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TECHNISCHE UNIVERSITÄT DRESDEN

Efficient response to cascading disaster spreading

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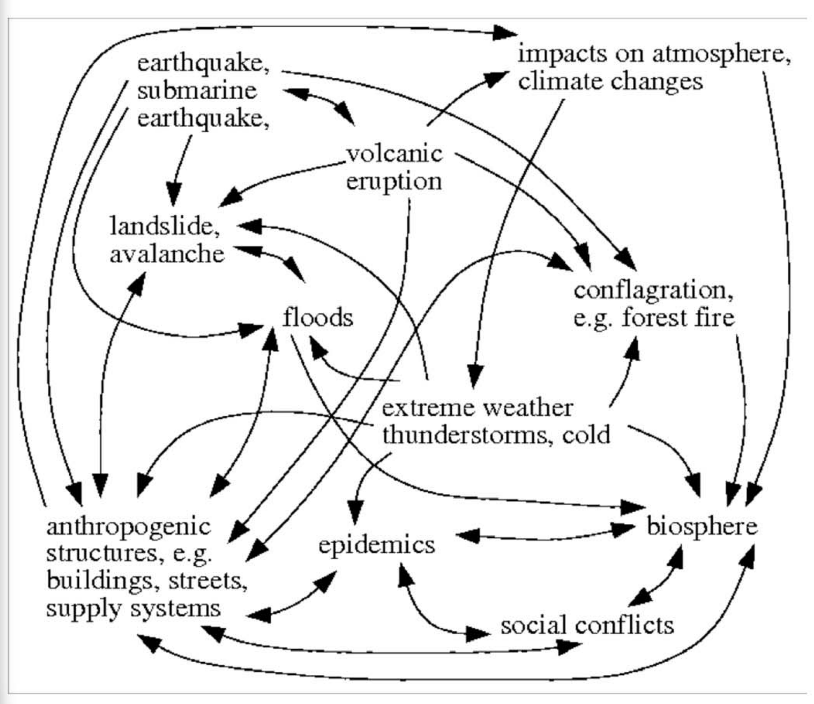
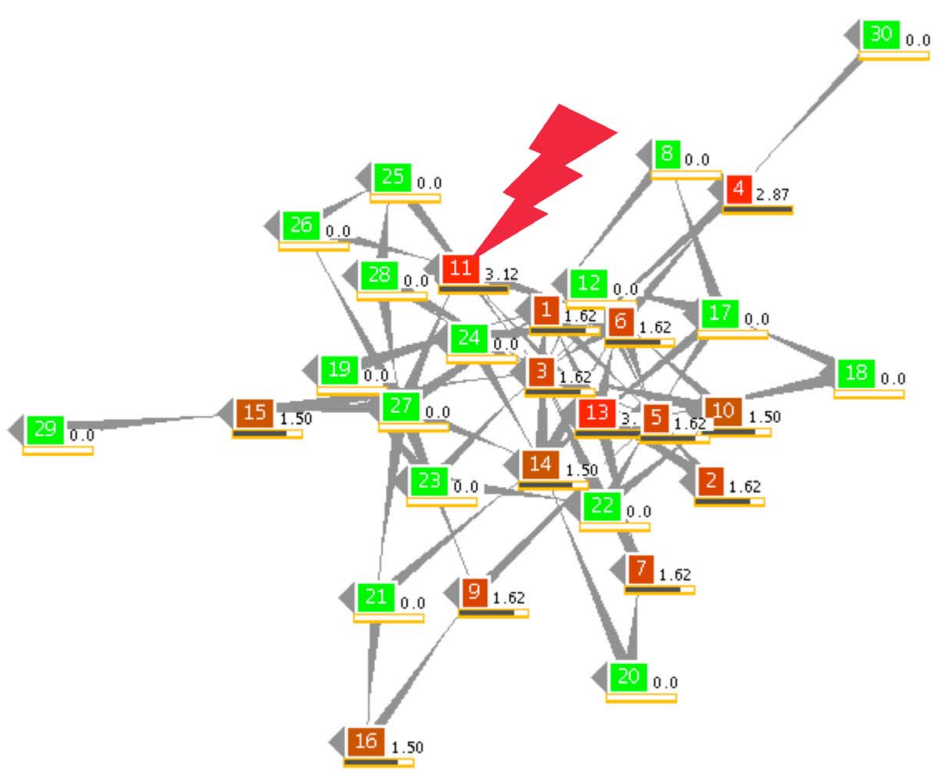
1. Introduction

We study the effectiveness of recovery strategies for a dynamic model of failure spreading in networks. These strategies control the distribution of resources based on information about the current network state and network topology. In order to assess their success, we have performed a series of simulation experiments. The considered parameters of these experiments are the network topology, the response time delay, and the overall disposition of resources. Our investigations are focused on the comparison of strategies for different scenarios and the determination of the most appropriate strategy. The investigation of causal networks provides a methodology which allows one to assess the dependencies and potential cascading effects.



Example of empirical causal network



Snapshot of a disaster spreading simulation visualized by TouchGraph

2. Modeling the dynamics of disaster spreading

A. Node dynamics:

$$\frac{dx_i}{dt} = -\frac{x_i}{\tau} + \Theta\left(\sum_{j\neq i} \frac{M_{ij}x_j(t-t_{ij})}{f(O_i)} e^{-\beta t_{ij}/\tau}\right) + \xi_i(t)$$

x_i - state of the node

$x_i = 0$ - usual situation

$x_i > \theta_i$ - node is destroyed

θ_i - node threshold

$\xi_i(t)$ - internal noise

a, b, α, β - fit parameters

$$\Theta(x) = \frac{1-\exp(-\alpha x)}{1+\exp[-\alpha(x-\theta_i)]}$$

$$f(O_i) = \frac{aO_i}{1+bO_i}$$

t_{ij} - time delay

$1/\tau$ - healing rate

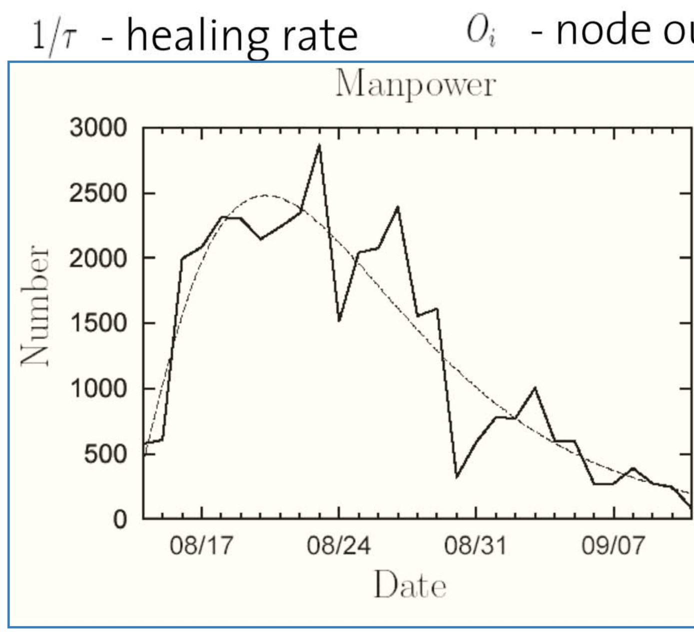
M_{ij} - link strength

O_i - node out-degree

B. Mobilization of resources:

$$r(t) = a_1 t^{b_1} e^{-c_1 t}$$

$a_1 = 530$ $b_1 = 1.6$ $c_1 = 0.22$



Manpower fighting the Elbe river flooding in August 2002

C. Activation of resources:

Assumptions:

▸Resources have only a positive influence on the state of the node

▸Initial recovery rate is positive (internal resources) $1/\tau_i = 1/\tau_{start} > 0$

▸The speed of recovery process is limited i.e. for $R_i \to \infty$ we get $1/\tau_i(t) = 1/\beta_2 > 0$

$$\frac{1}{\tau_i(t)} = \frac{1}{(\tau_{start} - \beta_2)e^{-\alpha_2 R_i(t)} + \beta_2}$$

$R_i(t)$ - cumulative resources

τ_{start} - initial healing rate

α_2, β_2 - fit parameters

D. Disaster management and disaster recovery strategies:

▸Network topology

▸Level of damage

S_1 - uniform dissemination

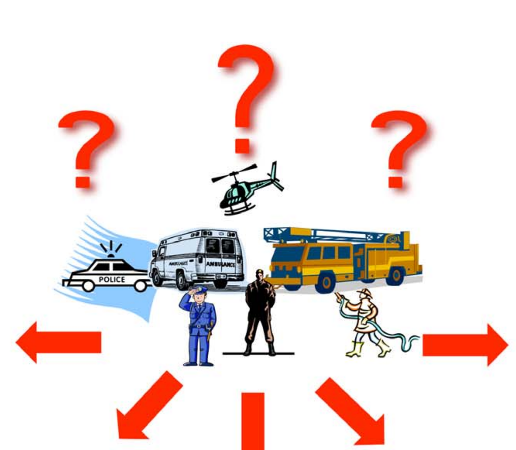
S_2 - out – degree based dissemination

S_3 - uniform reinforcement of challenged nodes

S_4 – simple targeted reinforcement of destroyed nodes

S_5 – simple targeted reinforcement of highly connected nodes

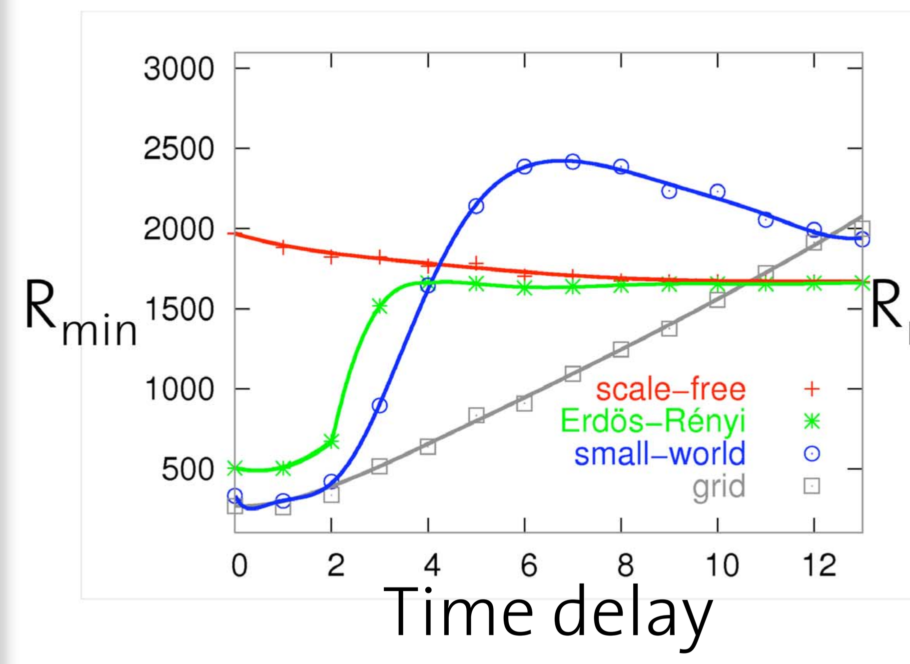
S_6 – out – degree based targeted reinforcement of destroyed nodes



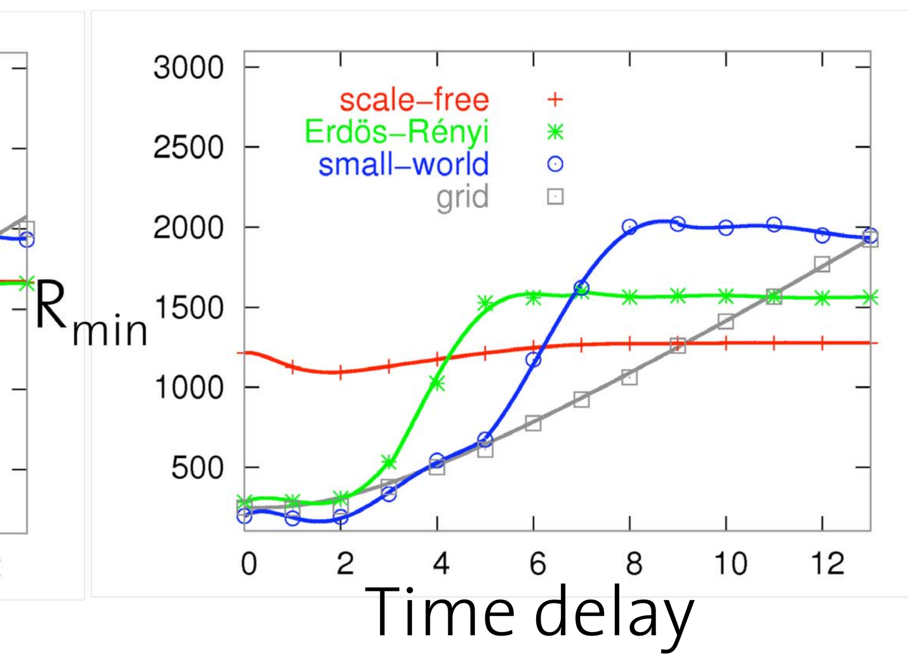
3. Worst case scenario

We determined the minimum required resources R_{min} as a function of the response strategy and the network topology, and we study how R_{min} changes when the response time delay increases. R_{min} is the minimum quantity of resources that guarantees the complete recovery of the network for each particular scenario. We estimate this quantity by performing a huge number of numerical calculations separately for each studied network. In each simulation run, the location of the initial disturbance and the time delays t_{ij} are randomly varied.

Is the network able to recover ?



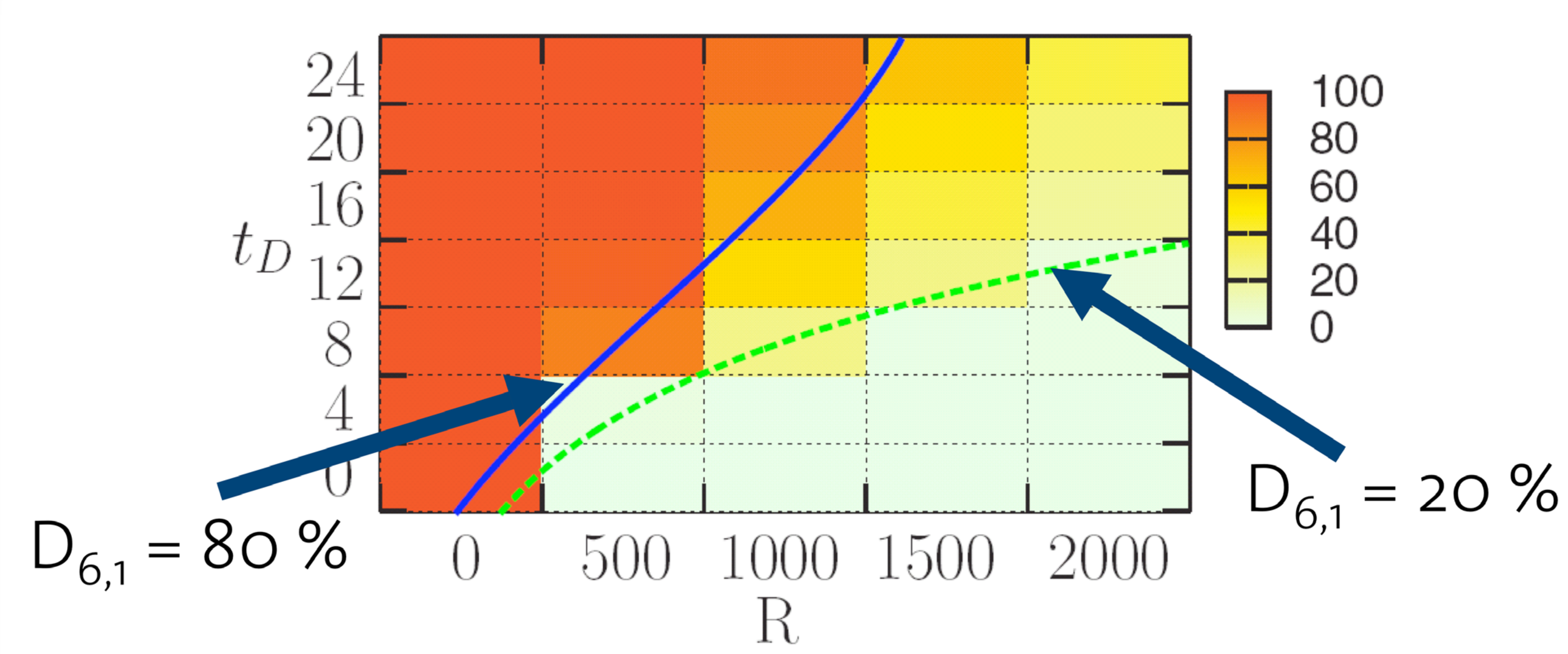
S3 - uniform reinforcement of challenged nodes



S4 – simple targeted reinforcement of destroyed nodes

4. Average impact of the different strategies

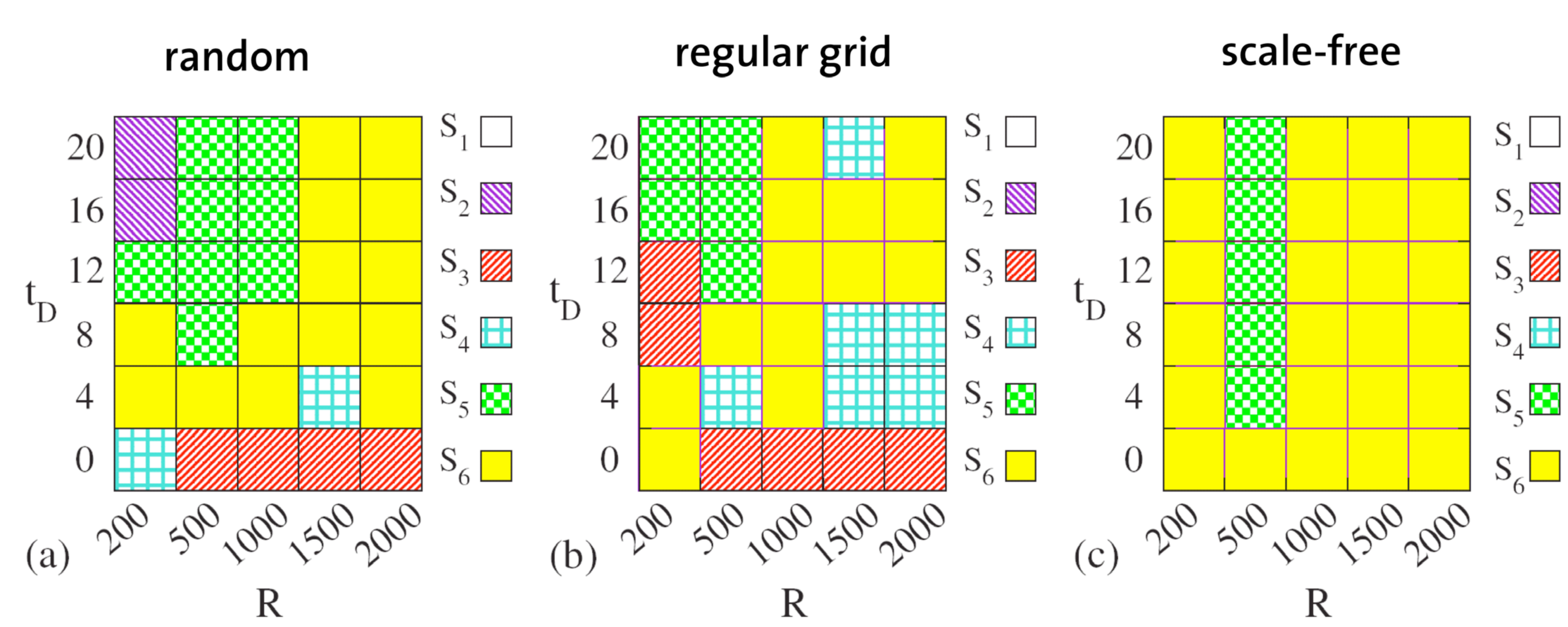
A. Relative difference in damage between strategies S_6 and S_1



1. The promptness of recovery activities has a crucial influence on their efficiency.

2. Optimization of protection strategies is possible in certain parameter regions.

B. Most efficient strategies



There is no unique optimal response strategy:

1. Strategies based on the network structure has been proved as the most suitable for scale-free structures.

2. Strategies based on the damage information are more appropriate for regular networks.

3. The situation in random and small-world networks depends on the time delay:
(short time delay => damage based strategies)
(large time delay => network structure based strategies).

Chair of Sociology, in particular of Modeling and Simulation