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What are Simulations? An Epistemological Approach

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Abstract

Contemporary sciences use a wide and diverse range of computational simulations, including in the areas of aeronautics, chemistry, bioinformatics, social sciences, AI, the physics of elementary particles and most other scientific fields. A simulation is a mathematical model that describes or creates computationally a system process. Simulations are our best cognitive representation of complex reality, that is, our deepest conception of what reality is. In this paper we defend that a simulation is equivalent epistemologically and ontologically with all other types of cognitive models of elements of reality. Therefore, simulations cannot be considered secondary nor weak instruments to approach to the reality analysis.

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Keywords: model, computer, simulation, epistemology, representation.

1. Introduction

Contemporary sciences use a wide and diverse range of computational simulations, including in the areas of aeronautics, chemistry, bioinformatics, social sciences, AI, the physics of elementary particles and most other scientific fields. Based on the latest tendencies, computational simulations have become a basic part of today's scientific research. One can search for 'computer simulation' in the databases of top journals such as *Science* or *Nature* and one will get a large and ever increasing number of hits. Since the 1960's computers have been incorporated into all the principal scientific activities and research projects and today they represent a basic framing technology in a wide range of disciplines.

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Have computers changed the ways in which science is done? Before answering this question, we should ask ourselves what the different experimental ways to gain scientific knowledge have been historically. It will be helpful in understanding our present situation to think about the epistemological approaches of our ancestors.

1.1. A taxonomy of experiments:

Historically, humans have developed different kinds of techniques to be able to understand and control Nature, and the computer simulation is one of the more recent ones. Let’s look at some of the basic experimental approaches:

Table 1. A taxonomy of experiments.

Experiments	Material	Nature	*In vivo*
		Laboratory	*In vitro*
	Non-material	Computational	*In silico*
			In virtuo
		Thought (Gedankenexperiment)	*In mente*
	Hybrid	Computational-material	*In mixtura*

Material experiments are those carried out on Nature itself, such as Newton’s analysis of the diffraction of light. Laboratory experiments are those performed in controlled laboratory conditions, such as Ramon y Cajal’s research on neurons. These first two kinds of experiments are related to material experiences, but experiments can also be non-material. Within this category fall computational experiments, executed using computational devices (*in silico*, with a pre-established and fixed process allowed to run its course, or *in virtuo,* as computer-based simulation, but with the possibility of disturbing a model that is being run, [1]. Similarly, thought experiments, the classic Gedankenexperiments, typically within the philosophical and mathematical arena, but also in the sciences (we might think of Galileo’s mental experiments for example) [2-7]. Finally, we find hybrid experiments [8], being a mixture of material and non-material experiments.

1.2. Defining simulations.

Among all these kinds of experiments, computational experiments, or simulations, constitute one of the most active areas at the present time. Modeling and simulation are very generic terms for very different activities, techniques and purposes; it is therefore understandable that simulations have a controversial status amongst theoreticians and practitioners from different scientific fields. Questions that might be debated include: Can they replace ‘real experiments’ (such as animal testing)? Are they merely helpful tools or sophisticated games?... And more fundamental questions arise, such as: What are simulations? What is their epistemological status?

With the growing and more fundamental use of these kinds of experiments, and with the increase in computer intensive techniques within scientific research [9], different attitudes towards their nature and scientific meaning have been voiced. Are they true experiments or just pseudo-empirical results used to generate new hypotheses and to further develop a theoretical model? What is their epistemic range and their ontological nature? In recent years several studies on philosophy and simulations have appeared [10-23], covering a broad spectrum of theoretical aspects related to simulations, such as the relation between models and simulations [24, 25], simulations in physics [26] or their epistemology [27]. First of all, we should point out that the exact definition of Computer Simulations is a complex issue. The definitions vary according to the different areas of specialist expertise. We can find basic and repetitive concepts across all, or at least most, of these definitions: mathematics, models, computer, process and system. Therefore, our best and simplest definition of simulation must be: “a mathematical model that describes or recreates computationally a system process”.

With that definition, we accept the dynamic nature of the system process and the underlying mathematical structure computationally implemented. We can now look at the history of simulations to understand the historical framework in which they were developed, and their evolving nature.

1.3. The ontological status of simulations.

As has been pointed previously, in this paper we defend that a simulation is equivalent epistemologically and ontologically with all other types of cognitive models of elements of the reality. Therefore, simulations cannot be considered secondary nor weak instruments to approach to the reality analysis [28].

Any way to capture and codify reality in a human shared context (algorithms, formula, words, signs...) becomes our only way to think that reality. Without these tools, reality itself cannot be apprehended nor thought. It is just beyond our minds.. It is a frequent mistake to think or to defend that any of the cognitive tools we use to embrace reality is truer than another one, as if in some moment we could touch directly the reality with our minds, appearing the thing itself to our senses. Any perception is, by definition, a short and particular capture and description of an event. When I'm seeing red, following the beautiful example of [29], what I'm seeing is a property of a surface or an object, but even despite of the fact that we can measure physically that color (aprox. 650 nm of light wave), the light could be considered as wave or corpuscle, or consider the real pattern of the sunlight over the object, or the object itself that shares this characteristic, or the meaning of the red color in the social context in which appears...and we'll never would be able to finish about possible points of view about reality. People with synesthesia could also perceive more information with red, or the first official cyborg of the world (Neil Harbisson) understands sonochromatically red as an F note (363.797 Hz)[2]. There is nothing like red, but out bodily and mind interpretation of some properties. Perhaps exists something real and pure, the *noumenon,* from which emerge our perceptions, but unfortunately nobody can access to it. Instead, we must conclude that there is nothing like the reality itself. Perhaps we can consider that there are clusters of properties than tend to be statistically together, and that the reason of this fact is that something is a real object with real properties. But, again, as soon as we try to define some of its true aspects we are only making a reduction of the several possible ways by which that object can be understood or explained. Computer simulations are not less real than experiments about laws of nature performed in controlled laboratories. Concepts supervenes reality, although we cannot be sure about what reality is, beyond our own concepts.

Could be argued against this that real experiments involve real objects that can act independently as the theoretical model predicts, while in simulations, the object itself is already a model of the true object. My answer to this reply is easy: in real experiments we are not working with true objects instead of with objects which we think that have some performative qualities according to our expectations. We only read some of the characteristics of these objects, those that fit with our theories and/or interests. Only in a few cases in which a paradigm shift is threatening, objects seems not to behave according to their expected response and even in these situations it is very difficult to be convinced about the *new* true nature of this object.

The more cutting-edge is the level of our research, the more evident is that there is no distance between our representations and the reality itself. For example: particle physics works with huge databases, capturing petabytes of data that must be also computationally processed. And in some levels of this kind of studies there is no possible to make experiment, but only computational simulations (for example about the origin of the universe). In all these cases we are not dealing with real matter, but with our conceptual tools to understand it. They are as real as our belief on their consistency, but nothing else. In this case, we are not talking about real things but about concepts that we think that capture those things. In this sense the representation of the reality is ontologically-dependant of our tools, not about the reality itself. Consequently, powerful computer simulations are as true as real models of reality. They are always conceptual representations of an undergrounded level of physical events. The only true experiment should experiment with all related research properties that we wish to study and that are present in the universe, all together and at the same time. The property electron should be checked with all electrons of the universe at the same

[2] http://en.wikipedia.org/wiki/Neil_Harbisson.

time. If it is not possible, selecting one electron or making a computer simulation of a group of electrons it is nothing so different or real. We capture as much as the basic properties of the entities we study, ort at least those we consider really the basic ones. But we never know if it is enough. Then, we decide to assign values of reality to our mind concepts, not to the reality itself. This is my claim in this paper: computer simulations are most of times the deeper and sharper face of our scientific minds. And they are as true as any theory that can emerge from a net of concepts 'empirically obtained'.

The complexity surrounding simulations is not only semantic, since there are also conceptual divergences between experts about the meaning of the word 'simulation', and the issues concerning the differing types of computational events that we might call simulations.

1.3. Philosophical positions regarding simulations:

The plethora of philosophical analyses of simulations can be schematized in the following way [31] according to their considered nature:

- I- Thesis 1: A computer simulation is an experiment.
  - I-1- A genuine experiment: Artificial life
    - I-2- A kind of experiment: A simulation imitates the granularity of nature
- II- Thesis II: A computer simulation is only a tool.
  - II-1- A tool to treat real experiments
  - II-2- A theoretical tool.
    - II-2-1- A numerical method among others, according to statisticians
    - II-2-2- A conceptual argument
    - II-2-3- An opaque thought experiment
- III- Thesis III: A computer simulation is an intermediate between theory and experiment.
  - III-1- A new means of capturing and understanding complexity without comprehending it
  - III-2- A step-by-step computation is an a priori experiment, and, in many cases, it works as a substitute for an experiment impossible to make in reality
  - III-3- Simulation is a "trading zone" between theorists and experimenters

2. Models in science: saving the appearances?

In the 17th century, the English poet John Milton wrote these lines (*Paradise Lost*, Book 8, *SA* 48): "Conjecture, he his fabric of the heavens/Hath left to their disputes, perhaps to move/His laughter at their quaint opinions wide/Hereafter, when they come to model heaven,/And calculate the stars; how they will wield/The mighty frame; how build/deconstruct, contrive,/To save the appearances; how gird the sphere/With centric and eccentric scribbled o'er,/Cycle and epicycle, orb in orb". Milton was giving an exemplary exposition of the concept of *Saving the Appearances* or, otherwise, how to distinguish between the model and the reality. In the end, it was a debate about the nonsensical development of Aristotelian-Ptolemaic geometrical astronomy. Do our models (as simulations) truly represent reality or are they merely designed to be a way of thinking *about* reality, albeit far removed from the true physical nature of things? Something I hope that my analysis of models will show is that simulations constitute a special kind of model and are in themselves, at a certain level, real events.

Although we have been talking about several desirable characteristics of models, it is difficult to find a broad consensus as to what models are and, more specifically, the nature of this special dynamic kind of model: the simulation. We must also consider the huge amount of existing literature on models, dating back to the 1960's [39-44], that stemming from the renewed interest of the 1980's and [45-49], and finally that of the initial years of the 21st century [50-52].

The Cambridge English Dictionary (http://dictionary.cambridge.org/), defines 'model' as: "a representation of something, either as a physical object which is usually smaller than the real object, or as a simple description of the object which might be used in calculations". Here then, the main idea is that a model is a surrogate of a real thing or event, that constitutes a basic practice within scientific activities, and that its conceptual role lies somewhere between those of empirical data and theory. To be more precise and comprehensive, [32] provide us with an excellent taxonomy of models, based on their different approaches: as a representation of a selected part of the world (target system) [, also called minimal models or caricature models] a theory (or the laws and axioms of that theory), physical object, fictional objects, Set-theoretic structures (mathematical models), descriptions, equations, gerrymandered ontologies….

What can be deduced from these conceptual categories is that there are as many different views of the nature of models as there are different viewers to observe them, from realistic or faithful representations to subjective entities (cases such as non-representational toy (or study) models. These might be used to test new theoretical tools, which are at the same time used later to build representational models.

[53] also differentiates between (a) idealizations: characterization of a system or entity where all its properties are deliberately distorted in a way that makes them incapable of accurately describing the physical world; (b) abstractions: representation that does not include all of the systems properties, leaving out features that the system has in its concrete form, and (c) approximations (mathematical): here, simplification arises within the mathematical context. In terms of physics, we can find models at several tractable levels: a) the level of electronic-structure (nuclei and electrons); b) the DFT (density functional theory). This involves the analysis of the first principles that make matter possible. That is, the analysis of time/matter from its beginnings (ab initio), 300-400 atoms; c) atomistic or molecular (atoms and molecules): molecular dynamics and Monte Carlo, Finite element Method Finite-element (set of structural elements), continuum (medium by fields and distributions).As a conclusion to the foregoing account of models, we can state that models are different kinds of entities. But what might their desirable properties be? According to [54] models must be *explanatory* and *isomorphic* to the natural system that realizes the phenomenon. Furthermore, models must be evaluated [55, Chap. 3] in terms of their explanatory success. Nevertheless, we know that explanatory success is not, in itself, evidence of truthfulness: the undetermination of theories explains why Ptolemaic and Copernican models of cosmological movement agree with data and explain them successfully, although both are false. Such is the case in Newtonian physics too. Beyond physics, we can observe that models used in game theory and economics do not achieve a high level of similarity with the thing modeled either, but provide us with only partial explanations. If transparency has not been fully achieved it is very difficult to talk about the *coherence* of the model, because we cannot check the whole process in detail. Or we must trust in *extensional devices* such as AI verification software.

In summary, models should be: a) explanatory., b) isomorphic (and non-trivial), in order to fit closely with reality, c) robust (and ceteris paribus), d) transparent, e) coherent: avoiding bugs (but not *features* of the main system in which the model runs. This is important with computational models and floating-point arithmetic), f) able to provide control.

3. . What represents reality? The new status of simulations.

If simulations are a special kind of model, their natures are blurred in the same way. We need physical observation (albeit incomplete) and theory to construct a simulation, which is, by definition, constricted by several requirements, such as involving a finite time or complexity when running [61] And they must have a statistical calibration applied to them. There are further restrictions on models: in some cases, such as NP complete problems, our computer simulation can be insoluble; and according to the Skolem-Löwenheim theorem, a model represents at least a countable infinite set. Finally, we must take into account that a simulation, by its complex nature is a cross-disciplinary activity.

Models must be built, coded, verified (debugged), run and, finally, validated [62] There is a design phase and an analysis phase. Usually dynamic, computational models must include stochastic variables and, in order to show a multidimensional complexity, Monte Carlo tools.

As a special kind of model, simulations are necessary distributed tools of our cognitive, necessary for our diagrammatic reasoning. But do simulations are models? According to Simpson [63] they aren't. His argument goes as follows: “simulations are inherently (partially) false characterizations of the world (they are at best only *similar* to actual processes and never identical to them), raising the question of *how* we can justify any claim that simulations lead us to (partial) truth whenever they are used”. His idea is that there is a scale of perfection from reality to models and simulations, the latter being less perfect than the former.

But this is a biased idea about simulations and models: similitude is not the consolation prize of lack of reality. All our approaches to reality are, to a greater or lesser degree, a construction of meaning through tools of imitation such as language, numbers or images. As [38:17] says: “any abstraction, verbal or mathematical, which attempted to describe the world or some distinct part of it were modelings from this point of view”.

Therefore, we could talk about precision of similarity but not of the ontological pre-eminence of any one of these forms in its approach to reality. They are not merely (improved) representations, but the best ways to understand and manipulate the world, our latest and best hope of bringing our thoughts into resonance with reality. Simulations are, at the same time, syntactic and semantic structures of knowledge.

Models can be abstract entities, physical instruments, virtual instruments, mediators or take on whatever role we wish to attribute to them (e.g. dynamism). As with all fundamental concepts in the philosophical arena, ‘model’ is a polysemous word with widely differing interpretations: examples include mental representations, verbal descriptions or logico-mathematical formalizations. They might also be explanatory or predictive.

The difference between models and simulations is, perhaps, the use of computational tools which enable us to run extremely complex collections of representative relationships, something impossible with the classical uses of (mathematical) models or thought experiments [58]. In this case, a simulation could contain several layers of models that must be sanctioned [21]. But, in the end, we can make models to float in a kind of limbo. This sort of approach to models is a different and interesting perspective within the epistemological analysis of knowledge: there are things and there are words (as hypotheses), but models are in no way as real as their ‘counterfactuals’. They aren’t on the Earth (reality), nor in the heavens (linguistic hypothesis)… so they must be in limbo.

From a representational approach to knowledge, this is a complete misunderstanding of the human approach to the reality. Models are as real as our words and our ideas about the world. Before establishing an ontological gap between simulations and reality we should consider what reality itself is. Because the real question is: what does ‘reality’ represent? When we create a simulation, it can be either fully representational (the reproduction of a whole system), locally representational (a simulation of restricted subsections of a system) or non-representational (a new entity, such as Alife), but in the end, the question resides in *representation itself*. When we compare a representative simulation with reality, we are not checking a copy against the original, but one computer/mental construction against a complex cognitive caption. Checking a simulation against reality implies having clear limits delineating the real entity under analysis. However we are not checking the real entity, but rather, some of its more important features in terms of our epistemic interests (filtered by possible historical epistemic approaches).

Thus, simulations are not bad quality copies, but special cases of the construction of meaning (this is an example of a sentence which meaning can be used to elaborate the abstract). In fact, if we accept the previous argument, we must conclude that they are as real as other entities we might analyze (‘as real as any other way to consider a piece of reality, i.e. to interact with the world’).

4. Representation and reality.

Are things really what we think they are? This a basic question for lovers of knowledge, to know if we genuinely perceive true reality and not just our dreams and wishes. Is there any ‘Dinge an sich’ that we can obtain definitively or are we blind-mediated by our senses? Trying to avoid a psychologist approach to knowledge, Frege (1918-1919) affirmed that “Nicht alles ist Vorstellung. Sonst enthielte die Psychologie alle Wissenschaften in sich oder wäre wenigstens die oberste Richterin über alle Wissenschaften. Sonst beherrschte die Psychologie auch die Logik und die Mathematik"[3]. But how can we know that our thoughts are true?

This is a nonsensical idea, leading to an infinite regression. I cannot know (from 'outside' my own brain) what causes the neural activity, because I am only neural activity (it is like trying to think about time and space from a standpoint outside them both); neither can I truly observe the neural reality stimulation affecting another human brain, because I am only experiencing *my own* neural activity, not that of the other person (to be honest, how can I know which is the true reality that causes neural activity in another brain?... thus, truth would consist in looking at events and their neural correlation, which is clearly an impossible option). We are faced, in both cases, with an elaborated form of solipsism, by way of a modern type of pseudo-neurological approach.

4.1. Representation, explanation and reality.

It would be a naïve idea to think that only computational simulations are representations of reality, and exclude our thoughts and languages from that representational category. Simulations aren't second-order representations; they are true reality, just as true as our words and our numbers or ideas are. We must also consider that humans, by nature, believe their thoughts to be real. 'Reality' is only a word necessary to explain why our representational state is better than the previous one, without appealing to the sociological relativist approach. Because, can we think beyond our conceptual models? Are our models simple representational surrogates for reality? The fact is that we never apprehend reality, only a symbolic approach to it through our references to logic, rules, frames, semantic nets, images, as technologies of representation of knowledge. But they are not simply the conceptual formalization of our thoughts, they *are* our thoughts. Without them, we cannot think about real entities. Our (mediated) thoughts are our closest approach to real events in the world. And we must accept at the same time that "a better representation cannot save us: all representations are imperfect, and any imperfection can be a source of error" [66]. Another important aspect is that our representations, like our cognitive system, cannot consider all attributes of the world: we must attend to some aspects and while ignore others. Meaning is something that adheres to limited aspects of reality, not to its totality. We cannot apprehend the world itself, but only address ourselves to its fragmentary manifestations. Otherwise, *thinking* would amount to *being* the world. Our different ways of choosing between different representational forms (logic, frames, connectionist, rational agents,…) implies the selection of a conception about the nature of reasoning and knowing. This is why representation and reasoning are intertwined activities.

4.2. Isomorphism, similarity and analogy.

Models can be isomorphic but this is not a necessary characteristic of a model, because at a certain level, that is, the useful level, the world is opaque. At a certain level we are Platonists and Antiplatonists at the same time: we believe in the mathematical fundaments of nature but we don't believe in the existence of a more real world, beyond that of our representations, one that we could apprehend directly. Some 'reality' must exist, but we are always faced only with its representations. When someone says to me "well, the way to prove a model is to compare it with reality, through an experiment or observation", what she or he is telling me is that the only way to know whether a model x of a chunk of reality R is true, consists in developing a new model of reality, X, and calling it 'the true nature of things', although in fact it is nothing more than another model with which to compare the first. There is no true nature of things, since we never see all the possible states of reality, only those which we are prepared to accept in a collectively agreed subjective way. According to this reasoning, I don't deny reality, but would insist upon the

3 Not everything is an idea. Otherwise psychology would contain all the sciences within it, or at least it would be the highest judge over all the sciences. Otherwise psychology would rule over logic and mathematics. It has been quoted from (to be included into the footnote): Gottlob Frege: Der Gedanke. Eine logische Untersuchung.Beiträge zur Philosophie des Deutschen Idealismus, 2. 1918-1919, S. 58—77. Translated as 'The Thought. A Logical Enquiry.' M. Quinton (trans.) Mind, 65 (1956): 289-311.

deeply representational nature of human thinking. If this is correct, computer simulations are not mere copies of copies (theoretical models), but true reality, in a special sense: they are all that we can know about reality until we find a new reality. This is, for me, the transitive nature of representation. Simulation is a process of creating a representation that corresponds to the elements of another representation. We can summarise this by referring to the Watanabe *Ugly Duckling* Theorem [67]there can never be a rigorously objective way to ascribe a measure of similarity (or dissimilarity) between any two randomly chosen subsets of a given set. The absolute validity of any partitioning of the world into a specific set of *objects* and *relations* which, as we have argued, constitutes the very essence of physics, is therefore, fundamentally, arbitrary.

For that reason the distinction between simulations and experiments made by plenty of authors, based on the idea that the former require some prior knowledge, whilst the latter do not, must be considered to be fundamentally flawed; "models, experiments and simulations can be thought of as tokens of the same kind, somehow located between our statements about the world, and the world itself" [68]. All our approaches to reality are semantic, without the possibility of establishing an ontological order between them: the classic chain world-words-observations-models-experiments-true knowledge is a biased way of classifying our cognitive approaches to reality, whatever it may be. [68] affirm that experiments-simulations-models stand somehow in between what we say about the world and the world itself, but my point is that all three are all that we can think about the world.

Simulations represent the syntactic (development according to internal rules) and semantic (the isomorphism question) properties of reality. But to be argumentatively honest, when we create simulations, we produce a new kind of ontological relationship: syntax is subordinated to semantics. The meaning we wish to extract, being the final objective of simulations, forms the basis for their structural syntax. This is the consequence of our inability to deal directly with reality itself, and our necessity to appeal to it with our knowledge proposals. All semantics contain a specific syntax, and not the reverse. We cannot reasonably believe that the inner structure of the studied object is true, before its meaning is apprehended. The paradox of this situation can be sketched in this way:

Reality (syntax➔ semantics) ⇐➔ Simulation (semantics ➔ syntaxis)

The semantic characteristics of nature belong only to the human cognitive domain, not to nature itself. In this case, the syntax creates semantics in our brains. With the next step, the creation of a simulation, our search for meaning guides us in finding its structure, that is, we move from semantics to syntax. If our simulation is correct, syntactic structures might agree, although this is difficult to affirm: we find sense in the semantic side of reality, not in its structure. In this way, we are Platonic realists but with an Aristotelian search for observable events. Simulations respond to both necessities: they offer us a *visible* world that is as perfect and real as we can know, or the only reality that we can process mentally.

5. Final conclusion

Simulations are a basic part of contemporary scientific practices and can be considered true experiments. According to the above sequential arguments, we must conclude that simulations are our best cognitive representation of complex reality, that is, our deepest conception of what reality is. Furthermore, there is no greater distance between objects and simulations than there was previously between things and words: simulations are not a secondary class of thoughts (less real), from a Platonist point view, but in fact our only way of thinking about certain kinds of entities. If a fiction, they nevertheless remain our only way of understanding our world, and are as close to or as far from reality as were our linguistic theories of the past and up to the current day. Computer simulations are just the next step on the path of knowledge, our best and probably our only way to deal with the complexity of the universe.

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