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Conceptual Superposition

The Aesthetics of Quantum Simulation

The idea of quantum simulation, first conceived by Richard Feynman in his influential 1982 lecture "Simulating Physics with Computers"[2], introduced a peculiar new way of thinking about computer simulation and the relation between the material and the symbolic in general. In this paper, I examine the conceptual implications of quantum simulation. I argue, that these implications can be understood as a form of conceptual superposition - which is, at its very core, an aesthetic principle.

Without taking quantum simulation into consideration, computer simulation usually denotes the computation of solutions to, or the 'articulation'[3] of, a mathematical model of "real-world" material processes. A necessary prerequisite to this articulation, as to all human understanding of "real-world" material processes, is a symbolic distance, a non-identity 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

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[2] Feynman, Richard P.. "Simulating physics with computers". In: Journal of Theoretical Physics 21 (6), 1982: 467-488. See also Feynman, Richard P.. Lectures on Computation. Addison-Wesley Publishing Company, 1996.

[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.

to distinguish three consecutive steps of symbolization: formalization (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, rendering the resulting relationship between the material and the symbolic to be at least as arbitrary as the one 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 processes it represents but that claims to reproduce their functionality.[4]

Bruno Latour suggests that this preservation of functionality takes place 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."[5]

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[4] The exploration of this assumption's ontological truth is subject of a whole discourse within the history of science. 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.

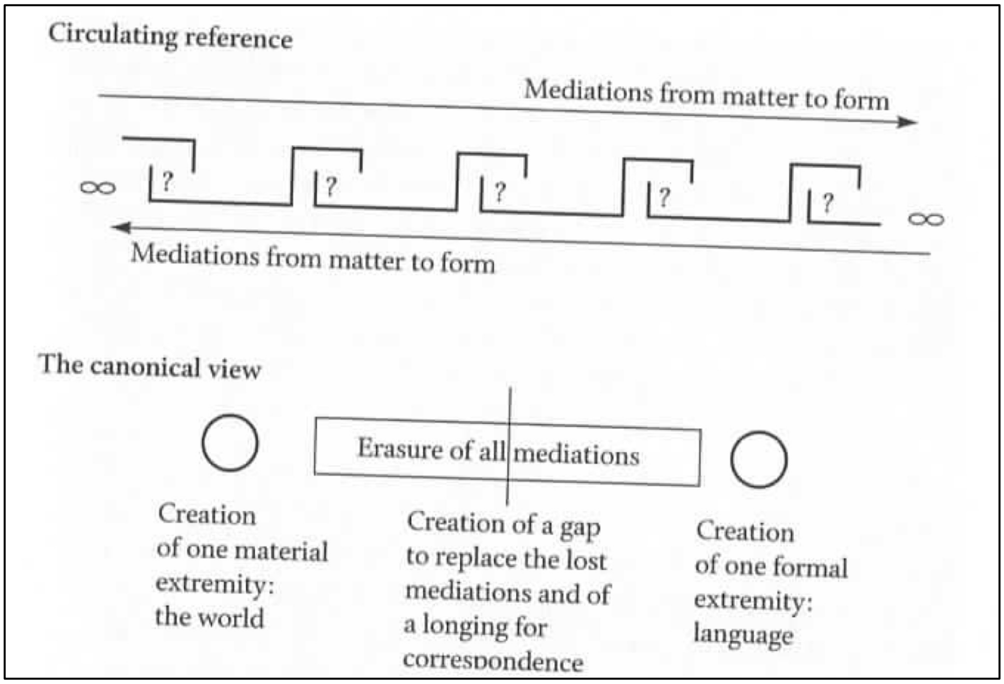

Fig. 1: Bruno Latour, the chain of reference and the canonical view[6]

This oscillation between the material and the symbolic[7] forms what Latour calls a "chain of reference". It is important to keep in mind that this chain of reference does not replace the symbolic distance, it is the symbolic distance. The discreteness of the symbolic operation is kept, the wide gap (of, for instance, a purely language-based description that Latour calls the "canonical view") is just replaced by a number

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[6] ibd., 73

[7] 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. *Science in Action. How to follow scientists and engineers through society.* Cambridge, MA: Harvard University Press, 1987 and Latour, Bruno. *We Have Never Been Modern*. Cambridge, MA: Harvard University Press, 1991.

of smaller gaps and those gaps still need to be "jumped" and cannot be "bridged"[8].

For instance, as we measure a "real-world" material 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 first step - formalization - is a complex achievement already, as it is based on a variety of basic human faculties (for instance the concept of the set[9]). The numbers, however, appear as "raw data"[10] to the next step in the chain of reference. Similarly, 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 that can be constructed for computer simulation. In the first step, data gained from the observation of "real-world" material processes is cast 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, consisting of the "visualization" of "raw data" to determine the next step's design, is likely but we are not concerned with this aspect of

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[8] However, as the symbolic operation exists in the "real", material world, as a faculty of "real", material human beings, this interpretation itself is fueled by the very same symbolic operation it is looking at.

[9] It is no coincidence that all of mathematics can be constructed from set theory.

[10] As Claude Lévi-Strauss discovered that even the mythological antipodes of "raw" and "cooked" translate to well-structured abstract knowledge[10], 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.

the chain of reference in this paper.[11]

Our intuition tells us that this method should be more or less infallible, given a good enough understanding of the "real-world" material processes we would like to simulate. As it turns out, however, the method fails miserably when it is applied to quantum processes. Because quantum mechanics is inherently based on probability, the second step, discretization, becomes impossible even for low complexity quantum processes. Richard Feynman argues that, when it comes to the computer simulation of quantum particles, 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, ..., $h_{r.}$ 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.[12]

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

[11] See Latour 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

[12] Feynman 1982, 472

nature that we are trying to simulate) would lead to an exponential growth in the required computational power.

Hence, the reason for the rupture in the chain of reference, when it comes to quantum processes, is the excessive (usually exponential) complexity of inherently non-deterministic quantum problems within the deterministic computer systems of today. That is why the goal of quantum simulation, as defined by Feynman, 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"[13] in order to reduce the complexity of such problems to be non-exponential. That, however, is only possible if the physical system of the simulation has the same properties as the physical system that is being simulated. This is where Feynman introduces the idea of quantum computing, the idea of a computer performing calculations with the help of basic elements that make direct use of quantum processes, such as superposition and entanglement - an idea that has become a major discipline within physics and computer science since its conception roughly thirty years ago.

A parallel strand of research today is concerned with non-universal or experimental quantum simulators that only work for the exploration of very specific quantum properties but are easier to realize. In comparison to a full, universal quantum computer, "if we are more modest and only demand our simulator to imitate certain physically interesting systems that cannot be simulated with classical

[13] Feynman 1982, 469

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."[14]

We will not go further into the technical aspects of (universal or experimental) quantum simulation in the framework of this paper, as the ontological consequences are strikingly evident at this point already: Quantum 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. The chain of reference suddenly becomes a Penrose staircase, where at the highest level of abstraction we fall immediately back to the material - but keep ascending anyway. Quantum simulation treats the material as symbolic, it symbolizes the material - not by referencing it (not even in a mediated way), but by making it an actual symbolic system, that exists in the real world like the electric charges that do not represent, but are our thoughts in the realm of the material. Quantum simulation is a concept at work in the most Hegelian sense[15].

[14] Cirac, J. Ignacio; Zoller, Peter. "Goals and opportunities in quantum simulation". In: Nature Physics 8, 2012: 264-266. See also: Franchini, Fabio et. al.. " Local Convertibility and the Quantum Simulation of Edge States in Many-Body Systems". In: Physical Review X, 4, 041028 (2014).

[15] For Hegel's idea of the "concept at work", see the famous chapter on the dialectics of the master and the slave in the Phenomenology of Spirit: Hegel, G.W.F.. *Phänomenologie des Geistes*. Frankfurt am Main: Suhrkamp, 1970: 137.

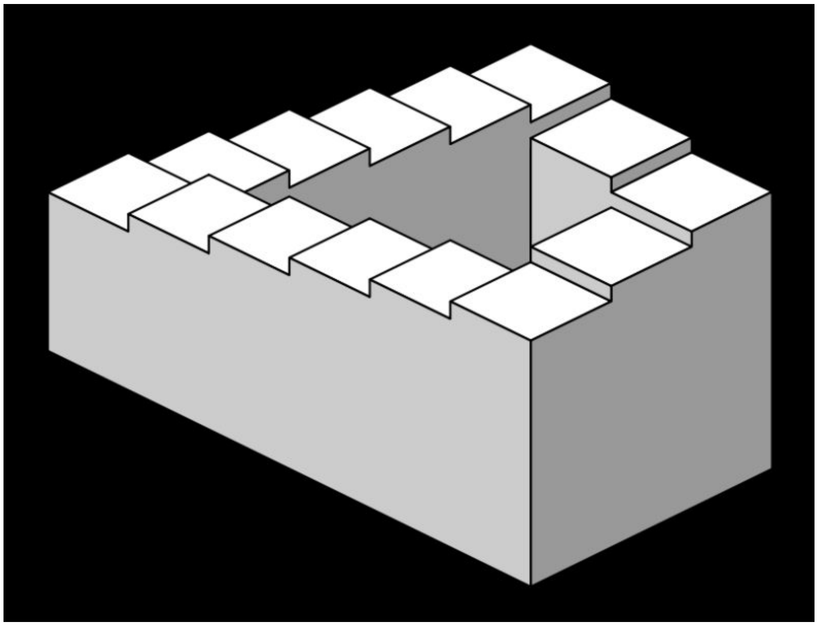

Fig. 2: Penrose stairs

This peculiar process of the symbolization of the material that lies at the very core of quantum simulation, however, seems to be also at work in art, as first described by Walter Benjamin in his investigation of the notion of "Technik".

Taken from Benjamin's famous essay "The Author as Producer", the German original term - in comparison to the term "technique" that is usually used in translations - points to the double character of technology use in a work of art. The English edition's translator's note turns out to be quite aware of this fact: "Benjamin uses the word Technik to denote [the] aesthetic technique of a work, but with considerable scientific and manufacturing connotations. Thus it is also close to "technology" – the technical means by which a work is produced, its means of production"[16]. One should add that when Benjamin speaks of the "work" ("Werk") instead of the "artwork" ("Kunstwerk") there is a similar double denotation. "Werk" without the "Kunst" prefix denotes a mechanism (for example a clock) or even a whole factory. "Technik" thus refers not only to a work's means of production but to the general relationships of production. As Benjamin puts it: "Namely, instead of asking: what is the relationship of a work of art to the relationships of production of the time? Is it in accord with them, is it reactionary or does it strive to overthrow them, is it revolutionary? - in place of this question, or in any case before asking this question, I would like to propose another. Before I ask: how does a [...] work stand in relation to the relationships of production of a period, I would like to ask: how does it stand *in* them?"[17]

This is exactly the process of the symbolization of the material. For the work of art, technology, at the same time, exists as "raw material" and as form, even more, it becomes form without ever losing its material character.

Theodor W. Adorno's concept of the logic of art takes this idea even further. For Adorno, art is the "social antithesis to society"[18], both deeply rooted in the fabric of reality and at the same time completely removed from it. In addition to that, however, it has the same kind of relation with rationality:

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[16] Benjamin, Walter. "Der Autor als Produzent". In: *Gesammelte Schriften II-2*. Frankfurt am Main, 1974: 102.

[17] ibd., 96

[18] Adorno, Theodor W.. *Aesthetic Theory*. Translated by Robert Hullot-Kentor. London, New York, 2004, 8.

> The logic of art, a paradox for extra-aesthetic logic, is a syllogism without concept or judgment. It draws consequences from phenomena that have already been spiritually mediated and to this extent made logical. Its logical process transpires in a sphere whose premises and givens are extralogical. The unity that artworks thereby achieve makes them analogous to the logic of experience, however much their technical procedures and their elements and the relation between them may distance them from those of practical empirical reality. The affiliation with mathematics that art established in the age of its dawning emancipation and that today, in the age of the dissolution of its idioms, once again emerges as predominant, marked art's emerging self-consciousness from its dimension of logical consistency. Indeed, on the basis of its formalism, mathematics is itself aconceptual; its signs are not signs of something, and it no more formulates existential judgments then does art; its aesthetic quality has often been noted.[19]

In other words, art is a coherent reflection on the impossibility of coherence, in the realm of material experience, comparable to metamathematics in the realm of the symbolic[20]. By sculpting experience, art builds up coherence from matter without forcing matter into symbols, but still forming it into a symbolic system - as Adorno points out, art "draws consequences" - logical consequences - "from phenomena". Again: matter, for art, exists at the same time in its material and its symbolic state, it is cast into a symbolic system without symbols - it is in a state of conceptual superposition. This state of conceptual superposition, both within art and quantum simulation, is thus, at its core, an aesthetic principle.

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[19] ibd., 6

[20] See Cantor, Georg. "Ueber eine elementare Frage der Mannigfaltigkeitslehre". In: Jahresbericht der Deutschen Mathematiker-Vereinigung. Leipzig, Stuttgart, Wiesbaden, 1892 and Gödel, Kurt. "Über formal unentscheidbare Sätze der Principia Mathematica und verwandter Systeme I". In: Monatshefte für Mathematik und Physik 38, 1931.