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RETURNING TO LOCKE'S LIBERALISM

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P.J. Antsaklis, "Large Networks but Small Worlds," Review of the book Duncan J. Watts: Small Worlds: The Dynamics of Networks between Order and Randomness. (Princeton: Princeton University Press, 1999. pp. xv, 262.), The Review of Politics, Vol.63, No.1, pp. 192-195, Winter, 2001.

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and the absence of needed ones. Simon went so far as to say that, in the current phase of democracy, the essential task is to eliminate alienation through unequal exchange. Fourth, Simon does not assume that the market is in fact free and guarantees liberty, equality, and justice. Far from asserting that economics and politics are separable realms, Simon holds that democracy itself needs to make value judgments concerning all that pertains to the human good, and this would include the entire realm of economics. Finally, Simon shared the concern that technology increased the tendency to encourage the struggle for power in society and to restrict the pursuit of happiness as something in line with human nature, interior, and enjoyable in peace and in common. Recognizing that a return to former conditions is not realistic, Simon nonetheless affirms the value of preserving the family farm as important to democracy, reaffirming Jefferson's vision.

In the last chapter, Kuic explores the way Simon relates democracy to leisure, culture, and work. Simon certainly wishes to promote the contemplative ideal as opposed to the demiurgical. Nevertheless, there is always the danger that the result might be the glorification of leisure, an overemphasis on the unnecessary, and an underemphasis on the core intellectual and moral virtues upon which democracy depends. Kuic notes that authors such as Rorty and Rawls try to build democracy on the inadequate basis of selfish utilitarian calculations by the morally unencumbered. Simon preferred to ground it in the free choices (properly understood) of morally responsible citizens. At the end, Kuic reminds the reader of Simon's realism, which is a progressivism of a specific kind. Renouncing both facile optimism and all disillusionment, it "arouses in our souls an uncompromising will to act and to struggle for the better world whose realization our nature, from the depths of its wretchedness, demands" (p. 154). Thanks to Kuic, many will be made aware of just how far Simon went to show how democracy properly understood is the result of such a will.

—Thomas R. Rourke

LARGE NETWORKS, SMALL WORLDS

Duncan J. Watts: *Small Worlds: The Dynamics of Networks between Order and Randomness.* (Princeton: Princeton University Press, 1999. Pp. xv, 262. $39.50.)

It is not uncommon after meeting a stranger at a social gathering to find out that you both know the same person and to exclaim, "Well, it's a small world." The small-world phenomenon describes the claim that even when two people do not have an acquaintance in common they are separated by only a short chain of intermediaries. Is it then true, as it is often said, that each one of us is only six handshakes away from the President of the United States? Maybe not, but the number of separating handshakes is probably surprisingly small indeed. And a friend of mine said that she danced with a man who had danced with a girl who had danced with the Prince of Wales! It is a small world after all!

Whenever networks describe behaviors of interest there is certainly the potential for the small-world phenomenon, but under what conditions does it arise? First note that networks are very important and they are all around us. We are surrounded by networks! There are networks of friends and acquaintances in society, networks of employees in an organization, networks of markets in an economy, networks of neurons in biological systems, electric power networks, telephone networks, the Internet. The importance of networks has already been recognized in many disciplines that deal with complex systems, such as in sociology, economics, ecology, epidemiology, neurobiology, computer science. Networks and particularly social networks have been studied in the past to see whether they exhibit the small-world phenomenon; however, the conditions under which this may happen are not well understood, and this is exactly the topic addressed in this book.

Duncan Watts uses graph theory and puts forth particular graph models to describe the connections and establish the conditions under which network models, and by extension the systems they describe exhibit the small-world phenomenon. This book focuses primarily on how systems behave and how that behavior is affected by their connectivity. Several of the topics addressed represent work in progress. There was a recent article by the author in the prestigious journal *Nature* (Watts, D. J., and Strogatz, S. H.. "Collective Dynamics of 'Small-World' Networks," *Nature* 393 (1998): 440-42) that brought renewed attention to the small-world phenomenon, and this book represents an elaboration of the ideas in that article.

This book is a serious effort to shed light into the small-world phenomenon using graph theory and models. Graph-theoretic models are introduced in Part I (chapters 2 through 5) and used to examine three real world applications described by a collaboration network, an electric power network, and a network of neural connections in a popular worm. In Part II (chapters 6 through 9) dynamical systems coupled by small-world graphs are used to model and study several important problems such as the spread of infectious diseases.

Chapter 1 of the book is an introduction with the catchy title "Kevin Bacon, the Small World, and Why it All Matters." The small-world phenomenon is illustrated by looking at actors who have acted in a film with Kevin Bacon (another actor), or have been in a film with an actor, who has been in a film with Kevin Bacon and so on. For example, Elvis Presley has a so-called Bacon number of 2, since he was in a film with Walter Matthau, who in turn was in a film with Kevin Bacon. Walter Matthau has a Bacon number of 1. The curious thing is that it has been claimed that no one who has ever acted in an American film has a Bacon number greater than 4! This illustrative example is studied further in chapter 5 using the models introduced in chapter 3. By exhaustively searching the Internet Movie Database (a convenient resource available at *www.us.imdb.com*) that contains information about almost all movies ever made, it was determined that the highest finite Bacon number (of any nationality) is 8. It should be mentioned that the existence and availability of such searchable database containing information about systems of interest is certainly a rarity. So the question is whether small worlds are actually common and whether it is possible to find general conditions under which the world can be small. A brief review of published results on the small-world phenomenon that is given in chapter 2 reveals some of the difficulties. It is then decided that graph-theoretical models are perhaps appropriate and the rest of chapter 2 is devoted to providing background on the theory of graphs. This background is very important to understand and appreciate the results and conjectures in the rest of the book.

A graph-model representation of the Kevin Bacon Hollywood network in the above example would have each actor on a vertex of the graph (n vertices), and if an actor appeared in a movie with another actor then there would be an edge connecting the corresponding vertices—there are in general M edges. Now M=(nxk)/2 and so k gives an indication of the average number of edges at a vertex of the graph. If for example each vertex is connected to all other (n-l) vertices then k=n-l. The graphs of interest here are always connected—there is always a path from a vertex to any other vertex—and satisfy the sparseness condition—k is much smaller than n (*i.e.* k<<n).

Watts introduces three candidate graph models in chapter 3 that are conveniently parameterized to contain both ordered and random graphs. As the parameter increases more random connections are allowed and so the graph becomes more connected. These models exhibit a fascinating phenomenon that is not uncommon in the sciences. The fact that a property appears relatively suddenly after some "critical mass" has been built up—here after enough random connections are allowed the characteristic path length L of the graph, which is the shortest path on the average between two vertices (p. 29), tends to drop rather suddenly and dramatically. These models are studied using computer simulations in chapter 3 and analytical techniques in chapter 4, and they are used throughout the book to determine the most general conditions under which the elements of a large sparsely connected network will be close to each other. A small-world graph can now be redefined in a model-independent fashion, in terms only of n and k. Specifically (p. 114), a small-world graph is a graph with n vertices and average degree k that exhibits characteristic path length L approximately equal to the L of a random graph with the same n and k, but with clustering coefficient much larger than that of the random graph which is approximately equal to k/n. Note that the clustering coefficient characterizes the extent to which vertices adjacent to a vertex are adjacent to each other (p. 33); this coefficient is very small (approximately equal to k/n) in large random graphs and it is larger (but always less than 1) in highly clustered graphs.

As it is stated (p. 241): "The key to generating the small-world phenomenon is the presence of small fraction of very long-range, global edges, which contract otherwise distant parts of the graph, whilst most edges remain local, thus contributing to the high clustering coefficient." If the graph of Kevin Bacon is examined, it is seen that here n=225,226, k=61, L=3.65 and the clustering coefficient is about .8 which clearly indicates that it is indeed a small-world graph; it can be shown that it has approximately the same length L as an equivalent random graph, but it is orders of magnitude more

clustered. Two more examples are examined in chapter 5, the graph of the Western States Power Grid and the graph of neural connections of the well-documented tiny worm called *C. elegans.*

In Part II of the book the attention shifts to dynamical systems. The vertices of the graph now represent dynamical systems and the edges denote coupling relationships between the systems. The relationship between structure and dynamics is studied. In view of the observed fact that many of the most dramatic changes in the structural statistics of the graphs occurred as the result of the rewiring of only a small fraction of the edges, the question addressed via the models developed in earlier chapters is whether small rearrangements in the coupling network of a distributed dynamical system cause large changes in the corresponding global dynamical properties. Small-world phenomena in networks of dynamical systems are of course highly relevant to understanding the mechanisms of disease spreading in populations and this is studied in chapter 6. Note for example that international airports that provide links among large cities with clusters of population make the distance between infected populations and uninfected ones rather small and increase the possibility of spreading the disease. Global computation in Cellular Automata is discussed in chapter 7, Cooperation and the Prisoner's Dilemma is addressed in chapter 8, while in chapter 9 Coupled Phase Oscillators are discussed, all using the graph theoretic models introduced in chapters 3 and 4.

This book makes fascinating reading, but not easy reading—the reader needs to invest some time into it. Descriptions can be dense and technical, and some working knowledge of the theory of graphs is highly recommended. There are of course other approaches to the small-world phenomenon driven primarily by particular application areas. For example in addition to the social networks there has been interest recently in the small-world phenomenon in the World Wide Web. It is worth mentioning that the claim was made in Albert, Jeong and Barabasi, "Diameter of the World Wide Web" (*Nature* 401 [1999]:130-31), that most of the 800 million documents on the Web may be reached by 19 clicks of the mouse (see also *http://www.nd.edu/~networks/*). Fascinating!

What is the political significance of research in the small-world phenomenon? There are perhaps many answers to this question, but an obvious answer is that small-world information networks make possible the rapid spread of new ideas, political and otherwise. Understanding better the small-world phenomenon will influence the way political campaigns are designed, media advertising is implemented, newspapers and books are published and movies are released. In this book, Watts provides background material and references from several disciplines, and this will be very useful to someone who would like to get involved in this exciting and highly challenging research area on the ground floor. The topic is difficult but the potential payoff is high. We have only started scratching the surface in our understanding of the small-world phenomenon, and this is an excellent book for the seriously interested reader.

—Panos J. Antsaklis