An Ontology Selection and Ranking System Based on the Analytic Hierarchy Process

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Outline

1. **Project Domain**
   - Ontology Evaluation
   - Analytic Hierarchy Process

2. **AHP adaptation for Ontology Evaluation**
   - Criteria Tree
   - Metrics for Atomic Criteria
   - Including Negative Criteria
   - Alternative Weight Elicitation

3. **Domain Coverage**

4. **System Design**

5. **Experiments**

6. **Conclusions**
Ontology Evaluation and Selection

- **MCDM** problem (Multiple-Criteria-Decision-Making): *domain coverage, size, consistency* etc.

- Both **qualitative** (*language expressivity*) and **quantitative** (*number of classes*) criteria

- Both **positive** (*domain coverage*) and **negative** (*inconsistencies, unsatisfiable classes*) criteria

- Depends on **evaluation context** (wide knowledge representation, efficiency, re-usability)
Analytic Hierarchy Process

- **MCDM** solution developed by Thomas Saaty in early 1970s;

*Figure*: Hierarchy of problem goal, criteria and alternatives
Criteria Preference - Pairwise Comparisons

- criteria **weights** ↔ derived from **pairwise comparisons** between **brother nodes** → positive reciprocal matrix

\[
A = \begin{bmatrix}
1 & a_{12} & a_{13} & \ldots & a_{1n} \\
1/a_{12} & 1 & 1/a_{23} & \ldots & a_{2n} \\
1/a_{13} & 1/a_{23} & 1 & \ldots & a_{3n} \\
\vdots & \vdots & \vdots & \ddots & \vdots \\
1/a_{1n} & 1/a_{2n} & 1/a_{3n} & \ldots & 1
\end{bmatrix}
\]

\[a_{ij} = a_i/a_j\]

- the **PC (Pairwise Comparisons) matrix** can contain **inconsistent judgments**
**Definition**

A reciprocal matrix $A$ is said to be **(cardinally) consistent** if $a_{ij} = a_{ik}a_{kj} \forall i,j,k$ where $a_{ij}$ is called a direct judgment, given by the Decision Maker, and $a_{ik}a_{kj}$ is an indirect judgment.

**Definition**

A reciprocal matrix $A$ is said to be **ordinally transitive (ordinally consistent)** if $\forall i \exists j, k \text{ s.t. } a_{ij} \geq a_{ik} \Rightarrow a_{jk} \leq 1$. 

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[Diagram of a network with nodes labeled Crit1, Crit2, Crit3, and edges connecting them with numerical values 2 and 6.]
Cardinal Consistency Metrics

- **Consistency Ratio (CR):** \( \frac{\lambda_{\text{max}} - n}{n-1} / R_I \)

- **Consistency Measure (CM):** \( \max(CM_{i,j,k}), \quad i \neq j \neq k \)
  \[ CM_{i,j,k} = \min\left( \frac{a_{ij} - a_{ik}a_{kj}}{a_{ij}}, \frac{a_{ij} - a_{ik}a_{kj}}{a_{ik}a_{kj}} \right) \]

- **Congruence (\( \Theta \)):** \( \Theta_{ij} = \frac{1}{n-2} \sum_{k=1}^{n} \delta(a_{ij}, a_{ik}a_{kj}), \quad i \neq j \neq k \)
  \[ \delta(a_{ij}, a_{ik}a_{kj}) = |\log(a_{ij}) - \log(a_{ik}a_{kj})| \]
  \[ \Theta = \frac{2}{2(n-1)} \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \Theta_{ij} \]
The Number of Three-way Cycles (L):

\[ E_i \rightarrow E_j \rightarrow E_k \rightarrow E_i \]

- \( \log(a_{ij}) \log(a_{ik}) \leq 0 \) and \( \log(a_{ik}) \log(a_{jk}) < 0 \) OR
- \( \log(a_{ij}) = 0 \) and \( \log(a_{ik}) = 0 \) and \( \log(a_{jk}) \neq 0 \)

Dissonance (\( \Psi \)):

\[ \Psi_{ij} = \frac{1}{n-2} \sum_k \text{step}(− \log a_{ij} \log a_{ik} a_{kj}), \quad i \neq j \neq k \]

\[ \text{step}(x) = \begin{cases} 
1, & \text{if } x > 0 \\
0, & \text{otherwise} 
\end{cases} \]

\[ \Psi = \frac{2}{n(n-1)} \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \Psi_{ij} \]
Elicit weights

**right eigenvector** \( w = (w_1, ..., w_n) \) is calculated from its PC matrix \( A \):

\[
Aw = \lambda_{max} w
\]

(1)

where \( \lambda_{max} \) is largest **eigenvalue** of \( A \)
Weight Elicitation Accuracy Metrics

- **TD** → *Total Direct Deviation from Direct Judgments*:
  \[
  TD(w) = \sum_{i=1}^{n} \sum_{j=1}^{n} (a_{ij} - \frac{w_i}{w_j})^2
  \]

- **TD2** → *Indirect Total Deviation from Indirect Judgments*:
  \[
  TD2(w) = \sum_{i=1}^{n} \sum_{j=1}^{n} \sum_{k=1}^{n} (a_{ik}a_{kj} - \frac{w_i}{w_j})^2
  \]

- **NV** → *Number of Priority Violations*:
  \[
  NV(w) = n - 1 \sum_{i=1}^{n} \sum_{j=i+1}^{n} v_{ij}
  \]

  \[
  v_{ij} = \begin{cases} 
  1, & \text{if } (w_i < w_j) \text{ and } (a_{ij} > 1) \\
  0.5, & \text{if } (w_i \neq w_j) \text{ and } (a_{ij} = 1) \\
  0.5, & \text{if } (w_i = w_j) \text{ and } (a_{ij} \neq 1) \\
  0, & \text{otherwise}
  \end{cases}
  \]
Alternatives evaluation - Weighted Sum Method

- assess and normalize alternative \( i \) for each atomic criterion \( k \)
  \[ \Rightarrow V_{i, leaf_k} \]

- moving up trough the tree, for each node alternative values are defined as a weighted sum of the values computed below for each tree level.

\[ V_{i_k} = V_{i1} \times w_{1k} + V_{i2} \times w_{2k} + ... \quad (2) \]

where \( (w_{1k}, w_{2k}, ...) = w_k \) is the eigenvector of non-leaf criterion \( k \) and \( V_{i_k} \) represents the value of alternative \( i \) evaluated against criterion \( k \).

- \( V_{i, goal} = \text{global value of alternative } i \)
A proposed solution for defining metrics for qualitative criteria (language expressivity, inconsistency)

**Algorithm 1** Define Qualitative Criterion metric (ontology)

IF (Qualitative Criterion) is atomic property THEN
   IF ontology has property Qualitative Criterion metric THEN
      Qualitative Criterion metric(ontology) := 1
   ELSE Qualitative Criterion metric(ontology) := 0
ELSE DECOMPOSE Qualitative Criterion
24 language features to assess Language Expressivity
Including Negative Criteria

Negative (Cost) Criteria

- original AHP: use different trees for **benefit** and **cost** criteria
- proposed solution: include **negative** criteria in the same tree
- leaf level negative criteria: *inconsistency, unsatisfiable classes*

\[
\overline{\text{leaf}_i} = 1 - \text{leaf}_i, \quad \text{if criterion leaf is negative} \quad (3)
\]
Assessing alternatives

- existing solutions: human **manual** evaluation, using PC matrices (*PriEst*) and fuzzy intervals (*ONTOMETRIC*)
- **proposed solution**: **automatically**, from ontology measurements
### Alternatives Measurements Normalization

<table>
<thead>
<tr>
<th>Method</th>
<th>steps</th>
<th>sum to 1</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Weighted Arithmetic Mean</strong></td>
<td>step 1: $\bar{\text{leaf}}_i = \text{leaf}_i / \sum_j \text{leaf}_j$</td>
<td>√</td>
</tr>
<tr>
<td></td>
<td>step 2: $V_i \text{leaf} = \begin{cases} \bar{\text{leaf}}_i, &amp; \text{leaf - positive} \ 1 - \bar{\text{leaf}}_i, &amp; \text{leaf - negative} \end{cases}$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>step 3: $V_i \text{leaf} = V_i \text{leaf} / \sum_j V_j \text{leaf}$, leaf - negative</td>
<td></td>
</tr>
<tr>
<td><strong>Max Normalization</strong></td>
<td>step 1: $\bar{\text{leaf}}_i = \text{leaf}_i / \text{Max(leaf}_j)$</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>step 2: $V_i \text{leaf} = \begin{cases} \bar{\text{leaf}}_i, &amp; \text{leaf - positive} \ 1 - \bar{\text{leaf}}_i, &amp; \text{leaf - negative} \end{cases}$</td>
<td></td>
</tr>
</tbody>
</table>
Knowledge Domain: **terms** to be searched in ontology concepts

**lexical** and **semantic** search: WordNet
  - **synonyms**
  - polysemy disambiguation

\[ T = \{ \langle t_i, \text{Syn}(t_i) \rangle \mid i \geq 1 \} \]
Domain Coverage Metric

The **coverage** of a given domain $T$ for an ontology $O$ is the ratio of terms matched by classes of the ontology:

$$\text{DomainCoverage}(T, O) = \frac{\text{matched}(T, O)}{|T|},$$

where $|T|$ counts the $\langle t_i, \text{Syn}(t_i) \rangle$ pairs;

$\text{matched}(T, O)$ = the number of pairs $\langle t_i, \text{Syn}(t_i) \rangle$ for which $\exists$ a class $c \in O$ s.t. $c = t_i$ or $c \in \text{Syn}(t_i)$
System Architecture

```
<<component>>
priority-code.v3
PriEsTGUI

<<component>>
WordNet KnowledgeBase

<<component>>
com.clarkparsia.pellet.owlapi

<<component>>
org.semanticweb.owlapi

<<component>>
reasoner.OWLReasoner

<<component>>
model.OwlOntology

<<component>>
com.lowagie.text

<<component>>
AHP Ontology Evaluation System

<<component>>
Domain Coverage Module

<<component>>
AHP Implementation Module

<<component>>
Ontology Measurement Module

<<component>>
ReportCreator

<<component>>
model

<<component>>
DAO

<<component>>
Database

<<component>>
JPA
```

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Project Domain
AHP adaptation for Ontology Evaluation
Domain Coverage
System Design
Experiments
Conclusions
Functionality

Decision Maker (Business User)
- terms and synonyms
- domain coverage threshold
- pairwise comparisons
- consistency measurements

Retrieve ontologies and store metadata
- generate
- Ontology Measurement Report

Define a use case desired Domain
- generate
- Domain Coverage Report

Preselect ontologies
- Input AHP Criteria preferences

Start AHP evaluation
- generate
- AHP Evaluation Report
Domain Definition

Concept (noun)
sail

Get Synonyms

Add concept to Search Terms List

Add synonym for concept

cruise

Search Terms List
< tourist, < holidaymaker, tourer> >
< sail, > >

Synonym

WordNet synonyms:
SENSE: a large piece of fabric (usually canvas fabric)
sail
canvas
canvass
sheet

SENSE: an ocean trip taken for pleasure:
cruise
sail

Reset
Done
Functionality

- Retrieve ontologies and store metadata
- Define a use case desired Domain
- Preselect ontologies
- Input AHP Criteria preferences
- Start AHP evaluation

- Ontology Measurement Report
- Domain Coverage Report
- AHP Evaluation Report
Domain Coverage Pre-selection
Functionality

- Retrieve ontologies and store metadata
- Define a use case desired Domain
- Preselect ontologies
- Input AHP Criteria preferences
- Start AHP evaluation

- terms and synonyms
- domain coverage threshold
- pairwise comparisons
- consistency measurements

- generate
- generate
- generate

- Ontology Measurement Report
- Domain Coverage Report
- AHP Evaluation Report
AHP using PriEsT Components
Inconsistency
Inconsistency

<table>
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<tr>
<th></th>
<th>LanguageExpressivity</th>
<th>Size</th>
<th>Cohesion</th>
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<tbody>
<tr>
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<td>6</td>
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<td>LanguageExpressivity</td>
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<td>Cohesion</td>
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<td>DomainCoverage</td>
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<td>4</td>
<td>6</td>
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</table>

\[ \Psi = 0.333 \]

\[ \Theta = 1.573 \]

\[ L = 3 \]

\[ CR = 0.625 \]

\[ CM = 0.988 \]

- Global Dissonance
- Global Congruence
- Individual Congruence
- Individual Dissonance

three-way cycle L3
most inconsistent CM
## Alternatives Evaluation

### Options

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<tr>
<th>Options</th>
<th>3101</th>
<th>3102</th>
<th>3105</th>
<th>3107</th>
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### Vectors

#### Gantt View

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<tr>
<th>vector</th>
<th>TD</th>
<th>NV</th>
<th>TD2</th>
<th>method</th>
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<tbody>
<tr>
<td>0.297</td>
<td>0.099</td>
<td>0.091</td>
<td>0.128</td>
<td>0.385</td>
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<td>169.706</td>
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#### Numeric Values

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<td>0.172</td>
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### Best Ontology Sub-criteria Weights

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<th>NV</th>
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<td>EV</td>
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### Ontology Weights for Avg. Sub-classes

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<td>0.106</td>
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</table>
Evaluating the domain coverage of ontologies from online repositories in **tourism** domain

<table>
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<tr>
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<th>Ontology URI</th>
<th>Domain Coverage</th>
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<td><a href="http://reverse.net/A1/otm/OTN.owl">http://reverse.net/A1/otm/OTN.owl</a></td>
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<td><a href="http://fivo.cyf-kr.edu.pl/ontologies/test/VOTours/TravelOntology.owl">http://fivo.cyf-kr.edu.pl/ontologies/test/VOTours/TravelOntology.owl</a></td>
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<td>0.0</td>
</tr>
</tbody>
</table>

1. cruise (sail)
2. mountain (mount)
3. monument (memorial)
4. museum
5. travelling (travel, traveling)
6. camping (tenting, bivouacking, encampment)
7. hiking (hike, tramp)
Alternative Normalization

Ontologies with both negative and positive characteristics were evaluated. Final ontology AHP evaluation values for different normalization methods:

- different rankings
- Max Normalization differentiates alternatives better

<table>
<thead>
<tr>
<th>id</th>
<th>Weighted Arithmetic Mean</th>
<th>Max Normalization</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>0.180</td>
<td>0.923</td>
</tr>
<tr>
<td>2</td>
<td>0.179</td>
<td>0.929</td>
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<tr>
<td>3</td>
<td>0.177</td>
<td>0.921</td>
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<td>0.173</td>
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<td>0.865</td>
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<tr>
<td>6</td>
<td>0.120</td>
<td>0.677</td>
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Consistency and Accuracy

Weight elicitation results for medium inconsistency in PC matrices

- inconsistency alters elicitation accuracy

Table: Medium Inconsistency Results

<table>
<thead>
<tr>
<th>PC matrix</th>
<th>input inconsistency</th>
<th>output inaccuracy</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>CR</td>
<td>CM</td>
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<tr>
<td>Best Ontology</td>
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<td>Language Expressivity</td>
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<tr>
<td>Size</td>
<td>0.012</td>
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Conclusions

Our proposed adaptation of the Analytic Hierarchy Process has proved useful and effective ontology evaluation domain. Contributions:

- a hierarchy of independent criteria that describe the quality of an ontology;
- an AHP adaptation for integrating cost and benefit criteria in the same tree;
- an automated system for ontology measurement and evaluation;
- a reliable domain coverage evaluation and pre-selection functionality;

Thank you for your attention!