Gregory Benford - Biotech And Nanodreams

If this century has been dominated by bigness--big bombs, big rockets, big wars, giant leaps for mankind -- then perhaps the next century will be the territory of the tiny.

Biotech is already well afoot in our world, the stuff of both science fiction and stock options. Biology operates on scales of ten to a hundred times a nanometer (a billionth of a meter). Below that, from a few to ten nanometers, lie atoms.

Nanotechnology -- a capability now only envisioned, applauded and longed for -- attacks the basic structure of matter at the nanometer scale, tinkering with atoms on a one-by-one basis. It vastly elaborates the themes chemistry and biology have wrought on brute mass. More intricate, it can promise much. How much it can deliver depends upon the details.

It is easy to see that if one is able to replace individual atoms at will, one can make perfectly pure rods and gears like diamond, five times as stiff as steel, fifty times stronger. Gears, bearings, drive shafts -- all the roles of the factory can play out on the stage that for now only enzymes enjoy, inside our cells.

For now, microgears and micromotors exist about a thousand times larger than true nanotech. In principle, though, single atoms can serve as gear teeth, with single bonds between atoms providing the bearing for rotating rods. It's only a matter of time and will.

Much excitement surrounds the possibility of descending to such scales, following ideas pioneered by Richard Feynman, in his 1961 essay, "There's Plenty of Room at the Bottom." Later this view was elaborated and advocated by Eric Drexler in the 1980s. Now some tentative steps toward the nanometer level are beginning.

Such control is tempting. Like most bright promises, it is easy to see possibilities, less simple to see what is probable.

Nanotech borders on biology, a vast field rich in emotional issues and popular misconceptions. Many people, well versed in 1950s B-movies, believe that radiation can mutate you into another life form directly, not merely your descendants -- most probably, indeed, into some giant, ugly, hungry insect.

Not all fiction about nanotech or biotech is like this -- there are good examples of firm thinking in Greg Bear's Queen of Angels and the anthology Nanodreams edited by Elton Eliott, and elsewhere.

All too often, though, in the hands of some science fiction writers, nanotech's promised abilities -- building atom by atom for strength and purity, dramatic new shapes and kinds of substances -- lead to excess. We see stories about quantum, biomolecular brains for space robots, all set to conquer the stars. About miraculous, overnight reshaping of our entire physical world -- the final victory of Information over Mass. Or about accelerated education of our young by nanorobots which coast through their brains, bringing encyclopedias of knowledge disguised in a single mouthful of Koolaid.

Partly this is natural speculative outgassing. One can make at least one safe prediction: such wild dreams will dog nanotech. The real difficulty in thinking about possibilities is that so little seems ruled out. Agog at the horizons, we neglect the limitations -- both physical and social.

Nanotech holds forth so much murky promise that writers can appear to be doing hard sf, while in fact just daydreaming. Not only is the metaphorical net not up on this game of dream tennis, it isn't even visible.

People can tell disciplined speculation from flights of fancy when they deal with something familiar and at hand. Nanotech is neither. Worse, it touches on the edge of quantum mechanical effects, and nothing in modem physics has been belabored more than the inherent uncertainties of the wave-particle duality, and the like. People often take uncertainty as a free ticket to any implausibility, flights of fancy leaving on the hour.

Developing a discipline demands discipline. Dreaming is not enough.

One point we do know must operate in nanotech's development: nothing happens in a vacuum. The explosion of biotech, just one or two orders of magnitude above the nanotech scale, will deeply shape what comes of nanotech.

The transition is gradual. The finer one looks on the scale of biology, the more it looks mechanical in style. The flagella that let bacterium swim work by an arrangement which looks much like a motor, each proton extruded by the motor turns the assembly a small bit of a full rotation. Above that scale, the "biologic" of events is protean and flexible, compared with mechanical devices. Below it, functions are increasingly more machine-like. The ultimate limit to this would be the nanotech dream of arranging atoms precisely, as when a team at IBM spelled out the company initials on a low temperature substrate. But widespread application of such methods lies probably decades away, perhaps several. The future will be vastly changed by directed biology, before nanotech comes fully on stage.

Consider a field of maize -- corn, to Americans. At its edge a black swarm marches in orderly, incessant columns.

Ants, their long lines carrying a kernel of corn each. Others carry bits of husk; there an entire team coagulates around a chunk of a cob. The streams split, kernel-carriers trooping off to a ceramic tower, climbing a ramp and letting their burdens rattle down into a sunken vault. Each returns dutifully to the field. Another, thicker stream spreads into rivulets which leave their burdens of scrap at a series of neatly spaced anthills. Dun-colored domes with regularly spaced portals, for more workers.

These had once been leaf-cutter ants, content to slice up fodder for their own tribe. They still do, pulping the unneeded cobs and stalks and husks, growing fungus on the pulp deep in their warrens. They are tiny farmers in their own right. But biotech had genetically engineered them to harvest and sort first, processing corn right down to the kernels.

Other talents can be added. Acacia ants already defend their mother trees, weeding out nearby rival plants, attacking other insects which might feast on the acacias. Take that ability and splice it into the corn-harvesters, and you do not need pesticides, or the dredge human labor of clearing the groves. Can the acacia be wedded to these corn ants? We don't know, but it does not seem an immense leap. Ants are closely related and multi-talented. Evolution seems to have given them a wide, adaptable range.

Following chemical cues, they seem the antithesis of clanky robots, though insects are actually tiny robots engineered by evolution. Why not just co-opt their ingrained programming, then, at the genetic level, and harvest the mechanics from a compliant Nature?

Agriculture is the oldest biotech. But everything else will alter, too.

Mining is the last great industry to be touched by the modem. We still dig up crude ores, extract minerals with great heat or toxic chemicals, and in the act bring to the surface unwanted companion chemicals. All that suggests engineering must be re-thought -- but on what scale? Nanotech is probably too tiny for the fight effects. Instead, consider biomining.

Actually, archaeologists have found that this idea is quite ancient. Romans working the Rio Tinto mine in Spain 2000 years ago noticed fluid runoff of the mine tailings were blue, suggesting dissolved copper salts. Evaporating this in pools gave them copper sheets.

The real work was done by a bacterium, Thiobacillus ferroxidans. It oxidizes copper sulfide, yielding acid and ferric ions, which in turn wash copper out of low grade ores. This process was rediscovered and understood in detail only in this century, with the first patent in 1958. A new smelter can cost a billion dollars. Dumping low quality ore into a sulfuric acid pond lets the microbes chew up the ore, with copper caught downhill in a basin; the sulfuric acid gets recycled. Already a quarter of all copper in the world comes from such bio-processing.

Gold enjoys a similar biological heritage. The latest scheme simply scatters bacteria cultures and fertilizers over open ore heaps, then picks grains out of the runoff. This raises gold recovery rates from 70% to 95%; not much room for improvement. Phosphates for agriculture can be had with a similar, two-bacterium method.

All this, using "natural biotech." Farming began using wild wheat -- a grass. Immunology first started with unselected strams of Penicillium. We've learned much, mostly by trial and error, since then. The next generation of biomining bacteria are already emerging. A major problem with the natural strains is the heat they produce as they oxidize ore, which can get so high that it kills the bacteria.

To fix that, researchers did not go back to scratch in the lab. Instead, they searched deep-sea volcanic vents, and hot springs such as those in Yellowstone National Park. They reasoned that only truly tough bacteria could survive there, and indeed, found some which appear to do the mining job, but can take near-boiling temperatures.

Bacteria also die from heavy metal poisoning, just like us. To make biomining bugs impervious to mercury, arsenic and cadmium requires bioengineering, currently under way. One tries varieties of bugs with differing tolerances, then breeds the best to amplify the trait. This can only take you so far. After that, it may be necessary to splice DNA from one variety into that of another, forcibly wedding across species. But the engineering occurs at the membrane level, not more basically --no nanotech needed.

This is a capsule look at how our expectations about basic processes and industries will alter long before nanotech can come on line. What more speculative leaps can we foresee, that will show biotech's limitations? -- and thus, nanotech's necessity.

Consider cryonics. This freezing of the recently dead, to be repaired and revived when technology allows, is a seasoned science fictional idea, with many advocates in the present laboring to make it happen. Neil R. Jones invented it in an sf story in the 1931 Amazing Stories, inspiring Dr. Robert Ettinger to propose the idea eventually in detail in The Prospect of Immortality in 1964.

It has since been explored in Clifford Simak's Why Call Them Back From Heaven? (1967), Fred Pohl's The Age of the Pussyfoot (1969), and in innumerable space flight stories (such as 2001: A Space Odyssey) which use cryonics for long term storage of the crew. Fred Pohl became a strong advocate of cryonics, even appearing on the Johnny Carson show to discuss it. Robert Heinlein used cryonics as part of a time-traveling plot in The Door Into Summer. Larry Niven coined "corpsicle" to describe such "deanimated" folk. Sterling Blake treated the field as it works today in Chiller. Cryonics is real, right now. About fifty people now lie in liquid nitrogen baths, awaiting resurrection by means which must involve operations below the biotechnical.

Repairing frozen brain cells which have been cross-slashed by shear stresses, in their descent to 77 degrees Absolute, then reheated --well, this is a job nothing in biology has ever dealt with. One must deploy subcellular repair agents to fix freezing damage, and replenish losses from oxygen and nutrient starvation. A solvent for this is tetrafluoromethane -- it stays liquid down to minus 130 degrees Centigrade.

To further repair, one must introduce line-layers, workhorse cells to spool out threads of electrical conductor. These tiny wires could power molecular repair agents -- smart cells, able to break up and sort out ice crystals. Next comes clearing blood vessels, the basic housekeeping, functions which can all be biological in origin.

Then nanotech becomes essential. The electrical power lines could feed a programmed cleanup crew. They would stitch together gross fractures, like good servants dusting a room, clearing out the dendrite debris and membrane leftovers that the big biological scavenger units missed.

Moving molecular furniture around at 130 degrees below freezing will take weeks, months. One has to be sure the "molyreps" -- molecular repair engineers -- do not work too fast, or else they would heat the patient up all on their own, causing further shear damage.

How do they get the damaged stuff back in place, once they'd fixed it? Special units -- little accountants, really -- would have to record where all your molecular furniture was, what kind of condition it was in. They look over the debris, tag it with special identifying molecules, then anchor it to a nearby cell wall. They file that information all away, like a library. As repair continues, you slowly warm up.

These designer molecules must be hordes of microscopic fanatics, born to sniff out flaws and meticulously patch them up. An army that lived for but one purpose, much as art experts could spend a lifetime restoring a Renaissance painting. But the body is a far vaster canvas than all the art humanity had ever produced, a network of complexity almost beyond comprehension.

Yet the body naturally polices itself with just such mobs of molecules, mending the scrapes and insults the rude world inflicted. Biotech simply learns to enlist those tiny throngs. That is true, deep technology --co-opting nature's own evolved mechanisms, guiding them to new purposes. Nanotech goes beyond that, one order of magnitude down in size.

Not necessary to get good circulation in the cells again -- just sluggish is enough. A slow climb to about minus a hundred degrees Centigrade. A third team goes in then, to bond enzymes to cell structures. They read that library the second team had left, and put all furniture back into place.

So goes the Introduction to Molecular Repair For Poets lecture, disguising mere miracles with analogies.

Months pass, fixing the hemorrhaged tissue, mending tom membranes, splicing back together the disrupted cellular connections. Surgeons do this, using tools more than a million times smaller than a scalpel, cutting with chemistry.

Restriction enzymes in bacteria already act like molecular scissors, slicing DNA at extremely specific sites. Nanotech would sharpen this kind of carving, but much of the work could probably be bioengineered, working at larger scales.

With such abilities, surgeons can add serotonin-derived neurotransmitters, from a psychopharmacology far advanced beyond ours. They inhibit the switches in brain chemistry associated with emotional states.

A patient reviving may need therapy, cutting off the memories correlated with those emotions that would slow recovery. Such tools imply medicine which can have vast social implications, indeed.

Here is where the future peels away from the foreseeable. Nanotech at this stage will drive qualitative changes in our world, and our world views, which we simply cannot anticipate in any detail. All too easily, it looks like magic.

Suppose the next century is primarily driven by biotech, with nanotech coming along as a handmaiden. Do we have to fear as radical a shift in ideas again, with nanotech?

Biotech looks all-powerful, but remember, evolution is basically a kludge. Organisms are built atop an edifice of earlier adaptations. The long, zigzag evolutionary path often can't take the best, cleanest design route.

Consider our eyes, such marvels. Yet the retina of the vertebrate eye appears to be "installed" backwards. At the back of the retina lie the light-sensitive cells, so that light must pass through intervening nerve circuitry, getting weakened. There is a blind spot where the optic nerve pokes through the optical layer.

Apparently, this was how the vertebrate eye first developed, among creatures who could barely tell darkness from light. Nature built on that. The octopus eye evolved from different origins, and has none of these drawbacks.

Could we do better? A long series of mutations could eventually switch our light-receiving cells to the front, and this would be of some small help. But the cost in rearranging would be paid by the intermediate stages, a tangle which would function more poorly than the original design.

So these halfway steps would be selected out by evolutionary pressure. The rival, patched-up job works fairly well, and nature stops there. It works with what it has. We dreaming vertebrates are makeshift constructions, built by random time without foresight. There is a strange beauty in that, but some cost -- as I learned when my appendix burst, some years ago. We work well enough to get along, not perfectly.

The flip side of biology's deft engineering marvels is its kludgy nature, and its interest in its own preservation. We are part of biology, it is seldom our servant, except incidentally. In the long ran, the biosphere favors no single species.

The differences between nanotech and biotech lie in style. Of course functions can blend as we change scales, but there is a distinction in modes.

Cells get their energy by diffusion of gases and liquids; nanotech must be driven by electrical currents on fixed circuits. Cells contain and moderate with spongy membranes; nanoengines must have specific geometries, with little slack allowed. Natural things grow "organically," with parts adjusting to one another, nanobuilders must stack together identical units, like tinker-toys.

The Natural style vs. the Mechanical style will be the essential battleground of tiny technology. Mechanicals we must design from scratch. Naturals will and have evolved; their talents we get for free. Each will have its uses.

Naturals can make things quickly, easily, including copies of themselves--reproduction. They do this by having what Drexler terms "selective stickiness" -- the matching of complementary patterns when large molecules like proteins collide. If they fit, they stick. Thermal agitation makes them smack into each other many millions of times a second, letting the stickiness work to mate the fight molecules.

Naturals build, and as time goes on, they build better -- through evolution. In Naturals, genes diffuse, meeting each other in myriad combinations. Minor facets of our faces change so much from one person to the next that we can tell all our friends apart at a glance {except for identical twins, like me).

These genes collide in the population, making evolutionary change far more rapid because genes can spread through the species, getting tried out in many combinations. Eventually, some do far better, and spread to everyone in later generations.

This diffusion mechanism makes sexually reproduced Naturals change constantly. Mechanicals -- robots of any size, down to nanotech -- have no need of such; they are designed. There is no point in building into nanomachines the array of special talents needed to make them evolve --in fact, it's a hindrance. It could become a danger, too.

We don't want nanobots which adapt to the random forces of their environment, taking off on some unknown selection vector. We want them to do their job. And only their job.

So nanotech must use the Mechanical virtues: rigid, geometric structures; positional assembly of parts; clear channels of transport for energy, information and materials. Mechanicals should not copy Naturals, especially in aping the ability to evolve.

This simple distinction should lessen many calls of alarm about such invisible, powerful agents. They can't escape into the biosphere and wreck it. Their style and elements are fundamentally alien to our familiar Naturals, born red in tooth and claw.

Nanobots' real problem will be to survive in their working environment, including our bodies. Imagine what your immune system will want to do to an invading band of unsuspecting nanobots, fresh off the farm.

In fact, their first generation will probably have to live in odd chemical soups, energy rich (like, say, hydrogen peroxide or even ozone) and free of Natural predators. Any escaping from their chemical cloister will probably get eaten -- though they might get spat right back out, too, as indigestible.

The "gray goo" problem of nanotech, in which ugly messes consume beautiful flora and fauna, need not occur, precisely because the goo will be gray. It need not have built into it the rugged, hearty defenses which are the down payment for anything which seeks to use sunlight, water and air to propagate itself. Gray goo will get eaten by green goo -maybe by a slime mold, which has four billion years of survival skills and appetite built in.

So nanotech will not be able to exponentially push its numbers, unless we deliberately design it that way, taking great trouble to do so. Accidental runaway is quite unlikely. Malicious nanobots made to bring havoc, though, through special talents -- say, replacing all the carbon in your body with nitrogen -- could be a catastrophe.

When machines begin to design themselves, we approach the problems of Natural-style evolution. Even so, design is not like genetic diffusion. In principle, it is much faster. Think of how fast cars developed in the last century, versus trees.

That problem lies far beyond the simple advent of nanotech. It will come, but only after decades of intense development one or two levels above, in the hotbed of biotech.

What uses we make of machines at the atomic level will depend utterly on the unforeseeable tools we'll have at the molecular level. That is why thinking about nanotech is undoubtedly fun, but perhaps largely futile. Certainly such notions must be constrained by knowing how very much biology can do, and will do, long before we reach that last frontier of the very, very small.

The End

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