A. K. DEWDNEY

The Planiverse Project: Then and Now

Is a two-dimensional universe possible, at least in principle? What laws of physics might work in such a universe? Would life be possible? It was while pondering such imponderables one steamy summer afternoon in 1980 that I came to the sudden conclusion that, whether or not such a place exists, it would be possible to conduct a gedanken experiment on a grand scale. It was all a question of starting somewhat mathematically. With the right basic assumptions (which would function like axioms), what logical consequences might emerge?

Perhaps the heat was getting to me. I pictured my toy universe as a balloon with an infinitesimal (that is to say, zero-thickness) skin. Within this skin, a space like ours but with one dimension less, there might be planets and stars, but they would have to be disks of two-dimensional matter. In laying out the basic picture I followed informal principles of simplicity and similarity. Other things being equal, a feature in the planiverse should be as much like its counterpart in our universe as possible, but not at the cost of simplicity within the two-dimensional realm. The simplest two-dimensional analog of a solid sphere is a disk.

What sort of orbits would the planets follow? In our own universe, Newtonian mechanics takes its particular form from the inverse-square law of attraction. A planet circling a star, for example, "feels" an attraction to that star which varies inversely with the square of the distance between the two objects. The same reason in the planiverse leads to a different conclusion. The amount of light that falls on a linear meter at a distance $2x$ from a star is one-half the light that reaches the square at a distance x from the star. (see Figure 1); correspondingly, attraction is proportional to the inverse first power of the distance

The resulting trajectory is not a conic section, but a wildly weaving orbit, as in Figure 2.

The figure resembles a production of that well-known toy, the spirograph, in which gears laid on a sheet of paper roll around each other. A pencil inserted in a hole in one of the gears might trace such a figure. Are the two-dimensional orbits spirograph figures? Probably not. They look like epicycles, the paths that early astronomers thought might explain the looping orbits of Mars and Jupiter in an Earth-centered system! (It is tempting to conclude that what goes around comes around.)

Encouraged by such speculations, I begin to develop the impression that such a universe might actually exist. It would be completely invisible to us three-dimensional beings, wherever it might be. But places, even imaginary ones, need names. What could a two-dimensional universe be, but the Planiverse?

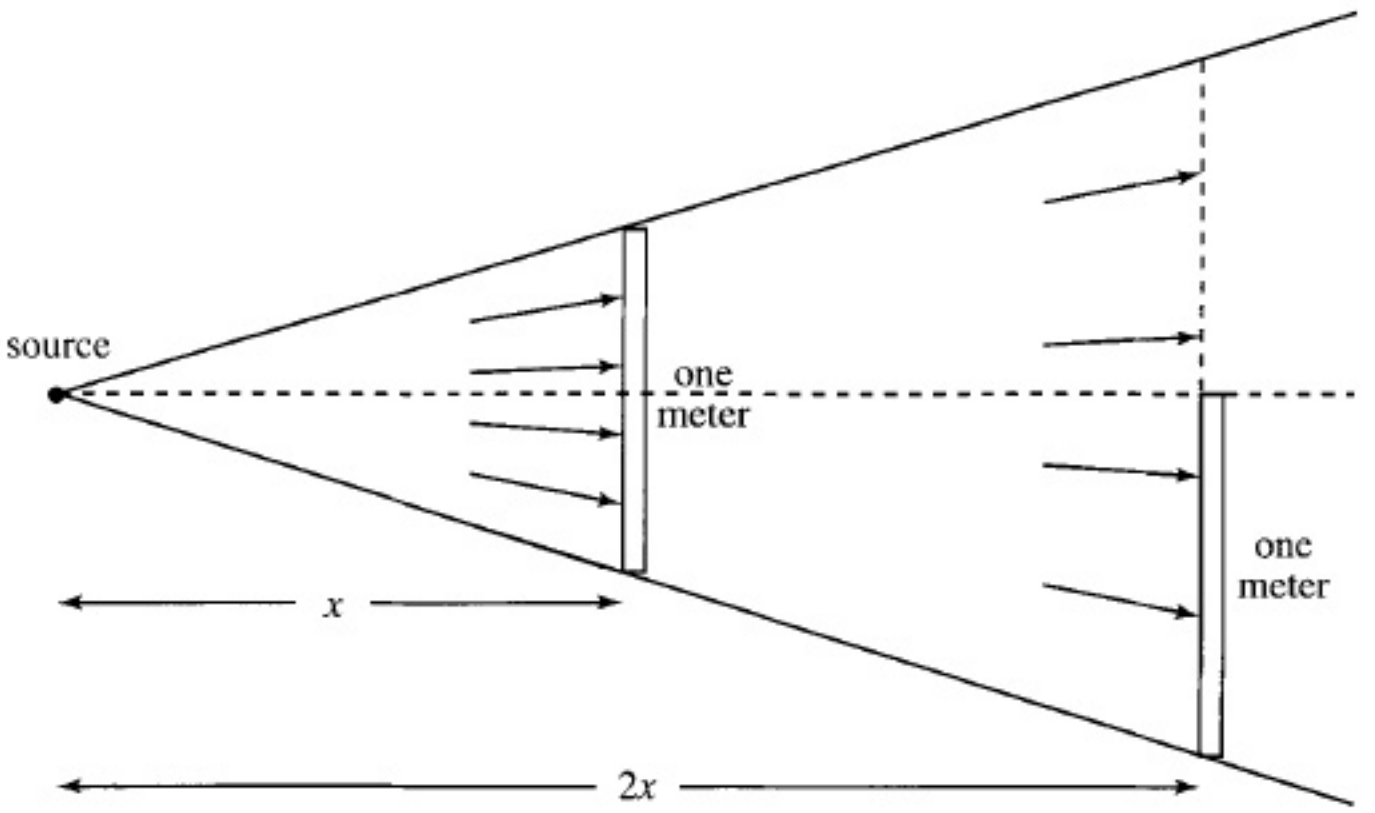

Figure 1. The law of gravity.

In a fit of scientific irresponsibility I sent a letter to Martin Gardner, then author of the Mathematical Games column for *Scientific American* magazine. I included several speculations, including the drawing of a two-dimensional fish shown in Figure Three below.

Gardner wrote back, saying that he not only found the planiverse a delightful place, he would devote a forthcoming column to it. His column, which appeared in July, 1980, lifted our speculations about two-dimensional science and technology to a new level by bringing it to the attention of a much wider public. Among those who read Gardner's column were not only scientists and technologists, but average readers with novel and startling contributions of their own.

I left for a sabbatical at Oxford that summer, hoping to work on the theory of computation and hoping also to get away from the planiverse project, which was claiming more and more of my time. I stayed in an abbey in the village of Wytham, near Oxford. There was leisure not only to work on the logical design for an entirely new way to compute things, but the opportunity to work on the Planiverse Project, a paper symposium with colleague Richard Lapidus, a physicist at the Stevens Institute of Technology in New Jersey. Our symposium had contributions from around the world on everything from two-dimensional chemistry and physics to planetary theory and cosmology. There was, moreover, a section devoted to technology, wherein the only feasible two-dimensional car ever designed appeared for the first time. It had no wheels, but was surrounded by something like a tank tread that ran on disk-bearings. The occupants got in and out of the vehicle by unhooking the tread.

The Planiverse Project was now proceeding at a satisfying rate. I assumed that within a few years it would die away to nothing. We would have had our fun, no harm done.

But a press release, written by a journalist at my home institution in the fall of 1981, changed all that. Wire services

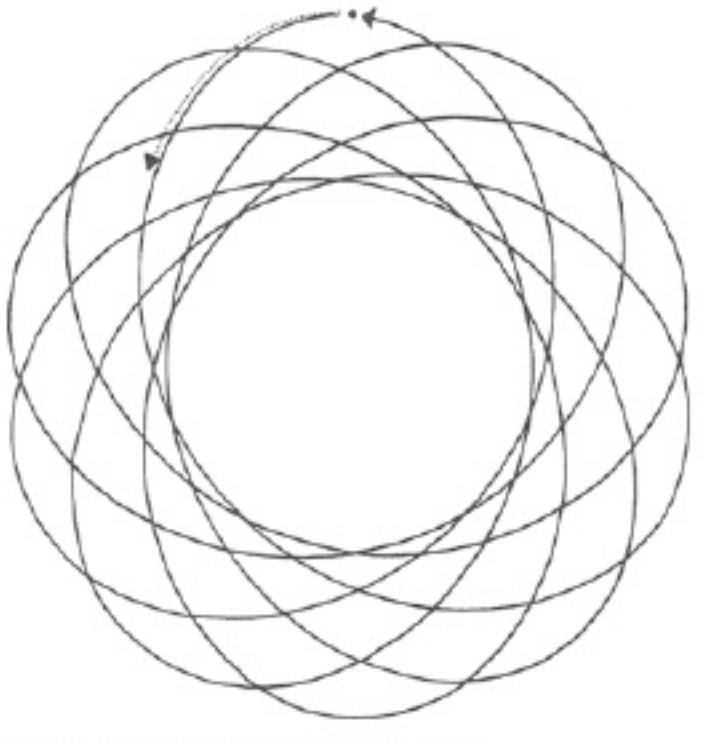

Figure 2. Orbit of a two-dimensional planet.

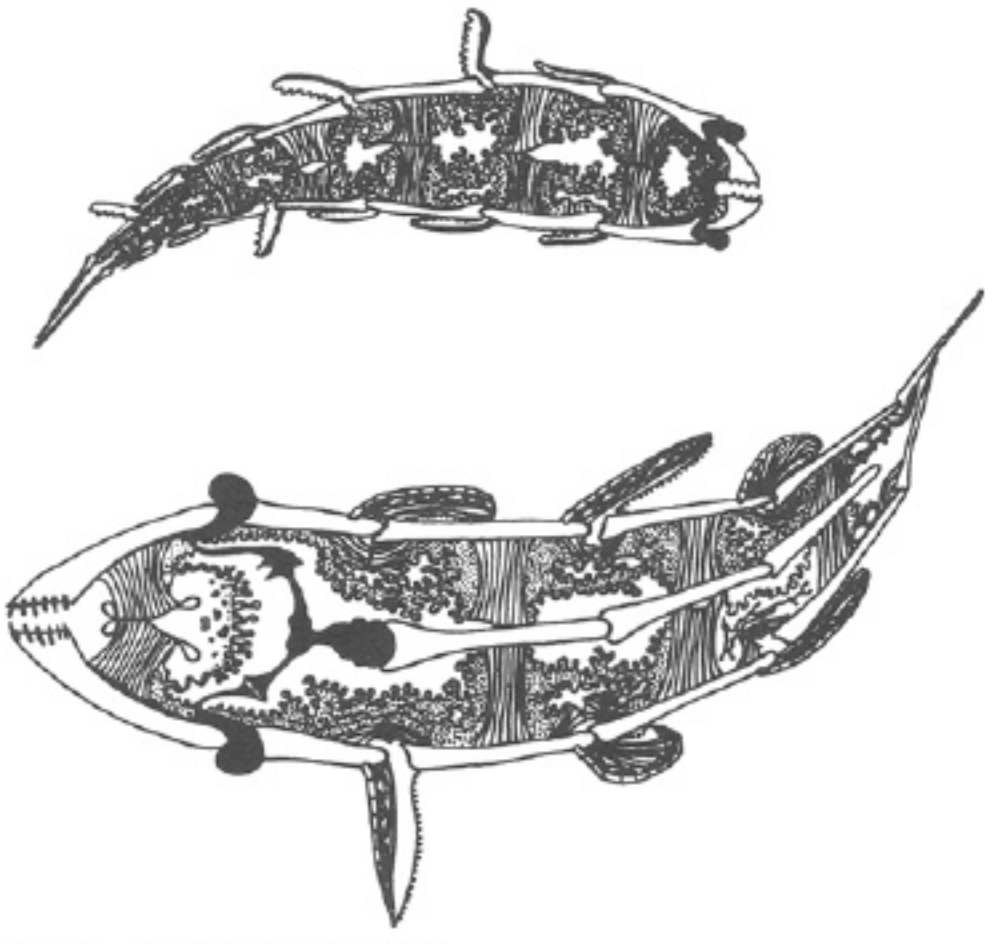

Figure 3. Two-dimensional fish.

Figure 4. Planiversal vehicle.

picked it up with the glee reserved for UFO reports and escaped lions. There followed a rush of magazine and newspaper articles, as well as television stories publicizing our two-dimensional world. In particular, a piece in *Newsweek* magazine caught the attention of publishers.

In the midst of a series of papers on programming logic, I was suddenly face to face with a big writing job. There were contracts with Poseidon Press (Simon & Schuster) in the US, with Pan/Picador in England, and with McClelland & Stewart in Canada. I viewed these new responsibilities with irritation. It was assuredly fun to think about the planiverse, but my research came first. And was I not in danger of being regarded as a nut-case? The media were no help. One interviewer asked, "So, Professor Dewdney. Are you saying the Earth is flat after all?" (He was serious!)

The writing job, as I finally came to view it, would have to weave together all the scientific and technical elements that had emerged from the Planiverse Project. But a compendium of these speculations, no matter how wild or entertaining, would surely prove a dry read. It would have to be a work of fiction, set in the planiverse itself. There would be a planet called Arde, a disc of matter circling a star called Shems. There would be a hero named Yendred (almost my name backwards) and his quest for the third dimension or, at least, a spiritual version of it. Yendred is convinced that the answer to his quest lies on the high

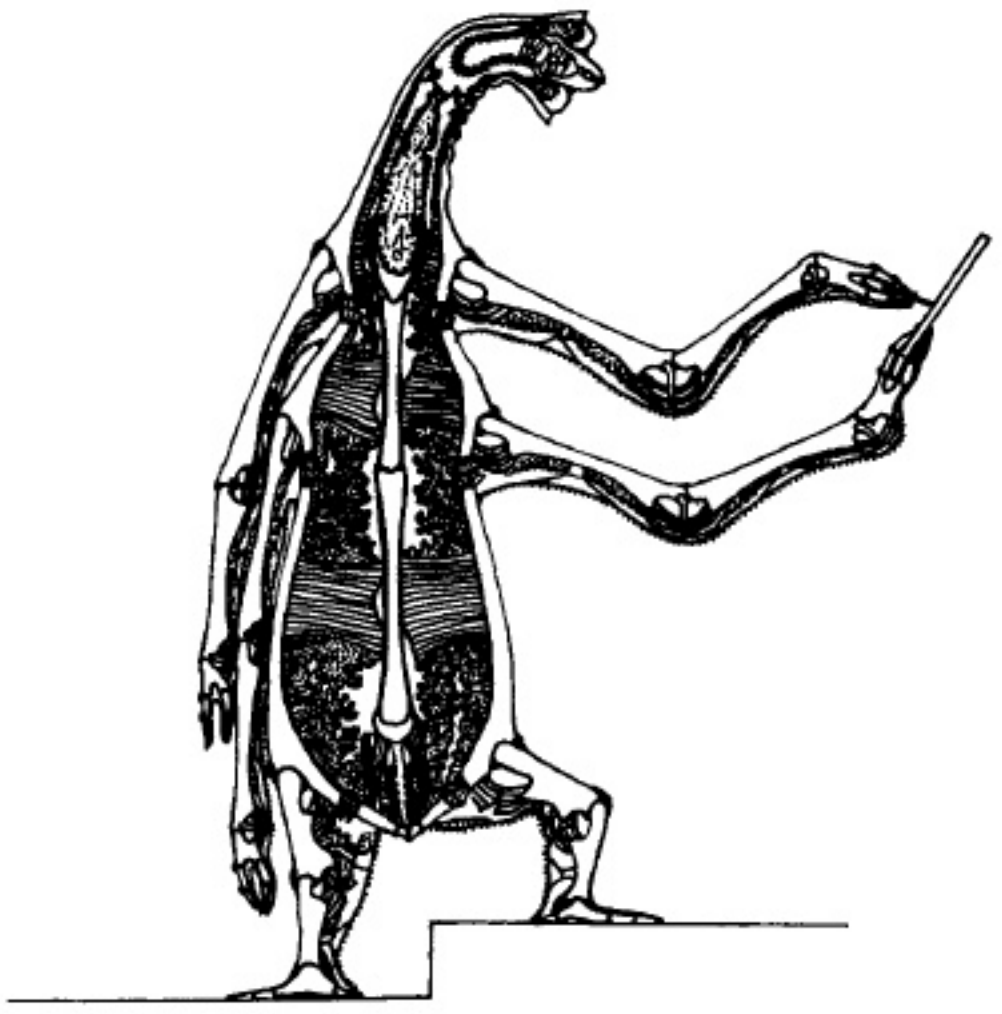

Figure 5. Yendred, a typical Ardean.

plateau of Arde's lone continent (a requirement of two-dimensional plate tectonics).

All the elements of our earlier speculations now fell more or less into place. Think for a moment of even the humblest respects in which a two-dimensional existence on the "surface" of Arde might differ from our own.

The Jordan curve theorem's implications for Arde were profound. Closed curves lurked everywhere.

Consider, for example, Ardean soil, a mechanical mixture of two-dimensional grains and pebbles in which any pocket of water finds itself permanently trapped within the closed circle of surrounding stones. The water cannot percolate, as our groundwater does, up or down. It is trapped, at least until the soil is mechanically disturbed. Consider also the simple matter of Yendred attempting to lift a two-dimensional plank on the Ardean surface. The plank, the ground, and Yendred himself would form a simple closed curve, and the air trapped inside the enclosed space would become increasingly rarefied. The plank would seem to get heavier and heavier. Perhaps readers can imagine themselves to be Ardeans lifting such a plank. If you were Yendred, what technique would you adopt to make it easier?

But for every disadvantage of life in two dimensions, there seems to be an equal and opposite advantage. Bags and balloons are trivial to make—from single pieces of string! Yendred's father, who takes him fishing near the beginning of the book, never has trouble with tangled lines, for knots in two-space are impossible. Moreover, sailing requires nothing more than a mast!

Yendred sets out on his quest shortly after the fishing trip with his father. His home, like all Ardean homes, is underground. The surface of Arde must be left as pristine as possible. There are travelling plants and periodic rains which make temporary rivers, basically floods. Any surface structure would either disrupt the delicate one-dimensional ecology or be swept away, in any case. A simple pole stuck in the ground would become a dam which could never withstand the force of kilometers of water that would rapidly build up behind it.

In the Ardean cities which Yendred must walk through (or over) on his travels to the high plateau, we encounter the acme of two-dimensional infrastructure. There is no skyline, only the typical Ardean surface periodically marred by traffic pits. If an eastbound Ardean should happen to encounter a westbound colleague, one of them must lie down and let the other walk over him/her. Elaborate rules of etiquette dictate who must lie down and who proceed, but in an urban context there is no time for niceties. Whenever a westbound group of Ardeans encounters a west-pit, they descend the stairs, hook up an overhead cable and wait. At the sound of a traffic gong, an eastbound group marches across the cable. What would be a tightrope act in our world amounts to little more than a springy walk in two dimensions for the eastbounders. West-pits and east-pits alternate so that neither direction has an advantage over the other.

From a privileged view outside the Planiverse, the "skyline" of an Ardean city resembles an inverted Earth-city skyline. Yendred passes over numerous houses, apartment

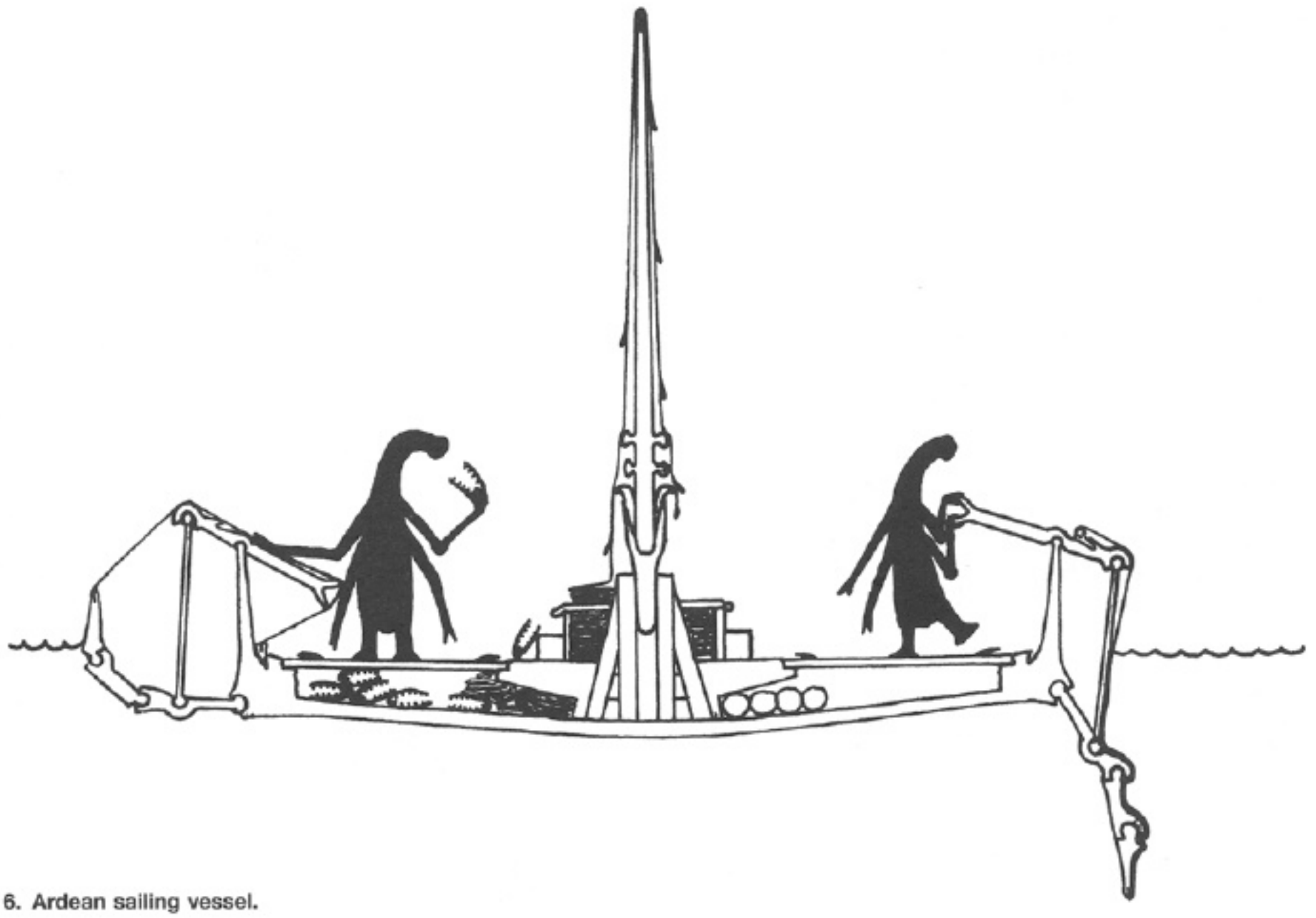

Figure 6. Ardean sailing vessel.

buildings, and factories, marked only by the exit or entrance of fellow citizens bent on private tasks like so many two-dimensional ants. Overhead pass delivery balloons, each with its cargo of packages. Balloon drivers adjust to near-neutral buoyancy, then take great hops over their fellows.

Access to underground structures is managed by swing-stairs. Although some of the larger structural beams are held together by pegs, the fastener of choice is glue. Wires (yes, the Ardeans have electricity) run only short distances, from batteries to appliances. Electrical distribution is out of the question since power lines would trap everyone within their homes. Reading by the feeble glow of a battery-powered lamp, an Ardean might reach for his favorite book, reading text that resembles Morse Code, one line per page. This demands a highly concentrated prose style that is more suggestive than comprehensive.

The population of Arde is not great. Only a few thousand individuals inhabit its lone continent. Consequently, the Ardeans have no great demand for power machines, the steam engine sufficing for most needs, such as elevators and factories. Readers might be able to figure out the operation of an Ardean steam engine from the accompanying illustration alone.

A boiler converts water into steam, and when a valve opens at the top of the boiler, the steam drives a piston to the right. However, this very motion engages a series of cams that close the valve. The steam then enters a reservoir above the piston and escapes when the piston completes its travel to the head of the "cylinder." Interestingly, almost any two-dimensional machine can also be built in three dimensions. It must be given some thickness, of course, and it must also be enclosed between two parallel plates to simulate the restriction of no sideways movement. I have often wondered whether we could build a car with a one-inch thick steam engine mounted underneath. Think of the additional room that would provide!

Ardean technology is a strange mixture of advanced and primitive machines. Although steam engines are the main

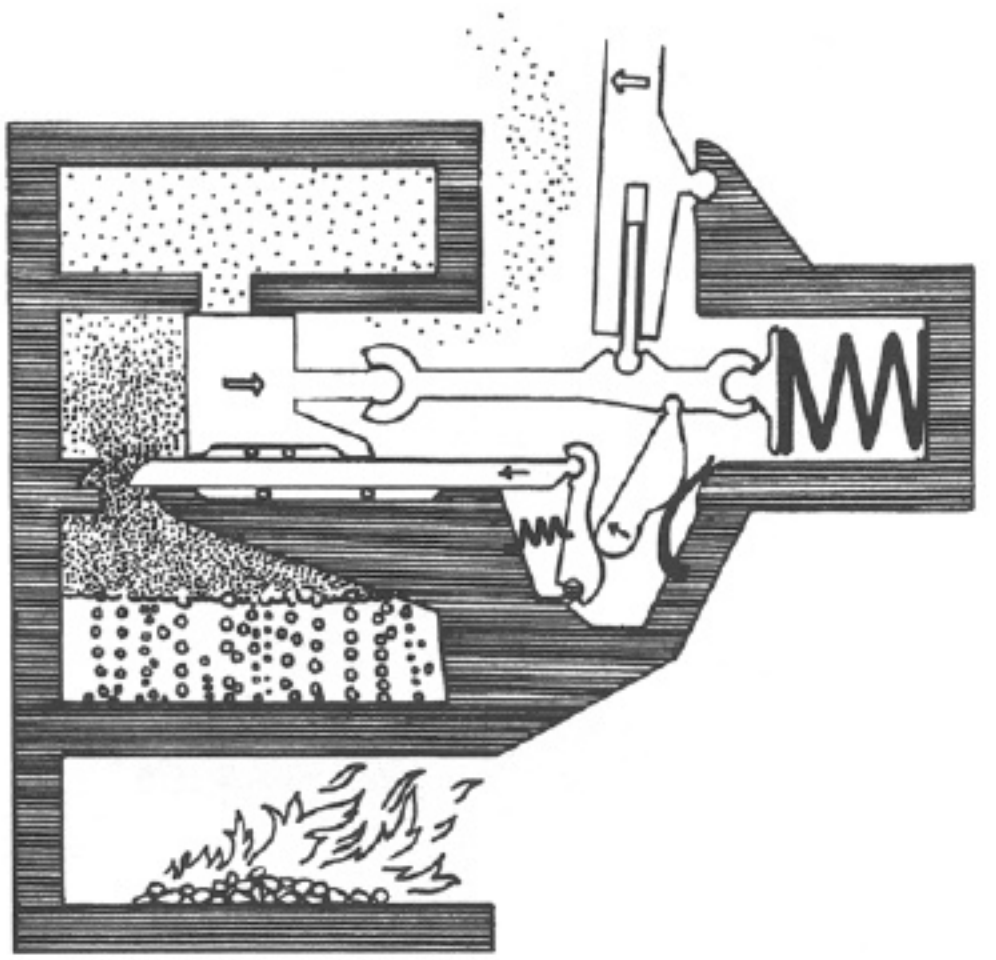

Figure 7. A steam engine.

power source, rocket planes travel from city to city, while space satellites orbit overhead. It is absurdly easy to make space stations airtight. Any structure that contains at least one simple closed curve is automatically airtight.

And of course, there are computers! These operate on the same binary principles (0 and 1) as our own do. Ardean technologists had a difficult time developing the appropriate circuits, however, owing to the impossibility of getting wires to cross each other. One brilliant engineer finally hit on the idea of a "logic crossover." Symbolically rendered below, this circuit consists of three exclusive-or gates, each transmitting a logic 1 signal if and only if exactly one input is a 1.

No matter what combination of zeros or ones enter this circuit along the wires labelled x and y, the same signals leave the circuit along the wires bearing these labels. Readers may readily satisfy themselves that if x and y both carry a zero (or one), for example, then both output lines will also carry this signal. But if x is one and y is zero, the middle gate will output a one which will cancel the x-signal in the upper gate and combine with the zero on the y-input in the lower gate to produce a one.

Fun though technology may be, it isn't until he visits the Punizlan Institute of Technology (PIT) that Yendred encounters the deep scientific ideas of his time. Scientists at PIT have developed a periodic table of the elements based on the theory that while just two electrons can occupy the first shell of a planiversal atom, up to six can occupy the second shell. We have labelled the planiversal elements with the symbols of the elements from our own universe which they most resemble.

Strangely, the planiversal elements quickly run out, owing to the instability of very large planiversal atoms. In the planiverse, one simply cannot pack as many neutrons and protons into a small space as one can in our universe. Consequently, nuclear forces (other things being equal) must act across larger distances and the nuclear components are rather less tightly bound. Quite possibly, there is a lot more radioactivity in the planiverse than in our own.

Other strange features of the planiverse include rather low melting points and the strange behaviour of sound waves. Low melting points might militate against the possibility of life, except that chemical reactions proceed at lower temperatures, in any event. Sound waves travel much farther and have a very strange property first deduced by

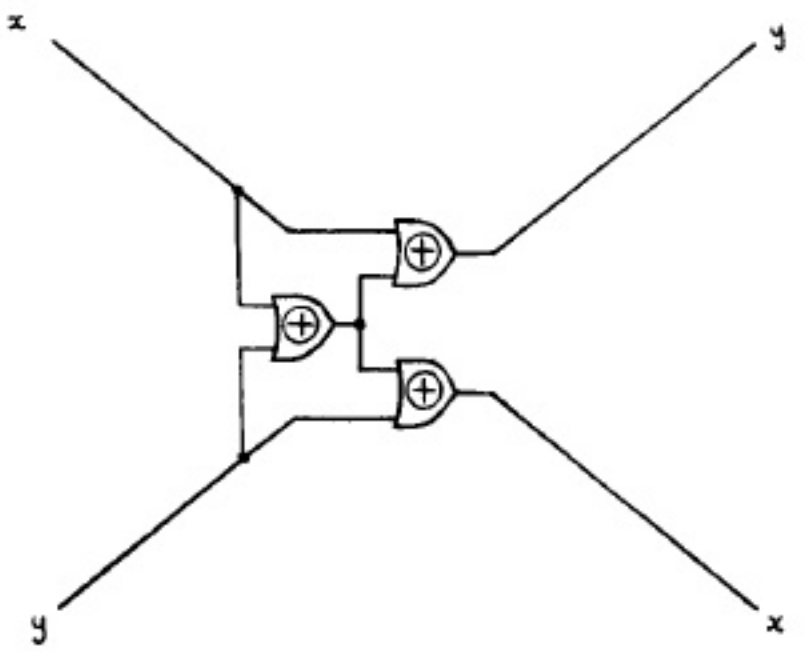

Figure 8. A logic crossover.

Earth scientists some time ago. If one sounds a note on Arde, the sound wave alters as it travels. A sharp attack smears out in time, so that a single note of C, for example, is heard at a distance as a glissando rising from some lower pitch and asymptotic to C.

Cosmologically speaking, Ardean scientists have much to ponder. Like us, they wonder if their universe is closed like a balloon (we say it is) or open like a saddle-shaped space. It is apparently expanding, and the balloon analogy, so often used to illustrate how our own universe is apparently expanding, can be taken quite literally. A deeper question concerns the orientability of the planiverse. Perhaps it is really a projective plane, so that Yendred, travelling by rocket across the planiverse, might return to find that everyone has reversed their handedness and all Ardean writing appears backward.

As for space travel, another problem awaits the rocket voyager. There is no escape velocity in the planiverse. The amount of work required to escape the gravitational field of an isolated planet is infinite! (Try integrating $1/x$ from 1 to infinity.) However, if one can travel far enough to fall under the gravitational influence of some other body, the infinite escape velocity no longer matters.

The Planiverse Project had the most fun designing two-dimensional life forms. Readers who turn back to the picture of the fish (Figure 3) will find a creature with a well-developed exoskeleton, like an insect, and with a rudimentary endoskeleton, as well. The key anatomical component in any two-dimensional life form is the zipper or-

1 H													2 He
3 Li	4 Be									5 C	6 O	7 F	8 Ne
9 Na	10 Mg									11 Si	12 S	13 Cl	14 Ar
15 K	16 X					17 X	18 X	19 X	20 X	21 X	22 X	23 Br	24 Kr
25 Rb	26 X					27 X	28 X	29 X	30 X	31 X	32 X	33 I	34 Xe
35 Cs	36 X	37 X	38 X	39 X	40 X	41 X	42 X	43 X	44 X	45 X	46 X	47 At	48 Rn

Figure 9. Planiversal table of the elements.

Other Attempts at Two-Dimensional Universes

The Planiverse has had a long evolutionary history, marked by previous books on two-dimensional worlds. The first of these was *Flatland*, written in 1884 by Edwin A. Abbott, an English clergyman. Some years later, in 1907, Charles Hinton, an American logician, wrote *An Episode of Flatland*, which reorganised Abbott's tabletop world into the somewhat more logical disk planet that he called Astria. Much later, in 1965, Dionys Burger, a Dutch physicist, published *Sphereland*, which attempted to reconcile Abbott's and Hinton's worlds and then to use the resulting two-dimensional universe to illustrate the curvature of space.

For all their charm, these books have various shortcomings. Abbott made no attempt to endow his universe with coherent physics. His beings float about in two-space with no apparent mode of propulsion. Being geometrical figures, they have no biology at all. Hinton's universe is rather more like the planiverse, his planet being a disk. But Hinton, immersed in a sort of socialist Utopian fantasy, keeps forgetting the restrictions of his characters' two-dimensionality, seating his characters "side by side" at a banquet, for example. Berger attempts to reconcile the two previous universes, but he is really after just an expository vehicle to illustrate various ideas about space and physics.

gan, two strips of interdigitating muscle that meet to form a seam. Just inside the fish's bony jaws, for example, the muscles which crush and chew the prey also part to admit its fragments into a digestive pouch. Because portions of the two muscles are always in contact, structural integrity is maintained. The fragments are enclosed in a pocket that travels along the seam from front to back.

Yendred, after many adventures, finally reaches the high plateau and meets the mysterious Drabk, an Ardean who has developed the ability to leave the planiverse entirely and move "alongside" it, so to speak. Since *The Planiverse* is about to re-appear, I will not give the plot away, but I had better mention the *deus ex machina* that makes it all possible: In the book a class project results in a program called 2DWORLD that simulates a two-dimensional world, including a disk-shaped planet the students call Astria. Imagine the student's surprise when 2DWORLD turns out to be a sophisticated communication device which, by a Theory of Lockstep, begins to transit images of an actual two-dimensional universe, including a planet called Arde and a being called Yendred!

When *The Planiverse* first appeared 16 years ago, it caught more than a few readers off guard. The line between willing suspension of disbelief and innocent acceptance, if it exists at all, is a thin one. There were those who wanted to believe (despite the tongue-in-cheek subtext) that we had actually made contact with a two-dimensional world called Arde.

It is tempting to imagine that those who believed, as well as those who suspended disbelief, did so because of the persuasive consistency in the cosmology and physics of this infinitesimally thin universe, and in its bizarre but oddly workable organisms. This was not just your run-of-the-mill science fiction universe fashioned out of the whole-cloth of wish-driven imagination. The planiverse is a weirder place than that precisely because so much of it was worked out in the Planiverse Project. Reality, even the pseudo-reality of such a place, is invariably stranger than anything we merely dream up.

REFERENCES

Edwin A. Abbott, *Flatland: A Romance of Many Dimensions*. Princeton University Press, Princeton, 1991.

Charles H. Hinton, *An Episode of Flatland*. Swan Sonnenschein & Co. London, 1907.

Dionys Burger, *Sphereland: A Fantasy About Curved Spaces and an Expanding Universe*. Thomas Y. Crowell Company, New York, 1965.

A. K. Dewdney. *The Planiverse: Computer Contact with a Two Dimensional World*. Poseidon Press (Simon & Schuster), New York, 1984. A new edition soon by Copernicus Books (Springer Verlag), New York, 2000.

AUTHOR

A.K. DEWDNEY

Department of Computer Science
University of Western Ontario
London, Ontario N6A 5B7
Canada
e-mail: akd@csd.uwo.ca

A.K. (Kee) Dewdney was born in London, Ontario, and did undergraduate work there. He then did graduate work at the Universities of Waterloo and Michigan, completing his PhD at Waterloo in 1974. His thesis, extending some graph-theoretic theorems to higher dimensions, did not concern computers, and Dewdney was pleased to discover that (like much of discrete mathematics) it counted as computer science and brought him close to theory of computation. His service as columnist for *Scientific American* tended to crowd out his other activities, but in recent years he can follow his many interests, having taken early retirement at UWO and no longer having those *Scientific American* monthly deadlines. Among his books is *A Mathematical Mystery Tour* (Wiley, 1999), which seeks to answer the notorious question, Is mathematics discovered or created?