Revisiting Natural Language Interfaces to Databases

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Introduction

- The basic problem:
  - configuration:
    DB + linguistic knowledge → NL Interface
  - querying:
    NL queries + NL Interface → NL answers
- Some extra requirements:
  - query paraphrasing
  - update operations
  - configuration tools

A Great Problem for Computational Linguistics

- Semantics restricted to a well behaved case:
  - may evaluate the performance of various syntactic theories
  - controlled environment for study of anaphora, ellipsis, dialogue, context...
- Could be useful
  NL could give advantage over **forms based**, **metaphor based** or **formal language** interfaces[a]
  - people already know natural language - no training!
  - forms and metaphor based approaches have difficulty with negation, quantification and high conceptual complexity
  - meta-level questions
  - dialogue and query refinement
- DEMO! `www.cs.umu.se/~mjm/step`

[a] Key word search is generally too weak for relational databases.

Overview

- Basic notions:
  - databases
  - semantic interpretation
- Basic approaches:
  0. syntax based systems
  1. **semantic grammars**
  2. **transportable systems**
- Some history... what happened?
- Recent work:
  - Microsoft English Query
  - Precise
  - STEP
- Evaluation
- Future prospects and summary

Question: What is a 'database'?

Answer: "A relational database!"

A set of relations $\mathbf{R} = R_1, ..., R_n$, each with an associated arity

A database state D is the set of extensions (i.e. tuple sets) for each relation

Σ is the set of functional dependency (primary key) and inclusion dependency (foreign key) constraints

$\Sigma \models D$ when D does not violate Σ

A query is Q a formula over some set of m free variables

Answers to Q, $A = Q(D)$ are m-tuples that satisfy the query over the structure associated with D

An Example Database

Schema:

Restaurant(<u>id</u>, name, address, city, phone)
Type(<u>id</u>, type)
Location(<u>id</u>, lat, long)

Queries:

"List the Italian restaurants":

$$\{x | Restaurant(x) \wedge (\exists y)(Type(y) \wedge x.id = y.id \wedge y.type =' Italian')\}$$

"Give the phone number of Rex?":

$$\{x.phone | Restaurant(x) \wedge x.name =' Rex'\}$$

What is Semantic Interpretation?

$$I(W, C) \rightarrow \{Q_1, ..., Q_m\}$$

where $W = w_1, ...w_n$ is a sequence of words, C is the context[a] and $Q_1, ..., Q_m$ are logically distinct queries.

For a given population of sentences Ω:

I is 'sound' if for all $W \in \Omega$ and all $Q \in I(W, C)$, Q is a reasonable interpretation of W in the context C.

I is 'complete' if for all $W \in \Omega$, for all Q that are reasonable interpretations of W in the context C, $Q \in I(W, C)$.

Accuracy of I for a representative sample of $\Omega' \subseteq \Omega$ is ...

[a] We shall only consider $C = \emptyset$ here.

Syntax Based Systems

- Parse word sequence to parse tree(s)
- Use 'knowledge' to map from parse tree(s) to database queries.

$S \rightarrow VP$
$VP \rightarrow V \cdot NP$
$NP \rightarrow ProperNoun | Det \cdot Nominal$
$Nominal \rightarrow Nominal \cdot PP | N | ADJ \cdot Nominal$
$PP \rightarrow P \cdot NP$
$Det \rightarrow$ "`the`"
$P \rightarrow$ "`of`"
$V \rightarrow$ "`list`"|"`give`"
$N \rightarrow$ "`phone number`"|"`restaurants`"
$ProperNoun \rightarrow$ "`Rex`"
$ADJ \rightarrow$ "`Italian`"

  - Mapping knowledge is notoriously difficult to encode
  - High degree of ambiguity in large grammars
  - Not bi-directional

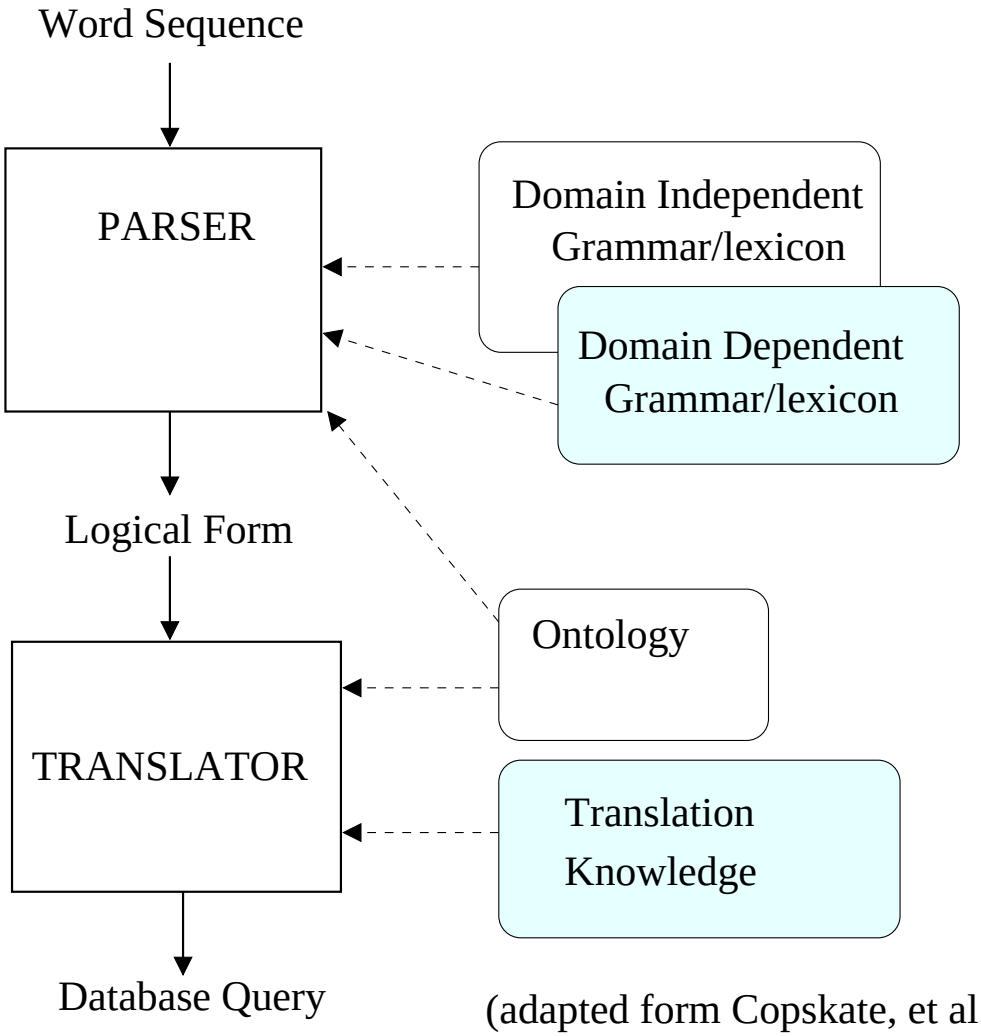
Semantic Grammars

- Basing 'syntactic categories' on domain concepts

$S \rightarrow AR \quad \{Query(AR.sem)\}$
$S \rightarrow RS \quad \{Query(RS.sem)\}$
$AR \rightarrow$ "`give the`" PS "`of`" R "`?`" $\quad \{PS.sem|R.sem\}$
$PS \rightarrow$ "`phone number`" $\quad \{x.phone\}$
$PS \rightarrow$ "`address`" $\quad \{x.address\}$
$RS \rightarrow$ "`list the `" $R \quad \{x|R.sem\}$
$R \rightarrow \$C_1$ "`restaurants`"
$\{Restaurant(x) \wedge$
$(\exists y)(Type(y) \wedge x.id = y.id \wedge y.type = \$C_1)\}$
$R \rightarrow$ "`restaurants`" $\quad \{Restaurant(x)\}$
$R \rightarrow \$C_1 \quad \{Restaurant(x) \wedge x.name = \$C_1\}$

+ Can give surprisingly robust solutions in closed domains
– Must build grammar for each new schema
– A black art
– Not (immediately) bi-directional

Transportable Systems



(adapted form Copskate, et al.1990)

- Uses very large domain independent grammars (with attached semantics).
- Maps to *some* domain independent representation language.
- *Translation knowledge* maps the abstract meaning representations to queries over the database relations.

Example *A Domain Independent Grammar*

$S \rightarrow VP \quad \{IMP(VP.sem(Hearer))\}$

$VP \rightarrow V \cdot NP \quad \{V.sem(NP.sem)\}$

$NP \rightarrow ProperNoun \quad \{ProperNoun.sem\}$

$NP \rightarrow Det \cdot Nominal \quad \{\langle Det.semxNominal.sem\rangle)\}$

$Nominal \rightarrow Nominal \cdot PP$

$\{\lambda z.Nominal.sem(z) \wedge PP.sem(z)\}$

$Nominal \rightarrow Noun \quad \{\lambda x.ISA(x, Noun.sem)\}$

$PP \rightarrow P \cdot NP \quad \{P.sem(NP.sem)\}$

$Nominal \rightarrow ADJ \cdot Nominal$

$\{\lambda z.Nominal.sem(x) \wedge AM(x, ADJ.sem)\}$

$Det \rightarrow$ "`the`" $\quad \{\exists!\}$

$Det \rightarrow$ "`a`" $\quad \{\exists\}$

$P \rightarrow$ "`of`" $\quad \{\lambda x, y.OF(x, y)\}$

— adapted from Jurafsky and Martin, 2000.

Example *Lexicon*

$V \rightarrow$ "`list`"
$\{\lambda x, y. \exists e ISA(e, listing) \wedge Actor(e, y) \wedge Object(e, x)\}$
$V \rightarrow$ "`give`"
$\{\lambda x, y. \exists e ISA(e, giving) \wedge Actor(e, y) \wedge Object(e, x)\}$

$N \rightarrow$ "`phone number`" $\{phoneNumber\}$
$N \rightarrow$ "`restaurants`" $\{restaurant\}$
$ProperNoun \rightarrow$ "`Rex`" $\{Rex\}$
$ADJ \rightarrow$ "`Italian`" $\{Italian\}$

Example *Mapping to intermediate form with complex terms*

$$\frac{P(e,\langle(\exists!x)(\phi(x))\rangle)}{(\exists!x)(P(e,x)\wedge\phi(x))}$$

"List the Italian restaurants":

$IMP((\exists e)(ISA(e, listing) \wedge Actor(e, Computer)\wedge$
$(\exists!z)(Object(e, x) \wedge restaurant(z)\wedge$
$AM(z,' Italian')))))$

"Give the phone number of Rex?":

$IMP((\exists e)(ISA(e, giving) \wedge Actor(e, Computer)\wedge$
$(\exists!z)(Object(e, z) \wedge phoneNumber(z)\wedge$
$OF(z,' Rex')))))$

Example *Translation Knowledge*

IF

$$IMP((\exists e)((\mathit{ISA}(e, \mathit{listing}) \vee \mathit{ISA}(e, \mathit{giving}) \vee ...) \wedge \mathit{Actor}(e, \mathit{Computer}) \wedge (\exists! x)(\psi(x))))$$

THEN for each $a \in Eval(Translate(\psi(x)))$

$$DECL(\{x \mapsto a\}\psi(x))$$

Translation knowledge:

$$\{x|\mathit{restaurant}(x)\} \rightarrow \{x.\mathit{name}|\mathit{Restaurant}(x)\}$$

$$\{x|\mathit{phoneNumber}(x) \wedge \mathit{OF}(x, \$C_1)\} \rightarrow \{x.\mathit{phone}|\mathit{Restaurant}(x) \wedge x.\mathit{name} = \$C_1\}$$

$$\{x|\mathit{restaurant}(x) \wedge \mathit{AM}(x, \$C_1)\} \rightarrow \{\mathit{Restaurant}(x) \wedge (\exists y)(\mathit{Type}(y) \wedge x.\mathit{id} = y.\mathit{id} \wedge y.\mathit{type} = \$C_1)\}$$

Transportable Systems

+ Only (part of) the lexicon and translation knowledge needs to be ported to new database
+ Evaluates open domain grammars
+ Bi-directionality — depending on the grammar
+ Ontology may mediate between query and DB

– Statistical parsers may need to be retrained
– Translation knowledge not always trivial to encode even with tools
– Idioms and domain specific style must somehow be encoded
– Sentence fragments and ill-formed input

Classifying (some of) the 20th century work

'database'	Syntax based systems	Semantic grammars	Transportable systems
Relational		RENDEZ-VOUS, EUFID, PLANES, Q/A	TEAM, TELI, *JANUS*
Prolog	CHAT		MASQUE, LOQUI
Semantic Network/ Description Logic	LUNAR	LADDER	JANUS,ASK

Difficulties

- Linguistic/Conceptual coverage not obvious
  - users over estimate coverage
  - users under estimate coverage
  - users conflate linguistic and conceptual limitations
  - some empirical work suggests that linguistic limitations more serious
- Limited Context/Register handling
  - in informal register 'and' can mean 'or'
  - users prefer brevity over grammatical correctness
- Inappropriate Medium
- Tedious/expensive configuration

Backing out of the problem...

Jaime G. Carbonell: "Is There Natural Language after Data Bases?" COLING 1984: 186-187

- Symantex started with Q&A!, but now does virus protection
- Computational Linguistics went in a different direction:
  - Statistical/Probabilistic NLP
  - Lexical Semantics (POS tagging)
  - Information Extraction
  - ...

Why now?

- Lexical databases! (WordNet)
- Mature relational database technology
- Fast theorem provers
- Web-based evaluation
- Statistical parsers (modifier attachment)
- Ontologies
- Speech recognition always improving
- ...

Recent Work

- Microsoft English Query (1999)
  - \+ authoring wizards
  - – no paraphraser, no response generator, no update query support
  - – failed...
- PRECISE (2003)

  reduces semantic analysis to a graph matching problem

  works for limited class of so called *semantically tractable queries*
  - \+ requires very little configuration
  - \+ leverages domain independent grammars
  - \+ they put up a web interface!
  - – not clear how to address more expressive queries
  - – no paraphraser
  - – they took away web interface!
- STEP (2004-?)

PRECISE (2003) *Simplified*

D: a dictionary of words (or word sequences) (e.g. D = 'aardvark',...)
W : wh-words 'who', 'what',...
F : function words 'a', 'the', 'in'...

$E = E_r \cup E_a \cup E_v$: a set of database elements (relations, attributes and values)

$N \subseteq E \times D$: a binary naming relation

$N_w \subseteq N$: a set of appropriate wh-words paired with relations and attributes,
$N_w \subseteq E_r \cup E_a \times W$).

P: part of relation $P(E, E') \subseteq E \times E$ (e.g. an attribute is part of a relation, a value is part of a attribute)

PRECISE(2003)

$Parse(w_1, ..., w_m) \rightarrow (T, AT)$ where T is a set of tokens ($T \subseteq D$) and AT is a binary relation over T.

Function words in $w_1, ..., w_m$ are stripped from word sequence: $F \cap T = \emptyset$

AT denotes syntactic attachment and is obtained from a domain independent grammar (currently Charniak's parser)

A matching M of T to E is a pairing of every token $t \in T$ with some entity $e \in E$ such that $(e, t) \in N$.

M is *valid* if for all $(t, e) \in M$:

if $(t, e) \in M$ where $e \in E_a \cup E_v$ then some $(t', e') \in M$ where $P(e, e')$ and $AT(t, t')$

W is semantically tractable iff there exists a valid matching for $Parse(W) = (T, A)$ where there is at least one token $t \in W$

"Theorem 1. PRECISE is sound and complete for any semantically tractable question."

Let's evaluate this claim...

STEP (2004-)

- Uses a phrasal lexicon:
  - a type of highly structured semantic grammar
  - tools help rapid authoring
  - customization of phrases
- Includes a query paraphraser
- Enables natural language based database updates
- Has captured 1000s of geography queries

Would like to say more, but don't have the time...

Evaluation

- Benchmark studies:

  human built 'gold standard' of NL sentences/logical queries pairs (possibly obtained through "WOz" studies)

  \+ Can set a bar on the expressivity of queries (see Copeskate and Spark Jones, 1990)

  – Hard to trust accuracy reports

- Task-based studies:

  Compare performance of approaches for a given task

  \+ Randomized experiments (via web)

  – Lots of subjective interpretation of results

  – Requires full fledged prototype

- Fielded systems studies:

  \+ Web interface to satisfy real needs!

  \+ Capture real queries

  – Still looking for winner! How about BASEBALL?

  – Requires product level robustness

Conclusions

- NL interfaces to databases is an important, though currently understudied area
- It is critical to work over standard *relational* databases
- It is critical to paraphrase queries
- Dialectic between Semantic Grammars and Transportable Systems
- Advances of the past 15-20 years in computational linguistics/databases can impact this area
- STEP represents a comprehensive, semantic grammar based approach under active development