A Bounded Rational Review of Approximation and Undecidability in Economic Modelling

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Abstract: - The paper aims at: a) showing that approximation and undecidability refer to entirely different and incommensurable kinds of uncertain knowledge processing and have non-intersecting application domains; b) exposing the shortcomings of conservative approaches (including approximation theory) for treating “real-world undecidability” in applications meant for open, dynamic, and uncertain environments (first of all where modelling decision-making is concerned); c) outlining the rationale and the approach (based on bounded rationality) to deal with all kinds of uncertainty arising in economic modelling. (The mechanisms involved are only briefly suggested, being described in papers referred to.) Among the conclusions: approximation is still a valuable asset in modelling but mainly aiming at effectiveness, not at uncertain knowledge processing, because of its atemporality (mainly its ineffectiveness in dealing with future events); the bounded-rationality approach proposed in this paper enables both better economic models and better modelling (being based on trends in economic modelling as well as on agent-oriented software engineering).

Key-Words: - approximation; undecidability; open, heterogeneous, dynamic, and uncertain environments (OHDUE); uncertain knowledge processing; economic modelling

1 Introduction
Paradoxically, the hub of the title – and of the whole paper – is (the polysemy of) a preposition: versus. At first, it articulates the comparison between two concepts – both playing key roles in modern computer science (CS) – and emphasises the evolution of their relationship: alongside in the past, almost contrasting now. (Moreover, as facets of uncertainty, they are theoretically still in conjunction, but practically in growing opposition.) However, behind the scenes, both are seen as significant placeholders for two fundamental fields – mathematics and informatics – or, more far-reaching, for two divergent ways of thinking about the actual correlation between metamathematics and information technology (IT). Here, metamathematics is used in both connotations: “scientific reflection and knowledge about mathematics” and “branch of logic or metalogic”; IT is used in its current meaning, but with the undertone that it is rather a more comprehensive definition of informatics than its synonym (a scrutiny of the “IT” concept is given in [1]). Considering that the “Weltanschauung”-gap between computational-oriented mathematics and CS (obvious and deep in agent-orientation) is widening, the far target is to bridge (or, at least, to diminish) it, explaining the standpoint of modern artificial intelligence (AI) in this matter.

To approach its target, the paper has three specific aims:
   a) Showing that approximation and undecidability refer to entirely dissimilar and incommensurable kinds of uncertain knowledge processing (approximation is deterministic and atemporal, whereas undecidability is inherently non-deterministic and has an essential temporal dimension) and demarcating, on this basis, their non-intersecting application domains, focusing on decision making in economic modelling; relevant examples are found in applications for both real-world problems (e.g., economic modelling based on the bounded rationality principle [14] [13]) and small scope toy problems.
   b) Highlighting the inadequacy of conventional mathematical methods (not just approximation theory but most algorithm-based computational techniques, from Bayesian inference to fuzzy logic) for treating undecidability in applications meant for OHDUE (mainly dynamic, and uncertain environments where decision-making is concerned).
   c) Outlining, on this groundwork, the rationale and the approach to solve problems involving decision making under uncertainty. (The architectonics, based on trivalent logic semantics, and the mechanisms involved – being outside the workshop scope – will be described in [8] [3].)

Accordingly, the rest of this paper is organised as...
follows: After examining related work and summarising the history of this undertaking (Section 2), its “start vector” components are outlined: the rationale (mainly the premises) and the approach (Section 3) highlight the sundown of the algorithmic age in IT, because of interaction in dynamic environments. On this groundwork, Section 4 is the core of the contention, identifying the problem, i.e. revisiting (some) basic concepts. Section 5 addresses decision making in economic modelling from the perspective of bounded rationality, suggesting the axes of a pragmatic and affordable software solution. Conclusions and future work (Section 6) close the paper.

2 Related Work and History
Since this undertaking is unconventional and seems to be innovative, related work proprio sensu is hard to find. Hence, before condensing its history, some examples are given; they stem from very recent articles (since 2005) in related domains or show conventional applications of the concepts involved:
- Non-deterministic software;
- Non-deterministic decision-making [21];
- Uncertain knowledge processing [20]. Qualitative and quantitative uncertainty assessment are presented in [19];
- History. The prehistory (before 2002) of this undertaking includes three distinct but interrelated fields: a) interparadigmatic synergy; b) anthropocentric systems; c) exception-based. The necessary software mechanisms were based on structured exception handling applied in real time software engineering. Approaches, results, and standpoint are presented in [1].
- The history (since 2003) includes more focused research regarding diverse aspects of uncertainty and/or temporal dimension in agent-oriented applications designed for OHDUE:
  a) Implicit non-deterministic approach: a1) affective computing (asynchronous reaction to environment stimuli, emotion as asymmetric temporal function, controlling ethical agent behaviour [4]); a2) user-driven heuristics (even in stigmergic coordination); a3) human-agent interaction (computer-aided semiosis [7], visual ontologies).
  b) Explicit non-algorithmic agent design: b1) emulating agent self-awareness (Gödelian self-reference, self-cloning, dynamic ontologies [5]); b2) e-maiectics (inductive learning, self-referencing coach, action-oriented “Simon-type learning” [16]).

A distinct strand regarded formal methods applied in economic modelling: on the way of developing mechanisms able to generate economic processes, designing conventional techniques for process modelling (based on abstract state machines) showed the intrinsic limits of deterministic tools in non-deterministic environments [9]. Trying afterwards to achieve intelligent system modelling (using total fuzzy grammars [10]), proved that the gap is deeper than supposed earlier.

3 Rationale and Approach
Since this paper defends an IT stance in a mathematical setting, for the sake of simplicity, the focus is not on separated conceptual categories but on the way changes are perceived and assimilated (“from … to”).

Rationale. The basic idea is that the dynamics of every facet of our society – first of all, economy – are so intense that no field of study could afford a slower development pace. To adapt to transformation, it must be recognized in state of affairs and in tendencies. The main changes are visible alike in most non-trivial IT applications but reference will be made to DSS (since decision-making is affected above all by undecidability) and, where suitable, to economic modelling:
- Environment. From limited, homogeneous, changing slowly, deterministic (even if partly approximated or even unknown) to open and heterogeneous (the resources involved are unalike and their availability is not warranted), dynamic (the pace of exogenous and endogenous changes is high) and non-deterministic (even if partly known: both information and its processing rules could be revisable and intrinsically non-deterministic – as most environmental and almost all human stimuli generators).
- System exposed to decision-making. From predominantly automated system, moderately complex, not under the direct control of the monitoring system (with which it is associated), disconnected from it (the controlled and the monitoring system can scarcely act on each other) to man-machine system (probably BASYS: “balanced automation system”), highly complex (multi-distributed – mainly in space, but also in time and organization), under real-time control (the subsystems act on each other – at least, communicate intensely), almost always online. (Any economic nontrivial application is a blatant example.)
- User expectations (emphasis on decisions regarding economic modelling). From “ancillary tool” (information retrieval, statistic processing, user-friendly graphics) to “active help”.
- Task. From “solving problems” (manageable complexity, well-defined, monocriterial, optimal solution, accurate, offline, sequential, acceptable time restrictions, low risk, conventional business) to “managing situations” (high complexity, multicriterial, Pareto optimality, approximate, online, parallel, critical response time, high risk, virtual enterprise).
- System Architectonics. From “program package”
(purely algorithmic, clear specification, tested against that specification) to “software process” (labelled or not as “agent”, vaguely specified, validated against end-user expectation) considering two new fundamental design-space dimensions: Time and Uncertainty.

- **IT paradigms.** The last shift is from “client-server” to “computing as interaction”, “Algorithmic reasoning”, instead of being perceived as a side effect of “analogue humans loosing the battle with digital computers”, became a paradigm in the very sense of Kuhn. (Unfortunately, for many people involved, it still is.) On the other hand, after a decade of success stories, within AI, expert systems (based on the Newell-Simon hypothesis) began to disappoint, because of their bittleness (in all nuances of the word), showing the actual limits of the symbolic paradigm in an algorithmic framework. The reaction was prompt, overwhelming, and exaggerated: “GOFAI” (Good Old-Fashioned AI) has to be replaced by “BIC” (Biologically Inspired Computing), based on sub-symbolic paradigms. Though, their inherent non-algorithmic essence is rather ignored (for instance, “evolutionary algorithm” is not yet perceived as oxymoron, overlooking the fact that only the simulation is algorithmic).

- **IT infrastructure.** It is sufficiently advanced in both facts (nanoelectronics, broadband communication, semantic web, multimodal interfaces, etc.) and trends (Moore’s law is expected to hold at least other ten years, agent technology advances steadily [15] – increasing user acceptance –, agent-oriented software engineering the dominant IT development paradigm [15]) to allow matching user expectations for most IT applications).

- **Diminishing role of algorithms and (bivalent) logic.** The geometrically increasing computing power (due to Moore’s law) promotes at least five factors tending to reduce radically their purpose in IT – at least for applications affordable on usual configurations [6]:
  a) Since deterministic applications are vanishing (because of OHDUE), the conventional algorithm is not anymore program backbone; b) Even when still useful, the conventional algorithm is not anymore the main programming instrument (being hidden in procedures easily reached in a host of libraries or being generated by 4GL); c) In AI, the symbolic paradigm is steadily replaced by several sub-symbolic ones, based on fine-grain parallelism; d) Even when symbols are used, they are stored in and retrieved from huge and cheap memory, rather than processed through sophisticated reasoning schemes (case-based reasoning is just an example); e) Cognitive complexity of new, sophisticated logics is too high for a designer, when “cut and try” is affordable.

**Diagnosis: Main Weaknesses of Conventional Modelling.** They stem from inappropriate conceptualising, based on rigid, algorithmic (i.e., deterministic, almost sequential, “computational”, and atemporal processing), meant for decision making as step by step solving of arising problems, not as continuous process of dealing with unexpected, potentially risky, fast changing situations requesting immediate – albeit not optimal – response. Sectorial (but strongly interrelated) aspects are:

- **Poorly reflected (or absent) temporal dimension.** Since the agent is a process – now acknowledged as such by a formal standard [11] – its temporality cannot be disregarded anymore.
- **Poor concurrent programming.** Often such situations are handled by resource wasting “active wait loops” or counterproductive “mutexes” instead of a simple Wait (for an event) with Timeout.
- **Distorted prediction.** Bayesian inferences are considered unsuitable to decision-making (this aspect is investigated in [8]).
- **Misunderstood uncertainty.** See next section.
- **Fake intelligence.** Although intelligent system behaviour – whatever that could mean – is not a minor user expectation, neither conventional AI technology, nor design philosophy were yet able to offer it in a user-relevant manner.
- **Inaccurate complexity management.** When complexity is overwhelming (requiring unaffordable resources), instead of simplifying the model, subsymbolic paradigms – mainly artificial neural networks (ANN) or evolutionary algorithms (EA) – are used, ignoring their general weaknesses (no explanations, weak convergence, poor reliability because of inadequate exploitation/exploration ratio) or specific ones: need for training example sets (for ANN) or endogamic limitation (for EA). For instance, what responsible human will make critical (e.g., macroeconomic) decisions without any justification? Even recent powerful emergence-based paradigms are employed outside their application domain: for instance, stigmergic control is proposed for online decision support (even in fairytales the Queen of Ants is called to accomplish difficult tasks, not to give advice!).

In short, in real-world decision-making, the main challenge is to solve problems under time pressure. The challenge is far to be successfully faced.

**Approach.** Two perspectives guide the approach: anthropocentric systems, as non-negotiable goal, and agent-oriented software engineering (AOSE), as amendable means – depending on effectiveness.

Since the required change of mentality is profound

\footnote{Anthropocentrism means focusing on the human being as user, beneficiary, and, ultimately, raison d’être of any application or, more general, technology [3]. Here, “anthropocentric” is synonymous to “human-centred”.

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305

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and urgent, the approach must avoid “solutions in search of a problem”. Hence, total pragmatism to begin with: a) To validate the approach – at least in ovo – a relevant, cardinal, and for the most part ill-defined real-world problem is focused on: decision making in economic modelling. b) The solution must reduce complexity: b1) cognitive; that means obvious functionality, no sophisticated concepts or instruments (agents, temporal logics, explicit uncertain information processing, computability theory and computational complexity theory, Bayesian methods, certainty factors, etc.); b2) structural; that means simple mechanisms, immediate applicability in current designs; conventional software engineering. While the intended solution will be detailed in [8] and [3], the axes of a pragmatic and affordable software solution are set in the next two sections.

4. Revisiting Basic Concepts

Some basic concepts are revisited here through a double sieve: a) modern artificial intelligence (AI); b) the bounded rationality principle. The investigation is limited and sectorial, in line with the paper scope:

Before tackling the two target concepts, some of their relevant connotations could be suggested by related notions: for “approximate” the antonym, for “undecidability” a kind of genus proximus.

Is “Exact Science” an exact term? Web definitions: “Exact” means “marked by strict and particular and complete accordance with fact; accurate: (of ideas, images, representations, expressions) characterized by perfect conformity to fact or truth; strictly correct;” (http://wordnet.princeton.edu/perl/webwn?s=exact).

“The term exact science refers to fields of study that admit especially precise predictions and rigorous methods of testing hypotheses, especially reproducible experiments involving quantifiable predictions and measurements. The term implies a dichotomy between these fields and those such as sociology and economics, where prediction and experiment are more difficult. It also suggests that the former are more rigorous than the latter, and their results more reliable. Today the distinction is widely considered old-fashioned, and scientists very rarely use this term” (en.wikipedia.org/wiki:Exact science). Despite asserting that the distinction is old-fashioned (no mathematician dares any longer to consider economics as second-hand science), some relict prejudices are still strong: most mathematicians make believe that only quantifiable and predictable economic aspects are worth to be explored; worse, they use old-fashioned informatics to impose this conviction. (UML-based modelling is just one of the constraining tools.)

With the rightful self-confidence of an outstanding nineteenth century scientist, Lord Kelvin claimed: “When you can measure what you are speaking about, and express it in numbers, you know something about it”. On the other hand, from the height of modern IT, more than a century later, other voices begun to prevail: “In Western cultures, there is a deep-seated tradition according more respect to numbers than to words; but, as is true of any tradition, a time comes when the rationale for a tradition ceases to be beyond question” [22]. Here, “word” has two related but distinct undertones: “imprecise” and “natural”. Conventional modelling of economic processes is still based on numbers. Should it keep on that way?

Uncertainty as epistemic concept: The relationship between uncertainty and non-determinism is intricate (uncertainty is the “epistemic facet of non-determinism” [1]) but irrelevant in decision-making context, because uncertainty can appear in deterministic problems too (playing chess is a manifest example: certainty about the best move is given up to speed – better said, to inexorable time restrictions). Thus, research can avoid non-determinism and focus only on uncertainty, its species and degrees. Due to its vital role in any kind of decision-making, a subsection in [8] will be dedicated to this topic.

Approximation: “I don’t care. Go on!”

Definitions on the Web: “estimate: an approximate calculation of quantity or degree or worth”, “the quality of coming near to identity (especially close in quantity)” (wordnet.princeton.edu/perl/webwn); “inexact representation of something that is still close enough to be useful. Although approximation is most often applied to numbers, it is also frequently applied to such things as mathematical functions, shapes, and physical laws.” (en.wikipedia.org/wiki:Approximation). These definitions (firstly the last one) are relevant as regards: a) both the commonsensical and the scientific (mainly, mathematical) meanings of approximation; b) its role as degree of uncertainty (as “measure” of: imprecision, difference between a reported value and a real one, possible error or range of error, etc.); c) its major function as optimization tool. Indeed, extending Kowalski’s phrases from search to uncertainty, approximation – seen as a “don’t care”-like uncertainty –, can speed up remarkably data processing in key IT subdomains (e.g., image compressing). Caveat: approximation is inherently unsuitable for “don’t know”-like uncertainty, not even in deterministic contexts (as shown above with the chess example).

Undecidability: “I don’t know. What next?”

Definitions on the Web: a) “property of knowledge representation language that the truth of some of the true statements within that language cannot be established by any algorithm” (www.dbmi.columbia.edu/homepages/wandong/KR/krglossary.html); b) “Undecidable has more than one meaning in mathema-
tical logic: b1) A decision problem is called (recursively) undecidable if no algorithm can decide it, such as for Turing’s halting problem. b2) "Undecidable" is sometimes used as a synonym of "independent", where a formula in mathematical logic is independent of a logical theory if neither that formula nor its negation can be proved within the theory.” (en.wikipedia.org/wiki/Undecidability). Obviously such definitions are too “full of mathematics” to be thoroughly comprehended in common decision-making. On the contrary, the definition “Within a system, a statement is said to be undecidable when it cannot be shown to be either true or false.” (ddi.cs.uni-potsdam.de/Lehre/TuringLectures/MathNotions.htm is relevant for this paper. Indeed, even when the fact that accurate numeric data are hard to get is accepted, the emphasis is on approximated, predicted, evaluated by rule of thumb, or even on intrinsically fuzzy data, rather than on missing ones (lacking sensor or market information, delayed previous decisions, server crash etc.). However, decisions are difficult because a relevant event not happened yet, not because a result is imprecise. Moreover, its pragmatic corollary highlights a key aspect in decision-making: since any statement about a future event is undecidable, how to proceed in this case? Could it be predicted? (Prediction methods – first of all Bayesian – will be criticised in [8].)

5. Bounded Rationality in Economic Modelling

To avoid a misinterpretation of the section title, here are its non-targets to begin with. This section does not aim at: defending the very principle of bounded rationality (a half-century of scientifically uncontested history after being developed by the Chicago School and endorsed brilliantly by Simon [18] makes it futile); describing “models in which procedural aspects of decision making are explicitly included” [17] (it was convincingly done by Rubinstein in the seminal book referred to); advising bounded rationality as a means to improve economic modelling (the reason Kahneman received a Nobel Prize [14]); linking it to psychological (or psychosomatic?) processes or to communication faults that could explain (or not) ill-applied statistical thinking in decision-making (Gigerenzer proposed alternatives for decision making, based on simple heuristics [13] that “lead to better decisions than the theoretically optimal procedure” (en.wikipedia.org/wiki/Bounded rationality); for instance, priority heuristics [12]). Any such target would be far beyond the horizons of the workshop, the paper, and the authors.

The problem is that none of the aspects mentioned above are taken into account sufficiently (at least, here and now), neither in economic modelling, nor in decision-making whatsoever. Moreover, ignoring the fact that bounded rationality is “a form of behaviour associated with uncertainty where individuals do not examine every possible option open to them” (www.pestmanagement.co.uk/lib/glossary/glossary_b.shtml), the mathematical tools still recommended for modelling economic processes – taking place in OHDUE – are ill-applied when they try to deal with undecidability (approximation theory included).

On the other hand, the same aspects open wide prospects to successful economic modelling: indeed, those tools (first of all, approximation theory) could play a paramount role in decision-making seeking fast, albeit suboptimal, solutions. For instance, promising application areas for multivariate approximation were illustrated at this very workshop: image processing, form and motion recognition, surface design, web classification, networks. (As regards the dark side of applying approximation, a possible way out will be proposed in [8] and [3].)

Hence, considering bounded rationality in modelling, would have two convergent, major beneficial effects: reducing attempts in the counterproductive direction (i.e., treating undecidability) and promoting efforts in the valuable course (i.e., offering “just in time” answers). Thus, the paradox of approximation in modelling (both evil and blessing) would fade away.

6. Conclusions and Future Work

- Approximation and undecidability refer to incommensurable kinds of uncertainty (approximation is deterministic and atemporal; undecidability is non-deterministic and has a basic temporal dimension).

- Approximation theory has still a major role to play in artificial intelligence but mainly aiming at (sub)optimization and efficiency, not as instrument for treating uncertainty (its atemporality entails ineffectiveness in dealing with future events).

- Undecidability, as vital aspect of decision-making, cannot be treated neither through approximation, nor through conventional prediction methods.

- Corollary: undecidable must get a semantic status similar to that of true or false; hence, modern decision-making, to be able to deal with future contingents, requires trivalent logic semantics.

- Economic modelling cannot anymore avoid the consequences of bounded rationality. It has to accept undecidability as concept and to resort to approximation as means.

Future work. Since this research goes on, the milestones are set in the last paper describing it [3].
References:


