Patent subject matter eligibility

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A response to

Notice of Roundtables and Request for Comments Related to Patent Subject Matter Eligibility

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This response is specific to the second roundtable for which the USPTO has requested public feedback regarding larger questions concerning the legal contours of eligible subject matter in the U.S. patent system. "The public is invited to submit comments on any topics related to patent subject matter eligibility under 35 U.S.C. 101 that they deem relevant. This roundtable event is not seeking additional input on the examiner guidance and training examples [sought earlier]. Instead, the USPTO is seeking to promote conversation on how the current section 101 jurisprudence is evolving; what the optimum legal contours for patent eligibility should be; and how best to achieve these goals."

Second Roundtable: Exploring the Legal Contours of Patent Subject Matter Eligibility. December 5, 2016, 8 a.m. to 5 p.m., Stanford, CA.
Written comments are due by January 18, 2017.
Written comments should be sent by electronic mail message via the Internet addressed to 101Roundtable2@uspto.gov.

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Setting the context

Inventions come from inventors. The patent act requires inventors to be humans. However, in the post-industrial economy, humans may not be the only source or even the most important source of inventions. The new inventors are likely to be humanized robots comprising biological and non-biological components with phenomenal cognitive and computing abilities, agility of mind and body, and of physical strength and dexterity. Although the USPTO's Request for Comments does not require us to comment on this aspect, we believe that soon much greater clarity on the role of humanized robots in creating inventions must take place to provide a contemporary scenario in which the patent act must function and be interpreted. In the following paragraphs, we briefly provide our views on this emerging aspect to indicate the wider scenario in which the patent act will need to function before providing our comments on patent subject matter eligibility.

In a world comprising humanized robots, patent system reform is not about how the last war could have been fought better but how to fight the next war when new, yet untested weapons and their usefulness in the theatre remain uncertain. Field trials are not enough to decide their battle worthiness. This is the critical situation 'subject matter eligibility' under 35 U.S.C. 101 faces. The socio-economic context in which § 101 was originally created is no longer valid. Today innovations can come from machines embedded with artificial intelligence (AI) software capable of cognitive acts as IBM Watson and Google's AlphaGo have shown by decisively defeating world-class human champions. Further, biotechnology is on the verge of creating humanoids comprising biological and non-biological components that are capable of highly augmented powers of cognition, computing, sensing, analyzing, and of physical prowess. It is no longer in the realm of science fiction that advanced humanoids in the future will effectively outperform most humans in acts that in the past required some combination of mind and body functions. Advances in biotechnology in the next two decades, going by the credible forecasts made by Ray Kurzweil, is expected to advance at an exponential rate, paralleling those in information technology (IT) and IT-embedded technologies.[3] The judiciary's indifference to this development in interpreting 35 U.S.C. 101 is alarming given that inventors are poised to bring more powerful technologies faster than we naively imagine or the judiciary can anticipate.

Kurzweil identifies genetics, nanotechnology, and robotics as the three overlapping revolutions which will define the future of the millennials. Genetics will allow us to reprogram and even create novel biological entities (the intersection of information and biology); nanotechnology will allow us to manipulate matter at molecular and atomic scales (the intersection of information and the physical world); and robotics will allow us to create super-human non-biological intelligence (the building of strong artificial intelligence on an information base). These technologies are rapidly converging towards an integrated information-driven technology. Note that till now humanity had assumed that intelligence is its most important and powerful attribute. With rapid advances in AI, that assumption now appears to be deeply flawed.

The core of robotics is embedded AI; it defines the robot. The AI revolution is the most radical transformation human civilization will experience in the post-industrial era. Robots, singly and in groups, can consistently perform flawlessly at peak levels and can combine peak skills. This raises a fundamental question: What then is the statutory definition of an inventor or coinventor if a super-robot or a humanoid solves or assists a human to solve a problem and the solution appears novel and non-obvious to a natural human? The law requires an inventor to be human, capable of creating novel

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[3] Ray Kurzweil, The Law of Accelerating Returns, 2001, http://www.kurzweilai.net/the-law-of-accelerating-returns; Ray Kurzweil, The Singularity is Near: When Humans Transcend Biology, http://stargate.inf.elte.hu/~seci/fun/Kurzweil,%20Ray%20-%20Singularity%20Is%20Near,%20The%20(hardback%20ed)%20%5Bv1.3%5D.pdf. *See also*: Sveta McShane and Jason Dorrier, Ray Kurzweil Predicts Three Technologies Will Define Our Future, SingularityHub, 19 April 2016, http://singularityhub.com/2016/04/19/ray-kurzweil-predicts-three-technologies-will-define-our-future/

and non-obvious inventions as compared to the creativity of a person having ordinary skill in the art (PHOSITA) related to the invention. Such an inventor is legally entitled to seek a limited period monopoly on his invention's intellectual property and trade in it. Humanoids and AI-embedded machines, even if they produce novel and non-obvious inventions by human yardsticks, fail this legal requirement. First, because they are not humans; second, if one of them produces a novel and non-obvious invention, then, at least all clones, or members of the same robot class *en masse* can independently produce the same invention if required to do so. Technically, this makes the invention a PHOSITA-like creation and the AI software enabling its production as embedding prior art. Thus, no human can claim exclusive patent rights on the invention. Further, if embedded AI software or the bio-engineered brain of a humanoid has built-in ability to *ab initio* recreate the invention either by itself or through collaboration with other humanoids or AI-embedded robots, can it be considered an infringing act? If it turns out, post-patent grant, that such humanoids and AI-embedded robots predated an active patent, should the patent be annulled? Such queries demand reexamination of §§ 100-103 and 112, if not the restructuring of the entire patent system, perhaps with humanoid assistance. This is not a far-fetched scenario. An experimental AI authored science fiction film *Sunspring* has already made its online debut in June 2016.[4] Robot creativity is no longer fiction.

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[4] Annalee Newitz, Movie written by algorithm turns out to be hilarious and intense, Arstechnica, 09 June 2016, http://arstechnica.com/the-multiverse/2016/06/an-ai-wrote-this-movie-and-its-strangely-moving/

Patent subject matter eligibility

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Abstract

We address a fundamental question: "What is patentable subject matter under the patent act?" The present confusion and rise in opportunistic patent litigation seen in the U.S. today is due to the three judicially created exceptions to the U.S. Patent Act's broad patent-eligibility principles: 'laws of nature, natural phenomena, and abstract ideas' whose scope and validity are questionable. Here we examine the exceptions from the perspective of post-1900 understanding of physics, mathematics, algorithms, computations, life sciences, and information theory. We conclude that the exceptions are irrational and anachronistic. The judiciary's lack of expertise in science, technology, engineering, and mathematics (STEM) has made the patent system unstable by continuing to err in holding that the laws of Nature are known to mankind and form "part of the storehouse of knowledge of all men" and "free to all men and reserved exclusively to none." In fact, the real laws of Nature are unknown and likely to remain so forever; physicists "know" them only as conjectures open to refutation. We also point out deep existing connections between biotechnology and software and explain why both are patentable subject matter—they are two sides of the same coin. Our perspective leads us to suggest a definition for patentable subject matter and provide fundamental tests for patentability. Finally, for efficient working of the patent system, we suggest the creation of a statutory body, the Patent Validation Board, whose decisions on patent validity and extent of patent infringement will be final and binding on the courts. The courts should decide only non-STEM matters, *e.g.*, damages.

Key words: 35 U.S.C. 101, patent, patent-eligible, statutory subject matter, abstract ideas, laws of nature, natural phenomena.

1 Cogito ergo sum

Scientists estimate that life arose some 4 billion years ago, in accordance with the laws of physics and chemistry,[7] yet how non-living, carbon based chemicals became alive remains a mystery. It is possible that yet unknown natural processes exist that can explain the mystery. The speed with which molecular biology is unfolding via genetic engineering, the mysteries of the living world may unfold faster than we imagine. When that happens, can the SCOTUS (Supreme Court of the United States) rationally claim that the diligently discovered conjectured "laws of Nature" are unpatentable subject matter and that these laws are preexisting "part of the storehouse of knowledge of all men". Humans possess some unusually developed[8] mental traits—self-reflection, and moral, ethical and aesthetic values—that we have come to believe are an essential part of what we call the human condition. Self-reflection is the mental process by which we seek and create knowledge through continuous exploration, individually and collectively. In mathematics, self-reflection surfaces as *self-referential*, in algorithm design as *iteration*, and in control system engineering as *feedback loop*. In addition, we are acutely self-aware—"Cogito ergo sum" (I think, therefore I am)[9], said René Descartes (1596-1650) while attempting to find foundational nuggets of knowledge. This self-awareness and the systematic

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[7] Hazen (2005).

[8] We deliberately refrain from using the word "unique" since we know very little about the rest of the animal kingdom, including our closest living relatives the apes.

[9] The converse, "I am, therefore I think" appears to be equally true.

pursuit of knowledge became intimately connected with our natural sense of justice, "willing to punish unfair actions even if the consequences of such outrages harm our own interests. Also, we appreciate searching for novelties, listening to music, viewing beautiful pictures, or living in well-designed houses. But why is this so? What is the meaning of our tendency, among other particularities, to defend and share values, to evaluate the rectitude of our actions and the beauty of our surroundings? What brain mechanisms correlate with the human capacity to maintain inner speech, or to carry out judgments of value? To what extent are they different from other primates' equivalent behaviors?"[10]

The 21st century will perhaps enlighten us, given the ongoing rapid advances in genome sequencing, data analytics, artificial intelligence software, and the enormous expansion of the R&D population engaged in answering such questions. Comparative genome studies that include our closest living relatives the apes, and our closest extinct relative the Neanderthal are expected to reveal genes that are necessary for specific human traits, and a better understanding of what distinguishes us from other species from a genetic point of view. These efforts, we hope, would help us uncover the biology behind human cognition, language and culture[11] that led to the forming of human societies and how intellectual property and its protection has emerged as central to our modern socio-economic structure that has scaled itself from the family as a unit to the whole world as a unit.[12]

1.1 Patentable subject matter and its interpretation by SCOTUS

Of central importance to U.S. patents is § 101 of the Patent Act of 1952. It broadly stipulates what can be patented (it remains unchanged after the America Invents Act[13] (AIA)):

> 35 U.S.C. 101 Inventions patentable.
>
> Whoever invents or discovers any new and useful process, machine, manufacture, or composition of matter, or any new and useful improvement thereof, may obtain a patent therefor, subject to the conditions and requirements of this title.

In 1952, when the patent laws were recodified, Congress replaced the word "art" with "process", but otherwise left the earlier language intact. Among the categories of inventions deemed by Congress to be patentable, the first, "process", defines "actions" (*i.e.* inventions that consist of a series of steps or acts to be performed – the *verbs* or in mathematics, the *operators*). The remaining three categories define "things" or "products" – the *nouns* or in mathematics, the *operands*. Subsections (a) and (b) of § 100 provide definitions of the terms "invention" and "process" as follows (they remain unchanged after AIA):

> 35 U.S.C. 100 Definitions.
>
> When used in this title unless the context otherwise indicates -
>
> > (a) The term "invention" means invention or discovery.
> >
> > (b) The term "process" means process, art, or method, and includes a new use of a known process, machine, manufacture, composition of matter, or material.

The definitions are not useful since the terms "invention" and "process" are used in their respective definitions; they merely list near synonyms. Discerning their meaning is left to our intuition.

Invention is an observer centric, dynamic concept. What appears as an invention to an observer at any time depends on his stored knowledge, his ability to anticipate and correlate events and observations,

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[10] NAP (18573) (2014).

[11] Pääbo (2010).

[12] *Vasudhaiva Kutumbakam* is a Sanskrit phrase found in Hindu texts such as the Maha Upanishad, which means "the world is one family".

[13] AIA (2011).

his interest, *etc*. All inventions germinate as an idea in a person's mind. There is no recipe for creating an invention; it can occur serendipitously ("out of the blue" usually ending in an "aha!" discovery) or by following a plotted course or "prospecting" (the deliberate, tenacious, and laborious process of pursuing a line of work with various levels of uncertainty at different stages with the possibility of the goal also changing as one progresses and/or regresses) or some combination of the two. Nevertheless, such things as a musical composition, literary work, compilation of data, or legal document (*e.g.*, an insurance policy) *per se* are not patentable because they are deemed unclassifiable as a process, machine, manufacture, or composition of matter.[14] Statutory subject matter must, of necessity, be expressed in broad terms and interpreted with an open mind. Because patents are granted for new technology, it is not possible for law makers to enumerate specific categories (*e.g.*, software-based inventions or genetic material based inventions) in the patent statutes by forecasting the future development of technology or scientific knowledge.

Presently there are two important statutory subject matter exceptions: atomic weapons[15], and inventions that claim a human or encompass a human organism[16]. In addition, some judicially created exceptions exist, the most important of them are abstract ideas (such as mathematical formulas), laws of nature and natural phenomena since they are neither process, machine, manufacture, nor composition of matter. (In the following sections, we argue that the judicial basis for these exceptions are unsound.[17]) There is financial exclusion too! Getting a patent is expensive, and protecting it, if infringed, via litigation is usually prohibitive. This works to the advantage of corporations with large R&D budgets and huge cash reserves. They tend to develop a natural monopoly in patents compared to individual inventors with very limited capacity to deal with litigation, which they may be forced into by wealthier patentees or alleged infringers. In this sense the law is inequitably exclusive.

The exceptions apart, prior to 1980, the USPTO (United States Patent and Trademark Office) had assumed that software and living matter were *not* statutory subject matter and hence outside the ambit of the patent act. That changed in 1980 when, based on Committee Reports accompanying the 1952 Patent Act, the SCOTUS in *Diamond* v. *Chakrabarty*, made clear that Congress intended statutory subject matter to "include anything under the sun that is made by man."[18] The narrow task before the court in this case was to "determine whether Chakrabarty's micro-organism constitute[d] a "manufacture" or "composition of matter" within the meaning of the statute." The court ruled that Chakrabarty's micro-organism qualified as patentable subject matter because his claim was not to a hitherto unknown natural phenomenon, but to a non-naturally occurring manufacture or composition of matter – a product of human ingenuity having a distinctive character and use. That the invention was living matter was of no legal consequence. It added that a categorical denial of patent protection for "inventions in areas not contemplated by Congress … would frustrate the purposes of the patent law."[19] The broad language of the statute is deliberate and shows Congress' intent to give the patent laws wide scope. § 101 is a "dynamic provision designed to encompass new and unforeseen inventions."[20] Despite dramatic changes in technology, it has generally served well for over 200 years.

1.2 Patentable subject matter – a revised view

On the face of it, the *Diamond* v. *Chakrabarty* decision appeared logical but it produced unintended consequences. By including "anything under the sun" it opened the floodgates for patents in software,

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[14] The listed things are usually protected under copyright law.

[15] 42 US Code § 2181 - Inventions relating to atomic weapons.

[16] USPTO, Evaluating Subject Matter Eligibility Under 35 USC § 101: August 2012 Update, http://www.uspto.gov/sites/default/files/patents/law/exam/101_training_aug2012.pdf. *See also*: Section 33(a) of the America Invents Act 2011; 35 U.S.C. 101; and Animals – Patentability, 1077 Off. Gaz. Pat. Office 24 (April 21, 1987).

[17] Earlier articulated in Bera (2015c).

[18] S Rep. No 1979, 82d Cong., 2d Sess., 5 (1952); H.R. Rep. No. 1979, 82d Cong., 2d Sess., 6 (1952).

[19] SCOTUS (1980).

[20] SCOTUS (2001).

business methods, and biotechnology. The USPTO found itself unprepared both in terms of its repository of related prior art and of qualified patent examiners to deal with patent applications that began to pour in. It also became unsure when a patent application could be safely rejected under the Court's decision. An unusual number of dubious, and some outright "silly", patents began to emerge. The gathering storm brewed patent trolls and patent wars emerged from unexpected sources. It is now time to revisit patentable subject matter. We therefore begin with an interpretation that is consistent with the patent act and Congress' intent to grant patents to "include anything under the sun that is made by man" without debilitating the free-market economy. Our interpretation is:

> Anything that has existed or exists or can exist in nature in the absence of a thinking human belongs to prior art. Anything, since a thinking human began to populate the Earth, that exists or is known to have existed or was conclusively known that it could have been created by human, machine, or some human-machine combination in the past also belongs to prior art, except those human-created inventions which have been held secret so diligently that unless disclosed by the inventor they would remain so. Anything else that reasonably could not have been created in nature without human intervention, observation, insight, serendipity, reasoning, ideation, or ingenuity, is eligible patent subject matter if that invention is replicable by others, if necessary, after diligent training, instruction, access to necessary materials, and availability of the requisite environment. A patent may be granted to an invention if it qualifies as patentable subject matter provided it fulfills all other statutory requirements required by man-made laws for the grant of a patent and without being an embarrassment to society.[21]

The Patent Act, as it stands, in addition to stating that an invention must come from a human inventor, requires the invention to be useful (§ 101) to society, and from the perspective of a PHOSITA (person having ordinary skill in the art) related to the invention, novel (§ 102), non-obvious (§ 103), and clearly described, including ownership of the IP territory claimed (§ 112). These four core requirements of patent grant are not discussed in this response. Here we shall focus on the nature of knowledge explosion that powers the post-industrial economy (Section 2), and in that light why certain changes are necessary in deciding what is patentable subject matter (Section 4).

1.3 A STEM handicapped judiciary

In the United States, the judiciary is the sole authority to interpret the Constitution (including its provisions for religious freedom) and laws passed by the legislature and to nullify laws that violate that interpretation. Its highest court is the Supreme Court, comprising nine members (Justices) who are granted lifetime appointments to insulate them from short-term political influence. To promote continuity with past decisions, the Court uses the doctrine of precedent (*stare decisis*; "to stand by things decided"). These two built-in institutional rigidities induce resistance to change and precedents may continue to influence new cases even when the context differs. Thus, reversals or reformulations are rare. Not surprisingly judicial interpretations change rather sedately; change is more likely when new members of the judiciary apply the law to new contexts. The world has gingerly moved from relying on theological ignorance to judicial ignorance about the laws of Nature.

A lack of science, technology, engineering, and mathematics (STEM) expertise in the SCOTUS means it has a fuzzy grasp of what drives STEM advances, the culture of curiosity-driven pursuit of knowledge that pervades the scientific research community, a scientist's natural desire to share his discoveries with all, the evolutionary history of science-rooted and science-driven technologies, and the risk-laden adjustments businesses must make to seamlessly blend with the knowledge-driven global economy. This leads to uninformed judicial decisions in patent cases, especially when dealing with infringement and patent validity in the newer, emerging, and vitally important technologies such as biotechnology, software, modern medical diagnostic and treatment, artificial intelligence, *etc*. The SCOTUS's present

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[21] An earlier version appears in Bera (2015c).

misgivings, after it declared in 1980 that "anything under the sun that is made by man"[22] is patent eligible, is visible in its trepidation, reluctance, and unseemly caution when deciding what constitutes statutory subject matter, which the patent law in broad terms states are "process, machine, manufacture, or composition of matter", from which the Court has excluded "laws of nature, natural phenomena, and abstract ideas" as being patent-ineligible. To these the Leahy-Smith America Invents Act (AIA), Pub. L. 112-29, sec. 33(a), 125 Stat. 284, has added:

> Notwithstanding any other provision of law, no patent may issue on a claim directed to or encompassing a human organism.

This exclusion is questionable given that modern advances in synthetic biology[23] clearly indicate that human-designed organisms are scientifically possible and that it may one day create far superior humans with tailored physical and mental attributes. Does this exclusion in the patent act indicate an influence of the Church (or generally, of religion) in the affairs of the State? When the techniques of synthetic biology percolate down to high school biology laboratories, as it one day will, what exactly will this exclusion accomplish? Unenforceable laws invite anarchy.

When the SCOTUS excluded the triad—'laws of nature, natural phenomena, and abstract ideas'— from getting patents, it never provided, in STEM terms, its understanding of the triad. It still cannot for lack of STEM expertise. Hence confusion about the triad's exclusionary boundary prevails and encourages opportunistic litigation. We therefore explain what the triad means to STEM experts, post-1900. The judiciary's fundamental error is to hold that the laws of Nature are "part of the storehouse of knowledge of all men" and "free to all men and reserved exclusively to none." The post-1990 advances in physics, mathematics, algorithms, computations, life sciences, and information theory clearly indicate that no human knows the real laws of Nature and perhaps never will. Physicists "know" them only as refutable conjectures. The real laws of Nature are prior art but held by Nature as trade secrets. Two recent cases[24] related to personalized medicine decided by the SCOTUS show the danger of courts deciding issues without a deep understanding of the scientific discovery process and the symbiotic interdependency between scientific research and the industrial application of that research in human welfare. In 2012, the Mayo Collaborative Services v. Prometheus Laboratories, Inc. decision struck down two patents on medical diagnostics, and in 2013, the Association for Molecular Pathology v. Myriad Genetics decision threw out patents on gene sequences used to assess cancer risk. Both decisions have created apprehensions that inventions important for marketing personalized medicine may take a hit because such decisions may inhibit investors from funding research if inventors feel barred from getting patents to commercialize their inventions.[25] The courts should bow out from ruling in patent cases where STEM expert opinion is crucial. Matters of patent validity and extent of patent infringement should be the exclusive province of a body of STEM experts, *e.g.*, a Patent Validation Board (PVB) (see Section 5.2). Its opinion should not be contestable in a court.

2 How STEM came to rule post-industrial economy

Since the three judicial exceptions (triad) have been widely adopted globally and are well entrenched in law, it is necessary to explain their invalidity in detail. Further, given that judges are not trained or have doctoral degrees in STEM, it is necessary to describe at length the state of STEM knowledge prior to 1900, and the advances made since that necessitate revisiting the triad. The description is divided into two parts: (1) STEM before 1900 when the triad was declared, and (2) explosion of STEM knowledge since 1900, when scientist learnt that they do not know the real laws of Nature.

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[22] SCOTUS (1980).

[23] Bera (2015a).

[24] These are SCOTUS (2012) and SCOTUS (2013).

[25] Ledford (2016).

2.1 STEM before 1900

The modern patent system, in a sense, draws inspiration from Galileo Galilei (1564 – 1642), the father of modern physics, who in 1594, had petitioned for and was granted a patent for a machine which he had invented "for raising water and irrigating land".[26] In 1623, the same Galileo wrote,

> Philosophy [*i.e.* physics] is written in this grand book, the universe, which stands continually open to our gaze, but it cannot be understood unless one first learns to comprehend the language and interpret the characters in which it is written. It is written in the language of mathematics, and its characters are triangles, circles, and other geometrical figures, without which it is humanly impossible to understand a single word of it; without these, one is wandering around in a dark labyrinth.[27]

In 1637 René Descartes (1596–1650) published his masterwork, *Discourse on the Method of Reasoning Well and Seeking Truth in the Sciences.*[28] In that he unified geometry and algebra for the first time into what became coordinate geometry. Descartes assigned number-pairs to the points of plane Euclidean geometry, and proved geometrical theorems about points by proving algebraic theorems about numbers. Euclidean geometry thus became a branch of algebra. Its great advantage was that one "could borrow all that was best both in geometrical analysis and in algebra, and correct all the defects of the one by help of the other." A few centuries later, computer graphics sailed in because geometric figures could be given algebraic form and plotted on a computer screen pixel-by-pixel. Descartes, *de facto*, had enabled the future of modern computer graphics.

While Descartes was alive, in the year Galileo died, an intellectual colossus, Isaac Newton (1642–1727), was born, who put physics on a sound mathematical footing. His book *Philosophiæ Naturalis Principia Mathematica*[29] ("Mathematical Principles of Natural Philosophy"), first published in 1687, laid the foundations for classical mechanics. He also shares credit with Gottfried Leibniz for the development of calculus. For the first time, one could get a feel of the Universe in precise mathematical language that described the action of forces on matter and its motion rather than from divinity.

While Newton pinned down the mathematical description of the gravitational force acting between masses, James Clerk Maxwell (1831–1879), nearly two centuries later, provided the mathematical description of the electromagnetic force[30] (1864). Newton's equations of motion and his law of gravitation, complemented by Maxwell's equations of electromagnetism pretty much made up the *force* and *motion* knowledge required to deal with the engineering and technology of the time. During Maxwell's lifetime, the laws of thermodynamics were also discovered with a central role played by Léonard Sadi Carnot (1824)[31] and Rudolf Clausius (1850)[32]. In 1854, Lord Kelvin gave a definition of thermodynamics as follows:

> Thermo-dynamics is the subject of the relation of heat to forces acting between contiguous parts of bodies, and the relation of heat to electrical agency.[33]

The laws of thermodynamics provide fundamental mathematical relations between *temperature*, *energy*, and *work* along with certain general constraints[34] applicable to all materials and processes. Thermodynamics established the crucial notion of *entropy*, which essentially is a measure of the number of specific ways in which a thermodynamic system may be arranged. So, this is where the best

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[26] Bugbee (1967), p. 24.

[27] Galileo (1623). The only modern scientist known by his first name.

[28] Descartes (1637).

[29] Newton (1687).

[30] Maxwell (1865).

[31] Carnot (1824). Carnot introduced the first modern definition of *work* as weight lifted through a height.

[32] Clausius (1850). Clausius defined the term *entropy* as the heat lost or turned into waste.

[33] Thomson (1854). In this paper, William Thomson (Lord Kelvin) first coined the term *thermo-dynamics*.

[34] For example, it forbids the existence of a perpetual motion machine in nature.

of scientific knowledge, with precise mathematical descriptions, was when the industrial revolution (1760-1840) was ushered in. The French Revolution began in 1789. Notable inventions made during the industrial era include: steam engine (James Watt, 1769; it became a major driver of the industrial revolution); sewing machine (Thomas Saint, 1790); vaccination (Edward Jenner, 1796); the telegraph (Samuel Morse, 1837); rubber vulcanization (Charles Goodyear, 1839); internal combustion engine (Jean Lenoir, 1858); typewriter (1860s); the telephone (Alexander Graham Bell, 1876); the electric bulb (Thomas Alva Edison, 1879); first practical automobile powered by an internal combustion engine (Karl Benz, 1885); AC motor and transformer (Nikola Tesla, 1888); first human-controlled, powered and sustained flight of a heavier-than-air airplane (Wright brothers, 1903); *etc.*[35]

The industrial stage lasted only a few centuries and thus acted as a transitory phase before ushering in the present post-industrial stage.[36] The transition essentially reflected a fundamental change in the motive power driving economies – from brawn power augmented by industrial machines to brain power augmented by computing machines, and with it the source of innovation – from the artisan to the university educated knowledge professional. But even more remarkably, as John Maddox notes:

> The [nineteenth] century thus ended on a triumphant note. Not only had fundamental physics been reduced to a series of problems in mathematics that would in due course be solved, but the closing decades of the century were made prosperous by technology resting on science that was itself the product of the same century. The dyestuffs industry and the chemical industry more generally were the products of the atomic theory and what followed from it. The electrical industry (harbinger of the communications industry) had already begun to change the world. For science and technology, the nineteenth century was certainly the best there had yet been. Only now do we know that it was merely a beginning.[37]

2.2 Explosion of STEM knowledge since 1900

By 1900, scientific knowledge had advanced so much, or so it seemed, that Max Planck would later recall, “When I began my physical studies [in Munich in 1874] and sought advice from my venerable teacher Philipp von Jolly... he portrayed to me physics as a highly developed, almost fully matured science... Possibly in one or another nook there would perhaps be a dust particle or a small bubble to be examined and classified, but the system as a whole stood there fairly secured, and theoretical physics approached visibly that degree of perfection which, for example, geometry has had already for centuries.”[38] In 1875, Heinrich Hertz said, “Sometimes I really regret that I did not live in those times when there was still so much that was new; to be sure enough much is yet unknown, but I do not think that it will be possible to discover anything easily nowadays that would lead us to revise our entire outlook as radically as was possible in the days when telescopes and microscopes were still new."[39] In 1894, the American physicist Albert Michelson said, “The more important fundamental laws and facts of physical science have all been discovered, and these are now so firmly established that the possibility of their ever being supplanted in consequence of new discoveries is exceedingly remote. ... Our future discoveries must be looked for in the sixth place of decimals.”.[40] In 1895, Lord Kelvin (William Thomson, 1824-1907) had confidently said, “heavier-than-air flying machines are impossible” (at the Australian Institute of Physics), and in 1896 he said, “I have not the smallest molecule of faith

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[35] “In science credit goes to the man who convinces the world, not the man to whom the idea first occurs.” (Francis Galton)

[36] In comparison, the agricultural economy preceding it spanned about 12,000 years. *See*, *e.g.*, Bernstein (2004).

[37] Maddox (1998), p. 9.

[38] From a 1924 lecture by Max Planck (Sci. Am, Feb 1996 p.10). Quote reproduced from http://amasci.com/weird/end.html. Planck received the 1918 Nobel Prize in Physics “in recognition of the services he rendered to the advancement of Physics by his discovery of energy quanta”.

[39] Heinrich Hertz as a physics student. Quote reproduced from http://amasci.com/weird/end.html

[40] Albert. A. Michelson, speech at the dedication of Ryerson Physics Lab, U. of Chicago 1894. Quote reproduced from http://amasci.com/weird/end.html. Michelson received the 1907 Nobel Prize in Physics "for his optical precision instruments and the spectroscopic and metrological investigations carried out with their aid".

in aerial navigation other than ballooning ... I would not care to be a member of the Aeronautical Society."[41] The same Kelvin also told an assemblage of physicists at the British Association for the advancement of Science, in 1900, "There is nothing new to be discovered in physics now. All that remains is more and more precise measurement."[42] How wrong he and all others would prove to be within a few years!

Almost immediately, starting 1900, some breathtaking advances in physics (quantum mechanics (1900-1926), and theory of relativity (1905, 1916)), heavier than air flying machines (Wright brothers, 1903), foundations of mathematics (Gödel's theorem, 1931), mathematical algorithms and computing (the abstract Universal Turing Machine, 1936), biology (discovery of the double helix structure of the genetic information carrying DNA molecule, 1953), the microchip (1958), and space (men stepping on the surface of the Moon and safely returning to Earth, 1969) would be accomplished before 1970. This explosion of knowledge in science, technology, engineering, and mathematics (STEM), and their application was phenomenal. The view of the universe and the "laws" governing it, which the theory of relativity and quantum mechanics presented, were radically different from those presented by either Newton or the Church. Indeed, our very understanding of the nature and properties of space and time went through a paradigm shift creating such uncertainty in the minds of scientists that it became abundantly clear that humankind was not privy to the laws of Nature after all. In 1917, Albert Einstein had summed the turn of events succinctly, "No matter how we may single out a complex from nature ... its theoretical treatment will never prove to be ultimately conclusive ... I believe that this process of deepening of theory has no limits."[43] Thus, it is crucially important for the judiciary to note the dramatic change mankind's knowledge of the laws of Nature underwent. Here is a brief outline.

Newton (1687) had enunciated his version of the universal laws of motion in the belief that space and time were distinctly separate concepts.

> Newtonian space is Euclidean, infinite, and unbounded. Its geometric structure is completely independent of the physical matter occupying it. In it, all bodies gravitate toward one another without having any effect on the structure of space.[44]

And

> [A]bsolute, true, and mathematical time, of itself and from its own nature, flows equably without relation to anything external.[45]

Some two centuries later Einstein (1905 & 1916)[46] saw space and time inseparably linked in a radically new non-Euclidean geometry in which gravity was related to space-time curvature. Physicist John Wheeler pithily remarked: "Matter tells space how to curve, and space tells matter how to move."[47]

Around this time, physicists began to be fascinated with the notion of symmetry, already a pet topic of mathematicians. A thing is symmetrical if there is something we can do to it so that after we have done it, it looks the same as it did before. To mathematicians, and hence physicists, symmetry is invariance under transformations. (The null transformation, *i.e.*, doing nothing is excluded from the discussion.) That is, the end state looks the same after the transformation as the start state. That is, there is no loss or gain of information after the transformation. Such a transformation, if it was not

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[41] Quotes of Kelvin as they appear in: Kelvin, Lord William Thomson (1824-1907), Wolfram Research, http://scienceworld.wolfram.com/biography/Kelvin.html.

[42] Eric W. Weisstein, Kelvin, Lord William Thomson (1824-1907), Wolfram Research, http://scienceworld.wolfram.com/biography/Kelvin.html

[43] Albert Einstein, 1917. Quote reproduced from http://amasci.com/weird/end.html

[44] Hawking (2002), p. 1165.

[45] Hawking (2002), p. 1164.

[46] Einstein (1905a, b; 1916).

[47] Quotation from: The Restless World, Part IV, http://physicalworld.org/restless_universe/html/ru_4_24.html. In a Newtonian world, it would be "Matter tells matter how to move."

observed in action, would go completely unnoticed. This certainly puts a limit on our ability to observe Nature in its fastest actions and thus allows the human mind to make many conjectures about Nature that may never be verifiable beyond reasonable doubt.

In 1918, Emmy Nöther[48] produced a magnificent theorem in physics. In layman's language, it says that for every observable symmetry in Nature there is a corresponding entity that is conserved. And for every conservation law there is a corresponding symmetry. Newton had *assumed* space to be homogeneous and isotropic, *i.e.*, any point in space is indistinguishable from any other point, and likewise time to be homogeneous, *i.e.*, any instant of time is indistinguishable from another instant. This is known as space-time symmetry since there is no unique point in space or an instant in time, that can serve as an origin for either space or time with respect to which we can measure absolute locations or instants of time. We can only measure relative locations with respect to other objects in space and relative time intervals with respect to other events. Nöther connected this space-time symmetry to certain fundamental laws of physics[49], namely,

1. The law of conservation of momentum is a consequence of the homogeneity of space.
2. The law of conservation of angular momentum is a consequence of the isotropy of space.
3. The law of conservation of energy is a consequence of the homogeneity of time.

It is therefore not surprising that Euclid's fourth axiom in geometry (all right angles are congruent), must be true if space is homogeneous and isotropic, and that a geometrical figure in one place should have identical geometrical shape at any other place. Thus, it matters not where and when an object is in absolute terms, but where it is relative to other objects and events. The mind also uses subtle subconsciously detected invariances associated with objects to recognize familiar objects even when they are deformed or altered or out of sight. The laws of Nature are intrinsically laws of prohibition; no phenomenon can violate a law. Identifying conserved quantities (physical or abstract), *e.g.*, energy, momentum, *etc*., in Nature is the most prized achievement of a scientist. Richard Feynman, in his famous Messenger Lectures at Cornell University in 1964, said,

> When learning about the laws of physics you find that there is a large number of complicated and detailed laws, laws of gravitation, of electricity and magnetism, nuclear interactions, and so on. But across the variety of these detailed laws there sweep great general principles which all the laws seem to follow. Examples of these are the principles of conservation, certain qualities of symmetry …[50]

The analogue of this in jurisprudence would be the principles of natural justice, invariant with respect to where, when, and by whom justice is sought. Humankind and natural justice are inextricably linked with our innate beliefs about right and wrong, true and false about certain matters in life and the afterlife. However, advances in scientific knowledge, especially in molecular biology, have begun to challenge theological beliefs, such as those related to marriage and homosexuality and the "miracle" of life itself. New scientific knowledge has already begun to restructure society and has made it revisit its moral values. Paradise appears to be a less tempting place to visit in the afterlife; the physical world we find ourselves in is mysterious and fascinating enough to resist a journey to the afterlife.

The world looks even more mysterious from the point of view of quantum mechanics where a binary on-off switch can be simultaneously on *and* off, that is, to some observers it will appear to be 'on' and to others 'off'! It is not as mystical as it sounds, even though "I am in God, and God is in me" does sound mystical and beyond comprehension. A look at the picture ("My wife and my mother-in-law") in Fig. 1 should convince one that it is not so.[51] (At any instant, different people looking at the picture

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[48] Nöther (1918).

[49] Nöther (1918).

[50] Feynman (1965).

[51] Source of Fig. 1 is http://www.at-bristol.org.uk/Optical/Wife_main.htm

would see *either* a pretty girl *or* an old woman, and not some weird combination of the two.) It is perhaps unwise to further tax the non-physicist reader and stop with the remark that such discoveries in quantum mechanics made the world wake up to the fact that our so-called "laws of Nature" are all *conjectures* that originate in the minds of highly imaginative scientists. The laws of Nature are *not yet* known to mankind.

By 1934, Karl Popper (and many other scientists, *e.g.*, Einstein) had concluded that "The game of science is, in principle, without end. He who decides one day that scientific statements do not call for any further test, and that they can be regarded as finally verified, retires from the game."[52] (The time to overturn the judicial exceptions had come.)

Figure 1. My wife and my mother-in-law.

That game took a new turn in 1936 when Alan Turing, in trying to answer a deep mathematical question, described how one could mechanize the human act of computing. He essentially created an abstract mathematical model (the Universal Turing Machine, (UTM)) of a human-computer[53] (*e.g.*, a human trained to accurately follow instructions without applying his mind, using an unlimited supply of paper, pencil, and erasure – a human robot). It is now well established that Turing machines, recursive functions, λ-definable functions, cellular automata, pointer machines, bouncing billiard balls, Conway's Game of Life, *etc*. are equivalent in terms of what they can and cannot compute. Thus, the set of computable problems does not depend on the computational model. The abstract UTM thus serves as a generic written description of all classical (non-quantum) physical computing devices.

Then, Claude Shannon in 1948 lucidly provided a mathematical theory of information and connected it with physics (Shannon entropy) and discovered fundamental limits on signal processing operations such as data compression and the reliability of communicating and storing data.[54] In 1953, the remarkable discovery by James D. Watson and Francis H. C. Crick of the double-helix structure of cellular DNA (deoxyribonucleic acid)[55] and that the DNA molecule encodes within it all the genetic information needed to replicate itself[56] turned out to be the biggest discovery in biology since Darwin's theory of evolution (1859).[57] In 1961, Rolf Landauer complemented Shannon's work with the deep insight that "information is physical", *i.e.*, physical devices *are* needed to encode and process information. He also provided the lower theoretical limit of energy required in various computational steps.[58] Indeed, Landauer's principle provides a bridge between information theory and physics.

In 1973, the pioneering work of Cohen and Boyer in recombinant DNA technology[59] gave birth to genetic engineering and the biotechnology industry. In 2010, Craig Venter and his group created a bacterial cell controlled by a chemically synthesized genome.[60] Then in 2014, Floyd Romesberg and colleagues[61] reported the creation of a semisynthetic organism with an expanded genetic alphabet. The new letters in the alphabet were artificially created nucleotides not found in Nature. Along with these breakthroughs, the great promise of CRISPR (clustered regularly interspaced short palindromic repeats), and CRISPR-Cas9 gene editing technology pioneered by Feng Zhang[62], Jennifer Doudna, and

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[52] Popper (1934).
[53] Turing (1936).
[54] Shannon (1948).
[55] Watson & Crick (1953a).
[56] Watson & Crick (1953b).
[57] Darwin (1859).
[58] Landauer (1961).
[59] Cohen, *et al* (1973).
[60] Gibson, *et al* (2010).
[61] Malyshev, *et al* (2014).
[62] Cong, *et al* (2013).

Emmanuelle Charpentier[63] in 2012, as a new way of making precise, targeted changes to the genome of a cell or an organism has set the stage for major advances in synthetic biology. Synthesis capabilities have developed at a pace where DNA synthesis is now automated. All one need do is provide the desired DNA sequence to a vendor. Researchers in synthetic biology are now inching towards anticipating and pre-empting evolutionary events that if left to themselves would perhaps take a few million years to occur, and of even resurrecting extinct species. Another major advance was reported by Venter and his research group in March 2016 following their successful creation of a bacterial cell controlled by a chemically synthesized genome noted above. In fact, they succeeded in creating a bacterium that contains the minimal genetic ingredients needed for free living. The genome of this bacterium consists of only 473 genes, including 149 whose precise biological function is unknown. It is a minimalist version of the genome of Mycoplasma mycoides.[64] Mycoplasma are known to have some of the smallest genomes. M. mycoides used in the experiments started with 901 genes. (Other bacteria, including E. coli, may have 4,000 to 5,000 genes; humans have more than 22,000 genes.) In 2010, they had replicated the entire genome of M. mycoides and placed it into a cell of a different species, Mycoplasma capricolum, creating the first synthetic organism. In 2016, they had stripped down the M. mycoides genome to its essential elements before transplanting it to the M. capricolum shell, creating a minimal bacterium they call syn3.0. This bacterium has the smallest genome—and the fewest genes—of any freely living organism.

This complex integration of biology and traditional engineering driven by information processing and computing technologies, and algorithm design is moving so rapidly that a couple of decades hence, researchers may begin producing synthetic organisms designed to produce not only pharmaceutical products but also industrial products such as bio-fuels on a commercial scale. Of course, such STEM-rooted technologies bring not just potential and real socio-economic benefits but also perils of misuse, *e.g.*, by terrorists in waging biological attacks.

The path-breaking events of mid-20th century have brought about an unusually deeper understanding of Nature in mathematical terms than ever before. Information theory terminology is now freely used in molecular biology as is the theory itself. Genes are linear sequences of bases (like letters of an alphabet) that carry information (like words) for producing proteins (like sentences). DNA sequences are "transcribed" and "translated" into proteins, and genetic "information" is passed from one generation to another. It appears uncanny that molecular biology can be understood by ignoring chemistry and instead treating the DNA as a computer program (with enough input data included) in stored memory residing in a computer (the cellular machinery). These analogies are exploited by bioinformaticians in deciphering the information encoded in the DNA. The DNA is a vast chemical information database that *inter alia* carries the complete set of instruction for making all the proteins a cell will ever need. It is as if we were viewing Euclidean geometry not in terms of drawings but in terms of algebra.[65] Physically, the DNA is an informational polymer. Albert Lehninger lyrically put it: understanding the DNA is the study of "the molecular logic of the living state."[66] Indeed organisms are defined by the information encoded in their genomes. DNA is Nature's digital recording medium of life.

The following quotes express the general view of scientists of the descriptive power of mathematics as a language.

1. "Mathematics is a language plus reasoning; it is like a language plus logic. Mathematics is a tool for reasoning. … [I]t is impossible to explain honestly the beauties of the laws of nature in a way that people can feel, without their having some deep understanding of mathematics."[67] (Richard Feynman)

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[63] Sharlach (2014).

[64] Hutchison III (2016). *See also*: Saey (2016).

[65] Bera (2015a).

[66] Nelson & Cox (2006).

[67] Feynman (1965).

2. “The Unreasonable Effectiveness of Mathematics in the Natural Sciences”[68]. (Eugene Wigner)
3. “Our reality isn’t just described by mathematics – it is mathematics … Not just aspects of it, but all of it, including you.” In other words, “our external physical reality is a mathematical structure”.[69] (Max Tegmark)

Mathematicians did not create mathematics with the aim that one day physicists would find it useful. John von Neumann noted:

> A large part of mathematics which becomes useful developed with absolutely no desire to be useful, and in a situation where nobody could possibly know in what area it would become useful; and there were no general indications that it ever would be so. By and large it is uniformly true in mathematics that there is a time lapse between a mathematical discovery and the moment when it is useful ….[70]

Douglas Hofstadter, in a remarkable book,[71] showed how Gödel’s theorem[72] can be understood by analogy with Bach’s musical compositions and Escher’s paintings thereby showing that even those who revel in the arts can find tremendous beauty in mathematics. The modern computer scientist is not surprised. After all he encodes music and paintings in abstract binary strings (just as easily as he encodes mathematical algorithms) which a computer (using appropriate software and input-output hardware) decodes into music and painting at will.

One might thus conclude that the Universe itself is a computer ceaselessly performing mathematical calculations of the laws of Nature. We have traversed far from when Galileo famously said that the universe is written in the language of mathematics to Max Tegmark saying that the universe *is* mathematics. If Tegmark’s conjecture is right (there is no convincing refutation of it yet), his thesis represents a paradigm shift in the relationship between physics and mathematics. *Ipso facto*, it fundamentally affects how we define patent-eligible subject matter; an invention’s utility, novelty and non-obviousness; how an invention is described; and the expansive scope of the doctrine of equivalents in patent law.[73]

The twentieth century began by dazzling us with airplanes, automobiles, and radio and ended with spaceships, computers, cell phones, the Internet, and genetic engineering.[74] In just a century they dramatically and seamlessly changed the industrial economy into a post-industrial economy that is global, heavily consumer-oriented, talent-hungry, knowledge-centered, dependent on a university-educated and globally-mobile STEM workforce, and above all driven by innovation as never before.[75] Even more dazzling is the role mathematics and computing has begun to play in life sciences and technology development. A 2012 book, *Fueling Innovation and Discovery: The Mathematical Sciences in the 21st Century*, from the National Academies notes,

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[68] Wigner (1960).

[69] Tegmark (2014).

[70] Neumann (1954).

[71] Hofstadter (1979).

[72] See Section 2.5 for Gödel’s theorem.

[73] The doctrine of equivalents is a rule of claim interpretation under which a product or process, although not a literal infringement, is an infringement if it performs substantially the same function in substantially the same way to obtain the same result as a patented product or process. However, it is constrained by the rules of prosecution history estoppel, and the reverse doctrine of equivalents. This leads to a complex predator-prey kind of game where determining the victor can be a very messy process. The logistic map in physics captures some of the game’s basic features.

[74] For a timeline of inventions, see, *e.g.*, http://inventors.about.com/od/timelines/a/twentieth.htm. *See* Olson (2015). *See also*: NAP (19007) (2015): “The past half-century has witnessed a dramatic increase in the scale and complexity of scientific research. The growing scale of science has been accompanied by a shift toward collaborative research”. “The size of authoring teams has expanded as individual scientists, funders, and universities have sought to increase research productivity and investigate multifaceted problems by engaging more individuals. Most articles are now written by 6 to 10 individuals from more than one institution.”

[75] *See*, *e.g.*, Palmisano (2006). *See also*: Bera (2015a1).

> The mathematical sciences are part of everyday life. Modern communication, transportation, science, engineering, technology, medicine, manufacturing, security, and finance all depend on the mathematical sciences. [The book] describes recent advances in the mathematical sciences and advances enabled by mathematical sciences research.[76]

Creating public awareness about mathematical sciences in the post-industrial economy is now a critically felt need. It is widely believed that the twenty-first century belongs to advances in life sciences. The century has already begun creatively by creating and editing novel and non-obvious DNA sequences which speak for and describe themselves in a language those skilled in the art understand with precision, as to the invention the sequences stand for. These are self-describing inventions just as mathematical algorithms are when interpreted in a well-defined context.

The Galilean-Newtonian notion that we can observe, measure, and speculate about the world without changing it (absolute objectivity) and thereby proceed to know the "absolute truth" is emphatically negated by quantum mechanics. There is no part of the universe, ourselves included, that is ever free from the rest of the universe. Quantum mechanics does not claim to seek absolute truth; it only claims to correlate experience mathematically.[77] Only divine knowledge, if such a thing exists, divinely instilled in every human can be rightfully acknowledged as "part of the storehouse of knowledge," "free to all men and reserved exclusively to none". A conjectured law of Nature is neither a fundamental truth nor an original cause. The gap between a conjectured law and a real law is not measurable. Conjectured laws are part of the storehouse of conjectures, free to all men only to the extent they have been shared with the public and not hidden as 'trade secrets'. That scientists have a long tradition of publicly sharing their discoveries for fame rather than fortune and augmenting the storehouse of scientific knowledge for the benefit of mankind is a boon. By equating conjectural knowledge with divine knowledge and invoking *stare* decisis, the SCOTUS perpetuates religious bias. Natural principles remain well-guarded secrets of Nature.

By now it is abundantly clear that the "laws of Nature" are not a storehouse of constant truths divinely handed to every living soul and therefore reserved exclusively to none. The actual laws of Nature remain Nature's trade secrets and hence do not belong to prior art even under patent law. Moreover, we have no means of ever ascertaining that any of the past, present, or future conjectures can eventually be established as a genuine law of Nature[78] that would satisfy the judicial criterion of being "beyond reasonable doubt". The conjectured laws of Nature are therefore *prima facie* patentable subject matter, a creation of human ingenuity and not a divine gift to all mankind. If any such conjecture, on a case-by-case basis, is to be denied a patent then it should be only after ensuring that it is in the "best interest" of society to do so (*e.g.*, to accelerate the flow of follow-on inventions). In short, a conjectured law of Nature while eligible for a patent is not necessarily entitled to it. A scientist will rarely feel grieved by this. The altruistic scientific community traditionally places its fundamental discoveries in the public domain after due scrutiny by its peers.

2.3 The STEM way of knowledge expansion

Historians know that the world is ruled by ideas and very little else. We see ideas at work all the time in scientific research (theory of relativity and quantum mechanics), in technology (the wheel, the steam engine, the chip and the computer), in *haute couture*, in art, music and dance. But new ideas are elusive; they do not come easily. In fact, they come rarely, perhaps, because we have an in-built resistance to dealing with anything unfamiliar. Novelty challenges our intellect, our general ability to cope, and it threatens to make our past achievements irrelevant. But the times are changing. There is

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[76] NAP (13373) (2012). The book "is geared toward general readers who would like to know more about ongoing advances in the mathematical sciences and how these advances are changing our understanding of the world, creating new technologies, and transforming industries."

[77] Zukav (1979), Chapter 1.

[78] Popper (1963).

now a sudden urge to seek out new ideas, especially in technology, in management, in administration, and even in managing our lives. Abstract ideas that are obviously implementable once articulated, may be legitimate patentable subject matter but they should not be patented because it is humanly impossible to prevent their infringement by humans with a functioning brain. However, novel and nonobvious products or processes the ideas spawn may be patent eligible subject matter. Historically, theorists in natural sciences, especially in physics, prefer theories which have logical elegance and beauty. Beauty is subjective and has no rigorous value, but the first quality is objective to the extent that it can be used in practice. In addition, they prefer simplicity, which is again subjective.

Aristotle (384 BC - 322 BC) in his book *Physics*[79] said that bodies that occupy places that are not natural for them are impelled to move, whereas those in their natural places are not. No natural motion can exist, if every point of space is equivalent. He also denied the existence of a vacuum. He reasoned that in a vacuum (*i.e.*, in a uniform space) nobody can say why a body set in motion would stop, for why should it stop in one place and not another? He also refused to accept the notion that time is independent of events. He reasoned quite simply that time cannot exist without change.[80] The Church was comfortable with Aristotle's views.

Newton considered space to be a void arena of things and phenomena. It was 3-dimensional, continuous, static, infinite, uniform, and isotropic. He believed that absolute space, in its own nature and regarding anything external, always remains similar and unmovable. In his view, time was also absolute and independent. He regarded it to be the "receptacle of events" and that the course of events did not affect the flow of time. Time was uni-dimensional, continuous, homogeneous, and infinite.[81] In his view, "All things are placed in time as to order of succession; and in space as to order of situation. It is from their essence or nature that they are places; and that the primary places of things should be movable, is absurd. These are therefore the absolute places; and translations out of those places, are the only absolute motions."[82] By early 20th century, the notion of space and time would once again undergo a radical change brought about by Albert Einstein.

By mid-20th century, scientists would reconcile themselves that they cannot know why the universe exists. The best they can do is make educated guesses as to how the universe works and pursue a methodology augmented by flashes of insight and serendipity to refine those guesses. The methodology begins with the unprovable *belief* that nature exhibits dynamic patterns (a succession of patterns we call states) with certain built-in deep mathematical symmetries so that if you knew the complete state at any instant and had knowledge of the laws of Nature, you can predict the entire history of the universe – past, present, and future. This belief makes us look for deep symmetries in the laws of Nature. So, physicists have become obsessed with symmetries. But more importantly, they have reconciled themselves that knowledge of the real laws of Nature may forever elude them.

When the SCOTUS excluded "laws of nature" from patentable subject matter, it erroneously assumed that they were known to man since time immemorial. That scientists who discovered them merely publicized what already existed. If it were so, it would belong to prior art and hence not patentable; there was no need to create a judicial exception. Further, anything in Nature, including the creation of humans and what they create *is* the handiwork of Nature. It appears that no amount of human ingenuity can accomplish what is prohibited by Nature. Thus, all process steps involved in a process invention represent only a permissible sequence or network of natural processes. Hence, what is patent-eligible is essentially a *sequence* or a *network* of natural processes concocted by a human mind, something that has not yet been seen in Nature and which is extremely unlikely to occur without human ingenuity in play with or without the aid of man-made machines (including Turing machines,

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[79] Aristotle (350 BCE).

[80] Vladimirov, *et al* (1987), p. 13.

[81] Vladimirov, *et al* (1987), p. 16.

[82] Scholium to the Definitions in *Philosophiae Naturalis Principia Mathematica*, Bk. 1 (1689); trans. Andrew Motte (1729), rev. Florian Cajori, Berkeley: University of California Press, 1934. pp. 6-12. Source: Stanford Encyclopedia of Philosophy, http://plato.stanford.edu/entries/newton-stm/scholium.html.

see Section 3.1). For example, in the absence of humans, Nature is extremely unlikely to come up with a sequence of processes that would create a jumbo jet (and, why should it?). Only such discoveries as are instinctively possible by all men can be "reserved exclusively to none". For the rest, man must discover and invent because

> We are products of nature, but nature has made us together with our power of altering the world, of foreseeing and of planning for the future, and of making far-reaching decisions for which we are morally responsible. Yet, responsibility, decisions, enter the world of nature only with us.[83]

Furthermore,

> Our aim as scientists is objective truth; more truth, more interesting truth, more intelligible truth. We cannot reasonably aim at certainty. Once we realize that human knowledge is fallible, we realize also that we can never be completely certain that we have not made a mistake.[84]

Since humans do not possess divine knowledge, human-designed processes, including mimicking of natural phenomena in a man-made environment become patentable subject matter. This is especially significant for biotechnology inventions that mimic natural phenomena for clinical use. (*See* Section 1.2 above where we provide our interpretation of patentable subject matter.)

2.4 Discovering knowledge via conjectures and refutations

Popper postulated that humans gather knowledge by trial and error, *i.e.*, by making *conjectures and refutations*.[85] Broadly, we guess laws of Nature as follows: (1) Hypothesize a causal relationship among things that raise our curiosity, and then try to demolish (refute) the hypothesis, say, by deep analysis or seeking new information that may demolish it. (2) Continue the demolition effort till such time the hypothesis shows defects. If the hypothesis is good enough, finding a defect may take a long time (even centuries), so a lot of patience and tenacity spanning generations may be required. (3) When a defect appears (experience shows, one day it will), modify the hypothesis or make a new one (this usually requires talent, being in the right intellectual environment, serendipity, or just plain luck) and go to step (2). The loop ends when one gives up voluntarily or involuntarily. The counterpart of this looping problem in computer science is the 'halting problem', the problem of not knowing if a looping operation will terminate after a finite number of steps in the absence of complete information. *See* Section 3.1. Irrespective of whether humans have free will or not, they appear powerless to create, delete, or amend the *Laws of Nature*, which have remained elusive to questioning and reasoning minds. Of course, if we banish all questions from our mind, there is no need to seek answers. As Marvin Minsky notes,

> There is also a different and more sinister way to make the world seem orderly, in which the mind has merely found a way to simplify itself. This is what we must suspect whenever some idea seems to explain too much. Perhaps no problem was actually solved at all; instead, the mind has merely found some secondary pathway in the brain, through which one can mechanically dislodge each doubt and difference from its rightful place! This may be what happens in some of those experiences that leave a person with a sense of revelation – in a state in which no doubts remain, or with a vision of astounding clarity – yet unable to recount any details. Some accident of mental stress has temporarily suppressed the capacity to question, doubt, or probe. One remembers that no questions went unanswered but forgets that none were asked! One can acquire certainty only by amputating inquiry.[86]

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[83] Popper (1947).

[84] Popper (1984).

[85] Popper (1963).

[86] Minsky (1988).

It has been said about the development of quantum mechanics that "The theory was not developed in a strictly logical way – rather a series of guesses inspired by profound physical insight, which by a thorough command of new mathematical methods was sewn together to create a theoretical edifice possessing amazing predictive power. In fact, quantum mechanics is considered the most successful theoretical physics construct of the human mind."[87] The mathematically profound aspects of quantum mechanics still astound physicists; indeed, they cannot comprehend it without mathematics! The subject defies intuition. Thus, knowledge of quantum mechanics, while "freely available to all men", is reserved for a few to understand, as is higher levels of mathematics. It turns out that our most successful conjectured "laws of Nature" have the ethereal quality of looking elegant, concise, and precise when mathematically stated.

Till the early-1900s, the distinction between conjecture and truth was not realised. Earlier scientists implicitly believed that if a phenomenon occurred in seemingly identical fashion every time it was observed, it would occur like that forever in accordance with the laws they had discovered (or rather, conjectured). Their belief, based on inductive logic, had no justification. This was known to David Hume (1711-1776), a Scottish historian, philosopher, economist, diplomat and essayist, but grossly under-appreciated by contemporary scientists. Inductive reasoning appears to be hard-wired in the human brain. While mathematicians are wary of inductive reasoning, physicists, for apparent lack of alternatives, use it to *conjecture* laws of Nature. Therefore, a physicist's conjectured law of Nature is not a commandment carved in stone.

Obviously, the judiciary does not yet see the laws of Nature in this light; truth is not knowable because humans have no means of recognizing it even if they come face-to-face with it. In man-made mathematical systems, truth is knowable and provable (barring certain pathological cases) because mathematicians create their own abstract universe and a decision process to decide what is true and false in that universe. When scientists make conjectural mathematical models of the real universe, they are forced to equate truth with belief, and thus an illusion is created, at least in the layman's mind, that scientists are in pursuit of truth. Scientists are only in pursuit of irrefutable conjectures; their use of mathematics makes their models internally consistent. This fine distinction between conjecture and truth in science was not understood till the twentieth century even by scientists (as we noted in Section 2.2). A contributing reason for this was the tyranny of the Catholic Church. So, it stands to reason that all patent related decisions by courts that are affected by judicial exceptions with respect to statutory subject matter must be revisited to ascertain when a conjecture was regarded as a truth before they are used as precedents to be blindly followed.

In the pursuit of scientific knowledge, early stage research produces data, correlations, conceptual frameworks, mathematical descriptions, insights, etc. These provide the fundamental building blocks very necessary for further consolidation stage research that may eventually lead to new technological products and processes. Thus, any impediment, *e.g.*, grant of patents, that thwart the consolidation stage must be avoided in the larger interests of society. It is in the applied research stage that viable commercial opportunities usually begin to appear, often requiring huge and risky investments. Promoters of such investments often require disaster mitigation incentives, *e.g.*, patents, if they are to invest at all. It is at the consolidation stage of research that serious patenting considerations begin to arise and a moral dilemma arises as to whether the *quid pro quo* criterion (the public must receive meaningful disclosure of the invention in exchange for being excluded from practicing it for a limited period) for patent grant is equitably met. In the applied research stage the moral dilemma is minimal. The dividing line between the consolidation stage and applied stage of research is seldom clear. Thus, the judiciary, unfamiliar with scientific research, is not the best arbiter of the moral dilemma. It cannot give due and equitable consideration to the traditions, culture, and beliefs of the STEM community, which fundamentally furthers scientific and technological advances for the larger benefit of mankind. It is the STEM community that must apply the *quid pro quo* criterion on a case-by-case basis.

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[87] Cresser (2011). *See also*: Styer (1999).

Between the publication of Newton's *Principia* in 1687 and the formalization of quantum mechanics around 1930, a physicist's understanding of space, time, matter, energy, force, *etc*. underwent dramatic changes. It is no longer possible to trust one's intuition to understand these changes because it requires university-level education in STEM to do so. Since the industrial revolution (1760-1840), the collective contribution of the STEM community is nothing but astounding. For example, the Moon is no longer a heavenly body untrodden by humans. And science is continually finding clever ways of dealing with natural disasters visited on humankind by divine atrocity. The difference between a religious belief and a scientific belief is that while the former is rigidly averse to scrutiny, revision, and tolerance, the latter is open to continuous scrutiny and revision by its untiring efforts at refutation to stay consistent with carefully observed facts. Man-made religion desires an unquestioning closed mind; science requires a questioning open mind but not so open that nothing stays there.

In answer to a request and query from a sixth-grade student in 1936: "We will feel greatly honored if you will answer our question: Do scientists pray, and what do they pray for?" Einstein replied:

> Scientific research is based on the assumption that all events, including the actions of mankind, are determined by the laws of nature. Therefore, a research scientist will hardly be inclined to believe that events could be influenced by a prayer, that is, by a wish addressed to a supernatural Being. However, we have to admit that our actual knowledge of these laws is only an incomplete piece of work (unvollkommenes Stückwerk), so that ultimately the belief in the existence of fundamental all-embracing laws also rests on a sort of faith. All the same, this faith has been largely justified by the success of science. On the other hand, however, everyone who is seriously engaged in the pursuit of science becomes convinced that the laws of nature manifest the existence of a spirit vastly superior to that of men, and one in the face of which we with our modest powers must feel humble. The pursuit of science leads therefore to a religious feeling of a special kind, which differs essentially from the religiosity of more naive people.[88]

2.5 Constraints in making conjectures

There is an important constraint on the conjectures scientists may choose. To be an admissible hypothesis or conjecture, it must be falsifiable, *i.e.*, in principle, there must be a test, if properly administered, *will* prove the hypothesis to be defective. For example, "Tomorrow the sun will either rise or not rise" is not an admissible hypothesis since this hypothesis can never be falsified. On the other hand, the hypothesis, "The sun will rise everyday forever" is admissible because, in principle, we can arrange to have the sun watched everyday forever. Likewise, ignorance of the divine laws of natural justice forces us to frame statutes that are falsifiable so that administration of justice can advance through refutation when it faces unexpected situations. Like science and mathematics, logic too underpins jurisprudence. Yet logic does produce paradoxes. For example, if under oath, a person says he will tell the truth and nothing but the truth, and then declares "I am a liar"[89], what is the law to make of his utterances? Such a declaration cannot be admissible evidence in court at least in the world we live in. However, "I am a truthful person" or "I lied" are perfectly admissible statements.

Likewise, mathematicians and physicists are amply aware of similar situations in their respective subjects. In mathematics, there are theorems (mathematical statements) which can neither be proven nor disproven (see Gödel's theorems below).[90] In physics, *e.g.*, it is impossible to engineer a perfect phonograph that can play all records. (Each phonograph has its own natural frequency at which it will malfunction; if a record contains that frequency, it cannot be played.)[91] Mathematicians know the

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[88] Jammer (1999), pp. 92-93. The quotes are from an English translation of a letter Einstein wrote in German to a sixth-grade student, Phyllis Wright, dated January 24, 1936.

[89] Logicians know this as the Epimenides paradox.

[90] That was the essence of Gödel's theorem.

[91] The example is cited in Hofstadter (1979).

source of such problems in the form of two remarkable theorems by Kurt Gödel. In plain English, they appear as:

> "Every system of arithmetic contains arithmetical propositions, by which is meant propositions concerned solely with relations between whole numbers, which can neither be proved nor disproved within the system."
>
> "Any formal system that is interesting enough to formulate its own consistency can prove its own consistency if and only if it is inconsistent."[92]

Its implication in jurisprudence is that it is impossible to form non-trivial laws which can decide all problems of society for which it was enacted. In an even deeper sense, all knowledge begins with our intuitive belief that certain statements in any branch of knowledge (*e.g.*, the axioms in mathematics or laws of Nature in physics) are true even though we are unable to prove or disprove them; we simply rely on our intuition and accept them because we have never come across a contradiction. It is on such assumed "truths" that we build an edifice of knowledge. In abstract mathematics, we manufacture "truths" so in that sense we pursue it for "amusement, to satisfy idle curiosity, or for strictly philosophical inquiry". In physics, we do the opposite, we search for "truth" without knowing which of our observations and correlations of gathered information will point us to the truth. In jurisprudence, it is a mix of the two; we legislate generally acceptable statutes (a blend of idealism and pragmatism) and in enforcing them we spend a lot of energy worrying about their consistency and their ability to resolve problems through litigation. The judicial system eventually unearths some of the paradoxes or defects inherent in it, and the legislature then attempts to correct it through amendments or new laws, and waits for the next defect to appear and the corrective process is repeated. The corrective process can never end.

Let us now look at another inconvenient situation. Consider the dialogue: *Query.* Where is the school? *Answer.* In front of the temple. *Query.* Where is the temple? *Answer*. In front of the school. This dialogue makes sense if one discovers either the temple or the school. Then the other is found easily. In science one needs to run into either a cause or an effect to discover the other, just as the judiciary must discover either the motive or the crime to find the other before conviction.

Finally, consider the following two sets of statements where each statement follows the template or form (*T*): "'noun' 'verb' 'noun'"[93]. The two sets are: (1) "*A* beats *B*"; "*B* beats *C*"; "*C* beats *A*". In principle, this is perfectly possible. Now consider (2) "*A* begets *B*"; "*B* begets *C*"; "*C* begets *A*". This is obviously wrong. All three statements taken together cannot be true. While the abstract template (*T*) provides no clue whether a statement, *e.g.*, "*A* verb *B*" will be true or conversely false, its truthfulness or otherwise may be found on a case-by-case basis only when the "verb" is given a specific meaning.

Clearly, the above template (*T*) if used to create a mathematical algorithm, in its abstract form, cannot be patentable subject matter until the abstract symbols in the algorithm are given specific meanings (*i.e.*, interpreted). Thus, only an interpreted algorithm is eligible as patentable subject matter.

2.6 Knowledge formation through iterative refinement

We saw in Section 2.4 that discovering laws of Nature is an iterative process. In the mid-20th century it was discovered that iterative processes can produce a wide range of unsuspected results. Indeed, scientists are now familiar with some generic aspects of iterative processes. Here we provide two very simple illustrative examples—Sierpinski triangle and Barnsley's fern. These are followed by two rather complicated examples (without their mathematical details).

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[92] *See*, *e.g.*, Hofstadter (1979), p.101, for an explanation of Gödel's theorem.

[93] This template appears in other familiar forms, *e.g.*, ('input' 'transformation' 'output') in engineering; ('operand' 'operator' 'operand') in mathematics and computer programming; *etc*.

(1) *Sierpinski triangle*

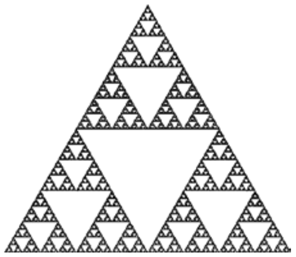

Figure 2 Sierpinski triangle

Begin with 3 points *A*, *B*, and *C* in a plane forming the vertices of an equilateral triangle. Now choose any point p_0 in the plane (not necessarily inside the triangle *ABC*). Next, randomly choose one of *A*, *B*, or *C* and move p_0 halfway toward the selected vertex, and call the new location of p_0 as p_1. To continue, again randomly choose one of *A*, *B*, or *C* and move p_1 halfway toward the selected vertex, and call the new location of p_1 as p_2. In general, p_{n+1} is obtained from p_n in similar fashion. The sequence of points p_0, p_1, p_2, …, p_{n+1}, … is called the orbit of p_0. Our curiosity lies in knowing the fate of the orbit of p_0 under the described iteration. Can you guess what the orbit will be? The orbit of p_0 (after omitting the first few iterations) is the Sierpinski triangle as seen in Fig. 2! The result is independent of the choice of p_0 and the sequence in which the vertices are chosen. It is quite a stunning use of randomness as the basis for creating regular shapes. In this case one could have drawn the figure by the alternate method of cutting out triangular pieces from a black paper triangle. The important thing to note here is that random processes can lead to shapes that at first glance appear strikingly Euclidean.

(2) *Barnsley's fern*

Consider the iterative scheme below, where in each iteration, a, b, c, d, e, f is selected from a randomly chosen row numbered (1-4) in the table below with some probability p.

$$\begin{pmatrix} x_n \\ y_n \end{pmatrix} = \begin{pmatrix} a & b \\ c & d \end{pmatrix} \begin{pmatrix} x_{n-1} \\ y_{n-1} \end{pmatrix} + \begin{pmatrix} e \\ f \end{pmatrix},$$

	a	*b*	*c*	*d*	*e*	*f*	*p*
1	+0.000000	+0.000000	+0.000000	+0.172033	+0.496139	-0.090510	+0.010000
2	+0.075906	+0.312285	-0.257105	+0.204233	+0.494173	+0.132616	+0.075000
3	+0.821130	-0.028405	+0.029799	+0.845280	+0.087877	+0.175709	+0.840000
4	-0.023936	-0.356062	-0.323405	+0.074403	+0.470356	+0.259738	+0.075000

After arbitrarily choosing the starting point (x_0, y_0), if we plot (x_n, y_n) (after ignoring the first few iterations), what do we see? The amazingly beautiful fern, first pictured by Michael Barnsley[94].

We can generate many more complex, life-like figures in similar fashion (see Fig. 3).

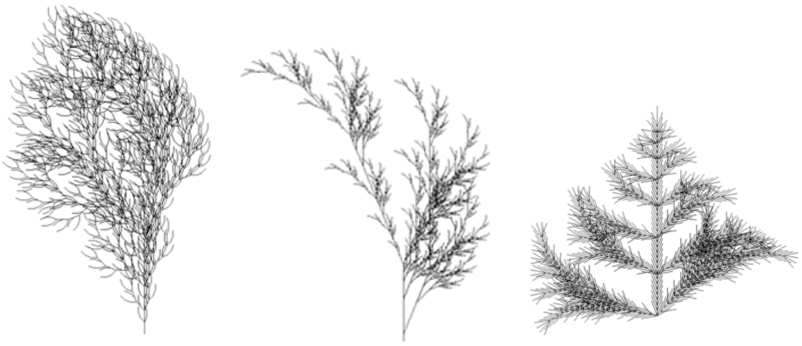

Figure 3 Fern-like examples. Source: Fractals, Chaos by P. Bourke, http://paulbourke.net/fractals/

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[94] Barnsley (1993).

(3) *Cauliflower*

Figure 4 Cauliflower.

Source: Formula unlocks secrets of cauliflower's geometry, Institute of Physics, 24 October 2012, http://www.iop.org/news/12/oct/page_58763.html

The cauliflower is another beautiful example of fractal geometry in Nature (Fig. 4). In 2012, the mathematics that describes the motif resembling the surface of a cauliflower was elucidated.[95] This motif (texture) is found in Nature across a wide range of scales: "they can be observed across length scales that range from tens of nanometers (surfaces of amorphous thin films) up to hundreds of microns (turbulent combustion fronts) and tens of centimeters (the familiar cauliflower plants)." The authors also show that "the surfaces of actual cauliflower plants and combustion fronts obey the same scaling laws, proving the validity of the theory over seven orders of magnitude in length scales."

"The term fractal defines a pattern that, when you take a small part of it, looks similar, although perhaps not identical, to its full structure. For example, the leaf of a fern tree resembles the full plant and a river's tributary resembles the shape of the river itself."[96] … "In spite of the widespread success of fractal geometry to describe natural and artificial fractal shapes, purely geometrical descriptions do not provide insight into the laws that govern the emergence of the shapes in time. We believe that by knowing the general laws that dictate how these patterns form and grow, it will help to identify the biological and physical mechanisms that are at play."[97]

(4) *Snow covered mountain*

Our final example (Fig. 5) is a mathematically generated natural scene of a snow-covered mountain.

Figure 5 Snow covered mountain, by Stevo-88.
Source: http://commons.wikimedia.org/wiki/File:Fractal_terrain_texture.jpg (placed in Public Domain by Stevo-88)

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[95] Castro, *et al* (2012). *See also*: Formula unlocks secrets of cauliflower's geometry, 24 October 2012, http://www.iop.org/news/12/oct/page_58763.html

[96] Formula unlocks secrets of cauliflower's geometry, Institute of Physics, 24 October 2012, http://www.iop.org/news/12/oct/page_58763.html

[97] Formula unlocks secrets of cauliflower's geometry, Institute of Physics, 24 October 2012, http://www.iop.org/news/12/oct/page_58763.html

The above examples provide a mere glimpse of how intricately mathematics can describe Nature that neither words nor poets can describe. Very intricate 3-dimensional objects can now be created using similar mathematical techniques and produced using 3D printing technology. Indeed, nature uses random iterative processes to create many living and non-living things. Determining those processes is a voyage of scientific discovery.

The ubiquitous existence of fractals in natural and mathematical systems became widely known to scientists in the early 1980s after the book, *The Fractal Geometry of Nature*[98] by Benoit Mandelbrot was published in 1982. Examples of fractals include crumpled paper balls, aggregates and colloids, trees, rocks, mountains, clouds, galaxies, polymers, fractures, and stock market fluctuations. Mandelbrot observed that “Clouds are not spheres, mountains are not cones, coastlines are not circles, bark is not smooth, nor does lightning travel in a straight line.”[99] Before Mandelbrot, Nature was generally regarded as noisy Euclidean geometry; *e.g.*, a mountain is a roughened cone. Paul Cezanne (1839 –1906), *e.g.*, instructed his young painters: “Everything in Nature can be viewed in terms of cones, cylinders, and spheres.”[100] Not anymore. They can now be seen more accurately as the outcome of iterated processes. Likewise, we discover laws of Nature via iterated conjectures.

Euclidean and Cartesian methods taught us how to turn equations into points and curves. In fractal geometry, we learn that even more intricate geometrical shapes are possible if, instead of solving an equation, we iterate upon it. As James Gleick poetically noted, “the equation becomes a process instead of a description, dynamic instead of static. When a number goes into the equation, a new number comes out; the new number goes in, and so on, points hopping from place to place. A point is plotted not when it satisfies the equation but when it produces a certain kind of behavior. One behavior might be a steady state. Another might be a convergence to a periodic repetition of states. Another may be an out-of-control race to infinity.”[101] That, in essence, is how Nature creates patterns in space over time; it uses randomised motion of matter and energy carriers, constrained by the laws of Nature, to paint 3D pictures in space.

What we have learnt is that shapes can be defined not just by solving an equation once, but by iterating it in a *feedback loop*. Fractal geometry is a product of self-referential (iterative; the input produces an output, which, in turn, becomes the new input) algorithms. Thanks to Mandelbrot, we have fractal geometry which is remarkably different from Euclidean geometry, a geometry that represents roughness with ease. What is amazing is that even trivial rules can produce self-organizing systems with patterns of behavior that look almost “natural.” It takes very little in terms of information content to mediate that sort of magic. So, are we the products of a network of autonomous agents interacting together in random sequences? Is it such a mystery that proteins respond to local stimuli to keep our hearts pumping, brains storing information by aggregating proteins, lungs breathing, *etc.*? Aren’t these evidences of algorithms at work? Are we algorithmic creations? Are we living examples of the raw austere beauty of mathematics? Nature does look far less mysterious, and certainly more mathematical, and above all, computable.

What computers compute is the result of executing mathematical algorithms without bringing in intelligence or emotion. Yet the output of mathematics, when interpreted (applied mathematics), has the tremendous ability to trigger intelligent activity or raise emotions in humans. Mathematics is an amazingly powerful language for communicating with intelligent humans and for discovery. It is so because axiomatized reasoning is an integral part of mathematics and cannot be separated from it.

The iterative method of gaining knowledge depends on the set of iterative functions (“beliefs”) we start with! Anything outside of the chosen beliefs will elude us forever. Sometimes to gain knowledge,

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[98] Mandelbrot (1982).

[99] Mandelbrot (1982).

[100] Panorama of Fractals and Their Uses, Mathematics Department, Yale University, http://users.math.yale.edu/public_html/People/frame/Fractals/Panorama/Nature/NatFracGallery/NatFracGallery.html

[101] Gleick (1987).

we must change or tweak our beliefs. Unfortunately, there appears to be no rational way of deciding what beliefs we must hold to acquire "true knowledge" about Nature and about ourselves. Physicists look at the world and try to guess the beliefs (laws of Nature) they should depend on; laws that Nature uses in endless iterations. Religions tell us what beliefs we should steadfastly hold and further tell us, without any opportunity for verification by judicial standards of "beyond reasonable doubt", what to expect when we are dead. As Dawkins notes in *The God Delusion*, "The whole point of religious faith, its strength and chief glory, is that it does not depend on rational justification. The rest of us are expected to defend our prejudices. But ask a religious person to justify his faith and you infringe 'religious liberty'."[102] Therein lies the crucial difference between physics and theology. The state has no legitimate authority over the realm of human conscience.

Ignorance of mathematics deprives us of deep understanding of Nature. As Feynman said,

> To those who do not know mathematics it is difficult to get across a real feeling as to the beauty, the deepest beauty, of nature. … If you want to learn about nature, to appreciate nature, it is necessary to understand the language that she speaks in.[103]

Galileo had made a similar observation in 1623.

2.7 Complex networks

Revolutionary discoveries of 20th century included quantum mechanics (to deal with microscopic level phenomena, $< 10^{-8}$ cm), theory of relativity (to deal with objects speeding close to the speed of light $\sim 10^{10}$ cm/sec), and non-linear dynamics (to deal with non-linear phenomena). All three provided unexpected concepts and insights and intellectually stunning results. However, the youngest among them, non-linear dynamics, was ushered in rather quietly. Unlike quantum mechanics and theory of relativity, non-linear dynamics covers systems of every scale and any speed. And, it encompasses all the existing disciplines in science (both natural and social sciences). There is, therefore, a clear opportunity to unify a multitude of diverse phenomena.[104] The study of dynamical systems is essentially an attempt to understand processes that generate change whether they be the motion of stars and galaxies, the flow of air and heat in the atmosphere, the gyrations of stocks in the stock market, the migration, rise and fall of populations, *etc*. In nonlinear systems, the behavior of the whole is different than the sum of its parts.

These 20th century developments in science and mathematics have made us realise that certain limits to the knowledge we can attain may exist. Indeed, humans (including scientists) acquire knowledge "guided by emotion and intuition as well as by cold reason and calculation"[105] and such limits to acquiring knowledge lead to fear and apprehension about the future and the ability of humans to deal with it. These limits, *e.g.*, make it impossible (1) to construct a complete, consistent mathematical description of reality (Kurt Gödel's incompleteness theorem); (2) to transmit matter or even information at speeds faster than that of light (Albert Einstein's special theory of relativity); (3) to have deterministic knowledge of the micro-realm (Werner Heisenberg's uncertainty principle in quantum mechanics); (4) to predict many phenomena, even in the macro-world (chaos theory in non-linear dynamics). All this happens within the stringent prohibitions enforced by the laws of Nature. Many things are impossible in the universe. Hence, oftentimes our pursuit of knowledge via conjectures will be misdirected. Humans may forever remain ignorant about the true nature of the universe. As John Horgan famously noted, "evolutionary biology keeps reminding us that we are animals, designed by natural selection not for discovering deep truths of nature, but for breeding."[106]

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[102] Dawkins (2006), p. 31.

[103] Feynman (1965), Chapter 2, The Relation of Mathematics to Physics, p. 58.

[104] Ford (1989).

[105] Horgan (2015).

[106] Horgan (2015).

The universe is a network of communicating objects, each with its own properties, states, and rules of engagement with other objects. In a nested manner, larger objects are networks of smaller objects. Thus, the universe appears networked at multiple levels, scales, and topologies. At a mathematical level, a quantum jump in our understanding of the generic properties of networks took place in the 20th century, much of which was summarized for scholars by Steven Strogatz[107] in 2001. The study of network is so fundamental that it provides unifying principles for understanding any kind of network, say, electrical circuits, electrical power grids, neural networks, the internet backbone, the World Wide Web, social networks, galaxies, power stations, transport networks, 'old-boy' network, cellular and metabolic networks, the metabolic network of the bacterium Escherichia coli, telephone call graphs, citation networks of scientists, the overlapping boards of directors of the largest companies in the United States, *etc*., given their individual dynamics and coupling architecture. The availability of powerful computers and sophisticated algorithms has made it feasible to probe their structure even at scales involving hundreds of millions of nodes in a network. We now know that the anatomy of a network plays a crucial role because structure always affects function. For example, the topology of social networks affects the spread of information and disease, and the topology of a power grid affects the robustness and stability of power transmission. Network dynamics also span a wide range: it may settle down to a stable state, show periodic pulsations, chaotic behavior, or even collapse.

What we are witnessing in patenting is the incipient chaotic behavior of an unstable social network comprising the STEM community, the legislature, the Patent Office, the judiciary, the business community and the patent-seeking community. Its genesis is the judiciary, which without deep STEM knowledge, is the anointed authority to interpret, *inter alia*, patent subject matter eligibility, while the true STEM experts who should decide that question, frettingly sit on the sidelines every time a patent litigation is in progress. Until STEM experts decide patent subject matter eligibility, network dynamics will ensure that the patent system cannot stabilize itself, much less fulfill its constitutional mandate.

2.8 Is mathematics physics and vice versa?

Abstract mathematics when suitably interpreted becomes applied, *e.g.,* when used to describe the workings of the universe. Physicists usually identify an available mathematical template (in rare cases even create one) on which to stick their interpretations of the Universe. Surprisingly, this has worked extremely well. So, the obvious question: "Is physics just interpreted mathematics, or is mathematics abstracted physics? Or are they simply two facets of the same thing? Or is it like the chicken and egg story: which came first?" Gregory Chaitin holds the view,

> Yes, I agree, mathematics and physics are different, but perhaps they are not as different as most people think, perhaps it's a continuum of possibilities. At one end, rigorous proofs, at the other end, heuristic plausibility arguments, with absolute certainty as an unattainable limit point.[108]

Max Tegmark, on the other hand, is emphatic: "Our reality isn't just described by mathematics – it is mathematics … Not just aspects of it, but all of it, including you." Thus, "our external physical reality is a mathematical structure".[109] While mathematics sticks to deductive logic, physics opportunistically uses inductive logic. Jurisprudence lies somewhere in between the continuum of possibilities.

Mathematics is abstract, austere, and typographical. It is only when mathematical objects (formulas, *etc*.) are interpreted, *i.e.*, given specific meaning by establishing a correspondence with real world objects and phenomena using man-made rules of correspondence (as we do with any other language) that mathematical objects cease to be abstract and describe patent eligible subject matter. When an inventor discovers a mathematical correlation, say, between glucose levels in human blood and diabetes, that discovery *is* patentable subject matter. While the correlation *captures* a natural

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[107] Strogatz (2001).

[108] Chaitin (2004).

[109] Tegmark (2014).

phenomenon, the conjectured correlation required human ingenuity to discover *and* apply usefully. In fact, all conjectured laws of Nature are essentially mathematical correlations, some of which may appear in statistical or probabilistic form as is often the case, *e.g.*, in medical diagnosis and suggested cures or in quantum mechanics or in statistical mechanics or in information theory.

3 Inventions are mathematically describable

Tegmark's view that "our external physical reality is a mathematical structure"[110], implies that a formal and precise mathematical description of an invention exists. Such a description is indeed desirable where each mathematical symbol is given its physical interpretation. This would immediately allow the power of mathematics, computation, information processing, and interpretation to be brought together in describing the invention comprehensively. Also, since "information is physical"[111], the information carrier may well be biological, and the physical processes by which information is processed differ, but the information will not at any stage. We outline two examples: information carried and processed by (1) digital computers (Section 3.1), and (2) biological cells (Section 3.2).

3.1 Algorithms and computing machines

An algorithm is a step-by-step problem-solving procedure, often an established, recursive computing procedure for solving a problem in a finite number of steps. Devising an algorithm requires insight, creativity and intellect, but once created, its execution is completely mechanizable. This was shown by Alan Turing in a brilliant paper[112] in 1936 in which he described an abstract mathematical model, now known as the universal Turing machine (UTM), which mimicked a human computer, acting without the benefit of insight. He showed that this machine, using a programming language he had designed[113], could be instructed to simulate any logical or arithmetical operation. The class of functions computable by a UTM corresponds exactly to the class of functions which we would naturally regard as being computable by an algorithm. Turing did this before there were any real computers.[114]

Just as Gödel had shown that a non-trivial axiomatic arithmetical system is incomplete (*i.e.*, there are theorems that can neither be proved nor disproved in the system), Turing showed that there is no general algorithmic way to decide in advance if a program-data combination when executed will eventually halt. This is the famous halting problem in computer science. Of course, one can decide for certain combinations of programs and input data[115], but it cannot be done for every possible program and input data. The issue is not whether a program will halt after a certain time limit (which can be answered by running the program up to the time limit) but whether it will ever halt. The problem is of not knowing when to give up. Turing also deduced that if there is no way of knowing in advance by a calculation, then there is no way of knowing it in advance by reasoning either. That is, *there is no axiomatic system, which will enable one to deduce in advance whether a program will halt or not*. This also means that any axiomatic system can be arithmetized and studied as an arithmetical system. By

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[110] Tegmark (2014).

[111] Landauer (1961); Landauer (1991).

[112] Turing (1936). In this epochal paper, Turing defines the Turing machine, formulates the halting problem, and shows that it as well as Hilbert's Entscheidungsproblem is unsolvable.

[113] Turing realized that the choice of the symbolic system was of no significance in the mathematical abstraction of the computer if the symbols were used consistently and their number was finite. With a finite alphabet set, one can place each symbol in a one-to-one correspondence with a unique pattern of any two symbols (such as 0 and 1). Hence, rather than deal with many esoteric symbols, Turing considered a machine capable of reading and writing just two kinds of symbols (say, 0 and 1) with blank spaces or some other convention to identify the boundaries between distinct symbols.

[114] To understand Turing's papers of the period, it is necessary to bear in mind that when he uses the words 'computer', 'computable', and 'computation', he employs them as pertaining to *human calculators*. In 1936, 'computers' were human clerks who worked in accordance with effective (synonymous to mechanical) methods.

[115] Given a specific algorithm, one may often show that it must halt for any input, and in fact computer scientists often do just that as a part of a correctness proof. However, each such proof requires new arguments: there is no mechanical, general way to determine whether algorithms halt.

an axiomatic (also called formal) system we mean a system comprising a set of symbols; a grammar for combining the symbols into statements; a set of axioms, or statements that are accepted without proof; and rules of inference for deriving new statements (theorems). A proof is a listing of the sequence of inferences (arguments) that derive a theorem. It is vital that a proof be formally (*i.e.* mechanically) verifiable. Thus, there is a correspondence between an axiomatic system and a computational system whereby a proof is essentially a string processing computation (see Table 1).

Table 1 Correspondence between axiomatic and computational systems.

Axiomatic system	**Computational system**
Axioms	Program input or initial state
Rules of inference	Program interpreter
Theorem(s)	Program output
Derivation	Computation

Source: Lewis (2001).

A proof in axiomatic mathematics is an impeccable argument that uses only the methods of pure logical reasoning. The reasoning is such that it enables one to infer the validity of a given mathematical assertion from the pre-established validity of other mathematical assertions or the axioms. Once a mathematical assertion has been established by this procedure, it is called a theorem. Axiomatic mathematics is about axioms, theorems, and proofs. Likewise, jurisprudence is about statutes, case law, and arguments.

The UTM gives a new meaning to the *doctrine of equivalents* in patent law. If any software and a UTM combination that simulates the actions of a hardware, then that combination must be treated as hardware-equivalent. Only when a physical manifestation of a process is required outside of the human mind to produce an output (physical or mental) must the software be encoded in physical matter and the UTM must be a physical embodiment. In principle, all mathematical stuff can be written in mathematical language and encoded in software using a programming language and vice-versa with identical information content. The function of any physical machine that can be described in mathematical language can be simulated on a UTM using appropriate software. This means that if a machine fulfills the statutory requirements of a patentable invention, then so does the corresponding software *per se* when appropriately documented and annotated to establish the correspondence between itself and the machine and vice-versa. The courts have only partially understood this equivalence between hardware and software.[116] Software is the formal written description of the machine it mimics with all the details that an expert need know about the machine to simulate its actions using a UTM.

The UTM is completely equivalent, in its action, to that of a modern general-purpose computer—with the specific idealization that the computer must have access to an unlimited storage capacity. It is due to Turing that the ideas of computers and computation have become a force in mathematical thinking. By introducing mathematically well-defined machines, Turing could capture the essence of computational processes and algorithms. His theory of computation provided a deep understanding of algorithmic procedures, and in the process, he ushered in the modern computer revolution.[117]

Doing mental arithmetic requires no physical device other than a functioning brain. It is the brain's limited capacity to retain information in its memory and its limited processing speed when processing

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[116] *See*, *e.g.*, CAFC (1994), citing *In re Freeman*, 573 F.2d 1237, 1247 n.11 (CCPA 1978); *In re Noll*, 545 F.2d 141, 148 (CCPA 1976); *In re Prater II* (415 F.2d 1393, 1969 Aug 14) at 1403 n.29.

[117] Penrose (1989), Chapter 2.

information that forces humans to resort to the use of inanimate hardware when dealing with lengthy computations. Note that mathematical algorithms can be meticulously and precisely articulated (described) and therefore an algorithm does not become non-statutory subject matter in patent law simply because that algorithm can be executed wholly in the mind. In fact, the Indian mathematician Srinivasa Ramanujan[118] was amazingly capable of doing just that. Algorithmic thinking wholly done in the mind (*e.g.*, executing business methods) is statutory subject matter for patenting purposes if it can be, and usually is, articulated in mathematical language. This includes structured decision making processes even if they have probabilistic and stochastic elements included in them. Probability and statistics are well established topics in mathematics and can be clearly described to fulfil the statutory enablement requirement. Of course, enforcing such patents is an entirely different matter! Some business methods cannot even be protected as trade secrets.

Man-made algorithms and laws of Nature cannot be clubbed in the same class just because both can be expressed in mathematical language in computable form. Man-made algorithms require human intervention to create while laws of Nature (not conjectured laws of Nature) already exist and were not created by man and man has no known capability to amend them even if one were to concede that man has free-will. In fact, any exercise of free will, if possible, would amount to saying that at least one human is powerful enough to modify a law of Nature, no matter how small the modification, and dramatically change the functioning of the universe as we currently understand it. For example, changing the law of conservation of energy by the minutest amount would mean a very different universe. The notion of free will is rationally incompatible with our current understanding of the universe. To that extent, there can be no invention that is not entirely confined by the laws of Nature. We are their prisoners.

Any mathematical algorithm can be interpreted in infinite number of ways by attaching specific meanings to the symbols (symbol-meaning correspondence) in an algorithm. Some interpretations may be abstract and some may reflect or correspond to real world values. An algorithm can and frequently is developed without any interpretation in mind or without any reference to the real world.[119] A substantial number of algorithms now used by physicists to explain the real world or manipulate it were developed much before they were given real world interpretations by physicists. Now that physicists increasingly believe that the universe is describable in mathematics and mathematics alone, it increasingly appears that our universe is essentially an abstract mathematical structure and thus has an interpretation-free existence too.[120] While abstract mathematics, like abstract art, can be given physical form, it remains abstract for want of an interpretation.

So, the SCOTUS erred when it said,

> "A principle, in the abstract, is a fundamental truth; an original cause; a motive; these cannot be patented, as no one can claim in either of them an exclusive right." *Le Roy v. Tatham,* 55 U.S. (14 How.) 156, 175 (1852). Instead, such "manifestations of laws of nature" are "part of the storehouse of knowledge," "free to all men and reserved exclusively to none." *Funk Bros. Seed Co. v. Kalo Inoculant Co.,* 333 U.S. 127, 130, 76 USPQ 280, 281 (1948).[121]

Since the time the SCOTUS made these statements, our understanding has dramatically changed. Today, a mathematical principle, stated in the abstract, is a man-made assertion which mathematicians in their jargon label as "truth"; it should not be confused with the "fundamental truth" that the SCOTUS refers to. That "fundamental truth" remains unknown to man. Mathematics provides an original language and the means to pursue science and technology in a rational and systematic way. Abstract mathematical principles *per se* cannot be patented; specific interpretations

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[118] *See*, *e.g.*, O'Connor & Robertson (1998). and Hoffman ().

[119] For example, finding the roots of a polynomial or the solution of a set of linear algebraic equations.

[120] In an interpretation-free universe, asking "What is the meaning of life?" is meaningless.

[121] MPEP (2106) ().

of mathematical principles may be patented if those interpretations, in view of prior art and, in principle, can be used by persons skilled in the relevant art(s), without undue extra effort in divining the invention, to create the invention, and that too only if the grant of a patent is, overall, more beneficial to society than not granting it. What the SCOTUS refers to as “manifestations of laws of nature” are actually *statistically significant correlations* discovered by scientists and labelled by them as “laws of Nature”. A less confusing label would have been “human-conjectured laws of Nature and therefore open to refutation”. They did not discover the “laws” through “divine revelation”. The actual laws of Nature continue to remain hidden from mankind. Much of our conjectured scientific knowledge is based on observations of natural phenomena, natural regularities, our ability to make hypothesis-based correlations and above all an abiding faith that laws of Nature are mathematical.

Modern physics is not about knowing or memorizing a lot of facts but in being able to grasp the “right” man-made concepts, explanations and theories. Invariably, its best predictions and descriptions are made in mathematical language.[122] The purpose of a great mathematical theory is to be able to make ‘predictions in principle’ using algorithms. We talk of ‘in principle’ because it may not be always possible for one to compute all that would be needed to generate a prediction because of technological infeasibility or even because it is too compute-intensive despite all available computing resources of the universe. In any mathematical formula with free variables we essentially capture an infinite amount of information and an infinite number of interpretations beyond those for or from which the formula was conjectured or derived.

Patent law does not grant patents to things that have an abstract description only. It cannot because it is disembodied from the physical world until interpreted. However, once a *specific interpretation* of an abstract description, which can be *verifiably related to the physical world* we live in, is provided a patent may result. An abstract description with its accompanying interpretation(s) to describe an invention should be encouraged because it would eliminate the misuse of clever draftsmanship that could lead to misinterpreting of patent statutes. Mathematical language was designed to eliminate ambiguity in communication.

3.2 Molecular biology is mathematical and informational

We define the information content of an object as the minimal size of the set of instructions that we need to be able to reconstruct the object, or better, the state of the object.[123] Implicit here is that information can be encoded in physical systems. Indeed, without a physical device we cannot store, transmit, process, or receive information. Moreover, the laws of physics dictate the properties of these devices and therefore they limit our capabilities for information processing. Hence, information theory cannot be a purely mathematical concept because the laws of physics dictate the properties of its basic units.

This rather obvious fact became obvious to information theorists only in 1961 with the publication of a landmark paper by Rolf Landauer,[124] who realizing that physical devices are needed to encode information, showed that there is a fundamental asymmetry in the way Nature allows us to process information. In fact, he proved the surprising result that all but one operation required in computation could be performed in a reversible manner. For example, copying classical information can be done reversibly and without wasting any energy, but when information is erased there is a minimum energy cost involved per classical bit to be paid. That is, the erasure of information is inevitably accompanied by the generation of heat. Indeed, Landauer’s principle provides a bridge between information theory and physics via thermodynamics. That insight and the abstract UTM have brought about a sea-change in the way we look at information and computation. The quantum physicist David Deutsch notes:

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[122] Deutsch (1998), Chapter 1, p. 2.

[123] Burgin & Diaz (2011).

[124] Landauer (1961, 1991).

> The theory of computation has traditionally been studied almost entirely in the abstract, as a topic in pure mathematics. This is to miss the point of it. Computers are physical objects, and computations are physical processes. What computers can or cannot compute is determined by the laws of physics alone, and not by pure mathematics. One of the most important concepts of the theory of computation is *universality*. A *universal computer* is usually defined as an abstract machine that can mimic the computations of any other abstract machine in a certain well-defined class. However, the significance of universality lies in the fact that universal computers, or at least good approximations to them, can actually be built, and can be used to compute not just each other's but the behavior of interesting physical and abstract entities.[125]

Modern biologists view the DNA (deoxyribonucleic acid) as a nucleotide string of encoded information, something like a long tape containing both program and data for a universal Turing machine. The DNA's interaction with the rest of the cell's machinery is nothing but a series of computational steps. Not surprisingly, bioinformatics as a discipline has so many computer scientists in its ranks, many of them holding joint academic appointments in the departments of biology and of computer science.

Such "biological" computations are not completely based on classical logic but also on quantum logic. It turns out that quantum computers can do what classical computers do plus some more[126]. Future surprises and breakthroughs will most likely come from the exclusively quantum part of the logic, a realm where our normal reasoning fails. It is a branch of knowledge, which is understood with difficulty even by the experts in the field! No one has yet claimed to have developed any intuition for it.

Theories of quantum computing and quantum information have already provided some breathtaking results in teleportation, encryption and code breaking, parallel computing, *etc*. What new disruptive technologies they will spawn is difficult to foretell. That there will be some is obvious. That they will eventually encompass biology, as it previously did astronomy, appears inevitable. Interestingly, the mathematical representation of quantum mechanics has several interpretations of the universe.[127]

Molecular-biology-rooted biotechnology inventions are expected to dominate 21st century commerce because of biotechnology's tremendous potential to contribute to human health, food security, and the environment. The current focus of biotechnologists is on "developing tools and methods that would enable them to encode, in artificially created or natural DNA, basic genetic functions in novel combinations by design. The aim is to artificially create biological systems of increasing size, complexity, and tailored functionality. These systems are clearly patentable subject matter. All players involved in creating and commercializing this knowledge-and-capital intensive emerging technology are obviously deeply interested in knowing how they would gain or lose from the intellectual property (IP) system in place and whether that system needs to be changed, replaced, or abolished from their respective perspective."[128] To address the concerns of biotechnologists, the patent system must address the issue of subject matter eligibility in patent law comprehensively.

3.3 Advancing frontiers in bioscience

When relatively powerful microprocessors became available around 1975, enterprising entrepreneurs helped spark the information revolution. That, in turn, along with tools such as optogenetics[129] and multiple forms of microscopy, is now powering, indeed, creating a revolution in computer modeling in bioscience.[130] Such revolutions are fertile grounds for pioneering patents, given the complexity of biology. Deconstructing the mysteries of life with the aim of establishing reliable and predictive

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[125] Deutsch (1998), p. 98.

[126] Nielsen & Chuang (2010).

[127] *See*, *e.g.*, Bera & Menon (2009).

[128] Bera (2015a).

[129] Optogenetics is a biological technique which involves the use of light to control cells in living tissue, typically neurons, that have been genetically modified to express light-sensitive ion channels.

[130] Allen (2016).

models, and putting that knowledge to the service of mankind would be an amazing triumph of human ingenuity. To enable such advances, the scientifically advanced nations, philanthropists, governments, universities, and private companies have contributed much. Yet more appears necessary in funding fundamental science and researchers pursuing out-of-the-box approaches at the bleeding edge of knowledge. Their approaches necessarily require interdisciplinary collaborations that span across disciplines, including bioscience, mathematics, computer science, medicine, engineering, *etc*. This is not new to the bioscience community, given their experience in the highly successful Human Genome Project which required the convergence of massive computing power, new algorithms, expertise in experimental biology, and wide support from public and private sectors. What is lacking is a robust and equitable patent system that can support the inventions that will follow from the new knowledge that unfolds.

4 Fundamental tests of patentability

The base reference for measuring human ingenuity is obviously a world in which no humans exist. Therefore, the very first test of patentable subject matter is: Could the invention under consideration possibly have occurred or likely to occur in our planet in the absence of intelligent and thinking humans? (*Yes*, *means not patentable.*) For example, it is inconceivable that a modern jetliner could have ever occurred in the absence of intelligent and thinking humans. The second test is: If the invention could occur in the future in our planet devoid of humans, would the presence of intelligent and thinking humans accelerate the process of bringing forth that invention not by their mere presence but by observation, analysis, and deliberate intervention. (*No*, *means not patentable.*) The third test is: If the problem the invention solves was posed to other humans, would several of them (in a statistical sense) have come up with the invention or a similar invention or a superior invention, say, within a specified 'short' period of each other. (*Yes*, *means not patentable.*) Finally, if a computer, such as IBM's *Watson*[131], or Google's AlphaGo[132] and their successors was given the task of solving the problem, would it solve the problem in a few years. (*Yes*, *means not patentable.*) Note that a mathematical solution to the problem is a valid solution. Further, an algorithmic solution is implementable on a Universal Turing Machine (UTM) and hence on a sufficiently powerful physical computer.

The invention is not patentable if the answer is *not patentable* to any of the four questions.

When an observing inquisitive mind finds promising patterns or correlations, whether deterministic or statistical, it may later use them to solve problems. Whether ingenious solutions beyond the reach of PHOSITAs arrived at by this Popperian method should be patented without interfering or hindering further spread or development of useful knowledge (the constitutional requirement), must be made by a statutory body steeped in STEM-knowledge, *e.g.*, a Patent Validation Board (PVB)) comprising members from the patent office, the national science academies, and other eminent STEM experts, since a bright line rule cannot be formulated. The PVB and its relationship with the USPTO is described in Section 5.2. In brief, the PVB will have the enormous moral responsibility of deciding when the grant of a patent to a given invention would adversely affect the society at large based on parameters that cannot be objectively quantified. That is, it must deal with "the difficulty of drawing a line between the things which are worth to the public the embarrassment of an exclusive patent, and those which are not"[133]. To support the PVB, the USPTO will have the great responsibility of ensuring that it does not admit overbroad and indefinite claims, which once admitted, would invite litigation. The patent act needs to be amended so that there is no presumptive validity of a patent based solely on the USPTO's examination of the patent application. Once the invention is granted a provisional patent by

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[131] IBM (2010). Watson uses natural language processing and machine learning to reveal insights from large amounts of unstructured data that include news articles, research reports, social media posts and enterprise system data.

[132] Google (2016).

[133] Jefferson (1813).

the USPTO, and subsequently validated by the PVB, the patent's validity cannot be further contested in any forum. (See Section 5.2.)

4.1 Considerations before patent grant

Einstein once said, "The only thing that interferes with my learning is my education." One may similarly say that "The only thing that interferes with judicial interpretation of patent subject matter eligibility is *stare decisis*." The time has come for a major overhaul of the patent system.

A pragmatic two stage process for patent grant would be to ask: (1) Is the invention patentable under the statutes? And in the process, pointing out anomalies in the statutes if a reasoned conclusion cannot be drawn. (2) If the invention is patentable, should it be denied a patent if it could be an "embarrassment" to society in its present state of evolution *and* rate of evolution or should it be granted a patent with obligatory social conditions (decided on a case-by-case basis, *e.g.*, in the case of (potential) standard essential patents) attached[134], in consultation with the patentee? This question should be answered by a separate statutory body (*e.g.*, the PVB) and no other.

The following should be considered before a patent grant:

1. *Human ingenuity* criterion. The patent application must describe an invention the creation of which required such human ingenuity without which it is extremely unlikely that the invention would have occurred or might occur at some distant time in the future or occur spontaneously over which humans have no direct or indirect control.
2. *Quid pro quo* criterion. Establish a clearer equitable *quid pro quo* criterion for patent grant. Any equitable criterion must bear in mind its effect on public health and safety, effect on skill development, impact on global commerce, freedom to practice technology and service standards, *etc*. The criterion must necessarily be statistical in which some benefit, some do not, some are indifferent, and some are antagonistic. This criterion must be periodically reviewed.
3. *Unenforceability* criterion. If a claimed element of a patented invention (*e.g.*, a diagnostic test), in principle, can be performed wholly in the mind by any person, and this fact is known prior to patent grant, then the claim should not be allowed. If this fact becomes known post-grant, then the claim cannot thenceforth be infringed by any act that would otherwise have been considered infringing. This is because infringement of such claims cannot be controlled without violating a person's natural right to free thought. In this respect the patent is unenforceable.
4. *Scientific discovery and algorithm* criterion. Inviolable laws of Nature are universally pervasive. They primarily deal with matter, energy, space, time, motion, forces, and transformations of matter and energy. They govern all human activity, including detection of natural phenomena by observers, sensors and detectors, as well as conjecturing laws of Nature and creating patentable inventions. A conjectured law of Nature is patent eligible subject matter. A mathematical algorithm with an accompanying specific interpretation that connects it to the real world is also patentable subject matter. Interpretations not categorically claimed in a patent cannot be claimed under the doctrine of equivalents in patent enforcement.
5. *Process* criterion. If a product of Nature is produced in a non-natural way (process) using human ingenuity, then the process but not the product is patentable. If a product is producible by several different processes, then only such processes are patentable where human ingenuity was involved in designing them. A process patent, when practiced, may infringe a product patent if the process produces a patented product at any intermediate stage in the process and such a product is separated out and released in commercial channels without a license from the product patent owner. If not separated, it should be treated as a product of nature.

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[134] Bera (2015b).

5 How best to achieve the goals

The STEM community is now deeply aware that all advanced branches of science, technology, and engineering increasingly use mathematics as their *lingua franca* because it is both a language of communication and a vehicle for reasoning. Mathematics abhors ambiguity. It is mathematics that allows us to seamlessly integrate hitherto knowledge silos. The import of this has not yet seeped into the consciousness of either the legislature or the judicial system. The USPTO is aware of it but has not been aggressive enough to cogently enlighten either body about it. In the existing system, generalist judges ignorant of the technical arts that support a patent hear and encourage arguments in litigation that deviate from the "substance of what the patentee invented and how significant that invention really is" to "the scope of legal rights not by reference to the invention but by reference to semantic debates over the meaning of words chosen by lawyers"[135].

Clearly, the focus should be on the invention, not on semantics. Even if there is an unavoidable sematic debate, it should be resolved by STEM experts, not lawyers dissecting legalese. Arguments escalate because judges are neither inventors nor STEM experts nor PHOSITAs who would instinctively know when and where to draw a line based on professionally accepted definitions, norms and conventions and thus close arguments early. Over time, frustration over court decisions on patent infringement has increased, reaching a crisis-like situation.[136] Because of this, two technology areas have become particularly vulnerable—software and biotechnology—because the judiciary, and, to an extent, the USPTO are unaware of the deep connections between them. Tegmark's mathematical understanding of the universe has yet to percolate to them.

Software and biotechnology share some core commonalities (see Sections 3.1 and 3.2). They are two sides of the same coin! Both deal with information and information processing. Both facilitate the creation or transformation of material into products and related processes. The two sides are:

Software: Abstraction drives reality via mechanization.

Biotechnology: Living reality is encoded in software abstraction.

Software inventions use abstract mathematics to process information where both the input data (coded in numbers) provided to start the processing and the output data (also coded in numbers) produced at the end of processing are isomorphically interpreted in terms of patentable products and processes that belong to the real world. In biotechnology inventions, one looks at products and processes in the real world related to living matter to determine the isomorphism that will describe how the DNA (deoxyribonucleic acid), functioning as software, codes information related to them. The cellular machinery then uses that information to activate processes and produce products. Finding the required isomorphism involves cutting-edge R&D. Once found, human-engineered DNA sequences can be created to function as software and run in an appropriate chemical environment that serves as the computer for processing the DNA and create patentable products, which may be a drug, radiated energy, other DNA sequences, *etc*.

In software inventions, information processing is carried out by real-life inanimate machinery (digital computer), fully describable as a universal Turing machine (UTM) in abstract mathematics. But such processing can also be carried out by biological matter (*e.g.*, the human brain or cellular matter). Modern inventions are now so deeply rooted in STEM that it is no longer possible for generalist judges to understand them. We therefore suggest certain remedies that would enable the workload related to patent grant, validation, and infringement to be equitably shared by the patent office, the judiciary, and the proposed Patent Validation Board (PVB).

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[135] Burk & Lemley (2009).

[136] *See*, *e.g.*, Jones (2014). *See also*: Key Patent Law Decisions of 2014, Jones Day, March 2015, http://www.jonesday.com/key-patent-law-decisions-of-2014-03-26-2015/

5.1 Balancing forces in the patent system

The essence of the patent system is to strike an equitable balance between private incentives and protection of public interest, not indiscriminate distribution of private incentives. It is thus necessary to assess if the invention may have occurred without incentives. Perhaps the Bayh-Dole Act of 1980 needs to be revisited and tweaked so that institutions like the National Institutes of Health can frame their patenting policies with greater flexibility, especially with respect to the research grants it awards to various research groups whose patent-eligible inventions may have a critical impact on public health and related spending, depending on whether they are patented or not and, if patented, the manner in which they are allowed to be accessed by others.

The U.S. Federal Government comprises three branches: legislative, executive and judicial. Each branch has its own powers and responsibilities, including how they may interface with the other branches.[137] The patent system was created by the legislature, is administered by the executive, and patent law is interpreted and disputes adjudicated by the judiciary. In a substantial way, all three government branches have failed to nurture a patent system that is robust, fair, progressive, and suited for the post-industrial economy.

The courts have found themselves in a fuzzy role because, as Jefferson noted,

> there were still abundance of cases which could not be brought under rule, until they should have presented themselves under all their aspects; and these investigations occupying more time of the members of the board than they could spare from higher duties, the whole was turned over to the judiciary, to be matured into a system, under which every one might know when his actions were safe and lawful. Instead of refusing a patent in the first instance, as the board was authorized to do, the patent now issues of course, subject to be declared void on such principles as should be established by the courts of law. This business, however, is but little analogous to their course of reading, since we might in vain turn over all the lubberly volumes of the law to find a single ray which would lighten the path of the mechanic or the mathematician. It is more within the information of a board of academical professors, and a previous refusal of patent would better guard our citizens against harassment by law-suits. But England had given it to her judges, and the usual predominancy of her examples carried it to ours.[138]

The U.S. patent system seeks to encourage the creation of new inventions and their dissemination. The *quid pro quo* expectations of society vis-à-vis a patent has two main aspects. First, a need to draw "a line between the things which are worth to the public the embarrassment of an exclusive patent, and those which are not"[139], and second, full public disclosure of the invention by the inventor.

The first (the "embarrassment") is a subjective matter of equity that gives the judiciary enough leeway to vary the terms of the argument depending on one's sublime ethical, political and religious leanings so that one can prove virtually anything. This is amply reflected in the many divided or convoluted judicial opinions. Mathematicians know this happens when an axiomatic system (which the legal system valiantly tries to emulate) is inconsistent or applicable rules of inference have been incorrectly applied.[140] Injection of subjectivity in the interpretation of law allows inconsistencies to surreptitiously creep in and *stare decisis* perpetuates them. This has resulted in patents becoming potent weapons of business war in the hands of patentees to selectively destroy competing inventors, retard further development of crucial improvements, raise the cost of doing R&D, deny timely benefits of additional useful, novel, and non-obvious products and processes to society, and burden courts with plentiful, unnecessary, acrimonious, and expensive litigation. The second (specification), is a matter of law and its fulfillment must be decided on available facts, if necessary, by relying on the expertise of relevant

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[137] *See* http://www.house.gov/content/learn/branches_of_government/

[138] Jefferson (1813).

[139] Jefferson) (1813).

[140] Hofstadter (1979).

experts. The role of the PVB *inter alia* would be to deal with these two main aspects so that "a previous refusal of patent would better guard our citizens against harassment by law-suits".

5.2 The USPTO & the Patent Validation Board

The USPTO is understaffed, overworked, under-trained, ill-equipped and incentivized in a manner that makes it ill-suited for a highly dynamic post-industrial economy that must constantly guard against obsolescence because of exponentially advancing rate of technology development. The USPTO's set up encourages patent examiners to approve, almost by default, most applications and transfer the burden of resolving patent validity and infringed claims to the judiciary, an entity devoid of STEM expertise. The USPTO also ignores the fact that the pace of innovation varies by industry and hence PHOSITA profiling is of paramount importance in examining patent applications. Thus, in practice, the USPTO granted patents are *de facto* provisionally granted patents. We suggest that it be formally declared so by amending the law (*e.g.*, 35 USC § 282).

The legal validity of a patent's claims, if challenged, should be decided not by the courts but by an independent statutory body, which we here call the *Patent Validation Board* (PVB). This must be an independent body, because if it is inside an existing organization, *e.g.*, the USPTO, its existing culture will kill it. The PVB must be the final authority to decide if the claims of a granted patent are valid in law so that the public may know the precise legal limits of patent protection (including those deemed to fall under the present doctrine of equivalents) without recourse to judicial ruling. The Board's decision shall not be contested in a court of law unless there is clear evidence of corrupt practices indulged by the Board that could have impacted the decision. On such evidence, the court shall have the patent re-examined by a new Board. The Board may ask the USPTO to re-examine and provisionally reissue an amended version of the patent, if feasible. Such a reissued patent shall be treated as a new provisional patent for validation purposes. A provisional patent needs to be validated only once by the Board; it can be done at any time during the provisional patent's tenure and the validation may be requested by any one. It would be in the interest of the patentee to have his patent validated and thus legally secured before engaging in any licensing or other commercial activity or litigation.

The Board should comprise experts in patent examination, STEM experts, experts in patent law and members from the National Academies, all suitably chosen keeping the patented invention in mind. The Board should be supported by an expert prior art search team. The Board may also crowd-source to find prior art. The Board shall *de novo* determine the relevant PHOSITA for the patent. The first question it should settle before anything else is the *quid pro quo* aspect of patent grant: "Would society have benefited more if the patent had not been granted without being unfair to the patentee?" If the answer is yes, the patent should be revoked. The Board must decide keeping in mind the words of Thomas Jefferson:

> Considering the exclusive right to invention as given not of natural right, but for the benefit of society, I know well the difficulty of drawing a line between the things which are worth to the public the embarrassment of an exclusive patent, and those which are not.[141]

The real strength of the Board lies in the cutting-edge knowledge STEM experts and members from the National Academies bring to evaluate the usefulness, novelty, non-obviousness of a given invention and whether it has been adequately described for an expert in the relevant arts to understand the invention and its implementation. They also bring the expertise needed to decide the extent to which the doctrine of equivalents can be applied in scoping the invention. This eminent body, in principle, is ideally suited to focus on what the patentee actually invented, how significant that invention is, and whether the grant of a patent to it would encourage innovation without being an embarrassment to society.

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[141] Jefferson (1813).

The PVB would have an instinctive understanding of a PHOSITA given that the normal duties of a STEM expert include hiring, mentoring, and supervising PHOSITAs. Science is an intensely human enterprise. The STEM experts are the right people to decide *inter alia* if the requirements of 35 U.S.C. § 112 (a, b) have been fulfilled in letter and spirit, not the courts.

At another level, the PVB is the ideal body to eliminate abuse of the litigation process by patentees who invent one thing and later claim to own something else entirely different, *e.g.*, under the doctrine of equivalents or by resorting to clever semantic debates which would not pass muster with the PVB. The PVB could rejuvenate the *doctrine of pioneer patents* so that important advances receive broader protection (subject to the patentee agreeing to license them under FRAND (fair, reasonable, and non-discriminatory) terms) than other patents. The creation of the PVB obviously requires that 35 U.S.C. 282 be amended and made consistent with the mandate of the PVB. The courts should strictly refrain from getting involved in STEM related aspects of an invention. That the courts are presently involved is an unfortunate legacy from the very early days of patent law in the United States. Patent licenses should be legally and prospectively valid only after the validity of the patent is certified by the PVB. Further, courts should decide patent infringement cases of only valid patents and after the PVB has determined the extent the patent claims are trespassed.

In short, the PVB will be a statutory body created by Congress for the following reasons:

1. To serve as the final authority on deciding patent validity and in infringement cases, decide the extent a valid patent has been infringed. It will set up its own processes for deciding patent validity and extent of patent infringement.
2. Once the PVB is established, the judiciary will have no say in STEM-related matters in patent litigation. Thus, there will be no need for the judicially created doctrine of equivalents, Markman hearings, prosecution history estoppel, and reverse doctrine of equivalents, if the patented invention is described per the standards set by the PVB. The judiciary will confine itself to deciding only the quantum of damages to be awarded in litigation of valid and infringed patents.

While President Lincoln sagaciously created the National Academy of Sciences by an Act of Congress in 1863, as a private, non-governmental institution to meet the government's urgent need for an independent adviser on scientific matters and to "investigate, examine, experiment, and report upon any subject of science," no president since has shown similar sagacity in creating a PVB of similar STEM caliber to meet the nation’s need for an independent body to “investigate, examine, experiment, and report upon any aspect of patent grant”. It is ironical that in a STEM-driven post-industrial era, one feels “gratified when a politician shows that they know about science, [when] they all should.”[142] In America, the most STEM-advanced country in the world, lawmakers being scientifically ignorant is politically acceptable because the electorate doesn’t care about scientific literacy. So, most science funding is decided by STEM-ignorant politicians on behalf of the public. America desperately needs a PVB so that a “board of academical professors” can “better guard [its] citizens against harassment by law-suits”.

5.3 Redefining judiciary’s role in patent litigation

The judiciary’s Achilles heel is its lack of training in and appreciation of mathematical logic and how word-meaning associations occur in the human mind.[143] Mathematics is an axiomatic (or formal) system built for unambiguous communication. In mathematics, an *axiom* is a proposition regarded as a self-evident truth; postulate. The word *axiomatic* means ‘of, relating to, or having the nature of an axiom; self-evident’. The users of an axiomatic system, by rigorous training, “know” the meaning of every word and symbol in the system *and* the context in which it is used. Semantic debates are ruled out. By STEM standards, jurisprudence is far from being axiomatic in resolving patent disputes. It lacks

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[142] Nature Editorial (20160421) (2016).

[143] To understand the relationship between words and meaning, see, *e.g.*, Hofstadter (1979*). See also*: Russell (1918).

the ability to frame carefully crafted questions related to patent validity and infringement. Answers to such questions require active involvement of STEM experts, hence the need for a PVB. For example, the doctrine of equivalents depends on discovering and identifying certain isomorphisms related to the invention and their implementation that would have been obvious to a relevant PHOSITA. The doctrine cannot apply to an isomorphism that is "a source of wonderment" to an expert or implementable using technologies unknown at the time the patent application was filed. Thus, judges can insidiously develop personal biases and vitiate court rulings. Lee rightly notes:

> In an ideal world, personal biases would be irrelevant to judging. The job of a federal judge is to fairly apply the Constitution and federal statutes to particular cases. If the law were perfectly clear and unambiguous [axiomatized], it would be irrelevant who was put in charge of interpreting it. Of course, law doesn't actually work that way. Congress has defined patent law using general terms like "obvious," "novel," and "process." The courts give concrete meaning to those terms through a series of precedents. Hence, the biases of a court can have a significant impact on how the law is interpreted.[144]

Thus, every 5-4 SCOTUS ruling becomes a lottery draw. And therein lies danger. Shapiro notes:

> I believe there is manifest danger in binding rulings, particularly in the field of patent law, made by courts that do not understand the issues before them. Justice Scalia's proclamation in Myriad[145] that the issues discussed were beyond the understanding of the court should raise serious red flags. Indeed, it is hard to imagine that any court, or system of law, can maintain institutional legitimacy, if it issues decisions that demonstrate misunderstanding of the field, or are not logically supported.[146] (Internal citation omitted.)

It is therefore imperative that issues related to patent validity and scope be decided by the PVB and not the courts. The courts should confine themselves to deciding non-STEM issues, *e.g.*, quantum of damages related to infringed patents. This division of labor between the PVB and the courts makes eminent sense since only about 5% of USPTO granted patents are used in commerce.[147] Thus, by drastically reducing their number, say by 80%, by rigorous PVB scrutiny the patent system can rid itself of its present mess and become credible, robust, and substantially litigation-free.

6 Concluding remarks

Deciding patent subject matter eligibility remains a difficult question in patent law. Much of the confusion and opportunistic patent litigation today comes from three judicially created exceptions to the U.S. Patent Act's broad patent-eligibility principles: 'laws of nature, natural phenomena, and abstract ideas' whose scope and limitations remain unclear. We revisit the exceptions based on our modern understanding of physics, mathematics, algorithms, computations, life sciences, and information theory. We conclude that a rigid adherence to the exceptions by the courts to maintain *stare decisis* in jurisprudence is not only irrational but also outside their competence to decide such matters. The judiciary singularly lacks the deep knowledge of science, technology, engineering, and mathematics (STEM) needed to deal with the dramatic changes STEM has undergone post-1900. It therefore continues to err in believing that the laws of Nature are known to mankind and that they are "part of the storehouse of knowledge of all men" and "free to all men and reserved exclusively to

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[144] Lee (2012).

[145] SCOTUS (2013). Justice Scalia wrote: "I join the judgment of the Court, and all of its opinion except Part I–A and some portions of the rest of the opinion going into fine details of molecular biology. I am unable to affirm those details on my own knowledge or even my own belief. It suffices for me to affirm, having studied the opinions below and the expert briefs presented here, that the portion of DNA isolated from its natural state sought to be patented is identical to that portion of the DNA in its natural state; and that complementary DNA (cDNA) is a synthetic creation not normally present in nature."

[146] Shapiro (2015).

[147] Walker (2014).

none.” In fact, physicists “know” the so-called “laws of Nature” only as conjectures and not as “truths”. We also note the deep connection between biotechnology and software and their suitability as patentable subject matter—they are two sides of the same coin. We have suggested a definition for patentable subject matter and some fundamental tests for patent grant. We have further suggested the creation of a new statutory body, the *Patent Validation Board* (PVB) with the final authority to decide questions of patent validity and the extent of patent infringement. The judiciary’s role would then stand truncated to awarding damages in patent infringement cases based on the decisions of the PVB. The USPTO’s role will also be truncated to grant only provisional patents for subsequent validation by the PVB for legal standing.

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