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Connect the Dots: Patents and Interdisciplinarity

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CONNECT THE DOTS: PATENTS AND INTERDISCIPLINARITY

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Abstract

This Article unravels a troubling paradox in the ecosystem of innovation. Interdisciplinarity is widely recognized as a source of valuable innovation and a trigger for technological breakthroughs. Yet, patent law, a principal legal tool for promoting innovation, fails to acknowledge it in an explicit, consistent manner. Moreover, although the scientific understanding of the significance of interdisciplinarity for innovation increasingly relies on big data analyses of patent databases, patent law practically ignores patent data as a source of information about interdisciplinary innovation. This Article argues that patent law should connect the dots—explicitly recognize interdisciplinarity as a positive indication when deciding whether an invention deserves patent protection and use information derived from patent databases to evaluate the interdisciplinarity of inventions. Relying on cutting edge research in economics and network-science, this Article explores nuanced manners for implementing these proposals, calling, ultimately, for the development of an algorithmic "recombination metric" that would allow courts and patent offices to identify interdisciplinary inventions in an accessible, standardized manner.

The adoption of this Article's proposals would align patent doctrine with its ultimate goal of promoting high-risk, socially valuable, innovation; inject an objective and measurable criterion into various patent doctrines famously criticized for their ambiguity and unpredictability; and allow patent law to realize some of the enormous potential of patent data—a treasure that current patent doctrine leaves untapped.

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Introduction

Albert Einstein wrote in 1945 that "combinatory play seems to be the essential feature in productive thought."[1] Decades later, Einstein's observation finds support in ample research concerning the relations between interdisciplinarity, recombination, and innovation. This literature demonstrates that interdisciplinary innovation that "connects the dots" between disparate fields is crucial for technological progress, increases the likelihood of radical breakthroughs, and holds potential solutions to some of the great technological challenges of our era.[2] Research further instructs that the essence of interdisciplinary innovation is "recombination"—

1. Letter from Albert Einstein to Jacques Hadamard (n.d.), *in* The Creative Process 32, 32 (Brewster Ghiselin ed.,1985) (Einstein wrote the letter in response to a query by the French mathematician Jacques Hadamard).

2. *See, e.g.*, Julie Thompson Klein, Interdisciplinarity: History, Theory, and Practice 12 (1990) (discussing the relationship between interdisciplinarity and developments "at the 'frontiers' of knowledge"); Andrew Barry et al., *Logics of Interdisciplinarity*, 37 Econ. & Soc'y 20, 40–41 (2008) (discussing the close links between interdisciplinarity and the logic of innovation); *see also infra* notes 42–44 and the accompanying text.

new combinations of pre-existing elements that were not previously combined.[3] Indeed, the history of science indicates that many revolutionary developments, from car technology to Edison's lighting system, resulted from their innovator's ability to "connect the dots" and combine previously disparate technologies.[4] The accumulating understanding of the interrelations between interdisciplinarity, recombinations and innovation is already exploited in various academic and real-world contexts, from evaluating the novelty of academic scholarship[5] to assessing grant proposals,[6] to directing corporate research and development activities.[7] More generally, facilitating interdisciplinarity has become a high policy priority.[8]

However, patent law fails to acknowledge the significance of interdisciplinarity for innovation in an explicit, deliberate, and consistent manner. The interdisciplinarity of an invention does not play a clear role in the decision whether to afford it patent protection. In the eyes of patent doctrine, combinations of preexisting technologies in an invention are viewed not as a virtue but at the most as an excusable flaw.[9] Moreover, in evaluating the *nonobviousness* of an invention (a principal condition for affording it patent protection), patent doctrine lacks any consistent way to separate obvious combinations from combinations which could be the embodiment of valuable interdisciplinarity.[10] And while in some cases patent doctrine (primarily, the "analogous art" doctrine) indirectly awards a certain advantage to inventions that draw from

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3. *See, e.g.*, ANDREW HARGADON, HOW BREAKTHROUGHS HAPPEN: THE SURPRISING TRUTHS ABOUT HOW COMPANIES INNOVATE 31 (2003) (explaining that innovation is a process of reassembling already existing ideas and technologies in novel ways); JOSEPH SCHUMPETER, BUSINESS CYCLES: A THEORETICAL, HISTORICAL, AND STATISTICAL ANALYSIS OF THE CAPITALIST PROCESS 88 (1939) ("[I]nnovation combines factors in a new way . . . ."); Lee Fleming & Olav Sorenson, *Science as a Map in Technological Search,* 25 STRATEGIC MGMT. J. 909, 910 (2004) (conceptualizing recombinations as the essence of innovation). These and additional sources are discussed in detail in Part I, *infra.*

4. For a discussion of these and other examples, see *infra* notes 27–31 and accompanying text.

5. *E.g.*, Brian Uzzi et al., *Atypical Combinations and Scientific Impact,* 342 SCI. 468, 471 (2013) (using a metric based on "recombinations" of citations to assess and rank the novelty of academic papers).

6. Kevin J. Boudreau et al., *The Novelty Paradox & Bias for Normal Science: Evidence from Randomized Medical Grant Proposal Evaluations* 3 (Harvard Bus. Sch., Working Paper, No. 13-053, 2012), http://dash.harvard.edu/handle/1/10001229 (measuring the novelty of grant proposals by using a metric based on unique combinations of keywords).

7. HARGADON, *supra* note 3, at 123–31 (demonstrating how insights about recombinations and "technology brokering" can direct entrepreneurship and manage innovation processes). This literature is discussed in more detail in Part III, *infra.*

8. *See, e.g.*, NAT'L ACADS., FACILITATING INTERDISCIPLINARY RESEARCH (2005).

9. *See* the discussion of "combination patents" in Part II-A, *infra.*

10. *See infra* Part II-A.

disparate fields of art, it does not possess a clear, theoretically robust concept of interdisciplinarity nor an objective criteria for applying these principles to practice.[11]

This general approach of patent law is ironic, given that cutting-edge insights about the significance of interdisciplinarity and recombinations for innovation generate, in fact, from big data analyses of patent databases.[12] A large body of research in economics, network science, and management science, clarifies that patent databases—beyond being formal registries of legal rights—are also a rich source of information about innovation.[13] The citation of earlier patents by following patents, the classification of patents into various technological subclasses by the Patent Office, and additional data routinely recorded in patent registries, provide ample information about innovative processes, about the relations between technological fields, and about the characteristics of particular inventions.[14]

Most importantly for our purpose, data about inventions' backward citations (*i.e.,* the earlier patents cited by newer inventions) and about the assignment of inventions into technological subclasses reflects the technological "building blocks" that comprise

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11. *See* discussion of the "analogous art" doctrine *infra* Part II-B.

12. I use the terms "big data" or "big data analyses" here in a broad sense, which refers to practices of mining datasets to extract value, insights, and predictions. For this meaning, along with various definitions of "big data," see, for example*,* Neil M. Richards & Jonathan H. King, *Big Data Ethics*, 49 Wake Forest L. Rev. 393, 394 (2014).

13. For several prominent examples, see Patents, Citations and Innovations (Adam B. Jaffe & Manuel Trajtenberg eds., 2003) (demonstrating the usefulness and the various uses of data about patent registration and patent citations as a tool for studying innovation); Peter Erdi et al. *Prediction of Emerging Technologies Based on Analysis of the U.S. Patent Citation Network*, 95 Scientometrics 225, 226 (2013) (observing that "[p]atent data long has been recognized as a rich and potentially fruitful source of information about innovation and technological change"); Hyejin Youn et al., *Invention as a Combinatorial Process: Evidence from US Patents*, J. Royal Soc'y, May 6, 2015, ("[I]nventions . . . that are patented, leave behind a documentary trail, enabling us to study the invention processes in a systemic way. . . . [Patents are] footprints of invention . . . ."). For research illustrating specific uses of patent data to study innovation, see Lee Fleming, *Recombinant Uncertainty in Technological Search*, 47 Mgmt. Sci. 117 (2001) (using patent subclasses as proxies for the technological building blocks of inventions); Manuel Trajtenberg, *A Penny for Your Quotes: Patent Citations and the Value of Innovation* 21 RAND J. Econ. 172 (1990) (using patent citations as an index of the importance or value of patents). Evolving legal scholarship from the recent decade has also begun to recognize the potential significance of patent data for legal analysis in the field of innovation. Pioneering, though certainly non-exhaustive, works in this strand are John R. Allison et al., *Valuable Patents,* 92 Geo. L. J. 435 (2004) (using patent data to study the attributes of valuable patents) and Katherine J. Strandburg et al., *Law and the Science of Networks: An Overview and an Application to the "Patent Explosion"* 21 Berkeley Tech. L.J. 1293 (2006) (explaining why network analyses of patent data should be of interest to legal scholars).

14. *See* sources cited *supra* note 13; *see also* discussion *infra* Part III-A.

inventions.[15] This data is recorded as a matter of course with respect to each and every patent application and can indicate whether the invention connects previously unconnected dots by combining building blocks which were not previously combined, or conversely, whether it is comprised of technological building blocks that are routinely combined.[16] In other words, patent data contains information about recombinations that can provide a proxy for inventions' level of interdisciplinarity. Some of the studies in this vein further indicate that new recombinations in the technological subclasses, or in the backward citations of an invention, may constitute a proxy for breakthrough inventions,[17] thus, reinforcing the theoretical insights regarding the value of transcending disciplinary boundaries.

Against this background, it is indeed puzzling that patent law—the primary legal branch conferred with the task of promoting innovation—fails to embed interdisciplinarity in a clear, predictable manner, and completely ignores patent data as a possible means for identifying inventions that bridge distant fields of knowledge.

This Article argues that patent law cannot remain oblivious to the tight links between interdisciplinarity, recombinations, and innovation. In order to align patent doctrine with the realities of innovation, patent law, too, should connect the dots: recognize interdisciplinarity as a positive indication for an invention's nonobviousness, and use information about recombinations, derived from patent data, to evaluate an invention's interdisciplinarity.

In furtherance of these proposals, this Article takes a close look at prominent traits of interdisciplinary innovation, particularly its dynamic dimension and its "high-risk, high-gain" nature. It then explores in detail the use of patent data to identify interdisciplinary inventions. The analysis demonstrates that a metric based on recombinations in inventions' backward citations and subclasses captures the traits of interdisciplinarity and that such a metric

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15. *See, e.g.*, Fleming, *supra* note 13, at 123 (explaining that patents subclasses can serve as proxies for inventions' technological building blocks); Manuel Trajtenberg et al., *University Versus Corporate Patents: A Window on the Basicness of Invention*, *in* PATENTS, CITATIONS AND INNOVATIONS 51, 56 (Adam B. Jaffe & Manuel Trajtenberg eds., 2003) (explaining that backward citations are proxies for the "antecedents" of a patent). I discuss this literature in detail in Part III *infra*.

16. *See* sources cited *supra* note 15.

17. *See, e.g.*, Sam Arts & Reinhilde Veugelers, *Technology Familiarity, Recombinant Novelty, and Breakthrough Inventions*, 24 INDUS. & CORP. CHANGE 1215 (2014); Kristina B. Dahlin & Dean M. Behrens, *When Is an Invention Really Radical?: Defining and Measuring Technological Radicalness*, 34 RES. POL'Y 717 (2005); Fleming, *supra* note 13. This literature is discussed in detail in Part III-A, *infra*.

could serve as a tool for identifying interdisciplinary inventions *ex ante*.

The Article then proceeds to explore nuanced manners for incorporating these insights in patent doctrine. Ultimately, it suggests that patent law explicitly recognize interdisciplinarity as a positive factor in the nonobviousness analysis. It further proposes to develop an algorithmic "recombination metric" which would allow examiners, courts, and patentees to assess the interdisciplinarity of inventions in an accessible, standardized manner. It further sketches, in broad strokes, prominent features of such a recombination metric and proceeds to discuss some of its limitations.

Interdisciplinarity has so far received only limited attention in intellectual property scholarship. Several studies have importantly highlighted its value for innovation and suggested that patent law should facilitate it.[18] Yet, the role of recombinations in this respect is insufficiently explored,[19] and the questions of how to incorporate interdisciplinarity into patent policy and how to evaluate it in a relevant, consistent manner remain largely unanswered. This Article attempts to fill in this gap: it offers a focused exploration of interdisciplinary innovation and suggests a new and measurable way for patent law to identify interdisciplinary inventions, using existing tools developed outside the legal field. In a self-referential manner, then, one of this Article's primary contributions may be "connecting the dots."

Adopting this Article's proposals holds numerous potential advantages. Primarily, recognizing interdisciplinarity as a factor in the

18. *See, e.g.*, Peter Lee, *Social Innovation*, 92 Wash. U. L. Rev. 1, 67 (2014) (discussing policy measures beyond intellectual property law to foster interdisciplinary innovation); Laura Pedraza-Fariña, *Patents and the Sociology of Innovation*, 2013 Wis. L. Rev. 813, 867 (2013) [hereinafter Pedraza-Fariña, *Patents*] (arguing that interdisciplinarity should be taken into account as part of patent law's nonobviousness inquiry); Brenda Simon, *The Implications of Technological Advancement for Obviousness,* 19 Mich. Telecomm. & Tech. L. Rev. 331, 351–61 (2013) (arguing that patent nonobviousness doctrine should be adapted to facilitate interdisciplinary collaboration); Saurabh Vishnubhakat & Arti K. Rai, *When Biopharma Meets Software: Bioinformatics at the Patent Office,* 29 Harv. J.L. & Tech. 206 (2015) (presenting empirical evidence that patent applications in the interdisciplinary field of bioinformatics are of better quality relative to patent applications in the field of software, and discussing normative implications for the examination of interdisciplinary patent applications); *see also* the discussion *infra* Part I-B(2).

19. Prominent exceptions are John Dubiansky, *The Role of Patents in Fostering Open Innovation*, Va. J.L. & Tech., Fall 2006, at 12–15 (analyzing the role of contemporary patent doctrine in supporting open innovation, in light of theories of "recombinant innovation") and Vishnubhakat & Rai, *supra* note 18, at 238–39 (discussing "the combinatorial process of invention"). I myself have suggested elsewhere that recombinations could identify paradigm-shifting innovation. Michal Shur-Ofry, *Non-Linear Innovation,* 61 McGill L.J. 563, 599–604 (2016). While the present analysis develops and elaborates this idea, this Article's focus is on interdisciplinary innovation, not on paradigm shifts.

patentability analysis would better align patent law with the aim of promoting risky and socially valuable innovation. In addition, embedding the notion of recombinations into patent law in the manner proposed herein would introduce a concrete and measurable criterion into the nonobviousness doctrine, famously criticized for its uncertainty and inconsistency. Altogether, then, this Article could also contribute to the effort to improve patent quality, an issue that has been at the focus of attention of both scholars and the Patent Office in recent years.[20] Lastly, and more generally, implementing the scheme proposed in this Article would resolve the existing paradox in our innovation system and would allow *patent law* to realize some of the enormous potential of *patent data*—a cluster of valuable information which the current legal regime leaves untapped.

The discussion proceeds as follows: Part I describes the inter-relations between interdisciplinarity, recombinations, and innovation. Part II turns to examine patent doctrine's ambivalence toward interdisciplinary inventions, concentrating on two doctrinal issues: the treatment of combination inventions and the analogous art doctrine. Part III lays out the proposal to explicitly recognize interdisciplinarity as a factor in the patentability analysis and to use patent data about recombinations as a proxy for an invention's interdisciplinarity. It then proceeds to discuss specific manners in which these proposals could be implemented, concentrating on the introduction of an algorithmic metric. Part IV addresses several potential objections to these proposals, prominently that analyses derived from patent data may be subject to "noise" or manipulation and that innovation is not always interdisciplinary. The final Part concludes that adopting this Article's proposals would improve patent law as a tool for promoting valuable innovation.

20. For a few non-exhaustive illustrations of literature addressing the need to improve patent quality and examining various manners for achieving this goal, see Arti K. Rai, *Improving (Software) Patent Quality Through the Administrative Process*, 51 HOUS. L. REV. 503 (2013); Stephen Yelderman, *Improving Patent Quality with Applicant Incentives*, 28 HARV. J.L. & TECH. 77 (2014); Colleen V. Chien, *Comparative Patent Quality* (Santa Clara Univ. Legal Studies, Research Paper No. 0216, 2016), https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2833980; see also VALENCIA M. WALLACE, DEPUTY COMM'R FOR PATENT QUALITY, USPTO, ENHANCED PATENT QUALITY INITIATIVE (2016), https://www.uspto.gov/sites/default/files/documents/2_3_2016%20PPAC%20Public%20Presentation%20%5BRead-Only%5D.pdf.

I. Interdisciplinarity, Recombinations, and Innovation

A. *"Novelty in Itself"*

The recognition that valuable innovation often involves connecting disparate fields has been growing throughout the past century. This understanding is itself a combined product of insights from a range of scholarly disciplines. For example, economist Joseph Schumpeter observed decades ago that combining components in a new way is the ultimate source of innovation.[21] Research in psychology has long considered linking elements into new combinations as a defining feature of the creative process.[22] Recent scholarship in the field of management science maintains that novelty emerges from "brokering" and synthesizing ideas and technologies from different industries.[23] Scholars engaged in the history of innovation similarly highlight that valuable technological innovation often emerges from the combination of previously existing—but unconnected—knowledge.[24] This literature indicates that recombining existing, but previously disparate, technologies can create a revolutionary change, "a whole that is greater by far than the sum of its parts."[25] All in all, recombination of existing, but disparate, elements is the essence of the link between interdisciplinarity and innovation, and the notion that such recombination is central for valuable innovation has become common ground in innovation theory.[26]

The automobile is one paradigmatic illustration. The development of car technology involved the recombination of various pre-

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21. Schumpeter, *supra* note 3, at 88.

22. Sarnoff A. Mednick, *The Associative Basis of the Creative Process*, 69 Psychol. Rev. 220, 221 (1962) (defining creative thinking as "the forming of associative elements into new combinations"); *cf.* Amy L. Landers, *Ordinary Creativity in Patent Law: The Artist Within the Scientist*, 75 Mo. L. Rev. 1, 60 (2010) (highlighting the importance of remote sources for creativity).

23. *See, e.g.*, Hargadon, *supra* note 3, at 26 (maintaining that revolutionary innovation emerges from "seeing the same elements of a technology but recognizing different connections . . . between them"); Andrew Hargadon & Robert I. Sutton, *Technology Brokering and Innovation in a Product Development Firm,* 42 Admin. Sci. Q. 716 (1997).

24. Abbott Payson Usher, A History of Mechanical Innovation 66 (Dover Publ'ns rev. ed. 1982) (1929) (describing novelty and invention as emerging out of the synthesis of familiar items).

25. Hargadon, *supra* note 3, at 51.

26. Uzzi et al., *supra* note 5, at 471 ("[C]ombinations of existing material are centerpieces in theories of creativity, whether in the arts, the sciences, or commercial innovation. . . . ."); *cf.* Dubiansky, *supra* note 19, at 12 (describing innovation as a process of creating new ideas through the combination of existing knowledge and ideas).

existing technologies, including the combustion engine, the bicycle, and the carriage.[27] These technologies might not seem so distant to contemporary readers, but when cars were first developed they were largely unrelated.[28] Edison's lighting system is another famous example. In developing his electrification scheme, Edison bridged many "small worlds" of his time,[29] drawing analogies between various technological fields, such as illuminating gas and electric energy.[30] These technologies were, at the time, so disparate that many of Edison's contemporaries regarded him as "either a fool in pursuit of the impossible or a fraud."[31] More recently, the combination of telephony, computing, and visual display technologies led to the development of devices that preceded today's smartphones.[32]

Some of the virtues which interdisciplinarity holds for innovation are intuitively apparent. Transcending disciplinary boundaries allows to surpass limitations set by the paradigms and methodologies of a single discipline, enables potential innovators to identify common problems and to import methodologies from one field to solve challenges in another, and accelerates the emergence of new insights.[33]

Yet, importantly for our discussion, the synthesis of ideas and technologies from disparate disciplines does not merely provide specific technological solutions. It can also introduce new contexts as well as new frameworks for innovation.[34] This, in turn, implies

27. GEORGE BASALLA, THE EVOLUTION OF TECHNOLOGY 57 (1988); Lee Fleming & Olav Sorenson, *Technology as a Complex Adaptive System: Evidence from Patent Data,* 30 RES. POL'Y 1019, 1020 (2001).

28. Carolina Castaladi et al., *Related Variety, Unrelated Variety and Technological Breakthroughs: An Analysis of US State-Level Patenting,* 49 REGIONAL STUD. 767, 777 (2015); *see also* BASALLA, *supra* note 27, at 57–59.

29. HARGADON, *supra* note 3, at 134 (describing Edison and his organization as a paradigmatic example for bridging small worlds).

30. BASALLA, *supra* note 27, at 47–49; HARGADON, *supra* note 3, at 24 (explaining that Edison's system of electric light "combined elements of the telegraph, the arc light, and even the existing gas lighting industry"); Martin L. Weitzman, *Recombinant Growth,* 113 Q.J. ECON. 331, 334 (1998) (describing Edison's idea of a complete lighting system as combining the idea of an electric candle with the established idea of a gas distribution system).

31. BASALLA, *supra* note 27, at 49.

32. Castaladi et.al, *supra* note 28, at 769 (referring to the elements combined by smartphone technology).

33. KLEIN, *supra,* note 2, at 104–07.

34. MICHAEL GIBBONS ET AL., THE NEW PRODUCTION OF KNOWLEDGE 5 (1994) (explaining that a particular transdisciplinary solution can become "a cognitive site from which further advances can be made"); HARGADON, *supra* note 3 at 27 (maintaining that those who connect between different worlds "[think] differently about the people, the idea, and the objects they see"); Barry et al., *supra* note 2, at 26 (maintaining that interdisciplinary research may lead to

that interdisciplinary endeavors may sometimes yield breakthroughs that open up new fields and form platforms for many additional technologies and inventions.[35] For example, insights that engineering can mimic structures and materials from living organisms led to recombinations of elements from the fields of biology, engineering, and design.[36] The new connections formed between these fields opened the way to innumerous technologies, from the design of "smart" fabrics,[37] through self-cleaning surfaces,[38] to silent trains[39]—and led to the emergence of a new field now known as biomimetics.[40] Connecting previously unconnected dots, then, is described as "novelty in itself"[41] and constitutes an important tenet of any innovation ecosystem.

In light of these apparent virtues, interdisciplinarity has become a pervasive form of knowledge production.[42] Many scholars believe that interdisciplinarity carries the potential of bringing science and technology closer to real societal needs and holds the key to many

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forms of novelty); Castaladi et al., *supra* note 28, at 768–69 (observing that connecting previously unrelated technologies can lead to whole new functionalities and applications, and span new technological trajectories).

35. Castaladi et al., *supra* note 28, at 768–69 (observing that breakthroughs and radical innovations often stem from previously unrelated technologies from disparate fields of knowledge); *see also* sources cited *infra* Part III (empirically supporting the connection between breakthroughs and recombinations).

36. *See* Julian F.V. Vincent et al., *Biomimetics: Its Practice and Theory*, 3 J. ROYAL SOC'Y INTERFACE 471 (2006) (describing Biomimentics as the transfer of ideas from biology to technology).

37. *See* Thomas Stegmaier et al., *Bionics in Textiles: Flexible and Translucent Thermal Insulations for Solar Thermal Applications*, 367 PHIL. TRANSACTIONS ROYAL SOC'Y 1749 (2009) (describing the development of clothes with translucent thermal insulation, based on insights from the fur of polar bears).

38. *E.g.*, Y.T. Cheng et al., *Effects of Micro and Nano-Structures on the Self-Cleaning Behavior of Lotus Leaves*, 17 NANOTECHNOLOGY 1359 (2006) (describing how the structure and qualities of lotus leaves can be used to design self-cleaning surfaces).

39. Pallavi K. Bhure et al., *Applications to Fast and Fuel Efficient Transportation*, 4 TECHTALK@KPITCUMMINS, Oct.–Dec. 2011, at 31, 32, http://www.kpit.com/resources/downloads/tech-talk/tech-talk-october-december-2011.pdf (describing a train engineered to imitate owl's feathers, in order to decrease noise).

40. *See* Vincent et al., *supra* note 36.

41. Castaladi et al., *supra* note 28, at 769 ("The recombination is a novelty in itself . . . ."); *see also* HARGADON, *supra* note 3, at 76 (maintaining that bridging distant worlds is "critical" in the innovation process); Dubiansky, supra note 19, at 30 ("Novelty is expressed through the act of recombination itself.").

42. Veronica Boix-Mansilla, *Assessing Expert Interdisciplinary Work at the Frontier: An Empirical Exploration,* 15 RES. EVALUATION 17, 17 (2006) (explaining that interdisciplinarity research is today a vital form of knowledge production).

of the grand challenges facing humanity, from fighting serious diseases, to mitigating climate change.[43] Thus, a major study by the United States National Academies declares:

> [A]s a mode of discovery and education, [interdisciplinary research] has delivered much already and promises more—a sustainable environment, healthier and more prosperous lives, new discoveries and technologies to inspire young minds, and a deeper understanding of our place in space and time.[44]

Against these insights, and given patent law's explicit mission of promoting innovation,[45] the importance of patent law's stance toward interdisciplinarity and recombinations becomes apparent. Before exploring this question, the next paragraphs take a close look at two prominent attributes of interdisciplinary innovation, which are relevant for the inquiry that follows.

B. *Traits of Interdisciplinary Innovation*

1. Distance and Dynamism

The examples of Edison's lighting system and the development of car technology[46] reveal an important trait of interdisciplinarity: disciplines are not static. Rather, the distance between domains, technological fields, and technological components varies over time. Technologies and fields which were once disparate—such as the carriage, the bicycle, and the engine in the beginning of the twentieth century—can become closer as more and more links are

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43. GIBBONS ET AL., *supra* note 34, at 54 (describing transdisciplinarity as "Mode 2" science, which is shaped by and correlates to social needs); John G. Bruhn, *Beyond Discipline: Creating a Culture for Interdisciplinary Research* 30 INTEGRATIVE PHYSIOLOGICAL & BEHAV. SCI. 331, 335 (1995) (maintaining that collaboration among various disciplines is required in order to tackle social questions such as genetic research, AIDS, pollution, aging, or cancer); Salim S. Abdool Karim, *Stigma Impedes AIDS Prevention* 474 NATURE 29, 31 (2011) (arguing that solutions to the AIDS epidemic in Africa must involve interdisciplinary collaboration between the biomedical and behavioral sciences); Alfredo Yergos-Yergos et al., *Does Interdisciplinary Research Lead to Higher Citation Impact? The Different Effect of Proximal and Distal Interdisciplinarity*, 10 PLoS ONE e0135095 (2015), http://journals.plos.org/plosone/Article?id=10.1371/journal.pone.0135095 (explaining that the logic of interdisciplinarity is particularly convincing with respect to "grand societal issues or challenges, such as climate change, . . .").

44. NAT'L ACADS., *supra* note 8, at 1.

45. *See* U.S. CONST. art. I, § 8, cl. 8. (empowering Congress to "promote the Progress of Science and useful Arts, by securing for limited Times to Authors and Inventors the exclusive Right to their respective Writings and Discoveries").

46. *See supra* notes 27–31 and accompanying text.

formed between them (in our example, due to the introduction and success of the first automobiles).[47] As links among fields become more common the distance between them narrows, and at times they may even converge to form new fields of science.

Nanotechnology is perhaps the most prominent example from recent years. Several decades ago, it was probably unheard of to combine biology, physics, pharmacology, medicine, computer science, and mechanical engineering in a single technology. Yet nowadays these fields are frequently linked as part of nanotechnology, often referred to as a case of "mega-interdisciplinarity."[48] Likewise, components such as sand and aluminum were disparate from the field of electric engineering during the 1940s, yet nowadays these materials are an integral part of hardware engineering, routinely combined in the semiconductor industry.[49]

In other words, what was once a unique and innovative combination between remote technologies, materials, or disciplines, may become routine with the lapse of time. As far as innovation is concerned, then, not all combinations are alike: the dynamic nature of interdisciplinarity must be taken into account when attempting to recognize those combinations that link together distant technological building blocks. This dynamic trait is highly relevant for any patent regime seeking to promote interdisciplinarity, and I return to it later.[50]

2. "High-Risk, High-Gain"

A second feature of interdisciplinarity that is relevant for our discussion is its "high-risk, high-gain" nature. Despite its enormous potential to benefit innovation and produce radical improvements

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47. *See, e.g.*, Castaladi et al., *supra* note 28, at 768–69 (explaining that because breakthroughs serve as platforms for subsequent innovation, initially unrelated technologies which underlie breakthrough innovations "become more related over time"); Erdi et al., *supra* note 13, at 231–32 (discussing the possible merging of technological fields); Fleming, *supra* note 13, at 119–21; Gergely Palla et al., *Quantifying Social Group Evolution*, 446 NATURE 664 (2007) (introducing the concept of the previously separate communities merging or splitting over time).

48. Dana Nicolau, *Challenges and Opportunities for Nanotechnology Policies: An Australian Perspective,* 1 NANOTECHNOLOGY L. & BUS. 446, 451 (2004) (explaining that "at the nanolevel the differences between very different disciplines, such as mechanics and chemistry, begin to blur to a large extent"); *see also* Jacob S. Sherkow, *Negativing Invention*, 2011 BYU L. REV. 1091, 1116 (2011) (describing how nanotechnology combines technologies "previously thought to be wholly separate from one another").

49. *See* Fleming, *supra* note 13, at 118–19.

50. *See infra* notes 120–28, 157–64, and accompanying text.

(as discussed earlier in this Part), interdisciplinary innovation is not free from risks and obstacles. In fact, the opposite is true: connecting previously disparate fields is generally more difficult and involves a higher likelihood of failure in comparison to innovation which is more "local" or confined to a single discipline.[51]

Literature offers various explanations for this "high-risk" attribute. These include scientists' difficulty to master more than one discipline, obstacles of communication among different disciplines due to lack of common language or cultural discrepancies,[52] and organizational barriers stemming from the institutional structure of science in disciplinary domains.[53] Thus, innovators who transcend disciplinary boundaries are more likely to encounter suspicion and resistance on behalf of those more embedded in a disciplinary approach.[54] Scientific boundaries are also reflected in scientific journals and academic funding schemes. Journals may encourage researchers to write to a specific audience and discourage crossing disciplinary boundaries, while traditional funding sources, too, are frequently organized in a disciplinary manner.[55] A prominent example for these structural barriers concerns the efforts to fight the spread of AIDS. Researchers maintain that a major obstacle in this endeavor is the difficulty to bridge the gap between anthropology and biomedical sciences, due to the hierarchical organization of science and the still-sharp division between the medical and

51. *See, e.g.*, Castaladi et al., *supra* note 28, at 770 (innovation which combines previously unrelated domains is more likely to fail, yet if successful, it also has greater chances to be of radical nature); Fleming, *supra* note 13, at 130–31 (combining elements that have rarely been used together often fails); Fleming & Sorenson, *Technology as a Complex Adaptive System, supra*, note 27, at 1036 (new recombinations might produce useful radical innovations but also involve a high degree of uncertainty); Uzzi et al., *supra* note 5, at 468 ("[T]he production and consumption of boundary-spanning ideas . . . raise[s] well-known challenges. . . . .").

52. *See, e.g.*, Jack M. Balkin, *Interdisciplinarity as Colonization,* 53 WASH & LEE L. REV. 949, 956–57 (1996) (discussing the "different cultural software" installed in members of different disciplines); Bruhn, *supra* note 43, at 339–40 (discussing the difficulties of researchers to accommodate the differences in the way disciplines approach research); Leigh Price, *Critical Realist versus Mainstream Interdisciplinarity* 13 J. CRITICAL REALISM 52, 64 (2014) (discussing the possible incommensurability of research approaches).

53. *See* NAT'L ACADS., *supra* note 8; Yergos-Yergos et al., *supra* note 43, at 4 (explaining that the disciplinary structure of science puts interdisciplinarity at a disadvantage and makes it difficult to appreciate the value of interdisciplinary research).

54. Balkin, *supra* note 52, at 956 (maintaining that a scholar interfering with the disciplinary mechanism "is likely to be attacked as surely as one who tries to disturb the eggs in a mother eagle's nest"); Pedraza-Fariña, *Patents, supra* note 18, at 843–47 (discussing "[r]esistance to outsider approaches" due to the specialization-oriented structure of science).

55. Bruhn, *supra* note 43, at 331 ("[M]ost . . . journals discourage papers that cross disciplinary boundaries . . . [and] "interdisciplinary research is . . . out-of-synchronization with traditional funding sources."); *cf.* Christopher S. Yoo, *Toward a Closer Integration of Law and Computer Science,* 57 COMM. ACM 33, 35 (2014) (observing that "innovative interdisciplinary research needs conferences, journals, and other similar institutions . . . .").

behavioral fields.[56] More generally, the potential of interdisciplinary innovation for achieving significant breakthroughs goes hand in hand with higher uncertainty, greater chances to encounter objection, and substantial likelihood of failure.

Patent scholarship has long recognized that patent law's set of incentives is particularly needed with respect to socially desirable innovations that are also "high-risk": simply put, in the absence of the incentives provided by patents, the high levels of uncertainty surrounding risky innovation might discourage innovators from pursuing such projects in the first place.[57] Therefore, one could expect that patent law would readily embrace interdisciplinary innovation, due to its "high-risk, high-gain" nature. Indeed, several scholars have recently stressed the significance of interdisciplinary innovation, and suggested that patent law facilitate interdisciplinary collaborations, and consider the interdisciplinary nature of inventions as part of the nonobviousness analysis.[58] Yet, the question whether and how these insights could translate into doctrinal tools remains largely unanswered. A quick look at patent law, to which we now turn, reveals that patent doctrine does not reflect the accumulating understanding of the significance of interdisciplinarity for innovation in a clear manner. At best, patent law's attitude toward

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56. Abdool Karim, *supra* note 43, at 31 (explaining that fighting AIDS requires the combination of medical technology with methods for generating change in individual behavior, and observing: "[The obstacle] emanates not only from our failure, as researchers, funders and clinicians, to fully appreciate that every biomedical prevention strategy includes a behavioral change but also from counterproductive hierarchies and territorialism within science.").

57. *See, e.g.*, Michael Abramowicz & John F. Duffy, *The Inducement Standard of Patentability*, 120 Yale L.J. 1590 (2011) (arguing that patents should be awarded to inventions, which, absent the patent would not have been made); Pedraza-Fariña, *Patents*, *supra* note 18, at 832 (arguing that patent law should take into account social factors that influence the levels of risks which innovators face); Robert P. Merges, *Uncertainty and the Standard of Patentability*, 7 High Tech. L.J. 1, 2 (1992) (maintaining that patent law's nonobviousness threshold seeks to reward inventions "that . . . prospectively, have a low probability of success"); Michael J. Meurer & Katherine Strandburg, *Patent Carrots and Sticks: A Model of Nonobviousness,* 12 Lewis & Clark L. Rev. 547, 573 (2008) (patent law's nonobviousness threshold should "prod potential inventors toward more difficult, socially preferable research projects").

58. *See* Pedraza-Fariña, *Patents*, *supra* note 18, at 861–67 (maintaining that interdisciplinarity should be taken into account as part of patent law's nonobviousness inquiry); Simon, *supra* note 18, at 351–54 (2013) (arguing that patent law's nonobviousness doctrine should facilitate interdisciplinary collaboration); Vishnubhakat & Rai, *supra* note 18 (comparing the quality of interdisciplinary bioinformatics patents to that of software patents, and discussing normative implications for the examination of interdisciplinary patents); *cf.* Dubiansky, *supra* note 19, at 30 (maintaining that patent law "is not blind to the recombinant nature of the innovation process").

interdisciplinarity can be described as ambiguous and inconsistent.[59]

II. INTERDISCIPLINARITY AND PATENT DOCTRINE

Does patent law consider interdisciplinarity in the decision whether to afford or deny patent protection? Two related aspects of patent law are particularly relevant for our discussion. The first is patent law's treatment of "combinations patents," namely inventions that are comprised of pre-existing elements. The second is the doctrine of "analogous art."

Both aspects concern the threshold for obtaining patent protection and, more specifically, the nonobviousness requirement. Nonobviousness implies that the difference between the invention at stake and the previous state of the art ("prior art" in patent parlance) has to be sufficient, so that the invention would not have been obvious "to a person having ordinary skill in the art to which the claimed invention pertains."[60] In other words, the invention has to represent a technical advance that is not merely a trivial step forward in the state of the art.[61] The nonobviousness requirement is considered the "ultimate condition for patentability."[62] Yet, the question whether the difference between a particular invention and the prior art is sufficient in order to render an invention nonobvious is most difficult to determine.[63]

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59. To clarify, this Article's focus on patent law as a principal legal vehicle for promoting interdisciplinary innovation does not imply that patent law is the *sole* means for advancing interdisciplinarity. The discussion in this section indicates that various measures "beyond IP" obviously play an important role in furthering this goal, for example, the removal of institutional barriers to facilitate collaborations between academic disciplines, the calibration of grants and prizes' schemes to support interdisciplinarity, and more. *See, e.g.*, Laura G. Pedraza-Fariña, *Constructing Interdisciplinary Collaboration: The Oncofertility Consortium as an Emerging Knowledge Commons, in* GOVERNING MEDICAL KNOWLEDGE COMMONS 259 (Katherine Strandburg et al. eds., 2017) (exploring features that facilitate interdisciplinary collaboration by analyzing the case study of the NIH-funded Oncofertility Consortium).

60. 35 U.S.C. § 103 (2012) ("A patent . . . may not be obtained . . . if the *differences* between the claimed invention and the prior art are such that the claimed invention as a whole would have been obvious before the effective filing date of the claimed invention to a person having ordinary skill in the art to which the claimed invention pertains.") (emphasis added).

61. *See, e.g.*, Alan L. Durham, Patent Law Essentials 4–5, 96–97 (1999).

62. Christopher A. Cotropia, *Predictability and Nonobviousness in Patent Law After KSR*, 20 MICH. TELECOMM. & TECH. L. REV. 391, 395 (2014).

63. *See, e.g.*, Gregory N. Mandel, *The Non-Obvious Problem: How the Indeterminate Non-Obvious Standard Produces Excessive Patent Grants*, 42 U.C. DAVIS L. REV. 57, 89 (2008) ("[T]he nonobviousness standard is substantially indeterminate . . . ."); Simon, *supra* note 18, at 337 ("Assessing whether an invention is obvious is . . . particularly challenging . . . .").

A. *Combination Inventions*

The difficulty of determining nonobviousness is especially pronounced with respect to inventions comprised of pre-existing elements known from previous technologies, often referred to as "combination inventions" or "combination patents." The doctrinal treatment of combinations under patent law is particularly relevant for our purposes since, as the foregoing discussion indicates, new combination of elements from disparate fields of arts is the essence of interdisciplinary innovation.[64] However, a quick look at patent doctrine reveals that its attitude toward combination inventions is hesitant and ambiguous.

In fact, although patent law has been struggling for decades to distinguish new combinations that are obvious and un-patentable from those that are nonovbvious and hence patentable, its position is still far from clear. While some courts expressly recognize that the very act of combining pre-existing materials may be the embodiment of valuable innovation,[65] others tend to describe combination inventions as "mere aggregations" and are skeptical as to the whether an invention which "simply arranges old elements"[66] where "every element . . . was known to prior art"[67] can actually qualify for patent protection.

Although combination inventions reached the Supreme Court in *KSR International Co. v. Teleflex Inc.*,[68] that decision did not provide any clear guidance on this issue. In fact, the *KSR* decision clearly reflects the tension inherent in patent doctrine when approaching combinations. On the one hand, the court expressed intuitive skepticism toward combination inventions,[69] while on the other hand, it

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64. *See supra* Part I.

65. For a famous example, see the words of Justice Hand in *B.G. Corp. v. Walter Kidde & Co.*, 79 F.2d 20, 22 (2d Cir. 1935):

> All machines are made up of the same elements; rods, pawls, pitmans, journals, toggles, gears, cams, and the like, all acting their parts as they always do and always must. All compositions are made of the same substances, retaining their fixed chemical properties. But the elements are capable of an infinity of permutations, and the selection of that group which proves serviceable to a given need may require a high degree of originality. It is that act of selection which is the invention . . . .

Id. For another example, see Nickola v. Peterson, 580 F.2d 898, 912 n.22 (6th Cir. 1978) ("Unable to create from nothing, man must use old elements, which must perform their normal individual functions.").

66. Sakraida v. AG Pro, Inc., 425 U.S. 273, 282 (1976).

67. Great Atl. & Pac. Tea Co. v. Supermarket Equip. Corp., 340 U.S. 147, 149 (1950).

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

69. Id. at 418 ("[C]ommon sense directs one to look with care at a patent application that claims as innovation the combination of two known devices according to their established functions . . . .").

acknowledged that most innovation consists of combinations of existing building blocks.[70] While the *KSR* court emphasized that the distinction between obvious and nonobvious combinations rests on the *difference* between the prior art and the invention, as instructed by the Patent Act,[71] the court refrained from introducing any formal or objective standard for evaluating that difference.[72] The decision rejected the previous TSM ("teaching, suggestion, or motivation") test, introduced by the Federal Circuit, which examined whether the prior art disclosed some teaching, suggestion, or motivation to combine the elements comprising the invention (a positive answer implies obviousness).[73] Instead, the *KSR* court warranted an "expansive and flexible" approach to nonobviousness determination.[74] In the absence of any clear criterion for discerning obvious combinations from nonobvious ones, the weight that should be attached to interdisciplinarity in this analysis remains unclear.

More broadly, the rich evidence about the significance of interdisciplinarity and recombinations for innovation does not resonate in patent law's approach to combination inventions. The doctrine neither explicitly acknowledges that certain combinations may be the ultimate mark of groundbreaking innovation nor suggests any clear criterion to distinguish those potential breakthroughs from other, more trivial combinations that do not deserve patent protection. Despite occasional statements that all innovation results from combinations of previous building blocks, the

70. *Id.* at 418–19 ("[I]nventions in most, if not all, instances rely upon building blocks long since uncovered, and claimed discoveries almost of necessity will be combinations of what, in some sense, is already known.").

71. *Id.* at 406 ("Section 103(a) forbids issuance of a patent when 'the differences between the subject matter sought to be patented and the prior art are such that the subject matter as a whole would have been obvious at the time the invention was made to a person having ordinary skill in the art to which said subject matter pertains.'"); *see also* Cotropia, *supra* note 62, at 402 (explaining that the nonobviousness inquiry focuses on determining whether the gap between the prior art and the invention is large enough for the invention to warrant patent protection).

72. *See, e.g.*, Daralyn J. Durie & Mark A. Lemley, *A Realistic Approach to the Obviousness of Inventions*, 50 WM. & MARY L. REV. 989, 999 (2008) ("KSR is a bit of a Rorschach test, offering language that can be twisted to support virtually any view of obviousness law.").

73. *See* Rebecca S. Eisenberg, *Pharma's Nonobvious Problem,* 12 LEWIS & CLARK L. REV 375, 390 (2008) (noting that the Supreme Court "turned just about every move that the Federal Circuit has made to standardize and formalize the analysis of (non)obviousness on its head," specifically discussing the TSM test). For the Federal Circuit's TSM test, see, for example, *In re* Lee, 277 F.3d 1338, 1343 (Fed. Cir. 2002); *In re* Dembiczak, 175 F.3d 994, 999 (Fed. Cir. 1999). However, *KSR* did not completely bar taking the TSM test into consideration as part of the "flexible," "expansive," approach instructed by the court. *KSR*, 550 U.S. at 418 (the court noting that the TSM test "captured a helpful insight"); Eisenberg, *supra*, at 390 ("The [Supreme] Court did not even disapprove of the TSM approach, so long as it is used flexibly.").

74. *KSR*, 550 U.S. at 415.

general sentiment emerging from patent cases regards the combination of preexisting elements not as a potential source of groundbreaking innovation, but at most, as an excusable flaw.[75]

B. *Analogous Art*

A second principle relevant for our discussion is the analogous art doctrine. This court-made doctrine was designed to assist courts in deciding which prior art should be taken into account in the nonobviousness analysis, in light of the Patent Act's provision that the invention must not seem obvious to "a person having ordinary skill *in the art to which the claimed invention pertains*."[76] The doctrine instructs that, when measuring the invention's nonobviousness *vis-à-vis* the prior art, only prior art which is "analogous" should be considered.[77] Conversely, non-analogous prior art that is "too remote" from the invention cannot support a rejection of patentability due to obviousness.[78] Case law further instructs that analogous prior art includes prior art "from the same field of endeavor" as the invention or prior art which is "reasonably pertinent" to the problem faced by the inventor even if not from the same field.[79]

At first sight, the analogous art doctrine seems like a promising tool for incorporating interdisciplinarity into patent law. While the doctrine is not phrased in terms of interdisciplinarity, it implicitly recognizes that deriving solutions from a remote technological field is unlikely to be an obvious endeavor. Its reference to the relationship between the prior knowledge and the invention as "*analogous*" versus "*remote*," is consistent with the insights of innovation scholarship that "distance matters" and that drawing technologies from disparate fields may be particularly valuable.[80] Moreover, while the

75. *Cf.* Durie & Lemley, *supra* note 72, at 994 ("Inventions that take the form of a combination of existing ideas present particular problems for obviousness analysis."); Dubiansky, *supra* note 19, at 31 (observing that "there was once a heightened requirement on combination patents" but arguing that today this is no longer the case); Joshua D. Sarnoff, *Bilcare, KSR, Presumptions of Validity, Preliminary Relief, and Obviousness in Patent Law*, 25 CARDOZO ARTS & ENT. L.J. 995, 1028–29 (2008) (describing the hesitant approach of the *KSR* court towards granting a patent based on a combination).

76. 35 U.S.C. § 103 (2012) (emphasis added).

77. For prominent case law introducing and implementing this test see, for example, Innovention Toys, LLC v. MGA Entm't, Inc. 637 F.3d 1314, 1321 (Fed. Cir. 2011); *In re* Bigio, 381 F.3d 1320, 1325–26 (Fed. Cir. 2004); *In re* Clay, 966 F.2d 656, 658 (Fed. Cir. 1992).

78. *Clay*, 966 F.2d at 658; SHELDON HALPREN ET AL., FUNDAMENTALS OF UNITED STATES INTELLECTUAL PROPERTY LAW 229 (2011).

79. *Innovention Toys*, 637 F.3d at 1321; *Clay*, 966 F.2d at 658.

80. *See supra* Part I-B(1) (discussing "distance and dynamism").

doctrine presumes that drawing from different fields of art is likely less obvious than drawing from the same field to which the invention belongs, it also recognizes that art in other fields could be "reasonably pertinent" to the invention. As the foregoing discussion clarifies, this would indeed be the case, when links between fields become more and more frequent and the distance between them narrows.[81]

However, a closer look at the application of the doctrine in court cases reveals, again, a complex and ambiguous picture. First, courts face significant difficulties in distinguishing analogous from non-analogous art and fail to implement the doctrine in a consistent and predictable manner.[82] To illustrate, fasteners for clamps and fasteners for garments were considered non-analogous in one case (implying that the invention at stake was nonobvious and hence patentable),[83] while rocket science was held analogous to bottle inspection in another case (rendering the invention at stake obvious and the patent invalid).[84] These and additional cases demonstrate that courts lack a clear and measureable standard for analogous art determination.[85] In the absence of such a standard, the vagueness and inconsistencies in the application of the doctrine led commentators to describe it as "erratic,"[86] "subjective,"[87] and even "schizophrenic."[88]

81. *See supra* notes 48–49 and accompanying text (discussing the varying distance between disciplines and technologies).

82. Pedraza-Fariña, *Patents*, *supra* note 18, at 865 (acknowledging the difficulties to delineate sharply the contents of analogous art and distinguish between routine and non-routine interdisciplinarity); Sherkow, *supra* note 48, at 1094 ("[T]he delineation between analogous and nonanalogous arts is not clear."); Simon, *supra* note 18, at 354 (noting that there is "a lack of guidance from the Federal Circuit about how to define the field of invention").

83. *In re* Oetiker, 977 F.2d 1443, 1447 (Fed. Cir. 1992).

84. George J. Meyer Mfg. Co. v. San Marino Elec. Corp., 422 F.2d 1285 (9th Cir. 1970).

85. *See, e.g.*, Innovention Toys, LLC v. MGA Entm't Inc., 637 F.3d 1314 (Fed. Cir. 2011) (analogizing a software game and a physical board game); Daiichi Sankyo Co. v. Apotex, Inc., 501 F.3d 1254, 1259 (Fed. Cir. 2007) (considering general practice medicine analogous to otological drug development); Weather Eng'g Corp. v. United States, 614 F.2d 281 (Fed. Cir. 1980) (analogizing chemical cloud seeding technology with airborne detonable devices); *see also* Jeffrey T. Burgess, *The Analogous Art Test*, 7 BUFF. INTELL. PROP. L.J. 63, 70 (2009); Sherkow, *supra* note 48, at 1109–11.

86. Burgess, *supra* note 85, at 70 (observing that "case law appears erratic on this issue").

87. Hillary K. Dobies, *New Viability in the Doctrine of Analogous Art*, 34 IDEA 227, 229 (1994) (maintaining that the finding of analogous art "is by definition, somewhat subjective"); Sherkow, *supra* note 48, at 1091 (referring to the analogous art inquiry as "subjective, and at times, arbitrary . . . "); Simon, *supra* note 18, at 354 (describing the analogous art test as "subjective and unpredictable").

88. Sherkow, *supra* note 48, at 1112 (referring to the "schizophrenia of the analogous art doctrine").

In addition, similar to patent doctrine's treatment of combination inventions, the analogous art doctrine too does not explicitly acknowledge the significance of interdisciplinarity for innovation. The traditional justification for the doctrine is not the need to promote interdisciplinarity but, rather, the difficulties of an inventor (or, more accurately, a PHOSITA—the "person having ordinary skill in the art" whose hypothetical opinion is used to evaluate the obviousness of the invention)[89] to access prior art outside her own field.[90] However, with the advance of sophisticated search technologies, some courts seem to suggest that modern PHOSITAs are expected to be familiar with a broader scope, possibly even the entire universe, of prior art.[91] As stipulated by one court:

> It may be that at an earlier time in our history most inventions relating to locks were made by locksmiths and most inventions relative to plows . . . [by] those who made or used plows. At that time and in those days perhaps the "subject matter" of the invention was the lock or plow and the "art" the art of lock and plow making. *In today's world,* a world of extensive and rapid communication of scientific and industrial knowledge *a world of institutions of higher learning and private laboratories which gather men of all disciplines . . . the questions arising in a particular industry are answered not only by those who have learned the lessons of that industry but also by those trained in scientific fields having no necessary relationship to the particular industry.*[92]

Additional case law expresses a similar sentiment.[93] Consequently, as more diverse fields of art are deemed analogous to an

89. 35 U.S.C. § 103 (2012).

90. Halpren et al., *supra* note 78 at 229 (explaining that the underlying rationale for the doctrine is that it is "unfair" and "unrealistic" to require inventors to be presumptively aware of non-analogous prior art).

91. Sherkow, *supra* note 48, at 1115–20 (describing courts' trend toward analogizing disparate arts); Simon, *supra* note 18, at 333 ("As access to searchable information and computing capabilities expand, it might appear that very few inventions are nonobvious enough to merit patent protection.").

92. George J. Meyer Mfg. Co. v. San Marino Elec. Corp., 422 F.2d 1285, 1287 (9th Cir. 1970) (holding that missile tracking and star tracking are analogous to bottle inspection) (emphasis added).

93. *See* Graham v. John Deere Co., 383 U.S. 1, 19 (1966) ("Technology, however, has advanced—and with remarkable rapidity in the last 50 years. Moreover, the ambit of applicable art in given fields of science has widened by disciplines unheard of a half century ago. It is but an evenhanded application to require that those persons granted the benefit of a patent monopoly be charged with an awareness of these changed conditions."); *see also* Schering Corp. v. Apotex Inc., No. CV-09–6373, 2012 WL 2263292, at *15 (D.N.J. June 15, 2012) (the definition of the PHOSITA should take into account that the development of a patent is "a multidisciplinary process"). The decision in *KSR International Company v. Teleflex Incorporated,*

invention, the more prior art references can be cited against it, and the greater its likelihood to be deemed obvious—and unpatentable.[94]

This latter approach indeed recognizes the significance of interdisciplinarity but regards it as a trivial default choice in today's world, ostensibly available to each and every inventor (or PHOSITA). It disregards the high-risk nature of the interdisciplinary endeavor and the challenges of transcending disciplines, which far exceed the ability to search or access prior art.[95] It further ignores the dynamic dimension of interdisciplinarity and blurs the distinctions between disciplines that are *routinely* combined and those that are *seldom* linked, and between prior art that is close the invention and prior art that is distant from it.[96] By taking interdisciplinarity for granted without any nuanced distinctions, this approach considerably weakens the potential of the analogous art doctrine to serve as a tool that supports high-risk interdisciplinary innovation.

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Altogether, the discussion in this Part demonstrates that patent law's treatment of interdisciplinary innovation is at best ambivalent and inconsistent. Most prominently, patent doctrine does not incorporate a robust concept of interdisciplinarity and lacks any concrete, objective standard to evaluate the "difference" (or "remoteness," or "gap") between the invention's building blocks or between the invention and the prior art. In the absence of such tools, courts and examiners have great difficulties distinguishing valuable recombinations of distant technologies from "mere aggregations" of analogous components.

Yet there might actually be a more objective way to make these distinctions, to measure the difference between the invention and its building blocks, and to apply the nonobviousness doctrine in a manner that would better support interdisciplinary innovation. The next Part explores this potential measure and describes how the concepts of interdisciplinarity and recombinations could be incorporated into patent doctrine.

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550 U.S. 398 (2007), discussed earlier reflects a somewhat similar approach, by holding *erroneous* the assumption that "a person of ordinary skill attempting to solve a problem will be led only to those elements of prior art designed to solve the same problem." *KSR*, 550 U.S. at 420.

94. Pedraza-Fariña, *Patents*, *supra* note 18, at 865; Sherkow, *supra* note 48, at 1091; Simon, *supra* note 18, at 370 (making similar observations).

95. *See supra* Part I-B(2).

96. *See supra* Part I-B(1).

III. Connect the Dots: A Proposal

This Article's proposal is twofold: first, patent law should explicitly consider interdisciplinarity as a positive indication for the nonobviousness of an invention. Second, as a proxy for an invention's interdisciplinarity, patent doctrine should take into account information derived from patent data about recombinations in the invention's building blocks.

This Part begins with a quick look at the use of patent data to identify traits of innovation and innovative processes, and "zooms in" to closely examine possible manners to identify recombinations—the ultimate mark of interdisciplinarity—in patent data. It then explores the possible introduction of a "recombination metric" to evaluate interdisciplinarity, and the manners in which these insights could be incorporated into patent doctrine.

A. *Identifying Recombinations in Patent Data*

A growing body of literature in the fields of economics, business management, and network science suggests that patent data provides a wealth of information about the inventive process, about the relations between technological fields, and about the technological origins of specific inventions.[97] This data results from the registration of millions of patents in Patent Offices as public documents. This registration is performed in a highly structured manner, which includes not only the description of the invention itself but also information pertaining to its inventors, legal owners, the technological areas to which the invention belongs, and the prior art.[98] The recent decades have witnessed an upsurge in the use of big data analyses of patent databases to extract various insights and predictions, from identifying technological breakthroughs,[99] through studying the traits of litigated patents,[100] to exploring the evolution

97. *See* sources cited *supra* note 13; *see also* R&D, Patents and Productivity (Zvi Griliches ed., 1984); Jacob Schmookler, Invention and Economic Growths (1966).

98. Adam B. Jaffe & Manuel Trajtenberg, *Introduction*, in Patents, Citations and Innovations 1, 3 (Adam B. Jaffe & Manuel Trajtenberg eds., 2003) .

99. *See, e.g.*, Trajtenberg, *A Penny for Your Quotes*, *supra* note 13 (using forward citations to identify inventions that represent breakthroughs); *see also* discussion *infra* notes 129–34 and accompanying text.

100. *See, e.g.*, Allison et al., *supra* note 13 (studying the differences between litigated and non-litigated patents by examining correlations to various factors recorded in patent databases); Jean O. Lanjouw & Mark Schankerman, *Characteristics of Patent Litigation,* 32 RAND J. Econ. 129 (2001) (examining the characteristics of litigated patents by using information derived from patent databases).

of new technological fields.[101] The following discussion concentrates on one use, relevant for our purposes: identifying inventions that connect distant technological building blocks, by searching for the ultimate mark of interdisciplinary innovation—recombinations.[102]

Which relevant information with regard to recombinations can be obtained from analyzing patent data? How can it be used to signal technologies that connect disparate dots and distinguish them from more ordinary combinations? Economic and network literature highlights two types of data recorded in patent databases that are particularly important for this purpose: patent citations and patent classifications.[103]

1) Patent citations are citations of prior art pertaining to the invention, which appear on each patent application. These citations are commonly comprised of previous patents but also, possibly, of additional scientific literature.[104] As the discussion of patent doctrine clarifies, prior art plays a crucial legal role in the decision whether the invention at stake deserves patent protection, since the nonobviousness of the invention is determined according to its difference from the prior art.[105] The citation of relevant prior art is therefore required as part of submitting a patent application.[106] Hence, citations are initially contributed by the patent applicants and then reviewed by the Patent Office examiners, who often contribute additional citations.[107] For any given invention citations may be "backward" or "forward" looking. *Backward citations* (or "citations

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101. *See, e.g.*, SCHMOOKLER, supra note 97 (using technological classifications of patents to identify growth in particular industries); Erdi et al., *supra* note 13 (using analyses of patent citations to predict the emergence of new technological fields).

102. *See supra* Part I-A (discussing the concept of recombinations as the essence of interdisciplinary innovation).

103. Brownyn H. Hall, Adam B. Jaffe & Manuel Trajtenberg, *The NBER Patent Citations Data File: Lessons, Insights, and Methodological Tools, in* PATENTS, CITATIONS AND INNOVATIONS 403, 414–21 (Adam B. Jaffe & Manuel Trajtenberg eds., 2003) (discussing these parameters and their significance).

104. Erdi et al., *supra* note 13, at 227–28; Jaffe & Trajtenberg, *Introduction*, *supra* note 98, at 3. In order to simplify the discussion, I concentrate on citations of patents but return to the issue of scientific literature later. *See infra* Part III-B.

105. *See supra* Part II.

106. *See* Duty to Disclose Information Material to Patentability, 37 C.F.R. § 1.56(a) (2011) ("Each individual associated with the filing and prosecution of a patent application has a duty of candor and good faith in dealing with the Office, which includes a duty to disclose to the Office all information known to that individual to be material to patentability . . . ."); *see also* Erdi et al., *supra* note 13, at 226; Trajtenberg et al., *University Versus Corporate Patents, supra* note 15, at 53.

107. Nature of Examination, 37 C.F.R. § 1.104 (2011) ("[T]he examiner shall make . . . a thorough investigation of the available prior art relating to the subject matter of the claimed invention."); Juan Alcácer et al., *Applicant and Examiner Citations in U.S. Patents: An Overview and Analysis*, 38 RES. POL'Y 415, 415 (2009).

made") are the preceding patents *cited by* the invention, while *forward citations* (or "citations received") are the subsequent patents *citing* that invention.[108] Citations, therefore, reflect *relations* between the invention and additional—previous and following—inventions. Roughly speaking, backward citations reflect the invention's technological antecedents ("parents"), while forward citations reflect its technological decedents ("children").[109] For the purpose of identifying, *ex ante*, interdisciplinary inventions that draw from disparate technological fields, backward citations are more relevant, and I return to them shortly.

2) Patent classifications are assigned to each patent application by the Patent Office according to the invention's technological features, under an internationally harmonized classification system.[110] The system has a "tree-branch" structure, with classes splitting into more specific subclasses at each level. To illustrate, at the most specific, nine-digit, alphanumeric level, there are currently over 150,000 patent subclasses, while at a higher, more general, three-digit level, there are several hundred subclasses.[111] Inventions are assigned to at least one of the subclasses but can be assigned to multiple subclasses. The primary purpose of the classification system is to increase the efficiency of the examination procedure, by facilitating search for prior art and by allowing examiners and stakeholders to search databases for documents in various languages through the use of the classification symbols.[112] Patent classifications have been rather neglected in patent law scholarship.[113] In contrast, economists and network scientists have long

108. Trajtenberg et al., *University Versus Corporate Patents*, *supra* note 15, at 56.

109. Lanjouw & Schankerman, *supra* note 100, at 138; Trajtenberg et al., *University Versus Corporate Patents*, *supra* note 15, at 57.

110. *See generally* Heather J.E. Simmons, *Categorizing the Useful Arts: Past, Present, and Future Development of Patent Classification in the United States*, 106 L. Libr. J. 563, 571 (2014). Until recently different classification systems were used by the USPTO and by the European Patent Office. A combined effort has resulted in a unified system—the Cooperative Patent Classification (CPC) system that has been in use since 2013. *See Cooperative Patent Classification*, USPTO, https://www.uspto.gov/web/patents/classification/cpc/html/cpc.html (last visited Oct. 19, 2017); *see also Classification Standards and Development*, USPTO http://www.uspto.gov/patents-application-process/patent-search/classification-standards-and-development (last updated Oct. 19, 2017) (providing an overview of the recent process of international harmonization of the patent classification system).

111. *See* USPTO, Overview of the US Patent Classification System (2012), http://www.uspto.gov/patents/resources/classification/overview.pdf; World Intellectual Prop. Org., Guide to the International Patent Classification (2017), http://www.wipo.int/export/sites/www/classifications/ipc/en/guide/guide_ipc.pdf.

112. Simmons, *supra* note 110, at 569–70.

113. There are of course exceptions. *See, e.g.*, Allison et al., *supra* note 13 (studying the relations between litigated patents and classifications); Strandburg et al., *supra* note 13, at 1343–44 (maintaining that a methodology based on patent citations may be used in order to

recognized the positive externalities of the classification system for innovation research: the systematic classification of patents into technological subclasses allows to identify different technological components comprising inventions.[114] Much like backward citations, then, patents' classifications reveal important information about the technological "building blocks" of inventions.

How can information about an invention's backward citations and subclasses be used to evaluate interdisciplinarity? The answer lies in the concept of recombinations—a crucial feature of interdisciplinary innovation.[115] Since backward citations and subclassifications are proxies for an invention's technological building blocks, a finding that an invention incorporates new or rare combinations of these building blocks can signal that it is highly interdisciplinary.

A principal method used for this evaluation is a metric based on *co-citations*.[116] Long recognized in the social sciences, a co-citation metric examines the frequency with which two underlying items are cited together by a later item.[117] This metric therefore informs whether a particular item (in our case: a technological invention) relies on previous items (in our case: previous technological components) that are regularly combined, or perhaps forms new combinations, by co-citing items that were not previously combined.[118] To illustrate, take the example of academic articles: an

evaluate and explore existing patent classification schemes); Saurabh Vishnubhakat, *The Field of Invention*, 45 HOFSTRA L. REV. 899 (2017) (discussing the administrative power to classify the field of invention, and advocating that the use of these classifications by the courts holds numerous benefits for patent law); Vishnubhakat & Rai, *supra* note 18, at 239–40 (acknowledging that patent classifications reflect technological building blocks of inventions and combinatorical processes).

114. *See, e.g*, Arts & Veugelers, *supra* note 17, at 1223 ("The technology classes of a patent capture the technology fields covered by the patent while the subclasses . . . correspond to the different components or technologies used to create the invention . . . . ."); Erdi et al., *supra* note 13, at 230 (indicating that the classification system can be used "in understanding . . . the relationships among categories of technologies, and the evolution of a technology category . . . "); Fleming, *supra* note 13, at 123 (proposing that subclasses serve as proxies for technological origins of inventions); Youn, *supra* note 13, at 2 (using patent classifications as proxies for technological capabilities); *cf.* Jaffe & Trajtenberg, *Introduction*, *supra* note 98, at 12–13 (suggesting that patent classifications can be used to evaluate whether inventions are "original," namely synthesize and draw on previous research from different fields).

115. *See supra* Part I-A.

116. For the notion of co-citation, see Henry Small, *Co-citation in Scientific Literature: A New Measure of the Relationship Between Two Documents*, 24 J. AM. SOC'Y INFO. SCI. 265 (1973). A prominent example for the use of co-citations in studying the technological building blocks of inventions is Fleming, *supra* note 13. This and additional literature is discussed in the following paragraphs.

117. Small, *supra* note 116, at 265.

118. Notably, the co-citation metric is not binary and is not confined to "regular" versus "new" recombinations but allows to measure the level of recombination against a continuum.

article which cites previous articles that were never cited together before in a single paper is probably more interdisciplinary than an article whose combinations of citations appeared before in numerous other papers.[119]

One can similarly apply this principle to the realm of patents.[120] Because subclasses and backward citations reflect the technological building blocks comprising inventions, examining their co-citations can signal an invention's level of interdisciplinarity. A patented invention that is classified into two technological subclasses that did not previously appear together in a single patent likely connects distant technological building blocks and is probably more interdisciplinary than an invention whose co-classifications are prevalent in many preceding inventions. Likewise, an invention that co-cites distant patents that were not previously cited together is likely more interdisciplinary that an invention whose combination of prior art was repeatedly co-cited in many previous inventions.[121] In other words, since backward citations and technological subclasses are (indirect) proxies for the technological building blocks of an invention, new or infrequent recombinations of these elements can signal the invention's interdisciplinarity.

Moreover, a metric which identifies recombinations of prior art or technological subclasses (hereinafter referred to as a "recombination metric") captures the two principal traits of interdisciplinarity that emerged from our previous discussion. *First,* it reflects the *dynamic* nature of interdisciplinary innovation.[122] The

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For example, a combination of previous components may be rare but not entirely new. *See* Small, *supra* note 116, at 268 (explaining that co-citations reflect whether and *how much* ideas are associated).

119. *See* Vincent Larivière et al., *Long-Distance Interdisciplinarity Leads to Higher Scientific Impact* 10 PLoS ONE e0122565 (2015), http://journals.plos.org/plosone/Article?id=10.1371/journal.pone.0122565 (using co-citations to evaluate the interdisciplinarity of academic papers); Uzzi et al., *supra* note 5 (using a metric based on co-citations to measure the novelty of academic papers).

120. For the use of co-citation measures in economic and network analyses of patent data, see, for example, Erdi et al., *supra* note 13 (using co-citations to identify the emergence of new technological fields); Fleming, *supra* note 13, 122 (using a recombination metric of patent subclasses as a proxy for the distance between the technological building blocks comprising inventions); Lanjouw & Schankerman, *supra* note 100, at 138 (using co-classifications to measure the technological similarity, or difference, between a patent and its antecedents); Trajtenberg et al., *University Versus Corporate Patents*, *supra* note 15, at 61 (using co-classifications to measure the distance of a patent from its antecedents); compare Castaladi et al., *supra* note 28 (using patent classifications and citations to evaluate technological variety); see also sources cited *infra* note 136.

121. *Cf.* Strandburg et al., *supra* note 13, at 1346 (observing that interdisciplinary patents will likely "cite patents in disparate fields"); *see also infra* notes 157–63 and accompanying text (discussing the question of how to measure the "distance" between prior art citations).

122. *See* discussion of "Distance and Dynamism" *supra* Part I-B(1).

frequency of the combination and the possible changes in such frequency over time are an integral part of this metric.[123] A recombination metric is therefore inherently dynamic and sensitive to the temporal changes in the distance between technological building blocks.[124] To illustrate, consider an invention filed in 1970 that co-cites, for the first time, patents from the fields of rocket science and bottle inspection.[125] Now assume that in the decades that lapsed this combination of prior art was co-cited by many subsequent inventions. Under a recombination metric, the first invention would rank as highly interdisciplinary, whereas an invention filed today with exactly the same set of co-citations would rank much lower. A recombination metric, therefore, can provide us with a time-sensitive tool which patent doctrine is currently lacking: one that allows to distinguish inventions that bridge distant technologies, from other, more routine, combinations.[126]

Second, a developing strand in network and economic research suggests that a recombination metric may also reflect the additional attribute of interdisciplinary innovation—its "high-risk, high-gain" nature.[127] These studies indicate that new recombinations in the technological subclasses or in the backward citations of an invention may be proxies for high impact, breakthrough inventions.[128] As an indication of breakthrough inventions, most of these studies use the number of forward citations, *i.e.,* the citations received by a patent—the underlying assumption being that high impact inventions serve as platforms for numerous subsequent technologies and therefore receive a large number of forward citations.[129] This assumption has now been corroborated by numerous studies that demonstrate positive correlations between highly cited patents and

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123. Small, *supra* note 116, at 265 (explaining that the frequency with which two items are cited together may change over time).

124. *Cf.* Erdi et al., *supra* note 13, at 232–33 (using a metric based on patent citation data to capture the time evolution of technological fields).

125. The example is hypothetical yet inspired by the case of *George J. Meyer Manufacturing Company v. San Marino Electric Corporation*, 422 F.2d 1285 (9th Cir. 1970), which considered whether a bottle inspection machine which drew upon a missile tracking technology was patentable.

126. *See supra* notes 71–74, 90–96, and accompanying text (discussing the patent doctrine's difficulties to make these distinctions).

127. *See* the discussion *supra*, Part I-B(2).

128. *See, e.g.*, Arts & Veugelers, *supra* note 17; Dahlin & Behrens, *supra* note 17; Fleming, *supra* note 13; Dennis Verhoeven et al., *Measuring Technological Novelty with Patent-Based Indicators*, 45 RES. POL'Y 707 (2016). This literature is discussed in detail in the following paragraphs.

129. Trajtenberg, *A Penny for Your Quotes*, *supra* note 13, at 184 ("[A] patent would be regarded as important if it opened the way to a successful line of further innovations; the patents coming in its wake would naturally cite it, and hence, those citations could be taken as first-hand evidence of the path-breaking nature of the original patent.").

various indications for social (and private) value of the underlying inventions. The latter include high expert evaluations of the underlying technologies;[130] willingness of patent owners to pay renewal fees;[131] the R&D amounts invested in the underlying technologies;[132] and the likelihood of the patent to be involved in litigation.[133] All in all, the number of forward citations has become an acceptable, if "noisy," indication for high-impact, breakthrough inventions.[134]

Pioneered by the work of Lee Fleming, the above-mentioned vein of research explores the technological building blocks of breakthrough inventions by examining the sub-classifications and backward citations of the highly-cited patents.[135] Based on the theoretical conceptualization of recombinations as a source of highly valuable innovation, these studies examined (albeit with certain methodological variations) whether the building blocks of breakthrough inventions contain new recombinations of subclasses or backward citations, relative to "ordinary" inventions. The general

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130. *See* M.B. Alberta et al., *Direct Validation of Citation Counts as Indicators of Industrially Important Patents,* 20 RES. POL'Y 251 (1991) (showing that highly cited patents are valued by researchers and inventors as technically important).

131. Dietmar Harhoff et.al, *Citation Frequency and the Value of Patented Inventions*, 81 REV. ECON. STAT. 511, 515 (1999) (demonstrating that patents renewed to their full term were "more highly cited than patents allowed to expire before their full term").

132. Trajtenberg, *A Penny for Your Quotes*, *supra* note 13 (showing a close association between forward citations and R&D expenditures, in the field of computed tomography (CT) scanners).

133. Allison et al., *supra* note 100, at 437 (assuming that "litigated patents are at least a subset of the most valuable patents"); *id.* at 455 (demonstrating that litigated patents receive significantly more citations than other, ordinary, patents); *see also* Brownyn Hall et al., *Market Value and Patent Citation: A First Look*, 36 RAND J. ECON. 16, 33 (2005) (demonstrating a link between patent citations and a firm's market value).

134. *See, e.g.*, Arts & Veugelers, *supra* note 17, at 1218 (observing that citations received are a measure of inventions' impact); Dahlin & Behrens, *supra* note 17, at 721 ("Forward citations are . . . a metric of impact . . . ."); Fleming, *supra* note 13, at 122 ("Citations to a patent correlate with its technological importance and value."); *see also* Talya Ponchek, *Does the Patent System Promote Scientific Innovation?: Empirical Analysis of Patent Forward Citations*, 25 ALB. L.J. SCI. & TECH. 289, 320 (2015) (measuring the relations between forward citations and scientific collaborations and observing that forward citations are "directly related to the measurement of innovation value"); Michael Risch, *Patent Troll Myths*, 42 SETON HALL L. REV 457, 478–81 (2012) (noting that "[l]arge numbers of citations received . . . imply that [the cited patents] are more than trivial patents"). *But cf. infra* Part IV-A (discussing the "noise" and limitations of using forward citations as a metric) .

135. Arts & Veugelers, *supra* note 17 (analyzing a dataset of 84,119 biotechnology patents); Dahlin & Behrens, *supra* note 17 (investigating 571 mechanical inventions concerning tennis-rackets); Fleming, *supra* note 13, at 121 (analyzing a dataset of 17,264 patents from various domains); Verhoeven et al., *supra* note 128, at 719 (identifying breakthroughs out of a database of 5,297,283 patent applications filed between 1980 and 2011); *cf.* Wilfred Schoenmakers & Geert Duysters, *The Technological Origins of Radical Inventions*, 39 RES. POL'Y 1051 (2010) (analyzing the dispersion of subclasses of 157 radical patents selected out of a pool of 300,000 patents).

picture emerging from this literature is that breakthrough inventions are indeed more likely to re-combine technological subclasses or backward citations that never, or rarely, appeared together before in a single patent.[136]

Although this line of research is still developing and its findings should not be overstretched, it provides certain empirical support to the abundant theoretical literature that transcending disciplinary boundaries has the potential to yield "high-gain," valuable innovation.[137] And, most importantly for our purposes, it lends further support to the notion that a recombination metric could serve as a suitable proxy for identifying interdisciplinary inventions.

Moreover, the recognition of the tight links between recombinations, interdisciplinarity, and valuable innovation, and the related use of metrics based on recombinations are spreading across domains. For example, co-citations recombination metrics were used to evaluate the innovativeness and interdisciplinarity of scientific literature,[138] to identify groundbreaking grant proposals in the field of medicine,[139] to predict the emergence of new technological fields,[140] and, recently, to measure technological novelty.[141] In real-

136. Arts & Veugelers, *supra* note 17, at 1230–39 (analyzing recombinations of subclasses and concluding that "combining formerly uncombined technologies increases the chance of inventing a breakthrough"); Dahlin & Behrens, *supra* note 17 (demonstrating that a measure based on difference of backward citation structure from previous inventions can identify potentially radical inventions); Fleming, *supra* note 13, 130 (analyzing recombinations of patent subclasses and concluding that technological breakthroughs derive from new combinations of well-used, but previously disconnected, technological components); Verhoeven et al., *supra* note 128, at 719 (analyzing 5,297,283 inventions and finding that breakthrough patents scored high under a "technological novelty index" based on recombinations); *cf.* Schoenmakers & Duysters, *supra* note 135, at (analyzing the spread of backward citations of radical patents across different subclasses, and suggesting that "[t]he combination of knowledge from domains that might usually not be connected seems to deliver more radical inventions").

137. Interestingly, some of this research also indicates that inventions with new recombinations of building blocks are also more likely to fail, in relation to other inventions. *E.g.*, Fleming, *supra* note 13, at 130–31. This implies that a recombination metric may also reflect the "high risk" dimension of interdisciplinary innovation discussed in Part I-B(2), *supra*.

138. Larivière et al., *supra* note 119 (using a similar metric to assess the interdisciplinarity of academic papers); Uzzi et al., *supra* note 5, at 468 (using the prevalence of "recombinations" in citations appearing in academic papers to assess and rank the novelty of those papers).

139. Boudreau et al., *supra* note 6, at 3 (measuring the novelty of research proposals by the prevalence of "unique combinations" of keywords in the medical field ("MeSH terms") that have not previously appeared in published medical literature).

140. Erdi et al., *supra* note 13 (using co-citation methods to predict the emergence of new technological fields).

141. Verhoeven et al., *supra* note 128 (proposing an index of technological novelty based on various measurements of combinations in citations, subclasses, and scientific literature of inventions). Notably, this study attempts to use patent data in order to produce *ex ante* evaluations of inventions. Although its focus is on "technological novelty," the design of a predictive

world contexts, these notions are used to direct entrepreneurs and corporations toward developing radical innovation[142] or to assess individuals' level of creativity.[143]

Against this broad recognition, patent law's failure to explicitly consider the significance of interdisciplinarity and recombinations is striking. This is so not only because patent law's primary mission is to promote innovation but also because the scientific understanding of the connections between recombinations, interdisciplinarity, and innovation is increasingly based on patent data. While various disciplines now treat patent databases as invaluable sources of information about the processes, histories, components, and directions of innovation,[144] the law of patents still seems to regard them as static registries.

The ensuing conclusion is apparent. Patent law should "connect the dots"—recognize interdisciplinarity as a proxy for nonobviousness and use a recombination metric based on patent data as a proxy for an invention's interdisciplinarity.

The following sub-Part proceeds to take a closer look at this proposal and explores manners for its implementation in patent doctrine.

B. *Back to Patent Doctrine: Implementation*

Equipped with the tools for identifying recombinations in patent data, we now return to patent law. How can the aforesaid insights be incorporated into patent doctrine?

The most straightforward way to recognize interdisciplinarity as a factor in patent law would be to incorporate it as one of the "secondary considerations"—a set of factors developed in case law to assist

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tool is consistent with this Article's approach. *Cf.* Maayan Perel, *An Ex Ante Theory of Patent Valuation*, 14 J. HIGH TECH. L. 148 (2014) (suggesting that the PTO engage in an *ex ante* evaluation of patents' quality according to a series of parameters, to be followed by an *ex ante* regulatory limitation on licensing prices).

142. HARGADON, *supra* note 3, at 208–15 (providing guidelines for organizations pursuing innovation, based on the concepts of recombination and "technology brokering"); *cf.* Dahlin & Behrens, *supra* note 17, at 718 (suggesting that policy makers can use metrics based on patent-data to predict and prepare for radical change); Fleming, *supra* note 13, at 130–31 ("Organizations that seek technological breakthroughs should experiment with new combinations, possibly with old components.").

143. The RAT–Remote Associative Test in psychology measures individual creativity by examining subjects' ability to find links which combine remote elements. *See* Mednick, *supra* note 22, at 227.

144. *See* sources cited *supra* note 97.

courts in determining non-obviousness.[145] Thus, if an invention is highly interdisciplinary, this would support a nonobviousness determination by both the courts and the Patent Office.[146] Concomitantly, this Article recommends the introduction of a recombination metric based on big data analyses of patent data as a proxy for inventions' interdisciplinarity.

To illustrate, consider again the example of rocket science and bottle inspection:[147] a recombination metric may reveal that an invention which combines these technologies is highly interdisciplinary since it is classified into subclasses that rarely appeared together before in a single invention. This information would constitute an indicia for its nonobviousness that would support the patentability of the respective invention. Conversely, assume that a recombination metric discloses that an invention which combines board games and computer technology is assigned to subclasses that appeared together in numerous previous patents.[148] This would rank the invention's interdisciplinarity lower and could imply that the gap between the invention and its underlying building blocks may be insufficient for crossing the nonobviousness threshold.[149]

1. Algorithmic Recombination Metric

Ultimately, this Article's proposals call for the development of an algorithmic recombination metric that would examine each patent application, search its combinations of sub-classifications and backward citations, compare them to the prior art by datamining patent

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145. *See* Graham v. John Deere Co., 383 U.S. 1, 17–18 (1966) (introducing "secondary considerations"); *see also* Jonathan J. Darrow, *Secondary Considerations: A Structured Framework for Patent Analysis*, 74 ALB. L. REV. 47 (2011); Natalie A. Thomas, Note, *Secondary Considerations in Nonobviousness Analysis: The Use of Objective Indicia Following KSR v. Teleflex,* 86 N.Y.U. L. REV. 2070 (2011). The list of secondary considerations includes, *inter alia*, the commercial success of the invention, the extent of licensing, immediate copying by competitors, failure of others to develop the same invention, and a long-felt need for the invention. *See generally* Darrow, *supra* at 50 (detailing these and additional considerations).

146. *Cf.* Pedraza-Fariña, *Patents*, *supra* note 18, at 867–68 (maintaining that the sociological approach to patent law should result in the recognition of new secondary considerations for nonobviousness that would encourage uncertain, risky, inventions).

147. *See supra* note 125 and accompanying text.

148. The example, though hypothetical, is based on Innovention Toys, LLC v. MGA Entm't Inc., 637 F.3d 1314 (Fed. Cir. 2011) (discussing whether a software game and a physical game are analogous).

149. See *supra* Part II (discussing the difficulties of current patent doctrine to evaluate the sufficiency of the gap between the invention and the prior art).

data, and rank the invention's level of interdisciplinarity. The multiple studies which constructed co-citation metrics, the spreading use of such metrics as discussed in the previous Part, together with current computer science tools, all imply that devising an algorithmic recombination metric is a completely feasible task.[150]

Ideally, such an algorithm would be developed by the Patent Office, so as to create a standardized metric that can be made accessible to courts, patent examiners, patentees, and third parties.[151] Its construction by the Patent Office could also mitigate anxieties expressed in recent literature concerning algorithms designated to assist human decisions.[152] Notably, the aforesaid concerns do not arise in their most acute form under this Article's proposal because the suggested recombination algorithm will neither produce any definitive decisions nor constitute a single factor in the patentability analysis, and, therefore, will not substitute examiners' or courts' discretion in the decision whether to afford patent protection.[153] Nevertheless, even if these concerns apply to some lesser extent in our case, they could be further eased if the Patent Office undertakes to construct the algorithm and embeds principles of transparency as to its underlying parameters into the design.[154]

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150. For existing uses of co-citation metrics, see, for example, Boudreau et al., *supra* note 6, at 3 (developing a co-citation based metric to measure the novelty of research proposals); Uzzi et al., *supra* note 5 (developing a co-citation index to evaluate the novelty of 17.9 million papers spanning all scientific fields); see also sources cited *supra*, notes 138–43; compare Verhoeven et al., *supra* note 128 (proposing a co-citation based score to measure technological novelty).

151. *Cf.* Allison et al., *supra* note 100, at 464 (suggesting that the PTO create an objective algorithm to evaluate the complexity of patents, in order to conduct a more rigorous examination of more complex applications, and suggesting that such algorithm be based on the number of claims and prior art citations); Yoo, *supra* note 55, at 35 (advocating stronger interrelations between law and computer science).

152. For recent discussions of these concerns see, for example, Jack M. Balkin, *The Three Laws of Robotics in the Age of Big Data*, 78 Ohio St. L.J. (forthcoming 2017), https://ssrn.com/abstract=2890965 (arguing that the use of algorithms should be subject to obligations of transparency, due process, and accountability); Maayan Perel & Niva Elkin-Koren, *Accountability in Algorithmic Copyright Enforcement*, 19 Stan. Tech. L. Rev. 473 (making a similar argument with respect to algorithmic enforcement of copyright infringement); compare Joshua A. Kroll et al., *Accountable Algorithms*, 165 U. Pa. L. Rev. 633 (2017) (introducing computer science concepts that can be used to set out and verify algorithmic compliance with standards of legal fairness for automated decisions).

153. For further discussion of this point, see Part IV-C *infra*.

154. *See* sources cited *supra*, note 152 (proposing similar solutions); *cf.* Deven R. Desai & Joshua A. Kroll, *Trust But Verify: A Guide to Algorithms and the Law*, 31 Harv. J.L. & Tech. (forthcoming 2017), https://ssrn.com/abstract=2959472 (arguing that public systems that use software for decision making should be able to generate verifiable evidence as to the decisions it produces).

This Article neither purports to draw full specifications for an "interdisciplinarity algorithm" nor to oversimplify the challenges it entails.[155] Rather, its aim is to set out a theoretical framework for the consideration of interdisciplinarity as a factor in the patentability analysis and alert policy makers to the availability of patent data and existing methodological tools that can be applied to advance this purpose. Therefore, the next paragraphs sketch, in broad strokes, a few factors that should be taken into account in devising a recombination metric to assess interdisciplinarity. The details of the proposed algorithm, however, are left to the Patent Office or to future research.

One important feature is the *distance* between technological fields. Ample literature demonstrates that connecting distant technologies is more risky, may possibly yield radical innovation, and, in general, is more interdisciplinary, in comparison to "local" combinations.[156] To illustrate, an invention which cites for the first time two mechanical patents is probably less interdisciplinary than an invention which cites for the first time a patent from the field of metallurgy and a patent from the field of computational linguistics. Therefore, a recombination metric should not only consider the frequency of co-citations but also attempt to evaluate the distance between the invention's building blocks (i.e., the distance between its backward citations and between its subclasses) in a more nuanced manner.

Economic and network literature offers various potential ways to do so. For example, distance between subclasses may take into account the hierarchy level of sub-classification: an invention which recombines subclasses at the three-digit, more general, level, is likely more interdisciplinary than an invention which forms new connections between subclasses at the more specific nine-digit level.[157] Distance between items of prior art that are cited together by an invention could be measured by examining their "degree of separation," namely how many citation-steps were required to get

155. *See infra* Part IV (discussing the primary challenges).

156. *See* sources cited *supra* note 51 and accompanying text; *see also* Dubiansky, *supra* note 19, at 12 ("[N]ew innovations are created by the novel recombination of disparate ideas. It is not the simple volume of ideas, but their diversity, which leads to the novelty of new innovations."); Erdi et al., *supra* note 13, at 5 ("[D]istant combinations, . . . though rare, when they occur provide major new knowledge. . . . ."); Mednick, *supra* note 22, at ("The more mutually remote the elements of a new combination, the more creative the process of solution."); Jeroen C.J.M. van den Bergh, *Optimal Diversity: Increasing Returns Versus Recombinant Innovation*, 68 J. ECON. BEHAV. & ORG. 565, 577–78 (2008) (emphasizing the value of disparate technologies for radical innovation).

157. For the "tree-branch" structure of the patent classification system, see *supra* notes 110–11 and accompanying text.

from one patent to another prior to their co-citation by the relevant invention.[158] These options are not exhaustive.[159] The important point is that any interdisciplinary recombination metric should take into account not only co-citation frequency but also more nuanced indications of the distance between the items co-cited by the invention.

In addition, the design of a recombination metric should address citations of *scientific literature*. As mentioned earlier, patents can cite previous academic papers, not merely previous patents.[160] Possibly, interdisciplinary inventions that integrate scientific and technological knowledge are more prone to citing scientific literature.[161] In any case, a recombination metric should consider citations to scientific literature, in a manner akin to citations to patents. Concrete ways for doing so were recently introduced in network literature.[162]

Finally, another feature of a recombination metric could be a graphical interface. In light of recent developments in network data visualization tools, one could easily envision an algorithm that maps the networks of patent citations and patent subclasses and graphically connects previously unconnected dots on that map, so as to alert the user that the invention before her connects disparate technological components.[163]

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158. *See, e.g.*, Erdi et al., *supra* note 13, at 227 (describing the methodology of measuring the distance between patents according to the shortest path along the patent citation network).

159. For example, Trajtenberg, Henderson and Jaffe suggested an "originality measure" for examining whether a patent draws from a broad base of technology fields, which uses both citations and the classifications to which they belong as a measure of distance. Trajtenberg et al., *University Versus Corporate Patents*, *supra* note 15, at 61*; see also* Lanjouw & Schankerman, *supra* note 100, at 138 (using a similar yardstick based on citations and classifications to measure the distance between an invention and its "parents").

160. *See supra* note 104 and accompanying text.

161. *Cf.* Michelle Gittelman & Bruce Kogut, *Does Good Science Lead to Valuable Knowledge? Biotechnology Firms and the Evolution of Logic of Citation Patterns*, 49 MGMT. SCI. 366 (2003) (suggesting a positive correlation between citations to scientific literature and high-impact inventions).

162. Verhoeven et al., *supra* note 128, at 711 (integrating citations of scientific literature in an index designed to measure technological novelty, and using the classifications of the journals in which the cited scientific literature was published to evaluate distance).

163. For examples of data-visualization tools of patent citations and classifications, see Loet Leydesdorff, *Patent Classifications as Indicators of Intellectual Organization*, 59 J. AM. SOC'Y INFO. SCI. & TECH. 1582 (2008) (presenting visualizations of the relations between patent subclasses); Christian Sternitzke et al., *Visualizing Patent Statistics by Means of Social Network Analysis Tools,* 30 WORLD PAT. INFO. 115 (2008) (demonstrating different visualizations of patent citation networks).

2. Additional Means

Until the Patent Office rises to the challenge and develops a recombination metric, patent law can take interdisciplinarity into consideration through additional means. One option available to parties is to generate their own algorithmic analyses with regard to the prevalence or absence of new recombinations in the building blocks comprising certain inventions. The data required for such analyses is in many cases publicly available and as the discussion above demonstrates, it is already used in numerous scholarly studies. Therefore, courts could afford a certain weight to analyses of patent data performed on behalf of parties in order to generate insights about the distance between their inventions' technological building blocks and their level of interdisciplinarity.

A "softer" available alternative is the use of expert opinions to evaluate whether the combination of technological building blocks comprising a certain invention is rare, or conversely, frequent. At times, such insights might be almost intuitive, possibly even within the ambits of judicial notice. However, the analysis in this Article clarifies that the distinction between "rare" and "frequent" is critical and should be part of any evaluation of interdisciplinarity, whether by experts or by courts. Contrary to the assumption of some courts in the cases reviewed earlier,[164] combining technologies from different technological fields is not always expected, and the nuances are crucial. When referring to interdisciplinarity, courts and examiners alike must not confine the analysis to whether the invention draws from different fields but should inquire to what extent those fields have been linked before ("rarely" implies high interdisciplinarity and vice versa).[165]

In addition to incorporating interdisciplinarity as a consideration in the nonobviousness analysis, this Article's insights could be used to improve the two current patent law doctrines that are particularly relevant to interdisciplinary innovation: the (non)obviousness of combination inventions and the analogous art doctrine.[166] The earlier discussion demonstrated the current difficulties of patent

164. *See supra* notes 90–96 and accompanying text.

165. Several scholars have recently raised similar proposals with respect to team-based work. *See, e.g.*, Pedraza-Fariña, *Patents supra* note 18, at 867 (maintaining that patent law should reward interdisciplinary teamwork when it is *unusual* but not when teams are *routinely* engaged in cross-disciplinary research) (emphasis added); Vishnubhakat & Rai, *supra* note 18, at 239 (proposing that patent examination distinguish between team work in a field which has become "routinely interdisciplinary" and interdisciplinarity which is "still nascent").

166. *See supra* Part II.

law to distinguish combinations that are "mere aggregations" from those that represent "novelty in itself," and to decide whether a certain prior art is analogous to, or remote from, the invention.[167] Consequently, these doctrines, and the nonobviousness requirement more generally, were all criticized as "subjective," "indeterminate," and even "schizophrenic."[168] Embedding a recombination metric in patent doctrine may mitigate the difficulties. When the subject of analysis is a combination invention a recombination metric could signal whether the components comprising the combination were remote (in which case their combination bridges a significant gap and is likely nonobvious) or perhaps proximate (in which case the invention may be obvious).[169] Similarly, such a metric could assist in delineating the scope of analogous art in a more predictable manner.[170] All in all, its use might improve patent quality by introducing a relevant and measurable criterion into the nonobviousness analysis, the analogous art doctrine, and the treatment of combination inventions.

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Altogether, the discussion above demonstrates that adopting this Article's proposals carries numerous advantages for patent doctrine and innovation alike. First, incorporating interdisciplinarity as a factor in the patentability analysis would better align patent law with the ultimate aim of promoting risky and socially valuable innovation.[171] Second, introducing a recombination metric into patent law will inject a clear and measurable criterion that will assist calibrating existing doctrinal tools. Finally, adopting this Article's proposals would resolve the current paradox, whereby *patent law* disregards the wealth of information available in *patent data*. Recognizing interdisciplinarity as a factor in the nonobviousness analysis and using patent data analyses to evaluate it could be a first step

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167. *Id.*

168. *See, e.g.*, Durie & Lemley, *supra* note 72, at 999 (assimilating the nonobviousness test under KSR to a "Rorschach test"); Mandel, *supra* note 63, at 60, 127 (criticizing the indeterminacy of the nonobviousness standard that "cannot be applied consistently," and arguing that it creates "a suite of ills for the patent system and technological innovation"); Sherkow, *supra* note 48, at 1112 (referring to the "schizophrenia of analogous art inquiries"); Simon, *supra* note 18, at 337 (describing the nonobviousness test as "highly subjective"); *see also* discussion *supra* notes 63–72, 82–87 and accompanying text.

169. *See supra* Part II-A (discussing combination inventions).

170. *See supra* Part II-B (discussing the analogous art doctrine); *cf.* Strandburg et al., *supra* note 13, at 1293, 1343–44 (2006) (suggesting that patent citations may be a useful means to explore the connections between different technical fields, and determine the contours of analogous art).

171. *See supra* note 57 and accompanying text.

that would allow patent law to begin realizing some of the enormous potential of patent data, a potential which the current legal regime leaves untapped.

Nonetheless, like most proposals for law reform, the one put forth in this Article is clearly not free of difficulties and should be advanced with caution. The following Part takes a closer look at some of these challenges and discusses possible solutions.

IV. OBJECTIONS AND LIMITATIONS

The following sections highlight three sets of concerns relating to this Article's proposals. The first refers to the reliability of the data derived from patent databases. The second addresses risks of manipulation by patentees attempting to artificially influence their interdisciplinarity rank. The third concerns a more general point—that innovation is not always interdisciplinary.

A. *"Noise"*

The proposal to use patent data to evaluate interdisciplinarity raises questions of reliability. How reliable are patent citations and patent classifications as proxies for inventions' technological building blocks? As a measure of technological distance? Indeed, literature recognizes that patent data cannot yield perfectly accurate signals of innovation traits and processes.[172] For example, scholars have observed that patent citations can occur for a variety of reasons, including "rich get richer" dynamics or social inclination to cite the patents of high-status industry players.[173] Similarly,

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172. *See, e.g.*, Jaffe & Trajtenberg, *Introduction*, *supra* note 98, at 12 (observing that "patent citations do constitute indeed a 'paper trail' of knowledge spillovers, though one that is incomplete and mixed in with a fair amount of noise").

173. *E.g.*, Dahlin & Behrens, *supra* note 17, at 733 (describing "the social constructivist view of patent citations"); Joel M Podolny & Toby E. Stuart, *A Role-Based Ecology of Technological Change,* 100 AM. J. SOC. 1224 (1996) (maintaining that the status of patentees in the industry can affect technological change and patent citations); Sergi Valverde et al., *Topology and Evolution of Technology Innovation Networks* E 76, PHYSICAL REV. E 056118, 056118-6 (2007) (suggesting that patent citations display a certain "rich get richer" dynamics, whereby highly cited patents receive more citations); *cf.* John R. Allison, Mark A. Lemley & David L. Schwartz *Understanding the Realities of Modern Patent Litigation* 92 TEX. L. REV. 1769, 1798–99 (2014) (examining district court patent litigation and finding no correlation between forward citations and validity); Ponchek, *supra* note 134, at 319–20 (discussing several drawbacks of using patent forward citations as a proxy); David S. Abrams, Ufuk Akcigit & Jillian Popadak, *Patent Value and Citations: Creative Destruction or Strategic Disruption*? (Nat'l Bureau of Econ. Research, Working Paper No. 19467, 2013), http://www.nber.org/papers/w19647.pdf

patent citation patterns vary across different technological areas,[174] and some recent evidence suggests that such patterns also change over time.[175] Likewise, the current PTO classification system may not provide a precise reflection of technological fields and subfields, and its accuracy may vary across technological domains.[176] In addition, the system is dynamic, with the PTO introducing new subclasses from time to time to adapt to technological change.[177] These adaptations may affect any metric based on recombination of subclasses.

Some of these concerns can be addressed when designing a recombination metric. For example, the pioneering works on patent data by economists Hall, Jaffe, and Trajtenberg suggested ways to control for variations among technological fields.[178] Fleming's influential work on recombinations accounted for the introduction of new subclasses,[179] while a recent work by Kuhn and Younge maintains that a model based on text analysis may be used to fine-tune citation analysis.[180] Insights generated from future research would likely further improve the signal-to-noise ratio. This Article's proposals may also warrant a careful assessment (and possibly, improvement) of the current classifications and a meticulous treatment of both citations and classifications by patent examiners so as to improve overall accuracy. Yet one should acknowledge that using information derived from patent data as an indication for innovation processes will never be completely free of noise.

(arguing that the relationship between the number of citations and the value of inventions is not proportional but is an "inverted-U" relationship).

174. Hall et al., *The NBER Patent Citations Data File*, *supra* note 103, 435 (observing that "the number of citations made per patent varies by technological field").

175. Jeffrey M. Kuhn et al., Patent Citations Reexamined: New Data and Methods (Aug. 10, 2017) (unpublished manuscript), https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2714954) (suggesting that the data generating process for patent citations changed substantially during the recent decade so that, nowadays, more citations are created per patent).

176. *E.g.*, Dahlin & Behrens, *supra* note 17, at 722 (maintaining that the breadth of subclasses varies greatly across technologies); Fleming, *supra* note 13, at 129 (highlighting differences between subclasses in digital hardware patents and financial patents, noting that the latter tend to be classified in fewer subclasses); *cf.* Allison et al., *supra* note 13, at 455 (arguing that the current classification system is "flawed" in reflecting separate technologies); Kenneth A. Younge & Jeffrey M. Kuhn, Patent to Patent Similarity: A Vector Space Model (Aug. 19, 2016) (unpublished manuscript), https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2709238 (maintaining that patent classifications provide only a rough measure for the distance between technologies, and proposing an alternative method based on text analysis).

177. Fleming, *supra* note 13, at 124; *see, e.g.*, Erdi et al., *supra* note 13 (studying the emergence of new subclasses).

178. *See, e.g.*, Hall et al., *The NBER Patent Citations Data File, supra* note 103, at 451.

179. Fleming, *supra* note 13, at 124–25.

180. Kuhn & Younge, *supra* note 175.

Nonetheless, as elaborated throughout this Article, there is by now ample evidence that, despite these imperfections, patent citations and patent subclasses are still significant proxies for innovation and innovation processes and the spreading use of this data is telling.[181] Moreover, the imperfect proxies resulting from analyzing patent data still provide a measurable and objective criteria, in comparison to existing patent doctrine that fails to provide *any* clear guidelines for assessing the distance between an invention and its technological building blocks or for identifying interdisciplinary inventions.[182]

The aforesaid limitations, however, instruct a cautious approach when using a recombination metric to evaluate interdisciplinarity. This Part returns to this point shortly, after discussing an additional worry.

B. *Manipulation*

A second, related concern is the risk of manipulation, or strategic citation. If interdisciplinarity becomes a factor in the nonobviousness analysis, patentees may try to manipulate their inventions' "rank" under a recombination metric by introducing artificial citations to distant patents that have nothing to do with the actual invention.[183]

Several factors mitigate this concern. From a legal perspective, misleading citations are contrary to patentees' duties of candor, a breach of which could, under certain circumstances, result in the loss of the patent.[184] In addition, the design of a recombination metric can attach more weight to patent subclasses—a component

181. *See, e.g.*, Erdi et al., *supra* note 13, at 228, 238 (observing that citations represent, "even with noise, the innovation process," and that the patent classification system "appears to show sufficient robustness" for studying the emergence of new technological fields); Jaffe & Trajtenberg, *Introduction*, *supra* note 98, at 12 ("[S]till, the large volume and wide coverage of patent citation data make them extremely useful . . . ."); *see also* sources cited *supra* notes 129–34 and accompanying text.

182. *See supra* note 168 and accompanying text.

183. *Cf.* Ryan Lampe, *Strategic Citation,* 94 REV. ECON. & STAT. 320, 320 (2012) (exploring an opposite phenomenon, whereby patentees withhold citations of relevant prior art, and maintaining that applicants withhold between 21% and 33% of relevant citations).

184. *See* Duty to Disclose Information Material to Patentability, 37 C.F.R. § 1.56 (2011) ("[N]o patent will be granted on an application in connection with which fraud on the Office was practiced or attempted or the duty of disclosure was violated through bad faith or intentional misconduct."); *cf.* Christopher A. Cotropia, Mark A. Lemley & Bhaven Sampat, *Do Applicant Patent Citations Matter*?, 42 RES. POL'Y 844, 844 (2013). It should be noted, however, that the usual cases concerning misleading citations are cases of "under citation" (whereby patentees ignore relevant art), and not cases of "over-citation" (citing irrelevant art).

not controlled by the patentees[185]—or to examiner citations, namely prior art which is cited by patent examiners rather than by applicants.[186] Lastly, with recent developments in the field of big data and computerized text analysis, it may be possible to identify and exclude at least some attempts for manipulation.[187]

C. *Not All Innovation Is Interdisciplinary*

Finally, this Article's focus on interdisciplinary innovation does *not* imply that all innovation is interdisciplinary. Undoubtedly, many valuable technological advances are the product of disciplinary (rather than interdisciplinary) endeavor.[188] Indeed, this may be the majority of inventions, and some of the literature reviewed throughout this Article suggests that those more "local" innovations enjoy more certainty and less chances of failure.[189]

While this Article advocates the consideration of interdisciplinarity as a *positive* indication in the patentability analysis, it neither argues that interdisciplinarity should serve as a *sole* proxy for an inventions' nonobviousness nor that lack of interdisciplinarity should negate patent protection. The recommendation to recognize interdisciplinarity as an additional "secondary consideration" in evaluating nonovbviousness does not imply otherwise. Just like other secondary considerations currently recognized by the courts, interdisciplinarity should become a relevant, but certainly not the sole, factor in the patentability analysis.

More generally, considering that not all innovation is interdisciplinary, and that a recombination metric cannot be completely free of errors, the introduction of these factors into patent doctrine should be cautionary. Interdisciplinarity should not become a *sine-*

185. *See supra* notes 111–14 and accompanying text.

186. *See* Alcácer et al., *supra* note 107 (demonstrating that examiner citations account for sixty-three percent of all citations on the average patent, and that forty percent of patents have all citations added by examiners); Cotropia et al., *supra* note 184 (presenting evidence that patent examiners tend to rely on and cite references they find themselves).

187. For example, by using text analysis to compare the invention's description in the specifications with the text of its citations. For recent uses of computerized text analysis methods to analyze patent data, see Kuhn et al., Patent Citations Reexamined, *supra* note 175; Younge & Kuhn, Patent to Patent Similarity, *supra* note 176.

188. *Cf.* Sarah Kaplan & Keyvan Vakili, *The Double-Edged Sword of Recombination in Breakthrough Innovation*, 36 Strategic Mgmt. J. 1435 (2015) (using text-analysis of 2,826 nanotechnology patents to argue that patents based on "local search" represent higher cognitive novelty); Sherkow, *supra* note 48, at 1124 (highlighting types of inventions that are produced laboriously and embody less creativity)

189. *See, e.g.*, Castaldi et al., *supra* note 28, at 769–70*; see also supra* Part I-B(2) (discussing the high-risk nature of interdisciplinary innovation).

qua-non condition for nonobviousness, and a recombination metric should not serve as a sole arbiter of patentability. It should not be applied mechanically nor should it replace the discretion of courts or examiners. Rather, it could be supplemented, or rebutted, by additional evidence for evaluating interdisciplinarity, as suggested in the previous discussion.

Nonetheless, the analysis in this Article suggests that incorporating interdisciplinarity as a factor in the nonobviousness analysis and introducing a recombination metric to evaluate it would benefit innovation and patent doctrine alike. These factors deserve to become tools in the toolbox of patent law.

CONCLUSION

"We are not students of some subject matter, but students of problems. And problems may cut right across the borders of any subject matter or discipline."[190] This astute observation of Karl Popper, the renowned philosopher of science, best explains the importance of interdisciplinarity for innovation. Decades later, science widely acknowledges that cutting across disciplines and connecting distant dots are essential in order to promote valuable innovation. The notion of recombinations—new combinations of preexisting elements—as the essence of interdisciplinary innovation is also widely recognized.

Yet although the scientific understanding of the importance of interdisciplinarity for innovation increasingly relies on insights derived from patent data, ironically these insights do not reflect upon patent law. And although encouraging interdisciplinarity has become a high policy priority, as far as patent law is concerned, interdisciplinarity is still in the shadows.

This Article calls for a change of perception. The analysis demonstrates that patent law should explicitly acknowledge interdisciplinarity as a positive factor in the patentability analysis. It further demonstrates that interdisciplinary inventions leave "footprints" in patent data, and suggests that patent law use these footprints to identify them. Ultimately, this Article envisions the design of a "recombination metric" that would allow to evaluate inventions' interdisciplinarity in an accessible, standardized manner. Incorporating these proposals into patent doctrine would better align patent law with the realities of innovation, add clarity to

190. KARL POPPER, CONJECTURES AND REFUTATIONS 67 (1963).

existing patent doctrines, and allow patent law to realize the enormous potential of patent data as a rich source of information about innovation.

By synthesizing insights and extant methodological tools from diverse disciplines, patent law can better promote interdisciplinary innovation. Patent law, therefore, should connect the dots.