Wrocław University of Technology

(Network's) Models of epidemiology

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Table of context

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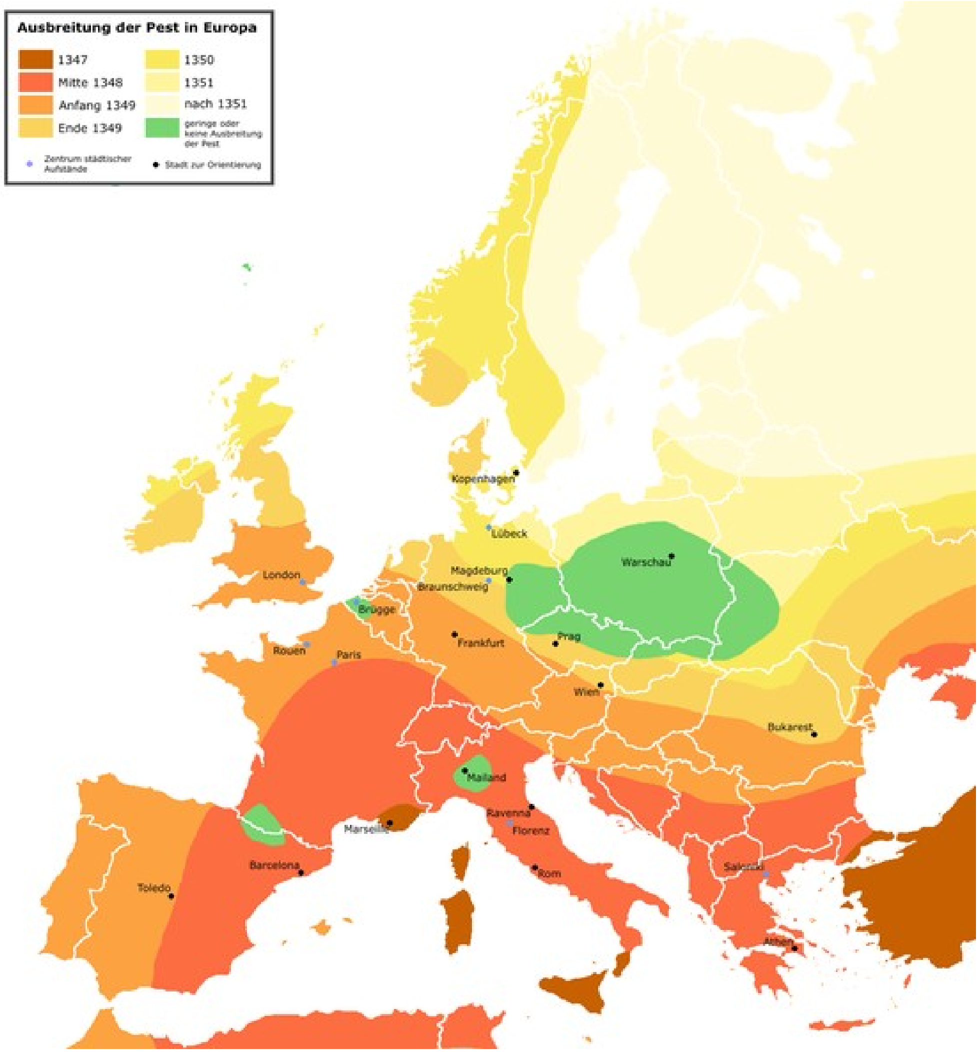
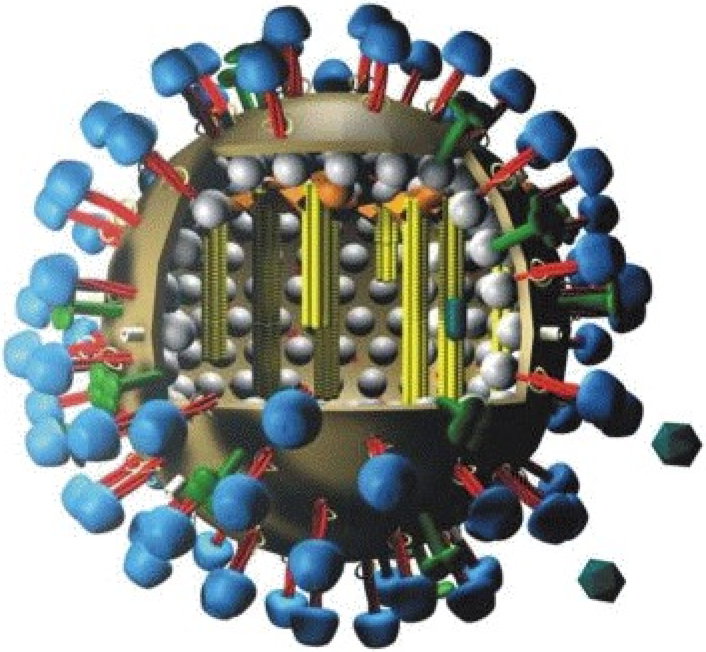
Epidemics



Black Death (PDE)

Epidemics



H5N1 influenca - bird flu 2005
H1N1 influenca - swine flu 2009
(Networks)

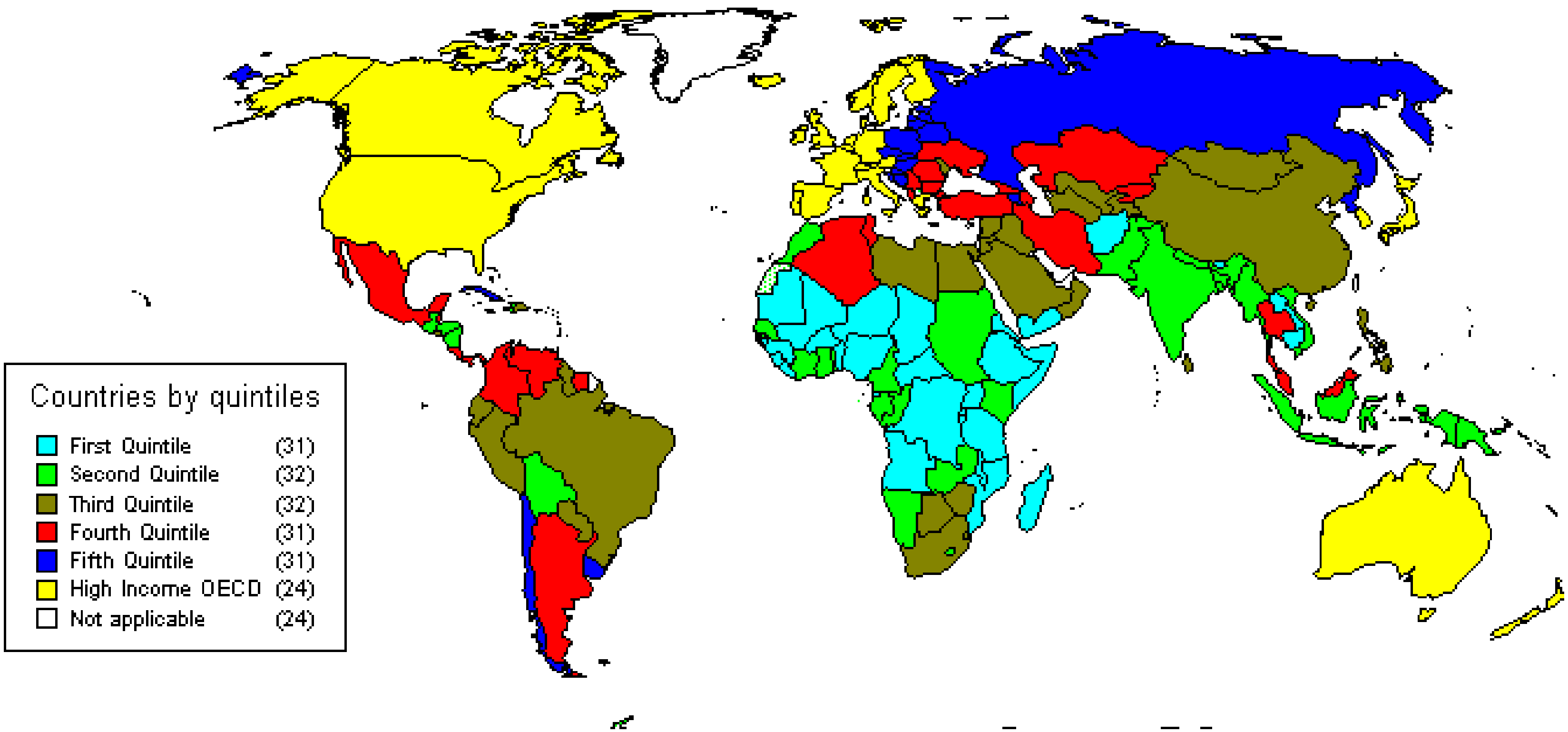
Epidemics

Plant's diseases - rhisobia (CA)

Epidemics

Animal's diseases
Mad Cow - BSE
(CA, Networks)

Epidemics



Differential equations vs Netwoks

Data!!!

Before differential equations, Bernoulli Model

Wrocław – from the beginig of smallpox epidemiology modeling up to erudation of disease

In Poland smallpox **last time appeared in Wroclaw in 1963,** but it was stopped by the actions of the government and epidemiologists. Moreover smallpox was eradicated by WHO in 1979. **Bernoulli (1760) actually used date provided from Wroclaw** to estimate his model.

Before differential equations, Bernoulli Model

This Swiss mathematician **was the first to express the proportion of susceptible individuals of an endemic infection** in terms of the force of infection and life expectancy. His work describe smallpox, which cause a lot of epidemics in big European cities at his time. Smallpox devastated earlier the native Amerindian population and was an important factor in the conquest of the Aztecs and the Incas by the Spaniards.

Before differential equations, Bernoulli Model

I simply wish that, in a matter which so closely concerns the well-being of mankind, no decision shall be made without all the knowledge which a little analysis and calculation can provide.

Daniel Bernoulli, presenting his estimates of smallpox
Royal Academy of Sciences-Paris, 30 April 1760

Before differential equations, Bernoulli Model

Bernoulii based at work of famous British **astronomer – Edmund Halley** „An Estimate of the Degrees of the Mortality of Mankind, drawn from curious Tables of the Births and Funerals at the City of Breslaw" published in Philosophical Transactions 196 (1692/1693).

In 17^{th} century English Breslaw means Breslau-German name of Wrocław.

Before differential equations, Bernoulli Model

Survivors according to Halley	Not having had smallpox	Having had smallpox	Catching smallpox each year	Dying of smallpox each year	Total smallpox deaths	other diseases each year
1300	1300	0				
1000	896	104	137	17,1	17,1	283
855	685	170	99	12,4	29,5	133
798	571	227	78	9,7	39,2	47
760	485	275	66	8,3	47,5	30
732	416	316	56	7	54,5	21
710	359	351	48	6	60,5	16
692	311	381	42	5,2	65,7	12,8
680	272	408	36	4,5	70,2	7,5
670	237	433	32	4	74,2	6
661	208	453	28	3,5	77,7	5,5
653	182	471	24,4	3	80,7	5
646	160	486	21,4	2,7	83,4	4,3
640	140	500	18,7	2,3	85,7	3,7
634	123	511	16,6	2,1	87,8	3,9
628	108	520	14,4	1,8	89,6	4,2
622	94	528	12,6	1,6	91,2	4,4
616	83	533	11	1,4	92,6	4,6
610	72	538	9,7	1,2	93,8	4,8
604	63	541	8,4	1	94,8	5
598	56	542	7,4	0,9	95,7	5,1
592	48,5	543	6,5	0,8	96,5	5,2

Table 1. Smallpox in Wroclaw [D. Bernoulli]

Before differential equations, Bernoulli Model

Bernoulli has constructed table with 'natural state with smallpox', in contradistinction to the third column, which shows the 'state without smallpox' and which gives the number of survivors each year assuming that nobody must die of smallpox. Difference between second and third column gave him **a gain in people's lives**. He introduced 'total quantity of life' of the whole generation.

Differential equations

Suppose that population is divided into three classes: the susceptibles (S) who can catch the disease; the infectives (I), who can transmit disease and have it; and the removed (R) who had the disease and are recovered (with immune) or isolated from society. Schema of transition can be represented:

$$S \to I \to R$$

W. O. Kermack and A. G. McKendrick, 1927

Differential equations

$$\frac{dI}{dt} = rSI - aI \,,$$

$$\frac{dS}{dt} = -rSI \,,$$

$$\frac{dR}{dt} = aI$$

Where transmission rate is: $r = \beta C/N$

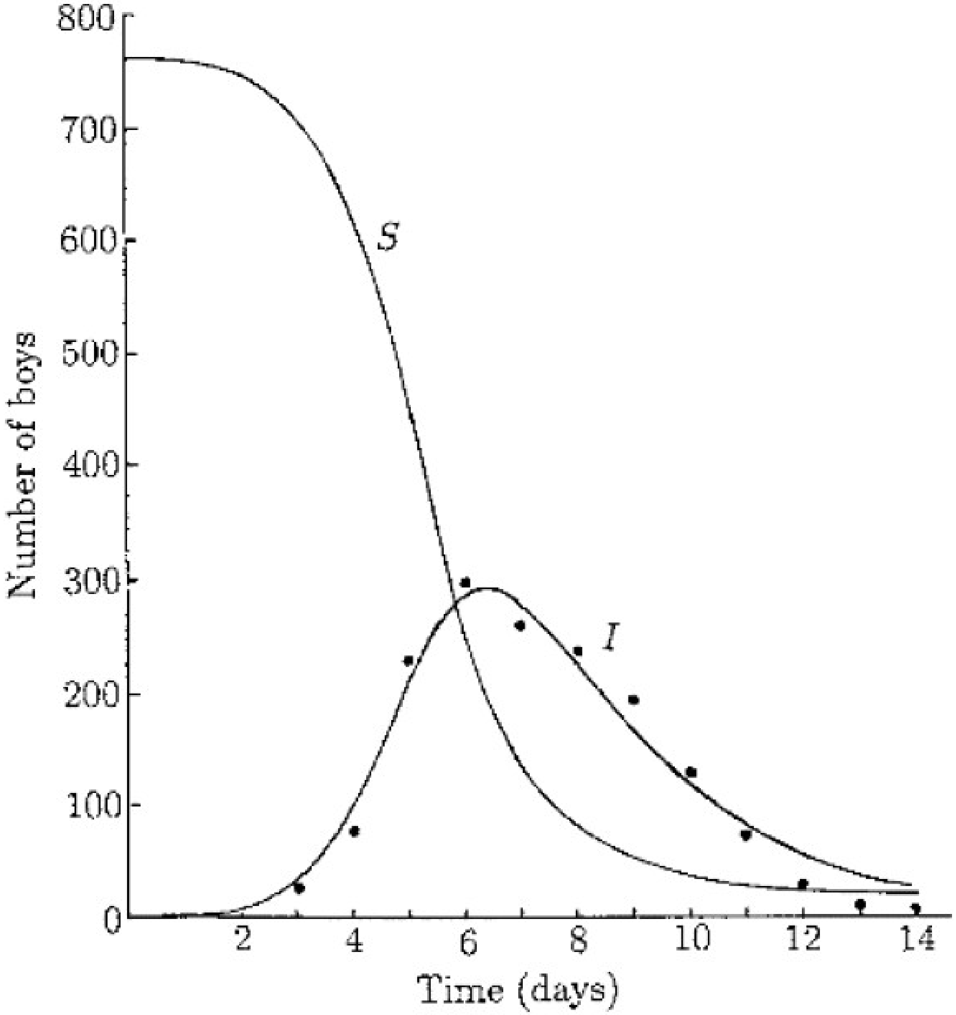
β – infectivity rate, C – contact rate, a – recovery rate

Differential equations

$$R_0 = \frac{r S_0}{a}$$

where R_0 is basic reproduction rate of the infection. This rate is crucial for dealing with and an epidemic which can be under control with vaccination for example. Action is needed if $R_0>1$, because epidemic clearly ensues then.

Differential equations



Influenza epidemic data (●) for a boys boarding school as reported in UK in 1978. The continous curves for *I* and *S* were obtained from a best fit of numerical solution of SIR system with parameters: S_0=762, I_0=1, S_c=202, r=0,0022/day.

Agent-based models

Differential equation vs Agent-based models

Network of contacts:

In an SIR-type model, the population is split into three different groups and the majority of the population is placed in the susceptible compartment. All information about society is used in microsimulation, so it can give better prediction, then differential equations

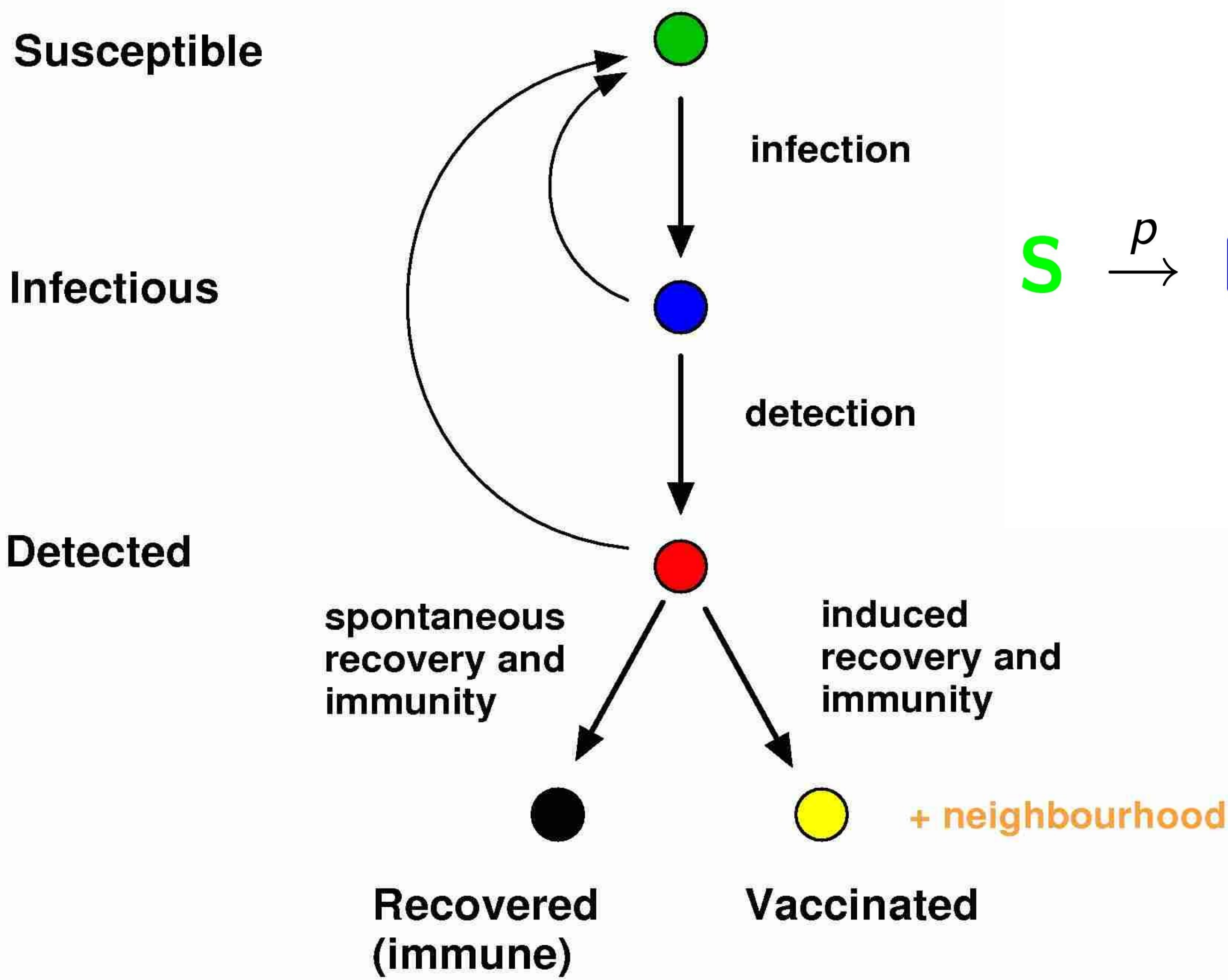
Agent-based models vs DE

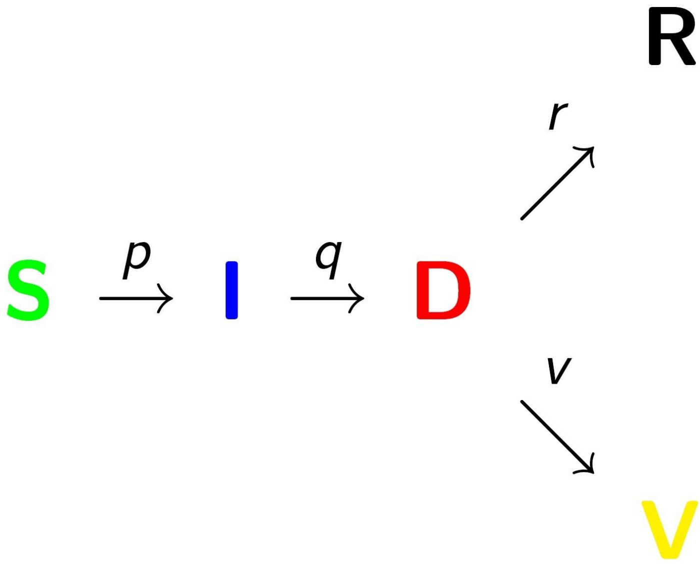
Differential equations were first applied to describe and predict those phenomena (in use since the 18th century when even the definition of „differential equation"has not been known). Epidemiological models that treat transmission from the perspective of differential equations do exist in older literature, but recently agent-based models appear even more often. Both approaches use variations of SIR (susceptibles - infectives - removed) concept, so sometimes **the same problem could be solved in both ways**. Not always, because computer simulation has changed the world of mathematical modeling, agent-based models give better predictions and some hints for decision-makers even parallel development of numerical methods for differential equations. On the other hand, **differential equations allow us to understand the core process, which could be missing in the agent-based approach**. As a result, both perspectives are common among epidemiologists and **depend on theoretical or applied aspect** percentage representations differ.

Celluar Automata

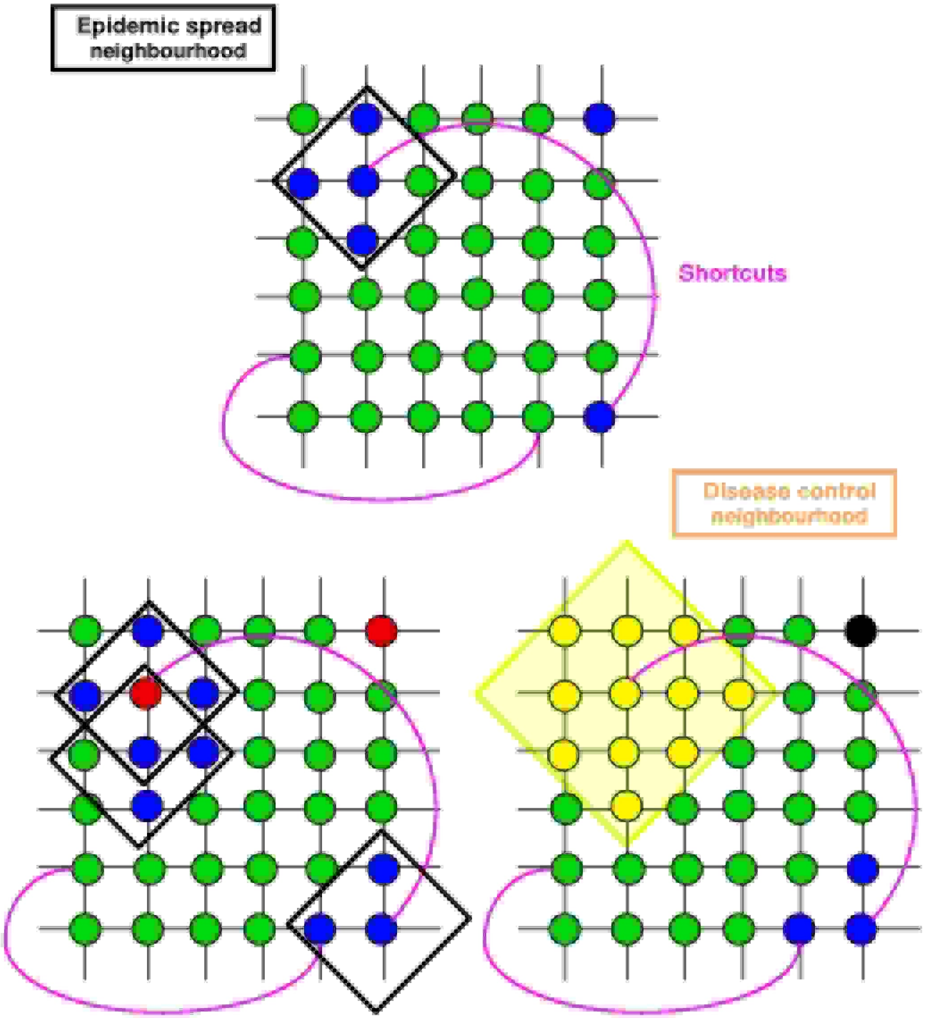
Cellular Automata were invented in early 50^{th}. There based on some designed topology of elements which have some possible number of states and they can evaluate in time. A cellular automaton may be also a collection of "colored" cells on a grid of specified shape that evolves through a number of discrete time steps according to a set of rules based on the states of neighboring cell.

Celluar Automata



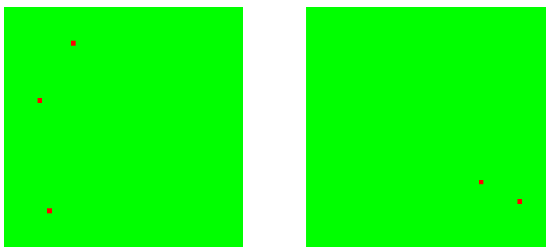


Celluar Automata

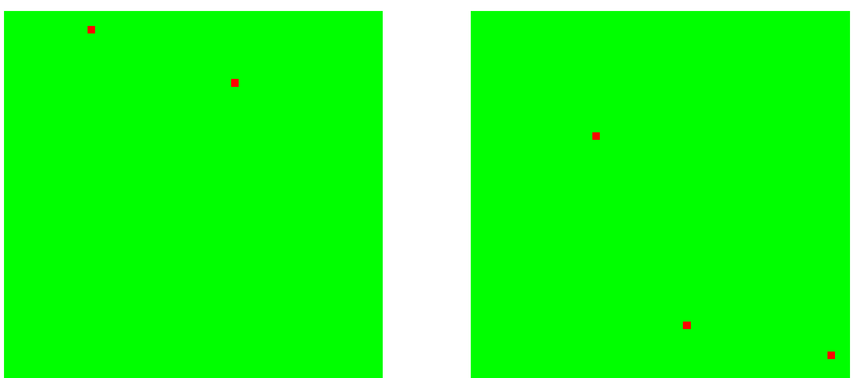


Celluar Automata

No additional links



With additional links

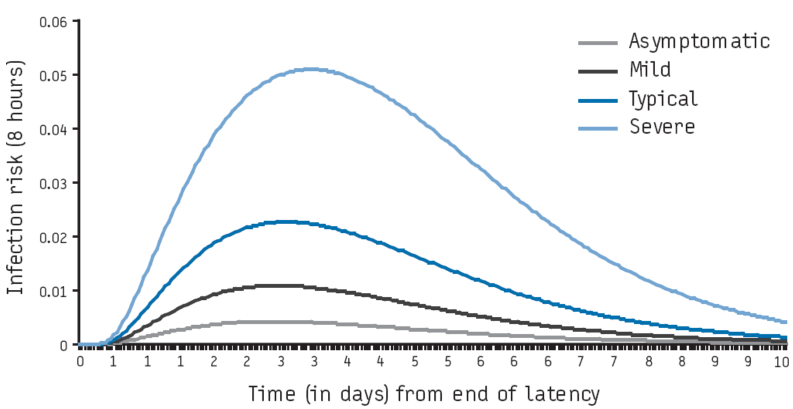


H1N1 - introduction

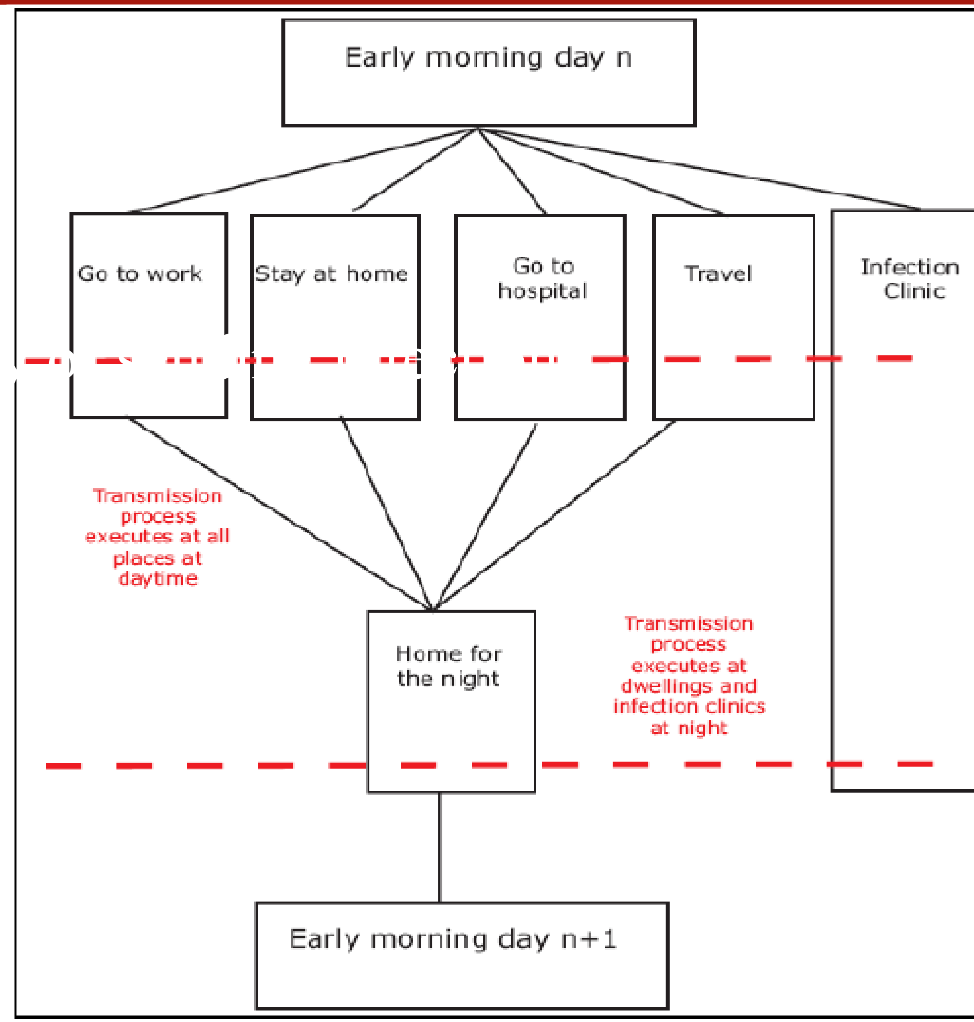
H1N1 - MicroSim

Disease transmission is performed twice daily at 9 am and 5 pm. Programme checks where are all persons during that day hours and night hours.

We have for exmaple profiles of probability of sending infections



Profile of probability (sending H1N1) [adopted F. Carrat]



The daily routines for the simulated persons. [L. Brouwers]

H1N1 - Realization

The outbreak of pandemic influenza in Sweden starts depend of method in June or in September. R_0 -value corresponding approximately to 1.4 in main model, because that was observed in New Zealand during their outbreak. The viral infectivity is markedly initially R_0 value of approximately 2.1 in preliminary method.

$$R_0 = \frac{-\ln\left(\frac{A}{S_0}\right)}{1 - \frac{A}{S_0}}$$

Immunity was calibrated in model to obtain R_0- 1.4

S_0: Total number of susceptible individuals before the outbreak

A: Total number of susceptible individuals after the outbreak

This formula is defined as is the average number of individuals a typical person infects under his/her full infectious period, in a fully susceptible population.

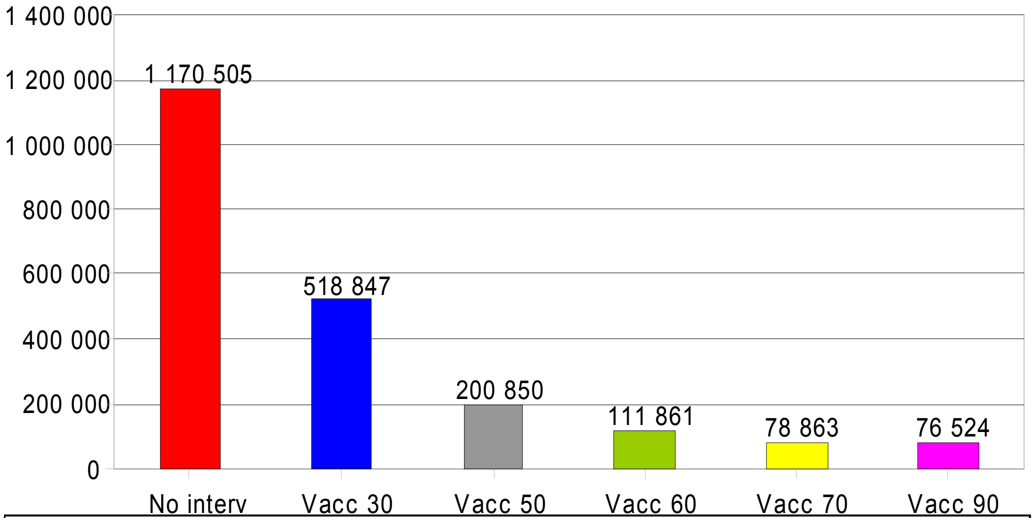
H1N1 - Cost & Vaccination

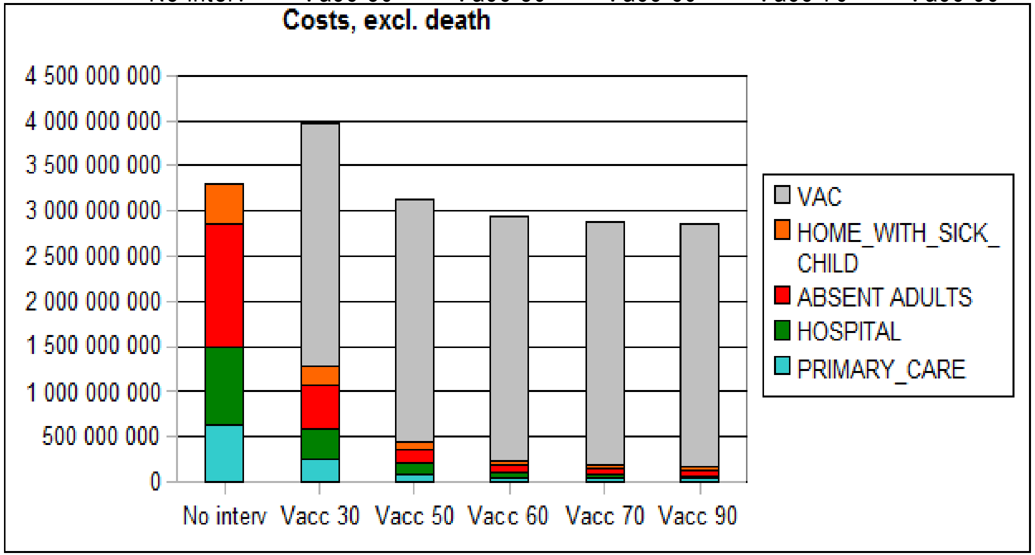
To compare the societal costs of the scenarios, the following costs—obtained from health economists at the Swedish Institute for Infectious Disease Control —were used.

- Cost of one day's absence from work, for a worker: SEK 900.
- Cost of treatment by a doctor in primary care: SEK 2000.
- Cost of one day's inpatient care: SEK 8000.
- Cost of vaccine and administration of vaccination for one person: SEK 300.

The following scenarios were compared: no response, the vaccination coverage of 30%, 50%, 60%, 70% or 90% in simulation.

H1N1 - Results





No. of infections (upper graph) and cost of pandemia (lower graph) for different scenarios [by L. Brouwers].

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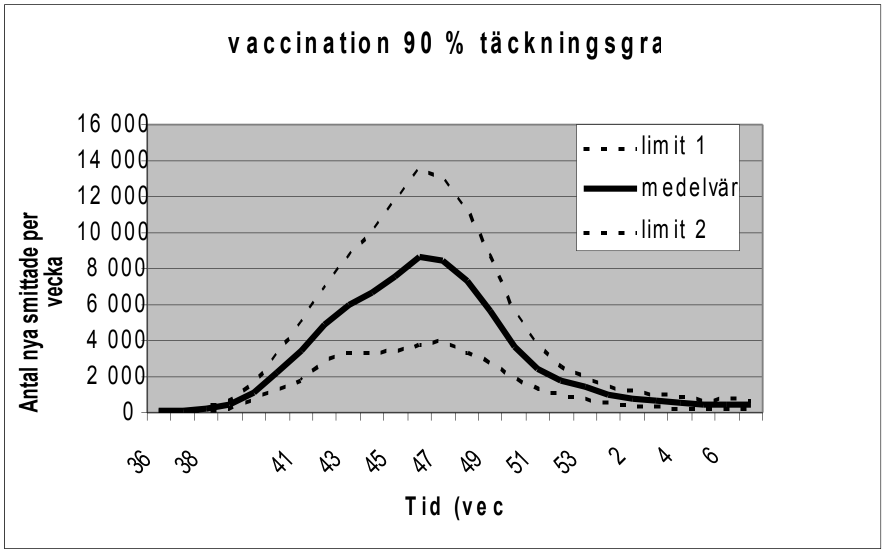
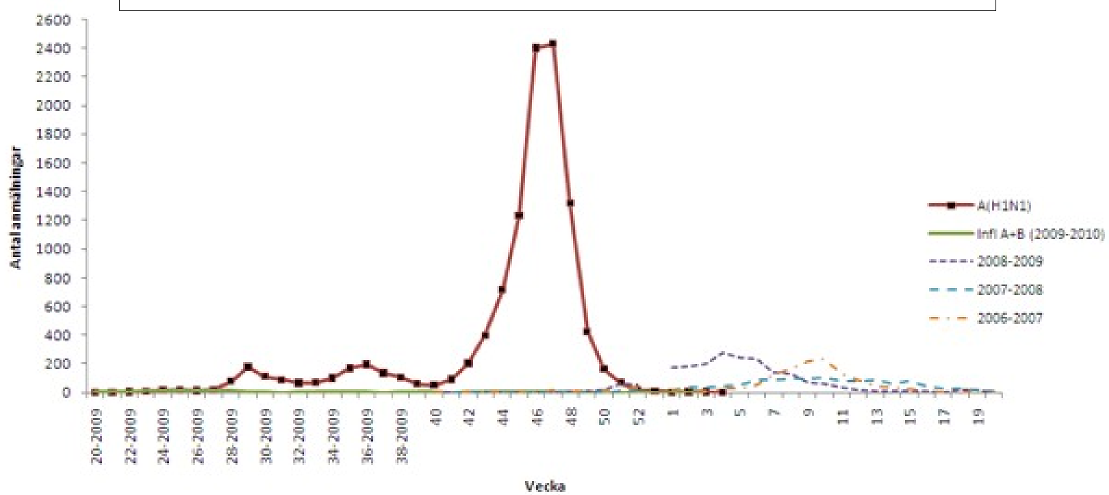
H1N1 - Simulation & Reality





No. of infections per week in simulation (upper graph by L. Brouwers) and cases collected by The Swedish Institute for Infectious Disease Control (lower graph by SMI).

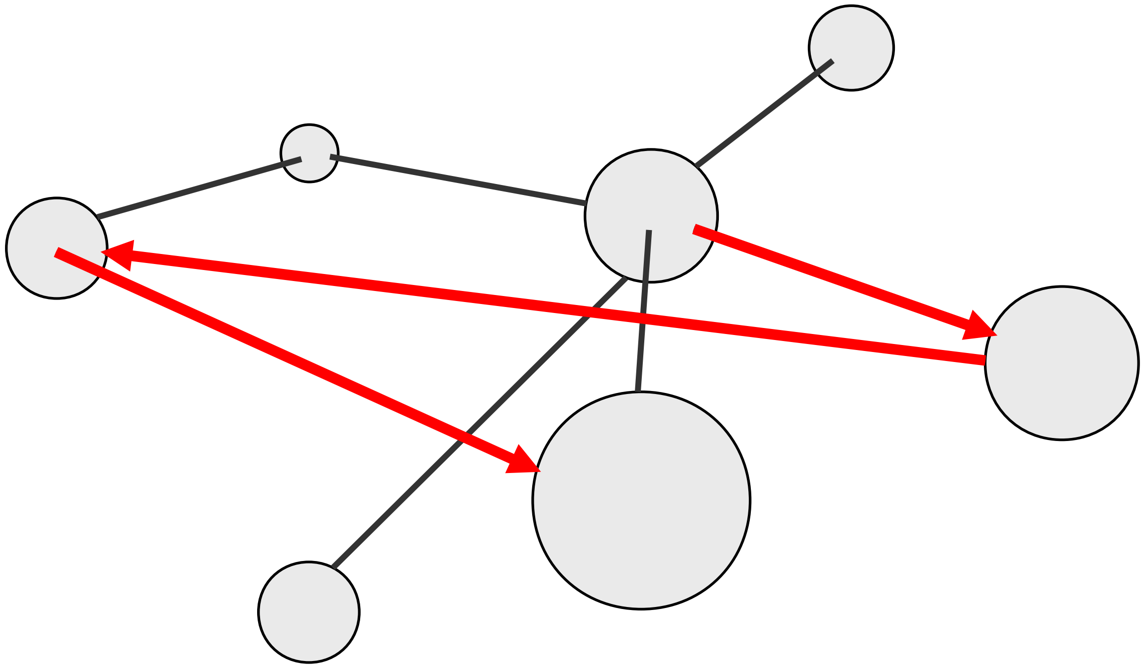
Network Theory - introduction

An agent/object's actions are affected
by the actions of others around it.

NETWORK

Actions, choices, etc. are not made in isolation
i.e. they are contingent on others' actions, choices, etc.

Network Theory - terminology

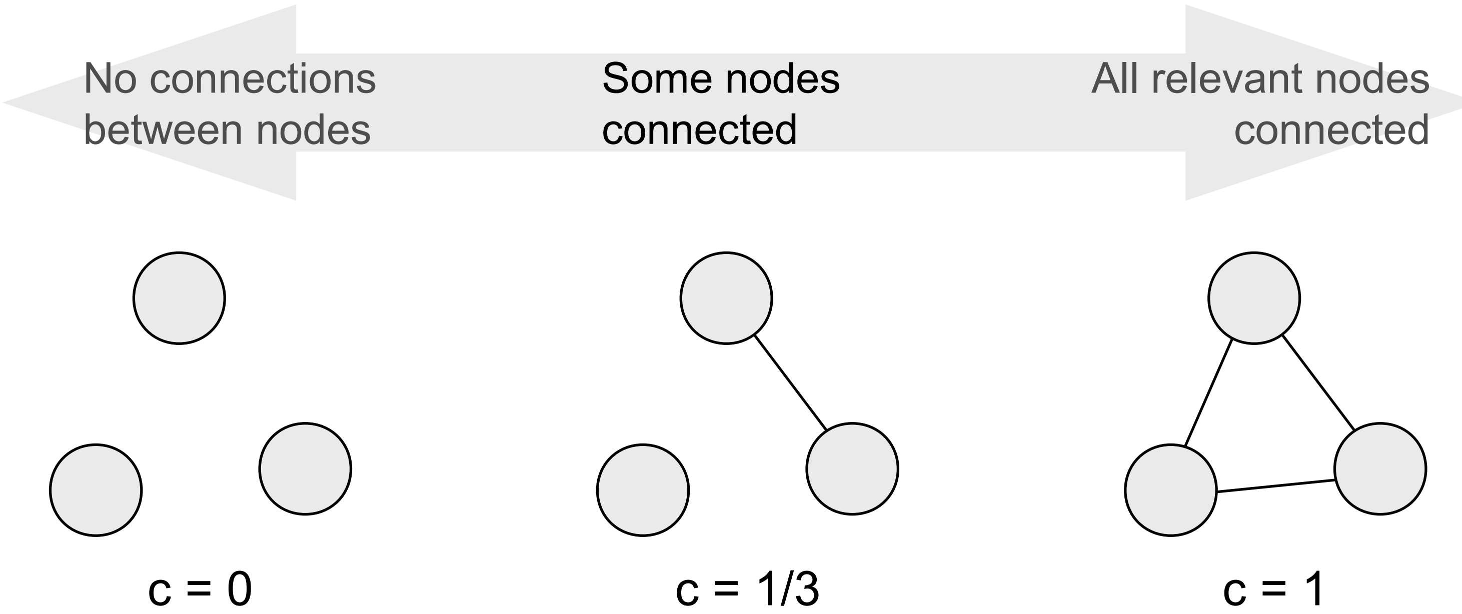


Node = individual components of a network e.g. people, power stations, neurons, etc.

Edge = direct link between components (referred to social networking as a relationship between two people)

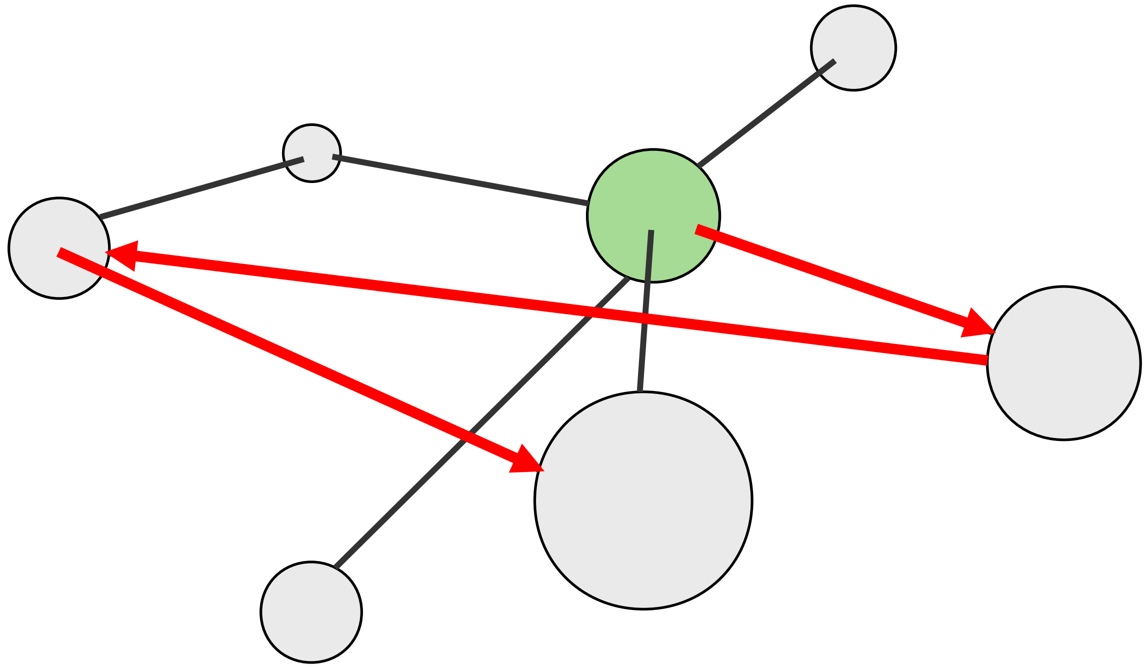
Path = route taken across components to connect two nodes

Network Theory - clusters



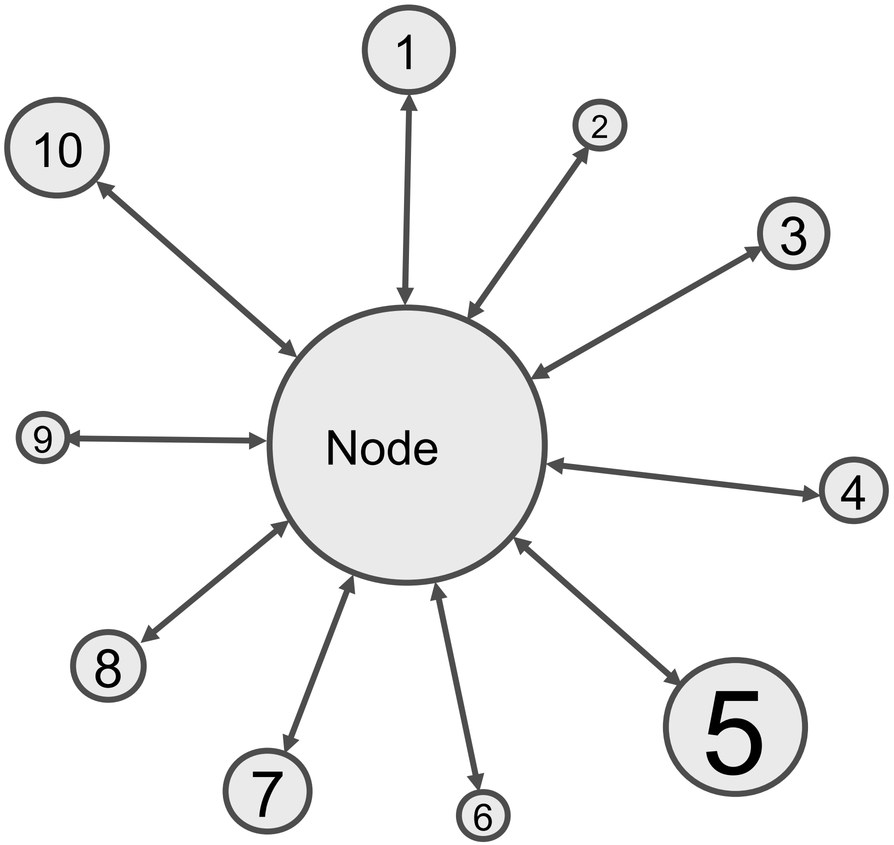
Clustering coefficient counts numer of triangles in networks

Network Theory - paths



Average path length

Network Theory - node's degree

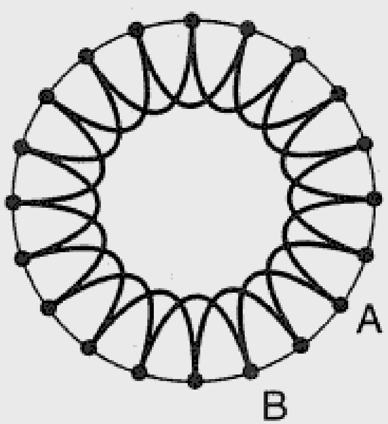


Degree distribution

Network Theory - randomness

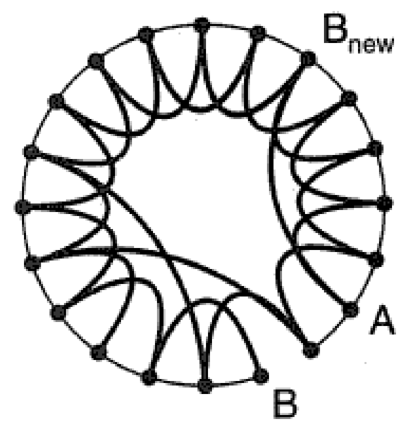
1. Grid/lattice network

(structure, order)



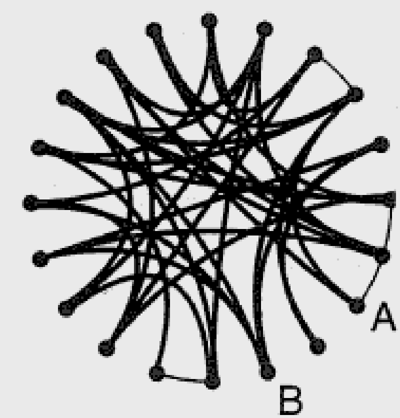
2. Small-world network

(a mix of order and randomness)



3. Random network

(randomness)



β=0 << Level of randomness of links >> β=1

Randomness

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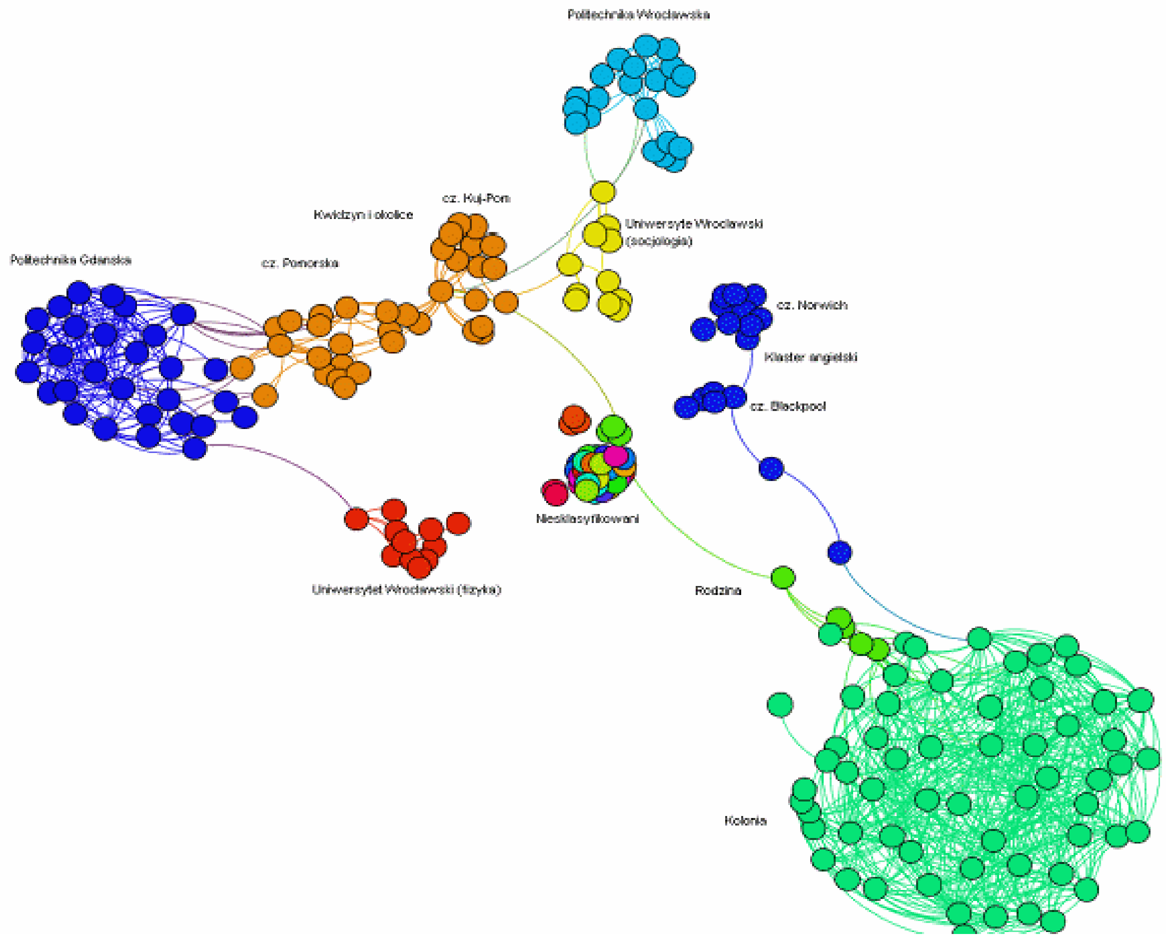
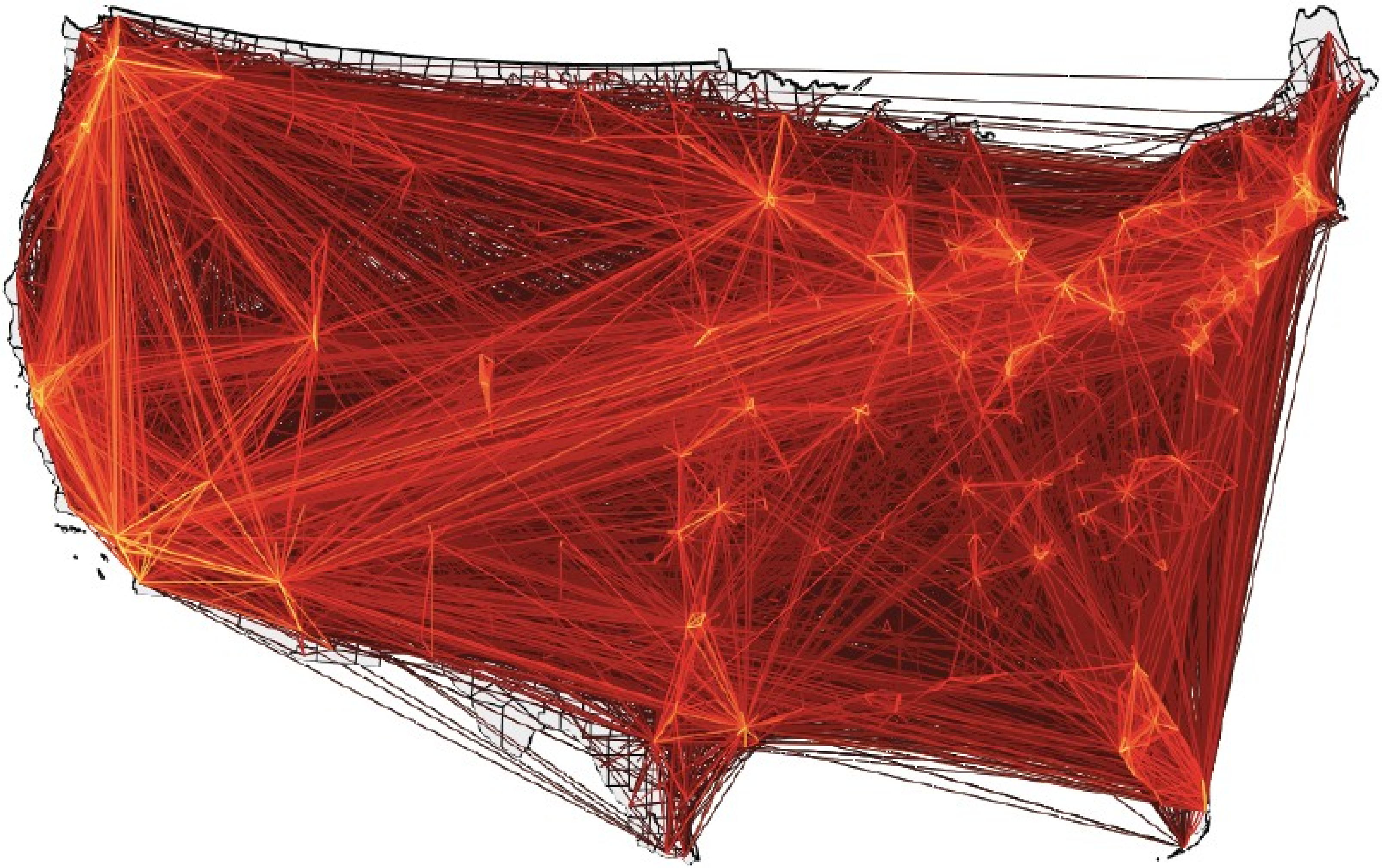
Network Theory - communities



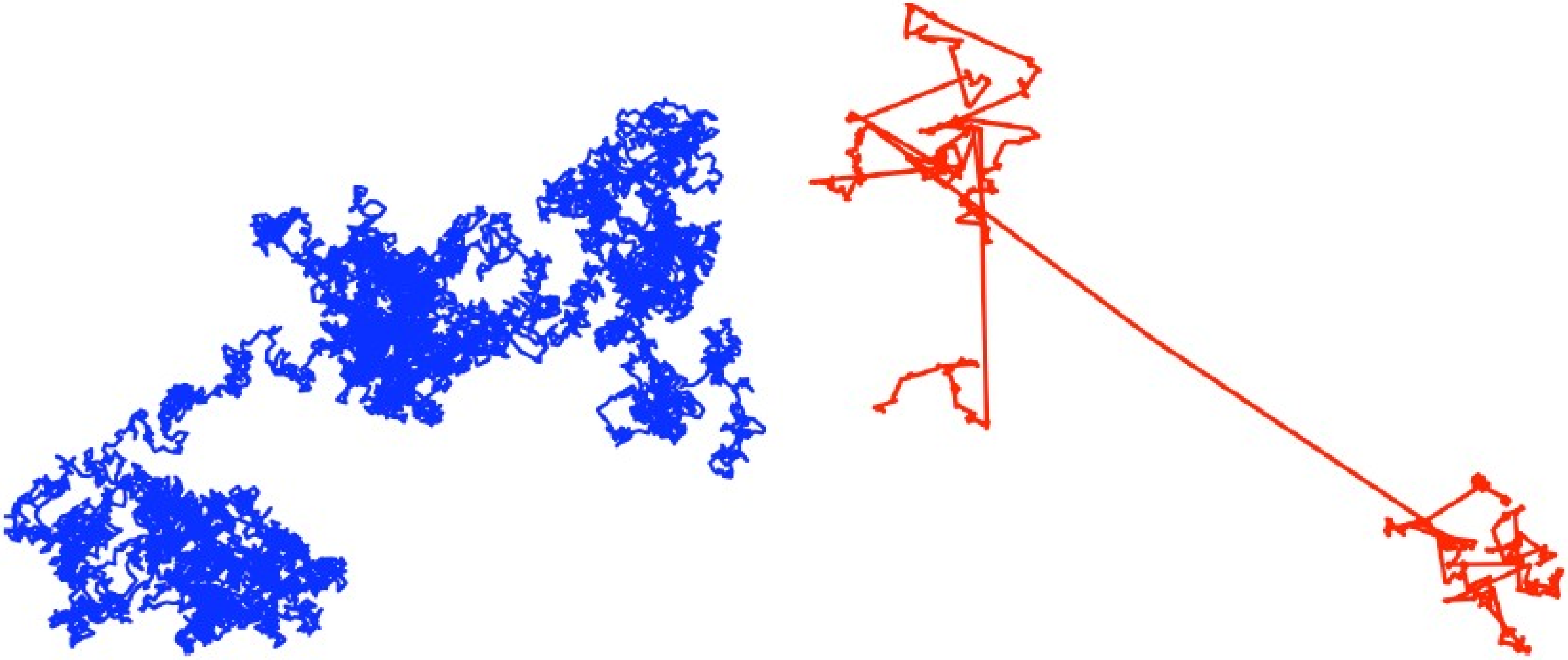
Communities detection

Where's George

Where's George

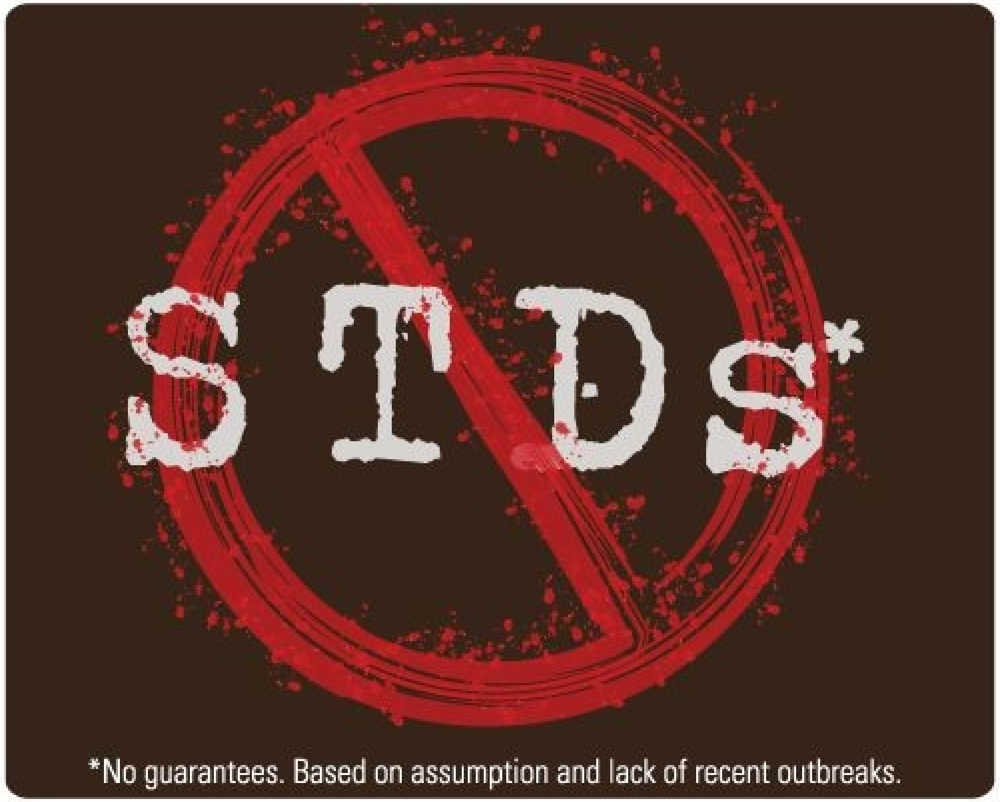


Where's George



2 scales of movements

Sexually transmitted infections (STI)



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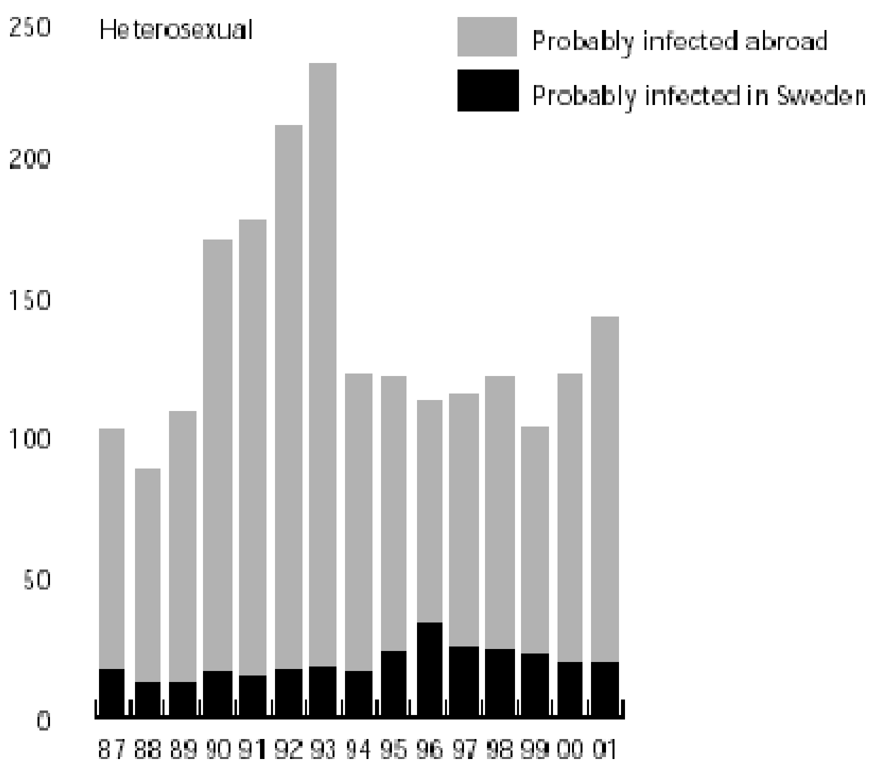
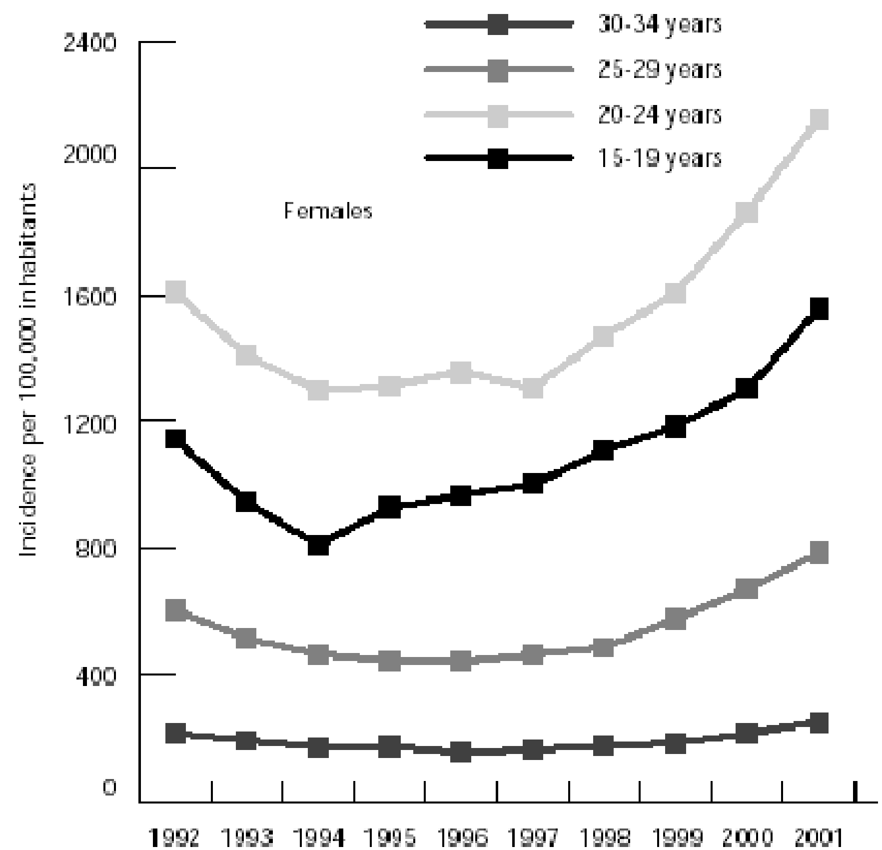
STI - problem

Probability of transmission per contact (β)

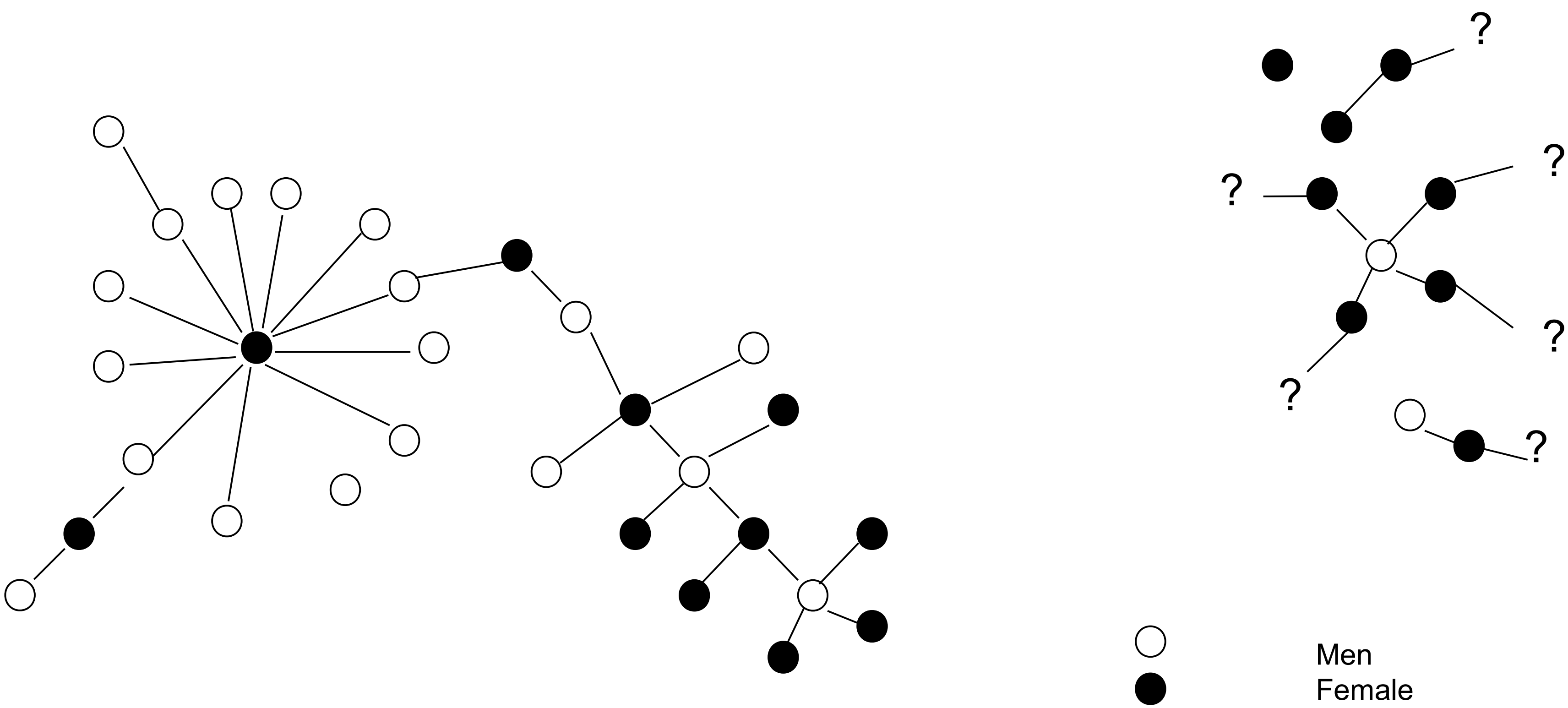
HIV 0,08-1,7%



Chlamydia 2-60%



STI - networks



Liljeros, 2004

STI - data

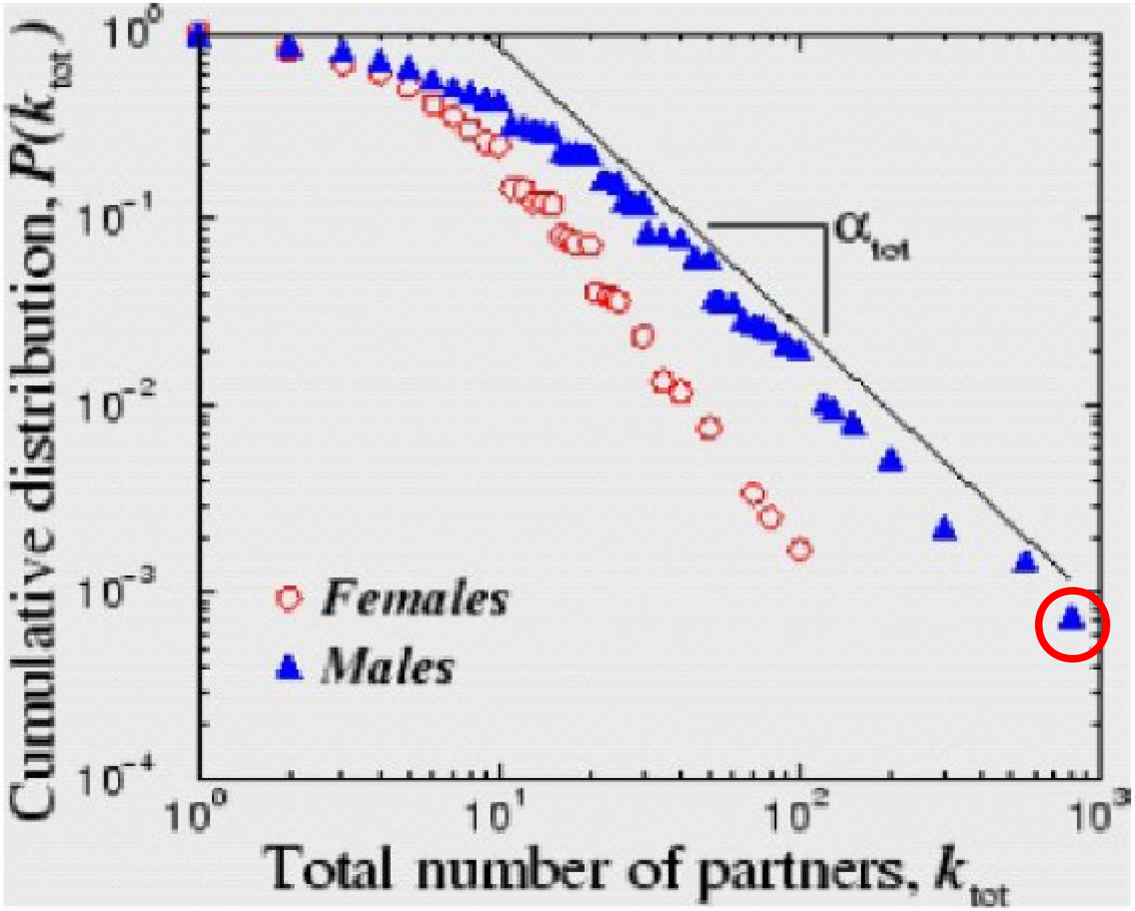
- **Difficulties with access**
- **Sensitivity informations**
- **Bioethical comities**

STI - data

- Difficulties with access
- Sensitivity informations
- Bioethical comities

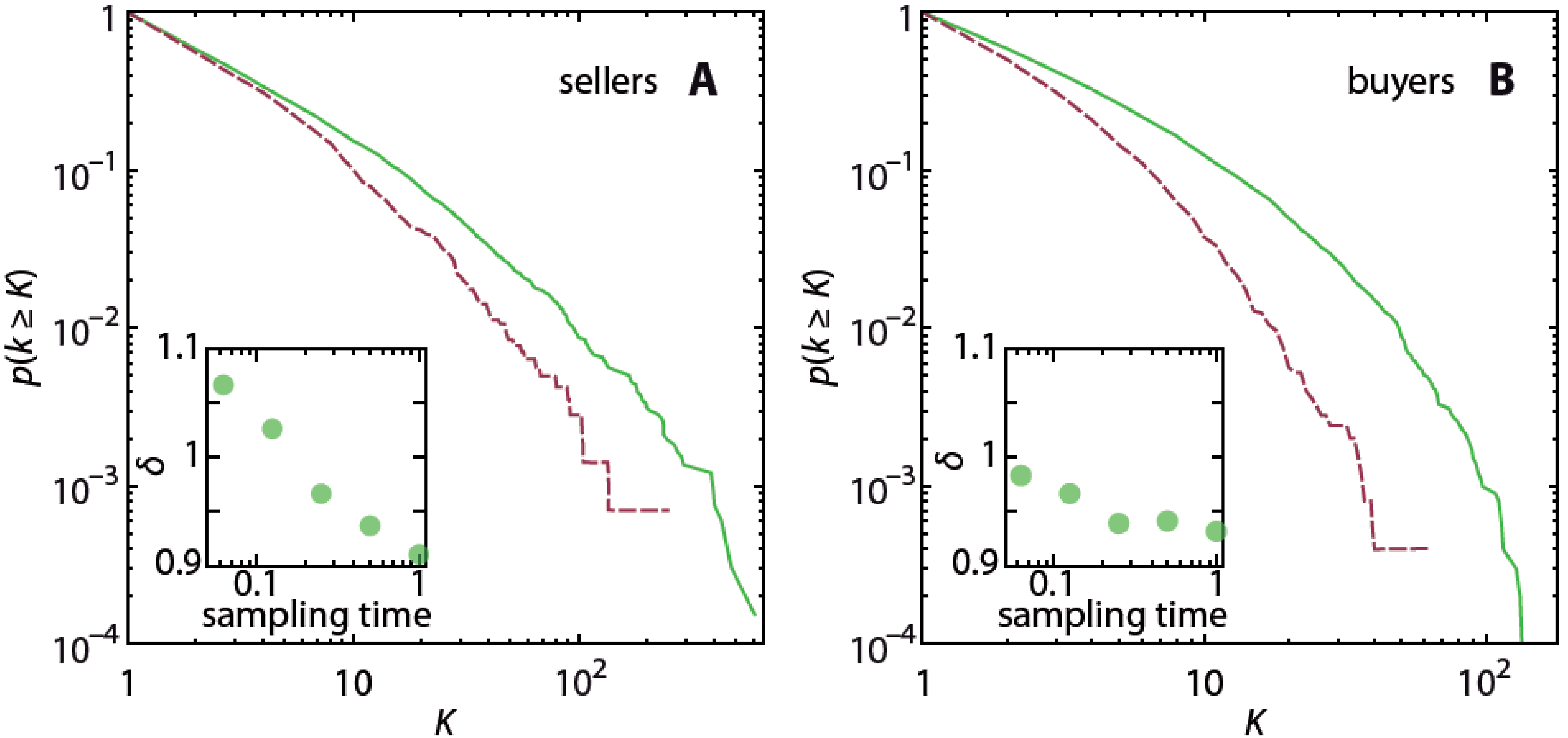
- sexuality of Gots
- prostitution in Brazil

STI - data (Gothland)



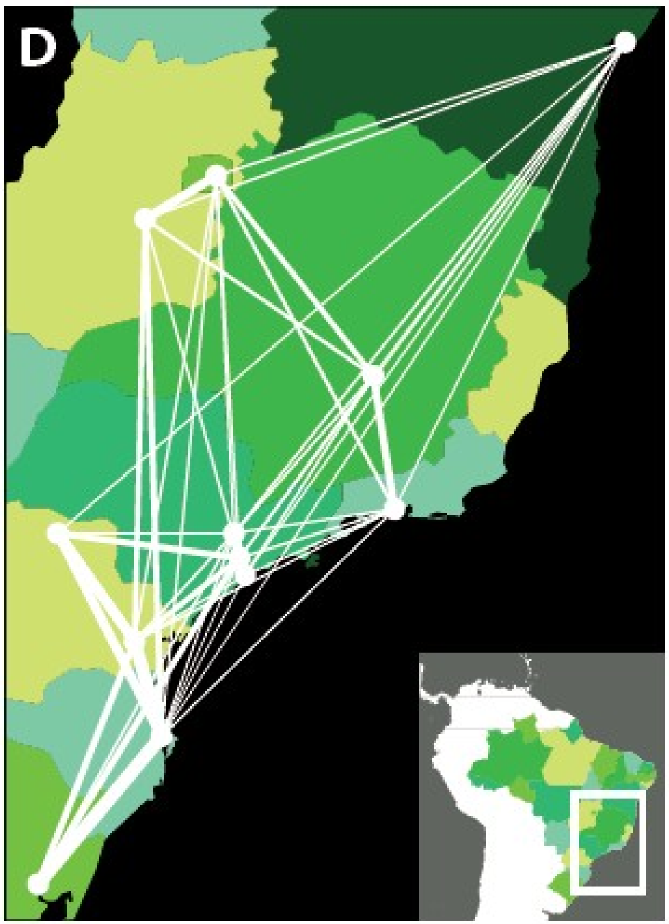
Liljeros, 2001 (Nature)

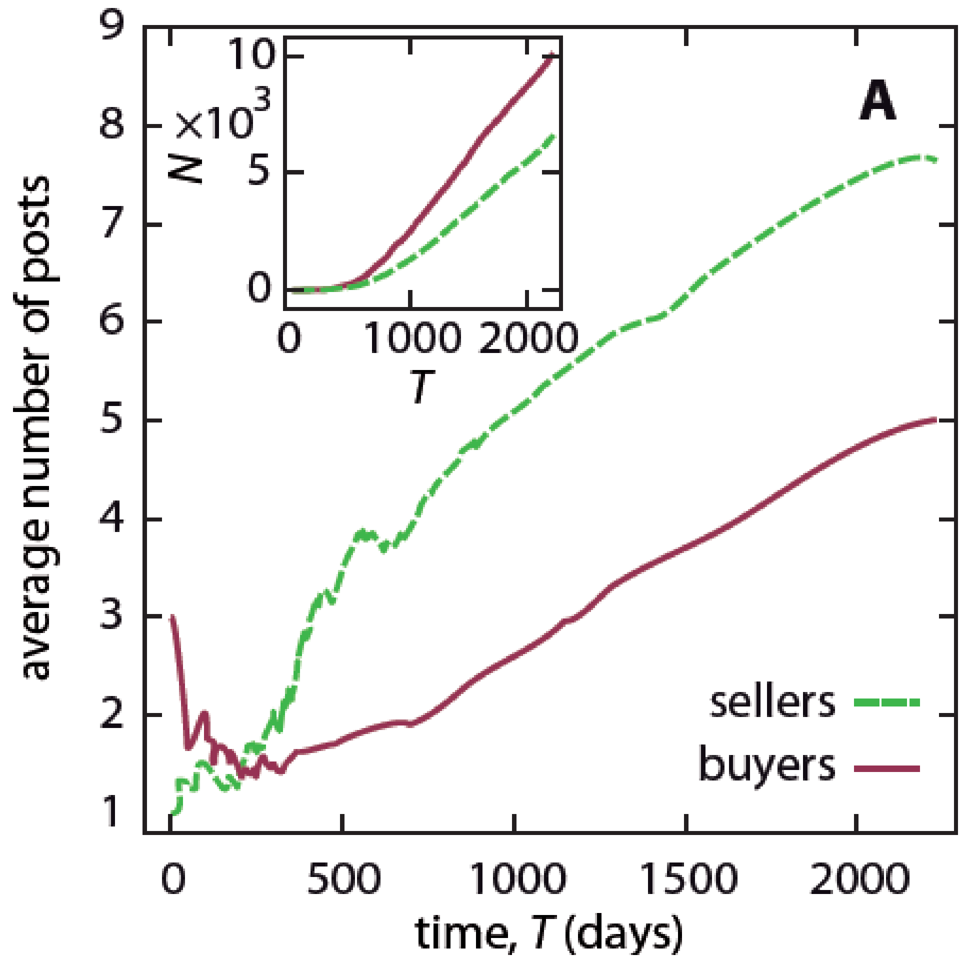
STI - data (Brazil)



Liljeros, 2010 (PNAS)

STI - data (Brazil)

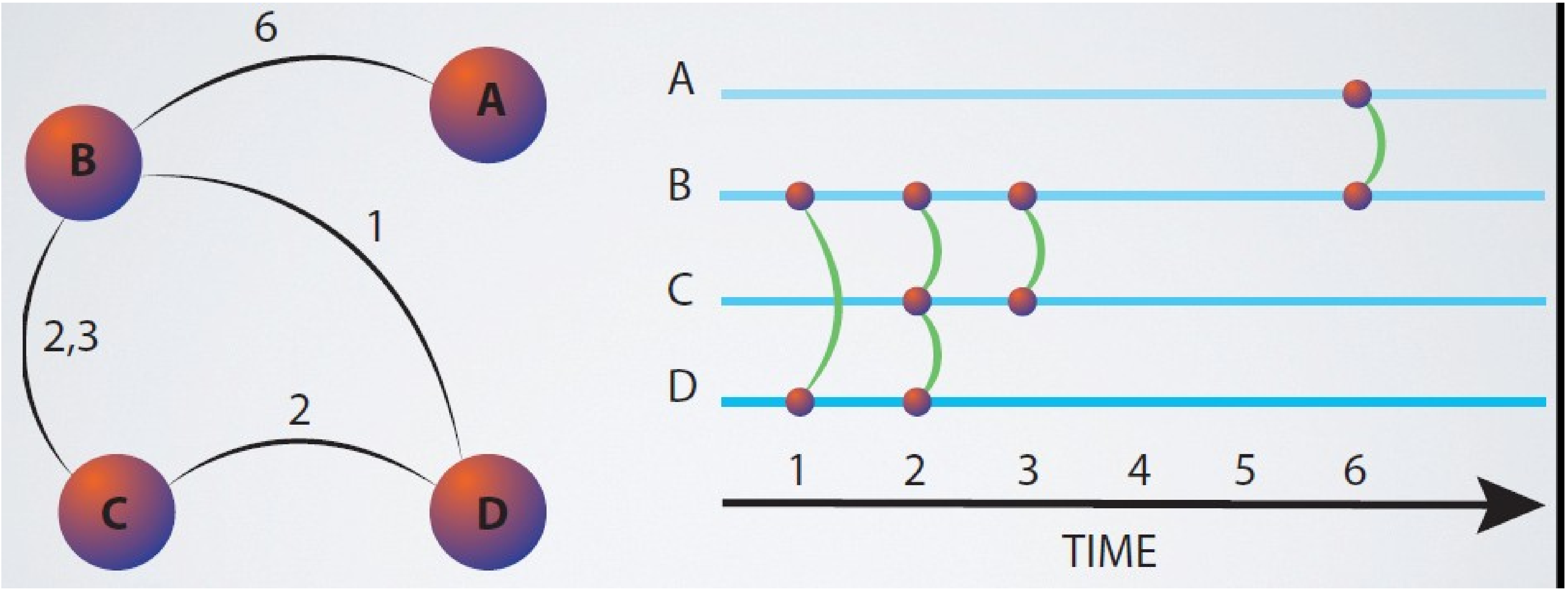




Liljeros, 2010 (PNAS)

STI - model

Time and intensity of contacts does matter



Rocha, 2011

STI - future…

Research in plans