Introduction

The Coming Artificial Invention Age

THERE IS AN UNSEEN COMPUTER REVOLUTION under way: the revolution in computer-automated inventing. Computers are now designing products in ways that previously required human ingenuity, thereby ushering in a new era that I refer to as the Artificial Invention Age.[1]

This isn't Steven Spielberg's next science fiction movie. Artificial invention technology[2] is already here, and we're already buying and using its creations. For example, Stephen Thaler of Imagination Engines used computer software called the Creativity Machine, which is modeled after the creative processes of the human brain, to invent the crossed-bristle configuration of the Oral-B CrossAction toothbrush. One user of the Creativity Machine has described it as "Thomas Edison in a box."[3] Gregory Hornby of the NASA Ames Research Center used "evolutionary" software to dream up a tiny antenna—a weird little object looking for all the world like an unwound paper clip—that is now on a space mission (see Figure 1).[4] He admits that no human engineer would have thought of an antenna that looked so crazy, yet the antenna works better than previous human designs.[5] John Koza of Genetic Programming used "genetic programming" software to create a new controller, a kind of device found in everything from thermostats to automobile cruise control systems. The proof of the controller's novelty is in the pudding—or perhaps I should say in the patent that the U.S. Patent Office granted not only on the controller itself but also on the computer-automated method that Dr. Koza used to invent it.[6]

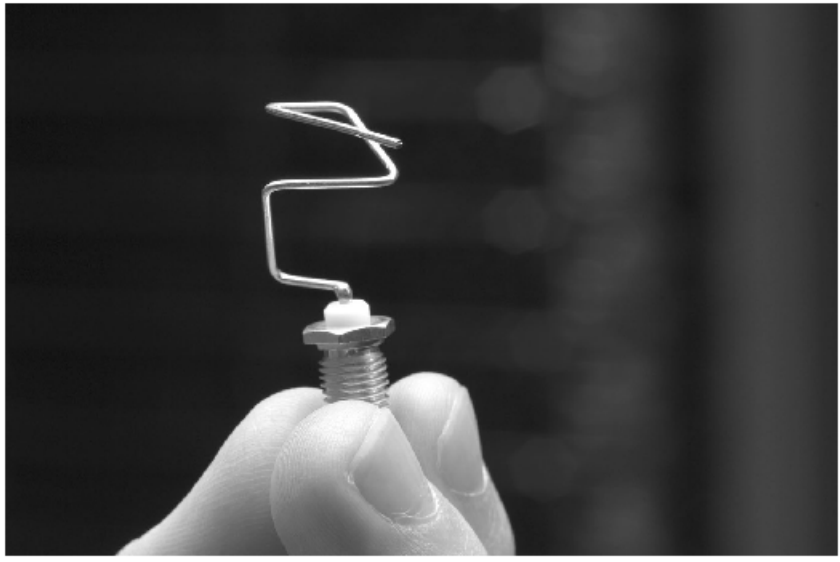

FIGURE 1 Antenna in space. Courtesy NASA.

Genies in a New Guise

Software, not a human inventor, devised the designs for each of these products.[7] The latest generation of artificial invention software therefore differs qualitatively from all previous tools inventors have used to assist them in inventing, from the very first stone with which a human sharpened a branch into a spear, to the computer aided design (CAD) software used by today's automotive engineers to construct 3D models of tomorrow's car engines. Even the most advanced technology of the Industrial Age could not conceive the shape of a new airplane wing, evaluate the efficiency of airflow around that wing, and then modify the wing's design to make it even more aerodynamic. Such acts could only be performed by a human mind.

Not any more. Dr. Thaler did not tell the Creativity Machine to use a crossed-bristle configuration for the CrossAction toothbrush. Instead he fed existing toothbrush designs into the Creativity Machine and then gave the Creativity Machine objective data about how effectively each of those toothbrushes cleaned teeth. Solely from this information, the Creativity Machine discovered what makes one toothbrush better than another at brushing teeth,

and produced the crossed-bristle design on the basis of that discovery.[8] Nor did Dr. Koza tell his genetic programming software which components to use in the controller he patented. Instead, he merely told the software which *criteria* he needed a controller to satisfy, and in response the software *automatically* devised a controller that satisfied those criteria.

This will be the role of human inventors in the Artificial Invention Age: to formulate high-level descriptions of the problem to be solved, not to work out the details of the solution. Filling in those minutiae is precisely the task at which artificial invention technology excels.[9] In this sense, a computer running artificial invention software is like a genie, and the problem description that the human inventor supplies to the software—such as "generate an antenna that weighs less than a pound and can transmit and receive FM radio signals"[10]—is like a wish.[11] Once given this problem description (wish), the artificial invention software (genie) produces a design for a concrete product—a toothbrush, an antenna, a controller—that solves the stated problem. Such a design is the inventor's wish come true. This *fundamental structure of a wish*, shown in Figure 2, is evidence of Arthur C. Clarke's Third Law: "Any sufficiently advanced technology is indistinguishable from magic."

Human and Computer: A New Partnership

Artificial invention technology will reduce the amount of time and money required to produce new inventions, but that will not be its most profound effect. As the photo of the NASA antenna makes clear, artificial inventions generated by software often appear bizarre to human eyes, even those of technical experts. Today's software can even produce inventions that human inventors previously declared unattainable. For example, John Koza used his genetic

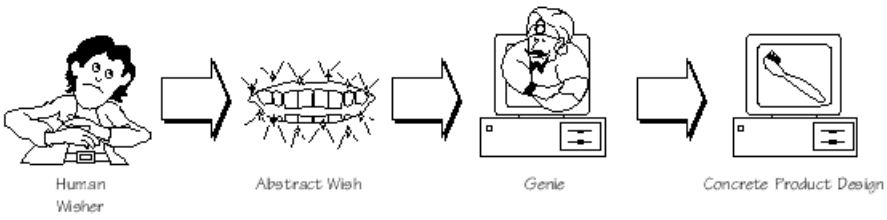

FIGURE 2 The fundamental structure of a wish. Courtesy Spinney Associates

programming software to produce a circuit consisting only of resistors and capacitors with a gain (amplification factor) of greater than two, even though skilled electrical engineers in the field had claimed that such a circuit could not be created.[12] One reason computer-generated designs often confound human experts in this way is that artificial invention software lacks the biases and blind spots that can keep human inventors from considering possibilities that are fruitful but violate conventional design wisdom.[13] Artificial invention technology therefore not only allows inventors to focus on high-level design rather than low-level details; it also enables them to produce inventions that they could not have created *at all* without such technology.

Note that I say invention automation technology enables *human inventors* to invent more effectively, *not* that the technology itself has become an inventor. Although it certainly is true that artificial invention technology can automate significant *parts* of the inventive process—such as selecting and combining components into a final design—this does not mean such technology will make human inventors obsolete in the Artificial Invention Age. Rather, human inventors will remain in the driver's seat for the foreseeable future, formulating wishes and using them to steer the technology toward its final destination. Today's artificial invention technology can invent nothing of its own volition, just as a genie can only sit idly by without an Aladdin to make a wish.

The fact that artificial invention technology automates the inventive process only partially does not diminish its significance. First, as we've already seen, even such partial automation automates the kind of physical design processes that, until now, were the exclusive province of human creativity. Second, every kind of machine-automated process we've ever encountered is partial in the sense that it requires some human involvement to guide it. Yet the incompleteness of such automation does not make it unworthy of attention. Take the automobile, whose very name means "automated motion machine." No one today would deny that the automobile did in fact automate transportation in a noteworthy way, even though if you sit down in a car it will take you nowhere on its own volition. You, the human operator, must still control its every turn. If you get stopped for speeding, your plea that the car exceeded the speed limit "automatically" will fall on deaf ears.

This is just one example of a more general phenomenon: that humans and machines always interact with each other as a system, even when those machines automate a task previously performed by humans. Inventors and the

tools they use are no exception. Long before there were computers, inventors used physical tools, ranging from hammers to line levels to scales, to help them build, test, and measure their inventive works-in-progress. Inventors are also expert at leveraging conceptual tools (such as the laws of physics expressed in mathematical language) to help them design new machines, predict their performance, and understand their reasons for failure. It is hard to imagine inventors engaging in any but the simplest inventive activity without using tools.

Inventors are masters at using tools, but also at inventing new tools to boost their own inventive abilities. Early humans learned to use one rock to sharpen another, and then to use that newly sharpened rock to carve a boat from a fallen tree. Savvy inventors will use artificial invention technology in the same way, to boost their inventive abilities to previously undreamt heights. Focusing exclusively on the possibility that computers will *replace* human inventors overlooks the more complex, probable, and promising prospect that inventors will leverage computers to *augment* their inventive skills and thereby surpass the inherent limitations of their own minds.

Therefore, although today's artificial invention technology is the next step in the age-old evolution of tools used by inventors, it is a step with profound consequences for how we invent because it will produce a qualitative shift in the division of labor between human inventors and their tools, and a corresponding increase in the power of the human-computer inventive system. Human inventors, once responsible for designing every detail of their inventions, will be freed (and highly valued for their ability) to identify the problems they are trying to solve, and to pose those problems to artificial invention software in a language the software can understand. The software will then do the rest.

Genies v1.0 and Beyond

Today's artificial invention technology is a logical extension of the technology that computer programmers have been using for decades to create software. Unlike previous generations of innovators, who forged their inventions by molding, cutting, and extruding raw materials to match their designs, computer programmers bend computers to their will by writing computer programs consisting of instructions. Then they provide those instructions to a computer, which automatically transforms the instructions into working software in the computer's memory or on the CD that you buy in a store. In

this sense, computers have *always* been like genies, transforming the wishes of programmers into reality.

Getting a genie to do your bidding isn't quite as simple, however, as just putting your wish into words. Anyone who's read a story about genies or wishing (think of the myth of King Midas) knows that wishing can be a tricky—and even dangerous—business.[14] One slip of the tongue and you may find yourself turned into a toad rather than bathed in riches. Successful wishing requires you to phrase your wish using just the right magic words. Computer programming works the same way, requiring mastery of programming languages whose rules must be followed with extreme precision. Every time your computer crashes you can rest assured that some software on your computer was written by a programmer who didn't follow the wishing rules to a T. Similarly, although inventors in the Artificial Invention Age will not need to muck around with the low-level details of their inventions, they will still need expertise of another kind to write instructions that can successfully command a computer to produce working inventions.

We've all witnessed firsthand the benefits of this early version of computers as artificial genies in contexts extending far beyond our desktop computers. Manufacturers of everything from televisions to microwave ovens to radar systems have been replacing old mechanical and electrical components with software for decades, not just because software is cheaper to manufacture and distribute but because software is faster, easier, and less expensive to design. Why pay an electrical engineer to design a complex circuit for calculating a mathematical formula when a computer programmer can do the same job by writing one line of computer code, a one-sentence wish?

The same basic technique that automatically transforms the instructions written by programmers into working software is also used to create the microprocessors of modern computers themselves. No human engineer or team of engineers could hope to design manually the billions of transistors in a modern microprocessor. Instead, electrical engineers design a new processor by writing instructions in a "hardware description language" (HDL) explaining what they want the processor to *do* and then give the description to software that transforms the description into a schematic for a processor.[15] Tomorrow's engineers will use similar techniques to design the next generation of nanotechnology precisely because of the complexity of the technology and the benefits of computer-automated inventing.

Inventing by wishing is here to stay. Combine artificial invention tech-

nology's ability to automatically create machine designs with continuing improvements in low-cost automated manufacturing and networked collaboration, and you'll see we stand poised for an exponential expansion of the ability to satisfy our material needs.

A Roadblock: Patent Law

Yet there's a roadblock standing in the way of this bright future: patent law. Today, patent law determines *who owns inventions*. Tomorrow, patents on artificial invention technology will determine *who owns the right to invent*. Patent law will therefore confer awesome power on those who take advantage of it—too much power, if we don't begin to update patent law now.

Just imagine if Henry Ford had been given absolute control over who could and could not use an assembly line to speed production and lower costs, or if telegraph inventor Samuel Morse had obtained the power to block anyone else from using not just the telegraph but *any* machine capable of transmitting messages over long distances using electricity. (In fact, Morse attempted to obtain just such a broad patent but was shot down by the U.S. Supreme Court in 1854.[16]) Granting powerful patents to inventors of early advances in artificial invention technology could bestow on such patent owners the ability to block competitors, and the public more generally, from using such technology to produce their own inventions. Such patents, if granted improvidently, could concentrate in the hands of a few the ability to use what may turn out to be the most effective techniques for inventing in the 21st century. In this scenario, patent law would stifle innovation instead of promoting it.

We should not, however, rule out patents on artificial invention technology or the inventions it produces simply because such patents could be abused. Other new technologies, from traditional software to gene sequencing, have required us to rethink how we should apply patent law to them to ensure that the resulting patent rights are neither too weak nor too strong, since erring in either direction can impede technological progress. The advent of the Artificial Invention Age brings us to another such inflection point. If a computer running powerful artificial invention software is like a genie, and if the instructions that a human gives to such a computer are like a wish, then we must squarely face the question, Should artificial genies, or the wishes they grant, or the inventions they produce, be patentable?

My answer to all three parts of this question is a qualified yes, because all such patents will play an important role in promoting innovation in the Artificial Invention Age, so long as such patents are examined particularly carefully to ensure that only the right ones are granted. Recall the Creativity Machine, which Stephen Thaler used to design the CrossAction toothbrush. Dr. Thaler obtained a patent on the Creativity Machine, in which he described how the Creativity Machine works. Now anyone with the right technical background can read the patent and—once the patent expires—build and use her own Creativity Machine *for free*. Dr. Thaler would have had little reason to publish such a description, given that his competitors could have used it to compete against him, were it not for the patent rights that he received in exchange. In this way, the patent system performed its intended role of expanding the public's knowledge about a significant technological advance.

As people such as Dr. Thaler develop even more powerful artificial genies, the lure of patent protection for those genies will encourage them both to continue innovating and to describe their inventions in patents, which are published for the world to read. If we deny patent protection to artificial invention technology, or confer protection that is too weak, the Stephen Thalers of the world may forgo inventing the next Creativity Machine, or keep it a secret, making money by charging companies for the right to use it in private to generate new inventions. In this scenario, too, the public loses because the only players who will benefit from artificial invention technology are those who can afford to pay for the right to use it.

Standing at the outset of the Artificial Invention Age, therefore, we must ensure that patent law strikes the right *balance* when allocating ownership rights in artificial invention technology and the inventions it produces. Patent rights, like Goldilocks's porridge, must be neither too strong, nor too weak, but just right. If we fail to strike the right balance, the cost to our economy, to the growth of technology, and even to the quality of our lives will be incalculable.

We have every reason to believe, however, that patent law as it exists today will strike the *wrong* balance if we apply it to artificial invention technology. Those who crafted the patent system over the course of centuries never dreamed that machines, rather than humans, would one day design inventions. Like a car driven at twice its rated speed limit, patent law will break down if it is applied to artificial invention technology.

We can already see the cracks in the dam as patent law rattles even in the face of old-fashioned software. Part of the problem is the sheer number of

patent applications for software. About 15 percent of *all* patents granted in the United States are now for software, with the number of such applications increasing eighteenfold over 20 years.[17] An inventor who files a patent application often waits for years until a patent examiner even reads the application for the first time. Government patent offices simply can't process this flood of patent applications effectively, and artificial invention technology will only open the floodgates wider.

One reason for this increase in software patent applications is that companies are becoming increasingly savvy about using patents as sword and shield in battle against their competitors. Large companies routinely obtain software patents as trading chips with other companies, or to block competitors; small companies patent their software to secure their investment and protect themselves against copying by bigger companies. More controversially, some small companies don't invent at all; they simply round up obscure software patents so they can collect royalties, licensing fees, and judgments from other companies using the technology.[18] Both Microsoft and Research in Motion (manufacturer of the Blackberry) learned this lesson the hard way when they were sued for patent infringement by small companies and each paid over *half a billion dollars* as a result.[19] There is every reason to think that companies will apply the same strategies to artificial invention technology and the inventions it produces.

The response of the courts to the ever-widening vortex of litigation generally has been to expand the range of software that can be patented, without acknowledging the role of automation in the process of inventing software, thereby escalating the problem instead of bringing it under control. Meanwhile, patent offices worldwide have done little to reform their software patent practices.

There is, however, a deeper problem with software patents. Patent law—which was designed to apply to concrete inventions such as the cotton gin and light bulb, whose physical structure we could understand and describe clearly and directly—still has not figured out how to grapple with something as seemingly ephemeral as software.

This problem will only intensify once patent law wrestles with artificial invention technology. It will be like trying to define legal rules for patenting the genie and the wish, rather than the lamp. Should Stephen Thaler's patent on the Creativity Machine enable him to prohibit anyone else from using the Creativity Machine to invent anything? Should the patent give Dr. Thaler

ownership of *all* of the toothbrushes that the Creativity Machine invents, or *could* invent—even if there are thousands of them? Dr. Thaler told me that although he could flood the Patent Office with such patent applications, so far he has chosen not to do so. What happens when he and others in the field of artificial invention decide to stop playing Mr. Nice Guy?

Several factors are converging to produce a perfect storm of legal conflict in this field. First, it is only in the last few years that artificial invention technology has become capable of reliably producing useful real-world inventions, rather than academic curiosities. Second, private for-profit companies based on artificial invention technology are now springing up around the world. Third, massive government and private funding of nanotechnology and biotechnology will drive further development and use of artificial invention technology because human designers cannot handle the complexity involved in manually designing the next generation of inventions in such fields.

Companies have already begun to obtain patents on artificial invention software and on inventions generated using it. The history of patents in other technological fields tells us that it is only a matter of time before disputes over ownership of such patents reach boardrooms and courtrooms in large numbers. If we begin *now* to reshape patent law to fit the new inventive paradigm made possible by artificial invention technology, the winners and losers will be sorted out in a way that promotes innovation and helps to usher in the most promising incarnation of the Artificial Invention Age.

Adapting to Invention Automation

The future, however, won't wait for patent law. Even if patent law remains unchanged in the Artificial Invention Age, everyone who comes into contact with artificial invention technology will need to learn how to adapt to it—and soon. The biggest advances are very nearly upon us, with effects potentially as profound as those of the Industrial Age. Individual programmers, scientists, and engineers who don't currently use the latest artificial invention technology (and this is the vast majority) will need to become adept at using it if they want to avoid being replaced by it. High-tech companies need to begin now to prepare for the effects of artificial invention technology on their businesses. Such companies not only need to get better acquainted with how such technology works and what kinds of teams must be assembled to exploit it;

they have to revisit their entire patent strategy, since the typical, knee-jerk approach of patenting everything that moves may or may not work in the Artificial Invention Age.

Patent lawyers like me will also need to get their minds around artificial invention technology so that they can best advise their clients. In particular, innovative companies will need to adopt nuanced legal strategies that take the operation and effects of artificial invention technology into account, whether they are obtaining patents on artificial invention technology or attempting to defend themselves against such patents.

Artificial invention technology even promises to enable consumers to become active "prosumers": producers *and* consumers of technology. Forward-looking companies, in a break from the traditional "take what we've got to sell you and be happy with it" model of doing business, are already engaging and even *collaborating* with their customers to create their next generation of products. Such developments, combined with artificial invention software and advances in low-cost "desktop manufacturing" technology, promise to bring true inventive power to the masses.

Such exhilarating possibilities, however, will only come to pass if patent law does not stand in the way. If we do nothing, control over artificial invention will fall to those players who are savvy enough to game the existing system to their private benefit. To avoid this, patent law must be reformed; it *can* be reformed, and now you will learn how.