From Sentiment Analysis to Preference Aggregation

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[Joint work with Andrea Loreggia, Francesca Rossi and Vijay Saraswat]
What is the collective sentiment about ...?

Sentiment140

shutdown

Sentiment analysis for shutdown

Sentiment by Percent

Sentiment by Count

Tweets about: shutdown

Shoq: RT @hapkidogal: McCain rips Cruz over shutdown: ?Stop! You’re wrong, you’re crazy!? | The Raw Story http://t.co/e51y5wVBuj @Shoq @maddow @K?
Posted: 20 seconds ago

RickyRayinGA: Now today @WhiteHouse Will Justify @SenTedCruz #shutdown over #Obamacare #ACA @CNN @NBCNews @CBSNews @foxnews @whpresscorps @SpeakerBoehner
Posted: 1 minute ago

moley777: RT @Tsek_Bastard: S/O to the people that are killing Krejcir's crew -You're scaring away the Eastern Europeans! Strip-Clubs will shutdown?
Posted: 1 minute ago

LindahSindy: #GOPshutdown If only bartenders in DC were gvt employees. Boehner would have ended the #shutdown days ago
The results for this query are: Accurate Inaccurate
Aggregation of individual polarities (like/dislike)

Collective sentiment

40%
60%
A problem: multiple alternatives

We extract the following sentiment about two candidates running for election:

But what if preferences are the following:

<table>
<thead>
<tr>
<th>21 voters</th>
<th>a</th>
<th>b</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 voters</td>
<td>b</td>
<td>a</td>
</tr>
<tr>
<td>4 voters</td>
<td>a</td>
<td>b</td>
</tr>
</tbody>
</table>

Sentiment analysis predicts a different winner than majority aggregation!
1. Basic definitions: sentiment analysis and preference aggregation

2. Multiple alternatives:
   - Basic collective sentiment paradox
   - Counting paradoxes

3. Data structures from individual text:
   - pure sentiments (polarity)
   - pure preference (preorder)
   - sentiment and preferences (SP-structures)

4. Aggregation of SP-structures: Borda\(^*\) rule

5. Open problems: six challenges in preference analysis
Ingredients:

- An entity $x$ (no assumption about its structure)
- A corpus of individual expressions $\mathcal{T}$ by a set of individuals $\mathcal{I}$
- A notion of polarity: $\{+, -, N\}$, 5-star scale or graded sentiment

Several NLP techniques used to extract the collective sentiment:

- entity extraction to find expressions mentioning $x$ in $\mathcal{T}$
- word-count, Naive Bayes, and other machine learning techniques to extract the polarity of a single expression in $\mathcal{T}$

Most common approach:
The percentage of positive expressions is the collective sentiment about $x$
Preference Aggregation

Ingredients:

- A set of candidates $\mathcal{X}$
- A set of individuals $\mathcal{I}$ expressing preferences as linear/weak orders on $\mathcal{X}$ or as sets of approved candidates in $\mathcal{X}$

Voting rules are used to identify a set of most preferred candidates. Several rules are possible!

We focus on two definitions of voting rules:

**Borda rule - linear orders**: if a voter ranks candidate $c$ at $j$-th position this gives $j$ points to $c$. The alternatives with highest score are the winners.

**Approval voting - sets of candidates**: the winners of approval voting are the candidates which receive the highest number of approvals.
Part I:
The Problem
Basic collective sentiment paradox

Two candidates $a$ and $b$ are competing in an election:

- Sentiment analysis extracts 100% positive comments for $b$
- Majority rule elects $a$ with a majority of 90 vs 10

Alternatives at the left of $|$ are positive, preferences from left to right:

<table>
<thead>
<tr>
<th>90 voters</th>
<th>$a$</th>
<th>$b$</th>
<th>10 voter</th>
<th>$b$</th>
<th>$a$</th>
</tr>
</thead>
</table>

Majority rule winner: $a$
Collective sentiment predictor: $b$

Sentiment analysis can give the wrong result when predicting the majority rule!

More generally: sentiment analysis is problematic in comparing more than two alternatives
Counting paradoxes: characterisation

A simple result to characterise collective sentiment paradoxes:

Proposition

A collective sentiment paradox with 2 candidates occurs iff:

\[ N(a|b) \geq N(b|a) \]

\[ N(ba|) + N(b|a) + N(|ba) > N(ab|) + N(a|b) + N(|ab) \]

or symmetrically for \( b \) winning in SA.

How to quantify the fraction of paradoxical profiles?

Awkward formula:

\[ \sum_{l=n+1}^{n} \binom{n}{l} \sum_{t=0}^{n-l} \binom{l}{t} 2^{l-t} \sum_{m=t}^{n-l} \binom{n-l}{m} 2^{n-l-m} \]
Counting paradoxes: simulation

We performed experiments with 2 entities:

- sampling 10,000 profiles with the impartial culture assumption
- enumerating all paradoxical profiles up to $|I| = 93$ (see figure below)

Figure: % of collective sentiment paradoxes

Sentiment analysis and preference aggregation differ in 30% of the profiles
Part II:
Data Structures
Mix the ingredients of sentiment analysis with those of preference aggregation:

- A set of entities/items/alternatives $\mathcal{X}$
- A corpus $\mathcal{T}_i$ of individual expressions for each $i$ in a set $\mathcal{I}$ of individuals
- What is the most preferred entity?

Lesson learned from collective sentiment paradoxes:
Polarity extraction is not sufficient if we want to compare entities!

What data structure we can/want to extract from individual expressions?

- polarity/graded polarity/score
- only binary comparisons between alternatives
- a combination of sentiment and preference
Raw Data Extraction

Two forms of opinions can be extracted with existing NLP techniques:

- Objective opinions: "Nikon is a good camera" → score of a single entity
- Comparative opinions: "I prefer Canon to Nikon" → binary comparisons

Definition

The raw data extracted from individual expressions $T_i$ is a tuple $(\sigma_i, P_i, N_i)$:

- $\sigma_i : D_i \rightarrow \mathbb{R}$ to represent objective opinions on $D_i \subseteq \mathcal{X}$
- subsets $P_i$ and $N_i$ of $\mathcal{X}$ preordered by $\leq_P$ and $\leq_N$, representing positive and negative comparative opinions


Ganapathibhotla and Liu, Mining Opinions in Comparative Sentences, COLING-2008.

Jindal and Liu, Mining Comparative Sentences and Relations, AAAI-2006.
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Example

Three entities $a$, $b$ and $c$, and three individuals:

- $\sigma_1(a) = 5$, $\sigma_1(b) = \sigma_1(c) = 4$ and $P_1 = N_1 = \emptyset$
- $\sigma_2(b) = 1$, $P_2 = \emptyset$, and $N_2 = \{a, c\}$ with $a \geq^N_2 c$
- $\sigma_3(c) = 0$, $P_3 = \{a, b\}$ with $a \geq^P_3 b$, and $N_3 = \emptyset$
Pure Sentiment Data

Definition

The **pure sentiment data** associated with raw data \((\sigma_i, P_i, N_i)\) is a function \(S_i : \{D_i \cup P_i \cup N_i\} \rightarrow \{+, -, 0\}\) defined as:

\[
S_i(c) = \begin{cases} 
\text{sgn}(\sigma_i(c)) & \text{if } c \in D_i \setminus (P_i \cup N_i) \\
0 & \text{if } \sigma_i(c) = 0 \\
+ & \text{if } c \in P_i \\
- & \text{if } c \in N_i 
\end{cases}
\]

Example

**Pure sentiment data only deals with polarities:**

- \(S_1(a) = S_1(b) = S_1(c) = +\)
- \(S_2(b) = + \text{ and } S_2(a) = S_2(c) = -\)
- \(S_3(a) = S_3(b) = + \text{ and } S_3(c) = 0.\)

The **most popular candidate** using approval voting is **b**.

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Pure Preference Data

Definition

The pure preference data associated with raw data \((\sigma_i, P_i, N_i)\) is a preordered set \((D_i, \preceq_i^D)\) where 
\[ D_i = D_i \cup P_i \cup N_i \] 
and

\[ x \preceq_i^D y \iff \begin{cases} 
  x \preceq_i^P y \text{ and } x, y \in P_i & \text{or} \\
  x \preceq_i^N y \text{ and } x, y \in N_i & \text{or} \\
  x \in N_i \text{ and } y \in P_i & \text{or} \\
  \sigma_i(x) \preceq \sigma_i(y) \text{ and } x, y \in D_i 
\end{cases} \]

Example

Pure preference data only deals with pairwise comparisons:

- \(a \succeq_1 b \sim_1 c\)
- \(b \succeq_2 a \succeq_2 c\)
- \(a \succeq_3 b \succeq_3 c\)

The most preferred candidate using the Borda rule is \(a\).
Sentiment Preference Structures

Definition

An SP-structure over $\mathcal{X}$ is a tuple $(\mathcal{P}, \mathcal{N}, \mathcal{Z})$ such that:

- $\mathcal{P}$, $\mathcal{N}$ and $\mathcal{Z}$ form a partition of $\mathcal{X}$
- $\mathcal{P}$ and $\mathcal{N}$ are ordered respectively by preorders $\preceq^\mathcal{P}$ and $\preceq^\mathcal{N}$

An SP-structure $(\mathcal{P}_i, \mathcal{N}_i, \mathcal{Z}_i)$ can be extracted from raw data $(\sigma_i, P_i, N_i)$:

- $\mathcal{P}_i$ is the union of $P_i$ and the set of entities with positive score
- Analogously for $\mathcal{N}_i$. $\mathcal{Z}_i$ is the set of entities with zero or no score
- Preordered relations extracted from $\sigma_i$ and copied from $P_i$ and $N_i$

SP-structures combine (interpersonally non-comparable) scores with (incomplete) pairwise comparisons between entities
**Example**

<table>
<thead>
<tr>
<th>Agent 1</th>
<th>Agent 2</th>
<th>Agent 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>$a$</td>
<td></td>
<td>$a$</td>
</tr>
<tr>
<td>$\mid$</td>
<td></td>
<td>$\mid$</td>
</tr>
<tr>
<td>$b \sim c$</td>
<td>$b$</td>
<td>$b$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>$c$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$\mathcal{Z}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$a$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\mid$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$c$</td>
<td></td>
<td>$\mathcal{N}$</td>
</tr>
</tbody>
</table>

*Table: SP-structures extracted from the previous example.*
Part III:
Aggregation of SP-structures
Aggregating SP-structures

Definition

The Borda$^*$ score of entity $c \in \mathcal{X}$ in SP-structure $(\mathcal{P}, \mathcal{N}, \mathcal{Z})$ is defined as:

$$s^*(c) = \begin{cases} 
2 \times |\text{down}^\mathcal{P}(c)| + |\text{inc}^\mathcal{P}(c)| + |\mathcal{Z}| + 1 & \text{if } c \in \mathcal{P}_i \\
-2 \times |\text{up}^\mathcal{N}(c)| - |\text{inc}^\mathcal{N}(c)| - |\mathcal{Z}| - 1 & \text{if } c \in \mathcal{N}_i \\
0 & \text{if } c \notin \mathcal{P}_i \cup \mathcal{N}_i
\end{cases}$$

Given a profile $S$ of SP-structures, the most popular candidates are the ones maximising the sum of the individual Borda$^*$ score:

$$B^*(S) = \arg\max_{c \in \mathcal{X}} \sum_{i \in I} s^*_i(c)$$
Example of using Borda*

<table>
<thead>
<tr>
<th>Agent 1</th>
<th>Agent 2</th>
<th>Agent 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td></td>
<td>a</td>
</tr>
<tr>
<td></td>
<td>b</td>
<td></td>
</tr>
<tr>
<td>b</td>
<td>b</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>c</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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The most preferred candidate under the Borda* rule is a.
What we know about Borda*

A profile is purely preferential if all comparisons are positive (negative) for all individuals. A profile is purely sentimental if only positive/neutral sentiment is expressed and no pairwise comparison.

Theorem
If a profile $S$ is purely preferential, then $B^*(S) = Borda(S)$.
If a profile $S$ is purely sentimental, then $B^*(S) = Approval(S)$.

Axiomatic properties adapted from Social Choice Theory:

Theorem
The Borda* rule satisfies consistency, faithfulness, neutrality and the cancellation property.

Theorem
If $S$ is a profile in which all individuals rank $a$ above $b$ then $b \notin B^*(S)$.
Part IV: Open Problems
Six challenges to study the use of preference/voting tools in sentiment analysis:

1. What preferences/opinions can be extracted from the individuals text?  
   *Our proposal: sentiment score and pairwise comparison (raw data)*

2. How to best represent (compactly) individual preferences and sentiments?  
   *Our proposal: SP-structures based on preorders*

3. How to aggregate the individual information into a collective opinion?  
   *Our proposal: generalise Borda and Approval with the Borda\(^*\) rule*

4. Is it possible to identify influencers and prevent strategic behaviour?  
   Example: creation of fake accounts (cloning)...

5. How should preference aggregation methods be validated?

6. How to deal with big data in sentiment and preference analysis?
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Thank you for your attention!