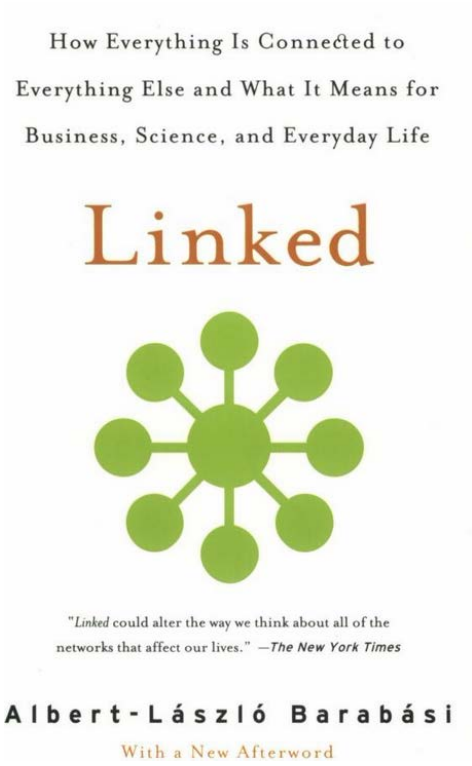
Financial Network Analyzer and Interbank Payment Systems

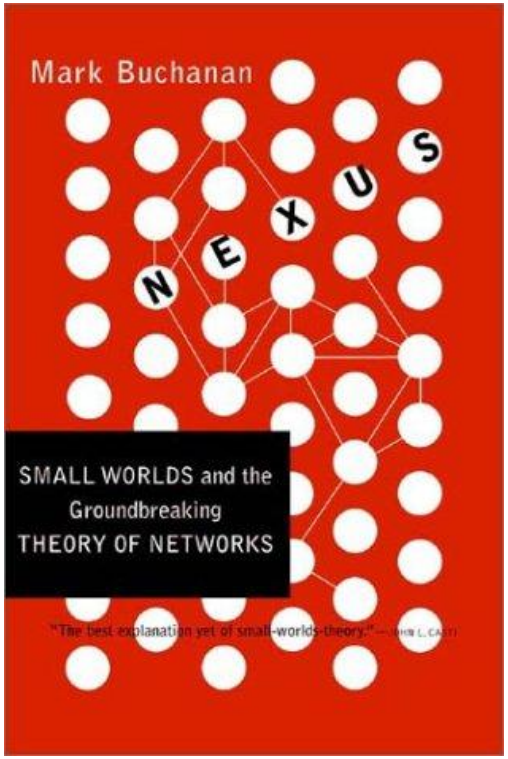
Kimmo Soramäki
www.financialnetworkanalysis.com

Financial Network Workshop 2011
West Point Military Academy
8th April 2011

Growing interest in networks



2003



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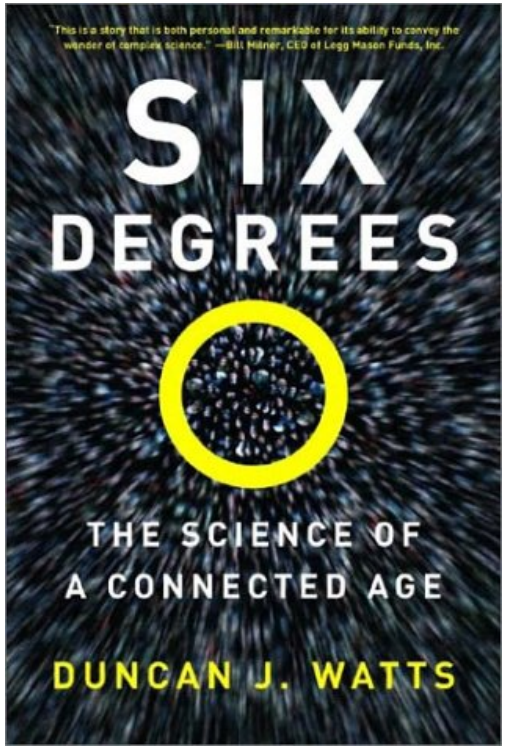

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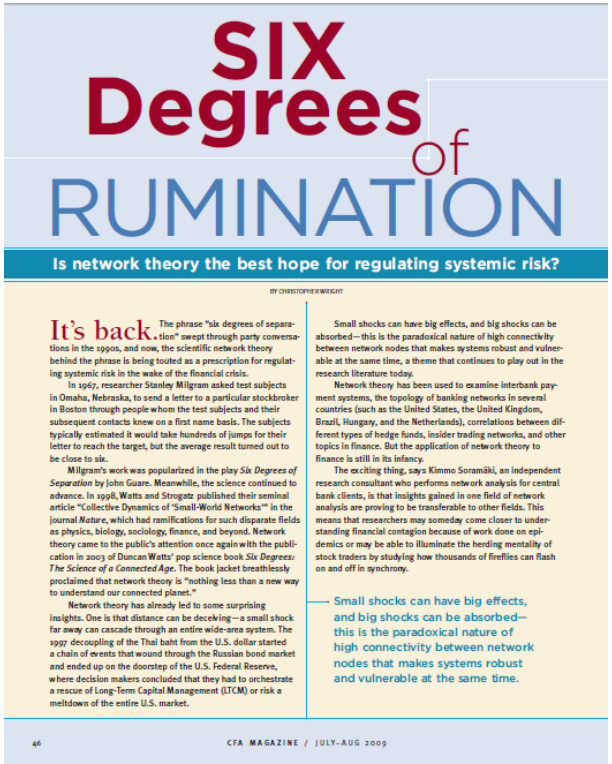


SIX Degrees of RUMINATION

Is network theory the best hope for regulating systemic risk?

BY CHRISTOPHER WRIGHT

It's back. The phrase "six degrees of separation" swept through party conversations 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 1967, 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.

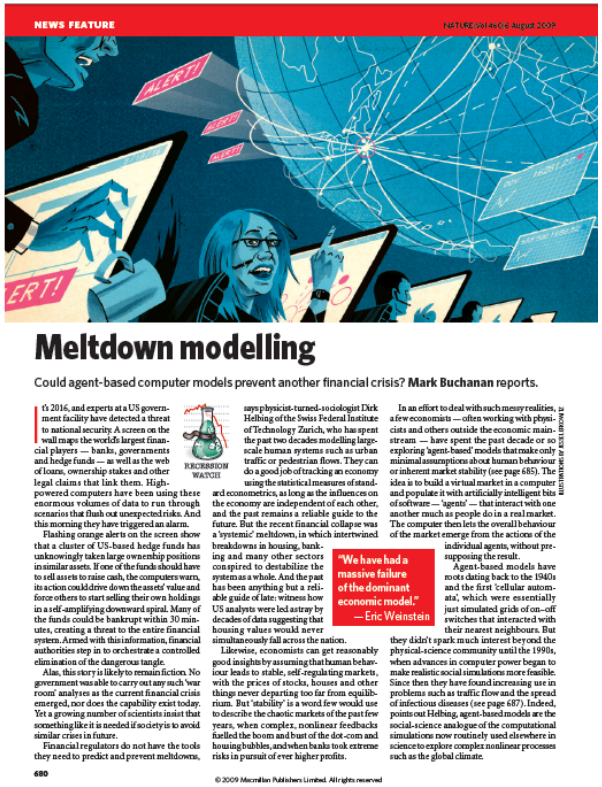
The exciting thing, says Kimmo Soramäki, an independent research consultant who performs network analysis for central bank clients, is that insights gained in one field of network analysis are proving to be transferable to other fields. This means that researchers may someday come closer to understanding 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.

> 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.

46 CFA MAGAZINE / JULY–AUG 2009

"Is network theory the best hope for regulating systemic risk?"

CFA Magazine, July 2009



NEWS FEATURE NATURE|Vol 460|6 August 2009

Meltdown modelling

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

It's 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 flush out unexpected risks. And this morning they have triggered an alarm.

Flashing orange alert 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.

Alas, this story is likely to remain fiction. No government was able to carry out any such 'war room' analyses 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 society is to avoid similar crises in future.

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

RECESSION WATCH

Likewise, 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 685). The idea is to build a virtual market in a computer and populate it with artifically 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 presupposing 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 687). 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.

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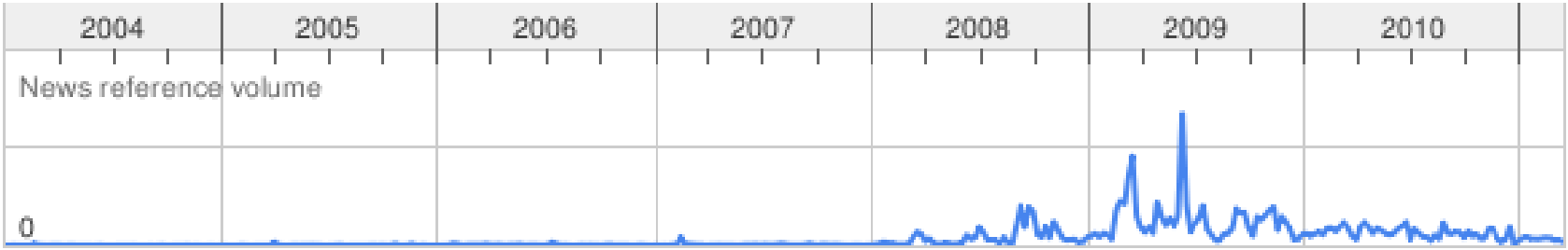
"Meltdown modeling - Could agent-based computer models prevent another financial crisis?"

Nature, August 2009

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

Science, July 2009

We are talking about systemic risk ≠ systematic risk



News articles mentioning “systemic risk”, Source: trends.google.com

- The risk of disruption to a financial entity with spillovers to the real economy
- Risk of a crisis that stresses key intermediation markets and leads to their breakdown, which impacts the broader economy and requires government intervention
- Risk that critical nodes of a financial network cease to function as designed, disrupting linkages

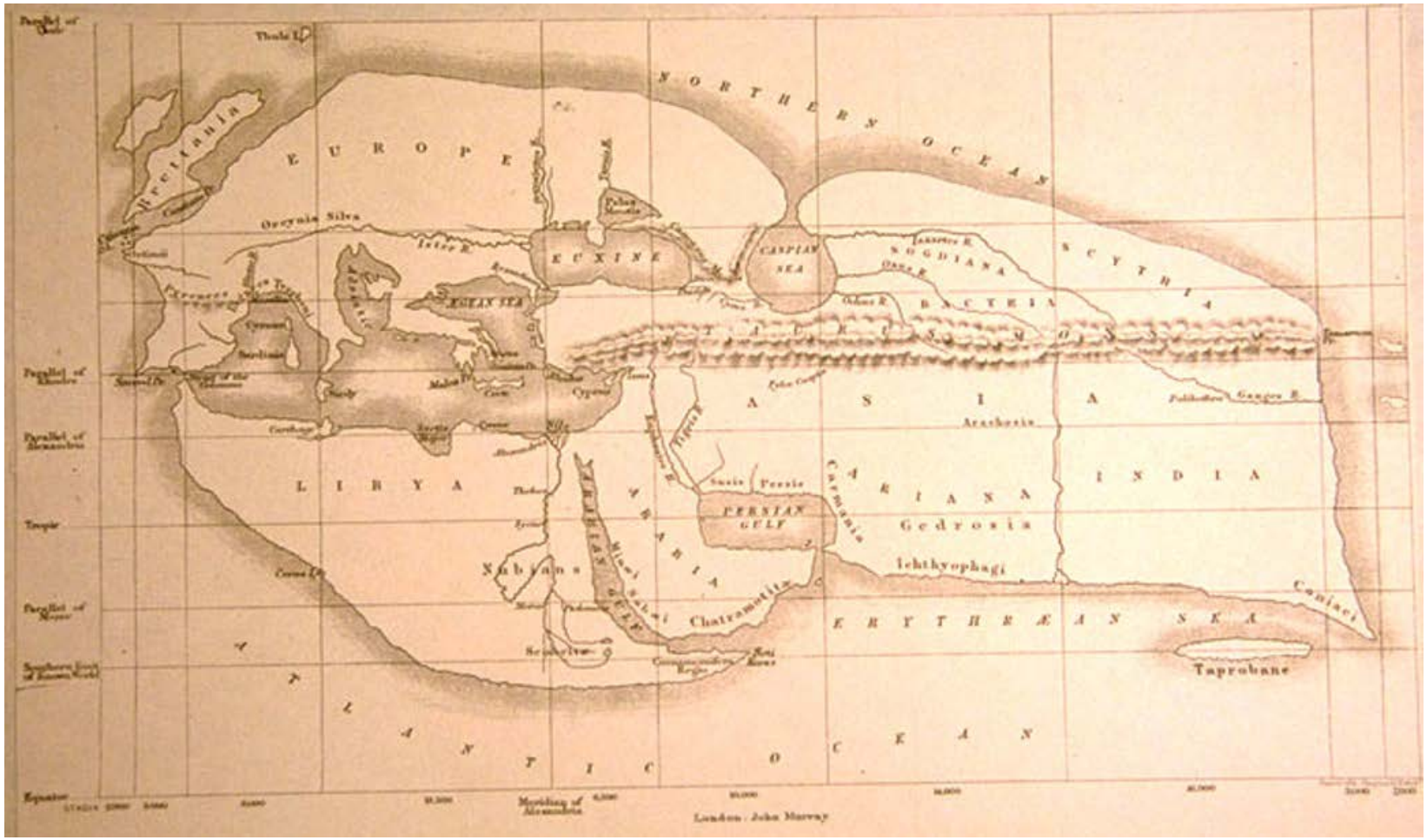
-> some chain of events that starts or gets magnified in the finance sector and makes us all worse off

“Too big to fail”

+

“Too interconnected to fail”

We need some cartography

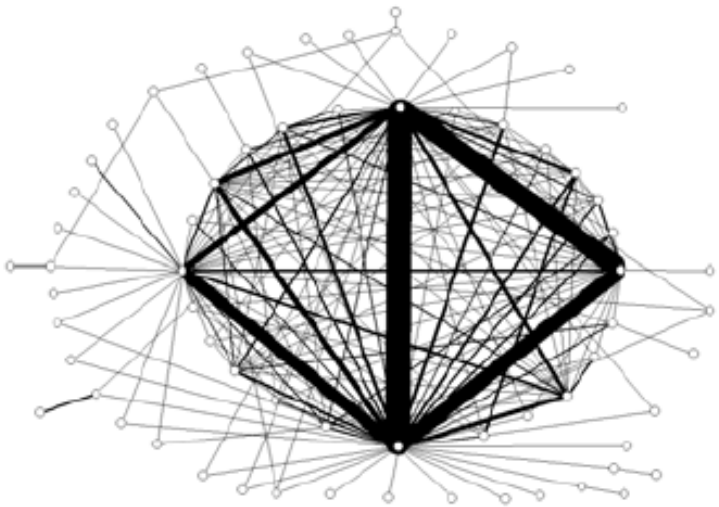


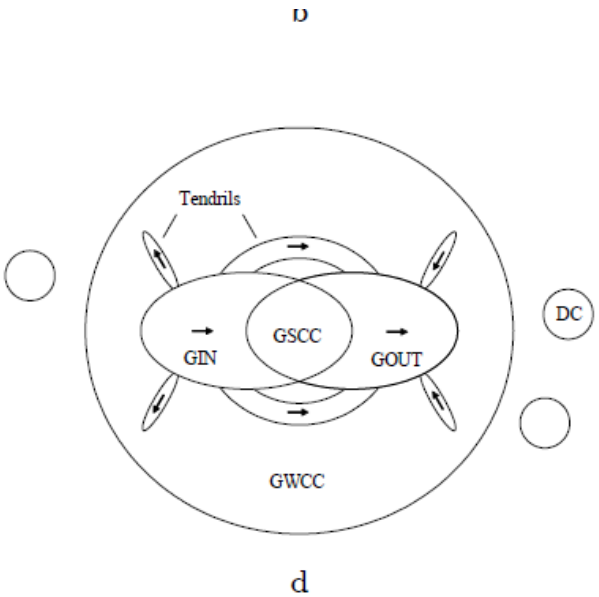
19th century reconstruction of Eratosthenes' map of the known world, c.194 BC.

… on the interconnections

Paul Butler, December 14, 2010

Payment flows in Fedwire

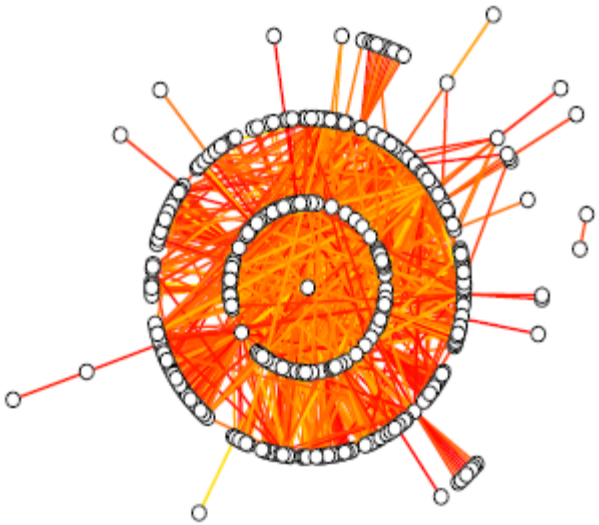




Soramaki, K, M.L. Bech, J. Arnold, R.J. Glass and W.E. Beyeler (2007), “The topology of interbank payment flows”, Physica A, Vol. 379, pp 317-333, 2007.

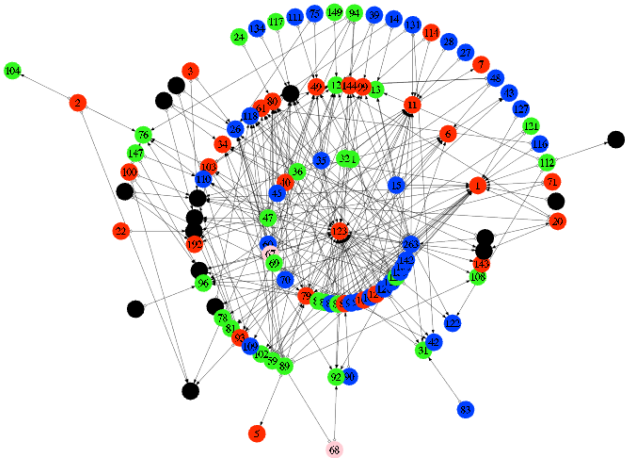
Overnight lending networks

Federal funds



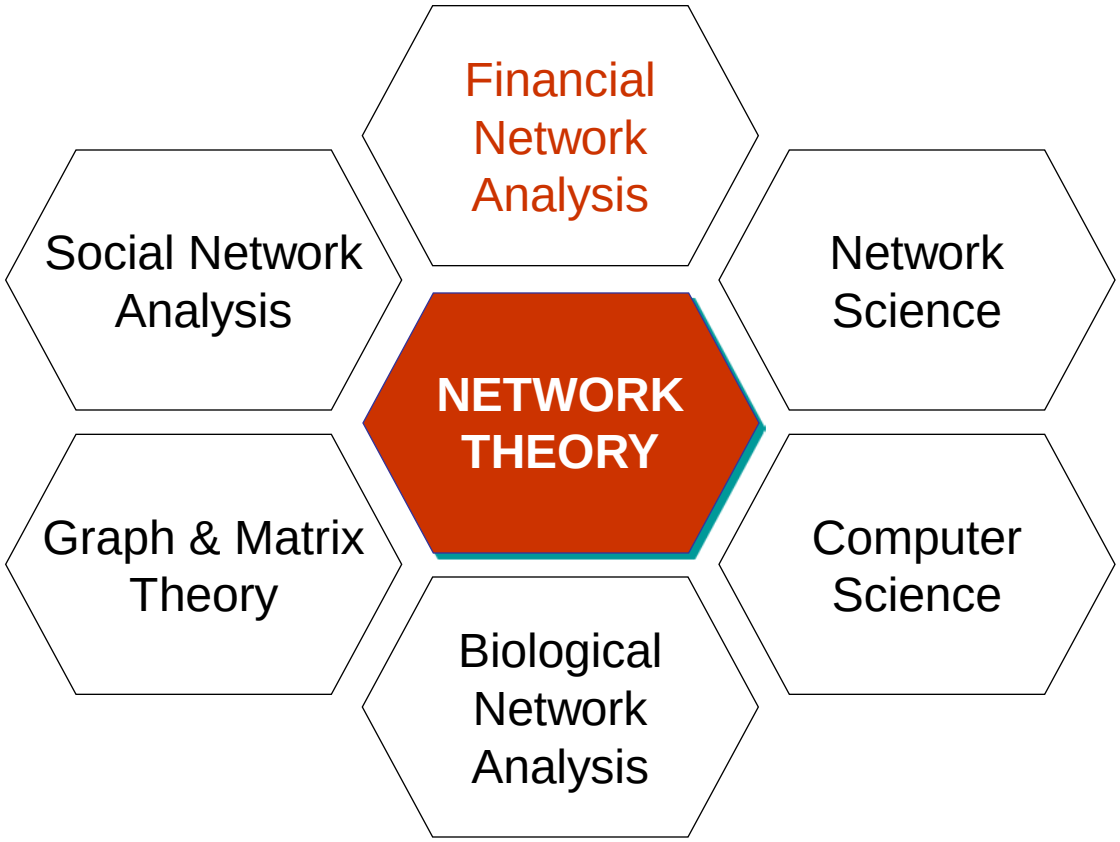
Bech, M.L. and Atalay, E. (2008), “The Topology of the Federal Funds Market”. ECB Working Paper No. 986.

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

Network theory and related fields

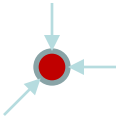


Main premise of network analysis: Structure of links between nodes matters

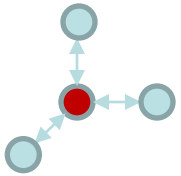
- The properties and behaviour of a node cannot be analysed on the basis its own properties and behaviour alone.
- To understand the behaviour of one node, one must analyse the behaviour of nodes that may be several links apart in the network.
- Bottom up approach. Generalize and describe.
- Financial context: network of interconnected balance sheets
- Should we let the next Lehman fail?

Systemic importance = “centrality”

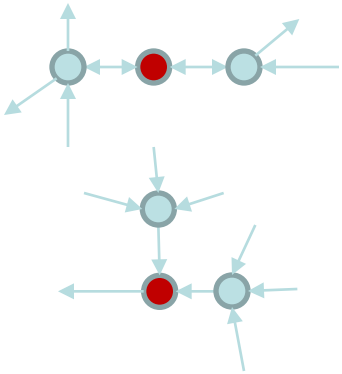
Degree: number of links



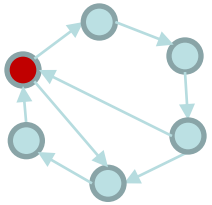
Closeness: distance to other nodes via shortest paths



Betweenness: number of shortest paths going through the node



Eigenvector: nodes that are linked by/to other important nodes are more central



Markov: probability that a random process is at a given node

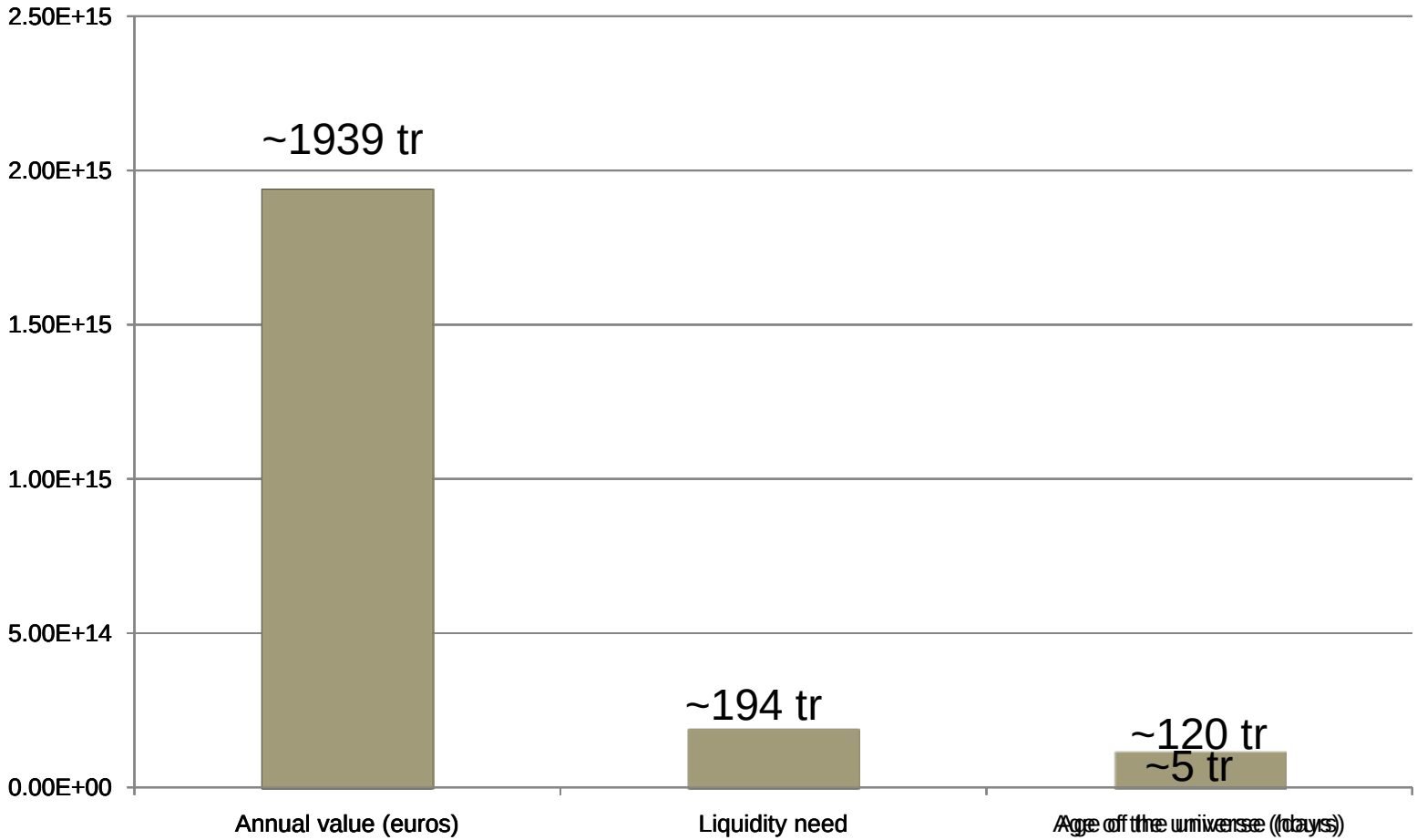
We need to model the process

- We need better models of systemic risk and contagion

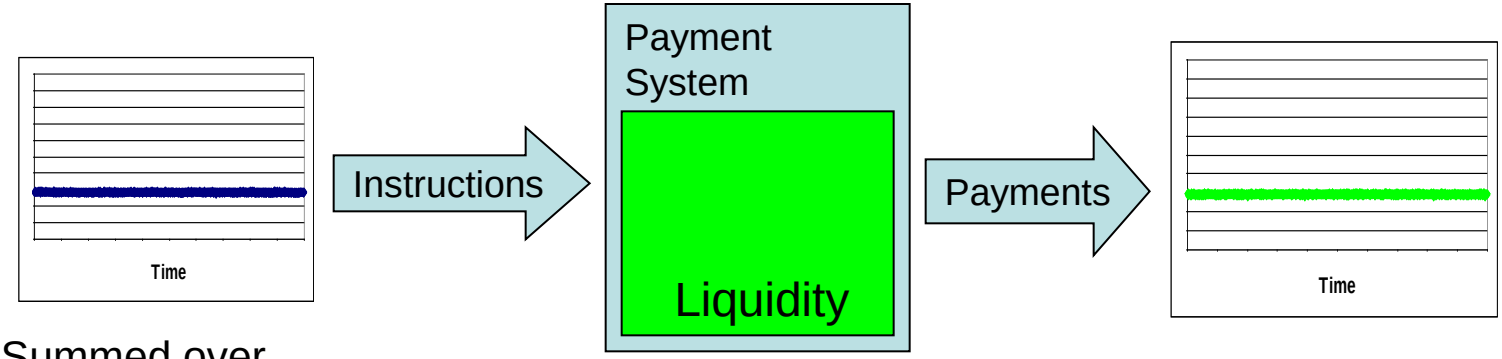
- The models must incorporate

  – Topology of interactions
  – System dynamics
  – Economic behavior

Payment systems

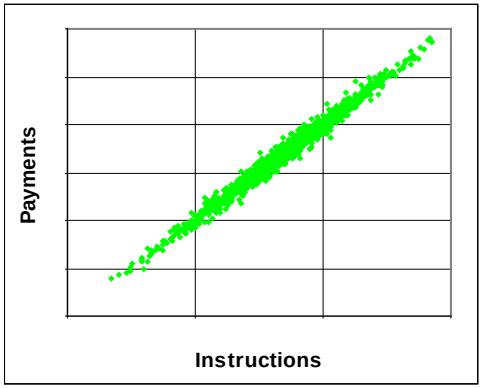


Example on system dynamics: payment systems



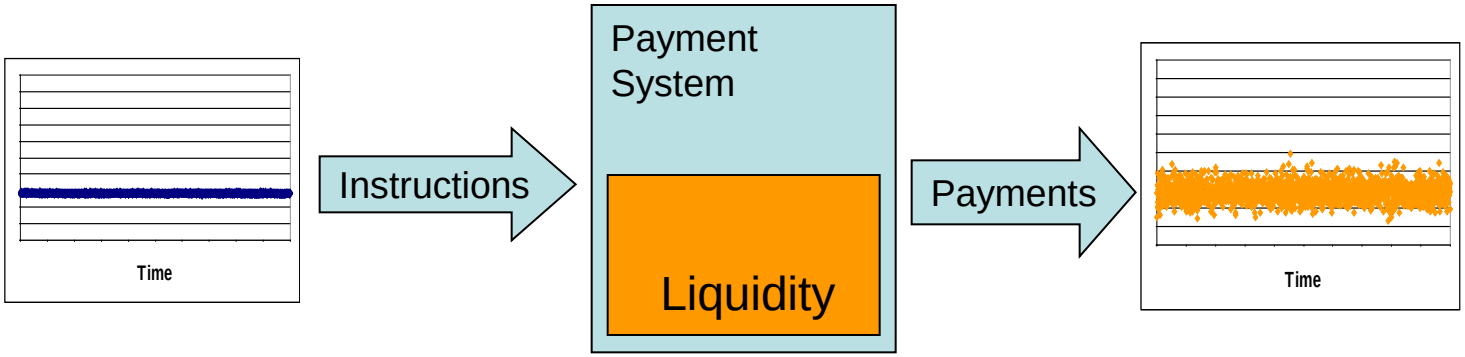
Summed over the network, instructions arrive at a steady rate

When liquidity is high payments are submitted promptly and banks process payments independently of each other

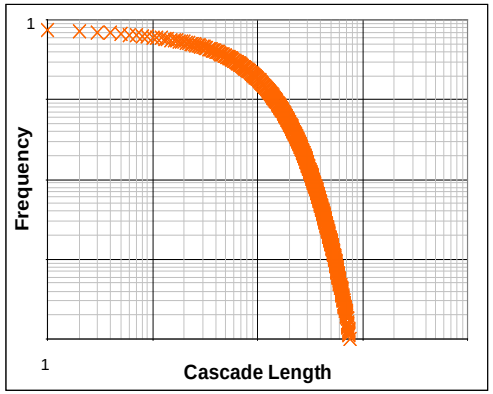


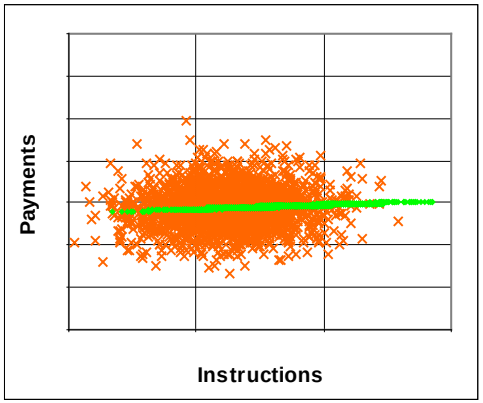
Source: Beyeler, Glass, Bech and Soramäki (2007), Physica A, 384-2, pp 693-718.

… have complex dynamics



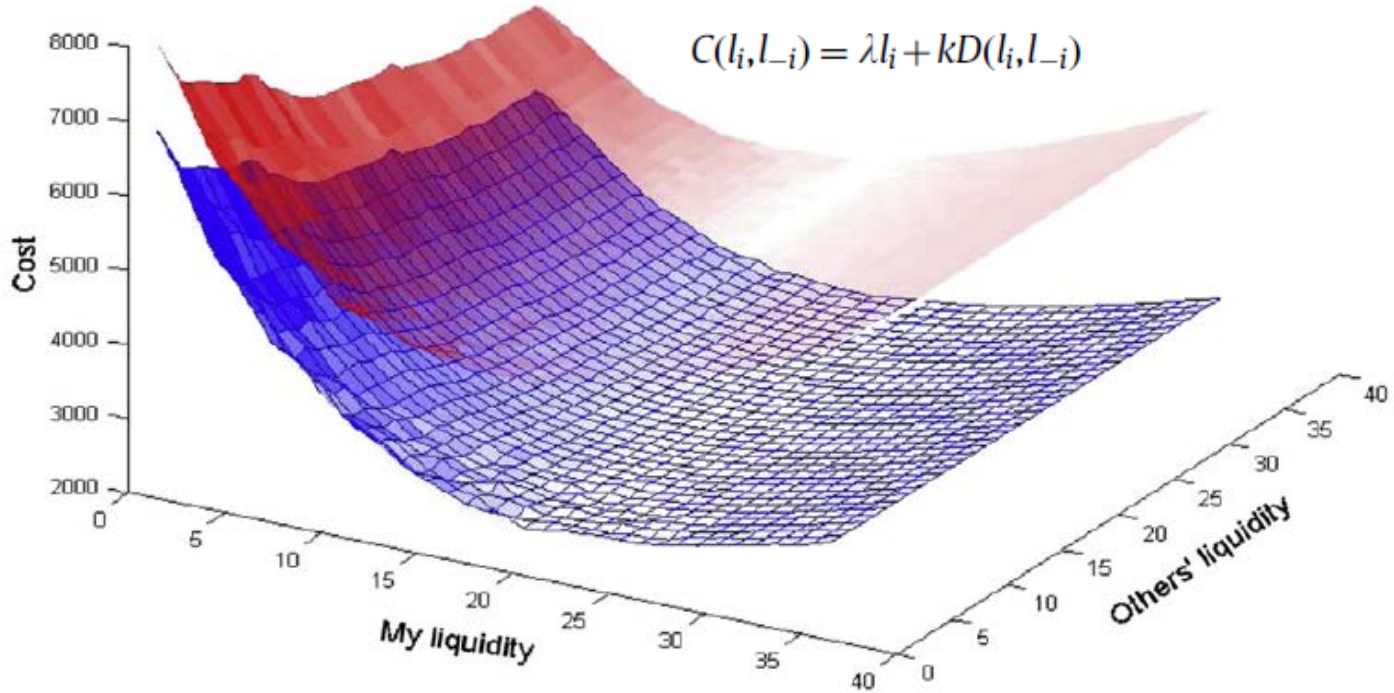
Reducing liquidity leads to episodes of congestion when queues build, and cascades of settlement activity when incoming payments allow banks to work off queues. Payment processing becomes coupled across the network





… and economic agents

- E.g. Banks liquidity choice in a payment system depends on other banks' liquidity choice
- Red = high price for liquidity, Blue = low price for liquidity



Source: Galbiati and Soramäki (2010), Journal of Econ. Dynamics and Control, in press

The road ahead

- We need better models of systemic risk and contagion
- We will have much more frequent and granular data
- We need better tools that can run the new models with the new data

- Open source project with a commercial support option

- Sponsored by
  Norges Bank
  European Central Bank
  Bank of England

- Version 2.0 will be released in April.

Objectives of FNA

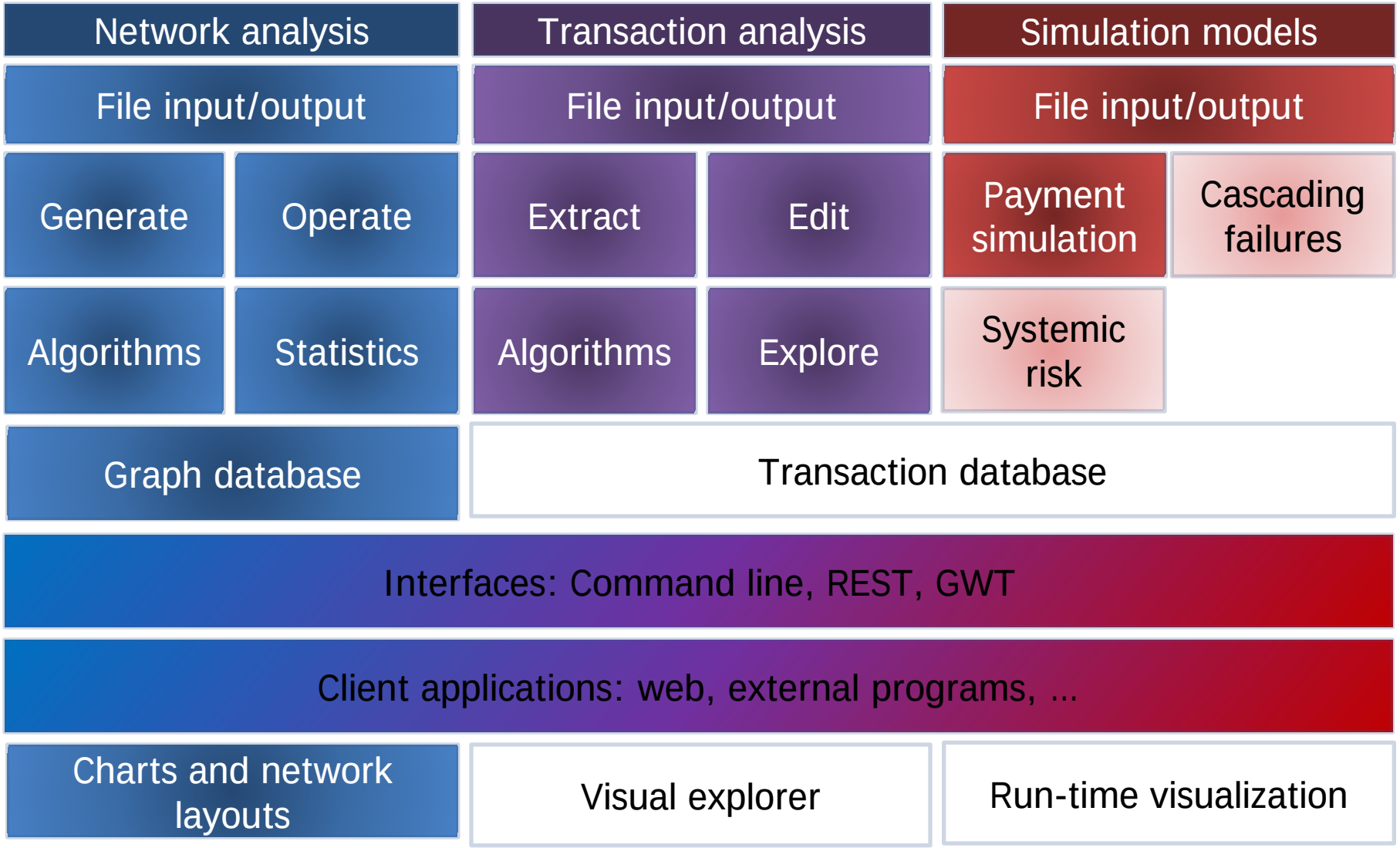
- Provide a tool for time series analysis of network data in finance
- Integrate data analysis, visualization and exploration
- Provide a platform for building agent based and simulation models
- Make advances in research available to policy

Roots

- Bof-PSS2
  - Bank of Finland, 1997-
  - Payment system simulator
  - Used in ~60 central banks

- Loki
  - Sandia National Laboratories , 2004-
  - Toolkit for network analysis and ABM

The big picture



Demo

fna

User Manual Logout

ANALYSIS CHARTS

```
Analyzing network '2010-2Q' ...
Result saved as vertex property 'degree'
Execution time 00:00:01.125

net_id,vertex_id,degree
2010-2Q,United States,18.000
2010-2Q,United Kingdom,18.000
2010-2Q,Turkey,17.000
2010-2Q,Switzerland,18.000
2010-2Q,Sweden,18.000
5 vertices listed
Execution time 00:00:00.027

Analyzing network '2005-1Q' ...
This analysis needs normalized weights.
Result saved as arc property 'n_normalize#normweight'
Result saved as arc property 'v_normalize#normweight'
Result saved as vertex property 'evc'
Analyzing network '2005-2Q' ...
```

```
peek -file results/rrgs-out-offsetfifo-test.txt
chart -scatter evc,degree -saveas scatter2.html
chart -line value_sum -saveas line.html
list -n
aggregate -a2n value -operation sum
chart -graph id=2010-1Q,vertices=15,vp=evc,ap=value,af=0.0003 -saveas graph3.html
chart -graph id=2010-1Q,vertices=15,vp=evc,ap=value,af=0.003 -saveas graph2.html
list -v -desc -range 1-5
analyze -name evc
list -v -desc -range 1-5
```

version 2.0.1 (dev)

>>

Uploads

Results

Charts

Scripts

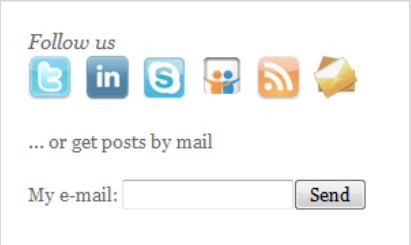
Sort by Last modified

validations.txt	11:07
transpose.txt	11:07
validate.txt	11:07
testerrors.txt	11:07
testall.txt	11:07
test.txt	11:07
t2fixtime.txt	11:07
t2.txt	11:07
symmetrize.txt	11:07
savepajek.txt	11:07
savelist.txt	11:07
run.txt	11:07
peek.txt	11:07
paymentsimulation.txt	11:07
memory.txt	11:07
match.txt	11:07
manual.txt	11:07
loadproperties.txt	11:07
loadpajek.txt	11:07
list.txt	11:07
loadlist.txt	11:07

Thank you

More information:

www.financialnetworkanalysis.com



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