Tracking Systemic Risk in the International Banking Network

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Overview

- In the build up to the crisis, large banking groups had become highly interdependent across national borders
  - Lehman's global business operated with over a 100 data systems that were owned and managed by some of the 6,000 legal entities within the group worldwide.
- Because the system was so intertwined, the financial crisis was transmitted rapidly through default chains, funding squeezes, fire sale externalities and rash of counterparty fear.
- In this paper we use network theory to help understand the transmission of financial stress in this complex system.

- Our focus is on the international banking network
- A set of bilateral claims (links) of different banking groups (nodes) on each other
- A banking group includes all the banks operating in a particular country
- We separate banking groups into their funding and credit arms
- This allows us to distinguish between two different channels of contagion
  - Banks defaulting on loans transmit stress to their creditors via a credit channel.
  - Banks refusing to make loans transmit stress via a funding channel.

- Our goal is to understand how financial stress travels through the network
- In particular we want to know when stress is likely to be contained in a particular country or group of countries and when it is likely to become broadly systemic
- The first task is to identify the appropriate modular structure of the network
  - Put nodes into clusters if they are *sufficiently* more likely to transmit stress between themselves than to the whole system

- Once we know the modular structure of the network, we can examine the propensity for each module to transmit, or conversely to contain financial stress
- In a safer network, the most important modules will have a lower capacity to transmit financial stress
  - those modules will act as absorbers
- If instead the important modules have a high propensity to transmit contagion, then financial stress will crisscross many national boundaries and become truly systemic

Findings

- Significant changes in modular structure since 1985
  - Late 1980s saw formation of large super cluster: Japan, United Kingdom, the United States and the Cayman Islands.
  - That cluster breaks up by the beginning of the 1990s
- Persistent relationships
  - US & KY and DE & LU almost always together (except 2008 Q4)
  - Scandinavian group together since 2001
- Relevance and irrelevance of geographic location
  - Scandinavian group, DE & LU
  - Canada not with US (except 1997 Q1)
- Increase in systemic risk up to 2008 Q2
  - Still relatively high

Previous work

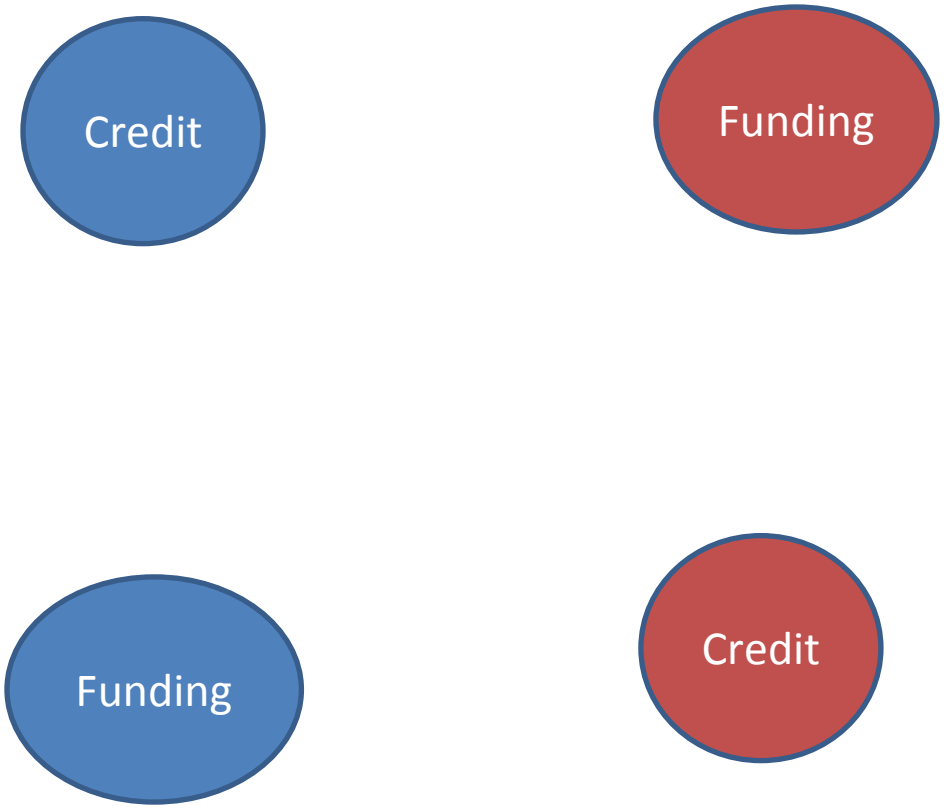
- Models aimed at simulating financial stress across the network
  - The latest generation of these simulation network models feature sophisticated transmission through funding and firesale externalities and not just through chains of credit tightening.
    - Gauthier, He and Souissi (BoC working paper, 2011)
  - Naturally they require quite a few calibrations and detailed modelling of the behaviour of each node.
  - The results they report are more in the form of specific experiments.

Previous work cont…

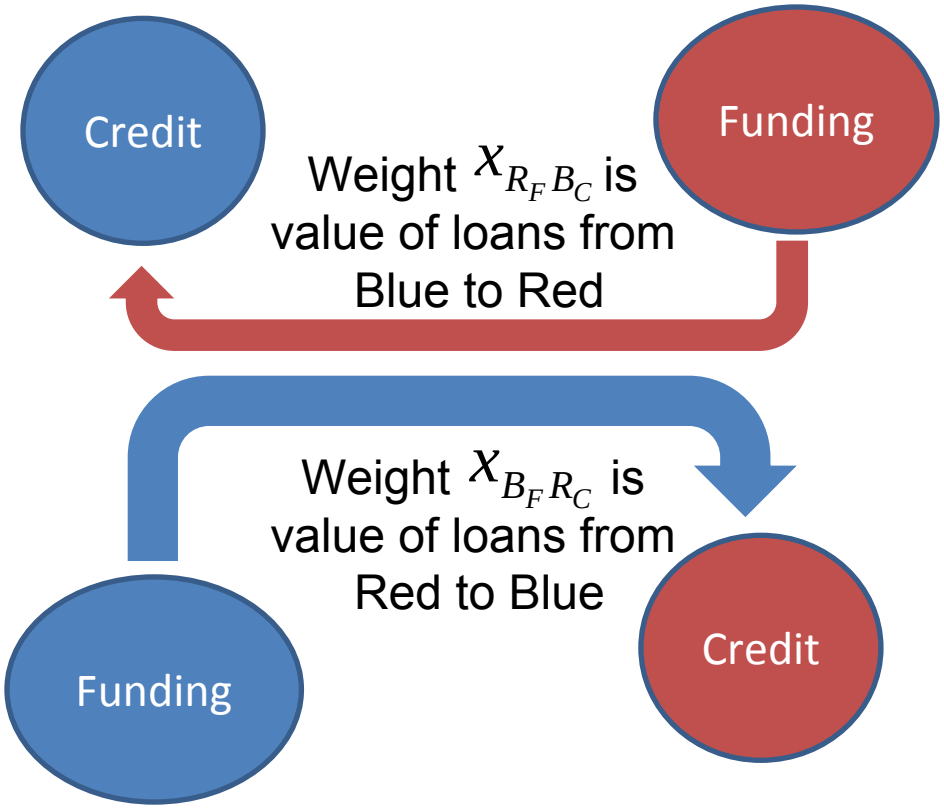
- Our paper falls into another strand of the literature which, rather than simulating particular experiments, aims to summarize features of the network, using *network measures* without imposing too many assumptions.
  - Goetz von Peter, *BIS Quarterly Review*, 2007
- Within this subgenre, no other papers consider modular structures

Specification of the Network: Banking Groups

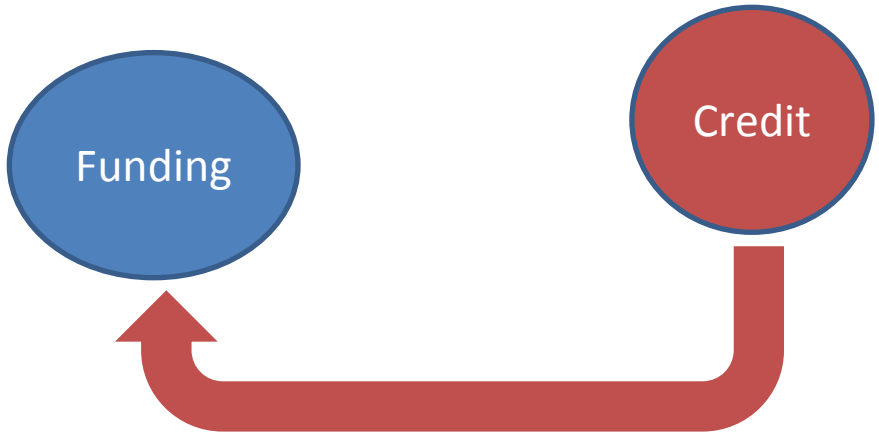
Bring in funding and credit by splitting nodes



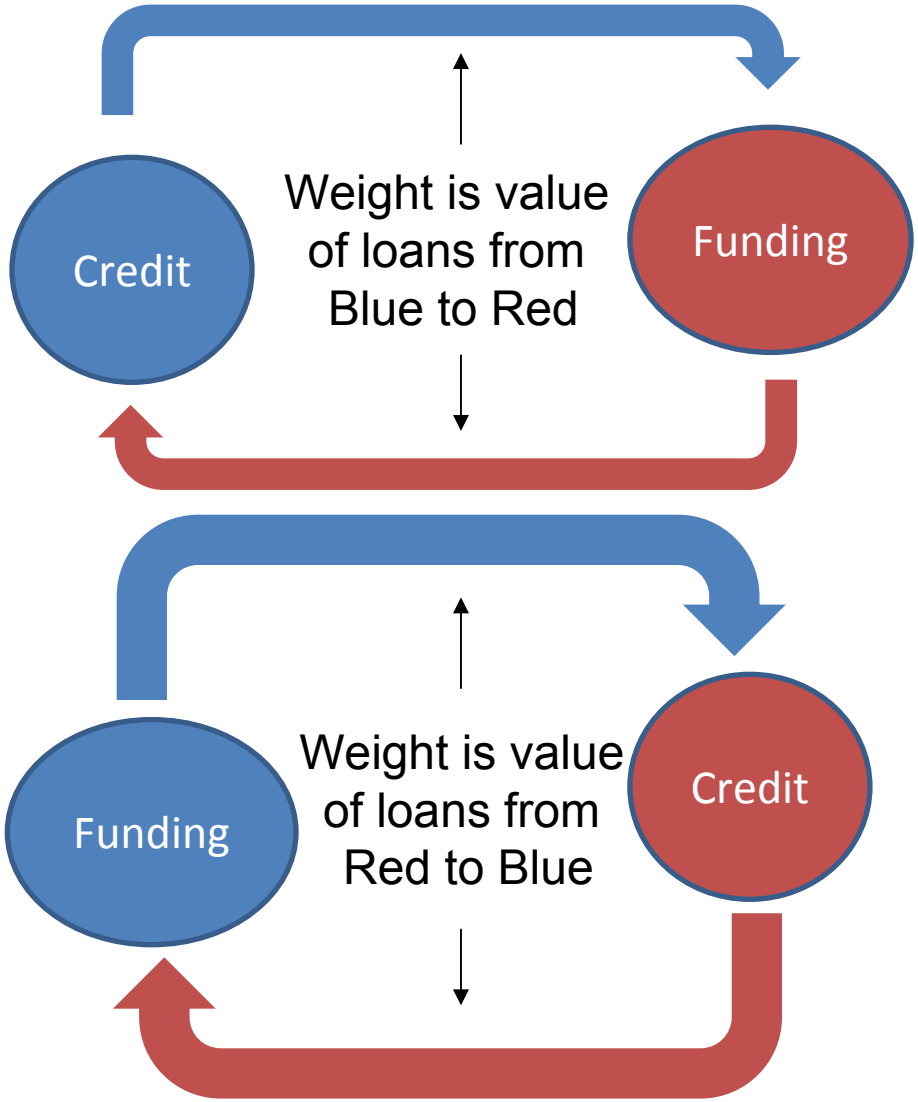
Define Relationships: Credit channel



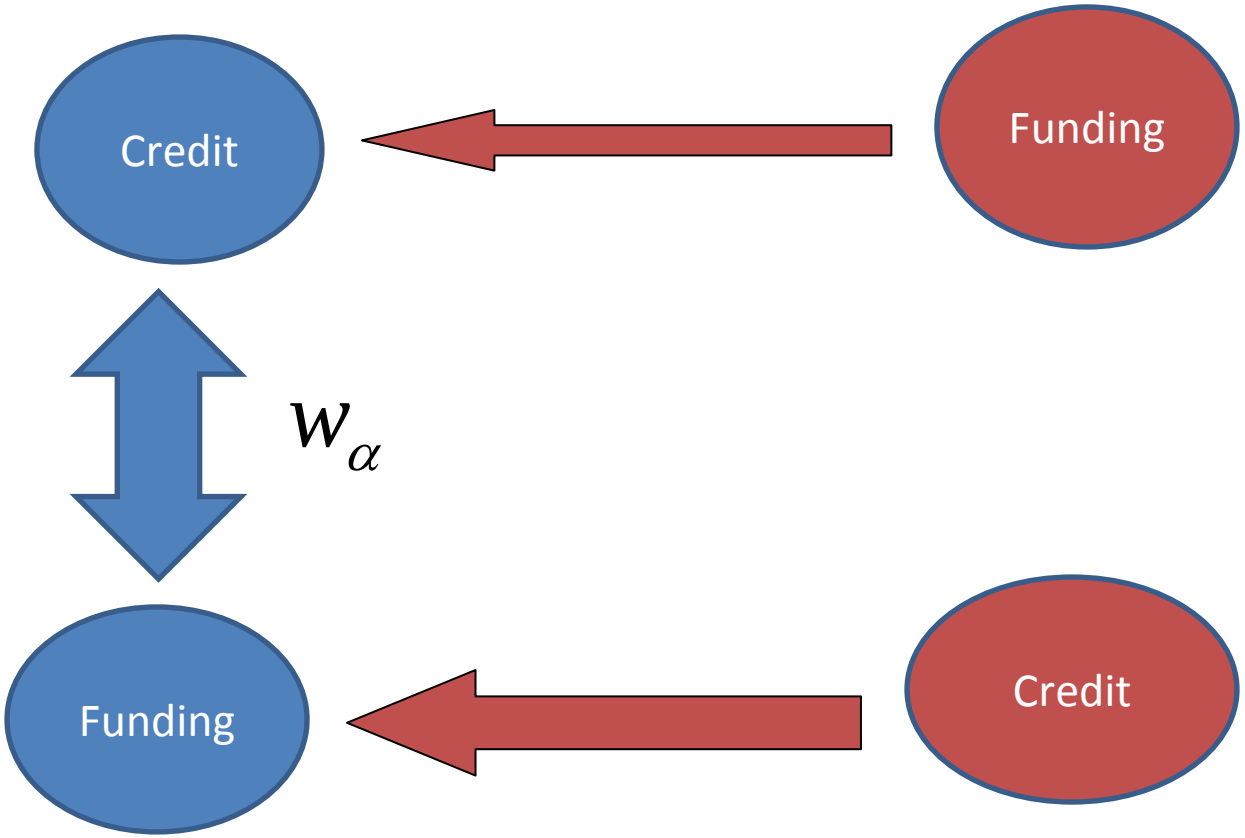
Define Relationships: Funding channel



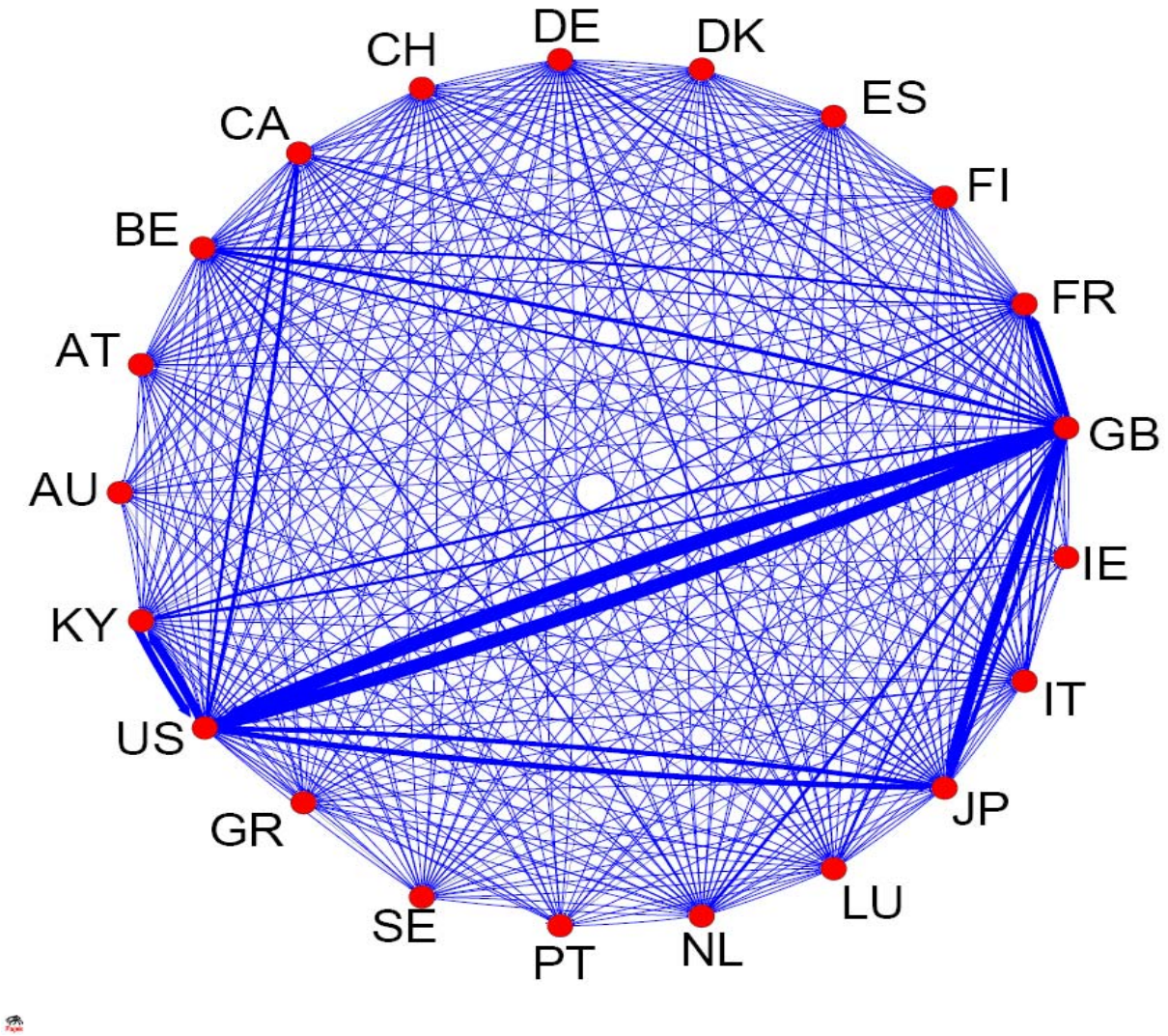
Define Relationships: Symmetry



Allow for absorption

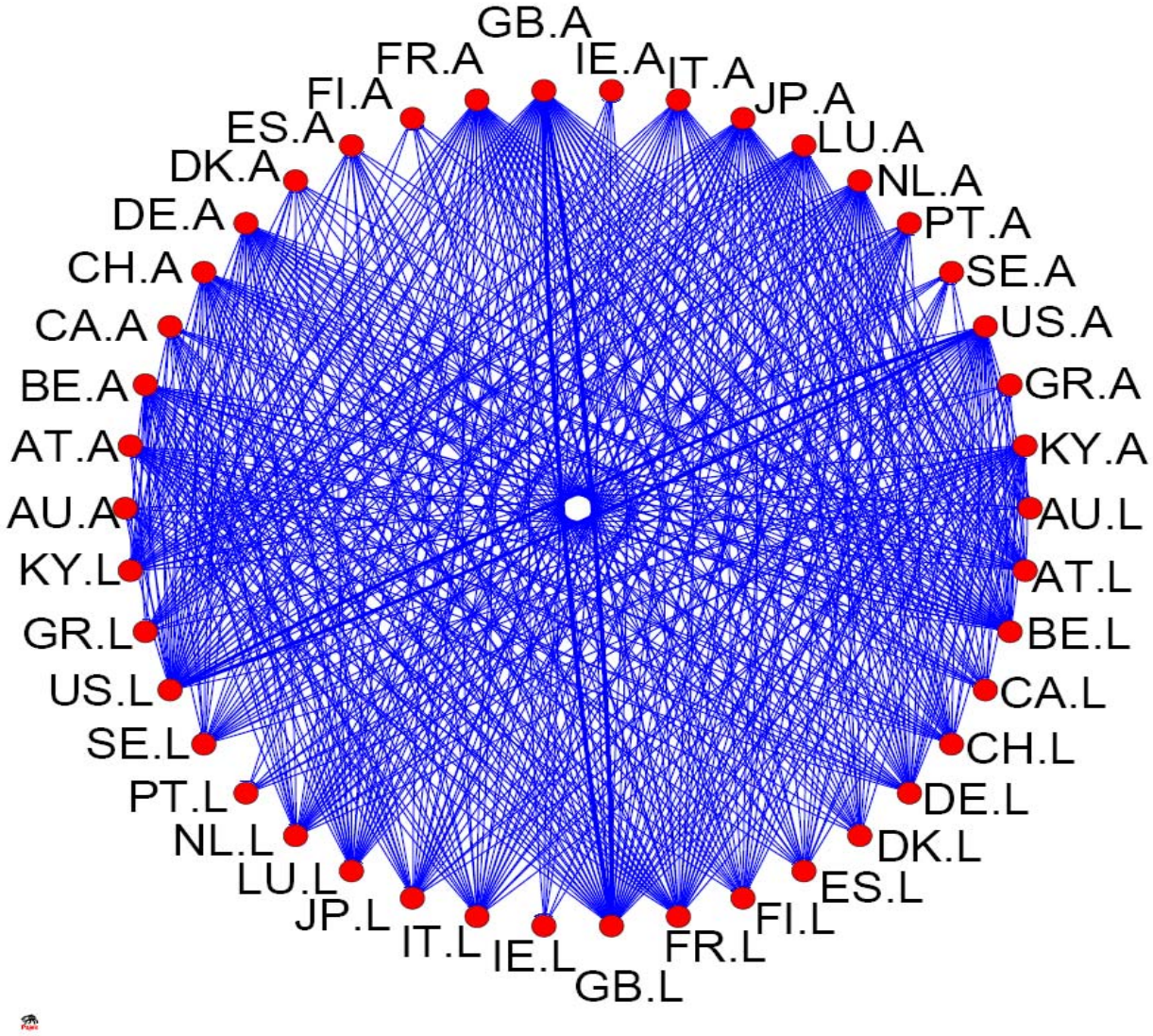


The Locational Banking Network 1985 Q1



Source: BIS Locational by Residence and own calculations

Nodes after split 1985 Q1



Source: BIS Locational by Residence and own calculations

Matrix of Contagion Frequency

$$V = (v_{\alpha_J \beta_K})_{\alpha_J \beta_K}$$

where $\alpha, \beta \in \{1,\ldots,n\}, \quad J, K \in \{C, F\}.$

- 2n x 2n matrix
- Premise is that stress is transmitted through the financial network in a manner that is proportional to these capacities.

Markov Transition Matrix

$$\Pi = \left(\pi_{\alpha_J \beta_K}\right)_{\alpha_J, \beta_K} = \left(\frac{\nu_{\alpha_J \beta_K}}{\sum_{\alpha_J} \nu_{\alpha_J \beta_K}} \right)_{\alpha_J, \beta_K}$$

where $\alpha, \beta \in \{1, \ldots, n\}, \quad J, K \in \{C, F\}.$

- Goal is to find the best modular description with respect to Π

Mr. Contagion

- Stress is modeled as a flow
- We want to find modular structures within the network that are significant with respect to these flows.
- Utilize Rosvall and Bergstrom's map equation
  - Used to cluster scientific fields (Map of Science)
- At the core of RBs' approach is a formula that tells us how efficient any particular modular structure is at describing the path of an imaginary traveler, whom we call Mr. Contagion, around the network, given information about the stochastic process that determines his movements.

Data

Compressing ⟷ Finding patterns

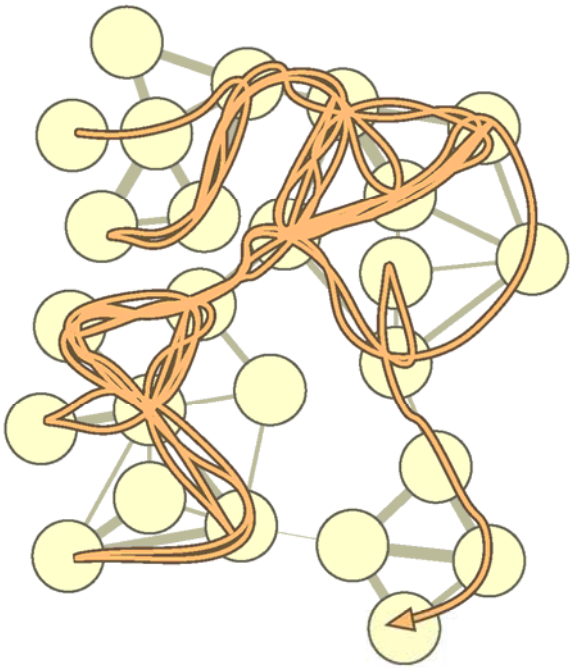
Minimum description length (MDL) statistics.

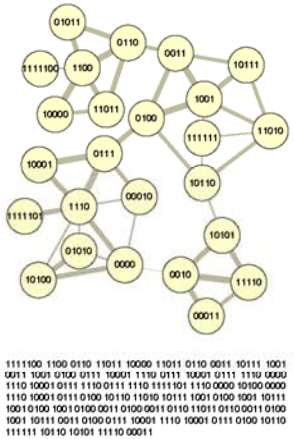
Data

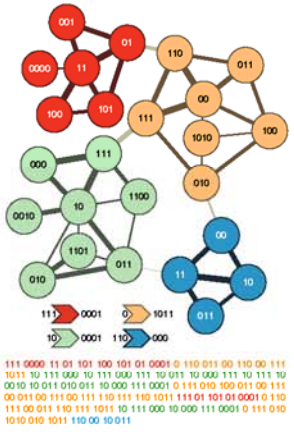
Compressing ⟷ Finding patterns

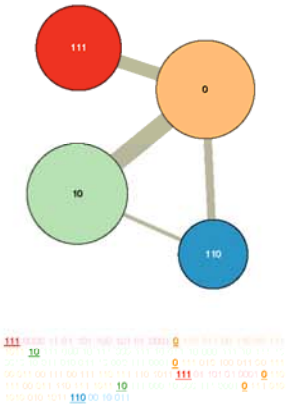
“If we can find a good code for describing flow on a network, we will have solved the dual problem of finding the important structures with respect to that flow.” (RB)

Maps by compressing flow of information on networks







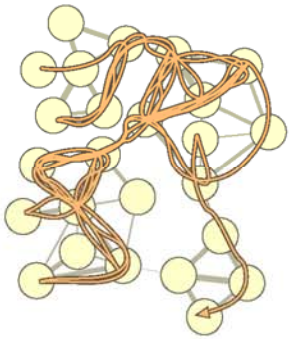


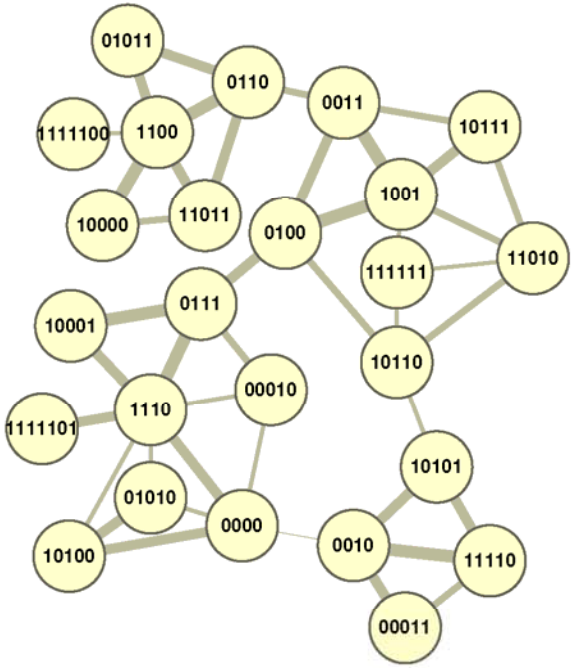
Huffman Code

1. At each step the characters you have seen do not yet correspond to any item, or they correspond to exactly one
2. Encoded message is shortest satisfying 1.

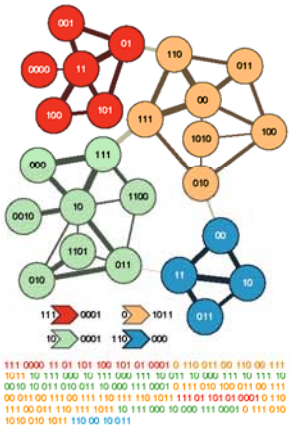
Describing flow is a coding game

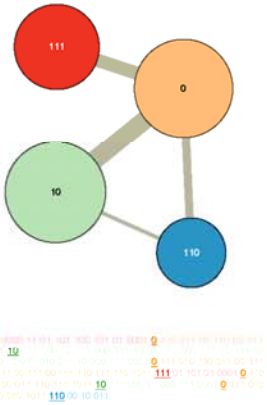
— objects deserve unique names





1111100 1100 0110 11011 10000 11011 0110 0011 10111 1001
0011 1001 0100 0111 10001 1110 0111 10001 0111 1110 0000
1110 10001 0111 1110 0111 1110 1111101 1110 0000 10100 0000
1110 10001 0111 0100 10110 11010 10111 1001 0100 1001 10111
1001 0100 1001 0100 0011 0100 0011 0110 11011 0110 0011 0100
1001 10111 0011 0100 0111 10001 1110 10001 0111 0100 10110
111111 10110 10101 11110 00011



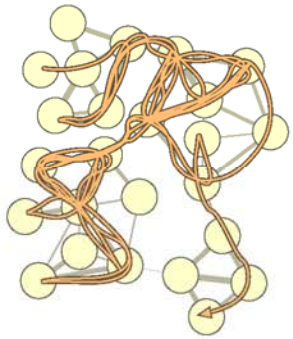


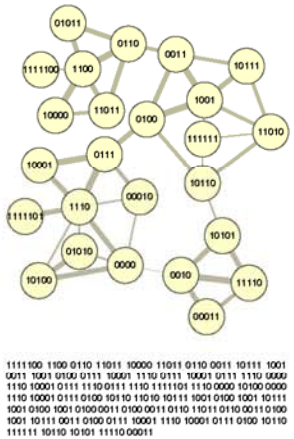
Modular Structure

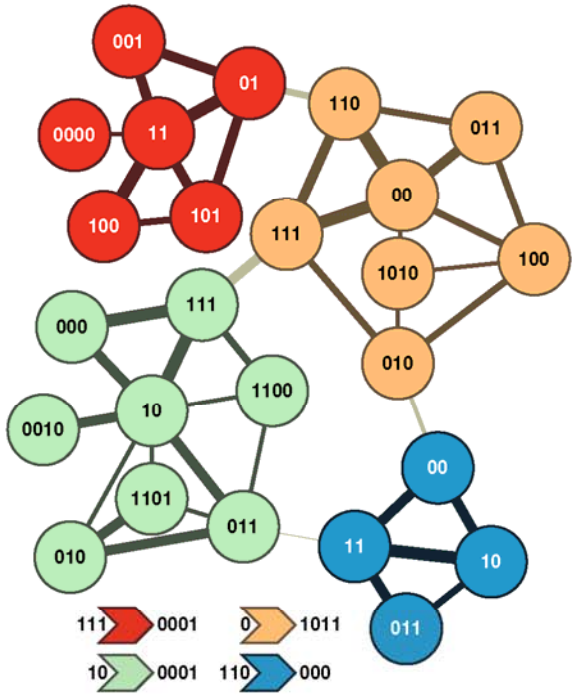
- RB apply Huffman coding in a “tiered” way, saving code by using two types of code books
  - module codebooks & index codebook
- Can reuse code words in different modules
- Transforms the problem of minimizing the description length of places traced by a path into the problem of how we should best partition the network with respect to this flow
- Trade-off costs and benefits measured in terms of bits

Simplify and highlight

— important objects deserve unique names



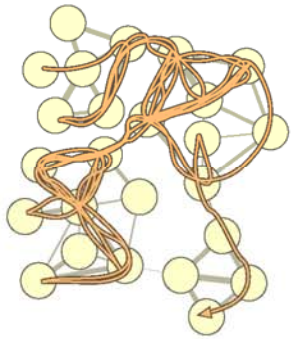


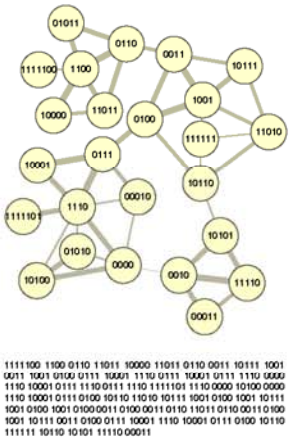


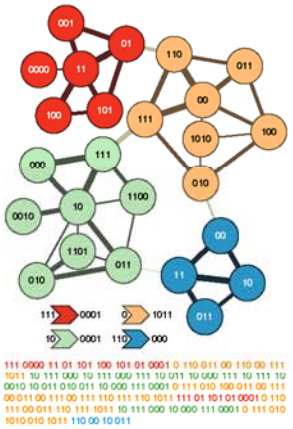
111 0000 11 01 101 100 101 01 0001 0 110 011 00 110 00 111 1011 10 111 000 10 111 000 111 10 011 10 000 111 10 111 10 0010 10 011 010 011 10 000 111 0001 0 111 010 100 011 00 111 00 011 00 111 00 111 110 111 110 1011 111 01 101 01 0001 0 110 111 00 011 110 111 1011 10 111 000 10 000 111 0001 0 111 010 1010 010 1011 110 00 10 011

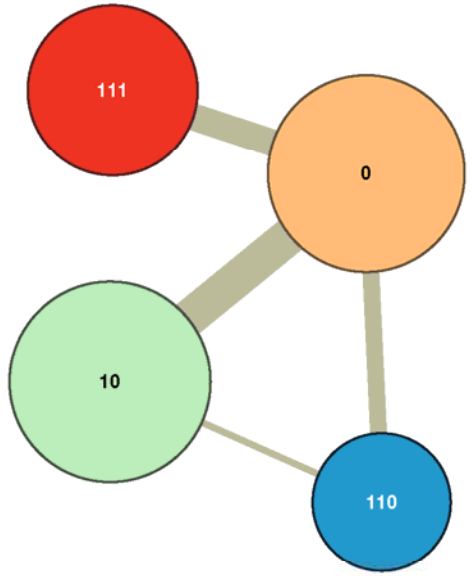
Simplify and highlight

— highlight important objects and filter away details









naming places

Shannon's Source Code Theorem

- RB do not need to actually produce code for each partition
- Rather, they calculate the theoretical limit for all of the different partitions and pick the one that is best (gives shortest description length)
- If you want to describe the states of a random variable X, that occurs with frequency p_i, then the average length of a codeword can be no less than the entropy of X:

$$H(X) = -\sum_{i=1}^{n} p_i \log(p_i)$$

The map equation

$$L(\mathsf{M}) = q_{\curvearrowright} H(\mathcal{Q}) + \sum_{i=1}^{m} p^{i}_{\circlearrowright} H(\mathcal{P}^{i})$$

The map equation tells us the minimum description length for a particular modular structure

The map equation

frequency of inter-module movements

frequency of movements within module *i*

$$L(\mathsf{M}) = q_{\curvearrowright} H(\mathcal{Q}) + \sum_{i=1}^{m} p^i_{\circlearrowright} H(\mathcal{P}^i)$$

code length of module names

code length of node names in module *i*

Perron-Frobenius

- Mathematically the values p_i are computed as the dominant (right) eigenvector of the Markov transition matrix of contagion

$$p = \Pi p$$

  where $p = [p_1,\ldots,p_{2n}]'$.
- This measure of eigenvector centrality can be reliably calculated if the Markov transition matrix is irreducible.
- p_i is the prestige (aka PageRank) of node *i*
- Prestige tells us how often stress visits each location in the network

Modelling Intrabanking Group Transmission (w_α)

- Prestige of banking group α

$$p_\alpha = \frac{½(\sum_\beta x_{\beta_F \alpha_C} + \sum_\beta x_{\alpha_F \beta_C}) + w_\alpha}{\sum_\beta \sum_\gamma x_{\beta_F \gamma_C} + \sum_\beta w_\beta}$$

- If $w_\alpha = 0$ then prestige depends only on the sum of assets and liabilities
- 800 liabilities and 400 assets same as 400 liabilities and 800 assets

Big Borrowers

- Our starting point is that a banking group with a large interbank funding requirement relative to its interbank assets is more susceptible to shocks

$$w_\alpha = \sum_{\beta \neq \alpha} x_{\alpha_F \beta_C}$$

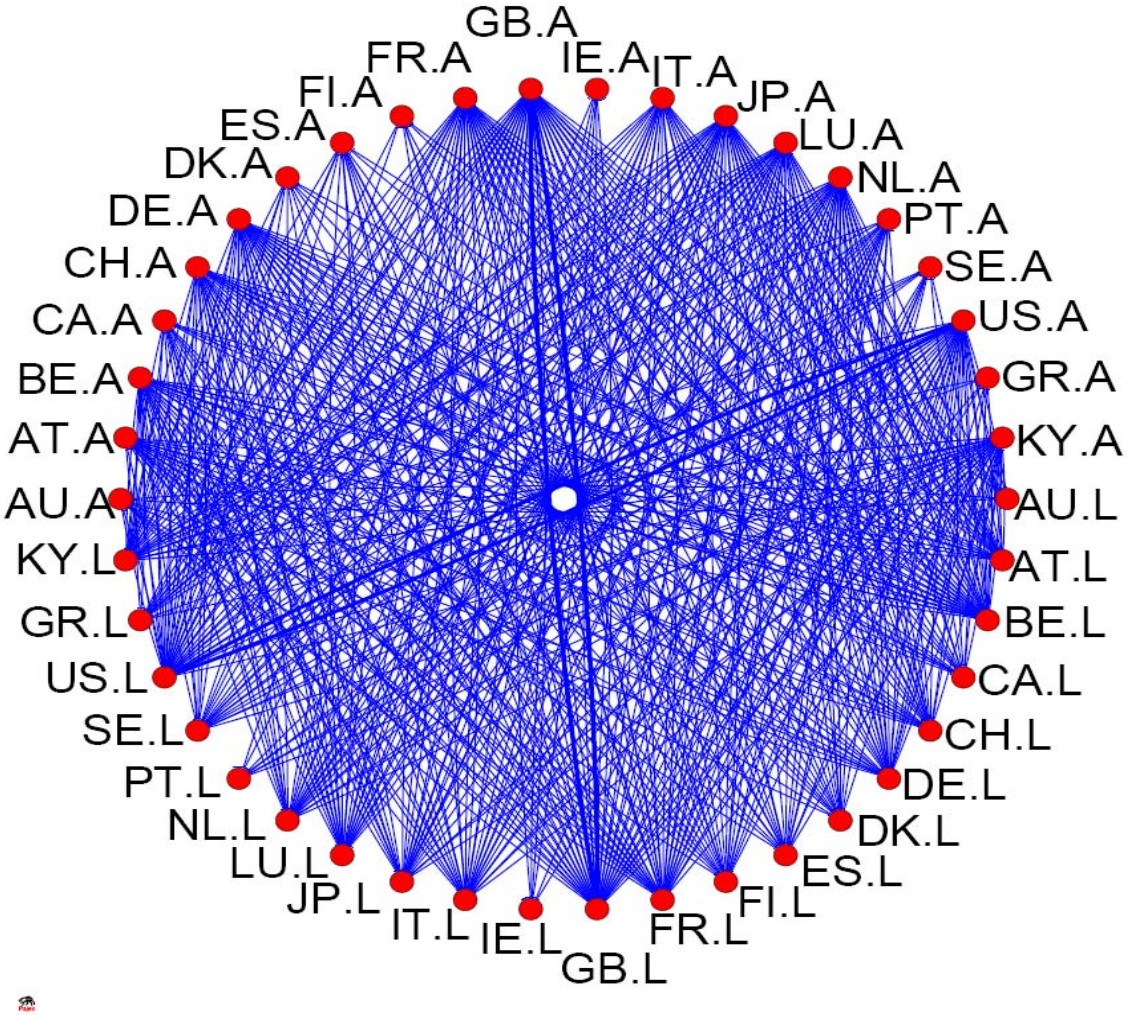
- Prestige depends on total assets and liabilities of banking group and net position

$$p_\alpha = \frac{1}{2} \frac{(\sum_\beta x_{\beta_F \alpha_C} + \sum_\beta x_{\alpha_F \beta_C})}{\sum_\beta \sum_\gamma x_{\beta_F \gamma_C}} + \frac{1}{4} \frac{(\sum_\beta x_{\alpha_F \beta_C} - \sum_\beta x_{\beta_F \alpha_C})}{\sum_\beta \sum_\gamma x_{\beta_F \gamma_C}}$$

Data

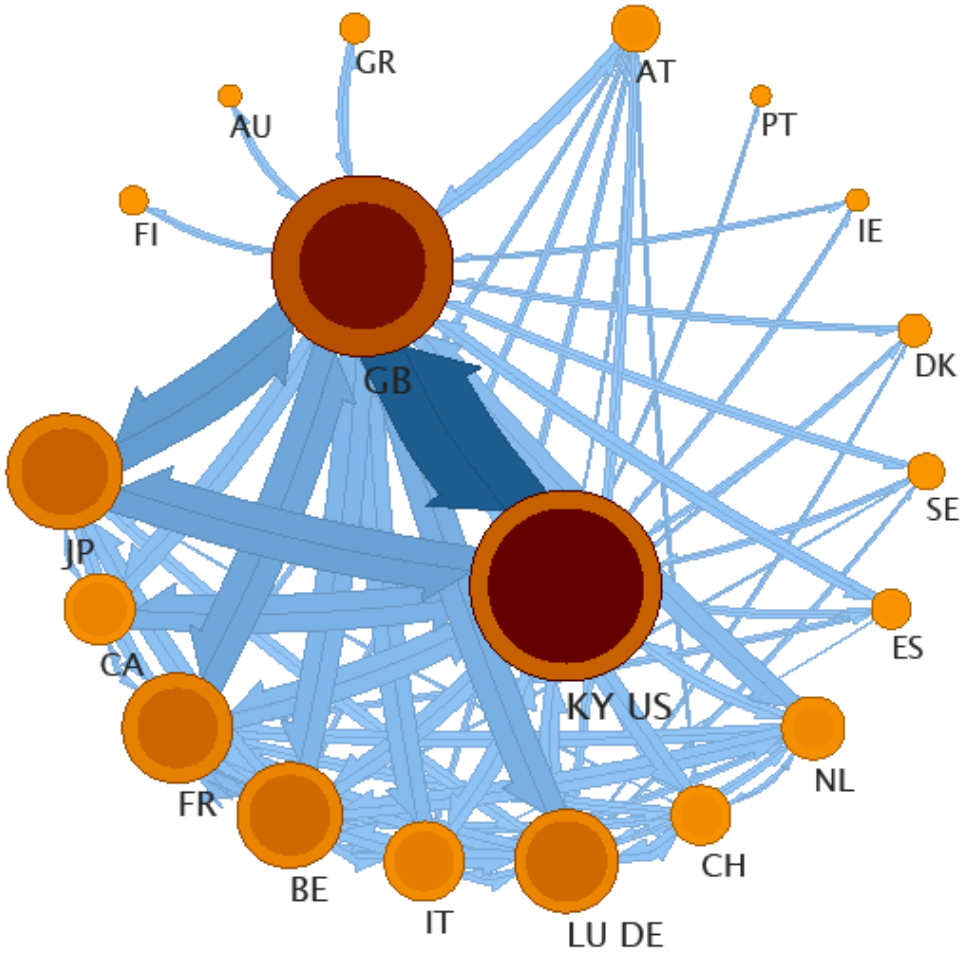
- Bank for International Settlements locational statistics.
- We included the following 21 reporting countries in our network: Austria, Australia, Belgium, Canada, Cayman Islands, Switzerland, Germany, Greece, Denmark (excluding Faeroe Islands and Greenland), Spain, Finland, France (including Monaco), United Kingdom (excluding Guernsey, Isle of Man and Jersey), Ireland, Italy, Japan, Luxembourg, Netherlands, Portugal, Sweden, and the United States.
- These countries representing about 73% of total reported claims on banks.
- 1985 Q1 to 2009 Q3

1985 Q1



Source: BIS Locational by Residence and own calculations

Illustration: Modular network (1985 Q1)

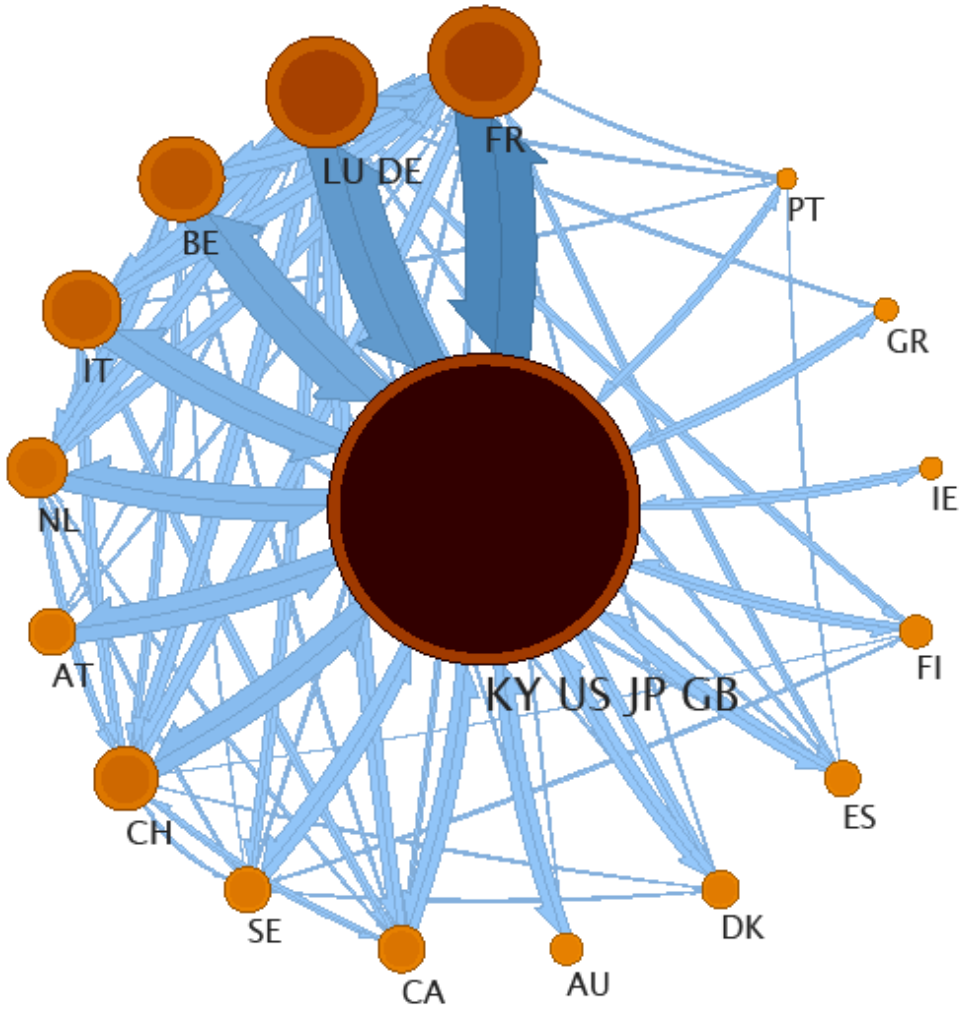


Source: Bank for International Settlements, Locational by Residence data and own calculations.

Changes in modular structure

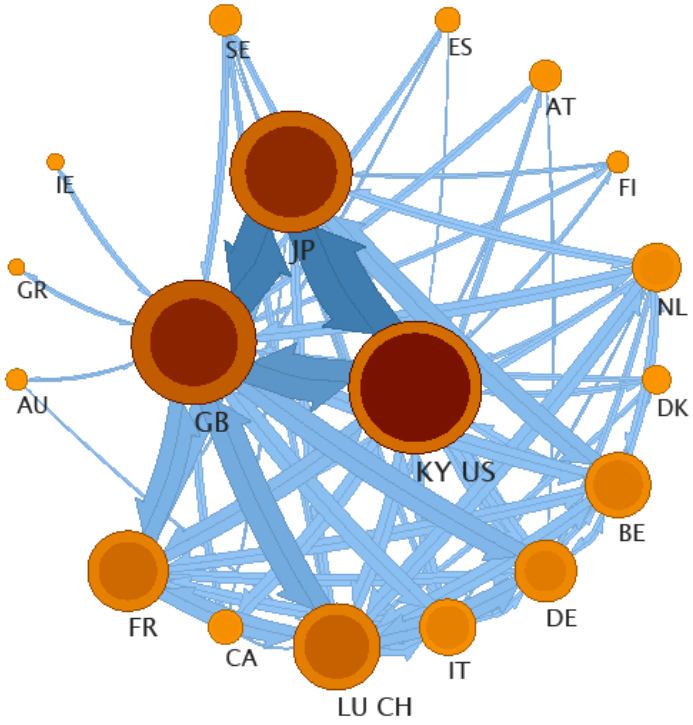
- In the late 1980s, Japanese banks expanded their overseas operations and this move is reflected by the inclusion of Japan in a large super cluster, along with the United Kingdom, the United States and the Cayman Islands.

Modular network (1989 Q3)

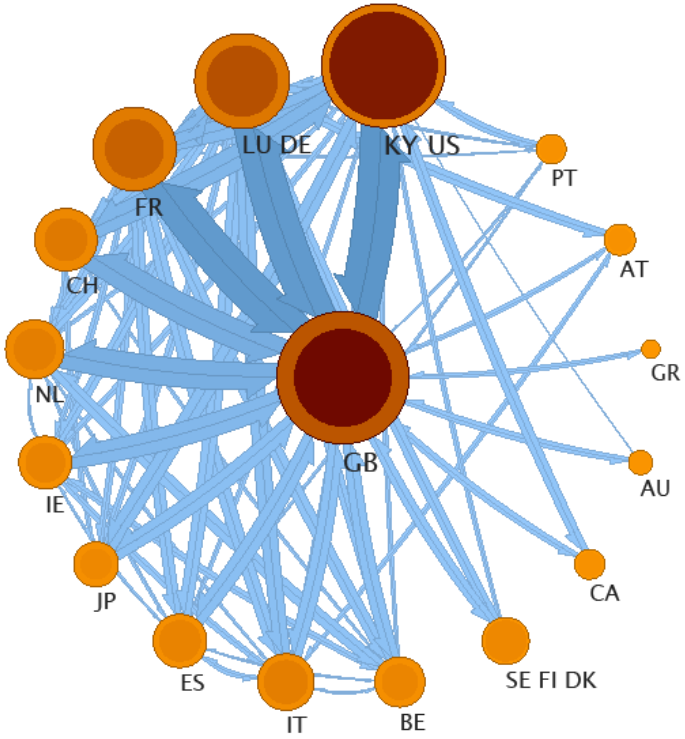


Changes in modular structure

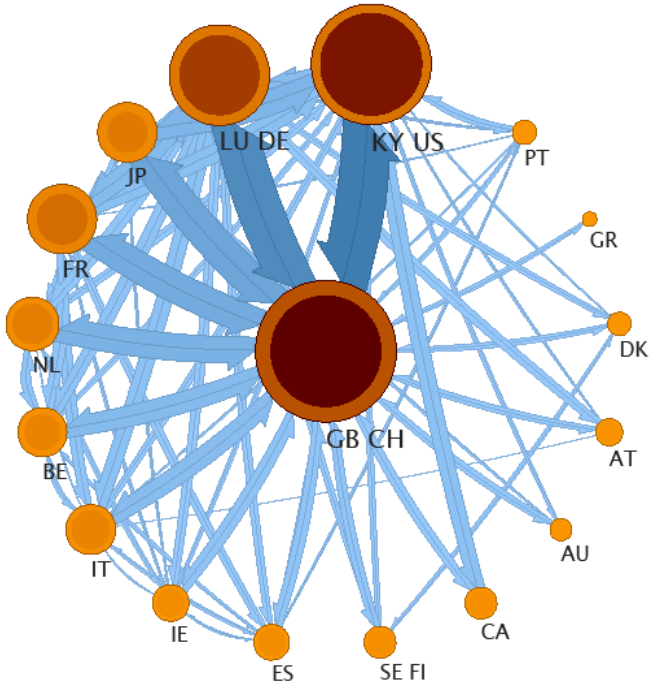
- That cluster breaks up by the beginning of the 1990s due to the emergence of the Japanese banking crisis.
- Over the next decade and a half, European banking groups increase in relative importance and accordingly we see many smaller, but still influential, clusters appear in our maps.



1989 Q4



2007 Q1

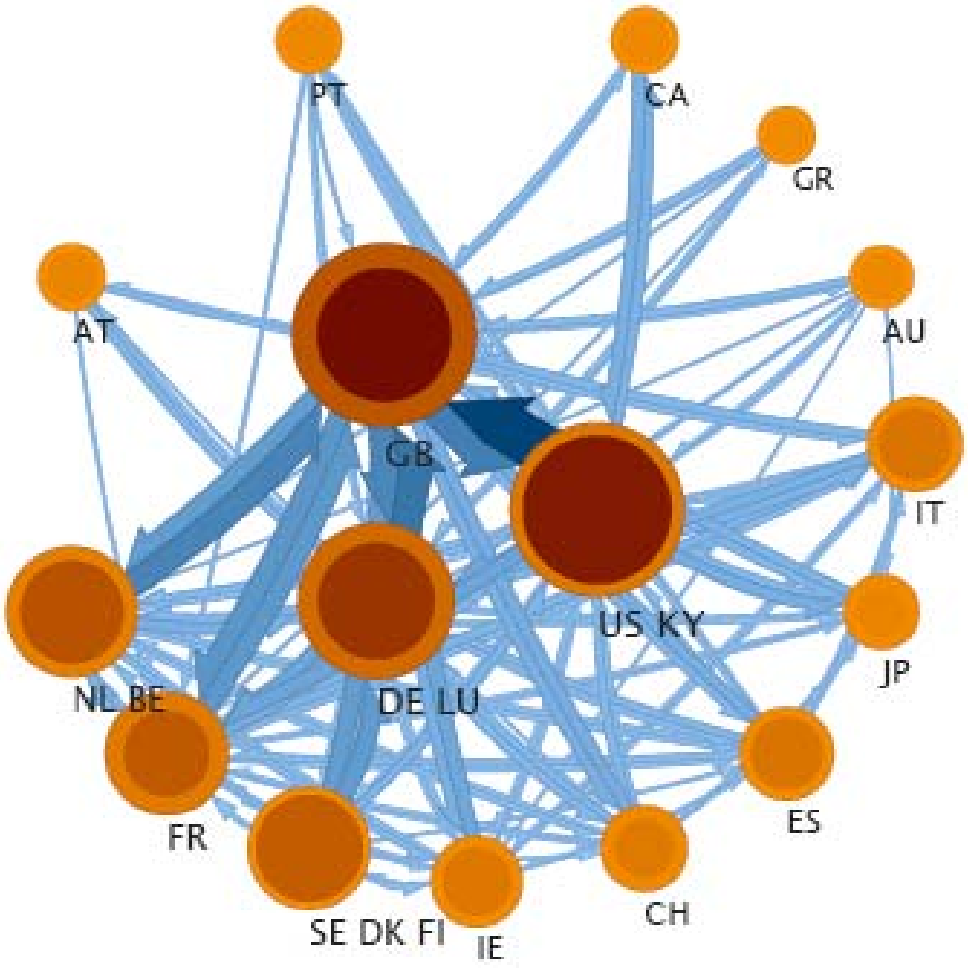


2000 Q1

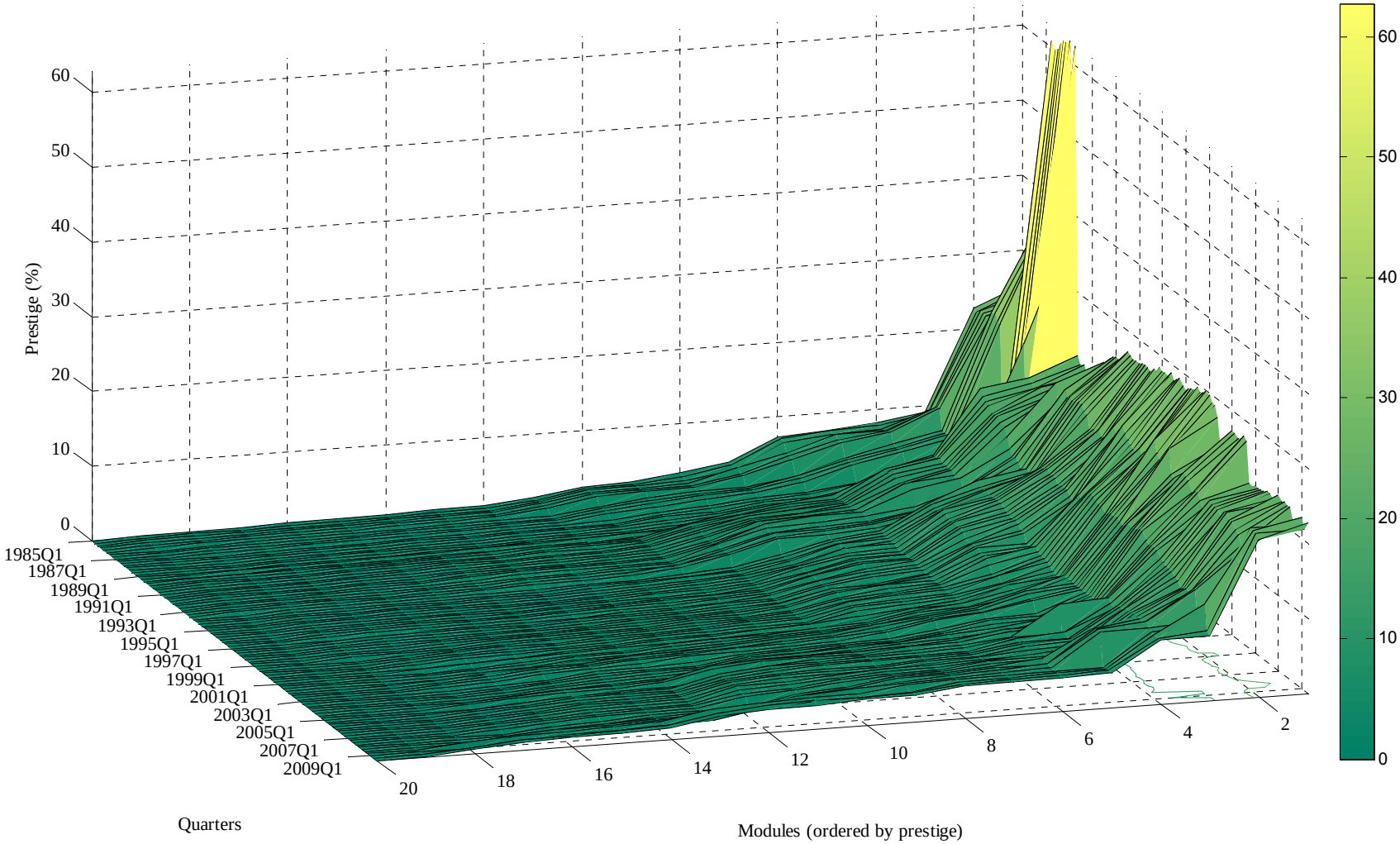
Changes in modular structure

- In general less absorption. More travel around the network.

Modular network (2008 Q3), Lehman Brothers



Density of prestige (% visits at each module)



Source: Bank for International Settlements Locational by Residence data and own calculations.

Tracking Contagion Over Time

- Flow that reaches module *i* can remain there or exit

$$q_{i\rightarrow} = \sum_{\beta_C \in i} \sum_{\alpha_F \notin i} \pi_{\alpha_F \beta_C} p_{\beta_C} + \sum_{\beta_F \in i} \sum_{\alpha_C \notin i} \pi_{\alpha_C \beta_F} p_{\beta_F}$$

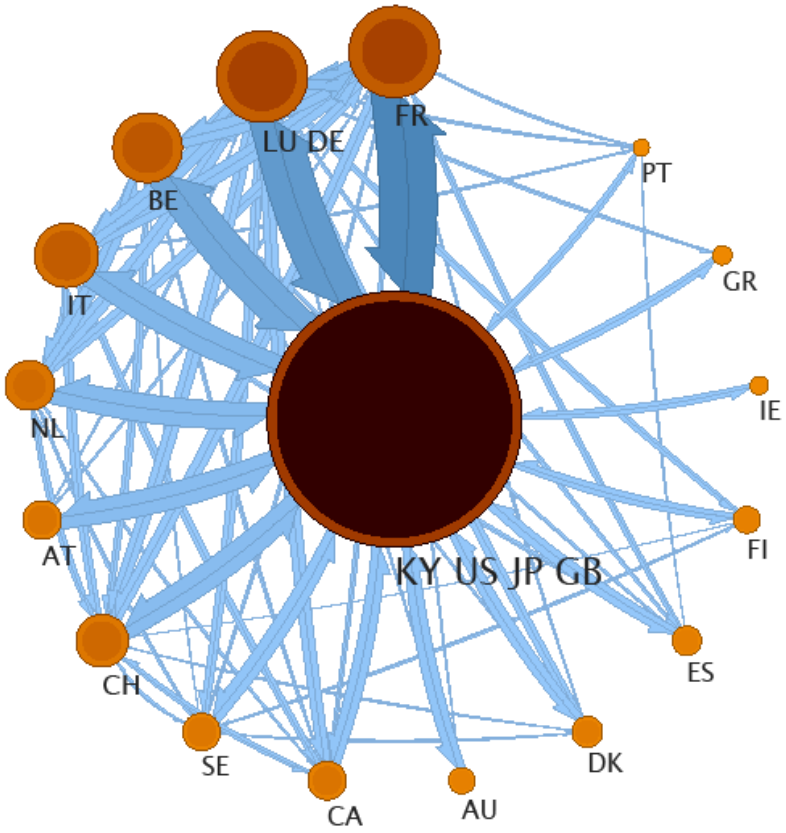
- Tells us how often stress that reaches module *i* exits on next step

$$q_{\rightarrow} = \sum_i q_{i\rightarrow}$$

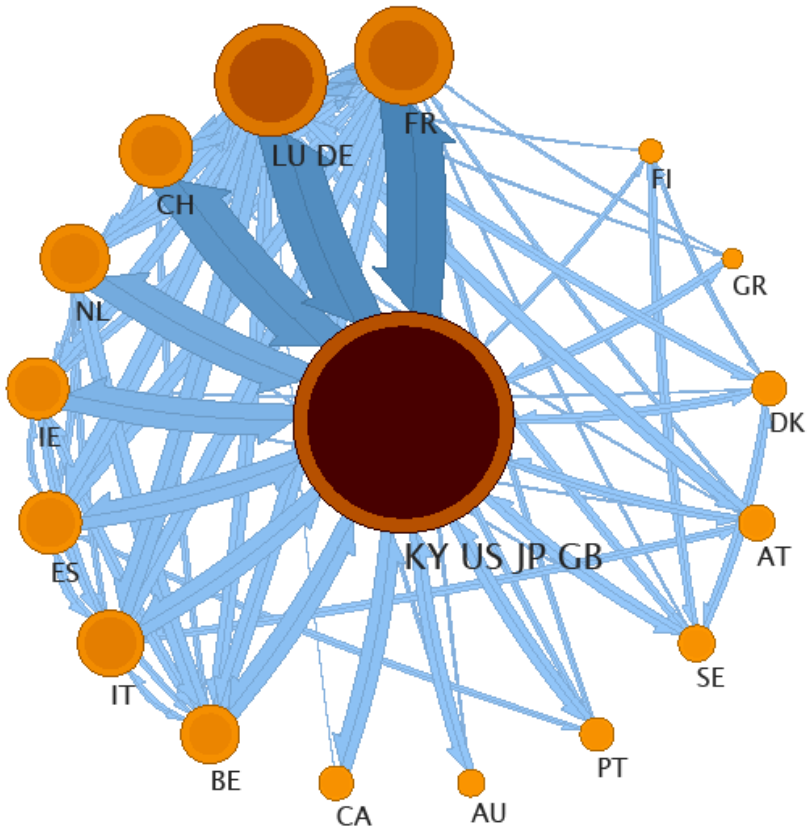
- Tells us how often shocks travel between modules

Counterfactual

- $q_{\rightarrow}$ gives us a sense of how broadly contagious shocks are.
- However, values of this measure are not easily comparable across time periods with different modular structures.
- Need to select a benchmark structure and compute $q_{\rightarrow}$ over time holding benchmark structure fixed.
- Tells us whether system-wide contagion increases and gives insight into why changes in modular structure are produced by the map equation.

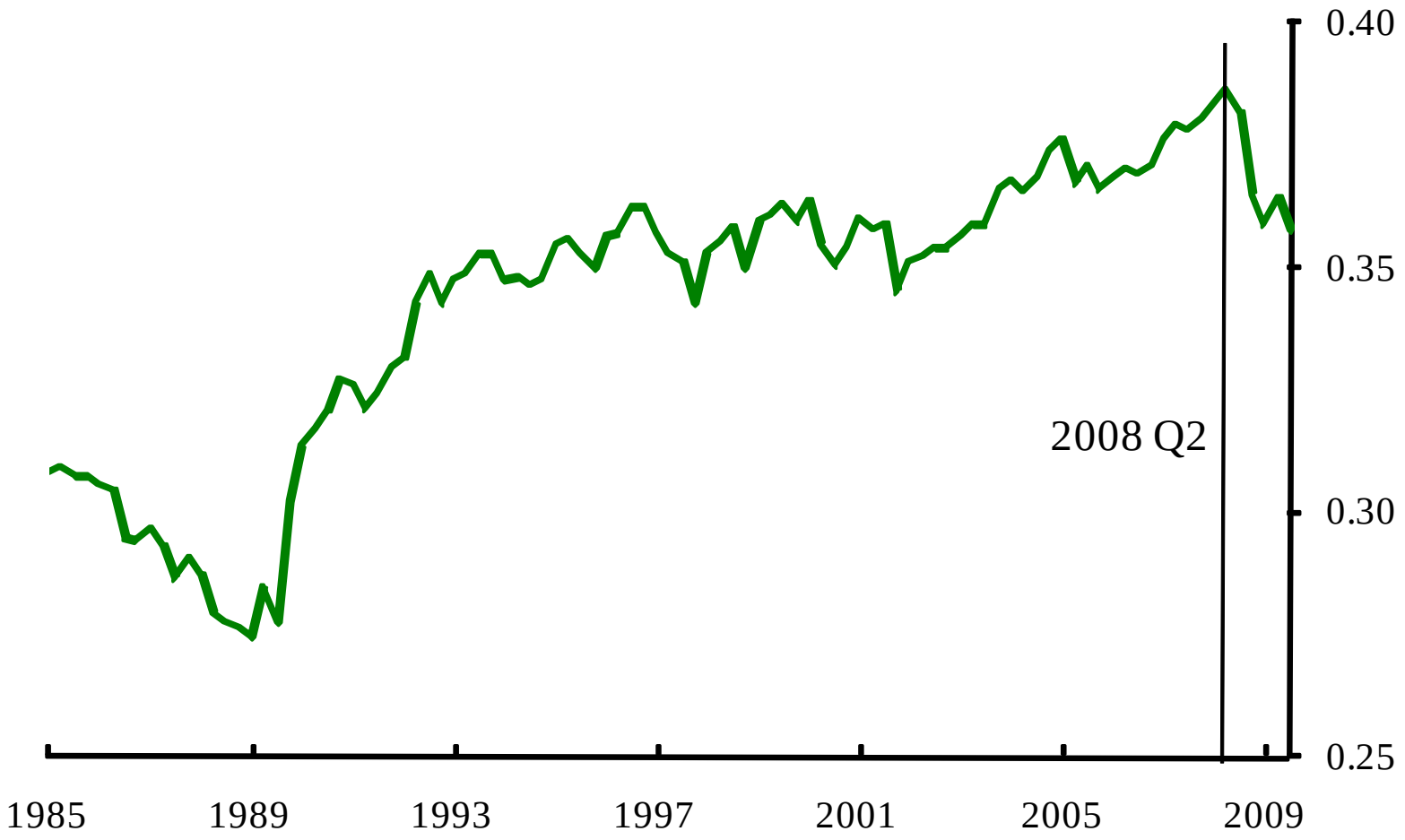


Modular network (1989 Q3)



Modular network (1989 Q3 on 2007 Q1 data)

Probability of Mr Contagion travelling outside
1989 Q3 fixed modular structure



Robustness Checks

- Apply map equation without splitting nodes
  - One large cluster
- Modularity a la Newman
  - Focus on pairwise relationships
  - Always 21 modules
- Consolidated data
  - Similar results but fewer multi-country modules
  - less reliable data

Concluding Remarks

- Significant changes in network structure since 1985
  - Disintegration of single financial centre
- Network became more broadly contagious prior to the crisis
  - Increased systemic risk
- Level of contagion still high
  - Threat may be reduced
  - contagious capacity not the same as severity of impact
  - There has also been a great reduction in the scale of the network since early 2008; possible strengthening of balance sheets


Thank You