Whom to Ask?

Jury Selection for Decision Making Tasks on Micro-blog Services

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“Is Istanbul the capital of Turkey?”
Social Network/Media services

the **virtualization** and **digitalization** of people’s social activities
• Minor as dressing for a banquet
• Major as prediction of macro economy trends

“two-option decision making tasks”
Wisdom of Crowd

“The basic argument there, drawing on a long history of intuition about markets, is that the aggregate behavior of many people, each with limited information, can produce very accurate beliefs.” –D. Easley, J. Kleinberg, “Networks, Crowds, and Markets”
Crowdsourcing-powered DB Systems

• Qurk, “Human powered Sorts and Joins”, VLDB’2012(MIT)

• Deco, “A System for Declarative Crowdsourcing”, VLDB’2012(Stanford)

• CrowdDB, “Answering Queries with Crowdsourcing”, SIGMOD’2011(Berkeley)
General Crowdsourcing Platforms

AMT
Requesters → AMT

MTurk workers
(Photo By Andrian Chen)
Can we extend the magic power of Crowdsourcing onto social network?
Microblog Users

• Simple
  – 140 characters
  – ‘RT’ + ‘@’

• But comprehensive
  – Large network
  – Various backgrounds of users
Why Microblog Platform?

<table>
<thead>
<tr>
<th></th>
<th>Social Media Network</th>
<th>General Purpose Platform</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Accessibility</strong></td>
<td>Highly convenient, on all kinds of mobile devices</td>
<td>Specific online platform</td>
</tr>
<tr>
<td><strong>Incentive</strong></td>
<td>Altruistic or payment</td>
<td>Mostly monetary incentive</td>
</tr>
<tr>
<td><strong>Supported tasks</strong></td>
<td>Simple task as decision making</td>
<td>Various types of tasks</td>
</tr>
<tr>
<td><strong>Communication</strong></td>
<td>‘Tweet’ and ‘Reply’ are enough</td>
<td>Complex workflow control mechanism</td>
</tr>
<tr>
<td><strong>Infrastructure</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Worker Selection</strong></td>
<td><strong>Active</strong>, Enabled by ‘@’</td>
<td>Passively, No exact selection</td>
</tr>
</tbody>
</table>
Outline

• Running Example
• Problem Definition
• Jury Selection Algorithms
• Evaluation
Motivation – Jury Selection Problem Running Case(1)

- Given a decision making problem, with budget $1, whom should we ask?

Is Döner Kebab available in Hong Kong?

$$\{A, B, C, D, E\} \epsilon (0.0704) \ r(\$1.6)$$

$$\{A, B, C\} \epsilon (0.072) \ r(\$0.6)$$

$$\{A, F, G\} \epsilon (0.208) \ r(\$0.55)$$

$$\{A, B, C, D, E\}$$

$$\epsilon (0.3) \ r(\$0.4)$$

$$\epsilon (0.2) \ r(\$0.2)$$

$$\epsilon (0.2) \ r(\$0.1)$$

$$\epsilon (0.1) \ r(\$0.3)$$

$$\epsilon (0.4) \ r(\$0.6)$$

$$\epsilon (0.4) \ r(\$0.15)$$

$$\epsilon (0.4) \ r(\$0.1)$$
Motivation – Jury Selection Problem
Running Case (2)

• $\varepsilon$: error rate of an individual
• $r$: requirement of an individual, can be virtual
• Majority Voting to achieve final answer

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Motivation – Jury Selection Problem
Running Case(2)

Worker: Juror
Crowds: Jury
Data Quality: Jury Error Rate

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Motivation – Jury Selection Problem Running Case(3)

• If \((A, B, C)\) are chosen (Majority Voting)
  
  \[ JER(A,B,C) = 0.1 \times 0.2 \times 0.2 + (1 - 0.1) \times 0.2 \times 0.2 + 0.1 \times (1 - 0.2) \times 0.2 + 0.1 \times 0.2 \times (1 - 0.2) = 0.072 \]

  – Better than \(A(0.1), B(0.2)\) or \(C(0.2)\) individually
Motivation – Jury Selection Problem Running Case(4)

• What if we enroll more
  – $\text{JER}(A,B,C,D,E) = 0.0704 < \text{JER}(A,B,C)$
  – The more the better?

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Motivation – Jury Selection Problem
Running Case(5)

• What if we enroll even more?
  – $\text{JER}(A,B,C,D,E,F,G) = 0.0805 > \text{JER}(A,B,C,D,E)$
  – Hard to calculate JER

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Motivation – Jury Selection Problem
Running Case(6)

• So just pick up the best combination?
  – JER(A,B,C,D,E)=0.0704
  – R(A,B,C,D,E) = $1.6 > budget($1.0)

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Motivation – Jury Selection Problem

Running Case(7)

<table>
<thead>
<tr>
<th>Crowd</th>
<th>Individual Error-rate</th>
<th>Jury Error-rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td>A</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>C,D,E</td>
<td>0.2,0.2,0.3</td>
<td>0.174</td>
</tr>
<tr>
<td>A,B,C</td>
<td>0.1,0.2,0.2</td>
<td>0.072</td>
</tr>
<tr>
<td>A,B,C,D,E</td>
<td>0.1,0.2,0.2,0.3,0.3</td>
<td>0.0703</td>
</tr>
<tr>
<td>A,B,C,D,E,F,G</td>
<td>0.1,0.2,0.2,0.3,0.3,0.4,0.4</td>
<td>0.0805</td>
</tr>
</tbody>
</table>

Worker selection for maximize the quality of a particular type of product: **the reliability of voting.**
Outline

• Motivation
• Problem Definition
• Jury Selection Algorithms
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Problem Definition

• Jury and Voting

**Definition 1 (Jury).** A jury $J_n = \{j_1, j_2, \cdots, j_n\} \subseteq S$ is a set of jurors with size $n$ that can form a voting.

A Jury $J_n = \{j_1, j_2, j_3\}$ with 3 jurors

**Definition 2 (Voting).** A voting $V_n$ is a valid instance of a jury $J_n$ with size $n$, which is a set of binary values.

A Voting $V_n = \{1, 0, 1\}$ from $J_n$
Problem Definition

• Voting Scheme

**Definition 3** (Majority Voting - MV). Given a voting $V_n$ with size $n$, Majority Voting is defined as

$$MV(V_n) = \begin{cases} 
1 & \text{if } \sum j_i \geq \frac{n+1}{2} \\
0 & \text{if } \sum j_i \leq \frac{n-1}{2}
\end{cases}$$

A Voting $V_n = \{1,0,1\}$ from $J_n$

$$MV(V_n) = 1, (\sum j_i = 2 > 1)$$
Problem Definition

- Invididual Error-rate

**Definition 4** (Individual Error Rate - $\epsilon_i$). The individual error rate $\epsilon_i$ is the probability that a juror conducts a wrong voting. Specifically

$$\epsilon_i = Pr(\text{vote otherwise} | \text{a task with ground truth } A)$$

<table>
<thead>
<tr>
<th>Juror</th>
<th>Error Rate $\epsilon$</th>
<th>Probability $r$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$j_1$</td>
<td>$\epsilon(0.1)$</td>
<td>$r(0.3)$</td>
</tr>
<tr>
<td>$j_2$</td>
<td>$\epsilon(0.3)$</td>
<td>$r(0.4)$</td>
</tr>
<tr>
<td>$j_3$</td>
<td>$\epsilon(0.2)$</td>
<td>$r(0.2)$</td>
</tr>
</tbody>
</table>

A Voting $V_n = \{1,0,1\}$ from $J_n$

**Definition 5** (Carelessness - $C$). The Carelessness $C$ is defined as the number of mistaken jurors in a jury $J_n$ during a voting, where $0 \leq C \leq n$. 
Problem Definition

**Definition 6 (Jury Error Rate - \( JER(J_n) \)).** The jury error rate is the probability that the Carelessness \( C \) is greater than \( \frac{n + 1}{2} \) for a jury \( J_n \), namely

\[
JER(J_n) = \sum_{k=\frac{n+1}{2}}^{n} \sum_{A \in F_k} \prod_{i \in A} \epsilon_i \prod_{j \in A^c} (1 - \epsilon_j)
\]

\[= \Pr(C \geq \frac{n + 1}{2} \mid J_n)\]

where \( F_k \) is all the subsets of \( S \) with size \( k \) and \( \epsilon_i \) is the individual error rate of juror \( j_i \).
Problem Definition

• Crowdsourcing Models (model of candidate microblog users)

**Definition 7**  *(Altruism Jurors Model - AltrM).* While selecting a jury \( J \) from all candidate jurors (choosing a subset \( J \subseteq S \)), any possible jury is allowed.

**Definition 8**  *(Pay-as-you-go Model - PayM).* While selecting a jury \( J \) from all candidate jurors (choosing a subset \( J \subseteq S \)), each candidate juror \( j_i \) is associated with a payment requirement \( r_i \) where \( r_i \geq 0 \), the possible jury \( J \) is allowed when the total payment of \( J \) is no more than a given budget \( B \), namely \( \sum_{j_i \in J} r_i \leq B \).
Problem Definition

• Jury Selection Problem (JSP)

Definition 9 (Jury Selection Problem - JSP). Given a candidate juror set $S$ with size $|S| = N$, a budget $B \geq 0$, a crowdsourcing model (AltrM or PayM), the Jury Selection Problem (JSP) is to select a jury $J_n \subseteq S$ with size $1 \leq n \leq N$, that $J_n$ is allowed according to crowdsourcing model and JER($J_n$) is minimized.

We hope to form a Jury $J_n$, allowed by the budget, and with lowest JER
Outline

• Motivation
• Problem Definition
• Jury Selection Algorithms
• Evaluation
Computation of Jury Error Rate

• The number of careless jurors (Carelessness-C) is a random variable following Poisson Binomial Distribution

\[ JER(J_n) = \sum_{k=\frac{n+1}{2}}^{n} \sum_{A \in F_k} \prod_{i \in A} \varepsilon_i \prod_{j \in A^c} (1 - \varepsilon_j) \]

\[ = \Pr(C \geq \frac{n + 1}{2} | J_n) \]

• The naïve computation of JER is exponentially increasing
Computation of Jury Error Rate (2)

- Alg1: Dynamic Programming to compute JER in $O(n^2)$

**Lemma 1.** The calculation of JER of Jury with size $n$ can be split into smaller ones:

\[
\Pr(C \geq L | J_n) = \Pr(C \geq L - 1 | J_{n-1}) \cdot \epsilon_n + \Pr(C \geq L | J_{n-1}) \cdot (1 - \epsilon_n)
\]

where

\[
\begin{align*}
\Pr(C \geq 0 | J_m) &= 1 \quad \forall \quad 0 \leq m \leq n \\
\Pr(C \geq m | J_n) &= 0 \quad \forall \quad m > n
\end{align*}
\]


Computation of Jury Error Rate (3)

• Alg2: Convolution-based to compute JER in $O(n \log^2 n)$
  – Treat probability distribution as coefficients of polynomials
  – Divide larger jury in two smaller juries
  – Merge by polynomial multiplication
    • Can be speeded up by using FFT
Computation of Jury Error Rate(4)

- Alg2: Convolution-based to compute JER in $O(n\log^2 n)$

---

**Algorithm 1 Convolution-based Algorithm (CBA)**

**Input:** A jury $J_n$

**Output:** the vector of distribution of $C$, $D_C$

1: if $n = 1$ then
2: $D_C[0] = 1 - \epsilon_1$ ;
3: $D_C[1] = \epsilon_1$ ;
4: return $D_C$;
5: else
6: Dividing $J_n$ into two parts: $J_{n1}$ and $J_{n2}$, where $|J_{n1}| = \lfloor \frac{n}{2} \rfloor$ and $|J_{n2}| = \lceil \frac{n}{2} \rceil$;
7: $D_{C1} = CBA(J_{n1})$;
8: $D_{C2} = CBA(J_{n2})$;
9: $D_C =$ convolution of $D_{C1}$ and $D_{C2}$;
10: end if
11: return $D_C$;

---

- Divide into two smaller juries
- Merge, using FFT to speed up convolution
Computation of Jury Error Rate (5)

- Alg3: lower bound of JER in $O(n)$ time
  - Paley-Zygmund inequality

**Lemma 3 (Lower Bound-based Pruning).** Given a jury with size $n$, the lower bound of $\text{JER}(J_n)$ is shown as follows,

$$\text{JER}(J_n) \geq \frac{(1 - \gamma)^2 \mu^2}{(1 - \gamma)^2 \mu^2 + \sigma^2}$$

where $\mu = \sum_{i=1}^{n} \epsilon_i, \sigma^2 = \sum_{i=1}^{n} (1 - \epsilon_i) \epsilon_i$, and $\gamma = (\frac{n+1}{2} / \mu) \in (0, 1)$. 
**JSP on AltrM(1)**

- Monotonicity with given jury size on varying individual error-rate

\[
\text{Lemma 4. The lowest JER originates from the Jurors with lowest individual error-rate among the candidate jurors set } S.
\]

\[
\text{Proof. W.l.o.g, we pick one } j_i \text{ of the } n \text{ jurors in a given Jury } J_n \text{ with size } n. \text{ Then } JER(J_n) \text{ can be transformed as below:}
\]

\[
JER(J_n) = \Pr(C \geq \frac{n+1}{2} | J_n)
\]

\[
= \epsilon_i(\Pr(C \geq \frac{n+1}{2} - 1 | J_{n-1}))+ (1 - \epsilon_i)(\Pr(C \geq \frac{n+1}{2} | J_{n-1}))
\]

\[
= \epsilon_i(\Pr(C = \frac{n+1}{2} - 1 | J_{n-1}))+ (\Pr(C \geq \frac{n+1}{2} | J_{n-1}))
\]

\[
= \epsilon_i \cdot A + B
\]

- In English: “best jury comes from best jurors”
- Decide the size
JSP on AltrM(2)

• Algorithm for JSP on AltrM

Alg_AltrM{
1. Sort according to error-rate;
2. Starting from 1 to n, increase the jury size by two;
   1. Compute JER;
   2. Update best current jury;
3. Output best jury;
}

//keep the size odd

Might be convex, future work
JSP on PayM(1)

• Budget is a constraint
• Objective function is JER
• NP-hardness
  – Reduce to an $nth$-order 0-1 Knapsack Problem

\[
\text{optimize } \sum_{i_1 \in n} \sum_{i_2 \in n} \ldots \sum_{i_n \in n} V[i_1, i_2, \ldots, i_n] \cdot x_1 x_2 \ldots x_n
\]

Given an instance of traditional KP, we can construct an $nOKP$ instance by defining the profit $n$-dimensional vector as $V[i, i, \ldots, i] = p_i$ and $V[\text{otherwise}] = 0$ for all $i$, where $p_i$ is the profit in traditional KP. The weight vector and objective value remain the same. □
JSP on PayM(2)

• Approximate Algorithm

Alg_PayM{
1. Sort according to (requirement * error-rate);
2. Starting from 1 to n, increase the jury size by two;
   1. Keep track of pair;  //increment might be conducted by size of 1
   2. Check whether adding new juror will exceed budget;
   3. If so, compute and compare JER;
   4. Update best current jury;
3. Output best jury;
}


Outline

• Motivation
• Problem Definition
• Jury Selection Algorithm
• Evaluation
Parameter Estimation

• How to estimate such parameter is itself a research topic

• Individual Error Rate ($\varepsilon$) -- ‘RT’ graph
  – PageRank and HITS
  – The score in rank is normalized to be the individual error rate

• Integrated requirement ($r$) – account info
  – Account Age and Account Activity
Data Preparation

• We test our algorithms on both synthetic data and real Twitter data

• Varying
  – Size
  – Mean
  – Variance

• 3.4GHz Win7 PC, programmed in C++
(a) Jury Size v.s. Individual Error-rate

• Mean = 0.5 is the turning point
• On the right side, “truth rests in the hands of a few.”
• While the budget increases
  • The total cost also increases
  • The jury error rate decreases
• Green – Accurate Algorithm (test with N=20)
• Blue – approximation algorithm
  • $O(n \log n)$
  • Good approximation on JER

(e) APPX v.s. OPT on Total Cost  (f) APPX v.s. OPT on JER
Take-away and Future Work

• Take-away
  – Cultivate a pool of candidate jurors
  – JER deceases very fast according to the size of jury

• Future Work
  – Beyond direct payment
    • Prediction Market
  – Beyond decision making
    • Campaign Boosting
Thank You

• Q & A

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