Logic State Analyzers Birthing Pains
Chuck House

Foreword
Mr. Phenomenon, Chuck House

*What words come to mind when you think of the 2009 book **HP Phenomenon**? Comprehensive, insightful, strategic, historical, illuminating, thorough, definitive, interesting, analytical, fascinating, biographical, all presented with a sweeping view of how Hewlett-Packard, the pre-eminent high-tech company of the 20th Century got that way.*

When Chuck House and Ray Price did their methodical 10-year research about HP's inner operations and their emerging modes of strategic product planning, they interviewed nearly 600 people, reviewed hundreds if not thousands of documents (there were 1,114 footnotes). From all of this mass of research, they compiled their essential treatise on the amazing success of how HP seemed to almost always envision and choose the right new product performance to beat the new technologies that were just coming into the market.

The central business strategy of HP was ALWAYS the strategic product plan. In the early years, it was mostly internal discussions among the principles. New products were forced by the measurement technology of HP's customers' immediate near term requirements. In the 1960s, the development of the moving 5-year product plan became well organized and well honed. As the products moved to desktop computers and then to mid-range computer systems, the R&D funding became staggering, mistakes VERY costly, and decisions much more cautious.

These elements of business and product strategies became excruciatingly complex in John Young's years as CEO, because HP was then playing with the Big Boys; IBM, DEC, GE, and more. The stakes were crucial for proper decisions on technologies which drove operating systems, software, firmware, and long-shots like RISC. Chuck and Ray made those complex times meaningful and were masterful in their analysis.

*Thus **HP Phenomenon** delivered a remarkable picture in describing and analyzing the EVENTS and PROCESSES of company progress. It was biographical to the extent that all those unique personalities had their places in the ultimate business success. But it did NOT deliver any of the life and times of the author Chuck House himself. House's memories of his HP period were partially revealed in several associated articles here on this website under the "Other HP Writings" section, GR vs. HP, and the story of the HP 1300A display.*

This HP Memory of Chuck House, on the "Birthing of the HP Logic Analyzer" business for some 10+ years is much more descriptive of the life and times of Chuck. It shows his personal involvement, incisive thinking and detailed analysis which he went through in guiding his teams to beat the competition in some EXCEEDINGLY complex technologies. Sometimes in that period, it seemed that technologies were moving ahead with the speed of light.

We remember the first halting logic products, one from the F&T division was a simple clip-on display which enveloped an integrated circuit package, with 14 tiny LED lights. From there, an oscilloscope was commandeered to display tabular columns of algorithmic state conditions. Then life got A LOT more complicated, and Chuck House's imagination and diagnostic abilities showed through.

This Logic Analyzer period for House represented only about 30% of his life career. He had HP experience with the 1300A display which he developed against the specific directions of Dave Packard. He spent some years at HP's Palo Alto headquarters, with responsibilities in corporate engineering planning. He moved to Intel for a decade and later to Stanford to lead their programs on Modern Media Innovations. Lastly, he was just appointed to the post of Chancellor of the Cogswell College, a digital media teaching institution. This HP Memory shows us how he thinks.

---John Minck

Introduction

In early 1970, I was striving to become a successful program manager, to erase the image of earlier gaffes at Hewlett-Packard's Colorado Springs oscilloscope division. I had wangled the chance to lead 'Next Gen' – HP's bold but belated effort to match Tektronix's new 7000 series.

Our program was defined around four contributions – what one wag called, "Smaller, Faster, Cheaper, Lighter." The Tektronix units by comparison to all previous oscilloscopes were "high, wide and handsome," making traditional measurements with more accuracy, precision, sophistication and ease, with a greater price tag than ever before.

On March 23, 1970 in New York City, senior circuit designer Kent Hardage and I were sharing a room in the ritzy Plaza Hotel looking out on New York's Central Park. Neither he nor I had ever known such opulent and plush style – quite an experience for two engineers from 'the sticks.' We had lunch in the hotel, discovering that they expected a coat and tie. The menu was amazing, we'd never seen so many different names for pasta.

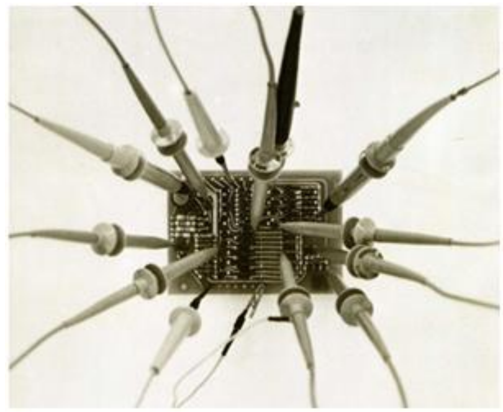
We were attending the annual IEEE International Convention with sixty thousand others. It was the biggest show of its day for vendors to demonstrate their wares – an early precursor of today's extravagant Las Vegas Consumer Electronics Show aimed at gadget happy consumers.

Taciturn and gruff, Kent was a hard-core hardware design engineer, one of HP's best in Colorado Springs. He and I were there to evaluate the new Tektronix 7000 Series oscilloscope family – a competitive spying operation for our Next Gen boxes, so to speak. It hardly was covert because we had to wear our conference badges, and it took the Tektronix team less than three minutes to figure out who we were, what we were doing, and thus to develop a coping strategy. Oddly, they let us in. We knew the functionality better than most folk in their booth; surprisingly, we were invited to stay and exhibit their new ‘scope to potential customers.

Inexplicably, I found myself showing their new boxes to erstwhile customers for several hours, after one of them exclaimed, “You demonstrate our features better than we do!”

The learning from the experience demo’ing the box was better than any imaginable market research trip. Potential customers admired the equipment but the oft repeated question “What does it do that I cannot do today?” was a terrific lead-in for us to ask, “What measurements do you need that you cannot do today?” Kent and I asked this so many times we lost track.

The most immediate need was to watch more signals simultaneously – new integrated circuits were confusing designers with their complexity, and many booth visitors were hopeful that by combining two four-channel vertical amplifiers, they could gain some understanding of these new circuit devices. With eight channels (we even tried twelve for a few folk), screen clutter was an issue, and the probing problems became physically daunting as well.



This amount of digital data probing should help understand what's happening on the PC Board.

Over dinner, we traded notes. Kent, involved heavily in HP’s recently introduced very high frequency ‘scope, was incredibly detailed in some of his observations, particularly with respect to sweep circuit non-linearity and CRT spot defocusing. My focus had been both on vertical amplifier distortions, and interactions between the ‘scope functionality and time-shared characters that ‘gave answers’ – rise times, pulse widths, and other ‘analytic data.’

But the real learning was sociological – or as we engineers saw it, business issues rather than technology. We learned, for example, how big their R&D team was, how long it took to develop the equipment, and which capabilities still needed further refinement. The 7000 Series was like an overgrown Swiss Army knife – with up to four plug-ins, it could be configured to make virtually any known measurement for design engineers or technicians. Such complexity, coupled with a novel concept for displaying ‘answers’ on the CRT, was historically unavailable from any instrument manufacturer. It was a huge bet on the future of instrumentation – by the 2nd largest instrumentation company. Our employer, Hewlett-Packard, was the obvious target.

The Tektronix 7000 Series (Swiss Army Knife?)

The basic premise for the Tek 7000 Series was that electronics designers used only four basic equipments – voltmeters, oscillators, oscilloscopes, and spectrum analyzers – with occasional additional needs (e.g. ammeters, distortion analyzers). Why not put all of them in one box?

If this strategy worked, the advantage for Tektronix was obvious. They were leaders in ‘scopes, but also-rans to HP in nearly every other category. The 7000 Series was thus intended to embed all tools that an electronics engineer might ever need, inside one mainframe, with an integrated systems approach to display readouts as well as electronic interaction between various tools. It augured to give them entrée for a host of related tools that HP then dominated.

HP had much to lose if this approach worked, but at HP headquarters in Palo Alto, there was surprisingly little concern. HP strategists felt that the various sub-disciplines of electronics were sufficiently separated, and each so sophisticated, that it was folly to centralize the functions. It was the classic specialist versus generalist argument – hard to know the results up-front, even hard to know until the experiments have run for a lengthy time. Both views could be correct.

My perspective, though, was different. We were not trying to answer a need perceived in Palo Alto; instead, we were trying to leverage HP strengths in voltmeters, spectrum analyzers, etc. into more ‘scope sales. Our market belief was based in part on the remarkable success HP had crafted with the HP 140/141 ‘scope platform, when it added spectrum analyzer and network analyzer capability to that venerable mainframe. But the 140/141 platform only handled two plug-ins, and it was restricted both in power and CRT capability to relatively low-frequency ‘scope functions. Our Next Gen program was defined around several contributions – up to eight plug-ins, very high frequency capability, stored memory and novel user interfaces.

Standing in the Tektronix booth, I never heard a potential customer excited about combining spectrum analysis with time-domain measurements. No one seemed enthused enough about active display answers to want to pay the overhead costs. By contrast, almost everyone seemed to have requirements for integrated circuit testing, either at the device or the board level. There wasn’t agreement on what was needed, but there was widespread belief that it was ‘the problem’.

My Next Gen program, under way for twenty months, didn’t address these issues either. We’d already spent $2 million, with a burn rate that had to escalate for our next phase. We were, at best, two years from delivery. The Tek engineers told me that they had spent $34 million dollars and seven years of effort, to get to this show with an incomplete line. Whew!

Worse, my team was having trouble debugging our own prototype scheduled for a division review in four weeks. That review would be with two guys notoriously chary about poor engineering detail execution – Packard and Hewlett, headed to Colorado Springs in late April. It was not hard to figure out what to do. I had to cancel Next Gen.

The first problem was that I was in love with it. The second problem was that I viewed this as my redemption opportunity. I had defined the program, sold it to management, investigated and selected the new technologies, built a crackerjack team, and made great progress compared to historic efforts. It was, as I saw it, my chance for recovery from some prior management miscues, including the time I’d pissed off Packard by continuing the displays program.

To recommend that we disband the effort seemed like a suicidal path, especially if I had no alternative answer for what might be a better path to take.

Next Gen by now was a sizable bet – in fact, the largest bet we had underway in the division – and fundamentally, the only chance we had to match Tektronix, however late and understaffed we’d be. So the third problem was, “What now?” And since I had no answer, canceling the project would be a certain death knell for my management hopes.

In my heart, though, I knew that the project was doomed. We’d never be able to match Tek’s functionality or capability, not with the constraints on R&D spending at the division. Faced with the idea of continuing a fatally flawed project, versus boldly arguing that it should be disbanded, nonetheless turned out to be a quite difficult emotional decision. So obvious in hindsight, these things are seldom clear when you’re in the heat of battle.

I reflected on the display program for which I'd disregarded Packard's dictum. There the decision had open-ended possibility: if the project were to complete within the year, we had a chance to prove its value in the market. If we failed to finish, we'd been able to run a great low-cost experiment. Here the circumstance was different. If the analysis that Kent and I conducted was correct, no sanguine event in a year could 'save us.' We had no hope of completion in a year. If we did succeed in getting back on schedule, we'd still face a much better funded, more complete competitor with a head-start. Most importantly, there was no new measurement contribution in the plan – we'd be ducking the same problem that Tektronix avoided.

It took many sleepless nights to resolve this situation in my own mind. Today, the question that recurs is "Why did it take so long to get to this answer?"

The next question was how and when to cancel the program. I felt a strong obligation to support my team. They were working twelve to fourteen hour days to complete the breadboard for the annual review. To pull the plug on that, a mere three weeks before the event, seemed unfair, especially given recent progress and palpable enthusiasm. Yet, it felt duplicitous not to tell the team that no matter how well they did, the program wouldn't continue.

I was torn – a true dilemma, where neither choice is any good at all.

My team tried to explain in self-defense why they were having so much difficulty, ironically pulling me into the project more deeply. They showed me a maze of wiring between multiple connectors that mated plug-ins to the main frame, and they spared no detail in describing how hard it was to keep track of several hundred wiring connections, with no tools to facilitate it. More significantly, they laboriously discussed the data being shipped back and forth from a plug-in to the main frame, and the difficulty and importance of agreeing on data structure formats.

I'd never worried about the details about how computers actually worked. I knew that bits, combined into bytes and words, flowed through registers in sequence, determined by a software program. But what those words looked like, and how they were coded, was a mystery. No one on the team had been conversant with these 'normal' computing standards when they started, but they now patiently explained to me about issues surrounding MSBF (Most Significant Bit First) or LSBF (Least Significant Bit First), plus EBCDIC (Extended Binary Coded Decimal Interchange Code) and ASCII (American Standard Code for Information Interchange) codes, and even hexadecimal versus octal machine code. Which 'word' came first in serial word streams bedeviled our communications bus decisions in the prototype.

So this was more complicated, not because of electronics design problems with these new complex integrated circuits, but rather because we had little awareness of the contextual meaning and coding requirements of the more complex data being manipulated. The *aha* moment, late one night, was realizing that this was what some erstwhile customers had been trying to tell us in New York City two weeks ago. Kent and I just didn't know enough then to hear what they said.

Dave and Bill Cancel the Next Gen Program

For the fateful meeting with Messrs Packard and Hewlett, we had made enough progress that the development team was proud of their accomplishment. And then I proffered the opinion, without having cleared it with my own bosses (as I now recall the situation), that the chase was unimportant – that the world didn't think that the Tektronix product, investment notwithstanding, was worth it. In short, there was no significant measurement contribution beyond what was already available in the market. These two patriarchs understood – almost in unison, they chimed, "Then what is the real contribution to be made?"

Cancelling the Next Gen program notwithstanding, late spring 1970 was actually a positive time for HP Colorado Springs. A year before, the division had introduced the HP 183A, the world's highest frequency direct-writing oscilloscope (250 MHz), 150% faster than anything from Tektronix. Market acceptance was stunning. Project manager Jim Pettit, who'd started work at HP the same month as me, Kent Hardage whom I'd traveled to New York with, and Al DeVilbiss, who had designed the vertical amplifier for the HP 1300A Display system that got me in trouble with Packard, were the key developers for this wonder box.

The displays business, now astutely led by Coloradoan John Riggen, was also quite profitable, and with the division now competitive in the high frequency arena with Tektronix, our Palo Alto bosses were willing to let us experiment a bit more than usual.

Strangely, when I renounced Next Gen, eating humble pie in front of the division, it seemed to humanize me to some folk – a lesson I hadn't previously learned. Partially in atonement, when we canceled Next Gen, I was allowed to set up a modest investigation for a 'digital scope' program, a series of prototype ideas intended to test some very different types of tools that might help for these new digital circuit technologies that were starting to present themselves.

This 'digital 'scope' idea was not just a sudden inspiration, born out of Next Gen frustration, in a situation where no one else had noticed these issues. *Au contraire*. There had been four previous project managers working on 'digital tools' in our lab, plus several projects in other groups around HP. So, in one respect, this was hardly a risky proposition. If I failed, I could point to the previous attempts and say, "Well, it's a really tough problem." If, on the other hand, I were to succeed, it would dimensionally set me apart from the previous managers. The question was, what will we do differently this time? The remarkable thing, in hindsight, is that we were given a free hand to discover as best we could what might work.

I spent much time thinking – philosophically musing if you will – about what really was happening before our very eyes. One way to figure out what is happening is to go look. I sent our small team out to where 'digital designers' worked. What do they actually do in their designs? What is hard for them, and what helps? It would have been nice to find dedicated groups of folk who had only the new problems. Instead, hybrid systems abounded. In all labs, oscilloscopes were by far the most prevalent debugging tools. And we didn't yet have anything new to describe, so it wasn't really product marketing research so much as process observation.

But there were concrete ideas that we used as metaphors. When transistors arrived on the scene in the late 1950s and early 1960s, experienced circuit designers who were intuitively great with vacuum tube designs mostly struggled – the colleges used this example to describe why a scientific education rather than a technical education was better: "if you learn semiconductor physics, you can handle the duality of holes and electrons, whereas there is no equivalent concept of holes in a vacuum tube." At age twenty, I had thought such an argument silly, but when I had joined the workforce, there were indeed a number of circuit designers – derisively called cookbook engineers – who couldn't make the shift in thinking.

I've seen this happen numerous times in electronic circuit design. The shift from transistors to integrated circuits (groups of transistors which acted as a function, rather than as movement of holes or electrons) derailed many. Going from small-scale integration (SSI) to medium-scale (MSI), large-scale (LSI) and then very-large-scale (VLSI) changed the rules each time. When the key ingredient in designs changed from hardware to software, many more were disabled.

The particular design perspective that emerged from the MIT Radiation Lab experience in World War II was that while linear circuits worked well for communications and control systems, switching circuits worked better for systems such as radar, sonar, and computers. The value of oscilloscopes became quickly evident, which Tektronix capitalized on in the late 1940s for military designs for Korean equipments and Cold War electronics. Although the two largest instrument manufacturers – General Radio and HP – each designed early oscilloscopes, both companies were founded and led by communications designers who struggled with this new switching circuits design paradigm. Each company misunderstood the importance of 'scopes to the new electronics, allowing a nascent Tektronix to fill the void.

As coincidence would have it, I was completing a Master's Degree in history at the local university. An unusual focus for a Caltech scientist, even more so for a Hewlett-Packard engineer, it often engendered conversation at cocktail parties: "Why?"

Focused on the history of technology, the quest took me to Princeton, where I met with Dr. Thomas Kuhn about a possible PhD. Kuhn, a cadaverous figure, had garnered some fame, even notoriety, in both history and scientific circles for his insightful 1962 book, *The Structure of Scientific Revolutions*. A turgid book to read, it nonetheless outlined an impressive series of studies in history where new scientific theses were advanced, only to be categorically dismissed by those in power – essentially 'conventional wisdom' won, even if overwhelming evidence marshaled to the contrary. The new ideas essentially had to wait until the 'old guard' died.

Kuhn, a stooped, cranky curmudgeon at 57, was not open to new ideas that stretched his own thesis, which both surprised and dismayed me at the time. Naiveté is so easy when you're young. I had little appreciation for how much opprobrium he'd endured from the intellectual community assailing his thesis – and here I was, arguing that his thesis matched a crass commercial situation that in hindsight was quite unimportant to a serious scholar. A wave of the hand was summarily dismissive, as he said "at 29, you're too old to invest time in teaching you."

Flying home, I couldn't shake the notion that his thesis fit our situation – we were seeing new measurement needs from an old paradigm – and it was proving, as he prophesied, very hard to let go of the old beliefs and assumptions. With forty years more experience, it is now much easier to recognize the problem – but then it was strange, baffling, and difficult.

What's all this "Logic" Talk?

There certainly was a nugget of truth buried in this set of unusual problems that we faced. A few phone calls to friends in HP computer divisions were revealing. I'd start with a description of our issues, and almost immediately they'd respond with a similar horror story. Asking what tools they used elicited laughter or sober reflection that, "Hummn, there really aren't any."

The problem was that none of the descriptors helped to categorize the needed tools. Yes, we were going from linear circuits to switching circuits, and 'scopes worked great for that analysis. Yes, we were shifting from transistors to integrated circuits, but 'scopes still probed signals at IC pins. And yes, the integrated circuits generated functions – operational amplifiers, AND and OR gates, and flip-flops – but 'scopes could still manage these signals. And then – aha!

We realized that some of the new computer circuits created 'logical' combinations of parallel circuits – it was both these combinations and the switching behaviors which could not easily be monitored. 'Race conditions' can occur in parallel circuits – did circuit A get done before B? Keeping track of the finite rise and fall times of the switching behavior of multiple circuit gates became daunting. If eight rise and fall times were all displayed in perfect order on an oscilloscope, it was difficult but possible to discern some 'false positive' and 'true negative' events that only lasted very briefly, but could actually create anomalous failure modes.

Integrated circuit (IC) design itself was hobbled by similar questions, and novice IC designers at HP begged us for tools to be able to probe their small-scale integrated chips to examine them for race conditions. But we wanted to focus on system, not chip, testing.

The logical combinations were the more interesting phenomena, we felt. Called synchronous design by some and algorithmic state design by others, such designs were functional in nature rather than determined by electronic parameters. In other words, the devices would all be in a steady-state mode, describable as an event-time, and a switching action would shift everything into a new steady-state event-time. There would be no reason to sample the intermediate switching actions because nothing mattered functionally until the next true steady-state event.

What was hard for test equipment designers was to decide to concentrate on the steady-state conditions rather than on the switching behavior. Heretofore, the most interesting things to analyze were the dynamic transitions, not the sequence of steady state conditions. Somehow, our design group came to believe that handling the complexity of so many signals might better be handled by ignoring the transitional behaviors, instead monitoring and decoding the increasingly complicated 'state conditions' in-between the switching times.

It would be nice to report that we sat down around a table and discussed these issues rationally, and sometime during the meeting, we had that *aha* moment and we all left the room in agreement that this, *THIS* would be the breakthrough idea.

It of course didn't happen that way. We gathered up several folk with a bit of digital design experience, reassigned the bulk of the team on the Next Gen project to other 'scope projects, and tried to imagine tools that would help. Circuit designers Duncan Terry, Virgil West, and Kurt Gfeller, plus product designer Jim Freeman and I from the Next Gen system (down from twelve) built a Digital Waveform Display Conditioner prototype (nicknamed DWDC, or *D'wuck*), that tried out several concepts – pattern triggers for both parallel and serial data streams, digitized or clocked event delays rather than linear time, and specialized small high-impedance probes.

Then, the bottom fell out of the electronics business. HP President Bill Hewlett announced over the public address system on a clear Friday morning, June 26, 1970, that the company would take every second Friday off without pay for the foreseeable future, until the economy recovered. Fortunately for us, our peripatetic division manager, Bill Terry, persuaded Bill Hewlett that our division should be exempt, because we had Tektronix under pressure for the first time. Indeed, initial Tek 7000 sales reports were poor, just as Kent and I had speculated.

In subsequent months, we ran many D'wuck experiments. Each feature or functionality taught us something; the set showed that random logic chip combinations were less important than gated logic arrays. Gated logic arrays made synchronized designs possible. The Intel 1103 D/RAM (Dynamic Random Access Memory) was the integrated circuit chip that made the difference. Announced in October 1970, it offered a 'low-cost high-speed memory' semiconductor chip with one thousand bits of memory, enough for 128 eight-bit words.

HP Loveland had been producing desktop calculators since late 1968; this D/RAM chip augured to alter greatly their cost/performance ratio. The first major adopter of Intel's chip, they consumed one-third of the world's D/RAM consumption for 1971 and 1972 in the new HP 9800 desktop calculators. Thus, one hundred thirty miles away, in a collegial Hewlett-Packard lab friendly with ours, we had a 'next-bench' lab to study.

HPL 9830A Desktop Computer finds office applications.
HP Memory Collection

Engineers and Marketing Research

With the HP Loveland insights, the D'wuck prototype came together, and I scheduled a key market research trip to the Bay Area. On Monday, June 21, 1971, I proudly stood in front of thirty-three digital designers in the HP Cupertino, California minicomputer lab, with Bert Forbes as my host. Bert, affable and smart as a whip, had listened on the phone to my story, and promised an audience. As I intoned our approach and findings, my Swiss émigré designer Kurt Gfeller turned on the D'wuck – and smoke filled the room. Gfeller started babbling in German. Not an auspicious start.

The next three days would be profoundly important. Bert gave us a lab bench to work on. By Thursday, the D'wuck worked. W e only drew a crowd of six this time. But one invited us back into his test bay, and soon we all saw the LRCC (Longitudinal Redundancy Checksum Character) pulse on their disc drive, displayed on our 'scope CRT. The entire group was excited – "We've never seen that before. WOW!!!"

We did several other measurements that seemed to dazzle them, and then Bert did something that changed our world. He called a friend at IBM Santa Teresa labs, and said, "We've got some guys here with a box you should see."

Friday, we went to the IBM Santa Teresa research lab, the group that invented the RAMAC (i.e. Random Access Method of Accounting and Control), the first random access disc drive dating back to 1956. Now mid-1971, they were trying to perfect what would become the first Winchester disc drive. They loved the D'wuck; in fact, they wanted us to leave it with them, rather than take it back to Colorado. We refused, saying that this was the only unit in the world. They reluctantly let us go. Duncan voiced it, driving out: "There might be something here."

Reality set in as we returned home to HP Colorado Springs.

I held a small seminar to describe our market research findings. To illustrate the value of our serial pattern trigger capability, I carefully drew how LRCC validation checks operate for computer systems. Then I sketched an outline of how the addressing schema for satellite communications worked, pointing out that we'd have to widen the pattern search, but conceptually it was analogous. It was a careful, meticulous, precise presentation.

Walking out, my reserved supervisor, John Strathman, uncharacteristically threw his arm over my shoulder, and said, "That was the finest technical talk I've ever heard you give." Since he'd often given me feedback of the form, "Don't exaggerate so much," this felt like high praise.

Over the next week, though, a different message seeped through the division: "House doesn't believe in it. He gave a dry technical talk, for crying out loud. No enthusiasm whatsoever."

We were put 'on hold' – told to wait for some 'decisions' before we started the next design. And then, for days, the management staff was locked in huddles. Rumors were rift – "This program goes, that one stays…." The ambiguity got to us, and somehow one Friday our HP team of five got fed up, and decided to quit *en masse*. We didn't know what next to do, but we knew we were done working for HP. They just didn't get it. We bundled up all of the D'wuck work, wrote out resignations, put them all in an envelope, destined for the HR director's desk.

The envelope found its way to Strathman's boss Dar Howard, who was home in bed recuperating from unexpected back surgery. Howard's surgery accounted for the re-organization delay, which in turn had fueled our precipitous action. Dar, my sponsor for the original display box, shielding me from Packard's dictum to cease development, now appealed to me, saying "You've done what we need with this 'digital scope' stuff. I have been trying to get you some real help, and we've figured it out. Don't leave now."

He shared some privileged information. IBM Poughkeepsie had called him after we'd been to the IBM Santa Teresa labs. They loved the D'wuck, which impressed Dar's management team. But budgets had become much tighter. While HP had relented on the nine-day fortnight after nine months, Tektronix had matched the HP183 specs, slowing our division sales. Dar and his team had decided to ship our sampling 'scope technology to the sister division in Japan, and our pulse generator lines to the German division. This would free up some of the better digital designers in our division – those who knew about sampling and pulse generation rather than linear circuits – to work in this new arena that my small team had been exploring. Our group would grow – from five to eighteen people. Howard cajoled: "This is your big chance."

I told the team, and we all agreed to stay. It was another few weeks before I learned that Dar intended for Jim Pettit to manage the group, not me. And still more weeks to find out how the group would be composed. It was a polyglot group, assembled from four different labs on-site, with little history in common. It wasn't, in retrospect, very hard to imagine why Pettit was a better choice to manage the group; I'd not exhibited a lot of tolerance for ambiguity in the past.

And then, some serendipity. HP had hired Roy Hayes from Tektronix. Roy, a linear circuit designer, co-owned a tractor with a Tektronix design engineer who lived in Beaverton, Oregon. The question became: "Would you consider buying out his half-interest?" I said, "Sure" and Roy and I hopped into his van and drove to Portland, where he arranged for us to stay with Merle Kaufmann, the tractor owner, while I filled a rental trailer with the tractor, plus trees and shrubs.

The van lacked a trailer hitch; every night Roy and Merle would go to someone else's place to build one while I babysat Merle's kids. And some Tektronix engineer would knock on the door, ask for Roy or Merle, and when I'd say, "They're not here, but I'll tell you where they are," they'd reply, "Oh, are you Chuck House? You're working on digital 'scopes? I'd love to talk." I invited them in. We compared notes on testing these new logic systems, for three nights. I learned a lot from them; I am sure they learned a lot from me. We each lamented that neither company's management seemed interested. And then we parted, not to meet again for years.

Back in the Springs, Jim Pettit and I guardedly eyed each other. I respected his ability, but the thought that he'd manage my program was more than galling. And he had little sensitivity to the issues we'd been wrestling with for a couple of years now. It is very hard for practiced managers to shift thinking, even harder if they believe that the methods they've been using were successful – and he had every reason to think his methods had worked, and little reason to think mine had.

As the holidays approached, Jim came to my home one Saturday to work on our proposal for a Monday review with some Palo Alto folk. Jim, unaware that we'd sold our home, was surprised to find us living in a two bedroom rental home in a decidedly low rent district. Gayle's brother was living with us and our three girls; it was easy to deduce that we were 'unfettered' in terms of staying with HP. I did nothing to ease his mind on the topic when he inevitably raised it.

New Year's Eve, December 31st, 1971, my wife and I were reflecting, champagne glasses in hand – the past year and a half seemed like a blur. Neither Gayle nor I could quite put it in words, but the pace had been exhausting, the energy expended quite high, and the costs seemed overwhelming. And she was expecting – a son to join our three daughters, due in July 1972. But the piece of big news that night, wonder of wonders, was that Jim Pettit was headed for a new job in HP Palo Alto, and I would get my group at HP back.

My Old Group Looks at Management Style and Processes

The next week, I took stock. The eighteen members of the team were quite a menagerie. Duncan, Jim, Virgil and Kurt were there from the original group; they felt some entitlement to be first among equals, since they'd been pioneering with the D'wuck. Pettit had not listened much to them in his few weeks at the helm; they were overjoyed to have me back as their leader.

There were four experienced designers from the sampling lab, notably phlegmatic Al Best and clever but enigmatic Bill Farnbach. There were also four from the pulse generator lab, including fiery leader Eddie Donn and skeptical Jeff Smith. Seven of these eight were senior designers, compared to the original team. Five designers from the 'scope lab rounded it out, none with stand-out skills as I remember it. The whole feeling seemed to me to resemble that of expansion baseball teams in the major leagues – where every extant owner offered the new team some utility infielders, disabled ballplayers, or fading stars; none were invested in having the new team produce a winning club in the foreseeable future.

Despite all eighteen people sharing the vaunted 'HP Way culture' in the same Colorado Springs division for years, there was precious little bonding amongst the group. Vocabularies for the design issues were different; perspectives varied widely. Debates about which measurements mattered were easy to stimulate; resolution was not. Attitudes about whether we were doing 'something new' or instead should simply be building 'scope accessories were strongly held, and bitterly contested. The erstwhile leadership – me, taciturn Duncan Terry, edgy Bill Farnbach, volatile Eddie Donn, and placating marketer Dick Cochran – had three things in common: mistrust of and even lack of respect for each other, profound lack of understanding of these new devices and their design and test issues, and essentially no management maturity.

Other than those limitations, we were a pretty good leadership team.

The group we managed wasn't so sure, and we weren't so sure about them apparently. The roster listed eighteen names to start the year, and ended with twenty-one. But an astounding eighty-two names graced the list during the year. Hardly the image of a stable, controlled, well-managed operation, it did not win many points for the kind, gentle, humane HP Way. Of the sixty-one who were intermittently on the roster during the year, nearly all found other roles within HP, so it wasn't really a hatchet job. Such roiling turmoil was unheard of then at HP; a decade hence in the hotly competitive entrepreneurial Silicon Valley world, such turnover would not be surprising, and HP's typically genteel approach increasingly seemed anachronistic.

Challenges abounded six months after taking over the digital 'scope program from Jim Pettit. Many doubted my ability to manage, others questioned the vision, almost all seemed uncertain of the strategic and tactical plans that might produce positive results. To be truthful, in the dead of night, my self-doubts were substantial as well. To deal with this, I developed the chart shown in Table 1-1, as a way of calibrating how I felt about things at any given time. With the chart, I could ask members of the team where they thought we stood – it became a litmus paper test of our confidence level. In retrospect, I'd found a semi-quantifiable way to communicate our fears, hopes, and beliefs in a manner that could surface differences of opinion, and tackle real issues.

Table 1-1
Six Stages of Leadership Capability

A	*Adrift at Sea*	*No notion of the VISION OR of useful things to do*
B	*Working on USEFUL things*	*Not sure that they're the RIGHT things*
C	*Working on the RIGHT things*	*Not sure that they're SUFFICIENT*
D	*You've got the VISION*	*Not sure how to REALIZE it*
E	*You've got the VISION AND the PLAN*	*Enviable situation, but lots of HARD WORK ahead*
F	*YOU Think You have the VISION and the PLAN*	*You're wrong, or unable to persuade others you're right*

The chart was built to analyze 'vision' situations. Let's walk through the various stages:

- **A** - **Are we adrift at Sea?** To be adrift at sea is really terrible because every direction looks exactly the same, and there is the very real fear that if you start paddling, you will go further from help than closer. There is no vision of where to go. As a leader, you are virtually immobilized. You have no way of knowing what to do, and it is very depressing. Groups with such leadership are not happy groups to encounter.

- **B -** You can be **working on useful things** and know it, while still having little expectation that they are the right things. Many leaders and many more employees spend their lives doing this. Most people in this situation are hoping that someone momentarily will come along with 'the vision.'

- **C -** You can be **working on the right things** , while either knowing that they are insufficient, or worried that they might not be adequate. A self-appraisal here might take the form: "We're working on the kind of stuff that could help. I know I am going in the right direction. I'm not sure I am equal to the task, I don't know if we can swim the Pacific."

- **D** - **You've got the vision.** This is a wonderful situation to be in - you know where to go, and you can describe it with clarity and enthusiasm. You just don't know what to do to achieve it. Such people are called visionaries, but seldom are they called entrepreneurs. The leadership from visionaries often evokes this kind of response: "Yep, you are right. That is exactly where we ought to be going. I have not the foggiest idea how to get there from here, but when we see more evolution, I will be happy to work on it."

- **E** - **You've got the vision and the plan.** This is an enviable spot - people gravitate to you: "I want to sign up to work for that leader. We know where we are going, we have a plan, and we have communicated it - we're all one on this. It is going to be terrific." Once an "E" leader, people often think you can 'do it again' - the serial entrepreneur syndrome.

- **F** - **You think you have the vision and the plan.** This stage is a too-frequent variant of the E stage. It can read " **you** think... or you **think...**" If the former, the issue is clearly to persuade others that your vision and/or plan (and maybe leadership ability) is credible. If the latter, your job is to convince yourself. In my experience, the more that the vision involves structural change, it greatly increases the likelihood that you'll be perceived in the F-stage than the E-stage. It seems not to matter whether the structural challenge is in technology, marketing, distribution, or manufacturing. For my taste, the F-stage is far more fun for the leader than an E-stage - more challenge, excitement, and satisfaction.

This chart can be helpful for a leader or manager of any program. Imagine giving it to each member of your team at, say, quarterly intervals - you cannot miss getting a sense of whether their confidence is growing or waning in the project or in your leadership. Bear in mind that if you yourself do not have a vision of where you and the team are trying to go, it is incredibly hard to build a consensus about how to get there. If you do not appeal to the underlying ego-driven needs of the individuals who are going to take the journey with you, it will be very hard to build the team. Because the journey to realize a new vision is almost always so difficult and unknown, it is really important that you as the leader be able to appeal to your team at more levels than just the game plan written out in some procedural way.

Point of view is obviously crucial to the success of leaders - nowhere is this more true than in these truly innovative entrepreneurial or intrapreneurial environments. Table 2 below shows some common perspectives about your program and your own leadership, as seen by your managers, and your team, for each of the six stages. In fact, it is often easier to find out how people really view the program by asking these seemingly peripheral questions - that way, they don't have to be directly confrontive with you, but they can express their doubts about the program without putting personal invective into the equation.

Table 1-2
Multiple Perspectives of the Six Stages of Leadership Capability

		Self view	Other views: As manager	Other views: As Leader
A	***Adrift at Sea*** *No notion of the VISION OR of useful things to do*	Despair	Ineffective	???
B	***Working on USEFUL things*** *Not sure that they're the RIGHT things*	Fearful	Pedestrian	Vacillating
C	***Working on the RIGHT things*** *Not sure that they're SUFFICIENT*	Hurried	Competent	Cautious *or frenetic*
D	***You've got the VISION*** *Not sure how to REALIZE it*	Aha! Now what?	???	???
E	***You've got VISION and PLAN*** *Enviable situation, but lots of HARD WORK ahead*	Self-*confident*	Effective	*Charismatic*
F	*You Think You'v* ***VISION, PLAN*** *You're wrong, or unable to persuade others you're right*	Misunderstood frustrated	Pig-headed	Arrogant

For our polyglot digital tools team, I would use this chart several times that first year. It was a useful discriminator for "who got it" and who didn't, as well as for those who had enlisted versus Doubting Thomases who'd adopted a 'wait-and-see' attitude. In mid-1972, the digital team had strong belief that we were working on the right things, but not that we had 'the vision' yet. Bear in mind that I'd been an HP manager in this small division for most of a decade, seldom viewed as a leader in an E-stage or F-stage role. As 'our vision' crystalized over the year, rich debates between competing factions erupted, not easily resolved. Views of our leadership more often surfaced words like *pig-headed* or *arrogant* than *charismatic* or *inspired.*

Backing the Kids

Oh, my gawd. He took me literally. Virgil, our prototypical nerd, nicknamed 'high pockets' for the high-waisted dress slacks he wore, was calling from the Denver airport, beseeching my help. His words didn't make sense, as his high-pitched voice blurted out: "I cannot get on the plane, I put my tickets in the mailbox."

This thin, painfully shy, angular man hiding behind his horned rim glasses had three master's degrees - in astronomy, quantum physics, and circuit design - but he persistently seemed unable to synthesize answers at the intersection of those fields. And now, this. He was on his way to Atlanta, to see how electrical engineers were designing products using integrated circuits (ICs). His mistake? He'd written out his bills - telephone, utility, and garbage - and handed them to the airline counter clerk, after he'd put his airplane tickets in the USPS box outside.

At the start of the year, I had had an inspired thought - at least it felt like it at the time. The idea was to formalize the market research tactics that I had used on both the display box and the Next Gen investigation in previous years. This R&D lab was created to build tools for designers who might use these new integrated circuits (ICs). But none of us had used ICs ourselves.

So my idea was that each designer should go spend a week in a lab where designers were actually using these devices, and try to figure out what kinds of tools would help them. And in the first few months, half of my designers had done so, giving us many ideas.

But half of the designers had not gone anywhere - they hadn't even made plans to go. I lost patience at our monthly luncheon in June, and said something to the effect of "I don't care if all you do is go to Atlanta, and find out how the restrooms work - you'll have learned something."

Virgil, eager-to-please, promptly filed a trip request to go to Atlanta. He asked me what I expected him to find out, and I'd said, "If you know what you'll find, you don't need to go."

Circuit design with discrete devices had a sixty year history - using either vacuum tubes or transistors as amplifying elements. For forty years, communications circuits for AM or FM radio had dominated the work, and many tools - including oscillators and voltmeters - had evolved to help both designers and maintenance people. Analyzing such circuits was named the *frequency domain*. World War II had stimulated a second class of circuits, called switching circuits, to build different kinds of systems - radar, sonar, and television. These circuits needed new design and analysis tools, primarily pulse generators and oscilloscopes - a field called *the time domain*.

Both frequency and time domain designs used discrete parts, wherein each device did one thing, and it connected to the whole circuit via two or three nodes or 'pins' that could be probed to see the voltage as a function of time or of frequency. The breakthrough idea of integrated circuits was that multiple discrete devices could be put on one semiconductor 'chip', thus making a complete circuit function within one 'device'. This creation earned a Nobel Prize in Physics in 2000 for its 1958 co-inventor, Jack Kilby of Texas Instruments.

IC industry progress was rapid over the first dozen years. Gordon Moore, co-founder of Intel Corporation, predicted in 1965 that the number of devices on a chip could double every two years. This became known as Moore's Law. In 1972, Intel introduced the first microprocessor on a chip, the Intel 4004, with 2,300 transistors, mind-boggling for circuit designers of the day. And even though Moore's Law suggested that this number could become two billion devices by the turn of the century, none of us then imagined such a future. Moore's Law has held now for more than fifty years, giving rise to an Information Age product explosion - cellphones, laptops, entertainment devices, as well as automated systems for airplane guidance or traffic control to sophisticated banking and manufacturing operations.

Integrated circuits posed a major paradigm shift in requirements - and the instrumentation world had no answer for the design and analysis issues for this new class of devices. Drawing on the frequency vs. time domain duality, I postulated that this new category should be termed the *data domain*. As a term, it caught on. But that didn't answer the fundamental question - how do you design analysis tools for the data domain?

Bill Hewlett, HP's founder, had for years offered sage advice about such situations: first, "marketing is too important to leave up to marketing people"; and second, "we believe in the Next Bench Syndrome". The Next Bench Syndrome meant that HP engineers didn't have to travel for market research - we just solved problems that the design engineer at the next bench in the lab was experiencing. But Hewlett's dictum couldn't work if the problems weren't in nearby labs. The parent company, based in Palo Alto near dozens of leading-edge electronics companies, was close to many designers using such devices. My lab was thirteen hundred miles away, in a Wild West resort town with scant electronics activity. Except for Denver, a banking, commerce, and mining town, there wasn't another city within five hundred miles. There was no choice for our team but to travel to other companies and other HP labs to find designers using ICs. Citing Hewlett's sayings, I insisted that every designer spend a week with potential customers during 1972. Upon return, they were to report their findings to our monthly luncheon. We would then have a group debate about the lessons learned from those trips.

This travel decision was not without critics. My peers were certain that our 'kids' were unskilled with customers, and that such travel was profligate with Hewlett-Packard monies. They pointed out that engineers notoriously seek to find customers who agree with them, rather than independent unbiased input. There was a snobbish belief that our designers were so naïve, unsophisticated, or even crude that their presence would reflect badly on HP's reputation. True, we did have a motley crew. Field sales engineers still wore coats and ties to call on customers - I'd wager that half of our designers didn't own a tie. Peers invoked personal hygiene habits and salty language as reasons to keep the 'kids' out of customer facilities as well.

I had a different concern. What if we couldn't figure out the riddle? My view was that more brains are better on this problem - it was just not at all clear what kinds of solutions might best work. So I had to bet on the 'kids' - they were the only chance we had. My peers grudgingly agreed, if a field sales person set up the meetings and accompanied every engineer to a customer.

Many of these designers had never been to a customer facility in their lives; they were very unclear on what they were to do. I used our monthly luncheon meetings to describe how they might go about it. Their questions included, "where do I go?"; "what should I be looking for", and "what do you expect me to find?" Some engineers couldn't wait to go; others seemed frozen at their lab benches. Two product marketing managers, Dick Cochran and Bruce Farly, helped them choose which customers to visit, and what to look for and ask while they were there. In effect, they gave training classes in market research. The biggest point was not to ask "What do you need?" but to ask "What are you trying to do? Show me what you do and how you do it."

Importantly, we had *carte blanche* to design our strategy without interference or help from corporate planners - a legacy of HP's unusually decentralized organizational structure, and Hewlett's belief that innovation in remote divisions was a vital force for corporate renewal. We began with the idea that we wanted to build a 'digital 'scope, rather than an analog 'scope. Our definition of a 'digital 'scope' was not an analog 'scope with digitized readouts, but instead a tool as analogously valuable for digital designers as 'scopes were for analog designers.

We just didn't know the features yet. And Virgil couldn't even catch his plane to Atlanta.

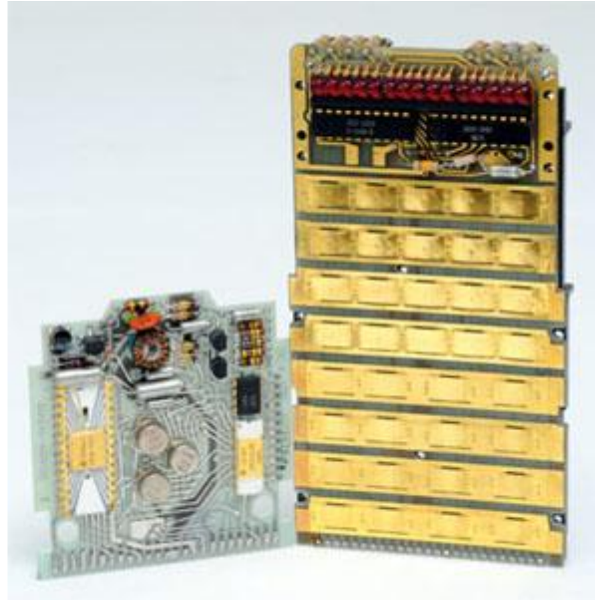
Finding receptive companies to visit wasn't as hard as we expected. But the trip reports were often conflicting. Burly, argumentative Dan Kolody, with previous IC design experience, visited five different design teams in Phoenix - at Motorola, Honeywell, and Hughes Aircraft. He found a plethora of integrated circuits with exotic mnemonics - RTL, DTL, TTL, and ECL - each a family cluster that required a specific set of voltages, pin-outs, fan-outs and design rules. But RTL (Resistor-Transistor-Logic) was not compatible with TTL (Transistor-Transistor-Logic), and so forth. Emitter-coupled Logic (ECL), five times faster than any other family, naturally was the choice for military systems, but it was incompatible with all other ICs.

Back home, Kolody shared his learning. Half the team challenged him, calling him just a classic 'scope designer looking for the highest frequency problem on which to masturbate. Those were fighting words; the group polarized almost instantly - Kolody. loud and profane, rose to the bait like a small-mouth bass in spawning season. Amicable discussions eluded us for months.

An independent team led by urbane Sam Lee traveled to IBM Poughkeepsie, NY, and to Burroughs in Blue Bell, PA. Their high-frequency requirements, also ECL, were well in excess of 100 MHz, for multi-pin integrated circuits used by the hundreds on large printed circuit boards. It boggled our minds. Corroborating trips to computer manufacturers Control Data and Sperry in Minneapolis, MN and Cray Research in Chippewa Falls, WI affirmed these needs. Soft-spoken, but standing tall, Lee delivered his sobering report to a silent audience.

Another team, with methodical Bruce Farly and gregarious John Marshall, found companies designing with lower-frequency TTL logic. These were companies like Raytheon Data Systems, building airline reservation systems, and NCR, building Point-of-Sale terminals such as Wendy's hamburger cash registers with lettuce and mustard keys. These companies were all enamored of Stanford University methodologies such as Quine-McCluskey gate minimization rules. These methods were concepts familiar to HP lab designers in the Bay area, but no one at our division had ever heard of them. Bruce and John were both careful, patient journalists, recording what they saw without putting judgment on their observations. Not so for some of the team. Passions could run high, and arguments often ensued.

The HP-35; World's First Scientific Pocket Calculator.
HP Memory Collection



Internal sub-assemblies of the HP-35
HP Memory Collection

Baby-faced Bill Farnbach, a surprisingly caustic manager, and his precocious lab technician Chuck Small were fascinated by the algorithmic state machine (ASM) designs used in HP's desktop calculators and the very exciting handheld calculators from Palo Alto that debuted in January, 1972. While the desktops were the highest volume user of Intel D/RAMs, they lacked an integral microprocessor. The handhelds used a very simple microcomputer, a one-bit chip from Mostek Corporation. As a group, we were profoundly impressed by HPite Chris Clare's *Algorithmic State Machine Design* book, which described an analytic design technique of state variable mathematics taught only in specialized places (*e.g.* the prestigious Indian Institute of Science in Bangalore). Brilliant, insouciant Clare, teaching one semester at Stanford, was invited not to return - his *avant garde* concepts were far more advanced than Quine-McCluskey.

One problem with the Intel circuits was that they were based on Metal Oxide Semiconductor (MOS) technology, only one-tenth as fast as even the slowest TTL chips. P/MOS was the original technology, then N/MOS processing produced speeds twice as fast. Complimentary MOS, or C/MOS, had the additional advantage of a quiescent state which drew almost no power - making it the right choice for battery-operated equipment. But these were toy applications, idiotic in the view of "real" designers because they were so slow.

The team, combative all spring and summer, never could agree. I concluded to let the market decide. So we initiated a multi-faceted strategy by autumn. First, Duncan Terry expanded the *D'wuck* into a 'scope-like machine, with focus on real-time attributes and a wide-word serial trigger. This box, defined around IBM and Bell Labs needs, emphasized historic analog designer skills with augmented 'scope functionality. Consequently, it was viewed with suspicion by the new recruits to the program. It proved an expensive dud, even at IBM and Bell Labs.

Second, Kolody's team built some accessory boxes, tools intended to work as 'scope trigger signals. These units, aimed at TTL and ECL IC families, failed to ignite much customer interest.

The third group was hunkered down, trying to solve digital communications problems. They chose a new European communication standard from CCITT (**C**omité **C**onsultatif **I**nternational **T**éléphonique et **T**élégraphique) which enabled 'digital telephon". We built an end-to-end system tester, the HP 1645A Pseudo Random Bit Generator, to test the pioneering Austrian phone system. European telephone system designers bought enough systems to keep us going.

The HP 1620A Pattern Analyzer
HP Memory Collection

The fourth group was the most speculative - after studying the new P/MOS Intel chips, Bill Farnbach constructed a low-frequency (10 MHz) sampling system with twelve parallel channels. It was a useful tool that displayed a sequence of register events within a microcomputer, while the chip executed a small program. Farnbach, experienced at sampling domain frequencies one hundred times faster, was a one-man-band in terms of defining the features and the approach.

The HP 1645A
HP Memory Collection

Our First Logic Product Breakthrough

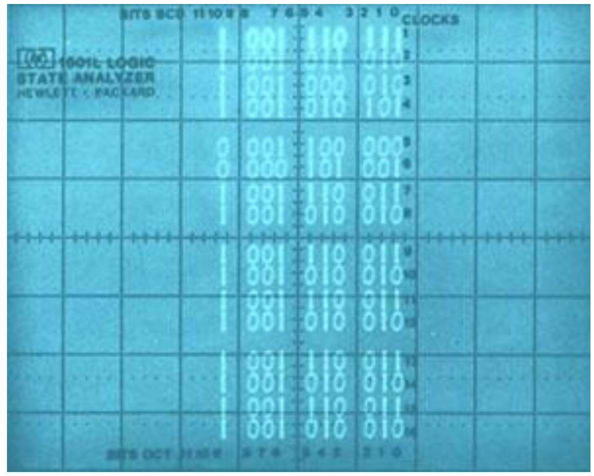
The breakthrough result was the HP 1601L Logic State Analyzer, a plug-in for an HP 180A 'scope mainframe that could handle twelve input signals, printing the results as either a "1" or a "0" at each event-time. Assembling twelve signals side-by-side gave a "machine state" that could be organized as twelve binary, four octal, or three hexadecimal words. The HP 1601L (picture below) was introduced at the WESCON trade show in Anaheim, California in August 1973.

Dick Cochran, left, discusses 1601L LSA with Wescon Visitors. Measure Magazine, August 1973.

It seems crazy to imagine now, but this unit represented a paradigm shift that confused many folk. At a division review demonstration, HP's corporate development director uttered in frustration, "Time always flows left to right; you're telling me that it goes top to bottom?" Computer folk said, "Twelve channels? All computers have sixteen or more." The same folk also said, "No one builds 10MHz systems, they're all 20MHz and up." And almost all early visitors wanted to know how you'd see rise times on fast channels, or compare race conditions.

Launched in August 1973, the sales team struggled at first, but a few salesmen did enjoy success. Whereas the large screen display had sold forty units within the first four months, this first logic state analyzer sold ninety-one units by year end. The division manager, Hal Edmondon, was happy, and I was invited by Bill Terry, the newly named Instrument Group Vice President, to Las Vegas for the annual sales kick-off, with all one hundred eighty salesmen.

The HP 1601L Logic State Analyzer
HP Memory Collection



The HP 1601L Display

In retrospect, it is clear that Terry expected me to give an upbeat sales talk, which was the normal mode for division presenters invited to speak to this group. I hadn't really spent much time with Bill since he'd left Colorado Springs, and there we'd last faced off on the question of how he'd concluded that only thirty-one large screen displays could be sold. I focused the talk to the sales team on how well individuals were dealing with this new logic tool.

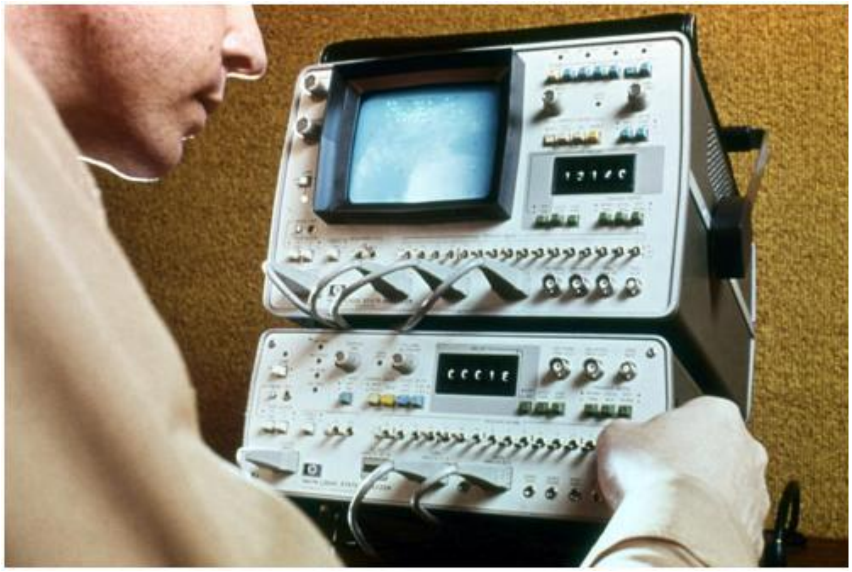
I singled out two folk - a superb young Denver-based chap who had sold eleven analyzers to ten different customers in four months, and veteran Jack Zorn in our Boston office, who had sold seventeen units to Raytheon Data Systems outside Boston. I'd been out to visit each, and I shared that Jack had simply found a 'digital guy' within Raytheon, who became enthused and the orders just started coming for Jack without any further effort. By contrast, the Denver fellow had become a bit of an expert on microcomputer chips, and he demonstrated the features of the new analyzer with exuberance to each prospective customer. Using these two extremes as examples of 'how to do it', I went on to note that only seven salesmen had sold more than two units. Gratuitously supplying the results, I shared that one person had sold six, another four, and three people had sold three. Twenty-eight had sold one; one hundred thirty-seven had yet to succeed.

In fact, three major sales regions had never sold a unit - an embarrassing factoid to be sure, and one that the sales leadership did not appreciate being mentioned. Terry was livid, but not nearly as enraged as some of his regional sales managers. I did not appreciate the gravity of this political error; suffice to say that it earned me a reputation if not accolades with the field force.

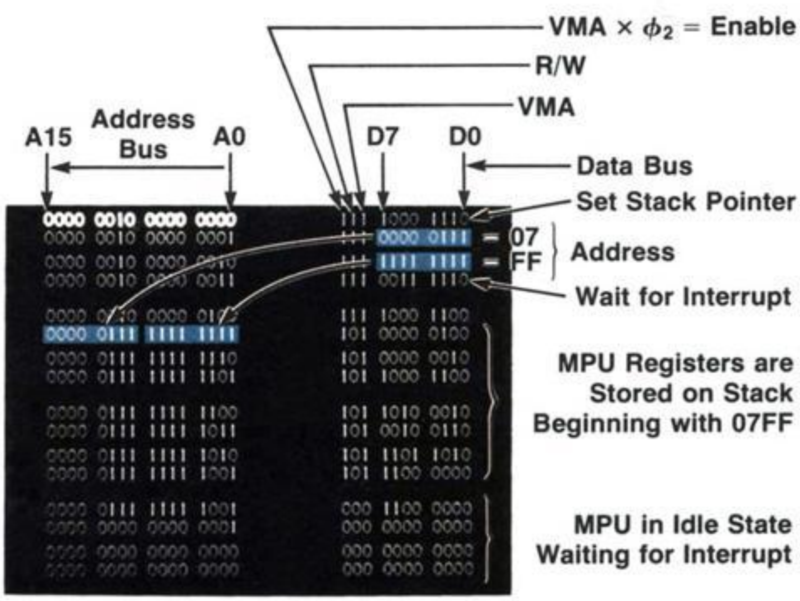
A year later, it was clear that the HP 1601L passed the 'customer excitement' test. And the HP 1645A opened up a new market for HP. We got a few sales, we got noticed, and we learned a lot. The team embraced the notion that synchronous design was important. Importantly, we came to trust each other, jelling as a team. Thank goodness, our group was allowed to continue. We retitled ourselves, "Logic Analyzer Lab." The road would be rocky, but we were underway.

How did we do financially? The HP 1645A PRBS Generator and the HP 1601L Logic Analyzer plug-in each sold several dozen units per month; eventually each produced about $3 million revenues, with net profits approaching twelve percent. HP's R&D lab goal was a profit return of six times investment. Our development 'burn rate' was about $1.1 million per year, so back-of-an-envelope accounting for the twenty months it took to "get to market" penciled out returns of maybe $0.40 per dollar invested instead of the $6.00 goal. Not so hot.

The next round featured new cabinets and linkage. The HP 1600A and HP1607A, bundled as the HP 1600S (Picture below), allowed 16 or 32 bits versus 12 bits for the HP 1601L.



The HP 1600S Logic State Analyzer 'system



The HP 1600S Display Screen

These products, once we learned how to market them, sold several hundred units per month. They cumulatively sold about $38 million in revenues, with 17 percent margins - giving a respectable $3.25 return per dollar invested. We hadn't hit the ball out of the park, but we were still at bat. We were earning our own way by this point; importantly, we were getting press.

The launch of the second round was troubled though. I was supposed to manage the R&D and product marketing program, not the sales success. That was the task of our sales team, both within the division and across HP's far-flung worldwide sales offices. Intrapreneurs, according to Gifford Pinchot's Ten Commandments, "circumvent any orders aimed at stopping the dream." I'd done it on the HP 1300A Display when Packard tried to stop it. Now a new threat emerged.

Our division sales manager, Bob MacVeety, returned from the annual July 1976 sales quota setting meeting with a $6.6 million Logic quota, after 1975 sales of $4.1 million. Bob was enthused that the notoriously chary field force accepted a stunning sixty-one percent increase.

MacVeety unwisely chose to share his quota setting achievement in a division staff meeting rather than telling me first - a big mistake for both of us. I blew up in the meeting - literally coming apart at the seams. Shouting "it should be $16.6 million, not 6.6," I stormed out of the room. I couldn't believe the level of my anger; my hunch is that no one else in the room could either. Fortunately for me, Hal Edmondson, the division manager took my side. We set a new goal, ignoring the field force - "$16.6 or Bust," built on the Colorado Springs history of "Pikes Peak or Bust" by the original gold miners. Even more fortunately, MacVeety had the maturity to perceive that my anger wasn't personally directed; he proved a tremendously helpful partner.

Selling is More Than Developing a Great Product

Three independent marketing ideas made the program work.

The first marketing idea - a brilliant one - was MacVeety's. He created the Logic Analyzer Belt Buckle. Selling ten Logic Analyzers earned a Bronze unit with the person's name and the date engraved on the back; twenty-five earned a Silver, fifty a Gold, one hundred a Platinum.

Logic Analyzer Belt Buckle
House Collection

Just as Boy Scout merit badges built energy and enthusiasm, these garish buckles - nearly three inches wide, five inches long, weighing half a pound, and fashioned after gunslinger buckles from Colorado Gold Rush days - became a cult hit with the HP sales force. Salesmen wearing them to annual conventions would whip off their belt and compare dates of success. Bob, a 'good ole boy' at heart, created a wall-mounted kit to hold all four, with a suitable certificate. This idea, which I thought completely corny, proved to be one of the best incentive programs I've ever seen. They became collector's items.

Second was the idea of training the sales force, but doing so subtly, with a seminar that they invited their key customers to attend. This was conceived by William Wagner, who came to us from Motorola after we demonstrated to a surprised design team there that we knew about their unannounced 'look-ahead' feature in the new Motorola 6800 microprocessor. Wagner reasoned that a seminar teaching the fundamentals of microprocessor design with proper tools would be effective. He spent nine months designing a 'suitcase' of experiments and writing a set of twenty test cases - it was a leading edge showcase. Six 'teachers' from our product marketing group, plus Bill Farnbach and I, took this show "on the road" for a year. 25,000 attendees enrolled for a two-day free seminar, averaging one hundred attendees per group - it was a spectacular success.

Third, John Marshall and Bruce Farly constructed a University Associates program that eventually involved more than one hundred engineering schools with grants of $10,000 of logic analyzer equipment, selected by faculty who attended a three-day intensive at our division (plus two days at a Colorado ski resort). The hook? The faculty person had to design a lab course using the equipment, and a year later, report to our next meeting how well the course worked.

The surprise for me was the enthusiasm that this program generated both for faculty and for our own team. Many of our junior designers loved the idea of 'teaching their old professor' something new! The motivation they had to demonstrate their own growth since leaving school was immense, as was the camaraderie that this close involvement built between our team and faculty who hitherto had not given much credence to our division's tools.

More importantly, over time this gave rise to new curricula, developed by a cadre of faculty who came to know each other through our program. Years later, they had become the leaders of the 'next generation' of college professors teaching electronic design to countless students, cementing digital logic design or *data domain* concepts firmly in the landscape.

Again, it would be great to report that this was a mostly smooth path to success. Alas, it was not. We had stormy fights, defections, and casualties within the group; relations with other Colorado Springs groups were often strained. Interactions with the HP Santa Clara Division, busy building their own interpretation of 'digital tools', were volatile shouting matches rather than synergistic. We did continue to use HP divisions for market research. Returning from one trip to HP Fort Collins, we stopped in Denver for dinner. Over dessert, one designer said, "You know, they used to know so much more than we did; it's amazing how far we've come."

Asynchronous latching for the HP 1600S was a great example of the value of such visits. We had learned the internal state flow synchronous measurement well - so well in fact that when questions arose about comparing two asynchronous machines, we didn't listen. True, we had heard customers cite that we'd missed the required number of channels with the HP 1601L and its twelve channels, fashioning two units - the HP 1600A with a display CRT, and its accessory unit, the HP 1607A without a CRT, each with 16 channels. The two could be linked - *e.g.* the HP 1600S - to create a 32 channel machine to watch synchronized dual 16-bit register flows. So we were relatively smug about our 'listening ability' - we heard well what we wanted to hear.

The Logic Technology Explodes

What couldn't be done with these linked machines, though, was "handshake" between two different microcomputer systems; displaying first one and then the other on screen. Somehow our team just couldn't hear this *asynchronous handshake* idea as a valid request. "Why would you want to?" went the argument. Much unwarranted energy and time was consumed with this debate, until one day pragmatic Bruce Farly had heard enough. He called the Loveland team, saying, "We'd like to bring our new prototypes up." On site, within minutes the feedback was, "Boy, it'd sure be useful if we could look at this machine interacting with that one." Which we couldn't do. Finally setting aside our pride factor, a relatively simple change enabled it. It became a most important feature for minicomputer designers.

Years later, I had the privilege of listening to Irwin Jacobs, founder of Qualcomm, explain to a Computer History Museum audience just how important this asynchronous handshake mode was for his first company, Link-a-Bit, when he tried vainly for months to get IBM engineers to listen to him. Harking back to the analysis that I had done for Bill Terry's sales force, I approached Jacobs afterwards to say that Link-a-Bit had been the seventh buyer of our first Logic Analyzer. He straightened up, surveyed the small group around him, stuck out his hand and said, "Congratulations, that instrument made my company."

These tools did enable key computer developments. In 1977, the second largest computer company in the world, Digital Equipment Corporation, had a new product under development. The DEC VAX-780 had Virtual Address eXtensions, a unique method of extending 16-bit computer address space to a 32-bit address. The power of this bit-doubling, non-intuitive to the lay person, changes addressable locations from a mere sixty-five thousand to 4.3 billion spaces. Virtualizing this space was a brilliant technical approach, novel and effective, but hard to debug.

To analyze the VAX operation, DEC engineers needed our tools, but feared we'd share their designs with HP's computer group. HP computer managers argued that our products should be built primarily for HP's computer group, to give them an edge against stiff competition. I felt that our Logic Analyzer tools could only be 'best' if we understood the toughest measurements in computing, problems more apt to occur with some of HP's many competitors. I passionately argued that "instrumentation engineers have to maintain a Swiss-like neutrality" for all users.

The decision to help DEC was affirmed by the Executive committees and Board of Directors of both companies. Under non-disclosure rules, we put five people in DEC's lab for several months. Legendary Gordon Bell, DEC's R&D VP, would much later note that "HP's program-controlled logic analyzers allowed engineers to test and debug these complex systems."

IBM's R&D Vice President Joel Birnbaum wrote in 2011 that, "It is easy to forget how very difficult it was to evaluate design decisions and resultant performance characteristics of digital circuitry before these instruments were developed. From 1971-75, it is not an exaggeration to say that this single-cycle, microcode-free style of machine design, so cache-and timing-dependent, could not have succeeded at IBM without the Hewlett-Packard instruments."

The Data Domain

Electronics magazine, the leading publication for electronic engineers, took a bold step, putting a new concept, *The Data Domain*, on its front cover in May 1975. Two lengthy articles two weeks apart made the point that these microcomputer marvels were ushering in a new perspective for designers - electronics would never again be the same.

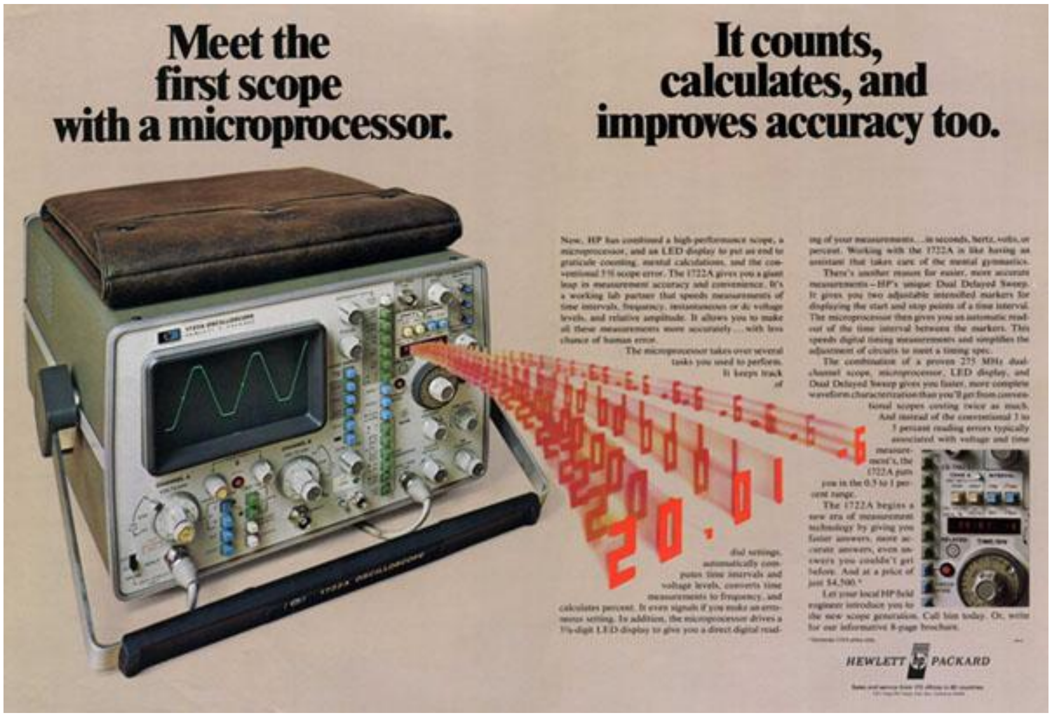
The editors were nervous when we outlined the thesis for them in January 1975 - they said, "This really reduces the importance of everything our magazine has always stood for. And we're not sure our audience is ready for this."

Somehow, we persuaded them. I think in retrospect it was obvious, but I recall that it was a half-day of argument and debate. I felt it important that they really understood the distinction between and significance of the *frequency domain* and *time domain* descriptors on which MIT's Ernst Guillemin had spent so much time in the 1950s, trying to change electronics from worrying just about continuous wave theory to focusing on switching theory. Radar and computers, with invaluable oscilloscope tools, couldn't happen with only a frequency domain perspective.

I drilled this point home with the *data domain* . No longer will designers really care about pulse shapes, rise and fall times, overshoot and ringing, any more than radar systems worry about carrier frequencies and modulation. They instead will worry about logic state, register contents and flow, and flag line settings - in short, the data status of the machine in terms of *data* events, not in terms of either time or frequency events and parameters.

The editors bought it. And they gave us two seminal articles to illustrate our thesis. It was a watershed moment, and the products changed the world. But we still didn't have buy-in from the Colorado Springs management staff. I invited designers Tom Whitney and Chris Clare out from Palo Alto to describe how the exciting HP handheld calculator was invented. Clare had given us copies of his algorithmic state design book; Whitney provided some microprocessor chips.

Walt Fischer in HP's 'scope lab had taken one of these microcomputer chips and embedded it into the HP 1700 family of portable scopes, calculating rise and fall times and pulse width for signals shown on screen between two dots movable by the user. Since it was the first HP instrument to incorporate a microprocessor, it got considerable fanfare, once again beating Tek.



HP 1722A, Double-page advertising in Electronics Magazine, January 23, 1975
HP Memory Collection

While the HP 1722A was indeed a 'digital 'scope', it was not a new paradigm - it merely digitized measurements that 'scopes had made for years. Somewhat shamelessly, we traded on this for our second generation Logic State Analyzer machines, borrowing existing HP 1700 'scope tooling to save costs, but also to provide an image that these were 'normal' extensions of 'scopes, even though they weren't.

HP 1740A, and HP 1607A combination
HP Memory Collection

For the HP field force, this was psychologically important - the boxes came from the same division, they 'looked the same' from external appearance, and we even created datasheets and application notes describing how the HP 1740A and the HP 1607A could be linked to find both synchronous logic errors and asynchronous spurious signals. Nonetheless, the net result for the local HP executive team was still a fair amount of skepticism and cloudy understanding at best of our true contribution. How to solve this conundrum?

Was it important to solve? The emphatic answer: "YES." Bob MacVeety's willingness to accept a ridiculous quota from the HP sales force revealed that he was playing by 'the book' rather than with innate belief in the kind and impact of these new equipments. I had worked out a strategic positioning paper - "One Strategic Cycle equals Three Product Cycles" - which characterizes much of what I still teach today. We needed a string of three successive product families to establish a solid leadership position. But the third wave was at risk.

This second generation of equipment, while a logical follow-on to the HP 1601L, was at best evolutionary - fixing the channel count, and mostly providing a way to handle wider busses. If these intermediate tools didn't 'blow the doors out', we'd not get third-round funding, or wouldn't get it soon enough to maintain momentum.

The machines our lab now envisioned would use microprocessors themselves for significant new capability. We imagined a line of dedicated bus analyzers, some serial and some parallel, and all would display answers in 'data domain' format rather than as simple "1's" and "0's".

A corollary of a fully thought-out Strategic Cycle approach is that the costs to build the third generation of equipments dwarf investment in the first two rounds. Such a third generation bet needs to start well before the second generation is ready for launch. Such processes are seldom taught in management schools nor appreciated by corporate consultants. This is why many corporate innovation initiatives lose momentum; we now found ourselves in that precarious spot - needing huge support for the third round of investment, before results were in from the second.

For fiscal year 1976, the Logic Analyzer group booked $12.9 million in orders, and delivered $11.8 million to customers, almost double what the sales force quota had been. I was thrilled - we'd tripled the sales from the previous year, established HP as *the* leader in Logic Analyzers in the world, and we'd 'taught' the sales force a lesson. But I wasn't prepared for the reaction in the overall division, or even within our group. People had internalized "16.6 or Bust" to the point that $12.9m was seen as a monumental disaster. Nothing I could say was able to assuage this point for people. We got tarred with a 'loser' label within the larger division; people even in Logic felt badly, as though we'd been whipped.

Support from the executive team waned, both for our group and my brand of leadership.

What to do? I decided to construct and teach a ten week workshop to the Colorado Springs management team. HP had from inception believed in promoting design engineers into all key jobs of the company; every member of Hal Edmondson's division staff had an engineering background. I traded heavily on this, setting up a workshop project where in teams of two, these folk would define, design, and build a calculator. Meeting at 7am every Tuesday for two hours, they came. The class studied how a four-bit microprocessor worked, and how to connect a keyboard and recognize keystrokes. We figured out together how light-emitting diode (LED) readouts were driven to make the right numbers. And then it was 'build time'.

For test equipment, anyone was free to use tools that they knew from their history - 'scopes, voltmeters, etc. - and they could use our Logic State Analyzers if they desired.

It wasn't long before the lessons began to show their worth. There just was no way to figure out what was happening with these small but powerful chips using any tool that was historically available. Yet it was simple to discern proper operation using the new tools.

Once the class had their calculators 'up and running', we moved to more sophisticated goals, such as linking two machines, illustrating the more interesting features of our latest products. For the last two classes, a couple of our key designers described some possible extensions. 'Lightbulbs' dawned around the room. Resistance to our 'third investment wave' waned.

This would prove to be the breakthrough that 'made the line.'

The Wave of the Future--Microprocessors

While ASM designs had proliferated, the rapid growth of microprocessors changed the rules. We built microprocessors into our entire line, the first time any test equipment vendor used microprocessors in tools to monitor microprocessors. More capabilities were added to these state analyzers - wider busses, sequential state triggering, and alternative displays, including decoded octal, hexadecimal, and microprocessor mnemonic instruction sets that replaced the "1's" and "0's" and state space maps that helped illustrate more complex state flows.

The first product out of the gate was led by Jeff Smith, an experienced sampling 'scope and pulse generator designer, who teamed with a native Colorado Springs software developer, Tom Saponas to define and create the HP 1611A Logic State Analyzer. The HP 1611A featured 'plug-in personality modules', each tuned for individual microcode instruction sets for a specific microprocessor from one company. The first module released was for Intel's newly released 8080 microcomputer. Personality module designers included Gail Hamilton, Dave Hood and Debbie Ogden. Don Bloyer, Don Miller and Roger Molnar contributed product design skills, each of them experienced in our 'scope labs.

The HP 1611A Logic State Analyzer
HP Memory Collection

One afternoon, Debbie approached me, with a request. She timidly said, "I'd like to become a lab manager like you. What were the three most important things you learned along the way?"

I'd not been asked something like that before - startled, I blurted out the first thing that came to mind: "I got a History degree in the History of Science and Technology, I joined the Colorado Air Pollution Control Commission, and I bought a plant nursery with my wife." Debbie looked at me as though I had three heads. In retrospect, it wasn't that bad an answer, but in truth, it stopped her cold. So then, I had to take a few minutes to explain - in actuality I had to figure out why such an answer came so easily to me.

The history degree, I explained, allowed me to learn from history - so that you don't have to repeat every mistake along the way. The example I used was the learning from historian Thomas Kuhn's thesis about the structure of scientific revolutions, which admirably described how our management, our customers, and our competitors all reacted to our products - disbelief in the new thesis, and a redoubling of efforts on the conventional wisdom approaches.

The air pollution work, I told her, was the first time that I found myself in a situation where I knew very little about the science or technology, and yet I was expected to make decisions. How do you handle decision making in the absence of adequate knowledge? The conclusion was that it is okay to ask 'dumb questions' - you're not expected to know everything.

The nursery business was perhaps most important: when I couldn't meet payroll, I really 'got it' about cash flow and profits. To my surprise, I found that HP financing worked the same. Ironically, the *Return Map* that Ray Price and I installed at HP and wrote for the *Harvard Business Review* had its origin in teaching nursery employees about return on roses and shrubs.

Debbie and I sat together, pondering these answers. I still wonder why they came so quickly.

New contributors joined our group - George Haag, from the California Data Terminals division, led the flagship HP 1610A (Figure 3a) development, a high, wide, and handsome $10,000 state machine. Haag, an erudite but bellicose leader, led a skilled team - experienced circuit designers Justin Morrill, Jim Donnelly and Steve Shepard; the division's first software developer Gordon Greenley; and long-time mechanical 'scope designer Don Skarke.

Figure 3. (a) HP 1610A Logic State Analyzer ------------ (b) HP 1615A Logic State / Timing Analyzer

Many folk within the Logic division viewed this product as overkill - too expensive, too late, out of touch with the emerging microprocessors, but Haag's insight came from the minicomputer world, not the microprocessor world. This is the box that appealed to the Cupertino divisions, to Digital Equipment, and importantly, changed IBM's outlook on these tools. Extensions of this line designed for the nascent Reduced Instruction Set Computer (RISC) architectures in 1981 would give HP Labs important insights for a major restructuring of the mainframe computer world, which brought DEC to their knees and eventually even dethroned IBM.

The major bet of the Logic team was instead on the HP 1615A, our first one defined as a combination Logic Timing and State Analyzer. Logic Timing Analyzers portrayed logic signals as pseudo timing diagrams, much easier for conventional electronic engineers to grasp (HP managers from Palo Alto liked these better, since time still went from left to right). Biomation and Tektronix competition mostly built Logic Timing Analyzers; their designers still struggled with the paradigm shift to think in instruction sets and register flow. Thomas Kuhn's thesis was holding true in our field as surely as in the Copernican astronomical revolution in Galileo's time.

Bill Martin and John Scharrer teamed up with Bob Wickliff to create the HP 1615A, and it rightly proved to be a winning combination - with a $6,800 price tag, it matched the best Logic Timing Analyzers from the competition, and in addition handled up to 24 channels of synchronous state

HP's sales force was much more comfortable with this switch-hitting machine than with our state analyzers. They loved selling head-to-head against Biomation and Tektronix - good salesmen always do.

But the real point of this machine was much more significant than that. The *HP Journal* article, co-authored by the three ex-scope designers Scharrer, Wickliff and Martin, brilliantly outlined the unique capabilities for designers using the combination of asynchronous and synchronous analysis - along with a 'glitch trigger' that captured sales folk and designer imaginations alike. This unique 'glitch trigger' - a throw-back to old concerns about 'race conditions' - actually did have important value on occasion for isolating misbehaving circuitry.

The HP 1615A was the first HP Logic Analyzer product to book $15 million per year. Only a very few HP instruments - the historic counter from Santa Clara division, the big Spectrum Analyzer from the Microwave division, the HP 180A 'scopes, and the HP 1700 series portable 'scope series - ever reached this level. While it was a big accomplishment for the group, from my standpoint, it was a signal achievement in terms of marrying the talents of our 'scope designers with logic designers to build truly amazing merged capabilities.

Two other products, each uniquely defined, debuted also. Bill Farnbach contributed a portable version for field work, the HP 1602A. Chuck Small was his project leader, and versatile Al DeVilbiss - who had done so much in both 'scopes and displays - was the software developer. The expectation was that this would be a 'portable scope' equivalent - volumes would be correspondingly huge. The price point, the size and weight, and the ease of use all contributed beautifully, but we hadn't reckoned on the enormous time lag for adopters. Lab designers were just learning these tools; service groups weren't about to jump in yet.

The HP 1602A Logic State Analyzer
HP Memory Collection

John Poss, Bob Erdmann, and Rick Vestal teamed to define and build the HP 1640A, a serial bus analyzer that was the first logic analyzer to decode transmitted text, in ASCII character format. We had a request from Y-HP, our Japanese division, to do this also for JIS-7 code; when we made the conversion, we had a hard time finding any Japanese near Colorado Springs who could verify operation. The unique requirements of this unit led me to think hard about partners.

Collectively, the line-up was formidable. It took the industry by storm, creating profitable sales unheard of for the division - cumulative revenues passed $100 million within three years: return on investment exceeded 10:1. Once our seminars began, coupled with the *Electronics* stories, we attracted attention. Sales blossomed, editors visited, and stories accumulated. It is seductive to be wanted, to be noticed. It also has its costs, of which we were blissfully unaware.

The HP 1640B Serial Data Analyzer
HP Memory Collection

We had come a long way. We had a vision, and we had a plan that most people understood, and worked on diligently. The wider division, not to mention HP leadership elsewhere, was more chary. Many cross-currents flow within and around organizations; leadership is seldom universally acknowledged. Plenty of 'not-quite-converted' Monday-morning quarterbacks still existed in the parent division.

Being noticed

Hard to imagine today, but scanners, bar codes, and RFID tags did not exist in 1975; grocery stores had no automation. *MSI Data*, a tiny Costa Mesa, CA company, had a novel device: a 'portable grocery checker' designed for *Alpha Beta*, a California grocery store.

The device weighed two pounds with a keypad and a display; it fit roughly into your hand. The idea was that a clerk could carry it up and down aisles, to list items that needed restocking. They intended these units to communicate with the back room, so staff could be loading carts with restocking supplies even as the clerk wandered the aisles. It used Intel's 4004 micro-computer chip; MSI's team said that they were Intel's highest volume purchaser of those chips.

This was in October 1975, three months after the quota dust-up. MSI Data wanted to hire an R&D Vice President, and a recruiter found me - the inducement, besides a handsome salary and bonus, was a hefty stock option and a chance to move back 'home' to Orange County, CA.

I barely knew the terms 'start-up' or 'stock option', and it was intriguing, to say the least. And it was a precursor of increasing notoriety. Executive recruiters - *headhunters*, a term that I'd not heard before - began to show up. Farnbach and I were the visible targets - we'd bylined the articles and given training seminars. 'Back home' after a quick visit, I met with our HP General Manager Hal Edmondson and described the MSI Data opportunity. Edmondson's quick response was to create a 'Logic Analyzer group', and he promoted me to run it, the first time that I was asked to manage multiple functions (R&D and Marketing). Hal included a moderate raise and modest stock options. I now was a 'general manager' of sorts, and I was very proud of the major R&D program underway that augured to give us unquestioned leadership when it arrived.

Complicating events were swirling, though - innovation was not just happening at our place, but throughout the industry. Along with our efforts to teach seminars and encourage the field force to drive toward a bold "$16.6" sales goal we kept hearing odd comments about a 'new device' - an *emulator*, whatever that might be. Each microcomputer manufacturer seemed to have one; the two most prominent were the *Intellec 8* from Intel, and Motorola's *MDS*, which stood for Microprocessor Development System (Figure 4).

Our problem, although we didn't yet know it, was that we were focused on 'yesterday's competition'. Tektronix entered the Logic Analyzer business with a combination Logic State and Logic Timing machine, the DAS 9000 (Digital Analysis System), a bulky box not unlike our original *D'wuck* definitions. Tek, with lots of historic cachet with electronic engineers, got an audience for this machine. Nimble pioneers of Logic Timing Analyzers, start-up Biomation and long-time radio test vendor EH Research, were able to thrive for a time against Tek. We debated whether to change our Logic State thesis and fight the Logic Timing zealots, or to meld the two capabilities. Our field force, struggling with our radical paradigm, helped with that decision.

(a) Intel *Intellec 8* Program Development Station (b) Tektronix DAS 9100 Logic Analyzer

Figure 4

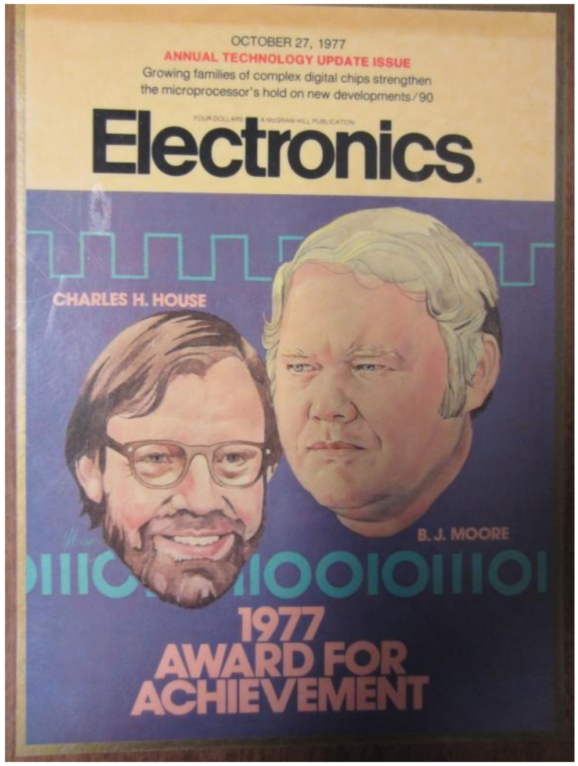
As the third-generation products made progress during 1976, Hal came back to me with a 'new opportunity.' He wanted me 'back in marketing', but truth be known, he and others were frustrated by my seeming inability to manage a sizable group. His proposal was that I become HP's first Strategic Planning Manager, reporting directly to him, with a couple of people, to redefine the strategy for the whole division. "Whoo-boy, here we go again", I thought. Hal's plan was simple - "John Cardon, a practiced R&D manager who can both motivate people and get the current products finished on time and budget will take over your lab. You and I can define a stronger presence for oscilloscopes and displays, to really wound Tektronix."

November 1st, 1976 launched HP's 1977 fiscal year; John Cardon took over *my lab*. The products did indeed come to completion; he comported himself well, focusing tightly on schedules. My role, however, struggled. Traction eluded me - we'd tried a million things against Tektronix over the twenty-two years we'd competed. We'd pioneered Sampling Scopes, Displays, Very High Frequency Scopes, Variable Persistence Scopes, and Microprocessor Controlled Scopes as well as Logic Analyzers - and Tektronix had historically answered each initiative within twenty-four months, and taken market leadership within another two years.

My strong fear was that they'd do it again in Logic; that was a big part of the motivation to persist with the third generation equipments so boldly. Edmondson, on the other hand, felt that the game for HP still was to 'beat Tektronix' in the main scope business; ancillary equipment lines could never satisfy Palo Alto, and hence satisfy his own vice-presidential ambitions at HP.

We had a stalemate underway.

And my periodic forays into the Logic lab told me that the team was losing enthusiasm - the drive and the zest for creating and evangelizing these new tools seemed muted. Not good.



Cover of Electronics Magazine, October 27, 1977
House Collection

And the Winner is!

And then - an incredible surprise. I was selected for a prestigious award - the *Award of Achievement*, given by *Electronics* magazine. It was their fourth annual selection of a person for creation of products that revolutionized electronics. Their cover picture showed Bill Moore, CEO of start-up Biomation based in Cupertino, CA, and me - we were jointly selected for the creation of Logic Analyzers - Biomation for Logic Timing and HP for Logic State analyzers. Biomation had created an eight-channel Logic Timing Analyzer the year before the HP 1601L. It was also a 10 MHz machine, which displayed a stylized waveform with time running from left to right on-screen, the same way that oscilloscopes did. Biomation's box was an easier 'sell' to classic analog designers, and they did enjoy considerable success for a time. Biomation's newer designs emphasized faster sampling rates up to 200 MHz, lots faster than our systems.


Electronics Award Plaque
House Collection

McGraw-Hill, *Electronics'* publisher, hosted a luncheon for the two of us in New York City, presenting each of us with a bronze plaque featuring a bust of our profile. The clean-shaven Moore must have been easier for the sculpturer than my bearded visage. My shock at the lunch was discovering that Moore had little comprehension of either the significance or even the technology of his company's contribution - he was an early incarnation of "the empty suit" that would become the sneering tagline for IBM's executives a decade later.

I was thrilled at the time. The advantage for us was palpable. It was clear that our technical competitor was Ray Tottingham, Moore's VP of R&D, rather than Moore. Their marketing team was undistinguished - we had a free field, it seemed to me. Moreover, they gave 'proof' that this was a respectable new approach for designers. It is always much easier to sell a head-to-head product against a competitor, than to establish a new thesis alone against a prevailing paradigm.

The magazine cover catapulted me into the limelight. I answered the next headhunter call. It led to meeting Jerry Sanders, the flamboyant founder and CEO of Advanced Micro Devices (AMD). AMD was licensed to produce Intel microprocessors, but they were not licensed to build *Intellec* development systems. Sanders was forming a partnership with giant Siemens of Germany, to create Advanced Micro Computer Systems (AMC) for building development systems. Would I consider becoming CEO? Their main competitor? Intel.

I immediately thought, "Why aren't we considering Intel to be our main competitor instead of Tektronix?" But I quickly dismissed the idea, concentrating on the man seated across from me in the living room of his palatial Woodside estate. His wife Linda served us breakfast at a patio table; she was dressed in an unusually revealing blouse - I could scarcely focus on the topic at hand. Her scanty attire, I learned later, was a trademark, both in private and public forums.

Outlining the magnitude of the opportunity, Sanders was dismissive of Intel's leadership in the area, arguing passionately that prospective customers were begging him for relief from the usurious pricing and captive market situation that the Intellec Systems gave to Intel for their chip sales. Just as he'd done with cross-licensing of the chips, he intended to 'emulate' their emulators. The advantage with Siemens as a partner was the European channel, plus their long-standing ability with systems-level, rather than chip-level, designs.

This job had perks that wouldn't quit, compared to anything I had heard before. Options? Sure, in copious quantities. Salary, yup, with huge potential bonuses. He leaned forward, and said, "Take a look at the cars out there." The driveway had a slew of fancy machines, including a Ferrari, a Bentley, and an open-seat roadster replica of something from the twenties.

It was intoxicating, to be honest. Fame and fortune if you go down this path, and clearly wine, women, and song to boot. Pretty heady for a Caltech nerd, and bold enough to satisfy most entrepreneurs or intrapreneurs of the day. The fact that it was backed by two huge corporations, on the one hand, and that the desired product was mostly a knock-off rather than an original creation out of whole cloth on the other hand, rendered it "almost risk-free."

I was terrified by the whole experience.

I did share the opportunity with my boss, Hal Edmondson, once back at HP. And he reacted this time with alacrity. He created the Logic Systems Operation, one step shy of a division - its own manufacturing, marketing and R&D functions; he invited me to run it. I jumped at the chance; this was the 'right' promotion.

The new Operation would start November 1 st, 1977; I was thrilled to jump back into management, for a real leadership position. We'd just finished rolling out the third generation family; the mood was heady. I was invited to speak at HP's annual eastern sales conference, to wax eloquent about these new marvels. The meeting was at Le Chateau Montebello, located seventy-five miles north of Montreal, on the Quebec bank of the Ottawa River - a fabled resort for momentous world meetings with the largest log structure in the world. We flew from the Montreal airport in a four-seat airplane, just the pilot and me. The glowing oaks and maples in early October were heaven-sent for a Colorado nursery owner. Two people at the meeting stood out. The first was Diven Meredith, a keynote speaker whose job was to talk about innovation and creativity. The second was Doug Chance, a rising star in HP's computer group in Palo Alto.

HP's emcee for the day showed the October 1977 cover of *Electronics* to the assembled audience when he introduced me. Meredith had read the article; he was an inventor of note himself. Meredith and a fellow named Morse had invented a freeze-dry process for orange juice before World War II - Sunkist waited until the patents expired to pick up the process, but Meredith had persevered and built a tidy business with the ideas. We talked at length about the pitfalls of innovation, especially within companies. Ironically, I would meet his niece seven years later, and eventually marry her.

Doug Chance, a key HP microwave division manager, recently had been tapped to run the engineering computer group. He and I talked about the goals of his new group, and the role that logic analyzers had played to help those design teams. And then, he delivered surprising news: my new Logic Systems Operation was supposed to create a new line of HP gear - *Program Development Systems*. He blithely said, "Here's what we want you to do."

"What we want you to do?" I could hardly process this statement. I'd become accustomed to defining the arena and running the show. Was I about to go to work for someone else? What was going on here? And then I realized that what I had been preaching was now happening to me. Innovation changes everything. Your opportunity is also open to someone else. Guess who? Other innovators, that's who. And strange as it may seem, because existing competitors 'know the rules', they are among the least likely to be your key competitors in the 'new order'.

The nature of the competition from existing competitors almost always has one of two patterns. First, they redouble their efforts to improve the old or existing products, to show that the new approach is really not (yet) necessary. Second, when it becomes dramatically obvious that the shift is happening, they'll usually try to meld the two ideas in an awkward way. But in a turbulent 'new world' there are additional vantage points from which to watch.

It became crystal clear, strolling in the crisp autumn morning along the Ottawa River**,** that Doug Chance and many California HP folk had a different vantage point than ours in Colorado Springs. And they intended to impose an influence on our program. I'd just turned down a job with AMD to build the same thing HP now wanted. While I'd become very nervous about the assignment at AMD, their reward package was disproportionately higher. Had I made a mistake?

In hindsight, yes, we could have, and should have, viewed Intel rather than Tektronix as the competitor, but this is extremely hard to do, especially if you've been locked in a head-to-head battle for years, and this new idea seems like the breakthrough you've sought for so many years. Of course you'll focus on beating your biggest foe - whoops, who's this other company? The biggest resistance to innovation in our place was centered in our own leaders - our executive staff didn't understand, and hence couldn't support it in good conscience. They had to be shown, coaxed, cajoled into understanding the issues enough to quit resisting - even though they weren't being asked to invent in the new arena, it would have helped if they'd not fought those who were.

Creativity and innovation, often lauded, is actually feared more than it is embraced by most managements. They espouse innovation, but actions belie the words. Why? True innovation clouds the future, and predictability goes out the window. Most managers really want to avoid risk, especially if visible failure might be involved. Our division management proved no exception, and it was a struggle with these attitudes to find an approach to win their support.

Entrepreneur vs Intrapreneur

Successful inventors have a relatively easy task - to invent something new. Innovators, though, have to make inventions succeed in a marketplace. If the innovator is an entrepreneur, the game is to build a motivated, skilled team and find patient investors. If the innovator is an intrapreneur, the game also includes building a motivated, capable team but the funding must come from the parent company. Consequently, the intrapreneur has to persuade the company to accept and be grateful for the innovation.

Entrepreneurs have a natural advantage over intrapreneurs these days. It wasn't always true. Until the idea of venture capital (VC) became established, in Silicon Valley in the 1970s and 1980s, there were few entrepreneur options if their idea involved any significant amount of capital. Even today - 2011 - almost half of the United States venture capital industry, and one-third of the world's venture capital investment, is located within fifteen miles of Sand Hill Road and Interstate 280 in Menlo Park, California, so a fortunate few find it easier to locate funders.

But there are dozens of VCs, and hundreds of 'angel investors' for the erstwhile entrepreneur, and it is not a strange idea any longer to back new ideas in expectation of sizable rewards.

The intrapreneur by definition has just one source - his or her company. And if that doesn't work, then what? For the HP 1300A Display, I was lucky enough to have my boss' boss support me against his peers. The first logic product was endorsed because IBM called my bosses. The next two situations were helped when fortuitous outside job offers spurred reaction by my boss. Those offers wouldn't have occurred if I weren't 'known' via articles, speeches, and workshops. You are always selling yourself, both inside and outside the company, if you're an intrapreneur. But the company has to back you - intrapreneurs don't start companies, they work at them.

There is always an even better idea being born somewhere else. For the displays line, we developed a very satisfactory alternative business for 'scope CRTs - until fast dynamic memory came along, and much cheaper electromagnetic CRTs - and then liquid crystal displays, such as the one on your PC or Netbook today - provided a cheaper, smaller, lighter, more focused display. Tektronix did not beat us - another technology did. But we got a great fifteen year run.

Logic State Analyzers were a much better idea for data domain questions than oscilloscopes. Tektronix never came close to us, nor did anyone else. Tek did match our Logic State Analyzer revenues with their Logic Timing Analyzers, because they still captured the hearts and minds of engineers who analyzed the new circuits with the old parameters. When the two functionalities merged, we had a dogfight for a decade. But all of these tools were best suited to MSI and LSI (medium- and large-scale integration) chips in moderate-sized systems.

As chip densities rapidly increased, programming tools became quickly more important than logic state analyzers. Synthesis requirements precede analysis needs. Thus, PDS technology, coupled with emulators for bus register flow - not 'scopes - overtook Logic Analyzers.

With the benefit of hindsight, forty years later, it is interesting to consider the distinctions of frequency domain, time domain, and data domain electronic engineering tools in terms of overall market revenues. In 1970, the worldwide frequency domain instrumentation market was roughly $185 million - HP supplied almost eighty percent of it, while Tektronix had less than five percent. The time domain business was $210 million, split with $160 million in 'scopes and $50 million in counters. Tek had eighty-five percent of the 'scope business and no counters. HP had ten percent of the 'scope business and fifty percent of counters. No data domain existed.

Data domain revenues exploded, going from $33 to $377 million, an astounding eleven hundred percent growth, from 1975 to 1980. But frequency and time domain tools grew heavily as well, so it was hard to know where to place the investments. Within data domain tools, though, PDS systems ($271m) had most of the growth - Logic Analyzers just crested $100m.

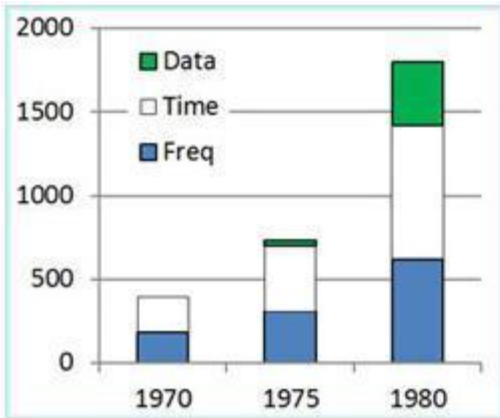


Figure 5. $ Million Revenues by year

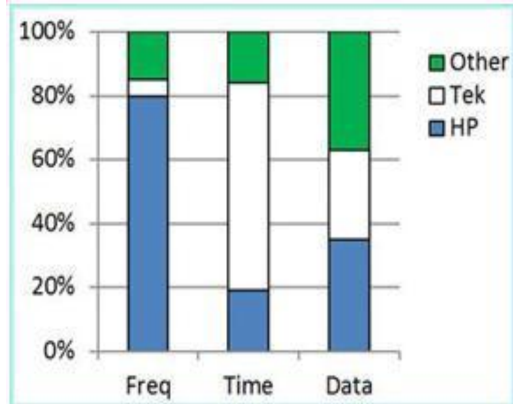


Figure 6. $ Million Revenues by category (1980)

HP overall revenues reached three billion and Tektronix neared one billion in 1980, each company tripling in size in a mere five years. And Tektronix now had eighty-seven percent of the 'scope business; HP Colorado Springs had declined to eight percent. So the fact that my logic group had a slim lead over Tek - 35% vs 28% - in a market one-seventh as big as 'scopes didn't impress Colorado Springs division management. And the fact that the PDS business was almost three times as big as logic analyzers had been noticed in Palo Alto. No one yet knew that by 2010 HP Logic Analyzers would sell $2.8 billion of Logic Analyzers, half the world's supply. The front end of the innovation "S-curve" is a nascent part of the eventual profile, yet almost all of the decisions about eventual investment and competitive stances are decided by then.

Creating and Sharing the Vision

Doug Chance's words echoed in my ears on the way back to Colorado Springs from Ottawa. We'd become good - incredibly good, in fact - at our Data Domain expertise, and we had done something that eluded our divisional brethren for two decades: whipped our major competitor, Tektronix. We'd become E-stage leaders, with a radical vision and a plan, and we'd executed that plan very successfully. Now, it felt like we were being asked to throw much of that away.

I had long used a simple matrix to describe the difficulties of learning new material - I called it the 'shoelace tying diagram.' Fidgeting on the plane, I found myself sketching the diagram again on the back of a napkin. Although I'd frequently drawn it for new members of the team, additional insights came to me as the plane droned onward.

Most of our daily tasks are performed habitually, which is to say in a semi-conscious or nearly unconscious state of mind. We get up and get ready without 'thinking' - putting on our shoes, cleaning our teeth, pouring milk on the cereal, backing out of the driveway, and so forth. And so it goes throughout the day. We see cars all around us as we drive to work, yet with the possible exception of a new type of vehicle, probably could not describe any of the cars we saw if asked at lunch. Certainly no one could say how many SUVs they passed on the way to work.

These quick examples illustrate two kinds of information - the color of your toothbrush was once learned, but is now *unnecessary information* unless you share a bathroom sink with others; the number of SUVs along your route as you traveled is *latent information*, ignored because it is not relevant unless someone asks about it. Latent knowledge is discoverable, if you seek it.

Many of us are familiar with the terms *explicit knowledge* and *tacit knowledge* - along with the notion that we can teach explicit knowledge, in a training class for example, while it is tough to teach tacit knowledge even though it can be learned. How do you learn tacit knowledge? By assimilation or emulation once you are in a group which 'has it'. Apprenticeships do this.

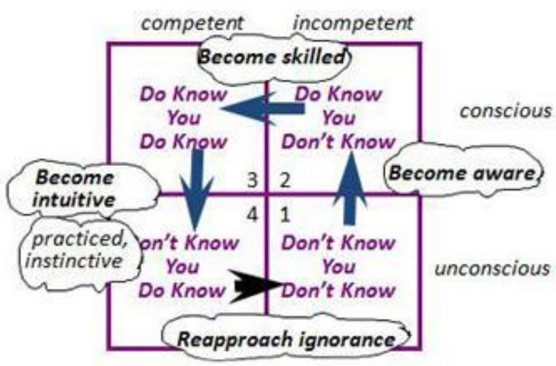


Figure 7. Conscious and unconscious problem solving capability

The picture above illustrates the shoelace tying diagram. Imagine back to when you did not know how to tie your shoe laces - is it possible to think back that far? Then there came a time when someone pointed out for you that you did not know how to do this task. You might remember the person with some fondness. You have just been changed from an Unconscious Incompetent into a Conscious Incompetent, going from the lower right-hand quadrant to the upper right-hand.

Learning progresses as a counter-clockwise move around this diagram. I suspect you've had experience going to a friend's home and a young child comes running up, saying: "I know how to tie my shoes, watch." Then they proceed to show you that they don't quite have it down yet. Project reviews often have this quality: "I have this neat prototype. Here, let me show you how it works." Two mouse-clicks into the demonstration, you discover that it *almost* works.

Many lessons might be drawn from such a chart. First, it is fair to observe that Productivity improvements are usually viewed as moving from the upper right-hand quadrant to the lower-left quadrant. The idea is to move your team from learning the initial concepts to practicing them, and then to intuitive easy operational behavior. Many companies prefer to hire new college graduates, wasting no time unlearning a different company's processes and values.

Training departments, schools, and universities exist for the purpose of moving novices, using explicit material, across the top of the matrix - from quadrant 2 (upper-right) to quadrant 3 (upper left), topic by topic for whatever curriculum is deemed relevant. Practice - lots of it - moves a person from quadrant 3 to quadrant 4, from a Conscious Competent to an Unconscious Competent. The practice time routinizes the behavior - in sports, the quarterback learns a host of nuanced things about how much lead time, how to 'read' a defense, knowing when to scramble, and what to do when weather conditions change things. Such skills become ingrained, highly tuned and efficient, and performance improves accordingly.

This works for teams just as much as for individuals - teams that work together for extended time develop understanding, trust, and mutual interactions that are sophisticated, smooth, and effective, almost without trying.

But notice a curious element of this learning, and this positioning on the matrix. If we get a team 'intuitive and efficient' we have basically moved them into the fourth quadrant, an 'unconscious competence' quadrant, which over time can render the group somewhat inarticulate and even inexplicit about what they know and believe. Then, if a structural change comes along - a context-challenging situation - the group may not recognize it for what it is.

Imagine that as events move along, things get harder, profits more elusive, or efficiencies less pertinent. The typical response is to try to figure out 'what happened' or 'what we need to do to recapture what we once did so well.' A classic response, often from higher level management in conjunction with the HR / training department, is to 'go back to the basics', to 'revisit what made us great', to re-instill the 'things we once knew so well.'

But if the lower half of the diagram is "unconscious" - you don't really know whether you *do know* or you *don't know* what to do in this situation. Intuition - or the long-ago learned response - might be exactly right, but it could also be tragically wrong. Flight simulators train pilots for a myriad of emergencies, so that their 'intuitive' responses will be good ones.

Being open to new ideas - in effect, willing to stop in the midst of something that has felt comfortable, but has changed character somehow - is not all that easy. Often, it seems that the more expert or powerful someone is or has been, the more they tend to want to stay in that comfort zone rather than admit that they really don't know what to do in this instance.

To some degree, this accounts for why old paradigms die hard. An additional complication is that the new paradigm - the changed situation - is usually cloudy, fuzzy, and inexplicit. The old paradigm - the one that we've come from - has rules, well-established articulated procedures and processes. The new one is at best dimly-viewed, half-conceived, and dichotomous - even for the visionary who senses or even grasps it. Thus someone in that D-stage described earlier - who has the vision, but isn't sure how to realize it - has quite a task to persuade 'the rest of the team' but especially to elicit support from the most influential and powerful of the 'old guard.'

This is the special challenge of the intrapreneur. Interviews with many serial innovators reveal phrases like this: "How can I get my boss (or the engineering council, or . . .) to support working on my dream if I do not yet understand it very clearly?" Or "How can I persuade ten (or a hundred) people who might help me carry out my concepts if I cannot articulate it well?"

Entrepreneurs usually labor alone through this period, maybe with their own funds, or with funds from one or a few speculative investors; the intrapreneur's special burden is that they are operating in a larger setting, one where quadrant 3 and 4 'conventional wisdom' is all about them, while they "see clearly" that the situation is more like quadrants 1 and 2.

Phrased this way, it is easy to see the plight of the intrapreneur - once they recognize that the situation has been fundamentally altered, they begin their own odyssey - from quadrants 4 to 1, then 2, hopefully to 3 and maybe then back to 4 with new rules. But as they travel this lonely path, they will "look and feel" like A, B, C stage leaders (Table 1-2) until they themselves reach quadrant 3. Then, and only then, will most managers take them seriously.

Once I had drawn the Competence Matrix and compared it to the Leadership Stages, I felt relieved - relieved in the sense that I could now see why it had taken so long to come to grips with the Logic a nalyzer definitions. The first issue - raised so clearly while standing in the Tektronix booth - was that all of the extant instrumentation no longer met the design needs of customers. What would? Well, I didn't have a clue, but my own team supplied some important elements when they couldn't build our prototype due to a host of new data domain problems.

We didn't know to call them data domain problems, though, until we'd wrestled with some ideas, built a half-dozen prototypes, and taken a couple dozen 'market research' trips. Almost all of this work would be thrown away before we hit upon some definitions that 'stuck'. Even then, the first products that we released failed the economic payback equation pretty seriously, even as we were well embarked on the second investment set.

The second set of products enabled us to get some traction with the sales force, and with the required investment returns, but they weren't enough to generate significant support for keeping the investment momentum going. We only got that third round by essentially taking the division management team through a crash course that toured them from quadrant 4 in their belief system to quadrants 1, 2 and then 3 within a ten week workshop.

The third round turned out so successful that our local management touted us to headquarters - and HQ promptly cannibalized our team for *their vision* , not ours. Worse, our local managers lacked sufficient perspective to realize that if this were cannibalized, that we'd lose the initiative, and once again be beholden to Tektronix, just as the previous twenty years had done.

Once I had built this perspective for myself, I wrestled with the question of whether we could forestall the incursion of 'directives from above' - and concluded that seemed unlikely at best. At the same time, it seemed worth trying to diagram, in some sort of flow-chart manner, how we'd done all of this. I think I harbored some sense that this might prove useful later.

The chart that emerged is shown in Figure 8. I called it the Strategic Cycle, noting that it takes three Product Cycles to have a complete Strategic Cycle. The diagram includes not just the Strategic Cycle, but the Visioning and the Strategic Planning sections as well.

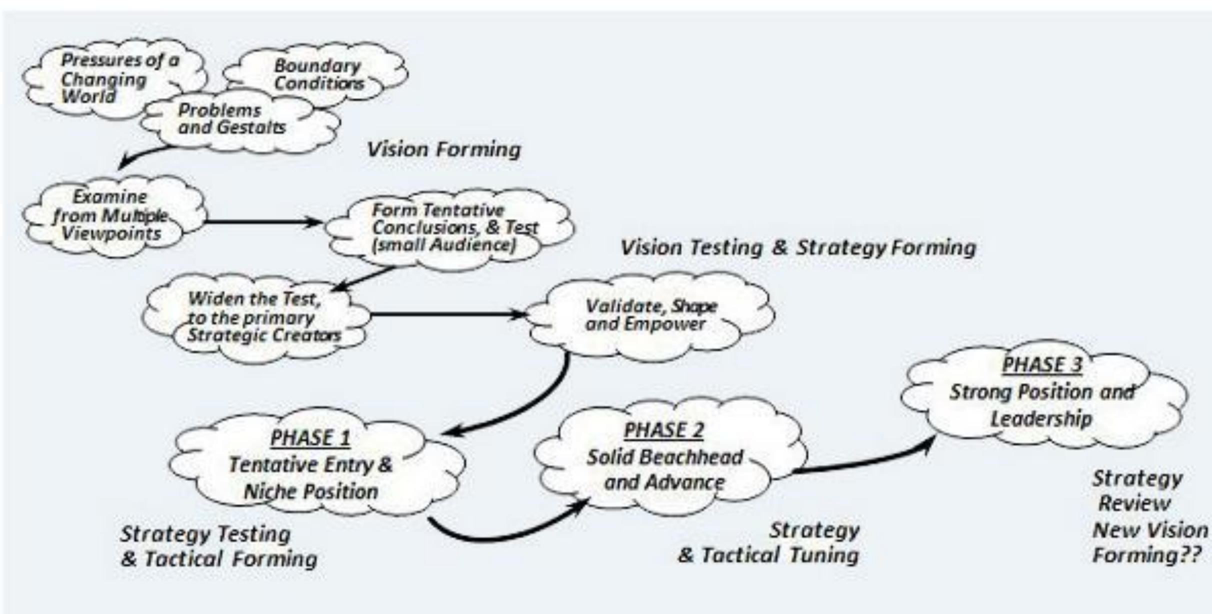


Figure 8. The Strategic Cycle

Contemplating this flow-chart alongside Table 1 and Figure 7 was revealing. Thinking back to standing in the Tektronix booth demo'ing their new 'scope to customers, that day moved me to a Conscious Incompetent person from an Unconscious state. I thought that I was an Unconscious

Competent who understood oscillography well, quite suited to managing the Next Gen program as a result. In fact, I was an Unconscious Incompetent about the nature of the new measurement requirements - and the booth visitors served the same purpose for me as that older sibling does for the child who doesn't yet know that they need to learn to tie their shoelaces.

On the Leadership table, I had just moved from what I thought was an E-stage (or F-stage, depending on whom was asked), to an A-stage - completely adrift at sea, no idea where to turn.
So what do you do in such situations? In somewhat pell-mell fashion, we followed the flow-chart. Specifically, we traveled and listened - from multiple viewpoints, to many problems, with lots of boundary conditions. And we formed a tentative thesis - the *d'wuck.*

The d'wuck was good enough to test the thesis on 'a very small audience' - and with help from Bert Forbes, it found a very credible audience at IBM. That was enough to convince Dar Howard that we were at the B-stage of leadership, and moving to the C-stage - certainly we had done some useful things, and it now appeared that we were doing a few right things. It earned us the chance to build a larger group, which in trying to validate the thesis, reshaped it sizably, and led eventually to a couple of tentative products. The HP 1601L and the HP 1645 thus were the initial salvos of Phase 1.

We could now be said to have reached the D-stage and to a degree the F-stage of the Leadership chart. By the time that we defined the HP 1600S with asynchronous latching, and the next round of equipments - ala the HP 1610 and the HP 1615 - and then we defined and codified the data domain principles, we clearly fit an E-stage leadership situation. And we were now Conscious Competents, aware of and becoming good at what we were doing.

When I drew the flow-chart, however, and as I have described the evolution in these pages so far, I was still operating at a lower level than these tables and charts might suggest. I had been viewing the HP-1601L as Phase1, the HP-1600S as Phase 2, and the HP-1610 as Phase 3. In this view, PDS systems were alien forces, something being foisted upon us against our wishes.

A different perspective occurred to me as we neared our destination airport. Actually, all of the technology and approach of the HP-1600S was virtually unchanged from the HP-1601L - to us, it seemed different because of: (a) being almost two years later, (b) new cabinetry, with connections back to true 'scopes; and (c) it was much more capable in terms of specific features. But in terms of circuit technology, user-interface, display nomenclature, and signal connections, it was essentially identical. To the customer, it was refinement, not break-through. All Phase 1.

By contrast, the HP-1610 and HP-1615 (plus the others in the family) were radically novel by comparison - new displays, new circuitry approach, new user-interface, completely new look-and-feel cabinetry, totally different signal probing methodology - everything had changed.

Thought about this way, we had just completed the entry products for Phase II, and we hadn't given much thought at all to Phase III. No one looks very far ahead if they feel behind the power curve, giving all of their attention to gaining traction in the tough environment of the moment.

So, instead of feeling depressed about not having done much with respect to Phase III, I had an opportunity to accept the proferred prize, the PDS challenge, and declare victory. Why didn't I feel victorious? Again, it came back to 'control' - I liked being in charge of creating change, and I bridled when someone else told me what to do. How much this related to long-simmering issues with my father is hard to say, but on many days, this has felt quite emotional for me.

It would be wonderful to report that this all became clear, and I objectively sat down and decided to be grateful for the guidance and support as we broadened our perspective. It didn't happen that way - once again, many sleepless nights went by, as I wrestled with myself over this conundrum. Eventually, though, I came to grips with it, agreeing that the 'right answer' to have total leadership in the *data domain* would mean to have leading-edge products for both design and analysis of systems being built with integrated circuits and microprocessor controllers. To date, Tektronix had only ventured weakly into the data domain, trying to tie it back to time domain analysis tools. Intel had done only data domain design tools for microcontroller designers, without thought of providing real-time analysis tools for a total range of IC designs. HP Logic Systems Division (we loved the acronym) would be the integrating force, the overall provider, of data domain tools, if we could master the PDS challenge.

1The HP 64000 Program Development System
HP Memory Collection

The Third Generation--PISCES

We were, however, very late to the party. And, in effect, we were almost back to A-stage leadership - no idea quite where to go or what to do to get started. All we knew was that we didn't want to copy the answers that already existed. So we began afresh - with a new visioning exercise - with a team that was firmly in the synchronous digital design world at least.

PISCES (HP Code Name for the HP 64000 Program Development System)

(PISCES = Practically Intelligent Structured Computer Emulation System or a Zodiac sign)

I was late that morning, very frustrated when traffic was tied up at the Garden of the Gods Road off-ramp from Interstate 25 in Colorado Springs. Police lights were flashing - a person on a gurney was being loaded into an ambulance. I was instantly sick - the motorcycle looked like that of George Haag, our pugnacious program manager for PISCES.

The HP logic analyzer sales team was in town for two days. We were scheduled that Monday morning - September 11, 1978 - to share the functionality, status and progress rate of our new Program Development System (PDS). Intended to compete with Intel's *Intellec* series and similar products from Motorola and others, our PDS (with the Zodiac code-name *PISCES*) was a bold step into a much more competitive, sophisticated arena than traditional HP instrumentation.

My walk along the Ottawa River with Doug Chance in October 1977 indeed presaged HP executive 'help' from Palo Alto and Cupertino, California. This new product sector purported to be a much larger and more important product contribution than logic analyzers - in a market that HP couldn't duck. The California opinion was that our Colorado Springs team was the most skilled and able to take on this challenge; they were insistent that we take the resources from our recently updated Logic Analyzer program and apply them to this code generation / emulation world of microprocessor development rather than competing more strongly against Tektronix.

George Haag, the obvious choice to lead this challenge, was fresh from leading HP's 1610A flagship for our third generation logic analyzers, with relevant design experience in two HP computer divisions. Pulling together a crackerjack team, Haag seized the opportunity to define an elegant networked computer system unlike anything within the computer industry at the time.

Six months later, HP's new CEO, John Young, taking over from founder Bill Hewlett, visited our division to review the program. We invited twenty key HP R&D leaders to solicit their advice and support. It was a fractious meeting. HP R&D divisional managers had a notorious NIH (Not Invented Here) reputation - and these visitors lived up to expectations. George and his key lieutenant, Tom Saponas, did a yeoman job of explaining, debating, and combating the various factions represented. In the aftermath, the program was validated for Young, and additional resources were granted to accelerate PISCES on a fast-track development.

During quota setting in July, rumors of this altered strategic direction befuddled the instrument sales force - unnerving them as they were grappling with how best to sell our new third-generation logic analyzer tools. They fretted - was our Logic Analyzer operation headed into computers, and if so, would sales responsibility shift to the separate computer sales force? Logic analyzer sales were up sixty-five percent for the year; no other instrumentation product line had growth even half this rate. At the same time, it had become clear that microprocessors and microcontrollers were emerging as important design elements, and this Logic Analyzer product line was their entrée into this emerging design arena. They didn't want to lose it.

At the July meeting, we invited the field sales team to Colorado Springs for two days in September, both to give them deeper training on the third generation analyzers and to assure them that PISCES would be theirs to sell. We confidently anticipated that the logic analyzer line could grow by another fifty percent in 1979, and they accepted quotas accordingly; we also told them that PISCES would be available a year later, for the 1980 quota setting timeframe.

Unfortunately, we had not made as much progress on PISCES during the summer as we had hoped, and much anxiety surrounded this Monday meeting. Getting through the tangled traffic scene, I learned to my dismay upon arrival at HP that it was George's motorcycle that I'd seen. Saponas had just talked to the hospital - George was in ICU, with critical head trauma.

Walking to the front of the room to launch this event was one of the hardest jobs I ever faced.

The group appropriately shared a quiet moment, but by the end of the day, much angst floated through the audience. They voiced their belief that we were struggling to invent an incredibly complex system, on a relatively short time schedule, and now we'd lost the charismatic, driving leader - there was no way that we could get home on schedule, if at all. The group, dispirited, broke for dinner - Tom and I meanwhile had been twice to the hospital where it was clear that George had sustained major injuries.

The next morning, things came to a head; the PDS team rallied, and Saponas stood up and took command of the meeting. He solemnly vowed that the schedule would be met - the product would introduce September 11, 1979. I was impressed by the dedication and motivation of the PDS team - everyone on the team seemed fully committed to meeting this high-profile goal.

The unorthodox definition of the product was part of the problem. This was a computer-based system, in every sense of the word. Each 'development seat' looked to a user like a big stand-alone terminal, not unlike the medium-sized terminals HP was already supplying for computer users on HP's minicomputer-based time-shared systems. The term 'work-station' was not yet used in the computing world, but it was an apt descriptor for each of these development stations. Both in terms of the internal architecture and technology, and the inherent 'stand-alone' computing power, these seats were much more like the Engineering Desktop Calculators from HP Fort Collins than 'smart terminals' available from most computer vendors.

Even more innovative, the system had no 'master controller' - it was the first peer-network system the world would see, running as a set of totally shared stations on a high-speed local area network - a very early "cloud computing" configuration. The 'secret sauce' was a shared disc drive, the first HP version of the novel Winchester disc drive invented not long before at IBM Almaden, abetted by our own logic analyzers. This architecture was a total inversion of the extant computer systems of the day, which all used a master CPU or central processing unit to control many data-entry terminals, with several disc drives for lots of data storage. Our design, with no CPU, used one disc drive to synchronize the set of powerful terminals (Figure 9).

Competing PDS systems used a very simple architecture by comparison, where each developer had a full CPU-like terminal with its own on-board floppy disc drive. No connection existed to other developer seats; each developer worked independently on their own code. Synchronization was a tedious, manual process after code development of a segment was complete. Floppy drives, while cheaper than a Winchester drive, lacked memory size and speed.

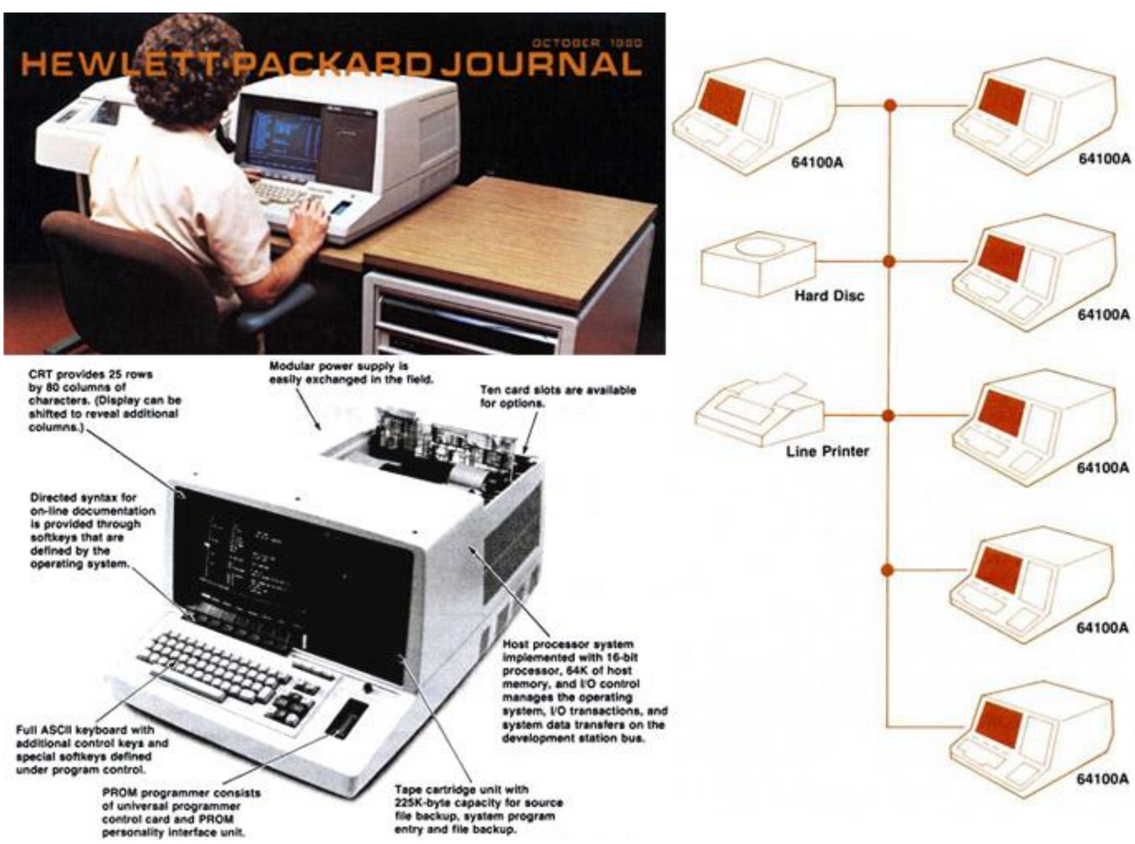


Figure 9. HP 64000S Program Development System (PDS)

Additionally, borrowing heavily from other HP divisions which built computer peripherals, PISCES was designed to be 'plug-compatible' with many devices - other disc drives if more memory was needed, printers, and remote displays, along with computer diagnostics and disc-resident maintenance manuals. No other PDS vendor allowed this type of resource sharing.

Thus, our system was designed from the beginning for development teams, rather than individual developers - teams writing hundreds of thousands of lines of embedded code. It arrived coincident with the shift from eight-bit microprocessors most useful for small tasks such as gas pump controllers and grocery store checkout 'cash registers' to the new sixteen-bit micros that were emerging for true computer-like tasks - including soon-to-emerge personal computers, although none of us appreciated just yet how revolutionary those PCs would become.

Moreover, PISCES was designed for engineers rather than computer programmers. "Guided syntax soft keys" allowed easy construction of commands in engineering terms, providing a significantly faster learning curve for designers new to microprocessors. This functionality, and a large-screen display for the developer, allowed much more rapid development of code bases.

The *coup de grace* was that the machine featured 'universal emulation' which meant that a developer could develop microcode for a microprocessor from one vendor, and then *cross-target* it so that it could run on a different microprocessor from another vendor. This feature, universally praised by developers, was despised by the microprocessor vendors. Until PISCES, microprocessor vendors built PDS systems dedicated only to their own chips. If you wrote code on an Intel *Intellec*, that code only ran on an Intel microprocessor. Motorola, AMD, and Zilog built their own PDS systems - all fractious and non-standard.

We painfully learned many lessons. One key finding: disc drives of that era were not very reliable, so two coping strategies existed. One was 'consistent back-up' so that data would be preserved if a head crash occurred; the other used multiple discs to provide data redundancy. Our system, using just one disc per system, inverted the failure risk factor. It was an architectural marvel - getting a much higher speed, larger memory system with synchronized code-streams from multiple developers, but it made the integrity of the whole system dependent on the least reliable component. Fortunately, Winchester disc drive failure rates improved substantially; we lucked out rather than really understood this nuance.

In order to create PISCES, our team took advantage of an historic HP strength. HP had a wildly decentralized divisional organization, a legacy of Hewlett's belief that contribution, creativity, and market success were dependent on small nimble teams unhampered by corporate strategic plans and rules. A big part of Hewlett's genius for this decentralized organization was a long-standing culture of sharing technology between divisions. If you knew that someone in another division had a device, a component, or a process that could help you, you could ask for their help - and it was expected that they would grant it. Parts in production could be transferred at factory cost to be used in your new design, and products under development might even be done jointly, if both parties agreed. And for the most part, they did agree.

This collegial concept dated back over twenty years, to the first divisions created in the late 1950's; it worked well as the corporation spawned new divisions, usually in remote geographies.
'Groups' had emerged to cluster the rapid proliferation of divisions, as the company entered new markets - so by 1978 there were groups for Electronic, Medical, and Chemical Instruments, plus Devices, and Computing Systems. As groups emerged, rules changed somewhat - you were collegial within your own group, but maybe not so much with other groups. No division 'crossed the boundaries' between groups to link unrelated technologies. No one explained this shift in rules; importantly, this situation hadn't been tested very hard since pertinent technologies were increasingly differentiated

between groups. Until PISCES. To meet our aggressive development schedule, we sought to borrow rather than invent wherever possible.

George Haag and Tom Saponas had each spent several years in computer divisions, so they knew many designers and technologies well. Moreover, the computer divisions knew our logic analyzer products well - they were the chief users of such tools. The PISCES team borrowed technology, components, and processes from fourteen divisions around the company - not always smoothly. In particular, we became a thorn in the side of the disc drive division. At first we thought this due to our stiff requirement for a reliable Winchester drive, but when our volume requirements appeared to tax their own plans, they became concerned about profit margins, delivery schedules, and logistical issues. The collegiality capsized.

After several frustrating meetings in Boise, Idaho, we decided to build disc drives ourselves - the hell with them! This, while not expressly ruled out by HP's lax business organization, was confrontive, earning us interviews in Palo Alto to discuss just what we were trying to do, and why 'we weren't able to get along' with our sister division. I was incensed - the problem was them, not us. Here was a division deciding to disbar another from buying its products, and then asking that the other be precluded from finding alternatives. Much discussion ensued; they grudgingly agreed to sell us drives to our requirements - we agreed to drop our plans to compete.

Our PISCES team had burgeoned, by now comprising most of the Logic Analyzer R&D operations, which meant that new Logic Analyzer product design took a three year hiatus. Sales did grow by another fifty percent in fiscal 1979, but Tektronix's new Digital Analysis System in 1980 would shortly blunt our sales growth. This was a major mistake - you never abandon a hard-fought win just as the momentum builds. But - we did. The philosophy that allowed this error was also a legacy of Hewlett's decentralization belief - that each division can autonomously choose its R&D programs. Thus, even though Palo Alto management forced us to get into the PDS arena, we weren't able to persuade our own group management to use R&D funds from stodgier analog instrumentation lines to keep logic analyzer R&D momentum.

My response was to try to find help from some of HP's international divisions. HP had expanded overseas early in its corporate history, with operations in Germany, Japan, and England. Those operations all sought to replicate HP's classic division model of autonomous R&D teams and product lines. When Dar Howard restructured the Colorado Springs lab to accommodate the digital 'scope ideas in 1970, he had offered segments of his lab to these teams. Germany had seized the bait for both low-frequency 'scopes and pulse generators; Japan had done the same for sampling oscilloscopes.

Three of us - product marketing manager Don Wilkins, hawking the new microprocessor-based HP 1722A, me with the HP 1600S, and the Colorado Springs Quality Assurance manager, Ron Given, had spent a product launch week in northern Europe in spring 1975. It was a heady time for my wife and I - neither of us had traveled to Europe previously, and it was stimulating for widening my perspective. I was pleasantly surprised by how many designers and technicians spoke English, but in common with many American travelers, I also found that spending some time trying to communicate in their tongue, and showing interest and some prior knowledge about local history and culture worked wonders to build collegiality.

Selling the International Divisions

In early 1978, I took our Logic Analyzer executives - Chuck Gustafson (R&D), Erik Lessing (Marketing), and Jeff Kalin (Manufacturing) - to Germany for the purpose of asking them to manufacture, sell, and even co-develop logic analyzers, since the PISCES program occupied us. The Germans were receptive. Looking back now, it is hard to explain why I felt I had the power to make such a request, let alone agree to move part of the program. In corporations today, such moves would have to be proposed, vetted, and approved by a long chain of managers and committees - in HP then, you just took the initiative. 'Local folk' either praised it or said "no."

In December, 1978, I took a similar trip to Asia with product marketing manager Norm Hall. The goal here was two-fold: first, to get HP's partner, Y/HP, more excited about the Logic Analyzer products, and second, to stimulate interest in other countries such as Korea, Taiwan, and even India. Though familiar with Europe, I was scarcely prepared for the masses of Asia, especially the poverty so evident in India. Characters seemed illegible, faces were inscrutable, mannerisms less understood. We took a short orientation / protocol course that helped a bit.

I needn't have worried. Norm Hall had pre-arranged the trip in such a way that everywhere I was feted as 'America's Engineer of the Year', playing off the year-old *Electronics* cover story, and the fact that I had just been elected to the IEEE *Spectrum* Board, IEEE's leading magazine. In each country, our hosts found the local 'Engineer of the Year', whether named by their IEEE chapter, some magazine, or whatever means. And that led inevitably to a 'state dinner' of sorts, with English as the *lingua franca* and logic analyzers a favorite topical issue. It was alternately heady and intimidating - the latter especially when a local favorite food specialty was prepared. I was always served first, which wasn't as big a treat as one might think. For example, we had whale blubber and *fugu*, the well-known poisonous puffer fish, in Japan. In Taipei, I was invited to pluck a fresh eyeball from a flopping flounder at the table. In Hyderabad, India, I almost became ill when a monkey was beheaded and I was offered the warm brains as a delicacy.

Admittedly, we had our hands full with PISCES. The magic date of September 11, 1979 was fast approaching - and the sales team was certain that we would not fulfill our promise. George Haag, surviving his horrific accident, entered a long rehabilitation program. Saponas, along with Chuck Gustafson and Mike Davis, supplied superb leadership. As we neared the deadline, we were able to cobble together enough of a system to announce it to the world.

Our goal was to introduce PISCES in grand fashion. We announced simultaneously in Japan, Europe, and America - a feat never before tried by HP. Saponas and I launched at a major press conference in Paris, while Gustafson and our product marketing maven John Marshall did so simultaneously in Munich, Germany. We held press conferences in New York and Palo Alto the same day, as well as in Tokyo Product marketing manager John Marshall would later tally that we got fifty-seven magazine and newspaper stories around the globe that week!

The introduction was a bit premature, in the sense that our 'universal emulation' capability only had one microprocessor target available at launch. But within a year, PISCES - now called the HP 64000S - had targeted most of the major microprocessors of the day, and sales were brisk. Which brought about the next problem - how to service and support these equipments, quite unlike anything our instrument sales force and service technicians understood.

Service required both the instrument and the computer support teams. Servicing printers, for example, or disc drives, was an unknown for the instrument group and yet these products were fundamental to PISCES system performance. And the computer service teams had no comprehension about logic analyzers or emulators, or even the smart terminals that we were supplying. So it took a melding of the strengths of each to satisfy customers. Unfortunately, this became a bit of a political nightmare, since we were proposing to build a 'merged team' across two increasingly separated groups within the larger Hewlett-Packard.

A bigger surprise awaited, which surfaced as we started getting field failures. Our system was failing at prodigious rates compared to historic instruments of the company - rates three to four times higher than anything in anyone's memory. When we'd talk to the computer divisions, though, PISCES failure rates were two, three or even four times better than anything they knew about - mostly due to our more conservative instrument design approaches with components.

My bosses, both at the division and the group level, barked, "What the hell is going on?" The answer was that each group had evolved - from a common history of acceptable failure rates in the 1960s, the computer group found that speed of development was far more important than quality in order to compete. Their failure rates crept up, and in some places even leapt up. But they consistently produced the highest quality computer equipment in the industry nonetheless. Within a decade, the computer group average failure rate was more than ten times worse than that of the instrument group - unnoticed by anyone in corporate, or by customers.

But now we had joined the two in an unholy alliance - and we were simultaneously the worst instruments ever produced by HP, and the best computer systems ever built. I now had three problems. First, the computer group divisions were sore at us for exposing their crappy quality, and bringing them into the corporate spotlight. Second, my bosses were in the instrument group, and so was my sales force. And they were beyond upset with our flawed PISCES system. If your sales team is sore at you, this is not good; if your bosses chime in, that can be even worse. Third, we had chosen an architecture - the expensive shared disc drive - that put the weakest quality link at the heart of the system. And when this failed, a whole team of developers were stranded. Some of our customers were incensed when this situation happened to them.

Engineers are trained to believe that there is indeed a 'best solution' for every problem; other disciplines - philosophy, political science, or business school - teach about dilemmas and compromise. Unwittingly, we had exposed a dilemma in HP's historic organizational model - how do you bridge two autonomous groups when they have each pursued appropriate goals with classic HP values, and arrived at fundamentally dichotomous value propositions? I scarcely perceived at the time that this challenge would soon pre-occupy the next phase of my career.

Break-throughs versus Incrementalism—Lessons Learned

All of the problems described above were largely internal issues - the external world presented its own set of challenges. When Palo Alto management tasked us with the goal of producing a PDS in short order, we began a systematic assessment of our erstwhile competition. For the meeting in autumn 1978, we'd compiled a list of more than thirty competitors who had announced product. Twenty had delivered machines, and eight were outspending us. I decided that it'd be worth understanding who was managing those eight companies, and we put together a list of names for the top four managers (president or general manager, and three vice-presidents or equivalent for engineering, marketing, and manufacturing) for those eight. The forty-third company to announce a PDS, we were really late in a crowded field.

Tektronix, upon learning that HP planned to enter the PDS market, rushed a "poor man's development system" to market, essentially copying the first generation *Intellec* approach. This enabled them to beat us to market by a year, and their brand name gave them beginning impetus. Unfortunately for Tek, their solution didn't scale to larger code generation requirements of the newer sixteen-bit microprocessor chips. Nor did most of the other competitors.

At the end of our first year of sales, we had 7% of the PDS market, Tektronix had 10%, and Intel had 47%. Within another year, we passed Tektronix, and, except for Intel, trounced the rest - many folded their operations within that year. HP became the "universal emulator" company; the other semiconductor companies approached us to build an emulator for their current best microprocessor, giving designers a choice to cross-target, avoiding the "Intel lock".

Four years later (1984), Intel marketshare had 'shrunk' to 34%, HP was now 21%, firmly in second place, and Tektronix still had 10%. Tek's revenue peaked at $63 million that year. Intel also peaked that year, at $205 million; the 1985 memory chip crisis for Intel was nearly catastrophic. Surprisingly, HP's PDS program surpassed Intel in 1986, with 25% total share.

How successful was our program? Measured in terms of revenues and profits, quite so. It was a rollicking ride. Figure 10 shows revenue evolution of the first fifteen years of this field, a period that cumulatively amassed over four billion in PDS sales. The five years from 1981-1985, the peak competitive years, had sixty percent ($2.4 billion) of those sales.

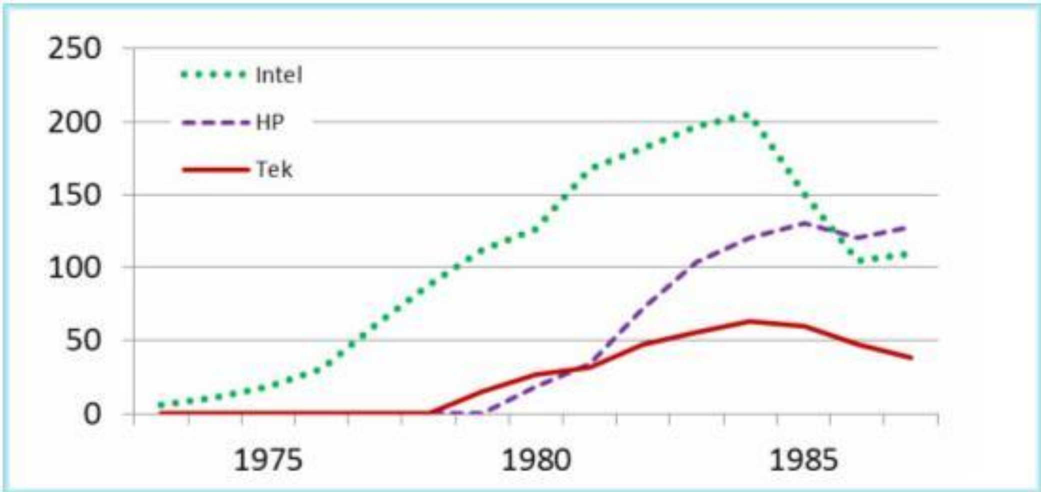


Figure 10. PDS Revenues ($ millions/year)

Intel, with cumulative sales of $1.6 billion by 1987, had clearly defined the category, and used it to superb advantage to sell microprocessor chips. It is hard to imagine today, but in 1981 - the first serious year for HP's PDS in the marketplace - the *Intellec* was twenty-two percent of Intel's sales, and more than two hundred percent of their profits. At Intel, there were serious discussions about whether Intel should go into the equipment business, but HP and Tektronix entrees by 1982 were blunting both the growth and enthusiasm at Intel for this product sector.

But factoring in the lost momentum for Logic Analyzers, it was a painful experience. I was wedded, emotionally and philosophically, to the logic line. We'd introduced our first Logic State Analyzer in 1973, contemporaneous with the first Intel PDS system. Singlehandedly. we'd defined the sharp distinction between *logic timing* and *logic state* analyzers.

HP's pioneering Logic Analyzer line cumulatively sold $150 million, besting our old nemesis Tektronix ($99 million) in the first seven years, through the end of 1980. Those were satisfying years, especially given the doormat status that our 'scopes always suffered (Fig. 11).

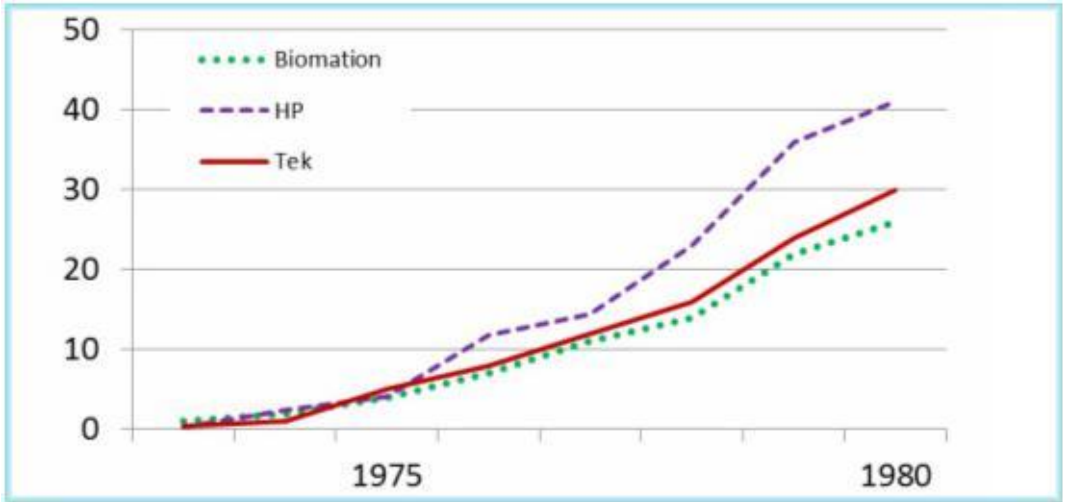


Figure 11. Logic Analyzer sales (Biomation, HP, and Tektronix) 1972-1980

We weren't yet familiar with the concept of 'opportunity costs', but events surrounding the choice to shift R&D resources from Logic to the PDS program would demonstrate it beautifully. Tektronix, by deciding to build a "me too" offering for the PDS market, kept the heat on for logic analyzers. Affirming my fears, HP's next five years of logic analyzer sales flattened - in fact, they dropped for several years as Tek's new products took a toll. Once momentum is lost, it is very hard to regain. This was one of the key learnings of the period, and a hard pill to swallow for the HP Colorado Springs team. It would be four years before significant R&D resources were again applied to Logic Analyzers; HP didn't regain the leadership mantle for eight years.

Interestingly, by the time that HP caught Tektronix in Logic Analyzers, the PDS business was ebbing away. Even though forty competitors announced, within five years of entering, Biomation disappeared, and within ten years, Tektronix pulled the plug. HP stayed in for twenty, outlasting even Intel, but it was a relatively brief, if exciting, product arena.

Figure 12 illustrates thirty-three years of sales fortunes ($M/year) of the three key Logic Analyzer vendors - Biomation, Tek, and HP. Intel never produced or sold logic analyzers.

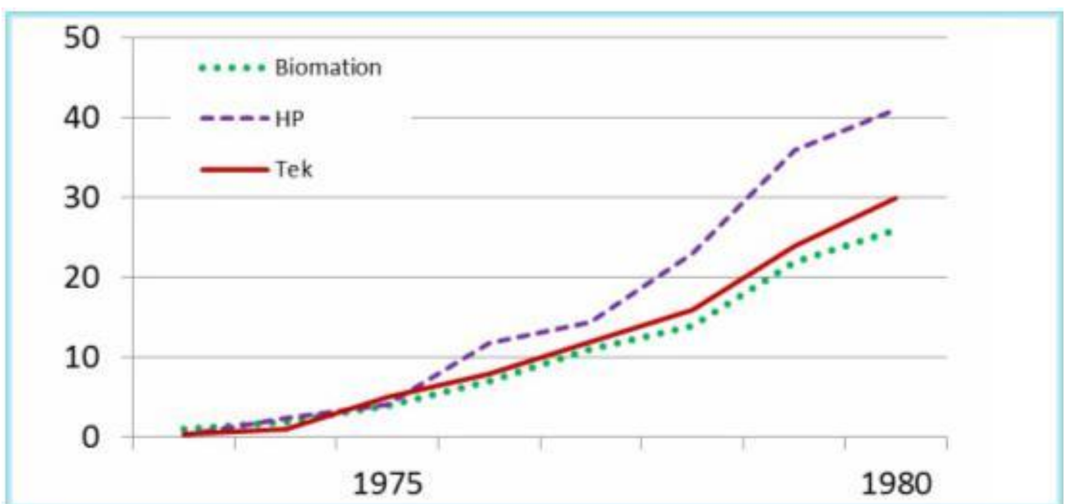


Figure 12. **Logic Analyzer sales 1973-2005**

Several clear decision points stand out in Figure 12 Biomation, the original logic timing pioneer, competed successfully for a decade, before enduring a decade-long slow decline. Tektronix, with a strong merged 'scope/logic timing/logic state analyzer (DAS 9100) debuting in 1981, was able to double sales in four years, asserting domain leadership. A bold logic state/timing analyzer, the HP 16500A, answered the charge in 1988 with a significantly improved user interface, high performance, and attractive pricing. This product family doubled HP sales overnight, and cut Tek sales in half as they enduring revenue slide for a decade.

The early 1990's revealed an interesting pattern - both Tek and HP enjoyed healthy growth, each growing more than sixty percent during a period when many more microcontroller designs emerged for both consumer and industrial markets. In effect, the *data domain* revolution - from an analysis standpoint - had to await the demise of PDS systems before classical analytic tools were widely adopted. The final chapter - Tek overtaking Agilent in 2002 - resulted from the disruptive activities at Agilent after the defocusing divestiture from HP.

All told, Hewlett-Packard and its spin-out test company, Agilent, have sold nearly five billion dollars of data domain equipment, which in turn have fueled incredible designs of almost every digital electronic product that our society uses. Intel *Intellecs* sold $2.3 billion - but despite what textbooks say about 'first mover advantage' HP was able to surmount the early Intel lead, not to mention all of the other forty competitors. Overall, HP managed to hold and extend its lead over its traditional foe in data domain tools versus Tektronix's long hegemony in oscilloscopes.

What happened to the leadership for this PDS arena? Forty entrees is a lot of competition. Statistics about such a group are seldom collected - it is quite rare that anyone would assemble them. Because I felt like a 'fish out of water' at the time, I'd compiled a list of the leaders at the eight top companies, plus our own team. When I left the Logic program in the spring of 1982, moving to a 'corporate job' in Palo Alto, I found the original list that I'd composed in the spring of 1978. It was an interesting quest to find out 'what happened' to this group of managers.

Of the top four managers for the top nine PDS companies, after two years of PISCES sales, an astounding thirty-one of thirty-six original managers (including ours) had lost their jobs. Several (five) were promoted; one became a multi-millionaire. All lived, though one died of a heart attack a year later. Seventeen lost their wives, a stunning and deeply troubling statistic.

For a number of years, I would tell audiences that such sociology was typical of companies who got caught up in the Silicon Valley feeding frenzy, abetted by too much venture capital and too little time for analysis. And I'd observe that entering a field in a 23^{rd} or 43^{rd} position wasn't a very good idea, in terms of putting a marriage 'at risk'. Later, I've come to realize that it doesn't really matter whether your group is first or 43^{rd}, it will essentially be a brutal competitive tussle for the leadership at every one of these companies.

Yes, it is easier to prevail in a top position if you're among the 'first movers' but it is inescapable that if the venture world considers this field to be able to 'coin money', investment funds will flow for many competitors. Such investments necessarily drive a mind-numbing pace and momentum for virtually all competitors. This clearly is one of those situations akin to what President Harry Truman said: "if you can't stand the heat, get out of the kitchen."

Many studies in recent years have averred that ready access to venture capital fuels Silicon Valley innovation and leadership; this case history reveals a different pattern. Yes, Biomation was a Silicon Valley start-up, funded by angels more than venture capitalists, but Tektronix was a Portland, Oregon company, and HP's operation was in Colorado Springs. Motorola had a sizable group, in Austin, Texas, and Intel's team was half in Silicon Valley, half near Portland. Virtually all of these were funded by corporate investment rather than start-up VC monies, and almost without exception they were not really Silicon Valley companies or divisions. It is true that many of the other forty companies were fashioned by venture capital seed money; it is likewise true that none of them survived. So, this was in effect just solid corporate renewal.

Whether innovation occurs because of opportunity, funding agents, or inspired thought, one thing that stands out in these cases is the fact that no program stands in isolation. These are competitive scenes that have a context, a historical cast, and a feeling that these are marathons rather than sprint races. Nonetheless, each individual project will feel "stand-alone" to the team working on it. Figure 13 portrays an investment scenario (R&D, manufacturing tooling, and market research plus product launch material), and sales revenue on a timeline. The intrapreneur task is to shorten the time and investment 'burn rate' between ***t -½*** and ***t 1 ½*** while lengthening ***t 1*** to ***t 6*** and raising the mature sales rate.

Building on the Strategic Cycle concepts of Figure 8, Figure 13 illustrates successive development phases. In order to build sales momentum, a second product set must be available for sale not long after sales for the first product set mature. Thus, between ***t 2*** and ***t 3*** , a new program needs to be introduced.

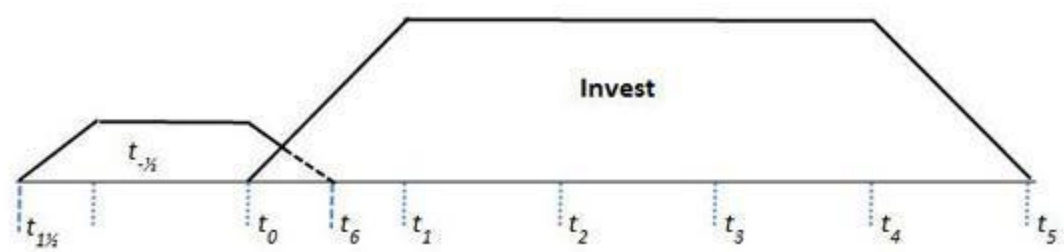


Figure 13. Investment timing and rates for one Product Cycle

Assume for the moment that R&D time will be roughly constant. This means that concept planning and R&D for the second generation (Phase 2) has to start long before the Phase 1 products are introduced. Ditto for Phase 3, where R&D for the third phase must start at the same time Phase 1 goes to market. For relatively slow-moving markets, these requirements are tough enough - for dynamic technologies, they can be daunting indeed.

Figure 14 can be interpreted several ways. Successive phases might be no more than 'line rounding' - relatively simple modifications or additions to an existing technology base - or they might be significant redefinitions of the extant technology or functionality. If the former, the presumption is that continual fast refinement is adequate to remain competitive, whereas the latter is more appropriate where market evolution is fast-paced and requirements are fluid.

Either way, the closely coupled investment requirements are not intuitive to most managers, since the challenges of today's issues often feel quite full-time, precluding any sense of ability to view today's programs in a larger time-context. In my experience, the need to begin investments for tomorrow's phases and even phases for the day after tomorrow determines a group's eventual ability to lead a market. Perhaps the toughest challenge that the intrapreneur faces is to illumine this requirement for nested successive investments to his or her management team.

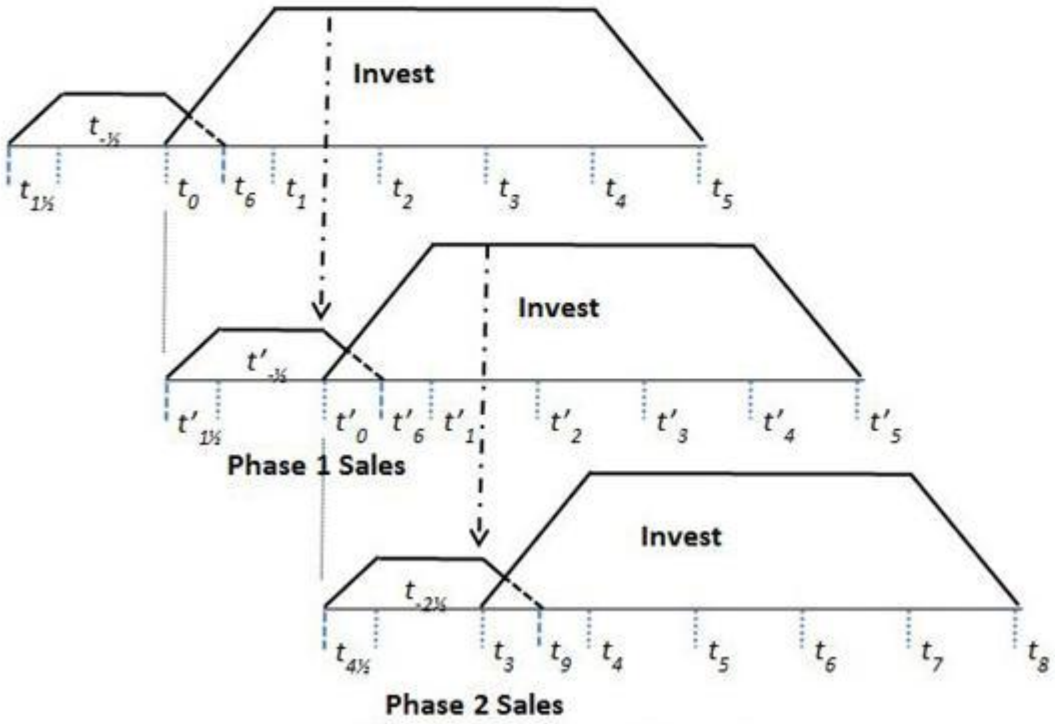


Figure 14. Timing cycles for the Strategic Cycle

The difference in the two approaches - breakthrough vs. refinement - can be shown with two parallel programs in the oscilloscope division during the 1970's.

(a) HP 1700A (1971) (b) HP 1722A (1974) (c) HP 1740A (1975)

Figure 15. **Evolution of HP's Portable Oscilloscope line**

Figure 15 shows evolution from the HP 1700 portable 'scope, HP's first entrée into mobile 'scopes for field support on computer systems, to the HP 1722 portable 'scope with digital readouts, to the substantially higher quality, lower cost HP 1740 that combined some digital and analog measurements. All look similar, and they clearly use similar technology.

By contrast, Figure 16 shows three phases of *data domain* products from the Logic Analyzer team in the same HP Colorado Springs 'scope division. Each family looks substantially different and they obviously are based on rapidly evolving technologies. Competitors late to the party would have (and did have) a hard time matching these evolutionary leaps.

Figure 16. **Evolution of HP's Logic Analyzer line**

SEVEN RULES

The stories described herein represent a wandering personal odyssey. There were no books or coaching, nor courses to take in school. I was fortunate to work for Hewlett-Packard, a company led by two engineers whose instincts were to create, to innovate, and to base those innovations on contribution to the customer. Their intuition led them to fashion unique guidelines, 'rules' which insisted that designers, indeed employees in every level and function of the company, innovate. Without knowing the word *intrapreneur*, they asked each of us to be one.

Here's an HP recruiting advertisement from *Electronics* magazine, October, 2, 1967:

> *"The one catch in having a bright idea at Hewlett-Packard . . . you may be the one who has to make it work. If you're an ivory tower engineer who'd prefer to turn your bright idea over to someone else and hope for the best, Hewlett-Packard may not be the place for you. If, on the other hand, you thrive on the chance to learn and work in all areas of operation, and the opportunity to follow your concept through every stage from research to marketing, then we believe you will prosper at Hewlett-Packard.*
> *Here you'll find opportunity to exercise your own initiative and judgment; freedom from chains of command; the challenge of 'sticking your neck out' when you have something to contribute; and a chance to become totally involved in your project."*

How could you not learn that contribution was expected of you? As I traveled this path, some supportive 'rules' emerged. Much later, I appreciated just how empowering and unique these ideas and concepts still are for modern corporations. They are an *Intrapreneur's Rulebook.*

The seven rules describe important leadership choices by which an intrapreneur operates - heavy emphasis rests on rapid-fire exploratory activity, always testing a thesis on a desired audience, perpetually asking "why" of your team, clients, and company approach. But more fundamentally, the rules require a clear focus on the goal - the contribution to be made - and on specific things that are crucial to success: using your team, honoring your supporters, knowing the territory deeply, very thoroughly, in terms of features, needs, and competition.

Table 1-3
The Intrapreneur's Rulebook

Intrapreneur's Rulebook

1. Make a contribution
2. Do your own market research
3. Know your competitors
4. Ask "why" – all the time
5. Iterate like crazy
6. Use your team

Since intrapreneurs reside inside a corporation with abundant resources all about compared to an entrepreneurial start-up, they have a decided advantage of being able to tap the best ideas, brainpower and creativity of multiple people - if they will only do so. But to some degree, this requires skill that intrapreneurs and entrepreneurs sometimes lack.

To really empower other folk, you have to allow them space and time to make their own mistakes, learn their own lessons, but especially to imbue their own passion into the tasks at hand. Similarly with your bosses, many of whom will seem recalcitrant, unenthusiastic, or downright hostile to some or many of your best ideas. The secret is to bring them along, to empower them to become part of the success rather than fight them at every turn. These two capabilities - constructing and leading a true team, and encouraging and in effect creating supportive bosses - are well outside the normative prescriptions for 'how intrapreneurs operate'.

There is this pernicious belief that intrapreneurs must be combative, fighting for what should be obvious but isn't, daring the company to fire them almost with regularity. Yes, those elements go with the territory, but only episodically. There will be no long-term success if these fundamental teamwork ingredients are missing. Let's take each rule in turn, and examine it in light of the case studies presented to date:

1. Make a Contribution

HP designers used the phrase "Smaller, Faster, Cheaper, Lighter" to connote the classic improvement categories. But the distinctions usually were that it had to be significantly so - ten times improvement rather than ten percent incremental gain. One thousand percent requires thinking about the problem and its possible solution in very different terms than ten, twenty or even thirty percent improvement. A thousand percent? Re-think, restructure the entire problem.

To be sure, not every project did a thousand percent increase, but the idea fundamentally was to make a dramatic, unexpected contribution - easily a 'game-changer' which could then be followed by a rapid succession of refinements. The set might be composed perhaps of something that was a four-to-one improvement, followed by three thirty percenters. This, taken together over four quick-succession projects, would yield nearly a thousand percent improvement - essentially without heroics once the initial breakthrough project was defined.

Such a cluster of projects could be thought of as a Phase in Figure 2-8. For the Logic team, the first Phase was the HP 1601L, followed by the 1600A, 1607A, and 1600S. These four projects, for example, changed the parallel channel tracking from two to twelve, then sixteen, and finally thirty-two while simultaneously changing memory depth from one to sixteen to two hundred fifty-six. All this, plus numerous indexing features and other contributions - each one with the same technology thrust, essentially as one Phase, completed in less than two years.

Phase II was the microprocessor-based suite of products, starting with the HP 1611A, then the 1610A, followed by the 1615A, 1602A and 1640A. With expanded channel count, memory depth, and 'look-and-feel,' the really important contributions were different: on-board calculation, displays in higher-level coded form including mnemonics, ASCII characters, and embedded logic state and timing diagrams. The first of this group was marketed twenty-two months after the last Phase I project; the suite took twenty-seven months for four key projects.

Clearly the original X-Y display was a breakthrough contribution, as were the follow-on projects in both the industrial control market and the medical monitoring arenas. So, as specific projects, these all met the test.

The biggest challenge, in retrospect, was the PDS business. All of the others were inventions, differentiated by the fact that no company was building anything remotely like them. The PDS business, on the other hand, was characterized by a slew of competitors - forty of them announced by the time we decided to enter that warzone. How do you define 'contribution' in that space? And if you don't define a breakthrough contribution, how will you possibly be noticed, let alone prevail? The facts speak for themselves - we really did in fact deliver major new contributions, and we did 'win' in the marketplace with them. How, you might fairly ask, was that done? And that, of course, leads to the next several rules.

2. Do Your Own Market Research

As I drove to the airport in Albuquerque with the only extant demonstration X-Y Display box in the world, I mused about the irony of the excitement at the customer site versus the tepid view at my home division. By the time the trip was complete, more than twenty enthusiasts surfaced; I was primed and ready to conquer! I probably should have told someone more forcefully back home, because the marketing department almost scuttled the project when David Packard came by for a project review.

I learned from that one. And I made sure for the *d'wuck* tour that several people went, and that we got an audience back home. And when the digital 'scope team was assembled, my belief was that each of the designers needed to get 'infected' with customer religion. In terms of passion for what we were embarking on, it paid handsome dividends. You name it - in terms of knowledge, perspective, and desire - the trips built engagement, enthusiasm, and judgment.

When tough questions surfaced, such as the asynchronous trigger issue, we could turn again to our 'customers' and do on-the-ground market research. Very efficient and very accurate. Why more designers don't 'go ask' is beyond me, frankly. Same holds true for CEO's, I think.

The PISCES program coalesced our perspective. Here, a presumptive answer existed in the marketplace - was it good enough? Our team, by now practiced in market 'sleuthing' found that the parameters had in fact changed since the current equipments had been defined. The problem had morphed - into a tougher, more systems-oriented team requirement.

Our team, within limits, had design strengths to step up to a much more complicated solution than anything we'd ever done, or anything available from competitors. More importantly, we had access to superb computer subsystem components from other HP divisions, so if we could 'team-play', we had deep reserves upon which to draw. But because it was a different 'reading' of the marketplace, the naysayers lined up - "too expensive, too late to market, too grand, too much software overhead, etc..." Naysayers often have a lot of fun at these parties.

Through all of this political fog, abetted by the fact that we'd been ordered into this space instead of us being in charge of our own destiny, the meaningful constant was the voice of the intended customer. Know that voice, hear it clearly, and you cannot go too far wrong.

3. Know your Competitors

This is a tricky point to make, because you have to do it ethically - I'm not talking about how to hire pretexting specialists or spies, but intelligence gathering of a very different kind. First of all, you should know your true competitors. The fact that we misunderstood the PDS impact for several years is mute testimony to the blinders we wore in that respect re the data domain. We, after all, had defined the domain - "what do you mean, we don't know the key players?" But, factually, we only understood our corner of the data domain world. Big problem!

How to know your competitor? You cannot really call and invite them to lunch, can you? For one thing, there are legal sanctions about collusion with intent to price-fix or otherwise do nefarious things, and who's to know what you talk about in a clandestine meeting. For another, most competitors, upon receiving such an invitation, would say "no" or something more pithy.

So how did I get to meet the Tektronix folk? For Next Gen, it was at a public Trade Show. For the logic analyzer discussions, I was in 'their town' for personal reasons, and they sought me out - I don't know to this day whether they were trying to 'pump' me for competitive G-2 or if instead it was just top designers discussing issues that none of us understood very well. It felt more like a professional society meeting - an IEEE or ACM meeting - which of course is a great way for designers to get together legally, to debate current issues in front of an audience. For all of the PISCES competitors, it was either attending and participating in panels at IEEE meetings or actually being beseeched by several companies to have us include their capability in our new, more generalized approach so that they could concentrate on making chips rather than tools for designers to be able to program their chips. Tools thus were a means to an end, and they were (or at least some managers at their company were) willing to open up with us. By the way, be of no mind that there will be multiple meetings with such folk - it is imperative to use any chance meeting as a great opportunity to learn all that you can about 'the other guy.'

4. Ask "why" all the time

Everyone is familiar with the four-year-old child who constantly asks, "Why?" If you answer, "Well, that is because...", the quick comeback is the same question: "Why?" Such behavior, oft thought cute in children, becomes maddening behavior in business, especially for managers. But for the creative team, the intrapreneuring team, this question needs to be constantly refreshed. New paradigms are unknown, unmapped, with barely discernable patterns. "Why?" matters.

5. Iterate like crazy

Precisely because asking "Why?" yields multiple answers, it makes sense to build multiple prototypes to test those wide-ranging possible answers. Some will stick, many will not. Those that stick will evolve or morph into something different still; market testing will warp features and even functionality. The speed of evolution is the key here. The game is not to get the first product right so much as it is to get the first product shipped; then, fast turn-around to the next product is much more valuable than extra time to get the definition 'right'.

For engineers, who constantly love tinkering, this might seem an easy point. But engineers like to tinker upfront, to iterate the specifications before completing a prototype rather than buttoning it up and shipping the erstwhile product to a real customer. The process I found much more effective was to imagine that the shipped products - versions 1, 2, 3 and so forth - were the tinkering experiments. And that, for perfectionist engineers, is psychologically a struggle. But I would urge you - iterate like crazy, with products 'on the market', or at least, 'out of your lab'.

6. Use your team

Teams come in many sizes - and they may or may not be collocated. For the X-Y Displays, our team was quite small, but each member contributed heavily to the definitions, possible users, and specific skills and tasks. For the *d'wuck* , different members of the small team contributed features - features that the next team, the digital 'scope team, spent time validating and refining, before dismissing some ideas and pursuing new ones. As the various logic products were first introduced, the learning from each experiment informed the group for the next set of definitions.

Until Phase II of Logic Analyzers, our 'team' was our local team. But in discovering that we needed to educate the HP sales force and some key faculty at universities teaching logic concepts, we began to understand the idea of 'extended teams'. Building a working team requires several things - a shared goal is imperative, and balanced rewards are important. But we found that mutual trust was perhaps the most important element - trust that every member will be respected, nurtured, and valued. Such a phrase is easy to write, and easy to say. It is profoundly difficult when things aren't going well and stress levels are rising - which is precisely when it is most crucial to maintain trust.

PISCES presented special challenge for our notion of teamwork. For the logic lines, it was relatively easy to establish collegial relationships between us and the sales force - they were paid well if they could sell our products. Ditto for the university professors - their co-operation was rewarded with equipment grants. For PISCES, the major reward for collaborators at other HP divisions was psychic - Hewlett's personal legacy with the company was an expectation that any group would help another when it was possible to do so, but there were no monetary or direct rewards for being a good corporate citizen.

Thus, our requests - especially for modifications to some key technical material - were above and beyond the normal call of co-operative teamwork, especially because we had no 'tradebait' of consequence for any of them. Relationship management - teamwork supported by friendship and shared 'higher-level' psychic reward 'for the good of HP' - was the only rationale available. Teamwork built on such threads can work in a strongly collegial culture; these bonds become tenuous as people move around or leave the company, or the personal touch becomes infrequent as the company grows larger. Groups that have learned to develop and maintain such ties for key partnerships enjoy much better productivity and effectiveness as a rule - but often the root reasons, which themselves take time and effort, are obscured from management understanding.

7. Honor your bosses

This often gets stated - particularly in Intrapreneurship courses - as "honor your sponsors". Which in itself is both appropriate and affirming. Many intrapreneur sponsors have had to 'go out on a limb' to back an unpopular idea and/or person - counsel to honor them is well-placed, and this rule can be interpreted to include them. But here I am trying to get at something deeper, to get at the core sometimes of the real problem - honoring your most active opposition, almost precisely if they are your bosses. Find ways to understand their concerns - treat this as a market research question: "what would it take to have them understand and support you?"

The best example to illustrate this was the conclusion that we had to create a workshop to teach the Colorado Springs executive team about microprocessors and the needed measurements in order to fund our Phase 2 program. The course was revealing to them in a relatively objective manner, giving them personal insight into the design issues of these new chips, and the value of our programmatic solutions. They still had lots of resource constraints, and some personal prejudices to boot, but the ambiguity or even obscurity of what we were trying to accomplish had been stripped away. Future discussions had the characteristic of reasoned negotiations rather than dictatorial fiats. In short, by honoring our bosses' comprehension needs, we reduced antagonism greatly and moved toward support.

A second example, more profound in some ways, was honoring the Palo Alto leadership who had forced us to go into the Product Development System business. They were not high on our list of favorite folk, and we had spent considerable time debating how to bring our own brand of insouciance to the table with the bold PISCES definitions, so the requested review augured to be acrimonious. The solution - to honor our Palo Alto bosses by inviting a wide coterie of their trusted lieutenants, and creatively and actively engaging with those visitors on 'the merits' of our program rather than spending time on charter fights, territorial imperatives, or past history of various divisional slights. Not only did this win points for our openness and candor, winning a chance to continue, but it surprisingly led to an infusion of more investment when the visitors urged 'go faster, this is terrific.' We couldn't have made the case as well as they did for us.

Menlo Park, CA
January 17, 2012

hp Memories

This memory of Chuck House's career at *hp* results from the work of the www.hpmemory.org website of Marc Mislanghe who with John Minck (and Chuck) edited and expanded Chuck's previous article on the Birthing of HP Logic Analyzers. It reveals a lot about his management style and experiences while at HP.

One of the main objectives in starting this website five years ago was (and still is today) to get in touch with people who have worked at *hp* from the birth of the company up to today. We are interested in hearing your memories no matter what division or country you worked in, or whether you were in engineering, marketing, finance, administration, or worked in a factory. This is because all of you have contributed to the story of this unique and successful enterprise.

Your memories are treasure for this website. While product and technology are our main concern, other writings related to the company life are highly welcome, as far as they stay inside the *hp* Way guidelines.

Anybody Else? Please get in touch using the Contact US form at "www.hpmemory.org."

The HP Logic Test Family in 1979 - Measure Magazine, January 1979