6

PATENTED TECHNOLOGY AS A MODEL SYSTEM FOR CULTURAL EVOLUTION

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OVERVIEW AND CONTEXT

In this chapter, I argue that the study of cultural evolution would benefit from model systems that are analogous to the model organisms studied in biology and that patented technology would make an excellent model system. My argument has three main steps. First, I note an important epistemic benefit provided by model organisms in biology: knowledge about a model organism illuminates nonmodel organisms both by providing a baseline for comparison with nonmodels and by allowing us to extrapolate knowledge about the model to similar nonmodel organisms. Model organisms are often relatively easy to learn about and understand, so information about the model organisms accumulates from many perspectives, and this information becomes increasingly integrated over time. Second, I argue that the analog of model organisms, which we can refer to as *model cultural systems,* provides analogous epistemic benefits for the study of cultural evolution. Or, at least, a model cultural system *would* provide those epistemic benefits if it existed. Third, I argue that patented technology has all the hallmarks of an excellent model system for at least three important aspects of cultural evolution: the way traits flow in the *hyperparental* genealogies that are characteristic of cultural evolution, the open-ended innovation characteristic of many cultural systems, and the new automated methods and tools for mining huge digital data sets to visualize and quantify the evolution of cultural traits. Patented technology nicely illustrates these three aspects of cultural evolution and provides a relatively easy way to learn more about all three.

Although the standard methodologies for investigating cultural evolution do not include things like model organisms in biology, this is an unfortunate missed opportunity. There have been other proposals for "model organisms" for the study of cultural evolution, such as Weismann diagrams (Griesemer and Wimsatt 1989) and Punnett squares (Wimsatt 2012). When we see why model organisms are so useful in biology, we can see why the study of cultural evolution would enjoy similar epistemic benefits if it too studied appropriate model systems. The use of model systems would mark a constructive milestone in the study of cultural evolution, especially the evolution of technology.

The central aim of this chapter is to show why patented technology is an excellent candidate model system for cultural evolution. Just as biology has a number and variety of model organisms, presumably, the study of cultural evolution would benefit from a number and variety of model systems; I propose patented technology as one excellent example. Many proposed model organisms never end up being adopted by biologists as model organisms. *Lords of the Fly* (Kohler 1994) and similar studies document many unforeseen and unintended contingencies that have influenced which organisms have become successful model organisms. Analogous unforeseeable and unintended future contingencies will presumably influence which systems become successful models for cultural evolution and whether patented technology is among them.

I will use the term *cultural evolution* to refer to the change over time of any population of cultural items. Many different kinds of cultural items can exist in populations, so there can be many kinds of cultural evolution. One consists of the evolving mental states (concepts, beliefs, behaviors, fashions, designs, etc.) found in some group of humans (e.g., Cavalli-Sforza and Feldman 1981; Boyd and Richerson 1985). Another kind consists of the physical artifacts and tools that humans invent and use or the commercial products that humans buy and sell (e.g., Basalla 1988; Rogers 2003; Arthur 2009). The focus in this chapter is a third specific kind of cultural population—the new inventions that humans have created over time—for which patented technology can serve as an easily ascertainable proxy.

Many things humans invent are not patented, and many never could be. But patented technology still is a precisely delimited subset of inventions that is especially easy to study and understand. To be sure, the evolution of patented technology is not representative of all other kinds of cultural evolution; technology is one unique subset of culture, and only a small fraction of human inventions is ever patented. Of course, neither is any model biological organism representative of every aspect of the natural organisms it represents. This chapter makes the case that patented technology is a good model for at least three important characteristic phenomena in cultural evolution: the microlevel, hyperparental flow of cultural (technological) traits; macrolevel, open-ended innovation in new cultural entities (inventions); and automated data-mining methods for extracting and representing the content, or meaning, of cultural entities (inventions).

Many organisms are the subjects of biological experiments, but as Ankeny and Leonelli (2011) have noted, only a few are singled out as model organisms; these include the bacterium *Escherichia coli,* the fruit fly *Drosophila,* and vertebrates like the zebra fish and mouse (a mammal). Sometimes the term *model system* is used for *populations* of organisms *(microbial model systems).* Just like model organisms and systems in biology, model cultural systems would be complex natural systems that exist in the real world, evolve over time, and are studied empirically. Conditions are ripe for students of cultural evolution to make a standard component of their methodology the focus on a few model cultural systems, such as patented technology.

Focusing on a few model systems does not ignore or deny the value of other methods for studying cultural evolution. Rather, it augments them with a powerful new method. Case studies are one traditional method in the study of actual cultural systems (e.g., Ankeny 2012). Case studies share some important features with model systems. Both empirically investigate actual cultural systems, and both focus on just one system. A narrow focus makes it easier when studying something very complex and diverse. But case studies and model systems also have an important difference. Each case study is typically unique and individual, and different scholars study different cases. *Pattern and process in cultural evolution* (Shennon 2009), for example, is full of case studies and phylogenies of material culture, and no two chapters focus on the same case. Information from different cases is collected and sometimes compared, but it is very rare for many studies to focus on the same case. For this reason case studies typically cannot support broad generalizations about other cultural systems. By contrast, model systems *are* used to support broad generalization about other systems; that is their central epistemic function. And they can perform that function because a scientific community has collectively learned a lot about a single system. Pooling the results of a great many independent studies of the same model system is one of the defining hallmarks of model systems, and it helps explain why they support generalizations about similar nonmodel systems. So, a collective focus on a few model systems would complement traditional case studies.

Amassing many unique and different case studies is valuable for the study of cultural evolution, but so is learning a lot about a few model systems if what is learned can be extrapolated to other similar cultural systems.

Most of the things that are called *models* in the study of culture are not the sort of model cultural systems I am proposing. For example, the small-scale physical model of the San Francisco Bay discussed by Weisberg (2013) was built by humans to represent a larger target system: the actual San Francisco Bay. But model cultural systems and model organisms exist naturally and independently whether anyone studies them, or not, at least initially. (It turns out that many model organisms eventually become significantly altered and reshaped by scientists, usually in order to make them easier to study in the laboratory.)

The study of model cultural systems also differs from and complements the tradition of studying cultural evolution with theoretical, mathematical, and (more recently) computational models—which I will lump together and call *formal models.* Formal models include the pioneering mathematical work of Cavalli-Sforza and Feldman (1981) and Boyd and Richerson (1985), as well as the agent-based computer model of Arthur and Polak (2006). The behavior produced by formal models can be compared with empirical observations of actual cultural systems. But though both are called "models," formal models and model cultural systems are quite different. Formal models are purely mathematical objects and not real cultural systems. By contrast, a model cultural system is a real cultural system, which is what we compare with formal models. This shows one way that model cultural systems would complement existing methods of studying cultural evolution.

Focus on a single model cultural system also complements the diverse range of work on cultural and technological evolution that concentrates on the similarities and differences between cultural and biological evolution. This includes not only verbal theories that use "memes" to describe and explain cultural evolution (Dawkins 1976) but also empirical studies of individual cases and comparison of their behavior with formal models and verbal theories (see Ziman 2000). Like the authors in *Pattern and Process in Cultural Evolution* (Shennon 2009), those in *Technological Evolution as an Evolutionary Process* (Ziman 2000) each discuss a different distinctive case.

The reasons why model organisms benefit biology suggest that model systems would also benefit the study of cultural evolution. One key reason is the vast complexity of the natural systems under investigation. Part of what makes biological organisms so hard to understand is their complexity and great variety of forms. One way in which biology copes with this complexity and variety is to identify certain organisms as "model" organisms, to learn a great detail about the model organisms, and then to leverage that knowledge to draw conclusions about nonmodel organisms. In this way model organisms help biologists "to deconstruct the complexity of nature into its constituent parts and to explore the role of each part in creating patterns in nature, first in isolation, then in combination" (Jessup et al. 2004).

Like biological evolution, cultural evolution is extraordinarily complex, "a complex beast . . . [with] multiple evolving and interdependent lineages acting on different time and size scales" (Wimsatt 2013, 564; see also Andersson, Törnberg, and Törnberg 2014). Wimsatt notes that one way to cope with this complexity is to "seek the right organism for the job" and be "opportunistic in seeking cases that are tractable and can generate relatively crisp and unambiguous data" (Wimsatt 2013, 565). If we could amass knowledge about a single model cultural system, we could then compare it with what we learn about other cultural systems and extrapolate it to other cultural systems that are similar to the model in the relevant respects. One concrete constructive way to follow Wimsatt's advice would be to adopt patented technology as a model system for cultural evolution.

The rest of this chapter elaborates the case for adopting patented technology as a model system for cultural evolution, especially for the trait flow over time in hyperparental (highly reticulate) genealogies, for the open-ended way in which cultural populations evolve, and for new methods and tools for the automated mining of big digital data sets of actual cultural population. It first reviews the epistemic hallmarks that make model organisms so useful in biology and explains why model systems would have similar benefits for the study of cultural evolution. Then it shows why patented technology excels at all the hallmarks of a model system for cultural evolution. The chapter concludes with a summary of the main argument and a glance at its larger implications.

MODEL BIOLOGICAL ORGANISMS AND MODEL SYSTEMS FOR CULTURAL EVOLUTION

There is a wealth of recent literature about model organisms (Kohler 1994; Endersby 2007; Jessup et al. 2004; Ankeny and Leonelli 2011; Ankeny 2012; Love and Travisano 2013; Levy and Currie 2014). The literature covers many issues, but this chapter focuses mainly on the hallmarks that explain the

	[A] model organisms in biology
1. The model illuminates many nonmodel systems in one or both ways:	
(1a) it is a baseline to compare with nonmodels	✓
(1b) information about it can be extrapolated to similar nonmodels	✓
2. Information about the model is amassed	✓
3. It is relatively easy to understand the model because of its excellence in:	
(3a) information quality and access	✓
(3b) scientific analysis tools	✓
(3c) empirical observability	✓
(3d) experimental manipulability	✓

Figure 6.1. The main epistemic benefits of model organisms for biology *(row 1)* and some hallmarks *(rows 2 and 3)* that explain those epistemic benefits.

important epistemic benefits of model organisms for biologists. There is general agreement in the literature about these hallmarks, and they are listed in Figure 6.1.

The central epistemic benefit provided by model organisms (Figure 6.1, *row 1*) is that what is known about a model organism illuminates many nonmodel organisms. There are at least two kinds of illumination that a model organism can provide, and they can be distinguished using the distinction between the *phenomena* (behavior) exhibited by a model or a nonmodel organism and the *mechanisms* that explain those phenomena (Love 2015). First, model organisms tend to be much better understood than nonmodel organisms, and this enables our knowledge of the characteristic phenomena involving model organisms to serve as a common baseline for comparison with the phenomena exhibited by nonmodel organisms *(row 1a).* Comparison with a standard and well-understood baseline is informative whether or not similar mechanisms produce the phenomena in both model and nonmodel. What matters is that the behavior of model and nonmodel organisms can be compared; what matters is the similarity of their phenomena.

A second, deeper kind of illumination comes when model and nonmodel are so similar that our knowledge about the model can be extrapolated to the nonmodel organisms (Figure 6.1, *row 1b*). In practice, many model and nonmodel organisms are similar in ways that justify using the models as proxies or representatives for the nonmodels, standing in for them and sanctioning inferences about them. Ankeny and Leonelli (2011) refer to both the relatively wide "representational scope" of models organisms (nonmodels illuminated) as well as their especially wide "representational target" (questions and theories addressed).

One of the reasons we can usefully compare the phenomena and mechanisms in models and nonmodels is that information about a model organism is amassed from many perspectives (Figure 6.1, *row 2*). This information is incrementally integrated when this is thought to be relevant. A broad range of questions and theories can be addressed with a model organism because so much knowledge about one organism has been collected and annotated. Focusing on a single organism enables scientists to amass all of the gory details needed to understand the phenomena and underlying mechanisms found in even one very complex organism. The detailed knowledge accumulated about a model organism can drive the development of new scientific technologies and techniques, and it can foster productive careers for a community of professional scientists. Amassing and integrating information about model organisms are good examples of characteristic activities in what Kuhn calls "normal" science and what Lakatos calls a "progressive" research program

Row 3 of Figure 6.1 identifies another typical hallmark of model organisms: it is relatively easy to learn about the behavior of a model organism (Jessup et al. 2004). Since a model organism is easier to study, it is easier to observe and describe its behavior and therefore easier (eventually) to figure out the underlying causal mechanisms and explain its behavior. A model organism might be especially easy to understand because of the availability of abundant reliable data *(row 3a).* For example, the quick reproductive cycle of the bacterium *E. coli* and the ability to stop, store, and restart the evolution of bacterial populations help make *E. coli* a useful model organism for experimental studies of evolution (Love and Travisano 2013). Other important practical considerations include low experimental costs and the commercial availability of standardized lines of experimental organisms (Ankeny and Leonelli 2011). In general, a key epistemic hallmark of model organisms is the availability of abundant, detailed, accurate, and inexpensive information.

The applicability of powerful scientific tools and techniques can be another reason why model organisms are easy to understand (Figure 6.1, *row 3b*). These can include laboratory practices and know-how, as well as training and mentoring practices. Shared scientific tools and techniques in a scientific community are other hallmarks of model organisms (Ankeny and Leonelli 2011) and another source of their epistemic benefits for biology.

Another hallmark of model organisms is the possibility of recording precise empirical observations about the model's behavior *(row 3c).* Detailed and precisely controlled observations about a model's behavior in a variety of circumstances enable useful information about the model to be amassed. Similarly, practical methods for the precise experimental manipulation of model organisms *(row 3d),* especially with microscopic and molecular techniques, are another hallmark of model organisms.

Using the hallmarks of model organisms as a guide, we can construct a table of analogous epistemic hallmarks for cultural evolution (Figure 6.2). Though the epistemic hallmarks of model cultural systems and model organisms turn out to be very similar, we will see that they are not identical.

As with model organisms, central to the epistemic benefits of a model cultural system would be the model's ability to illuminate many nonmodel systems (Figure 6.2, *row 1*). And as with model organisms, a model cultural system would illuminate nonmodels, either by serving as a common baseline for comparison *(1a)* or by knowledge about the model being extrapolated to similar nonmodels *(1b).* The epistemic benefits of a model cultural system would also typically stem from a second hallmark shared with model organisms: amassing information about a single model from a wide variety of perspectives and sources (Figure 6.2, *row 2*). A third shared hallmark would be the relative ease with which a model cultural system can be studied and understood (Figure 6.2, *row 3*). Abundant clean data about the model would obviously help *(3a),* as would excellent scientific tools and techniques *(3b).* Both make it much easier to understand the model system and to share that information with a community of cooperating scientists. A third obvious epistemic benefit that model cultural systems would share with model organisms would be extensive, precise, detailed, and accurate observations of a model system in a controlled variety of circumstances *(3c).*

Although the hallmarks of model cultural systems generally parallel those for model biological organisms, there is one important difference *(3d).* Unlike with biological organisms, experimental manipulability of real cul-

	[A] model organisms in biology	[B] model systems for cultural evolution
1. The model illuminates many nonmodel systems in one or both ways:		
(1a) it is a baseline to compare with nonmodels	✓	✓
(1b) information about it can be extrapolated to similar nonmodels	✓	✓
2. Information about the model is amassed	✓	✓
3. It is relatively easy to understand the model because of its excellence in:		
(3a) information quality and access	✓	✓
(3b) scientific analysis tools	✓	✓
(3c) empirical observability	✓	✓
(3d) experimental manipulability	✓	×

Figure 6.2. Comparison of model organisms *(column 2)* and model cultural systems *(column 3)* with respect to their main epistemic benefits and the hallmarks that explain them. Note that the epistemic benefits are almost exactly the same. The one difference is row *(3d)*. The *check* in this row indicates that excellent experimental manipulation is a hallmark of model organisms, while the × indicates that experimental difficulty or ethical constraints typically block experimental manipulation of the humans in model cultural systems.

tural populations is typically not possible with a model cultural system because it is either impractical or unethical or both. For example, the study of the patent record would benefit enormously if we could observe what would happen in counterfactual situations without certain actual technological inventions, or with certain possible inventions. But it is impossible to rewrite history, and it is very difficult to evaluate the relevant counterfactual situations with any confidence. Furthermore, even if we could experimentally manipulate the actual evolution of technology, to do so might be irresponsible or unfair or inappropriate. Because of this, a model cultural system typically lacks the experimental manipulability that is among the hallmarks of model organisms. With this one understandable exception, Figure 6.1 shows that model systems for the study of cultural evolution share most of the important epistemic benefits of model organisms. Even if actual cultural populations are not manipulated in experiments, a sufficient number of precisely controlled observations can teach us a lot about a model system, and we might be able to extrapolate what we have learned to other cultural systems.

BACKGROUND ON THE EVOLUTION OF PATENTED TECHNOLOGY

Technology is only a small part of human culture, and only a small fraction of technologies are ever patented. Nevertheless, patents are an ideal context for investigating cultural evolution for a variety of reasons. Basalla (1988) stressed the great context for observing and describing the evolution of cultural variation provided by patented technology. More recently, Mesoudi (2011) emphasized that patent technology enables us to precisely identify individual cultural entities and to document the details of cultural phylogenies and cultural diversity. This chapter's argument for patented technology as a model cultural system follows in the same general spirit as Basalla and Mesoudi.

Part of the reason why patented technology would make a good model cultural system is the wealth of empirical analysis of patent citations collected in Jaffee and Trajtenberg (2002). Jaffee and Trajtenberg have documented the economic value of patent citations, and they have used patent citations to compare the flow of knowledge among different technology sectors, different social institutions, and different political states. The patent record includes a great deal of information about each patented invention, and human experts vet and collate the information. For example, patent examiners at the United States Patent and Trademark Office (USPTO) label each invention with a string of numerical codes that describe its important technological capacities, and these patent technology codes can be used to better understand "the nature and rate of technological change" (Strumsky, Lobo, and van der Leeuw 2012).

Dates, citations, and technology codes are just a small fraction of the information in the patent record. The information includes the unique identification number assigned to each patent, along with standardized information about when the invention was filed with the USPTO, when it was granted a patent, and the inventors of the patent. The record also contains text describing the invention's important technological features, including a title, an abstract, and a list of "claims" that describe the invention's novel technological features. Current text-analysis tools include automated methods for mining the text in the patent record and identifying the key technological features of each invention. The record also lists the USPTO technology codes that correspond to the main technological capacities contained in an invention. One can view a new invention as coming into existence (being "born") when it is granted by the USPTO and as "reproducing" whenever another patent cites it as so-called prior art" (earlier patented inventions that are relevant to a new patent's claims of originality). Then one can reconstruct the complete genealogy of every patented invention. This is one reason why patented technology is an exceptionally rich and feasible context for studying the evolution of cultural traits.

Cultural and biological evolution are often compared, so it is worth stressing that the population of patents has some properties never found in biological populations. One simple example is that existing patents never die and go out of existence. A more important example is the hyperparental genealogies that they form. On average a patent's prior art consists of roughly a dozen earlier inventions; the magnitude of this number demonstrates the hyperparental nature of patented technology. Formal tools for describing hyperparental inheritance networks have only recently been developed (Kerr and Godfrey-Smith 2009; see chapter 5 of this volume), so how well traits flow through hyperparental genealogies is an open but answerable empirical question. Hyperparentality makes a new invention's technological features a mix and combination of many earlier sources, and those features are often intentionally modified and blended by individual rational agents, so parent–offspring connections might be too degraded to enable certain kinds of natural selection to occur (Godfrey-Smith 2009, 2012).

Many complex causal webs affect cultural evolution. Patented technology is affected by things like technology inventors and designers, technology users and consumers, and economic markets and social institutions (Jaffe and Trajtenberg 2002; Arthur 2009; Caporael, Griesemer, and Wimsatt 2014). The evolution of technology involves evolution in many different populations, four of which are depicted in Figure 6.3. Each population is evolving over time, and as the arrows suggest, the populations are causally connected; entities in each interact with entities in the others, so the figure depicts only part of the story. A more exhaustive list of factors affecting cultural evolution has been compiled by Wimsatt (2013).

Population I in Figure 6.3 consists of people who design technological products to be sold in economic markets. Members of this population borrow ideas from each other, and ideas spread and diffuse through the population as people interact. Population II consists of the patented technologies

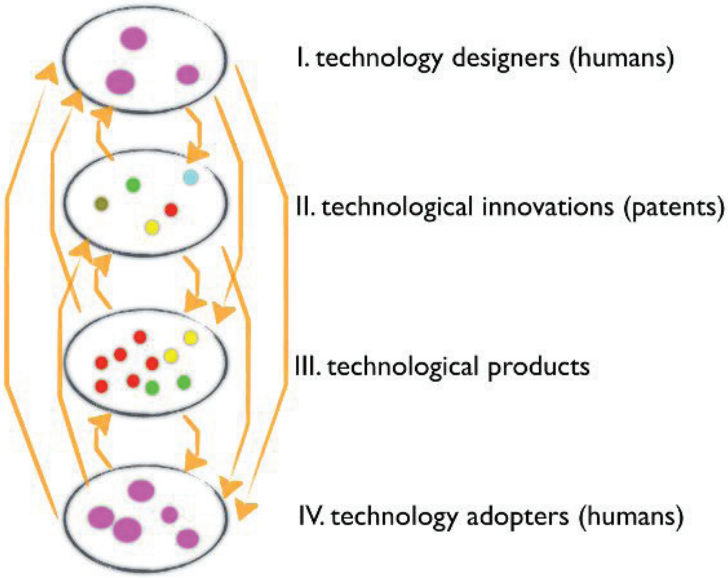

Figure 6.3. Four of the populations involved in the evolution of technology; the *arrows* suggest some of their interactions.

themselves; this population consists of each actual individual technological innovation, or at least those that are patented. The canonical description of a patent is simply the text in its title and abstract, as shown in the patent record. Unlike population I, the members of population II are not people but designs of specific kinds of technologies. Population III consists of commercial products in actual economic markets. These products are usually material objects, which are part of what is called *material culture.* Products compete with one another for market share and diffuse when first introduced to niches. Markets for products are affected by many kinds of factors, both endogenous and exogenous. Population IV consists of people who adopt and use technological products in their daily lives. Consumers select which technology products to buy and adopt, and preferences and fads diffuse through the population as consumers interact. Studies of cultural evolution often focus on the cultural traits of some population of *humans,* such as populations I and IV. I focus on evolution in exemplars of population II: *patented inventions.* The evolution of each of these populations and their interactions is worthy of study.

Each patented invention corresponds to a specific invention. A patented invention is not just an idea in someone's mind (e.g., those who invent or use it), for those ideas change over time and come in and out of existence. A patented invention persists even if nobody thinks of it. Patented inventions are abstract because they are *kinds* of technology with an open-ended range of instances. If a material or physical device is patented, the patent covers not some specific instance of the device but that *kind* of device.

Each patent cites some number of earlier patents. It is common to use a patent's citations of earlier patents as a proxy for a genealogical link between an invention and its technological "parents" (Jaffee and Trajtenberg 2002; Chalmers et al. 2010; Buchanan, Packard, and Bedau 2011; Bedau 2013). All of these nodes and links together comprise a genealogy that continually grows and evolves in new and unpredictable directions. We can identify the most heavily cited patents as the main drivers of the subsequent evolution of technology. Future patents build on and cite some patents more than others, and the main drivers emerge over time from this selection process. It turns out that the main drivers of technological innovation over the past forty years include bubble jet printers, polymerase chain reaction (PCR), and stents (Buchanan, Packard, and Bedau 2011).

Figure 6.4 shows part of the genealogy of U.S. utility patent number 3938459, for a certain type of minesweeper used by the U.S. Navy. Time flows from top to bottom in this genealogy, and the original minesweeper patent is the large star at the top right. All of the other patents shown in this figure are direct descendants of patent 3938459. Citations of parents by children are indicated by arrows. One can distinguish at least four large lineages, and some of them have complex internal interconnections.

Note that Figure 6.4 shows only the direct descendants of the minesweeper patent—only a small fraction of patents in the genealogy. In particular, the hyperparental structure in the genealogy is artificially downplayed. To better indicate the hyperparental structure of patent genealogies, Figure 6.5 shows all of the parents of each of the large circular nodes in Figure 6.4. While Figure 6.4 contains 36 large nodes, including the parents of those nodes reveals an order of magnitude more parents in the genealogy (Figure 6.5 contains 558 nodes). Hyperparental, indeed! Furthermore, including all of the parents of the first thirty-six descendants highlights the separate lineages in the genealogy; the four main lineages visible in Figure 6.4 are very clearly delineated in Figure 6.5, and so is the complex sublineage structure on the far left and far right. In general, Figure 6.5 shows a lot

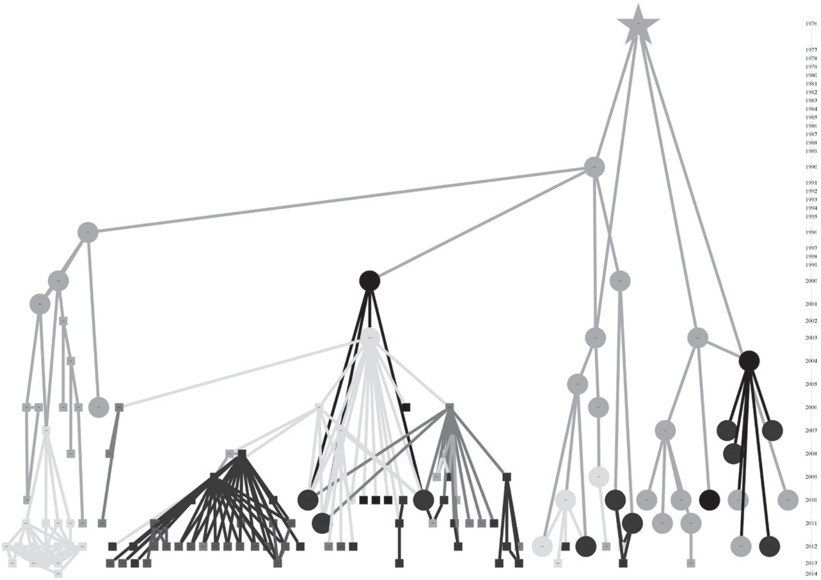

Figure 6.4. The genealogy of patent number 3938459 *(the large star at the top right):* The invention of a kind of minesweeper used by the U.S. Navy. Up to nine generations of descendant nodes are shown. Time flows from top to bottom. Nodes are individual inventions, and links indicate parents cited by their children. Only descendants that receive at least one citation are shown. Nodes and the links below them are colored six different shades of gray to reflect the patent's technological category (either Chemical, Computers and Communication, Drugs and Medical, Electrical and Electronic, Mechanical, or Other). The first three generations of descendants are shown as large circles to indicate how this is connected to the genealogy in Figure 6.5.

of cross-citation within each of the four main lineages and very little cross-citation between the main lineages.

Hyperparental network structures like those in Figure 6.5 are common in cultural populations but relatively rare in biological populations; biological genealogies are typically hypoparental rather than hyperparental. Microbes are known to experience a significant amount of horizontal gene transfer, and their resulting reticulated genealogies have some similarity to the hyperparental network structure in cultural populations. But most patents cite dozens of prior patents, so the degree and rate of hyperparental quality in the patent population is on a vastly larger scale than the horizontal gene transfer in microbial populations.

Some biological innovations are said to "open the door" to quite new and different kinds of subsequent biological innovations (Kauffman 2000; Bedau 2009); in an analogous fashion, some inventions seem to open the door to

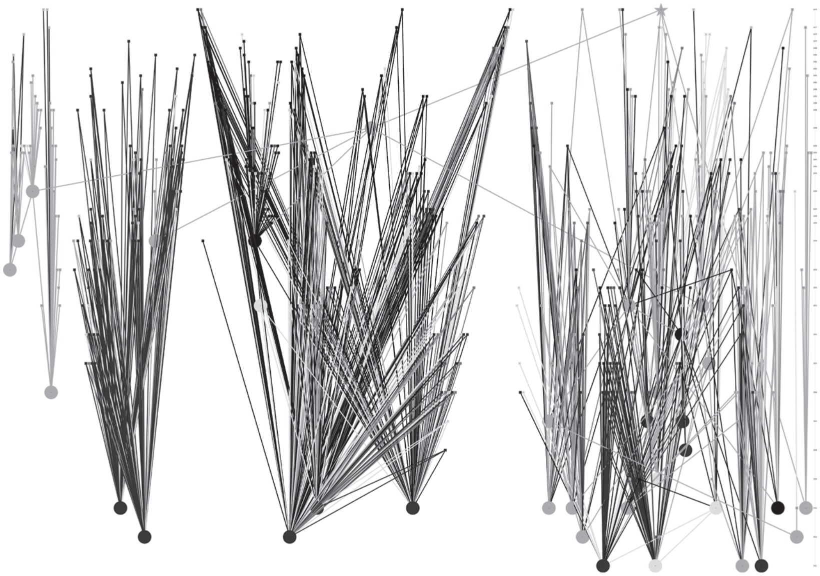

Figure 6.5. Another view of the genealogy of patent number 3938459, showing the parents of the patents in the first three generations of descendants (i.e., the large nodes in Figure 6.4); descendants in subsequent generations (and their parents) are omitted. Nodes and the links below them are colored six different shades of gray to indicate a patent's overall technological category, and only descendants that receive at least one citation are shown.

quite new and different kinds of innovations. Door-opening innovations increase the degree of innovation in the evolution of cultural populations. If one measures the degree to which an invention is door opening by the diversity of its offspring, then patent citation data show that many of the main drivers of technological innovation are highly door opening (Buchanan, Packard, and Bedau 2011).

Various tools make it easy to extract the technological *content,* or meaning, of a patent from the text in the patent record. One especially simple metric is TF-IDF *(term frequency, inverse document frequency);* the TF-IDF value of a term in a document from a corpus is the product of both the term's frequency in the document and the log of the inverse of the term's frequency in the entire corpus. This metric identifies the words in a document that most distinguish it from the other documents in a corpus. Although TF-IDF has known weaknesses and blind spots, it does a good job of automatically extracting key words that describe a patent's technological content from the text in a patent's title and abstract. Chalmers et al. (2010) extracted the most

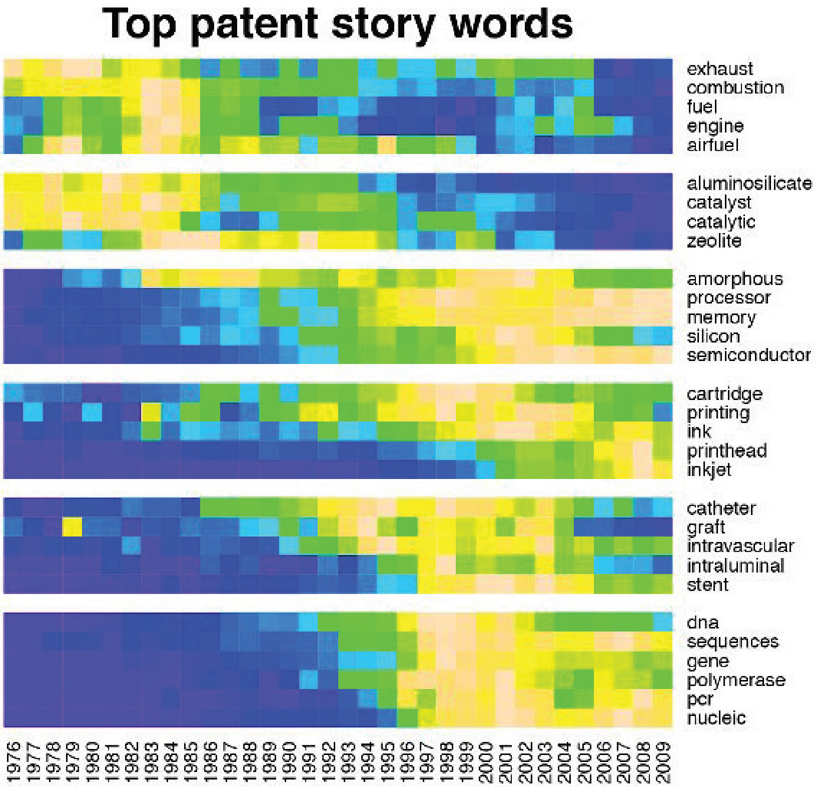

Figure 6.6. A heat map of the frequency of key words with especially high TF-IDF scores in the patents issued each year (lighter shades reflect higher values). Reprinted with permission from Chalmers et al. (2010).

important TF-IDF key words in all of the new patents issued each year and mapped their annual frequencies in a series of heat maps in which lighter colors (higher "temperatures") correspond to more frequent traits (Figure 6.6).

Heat maps like Figure 6.6 are a macrolevel description of the evolution of the content of patented inventions. By contrast, a *micro*level description might depict the content of each separate invention in a patent's genealogy, and it might show in precise and complete detail how the *content* of inventions changes over time in each lineage. The general idea would be to color the nodes in the genealogies in Figures 6.4 and 6.5 to encode the overall technological content of that invention. One easy and useful way to encode the overall technological content of each invention is to classify each into a few kinds of technologies, using the technology codes assigned to each patent by patent examiners. Figures 6.4 and 6.5 depict a familiar sixfold classification of technology categories proposed by Hall, Jaffee, and Trajtenberg (2002) and adopted by the National Bureau of Economic Research (NBER). Six gray colors encode the six general kinds of technology: Chemical, Computers and Communication, Drugs and Medical, Electrical and Electronic, Mechanical, and Other.

If we observe how traits flow in patent genealogies by close examination of the distribution of gray colors in Figures 6.4 and 6.5, we note the following conclusions. First, there are examples of all six categories among the 131 nodes shown in Figure 6.4. The minesweeping patent is classified by the USPTO as Mechanical, and all of the immediate descendants of the minesweeping patent are also classified as Mechanical. But the 36 patents in the first three generations of descendants already exhibit three other technology categories (Chemical, Computer and Communications, and Other), and the 131 patents in Figure 6.4 include examples from the two remaining categories (Drugs and Medical; Electrical and Electronic). Furthermore, the four main different lineages in Figure 6.4 contain distinctive categories of patents; the first large lineage on the far left contains mostly Mechanical and Other patents, while the second large lineage on the left contains mostly Computer and Communications and Drugs and Medical patents. The two remaining large lineages on the right both have a more complex internal citation structure, with patents from at least four different NBER categories.

Examination of the colors (NBER categories) of all the parents shown in Figure 6.5 underscores our earlier conclusions. The four different lineages each have parents from different distinctive NBER categories. The parents in the first large lineage on the far left are virtually all either Mechanical or Other patents, and the parents in the second large lineage on the left are mostly either Computers and Communications or Drugs and Medical patents. Most of the parents in the large lineage in the middle of Figure 6.5 are Electrical and Electronic parents, although parents are also in many other categories. The lineage on the right with the complex internal structure includes parents from all different categories; many are Mechanical patents, and some are Electrical and Electronic, Computer and Communications, or Chemical patents. Furthermore, we can observe that certain sublineages have different and distinctive distributions of categories of parents. Genealogies like those in Figures 6.4 and 6.5 provide detailed, empirical microlevel descriptions of what specific technological categories have flowed through the actual genealogy of any specific patent. Such genealogies can be colored to reflect a wide variety of other kinds of traits, including those that are reconstructed from the text in a patent's title and abstract.

PATENTED TECHNOLOGY AS A MODEL CULTURAL SYSTEM

Given what we now know about patented technology, it is easy to see that it would be an excellent model system for the study of cultural evolution, for it has all of the hallmarks of a model cultural system (Figure 6.2), at least for open-ended evolution, for trait flow in hyperparental cultural genealogies, and for methods and tools for studying trait flow.

Patented technology provides an interesting form of open-ended cultural innovation, and similar phenomena are exhibited by many other cultural systems. So, even if different mechanisms underlie innovation in different cultural systems, patented technology would still provide a standard baseline against which other forms of open-ended cultural innovation could be compared and contrasted. Recent discussions of "revolutionary" modifications of entrenched systems (Wimsatt and Griesemer 2007) and of "redomaining" and its significance (Arthur 2009) suggest that there might be some significant similarity of the mechanisms behind the open-ended evolution in many cultural systems.

There certainly is at least one important similarity in the mechanisms that produce the trait flow that can be observed in cultural systems: their hyperparental structure. For this reason, patented technology would be an excellent model system for the flow, over time, of technological traits through hyperparental patent citation networks. Since similar hyperparental mechanisms operate in many other cultural systems, lessons about hyperparental trait flow in patent populations should be applicable to many other cultural populations. Patent citation networks can "represent" the hyperparental mechanisms in other cultural systems and thus license inferences about the trait flow phenomena exhibited by those systems. This is an important epistemic benefit that patented technology would bring to the study of cultural evolution.

In addition, the same tools used to describe the flow of the content or meaning shown in Figures 6.4 and 6.5 could be used to describe the flow over time of the content or meaning of many other cultural systems. For this reason, patented technology would make a great laboratory for developing and demonstrating new methods and tools for describing trait flow phenomena and for unpacking the mechanisms behind those phenomena. Those new methods include new ways to observe cultural systems by using machine-learning and language-processing algorithms to automate the mining digital data repositories, such as patent records. Even if somewhat different mechanisms are behind the trait flow phenomena observed in different cultural systems, the mere similarity of the data produced by the different systems is enough to explain why the same methods and tools can be applied to both. The analogs of Figures 6.2, 6.3, and 6.4 can be made for many other cultural systems, given raw data over time about trait frequencies. Patented technology "represents" many other cultural systems in the respects that are relevant for applying the new scientific methods.

One reason that patented technology would make a great model system is the patent record. This public and widely accessible resource makes it relatively easy to describe and explain the diversity of existing technologies and their evolutionary origin, given a precise description of every patented invention, including when it was invented and all of its prior art. The growing mass of data about human social and cultural behavior creates confidence that lessons learned from studying patented technology will be adapted and extended to other cultural systems. In addition to citation information already available in sources like the Scientific Citation Index and LexisNexis, and in addition to textual data streaming from traditional mass media outlets like the Associated Press and the *New York Times,* a new wealth of information is being generated on the web *(Wikipedia),* including social media like Facebook and Twitter and mobile apps like texting and Tinder.

The patent record also makes it much easier to amass information about patented technology from public patent records, in no small part because of the patent record created by the USPTO. Various human experts (the patent examiners, the inventor, the inventor's lawyers, etc.) help make the patent record accurate and complete. Patented technology and citation networks have been studied in a number of scientific fields, ranging from scientometrics and bibliometrics to science and technology studies. Information about patented technology has already started to accumulate (Figure 6.2, *row 2*), and Venturini, Jensen, and Latour (2015) recently articulated the special value that these new digital repositories have for cultural studies (citations below in the original):

> The most interesting feature of digital media is that everything that they mediate becomes potentially traceable and often actually traced (Rogers 2013).

> Such traceability creates data that are as rich/thick as those collected by ethnographic techniques but covering much larger populations. Everyday new public and private archives are swallowed by computer memories, economic transactions migrate online, social networks root in the Web, and the more this happens, the more traces become available on the collective dynamics that used to be hidden by the quali-quantitative divide (Latour et al. 2012).

Patented technology is also relatively easy to understand (Figure 6.2, *row 3*). Excellent information, tools, and techniques for analyzing it enable extraordinarily precise observations of this example of cultural evolution. The information in the patent record is publicly available and relatively accurate, and it is continually updated as new patents are issued. In addition, citations make it easy to reconstruct the entire genealogy of any patented invention, and powerful statistical tools and techniques make it easy to identify each patent's technological content. This makes the patent record especially fruitful for illuminating microlevel hyperparental genealogies and macrolevel open-ended evolution, as well as showing how to extract cultural content or meaning from big data.

If patented technology becomes a model cultural system, the study of patents would not be limited to mining the patent record. Quite the opposite! A system becomes like a good model for other cultural systems only after being studied by many people from many different perspectives. To amass and share detailed information about a single system takes a scientific community, and a special epistemic opportunity is created when a scientific community accumulates, curates and vets, and incrementally integrates information about a single cultural system. This accomplishment requires the investment of time and energy by a diverse cast of characters, including experts on policies and practices at the USPTO; on the psychological, social, economic, and political influences on patenting activities; and on the connections between innovation and other factors such as geography, gender, and governmental investment.

THE IDENTIFICATION of good model organisms has been a great epistemic boon for biology, helping constrain and unpack some of the complexity of life. Figure 6.2 lists the epistemic benefits of model systems for the study of cultural evolution, and patented technology exemplifies the entire list. One reason is that the patent record is full of precise and detailed information about the novel and useful features of each patented invention. Another is the existence of tools for reconstructing the genealogy of an invention and each invention's technological content (illustrated in Figures 6.2–6.4).

Patented technology could illuminate many important questions about cultural evolution. One is the impact of culture's characteristic hyperparental genealogies. Cultural evolution's hyperparental quality is one important way it differs from biological evolution. This makes cultural evolution harder to study and understand. Citations in the patent record provide a precise picture of the parent–offspring connections between patents. Patented technology also exhibits interesting macrolevel open-ended evolution that is relatively easy to describe and compare with other cultural or biological populations. Patented technology also illustrates powerful new scientific methods for extracting semantic content from textual data. Those methods could be adapted and extrapolated to describe and eventually explain the flow of semantic content in various kinds of cultural genealogies reconstructed from citations in scientific or other professional publications, in social media on the web like Facebook and Twitter, or in other digital repositories generated by texting and email.

Today, patented technology excels in all the hallmarks of model systems, and it could bring the epistemic benefits of model organisms to the study of cultural evolution. Adopting a model cultural system like patented technology could also foster a new form of interdisciplinary cooperation and collaboration in a new kind of interdisciplinary research community. It remains to be seen whether the study of cultural evolution will take advantage of this new opportunity.

NOTES

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