Restoring and Demonstrating 1960s Vintage Computers at the Computer History Museum

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Abstract:
Beginning in 2003, the Computer History Museum in Mountain View, California, sponsored long-term projects to fully restore and demonstrate three large 1960s vintage computers: a DEC PDP-1 and two magnetic-tape IBM 1401 systems. By 2005, a small volunteer team of engineers had restored the PDP-1. By 2010, another volunteer team of over a dozen retired IBM customer engineers restored two 1401 systems plus various unit-record equipment. In 2013, the museum opened two public demonstration labs to showcase the restored computers: in the DEC PDP-1 Demo Lab, visitors can pit dueling Spacewar! spaceships against each other on its cathode ray tube display. In the IBM 1401 Demo Lab, docents invite visitors to keypunch their names into punched cards that are then printed on its lively line printer. In this paper, we cover the restoration of the 1960s systems, how they are demoed and used, restoration logistics, ingredients for success, and conclude with thoughts on "Why restore and demo vintage computers?"

Introduction

Museums help shape the identity and character of a community by preserving and curating artifacts, chronicling key accomplishments, and presenting the human stories that underlie them. Our belief is that a technology museum can dramatically enrich its visitor experience by exhibiting and demonstrating authentically restored and operational vintage computers. Nevertheless, museum staff may feel unprepared to take on the challenges of a vintage computer restoration and demo project. What are the ingredients for a successful project? In this paper, we present an account of the successful restoration and demonstration of three 1960s vintage computers at the Computer History Museum (CHM).

The CHM's mission is "to preserve and present for posterity the artifacts and stories of the Information Age" while bringing the history of computing to life via public exhibits, educational programs, volunteer docent-led tours, speaker series, national media and radio programs, and community outreach. In 1979, the museum, then located in Boston, began assembling what is now the largest collection of computing artifacts in the world.

In 2002, the CHM moved into its current facility at 1401 N Shoreline Blvd, Mountain View, in the heart of Silicon Valley. As the staff began strategizing on goals and exhibits, including plans for a flagship exhibition on computing history, a passionate volunteer petitioned the staff to shepherd a volunteer-driven project to restore and demonstrate a 1960s large vintage computer, believing that it could enrich the visitor experience.

In this paper, we summarize the CHM's two volunteer-based projects that restored three large 1960s vintage computers: a DEC PDP-1 and two magnetic-tape IBM 1401s.[1] We also discuss how they are regularly demonstrated and their on-going usage. We conclude by recommending

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[1] Beginning in 1998, CHM volunteers earlier restored an IBM 1620, "a prototype of a successful artifact intervention" (Spicer, 2005). It is no longer demonstrated to visitors, mainly due to the absence of compelling peripherals. Another team has restored a vintage IBM 350's fifty-platter stack and servo access arm — the world's first commercial disk drive — demoed every Wednesday in the Museum's main Revolution exhibit.

ingredients for a successful restoration and demonstration project and our thoughts on "Why restore and demo vintage computers?"

Restoration of a DEC PDP-1 from Massachusetts

A restored vintage computer should offer a compelling visitor experience. In 2003, volunteers recognized that the DEC PDP-1, an early display-based interactive computer, would fulfill that objective. In particular, visitors could play the legendary Spacewar! video game on its large cathode ray tube (CRT). Spacewar!, an expression of the 1960s MIT hacker culture that shaped the early days of computing, was arguably the inspiration for the video-gaming industry. While only 55 PDP-1s were produced, they had a prominent presence at leading universities, including MIT, Harvard, Yale, Columbia, and Stanford.

Selecting between the three in its collection, the museum elected to restore a PDP-1 it had acquired from a small Boston firm in 1978. Starting in 1962, the firm had rented it out for human-machine research, such as investigating interface designs in early electronic word processing. Beginning in 2003, meeting once a week in a CHM conference room, a small volunteer team of engineers restored, over two years, its transistor-based CPU mainframe, point-plot Model 30 CRT display, paper tape reader, and Soroban console typewriter (Bickley, 2007).

Applying standard practice to its old power supplies, the restoration began by reforming their electrolytic capacitors.[2] The main challenges were the finicky CRT deflection amplifiers and the console typewriter. The team elected to substitute contemporary power supplies for the CRT's 10 kV anode and the light pen's 1 kV photomultiplier tube. A local typewriter repair shop was happy to take on the console typewriter. Only four printed circuit cards — DEC System Building Blocks — were found to be faulty. To enable visitors to play Spacewar!, the team built two button-actuated control boxes mounted on the exhibit railing (Figure 1).

The PDP-1 was fully operational and ready to demonstrate by 2005, when the team began giving weekly demonstrations. The following year, it was moved to a room just around the corner from the main entrance. The back wall has a large vintage photograph of engineers attending to a PDP-1 in DEC's Maynard, MA facility. A looping video inside conveys the historical significance of the PDP-1 and Spacewar! (Plutte, 2014).

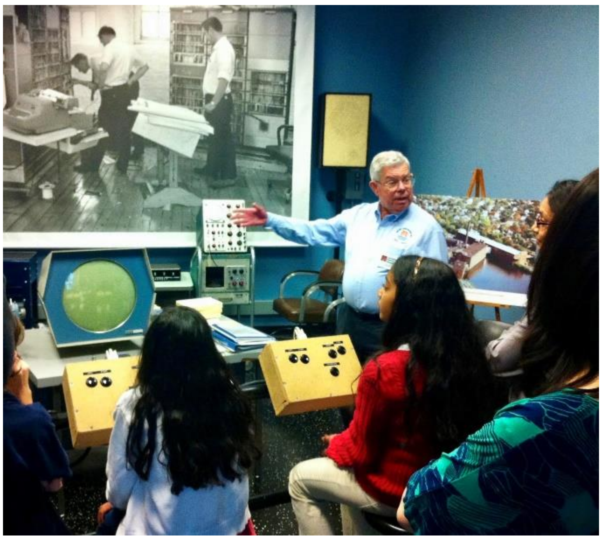

Figure 1. Volunteer and Spacewar! author Steve Russell gives a live demo in the DEC PDP-1 Demo Lab

[2] After removal, a programmable power supply slowly ramps up the applied voltage on a single capacitor (while safely limiting current), redepositing a natural oxide layer on its positive plate.

The PDP-1 is demoed on the first and third Saturdays of every month and Spacewar! tournaments are held quarterly (Russell, 2011; Verdiell and Bickley, 2017). Volunteers speak to DEC's lab instrument and computer business and demo the mesmerizing Snowflake and Minskytron CRT drawing programs. They next invite visitors to pit dueling Spacewar! spaceships against each other on the ghostly long-persistence phosphor CRT using the push-button control boxes. As an invaluable historic tie-in, two team members are Spacewar! authors. Another of the original MIT hackers presents the PDP-1 playing transcoded Bach scores in four-part harmony. Every December, continuing a vintage MIT tradition, a sing-along features the PDP-1 playing synthesized holiday music.

Restoration of an IBM 1401 from Germany

In 2003, while participating in the PDP-1 restoration, we became aware of an IBM 1401 listing on the German eBay. As many people had strong memories of 1401s — the world's most popular computer in the mid-1960s — the museum staff and volunteers felt that it would offer a compelling vintage computer demonstration. Visitors could keypunch cards, experience its lively chain printer and see spinning magnetic tape drives — the iconic face of computers in the 1960s. With over 15,000 installed worldwide, the business-oriented 1401 Data Processing Systems were an inflection point in computing history, leading the IT industry's transition from decades of unit-record equipment and accounting machines to an era of ubiquitous and more flexible stored-program computing. For many, the 1401 was their first experience with hands-on programming (Garner and Dill, 2010; Garner, 2013a).

When I volunteered to lead the project, my first question was "What is an IBM 1401?" When IBM announced it in 1959, I would not even have been tall enough to reach its control panel. Intrigued with the challenge of bringing a large 1960s vintage computer back to life and, having joined IBM Almaden Research in San Jose, I was curious about IBM's computing heritage. (My nascent computing experiences were on DEC, SDS, Univac, and GE systems.) But first I had to find volunteers with the hands-on instinct and experience to tackle the mechanically rich equipment. Following a tip, I placed an "An IBM 1401 Needs Help" ad in the region's IBM San Jose Retirement Club newsletter. Within a month, over a dozen retired IBM customer and manufacturing engineers stepped forward to help with its restoration (Garner, 2013b; Ross, 2009) — see Figure 2.

The German 1401, which we designated as the "DE 1401", was built in 1964 and operated by an insurance company 24x7 for eight years. In 1972, an entrepreneur procured it for his family service business in Hamm, Germany. In 1977, he mothballed it in a detached automobile garage for 27 years. After arriving at the museum in 2004, the new team of about a dozen volunteers rallied to meet the challenge with a spirit of commitment and determination. Many had been IBM Customer

Figure 2. IBM 1401 volunteer restoration team, vintage attire

Engineers responsible for keeping businesses up and running 24x7 from the 1950s onward. Some regarded the CHM as yet another mission-critical client, but fortunately without the stress and pressure of needing to get a customer's system back up and running ASAP.

The DE 1401 came with over a dozen units: 1401 CPU mainframe, 1406 extended core memory, and its electro-mechanical peripherals — 1402 card reader/punch, 1403 line printer, six 729 tape drives — along with various 1940s unit record equipment — several 026 key punches, 083 sorter, 077 collator, and a 513 reproducing punch. Luckily, the museum's facility had a 1,400 square-foot raised-floor server room that could accommodate the 12-kilowatt load, workbenches, test equipment, and volunteers. From photos taken in Germany, the team felt that the restoration was going to be challenging due to its prolonged storage in a humid climate.

We began the restoration by reforming the electrolytic capacitors in its over two dozen power supplies, replacing several due to deteriorated seals. Given its German pedigree, we searched for a source of 50 Hz, 3-phase power to convert from Europe's 50 Hz, 380 VAC to America's 60 Hz, 208 VAC power levels. We eventually acquired a robust 18-KVA Pacific Power 390-G analog converter. We deemed the alternative, modifying the ferroresonant supplies to run at 60 Hz and altering pulley ratios, as impracticable.

We began bug shooting the 1401 circuits and equipment using only oscilloscopes, schematics, and vintage manuals and tools. Given the project's size, a website scribe was enlisted to steadfastly photograph and record work sessions, biographies, manuals, schematics, specifications, part catalogs, vintage photos and memos, documents, anecdotes, and whatever else was fitting (Thelen, 2004).

While addressing the rusted metallic surfaces, we surprisingly found that corrosion had also impacted the discrete electronic devices. Diode leads had rusted through and even occasionally broken their glass encapsulants. Corrosion had also caused transistor leads to break open or compromise hermetically sealed packages. We learned that iron was used as an ingredient in device leads and packages as it, ironically, made for a better seal. We also found many faulty inductors, capacitors, and resistors, cracked board traces and corroded connector pins, and faulty fuses and circuit breakers. Luckily, there were no defects in the five miles of internal cable bundles or in the Gardner-Denver wire-wrapped backplane.

The 1950s germanium alloy-junction transistor used in the 1401 — the second type of transistor after the world's first point-contact device — had a reputation for being finicky and, since it does not possess a natural oxide layer like silicon, susceptible to surface contaminates. Over three decades of storage, air infiltration and other failings resulted in transistors with excessive leakage currents, low betas, opens, shorts, and unexplained "loopy" I-V curves. These faults led to difficult-to-find inter-signal circuit shorts and perplexing intermittent self-oscillating flip-flops. In the 1950s, solid-state transistors were heralded as a leap in reliability compared to vacuum tubes; now, half a century later, they no longer seem invincible.

One controversy was whether it was safe to treat the Standard Modular System (SMS) printed circuit card edge connector traces with commercial lubricant and corrosion inhibitors. I studied the corrosion literature and enlisted IBM Poughkeepsie's Materials and Process Engineering department to analyze the metallurgy of SMS edge traces. Their X-ray fluorescence analysis revealed a robust Au-Ni-Cu metal stack-up with 100 micro-inches of gold showing no porosity and little surface wear. Given the thickness of the gold layer, unheard of in contemporary connectors, they recommended at most cleaning the edge traces with isopropyl alcohol and cautioned against using commercial contact lubricants.

Restoration of an IBM 1401 from Connecticut

For three years we painstakingly tracked down and repaired over a hundred faulty SMS cards in the DE 1401. With no end in sight, I began to wonder whether it had been afflicted by too many corroded transistors. Luckily, in 2007, I received a call offering another 1401 system, a duplicate twin of the DE 1401. Built in 1961, it too had been operated by an insurance company 24x7, for eleven years. Also in 1972, an entrepreneur bought this 1401 for his family IT services business in Darien, Connecticut, and operated it in their home's humidity controlled basement until 1995, where it remained for another 13 years (without humidity control).

I petitioned the museum staff to procure what we designated as the "CT 1401" as a replacement for the evidently over corroded DE 1401. We raised funds from a dozen generous donors and on a rainy May day in 2008, a rigger extracted the heavy units from the home's basement. Perhaps sensing a twin sibling rivalry, or that its time was up, the week the CT 1401 arrived, the DE 1401 began to work (Figure 3)! Within eight months the CT 1401 was up and running.

One of the key restoration challenges was how to bring up the model 729 magnetic-tape drives and the CPU's Tape Adapter Unit (TAU). We wanted to debug the TAU first, but how without a working tape drive? The tape team decided to embark on what became a six-year project to design a sophisticated 729 analyzer and emulator unit that emulates up to six drives at various tape densities and transfer rates (Figure 4).

Users can remotely load and write virtual tape images using the GUI or web interface, patterned after the switch and lights panel at the top of a 729. The backend unit monitors and controls all 50 signals on the TAU-to-729 interface bus, using tunable op-amp circuits to mimic signal waveforms and cycle-accurate firmware running in an 8-bit, 8 MHz PIC-based DLP-245 microcontroller. The tape team coded thousands of lines of assembly code, C, Java, and HTML.

We first brought up the TAUs and then four tape drives on each system (of various models and ages, out of an original six units per system). Using a volunteer's machine shop, the tape team replaced the bearings and refurbished the magnetic powder clutches in the DE 729s. That resourceful and successful accomplishment notwithstanding, the rest of the team elected not to refurbish the CT 729s (nor the 1402 punched card units or 1403 line printers), electing instead to service individual components as they fail — rather than disassemble, refurbish, and reassemble entire units, each comprising thousands of components.

By 2010, the team had volunteered over 20,000 work hours coaxing both 1401 systems into an operational, maintainable and demonstrable condition. With both systems working, I petitioned the museum staff to retain them both so that live demonstrations could go on when one was down.

Figure 3. CHM's IBM 1401 restoration lab, before remodel; CT 1401 on left and DE 1401 on right

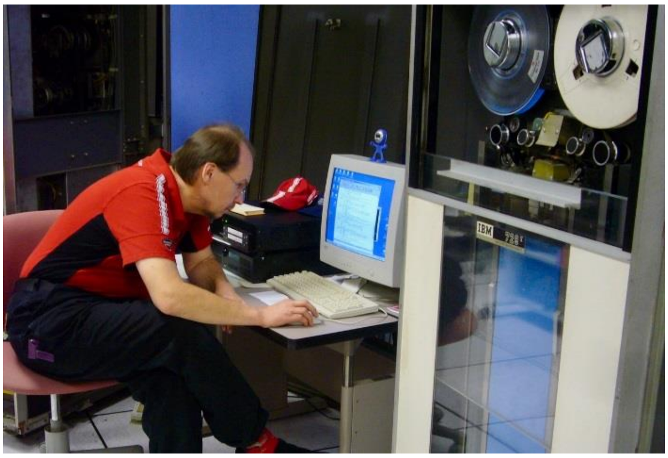

Figure 4. 729 analyzer and emulator

While we had proven that IBM's engineers had designed equipment that is still working after half a century, we also realized that live demonstrations could be easily foiled when any of a system's half-a-million aged components failed.

Luckily, it is has not been difficult to acquire authentic replacement parts. "New old stock" alloy-junction germanium transistors are available on the web and hundreds of spare SMS cards came either with the systems or were donated. While we have an inventory of 260,000 IBM-spec-compliant blank punched cards, we are on the lookout for a new source of cards for every day demo use.

An initial long-term viability concern was the 1403's print-chain assembly; in particular, its plastic band precisely encapsulating many loops of 3-mil wire to which type slugs are attached. Given that print chains had a reputation for breaking, we had elected not to run the infamous 1403 music programs that concurrently fire numerous print hammers. Thankfully, a retired IBMer at the TechWorks! in Binghamton, NY, who had worked on the 1403-N1 printer in the early 1960s, built a custom wire-winding jig and mandrel and crafted a new band and print chain using slugs from an existing broken chain — flawlessly operational for over a year.

The IBM 1401 Demonstration Experience

By 2010, both 1401s were up and running well, but we could not open the lab to the general public because it did not conform to building code's Class A public space. One requirement was for a second door for emergency egress. So we raised funds to remodel the lab and develop a public exhibit with interpretive displays.

In the 1960s, IBM architected theatrical and formal looking computer showrooms viewable through large plate-glass windows. Reflecting that history, the museum designed a showroom for the dual 1401 systems (Figure 5). Visitors enter the IBM 1401 Demo Lab from one side, proceed up onto a raised floor viewing area with equipment just behind an open railing, and depart the opposite side. The walls are colored vintage red-orange and sky-blue, matching a vintage showroom photo. The entry wall has a floor-to-ceiling professional photograph of a street-side showroom with bystanders peering in at a 1401 and its larger cousin. The back wall features interpretive graphics about the 1401 and its era. Looping videos on the wall behind the systems chronicle the 1401's heritage and show scenes from the restoration project (Plutte and Lonnquist, 2013). On the way out, visitors can peruse a gallery of vintage marketing and customer 1401 photographs.

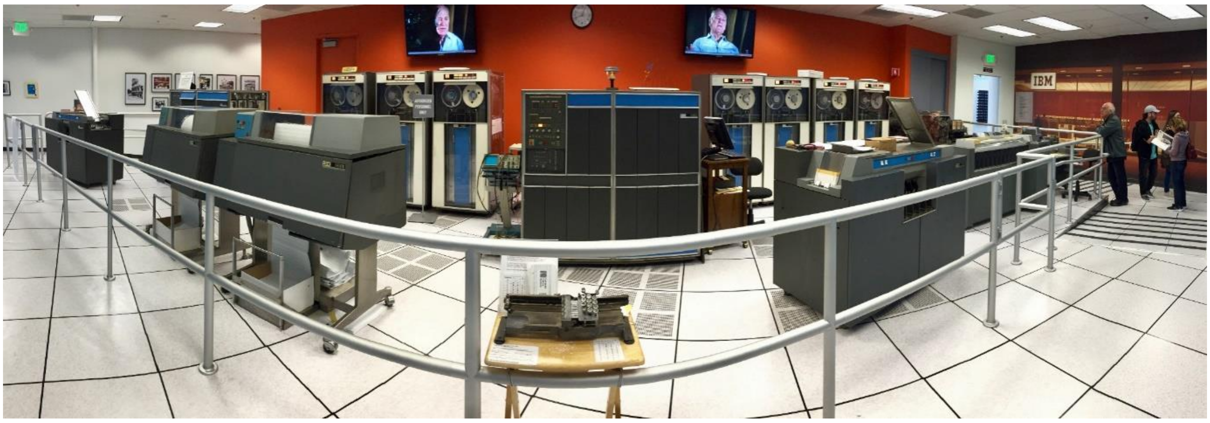

Figure 5. The Computer History Museum's IBM 1401 Demo Lab

The IBM 1401 Demo Lab opened to the public with a gala event in June 2013. Live 1401 demonstrations occur every Wednesday afternoon and Saturday morning and also for special events, high school and college class excursions, and 200-plus student Field Trip Days. Due to our redundant systems, docents have presented 1401 demos without interruption since the lab opened.

To prepare for public demonstrations, the museum augmented its volunteer interpreter training program to assist docents in presenting compelling demo experiences to audiences of all ages from around the world. With guidance from the museum's education team, they learn interpretive principles, techniques and universal themes to help deliver cohesive and relevant demonstrations. A pair of docents carry out the demos: the lead does most of the talking while an assistant handles logistics, such as loading punched cards, pushing buttons, and diagnosing machine problems (Madsen, 2017; Ross and Laughton, 2016). Naturally, there are awkward glitches, particularly with the 1402 card readers and 729 tape drives, but they soldier through them, manifesting the challenge of running a half-century-old computer.

The visiting public is generally enthralled and captivated by the live demos, particularly the younger visitors. There are smiles, questions and quizzical looks of astonishment: "This is what a computer was like back then?" Some experience punched cards for the first time and find it hard to believe they were the prevailing way to get information into a computer. Younger engineers come away with a sense of how much more convenient programming is today and better appreciate how applications had to be squeezed into just 16K characters or less of memory. Visitors respond with amazement when shown the two-inch-diameter 1950s equivalent of today's USB cable (Figure 6). They are surprised to hear that, at the 1401's memory's inflation-adjusted cost of $20 per byte, a mobile phone would set them back over a trillion dollars. They are also surprised that one of our 1401 systems would go for $2.5 million in today's currency.

Demo sessions are generally half an hour, beginning with the question: "What do your senses say about this room?" The lead docent describes pre-1960s business data processing and demos the 083 sorter as an impressive example of the era's electromechanical unit-record equipment — cards flying through at over 16 per second while sorting on one column. Moving on to the 1401, they discuss how it revolutionized the business IT market by supplanting decades of unit-record accounting machines.

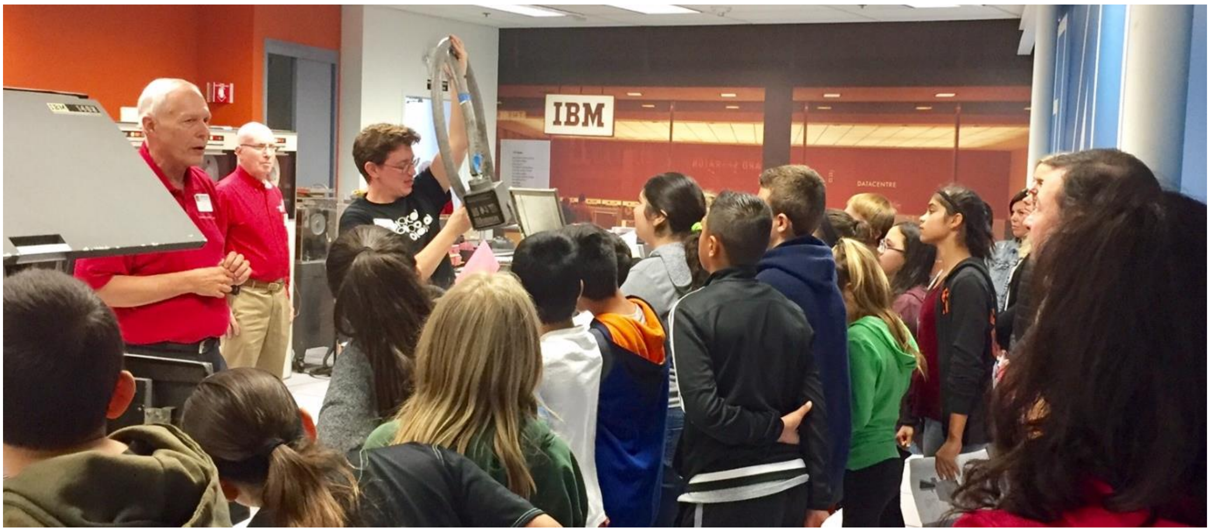

Figure 6. CHM's IBM 1401 demo lab demo session, showing inter-unit cabling

Next the docents invite a visitor to keypunch their name. After adding their punched card to the 'BigPrint' demo deck, the 1403 chain printer noisily hammers it out in big letters: "ALAN TURING VISITED THE COMPUTER HISTORY MUSEUM ON JULY 22, 2015" (Figure 7).

The demo continues with the 'Powers-of-Two' program, rapidly printing a new line every 10th of a second for each number in the series 2, 4, 8, and so on, until all 132 columns are filled. The cadence of print hammers pounding out increasingly wider lines builds to a cacophonous crescendo, particularly with its cover open.

The docents then demo the tape drives, with their reels rapidly starting and stopping and loops of tape jiggling behind glass-paned vacuum columns. The docents demo the tape drives either via the TAU control panel or a program that mimics a tape sort. A high-speed rewind of four tape drives dramatically ends the demo. Visitors are invited to linger, ask additional questions, and keypunch a card. Younger visitors are particularly drawn to keypunches and enjoy composing "secret" messages as patterns of holes in punched cards.

With large school groups, the docent may suggest: "If you ask a bona fide question, you can punch a card and get a printout." Hands shoot up (Figure 8a). For special events, BigPrint name cards can be punched in advance via the lab's PC-controlled 029 keypunch. An 026 keypunch can also be positioned outside the lab to reduce queueing.

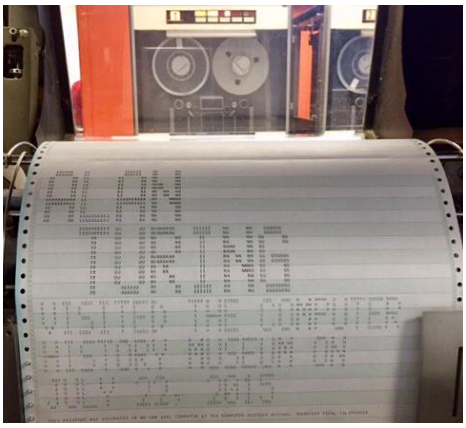

Figure 7. Visitor's name on 1403 line printer.

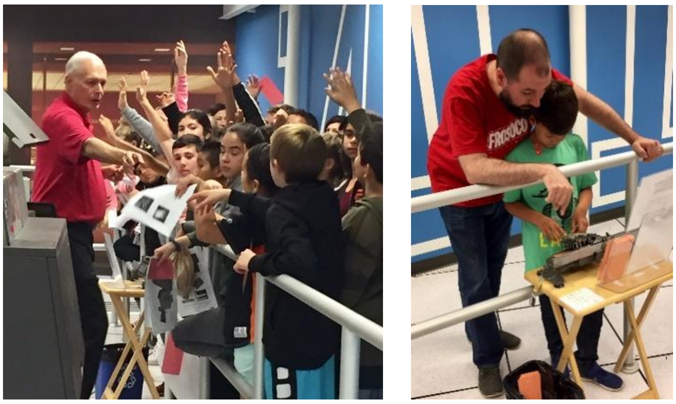

Figure 8.

(a) Left: Asking questions for a chance to keypunch

(b) Right: Trying out an IBM 001 manual keypunch

The lab features a diminutive 1920s IBM 001 Manual Keypunch where motivated visitors doggedly press buttons to punch holes, one column at a time — an engaging way to touch and engage with vintage punched card hardware (Figure 8b).

Ongoing Exploration and Programming of the IBM 1401

The fully operational 1401s have drawn the attention of nearby Silicon Valley engineers, intrigued by how they differ from contemporary computers. Quoting from one: "Studying old computers such as the IBM 1401 is interesting because they use unusual, forgotten techniques. Old computers are also worth studying because their circuitry can be thoroughly understood. After careful examination, you can see how arithmetic, for instance, works, down to the function of individual transistors" (Shirriff, 2015d). Steve Wozniak enthusiastically felt that the 1401 is "cool" because people can explore and learn how computers function from discrete transistors up to basic programming. A precocious ten-year-old visitor, quickly mastering the 1401's easy-to-learn instruction set, coded and ran a simple "Hello World" program.

Several volunteers and visitors have coded extraordinary non-business programs for the 1401, including an implementation of the SHA-256 cryptographic hash function used by Bitcoin (Shirriff, 2015b), a fractal Mandelbrot graphical printout (Figure 9) (Shirriff, 2015a), and an elementary 3D ray-tracing program (Kesteloot, 2014). Our contemporary studies of the 1401's architecture include exploration of its qui-binary decimal encoding for arithmetic error detection (Shirriff, 2015d) and an elucidating look at its magnetic core memory circuits (Shirriff, 2015c). Another volunteer authored a 1401 theory of operations manual using contemporary electrical engineering terminology (Fedorkow, 2017).

Another extraordinary use of the 1401 came from a San Jose State University compiler class student who authored a challenging Small-C cross compiler for it. He also wrote an iOS app that re-renders a photograph for the 1403 printer using a vintage grayscale-to-overprinted-characters algorithm. And a media-savvy volunteer has produced several widely viewed videos featuring the restoration team debugging and maintaining the systems (Verdiell, 2015 and 2017).

For creating new 1401 software, an integrated development and simulation environment called ROPE is available for Windows, Linux, and Mac OS (Mak, 2012). ROPE integrates a GUI, a 1401 Autocoder assembler and the SimH 1401 simulator. Users can edit, assemble, and debug a program using breakpoints, while separate windows display the contents of memory, CPU indicators, and line-printer output. ROPE produces an object deck image that can be punched using our PC-controlled 029 keypunch.

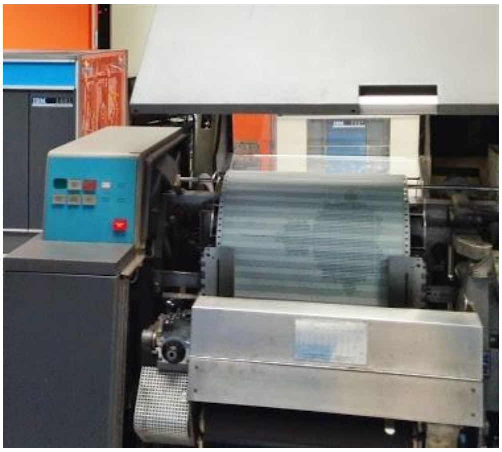

Figure 9. Mandelbrot Set fractal on IBM 1403 line printer

We have two PC-based methods to get information in and out of the 1401s. Using the 729 tape analyzer and emulator's web interface, a tape image can be virtually read or written from any IP-connected browser. We regularly run the vintage 1401 diagnostics this way. We also interfaced a PC to the 1401's serial port. (The CT 1401's owner had hooked up an Altair 8800 for this same purpose).

Exploring the 1401's history has connected the team with the IBMers who designed and brought it to market in the late 1950s. For the 50th anniversary of its 1959 announcement, I tracked down its design architect, development program manager, market planner, hardware and software developers, and the co-designer of its Parisian predecessor prototype — the World Wide Accounting Machine. In 2009, I organized a "50th Anniversary of the Legendary 1401" celebratory event with presentations by the original leadership team, recordings of their oral histories, and a commemorative pamphlet (Wichary et al., 2009).

Restoration Logistics

In 2007, the museum formed a committee to formulate a Restorations Policy. This policy outlines restoration project goals, intervention types (conservation, restoration, reconstruction, replication, and model), criteria for selecting candidates, and monitoring of projects (including a restoration team staff liaison). The museum has classified the restored PDP-1 and 1401s as part of its study collection, separate from artifacts accessioned into its permanent collection. In addition to the machine being restored, another instance should be preserved unmodified in the permanent collection.

The museum also issued companion Restoration Guidelines that emphasize safety first and stipulate that two restorers must be present when equipment is open and energized. Its covenants include: maintaining historical integrity and authenticity, reversible alterations, and recording and logging of restoration activities.

To house test equipment and maintenance tools, the museum generously provided a 480 square foot workshop near the demo labs. The shop's equipment, tools, electronic test equipment and spare parts are donated items or personal property. Classic-computing aficionados worldwide also donate vintage parts, tools, and equipment after finding our 1401 restoration website.

Safety of the volunteers and visitors is paramount. In addition to the two-person work rule, a light fixture atop the mainframes indicates when high voltages are present inside the equipment. The museum is in an earthquake-prone region, so sudden shaking of the heavy 1-to-2 ton units is a concern. While some are resistant to toppling because of their low center of gravity, to prevent units from scooting across the floor during an earthquake we placed C-shaped stabilization clips around their casters. In the 026 keypunches, we bypassed timeworn selenium rectifiers with silicon diodes, which could otherwise emit an odiferous toxic gas when they fail.

Ingredients for Successful Restoration and Demonstration Projects

Based on the CHM's restoration and demonstration project experience, here are my recommended ingredients for a successful project:

Compelling demo: From a project's inception, it needs to offer a compelling demo experience to visitors of all ages. Large and noisy peripherals hold attention and interest. Blinking lights are not so meaningful. Live demonstrations not only explain how a restored computer works, but should also cover why it was developed and how it was used. As a gateway to the past, broader social narratives can also be conveyed.

Restoration team: The size of the team needs to be commensurate with the size of the restoration project. Restorers do not need to have hands-on experience with a particular machine, but must be willing to roll up their sleeves and attack difficult challenges. For the long haul, younger folk need to be enlisted so that elders can pass down skills, empirical knowledge, tricks-of-the-trade, stories, anecdotes and enthusiasm.

Restorer temperament: A key motivator is the satisfaction that comes from interacting with wide-eyed visitors experiencing live "compusaurs" and hearing first-person stories and anecdotes. Nostalgically fixing old hardware isn't enough. A playful sense of humor, camaraderie, and sense of adventure helps to keep spirits high. Restorers may enjoy interacting with visitors ambling through the lab during restoration sessions, enlivening tedious work. Social get-togethers with spouses and families are valuable.

Restoration pace: Unlike the frenzied pace of new product development, where value declines the longer a project takes, a restored vintage computer becomes more valuable the longer it takes. Thus, restorers are rarely subject to schedule pressure and can take the time to study all the angles or unintended side effects of a contemplated machine alteration.

Museum liaison: The museum's restoration-staff liaison needs to keep a pulse on the volunteers' concerns, advocate for their needs, and keep them abreast of the museum's activities.

Dual systems: Ideally, if two systems are available, demos can still go on when one is down. Also, the restoration team can compare the behavior of one against the other to resolve issues.

Workshop: A workshop is needed to separately house the potpourri of tools, equipment, spare parts and workbenches for troubleshooting, inspecting, and repairing circuit cards and mechanical items.

Web scribe and documentarian: The project should have a website master and scribe responsible for recording restoration activities, archiving manuals and documents, maintaining team member bios, photos, email exchanges, and so on. Relying on team members to contribute to a generic blog doesn't work.

Why Restore and Demo Vintage Computers?

Visitors appreciate a museum that supports restorers putting their hearts and minds into keeping vintage computers alive and sharing their personal stories. A restoration project can help fulfill a museum's mission of preserving and interpreting computing history by promoting and chronicling the maintenance, operation and demoing of a vintage computer — not possible with conventional static artifact preservation.

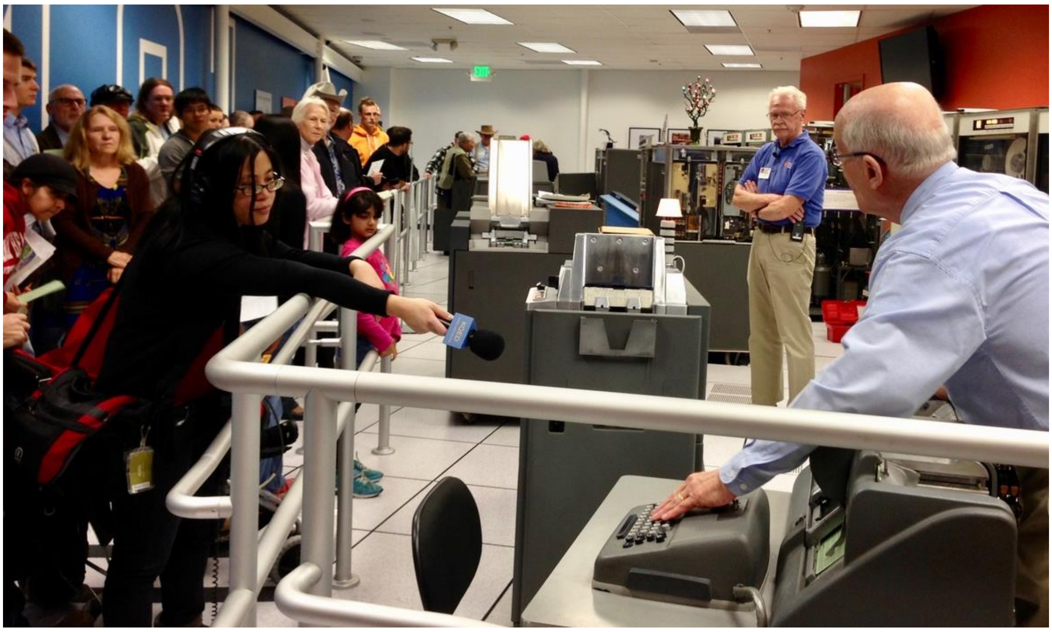

Figure 10. A live 1401 demo and time machine experience

When demonstrating the authentic sights, sounds and smells of a living vintage computer, we connect with visitors' minds and imaginations, taking them on a time-machine journey to an era of chattering punched card equipment, cacophonous printers, whirling tape drives, synthesized music, and ephemeral CRT images (Figure 10). As they become immersed in the experience and hear the history and stories, we also help fulfill the museum's education mission. As they see firsthand how computers have dramatically changed over the past half century, they may even ponder: "What will the world of computing be like in the next half century?"

Acknowledgments

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