Containment of Conjunctive Object Meta-Queries

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F-Logic (Frame-Logic)

F-Logic

- object-oriented formalism [Kifer & Lausen, JACM 1985]
- raised interest in the academia and commercially
  - building ontologies
  - reasoning in the Semantic Web
- meta-querying capability
- we will use a subset of F-Logic queries called **F-Logic-Lite**

Restrictions in F-Logic Lite

- no negation
- no default inheritance
- limited form of cardinality constraints

Query containment

- Well known problem in:
  1. query optimisation
  2. schema integration
  3. object classification (in DLs)
  4. service discovery
  5. . . .
- amounts to check whether the result of a query is always contained in the result of another, for all databases

Query containment under constraints

- QC considering only databases that satisfy certain constraints
- relevant cases:
  1. functional and inclusion dependencies
  2. extended ER schemata
  3. Description Logic knowledge bases

Our contribution

1. we give a relational encoding of F-Logic Lite
   - axioms in first-order rules
2. we consider containment of conjunctive meta-queries over relations encoding F-Logic Lite under the above rules
3. we provide a technique to decide query containment in such a case
4. we prove that checking containment is in NP

Outline

F-Logic formalism by examples

Classes, subclasses and members

- `john:student` states that object `john` is a member of class `student`;
- `freshman::student` and `student::person` state that class `freshman` is a subclass of the class `student` and `student` is a subclass of `person`

The above statements imply, for instance, that the following F-Logic formulae are true:

1. `john:person` (`john` is a student)
2. `freshman::person` (class `freshman` is a subclass of `person`)

F-Logic formalism by examples (contd.)

Attributes

- `john[age->33]` means that object `john` has an attribute, age, whose value is 33;
- an attribute may have more than one value

F-Logic formalism by examples (contd.)

Signature statements: type constraints

- `person[age*=>number]` (type constraint) says that the attribute age of class `student` has the type `number`
- this type is inherited by subclasses and class instances of `person`
- this acts as a constraint on the statements of the form `john[age->33]`

F-Logic formalism by examples (contd.)

Signature statements: cardinality constraints

- `person[age {0:1} *=> number]` says that the attribute age has at most one value
- `person[name {1:*} *=> string]` says that the name attribute is mandatory in class `person`

A F-Logic feature

Classes are also objects

- statements like `student:class` are correct
- in this case `students` occurs as an object instead of a class
- it does not follow from this and the previous statements that `john:class`, `freshman:class`, or `student::class`

Meta-queries examples

- Query `?- X::person.` could have answers `X = employee` and `X = student`
- Query `?- student[Att*=>string].` could have answers `Attr = name` and `Attr = major`
- Query `?- student[Att*=>string], john[Att->Val].` asks for attributes of class `student` of type `string` that have a defined value for object `john`;
  - `john` does not need to be a member of `student`

Meta-query Containment

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Consider the meta-queries:

```
q1(A,B) :- T1[A*=>T2], T2::T3, T3[B*=>_].
q2(A,B) :- T1[A*=>T2], T2[B*=>_].
```

- q1 asks for pairs of attributes A,B s.t. the range of A is contained in the domain of B
- it is easy to see that q1 is contained in q2

Low-level encoding of F-Logic Lite

- member(O, C): object O is a member of class C. This is the encoding for $O : C$.
- sub(C_1, C_2): class C_1 is a subclass of class C_1. This encodes the statement $C_1 :: C_2$.
- data(O, A, V): attribute A has value V on object O. This is the encoding for $O[A\text{->}V]$.
- type(O, A, T): attribute A has type T for object O (recall that in F-logic classes are also objects). This encodes the statements of the form $O[A{*}{=}{>}T]$.
- mandatory(A, O): attribute A is mandatory for object (class) O, i.e., it must have at least one value for O. This is an encoding of statements of the form $O[A\{1{:}*\}{*}{=}{>}\_]$.
- funct(A, O): A is a functional attribute for the object (class) O, i.e., it can have at most one value for O. This statement encodes $O[A\{0{:}1\}{*}{=}{>}\_]$.

Axioms

Type correctness

$\mathrm{member}(V, T)\ \texttt{:-}\ \mathrm{type}(O, A, T), \mathrm{data}(O, A, V)$

Subclass transitivity

$\mathrm{sub}(C_1, C_2)\ \texttt{:-}\ \mathrm{sub}(C_1, C_3), \mathrm{sub}(C_3, C_2)$

Membership property

$\mathrm{member}(O, C_1)\ \texttt{:-}\ \mathrm{member}(O, C), \mathrm{sub}(C, C_1)$

Functional attribute property

$V = W\ \texttt{:-}\ \mathrm{data}(O, A, V), \mathrm{data}(O, A, W), \mathrm{funct}(A, O).$
Notice that the equality predicate is used in the head.

Axioms (contd.)

Mandatory attributes definition

$\forall O, A\ \exists V\ \text{data}(O, A, V)\ \text{:-}\ \text{mandatory}(A, O)$

Notice that this is not a Datalog rule: there is an existentially quantified variable in the head

Inheritance of types from classes to members

$\text{type}(O, A, T)\ \text{:-}\ \text{member}(O, C), \text{type}(C, A, T)$

Inheritance of types from classes to subclasses

$\text{sub}(C, C_1), \text{type}(C_1, A, T)$

Supertyping

$\text{type}(C, A, T)\ \text{:-}\ \text{type}(C, A, T_1),\ \text{sub}(T_1, T)$

Axioms (contd.)

Inheritance of mandatory attributes to subclasses

$$\mathrm{mandatory}(A, C) \;\text{:-}\; \mathrm{sub}(C, C_1), \mathrm{mandatory}(A, C_1)$$

Inheritance of mandatory attributes from classes to their members

$$\mathrm{mandatory}(A, O) \;\text{:-}\; \mathrm{member}(O, C), \mathrm{mandatory}(A, C)$$

Inheritance of functional property to subclasses

$$\mathrm{funct}(A, C) \;\text{:-}\; \mathrm{sub}(C, C_1),\ \mathrm{funct}(A, C_1)$$

Inheritance of functional property to members

$$\mathrm{funct}(A, O) \;\text{:-}\; \mathrm{member}(O, C), \mathrm{funct}(A, C)$$

Meta-query containment

- We denote the set of rules by Σ_{FL}
- Meta-queries are conjunctive queries over the predicates encoding our formalism
- Given two (meta)-queries q_1 and q_2, we say that q_1 is contained in q_2 with respect to Σ_{FL}, denoted $q_1 \subseteq_{\Sigma_{FL}} q_2$, if for every database B that satisfies Σ_{FL} we have $q_1(B) \subseteq q_2(B)$
  - $q(B)$ denotes the result of query q on B

Chasing queries

- Axioms that encode F-Logic Lite are tuple-generating dependencies (TGDs) and equality-generating dependencies (EGDs)
- Chase for such classes of queries is known [Fagin et al. ICDT 2003]
- Chasing wrt a TGD generates a new conjunct in the query
- Chasing wrt an EGD equals two symbols (a variable and a constant or two variables)
  - the chase fails if chasing wrt an EGD equals two constants

Chasing and chase graph: example

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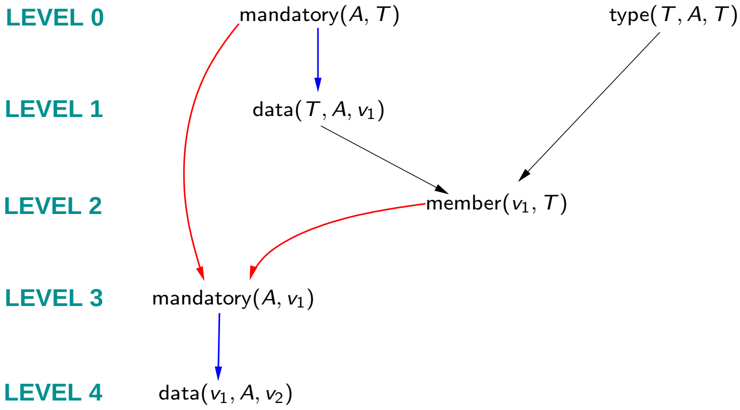
Query to chase

$q()$:- mandatory(A, T), type(T, A, T)



Property of the chase

This is derived from [Fagin et al. ICDT 2003]

Theorem

Given two conjunctive meta-queries q_1 and q_2, we have $q_1 \subseteq_{\Sigma_{FL}} q_2$ if and only if there exists a homomorphism that sends the conjuncts of $body(q_2)$ to conjuncts in $chase_{\Sigma_{FL}}(q_1)$ and $head(q_2)$ to $head(chase_{\Sigma_{FL}}(q_1))$

- $chase_{\Sigma_{FL}}(q_1)$ is the chase of q_1 wrt Σ_{FL}
- a homomorphism is a function that sends constants into themselves (and variables to variables or constants), preserving the structure of the predicates
- $head(chase_{\Sigma_{FL}}(q_1))$ is the head of q_1, possibly altered by chasing q_1

Observations

- Due to an existentially quantified variable in the head of one of the rules, the chase might be infinite
- The previous property does not provide an angorithm for deciding containment
- **Plan of attack:**
  1. prove that if there is a homomorphism from q_2 to $chase_{\Sigma_{FL}}(q_1)$ with the desired properties, there is another from q_2 to a finite segment of $chase_{\Sigma_{FL}}(q_1)$
  2. provide an upper bound (max no. of levels) for the above segment, depending on the queries
  3. show that we can check containment by guessing a homomorphism from q_2 to the finite segment

How to construct the chase

- First we chase wrt all rules except for the one that "invents" a fresh value ($\exists$ in the head)
- We consider all the conjuncts obtained in this way as a new query (level 0)
- Then, we chase such query
- ... all this for technical reasons

Infinite chase

The only way to have an infinite chase is to have in q_1 a set of conjuncts of the form

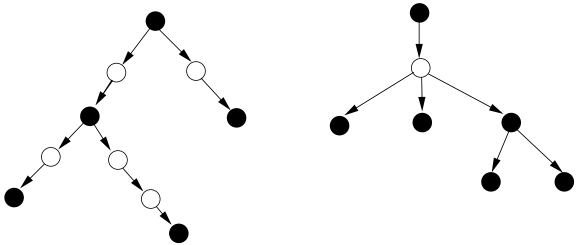
$$
\begin{array}{l}
\mathrm{mandatory}(A_1, T_1) \\
\mathrm{type}(T_1, A_1, T_2) \\
\ldots \\
\mathrm{mandatory}(A_{k-1}, T_{k-1}) \\
\mathrm{type}(T_{k-1}, A_{k-1}, T_k) \\
\mathrm{mandatory}(A_k, T_k) \\
\mathrm{type}(T_k, A_k, T_1)
\end{array}
$$

Locality of the chase

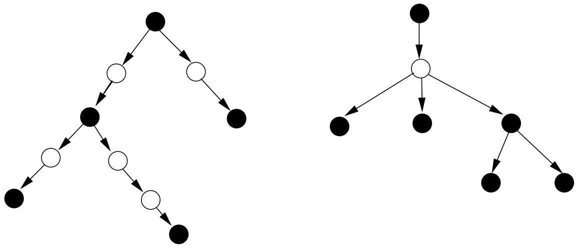
- In the chase woth TGDs, conjuncts are added according to more than one existing conjuncts
- However, the chase enjoys **locality** properties:
  - conjuncts at level 0 act as a map, driving the chase
  - every added conjunct is due to a conjunct at level 0 and another (with minor exceptions)
  - if we consider only the latter, we have **paths** in the graph as for IDs; such paths are called primary
  - Due to the application of some rules, primary paths may branch

Proving decidability

- Assume there is a homomorphism μ from q_2 to $chase_{\Sigma_{FL}}(q_1)$ with the desired properties
- Consider a graph (forest) of the image of q_2 wrt μ, considering the primary paths among them and the conjuncts where branching happens



Proving decidability (contd.)



Regularity

- Primary paths evolve according to “regular” patterns
- Therefore, it is possible to excise the paths between adjacent nodes until they cover $2 \cdot |q_1|$ levels or less
- after every excision, the obtained conjuncts are still the image of q_2 wrt some homomorphism

Proving decidability (contd.)

Main result

Consider queries q_1, q_2; if there is a homomorphism from q_2 to $chase_{\Sigma_{FL}}(q_1)$ with the desired properties, there is another from q_2 to a set of conjuncts in $chase_{\Sigma_{FL}}(q_1)$ such that none of these conjuncts is at level greater than $2 \cdot |q_1|$

Complexity: upper bound

Theorem

Checking containment of F-Logic Lite meta-queries can be decided by a nondeterministic algorithm that runs in polynomial time in $|q_1|$ and $|q_2|$

Proof by guessing $|q_2|$ conjuncts in the first $2 \cdot |q_1|$ levels of $chase_{\Sigma_{FL}}(q_1)$

Conclusions

Wrap-up

- F-Logic is a popular tool for building ontologies
- We considered a relevant subset called F-Logic Lite
- Relational encoding
- Meta-query containment by chasing
- Complexity result

Future work

- Tight lower complexity bound
- More expressive query languages
- Finding a more general class of queries for which the same techniques apply