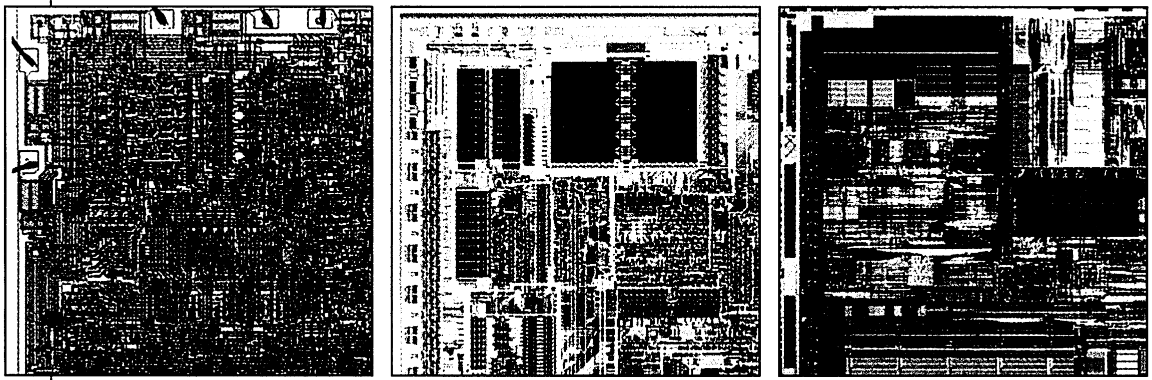
with "optical interconnects" that would use photons to speed data transfer onto and off chips. All these efforts, Marcyk says, are geared to keeping increases in computing power marching along. "It's our job to make Gordon Moore look like a genius," he says, referring to Moore's oft-quoted 1965 prediction that the number of transistors on chips would double every 2 years.

Maintaining that pace also involves plenty of work beyond the confines of RP1. In a nondescript office complex just down the road, Rattner and his colleagues in the microprocessor research group are working on designs for the high-density chips that Marcyk's team is learning to build. Topping Rattner's list are microprocessors hardwired for vision and hearing. Such chips, says Rattner, will one day allow your computer to recognize you when you walk in the room, turn itself on, and fetch your latest e-mail, access the Web, or launch other programs you tell it to launch. Literally *tell*, Rattner says, because new hardware designs are also expected to vastly improve today's rudimentary voice recognition systems. "On these foundations you can build all sorts of unique and wonderful tools," such as computers that control all the appliances in your house with simple voice commands, says Rattner.

Many of those tools will likely come from the Intel Architecture Lab (IAL), also centered in the Hillsboro complex. Here, researchers are pushing the limits in an area that few realize has long been an Intel hotbed: software. According to IAL researcher Steven Spina, Intel researchers actually did the lion's share of developing components of now-standard programs, such as RealPlayer—a music and video player—and an animation program called Shockwave that has been downloaded by more than 200 million users worldwide. Spina and Vara say that although Intel spent millions on the products, it essentially gave away the licensing rights. The idea, Vara explains, is to create must-have applications that will drive demand for new computers, most of which will presumably be powered by Intel chips. "We want to continue to grow the entire computing pie," says Vara.

Spina and his IAL colleagues have several software packages on the horizon. One converts video coverage of sporting events into three-dimensional animation that can be viewed from any angle on the field, including the perspective of specific players, referees, coaches, and even the ball. Another is a set of video games that track a player's real-life motions by camera and use them to control the action on screen. More mundanely, the researchers envisage computers that start up in seconds rather than the 1 to 2 minutes that we've come to tolerate first thing in the morning. Inventing new computer applications is a job Spina and his colleagues clearly enjoy. "This is a place where we get to be around a lot of cool stuff and get to play," Spina says.



Small wonders. Silicon chips from 1971, 1982, and 2000 (the Intel 4004, 286, and Pentium 4, respectively) show the progress that researchers have made in miniaturizing electronic circuitry.

CREDITS: INTEL

But with the semiconductor industry in the midst of a wrenching downturn, it's not clear how long the toys—and the money to buy them—will keep coming. Also unclear is how long the corporate glasnost will continue to offer outside researchers insight into the possible road ahead and a chance for Intel's own legions of trained talent to talk in detail about their latest work.

"I don't know if this is a fluctuation or a sustained trend," says Isaac. "[Intel] still is not as open as IBM or Bell Labs would be," says Cornell's Tiwari, but for a company better known as a consumer of research than as a provider, the trend is in the right direction.

—ROBERT F. SERVICE

NEWS

Better Searching Through Science

Next-generation search tools now under development will let scientists drill ever deeper into the billion-page Web

In the beginning, the Web was without form, and void. Vast heaps of information grew upon the deep, and it was good for one's desktop. But users across the land were befuddled and could not find their way. There arose the tribes of the Yahoos, the HotBots, and the AltaVistas to bring order out of chaos. Google and CiteSeer prospered and lent guidance. But researchers and scientists, learned ones who had built the Web in their own image, yearned for something more. …

As myths go, this one may lack staying power, but there is no doubt that in some sense scientists have been victims of their own success. The real creation story is that the World Wide Web began as an information-sharing and -retrieval project at the European particle physics lab CERN, and many scientists of all fields now depend vitally on the Internet to do their jobs. It's only recently that it has evolved into a convenient way to buy stuff. And although this commercial proliferation has been good for the Web's growth, it has frustrated researchers seeking quality content and pinpoint results among the noise and spam.

Now, a handful of companies and academic researchers are working on a new breed of search engines to undo this second curse of Babel. "I think the real action is in focused and specialized search engines," says Web researcher Lee Giles of Pennsylvania State University, University Park. "This is where we're going to see the most interesting work."

The first generation of search engines was based on what computer scientists such as Andrei Broder of AltaVista like to call classic information retrieval. Stick in a key word or phrase, and the software scurries around looking for matching words in documents. The more times a word pops up, the higher the document ranks in the output results.

But ranking by hits did not say how important or authoritative or useful the pages might be. "The original idea was that people would patiently look through 10 pages of results to find what they wanted," says Monika Henzinger, director of research at Google. "But we

ILLUSTRATION: TERRY SMITH

soon learned that people only look at the first set of results, so ranking becomes very important." Some early services, most famously Yahoo, tried to work around this problem by using human analysts to construct Web directories that retained only the most useful or authoritative Web sites. Metaengines—Web sites that shot a query off to dozens of search engines—gave coverage another boost.

Then, starting about 3 years ago, a second generation of tools appeared whose software performs link analysis: not only digesting the content of pages but also scoping out what the pages point to and what pages point at them. Google is considered the commercial pioneer in this field, but other companies such as NEC have funded development of sophisticated Web structure analyzers such as CiteSeer and Inquirus. And it's still a topic of intense basic research at academic incubators like the alma mater of Google's founders, Stanford University.

Nowadays, Broder says, virtually every large search engine does some form of link crunching and has ranking functions that order the results. These ranking algorithms are closely guarded secrets. "They are the magic sauce in the recipe," Broder explains. At Google, a system called PageRank measures the importance of Web pages by "solving an equation of 500 million variables and more than 2 billion terms," according to Google's Web site. Says Henzinger, "The idea is that every link is a vote for a Web page, but the votes are weighted by the importance of the linking page."

According to Broder, the goal of a third generation of search engines now on the drawing boards "is to figure out the intent behind the query." By looking at patterns of searches and incorporating machine intelligence, software may anticipate what an engine user really wants. That knowledge should help it narrow and focus the search.

Future search technology will also begin to track its human users much more closely—for example, divining that a query about "Mustang" refers to the car, not the animal. In its Inquirus-2 project, for instance, NEC has been looking at ways to reformulate a query based on the user's information needs before zipping it off to other search engines. Other search engines are starting to present the results in a file cabinet stack of categorized folders.

Privacy issues aside, the ramp-up in search engine power is bound to benefit scientists. An example of a specialized search engine for scientists is Scirus, a joint venture launched in April between FAST, a Norwegian search engine company, and the Elsevier Science publishing group. Scirus is a search interface that taps into Elsevier's proprietary journal content while simultaneously searching the Web for the same key words. "We found that scientists were searching proprietary databases as well as the Web," says Femke Markus, Elsevier's project manager for Scirus. "Wouldn't it be ideal to have one search engine to do both? We [also] would like to let people know that we have journals that might be useful to them."

FAST's chief technology officer, John Lervik, says that Scirus was designed to filter search results to present matches only from Web pages with scientific content. "For the Web content, we filter on the basis of some attributes like domain. A Web site ending in '.edu' is more likely to have scientific content, for instance." More important, he says, "we can do automatic categorization to estimate whether something is scientific content or not." And like Google, Scirus also searches content in PDF files, a document format widely used in scientific research.

Such searching power does raise perils. Some users fear that tailored search engines might promote the Web content of one publisher under the guise of an omniscient search engine. Queries to Scirus, for example, yield not only free Web content at universities and research labs but also links to subscriber-only content in the Elsevier journals and MEDLINE.

Markus says Scirus does not stack the deck. "We've joked about it: Can't we raise the ranking and make sure the top 20 is always Elsevier?" she says. "But that would be very bad for us. Everyone would say, 'Hey, you're only pretending to launch an independent platform.' " Markus says her team is inviting other publishers, including the Los Alamos physics preprint server, to have their content indexed on Scirus.

John Lervik at FAST also denies any bias. "We use the same relevance algorithms for everything, and we don't emphasize ScienceDirect [Elsevier's online journal gateway] over anything else." Lervik also

A SMATTERING OF SEARCH TOOLS

ResearchIndex (CiteSeer)	researchindex.org or citeseer.nj.nec.com	Project at NEC Research Institute to use autonomous citation indexing. Can search content in postscript and PDF files.
Cora	cora.whizbang.com	Special-purpose search engine for computer science resources developed by Carnegie Mellon University.
Scirus	www.scirus.com	Joint venture between FAST and Elsevier to search scientific Web pages and subscription content at ScienceDirect and BioMedNet.
Search4Science	www.search4science.com	Meta–search engine for scientists; includes colleague search and science news headlines.
Leiden University	www.leidenuniv.nl/ub/biv/specials.htm	List of specialty search engines.
SearchAbility	www.searchability.com/academic.htm	Guide to academic search engines.
Teoma	www.teoma.com	Beta-test search engine provides "authoritative" Web page results, grouped into categories, plus "expert" recommendations.
Search Engine Watch	searchenginewatch.com	Lists of specialty search engines and tips for searching; info for search engine researchers.
Search Engine Guide	www.searchengineguide.com	Current news about the business; lists of engines.
Applied Semantics	www.appliedsemantics.com	Ontology-based search engine with meaning-based search.
Semantic Web Activity	www.w3.org/2001/sw	Information about efforts to add machine-readable description data to Web pages.
WiseNut	www.wisenut.com	Context-dependent Web search engine developed by founder of mySimon comparison shopping site.
Lasoo	www.lasoo.net	Location-based search tool focuses search on selected geographical area.

wants users to speak up if they see anything fishy.

Another challenge for both the specialized and general-purpose search engines is the "hidden Web"—databases that search engines do not index, either because their content has a short shelf life (such as daily weather reports) or because they are available to subscribers only. The publishers of *Science*, *Nature*, and other journals charge fees for online access to the full text of research papers. Although abstracts may be available, and the citations can readily be discovered by search engines such as Google, the data and full text may never be seen by search engines. This is partly why Elsevier cranked up the Scirus Project. "Because of our firewalls and subscriptions, engines like Google cannot get in and index us," says Markus.

Unbiased? Publishers who run search engines say they are resisting the temptation to push their own products.

These barriers pose a dilemma for researchers who want the stamp of peer-review approval and publication in a high-profile journal but who also want the world to know about their work. It has also led to a continuing debate about whether scientific research publications should be free and available without restriction on the Web (*Science*, 14 July 2000, p. 223). At the moment, *Science* and *Nature* both allow authors to post copies of papers on their Web pages after a period of time. By then, however, it may no longer be the breaking news that researchers are looking for.

Other researchers believe that the highest quality search tools will come not from rejiggering the search engines but from a whole new way of creating Web content. One initiative, called the "semantic Web," is being promoted by a team that includes Tim Berners-Lee, the father of the World Wide Web, who is now at the Massachusetts Institute of Technology. The goal is to incorporate "metadata"—a description of what a document is about—into every Web page, in a form that computers can easily digest and understand. To scientists wrestling with information overload, that might mark the first big step toward paradise regained.

–DAVID VOSS

NEWS

The Quandary of Quantum Information

Scientists are excited by the potential of quantum computing but increasingly confused about how it works

If even the newest, speediest personal computers don't thrill you, consider what's in store if quantum computing lives up to its promise. By using the strange properties of quantum objects to store and manipulate information, quantum computers, if they can ever be built, would crack the codes that safeguard the Internet, search databases with incredible speed, and breeze through hosts of other tasks beyond the ken of ordinary computing.

Useful quantum computers are still at least years away; right now, the most advanced working model can barely factor the number 15. Nonetheless, the past few years have seen a flurry of advances, as physicists figure out how to use quantum information to perform feats that are impossible in the classical world. Yet even as theorists crank out quantum software, they have been astonished to discover that a phenomenon long considered essential for quantum computing appears to be dispensable after all. That leaves them wondering just which exotic properties of the quantum realm combine to give quantum computers their incredible potential. "People are looking for where the power of quantum computing is coming from," says Raymond Laflamme, a physicist at the University of Waterloo in Ontario. And the deeper they peer beneath the surface, the more paradoxes they discover.

At first glance, a quantum computer shouldn't be more inscrutable than the computer on your desktop; both are essentially machines that process information. In 1948, Bell Labs scientist Claude Shannon laid the groundwork for modern computing by founding information theory, a new discipline that did for information what the laws of thermodynamics did for heat. A PC, true to Shannon's vision, processes information by manipulating "bits," binary digits that can have a value of either 0 or 1. A 1 can be a high voltage, a closed switch, or a bright light, whereas a 0 can be a low voltage, an open switch, or a dim light: The medium is certainly not the message. But however the bits are represented, the computer uses an algorithm to make those ons and offs dance a jig, and out pops the desired answer.

What makes quantum information much more intricate than classical Shannon information is that quantum computers, unlike their classical counterparts, can exploit the laws of the subatomic realm. Instead of manipulating bits, quantum computers store information on quantum-mechanical objects such as atomic nuclei, photons, or superconductors. A "qubit" might be a 1, for instance, if a photon is polarized vertically rather than diagonally, if an atom's spin is pointing up rather than down, or if current in a loop of superconductor is moving clockwise rather than counterclockwise.

But the laws of quantum mechanics make qubits quite different from bits. Instead of having to choose between being a 0 or a 1, a qubit can be both at once—an idea that physicist Erwin Schrödinger mocked with his famous half-alive, half-dead cat. But this "superposition" of different quantum states is quite real; for instance, last year, teams from Delft, in the Netherlands, and New York state, showed that superconducting loops can carry currents that run both clockwise and counterclockwise at the same time (*Science*, 31 March 2000, p. 2395). Under the right circumstances, manipulating a single qubit in superposition is equivalent to running a classical computer twice—once with the bit set to 0 and another time with the bit set to 1, potentially giving a quantum computer a speedup over a classical one.

A second quirk of qubits that makes the quantum computer incredibly powerful is entanglement. When two quantum objects are entangled, their fates are linked. The most famous incarnation of entanglement is Einstein's "spooky action at a distance," in which, if one entangled atom is poked, its entangled twin feels the prod, even if it's halfway across the universe. In theory, any number of particles can be entangled. Mathematically, such clusters are yoked together to form, in effect, a single object—you can't manipulate one member without considering the effect on the others. In principle, this more-than-the-sum-of-their-parts effect allows qubits to be linked into larger and larger quantum systems capable of storing staggering amounts of information. Two entangled qubits can be equivalent to four sets of two bits—(0, 0), (0, 1), (1, 0),