INTERNATIONAL ISLAMIC UNIVERSITY MALAYSIA

Information Security in Scale Free Networks

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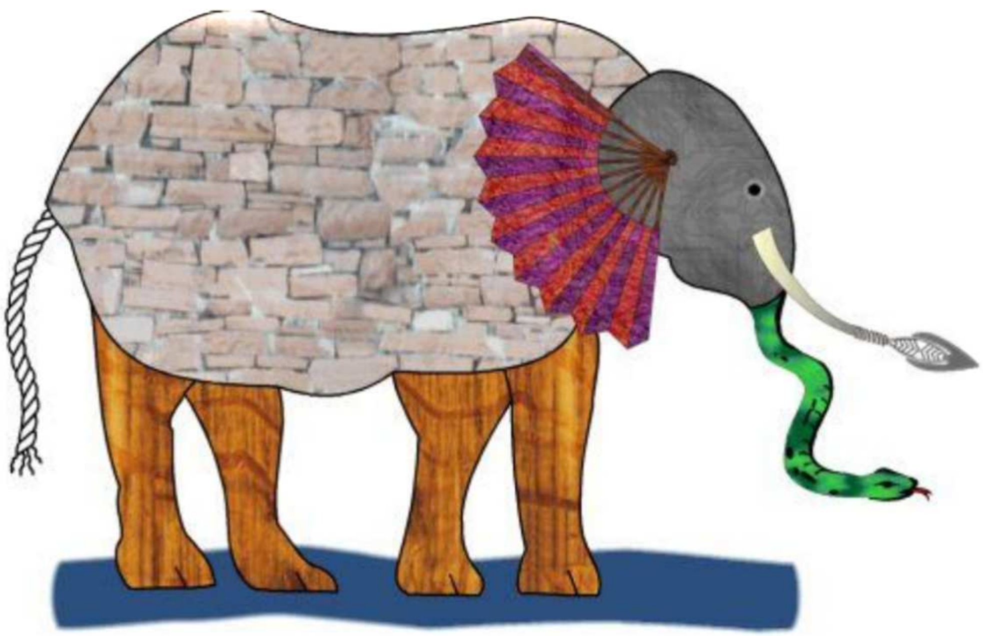
Outline of Presentation

- **Background:** Birth of Network Science
- **Motivation:** From Disorder to Order
- **The Problem:** Addressing the phase transition from **The rich get richer** to **Winner takes all**
- **Information Security in Scale Free Networks**
- **Conclusion**

Human Perceptions



John Godfrey Saxe's (1816-1887) version of the famous Indian legend,

It was six men of Indostan
To learning much inclined,
Who went to see the Elephant
(Though all of them were blind),
That each by observation
Might satisfy his mind.

"The only man who behaves sensibly is my tailor; he takes my measurements anew every time he sees me, while all the rest go on with their old measurements and expect me to fit them."

George Bernard Shaw

Reductionism and Complexity

- A better understanding of the pieces cannot solve the difficulties that many research fields currently face
- There is no cancer gene: a typical cancer patient has mutations in a few dozen of around 300 genes
- No single regulation can legislate away the economic malady that is troubling us today
- Consciousness cannot be reduced to a single neuron
- In fact the more we know of the **PIECES** the less we understand the **WHOLE**

Networks are Everywhere

- The brain is a network of nerve cells connected by axons
- The cells themselves are networks of molecules connected by biochemical reactions
- Societies too are networks of people linked by friendships, professional ties etc.
- Food webs and ecosystems can be represented as networks of species
- Internet, power grids, language (made up of words connected by syntactic relationships) …

Novelty of Network Study

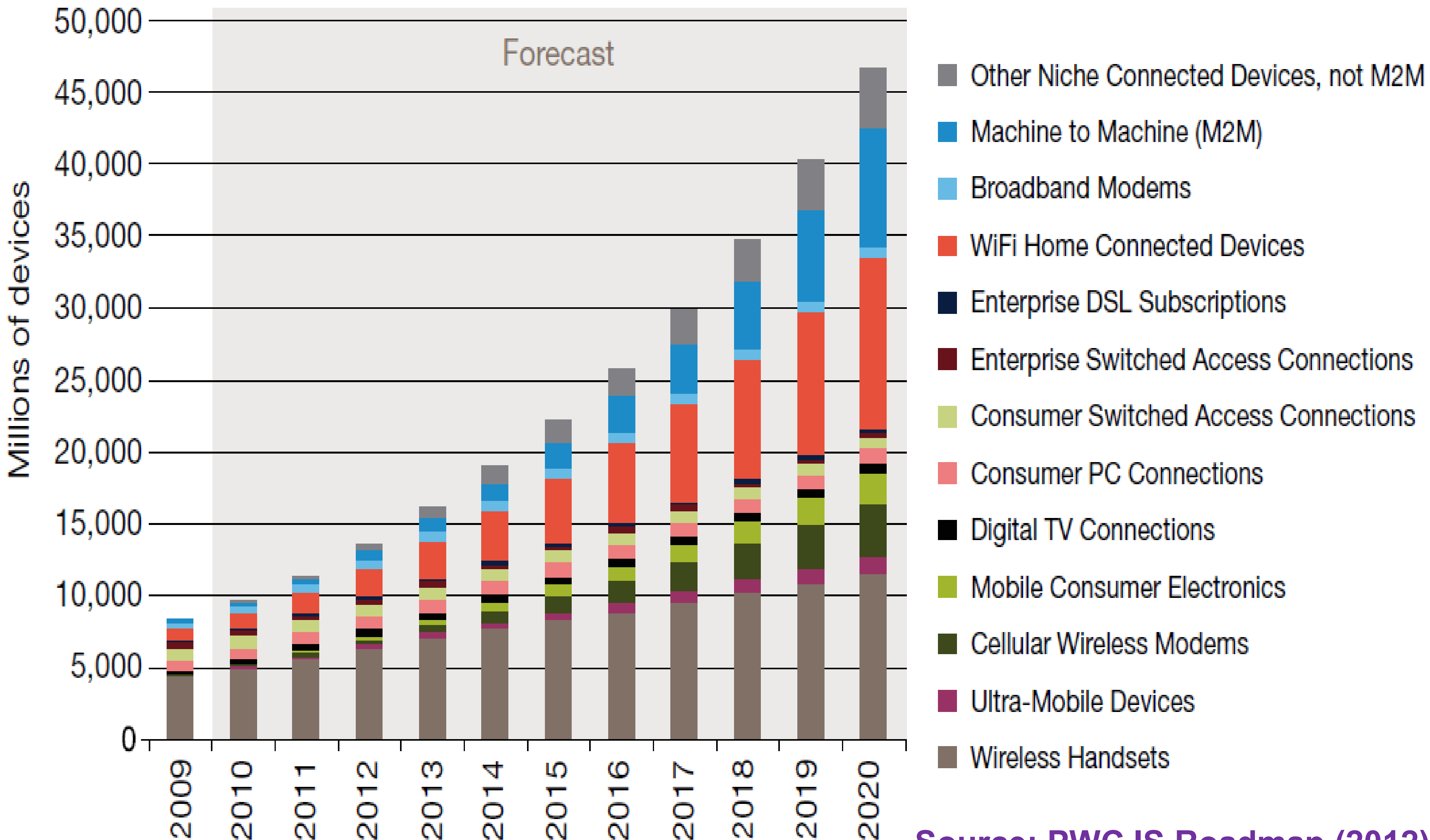
- The novelty lies in **Scale** and **Complexity**
- The driving force behind this change is **DATA**
- The current science of networks is fueled by the availability of vast amounts of information about them
- Fuelled by cheap sensors and high throughput technologies the data explosion that we witness today, from social media to cell biology is offering to **MAP** the inner workings of many complex systems

DIGITAL ROADMAP

- 2000-2010: Withdrawal
- 2010-2020: Effervescence
- Beyond 2020: The Attoscopic World

Michel Riguidel "Digital Security in the Future", ICT Shaping the World: A Scientific View , Wiley (2009)

Figure 4: Proliferation of devices – growth of global IP connected devices, 2009-2020

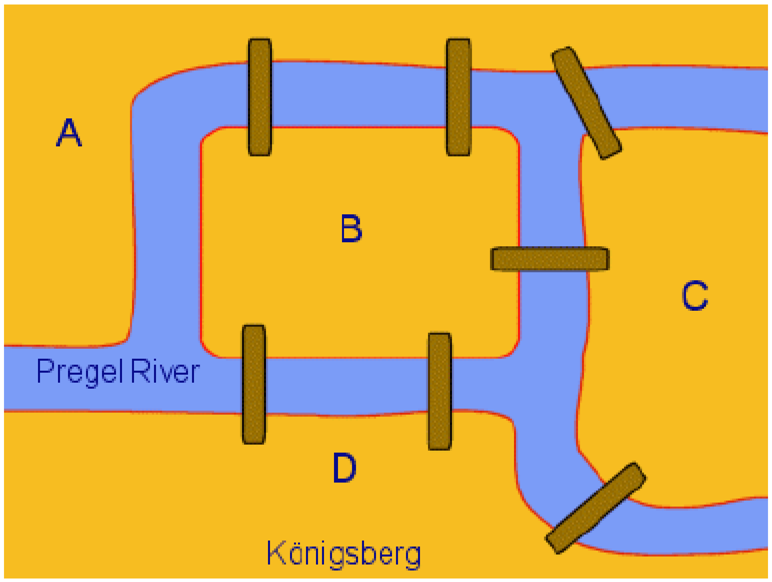


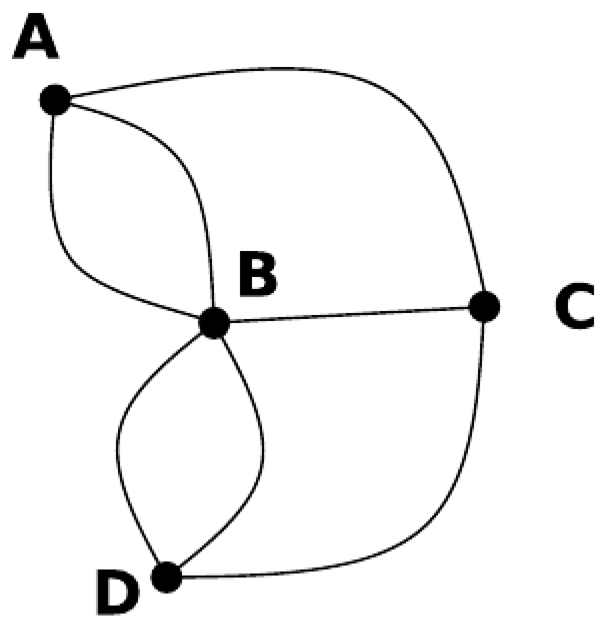
Source: PWC IS Roadmap (2012)

Graph Theory: Basis for thinking about networks

- Originated by Euler in 1741
- In Konigsberg (his home) the patrons of coffee shops tried to solve the ‘bridge problem’
- Could a person cross all the bridges without crossing one twice?

Reformulating the problem





- By replacing land area with nodes and each bridge with a link Euler obtained a graph with four nodes and seven links

No Solution!

- A solution path cannot exist on a graph that has more than two nodes with an odd number of links
- Euler declared: "The existence of the path does not depend on our ingenuity to find it. Rather it is a property of the graph"
- $\Rightarrow$ Graphs (or networks) have properties hidden in their construction that limit or enhance our ability to do things with them

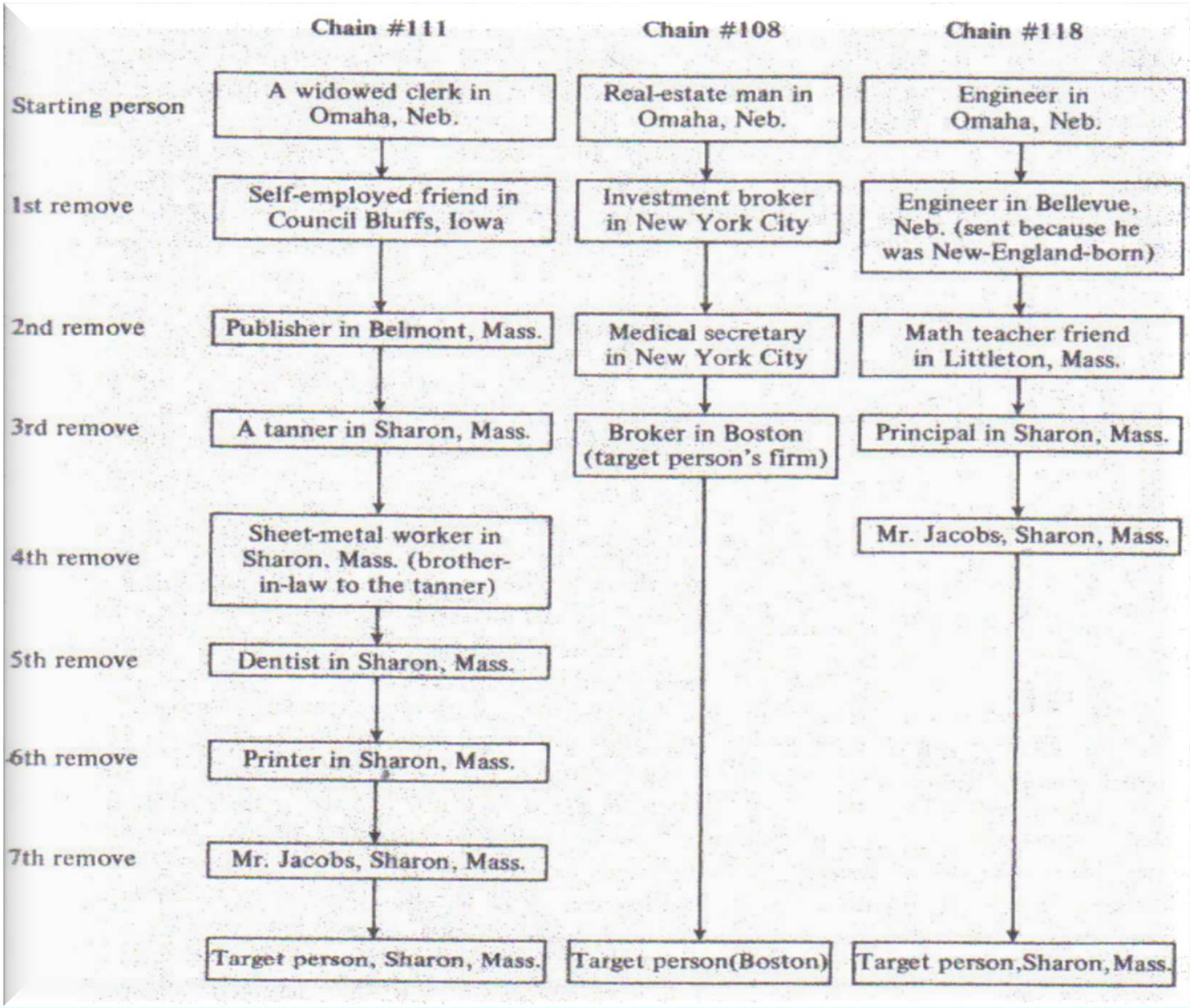
A Small World

- Have you ever experienced your new acquaintance is your friend's friend?
- Have you ever said "What a Small World!!"?
- <u>Question</u>: For given any two persons in the world, how many intermediate persons are needed to connect the original two persons?

Stanley Milgram's Experiment

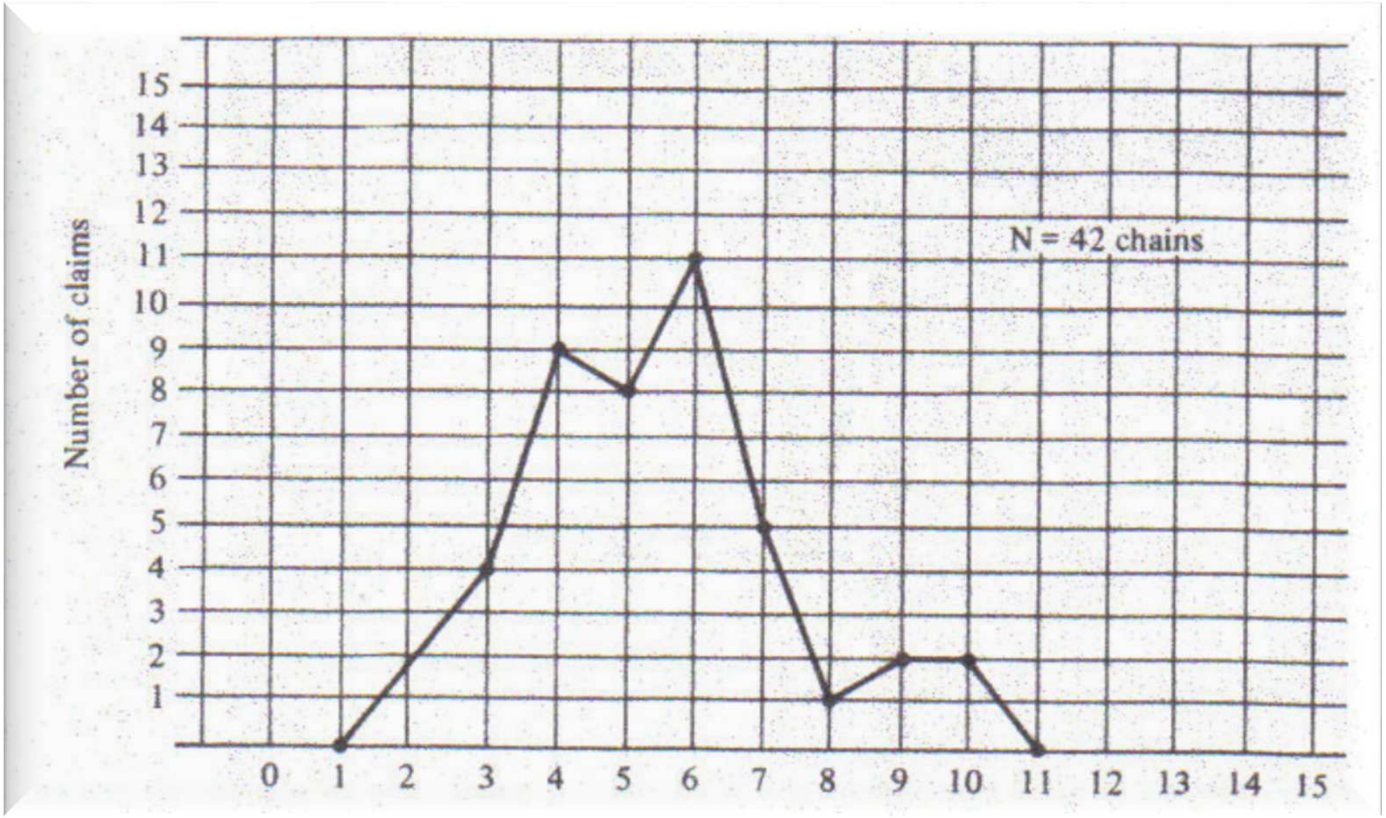
- He sent mails to random people in Kansas and Nebraska, and asked them to re-address the mail to their acquaintance who may know the two "target" persons, one in Sharon Massachusetts and the other in Boston.

Stanley Milgram (1967) The Individual in a Social World



Stanley Milgram (1967) The Individual in a Social World

Average Number of Intermediate persons is 5.5



How many people should ONE person know so that all the people in the world are completely connected?

Degree 1 A person links 50 people

Degree 2 50^2 = 2500 people

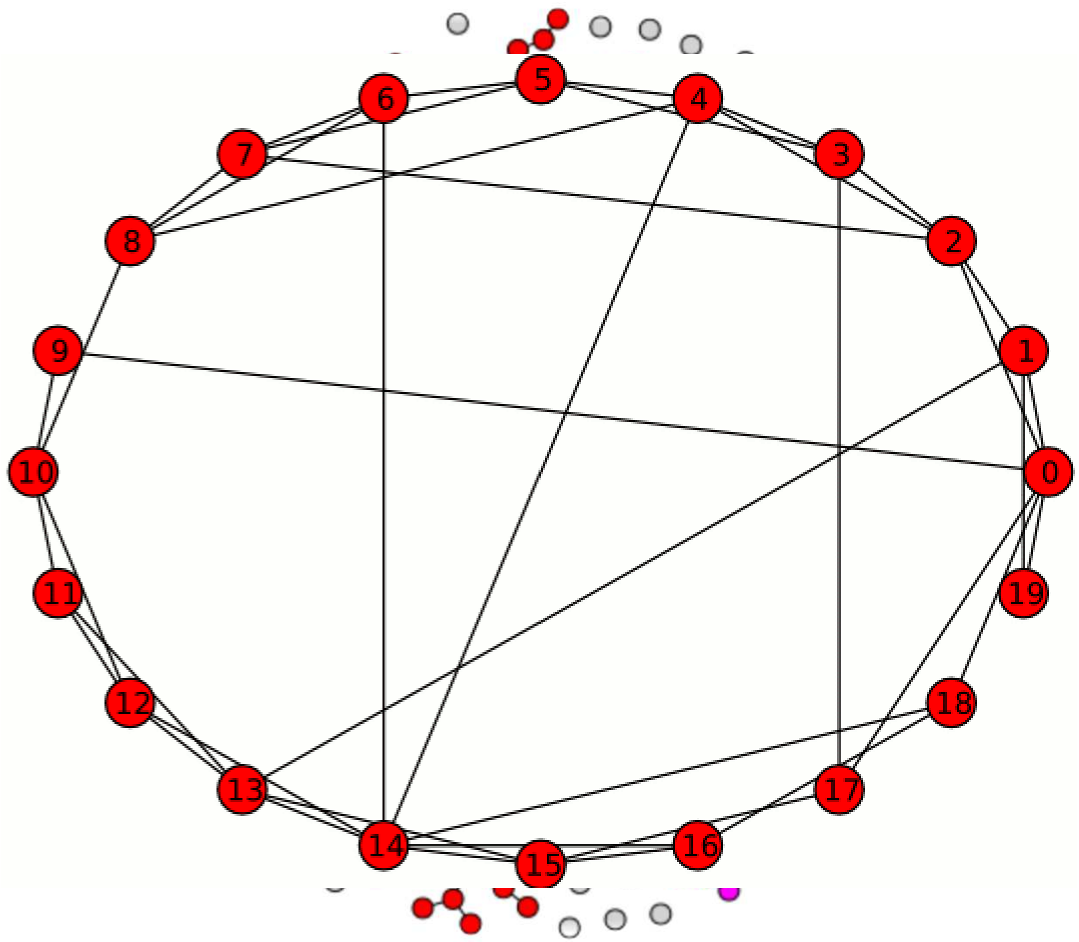
:

Degree 5 50^5 = 0.31 billion people

Degree 6 50^6 = 15.6 billion people

Six degrees are enough for 7.2 billion.

Small World Random Networks



The Real World is Smaller Than We Thought

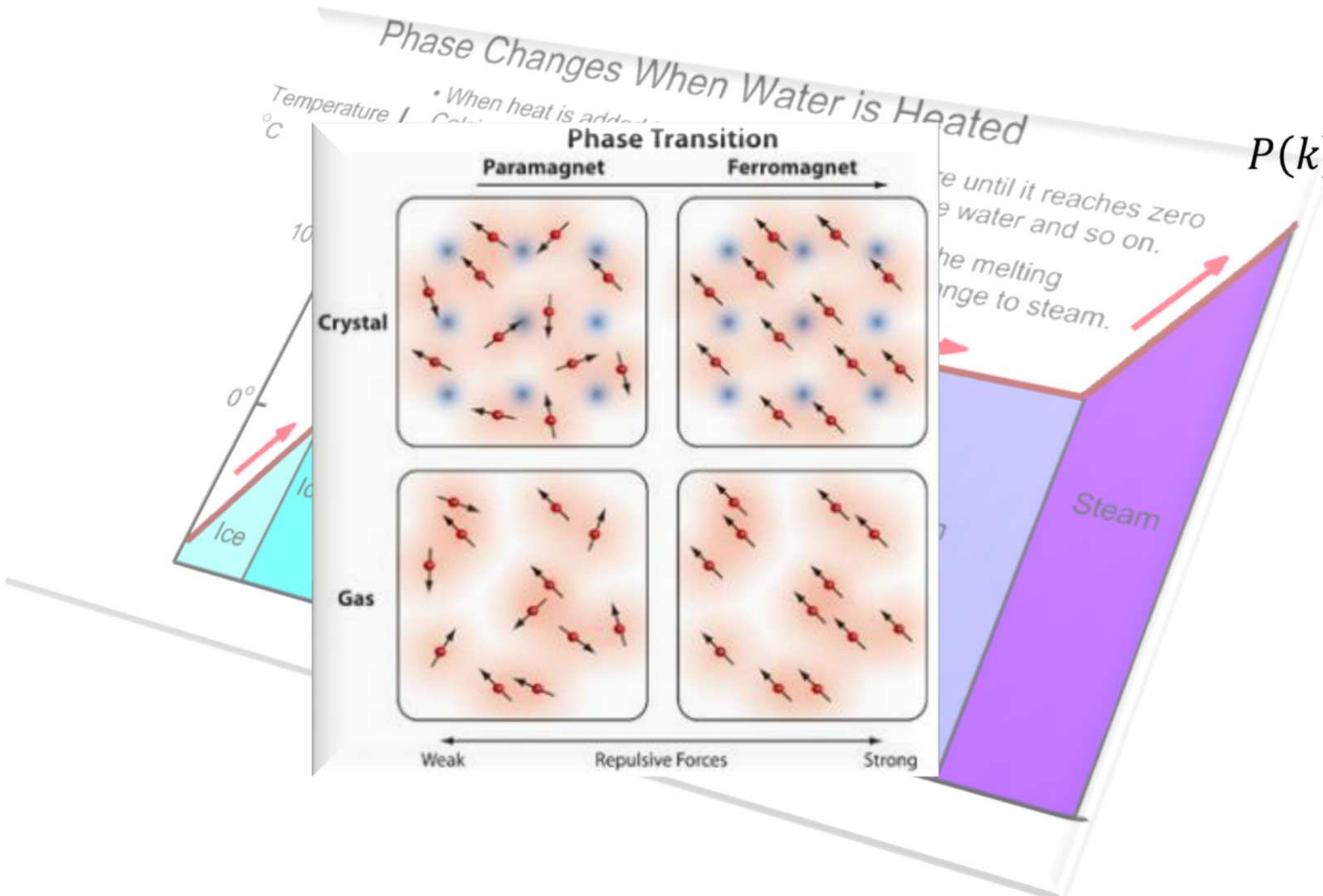
- Networks:
  - Small World[1] (follow a bell curve)
  - Scale Free[2] (obey power law distribution)

1. D. J. Watts and S. H. Strogatz, ‘Collective dynamics of small world networks’, Nature 393 (1998) 440-442
2. A. L. Barabasi and R. Albert , ‘Emergence of scaling in random networks’, Science 286 (1999) 509-512

Vilfredo Pareto – 80/20 Rule

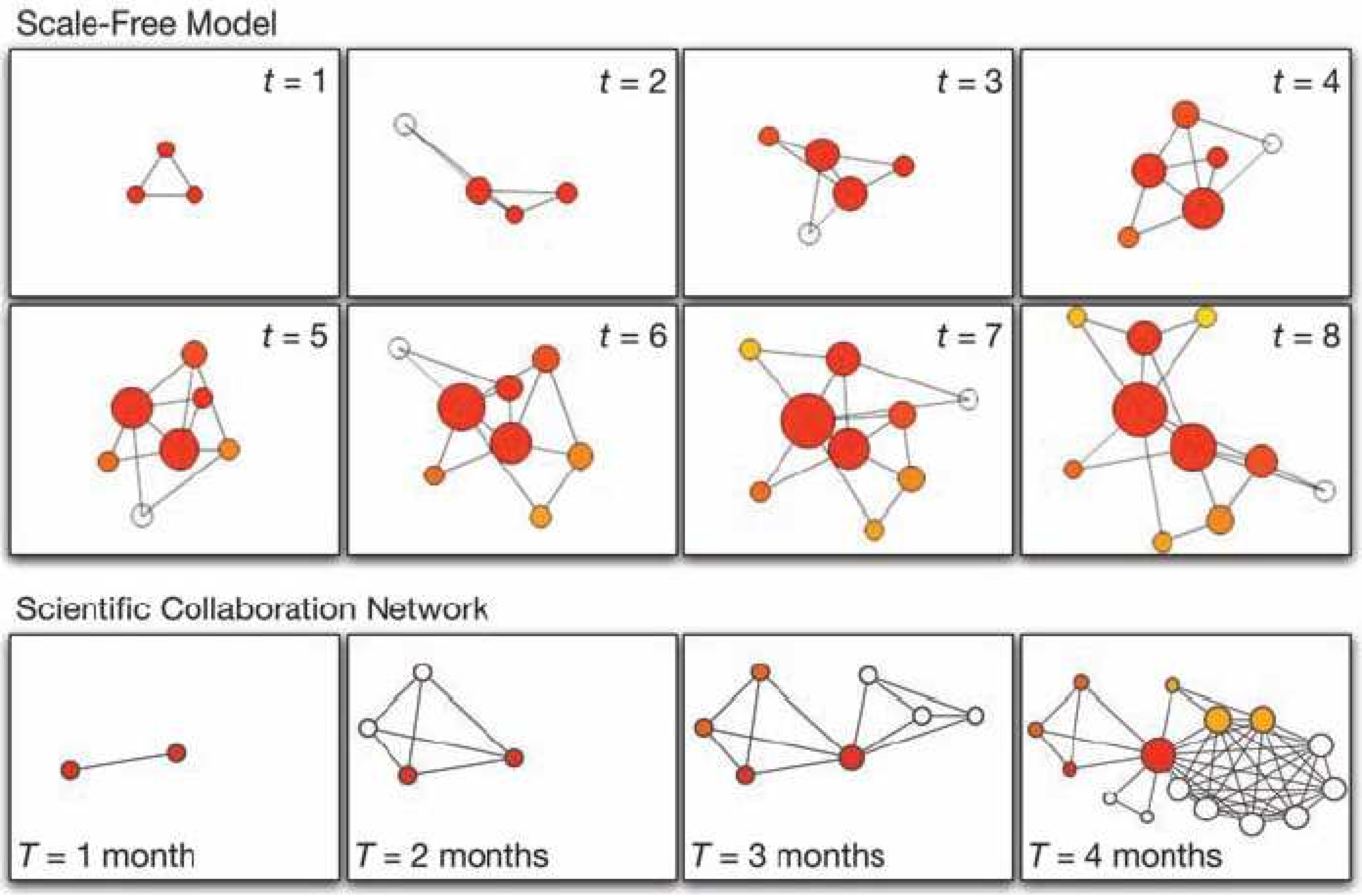
- He observed in 1906 that 20% of the Italian population owned 80% of Italy's wealth
- He then noticed that 20% of the pea pods in his garden accounted for 80% of his pea crop each year
- More importantly, he noticed that a few quantities in nature and economy defy the bell curve but instead follow a power law – 80/20 Rule

Phase Transitions: Random to Order



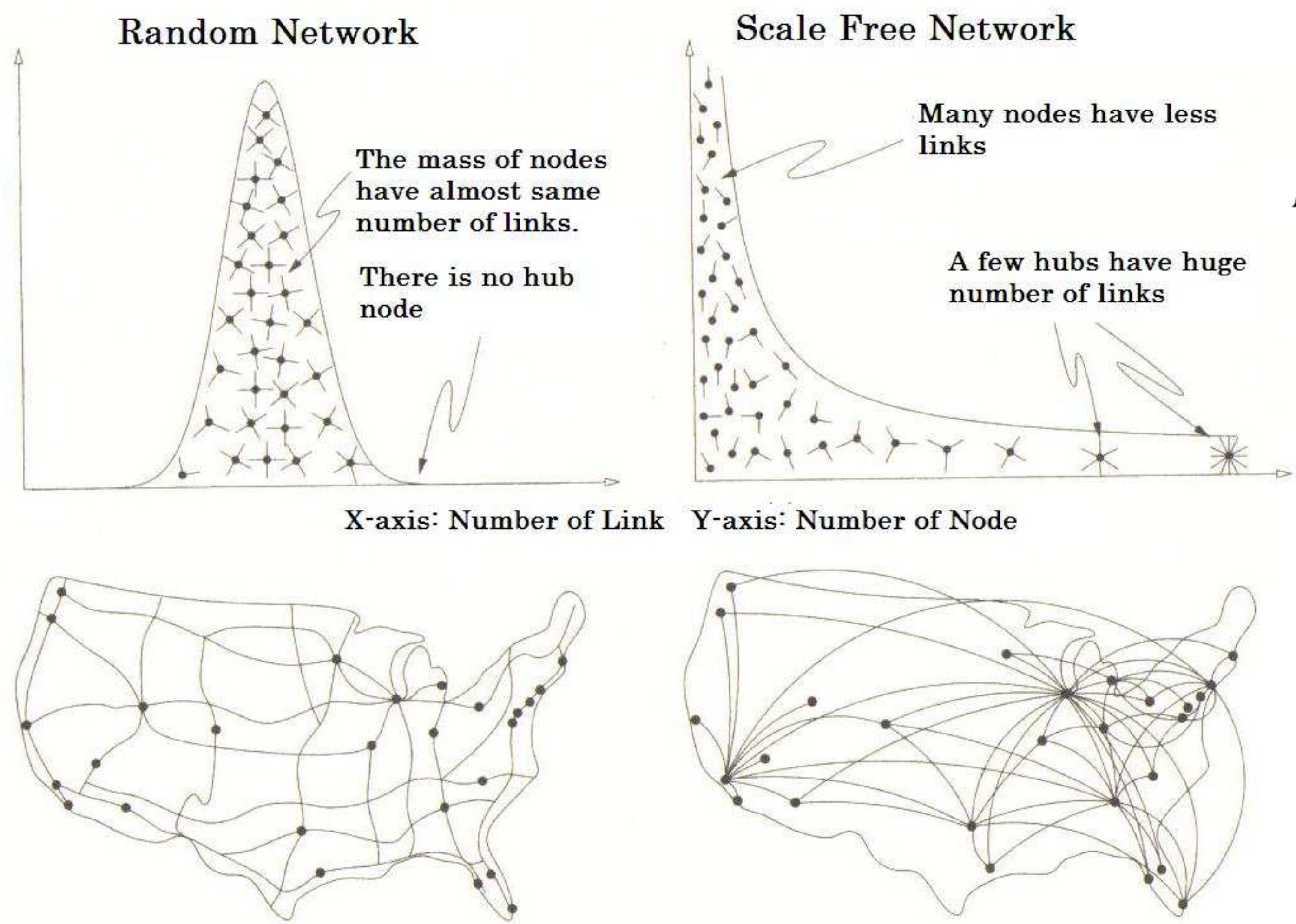
$$P(k) \sim k^{-\gamma}$$

Evolution of Scale Free Network: Growth and Preferential Attachment



Albert L. Barabasi , Science 325 (2009) 412-413

Random versus Scale Free Networks



$$P(k) \sim k^{-\gamma}$$

Albert L. Barabasi, 2002, LINKED: The New Science of Networks

Random vs Scale Free Network

- Some people have more chance to meet with new acquaintance than others
- Some sites, such as Yahoo! and MSN are linked with more sites than other normal sites
- Scale Free Network makes the degree of separation between nodes smaller since a person has more chance to connect with others through hubs
- Therefore, the world becomes even smaller

The Rich Get Richer

- The first mover has the advantage
- The winner's lead is never significant. It is always closely followed by a slightly smaller node that has almost as many links as the leader
- But how do **late comers** make it in a world where the rich get richer?

GOOGLE

- Google has violated the basic prediction of the scale free network
- Launched in 1997 and was a latecomer to the web, but in three years it became the largest hub and the most popular search engine
- To remain relevant in a competitive environment each node has a certain **FITNESS**
- $\Rightarrow$ A node's preferential attachment is driven by it's fitness and the number of links it has

Bosonic Networks

VOLUME 86, NUMBER 24 PHYSICAL REVIEW LETTERS 11 JUNE 2001

Bose-Einstein Condensation in Complex Networks

Ginestra Bianconi[1] and Albert-László Barabási[1,2]

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(Received 16 October 2000; revised manuscript received 26 January 2001)

The evolution of many complex systems, including the World Wide Web, business, and citation networks, is encoded in the dynamic web describing the interactions between the system's constituents. Despite their irreversible and nonequilibrium nature these networks follow Bose statistics and can undergo Bose-Einstein condensation. Addressing the dynamical properties of these nonequilibrium systems within the framework of equilibrium quantum gases predicts that the "first-mover-advantage," "fit-get-rich," and "winner-takes-all" phenomena observed in competitive systems are thermodynamically distinct phases of the underlying evolving networks.

DOI: 10.1103/PhysRevLett.86.5632 PACS numbers: 89.75.Hc, 03.75.Fi, 05.65.+b, 87.23.Ge

Mapping a Network to a Fermi Gas

APS/123-QED

Quantum - Classical Transition in Complex Networks

Marco Alberto Javarone[*] and Giuliano Armano[†]
DIEE - Dept. of Electrical and Electronic Engineering

In this letter, we illustrate our insights on complex networks, considering two referential structure: classical random networks and scale-free networks. We represent them as quantum gases defining a fermionic network model. In general, we suggest that many real complex networks have a quantum-mechanical nature that emerges when their structure becomes scale-free; such network configuration is obtained as few nodes acquire many more links than others, because of some parameter or randomly. The transition from classical random to scale-free network sounds as a cooling process of a physical system achieving equilibrium, despite the non-equilibrium nature of network evolution. During this process the transition from the classical regime to the quantum regime, or vice-versa (in heating processes), takes place.

A Quantum Optical Approach

JOURNAL OF MODERN OPTICS, 1995, VOL. 42, NO. 1, 171–189

Cooperative atomic behaviour and oscillator formation in a squeezed vacuum

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Abstract. Time-dependent (numerical) results are presented for super-radiant behaviour in the Dicke model of $N_a = 2, 3$ atoms in a broad band squeezed vacuum. This concerns the fluctuations and the intensity of the fluorescent radiation as well as the atomic population inversion of the system with atoms initially in an atomic coherent state. In the steady state, and in the $N_a \to \infty$, we show that the 'atomic' Dicke model behaves like a 'giant quantum oscillator', in which the number of excited atoms asymptotically approaches the average number of photons in the resonant mode of the squeezed vacuum, just as in the thermally driven case.

Dicke Model in a Broadband Squeezed Vacuum

Master equation for the atomic density operator in a rotating frame

$$\dot{\rho} = -\tfrac{\gamma}{2}(N+1)(-2S^{-}\rho S^{+} + S^{+}S^{-}\rho + \rho S^{+}S^{-})$$

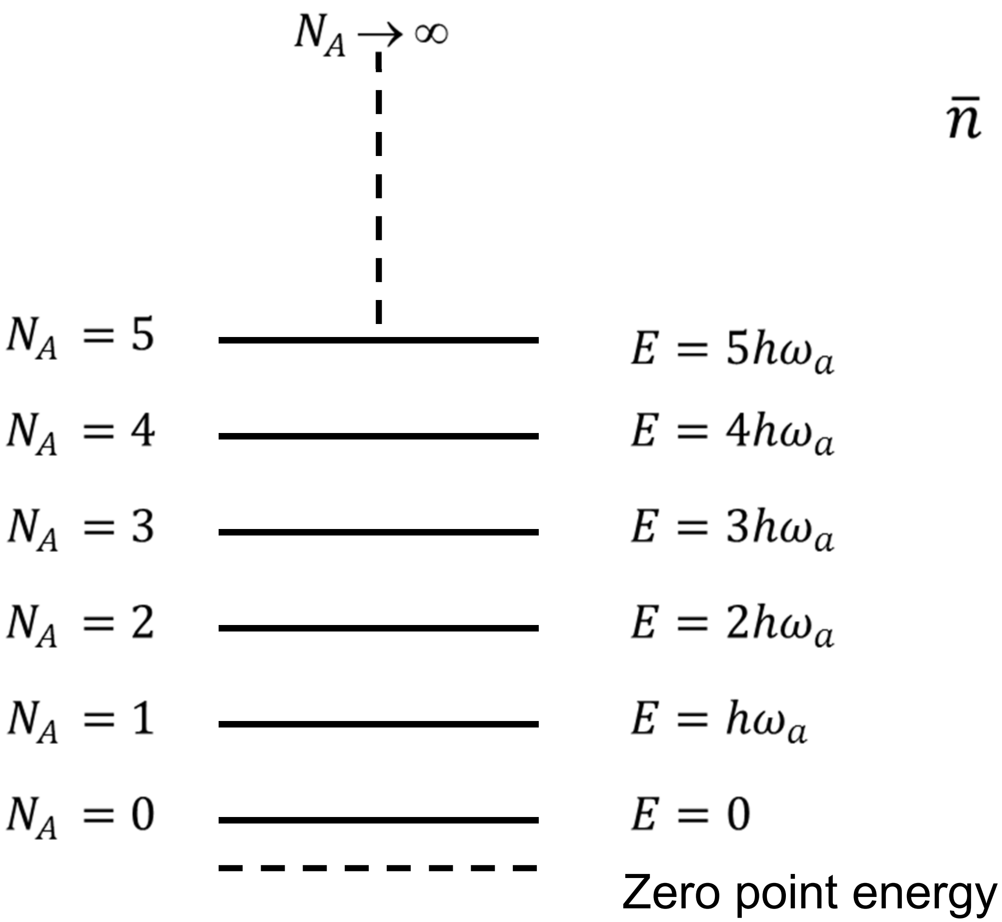
$$-\tfrac{\gamma}{2}N(-2S^{+}\rho S^{-} + S^{-}S^{+}\rho + \rho S^{-}S^{+})$$

$$-\tfrac{\gamma}{2}|M|e^{-i\emptyset}(2S^{+}\rho S^{+} - S^{+}S^{+}\rho - \rho S^{+}S^{+})$$

$$-\tfrac{\gamma}{2}|M|e^{i\emptyset}(2S^{-}\rho S^{-} - S^{-}S^{-}\rho - \rho S^{-}S^{-})$$

Collective Dicke Model = Giant Quantum Oscillator

(Average number of photons = Average number of excited atoms)



$$\bar{n} = \frac{1}{\exp\left(\frac{h\omega_a}{k_B T}\right) - 1}$$

Fermions to Bosons

- As with the Dicke model in a broad band thermal field, the squeezed vacuum case also induced the atomic system to behave like a macroscopic quantum oscillator for $N_A \to \infty$

- But for $N_A = 1$ it acts like a fermion like atom

- For $1 < N_A < \infty$ there is mixed Fermi-Bose behavior

RELATIONSHIP WITH INFORMATION SECURITY

Network Based Applications:

- Scale Free Networks are stable under random attacks but are weak when subjected to targeted attacks
- Malware Outbreak Analysis – treat hubs
- Mitigation of Malicious Attacks on Networks (CNII)
- Diffusion of Confidential Information on Networks
- Optimal Search on the Internet
- Design of efficient network topologies

Information Security: Threat from Within

INFORMATION SECURITY TECHNICAL REPORT 14 (2009) 186–196

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available at www.sciencedirect.com

ScienceDirect

www.compseconline.com/publications/prodinf.htm

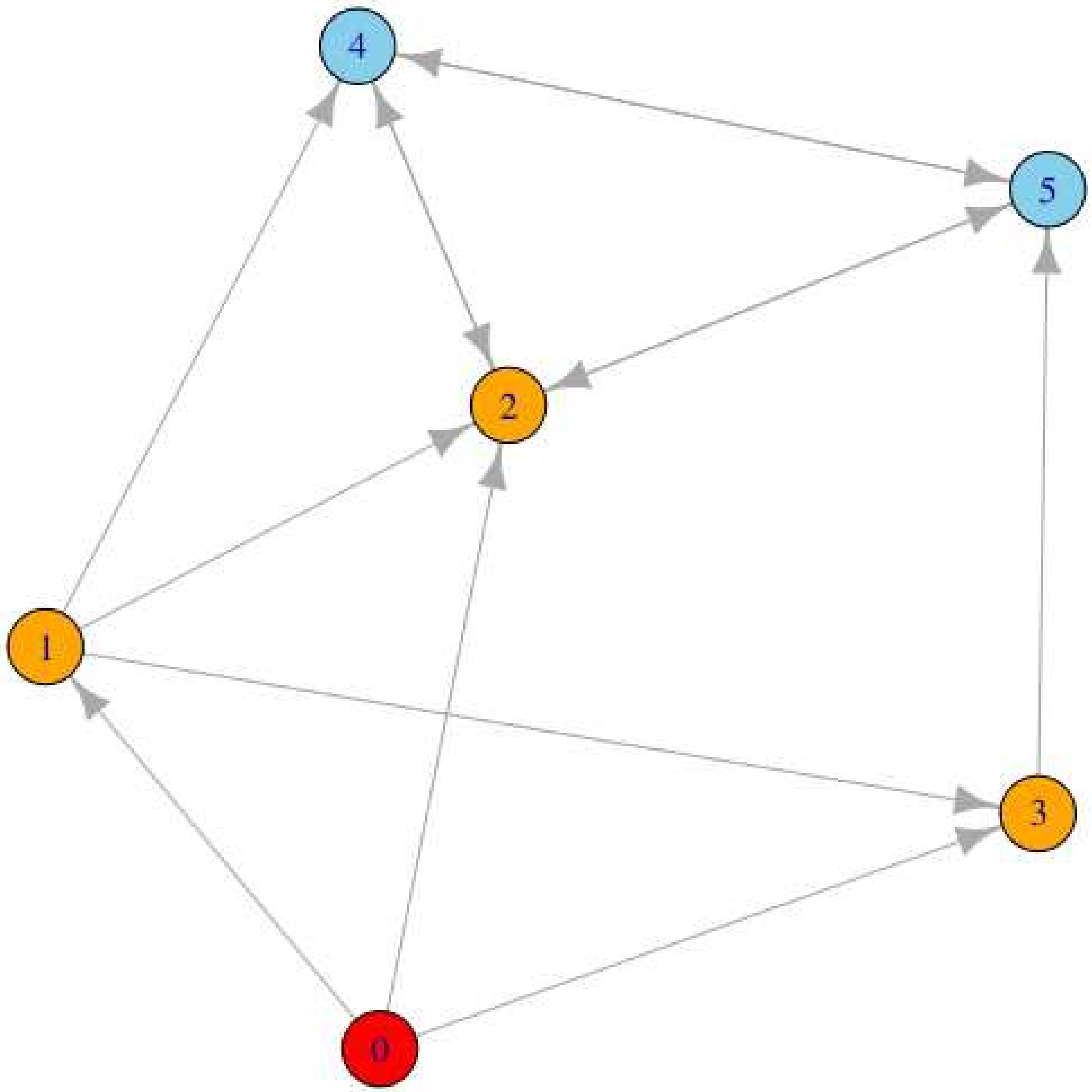
Information Security Technical Report

Human factors in information security: The insider threat – Who can you trust these days?

Carl Colwill

BT Security, UK

Uncovering the Missing Disease Spreader



An Example

Journal of Homeland Security and Emergency Management

Volume 6, *Issue* 1 | 2009 | *Article* 27

The Dynamics of Terrorist Networks: Understanding the Survival Mechanisms of Global Salafi Jihad

Jie Xu* Daning Hu†

Hsinchun Chen‡

Concluding Remarks

In this research we studied the evolution of the GSJ network to uncover the survival mechanisms of a terrorist organization. We found that three factors may have contributed to the survival of the network: growth, scale-free topology, and the ineffectiveness of the counterattack measures. The network experienced three distinct stages of growth from 1989 to 2003: emerging stage, maturing stage, and disintegrating stage. The network displayed different growth patterns in different stages. We found that the scale-free topology could partly account for the network's robustness, helping the network survive under constant counterattacks from authorities. The scale-free topology gradually emerged as new members joined in on an operational basis and the hubs acquired connections over time. On the other hand, the network could have remained active after numerous arrests of its members because the damages were localized within operations to a large extent. In addition, the leaders in the network are difficult to capture or remove and continue to function as hubs connecting members. Although numerous arrests and counterattacks have weakened the network, it still remains functional and has the potential to grow.

Note that findings in this study were obtained based only on the dataset about the Global Salafi Jihad and may not be generalized to other terrorist organizations. In addition, because of the possible data problems mentioned earlier, the results need further validation and verification. At this point we cannot draw definitive conclusions about the exact means by which terrorist organizations have survived over time. More reliable data and further research are needed to gain deeper insights into the underlying mechanisms for the survival of terrorist networks.

In Summary …

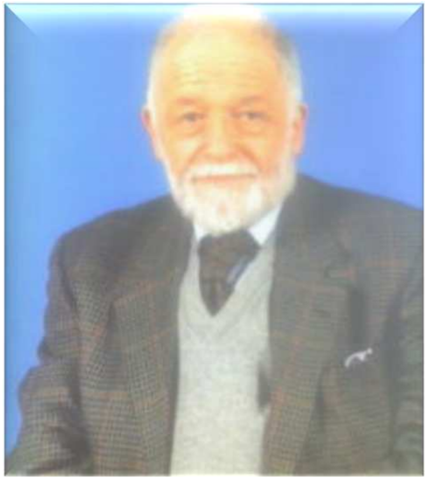
- <u>Origins and Applications of Network Science</u>

Conclusion

- The Scale Free Network model is a way forward to understand complex networks
- A Quantum Optical Approach has been proposed to explain the phase transition in Scale Free Network Theory
- Scale Free Networks offer solutions to mitigate information security threats
- Network Science: Data based mathematical models of complex systems are offering a fresh perspective of connecting the whole and its constituents

Acknowledgement

- MOHE FRGS No. 11-042-0191
- In Memory of Robin Bullough



Thank You