Sources

We are surrounded by systems becoming more complex, from embryos and ecosystems to industrial processes and international law.
(Jack Cohen, speaker at the September '04 Lab)

The major premise of The Lab is that we need new vocabulary, new mental models, new ways of thinking, different concepts to help decision-making in our highly complex, highly interconnected, rapidly changing business world.

Events and their circumstances are complicit processes; there are no simple cause and effect relationships. Actions, events, contexts are multi-causal and recursive; interacting complex systems modify each other, over and over, and any result can differ radically from what's gone before. Sub-plots can take new significance when external events or accidents impinge. MG Rover closes, and the whole supply network changes irreversibly as companies and people take other routes, becoming different identities in a different world. Old rules don't work, order whirls, surprise is unnervingly insistent, no-one is in control.

Gauges on the dashboard make a difference

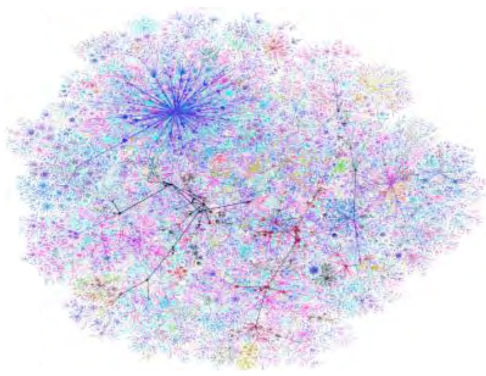
But our minds baulk at apparent randomness and disorder. Some people flail and try to "simplify complexity" or demand quick meaning from the inexplicable in order to manage or control it. Yet if a system can be seen in its full exuberant state, however complicated and difficult, previously hidden opportunities will emerge.

Just as a dashboard, full of carefully calibrated gauges, cannot be mistaken for the moving car, no single mental model provides The Answer. New perceptions, new gauges will help us, as the Game Theory analysis of the Ford and Toyota supply chains did at the last Lab meeting, to see non-sense for what it is, and to make new-sense of what's happening and might happen.

A new suite of gauges: networks & their dynamics

Networks and their dynamics give us another important suite of mental models. In his book *Sync,* Steve Strogatz says: *Disparate networks show the same three tendencies: short chains, high clustering, and scale-free link distributions. These coincidences are eerie, and baffling to interpret.*

This eeriness is familiar to us when, say, we bump into a school friend from decades ago in some foreign city. We're surprised at the *small world* we've just encountered. Amazement at the meeting, however, is misplaced.



Graph of the router level connectivity of the Internet measured by Hal Burch & Bill Cheswick's Internet Mapping Project

Not just social networks, many others are "small worlds' too. Markets, epidemics, traffic flows, supply chain interactions, the Internet router system, food webs in ecologies, Fortune 1000 directors, ownership of German banks, the Kevin Bacon game (the Internet Movie Database exploration), the metabolic network of E *coli,* the neurons in our brains.

The work of Strogatz, Mark Newman, Duncan Watts and others indicates there are similar processes and dynamic patterns in all small world networks. The number of links between nodes is surprisingly low, and "weak ties", the often unnoticed connections between far-away nodes, drive network dynamics in unexpected ways. For example, the Iowa Electronic Market, linking a few traders' distributed intelligence, better predicts election results than carefully researched polls of thousands; traffic lights break down causing lorries to snarl up miles away; a rehousing policy, crack on the streets, fewer physicians, and Baltimore suddenly had to cope with spiralling rates of sexually transmitted diseases.

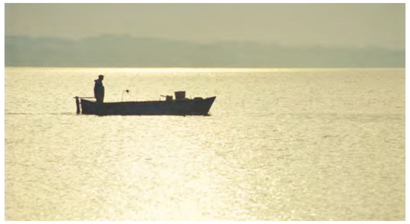
Million to one chances happen nine times out of ten

Here are two further examples of social small worlds, both fact not fiction: Last year I set 27 Italian postgrads in Pisa the task of discovering how close they were socially to my son. Predictably within minutes, we found everyone in the class was within one or two 'degrees' from him; one man even knew of him by name, several others were friends of his friends.

A few hours after hearing my then-teenage daughter was seriously ill in a Bandung hospital (it's in Java and yes, she's fine now!), my cousin's friend's Thai wife, her existence unknown to us earlier that day, was at her bedside. It would have been a different friendly face there, had my cousin been out when I telephoned him.

Small worlds & the strength of weak ties

So what appear amazing coincidences are, in fact, everyday commonplaces. And this is how it works: Imagine two kinds of society: CAVEMAN where everyone knows everyone else, and there are no visitors; it's a densely clustered, closed network. In contrast, people live alone in SOLARIA, rarely meeting across a sparse landscape. Any random connection between any two individuals is as likely as any other.



A Salento boatman: reproduced with kind permission of Ronny Leva

Most people's social relationships comprise elements of CAVEMAN and SOLARIA, and everything in between.

We belong to several dense CAVEMAN-like clusters of *strong ties*, perhaps family, work colleagues, sports or other affiliation groups. People also have many more *weak ties*, up to 2000 or so (more with address books and other memory aids) through acquaintances, friends of friends and SOLARIA-like random meetings.

Weak ties are the bridge between two densely-knit social clusters. If only one person from a cluster knows someone from another quite separate cluster, then *everyone* is in a small world network. Watts' theoretical work on small worlds proves ***very few random links make dense clusters highly connected.***

Thereby Thai comforters can be at Javan bedsides of Brummie kids whose brothers are known to Pisan postgrads.

From the birth of cities to 21st century connectivity, random links of different viewpoints and diverse expertise has driven human creativity, ingenuity and inventiveness. Indeed, recent Harvard Business School research suggests innovation happens through *weak* not strong social ties. Of the UK cluster policy, Pandit & Cook show companies near others in *related* lines of activity are more successful than those in the *same* line. The DTI Science & Innovation Strategy encourages *multidisciplinary* lines of research, believing this will generate innovation.

Taipei market: reproduced with kind permission of Ronny Leva

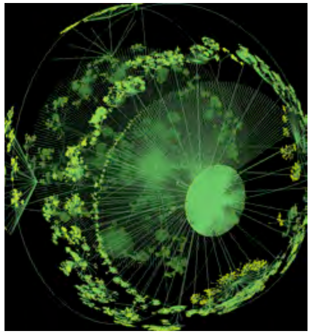
Mavens, salespeople & hubs

Stanley Milgram, the Yale-based social scientist famous for his experiments on human obedience, also carried out an intriguing social experiment in the 1960s. Randomly selected people in Nebraska and Kansas were asked to send packets to specific targets in the Boston area, via people they knew personally on first-name terms. No transfer took more than six people, hence the notion we are only 'six degrees of separation' from each other. Watts points out the evidence from the Milgram experiment is more tenuous than many believe; nonetheless, social relationships are in small world networks.

For beliefs, values and ideas to spread, Milgram asserted three kinds of people are needed: *mavens* (specialist experts), *salespeople* (persuaders) and, finally, *hubs*, people who are highly connected, i.e. people with many weak ties.

Scale-free networks

Albert-Laszlo Barabasi, a brilliant Transylvanian physicist now in the States, has shown that if there is growth and preferential attachment simultaneously in any network, then hubs and power laws emerge too. He termed these networks *scale-free;* put simply, the nodes of a scale-free network are neither randomly nor evenly connected. In any *scale-free* network, it's likely many transactions are funneled through a well-connected hub, such as Chicago O'Hare Airport, or the Google portal. The whole network is vulnerable at such hubs, hence scale-free networks occasionally collapse catastrophically and unpredictably. The US power grid is a scale-free small world network and, rarely but dramatically, fails. Experts (see Slate) gave managers the counterintuitive advice to loosen control of the network, and to allow many small failures in order to grow and sustain robustness in the whole system. (NOTE: 'Small world' networks can be *either* scale-free *and/or* have randomly distributed connections.)



3D hyperbolic graph of Internet topology, developed by Young Hyun at CAIDA.

Networks are not structures, but dynamic, non-linear, recursive, emergent, often (but not always) scale-free *processes*. They are usually highly robust, though ***efficiency always, but always generates fragility in a network***.

(Both Internet topology graphs reproduced with kind permission of Martin Dodge at UCL's Cybergeography Project.)

The Everett Roger model: diffusion of innovations

In 1962, the American sociologist and statistician, Everett Rogers described the diffusion of innovations as a bell curve with innovators (2.5%), early adopters (13.5%), early majority (34%), late majority (34%) and laggards (16%). Despite being widely cited and very influential, this simplistic model is now woefully inadequate, if not plain wrong. (Still useable, however; models can sometimes be helpful and wrong, especially if you know how they're wrong!)

Milgram's work and Barabasi's findings of scale-free social networks suggest a bell-curve model has to be off the mark; there cannot be a linear progression from group to group. Fads and fashions do indeed cascade, and equally good or better innovations wither. Something else must be going on in the network.

Viral marketeers work on the premise that the diffusion of an idea is like that of disease. Though sometimes useful, their models miss at least four important points. The first is that epidemics are really ever so complicated, not easily modelled or copied at every level. Disease is always multi-causal, some factors weigh heavily, some slightly, some important only sometimes, some factors rarely or never.

Infection, immunity & Great-Grandma's latest addiction

What might be the factors involved when gregarious Great Grandma . . . 92-years young, Centro bus-pass aficionado, avid bookworm, marmalade-maker extraordinaire, persistent putter of plastic bags into the backs of cupboards as well as Jacques Brel devotee . . . toddles along to chat to young Joe, film-buff and keen-as-mustard techno-hippy in the local Apple store, and buys from him the means for her new addiction, being ear-plugged to her recently-purchased iPod?

What are the changes in the environmental context, enabling this particular agent (an iPod) to enter this unlikely host (Great-Grandma, avowedly immune, *I'm too old for computers, dear*)?

Epidemics: agents, hosts, vectors & rates of infection

There are many factors, most of them hugely complicated, involved in the spread of a disease, and all these factors interact with each other. The ensuing complexity inevitably leads to unpredictability at many levels.

But, although it can seem quite random at some levels (e.g. whether an individual 'catches' a disease), patterns can emerge at a population level. Epidemiology is the study of infections and disease in *populations*, not individuals, hence hugely useful for social and healthcare decision-makers whose advice often conflicts with citizen choice — infant vaccination, animal culls, rabies policies at UK ports, etc.

If the disease agent, be it virus or bacterium, infects a host who, before recovery or death, infects one or more other hosts, there is a chance of an epidemic occurring. An agent can infect a host directly or, sometimes via a vector, which can be animate or inanimate. Host carriers can be true (i.e. infected but not diseased), incubatory (that is to say, the agent has 'caught' the disease, is infected *and* the agent has replicated enough times to make the host infective but not yet ill) or convalescent.

The factors for disease epidemics

The many causal factors for disease are often categorised as:

(i) *the probability of transmission,* dependent on infectivity (how easily the transmission occurs), virulence (the degree or the ability of the agent to cause disease in most hosts) and pathogenicity (how ill the host becomes)

(ii) *the duration of the infectivity* - e.g. Ebola is 2-3 days; measles is 9-10 days, HIV, with some drug regimes in some hosts, is now 10+ years

(iii) *contact rates* - i.e. who comes into contact with the agent

(iv) *susceptibility,* the determinants for which can be changed through the physical environment (e.g. temperature, nutrients, toxins), interventions (e.g. vaccines, animal dips, movement controls, quarantine) or other biological conditions (e.g. being in utero, immunosuppression)

It is the fourth of these, ***susceptibility***, which is the fuel by which epidemics run.

But it gets even more complicated than this: a host's susceptability depends on all the factors above *and* upon whether or not the agent is, itself, changing.

Susceptibility as fuel . . .

Some agents, such as measles and other apparently 'childhood' diseases, don't change over time-scales relevant to us. So when the number of susceptibles drops through death, natural or cross immunity effects or vaccination, the disease dies down, flaring again only when the number of susceptibles rises through births, movement of people or loss of immunity. In a sparsely-populated place such as Iceland, measles dies out for years, until a visiting infective sparks it off again.

In contrast, the genetic coding of HIV and influenza allows variability; agents can change through *drift* (to which the host has partial immunity) or *shift* (to which the host hasn't any immunity). Thus immunity from last year's 'flu, or from one kind of HIV is little or no protection from new infection.

The second & third points viral marketeers miss . . .

As well as underestimating the complexity of epidemics, viral marketeers often don't fully recognise two *qualitative* differences between the spread of disease and that of an idea. An individual is much more likely to be 'infected' by an idea or product they have never had direct contact with, providing *a friend or influencer has been exposed* to it. An innovation's success requires a trade-off between local reinforcement (you *believe* an idea/product is good through endorsement) and *global* connectivity, as well as the local connectivity disease requires.

And, unlike disease, percolation of an idea can be *prevented* because the network is very well-connected. Too much information and some networks clog or go into overload (too many opinions, spam on the Internet, traffic congestion).

And a fourth point: networks are diversity engines

As in biological systems, industries are in symbiosis with each other, as well as competition. Moreover, many highly dynamic complex systems interact *as quickly as ideas* take hold. Very rapid recursion is therefore inevitable, generating ever more diversity. The new materials, new software of Great-Grandma's iPod makes hard-drive, music-maker, personal organiser, et al freeing, as all technology does, today's imagineers and engineers — and consumers — from past constraints.

The world's first and only rotating boat lift, created by a complex network of ideas and people - imagination, design & engineering, materials & control systems impossible a few years ago

The Falkirk Wheel raises 600 tonnes of water over (115ft) in under 4 minutes, using only 1.5kW energy.

Finding Great-Grandma . . .

Despite being only six degrees from each other, it can be difficult to find a gregarious Great-Grandma. Sometimes, as with Thai comforters, relying on social networks is good enough to find the target; after all, people have a finely tuned sense of social distance. (I called my cousin because I half-recalled his best man was now living in Indonesia; second on my list was a colleague whose importer-exporter brother works out of Perth in Australia.)

But it's a mathematically intractable problem if the search end point is unknown, and is aptly called the *small world search problem*.

One approach is to broadcast everyone. But this is costly or if, as said earlier, the cost is low or zero (e.g. email), then the system itself clogs or overloads.

The models offered by viral marketeers can be successful with "flu-like" fashion goods. (Sony *gave away* their PlayStation to fashionably gadget-geek young men in populous towns to feed the infectivity). But disease models are inadequate when the connections or networks between products and buyers are more complex.

What always pays off in a complex network is investment in the network itself. Contrary to corporate and popular belief, the network can have as great, if not more influence on the success or failure of an innovation as the inherent appeal of the innovation itself. Thus investment in the *network* (think Napster, think freely-bundled iTunes) will pay off handsomely.

Disconcertingly for business strategists, though, where opportunities will emerge is unknown until they begin to happen. But happen they will.

Further reading

Barabasi, Albert-Laszlo *Linked: The new science of networks.* Plume Books, 2003. (The first chapter can be downloaded from his web page at Notre Dame University)

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Kelly, Kevin *New rules for the new economy: 10 ways the network economy is changing everything.* Fourth Estate, 1999. (Or download free from www.kk.org)

Strogatz, Steven *Sync: the emerging science of spontaneous order.* Penguin, 2004.

Watts, Duncan J *Six degrees: The science of a connected age.* Vintage, 2004.