

Measuring Human Contact Networks & the mathematics of how diseases spread


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University of Cambridge Computer Laboratory*



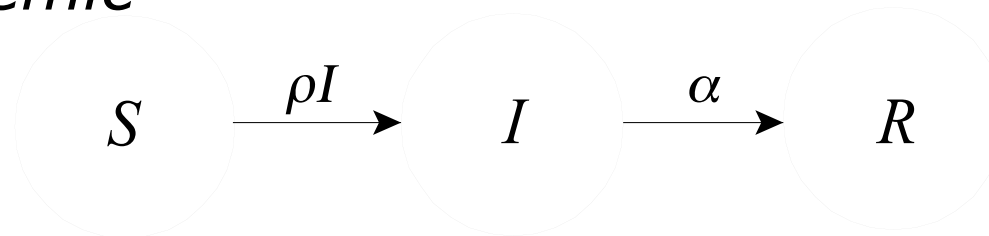
Spread of Infectious Diseases

- Thread to public health: e.g.,  , SARS, AIDS
- Current understanding of disease spread dynamics
 - Epidemiology: Small scale empirical work
 - Physics/Math: Mostly large scale abstract/simplified models
- Real-world networks are far more complex
 - ➔ Advantage of **real world data**
 - ➔ Emergence of wireless technology for proximity data (tiny wireless sensors, mobile phones...)
 - ➔ Post-facto analysis and modelling yield insight into human interactions
- **Model realistic infectious disease epidemics and predictions**





*Susceptible, Infected, Recovered: the SIR Model
of an Epidemic*





What is a Mathematical Model?

a mathematical description of a scenario or situation from the real-world

focuses on specific quantitative features of the scenario, ignores others

a simplification, abstraction, “cartoon”

involves hypotheses that can be tested against real data and refined if desired

one purpose is improved understanding of real-world scenario



The SIR Epidemic Model

First studied, Kermack & McKendrick, 1927.

Consider a disease spread by contact with infected individuals.

Individuals recover from the disease and gain further immunity from it.

S = fraction of *susceptibles* in a population

I = fraction of *infecteds* in a population

R = fraction of *recovereds* in a population

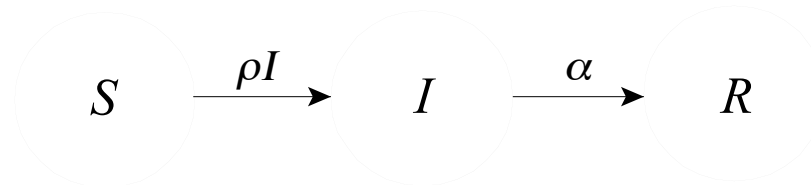


The SIR Epidemic Model (Cont'd)

- *Differential equations* (involving the variables S , I , and R and their rates of change with respect to time t) are

$$\frac{dS}{dt} = -\rho SI, \quad \frac{dI}{dt} = \rho SI - \alpha I, \quad \frac{dR}{dt} = \alpha I$$

- An equivalent *compartment diagram* is





Parameters of the Model

- ρ = the *infection rate*
- α = the *removal rate*
- The *basic reproduction number* is obtained from these parameters:

$$N_R = \rho / \alpha$$

- This number represents the average number of infections caused by one infective in a totally susceptible population. As such, an epidemic can occur only if $N_R > 1$.



Vaccination and Herd Immunity

If only a fraction S_0 of the population is susceptible, the *reproduction number* is $N_R S_0$, and an epidemic can occur only if this number exceeds 1.

Suppose a fraction V of the population is vaccinated against the disease. In this case, $S_0 = 1 - V$ and no epidemic can occur if

$$V > 1 - 1/N_R$$

The *basic reproduction number* N_R can vary from 3 to 5 for smallpox, 16 to 18 for measles, and over 100 for malaria [Keeling, 2001].



Case Study: Boarding School Flu

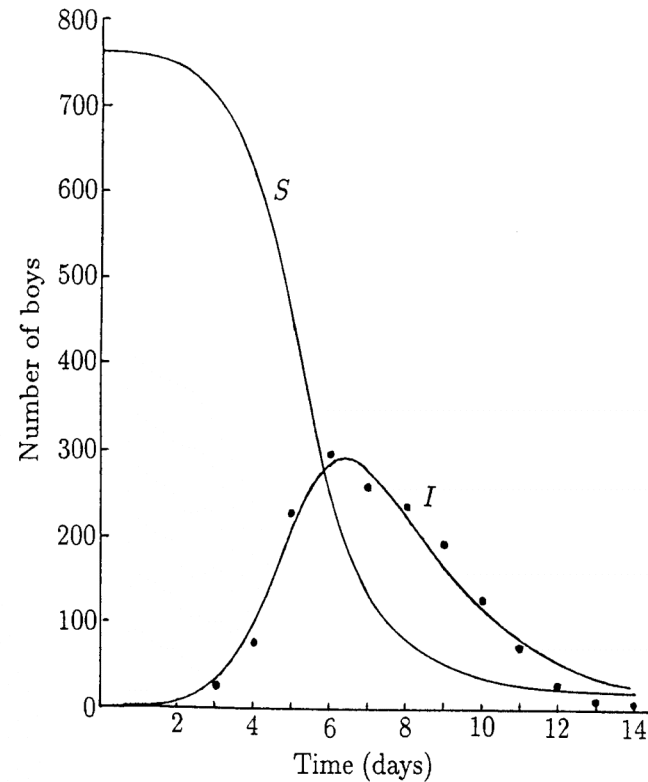
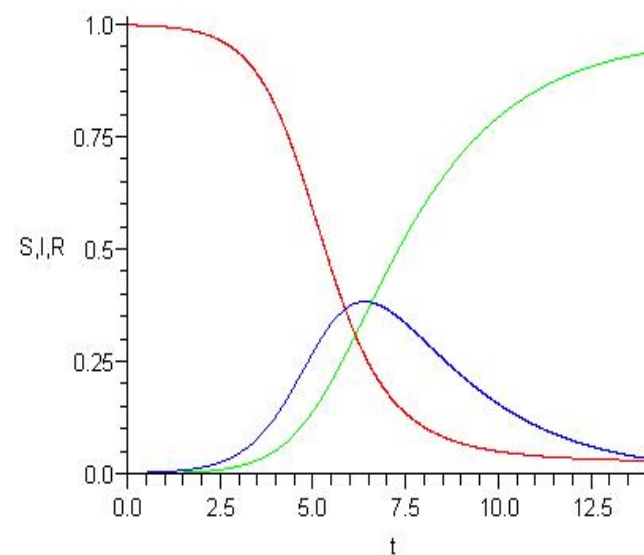
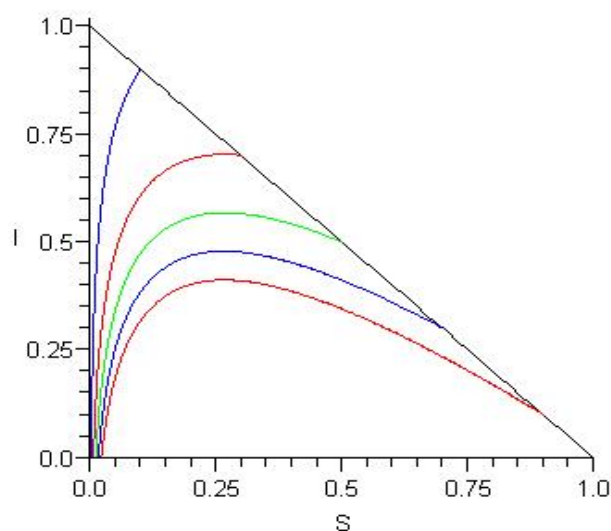


Fig. 19.3. Influenza epidemic data (\bullet) for a boys boarding school as reported in British Medical Journal, 4th March 1978. The continuous curves for the infectives (I) and susceptibles (S) were obtained from a best fit numerical solution of the SIR system (19.1)–(19.3): parameter values $N = 763$, $S_0 = 762$, $I_0 = 1$, $\rho = 202$, $r = 2.18 \times 10^{-3}/\text{day}$. The conditions for an epidemic to occur, namely $S_0 > \rho$ is clearly satisfied and the epidemic is severe since R/ρ is not small.

Boarding School Flu (Cont'd)

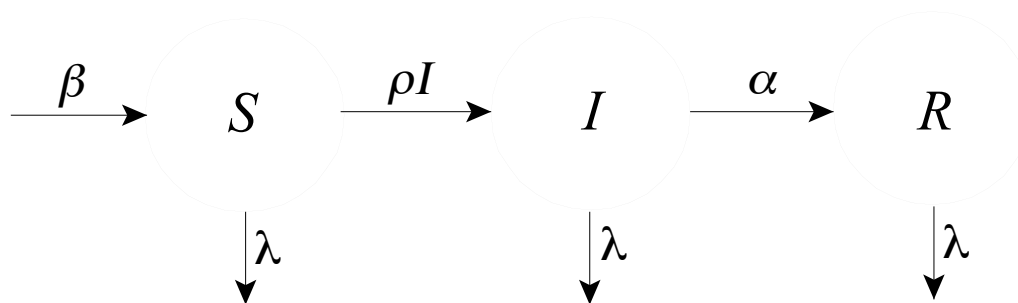
- In this case, time is measured in days, $\rho = 1.66$, $\alpha = 0.44$, and $R_N = 3.8$.



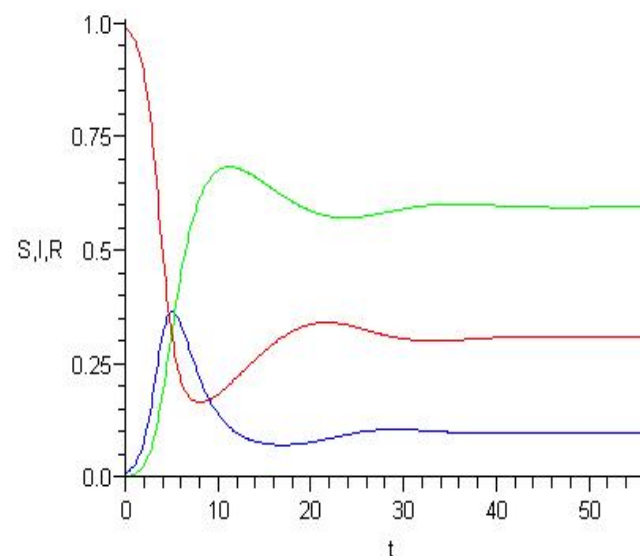
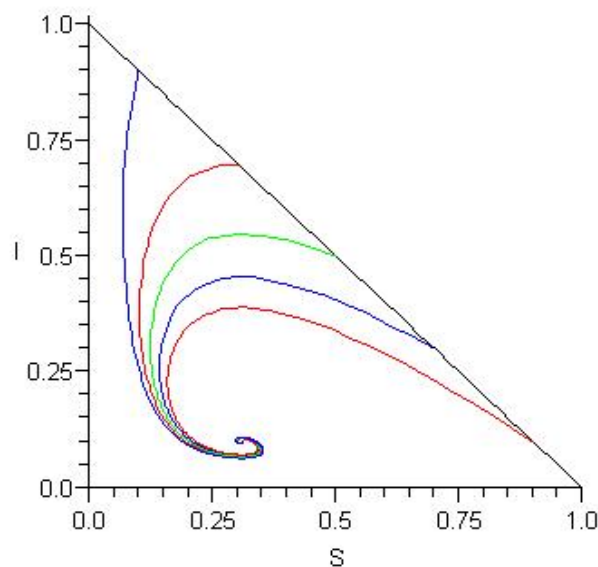
Flu at Hypothetical Hospital

- In this case, new susceptibles are arriving and those of all classes are leaving.

$$\frac{dS}{dt} = \beta - \rho SI - \lambda S, \quad \frac{dI}{dt} = \rho SI - \alpha I - \lambda I, \quad \frac{dR}{dt} = \alpha I - \lambda R$$



- Flu at Hypothetical Hospital (Cont'd)*
- Parameters ρ and α are as before. New parameters $\beta = \lambda = 1/14$, representing an average turnover time of 14 days. The disease becomes *endemic*.





Case Study: Bombay Plague, 1905-6

- The R in SIR often means *removed* (due to death, quarantine, etc.), not *recovered*.

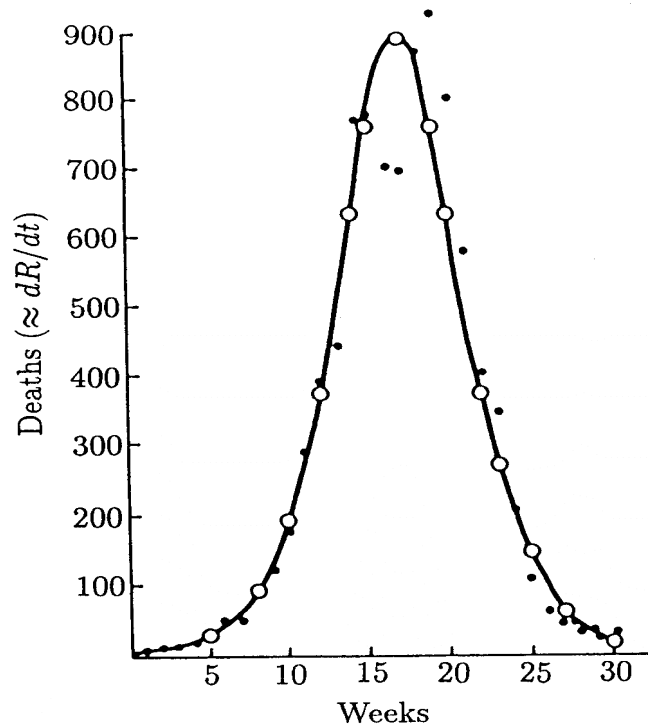


Fig. 19.2. Bombay plague epidemic of 1905–6. Comparison between the data (●) and theory (○) from the (small) epidemic model and where the number of deaths is approximately dR/dt given by (19.16). (After Kermack and McKendrick 1927)



Eyam Plague, 1665-66

Raggett (1982) applied the SIR model to the famous Eyam Plague of 1665-66.

<http://www.warwick.ac.uk/statsdept/staff/WSK/Courses/ST333/eyam.html>

It began when some cloth infested with infected fleas arrived from London. George Vicars, the village tailor, was the first to die.

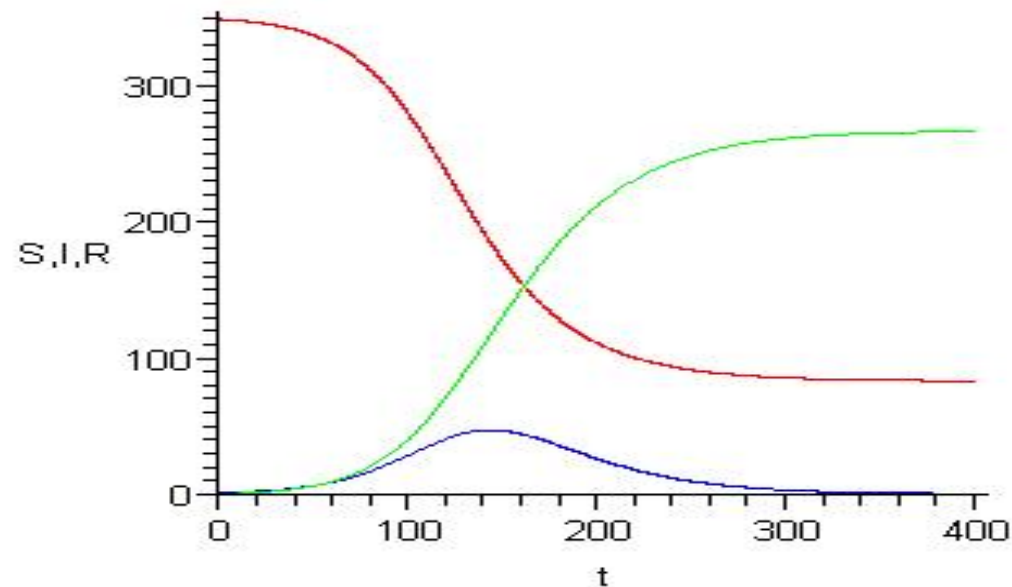
Of the 350 inhabitants of the village, all but 83 of them died from September 1665 to November 1666.

Rev. Wm. Mompesson, the village parson, convinced the villagers to essentially quarantine themselves to prevent the spread of the epidemic to neighboring villages, e.g. Sheffield.



Eyam Plague, 1665-66 (Cont'd)

- In this case, a rough fit of the data to the SIR model yields a basic reproduction number of R_N





Enhancing the SIR Model

Can consider additional populations of disease vectors (e.g. fleas, rats).

Can consider an *exposed* (but not yet infected) class, the SEIR model.

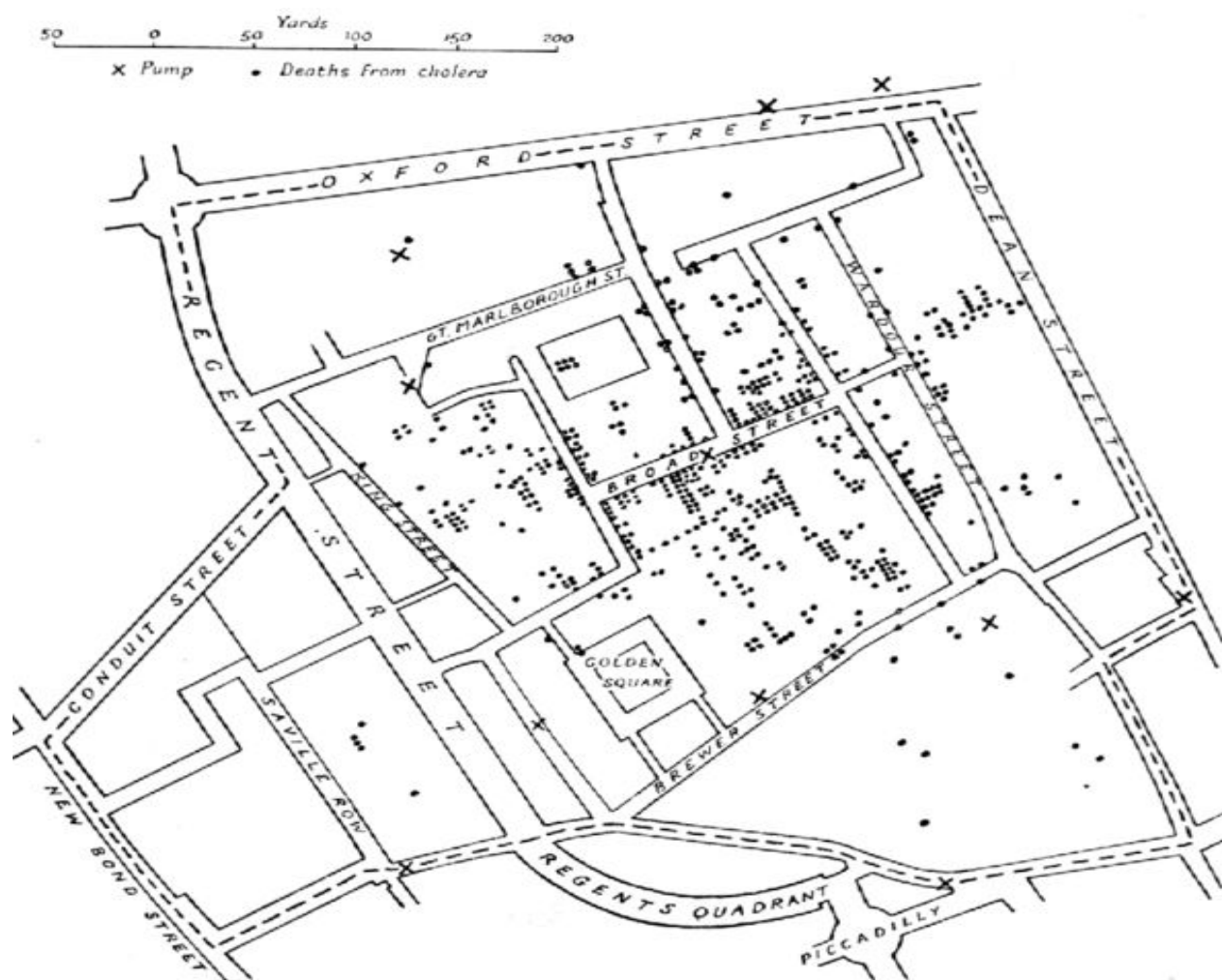
SIRS, SIS, and double (gendered) models are sometimes used for sexually transmitted diseases.

Can consider biased mixing, age differences, multiple types of transmission, geographic spread, etc.

Enhancements often require more compartments.



Geo-mapping,, Snow's Ghost Map





We meet, we connect, we communicate

We *meet* in real life in the real world

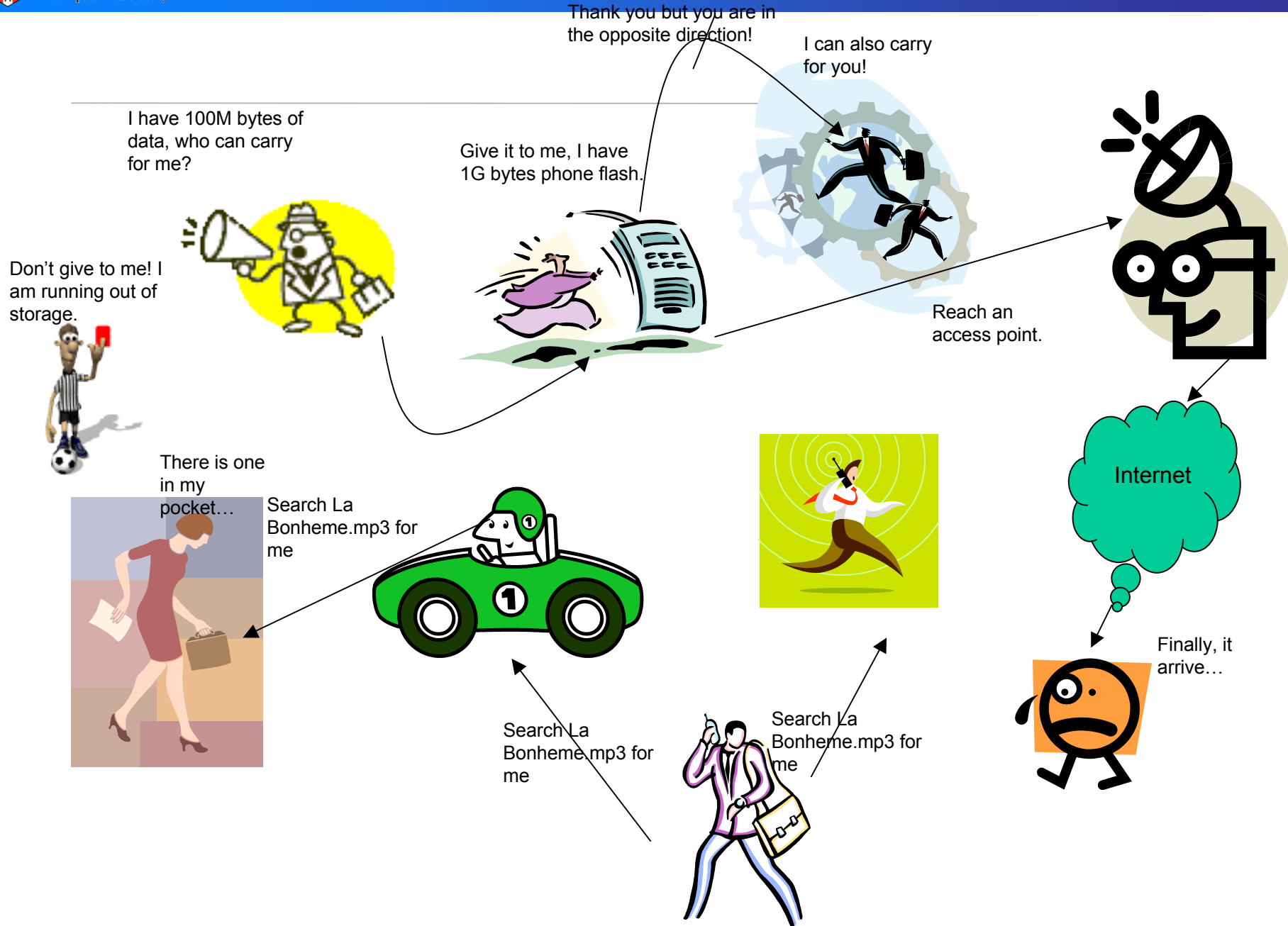
We use text *messages*, phones, IM

We make *friends* on facebook, Second Life

How are these **related**?

How do they **affect** each other?

How do they **change** with new technology?





My facebook friendswheel





My email statistics!

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http://mail.google.com/mail/?ui=2&shva=1#inbox

Most Visited Getting Started Latest Headlines Apple Amazon eBay Yahoo! News

Facebook Home Google Mail - Inbox (34778) Blogger: Dashboard BBC NEWS | News Front Page 1-Way Aerial Amplifier Mozilla Firefox Start Page Capture a Screen Shot with...

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Chat

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Jon Crowcroft

Richard Mortier

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Jon Crowcroft

Nishanth Sastry

Options Add Contact

Labels

direct (29)

Edit labels

Invite a friend

Give Google Mail to:

Send invite 50 left

Preview Invite

Engadget - Denon jumps in the vinyl-to-MP3 turntable game with DP-200USB - 1 hour ago

Web Clip

Archive Report Spam Delete More Actions Refresh

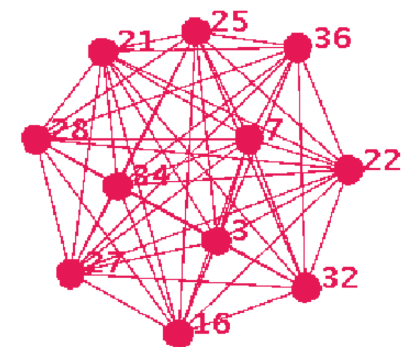
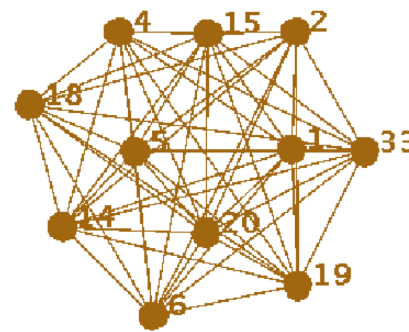
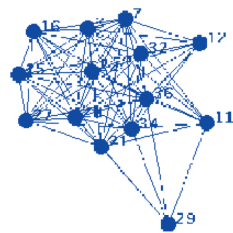
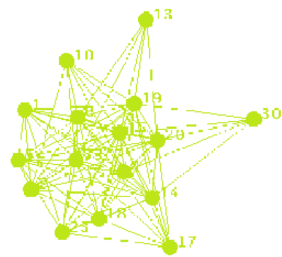
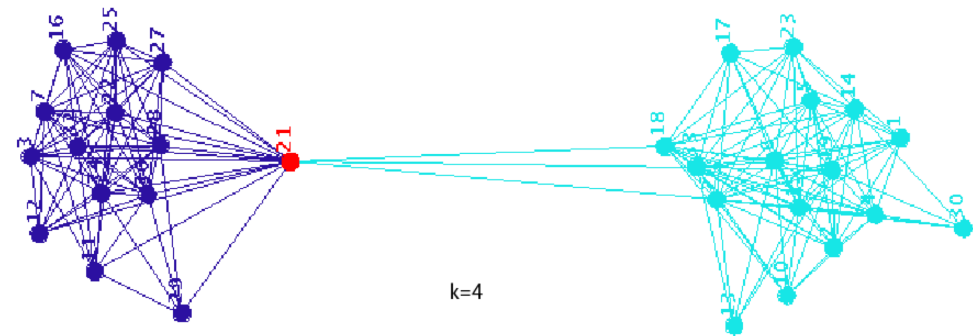
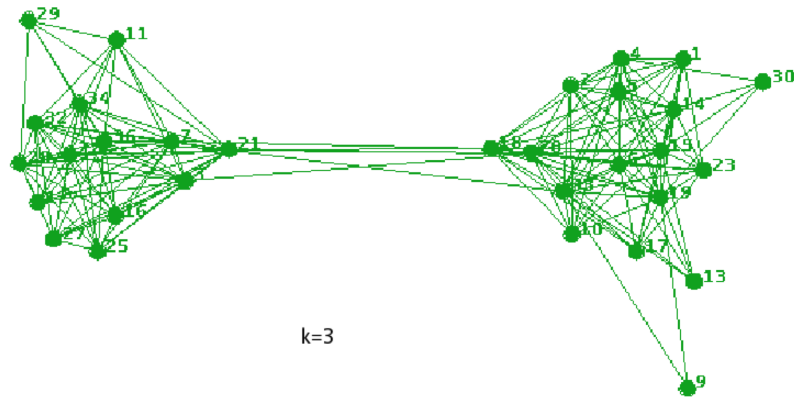
Select: All, None, Read, Unread, Starred, Unstarred

1 - 50 of 39205 Older Oldest

Alan, Frank, Jon, Neil (4)	[Response requested] Teaching Planning - To: all Computer Laboratory Schedule J teaching staff. As I mentioned in the Wednesday Meeting ...	9:34 am
Marshall, Gunter, Stig (7)	[MBONED] WGLC on SSMPIG - We have been asked by Stig about this and feel that SSMPIG is ready for WGLC. Please comment on ...	9:30 am
Aaron, Ted, Jon (3)	[discuss] GENI System Requirements - On Mon, Oct 20, 2008 at 03:31:22PM -0400, Aaron Falk wrote: > GENI System Requirements ...	9:10 am
Sue, Jon (4)	quick question on highly utilized links - Hi Jon, How's it going? I've got a quick question that I thought you might have an answer ...	9:09 am
ken, R. Jon (16)	IPv10.0 paper - attached is the white paper I sent over to Darpa on IPv10. Its rather informal in some places and ...	9:09 am
Cecilia Mascolo	Re: sensor posters any one? - yes On 22 Oct 2008, at 07:21, Jon Crowcroft wrote: > Forwarded Message ...	9:04 am
Nishanth, Jon (2)	thesis plan thoughts - Hi Jon I am still in the middle of rewriting thesis plan, but here are the two options in my head ...	8:57 am
Helen, Jon (2)	Vodafone Lecture, February 2009 - Dear all I have provisionally booked The Royal Academy of Engineering's in-house lecture ...	8:55 am
Mahesh Marina	PhD position in Edinburgh - Dear all, I am writing to seek your help in finding a UK/EU candidate for a fully funded PhD ...	7:55 am
COMNET	Notification of ACCEPTANCE Decision for COMNET-D-08-2716R1 - Dear Dr. Crowcroft, For this manuscript Performance Evaluation of Data-Centric Information ...	7:45 am
Parviz, Steven, Paul (4)	[ita-alliance] Downloading files from ITACS - Dear All: I have received a number of e-mails/calls indicating many of you have problem in ...	7:39 am
George, Steve (4)	Your CL visit - Just talking to Jon Crowcroft. He and I could do a 4 pm meeting this Friday (17th). Followed by a ...	5:23 am
Polyzos, George, George (3)	WCM-08-0007.R1 - Invitation to review - Dear Jon, I'm sure you have various reviewing assignments, but would you consider taking a ...	5:04 am
Ian, Neil, Ian, Richard (8)	FIPR Alert: GAK notice decision - You have received this message from the "FIPR Alert" mailing list run by the Foundation ...	12:32 am
Info (2)	ICST - SIMUTools'09: Call for papers - Submission deadline EXTENDED to November 2 - Our apologies if you receive multiple copies of this message) due to the numerous requests ...	11:52 pm
Rashid Mehmood	Reference Request from Surrey - Hi John, University of Surrey, Centre for Communication Systems Research (CCSR) has shortlisted ...	11:05 pm
S.Aleva	CCNR & Barabási Lab Announcements - Center for Complex Network Research (CCNR) CCNR tenure-track position Assistant Professorship in ...	11:05 pm
BB-ubicomp, Marta (5)	[grandchallenge] October 30th/31st retreat @ Crowne Plaza hotel, Nottingham - Dear all, I have the following names confirmed for the above retreat, aimed at working on follow ...	10:48 pm
Facebook	direct: Babak Ayazifar also commented on Randy Howard Katz's posted item... - Babak also commented on Randy Howard Katz's posted item: "She may shut down all of ...	10:42 pm
M. Mallya	Wolfson Wine Tasting - this saturday - Welcome to Wolfson Wine Tasting. We will be kicking off this year with our first tasting this ...	9:58 pm
BB-ubicomp, Jon, Morris (3)	[grandchallenge] Workshop funds application for consideration - I thubk I can see the relevance of a workshop on Sensory Augmentation Research and that it ...	Oct 21
Amy Mokady	Do you have a project with commercial potential? - i-Teams are currently looking for projects for i-Teams for Lent and Easter terms (www ...	Oct 21
Peter Sewell	lab TSG/ARG/CPRG research groups -> PLS - Dear all, this is just to let you know that we've tied up the structure of the lab ...	Oct 21
The IESG	Last Call: draft-ietf-isis-wg-extlsp (Simplified Extension of LSP Space for IS-IS) to P... - The IESG has received a request from the IS-IS for IP Internets WG (isis) to consider the ...	Oct 21
The IESG	Last Call: draft-ietf-isis-hmac-sha (IS-IS Generic Cryptographic Authentication) to Pro... - The IESG has received a request from the IS-IS for IP Internets WG (isis) to consider the ...	Oct 21
Scott, Avri (3)	Re: from the Firefly guy - On 10/20/08 10:59 PM, Stev Knowles allegedly wrote: >> joss whatever ... >> http ...	Oct 21
Gorry Fairhurst	[MBONED] WGLC on SSMPIG - Comments on draft-ietf-mboned-ssmping-05.txt - I have read version -05 of the ssmping spec, and see the following: 1) I think this protocol is a ...	Oct 21
Tesco.com	25% Off All Top 40 Chart Downloads When You Buy Anything In Store! - If this email is not displayed correctly, please click here. To ensure that your Tesco emails get ...	Oct 21
ENASE Secretariat	CFP ENASE-2009 (Milan - Italy) - 4th International Conference on Evaluation of Novel Ap... - Dear Jon Crowcroft. We invite you to submit a paper to ENASE-2009 (the 4th Internation ...	Oct 21
Ronnie Sant	Last Chance to Attend - Get a Complimentary All-Access Pass for the 2008 Financial Serv... - Last Chance to Attend Get a Complimentary All-Access Pass 2008 Financial Services ...	Oct 21
Mark Kirstein	P2P Traffic to Grow Almost 400% over the Next 5 Years, as Legitimate P2P Applications B... - MultiMedia Intelligence Brief P2P Traffic to Grow Almost 400% over the Next 5 Years, a ...	Oct 21
Jon, Kylie (2)	kelly joe Phelps - awesome slide guitar/voice - just caught him on a bbc series about "guitar heroes" but he's really standout ...	Oct 21
rfc-editor	RFC 5372 on Payload Format for JPEG 2000 Video: Extensions for Scalability and Main Hea... - A new Request for Comments is now available in online RFC libraries. RFC 5372 Title: ...	Oct 21
rfc-editor	RFC 5371 on RTP Payload Format for JPEG 2000 Video Streams - A new Request for Comments is now available in online RFC libraries. RFC 5371 Title: RTP Payload ...	Oct 21
rfc-editor	RFC 5344 on Presence and Instant Messaging Peering Use Cases - A new Request for Comments is now available in online RFC libraries. RFC 5344 Title: Presence and ...	Oct 21
rfc-editor	RFC 5254 on Requirements for Multi-Segment Pseudowire Emulation Edge-to-Edge (PWE3) - A new Request for Comments is now available in online RFC libraries. RFC 5254 Title: ...	Oct 21
Ocado	Get free deliveries with Ocado on Demand - Having trouble reading this email? View the web version. Ocado Home Wines Ideas Offers Recipes	Oct 21



Cliques and Communities





We are still learning about this!

There are big problems understanding this

Data?

Privacy?

Usefulness?

Spread of Infectious Diseases

- Thread to public health: e.g., , SARS, AIDS
- Current understanding of disease spread dynamics
 - Epidemiology: Small scale empirical work
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- **Model realistic infectious disease epidemics and predictions**





The FluPhone Project

- Understanding behavioural responses to infectious disease outbreaks
- Proximity data collection using mobile phone from general public in Cambridge

<https://www.fluphone.org>



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FluPhone Study

This is the home page for the FluPhone study. A study to measure social encounters made between people, using their mobile phones, to better understand how infectious diseases, like 'flu, can spread between people.

This study will record how often different people (who may not know each other) come close to one another, as part of their everyday lives. To do this, we will ask volunteers to install a small piece of software (called FluPhone) on their mobile phones and to carry their phones with them during their normal day-to-day activities. The software will look for other nearby phones periodically using Bluetooth, record this information and send it back to the research team via the cellular phone data service. This information will give us a much better understanding of how often people congregate into small groups or crowds, such as when commuting or through work or leisure activities. Also, by knowing which phones come close to one another, we will be able to work out how far apart people actually are, and how fast diseases could spread within communities. We are also asking participants to inform us of any influenza-like symptoms they may experience during the study period, so that we can match the spread of 'flu to the underlying social network of encounters made.

If you wish to take part in this study, please read the study information below, and then click [here](#) to start the registration process.



News:

- The pilot study within the university will start on the April 1st, 2010
- The webpage is up!



Sensor Board or Phone or ...

- iMote needs disposable battery
 - Expensive
 - Third world experiment
- Mobile phone
 - Rechargeable
 - Additional functions (messaging, tracing)
 - Smart phone: location assist applications

- Provide device or software



Phone Price vs Functionality

- $\sim < 20$ GBP range
 - Single task (no phone call when application is running)
- $\sim > 100$ GBP
 - GPS capability
 - Multiple tasks – run application as a background job
- Challenge to provide software for every operation system of mobile phone
- FluPhone
 - Mid range Java capable phones (w/ Bluetooth JSR82 –Nokia)
 - Not yet supported (iPhone, Android, Blackberry)

Experiment Parameters vs Data Quality

- Battery life vs Granularity of detection interval
- Duration of experiments
 - Day, week, month, or year?
 - Data rate
- Data Storage
 - Contact /GPS data <50K per device per day (in compressed format)
 - Server data storage for receiving data from devices
 - Extend storage by larger memory card
- Collected data using different parameters or methods → aggregated?



Proximity Detection by Bluetooth

- Only $\sim 15\%$ of devices Bluetooth on
- Scanning Interval
 - 5 mins phone (one day battery life)
- Bluetooth inquiry (e.g. 5.12 seconds) gives $>90\%$ chance of finding device
- Complex discovery protocol
 - Two modes: discovery and being discovered

Make sure to produce reliable data!

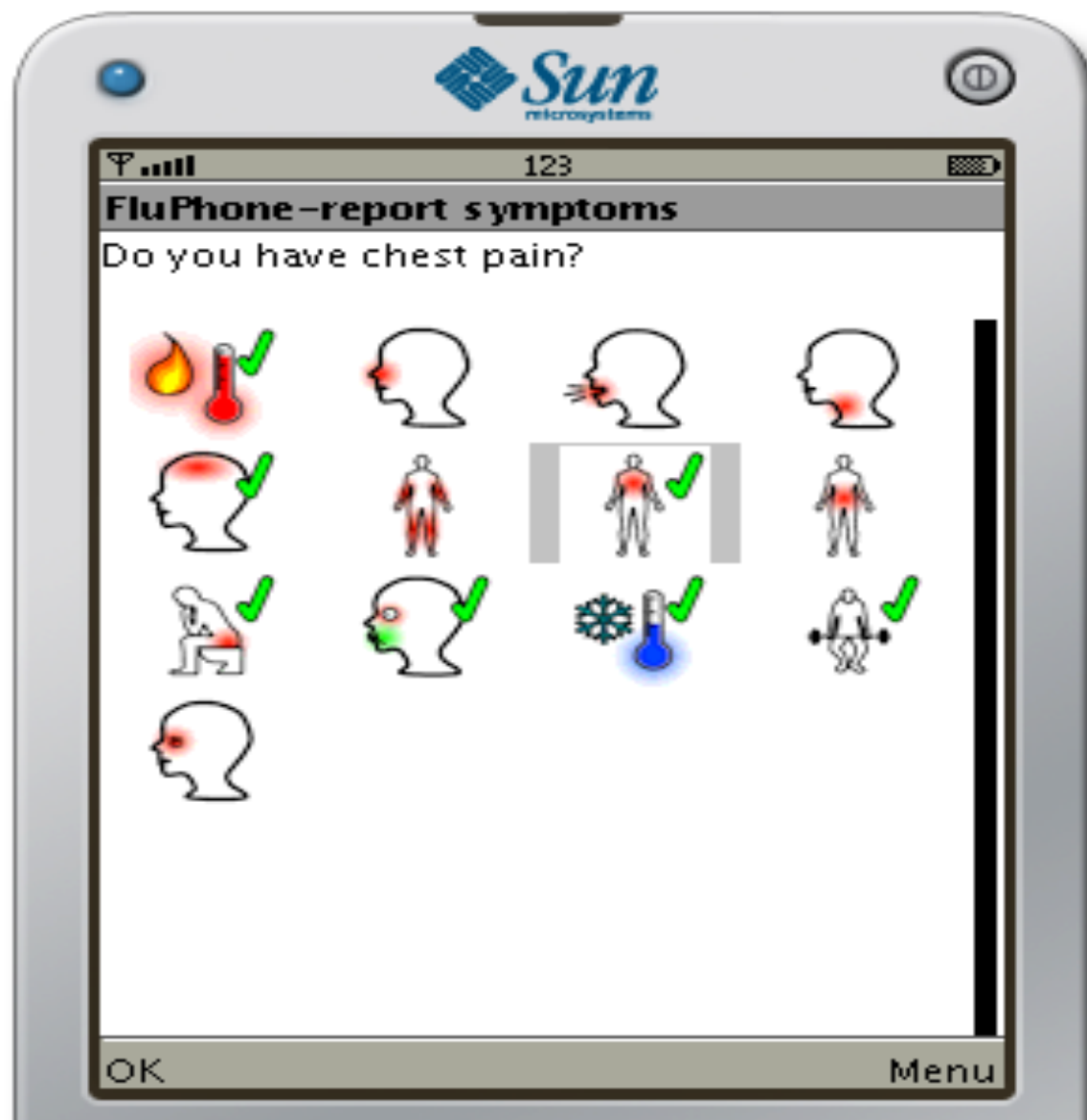


FluPhone





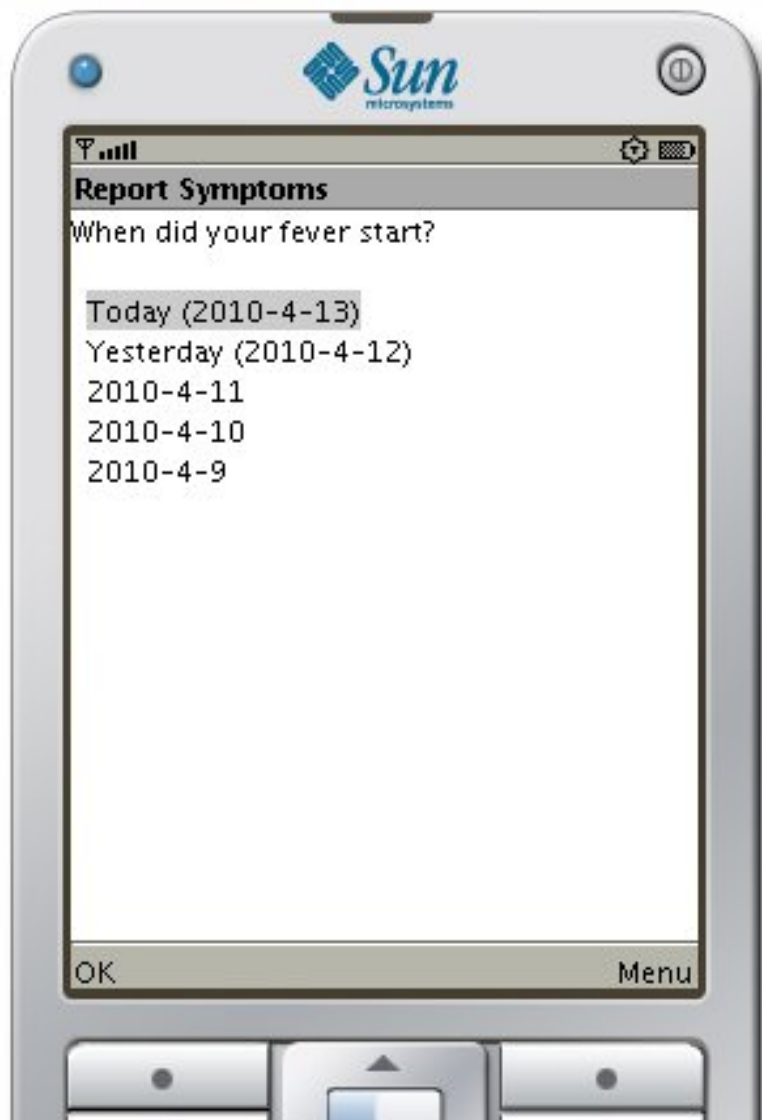
FluPhone



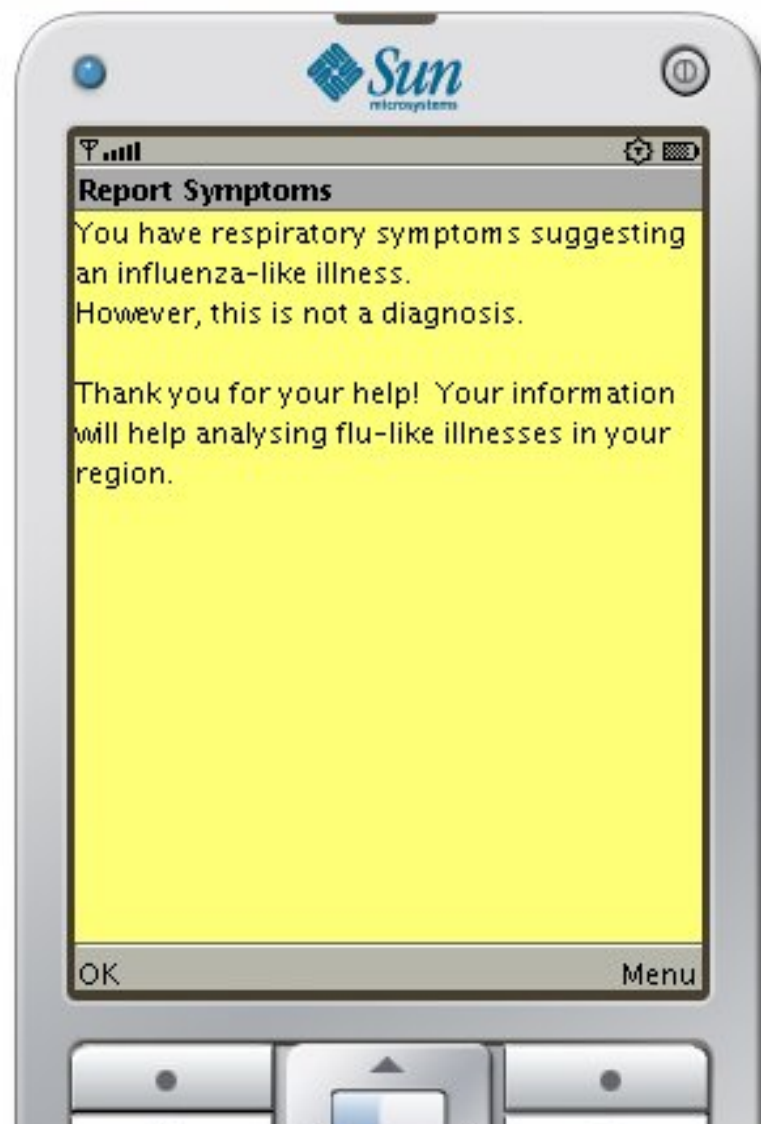


FluPhone

MIDlet View Help



MIDlet View Help





Data Retrieval Methods

- Retrieving collected data:
 - Tracking station
 - Online (3G, SMS)
 - Uploading via Web
 - via memory card

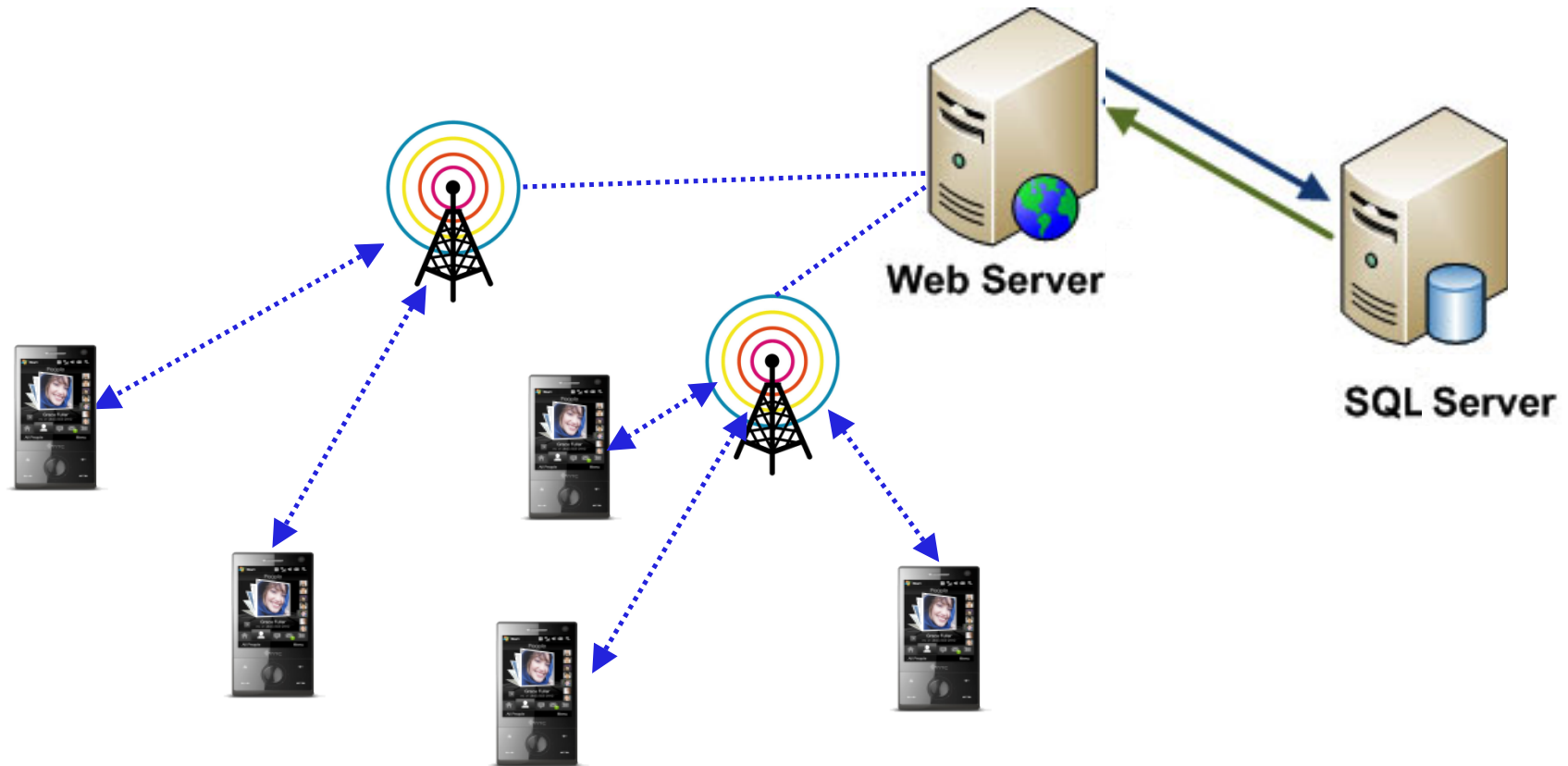
- Incentive for participating experiments

- Collection cycle: real-time, day, or week?



FluPhone Server

- Via GPRS/3G FluPhone server collects data





Security and Privacy

- Current method: Basic anonymisation of identities (MAC address)
- FluPhone server – use of HTTPS for data transmission via GPRS/3G
- Anonymising identities may not be enough?
 - Simple anonymisation does not prevent to be found the social graph
- **Ethic approval tough!**
 - **~40 pages** of study protocol document for FluPhone project – took several months to get approval



Currently No Location Data

- Location data necessary?
 - Ethic approval gets tougher
 - Use of WiFi Access Points or Cell Towers
 - Use of GPS but not inside of buildings
- Infer location using various information
 - Online Data (Social Network Services, Google)
 - Us of limited location information – Post localisation

Bluetooth Big Brother uses mobiles and laptops to track thousands of Britons


By DAVID DERBYSHIRE
Last updated at 8:15 AM on 22nd July 2008

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A Big Brother network of hidden scanners is monitoring hundreds of thousands of Britons without their knowledge, it emerged yesterday.

Scientists track people walking around cities, using the Bluetooth signals from their mobiles, laptops and handheld computers.

Scanners in bars, offices and universities register nearby Bluetooth devices and send the information to a central database.



SCANNING YOUR EVERY STEP

1 Bluetooth mobile phones, laptops, handheld computers, earpieces and digital cameras broadcast a unique code and name.

BATH!





Consent



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Email: Password:
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Consent

This page asks for you to agree to be a participant in the study. It is important that you understand and agree with the consent and study information.

See [here](#) for information about this study.

You must read [this software disclaimer](#).

If you are under 16 years old, we require that your parent or carer provide their consent for you to take part in this study. You must be over 12 years old to take part in this study.

To participate in this study, you must:

- have read, understand and agree with the consent and study information;
- have access to a compatible mobile phone;
- have read, understand and agree with the Fluphone software disclaimer;
- agree to download and run the FluPhone software application on your mobile phone;
- agree for the Fluphone application to use the Bluetooth function of your mobile phone;
- agree for the Fluphone application to send the data it collects to the study team via your network connection, and that this may incur a cost to the billpayer of the phone;
- be willing to allow your data and the information that the FluPhone software collects on your phone to be used for scientific research by the study team.

Please note: You have to fill in all fields.

1. Please click the appropriate one:	<input type="radio"/> I am under 16 years old, but over 12 years old, and have parental or carer consent for me to take part in this study.
	<input type="radio"/> I am over 16 years old and wish to take part in this study.
2. Please click the appropriate one:	<input type="checkbox"/> I have the permission of the bill payer to use this mobile in the study.
	<input type="button" value="Submit"/>



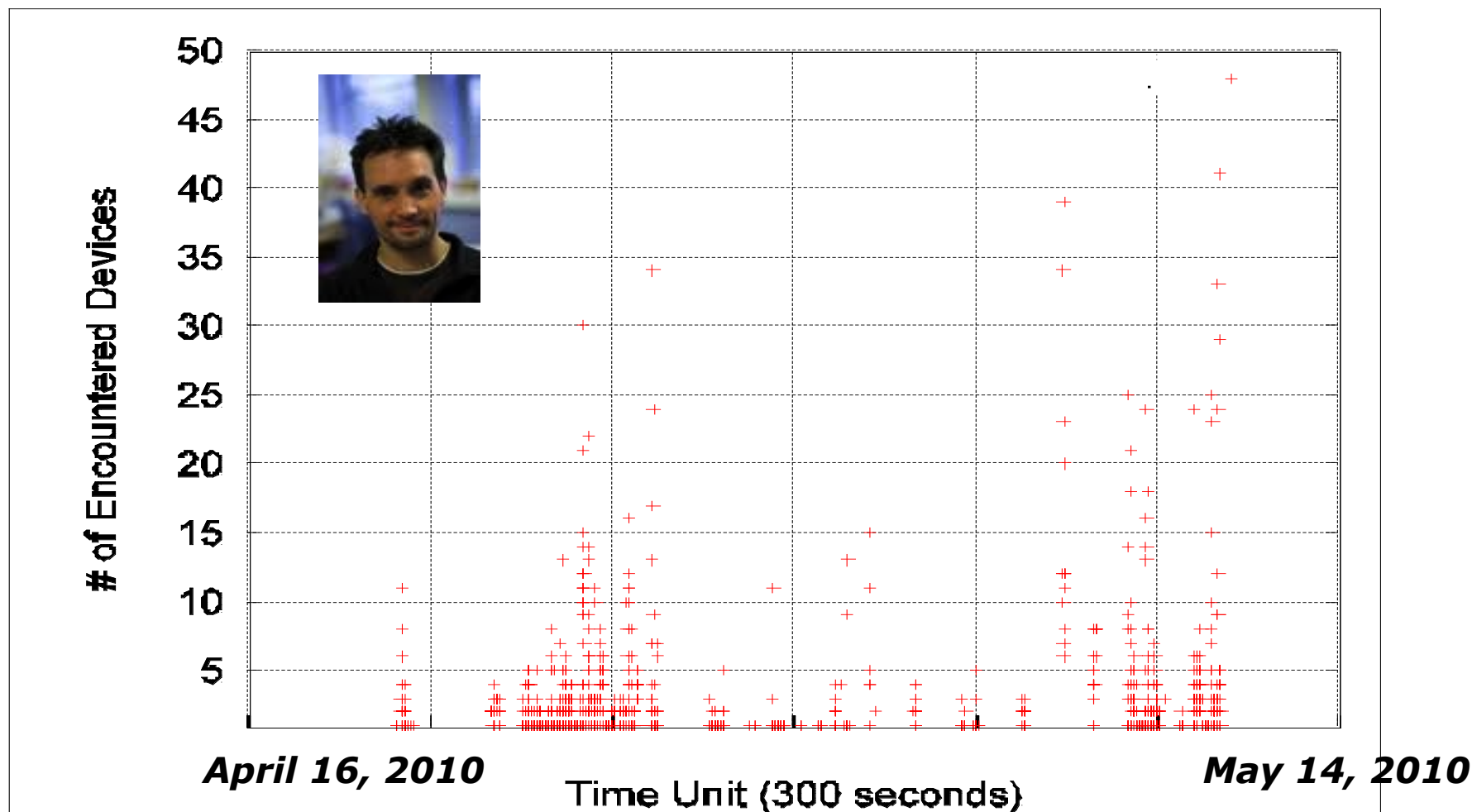
Study Status

- Pilot study (April 21 ~ May 15)
 - Computer Laboratory
 - Very few participants – people do not worry flu in summer
- **University scale study (May 15 ~ June 30)**
 - Advertisement (all departments, 35 colleges, student union, industry support club, Twitter, Facebook...)
 - Employees of University of Cambridge, their families, and any residents or people who work in Cambridge
 - Issues
 - Limited phone models are supported
 - Slightly complex installation process
 - Motivation to participate...



Encountered Bluetooth Devices

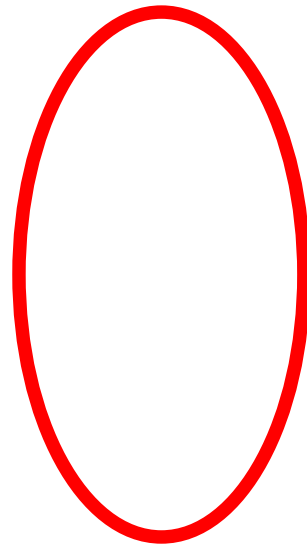
- A FluPhone Participant Encountering History





Existing Human Connectivity Traces

- Existing traces of contact networks
- ..thus far not a large scale



- Let's use Cambridge trace data to demonstrate what we can do with FluPhone data...



Analyse Network Structure and Model

- Network structure of social systems to model **dynamics**
- Parameterise with interaction patterns, modularity, and details of time-dependent activity
 - Weighted networks
 - Modularity
 - Centrality (e.g. Degree)
 - Community evolution
 - Network measurement metrics
 - Patterns of interactions

Publications at:

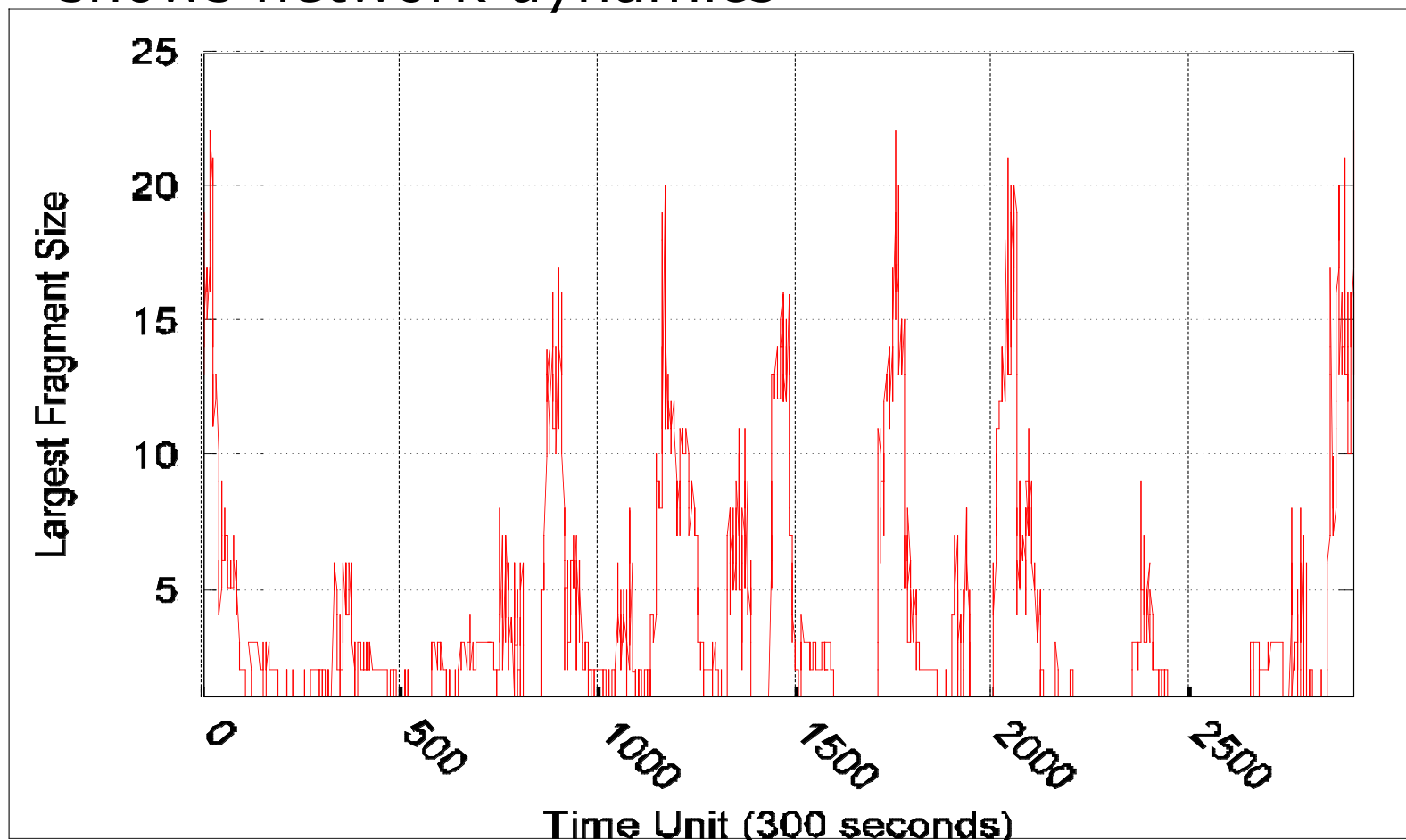
<http://www.hagggleproject.org>

<http://www.social-nets.eu/>



Regularity of Network Activity

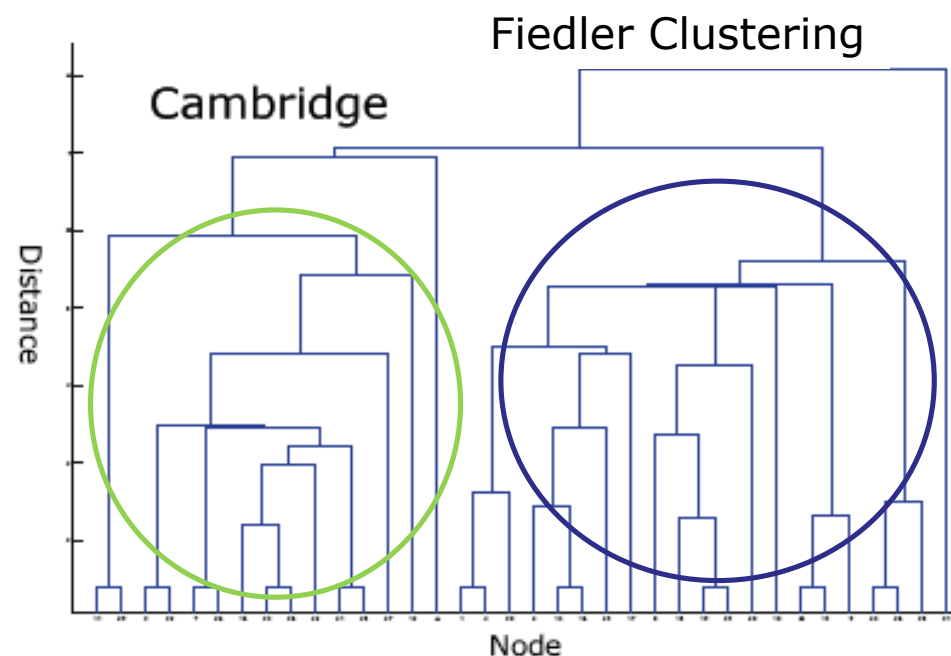
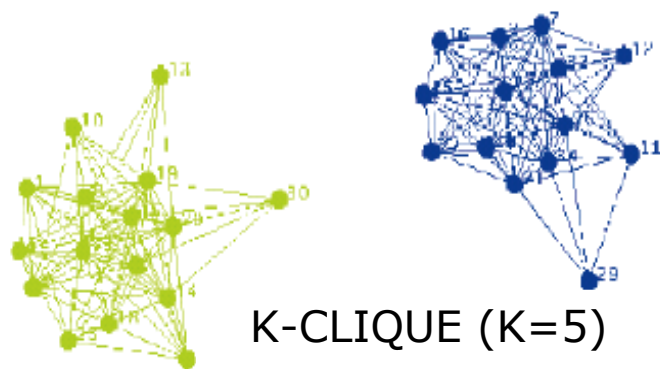
- Cambridge Data (11 days by undergraduate students in Cambridge): Size of largest fragment shows network dynamics





Uncovering Community

- Contact trace in form of weighted (multi) graphs
 - Contact Frequency and Duration
- Use community detection algorithms from complex network studies
 - K-clique, Weighted network analysis, Betweenness, Modularity, Fiedler Clustering etc.





Simulation of Disease – SEIR Model

Four states on each node:

SUSCEPTIBLE → **E**XPOSED → **I**NFECTED → **R**ECOVERD

Parameters

p: exposure probability

a: exposed time (incubation period)

t: infected time

Diseases

D1 (SARS): $p=0.8$, $a=24\text{H}$, $t=30\text{H}$

D2 (FLU): $p=0.4$, $a=48\text{H}$, $t=60\text{H}$

D3 (COLD): $p=0.2$, $a=72\text{H}$, $t=120\text{H}$

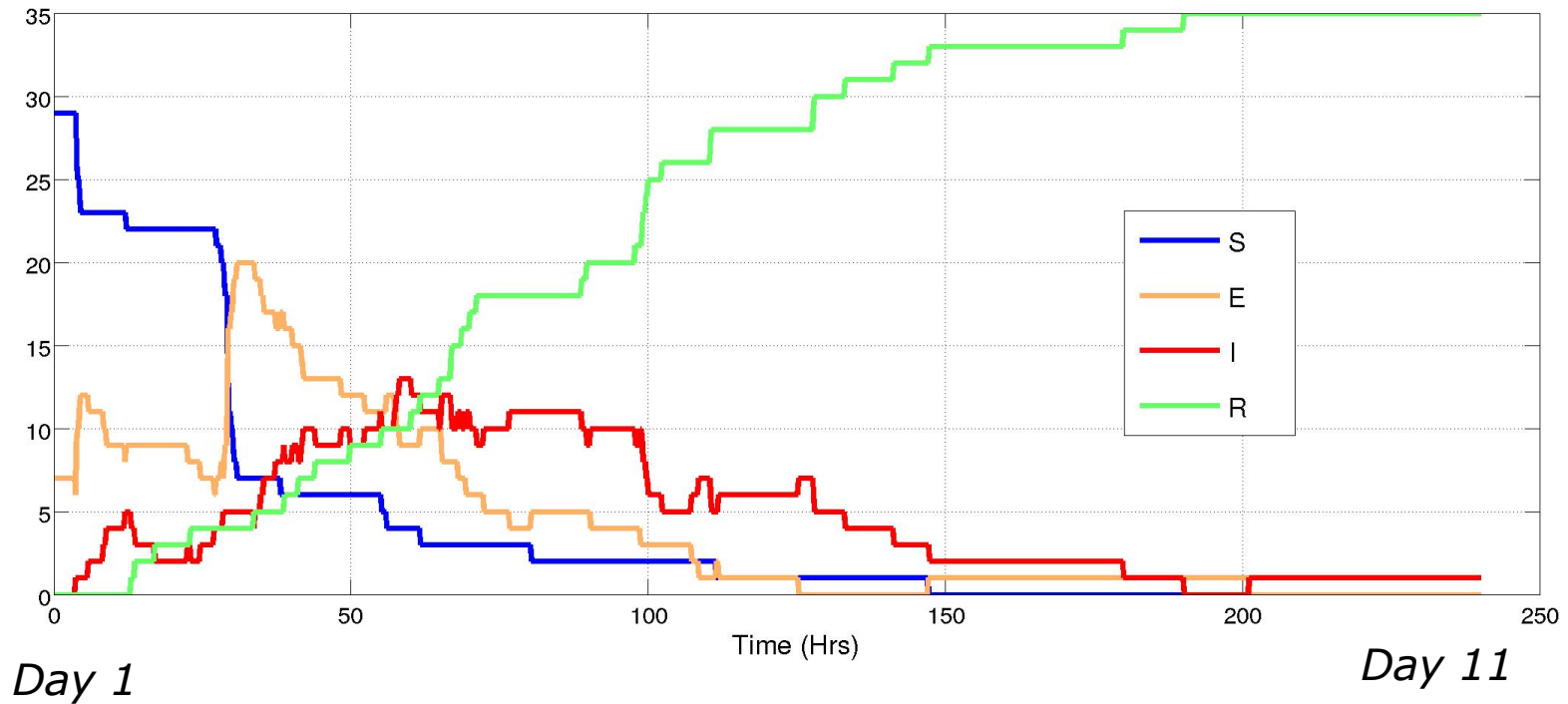
Seed nodes

Random selection of 20% of nodes (=7) among 36 nodes



SARS

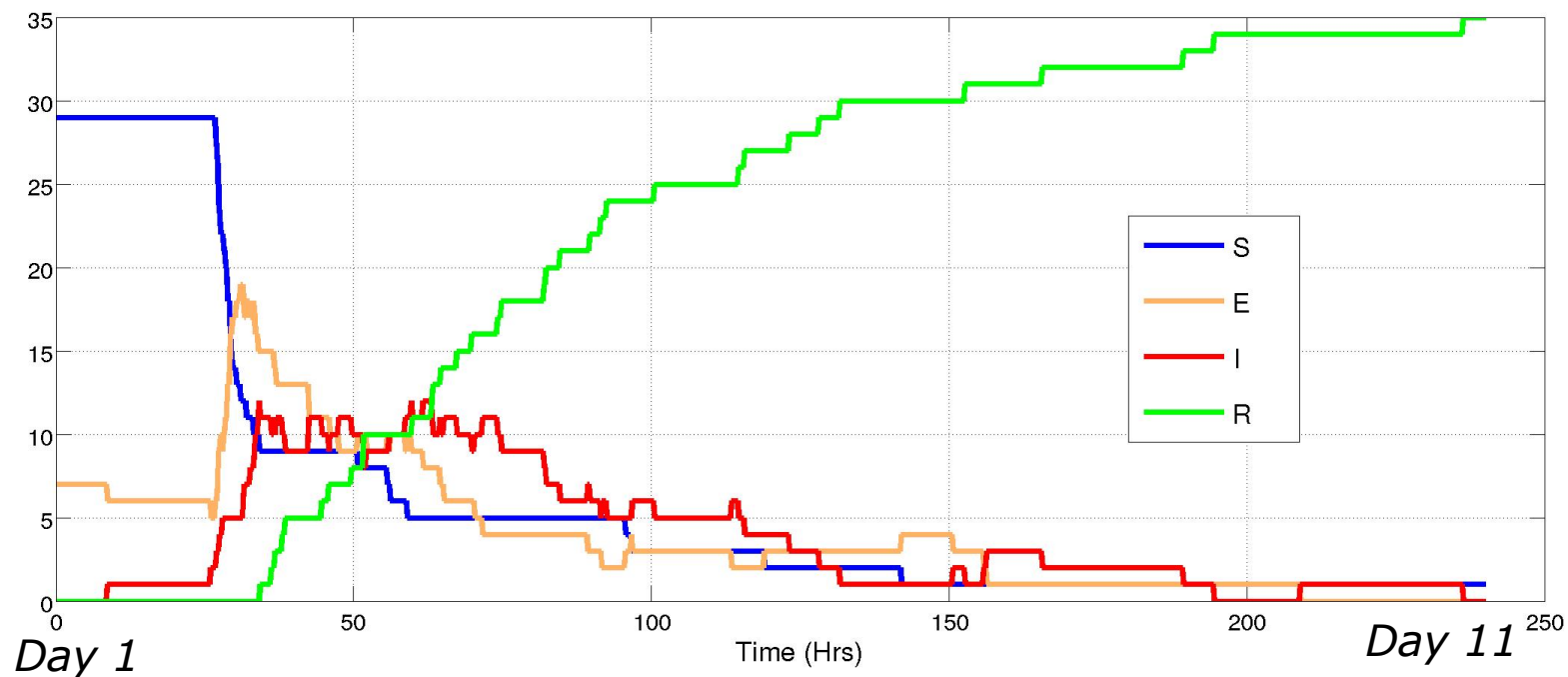
- Exposure probability = 0.8
- Exposed time = 24H (average)
- Infected time = 30H (average)





Flu

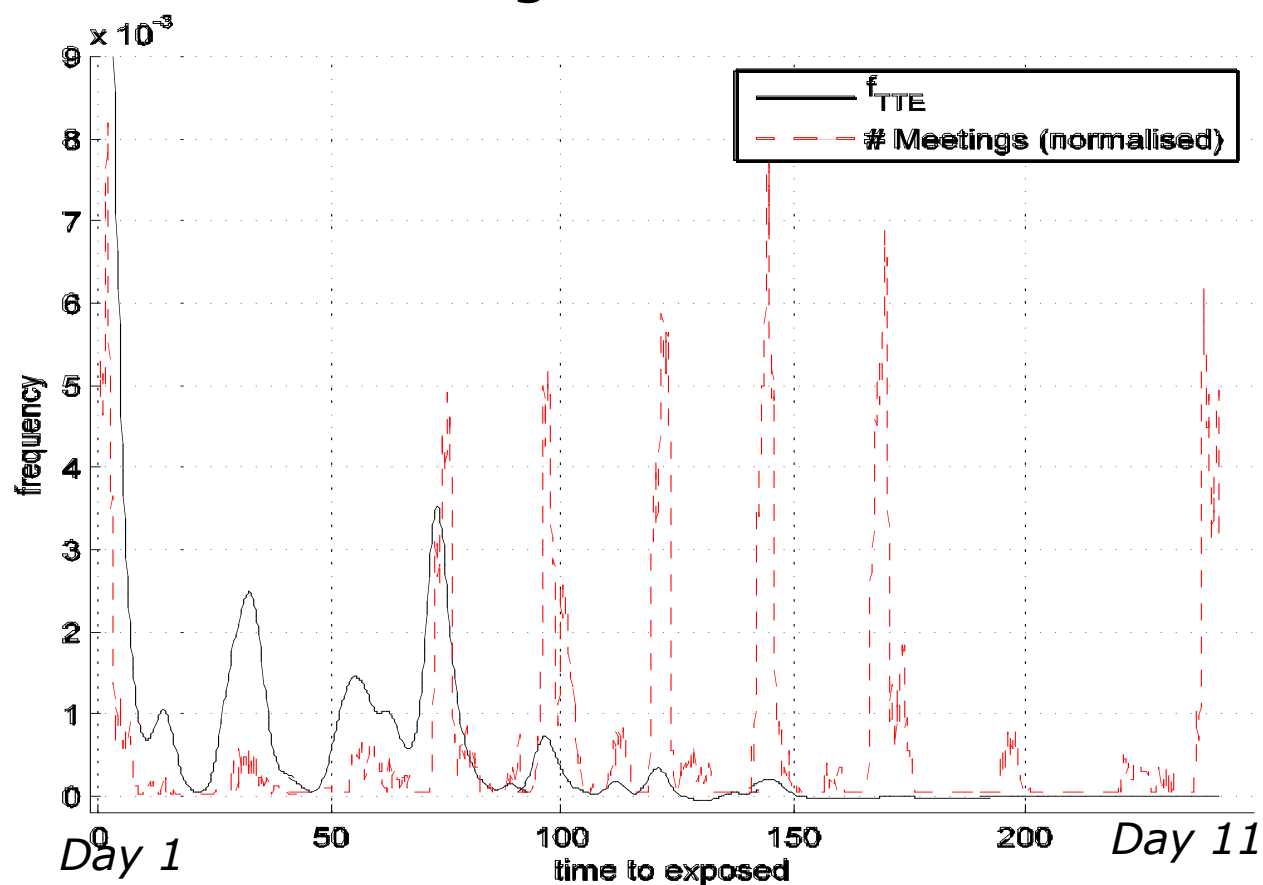
- Exposure probability = 0.4
- Exposed time = 48H (average)
- Infected time = 60H (average)





Time to Exposure vs #of Meetings

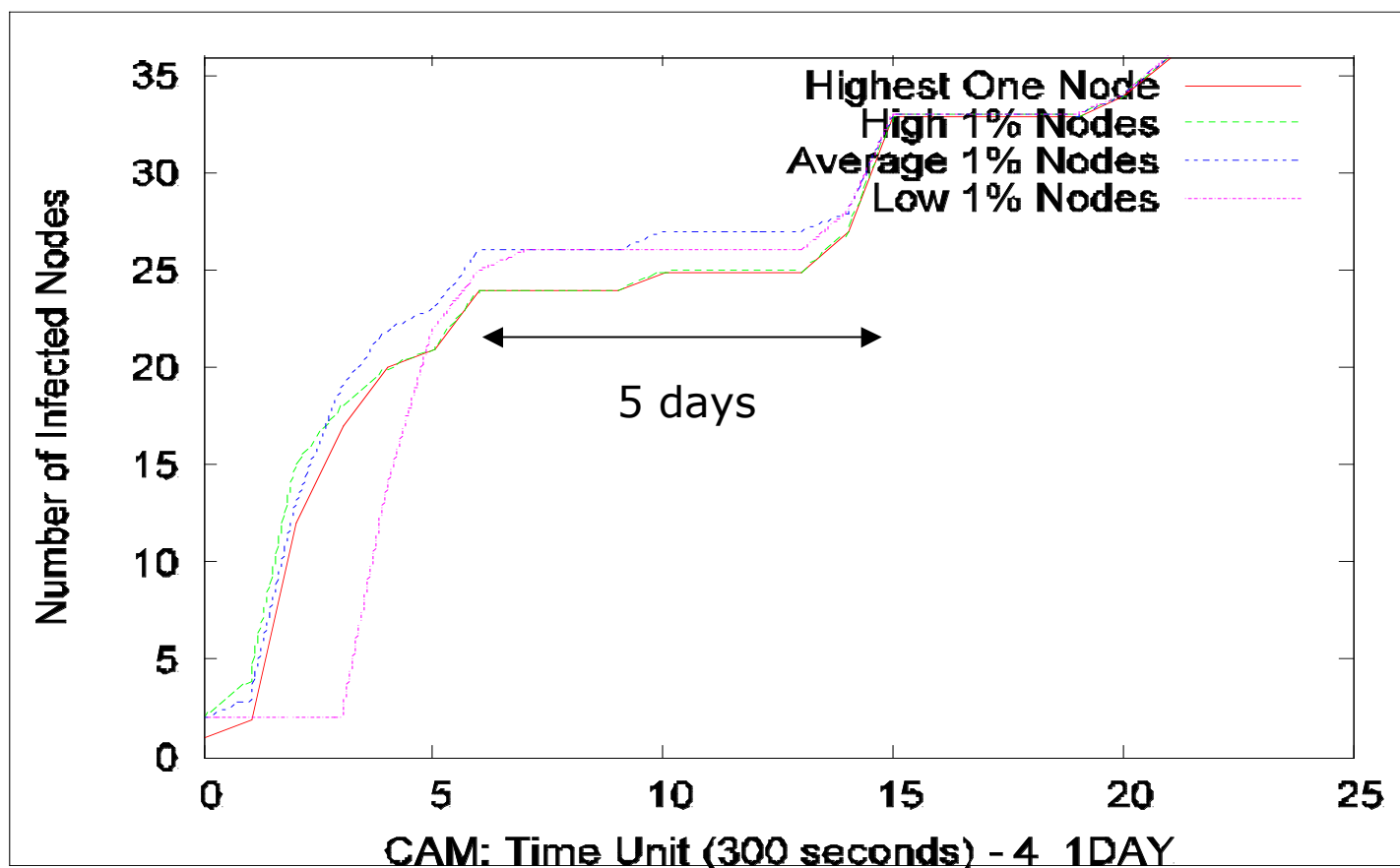
- Distribution of time to infection (black line) is strongly influenced by the time dependent adjacency matrices of meetings





D0: Simple Epidemic (3 Stages)

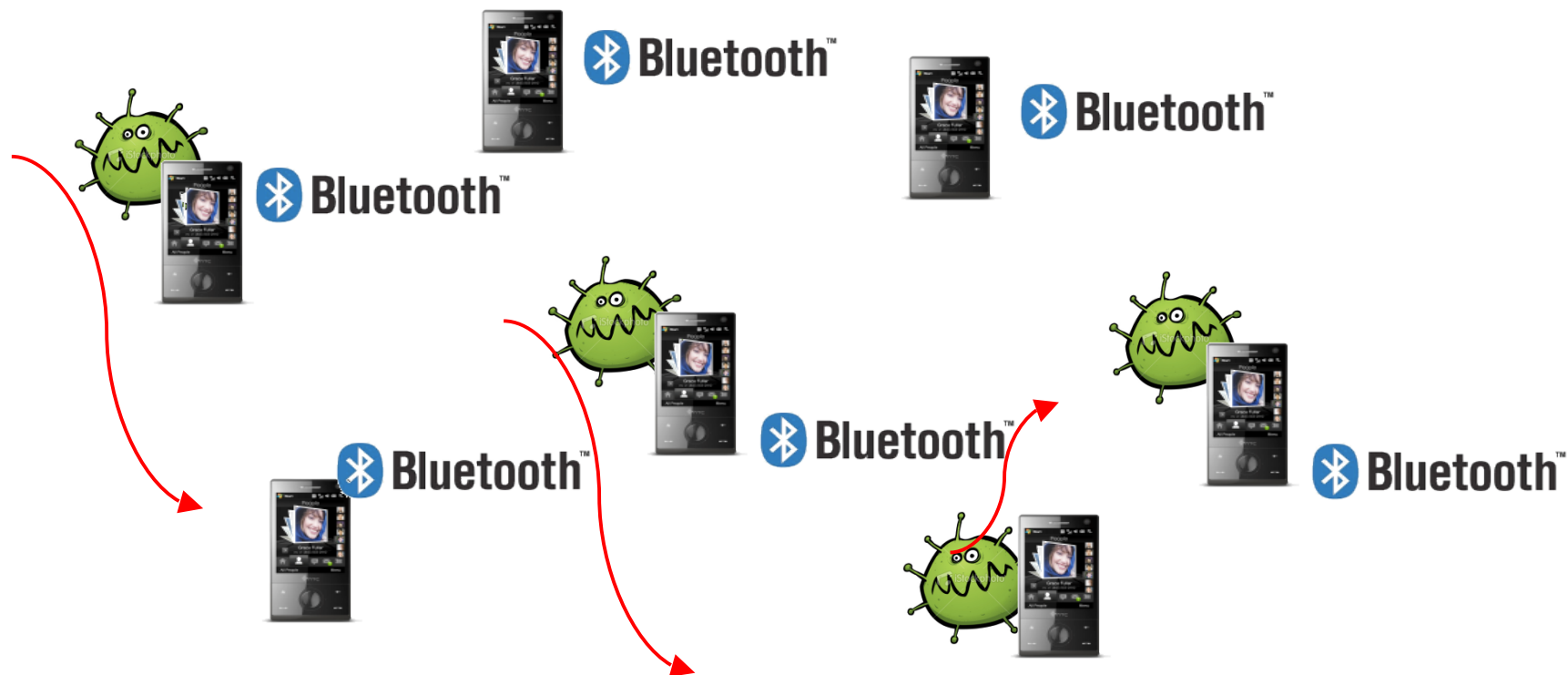
- First Rapid Increase: Propagation within Cluster
- Second Slow Climbing
- Reach Upper Limit of Infection





Virtual Disease Experiment

- Spread virtual disease via Bluetooth communication in proximity radio range
- Integrate SAR, FLU, and COLD in SIER model
- Provide additional information (e.g. Infection status, news) to observe behavioural change





Conclusions

- Quantitative Study
- Lots more to be done
- Acknowledge Veljko Pejovic, Daniel Aldman, Tom Nicolai, and Dr Damien Fay



The FluPhone Project

<http://www.cl.cam.ac.uk/research/srg/netos/fluphone/>
<https://www.fluphone.org>

Email: flu-phone@cl.cam.ac.uk



[Main page](#) [Information](#) [Help](#) [Contact us](#)

Email: Password:
[Forgotten your password?](#)

FluPhone Study

This is the home page for the FluPhone study. A study to measure social encounters made between people, using their mobile phones, to better understand how infectious diseases, like flu, can spread between people.

This study will record how often different people (who may not know each other) come close to one another, as part of their everyday lives. To do this, we will ask volunteers to install a small piece of software (called FluPhone) on their mobile phones and to carry their phones with them during their normal day-to-day activities. The software will look for other nearby phones periodically using Bluetooth, record this information and send it back to the research team via the cellular phone data service. This information will give us a much better understanding of how often people congregate into small groups or crowds, such as when commuting or through work or leisure activities. Also, by knowing which phones come close to one another, we will be able to work out how far apart people actually are, and how fast diseases could spread within communities. We are also asking participants to inform us of any influenza-like symptoms they may experience during the study period, so that we can match the spread of flu to the underlying social network of encounters made.

If you wish to take part in this study, please read the study information below, and then click [here](#) to start the registration process.

For more detailed information about the study, please visit the [study information page](#).



News:

- The pilot study within the university will start on the April 1st, 2010
- The webpage is up!



Reserve Slides

Visualisation of Community Dynamics



Data Collection

- Robust data collection from **real world**
- Post-facto analysis and modelling yield insight into human interactions
- Data is useful from building communication protocol to understanding disease spread

Modelling Contact Networks: Empirical Approach

Classification of Node Pairs

- Pair Classification:

I: **Community**

High Contact N^o - Long Duration:

II: **Familiar Stranger**

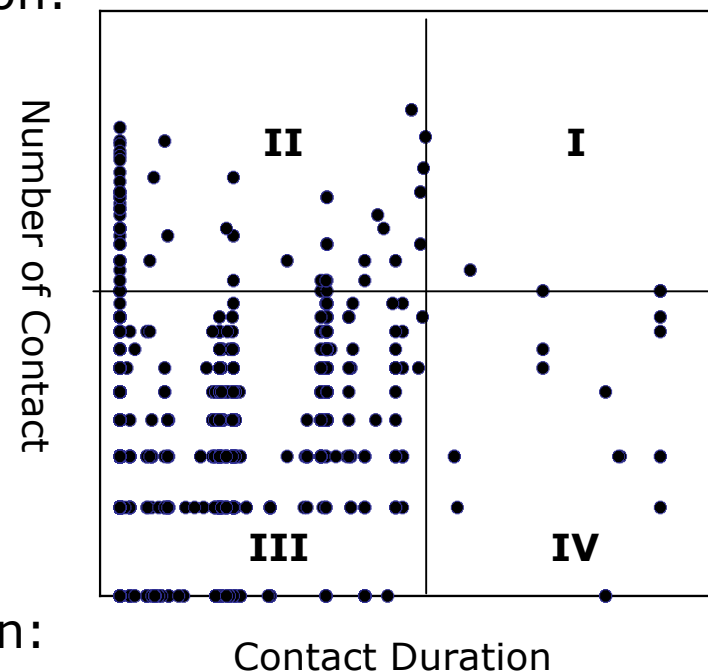
High Contact N^o - Short Duration:

III: **Stranger**

Low Contact N^o - Short Duration:

IV: **Friend**

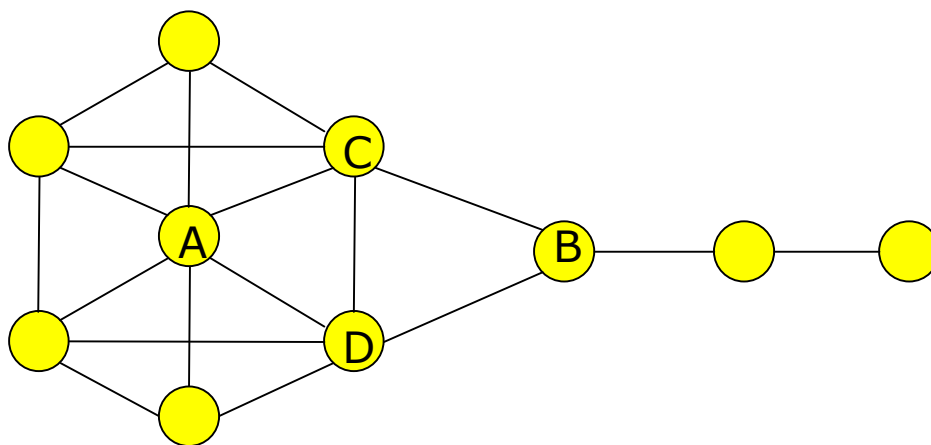
Low Contact N^o - High Duration:





Centrality in Dynamic Networks

- Degree Centrality: Number of links
- Closeness Centrality: Shortest path to all other nodes
- Betweenness Centrality: Control over information flowing between others
 - High betweenness node is important as a relay node
 - Large number of unlimited flooding, number of times on shortest delay deliveries → Analogue to Freeman centrality





Betweenness Centrality

- Frequency of a node that falls on the shortest path between two other nodes

