

# Network theory and systemic importance

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The views expressed in this presentation do not necessarily reflect those of the European Central Bank

# Growing interest in networks

How Everything Is Connected to  
Everything Else and What It Means for  
Business, Science, and Everyday Life

## Linked

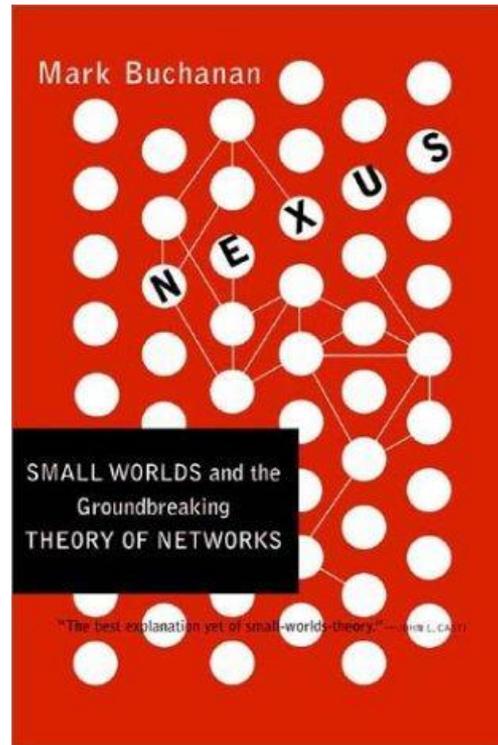


"Linked could alter the way we think about all of the  
networks that affect our lives." —*The New York Times*

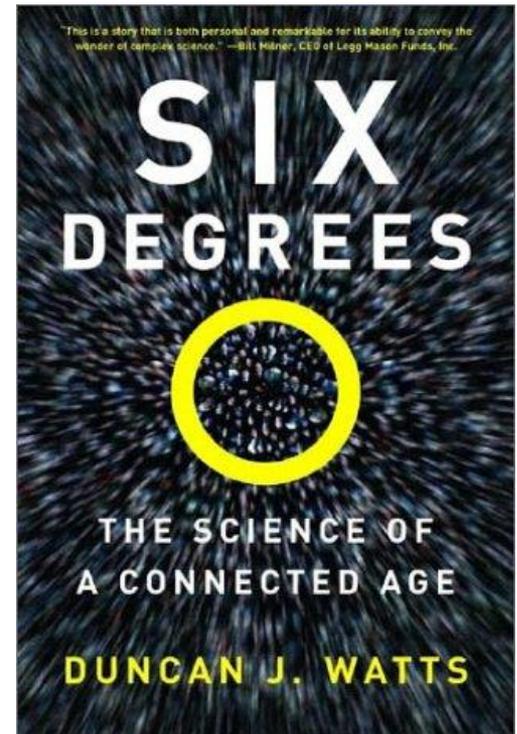
**Albert-László Barabási**

*With a New Afterword*

2003



2003



2004

# SIX Degrees of RUMINATION

Is network theory the best hope for regulating systemic risk?

**It's back.** The phrase "six degrees of separation" in the 1990s, and now, the scientific network theory behind the phrase is being touted as a prescription for regulating systemic risk in the wake of the financial crisis.

In 1972, researcher Stanley Milgram asked test subjects in Omaha, Nebraska, to send a letter to a particular stockbroker in Boston through people whom the test subjects and their subsequent contacts knew on a first name basis. The subjects typically estimated it would take hundreds of jumps for their letter to reach the target, but the average result turned out to be close to six.

Milgram's work was popularized in the play *Six Degrees of Separation* by John Guare. Meanwhile, the science continued to advance. In 1998, Watts and Strogatz published their seminal article "Collective Dynamics of 'Small-World Networks'" in the journal *Nature*, which had ramifications for such disparate fields as physics, biology, sociology, finance, and beyond. Network theory came to the public's attention once again with the publication in 2003 of Duncan Watts' pop science book *Six Degrees: The Science of a Connected Age*. The book jacket breathlessly proclaimed that network theory is "nothing less than a new way to understand our connected planet."

Network theory has already led to some surprising insights. One is that distance can be deceiving—a small shock far away can cascade through an entire wide-area system. The 1997 decoupling of the Thai baht from the U.S. dollar started a chain of events that wound through the Russian bond market and ended up on the doorstep of the U.S. Federal Reserve, where decision makers concluded that they had to orchestrate a rescue of Long-Term Capital Management (LTCM) or risk a meltdown of the entire U.S. market.

Small shocks can have big effects, and big shocks can be absorbed—this is the paradoxical nature of high connectivity between network nodes that makes systems robust and vulnerable at the same time, a theme that continues to play out in the research literature today.

Network theory has been used to examine interbank payment systems, the topology of banking networks in several countries (such as the United States, the United Kingdom, Brazil, Hungary, and the Netherlands), correlations between different types of hedge funds, insider trading networks, and other topics in finance. But the application of network theory to finance is still in its infancy.

The exciting thing, says Kimmo Soramäki, an independent research consultant who performs network analysis for central bank clients, is that insights gained in one field of network analysis are proving to be transferable to other fields. This means that researchers may someday come closer to understanding financial contagion because of work done on epidemics or may be able to illuminate the herding mentality of stock traders by studying how thousands of fireflies can flash on and off in synchrony.

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## Meltdown modelling

Could agent-based computer models prevent another financial crisis? Mark Buchanan reports.

By 2016, and experts at a US government facility have detected a threat to national security. A screen on the wall maps the world's largest financial players — banks, governments and hedge funds — as well as the web of loans, ownership stakes and other legal claims that link them. High-powered computers have been using these enormous volumes of data to run through scenarios that think out unexpected risks. And this morning they have triggered an alarm.

Flashing orange alerts on the screen show that a cluster of US-based hedge funds has unknowingly taken large ownership positions in similar assets. If one of the funds should have to sell assets to raise cash, the computers warn, its action could drive down the assets' value and force others to start selling their own holdings in a self-amplifying downward spiral. Many of the funds could be bankrupt within 30 minutes, creating a threat to the entire financial system. Armed with this information, financial authorities step in to orchestrate a controlled elimination of the dangerous tangle.

Also, this story is likely to remain fiction. No government was able to carry out any such 'war room' analysis as the current financial crisis emerged, nor does the capability exist today. Yet a growing number of scientists insist that something like it is needed if we are to avoid similar crises in future.

Financial regulators do not have the tools they need to predict and prevent meltdowns.



BUCHANAN/WATSON

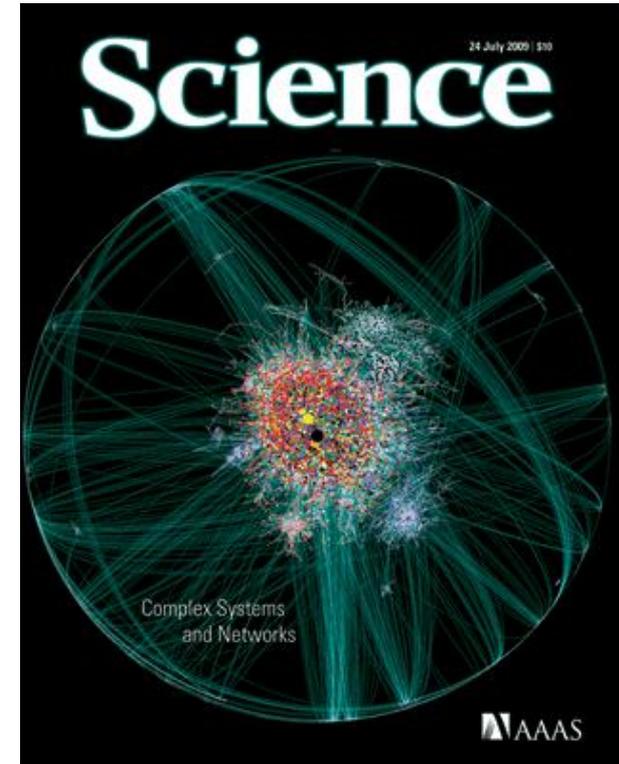
says physicist-turned-sociologist Dirk Helbing of the Swiss Federal Institute of Technology Zurich, who has spent the past two decades modelling large-scale human systems such as urban traffic or pedestrian flows. They can do a good job of tracking an economy using the statistical measures of standard econometrics, as long as the influences on the economy are independent of each other, and the past remains a reliable guide to the future. But the recent financial collapse was a 'systemic' meltdown, in which intertwined breakdowns in housing, banking and many other sectors conspired to destabilize the system as a whole. And the past has been anything but a reliable guide of late: witness how US analysts were led astray by decades of data suggesting that housing values would never simultaneously fall across the nation.

Like wise, economists can get reasonably good insights by assuming that human behaviour leads to stable, self-regulating markets, with the prices of stocks, houses and other things never departing too far from equilibrium. But 'stability' is a word few would use to describe the chaotic markets of the past few years, when complex, nonlinear feedbacks fuelled the boom and bust of the dot-com and housing bubbles, and when banks took extreme risks in pursuit of ever higher profits.

**"We have had a massive failure of the dominant economic model."**  
—Eric Weinstein

In an effort to deal with such messy realities, a few economists — often working with physicists and others outside the economic mainstream — have spent the past decade or so exploring 'agent-based' models that make only minimal assumptions about human behaviour or inherent market stability (see page 68). The idea is to build a virtual market in a computer and populate it with artificially intelligent bits of software — 'agents' — that interact with one another much as people do in a real market. The computer then lets the overall behaviour of the market emerge from the actions of the individual agents, without pre-

supposing the result. Agent-based models have roots dating back to the 1940s and the first 'cellular automata', which were essentially just simulated grids of on-off switches that interacted with their nearest neighbours. But they didn't spark much interest beyond the physical-science community until the 1990s, when advances in computer power began to make realistic social simulations more feasible. Since then they have found increasing use in problems such as traffic flow and the spread of infectious diseases (see page 67). Indeed, points out Helbing, agent-based models are the social-science analogue of the computational simulations now routinely used elsewhere in science to explore complex nonlinear processes such as the global climate.



“Is network theory the best hope for regulating systemic risk?”

CFA Magazine, July 2009

“Meltdown modeling - Could agent-based computer models prevent another financial crisis?”

Nature, August 2009

“... need for new and fundamental understanding of the structure and dynamics of economic networks.”

Science, July 2009

It was the **ultra-interconnectedness** of the nation's financial institutions that posed the biggest risk of all [...] every firm was now dependent on the others – and many **didn't even know it**. If one fell, it could become a series of falling **dominoes**.

*“Too Big to Fail”, Andrew Ross Sorkin 2009*

... given the fragile condition of the financial markets at the time, the **prominent position** of Bear Stearns in those markets, and the expected **contagion** that would result from the immediate failure of Bear Stearns, the best alternative available was to provide temporary emergency financing to Bear Stearns ...

*Minutes of the Board of Governors of the Federal Reserve System, 14 March 2008*

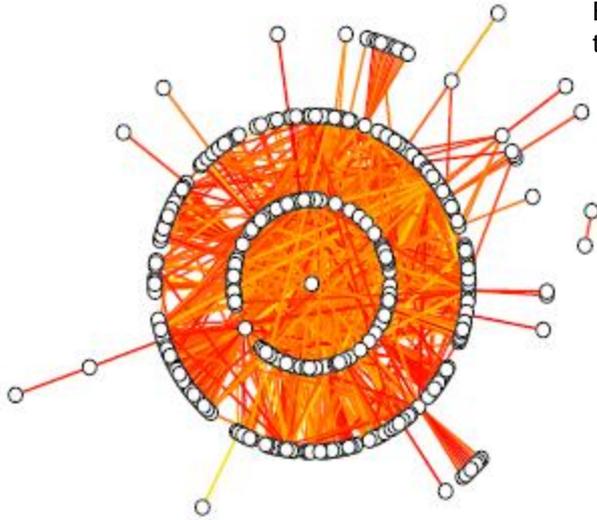
“Too big to fail”

+

“Too interconnected to fail”

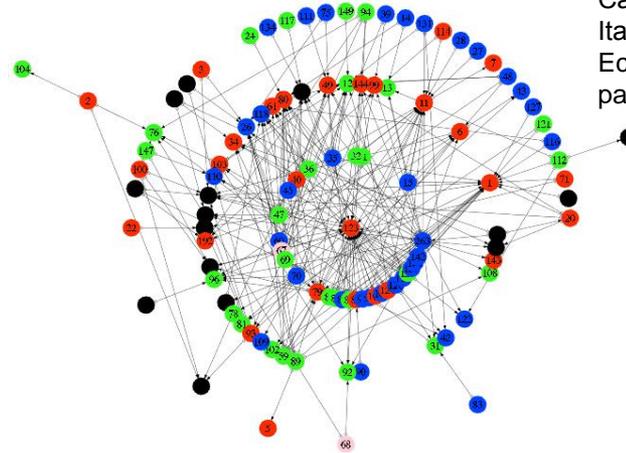
# Visualizing financial networks

## Federal funds



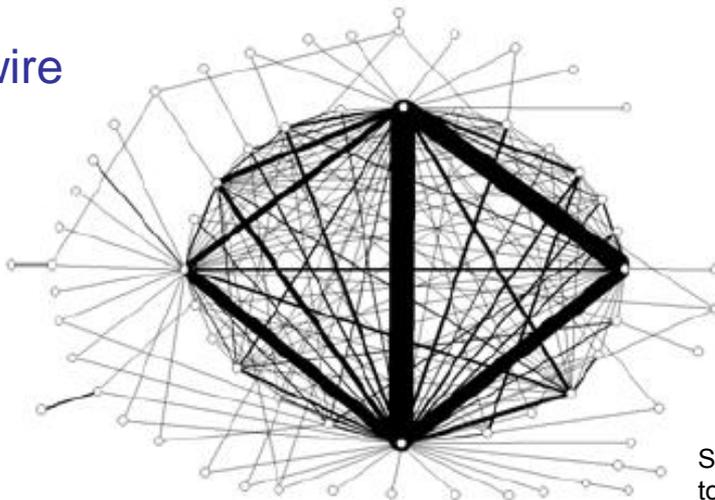
Bech, M.L. and Atalay, E. (2008), "The Topology of the Federal Funds Market". ECB Working Paper No. 986.

## Italian money market



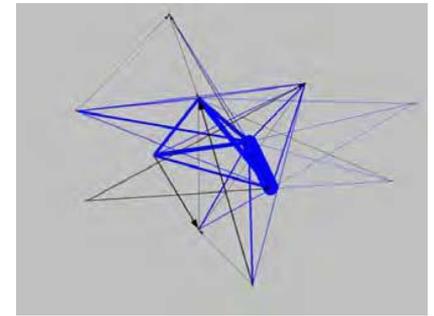
Iori G, G de Masi, O Precup, G Gabbi and G Caldarelli (2008): "A network analysis of the Italian overnight money market", Journal of Economic Dynamics and Control, vol. 32(1), pages 259-278

## Fedwire



Wetherilt, A. P. Zimmerman, and K. Soramäki (2008), "The sterling unsecured loan market during 2006–2008: insights from network topology", in Leinonen (ed), BoF Scientific monographs, E 42

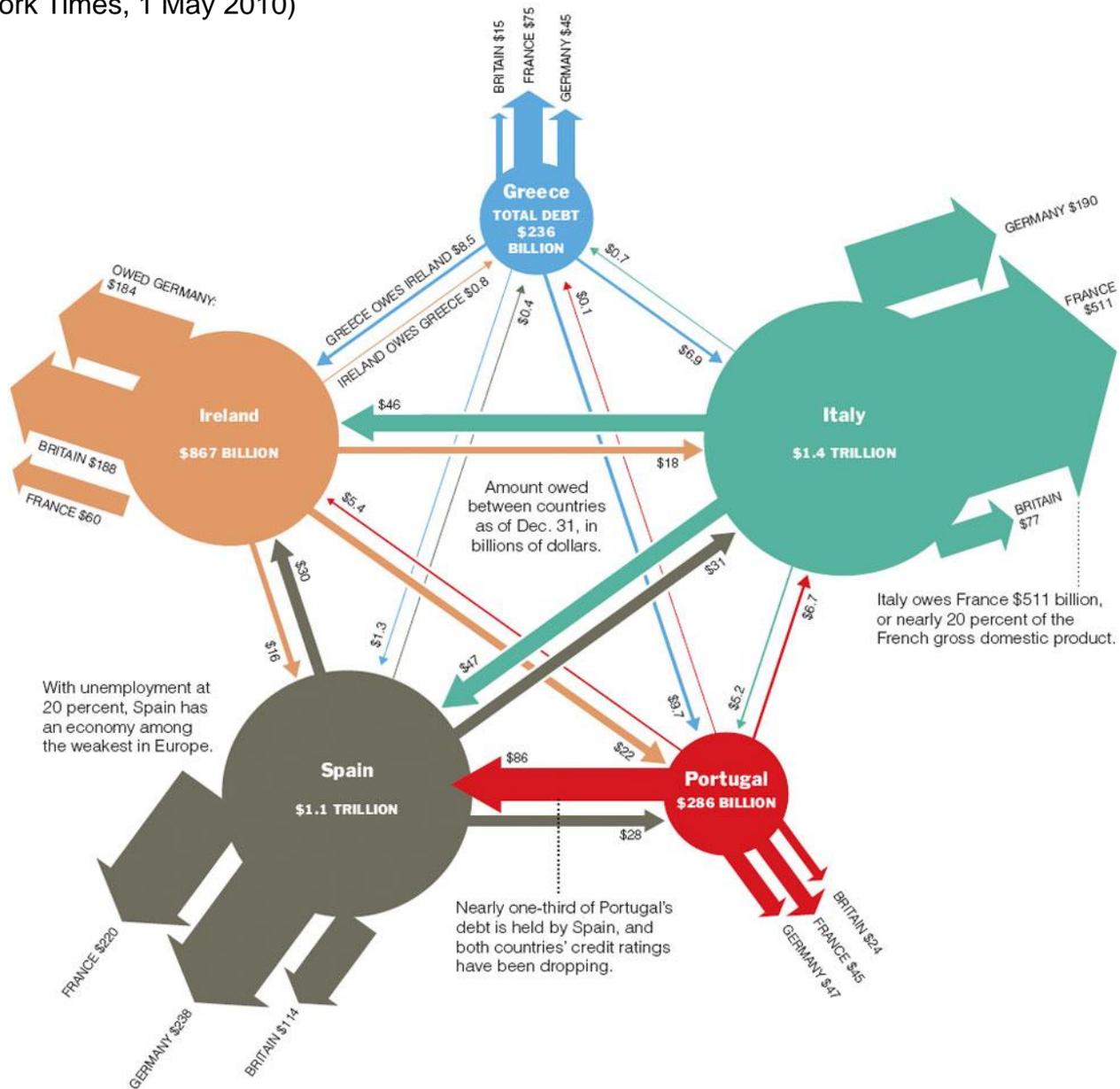
## Unsecured sterling money market



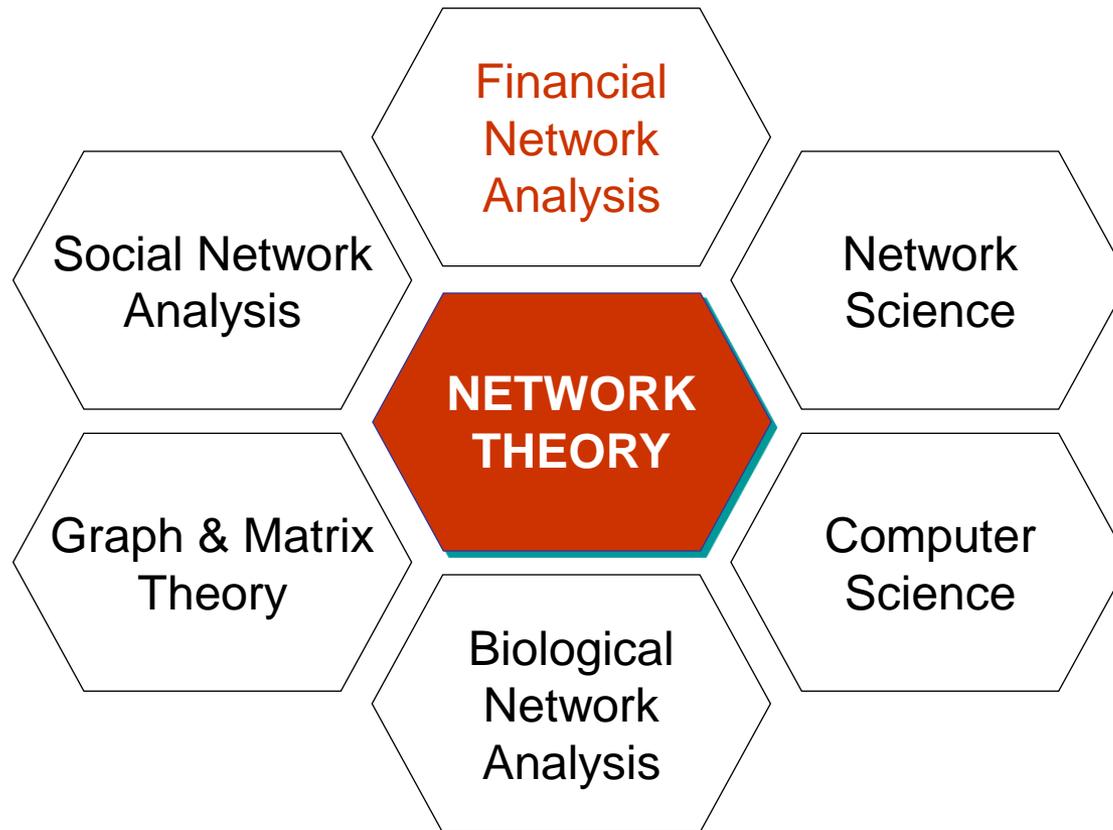
Soramaki, K, M.L. Bech, J. Arnold, R.J. Glass and W.E. Beyeler (2007), "The topology of interbank payment flows", Physica A, Vol. 379, pp 317-333, 2007.

# Europe's Web of Debt

(Bill Marsh / The New York Times, 1 May 2010)



# Network theory and related fields



Main premise of network analysis:  
the structure of the links between nodes matters

The properties and behaviour of a node cannot be analysed on the basis its own properties and behaviour alone.

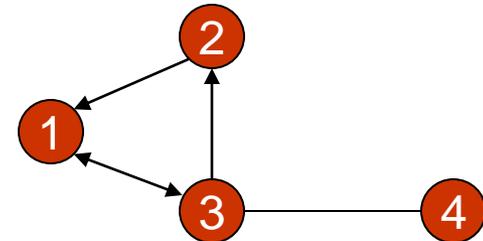
To understand the behaviour of one node, one must analyse the behaviour of nodes that may be several links apart in the network.

Bottom up approach. Generalize and describe.

Financial context: network of interconnected balance sheets

# Network basics

- Terminology
  - node/vertex -> Bank/banking group
  - link/tie/edge/arc -> Financial interlinkages, bilateral positions, exposures
  - directed vs undirected
  - weighed vs unweighted
  - graph + properties = network



- Algorithms/measures
  - Centrality -> Systemical importance
  - Flow -> Liquidity
  - Community/pattern identification
  - Distance, shortest paths
  - Connectivity, clustering
  - Cascades, epidemic spreading -> Contagion

# Systemic importance

A risk-adjusted rate could be designed to address the contribution to systemic risk. Ideally, the rate would vary according to the size of the **systemic risk externality**, e.g. based on a **network model** which would take into account all possible channels of contagion.

*IMF report for the Meeting of G-20 Ministers, April 2010*

# Centrality in network theory

The relative importance of a vertex within the graph

Depends on network process:

Trajectory: geodesic paths, paths, trails or walks

Transmission: parallel/serial duplication or transfer

Table 1  
Typology of flow processes

	Parallel duplication	Serial duplication	Transfer
Geodesics	<No process>	Mitotic reproduction	Package delivery
Paths	Internet name-server	Viral infection	Mooch
Trails	E-mail broadcast	Gossip	Used goods
Walks	Attitude influencing	Emotional support	Money exchange

# Centrality measures in network theory

degree: number of links

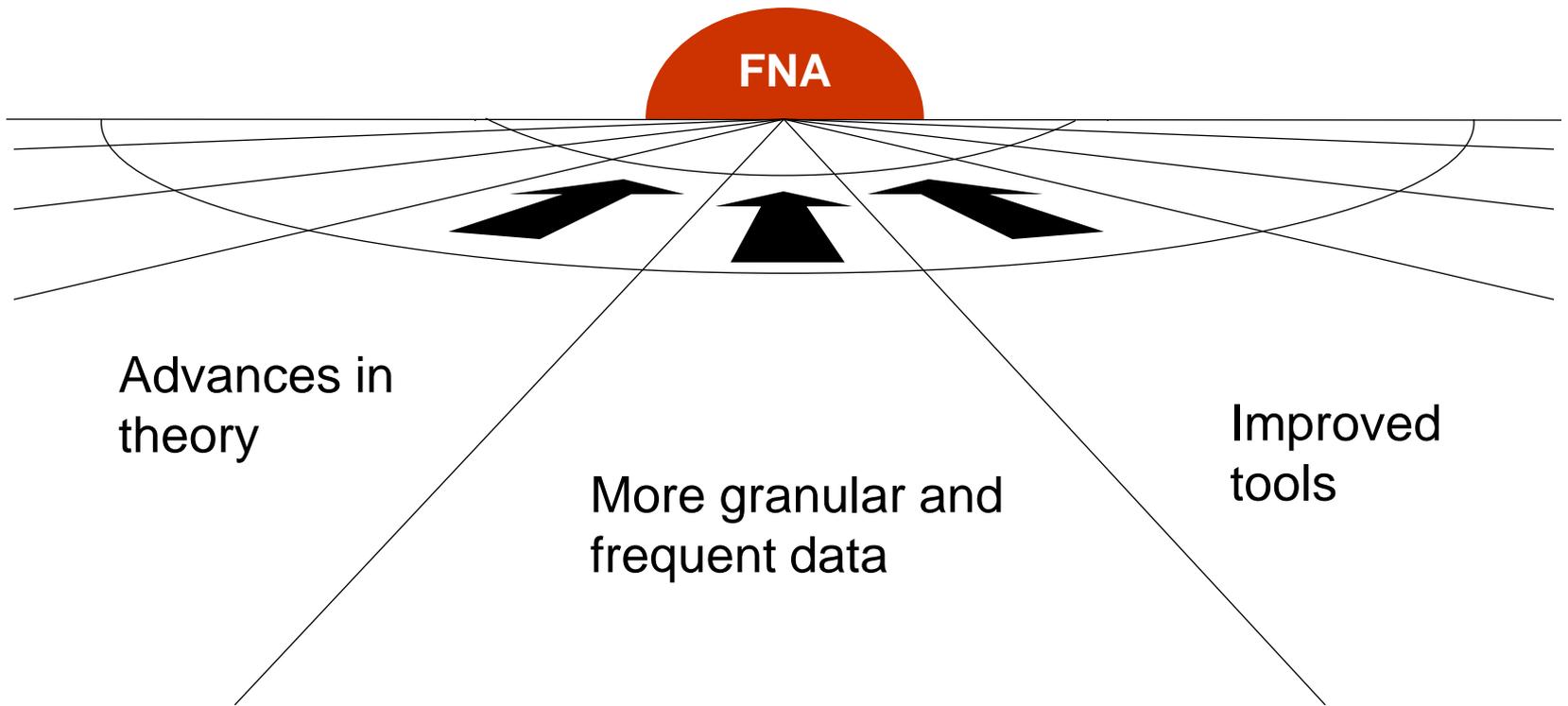
closeness: distance to other nodes via shortest paths

betweenness: number of shortest paths going through the node

**eigenvector**: nodes that are linked by/to other important nodes are more central (parallel duplication via walks)

**markov**: probability that a random process is at a node (transfer via walks)

# Road ahead



Advances in  
theory

More granular and  
frequent data

Improved  
tools

## Advances in theory

- able to identify the contagion channels in different parts of the financial system
- explain the formation and information content of links between financial institutions and their behaviour under normal and stress situations.
- models of systemic risk could make sense of real economic interactions among market

## More granular and frequent data

- a key prerequisite for financial network analysis as a surveillance tool
- more granular and frequent, long enough time series for a statistical analysis of different market conditions
- regulators and overseers should continue to develop ways to systematically collect, share and analyse the data from both market sources and financial infrastructures.

## Improved tools

- Tools for network analysis/data mining have developed substantially over the last few years.
- Ongoing work: “Financial Network Analyzer” ([www.financialnetworkanalysis.com/fna](http://www.financialnetworkanalysis.com/fna))

# Thank you

More information:

June Risk Magazine article

June ECB Financial Stability Review

My blog: [www.financialnetworkanalysis.com](http://www.financialnetworkanalysis.com)

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