Uncertainty and Time in Modern Artificial Intelligence

Boldur-Eugen BĂRBAT
Sibiu
bbarbat@gmail.com

Florin Gheorghe FILIP
The Romanian Academy
ffilip@acad.ro

***Abstract* — After finding out the main reason for decision-makers distrust in computer support (low model interpretability due to low NL-capability), the paper outlines the shift towards semiotic-oriented software proposing *Cybernetic Modelling*, a modelling sub-species aimed at enhancing large-scale living systems model efficiency and user acceptance. Uncertainty due to future events is treated via third IF value ("*Undecidable* in the time span given") avoiding probabilities. Time extension allows distinct temporal dimensions. (A Proof-of-Concept example describing a model for homeostasis with hysteretic delay is given in a related paper.)**

***Index Terms* — decision support systems (DSS), Generalized Theory of Uncertainty (GTU), natural language (NL)-capability, large-scale living systems (LS2), Wienerian time.**

If a machine is expected to be infallible,
it cannot also be intelligent.
ALAN TURING, 1946 [21]

I. *INTRODUCTION*: EXPLAINING THE TITLE

"The term Artificial intelligence (AI) is commonly used to indicate a branch of computer science aiming at making an artefact reason in a way which is similar to human manner of reasoning" [12]. This claim is undeniable and lasting. However, an open question is whether the "human manner of reasoning" is reducible to algorithmic (precise, apodictic, atemporal or sequential) robot-like reasoning. Due to the vast achievements of robotics as well as to the striking abilities of anthropomorphic robots to simulate human behaviour, the affirmative opinion prevails. On the other hand, decision-maker (paradoxical) distrust in computer support triggered modern AI to return to sources. Here "modern" means that new approaches to uncertainty and time challenge last century software engineering paths. Asserting that human beings and robots are distinct cognitive species (hence the *exclusive OR*) in Section 2, where the main differences are outlined, the paper chooses decision support systems (DSS) as (discrete) leitmotif. On this groundwork, the next three sections tackle the triad of (approaches to) the cardinal cognitive concepts that hinder humans to understand models they are supposed to accept: probabilities, uncertainty, time. Thus, the "DSS paradox" is solved: *probabilities* lack NL-capability since humans are not probabilistic beings (Section 3); humans fear looming events more than *uncertainty* due to ignorance (Section 4); humans live in irreversible (Bergsonian) *time* (Section 5). Conclusions (Section 6): a paradigmatic shift in modelling large-scale living systems (LS2) is needed. Its prerequisite (from the perspective of post-industrial decision making), is a conceptual (collaborative, peaceful) divorce between program-oriented robotics and processes-oriented AI.

II. *PROBLEM*: ROBOTS *XOR* HUMAN BEINGS?

In a very short history of AI, Simon's "Administrative Behavior" is seen as theoretical and the "Logic Theorist" as practical forerunner of both DSS and AI itself [10]. While "Behavior" refers – fuzzily – to the human limitation of bounded rationality [9], "Logic Theorist" claims (and starts) the supremacy of (pure) algorithmic reasoning. Thus, the DSS paradox is not just foretold but started too (still hidden in Simon's avowal: *I am a monomaniac. What I am a monomaniac about is decision making*).

Indeed, accepting (wholeheartedly) DSS is still under the sign of paradox, since real-world decision makers do not trust help the computers could give them in supporting their decisions, while, on the other hand, they entrust computers to make decisions in large and vital areas – in the very sense of "vital". An outstanding example is the field of Automatic Control – above all after the worldwide industrial acceptance got by fuzzy controllers – where billions of "imprecise *IF*s" are executed every second. This paradox is rather frustrating considering the impressive achievements of "Computer-Aided *X*", where *X* – starting from engineering subdomains – stays nowadays for almost any sphere of intellectual activity. Moreover, the increasing use of the strange syntagm "intelligent algorithms" (how feels a human when lauded "intelligent like an algorithm"?) deepens the paradox and reveals obscure semantic changes.

Recent research shows that the paradox lasts and is linked to model interpretability: "Interpretability means that any HR decision based upon analytics should be properly motivated and can be simply explained […]. This quest for simplicity discourages the use of overly complex analytical models" [1]. "[There are] needs for improved methods development and applications, especially in terms of ease-of-understanding for domain experts and citizen scientists. We […] suggest developing holistic and meaningful interpretable architectures" [15]. "The use of algorithmic data-driven decision processes may also result in individuals […] being denied opportunities based […] on the actions of others. [A]dopting black-box approaches […] could lead to forms of *algorithmic stigma* […], and the stigmatizer will be an unaccountable machine" [14]. "As data-driven decisions increasingly affect […] our lives, […], we argue for […] addressing these concerns, comprising [:] (iii) Improving the transparency and control of data- and model-driven decision making; (iv) Looking beyond the algorithm(s) for sources of bias and unfairness" [2]. "[I]ncreased physical realism comes at the expense of model tractability and manageable data requirements" [19].

Conceptual distinctions are badly needed: The paper's stance is that AI is mirrored by *word*-oriented, Turing-*test*-like, NL interfaces (aimed at managing *situations*, as in "The Imitation Game"), rather than by *number*-oriented, Turing-*machine*-like algorithmic, precise, software (aimed at solving *problems*, in line with the Church-Turing thesis). "Corollary: since services are processes assessed in NL, according to "Nlbis" (where NL stays for the *N*atural *L*ogic underpinning it), the practicability of AI in post-industrial engineering, can be substantiated *only* by systems with high NL-capability" [5]. However, when providing services involves simple human-computer interfaces, as in the case of search engines, applications can succeed with "NL-capability achievable via algorithmic software. Google is archetypical: its NL-capability necessary in the interface is reduced to a single phrase: "About … results"" [5].

The features of human decision-makers, regarded as LS2 since they are complex both *structurally* (as *given living* systems) and *cognitively* (as *large-scale* systems) are:

- *LS2 are complex*. Their complexity has two dissimilar components. Cognitive complexity depends on model *interpretability*, while structural complexity depends on model *relevance*. (Details in Section 3.)

- *LS2 are nondeterministic* and *open*. Taken together, the concepts express user perception that uncertainty is the epistemic facet of nondeterminism, while any kind of "Closed World Assumption" is out of question. (Section 4.)

- *LS2 evolve in irreversible time.* "Irreversible" has here the old, simple Augustinian meaning: even for God *Undo* is impossible. Real-world events are unique and cannot unhappen. "Irreversible" time is called *Bergsonian* (after Wiener). Hence, LS2 must be modelled as *processes*, requiring Bergsonian time – at most simulated through closed Newtonian time. (Section 4 and Section 5.)

Operational corollaries are presented and exemplified in a related paper. In short: LS2 models cannot be precise, algorithmic, apodictic, atemporal or sequential. All these restrictions should be reckoned with and mirrored in the modelling language as *sine qua non* for acceptance.

III. *LANGUAGE*: FROM NUMBERS TO WORDS

"[S]ome decision support systems are oriented towards the left hemisphere of the human brain, some others are oriented towards the right hemisphere. While in the former case, the quantitative and computational aspects prevail, in the later one, pattern recognition and the analogy-based reasoning are resorted to" [12]. The (non-sharp) distinction between the two brain hemispheres was agreed with in research but very rarely reckoned with in modelling DSS. "Cicero […] stated […] "The number does not matter, the quality does"" [11]. Quoting Cicero in a number-based study dedicated to DSS, in the context of "other opinions about the compulsoriness of expressing the knowledge in numbers" [11] is telling. Indeed, a shift from numbers to words is a vast conceptual journey from Kelvin to Zadeh. From an AI stance, the opposing factors are: *deterministic* environment (closed/known), *problem* (quantity/precision/certainty), lasting *solution* (general/algorithmic/optimal) vs. *nondeterministic* environment (open/uncertain), *situation* (quality/imprecision/uncertainty) temporary *answer* (local/nonalgorithmic/suboptimal,). From a software engineering stance, the diverging approaches are: *programs* (sequential/object-oriented) vs. *processes* (parallel/agent-oriented) [9].

The reigning paradigm is felt as inadequate: "researchers should turn to anti-computationalist proposals in the cognitive sciences in order to develop non-algorithmic views of language use that do not make communication […] mysterious. Approaches like ecological psychology, […] have shown how complex, open-ended competences can be explained without positing underlying rule-guided processes" [8]. "New safety critical systems are about to appear in our everyday life […]. A hazardous behavior of those systems […], may lead to catastrophic consequences. Well-known risk analysis methods […] have to be extended or adapted due to the non-deterministic behavior of those systems" [13]. "A major challenge in the software verification of autonomous systems […] is that they frequently rely on highly complex, non-deterministic software modules that are not amenable to current verification techniques [7]. "Basically, a natural language is a system for describing perceptions. Perceptions are intrinsically imprecise, reflecting the bounded ability of human sensory organs, and ultimately the brain, to resolve detail and store information. Imprecision of perception is passed on to natural languages" [22]. "In his 1999 paper, where he launched "computing with words", asserting that humans are able to perform mental tasks "without any measurements and any computations", Zadeh goes beyond "tolerance for imprecision". [H]e adds – albeit implicitly – to his "Rationale 2 for granulation: precision is costly", a "Rationale 3: precision is unnatural" (from a bounded rationality stance, in the very meaning of Simon). [H]uman decision-making is perceived and treated as risk management. Humans sense risk in Bergsonian time, as made obvious in insurance policy: companies compute probabilistic (their operational risk) but pay possibilistic (according to NL-perception of future contingency)" [5] (e.g. the legs of famous soccer players or Hollywood stars).

Thus, the question in the title of [17] is hardly rhetorical (maybe too pessimistic). Hopefully, the opportunity exists.

The shift towards semiotic-oriented software was tried in *Cybernetic Modelling*, a new modelling sub-species aimed at enhancing LS2 model *efficiency* (software engineering stance) and user *acceptance* (service-oriented engineering stance). Starting from the premises that model tractability is crucial for both efficiency and acceptance, and that NL-capability is sufficient condition for tractability, the method avoids anything with low or without NL-capability (e.g., probabilities, precision, bivalence, difficult numerical mathematics). Intractable differential equations are evaded via discrete-time modelling. A Proof-of-Concept example illustrating a model for homeostasis with hysteretic delay (due to unpredictable anthropogenic disturbance) based on an (over)simplified Lotka-Volterra model for predators-prey species is given in the related paper mentioned above.

IV. *UNCERTAINTY*: FROM PASCAL TO ZADEH

The relation between decision makers and uncertainty was uneasy from the very beginning: "*Tout joueur hasarde avec certitude pour gagner avec incertitude*" (as father of probabilities, Pascal is an authority in preterminologic risk management). Moreover, no gambler's strategy could ever affect rising Monegasque wealth, despite lacking any visible (casino) counter-strategy. The issue is called "Gambler's fallacy" and is still misunderstood even in Academia: "In the face of uncertainty, human judgment and decision-making often tends to deviate from the realm of rationality. Gambler's fallacy and its opposite, hot outcome, are two such departures from laws of probability involving random streak of events" [20].

GTU made two advances: "a) moving from "information is statistical in nature" to "information is a generalized constraint"; b) setting as target "achievement of NL-capability" [22]. Both are for service-oriented engineering […] as valuable as moving from crisp to fuzzy sets was for product-oriented engineering. Both have less visible success than their last-century counterparts had because they are judged according to the reigning paradigm(s) – not because of their possible open-ended scientific value" [5].

An elusive form of uncertainty is implied in *Shannonian uncertainty*. GTU suggest that "the problem lies not in the fact that logarithms of probabilities lack NL-capability. GTU, defining information as general constraint, and focusing on *I*-meaning, implies *intensional* assessment at the user, not *extensional* measurement at the provider. Using the term pair "user-provider" instead of "receiver-sender" […], it underlines the idea that the fundamental concept of information cannot rely on formulae introduced in the late 40s, when information was just *transmitted*, not yet *processed*. In short, […] the illocutionary force of a very predictable, only three-phoneme long, "Yes" at a wedding ceremony is not described by the number of bits necessary to notice it, no matter the distance" [5]. Thus, "information […] cannot be reduced to the Shannonian approach, even […] called a "mathematical theory"" [6].

In [3] a trivalent "*IF*" was unfolded considering that "the concept of "uncertainty" was treated inadequately […] main weaknesses: a) insufficient theoretical rigour (undecidability is considered primarily atemporal – keeping its initial mathematical meaning); b) poor practical effectiveness (confusing "unknown" with "unknowable" and applying sophisticated prediction methods in inappropriate contexts); […] DSS are explicitly referred to because "IF" is the basic tool for decision-making. […] Since the key aspect in decision-making is to handle "*don't know*"-like uncertainty […], it is appropriate to a third value meaning something like "Caveat: I don't know (yet)", "unknowable" or "unknown"" [3]. Reducing the alternatives, there were two candidates for the meaning(s) of the third truth value: *Łukasiewicz*. [T]he third value – "**i**" for "indeterminate", interpreted as "unknowable" or "problematical" – is semantically very close to the real-world decision-making problems. (On the contrary, the "½" notation […] is totally unacceptable […] *Kleene*. The third value in this logic is "**u**", interpreted as "undefined" or "undetermined" or "unknown" – with two connotations: "permanently unknown" or "temporary lack of knowledge". The second meaning is helpful for postponing decisions and is actually used in data base applications. […] Hence the semantics of the third value in a "three-output IF" should be based on a blend of a Łukasiewicz "**i**" interpreted as "unknowable" or "problematical" and a Kleene "**u**" interpreted as "temporary lack of knowledge". Thus, the semantics of "*Undecidable*" is refined to "*Undecidable* in the time span given". In fact, it gives a chance to the "yet" in "I don't know (yet)", postponing the verdict of "*Undecidable*" [3]. (Avoiding the "½" notation with its "50% probability" connotation, the trivalent "*IF*" proved adequate for *Cybernetic Modelling*.)

GTU gave a final blow to the use of probabilities in new AI: "There is a deep-seated tradition in science of dealing with uncertainty [...] through the use of probability theory. Successes of this tradition are undeniable. But as we move further into the age of machine intelligence and automated decision-making, a basic limitation of probability theory becomes a serious problem. More specifically, in large measure, standard probability theory, [...], cannot deal with information described in natural language" [22]. However, in automation and in robotics probabilities are unavoidable.

V. *TIME*: FROM NEWTON TO WIENER (AND BACK)

"Our reasoning about time, including the formal logical one, builds upon a mathematical/geometrical representation of it. […] Of course our experience of temporality is more complex than this and encompasses also many phenomenological aspects. […] Bergson famously drove philosophical investigation into this wider field" [18].

"[C]onventional models circumvent the crucial role of NL, despite the well-known examples of Lewis Carroll and Kleene showing that *AND*, perceived as noncommutative operator, suggest succession in irreversible (Bergsonian) time. Moreover, ignoring the failure of *CYC*-like ontologies – and even the hurdles met by "precisiated-domain" ones – models are yet either atemporal or have rudimentary temporal dimension, reflecting in algorithmic *LOOP*s reversible (Newtonian) closed time. (Effectiveness of such time in automation and robotics has no probative force, since robots need NL-capability at most in interfacing with users.) The principle of cointensive precisiation is hardly applicable to future contingents. (For instance, what *mh*-precisiands – where *m* stays for *i*-meaning – may be user-NL-interpretable when the precisiend is an unhappened event, even expressed intensionally?)" [5].

Coping with user dissatisfaction with modelling stability (during the setting up of Cybernetic Modelling), it became clear that "predictive models predict *synchronically* (*biodiversity* seen as spatial *distribution*) but cannot predict *diachronically* (*stability* seen as *evolution*). […]. To *predict evolution* a statistically relevant amount of *temporal information* is required (perhaps requiring several temporal dimensions)" [4]. That triggered the idea to propose a time extension: "Wienerian time $\mathfrak{w}$ is defined as complex-valued extension of physical time **t**. Its real part is noted

Re ($\mathfrak{w}$) = $\mathfrak{b}$ (from Bergson) and its imaginary part is noted **Im ($\mathfrak{w}$) = $\mathfrak{t}$** (any time species compatible with, Newtonian time **t = 1 / ω,** as measured by any ordinary clock).

Definition. $\mathfrak{w} =_{def} 1 / p$ *where*" [4] **p** is the operator in the Laplace transform (e^{pt}) i.e. the complex frequency

$p = \sigma + j\omega$. "Thus, $\mathfrak{b}$ can stand for Bergsonian time since: […] $\mathfrak{b}$ exists *iff* **σ** – that symbolises *irreversibility* (e.g., thermodynamic losses, biologic decay) – exists; indeed, if $\sigma = 0$ (no decay), $\mathfrak{b} = 0$ while the Laplace and Fourier transform become equivalent (undamped oscillation, described by $e^{j\omega t}$). […] Moreover, since in physical reality, $\sigma << \omega$ (at least in all practical situation with technological importance, as for instance any kind of oscillations), its numerical value is proportional to the numerical value describing intensity of *irreversible* decay" [4]. Despite finding out that "system world" (homeostasis loop) and "perturbation world" (non-deterministic, invasive intervention causing the hysteretic delay), are two distinct Kripke worlds, the Proof-of-Concept application could not prove that they must have different temporal dimensions. Hence, it is a challenge to further (common?) research.

VI. *CONCLUSION*: A NEEDED ACADEMIC DIVORCE

About the triad of (approaches to) main concepts (NL-capability, uncertainty, time) that impair LS2 model interpretability, it would be ill-suited to draw conclusions since the Proof-of-Concept is presented in a related paper.

Still, some points regarding DSS or LS2 can be inferred:

- DSS can inform, motivate, or assist but – no matter how majestic they are as *large* systems – they cannot advise because they are not *living* systems; they are unable to convey knowledge inline with human experience and habits, human way of anticipating (near future) events, and first of all, having a human-like sense of time.
- A paradigmatic shift from *numbers* towards *words* is needed for both efficiency and acceptance of LS2 models.
- Its prerequisite, from the perspective of post-industrial (service-oriented) engineering, is a peaceful, collaborative, academic – in all meanings of the word – *conceptual divorce* between program-oriented *robotics* and processes-oriented *AI*. (If not, Turing's offspring would have family problems, becoming a kind of Бра́тья Карама́зовы.)
- The transdisciplinary opening of chief importance is: blending synergistically the new approaches to *uncertainty* and *time* with essential research about *anticipation* [16] (and risk management), targeting a new generation of DSS.

REFERENCES

[1] Baesens, B., De Winne, S., & Sels, L. Is your company ready for HR analytics? 2017. Available: http://ilp.mit.edu/media/news_articles/smr/2017/58210.pdf

[2] Barocas, S., *et al*. Big Data, Data Science, and Civil Rights, 2017. Available: https://arxiv.org/ftp/arxiv/papers/1706/1706.03102.pdf

[3] Bărbat, B.E. DOMINO: Trivalent Logic Semantics in Bivalent Syntax Clothes, 2007. Available: http://univagora.ro/jour/index.php/ijccc/article/view/2362

[4] Bărbat, B.E. Complex Time for Chaoplex Systems: From Newton to Wiener, 2013. Available: http://www.math.md/files/csjm/v21-n2/v21-n2-(pp225-241).pdf

[5] Bărbat, B.E. *Letter* (submitted in support of the nomination of Prof. Lotfi A. Zadeh for the 2014 ACM A. M. Turing Award), November 21, 2013.

[6] Bi, L., Igamberdiev, A. U., & Marijuán, P. C. Information and Symmetry: Adumbrating the Abstract Core of Complex Systems, 2017. Available: http://www.mdpi.com/2078-2489/8/1/35/htm

[7] Consiglio, M. *et al*. ICAROUS Integrated configurable algorithms for reliable operations of unmanned systems, 2016. Available: http://ieeexplore.ieee.org/abstract/document/7778033/.

[8] de Prado Salas, J. G. Metaphor and engaged coordination, 2016. Available: http://www.sciencedirect.com/science/article/pii/S0388000115000868

[9] Fabian, R.D. *Bounded Rationality in Agent Orientation - "Just-in-Time" Visual Pattern Recognition*, 2011. Available: http://scribe.ulbsibiu.ro/dspace/bitstream/123456789/846/1/Ralf_Fabian_Phd_Thesis.pdf

[10] Filip F. G. Sisteme suport pentru decizii. Ed. Tehnica Bucuresti ("Decision Support Systems") (In Romanian.), 2007.

[11] Filip, F. G., Suduc, A. M., & Bîzoi, M. (2014). DSS in numbers. *Available:* http://www.tandfonline.com/doi/abs/10.3846/20294913.2014.890139

[12] Filip, F.G., Zamfirescu, C.B., Ciurea, C. Computer-Supported Collaborative Decision-Making, 2017. Available: https://link.springer.com/book/10.1007/978-3-319-47221-8

[13] Guiochet, J. (2016). Hazard analysis of human–robot interactions with HAZOPUML. Available:http://www.sciencedirect.com/science/article/pii/S092575351500346X

[14] Lepri, B., *et al*. The Tyranny of Data? The Bright and Dark Sides of Data-Driven Decision-Making for Social Good, 2017. Available: https://link.springer.com/chapter/10.1007/978-3-319-54024-5_1

[15] Miotto, R., *et al*. Deep learning for healthcare: review, opportunities and challenges, 2017. Available:https://academic.oup.com/bib/article-abstract/3800524/Deep-learning-for-healthcare-review-opportunities

[16] Nadin, M. Anticipation and the Brain, 2017. Available: https://link.springer.com/chapter/10.1007/978-3-319-45142-8_9

[17] Nadin M. Semiotic Engineering – An Opportunity or an Opportunity Missed? 2017. Available: https://link.springer.com/chapter/10.1007/978-3-319-56291-9_6

[18] Proietti, C. Time of Logics and Time of Physics, 2017. Available: https://link.springer.com/chapter/10.1007/978-3-319-53725-2_3

[19] Rødseth, K.L. Axioms of a polluting technology: a materials balance approach, 2017. Available: https://link.springer.com/article/10.1007/s10640-015-9974-1

[20] Sarkar, A. The Gambler's Fallacy and Hot Outcome: Cognitive Biases or Adaptive Thinking for Goalkeepers' Decisions on Dive Direction […]2017. Available: https://etd.ohiolink.edu/pg_10?0::NO:10:P10_ACCESSION_NUM:bgsu1483529030818181

[21] Wiederhold, G.. *et al*. Uncertainty and Methods for Dealing with Uncertainty. *IBM Stuttgart, Dec*. 1987.

[22] Zadeh, L.A. Generalized Theory of Uncertainty (GTU) – Principal Concepts and Ideas. Computational Statistics & Data Analysis 51(1), 15–46, 2006.