Conceptual schemas and ontologies for database access: myths and challenges

KRDB Research Centre
Knowledge Representation meets DataBases

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Summary

- What is an Ontology
- Description Logics for Conceptual Modelling
- Queries via a Conceptual Schema

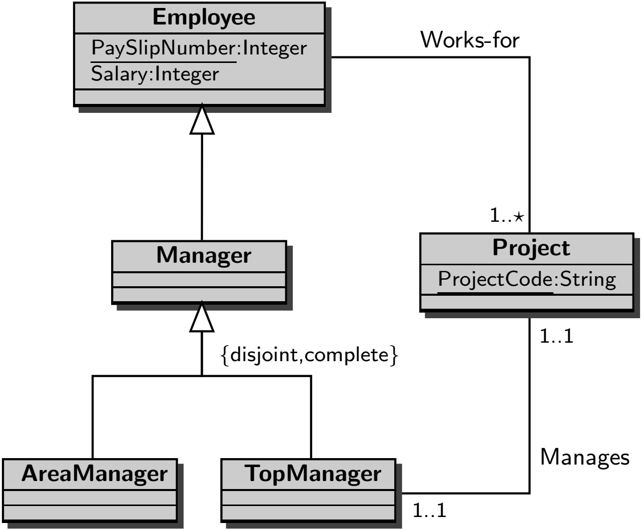
What is an Ontology

- An ontology is a formal conceptualisation of the world: a conceptual schema.
- An ontology specifies a set of constraints, which declare what should necessarily hold in any possible world.
- Any possible world should conform to the constraints expressed by the ontology.
- Given an ontology, a *legal world description* is a finite possible world satisfying the constraints.

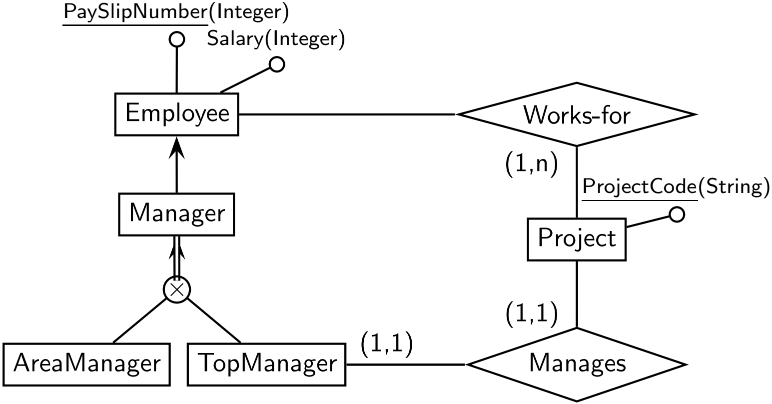
Ontologies and Conceptual Data Models

- An ontology language usually introduces concepts (aka classes, entities), properties of concepts (aka slots, attributes, roles), relationships between concepts (aka associations), and additional constraints.
- Ontology languages may be simple (e.g., involving only concepts and taxonomies), frame-based (e.g., UML, based on concepts, properties, and binary relationships), or logic-based (e.g. OWL, Description Logics).
- Ontology languages are typically expressed by means of diagrams.
- Entity-Relationship schemas and UML class diagrams can be considered as ontologies.

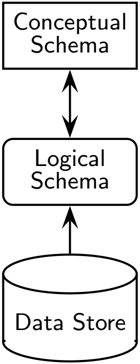
UML Class Diagram



Entity-Relationship Schema



The role of a Conceptual Schema



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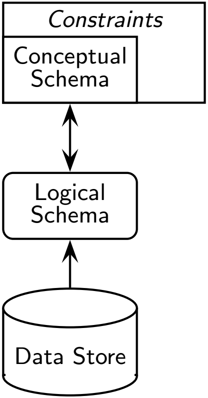

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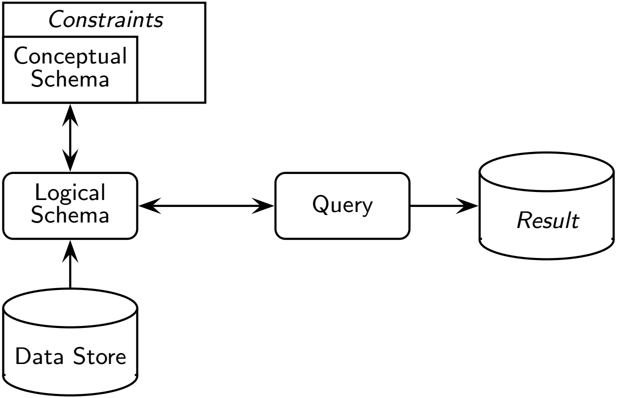

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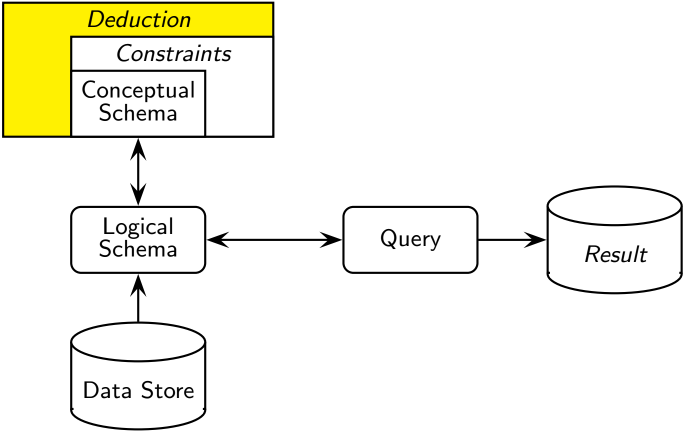
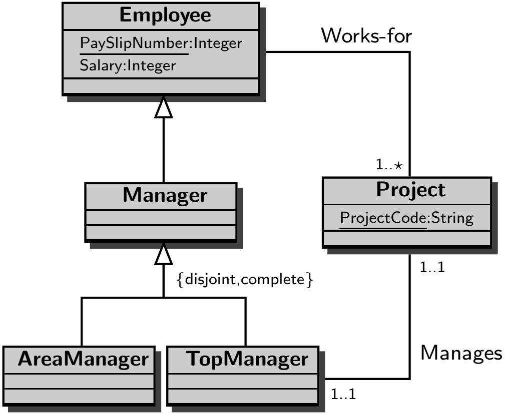
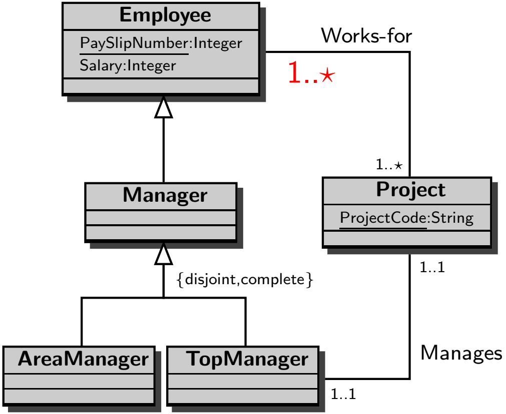


Reasoning with Conceptual Schemas



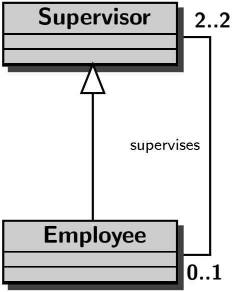
- Managers do not work for a project (she/he just manages it):
  $\forall x. \texttt{Manager}(x) \rightarrow \forall y. \neg \texttt{WORKS-FOR}(x, y)$

Reasoning with Conceptual Schemas



- Managers do not work for a project (she/he just manages it):
  $\forall x. \texttt{Manager}(x) \rightarrow \forall y. \neg \texttt{WORKS-FOR}(x, y)$
- If the minimum cardinality for the participation of employees to the *works-for* relationship is increased, then ...

Infinite Domain: the democratic company



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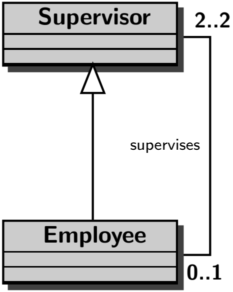
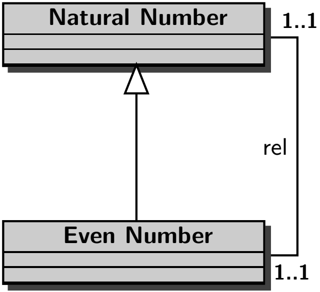


implies
"the classes Employee and Supervisor necessarily contain an infinite number of instances".

Since legal world descriptions are *finite* possible worlds satisfying the constraints imposed by the conceptual schema, the schema is inconsistent.

Bijection: how many numbers



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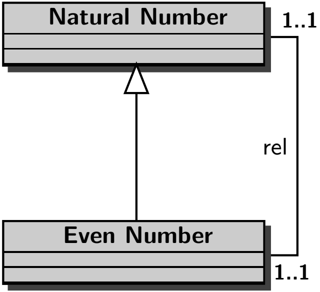

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"the classes Natural Number and Even Number contain the same number of instances".

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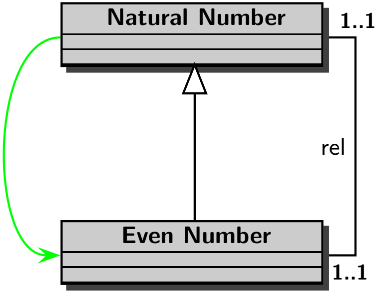

implies
"the classes Natural Number and Even Number contain the same number of instances".

Only if the domain is finite: Natural Number $\equiv$ Even Number

Summary

- Logic and Conceptual Modelling
- Description Logics for Conceptual Modelling
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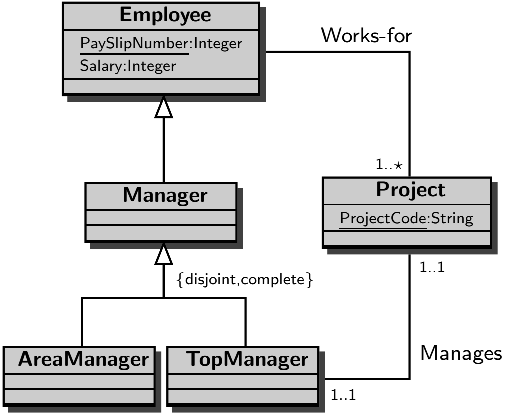
Encoding Conceptual Schemas in (Description) Logics

- Object-oriented data models (e.g., UML and ODMG)
- Semantic data models (e.g., EER and ORM)
- Frame-based and web ontology languages (e.g., DAML+OIL and OWL)

Encoding Conceptual Schemas in (Description) Logics

- Object-oriented data models (e.g., UML and ODMG)
- Semantic data models (e.g., EER and ORM)
- Frame-based and web ontology languages (e.g., DAML+OIL and OWL)
- Theorems **prove** that a conceptual schema and its encoding as DL knowledge bases constrain every world description in the same way – i.e., the models of the DL theory correspond to the legal world descriptions of the conceptual schema, and vice-versa.

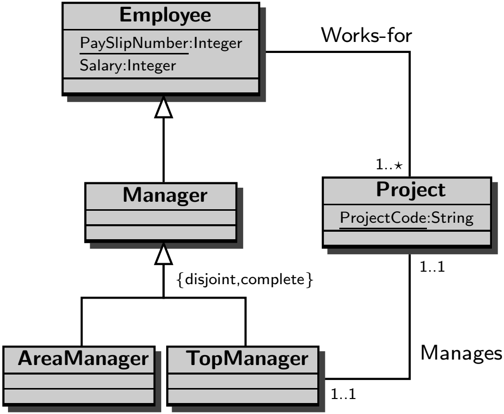


$$
\begin{array}{lcl}
\texttt{Works-for} & \sqsubseteq & \texttt{emp}/2 : \texttt{Employee} \sqcap \texttt{act}/2 : \texttt{Project} \\
\texttt{Manages} & \sqsubseteq & \texttt{man}/2 : \texttt{TopManager} \sqcap \texttt{prj}/2 : \texttt{Project} \\
\texttt{Employee} & \sqsubseteq & \exists^{=1}[\texttt{worker}](\texttt{PaySlipNumber} \sqcap \texttt{num}/2 : \texttt{Integer}) \sqcap \\
 & & \exists^{=1}[\texttt{payee}](\texttt{Salary} \sqcap \texttt{amount}/2 : \texttt{Integer}) \\
\top & \sqsubseteq & \exists^{\leq 1}[\texttt{num}](\texttt{PaySlipNumber} \sqcap \texttt{worker}/2 : \texttt{Employee}) \\
\texttt{Manager} & \sqsubseteq & \texttt{Employee} \sqcap (\texttt{AreaManager} \sqcup \texttt{TopManager}) \\
\texttt{AreaManager} & \sqsubseteq & \texttt{Manager} \sqcap \neg\texttt{TopManager} \\
\texttt{TopManager} & \sqsubseteq & \texttt{Manager} \sqcap \exists^{=1}[\texttt{man}]\texttt{Manages} \\
\texttt{Project} & \sqsubseteq & \exists^{\geq 1}[\texttt{act}]\texttt{Works-for} \sqcap \exists^{=1}[\texttt{prj}]\texttt{Manages} \\
\ldots & &
\end{array}
$$

Set-based Constraints

$$\text{Works-for} \subseteq \text{Employee} \times \text{Project}$$
$$\text{Manages} \subseteq \text{TopManager} \times \text{Project}$$
$$\text{Employee} \subseteq \{e \mid \sharp(\text{PaySlipNumber} \cap (\{e\} \times \texttt{Integer})) \geq 1\}$$
$$\text{Employee} \subseteq \{e \mid \sharp(\text{Salary} \cap (\{e\} \times \texttt{Integer})) \geq 1\}$$
$$\text{Project} \subseteq \{p \mid \sharp(\text{ProjectCode} \cap (\{p\} \times \texttt{String})) \geq 1\}$$
$$\text{TopManager} \subseteq \{m \mid 1 \geq \sharp(\text{Manages} \cap (\{m\} \times \Omega)) \geq 1\}$$
$$\text{Project} \subseteq \{p \mid 1 \geq \sharp(\text{Manages} \cap (\Omega \times \{p\})) \geq 1\}$$
$$\text{Project} \subseteq \{p \mid \sharp(\text{Works-for} \cap (\Omega \times \{p\})) \geq 1\}$$
$$\text{Manager} \subseteq \text{Employee}$$
$$\text{AreaManager} \subseteq \text{Manager}$$
$$\text{TopManager} \subseteq \text{Manager}$$
$$\text{AreaManager} \cap \text{TopManager} = \emptyset$$
$$\text{Manager} \subseteq \text{AreaManager} \cup \text{TopManager}$$

Deducing constraints



Managers are employees who do not work for a project (she/he just manages it):

$\texttt{Employee} \sqcap \neg(\exists^{\geq 1}[\texttt{emp}]\texttt{Works-for}) \sqsubseteq \texttt{Manager}, \quad \texttt{Manager} \sqsubseteq \neg(\exists^{\geq 1}[\texttt{emp}]\texttt{Works-for})$

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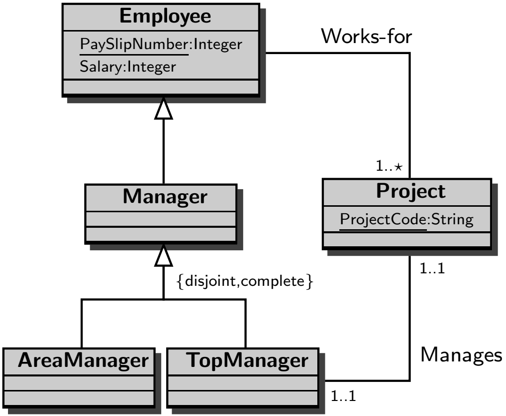

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$\models$ For every project, there is at least one employee who is not a manager:
$\texttt{Project} \sqsubseteq \exists^{\geq 1}[\texttt{act}](\texttt{Works-for} \sqcap \texttt{emp} : \neg\texttt{Manager})$

i•com: **Intelligent Conceptual Modelling**

- i•com allows for the specification of multiple EER (or UML) diagrams and inter- and intra-schema constraints;
- Complete logical reasoning is employed by the tool using a hidden underlying $\mathcal{DLR}$ inference engine;
- i•com verifies the specification, infers implicit facts and stricter constraints, and manifests any inconsistencies during the conceptual modelling phase.

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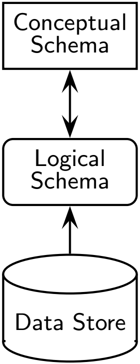

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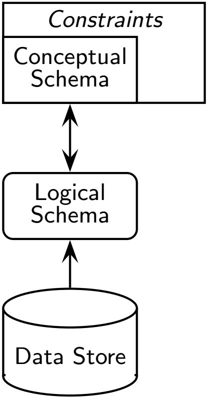

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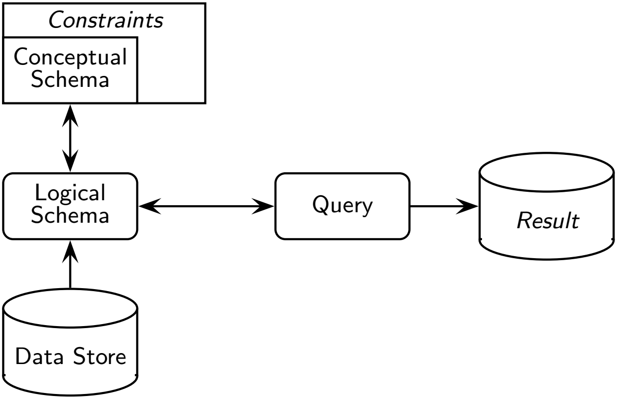

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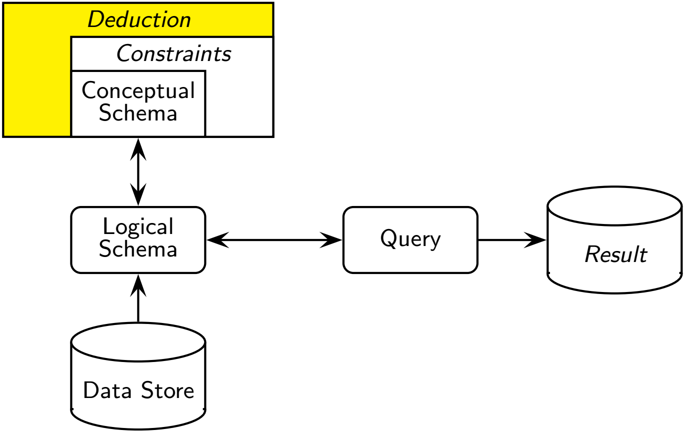

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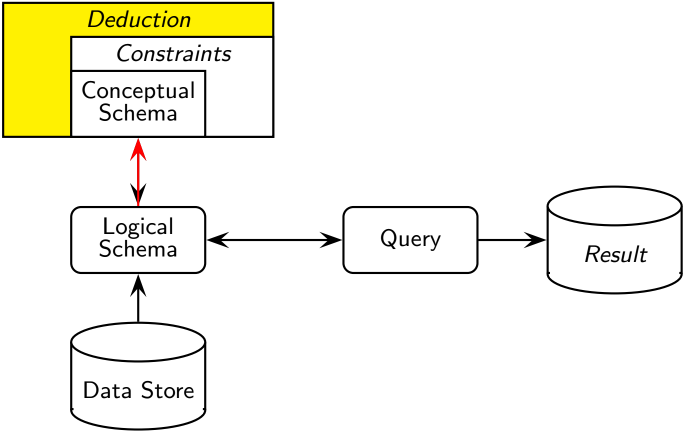

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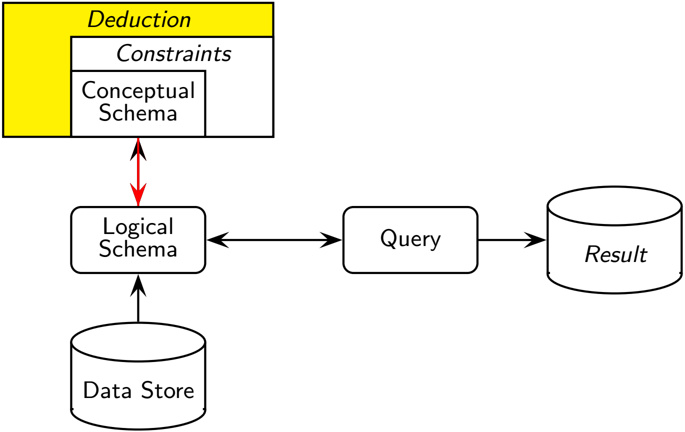

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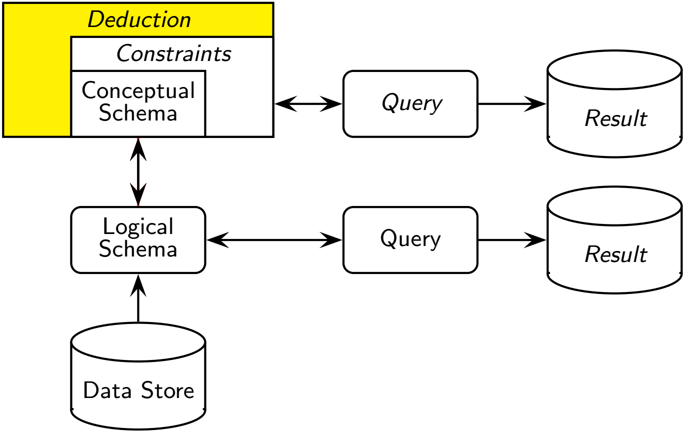

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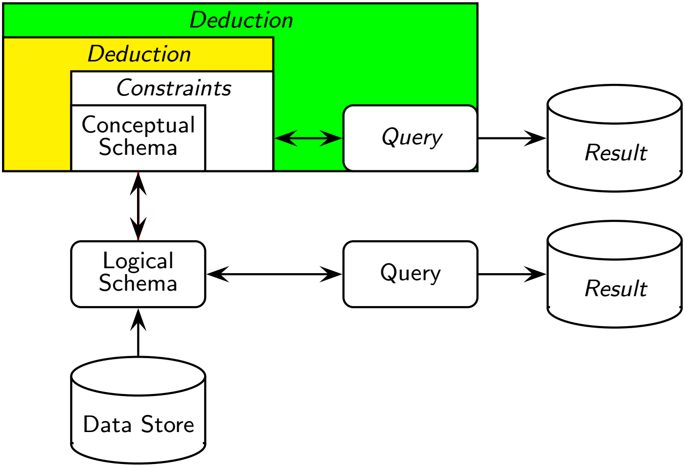

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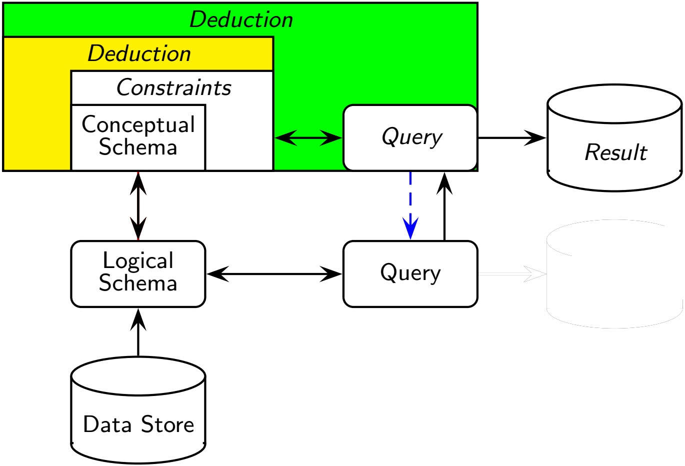

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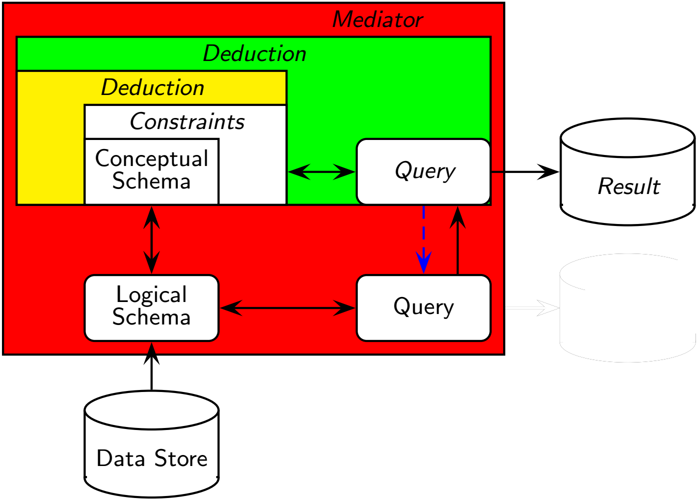

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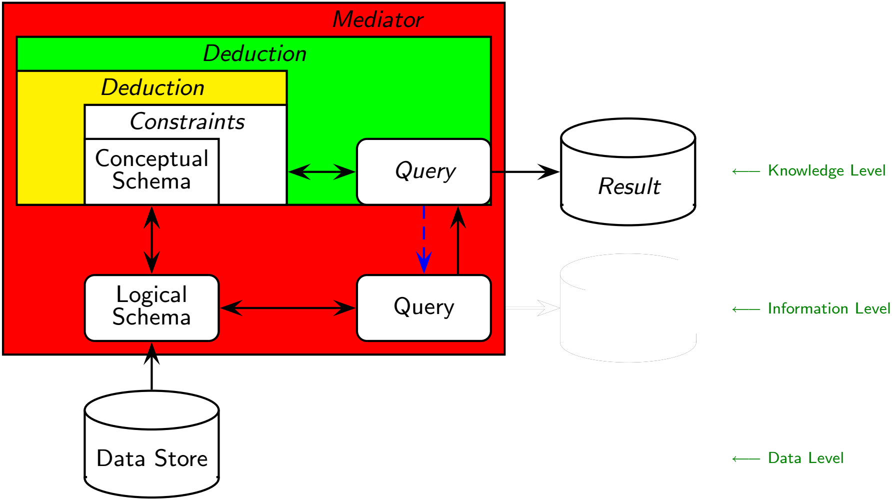

Queries via Conceptual Schemas: the DB assumption

- Basic assumption: consistent information with respect to the constraints introduced by the conceptual schema
- DB assumption: complete information about each term appearing in the conceptual schema
- *Problem*: answer a query over the conceptual schema vocabulary

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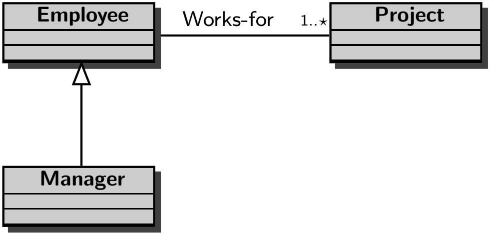
- Basic assumption: consistent information with respect to the constraints introduced by the conceptual schema
- DB assumption: complete information about each term appearing in the conceptual schema
- *Problem*: answer a query over the conceptual schema vocabulary
- *Solution*: use a standard DB technology (e.g., SQL, datalog, etc)

Example with DB assumption



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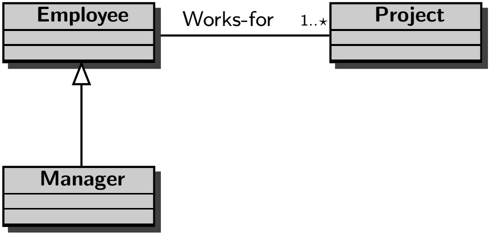

Employee = { John, Mary, Paul }
Manager = { John, Paul }
Works-for = { ⟨John,Prj-A⟩, ⟨Mary,Prj-B⟩ }
Project = { Prj-A, Prj-B }

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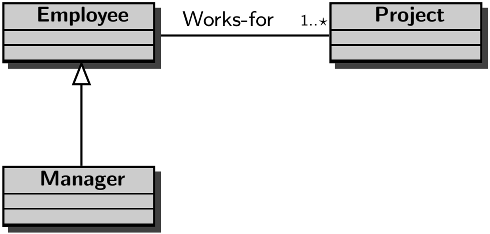

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Project = { Prj-A, Prj-B }

Q(X) :- Manager(X), Works-for(X,Y), Project(Y)
$\Longrightarrow$ { John }

Weakening the DB assumption

- The DB assumption is against the principle that a conceptual schema presents a richer vocabulary than the data stores (i.e., it plays the role of an ontology).

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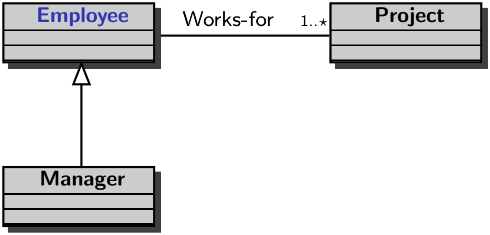
- The DB assumption is against the principle that a conceptual schema presents a richer vocabulary than the data stores (i.e., it plays the role of an ontology).
- Partial DB assumption: complete information about *some* term appearing in the conceptual schema
- Standard DB technologies do not apply
- The query answering problem in this context is inherently complex

Example with partial DB assumption



Manager = { John, Paul }

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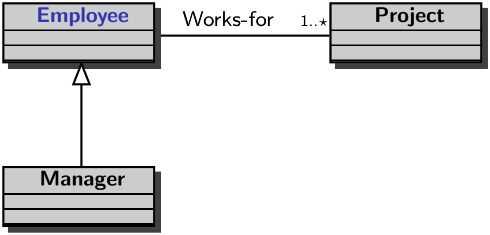
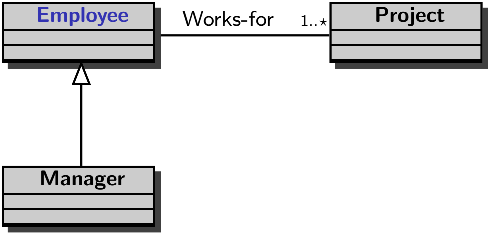



```
Manager = { John, Paul }
Works-for = { ⟨John,Prj-A⟩, ⟨Mary,Prj-B⟩ }
Project = { Prj-A, Prj-B }

Q(X) :- Employee(X)
```

Example with partial DB assumption



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Q(X) :- Employee(X)
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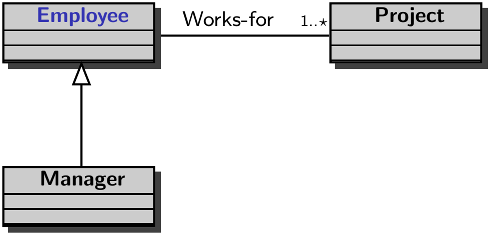
Example with partial DB assumption

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Q(X) :- Employee(X)
⟹ { John, Paul, Mary }

⟹      Q'(X) :- Manager(X) ∪ Works-for(X,Y)
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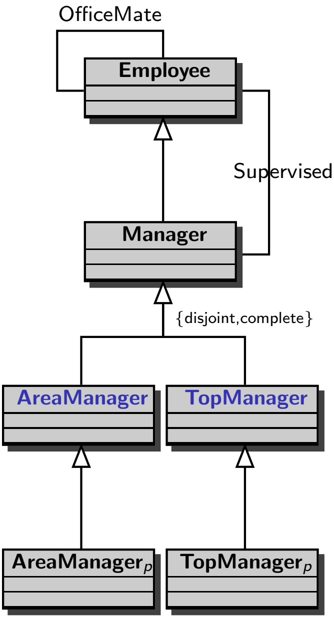
Andrea's Example



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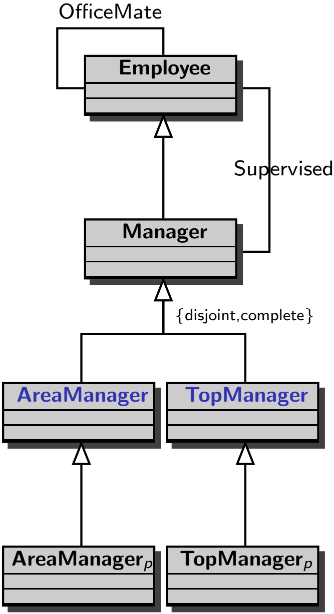
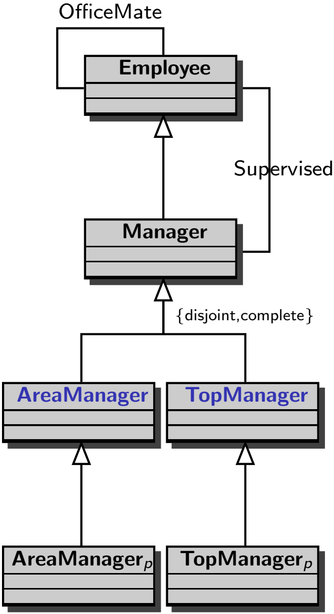



```
Employee = { Andrea, Paul, Mary, John }
Manager = { Andrea, Paul, Mary}
AreaManager_p = { Paul }
TopManager_p = { Mary }
Supervised = { ⟨John,Andrea⟩, ⟨John,Mary⟩ }
OfficeMate = { ⟨Mary,Andrea⟩, ⟨Andrea,Paul⟩ }
```

Andrea's Example



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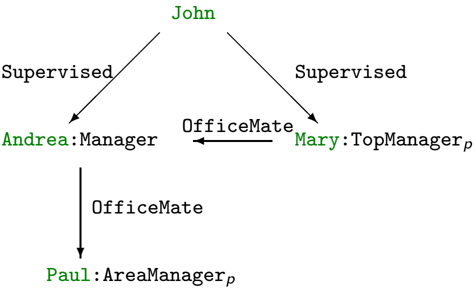

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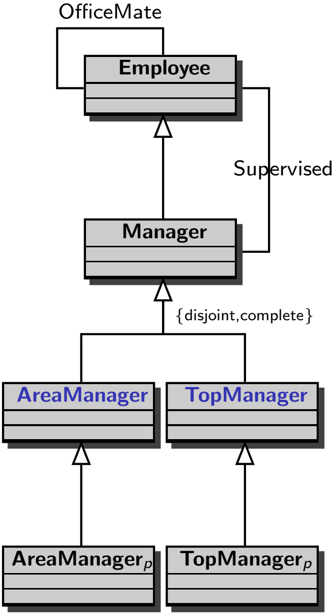

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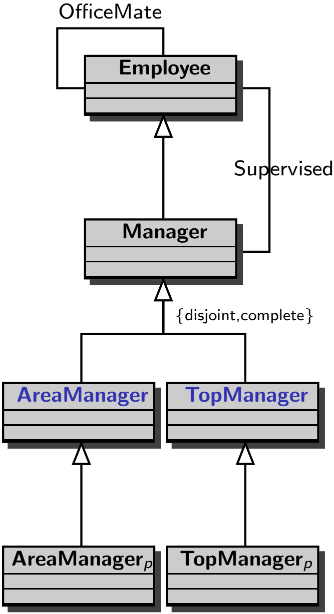

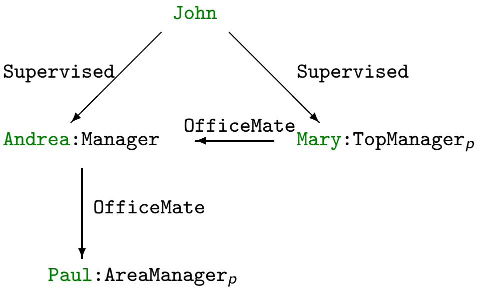

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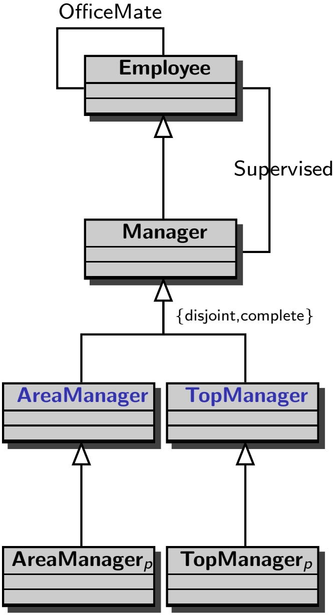
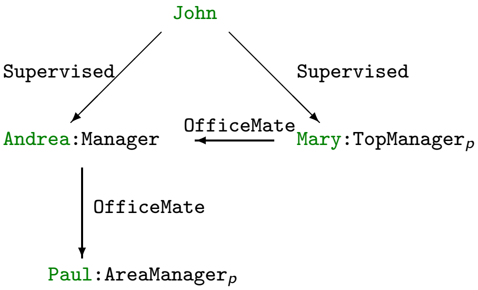
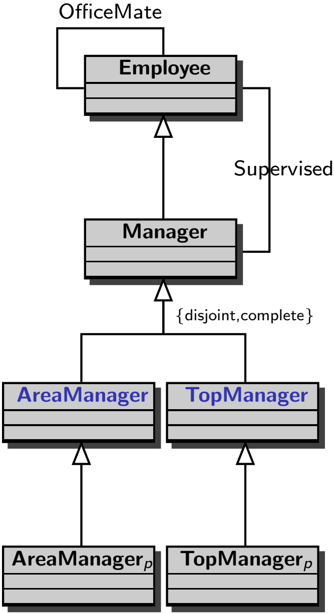
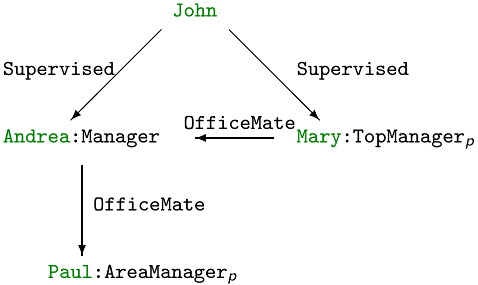





```
Q(X) :- Supervised(X,Y), TopManager(Y),
        Officemate(Y,Z), AreaManager(Z)
```

Andrea's Example (cont.)



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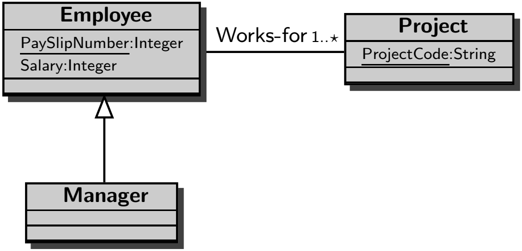
$\Longrightarrow$ { John }

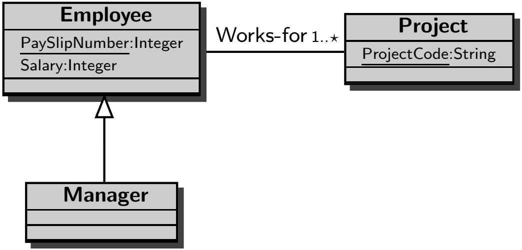
View based Query Processing

- Mappings between the conceptual schema terms and the information source terms are not necessarily atomic.
- Mappings can be given in terms of a set of sound (or exact) views:
  - GAV (*global-as-view*): sound (or exact) views over the information source vocabulary are associated to terms in the conceptual schema
    - both the DB and the partial DB assumptions are special cases of GAV
    - an ER schema can be easily mapped to its corresponding relational schema in some normal form via a GAV mapping
  - LAV (*local-as-view*): a sound or exact view over the conceptual schema vocabulary is associated to each term in the information source;
  - GLAV: mix of the above.
- It is non-trivial, even in the pure GAV setting - which is wrongly believed to be computable by simple view unfolding.

Sound GAV mapping

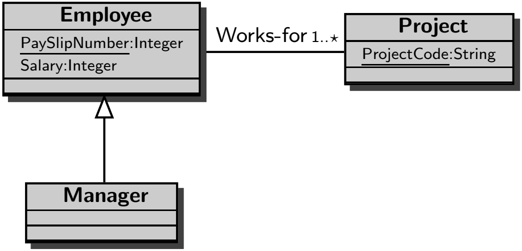


Sound GAV mapping




```
1-Employee(PaySlipNumber,Salary,ManagerP)
2-Works-for(PaySlipNumber,ProjectCode)
```

Sound GAV mapping



1-Employee(PaySlipNumber,Salary,ManagerP)
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```
Employee(X)  :-  1-Employee(X,Y,false)      Works-for(X,Y)  :-  2-Works-for(X,Y)
 Manager(X)  :-  1-Employee(X,Y,true)          Salary(X,Y)  :-  1-Employee(X,Y,Z)
 Project(Y)  :-  2-Works-for(X,Y)
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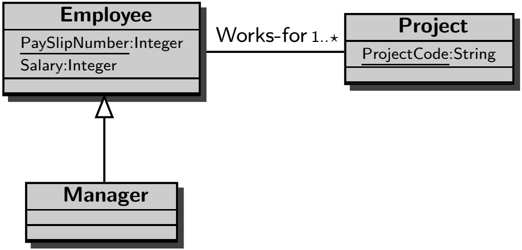
Sound GAV mapping

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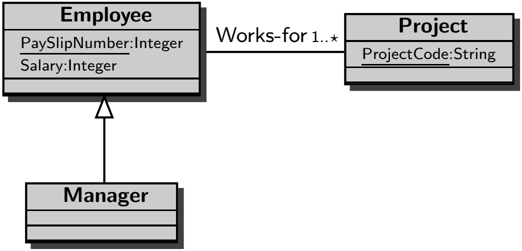
Sound GAV mapping

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```
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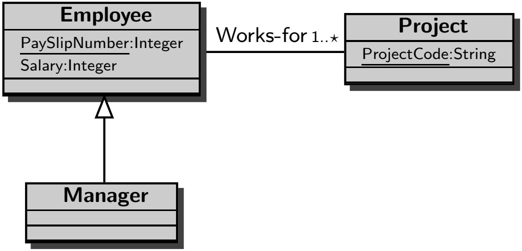
⟹        Q'(X) :- 1-Employee(X,Y,Z) ∪ 2-Works-for(X,W)
```

Sound GAV mapping

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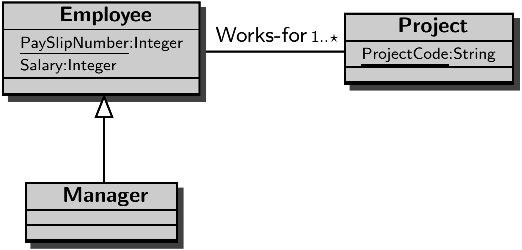
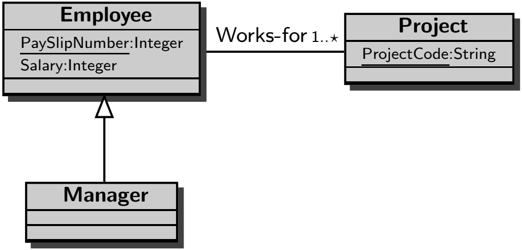
← not coming from unfolding!

Sound LAV mapping



Sound LAV mapping



`1-Employee(PaySlipNumber,Salary,ManagerP)`
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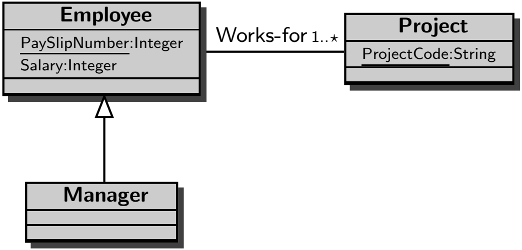


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```
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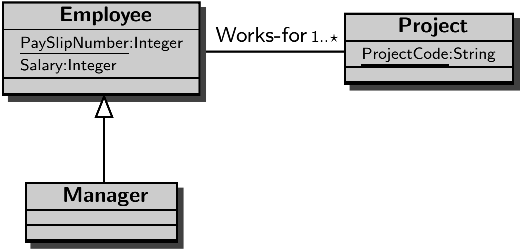
 2-Works-for(X,Y)   :-   Works-for(X,Y)
```

Sound LAV mapping



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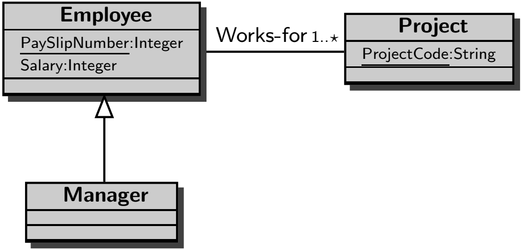

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 2-Works-for(X,Y)   :-   Works-for(X,Y)
```
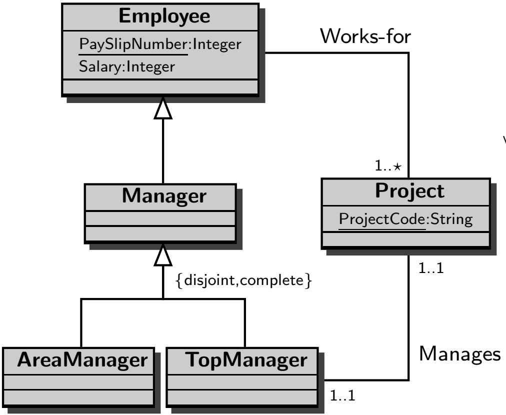

Q(X) :- Manager(X), Works-for(X,Y), Project(Y)
$\Longrightarrow$ Q'(X) :- 1-Employee(X,Y,true), 2-Works-for(X,Z)

Reasoning over queries

`Q(X,Y) :- Employee(X), Works-for(X,Y), Manages(X,Y)`



$\forall x. \mathtt{Manager}(x) \rightarrow \forall y. \neg \mathtt{WORKS\text{-}FOR}(x, y)$

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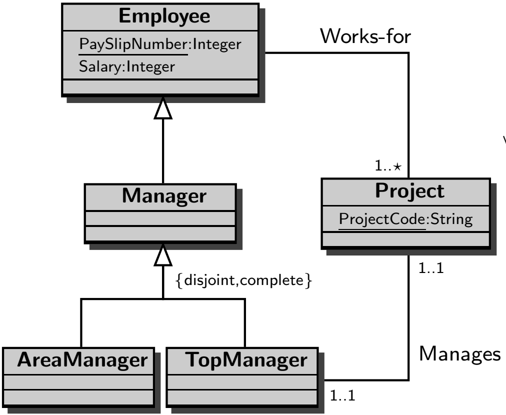

$\forall x.\, \texttt{Manager}(x) \rightarrow \forall y.\, \neg \texttt{WORKS-FOR}(x, y)$

$\rightsquigarrow$ INCONSISTENT QUERY!

Conclusions

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(i.e., an ontology)
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Pay attention!