Inferential Approach to Mining Surprising Patterns in Hypergraphs

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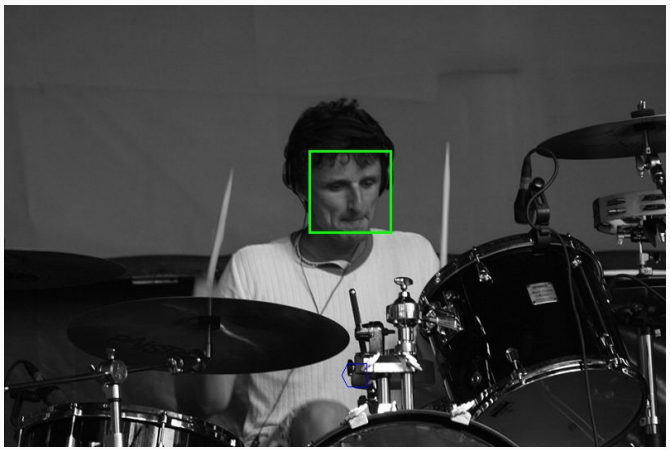
Reframing learning as reasoning



$\Rightarrow$

$\mathcal{T} \vdash \mathcal{F}$

Reframing mining surprising patterns as reasoning

1. Learning frequent patterns
2. Assessing their surprisingness

Inference Control Meta-learning

Learning how to reason efficiently

Inference Control Meta-learning

Unified Rule Engine

- Evolves Inference Trees

$$\dfrac{A \qquad \dfrac{A \to C \qquad C \to B}{A \to B}\,(\text{DED})}{B}\,(\text{MP})$$

Inference Control Meta-learning

Unified Rule Engine

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- Control Rules to select premises and rules

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Inference Control Meta-learning

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$$\dfrac{A \qquad \dfrac{A \to C \qquad C \to B}{A \to B}\,(\text{DED})}{B}\,(\text{MP}) \quad \Rightarrow \quad \begin{array}{c} ? \\ \xrightarrow{\text{DED}} \\ \xrightarrow{\text{MP}} \end{array}$$

Mining Frequent Patterns

Brute force algorithm:

- $\mathcal{D}$: *database*
- S: *minimum support*
- $\mathcal{C}$: *pattern pool*
- P, Q: *patterns*

1. Select P from $\mathcal{C}$
2. Select *specialization* Q of P such that $S \leq \texttt{support}(Q, \mathcal{D})$
3. Add Q to $\mathcal{C}$
4. Repeat

Mining Frequent Patterns as Reasoning

$$\frac{S \leq \texttt{support}(Q, \mathcal{D}) \qquad \texttt{spec}(Q, P)}{S \leq \texttt{support}(P, \mathcal{D})}\ (\mathsf{AP})$$

Mining Frequent Patterns as Reasoning

$$\frac{S \leq \texttt{support}(Q, \mathcal{D}) \qquad \texttt{spec}(Q, P)}{S \leq \texttt{support}(P, \mathcal{D})}$$ (AP = A Priory Property)

Mining Frequent Patterns as Reasoning

$$\frac{S \leq \texttt{support}(Q, \mathcal{D}) \qquad \texttt{spec}(Q, P)}{S \leq \texttt{support}(P, \mathcal{D})}\ \text{(AP = A Priory Property)}$$

$$\frac{S \leq \texttt{support}(P, \mathcal{D}) \qquad \texttt{spec}(P, \mathit{Top})}{S \leq \texttt{support}(\mathit{Top}, \mathcal{D})}\ \text{(AP)}$$

Mining Frequent Patterns as Reasoning

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$$\Downarrow$$

$$\frac{\dfrac{S \leq \texttt{support}(Q, \mathcal{D}) \qquad \texttt{spec}(Q, P)}{S \leq \texttt{support}(P, \mathcal{D})}\ \text{(AP)} \qquad \texttt{spec}(P, \mathit{Top})}{S \leq \texttt{support}(\mathit{Top}, \mathcal{D})}\ \text{(AP)}$$

Mining Frequent Patterns as Reasoning

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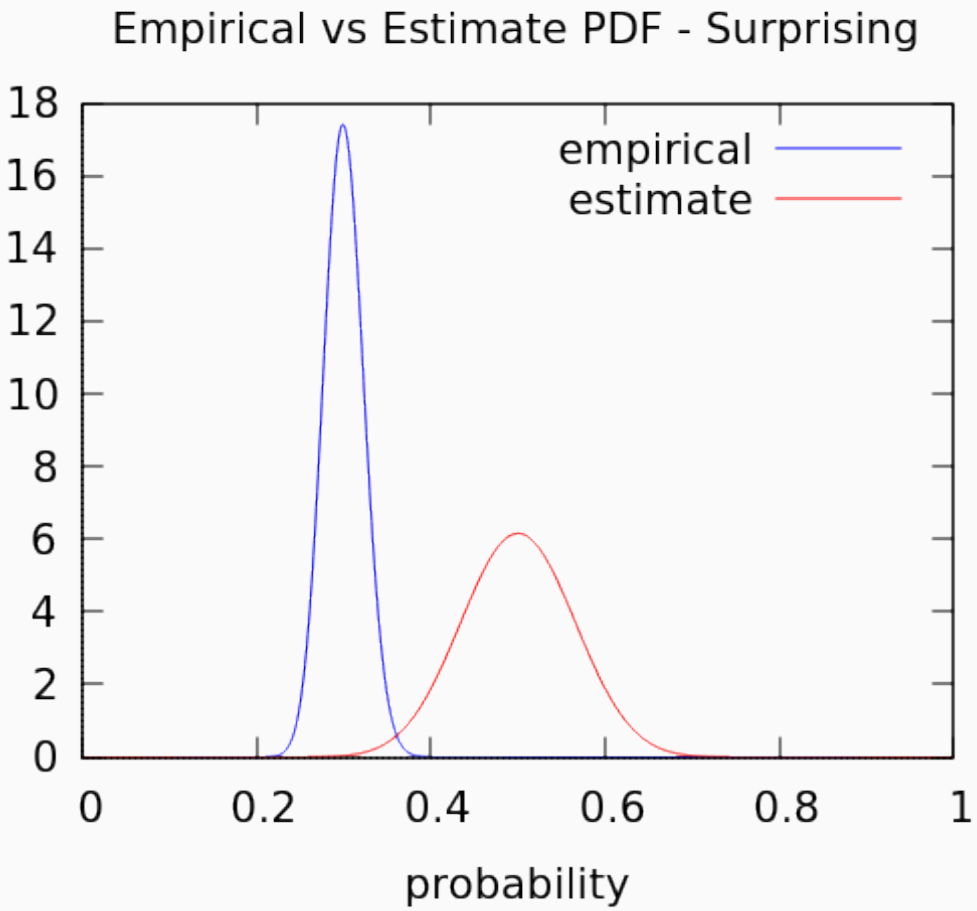
$$\Downarrow$$

$$\dfrac{\dfrac{\dfrac{S \leq \texttt{support}(R, \mathcal{D}) \qquad \texttt{spec}(R, Q)}{S \leq \texttt{support}(Q, \mathcal{D})}\ \text{(AP)} \qquad \texttt{spec}(Q, P)}{S \leq \texttt{support}(P, \mathcal{D})}\ \text{(AP)} \qquad \texttt{spec}(P, \mathit{Top})}{S \leq \texttt{support}(\mathit{Top}, \mathcal{D})}\ \text{(AP)}$$

Mining Surprising Patterns

Definition

surprise: contrary to expectation



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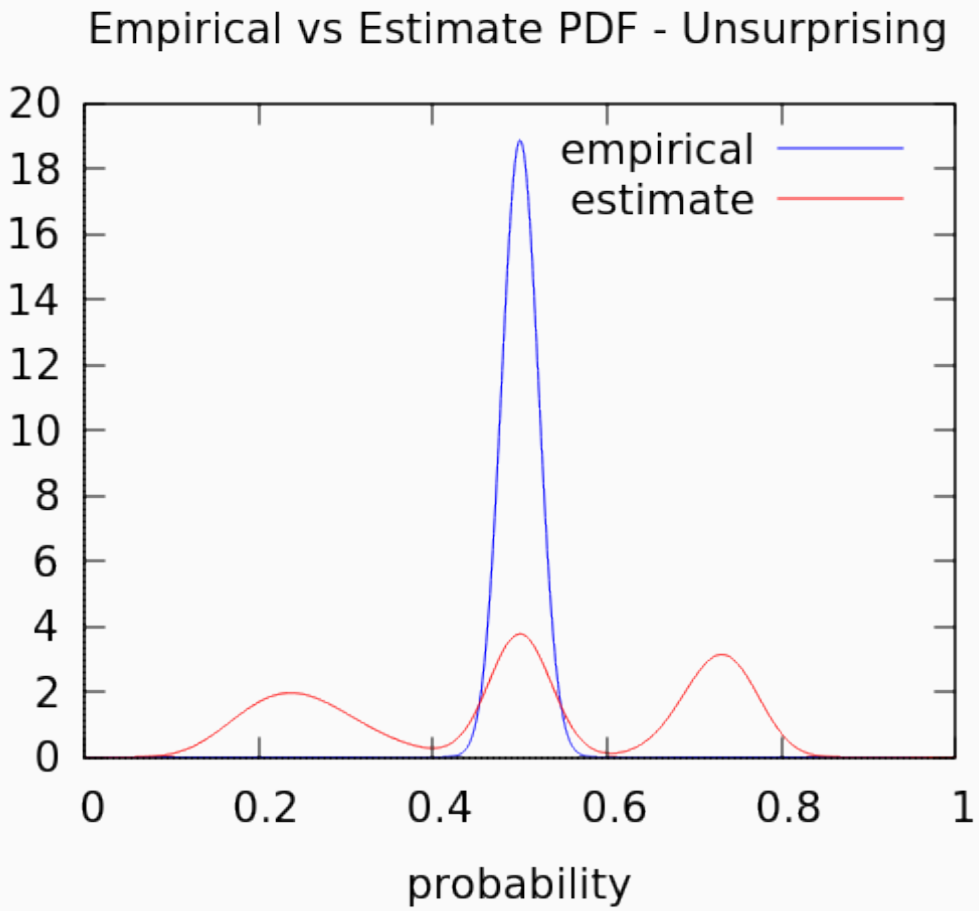

Mining Surprising Patterns as Reasoning

$$\dfrac{S \leq \texttt{support}(P, \mathcal{D}) \qquad \dfrac{\dfrac{P \qquad \mathcal{D}}{\texttt{emp}(P, \mathcal{D})}\,(\text{DE}) \qquad \dfrac{?}{\texttt{est}(P, \mathcal{D})}}{\texttt{jsd}(P, \mathcal{D}))}\,(\text{JSD})}{\texttt{surprising}(P, \mathcal{D}, \texttt{jsd}(P, \mathcal{D}))}\,(\text{S})$$

Mining Surprising Patterns as Reasoning

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Mining Surprising Patterns as Reasoning

$$\dfrac{S \leq \texttt{support}(P, \mathcal{D}) \qquad \dfrac{\dfrac{P \qquad \mathcal{D}}{\texttt{emp}(P, \mathcal{D})}\,(\text{DE}) \qquad \dfrac{\vdots \qquad\qquad \vdots}{\texttt{est}(P, \mathcal{D})}}{\texttt{jsd}(P, \mathcal{D}))}\,(\text{JSD})}{\texttt{surprising}(P, \mathcal{D}, \texttt{jsd}(P, \mathcal{D}))}\,(\text{S})$$

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Mining Surprising Patterns as Reasoning

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Dynamic Surprisingness!

Examples

SUMO: *Suggested Upper Merged Ontology*

- 25K terms
- 80K axioms
- Covers many domains
  - Economy
  - Finance
  - Food
  - Sports
  - Music
  - . . .
- Open Source

Domain: Geography

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         (PresentLink
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               (ConceptNode "SaltWaterArea")
            )
            (InheritanceLink
               (VariableNode "$X")
               (ConceptNode "MaritimeClaimArea")
            )
         )
      )
      (ConceptNode "sumo")
   )
)
```

Domain: CountriesAndRegions

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   (ListLink
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            (VariableNode "$Y")
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               (ListLink
                  (VariableNode "$X")
                  (ConceptNode "WesternEurope")
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            )
            (EvaluationLink
               (PredicateNode "dependentGeopoliticalArea")
               (ListLink
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      (ConceptNode "sumo")
   )
)
```

Domain: CountriesAndRegions

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            (VariableNode "$Y")
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               (VariableNode "$X")
               (ConceptNode "EuropeanNation")
            )
            (EvaluationLink
               (PredicateNode "dependentGeopoliticalArea")
               (ListLink
                  (VariableNode "$Y")
                  (VariableNode "$X")
               )
            )
         )
      )
      (ConceptNode "sumo")
   )
)
```

Domain: CountriesAndRegions

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(EvaluationLink (stv 0.98350379 1)
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               (ListLink
                  (VariableNode "$X")
                  (ConceptNode "NorthAtlanticOcean")
               )
            )
            (MemberLink
               (VariableNode "$X")
               (ConceptNode "AmericanState")
            )
         )
      )
      (ConceptNode "sumo")
   )
)
```

Domain: Economy

```
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         (PresentLink
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               (PredicateNode "economyType")
               (ListLink
                  (VariableNode "$X")
                  (ConceptNode "AdvancedEconomy")
               )
            )
            (EvaluationLink
               (PredicateNode "economyType")
               (ListLink
                  (VariableNode "$X")
                  (ConceptNode "DevelopedCountry")
               )
            )
         )
      )
      (ConceptNode "sumo")
   )
)
```

Domain: Government

```
(EvaluationLink (stv 0.98293616 1)
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   (ListLink
      (LambdaLink
         (VariableNode "$X")
         (PresentLink
            (EvaluationLink
               (PredicateNode "organizationalObjective")
               (ListLink
                  (VariableNode "$X")
                  (ConceptNode "SocialDevelopment")
               )
            )
            (EvaluationLink
               (PredicateNode "organizationalObjective")
               (ListLink
                  (VariableNode "$X")
                  (ConceptNode "EconomicDevelopment")
               )
            )
         )
      )
      (ConceptNode "sumo")
   )
)
```

Examples