

Inside the Black Box

(from *A Shortcut Through Time* by George Johnson, Knopf 2003)

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 concert goes 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, incensing the neighbors into calling the police.

This was still the era of the vacuum tube, before those wonderful 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 Boy's 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 zig-zag 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 invisibly 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, was 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.

Here was the best part: it was only incidental that this see-sawing cascade was being pushed and pulled with electricity. One could imagine a completely hydraulic system where the signal was carried by tubes of vibrating fluid moving a series of larger and larger mechanical diaphragms. In theory you could make the fulcrums from gears and pulleys or wooden spools and string.

There were good reasons for not using these clunkier technologies. The delicate, nearly weightless electrons could be controlled with a finesse not possible with mechanical parts. The point of the mental exercise was not to make hydraulic guitar amps, but to abstract the concept of audio amplification beyond its incidental underpinnings. Peeled away from one particular embodiment, the Fender amplifier, the idea revealed itself as simple and profound. I didn't need

or want to understand amplification with the fine-grained acumen of an engineer. I didn't care about being able to perform a mathematical analysis of the circuits or to understand the finer nuances of esoteric concepts like the "hysteresis" of a transformer or the "mutual conductance" of a tube. I just wanted a gut-level feel for what those electrical parts were doing.

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.

Then I took on television.

This turned out to be a little harder, but I soon found that you could adjust the focus of your curiosity up and down, from fine to fuzzy. You may have neither the time nor the inclination to grasp a video circuit in great detail. Suppose you have gleaned from your reading that some conglomeration of components called an oscillator -- a kind of electrical spring capable of rhythmically plucking itself -- produces a vibrating electrical signal, which is fed into an electromagnet, a yoke of wire coiled around the neck of the picture tube. The result is a fluctuating field that drives a beam of electrons sweeping back and forth, up and down, painting an image on the phosphor screen.

Now just draw a line around the appropriate squiggles on the schematic diagram and treat everything inside as a black box. Color it solid black, if you'd like, for from now on you will ignore whatever is within. You can take it on faith that, given a certain input, the circuitry 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 circuitry into bigger and cruder chunks. Most people look at the 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 (with an audience of one). Whether you are taking on molecular biology, cosmology, or

dendrochronology (we'll leave that word a black box), you are learning as you go along. Like a pilot of a plane looking down from on high, you let the minor geographical details blur together, leaving you to concentrate on the most arresting features of the terrain. When you spot some particularly alluring region, a chain of mountains or a convergence of streams, you can swoop down closer for a finer look, but not so close that you become lost in the details, forgetting the lay of the land.

You are not an expert taking stuff you already know and simplifying it for a general audience. You are part of the audience -- at first, anyway. As your exploration proceeds, you become an unusually active participant, downloading papers from the Web, scrutinizing the hieroglyphics, trying to glean enough from the introduction and the conclusion to ask a few good questions. Before long you are barraging the scientists with emails and telephone calls, then visiting some of them in their labs. But you always maintain a certain distance, a detachment. That is part of your bargain with the reader. You have no axe to grind. The goal is to show how some new discovery looks to an interested outsider, writing for other interested outsiders, using metaphor instead of mathematics.

Over the years I've tried to use this approach to give both readers and myself crash courses in artificial intelligence, the neurobiology of memory, particle physics, and the new science of complexity. A couple of years ago, Kevin Kelly, one of the founders of Wired magazine, urged me to take on what may be the hardest task yet: explaining something called quantum computing. I'd written about some of the developments for The New York Times, describing how scientists were trying to compute using invisibly small strings of atoms. People who follow science or science fiction have a vague notion that quantum mechanics somehow defies the restrictions of ordinary reality, allowing tiny objects to take quantum leaps from one point to another, without traversing the space in between, or to somehow exist in multiple places. Exploiting such loopholes, a quantum computer would be able to do vast numbers of calculations all at the same time, solving problems that would be otherwise impossible.

What the world needs, Kelly told me, is a short book (emphasis on "short") that would explain how one of these machines would work. Is this pie-in-the-sky theorizing, or is everything we know about to change?

So I began the cycle anew, the gathering of papers, the dispatching of questions, the visiting of labs. Along the way, I decided to abandon some of the usual tools of the trade. Much as I like to write and read narratives that weave together the science and the personalities of scientists, I decided that this book would be a little different. The story would be driven entirely by the ideas. I wouldn't concern myself with the way one mathematician's mustache wiggles when he talks or the ghostly appearance of a certain nocturnal British physicist who believes the myriad calculations of a quantum computer each take place in a different universe. Sticking to the ideas, I hoped, would impart a crispness to the book and speed passage from beginning to end.

Like any kind of writing, science writing involves spinning an illusion. All the hard intellectual work -- digging through the piles of papers and reference books, reading the same paragraph a dozen times before firing off yet another emailed plea for clarification -- all this takes place behind a curtain, carefully hidden from view. What ultimately emerges, Oz-like, is a narrator who speaks with the resounding, omniscient voice of authority, a being seemingly born with encyclopedic knowledge instantly retrieved and dispensed. And that, of course, is a fiction. A friend who was reading one of my books once asked, "Do you actually know all those things you put in there, or do you have to look them up?" She was relieved to hear that what seemed a smooth flow of erudition was haltingly cobbled together after multiple trips to the library. "But isn't that cheating?" she said. I think she was kidding, but sometimes I feel that way. I leaf through the index of a book I've written and marvel, "What in the world did I have to say about Plotinus or Aristotle?"

This time I have tried not to cheat. In the pages that follow, the surface has been left somewhat translucent offering dim glimpses of the man behind the curtain fumbling at the controls -- straining to grasp an idea with an imprecise metaphor, only to discard it for another with a tighter fit, closing in on an airy notion from several directions, triangulating on approximate truth.

I've also tried to resist the temptation to say too much. Fascinating as they are, many of the more tangential details of quantum mechanics and computer science -- the two threads that wind through this story -- will remain wrapped inside their boxes. We are operating here on a need to know basis. (Those who want to look deeper can refer to my annotations at the end of the book, called "The Fine Print," a section that can also be taken as a gloss on the nature and limitations of science writing.)

More than ever, I want the reader to feel that we are both on the same side -- outsiders seeking a foothold on the slippery granite face of a new idea. My guiding light has been a statement by the writer Alan Lightman about what makes a good essay. I think it applies as well to a good nonfiction book:

"For me, the ideal essay is not an assignment, to be dispatched efficiently and intelligently, but an exploration, a questioning, an introspection. I want to see a piece of the essayist. I want to see a mind at work, imagining, spinning, struggling to understand."