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

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Outline

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;

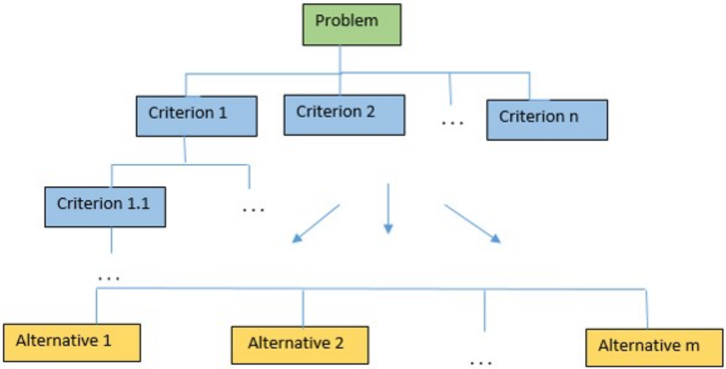


Figure : Hierarchy of problem goal, criteria and alternatives

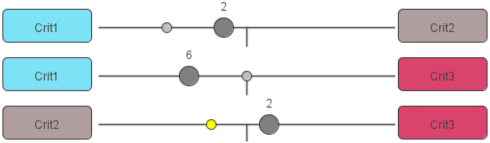
Criteria Preference - Pairwise Comparisons

- criteria **weights** $\Leftarrow$ derived from **pairwise comparisons** between **brother nodes** $\rightarrow$ positive reciprocal matrix

$$A=\begin{bmatrix} 1 & a_{12} & a_{13} & \cdots & a_{1n} \\ 1/a_{12} & 1 & 1/a_{23} & \cdots & a_{2n} \\ 1/a_{13} & 1/a_{23} & 1 & \cdots & a_{3n} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ 1/a_{1n} & 1/a_{2n} & 1/a_{3n} & \cdots & 1 \end{bmatrix}$$

$$a_{ij} = a_i / a_j$$

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



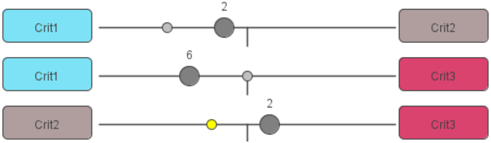
PC matrix Consistency

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* $\forall i \quad \exists j,k \text{ s.t. } a_{ij} \geq a_{ik} \Rightarrow a_{jk} \leq 1.$



Cardinal Consistency Metrics

- **Consistency Ratio (CR)**: $\frac{\lambda_{max}-n}{n-1}/RI$
- **Consistency Measure (CM)**: $max(\overline{CM}_{i,j,k}), \quad i \neq j \neq k$
  $\overline{CM}_{i,j,k} = min(\frac{a_{ij}-a_{ik}a_{kj}}{a_{ij}}, \frac{a_{ij}-a_{ik}a_{kj}}{a_{ik}a_{kj}})$
- **Congruence (Θ)**: $\Theta_{ij} = \frac{1}{n-2}\sum_{k=1}^{n}\delta(a_{ij}, a_{ik}a_{kj}), \quad i \neq j \neq k$
  $\delta(a_{ij}, a_{ik}a_{kj}) = |log(a_{ij}) - log({}_{ik}a_{kj})|$
  $\Theta = \frac{2}{2(n-1)}\sum_{i=1}^{n-1}\sum_{j=i+1}^{n}\Theta_{ij}$

Ordinal Consistency Metrics

- **The Number of Three-way Cycles (L)**:
  $E_i \to E_j \to E_k \to E_i$
  - $log(a_{ij})log(a_{ik}) \leq$ and $log(a_{ik})log(a_{jk}) < 0$ OR
  - $log(a_{ij}) = 0$ and $log(a_{ik}) = 0$ and $log(ajk) \neq 0$
- **Dissonance(Ψ)**:
  $$\Psi_{ij} = \frac{1}{n-2} \sum_k step(-\log a_{ij} \log a_{ik} a_{kj}), \quad i \neq j \neq k$$
  $$step(x) = \begin{cases} 1, & \text{if } x > 0 \\ 0, & \text{otherwise} \end{cases}$$
  $$\Psi = \frac{2}{n(n-1)} \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \Psi_{ij}$$

Eigenvalue Method

- elicit weights
- **right eigenvector** $w = (w_1, ..., w_n)$ is calculated from its PC matrix A:

$$Aw = \lambda_{max} w \tag{1}$$

where λ_{max} is largest **eigenvalue** of A

Weight Elicitation Accuracy Metrics

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

$$v_{ij} = \begin{cases} 1, & \text{if } (w_i < w_j) \text{ and } (a_{ij} > 1) \\ 0.5, & \text{if } (w_i \neq w_j) \text{ and } (a_{ij} = 1) \\ 0.5, & \text{if } (w_i = w_j) \text{ and } (a_{ij} \neq 1) \\ 0, & \text{otherwise} \end{cases}$$

Alternatives evaluation - Weighted Sum Method

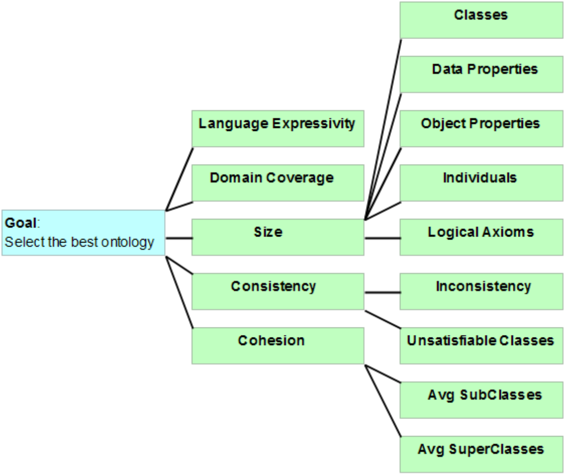
- assess and normalize alternative i for each **atomic criterion** k $\Rightarrow V_i leaf_k$
- **moving up** trough the tree, for each node **alternative values** are defined as a **weighted sum** of the values computed below for each tree level.

$$V_{ik} = V_{i1} * w_{1k} + V_{i2} * w_{2k} + \dots \tag{2}$$

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

- $V_i goal$ = global value of alternative i

Ontology Criteria



Qualitative Criteria

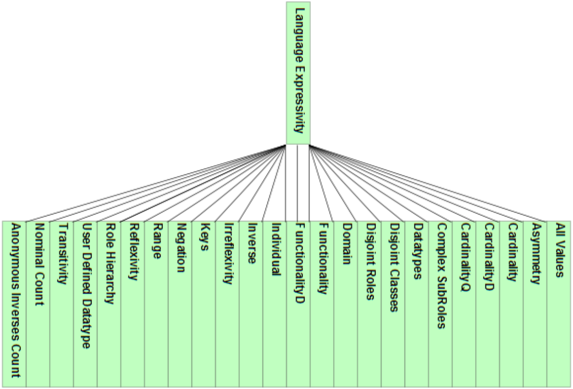
- proposed solution for defining metrics for **qualitative criteria** (*language expressivity, inconsistency*)

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

Language Expressivity

24 language features to asses Language Expressivity



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*

$$\overline{leaf_i} = 1 - \overline{leaf_i}, \quad \text{if criterion leaf is negative} \qquad (3)$$

Assessing alternatives

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

Alternatives Measurements Normalization

Method	steps	sum to 1
Weighted Arithmetic Mean	**step 1:** $\overline{leaf_i} = leaf_i / \sum_j leaf_j$ **step 2**: $V_i leaf = \begin{cases} \overline{leaf_i}, & \text{leaf - positive} \\ 1 - \overline{leaf_i}, & \text{leaf - negative} \end{cases}$ **step 3:** $V_i leaf = V_i leaf / \sum_j V_j leaf$, leaf - negative	$\surd$
Max Normalization	**step 1:** $\overline{leaf_i} = leaf_i / Max(leaf_j)$ **step 2**: $V_i leaf = \begin{cases} \overline{leaf_i}, & \text{leaf - positive} \\ 1 - \overline{leaf_i}, & \text{leaf - negative} \end{cases}$	X

Search Using Synonyms

- Knowledge Domain: **terms** to be searched in ontology **concepts**
- **lexical** and **semantic** search: WordNet
  - **synonyms**
  - polysemy disambiguation
- $T = \{\langle t_i, Syn(t_i)\rangle \quad | i \geqslant 1\}$

Domain Coverage Metric

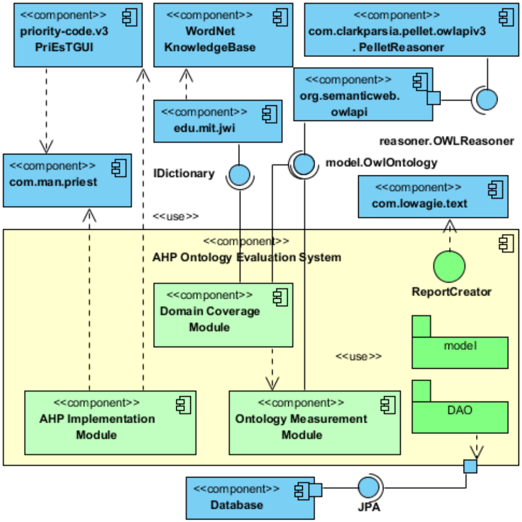
The **coverage** of a given domain T for an ontology O is the ratio of terms matched by classes of the ontology:

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

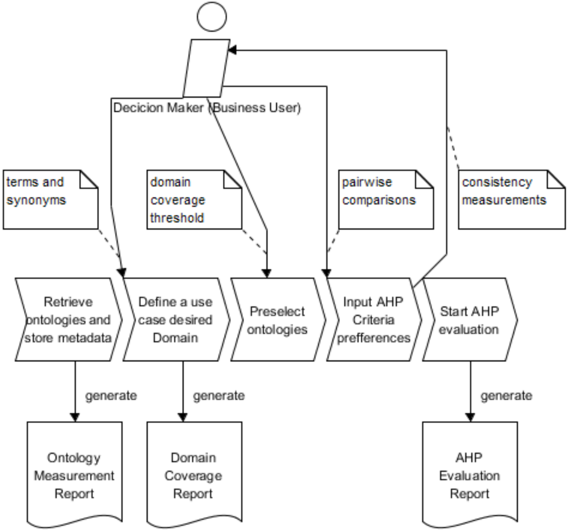
where —T— counts the $\langle t_i, Syn(t_i)\rangle$pairs;

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

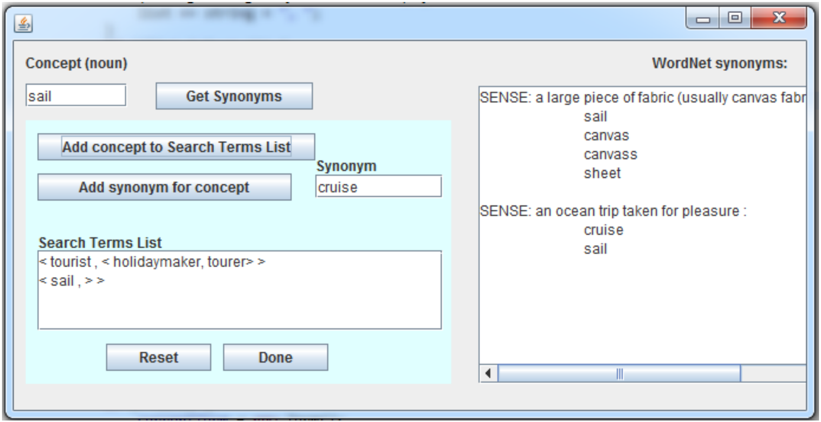
System Architecture



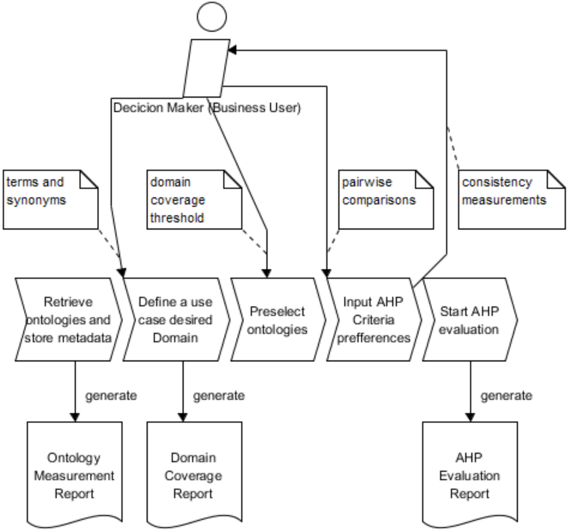
Functionality



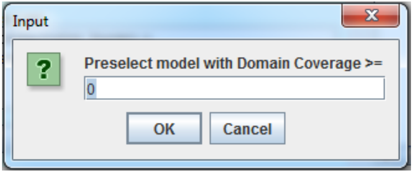
Domain Definition



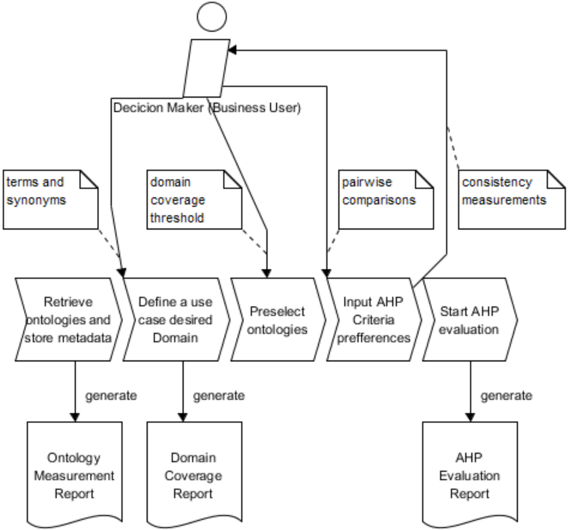
Functionality



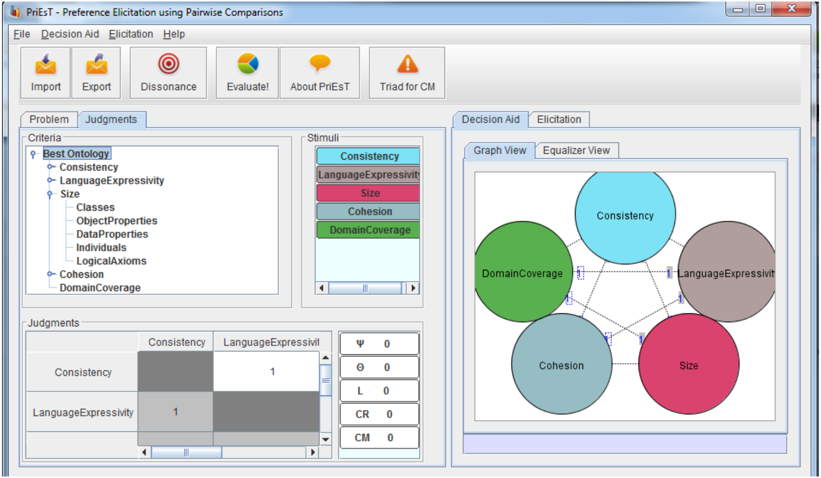
Domain Coverage Pre-selection



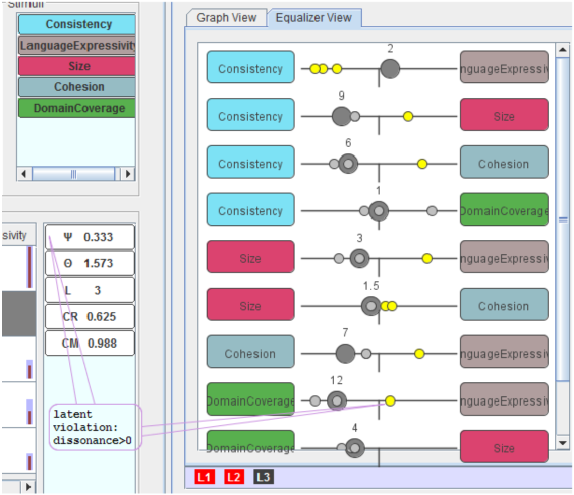
Functionality



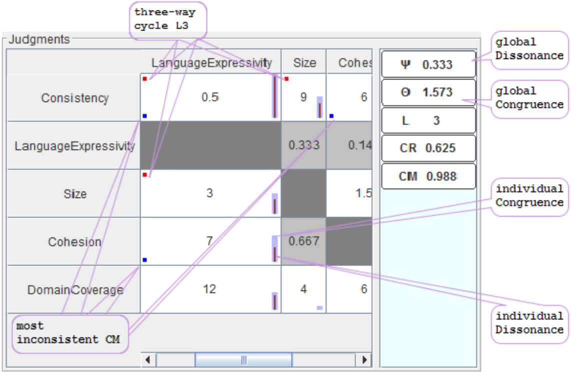
AHP using PriEsT Components



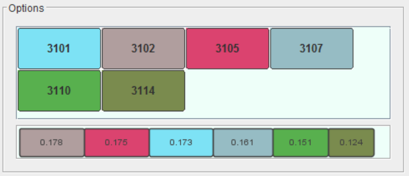
Inconsistency



Inconsistency



Alternatives Evaluation



Vectors | Gantt View | Numeric Values

vector	TD	NV	TD2	method
0.297 0.099 0.091 0.128 0.385	169.706	3	5160.316	EV

Best Ontology Sub-criteria Weights

Vectors | Gantt View | Numeric Values

vector	TD	NV	TD2	method
0.22 0.172 0.183 0.189 0.106 0.13	0	0	0	EV

Ontology Weights for Avg. Sub-classes

Domain Coverage

Evaluating the domain coverage of ontologies from online repositories in **tourism** domain

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

Ontology Id	Ontology URI	Domain Coverage
102	http://rewerse.net/A1/otn/OTN.owl	0.2857
103	http://harmonisa.uni-klu.ac.at/ontology/skeleton.owl	0.0
104	http://www.info.uqam.ca/Members/valtchev_p/mbox/ETP-tourism.owl	0.1429
105	http://harmonisa.uni-klu.ac.at/ontology/moland.owl	0.1429
106	http://fivo.cyf-kr.edu.pl/ontologies/test/VOTours/TravelOntology.owl	0.1429
107	http://cui.unige.ch/isi/onto/2010/urba-en.owl	0.5714
108	http://en.openei.org/wiki/Special:ExportRDF/South_Africa_Department_of_Environment_Affairs_and_Tourism	0.0
109	http://en.openei.org/wiki/Special:ExportRDF/Climate_Change_Adaptation_and_Mitigation_in_the_Tourism_Sector	0.0
111	http://jxml2owl.projects.semwebcentral.org/sample/tourism.owl	0.0
112	http://iri.columbia.edu/~benno/data_center.owl	0.0
113	http://www.pms.ifi.lmu.de/rewerse-wga1/otn/OTN.owl	0.2857
114	http://aabs-semanticweb-prototypes.googlecode.com/svn-history/r2/trunk/ontologies/2007/02/Test/needs.rdf	0.0
115	http://aabs-semanticweb-prototypes.googlecode.com/svn-history/r2/trunk/ontologies/2007/02/Flight/Flight.owl	0.0
116	http://aabs-semanticweb-prototypes.googlecode.com/svn-history/r2/trunk/ontologies/2007/02/Places/Places.owl	0.1429
117	http://www.esd.org.uk/standards/lgcl/1.03/lgcl-schema/lgcl.xml	0.0
118	http://www.cs.ox.ac.uk/isg/ontologies/lib/GardinerCorpus/http___protege.stanford.edu_plugins_owl_owl-library_travel.owl/2009-02-13/00120.owl	0.1429
119	http://harmonisa.uni-klu.ac.at/ontology/realraum.owl	0.0

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

id	**Weighted Arithmetic Mean**	**Max Normalization**
1	0.180	0.923
2	0.179	0.929
3	0.177	0.921
4	0.173	0.878
5	0.155	0.865
6	0.120	0.677

Consistency and Accuracy

Weight elicitation results for medium inconsistency in PC matrices

- inconsistency alters elicitation accuracy

Table : Medium Inconsistency Results

PC matrix	**input inconsistency**					**output inaccuracy**		
	CR	CM	L	Θ	Ψ	TD	TD2	NV
Best Ontology	0.022	0.603	0	0.395	0.033	6.211	53.115	0
Language Expressivity	0.028	0.95	150	0.106	0.008	62.358	4647.295	2
Size	0.012	0.5	0	0.299	0.33	979.823	10647.875	1

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!