Voyage of the DNA Treader

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Richard Feynman was right: there is plenty of room at the bottom, and the beeping, lumbering trashcans of 1950s science fiction are gradually giving way to micro-droids the size of a speck of dust . . . or even a molecule.

But this new breed of invisibly tiny robots raises a new question: how can even rudimentary intelligence be squeezed into something whose largest moving part consists of a handful of atoms? One solution, says Caltech graduate student in computation and neural systems Nadine Dabby, is to build the smarts into the environment instead.

At January's TEDxCaltech conference, Dabby will present a one-molecule robot capable of following a trail of chemical breadcrumbs. A paper she co-authored in *Nature* last May describes a "molecular spider" that can be coaxed to "walk" down a predetermined path.

The "legs" of the spider are made of short segments of DNA, as are the "substrate molecules" making up the path, each of which is anchored at one end like a blade of grass. Leg and substrate can bind together temporarily, but this process leaves the substrate slightly less "sticky" than it previously was, and the next leg that contacts it will not be held so long. That subtle difference in stickiness is what produces the robot's walking behavior. With no sense of direction, plan, or purpose, its legs continually flutter around randomly, like those of the proverbial drunkard in probability studies. But because they are held less firmly by substrate that has previously been visited, the overall motion tends to proceed in the forward direction.

The breadcrumb pathway is laid out on the surface of a self-assembling biomolecule, generated by a process called "DNA origami." Developed at Caltech in Erik Winfree's bioengineering lab by then-postdoc Paul W. K. Rothemund (now a senior research associate), this technique weaves a single DNA strand into a space-filling rectangle. Long parallel stretches alternating with sharp U-turns create a pattern reminiscent of the back-and-forth track of a farmer plowing a field.

To cement the woven DNA in place, several much shorter DNA snippets are added; these "staple strands" bind at specific positions along the woven molecule's length, clamping adjacent runs together like Zip-ties around a power cord. And those staple strands have a second function: they act as anchors for the substrate molecules that define the path. The rough 16 x 12 grid into which they fall isn't dense enough to create very elaborate labyrinths, but it did allow the researchers to set up a few straightaways, some bends, and a sharp turn or two.

Technically, the spider has not eight legs but four, and it only walks on three of those. The fourth is used to bind the molecule to its start position, until a chemical signal from the researchers breaks the bond and sends the robot on its way. (Picture a three-legged iguana tethered to a post; the leash snaps, and the creature stumbles off on its rubbery legs.)

And what does a nano-bot in action look like? Using fluorescent markers and atomic-force microscopy, the team successfully produced a short and rather grainy "movie" of a spider actually making its sticky-footed way up the garden path.

With a pace measured in nanometers per minute, the tiny tripper isn't likely to break any land speed records. Nevertheless, Dabby muses, given a few enhancements to its ability to interpret and alter its molecular environment, the robot could function as a biological computer, executing arbitrarily complex algorithms.

That first small step down a tiny trail of DNA just might represent one giant leap for bot-kind.

Source: California Institute of Technology