Large-scale Social Sensing
(with Humans as Sensors)

Tarek Abdelzaher
Dept. of Computer Science
University of Illinois at Urbana Champaign
Earthquake Shakes Twitter Users

Using Humans as Sensors:

- Assumption: Each Twitter user is regarded as a sensor. A sensor detects a target event and makes a report probabilistically.
- Assumption: Each tweet is associated with a time and location, which is a set of latitude and longitude.
Earthquake Shakes Twitter Users

Using Humans as Sensors:
Event Detection: The Classifier

- Not all occurrences of a keyword (e.g., “earthquake” or “shaking” is about an ongoing event:
  - I am afraid of earthquakes
  - Shaking hands with boss
- How to solve this? (How to classify occurrences that constitute “sensing” of an ongoing event from others?)
Event Detection: A Probabilistic Model

- Spikes in occurrence of related keywords help detect corresponding events:

  - Earthquake-related keywords
  - Typhoon-related keywords

When a user detects an event at time 0, the time to make a tweet follows and exponential distribution.
Event Tracking

- Given (i) detected noisy location of the event at each point in time and a (ii) mobility model for the event, compute the most likely trajectory.

- Multiple tracking techniques available in literature:
  - Kalman filter
  - Particle filter
Information Diffusion

- Assuming little/no diffusion (no retweets)

Diffusion of Earthquake tweets

Diffusion of Typhoon tweets
Evaluation

- Detection of an Earthquake
Evaluation

Detection of an Earthquake

<table>
<thead>
<tr>
<th>Date</th>
<th>Actual center lat.</th>
<th>Median (baseline) lat.</th>
<th>Weighted ave. (baseline) lat.</th>
<th>Kalman filters lat.</th>
<th>Particle filters lat.</th>
<th>Average distance</th>
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</table>

Average distance 5.47 3.62 3.85 3.01
Evaluation

- Detection and tracking of a Typhoon
**Evaluation**

- **Detection and tracking of a Typhoon**

<table>
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**Average distance** 4.39 4.02 9.56 3.58
The Human Sensor Model

- Humans are better at binary observations. For measurements on a scale, use sensors
- Examples of actual Twitter feeds that can be thought of as “binary observations”:
  - “Crash blocking lanes on I-5S @ McBean Pkwy in Santa Clarita”
  - “105E past LakewoodB: traffic stopped to clear tire debris out of lanes”
  - “@BostonGlobe: BREAKING NEWS: Shots fired in Watertown; source says Boston Marathon terror bomb suspect has been pinned down.”
  - “The police chief of Afghanistan's southern Kandahar province has died in a suicide attack on his headquarters.”
  - “Yonkers mayor has lifted his gas rationing order. Fill it up! #SandyABC7”
Dow Jones Hickup

- Dow Jones lost 150 points on a rumor of two explosions in the White House on April 23rd, 2013
Reconstructing Event Timelines
The Apollo Fact-finder

Clean Event Summary?

People

Claim Clusters

Network of Claims and Sources

Claim Credibility Assessment

Source Credibility Assessment

Boston Bombing

Hurricane Sandy

Egypt unrest
The Apollo Fact-finder

- Define $a_i$ as:
  - $P$ (source$_i$ makes an original observation | it is true)

- Define $b_i$ as:
  - $P$ (source$_i$ makes an original observation | it is false)

- What are the source reliability parameters that maximize the probability of received observations?

$$P(SC|\theta) = \sum_z P(SC, z|\theta)$$
Humans as Sensors

True Assertion

False Assertion

Reliability of Participant $i$

$t_i = P(C_j^t | S_i C_j)$

$S_i C_j$ : participant $i$ claims assertion $j$

Speak Rate of Participant $i$

$s_i = P(S_i C_j)$

Participant $i$ speak with rate $s_i$
Using Bayesian Theorem:

\[ a_i = P(S_i C_j | C_j^i) \]

Using Bayesian Theorem: \( a_i = \frac{t_i \times s_i}{d} \)

where \( d \) is the overall prior that a randomly chosen assertion is true

\[ b_i = P(S_i C_j | C_j^f) \]

Using Bayesian Theorem: \( b_i = \frac{(1-t_i) \times s_i}{1-d} \)

where \( d \) is the overall prior that a randomly chosen assertion is true
Expectation Maximization

Expectation Maximization

\[ L(\theta; X) = p(X|\theta) = \sum_Z p(X, Z|\theta) \]

**Expectation Step (E-step)**

\[ Q(\theta|\theta^{(t)}) = E_{Z|X,\theta^{(t)}}[\log L(\theta; X, Z)] \]

**Maximization Step (M-step)**

\[ \theta^{(t+1)} = \arg\max_{\theta} Q(\theta|\theta^{(t)}) \]

Find MLE of estimation parameter and values of hidden variables

\[ Z = \{z_1, z_2, \ldots, z_N\} \text{ where } z_j = 1 \text{ when assertion } C_j \text{ is true and } 0 \text{ otherwise} \]

\[ X \]

Observation Matrix

\[ \theta = (a_1, a_2, \ldots, a_M; b_1, b_2, \ldots, b_M; d) \]
Expectation Maximization

Likelihood function of EM

\[ L(\theta; X, Z) = p(X, Z|\theta) \]

\[ = \prod_{j=1}^{N} \left\{ \prod_{i=1}^{M} a_i^{S_i C_j} (1 - a_i)^{(1 - S_i C_j)} \times d \times z_j + \prod_{i=1}^{M} b_i^{S_i C_j} (1 - b_i)^{(1 - S_i C_j)} \times (1 - d) \times (1 - z_j) \right\} \]

Expectation Step (E-Step)

\[ Q(\theta|\theta^{(t)}) = E_{Z|X,\theta^{(t)}}[\log L(\theta; X, Z)] \]

\[ = \sum_{j=1}^{N} \left\{ p(z_j = 1|X_j, \theta^{(t)}) \times \left[ \sum_{i=1}^{M} (S_i C_j \log a_i + (1 - S_i C_j) \log (1 - a_i) + \log d) \right] 
+ p(z_j = 0|X_j, \theta^{(t)}) \times \left[ \sum_{i=1}^{M} (S_i C_j \log b_i + (1 - S_i C_j) \log (1 - b_i) + \log (1 - d)) \right] \right\} \]

Maximization Step (M-Step)

\[ a_i^{(t+1)} = a_i^* = \frac{\sum_{j \in S_{i,t}} Z(t, j)}{\sum_{j=1}^{N} Z(t, j)} \]

\[ b_i^{(t+1)} = b_i^* = \frac{K_i - \sum_{j \in S_{i,t}} Z(t, j)}{N - \sum_{j=1}^{N} Z(t, j)} \]

\[ d_i^{(t+1)} = d_i^* = \frac{\sum_{j=1}^{N} Z(t, j)}{N} \]

Iterate
EM outperforms state-of-art heuristics

Parameters:
Number of Participants: 20-110, Number of True Assertions: 1000, Number of False Assertions: 1000, Average Number of Claims per Participant: 100
Simulation
Simulated Geotagging

\[ P_c: \text{probability to continue} \]

**False Negatives:**
Missed Litter Locations/Total Litter

**False Positives:**
Incorrectly labeled Locations/Total Locations

- **Reported Litter**
- **Litter**
- **Trail**
Simulated Geotagging

(a) False Negatives (missed/total litter)  (b) False Positives (false/total locations)

Litter Geotagging Accuracy versus Number of People
Twitter-based Evaluation (Hurricane Irene)

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<tr>
<th>#</th>
<th>Media</th>
<th>Tweet found by EM</th>
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<tbody>
<tr>
<td>1</td>
<td>East Coast Braces For Hurricane Irene; Hurricane Irene is expected to follow a path up the East Coast</td>
<td>@JoshOchs A #hurricane here on the east coast.</td>
</tr>
<tr>
<td>2</td>
<td>Hurricane Irene’s effects begin being felt in NC, The storm, now a Category 2, still has the East Coast on edge.</td>
<td>Winds, rain pound North Carolina as Hurricane Irene closes in <a href="http://t.co/0gVOSZk">http://t.co/0gVOSZk</a></td>
</tr>
<tr>
<td>3</td>
<td>Hurricane Irene charged up the U.S. East Coast on Saturday toward New York, shutting down the city, and millions of Americans sought shelter from the huge storm.</td>
<td>Hurricane Irene rages up U.S. east coast <a href="http://t.co/u0XiXow">http://t.co/u0XiXow</a></td>
</tr>
<tr>
<td>4</td>
<td>The Wall Street Journal has created a way for New Yorkers to interact with the location-based social media app Foursquare to find the nearest NYC hurricane evacuation center.</td>
<td>Mashable - Hurricane Irene: Find an NYC Evacuation Center on Foursquare ... <a href="http://t.co/XMtph99">http://t.co/XMtph99</a></td>
</tr>
<tr>
<td>5</td>
<td>Following slamming into the East Coast and knocking out electricity to more than a million people, Hurricane Irene is now taking purpose on largest metropolitan areas in the Northeast.</td>
<td>2M lose power as Hurricane Irene moves north - Two-million homes and businesses were without power ... <a href="http://t.co/tZWkEU3">http://t.co/tZWkEU3</a></td>
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<tr>
<td>6</td>
<td>Irene remains a Category 1, the lowest level of hurricane classification, as it churns toward New York over the next several hours, the U.S. National Hurricane Center said on Sunday.</td>
<td>Now its a level 1 hurricane. Let’s hope it hits NY at Level 1</td>
</tr>
<tr>
<td>7</td>
<td>Blackouts reported, storm warnings issued as Irene nears Quebec, Atlantic Canada.</td>
<td>DTN Canada: Irene forecast to hit Atlantic Canada <a href="http://t.co/MjhmoJn">http://t.co/MjhmoJn</a></td>
</tr>
<tr>
<td>8</td>
<td>President Barack Obama declared New York a disaster area Wednesday. The New York Times reports, allowing the release of federal aid to the state's government and individuals.</td>
<td>Hurricane Irene: New York State Declared A Disaster Area By President Obama</td>
</tr>
<tr>
<td>9</td>
<td>Hurricane Irene's rampage up the East Coast has become the tenth billion-dollar weather event this year, breaking a record stretching back to 1980, climate experts said Wednesday.</td>
<td>Irene is 10th billion-dollar weather event of 2011.</td>
</tr>
<tr>
<td>10</td>
<td>WASHINGTON - On Sunday, September 4, the President will travel to Paterson, New Jersey, to view damage from Hurricane Irene.</td>
<td>White House: Obama to visit Paterson, NJ Sunday to view damage from Hurricane Irene</td>
</tr>
</tbody>
</table>

Top correct tweets found by EM matches well with Media Reports
A Maximum Likelihood Estimation Problem

- Joint estimation of
  - Source reliability
  - True/false value of each observation

- Given
  - Who said what

$$P(SC|\theta) = \sum_z P(SC,z|\theta)$$
Source Dependencies

- Joint estimation of
  - Source reliability
  - True/false value of each observation
- Given
  - Who said what, and
  - Correlations between sources

\[ P(SC|SD, \theta) = \sum_z P(SC, z|SD, \theta) \]
Reconstructing Event Timelines

A Twitter Example

Social Network

Clean Event Summary?

People

Information (consistency) Network

Boston Bombing

Hurricane Sandy

Egypt unrest
Expectation Maximization

Likelihood Function Incorporating Source Dependency

\[
P(SC, z | SD, \theta) = \prod_{j=1}^{N} P(z_j) \times \left\{ \prod_{g \in M_j} P(S_g C_j | \theta, z_j) \prod_{i \in c_g} P(S_i C_j | S_g C_j) \right\}
\]

\[
P(z_j) = \begin{cases} 
  d & z_j = 1 \\
  (1 - d) & z_j = 0 
\end{cases}
\]

\[
P(S_g C_j | \theta, z_j) = \begin{cases} 
  a_g & z_j = 1, S_g C_j = 1 \\
  (1 - a_g) & z_j = 1, S_g C_j = 0 \\
  b_g & z_j = 0, S_g C_j = 1 \\
  (1 - b_g) & z_j = 0, S_g C_j = 0 
\end{cases}
\]

\[
P(S_i C_j | S_g C_j) = \begin{cases} 
  p_{ig} & S_g C_j = 1, S_i C_j = 1 \\
  1 - p_{ig} & S_g C_j = 1, S_i C_j = 0 
\end{cases}
\]
Expectation Maximization

### E-Step

\[
Q \left( \theta | \theta^{(n)} \right) = \sum_{j=1}^{N} \left\{ Z(n, j) \times \left[ \sum_{g \in M_j} \left( \log P(S_g C_j | \theta, z_j) \right) \right. \right.
\]
\[
+ \sum_{i \in c_g} \log P(S_i C_j | S_g C_j) \left. \right] \left. \right\} + \log d
\]
\[
+ (1 - Z(n, j)) \times \left[ \sum_{g \in M_j} \left( \log P(S_g C_j | \theta, z_j) \right) \right. \right.
\]
\[
+ \sum_{i \in c_g} \log P(S_i C_j | S_g C_j) \left. \right] \right\} + \log(1 - d) \right\} \right\}
\]

### M-Step

\[
a_{g}^{(n+1)} = a_{g}^{*} = \frac{\sum_{j \in S_j g} Z(n, j)}{\sum_{j=1}^{N} Z(n, j)}
\]
\[
a_{i}^{(n+1)} = a_{i}^{*} = \frac{\sum_{j \in S_j g \cap S_j i} Z(n, j)}{\sum_{j \in S_j g} Z(n, j)}
\]

for \( i \in c_g \)

\[
b_{g}^{(n+1)} = b_{g}^{*} = \frac{\sum_{j \in S_j g} (1 - Z(n, j))}{\sum_{j=1}^{N} (1 - Z(n, j))}
\]

\[
b_{i}^{(n+1)} = b_{i}^{*} = \frac{\sum_{j \in S_j g \cap S_j i} (1 - Z(n, j))}{\sum_{j \in S_j g} (1 - Z(n, j))}
\]

for \( i \in c_g \)

\[
d^{(n+1)} = d^{*} = \frac{\sum_{j=1}^{N} Z(n, j)}{N}
\]
### Collected Data Traces

<table>
<thead>
<tr>
<th>Trace</th>
<th>Hurricane Sandy</th>
<th>Hurricane Irene</th>
<th>Egypt Unrest</th>
</tr>
</thead>
<tbody>
<tr>
<td>Locations</td>
<td>16 cities in East Coasts</td>
<td>New York</td>
<td>Cairo, Egypt</td>
</tr>
<tr>
<td># of users tweeted</td>
<td>7,583</td>
<td>207,562</td>
<td>13,836</td>
</tr>
<tr>
<td># of tweets</td>
<td>12,931</td>
<td>387,827</td>
<td>93,208</td>
</tr>
<tr>
<td># of users crawled in social network</td>
<td>704,941</td>
<td>2,510,316</td>
<td>5,285,160</td>
</tr>
<tr>
<td># of follower-followee links</td>
<td>37,597</td>
<td>3,902,713</td>
<td>10,490,098</td>
</tr>
</tbody>
</table>
The Experiments

- Run the maximum likelihood estimator on Twitter data to determine the probability of correctness of different tweets.
- Sort tweets by probability of correctness.
- Give the top N tweets to a human for “grading”.
- Human must investigate each tweet to determine if it is true.
- Any tweet that cannot be shown to be true is considered “unconfirmed”.
- Compare the percentages of unconfirmed tweets across different credibility estimation algorithms.
The Experiments

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**Note:** To remove bias, the grader was not told which algorithm “believed” which tweet.
Evaluation: Sandy Trace
A Comparison of Confirmed True Tweets

- RT: Retweet
- FF: Follower-Followee
- EC: Epidemic Cascade

18% vs 32%
Evaluation: Irene Trace
A Comparison of Confirmed True Tweets

RT: Retweet
FF: Follower-Followee
EC: Epidemic Cascade

15% 36%
Evaluation: Egypt Trace
A Comparison of Confirmed True Tweets

- RT: Retweet
- FF: Follower-Followee
- EC: Epidemic Cascade

Graph showing the comparison of confirmed true tweets with different methods and attributes.
### Example

<table>
<thead>
<tr>
<th>#</th>
<th>Media</th>
<th>Tweet found by Apollo-social</th>
<th>Tweet found by Regular EM</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Rockland County Executive C. Scott Vanderhoef is announcing a Local Emergency Order restricting the amount of fuel that an individual can purchase at a gas station.</td>
<td>Rockland County Orders Restrictions on Gas Sales - Nyack-Piermont, NY Patch <a href="http://t.co/cDSrqpA2">http://t.co/cDSrqpA2</a></td>
<td><strong>MISSING</strong></td>
</tr>
<tr>
<td>2</td>
<td>New York City Mayor Michael Bloomberg has announced that the city will impose an indefinite program of gas rationing after fuel shortages led to long lines and frustration at the pump in the wake of superstorm Sandy.</td>
<td>Gas rationing plan set for New York City: The move follows a similar announcement last week in New Jersey to ease... <a href="http://t.co/nkmF7U9I">http://t.co/nkmF7U9I</a></td>
<td>RT @nytimes: Breaking News: Mayor Bloomberg Imposes Odd-Even Gas Rationing Starting Friday, as Does Long Island <a href="http://t.co/eax7KmVi">http://t.co/eax7KmVi</a></td>
</tr>
<tr>
<td>3</td>
<td>New Jersey authorities filed civil suits Friday accusing seven gas stations and one hotel of price gouging in the wake of Hurricane Sandy.</td>
<td>RT @MarketJane: NJ plans price gouging suits against 8 businesses. They include gas stations and a lodging provider.</td>
<td><strong>MISSING</strong></td>
</tr>
<tr>
<td>4</td>
<td>The rationing system: restricting gas sales to cars with even-numbered license plates on even days, and odd-numbered on odd days will be discontinued at 6 a.m. Tuesday, Gov. Chris Christie announced on Monday.</td>
<td># masdirin City Room: Gas Rationing in New Jersey to End Tuesday # news</td>
<td>RT @nytimes: City Room: Gas Rationing in New Jersey to End Tuesday <a href="http://t.co/pYIVOMpo">http://t.co/pYIVOMpo</a></td>
</tr>
<tr>
<td>5</td>
<td>New Yorkers can expect gas rationing for at least five more days: Bloomberg.</td>
<td>Mayor Bloomberg: Gas rationing in NYC will continue for at least 5 more days. @eyewitnessnyc #SandyABC7</td>
<td>Bloomberg: Gas Rationing To Stay In Place At Least Through The Weekend <a href="http://t.co/mmqqjYRx">http://t.co/mmqqjYRx</a></td>
</tr>
</tbody>
</table>

**TABLE III.** GROUND TRUTH EVENTS AND RELATED CLAIMS FOUND BY APOLLO-SOCIAL VS REGULAR EM IN SANDY
Another Example

Shark in the street!
Another Example

The Washington Post

Shark in the street!

FAKE!