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Surgically Precise but Kinematically Abstract Patent Claims

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ARTICLE

SURGICALLY PRECISE BUT KINEMATICALLY ABSTRACT PATENTS

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ABSTRACT

Like many other animals, humans have extended the functional reach of their bodies by inventing tools to achieve their goals. At the most fundamental level, progress in the useful arts can be measured by the extent to which humans can make and use these tools to produce the results and effects they desire. Patent claims properly demarcate this progress when they define these tools (or methods of making or using them), not merely where and how far the tools reach. Kinematic properties, which describe the geometric motions of structural elements without regard to the forces that cause them to move, should therefore not be considered sufficiently concrete to delineate the scope of a mechanical patent claim.

This Article critically examines kinematically abstract claims in the U.S. surgical robotics industry, where claims purporting to cover all mechanisms exhibiting a specific kinematic property are widespread. First, it describes the role of patents and kinematic claiming in Intuitive Surgical's emergence as the industry's monopolist in 2003 and in some of the subsequent challenges the company has faced from competing innovators and patent owners. Second, it draws on results from physics and geometry to explain why kinematically abstract claims logically fall under longstanding doctrinal exclusions of mathematical theorems and

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abstract ideas from patent-eligible subject matter. Finally, it examines the patent-eligibility of a claimed surgical manipulator whose design incorporates kinematic data captured from procedures performed by kinesthetically skilled surgeons. From this case study, broader questions emerge about the kinds of progress and skill that fall within the patent system's ambit, with further consequences for the political economy of labor and downstream innovation in the age of automation.

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I. INTRODUCTION

Scholars are prone to describing patent scope figuratively—and therefore imprecisely[1]—through the geographic conceits of real

1. *See, e.g.*, Andrew Chin, *The Ontological Function of the Patent Document*, 74 U. PITT. L. REV. 263, 273–74 (2012) (describing set theory as providing an "imprecise and inadequate ontological description" of claim scope); Mark A. Lemley & Carl Shapiro,

property[2] and the mathematical abstractions of set theory.[3] In the field of surgical robotics, however, patents often literally define their scope in geometrically precise terms with respect to the location of a patient's body on the operating table.[4] For example, a patent claim recently issued to a subsidiary of Intuitive Surgical, Inc.[5] recites a robotic manipulator of a surgical instrument inserted into "a body cavity of a patient through a remote center of manipulation," comprising:

> a base link configured to be held in a fixed position relative to the patient . . . and a linkage coupling the instrument

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Probabilistic Patents, 19 J. ECON. PERSP. 75, 76 (2005) (contrasting the uncertain validity and scope of patent rights with the uncertain validity of real property titles); Peter S. Menell, *Intellectual Property and the Property Rights Movement*, 30 CATO REV. BUS. & GOV'T REG. 36, 39 (2007) (arguing that a unitary view of real and intellectual property overlooks "many structural differences"). *But cf.* Alan Devlin, *Indeterminism and the Property-Patent Equation*, 28 YALE L. & POL'Y REV. 61, 104 (2009) (concluding that the analogy between real and intellectual property is strained "only if one characterizes the law of real property as entailing dogmatic and unqualified rights to exclude").

2. *See, e.g.*, In re Vamco Mach. & Tool, Inc., 752 F.2d 1564, 1577 n.5 (Fed. Cir. 1985) ("[C]laims are . . . like the descriptions of lands by metes and bounds in a deed which define the area conveyed but do not describe the land.") (emphasis omitted); Dan L. Burk & Mark A. Lemley, *Is Patent Law Technology-Specific?*, 17 BERKELEY TECH. L.J. 1155, 1166 n.46 (2002) ("A patent is most similar to a real property deed specifying the metes and bounds for a parcel of land."); Arti K. Rai, *Engaging Facts and Policy: A Multi-Institutional Approach to Patent System Reform*, 103 COLUM. L. REV. 1035, 1044 (2003) ("A patent is a written document that describes and claims an invention much like a land deed might describe and claim a piece of property."); Frank H. Easterbrook, *Intellectual Property is Still Property*, 13 HARV. J.L. & PUB. POL'Y 108, 109 (1990) (analogizing the exclusionary patent right to the law of trespass); Edmund W. Kitch, *The Nature and Function of the Patent System*, 20 J.L. & ECON. 265, 271–75 (1977) (analogizing patent claims to mineral claims on U.S. public lands).

3. *See, e.g.*, Thomas D. Brainard, *Patent Claim Construction: A Graphic Look*, 82 J. PAT. & TRADEMARK OFF. SOC'Y 670, 671–72, 674–81 (2000) (depicting "[t]he patent concepts of validity, infringement, prior art, the doctrine of equivalents, file history estoppel and principles of claim differentiation" with Venn diagrams); Raj S. Davé, *A Mathematical Approach to Claim Elements and the Doctrine of Equivalents*, 16 HARV. J.L. & TECH. 507, 518–23 (2003) (using Venn diagrams to illustrate doctrine of equivalents and prosecution history estoppel); Charles L. Gholz, *A Critique of Recent Opinions in Patent Interferences*, 86 J. PAT. & TRADEMARK OFF. SOC'Y 464, 476–82 (2004) (using Venn diagram to illustrate blocking situation resulting from interference decision); Samson Vermont, *A New Way to Determine Obviousness: Applying the Pioneer Doctrine to 35 U.S.C. § 103(a)*, 29 AIPLA Q.J. 375, 418–24, 428–29 (2001) (describing anticipation and obviousness in terms of Venn diagrams). *But cf.* Jeffrey A. Lefstin, *The Formal Structure of Patent Law and the Limits of Enablement*, 23 BERKELEY TECH. L.J. 1141, 1159–67 (2008) (finding that "[n]early all of the doctrines of patent law . . . may be posed almost as mathematical set-functions whose truth value is described in terms of the claimed subject matter," but concluding that "patent law [is] not reducible to a simple set-theoretic system" insofar as it is impossible "to formulate a doctrine of enablement as a simple function of exclusion or inclusion").

4. *See infra* notes 5–6 and accompanying text.

5. Patentee Intuitive Surgical Operations, Inc. operates as a subsidiary of Intuitive Surgical, Inc. *See Intuitive Surgical, Inc. Subsidiaries*, SEC.GOV, https://www.sec.gov/Archives/edgar/data/1035267/000119312510016932/dex211.htm (last visited Oct. 7, 2017).

> holder to the base link, first and second links of the linkage being coupled to limit motion of the second link relative to the first link to rotation about a first axis intersecting the remote center of manipulation, the linkage further including three rotationally coupled rotary joints configured to generate constrained parallelogram motion of the linkage by which motion of the instrument holder is limited to rotation about a second axis intersecting the remote center of manipulation . . . .[6]

By virtue of this unusually well-mapped patent landscape, the field of surgical robotics presents a unique case study of the relationship between patent scope and progress in the useful arts.

The critical focus of this study is on the *kinematic* nature of many patented inventions in the surgical robotics field. Kinematic patent claims describe systems of structural elements that move in a desired way without regard to their masses or to the forces acting on them.[7] In the example above, Intuitive's claim is kinematic in that the links of the manipulator mechanism are described only in terms of their motions relative to each other and to the patient.

Part II of this Article highlights the strategic importance of manipulator patents in the development of the surgical robotics industry, wherein Intuitive has attained a monopoly position but has faced challenges from, *inter alia*, an open-source system development project, an individual surgeon–inventor, and a non-practicing patent assertion company. Part III uses a theoretical explanation and several example mechanisms to demonstrate that kinematic claims are unpatentably abstract, insofar as they are neither grounded in a causal account of utility nor directed to an inventive application of the underlying geometric theorem. Part IV provides a case study of mechanical claims in a pending patent application for a surgical robot design that incorporated the kinesthetic expertise of a number of surgical clinicians. The Article concludes with a discussion of some intriguing implications for patent doctrine.

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6. U.S. Patent No. 9,295,524, cl. 1 (filed May 31, 2013) (issued Mar. 29, 2016).

7. *Kinematics*, AMERICAN HERITAGE DICTIONARY (5th ed. 2017), (defining "kinematics" as "[t]he branch of mechanics that studies the motion of a body or a system of bodies without consideration given to its mass or the forces acting on it").

II. Kinematic Claims in the Surgical Robotics Industry

A. *Intuitive Surgical's Monopoly*

The current state of the U.S. surgical robotics industry can be traced to the late 1980s, when various research groups began exploring the use of remote-controlled robotic manipulation technologies to improve minimally invasive surgical procedures.[8] Research groups at the University of California at Santa Barbara and SRI International (formerly Stanford Research Institute[9]) developed prototypes that led to the formation of Computer Motion, Inc. and Intuitive Surgical, Inc., respectively, in the mid-1990s.[10] Computer Motion introduced the ZEUS Surgical System in 1997, and Intuitive began marketing the da Vinci Surgical System in 1999.[11] While there were substantial differences between the two systems,[12] the companies regarded each other as competitors[13] and eventually sued each other for patent infringement.[14]

The U.S. District Court for the Central District of California eventually granted Computer Motion's motion for summary judgment that Intuitive had literally infringed one of Computer Motion's patents.[15] Meanwhile, the U.S. District Court for the District of Delaware granted Intuitive summary judgment that Computer Motion had literally infringed a patent that IBM had licensed to Intuitive.[16] Before either case went to trial, however,

8. Simon DiMaio et al., *The da Vinci Surgical System*, *in* SURGICAL ROBOTICS: SYSTEMS APPLICATIONS AND VISIONS 199, 201–02 (Jacob Rosen et al. eds., 2011).

9. *See Corporate History*, SRI INT'L, https://www.sri.com/about/corporate-history [https://perma.cc/H67K-HPBL].

10. *See* DiMaio, *supra* note 8, at 201–02.

11. *See id.* at 203.

12. *See id.* at 204 ("ZEUS was smaller, had a lower price point, but as less capable. da Vinci was bulky and often accused of being over-engineered."); *cf.* Katherine J. Herrmann, Note, *Cybersurgery: The Cutting Edge*, 32 RUTGERS COMPUT. & TECH. L.J. 297, 302–03 (2006) (noting functional differences between ZEUS and da Vinci, but concluding that "[d]espite the differences, it is sufficient to say that these robots represent, quite literally, the cutting edge of medical technology.").

13. *See* Herrman, *supra* note 12, at 302 n.26.

14. *See* Margo Goldberg, Note, *The Robotic Arm Went Crazy! The Problem of Establishing Liability in a Monopolized Field*, 38 RUTGERS COMP. & TECH. L.J. 225, 238–39 (2012) (describing Intuitive and Computer Motion as "involved in heavy competition through multiple patent infringement lawsuits.").

15. *See* Findings of Fact and Conclusions of Law Denying Defendant's Motion for Summary Judgment of Noninfringement of U.S. Patent 6,244,809 and Granting Plaintiff's Cross Motion for Partial Summary Judgment of Literal Infringement of U.S. Patent 6,244,809 at 7–9, Comput. Motion, Inc. v. Intuitive Surgical Inc., No. CV 00-4988 CBM-RC (C.D. Cal. filed Feb. 7, 2003) (finding literal infringement of claim 1).

16. *See* Intuitive Surgical, Inc. v. Comput. Motion, Inc., 214 F. Supp. 2d 433, 441 (D. Del. 2002) (finding literal infringement of claims 1, 2, 6, 13, and 14 of U.S. Patent

Intuitive Surgical ended the patent litigation by acquiring Computer Motion in a 2003 stock-for-stock merger.[17] The merger thereby resolved what could soon have proved to be a conflict over mutually blocking technologies.[18] The presumed efficiency of this result was apparently sufficient to deflect antitrust scrutiny,[19] even though the merger resulted in the discontinuation of ZEUS[20] and effectively extinguished competition in the surgical robotics industry,[21] and even though less restrictive approaches such as cross-licensing or a joint venture might have been available.[22]

6,201,984).

17. Intuitive Surgical, Inc., Registration Statement (Form S-4) at 36–37 (Mar. 28, 2003) (describing material terms of the stock-for-stock merger).

18. While the defendants in each case could still have prevailed by proving invalidity or unenforceability of the infringed claims by clear and convincing evidence, both Intuitive and Computer Motion acknowledged the significant risk of liability for patent infringement. *See id.* at 43–45 (stating among reasons for the merger that Intuitive's directors "weighed the possibility that the litigation could result in . . . Intuitive Surgical being required either to obtain a license from, and pay damages and/or royalties to, Computer Motion or, in the event the parties were unable to agree on the terms of a license, to redesign or withdraw from the market one or more of Intuitive Surgical's products or product configurations," and that Computer Motion's directors considered potential benefits of the merger including "the elimination of the potential withdrawal from the market of one or more of Computer Motion's products or product configurations").

19. The search ("Intuitive Surgical" & "Sherman Act") in Westlaw's ALLFEDS database yields no results. *See* Search for "Intuitive Surgical" and "Sherman Act", WESTLAW, http://www.westlaw.com (search in search bar for "Intuitive Surgical" and "Sherman Act") (last visited Oct. 26, 2017). On the relevance of blocking patents to antitrust review of mergers, *see* Susan A. Creighton & Scott A. Sher, *Resolving Patent Disputes Through Merger: A Comparison of Three Potential Approaches*, 75 ANTITRUST L.J. 657, 675–76 (2009) (outlining a judicial approach for reviewing the resolution of a patent dispute through merger by focusing on "an inquiry into the 'scope of the exclusionary potential' of the patent").

20. *See* Goldberg, *supra* note 14, at 243 (citing SURGICAL ROBOTICS HERE AND THERE, http://surgrob.blogspot.com/2010/03/vintage-report-on-intuitive-vs-computer.html) [https://perma.cc/FDM8-VAN5].

21. *See* Jean Bouquet de Joliniere et al., *Robotic Surgery in Gynecology*, 3 FRONTIERS IN SURGERY, no. 26, May 2016, at 1 (tracing Intuitive's monopoly to its 2003 acquisition of Computer Motion); Goldberg, *supra* note 14, at 243–44 (same); *see also* Creighton & Sher, *supra* note 19, at 677 (noting that "[m]ergers also may go beyond the exclusionary potential of [a] patent because they last beyond the patent's term").

22. *See* Creighton & Sher, *supra* note 19, at 675–76 (explaining that a merger might appear reasonable to a reviewing court "where the parties, acting in good faith, were unable to resolve their differences through less-restrictive means (e.g., a license or a joint venture)").

To this day, Intuitive continues to hold a monopoly in the robotic surgical systems market[23] and is now worth $36 billion.[24] Intuitive has sold more than 3,800 da Vinci systems worldwide,[25] which have been used in more than three million minimally invasive surgical procedures.[26] While intellectual property and regulatory bottlenecks have long entrenched Intuitive's market dominance,[27] some commentators have predicted that the expiration of Intuitive's oldest patents between now and 2022 will open up the market to new competition.[28]

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23. *See* Travis Johnson, *Intuitive Surgical: Staking Out New Markets for Da Vinci Robot*, SEEKING ALPHA (Sep. 21, 2006, 3:00 PM), http://seekingalpha.com/article/17253-intuitive-surgical-staking-out-new-markets-for-da-vinci-robot [https://perma.cc/Z2V6-YN6C] ("The da Vinci is the only widely capable surgical robot approved by the FDA, and essentially enjoys a monopoly position in its niche."); SAGE Publications, 3 SAGE SOURCEBOOK OF MODERN BIOMEDICAL DEVICES: BUSINESS ENVIRONMENTS IN A GLOBAL MARKET 729 (2007) (tracing Intuitive's monopoly to the failure of competitor Integrated Surgical Systems in 2005). Intuitive's da Vinci surgical system has been especially dominant in the field of minimally invasive surgery, *see* Caroline Lau, *U.S. Robotic Surgery Market Set to Diversify and Grow: Intuitive Surgical's 'da Vinci' Robot Revenues to Increasingly Rely On Procedures and Services*, GLOBENEWSWIRE (Nov. 27, 2014), https://globenewswire.com/news-release/2014/11/27/686891/10110222/en/U-S-Robotic-Surgery-Market-Set-to-Diversify-and-Grow-Intuitive-Surgical-s-da-Vinci-Robot-Revenues-to-Increasingly-Rely-On-Procedures-and-Services.html [https://perma.cc/MJR6-5MLF] (describing the minimally invasive surgical robotics field as "nearing saturation" and "dominated by Intuitive"), and is being used in as many as thirty-five percent of prostatectomies performed in the United States. Aaron Smith, *Robots Grab Chunk of Prostate Surgery Biz*, CNNMONEY.COM (Mar. 23, 2007, 12:15 PM), http://money.cnn.com/2007/03/23/news/companies/intuitive_surgical; RICHARD J. ABLIN & RONALD PIANA, THE GREAT PROSTATE HOAX 104–05 (2014) (noting that the da Vinci system's FDA approval gives Intuitive "a monopoly on robotic prostatectomies").

24. *See Intuitive Surgical, Inc.*, YAHOO! FINANCE, http://finance.yahoo.com/quote/ISRG?p=ISRG [https://perma.cc/U8RB-Q39X] (stating market cap of $13.749 billion).

25. *See Investor FAQ*, INTUITIVE SURGICAL, http://phx.corporate-ir.net/phoenix.zhtml?c=122359&p=irol-faq#22324 [https://perma.cc/RF7B-NBTE].

26. *See Frequently Asked Questions*, INTUITIVE SURGICAL, https://www.intuitivesurgical.com/company/faqs.php#3 [https://perma.cc/CY7J-VKKT].

27. *See* Intuitive Surgical, Inc., Annual Report 2016 (Form 10-K), at 11 (Feb. 6, 2017) (stating that Intuitive owns or holds exclusive field-of-use licenses for more than 2,400 U.S. and foreign patents and 1,800 U.S. and foreign patent applications); Naomi Lee, *Robotic Surgery: Where Are We Now?*, 384 LANCET 1417 (2014) (identifying Intuitive's da Vinci system as "the only robot approved by the FDA for soft tissue surgery"); Tim Sparapani, *Surgical Robotics and the Attack of the Patent Trolls*, FORBES (June 19, 2015, 1:25 PM), https://www.forbes.com/sites/timsparapani/2015/06/19/surgical-robotics-and-the-attack-of-patent-trolls ("Intuitive Surgical's longevity (its first system was approved by the FDA in 1999) and perpetual innovations may help it to stave off competition from global business giants as well as upstarts that are planning to enter the market at a lower price.").

28. *See* Amanda Ciccatelli, *Dominant Robotic Surgery Patents Expiring This Year. So What's Coming Next?*, INSIDE COUNSEL (Aug. 23, 2016), http://www.insidecounsel.com/2016/08/23/dominant-robotic-surgery-patents-expiring-this-yea [https://perma.cc/K7CZ-PGH2]; Josué Villalta, *Could Patent Expirations Be a Chink in Intuitive Surgical's Armor?*, MDDI ONLINE (Aug. 25, 2016, 6:58 PM), https://www.mddionline.com/could-patent-expirations-be-chink-intuitive-surgical%E2%80%99s-armor [https://perma.cc/T4RK-TUPF]; *see also* Barry A. O'Reilly, *Patents Running Out: Time to Take Stock of Robotic Surgery*, 25 INT'L UROGYNECOLOGY J. 711, 712–13 (2014) (noting that "over the last 10

B. Applied Dexterity's Open-Source Challenge

Another research group formed in the 1990s, led by Blake Hannaford at the University of Washington and Jacob Rosen at UCLA, formed the startup company Applied Dexterity in 2013[29] to market the RAVEN, a surgical robot controlled by open-source software.[30] Among Intuitive's many potential competitors,[31] Applied Dexterity is of particular interest from an intellectual property perspective because of its unique strategic decision to leverage open-source development for RAVEN's control software.[32] Researchers at eighteen universities have been conducting a wide range of studies with RAVEN and have agreed to share any platform software improvements with the user community.[33] To the company's founders and some observers, RAVENS's open

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years, patents have expired, and many companies around the world are at various stages of robotic surgical technology development" that may compete against Intuitive's monopoly "over the next couple of years"); Zack Panos, *Disrupting da Vinci? New Surgical Robots on the Horizon*, ADVISORY BOARD (Aug. 24, 2015), https://www.advisory.com/research/service-line-strategy-advisor/expert-insights/2015/disrupting-da-vinci [https://perma.cc/W9QG-3JSZ] ("With many of Intuitive's patents expiring in 2015 and 2016, we may begin to see new players enter the robotic surgery market in the next few years."); Trefis Team, *Factors That Can Impact Our Valuation For Intuitive Surgical Going Ahead*, FORBES (Dec. 27, 2016, 1:34 PM), https://www.forbes.com/sites/greatspeculations/2016/12/27/factors-that-can-impact-our-valuation-for-intuitive-surgical-going-ahead/ ("[C]ompetition is likely to increase going forward, as Intuitive's patents begin to expire and the efficacy of robotic surgery is clearly established.").

29. *See History*, APPLIED DEXTERITY, http://applieddexterity.com/about/history/ [https://perma.cc/BM3E-8YZB]; Paul Hyman, *Open-Source Surgical Robot Fuels University Research*, ACM NEWS (Jan. 24, 2012), https://cacm.acm.org/news/145461-open-source-surgical-robot-fuels-university-research/fulltext.

30. *See Open Source Innovation*, APPLIED DEXTERITY, http://applieddexterity.com/ [https://perma.cc/7C35-M582].

31. *See, e.g.*, Becka DeSmidt, *A Better, Cheaper Surgical Robot on the Way?*, ADVISORY BOARD (June 5, 2013, 9:40 AM), https://www.advisory.com/research/service-line-strategy-advisor/the-pipeline/2013/06/a-better-cheaper-surgical-robot-on-the-way [https://perma.cc/3VSU-NW5S] (naming the University of Washington, Titan Medical, SOFAR, and the ARAKNES project); Frank Tobe, *As Intuitive Surgical Continues to Shine, Competitors Are Entering the Fray*, ROBOT REPORT (Oct. 7, 2016), https://www.therobotreport.com/news/as-intuitive-surgical-continues-to-shine-competitors-are-entering-the-fray [https://perma.cc/LD5Q-6HJ9] (naming Verb Surgical, Medtronic, TransEnterix, Titan Medical, Medrobotics, Smith & Nephew, OMNI, Auris Surgical Robotics, Stryker, Medtech, and Cambridge Medical Robotics).

32. *See An Open-Source Robo-Surgeon*, ECONOMIST (Mar. 3, 2012), http://www.economist.com/node/21548489 (describing RAVEN as "the first surgical robot to use open-source software").

33. *See* Hannah Hickey, *Surgical Robots to Provide Open-Source Platform for Medical Robotics Research*, UW NEWS (Jan. 12, 2012) http://www.washington.edu/news/2012/01/12/surgical-robots-to-provide-open-source-platform-for-medical-robotics-research/ [https://perma.cc/QPQ7-GC2K] (indicating seven research universities who will provide collaborative research through use of the RAVEN's open source platform); *see also RAVEN Sites*, APPLIED DEXTERITY, http://applieddexterity.com/community/RAVEN-sites/ [https://perma.cc/T6EF-3DM9] (naming eighteen research institutions now using the RAVEN's open source platform).

collaboration holds at least the eventual promise of leapfrogging da Vinci's proprietary approach.[34]

Applied Dexterity also has a proprietary side. The company[35] and its founders[36] hold a number of patents and patent applications covering various mechanical aspects of the RAVEN system, suggesting a hybrid approach to technology development and appropriation.[37]

Like Intuitive's example claim above,[38] many of Applied Dexterity's mechanical patent claims are kinematic in nature. For example, Claim 1 of one of the company's pending patent application is directed to a device in which "the tool axis and the common revolute joint rotational axis subtend[] a first angle" and "the convergent rotational axes subtend[] a second angle."[39]

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34. *See An Open Source Robo-Surgeon*, *supra* note 32 ("Even if researchers keen to experiment with new robotic technologies and treatments could afford one, they cannot tinker with da Vinci's operating system. None of that is true of the RAVEN."); Larry Greenemeier, *Robotic Surgery Opens Up*, SCI. AM. (Feb. 11, 2014), https://www.scientificamerican.com/article/robotic-surgery-opens-up/ [https://perma.cc/F862-6H3V] (describing RAVEN's open-source approach as an effort to address Intuitive Surgical's "growing pains" as a single company trying to "meet growing demand while still delivering a safe product").

35. *See Patents*, APPLIED DEXTERITY, http://applieddexterity.com/pat/ [https://perma.cc/Q2XD-GWCP] (listing U.S. Patent No. 6,969,385 B2 ("Wrist with Decoupled Motion Transmission") and U.S. Patent Application Serial No. 13/908,120 ("Spherical Motion Mechanism")). Applied Dexterity is a spinoff of the University of Washington Center for Commercialization, which is named as an assignee on several other patents on which Hannaford and Rosen are named co-inventors. *See, e.g.*, *Applied Dexterity,* COMOTION, http://comotion.uw.edu/startups/applied-dexterity [https://perma.cc/Z2WW-8JB5]; U.S. Patent Application Serial No. 13/908,120 (filed Jun. 3, 2013); U.S. Patent Application Serial No. 12/825,236 (filed Jun. 28, 2010); *see also* Vikram Jandhyala, *The UW CoMotion Story*, COMOTION (Jan. 28, 2015), http://comotion.uw.edu/news/uw-comotion-story [https://perma.cc/7JKR-3EYY].

36. *See* Joanne Pransky, *The Pransky Interview: Professor Jacob Rosen, Co-Founder of Applied Dexterity and ExoSense*, 43 INDUS. ROBOT 457, 457 (2016) (stating that Rosen has filed eight patent applications).

37. *See generally* Greg R. Vetter, *Commercial Free and Open Source Software: Knowledge Production, Hybrid Appropriability, and Patents*, 77 FORDHAM L. REV. 2087, 2130–31 (2009) (describing "the strategic advantages of patents" that can be combined with the benefits of open-source software development in a hybrid approach to technology appropriation).

38. *See supra* text accompanying note 6.

39. Claim 1 of Applied Dexterity's application reads:

1. A device comprising:

> a first link having ends terminated in a base revolute joint and a common revolute joint, the revolute joints having convergent rotational axes and each rotational axis forming an acute angle with a longitudinal axis of the first link, the base revolute joint coupled to a base;
>
> a second link coupled to the common revolute joint at a first end, the second link having a second end and the second link in a serial cantilever configuration with the first link, the rotational axis of the common revolute joint forming an acute angle with a longitudinal axis of the second link, wherein the second end of the second link includes a tool holder, the tool holder having a tool axis aligned to pass through a point coincident with an

Dependent claims add further kinematic limitations. For example, claim 12 is directed to "[t]he device of claim 1 wherein the first angle is about 40 degrees and the second angle is about 52 degrees."[40]

A distinctive aspect of RAVEN's development has been the involvement of surgeons in the robot's design. Hannaford and Rosen's team first created the Blue DRAGON, "a system for monitoring the kinematics and the dynamics of endoscopic tools in minimally invasive surgery for objective laparoscopic skill assessment."[41] The Blue DRAGON has sensors for measuring the positions and orientations of two endoscopic tools, measuring the forces and torques applied to the tools by the surgeon's hands, and detecting contact between the tools and the patient's tissues.[42] Hannaford and Rosen's team used the Blue DRAGON to capture data from minimally invasive procedures performed by thirty surgeons operating on pig tissues,[43] including five board-certified laparoscopic surgeons who had each performed at least 800 surgeries and practiced as attending physicians.[44] With this data, the team was able to identify 40 degree and 52 degree angles as optimal design parameters for the mechanism described in the claim above.[45] Part III of this Article will provide a more detailed discussion of how the surgical data was used in RAVEN's mechanical design and how patent law should regard the surgeons' contributions to the design process. It suffices for now to note that most of the surgeons whose techniques were captured in

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> intersection of the convergent rotational axes, the tool axis and the common revolute joint rotational axis subtending a first angle; and
>
> the convergent rotational axes subtending a second angle, such that the first angle differs from the second angle, the first and second links and the revolute joints enabling a position of the tool holder to be selectively manipulated.

U.S. Patent Application Serial No. 13/908,120 , cl. 1 (filed Jun. 3, 2013).

40. *See id.* at cl. 12; *see also id.* at cls. 2-13 (adding further kinematic limitations to claim 1).

41. Jacob Rosen et al., *The Blue DRAGON: A System for Monitoring the Kinematics and the Dynamics of Endoscopic Tools in Minimally Invasive Surgery for Objective Laparoscopic Skill Assessment*, *in* MEDICINE MEETS VIRTUAL REALITY 412 (J.D. Westwood et al. eds., 2002).

42. *See id.* at 413–14.

43. *See* Jacob Rosen et al., *RAVEN: Developing a Surgical Robot from a Concept to a Transatlantic Teleoperation Experiment*, *in* SURGICAL ROBOTICS: SYSTEMS APPLICATIONS AND VISIONS 159, 161 (J. Rosen et al. eds., 2011).

44. *See* U.S. Patent Application Serial No. 13/908,120 at [74] (filed Jun. 3, 2013).

45. *See* Rosen, *supra* note 43, at 177 ("For the serial manipulator optimized for the DWS, the best design was achieved with link angles of $\alpha_{13} = 52$ (Link 1) and $\alpha_{35} = 40$ (Link 2) with a composite score of 0.0520"); U.S. Patent Application Serial No. 13/908,120 at [223] & cl. 12 (filed Jun. 3, 2013).

the study were not named as co-inventors on Applied Dexterity's patents or patent applications.[46]

C. Brookhill and Alisanos: Surgeons and a "Troll" Take Their Cuts

In the years leading up to the Computer Motion merger, Intuitive faced another patent adversary in the entrepreneurial Manhattan surgeon Dr. Peter J. Wilk. Wilk had been profiled in a 1995 *New York Times* article as a doctor who had chosen to turn his "innovative medical techniques or theories into a commodity" by acquiring 140 patents on medical devices and techniques, bypassing the rigorous testing required by medical journals.[47] For example, Wilk was able to patent a new coronary bypass technique without testing it.[48] He subsequently licensed the patent to a large institution that "agreed to spend whatever it took" to determine whether the invention was a "potential replacement" for existing methods, and ultimately found that it was not.[49] Despite this, Wilk said this was "a good example of the patent system at work," in that "the idea was only explored because I thought of it, it was patented and protected, so this company felt they could expend themselves because if it proved

46. Dr. Mika Sinanan, a University of Washington surgery professor and clinician in minimally invasive gastrointestinal surgery, *see Mika N. Sinanan M.D., Ph.D.*, UW MEDICINE, http://www.uwmedicine.org/bios/mika-sinanan [https://perma.cc/9MRE-U9QX], was a principal member of the original RAVEN development team and is a frequent coauthor and co-inventor with Hannaford and Rosen. *See generally* Pransky, *supra* note 36, at 458 (naming Sinanan as a mentor and collaborator with Rosen on the original development of RAVEN); Rosen, *supra* note 43 at 159–60 (chronicling the RAVEN project and naming Sinanan as coauthor). Sinanan was one of the thirty surgeons who participated in the study, *see* Mika Sinanan, personal correspondence with Author, Oct. 16, 2017, but other surgeons were not named as co-inventors.

47. Sabra Chartrand, *Why Is This Surgeon Suing?: Doctors Split Over Patenting of Their Techniques*, N.Y. TIMES, June 8, 1995, at D5. The same article also reported on House Bill 1127, Medical Procedures Innovation and Affordability Act, H.R. 1127, 104th Cong., (1st Sess. 1995), an unsuccessful precursor of § 287(c)'s immunity for a "medical practitioner" engaged in "medical activity" from patent infringement liability. *Id.* at D1, D5. *See* 35 U.S.C. § 287(c) (1997); Brett G. Alten, Note, *Left to One's Devices: Congress Limits Patents on Medical Procedures*, FORDHAM INTELL. PROP., MEDIA & ENT. L.J., 837, 860–65 (1998) (chronicling the failure of House Bill 1127).

48. *See* Chartrand, *supra* note 47, at D5.; U.S. Patent No. 5,287,861 (filed Oct. 30, 1992) ("Coronary artery by-pass method and associated catheter").

49. *See* Chartrand, *supra* note 47, at D5. Notably, this failure to commercialize Wilk's bypass technique did not vitiate the invention's patentable utility. *See, e.g.*, Studiengesellschaft Kohle v. Eastman Kodak, 616 F.2d 1315, 1339 (5th Cir. 1980) ("To require the product to be the victor in the competition of the marketplace is to impose upon patentees a burden far beyond that expressed in the statute.").

successful they would be able to recoup their money and make a lot more."[50]

Wilk's inventions also included an "automated surgical system and apparatus," the subject of a patent filed in 1991 and issued in 1993.[51] Wilk subsequently assigned the patent to the entity Brookhill-Wilk 1, LLC ("Brookhill"). In 2000, Brookhill sued Intuitive in the Southern District of New York[52] for infringing at least the patent's independent claims, each of which recited the limitation "to a remote location beyond a range of direct manual contact with said patient's body and said endoscopic instrument."[53] Intuitive's da Vinci system was indisputably designed for use in the same operating room with the patient and instruments.[54] After construing the term "remote location" as limited to "a location outside of the operating room where the patient is located,"[55] the district court granted summary judgment to Intuitive. On appeal, however, the Federal Circuit rejected the district court's construction as improperly reading limitations from the specification into the claims,[56] and instead construed the

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50. *Id.* Wilk is identified as a faculty member of SEAK, Inc., a continuing education, publishing and consulting company that "specializes in showing physicians how to supplement or replace their clinical income." *About SEAK & Our Faculty*, SEAK, http://www.supplementalincomeforphysicians.com/about-seak/ [https://perma.cc/2V5W-S3RE].

51. *See* U.S. Patent No. 5,217,003 (filed Mar. 18, 1991) (issued June 8, 1993) [hereinafter '003 patent].

52. Brookhill also sued Computer Motion for patent infringement in 2001, but agreed to dismiss the case after an adverse claim construction ruling. *See* Computer Motion, Inc., Amendment No. 3 (Form 10-K/A Annual Report) at 11 (Dec. 31, 2002).

53. '003 patent, at cls. 1, 10, 17. For example, claim 1 of the '003 patent read:

> A surgical method, comprising the steps of: inserting an endoscopic instrument into a patient's body; obtaining a video image of internal body tissues inside said patient's body via said endoscopic instrument; transmitting, over an electromagnetic signaling link, a video signal encoding said video image *to a remote location beyond a range of direct manual contact with said patient's body and said endoscopic instrument*; receiving actuator control signals from said remote location via said electromagnetic signaling link; inserting into the patient's body a surgical instrument movable relative to the patient's body and said endoscopic instrument; and automatically operating said surgical instrument in response to the received actuator control signals to effect a surgical operation on said internal body tissues.

'003 patent, at cl. 1 (emphasis added).

Brookhill also brought claims against Intuitive for infringement of a patent that had been a continuation-in-part of the '003 patent, but withdrew these claims before Intuitive's motion for summary judgment. *See* Brookhill-Wilk 1, LLC v. Intuitive Surgical, Inc., 178 F. Supp. 2d 356, 358 (S.D.N.Y. 2001) (citing U.S. Patent No. 5,368,015).

54. *See id.* at 364, 366.

55. *See id.*

56. Brookhill-Wilk 1, LLC v. Intuitive Surgical, Inc., 334 F.3d 1294, 1301 (Fed. Cir.

term broadly "to encompass not just locations that are 'far apart' or distant,' but also those locations that are merely 'separated by intervals greater than usual," including locations inside the operating room.[57] The appeals court reversed and remanded the case for trial.[58] Before trial, Intuitive, having by then acquired Computer Motion, settled with Brookhill by purchasing a fully paid-up, perpetual, exclusive license for $2.6 million.[59]

Because of *Brookhill-Wilk*'s high profile—to this day, the case has produced the Federal Circuit's only reported decisions in a surgical robotics patent infringement case[60]—the case received attention not only in legal scholarship[61] but also in medical literature. In a 2008 article published in the *International Journal of Medical Robotics and Computer Assisted Surgery*, Veteran's Administration surgeon Thomas McLean and University of Kansas patent scholar Andrew Torrance reviewed the case in detail and discussed the potential exclusionary effects of Brookhill's patents on the surgical robotics industry.[62]

According to the authors, Brookhill's claims were so broad that any company other than Intuitive who marketed "any surgical instrument that allows . . . a surgeon to stand away from the operating table must now be prepared to defend itself in a patent infringement lawsuit."[63] As the exclusive licensee, Intuitive would be in a position to bankroll Brookhill's subsequent patent infringement litigation, and could even sue to enforce Brookhill's patents on its own.[64]

2003) (quoting Teleflex, Inc. v. Ficosa N. Am. Corp., 299 F.3d 1313, 1328 (Fed. Cir. 2002)) (finding that "[n]o statement in the written description . . . constitutes a limitation on the scope of the invention," and therefore that the court is "'constrained to follow the language of the claims'").

57. *See id.* at 1302.

58. *See id.* at 1304.

59. *See* Intuitive Surgical, Inc., Annual Report (Form 10-K) at 21 (Mar. 12, 2004).

60. A search in Westlaw's CTAF database for (surg! /s robot!) yields only the two reported decisions in Brookhill-Wilk 1, LLC. v. Intuitive Surgical, Inc. *See* Search for "surg! /s robot!", WESTLAW, http://www.westlaw.com (search in search bar for "surg! /s robot") (last visited Oct. 26, 2017).

61. *See, e.g.*, *Cases and Recent Developments: Refusing to Limit Construction of the Term "Remote Construction" Based on the Intrinsic Record*, 13 FED. CIR. B.J. 182–84 (2003) (reviewing the Brookhill-Wilk litigation); Herrmann, *supra* note 12, at 302 n.26 (same).

62. T.R. McLean & A.W. Torrance, *Are the Brookhill-Wilk Patents Impediments to Market Growth in Cybersurgery?*, 4 INT'L J. MED. ROBOTICS & COMP. ASSISTED SURGERY 5–6 (2008).

63. *See id* at. 6.

64. *See id.* Intuitive's exclusive license, *see* Intuitive Surgical, Inc., Annual Report, Settlement and License Agreement (Form 10-K), Ex. 10.14 § 3.1 (Jan. 8, 2004) (granting

The authors did point out that Brookhill's patents would continue to be subject to an invalidity challenge.[65] They highlighted two then-recent Supreme Court developments as suggesting that at least Brookhill's process claims "appear to be especially ripe to be held invalid by the courts."[66] The authors read Justice Breyer's dissent from the dismissal of *LabCorp v. Metabolite*[67] as indicating that "the days of routinely valid medical process patents may be limited,"[68] and the *KSR v. Teleflex* decision[69] as signaling more generally that "the days of liberal patent granting [may be] numbered."[70] In light of the *KSR* Court's observation that an invention may be obvious where "market pressure" might have motivated one of ordinary skill to find the same solution,[71] the authors suggested that "a pent-up demand in the laparoscopic surgery market for improved optics and instrument dexterity" at the time of Wilk's invention could show his remote surgery methods were "an obvious extension of laparoscopic surgery."[72] The authors concluded that the developments in *LabCorp* and *KSR* could prevent Brookhill's patents from "stifling . . . growth in the cybersurgery market."[73]

A decade after McLean and Torrance's article, Intuitive's assists from the Computer Motion acquisition[74] and the Brookhill license[75] have sufficiently faded into history such that commentator Tim Sparapani recently attributed Intuitive's dominance solely to its first-mover advantage and "perpetual innovations."[76] In Sparapani's view, Intuitive's market dominance

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Intuitive an exclusive license, inter alia, to make, use, sell, offer to sell, and import any surgical robotics product under the Brookhill patents), appears to be broad enough to support licensee standing. *See* WiAV Sols. LLC v. Motorola, Inc., 631 F.3d 1257, 1266–67 (Fed. Cir. 2010) (holding that a licensee is an exclusive licensee with standing to sue "if it holds any of the exclusionary rights that accompany a patent" that were allegedly infringed).

65. *See* McLean & Torrance, *supra* note 62, at 7.

66. *See id.*

67. Lab. Corp. of Am. Holdings v. Metabolite Labs., Inc., 548 U.S. 124 (2006) (Breyer, J., dissenting).

68. *See* McLean & Torrance, *supra* note 62, at 8.

69. KSR Int'l Co. v. Teleflex Inc., 550 U.S. 398 (2007).

70. *See* McLean & Torrance, *supra* note 62. at 7.

71. *See KSR*, 550 U.S. at 421.

72. *See* McLean & Torrance, *supra* note 62, at 8.

73. *See id.*

74. *See supra* text accompanying note 21

75. *See supra* text accompanying note 64.

76. *See* Sparapani, *supra* note 27. Sparapani, a data privacy law and policy consultant, was the former policy and government relations director at Facebook. *See id.*

and 3,300 issued or pending patents are better characterized as signs of the surgical robotics industry's dynamism than as barriers to competitive sources of innovation.[77] On the other hand, Sparapani believes "patent trolls and patent privateers threaten the surgical robotics industry's vitality and growth."[78]

Sparapani's column singles out a suit by Alisanos, LLC against Intuitive as problematic, not based on any facts of the case or any analysis of the patent claims,[79] but simply because Alisanos is a "patent privateer."[80] Sparapani's condemnation of such non-practicing plaintiffs applies with equal force to all industries: "When . . . neither the company suing nor the company for whose benefit a suit is being brought are actually producing products or services, innovative companies are harmed without benefits being provided to the public."[81] It is hard to see how such a broad category of lawsuits could be avoided, however, short of imposing a working requirement on patentees.[82] The absence of a patent working requirement in the United States would seem to be the starting point of any legal reform effort to address Sparapani's concerns. In failing to mention this feature of U.S. patent law, the column seems more interested in identifying heroes and villains than in offering solutions.[83]

The facts of *Alisanos v. Intuitive*[84] actually tell a more nuanced story. A team of designers, including former cardiac surgeon Ralph

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77. *See id.* ("Intuitive continues to introduce significant technological advancement in areas like diagnostics and enhanced imaging furthering the importance of intellectual property in medical robotics."); *cf.* United States v. Alcoa, 148 F.2d 416, 430 (2d Cir. 1945) (Learned Hand, J.) (explaining that the Sherman Act does not condemn one who has attained monopoly power "merely by virtue of his superior skill, foresight and industry"); J.R. Hicks, *Annual Survey of Economic Theory: The Theory of Monopoly*, 3 ECONOMETRICA 1, 8 (1935) ("The best of all monopoly profits is a quiet life.").

78. *See* Sparapani, *supra* note 27.

79. *See id.* ("I have no insight into whether the patent suits filed against Intutiive Surgical were frivolous—Medicanica [Alisanos's predecessor in interest] certainly did not think so . . . .").

80. *See id.*

81. *See id.*

82. *See, e.g.*, Maayan Perel, *From Non-Practicing Entities (NPE) to Non-Practiced Patents (NPPS): A Proposal for a Patent Working Requirement*, 83 U. CIN. L. REV. 747, 753 (2015) (proposing a working requirement as a solution to "the patent troll problem").

83. *Cf.* Edward Lee, *Patent Trolls: Moral Panics, Motions in Limine, and Patent Reform*, 19 STAN. TECH. L. REV. 113, 116–17 (2015) (arguing that use of the term "patent troll" may be unfairly prejudicial due to media's failure to mention the lack of a working requirement in U.S. patent law).

84. Complaint at 2–6, Alisanos, LLC v. Intuitive Surgical, Inc., No. 0:12-CV-61978 (S.D. Fla. Oct. 5, 2012).

de la Torre,[85] invented a "through-port heart stabilization system" and obtained a patent in 2003 for their employer, an early-stage medical device startup called Medcanica.[86] According to Alisanos's complaint, Medcanica had in the meantime tried and failed to negotiate a joint venture with Intuitive to commercialize the technology.[87] By the time the patent issued, Medcanica had run out of financing for further product development.[88] Eventually, Medcanica sold the patent to the patent-assertion entity Alisanos in exchange for a share of licensing profits.[89]

Alisanos filed suit in the Southern District of Florida on Oct. 5, 2012, alleging that one of the instruments Intuitive makes and sells for use with its da Vinci system, the "EndoWrist Stabilizer," infringed the patent. The case settled almost immediately, with the parties notifying the court one day before Intuitive's deadline to answer the complaint.[90] While the terms of the settlement were not disclosed, the agreement most likely included the purchase by Intuitive of a license to the patent-in-suit.[91] The suit thereby benefited the inventors through their employer Medcanica's share of the settlement proceeds, a result that might not have been possible in a system barring Alisanos as a non-practicing plaintiff.[92] At the same time, to the extent that potential competitors

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85. *See* RALPH DE LA TORRE, MD, http://ralphdelatorre.com/ [https://perma.cc/E65J-SEPJ] (stating that de la Torre was formerly Chief of Cardiac Surgery at Beth Israel Deaconess Medical Center).

86. *See* U.S. Patent No. 6,592,573 B2 (filed June 27, 2001) (issued July 15, 2003); Complaint, *supra* note 84, ¶ 6.

87. *See* Complaint, *supra* note 84, ¶¶ 9–11.

88. *See id.* ¶ 12.

89. *See id.* ¶ 15; Chevy Chase, *Alisanos LLC to License Large Medical Device Patent Portfolio Developed by Medcanica*, PRWeb (Nov. 1, 2012), http://www.prweb.com/releases/2012/11/prweb10080812.htm [https://perma.cc/6RHX-W4CD]; Medcanica had advertised its closed chest surgery patent portfolio through a patent brokerage with an animation apparently illustrating the invention's operation. *See For Sale: Medcanica Closed Chest Surgery Patent Porfolio.wmv*, YOUTUBE (Jan. 27, 2010), https://www.youtube.com/watch?v=SFCpR7hEc_0.

90. *See* Notice of Settlement, Alisanos, LLC v. Intuitive Surgical, Inc., No. 0:12-CV-61978 (S.D. Fla. Jan. 24, 2013); Order, Alisanos, LLC v. Intuitive Surgical, Inc., No. 0:12-CV-61978 (S.D. Fla. Jan. 3, 2013) (granting extension of time to answer until Jan. 25, 2013).

91. *See* Mark Crane & Malcolm R. Pfunder, *Antitrust and Res Judicata Considerations in the Settlement of Patent Litigation*, 62 ANTITRUST L.J. 151 (1993) ("Patent infringement cases are generally settled by execution of license (or cross-license) agreements between the parties and entry of a consent decree by the court in which the case is pending.").

92. *See* John M. Golden, *Patent Privateers: Private Enforcement's Historical Survivors*, 26 HARV. J.L. & TECH. 545, 601 (2013) ("Under appropriate circumstances, even the specialized patent-enforcement entities most vigorously denounced as 'trolls' could help produce a more socially optimal system, perhaps because of capacities to litigate or license

face a threat of patent assertion that Intuitive no longer faces, the primary beneficiary of *Alisanos* might ultimately be the "innovation company" Intuitive and not the "privateer" Alisanos, just as McLean and Torrance's article suggested Intuitive was able to entrench its monopoly in the wake of *Brookhill*.

These factual nuances of *Alisanos* do not redeem the many unambiguously problematic cases brought by non-practicing entities, including frivolous lawsuits.[93] *Alisanos* might still come in for criticism as a frivolous case, but detailed analyses of the validity and infringement of the asserted claims are beyond the scope of this Article, as they were beyond the scope of Sparapani's column.[94] In the meantime, this Article's examination of kinematic claims in surgical robotics patents might yield a more pertinent critical perspective on *Alisanos*. It is worth noting in this regard that as with other examples above, *Alisanos*'s claims-in-suit recite several elements in kinematic terms.[95]

The widespread practice of kinematic claiming in the surgical robotics industry raises two fundamental patent-eligibility concerns. Since a kinematic claim nowhere specifies the kinds of causal powers involved in the use of the claimed invention, it may encompass entities that are conceptually well-defined, but are physically incapable of being used to produce a beneficial result or effect.[96] Also, since a kinematic claim relies on generic structural

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more efficiently and even somewhat "democratically" to enable some fruits of enforcement to run to patentees lacking independent capacity to overcome patent enforcement's costly barriers.").

93. *See, e.g.*, Mark A. Lemley & A. Douglas Melamed, *Missing the Forest for the Trolls*, 113 COLUM. L. REV. 2117, 2176–77 (2013) (arguing that "[t]he law should do more to discourage frivolous suits or those driven by the expectation that the cost of litigation will drive defendants to settle even when faced with unmeritorious claims").

94. *See supra* note 76 and accompanying text.

95. Claim 1, the patent's broadest claim, reads:

> A heart stabilization device, comprising:
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> a) a shaft having a proximal end provided with a handle, a distal end, and defining a longitudinal axis; and
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> b) a pair of stabilization arm assemblies at said distal end of said shaft, each of said stabilization arms provided with a substantially rigid foot having a contact surface which is adapted to contact a surface of the heart, said feet having a first configuration in which said feet extend substantially parallel to said longitudinal axis and are substantially in contact with each other, and a second configuration in which feet extend substantially parallel to said longitudinal axis and are displaced relative to each other; and
>
> c) an actuator adapted to move said feet between said first and second configurations.

U.S. Patent No. 6,592,573 B2 (filed June 27, 2001).

96. The fact that a commercial embodiment of a kinematic claim has market value

elements to specify the moving parts of a mechanism, it may preempt all physical instantiations of a geometric theorem. Part III will discuss these concerns in detail.

III. KINEMATIC CLAIMS AND THE ABSTRACT-IDEAS EXCLUSION

For more than a century, the Supreme Court's abstract-ideas jurisprudence has been guided by the admonition that a patent is granted "for the discovery or invention of some practical method or means of producing a beneficial result or effect . . . and not for the result or effect itself."[97] As I have argued in previous articles,[98] this doctrinal distinction between a patent-ineligible abstract idea and a patent-eligible "practical method or means of producing a beneficial result or effect" grounds the embodiments of patent-eligible inventions in an ontological category of objects and processes having causal powers: i.e., dispositions to engage in processes that relate causes and effects.[99]

A filed patent application satisfies the disclosure requirement when it conveys to the reader a warranted ontological commitment to the kinds of causal objects and processes recited in the claims.[100] In this regard, the patent system appears to be ontologically committed to a wide range of causal processes (including those involving electrons and other unobservable entities)[101], thereby embracing the view of scientific realism

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does not establish that the claimed invention is a method or means of producing a beneficial result or effect. *See* Imperial Chem. Indus. v. Henkel, 545 F. Supp. 635, 645 (D. Del. 1982) ("[C]ommercial success is not the standard of usefulness under the Patent Act."); *see also* Lowell v. Lewis, 15 F. Cas. 1018, 1019 (D. Mass. 1817) (Story, J.) ("[W]hether [the invention] be more or less useful is a circumstance very material to the interests of the patentee, but of no importance to the public.").

97. Diamond v. Diehr, 450 U.S. 175, 182 n.7 (1981) (quoting Corning v. Burden, 56 U.S. 252, 268 (1853)); *see also* LeRoy v. Tatham, 55 U.S. 156, 175 (1852) ("A patent is not good for an effect, or the result of a certain process, as that would prohibit all other persons from making the same thing by any means whatsoever."); *see also* Andrew Chin, *Ghost in the "New Machine": How* Alice *Exposed Software Patenting's Category Mistake*, 16 N.C.J. L. & TECH. 623, 644 (2015) [hereinafter *Ghost in the "New Machine"*] (arguing that the Supreme Court also drew this distinction in Alice v. CLS Bank Int'l, 134 S. Ct. 2347, 2359 (2014)).

98. *See* Chin, *supra* note 1; *Ghost in the "New Machine"*, *supra* note 97.

99. *See* Chin, *supra* note 1, at 286–89 (citing BRIAN ELLIS, THE PHILOSOPHY OF NATURE: A GUIDE TO THE NEW ESSENTIALISM 48 (2002)).

100. *See id.* at 312–13 (describing the role of the written description in conveying ontological commitment to claims through the filed patent application); *id.* at 321–23 (describing the role of the enablement requirement in warranting the patent system's ontological commitment to claims through the filed patent application).

101. The search query "clm(electron) & da(2016)" to Westlaw's Patents & Applications database finds 1,709 U.S. patents issued in 2016 containing the word "electron" in at least one claim. *See* Search for "clm(electron)" and "da(2016)", WESTLAW, http://www.westlaw.com (search in search bar for "clm(electron)" and "da(2016)") (last

that "our best scientific theories give approximately true descriptions of both observable and unobservable aspects of a mind-independent world."[102] Thus, unless there are "factual reasons which would lead one skilled in the art to question the objective truth of the statement of operability,"[103] a patent applicant need not provide a working model[104] or a correct account of the invention's theory of operation,[105] but must convince one skilled in the art of the asserted utility.[106]

Like many other animals,[107] humans have extended the functional reach of their bodies by inventing tools to achieve their goals. At the most fundamental level, progress in the useful arts can be measured by the extent to which humans can make and use these tools to produce the results and effects they desire. The patent system promotes this progress in human capacity simply by incurring warranted ontological commitments to claimed kinds of tools (and methods of making or using them), regardless of whether the available theories for the tools' operation are correct or complete. As an ontological project, the patent system

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visited Oct. 26, 2017). By legally recognizing these claims, the patent system routinely incurs ontological commitments to electrons, even though no one has directly observed an electron. *See generally* THEODORE ARABATZIS, REPRESENTING ELECTRONS: A BIOGRAPHICAL APPROACH TO THEORETICAL ENTITIES 70 (2006) (providing a history of theoretical representations of the electron as an unobservable entity).

102. ANJAN CHAKRAVARTTY, A METAPHYSICS FOR SCIENTIFIC REALISM: KNOWING THE UNOBSERVABLE 212 (2007). Josh Sarnoff (personal communication) has astutely pointed out the parallels between my ongoing efforts to discern the patent system's ontological inventory, *see* Chin, *supra* note 1, at 306–09, and Mike Madison's earlier examination of the constitution of "things" brought into play by intellectual property law. *See* Michael J. Madison, *Law as Design: Objects, Concepts, and Digital Things*, 56 CASE W. RESERVE L. REV. 381–83, 385 (2005). There is also a methodological similarity: Madison proceeds by describing how certain themes in metaphysics and semantics, *inter alia*, "are recognized by the law, as the law borrows them and simplifies them for its purposes," while I follow the lead of Steven Smith in setting out to identify the patent system's metaphysical commitments through "the ways that lawyers talk and argue and predict and . . . judges decide and justify." Chin, *supra* note 1, at 270 (quoting Steven D. Smith, *Metaphysical Perplexity?*, 55 CATH. U. L. REV 639, 644–45 (2006)).

103. *In re* Gaubert, 524 F.2d 1222, 1224–25 (C.C.P.A. 1975); *In re* Isaacs, 347 F.2d 887, 890 (C.C.P.A. 1965) (citing *In re* Citron, 325 F.2d 248, 253 (C.C.P.A. 1963)); Sean B. Seymore, *Patently Impossible*, 64 VAND. L. REV. 1491, 1500–05 (2011) (describing the Patent Office's examination rubric for the operability requirement).

104. *See* USPTO, MANUAL OF PATENT EXAMINING PROCEDURE § 608.03 (Nov. 2015) ("With the exception of cases involving perpetual motion, a model is not ordinarily required by the Office to demonstrate the operability of a device. If operability of a device is questioned, the applicant must establish it to the satisfaction of the examiner, but he or she may choose his or her own way of so doing."); *see also In re* Houghton, 433 F.2d 820, 821 (C.C.P.A. 1970) (noting that the Patent Office did not require working model as proof of utility).

105. *See* Newman v. Quigg, 877 F.2d 1575, 1581–82 (Fed. Cir. 1989).

106. *See In re* Brana, 51 F.3d 1560, 1566 (Fed. Cir. 1995).

107. *See* Vicki K. Bentley-Condit & E.O. Smith, *Animal Tool Use: Current Definitions and an Updated Comprehensive Catalog*, 147 BEHAVIOUR 185, 195 (2010).

can recognize and promote progress in frictional seals, for example, regardless of whether the friction is occurring due to adhesion, asperity interlock, or macro-displacement.[108]

The abstract-ideas exclusion and other patent-eligible subject matter inquiries have a vital role in policing the boundaries of the patent system's ontological categories and ensuring that each claimed invention's "examination against prior art under the traditional tests for patentability"[109] is free of category mistakes.[110] For example, a § 101 rejection of a software claim may obviate a § 103 inquiry into "ordinary mathematical skill"[111] that would misplace mathematical properties into the patent system's ontological category of "beneficial result[s] or effect[s]."[112]

The study of causation and causal processes in analytical philosophy can illuminate § 101's categorical requirement that a patent-eligible invention be a "practical method or means of producing a beneficial result or effect." For example, consider the following hypothetical kinematic claim:

> A. An object on a cylindrical surface, said object moving counterclockwise on said cylindrical surface at a rate of at least one revolution per second.

As the next section will explain in detail, causal process theories grounded in the movements of entities through space-time are particularly well suited to addressing the question of whether such a claim is directed to a product or process capable of being used to cause some specified effect or a noncausal abstract idea.

A. Kinematic Claims and Causal Process Theories

The most prominent causal process accounts addressing the kinematic behavior of objects are the interrelated theories of Wesley Salmon and Phil Dowe.[113] Wesley Salmon's two causal

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108. This ontological account of the patent system serves in part as a response to Sean Seymore's contention that a patent document is "uninformative" if it does not disclose how or why the invention works. *See* Sean B. Seymore, *Uninformative Patents*, 55 HOUS. L. REV. 375 (2017). The goal of extending human capacity also serves as a counterpoint to our colleague Peter Lee's description of the patent system's focus on maximizing efficiency. *See* Peter Lee, *Toward a Distributive Agenda for U.S. Patent Law*, 55 HOUS. L. REV. 321 (2017).

109. *In re* Bilski, 545 F.3d 943, 1013 (Fed. Cir. 2008) (en banc) (Rader, J., dissenting).

110. *See Ghost in the "New Machine"*, *supra* note 97, at 638.

111. *See In re* Bernhart, 417 F.2d 1395, 1402 (C.C.P.A. 1969).

112. *See Ghost in the "New Machine"*, *supra* note 97, at 636–37, 638 n.77.

113. *See generally Causal Processes*, STANFORD ENCYCLOPEDIA OF PHILOSOPHY, https://plato.stanford.edu/entries/causation-process [https://perma.cc/4BWA-554A] (surveying the philosophical literature on causal process theories with extended treatments

process theories are presented in books published in 1984[114] and 1998;[115] Phil Dowe's causal process theory is presented in a 2000 volume.[116] Salmon acknowledged a heavy debt to Dowe in the development of his 1998 theory,[117] which is similar in many ways to Dowe's.[118] A full survey of these theories is beyond the scope of this Article; interested readers may consult the respective books for details. It is sufficient here to discuss certain salient features of Salmon's earlier theory and of Dowe's theory.

Salmon developed his first causal process theory (hereinafter referred to simply as "Salmon's theory") in the 1980s[119] as a "theory of causality in which processes rather than events are taken as fundamental."[120] In Salmon's theory, processes include "waves and material objects that persist through time,"[121] and may be represented by lines on a *space-time diagram*.[122] Space-time diagrams use a coordinate plane to depict the positions of objects over time relative to some *inertial reference frame*.[123] By convention, the vertical coordinate axis of a space-time diagram is devoted to time, so the diagram is limited to showing positions in only one dimension. For example, Figure 1 shows the trajectories of two balls of different masses moving in the same direction along a line, but at different speeds. After the more massive, faster black ball collides with the smaller, slower gray ball, their respective speeds change: the black ball decelerates slightly, and the gray ball accelerates away from it.

of Salmon's and Dowe's theories).

114. WESLEY C. SALMON, SCIENTIFIC EXPLANATION AND THE CAUSAL STRUCTURE OF THE WORLD (1984).

115. WESLEY C. SALMON, CAUSALITY AND EXPLANATION (1998).

116. PHIL DOWE, PHYSICAL CAUSATION (2000).

117. *See* Wesley C. Salmon, *Causality Without Counterfactuals*, 61 PHIL. SCI. 297, 298 (1994) ("I will attempt to show how the account can be modified so as to remove the genuine shortcomings. In this . . . endeavor I rely heavily on work of P. Dowe.").

118. *See* Phil Dowe, *Causality and Conserved Quantities: A Reply to Salmon*, 62 PHIL. SCI. 321, 321 (1995) ("Salmon and I agree on much.").

119. For a preliminary version of Salmon's earlier causal process theory, *see* Wesley C. Salmon, *Causality: Production and Propagation*, *in* CAUSATION (Ernest Sosa & Michael Tooley eds., 1993).

120. *See* SALMON, *supra* note 115, at 286.

121. *See id.*

122. *See id.*

123. *See generally* JÜRGEN FREUND, SPECIAL RELATIVITY FOR BEGINNERS: A TEXTBOOK FOR UNDERGRADUATES 47–78 (2008) (providing a general introduction to space-time and Minkowski diagrams). An inertial reference frame is an observational perspective that is "rectilinear, uniform, and irrotational (i.e. without any acceleration)," as is the case of objects that are "not acted upon by any forces" and are thus "subject to the principle of inertia." *See id.* at 4.

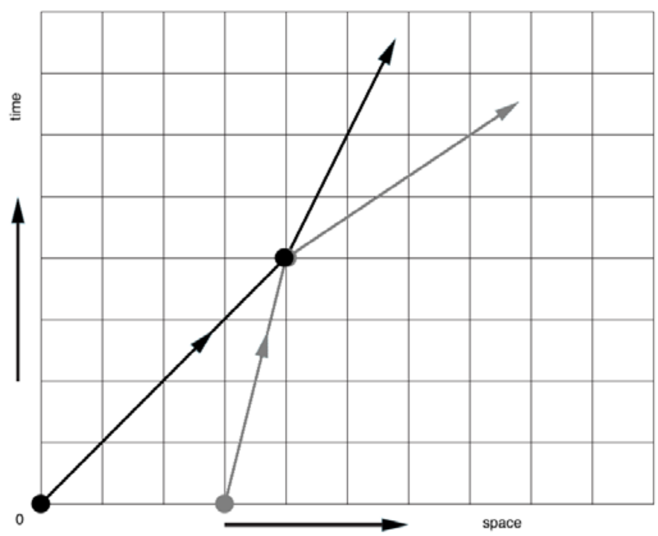

Figure 1. A space-time diagram illustrating the trajectories of two balls before and after a collision.

In illustrating the principles of special relativity, it is customary to set the scales for the coordinate axes so that a line with unit slope (i.e., at 45 degrees) represents an object moving at the speed of light. Space-time diagrams that employ this convention are called Minkowski diagrams, after Hermann Minkowski, the pioneering geometric interpreter of Einstein's special theory of relativity.[124] A *world line* is the trajectory of an object on a Minkowski diagram.[125] An *event* is represented by a point on a Minkowski diagram.[126]

Minkowski diagrams can geometrically illustrate the principle that the propagation of causal influence through space-time is limited by the speed of light.[127] As Salmon explains:

> [A]ny given event E_0, occurring at a particular space-time point P_0, has an associated double-sheeted light cone. All events that could have a causal influence on E_0 are located in the interior or on the surface of the past light cone, and all events upon which E_0 could have any causal influence are located on the interior or on the surface of the future light cone . . . Those events that lie on the surface of either

124. *See* DAVID J. GRIFFITHS, INTRODUCTION TO ELECTRODYNAMICS 503–04 (1999).
125. *See id.* at 503.
126. *See* FREUND, *supra* note 123, at 50–51.
127. *See* GRIFFITHS, *supra* note 124, at 504.

sheet of the light cone are said to have a lightlike separation from E_0.[128]

Figure 2 is a Minkowski diagram illustrating two events, A and B, relative to the inertial reference frames of two observers. From one observer's perspective, event A precedes event B; from the other observer's perspective, event B precedes event A. Note, however, that the light cones from events A and B are invariant with respect to inertial reference frames, since their surfaces may be traced out by objects moving at the speed of light. Thus, from either observer's perspective, A and B lie outside each other's light cones, and A and B are spacelike separated. The possibility of causal influence thus turns out to be a question not of temporal precedence, but of separation in space-time.

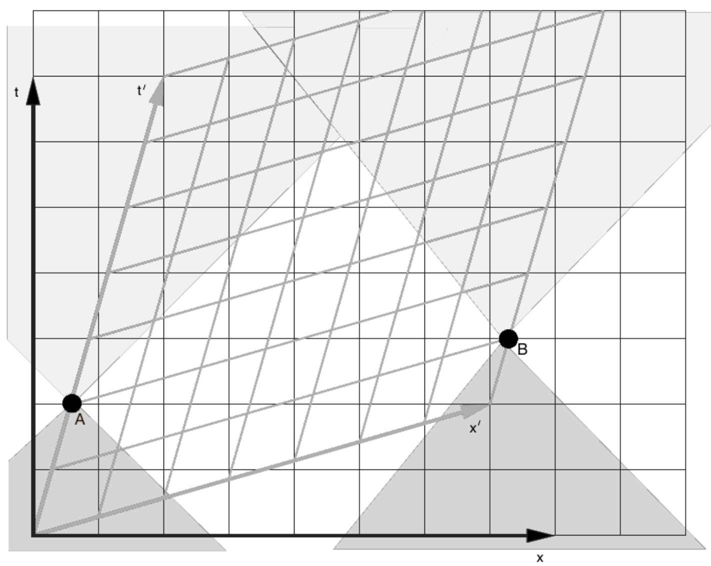

Figure 2. Light cones of events A and B. Neither event can have a causal influence on the other, because they do not lie in each other's light cones.

Just as some pairs of events may not causally influence each other, some lines on a Minkowski diagram may not represent processes capable of propagating causal influences. Salmon uses the term "causal process" to refer to a process (i.e., an entity represented by a line on a space-time diagram) that is capable of propagating causal influence and transmitting energy and

128. *See* SALMON, *supra* note 114, at 141.

information,[129] and uses the term "pseudo-process" to refer to a process that lacks these capabilities.[130] He notes that while causal processes are limited by the speed of light, pseudo-processes are not.[131]

As an example of a pseudo-process that exceeds the speed of light, Salmon describes a rotating spotlight mounted on a rotating mechanism at the center of a very large circular building.[132] If the rotation is fast enough (say, one revolution per second) and the enclosure is large enough (say, over 50,000 kilometers), then the spot of light that it casts on the walls of the enclosure moves at a velocity that exceeds the speed of light.[133] The spot is a process, in that it can be represented by a line on a space-time diagram. The spot is not, however, capable of propagating causal influence or transmitting energy or information.[134] In short, it is incapable of "transmitting a mark," in the following sense:

> [W]e can place a red filter at the wall with the result that the spot of light becomes red at that point. But if we make such a modification in the traveling spot, it will not be transmitted beyond the point of interaction. As soon as the light spot moves beyond the point at which the red filter was placed, it will become white again. The mark can be made, but it will not be transmitted.[135]

Because of this inability, Salmon describes the moving spot of light on the wall as "a paradigm of what we mean by a pseudo-process."[136] According to Salmon, "[t]he basic method for distinguishing causal processes from pseudo-processes is the criterion of mark transmission."[137]

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129. *Id.* at 146.

130. *See id.* at 141.

131. Salmon writes:

> Special relativity demands that we make a distinction between causal processes and pseudo-processes. It is a fundamental principle of that theory that light is a first signal—that is, no signal can be transmitted at a velocity greater than the velocity of light in a vacuum. There are, however, certain processes that can transpire at arbitrarily high velocities—at velocities vastly exceeding that of light. This fact does not violate the basic relativistic principle, however, for these 'processes' are incapable of serving as signals or of transmitting information. Causal processes are those that are capable of transmitting signals; pseudo-processes are incapable of doing so.

See id.

132. *Id.*

133. *Id.* at 143.

134. *Id.* at 142.

135. *Id.*

136. *Id.*

137. *See id.* The original use of the speed of light to separate causal processes from pseudo-processes is credited to Hans Reichenbach. *See* HANS REICHENBACH, THE PHILOSOPHY OF SPACE AND TIME 147–49 (1958).

Dowe rejects Salmon's mark-transmission criterion, finding that it "fails to adequately capture the distinction between causal and pseudo processes."[138] Dowe's causal process theory is based on the idea that "it is the possession of a conserved quantity, rather than the ability to transmit a mark, that makes a process a causal process."[139] The theory consists of two propositions:[140] First, "[a] *causal process* is a world line of an object that possesses a conserved quantity."[141] Second, "[a] *causal interaction* is an intersection of world lines that involves exchange of a conserved quantity."[142] Informally, the respective roles of causal processes and causal interactions are to transmit and produce *causal influence*.[143]

Dowe's theory defines a pseudo-process as a process that does not possess a conserved quantity.[144] A conserved quantity is "any quantity that is governed by a conservation law, and current scientific theory is our best guide as to what these are: quantities such as mass-energy, linear momentum, and charge."[145] Salmon's spot is also an example of a pseudo-process in Dowe's theory, because it does not possess a conserved quantity.[146]

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138. DOWE, *supra* note 116, at 79.

139. *See id.* at 89.

140. *Id.* at 90.

141. *Id.*

142. *See id.*

143. *See id.* at 147.

144. *See id.* at 94 ("To generalize, pseudo processes do not possess the type of physical quantities that are governed by conservation laws.").

145. *See id.* at 94.

146. Dowe explains:

> The causal processes involved . . . are the light beam (energy, momentum) and the wall (mass). The spot or moving patch of illumination cannot be ascribed a conserved quantity. It has other quantities: size, speed, position; but no conserved quantity. The exchange involved in the interaction between the wall and the light beam involves, for example, momentum (the light's momentum is changed on reflection by the wall) or energy (some energy of the reflected beam is lost to heat transferred initially to the molecules of the wall's surface, and subsequently dissipated). No energy is brought to the interaction by the spot or carried off by the spot. Spots do not possess energy.

Phil Dowe, *An Empiricist Defence of the Causal Account of Explanation*, 6 INT'L STUD. PHIL. SCI. 123, 127 (1992). Because a spot lacks tangible causes and effects, it is even more "transient," "fleeting" and intangible than the claimed "signal" at issue in *In re* Nuijten, 500 F.3d 1346, 1356 (Fed. Cir. 2007). In determining that "a transient electric or electromagnetic transmission" was not a patent-eligible "manufacture," Judge Gajarsa reasoned:

> While such a transmission is man-made and physical—it exists in the real world and has tangible causes and effects—it is a change in electric potential that, to be perceived, must be measured at a certain point in space and time by equipment capable of detecting and interpreting the signal. In essence, energy embodying the claimed signal is fleeting and is devoid of any semblance of permanence during transmission. Moreover, any tangibility arguably attributed to a signal is

According to Dowe, for two token events to be connected in a causal relation, it is necessary (but not sufficient) that a continuous line of causal processes and interactions can be traced between them.[147] Dowe appears to be correct,[148] at least as long as *negative causation* is excluded from consideration as a causal relation.[149] Negative causation "occurs when an absence serves as cause, effect, or causal intermediary."[150] While negative causation can figure in causal accounts of legal responsibility (e.g., in theories of negligence or breach of contract),[151] it does not have a place in the patent system's ontology of "useful Arts," inasmuch as the scope of the patent right is limited to affirmative acts such as making and using the structural elements or performing the steps recited in a claim.[152] Thus, it is reasonable to conclude that Dowe's theory accurately describes the instances of causal processes and causal interactions that display the causal powers of a claim's embodiments.

A kinematic claim may entail the exchange of a conserved quantity when an embodiment of the claimed invention is used, but does not set forth limitations regarding any such conserved

> embodied in the principle that it is perceptible—e.g., changes in electrical potential can be measured.

Id. at 1356.

147. *See* DOWE, *supra* note 116, at 146–48 (stating the encompassing necessary and sufficient condition as a "naïve process theory" and concluding that there is "reason to suppose that the naïve process theory does provide a necessary condition for singular causation"); Phil Dowe, *Causality and Explanation*, 51 BRIT. J. PHIL. SCI. 165, 173 (2000) ("We must conclude that the conserved quantity theory . . . provides only a necessary condition for singular causation."); Phil Dowe, *Causes Are Physically Connected to Their Effects: Why Preventers and Omissions Are Not Causes*, *in* CONTEMPORARY DEBATES IN PHILOSOPHY OF SCIENCE 189, 195 (Christopher Hitchcock ed., 2004).

148. It is worth noting that Dowe's conserved quantity account ultimately persuaded Salmon. *See supra* note 117 and accompanying text.

149. *Compare* Dowe, *supra* note 147, at 191 (arguing that cases involving negative events are not, strictly speaking, cases of causation); *with* Jonathan Schaffer, *Causes Need Not Be Physically Connected to Their Effects: The Case for Negative Causation*, *in* CONTEMPORARY DEBATES IN PHILOSOPHY OF SCIENCE 197, 197 (Christopher Hitchcock ed., 2004) (arguing that negative causation does not necessarily involve connection by causal processes and interactions).

150. *See* Schaffer, *supra* note 149, at 197.

151. *See id.* at 201 (citing H.L.A. HART & TONY HONORÉ, CAUSATION IN THE LAW 512 (2d ed. 1985)).

152. *See* 35 U.S.C. § 154. An absence is not cognizable as an element of a claim without a supporting structural element. *Compare* Margaret A. Boulware et al., *An Overview of Intellectual Property Rights Abroad*, 16 HOUS. J. INT'L L. 441, 447 n. 23 (1994) ("[O]ne cannot claim a 'hole' because a hole is 'nothing.' One must therefore claim some structure 'having a hole.'"); *with* Robert C. Faber, FABER ON MECHANICS OF PATENT CLAIM DRAFTING § 3.18, at 3–68 (2009) (noting that while "[y]ou may claim holes positively and make them claim elements," the "[b]etter practice is to claim "a [member] having a hole, groove, slot, aperture, etc.").

quantities.[153] For example, the embodiments of hypothetical claim A (introduced earlier)[154] include the spot pseudo-process described by Salmon:

> A. An object on a cylindrical surface, said object moving counterclockwise on said cylindrical surface at a rate of at least one revolution per second.[155]

This kinematic claim includes subject matter that cannot participate in the exchange of a conserved quantity and is physically incapable of "producing a beneficial result or effect."[156] The claim is therefore directed to a patent-ineligible abstract idea.

The characterization of a rapidly moving spot of light as a patent-ineligible abstract idea is probably not controversial. In contrast, however, it may seem counterintuitive that a claim directed to a surgical robot mechanism could be unpatentably abstract.[157] The following three sections will examine various kinematic mechanism claims, each of which recites generic structural elements that would effectively preempt all physical instantiations of a geometric theorem.[158] As the ensuing discussion will show, the issuance of such kinematic claims not only raises concerns under abstract-ideas jurisprudence, but impinges on the creative work of mathematicians.[159]

B. Preempting the Pythagorean Theorem

Credited to Pythagoras but possibly known to the Babylonians and/or the Chinese a millennium earlier,[160] the Pythagorean Theorem is known to us today as an equation, $a^2 + b^2 = c^2$, expressing the relationship between the length c of the hypotenuse of a right triangle and the lengths a and b of the other two sides[161] (also known as "legs"[162]). Stated more formally:

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153. *See supra* text accompanying note 7.

154. *See supra* text accompanying notes 112113.

155. This is true provided that the term "object" is construed, as Dowe construes it, to include a spot of light. *See* DOWE, *supra* note 116, at 91.

156. *In re* Bilski, 545 F.3d 943, 975 (Fed. Cir. 2008).

157. *See, e.g.*, Bilski v. Kappos, 561 U.S. 593, 632–33 (2010) (Stevens, J., concurring) (citing John R. Thomas, *The Patenting of the Liberal Professions*, 40 B.C.L. REV. 1139, 1166 (1999)) (tracing the historical inclusion of the mechanical arts within the category of patent-eligible "useful arts").

158. *See infra* Sections IV.B–IV.D.

159. *See infra* Section IV.E.

160. *See* ELI MAOR, THE PYTHAGOREAN THEOREM: A 4,000-YEAR HISTORY xi (2007); FRANK J. SWETZ & T.I. KAO, WAS PYTHAGORAS CHINESE? 66 (1977).

161. *See* MAOR, *supra* note 160, at xi.

162. *See* SERGE LANG & GENE MURROW, GEOMETRY 44 (1983).

> Theorem 1. (The Pythagorean Theorem) Let ΔABC be a right triangle, with its right angle at C. Then $AB^2 = AC^2 + BC^2$.[163]

Theorems cannot be the subject of a patent grant; only claims can.[164] What does it mean then to say that the Pythagorean Theorem is unpatentable? In *Parker v. Flook*, the Supreme Court describes a hypothetical attempt by a "competent draftsman" to claim the theorem in a patent application:

> A competent draftsman could attach some form of post-solution activity to almost any mathematical formula; the Pythagorean theorem would not have been patentable, or partially patentable, because a patent application contained a final step indicating that the formula, when solved, could be usefully applied to existing surveying techniques.[165]

The Court did not expressly cite any claim language in making these points.[166] Given the court's suggestion that the claim might contain a "final step" after the formula was "solved," however, it appears that the Court had in mind a process claim that recited steps for calculating $\sqrt{AC^2 + BC^2}$, followed by a final step using the result, AB, in a known method for solving some surveying problem.[167] The *Flook* Court would have found such a claim ineligible, even though it does not wholly preempt the formula $AB^2 = AC^2 + BC^2$ (because of the final surveying step), because the claim's only point of novelty is the formula $AB^2 = AC^2 + BC^2$. As we have seen in Part I, however, this "point of novelty" approach to eligible subject matter analysis is at least controversial, if not discredited. Moreover, the Pythagorean Theorem is a mathematical theorem, not merely a "formula" to be "solved."[168] This distinction was lost as the Court drew

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163. *See, e.g.*, RON LARSON ET AL., GEOMETRY: AN INTEGRATED APPROACH 459 (1995). In a triangle, it is conventional to use lowercase letters to denote the sides opposite the vertices denoted by the corresponding uppercase letters. *See* EDWIN E. MOISE, ELEMENTARY GEOMETRY FROM AN ADVANCED STANDPOINT 148 (1974).

164. *See* 35 U.S.C. § 112(b) ("The specification shall conclude with one or more claims particularly pointing out and distinctly claiming the subject matter which the [applicant] regards as [his] invention.").

165. Parker v. Flook, 437 U.S. 584, 590 (1978).

166. *Id.* at 590–91.

167. *Id.* at 590.

168. The government's brief in Benson argued for separate recognition of mathematical theorems as a categorical exclusion from patentable subject matter:

> For that reason, the Pythagorean Theorem, the binomial theorem, Gibbs' vectors, the Laplace Transform, the general theory of relativity, and Russell's theory of types, for example, even though the products of great intellectual effort, or a flash of genius, are not patentable under our law. Mathematical theorems, abstractions, ideas, and laws of nature are the property of everyone and the [exclusive] right of no one.

comparisons to Flook's invention, which had earlier been characterized as a "mathematical formula" followed by "conventional post-solution applications" of the formula.[169] Thus, while the *Flook* Court's exclusion of the Pythagorean Theorem from patent-eligible subject matter is "well-established," the case law has not clarified the implications of this exclusion for specific claims that recite the use of the Pythagorean Theorem.

Consider instead the following hypothetical apparatus claim:

B. An apparatus for measuring angles, comprising:

> a first leg member having a first end and a second end separated by a first distance a;
>
> a second leg member having a first end and a second end separated by a second distance b, the first end of said second leg member being attached to the first end of said first leg member; and
>
> a hypotenuse member having a first end and a second end separated by a third distance $\sqrt{a^2+b^2}$, the first end of said hypotenuse member being attached to the second end of said first leg member and the second end of said hypotenuse member being attached to the second end of said second leg member,
>
> whereby said first leg member and said second leg member form a right angle.

Two subtleties of claim construction are needed to understand the claim's scope. First, while the claim's preamble recites the function of measuring angles, the claim covers every apparatus that meets the claim's structural limitations, regardless of its intended function.[170] Second, there is a "heavy presumption" that claim terms carry their ordinary and customary meanings.[171] As the Federal Circuit found in *CCS Fitness, Inc. v. Brunswick Corp.*, the ordinary meaning of the term "member" is broad, and may refer to a "structural unit such as a . . . beam or tie, or a

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Brief for the Petitioner at 19, Gottschalk v. Benson, 409 U.S. 63 (1972) (No. 71-485).

169. *Parker*, 437 U.S. at 584–85; *cf.* Paine, Webber, Jackson & Curtis, Inc. v. Merrill Lynch, Pierce, Fenner & Smith, Inc., 564 F. Supp. 1358, 1366–67 (D. Del. 1983) ("[T]he Pythagorean theorem . . . is not patentable because it defines a mathematical formula. Likewise a computer program which does no more than apply the theorem to a set of numbers is not patentable.").

170. *See, e.g.*, Cross Med. Prods., Inc. v. Medtronic Sofamor Danek, Inc., 424 F.3d 1293, 1311–12 (Fed. Cir. 2005) ("To infringe an apparatus claim, the device must meet all of the structural limitations."); Hewlett-Packard Co. v. Bausch & Lomb Inc., 909 F.2d 1464, 1468 (Fed. Cir. 1990) ("[A]pparatus claims cover what a device *is*, not what a device *does*.") (emphasis in original).

171. CCS Fitness, Inc. v. Brunswick Corp., 288 F.3d 1359, 1366 (Fed. Cir. 2002). (citing Johnson Worldwide Assocs., Inc. v. Zebco Corp., 175 F.3d 985, 989 (Fed. Cir. 1999)).

combination of these,"[172] or a "distinct part of a whole."[173] This breadth makes "member" a preferred generic term for a structural unit in the drafting of mechanical patent claims.[174] Read in the context of the claim limitations,[175] each of the recited "members" can be any structural unit of the apparatus having two identifiable ends separated by a specified distance. The term "member" therefore covers, inter alia, any structural unit capable of representing a side of a right-triangle-shaped apparatus.[176]

On its face, then, Claim B covers every apparatus that may be made by attaching the respectively paired ends of three "members" whose lengths are related by the equation $a^2 + b^2 = c^2$, thereby forming a right triangle. It therefore appears that Claim 1 covers every mechanical application of the Pythagorean Theorem, and should be found patent-ineligible under *Mayo*.[177]

Unlike a robotic mechanism, the linkage of Claim B is rigid. Taken as a whole, the recited structure has no degrees of freedom: the three attachments fix the apparatus in a triangular configuration completely determined by the lengths of the members. The next section describes one of the most historically important mathematical results involving a linkage with movable parts.

C. Peaucellier's Theorem (or Invention)

James Watt is credited with inventing the steam engine, but he fell short of solving a fundamental mathematical problem arising from the engine's design: how to transmit rotary motion via a mechanical linkage to move a piston linearly up and down.[178] Lacking an exact solution, Watt instead built a simple four-bar linkage that could move a piston in an approximately straight line; i.e., within the tolerances of his engine design. Watt took special

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172. *See id.* at 1367 (quoting *Member*, MCGRAW-HILL DICTIONARY OF SCIENTIFIC AND TECHNICAL TERMS 1237 (5th ed.1994)).

173. *See id.* (quoting *Member*, AMERICAN HERITAGE DICTIONARY 849 (3d ed. 1996)).

174. *See* Richard G. Berkley, *Some Practical Aspects of Amendment Practice in the Electromechanical Arts*, *in* FIFTH ANNUAL PATENT PROSECUTION WORKSHOP 205.

175. *See* Robert C. Faber, *The Winning Mechanical Claim*, in ADVANCED PATENT PROSECUTION WORKSHOP 2009: CLAIM DRAFTING & AMENDMENT WRITING 321–22 (noting that construction of "member" as a claim element may require some guidance "perhaps obtained from the rest of the limitation including that element . . . [o]r perhaps referring back to the specification or drawing"). In this hypothetical, I assume that nothing in the specification or drawings further limits the meaning of "member."

176. *See* MOISE, *supra* note 163, at 55 (stating that each side of a triangle is a line segment); *id.* at 54–55 (showing that every line segment has two end points).

177. *See supra* text accompanying notes 97 (explaining *Alice/Mayo* test).

178. *See* RICHARD L. HILLS, POWER FROM STEAM: A HISTORY OF THE STATIONARY STEAM ENGINE 68–70 (1989).

pride in this linkage,[179] and in 1784 obtained a British patent on the linkage's use in "methods of directing the piston rods, the pump rods, and other parts of these engines, so as to move in perpendicular or other straight or right lines . . . so as to enable the engine to act on the working beams . . . both in the ascent and descent of their pistons."[180] Figure 3 provides an illustration of the linkage from Watt's patent specification.

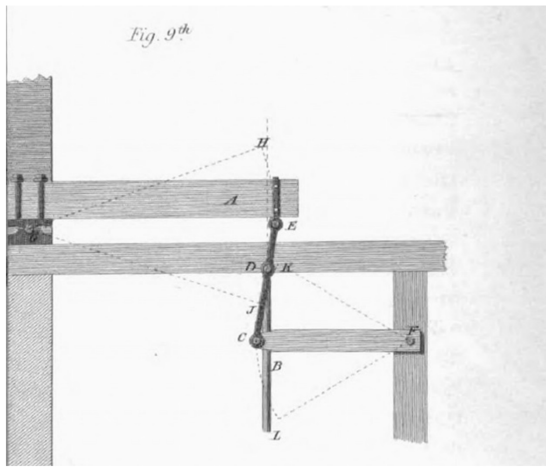

Figure 3. Watt's four-bar linkage.[181]

Despite the efforts of mathematicians as distinguished as Pafnutï L'vovich Chebyshev, the exact solution to Watt's problem did not appear for nearly eighty years, and then only in an obscure mathematics journal article.[182] In 1864, a French army captain named Charles Peaucellier published the following theorem as a letter to the *Nouvelles Annales*:[183]

179. *See id.* at 69 (quoting a letter from Watt to fellow inventor Matthew Boulton stating "I am more proud of the parallel motion than of any other mechanical invention I have ever made").

180. UK Patent No. 1,432 (1784), *reprinted in* ERIC ROBINSON & A.E. MUSSON, JAMES WATT AND THE STEAM REVOLUTION: A DOCUMENTARY HISTORY 114 (1969).

181. Fig. 9, 1784 Specification of Patent, *reprinted in* ERIC ROBINSON & A.E. MUSSON, JAMES WATT AND THE STEAM REVOLUTION 111–12 (1969).

182. *See* Eugene S. Ferguson, *Kinematics of Mechanisms from the Time of Watt*, *in* 27 CONTRIBUTIONS FROM THE MUSEUM OF HISTORY AND TECHNOLOGY 199–208 (2008), http://www.gutenberg.org/ebooks/27106 (describing the history of Peaucellier's mechanism).

183. *See* M. Peaucellier, *Correspondence*, 3 NOUVELLES ANNALES DE MATHEMATIQUES 414 (1864).

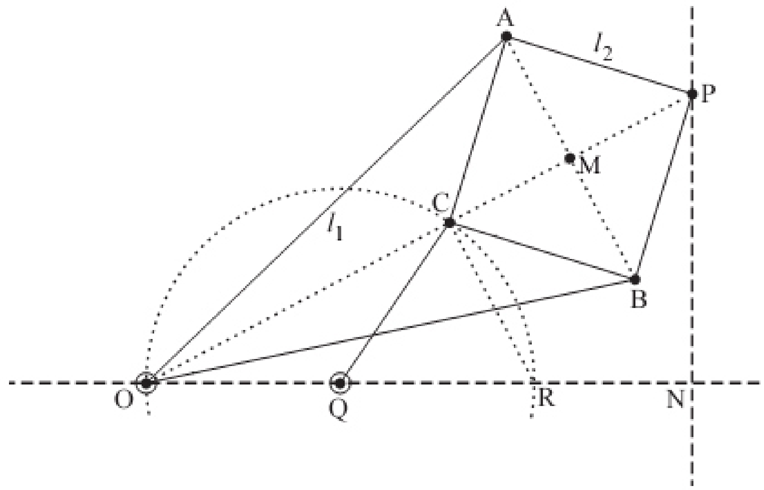

Figure 4. Peaucellier's linkage.

Theorem 2 (Peaucellier). In the planar linkage of Figure 3, suppose that *O* and *Q* are fixed in the plane, links *QC*, *OA*, *OB*, *AP*, *BP*, *AC* and *BC* satisfy $OQ = QC$, $OA = OB = l_1$, and $AP = BP = AC = BC = l_2$. Then as *C* moves on a circle centered at *Q*, *P* moves on a straight line perpendicular to $\overleftrightarrow{OQ}$.

Proof. Since *APBC* is a rhombus, its diagonals are perpendicular bisectors of each other; let *M* be their point of intersection. By the Pythagorean Theorem, $OM^2 + AM^2 = l_1^2$ and $PM^2 + AM^2 = l_2^2$; thus $OC \cdot OP = (OM - PM)(OM + PM) = l_1^2 - l_2^2$ is a constant. Since C moves on a circle centered at Q, we have $\angle OCR = 90°$. Drop perpendicular PN from P to $\overleftrightarrow{OQ}$; then $\Delta OCR \sim \Delta ONP$ and $ON = \frac{OC \cdot OP}{OR} = \frac{k^2}{2OQ}$ is a constant; i.e., N is stationary.

Thus P moves on a straight line perpendicular to $\overleftrightarrow{OQ}$. *Q.E.D.*

The elegance and simplicity of Peaucellier's solution to a decades-old problem caught the attention of the British mathematician J.J. Sylvester, who demonstrated the linkage's motion to colleagues at the Royal Society and the Athenaeum Club.[184] According to Sylvester, the eminent physicist Lord Kelvin described the linkage as "the most beautiful thing I have ever seen in my life."[185]

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184. *See* Ferguson, *supra* note 182.

185. *See id.* (citing James Joseph Sylvester, *Recent Discoveries in Mechanical Conversion of Motion*, 7 NOTICES PROC. ROYAL INST. GR. BRIT. 183 (1873–75)). Peter Lee (personal communication) has suggested that mathematical education and appreciation might be beneficial results or effects of linkages that are sufficiently independent of causal processes to support kinematic claims. While Lord Kelvin's considerable appreciation is not in doubt, determining in general whether such asserted utilities are specific or substantial, *see In re* Fisher, 421 F.3d 1365, 1371 (Fed. Cir. 2005), would likely lead to the kind of

The close kinship between Peaucellier's result and the Pythagorean Theorem should be apparent even to a reader several decades removed from high school geometry, and should give pause concerning the patent-eligibility of mechanisms based on either result. Peaucellier himself was content with publishing his result in a mathematics journal and did not seek a patent on his straight-line linkage; unfortunately, he was a historical outlier.[186] Kinematic claims to mechanical linkages have issued in U.S. patents to the present day. A patent issued in 1916 claiming "[a] constant product linkage comprising a large Peaucellier cell and a similar smaller Peaucellier cell, and connections to keep their corresponding angles equal,"[187] as illustrated in Figure 5, is a particularly egregious example, especially in light of Peaucellier's dedication of his groundbreaking linkage to the public domain of mathematical scholarship.

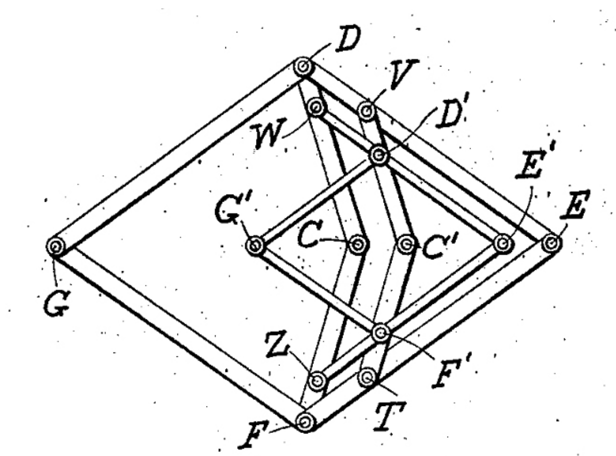

Figure 5. A patented linkage derived from Peaucellier's linkage.

The patent system's tolerance of kinematic claiming reflects a widespread failure to consider the claims of the mathematical community alongside the claims of patent applicants. The case

category mistake that patent-eligibility doctrine serves to avoid. Courts should not be put in the position of determining whether a mathematical property is sufficiently "specific and substantial" to meet the § 101 utility requirement. *See Ghost in the "New Machine"*, *supra* note 97, at 636–37 ("The patentability analysis of a claimed software-implemented invention should never leave a court in the position of determining how hard the math was."); *see also id.* at 638 (quoting *In re* Bilski, 545 F.3d 943, 1013 (Fed. Cir. 2008) (en banc) (Rader, J., dissenting) (arguing that the patent-eligible subject matter inquiry serves to "prevent[] future category mistakes in connection with 'examination against prior art under the traditional tests for patentability'").

186. *See* Peaucellier, *supra* note 183.

187. U.S. Patent No. 1,190,215, at cl. 1 (filed Mar. 13, 1915).

study in the next section will further illustrate the fundamental and integral role of mechanical linkages in the discipline of mathematics.

D. Yates's Linkage and the Sources of Mathematical Intuition

In 1931, University of Maryland mathematics professor Robert Yates derived a surface of constant curvature whose meridian cross-section could be generated by "rolling an ellipse along a straight line and taking the curve traced out by a focus."[188] At the suggestion of his colleague Frank Morley, Yates built a mechanical device for generating the cross-section, as shown in Fig. 2.[189] He then published a description of his device in the *American Mathematical Monthly*.[190]

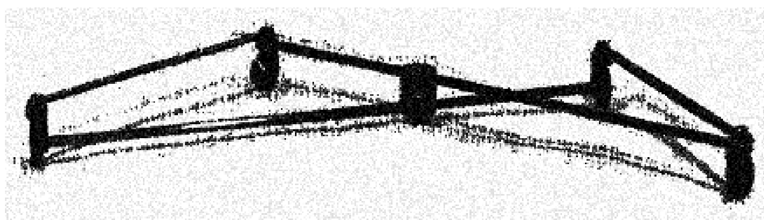

Fig. 2. Yates's linkage for generating the meridian cross-section of a surface of constant curvature.

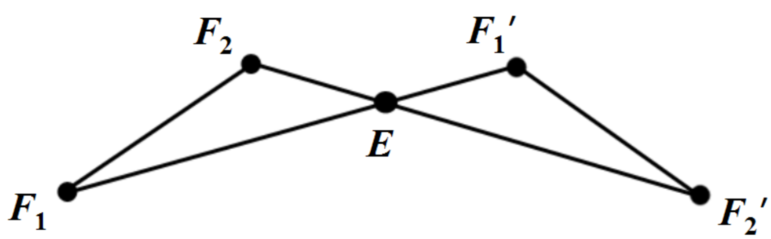

Fig. 3. Yates's linkage represented as a geometric figure in the plane.

Yates's linkage has the interesting property that when one of the shorter links is fixed in the plane, the point at which the two longer links intersect will trace out an ellipse. This result can be formalized in the following geometric theorem:

> Theorem 2. In Fig. 3, suppose that $F_1F_2 = F_1'F_2' = c$, $F_1F_1' = F_2F_2' = a > c$, $\overline{F_1F_2}$ is fixed in the plane, and E is the point of intersection of $\overline{F_1F_1'}$ with $\overline{F_2F_2'}$. Then as F_1' moves

188. *See* Robert C. Yates, *The Description of a Surface of Constant Curvature*, 38 AM. MATH. MONTHLY 573, 573 (1931).

189. *See id.*

190. *See id.* at 573–74.

in a circle about F_1, E traces an ellipse with foci F_1 and F_2.

Proof. By the SSS Theorem, we have $\Delta\, F_1F_2F_2' \cong \Delta\, F_2'F_1'F_1$, so $\angle F_1F_2'F_2 \cong \angle F_2'F_1F_1'$. By the SAS Theorem, $\Delta\, F_1F_2E \cong \Delta\, F_2'F_1'E$. Thus $F_2E = F_1'E$, and $F_1E + F_2E = F_1E + EF_1' = F_1F_1'$, a constant.

Yates's "mechanical description" immediately caught the attention of David Hilbert, one of the most influential mathematicians of the late 19th and early 20th century.[191] In his classic 1932 monograph, *Anschauliche Geometrie*,[192] Hilbert described Yates's linkage (Fig. 4):

> Let c and cN be two rods of the same length c. Let a_1 and a_2 be two other rods both equal to $a > c$ in length. Let the extremities F_1, F_2 of c and F_1N, F_2N of cN be linked to a_1 and a_2 by pin joints in such a way as to form a self-intersecting quadrilateral with opposite sides equal. . . . Let E be the point at which a_1 and a_2 cross. Its position on these two rods will change as the plane linkage assumes its various possible positions. At E we place a joint with two sleeves which are free to turn about E and in which the rods a_1 and a_2 can slide freely.[193]

Hilbert observed that when the rod c is held fixed, the point E traces out an ellipse with F_1, F_2 as foci and with a as the constant sum of its focal distances.[194] Following Yates's suggestion,[195] Hilbert also considered the case where F_1 and F_2 are no longer fixed, and where "two wheels Z_1 and Z_2 [are] mounted at any two points of the rods [F_1F_1' and F_2F_2'] in such a way as to be free to rotate about these rods but not to slide along them."[196]

191. *See* CONSTANCE REID, HILBERT-COURANT 218 (1986) (quoting mathematician Alfred Tarski) ("The future historian of science concerned with the development of mathematics in the late nineteenth and the first half of the twentieth century will undoubtedly state that several branches of mathematics are highly indebted to Hilbert's achievements for their vigorous advancement in that period.").

192. DAVID HILBERT & S. COHN-VOSSEN, GEOMETRY AND THE IMAGINATION (P. Nemenyi trans. 1990) (1952).

193. *Id.* at 283.

194. *See id.*

195. *See* Yates, *supra* note 188, at 574 ("Toothed wheels are placed at the extremities (or at any convenient point) of the rods representing the axis of the ellipse in order that each rod may move at right angles to itself. These wheels cut out two of the four degrees of freedom.").

196. HILBERT & COHN-VOSSEN, *supra* note 192, at 283–84.

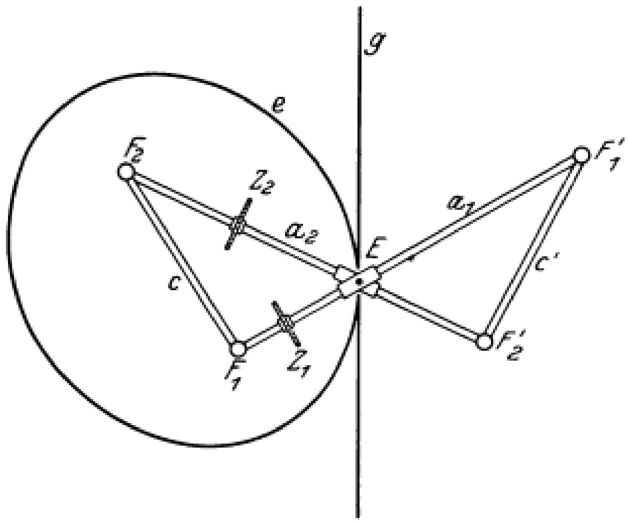

Fig. 4. Hilbert's diagram of Yates's linkage with wheels attached.[197]

From this construction, Hilbert was able to prove a new mathematical result. Hilbert wrote:

> Thus the study of Yates' apparatus leads to a peculiar geometrical theorem which may be formulated [as] follows: Given a roulette generated by a focus of an ellipse, on the normals to the roulette draw the points whose distance from the curve, measured in the direction of the center of curvature, is equal to the constant sum of focal radii for the ellipse; then the points thus marked out lie on another roulette generated by a focus of an ellipse; this ellipse is congruent to the first ellipse and rolls on the same curve as the first ellipse but on the opposite side of that curve.[198]

By studying the behavior of Yates's apparatus, Hilbert was able to prove a new mathematical result, his "peculiar geometric theorem."[199] Suppose, however, that Yates had been precluded from building his apparatus by the following hypothetical patent claim C:

C. An apparatus for drawing ellipses, comprising:

a base;

197. *Id.* at 283.

198. *Id.* at 284–85. A *roulette* is the curve traced out by a point rigidly attached to a plane curve as it rolls upon a second fixed plane curve. *See* 2 HOWARD EVES, A SURVEY OF GEOMETRY 271 (1965).

199. HILBERT & COHN-VOSSEN, *supra* note 192, at 284–85.

> a first link having a first end and a second end separated by a first distance c, both of said ends being attached to said base;
>
> a second link having a first end and a second end separated by a second distance $a > c$, the first end of said second link being connected by a revolute joint to the first end of said first link;
>
> a third link having a first end and a second end separated by said first distance c, the first end of said third link being connected by a revolute joint to the second end of said second link;
>
> a fourth link having a first end and a second end separated by said second distance a, the first end of said fourth link being connected by a revolute joint to the second end of said third link and the second end of said fourth link being connected by a revolute joint to the second end of said first link; and
>
> a revolute joint assembly slidably attached to said second link and to said fourth link, permitting said second link and said fourth link to slide independently of each other and to rotate independently of each other about an axial point E, said axial point E being located on said revolute joint assembly,
>
> whereby the movement of said axial point E relative to said base is constrained to the points of an ellipse whose foci are the first end and the second end of said first link and whose major diameter is a.

Courts have understood the term "link" in its ordinary meaning to refer to a generic structural element in a variety of claim construction contexts[200] (although the term "link" itself has not yet been judicially construed as an element of a claimed kinematic linkage).[201] Assuming that an ordinary meaning

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200. *See, e.g.*, Advanced Respiratory, Inc. v. Electromed, Inc., Civ. No. 00-2646 DWF/SRN, 2003 WL 118246, at *9 (D. Minn. 2003) (construing the term "rod" to mean "any straight link that transmits motion or power from one linkage to another within a mechanism"); Toro Co. v. Scag Power Equip., Inc., No. 8:01CV279, 2002 WL 1792088 at *4–5 (D. Neb. 2002) (finding that patentee's proposed construction of "connection means" to cover "a shaft, rod or arm, or a combination of mechanical links" would "in effect . . . cover any structure that will perform the function of connecting"); *cf.* Cordis Corp. v. Bos. Sci. Corp., No. CIV. 03-027-SLR, 2005 WL 1322966 (D. Del. June 3, 2005), at *1 & nn. 4 & 6 (finding the ordinary meaning of "links" to be "a piece or part . . . that holds two or more important elements together," but construing the term more narrowly in light of a specification describing links disposed circumferentially to maintain the stability of a stent's tubular structure).

201. *See generally* DAVID GARROD, GLOSSARY OF JUDICIAL CLAIM CONSTRUCTIONS IN THE MECHANICAL, ELECTRO-MECHANICAL AND MEDICAL DEVICES ARTS 207 (2010) (providing construction of "link" in a stent claim); ROBERT C. KAHRL & STUART B. SOFFER,

construction applies in the present context, it is straightforward to verify that Claim C covers every apparatus that may be made by attaching four links as depicted in Fig. 3 and described in Theorem 2 so as to produce a kinematic movement for the point *E*; i.e., Claim C covers every mechanical application of Theorem 2. In particular, Yates's linkage is a representative embodiment of Claim C.[202]

The granting of a patent on Claim C would have had significant consequences for the development of pure mathematics. Yates and Hilbert would not have been able to build the apparatus, let alone add the wheels necessary to produce the roulettes of an ellipse. Yates's article on the surface of constant curvature would have had to omit the mechanical description of the cross-section, and may not have been published at all. Hilbert would not have been able to analyze the behavior of Yates's linkage, and would not thereby have synthesized that analysis into his "peculiar geometric theorem."[203]

Since the progress of mathematics is so heavily dependent on the sustained efforts of individual mathematicians[204] with relatively brief productive life spans,[205] the preclusive effect of a 20-year patent term should not be underestimated. The issuance of Claim C would likely have precluded Hilbert from discovering and proving a more advanced geometric theorem. Yates's article and Hilbert's book were published only one year apart, and Hilbert passed away eleven years later.[206]

THESAURUS OF CLAIM CONSTRUCTION 370 (2011) (providing construction of "link" in an information technology claim); *cf.* Intuitive Surgical, Inc. v. Computer Motion, Inc., Civ. No. 01-203-SLR, 2002 WL 1822373 (D. Del. 2002) , at *1 (construing "robotic manipulator" as "[t]he moving parts of a robotic system made of links and joints. . .," but not construing "link").

202. In the case where F_1 and F_2 are not fixed in the plane, the "base" may be construed as the first member or any part thereof; *E* will still be constrained to move along an ellipse relative to this "base." *See* HILBERT & COHN-VOSSEN, *supra* note 192, at 284 (explaining when "the rod *c* [is] rigidly attached during the motion to a moving plane . . . the moving centrode must be the ellipse *e*").

203. *Id.* at 284–85.

204. *See, e.g.*, AMIR D. ACZEL, FERMAT'S LAST THEOREM: UNLOCKING THE SECRET OF AN ANCIENT MATHEMATICAL PROBLEM 2 (1996) (describing Andrew John Wiles's solitary work to complete the proof of Fermat's Last Theorem, for which he spent "seven years of his life a virtual prisoner in his own attic"); Peter G. Hinman & B. Alan Taylor, *The Mathematics Major at Research Universities*, *in* CONTEMPORARY ISSUES IN MATHEMATICS EDUCATION 27 (Estela A. Gavosto et al., eds., 1999) (explaining that the received wisdom that "mathematics is a solitary occupation" is valid for "research mathematics," though not for a "B.A. mathematician work[ing] in industry").

205. *See, e.g.*, SYLVIA NASAR, A BEAUTIFUL MIND 381 (1998) (quoting JOHN FORBES NASH JR., LES PRIX NOBEL 1994) ("Statistically, it would seem improbable that any mathematician or scientist, at the age of 66, would be able through continued research efforts to add to his or her previous achievements.").

206. *See* REID, *supra* note 191, at 213 (giving Hilbert's date of death as Feb. 14, 1943);

Hilbert's reliance on a mechanical apparatus to provide him with the necessary intuition for his "peculiar geometric theorem" is not at all unusual.[207] Mechanisms have long been recognized as a source of geometric intuition[208] and as mathematical teaching tools.[209] Furthermore, as mathematical philosopher John Nolt has pointed out, physical objects and geometric diagrams stand on equal footing as sources of geometric intuition, because "[t]he figures we perceive and probably also those we imagine are not quite geometrical, i.e., not composed of infinitesimally thin lines meeting at infinitesimally tiny points."[210] In other words, "geometrical diagrams are themselves physical objects. . . . The symbols are actually among the objects symbolized."[211]

E. Discussion

Mathematics, described by Kant as "the most resplendent example of pure reason,"[212] is no less abstract for its reliance on the concrete objects of empirical reality; indeed, mathematics relies for its internal coherence on its empirical origins. As John von Neumann wrote in his essay on "The Mathematician,"

> [M]athematical ideas originate in empirics, although the genealogy is sometimes long and obscure. But, once they are so conceived, the subject begins to live a peculiar life of its own and is better compared to a creative one, governed by almost entirely aesthetical motivations, than to anything else and, in particular, to an empirical science. There is,

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cf. Seymore, *supra* note 108, at 377–78 (expressing concern that the twenty-year patent term unduly delays experimentation into how and why a patented invention works).

207. HILBERT & COHN-VOSSEN, *supra* note 192, at 284–85.

208. *See, e.g.*, ROBERT S. TRAGESSER, HUSSERL AND REALISM IN LOGIC AND MATHEMATICS 16 (1984) (crediting philosopher Edmund Husserl (1859–1938) with understanding geometric intuitions as "acts of consciousness" that are "founded" in visually experienced objects but subject to "principles of reasoning different from those cogent and valid for [such] visually experienced objects").

209. *See* PEGGY ALDRICH KIDWELL ET AL., TOOLS OF AMERICAN MATHEMATICS TEACHING, 1800-2000, at 238–42 (2008). For recent pedagogical notes on the use of mechanical linkages in mathematics teaching, *see, e.g.*, BRIAN BOLT, MATHEMATICS MEETS TECHNOLOGY vi–viii & 57–94 (1991); David Dennis & Jere Confrey, *Geometric Curve-Drawing Devices as an Alternative Approach to Analytic Geometry: An Analysis of the Methods, Voice, and Epistemology of a High-School Senior*, *in* DESIGNING LEARNING ENVIRONMENTS FOR DEVELOPING UNDERSTANDING OF GEOMETRY AND SPACE 298 (Richard Lehrer & Daniel Chazen, eds., 1998); Daina Taimina, *Historical Mechanisms for Drawing Curves*, *in* HANDS ON HISTORY: A RESOURCE FOR TEACHING MATHEMATICS 89 (Amy Shell-Gellasch ed., 2007).

210. *See* John E. Nolt, *Mathematical Intuition*, 44 PHIL. & PHENOMENOLOGICAL RES. 189, 202 (1983).

211. *Id.* at 206.

212. IMMANUEL KANT, CRITIQUE OF PURE REASON 630 (Paul Guyer & Allen W. Wood trans. 1998).

> however, a further point which, I believe, needs stressing. As a mathematical discipline travels far from its empirical source, or still more, if it is a second and third generation only indirectly inspired by ideas coming from 'reality,' it is beset with very grave dangers . . . [A]t a great distance from its empirical source, or after much 'abstract' inbreeding, a mathematical subject is in danger of degeneration.[213]

In short, the freedom to make and use the fundamental empirical sources of mathematical intuition is necessary for the flourishing of mathematics.[214] Concern for this freedom counsels against the issuance of any patent that claims every mechanical application of a kinematic property because some mechanical structures are among "the basic tools of scientific and technological work."[215]

As Part II showed, the patent-eligibility concerns discussed here in Part III have not prevented the widespread issuance and assertion of kinematic patents throughout the history of the surgical robotics industry.[216] Even though Intuitive's present-day monopoly is not readily attributable to the prevalence of kinematic patents,[217] the emergence of new competition in the surgical robotics industry[218] provides an appropriate juncture to study the consequences of kinematic claiming on the strategic posture of its key players. Part IV will provide one such case study, on the development and patenting of Applied Dexterity's RAVEN manipulator, as a first step toward a deeper understanding of how the industry's future development might be affected by the untenable practice of kinematic claiming.

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213. John von Neumann, *The Mathematician*, *in* THE NEUMANN COMPENDIUM 618, 626 (F. Bródy & T. Vámos eds., 1995).

214. *See* KANT, *supra* note 212, at 630–31. In turn, Francis Su, past president of the Mathematical Association of America, has famously and persuasively argued that the activity of doing mathematics is instrumental in human flourishing. *See* Francis Su, *Mathematics for Human Flourishing*, 124 AM. MATH. MONTHLY 483, 485–86 (2017) (farewell address to the Joint Mathematics Meetings of the MAA and the American Mathematical Society); *see also* Kevin Hartnett, *The Mathematician Who Will Make You Fall in Love With Numbers*, WIRED, Feb. 5, 2017 (profile on Su with reporting on his farewell address).

215. Gottschalk v. Benson, 409 U.S. 63, 67 (1972).

216. *See supra* Part III.

217. *See supra* notes 21–23 and accompanying text (identifying other sources of Intuitive's monopoly power).

218. *See supra* note 28 and accompanying text.

IV. THE MAKING OF A KINEMATIC SURGICAL ROBOTICS CLAIM

A. Kinematic Foundations of Robotics

The essential task of a surgical robot is to manipulate a tool so as to replicate (and sometimes improve upon) the movements of the tool in the hands of a skilled surgeon.[219] A *manipulator* is the mechanism in a robotic system responsible for moving a tool into a desired position and orientation so that the robot can perform a task.[220] The manipulator's movement is defined by a connected set of rigid *links*.[221] The tool is typically located at the end of a link or chain or links, and is therefore often referred to as the manipulator's *end-effector*.[222] The links are connected by *joints*, the simplest of which are *revolute* or *prismatic*.[223] Revolute joints allow neighboring links to rotate to different angles, while prismatic joints allow links to slide to different displacements relative to each other.[224] *Actuators* are the power components of a robotic system that perform the work of executing the motions of the manipulator's joints.[225] *Sensors* acquire information regarding the manipulator's internal state and its interaction with the external environment that can be helpful in controlling the robot.[226]

Reliance on a manipulator's moving joints to control the movements of the end-effector frequently gives rise to the geometric problem of translating joint angles and displacements (the "joint space" description of the manipulator's position) into coordinates describing the end-effector's position and orientation in space (the "Cartesian space" description of the end-effector's position), and vice versa.[227] For example, suppose we wish to make a manipulator as in Figure 6 for moving an end-effector in the plane, consisting of two straight-line links connected to a base and to each other by revolute joints.[228]

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219. *See, e.g.*, REBECCA STEFOFF, ROBOTS 75 (2008) ("A human surgeon operates da Vinci by sitting at a console and manipulating his hands on a set of controls; the robotic arms copy his movements. In fact, the robot can be programmed to filter out the human operator's muscle tremors.").

220. *See* JOHN J. CRAIG, INTRODUCTION TO ROBOTICS: MECHANICS AND CONTROL 4 (2005).

221. *See id.* at 5.

222. *See id.*

223. *See id.*

224. *See id.*

225. *See generally* BRUNO SICILIANO, ET AL,, ROBOTICS: MODELLING, PLANNING AND CONTROL 191–209 (2010) (surveying robotic actuating systems and drives).

226. *See id.* at 209–30 (surveying robotic sensors).

227. *See* CRAIG, *supra* note 220, at 5–7.

228. *See* Berthold K.P. Horn, *Kinematics, Statics, and Dynamics of Two-Dimensional Manipulators*, *in* 2 ARTIFICIAL INTELLIGENCE: AN MIT PERSPECTIVE 273, 277 (Patrick

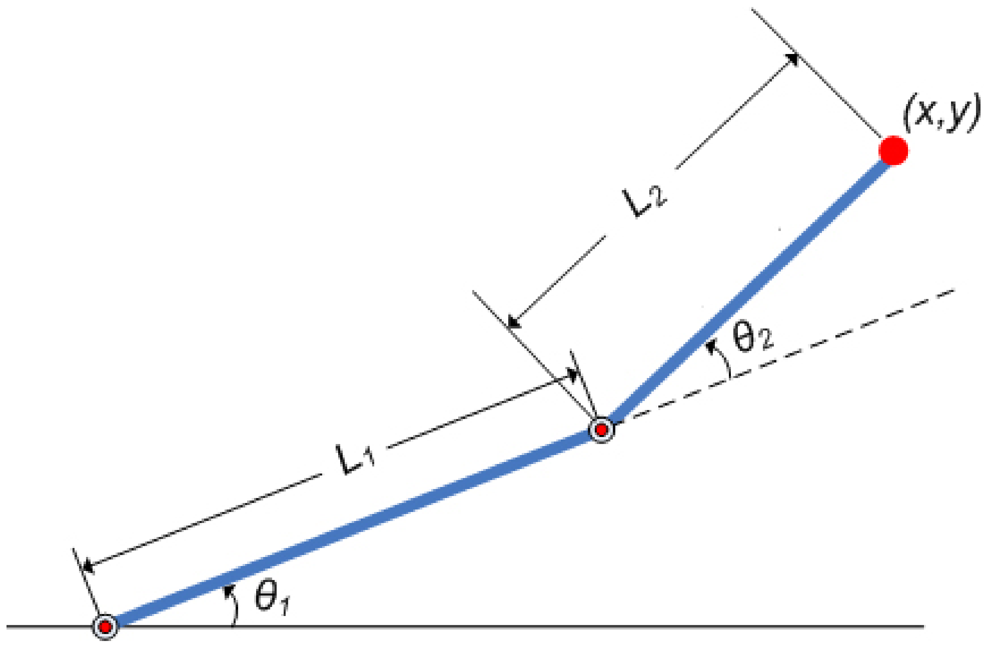

Figure 6. Kinematics of a two-link planar manipulator.

Suppose further that, starting from the base, the links are of length L_1 and L_2, with $L \; > L_2$. Given such a manipulator whose joints are set at angles θ_1 and θ_2, the *forward kinematics problem* is to calculate the Cartesian coordinates of the end-effector (x, y). A straightforward trigonometric calculation gives the solution as

$$x = (L_1 + L_2 \cos\theta_2)\cos\theta_1 - L_2 \sin\theta_2 \sin\theta_1$$

$$y = (L_1 + L_2 \cos\theta_2)\sin\theta_1 - L_2 \sin\theta_2 \cos\theta_1 .$$[229]

If instead we are given the Cartesian coordinates (x, y) of a desired location for the end-effector, the *inverse kinematics problem* is to calculate a set of joint angles θ_1 and θ_2, if one exists, that will position the manipulator's end-effector at this location. Another trigonometric calculation gives

$$\cos\theta_2 = \frac{(x^2 + y^2) - (L_1^2 + L_2^2)}{2L_1 L_2}$$

$$\tan\theta_1 = \frac{-L_2 \sin(\theta_2)x + (L_1 + L_2 \cos\theta_2)y}{L_2 \sin(\theta_2)y + (L_1 + L_2 \cos\theta_2)x}$$

from which solutions (θ_1, θ_2), if any, can be determined.[230] The point (x, y) has an inverse kinematics solution if and only if it can

Henry Winston & Richard Henry Brown eds., 1979).

229. *See id.* at 277–78.

230. *See id.* at 278–80.

be reached by the manipulator's end-effector (i.e., by setting the manipulator's angles to (θ_1, θ_2) so as to satisfy the equations above. While these equations may appear complex, they are actually relatively simple in that the inverse kinematics problem for manipulators in general does not always lend itself to analytical solutions.[231]

Note that by varying θ_2 continuously from 0 to 180 degrees, it is possible to move the end-effector to a point at any distance between $L_1 + L_2$ and $L_1 - L_2$ from the base. Varying θ_1 continuously from 0 to 360 degrees while holding θ_2 constant allows the end-effector to sweep through a circle. Thus the set of points reachable by the end-effector forms an annulus with outer diameter $L_1 + L_2$ and inner diameter $L_1 - L_2$.[232] This set of reachable points is referred to as the manipulator's *workspace*.[233] (By the same token, the workspace of point P of the Peaucellier linkage consists of a straight line, and the workspace of point E of Yates's linkage consists of an ellipse.)

Planning the motion of a manipulator involves the analogous problem of mapping velocities in joint space into Cartesian space and vice versa.[234] This problem can identify certain configurations of the manipulator, or *singularities*, from which it is infeasible for the joints to move quickly enough to produce even a relatively small movement of the end-effector.[235]

231. *See* CRAIG, *supra* note 220, at 106 ("Only in special cases can robots with six degrees of freedom be solved analytically."); *see also* Horn, *supra* note 228, at 280–81 ("[T]his method, while quite general, is in practice limited to solving only simple linkages.").

232. *See* Horn, *supra* note 228, at 281.

233. *See* CRAIG, *supra* note 220, at 7.

234. *See id.* at 6–7.

235. *See id.* at 7–9.

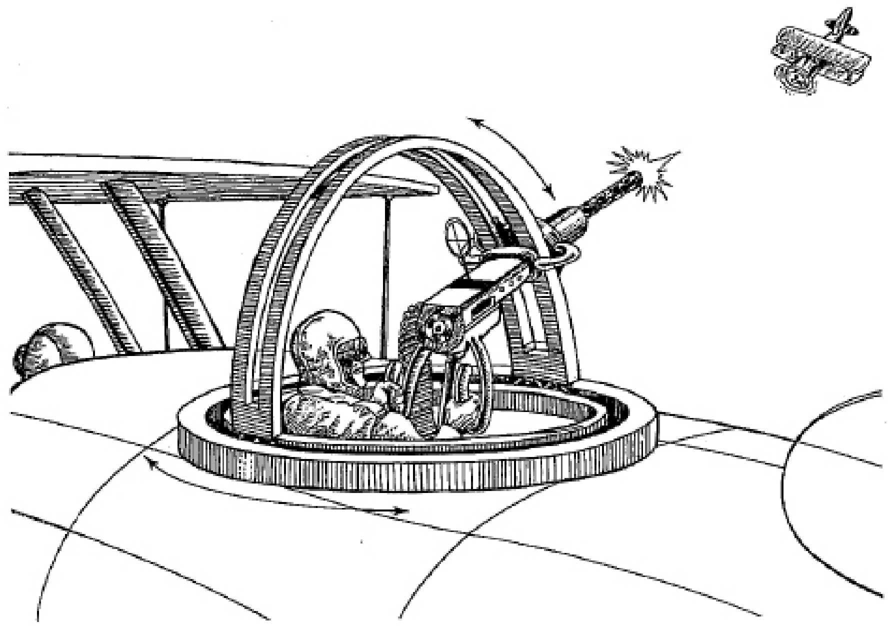

Figure 7. A biplane with a tail gun mounted on a mechanism with two revolute joints. A singularity arises in the configuration where the gun is pointing directly overhead.[236]

For example, as in Figure 7, the tail gun on a biplane might not be able to spin around quickly enough to track an enemy plane flying directly overhead.[237] The situation where the gun is pointing nearly straight up, requiring such rapid rotation to maneuver, is a singularity of the mechanism on which the tail gun is mounted.[238] The mathematical relationship between the joint velocities of a manipulator and the Cartesian velocities of the end-effector, from which such singularities can be identified, is given by the manipulator's *Jacobian matrix*, the details of which will not be presented here.[239]

B. Development of RAVEN's Manipulator

Applied Dexterity's RAVEN robot is based on the manipulator shown in Figure 8, consisting of three links and three revolute joints.[240] The manipulator is spherical in that the curved links are

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236. *See id.* at 8.

237. *See id.*

238. *See id.* at 8–9.

239. *See id.* at 150.

240. *See* Rosen, *supra* note 43, at 163. The team has also developed and claimed a more complex parallel manipulator that is not discussed here for the sake of brevity. *See id.* at 162–64; U.S. Patent App. No. 13/908,120 at [0176] (disclosing an example of the invention that "includes two (or multiples of two) links to mechanically constrain two degrees of

designed so that the axes of rotation of the three joints intersect at the center ("the remote center") of a sphere passing through the links.[241] When the device is used for minimally invasive surgery, a third link (formed by a surgical tool) terminating in the end-effector is inserted through a tool holder at the end of the second link (forming Joint 5).[242] Joint 5 may be rotary and/or prismatic.[243] The remote center is also the point of entry into the patient's body.[244]

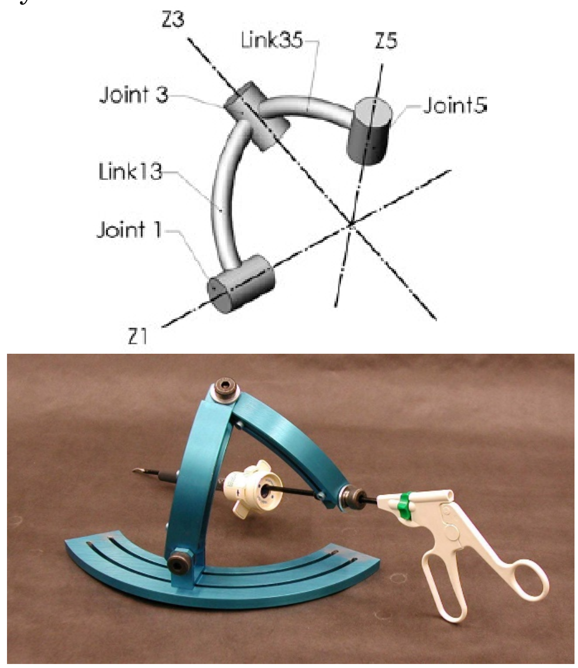

Figure 8. A schematic[245] and aluminum mock-up[246] of the RAVEN's spherical serial manipulator mechanism.

After working through the manipulator's forward and inverse kinematics,[247] RAVEN's designers sought to refine the mechanism so as best to avoid singularities when replicating a surgeon's

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motion to the surface of a sphere").

241. *See* Rosen, *supra* note 43, at 163.

242. *See id.* ("As configured for MIS, the end-effector of the mechanism is inserted through Joint 5."); U.S. Patent App. No. 13/908,120 at cl. 1 ("[T]he second end of the second link includes a tool holder, the tool holder having a tool axis aligned to pass through a point coincident with an intersection of the convergent rotational axes . . .").

243. *See* U.S. Patent App. No. 13/908,120 at cl. 17 (reciting an actuator "configured to manipulate the tool to provide at least one of rotary motion on a tool axis and prismatic motion on the tool axis").

244. *See* Rosen, *supra* note 43, at 162.

245. *See id.* at 163.

246. *See id.* at 183.

247. *See id.* at 164–67.

movements during minimally invasive surgical procedures. The designers considered 1,444 design candidates having varying lengths of Links 13 and 35 while retaining the manipulator's spherical property.[248] Using the Blue DRAGON, they recorded the movements of surgical tools by thirty surgeons performing seven different surgical tasks, and used this data to identify a desired "dexterous workspace" for the manipulator encompassing 95 percent of the tools' recorded movements.[249] Using Jacobian matrices, they formulated and calculated for each design candidate a proxy measure of its freedom from singularities (its "mechanism isotropy") at each point in the dexterous workspace.[250] Based on this measure, they determined the optimal design candidate would have Links 13 and 35 forming circular arcs subtending angles of 52 and 40 degrees, respectively.[251] This finding is the basis for the limitation added by dependent claim 12 of Applied Dexterity's '120 patent application.[252]

C. Applied Dexterity's Kinematic Patent Claims

With this background, we can discuss the patentability of claims 1 and 12 of Applied Dexterity's '120 patent application:

1. A device comprising:

> a first link having ends terminated in a base revolute joint and a common revolute joint, the revolute joints having convergent rotational axes and each rotational axis forming an acute angle with a longitudinal axis of the first link, the base revolute joint coupled to a base;
>
> a second link coupled to the common revolute joint at a first end, the second link having a second end and the second link in a serial cantilever configuration with the first link, the rotational axis of the common revolute joint forming an acute angle with a longitudinal axis of the second link, wherein the second end of the second link includes a tool holder, the tool holder having a tool axis aligned to pass through a point coincident with an intersection of the convergent rotational axes, the tool axis and the common revolute joint rotational axis subtending a first angle; and
>
> the convergent rotational axes subtending a second angle, such that the first angle differs from the second angle, the

248. *See id.* at 175.

249. *See* Mitchell J.H. Lum et al., *Multidisciplinary Approach for Developing a New Minimally Invasive Surgical Robotic System*, *in* PROC. 1ST IEEE/RAS-EMBS INT'L CONF. ON BIOMEDICAL ROBOTICS & BIOMECHATRONICS 841, 842–43 (2006).

250. *See* Rosen, *supra* note 43, at 170–73.

251. *See id.* at 177.

252. *See supra* note 40 and accompanying text.

> first and second links and the revolute joints enabling a position of the tool holder to be selectively manipulated.
>
> 12. The device of claim 1 wherein the first angle is about 40 degrees and the second angle is about 52 degrees.[253]

As of this writing, Applied Dexterity's '120 patent application has received a first office action communicating various § 102 and § 103 rejections. Almost all of the § 102 rejections are based on prior art publications by Hannaford and Rosen's research group.[254] Assuming that these can be overcome,[255] the patentability of the design insights derived from observed surgical movements will hinge in part on the examiner's argument that the angles of claim 12 were obvious because "discovering an optimum value of a result effective variable involves only routine skill in the art."[256]

The discussion in Part III of this Article strongly suggests that claims 1 and 12 of the '120 application should also be rejected under § 101 as directed to abstract kinematic principles. Like the hypothetical claim to Salmon's spot of light,[257] the claims recite objects having specified kinematic properties, but without any limitations as to causal powers and processes capable of "producing a beneficial result or effect."[258] Like the hypothetical claims to the right-triangle apparatus[259] and Yates's linkage,[260] claim 1 purports to cover every mechanical application of a mathematical theorem. The principal inventors themselves have candidly characterized the

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253. U.S. Patent Appl. No. 13/908,120, cls. 1, 12 (filed June 3, 2013).

254. *See* USPTO, Office Action in Examination of U.S. Patent App. No. 13/908,120, ¶¶ 2, 3 (Apr. 10, 2017) (rejecting several claims over Jacob Rosen et al., *Spherical Mechanism Analysis of a Surgical Robot for Minimally Invasive Surgery: Analytical and Experimental Approaches*, *in* MEDICINE MEETS VIRTUAL REALITY 13: THE MAGICAL NEXT BECOMES THE MEDICAL NOW 422, 422, 424, 426 (J.D. Westwood et al. eds., 2005); Mitchell Lum et al., *Kinematic Optimization of a Spherical Mechanism for a Minimally Invasive Surgical Robot*, *in* 5 IEEE INT'L CONF. ON ROBOTICS & AUTOMATION 829, 829–33 (2004)); *but see* USPTO, Office Action in Examination of U.S. Patent App. No. 13/908,120, ¶ 4 (Apr. 10, 2017) (rejecting one claim over U.S. Patent No. 6,355,048 (filed Oct. 25, 1999)).

255. The earlier of the two Hannaford–Rosen group references was published in the proceedings of an IEEE conference held from April 26 to May 1, 2004. *See* Lum, *supra* note 254. The '120 application claims priority as a continuation of an application filed on Apr. 25, 2005, less than a year after the conference. *See* U.S. Patent No. 13/908,120 at [0001] (filed Jun. 3, 2013).

256. USPTO, Office Action in Examination of U.S. Patent App. No. 13/908,120, ¶ 5 (Apr. 10, 2017). The examiner's argument finds apparent legal support in *In re* Boesch, 617 F.2d 272, 276 (C.C.P.A. 1980) ("[D]iscovery of an optimum value of a result effective variable in a known process is ordinarily within the skill of the art.").

257. *See supra* text accompanying note 155.

258. *See* Diamond v. Diehr, 450 U.S. 175, 182 n.7 (1981).

259. *See supra* text accompanying notes 170–177.

260. *See supra* text accompanying notes 200–202. Theorem 2 stands for the proposition that the workspace of Yates's linkage as claimed in claim 3 and shown in Figure 6 with base F_1F_2 and end-effector E is an ellipse. *See* text accompanying notes 189–191.

spherical manipulator's forward and inverse kinematics as "purely mathematical":

> Up to this point, the analysis has been purely mathematical. The manipulator could move through singularities, fold on itself and solve for arbitrary poses without regard to how a physically implemented device might accomplish this.[261]

Claim 1's recitation of a "tool holder" (instead of the generic concept of a rotary and/or prismatic joint with a third link terminating in an end-effector) serves to limit the field of use to minimally invasive surgery,[262] but this is immaterial to the patent-eligibility analysis.[263]

The additional limitations in claim 12 are intended to address the practical problem of "mov[ing] through singularities" when a "physically implemented device" is operating under the control of a surgeon performing a procedure.[264] This real-world context might persuade an examiner to agree that the inventors' efforts to optimize the manipulator's design — i.e., to "discover[] an optimum value of a result effective variable" — were not directed to a "purely mathematical" result.[265] Ultimately, however, claim 12 adds no causal limitations to claim 1, and is therefore equally susceptible to rejection under § 101.[266]

As for the § 103 analysis, the examiner might also be persuaded that solving this particular optimization problem necessarily involved more than ordinary skill, in light of the numerous heavily-cited academic publications that resulted from the Hannaford–Rosen group's design optimization efforts.[267] The only non-mathematical part of those efforts, however, was performed by the surgeons whose movements identified the dexterous workspace that formed the basis of the optimization calculations.[268] If the § 103 analysis is to avoid an improper inquiry into the mathematical difficulty of the inventors' optimization approach,[269] the inventors

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261. *See* Rosen, *supra* note 43, at 171.

262. *See supra* text accompanying notes 242–243.

263. *See* Bilski v. Kappos, 561 U.S. 593, 612 (2010) (citing Parker v. Flook, 437 U.S. 584, 584–85, 590 (1978)) ("*Flook* established that limiting an abstract idea to one field of use . . . did not make the concept patentable.").

264. Rosen, *supra* note 43, at 171.

265. USPTO, *supra* note 254, ¶ 5.

266. Rosen, *supra* note 43, at 171.

267. *See, e.g.*, GOOGLE SCHOLAR, https://scholar.google.com/scholar?cites=8622140283516909909 (last visited Oct. 26, 2017) (showing that Lum, *supra* note 254, has received 89 citations).

268. *See supra* text accompanying note 249.

269. *See Ghost in the "New Machine"*, *supra* note 97, at 636–37 ("[A] § 103 inquiry into the level of ordinary skill in the art is misplaced where the art in question, and the field of knowledge being advanced by the patent disclosure, is not one of the "useful Arts," but

would seem to be left with an appeal to the surgeons' kinesthetic expertise for the argument that the optimization entailed more than ordinary skill.[270]

The problematic patentability of Applied Dexterity's kinematic claims is somewhat ironic, given the company's commitment to open-source development of RAVEN's control software. Both claims 1 and 12 suffer from a mismatch between the category of objects and processes having causal powers[271] and a claimed manipulator whose links, joints, and movements are characterized entirely in kinematic terms without regard to masses or forces.[272]

No such mismatch would occur in claims directed to a robotic controller. As the Patent Office has observed, a manipulator operating under a specific control system does not preempt the mathematical theorems governing the manipulator's kinematic movements:

> A claim directed to a complex manufactured industrial product or process that recites meaningful limitations along with a judicial exception may sufficiently limit its practical application so that a full eligibility analysis is not needed. As an example, a robotic arm assembly *having a control system* that operates using certain mathematical relationships is clearly not an attempt to tie up use of the mathematical relationships and would not require a full analysis to determine eligibility.[273]

The analysis in this Article clarifies that "meaningful limitations" are those that ground the patent claim in the category of objects and processes having causal powers.[274] What makes designing and controlling a robot's actuators a "complex manufactured industrial" enterprise is the need for close attention to the masses of moving parts[275] and internal and external forces.[276]

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mathematics. The patentability analysis . . . should never leave a court in the position of determining how hard the math was.").

270. *Cf.* HOWARD GARDNER, FRAMES OF MIND: THE THEORY OF MULTIPLE INTELLIGENCES 231–33 (1983) (characterizing the work of the inventor as entailing "bodily intelligence" in addition to "logical-mathematical reasoning").

271. *See supra* text accompanying note 99.

272. *See supra* text accompanying notes 257–259; *see also* text accompanying note 7 (defining kinematic properties).

273. USPTO, *2014 Interim Guidance on Patent Subject Matter Eligibility*, 79 Fed. Reg. 74618, 74625 (Dec. 16, 2014) (emphasis added).

274. *Id.* at 74625.

275. *Id.*; *see, e.g.*, SICILIANO, *supra* note 225, at 192–93 (noting that timing belts and chains are kinematically equivalent, but the large mass of chains "may induce vibration at high speeds").

276. *See* SICILIANO, *supra* note 225, at 191–92 (outlining essential elements of the specification of an actuating system, wherein the power to be transmitted "can always be expressed as the product of a flow and a force quantity, whose physical context allows the specification of the nature of the power (mechanical, electric, hydraulic, or pneumatic)").

Thus, in a robotics patent, the recitation of a specific control system may sufficiently limit the practical application of the manipulator's kinematic properties to confer patent-eligibility.

For example, RAVEN's actuation and control system includes "Maxon EC-40 motors with 12:1 planetary gearboxes" to accommodate "the highest forces," power-off brakes along the axes "under the greatest gravity load," a cable system with a 7.7:1 motor-to-shoulder joint transmission ratio that "maintains constant pretension on the cables through[out] the entire range of motion," and a control system that accommodates "[f]orce and motion coupling between the axes."[277] Such design considerations might not be new or nonobvious, but they do directly address the transmission of energy and other conserved quantities through causal processes and present no issues under the abstract-ideas exclusion from patentable subject matter.[278] Even though open-source development is apparently accelerating Applied Dexterity's entry into the surgical robotics market,[279] the patent-eligibility concerns raised in this Article might have led the company to pursue patents directed to RAVEN's software innovations in real-time control and signal processing[280] instead of, or at least in addition to, its kinematic manipulator claims.

V. CONCLUSIONS

Like other kinds of patent claims that have raised subject matter eligibility concerns in recent years, kinematic claims also raise overbreadth issues.[281] In particular, kinematic claims directed to relatively modest advances in the mechanical arts are in tension with the doctrine of equivalents, which reserves its broadest protection for pioneering inventions.[282] In contrast, the effective scope of a kinematic claim may exceed the range of equivalents of a

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277. *See* Rosen, *supra* note 43, at 181.

278. *See supra* text accompanying notes 153–157.

279. *See supra* text accompanying notes 32–34.

280. *See* Andrew Chin, Alappat *Redux: Support for Functional Language in Software Patent Claims*, 66 SMU L. REV. 491, 502 (2013) (arguing that a software innovation specifying the involvement of real-time computational resources in causal processes is a concrete "practical method or means" and therefore not impermissibly abstract).

281. *See, e.g.*, Mayo Collaborative Servs. v. Prometheus Labs., Inc., 566 U.S. 66, 72 (2012) (concluding that patent-eligibility precedents "warn us against upholding patents that claim processes that too broadly pre-empt the use of a natural law"); Bilski v. Kappos, 561 U.S. 593, 611–12 (2010) (observing that "to patent risk hedging would pre-empt use of this approach in all fields").

282. *See* Thomas & Betts Corp. v. Litton Sys., Inc., 720 F.2d 1572, 1580 (Fed. Cir. 1983) ("[W]hile a pioneer invention is entitled to a broad range application of the doctrine of equivalents, an invention representing only a modest advance over the prior art is given a more restricted (narrower range) application of the doctrine.").

structurally identical claim with causal limitations, inasmuch as the kinematic claim purports to cover not only substantially similar ways, but all ways, of causing the claimed mechanism to function.[283] Thus, kinematic patent claims would be unduly broad even if they were deemed to reflect patent-eligible inventive advances in the mechanical arts rather than the kinds of mathematical results highlighted in this Article.[284]

This Article's conclusions about the patent-ineligibility and overbreadth of kinematic patent claims contribute to a broader debate about the kinds of inventive activity that fall within the patent system's ambit and the amounts of inventive progress that warrant the grant of exclusionary rights. In the robotics field, these questions have far-reaching consequences for the political economy of labor and downstream innovation.

This Article has highlighted the role of surgeons in the development of the surgical robotics industry and the patent landscape surrounding it, particularly in locations demarcated by the geometrically precise terms of kinematic claims. We have also seen how surgical practitioners put the "dexterity" in Applied Dexterity and its RAVEN manipulator, unencumbered by singularities. The company's patent application, however, would credit Hannaford and Rosen's group as inventors for applying that dexterity. Part IV's suggestion that the patentability of Applied Dexterity's claim 12 may rest on the kinesthetic expertise of surgeons leaves a tantalizing open question for inventorship doctrine in the age of robotics: whether one who contributes extraordinary human kinesthetic expertise necessary for the conception of an invention can and should be credited with co-inventorship.[285] Applied Dexterity was able to follow a proprietary approach in assembling a user community for the

283. *See* Graver Tank & Mfg. Co. v. Linde Aire Prods. Co., 339 U.S. 605, 608 (1950) (citation omitted) (recognizing applicability of the doctrine of equivalents to an accused device "if it performs substantially the same function in substantially the same way to obtain the same result" as the claimed invention).

284. The Supreme Court's patentable subject matter jurisprudence historically has been animated more by a requirement of invention in the application of otherwise unpatentable abstract ideas than by overbreadth and preemption concerns. *See* Katherine J. Strandburg, *Much Ado About Preemption*, 50 HOUS. L. REV. 563, 566, 582 (2012); Joshua D. Sarnoff, *Patent-Eligible Inventions After* Bilski*: History and Theory*, 63 HASTINGS L.J. 53, 59 (2011). Since any inventive features of a kinematic claim necessarily subsist in the movements of a mechanism without regard to the effects of those movements, such a claim would not reflect invention in the application of abstract kinematic properties.

285. *See* Burroughs Wellcome Co. v. Barr Labs., Inc., 40 F.3d 1223, 1228 (Fed. Cir. 1994) (citing Sewall v. Walters, 21 F.3d 411, 415 (Fed. Cir. 1994)) ("Conception is complete only when the idea is so clearly defined in the inventor's mind that only ordinary skill would be necessary to reduce the invention to practice, without extensive research or experimentation."); *see* Harris v. Clifford, 363 F.2d 922, 927 (C.C.P.A. 1966) (observing that one who merely provides a "pair of skilled hands" in reduction to practice has not contributed to conception).

RAVEN prototype from which it could refine its manipulator's kinematic properties, but as our colleague Liza Vertinsky has pointed out in this issue, such an approach to user innovation is not likely to be sustainable under patent law's existing inventorship doctrines.[286]

These questions in turn raise further questions at the interface between the patent system and labor economics. Can and should a worker who trains a robot to replicate her movements be recognized as a co-inventor of the trained robot? Does the answer depend on the worker's type or level of kinesthetic skill?[287] If so, should the resulting patent doctrines conform to established criteria in labor law and policy, such as those applicable to Fair Labor Standards Act exemptions? No longer limited to emulating and displacing blue-collar labor, robotic manipulators may be the next information technology to disrupt the political economy of the learned professions. While surgical robots might never fully replace human surgeons in the labor market,[288] the ongoing capture of data embodying kinesthetic surgical skill by the robotics industry is likely to raise novel legal issues. All of a surgeon's movements captured during a robot-assisted surgical procedure can be itemized, catalogued and evaluated, transforming standards of care.[289] Given the potential strategic value of kinesthetic data,[290] joint ventures and sponsorship agreements between manufacturers and academic medical centers

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286. *See* Liza Vertinsky, *Boundary-Spanning Collaboration and the Limits of Joint Inventorship Doctrine*, 55 HOUS. L. REV. 401, 432–36 (2017).

287. *See, e.g.*, Sean B. Seymore, *My Patent, Your Patent, Or Our Patent? Inventorship Disputes Within Academic Research Groups*, 16 ALB. L.J. SCI. & TECH. 125, 136 (2006) (citing ROGER E. SCHECHTER & JOHN R. THOMAS, PRINCIPLES OF PATENT LAW 235 (2004)) (explaining that inventorship analysis can be "tricky" and "highly fact specific").

288. *See, e.g.*, Michele Solis, *New Frontiers in Robotic Surgery*, 7 IEEE PULSE Nov./Dec. 2016, no. 6, at 55.(stating that "[c]urrent robots in the operating room are slaves to a surgeon master," but noting that automation "could free surgeons from tedious piecework such as suturing or tumor ablation"); Sarah Zhang, *Why an Autonomous Robot Won't Replace Your Surgeon Anytime Soon*, WIRED (May 4, 2016) https://www.wired.com/2016/05/robot-surgeon/ [https://perma.cc/LU8Z-FELC] ("[T]he robots are coming—they're just not coming for any doctors' jobs yet."); *but see* Thomas R. McLean, *Cybersurgery: Innovation or a Means to Close Community Hospitals and Displace Physicians?*, 20 J. MARSHALL J. COMPUTER & INFO. L. 495, 508–10 (2002) (arguing that widespread adoption of "automatic surgery" could occur whenever "society is ready to embrace the technology," resulting in the elimination of community hospitals, surgeons and physicians); Meghan Hamilton-Piercy, *Cybersurgery: Why the United States Should Embrace This Emerging Technology*, 7 J. HIGH TECH. L. 203, 218–20 (2007) (arguing that cybersurgery reduces the need for physicians and improves access to quality surgical services in the United States).

289. *See, e.g.*, Azhar Rafiq et al., *Objective Assessment of Training Surgical Skills Using Simulated Tissue Interface with Real-Time Feedback*, 65 J. SURG. ED. 270, 271–73 (2008) (describing software for evaluating suturing and knot-tying skills). *See generally* Carol E. Reiley et al., *Review of Methods for Objective Surgical Skill Evaluation*, 25 SURG. ENDOSC. 356 (2011) (surveying the literature).

290. *See supra* text accompanying notes 249–254 (describing the use of kinesthetic data in the optimization of RAVEN's manipulator).

will also be increasingly common, raising conflict-of-interest concerns.[291]

The practice of kinematic claiming is likely to be of growing concern to the surgical robotics industry, as well as the field of robotics in general. The expert kinesthetic training of a work robot, the optimization of a manipulator design, and even possibly the da Vinci robot vis-à-vis the Alisanos patent[292] are all examples of downstream innovation in robotics that might be foreclosed by kinematic claims. To paraphrase Michael Heller and Rebecca Eisenberg's classic commentary on the tragedy of the anticommons, defining property rights around kinematic properties is "unlikely to track socially useful bundles of property rights in future commercial products."[293] Concerns about a kinematic anticommons run parallel to long-running debates over the patenting of gene probes, and could likewise manifest themselves in decades of litigation as Applied Dexterity and other entrants compete against Intuitive in the marketplace and the courts. This Article has attempted to rectify these problems in advance to the extent possible, not by proposing any legal change, but by providing precise and stable criteria for identifying kinematically abstract claims under existing patent-eligibility doctrine.

291. *Cf.* Richard S. Saver, *Shadows Amid Sunshine: Regulating Financial Conflicts in Medical Research*, 145 CHEST 379, 380 (2014) (discussing ethical concerns relating to clinical trial sponsorship contracts between pharmaceutical companies and academic medical centers).

292. *See supra* note 95 and accompanying text.

293. *Cf.* Michael A. Heller & Rebecca S. Eisenberg, *Can Patents Deter Innovation? The Anticommons in Biomedical Research*, 280 SCI. 698, 699 (1998).