Where in the World Is Technology Going?

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Looking back at the major technological inventions and breakthroughs that have occurred within the last 15 years, we might wonder whether the pace can be maintained for the next 15. Rest assured, the answer is "Yes, to the n^{th} degree." In 1990, who could have imagined — other than those in research and development—the impact that the Internet, e-mail, cell-phones, PDAs, and laptops would have on the way people conduct their personal and professional lives.

Technology keeps changing so dramatically in such short periods of time that people who do not use it regularly risk feeling obsolete. Many people who did not grow up using computers and other "intelligent" technologies reacted to the introduction of these products with skepticism at first. Now, they cannot imagine life without information technology.

Most of us would agree that once we have become acclimated to technology, new devices are not quite so daunting, because the technological skills we have acquired make the transition to other technologies easier. Today's students, who have grown up in the age of information technology, have a great advantage over older generations in terms of the learning curve. Students are typically highly interested in technology and their lives are inundated with it.

Getting on the Information Superhighway

When the World Wide Web, and more specifically search engines, first became part of the Internet, it took luck to find a specific bit of information. The amount of data available was not nearly as voluminous as it is today.

By the late 1990s, Google's founders recognized that thousands of Web pages were being added to the Internet each day and the search engines at that time, which used keywords, could not keep up with the pace. Google had the breakthrough idea to combine its PageRank technology with an analysis of page content to identify a list of pages that were most relevant to the search. To this day, Google employs many mathematicians whose job is to develop algorithms that will make its search technology better and keep Google ahead of the competition. (Friedman)

In the near future, a new database will make its entrance onto the global stage — the Semantic Web. Once the Semantic Web gets up and running, it will be held in the same esteem as the Internet is today. In fact, the Semantic Web's creator is the same man who is credited with developing the World Wide Web (WWW), Tim Berners-Lee. Surely Google and other search engine companies are keeping a close eye on Berners-Lee and his plans for the new Web.

The Semantic Web

To define what the Semantic Web can do, it is helpful to understand why it is so much better than the WWW. Simply stated, the Semantic Web adds definition tags to information in Web pages and links them in such a way that computers can discover data more efficiently and form new associations between pieces of information, in effect creating a globally distributed database. The Semantic Web has been 15 years in the making, and Berners-Lee believes it will win acceptance because of its ability to extract meaning from widely dispersed information sources as easily as the WWW links individual documents. (Berners-Lee, Frauenfelder)

With more and more bits of information being added every day, Berners-Lee is counting on the Semantic Web to take off like the WWW did. The process will take time, however. The WWW contains a vast amount of information that the Semantic Web will one day utilize, but it cannot in its current format. There is no common global system for publishing data in a way that is easily processed. The data is scattered, and linking it requires human effort. The Semantic Web will facilitate relationships among the numerous databases to create links and make connections independent of the human mind. But first, all of the databases on the Internet now and in the future will have to be translated into a single common language that computers can understand to create this ever-expanding global database.

Most conventional databases are "relational" in nature, meaning they contain columns of information that relate to each other. An example is the information on temperature, wind speed, barometric pressure, etc., in a weather database. The relationships between the columns are the "semantics," or meaning, of the data and represent a typical example of one semantic Web page. (Berners-Lee, Fischetti)

For a database to become a Semantic Web page, it needs to be represented in machine-readable common language. Berners-Lee and his World Wide Web consortium, W3C, are in the process of deploying this language, called Resource Description Framework (RDF). RDF builds upon the widely used Extensible Markup Language (XML). The benefit in using RDF is that the information maps directly and unambiguously to bits of data that are relevant. In other words, it knows which bits of data are the semantics of the application and which bits are merely syntactic "junk."

The Semantic Web is about information sharing quickly on a global scale. The following examples, in Berners-Lee's words, show the power and capabilities that the Semantic Web will possess:

Example #1

> Suppose you're browsing the Web and you find a seminar advertised, and you decide to go. Now, there is all sorts of information on that page, which is accessible to you as a human being, but your computer doesn't know what it means. So you must open a new calendar entry and paste the information in there. Then get your address book and add new entries for the people involved in the seminar. And then, if you wanted to be complete, find the latitude and the longitude of the seminar, and program that into your GPS [Global Positioning System] device so you could find it.
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> It's very laborious to do all this by hand. What you would like to be able to do is just tell the computer, I'm going to this seminar. If there were a Semantic Web version of the page, it would have labeled information on it that would tell the computer this is an event, and what time and date it is. And it would automatically add your travel to your event book. It would add the people to your address book, and it would program your GPS to give you directions. It would have the relationships between the event and the various people chairing it. And those people would have Semantic Web personal pages, which contained information about how you could contact them.
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> Your address book can now grow from a closed repository of private data to a view on the people-related data in the world. (Berners-Lee, Frauenfelder)

Example #2

> The semantic search engine can apply logic to deduce which of its many responses to an initial search are useful. This would allow us to ask general questions of our computerized agents, such as "Did any baseball teams play yesterday in a place where the temperature was 22°C?" A program — call it a logic engine — would apply mathematical reasoning to each item found. The search engine might find six thousand

> facts involving baseball teams, and two million data items about temperatures and cities. The logic engine would analyze which bits of data refer to where a baseball team is, ascertain what the temperature was in certain towns, filter both sets of data, strip out all the junk, and respond: "The Red Sox played in Boston yesterday and the temperature was 22°C. Also, the Sharks played in Tokyo, where it was 22°C." A simple search would have returned an endless list of possible answers that the human would have to wade through. By adding logic, we get back a correct answer. (Berners-Lee, Fischetti)

By connecting relational databases, the Semantic Web can process information more intelligently. Berners-Lee says that getting the RDF language completed, for both semantics and syntax, was phase 1 of Semantic Web development. Phase 2 is getting people to use the language and begin building the database.

Berners-Lee is counting on life sciences, such as biology, pharmacology, genetics, and biotech, to drive the adoption of the Semantic Web, similar to the way physicists helped to propel the early WWW. This will ignite a creative boon in science and engineering.

"Life sciences are particularly suitable for pioneering the Semantic Web," according to Berners-Lee. For example, many databases and information systems used by drug researchers are already in, or are set to be transformed to, machine-readable format. (Bostrom) Information sharing among life scientists who are working on important and challenging projects, such as searching for cures for cancer and AIDS and discovering new drugs, could significantly accelerate the rate of progress.

DNA and Quantum Computing

At this moment, computer chip developers are working furiously to create faster and smaller microprocessors. Using conventional methods, further progress would be limited because the physics will not allow the technology to get any smaller unless new materials and engineering techniques are used. Scientists *have* found that new material, which happens to be plentiful and inexpensive: DNA. As long as there are cellular organisms, there will always be a supply of DNA.

DNA holds the potential to perform calculations many times faster and hold billions of times more data than silicon microchips. A DNA molecular computer works biochemically, using enzymes that react with DNA strands, causing chain reactions that do parallel processing. A DNA computer could, for example, be a tiny liquid computer — DNA in solution.

One pound of DNA has the capacity to store more information than all the electronic computers ever built; and the computing power of a teardrop-sized DNA computer, using the DNA logic gates, will be more powerful than the world's most powerful supercomputer. More than 10 trillion DNA molecules can fit into an area no larger than 1 cubic centimeter. With this small amount of DNA, a computer would be able to hold 10 terabytes (or 10 million megabytes) of data and perform 10 trillion calculations at a time. By adding more DNA, more calculations could be performed. (Bonsor) What makes DNA computing so much faster than the traditional silicon microprocessor is its ability to do parallel computing — to perform several different operations at once.

Nanotechnology holds the key for another type of revolutionary technology: quantum computing. Scientists believe that quantum computers have the potential of performing calculations billions of times faster than any silicon microprocessor. The quantum processing unit will not look anything like today's PC; in fact, it could resemble the cup of coffee on the desk next to the computer. (Gershenfeld and Chuang)

The memory of a silicon-based computer is made up of binary bits designated either as a "1" or a "0." The processor manipulates those bits by passing them through logic gates and back again. This sequential process takes time, because one job needs to occur before the next can begin. Quantum computers are not limited to just two states. They hold information as quantum bits, or qubits. A qubit can hold a one, zero, or a superposition of one and zero, meaning qubits can exist simultaneously as both. As with DNA computing, quantum computers can perform several operations at once.

Although quantum and DNA computing are still in their infancy, it has tremendous potential for physics, chemistry, materials science, nanotechnology, biology, and medicine, all of which are limited by the relatively slow speed and large size of the silicon chip.

Conclusion

The trends in technology described above underscore how integral biology, chemistry, and physics are to scientific advancements. Most of this information is not covered in textbooks or taught in classrooms. For students to obtain a real-world rigorous and relevant education, they need to explore the concepts behind the up-and-coming technologies. Let's start by getting students excited about learning science.

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