English summary

4.4 Emergency situations (continued)

- collective response (measurable by mobile-phone data)
- spatial patterns: decay with distance from event
- temporal pattern: sudden increase (catastrophes), slow increase (planned events)
- information cascades: many layers — — — — — —, few layers — — — —

5 Control & containment of outbreaks

5.1 Dataset

- All regulations → database to monitor animal/livestock trade/movement
- Germany: HI-Tier
- Network: nodes = agricultural premises (pig trade: 129,000)
  links = trade contacts (— — : 200,000/year)
- Structure of network: modularity
  \[ Q = \frac{1}{2m} \sum_{ij} \left[ A_{ij} - \frac{x_i x_j}{m} \right] \delta(i,j) \]
  \[ = \text{# links within cluster} - \text{# expected links (for random connections)} \]

5.2 Detection of outbreaks
- goal: identify nodes that reliably detect many outbreaks (different origins) at an early stage.

- ideas compare overlap of paths $P_i$ and $P_j$ starting at different nodes

\[ \text{Jaccard index } \theta_{ij} = \frac{|V_i \cap V_j|}{|V_i \cup V_j|} \quad V_i = \text{set of nodes on } P_i \]

\[ |V_i| = \# \text{ nodes} \]

- define clusters

- similarity of outbreaks for nodes of the same cluster

5.2 Detektion von Krankheitsausbrüchen (Fortsetzung)
• Modell: deterministischer SI R-Modell
  
  ⇒ (i) Ausdehnung mit Wahrscheinlichkeit $T_i$ im nächsten Zeitschritt
  (ii) Erholung nach $\mu^{-1}$ Schritten

• Betrachte alle möglichen Startpunkte

• Berechne Wahr scheinlichkei t, dass Krose $K$ bei insgesamt $n_k$
  Ausdehnungen bei Start im Cluster $j$ erst rekt wird: $T_j(k)$

  Bsp.: immer von einem einzigen Cluster angegriffen: $T_j(k)=1$, $T_{\notin j}(k)=0$
  immer von einem anderen Cluster angegriffen: $T_j(k)=\frac{1}{n_k}$

  ⇒ Entropie: $S(k)= -\frac{1}{\log n_k} \sum_j T_j(k) \log T_j(k) \xrightarrow{0 \text{ immer aus dem selben Cluster}} 1 \text{ immer verschieden}$
Figure 8. Properties of the surveillance system based on sentinel premises. (a) Fraction of outbreaks detected by the sentinels as a function of the minimum outbreak size of the epidemic, for two sets of sentinels (of 15 and 32 sentinels), corresponding to \((n_s = 30, \xi_s = 0.4)\) and \((n_s = 30, \xi_s = 0.45)\), respectively. (b) Boxplot of the time of infection of the 15 sentinels relative to the full duration of the outbreak, considering the detected outbreaks with final size being larger than 10. Each box is coloured according to the number of times \(n\) that the sentinel has been infected and a grey shaded area indicates 33% of the relative infec-

Einige wenige Knoten (geschickt gewählt) detektieren fast alle Ausbrüche zu einem frühen Zeitpunkt.
5.3 Kontrolle von Ausbreitungen

- Daten, deutsche Schweinehandel
- Zeitlich abhängiges/veränderliches Netzwerk
  Handelsnetz am \( \rightarrow \) verschiedene Tojen

- Kausalität

Diagramm mit Knoten und Pfeilen für verschiedene Tage (day 0, day 1, day 2, day 3, day X) und entsprechende Ausbreitungsbilder.
SIR Model

\[ \beta = 1, \]
\[ \gamma = 0.1, \]
\[ \varepsilon = 10^{-4}, \]
\[ n = 3218, \]
\[ N_\mu(0) = 100, \]
\[ S_\mu(0) = 100, \]
\[ S_1(0) = 99 \]
Figure 2. Infection model and adaptation mechanism. Nodes are arranged vertically with links between them for each day. Nodes can be in three states: susceptible, $S$ (empty circles), undiscovered infected $I^*$ (yellow), and detected infected $I$ (red). After $\delta$ days, infected nodes are detected and for $t \in [t^* + \delta, t^* + \kappa]$ – with $t^*$ being the time of infection – all outgoing links from the detected nodes (red) are randomly rewired to other susceptible or undetected nodes as starting point, e.g. the link $a$ is destroyed and instead the link $b$ is created. After $K$ days, infected nodes recover.

Figure 3. Typical time course of an epidemic. Prevalence (number of infected nodes, daily resolution) for a fixed infectious period $\kappa = 30$ d and different detection times $\delta$: unadapted $\delta = \kappa$ (blue), adapted $\delta = 15$ d (red) and $\delta = 10$ d (green).
Control of networks with time-varying topologies and applications to epidemiology

Goals and visions
- Characteristic analysis of time-dependent networks
- Early detection of epidemics, identification of most influential nodes in spreading processes
- Epidemic spreading on generic and real-world networks
- Adaptation rules of the network to counteract epidemics

Compartmental model of disease spreading

\[ S - I - R \]

Transmission rate \( \beta \)
Recovery rate \( \gamma \)

Coupling term -- in and out fluxes:
\[ \mathbf{I}^\ell \rightarrow \mathbf{I} = \sum_{\ell=0}^{\infty} p_\ell \mathbf{I}^\ell \]

\[ \mathbf{I} \rightarrow \mathbf{I}^\ell = \sum_{\ell=0}^{\infty} M_\ell \mathbf{I} \]

Isolated system

Time-varying network topologies
Schematic spreading process

Day 0 - day 2
Day 1 - day 3
Day 2 - day 6
Day 3 - day 1
Day 5 - day 1
Day 7 - day 1

State of node 5 depends on evolution of the network

Infectious period: \( k = 3 \)

Deterministic process: 100% chance of infection

Statistical networks overestimate probability of secondary infection and outbreak size \( \beta_{\text{true}} \)

Network extraction and deterministic model
Data set: number of nodes > 100,000 (on 2 years) aggregated number of edges = 257,732
Contact network on 2 days daily mean = 4929
Data source: Heinrich-und-infomationsystem Tier (HI-Tier)

Size of out-component \( |\text{out}^0| \) -- Centrality measure -- Ranking

Evolution of livestock trade network

Sensible dependence of out-component on day of primary infection \( i \) and infectious period \( k \)

Dynamics on temporal networks
Simulation of SIR model on empirical networks
Network diagnostics

Node degree histogram
Edge activity histogram

Dynamics on temporal networks

Biology systems and contagion processes as applications of control of temporal networks extracted from empirical, real-world datasets.

Control and overlap with projects of groups A and B:
- Adaptive control
- Spatio-temporal delay systems
- Observation and control of networks
- Time-varying coupling with hysteresis
- Analysis of complex networks

II. Numerical modeling of spreading diseases

Control of dynamics and adaptation rules

- Dealing with known contacts
- Dealing with random contacts
- Reduction/increase of outbreak size

Control concepts:
- Adaptive control
- Controllability of networks
- Temporal response of network

Role within Collaborative Research Center

BSc thesis: Florian Fleig (co-supervised by S. Vanchuk; A3)