UNIVERSITY OF CAMBRIDGE
Judge Business School

Centre for Risk Studies

A network model of financial contagion due to overlapping portfolios

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Stability of financial networks

- Financial networks: networks of financial institutions (banks) with mutual relationships (e.g. Allen and Gale 00, Boss et al. 05, Iori et al. 08, E Santos and Cont 10...)

- How can stress that originates in a part of the system propagate to the whole system? (e.g. Gai and Kapadia 10, Amini et al. 10, Georg 10, May and Arinaminpathy 10, May and Haldane 11, Arinaminpathy et al. 12, ...)

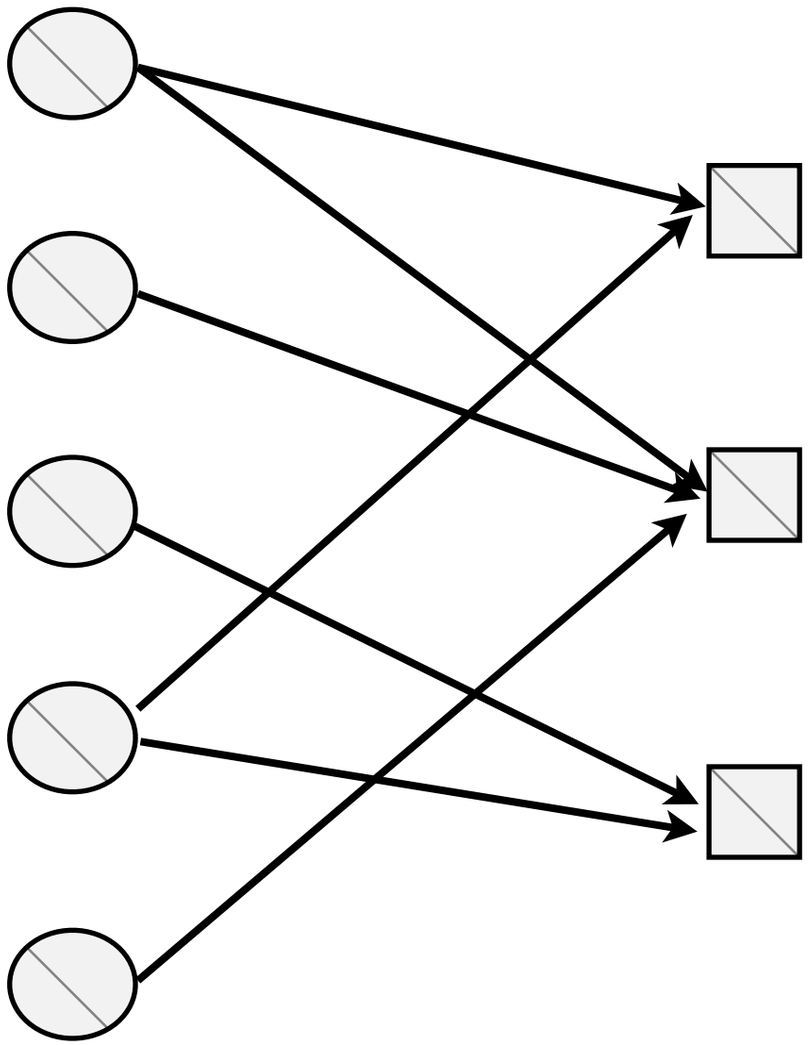
- Many contagion mechanisms: we focus on overlapping portfolios (common asset holdings)

Overlapping portfolios and Market Impact

- Market impact: prices respond to trades (e.g. Engle et al. 08, Bouchaud et al. 09)

- Portfolio liquidation ⇒ assets devaluation

- Banks with common assets are exposed to contagion



N banks

M assets

μ_b : average degree of banks (average diversification)

- Random network: links are drawn randomly
- Large network: $N, M \to \infty$, but finite N/M
- Sparse network: $\mu_b << N, M$

Balance sheet

Leverage: banks invest borrowed money

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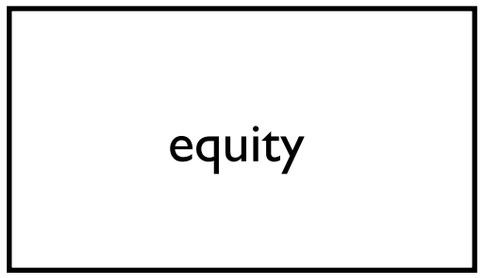

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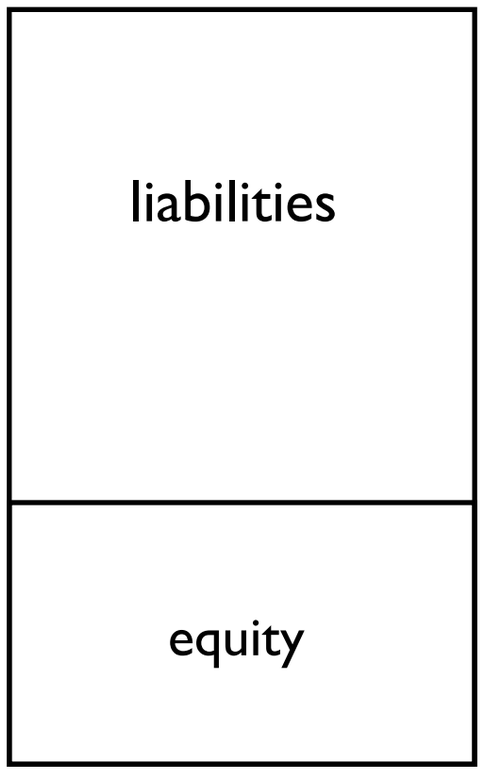

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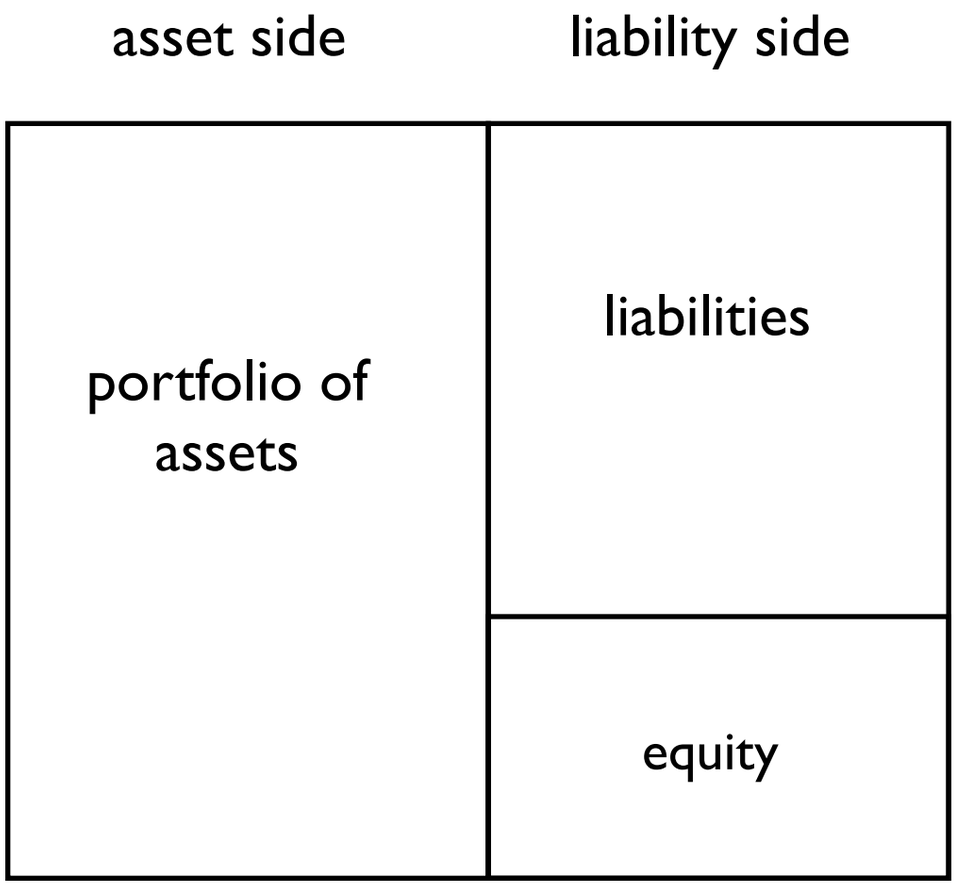

assets=liabilities+equity

Balance sheet

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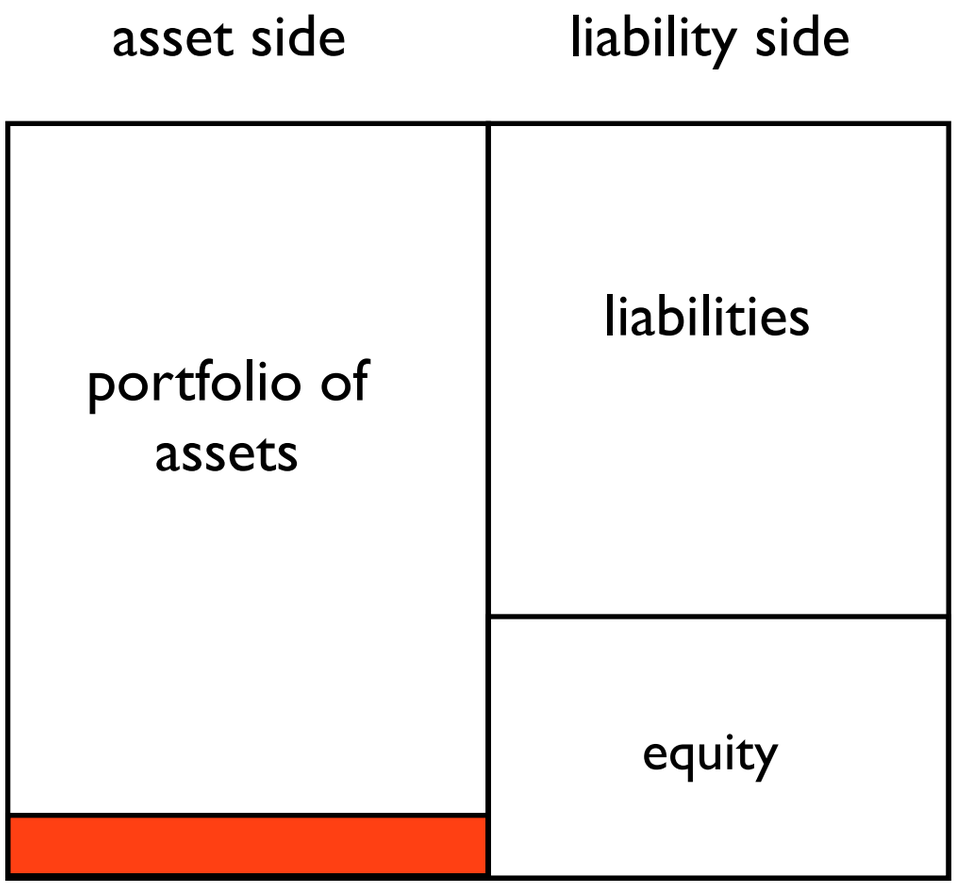

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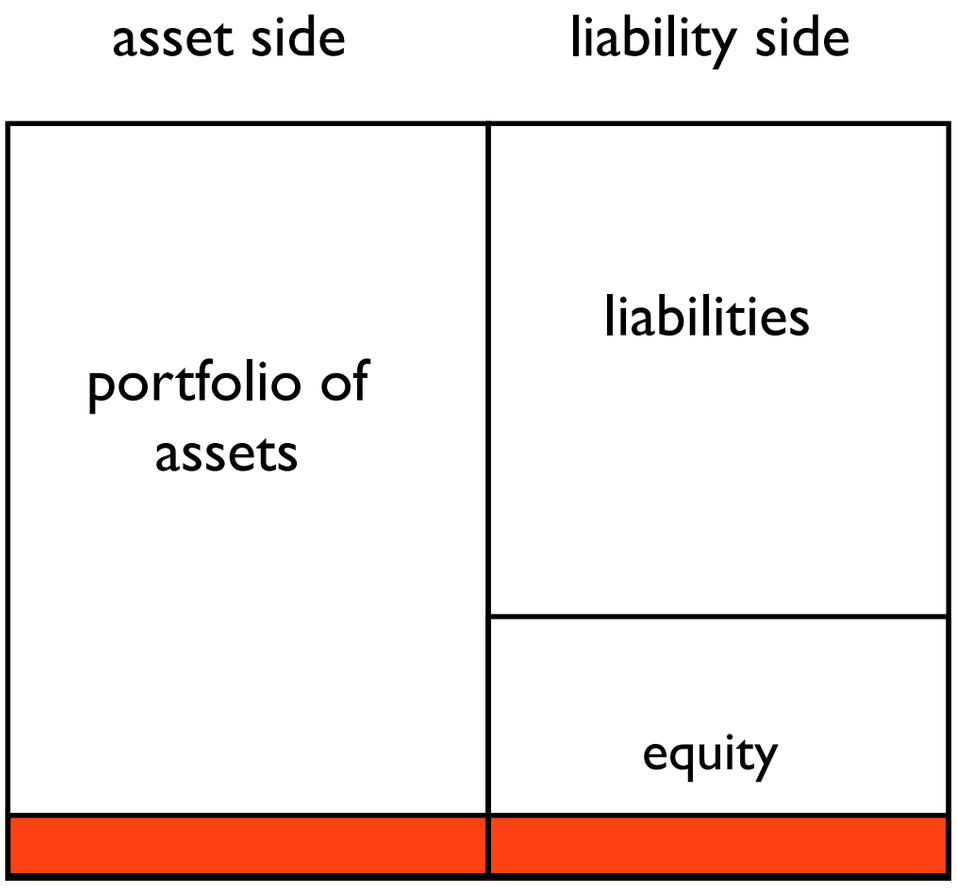

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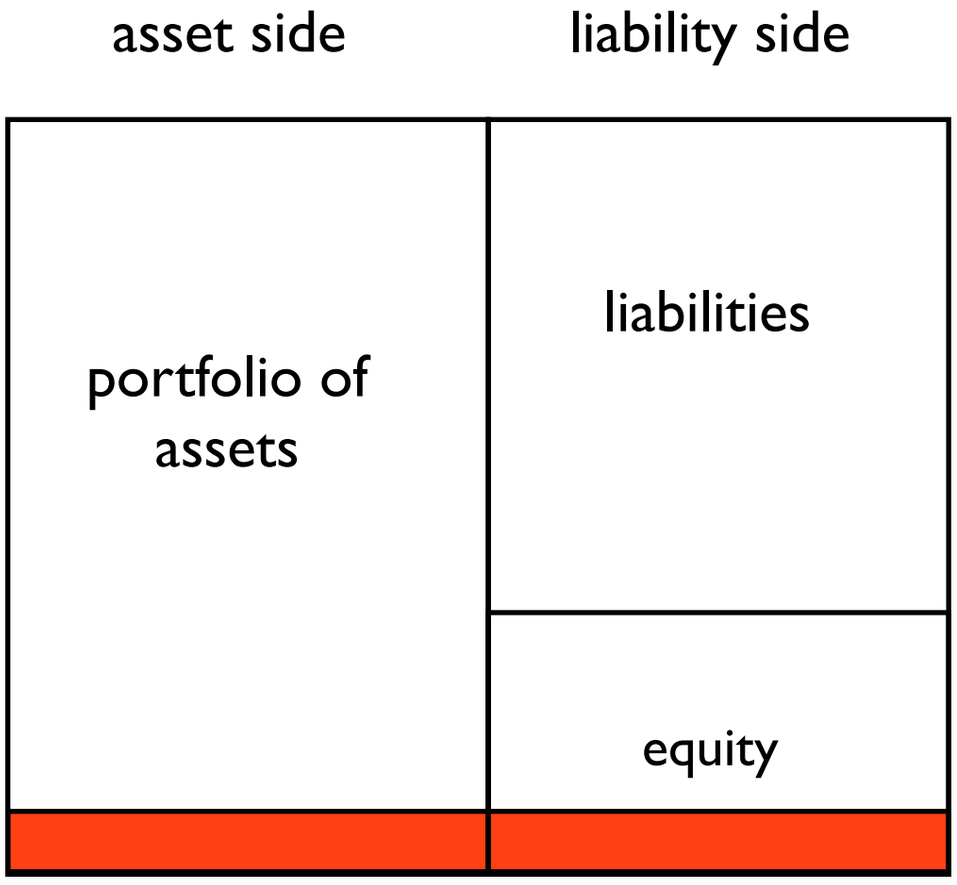


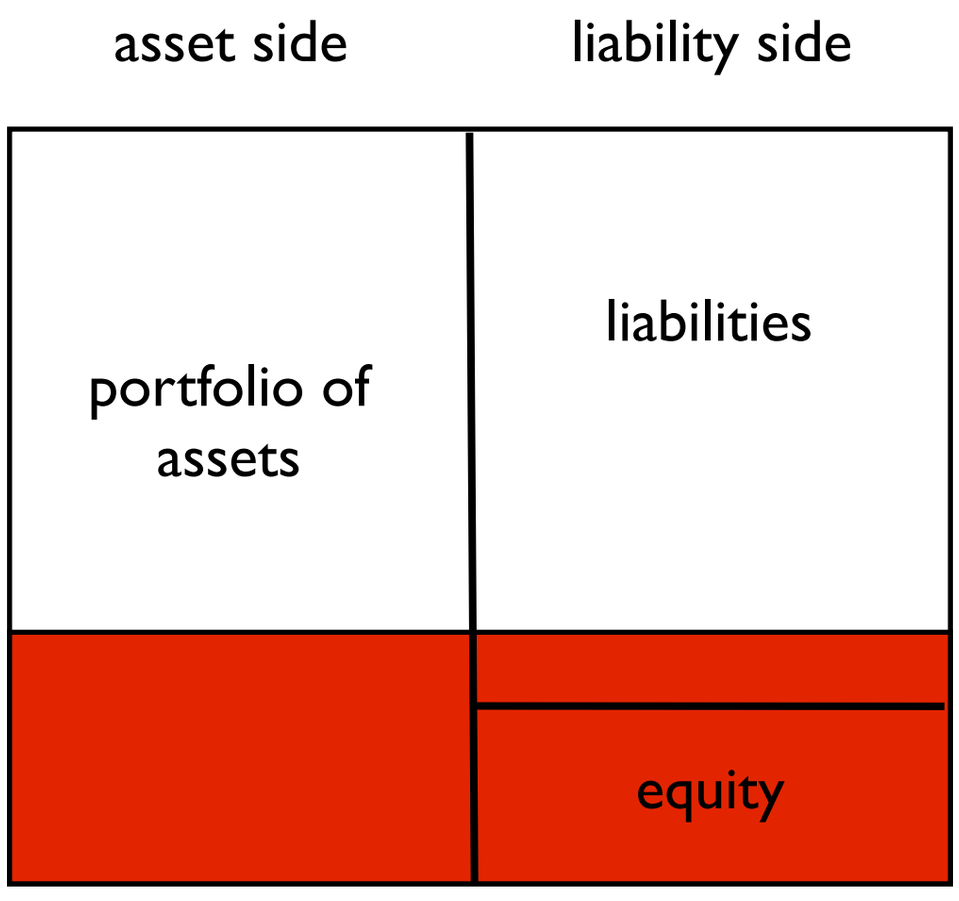
assets=liabilities+equity

$$\lambda = \frac{\text{assets}}{\text{equity}}$$

1% asset devaluation

λ % equity loss

Default



A bank defaults if assets < liabilities (loss>equity)

Stress Testing

- We start with a system of solvent banks and depress the value of a random asset;
- If bank i is insolvent, we assume its portfolio of assets undergoes a fire-sale
- p_a : price of asset a before bank i liquidates
- W_{ia} : number of shares of asset a owned by bank i
- price after liquidation: $p_a \longrightarrow p_a e^{-W_{ia}/(\sum_j W_{ja})}$

under what conditions do we observe global cascades of failures?

Relevant Parameters

- Average diversification, average degree of banks: μ_b

- Crowding: N/M

- Leverage: $\lambda = \dfrac{\text{assets}}{\text{equity}}$

Simplifying assumptions

- The size of the balance sheet is the same for all banks;
- Portfolio weights are uniform;
- Banks have the same initial leverage;

Some Definitions

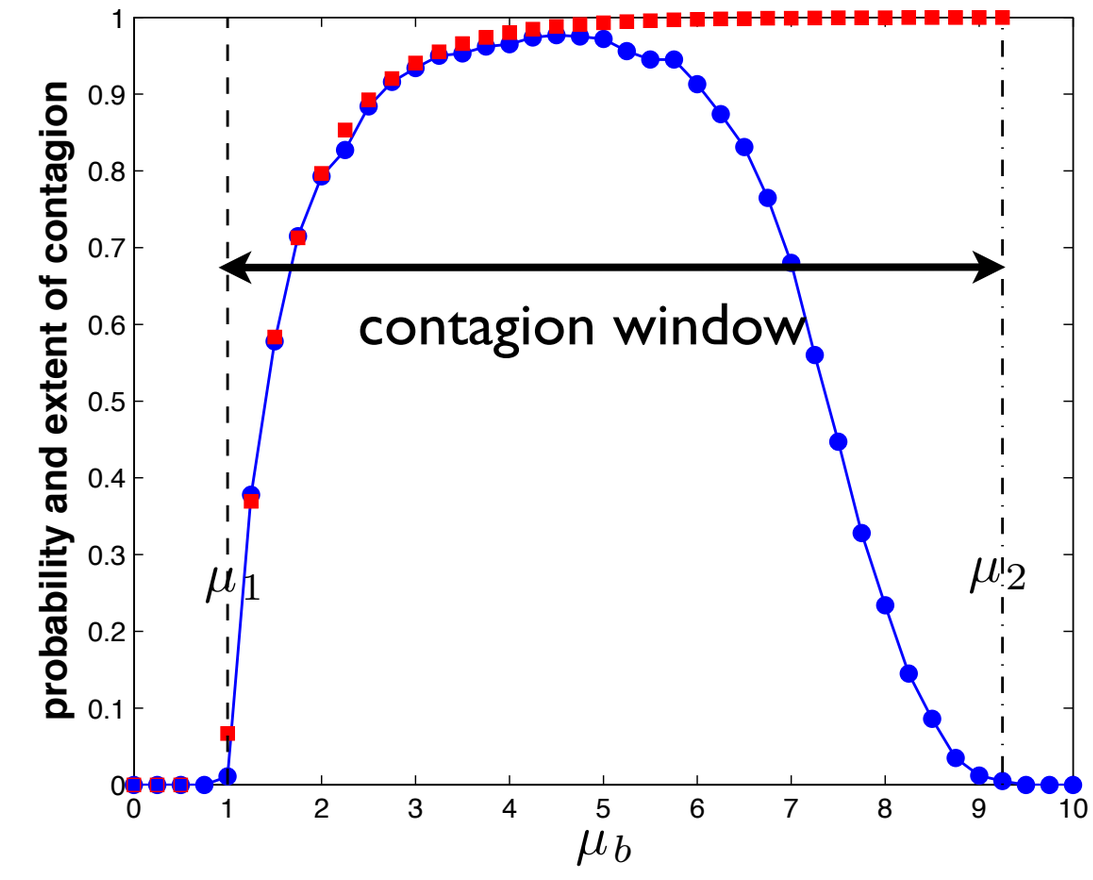
- There is a global cascade of failures if a finite fraction of an infinite system goes bankrupt (in simulations, if at least 5% of banks go bankrupt).

- Contagion probability: probability of observing a global cascade.

- Conditional extent of contagion: average fraction of bankruptcies given that a global cascade occurs.

$N/M = 1$

$\lambda = 20$

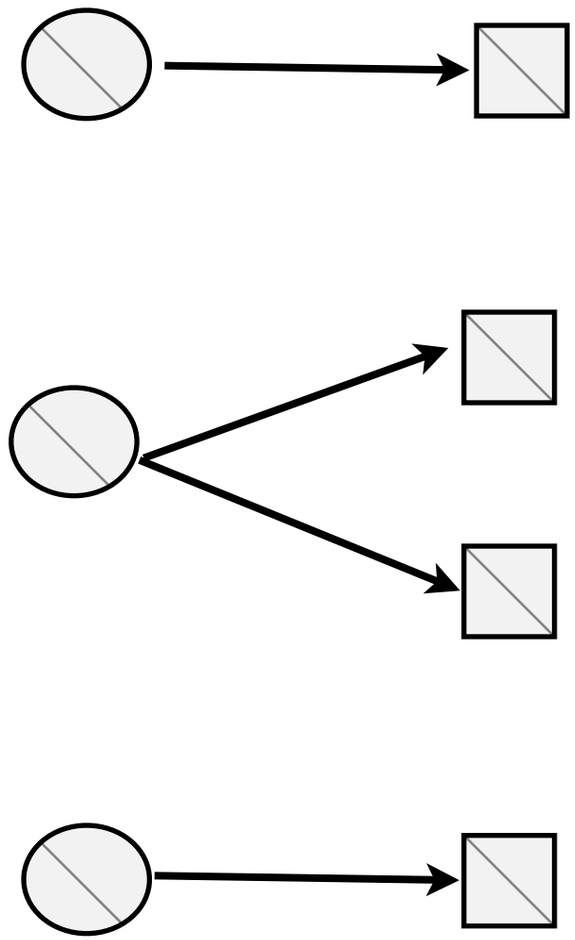


diversification

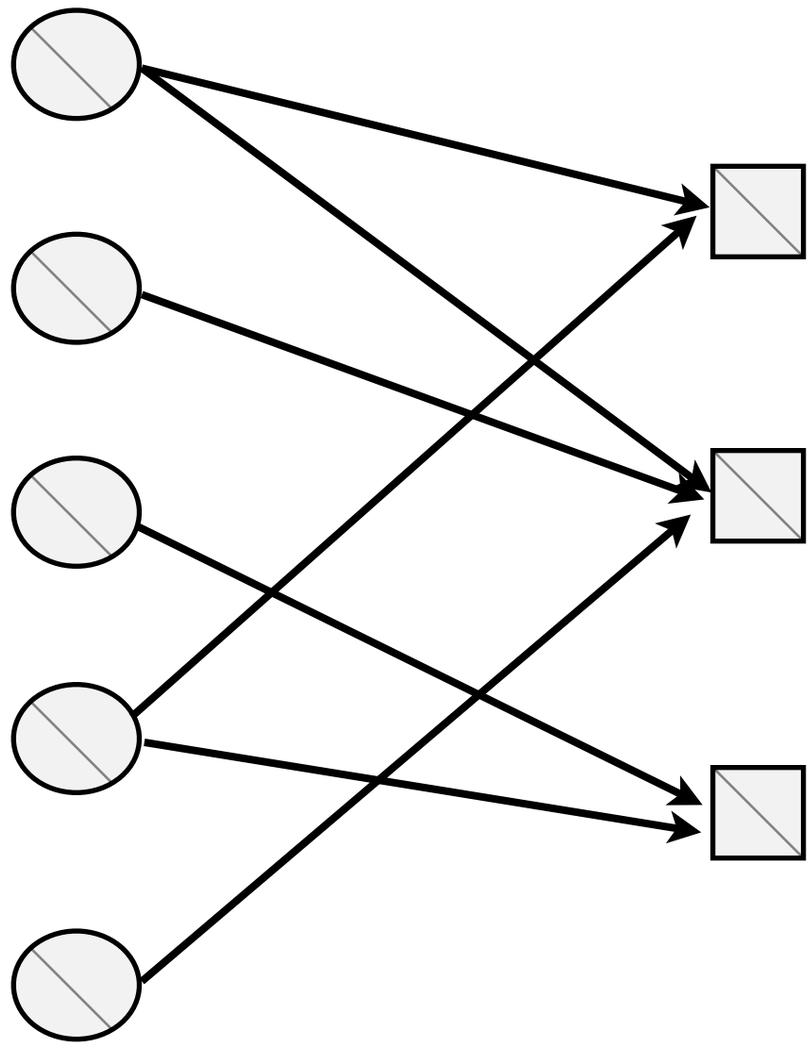
robust yet fragile

(see also Watts 02, Gai and Kapadia 11)

low diversification:
disconnected network



higher diversification:
network is well connected



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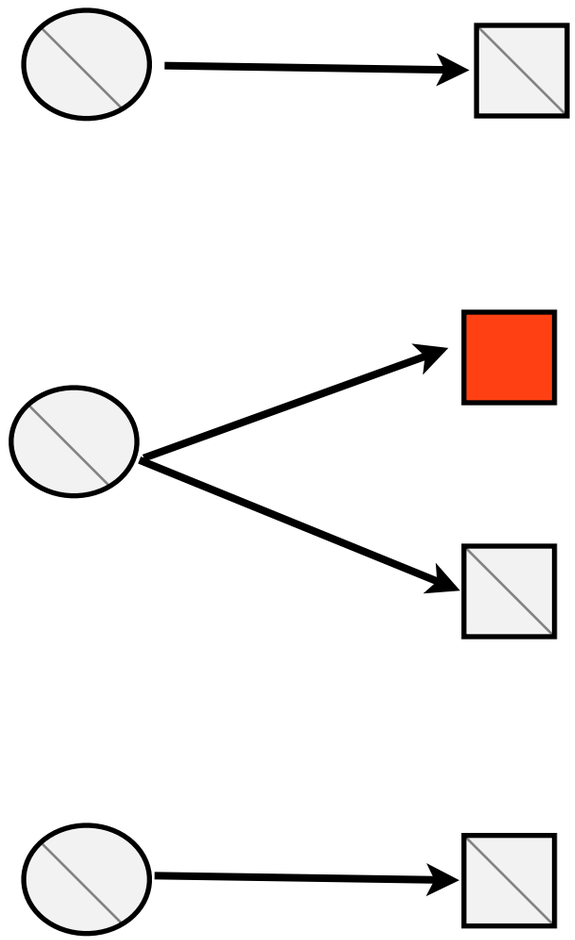

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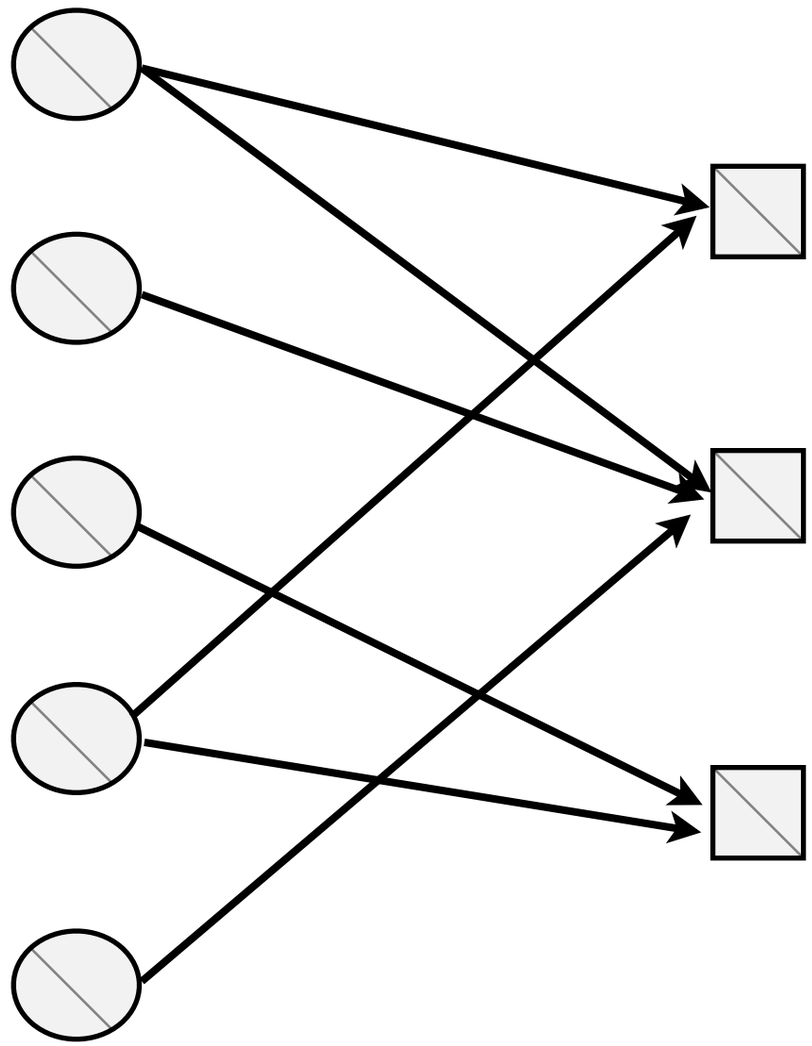

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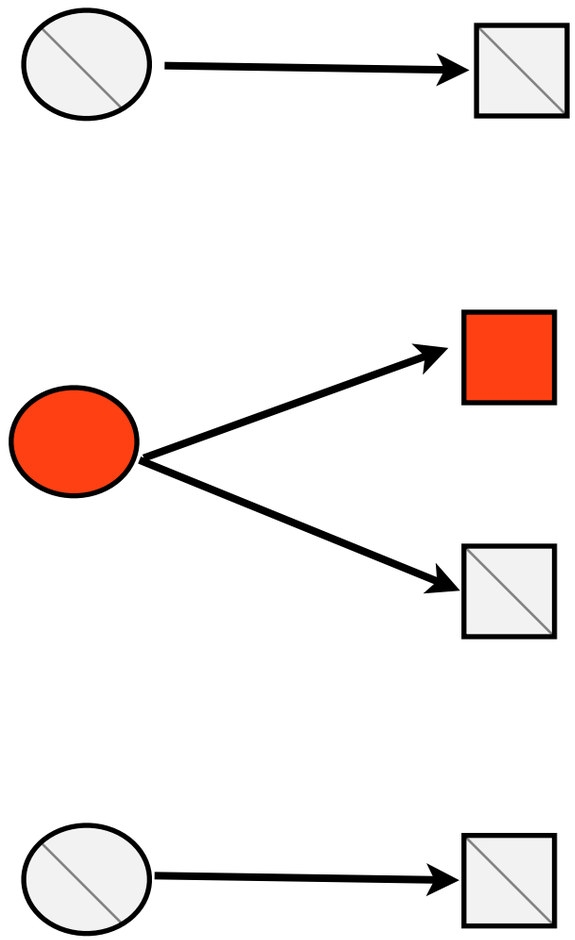

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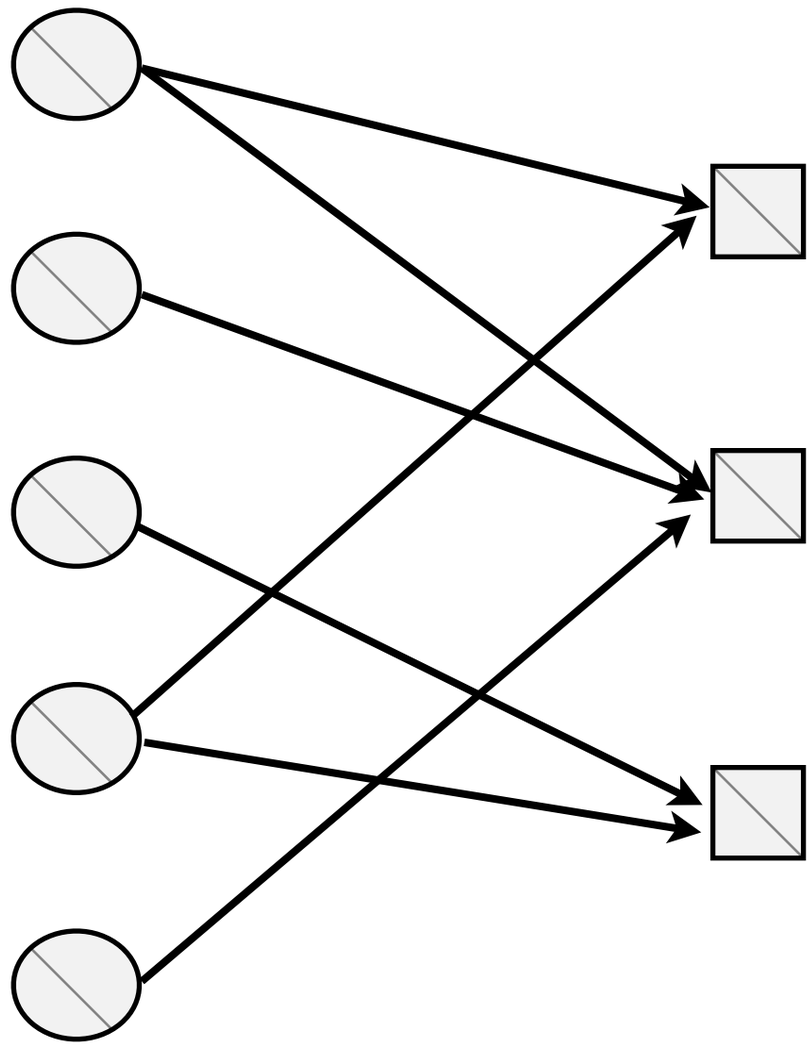

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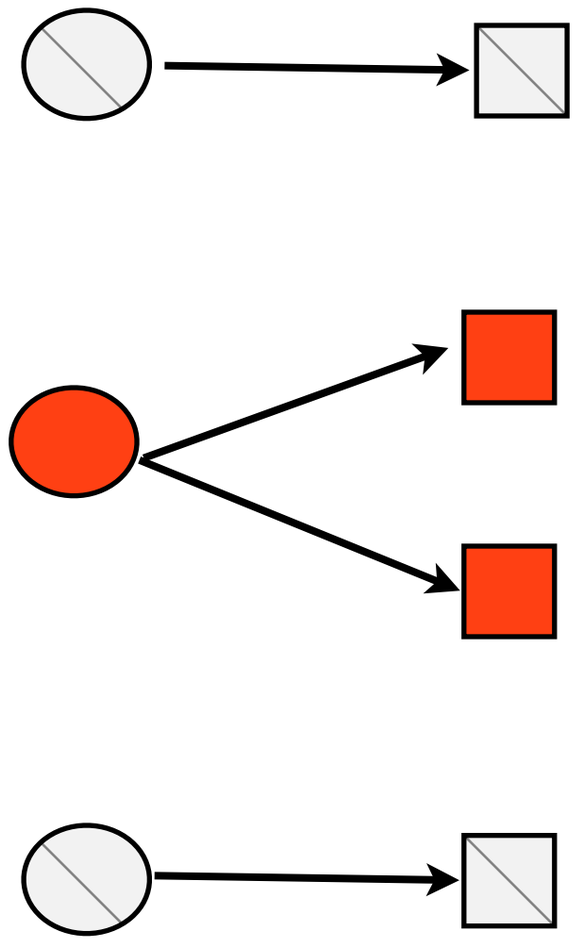

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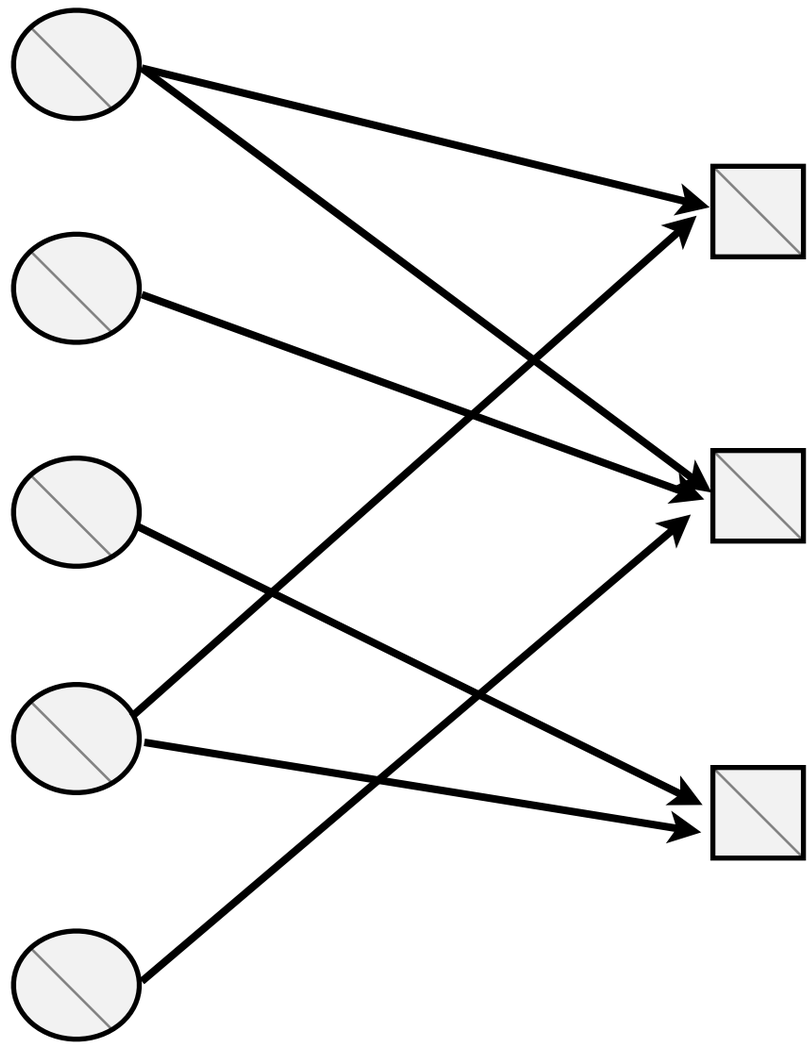

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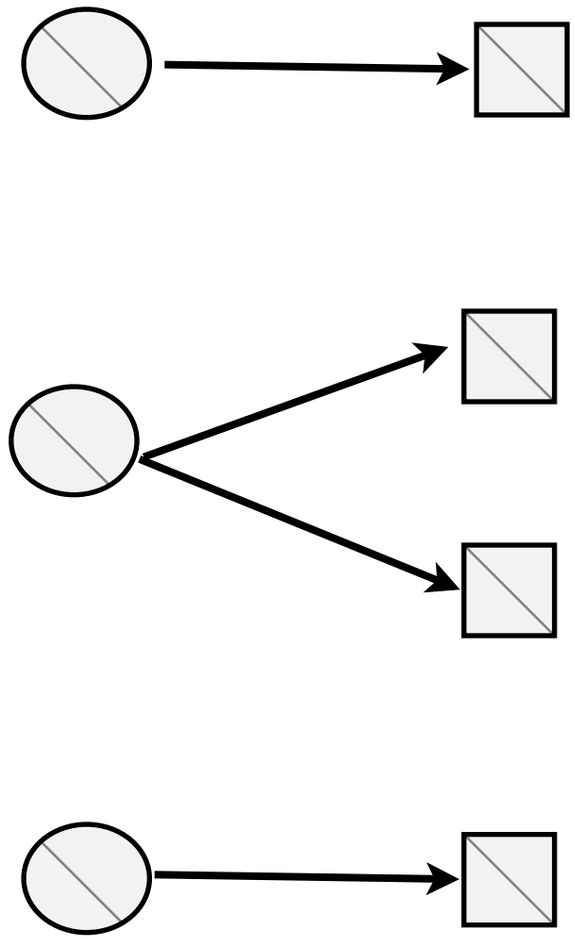

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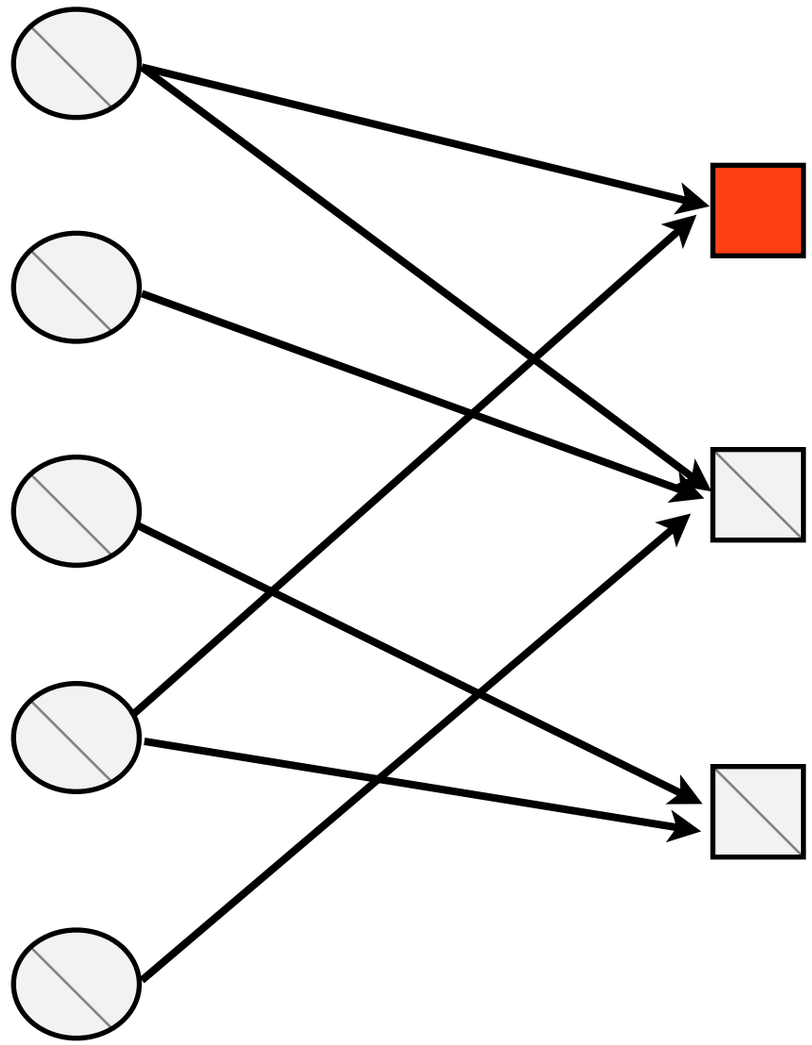

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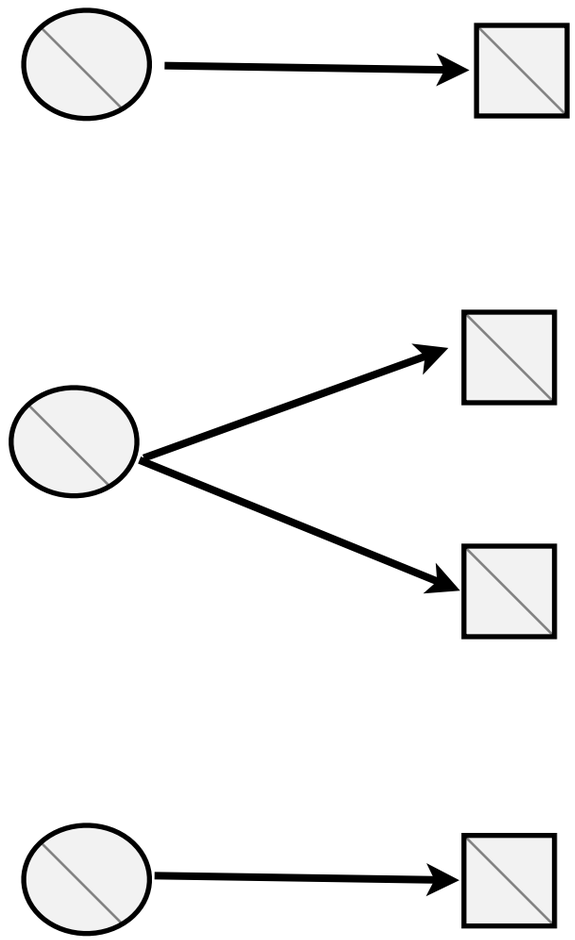

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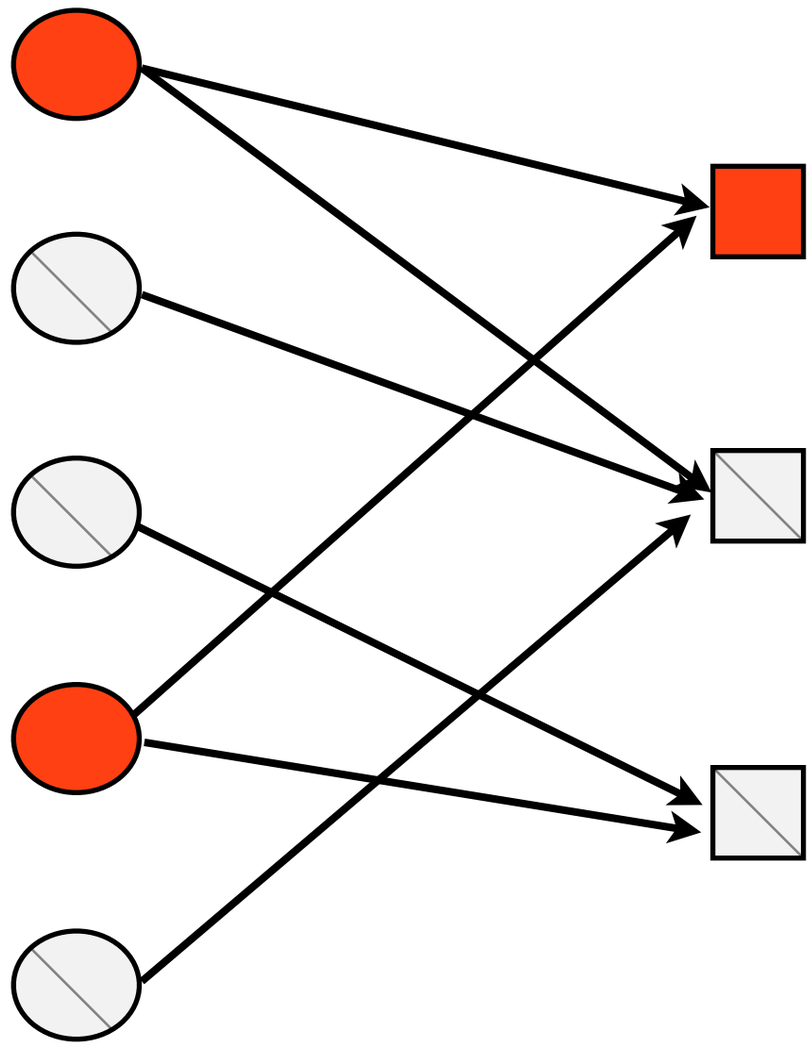

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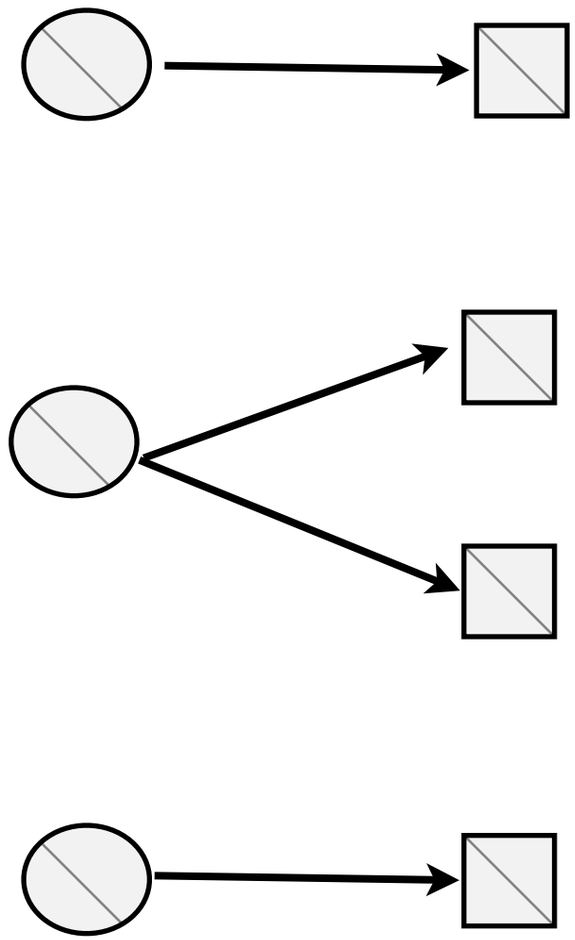

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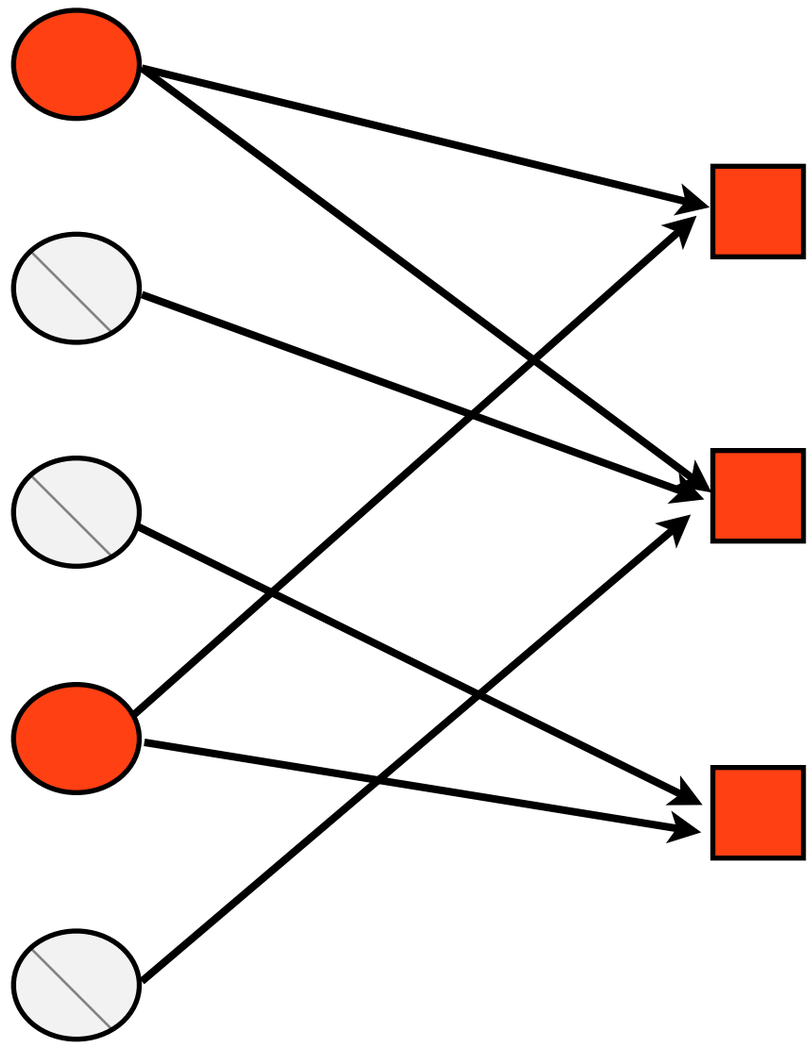

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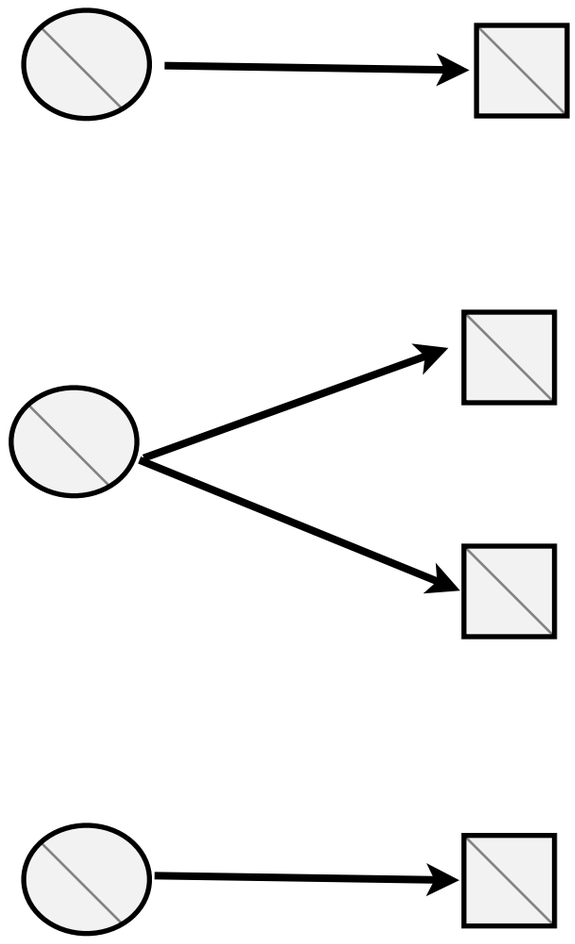

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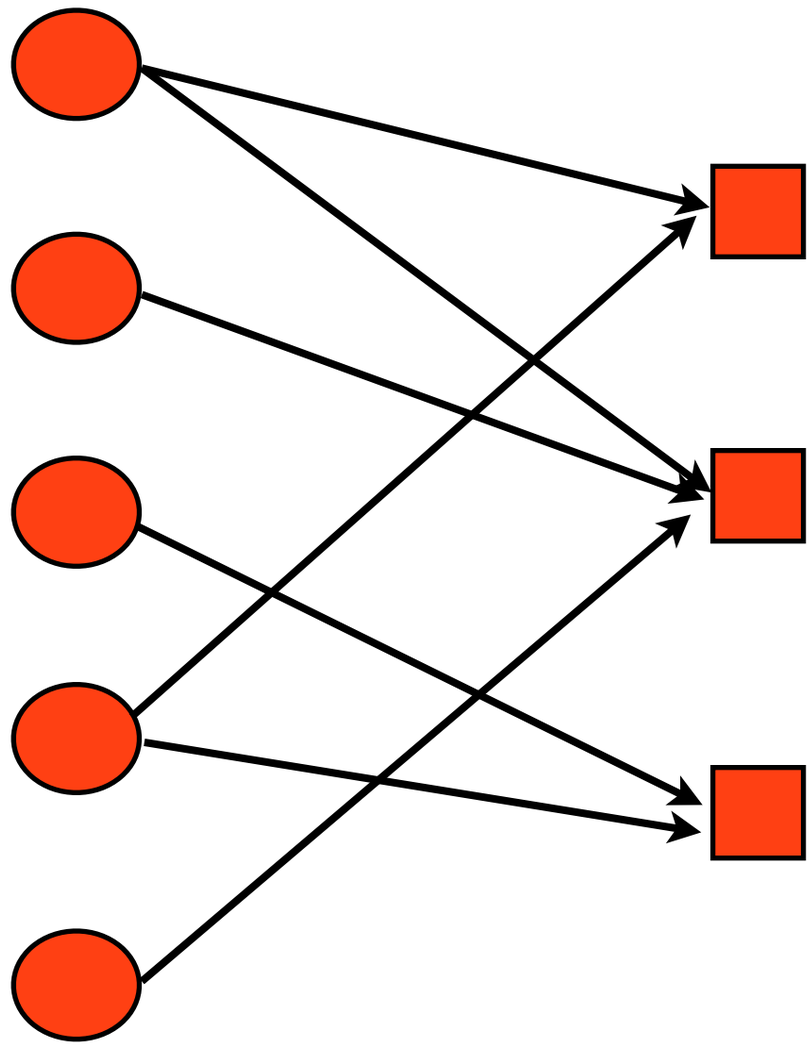

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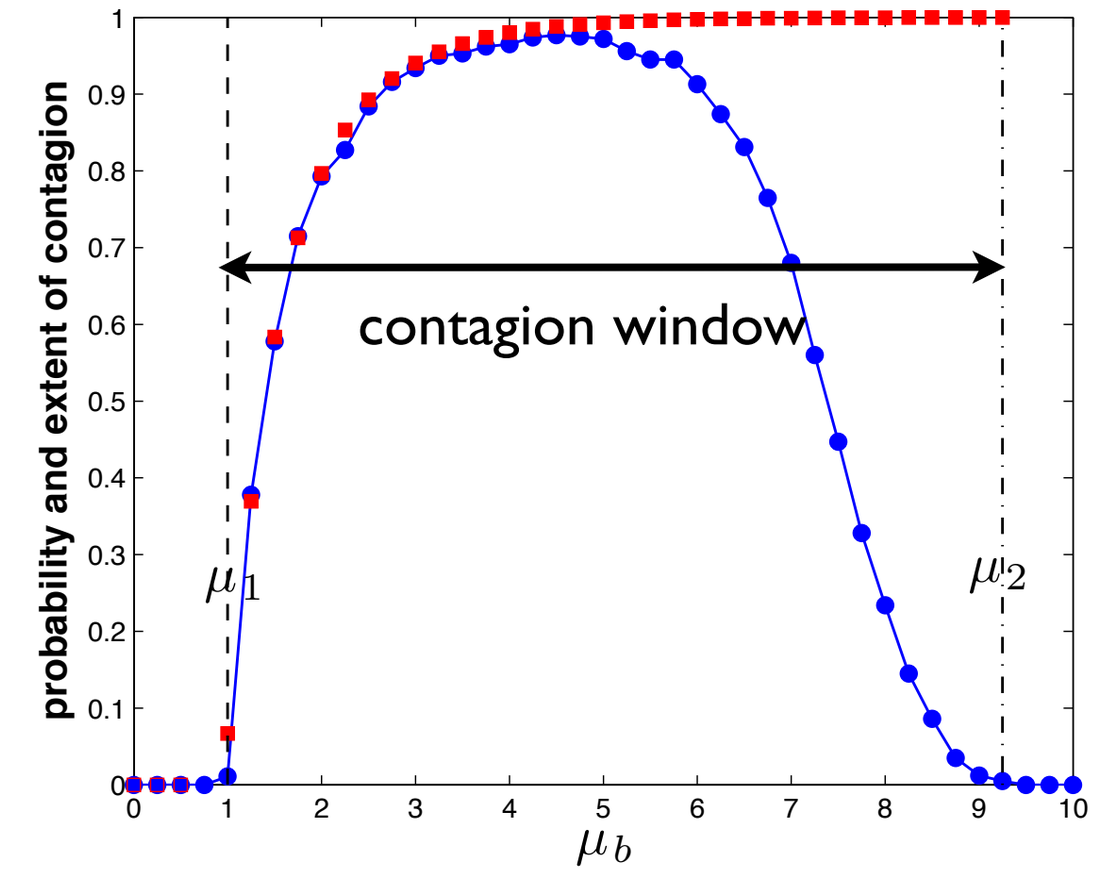

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robust yet fragile

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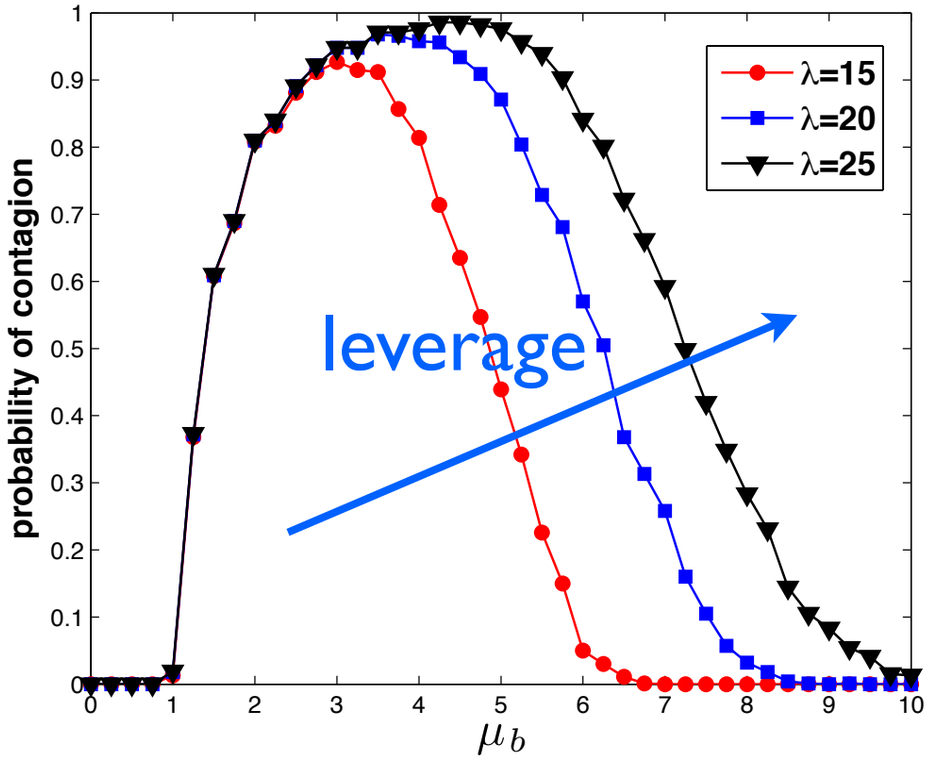
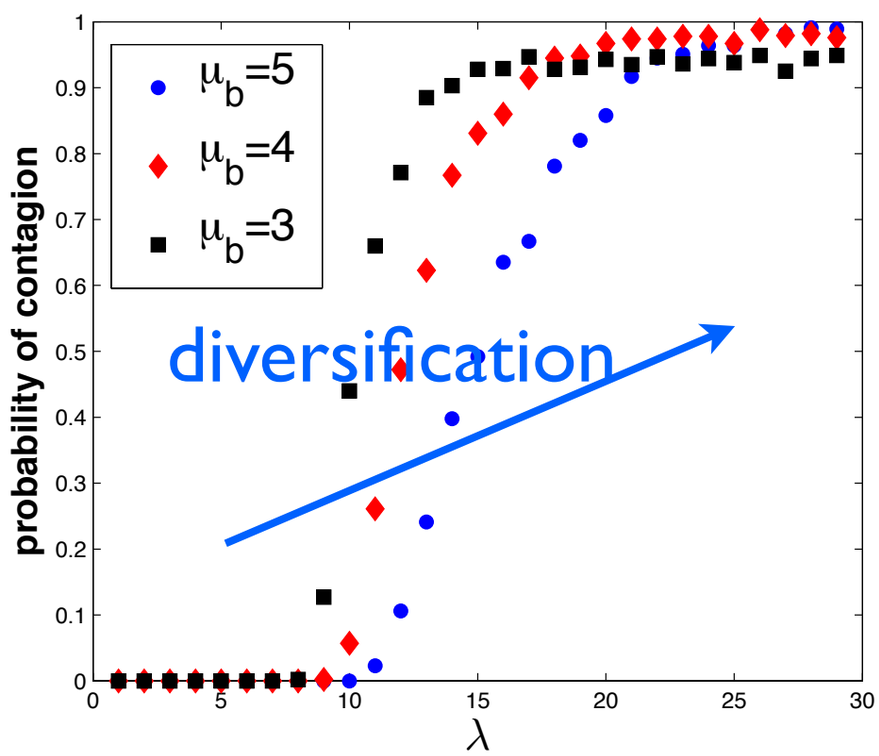
Leverage

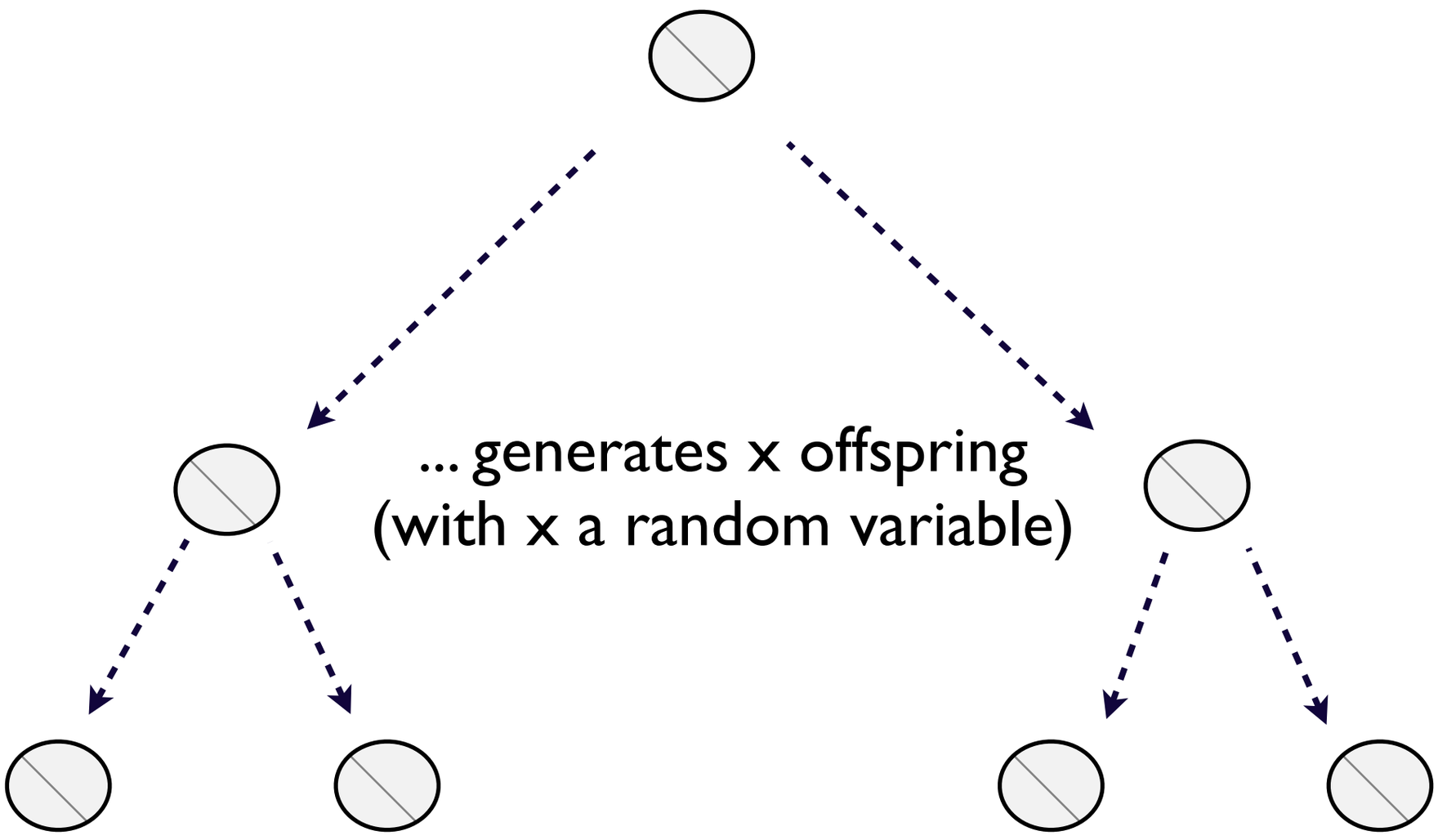




More leverage makes the system more unstable

Branching Processes

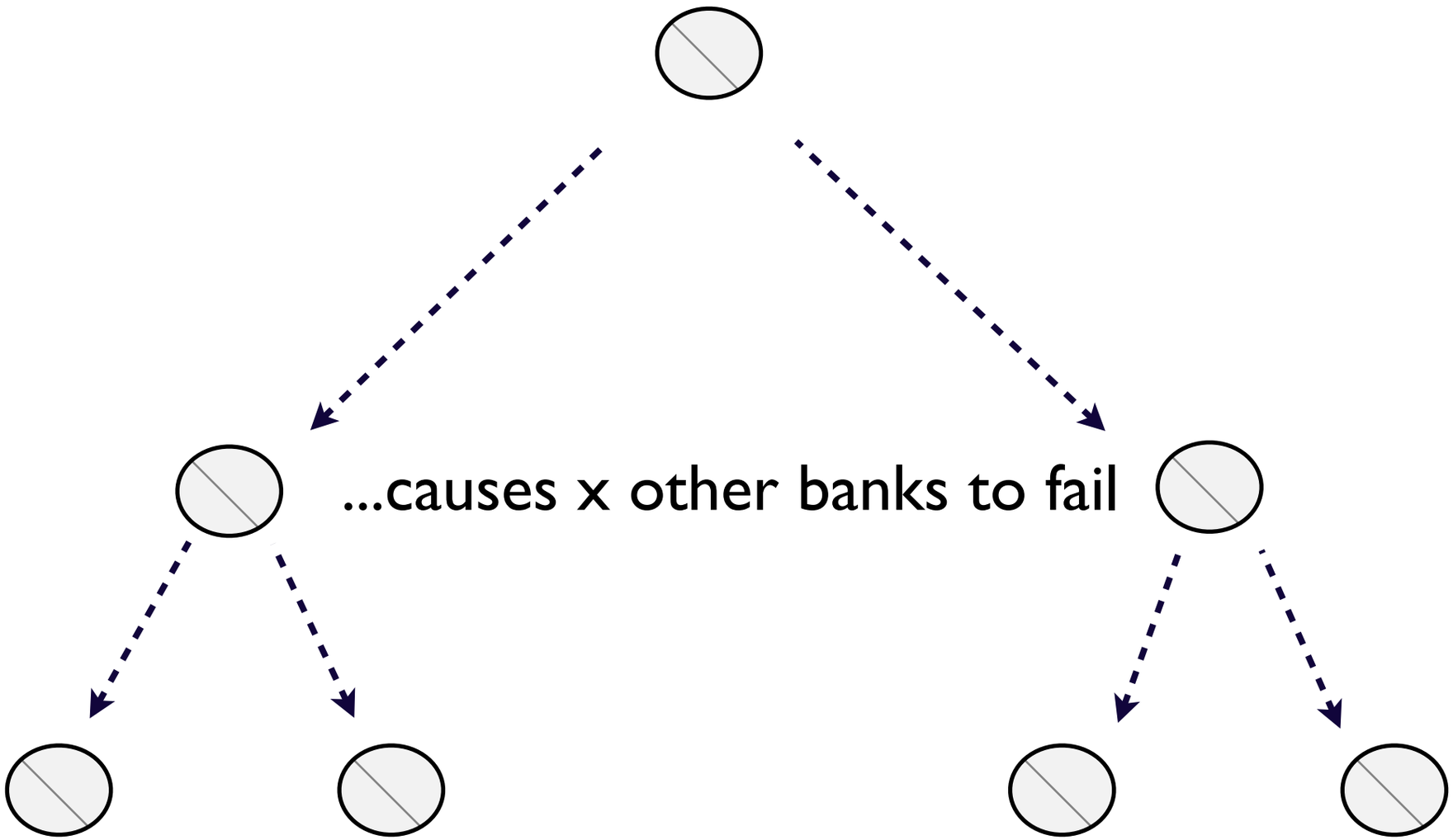
one ancestor...



the species survives with non-zero probability
if $E[x] > 1$

In our case

one bankrupted bank...



global cascades occur with non-zero probability
if $E[x] > 1$

Transition Matrix

Probability that i fails given the failure of j:

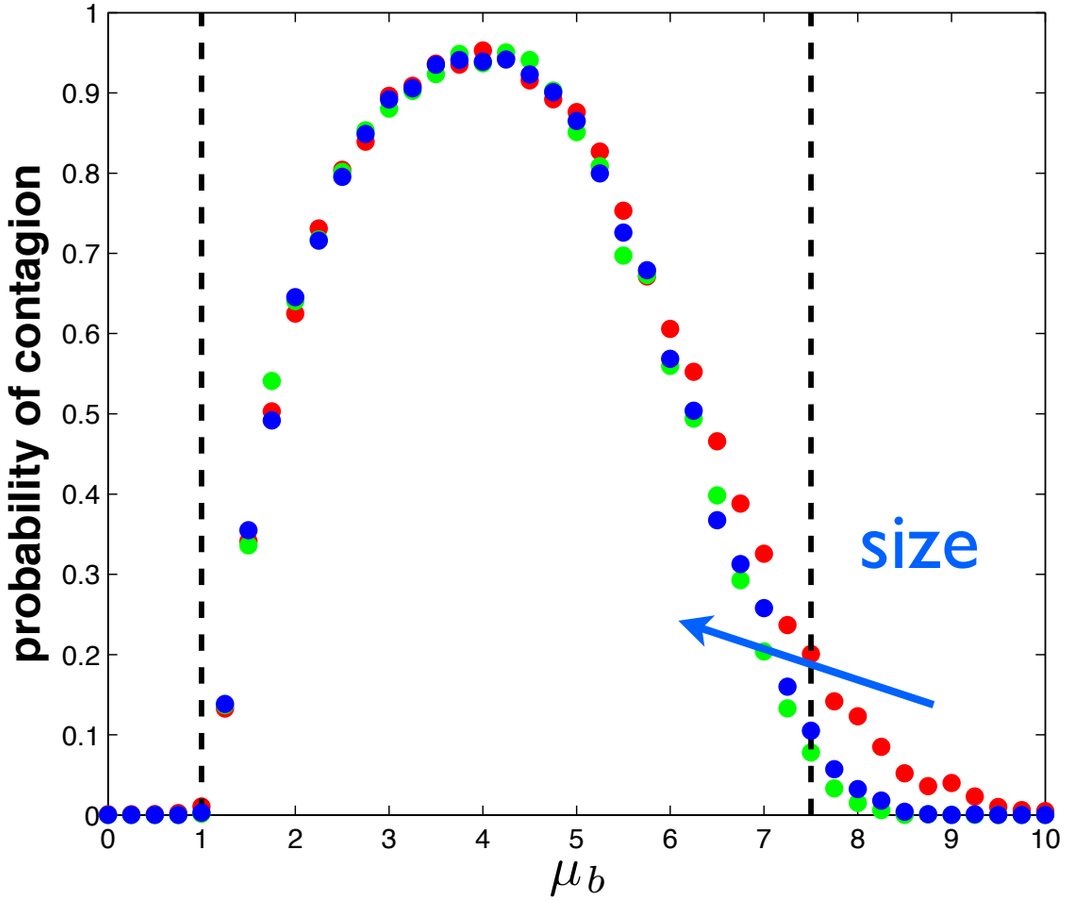
$$\mathcal{B}_{ij} = \text{Prob}\left[\sum_{a=1}^{M} Q_{ia} p_a \left(1 - f_a\left(Q_{ja}\right)\right) - E_i > 0\right]$$

Number of banks of type h that fail if a bank of type k fails.

$$\mathcal{N}_{hk} = N_h \sum_{a=1}^{M} \mathcal{P}(h,k|a) F(h|k,a)$$

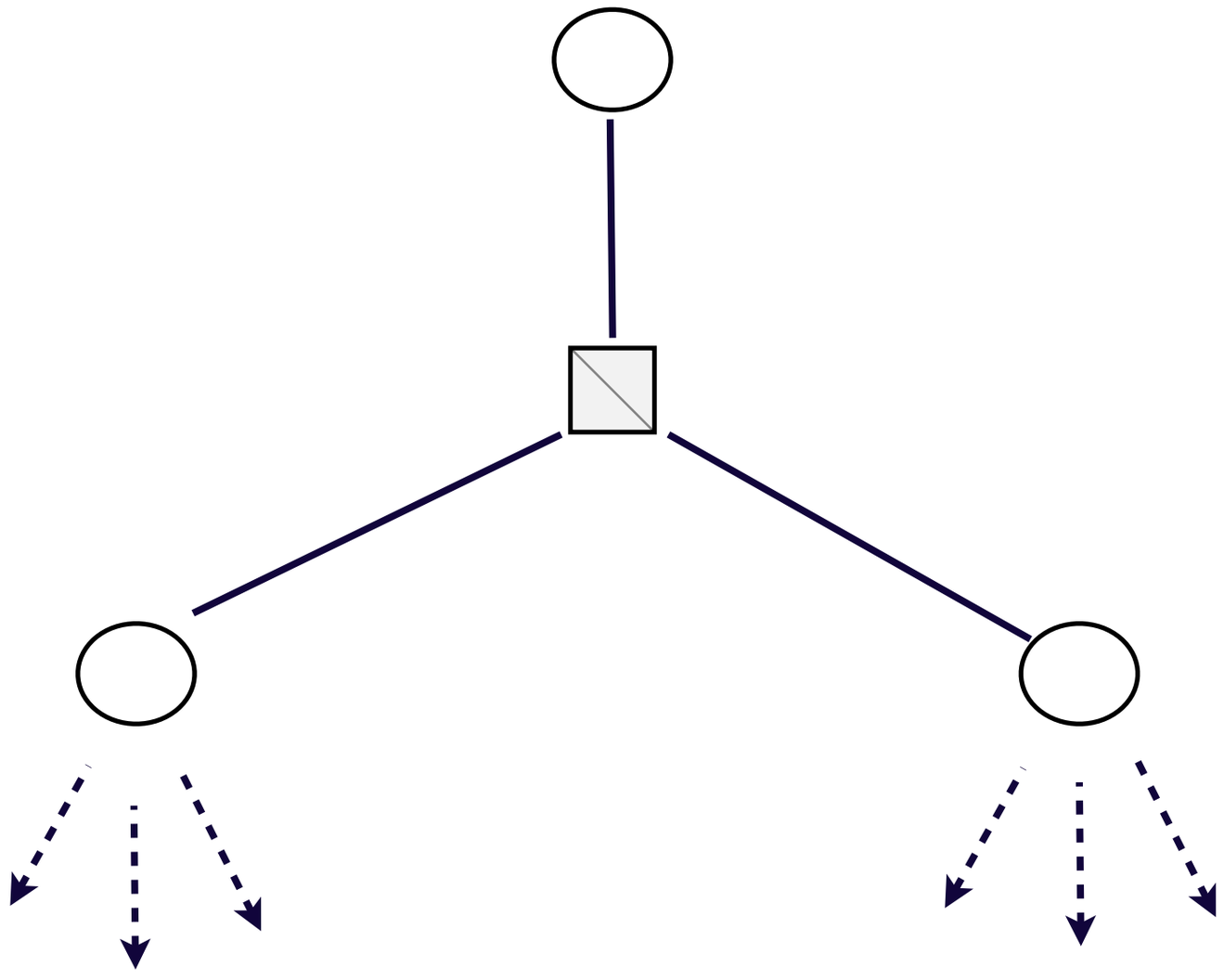
Compute the largest eigenvalue of the matrix to know about stability.

Simulations vs analytic approach



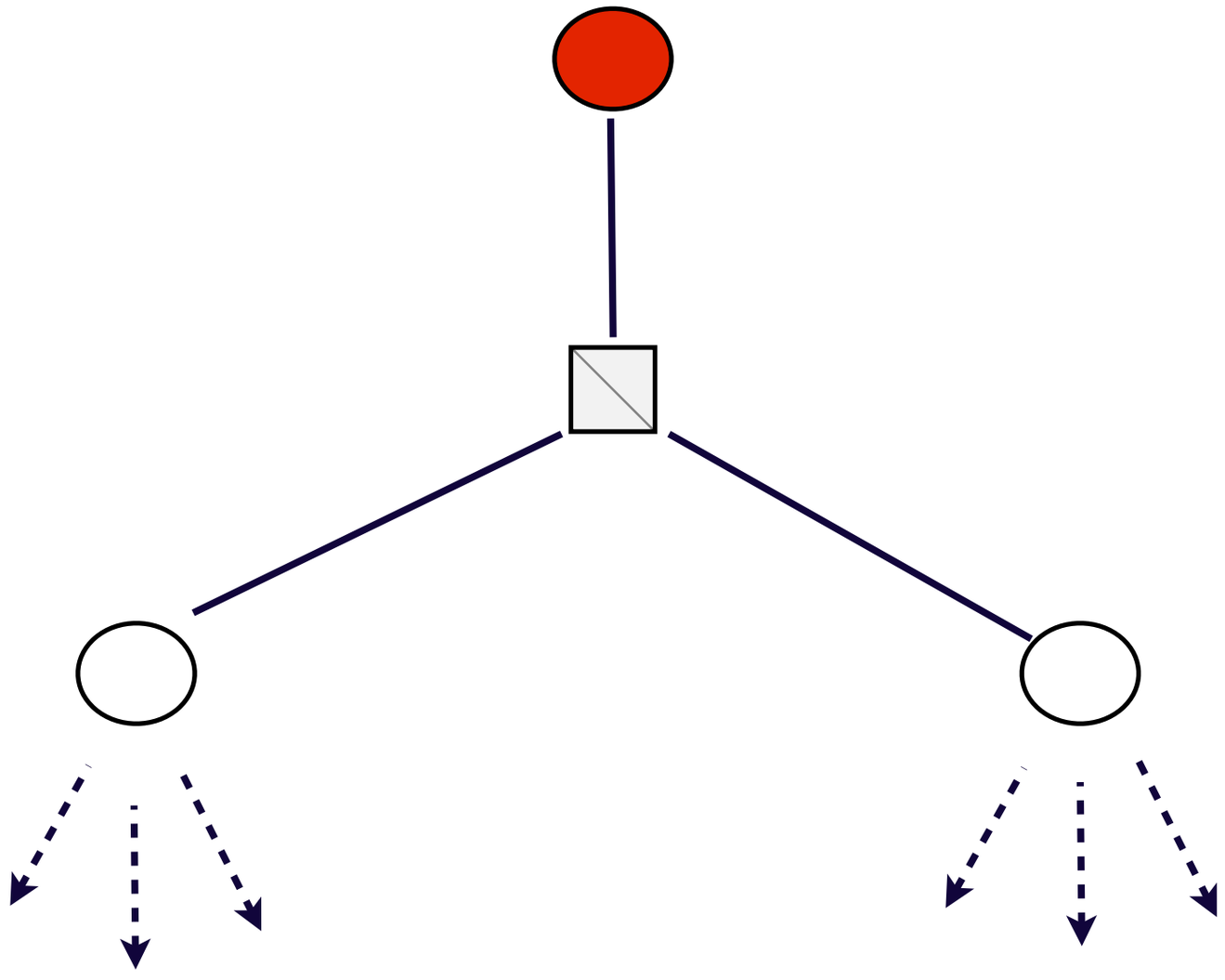
The analytic approach underestimates the width of the contagion window

Approximation



failures due to “siblings” are not accounted for

Approximation



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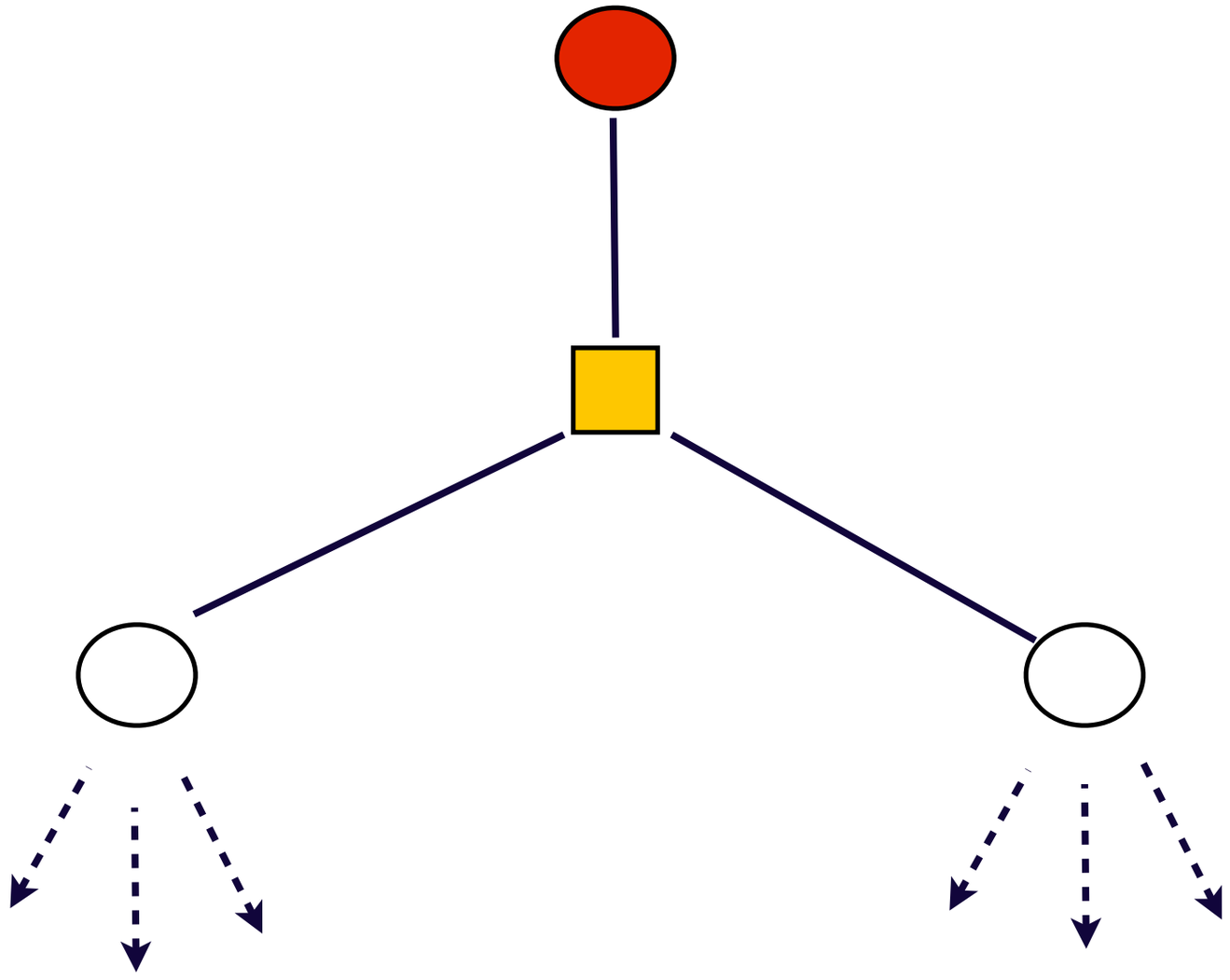

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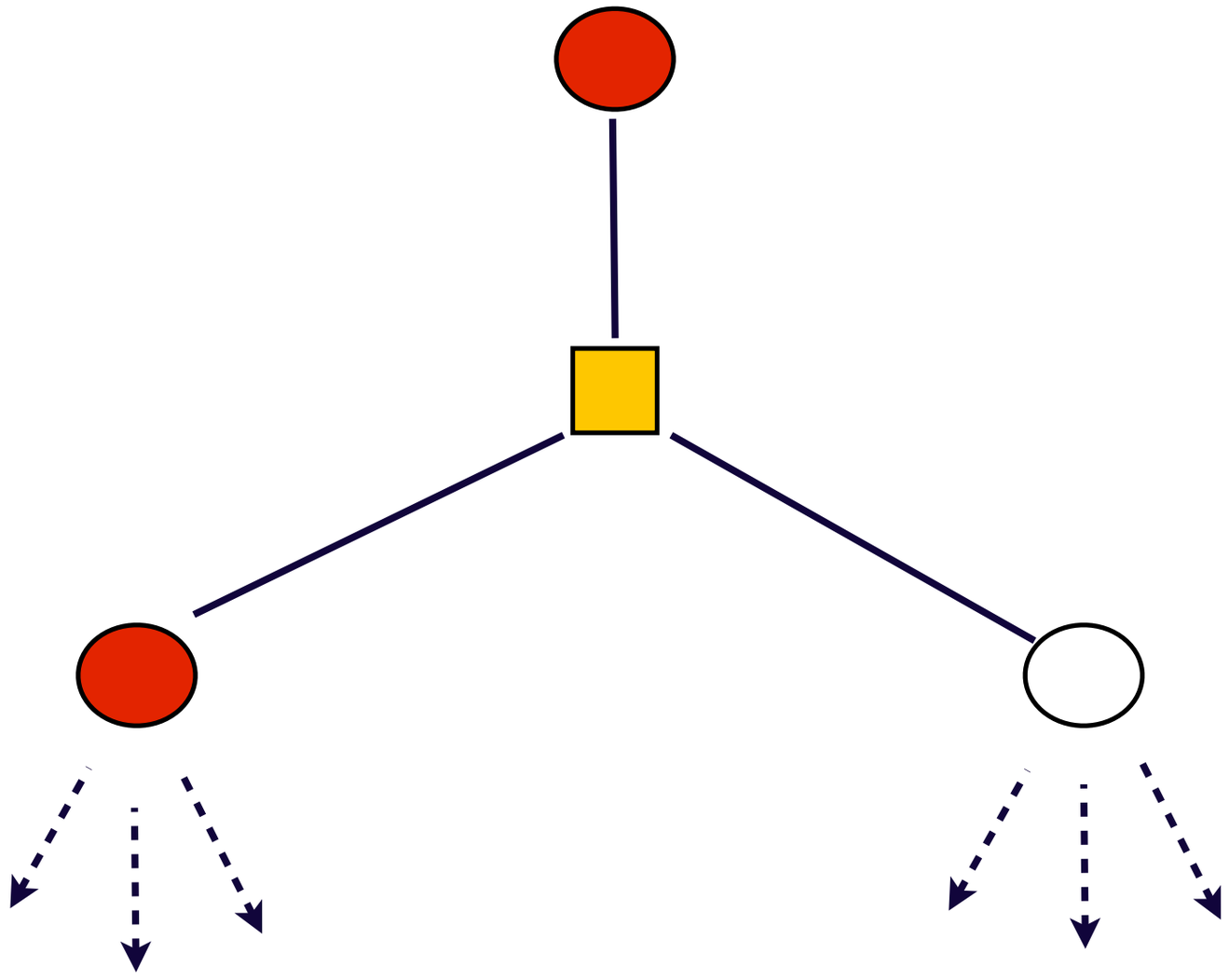

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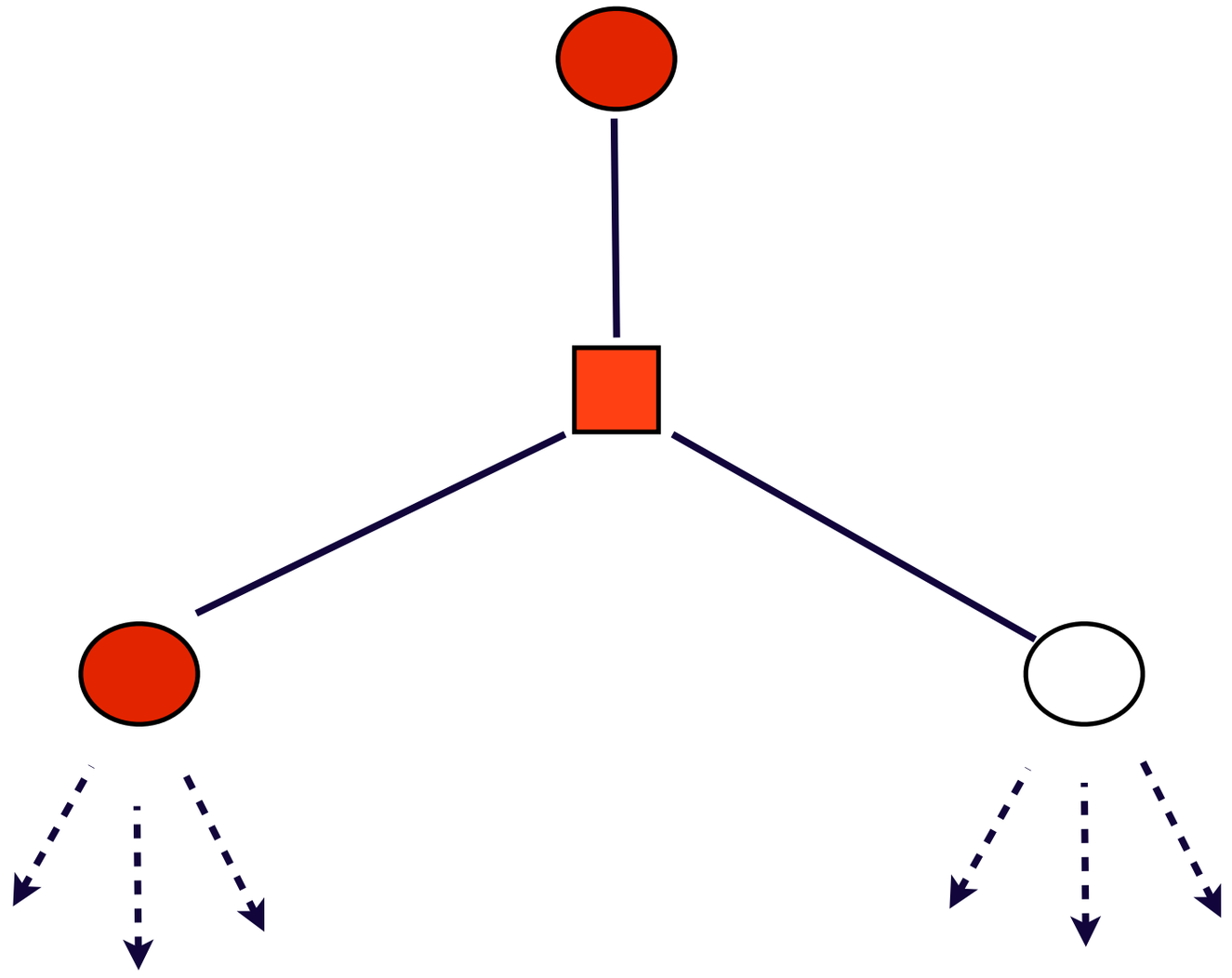

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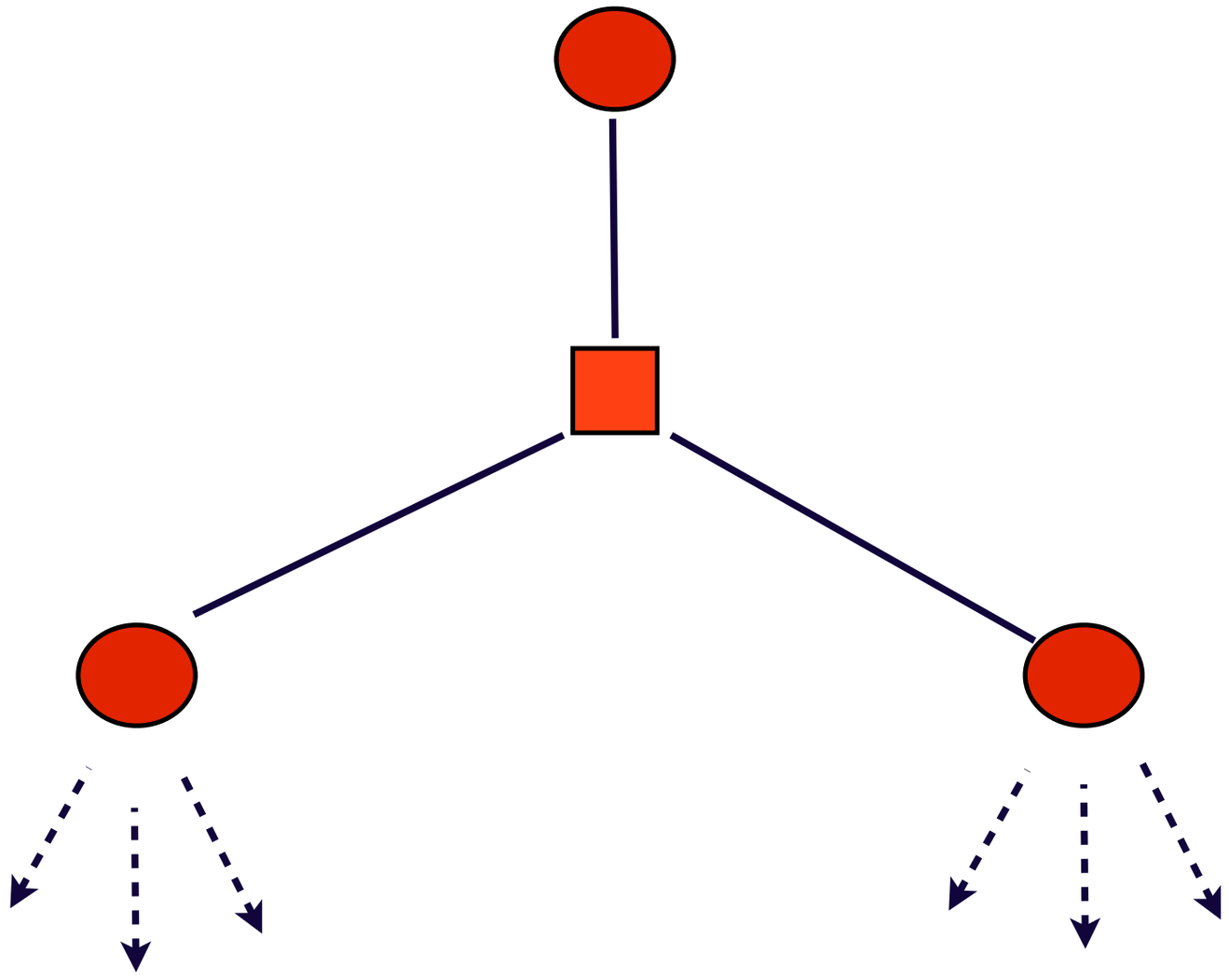

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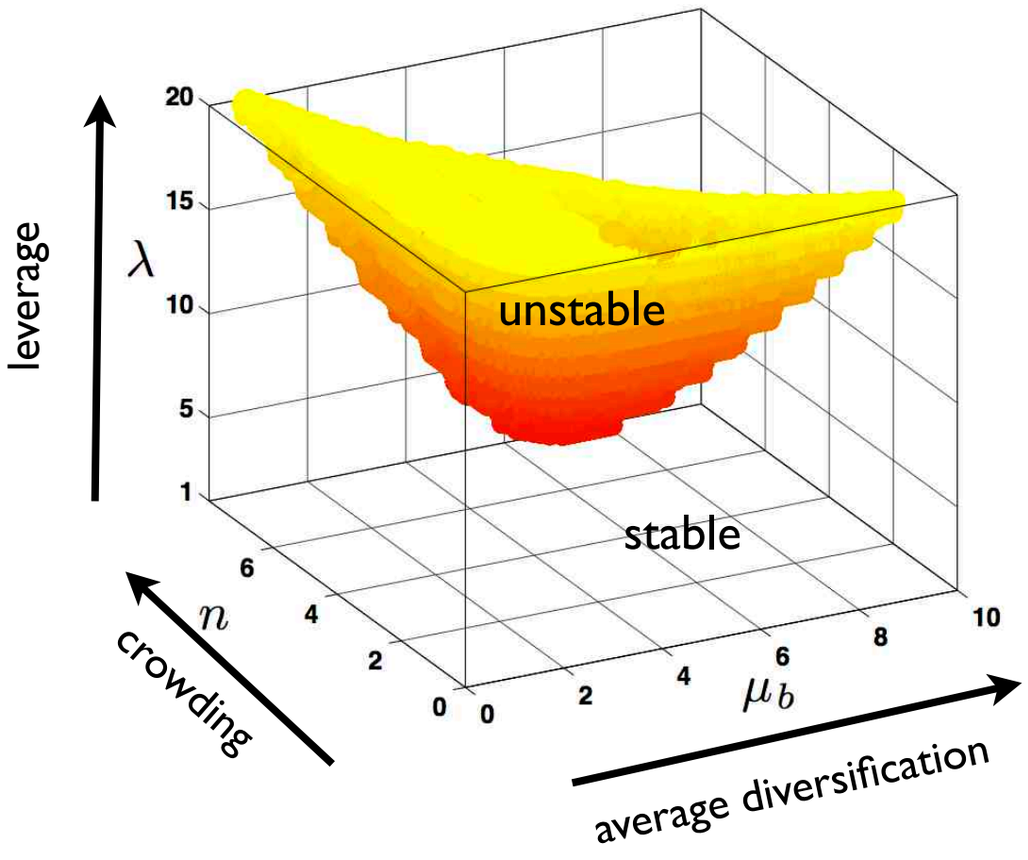
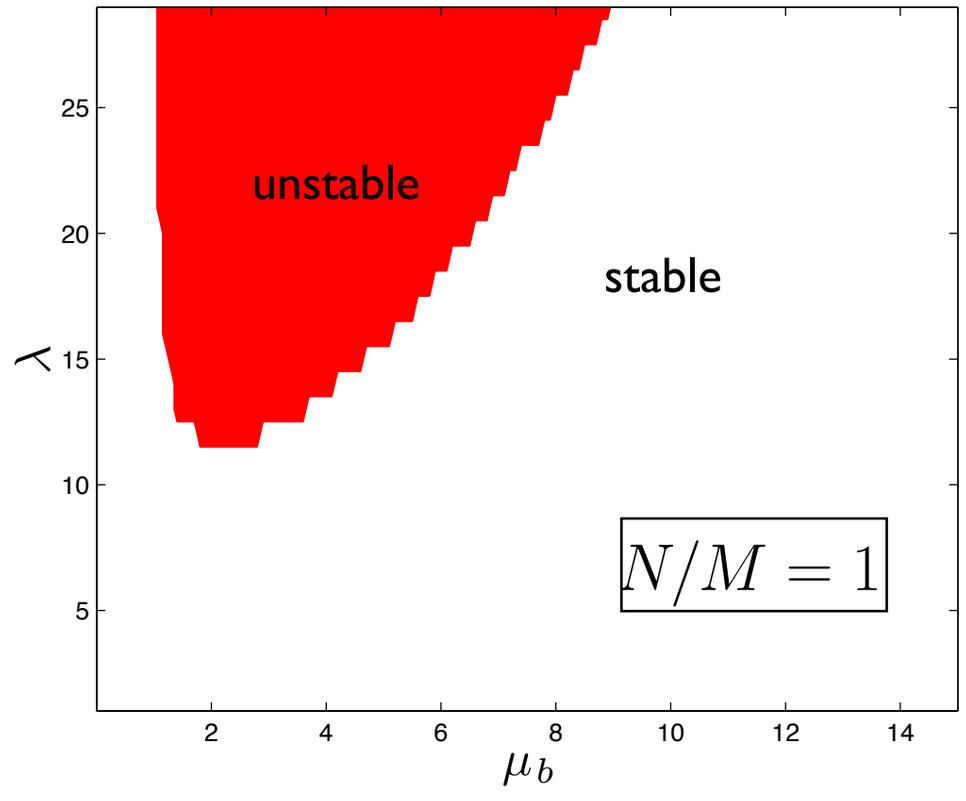
Phase Diagram



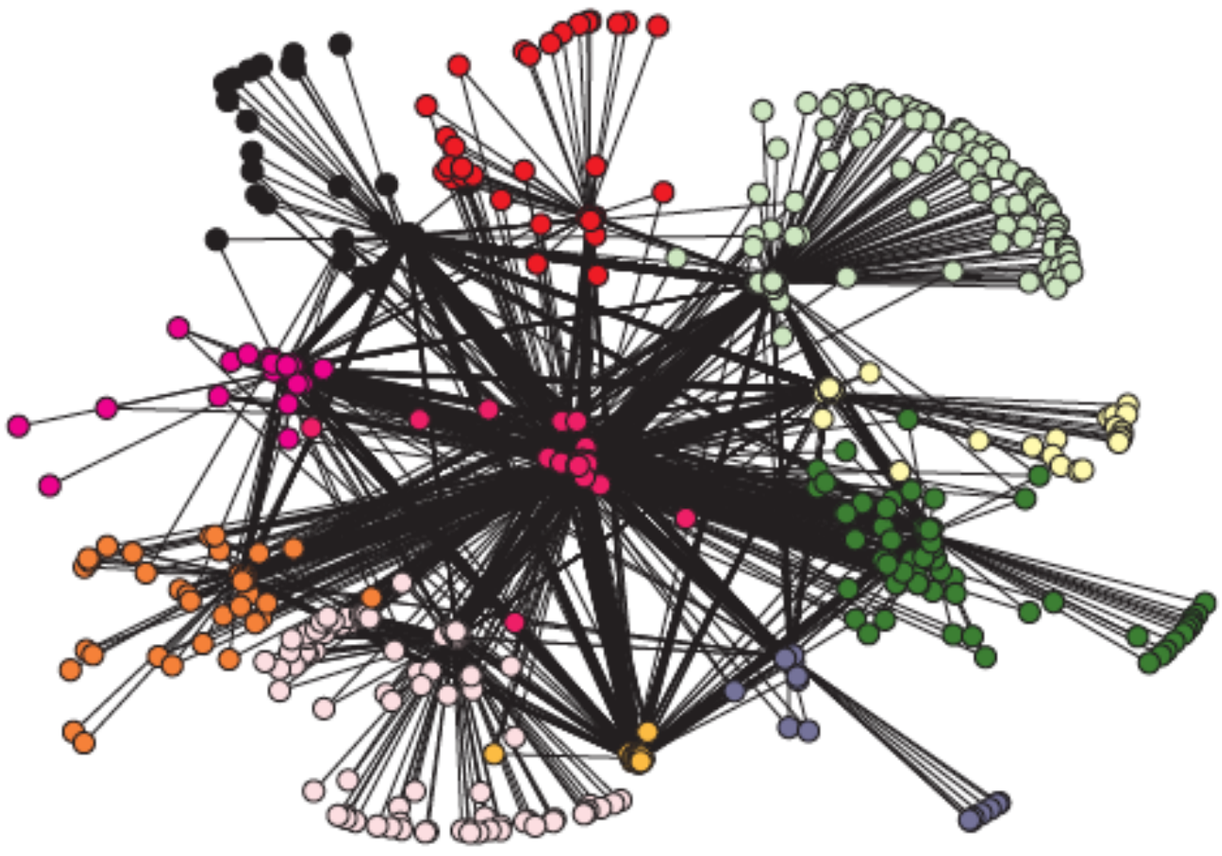


the system is stable if leverage is below a critical threshold

Summary

- Overlapping portfolios and market impact as a contagion mechanism.
- Contagion probability is non-monotonic in the average diversification and the relative number of banks to assets (crowding).
- The system exhibits a robust yet fragile behavior.
- Analytical characterization of phase space: branching process.

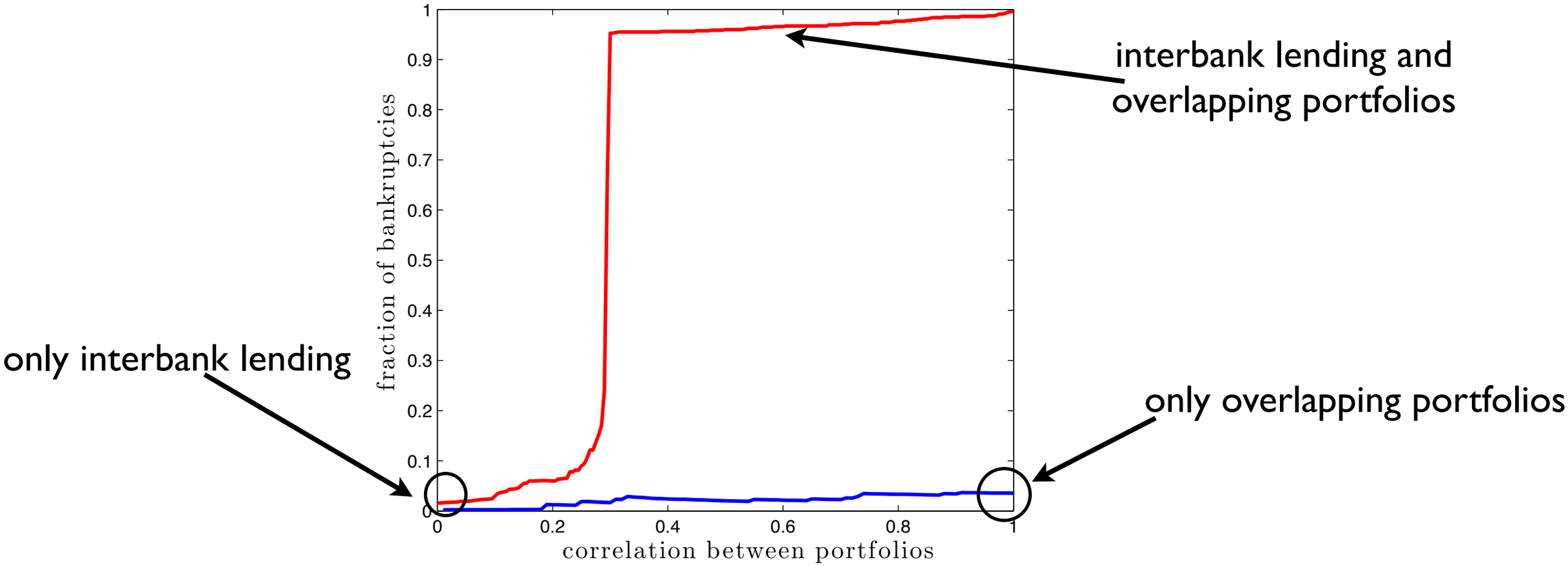
Interbank lending



(from Boss et al. 2003)

Interaction between contagion mechanisms

Caccioli, Farmer, Foti and Rockmore (2013)



The biggest contribution to systemic risk comes from the interaction between different channels

Related Literature

- Cifuentes, Shin and Ferrucci (2005): one asset common to all banks

- Beale et al. PNAS (2011): individual vs systemic risk

- Corsi, Marmi and Lillo, SSRN (2013): overlapping portfolios and financial innovation

- Huang, Vodenska, Havlin and Stanley, Scientific Reports (2013): empirical analysis of US commercial banks