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Steve Wozniak
with Gina Smith

iWoz

How I invented the personal computer, co-founded Apple, and had fun doing it

COMPUTER GEEK TO CULT ICON

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Additional praise for *iWoz*

"This memoir truly reflects its author, both in its subject matter and in its happy-go-lucky tone. . . . A welcome, fresh perspective for an industry that seems so far removed from its original ideals."

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"*iWoz* is Steve Wozniak's entertaining version of how [the birth of Apple] happened, but it is also a personal story about a smart kid who had a real love of engineering. . . . A sincere book."

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Computer Geek to Cult Icon:
How I invented the personal computer, co-founded Apple,
and had fun doing it

Steve Wozniak
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TO OUR

mothers & fathers

Contents

1. Our Gang: The Electronics Kids *11*
2. The Logic Game *25*
3. Learning by Accident *43*
4. The "Ethical" TV Jammer *56*
5. Cream Soda Days *75*
6. Phreaking for Real *93*
7. Escapades with Steve *112*
8. HP and Moonlighting as a Crazy Polack *119*
9. Wild Projects *137*
10. My Big Idea *150*
11. The Apple I *167*
12. Our Very Own Company *173*
13. The Apple II *186*
14. The Biggest IPO Since Ford *207*
15. The Woz Plan *222*
16. Crash Landing *234*
17. Have I Mentioned I Have the Voice of an Angel? *244*
18. Leaving Apple, Moving to Cloud Nine *259*
19. The Mad Hatter *277*
20. Rules to Live By *287*

Glossary *301*

Acknowledgments *311*

Chapter 1

Our Gang: The Electronics Kids

You usually start books like this by talking about your parents: who they were, or what they did for a living before you were born or while you were growing up. But the thing is, I never did know for sure what my dad did for a living. As early as I can remember, my brother, sister, and I all had to grow up with this secret. And as secrets go, oh man, this one was huge. We weren't even allowed to talk about his work or ask questions about it in the house. The conversation was strictly off-limits.

I did know Dad was an engineer, and I knew he worked in the missile program at Lockheed. That much he said, but that was pretty much it. Looking back, I figure that because this was in the late 1950s and early 1960s at the height of the Cold War, when the space program was so hot and top secret and all, probably that's why he couldn't tell me anything more about it. What he worked on, what he did every day at work, he'd say absolutely nothing about. Even up to the day he died, he didn't give so much as a hint.

I remember how in 1960, when I was ten, I finally understood why he'd never be able to. He said it was because he was a man of his word. Once, when he was explaining why you should never lie under oath in court, that's what he said: "I'm a man of my word."

Now, on my own, I managed to put together little bits and pieces. I remember seeing NASA-type pictures of rockets, and stuff related to the Polaris missile being shot from submarines or something, but he was just so closemouthed about it, the door slammed there.

I tell you this because I'm trying to point out that my dad believed in honesty. Extreme honesty. Extreme ethics, really. That's the biggest thing he taught me. He used to tell me it was worse to lie about doing something bad under oath than it was to actually do something bad, even like murdering someone. That really sunk in. I never lie, even to this day. Not even a little. Unless you count playing pranks on people, which I don't. That's comedy. Entertainment doesn't count. A joke is different from a lie, even if the difference is kind of subtle.

The other thing my dad taught me was a lot about electronics. Boy, do I owe a lot to him for this. He first started telling me things and explaining things about electronics when I was really, really young—before I was even four years old. This is before he had that top secret job at Lockheed, when he worked at Electronic Data Systems in the Los Angeles area. One of my first memories is his taking me to his workplace on a weekend and showing me a few electronic parts, putting them on a table with me so I got to play with them and look at them. I can still picture him standing there working on some kind of equipment. I don't know if he was soldering or what, but I do remember him hooking something up to something else that looked like a little TV set. I now know it was an oscilloscope. And he told me he was trying to get something done, trying to get the picture on the screen with a line (it was a waveform) stable-looking so he could show his boss that his design worked.

And I remember sitting there and being so little, and thinking: Wow, what a great, great world he's living in. I mean, that's all I

thought: Wow. For people who know how to do this stuff—how to take these little parts and make them work together to do something—well, these people must be the smartest people in the world. That was really what went through my head, way back then.

Now, I was, of course, too young at that point to decide that I wanted to be an engineer. That came a few years later. I hadn't even been exposed to science fiction or books about inventors yet, but just then, at that moment, I could see right before my eyes that whatever my dad was doing, whatever it was, it was important and good.

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A couple of years later—I was six, maybe seven—I remember Dad demonstrating another piece of equipment for a bunch of people at his company. A big group of people was there. These weren't just people he worked with, but also our whole family and other families, too. I think it was just a drilling machine he was demonstrating.

And my dad, even though I was just this little kid, told me I would be the one to get to throw the switch to turn it on. He said I had to do it at the exact right time.

I remember worrying about how I would know when the right time was and thinking: Now? Now? When should I do this? Now? My dad was busy talking and joking with the families of the guys who worked there, who were going to watch me do it. Then suddenly it felt like the right time. I can't explain why, but I just felt inside it was the right time. So I went ahead and threw the switch.

I heard a lot of laughter, and I didn't know why. Suddenly I realized I had thrown the switch too early. Now that I look back on this, I see this might be the beginning of my shyness, you know, getting butterflies in your stomach because you're afraid of failure when you have to talk or something.

Or maybe that was my first prank, but it was definitely unintentional!

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But there were also lessons from my dad, serious lessons that got me an incredibly early start in engineering. These lessons would always start because I'd ask a question. And I had a lot of questions.

Because my dad was an engineer, there were all kinds of interesting things lying around my house. And when you're in a house and there are resistors lying around everywhere, you ask, "What's that? What's a resistor?" And my dad would always give me an answer, a really good answer even a seven-year-old could understand. He was just an extremely good teacher and communicator.

He never started out by trying to explain from the top down what a resistor is. He started from the beginning, going all the way back to atoms and electrons, neutrons, and protons. He explained what they were and how everything was made from those. I remember we actually spent weeks and weeks talking about different types of atoms and then I learned how electrons can actually flow through things—like wires. Then, finally, he explained to me how the resistors work—not by calculations, because who can do calculations when you're a second grader, but by real commonsense pictures and explanations. You see, he gave me classical electronics training from the beginning. For engineers, there's a point in life when you understand things like how a resistor works. Usually it comes much later for people than it did for me. By the fourth grade, I really did understand things like that.

And my dad was always around to help me understand still more things. Like light. How does a lightbulb work? I wanted to know. Not many people my age knew—probably most people who are grown up still don't. But he explained it to me: first how

lights are made, then how electrons went through wires, and how those were what made a lightbulb glow. And I wanted to know how, how did it glow? So he went back to the beginning, explaining to me how Thomas Edison invented lightbulbs and what he had to figure out to do it. He realized that basically you had to create a vacuum—it had to be a vacuum because if there were oxygen in it, the wire would just burn up when it got hot. So this vacuum (remember, a vacuum has no air in it) is in this little bulb, and the point was to get heat—by moving a lot of electrons through a wire—into it.

And the more electrons that go through the wire—that is, the higher the current—the brighter the lightbulb will glow. Cool! I was eight or even younger when I understood this, and knowing it made me feel different from everyone else, different from all the kids I knew. I started to feel as if I knew secrets no one else knew.

I have to point out here that at no time did my dad make a big deal about my progress in electronics. He taught me stuff, sure, but he always acted as if it was just normal for me. By the sixth grade, I was really advanced in math and science, everyone knew it, and I'd been tested for IQ and they told us it was 200-plus. But my dad never acted like this was something he should push me along with. He pulled out a blackboard from time to time, a tiny little blackboard we had in our house on Edmonton Avenue, and when I asked, he would answer anything and make diagrams for it. I remember how he showed me what happened if you put a plus voltage into a transistor and got a minus voltage out the other end of the transistor. There must have been an inverter, a type of logic gate. And he even physically taught me how to make an AND gate and an OR gate out of parts he got—parts called diodes and resistors. And he showed me how they needed a transistor in between to amplify the signal and connect the output of one gate to the input of the other.

To this very moment, that is the way every single digital device on the planet works at its most basic level.

He took the time—a lot of time—to show me those few little things. They were little things to him, even though Fairchild and Texas Instruments had just developed the transistor only a decade earlier.

It's amazing, really, to think that my dad taught me about transistors back when almost no one saw anything but vacuum tubes. So he was at the top of the state of the art, probably because his secret job put him in touch with such advanced technology. So I ended up being at the state of the art, too.

The way my dad taught me, though, was not to rote-memorize how parts are connected to form a gate, but to learn where the electrons flowed to make the gate do its job. To truly internalize and understand what is going on, not just read stuff off some blueprint or out of some book.

Those lessons he taught me still drive my intelligence and my methods for all the computer designs I do today.

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But even with all of this—all the lessons and explanations a kid could understand—I want to tell you about the single most important lesson he taught me. Because this is what I have always hung on to, more than even the honesty thing. He drilled into me what it means to be an engineer. What I am talking about is what it means to be an engineer's engineer. A serious engineer. I so clearly remember him telling me that engineering was the highest level of importance you could reach in the world, that someone who could make electrical devices that do something good for people takes society to a new level. He told me that as an engineer, you can change your world and change the way of life for lots and lots of people.

To this day, I still believe engineers are among the key people in the world. And I believe that I will be one forever, and I have

dedicated my whole life to engineering. I realize that when engineers create something there is often an argument that the creation could be used for bad or good. Like the atomic bomb. My dad had the opinion that change is what moves the world forward and that's the path we're on and basically all change is good. That any device people want is good and should be made and not get stopped by governments or anyone else. And I came to that same view when I was very young, ten or maybe younger. Inside my head—and this is what has really stayed with me—I came to the view that basically, yes, technology is good and not bad.

People argue about this all the time, but I have no doubts about it at all. I believe technology moves us forward. Always.

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Now, you've got to realize that, electronics-wise, 1950s Northern California was another world compared to what things are like now. For example, where I was growing up, everybody who owned TVs and radios literally had to replace the bad vacuum tubes inside them themselves. Grocery stores had these giant tube testers that everyone in the family—kids, parents, everyone—knew how to use. I mean, we knew that when the TV went bad you opened it up and then took all the tubes to the grocery store, where you'd insert them in that machine. There was a meter on it that would tell you if the tube was good, weak, or bad. You could buy replacements for the bad tubes right there in the grocery store and take them home to reinsert in your TV.

In case you're too young to remember, this was a clunky solution, but it worked pretty well. The only bad part was the human effort this required—taking out the tubes, testing each of them, putting them back in. So much work! I used to look at those tubes, trying to take apart what they were made of. They were just little filaments—they ran hot and could burn out like a lightbulb. It was as simple as that. I remember wondering what it would take to build a tube that wouldn't burn out, or a TV that

didn't need tubes to work at all. How much easier they would be for people.

That's how I was, how I've always been—and still am, it seems. I've always had this technical side and then this human side. For instance, I remember telling my dad when I was ten that when I grew up, I wanted to be an engineer like him, but I also remember saying I wanted to be a fifth-grade teacher, like Miss Skrak at my school. Combining the human and the technical turned out to be the main thing for me later on. I mean, even when it came down to something like building a computer, I remember watching all those geeks who just wanted to do the technical side, to just put some chips together so the design worked.

But I wanted to put chips together like an artist, better than anyone else could and in a way that would be the absolute most usable by humans. That was my goal when I built the first computer, the one that later became the Apple I. It was the first computer to use a keyboard so you could type onto it, and the first to use a screen you could look at. The idea of usable technology was something that was kind of born in my head as a kid, when I had this fantasy that I could someday build machines people could use. And it happened!

Anyway, anyone you meet who knows me will tell you that that is exactly me—an engineer, but an engineer who worries about people a lot.

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According to my birth certificate, my full name is Stephan Gary Wozniak, born in 1950 to my dad, Francis Jacob Wozniak (everyone called him Jerry), and to my mom, Margaret Louise Wozniak. My mother said she meant to name me Stephen with an *e*, but the birth certificate was wrong. So Stephen with an e is what I go by now.

My dad was from Michigan; Mom was from Washington State. My dad and his brother, who later became a Catholic priest, were raised in a strict and pious Catholic household. But by the time

my parents had me—I'm the oldest of three—my dad had rebelled against that: the Catholicism, I mean. So I never got any exposure to religion. Church, mass, communion. What is that? Seriously, I couldn't tell you.

But from the earliest age, I had a lot of conversations with my parents about social policies and how things work. As for religion, if I asked, my dad would say, no, no, he was scientific. Science was the religion. We had discussions about science and truth and honesty, the first discussions of many that formed my values. And what he told me was, he just wanted things to be testable. He thought that to see if something is true, the most important thing is to run experiments, to see what the truth is, and then you call it real. You don't just read something in a book or hear someone saying something and just believe it, not ever.

I eventually came to conclude that, yes, I believed the same thing. And at a super young age, I knew I would do something scientific when I grew up, too.

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I forgot to mention before that my dad was kind of famous, in his own way. He was a really successful football player at Caltech. People used to tell me all the time that they used to go to the games just to see Jerry Wozniak play. And my mom, she was great to me and my younger brother and sister. She'd be home when we came home from school, and she was always really pleasant and funny and interesting and gave us stuff to eat that was special to us. And was she ever funny! I think it was from her—definitely not my dad—that I got this sense of humor of mine. The pranks I like to play, and the jokes. I have been playing pranks on people for years and years. And my mom, well, I guess you could thank her for that. She just has this wonderful sense of humor.

When I was in the sixth grade in 1962, my mother was big into Republican politics. She was a huge supporter of Richard Nixon, who was running for governor of California, and there was some

event in San Jose where Nixon was speaking and she said, "Oh, Steve, why don't you come along?" And she had a plan, a joke I would do. She wanted me to meet him and tell him, opening up a piece of paper, that I represented the Ham Radio Operators of Serra School, and that our group unanimously supported Richard Nixon's election for governor. The joke was, I was the only sixth-grade ham radio operator in the school, probably in the whole state. But I did it. I walked up to Nixon and presented the paper, which we literally wrote with a crayon just before leaving home.

I said, "I have something for you." Nixon was really gracious, I thought. He seemed kind, and he smiled at me. He signed one of my schoolbooks I had with me, and even gave me the pen he signed it with. About twenty flashbulbs went off, and I ended up on the front page of the *San Jose Mercury News* for this. Me! The only ham radio operator at Serra School and probably the youngest one in the whole state, representing a club made up of nobody but me, presenting a fake certificate like it was the real thing. And everyone believed it. Wow!

So it was funny and everything, but something bugged me, and I'm going to tell you that it still bugs me to this day. Why did nobody get the joke? Doesn't anybody check facts? The newspaper cutline said something like, "Sixth grader Steve Wozniak represents a school group that's for Nixon." They didn't get that there was no school group, that it was all a joke my mom made up. It made me think that you could tell a newspaperperson or a politician anything, and they would just believe you. That shocked me—this was a joke they took for a fact without even thinking twice about it. I learned then that you can tell people things—crazy jokes and stories—and people will usually believe them.

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We spent most of my early years in Southern California, where my dad worked as an engineer at various companies before the secret job at Lockheed.

But where I really grew up was Sunnyvale, right in the heart of what everyone now calls Silicon Valley. Back then, it was called Santa Clara Valley. I moved there when I was seven. It was all just really agricultural. It was totally different from the way it is now. There were fruit orchards everywhere. Our street, Edmonton Avenue, was just a short one-block street bordered by fruit orchards on three of four sides. So pretty much anywhere you drove on your bike you'd end up in an apricot, cherry, or plum orchard. And I especially remember the apricots. Every house on my block had a bunch of apricot trees in their yard—our house had seven of them—and in the fall the apricots would get all soft and kind of splatter wherever they landed. You can imagine what great projectile weapons they made.

When I think of that street, looking back, I think it was the most beautiful place you could imagine growing up. It wasn't as crowded back then, and boy, was it easy to get around. It was as moderate of temperature as anywhere else you could find. In fact, right around the time I moved there—this was 1958—I remember my mother showing me national articles declaring it to be the best climate in America. And as I said, since the whole place had barely been developed, there were huge orchards every which way you went.

Edmonton Avenue was actually a small Eichler subdivision—Eichler homes of that period were kind of famous for being architecturally interesting homes in middle price ranges. They stand out as special homes to this day. And the families in them were a lot like mine—middle class, with dads commuting to work at the new electronics and engineering companies starting up, and moms at home. Because of that, and the fact that a bunch of my friends could pretty easily get electronics parts and all kinds of wires from our dads' garages or company warehouses, I thought of us as the Electronics Kids. We grew up playing with radios and walkie-talkies and weird-looking antennas on our roofs. We played baseball and ran around, too. A lot.

I remember when I was in the fifth grade I was really athletic. I was always being told I was the best runner, the top athlete in school, the best baseball player, and I was really popular because of all that. But electronics was really my life, and I loved devising all kinds of projects with the Electronics Kids.

In fourth grade for Christmas, I got the most amazing gift from my parents. It was an electronics hobby kit, and it had all these great switches and wires and lights. I learned so much playing with that stuff. And it was because of that kit that I was able to do the neatest things with the Electronics Kids. I was the key kid in designing a house-to-house intercom connecting about six of our houses.

The first thing to do was to get the equipment we needed. The main thing was wire. But where were a bunch of kids supposed to get yards and yards of wire? And how we got it—it was just unbelievable. One of the guys in my group, Bill Werner, literally walked up to a phone guy and asked him if he could have some telephone wire. He'd seen long spools of it in the guy's truck, so he just asked him for one of them. I don't know why, but the telephone guy just gave it to him, saying, "Here's a cord, kid."

What Bill got was a spool of wire about a foot in diameter. It was a lot, a whole lot, of wire. It was two-wire cable, solid copper wire inside of plastic insulation in the colors white and brown, twisted every inch or so to keep the two wires together and to minimize electrical noise from being picked up. Think of it as a plus wire and a minus wire. If some electrical interference is strong, it gets picked up equally by the plus and minus wires due to their being twisted. The point is that there is never a single wire that is always slightly closer to the interference signal. The plus and minus wires serve to cancel out the interference. You get as much minus as plus. That's how telephone cords work, as I found out from this. It is also where the term "twisted-pair" comes from.

And so then I figured out what to do with all this cord, designing on paper really careful lines with my different-colored pens. And I figured out where the switches would be, and how we would connect carbon microphones (that's how microphones were back then) and buzzers and lights so we kids wouldn't be waking our parents up with loud noises that would let them know what was up. We had to make sure we could do this in absolute secrecy, and that we kids could turn the buzzers off at night so we could wake ourselves up just by the light.

Once we finished the design, the bunch of us rode our bikes down to Sunnyvale Electronics, the local store and hangout for kids like us. We bought all this neat stuff, the microphones and the buzzers and the switches, you name it.

The next thing we did was connect the wire between all the houses. There were these wooden fences that separated all the houses on our short little street, and we just went along the fence in broad daylight, stringing this wire along and stapling it in. You know, it's possible that putting staples into wire would short it out. We were so lucky that didn't happen. And we stapled that wire all the way up the block—from one of my friends' houses to mine, and then I set up my switch box, drilled some holes in it, mounted some switches, and you know what? It worked! So then we had a house-to-house secret intercom system so we could talk to each other in the middle of the night.

We were about eleven or twelve then, so I'm not trying to convince you this was a professional modern engineering system, but it really worked. It was just a tremendous success for me.

In the beginning, we used it to call each other, I guess it was just so cool to be able to talk to each other. We'd call each other up and say things like, "Hey, this is cool! Can you hear me?" Or, "Hey, press your call button, let's see if it works." Or, "Try my buzzer out, give me a call." That was about the first week or two, and after that we started using it as a way to sneak out at night.

It didn't ring in this case, it had to quietly buzz, and it had to work on lights. So Bill Werner or one of the other guys would signal me, or I would signal one of them, and we had a code that would mean different things. I can't tell you how many nights I woke up to that buzzer or a light thinking: Oh boy, we're going out tonight!

We were a group of kids who loved climbing out our windows and sneaking out at night. Maybe it was just to talk, or go out and ride bikes, or sometimes it was to toilet-paper people's houses. Usually girls' houses. Ha. We'd go out in the middle of the night and say things to each other like, "Does anyone know anyone who has a house we should toilet-paper tonight?" To tell you the truth, I never had any idea who we should toilet-paper—I never thought like that—but the other guys usually had someone in mind.

And then we would go to the all-night store and try to buy, like, twenty-five rolls of toilet paper. I remember the clerk saying, "Hey, why do I get the feeling that this isn't to be used for its intended purpose?" I laughed and told him that we all had diarrhea. And he sold it to us.

Chapter 2

The Logic Game

I did a lot of reading at night when I was a kid, and one of my absolute favorites was the Tom Swift Jr. series. I would just eat up those books so quickly; new issues would come out a couple of times a month and I'd devour them. I don't think it would be exaggerating at all to say he was truly my hero.

Now, Tom Swift Jr. was this kid—a teenager, actually—older than me but still a kid like me. So I looked up to him. And he was also a scientist/engineer who got to build things in a laboratory. Anything Tom wanted he could build, and he had his dad to help him with things. He'd go in and hook wires together and make contraptions at a company he and his dad owned. So Tom had his own company, he had his own modes of travel, and he had his best friend named Bud Barclay. Anyway, in my opinion, Tom Swift Jr. had the perfect life. And whenever there was a crisis on Earth, any kind of conflict that needed handling, he sprang into action. Say the authorities on Earth had detected some alien energy source and the only way to hold it back would be with a plasma field. Well, Tom Swift Jr. would build a plasma field. He could build a submarine if he wanted to. There was no limit to what he could build. I remember once he built a spaceship to win a race around the Earth to get the money to do something

good—you know, something good for the planet and all the people on it.

That was the kind of thing I wanted to do—build something that would end up allowing me to do something really good for people. I wanted to be a do-gooder from the start, just like Tom Swift Jr. was.

Well, my mom set a curfew at 9 p.m. every night. But after she turned the lights out, I used the light from this little streetlight outside my window to read. It hit my floor in one certain space. I would put the Tom Swift Jr. book down there on the floor where the light shone in, then put my head over the edge of the bed so I could read it late, late into the night. I wanted to be just like Tom Swift Jr.

And like Tom Swift Jr., I did work with my dad a lot on projects. In fact, my very first project—the crystal radio I built when I was six—was really all because of my dad. It took me a very long

My Hero

Tom Swift Jr. was the hero of a whole series of children's adventure novels published by the same people (Stratemeyer Publishing) that did the Nancy Drew and Hardy Boys titles.

James Lawrence, who said he had a deep interest in science and technology, was the author of most of the titles. I mentioned Bud Barclay already, Tom Swift Jr.'s best friend, but the stories had other elements in common. Anyone who's read them may remember dastardly spies from Eastern European countries like "Brungaria," and an amazingly capable element called "Tomasite," which could make anything atomic-powered.

One famous plot—I believe it was in book 22—involved scientifically regenerated dinosaurs. That was decades before *Jurassic Park*.

time in my life to appreciate the influence he had on me. He started when I was really young, helping me with these kinds of projects.

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My dad's and my relationship was always pretty much about electronics. Later, it became about what I did as an engineer working at Hewlett-Packard on calculators, or on the first computers I built at Apple. But first, for years and years, it was all about what Dad did in engineering. I watched, listened, and worked with him. It was about how fast he could show me things and how fast I could learn them.

Dad was always helping me put science projects together, as far back as I can remember. When I was six, he gave me that crystal radio kit I mentioned. It was just a little project where you take a penny, scrape it off a little, put a wire on the penny, and touch it with some earphones. Sure enough, we did that and heard a radio station. Which one, I couldn't tell you, but we heard voices, real voices, and it was just so darned exciting. I distinctly remember feeling something big had happened, that suddenly I was way ahead—accelerated—above any of the other little kids my age. And you know what? That was the same way I felt years later when I figured out how resistors and lightbulbs worked.

But now I had actually built something, something they didn't have, a little electronics thing I had done and none of them were able to do. I told other kids in the first grade, "I built a crystal radio," but no one knew what I was talking about. None of them. I felt at that moment a kind of glimmer that I might have a lead in things like this from then on. Does that sound crazy? But after building that little crystal radio and telling everyone about it, I knew I had done something most people would think was hard and few kids my age had done. And I was only six. I thought: Okay. That's done. What else can I do?

It's funny, because ever since that crystal radio project when I

was six, I've spent a lot of time trying to explain my designs and inventions to people who didn't know what I was talking about. So this has happened and keeps happening to me over and over. Even now.

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All through elementary school and through eighth grade, I was building project after electronic project. There were lots of things I worked on with Dad; he was my single greatest influence.

In the fifth grade, I read a book called *SOS at Midnight*. The hero of the book was a ham radio operator, and all his friends were ham radio operators. I remember how they sent each other messages with the ham radio and when, after the main guy got kidnapped, he was able to beat the kidnappers by cleverly rewiring the TV a little and sending out a signal to his friends. The story was okay—it was just a story. But what really got me was the fact that there were people who used these ham radios to speak to each other long distance—city to city, even state to state. Now, this was a time when it was hard for me to imagine even making a long-distance phone call you could actually afford. Ham radio was the most effective way to reach out to people in faraway places without leaving home—and cheaply. This was something that much later led to my phone phreaking (using special tones to make free long-distance calls) and then to my use of the ARPANET, which later evolved into the Internet we have today.

The other thing—the special thing—was on the last page of *SOS at Midnight*. It said how to become a ham radio operator. It said you can become a ham radio operator at any age. All you had to do was contact the American Radio Relay League (ARRL) for more information.

I went to school the next day and told my buddy on safety patrol, "I'm going to get a ham radio license!" I was really boasting, because no one back then knew what I was talking about.

Ham Radio Making a Difference

To this day, ham radio is popular all around the world. It's a hobby. Ham radio amateurs use their two-way radios to talk to each other, share information, and just have fun.

But it's more than a hobby. From the start, ham radio operators performed a public service in protecting the airwaves from radio pirates, and being extremely ethical about how they used public airways.

Many ham radio operators from the early days have gone on to make significant contributions to society. There is a lot of practical applicability in the building and use of ham radio. I'm a good example.

Ham radios were pretty obscure. But this kid I told, he said, "Oh, you know, there's this guy down the street, Mr. Giles, and he's teaching a class on this. Are you in it?" So this was really lucky. I remember being astounded. It turned out that on Wednesday nights Mr. Giles—who actually was a ham radio operator—had these classes I could take. I learned Morse code there, I learned some of the electronics calculations I needed, I learned what frequencies ham radio operators were allowed to use. Basically, I got to learn all the stuff that was going to be on the test you had to take to be a licensed ham radio operator. My dad saw what I was doing, and he got his license with me. We both took the test and passed when I was in the sixth grade. And for that Christmas, I got kits to build a Hallicrafters transmitter and a Hallicrafters receiver. In today's money, it probably cost a couple thousand dollars. That's a lot of money to spend on a sixth grader. And building the radio transmitter and receiver was a lot of work! You had to unpackage hundreds of parts. I had to learn to solder for that, too. In fact, I soldered together the whole

A Little More About the Transistor

The transistor will likely go down as one of the greatest inventions in modern history, ranking right up there with the car, the telephone, and Gutenberg's printing press. William Shockley and his team at Bell Labs invented the transistor in 1947.

Put most simply, a transistor is a tiny electronic device to control the flow of electricity. But a transistor is more than that. It has two key abilities: the first is to amplify an electric signal, and the other is to switch on or off (1 or 0), letting current through or blocking it as necessary.

Transistors are in practically all modern electronics these days, from musical birthday cards, to your car, to your personal computer. Since 1947—and this is what has made the computer revolution possible—it has become cheaper and cheaper to pack more transistors onto a computer chip every year. (This is known as Moore's Law, which Intel founder Gordon Moore defined in the 1960s. He said that every year manufacturing would get so good that double the number of transistors would be able to fit on a chip for the same price.)

A simple logic gate comprises about twenty transistors, compared to an advanced computer chip in a modern (circa 2006) computer, which can include as many as a billion transistors.

thing. We also had to go up on the roof and string antennas of a certain length, to be right for the signals I needed. This was the beginning of learning the kinds of things I would need later to design and assemble computer boards like the one that later became the Apple I.

I loved my transmitter and receiver. They were such standouts in ham radio quality—these days, I even see these models featured in radio museums and collectors' magazines. I didn't really get into talking to the other ham radio operators—they were so

much older than me and we really didn't have anything except for the ham radios in common. So after building it, I have to admit the whole thing got a little boring. But this experience was a major one. For one thing, I'm fairly sure I was one of the youngest ham radio operators in the country. That was huge for me. But even more importantly, I learned all about the process of getting a ham radio license—what I needed to know, what I needed to build the equipment—and then I built the radio. It gave me a lot of confidence for doing all kinds of other projects later on.

So my dad ended up being a key influence here, too. I mean, he even got his ham radio license with me—studying with me and taking and passing the test! The thing is, he never really tried to lead me in any direction or push me into electrical engineering. But whenever I got interested in something he was right there, always ready to show me on his blackboard how something worked. He was always ready to teach me something.

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My mom really pushed me along, too. In the third grade, when I started doing math flash cards at school, my mom practiced multiplication with me the night before we'd have to do them in school. And as a result, in school I was the only boy who could beat the girls at them. I remember a teacher said, "Wow, that's incredible. I never had a boy before who could beat the girls at flash cards." And again, that was high praise. Girls always seemed to get better grades than boys, I thought. And then I thought: Whoa. My gosh, I'm good at something—math—and I'm going to work harder at it. And I worked harder and harder to try to always be the best, to try to always be ahead. That's what really put me ahead at such a young age, this drive to keep my lead.

I had a teacher in both the fourth and fifth grades, Miss Skrak, who really praised my science projects, like I was the smartest kid in the class because I knew science so well. As you'd predict,

I accelerated even more later on. In sixth grade I was doing electronics projects most kids never figure out how to do even in high school-level electronics. So I was very lucky with all my teachers, especially Miss Skrak. She came along at just the right time in my life.

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At about this time, there was another lucky accident. I found this article about computers in one of the old engineering journals my dad had hanging around. Back then, back in 1960, writing about computers wasn't common at all. But what I saw was an article about the ENIAC and a picture of it. The ENIAC—which stood for Electronic Numerical Integrator And Computer—was the first true computer by most people's definition. It was designed to calculate bomb trajectories for the military during World War II. So it was designed back in the 1940s.

This journal had all kinds of pictures of huge computers and articles describing them. These computers were unlike anything I'd ever seen. One picture showed a big round tube that looked like a TV tube. And the article explained that the round tube was where these huge computers stored data. It used phosphor lights and then it could read if the phosphors (lights) were on or off—just like the digits 1 and 0 on today's computers can be interpreted as On or Off—and then it could reset them quickly. This, the article explained, was actually a way to store data, and I was just intrigued by that idea. I was about eleven years old at the time.

Suddenly I realized that some incredible things were just starting to happen with computers at these very early stages. Of course, they were nowhere near the point of making computers affordable or usable for the world. They weren't even talking about a point where anyone could buy a computer and put it in your house and learn how to use it yourself. I thought that would be just the best thing, and that was the dream—The Dream, I

have to put that in capital letters—because it was the single force that drove me for years afterward. How to make The Dream come true. I thought about that constantly.

There were so many incredible things happening with computers at that time, and I would never have known about them if I hadn't been too shy to do anything but read magazines at my house. The amazing thing was that at this early stage in my life, I'd managed to find this journal Dad had with this stuff in it. This was a magazine most people were never supposed to see or even be interested in because it was targeted to high-level government engineers.

After that, I was addicted. I started reading and rereading this journal and others my dad had. I remember one day finding an article on Boolean algebra. That's the type of mathematics computers use. And I learned about De Morgan's Theorem, which is what Boolean algebra is based on. And that's how logic became the heart of my existence, there in the fifth grade. I was learning that formula and figuring out how to use it so I could swap ANDs and ORs in logic equations. In logic, for instance, you might ask if a word starts and ends with a vowel. Well, then the formula would be an AND—there's a vowel at the beginning and a vowel at the end. That's AND in Boolean algebra. But what about a word that starts with a vowel but doesn't end with one, or the other way around, but not both? That's an OR statement in Boolean algebra.

And in this journal they had diagrams of AND gates and OR gates and I copied them, learning to draw them the standard way.

For instance, a half-moon shape with a dot in the middle represents an AND gate. If it has a plus sign in the middle instead of a dot, it's an OR gate. Then I learned how to draw a picture that represented an inverter—it's a triangle pointing to the right with a little tiny circle at the very end of its tip. What's funny is, I use these very same symbols when I design electronics to this day,

and I learned all this in my room with these journals in front of me on my bed in fifth grade.

Here's what was amazing to me back then. I thought to myself: Hey, at my current level of fifth-grade math, I am able to learn the math used by a computer—De Morgan's Theorem, Boolean algebra. I mean, anyone could learn Boolean algebra and they wouldn't even need a higher level of math than I already had in fifth grade. Computers were kind of simple, I discovered. And that blew me away. Computers—which in my opinion were the most incredible things in the world, the most advanced technology there was, way above the head, above the understanding, of almost everyone—were so simple a fifth grader like me could understand them! I loved that. I decided then that I wanted to do logic and computers for fun. I wasn't sure if that was even possible.

To say you wanted to play with computers in those days, well, that was so remote. It was like saying you wanted to be an astronaut. It was 1961; there weren't even real astronauts yet! The odds of being one seemed really slim. But logic was different. I could see that it just came so easily for me. And it always would.

So that's how computers became the heart of my life straight through. As a matter of fact, computer logic was something I eventually became better at than probably any other human alive. (I can't be sure of that, of course. Maybe there were really high-up people in colleges who were as good at applying De Morgan's Theorem in their heads.) But by the time I designed the first Apple computer, logic was my life. I know it sounds unbelievable, but I just loved logic and everything about it, even back then.

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I was in elementary school and junior high at a time when science projects were cool—when you weren't strange if you did one, and you got celebrated if you won an award. So I got celebrated a lot. My science fair projects are some of the things I am still proudest of. We're talking third, fourth, fifth, sixth, and

eighth grades here. (For some reason, I didn't enter a project in the seventh grade.) And these projects were hard, harder than kids many grades ahead of me could ever pull off, and I knew it even then. I put some science projects together that, for that audience of kids and judges, just blew their minds. I was like a hero, and I won all kinds of awards, including top honors at the Bay Area Science Fair.

The science fairs gave me the feeling of what I was and could be in the world, just by entering something good in a science fair. The teachers recognized something different about me immediately; some of them even started calling me Science Whiz because I had all these great projects in the science fairs. And probably as a result of that, by sixth grade I was doing electronics projects few people in high school could even understand yet. Those kinds of acknowledgments and those kinds of achievements made me want to keep working at those things until they would be my things in the world.

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My first science competition was in third grade, and I won. But the project was pretty simple, really. Basically I put together this little contraption with a light and a couple of batteries and a little wire—all mounted on a piece of wood. It was a working flashlight! A lot of people were surprised by that, and I won. No big deal, it turns out, because I felt inside it wasn't really that impressive, and I knew I would do even better the next time.

It was in the fourth grade that I did the first project that really taught me about things I would need later—physics, electronics, and the project materials. It was an experiment to see what would happen if you dipped these two carbon rods into any liquid of your choice. The carbon rods were connected by a wire to a lightbulb and an AC plug. By dipping the carbon rods into the liquid, the liquid in effect became one of the "wires." It could either act as a good wire or a bad wire—that is, it could conduct

electricity well or it could conduct electricity poorly. If the lightbulb glowed, brightly or dimly, you could see how well the liquid could conduct electricity.

I used every liquid I could get my hands on—water, Coca-Cola, iced tea, juice, beer. Which liquid conducts electricity best? (The answer turned out to be salt water.) This is an extremely important thing to know if you want to understand, for instance, hydroelectric machinery or even just plain old batteries.

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But the next experiment, man, that was a big one. What I did was build this giant real-life electronic model representing what each of the ninety-two atoms in the periodic table looks like in terms of its electrons.

In case you don't remember, electrons orbit the center of an atom in much the same way planets orbit the sun. The Earth, for instance, has a different orbit than, say, Neptune.

My project aimed to demonstrate, with the click of a switch, how many electrons orbit each atom in the periodic table, and which orbit around the nucleus they should be in. For instance, if I hit the switch for hydrogen, one light would turn on, in the orbit nearest the center of the hole, which represented the nucleus.

To pull off this project, I had to drill ninety-two holes in a big aluminum sheet. The holes were located toward the bottom; each one would hold one switch corresponding to each element. One switch would be for hydrogen, one for gold, one for helium, and so on.

Now, I painted a very large picture resembling a bull's-eye target—concentric circles in different colors, with a tiny target in the middle to represent the center of the atom, which is the nucleus. And I had to drill ninety-two holes into the big orbit picture, several in each orbit, corresponding to where the electrons could be in an atom.

The end result was this. Ask me to show you the electrons for any of the ninety-two natural elements. Let's say oxygen. I would hit the oxygen switch, and the eight lights representing the eight electrons that rotate around the oxygen atom would turn on, all in the proper orbits.

I knew what the proper orbits were because I'd used this big reference book called *The Handbook for Chemistry and Physics*.

This project ended up getting terribly complicated, because by the time I was dealing with all ninety-two elements I was stuck with dealing with ninety-two different sets of switches.

That got so tough I finally had to use the information my dad taught me about the diode, which is the first electronics part I ever learned about, really. Unlike a resistor, a diode is a one-way street. You can send electrons—that is, electricity—just one way. Electricity can go through, but it can't come back through. If you try, it will short everything out. And this was a problem because I'd gotten to the point where if I tried to turn on some middle-level element and its electrons, I wound up with a feedback path that ended up turning on a bunch of lower elements and extra electrons that really didn't belong there. Anyway, I needed a solution, and that's how I learned all about diodes.

Along with this huge display, I also displayed a large collection of elements. You know, jars of beryllium, pieces of copper, even a bottle of mercury. I got a lot of these samples just by asking a professor at San Jose State to donate them to me.

And yes, I won. First place. Blue ribbon. And that was cool.

But it wasn't the most important thing. Looking back on it now, I see this was an amazing learning experience, just classic. My dad guided me, but I did the work. And my dad, to his credit, never tried to teach me formulas about gravitational power and electric power between protons, or stuff like what the force is between protons and electrons. That would have been way

beyond what I could understand at that point. He never tried to force me to try and jump ahead because I wouldn't have learned it. I wasn't ready for that level of knowledge.

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In sixth grade, small step by small step, I learned how to build AND and OR gates, the basic building blocks of computer technology. Digital circuits figure everything out—and I mean everything—based on what is on (1s) and what is off (0s).

I was really getting into logic. My dad had helped me understand the concept of logic earlier by using the classic paper-and-pen tic-tac-toe game. This game, if you understand the logic, you will never, ever lose. That's what I based my next project on: the tic-tac-toe machine. The machine I built would never, ever lose. It is so totally a logic game, but it is also a psychological game because you can beat someone who thinks they can never be beaten. If the X is here and the other X is over there, what should the outcome be? This plywood was covered with parts and it was a huge project. And having a huge project is a huge part of learning engineering—learning anything, probably.

Doing long, long jobs that aren't just some real simple quick thing like a flashlight, but things that take weeks to build, really demonstrates that you've mastered something great. Like, for instance, creating a computerized tic-tac-toe machine that really works by logic.

Unfortunately, though, the system didn't win. It blew up. What I mean by blew up is, the night before the competition, some of the transistors started to put out smoke. Obviously something was wrong. I knew it was going to take forever to find out what piece of equipment had blown and there was no way I was going to be able to do this in time for the contest. What a disappointment, because I like to win. I always, as early as I can remember, wanted to be the best at things. And I often was, as luck had it.

But I also thought at the time that it didn't mean as much to

me at that point, just winning the science fair, because I knew, and my dad knew, that I had actually built this fairly complicated logic machine and it worked.

I mean, even as a kid it was obvious to me what the important thing really was. I said to myself, Look, showing someone an award from a science fair is not as important as knowing you already have the award somewhere at home. And that's not as important as having earned it, even if you don't have the award at home at all. And that's not as important as the most important thing: that you've done the learning on your own to figure out how to do it. I did that learning on my tic-tac-toe machine, and it was very, very close to being done and complete. I'm still proud of it. For me it's the engineering, not the glory, that's really important.

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Okay, so I'd built that tic-tac-toe system basically by putting together electronic gates. The idea was to put the gates together into a system of transistor circuits that would never let you beat it. And as I said, I came up with the rules by playing all possible games.

But in the eighth grade I did something altogether different. I came up with a machine I called the Adder/Subtractor. This would be the closest thing to an actual computer I'd ever designed. I can say this because I designed it so it would do something—you could add or subtract numbers, and the result would show up on an electric display—but also because it wasn't made up of just a set of logic gates like the tic-tac-toe machine. Addition and subtraction are logic, just like tic-tac-toe; based on inputting 1s and 0s, you can calculate what 1s and 0s come out.

The Adder/Subtractor wasn't more complicated in terms of size or construction time than the tic-tac-toe machine, but this project actually had a goal that was closer to real computing. A more important purpose than tic-tac-toe. We're taught to add

and subtract in school, but nobody teaches you tic-tac-toe. It's not that important. Adding numbers could put a man on the moon; tic-tac-toe couldn't.

My project had a function, a real function that was useful. You could input numbers, add or subtract one, and see your answer.

This Adder/Subtractor was about a foot square. I had a plastic board filled with holes and store-bought connectors I could plug down into the holes to form connection points. I plugged the connectors in where needed and soldered transistors and other parts to them.

I had ten little switches to represent 0s and 1s, and another set of switches to represent more than 0s and 1s. So if you wanted to add 3 plus 2, on one row you would have to toggle the rightmost two switches (which is equivalent to 0000000011, the binary number representing 3) on the top row. Then, to represent 2, I had to toggle the next to last switch to the right on the bottom row. In binary, that is 0000000010. The answer would show up in lights, the lights I had attached. In this example, two lights would be on—representing 0000000101, which represents 5. This would all be assuming that you had the Adder/Subtractor in "add" mode instead of "subtract" mode.

What was impressive about this was that I knew so many levels of electronics, logic, binary number theory, soldering, and all the experiences of my life so far just added up. I could explain to judges how binary numbers worked, how you added and subtracted them, and then I could explain how gates were made of diodes and transistors. I would then show the right combination of gates that made a one-bit adder (something that could only add 0 and 1). I could show them a simple modification I did that could do subtraction as well. I also told the judges how I'd solved a nonworking problem in the electronics of a gate, switching from resistors to diodes. That's real electronics know-how.

On the one board were ten Adder/Subtractor circuits side by

side handling carries and borrows (remember arithmetic) so you could add or subtract larger numbers—any number up to 1,023.

But here's the thing. I took it down to the Bay Area Science Fair one night, to set it up before the day of judging. Some people showed me where to put it and asked me if I'd like to tell them about it. I told them no, figuring that I'd just tell them the story on judging day. By then I'd gotten kind of shy. Looking back, I think I may have turned down the judges without knowing it.

When I showed up on judging day, all the projects already had their awards. The judging had already happened somehow! I had an honorable mention, and there were three exhibits that had higher awards than mine. I saw them and remember thinking they were trivial compared to mine, so what happened? I then looked in the fair brochure and those three projects were all from the school district that was putting on the fair.

I thought, Hey, I've been cheated. But that night, I showed the machine and talked to lots of people—including, I'm sure, the real judges—and it seemed like they really understood how big my project was. I mean, it was great and I knew it and everyone knew it. I was able to explain how I'd used logic equations and gates and how I'd combined gates and transistors with binary number (1s and 0s) arithmetic to get the whole thing working.

After that, the Air Force gave me its top award for an electronics project for the Bay Area Science Fair, even though I was only in eighth grade and the fair went up to twelfth grade. As part of the award, they gave me a tour of the U.S. Strategic Air Command Facility at Travis Air Force Base. And they gave me a flight in a noncommercial jet, my first-ever flight in any plane. I think I might have caught my love for flying then.

When I look back, that Adder/Subtractor was such a key project in my getting to be the engineer who ended up building the first personal computer. This project was a first step to that. It

was a large project, for one thing, involving more than one hundred transistors, two hundred diodes, and two hundred resistors, plus relays and switches. And it performed a function that was useful: addition and subtraction.

And thanks to all those science projects, I acquired a central ability that was to help me through my entire career: patience. I'm serious. Patience is usually so underrated. I mean, for all those projects, from third grade all the way to eighth grade, I just learned things gradually, figuring out how to put electronic devices together without so much as cracking a book. Sometimes I think, Man, I lucked out. It seems like I was just pointed in such a lucky direction in life, this early learning of how to do things one tiny little step at a time. I learned to not worry so much about the outcome, but to concentrate on the step I was on and to try to do it as perfectly as I could when I was doing it.

Not everyone gets this in today's engineering community, you know. Throughout my career at Apple and other places, you always find a lot of geeks who try to reach levels without doing the in-between ones first, and it won't work. It never does. That's just cognitive development, plain and simple. You can't teach somebody two cognitive steps above from where you are—and knowing that helped me with my own children as well as with the fifth graders I taught later on. I kept telling them, like a mantra: One step at a time.

Chapter 3

Learning by Accident

Throughout most of elementary school, I was a little shy, but at least I had a lot of friends and was really athletic. I was the de facto leader of the Electronics Kids because I already knew so much of the stuff we needed to build the things we wanted to build. This was a close group in the neighborhood, and that was great. I loved being able to excel at things, and having people recognize me for that. Not out of ego, really, just a drive to be the best.

I was good at swimming and football and made the All-Stars in Little League, where the other kids told me I was the best pitcher and runner and hitter on my teams. In fifth grade I was the smartest student in my class, according to my teachers at least, and I was elected school student body vice president. Do I sound like I'm bragging? I know I do, but I don't mean to. I was just so proud of all that. All these activities built up my self-esteem, and that was an important part of my internal development.

But things changed in sixth grade. I wasn't so popular anymore. In fact, suddenly it was like I was invisible. All of a sudden, other kids didn't recognize me as much for my math and science skills, which really bothered me. I mean, that's what I was best at. This was a time when a lot of students start flirting and engaging

in all kinds of small talk that I didn't relate to. So I wasn't included. My natural shyness just made me bottom out in sixth grade. I really stopped enjoying school so much. Socially, I went straight to the bottom.

I think of the years after that, seventh and eighth grades especially, as terrible years. Where before I was popular and riding bikes and everything, suddenly I was socially shut out and not popular at all. It seemed like nobody spoke to me for the longest time. I was in the advanced classes and got good grades, but I didn't have much enjoyment doing it.

As an example, I remember few teachers from those bad years.

The only way I can explain it is that when kids that age start getting social, your position in the group starts getting important to a lot of people. I've watched this happen with my own kids and the kids I've taught. Who are the talkers? Who makes the decisions? Who rises to the top? And because I became so shy when I hit adolescence—well, I just went to the bottom. It was a tremendous shock for me. Except for the science projects, which still got me recognized by my teachers and grown-ups, I felt terribly awkward. I couldn't identify with other kids my age anymore. The way they spoke—I felt like I didn't know their language anymore. And I'd feel too scared to talk because I thought I'd say the wrong thing.

At the same time I was starting to feel advanced, science- and electronics-wise, I felt shunned by all these kids who suddenly, and for no reason I could understand, just couldn't accept me anymore. I did electronics when a lot of others started hanging out and partying and drinking and going to, well, I guess you would call them make-out parties.

This started in sixth grade, and in many ways, that shyness is still with me. Even today. I have friends who can just go up and talk to anybody. They're suave and make friends so easily. Small talk, they can do that. I can't possibly do that. I can give speeches

because I've had something like thirty years of experience doing it, and I have techniques I use to make it easier, techniques I gained gradually from having to do public speaking for many years. I just make lots of jokes to get everyone laughing. Or I build and show off some electronic device to get people talking to me about it.

Or—and maybe you know this about me—I break the ice and make people laugh by pulling pranks on them. I could write a whole book on those pranks alone, that's for sure.

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I did a ton of pranks in junior high and high school. I got caught many times in junior high. The main thing I learned was that if you told a few others about a prank, the word spread and you got caught quickly. In high school I was careful in this regard. I made sure to keep my pranks quiet.

Once, for the benefit of everyone in my twelfth-grade driver's education class, I built an electronic siren—it sounded just like a real police siren—that I could start and stop, holding it under my chair in the dark during the movie that played as we drove in our simulators. I wanted to see if anyone braked and pulled over. I'd make it with tons of batteries so it would last a month or more and place it on top of the TVs that were in every classroom. (The TVs were up high, supported from and attached to the ceiling, so the teachers couldn't see my sirens.) The teachers would think the TV had a problem. It's hard to isolate where a very high pitch is coming from; I'd read that somewhere.

But later in the twelfth grade, I got caught again. Big-time.

I got the idea to build a little electronic metronome—you know, the thing that goes tick, tick, tick, to keep time when people take piano lessons. I built it, heard the ticking, and thought: Hey, this kind of sounds like a bomb. So I took some batteries, took the labels off the batteries so they looked like plain metal canisters, and I taped them together. And then I wrote in big letters on it: CONTACT EXPLOSIVE.

I thought: Oh, this will be funny. I'll stick it in Bill Werner's locker. I just happened to know his locker code. Bill's locker was near mine so I put my so-called electronic metronome in. Now, this was in the morning before school, and after I put it in there, I could barely hear it ticking. Nobody was going to be tricked by this if they couldn't even hear it! I'm thinking: What a bummer and what a waste if this thing isn't going to work. But when I came out of my last final that day, my counselor walked up to me and said: "Steve, the vice principal wants to see you in his office." This was a bad sign. Then again, I thought maybe there was a chance I was getting the math award for a math contest I had recently competed in and that's why he wanted to see me. So I didn't know for sure if I was in trouble or not.

Well, I sat in the chair in the office waiting for the vice principal to come in, and all of a sudden this police officer walks in the door carrying a box with wires coming out of it. And I just thought, Oh my god, they called the bomb demolition squad! Then they called me into a room and a cop said, "Look, your buddy told us everything." I figured the guy who told them was this guy I knew, Jerry, who was the only friend I'd told about the plan. But no, I later found out it was a mistake on my own part that got me caught. I realized many years later that they meant they had actually heard it from Bill Werner, whose locker they found it in. Turns out they'd hauled him out of a final—he looked at the design and said, "Oh, I know those components. Woz did it." Well, that's what I get for using some of the same parts Mr. Taylor, who lived next door to me, paid Electronics Kids like me and Bill Werner with when we worked in his yard.

So I could've denied it at that point, when I still thought it was Jerry who told them, and in fact, we all had an agreement that none of us involved in a prank would ever tell on the other ones. But anyway, I knew I was in big trouble, and finally they sat me down with the principal, and the vice principal, the counselor,

the dean, and two police officers. And the principal starts telling me how the English teacher, Mr. Stottlemeier, had heard a ticking sound in the locker. The principal, Mr. Bryld, told me how he opened the locker, clutched the device to his chest, and then ran all the way out to the football field and dismantled it!

I started laughing, even though I was trying not to, so then I tried to cough to cover it up. But I couldn't even do that, because I knew I had rigged the metronome with a switched resistor to start ticking faster when someone opened up the locker door.

I'll tell you, laughing about that—and how could I not laugh—well, it didn't fix the problem any. They debated for a while what to do with me, and decided to send me to juvenile hall—that's right, juvie!—for a night. Just one night.

The principal was terribly upset because there had been some actual bomb threats at the school a few weeks earlier. This wasn't a bomb. It was a metronome, a joke. But I still had to go to juvie that one night, and I did make some good use of my time while I was there. I thought: Well, what do they always say about prisoners in prisons? That they teach each other crimes. So I did my fair share. I pointed out to all these big tough guys in juvie how to remove the electrical wires on the ceiling fan. I said, "Take those wires off and touch them to the bars when the jailer comes to open the bars and he'll get shocked!" I sure had a fun time there. All those guys in there treated me really nice. This is way, way before it was cool to be a nerd, of course.

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Later, much later, I found a group where being a nerd was cooler. In the mid-1970s, a couple of years before we started Apple, I joined a club called the Homebrew Computer Club. I loved this group and attended almost every meeting from the time they started meeting in Gordon French's garage in Menlo Park every other Wednesday from 1975 up until 1977, the year we incorporated Apple. These people had the same dream I

had—to learn how to build a computer everyone could afford and use. These were my kind of people. Their prime focus was a build-it-yourself device called the Altair (which could be expanded into a usable computer with a huge amount of money) and the things you could do with it. And they used to have an hour or more of random announcements (called the "random-access period") where anyone who had anything to say could say it if they just raised their hand.

I had a lot to say, but I was unable to raise my hand or say a thing. I used to just sit on the edge of my chair listening to them tell every rumor in the industry about what technologies were coming out next. I was that shy. I was in the back row just like I had been in junior high school.

I finally ended up having to get up and show everybody two real computers I'd built. (One of these became the foundation for the Apple I designs.) And as soon as people saw what I had done, and that it was really impressive, suddenly we all had something to talk about.

From elementary school on, even up to starting Apple and beyond, I used my clever designs as an easier, more comfortable way to communicate with others. I believe all of us humans have an internal need to socialize. In my case it came out mainly by doing impressive things like electronics and incredibly showy and clever things like pranks.

It was probably the shyness thing that in the sixth grade and afterward put me on the hunt for electronics journals. That way, I could read about electronics stuff without having to actually walk up to someone and ask questions. I was too shy to even go to a library and ask for a book on computers called *Computers*. And because I was way too shy to learn the ordinary way, I ended up getting what was to me the most important knowledge in the world accidentally.

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Then, in high school, a lot changed again. Most of it had to do with an electronics teacher I had named Mr. McCollum. He had a huge, huge influence on me.

Now, Mr. McCollum was an interesting guy. For one thing, he was a military guy before he was a teacher, which meant he could tell a lot of jokes, even off-color jokes. So he related well to his students. Keep in mind that back then, the students in an electronics class were mostly low-performing students. Electronics was like a vocational course. There were only a few electronics students who, like me, were taking top classes in other areas. And remember that I was a math whiz. I won the math award from my junior high graduation and had won some yearly math awards from my high school, too.

Combine math and electronics and you know what you get? It's called engineering.

Mr. McCollum would stand there in front of us doing calculations on this big yellow slide rule. He would do more calculations on that slide rule than we even did in chemistry; the course was that intensive. And Mr. McCollum wrote that course himself. He wrote handouts that went in a logical order—you know, step by step, going up the electronics ladder. You learn one thing about resistors, then a more complicated thing, then you learn faster, then you put them together. It was such a good way to teach electronics that I used it later when I taught my own computer classes in later life.

And Mr. McCollum had the most amazing collection of electronics equipment, really advanced stuff. It was all test equipment I could never afford on my own, and it was better than what even most college-level labs had then. Mr. McCollum had been resourceful and had gotten the school to buy less expensive electronics kits in the few first years of Homestead High School. As his students learned electronics, they built the kits of equipment to take them further. Now, by my senior year, we had pretty complete labs.

So we had a lot of equipment. And what a fun class that was. You build something and it works. You don't stop finding things you forgot or did wrong until it works. And you learn about what happens when things go wrong, which is the number one thing former electronics students always remember about their classes. We all got zapped with accidental shocks now and then. Like the time I got hit with 22,000 volts from a TV set and flew back about five feet. Whoa. But that, I swear, is what hardware guys like me get used to. We grow up not fearing shocks as much as other people.

I now have a roulette shocker—four people stick in their thumbs and, to the accompaniment of music and flashing lights, it gradually slows down cycling until one person gets a shock. Hardware guys will play this game but software guys are always way too chicken.

Mr. McCollum let me do as much as I wanted—he even prevented me from getting bored by letting me go to work at a company during school hours on Fridays. It was Sylvania, in Sunnyvale, and I got to learn how to program a computer. Mr. McCollum said that I knew everything in his course and I'd just play pranks on the others in class. Well, we had no computer in our school, so that was the first time I really got face to face with a computer I could program, and after that there was no turning back.

I never thought I'd be near a computer in my life. I thought, Oh my god! Computers! I bought a FORTRAN book and told myself, I'm going to learn how to program. An engineer down there at Sylvania taught me how to use a keypunch. I remember typing out my first little program and his helping me put it into the computer and running it.

The first real program I tried to write was called the Knight's Tour. You jump a knight piece around the chessboard, only in valid moves for a knight, in a pattern so that it hits every one of

the sixty-four squares on the board exactly once. This is not easy to do. I wrote my program to go up two squares, then over one again and again, to try all the moves until you can't move again. And if it didn't hit all the squares by the time it got stuck, the program would back up and change a move and try again from there. It would keep backtracking as far as it needed and then kept going. That computer could calculate instructions a million times a second, so I figured it would be a cinch and would solve this problem quickly.

So here I am with my program and I'm planning how this is just the beginning of my solving all the sophisticated problems of the world, but guess what? The computer doesn't spit out anything. The lights on the computer flickered, and then the lights just stayed the same. Nothing was happening. My engineer friend let it run a while longer and said, "Well, probably it's in a loop." And he showed me what an infinite loop is—when a program gets stuck and does the same thing over and over and never ends. (Just as an aside, Infinite Loop is today the name of the street where the current Apple headquarters is located.) Anyway, the next week I went back and I wrote my program so that I could flip a switch in order to get printouts of whatever chessboard arrangement it was working on. I remember pulling the printouts out and studying them that very day and realizing something. The program was in fact working the way it was supposed to. I hadn't done anything wrong. It just wasn't going to come up with a solution for 10^{25} years. That's a lot longer than the universe has even been around.

That made me realize that a million times a second didn't solve everything. Raw speed isn't always the solution. Many understandable problems need an insightful, well-thought-out approach to succeed. The approach a program uses to solve something, the rules and steps and procedures it follows, by the way, is called an algorithm.

What Is the Knight's Tour?

The Knight's Tour is more than just a mathematical problem where you have to get a knight around a chessboard. It's an ancient puzzle, and people have been trying and failing at it for centuries. The goal is to move the knight sixty-four times so it lands on each and every chess square only once.

I found two sites you might like if you're interested in this. http://www.borderschess.org/KnightTour.htm is a Knight's Tour puzzle you can do without a chessboard. You do it online. Another page on the same site—http://www.borderschess.org/KTsimple.htm—is an actual instruction guide so you can learn how to do it and blow other people's minds! Good luck.

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I had this tremendous respect for teachers back then, I really did. I thought they were just the smartest people in the world, right up there with engineers. They were able to stand up there and talk so naturally, just teach us like that. I mean, I knew I was real smart, but because teachers had the ability to read up on topics and then talk about them with so much confidence, I figured they had to be much smarter than I was. I thought at the time that all my high school teachers were smart thinkers.

Now I'm a bit more cynical after seeing too many cases where intelligence in students is defined as everyone reading the same thing, including the same newspaper and magazine articles, and having the same answer, and agreeing with the way the matter is presented.

If you read the same things as others and say the same things they say, then you're perceived as intelligent. I'm a bit more independent and radical and consider intelligence the ability to think

about matters on your own and ask a lot of skeptical questions to get at the real truth, not just what you're told it is.

I had a really long walk to and from Homestead High School every day, and I started using that time to really think. It was a walk of a few miles, and I started to analyze my own intelligence. I was struggling in my head with the fact that I had been extremely smart in math and science and weaker in English and history. Why was that? Well, I figured those were more subjective categories, and I watched as nice, sweet-talking girls went up to the teacher and got their grades raised right there on the spot. And I thought: Well, gosh, when you're just writing words down, they're just words—it's all subjective and it's hard to tell what the real answer is. What I loved most about math was that you had to have an answer that was either correct or incorrect. You know what I mean? No gray areas—your answer was correct or incorrect and that was it. (Once I found I did have an answer that the teacher marked incorrect but I knew was right. And it turned out the book was wrong. Books do that sometimes.) Compare this to a book report or an essay you're supposed to write where there are so many interpretations and so many ways to write it. Who's to say which version the teacher will like? Who's to say who really understood the book, or who got more out of it?

And so somewhere on those long, long walks, I decided that logic was superior. This confirmed what I already thought, but I remember these walks really cementing the idea. I realized that I probably was not in the mainstream of people and social goings-on. I realized I thought differently than most other kids I knew. I thought: Hey, things are facts or things are lies. Mathematics is a truth because two plus two equals four, and if someday somebody finds out two plus two equals five, well, then we just have to come up with a new truth to deal with that. And to me, the very closest thing to truth—the main ethic I'd gotten from my dad and the ethic he'd ingrained in me—was logic. Logic was the

thing. I decided that the most important measure of a person was truth, and that the calculations engineers made were the mark of people who lived truthfully.

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One day at Sylvania I saw a manual entitled *The Small Computer Handbook*. I had this interest in computers but I only found out about them and how they worked by lucky accidents. This was one of my life's luckiest accidents.

The Sylvania engineers let me take this handbook home. Inside, it described the guts of the Digital Equipment PDP-8 minicomputer. This computer sat in a tall rack of equipment and had switches and lights and looked like it belonged on a factory floor or somewhere. I couldn't say exactly because I'd never seen a real computer anywhere other than Sylvania. This one handbook finally solved a search I'd been on since fourth grade to discover what a real computer was inside.

I had a good knowledge of logic design, combining parts to make logic circuits. Now I had a description of what a real computer was. On my own I sat down for many nights figuring out ways to combine logic parts to make one of these PDP-8 computers. That first computer design of mine on paper was huge and unfinished and probably full of errors. But it was just a start.

Over the next few years, beginning with my senior year in high school, I found ways to obtain manuals for almost every minicomputer being made. There was a flood of these minicomputers introduced in this time frame. They were taking computing to a smaller level than the huge machines that filled rooms. A typical minicomputer with enough memory to program (in a friendly programming language) was about the size of a microwave oven.

I got manuals for minicomputers from Varian, Hewlett-Packard, Digital Equipment, Data General, and many more companies. Whenever I had a free weekend, I'd take catalogs of logic components, chips, from which computers are made, and a par-

ticular existing computer description from its handbook, and I'd design my own version of it. Many times I'd redesign the same computer a second or third time, using newer and better components. I developed a private little game of trying to design these minicomputers with the minimum number of chips. I have no idea why this became the pastime of my life. I did it all alone in my room with my door shut. It was like a private hobby. I didn't share this activity with my parents, friends, teachers, or anyone over the years. It was that private.

Because I could never afford the parts to build any of my computer designs, all I could do was design them on paper. Typically, once I started a design, I'd stay up very late one or more nights in a row, sprawled on my bedroom floor with papers all around and a Coke can nearby. Since I could never build my designs, all I could do was to try and beat my own designs by redesigning them even better, using fewer parts. I was competing with myself and developed tricks that certainly would never be describable or put in books. I had a hunch after a year or so that nobody else could do the sorts of design tricks I'd come up with to save parts. I was now designing computers with half the number of chips the actual company had in their own design, but only on paper.

Chapter 4

The "Ethical" TV Jammer

A guy named Rich Zenkere was selected class clown of Homestead High Class of 1968. He was a funny guy who sat next to me in a lot of classes because in most of our classes we had to sit in alphabetical order. And Wozniak is pretty close to Zenkere in the alphabet. So Rich, some other guy who sat near us, Scott Sampson, and I agreed that the three of us should look for colleges together.

We planned to visit Caltech. We planned to fly down to Pomona, California, where Scripps, Pomona College, and California Polytechnic are located.

And then we got this great idea to visit the University of Colorado at Boulder. It was where Rich's dad had gone.

What an exciting time this was for me. I had never been out of California in my life. I remember we got on the plane in San Jose Airport, back when it had only two gates, and took a 707 to Denver. We drove from Denver to Boulder by taxi and arrived when it was too dark to see anything. We passed out from exhaustion in the hotel room. And then, in the morning, we turned on the TV to find that it had snowed something like a foot and a half the night before. So we pulled the drapes, and sure enough there were inches and inches of snow outside. We were all excited.

I had never been around real snow in my life. Where I lived, it might snow a little some years, but never enough to stick on the ground and definitely never enough to make a snowball with. So this was amazing! All of a sudden we were outside throwing snowballs at each other. This was a whole new adventure for me.

For some weird reason, we had shown up over Thanksgiving weekend. I guess we thought they'd have tours on a holiday, but of course they didn't. So we just kind of walked around the empty campus for a couple of days. At one point we actually found an engineering building and there was a student inside. He walked us around the halls and showed us where the different departments were. He showed us all the engineering stuff and talked to us about the kinds of engineering projects going on at Colorado.

Walking through the snow those two days, I was just so enamored of the place. The brick buildings were beautiful. Their reddish color looked so impressive up against the backdrop of the Flatiron Mountains. It was a college out in the middle of nowhere—it was about a mile walk to the city.

I thought, This is just so beautiful. It's so wonderful to walk around this campus in the snow. And it was that snow that made me decide this was the college I was going to be attending. Its entrance requirements were low compared to my grades and SAT scores—I had perfect 800 scores on all my science and math entrance tests except for chemistry, where I only got a 770. But this was the college I was going to go to. The snow made me decide. I made the final decision right then and there.

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The only problem was, my dad said Colorado would be too expensive. Next to some state university in New England, it charged the second-highest tuition in the country for out-of-state students.

But we finally worked out a deal. He said I could go to Colorado for my freshman year and then to De Anza Community

College, which was close to home, for my sophomore year. After that, I would transfer to the University of California at Berkeley for my junior year, where tuition would be much, much cheaper. I also applied to Berkeley—my parents forced me to—and I sent in my application on the very last day you could.

I was accepted at Colorado and my parents paid everything in advance that summer, including the dorm fees and the tuition fees. But then my dad kept imploring me to go to De Anza, it was so much closer to home and cheaper. And he could afford, then, to give me a car.

So I went down to register at De Anza and saw that the classes for chemistry, physics, and calculus were all full. What? I couldn't believe it. Here I was—the star science and math student at my high school and all set to be an engineer—and the three most important courses I needed were locked out.

It was horrible. I called the chemistry teacher on the phone, who said if I showed up I could probably get in, but I couldn't shake this terrible feeling that my future was shutting down. I could see it shutting down right in front of me. I felt my whole academic life was going to be messed up right from the start. And it was right then that I changed my mind, and decided to see if it was still possible to go to Colorado.

School had already started there, but after a couple of calls I found out I could still go. I had everything set up, airplane flight schedule and everything. I bought the tickets, went down to San Jose Airport, and flew into Colorado the next day. Just in time for the third day of classes.

I remember arriving on campus that fall and thinking it was so beautiful, early September in Colorado. The leaves were yellow and orange and gold, and I felt like I was just so lucky.

My roommate was Mike. The first thing I noticed when I walked into the dorm room with my bags was that he'd posted up about twenty foldout *Playboy* centerfolds on the walls.

Wow, that was different! But I thought Mike was a neat guy, and I used to like listening to his stories of life as a military brat, about his high school in Germany and all the experiences he had. He was very sexually advanced, I thought. Sometimes he'd tell me he wanted the room alone on certain nights, and I knew why. I'd say, Well, okay. I'd take this tape recorder I had and a bunch of reel-to-reel tapes—Simon & Garfunkel was my big group then—and I'd go over to Rich Zenkere's room and come back much later. I remember one time I was sleeping and he brought in this Mormon girl in the middle of the night. He was really something.

Meanwhile, I'd hang around with other friends I'd made in the dorm. I went to football games. Our mascot was a buffalo named Ralphie (a humiliating name for anyone!), and a bunch of students dressed like cowboys would race him around on the field before the game. Ralphie was a real buffalo. I remember how my friend Rich Zenkere told us that, twenty years earlier, Colorado's main rival back then, the Air Force Academy, managed to kidnap him. And when the Air Force Academy players showed up for the big game they cooked and ate poor Ralphie.

I believed the story at the time, but you never knew about Rich. He took things so lightly and easily, always smiling and joking about the most serious things. He was a little bit dishonest, though. We worked together washing dishes at a girls' dorm, and he ended up getting fired for faking time cards and stuff.

I spent a lot of time in Rich's room with him and his two roommates, Randy and Bud, playing hearts, poker, and bridge. Randy was interesting to me because he was a serious Christian—a born-again Christian—and the other two guys would denigrate him for it. Like he was dumb because of it. But I used to spend a lot of time talking to him about his beliefs. I had never had any kind of religious training whatsoever, so I was impressed when he told me about Christian things like "turning the other cheek" and

forgiveness. I definitely became his friend. So anyway, we'd usually play cards late into the night, and I remember thinking, This is just the best year of my life. It was the first time in my life I could decide what to do with my time—what to eat, what to wear, what to say, what classes to take and how many.

And I was meeting all kinds of interesting people. The bridge thing ended up getting huge for me. We started playing it right around finals week, and then it stuck. The four of us played bridge right off the seat of our pants. We didn't have any books or tables in front of us, or anything that normal bridge players use. We just sort of figured out for ourselves what bridge bids worked and which ones didn't. I mean, in my mind, bridge is more sophisticated than other games.

A lot of card games are based on "tricks" where one person puts a card down and the other players follow with their own cards, and the highest-ranking card of the suit of the first card down wins. That's a trick. Now, in hearts, you try to avoid taking certain cards: for example, every heart you win in a trick counts against you. In spades, you have a round of bidding first, betting how many tricks you and your partner—the person across the table from you in a game of four players—will take. If you bet five tricks and get that many, you get fifty points. But if you overbid and don't get as many tricks as you thought you would, you lose that many points. In spades, all of the spades have the special ability to trump the other cards.

But bridge is at the top end. You not only bet how many tricks you can take with your partner, whose hand you cannot see, but you also have to bet which suit will be the trump suit that beats all other suits.

Bridge is such a good balance of strategy and offense and defense. And at the same time, you're looking at your hand and trying to guess what others might have and passing signals for the bidding. You have to play on so many levels at once. We really