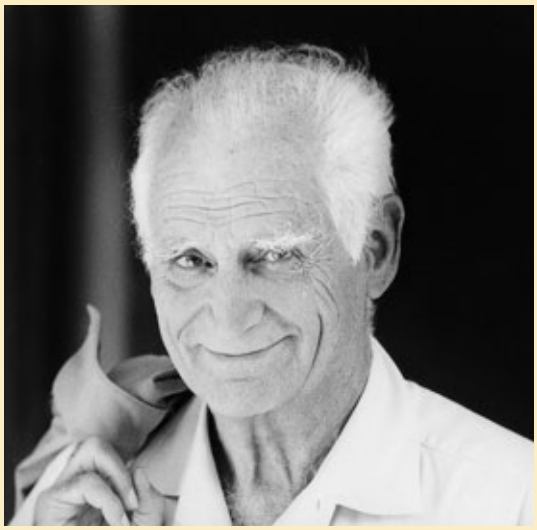
SIMULATION, A NEW TECHNIQUE, AN ANCIENT TRADITION



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The folded forms of one protein rotating and slowly unfolding on the computer screen, allowing glimpses of sites we could never observe directly; long-term models mimicking climate evolution or aging of nuclear waste; or another, of opposite scale, showing the atomic contact of a hyper-sharp tip with a surface… these are commonplace practices – so-called simulation practices –, required by the fact that such processes are outside of the common conditions of experience.
How indeed is one to handle a molecule, or even a single atom, or, conversely, large numbers of constraints over millennia and across the entire planet – continents, seas and atmosphere? None of this is within hand's reach; none of these giga- or nano-magnitudes of space and time may be handled directly in the laboratory. The scales and dimensions themselves thus make such modeling in virtual images a requisite. With their digital, numerical power, only the new technologies may thus accelerate time, expand space, multiply dimensions, constraints and connections, in short contribute to representation of the unrepresentable.

An epistemological shift

These simulation techniques expand the very notion of what is a phenomenon. With his systems of differential equations, Laplace demonstrated, for instance, the stability of the solar system, to a very good approximation. One century later, through celebrated theorems, Poincaré led us to doubt this – though, even before Laplace, the *chevalier* d'Arcy had pointed out, as early as the 18th century, that, for three bodies, the problem turned out not to be integrable. However, we certainly were in no doubt as to the epistemological status of such stability, or instability: this was a result – mathematical, mechanical, probabilistic… In no way would we have thought of them as being "phenomena," or imagined subjecting them to "experiment," since testing or checking them requires hundreds of millions of years.
This is one of the best cases for understanding, with all the clarity in the world, the meaning of the phrase: going outside the conditions of possible experience or experiment. No laboratory could either prepare the experiment, or carry it out. Now a numerical simulation, on the other hand, allows the behavior of the small planets to be described, more chaotic, by far, than that of the major ones, over such a vast time span. A purely mathematical result, or pertaining to celestial mechanics, then becomes a kind of fact, a quasi-experimental quasi-phenomenon. Simulation straddles the usual epistemological classifications, making them porous.

Caution: the qualitative conditions

Better for a surgeon, moreover, to train initially on procedures on virtual images, before incising with his scalpel the flesh and bones of a patient, or for a nuclear weapon to explode on screen rather than in the environment; better that, taking the risk of making mistakes, causing their destruction and having to rebuild them, an architect test in a simulation the seismic resistance of a tower block, a road bridge, or the watertightness of a tunnel.
We have then left the conditions of the experiment, going for its goals, consequences or finality, going from epistemology to economics, from the purely quantitative to prevention of a potential risk or an actual hazard… in short, we are entering the realm of ethics.
Simulation is carried out, out of necessity, in the one case, out of prudence or caution, in the other. In either case, the very concept of experiment is expanded.

Trials or images?

The practice has been known to us for a long time, of using mockups, models or prototypes. Michelangelo would neither sculpt nor put a building, before he had shown Pope Julius II, beside his drafts, preliminary scale roughs of their shared projects. Likewise, thousands of others have acted, or will act with their patrons. Shipbuilding or series production are only launched once one has tested, put through trials, verified… a prime exemplar, a number zero… whether it be a new nave, a ballpoint pen or a residence. We invariably experiment on a pilot, a control. Of course, risks remain: that of scaling effects, for the ship, once finally built, may not behave at sea as the initial model in the testing tank; or the risk of the exceptional, since ultimately no one single product assimilates to any other one. But that object does exist, the artist, the patron, the engineer, the customer… can touch it. Thus the trial is a reassurance.

Here, on the other hand, nothing but images. What we cannot make, we picture. What we cannot fabricate, what we are in awe of, we represent. Thus does the virtual arise out of the actual. Are we to judge simulation techniques in this light? Does the very word not betray a dissimulation, whose artfulness is ultimately bent on betrayal? Is switching to images no more than a retreat into an imaginary, where the so-called experimental sciences experience a loss of "reality"? At times, I can detect, in the eye of some Ancients, just such a supercilious suspicion. These new methods, they claim, will imbue the young with bad habits; they will lose the sense, the feeling for the concrete. Gone is the hand, gone the plough, gone the hand to the plough. But what do we mean, with such practical parlance, and agricultural metaphors?

The history of science can provide an answer to these questions. It sometimes holds a contemporary to be most ancient, and the ancient, by way of compensation, to be rather modern. No, I do not believe one is switching quite so suddenly, and only nowadays, from "reality" to its "representation." Let these ancients thus take heart, in reflecting on their own reality, on the concrete their own hands handle, and finally on the meaning of experience, and experiment.

What does one term an experiment?

From when can one date the first experiment, whether true or imagined? According to many ancient texts, from Pythagoras himself. Having heard, as everybody else, the sounds made by a blacksmith hitting with his sledgehammer the hot iron on the anvil, he sought, so it is said, to reproduce them, by hanging different weights on strings, which were set to vibrate; in such manner did he measure, for the first time, the harmonic ratios of third, fourth, fifth… How does this experimentation begin, if not by a simulation? By switching from strike of sledgehammer on resounding steel, to the strings he set to vibrate, by switching, I say, from the passively perceived to the actively produced, Pythagoras reproduced sounds; seeking to imitate them, he simulated. Agreed, he made use of strings and weights, both tangible and resilient; it remains that, with such "hard" resources, reproduction does imitate and simulate.

What, then, does one term an experiment? When practitioners call it a "manipulation" (as in French), they know such a term assumes a hand, and a certain material before it. Now the said manipulation virtually never took place out in the open or out there in nature, as one is wont to say, nor on the things themselves, directly on that dough-like wax mentioned by Descartes, for instance. Pythagoras cuts his ramble short, and, as one would say nowadays, leaves the field and pensively goes home, reconstructs the phenomenon he seeks to investigate, refines it, frees it from parasitic noises, he does not take it up "as is" or as he was able to identify it *in situ* or *in vivo* – but he does reproduce it and repeat it. But what do these words mean: reproduced, and repeatable, unless it be imitable and simulated?

For I forget which anniversary, we had endeavored to repeat Blaise Pascal's celebrated experiment on atmospheric pressure, reputedly performed atop the Puy de Dôme. Needless to say, we failed in the attempt. How was one to transport, in the conditions prevailing at the time, in other words by donkey, without breaking it, a fragile, nigh-interminable column, and, moreover, one made in the early years of glass manufacture? We soon came to suspect that Pascal had indulged, as so many others, and in this as in other instances, in thought experiments. He would simulate in narratives, as we do on computers!

Palais de la Découverte

Torricelli's air-pressure experiment was reputedly repeated atop the Puy de Dôme by Périer, at the behest of Pascal. One may wonder, today, whether the narrative of that experiment was not… a simulation!

And to actually carry out such experimentation, as any other, it would be advisable to build and set up cabinets, as they used to be called, laboratories in other words, that would be gradually transformed by instruments in both appearance and in size, rather than go out in the field, on the ground, where we do not control the conditions. In this novel environment, highly abstract, artificial, technical, elaborate, sophisticated even, what are the ancient or classical physicists doing, or even those of the 19th and 20th centuries, if not reproducing, that is imitating or simulating facts that unfold out in the open? Where is the concrete, the "actual"? On top of Puy de Dôme, or on the laboratory bench? On the latter, is one not, from the first, engaged in simulating what happens on the former? Let me state it again, the point that, in the laboratory, one is imitating a fact through an apparatus of glass, brass wires, or iron rods… in short by means of hard things, and not signs or codes, in no way precludes that this still stands as reproduction, hence imitation. Moreover, it must be repeatable by any physicist. Look again, carefully, at the celebrated maxim: "*In identical circumstances, identical causes produce identical effects*;" thrice repeated, the word *identical* does carry conviction, admittedly extracts our support as to this principle, however, if one examines what it means, this requires, once again, imitation. Maximized control of conditions and realization guarantees the repetition's fidelity.
And what, finally, does one mean by "conditions of the experiment"? The set of requisites that make it reproducible, controllable and faithful unto itself, in other words requisites for simulation. Does every experiment, then, somehow presuppose several kinds of simulation? Who can deny this? It reaches outside the "actual," as is, from the very dawn of experimental physics.

Variations on the actual

"Throughout the ages, man has espied falling bodies, was amazed by thunder and rainbow, contemplated the stars…" Thus runs the statement of the commonest of shibboleths in the history of science, as practiced all too naively: without fail, you may recognize bad books by just such an opening. How is one to rid oneself of such foolishness? By stating, again and again, be it opportune or importunate, that there were neither stars nor falling bodies nor thunder for the Chaldaeans or the Chinese, nor yet for the Egyptians or Aristotle either, even though they might at times use the same word, give or take the translation; that the heaven, to their eyes, did not have that selfsame reality it possesses to the eyes of today's astrophysicists – whose data, moreover, are altogether different from those of a Galileo or Tycho Brahe… Newton assessed the world to be four thousand years old… Ancient Greek does not even have a word to say "volcano," even though one of the most resplendent of Hellenic civilizations perished with all its denizens in the Santorin caldera…
Reality changes along with practices and fears, religions and myths, theories and means of observation, with tools and apparatus. By the same token, commonly-held perception and the very objects change as to their objectivity. Deity, soul of the departed, hole in a brazen shield, shoulder of Orion… a star takes millennia to turn into what it appears to us as being nowadays: an evolving, temporary set of nuclear reactions. This "throughout the ages" just never happened, that stable "man" had his abode in no place, the "real" world and "real" objects varied over varying time spans to accord with varying meanings.

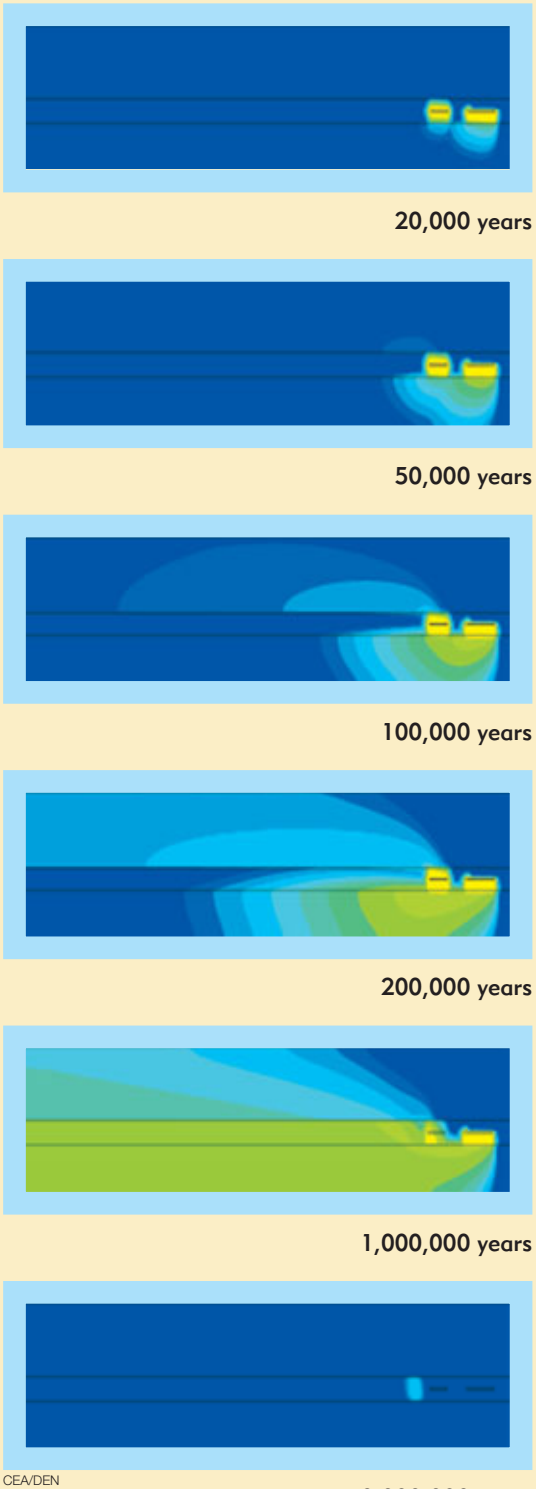
To each generation, or very nearly so, its reality. I have known in my youth – not so long gone after all – scientists, anything but second-rate, fiercely deny the existence of tectonic plates or large biological molecules. They deemed them to be imaginary, virtual… simulated! In this, they were only expressing their own way of being behind the times, and impending retirement. They could not see reality was going over. The reality simulation techniques are concerned with thus seems to me to be no less – or no more – "actual" than that of those supercilious Ancients who believe they, on the other hand, did manipulate it more, and better, than their successors, because they used sliderules, whereas their children took up computers from a tender age. Yes indeed, this reality does depend, in the latter case, on computational power.
Which is not to say there is nothing "real." In stating this, I am not giving in to any relativism, whether subjective, as that of opinions and of tastes, or cultural or sociological, as that of ideologies, of laws, of institutions and customs. To say reality changes does not mean it vanishes. I believe it to be actually present, and a promise, as an unending task, forever yielding to our grasp as some asymptotic horizon, behind the succeeding profiles of theories and truths discovered by sciences in the course of their history. Initially absent, changing over time, but converging to a limit, though sciences know nothing of its ultimate accessibility. That it does exist, the accuracy of our predictions and effectiveness of our applications offer us daily incontrovertible proof.

Variations in laboratories

One ought thus to define generations of experiments or of laboratories, just as one speaks of generations of computers. All are dependent on the state of technology. This technicity changes over time, even as increases may be seen in the fineness and scope of simulations. What is there in common, indeed, between the huge apparatus at CERN, and the self-styled lab at my old *lycée*, where the Atwood machine stood cheek by jowl with the Wheatstone bridge? And what did that room hold in common with those presided over by Galileo's inclined plane, Roberval's scales, and the Magdeburg hemispheres?
The locus for simulations, the scale model of a – well delineated – subset of nature, each state of the laboratory is bent on a different world, that of classical mechanics, that of electromagnetism, that of quantum physics… Whereas previous generations would often follow on one another in one single such state, I shall thus have lived through several states of the laboratory, wherein, for the last one of these states, computers proliferate. Again, is the virtual drawing into the actual, or does it take us out of it?

What does one term virtual?

So far as I know, use of the term does not date from the computer age. The virtual image has served optics since the classical era at least; virtual work has been the concern of mechanics since Lagrange; and atomic physics makes use of that same term, with regard both to nuclei and to the emission of a particle. Even predating the birth of physics properly so called, the virtual was thus imbuing optics and mechanics, then still mathematical and almost bereft of experiment. These three disciplines do indeed investigate "actual" reality, but they have been including in this the possible for quite a long time. Nothing new under the sun.



CEA/DEN

Simulation of a release of iodine into the geological environment by a radioactive-waste disposal site, in accordance with a package-alteration scenario. Only long-term modeling can mimic aging of such waste over millennia.

That the thrust of the possible is presently getting stronger, that it increasingly borders on and surrounds the said "actual," here is a gain that accounts for the world more often than it detracts from its reality. We still think these issues by means of a classical logic, whose basic square displays the opposition of the particular and the general, of assertion and negation. I hold, for my part, for modal logic: we think a contingent world and experiment on it, by manipulation of the possible up to the limits of the impossible, and discovery of necessary laws. More flexible than the older one, the square of modes yields a better account of our breakthroughs. By patiently plotting the outlines of various sites sculpting certain large molecules, responsible for illnesses, simulations make it possible to discover, or even invent medicines that, by matching precisely the said site, will inhibit its deleterious functions. Though it be obtained by means of possible images, what could be more real, even if contingent, than a cure? What is more "real" than avoiding possible accidents in nuclear plants, or when faced with high-pressure apparatus?

What does one term abstract?

Thus gaining right of abode in our epistemology, the virtual thus occupies a vast space, intermediate between the abstract, on the one hand, and the concrete, on the other, between theory and applications, between mathematics and techniques properly so called. As a link, it binds together what I cannot hold before my eyes and what I can have a representation of. It carries out that function whether it be in the virtual images or work of our predecessors, or in the simulation of climate or the modeling of macromolecules.
Conversely, what, then, is the abstract or the theoretical, if not the totality of all possible virtuality? Mathematics express reality, that is to say all of the possible, and experiments yield profiles of the contingent world. Granted that, *simulation in virtual images extracts the abstract from its own realm to provide us, in turn, with profiles of the latter*. Now, once again, what is an experiment, if not a falsification, in the Popperian sense, of the abstract? Ergo, simulation holds a status similar to that of experiment. That is what I wanted to demonstrate. It broadens it, varies its conditions and its goals, shortens the path between it and theory, and thus gives it a new guise. You may thus understand it as an extension or generalization of experiment. However, from generation to generation, that experimental guise has changed a number of times. Indeed, we have just passed into a new stage, but this is on a path that the history of science acknowledges as canonical.

Simulacra

I cannot resist, finally, the pleasure of quoting, once again and ever more, old Lucretius, whom physicists have stopped reading (Jean Perrin knew him by heart), because he writes in Latin, and Latin scholars never understand, because he does good physics. Over two thousand years ago, he claimed we perceive by means of simulacra; he thus termed diaphanous membranes that broke away from things and flew off, through the air, from perceived to perceiver. Scaling down, they conserved these things' shape and thus came to hit the eye. While bizarre, such an explanation of perception does hit it right, to some extent: these simulacra simulate by way of similitude! We may only ever know through imitation. Gazing at the evolutions, before my bedazzled eyes, of the sites and folds of molecules, I cannot help but dream, with the ancient Latin poet, that they are sending off to me their own simulacra.

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