

Towards a Type-2 Fuzzy Description Logic for Semantic Search Engine

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Outline

- Background
- Related Work
- Basic Concepts
- Type-2 Fuzzy *ALC*
- The Semantic Search Engine Based on Type-2 Fuzzy Ontology
- Conclusions and Future Work

1. Background

Background

- Semantic search (R. Guha, WWW 2003)

- Semantic Web + Search Engine
 - finds out the **internal knowledge** in Knowledge Base (KB) to improve the search results gained by current search engines

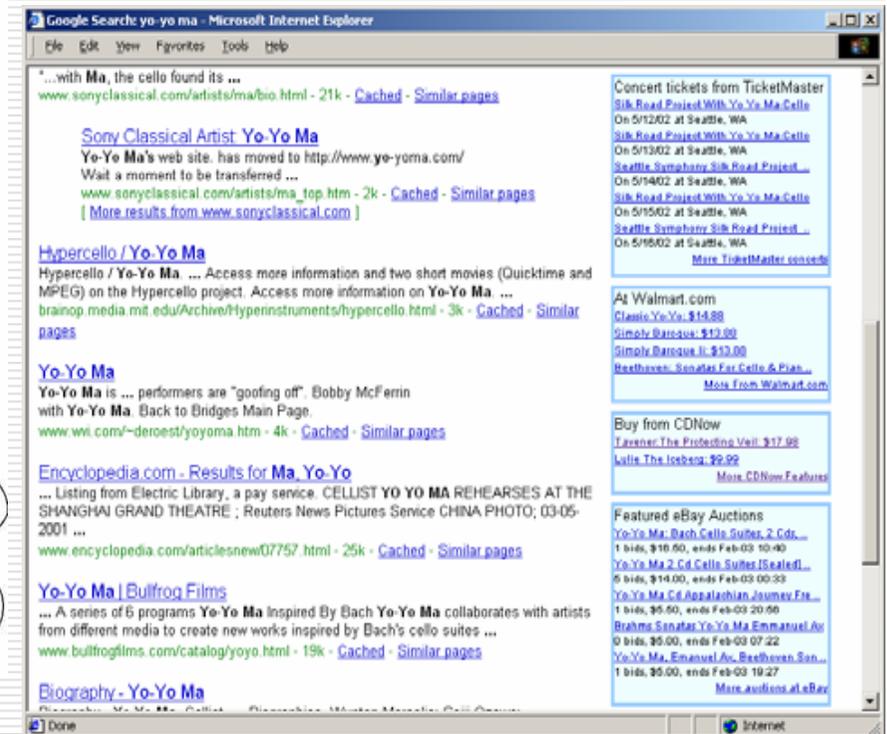
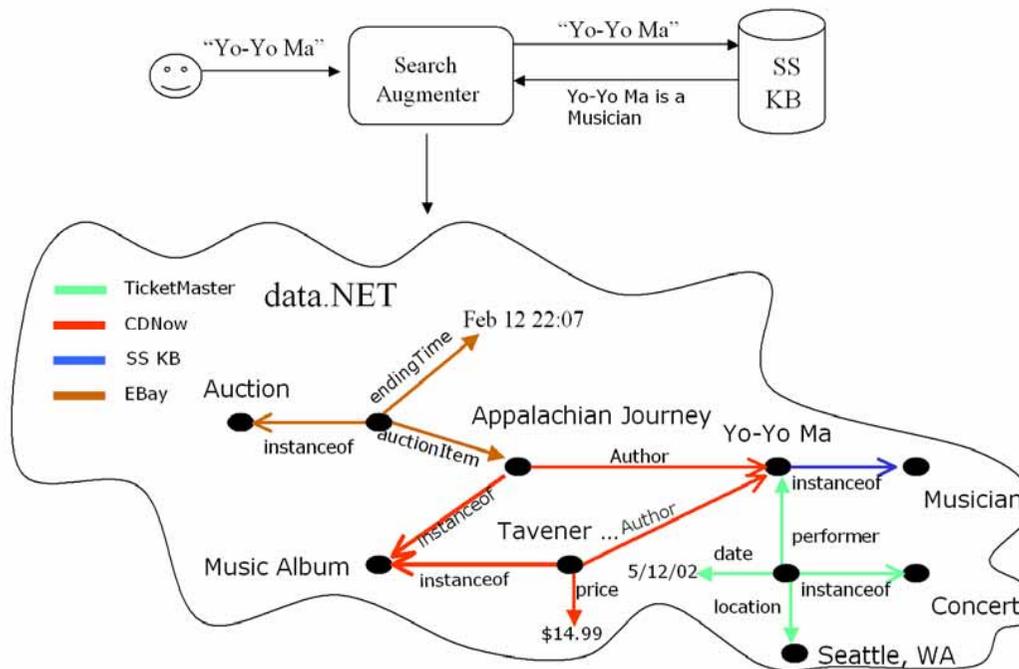
 - evolves to next generation of search engines **built on Semantic Web**

- Two types of search
 - searching the current Internet

 - searching the Semantic Web portals

2. Related Work

Related Work-Tap



Tap

The screenshot shows a Microsoft Internet Explorer browser window with the address bar displaying "Google Search: yo-yo ma". The main content area contains search results for "yo-yo ma". The first result is from Sony Classical, with a snippet: "...with **Ma**, the cello found its ...". Below this is a link to "Sony Classical Artist: Yo-Yo Ma" and a message that the website has moved to "http://www.yo-yoma.com/". Other results include "Hypercello / Yo-Yo Ma", "Yo-Yo Ma" (with a snippet about performers "goofing off"), "Encyclopedia.com - Results for Ma, Yo-Yo", and "Yo-Yo Ma | Bullfrog Films". On the right side of the browser window, there are several sponsored or featured links, including "Concert tickets from TicketMaster", "At Walmart.com" (listing classical music items like "Classico Yo-Yo: \$14.88"), "Buy from CDNow" (listing "Taverner: The Protecting Veil: \$17.98"), and "Featured eBay Auctions" (listing various Yo-Yo Ma CDs and recordings).

Google Search: yo-yo ma - Microsoft Internet Explorer

File Edit View Favorites Tools Help

"...with **Ma**, the cello found its ...
www.sonyclassical.com/artists/ma/bio.html - 21k - [Cached](#) - [Similar pages](#)

[Sony Classical Artist: Yo-Yo Ma](#)
Yo-Yo Ma's web site. has moved to <http://www.yo-yoma.com/>
Wait a moment to be transferred ...
www.sonyclassical.com/artists/ma_top.htm - 2k - [Cached](#) - [Similar pages](#)
[[More results from www.sonyclassical.com](#)]

[Hypercello / Yo-Yo Ma](#)
Hypercello / Yo-Yo Ma. ... Access more information and two short movies (Quicktime and MPEG) on the Hypercello project. Access more information on Yo-Yo Ma. ...
brainop.media.mit.edu/Archive/Hyperinstruments/hypercello.html - 3k - [Cached](#) - [Similar pages](#)

[Yo-Yo Ma](#)
Yo-Yo Ma is ... performers are "goofing off". Bobby McFerrin with Yo-Yo Ma. Back to Bridges Main Page.
www.wwi.com/~deroest/yoyoma.htm - 4k - [Cached](#) - [Similar pages](#)

[Encyclopedia.com - Results for Ma, Yo-Yo](#)
... Listing from Electric Library, a pay service. CELLIST YO YO MA REHEARSES AT THE SHANGHAI GRAND THEATRE ; Reuters News Pictures Service CHINA PHOTO; 03-05-2001 ...
www.encyclopedia.com/articlesnew/07757.html - 25k - [Cached](#) - [Similar pages](#)

[Yo-Yo Ma | Bullfrog Films](#)
... A series of 6 programs Yo-Yo Ma Inspired By Bach Yo-Yo Ma collaborates with artists from different media to create new works inspired by Bach's cello suites ...
www.bullfrogfilms.com/catalog/yoyo.html - 19k - [Cached](#) - [Similar pages](#)

[Biography - Yo-Yo Ma](#)
Biography: Yo-Yo Ma, Cellist ...

Concert tickets from TicketMaster
[Silk Road Project With Yo Yo Ma-Cello](#)
On 5/12/02 at Seattle, WA
[Silk Road Project With Yo Yo Ma-Cello](#)
On 5/13/02 at Seattle, WA
[Seattle Symphony Silk Road Project ...](#)
On 5/14/02 at Seattle, WA
[Silk Road Project With Yo Yo Ma-Cello](#)
On 5/15/02 at Seattle, WA
[Seattle Symphony Silk Road Project ...](#)
On 5/16/02 at Seattle, WA
[More TicketMaster concerts](#)

At Walmart.com
[Classico Yo-Yo: \\$14.88](#)
[Simply Baroque: \\$13.88](#)
[Simply Baroque li: \\$13.88](#)
[Beethoven: Sonatas For Cello & Pian ...](#)
[More From Walmart.com](#)

Buy from CDNow
[Taverner: The Protecting Veil: \\$17.98](#)
[Lulie The Iceberg: \\$9.99](#)
[More CDNow Features](#)

Featured eBay Auctions
[Yo-Yo Ma: Bach Cello Suites, 2 Cds, ...](#)
1 bids, \$16.50, ends Feb-03 10:40
[Yo-Yo Ma 2 Cd Cello Suites \[Sealed\] ...](#)
5 bids, \$14.00, ends Feb-03 00:33
[Yo-Yo Ma Cd Appalachian Journey Fre ...](#)
1 bids, \$5.50, ends Feb-03 20:56
[Brahms Sonatas Yo-Yo Ma Emmanuel Ax](#)
0 bids, \$5.00, ends Feb-03 07:22
[Yo-Yo Ma, Emanuel Ax, Beethoven Son ...](#)
1 bids, \$5.00, ends Feb-03 19:27
[More auctions at eBay](#)

Done Internet

Related Work

- **Swoogle** is a prototype system of information retrieval (IR). The search results are physical documents on Semantic Web (such as RDF and OWL files).
 - It has not used the semantic structure information in documents.

- Turing center in the University of Washington develops the system **KnowItAll** to extract the information on the Web.
 - Its long-term aim is to replace the search engine by information extraction.

Existing Problems

- What is the semantic search engine based on classical ontology cannot do?
 - Limits of classical ontology

- How to build semantic search on traditional Web?

- What about the type-1 fuzzy DL named *FALC*?

Our Solution

- Type-2 fuzzy *ALC*
 - type-2 fuzzy *ALC* use an interval to show the membership, which can describe imprecise knowledge much better than type-1 fuzzy *ALC* .

- Semantic search engine based on type-2 fuzzy ontology
 - type-2 fuzzy ontology can improve the precision of the semantic search engine.

3. Basic Concepts

DL : TBox & ABox

- TBox is the vocabulary of a DL system in an application domain. It contains the terminologies to define the real world.
- ABox contains assertions about named individuals in terms of this vocabulary. It describes the instances in the world.

ALC

- ALC concepts and roles are built as follows: Use letter A for the set of atomic concepts, C for the set of complex concept defined by descriptions and R for the set of roles.
- Starting with: (1) $A, B \subseteq A$ (2) $C, D \subseteq C$ and (3) $R \subseteq R$.
- The concept terms in TBox can be defined with the format as following inductively: $C \sqsubseteq f(A, B, R, \sqcap, \sqcup, \forall, \exists, \dots, \top)$ (partial definition) and $C \sqsubseteq f(A, B, R, \sqcap, \sqcup, \forall, \exists, \dots, \top)$ (full definition).
- \perp and \top are two special atomic concepts named “bottom concept” and “universe concept”.

FALC (Type-1 fuzzy ALC)

- As same as classic *ALC*, A , C and R are defined as the set of atomic fuzzy concepts, complex fuzzy concepts, and fuzzy roles in *FALC*.
- It is easy to prove that $C \sqcap D$, $C \sqcup D$, $\neg C$, $\forall R.C$ and $\exists R.C$ are also fuzzy concept.
- The fuzzy interpretation in *FALC* is a pair $I = (\Delta', \cdot')$, and \cdot' is an interpretation function mapping fuzzy concept and role into a membership degree function $C' = \Delta' \rightarrow [0,1]$ and $R' = \Delta' \times \Delta' \rightarrow [0,1]$.

FALC syntax and semantics

$$\top^I(d) = 1$$

$$\perp^I(d) = 0$$

$$(C \cap D)^I(d) = \min\{C^I(d), D^I(d)\}$$

$$(C \cup D)^I(d) = \max\{C^I(d), D^I(d)\}$$

$$\neg C^I(d) = 1 - C^I(d)$$

$$(\forall R.C)^I(d) = \inf_{d' \in \Delta^I} \max\{1 - R^I(d, d'), C^I(d)\}$$

$$(\exists R.C)^I(d) = \sup_{d' \in \Delta^I} \min\{R^I(d, d'), C^I(d)\}$$

4. Type-2 Fuzzy *ALC*

Type-2 Fuzzy Sets

- Different from the type-1 fuzzy sets, type-2 fuzzy sets use an interval to show the membership.
- We denote the membership in type-2 fuzzy sets with $\overline{\mu}_A$ instead of μ_A in type-1 fuzzy sets:
$$\overline{\mu}_A(x) = [\mu_A^L(x), \mu_A^U(x)]$$
- We call $\mu_A^L(x)$ and $\mu_A^U(x)$ the primary membership and secondary membership, and x is an instance in the fuzzy sets U

Triangular Norms

- We call the interpretation I triangular norm if it satisfies the conditions:
 - $I(0,0)=0, I(1,1)=1$
 - $a \leq c, b \leq d \Rightarrow I(a, b) \leq I(c, d)$
 - $I(a, b) = I(b, a)$
 - $I(I(a, b), c) = I(a, I(b, c))$

- The triangular norm is named T norm if $I(a, 1)=a$ ($a \in [0,1]$). The corresponding name of triangular norm is S when $I(0,a)= a$ ($a \in [0,1]$)

Imprecise Axioms in Type-2 Fuzzy *ALC*

- $\text{Bird}_{[0.9,0.95]} \sqsubseteq \text{Animal} \sqcap \text{FlyingObject}$
- the atomic concepts can be divided into two sets, the name symbols N_T that occur on the left-hand side of some axiom and the base symbols B_T that occur only on the right-hand side of axioms.
- It is certainly that the B_T exist in the DL system, but the N_T are not.
- $\text{Meat-eatingBird} \sqsubseteq \text{Bird}_{[0.9,0.95]} \sqcap \text{Meat-eatingObject}$
- How to calculate the fuzzy interval of Meat-eatingBird?

Imprecise Axioms in Type-2 Fuzzy *ALC*

- Triangular norms (T_2 and S_2): $T(a,b) = ab/[1+(1-a)(1-b)]$, $S(a,b) = (a+b)/(1+ab)$
- $\mu^L(\text{Meat-eatingBird}) = (0.9 \times 1)/[1 + (1-1)(1-0.9)] = 0.9$.
- $\mu^U(\text{Meat-eatingBird}) = (0.95 \times 1)/[1 + (1-1)(1-0.95)] = 0.95$.
- The membership of atomic concept Meat-eatingBird is in scope $[0.9, 0.95]$.

The Syntax and Semantics of Type-2 Fuzzy *ALC*

Constructor	Syntax	Semantics
Top (Universe)	\top	Δ^I
Bottom (Nothing)		
Atomic Concept	$A_{[a,b]}$	$A_{[a,b]}^I \subseteq \Delta^I$
Atomic Role	$R_{[a,b]}$	$R_{[a,b]}^I \subseteq \Delta^I \times \Delta^I$
Conjunction	$C_{[a,b]} \sqcap D_{[c,d]}$	$(C \sqcap D)_{[T(a,c), T(b,d)]}^I$
Disjunction	$C_{[a,b]} \sqcup D_{[c,d]}$	$(C \sqcup D)_{[S(a,c), S(b,d)]}^I$
Negation	$\neg C_{[a,b]}$	$C_{[1-b, 1-a]}^I$
Value restriction	$\forall R_{[a,b]} \cdot C_{[c,d]}$	$\forall y. S(R_{[1-b, 1-a]}(x, y), C_{[c,d]}(y))$
Full existential quantification	$\exists R_{[a,b]} \cdot C_{[c,d]}$	$\exists y. T(R_{[a,b]}(x, y), C_{[c,d]}(y))$

The Syntax and Semantics of Type-2 Fuzzy *ALC*

- The fuzzy interpretation in type-2 fuzzy *ALC* is a pair $I = (\Delta', \cdot')$, and \cdot' is an interpretation function that map fuzzy concept and role into a membership degree interval: $C' = \Delta' [a, b]$ and $R' = \Delta' \times \Delta' [a, b]$, and a, b must satisfy $0 \leq a \leq b \leq 1$.

The Syntax and Semantics of Type-2 Fuzzy *ALC*

- The interpretation of type-2 fuzzy *ALC* must satisfy the next equations: for all $d \in \Delta^I$
- $\top I(d) = [1, 1]$
- $\perp I(d) = [0, 0]$
- $C I(d) = [(C(d)), (C(d))]$
- $(C \sqcap D) I(d) = [T\{(C(d)), (D(d))\}, T\{(C(d)), (D(d))\}]$
- $(C \sqcup D) I(d) = [S\{(C(d)), (D(d))\}, S\{(C(d)), (D(d))\}]$
- $\neg C I(d) = [1 - (C(d)), 1 - (C(d))]$
- $(\forall R.C) I(d) = \inf_{d'} \Delta I [S\{1 - (R(d, d')), (C(d'))\}, S\{1 - (R(d, d')), (C(d'))\}]$
- $(\exists R.C) I(d) = \sup_{d'} \Delta I [T\{(R(d, d')), (C(d'))\}, T\{(R(d, d')), (C(d'))\}]$

Type-2 fuzzy OWL

- There are some differences between OWL and type-2 fuzzy OWL in the abstract syntax of “Description” and “Fact” in type-2 fuzzy OWL, which are proposed as following:

- *Description ::= ‘classID (‘ [classID] {‘fuzzy:LowerDegree(‘ Lowerdegree‘)} {‘fuzzy:UpperDegree(‘ Upperdegree‘)} (‘ Lowerdegree Upperdegree‘)’)’*
|restriction|‘unionOf (‘ {description } ‘)’ |‘intersectionOf (‘ {description } ‘)’
|‘complementOf (‘ { description } ‘)’
|‘one of (‘ { individualID } ‘)’
Fact ::= Individual
Individual ::= ‘Individual (‘ [individualID] { annotation } { ‘type (‘type‘)’ {‘fuzzy:LowerDegree(‘ Lowerdegree‘)} {‘fuzzy:UpperDegree(‘ Upperdegree‘)} ‘ }’ (‘ Lowerdegree Upperdegree‘)’)’
Lowerdegree ::= degree
Upperdegree ::= degree
degree ::= ‘degree(‘ real-number-between-0-and-1-inclusive‘)’

Reasoning in Type-2 Fuzzy *ALC*

□ Tableau algorithms

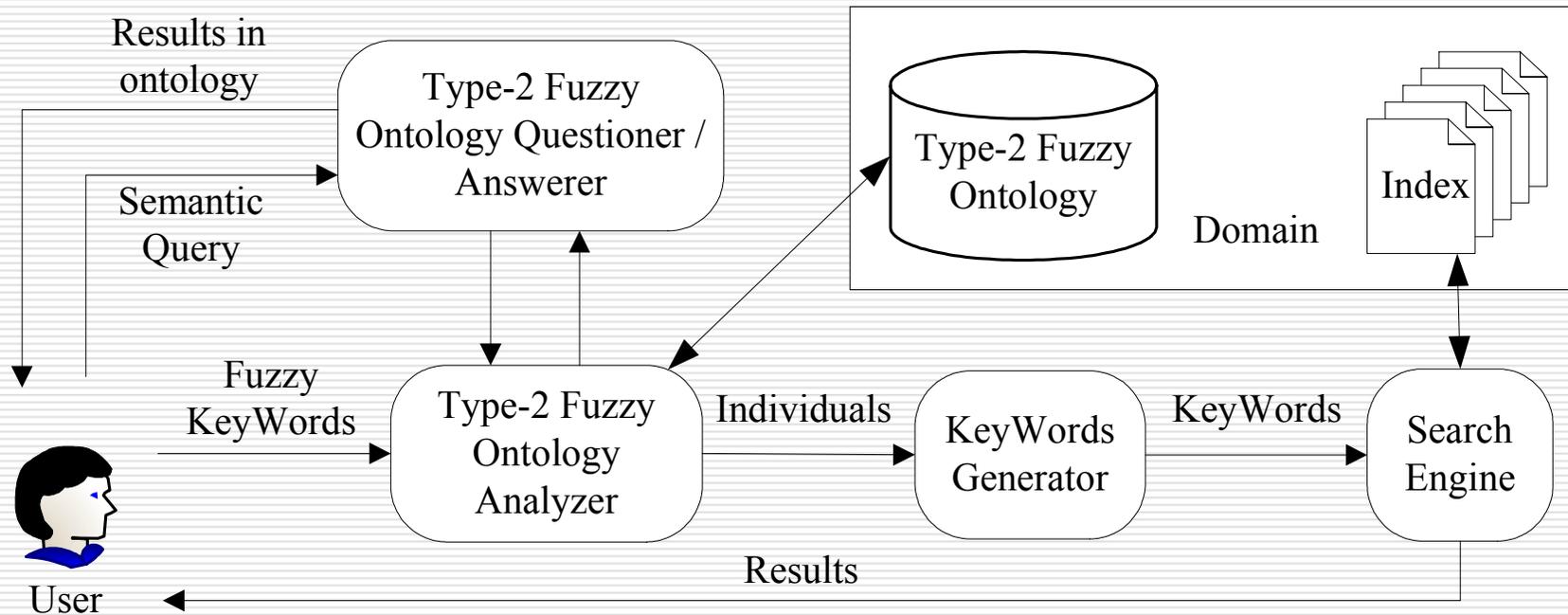
- Tableau algorithms are the most famous and basal algorithms in DL reasoning. Tableau algorithms use negation to reduce subsumption to (un)satisfiability of concept descriptions instead of testing subsumption of concept descriptions directly: $C \sqsubseteq D$ iff $\neg C \sqcap D = \perp$. We can check whether the concept is unsatisfiable with those algorithms.

Reasoning in Type-2 Fuzzy *ALC*

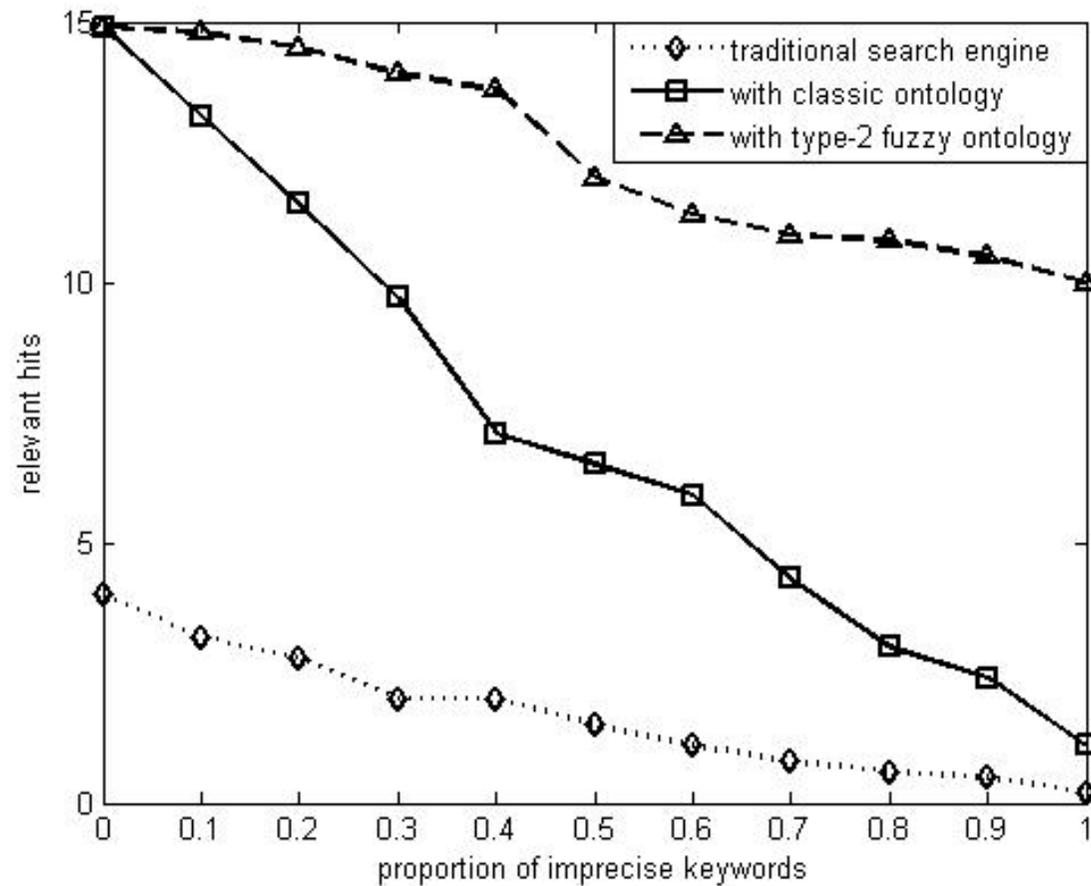
- Type-2 fuzzy tableau algorithms
 - 5 rules: \cap -rule, \sqcap -rule, \sqcup -rule, \exists -rule, \forall -rule
- the process of tableau will stop when anyone of following conditions is established:
 - Any obvious clash ($\perp(x)$, $(C \sqcap \neg C)(x)$, etc.) is found in process of algorithm.
 - All rules (\sqcap -rule, etc.) have been executed.
 - Any fuzzy clash ($C[0,0](x)=[c,d]$, $C[a,b](x)=[c,d]$, $C[c,d](x)=[a,b]$ with $a < b < \overline{TL}$, $C[a,b](x)$ and $C[c,d](x)$ with the intervals $[a,b]$ and $[c,d]$ do not overlap) happened in process of algorithm.
- Complexity of type-2 fuzzy tableau algorithms
 - $O(2n)$ (n is the number of atomic concepts describing complex concept C)

5. The Semantic Search Engine Based on Type-2 Fuzzy Ontology

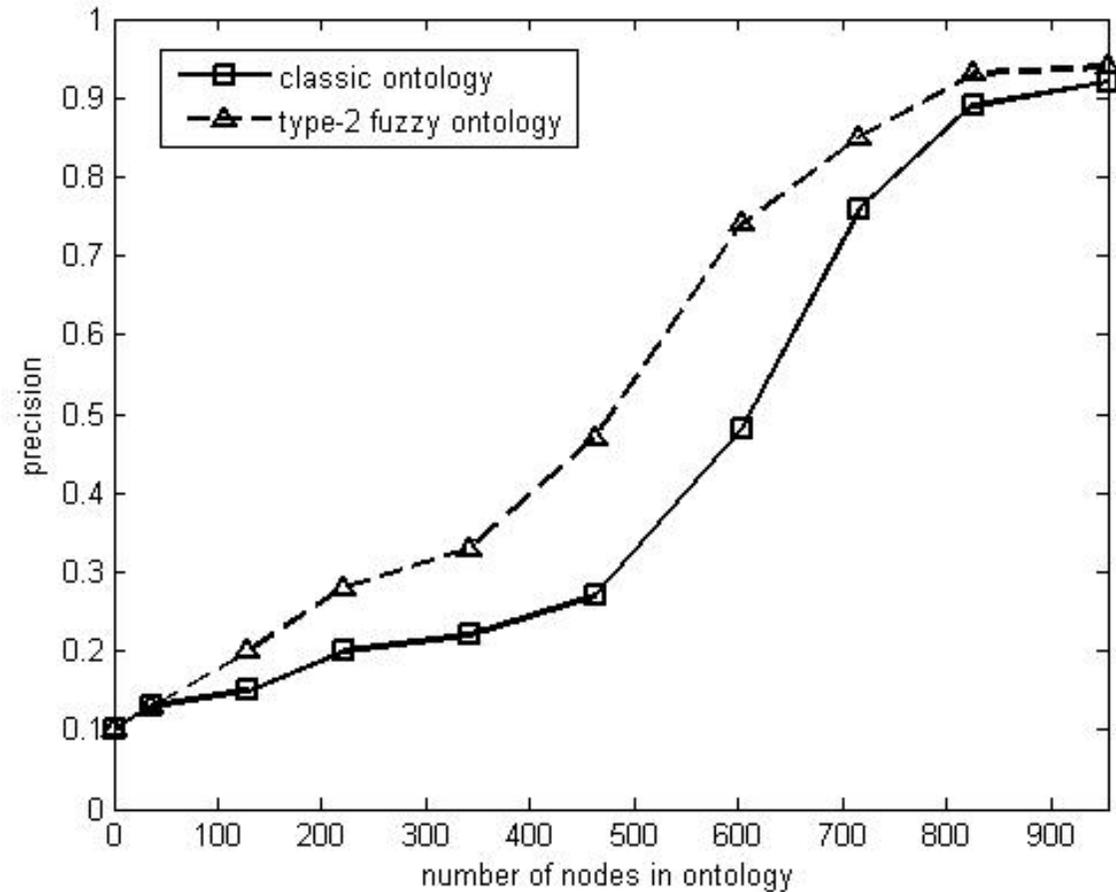
Architecture of Type-2 Fuzzy Semantic Search Engine



Experiments and Analysis(1)



Experiments and Analysis(2)



Conclusions and Future Work

- Type-2 fuzzy *ALCN*, *SHOIN(D)*
- Ontology explainer based on Type-2 fuzzy DL
- Ontology reasoner based on Type-2 fuzzy DL



Thanks!

<http://idc.hust.edu.cn>