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Chapter 20. Explanatory Writing

by George Johnson

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I remember with some precision when I began believing that there is nothing so complex that a reasonably intelligent person cannot comprehend it. It was a summer day, when I was 15 or 16, and my best friend, Ron Light, and I decided that we wanted to understand how a guitar amplifier works. We both played in a mediocre 1960s-era garage band. While Ron went on to become a fairly accomplished guitarist, I was slowly learning that any talent I had didn't lie within the realm of music. Already the aspiring little scientist, I was able to learn enough of the logic of basic harmony theory to execute the mindlessly simple algorithms called bass riffs, and if pressed I could even fire off a bass solo, the dread of concertgoers everywhere. But my approach to the performance was purely intellectual. I didn't have rhythm, or maybe soul.

Poring over the symbols on the circuit diagram of Ron's Fender Deluxe Reverb amplifier seemed infinitely more interesting than trying to read music. I wanted to know what that impressively convoluted blueprint really meant, how electricity flowing through the labyrinth of wires and components could cause the tiny vibration of a guitar string to be multiplied so many times that it rocked the walls of the living room, inciting the neighbors to call the police.

This was still the era of the vacuum tube, before those glowing glass envelopes were replaced by coldly efficient transistors and microchips. Electronics was pretty simple to understand. I had already learned some basics from *The Boys' Second Book of Radio and Electronics* and the guide for the Boy Scout electricity merit badge (the colorful embroidered patch was decorated with a human fist clutching zigzag lightning bolts). In a typical circuit, there were resistors that, true to their calling, resisted electricity, pinching the flow of electrons. There were capacitors, also aptly named, that stored electrical charges. There were tightly wound coils of copper wire called inductors that would hold energy in the form of electromagnetic fields. Finally, there were the vacuum tubes themselves, mysterious pockets of illuminated nothingness inside of which the actual amplification took place.

At first the detail and complexity of the schematic, showing how all these parts fit together inside the Fender's vinyl-covered wooden cabinet, were overwhelming. I could feel my mind start to shut. But with the help of some slightly more advanced books from the

Albuquerque Public Library, I realized that I was taking the wrong approach. The trick was to break down the diagram into pieces, master each one, and then put them back together again.

Before long I could place my finger on the diagram and follow the path of the vibrating electrical signal—a replica of the sound of the twanging guitar or the thumping bass—as it traveled through the maze of squiggly lines. Each of the mysterious vacuum tubes, I came to see, was nothing more than a lever. The minuscule fluctuating voltage emerging from the guitar was fed to the first tube, where it was used to operate a gate that controlled a second, much bigger voltage. What resulted was a larger copy of the original signal. This was sent on to the next tube and leveraged again. Step by step, the undulating swings were transformed into ones wide enough to move the cone of the loudspeaker, which would ripple the air and shake your eardrums and stimulate the auditory nerve—a kind of neural guitar pickup that turned the vibrations back into electricity again, input for the brain. By the time I was in college, I could zero in on a malfunctioning circuit and repair it. I could add tubes to the output stage of a lowly Deluxe Reverb, turning it into a more powerful and expensive Super Reverb. I was amazed that I could get so far with just the broad outlines of understanding.

Whether I was trying to comprehend the workings of a television, a digital computer, or the molecular circuitry inside a cell, the technique was the same: Draw a line around a small portion of the mechanism and treat everything inside as a black box. Color it solid black, if you'd like, for now you will ignore whatever is inside. You can take it on faith that, given a certain input, the box produces a certain output. Later on, if you like, you can pry off the lid and zoom in closer for a more detailed view. Or you can pan outward, lumping the pieces into bigger and cruder chunks. Most people look at a whole TV as one big black box that takes signals from the air and magically turns them into sound and pictures. Any device, no matter how complex, can be understood on many different levels of abstraction.

I didn’t appreciate back then that I was already approaching the world like a science writer.

Suppose you want to describe how a brain cell, or neuron, works. In an early chapter of a book about memory, I gave myself the luxury of two fat paragraphs:

> **Each neuron receives electrical impulses through a treelike structure called a dendrite, whose thousands of tiny branches funnel signals into the cell. In computer jargon, the dendrite is the neuron’s input device. While some of the arriving signals stimulate the neuron, others inhibit it. If the pluses exceed the minuses, the neuron fires, sending its own pulse down a stalk called an axon. The axon is the output channel. It feeds, through junctions called synapses, into the dendrites of other cells . . .**

That seemed like just enough to create a mental picture of the basic mechanism without scaring off too many people. Then, to advance the narrative as quickly as possible, I engaged in some hand waving, glossing over a century of research with a sentence I hoped would entice readers with the promise of what lay ahead: “The resulting circuitry is complex beyond imagination. A single neuron can receive signals from thousands of other neurons; its axon can branch repeatedly, sending signals to thousands more. . . .”

Then an initial evocation of what synapses are:

> **While information is carried inside a neuron by electrical pulses, once the signal reaches the end of the axon it must be ferried across the synaptic gap by chemicals called neurotransmitters. On the other side of the synapse, the dendrite contains structures called receptors that recognize these transmitting molecules. If enough are registered, then the second cell fires. . . .**

As the book unfolded, I would unwrap more boxes, revealing microscopic ion channels opening and closing, triggering physical changes in the cells. I’d describe the molecular cascades that strengthen the synapses, linking the neurons into the circuitry that encodes new memories.

But for now I was content to drive home the point with a simple coda: “A neuron can be thought of as a cell whose specialty is to convert chemical signals to electrical signals, then back to chemical signals again.”

That was the shard I wanted to lodge in the reader’s mind.

More often you must evoke a phenomenon more compactly. In a piece for *Time* magazine, I barely had the leisure to remove the outer wrapping:

> **Scientists have long believed that constructing memories is like playing with neurological Tinkertoys. Exposed to a barrage of sensations from the outside world, we snap together brain cells to form new circuitry-patterns of electrical connections that stand for images, smells, touches, and sounds.**

With a considerable expanse to cover in 2,000 words or less—the newest theories of how experience leaves its mark on the brain—I had to leave the neuron itself inside its box. It was enough to think of it as a unit to be combined with other units to form the neurological maps called memories.

Whether you are writing a newspaper story, a book, or something in between, the procedure is the same. You start with all the wrappings on. With a few verbal brush strokes you rough out a mental picture, activating a few neurons in the reader's brain: Superstring theory, you begin (this was for the *New York Times*), is "a kind of mathematical music played by an orchestra of tiny vibrating strings. Each note in this cosmic symphony represents one of the many different kinds of particles that make up matter and energy."

A bit later, you peel back another layer: "To give the strings enough wiggle room to carry out their virtuoso performance, theorists have had to supplement the familiar three dimensions of space with six more—curled up so tiny that they could be explored only with an absurdly powerful particle accelerator the size of an entire galaxy."

You're on your way. Never mind, for now, why it takes vast energies to study extremely small things. Don't explain too much too soon: "It's a fact of life on the subatomic realm that smaller and smaller distances take higher and higher energies to probe.”

Hint to your reader: Stay tuned—for now you will just have to trust me.

I never did get around in that story to a good, crisp explanation of the energy–size connection. For the material that was to follow, the hand waving seemed enough. But the idea can be evoked with a metaphor. An ordinary microscope cannot resolve things much smaller than a single cell—light waves are too big and clumsy. Focusing more finely requires the shorter wavelengths of an X-ray microscope. X-rays, of course, are more penetrating than is visible light (smaller wavelength = higher frequency = more energy), so you can extrapolate: The smaller the object to be illuminated, the higher the frequency and the more powerful the beam.

Not every physicist is going to like that (though in fact it was a physicist, Maria Spiropulu at Fermilab, who suggested the analogy to me). All kinds of quantum mechanical subtleties have been swept under the rhetorical rug. Sometimes you just have to settle for a good approximation. We are interested outsiders writing for other interested outsiders using metaphor instead of mathematics. It is nice work if you can get it, explaining the strange in terms of the familiar.

The mathematician John McCarthy has a saying he likes to append to his Internet postings: “He who refuses to do arithmetic is doomed to talk nonsense.” Sometimes even a science writer must include some very simple math in a story. Presented the right way, the numbers come alive and take on the character of metaphor.

When I wrote *A Shortcut Through Time*, I was faced with evoking the potential power of an invisibly small experimental device called a quantum computer. One consisting of a string of just 64 atoms would, in theory, carry out 18 quintillion calculations at the same time.

For a “conventional” supercomputer like one recently built at Los Alamos National Laboratory to do that, I wrote, it would need millions of trillions of processors:

> **And so, all things being equal, it would occupy 750 trillion acres—roughly a trillion square miles. It wouldn’t fit on the planet. The surface of the Earth is just 200 million square miles, so a supercomputer as powerful as the invisible 64-atom quantum calculator would fill the surfaces of 5,000 Earths, assuming you could figure out a way to operate equipment on ocean-floating platforms.**

In my footnotes (called The Fine Print, a kind of running gloss on the nature and limits of science writing), I showed how I arrived at this figure and poked a little fun at the attempt:

> **[The Los Alamos computer has] about 12,000 processors in a space of half an acre. So say that the full one-acre floor would hold 24,000 processors, and roughly speaking, the whole computer would do that many calculations at the same time. So to do 18 quintillion calculations the area would expand by a factor of 10^{18} divided by 10^{3}, which comes out to about 750 trillion acres. A square mile is 640 acres, so we end up with more than a trillion square miles, 5,000 times the size of the**

> **surface of the Earth. Now actually, a single processor (though basically a serial calculator) can perform more than one operation during each machine cycle, so maybe the imaginary machine would occupy merely a thousand Earths. And perhaps before long the processors will be 10 times faster. So that brings us down to a hundred Earths. That's how it goes with these back-of-the-envelope calculations. The point of all the arithmetic is just to say that it would be very big indeed.**

A science writer is ultimately an illusionist. The conjuring is in the service of a noble cause: getting as close as linguistically possible to scientific truth.