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RICHARD FEYNMAN'S CURIOUS LIFE

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A Great Physicist's Visions of a Future for Tiny Objects

Richard Feynman, whose 100th birthday is coming, saw the potential of miniaturisation

The great physicist Richard Feynman, who would have turned 100 next month, left a multifaceted legacy. He transformed the way we do quantum theory, introducing powerful, beautiful new ways to visualise its weirdness. He left brilliant expositions of fundamental physics for students and the general public, and also wrote two best-selling collections of funny autobiographical stories.

One of my favourite Feynman contributions is a now-legendary talk entitled "There's Plenty of Room at the Bottom," which he delivered at California Institute of Technology (Caltech) in 1959. It's a rousing read, still fresh and inspiring. You can easily find it online. (http://www.zyvex.com/nanotech/feynman.html?mod=article_inline)

The "plenty of room" that Feynman referred to is the possibility of putting lots of information, and lots of action, into very small spaces. In the years since, parts of his vision have been realised and surpassed, but not all of it.

His central insight, simple yet profound, was that atoms, though very small, are usable building blocks. Thus, if you can learn to sculpt and prod at the level of atoms, you can achieve incredible feats of compression and miniaturisation. Remember that in 1959, top-of-the-line computers — expensive, high-maintenance and running on vacuum tubes — filled a large room. A modern smartphone is vastly more powerful and versatile.

In the talk, Feynman looked at memory — that is, storing information for later access. One of his examples had to do with storing the text of the *Encyclopaedia Britannica*. He suggested that by running a microscope backward and using concentrated light, one could write the whole thing on the head of a pin. His proposal anticipated how modern lithography sculpts tiny transistors and circuits for computer chips and makes CDs and DVDs.

Feynman then took up the concept of storing bits of information abstractly, in the 0s and 1s so familiar to us today. Here the possibilities, based on the smallness of atoms, passed from impressive to mind-boggling. If we were to build stable bit-storing 5x5x5 cubes, consisting of 125 atoms each, then in Feynman's words: "It turns out that all of the information that man has carefully accumulated in all the books in the world can be written in this form in a cube of material one 200th of an inch wide — which is the barest piece of dust that can be made out by the human eye."

The other main focus of Feynman's lecture was tiny machines. (His 1984 update, "Tiny Machines," is readily available as an online video. [https://www.youtube.com/watch?v=4eRCygdW--c&mod=article_inline]) In the 1959 talk, he envisaged machines, containing perhaps a few million atoms, that could "drill holes, cut things, solder things, stamp things out, mould shapes all at an infinitesimal level": industry at an atomic scale.

Nothing in physics rules this out. Indeed, we all house lots of impressive micromachinery in our bodies. There are clever proteins that can "walk" along fibrous cellular frameworks (microtubules) and transport payloads from one cell structure to another. It's entirely plausible that by combining micromachines borrowed from biology with chemical creations of our own, we will eventually achieve Feynman's vision of atomic industry. In 2016, the Nobel Prize in chemistry went to three scientists working in the U.S., France and the Netherlands "for the design and synthesis of molecular machines."

What's the point? As Feynman put it in 1959, you could "swallow the surgeon," ingesting little robots that could declog your arteries or annihilate tumours. The 1966 movie *Fantastic Voyage* featured that theme (though it went off the rails scientifically).

More profoundly, intelligent units could, like biological cells, carry instructions to make copies of themselves, while allowing for controlled variation. Self-replicating micromachines (not discussed by Feynman) would unleash the magic of exponential growth, opening a new epoch in engineering.

For computation, technology has fulfilled and in many ways gone beyond Feynman's vision. As for micromachinery, we've made a start, but there's still plenty of room for growth.