DebtRank: Too Central to Fail?

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   www.focproject.net
   foc forecasting financial crises
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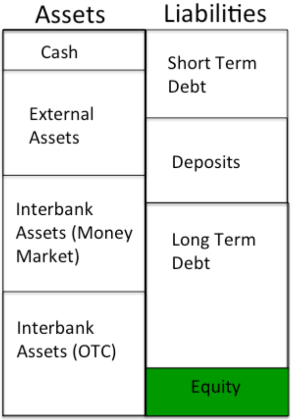
Outline

- Examples of network effects: default cascades and distress propagation
- DebtRank: a measure of SIFI
- Exercise on FED 1.2 TD emergency loans from 2008-2009
- Widgets
- Applications: regulation, counterparty risk and operational risk

Balance Sheet Structure



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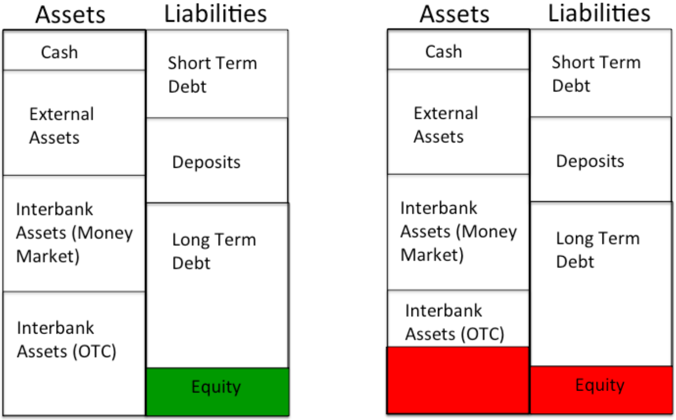
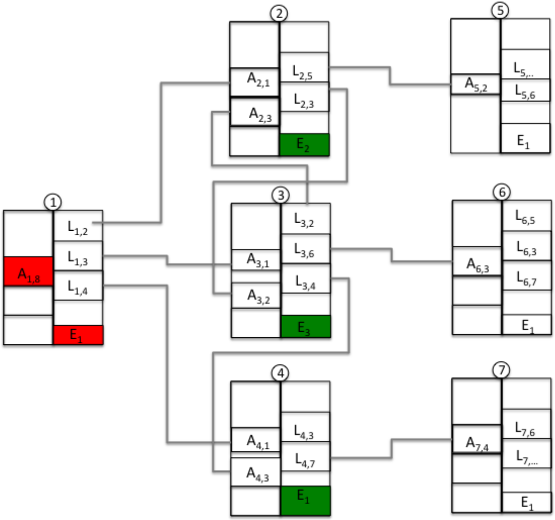


- Fundamental identity: Assets = Liabilities + Equity
- Equity <0 implies **default**

Default Cascade



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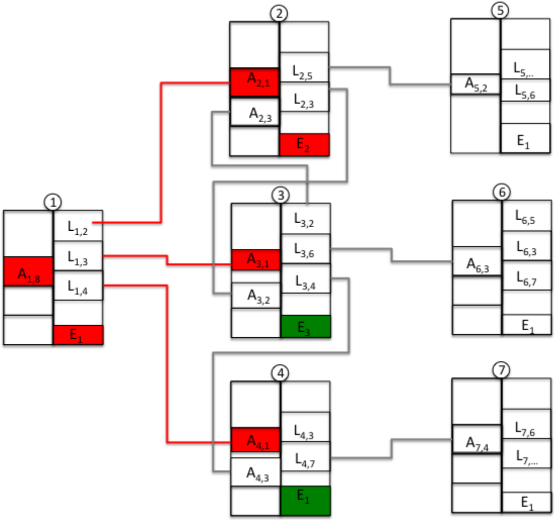

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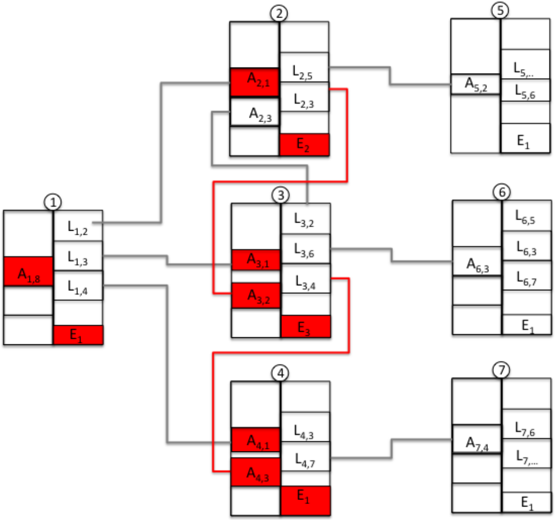

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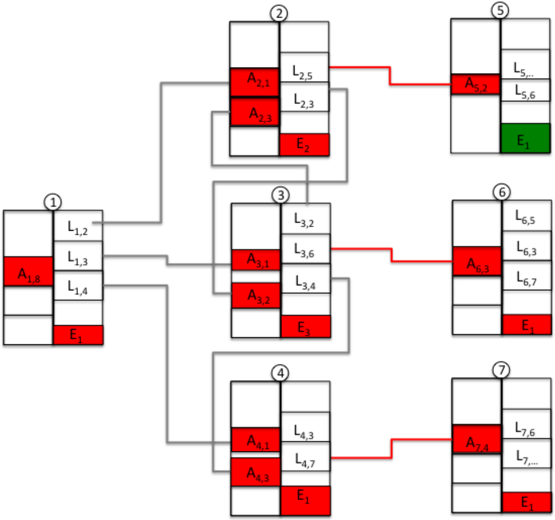
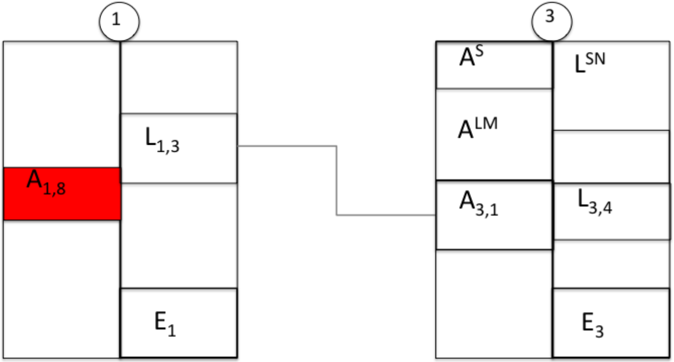


Devaluation Effect



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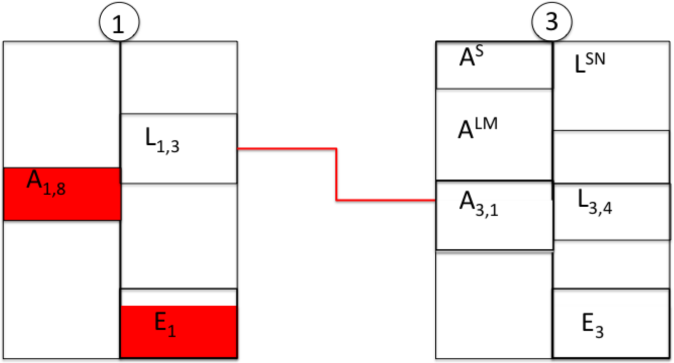

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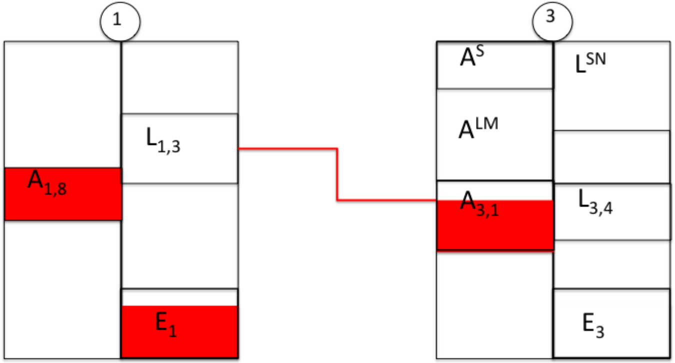

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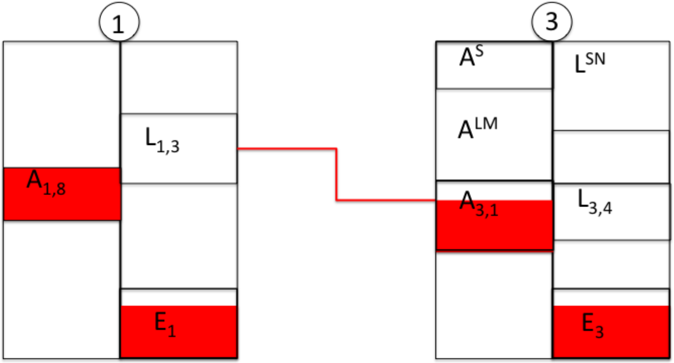
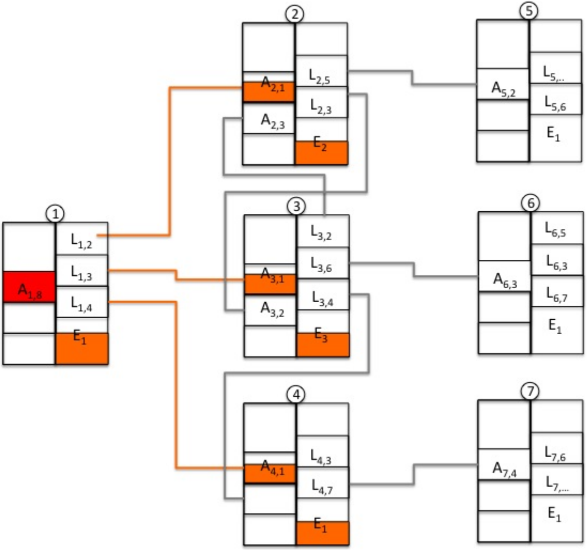


Distress Propagation: DebtRank



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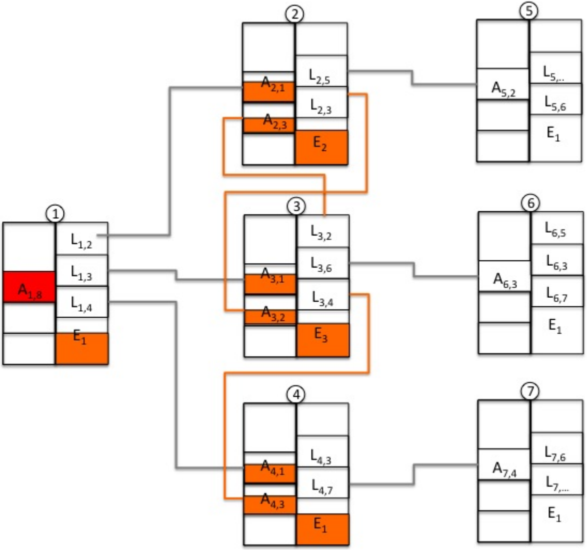

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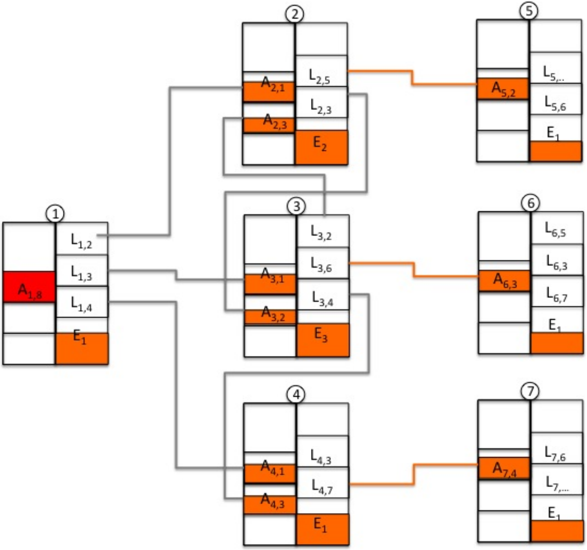

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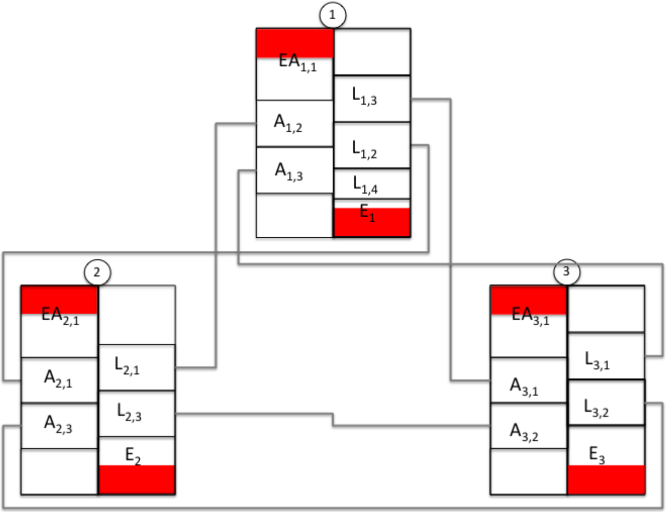
Shock to a Common External Asset



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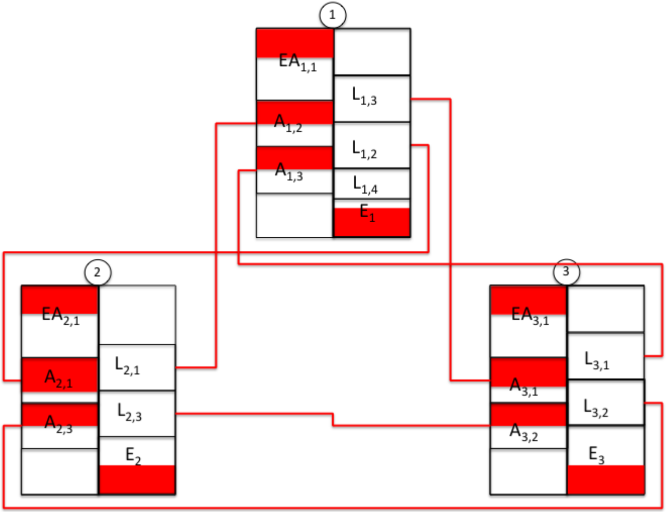

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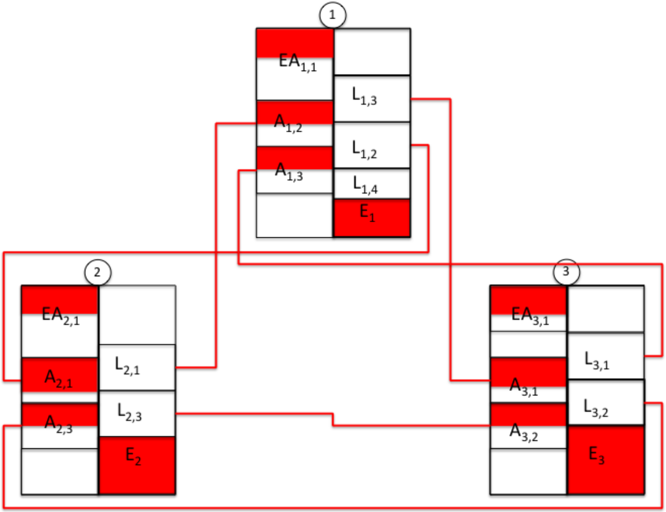

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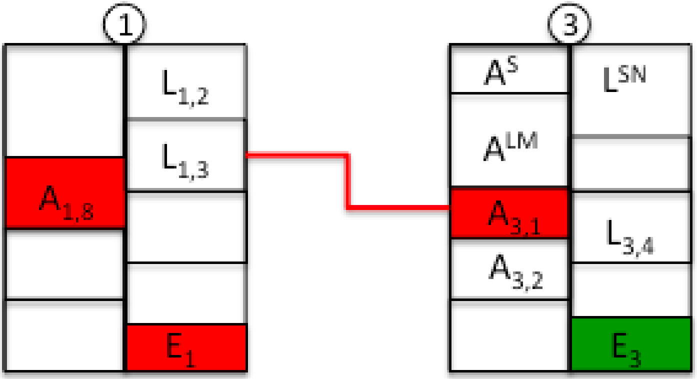
Run of Short Term Lenders



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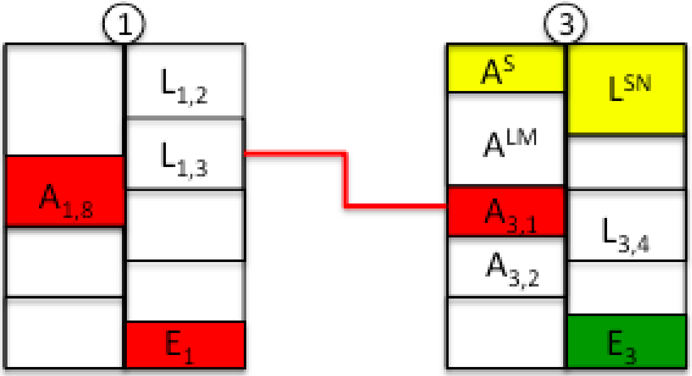

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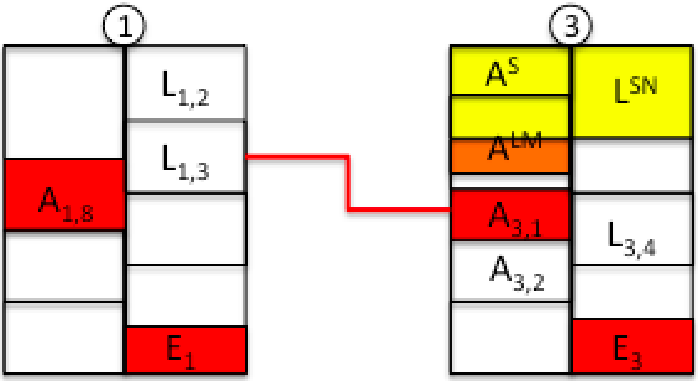
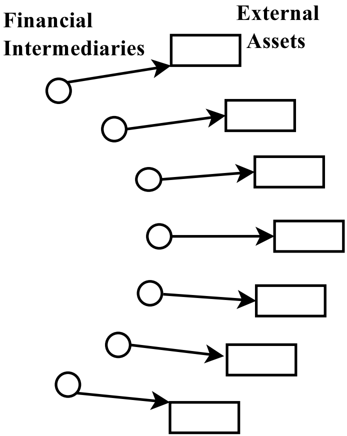


Network Effects: Take-home Message

- Financial networks:
  1. Nodes are: Banks, Assets, Funds
  2. Links are: any financial contract between two counterparties, but also investments in securities
- Network effects matter: distress can spread in ways that are not easy to anticipate
- Assessing systemic impact requires a network approach and calculations

Interacting Networks and Systemic Risk



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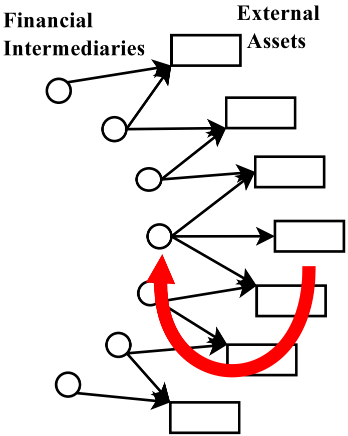

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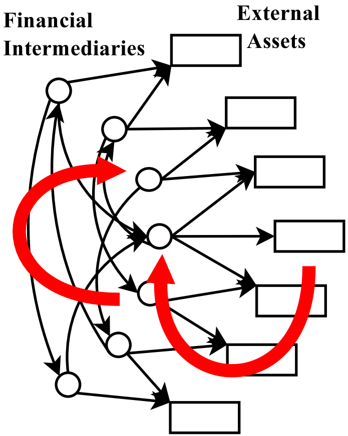

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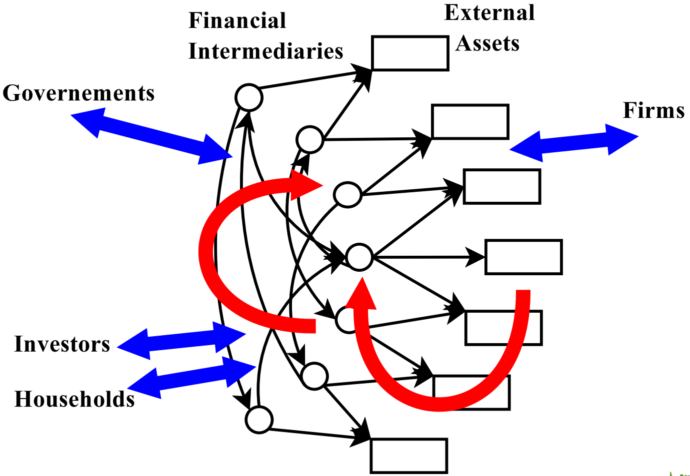

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- For **regulators and bankers**: measuring the systemic impact of the distress of one or more institutions
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- For **investors**: evaluating counterparty risk **beyond correlation**
  No network effects:
  - correlation $\rho = 0$: probability of joint defaults is p^N
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  With network effects
  - probability of joint defaults can be p (and not p^N) even with low correlation
  - potential massive **underestimation of Value-at-Risk**

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  - Risk diversification, but also amplification of distress and importing distress from others [Battiston, ..., Stiglitz, JEDC 2012]

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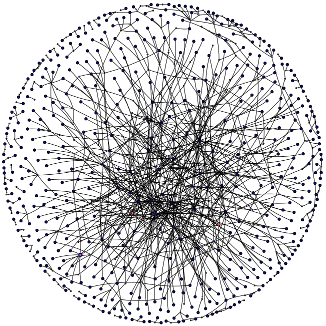
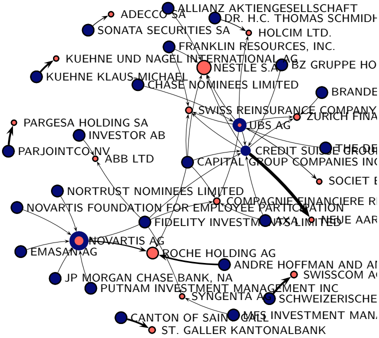
Network Effects: Take-home Messages

- **Liaisons can be dangerous**
  - Risk diversification, but also amplification of distress and importing distress from others [Battiston, ..., Stiglitz, JEDC 2012]
- Does the **market** take into account network effects?
- "Reducing individual risk always imply reducing systemic risk" : **not true**

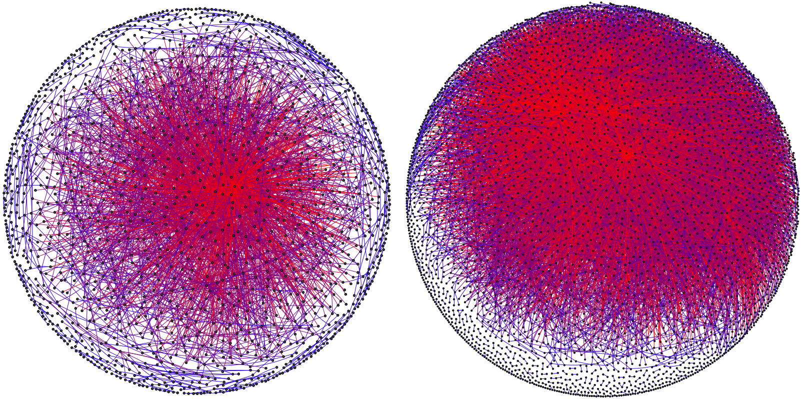
Empirical examples





Zurich Stock Market: ownership network and its *backbone*[1]

Empirical examples



UK (*left*) and US (NYSE) (*right*) stock market networks[2].

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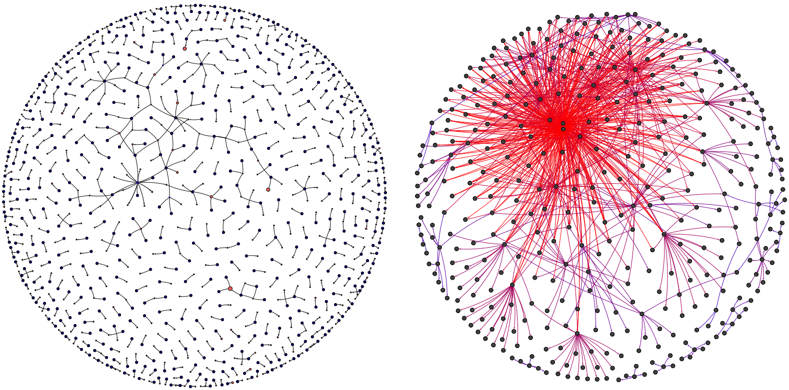
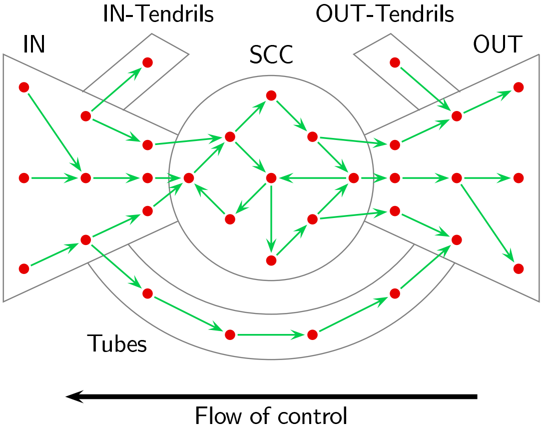
Empirical Examples



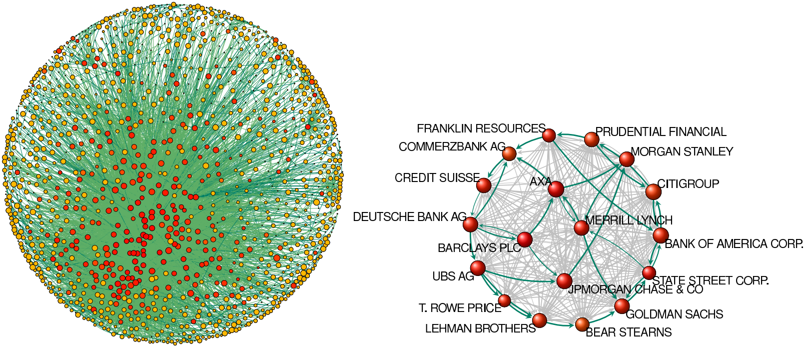
China (*left*) and Japan (*right*) stock market networks

The Structure of the Largest Component



A connected component with a **bow-tie** topology

The financial core of the TNC network



Ownership network around TNC worldwide **Left**: The core (1300 nodes). (**Right**) An example of few top financial institutions involved in many cycles. [Vitali ea., PLoS-ONE 2011]

DebtRank

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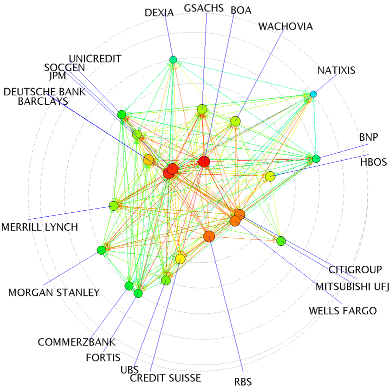
- Propagation channels
  - direct: balance sheet interlock (unipartite graph)
  - indirect: common asset (bipartite graph)
- DebtRank overcomes some limitations in
  - standard stress-test techniques at central banks
  - standard complex network mesures (e.g. betweenness, centrality etc.)

DebtRank



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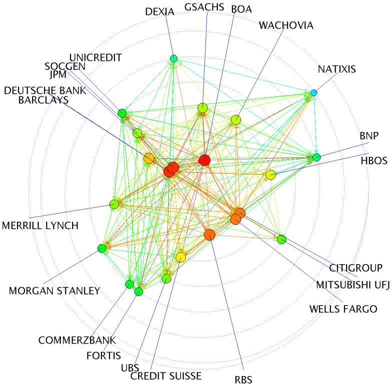

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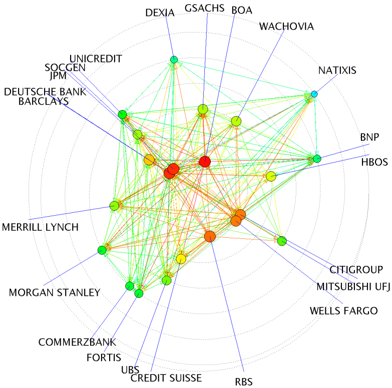

- more **central** = more systemically important
- **not just** a ranking
- systemic **economic loss** (e.g., euros) due to distress on one or more nodes
- **extension**/adaptation to social/biological contagion?

[Battiston, Puliga, Kaushik, Tasca, Caldarelli, DebtRank: Too-central-to-fail? (2012) Sci Rep. 2:541]

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Impact Matrix and Debtrank definition

- **exposure** of i to j, A_{ij} (e.g. lending, bond, stock shares).
- **core capital** of i, E_i.

1. Relative exposure of i to j, w.r.t. total exposure, $\frac{A_{ij}}{\sum_j A_{ij}}$, is generally small (sum up to 1)
2. Relative exposure of i to j, w.r.t. core capital: $Z_{ij} = \frac{A_{ij}}{E_i}$, (sum can easily exceed 1)

- **Direct Impact** of i on j defined as the exposure that j has towards i: $W_{ij} = Z_{ji}$, $W = Z^T$
- DebtRank: A node i is more central if it impacts strongly (large W_{ij}) many other central nodes: recursive!
- Each node propagate its distress only once (we tame reverberations)
- all formulas at doi:10.1038/srep00541
- widgets and infographics at: `http://ethz.focproject.net:8080/widget`

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Inspired by Network Centrality

- Adapting notion of Feedback Centrality to financial distress: a node is more important if it impacts on many high value and important nodes

$$c_i = \sum_j W_{ij} v_j + \sum_j W_{ij} c_j$$

$$c = (I - W)^{-1} W v$$

where $v =$ e.g. total asset

- Issues: need $\lambda(W) < 1$, but imposing row-stochasticity we could not compare values across time
- Strategy: keep impact matrix as is and tame cycles by **excluding walks already visited**
- Result: we obtain not just a ranking but an estimate of **fraction of total economic value in distress**

Applications: SIFI

- In several countries, Central Banks maintain a database of:
  - Balance sheet interlocking exposures between banks
  - Exposures to external assets
  - Core capital
- Build the impact matrix under various scenarios possibly taking into account market values
- Run DebtRank and GroupDebtRank to assess systemic impact of one or more institutions

Applications: Counterparty Risk

- Investors usually do not know the mutual exposures among counterparties. However,
- One can generate an ensemble of viable networks of exposures using available information
- Run DebtRank and GroupDebtRank on each network of the ensemble
- Obtain distribution of losses across counterparties, conditional to a given shock

Application: an exercise on FED data + BvD data

- Take banks' investment in each others equity share as a proxy of all **exposures**
- Focus on the largest borrowers from the FED in 2008-2010
  - 22 inst., peak lending 1.2 USD trillions, total assets 20 USD trillions)
- Incorporate dynamics of core capital (take market capitalization as a proxy of core capital)

Recipe

1. market capitalization as proxy of core capital
2. investments in equity as proxy of financial exposures
3. rescaling factor α, conservative scenario: in good the times every bank can sustain the default of at least 5 counterparties

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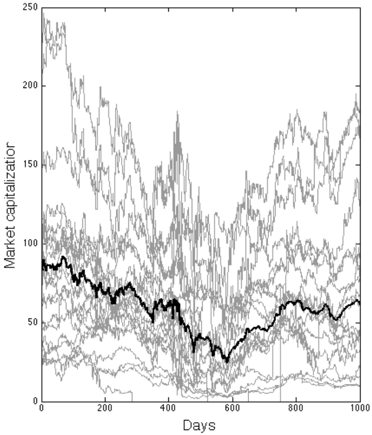

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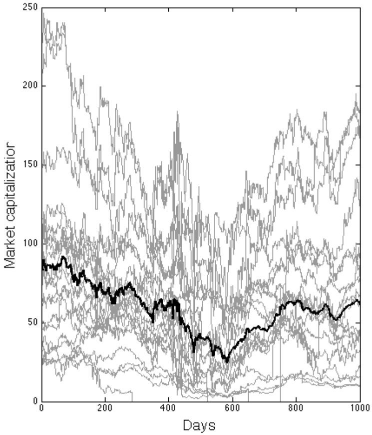

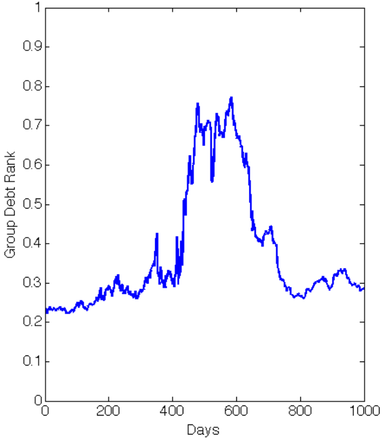

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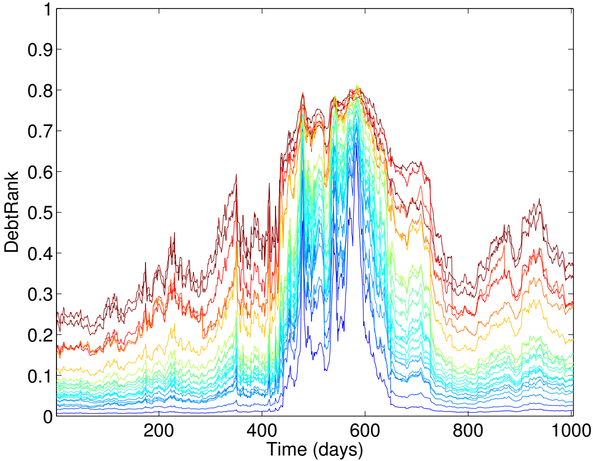
Debt Rank vs other Measures



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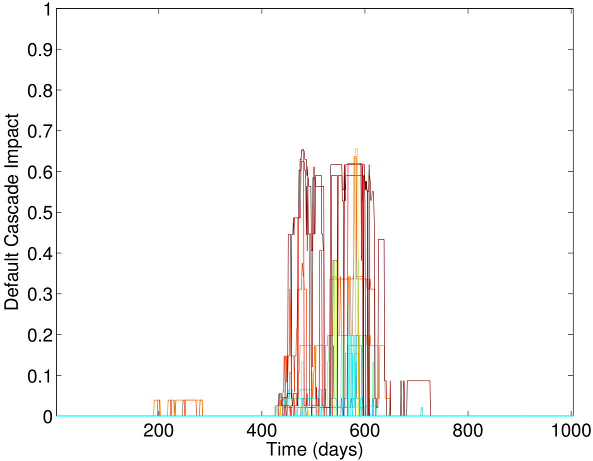

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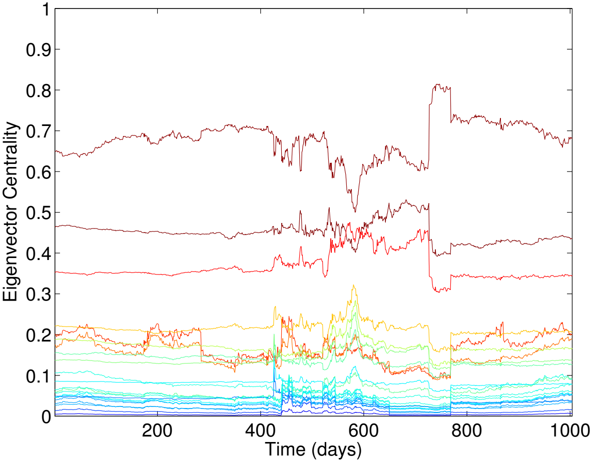

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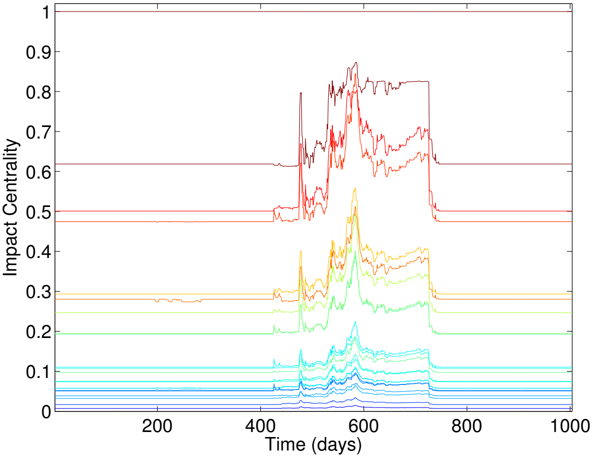
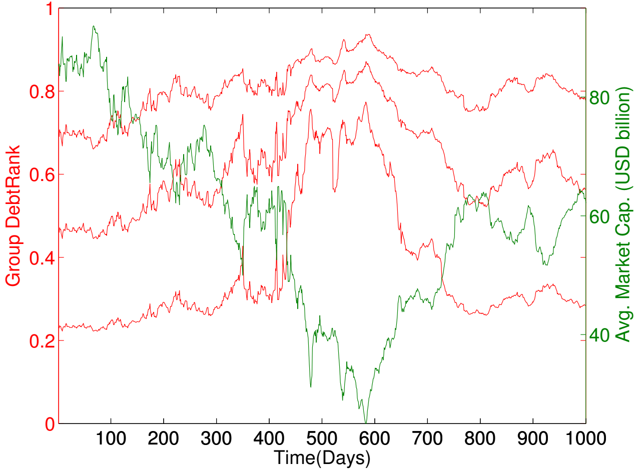


Group DebtRank

Recipe

1. A selected group of institutions is hit by a shock: for each a certain fraction $\phi_i < 1$ of equity vanishes
2. Propagate distress according to impact matrix as before (closed walks traversed only once)
3. Test various values of ϕ and impact scaling factor α

GroupDebtRank



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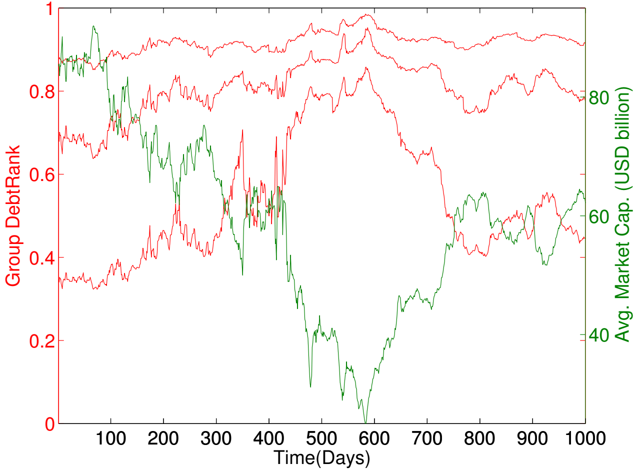

Conclusions

- Network effects matters for distress propagation: SIFI and counterparty risk
- DebtRank is a centrality-inspired algorithm to assess SIFI in network context, overcoming some limitations of state-of-the-art stress-testing
- From Too-Big-to-Fail to Too-Central-to-Fail
- Currently: a new method to evaluating VAR and ES in a network context

Financial Networks: a research agenda

1. Empirics: network structure
2. Link formation: evolution to stable/efficient structures
3. Node dynamics: propagation (e.g., information, distress)

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Meta-level

1. Feedback from structure onto incentives: political economy aspect

Financial Networks: a research agenda

Financial networks

1. Topology, Link formation, Node dynamics:
   e.g., FOC, various INET grants
2. Interacting networks: MULTIPLEX
3. Feedback from structure onto incentives:
   INET Nets sub-TaskForce

The FOC Project

- Forecasting Financial Crises (FOC)
- European project funded by FET-OPEN
- 13 partners (including ECB), coordinated by Guido Caldarelli at IMT Lucca
- Information:
  www.focproject.net
  widgets: http://ethz.focproject.net:8080/

Related events

- FOC-CRISIS School on Complex Financial Networks, IMT Lucca, October 24-27 2012
- INET Conference False Dichotomies, Waterloo, November 15-17 2012
- NetSci 2013

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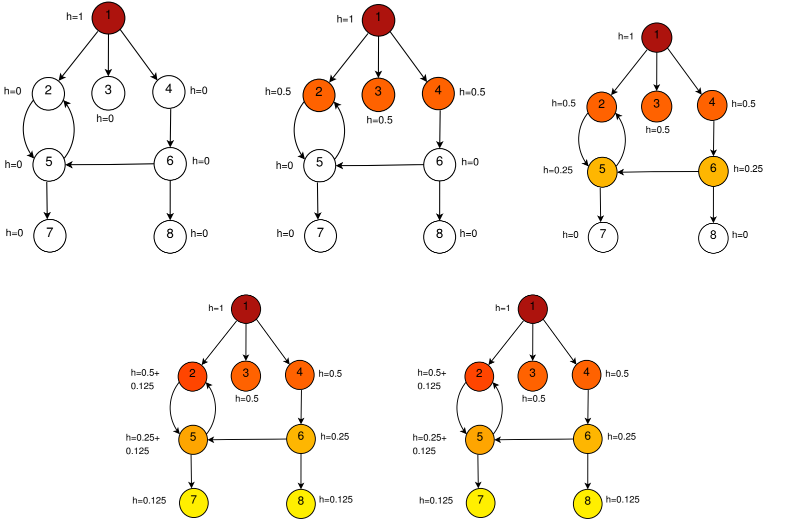
Debt Rank Dynamics

Centrality computation plus contraints on walks is equivalent to following algorithm.

- continuous variable $h_i \in [0, 1]$.
- 3 possible states, undistressed, distressed, inactive: $s_i \in \{U, D, I\}$.
- S_f: set of nodes in distress at time 1. $h_i(1) = \psi \, \forall i \in S_f$; $h_i(1) = 0 \, \forall i \notin S_f$, and $s_i(1) = D \,, \forall i \in S_f$; $s_i(1) = U \, \forall i \notin S_f$.

$$h_i(t) = \min \left\{ 1, h_i(t-1) + \sum_j W_{ji} h_j(t-1) \right\}, \text{ where } j \,|\, s_j(t-1) = D$$

$$s_i(t) = \begin{cases} D & \text{if } \; h_i(t) > 0 \;\; \& \;\; s_i(t-1) \neq I \\ I & \text{if } \;\; h_i(t-1) > 0 \\ U & \text{otherwise,} \end{cases}$$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