Current Comments

"It's a Small World After All"

Number 43 October 22, 1979

It has happened to most of us. You walk into an airport and suddenly you see an old friend or acquaintance. You say, "Isn't it a small world!" I met Harold Urey at a London airport this way about 15 years ago. A few years later, as I was about to climb the pyramids in Teotihuacan, Mexico, I saw my old friend Simon Newman of the United States Patent Office. It's not surprising, therefore, that someone wrote a song by that title. Walt Disney designed a delightful exhibit around this theme at Disneyland. As you ride the cable car through the tunnels, dolls of every nation sing "It's a Small World After All." I wonder if Disney knew that this "small world phenomenon" had been subjected to considerable scientific investigation.

There is a fair amount of literature derived directly from the term "small world phenomenon." Undoubtedly, statisticians indirectly considered one or more aspects of the problem long ago. Stanley Milgram of the City University of New York observes that the term was introduced in the social sciences by Ithiel de Solla Pool and Manfred Kochen while at MIT.[1] Belver Griffith of Drexel University states that Pool and Kochen's manuscript, first written in 1958 and only recently published in *Social Networks*,[2] is considered the foundation on which small world studies are based.[3] The authors originally hesitated to publish their manuscript because "we raised so many questions that we did not know how to answer."[2] But they hope that renewed interest in human network studies may answer their still unresolved questions.

About twelve years ago, in the first issue of *Psychology Today*, Milgram, while at Harvard University, described the small world problem this way. If you choose any two people at random, how many acquaintances must be linked together to complete a chain between them? X does not know Y but does know A, who knows B, who knows C, who knows D, who is Y's boss, spouse, professor, or whatever.[4] The number of these links determines the smallness of the world in which we live. The fewer the links the smaller the world. Of course, a definition of knowing or acquaintanceship is critical for precise studies. But, in fact, most researchers rely pretty much on the interpretation of participants in their studies.

Presumably Milgram was one of the first people to systematically count the number of intermediaries linking any two randomly chosen people.[5] Milgram selected three groups of "starters." The first group consisted of 100 Nebraskan stockholders. The second group consisted of 96 Nebraskans chosen at random. The third group consisted of 100 people living in the Boston area. The starters were all told about a "target" person, a stockbroker who lived near Boston, Massachusetts. Then they were given written instructions to send a document of some kind through the mail to someone who was more likely to know the target or know someone else who would.[6] The starters were told something about the target person to help them decide what acquaintance to select. But only those acquaintances they knew on a first name basis were permitted. This is a narrow definition of "knowing."

While 296 starters were selected originally, only 217 (73%) cooperated. However, only 64 of these (29%) started chains that reached the target stockbroker. Of these, twenty-four were Nebraska stockholders, 22 Bostonians, and 18 Nebraskans chosen at random.

Milgram found that an average of five intermediaries were needed to link two people, that is, a starter with a target![7] The documents reached the target through two major paths—occupational and residential. The former were generally the shorter paths. As the messages approached the target they often traveled along common pathways. Many messages reached one of three intermediaries who were probably "gatekeepers," people who have more than average contacts.[8]

Milgram and his student Charles Korte, now at North Carolina State University, also experimented with 540 Los Angeles starters to learn if there were differences in chain-length due to social factors. All starters were white. There were nine white and nine black targets in New York City. Only 5.5 intermediaries were required to complete a chain between a starter and a white target, but 5.9 between a starter and a black target.[1] This might demonstrate that whites are slightly less familiar with black social structures, but Milgram asserts that the difference in chain lengths is not statistically significant.

Since only 29% of the starting chains in the Nebraska-Boston study were completed, you might conclude that the number of intermediaries would be greater in a study having higher completion rates. John Hunter (Michigan State University) and R. Lance Shotland (Pennsylvania State University) point out that the probability of someone losing or discarding the relay document increases at every link in the chain.[9] Thus, if no documents are lost or discarded, chain lengths will be longer. Harrison White (Harvard University) designed a mathematical model to fit Milgram's Nebraska-Boston data and found that chain lengths increase from six to eight intermediaries when all chains are completed.[10] Stephen Fienberg and S. Keith Lee (University of Minnesota) confirm White's model with their own statistical analysis.[11] A.K.M. Stoneham (University of Cambridge)[12] and H.F. Andrews (University of Toronto)[13] use theoretical models to show how the size of a person's acquaintance network and his or her social class can lengthen or reduce a small world chain.

However, chain lengths in studies with high completion rates are not longer than Milgram's Nebraska-Boston chains having about five intermediaries. If anything, chain length is *not* significantly affected when the number of completed chains increases! Craig Lundberg (Oregon State University) directed two groups totaling 462 starters at targets working in the same Dallas business firms. With 263 completions (57%), the mean chain lengths for the two groups were 2.6 and 3.5 intermediaries.[14] Both chain lengths are significantly *shorter* than Milgram's Nebraska-Boston chains.

Shotland measured chain lengths between students, faculty, and administrators at Michigan State University. Fifty-five students and the same number of administrators and faculty acted as starters. Each starter was given six booklets to pass to two student targets, two faculty targets, and two administrator targets. Thus, a total of 990 chains were initiated and 69% reached their targets. The shortest chains extended from administrator starters to administrator targets and had a mean length of about one intermediary! The longest chains, from faculty starters to student targets, had a mean length of 5.55 intermediaries.[5] This is not significantly longer than Milgram's Nebraska-Boston chains, and it agrees exactly with his Los Angeles-New York chains with white targets (5.5 intermediaries).

Jean Guiot (Boston University) directed 52 French-Canadian starters from Montreal at a target person who also lived in Montreal. Forty-two chains (85%) reached the target, and the mean chain length was 4.7 intermediaries.[15] This is in close agreement with Milgram's Nebraska-Boston data. The mean length of chains originating with Boston starters was 4.4 intermediaries![7]

Several researchers modified Milgram's small world method to examine other aspects of social networks. Peter Killworth (University of Cambridge) and H. Russell Bernard (West Virginia University) used a "reverse" small world method to measure how many acquaintances a typical person uses as first steps in a small world experiment. Instead of using one target and many starters, they presented a list of 1,267 targets to each of 58 starters. For each of the targets the starters were asked to name an acquaintance who would act as the first link in a small world chain. They could choose to use the same acquaintance more than once. But a starter could choose a maximum of 1,267 different acquaintances if no choices were repeated. The results show that many choices *are* repeated—the typical starter chose only about 210 different acquaintances.[16]

Stephen Bochner (University of New South Wales, Australia), Eloise Buker and Beverly McLeod (Culture Learning Institute, Hawaii) examined friendship patterns between students living in an international dormitory.[17] In another study, Bochner modified Milgram's small world method to analyze acquaintance circles between people living in a high rise apartment building in Australia.[18] Bonnie Erickson and Paul Kringas (University of Toronto) determined how social distance between elected representatives in Ottawa and their constituents varies with the constituents' socioeconomic status.[19]

If you describe the small world problem to the average person, he or she may find it hard to believe that any two randomly chosen persons can be connected by only about five intermediaries. But then the average person doesn't have much insight or training in probability theory. Ask someone what the odds are of finding two people who have the same birthday at a gathering of 25 people. Most people find it hard to believe it is about even money.

Milgram says the small world problem is easier to understand when you "think of the two points [starters and targets] as being not five persons apart, but five 'circles of acquaintances' apart—five 'structures' apart."[4] Based on records kept by 27 persons of whom they came in contact with over 100 days, Ithiel Pool (MIT) and Manfred Kochen (University of Michigan) estimated that the average person's circle of acquaintances includes between 500 and 1,500 people.[2] Assuming the mean number of a person's acquaintances is 1,000 we can predict the number of links in a small world chain by asking what power of 1,000 will cover the total population involved. In a population the size of the US, it would take between two and three powers of 1,000 to cover 220 million people. Thus, the mean length of a minimum chain between two random persons in the US would be *less* than two intermediaries.

Small world studies suggest that it is indeed a small world—that individuals are not nearly as isolated as many of us may think.[20] We are all intimately connected in a web of "invisible" acquaintances. In fact, a network of casual acquaintance ties reaches a larger number of people and covers a greater social distance than strong family or friendship ties![21] Like "old boy networks," acquaintance networks make it easier for people to locate jobs,[22] exercise political influence,[23] and find available social services.[24]

Derek de Solla Price observes that "old boy networks" in science lead to more informal relations between scientists. "In a small group, like high-energy physicists or Israeli scientists, personal linkages make it very difficult to exercise the norm of impersonality. You know the other people too well and have too many emotional links to them to be completely dispassionate about whether their paper should be published or whether their grant should be funded. When you start with what is already a small world and not the whole world, the small world phenomenon is responsible for the breakdown of impersonality in scientific groups."[25]

Greater knowledge of the small world phenomenon among scientists might be useful in designing better communication systems. For example, Susan Crawford, director of the archive-library of the American Medical Association, interviewed 160 scientists involved in sleep research who informally contacted one another in the course of their studies. She found that 33 scientists were the focus of a great number of contacts. No scientist in the sleep research network was more than three persons removed from a "gatekeeper" scientist! In fact, information transferred to a gatekeeper scientist could be transmitted to 95% of the network scientists through only *one* intermediary or *less*.[26] Identification of similar gatekeepers in other scientific specialties could be a powerful tool in setting up lines of communication for rapid dissemination of current information.

I suppose it is not entirely surprising that one who studies citation networks or genealogical trees should be attracted to small world networks. Griffith's work on measuring informal communication in biomedical specialties is applicable.[27] Price's work on communication patterns in "invisible colleges"[28] is quite relevant, as is the more definitive work of Diane Crane.[29]

Price sees a relationship between small world studies, ISI®'s data on clusters of scientific subfields, and his own work on the growth of science. "The size of the Griffith-Small clusters of subfields is about the same size as a person's network of personal acquaintances and the size of the Royal Society in the 17th century—an order of magnitude of 100 or so individuals. Since the days of the Royal Society, when you had one or two such groups of 100 in the world, every seven or ten years the number of groups has been doubling. As the number of scientists has grown, the number of groups or clusters or small worlds grow accordingly. The growth of science goes on through this growth of the number of almost autonomous subfields that exist. This means that there is a very important constancy built into science."[25]

Based on personal experience, I'm sure that fewer than five intermediaries are required to connect any two scientists chosen at random. If you and I were to meet somewhere, there is a high probability that we would have a mutual first name acquaintance.

Although the world scientific community is spread throughout the globe, it is linked by common educational and professional/occupational contacts. If we include people we "know" through the literature then the chain is very short indeed. Failing anything else one can always talk about Linus Pauling, Harold Urey, Joel Hildebrand, or similar visible scientists. I've stopped counting the number of people I meet who took freshman chemistry with Joel Hildebrand. Professor Hildebrand has taught and lectured to over 100,000 freshmen, graduate students, and scientists.[30]

It is also probable that scientists meet more people professionally than the average individual. Science is indeed a very social business. For the elite there are academy memberships, international congresses, awards committees, and foreign scholar exchange programs. Every time a new contact is made the scientific world becomes smaller.

For the student just starting a scientific career it may not be very helpful to point out that he or she is linked to some other student in the world through a small group of well known scientists. But as I've said when discussing information encounter groups,[31] it is not all that difficult to establish useful links in the communications system of science. Perhaps a greater awareness of the small world phenomenon will make more people aware that the democracy of science is a reality, but only if you take advantage of the right opportunities.

The world of science, like the world at large, is vast. But we can identify, in science and in politics, "old boy networks" or whatever you may want to call them. Unlike politics, it is relatively easy to penetrate these scientific networks, if you have a legitimate basis for doing so.

The reason ISI is working so hard to produce maps of the small *and* large worlds of science is because I believe the ISI *Atlas of Science* will aid scientists in identifying the appropriate intermediaries between them and whatever "target" they choose. Of course, there's a point at which the simile becomes far-fetched. But in the computer graphic system we are developing all you do is key in the scientist's name and almost immediately you see all the "starters" to whom this target is linked. Fifteen years ago, my brother Ralph established the graph theoretic dimensions of this problem at ISI.[32] While the computer graphic system is based on citation linkages it could easily be modified for related purposes. For example, by feeding in the names of all editorial board members one could quickly determine influence networks in the journal publishing business. Or one could use such methods to identify potential subscribers for new journals and magazines.

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*Reprinted in: **Garfield E.** *Essays of an information scientist.* Philadelphia: ISI Press, 1977. 2 vols.