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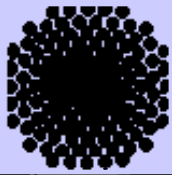
**School and Workshop on
Structure and Function of Complex Networks**

16 - 28 May 2005

Model of Mobile Agents for Contact Networks

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These are preliminary lecture notes, intended only for distribution to participants



Model of mobile agents for contact networks

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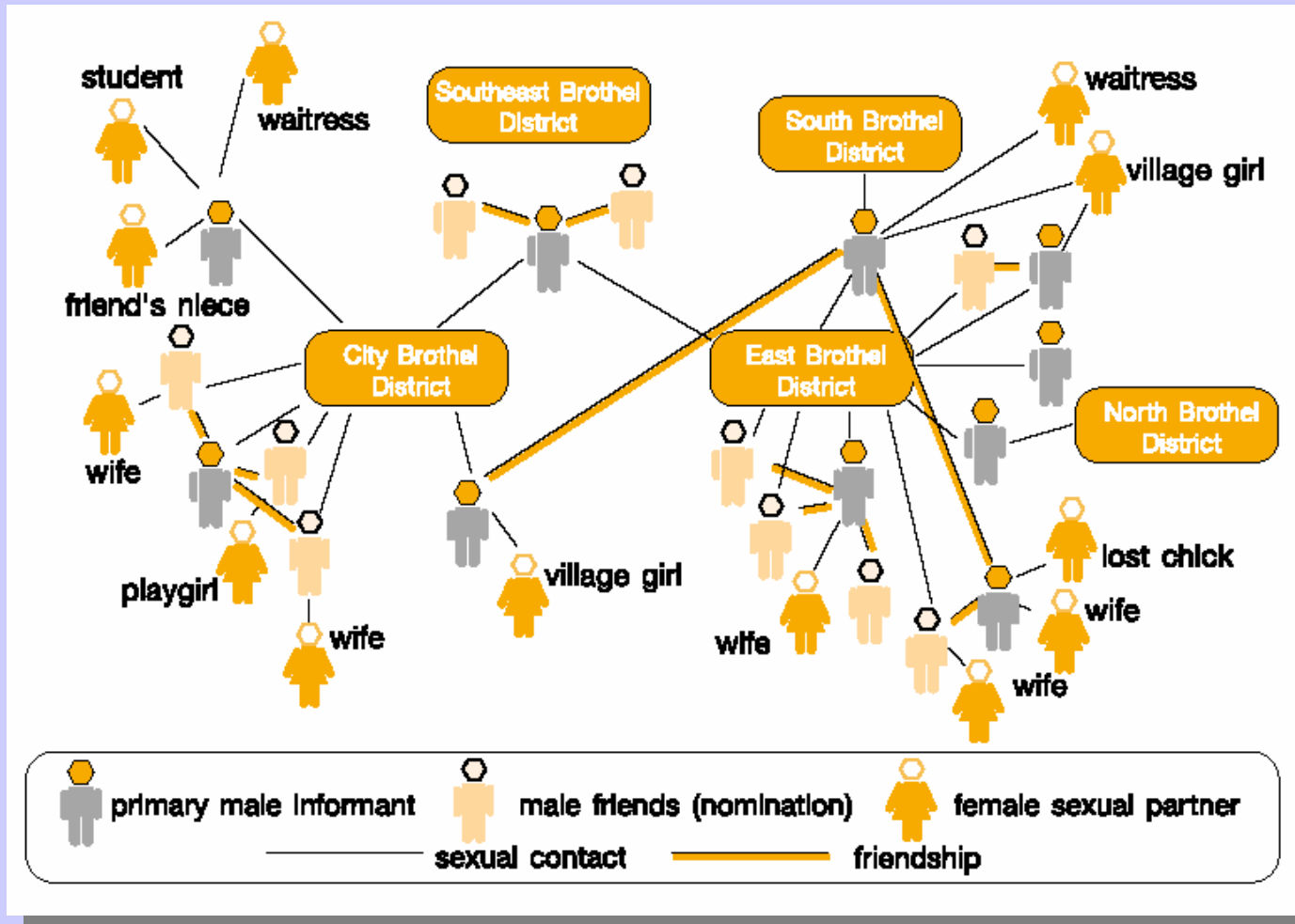


Social Networks



Contact networks of mobile agents

Social and Sexual Network of Young Northern Thai Men



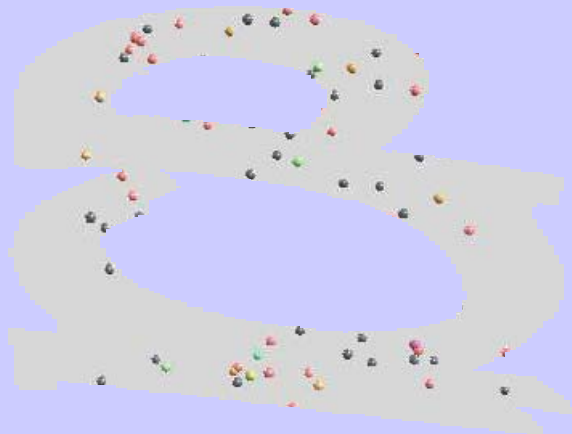
Source: Catherine C. Bond, "Building Connections".
PATH: Program for Appropriate Technology in Health



The Model

KCP

Contact networks of mobile agents



RGB scale for number of

partners



● Non-connected

Parameters of the ED simulation

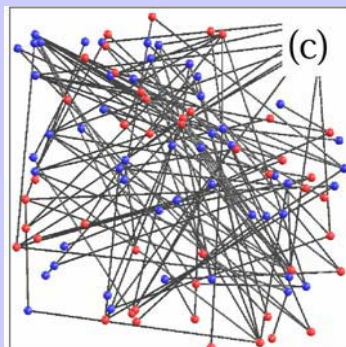
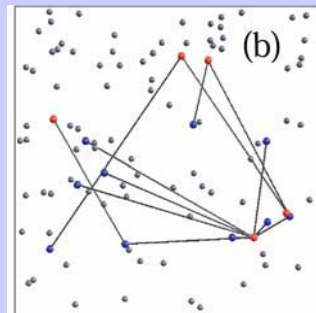
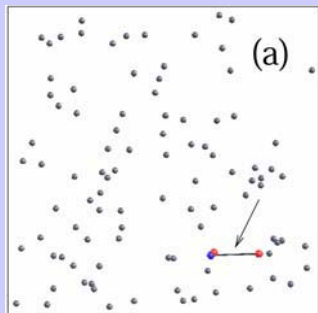
$$r=1 \quad \rho = N / L^2 \ll 1$$

Initial Conditions

$$\left| \vec{v}_0 \right| = 1 \quad N_{ntw} = 1$$

Collision rule for "sexual interactions"

$$\vec{v}(k_i) = \left(k_i^\alpha + \left| \vec{v}_0(i) \right| \right) \vec{\omega}$$



(ii) Between two connected agents with probability $(1-S)$

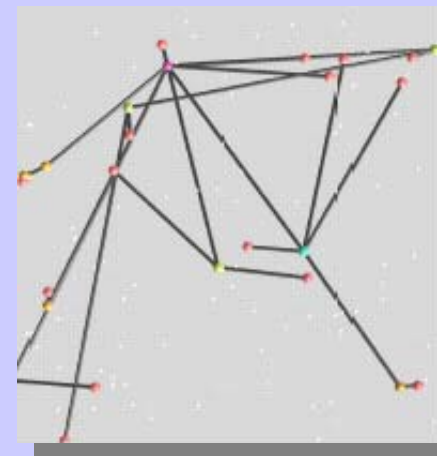
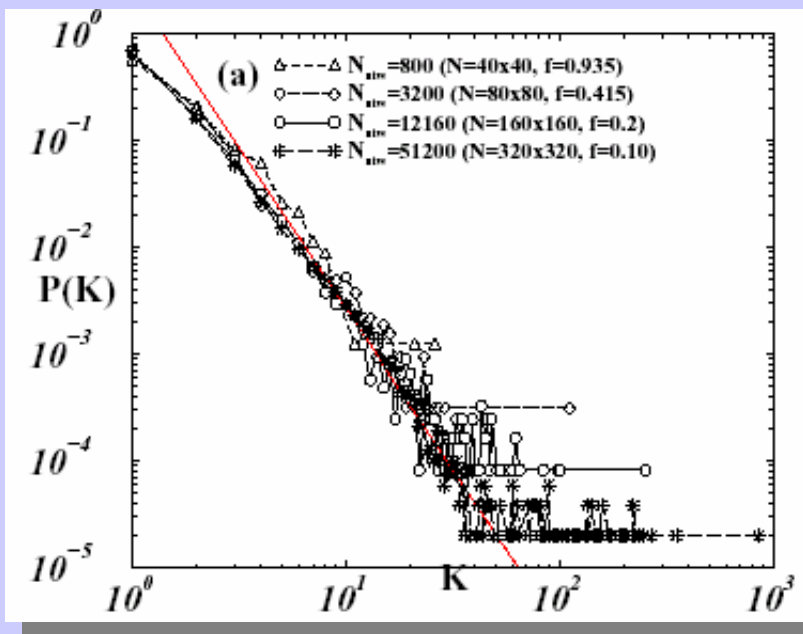
S is called "Selectivity"

$S=1$, only type (i) collisions are allowed



Velocity update rule

Contact networks of mobile agents

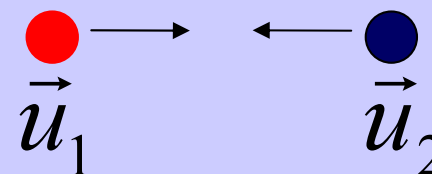


$$\vec{v}_1 = \alpha \vec{u}_1 + \beta \vec{u}_2$$

$$p = -(1 + f)$$

$$q = f \quad f \ll 1$$

$$\vec{v}(k_i) = \left(k_i^\alpha + \left| \vec{v}_0(i) \right| \right) \vec{\omega}$$

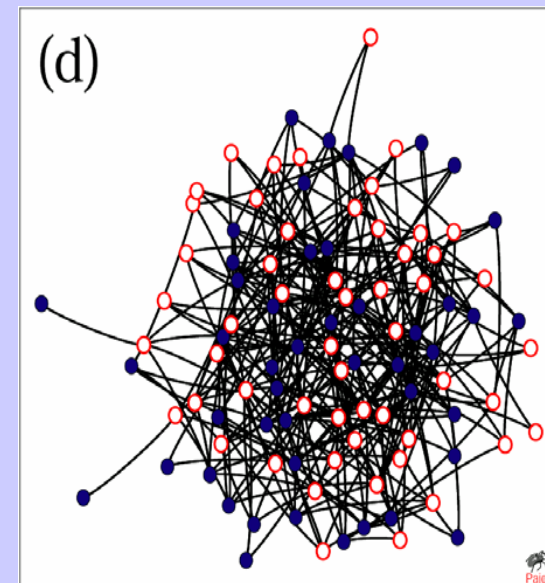
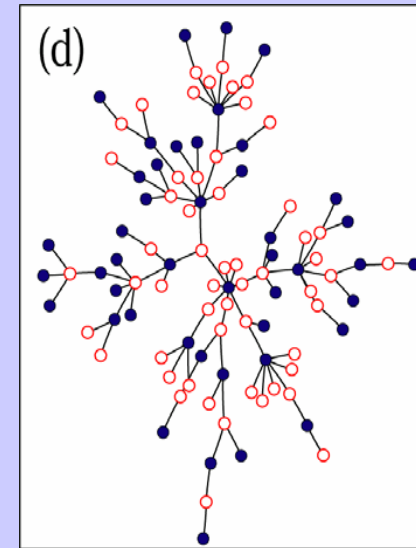
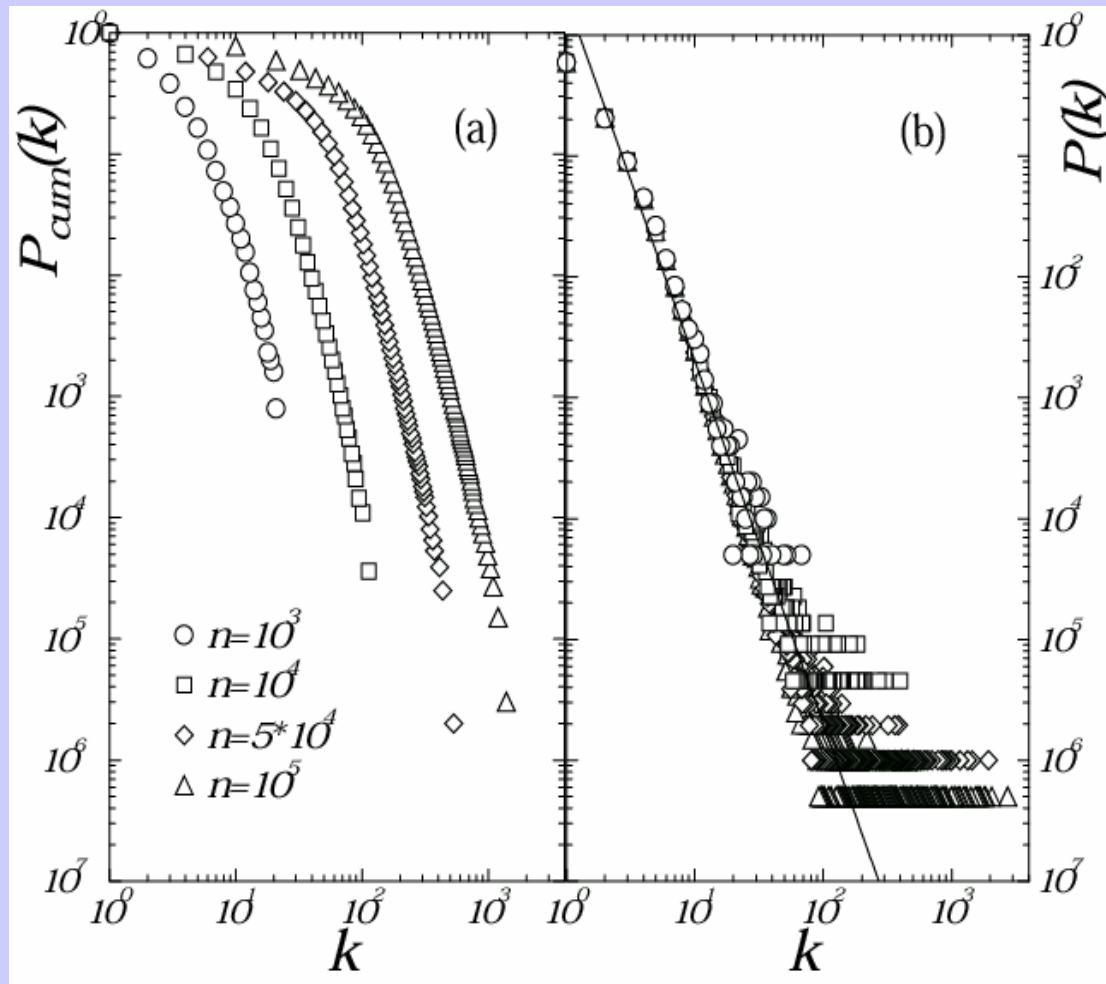




Results

KCP

Contact networks of mobile agents

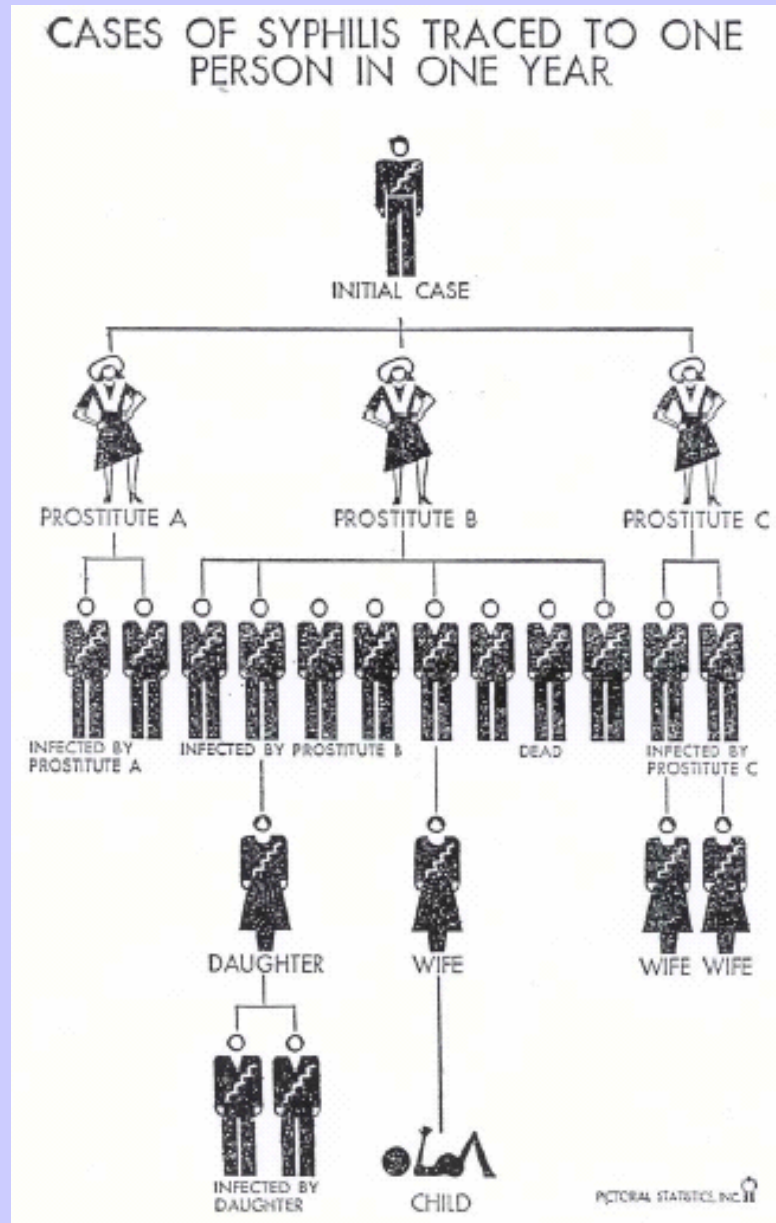


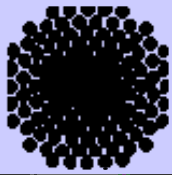


Sexually Transmitted Diseases

I^{CP}

Contact networks of mobile agents



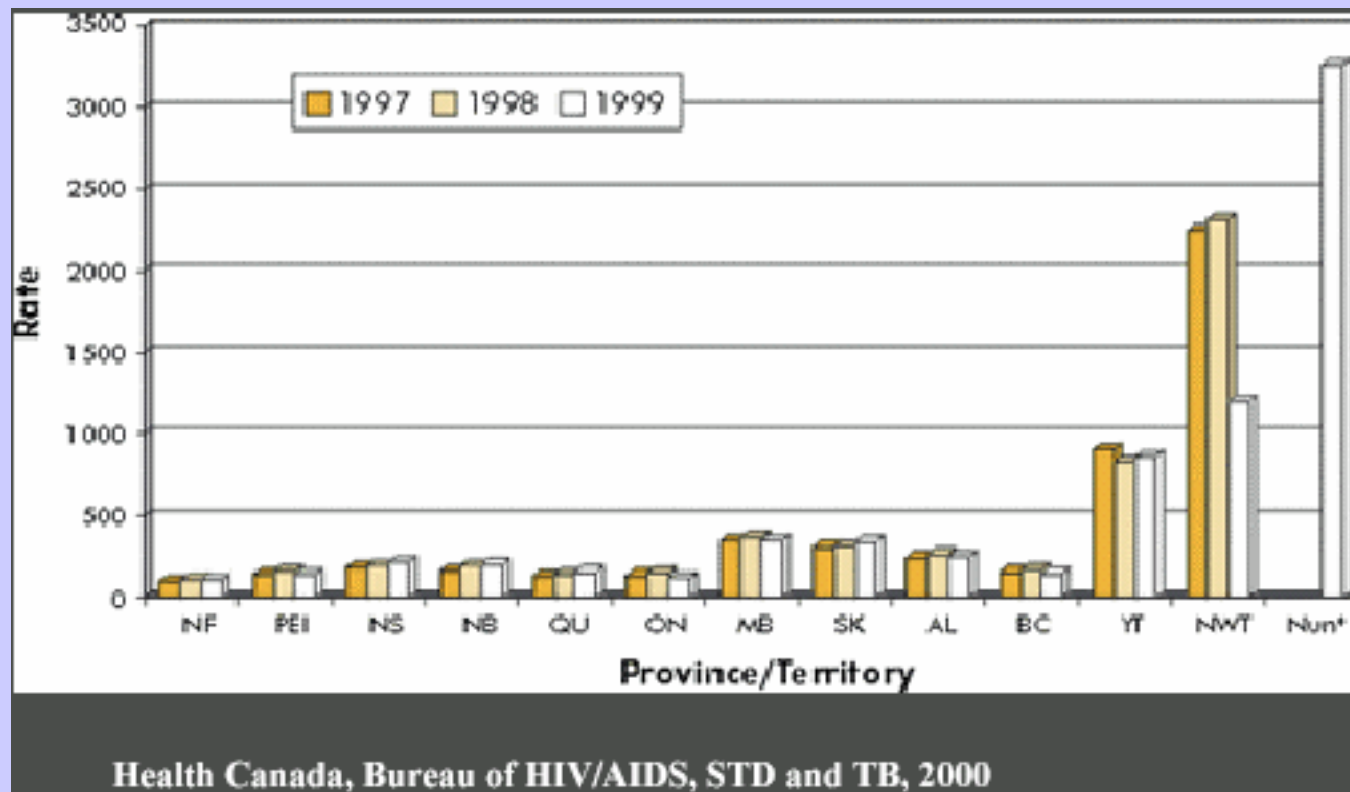


Sexually

KCP

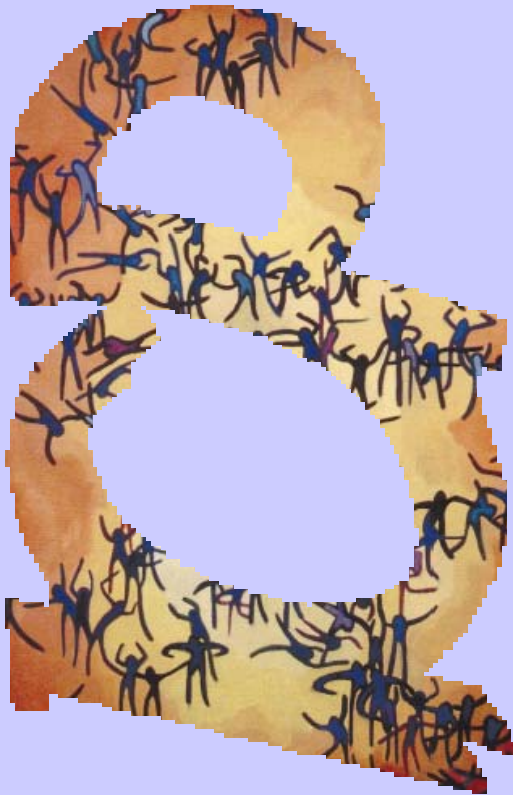
Contact networks of mobile agents

Reported Female Genital Chlamydia Rates per 100,000 in Canada by Province/Territory, 1997 to 1999

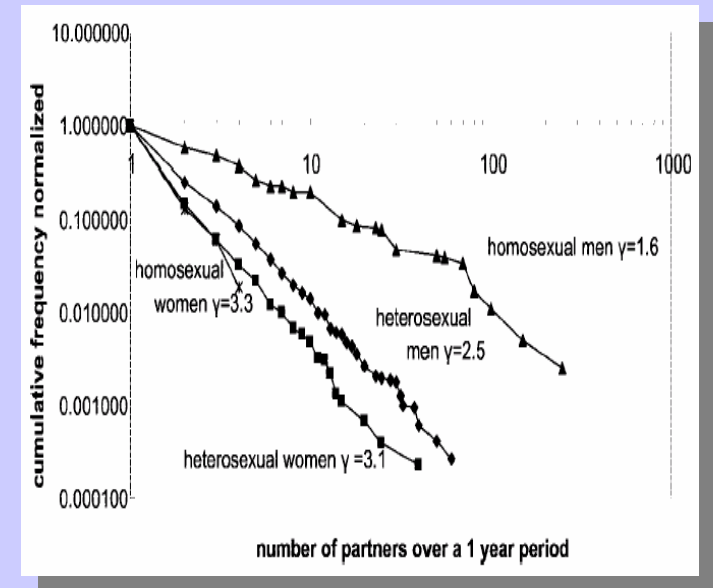
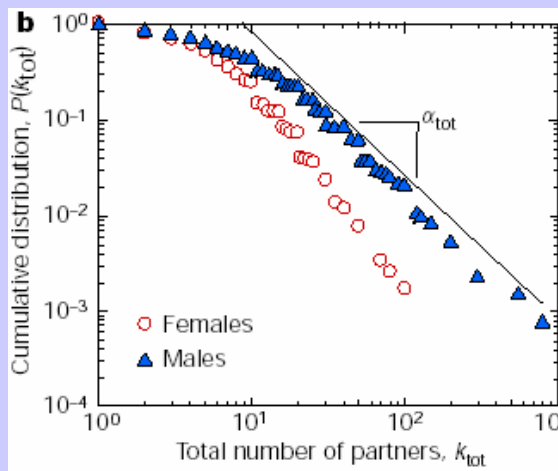
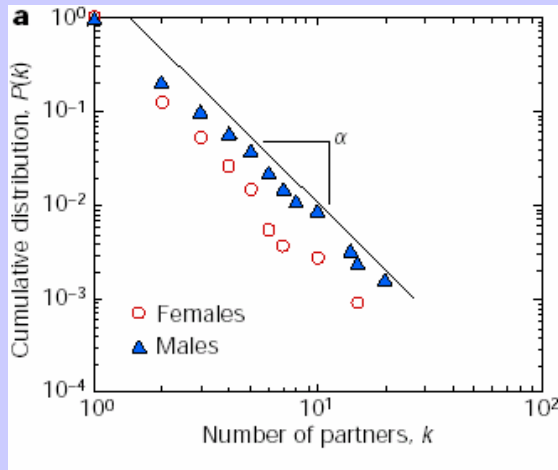


"The Web of Human Sexual Contacts"

F. Liljeros, C. R. Edling, L. A. N. Amaral, **H. E Stanley**, and Y. Aberg, *Nature* 411, 907-908 (2001).



Painting by Idahlia Stanley



A.SCHNEEBERGER, et. al. *Sex. Trans. Dis.*, Vol. 31, No. 6, p.380–387 (2004)

Contact Tracing



Patterns of Chlamydia and Gonorrhoea Infection in Sexual Networks in Manitoba, Canada

Contact networks of mobile agents

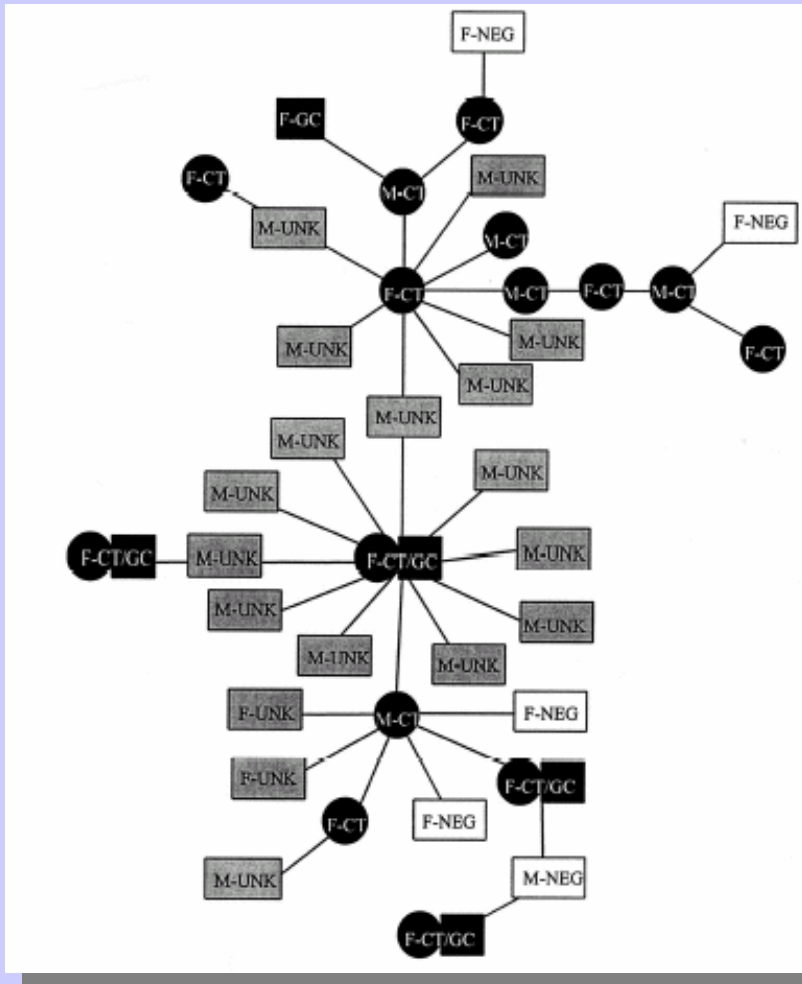


TABLE 1. Summary of the Number of Components of Size n Identified Within the Manitoba Sexual Network*

No. of individuals	No. of components	No. of individuals	No. of components
2	911	12	1
3	366	13	2
4	116	14	6
5	39	16	1
6	20	17	1
7	15	18	1
8	8	19	1
9	5	39	1
10	2	41	1
11	5	82	1

*Number of cases and contacts in database was 4544; 1503 components with 2 or more people were identified.

4544 Persons (Males:Females 1.27)
1503 components (clusters)

Legend

F: females M:males

■ ● Positive results

□ Negative results

■ Unknown results

J. L.WYLIE and A.J JOLLY, *Sex. Trans. Dis.*, **28**, 14-24 (2001)



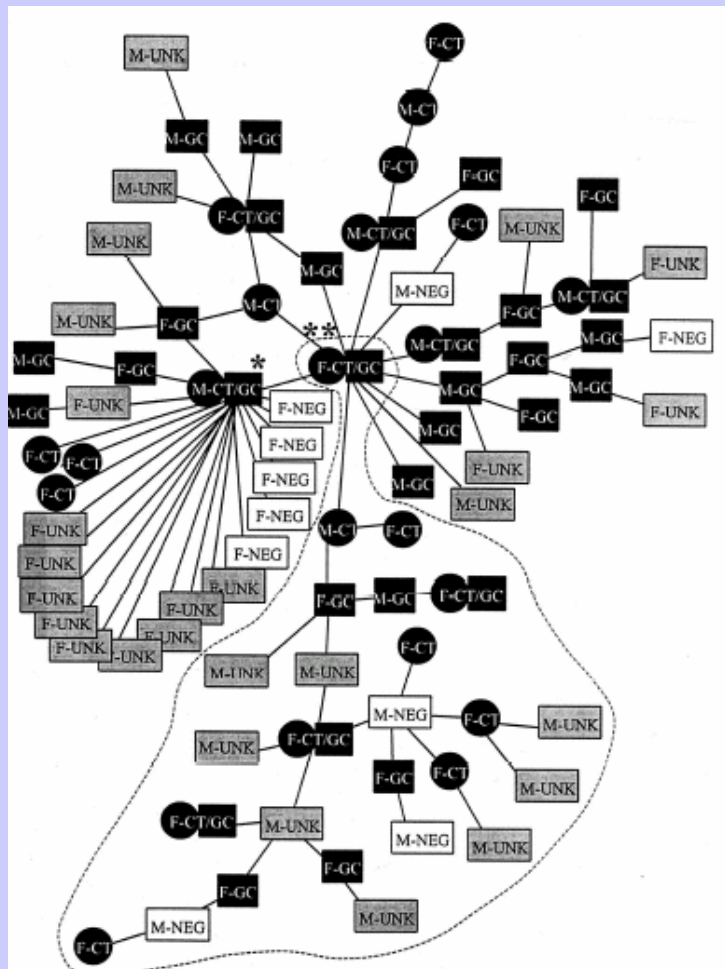
Empirical Data

KCP

Contact networks of mobile agents

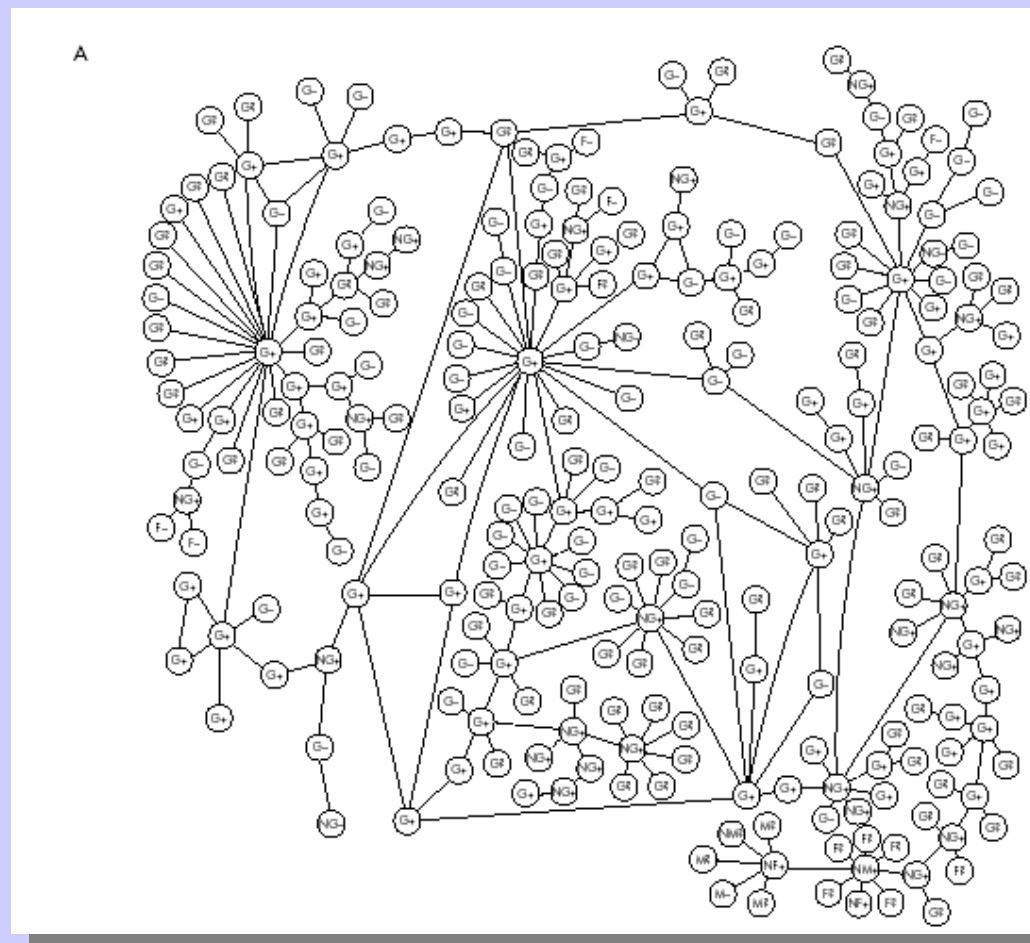
*Largest Connected Component Chlamydia
and Gonorrhea Infection in Sexual
Networks in Manitoba, Canada*

N=82



*Largest connected Component in the
early epidemic phase of HIV
transmission in Colorado Springs, USA*

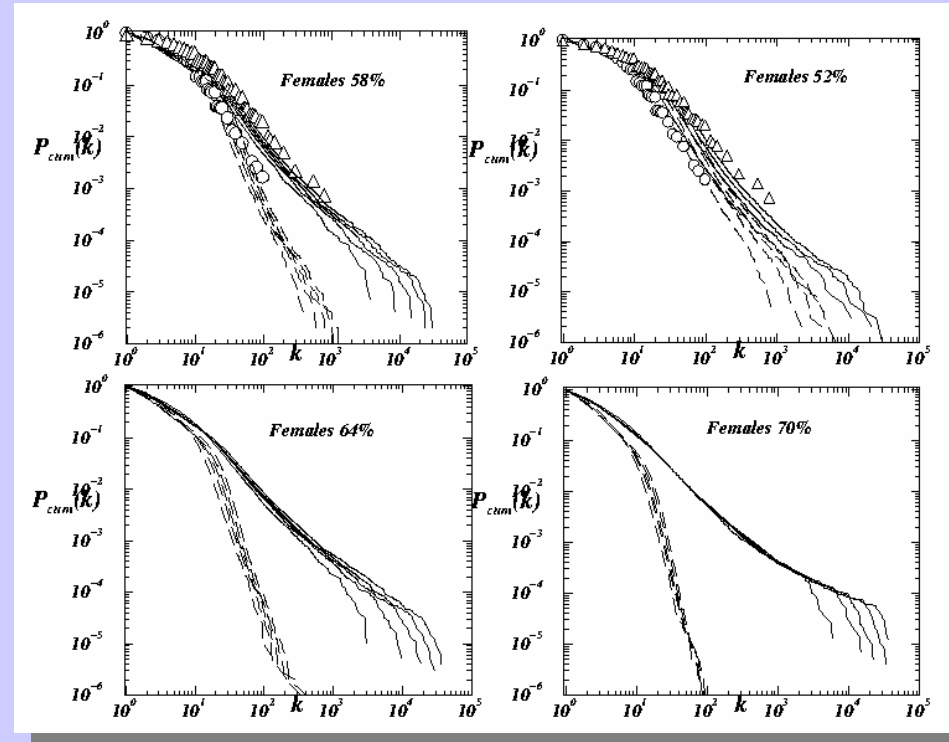
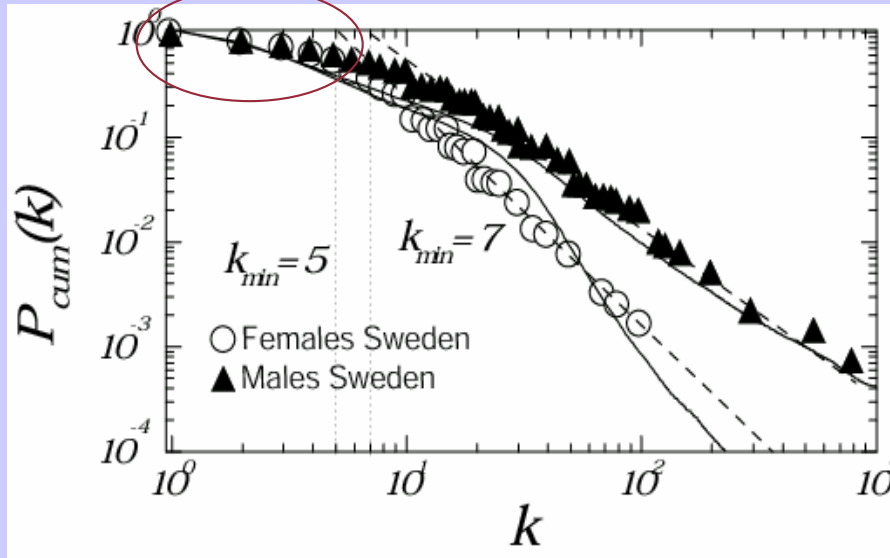
N=250



Analyzing Surveys

KCP

Contact networks of mobile agents



Discrepancy in empirical Data

$$\gamma_{mal} = 2.6 \pm 0.3$$

$$\gamma_{fem} = 3.1 \pm 0.3$$

$$\vec{v}(k_i) = \left(k_i^\alpha + \left| \vec{v}_0(i) \right| \right) \vec{\omega}$$

$$\left[\frac{\gamma_{fem} - 1}{\gamma_{fem} - 2} \right] K_{min}^{fem} = \left[\frac{\gamma_{mal} - 1}{\gamma_{mal} - 2} \right] K_{min}^{mal}$$

$$\alpha = 1.2 \quad n = 0.2N$$

Analyzing Contact Tracing

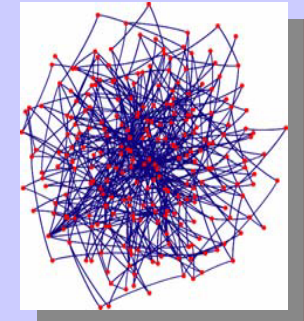
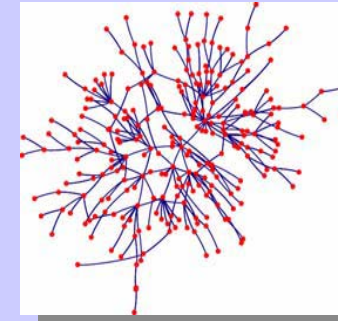
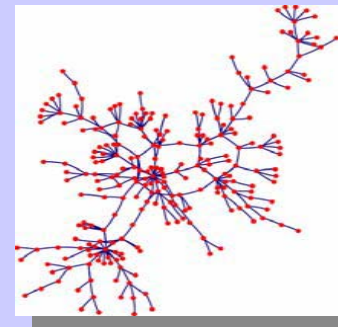
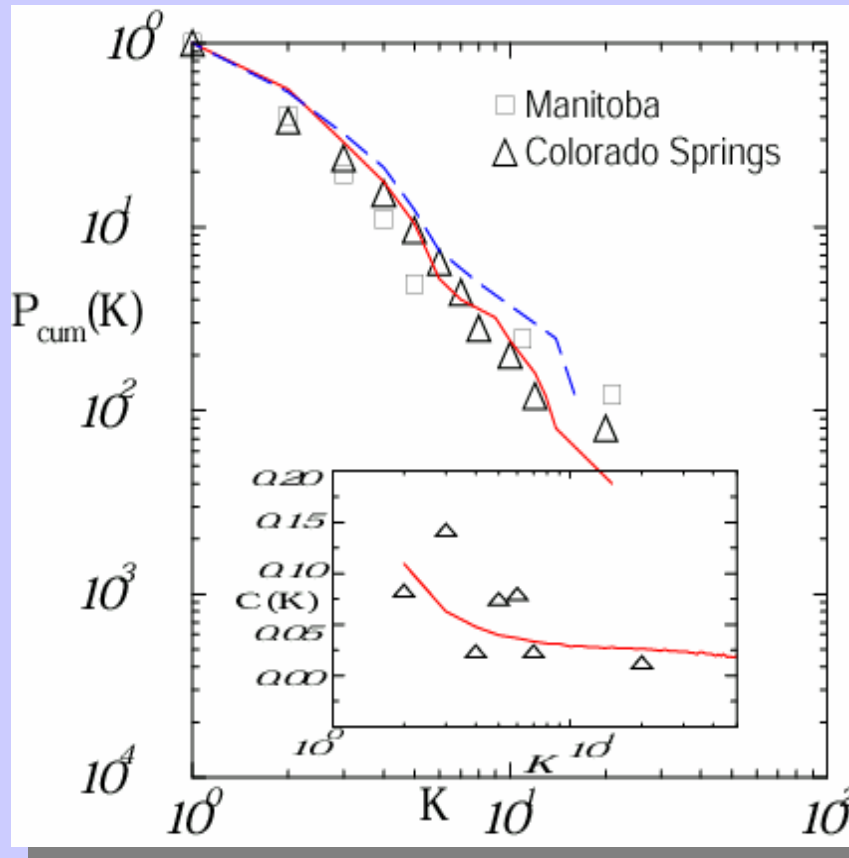
KCP

Networks

Colorado Springs

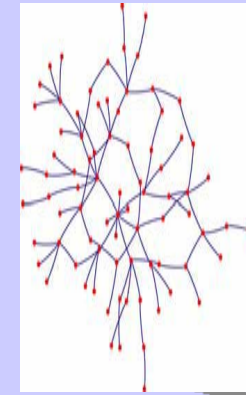
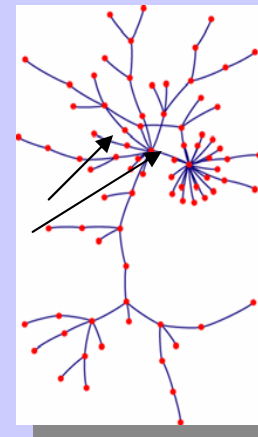
$S=0.9, \alpha=1$
 $N_{ntw}=250$

SF
 $K_{min}=2$



Manitoba

$S=0.98, \alpha=1$
 $N=81$

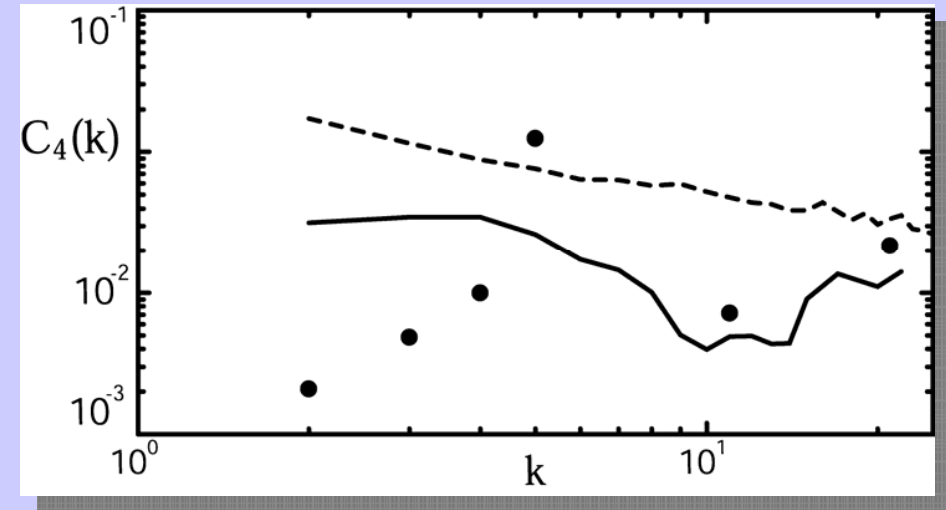
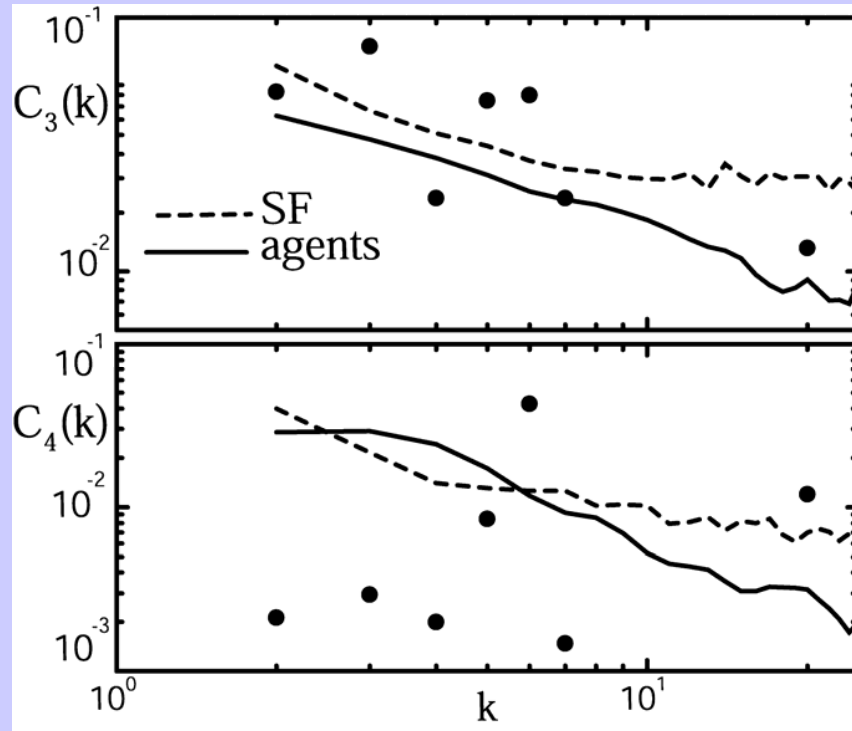


Contact networks of mobile agents

Counting Cycles

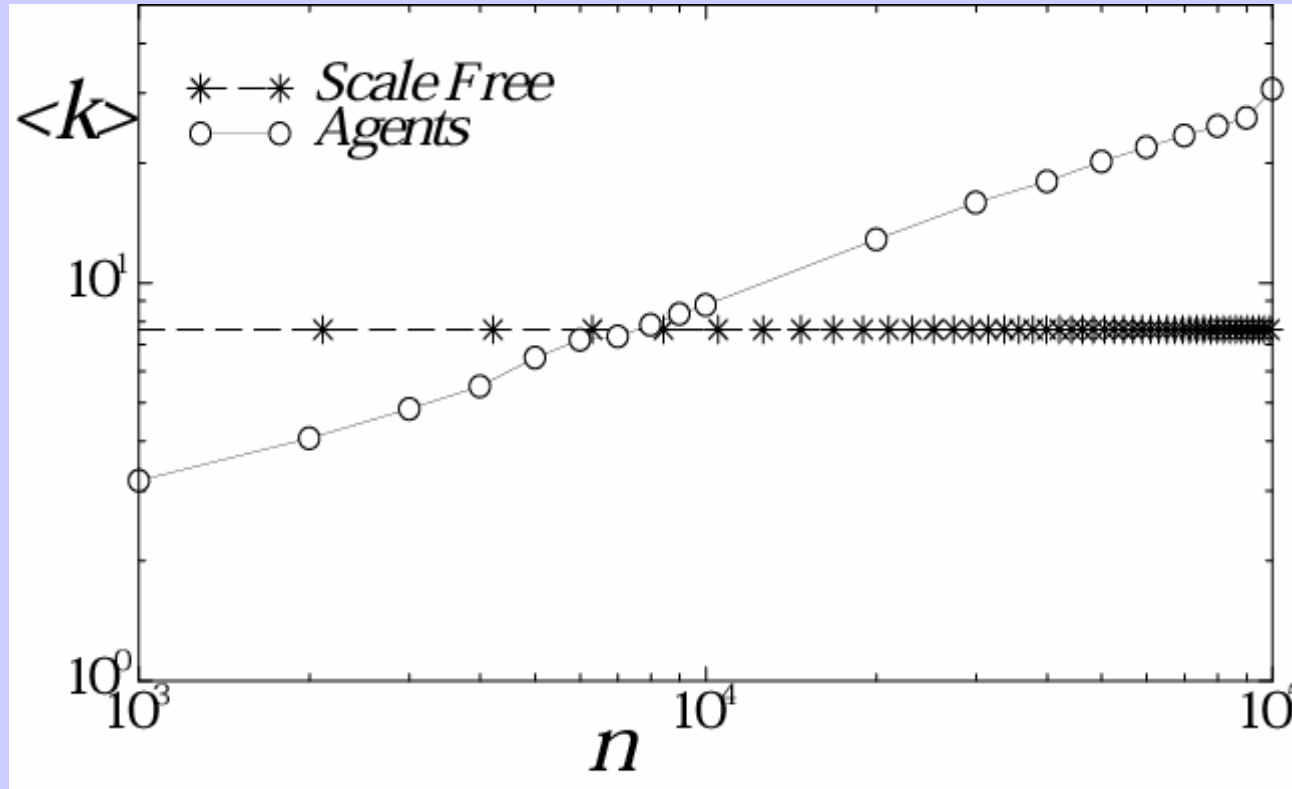
KCP

Contact networks of mobile agents



	N	L	T	Q	$\langle C_3 \rangle$	$\langle C_4 \rangle$
Heterosexual (Fig. 2a)	82	84	0	2	0	0.00486
Homosexual (Fig. 2b)	250	266	11	6	0.02980	0.00192
Heterosexual (Agent Model)	82	83.63	0	1.45	0	0.01273
Homosexual (Agent Model)	250	287.03	8.23	10.52	0.02302	0.01224
Heterosexual (Scale-free)	82	162	0	159.72	0	0.12859
Homosexual (Scale-free)	250	498	45.28	256.79	0.08170	0.02787

P.G Lind, MCG, H.J. Herrmann
cond-mat/0504241

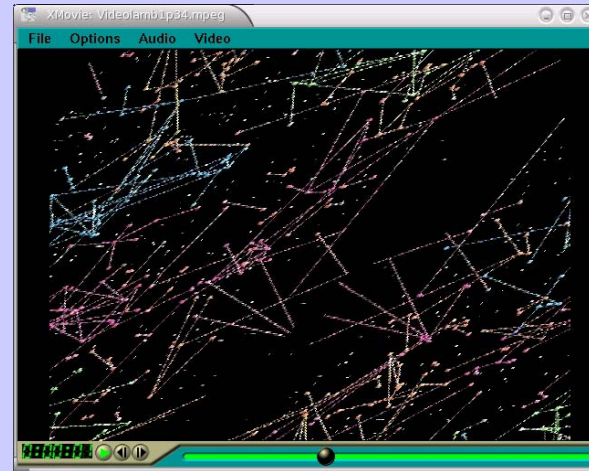


★ *In order to observe the behavior of the system into a quasi-stationary state we introduce birth and death of agents*

Quasi-stationary state

ICP

Labeling of Cluster sizes

isolated RGB scale for
cluster size $T_f=18.75$  $T_f=30.75$  $T_f=73.35$

Rules for generating the network

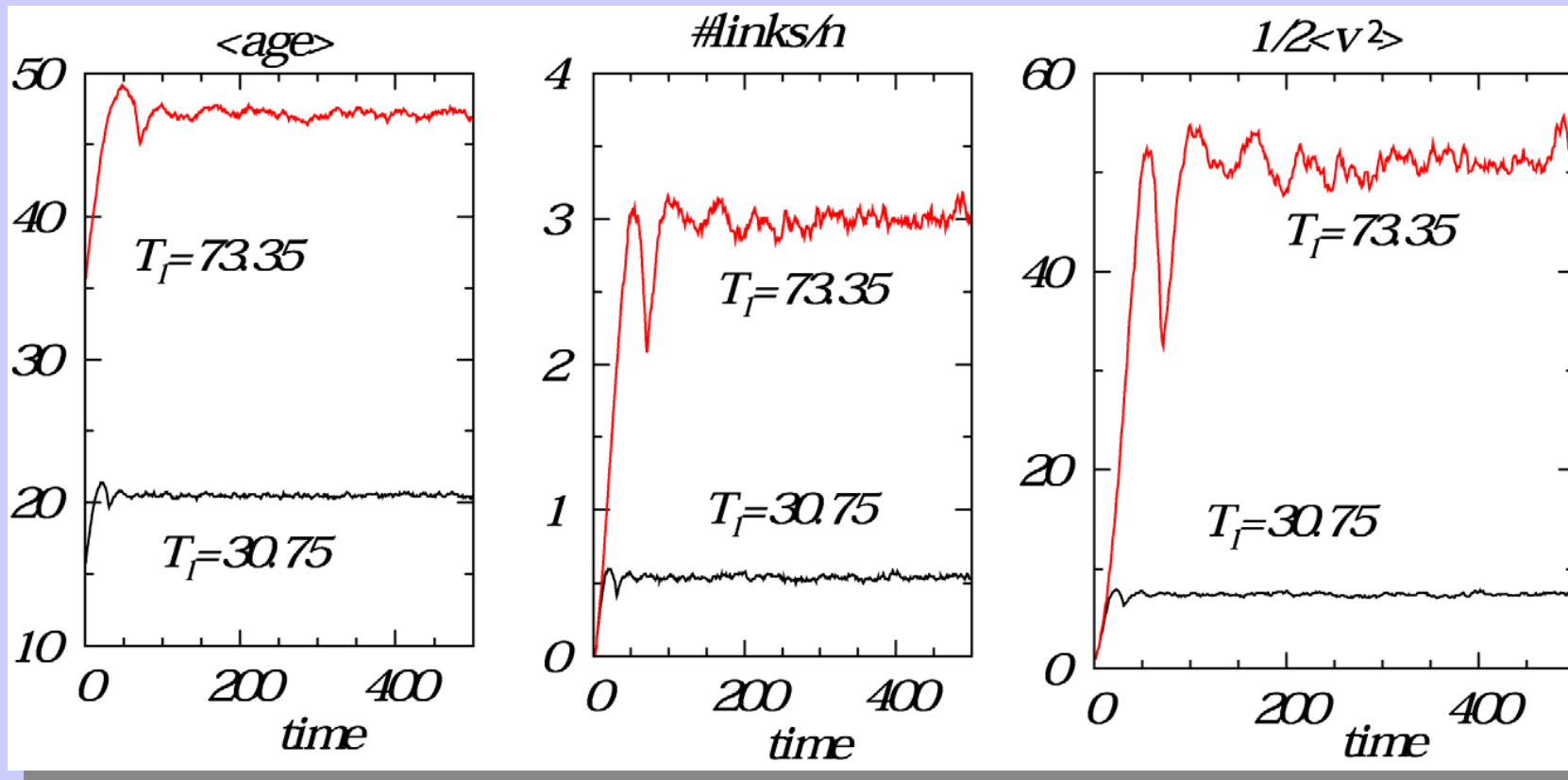
- ★ Each time one agent collides with other a bond between the two is created.
- ★ Each agent has an “age” distributed uniformly between 0 and a time of life (T_f). The “age” of each agent is incremented each time step until it reaches T_f when it dies (it is cut from the network). When one agent dies other enters into the system with random age.



Quasi-stationary state

KCP

Contact networks of mobile agents



Characteristic times

$$\tau_{MFP} = \frac{1}{\rho 2r_0} \sqrt{\frac{m}{2\pi \langle v \rangle}}$$



$$\tau_{eff} = T_l - \langle age \rangle$$

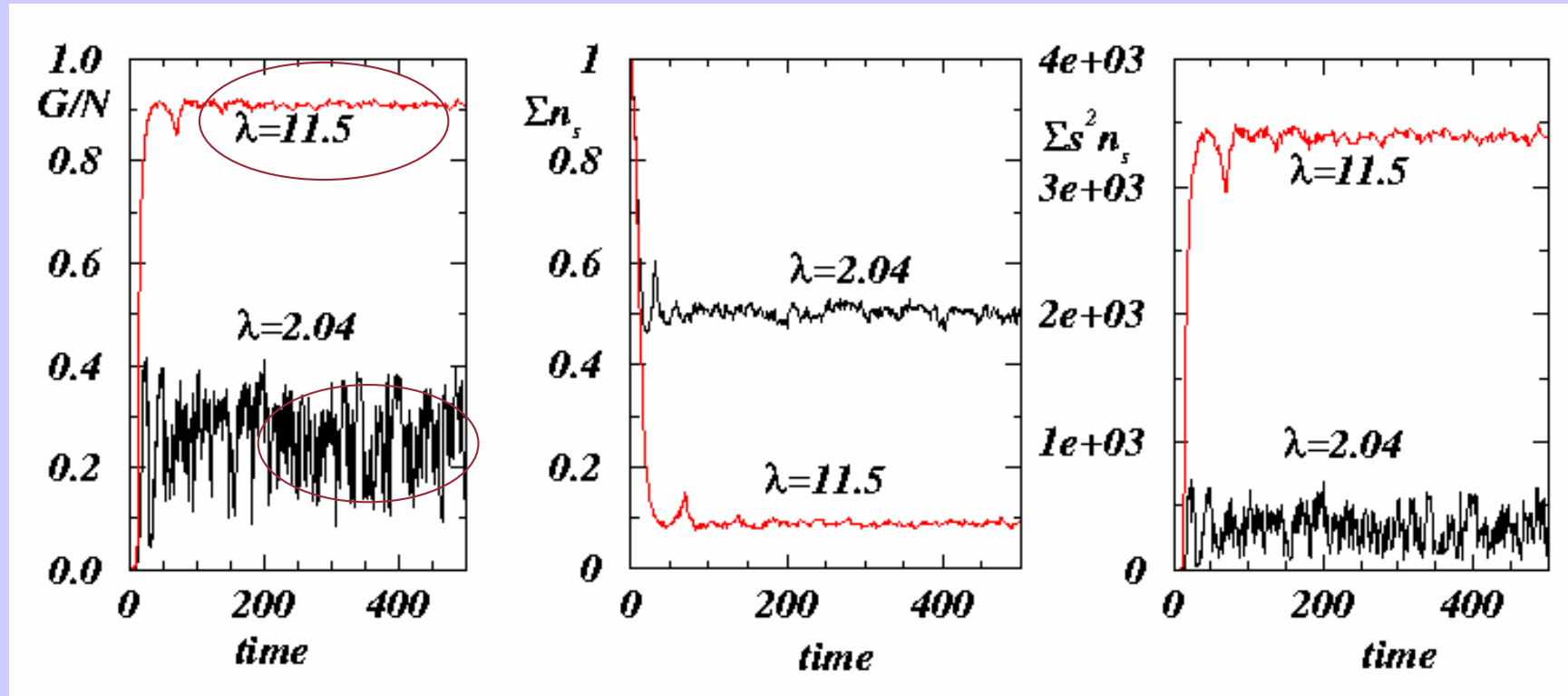
Control parameter

$$\lambda(T_l) \equiv \frac{T_l - \langle age \rangle}{\tau_{MFP}}$$

Cluster size distribution



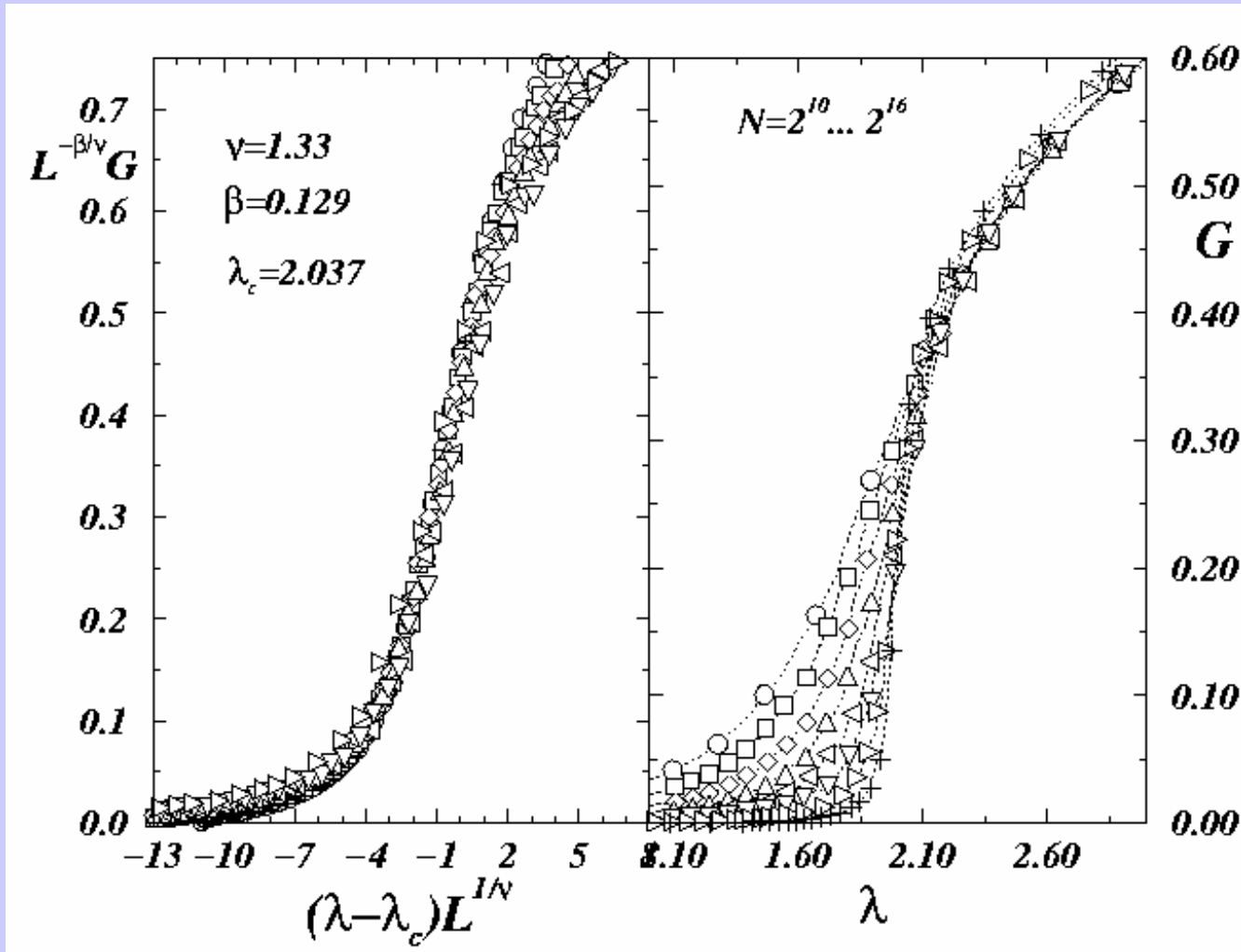
Contact networks of mobile agents



- Number of clusters of size s : N_s
- Fraction of agents at the largest cluster: G
- Total number of agents: N
- Clusters of size distribution: $n_s = \frac{N_s}{N}$

Scaling of the largest cluster **KCP**

Contact networks of mobile agents

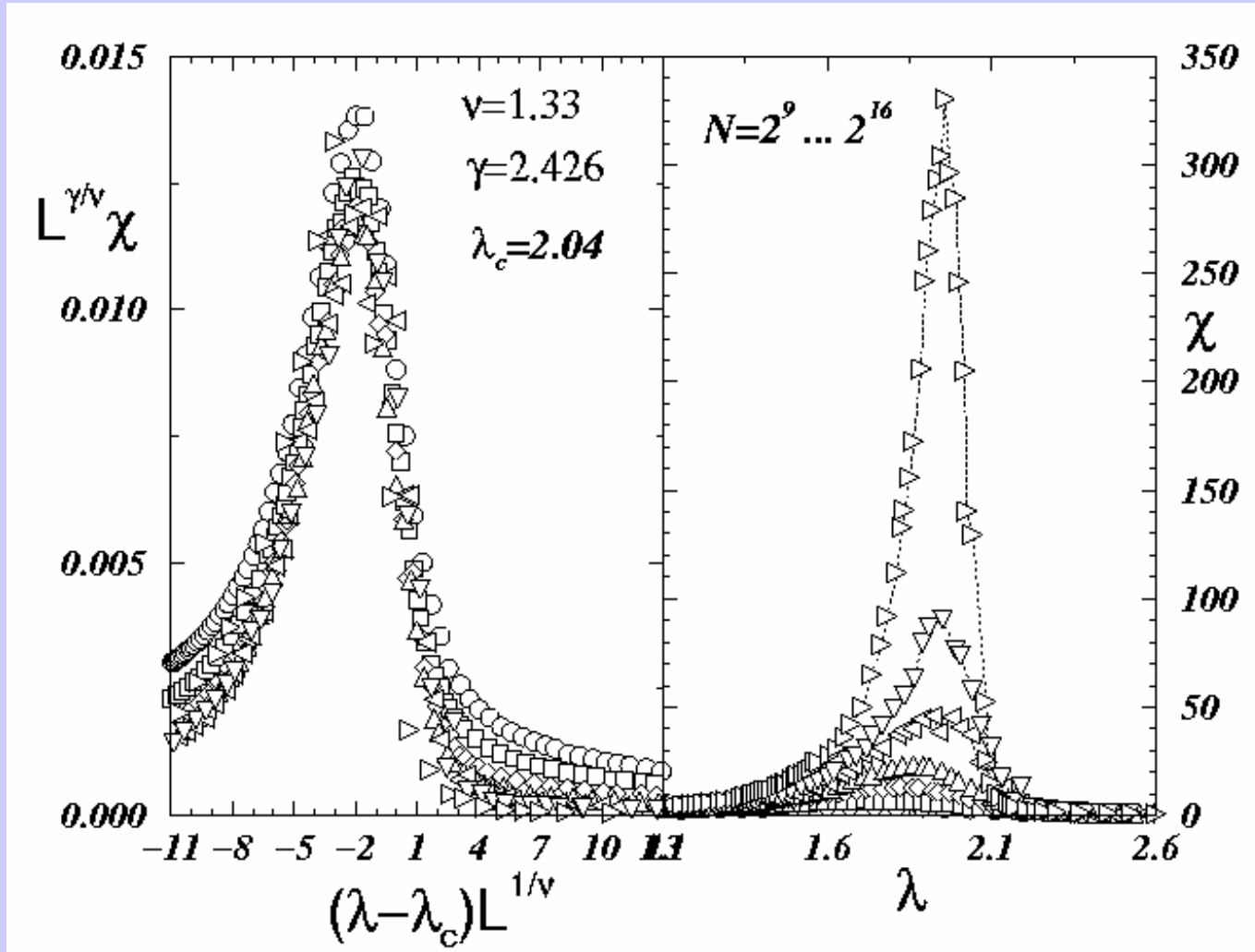


Scaling of the second moment of n_s



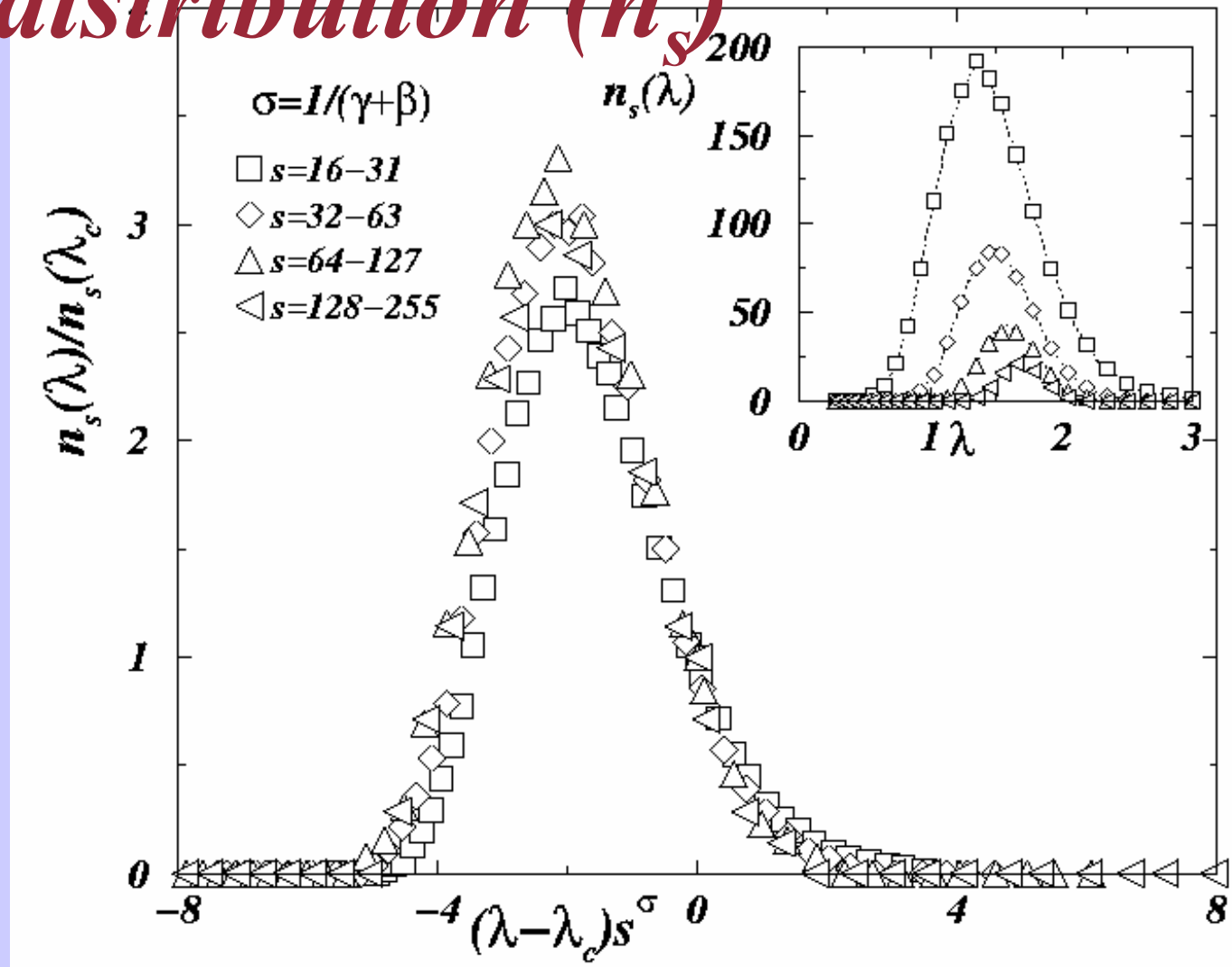
Contact networks of mobile agents

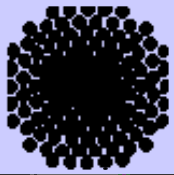
n_s



Scaling of the cluster size

distribution (n_s)





Critical Exponents

KCP

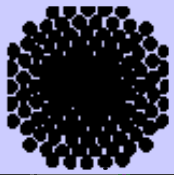
Contact networks of mobile agents

	Mean Filed	SW*	Moving Agents	Percolation 2D
ν	0.5	0.59 ± 0.05	1.3 ± 0.1	1.33333
γ	1	1.3 ± 0.1	2.4 ± 0.1	2.388888
β	1		0.13 ± 0.01	0.138888
σ	0.5		0.40 ± 0.01	0.3956

$$\sigma = 1/(\beta + \gamma)$$

$$D\nu = 2\beta + \gamma \quad (D = 2.01)$$

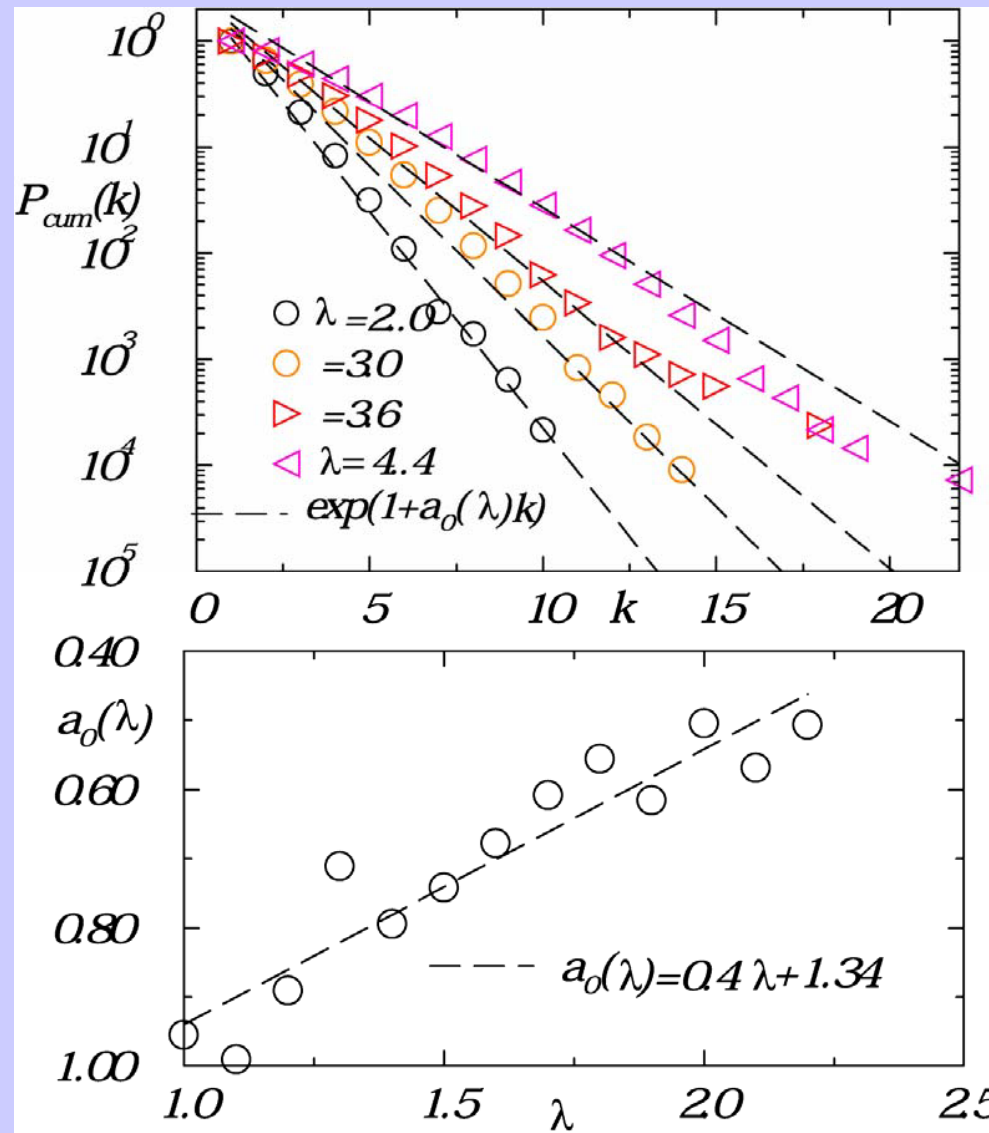
(* Newman and Watts, PRE, Vol. 60, 7332, (SW, $k=1$ $\phi=0.1$))



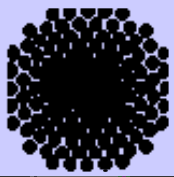
Characteristics of the

KCP

Contact networks of mobile agents



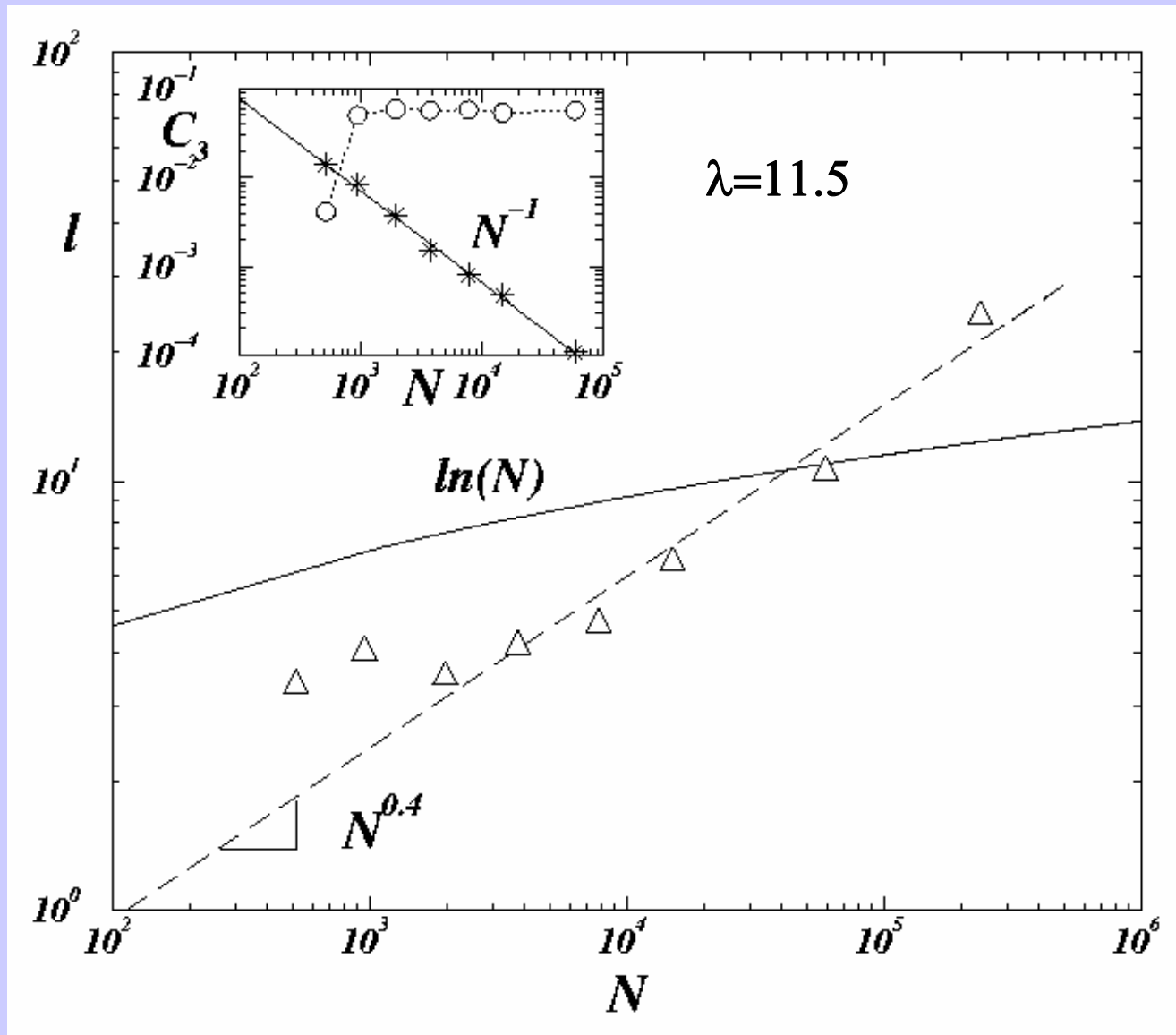
★ The degree distribution is an exponential characterized by λ



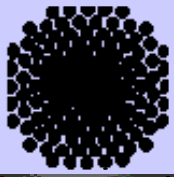
Characteristics of the

KCP

Contact networks of mobile agents



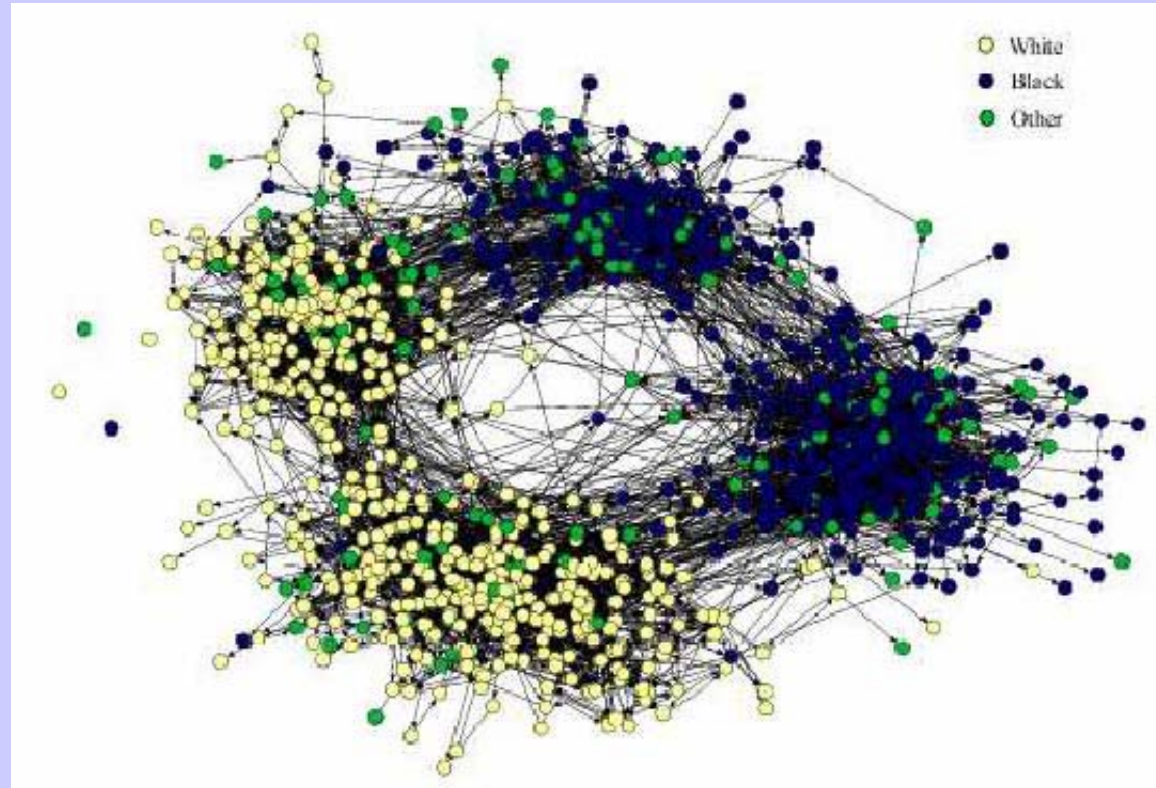
★ C_3 vs. λ
and l vs. λ
remain to be
studied



Comparison with

KCP

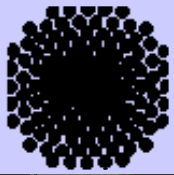
Contact networks of mobile agents



Add Health data base. Picture by James Moody

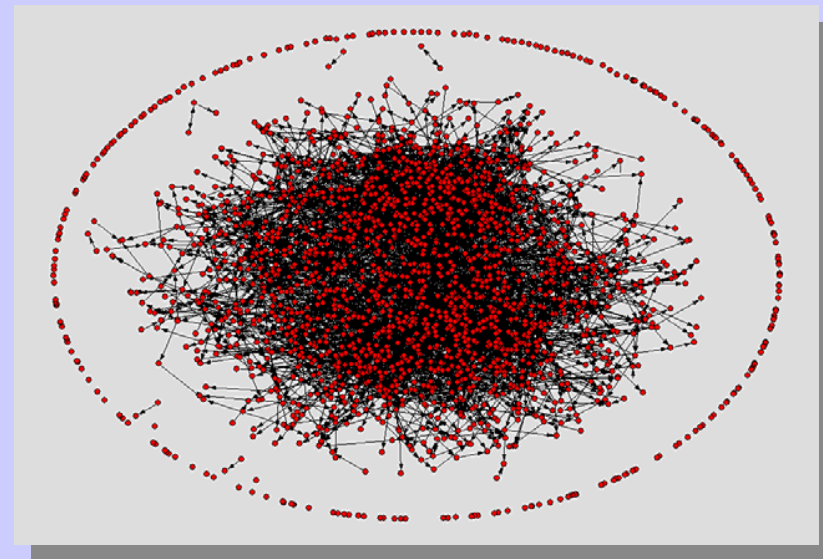
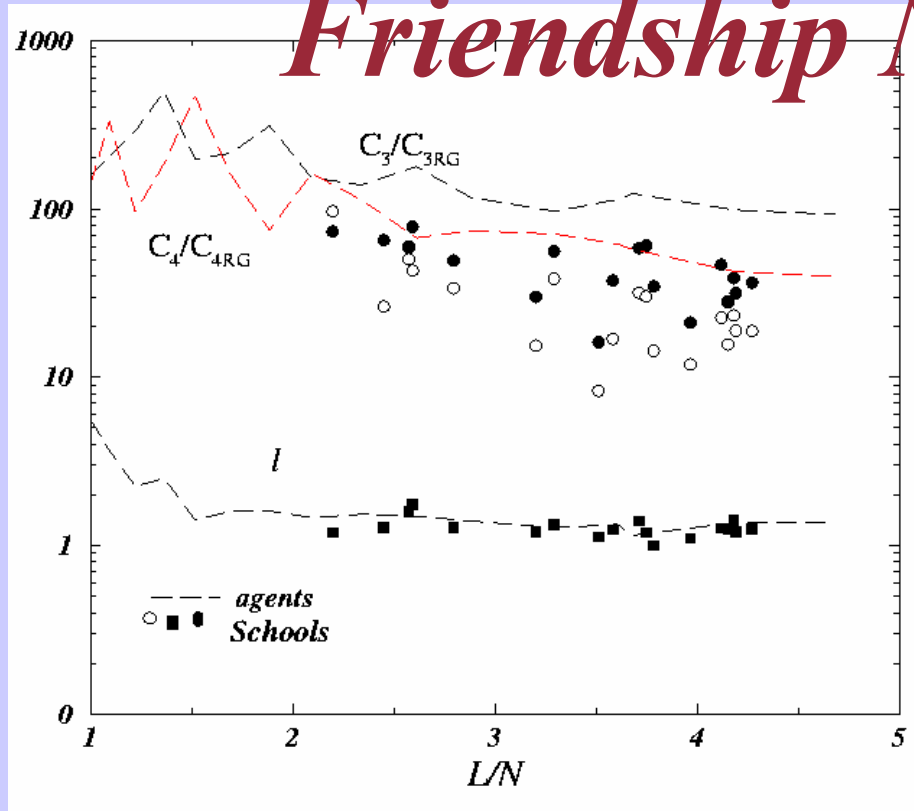
Friendship networks from 84 US schools.

Sizes of the networks (50-2000)



Comparison with Friendship Networks

Sample #33:



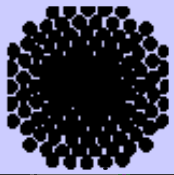
n=2250

Giant=1954

L/N=4.9

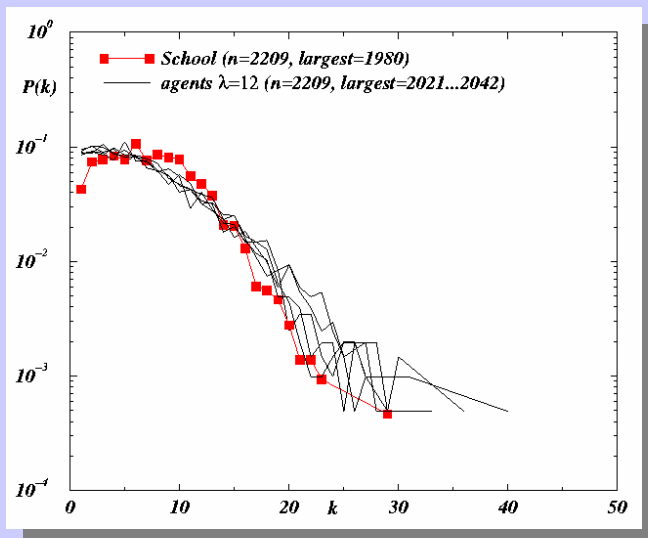
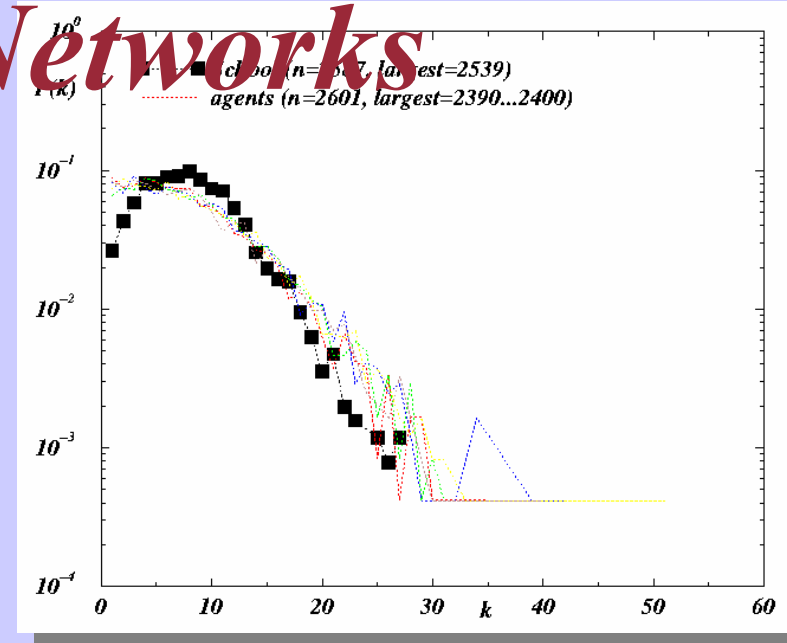
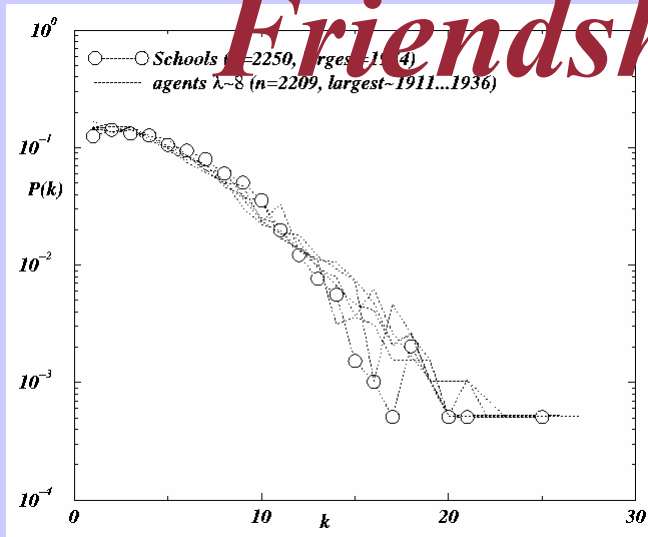
Contact networks of mobile agents

● Here e analyze the Giant cluster only



Comparison with Friendship Networks

Contact networks of mobile agents



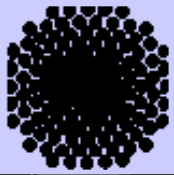
★ A detailed study of the topological characteristics of the empirical networks is in preparation.



Conclusions

KCP

- ✓ We present a model of contact network based on a system of mobile agents.
- ✓ Our model suggests that the growth mechanism of connected components of sexual networks is not pure scale-free, due to interaction among internal agents. This implies an increase on the mean number of partners with time. This differences should affect the results on spreading of infections.
- ✓ In a quasistationary version of the model the resulting contact network is exponential and can be used to model empirical data of friendship networks.

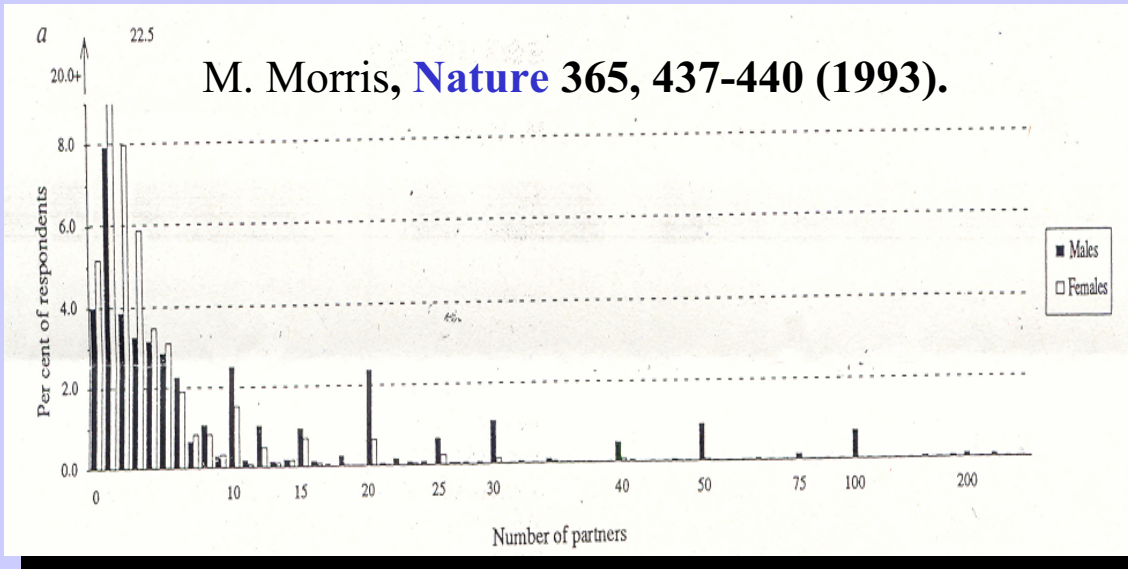


KCP

Contact networks of mobile agents



“Telling tails explain the discrepancy in sexual partners reports”



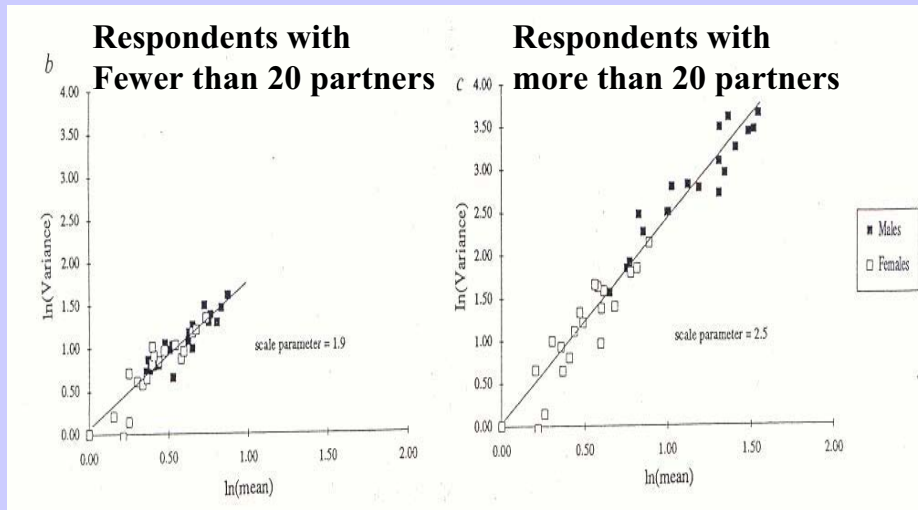
More than 60% of all contacts reported by men are unaccounted for!

Sample bias?

- 60% men with women under 18
- Each man average of 15 CSW
- 0.5-1.0% of Female population CSW

Reporting bias?

- All men over reporting 65%
- All women under reporting by 200%



Important Result: The explanations for the male:female discrepancy should be focused on the upper tail of the contact distribution