An Axiomatic Approach to Truth Discovery

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What is Truth Discovery?

- Lots of information is available today, from many different sources
    - The web
    - Social media platforms (Twitter, Facebook, …)
    - Crowdsourcing systems
- People often *disagree* with what is true. Who should we trust in this case, and what should we believe?
- **Truth discovery:** find *true facts* and *trustworthy data sources* when faced with conflicting information.

This talk

- Background and context to the problem
- Existing work in this area
- Our work:
    - How is it different?
    - What have we done?

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Setting the scene

- We have a number of *objects* (or *variables*) of interest
    - e.g. real world entities, questions
- *Data sources* claim different *facts* (or *values*) for these objects
- Claims can be conflicting
    - e.g. due to *poor or incomplete knowledge* or *deliberate misinformation*

Setting the scene (II)

- Need automatic methods for finding true facts
- Naive approach: take the information claimed by the most sources, i.e. perform a *vote*
- Will this work?
    - Anti-vaccine communities
    - ‘Fake news’ on Twitter

Setting the scene (III)

- Trouble with voting is that all sources are *equally weighted*
- It would be better to use *trust* information
  - Trustworthy sources are given more weight
  - Won't get misled by an untrustworthy majority
- **Note:** trust does not have an agreed upon formal definition. Interpretations vary across the literature

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Existing work

- Resolving conflicts in information is not new
    - Belief revision
    - Belief merging
    - Judgment aggregation
    - Argumentation
    - etc...
- Truth discovery is distinguished by its consideration of trustworthiness
- Many algorithms proposed in recent years
    - Similarities to machine learning methods
    - Mostly *unsupervised*: no ground truths for objects, and no known trustworthiness values

Example algorithm: *Sums*

- Perhaps one of the simplest algorithms is *Sums*
- Iterative: assigns each source s a sequence of *trust scores* $(T_n(s))_{n\in\mathbb{N}}$, and each fact f a sequence of *belief scores* $(T_n(f))_{n\in\mathbb{N}}$.
- Initially all scores are 0.5
- Update algorithm is as follows:
  - For each source s:
    - $T_{n+1}(s) \leftarrow \sum_{f\in\text{facts}(s)} T_n(f)$
  - For each fact f:
    - $T_{n+1}(f) \leftarrow \sum_{s\in\text{src}_n(f)} T_{n+1}(s)$
  - Divide each trust and belief score by the maximum
- Repeat until convergence

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Potential issues with existing work

- Many algorithms are opaque – difficult to see what the algorithm is actually *doing*
- Have to be evaluated empirically
- It is difficult to compare algorithms
- Would be useful to have some *theory* behind truth discovery: specifically *axioms*

The axiomatic method

- Popular in social choice, judgment aggregation…
- Common goals are *impossibility results* and *characterisation results*
- E.g. voting has *Arrow's Impossibility Theorem*
    - Three seemingly good axioms cannot hold at the same time
    - Highlights fundamental problem with voting
- E.g. Altman and Tennenholtz [1] characterised PageRank from Google
    - Found a set of *sound* and *complete* axioms for PageRank
- Idea: can we give truth discovery an axiomatic treatment?

[1] Alon Altman and Moshe Tennenholtz. 2005. Ranking systems: the PageRank axioms.

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- **Our work:**
    - How is it different?
    - **What have we done?**

Our work

- Applying axiomatic approach to truth discovery
- Defined a formal framework
- Formulated some axioms
    - Mostly inspired by social choice, JA and ranking systems
- An impossibility and characterisation result along the way
- Had a look at some existing truth discovery algorithms against our axioms

The framework: what is the input to the truth discovery?

- We consider a *very basic* form of truth discovery
- We have a finite set of sources $\mathcal{S}$, facts $\mathcal{F}$ and objects $\mathcal{O}$. We assume each object has a single *true fact* associated with it
- Input to the problem (the dataset) is called a *truth discovery network*, and is defined as a graph

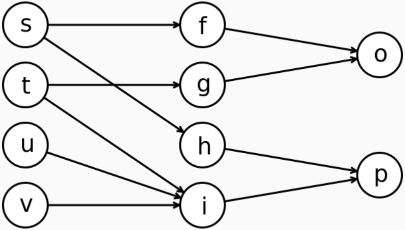

Figure 1: Example network

- Representing input as a graph is already common in the literature

The framework: what is the output?

- Outputs are usually numeric *trust scores* and *belief scores*
- These are not comparable between algorithms
- Scores induce *rankings* (tpos), which can be compared
    - Source ranking tells us who is *more trustworthy*
    - Fact ranking tells us which fact is *more believable*
- Algorithms are represented in the framework as functions, and are called *truth discovery operators*

- **Question:** what do you think is the most sensible ranking of f and g? Which fact should we believe?

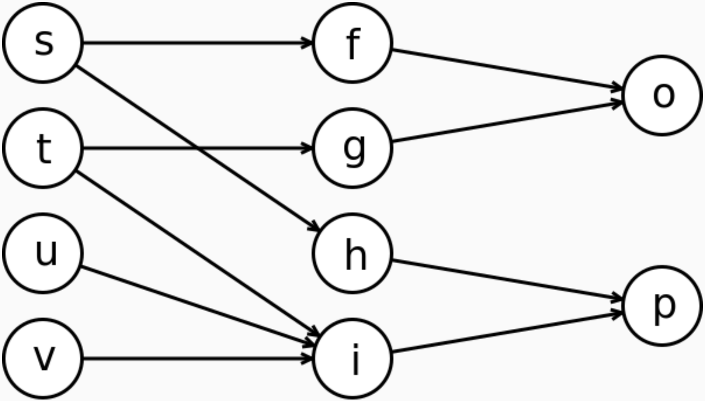

Figure 2: Example network

Network example revisited (II)

- *Sums* gives

$$s < u = v < t$$

$$f = h < g < i$$

- What about in this case?

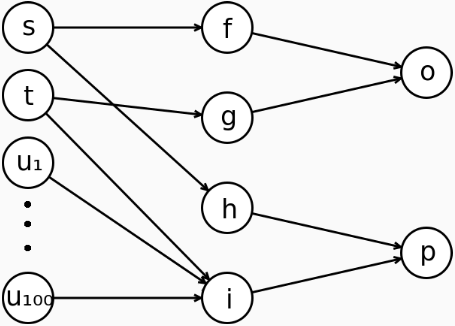

Figure 3: Modified example network

Axioms

- The framework provides the definitions required to formally state axioms
- Most axioms adapted from social choice
- I will only mention the important ones...

Coherence

- Axioms are supposed to represent intuitive *desirable properties* of operators
- Key principle of truth discovery: trustworthy sources make believable claims, and vice versa
- The trust and belief rankings need to *cohere* in this sense
- This idea is hard to pin down in general, but we can do so in specific cases...

Coherence (II)

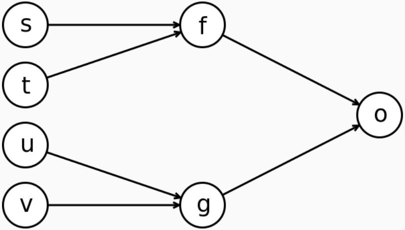

Figure 4: Coherence motivating example

- **Fact-Coherence:** If $s \sqsubset u$ and $t \sqsubset v$ then $f \prec g$
- **Source-Coherence:** If $f \prec g$ then $s \sqsubset u$
- This idea comes from axiomatic analysis of ranking systems under the name *transitivity* [2]
- We consider this the most important axiom

[2] Alon Altman and Moshe Tennenholtz. 2008. Axiomatic Foundations for Ranking Systems

Symmetry

- Rankings should depend on the *structure* of the network, not the *names* of sources and facts
- Consider swapping s with t and h with i:

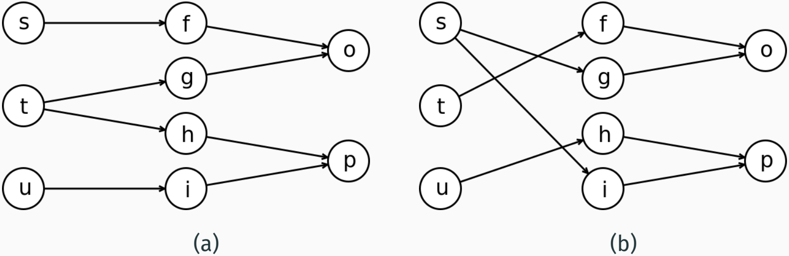

Figure 5: Isomorphic truth discovery networks

Monotonicity

- We don't want *Voting*, but more support is better in some sense...
- If f is at least as believable as g and extra support for f comes in, f should become *strictly* more believable

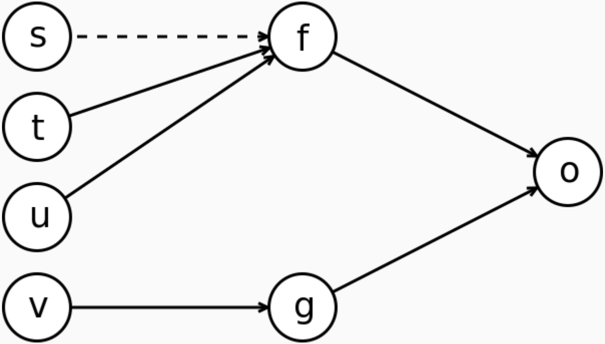

Figure 6: Monotonicity motivating example

- Notion of *independence* is important: the ranking of a source/fact should only depend on the stuff that is relevant to it

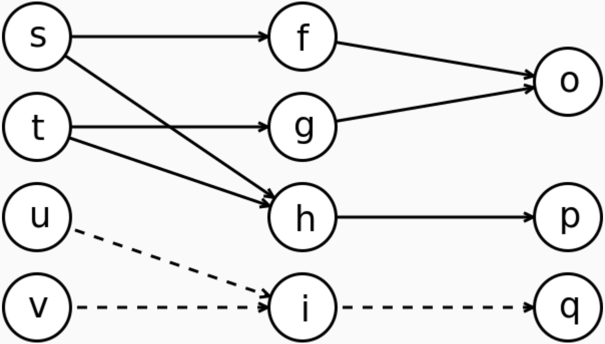

Figure 7: Independence motivating example

- e.g. are *u* and *v* relevant to *s*?

Per-object Independence (POI)

- First attempt at independence, obtained by translating social choice (esp. voting) version of independence
- If facts and sources for object o are the same in N and N', the ranking of o's facts is the same

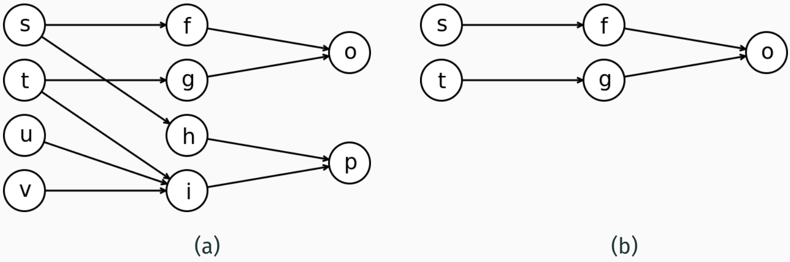

Figure 8: POI example

Is POI a good idea?

- POI means we cannot use inter-object links
- With Symmetry and Monotonicity, this is very bad: it implies *Voting* behaviour within the facts for each object

Theorem
Let T be any operator satisfying Symmetry, Monotonicity and POI. Then for any network N, object o and facts f, g for o, we have

$$f \preceq_N^T g \iff |\mathrm{src}_N(f)| \leq |\mathrm{src}_N(g)|$$

Impossibility

- Remember Coherence is our key axiom, which *Voting* fails
- Symmetry, Monotonicity and POI imply *Voting*-like behaviour
- Symmetry, Monotonicity, POI and Coherence? No

Theorem
There is no operator satisfying Coherence, Symmetry, Monotonicity and POI.

- This is the first impossibility result for truth discovery

Strong Independence

- Our first theorem almost characterises the fact ranking of *Voting*. Can POI be strengthened to get a full characterisation?
- **Yes.** Answer is to ignore objects altogether: the ranking of f and g depends only on the sources for f and g (*Strong Independence*)

Theorem
An operator T satisfies Strong Independence, Monotonicity and Symmetry if and only if for any network N and $f, g \in \mathcal{F}$ we have

$$f \preceq_N^T g \iff |\mathrm{src}_N(f)| \leq |\mathrm{src}_N(g)|$$

Final Independence axiom

- POI and Strong Independence are *not* desirable
- Our final version of independence is very weak: two nodes are relevant to each other if there is a path between them, i.e. if they are in the same *connected component* of the graph

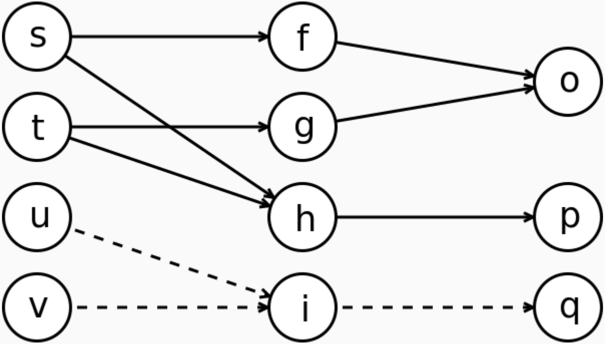

Figure 9: Independence example

- Those are the important axioms. Are they satisfied by actual truth discovery algorithms?

	Voting	SC-Voting	Sums	U-Sums
Coherence	X	X	✓	✓
Symmetry	✓	✓	✓	✓
Mon.	✓	✓	X	**?**
POI	✓	✓	X	X
Str. Indep	✓	✓	X	X
Indep.	✓	X	X	✓

Table 1: Satisfaction of the axioms for the various operators

- We conjecture that the **?** is a ✓

That's all!

- Thanks for listening
- Questions?