

Evolution of Technology Innovation Networks

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This year we are celebrating the 200th anniversary of the birth of Charles Darwin and the 150th anniversary of the publication of his masterpiece *The Origin of Species* (1859), a crucial milestone in our comprehension of the evolutionary forces shaping nature. Darwin explained life as the outcome of strong competition between species, which struggle for survival in a resource-limited environment. As the result of *natural selection* forces, organisms become more and more different over many generations of time. At some moment, these descendant organisms are so different from their ancestry that we cannot no longer group them together, and then, a new species is born (i.e., *speciation*).

Evolutionary theory is both a very elegant and powerful framework. It is so attractive, that researchers outside from biology have drawn parallels between their own topic of study (in particular, sociological and economic studies) and the principles of evolutionary theory. Indeed, evolution has deeply transformed the scientific thought and many intellectual fields. However, evolutionary theory has some limitations and it does not readily apply to every non-biological process of change. Can we understand the pattern of variation and the diversity of human inventions using a Darwinian approach?

In a related approach, archeologists, linguists and anthropologists have studied the evolution of cultural diversity using *phylogenetic trees* [1]. These trees describe the past relationships between cultures, languages or artifacts, assuming that cultural traits evolve by descent with modification. Similarly, biological phylogenetic trees (or *evolutionary trees*) show the evolutionary relationships between different species that are believed to have a common ancestor. A node in a phylogenetic tree represents the most common ancestor of a set of descendant nodes, which are linked to their ancestor through an edge.

The study of cultural diversity from an evolutionary perspective offers many advantages but some interesting challenges as well. At best, the phylogenetic tree is an hypothesis about how culture evolves under certain assumptions that might not hold for some cases. For example, how tree-like is cultural evolution? Recently, we have explored this issue with the patent citation network [2] from the United States Patent and Trademark Office (USPTO). This large database comprises some 3 million patents and all the citations from one patent to all the (related) preceding inventions (see figure). From this patent citation network, we can trace the sequence of intermediate steps towards a particular invention. Unlike phylogenetic trees, the patent network is not tree-like. We can clearly appreciate that the path to invention can be quite complex: there is vertical, horizontal and oblique inheritance and borrowing is widespread. Nature is far more limited when evolving organisms.

In the future, the analysis of this network will enable a more detailed understanding of the differences between natural and artificial evolution and the specific mechanisms underlying technological innovation. In addition, the patent citation networks can help us to understand the pattern of technology adoption in our society and across companies and industrial fields. Recent studies suggest the spread of technological innovations can be described by population contagion models [3], which were suitably adapted from epidemiology to the dynamics of invention. Here, the patent citation network enables the unambiguous identification of what inventions have been preceded by other ancestor inventions and to reconstruct the spread of innovations through time.

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- [1] Ruth Mace, Clare J. Holden, and Stephen Shemman, *The Evolution of Cultural Diversity: A Phylogenetic Approach*, UCL Press, London (2005).
 - [2] Sergi Valverde, Ricard V. Solé, Mark Bedau and Norman Packard, *Topology and Evolution of Technology Innovation Networks*, Physical Review E 76, 32767 (2007).
 - [3] Luís M. A. Bettencourt, David I. Kaiser, Jasleen Kaur, Carlos Castillo-Chavez, and David E. Wojick, *Population modeling of the emergence and development of scientific fields*, Scientometrics 75(3), 495-518 (2008).

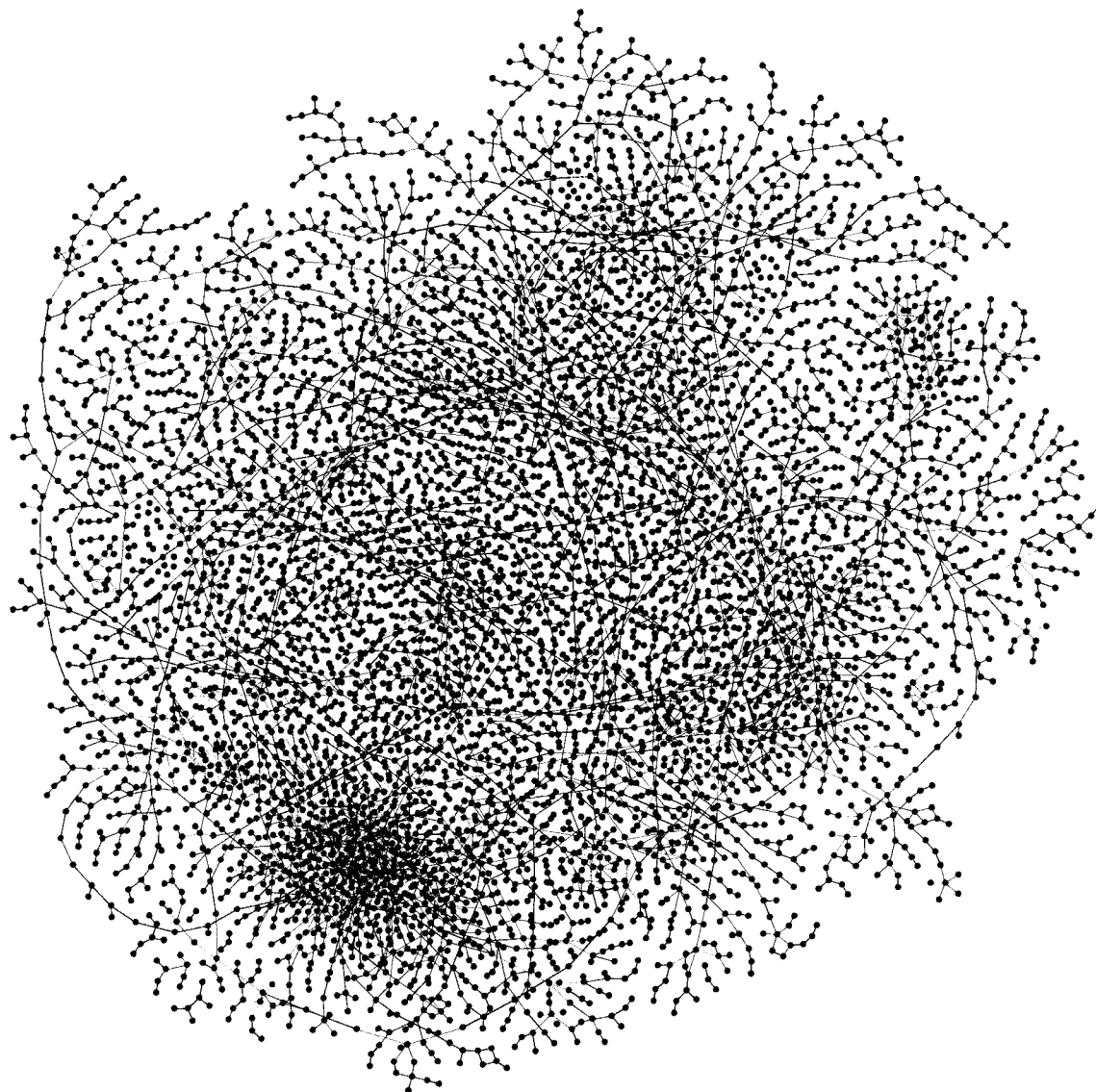


FIG. 1: Graphic representation of the patent citation network for the first 7000 patents in the USPTO database (<http://www.uspto.gov>), starting in 1963. Node and link color reflects the local density of connections. The network is quite heterogeneous, where a few patents are more heavily cited than the rest. In addition, patents appear to be clustered in the network according to the particular technological field they belong to.