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The Quantum Turn and the Post-post-digital Future of Computer Art

The idea of quantum simulation, first considered by Richard Feynman in his influential 1982 lecture "Simulating Physics with Computers"[2], introduced a peculiar shift not only to the notion of computer simulation but to the notion of simulation in general. In this paper, I examine how this shift is bound to change the way we think about the computer as a medium of art and how first traces of this change can be detected in the relatively new media art sub-genre of material or proto-computing.

Computer simulation usually denotes the computation of solutions to, or the 'articulation'[3] of, a mathematical model of a real-world process with a different process that may be physical or symbolic. A necessary prerequisite to the latter, as to all human understanding of real-world processes, is a symbolic distance between the simulation and the simulated. Whereas purely language-based "description" realizes this symbolic distance as one big leap from the material to the symbolic, in terms of computer simulation we have to distinguish three consecutive steps: numericalization (in the form of differential equations), discretization (in the form of difference equations), and mediatization (in the form of binary computation).

Each step realizes a higher level of abstraction, accumulating to a relation between the simulation and the simulated that can be regarded as as least as arbitrary as the relation invoked by purely language-based description. The simulation, however, is still recognized not only as a valid representation of the simulated (as a description would be), but as a model of the simulated, as a representation that not only points to the real-world process it represents but that claims to reproduce its functionality.[4]

Bruno Latour suggests that this preservation of functionality is possible because at every step of the process of abstraction "each element belongs to matter by its origin and to form by its destination; it is abstracted from a too-concrete domain before it becomes, at the next stage, too concrete again. We never detect the rupture between things and signs, and we never face the imposition of arbitrary and discrete signs on shapeless and continuous matter."[5] The oscillation between the material and the symbolic[6] forms what Latour calls a "chain of reference". The transformation from

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[2] Feynman, Richard P.. "Simulating physics with computers". In: Journal of Theoretical Physics 21 (6), 1982: 467-488.

[3] Schweber, Sam; Wächter, Matthias. "Complex Systems, Modelling and Simulation". In: Studies in History and Philosophy of Science Part B: Studies in History and Philosophy of Modern Physics 31 (4), 2000: 583-609.

[4] The exploration of this assumption's ontological truth is subject of a whole discourse within the history of science community. For an extensive overview see Frigg, Roman and Hartmann, Stephan, "Models in Science", The Stanford Encyclopedia of Philosophy (Fall 2012 Edition), Edward N. Zalta (ed.), URL = <http://plato.stanford.edu/archives/fall2012/entries/models-science/>.

[5] Latour, Bruno. "Circulating Reference: Sampling the Soil in the Amazon Forest". In: *Pandora's Hope: Essays on the Reality of Science Studies*. Cambridge, MA, 1999. Interestingly enough, this is also how contemporary computers work: through levels of abstraction that each treat the levels below them as "black boxes" of which only certain "public" properties may be considered for further computation.

[6] Latour famously expands on this idea in his Actor-Network theory that he developed together with Michel Callon and that includes the idea of "translation" as its central concept. See Latour, Bruno.

material to concept and the formation of an arbitrary relation presents itself not as one big leap, but as a series of tiny jumps that are somewhat easier to digest, sometimes forward, sometimes backward, sometimes without any movement at all.

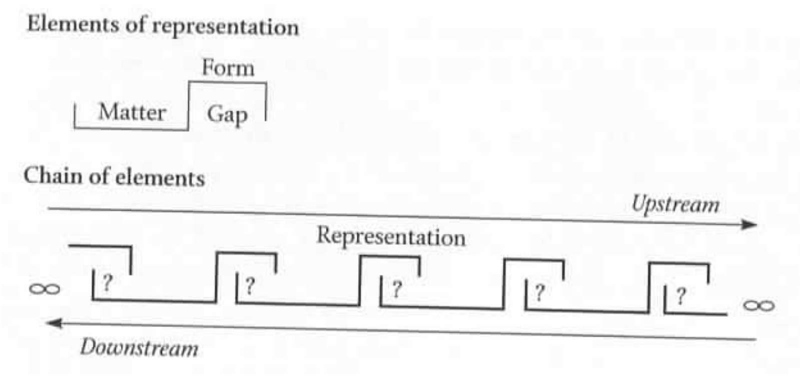

Fig. 1: Bruno Latour, the chain of reference[7]

For instance, as we measure a real-world process we come up with a series of symbols - in the case of computer simulation most likely numbers - that represent some property in space and time. In itself, this is a complex achievement of our abstract faculty already. The numbers, however, appear as "raw data"[8] to the next step in the chain of reference. Similarliy, at every step the symbolic is treated as material to the next level of abstraction.

In the light of this realization, let us look more closely at the three steps in the chain of reference that can be constructed for the notion of computer simulation. In the first step, data gained from the observation of material processes is casted into a differential equation. In the second step, this differential equation is treated as the material for a difference equation that usually involves some kind of approximation. In the final step, this difference equation is fed into a universal machine that calculates its results. The existence of an intermediate step of the "visualization" of some "raw data" is likeley but we are not concerned with this dimension of the chain of reference in this paper.[9]

Our intuition tells us that this should be a more or less infallible method, given a good enough understanding of the real-world process we would like to model. As it turns out, however, the process has one critical breaking point that comes to light through its application to quantum processes. This breaking point lies within the

[7] Latour 1999, 70.
[8] As Claude Lévi-Strauss discovered that even the mythological antipodes of "raw" and "cooked" translate to well-structured abstract knowledge[8], it should not come as a surprise that "raw data" does not present itself as an antinomy to us. See Lévi-Strauss, Claude. *Mythologiques I : Le Cru et le cuit*. Paris: Plon, 1964.
[9] See Latour, Bruno. *Science in action. How to follow scientists and engineers through society*. Cambridge, MA, 1987. Inge Hinterwaldner explores this dimension - in particular regarding the operativity of visualizations - even further in Hinterwaldner, Inge. "Parallel Lines as Tools for Making Turbulence Visible". In: Representations 124 (1), 2013: 1-42

seconds step, discretization. Because quantum mechanics is inherently based on probability, discretization fails at a certain, not very high level of complexity within the simulated process.

As Richard Feynman explains, "one way that we could have a computer that simulates a probabilistic theory, something that has a probability in it, would be to calculate the probability and then interpret this number to represent nature."[10] But then we face "a problem about discretizing probability. If you are only going to take k digits it would mean that when the probability is less that 2^{-k} of something happening, you say it doesn't happen at all. In practice we do that. If the probability of something is 10^{-700}, we say it isn't going to happen, and we're not caught out very often. So we could allow ourselves to do that. But the real difficulty is this: If we had many particles, we have R particles, for example, in a system, then we would have to describe the probability of a circumstance by giving the probability to find these particles at points $x_1, x_2, ..., x_R$ at the time t. That would be a description of the probability of the system. And therefore, you'd need a k-digit number for every configuration of the system, for every arrangement of the R values of x. And therefore if there are N points in space, we'd need N^R configurations."[11]

Taking this even further, Feynman explains that we will most likely end up with an even higher number of configurations, like N^N, so that "doubling the size of nature" (meaning the part of nature that we are trying to simulate) would lead to an exponential growth in the required computational power.

The reason for the rupture in the chain of reference as we try to simulate a quantum system, as it thus turns out, is the excessive (usually exponential) complexity of inherently non-deterministic quantum problems within the deterministic computer systems of today. Hence, the goal of quantum simulation is to have "the number of computer elements required to simulate a large physical system [...] only to be proportional to the space-time volume of the physical system"[12] in order to reduce the complexity of such problems to be polynomial. That, however, is only possible if the physical system of the simulation has the same properties as the physical system of the simulated. This is where Feynman introduces the idea of quantum computing, of a computer performing calculations through basic elements (later called qbits) that make direct use of quantum processes such as superposition and entanglement.

We will not go further into the technical aspects of quantum computing (or experimental quantum simulation[13], for that matter) in the framework of this paper as the ontological consequences are strikingly evident at this point already: Quantum

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[10] Feynman 1982, 471

[11] Feynman 1982, 472

[12] Feynman 1982, 469

[13] In using the term "experimental quantum simulation" I am referring to non-universal quantum simulators that can only be used for the exploration of very specific quantum properties but that are easier to realize. In comparison to a full quantum computer, "if we are more modest and only demand our simulator to imitate certain physically interesting systems that cannot be simulated with classical computers, a[n experimental] quantum simulator may be easier to construct, but still would be an important device for the development of science and technology." Cirac, J. Ignacio; Zoller, Peter. "Goals and opportunities in quantum simulation". In: Nature Physics 8, 2012: 264-266.

simulation means not only the simulation of quantum processes, but the simulation of quantum processes with quantum processes. Quantum simulation necessarily requires nothing less than the *simulated* to become the fabric of the *simulation*. Hence, for the notion of simulation, what used to be a complex process of negation through representation becomes identity, although a curious, not-quite, mediated kind of identity.

Of course classical computers are and always have been physical machines as well, machines that use material processes on the atomic level to represent abstract symbolic operations. In this regard, quantum simulation could be understood as merely a very specific application of computer simulation that requires a different set of tools.

Hence, it is not so much the ontology of technology that is challenged by quantum simulation, but the notion of the post-digital.

The idea of the post-digital was

Instead, quantum simulation revives Friedrich Kittler's dogma that "there is no software"[14]. Kittler, in his seminal text of the same name, posits that the constraints present in computer hardware translate themselves through whatever number of levels of abstraction into the software dimension. Though Kittler's argument is mainly concerned with Foucauldian power relations inscribed in the hardware, it gains in persuasiveness in the light of quantum computing, as suddenly, we end up in the realm of the *post*-post-digital, where the chain of reference is a circle, the maximum level of abstraction leads right back to the concrete and all black boxes become translucent.

The concept of the post-digital hast gained momentum (...)

The post-post-digital future, as it seems, is a future of a more radical fusion of software and hardware than ever before.

Historically, this (FPGAs etc.)

Historically, while the liquefaction of hardware with the invention and popularization of programmable logic devices, hardware description languages and related ideas was already a step towards this future, quantum simulation is the pivotal concept for it to become a critical mass.

If we finally consider the computer as a medium of art, Adorno's idea, that somehow art can function as a "social antithesis to society"[15], being both deeply connected to the fabric of reality and at the same time completely removed from it, realizes itself in a peculiar way: quantum superposition as applied dialectics. And while the realization of quantum computing (not to speak of quantum computing in an aesthetic context) may still take some time, computer art increasingly turns to all the

[14] Kittler, Friedrich. "Es gibt keine Software". In: *Draculas Vermächtnis: Technische Schriften*. Leipzig, 1993

[15] Adorno, Theordor W.. *Aesthetic Theory*. Translated by Robert Hullot-Kentor. London, New York, 2004

peculiar consequences of quantum simulation.

A symptom of this turn is a subgenre of media art that Mitchell Whitelaw described as proto-computing and that could also be described as material computing. (...)

Is this enough, however, to talk about a quantum turn (that is undeniably happening in science) in art? (...)