TECHNISCHE UNIVERSITÄT DRESDEN

DRESDEN concept

Faculty of Computer Science Chair of Automata Theory

ONTOLOGY REASONING FOR COMPLEX EVENT RECOGNITION

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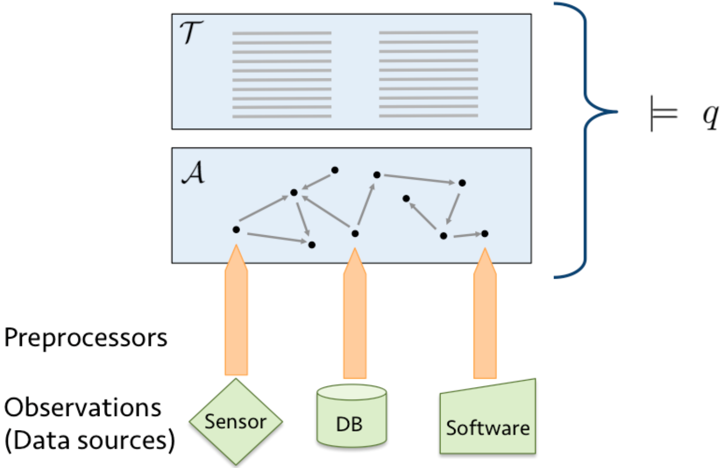
Before we start . . .

. . . a bit about myself

- Senior research and teaching fellow ("Privatdozent") at TU Dresden, Institute for Theoretical Computer Science
- Research interest:
  "Investigate reasoning services for formal ontology languages by methods from theoretical computer science"
- PI in several KR&R-related research projects
- service to the community:
  - WS co-chair of conferences: KI'15, KR'20
  - PC co-chair of conferences: JIST'17, KI'18
- RuleML+RR & me:
  - PC member: '17, '18, '19, '21
  - runner-up best paper award: 2019

A general view on ontology-based complex event recognition



Challenges for ontology-based complex event recognition

...can be addressed by which **DL extensions**?

• incomplete information use of standard assumptions	Defeasible DLs
• uncertain knowledge apply probabilities	Probabilistic DLs
• vague information admit vague queries	Relaxed queries
• contradicting information inconsistency-tolerant reasoning	Reasoning under repair semantics
• temporal modeling employ temporal reasoning	Temporalized DLs

DL KBs and DL reasoning

Concept descriptions

- are built from named concepts and roles
- by concept constructors (and role constructors) available in the DL

  E.g. by use of conjunction ($\sqcap$) and existential restriction ($\exists r.C$) :
  $\mathit{Person} \sqcap \exists \mathit{suffers\text{-}from}.\mathit{Disease}$

DL knowledge bases: and DL reasoning

TBox $\mathcal{T}$	ABox $\mathcal{A}$
$\vdots$	$\mathit{Person}(\mathit{bob})$
$\mathit{Patient} \sqsubseteq \mathit{Person} \sqcap \exists \mathit{suffers\text{-}from}.\mathit{Disease}$	$\mathit{Disease}(\mathit{cooties})$
$\vdots$	$(\mathit{bob}, \mathit{cooties})\mathit{suffers\text{-}from}$

Query types: subsumption $\mathit{Patient} \sqsubseteq \mathit{Disease}$
instance query $\mathit{Patient}(x)$
conjunctive query $\phi(x_1, \ldots, x_n) : \exists y_1, \ldots y_m.\mathit{Disease}(x_1) \wedge \ldots$

Dealing with incomplete (and contradictory) information

Defeasible DLs (DDLs)

- augment the KB by defeasible axioms
  - handle incomplete information by "standard assumptions"

    E.g.: $\mathit{Patient} \mathrel{\underset{\sim}{\sqsubset}} \exists \mathit{has\text{-}organ}.(\mathit{Heart} \sqcap \exists \mathit{located}.\mathit{LeftSide})$

  - can be "overridden" by contradicting information regarding exceptional instances

- reasoning in DDLs:
  - non-monotonic: old consequences obsolete under added information
  - can handle contradictory information gracefully!

Approaches for reasoning in Defeasible DLs . . .

By materialization

- subsumption queries $A \sqsubseteq B$:
  defeasible axioms used as material implications for A
- suffers from: quantification neglect
  defeasible information “omitted” for quantified objects $\leadsto$ propositional behavior

New approach: typicality models for $\mathcal{EL}_\bot$ [Pensel-Turhan-LPNMR-19], [Pensel-Turhan-IJAR-20]

- Idea: use the structure generated by reasoning in classical $\mathcal{EL}$ (canonical model) and “copy” its domain
- yields model-based semantics!
- reasoning algorithms for subsumption and instance checking by reduction to classical reasoning (+ complexity investigation)
- approach alleviates quantification neglect!

Dealing with contradictory information in temporal CQA

Reasoning under repair semantics:
Restore contradiction free versions of the KB and reason w.r.t. those.

ABox repair: in temporal setting:
maximal subset of the time-stamped data consistent with the TBox

There can be exponentially many repairs!

Different kinds of repair semantics:

- Brave semantics: reasoning w.r.t. one repair
- all ABox repair semantics (AR): reasoning w.r.t. all repairs
- intersection ABox repair semantics (IAR): reasoning w.r.t. the intersection of all repairs

IAR-answers $\subseteq$ AR-answers $\subseteq$ brave-answers

Temporal behavior of predicates: rigid / non-rigid (flexible over time)

Our results for inconsistency-tolerant temporal CQA

[Bourgaux-Koopmann-Turhan-SemWebJ-19]

We have explored the complexity landscape for:

$\{$brave, AR, IAR$\} \times \{\mathcal{EL}$, DL-Lite$\} \times \{$no rigid, rigid concepts, rigid concepts & roles$\}$

in regard of

- combined complexity (TBox, ABox and query are input)
- data complexity (ABox is input)

Lessons learned:

- Effect of temporal reasoning: increases data complexity
- choice of the repair semantics (brave, AR or IAR):
  - no increase for brave (compared to classical semantics) for combined complexity
  - IAR is always "cheapest" among the three repair semantics

Dealing with vagueness and imprecision by relaxed queries

Relaxed queries (a.k.a. queries under approximate semantics)

- retrieve tuples "similar" to classical answers
  complex event recognition: detect situations "close" to a critical one
- useful when exact query is hard to formalize
- closely related to top-*k* queries

Advantages of relaxing queries for DLs:

- user-defined and query specific notion of similarity
- DL KB stays classical

Investigated query types and approaches to model similarity:

1. instance queries by concept similarity measures
2. regular path queries by weighted transducers

Relaxing concepts by concept similarity measures

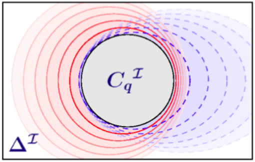
Concept similarity measures (CSM) := yield for a pair of concepts a value from [0,1]

- higher value indicates higher similarity
- used in ontology-based life science applications
- "well-behaved" CSMs: fulfill formal properties
  — constructed for $\mathcal{EL}$ in [Lehmann-Turhan-JELIA-12]

Relaxed instance queries

Individual a is relaxed instance of C_q w.r.t. $\mathcal{K}$, csm and t, iff there exists a concept description D s.t.

- $csm(C_q, D) \geq t$ and
- $D(a)$ holds w.r.t. $\mathcal{K}$



Results: [Ecke-Peñaloza-Turhan-KR-12, Ecke-Peñaloza-Turhan-IJAR-13]

- answering relaxed instance queries in $\mathcal{EL}$ in non-deterministic polynomial time
- algorithm implemented in ELASTIQ reasoner

Relaxing conjunctive two-way regular path queries

Query language: conjunctive two-way regular path queries

- retrieves *k*-tuples from labeled graph
- path query: regular language (specified by NFA)
- part of standardized ontology query language SPARQL

Notion of similarity:

- "distortion cost" of transforming data path word into query path word
- computed by a weighted transducer

Results: [FernándezGil-Turhan-AAAI-21]

- complexity of query entailment w.r.t. a threshold for the cost in lightweight DLs: $\mathcal{EL}$, DL-Lite
- complexity does *not* increase compared to classical semantics

Other research interests

- example-driven learning of concepts
  generate concepts (and queries) from positive examples
- reasoning in DLs with concrete domains
  concepts can refer to values (e.g. numbers) and predicates over these values
- ontology-mediated probabilistic model checking
  - combining verification technique with ontology reasoning
  - enhancing states of stochastic programs by information from ontologies