Unlike forms of life where natural patterns merely express the rules of reproduction, survival, and death, human life expresses an awareness of the outer world, a consciousness of social norms, and a civilizing force that seeks out knowledge, passing it on to the next generation.

Preface

Legal professionals who work in areas where law, science, and technology converge need not know the intricacies of science or technology, but they must develop a sense for how these fields are integrally related in today’s society. For example, grounding in how science works, what constitutes a valid science, and what its limitations are serve to assess how a scientific discovery or technological innovation affects a client’s interests. With this objective in mind, this text differs from similar works in that it provides an explanation of the particular sciences and technologies in the context of the cases chosen for analysis. However, rather than place undue emphasis on the technical aspects, we have endeavored to present ideas, cases, and examples that require no more than a high school-level understanding of science, technology, and mathematics. Armed with this level of background, the lawyer, policymaker, or regulator can efficiently employ experts to explain the deeper and specific complexities, so that in turn they can educate the bench, bar, and public alike. At the end of the day, to represent a client’s interests competently where law, science, and technology come together, an advocate must be qualified to analyze techno-scientific information as if it were within his or her sphere of knowledge. This text lays the basis for achieving this important objective.

The introductory chapters survey the question “What is science?” through two different lenses—that of the scientist and that of the legal practitioner. Examples are drawn from forensic science to illustrate the importance of practicing good science, followed by a short treatise on the philosophy of science. Having established “what science is,” we focus our attention on the important role that definition and interpretation play in framing the legal issues dependent on science and technology.¹

¹ Experimental science is nowadays crucially dependent on technology for the realization of its research settings and for the creation of circumstances in which a phenomenon will become observable. Theoretical research within technology has come to be often indistinguishable from theoretical research in science, making engineering science largely continuous with “ordinary” science. This is a relatively recent development, not more than a century old, and is responsible for great differences between modern technology and traditional, craft-like techniques. The educational training that aspiring scientists and engineers receive starts off being largely identical and only
This is followed by chapters on science policy (complexities in managing a national system and initiatives in genetic engineering); and, technology’s bearing on privacy and ownership of ideas, information, discovery, and invention as supported by intellectual property law in the context of software/computers, business methods, bioengineering, and ownership of our anatomical parts. In closing, we look briefly at economic and societal impacts when law, science, and technology converge.

Science has the potential to reduce suffering, extend life, and increase living standards. It contributes to the indomitable quest to understand our reality and to acquire ever more precise knowledge about our place in the universe. In the hands of the irresponsible, scientific and technological change can alter ecosystems, natural patterns, and the sustainability of all organisms, including man. A core idea advanced throughout this book is that humanity depends on a natural evolutionary course for its place in the future.² If, through an irresponsible and irreversible application of technology, we were to damage the patterns formed by nature, we would be accountable for affecting the moral ecology upon which all life depends. The advocate who practices in the field where law, science, and technology meet can stand as a centurion against forces that deny justice and damage the planet. We believe that moral ends, supported in sound legal regulation and practice, better secure the integrity of nature’s patterns. Books such as this one may, we hope, fulfill that goal and help bring common sense and an educated eye to issues that at times seem insurmountably complex.

gradually diverges into a science or engineering curriculum. . . . In 1966, in a special issue of the journal Technology and Culture, Henryk Skolimowski argued that technology is something quite different from science. As he phrased it, science concerns itself with what is, whereas technology concerns itself with what is to be.


2. Neal Feigenson asks: “What could ‘natural evolutionary course’ possibly mean after so many centuries of human intervention? Is a science that promotes intervention in good ways any more or less natural than science that’s used for bad? And of course, there are serious policy debates at the margins and sometimes at the core of some of the technologies, e.g., are genetically modified seeds a net good or a net bad for the world, or does it depend on how their use is regulated?” (Private correspondence, Mar. 9, 2013) (on file with author).
Since the beginning of the Enlightenment, hundreds of scientific theories have been offered and widely accepted—and later proven false. Some, because an older theory could not support the newly discovered facts, or superior explanations of a phenomenon were made obsolete by a successor that accounted for a broader set of observations. Some theories, such as “chicken soup can cure the flu,” are often quickly disposed of by the rigors of controlled scientific studies. Other theories stand for decades, to wit, Copernicus’s discovery that Earth revolved around the sun, or Einstein’s theory that hypothesized a fixed speed of light, answering the question of why differences in the speed of light were not observed when the Earth moved closer to and away from the sun. More recently, DNA science has produced indisputable evidence of innocence for many who were falsely convicted, calling into question a historic reliance on a range of forensic evidence including bite marks, fiber analysis, latent fingerprints, and firearms.\(^1\) In another instance, lawyers armed with a better working knowledge of statistics upset 30 years of bullet composition evidence for determining the origin of a bullet’s manufacture.\(^2\)

Nearly every scientific discipline has been viewed at one time or another with varying degrees of skepticism. Even today, when the value of science is beyond question, there remains reservation about its potential to answer the “great mysteries,” such as the origin of life, the framework of the universe, the cause of certain cancers, or the effect of fossil fuel emissions on global warming. But reservation and, more pointedly, doubt, skepticism, and conjecture constitute the heart of a system for advancing scientific knowledge. In many ways this plays out in self-critical assessments or peer-reviewed scientific claims, both essential tasks in sustaining science’s credibility and value as an engine for progress. According to physicist David Deutsch:

> Appearances are deceptive. Yet we have a great deal of knowledge about the vast and unfamiliar reality that causes them, and of the elegant, universal laws that govern that reality. This knowledge consists of explanations: assertions about what is out there beyond the appearances, and how it behaves. For most of the history of our species, we had almost no success in creating such knowledge. Where does it come from? Empiricism said that we derive it from sensory experience. This is false. The real source of our theories is conjecture, and the real source of our knowledge is conjecture alternating with criticism.

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We create theories by rearranging, combining, altering and adding to existing ideas with the intention of improving upon them. The role of experiment and observation is to choose between existing theories, not to be the source of new ones. We interpret experiences through explanatory theories, but true explanations are not obvious.¹

Unlike science, which attempts explicit answers about nature, fields of study such as philosophy, history, and, not surprisingly, law can often point us to where scientific answers might be found. We need look no further than the role the law has played in the diverse triumphs from using DNA analysis to convict criminals while exonerating victims of flawed forensic processes to debunking the doctrine of “separate but equal.”⁴ Sound law and science each logically analyze evidence, frame and identify issues, respect principles and precedence, and work in the direction that leads to justifiable answers. Both disciplines move from discrete facts to explicit questions that further lead to qualified, detailed answers. But unlike the law, science adds the necessity for verification based on forming a hypothesis, making observations, gathering and testing data, and drawing conclusions. Unlike law, science discovers and in so doing expands the ken of universal and epistemic relationships and meaning—ones not based on authority, subjectivity, time, or place. Scientific knowledge is objective in the sense that it is not based on human emotion or feelings, yet it is also progressive where it supplants the field with superior, albeit provisional, explanations. And although science works to conserve established theories, it has shown a capacity to undergo revision when assumptions and data fail to account for what is revealed by more cogent, deeper analysis or advanced instrumentation. We see this in innovations in forensic science where “generation one” science, often based on subjective interpretation, is replaced by “generation two” science, based on objective outcomes that leave little or no room for subjective interpretation.⁵ Science has the potential, more than any other human enterprise, to reveal epistemic truths upon which the universe and everything in it depend, but it is only through the processes of skepticism, criticism, and creativity that we approach a qualified understanding of nature.

Through modern science, discoveries and inventions deliver, cornucopia-like and in ever-shorter periods of time, new research tools, bioengineered species, and state-of-the-art computers. These transform society’s health, security, and productivity, as well as the environment. Technological capability advances through science, and, as in a symbiotic relationship, new technology allows scientists to delve deeper into

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⁴ Brown v. Bd. of Educ., 347 U.S. 483 (1954). Thurgood Marshall, arguing before the Supreme Court, relied on sociological tests, such as the one performed by social scientist Kenneth Clark, and other data demonstrating that segregated school systems had a tendency to make black children feel inferior to white children.

⁵ An example of “generation one” evidence is the use of bite mark analysis to identify a suspect, whereas “generation two” evidence would be the use of DNA analysis to identify a suspect.
And it is through this affinity that the latest technology floods the world with increasing rapidity; some would say this is for the greater good, but clearly it carries in its wake some unintended and harmful consequences. Eli Whitney’s cotton gin serves as a stark example of creating an economy that was prosperous for many, while greatly influencing the country’s acceptance of slavery. Following commercialization of the invention circa 1800, plantations in need of larger work forces expanded their slaveholdings in both numbers and territorial scope. Cotton production doubled each decade thereafter. Increased cotton crops motivated other inventors to create new machines to spin and weave, and to fabricate new cotton-based products. Transportation methods, both for the raw materials and the finished goods, began to change. Significantly, the cotton gin increased the demand for low-cost workers, causing an increase in slave importation (in 1790 there were six slave states; by 1860, that number had grown to 15). Between 1790 and 1808, when Congress banned the importation of slaves, Americans had condemned over 80,000 Africans to labor on ever-larger plantations. The enslavement of tens of thousands finally led to the Civil War, which killed hundreds of thousands utilizing the latest war technology.

Just as the cotton gin shaped an antebellum 19th century, the radio, aerodynamics, rockets, atomic fission, quantum electronics, and computers shaped the 20th century. In this new era, society is shaped by cyberspace, the genome, nanotechnology, cognitive neuroscience, and artificial intelligence. With each passing year, the time between basic discovery and practical application continues to compress. New discoveries by physicians, chemists, and biologists lead to new cures and drugs at lightning speed. This is occurring as programmers supply a progression of new programming languages and as engineers work to develop phone-like devices and mass storage that packs information into microscopic “dots and dashes” on new electromagnetic media for transmission over the Internet. Just what does this portend for our future? How can we better estimate the effects it will have on our society? This question begins and ends on the imperative to better understand what things mean as our society undergoes a technological revolution.

During the past quarter century, the realm of technology has been extended to processes that solve problems that, at bottom, constitute scientific and mathematical systems designed to manipulate symbols and syntax to achieve levels of semantic interpretation. We see how this manifests in the computer programs that conventionally employ languages compatible with electronic digital technology and more recently in new biological and chemical products that, through science, construct new molecular
languages. These multiple forms of language running on different forms of technology socially reconstruct the world in which we live.

Historically, technology has meant the knowledge for creating things, but its definition is far from static, mushrooming to encompass not only things of material substance, but also ideas about intangible substances, such as software processes. So as our forebears had to recalibrate their cultural compasses when Galileo announced that the moon was illuminated by a reflection of the sun on the Earth, we now need to better understand the expanded notion of technology, and perhaps recalibrate our psychological, social, and moral views as well.

Our artistic impulses run toward revealing the spiritual and sensate needs of our lives, while the utilitarian runs largely toward the persistent human motivation to invent our way into the future. And a phenomenon of the late 20th century has been a dramatic rise in the rate of output of both expressive content and inventive processes followed by a remarkable convergence of these once disparate modes of human activity. The union blurs the line between expression (for example, what we say) and technology (for example, how we do it). If we treat technology as a form of property, then at the interface, we must treat expression as a form of property. Incrementally we replace technologies that once sprouted from the physical elements of a material world with technology steeped in the rules of social constructs, definitions cast in a language. Property interests are no longer made apparent by barriers such as a wire fence or the operating machinations of a device. Today we merely define what something represents and then stake our claim to

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9. Leonard Adleman, *Molecular Computation of Solutions to Combinatorial Problem*, 266 Science 1021–24 (Nov. 11, 1994). The “Hamiltonian path problem” aka “The Traveling Salesman” is just one of a number of such mathematical problems referred to as NP-complete (non-deterministic polynomials) that have been encoded in molecular strands of DNA and solved using the tools of bioengineering. This was the first example of computation carried out at the DNA level and suggests a fundamental connection between biology and computer science. Since 1994 others have extended the methodology to solving other difficult mathematical problems (e.g., satisfiability problems) where combinatorial possibilities range in the millions. See also Leonard Adleman, *On Constructing a Molecular Computer: DNA Based Computers*, in DIMACS: Series in Discrete Mathematics and Theoretical Computer Science 1–21 (R. Lipton & E. Baum eds., Am. Mathematical Soc’y 1996).

10. Technology: 1. a The application of science, especially to industrial or commercial objectives. b. The scientific method and material used to achieve a commercial or industrial objective. 2. Electronic or digital products and systems considered as a group. . . . 3. Anthropology The body of knowledge available to a society that is of use in fashioning implements, practicing manual arts and skills, and extracting or collecting materials. Am. Heritage Dictionary (4th ed. 2000).

it. Such has been the concern over patenting DNA sequences,\textsuperscript{12} software, mathematical algorithms,\textsuperscript{13} and business methods.\textsuperscript{14}

Law moves much of what is characterized as technology into the abstraction of language in delineating intellectual property boundaries. From a legal standpoint, there exists a virtual layering of legal language over the language of which the technology itself consists, which as we see in decisions over the past several decades (especially in software and bioengineered products) can be a source of confusion to would-be property owners, users, and legal decision makers. In cases dealing with computer programs, DNA-based testing, and business methods, courts have had to tackle conundrums as to whether information necessarily exists in a tangible medium, such as a DNA sequence or a computer program, or if it is nonexistent but for the manner in which our social reality assigns meaning to a host of phenomena—some tangible and some that are simply products of individual conceptualizations. In part, the law, as determined by legislatures, agencies, and courts, attempts to concretize or define meaning on the basis of institutional norms, which may have no objective, epistemic basis.

With new forms of communications technology, new modes of business have sprung up in the form of abstract financial systems, such as online purchasing, banking, and investing. Our world has increasingly become one where wealth is largely driven by the supply and demand of intangibles, derivatives, futures, and monetary policies.\textsuperscript{15} Mathematicians and economists create market-based trading instruments that are deemed products, but exist only by virtue of a set of rules that define the trading

\textsuperscript{12} See In re Deuel, 51 F.3d 1552 (Fed. Cir. 1995), where the inventor utilized a gene database or library for screening placental cDNA in isolating and purifying a heparin-binding growth factor (HBGF) from bovine uterine tissue and sequenced its amino terminus. In the process it was discovered that the gene exhibited mitogenic activity. The inventor then determined the first 25 amino acids of the protein’s sequence and from those isolated cDNA molecules that encoded for bovine uterine and human placental DNA’s coding for HBGF. The American College of Medical Genetics, the American Society of Human Genetics, and the National Institutes of Health oppose the wholesale patenting of gene sequences. For differing viewpoints on the subject, see public comments at http://www.uspto.gov/web/offices/com/sol/comments/utilguide/index.html.

\textsuperscript{13} Computer software patents have evolved such that protection runs to a solution to a primarily mathematical problem. The computer has been relegated to the status of some vestigial artifact that harkens back to a time when it served to provide a substantial part of the functional apparatus. Today it often serves merely as a foundational element such as a base plate in mechanical inventions or an electrical power supply in electrical inventions.

\textsuperscript{14} “Recently there has been a marked increase in public attention to the operations of the United States Patent and Trademark Office (USPTO), and specifically, the workgroup responsible for examining patent applications in automated business data processing technologies, Class 705. On March 29, 2000, the USPTO announced a plan to improve the quality of the examination process in technologies related to electronic commerce and business methods.” U.S. Patent & Trademark Office, Automated Financial or Management Data Processing Methods (Business Methods) (White Paper, Ver. 1.43, Mar. 2000).

\textsuperscript{15} Much, if not most, business wealth today stems from intangible property. Black’s Law Dictionary 690 (6th ed. 1990) defines intangible property as “Property that cannot be touched because it has no physical existence such as claims, interests and rights.”
instrument itself. We observe this phenomenon in financial transactions that no longer consist of the exchange of material things (gold, coins, or paper denominations) but of the electrical transmission of signals representing data in the form of bits pursuant to algorithms. When we couple computer systems operating under the control of complex algorithms, we have technology that defies anyone’s ability to anticipate its influence on markets around the world. Behind the scenes, autonomous financial systems, making as many as one trillion trades per second, have resulted in damaging market swings that occur in matters of seconds rather than hours. This dematerialization of technologies (expending energy as it moves data seamlessly past political boundaries) has produced new challenges to how we, with the aid of the law, regulate its use and determine who owns what, and what rights, duties, and liabilities should flow from such ownership.

As engineers consider the next generation of computer-controlled mechanical robots (of which there were 8.6 million worldwide as of 2010), the world’s first self-replicating synthetic (human-made from chemical parts) genome in a bacterial cell has the potential to advance a new species of biologically controlled entities. President Barack Obama convened the President’s Commission for the Study of Bioethical Issues to identify the risks and ethical boundaries surrounding this development. The Commission held a series of public meetings in Washington, D.C., Philadelphia, and Atlanta to hear and assess claims about the science, ethics, and public policy relating to self-replicating synthetic biology. In December 2010, the Commission issued its report, New Directions: The Ethics of Synthetic Biology and Emerging Technologies, which discussed the ethical issues, the science, and the potential benefits to society. Within the realm of bioengineering, similar concerns are raised with creating new plant, animal, and transgenic species. One must ask: Can government policy keep up with the requirements for regulation and control?


18. The J. Craig Venter Institute made the announcement, which immediately led to a call to present the findings to President Obama’s Commission on Bioethics.


Joel Garreau, author of *Radical Evolution*, argues that we are at an inflection point in history; humanity as we know it today will be decidedly different on the other side of the inflection.\(^\text{21}\) Here are a few examples of what is before us: Biological sensors, specifically neuro-chips, have been implanted into neuroanatomy for well over a decade. Most of the research was not on anyone’s agenda until a microchip was implanted in a chimpanzee to control its neuromotor functions, thereby allowing it to control a computer cursor using only its thoughts.\(^\text{22}\) In 2005, a tetraplegic became the first person to control an artificial hand using a brain-computer interface.\(^\text{23}\) In May 2012, *Nature* reported that two tetraplegic individuals, who were unable to move their limbs as a result of damaged brain stems, had sensors containing almost 100 electrodes implanted in their motor cortex. These sensors recorded neuronal signals associated with the intention to move and allowed them to guide a robotic arm to reach and grasp objects using only brain activity.\(^\text{24}\)

That common branch between artificial systems and the biology of organization and patterns has recently emerged in the form of the molecular computer, a device capable of solving a wide category of mathematical problems. This invention is remarkable because neither electronic nor mechanic apparatuses in the conventional sense assist in its computation. Its primary asset is that the richly informational DNA has a combination-seeking feature extant in its molecular makeup. Mathematicians looking for solutions in combinatorial logic may have found a device well equipped to solve problems generally thought too computationally intensive for even the modern computer. In 1994, Leonard Adleman at the University of California applied a DNA molecule as a computational element to solve a classical mathematics problem referred to as the “Traveling Salesman” or Hamiltonian path problem.\(^\text{25}\) Since Adleman, the technology of molecular computing using synthetic DNA has skyrocketed.\(^\text{26}\)

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21. Joel Garreau argues that we are engineering the next stage of human evolution through advances in genetic, robotic, information and nanotechnologies, by altering our minds, memories, and metabolisms. Over the next 15 years, he says, these enhancements will become part of our everyday lives, as technology promises to make us smarter and vanquish illness—but unrestrained technology may bring about the ultimate destruction of our entire species. **Joel Garreau, Radical Evolution: The Promise and Peril of Enhancing Our Minds, Our Bodies—and What It Means to Be Human** (2005).


25. The mathematician Leonard Euler posed a similar problem referred to as the Seven Bridges of Konigsberg. In Euler’s setup there is an island in the middle of a river. Seven bridges cross the two branches of the river. The object is to plan a walk in such a way that you cross each of seven bridges just once. Today we know these problems take the form of a situation-space or a state-space problem where an operator or computational rule is applied to existing states to produce new states.

as patented silicon-based computer processes for executing software often protect
the underlying mathematical algorithm processed by the computer, the algorithmic
analogs presented in the form of DNA strands will need protections as well. It is not
a stretch to conjecture that the ideas applied to rationalize the effective patenting of
software algorithms will next be applied to patenting molecular computers.

Molecular computers have dense information storage capacities (1 bit per cubic
nanometer), rich parallelism, and immense energy efficiency (they need no active power
sources, yet a cell can perform $10^{19}$ operations using one joule of energy). One gram of
DNA (approximately 1 cc when dry) can hold as much information as approximately
one trillion CDs. The latest supercomputers operate in the range of about 1 billion
($10^{12}$) operations per second. By using DNA molecules, effective speeds of as much
as $10^{15}$ operations per second can be achieved. Molecular computer devices have not
been advanced by recent innovations in synthetic biology, but the expectation is that
synthetic DNA will prove to be another design of choice for these kinds of computers.
Considerable progress has been made demonstrating that the molecular computers
follow the same general principles as a Turing machine, the theoretical underpinning
for how hardware and software combine to carry out digital computation. 27 Recently,
scientists at Stanford University constructed from genetic material a biotransistor that
works inside of living bacteria. 28

Only when products meet the market do policy makers, courts, and legislators
begin to consider issues that emerge from how such devices are actually applied to
satisfy needs and solve problems and, inevitably, are misused or infringe on important
rights. For example, as in-the-body computers and telecommunications augment and
replace conventional drugs therapies, to what extent is the current regulatory process
prepared to address safety and efficacy related to these technologies? Unlike biological
experimentation and laboratory artifacts, computer-like devices in the abstract or in
the research phase typically do not undergo serious scrutiny outside of the academic
world. This delay-time between technological advance and policy advance has been a
repeating feature throughout history, although perhaps the time has come to anticipate
any potential problems that lie ahead. To this end, at least in the bioengineering
community, various commissions and private institutions are trying to anticipate
problems responses rather than wait until complications are upon us. 29

Property in the technology age takes on features that heretofore were nonexistent
or at least not essential to a determination of individual, commercial, or societal

27. P. Frisco et al., Simulating Turing Machines by Extended mH Systems. Com-
(May 3, 2013), http://www.sciencemag.org/content/early/2013/03/27/science.1232758.abstract
?sid=27de36f9-9333-4a17-b891-cdb5c2567577.
29. For an historical perspective on how the bioengineering community, industry, and the
federal government cautiously approached the potential hazards of inserting viral DNA into
bacteria, see Sheldon Krimsky, From Asilomar to Industrial Biotechnology: Risks, Reduction-
interests. Examples of intangible property might be the databases used to advance gene therapy that someday might correct fetal abnormalities before birth. Who will fund, own, and control these databases or gene therapies? Perhaps the government or insurance companies might provide funding. Perhaps the government or special hospitals will control access. Another example relates to the potential for technology that links biological implanted sensors to telecommunications. Who will own the sensor once implanted, and who will control the network? Will the company that produced the sensor own it? Or will the person in whom it has been implanted be the owner? Under what circumstances might service to the sensor terminate or disconnect from the network? One might consider myriad possibilities along these lines. The convergence of computers, communications, and new biological forms will alter the world as we know it, the first alteration by virtue of the society we construct and the second by the kinds of things we grow and manufacture.

A few of the above-mentioned computer developments may be more than a generation away from impacting daily life, but we cannot ignore that in many instances literary and musical expression in the form of software and traditional invention have already coalesced, that software integrates with biology, that financial systems are autonomous. These newer breeds of technology spawn new kinds of intellectual property that affect commerce, First Amendment rights, autonomy, and economic justice. In other words, information, literary expression, art, and technology flow into a common artery to create the new kinds of technologic and social objects, integrated, inseparable, and, of course, invaluable in one’s daily life. This has led to great commercial wars waged in courtrooms across the nation and the world about who has the rights to new business methods, music downloads, and book publishing. It is also raising moral questions related to robots driven by artificial intelligence that are used as drones for a wide range of applications from police surveillance to package delivery services. The next generation of policymakers, lawyers, and ethicists will have much to consider.

30. Intangible property is property that cannot be touched because it has no physical existence, such as claims, interests, and rights. Black’s Law Dictionary 690 (6th ed. 1990).
31. Francis Fukuyama makes a persuasive argument that future biotechnology will change human essence as well as our social reality. F. Fukuyama, Our Posthuman Future: Consequences of the Biotechnology Revolution (2002).
32. See N.Y. Times Co. v. Tasini, 533 U.S. 483 (2001) (holding that publishers violate the copyrights of freelance writers when they allow their articles to be included in electronic databases such as Lexis-Nexis without compensating the authors). See also A&M Records, Inc. v. Napster, C 99-05183-MHP, 2001 WL 227083 (N.D. Cal. Mar. 5, 2001), aff’d, 284 F.3d 1091 (9th Cir. 2002) (members of the Napster service had compressed and stored MP3 music files using software available on the Internet; court enjoined Napster from offering such services).