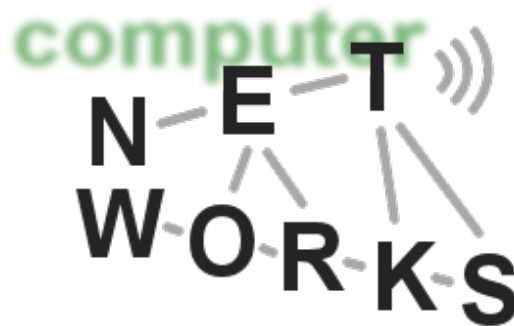


# Social Networks: Applications

Advanced Computer Networks  
Summer Semester 2013



# Recap: Information Cascading Model

- Consider an urn with 3 marbles. It can be either:
  - **Majority-blue**: 2 blue, 1 red
  - **Majority-red**: 1 blue, 2 red
- Each person wants to best guess whether the urn is majority-blue or majority-red
- Experiment: making decision one by one
- Analysis: Bayes' Rule (posterior probability)

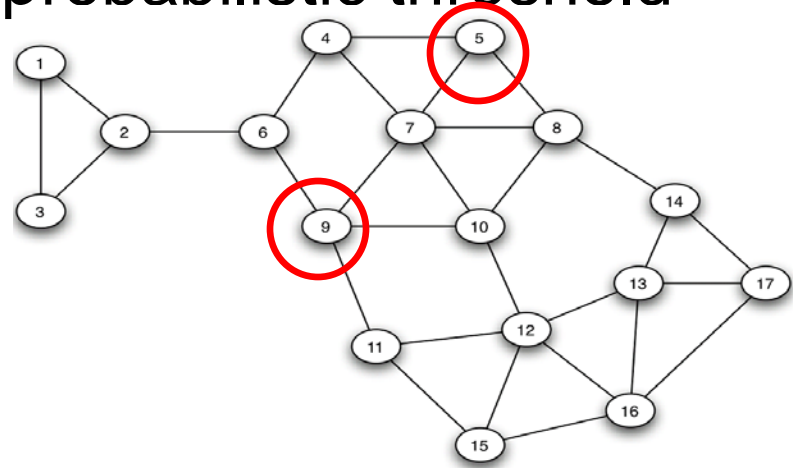
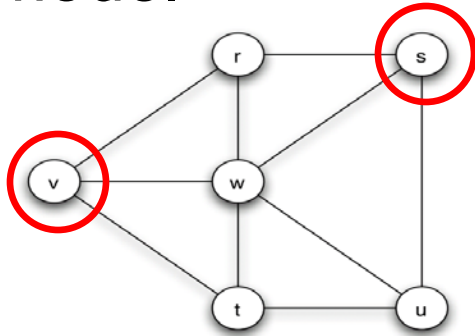
$$\Pr[A | B] = \frac{\Pr[A] \cdot \Pr[B | A]}{\Pr[B]}.$$

- Decision: based on the best probability

$$\Pr[\text{majority} - \text{blue} | \text{blue, blue, red}] = \frac{2}{3} \geq \frac{1}{2}$$

# Recap: Social Influence Maximization

- Problem: Finding  $k$  most influential nodes in a social network using the probabilistic threshold model



- The problem is shown to be NP-hard
- Heuristic solutions
  - Node degree
  - Distance centrality
  - Greedy

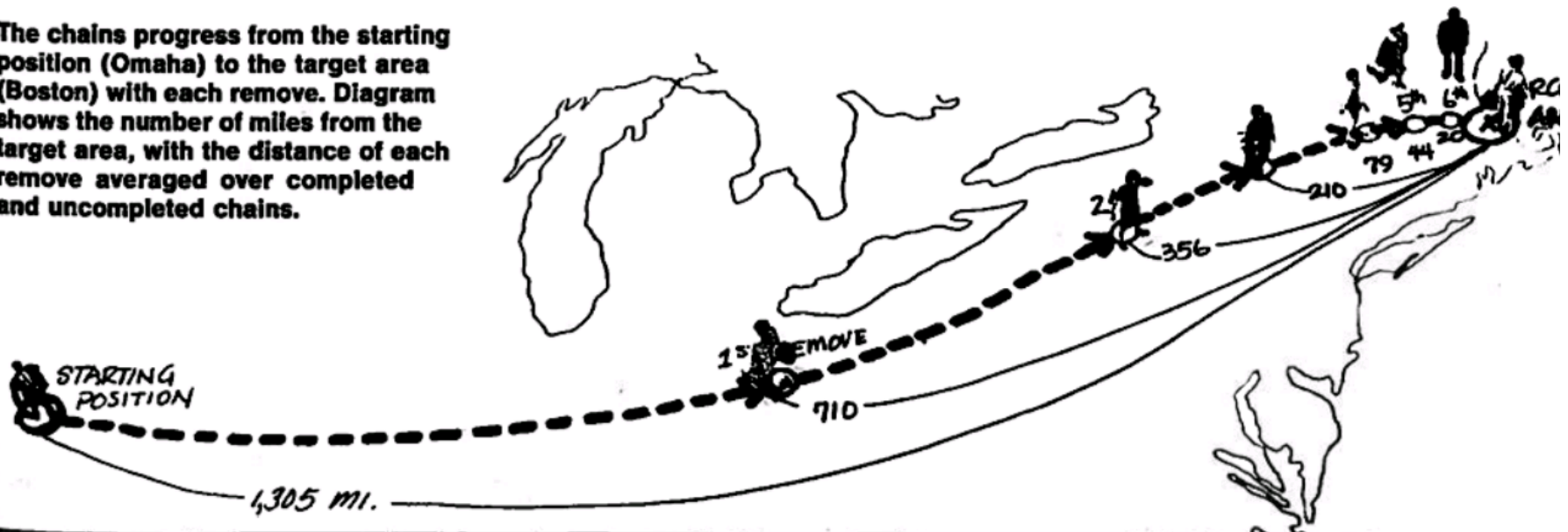
# Decentralized Search

## ○ Question

- In a Small World network, how to find the short path between a pair of nodes?

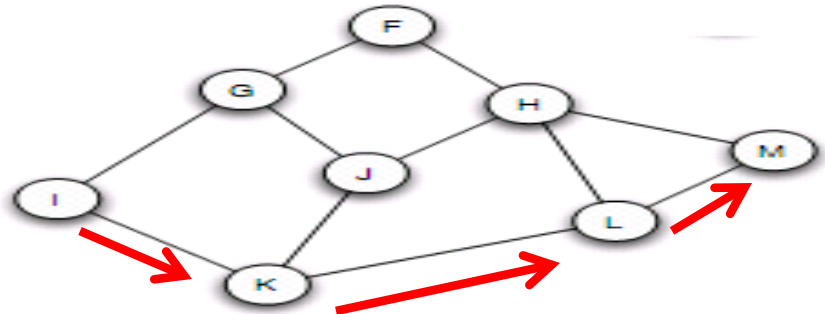
- Centralized strategy?
- Flooding?
- Milgram experiment: people collectively find short paths to the designated target -> **decentralized search is possible**

The chains progress from the starting position (Omaha) to the target area (Boston) with each remove. Diagram shows the number of miles from the target area, with the distance of each remove averaged over completed and uncompleted chains.



# Decentralized Search

- Node  $s$  sending a message to destination  $t$ 
  - $s$  only knows locations of its friends and locations of the target  $t$
  - $s$  only has local information, it does not know links of other nodes
- **Principle:**  $s$  send the message to its friend who is the closest to  $t$
- **Search path length:** the number of steps to reach  $t$

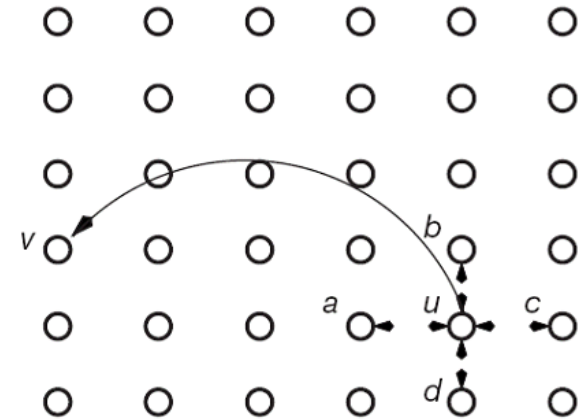


# A General Network Model

- One dimension: A ring
- Two dimension: A grid
- Each node has only one long link
- The probability of a long link from  $u$  to  $v$  is:

$$Pr\{u \rightarrow v\} \sim d(u, v)^{-q}$$

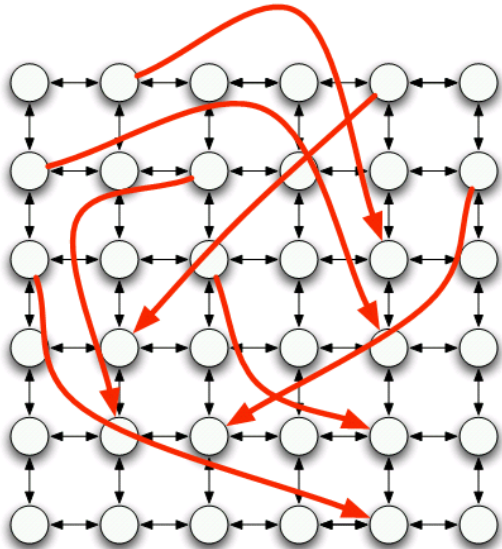
- Where  $d(u, v)$  is the distance (grid steps) between node  $u$  and  $v$ , and  $q$  is a **parameter**



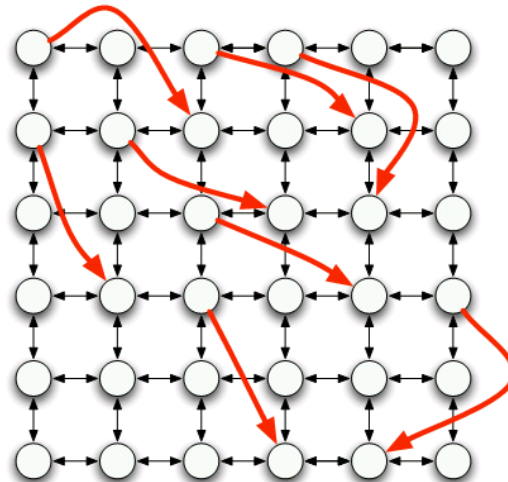
# Choosing the parameter $q$

$$Pr\{u \rightarrow v\} \sim d(u, v)^{-q}$$

- Different  $q$  yields different networks, which have different shortest path lengths
- $q=0$ : just like the Watts-Strogatz model
- $q \rightarrow +\infty$ : only links to nearby nodes



**Too random!**

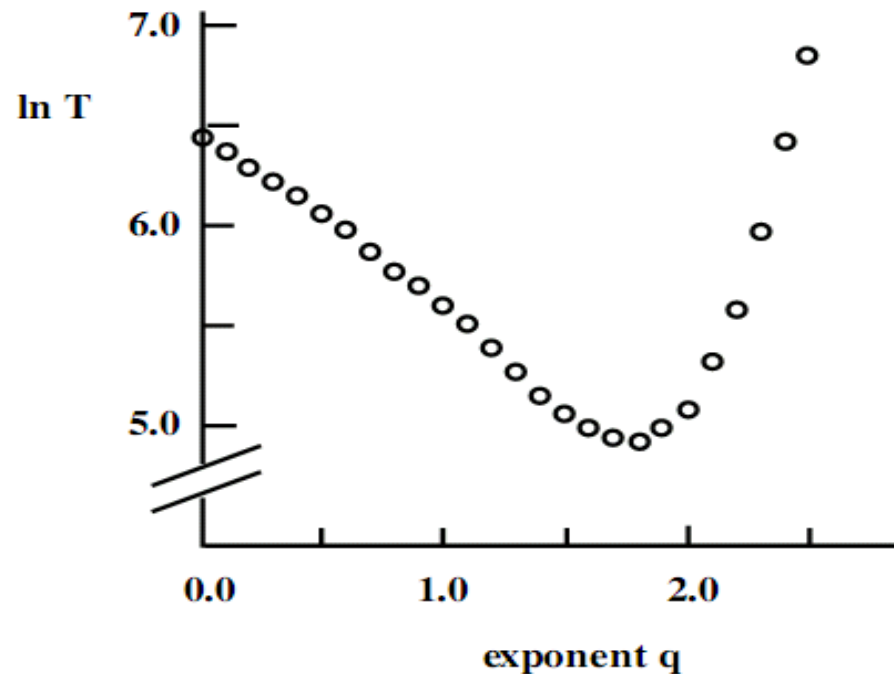


**Not random enough!**

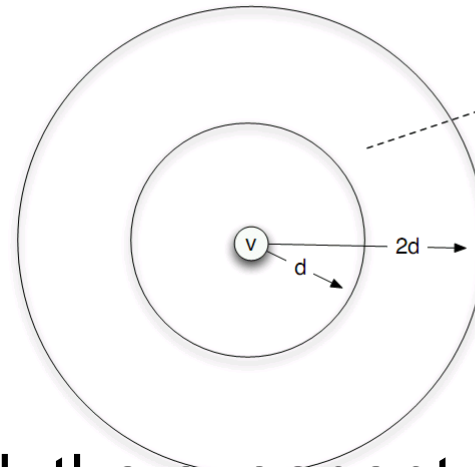


# What is the best value of $q$ ?

- Is there a value of  $q$ , making the search path achieves the shortest?
- Experiment on a two-dimensional grid
  - $q \approx 2$



# Inverse-Square Principle



number of nodes is proportional to  $d^2$

probability of linking to each is proportional to  $d^{-2}$

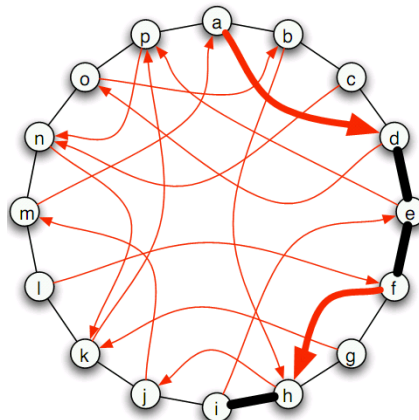
- For a two-dimensional grid, the exponent  $q = 2$  makes it best for decentralized search

$$Pr\{u \rightarrow v\} \sim d(u, v)^{-2}$$

- **Guess: for  $d$ -dimensional,  $q=d$ !**
- Rough explanation
  - The total number of nodes in an area is proportional to  $d^2$
  - The probability for  $v$  linking to the nodes is proportional to  $d^{-2}$
  - They cancel out  $\rightarrow$  making the probability from  $v$  to any other node in the area is independent of  $d$

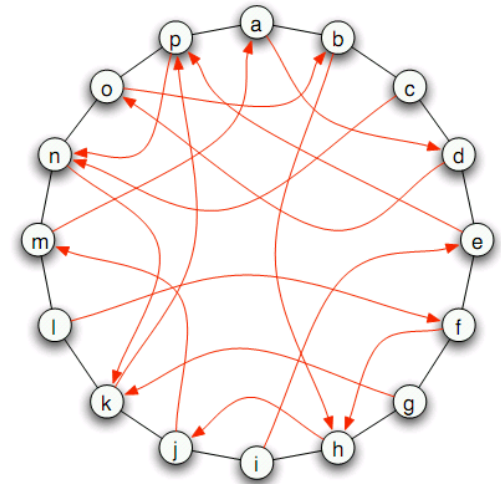
# Analysis the Model in 1-dimension

- Nodes are arranged in a ring.
- For 1 dimension,  $p=1$  is the best  $Pr\{u \rightarrow v\} \sim d(u, v)^{-1}$
- Each node knows only local information, performing decentralized search
- Search strategy: **Myopic search**
  - When a node  $v$  is holding the message, it passes it to the contact that lies as close to  $t$  on the ring as possible
  - Not guarantee to be shortest path
- Question: what is the expected length of search path?

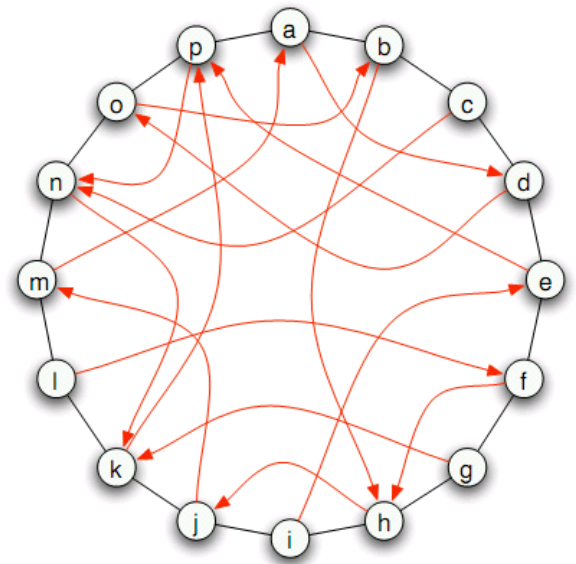


- Claim: for  $q=1$  in 1-dimensional model, we can get from  $s$  to  $t$  in  $O(\log(n)^2)$  steps.
- Proof:
- Normalization:  $Pr\{u \rightarrow v\} \sim d(u, v)^{-1}$ 
  - Let  $Z = \sum_{i \neq u} d(u, i)^{-1}$
  - The probability of linking from node  $u$  to  $v$  is:

$$Pr\{u \rightarrow v\} = \frac{d(u, v)^{-1}}{Z}$$



(b) A ring augmented with random long-range links.



(b) A ring augmented with random long-range links.

○ Since

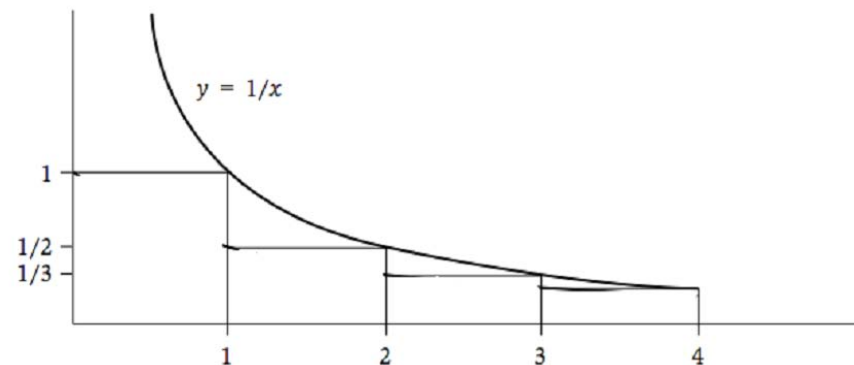
$$Z = \sum_{i \neq u} d(u, i)^{-1}$$

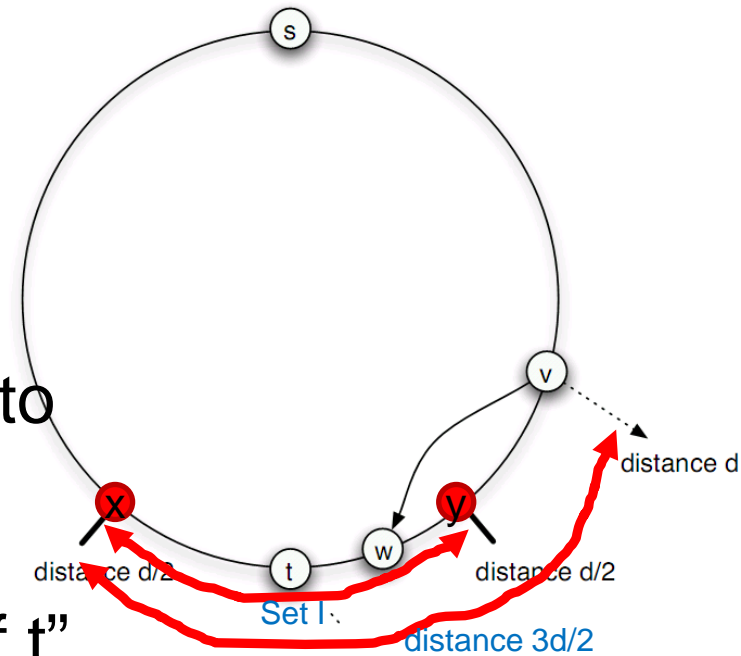
$$Z \leq 2 \left( 1 + \frac{1}{2} + \frac{1}{3} + \frac{1}{4} + \cdots + \frac{1}{n/2} \right)$$

$$1 + \frac{1}{2} + \frac{1}{3} + \frac{1}{4} + \cdots + \frac{1}{k} \leq 1 + \int_1^k \frac{1}{x} dx = 1 + \ln k.$$

○ We have

$$Z \leq 2(1 + \ln(n/2)) = 2\ln(n)$$

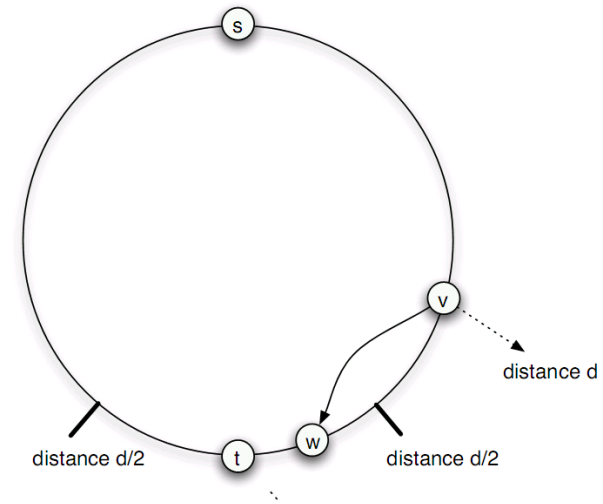




- For a node  $v$ , assume its distance to destination  $t$  is  $d$ , **when will the message enters  $d/2$  of  $t$ ?**
- Let  $I =$  “the set of nodes with  $d/2$  of  $t$ ”
  - The number of nodes in  $I$  is  $d+1$

$$\begin{aligned}
 Pr\{v \text{ points to } I\} &= \sum_{j \in I} Pr\{v \rightarrow j\} = \sum_{j \in I} \frac{d(v, j)^{-1}}{Z} \\
 &= \frac{1}{Z} \sum_{j \in I} \frac{1}{d(v, j)} \geq \frac{1}{Z} (d + 1) \frac{1}{d(v, x)} \geq \frac{1}{Z} d \frac{2}{3d} \geq \frac{2}{3Z}
 \end{aligned}$$

- Since  $Z \leq 2 \ln(n)$
- We have  $Pr\{v \text{ points to } I\} \geq \frac{1}{3 \ln(n)}$



- We have

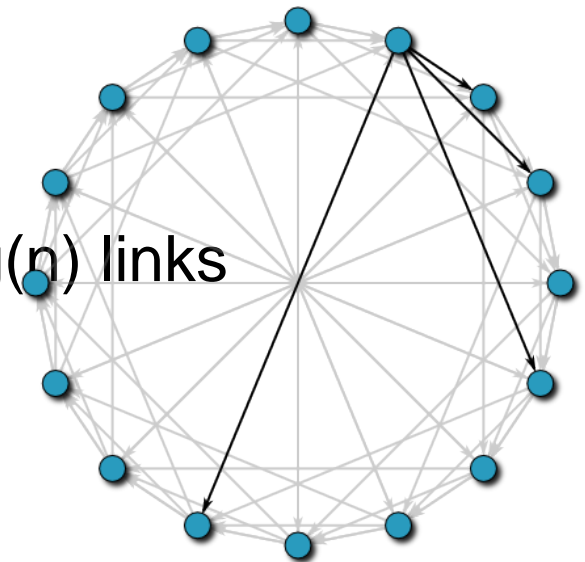
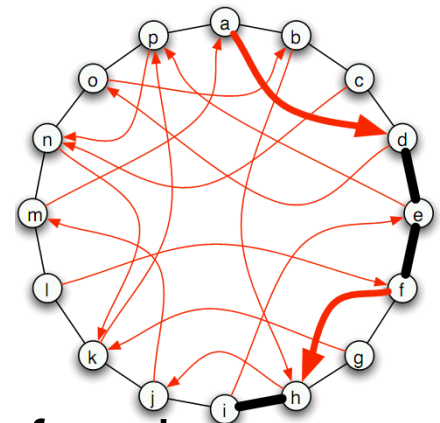
$$Pr\{v \text{ points to } I\} \geq \frac{1}{3 \ln(n)} = O\left(\frac{1}{\ln(n)}\right)$$

- It means within  $O(\ln(n))$  steps, we can get into  $I$  from  $v$  **(the distance is halved!)**
- Distance can be halved at most  $\log_2(n)$  times, so the expected time from  $s$  to  $t$  is

$$O(\ln(n) \cdot \log_2(n)) = \mathbf{O(\log(n)^2)}$$

# Summary

- In 1-dimensional ring structure
  - Each node knows only local information, performing decentralized search
  - Search strategy: **Myopic search**
  - $p=1$  achieves the shortest search path length
  - Expected search path:  **$O(\log(n)^2)$**
- Compare with P2P searching?
  - Chord
  - Each node has a FingerTable with  $\log(n)$  links
  - The search path length is  $O(\log(n))$ .





# Analysis in Two Dimensions

- For 2-dimensional grid,  $q=2$  achieves the best for decentralized searching
  - For  $n$ -dimensional, should be  $q=n$ .
- Analysis is similar to 1-dimensional case
  - Normalization:  $z$  is still  $O(\ln(n))$   $Z = \sum_{i \neq u} d(u, i)^{-2}$
  - The number of nodes within  $d/2$  of the target is  $O(d^2)$
  - The probability  $v$  link to one node in  $I$  is  $O(1/d^2Z)$
  - The probability of halving the distance is:  
 $O(d^2) * O(1/d^2Z) = O(1/Z)$  ( **$d$  is canceled out!**)
    - Similar, for  $n$ -dimensional, letting  $q=n$  will cancel out  $d$
  - The expected steps to halve the distance is  $O(Z) = O(\ln(n))$
  - The total expected steps from  $s$  to  $t$  is:  
 $\log_2 n * O(\ln(n)) = O(\log(n)^2)$
- This is called **Inverse-Square Principle**  $Pr\{u \rightarrow v\} \sim d(u, v)^{-2}$

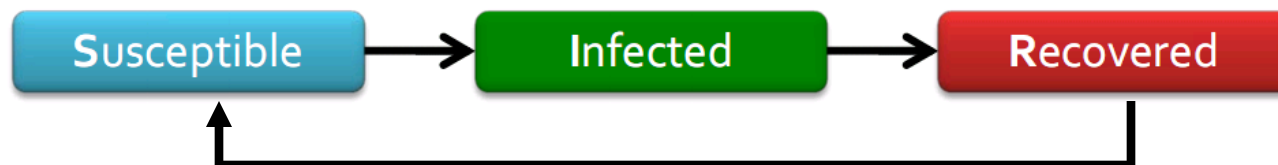
# Epidemics

# Spread of Contagious Diseases

- Spread of contagious diseases
  - Can pass explosively through a population
  - Determined by the properties of the virus: including its contagiousness, the length of its infectious period, and its severity
  - Also affected by network structures within the population it is affecting
- The spread of computer viruses
- Diffusion of ideas through social networks

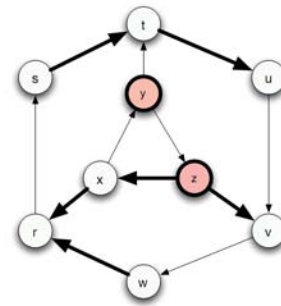
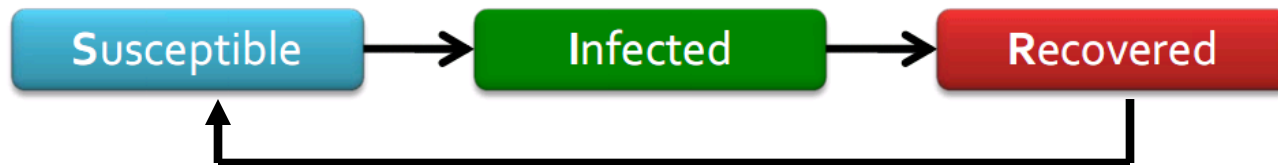
# The SIRS Epidemic Model

- Each node goes through the following potential stages: S-I-R-S
  - **Susceptible**: Before the node has caught the disease, it is susceptible to infection from its neighbors.
  - **Infectious**: Once the node has caught the disease, it is infectious and has some probability of infecting each of its susceptible neighbors.
  - **Removed**: After a particular node has experienced the full infectious period, this node is removed from consideration, since it no longer poses a threat of future infection.
  - **Susceptible**: after the removed stage, it returns to the Susceptible stage



## ○ Process

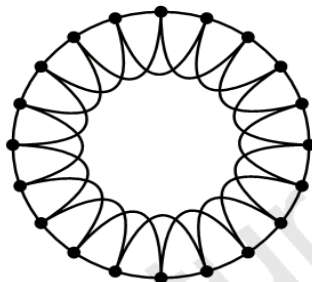
- Initially, some nodes are in the **I** state and all others are in the **S** state.
- Each node  $v$  that enters the **I** state remains infectious for a fixed number of steps  $t_I$ .
- During each of these  $t_I$  steps,  $v$  has a probability  $p$  of passing the disease to each of its susceptible neighbors.
- After  $t_I$  steps, node  $v$  is no longer infectious. It then enters the **R** state for a fixed number of steps  $t_R$ . During this time, it cannot be infected with the disease, nor does it transmit the disease to other nodes.
- After  $t_R$  steps in the **R** state, node  $v$  returns to the **S** state.



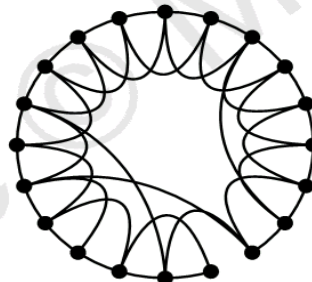
# Small-World Contact Networks

- **Recap: The 1-dimensional Watts-Strogatz Model**
- Starting from a ring lattice with  $n$  vertices and  $k$  edges per vertex.
  - Regular network with high clustering coefficient
- We rewire each edge at random with probability  $p$  ( $0 \leq p \leq 1$ ).
  - $p=0$ : regular network
  - $p=1$ : random network
  - $0 < p < 1$ : small world network

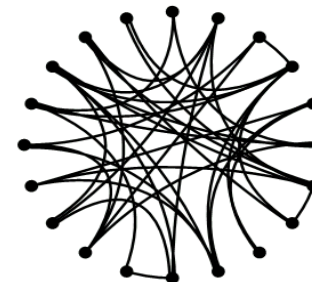
Regular



Small-world

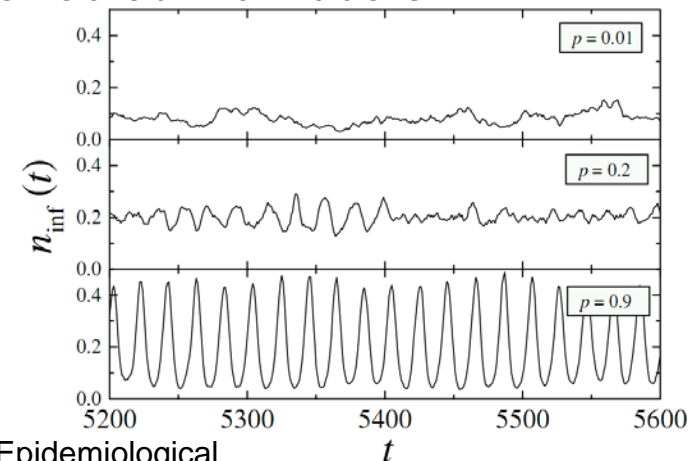
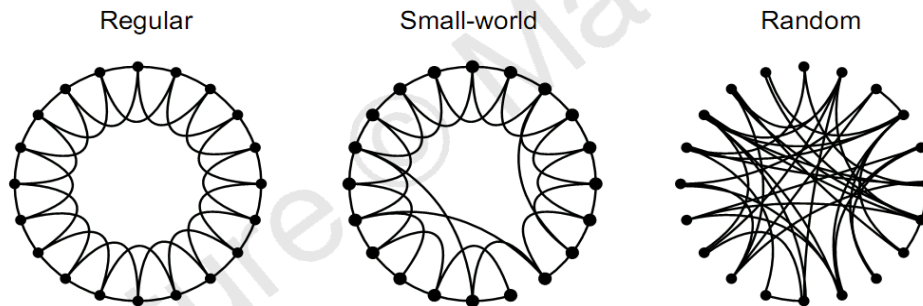


Random



# Small World Effect in the SIRS Model [1]

- Different behavior is observed depending on the value of  $p$ 
  - When  $p$  is small ( $p=0.01$ )
    - Disease transmission through the network occurs mainly via the **short-range local edges**
    - Flare-ups of the disease in one part of the network **never become coordinated** with other parts
  - When  $p$  increases ( $p=0.2$ )
    - These flare-ups start to **synchronize**
    - Oscillations intermittently appear and then disappear
  - For very large values of  $p$  ( $p=0.9$ )
    - There are **clear waves** in the number of affected individuals



[1] Marcelo Kuperman and Guillermo Abramson, Small World Effect in an Epidemiological

Model, PHYSICAL REVIEW LETTERS, Vol. 86, No. 13, 2001, 2909-2012.

FIG. 1. Fraction of infected elements as a function of time.

# Lecture next week

- Lecture room is temporary moved to **IFI 0.101** for next week (June 13).



# Case Study: Tracking Flu Using Twitter [2]

- Collecting information about epidemics:
  - The **location, timing and intensity** of an epidemic
  - Information is collected from school and workforce absenteeism figures, phone calls and visits to doctors and hospitals
- Gathering this information is a **difficult, resource-demanding, time-consuming** procedure
- Use of search engine data to detect Influenza-like Illness (ILI)
  - Geographic clusters with a heightened proportion of health-related queries
- **Using Twitter to detect ILI?**

# Data

- Twitter, UK
  - Daily average of 160,000 tweets
  - 24 weeks from 06/22/2009 to 12/06/2009
  - Twitter geolocation (geographical coordinates).
- Official health reports
  - Health Protection Agency (HPA), UK.
  - Region A = Central England & Wales
  - Region B = South England
  - Region C = North England
  - Region D = England & Wales
  - Region E = Wales & Northern Ireland

# Official Health Reports

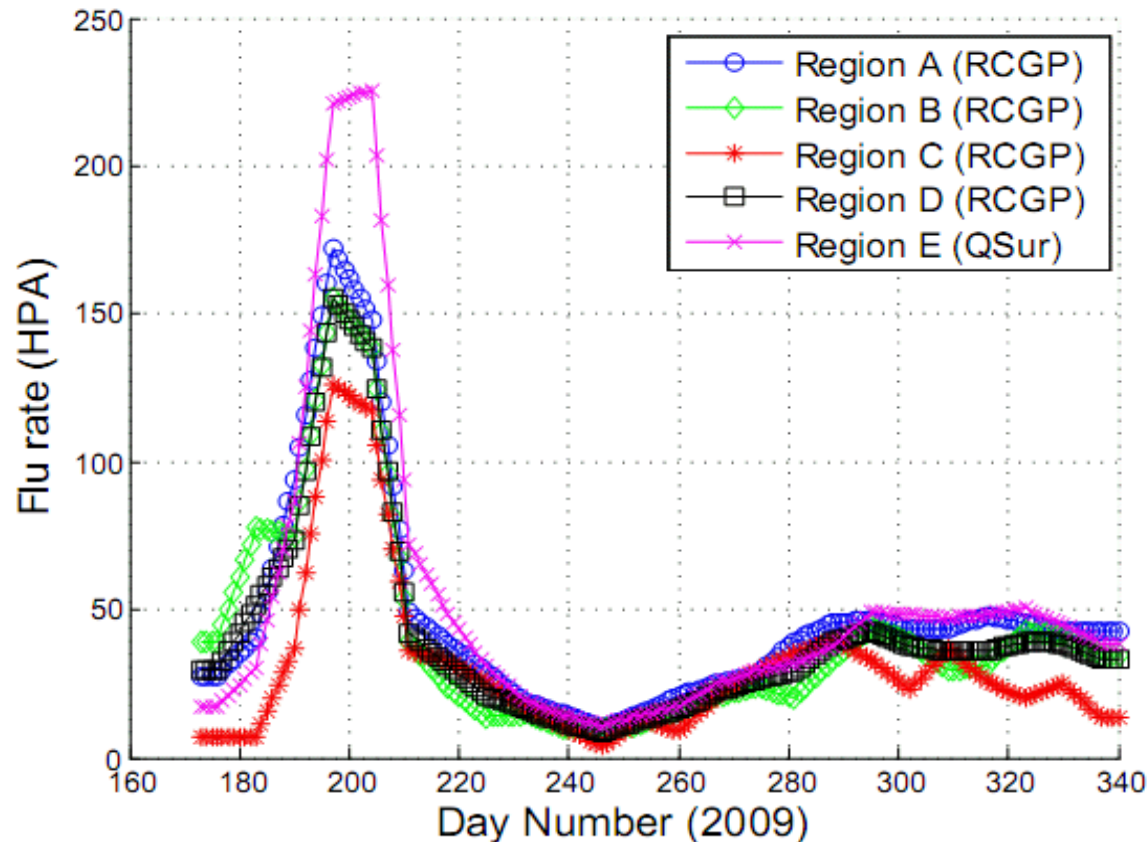
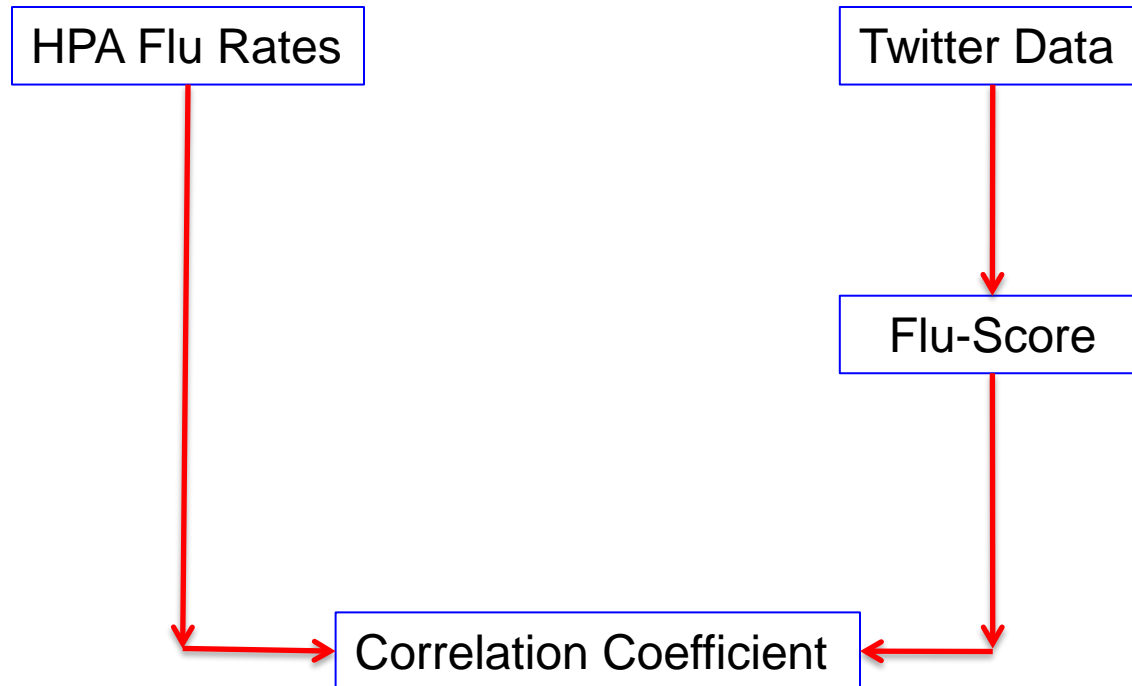


Fig. 1: Flu rates from the Health Protection Agency (HPA) for regions A-E (weeks 26-49, 2009). The original weekly HPA's flu rates have been expanded and smoothed in order to match with the daily data stream of Twitter (see section III-B).

# Methodology



# Computing Flu-scores

- The **daily set** of Tweets:

$$\mathcal{T} = \{t_j\}, \text{ where } j \in [1, n]$$

- **Textual markers**: expressing illness symptoms, e.g. fever, temperature, sore throat, infection, headache

- A **set of textual markers**:  $\mathcal{M} = \{m_i\} \quad i \in [1, k]$

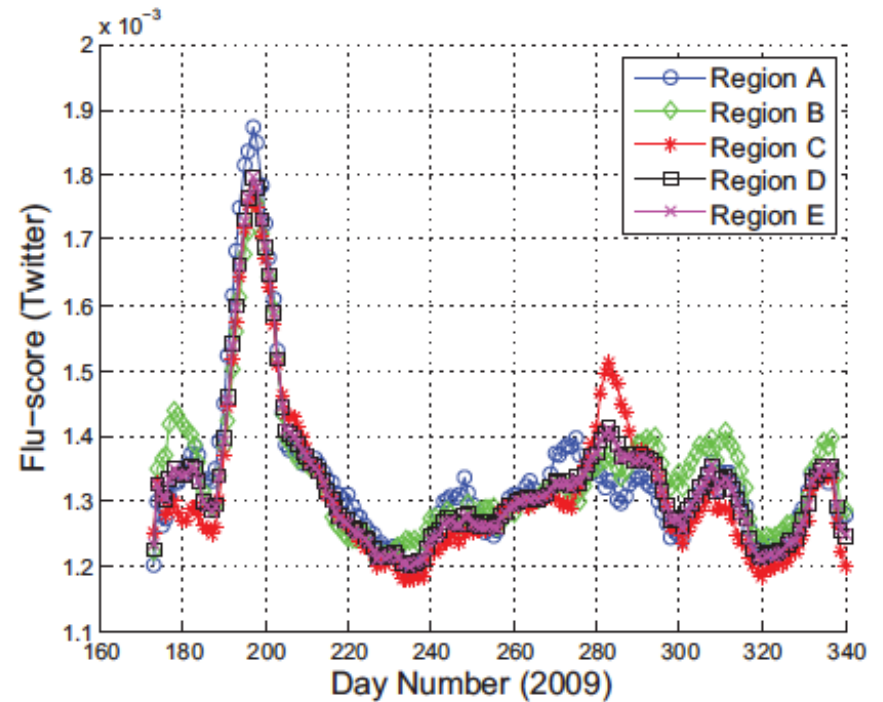
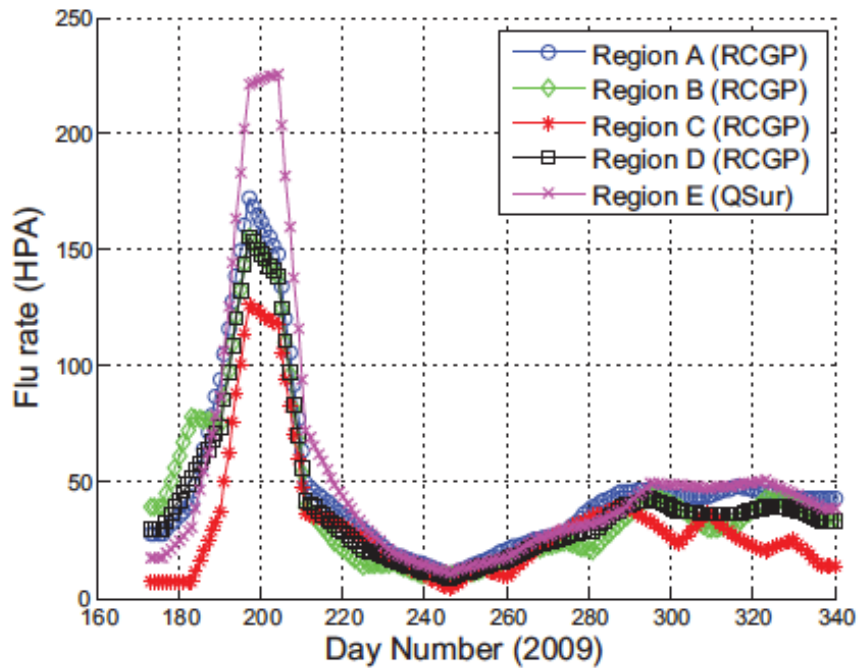
- Let  $m_i(t_j)=1$  if  $m_i$  appears in tweet  $t_j$ , otherwise=0

- The flu-score of a tweet  $t_j$ :  $s(t_j) = \frac{\sum_i m_i(t_j)}{k}$

- The flu-score of one day Twitter corpus

$$f(T, \mathcal{M}) = \frac{\sum_j s(t_j)}{n} = \frac{\sum_j \sum_i m_i(t_j)}{k \bullet n}$$

# Flu-rate vs Flu-score



# Correlation Coefficient

- A measure of the correlation (linear dependence) between two variables X and Y
- Giving a value between +1 and -1 inclusive

- Definition  $\rho_{X,Y} = \text{corr}(X, Y) = \frac{\text{cov}(X, Y)}{\sigma_X \sigma_Y} = \frac{E[(X - \mu_X)(Y - \mu_Y)]}{\sigma_X \sigma_Y}$ ,

- For a sample:

$$r_{xy} = \frac{\sum_{i=1}^n (x_i - \bar{x})(y_i - \bar{y})}{(n - 1)s_x s_y} = \frac{\sum_{i=1}^n (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^n (x_i - \bar{x})^2 \sum_{i=1}^n (y_i - \bar{y})^2}}$$

Correlation	Negative	Positive
None	-0.09 to 0.0	0.0 to 0.09
Small	-0.3 to -0.1	0.1 to 0.3
Medium	-0.5 to -0.3	0.3 to 0.5
Strong	-1.0 to -0.5	0.5 to 1.0

# Correlations between Twitter Flu-scores and HPA Flu rates

- Strong correlation is observed!
- It indicates linear correlation between Twitter flu-scores and HPA flu rates, thus the flu-scores can be used to predict flu rates!

Region	HPA Scheme	Corr. Coef.
A	RCGP	0.8471
B	RCGP	0.8293
C	RCGP	0.8438
D	RCGP	0.8556
E	QSur	0.8178



# Extensions

- Learning HPA's flu rates from Twitter flu-scores
  - Linear regression is used to build a weighted Twitter flu-scores to model flu rates
- Automatic extraction of ILI textual markers
  - Creating candidate markers from:
    - Encyclopedic reference
    - Informal references
  - Forming the flu-subscores with time series.

# Tracking Flu: Summary

- Tracking the flu outbreak in the UK using Twitter messages.
- High correlation between the flu-score and the HPA flu rates, greater than 95%.
- Advantages:
  - Less resource-demanding: only monitoring Twitter website, can be done automatically
  - More faster: can be done efficiently, while official reports need to delay 1 or two weeks
- Disadvantages
  - Still need sample data from official statistics for learning
  - Not everyone post their disease: could be not accurate
  - Not suitable for all sort of contagious diseases: some of them are not discussed in Twitter for privacy reason

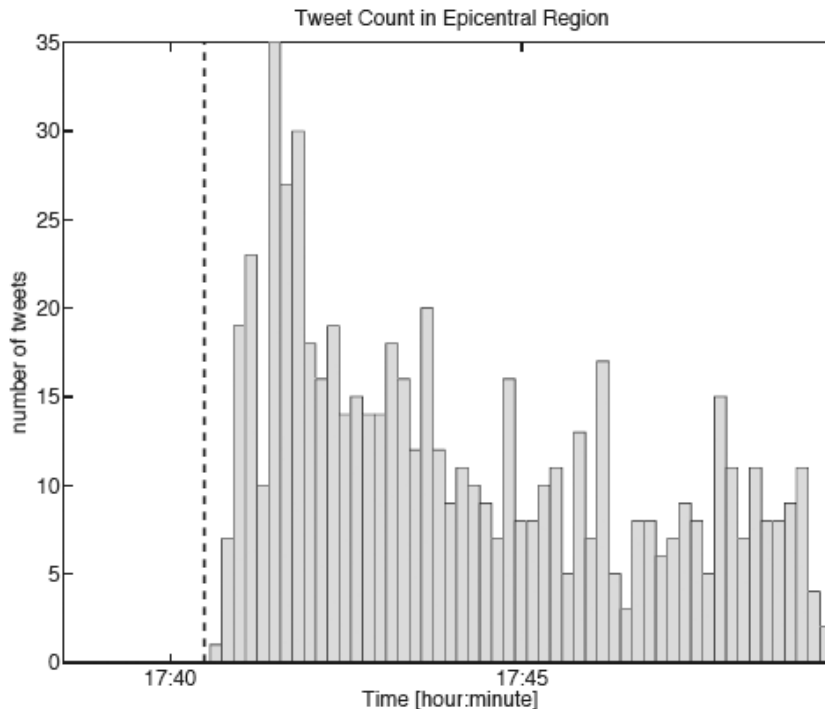
# Tracking Earthquake Using Twitter [3,4]

[3] Paul Earle, Michelle Guy, Richard Buckmaster, Chris Ostrum, Scott Horvath, and Amy Vaughan, OMG Earthquake! Can Twitter Improve Earthquake Response? U.S. Geological Survey, 2010

[4] Takeshi Sakaki, Makoto Okazaki, and Yutaka Matsuo. 2010. Earthquake shakes Twitter users: real-time event detection by social sensors. In Proceedings of the 19th international conference on World wide web (WWW '10). ACM, New York, NY, USA, 851-860.

Part of our slides are from the authors of [4]

- Subsequent earthquakes generated volumes of earthquake-related tweets
- Access to firsthand accounts of earthquake shaking within seconds of an earthquake is intriguing



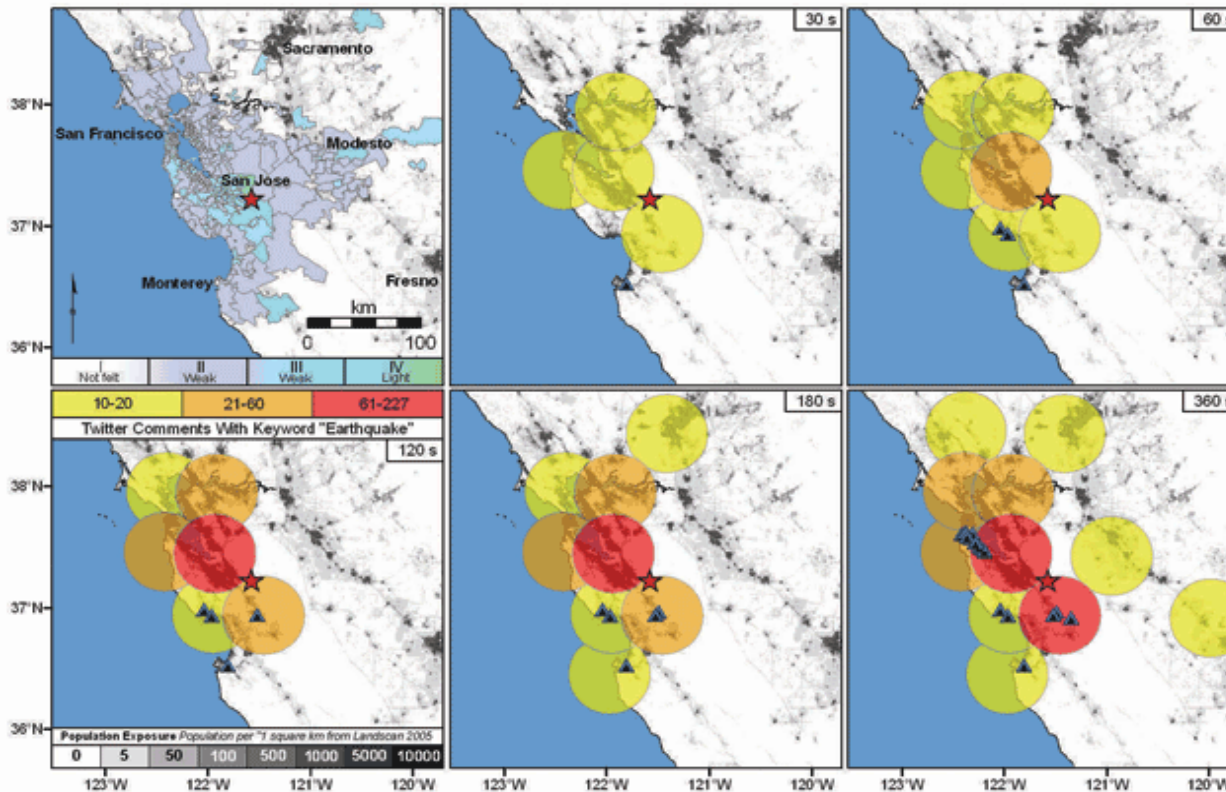
Tweet count following the 2009 MW 4.3 Morgan Hill, CA, earthquake. Tweets are binned in 10-second intervals, and the dashed line marks the origin time of the earthquake. After the earthquake, the tweet frequency quickly rose above the background level of less than one per hour to about 150 per minute.

# Using Twitter for Earthquake Detection and Assessment

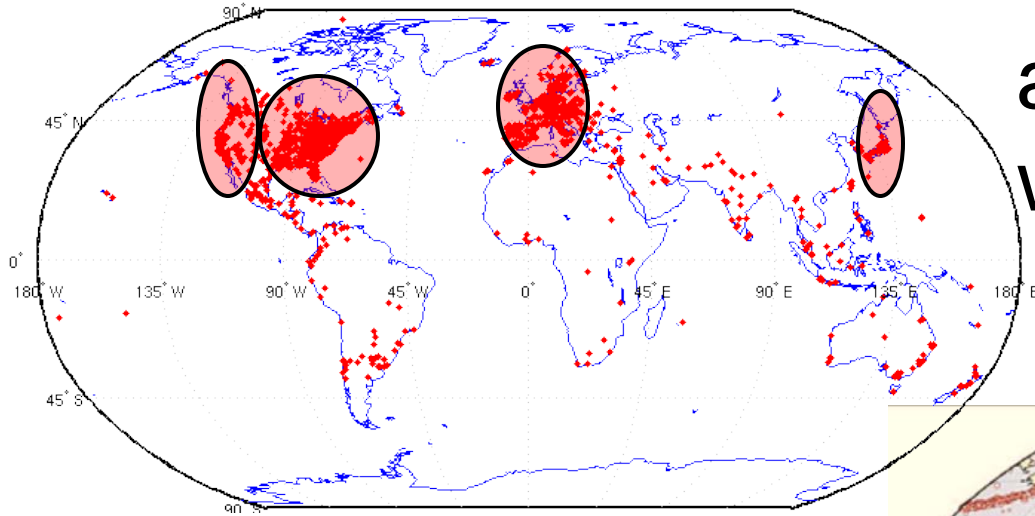
- **Real-time** nature of Microblogging
  - We can know what happens around other users in realtime
- **Public tweets** are stored in an openly searchable database
- **Earthquake Reports**
  - U.S. response time: **1.5-20 min**
- Earthquake detection using Twitter
  - The typical delay for tweet transmission is **5 seconds**
  - Earthquake could be detected in under **a minute**
- Twitter could be faster than Earthquake Wave!
  - An earthquake propagates at about **3–7 km/s** (for 100km, about **20s**)
  - **Early alarm is possible?**

# Mapping the Felt Region

- Morgan Hill, 30 March 2009, MW 4.3

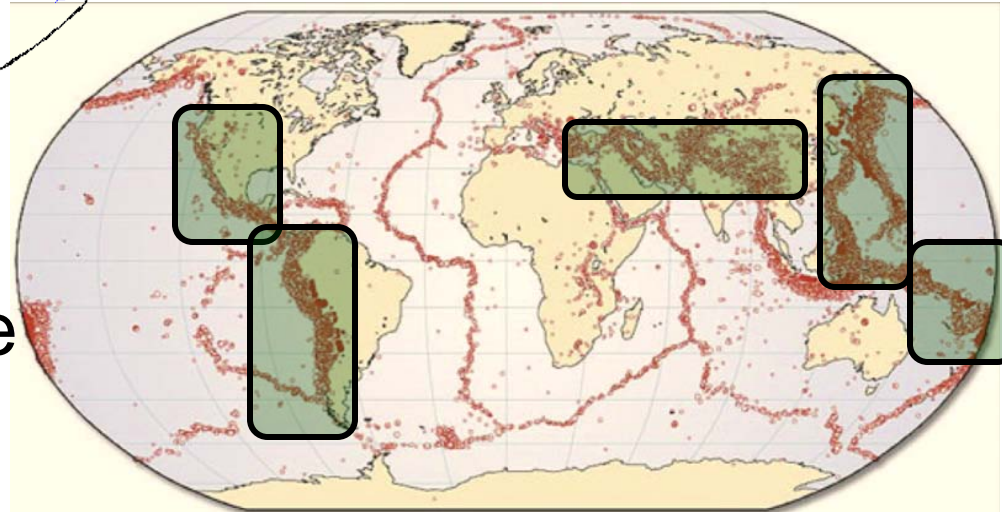


# Twitter and Earthquakes in Japan



a map of Twitter user world wide

a map of earthquake occurrences world wide



The intersection is regions with many earthquakes and large twitter users in Japan.

Other regions:

Indonesia, Turkey, Iran, Italy, and Pacific coastal US cities

# Event Detection Using Twitter

- Do semantic analysis on Tweet
  - To obtain tweets on the target event precisely
- Regard Twitter user as a sensor
  - To detect the target event
  - To estimate location of the target



# Semantic Analysis on Tweet

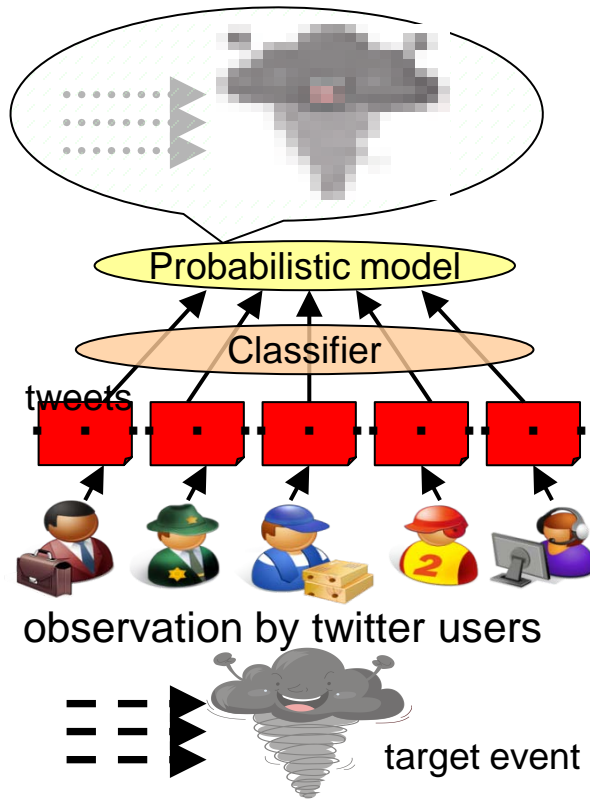
- ▶ Search tweets including keywords related to a target event
  - ▶ Example: In the case of earthquakes
    - ▶ “shaking”, “earthquake”
- ▶ Classify tweets into a positive class or a negative class
  - ▶ Example:
    - ▶ “Earthquake right now!!” ---positive
    - ▶ “Someone is shaking hands with my boss” --- negative
  - ▶ Create a classifier

# Semantic Analysis on Tweet

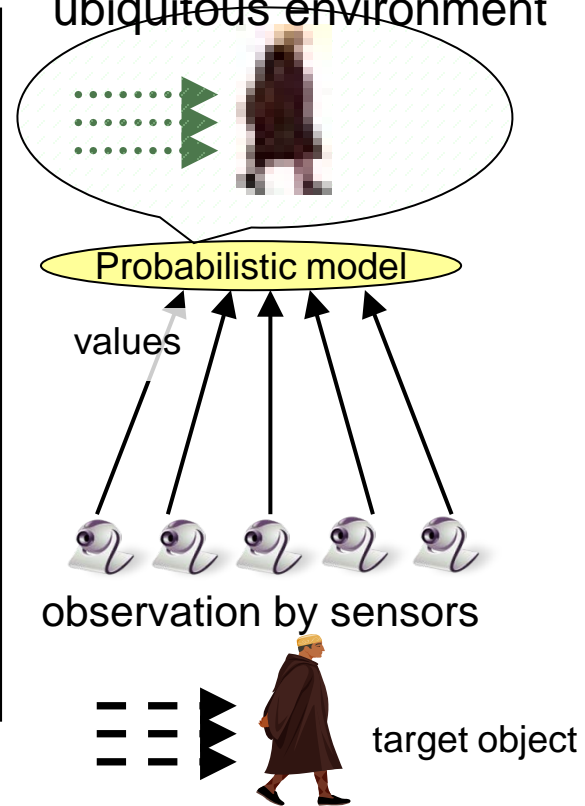
- ▶ Create classifier for tweets
  - ▶ use **Support Vector Machine(SVM)** - a machine learning algorithm
- ▶ Features (Example: I am in Japan, earthquake right now!)
  - ▶ **Statistical features** (7 words, the 5<sup>th</sup> word)  
the number of words in a tweet message and the position of the query within a tweet
  - ▶ **Keyword features** ( I, am, in, Japan, earthquake, right, now)  
the words in a tweet
  - ▶ **Word context features** (Japan, right)  
the words before and after the query word

# Tweet as a Sensory Value

Event detection from twitter

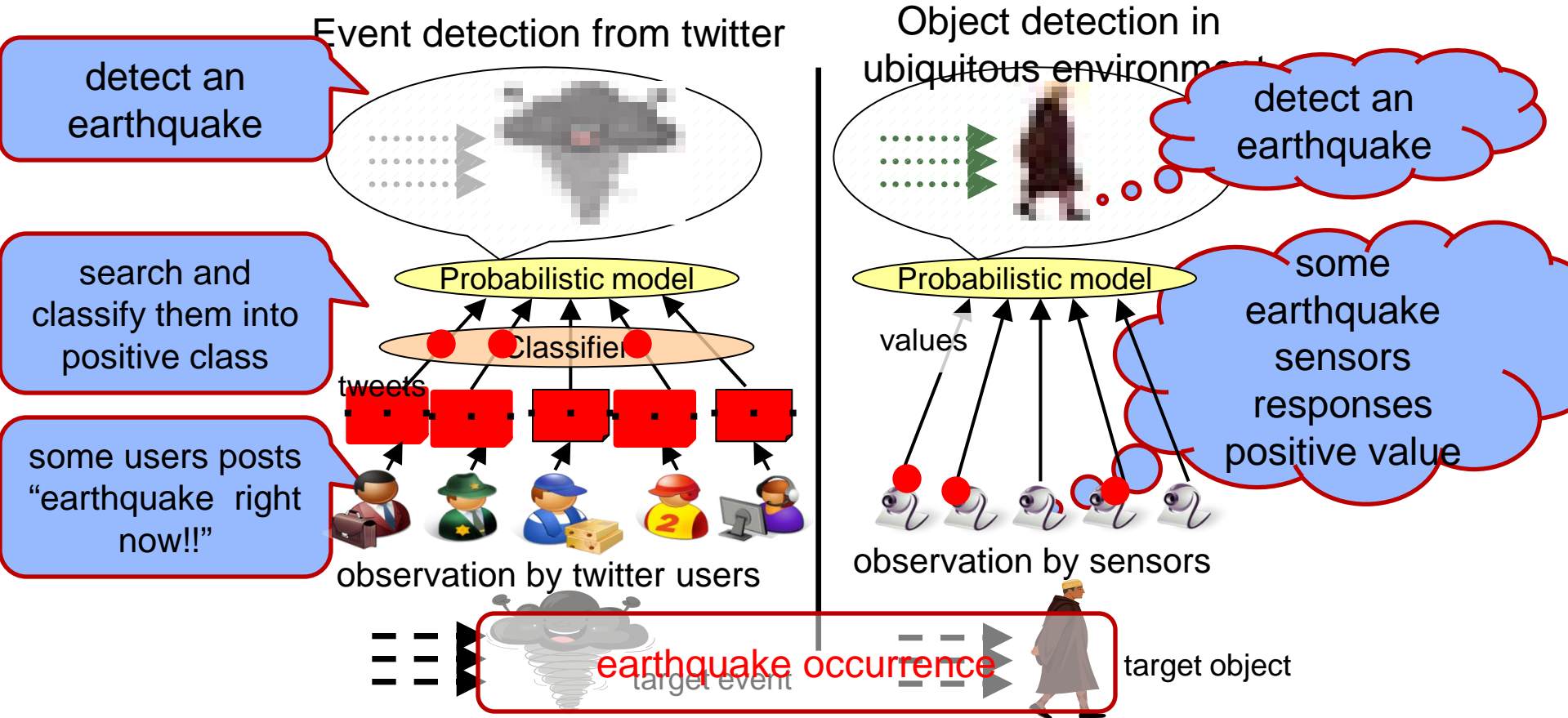


Object detection in ubiquitous environment



the correspondence between **tweets processing** and **sensory data detection**

# Tweet as a Sensory Value



We can apply methods for sensory data detection to tweets processing

# Tweet as a Sensory Value

- ▶ We make two assumptions to apply methods for observation by sensors
- ▶ Assumption 1: Each Twitter user is regarded as a sensor
  - ▶ a tweet → a sensor reading
  - ▶ a sensor detects a target event and makes a report probabilistically
  - ▶ Example:
    - ▶ make a tweet about an earthquake occurrence
    - ▶ “earthquake sensor” return a positive value
- ▶ Assumption 2: Each tweet is associated with a time and location
  - ▶ a time : post time
  - ▶ location : GPS data or location information in user’s profile

Processing time information and location information, we can detect target events and estimate location of target events

# Earthquake Location Estimation

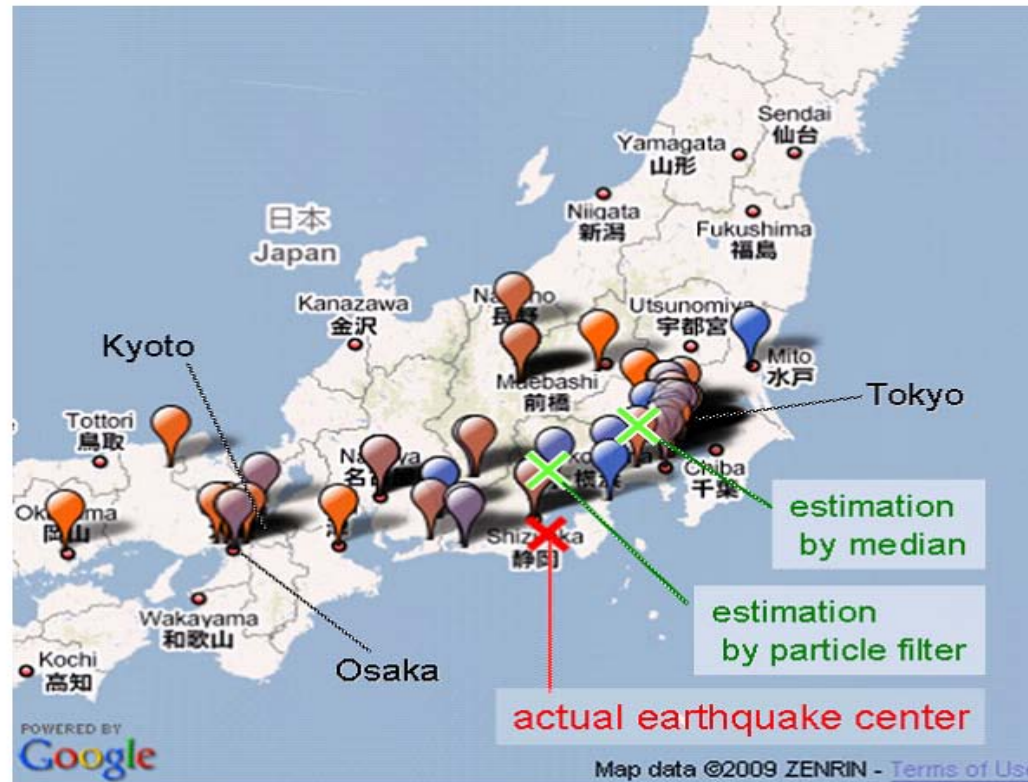


Figure 9: Earthquake location estimation based on tweets. Balloons show the tweets on the earthquake. The cross shows the earthquake center. Red represents early tweets; blue represents later tweets.

# Earthquake Reporting System

- Toretter ( <http://toretter.com>)
  - Earthquake reporting system using the event detection algorithm
  - All users can see the detection of past earthquakes
  - Registered users can receive e-mails of earthquake detection reports

Published	Location	Title	Screen_name	URL
2009-08-11 05:09:57	Saitama, Japan	地震おおいわー	tondol	<a href="http://twitter.com/tondol">http://twitter.com/tondol</a>
2009-08-11 05:08:56	unknown	地震。	tr0ly	<a href="http://twitter.com/tr0ly">http://twitter.com/tr0ly</a>
2009-08-11 05:08:53	iPhone: 35.509506,139.615601	揺れたね	Hakkan	<a href="http://twitter.com/Hakkan">http://twitter.com/Hakkan</a>
2009-08-11 05:08:53	Mie Prefecture	すごい地震だ [mb]	narude531 masu	<a href="http://twitter.com/narude531 masu">http://twitter.com/narude531 masu</a>
2009-08-11 05:08:52	Kawasaki city	地震だ！！	yaketazamma	<a href="http://twitter.com/yaketazamma">http://twitter.com/yaketazamma</a>
2009-08-11 05:08:52	unknown	地震こわいですかんへん	wzcc	<a href="http://twitter.com/wzcc">http://twitter.com/wzcc</a>
2009-08-11 05:08:52	Kansai	あら、地震？	HARU_IRO	<a href="http://twitter.com/HARU_IRO">http://twitter.com/HARU_IRO</a>
2009-08-11 05:08:52	Sakado, Saitama, Japan	地震だ	d_wackys	<a href="http://twitter.com/d_wackys">http://twitter.com/d_wackys</a>
2009-08-11 05:08:51	unknown	愛知も揺れたw	edoman	<a href="http://twitter.com/edoman">http://twitter.com/edoman</a>
2009-08-11 05:08:51	unknown	また地震 長いな	lauk.az	<a href="http://twitter.com/lauk.az">http://twitter.com/lauk.az</a>
2009-08-11 05:08:51	JP	地震なる	echomitt	<a href="http://twitter.com/echomitt">http://twitter.com/echomitt</a>

# Earthquake Reporting System

- Effectiveness of alerts of this system
  - Alert E-mails urges users to prepare for the earthquake if they are received by a user shortly before the earthquake actually arrives.
- Is it possible to receive the e-mail before the earthquake actually arrives?
  - An earthquake is transmitted through the earth's crust at about 3~7 km/s.
  - a person has about **20~30 sec** before its arrival at a point that is 100 km distant from an actual center



# Results of Earthquake Detection

- In all cases, we sent E-mails before announces of JMA
- In the earliest cases, we can sent E-mails in 19 sec.

Date	Magnitude	Location	Time	E-mail sent time	time gap [sec]	# tweets within 10 minutes	Announce of JMA
Aug. 18	4.5	Tochigi	6:58:55	7:00:30	95	35	7:08
Aug. 18	3.1	Suruga-wan	19:22:48	19:23:14	26	17	19:28
Aug. 21	4.1	Chiba	8:51:16	8:51:35	19	52	8:56
Aug. 25	4.3	Uraga-oki	2:22:49	2:23:21	31	23	2:27
Aug.25	3.5	Fukushima	2:21:15	22:22:29	73	13	22:26
Aug. 27	3.9	Wakayama	17:47:30	17:48:11	41	16	1:7:53
Aug. 27	2.8	Suruga-wan	20:26:23	20:26:45	22	14	20:31
Ag. 31	4.5	Fukushima	00:45:54	00:46:24	30	32	00:51
Sep. 2	3.3	Suruga-wan	13:04:45	13:05:04	19	18	13:10
Sep. 2	3.6	Bungo-suido	17:37:53	17:38:27	34	3	17:43

# Discussion

- Advantages
  - No need of dedicate devices
  - Provide a fast detection and assessment of earthquake
  - Possibility of early alarm
- Limitations of earthquake detection with Twitter
  - Need enough Twitter samples
    - Depend on the population distribution of Twitter
    - If the center of a target event is in an oceanic area, it's more difficult to locate it
    - The number of tweets maybe not as large as we had anticipated.
  - Could be not accurate
    - Interfered by retweets (not in the earthquake area)
    - Incorrect tweet geolocations
  - Could be unstable
    - The network service is not reliable when earthquake happens
    - Vulnerable to hacker attacks
  - Still not fast enough

# Other Possible Applications

- Social life
  - Detect the hot news in the world
- Economy
  - Detect the trend of stocks
- Politics
  - Predict and evaluate president selection and other political events
- Science
  - Discover patterns of social interactions and influences

○ ...

# Summary

- Applications
  - Decentralized search
  - Epidemics
    - SIRS Model
    - Flu detection
  - Tracking Earthquake Using Twitter

# Thank You!

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