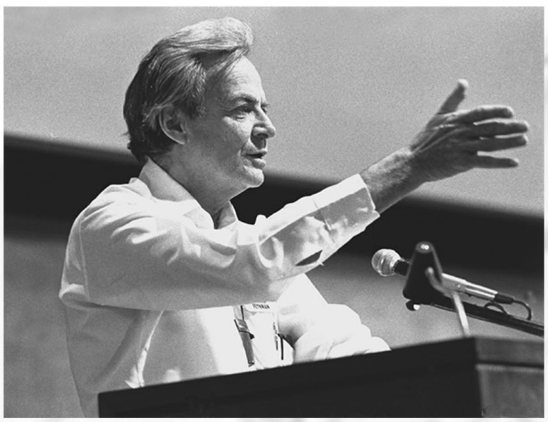
Richard Feynman

On quantum physics and computer simulation

. . . there is plenty of room to make [computers] smaller. . . . nothing that I can see in the physical laws . . . says the computer elements cannot be made enormously smaller than they are now. In fact, there may be certain advantages.
—1959

Might I say immediately . . . we always have had a great deal of difficulty in understanding the world view that quantum mechanics represents. . . . I cannot define the real problem, therefore I suspect there's not a real problem, but I'm not sure there's no real problem.



I mentioned . . . the possibility . . . of things being affected not just by the past, but also by the future, and therefore that our probabilities are in some sense "illusory." We only have the information from the past and we try to predict the next step, but in reality it depends upon the near future . . .I'm trying to get . . . you people who think about computer-simulation possibilities to . . . digest . . . the real answers of quantum mechanics and see if you can't invent a different point of view than the physicists . . .
. . . the discovery of computers and the thinking about computers has turned out to be extremely useful in many branches of human reasoning. For instance, we never really understood how lousy our understanding of languages was, the theory of grammar and all that stuff, until we tried to make a computer which would be able to understand language . . . I . . . was hoping that the computer-type thinking would give us some new ideas . . .

. . . trying to find a computer simulation of physics seems to me to be an excellent program to follow out. . . . the real use of it would be with quantum mechanics. . . . Nature isn't classical . . . and if you want to make a simulation of Nature, you'd better make it quantum mechanical, and by golly it's a wonderful problem, because it doesn't look so easy.
—1981

Feynman, R. 1959. There's Plenty of Room at the Bottom. Talk given at the annual meeting of the American Physical Society at Caltech. (Excerpt reprinted with permission from Caltech's *Engineering and Science*.)
———. 1981. Simulating Physics with Computers. Keynote address delivered at the MIT Physics of Computation Conference. Published in *Int. J. Theor. Phys.* **21** (6/7), 1982. (Excerpts reprinted with permission from the *International Journal of Theoretical Physics.*)

On “tiny computers obeying quantum mechanical laws”

. . . although I have done mostly physics, from time to time I pay attention to computers. Two years ago Carver Mead . . . discussed with us [that] there ought to be physical laws about the limits in computer design. . . . I got interested in the problem [the amount of heat generated by an operating computer] and worked it all out. It turned out that Charlie Bennett from IBM had worked it all out five years earlier. . . . if you have a reversible machine, the minimum energy requirement is essentially zero. . . . you can have millions and millions of primitive elements doing the calculation, but if the answer has only 40 bits then 40 kT is the minimum energy needed.

. . . An exciting discovery, made mostly by Fredkin, was that you can make a computer solely out ot reversible primitive elements. . . . With one primitive element [the Fredkin gate] we produce all the effects we need. In addition, the Fredkin gate is reversible. . . . . [and therefore] reversible computation is possible. . . .

The next question was what are the limits in computers due to quantum mechanics? . . . What I hoped to do was to design a computer in which I knew how every part worked with everything specified down to the atomic level. In other words I wanted to write down a Hamiltonian for a system that could make a calculation. Then I could calculate the various effects of the limits due to quantum mechanics.

Now, we can, in principle make a computing device in which the numbers are represented by a row of atoms with each atom in either of the two states. That’s our input. The Hamiltonian starts “Hamiltonianizing” the wave function. . . . The ones move around, the zeros move around . . Finally, along a particular bunch of atoms, ones and zeros . . . occur that represent the answer.

Nothing could be made smaller . . . Nothing could be more elegant. No losses, no uncertainties, no averaging. But can we do it? . . . how can I make the dynamics of quantum mechanics generate a long sequence of unitary matrices? . . . It has been suggested [by Paul Benioff, we believe] that [each unitary] operation . . . can be represented as the action of some Hamiltonian for a definite amount of time. . . . That’s an awful lot of external machinery. . . Let’s get all the atoms into the system. . . [And so, inspired by the ballistic models of Fredkin and Toffoli, Feynman designed a model of a quantum computer in which spin waves would travel through the device to monitor the computational progress. It was the first model after Paul Benioff’s].
—1983

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