


# Mobile Social Networks

*Jon Crowcroft & Eiko Yoneki & Narseo Vallina  
Rodriguez*

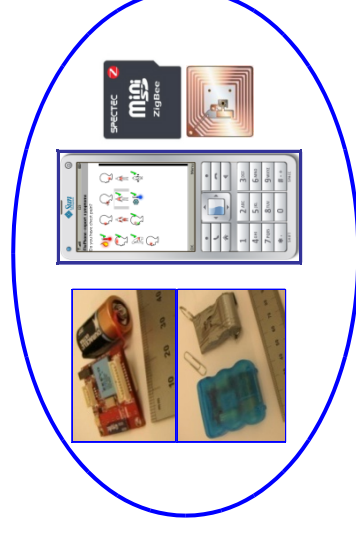
*[jon.crowcroft@cl.cam.ac.uk](mailto:jon.crowcroft@cl.cam.ac.uk), [eiko.yoneki@cl.cam.ac.uk](mailto:eiko.yoneki@cl.cam.ac.uk)*

*Systems Research Group  
University of Cambridge Computer Laboratory*

# I. Spread of Infectious Diseases

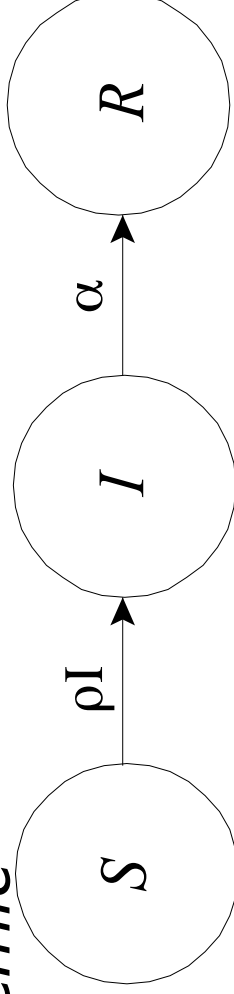
- Threat to public health: e.g.,  , SARS, AIDS
- Current understanding of disease spread dynamics
  - Epidemiology: Small scale empirical work
  - Physics/Math: Mostly large scale abstract/simplified models
- Real-world networks are far more complex
- ➡ Advantage of **real world data**
- ➡ Emergence 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**



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



# *What is a Mathematical Model?*

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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

e.g. celestial motion, chemical kinetics



# The SIR Epidemic Model

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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

$$S + I + R = 1$$

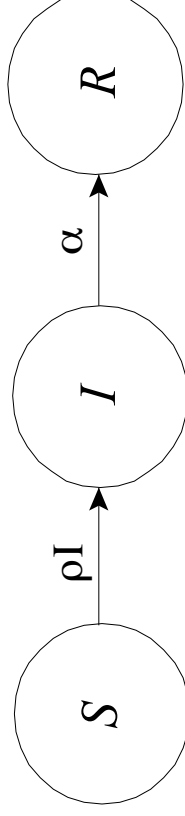
## The SIR Epidemic Model (Cont'd)

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- *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

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- $\rho$  = the *infection rate*
- $\alpha$  = 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

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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

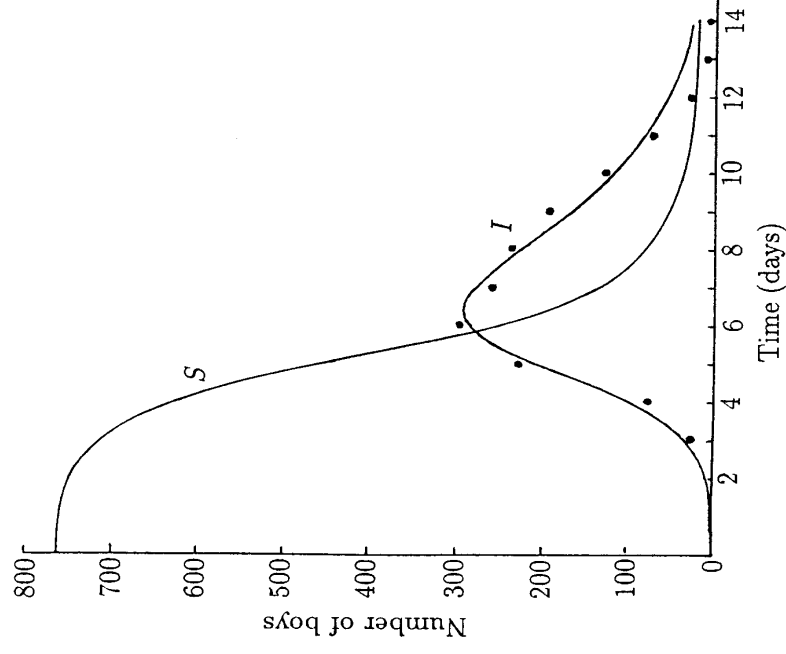
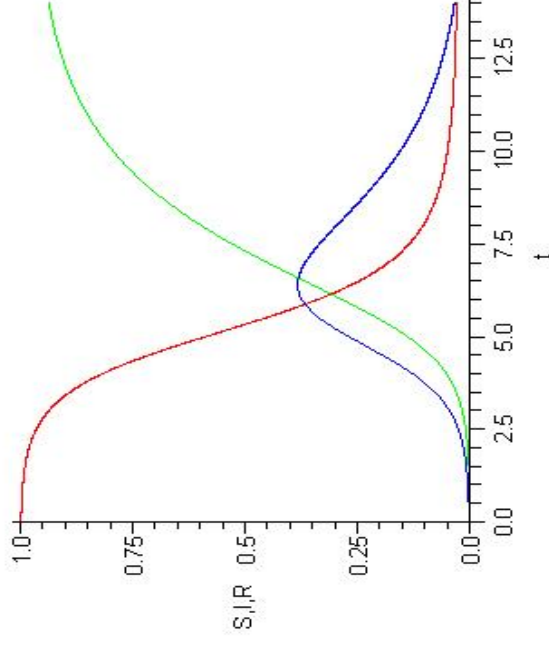
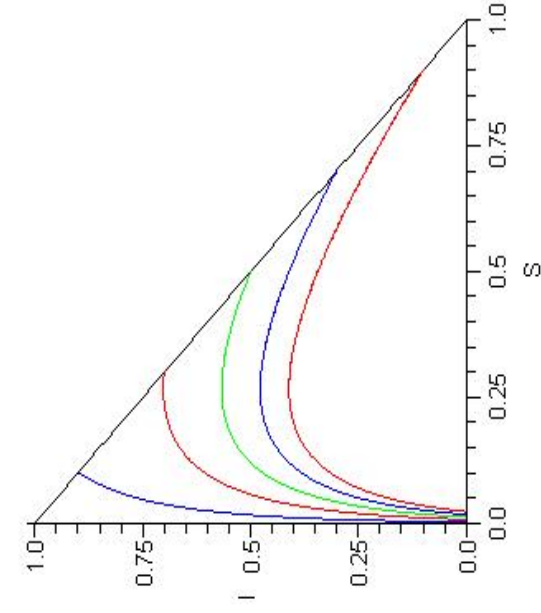


Fig. 19.3. Influenza epidemic data (•) for a boys boarding school as reported in British Medical Journal, 4th March 1978. The continuous curves for the infectives ( $I$ ) and susceptibles ( $S$ ) were obtained from a best fit numerical solution of the  $SIR$  system (19.1)–(19.3); parameter values  $N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

## Boarding School Flu (Cont'd)

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



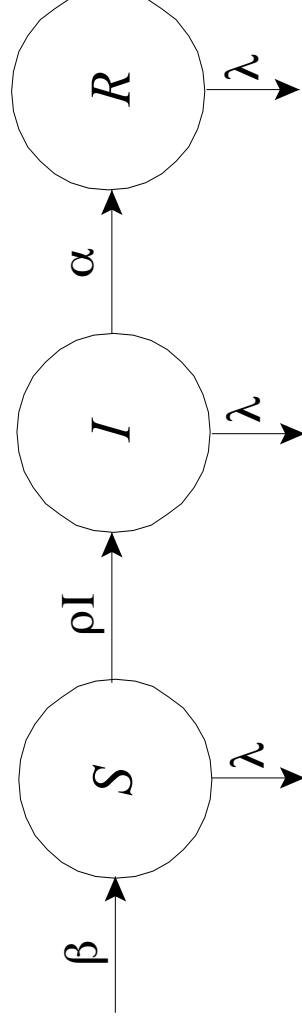
# Flu at Hypothetical Hospital

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- In this case, new susceptibles are arriving

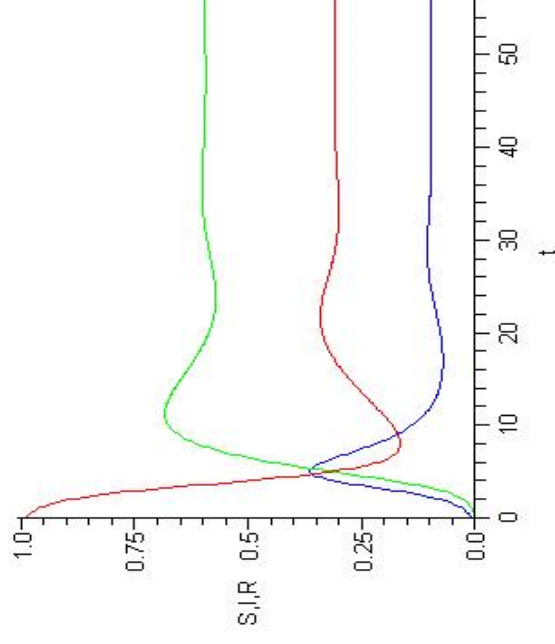
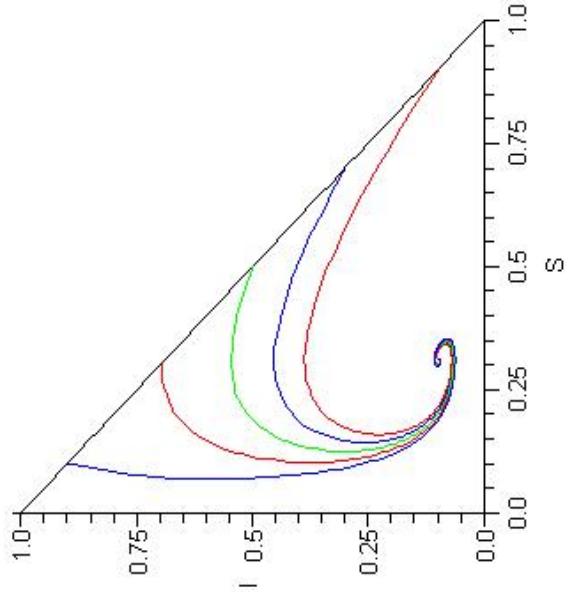
and those of all classes are leaving.

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



## *Flu at Hypothetical Hospital (Cont'd)*

- Parameters  $\rho$  and  $\alpha$  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*.

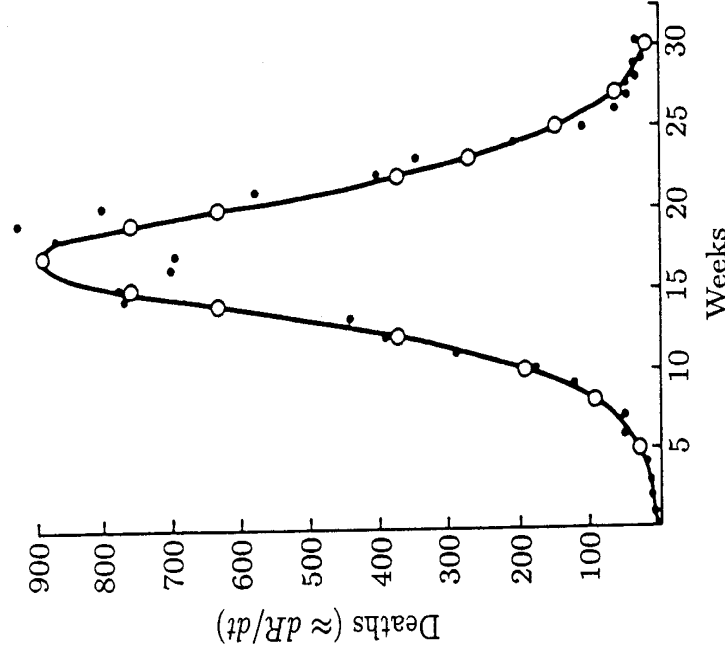


Fig. 19.2. Bombay plague epidemic of 1905-6. Comparison between the data ( $\bullet$ ) and theory ( $\circ$ ) from the (small) epidemic model and where the number of deaths is approximately  $dR/dt$  given by (19.16). (After Kermack and McKendrick 1927)

# *Eyam Plague, 1665-66*

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

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

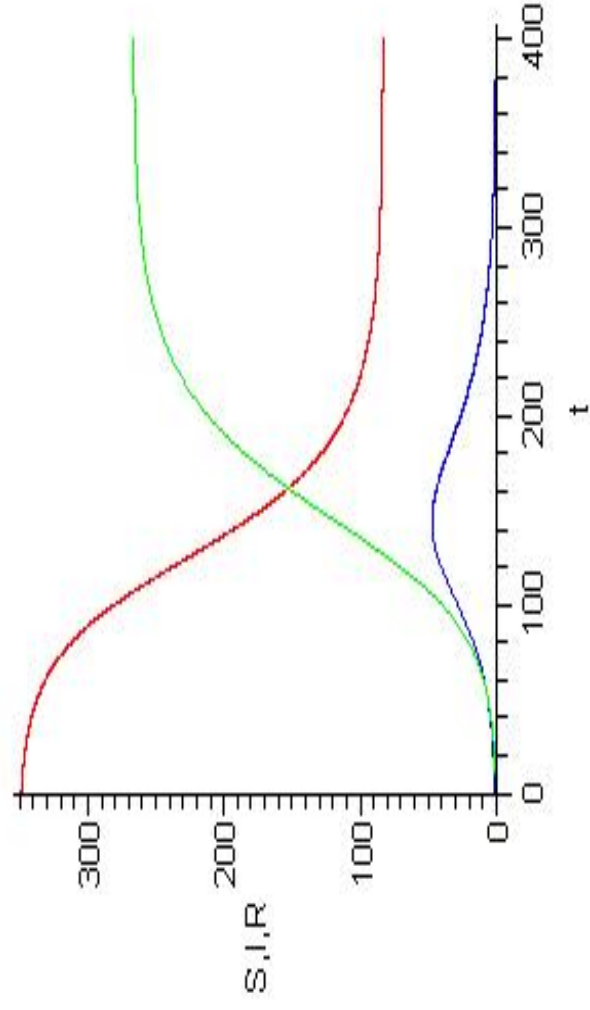
It began when some cloth infested with infected fleas arrived from London. George Vicars, the village tailor, was the first to die.

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

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

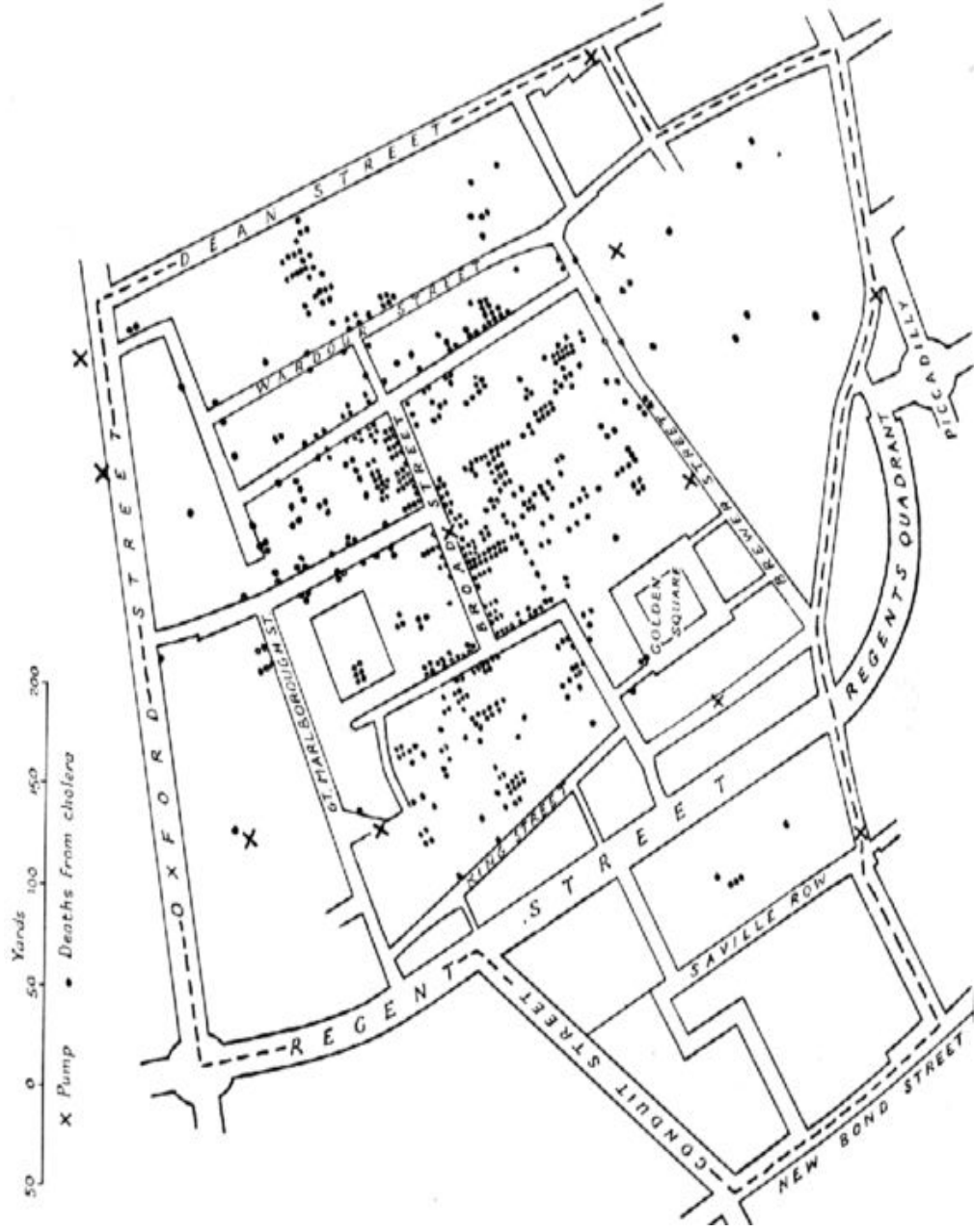
Can consider an *exposed* (but not yet infected) class, the SEIR model.

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*

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We *meet* in real life in the real world

We use text *messages*, phones, IM

We make *friends* on facebook, Second Life

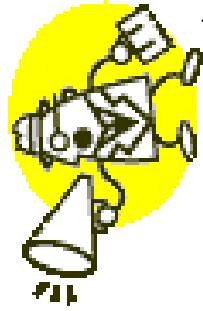
How are these **related**?

How do they **affect** each other?

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

Thank you but you are in the opposite direction!

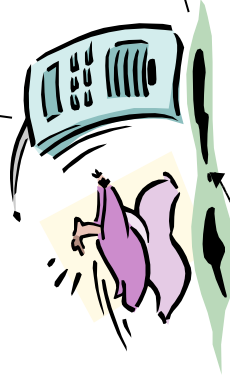
I have 100M bytes of data, who can carry for me?



Don't give to me! I am running out of storage.



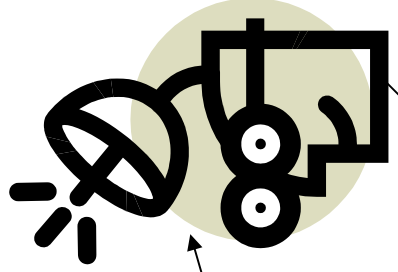
Give it to me, I have 1G bytes phone flash.



I can also carry for you!



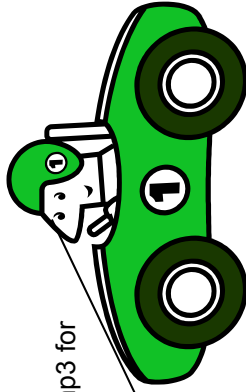
Reach an access point.



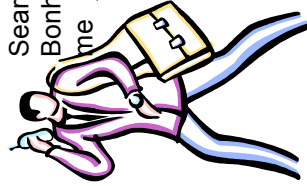
There is one in my pocket...



Search La Bonheme.mp3 for me



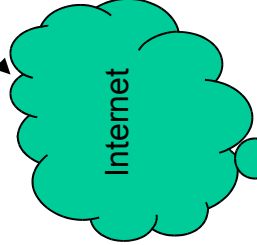
Search La Bonheme.mp3 for me



Search La Bonheme.mp3 for me



Internet

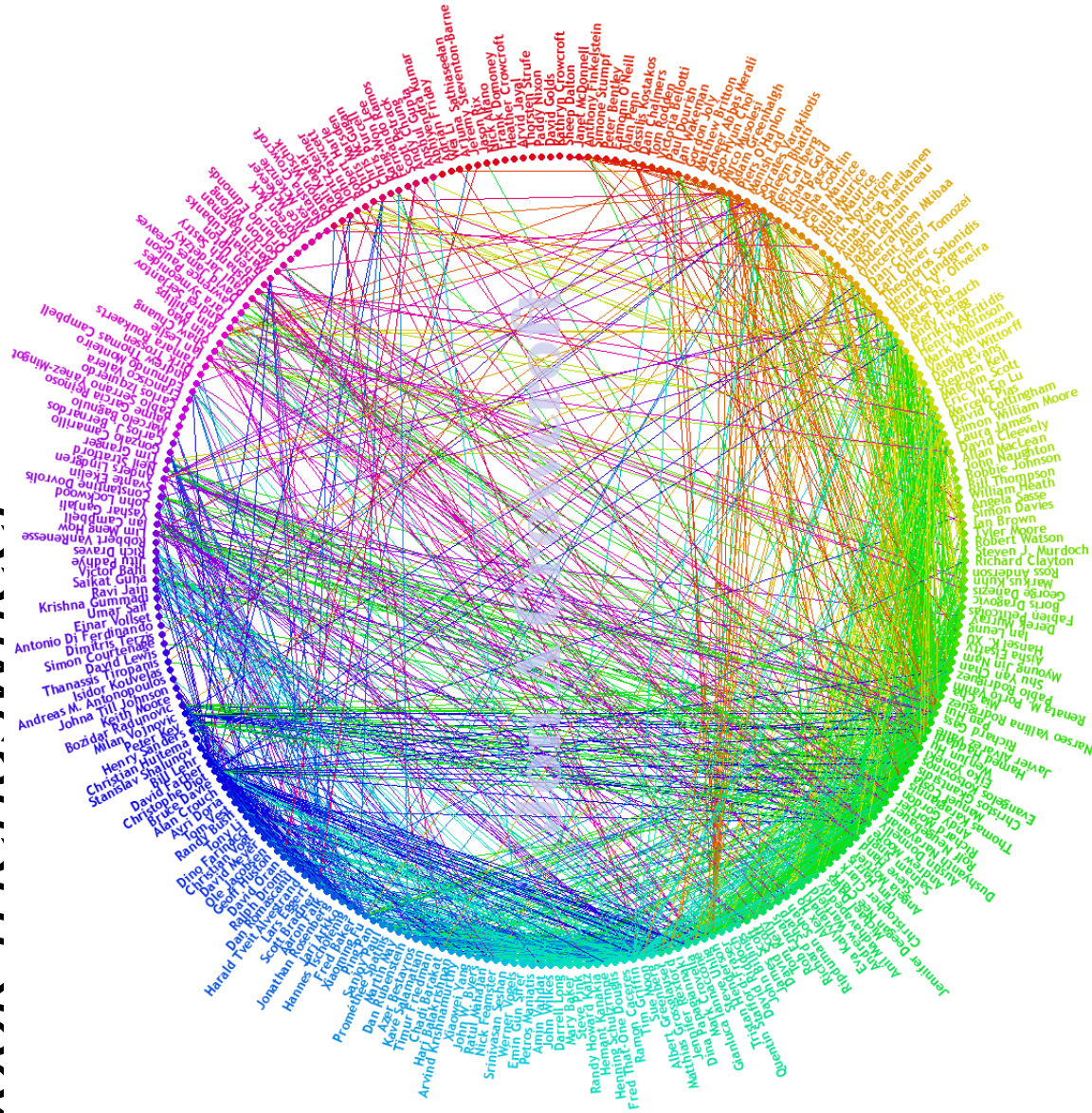


Finally, it arrive...





# My facebook friendswheel





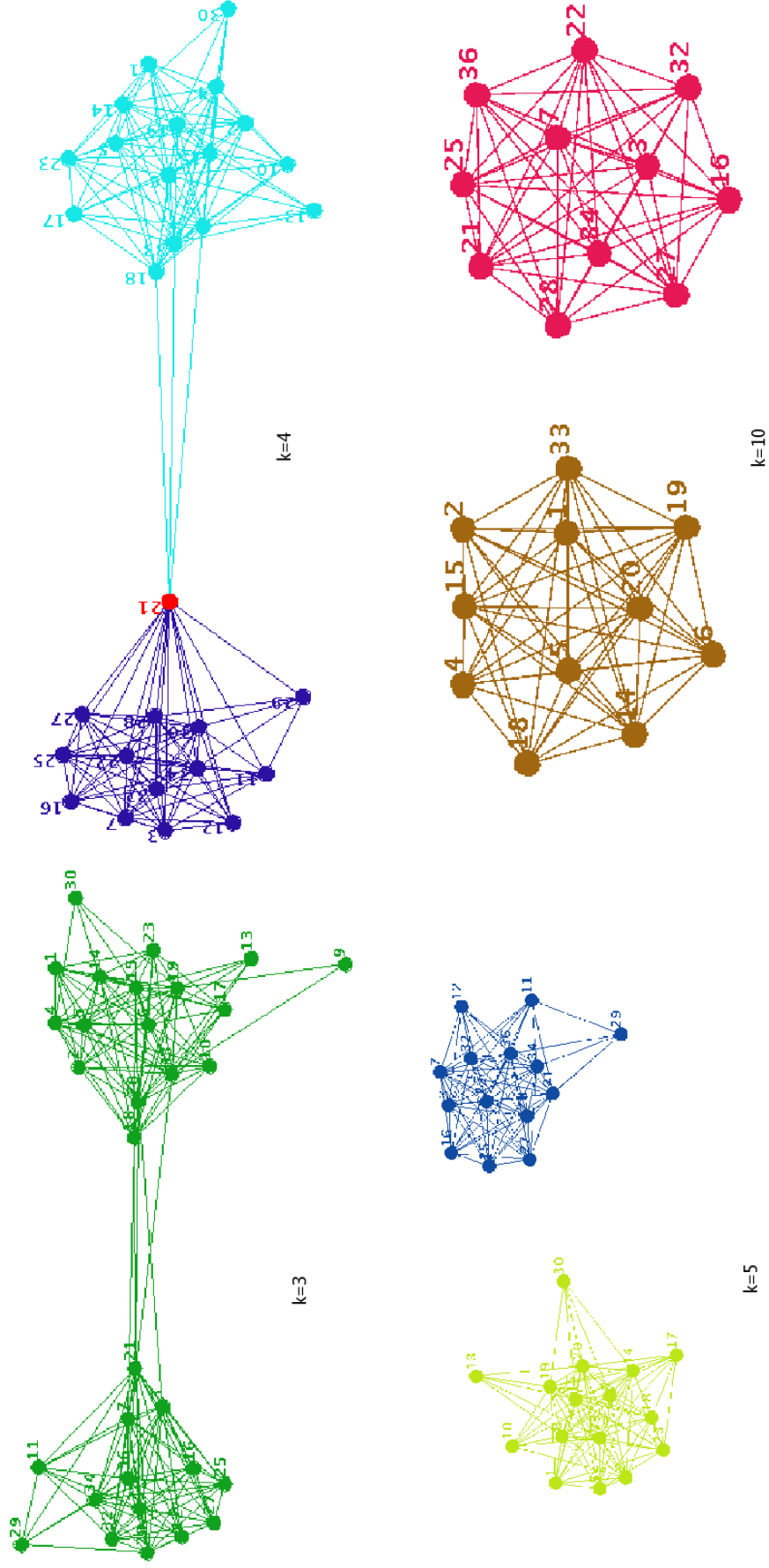
# My email statistics!

The screenshot displays a Gmail inbox with the following details:

- Page Header:** Wed 09:35, Web Clip, 1 - 30 of 30205 Older... Newest
- Search Bar:** Search Mail, Search the Web, Search the Web
- Navigation:** Compose Mail, Mail, Labels, etc.
- Filters:** Inboxes, Labels, etc.
- Table Headers:** Select, All, None, Read, Unread, Starred, Unstarred
- Table Content (Sample Rows):**

Sender	Subject	Time
Alan, Frank, Jon, Neil (4)	[RESPONSE requested] Teaching Planning - To: all Computer Laboratory Schedule / teaching staff. As I mentioned in the Wednesday Meeting...	9:34 am
[IMBONED] WGLC on SSMPING	We have been asked by Sig about this and feel that SSMPING is ready for WGLC. Please comment on ...	9:30 am
Marshall... Guntur, Sig (7)	[discuss] GENI System Requirements - On Mon, Oct 20, 2008 at 03:31:22PM, Aaron Falk wrote > GENI System Requirements ...	9:10 am
Aaron, Ted, Jon (3)	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
Sue, Jon (4)	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
Ken, R., Jon (16)	Re: sensor posters any one? - yes On 22 Oct 2008, at 07:21, Jon Crowcroft wrote: > Forwarded Message ...	9:04 am
Cecilia Mascolo	thesis plan thoughts - Hi Jon I am still in the middle of rewriting these plans, but here are the two options in my head ...	8:57 am
Nishanth, Jon (2)	Vodafone Lecture, February 2009 - Dear all I have provisionally booked The Royal Academy of Engineering's in-house lecture ...	8:55 am
Helen, Jon (2)	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
Mahesh Marina	Notification of ACCEPTANCE Decision for COMNET-D-08-2716R1 - Dear Dr. Crowcroft, For this manuscript Performance Evaluation of Data-Centric Information ...	7:45 am
PARIZ, Steven, Paul (4)	[ita-salliance] 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)	WGL-05-0007-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 - SMUToolbox: 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
S.Aveva	Reference Request from Surrey - Hi John, University of Surrey, Centre for Communication Systems Research (CCSR) has shortlisted ...	11:05 pm
Rashid Mahmood	CCNR & Barabási Lab Announcements - Center for Complex Network Research (CCNR) announce-track position Assistant Professorship in ...	10:48 pm
BB-ubcomp... Marks (5)	[grandchallenge] October 30th/31st retreat @ Crowne Plaza hotel, Nottingham - Dear all, The following names confirmed for the above retreat, aimed at working on follow ...	10:42 pm
Facebook	Re: Babak Ayzafar 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 ...	9:58 pm
M. Malliya	Wolfsen Wine Tasting - this Saturday - We will be kicking off this year with our first tasting this ...	Oct 21
BB-ubcomp, Jon, Morris (3)	[grandchallenge] Workshop funds application for consideration - I think I can see the relevance of a workshop on Sensory Augmentation Research and that it ...	Oct 21
Any 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 Sewall	lab TSC/ARG/CPRG research groups [> PLS - Dear all, this is just to let you know that we've tidied up the structure of the lab ...	Oct 21
The IESG	Last Call: draft-ietf-isis-wg-setup (Simplified Extension of LSP Space for ISIS) to P... - The IESG has received a request from the ISIS for IP Internets WG (ies) to consider the ...	Oct 21
Scott, Avri (3)	Last Call: draft-ietf-isis-tnac-sha (ISIS Generic Cryptographic Authentication) to Pro... - The IESG has received a request from the ISIS for IP Internets WG (ies) to consider the ...	Oct 21
Gorry Fairhurst	[IMBONED] WGLC on SSMPING - Comments on draft-ietf-isis-wg-setup-05.txt - I have read version -05 of the sampling spec, and see the following: 1) I think this protocol is a ...	Oct 21
Tasco.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 International ...	Oct 21
Ronnie Sant	Last Chance to Attend - Get a Complimentary AllAccess Pass for the 2008 Financial Serv... - Last Chance to Attend Get a Complimentary AllAccess Pass 2008 Financial Services ...	Oct 21
Mark Kirsten	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
Kyle (2)	kelly joe phelpis - awesome slide guitar/voic - just caught him on a bbc series about "guitar heroes" but he's really stunner ...	Oct 21
rc-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: RTP Payload ...	Oct 21
rc-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
rc-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
rc-editor	RFC 5254 on Requirements for Multi-Segment Pseudowire Emulation Edge-to-Edge (PWES) - A new Request for Comments is now available in online RFC libraries. RFC 5254 Title: ...	Oct 21

# Cliques and Communities



# *We are still learning about this!*

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There are big problems understanding this

Data?

Privacy?

Usefulness?

# Spread of Infectious Diseases

- Threat 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**

# 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>



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

Email:  Password:  [Log in](#)  
[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.

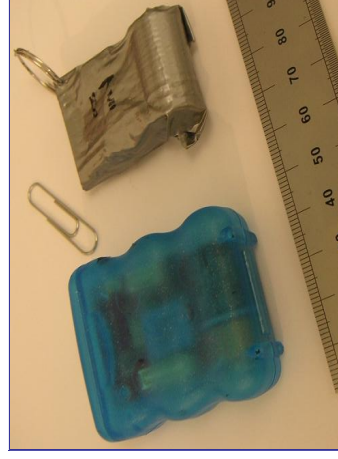


### News:

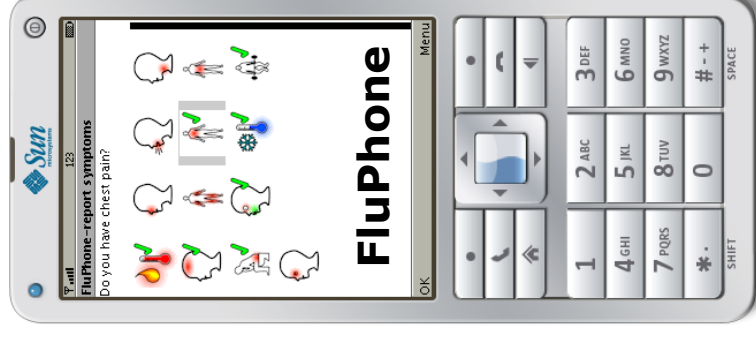
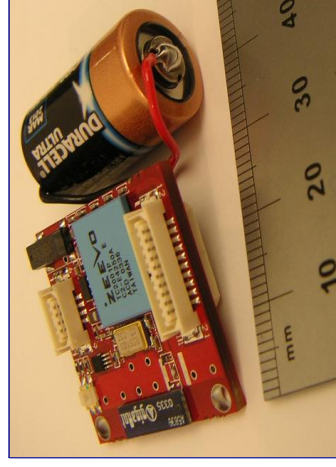
- The pilot study within the university will start on the April 1st, 2010
- The webpage is up!

# Various Data Collection

- Flu-like symptoms
- Proximity detection by Bluetooth
- Environmental information (e.g. in train, on road)
- Feedback to users
  - (e.g. How many contacts past hours/days)
- Towards potential health-care app
- Extending Android/iPhone platforms



**iMote**



## *Sensor Board or Phone or ...*

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- 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

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- $\sim < 20$  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*

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- 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*

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only ~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!**

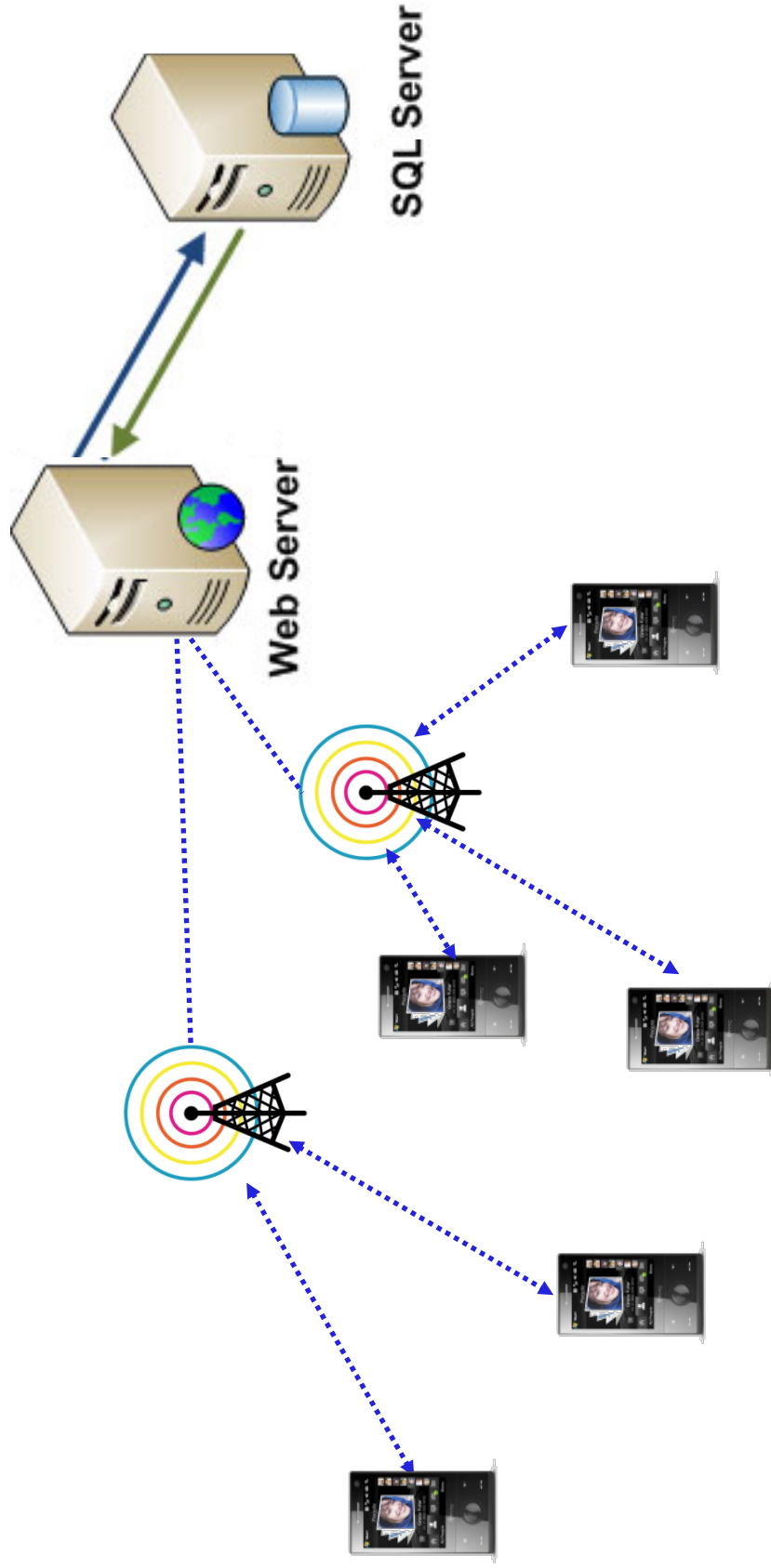
# *Data Retrieval Methods*

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- 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

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- 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 DEREVSHIRE  
Last updated at 8:15 AM on 22nd July 2008  
[Comments \(14\)](#) [Add to My Stories](#)

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

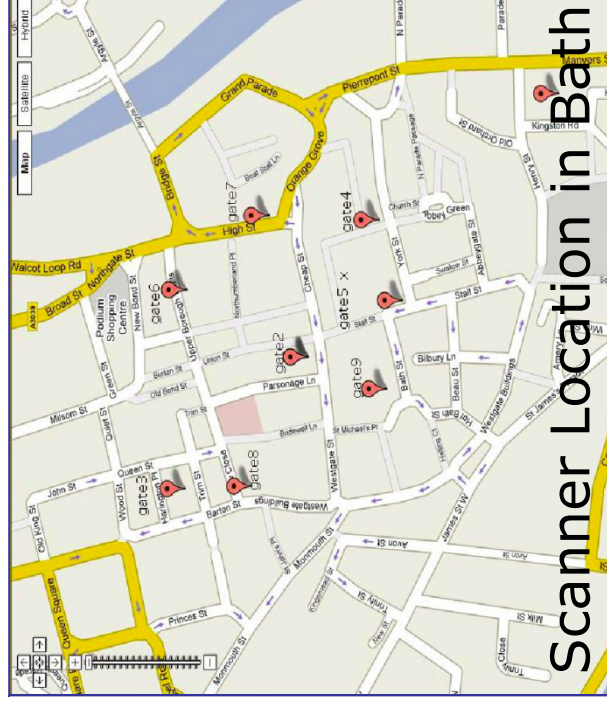
Scientists track people walking around cities, using the Bluetooth signals from their mobiles, laptops and handheld computers.

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, cameras and digital cameras broadcast a unique code and name.



# Consent



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

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

## 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

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- Pilot study (April 21 ~ May 15)
  - Computer Laboratory
  - Very few participants – people do not worry flu in summer

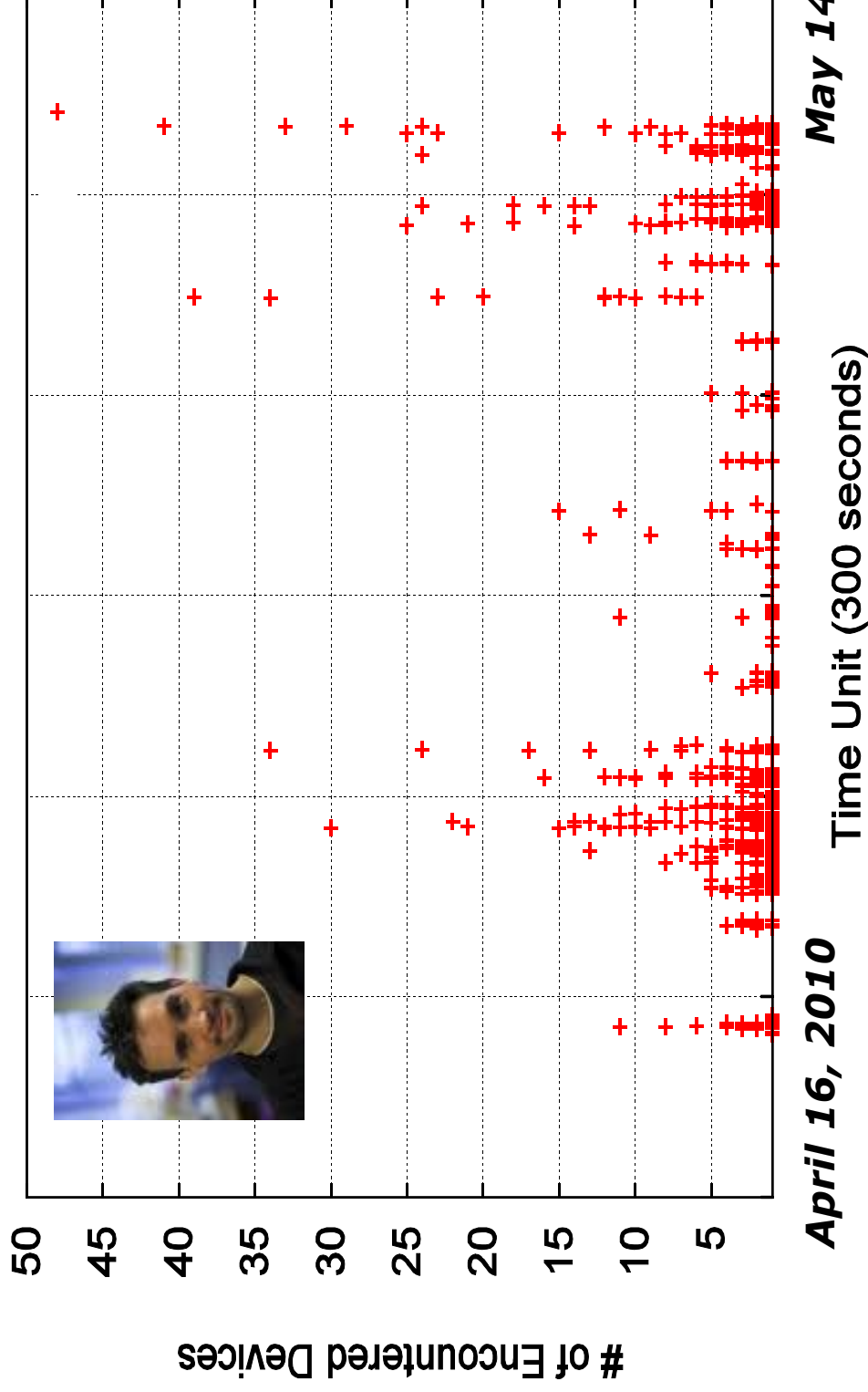
## University scale study (May 15 ~ June 30)

- 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

Experimental data set	MIT	UCSD	CAM	INFC06	BATH
Device	Phone	PDA	iMote	iMote	PC
Network type	Bluetooth	WiFi	Bluetooth	Bluetooth	Bluetooth
Duration (days)	246	77	11	3	5.5
Granularity (seconds)	300	600	120	120	Continuous
Number of Experimental Devices	97	274	36	78	7431

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

# Analyse Network Structure and Model

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- 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

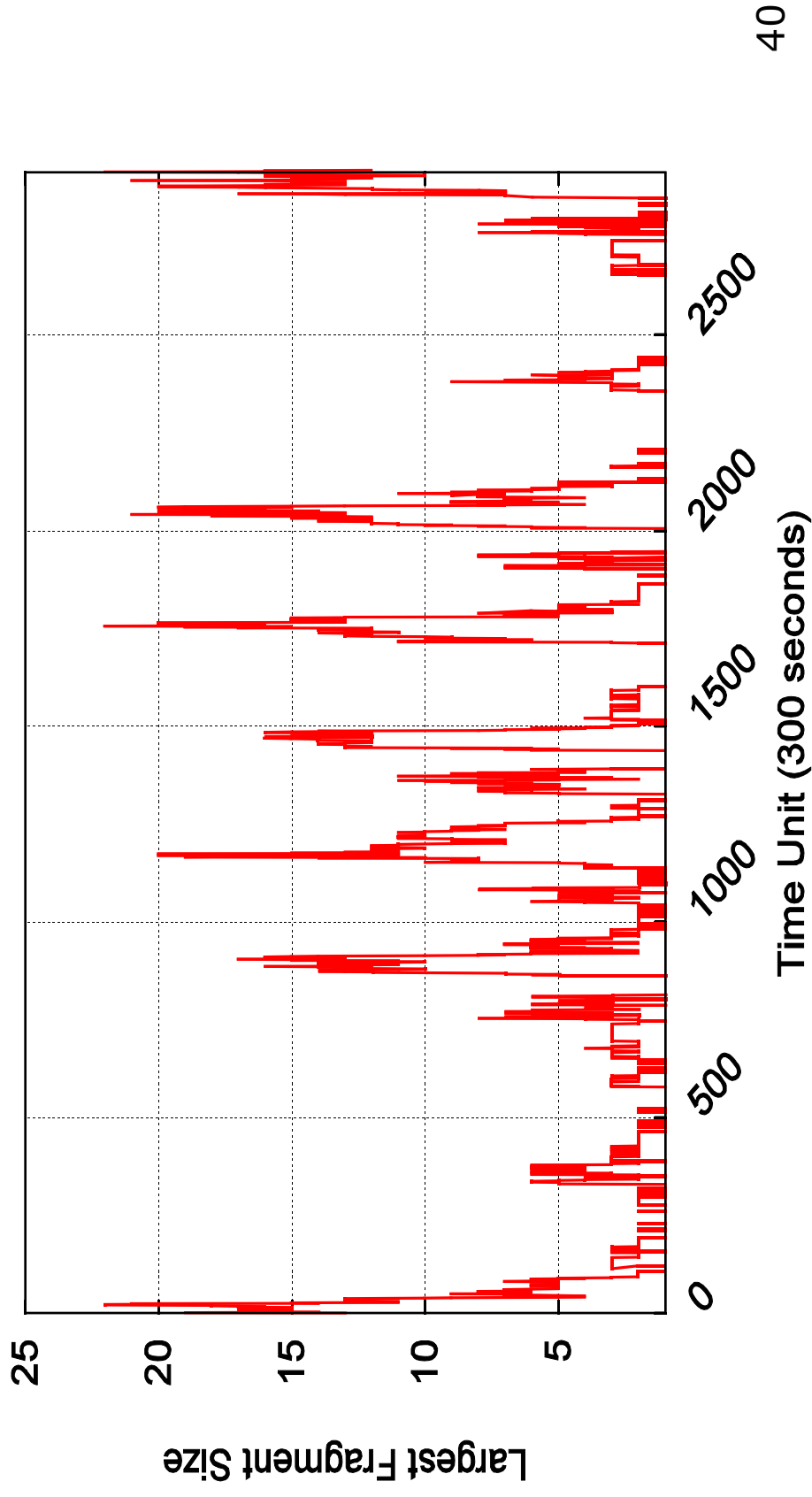
Publications at:

<http://www.haggleproject.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

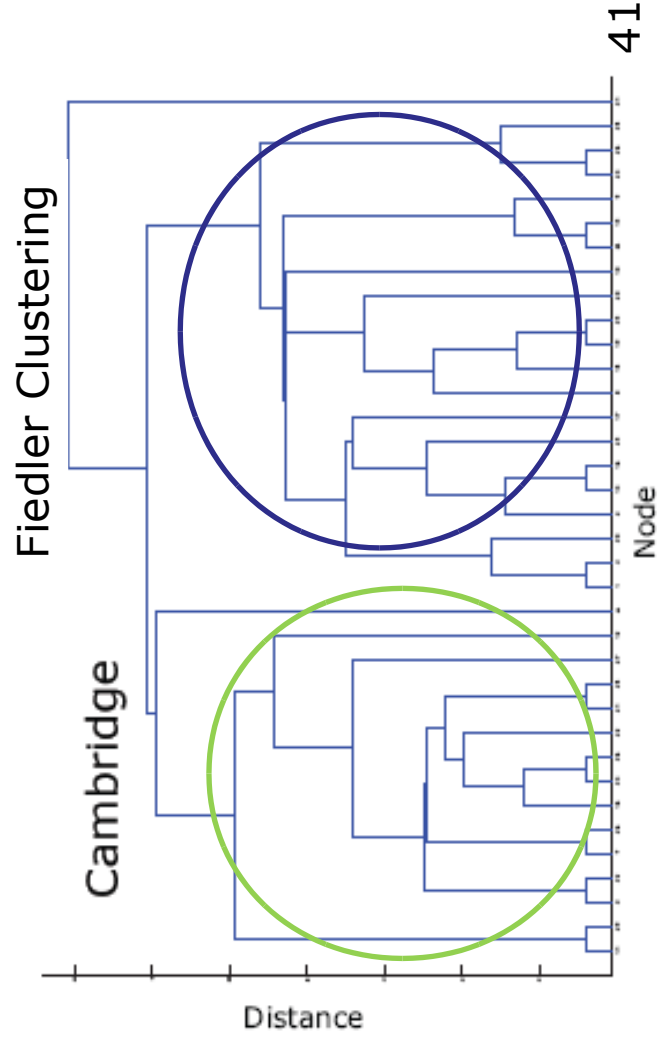
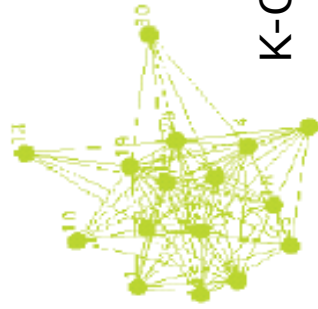


# Uncovering Community

- 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.



K-CLIQUE (K=5)



# Simulation of Disease - SEIR Model

Four states on each node:

**S**USCEPTIBLE  $\rightarrow$  **E**XPOSED  $\rightarrow$  **I**NFECTED  $\rightarrow$  **R**ECOVERD

Parameters

p: exposure probability

a: exposed time (incubation period)

t: infected time

Diseases

D1 (SARS): p=0.8, a=24H, t=30H

D2 (FLU): p=0.4, a=48H, t=60H

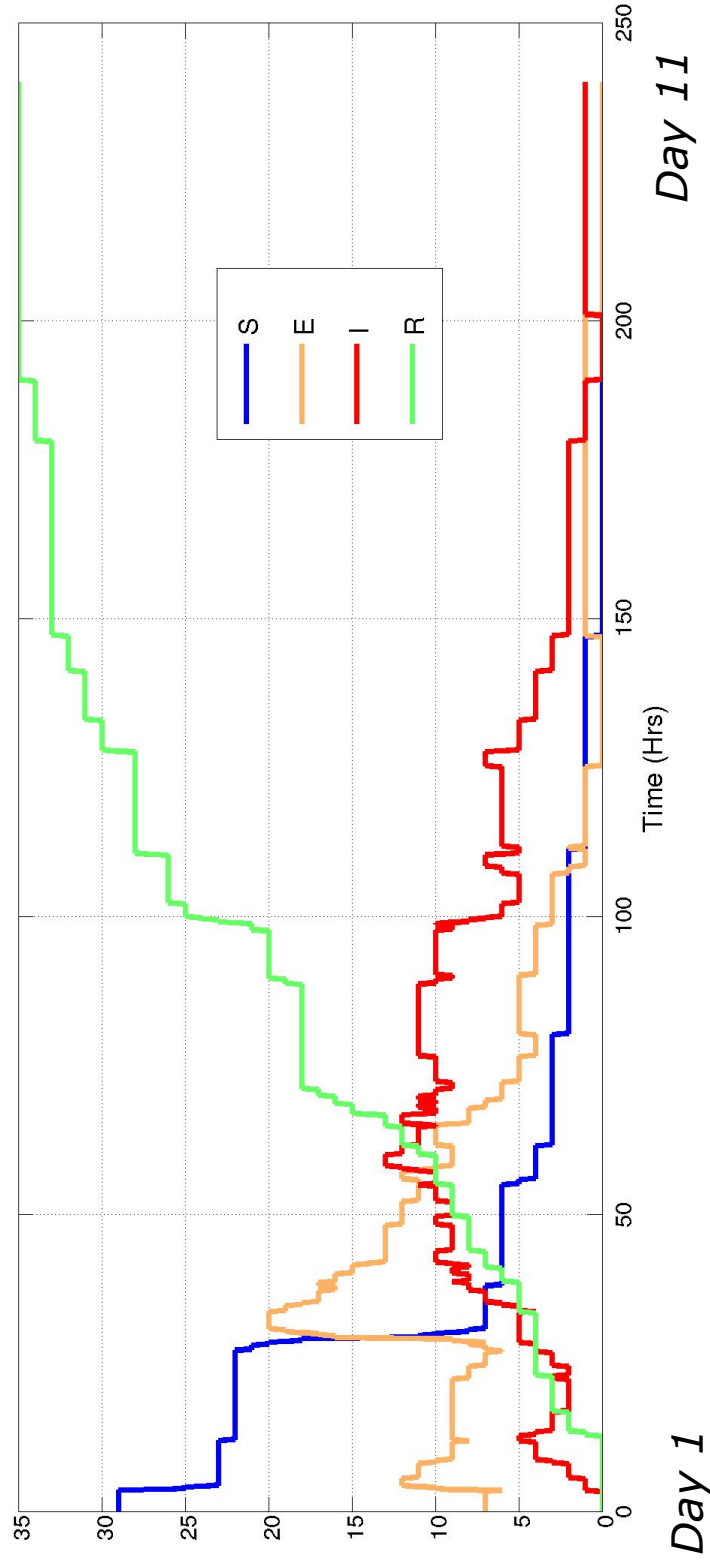
D3 (COLD): p=0.2, a=72H, t=120H

Seed nodes

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

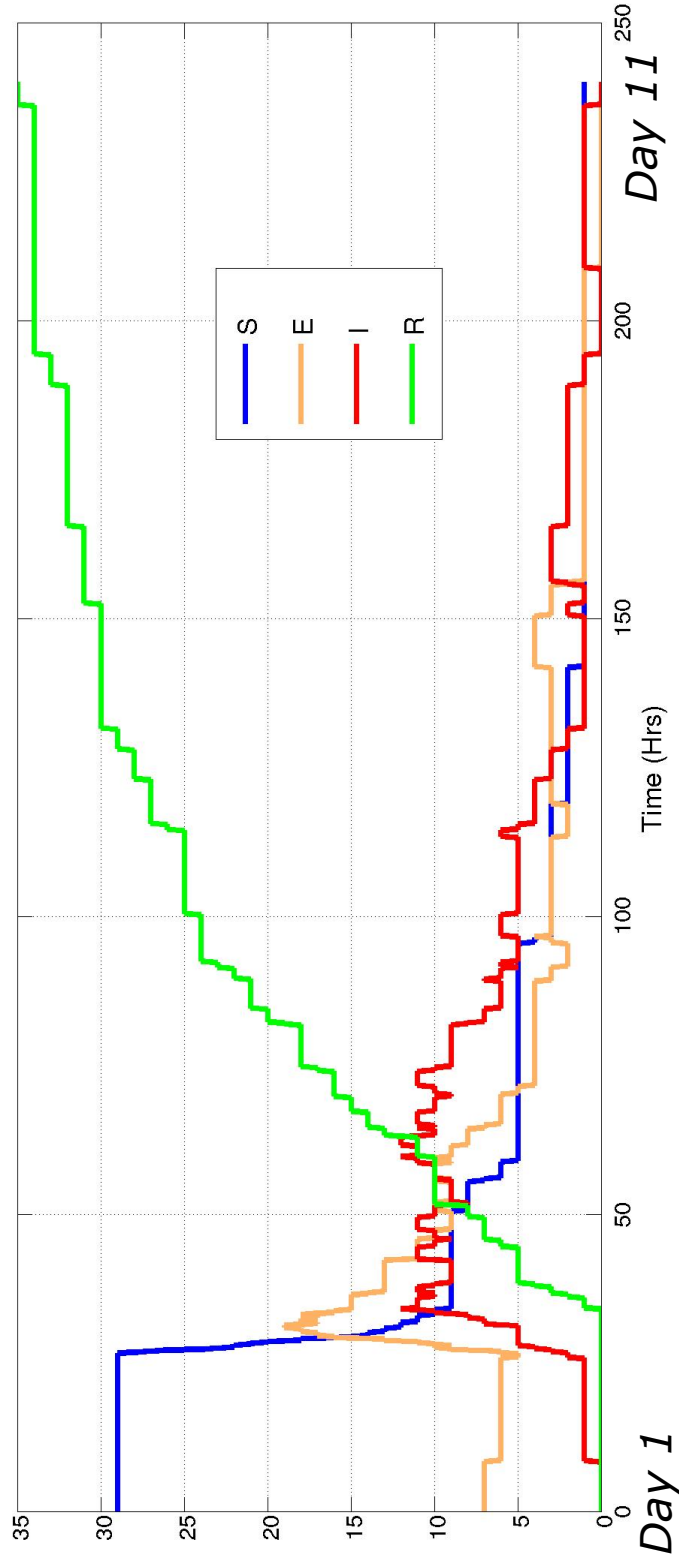
# SARS

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



# Flu

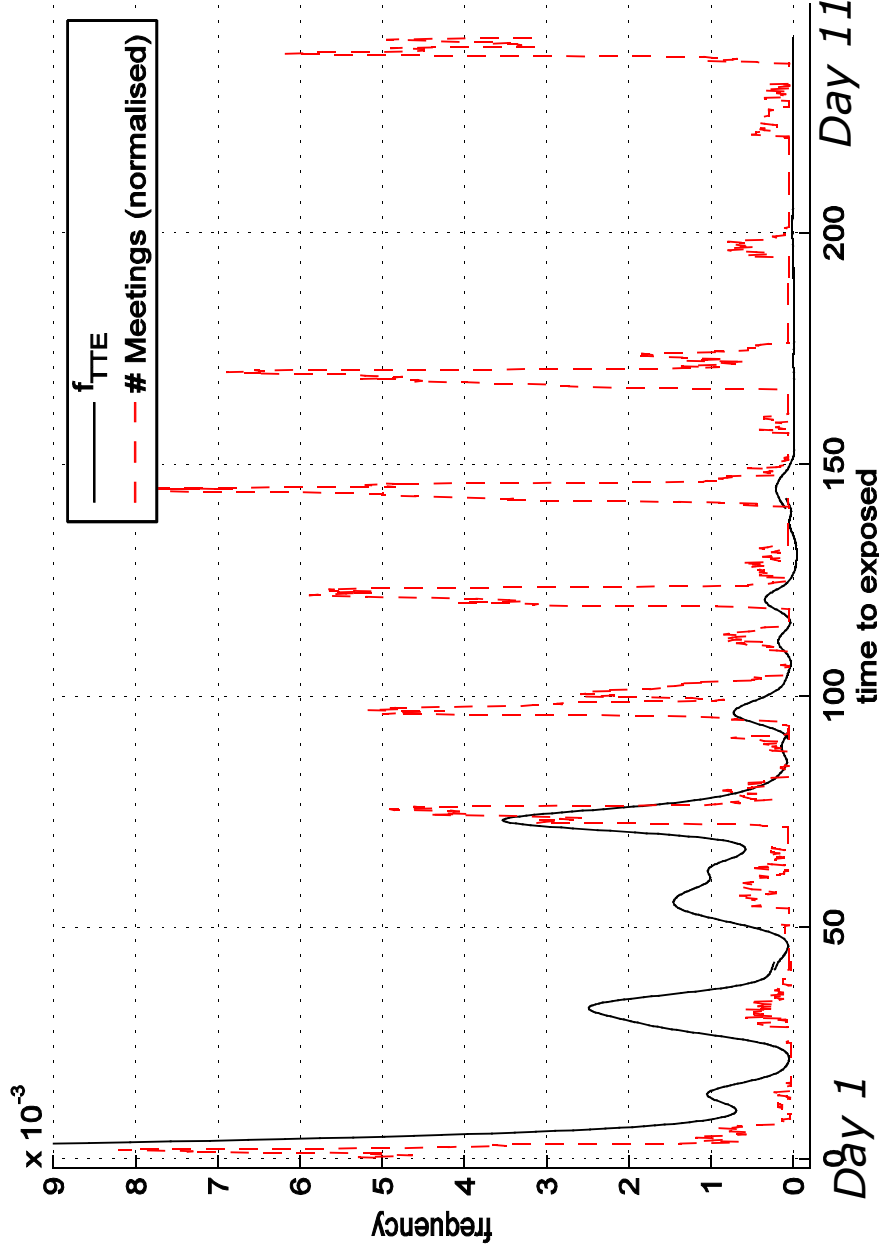
- Exposure probability = 0.4
- Exposed time = 48H (average)
- Infected time = 60H (average)





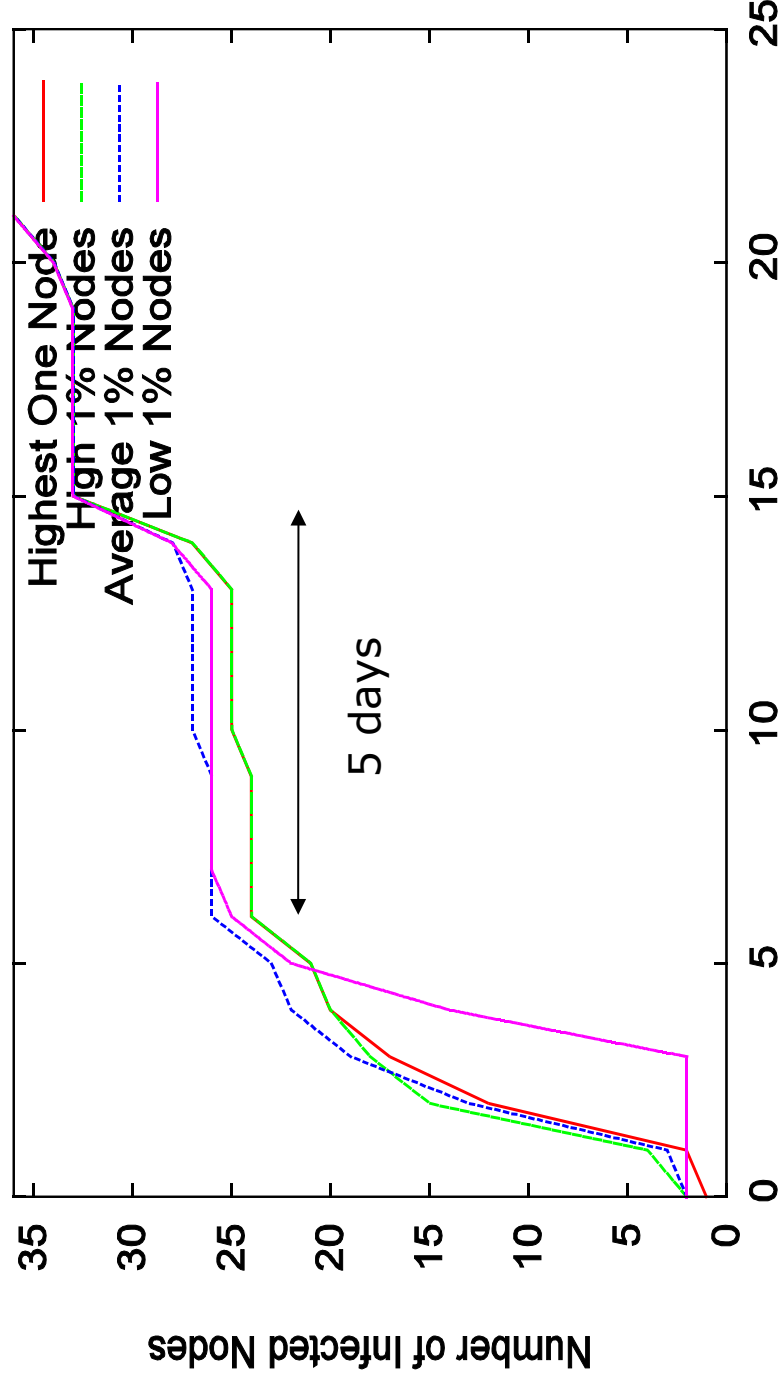
# *Time to Exposure vs #of Meetings*

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



# D0: Simple Epidemic (3 Stages)

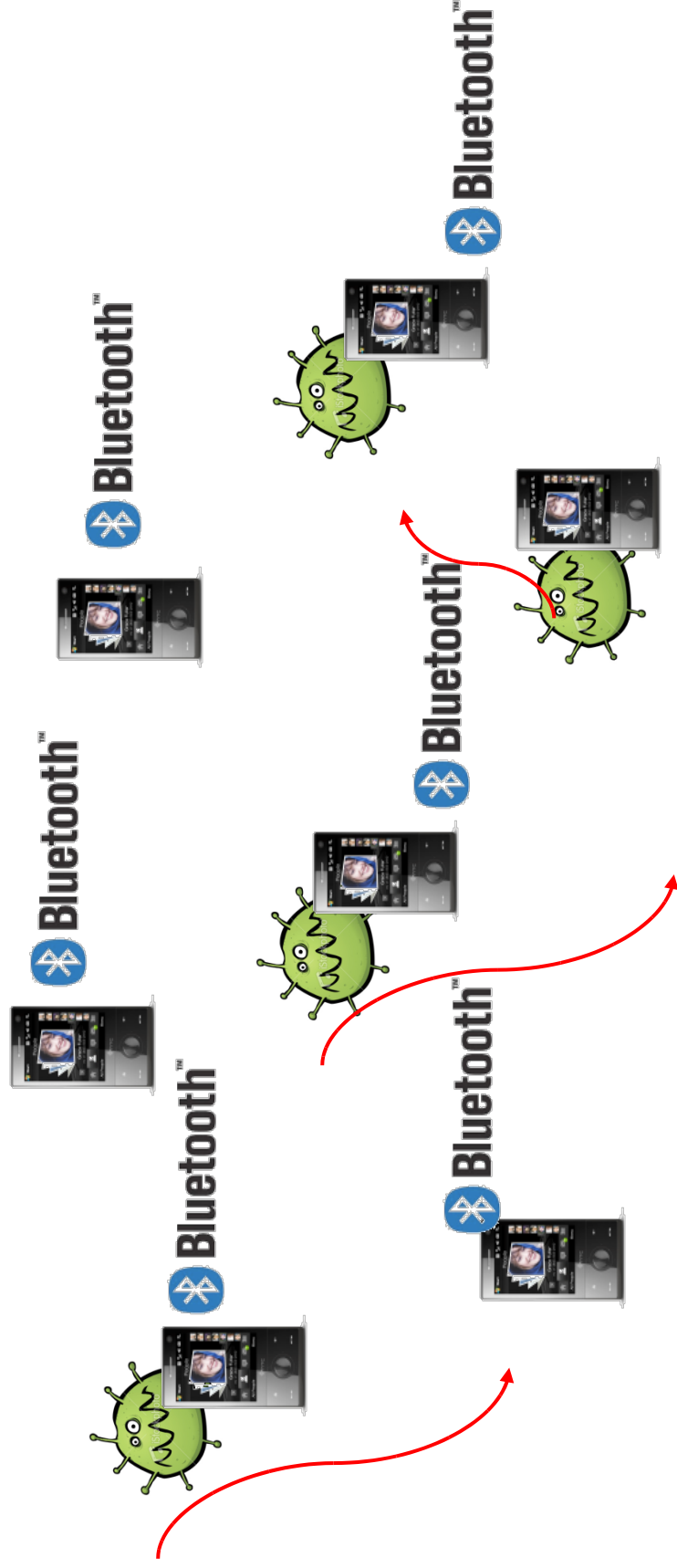
- First Rapid Increase: Propagation within Cluster
- Second Slow Climbing
- Reach Upper Limit of Infection



CAM: Time Unit (300 seconds) - 4\_1DAY

# 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



# The FluPhone Project

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

Email: [flu-phone@cl.cam.ac.uk](mailto:flu-phone@cl.cam.ac.uk)



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

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

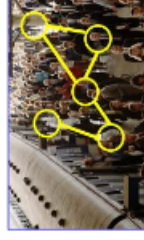
## FluPhone Study

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!



UNIVERSITY OF  
CAMBRIDGE

# **Erdos**

*Enabling opportunistic resources sharing in mobile Operating Systems*

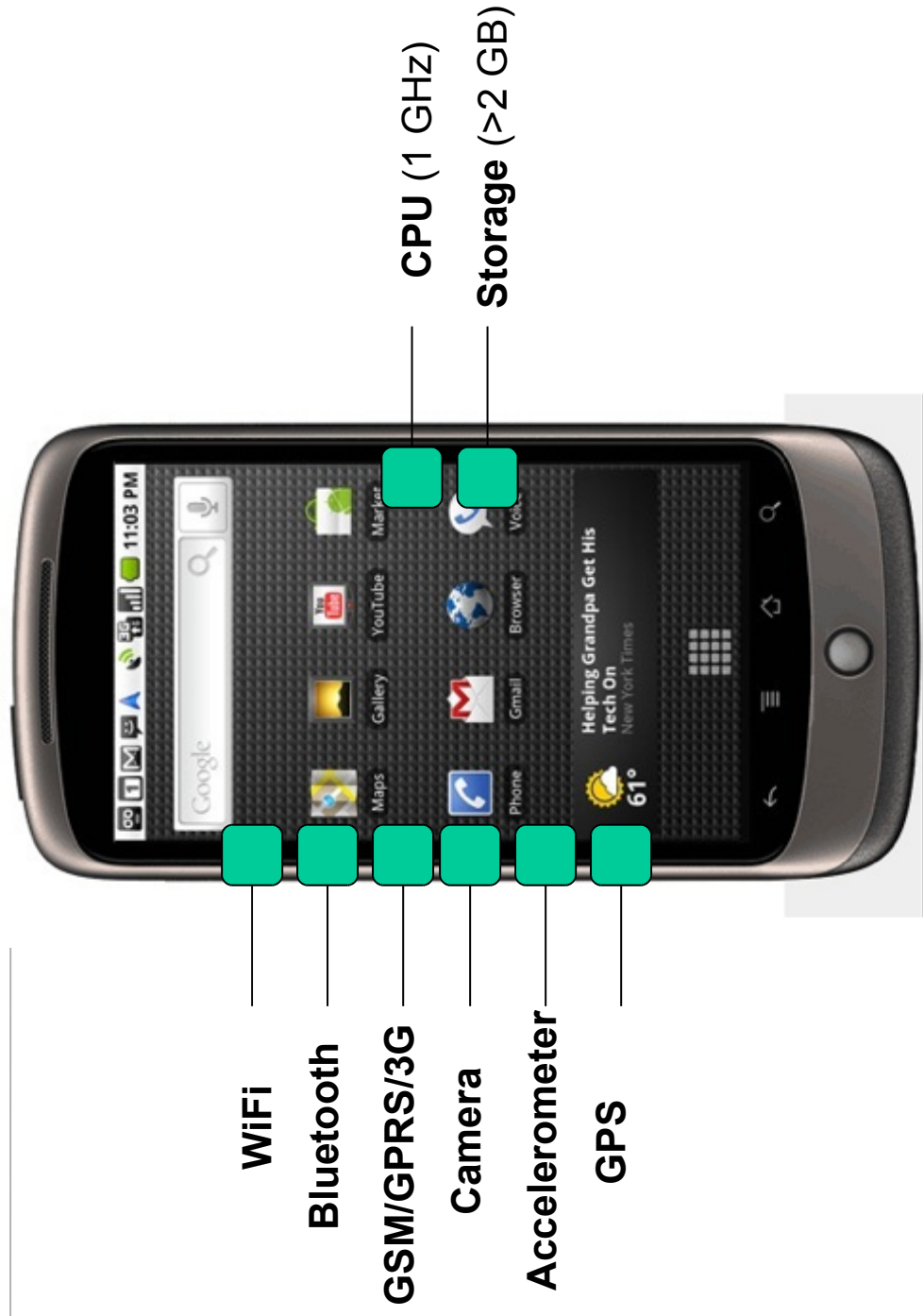
Narseo Vallina-Rodríguez

Jon Crowcroft

University of Cambridge

MUM 2010, Cyprus

# Motivation



# Motivation

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*“Energy is still the main limitation in mobile systems”*

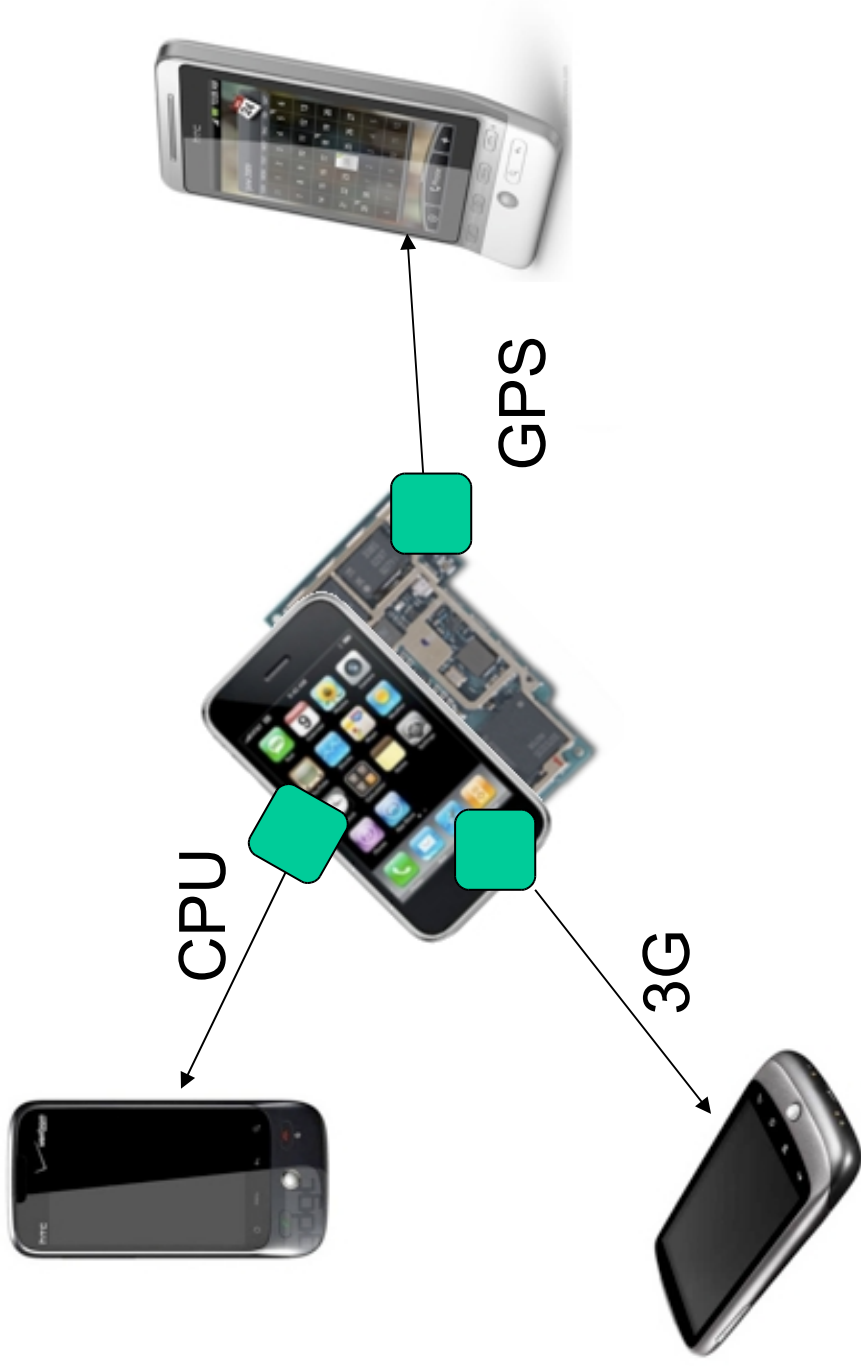


# Motivation

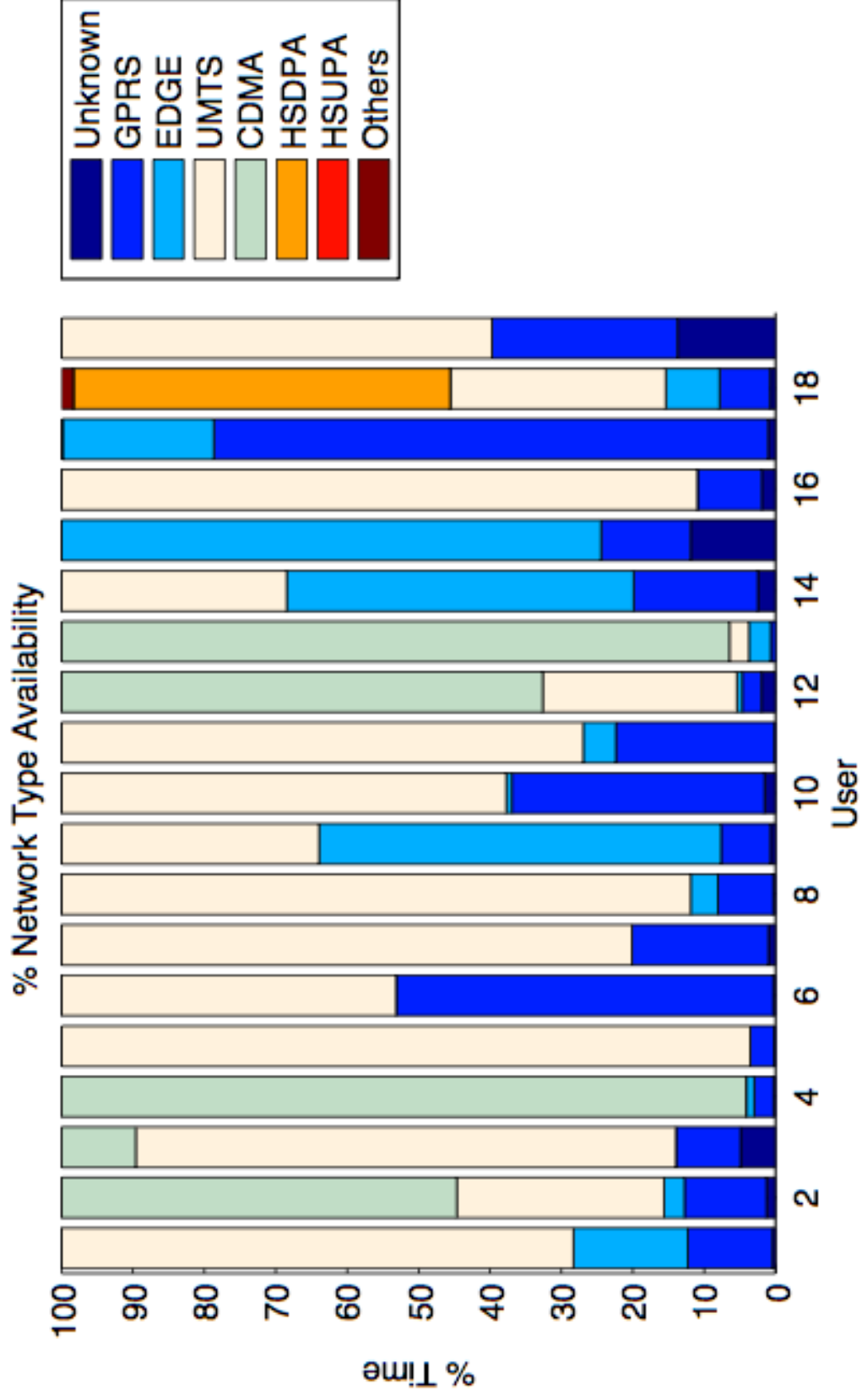




# Motivation

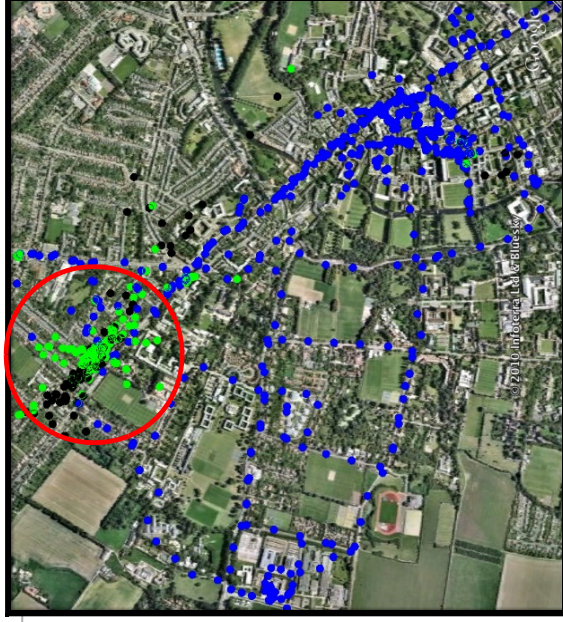
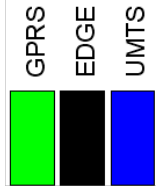
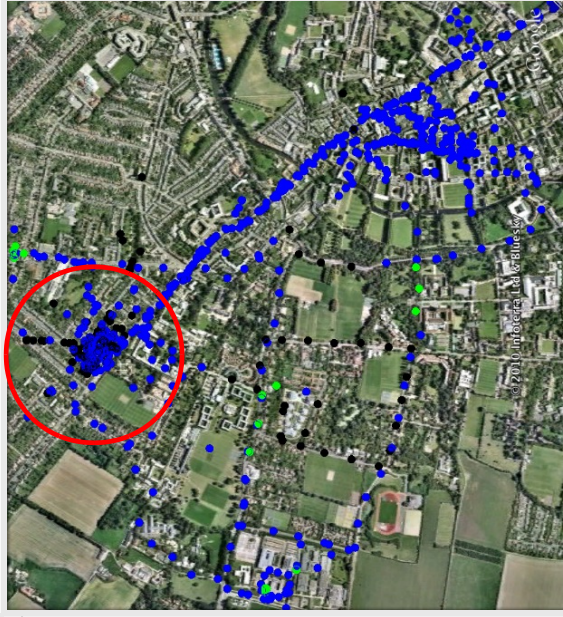


# Motivation



# Motivation

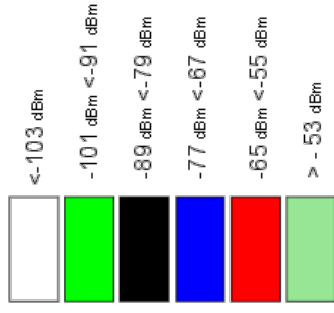
Network Type



Operator 1



Signal Strength



Operator 2



# *Motivation*

---

Why not sharing mobile resources  
opportunistically with other users?



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# II. Erdős



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## Social energy-aware OS

Access co-located resources opportunistically

Customised proactive resources management

Social connections provide access control

# Dataset Description

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18 Android OS users

1-2 weeks

Resources Tracker



*“Exhausting battery statistics”*. Mobiheld 2010



# Dataset Description

---

## Battery Statistics

Current  
Voltage  
Remaining Capacity  
Temperature  
Charging Status

## O.S. Info

CPU  
Process  
Memory

Time  
Location (Cell ID)  
Roaming  
Screen State

## Contextual

Airplane Mode  
Telephony State  
Cellular Network Type  
Cellular Network State  
WiFi State  
Bluetooth State  
GPS State  
Traffic

## Network & Telephony

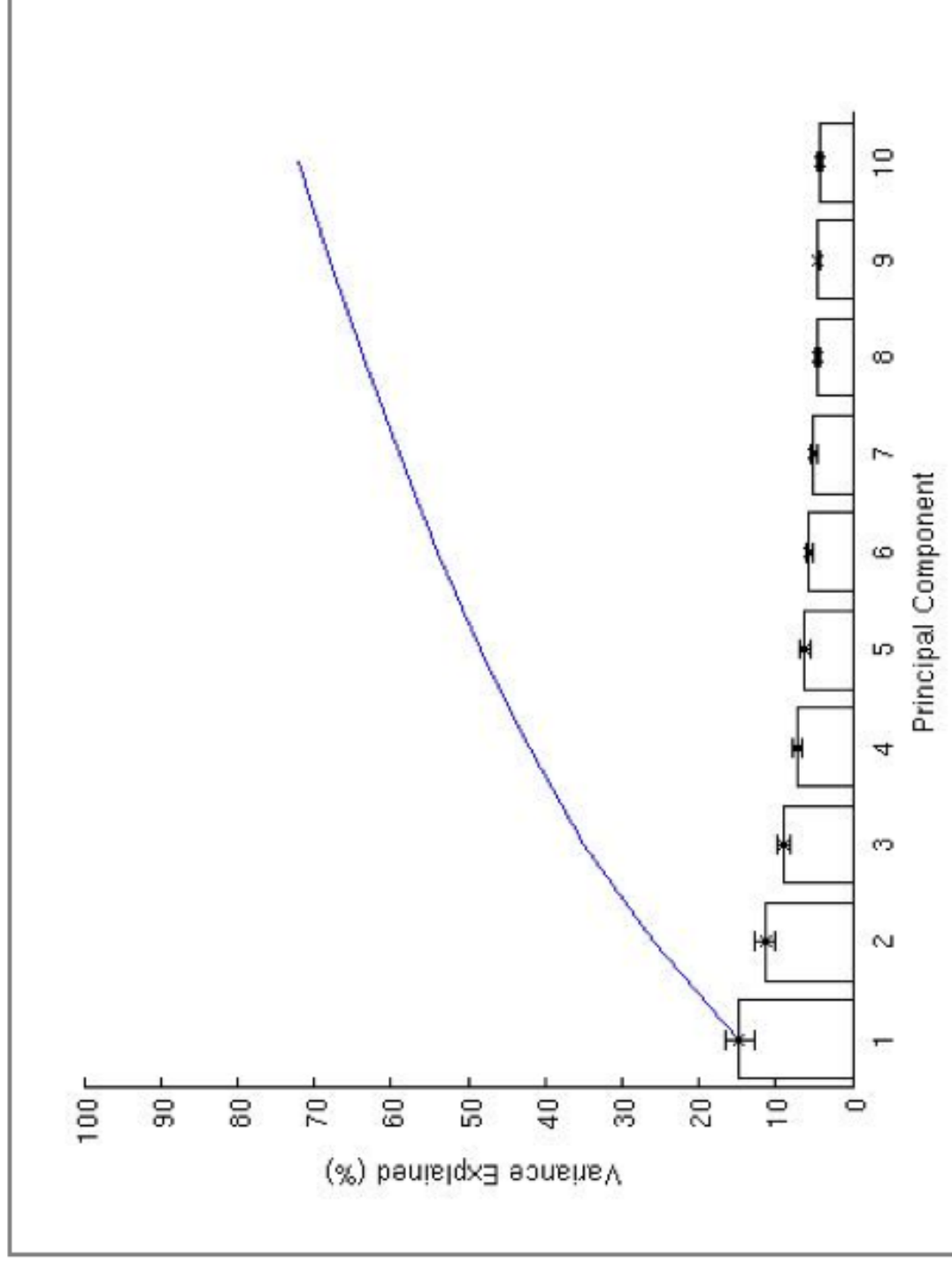
# Usage Analysis Tools

---

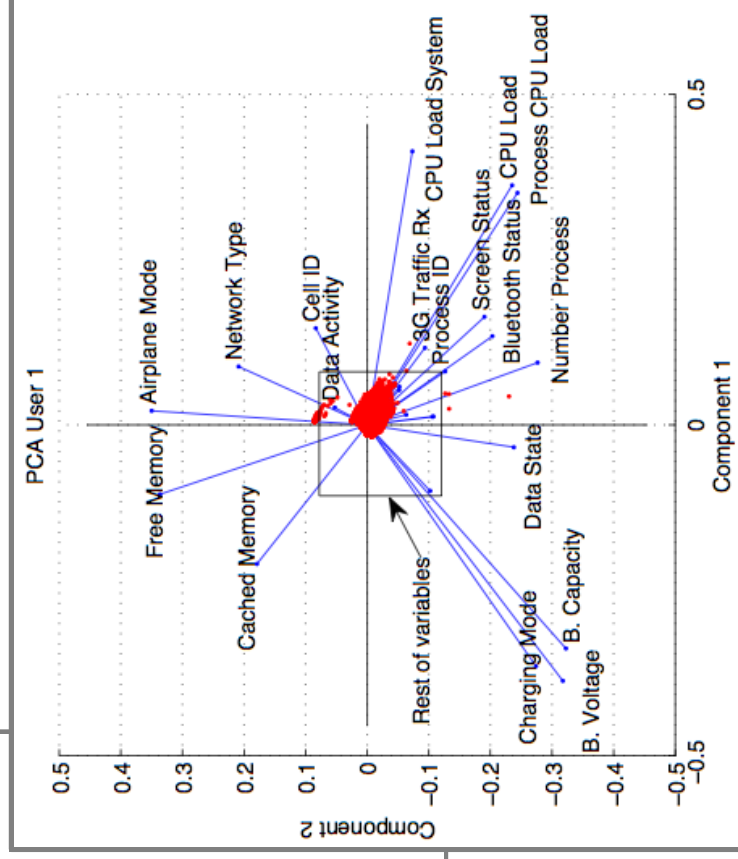
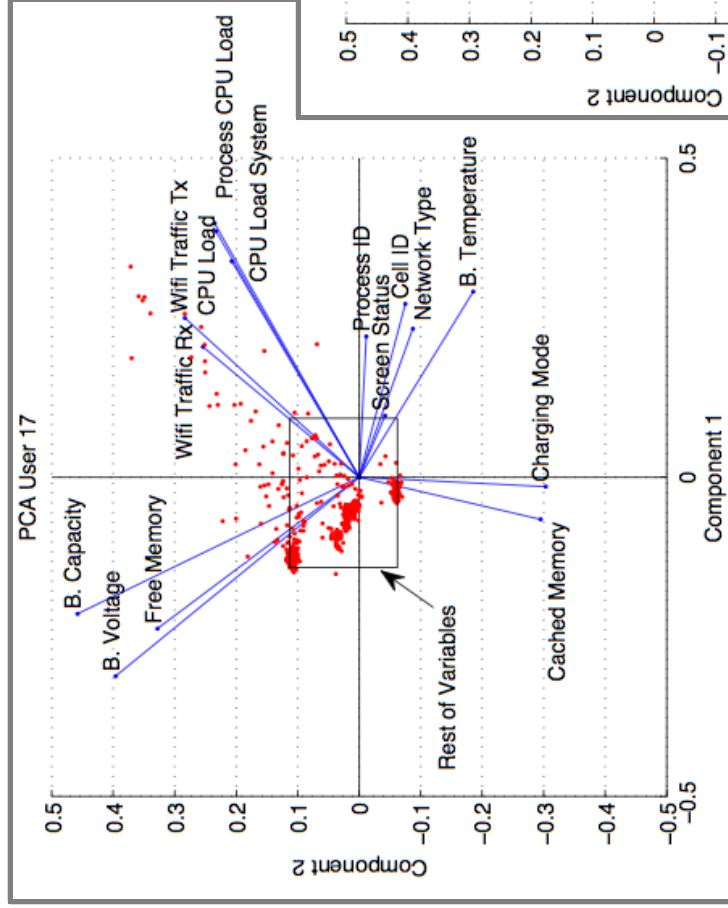
## Principal Component Analysis (PCA):

Transforms a number of possibly correlated variables into a smaller number of uncorrelated ones called Principal Components

# Principal Component Analysis



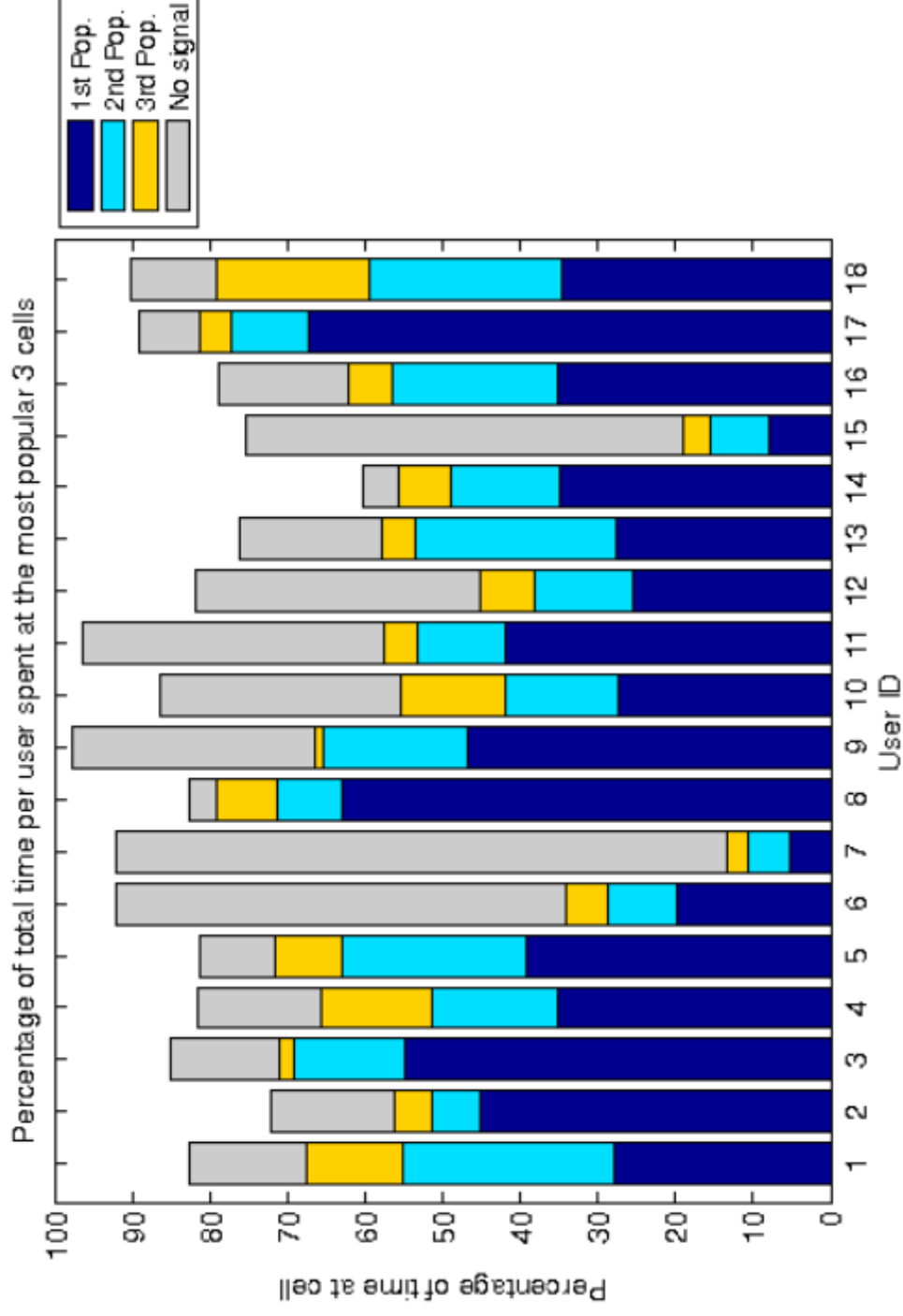
# Principal Component Analysis



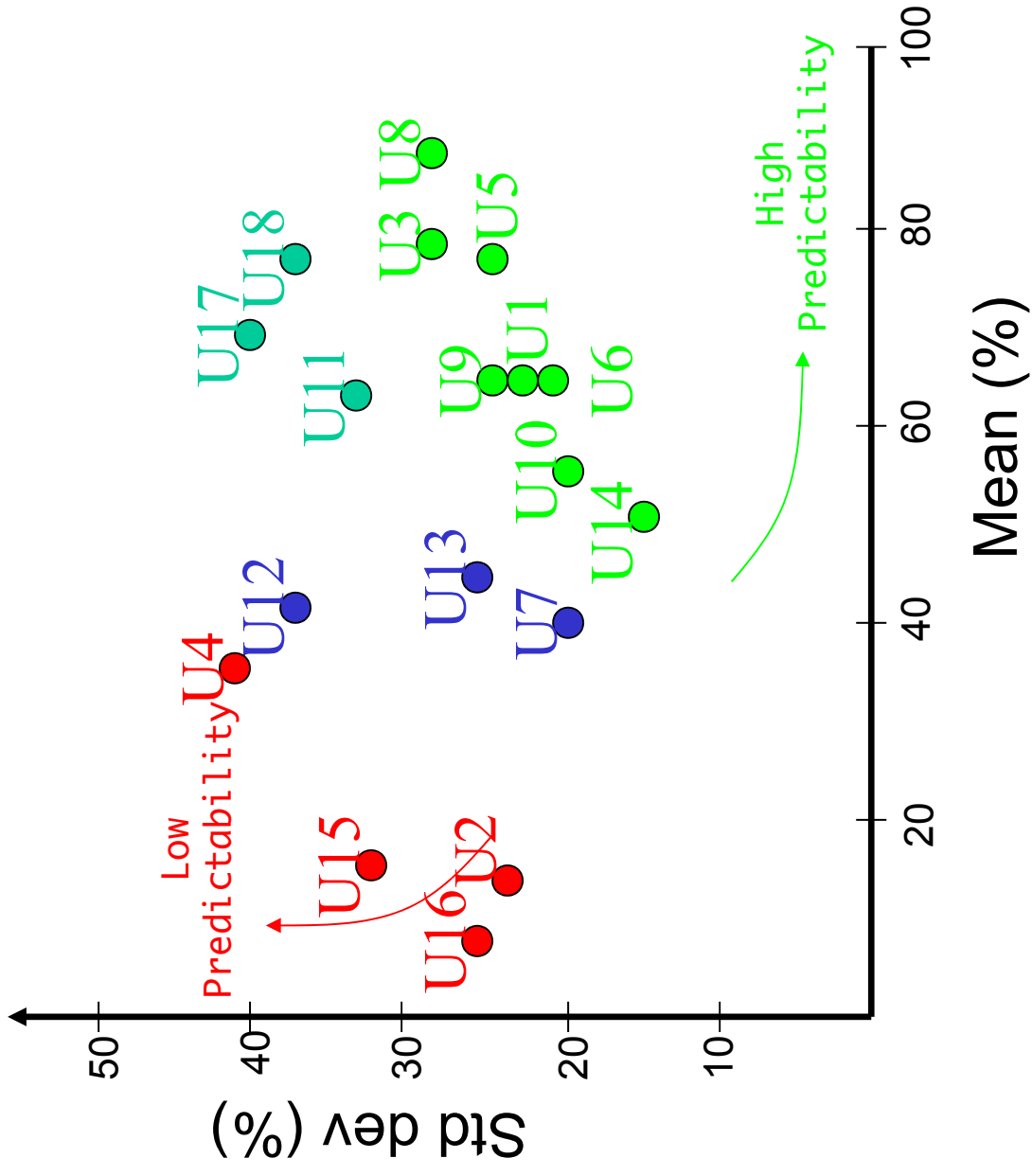


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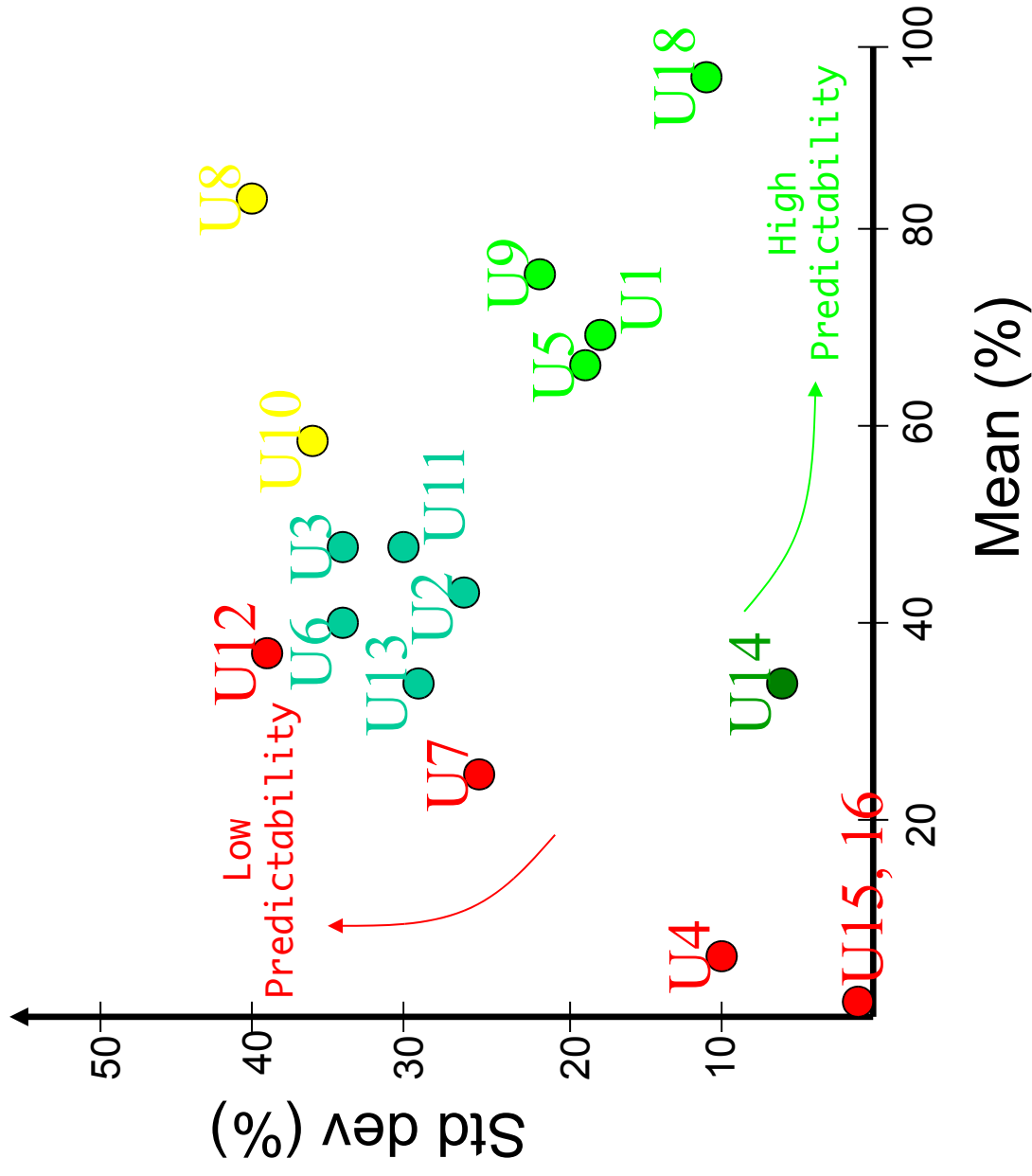
# Context importance



# Spatial context: Screen usage

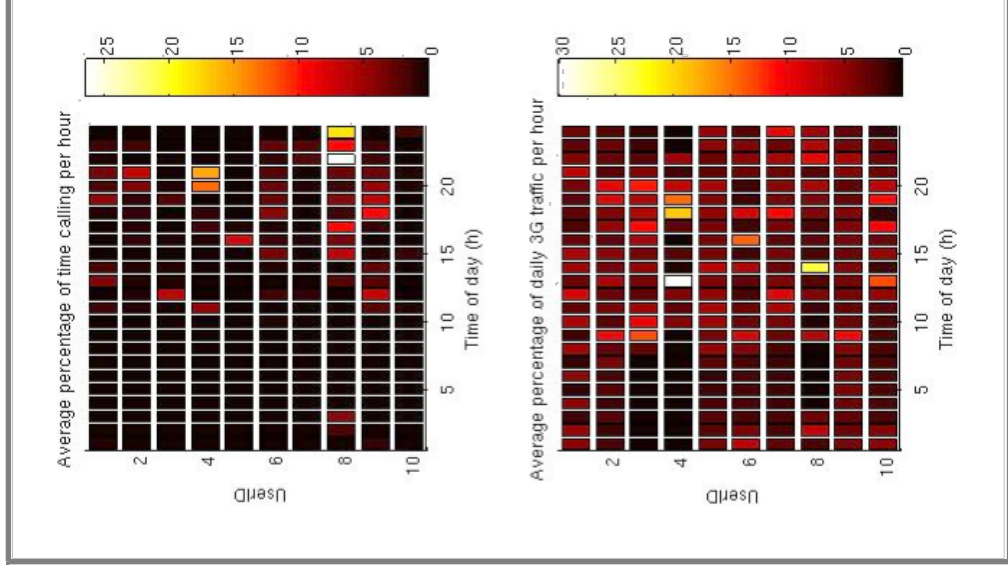
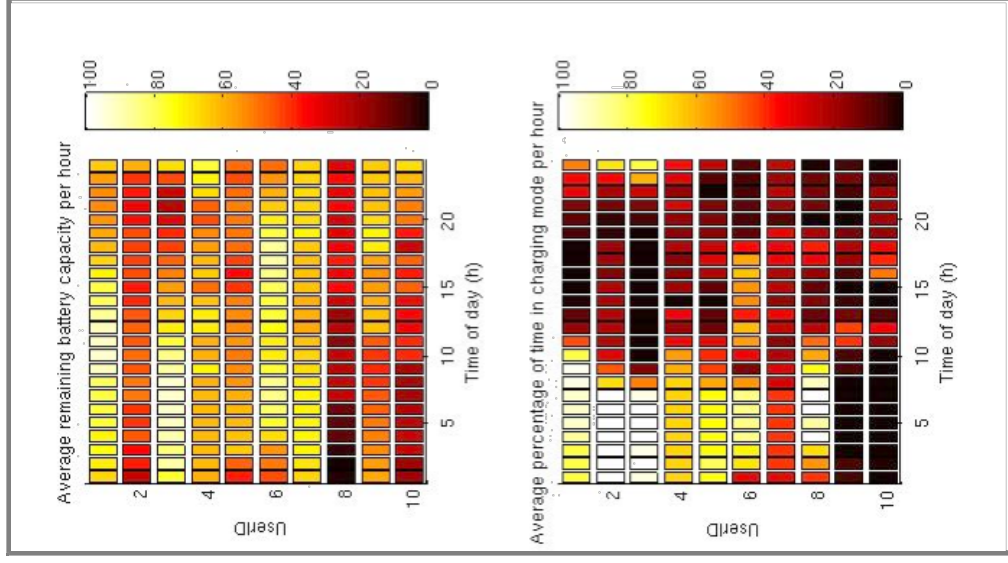


# Spatial context: Cellular traffic

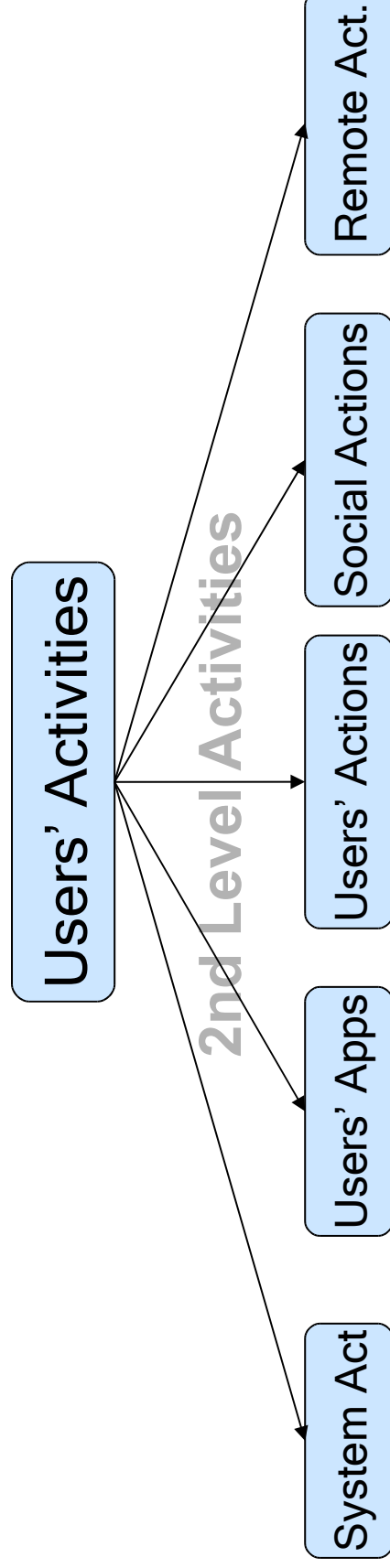




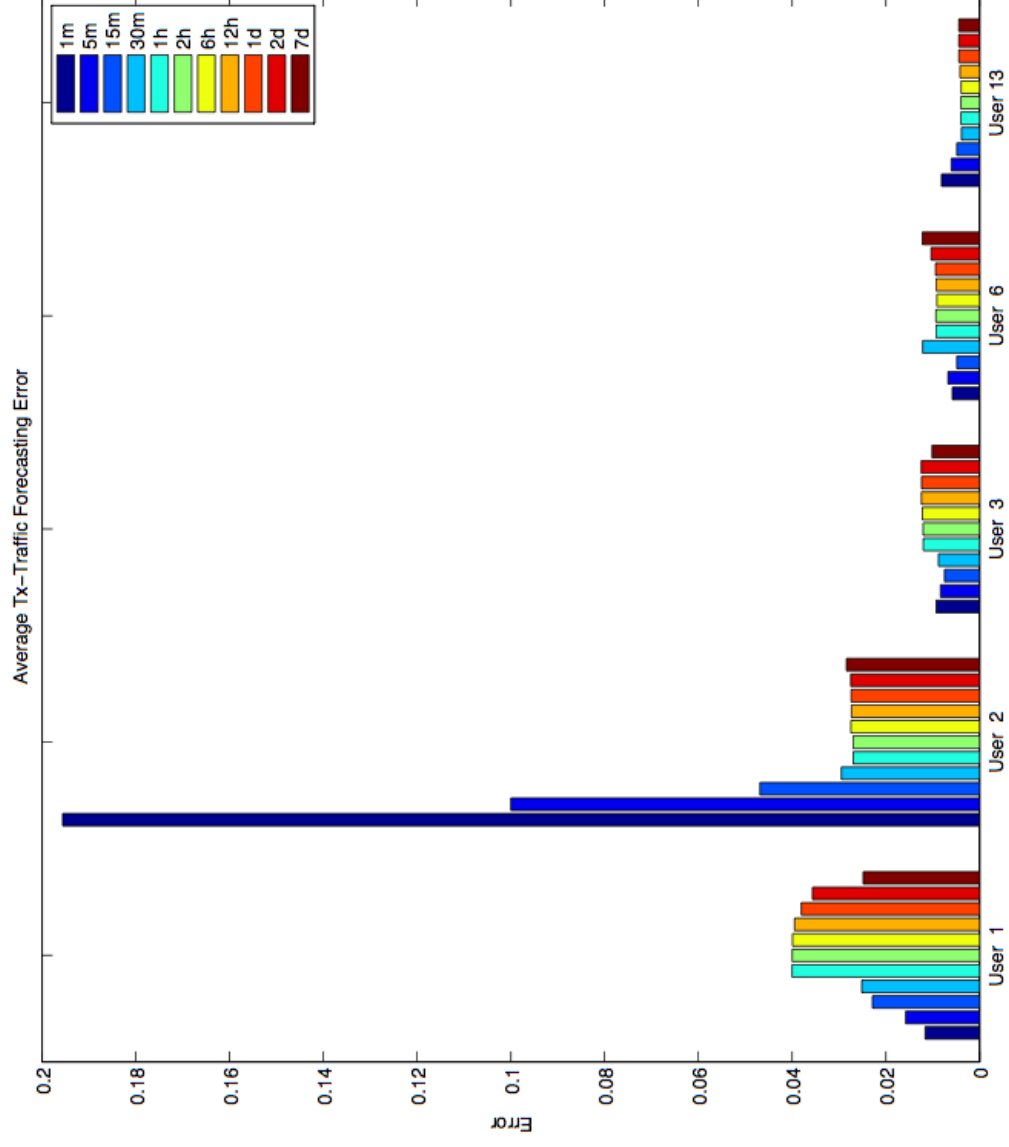
# Temporal context: *Daily usage*



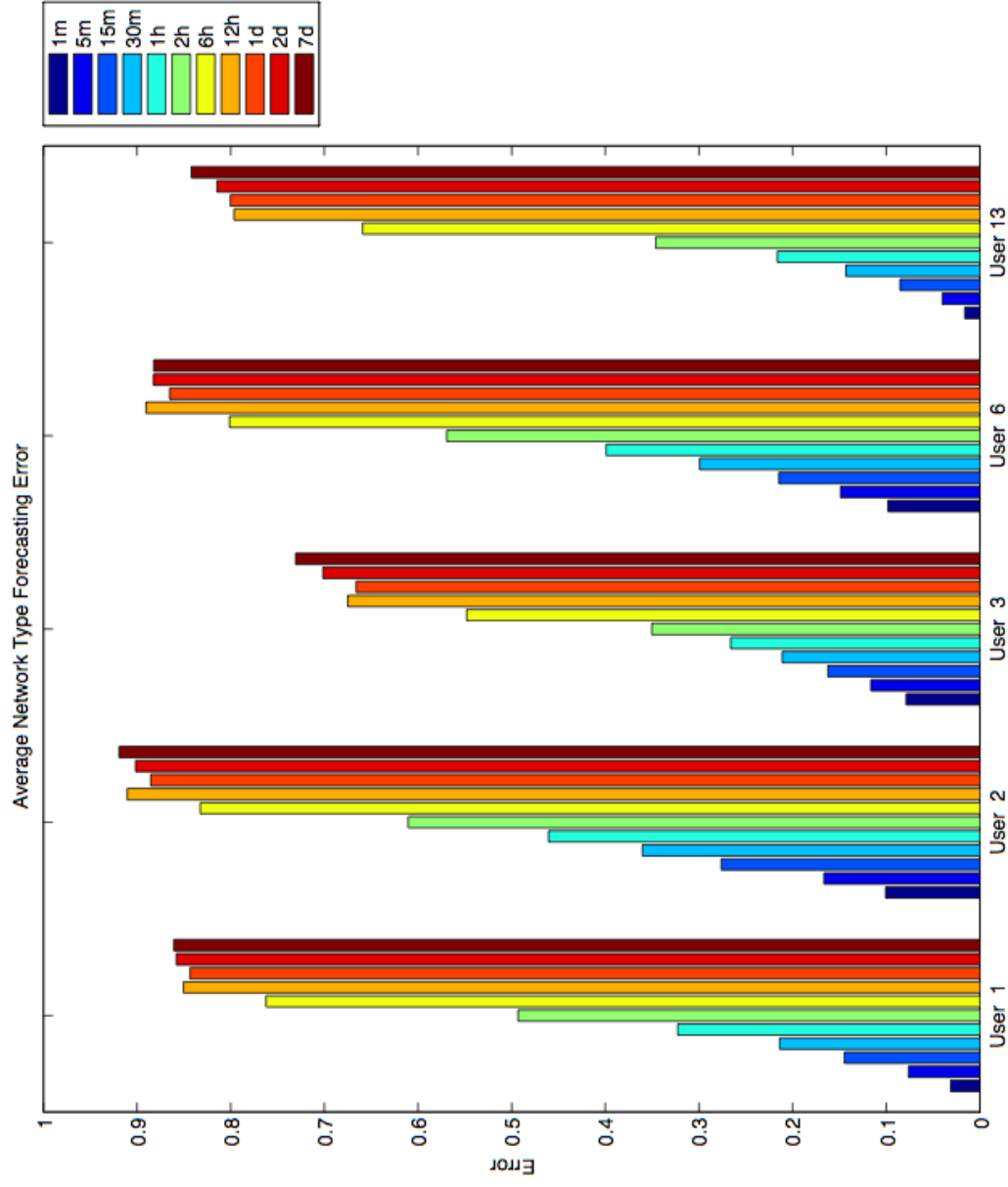
# Resources Allocations: *Activities*



# Forecasting Resources Demands



# Forecasting Resources State



# *Access Control*

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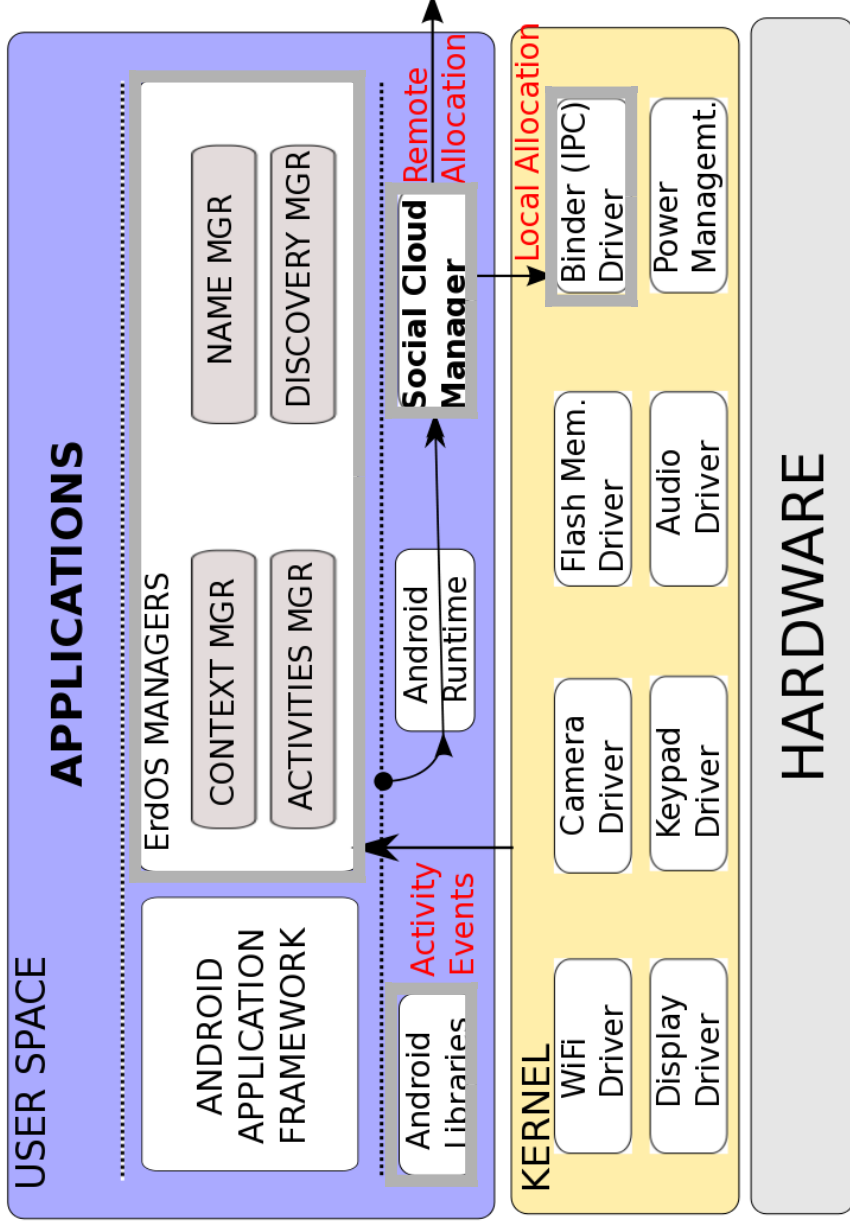
Social links facilitate access control and security

Unix-like permissions are made automatically based on users' social networks

Proximity reduces privacy and security issues

OSNs can help to exchange public keys

# Architecture



## Related work

---

- **Resource allocation and energy-aware OS**
  - **ECOSystem**. Zeng et al. ACM ASPLOS, 2002
  - **Quanto**. Stoica et al. USENIX 2008
  - **CinderOS**. Rumble et al. MOBIHELD 2009
- **Mobile usage and energy demand**
  - Falaki et al. ACM Mobisys 2010
  - Oliver, ACM HotPlanet 2010
  - Balasubramanian et al. ACM IMC 2010
  - Rice et al. ACM PerCOM 2010

# Conclusions

---

Energy is a primary target for optimization in mobile handsets

- Benefits in QoS and energy savings by accessing resources opportunistically
- Social links can be used for access control policies

Applications and users' behavior generate complex dynamics and interdependencies among resources

- Energy allocation and resources control must be customized to each user and handset
- Pro-active resources management aided by contextual information



# ***Future Work***

Finishing implementation as an Android OS extension

Performance/Scalability evaluation

Demonstrate benefits of sharing different resources (Cellular Nets, GPS, CPU)

Resources Discovery Protocols

Research on lighter forecasting techniques

Cloud Computing?

Security evaluation

Incentive schemes?

---

# *III*

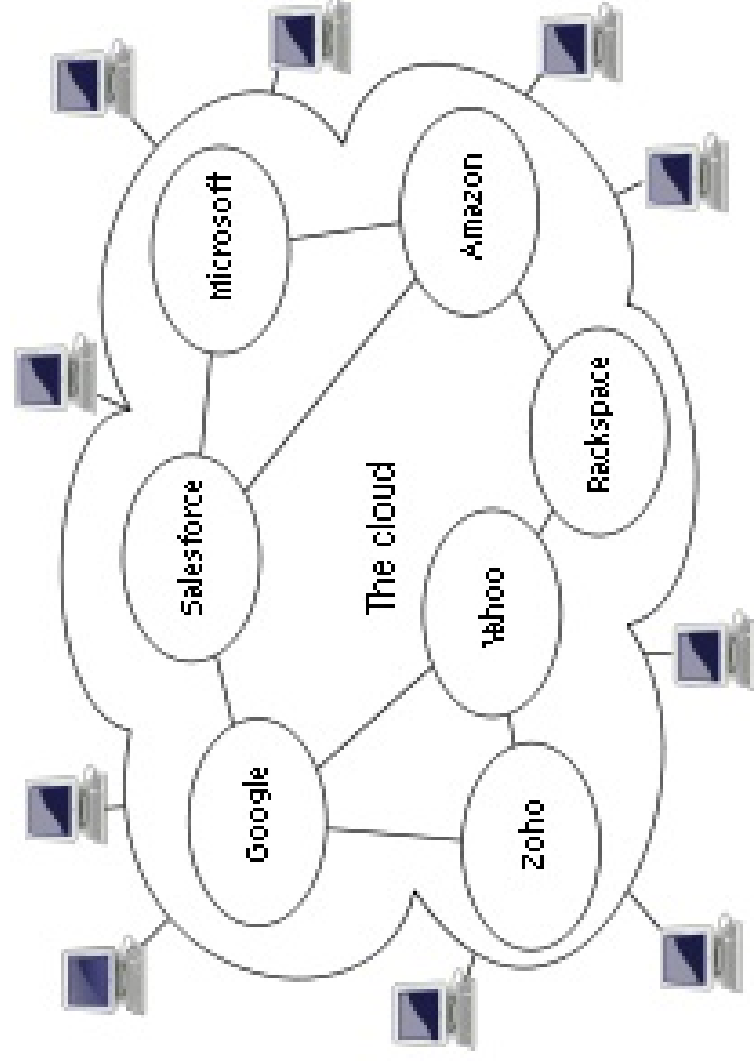
## *Droplets:- Condensing the Cloud*

<http://www.cl.cam.ac.uk/~jac22>

# From the Cloud...

---

The cloud has its risks...



# *Centralisation of PII*

---

What if

Provider goes broke

Lose all your family photos

Assets sold to another (unknown) provider

In a large organisation,

There will always be someone bad

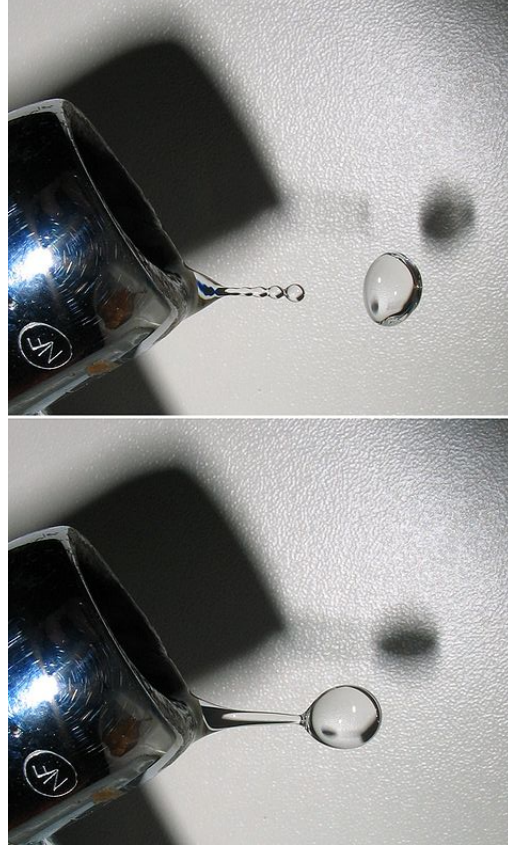
Who can datamine

Identity theft

And worse

# To Droplets

At the other extreme...



## *A fully decentralised approach...*

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Can obviate cloud risks

But introduces complexity

Management overhead (p2p/manet/dtn)

Availability/resilience

Total data loss if device stolen

Can we compromise

Between extreme centralisation...

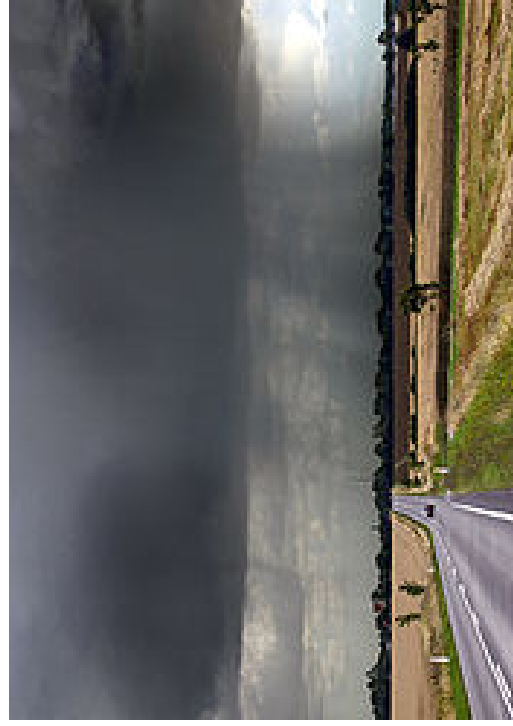
And extreme decentralisation?

# *Via extraction*

---

Firstly, we need to pull/push data

From/to the cloud...



*...and condensation*

---





*necessary, but not sufficient...*

---

Need to encrypt data

Both in Cloud

And in Mist

The mist is a collection of droplets -  
small objects with key/capability

and auditor

What about cloud business models?

Use privacy preserving advertising (MPI)

Use k-anonymity and threshold security

Use differential privacy for market research

# Implementation Details

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Platform	Google AppEngine	VM (e.g., on EC2)	Home Computer	Mobile Phone
Storage	moderate	moderate	high	low
Bandwidth	high	high	limited	low
Accessibility	always on	always on	variable	variable
Computation	limited	flexible, plentiful	flexible, limited	limited
Cost	free	expensive	cheap	cheap
Reliability	high	high	medium (failure)	low (loss)

## *To Conclude...*

---

Use contributed resources are fine

Home hub, phone, etc

But need to unify with cloud

Do so at API level

Have *both* decentralised and central

Advantages of both

Low latency access to home/pocket

High resilience in cloud

No loss of privacy if bad cloud/pick pocket



*That's all folks!*

Questions?

Thanks!

Email: [jac22@cl.cam.ac.uk](mailto:jac22@cl.cam.ac.uk)

<http://www.cl.cam.ac.uk/~nv240/erdos.html>