COMPUTER SIMULATIONS AND SCIENTIFIC EXPLANATIONS

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ABSTRACT: Computer simulations are important tools in scientific research but were not taken into consideration in the classical philosophical approaches on science. Recent developments in philosophy of science began to focus on their status and role in producing scientific knowledge. Scientific explanation is the major goal of scientific inquiry and was an important subject on the philosopher's working agenda. It is natural therefore to ask how simulations contribute to the achievement of this goal and look to the way the subject of explanation gets new aspects by reference to these scientific tools.
KEYWORDS: simulations, explanation, philosophical issues.

The topic of scientific explanation was a major one in philosophy of science concentrating the research interest during some of the most glorious decades of the field in the second part of 20^{th} century. The subject found its inception through Hempel's account[2] developed in the frame of the neopositivist view on science. After three decades of intense research the subject seemed to loose its prime status. I have argued elsewhere[3] that the fatigue from the 90s bore the seeds for a fresh approach on the topic. As the recent trends in philosophy of science showed the problem of explanation remains an important one and it finds itself in search of new ways of articulation in a context in which it is no more the subject of the old constraints for the received view.

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2 The main papers on the subject are gathered in Hempel, Carl G., *Aspects of scientific explanation*, New York, The Free Press, 1965.

3 In David-Rus Richard, *Explanation and understanding through scientific models: perspectives for a new approach to scientific explanation,* Iasi, Institutul European, 2012.

The traditional scientific units of reference i.e. the bearers of explanation were considered to be the scientific laws or the theories, as stated in Hempel's model. Larger units were also considered responsible for the explanatory qualities of scientific knowledge. Such is the case in Kitcher's account[4] where the entire corpus of knowledge taken under its best systematization determines the explanatory quality of the argumentative patterns that constitute the usual explanations. The recent reorientation towards more local philosophies of science[5] and the trends that take scientific practice and concrete scientific episodes as starting points for their analysis without searching to impose a predetermined view of science, opened also the possibility to take into account other types of entities as bearers of explanation. I have argued elsewhere for the possibility to reframe the explanation topic by considering scientific models as such bearers. Other local units might also be considered and were referred in the literature. Such are also computer simulations which increased in importance in the last years.

The philosophy of simulation – some landmarks

The philosophy of simulation might be seen as a brand new branch of philosophy of science that deals with the philosophical aspects of simulations. In the last years it increasingly drew the attention of philosophers due to the rise in importance of the computational methods in scientific research. Though some to the basic questions addressed by philosophers of simulation have already been around for some time, the complexity and the richness of the problems were unveiled in the recent work. As with any other philosophical interrogation one could distinguish metaphysical epistemological and ontological aspects that concentrated the research efforts of philosophers.

It was claimed[6] that the subject of simulations brings a totally new agenda in the field of philosophy of science. Frigg and Reiss[7] took an opposite stance and tried to argue that the philosophical issues raised

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4 His account might be found for example in Kitcher, Philip, 'Explanatory Unification', *Philosophy of Science*, 48, 1981, p. 507–3.

5 The characterization was coined by Nick Hugget in his paper 'Local philosophies of science', *Philosophy of Science*, 67(3), 2000, pp. 128–37.

6 An important adherent of this view is Paul Humphreys; his book *Extending Ourselves: Computational Science, Empiricism, and Scientific Method* Oxford, Oxford University Press, 2004 is one of the main contributions in this area of research.

7 In their paper 'The philosophy of simulation: hot new issues or same old stew?', *Synthese*, 169(3), 2009, pp. 593–613.

by simulations are not specific to them but only variants of problems already discussed in previous contexts. They present and discuss the 'novelty claim' by itemizing it into a list of such new points. The list comprises four claims: a metaphysical claim stating that simulations create a new sort of parallel world, an epistemic claim stating that simulations demand a new epistemology, a semantic claim that they demand a new analysis of how models and theories relate to reality and a methodological one that simulations lie 'in between' theorising and experimentation. The authors argue against the radical novelty of any of these problems and try to show that they are not specific to simulations and most of them could be seen as variants of problems that have been discussed in other contexts.

I will further try to review some of the main issues that engaged the debate in philosophy of simulation. A first view sends us to the central issue concerning the very nature of simulations, its identity. A computer simulation involves the implementation of a program through multiple runs. One might see the general pattern as defining the simulation, but as well we can take the runs as part of the simulations. Specific conditions of the implementation as the programming language or the computer might be taken into consideration as they might impact on the final result of the simulation.

Philosophers tried to overcome such difficulties and proposed definitions in general terms for a simulation. One of the first was formulated by Paul Humphrey who sees a simulation as "any computer-implemented method for exploring the properties of mathematical models where analytic methods are not available"[8], a definition which Winsberg characterizes as a narrow kind of definition picking on the general pattern and one run characterization. Humphrey's takes mathematical domain as the main reference for simulations. Winsberg[9] advanced a more comprehensive definition in which simulation is seen as a multistage process made out of different steps involving: "choosing a model; finding a way of implementing that model in a form that can be run on a computer; calculating the output of the algorithm; and visualizing and studying the resultant data"[10] capturing this away, as he underlines, the essence of

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8 Humphreys, Paul, 'Computer simulations'. in Fine A., Forbes M., & Wessels L. (eds.), *PSA 1990* (Vol. 2,). East Lansing, MI: Philosophy of Science Association.1991, p. 500.

9 In Winsberg, Eric, 'Computer Simulations in Science', in Zalta E. (ed.), *The Stanford Encyclopedia of Philosophy,* 2013 [Online].

10 In Winsberg, Eric, 'Computer Simulations in Science', in Zalta E. (ed.), *The Stanford Encyclopedia of Philosophy,* 2013 [Online].

a computer simulation study. It places this way a simulation in the range of the toolboxes used in scientific inquiry.

A more general definition not restricted to mathematical or computational domain is advanced by Hartmann[11] and takes simulation to be a process imitating another one that takes place in the target system. The definition uncouples also the idea of simulation from the computer kind of simulation so that the definition gains generality. Nevertheless it was criticized by Hughes[12] on the ground that it leaves out simulations that account for a system's structure not only its dynamic.

The quest for defining the proper nature of simulation finds its expression in other issues beyond the strict definition of a simulation. One such issue concerns the resemblance and difference of simulations from models in general. The subjects of models and modeling gained importance in the recent philosophical agenda and simulations were often seen as belonging to the same register. In the same way as models, simulations can also be seen as ‚autonomous mediators'[13] between theory and experiment. Nevertheless models lack usually the temporal dimension of simulations; besides, models are subjected to a variety of methods of solving being representations that engage a variety of exploration methods. For example analytical solutions can be found by mathematical proof, but some models, the ones expressed through mathematical equations, cannot be solved analytically and need simulations.

An observation that adds to the above discussion is the fact that a simulation involves an underlying model. This has consequences for the problem of the relation between the simulation and the real target system represented. It might be claimed that we have to consider the relation between the underlying model and the target system in order to characterize the relation between the simulation and the target system. In general the problem of this relation seems to find its place in the more general debate about how models represent reality.

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11 In Hartmann, S. (1996). The world as a process: Simulation in the natural and social sciences. In R. Hegselmann, U. Müller & K. Troitzsch (Eds.), *Modelling and simulation in the social sciences from the philosophy of science point of view,* Dordrecht, Kluwer, pp. 77–100.

12 Hughes, R. I. G. 'The Ising model, computer simulation, and universal physics', in M. S. Morgan & M. Morrison (eds.), *Models as mediators: Perspectives on natural and social science,* Cambridge, Cambridge University Press.1999, pp. 97–145.

13 Morrison advocated this view in *Models as mediators: Perspectives on natural and social science,* Cambridge, Cambridge University Press.1999.

Another important and much debated issue refers to the similarity between simulation and experiments. In many areas of science researchers appeal to simulation and consider them as a sort of experiment used to inquire into inaccessible aspects of a phenomenon, to characterize the behavior of a system under hard to reproduce circumstances or generate new data. There are also episodes in science in which new phenomena were revealed through simulations before getting them under normal experimental conditions[14]. One might therefore recognize the existence of many similarities between experiments and simulation that attracted the attention of philosophers.

The main interest for philosophy of science is to clarify in what sense can simulations be qualified as experiments but also what makes them different from laboratory experiments. Winsberg in his entry in *The Stanford Encyclopedia of Philosophy*[15] identifies two main theses that could be seen as concentrating the debate on these issues. An identity thesis stating that simulations are real instances of experimentation and an epistemological dependence thesis stating that the identity thesis offers reasons to believe that simulations provide warrants for hypothesis they support.

One main point against the identity thesis draws on the fact that simulations do not involve manipulation of the same kind of system as the target system. In the laboratory experiments the same material causes are at work as in the target system while simulations could bear only a formal similarity to the target system. Nevertheless, as the critiques showed, this position takes into account only a simplified version of the relation between the manipulated system and the target systems. One such critique indicates that in many experiments scientists are not directly interested in the system they manipulate but in some other phenomena that are instantiated by this system. Such is the case for example of Galileo's experiments with inclined planes, while the main interest was in falling bodies. In trying to clarify this situation and lift the confusion she sees in the relation between the manipulated system and the one it stands for, Peschard[16] draws a distinction between epistemic target and epistemic motivation. She

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14 Lehnard in Lenhard, Johannes, 'Surprised by a Nanowire: Simulation, Control, and Understanding', *Philosophy of Science*, *73*(5), 2006, pp. 605–16.presents us such a case in order to discuss the sort of understanding that simulation might give us.

15 http://plato.stanford.edu/entries/simulations-science/

16 Peschard, I., 'Modeling and Experimenting', in Humphreys P. & Imbert C. (eds), *Models, Simulations, and Representations*, London: Routledge, 2010.

argues that simulations are distinct from experiments in that their epistemic targets, as opposed to their epistemic motivation, are distinct from the objects being manipulated.

Another side of the debate touches on the epistemological inferiority of simulations in comparison to laboratory experiments. Winsberg[17] deflects the point by arguing that the comparative epistemological power depends on the quality of the background knowledge. In this sense a simulation of the solar system for example proves to be better than any possible experiment. Overall the issues raise by the similarity between simulations and experiments increased in complexity and the debate amplified in the last years without a point of resolution in sight.

The epistemological aspects of simulations brought also into debate other important topics such as their epistemic opacity, the relation to the topic of emergence or the role they might play in the structure of theories. I will not discuss them further but refer the interested reader to the recent reviews in the literature such as Winsberg's encyclopedia entry in the web-based *Stanford Encyclopedia of Philosophy (SEP).*

Above all in evaluating and discussing the epistemology of simulations one of the most important things to be considered is the different roles they could play in scientific inquiry. Simulations are used for many purposes but Winsberg sees them falling under three comprising categories: heuristic purposes, predicting data and generating understanding of the inquired systems. Scientists use them for heuristic purposes when they explore the characteristics of different representations. Using simulations for data prediction is also a widely spread practice in scientific and technical domains. Generating understanding brings us to the potential explanatory qualities of simulations since on the standard view understanding is gained through explanations.

Simulations & their explanatory virtues

Coming to our main interest in this paper, the topic of explanatory virtues, one might say that the subject received some attention in the new trend but nevertheless it does not seem to involve an intense debate as we can see form the history of the explanation topic. There is a kind of shyness to deal with the subject in a more direct way and this is probably a consequence of the fatigue related to the

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[17] Also in the previously cited work.

explanation topic. In his entry in *SEP*, Weisberg does not discuss in a distinct section the subject of explanation through simulations but mentions it only in the larger context of epistemic virtues of simulations. Instead in their review paper on philosophy of simulation Grüne-Yanoff and Weirich address in a special section the problem of explanation through simulations. Among the few authors that explicitly discussed the subject we can find Paul Weirich, Till Grüne-Yanoff and Ulrich Krohs.

One could from the beginning claim that the quest for explanatory virtues of simulations is in need of disambiguation. The ambiguity is coming actually from the not yet clarified nature, status and place of simulations as scientific tools. One might say it is in a way similar to the same quest regarding models; nevertheless in the last case there is a more recent consistent literature that offers some orientation. In case of models there are situations in which the problem is better articulated (as in case of theoretical models and can therefore be addressed by invoking the previous research attempts on explanation). One way to clarify this ambiguity is therefore to rebrand it in a modeling context. The solution is only a partial one since there are kinds of simulations for which the underlying model does not seem to have a prominent explanatory role without the implemented simulations.

Let's make some needed references to the different simulations considered. The first sort of simulations discussed in the literature and also the most widespread in scientific practice. They are used in physical and engineering sciences and implement the differential equations that model the system. Ulrich Krohs[18] is one of the authors that argue for the idea that such simulations do not explain in a direct way but only in an indirect way, mediated by the underlying theoretical model. The problem of explanation through simulations is in this case redefined as the problem of explanation through models.

The above solution is only a particular one that does not justice to the existing variety of scientific simulations. In case of another type of simulation the above move does not hold. In social sciences researchers use agent-based models that involve simulating the actions and interactions of many agents in long run. The goal of the investigation is to capture the emerging patterns that result at a macro-level. We will see how this works in case of a concrete situation that I will be later discussed in some detail. The theoretical model in such

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18 In Krohs, Ulrich, 'How Digital Computer Simulations Explain Real-World Processes', *International Studies in the Philosophy of Science*, 22(3), 2008, pp. 277–92.

cases presents us a static setting that describes the agents and the rules through which they interact and could be seen as doing only partially the explanatory workload of the simulation. Its implementation meaning the multiple runs through which the macro-patterns are generate, is actually contributing in an essential way to the explanation. There makes no sense to place the entire explanation in the realm of the theoretical model as in the previously discussed type of simulation.

A broader strategy that offers itself from the beginning in order to attack the problem of explanations through simulations is to see which of the already existing approaches on explanation fits the needs of such an inquiry. Given the rich literature on scientific explanation and the large range of approaches one might find inspiration from at least one of them. In fact this is a direct way to deal with the topic and also a necessary first step of addressing it.

If we are to look at the classical account that lies at the origin of the explanation debate – Hempel's deductive-nomological model – that conceives explanation as subsumption of facts to be explained under scientific laws or lawlike generalizations, one would find only a limited modality to pursue the investigation into explanatory virtues of simulations. The best move in order to claim such an approach as proper for our needs is the one mentioned above that makes reference to the underlying theoretical model. The underlying model incorporates the scientific laws and lawlike generalizations in its structure making them relevant to the situation under investigation. Simulations do not seem to have a particularly direct contribution to the explanation; one might see them as only instrumental, as auxiliary techniques that facilitate the finding of a solution for the equations that express the scientific laws Involved.

The above solution is limited to a specific type of simulations and diverts the attention on the richness and importance of simulations in today's scientific practice. In fact one may notice that no author tried to defend such a position and even the reference to the explanatory underlying theoretical model involves a larger perspective that does not restrict to a unique general account of scientific explanation. Other approaches on explanation seemed to enjoy more attention.

The unification approach[19] seems more adequate for the theoretical dimension of science for its big story about explaining the

[19] The approach that constructs explanation as unification promoted by Friedman's & Kitcher's accounts. For a good introduction one might use Salmon's book *Four Decades of Scientific Explanation*, Pittsburgh, University of Pittsburgh Press, 2006.

world. Nevertheless an attempt made by Juan Duran and presented in his talk at the conference *Models and Simulation 5*[20]. The class of simulations that he is looking at is characteristic for physical and engineering sciences and is related to the solution issue for partial differential equations. He modifies Kitcher's unification account in order to claim unification and explanation in a simulation context. Of course one would notice from the beginning that his account is also restricted to a specific class of simulations and does not do justice to their diverse nature. Unlike the appeal to the Hempelian account, this approach does not expedite the problem to models and the laws they incorporate. But this attempt to apply the unification account is singular in the philosophy of simulation landscape and it exposes its limitation originating mainly in its global theoretical character.[21]

The causal approach to explanation has drawn attention of the researchers in recent debates. Its success is mainly due to the more general and flexible idea that it incorporates, the one of tracking causal connections as the core of the process of articulating explanations. Recent proposals and debates on causal explanation unveiled the viability of the subject that survived the collapse of the explanation topic agenda.

The idea of simulation as explanatory when tracking causal links is also an appealing for its unification potential. Both the equation-based simulations and the agent-based simulations discussed earlier could be claimed to deliver some sort of causal information that might be considered as causal explanations. In simulating classical dynamics described by some differential equations this interpretation is directly linked to the equations rendering the causal story of the system. Few social scientists expressed also their conviction that agent-based models are in search of causal explanations. It might be claimed that in this last case simulations are used to generate a diversity of possible causal scenarios[22] that could be interpreted as potential explanations but not as actual ones.

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20 Conference *Models and Simulation 5,* University of Helsinki, Helsinki, Finland, June 2012.

21 A more detailed discussion of this characteristic of the unification approach could be found in my book *Explanation and understanding through scientific models: perspectives for a new approach to scientific explanation* Iasi, Institutul European, 2012.

22 This issue is discussed by Till Grüne-Yanoff in his paper ,'The Explanatory Potential of Artificial Societies', *Synthese*, 169(3), 2009, pp. 539–55.

Recently Marchionni and Yilkoski[23] used an account on causal explanation proposed by Woodward[24] that construes causality as counterfactual dependency in order to capture the explanatory potential of agent-based models (ABM). Their approach involves also the reference to mechanisms seen as descriptions of the networks of counterfactual dependencies, involving this way the influential and widely discussed idea of mechanisms. An explanatory model exposes the ingredients of such a mechanism representing this way the dependencies in a cognitive salient mode.

The idea that ABM simulations would provide causal explanations was criticized by Grüne-Yanoff[25]. He argues against such an interpretation as failing at least in some specific simulations as the so called artificial societies. One failure resides in the lack of validation of the causal laws that are assumed sometimes to be caught through the behavior rules of the agents. Grüne-Yanoff uses a particular example of an extinct society (of the Anasazi population) for which we have only indirect information of such rules. The idea that simulations will suffice to provide potential causal explanations is dismissed due to the absence of any "filter", i.e. a way to select an actual explanation from the large number of possible causal scenarios. Unlike Marchionni & Yilkoski he dismisses even Woodward's account as useless for providing such a filter due to the lack of independent evidence needed for the invariance of the relevant counterfactual statements. Instead he offers us a non-causal approach on the explanatory virtues of such a simulation.

His proposal takes such a simulation to provide rather a potential functional explanation. Functional explanations were discussed from the beginning in the literature[26] on scientific explanation as a particular sort of explanation limited to some scientific areas as biological sciences or social sciences. Such explanations are meant to explain the existence of a component of a system by reference to the function it performs as a component of that system; for example an explanation of the existence of hearts in organisms by pointing to the necessary functions performed in the organism that contribute

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23 Marchionni, Cathrina, & Ylikoski, Petri. 'Generative Explanation and Individualism in Agent-Based Simulation', *Philosophy of the Social Sciences*, 43(3), 2013, pp. 323–340.

24 Woodward, James, *Making Things Happen: A Theory of Causal Explanation*, Oxford University Press 2003.

25 In the same previously cited paper.

26 In Hempel's book *Aspects of scientific explanation* or Nagel's *The Structure of Science: Problems in the Logic of Scienific Explanation.*

to the well functioning of the entire organism. Grüne-Yanoff prefers a particular variant of the functional explanation as articulated by Cummins[27]. In Cummins' approach the capacity of a system to perform adequately is explained in terms of the capacities of the components it contains, and how they are organized. Nevertheless for Grüne-Yanoff the specific simulation discussed fails short to be an instantiation of the potential functional explanation due to the fact that it fails to reproduce the end part of the population evolution curve.

One of the few authors that explicitly advanced a general account for the explanatory virtues of simulations is Paul Weirich[28]. He delimits his intended target to simulations that are guided by models provide us objective explanations not only tentative ones or explanatory attempts. Simulations draw on the explanatory power of the underlying models. According to him, simulations provide explanations by identifying some of the factors at work in that situation. Rarely do they give us full explanations but usually they pick out only some of the factors and provide this way only partial explanation. In order to be partial, an explanation should provide "an accurate account of some factors explaining the phenomenon; that is, it describes their interactions and effects, or their workings, with precision"[29]. In this sense the Anasazi case mentioned previously cannot be taken as a partial explanation since it lacks such precision and accuracy.

I explicitly discussed and evaluated in detailed Grüne-Yanoff's proposal elsewhere[30]. My evaluation regarding the explanatory virtues of ABM models as the one in Ansazi simulation is to take such processes as providing explanatory suggestions that are still subjected to further qualifications. So such a simulation would make rather some explanatory suggestions. It indicates possible ingredients for an explanation and possible relations among them and it meets also Weirich's idea of factor identification. These factors could be further used in a functional explanation or in a causal mechanism explanation of a social system. The simulation does not impose a choice – so it remains an explanatory open suggestion that could be read in

27 Cummins, R., ,Functional analysis', *Journal of Philosophy*, 72 (20), 1975, pp. 741–65.

28 Weirich, Paul, 'The Explanatory Power of Models and Simulations: A Philosophical Exploration', *Simulation & Gaming*, 42(2), 2011, pp. 155–176.

29 Weirich, cited work, p. 159.

30 In David-Rus, Richard, 'Explaining by using artificial societies', *European Journal of Science and Theology*, 8(3), 2012, pp. 103–13.

different keys. A further detailed articulation has to be undertaken in a proper context of inquiry. This context is substantiated in the frame of a particular area of research form an empirical science that deploys the formal means and the exploration through simulations. The relevant questioning fall into the realm of this scientific area that determines also the 'explanatory virtues' of the simulations involved.

Morals and perspectives

I have tried in the first sections to offer a brief overview of the radically new direction of research in philosophy of science – the philosophy of simulation. The subject appears as an unsettled one, in search of its own identity and place in the larger agenda of the field. The novelty of the subject could make one become enthusiastic. One might temper his/her enthusiasm as some authors argued taken into account the continuity with the older philosophical agenda. Nevertheless considering the quite recent scientific and especially technological advancement that constitute the computational turn in science, new insights and challenges for philosophers might arise. This overall situation is reflected also in the particular subject of explanatory qualities of simulations in the overall economy of scientific inquiry.

After presenting in the last section the main ideas and directions regarding the explanatory virtues of simulations I'll try in this last conclusive section to emphasize some major morals resulted from the recent developments.

A first such moral is that we might call on a transfer of some conclusions from the explanation debate that seems to hold in the context of this particular inquiry. The main moral concerns the fact that we should not expect a unique, general schema available for all sorts of simulations. As I tried to present in the previous sections different kinds of simulations disclose different types of explanatory virtues. A second modulation in the explanatory characteristics of simulations is further induced by the particular field of application. In this sense the explanatory interest lies within the realm of the scientific area that deploys these formal tools. Simulations per se could therefore count as only half-realized or half-empty explanations (explanatory suggestions) for the real inquiry.

The third level of particularization is the one of the context of inquiry that captures the situation in practice. Even in the same scientific area the researchers might be after different answers and so different explanations. This narrow context adds a new level of contextuality and induces an additional constrain that might determine the explanatory virtues of simulations. Reaching a more general level one might claim that a pluralistic view on explanation through simulations is the most plausible one given the actual research landscape and results in philosophy of science.

The other interesting moral that emerges from the actual tendencies in philosophy of science draws on the subject of understanding. As I have discussed in another paper[31] the topic of scientific understanding seems to attract the attention of philosophers of science in recent years. Overcoming the inhibition set by the received view esp. in the frame of the explanation topic, the subject of scientific understanding has the potential to open new insights into old problems and reshape the philosophical analysis of scientific knowledge and practice. The move from the quest of explanatory virtues to the clarification of the kind of understanding that simulations could provide us might open new perspectives for analyzing the roles and position of simulations in the economy of scientific thought. Lipton suggestion[32] to take into account also the possibility of forms of understanding that are not generated through explanation i.e. understanding without explanation seems to engage the research in a quite unexplored area and contribute to an adequate analysis of simulations.

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