur, in [Madan and Gauthey, 2017l).

4. Temporary conclusion in CAID workshop context. Discussions are still welcome, yet the main points already clear today in reference to CAID context include the following ones: AI is part of general (i.e. human or machine-based) cognition; design implies concretization processes, which typically are cognitively much less demanding than symetric abstraction processes; similarly to humans, who are primarily made out of DNA, the mere *replication* of best practices should not be overlooked; modelling cannot be complete (at best, models can infinitesimally represent reality, be true) yet models are made to be good (goal-oriented, tractable); a quantitative approach in cognition allows to track improvements and to expertly optimize known solutions; only chance has the potential, sometimes, of yielding disruptive novelty (i.e. of successfully challenging the infinite complexity of reality); permanent synchronization with real world and assessment of humans-related values are mandatory to avoid critical threats and to pick opportunities, thus dynamically adapting immediate goals and related modelling and cognitive processes.

5. Conclusion

Emotions relate to occasional events, but the timely detection of possibly critical elements requires a permanent monitoring of circumstances in real world, along with appraisal of situation and, when appropriate, immediate and drastic updates in strategic goals, and, consequently, immediate and drastic updates in modeling, cognitive operations (e.g. planning) and actions in real world as well.

Appraisal implies an assessment of values, and ultimately values can only be defined in human-centered approach.

After briefly referring to a cognitive framework, this paper has proposed a more comprehensive view of emotions than it is usually done. Instead of event-driven or episodic phenomena, the latter imply a permanent, recurring assessment of threats and opportunities, critical for ultimately ensuring survival. This value assessment process must actually set targets, and *drives* cognition accordingly, which notably often calls for specific, dynamical, changes in modelling strategies. Many practical difficulties appear; in human-centered approaches, even for essentially identical core cognitive concepts, different words are usually chosen, depending on the specific nature of cases, human or machine-related; thus unwanted differences in connotations may undermine the message, while typically these domain-related differences should not be taken as relevant here. In fact, emotion-related processes, when actually implemented in robots, can effectively replicate human behaviours. This is also true for many more automated processes in our current, machine-based, automated world. Finally, the paper has described some representative applications in real world and has closed with a call for further discussions in CAID context.

Appendix A. Revisiting Basics

Emotions relate to the top of a conceptual pyramid that is rather large. The lower levels of this pyramid, while first established for long – most of them, probably millions of years ago – gradually appeared to need some renovations.

Thus let us introduce again these solid foundations: reality, imagination and models, time and speed, probability and information (for a longer presentation, re [Dessimoz, 2016b]). This Section terminates with a quick summary of expected potential, and known limits, of these foundations.

A.1 Reality

The first basic concept to address is reality. Unfortunately, reality itself is quite out of reach for our discussion. Any words and representations could only fail to describe, but a biased, infinitesimal part of reality.

The only and definitely pertinent statement that can be made about reality is the following one, due to the Ancient Greek Parmenides: "What is, it is".

A.2 Modelling, imagination and representations

The second basic concept to address is modelling. Modelling implies the infinite reaches of imagination, as in humans' cognitive universe.

Imagination allows for modelling. The word "modelling" is retained here to assert the imaginary nature of things, possibly somehow related to certain elements of reality; or not. In this sense, modelling provides the most essential, core part of a large number of other concepts, such as notably representation, word, image, idea, theory, type, example, signal, variable, qualia and "concept" itself.

A.3 Time and speed

The third basic concept to introduce, time, pragmatically attempts an "impossible", yet extremely important link across reality and imagination.

Time is but a dimension in a model, which denotes permanence, up to eternity. Its inverse, speed, characterizes change, up to discontinuity

As seen in paragraph 2.1, the real "is," it is right there, it is physical; time, on the other hand, is but an idea expressing the permanence and change of things. According to this idea, reality is wholly in the present moment, whereas our imagination can freely slide time's cursor "backwards," towards our memories, and "forwards," towards visions of the future. Appropriate real-world machines - timekeepers, clocks, watches - can surprisingly calibrate with superhuman precision in the real that conceptual time that is ever passing.

A.4 Information, uncertainty and probabilities

Probability is one of the primary dimensions to consider when modelling reality. Uncertainty is essentially its inverse; information is an antidote to uncertainty and both concepts are similarly estimated, in terms of quantity.

Probability is a measure of likelihood, the property of things that are expected to happen.

For our purpose, probabilities, and therefore, consequently, information must be estimated in priority from receiver's perspective.

A.5 Potential and limits of basic notions

Let us quickly state what are the best potential and main limits relating to the basic concepts sketched in above four subsections.

Reality is all what counts; but it remains impossible to be *fully* perceived and described in cognitive world.

Modelling in principle allows for an unlimited imaginary universe, and, even crude, may often help in reaching specific goals; but in practice it remains infinitesimal in power of representation of reality, and may "loose ground", i.e. reflect a wrong rendering of the real world.

The notion of time supports the massive (imaginary) representations of past and future worlds but connects to reality at best only for a thin, instantaneous present.

Information allows for a quantitative estimation of uncertainties and can compensate for them; but it cannot address reality itself, approaching the latter only via models. Moreover, we must keep in mind that by definition, information is subjective and quantitatively vanishes upon delivery.

App. B. Model for Cognitive Sciences (MCS)

The conceptual pyramid supporting emotions requires new layers, featuring core entities in cognitive realm, above classical foundations presented in App.A.

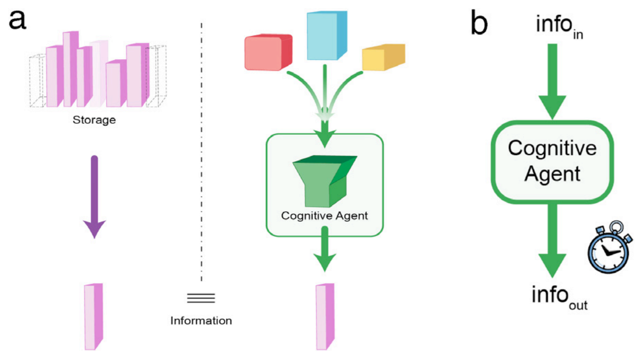

Figure 4. Cognition generates and delivers pertinent information (a). Main elements for quantitative estimation of cognition include incoming and outgoing information amounts, and processing time or speed (b).

First we recall why MCS theory of cognition was established and present its general framework; then the main concepts are briefly presented in two successive groups, first with more emblematic notions, then with some selected other ones (re. [Dessimoz, 2016b] for a more detailed presentation than what follows, in this section).

Finally, the section closes with a short summary of expected potential and known limits of cognition in general, and MCS in particular.

B.1 MCS and cognitive framework

Robotics had really started in the 60's of 20th century. Progressively, mechatronics had provided the main structures, wheels, limbs, joints and motors; signalling and control. In the 90's, for people at the edge of novelty in robotics, the time seemed to have come to implement cognition in machines.

Surprisingly, no proper definitions, nor measuring units were available for cognition. And consider an analogy, a human planning to jump over a wall: does it make sense to predict failure or success if we don't know the height of the wall? We had to elaborate axiomatic definitions and provide a metric system for cognitive realm; MCS was initiated.

Essentially, cognition has been defined in MCS context, as the ability to generate and deliver pertinent information. It requires a cognitive engine, an agent (re. Fig. 4).

B.2 Emblematic cognitive notions

MCS theory for cognition provides formal definitions for many cognitive concepts. Among the most relevant ones, we may find knowledge, expertise, learning, experience, intelligence and complexity, all presented in this subsection.

Knowledge, Knowledge, K, is the feature of a cognitive system capable of delivering the relevant information in a given cognitive domain; "to do right". Quantitatively, K relates to system input and output information quantities, and is measured in "lin" units.

Expertise. Expertise is the main notion in cognition, and has numerous informal synonyms in natural languages, including know-how, competences and skills; it characterizes the mix knowledge-cognitive speed; "to do right and fast". Expertise is quantified in "lin/s" units and thus appears as a cognitive speed.

Learning, MCS defines learning as a gain in expertise, and therefore features the same measuring units, "lin/s".

Experience. Experience is defined in MCS theory in two different ways, one simpler (time to visit the cognitive domain, unit: second , "s"), and the other one, more elaborate (amount of system input and output information witnessed, in the cognitive domain, "bit").

Intelligence. Intelligence is the capability of a cognitive system to learn. Quantitatively, it is estimated as the derivative of expertise with respect to experience; it may consequently appear as the property of cognitive acceleration.

Complexity. Complexity is defined in MCS theory of cognition as the quality of requiring a lot of information to be described. The metric unit is the same as for information, "bit".

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