Six degrees of interconnection

By Duncan Watts

When we talk about 'distance', we are usually referring to the separation between places or objects in physical space. There's a good reason for this association: in pretty much all of science and engineering, as well as in everyday problems like deciding where to live in relation to work, the notion of physical distance makes complete sense.

But as the technological revolution in communications and transportation enters its second century, and as social and economic forces continue to increase their dominance over our lives, physical space is proving to be a limited and often misleading conceptual framework. Sociologists, for example, have long thought in terms social space and the associated notion of distance between social actors.

Roughly speaking, social distance takes into account many kinds of non-physical separation, such as differences in wealth, education, nationality, religion or profession, which often turn out to be more relevant to social interaction than mere physical proximity. More recently, the social and mathematical sciences have joined forces to examine a new kind of space that is becoming increasingly central to our understanding of the modern world: network space.

One fascinating (and deceptively simple) example of the importance of network space to our understanding of the world is the small-world phenomenon: the claim that anyone on the planet can connect themselves to anyone else in only 'six degrees of separation'. Although ideas like six degrees have been floating around in popular culture for most of the last century, the small world phenomenon passed a critical test in the late 1960's in the form of an ingenious experiment, conducted by the social psychologist Stanley Mailgram.

Milgram gave letters to about 300 people in Boston and Omaha with instructions to deliver the letters to a single 'target' person (a Boston stockbroker). But the letters came with a condition: they could only be sent to someone who was a personal friend of the current holder, preferably someone closer to the target. These subsequent recipients got the same instructions, thus converting the letters into message chains: devices for probing the social fabric of the United States in search of one particular person.

Incredibly more than 60 of the letters did actually reach the target, and the average length of the message chains was about six. Milgram's conclusion was that individuals who according to our ordinary notions of physical and social space, should be impossibly distant, are in fact not much further than our closest associates.

To account for this paradox of distance and perception, we need to start thinking of individuals as nodes embedded in a vast and complex web of links that, in human networks, represent social, economic, and organizational ties. Because two nodes that are connected in this network space are "close" regardless of their physical and social proximity, short chains in network space can easily span large physical distances and even cross over social divides.

Physicality and sociality don't go away of course-often we know people because they live close to us and share important characteristics like education or profession-but their relationship with network space has remained a mystery for several decades. Milgram, you see, could not explain how his experiment worked, or how well his observations regarding a single target and a few hundred initial senders (who were not as randomly chosen as most people assume) would generalize to the whole world.

Furthermore, he could not have known what else his famous result of six degrees would turn out to be relevant to. And for 30 years after Milgram, no progress was made. In part, this was because experiments like his are hard to do on a large scale; in part, because network data is notoriously difficult to collect; and in part because the analysis of complex networks is virtually impossible to perform without powerful computers.

In the past five years, however, we have made great progress in our understanding of small-world networks through a combination of new theories, massive electronic datasets, and large-scale internet-based experiments (e.g. http://smallworld.sociology.columbia.edu).

We are also beginning to understand how the lessons of network space play out well beyond the boundaries of the social world. The small world phenomenon, for example, shows up not just in the social world, but also in biology, economics, engineering, and popular culture. Examples of small-world networks now include power grids, neural networks, networks of biochemical reactions, interlocking corporate boards of directors, collaboration networks of scientists, and even movie actors.

This last example, incidentally, explains why Kevin Bacon appears to be the center of the movie universe: pure luck (any other actor

you've ever heard of would have worked just as well). But why is this apparent ubiquity of the small-world phenomenon interesting, and what meaning does network space have in terms of our lives? 'Six degrees' sounds like a small number, but is it really? The answer, it turns out, is both yes and no, depending upon the specifics of the question being asked.

In terms of what we know about the world, and who we care about, being six degrees away from someone is a very long way indeed. We know quite a bit about our friends (one degree) and in general we care what happens to them. Sometimes we know something about friends of friends whom we have never met (two degrees) and if something bad happens to one of them, we may feel an uneasy sense of proximity.

We may also be prepared to help them get a job, or trust them to a good job of painting the house more than we would some anonymous competitor. But a friend-of-a-friend-of-a-friend? Who? Someone who is three degrees might as well be a stranger to whom we owe nothing, and from whom we can expect very little. What happens to them is no more relevant to us than if we read about it in the newspaper.

But sometimes what they know, what they do, and what happens to them is relevant to us; and our perception that it isn't can be misleading and even dangerous. The explosion of the HIV-AIDS virus into a global pandemic, for example, was driven in part by the widely-held perception that it was confined to gay men and intravenous drug users. If you didn't know anyone "like that" you didn't have anything to worry about.

Turns out, you did, and that what happens beyond our very limited network horizon can still be close enough to hurt us. Or help us: while we can't just call up a friend-of-a-friend-of-a-friend and ask them for a job, we can still find that person by making just the right sequence of connections over time. In fact, we do this routinely, both when "networking" at cocktail parties or tracking down a source over the phone via a series of referrals. We know that it works-we just don't understand how.

Well now we are starting to, thanks to the awesome power of modern computing and also to a growing community of researchers who are willing to reach across the boundaries of their disciplines to create new scientific synthesis. The implications of this nascent science of networks are vast.

Whether we are concerned about the contagion of ideas and disease, the explosion of cultural fads and bubbles in the stock market, whether we care about individuals solving their everyday

problems, or the massively coordinated activity of a firm rescuing itself from a catastrophic failure, we need to start thinking in terms of networks.

When searching for a job or solving difficult problems at work, we routinely make use of our social connections. When making decisions about what restaurant to visit, what movie to see, or whether or not to buy the hot new tech stock, we pay attention to the advice and actions of our friends. And when our computer gets infected by the latest worm / virus, it is our friends, colleagues, and correspondents who are most at risk.

At the heart of all these everyday scenarios is a network of relationships through which information, influence, and resources are transmitted. Sometimes the network helps us, and sometimes it hurts us-being connected is both a good and a bad thing. But like it or not, care about it or not, the network is always there. And when not just you, but everyone can be connected to everyone else through only six short linkages, then what goes around comes around faster than you think. In this day and age, that is a message worth thinking about.

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