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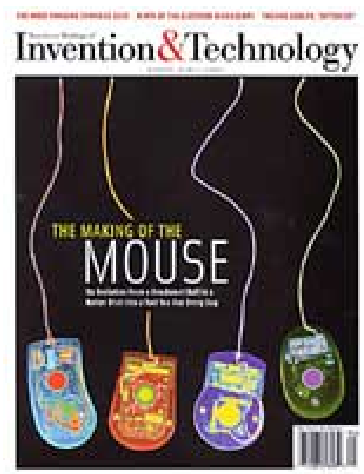


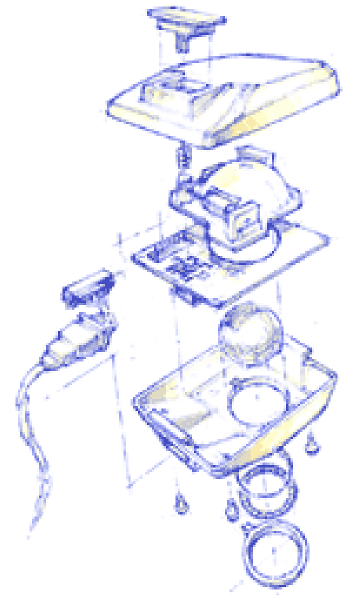
The Making of the Mouse

Apple Computer is commonly credited with having simply popularized someone else's idea—but it wasn't really like that at all

by Alex Soojung-Kim Pang

The story of the birth of the computer mouse is often told, and it is often told like this: Douglas Engelbart and his associates at the Stanford Research Institute invented the mouse in the 1960s; innovators at the Xerox Palo Alto Research Center refined it in the 1970s; and Steve Jobs saw it there in 1979, and his Apple Computer company then took it and brought it to market in the 1980s. This story is at best incomplete. It makes it sound as if Apple's move reflected business acumen more than technological innovation, and the truth is very different. Apple's mouse actually was to its predecessors what the DC-3 was to the Wright brothers' Flyer: not the first of its kind, but the breakthrough in technology and design that made possible a breakthrough in commercialization. Apple moved the mouse from the laboratory to the living room. This took a lot of very hard work, and the work has been neglected precisely because it was so successful.

The very first computer mouse was indeed invented by the computer pioneer Douglas Engelbart in the early 1960s. He publicly unveiled it at a now-famous multimedia demonstration at the 1968 Fall Joint Computer Conference in Menlo Park and San Francisco. It was a large wooden object with three buttons, part of his pioneering Online System for networked learning and collaboration. It was designed to enhance serious computer users' powers, not to help beginners, and six months' training was necessary to master its various commands and modes. (The word *mouse* emerged at the same time, based on the thing's shape and taillike cord; the following year, a researcher named Jack Kelley, who later became a noted furniture designer, created the first mousepad.) The mouse wouldn't begin to be associated with ease of use until the 1970s, when it was worked into systems developed at Xerox's Palo Alto Research Center, known as Xerox PARC.



THE BASIC DESIGN: Douglas Dayton drew an exploded view of what he helped work out in 1980. CLICK IMAGE TO SEE IDENTIFICATION OF PARTS

Xerox PARC was founded in 1970 to conceive and develop the "office of the future," and under the direction of Bob Taylor, formerly of the Defense Department's Advance Research Projects Agency, it became a mecca for cutting-edge computer research. There the mouse grew smaller and flatter, and its small, round buttons were replaced with big, rectangular ones. Engelbart's mouse had used two wheels attached to potentiometers to track its movement; PARC's replaced these with a ball bearing whose motion was read by a pair of rollers connected to electrical brushes that sent a signal to move the cursor onscreen. It became part of the Alto, an experimental computer system that used a graphical interface somewhat like those later popularized by Apple and Windows. A version of the Xerox PARC mouse went on the market in the late 1970s for $400; users had to spend another $300 for an interface to connect it to a computer. Not many bought it. (PARC engineers also worked on an optical mouse, a technology that has only recently reached the mass market.)

A number of Apple engineers had worked at the Stanford Research Institute (an outfit founded by a group of industrialists in conjunction with Stanford University) or at PARC and were familiar with mice, but the company didn't commit itself to using them on the Lisa and the more successful Macintosh until Steve Jobs saw a demo of the Alto and its successor, the Star, in 1979. That visit was not the eureka moment it has often been portrayed as, though; teams at Apple at work on the Lisa and Macintosh projects were already experimenting with graphical interfaces and input devices such as joysticks, touchpads, and mice, and among advanced computer designers at the time, mice were very much in the air. In fact, the visit to PARC was arranged to get Jobs up to speed on a cluster of technologies that a number of other Apple employees already knew about and wanted to pursue–to get him behind the cause.

Rather than have Apple's own designers work on the mouse, however, Jobs offered the project to Hovey-Kelley Design, a Palo Alto start-up founded by two graduates of Stanford University's Product Design Program, Dean Hovey and David Kelley. It isn't entirely clear why Jobs gave them this chance, but he did spread the risk by hiring a second company to produce a competing design. Hovey later recalled the meeting at which Jobs brought up the project: "I had a few ideas and wanted to talk to Steve about them, and we scheduled a time and got together. I started running down my list, and he said, 'Stop, Dean. What you guys need to do–what we need to do together–is build a mouse.' I had no idea what the mouse was. He explained what this thing was, and what it was all about, and I said, 'Gee, that sounds kind of interesting.' And when I walked out that door, I was ready to change the world."

The designers enjoyed considerable freedom to work on the mouse as they saw fit. At Hovey-Kelley, Dean Hovey served as informal project head and principal contact with Apple, Jim Sachs and Rickson Sun focused on the electrical and optical components, Jim Yurchenco took major responsibility for the mechanical design, and Douglas Dayton concentrated on the exterior. (Hovey-Kelley has since evolved into IDEO, one of the world's most renowned design firms.)

Jobs wanted a mouse that could be manufactured for just $10 to $35, a fraction of the cost of

Xerox's version, and that could work on his jeans. Put another way, he wanted Hovey-Kelley to take a $400 piece of technology developed by some of the greatest minds in the computer industry and dramatically improve its reliability while cutting its price by more than 90 percent. Jim Sachs later said about these requirements, "We thought maybe Steve wasn't getting enough meat in his diet; but for $25 an hour, we'd design a solar-powered toaster if that's what he wanted."

Sachs and his colleagues knew that to make the mouse so much cheaper and more reliable, they would have to radically simplify its basic mechanical design; make it with sturdier but less expensive materials, and make it easier to manufacture. Xerox PARC's mouse was too expensive, too delicate and failure-prone, and too hard to keep clean–a masterpiece of high-concept technology that was hopeless as a commercial product. Indeed, Sachs referred to it not as a product but as a laboratory instrument. The large ball at the heart of its detector system was encased in an elaborate gimbal assembly like a gyroscope's, and the assembly supported the weight of the mouse. This contrivance required very costly, high-precision parts. The encoders, which translated the ball's motion into an electrical signal, were made from expensive and undependable mechanical commutators similar to the wire-wrapped elements in electric motors. In normal use, dirt and dust quickly incapacitated the mouse. And it couldn't be cleaned without being opened with a screwdriver and partially dismantled.

DEAN HOVEY PIECED TOGETHER A FIRST CRUDE PROTOTYPE WITHIN DAYS, USING A BUTTER DISH AND A BAN ROLL-ON BALL.

Hovey pieced together a first crude prototype within days of his meeting with Jobs. As he later recalled, "The first place I went was to Walgreens, and I bought all the roll-on deodorants I could find on the shelves. They had these plastic balls in them that roll around. Then I went over to the housewares area and bought some butter dishes and plastic things that were about the size I might need to prototype something. Over the weekend I hacked together a simple spatial prototype of what this thing might be, with Teflon and a ball. The first mouse had a Ban Roll-On ball."

The Ban-and-butter-dish prototype convinced the team that a full-blown project was worth pursuing. The main challenges were to solve the problems of the ball bearing, the encoders, and dirt. Dean Hovey wanted to eliminate the gimbal around the bearing and avoid needing any device to push the ball onto the rolling surface. He solved that when he watched balls roll off a table in his office, whose floor wasn't quite level. "They'd roll off onto the floor, following the slant of the table," he remembered. "And I said, 'That's exactly what I want it to do: I want it to roll without slipping.' I put my fingers around a ball like a little cage. The ball was no longer being pushed on as a bearing support, it was actually free to roll, and we'd barely need to touch it to get the information about where it was moving. And we redesigned the mouse as a result of thinking of that."

Jim Sachs, meanwhile, attacked the encoding problem. Hovey-Kelley considered a number of different approaches, including both inserting magnets into the ball and stamping it with a spiral, so its position could be tracked optically, before Sachs came up with a design that grew out of work he had done with optical encoders as a student at the University of Michigan. He placed two identical optical detectors along the ball's equator, 90 degrees apart. Each utilized a roller that would roll against the ball and a slotted wheel that would turn with the roller. An LED on one side of the wheel shone through the slots to a phototransistor on the other side; as the mouse moved and the wheel spun, the phototransistor recorded the blinks of light and translated them into an electrical signal. The roller and slotted wheel were the encoder's only moving parts, so the system was relatively durable and impervious to dust. To keep the ball pressed against the encoders, Rickson Sun suggested adding a third, spring-loaded roller.

Each component of the mouse was turning out to be relatively simple, and the emerging

EACH COMPONENT WAS TURNING OUT TO BE RELATIVELY SIMPLE, BUT SACHS FEARED THEY'D NEED TOO MUCH PRECISION TO MASS-PRODUCE.

design was addressing key weaknesses of the Xerox mouse. But Sachs worried that all the parts together "required such precision that it probably couldn't be mass-produced." For example, the LEDs and phototransistors would have to be precisely aligned to function properly, and they'd have to stay in alignment when the mouse was dropped on the floor. As Sachs put it, the mouse was arising "at the intersection of technologies that weren't commonly combined before. Precision electronics had been made, and if you needed it to be extra reliable you could have military spec electronics, which were expensive; and you could have inexpensive electronics that didn't have tight tolerances. On the mechanical side, you could have very tight tolerances mechanically in a laboratory instrument, and it would be very expensive; but if it was inexpensive it was sloppy. So we needed to combine all of these, and be inexpensive yet have the performance of high mechanical and electrical tolerance–which was not anything that you could buy on the market."

Jim Yurchenco suggested constructing a single platform of injection-molded plastic that would hold the ball, rollers, LEDs, phototransistors, and idler wheel, fixing them all in place and eliminating alignment problems. Plastic was cheap, and it could be made with thousandths-of-an-inch tolerances by a careful manufacturer. But as Yurchenco recalled, it also carried risks: "There were a lot of very small features that had to be crammed into a very small space, and building a mold to do that was complex. Nobody had actually done this before, so it was never completely clear that it would work when you put it together."

The size of some of the parts and the tolerances required in the final design pushed the state of the art in plastic molding. Fortunately, Hovey-Kelley had connections to a community of skilled machinists and toolmakers in Silicon Valley, who had first worked for agricultural machinery companies and then electronics manufacturers before getting into computers. One local company, Micro Molding, became a major partner in making early versions of the platform and tooling.

Yurchenco spent several weeks working on the platform, which came to be known as the "ribcage." He did some of the work at the drafting table and much of it in his head. Placing the tiny components together in just the right way was only the first thing he had to think about. The design also had to be manufacturable; he observed that "there are many shapes that are very difficult to create in a mold for technical reasons, and in the end you have to be able to get that part out of the mold. You need to be able to open the tool, be able to eject the part, so you can close it and make another one. And that requires design features in the part that you wouldn't normally need for functionality." Finally, the rib cage had to be designed so people on an assembly line could snap in the components without too much difficulty.

Yurchenco's colleagues regarded his work as a tour de force of engineering and visualization, in which he managed to see fully in advance how the ball, encoders, and roller would interact before designing the part that would contain them. But he hardly worked in isolation. "Douglas [Dayton] had to decide what the shape would look like," he remembered, "and I would work back and forth with him and say, 'Okay, well I need a little more room here for this,' and he would change his shape slightly, or he would push back and say, 'I don't want to change that shape. Change your shape.' I would start by giving him a rough envelope of how big the components are, and he would come back to me and say, 'I want this thing to be about this big inside the hand.'" At the same time, Jim Sachs was figuring out the exact electronic parts that would go into the mouse, and, Yurchenco says, "we worked together to place those parts on the circuit board so his electronics would not be in the way of the parts I needed. I would say, 'This is my space, and this is your space,' and he would see if he could do his layout inside 'his' space. And if there were issues, we'd go back and negotiate."

The rib cage "turned out to be the linchpin," in Sachs's words, that made the whole design work. It was made so it held all the precision parts together firmly, protecting them from damage or falling out of alignment, yet its manufacture required no special skill once the injection mold had been made, and the LEDs, encoder wheels, and rollers could be snapped in easily by untrained assembly-line workers. Sachs summed up this achievement: "Through optical encoders, through a spring-loaded third roller, and through a unified cage to hold all these parts, we made a mouse mass-producible, reliable, and inexpensive. And hundreds of millions of them have been made."

Hovey-Kelley had reduced the device's susceptibility to dirt by eliminating the ball bearings and brushes, but dirt couldn't be kept out entirely. After trying and failing to include a "wiper ring" to remove dirt before it got inside the mouse, Yurchenco designed a ring-shaped cap on the mouse's bottom surface that users could remove without a tool, allowing them to take out the ball and clean the rollers.

The detector system, consisting of the optical encoders, a spring-mounted roller, and the rib cage; the unconstrained ball; and the cleaning ring constituted the core mechanical innovations in the Hovey-Kelley design. These were all worked out by the time serious attention turned to the exterior of the mouse in the summer of 1980. As Sachs recalled, "One of the big debates about the early mouse was, Was this something delicate that you would hold with the tips of your fingers, or was this something that you would grab, like the stick shift of a car or a sanding block?" The group had worried about this from the beginning. When Hovey bought his mouse-making ingredients at Walgreens and the hardware store, there were already a variety of handheld items scattered around the office, including gearshifts, sanding blocks, and bicycle handlebars (Hovey had designed bicycles). David Kelley and Douglas Dayton made a number of prototype shapes out of either wood or plastic and conducted tests in August to see how people held and used them. They ranged from square mice to wedge-shaped mice, a combination trackball and mouse, and one that came complete with "two little eyes like a mouse," Kelley remembered. "Apple rejected it completely."

THE MOUSE TEAM: The designers at Hovey-Kelley gather at a company retreat in Lake Tahoe around 1980. From left, in back, Jim Yurchenco, Jim Sachs, Douglas Dayton, Claire Hahn, and David Kelley. Meg Dayton and Liz and Dean Hovey sit on the log.

The tests were very informal, as Kelley described them: "Today, I'd bring in hand surgeons, to make sure that no muscle groups were used unnecessarily, and have tests with typical users; back then you'd use your intuition, and show it to whoever you could find, but not in any systematic way. We were just trying to get done so Steve [Jobs] wouldn't beat us up." The results showed that users held the mouse like a sanding block, putting their fingers around it and their palms on the table. This meant that a mouse that filled the hand was more comfortable and gave a greater feeling of control. It also became clear that the buttons should be spaced apart to reduce confusion, and that too much subtle detailing felt distracting.

Durability tests were conducted in October. By the end of 1980, 25 copies had been built and tested, and the focus turned to smaller details like the cord and plug. A new mouse with an injection-molded case and a button, which now bore a close resemblance to the final production design, was delivered in late March 1981. Most of the decisions about the design had been made independently by Hovey-Kelley, but two important ones were not. First, the design of the exterior case was done by Douglas Dayton together with Bill Dresselhaus, the principal designer of the Lisa computer at Apple. (The case for the Macintosh mouse would likewise be designed by the Macintosh team.) Second, the number of buttons the mouse would have was decided within Apple. That took several months of heated argument.

Engelbart had given the ur-mouse three buttons, but only, he said, because he couldn't figure out how to fit more. The people at Hovey-Kelley at first assumed that their mouse would have three buttons too, but by the time Dayton and Kelley made their models for testing in August, Apple's engineers had insisted on two-button models as well. There were also advocates of a single button, who were willing to trade what conventional computer designers saw as power and versatility for a radical degree of simplicity and accessibility. The debate ended in the early fall. Steve Jobs sided with the partisans of simplicity and ordered a one-button mouse for both the Lisa and the Macintosh. (One button is still the Apple standard; Windows computers generally use two.)

The Hovey-Kelley designers now spent a lot of time on that one button, thinking about its aesthetics and ergonomics, which would play a critical role in defining the feel of the device and affect the character of the Lisa and Macintosh user interface. The size of the body, weight of the ball, flexibility of the cord, and detailing of the sides of the case all subtly affected how solid, smooth, and precise the mouse would feel, but the button was something users would touch dozens of times during a session, as they opened documents, chose commands from the menu bar, positioned the cursor, and cut and pasted. Getting the button right would mean getting the mouse right.

What was right? The answer was defined in part by ergonomics. A user's finger would rest on the mouse while he or she was positioning the cursor, so the button couldn't be too sensitive. But the mouse also had to give a clear sense of interaction. A click was added to provide audible feedback when the button was pushed, confirming the response on the screen or signaling a problem if nothing happened, and the click was coordinated with a tactile signal, a clicky feeling. These precise qualities had to be fine-tuned over time; indeed, the Macintosh mouse was different from the Lisa because of how users had responded to the former. In order to make these subtle qualities come through consistently and reliably, Hovey-Kelley decided to use a relatively expensive high-tolerance microswitch that manufacturers could produce without any need for additional tinkering before its insertion into the mouse assembly.

This effort to get the button right was a matter of realizing what Jim Sachs called "the Zen of the product," the hard-to-describe yet crucial qualities that would define the experience users had with the mouse. Designing a rugged detector and encoding system, a rib cage to hold the electronics and mechanical parts together, and a removable cleaning ring were all necessary, but no one would actually want to use the thing unless they also paid careful attention to its ergonomics and aesthetics. These qualities were nearly impossible to describe in writing and thus had to be communicated through examples. As Sachs explained, "There was so much intangible intellectual property about how something works that it was really transferred verbally, or through team meetings about what was important. So a design team would sit down with a manufacturer and transfer their knowledge in an interpersonal communication rather than a technical specification. There are some things you simply can't document, or things where language fails us. The only solution we have found is to have a human go to the location, actually use all of their sense to determine–along with the written documentation–that it is what it's supposed to be. The Zen of the product is something you can't write down."

The willingness to obsess over details was something that Apple had already become famous for. It was generally understood as flowing from the scruffy obsessions of its engineers, who were allowed to flourish in the company's laid-back atmosphere. Where IBM or Hewlett-Packard engineers might sit in meetings to achieve consensus about specs and procedures, Apple engineers pulled stunts like Steve Wozniak's marathon redesign of the Apple II disk drive. Hovey-Kelley worked in a similar spirit. Jim Sachs recalled that David Kelley cut the stick shift of his BMW when he was experimenting with mouse shapes, and Dean Hovey dismantled appliances in his kitchen for parts for his prototypes; his wife discovered one morning that the refrigerator no longer worked, some critical pieces of it having gone into a mouse. "We all did the same thing," Sachs said. "We sacrificed circuitry, we sacrificed anything." Hovey explained, "When you're in one of those modes where you're building something and you need a part and the stores are closed, you figure, 'Either I can stop and wait, or I can go forward.' So I wreck the refrigerator, but it'll be $20 to fix it. It's no big deal. When you're in the midst of the passion of designing, you just do it."

THE PROJECT TURNED OUT TO BE A TEXTBOOK EXAMPLE OF RAPID PROTOTYPING, RELYING MORE ON MODELS THAN ON FORMAL SPECS.

Apple's mouse project turned out to be a textbook example of "rapid prototyping," of building something quickly to try out one's ideas about it, relying more on models and materials than on formal specifications or user tests. The ultimate purpose of rapid prototyping, a style of innovation taught at the Stanford Product Design Program that had produced nearly everyone at Hovey-Kelley, was to encourage ingenuity. As Kelley put it, "In order to have breakthrough ideas, you have to have a lot of ideas, all different from one another." Hovey said the program's goal was to turn students into "little Leonardo da Vincis–diverse in their expertise, skilled in many things, and diverse enough to create a whole product." In getting at that product, they frequently had to cross the boundaries between hardware and software. Sachs later argued that one reason the Apple user interface was superior (at first) to Windows was that the mouse was developed together with the rest of the interface, yielding a "very tight interaction" between input device and computer. Windows and the mice that went with it were added atop the DOS system, and consequently "the mouse would lag behind, or it would stutter, or you would have trouble making a precision alignment."

The ultimate users of technological designs typically notice bad design more easily than good design; it is the peculiar nature of a good user interface to be all but invisible. Hovey said about the outcome of the Apple mouse project, "From a product designer's perspective, you've done something wonderful because it's disappeared: the technology is not in the way, it's one with the person, and it works." Jim Sachs seconded this view: "The fact that the mouse was non-obtrusive and natural is the result of a lot of work." Few users ever notice the heft of the cord, or the feel of the button, or the silence of the ball as a mouse moves across the desk. And they're not supposed to. The mouse is one of those technologies whose invisibility is a measure of their success, the product of a process whose final act is to erase all traces of itself, leaving behind something that seems only natural in the arrangement of its parts and operation. It takes a substantial change in a mouse's design–adding a scroll wheel, or Apple's recent blunder introducing a hockey-puck-shaped mouse, or the recent emergence of an affordable optical one–to remind us that this is a technology that doesn't just exist but is created and evolves. Even mice have histories.

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PHOTOGRAPHS: TOP, COURTESY OF DEAN HOVEY; BOTTOM, COURTESY OF DAVID KELLEY

| Top of Page |