Data Modelling/Data Base Systems

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The Relational Model

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Faculty of Informatics

Acknowledgements

The slides are based on the slides (in German) of Sebastian Skritek.

The content is based on Chapter 3 of
(Kemper, Eickler: Datenbanksysteme – Eine Einführung).

For related literature in English see Chapter 3 and 4 of
(Ramakrishnan, Gehrke: Database Management Systems).

Overview

- The Relational Model
- Translation of a Conceptual to a Logical Schema
  - "Translation" of EER to a Relation Schema
  - Features of Relation Schemata
- Query Languages
  - Relational Algebra
  - Relational Calculus
  - Expressive Power of Query Languages

The Relational Model: Definition

phone book		
name: string	address: string	telNr: integer
Mickey Mouse	Main Street	4711
Minnie Mouse	Broadway	94725
Donald Duck	Highway	95672
...	...	...

The Relational Model: Definition

phone book		
name: string	address: string	telNr: integer
Mickey Mouse	Main Street	4711
Minnie Mouse	Broadway	94725
Donald Duck	Highway	95672
...	...	...

schema

The Relational Model: Definition

phone book		
name: string	address: string	telNr: integer
Mickey Mouse	Main Street	4711
Minnie Mouse	Broadway	94725
Donald Duck	Highway	95672
...	...	...

schema

instance

The Relational Model: Definition

name

phone book		
name: string	address: string	telNr: integer
Mickey Mouse	Main Street	4711
Minnie Mouse	Broadway	94725
Donald Duck	Highway	95672
...	...	...

schema

instance

The Relational Model: Definition

	phone book	
name: string	address: string	telNr: integer
Mickey Mouse	Main Street	4711
Minnie Mouse	Broadway	94725
Donald Duck	Highway	95672
...	...	...

name

attributes

schema

instance

The Relational Model: Definition

name	phone book			schema
attributes	name: string	address: string	telNr: integer	
tuple (row)	Mickey Mouse	Main Street	4711	instance
	Minnie Mouse	Broadway	94725	
	Donald Duck	Highway	95672	
	...	...	...	

The Relational Model: Definition

name

attributes

tuple (row)

schema

instance

phone book		
name: string	address: string	telNr: integer
Mickey Mouse	Main Street	4711
Minnie Mouse	Broadway	94725
Donald Duck	Highway	95672
...	...	...

field

The Relational Model: Definition

schema:

phone book: (name: string, address: string, telNr: integer)

instance

{
("Mickey Mouse", "Main Street", 4711),
("Minnie Mouse", "Broadway", 94725),
("Donald Duck", "Highway", 95672)
}

The Relational Model: Definition

schema:

phone book: (name: string, address: string, telNr: integer)

instance

{
("Mickey Mouse", "Main Street", 4711),
("Minnie Mouse", "Broadway", 94725),
("Donald Duck", "Highway", 95672)
}

attention:
no order

The Relational Model: Definition

schema:

phone book: (name: string, address: string, telNr: integer)

instance

{
("Mickey Mouse", "Main Street", 4711),
("Minnie Mouse", "Broadway", 94725),
("Donald Duck", "Highway", 95672)
}

attention:
no order
no duplicates

The Relational Model: Definition

Definition (relation)

Let $D_1, D_2, \ldots, D_n$ be domains.
A relation R over $D_1, D_2, \ldots, D_n$ is a subset of the Cartesian product of the domains:

$$R \subseteq D_1 \times \cdots \times D_n$$

n . . . arity of the relation

relational data base: set of relations

The Relational Model: Definition

Example

$$R \subseteq \text{string} \times \text{string} \times \text{integer}$$

The Relational Model: Definition

Example

$$R \subseteq \text{string} \times \text{string} \times \text{integer}$$

Mickey Mouse	Main Street	4711
Minnie Mouse	Broadway	94725
Donald Duck	Highway	95672
...	...	...

The Relational Model: Definition

Definition (tuple)

A tuple t is an element of a relation R.

$$t \in R$$

Example

$$t = (\text{“Mickey Mouse”}, \text{“Main Street”}, 4711)$$

The Relational Model: Definition

Definition (relation schema)

The schema of a relation consists of

- the name of the relation
- the list of the attributes

$$\mathrm{RelName}\colon (\mathrm{Attr}_1 : \mathrm{dom}_1, \ldots, \mathrm{Attr}_n : \mathrm{dom}_n)$$

Example

phone book: (name: string, address: string, telNr: integer)

Key

Definition (key)

A key is a minimal set of attributes, whose values identify a tuple uniquely.

Key

Definition (key)

A key is a minimal set of attributes, whose values identify a tuple uniquely.

Remark: In general several keys are possible to occur. A candidate for a key is picked as primary key (marked by underlining).

Example

phone book: (name: string, address: string, <u>telNr: integer</u>)
phone book: (<u>name: string, address: string</u>, telNr: integer)

Definition: Foreign Key

foreign key A foreign key is a set of attributes that point to the key of a(nother) relation.

Example

room: (roomNr: integer, description: string, place: string)

employee: (PNR: int, name: string,
roomNr: integer: room.roomNr)

Learning Objectives

- What is ... ? / What does ... consist of?
  - a relation
  - a relation schema
  - a key / a primary key
  - a foreign key

Translation of a Conceptual Schema to a Logical Schema

Translation of a Conceptual Schema to a Logical Schema

EER → Relation Schema

Summary: Concepts

Summary: Concepts

entity types

attributes

relationship types

weak entity types

generalization

key

"weak key"

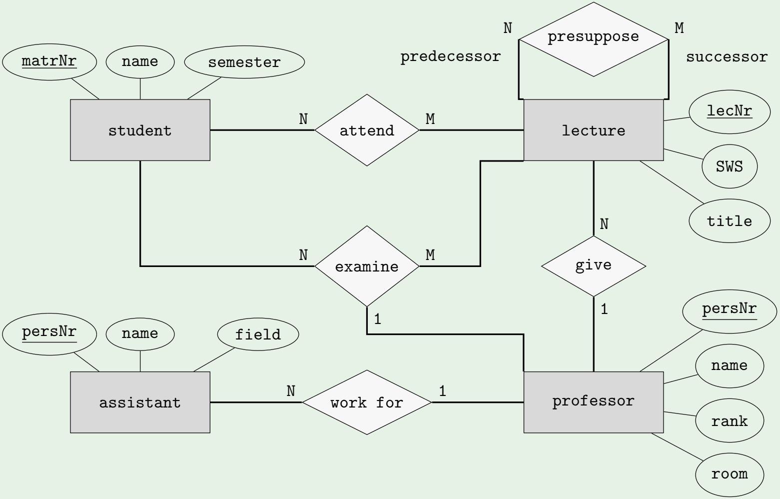
cardinalities

Summary: Concepts

entity types	
attributes	
relationship types	relation schema
weak entity types	key
generalization	foreign key
key	
“weak key”	
cardinalities	

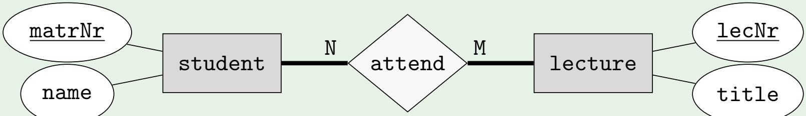
From EER to a Relation Schema: Uni-Schema

Example (university schema)



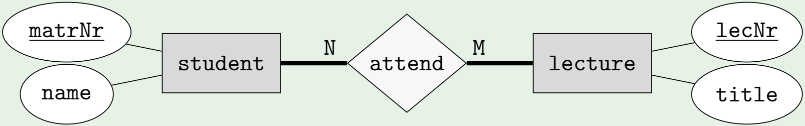
EER → Relation Schema: Intuition

Example



EER → Relation Schema: Intuition

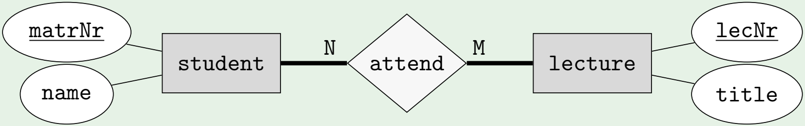
Example



student	
<u>matrNr</u>	name
24002	Xenokrates
25403	Jonas
26120	Fichte
26830	Aristoxenos
...	...

EER → Relation Schema: Intuition

Example

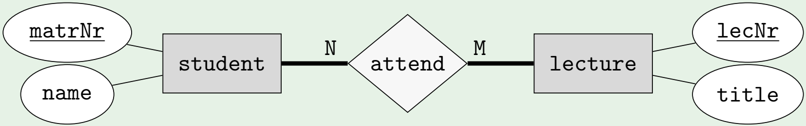


student	
matrNr	name
24002	Xenokrates
25403	Jonas
26120	Fichte
26830	Aristoxenos
...	...

lecture	
lecNr	title
5001	Grundzüge
5041	Ethik
4052	Logik
...	...

EER $\rightarrow$ Relation Schema: Intuition

Example



student

matrNr	name
24002	Xenokrates
25403	Jonas
26120	Fichte
26830	Aristoxenos
...	...

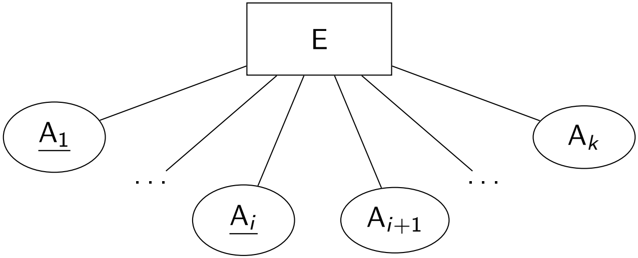
attend

matrNr	lecNr
26120	5001
24002	5001
24002	4052
...	...

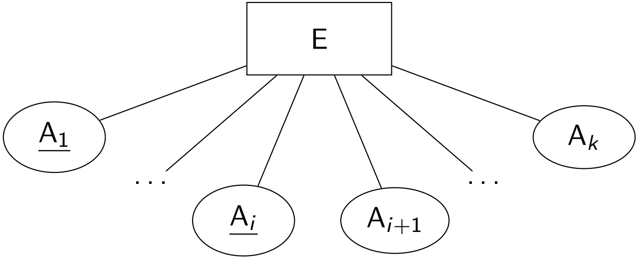
lecture

lecNr	title
5001	Grundzüge
5041	Ethik
4052	Logik
...	...

Relational Illustration of Entity Types



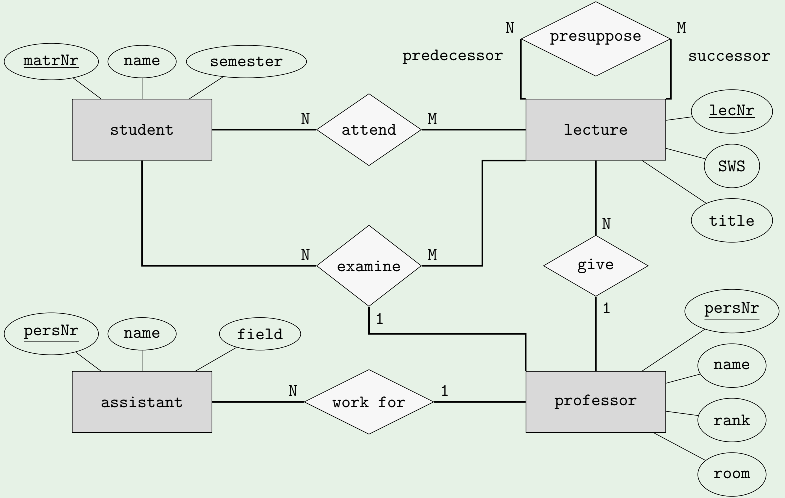
Relational Illustration of Entity Types



$$E: \; (\underline{A_1 : \text{type}_1, \ldots, A_i : \text{type}_i}, A_{i+1} : \; \text{type}_{i+1}, \ldots, A_k : \; \text{type}_k \;)$$

University Schema

Example (university schema)



Relational Illustration of Entity Types

relational illustration of the four entity types from the university schema

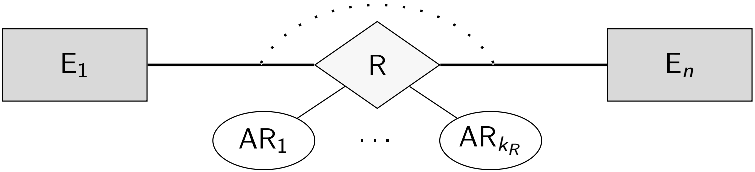
student: (<u>matrNr: integer</u>, name: string, semester: integer)

lecture: (<u>lecNr: integer</u>, title: string, SWS: integer)

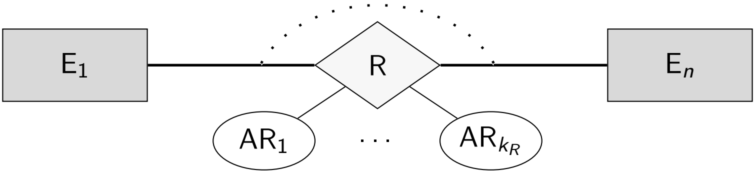
professor: (<u>persNr: integer</u>, name: string, rank: string, room: integer)

assistant: (<u>persNr: integer</u>, name: string, field: string)

Relational Illustration of Relationship Types



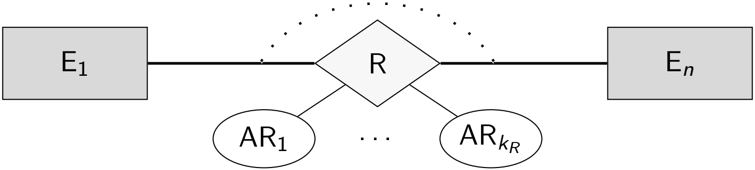
Relational Illustration of Relationship Types



intuitively:

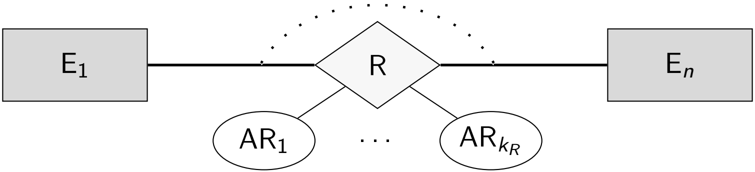
R: (key of *rel*(E_1), ..., key of *rel*(E_n), attributes of *R*)

Relational Illustration of Relationship Types



assumption: $E_i(\underline{A^i_1, \ldots, A^i_{k_i}}, B^i_1, \ldots B^i_{\ell_i})$ (for all $1 \leq i \leq n$)

Relational Illustration of Relationship Types



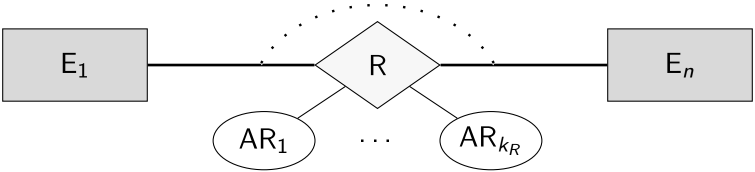
assumption: $E_i(\underline{A^i_1, \ldots, A^i_{k_i}}, B^i_1, \ldots B^i_{\ell_i})$ (for all $1 \leq i \leq n$)

R: (key of $rel(E_1)$

key of $rel(E_n)$

) attributes of R

Relational Illustration of Relationship Types



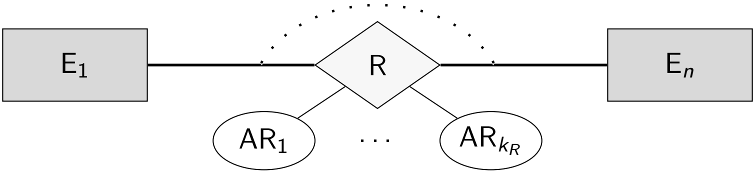
assumption: $E_i(\underline{A^i_1, \ldots, A^i_{k_i}}, B^i_1, \ldots B^i_{\ell_i})$ (for all $1 \leq i \leq n$)

$R\colon\ (\ A^1_1 : E_1.A^1_1, \ldots, A^1_{k_1} : E_1.A^1_{k_1},$ key of $rel(E_1)$

key of $rel(E_n)$

$)$ attributes of R

Relational Illustration of Relationship Types



assumption: $E_i(\underline{A^i_1, \ldots, A^i_{k_i}}, B^i_1, \ldots B^i_{\ell_i})$ (for all $1 \leq i \leq n$)

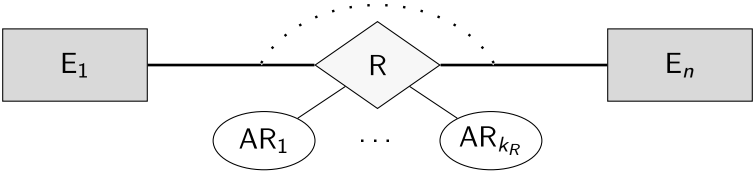
R: ($A^1_1 : E_1.A^1_1, \ldots, A^1_{k_1} : E_1.A^1_{k_1}$, key of $rel(E_1)$

$\ldots$,

$A^n_1 : E_n.A^n_1, \ldots, A^n_{k_n} : E_n.A^n_{k_n}$, key of $rel(E_n)$

) attributes of R

Relational Illustration of Relationship Types



assumption: $E_i(\underline{A^i_1, \ldots, A^i_{k_i}}, B^i_1, \ldots B^i_{\ell_i})$ (for all $1 \leq i \leq n$)

R: ($A^1_1 : E_1.A^1_1, \ldots, A^1_{k_1} : E_1.A^1_{k_1}$, — key of $rel(E_1)$

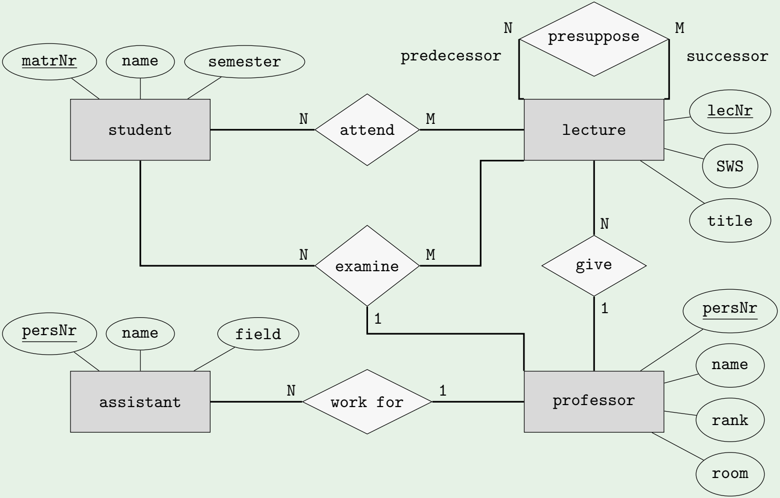
$\ldots$,

$A^n_1 : E_n.A^n_1, \ldots, A^n_{k_n} : E_n.A^n_{k_n}$, — key of $rel(E_n)$

$AR_1, \ldots, AR_{k_R}$) — attributes of R

From EER to a Relation Schema: Uni-Schema

Example (university schema)



Relational Illustration of Relationship Types

relational illustration of the relationship types from the university schema
(foreign key implicit)

attend: (*matrNr: integer*, *lecNr: integer*)
give: (*persNr: integer*, *lecNr: integer*)
work for: (*assPersNr: integer*, *profPersNr: integer*)
presuppose: (*predecessor: integer*, *successor: integer*)
examine: (*matrNr: integer*, *lecNr: integer*, *persNr: integer*, grade: decimal)

Relational Illustration of Relationship Types

relational illustration of the relationship types from the university schema
(foreign key implicit)

attend: (*matrNr: integer, lecNr: integer*)
give: (*persNr: integer, lecNr: integer*)
work for: (*assPersNr: integer, profPersNr: integer*)
presuppose: (*predecessor: integer, successor: integer*)
examine: (*matrNr: integer, lecNr: integer, persNr: integer,* grade: decimal)

Key?

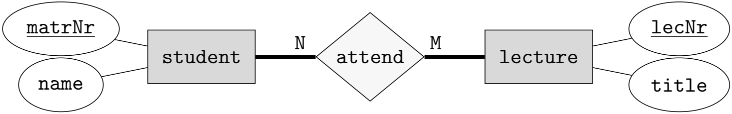
Relational Illustration of Relationship Types

relational illustration of the relationship types from the university schema
(foreign key implicit)

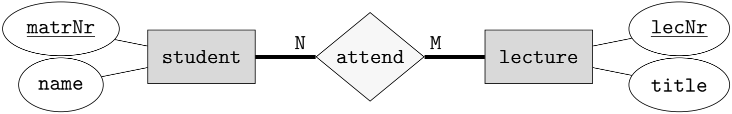
attend: (*matrNr: integer*, *lecNr: integer*) (N:M)
give: (*persNr: integer*, *lecNr: integer*) (1:N)
work for: (*assPersNr: integer*, *profPersNr: integer*) (N:1)
presuppose: (*predecessor: integer*, *successor: integer*) (N:M)
examine: (*matrNr: integer*, *lecNr: integer*, *persNr: integer*, grade: decimal) (N:M:1)

Key?

N:M Relationship (attend)



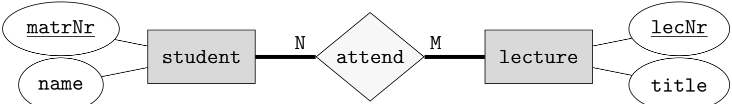
N:M Relationship (attend)



student	
matrNr	name
24002	Xenokrates
25403	Jonas
26120	Fichte
26830	Aristoxenos
28106	Carnap
29555	Feuerbach
...	...

lecture	
lecNr	title
5001	Grundzüge
5041	Ethik
5049	Mäeutik
4052	Logik
5216	Bioethik
...	...

N:M Relationship (attend)



student

matrNr	name
24002	Xenokrates
25403	Jonas
26120	Fichte
26830	Aristoxenos
28106	Carnap
29555	Feuerbach
...	...

attend

matrNr	lecNr
...	...

lecture

lecNr	title
5001	Grundzüge
5041	Ethik
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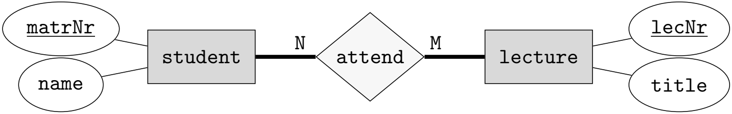
5216	Bioethik
...	...

N:M Relationship (attend)



student	
matrNr	name
24002	Xenokrates
25403	Jonas
26120	Fichte
26830	Aristoxenos
28106	Carnap
29555	Feuerbach
...	...

attend	
matrNr	lecNr
24002	4052
24002	5001
...	...

lecture	
lecNr	title
5001	Grundzüge
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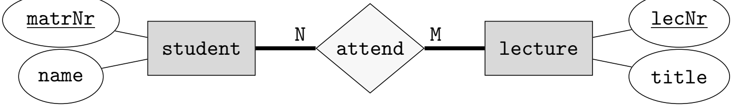
...	...

N:M Relationship (attend)



student	
<u>matrNr</u>	name
24002	Xenokrates
25403	Jonas
26120	Fichte
26830	Aristoxenos
28106	Carnap
29555	Feuerbach
...	...

attend	
matrNr	lecNr
24002	4052
24002	5001
26120	5001
...	...

lecture	
<u>lecNr</u>	title
5001	Grundzüge
5041	Ethik
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...	...

Key of N:M Relationships

The key of a relation that originated from a N:M relationship contains all foreign key attributes from entities involved in the relationship.

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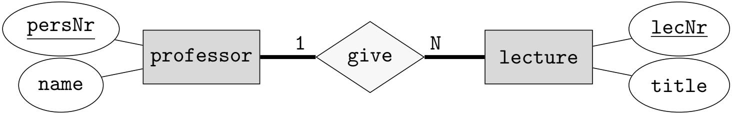
Example

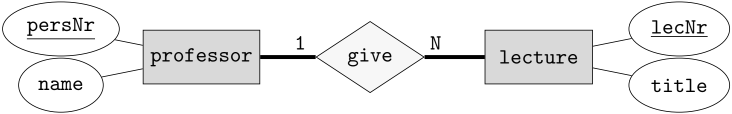
attend: ($\underline{\textit{matrNr: integer, lecNr: integer}}$) (N:M)

presuppose: ($\underline{\textit{predecessor: integer, successor: integer}}$) (N:M)

1:N Relationship (give)



1:N Relationship (give)

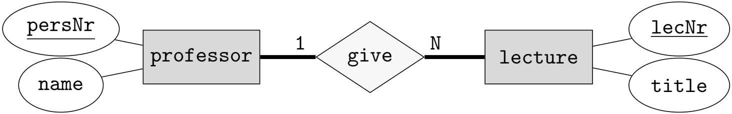


professor	
PersNrNr	name
2125	Sokrates
2126	Russel
2127	Kopernikus
2133	Popper
2134	Augustinus
2136	Curie

give	
persNr	lecNr
...	...

lecture	
lecNr	title
5001	Grundzüge
5041	Ethik
5049	Mäeutik
4052	Logik
5216	Bioethik
...	...

1:N Relationship (give)



professor	
PersNrNr	name
2125	Sokrates
2126	Russel
2127	Kopernikus
2133	Popper
2134	Augustinus
2136	Curie

give	
persNr	lecNr
2137	
2125	5041
2125	5049
2125	4052
2126	
...	...

lecture	
lecNr	title
5001	Grundzüge
5041	Ethik
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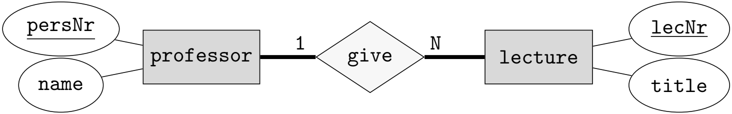
...	...

1:N Relationship (give)



professor	
PersNrNr	name
2125	Sokrates
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give	
persNr	lecNr
2137	5001
2125	5041
2125	5049
2125	4052
2126	5216
...	...

lecture	
lecNr	title
5001	Grundzüge
5041	Ethik
5049	Mäeutik
4052	Logik
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...	...

Key of 1:N Relationships

The key of a relation that originated from a 1:N relationship contains all foreign key attributes originating from the "N" side of the in the relationship involved entity.

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Example

give: (*persNr: integer*, <u>*lecNr: integer*</u>) (1:N)

Key of 1:N Relationships

The key of a relation that originated from a 1:N relationship contains all foreign key attributes originating from the "N" side of the in the relationship involved entity.

Example

give: (*persNr: integer*, <u>*lecNr: integer*</u>) (1:N)

work for: (<u>*assPersNr: integer*</u>, *profPersNr: integer*) (N:1)

Key of 1:N Relationships

The key of a relation that originated from a 1:N relationship contains all foreign key attributes originating from the "N" side of the in the relationship involved entity.

Example

give: (*persNr: integer*, <u>*lecNr: integer*</u>) (1:N)

work for: (<u>*assPersNr: integer*</u>, *profPersNr: integer*) (N:1)

examine: (<u>*matrNr: integer, lecNr: integer*</u>, *persNr: integer*, grade: decimal) (N:M:1)

Refinement of 1:N Relationships

- what we had:

professor: (<u>persNr: integer</u>, name: string, rank: string, room: integer)

lecture: (<u>lecNr: integer</u>, title: string, SWS: integer)

give: (<u>*lecNr: integer*</u>, *persNr: integer*)

Refinement of 1:N Relationships

- what we had:

  professor: (<u>persNr: integer</u>, name: string, rank: string, room: integer)

  lecture: (<u>lecNr: integer</u>, title: string, SWS: integer)

  give: (*<u>lecNr: integer</u>, persNr: integer*)

- refinement through combination of relations:

  professor: (<u>persNr: integer</u>, name: string, rank: string, room: integer)

Refinement of 1:N Relationships

- what we had:

  professor: (<u>persNr: integer</u>, name: string, rank: string, room: integer)

  lecture: (<u>lecNr: integer</u>, title: string, SWS: integer)

  give: (<u>*lecNr: integer*</u>, *persNr: integer*)

- refinement through combination of relations:

  professor: (<u>persNr: integer</u>, name: string, rank: string, room: integer)

  lecture: (<u>lecNr: integer</u>, title: string, SWS: integer, *persNr: integer: prof.persNr*)

Refinement of 1:N Relationships

- what we had:

  professor: (<u>persNr: integer</u>, name: string, rank: string, room: integer)

  lecture: (<u>lecNr: integer</u>, title: string, SWS: integer)

  give: (<u>*lecNr: integer*</u>, *persNr: integer*)

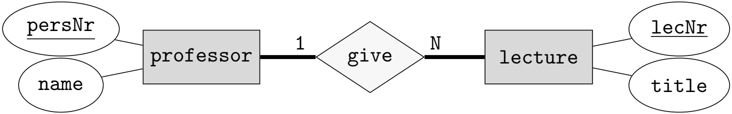
- refinement through combination of relations:

  professor: (<u>persNr: integer</u>, name: string, rank: string, room: integer)

  lecture: (<u>lecNr: integer</u>, title: string, SWS: integer, *persNr: integer: prof.persNr*)

Only relations with the same key can be combined!

Result of a Correct Combination



professor			
persNr	name	rank	room
2125	Sokrates	C4	226
2126	Russel	C4	232
2127	Kopernikus	C3	310
2133	Popper	C3	52
2134	Augustinus	C3	309
2136	Curie	C4	36

lecture			
lecNr	title	SWS	persNr
5001	Grundzüge	4	2137
5041	Ethik	4	2125
5049	Mäeutik	2	2125
4052	Logik	4	2125
5216	Bioethik	2	2126
...	...	...	...

Wrong Combination Results in Anomalies

professor				
persNr	name	rank	room	give
2125	Sokrates	C4	226	5041
2125	Sokrates	C4	226	5049
2125	Sokrates	C4	226	4052
2126	Russel	C4	232	5216
...	...	...	...	...
2136	Curie	C4	36	???

lecture		
lecNr	title	SWS
5001	Grundzüge	4
5041	Ethik	4
5049	Mäeutik	2
4052	Logik	4
5216	Bioethik	2
...	...	...

Wrong Combination Results in Anomalies

professor				
persNr	name	rank	room	give
2125	Sokrates	C4	226	5041
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...	...	...	...	...
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lecture		
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5001	Grundzüge	4
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...	...	...

problem key: relation professor needs a new key

Wrong Combination Results in Anomalies

professor				
persNr	name	rank	room	give
2125	Sokrates	C4	226	5041
2125	Sokrates	C4	226	5049
2125	Sokrates	C4	226	4052
2126	Russel	C4	232	5216
...	...	...	...	...
2136	Curie	C4	36	???

lecture		
lecNr	title	SWS
5001	Grundzüge	4
5041	Ethik	4
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5216	Bioethik	2
...	...	...

problem key: relation professor needs a new key

update anomaly: Sokrates moves

Wrong Combination Results in Anomalies

professor				
persNr	name	rank	room	give
2125	Sokrates	C4	226	5041
2125	Sokrates	C4	226	5049
2125	Sokrates	C4	226	4052
2126	Russel	C4	232	5216
...	...	...	...	...
2136	Curie	C4	36	???

lecture		
lecNr	title	SWS
5001	Grundzüge	4
5041	Ethik	4
5049	Mäeutik	2
4052	Logik	4
5216	Bioethik	2
...	...	...

problem key: relation professor needs a new key

update anomaly: Sokrates moves

insert anomaly: Curie is new and does not yet give a lecture. What is the key?

Wrong Combination Results in Anomalies

professor				
persNr	name	rank	room	give
2125	Sokrates	C4	226	5041
2125	Sokrates	C4	226	5049
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...	...	...	...	...
2136	Curie	C4	36	???

lecture		
lecNr	title	SWS
5001	Grundzüge	4
5041	Ethik	4
5049	Mäeutik	2
4052	Logik	4
5216	Bioethik	2
...	...	...

problem key: relation professor needs a new key

update anomaly: Sokrates moves

insert anomaly: Curie is new and does not yet give a lecture. What is the key?

delete anomaly: lecture Ethik does not take place

Null Values and how to Avoid Them

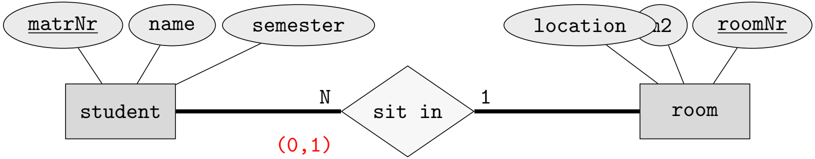
Example

Students that work as student assistant are assigned a room.
There are 25.000 students and 200 student assistants.

Null Values and how to Avoid Them

Example

Students that work as student assistant are assigned a room.
There are 25.000 students and 200 student assistants.



Null Values and how to Avoid Them

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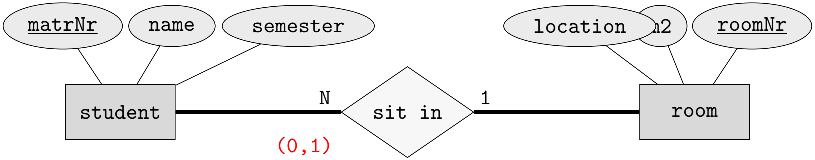

student: (<u>matrNr</u>, name, semester)

sit in: (<u>*matrNr: student*</u>, *roomNr: room*)

room: (<u>roomNr</u>, m2, location)

Null Values and how to Avoid Them

Example

Students that work as student assistant are assigned a room.
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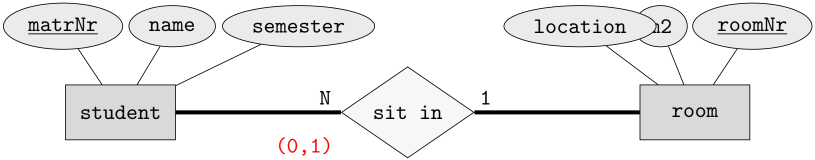


student: (<u>matrNr</u>, name, semester)

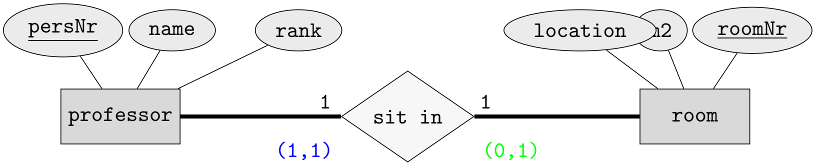
sit in: (<u>*matrNr: student*</u>, *roomNr: room*)

room: (<u>roomNr</u>, m2, location)

~~student: (matrNr, name, semester, *roomNr: room*)~~

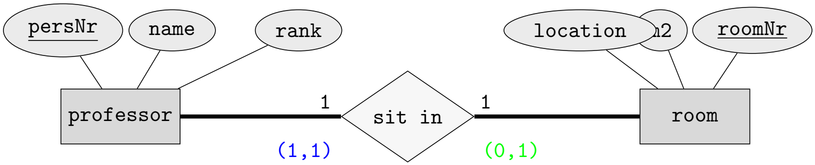
Nothing to be combined to avoid null values.

1:1 Relationship (sit in)



professor: (<u>persNr</u>, name, rank)
room: (<u>roomNr</u>, m2, location)

1:1 Relationship (sit in)



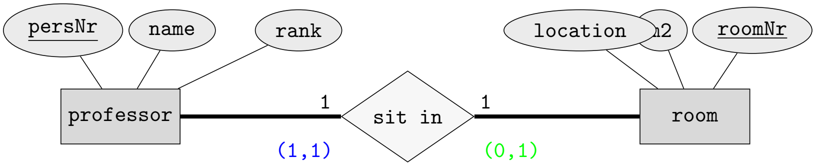
professor: (<u>persNr</u>, name, rank)

room: (<u>roomNr</u>, m2, location)

sit in: (<u>*persNr: professor*</u>, *roomNr: room*) or

(*persNr: professor* <u>*roomNr: room*</u>)

1:1 Relationship (sit in)



professor: (persNr, name, rank)

room: (roomNr, m2, location)

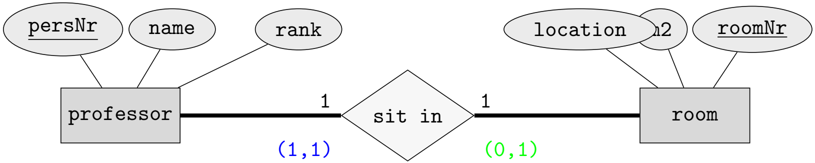
sit in: (*persNr: professor*, *roomNr: room*) or

(*persNr: professor* *roomNr: room*)

professor: (persNr, name, rank, *roomNr: room*)

room: (roomNr, m2, location)

1:1 Relationship (sit in)



professor: (persNr, name, rank)

room: (roomNr, m2, location)

sit in: (*persNr: professor*, *roomNr: room*) or

(*persNr: professor* *roomNr: room*)

professor: (persNr, name, rank, *roomNr: room*)

room: (roomNr, m2, location)

professor: (persNr, name, rank)

room: (roomNr, m2, location, *persNr: professor*)

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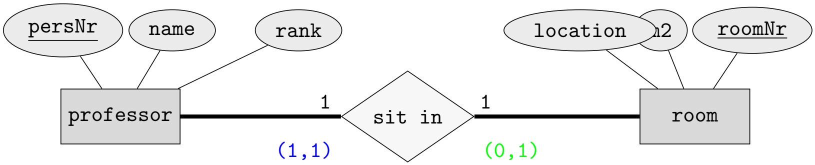
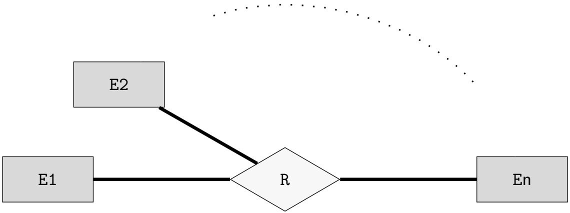


professor: (persNr, name, rank)
room: (roomNr, m2, location)
sit in: (*persNr: professor*, *roomNr: room*) or
(*persNr: professor* *roomNr: room*)
professor: (persNr, name, rank, *roomNr: room*)
room: (roomNr, m2, location)
professor: (persNr, name, rank)
room: (roomNr, m2, location, *persNr: professor*)

attention: avoidance of null values

Refinement of (min,max)-Notation



$$R \subseteq E_1 \times E_2 \times \cdots \times E_n$$

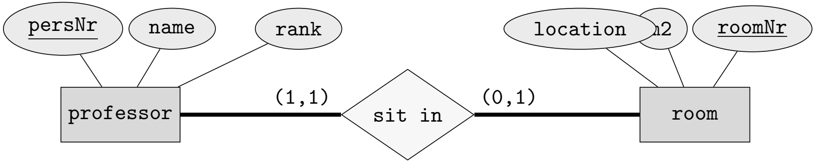
translation to a relation schema:

$$R^s : (key(E_1), key(E_2), \ldots, key(E_n))$$

(min,max)-notation: for every entity e_i of type E_i it holds that:

$$\min_i \leq \#\text{tuple of the form } (\ldots, e_i, \ldots) \in R \leq \max_i$$

Refinement of (min,max)-Notation



professor: (<u>persNr</u>, name, rank)

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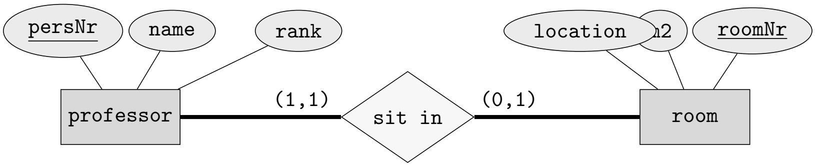

professor: (persNr, name, rank)

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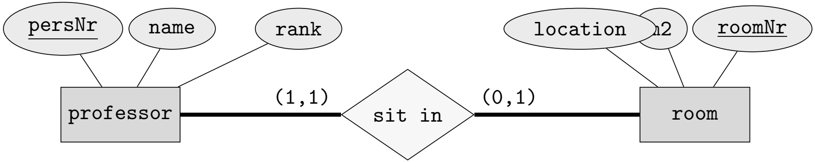
sit in: (*persNr: professor*, *roomNr: room*)

Refinement of (min,max)-Notation



professor: (<u>persNr</u>, name, rank)

room: (<u>roomNr</u>, m2, location)

sit in: (<u>*persNr: professor*</u>, *roomNr: room*)

professor: (<u>persNr</u>, name, rank, *roomNr: room*)

room: (<u>roomNr</u>, m2, location)

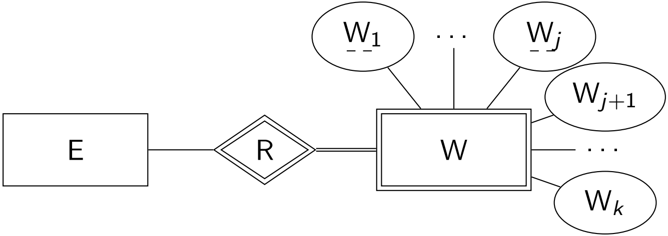
Refinement of (min,max)-Notation

The (min,max)-notation determines the number of times an entity (of type E) is allowed to occur in an instance of a relationship type.

(0,1) at most once $\Rightarrow$
relationship tuple is uniquely identified
key receives the foreign key attributes from E, combination might lead to null values

(1,1) exactly once $\Rightarrow$
relationship tuple is uniquely identified
each entity of type E is in a relationship
key receives the foreign key attributes from E, combine relationship with the relation E

Relational Illustration of Weak Entity Types



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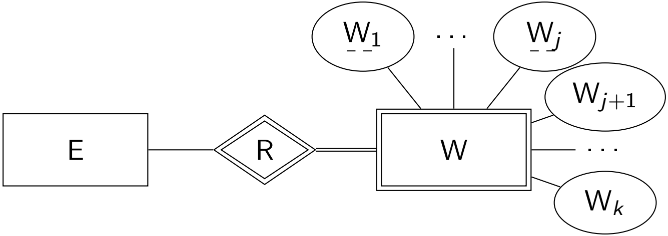


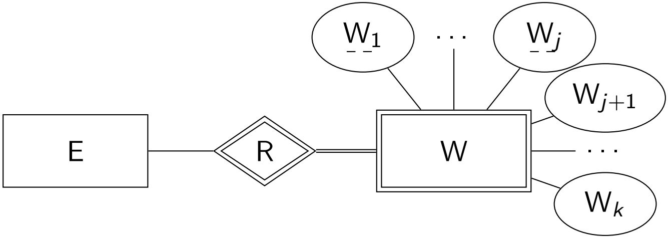
intuitively:

W (key of *rel*(E),

weak key of W,

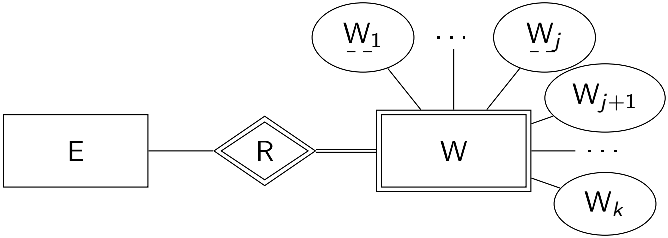
attributes of W)

Relational Illustration of Weak Entity Types



assumption: E: ($\underline{A_1, \ldots, A_i}, A_{i+1}, \ldots, A_n$)

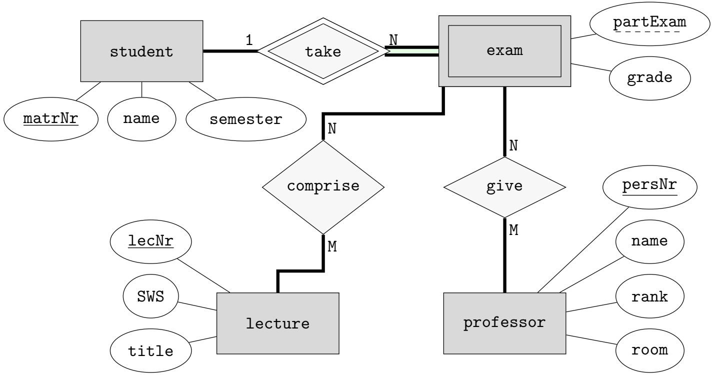
Relational Illustration of Weak Entity Types



assumption: E: ($\underline{A_1, \ldots, A_i,}A_{i+1}, \ldots, A_n$)

W: ($\underline{A_1 : E.A_1, \ldots, A_i : E.A_i, W_1, \ldots, W_j}, W_{j+1}, \ldots, W_k$)

Relational Illustration of Weak Entity Types



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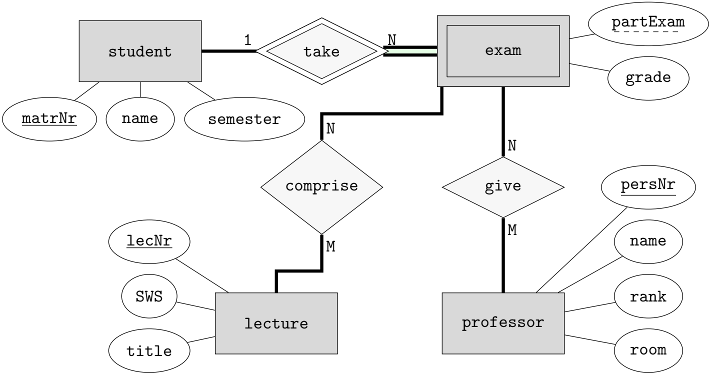
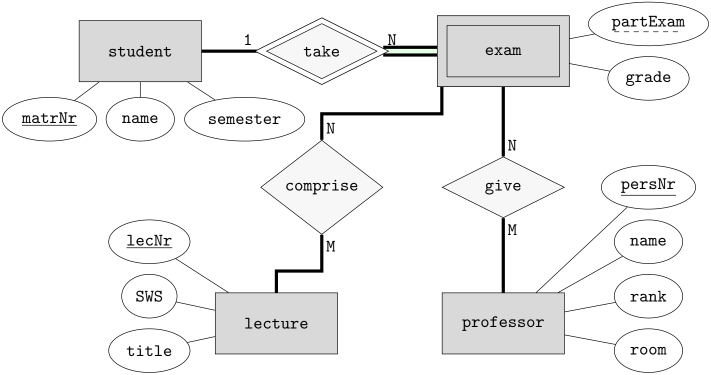


exam: (*matrNr: student.matrNr*, partExam, grade)

Relational Illustration of Weak Entity Types

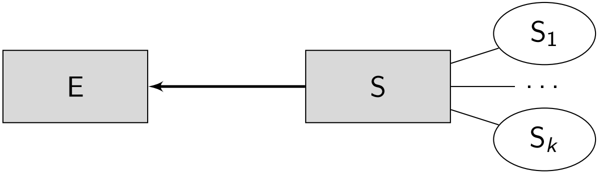


exam: (*matrNr: student.matrNr*, partExam, grade)

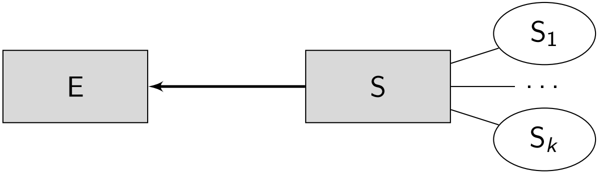
comprise: (*matrNr: exam, partExam: exm, lecNr: lecture*)

give: (*matrNr: exam, partExam: exam, persNr: prof*)

Relational Illustration of the Generalization



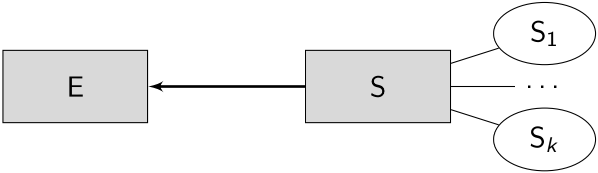
Relational Illustration of the Generalization



intuitively: “inherit” the key

assumtpion: E: $(\underline{A_1, \ldots, A_i}, A_{i+1}, \ldots, A_k)$

Relational Illustration of the Generalization



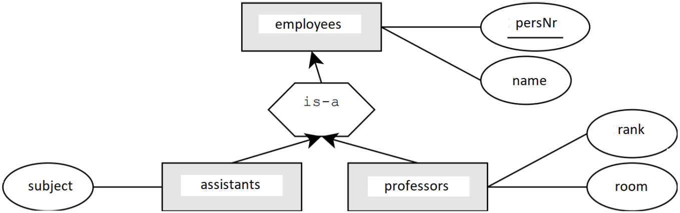
intuitively: “inherit” the key

assumtpion: E: $(\underline{A_1, \ldots, A_i}, A_{i+1}, \ldots, A_k)$

S: $(\underline{A_1 : E.A_1, \ldots, A_i : E.A_i}, S_1, \ldots, S_k)$

Relational Illustration of the Generalization

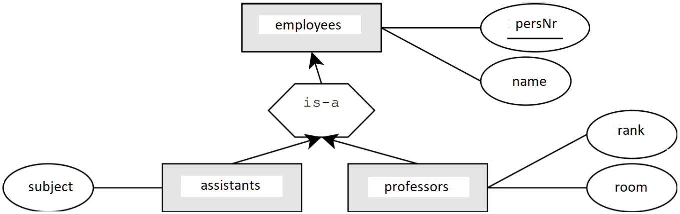
relational illustration of the generalization from the university schema



employee: (<u>persNr</u>, name)

Relational Illustration of the Generalization

relational illustration of the generalization from the university schema



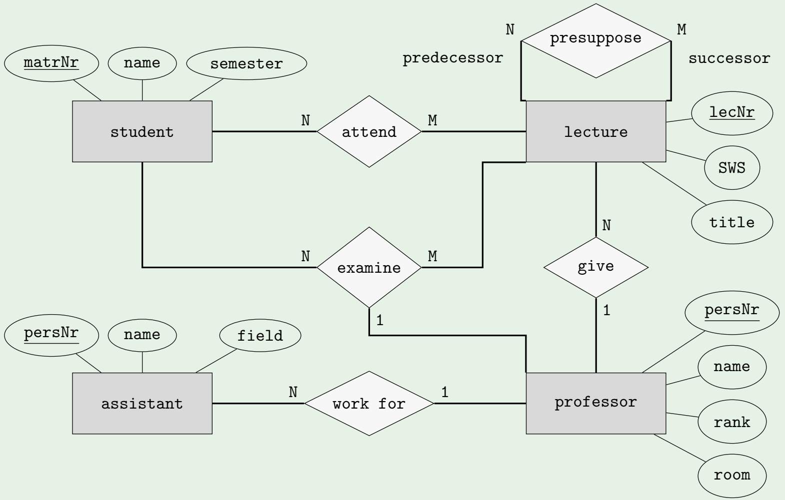
employee: (persNr, name)

professor: (*persNr: employee.persNr*, rank, room)

assistant: (*persNr: employee.persNr*, subject)

From EER to the Relation Schema: Uni-Schema

Example (university schema)



Relational University Data Base

student

matrNr	name	sem
24002	Xenokrates	18
25403	Jonas	12
26120	Fichte	10
26830	Aristoxenos	8
27550	Schopenhauer	6
28106	Carnap	3
29120	Theophrastos	2
29555	Feuerbach	2

professor

persNr	name	rank	room
2125	Sokrates	C4	226
2126	Russel	C4	232
2127	Kopernikus	C3	310
2133	Popper	C3	52
2134	Augustinus	C3	309
2136	Curie	C4	36
2137	Kant	C4	7

Relational University Data Base

lecture

lecNr	title	SWS	persNr
5001	Grundzüge	4	2137
5041	Ethik	4	2125
5043	Erkenntnistheorie	3	2126
5049	Mäeutik	2	2125
4052	Logik	4	2125
5052	Wissenschaftstheorie	3	2126
5216	Bioethik	2	2126
5259	Der Wiener Kreis	2	2133
5022	Glaube und Wissen	2	2134
4630	Die drei Kritiken	4	2137

presuppose

preNr	sucNr
5001	5041
5001	5043
5001	5049
5041	5216
5043	5052
5041	5052
5052	5259

Relational University Data Base

attend

matrNr	lecNr
26120	5001
27550	5001
27550	4052
28106	5041
28106	5001
28106	4052
28106	4630
29120	5001
29120	5041
29120	5049
29555	5022
25403	5022

assistant

persNr	name	field	boss
3002	Platon	Ideenlehre	2125
3003	Aristoteles	Syllogistik	2125
3004	Wittgenstein	Sprachtheorie	2126
3005	Rhetikus	Planetenbewegung	2127
3006	Newton	Kepler Gesetze	2127
3007	Spinoza	Gott und Natur	2126

examine

matrNr	lecNr	persNr	grade
28106	5001	2126	1
25403	5041	2125	2
27550	4630	2137	2

Learning Objectives

- How do we translate
  - entity types
  - relationship types
  - weak entity types
  - generalization relationships

  to the relational model?
- What do we have to take care of when translating relationship types?
  - How do we identify keys?
  - What can we do to obtain a minimal number of relations?
  - How can null values be avoided?
- What kind of anomalies can occur in a bad schema?

Query Languages

Query Languages

in this lecture:

- Relational Algebra
- Relational Calculus

Query Languages

in this lecture:

- Relational Algebra
- Relational Calculus

both languages

- form theoretical basis for SQL
- are equally expressive
- are closed under relations

Relational Algebra

The Relational Algebra

CODD 1970: A relational model for large shared data banks. Communications of the ACM, 13(6): 377-387

CODD 1972: Relational Completeness of Data Base Sub Languages. In: Rustin, R., Hrsg.: Database Systems, 33-64 Prentice Hall, Englewood Cliffs, NY, USA

The Relational Algebra

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procedural query language:

expression implicitly contains the execution plan for performing the query

The Relational Algebra

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procedural query language:
: expression implicitly contains the execution plan for performing the query

set based language:
: operations work with sets of tuples

Relational Algebra – Why (do we have to learn this)?

- basis of many (relational) query languages
- describes possible operations on relations
  (= tools and mindset)
- applications:
  - construction and optimization of query plans in DBMSs
  - as functions of "procedural" DB interfaces
  - communication about data base operations,
    description of possible procedures
  - development of algorithms for answering the query

Relational Algebra – Why (do we have to learn this)?

- construction and optimization of query plans in DBMSs

Example (postgres query plan)

```
Hash Join
 Hash Cond: (w.ssn = e.essn)
 -> Hash Join
    Hash Cond: (w.pno = p.pnumber)
    -> Seq Scan on workson w
    -> Hash
      -> Bitmap Heap Scan on project p
         Recheck Cond: ((pname)::text = 'Aquarius'::text)
        -> Bitmap Index Scan on projectpnameidx
           Index Cond: ((pname)::text = 'Aquarius'::text)
 -> Hash
    -> Seq Scan on employee e
       Filter: ((bdate)::text > '1957-12-31'::text)
```

Relational Algebra – Why (do we have to learn this)?

- as functions of "procedural" DB interfaces

Example (computations with SPARK data frames)

```
mDF.join(pDF,pDF("made") === mDF("name"))
 .select(mDF("name"),pDF("name"))
 .except(mDF
   .join(pDF,pDF("made") === mDF("name"))
 .join(dDF,dDF("for") === pDF("id"))
 .select(mDF("name"),pDF("name")))
```

Operators of the Relational Algebra

basic operators

- σ: selection
- π: projection
- $\cup$: union
- $-$: set difference
- $\times$: Cartesian product (cross product)
- ρ: renaming

Operators of the Relational Algebra

basic operators

σ: selection

π: projection

$\cup$: union

$-$: set difference

$\times$: Cartesian product (cross product)

ρ: renaming

$\bowtie$: join

$⟕$, $⟖$ bzw. $⟗$: left, right resp. full outer join

$\ltimes$ bzw. $\rtimes$: left resp. right semi-join

$\cap$: intersection

$\div$: division

Selection: $\sigma_F(R)$

Example

find all students that are studying for more than 10 semesters

student		
matrNr	name	semester
24002	Xenokrates	18
25403	Jonas	12
26120	Fichte	10
26830	Aristoxenos	8
27550	Schopenhauer	6
28106	Carnap	3

Selection: $\sigma_F(R)$

Example

find all students that are studying for more than 10 semesters

$$\sigma_{\text{semester}>10}(\text{student})$$

student		
matrNr	name	semester
24002	Xenokrates	18
25403	Jonas	12
26120	Fichte	10
26830	Aristoxenos	8
27550	Schopenhauer	6
28106	Carnap	3

Selection: $\sigma_F(R)$

Example

find all students that are studying for more than 10 semesters

$$\sigma_{\text{semester}>10}(\text{student})$$

student

matrNr	name	semester
24002	Xenokrates	18
25403	Jonas	12
26120	Fichte	10
26830	Aristoxenos	8
27550	Schopenhauer	6
28106	Carnap	3

$\sigma_{\textbf{semester}>10}(\textbf{student})$

matrNr	name	semester
24002	Xenokrates	18
25403	Jonas	12

Selection: $\sigma_F(R)$

- selection of tuples of the relation R through the formula F
- F uses comparison operators $(=, \neq, \leq, \geq, >, <)$, logical operators $(\neg, \vee, \wedge)$, attribute names from R and constants

Definition ($\sigma_{\mathrm{F}}(\mathrm{R})$)

- schema: $att(\sigma_{\mathrm{F}}(\mathrm{R})) = att(R)$
- instance: $\sigma_{\mathrm{F}}(\mathrm{R}) = \{t \in R \mid t \text{ satisfies } F\}$

evaluation of F for tuple t: replace all attribute names in F by the respective value in t

Projection $\pi_{A_i}(R)$

Example

find all ranks for professors

professor

persNr	name	rank	room
2125	Sokrates	C4	226
2126	Russel	C4	232
2127	Kopernikus	C3	310
2133	Popper	C3	52
2134	Augustinus	C3	309
2136	Curie	C4	36

Projection $\pi_{A_i}(R)$

Example

find all ranks for professors

$$\pi_{rank}(professor)$$

professor

persNr	name	rank	room
2125	Sokrates	C4	226
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Projection $\pi_{A_i}(R)$

Example

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2134	Augustinus	C3	309
2136	Curie	C4	36

$\pi_{rank}(professor)$
rank
C3
C4

projection $\pi_{A_i}(R)$

- selection of a set of attributes A_i from a relation R
- attention: duplicates are eliminated

projection $\pi_{A_i}(R)$

- selection of a set of attributes A_i from a relation R
- attention: duplicates are eliminated

Definition ($\pi_{A_i}(R)$)

Let A_i be a subset of the attributes from R

- schema: $att(\pi_{A_i}(R)) = A_i$
- instance: $\{t' \mid \exists t \in R \colon t.A_i = t'\}$

Selection and Projection

student		
matrNr	name	semester
24002	Xenokrates	18
25403	Jonas	12
26830	Aristoxenos	8
27550	Schopenhauer	6
26120	Fichte	10
28106	Carnap	3

Selection and Projection

student		
matrNr	name	semester
24002	Xenokrates	18
25403	Jonas	12
26830	Aristoxenos	8
27550	Schopenhauer	6
26120	Fichte	10
28106	Carnap	3

selection: select tuples

Selection and Projection

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24002	Xenokrates	18
25403	Jonas	12
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selection: select tuples

Selection and Projection

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matrNr	name	semester
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25403	Jonas	12
26830	Aristoxenos	8
27550	Schopenhauer	6
26120	Fichte	10
28106	Carnap	3

selection: select tuples

projection: project to attributes (columns)

Selection and Projection

student		
matrNr	name	semester
24002	Xenokrates	18
25403	Jonas	12
26830	Aristoxenos	8
27550	Schopenhauer	6
26120	Fichte	10
28106	Carnap	3

student
matrNr
24002
25403
26830
27550
26120
28106

selection: select tuples

projection: project to attributes (columns)

Union $R \cup S$

Example

find the names of all professors and assistants

Union $R \cup S$

Example

find the names of all professors and assistants

$$\pi_{name}(professor)$$

$\pi_{\textbf{name}(\textbf{professor})}$
name
Sokrates
...
Curie

Union $R \cup S$

Example

find the names of all professors and assistants

$$\pi_{name}(professor) \quad \pi_{name}(assistant)$$

$\pi_{\textbf{name}(\textbf{professor})}$

name
Sokrates
...
Curie

$\pi_{\textbf{name}(\textbf{assistant})}$

name
Platon
...
Spinoza

Union $R \cup S$

Example

find the names of all professors and assistants

$$\pi_{name}(professor) \cup \pi_{name}(assistant)$$

$\pi_{\textbf{name}}(\textbf{professor})$

name
Sokrates
...
Curie

$\pi_{\textbf{name}}(\textbf{assistant})$

name
Platon
...
Spinoza

Union $R \cup S$

Example

find the names of all professors and assistants

$$\pi_{name}(professor) \cup \pi_{name}(assistant)$$

$\pi_{\mathbf{name}}(\mathbf{professor})$
name
Sokrates
...
Curie

$\pi_{\mathbf{name}}(\mathbf{assistant})$
name
Platon
...
Spinoza

$\pi_{name}(professor) \cup \pi_{name}(assistant)$
name
Sokrates
...
Kant
Platon
...
Spinoza

Union $R \cup S$

- defined on two relations R, S with equal schema
- returns all tuples that occur in R or in S

Definition ($R \cup S$)

- precondition: $att(R) = att(S)$
- schema: $att(R \cup S) = att(R)$
- instance: $\{t \mid t \in R \text{ oder } t \in S\}$

Set Difference $R - S$

Example

find the (matriculation number of) students who have not taken an exam yet

$\pi_{\mathbf{matrNr}}(\mathbf{student})$

matrNr
24002
25403
26120
26830
27550
28106
29120
29555

$\pi_{matrNr}(examine)$

matrNr
28106
25403
27550

Set Difference $R - S$

Example

find the (matriculation number of) students who have not taken an exam yet

$$\pi_{matrNr}(student) - \pi_{matrNr}(examine)$$

$\pi_{\mathbf{matrNr}}(\mathbf{student})$
matrNr
24002
25403
26120
26830
27550
28106
29120
29555

$\pi_{matrNr}(examine)$
matrNr
28106
25403
27550

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Faculty of Informatics

Set Difference $R - S$

Example

find the (matriculation number of) students who have not taken an exam yet

$$\pi_{matrNr}(student) - \pi_{matrNr}(examine)$$

$\pi_{\mathbf{matrNr}}(\mathbf{student})$

matrNr
24002
25403
26120
26830
27550
28106
29120
29555

$\pi_{matrNr}(examine)$

matrNr
28106
25403
27550

$\pi_{matrNr}(student) - \pi_{matrNr}(examine)$

matrNr
24002
26120
26830
29120
29555

Set Difference $R - S$

- defined on two relations R, S with equal schema
- returns all tuples that occur in R but not in S

Definition ($R - S$)

- precondition: $att(R) = att(S)$
- schema: $att(R - S) = att(R)$
- instance: $\{t \mid t \in R \text{ und } t \notin S\}$

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Cartesian Product $R \times S$

Example

find all pairs of students and entries in “attend”

$$\text{student} \times \text{attend}$$

student × attend				
matrNr	name	sem	attend.matrNr	lecNr
24002	Xenokrates	18	26120	5001
24002	Xenokrates	18	27550	5001
...	...	...	...	...
24002	Xenokrates	18	25403	5022
25403	Jonas	12	26120	5001
...	...	...	...	...
29555	Feuerbach	2	29555	5022
29555	Feuerbach	2	25403	5022

Cartesian Product $R \times S$

- combines each tuple from R with each tuple from S
- schema from $R \times S$ is the union of the attributes from R and S
- size of the result: $|R \times S| = |R| * |S|$
- the usually "nicer" operation is the join

Cartesian Product $R \times S$

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- schema from $R \times S$ is the union of the attributes from R and S
- size of the result: $|R \times S| = |R| * |S|$
- the usually "nicer" operation is the join

Definition ($R \times S$)

Let $att(R) = (A_1, \ldots, A_m)$ and $att(S) = (B_1, \ldots, B_n)$.

- schema: $att(R \times S) = (A_1, \ldots, A_m, B_1, \ldots, B_n)$ (ensure that attribute names do not occur twice)
- instance: $\{t \mid \exists t_1 \in R\colon t.[A_1, \ldots, A_m] = t_1$ and $\exists t_2 \in S\colon t.[B_1, \ldots, B_n] = t_2\}$

Renaming $\rho_X(R)$

Example (renaming of attributes)

find the lecNr of all lectures that do not have a precondition

lecture			
lecNr	title	SWS	persNr

presuppose	
preNr	sucNr

Renaming $\rho_X(R)$

Example (renaming of attributes)

find the lecNr of all lectures that do not have a precondition

$$\rho_{\mathrm{lecNr} \leftarrow \mathrm{sucNr}}(\mathit{presuppose})$$

lecture			
lecNr	title	SWS	persNr

presuppose	
preNr	sucNr

Renaming $\rho_X(R)$

Example (renaming of attributes)

find the lecNr of all lectures that do not have a precondition

$$\rho_{\text{lecNr} \leftarrow \text{sucNr}}(\textit{presuppose})$$

lecture			
lecNr	title	SWS	persNr

presuppose	
preNr	sucNr

$\rho_{\textbf{lecNr} \leftarrow \textbf{sucNr}}(\textbf{presuppose})$	
preNr	lecNr

Renaming $\rho_X(R)$

Example (renaming of attributes)

find the lecNr of all lectures that do not have a precondition

$$\rho_{\text{lecNr}\leftarrow\text{sucNr}}(\textit{presuppose})$$

lecture			
lecNr	title	SWS	persNr

presuppose	
preNr	sucNr

$\rho_{\textbf{lecNr}\leftarrow\textbf{sucNr}}(\textbf{presuppose})$	
preNr	lecNr

$$\pi_{\text{lecNr}}(\text{lecture}) - \pi_{\text{lecNr}}(\rho_{\text{lecNr}\leftarrow\text{sucNr}}(\text{presuppose}))$$

Renaming $\rho_X(R)$

Example (renaming of relations)

find all pairs of students (matrNr) who attend (at least) one lecture together

attend	
matrNr	lecNr

Renaming $\rho_X(R)$

Example (renaming of relations)

find all pairs of students (matrNr) who attend (at least) one lecture together

attend	
matrNr	lecNr

attend	
matrNr	lecNr

Renaming $\rho_X(R)$

Example (renaming of relations)

find all pairs of students (matrNr) who attend (at least) one lecture together

attend	
matrNr	lecNr

attend	
matrNr	lecNr

$\rho_{S1}(\text{attend}) \quad \rho_{S2}(\text{attend})$

S1	
matrNr	lecNr

S2	
matrNr	lecNr

Renaming $\rho_X(R)$

Example (renaming of relations)

find all pairs of students (matrNr) who attend (at least) one lecture together

attend	
matrNr	lecNr

attend	
matrNr	lecNr

$$\rho_{S1}(\text{attend}) \times \rho_{S2}(\text{attend})$$

$\rho_{S1}(\textbf{attend}) \times \rho_{S2}(\textbf{attend})$			
S1.matrNr	S1.lecNr	S2.matrNr	S2.lecNr

Renaming $\rho_X(R)$

Example (renaming of relations)

find all pairs of students (matrNr) who attend (at least) one lecture together

attend	
matrNr	lecNr

attend	
matrNr	lecNr

$$\sigma_{S1.lecNr=S2.lecNr}\left(\rho_{S1}(\text{attend}) \times \rho_{S2}(\text{attend})\right)$$

$\sigma_{S1.lecNr=S2.lecNr}\left(\rho_{S1}(\textbf{attend}) \times \rho_{S2}(\textbf{attend})\right)$			
S1.matrNr	S1.lecNr	S2.matrNr	S2.lecNr
26120	5001	26120	5001
26120	5001	27550	5001
29555	5022	25403	5022
...	...	...	...

Renaming $\rho_X(R)$

- renaming of attributes $\rho_{A \leftarrow B}(R)$:

  $\rho_{A \leftarrow B}(R)$ renames attribute B of the relation R to A

Renaming $\rho_X(R)$

- renaming of attributes $\rho_{A \leftarrow B}(R)$:

  $\rho_{A \leftarrow B}(R)$ renames attribute B of the relation R to A

- renaming of relations $\rho_V(R)$

  relation R is renamed to V

Primitive Operators of the Relational Algebra

$\sigma_F(R)$: selection of tuples in R that satisfy F

$\pi_{A_i}(R)$: projection of attributes A_i

ρ: renaming of attributes or relations

$\cup$: union

$-$: set difference

$\times$ Cartesian product (cross product)

The Natural Join

Example (a very common kind of query)

Which students attend which lectures?

student		
matrNr	name	sem
26120	Fichte	10
25403	Jonas	12
...	...	...

attend	
matrNr	lecNr
26120	5001
27550	5001
...	...

lecture		
lecNr	title	...
5001	Grundzüge	...
5041	Ethik	...
...	...	...

The Natural Join

Example (a very common kind of query)

Which students attend which lectures?

student

matrNr	name	sem
26120	Fichte	10
25403	Jonas	12
...	...	...

attend

matrNr	lecNr
26120	5001
27550	5001
...	...

lecture

lecNr	title	...
5001	Grundzüge	...
5041	Ethik	...
...	...	...

$$\text{student} \times \text{attend} \times \text{lecture}$$

The Natural Join

Example (a very common kind of query)

Which students attend which lectures?

student

matrNr	name	sem
26120	Fichte	10
25403	Jonas	12
...	...	...

attend

matrNr	lecNr
26120	5001
27550	5001
...	...

lecture

lecNr	title	...
5001	Grundzüge	...
5041	Ethik	...
...	...	...

$$\sigma_{\text{student.matrNr}=\text{attend.matrNr}}$$
$$(\text{student} \times \text{attend} \times \text{lecture})$$

The Natural Join

Example (a very common kind of query)

Which students attend which lectures?

student

matrNr	name	sem
26120	Fichte	10
25403	Jonas	12
...	...	...

attend

matrNr	lecNr
26120	5001
27550	5001
...	...

lecture

lecNr	title	...
5001	Grundzüge	...
5041	Ethik	...
...	...	...

$$\sigma_{\text{student.matrNr}=\text{attend.matrNr} \wedge \text{lecture.lecNr}=\text{attend.lecNr}}$$
$$(\text{student} \times \text{attend} \times \text{lecture})$$

The Natural Join $R \bowtie S$

Example

Which students attend which lectures?

$$\pi_{St.MNr,N,S,VNr}(\sigma_{\text{student.matrNr}=\text{attend.matrNr}}(\text{student} \times \text{attend}))$$

student ⋈ attend

student		
matrNr	name	sem
24002	Xenokrates	18
...	...	...

attend	
matrNr	lecNr
26120	5001
...	...

student ⋈ attend			
matrNr	name	sem	lecNr
26120	Fichte	10	5001
27550	Schopenhauer	6	5001
27550	Schopenhauer	6	4052
28106	Carnap	3	5041
28106	Carnap	3	5001
...	...	...	...

The Natural Join $R \bowtie S$

- combines two relations R, S

1. constructs the Cartesian product of a relation
2. selects the tuples that take the same value on same attributes
3. removes attributes that occur twice
4. (degenerates to the Cartesian product in case there are no attributes with same names)

The Natural Join $R \bowtie S$

- combines two relations R, S
    1. constructs the Cartesian product of a relation
    2. selects the tuples that take the same value on same attributes
    3. removes attributes that occur twice
    4. (degenerates to the Cartesian product in case there are no attributes with same names)

$R \bowtie S$											
$att(R) \setminus att(S)$				$att(R) \cap att(S)$				$att(S) \setminus att(R)$			
A_1	A_2	$\dots$	A_m	B_1	B_2	$\dots$	B_k	C_1	C_2	$\dots$	C_n
$\dots$	$\dots$	$\dots$	$\dots$	$\dots$	$\dots$	$\dots$	$\dots$	$\dots$	$\dots$	$\dots$	$\dots$

The Natural Join $R \bowtie S$

Definition (natural join)

Let R, S be given with the following schemata: $R(A_1, \ldots, A_m, B_1, \ldots B_k)$ and $S(B_1, \ldots B_k, C_1, \ldots C_n)$. The natural join is defined as

$$R \bowtie S = \pi_{A_1,\ldots A_m, R.B_1,\ldots R.B_k, C_1,\ldots C_n} \sigma_{R.B_1=S.B_1 \wedge \cdots \wedge R.B_k=S.B_k}(R \times S)$$

$R \bowtie S$											
$att(R) \setminus att(S)$				$att(R) \cap att(S)$				$att(S) \setminus att(R)$			
A_1	A_2	$\ldots$	A_m	B_1	B_2	$\ldots$	B_k	C_1	C_2	$\ldots$	C_n
$\ldots$	$\ldots$	$\ldots$	$\ldots$	$\ldots$	$\ldots$	$\ldots$	$\ldots$	$\ldots$	$\ldots$	$\ldots$	$\ldots$

Ex: The Natural Join

Which students attend which lecture?

student

matrNr	name	sem
24002	Xenokrates	18
25403	Jonas	12
...	...	...

attend

matrNr	lecNr
26120	5001
27550	5001
...	...

lecture

lecNr	title	SWS	persNr
5001	Grundzüge	4	2137
5041	Ethik	4	2125
...	...	...	...

Ex: The Natural Join

student ⋈ *attend* ⋈ *lecture*						
matrNr	name	sem	lecNr	title	SWS	persNr
26120	Fichte	10	5001	Grundzüge	4	2137
27550	Schopenhauer	6	5001	Grundzüge	4	2137
27550	Schopenhauer	6	4052	Logik	4	2125
28106	Carnap	3	5041	Ethik	4	2125
28106	Carnap	3	5001	Grundzüge	4	2137
28106	Carnap	3	4052	Logik	4	2125
28106	Carnap	3	4630	Die drei Kritiken	4	2137
29120	Theophrastos	2	5001	Grundzüge	4	2137
29120	Theophrastos	2	5041	Ethik	4	2125
29120	Theophrastos	2	5049	Mäeutik	2	2125
29555	Feuerbach	2	5022	Glaube und Wissen	2	2134
25403	Jonas	12	5022	Glaube und Wissen	2	2134

Definition: Expressions of the Relational algebra

Definition (relational algebra)

the basic expressions of the relational algebra are:

- relations of the data base or
- constant relations

Definition: Expressions of the Relational algebra

Definition (relational algebra)

the basic expressions of the relational algebra are:

- relations of the data base or
- constant relations

let R and S be expressions of the relational algebra, then so are:

- $\sigma_F(R)$ and $\pi_{A_i}(R)$
- $R \cup S$, $R - S$, and $R \times S$
- $\rho_{A \leftarrow B}(R)$ and $\rho_V(R)$

Expressions of the Relational Algebra

Example

$$\pi_{name}(\sigma_{R.MN=St.MN}(\rho_R(\pi_{MN}(student) - \pi_{MN}(attend)) \times student)) \cup \pi_{name}(professor)$$

Expressions of the Relational Algebra

Example

$$\pi_{name}(\sigma_{R.MN=St.MN}(\rho_R(\pi_{MN}(student) - \pi_{MN}(attend)) \times student)) \cup \pi_{name}(professor)$$

professor

student

student

attend

Expressions of the Relational Algebra

Example

$$\pi_{name}(\sigma_{R.MN=St.MN}(\rho_R(\pi_{MN}(student) - \pi_{MN}(attend)) \times student)) \cup \pi_{name}(professor)$$

π_{name}

professor

student

π_{matrNr}

student

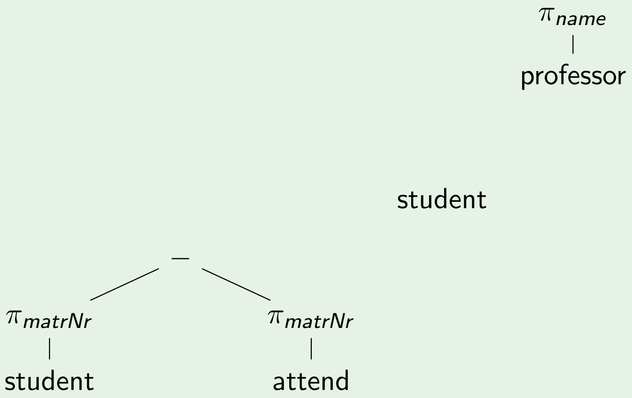
π_{matrNr}

attend

Expressions of the Relational Algebra

Example

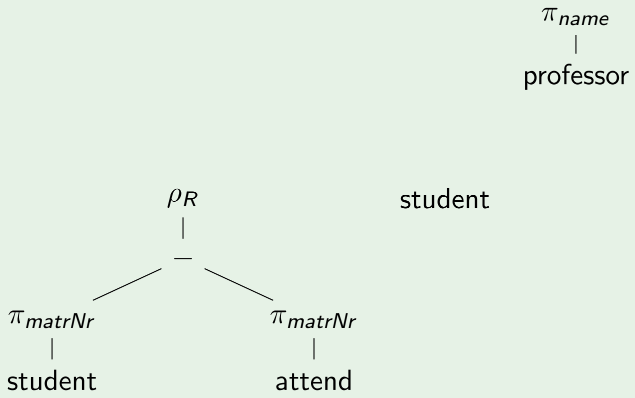
$$\pi_{name}(\sigma_{R.MN=St.MN}(\rho_R(\pi_{MN}(student) - \pi_{MN}(attend)) \times student)) \cup \pi_{name}(professor)$$



Expressions of the Relational Algebra

Example

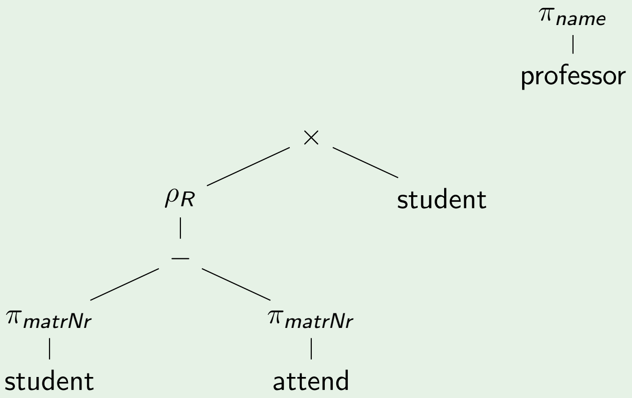
$$\pi_{name}(\sigma_{R.MN=St.MN}(\rho_R(\pi_{MN}(student) - \pi_{MN}(attend)) \times student)) \cup \pi_{name}(professor)$$



Expressions of the Relational Algebra

Example

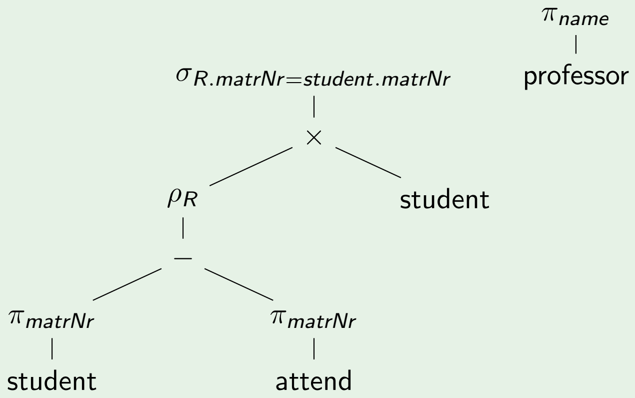
$$\pi_{name}(\sigma_{R.MN=St.MN}(\rho_R(\pi_{MN}(student) - \pi_{MN}(attend))\times student)) \cup \pi_{name}(professor)$$



Expressions of the Relational Algebra

Example

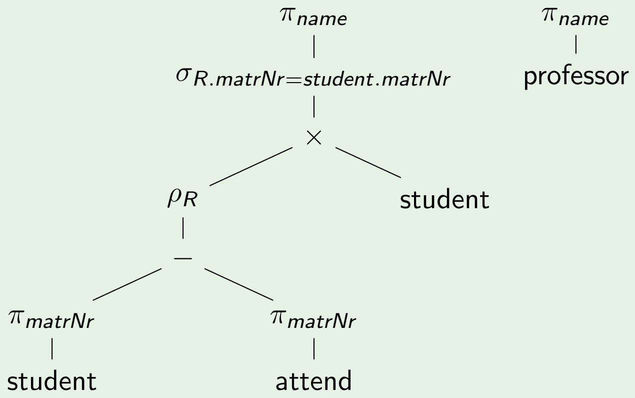
$$\pi_{name}(\sigma_{R.MN=St.MN}(\rho_R(\pi_{MN}(student) - \pi_{MN}(attend)) \times student)) \cup \pi_{name}(professor)$$



Expressions of the Relational Algebra

Example

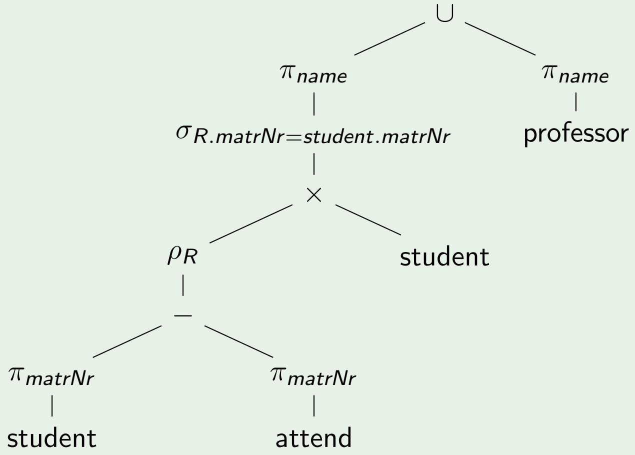
$$\pi_{name}(\sigma_{R.MN=St.MN}(\rho_R(\pi_{MN}(student) - \pi_{MN}(attend)) \times student)) \cup \pi_{name}(professor)$$



Expressions of the Relational Algebra

Example

$$\pi_{name}(\sigma_{R.MN=St.MN}(\rho_R(\pi_{MN}(student) - \pi_{MN}(attend)) \times student)) \cup \pi_{name}(professor)$$



Expressions of the Relational Algebra

Example

$$\pi_{name}(\sigma_{R.MN=St.MN}(\rho_R(\pi_{MN}(student) - \pi_{MN}(attend)) \times student)) \cup \pi_{name}(professor)$$

Expressions of the Relational Algebra

Example

$$\pi_{name}(\sigma_{R.MN=St.MN}(\rho_R(\pi_{MN}(student) - \pi_{MN}(attend)) \times student)) \cup \pi_{name}(professor)$$

Expressions of the Relational Algebra

Example

$$\pi_{name}(\sigma_{R.MN=St.MN}(\rho_R(\pi_{MN}(student) - \pi_{MN}(attend)) \times student)) \cup \pi_{name}(professor)$$

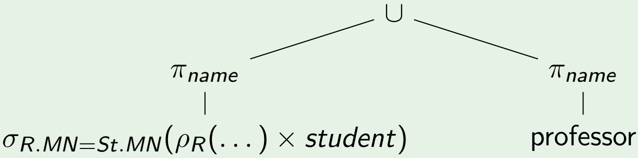
$$\cup$$

$$\pi_{name}(\sigma_{R1.MN=St.MN}(\dots)) \qquad \pi_{name}(professor)$$

Expressions of the Relational Algebra

Example

$$\pi_{name}(\sigma_{R.MN=St.MN}(\rho_R(\pi_{MN}(student) - \pi_{MN}(attend)) \times student)) \cup \pi_{name}(professor)$$



Expressions of the Relational Algebra

Example

$$\pi_{name}(\sigma_{R.MN=St.MN}(\rho_R(\pi_{MN}(student) - \pi_{MN}(attend)) \times student)) \cup \pi_{name}(professor)$$

$$\begin{tikzcd}[column sep=small]
 & & \cup \arrow[dll, dash] \arrow[drr, dash] & & \\
\pi_{name} \arrow[d, dash] & & & & \pi_{name} \arrow[d, dash] \\
\sigma_{R.MN=St.MN} \arrow[d, dash] & & & & \text{professor} \\
\rho_R(\pi_{MN}(student) - \pi_{MN}(attend)) \times student & & & &
\end{tikzcd}$$

Expressions of the Relational Algebra

Example

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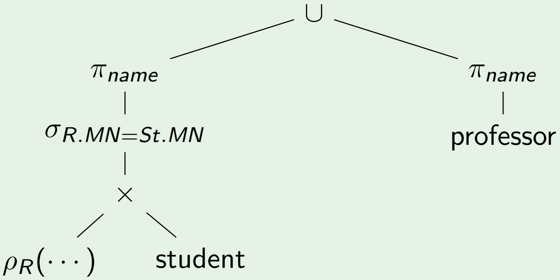

Expressions of the Relational Algebra

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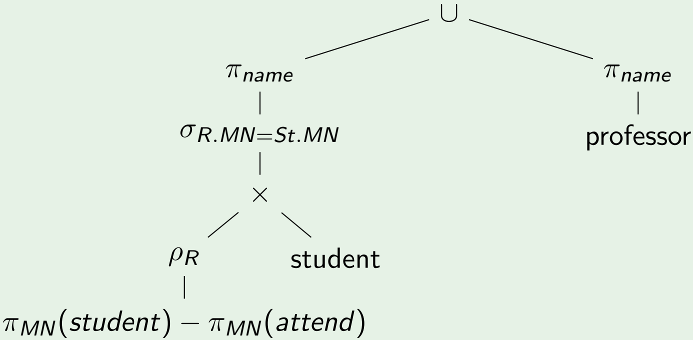

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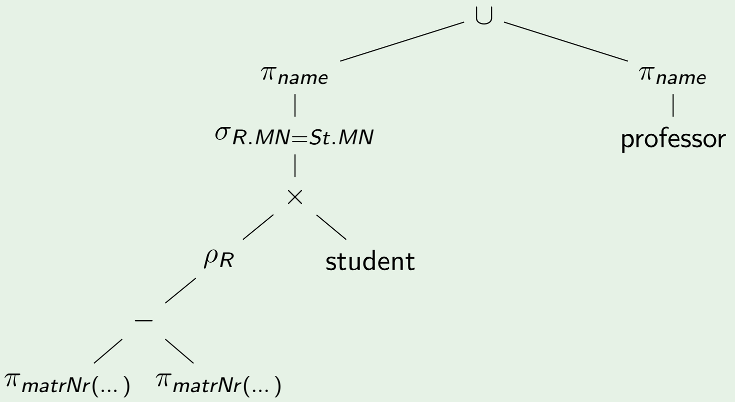

Expressions of the Relational Algebra

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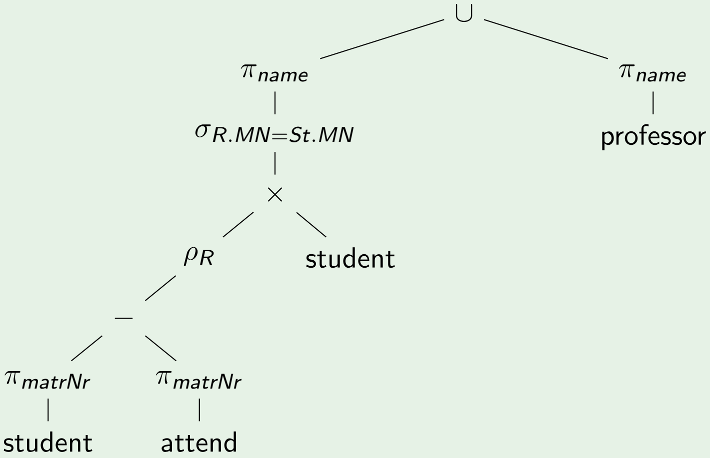

Ex: Evaluation of an Expression of the RA

schema:

$$R(A, B, C),\ S(B, D, E),\ T(A, C, D)$$

query:

$$\pi_{ACD}(\sigma_{E<5 \wedge C \neq 2}(R \bowtie S)) - T$$

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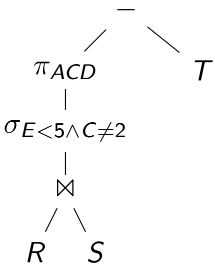

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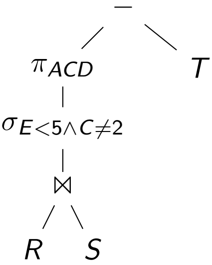

R		
A	B	C
1	2	3
7	1	4
2	4	3
3	4	7
1	1	1
7	4	2

S		
B	D	E
8	3	1
4	9	9
4	4	1
1	7	7
3	7	7

T		
A	C	D
1	3	3
3	7	4
7	4	9
7	2	7

Ex: Evaluation of an Expression of the RA

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$$R(A, B, C),\ S(B, D, E),\ T(A, C, D)$$

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8	3	1
4	9	9
4	4	1
1	7	7
3	7	7

T		
A	C	D
1	3	3
3	7	4
7	4	9
7	2	7

$$\begin{tikzcd} & - \arrow[dl, no head] \arrow[dr, no head] & \\ \pi_{ACD} \arrow[d, no head] & & T \\ \sigma_{E<5 \wedge C \neq 2} \arrow[d, no head] & & \\ {} & & \end{tikzcd}$$

A	B	C	D	E
7	1	4	7	7
2	4	3	9	9
2	4	3	4	1
3	4	7	9	9
3	4	7	4	1
1	1	1	7	7
7	4	2	9	9
7	4	2	4	1

Ex: Evaluation of an Expression of the RA

schema:

$$R(A,B,C),\ S(B,D,E),\ T(A,C,D)$$

query:

$$\pi_{ACD}(\sigma_{E<5 \wedge C \neq 2}(R \bowtie S)) - T$$

R		
A	*B*	*C*
1	2	3
7	1	4
2	4	3
3	4	7
1	1	1
7	4	2

S		
B	*D*	*E*
8	3	1
4	9	9
4	4	1
1	7	7
3	7	7

T		
A	*C*	*D*
1	3	3
3	7	4
7	4	9
7	2	7

$-$

π_{ACD} $\quad$ T

A	*B*	*C*	*D*	*E*
2	4	3	4	1
3	4	7	4	1

Ex: Evaluation of an Expression of the RA

schema:

$$R(A, B, C),\ S(B, D, E),\ T(A, C, D)$$

query:

$$\pi_{ACD}(\sigma_{E<5 \wedge C \neq 2}(R \bowtie S)) - T$$

R		
A	B	C
1	2	3
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S		
B	D	E
8	3	1
4	9	9
4	4	1
1	7	7
3	7	7

T		
A	C	D
1	3	3
3	7	4
7	4	9
7	2	7

$-$

A	C	D
2	3	4
3	7	4

T

Ex: Evaluation of an Expression of the RA

A	C	D
2	3	4

schema:

$$R(A, B, C),\ S(B, D, E),\ T(A, C, D)$$

query:

$$\pi_{ACD}(\sigma_{E<5 \wedge C \neq 2}(R \bowtie S)) - T$$

R

A	B	C
1	2	3
7	1	4
2	4	3
3	4	7
1	1	1
7	4	2

S

B	D	E
8	3	1
4	9	9
4	4	1
1	7	7
3	7	7

T

A	C	D
1	3	3
3	7	4
7	4	9
7	2	7

The General Join $R \bowtie_\theta S$

- combines two relations R, S, also in case they do not have attributes with the same name

  based on a logical condition θ

The General Join $R \bowtie_\theta S$

- combines two relations R, S, also in case they do not have attributes with the same name

  based on a logical condition θ

Definition

Let R and S be given with the following schemata:
$R(A_1, \ldots, A_n)$ and $S(B_1, \ldots, B_m)$.
Let θ be a predicate over the attributes $A_1, \ldots, A_n, B_1, \ldots, B_m$.
The general join is defined as

$$R \bowtie_\theta S = \sigma_\theta(R \times S)$$

The General Join $R \bowtie_\theta S$

- combines two relations R, S, also in case they do not have attributes with the same name

  based on a logical condition θ

Example (θ)

$$\begin{aligned}
\theta &= sem > 10 \wedge SWS = 4 \vee persNr = 2134 \\
\theta &= student.matrNr = attend.matrNr \wedge \\
&\quad attend.lecNr = lecture.lecNr \\
\theta &= lecture.lecNr = presuppose.preNr
\end{aligned}$$

Other Joins

natural join (revised): only those tuples that have found a "join-partner" remain in the result

L		
A	B	C
a_1	b_1	c_1
a_2	b_2	c_2

$\bowtie$

R		
C	D	E
c_1	d_1	e_1
c_3	d_2	e_2

$=$

$L \bowtie R$				
A	B	C	D	E
a_1	b_1	c_1	d_1	e_1

Other Joins

natural join (revised): only those tuples that have found a "join-partner" remain in the result

L		
A	B	C
a_1	b_1	c_1
a_2	b_2	c_2

$\bowtie$

R		
C	D	E
c_1	d_1	e_1
c_3	d_2	e_2

$=$

$L \bowtie R$				
A	B	C	D	E
a_1	b_1	c_1	d_1	e_1

full outer join: all tuples remain in the result

L		
A	B	C
a_1	b_1	c_1
a_2	b_2	c_2

$⟗$

R		
C	D	E
c_1	d_1	e_1
c_3	d_2	e_2

$=$

$L ⟗ R$				
A	B	C	D	E
a_1	b_1	c_1	d_1	e_1
a_2	b_2	c_2	NULL	NULL
NULL	NULL	c_3	d_2	e_2

Other Joins

left outer join: tuple from the left relation remain in the result

L		
A	B	C
a_1	b_1	c_1
a_2	b_2	c_2

$⟕$

R		
C	D	E
c_1	d_1	e_1
c_3	d_2	e_2

$=$

$L ⟕ R$				
A	B	C	D	E
a_1	b_1	c_1	d_1	e_1
a_2	b_2	c_2	NULL	NULL

Other Joins

left outer join: tuple from the left relation remain in the result

L		
A	B	C
a_1	b_1	c_1
a_2	b_2	c_2

$⟕$

R		
C	D	E
c_1	d_1	e_1
c_3	d_2	e_2

$=$

$L ⟕ R$				
A	B	C	D	E
a_1	b_1	c_1	d_1	e_1
a_2	b_2	c_2	NULL	NULL

right outer join: tuples from the right relation remain in the result

L		
A	B	C
a_1	b_1	c_1
a_2	b_2	c_2

$⟖$

R		
C	D	E
c_1	d_1	e_1
c_3	d_2	e_2

$=$

$L ⟖ R$				
A	B	C	D	E
a_1	b_1	c_1	d_1	e_1
NULL	NULL	c_3	d_2	e_2

Other Joins

semi-join from L with R (resp. R with L): all tuples from the relation L
(resp. R) that can be joined are selected

L		
A	B	C
a_1	b_1	c_1
a_2	b_2	c_2

$\ltimes$

R		
C	D	E
c_1	d_1	e_1
c_3	d_2	e_2

$=$

$L \ltimes R$		
A	B	C
a_1	b_1	c_1

L		
A	B	C
a_1	b_1	c_1
a_2	b_2	c_2

$\rtimes$

R		
C	D	E
c_1	d_1	e_1
c_3	d_2	e_2

$=$

$L \rtimes R$		
C	D	E
c_1	d_1	e_1

Intersection $R \cap S$

- defined on two relations R, S with the same schema
- returns all rows that occur in R and in S
- can be expressed via set-difference:

$$R \cap S = R - (R - S)$$

Intersection $R \cap S$

- defined on two relations R, S with the same schema
- returns all rows that occur in R and in S
- can be expressed via set-difference:

$$R \cap S = R - (R - S)$$

Example

find the persNr of C4-professors that give a lecture

$\pi_{persNr}(lecture) \cap \pi_{persNr}\sigma_{rank=C4}(professor)$

persNr
2137
2125
2126
2137

Relational Division $R \div S$

Example

Which studends have attended all 4h lectures?

attend

matrNr	lecNr
26120	5001
27550	5001
27550	4052
28106	5041
28106	5001
28106	4052
28106	4630
29120	5001
29120	5041
29120	5049

$\div$

$\pi_{lecNr}\sigma_{SWS=4}(lecture)$

lecNr
5001
5041
4052
4630

$=$

$R \div S$

matrNr
28106

FAKULTÄT FÜR INFORMATIK
Faculty of Informatics

Relational Division $R \div S$

Example

Which studends have attended all 4h lectures?

attend

matrNr	lecNr
26120	5001
27550	5001
27550	4052
28106	5041
28106	5001
28106	4052
28106	4630
29120	5001
29120	5041
29120	5049

$$attend \div \pi_{lecNr} \sigma_{SWS=4}(lecture)$$

$\div$

$\pi_{lecNr} \sigma_{SWS=4}(lecture)$

lecNr
5001
5041
4052
4630

$=$

$R \div S$

matrNr
28106

Relational Division $R \div S$

- defined on two relations R, S
- schema of S has to be a subset of the schema of R
- resulting schema: attributes of R without the ones from S
- result contains all tuples from $\pi_{att(R) \setminus att(S)}(R)$ that form a tuple in R with the ones in S
- counterpart to the Cartesian product:

$$T = U \times V \Rightarrow T \div U = V \text{ and } T \div V = U$$

- can be expressed by

$$R \div S = \pi_{\mathcal{R}-\mathcal{S}}(R) - \pi_{\mathcal{R}-\mathcal{S}}((\pi_{\mathcal{R}-\mathcal{S}}(R) \times S) - R)$$

(with $\mathcal{R} = att(R)$ and $\mathcal{S} = att(S)$)

Relational Division $R \div S$

Definition

Let R, S be relations, where $\mathcal{S} \subseteq \mathcal{R}$. Tuple $t \in R \div S$ in case there is for every tuple $s \in S$ a tuple $r \in R$ with:

$$\begin{aligned} r.\mathcal{S} &= s \\ r.(\mathcal{R} - \mathcal{S}) &= t \end{aligned}$$

More Examples

Example

find the lecNr of all the lectures that are second-level predecessors of lecture 5216 (= predecessor of predecessor of 5216)

presuppose	
predNr	sucNr

presuppose	
predNr	sucNr

More Examples

Example

find the lecNr of all the lectures that are second-level predecessors of lecture 5216 (= predecessor of predecessor of 5216)

$$\rho_{V_1}(\text{presuppose}) \quad \rho_{V2}(\text{presuppose})$$

presuppose	
predNr	sucNr

presuppose	
predNr	sucNr

More Examples

Example

find the lecNr of all the lectures that are second-level predecessors of lecture 5216 (= predecessor of predecessor of 5216)

$$\rho_{V_1}(\text{presuppose}) \quad \rho_{V2}(\text{presuppose})$$

presuppose	
predNr	sucNr

V_1	
predNr	sucNr

presuppose	
predNr	sucNr

V_2	
preNr	sucNr

More Examples

Example

find the lecNr of all the lectures that are second-level predecessors of lecture 5216 (= predecessor of predecessor of 5216)

$\rho_{V_1}(\text{presuppose}) \quad \rho_{V2}(\text{presuppose})$

presuppose	
predNr	sucNr

V_1	
predNr	sucNr

presuppose	
predNr	sucNr

V_2	
preNr	sucNr

$$\pi_{V_1.predNr}\left(\sigma_{V_1.sucNr=V_2.predNr \land V_2.sucNr=5216}\right.$$
$$\left.(\rho_{V_1}(presuppose) \times \rho_{V2}(presuppose))\right)$$

Learning Objectives

- What does it mean for a query language to be relationally closed?
- How are operators of the relational algebra defined?
- What are the operators of the relational algebra?
- What are correct expressions in the relational algebra?

Overview

Query Languages

- Relational Algebra
- Relational Calculus
- Expressive Power of Query Languages

Relational Calculus

The Relational Calculus

declarative query language: specifies which data is demanded, not how it is obtained

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set-oriented language: operations on sets of tuples

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queries in the relational calculus are of the form

$$\{t \mid P(t)\}$$

where $P(t)$ is a formula

The Relational Calculus

declarative query language: specifies which data is demanded, not how it is obtained

set-oriented language: operations on sets of tuples

queries in the relational calculus are of the form

$$\{t \mid P(t)\}$$

where $P(t)$ is a formula
there are two distinct, but equally powerful variations:

- the tuple relational calculus
- the domain relational calculus

The Tuple Relational Calculus

The Tuple Relational Calculus

Example

professor(persNr, name, rank, room)

- find all C4-professors

The Tuple Relational Calculus

Example

professor(persNr, name, rank, room)

- find all C4-professors

$$\{p \mid p \in professor \wedge p.rank = \text{‘C4’}\}$$

The Tuple Relational Calculus

Example

professor(persNr, name, rank, room)

- find all C4-professors

$$\{p \mid p \in professor \wedge p.rank = \text{`C4'}\}$$

- find the names of all C4-professors:

$$\{[p.name] \mid p \in professor \wedge p.rank = \text{`C4'}\}$$

The Tuple Relational Calculus

Example

professor(persNr, name, rank, room)
assistant(persNr, name, birthDate, boss)

- find pairs of professors and their respective assistants

$$\begin{aligned}\{[p.name, a.persNr] \mid p &\in \text{professor} \land \\ a &\in \text{assistant} \land \\ &p.persNr = a.boss\}\end{aligned}$$

The Tuple Relational Calculus

Example

$$\{[p.name, a.persNr] \mid p \in \text{profs} \wedge a \in \text{ass} \wedge p.\text{persNr} = a.\text{boss}\}$$

professor			
persNr	name	...	...
2125	Sokrates	...	...
2126	Russel	...	...
2127	Kopernikus	...	...

assistant			
persNr	...	...	boss
3002	...	...	2125
3003	...	...	2125
3004	...	...	2126

The Tuple Relational Calculus

Example

$$\{[p.name, a.persNr] \mid p \in \text{profs} \wedge a \in \text{ass} \wedge p.\text{persNr} = a.\text{boss}\}$$

professor

persNr	name	...	...
2125	Sokrates	...	...
2126	Russel	...	...
2127	Kopernikus	...	...

assistant

persNr	...	...	boss
3002	...	...	2125
3003	...	...	2125
3004	...	...	2126

result

name	persNr

The Tuple Relational Calculus

Example

$$\{[p.name, a.persNr] \mid p \in \text{profs} \wedge a \in \text{ass} \wedge p.\text{persNr} = a.\text{boss}\}$$

$p =$ (first professor row), $= a$ (first assistant row)

professor			
persNr	name	...	...
2125	Sokrates	...	...
2126	Russel	...	...
2127	Kopernikus	...	...

assistant			
persNr	...	...	boss
3002	...	...	2125
3003	...	...	2125
3004	...	...	2126

result	
name	persNr
Sokrates	3002

The Tuple Relational Calculus

Example

$$\{[p.name, a.persNr] \mid p \in \text{profs} \wedge a \in \text{ass} \wedge p.\text{persNr} = a.\text{boss}\}$$

professor

persNr	name	...	...
2125	Sokrates	...	...
2126	Russel	...	...
2127	Kopernikus	...	...

$p =$ (row 2125 Sokrates)

assistant

persNr	...	...	boss
3002	...	...	2125
3003	...	...	2125
3004	...	...	2126

$= a$ (row 3003)

result

name	persNr
Sokrates	3002
Sokrates	3003

The Tuple Relational Calculus

Example

$$\{[p.name, a.persNr] \mid p \in \text{profs} \wedge a \in \text{ass} \wedge p.\text{persNr} = a.\text{boss}\}$$

professor			
persNr	name	...	...
2125	Sokrates	...	...
2126	Russel	...	...
2127	Kopernikus	...	...

$p =$ (row 2125 Sokrates)

assistant			
persNr	...	...	boss
3002	...	...	2125
3003	...	...	2125
3004	...	...	2126

$= a$ (row 3004)

result	
name	persNr
Sokrates	3002
Sokrates	3003

The Tuple Relational Calculus

Example

$$\{[p.name, a.persNr] \mid p \in \text{profs} \wedge a \in \text{ass} \wedge p.\text{persNr} = a.\text{boss}\}$$

professor

persNr	name	...	...
2125	Sokrates	...	...
2126	Russel	...	...
2127	Kopernikus	...	...

$p =$ (row 2126)

assistant

persNr	...	...	boss
3002	...	...	2125
3003	...	...	2125
3004	...	...	2126

$= a$ (row 3004)

result

name	persNr
Sokrates	3002
Sokrates	3003
Russel	3004

The Tuple Relational Calculus

Example

student(matrNr, name, semester)
attend(matrNr, lecNr)
lectures(lecNr, title, SWS, heldBy)

- students who attend at lest one lecture

The Tuple Relational Calculus

Example

student(matrNr, name, semester)
attend(matrNr, lecNr)
lectures(lecNr, title, SWS, heldBy)

- students who attend at lest one lecture

$$\{s \mid s \in student \wedge \exists a \in attend(s.matrNr = a.matrNr)\}$$

The Tuple Relational Calculus

Example

student(matrNr, name, semester)
attend(matrNr, lecNr)
lectures(lecNr, title, SWS, heldBy)

- students who attend at lest one lecture

$$\{s \mid s \in student \land \exists a \in attend(s.matrNr = a.matrNr)\}$$

- matrNr of the students that attend all lectures

$$\begin{aligned}\{[s.matrNr] \mid s \in\ & student \land \forall l \in lecture(\\ & \exists a \in attend(a.lecNr = l.lecNr \\ & \land a.matrNr = s.matrNr))\}\end{aligned}$$

The Tuple Relational Calculus

Example (queries in the tuple relational calculus)

student	
matrNr	...
24002	...
25403	...
26120	...
26830	...

lecture		
lecNr	title	...
5041	Ethik	...
5049	Mäeutik	...
4052	Logik	...
5216	Bioethik	...

attend	
matrNr	lecNr
26120	5041
26830	5041
29120	5049
24002	4052
26120	4052
25403	5216
26120	5216

$$\{ \quad [s.matrNr] \mid s \in student \land \forall l \in lecture(\\ \exists a \in attend(a.lecNr = l.lecNr \land a.matrNr = s.matrNr))\}$$

The Tuple Relational Calculus

Example (queries in the tuple relational calculus)

student

	matrNr	...
s	24002	...
	25403	...
	26120	...
	26830	...

lecture

lecNr	title	...
5041	Ethik	...
5049	Mäeutik	...
4052	Logik	...
5216	Bioethik	...

attend

matrNr	lecNr
26120	5041
26830	5041
29120	5049
24002	4052
26120	4052
25403	5216
26120	5216

$$\{ \quad [s.matrNr] \mid s \in student \wedge \forall l \in lecture(\\ \exists a \in attend(a.lecNr = l.lecNr \wedge a.matrNr = s.matrNr))\}$$

The Tuple Relational Calculus

Example (queries in the tuple relational calculus)

student

matrNr	...
s 24002	...
25403	...
26120	...
26830	...

lecture

lecNr	title	...
l 5041	Ethik	...
5049	Mäeutik	...
4052	Logik	...
5216	Bioethik	...

attend

matrNr	lecNr
26120	5041
26830	5041
29120	5049
24002	4052
26120	4052
25403	5216
26120	5216

$$\{ \quad [s.matrNr] \mid s \in student \wedge \forall l \in lecture(\\ \exists a \in attend(a.lecNr = l.lecNr \wedge a.matrNr = s.matrNr))\}$$

The Tuple Relational Calculus

Example (queries in the tuple relational calculus)

student	
matrNr	...
s 24002	...
25403	...
26120	...
26830	...

lecture		
lecNr	title	...
l 5041	Ethik	... ✗
5049	Mäeutik	...
4052	Logik	...
5216	Bioethik	...

attend	
matrNr	lecNr
26120	5041
26830	5041
29120	5049
24002	4052
26120	4052
25403	5216
26120	5216

$$\{ \quad [s.matrNr] \mid s \in student \land \forall l \in lecture(\\ \exists a \in attend(a.lecNr = l.lecNr \land a.matrNr = s.matrNr))\}$$

The Tuple Relational Calculus

Example (queries in the tuple relational calculus)

student

matrNr	...
24002	...
25403	...
26120	...
26830	...

lecture

lecNr	title	...
5041	Ethik	... ✗
5049	Mäeutik	...
4052	Logik	...
5216	Bioethik	...

attend

matrNr	lecNr
26120	5041
26830	5041
29120	5049
24002	4052
26120	4052
25403	5216
26120	5216

$$\{ \quad [s.matrNr] \mid s \in student \wedge \forall l \in lecture(\exists a \in attend(a.lecNr = l.lecNr \wedge a.matrNr = s.matrNr))\}$$

The Tuple Relational Calculus

Example (queries in the tuple relational calculus)

student

	matrNr	...
s	24002	...
	25403	...
	26120	...
	26830	...

lecture

	lecNr	title	...	
	5041	Ethik	...	✗
l	5049	Mäeutik	...	✗
	4052	Logik	...	
	5216	Bioethik	...	

attend

matrNr	lecNr
26120	5041
26830	5041
29120	5049
24002	4052
26120	4052
25403	5216
26120	5216

$$\{ \quad [s.matrNr] \mid s \in student \land \forall l \in lecture(\\ \exists a \in attend(a.lecNr = l.lecNr \land a.matrNr = s.matrNr))\}$$

The Tuple Relational Calculus

Example (queries in the tuple relational calculus)

student

	matrNr	...
s	24002	...
	25403	...
	26120	...
	26830	...

lecture

	lecNr	title	...	
	5041	Ethik	...	✗
	5049	Mäeutik	...	✗
l	4052	Logik	...	
	5216	Bioethik	...	

attend

matrNr	lecNr
26120	5041
26830	5041
29120	5049
24002	4052
26120	4052
25403	5216
26120	5216

$$\{ \quad [s.matrNr] \mid s \in student \wedge \forall l \in lecture(\\ \exists a \in attend(a.lecNr = l.lecNr \wedge a.matrNr = s.matrNr))\}$$

The Tuple Relational Calculus

Example (queries in the tuple relational calculus)

student	
matrNr	...
24002	...
25403	...
26120	...
26830	...

lecture		
lecNr	title	...
5041	Ethik	... ✗
5049	Mäeutik	... ✗
4052	Logik	... ✓
5216	Bioethik	...

attend	
matrNr	lecNr
26120	5041
26830	5041
29120	5049
24002	4052
26120	4052
25403	5216
26120	5216

$$\{ \quad [s.matrNr] \mid s \in student \land \forall l \in lecture(\\ \exists a \in attend(a.lecNr = l.lecNr \land a.matrNr = s.matrNr))\}$$

The Tuple Relational Calculus

Example (queries in the tuple relational calculus)

student	
matrNr	...
s 24002	...
25403	...
26120	...
26830	...

lecture			
lecNr	title	...	
5041	Ethik	...	✗
5049	Mäeutik	...	✗
4052	Logik	...	✓
l 5216	Bioethik	...	✗

attend	
matrNr	lecNr
26120	5041
26830	5041
29120	5049
24002	4052
26120	4052
25403	5216
26120	5216

$$\{ \quad [s.matrNr] \mid s \in student \wedge \forall l \in lecture(\exists a \in attend(a.lecNr = l.lecNr \wedge a.matrNr = s.matrNr))\}$$

The Tuple Relational Calculus

Example (queries in the tuple relational calculus)

student	
matrNr	...
24002	...
25403	...
26120	...
26830	...

lecture		
lecNr	title	...
5041	Ethik	...
5049	Mäeutik	...
4052	Logik	...
5216	Bioethik	...

attend	
matrNr	lecNr
26120	5041
26830	5041
29120	5049
24002	4052
26120	4052
25403	5216
26120	5216

s

$$\{ \quad [s.matrNr] \mid s \in student \wedge \forall l \in lecture(\exists a \in attend(a.lecNr = l.lecNr \wedge a.matrNr = s.matrNr))\}$$

The Tuple Relational Calculus

Example (queries in the tuple relational calculus)

	student	
	matrNr	...
	24002	...
s	25403	...
	26120	...
	26830	...

lecture			
lecNr	title	...	
5041	Ethik	...	✗
5049	Mäeutik	...	✗
4052	Logik	...	✗
5216	Bioethik	...	✓

attend	
matrNr	lecNr
26120	5041
26830	5041
29120	5049
24002	4052
26120	4052
25403	5216
26120	5216

$$\{ \quad [s.matrNr] \mid s \in student \land \forall l \in lecture(\exists a \in attend(a.lecNr = l.lecNr \land a.matrNr = s.matrNr))\}$$

The Tuple Relational Calculus

Example (queries in the tuple relational calculus)

student

matrNr	...
24002	...
25403	...
26120	...
26830	...

s = 26120

lecture

lecNr	title	...
5041	Ethik	...
5049	Mäeutik	...
4052	Logik	...
5216	Bioethik	...

attend

matrNr	lecNr
26120	5041
26830	5041
29120	5049
24002	4052
26120	4052
25403	5216
26120	5216

$$\{ \quad [s.matrNr] \mid s \in student \land \forall l \in lecture(\\ \exists a \in attend(a.lecNr = l.lecNr \land a.matrNr = s.matrNr))\}$$

The Tuple Relational Calculus

Example (queries in the tuple relational calculus)

student	
matrNr	...
24002	...
25403	...
s 26120	...
26830	...

lecture		
lecNr	title	...
5041	Ethik	... ✓
5049	Mäeutik	... ✓
4052	Logik	... ✓
5216	Bioethik	... ✓

attend	
matrNr	lecNr
26120	5041
26830	5041
29120	5049
24002	4052
26120	4052
25403	5216
26120	5216

$$\{ \ [s.matrNr] \mid s \in student \land \forall l \in lecture(\exists a \in attend(a.lecNr = l.lecNr \land a.matrNr = s.matrNr))\}$$

The Tuple Relational Calculus

Example (queries in the tuple relational calculus)

student	
matrNr	...
24002	...
25403	...
26120	...
26830	...

lecture		
lecNr	title	...
5041	Ethik	...
5049	Mäeutik	...
4052	Logik	...
5216	Bioethik	...

attend	
matrNr	lecNr
26120	5041
26830	5041
29120	5049
24002	4052
26120	4052
25403	5216
26120	5216

$$\{ \quad [s.matrNr] \mid s \in student \wedge \forall l \in lecture(\\ \exists a \in attend(a.lecNr = l.lecNr \wedge a.matrNr = s.matrNr))\}$$

The Tuple Relational Calculus

Example (queries in the tuple relational calculus)

	student	
	matrNr	...
	24002	...
	25403	...
	26120	...
s	26830	...

lecture			
lecNr	title	...	
5041	Ethik	...	✓
5049	Mäeutik	...	✗
4052	Logik	...	✗
5216	Bioethik	...	✗

attend	
matrNr	lecNr
26120	5041
26830	5041
29120	5049
24002	4052
26120	4052
25403	5216
26120	5216

$$\{ \quad [s.matrNr] \mid s \in student \wedge \forall l \in lecture(\\ \exists a \in attend(a.lecNr = l.lecNr \wedge a.matrNr = s.matrNr))\}$$

The Tuple Relational Calculus

Example (queries in the tuple relational calculus)

student	
matrNr	...
24002	...
25403	...
26120	...
26830	...

lecture		
lecNr	title	...
5041	Ethik	...
5049	Mäeutik	...
4052	Logik	...
5216	Bioethik	...

attend	
matrNr	lecNr
26120	5041
26830	5041
29120	5049
24002	4052
26120	4052
25403	5216
26120	5216

$$\{ \quad [s.matrNr] \mid s \in student \wedge \forall l \in lecture(\\ \exists a \in attend(a.lecNr = l.lecNr \wedge a.matrNr = s.matrNr))\}$$

The Tuple Relational Calculus

Definition (syntax)

a tuple relational calculus query has the form:

$$\{t \mid P(t)\}$$

t ... tuple variable (sometimes tuple constructor); $P(t)$ ... formula, formulas are built from atoms (see definition)

The Tuple Relational Calculus

Definition (syntax)

a tuple relational calculus query has the form:

$$\{t \mid P(t)\}$$

t ... tuple variable (sometimes tuple constructor); $P(t)$ ... formula, formulas are built from atoms (see definition)

Definition (semantics)

A tuple t is in the result if it satisfies the formula $P(t)$.
The variable t is a free variable in the formula $P(t)$, therefore it is not bound by a quantifier ($\forall, \exists$).

The Tuple Relational Calculus

Definition (syntax: atoms and formulas)

atoms:

$t \in R$: t tuple variable; R relation name

$s.A \phi t.B$: s and t tuple variables; A and B attribute names; ϕ a comparison operator $(=, \neq, <, \leq, >, \geq)$

$s.A \phi c$: as above, c a constant

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Definition (syntax: atoms and formulas)

atoms:

$t \in R$: t tuple variable; R relation name

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$s.A\phi c$: as above, c a constant

formulas:

atoms are formulas

P formula, then so are $\neg P$ and (P)

P_1, P_2 formulas, then so are $P_1 \wedge P_2$, $P_1 \vee P_2$ and $P_1 \rightarrow P_2$

$P(t)$ formula with free variable t, then so are $\forall t \in R(P(t))$ and $\exists t \in R(P(t))$

The Tuple Relational Calculus

Example

student(matrNr, name, semester)
attend(matrNr, lecNr)
lecture(lecNr, title, SWS, givenBy)
professor(persNr, name, rank, room)

- students that attend at least one lecture given by Curie:

The Tuple Relational Calculus

Example

student(matrNr, name, semester)
attend(matrNr, lecNr)
lecture(lecNr, title, SWS, givenBy)
professor(persNr, name, rank, room)

- students that attend at least one lecture given by Curie:

$$\begin{aligned}\{s \mid s \quad &\in \quad student \wedge \exists a \in attend(s.matrNr = a.matrNr \\ &\wedge \quad \exists l \in lecture(a.lecNr = l.lecNr \\ &\wedge \quad \exists p \in professor(p.persNr = l.givenBy \\ &\wedge \quad p.name = \text{`Curie'})))\}\end{aligned}$$

The Tuple Relational Calculus

Example

student(matrNr, name, semester)
lecture(lecNr, title, SWS, givenBy)
attend(matrNr, lecNr)

- students that attend all 4h lectures

The Tuple Relational Calculus

Example

student(matrNr, name, semester)
lecture(lecNr, title, SWS, givenBy)
attend(matrNr, lecNr)

- students that attend all 4h lectures

$$\begin{aligned}\{s \mid s \;\in\; & \mathit{student} \wedge \forall v \in \mathit{lecture}(l.SWS \neq 4 \vee \\ & \exists a \in \mathit{attend}(a.lecNr = l.lecNr \\ & \wedge a.matrNr = s.matrNr))\}\end{aligned}$$

The Tuple Relational Calculus

Example

student(matrNr, name, semester)
assistant(persNr, name, birthDate, boss)
professor(persNr, name, rank, room)

- persNr of all professors and assistants

$$\{[p.persNr] \mid p \in professor \vee p \in assistant\}$$

- names of assistants that are also names of students

$$\begin{aligned}\{[p.name] \mid p \quad \in \quad & assistant \wedge \exists s \in student(\\ & p.name = s.name)\}\end{aligned}$$

The Tuple Relational Calculus

Example

assistant(persNr, name, birthDate, boss)
professor(persNr, name, rank, room)

- all assistants that are not professors

The Tuple Relational Calculus

Example

assistant(persNr, name, birthDate, boss)
professor(persNr, name, rank, room)

- all assistants that are not professors

$$\{a \mid a \in assistant \land \neg\exists p \in professor(p.persNr = a.persNr)\}$$

The Tuple Relational Calculus

Example

assistant(persNr, name, birthDate, boss)
professor(persNr, name, rank, room)

- all assistants that are not professors

$$\begin{aligned}\{a \mid a \ &\in \ assistant \land \neg\exists p \in professor(\\ &\quad p.persNr = a.persNr)\}\end{aligned}$$

$$\begin{aligned}\{a \mid a \ &\in \ assistant \land \forall p \in professor(\\ &\quad p.persNr \neq a.persNr\}\end{aligned}$$

The Domain Relational Calculus

The Domain Relational Calculus

Example

professor(persNr, name, rank, room)

- find all C4-professors

$$\{[p, n, r, o] \mid ([p, n, r, o] \in \mathit{professor} \wedge r = \text{‘C4’})\}$$

The Domain Relational Calculus

Example

professor(persNr, name, rank, room)

- find all C4-professors

$$\{[p, n, r, o] \mid ([p, n, r, o] \in professor \wedge r = \text{`C4'})\}$$

- find the names of all C4-professors

$$\{[n] \mid \exists p, o, r([p, n, r, o] \in professor \wedge r = \text{`C4'})\}$$

The Domain Relational Calculus

Example

professor(persNr, name, rank, room)
assistant(persNr, name, birthDate, boss)

- find pairs of professors and their corresponding assistants

$$\{[n, a] \mid \exists\ p, r, o([p, n, r, o] \in \mathit{professor} \wedge \exists\ m, f([a, m, f, p] \in \mathit{assistant}))\}$$

The Domain Relational Calculus

Example

student(matrNr, name, semester)
attend(matrNr, lecNr)
lecture(lecNr, title, SWS, givenBy)

- students that attend at least one lecture:

$$\{[m, n] \mid \exists s([m, n, s] \in \mathit{student} \land \exists v([m, v] \in \mathit{attend}))\}$$

The Domain Relational Calculus

Example

student(matrNr, name, semester)
attend(matrNr, lecNr)
lecture(lecNr, title, SWS, givenBy)

- students that attend at least one lecture:

$$\{[m, n] \mid \exists s([m, n, s] \in \mathit{student} \land \exists v([m, v] \in \mathit{attend}))\}$$

- matrNr of students that attend all lectures:

$$\begin{aligned}\{[m] \quad \mid \quad & \exists n, s([m, n, s] \in \mathit{student} \land \forall v, t, s, p \\ & ([v, t, s, p] \in \mathit{lecture} \rightarrow [m, v] \in \mathit{attend})\}\end{aligned}$$

The Domain Relational Calculus

Definition (syntax)

a domain relational calculus query has the form:

$$\{[v_1, v_2, \ldots, v_n] \mid P(v_1, v_2, \ldots, v_n)\}$$

$v_1, v_2, \ldots, v_n$ ... domain variables, representing a value in the domain of some attribute; $P(v_1, v_2, \ldots, v_n)$ a formula, formulas are built from atoms (see definition).

The Domain Relational Calculus

Definition (syntax)

a domain relational calculus query has the form:

$$\{[v_1, v_2, \ldots, v_n] \mid P(v_1, v_2, \ldots, v_n)\}$$

$v_1, v_2, \ldots, v_n$ ... domain variables, representing a value in the domain of some attribute; $P(v_1, v_2, \ldots, v_n)$ a formula, formulas are built from atoms (see definition).

Definition (semantics)

A tuple $[v_1, v_2, \ldots, v_n]$ is in the result if it satisfies the formula $P(v_1, v_2, \ldots, v_n)$. The variables $v_1, v_2, \ldots, v_n$ are free variables in the formula $P(v_1, v_2, \ldots, v_n)$ – therefore they are not bound by a quantifier $(\forall, \exists)$.

The Domain Relational Calculus

Definition (syntax: atoms and formulas)

atoms:

$[v_1, \ldots, v_n] \in R$: $v_1, v_2, \ldots, v_n$ domain variables; R is an n-ary relation name

$x\phi y$: x, y domain variables;
ϕ a comparison operator $(=, \neq, <, \leq, >, \geq)$

$x\phi c$: as above, c a constant

The Domain Relational Calculus

Definition (syntax: atoms and formulas)

atoms:

$[v_1, \ldots, v_n] \in R$: $v_1, v_2, \ldots, v_n$ domain variables; R is an n-ary relation name

$x \phi y$: x, y domain variables; ϕ a comparison operator $(=, \neq, <, \leq, >, \geq)$

$x \phi c$: as above, c a constant

formulas:

atoms are formulas

P formula, then so are $\neg P$ and (P)

P_1, P_2 formulas, then so are $P_1 \wedge P_2, P_1 \vee P_2$ and $P_1 \Rightarrow P_2$

$P(v)$ formula with free variable v, then so are $\forall v(P(v))$ and $\exists v(P(v))$

The Domain Relational Calculus

Example

student(matrNr, name, semester)
attend(matrNr, lecNr)
lecture(lecNr, title, SWS, givenBy)
professor(persNr, name, rank, room)

- name and matrNr of students that attend at least one lecture given by Curie:

$$\begin{aligned}\{[m,n] \quad | \quad & \exists s([m,n,s] \in \mathit{student} \wedge \\ & \exists v([m,v] \in \mathit{attend} \wedge \\ & \exists t,d,p([v,t,d,p] \in \mathit{professor} \wedge \\ & \exists a,r,u([p,a,r,u] \in \mathit{professor} \wedge \\ & a = \text{`Curie'})))\}\end{aligned}$$

The Domain Relational Calculus

Example

student(matrNr, name, semester)
attend(matrNr, lecNr)
lecture(lecNr, title, SWS, givenBy)
professor(persNr, name, rank, room)

- name and matrNr of students that attend at least one lecture given by Curie:

$$\begin{aligned}\{[m, n] \quad | \quad & \exists s, v, t, d, p, r, u([m, n, s] \in student \wedge \\ & [m, v] \in attend \wedge [v, t, d, p] \in professor \wedge \\ & [p, \text{`}Curie', r, u] \in professor))\}\end{aligned}$$

The Domain Relational Calculus

Example

student(matrNr, name, semester)
attend(matrNr, lecNr)
lecture(lecNr, title, SWS, givenBy)

- name and matrNr of students attending all 4h lectures

$$\begin{aligned}\{[m,n] \quad | \quad & \exists s([m,n,s] \in \mathit{student} \wedge \\ & \forall v,t,s,p(([v,t,s,p] \in \mathit{lecture} \wedge s = 4) \\ & \rightarrow [m,v] \in \mathit{attend})\}\end{aligned}$$

The Domain Relational Calculus

Example

student(matrNr, name, semester)
assistant(persNr, name, birthDate, boss)
professor(persNr, name, rank, room)

- persNr of all professors and assistants:

$$\{[p] \mid (\exists n, g, b([p, n, g, b] \in assistant) \vee (\exists r, a([p, n, r, a] \in professor)\}$$

- names of assistants that are also names of students:

$$\{[n] \mid \exists p, g, b, m, s([p, n, g, b] \in assistant \wedge [m, n, s] \in student)\}$$

The Domain Relational Calculus

Example

assistant(persNr, name, birthDate, boss)
professor(persNr, name, rank, room)

- all assistants that are not professors:

The Domain Relational Calculus

Example

assistant(persNr, name, birthDate, boss)
professor(persNr, name, rank, room)

- all assistants that are not professors:

$$\{[p] \mid \exists n, g, b \quad ([p, n, g, b] \in assistant \wedge \neg\exists n, r, a([p, n, r, a] \in professor))\}$$

The Domain Relational Calculus

Example

assistant(persNr, name, birthDate, boss)
professor(persNr, name, rank, room)

- all assistants that are not professors:

$$\{[p] \mid \exists n, g, b \quad ([p, n, g, b] \in \mathit{assistant} \land \neg\exists n, r, a([p, n, r, a] \in \mathit{professor}))\}$$

$$\{[p] \mid \exists n, g, b \quad ([p, n, g, b] \in \mathit{assistant} \land \forall n, r, a(\neg([p, n, r, a] \in \mathit{professor})))\}$$

Comparison: Tuple and Domain Relational Calculus

Example

all students attending at least one lecture

student(matrNr, name, semester)
attend(matrNr, lecNr)

- tuple relational calculus:

$$\{s \mid s \in student \land \exists a \in attend(s.matrNr = a.matrNr)\}$$

- domain relational calculus:

$$\{[m, n, s] \mid [m, n, s] \in student \land \exists v([m, v] \in attend)\}$$

Comparison: Tuple and Domain Relational Calculus

Example

student(matrNr, name, semester)
examine(matrNr, lecNr, grade)

- tuple relational calculus:

$$\{[s.matrNr] \mid s \in student \wedge \forall e \in examine(\\ s.matrNr = e.matrNr \rightarrow e.grade = 2)\}$$

- domain relational calculus:

$$\{[mnr] \mid \exists nam, sem([mnr, nam, sem] \in student) \wedge \\ \forall vnr, no([mnr, vnr, no] \in examine \rightarrow no = 2)\}$$

Comparison: Tuple and Domain Relational Calculus

Example

matNr of all the students that obtained in all exams the grade 2:
student(matrNr, name, semester)
examine(matrNr, lecNr, grade)

- tuple relational calculus:

$$\{[s.matrNr] \mid s \in student \land \forall e \in examine(\\ s.matrNr = e.matrNr \rightarrow e.grade = 2)\}$$

- domain relational calculus:

$$\{[mnr] \mid \exists nam, sem([mnr, nam, sem] \in student) \land \\ \forall vnr, no([mnr, vnr, no] \in examine \rightarrow no = 2)\}$$

Comparison: Tuple and Domain Relational Calculus

Example (semantics tuple relational calculus)

student

matrNr	name	sem
26120	Fichte	10
29555	Feuerbach	2
28106	Carnap	3
27550	Schopenhauer	6

examine

matrNr	lecNr	grade
28106	5041	2
27550	5001	2
28106	5001	2
26120	5001	2
27550	4052	1
25403	5001	1

result

matrNr

$$\{[s.matrNr] \mid s \in student \wedge \forall e \in examine(\\ s.matrNr = e.matrNr \rightarrow e.grade = 2)\}$$

Comparison: Tuple and Domain Relational Calculus

Example (semantics tuple relational calculus)

student		
matrNr	name	sem
26120	Fichte	10
29555	Feuerbach	2
28106	Carnap	3
27550	Schopenhauer	6

examine		
matrNr	lecNr	grade
28106	5041	2
27550	5001	2
28106	5001	2
26120	5001	2
27550	4052	1
25403	5001	1

result
matrNr
1 ?

$$\{[s.matrNr] \mid s \in student \wedge \forall e \in examine(s.matrNr = e.matrNr \rightarrow e.grade = 2)\}$$

$s = (1, 1, 1, 1)$?

Comparison: Tuple and Domain Relational Calculus

Example (semantics tuple relational calculus)

student

matrNr	name	sem
26120	Fichte	10
29555	Feuerbach	2
28106	Carnap	3
27550	Schopenhauer	6

examine

matrNr	lecNr	grade
28106	5041	2
27550	5001	2
28106	5001	2
26120	5001	2
27550	4052	1
25403	5001	1

result

matrNr
1 ?

$$\{[s.matrNr] \mid s \in student \land \forall e \in examine(s.matrNr = e.matrNr \rightarrow e.grade = 2)\}$$

$s = (1, 1, 1, 1)$? $s \in student$?

Comparison: Tuple and Domain Relational Calculus

Example (semantics tuple relational calculus)

student

matrNr	name	sem
26120	Fichte	10
29555	Feuerbach	2
28106	Carnap	3
27550	Schopenhauer	6

examine

matrNr	lecNr	grade
28106	5041	2
27550	5001	2
28106	5001	2
26120	5001	2
27550	4052	1
25403	5001	1

result

matrNr
1 ✗

$$\{[s.matrNr] \mid s \in student \land \forall e \in examine(s.matrNr = e.matrNr \rightarrow e.grade = 2)\}$$

$s = (1, 1, 1, 1)$? $s \in student$? $\Rightarrow$ ✗

Comparison: Tuple and Domain Relational Calculus

Example (semantics tuple relational calculus)

student		
matrNr	name	sem
26120	Fichte	10
29555	Feuerbach	2
28106	Carnap	3
27550	Schopenhauer	6

examine		
matrNr	lecNr	grade
28106	5041	2
27550	5001	2
28106	5001	2
26120	5001	2
27550	4052	1
25403	5001	1

result
matrNr

$$\{[s.matrNr] \mid s \in student \land \forall e \in examine(s.matrNr = e.matrNr \rightarrow e.grade = 2)\}$$

$s = (1, 1, 1, 1)$? $s \in student$? $\Rightarrow$ ✗

Comparison: Tuple and Domain Relational Calculus

Example (semantics tuple relational calculus)

	student	
matrNr	name	sem
26120	Fichte	10
29555	Feuerbach	2
28106	Carnap	3
27550	Schopenhauer	6

$s =$ (26120, Fichte, 10)

	examine	
matrNr	lecNr	grade
28106	5041	2
27550	5001	2
28106	5001	2
26120	5001	2
27550	4052	1
25403	5001	1

result
matrNr
26120 ?

$$\{[s.matrNr] \mid s \in student \wedge \forall e \in examine(s.matrNr = e.matrNr \rightarrow e.grade = 2)\}$$

Comparison: Tuple and Domain Relational Calculus

Example (semantics tuple relational calculus)

$s =$

student		
matrNr	name	sem
26120	Fichte	10
29555	Feuerbach	2
28106	Carnap	3
27550	Schopenhauer	6

examine		
matrNr	lecNr	grade
28106	5041	2
27550	5001	2
28106	5001	2
26120	5001	2
27550	4052	1
25403	5001	1

result
matrNr
26120 ?

$$\{[s.matrNr] \mid s \in student \land \forall e \in examine(s.matrNr = e.matrNr \rightarrow e.grade = 2)\}$$

$s \in student$

Comparison: Tuple and Domain Relational Calculus

Example (semantics tuple relational calculus)

student

matrNr	name	sem
26120	Fichte	10
29555	Feuerbach	2
28106	Carnap	3
27550	Schopenhauer	6

$s =$ (row 26120, Fichte, 10)

examine

matrNr	lecNr	grade
28106	5041	2
27550	5001	2
28106	5001	2
26120	5001	2
27550	4052	1
25403	5001	1

result

matrNr
26120 ?

$$\{[s.matrNr] \mid s \in student \land \forall e \in examine(s.matrNr = e.matrNr \rightarrow e.grade = 2)\}$$

$s \in student$ ✓

Comparison: Tuple and Domain Relational Calculus

Example (semantics tuple relational calculus)

$s =$

student		
matrNr	name	sem
26120	Fichte	10
29555	Feuerbach	2
28106	Carnap	3
27550	Schopenhauer	6

examine		
matrNr	lecNr	grade
28106	5041	2
27550	5001	2
28106	5001	2
26120	5001	2
27550	4052	1
25403	5001	1

result
matrNr
26120 ?

$$\{[s.matrNr] \mid s \in student \land \forall e \in examine(s.matrNr = e.matrNr \rightarrow e.grade = 2)\}$$

$s \in student$ ✓ $\forall e \in examine \ldots ?$

Comparison: Tuple and Domain Relational Calculus

Example (semantics tuple relational calculus)

$s =$

student		
matrNr	name	sem
26120	Fichte	10
29555	Feuerbach	2
28106	Carnap	3
27550	Schopenhauer	6

examine		
matrNr	lecNr	grade
28106	5041	2
27550	5001	2
28106	5001	2
26120	5001	2
27550	4052	1
25403	5001	1

result
matrNr
26120 ?

$$\{[s.matrNr] \mid s \in student \land \forall e \in examine(s.matrNr = e.matrNr \rightarrow e.grade = 2)\}$$

$s \in student$ ✓ $\forall e \in examine \ldots ?$

Comparison: Tuple and Domain Relational Calculus

Example (semantics tuple relational calculus)

$s =$

student		
matrNr	name	sem
26120	Fichte	10
29555	Feuerbach	2
28106	Carnap	3
27550	Schopenhauer	6

examine		
matrNr	lecNr	grade
28106	5041	2 ✓
27550	5001	2
28106	5001	2
26120	5001	2
27550	4052	1
25403	5001	1

result
matrNr
26120 ?

$$\{[s.matrNr] \mid s \in student \land \forall e \in examine(s.matrNr = e.matrNr \rightarrow e.grade = 2)\}$$

$s \in student$ ✓ $\forall e \in examine \ldots ?$

Comparison: Tuple and Domain Relational Calculus

Example (semantics tuple relational calculus)

student

	matrNr	name	sem
$s =$	26120	Fichte	10
	29555	Feuerbach	2
	28106	Carnap	3
	27550	Schopenhauer	6

examine

matrNr	lecNr	grade
28106	5041	2 ✓
27550	5001	2
28106	5001	2
26120	5001	2
27550	4052	1
25403	5001	1

result

matrNr
26120 ?

$$\{[s.matrNr] \mid s \in student \land \forall e \in examine(s.matrNr = e.matrNr \rightarrow e.grade = 2)\}$$

$s \in student$ ✓ $\forall e \in examine \ldots ?$

Comparison: Tuple and Domain Relational Calculus

Example (semantics tuple relational calculus)

$s =$

student		
matrNr	name	sem
26120	Fichte	10
29555	Feuerbach	2
28106	Carnap	3
27550	Schopenhauer	6

examine		
matrNr	lecNr	grade
28106	5041	2 ✓
27550	5001	2 ✓
28106	5001	2
26120	5001	2
27550	4052	1
25403	5001	1

result
matrNr
26120 ?

$$\{[s.matrNr] \mid s \in student \land \forall e \in examine(s.matrNr = e.matrNr \rightarrow e.grade = 2)\}$$

$s \in student$ ✓ $\forall e \in examine \ldots ?$

Comparison: Tuple and Domain Relational Calculus

Example (semantics tuple relational calculus)

student

	matrNr	name	sem
$s =$	26120	Fichte	10
	29555	Feuerbach	2
	28106	Carnap	3
	27550	Schopenhauer	6

examine

matrNr	lecNr	grade
28106	5041	2 ✓
27550	5001	2 ✓
28106	5001	2
26120	5001	2
27550	4052	1
25403	5001	1

result

matrNr
26120 ?

$$\{[s.matrNr] \mid s \in student \wedge \forall e \in examine(s.matrNr = e.matrNr \rightarrow e.grade = 2)\}$$

$s \in student$ ✓ $\forall e \in examine \ldots ?$

Comparison: Tuple and Domain Relational Calculus

Example (semantics tuple relational calculus)

$s =$

student		
matrNr	name	sem
26120	Fichte	10
29555	Feuerbach	2
28106	Carnap	3
27550	Schopenhauer	6

examine		
matrNr	lecNr	grade
28106	5041	2 ✓
27550	5001	2 ✓
28106	5001	2 ✓
26120	5001	2
27550	4052	1
25403	5001	1

result
matrNr
26120 ?

$$\{[s.matrNr] \mid s \in student \wedge \forall e \in examine(s.matrNr = e.matrNr \rightarrow e.grade = 2)\}$$

$s \in student$ ✓ $\forall e \in examine \ldots ?$

Comparison: Tuple and Domain Relational Calculus

Example (semantics tuple relational calculus)

$s =$

student		
matrNr	name	sem
26120	Fichte	10
29555	Feuerbach	2
28106	Carnap	3
27550	Schopenhauer	6

examine		
matrNr	lecNr	grade
28106	5041	2 ✓
27550	5001	2 ✓
28106	5001	2 ✓
26120	5001	2
27550	4052	1
25403	5001	1

result
matrNr
26120 ?

$$\{[s.matrNr] \mid s \in student \land \forall e \in examine(\\ s.matrNr = e.matrNr \rightarrow e.grade = 2)\}$$

$s \in student$ ✓ $\forall e \in examine \ldots ?$

Comparison: Tuple and Domain Relational Calculus

Example (semantics tuple relational calculus)

$s =$

student		
matrNr	name	sem
26120	Fichte	10
29555	Feuerbach	2
28106	Carnap	3
27550	Schopenhauer	6

examine		
matrNr	lecNr	grade
28106	5041	2 ✓
27550	5001	2 ✓
28106	5001	2 ✓
26120	5001	2 ✓
27550	4052	1
25403	5001	1

result
matrNr
26120 ?

$$\{[s.matrNr] \mid s \in student \wedge \forall e \in examine(s.matrNr = e.matrNr \rightarrow e.grade = 2)\}$$

$s \in student$ ✓ $\forall e \in examine \ldots ?$

Comparison: Tuple and Domain Relational Calculus

Example (semantics tuple relational calculus)

student

matrNr	name	sem
26120	Fichte	10
29555	Feuerbach	2
28106	Carnap	3
27550	Schopenhauer	6

$s =$ (26120, Fichte, 10)

examine

matrNr	lecNr	grade
28106	5041	2 ✓
27550	5001	2 ✓
28106	5001	2 ✓
26120	5001	2 ✓
27550	4052	1
25403	5001	1

result

matrNr
26120 ?

$$\{[s.matrNr] \mid s \in student \wedge \forall e \in examine(s.matrNr = e.matrNr \rightarrow e.grade = 2)\}$$

$s \in student$ ✓ $\forall e \in examine \ldots ?$

Comparison: Tuple and Domain Relational Calculus

Example (semantics tuple relational calculus)

$s =$

student		
matrNr	name	sem
26120	Fichte	10
29555	Feuerbach	2
28106	Carnap	3
27550	Schopenhauer	6

examine		
matrNr	lecNr	grade
28106	5041	2 ✓
27550	5001	2 ✓
28106	5001	2 ✓
26120	5001	2 ✓
27550	4052	1 ✓
25403	5001	1

result
matrNr
26120 ?

$$\{[s.matrNr] \mid s \in student \land \forall e \in examine(s.matrNr = e.matrNr \rightarrow e.grade = 2)\}$$

$s \in student$ ✓ $\forall e \in examine \ldots ?$

Comparison: Tuple and Domain Relational Calculus

Example (semantics tuple relational calculus)

$s =$

student		
matrNr	name	sem
26120	Fichte	10
29555	Feuerbach	2
28106	Carnap	3
27550	Schopenhauer	6

examine		
matrNr	lecNr	grade
28106	5041	2 ✓
27550	5001	2 ✓
28106	5001	2 ✓
26120	5001	2 ✓
27550	4052	1 ✓
25403	5001	1

result
matrNr
26120 ?

$$\{[s.matrNr] \mid s \in student \land \forall e \in examine(s.matrNr = e.matrNr \rightarrow e.grade = 2)\}$$

$s \in student$ ✓ $\forall e \in examine \ldots ?$

Comparison: Tuple and Domain Relational Calculus

Example (semantics tuple relational calculus)

$s =$

student		
matrNr	name	sem
26120	Fichte	10
29555	Feuerbach	2
28106	Carnap	3
27550	Schopenhauer	6

examine		
matrNr	lecNr	grade
28106	5041	2 ✓
27550	5001	2 ✓
28106	5001	2 ✓
26120	5001	2 ✓
27550	4052	1 ✓
25403	5001	1 ✓

result
matrNr
26120 ?

$$\{[s.matrNr] \mid s \in student \land \forall e \in examine(s.matrNr = e.matrNr \rightarrow e.grade = 2)\}$$

$s \in student$ ✓ $\forall e \in examine \ldots ?$

Comparison: Tuple and Domain Relational Calculus

Example (semantics tuple relational calculus)

student		
matrNr	name	sem
26120	Fichte	10
29555	Feuerbach	2
28106	Carnap	3
27550	Schopenhauer	6

$s =$ (26120, Fichte, 10)

examine		
matrNr	lecNr	grade
28106	5041	2 ✓
27550	5001	2 ✓
28106	5001	2 ✓
26120	5001	2 ✓
27550	4052	1 ✓
25403	5001	1 ✓

result
matrNr
26120 ?

$$\{[s.matrNr] \mid s \in student \land \forall e \in examine(\\ s.matrNr = e.matrNr \rightarrow e.grade = 2)\}$$

$s \in student$ ✓ $\forall e \in examine \ldots ?$ ✓

Comparison: Tuple and Domain Relational Calculus

Example (semantics tuple relational calculus)

student

matrNr	name	sem
26120	Fichte	10
29555	Feuerbach	2
28106	Carnap	3
27550	Schopenhauer	6

$s =$ (26120, Fichte, 10)

examine

matrNr	lecNr	grade
28106	5041	2 ✓
27550	5001	2 ✓
28106	5001	2 ✓
26120	5001	2 ✓
27550	4052	1 ✓
25403	5001	1 ✓

result

matrNr
26120 ?

$$\{[s.matrNr] \mid s \in student \land \forall e \in examine(s.matrNr = e.matrNr \rightarrow e.grade = 2)\}$$

$s \in student$ ✓ $\forall e \in examine \ldots ?$ ✓ $\Rightarrow$ ✓

Comparison: Tuple and Domain Relational Calculus

Example (semantics tuple relational calculus)

student

matrNr	name	sem
26120	Fichte	10
29555	Feuerbach	2
28106	Carnap	3
27550	Schopenhauer	6

$s =$ (26120, Fichte, 10)

examine

matrNr	lecNr	grade
28106	5041	2 ✓
27550	5001	2 ✓
28106	5001	2 ✓
26120	5001	2 ✓
27550	4052	1 ✓
25403	5001	1 ✓

result

matrNr
26120 ✓

$$\{[s.matrNr] \mid s \in student \land \forall e \in examine(s.matrNr = e.matrNr \rightarrow e.grade = 2)\}$$

$s \in student$ ✓ $\forall e \in examine \ldots ?$ ✓ $\Rightarrow$ ✓

Comparison: Tuple and Domain Relational Calculus

Example (semantics tuple relational calculus)

student

<u>matrNr</u>	name	sem
26120	Fichte	10
29555	Feuerbach	2
28106	Carnap	3
27550	Schopenhauer	6

$s =$ 29555 Feuerbach 2

examine

<u>matrNr</u>	<u>lecNr</u>	grade
28106	5041	2
27550	5001	2
28106	5001	2
26120	5001	2
27550	4052	1
25403	5001	1

result

<u>matrNr</u>
26120 ✓
29555 ?

$$\{[s.matrNr] \mid s \in student \land \forall e \in examine(s.matrNr = e.matrNr \rightarrow e.grade = 2)\}$$

$s \in student$ ✓ $\forall e \in examine \ldots ?$

Comparison: Tuple and Domain Relational Calculus

Example (semantics tuple relational calculus)

student

matrNr	name	sem
26120	Fichte	10
29555	Feuerbach	2
28106	Carnap	3
27550	Schopenhauer	6

$s =$ 29555 Feuerbach 2

examine

matrNr	lecNr	grade
28106	5041	2
27550	5001	2
28106	5001	2
26120	5001	2
27550	4052	1
25403	5001	1

result

matrNr
26120 ✓
29555 ?

$$\{[s.matrNr] \mid s \in student \wedge \forall e \in examine(s.matrNr = e.matrNr \rightarrow e.grade = 2)\}$$

$s \in student$ ✓ $\forall e \in examine \ldots ?$

Comparison: Tuple and Domain Relational Calculus

Example (semantics tuple relational calculus)

student

matrNr	name	sem
26120	Fichte	10
29555	Feuerbach	2
28106	Carnap	3
27550	Schopenhauer	6

$s =$ 29555 Feuerbach 2

examine

matrNr	lecNr	grade
28106	5041	2 ✓
27550	5001	2 ✓
28106	5001	2 ✓
26120	5001	2 ✓
27550	4052	1 ✓
25403	5001	1 ✓

result

matrNr
26120 ✓
29555 ?

$$\{[s.matrNr] \mid s \in student \wedge \forall e \in examine(s.matrNr = e.matrNr \rightarrow e.grade = 2)\}$$

$s \in student$ ✓ $\forall e \in examine \ldots ?$

Comparison: Tuple and Domain Relational Calculus

Example (semantics tuple relational calculus)

student

matrNr	name	sem
26120	Fichte	10
29555	Feuerbach	2
28106	Carnap	3
27550	Schopenhauer	6

$s =$ 29555 Feuerbach 2

examine

matrNr	lecNr	grade
28106	5041	2 ✓
27550	5001	2 ✓
28106	5001	2 ✓
26120	5001	2 ✓
27550	4052	1 ✓
25403	5001	1 ✓

result

matrNr
26120 ✓
29555 ?

$$\{[s.matrNr] \mid s \in student \land \forall e \in examine(s.matrNr = e.matrNr \rightarrow e.grade = 2)\}$$

$s \in student$ ✓ $\forall e \in examine \ldots ?$ ✓

Comparison: Tuple and Domain Relational Calculus

Example (semantics tuple relational calculus)

student

matrNr	name	sem
26120	Fichte	10
29555	Feuerbach	2
28106	Carnap	3
27550	Schopenhauer	6

examine

matrNr	lecNr	grade
28106	5041	2
27550	5001	2
28106	5001	2
26120	5001	2
27550	4052	1
25403	5001	1

result

matrNr
26120 ✓
29555 ✓

$$\{[s.matrNr] \mid s \in student \land \forall e \in examine(\\ s.matrNr = e.matrNr \rightarrow e.grade = 2)\}$$

$s \in student$ ✓ $\forall e \in examine \ldots ?$ ✓ $\Rightarrow$ ✓

Comparison: Tuple and Domain Relational Calculus

Example (semantics tuple relational calculus)

student

matrNr	name	sem
26120	Fichte	10
29555	Feuerbach	2
28106	Carnap	3
27550	Schopenhauer	6

$s =$ (28106, Carnap, 3)

examine

matrNr	lecNr	grade
28106	5041	2
27550	5001	2
28106	5001	2
26120	5001	2
27550	4052	1
25403	5001	1

result

matrNr
26120 ✓
29555 ✓
28106 ?

$$\{[s.matrNr] \mid s \in student \wedge \forall e \in examine(s.matrNr = e.matrNr \rightarrow e.grade = 2)\}$$

$s \in student$ ✓ $\forall e \in examine \ldots ?$

Comparison: Tuple and Domain Relational Calculus

Example (semantics tuple relational calculus)

student

matrNr	name	sem
26120	Fichte	10
29555	Feuerbach	2
28106	Carnap	3
27550	Schopenhauer	6

$s =$ (28106, Carnap, 3)

examine

matrNr	lecNr	grade
28106	5041	2
27550	5001	2
28106	5001	2
26120	5001	2
27550	4052	1
25403	5001	1

result

matrNr
26120 ✓
29555 ✓
28106 ?

$$\{[s.matrNr] \mid s \in student \land \forall e \in examine(\\ s.matrNr = e.matrNr \rightarrow e.grade = 2)\}$$

$s \in student$ ✓ $\forall e \in examine \ldots ?$

Comparison: Tuple and Domain Relational Calculus

Example (semantics tuple relational calculus)

student

matrNr	name	sem
26120	Fichte	10
29555	Feuerbach	2
28106	Carnap	3
27550	Schopenhauer	6

$s =$ 28106 Carnap 3

examine

matrNr	lecNr	grade
28106	5041	2
27550	5001	2 ✓
28106	5001	2
26120	5001	2 ✓
27550	4052	1 ✓
25403	5001	1 ✓

result

matrNr
26120 ✓
29555 ✓
28106 ?

$$\{[s.matrNr] \mid s \in student \land \forall e \in examine(s.matrNr = e.matrNr \rightarrow e.grade = 2)\}$$

$s \in student$ ✓ $\forall e \in examine \ldots ?$

Comparison: Tuple and Domain Relational Calculus

Example (semantics tuple relational calculus)

student

matrNr	name	sem
26120	Fichte	10
29555	Feuerbach	2
28106	Carnap	3
27550	Schopenhauer	6

$s =$ 28106 Carnap 3

examine

matrNr	lecNr	grade
28106	5041	2
27550	5001	2 ✓
28106	5001	2
26120	5001	2 ✓
27550	4052	1 ✓
25403	5001	1 ✓

result

matrNr
26120 ✓
29555 ✓
28106 ?

$$\{[s.matrNr] \mid s \in student \land \forall e \in examine(s.matrNr = e.matrNr \rightarrow e.grade = 2)\}$$

$s \in student$ ✓ $\forall e \in examine \ldots ?$

Comparison: Tuple and Domain Relational Calculus

Example (semantics tuple relational calculus)

student

matrNr	name	sem
26120	Fichte	10
29555	Feuerbach	2
28106	Carnap	3
27550	Schopenhauer	6

$s =$ (28106, Carnap, 3)

examine

matrNr	lecNr	grade
28106	5041	2 ✓
27550	5001	2 ✓
28106	5001	2
26120	5001	2 ✓
27550	4052	1 ✓
25403	5001	1 ✓

result

matrNr
26120 ✓
29555 ✓
28106 ?

$$\{[s.matrNr] \mid s \in student \land \forall e \in examine(s.matrNr = e.matrNr \rightarrow e.grade = 2)\}$$

$s \in student$ ✓ $\forall e \in examine \ldots ?$

Comparison: Tuple and Domain Relational Calculus

Example (semantics tuple relational calculus)

student		
matrNr	name	sem
26120	Fichte	10
29555	Feuerbach	2
28106	Carnap	3
27550	Schopenhauer	6

$s =$ (28106, Carnap, 3)

examine		
matrNr	lecNr	grade
28106	5041	2 ✓
27550	5001	2 ✓
28106	5001	2
26120	5001	2 ✓
27550	4052	1 ✓
25403	5001	1 ✓

result
matrNr
26120 ✓
29555 ✓
28106 ?

$$\{[s.matrNr] \mid s \in student \land \forall e \in examine(s.matrNr = e.matrNr \rightarrow e.grade = 2)\}$$

$s \in student$ ✓ $\forall e \in examine \ldots ?$

Comparison: Tuple and Domain Relational Calculus

Example (semantics tuple relational calculus)

student		
matrNr	name	sem
26120	Fichte	10
29555	Feuerbach	2
28106	Carnap	3
27550	Schopenhauer	6

$s =$ 28106 Carnap 3

examine		
matrNr	lecNr	grade
28106	5041	2 ✓
27550	5001	2 ✓
28106	5001	2 ✓
26120	5001	2 ✓
27550	4052	1 ✓
25403	5001	1 ✓

result
matrNr
26120 ✓
29555 ✓
28106 ?

$$\{[s.matrNr] \mid s \in student \wedge \forall e \in examine(\\ s.matrNr = e.matrNr \rightarrow e.grade = 2)\}$$

$s \in student$ ✓ $\forall e \in examine \ldots ?$

Comparison: Tuple and Domain Relational Calculus

Example (semantics tuple relational calculus)

student

	matrNr	name	sem
	26120	Fichte	10
	29555	Feuerbach	2
$s =$	28106	Carnap	3
	27550	Schopenhauer	6

examine

matrNr	lecNr	grade
28106	5041	2 ✓
27550	5001	2 ✓
28106	5001	2 ✓
26120	5001	2 ✓
27550	4052	1 ✓
25403	5001	1 ✓

result

matrNr
26120 ✓
29555 ✓
28106 ?

$$\{[s.matrNr] \mid s \in student \wedge \forall e \in examine(s.matrNr = e.matrNr \rightarrow e.grade = 2)\}$$

$s \in student$ ✓ $\forall e \in examine \ldots ?$ ✓

Comparison: Tuple and Domain Relational Calculus

Example (semantics tuple relational calculus)

student

matrNr	name	sem
26120	Fichte	10
29555	Feuerbach	2
28106	Carnap	3
27550	Schopenhauer	6

$s =$ 28106 Carnap 3

examine

matrNr	lecNr	grade
28106	5041	2 ✓
27550	5001	2 ✓
28106	5001	2 ✓
26120	5001	2 ✓
27550	4052	1 ✓
25403	5001	1 ✓

result

matrNr
26120 ✓
29555 ✓
28106 ✓

$$\{[s.matrNr] \mid s \in student \land \forall e \in examine(s.matrNr = e.matrNr \rightarrow e.grade = 2)\}$$

$s \in student$ ✓ $\forall e \in examine \ldots ?$ ✓ $\Rightarrow$ ✓

Comparison: Tuple and Domain Relational Calculus

Example (semantics tuple relational calculus)

student		
matrNr	name	sem
26120	Fichte	10
29555	Feuerbach	2
28106	Carnap	3
27550	Schopenhauer	6

$s =$ 27550 Schopenhauer 6

examine		
matrNr	lecNr	grade
28106	5041	2
27550	5001	2
28106	5001	2
26120	5001	2
27550	4052	1
25403	5001	1

result
matrNr
26120 ✓
29555 ✓
28106 ✓
27550 ?

$$\{[s.matrNr] \mid s \in student \land \forall e \in examine(\\ s.matrNr = e.matrNr \rightarrow e.grade = 2)\}$$

$s \in student$ ✓ $\forall e \in examine \ldots ?$

Comparison: Tuple and Domain Relational Calculus

Example (semantics tuple relational calculus)

	student		
	matrNr	name	sem
	26120	Fichte	10
	29555	Feuerbach	2
	28106	Carnap	3
$s =$	27550	Schopenhauer	6

examine		
matrNr	lecNr	grade
28106	5041	2
27550	5001	2
28106	5001	2
26120	5001	2
27550	4052	1
25403	5001	1

result
matrNr
26120 ✓
29555 ✓
28106 ✓
27550 ?

$$\{[s.matrNr] \mid s \in student \land \forall e \in examine(s.matrNr = e.matrNr \rightarrow e.grade = 2)\}$$

$s \in student$ ✓ $\forall e \in examine \ldots ?$

Comparison: Tuple and Domain Relational Calculus

Example (semantics tuple relational calculus)

student

matrNr	name	sem
26120	Fichte	10
29555	Feuerbach	2
28106	Carnap	3
27550	Schopenhauer	6

$s =$ 27550 Schopenhauer 6

examine

matrNr	lecNr	grade
28106	5041	2 ✓
27550	5001	2
28106	5001	2 ✓
26120	5001	2 ✓
27550	4052	1
25403	5001	1 ✓

result

matrNr
26120 ✓
29555 ✓
28106 ✓
27550 ?

$$\{[s.matrNr] \mid s \in student \land \forall e \in examine(s.matrNr = e.matrNr \rightarrow e.grade = 2)\}$$

$s \in student$ ✓ $\forall e \in examine \ldots ?$

Comparison: Tuple and Domain Relational Calculus

Example (semantics tuple relational calculus)

student

matrNr	name	sem
26120	Fichte	10
29555	Feuerbach	2
28106	Carnap	3
27550	Schopenhauer	6

$s =$ 27550 Schopenhauer 6

examine

matrNr	lecNr	grade
28106	5041	2 ✓
27550	5001	2
28106	5001	2 ✓
26120	5001	2 ✓
27550	4052	1
25403	5001	1 ✓

result

matrNr
26120 ✓
29555 ✓
28106 ✓
27550 ?

$$\{[s.matrNr] \mid s \in student \land \forall e \in examine(s.matrNr = e.matrNr \rightarrow e.grade = 2)\}$$

$s \in student$ ✓ $\forall e \in examine \ldots ?$

Comparison: Tuple and Domain Relational Calculus

Example (semantics tuple relational calculus)

student		
matrNr	name	sem
26120	Fichte	10
29555	Feuerbach	2
28106	Carnap	3
27550	Schopenhauer	6

$s =$ (27550, Schopenhauer, 6)

examine		
matrNr	lecNr	grade
28106	5041	2 ✓
27550	5001	2
28106	5001	2 ✓
26120	5001	2 ✓
27550	4052	1
25403	5001	1 ✓

result
matrNr
26120 ✓
29555 ✓
28106 ✓
27550 ?

$$\{[s.matrNr] \mid s \in student \land \forall e \in examine(s.matrNr = e.matrNr \rightarrow e.grade = 2)\}$$

$s \in student$ ✓ $\forall e \in examine \ldots ?$

Comparison: Tuple and Domain Relational Calculus

Example (semantics tuple relational calculus)

student

matrNr	name	sem
26120	Fichte	10
29555	Feuerbach	2
28106	Carnap	3
27550	Schopenhauer	6

$s =$ 27550 Schopenhauer 6

examine

matrNr	lecNr	grade
28106	5041	2 ✓
27550	5001	2 ✓
28106	5001	2 ✓
26120	5001	2 ✓
27550	4052	1
25403	5001	1 ✓

result

matrNr
26120 ✓
29555 ✓
28106 ✓
27550 ?

$$\{[s.matrNr] \mid s \in student \wedge \forall e \in examine(s.matrNr = e.matrNr \rightarrow e.grade = 2)\}$$

$s \in student$ ✓ $\forall e \in examine \ldots ?$

Comparison: Tuple and Domain Relational Calculus

Example (semantics tuple relational calculus)

student

matrNr	name	sem
26120	Fichte	10
29555	Feuerbach	2
28106	Carnap	3
27550	Schopenhauer	6

$s =$ 27550 Schopenhauer 6

examine

matrNr	lecNr	grade
28106	5041	2 ✓
27550	5001	2 ✓
28106	5001	2 ✓
26120	5001	2 ✓
27550	4052	1
25403	5001	1 ✓

result

matrNr
26120 ✓
29555 ✓
28106 ✓
27550 ?

$$\{[s.matrNr] \mid s \in student \land \forall e \in examine(s.matrNr = e.matrNr \rightarrow e.grade = 2)\}$$

$s \in student$ ✓ $\forall e \in examine \ldots ?$

Comparison: Tuple and Domain Relational Calculus

Example (semantics tuple relational calculus)

student

matrNr	name	sem
26120	Fichte	10
29555	Feuerbach	2
28106	Carnap	3
27550	Schopenhauer	6

$s =$ 27550 Schopenhauer 6

examine

matrNr	lecNr	grade
28106	5041	2 ✓
27550	5001	2 ✓
28106	5001	2 ✓
26120	5001	2 ✓
27550	4052	1 ✗
25403	5001	1 ✓

result

matrNr
26120 ✓
29555 ✓
28106 ✓
27550 ?

$$\{[s.matrNr] \mid s \in student \wedge \forall e \in examine(\\ s.matrNr = e.matrNr \rightarrow e.grade = 2)\}$$

$s \in student$ ✓ $\forall e \in examine \ldots ?$

Comparison: Tuple and Domain Relational Calculus

Example (semantics tuple relational calculus)

student

matrNr	name	sem
26120	Fichte	10
29555	Feuerbach	2
28106	Carnap	3
27550	Schopenhauer	6

$s =$ 27550 Schopenhauer 6

examine

matrNr	lecNr	grade
28106	5041	2 ✓
27550	5001	2 ✓
28106	5001	2 ✓
26120	5001	2 ✓
27550	4052	1 ✗
25403	5001	1 ✓

result

matrNr
26120 ✓
29555 ✓
28106 ✓
27550 ?

$$\{[s.matrNr] \mid s \in student \wedge \forall e \in examine(s.matrNr = e.matrNr \rightarrow e.grade = 2)\}$$

$s \in student$ ✓ $\forall e \in examine \ldots ?$ ✗

Comparison: Tuple and Domain Relational Calculus

Example (semantics tuple relational calculus)

student

matrNr	name	sem
26120	Fichte	10
29555	Feuerbach	2
28106	Carnap	3
27550	Schopenhauer	6

$s =$ 27550 Schopenhauer 6

examine

matrNr	lecNr	grade
28106	5041	2 ✓
27550	5001	2 ✓
28106	5001	2 ✓
26120	5001	2 ✓
27550	4052	1 ✗
25403	5001	1 ✓

result

matrNr
26120 ✓
29555 ✓
28106 ✓
27550 ?

$$\{[s.matrNr] \mid s \in student \land \forall e \in examine(s.matrNr = e.matrNr \rightarrow e.grade = 2)\}$$

$s \in student$ ✓ $\forall e \in examine \ldots ?$ ✗ $\Rightarrow$ ✗

Comparison: Tuple and Domain Relational Calculus

Example (semantics tuple relational calculus)

student

matrNr	name	sem
26120	Fichte	10
29555	Feuerbach	2
28106	Carnap	3
27550	Schopenhauer	6

$s =$ (27550, Schopenhauer, 6)

examine

matrNr	lecNr	grade
28106	5041	2
27550	5001	2
28106	5001	2
26120	5001	2
27550	4052	1
25403	5001	1

result

matrNr
26120 ✓
29555 ✓
28106 ✓
27550 ✗

$$\{[s.matrNr] \mid s \in student \wedge \forall e \in examine(s.matrNr = e.matrNr \rightarrow e.grade = 2)\}$$

Comparison: Tuple and Domain Relational Calculus

Example (semantics tuple relational calculus)

student		
matrNr	name	sem
26120	Fichte	10
29555	Feuerbach	2
28106	Carnap	3
27550	Schopenhauer	6

$s =$ 27550 Schopenhauer 6

examine		
matrNr	lecNr	grade
28106	5041	2
27550	5001	2
28106	5001	2
26120	5001	2
27550	4052	1
25403	5001	1

result
matrNr
26120 ✓
29555 ✓
28106 ✓

$$\{[s.matrNr] \mid s \in student \wedge \forall e \in examine(s.matrNr = e.matrNr \rightarrow e.grade = 2)\}$$

Comparison: Tuple and Domain Relational Calculus

Example (semantics domain relational calculus)

student		
matrNr	name	Sem
26120	Fichte	10
29555	Feuerbach	2
28106	Carnap	3
27550	Schopenhauer	6

examine		
matrNr	lecNr	grade
28106	5041	2
27550	5001	2
28106	5001	2
26120	5001	2
27550	4052	1
25403	5001	1

result
matrNr

$$\{[mnr] \mid \exists nam, sem([mnr, nam, sem] \in student) \land$$
$$\forall lnr, gr([mnr, lnr, gr] \in examine \rightarrow gr = 2)\}$$

Comparison: Tuple and Domain Relational Calculus

Example (semantics domain relational calculus)

student

matrNr	name	Sem
26120	Fichte	10
29555	Feuerbach	2
28106	Carnap	3
27550	Schopenhauer	6

examine

matrNr	lecNr	grade
28106	5041	2
27550	5001	2
28106	5001	2
26120	5001	2
27550	4052	1
25403	5001	1

result

matrNr
1 ?

$$\{[mnr] \mid \exists nam, sem([mnr, nam, sem] \in student) \land \forall lnr, gr([mnr, lnr, gr] \in examine \rightarrow gr = 2)\}$$

Comparison: Tuple and Domain Relational Calculus

Example (semantics domain relational calculus)

student

matrNr	name	Sem
26120	Fichte	10
29555	Feuerbach	2
28106	Carnap	3
27550	Schopenhauer	6

examine

matrNr	lecNr	grade
28106	5041	2
27550	5001	2
28106	5001	2
26120	5001	2
27550	4052	1
25403	5001	1

result

matrNr
1 ?

$$\{[mnr] \mid \exists nam, sem([mnr, nam, sem] \in student) \land \forall lnr, gr([mnr, lnr, gr] \in examine \rightarrow gr = 2)\}$$

$\exists nam, sem\colon [mnr, nam, sem] \in student?$

Comparison: Tuple and Domain Relational Calculus

Example (semantics domain relational calculus)

student

matrNr	name	Sem
26120	Fichte	10
29555	Feuerbach	2
28106	Carnap	3
27550	Schopenhauer	6

examine

matrNr	lecNr	grade
28106	5041	2
27550	5001	2
28106	5001	2
26120	5001	2
27550	4052	1
25403	5001	1

result

matrNr
1 ?

$$\{[mnr] \mid \exists nam, sem([mnr, nam, sem] \in student) \wedge \forall lnr, gr([mnr, lnr, gr] \in examine \rightarrow gr = 2)\}$$

$\exists nam, sem : [mnr, nam, sem] \in student?$ ✗

Comparison: Tuple and Domain Relational Calculus

Example (semantics domain relational calculus)

student

matrNr	name	Sem
26120	Fichte	10
29555	Feuerbach	2
28106	Carnap	3
27550	Schopenhauer	6

examine

matrNr	lecNr	grade
28106	5041	2
27550	5001	2
28106	5001	2
26120	5001	2
27550	4052	1
25403	5001	1

result

matrNr
1 ✗

$$\{[mnr] \mid \exists nam, sem([mnr, nam, sem] \in student) \land \\ \forall lnr, gr([mnr, lnr, gr] \in examine \rightarrow gr = 2)\}$$

$\exists nam, sem: [mnr, nam, sem] \in student?$ ✗ $\Rightarrow$ ✗

Comparison: Tuple and Domain Relational Calculus

Example (semantics domain relational calculus)

student

matrNr	name	Sem
26120	Fichte	10
29555	Feuerbach	2
28106	Carnap	3
27550	Schopenhauer	6

examine

matrNr	lecNr	grade
28106	5041	2
27550	5001	2
28106	5001	2
26120	5001	2
27550	4052	1
25403	5001	1

result

matrNr

$$\{[mnr] \mid \exists nam, sem([mnr, nam, sem] \in student) \wedge \forall lnr, gr([mnr, lnr, gr] \in examine \rightarrow gr = 2)\}$$

$\exists nam, sem\colon [mnr, nam, sem] \in student?$ ✗ $\Rightarrow$ ✗

Comparison: Tuple and Domain Relational Calculus

Example (semantics domain relational calculus)

student

matrNr	name	Sem
26120	Fichte	10
29555	Feuerbach	2
28106	Carnap	3
27550	Schopenhauer	6

examine

matrNr	lecNr	grade
28106	5041	2
27550	5001	2
28106	5001	2
26120	5001	2
27550	4052	1
25403	5001	1

result

matrNr
26120 ?

$$\{[mnr] \mid \exists nam, sem([mnr, nam, sem] \in student) \land \forall lnr, gr([mnr, lnr, gr] \in examine \rightarrow gr = 2)\}$$

Comparison: Tuple and Domain Relational Calculus

Example (semantics domain relational calculus)

student

matrNr	name	Sem
26120	Fichte	10
29555	Feuerbach	2
28106	Carnap	3
27550	Schopenhauer	6

examine

matrNr	lecNr	grade
28106	5041	2
27550	5001	2
28106	5001	2
26120	5001	2
27550	4052	1
25403	5001	1

result

matrNr
26120 ?

$$\{[mnr] \mid \exists nam, sem([mnr, nam, sem] \in student) \land \forall lnr, gr([mnr, lnr, gr] \in examine \rightarrow gr = 2)\}$$

$\exists nam, sem\colon [mnr, nam, sem] \in student$?

Comparison: Tuple and Domain Relational Calculus

Example (semantics domain relational calculus)

student		
matrNr	name	Sem
26120	Fichte	10
29555	Feuerbach	2
28106	Carnap	3
27550	Schopenhauer	6

examine		
matrNr	lecNr	grade
28106	5041	2
27550	5001	2
28106	5001	2
26120	5001	2
27550	4052	1
25403	5001	1

result
matrNr
26120 ?

$$\{[mnr] \mid \exists nam, sem([mnr, nam, sem] \in student) \land \forall lnr, gr([mnr, lnr, gr] \in examine \rightarrow gr = 2)\}$$

$\exists nam, sem: [mnr, nam, sem] \in student$?

Comparison: Tuple and Domain Relational Calculus

Example (semantics domain relational calculus)

student		
matrNr	name	Sem
26120	Fichte	10
29555	Feuerbach	2
28106	Carnap	3
27550	Schopenhauer	6

examine		
matrNr	lecNr	grade
28106	5041	2
27550	5001	2
28106	5001	2
26120	5001	2
27550	4052	1
25403	5001	1

result
matrNr
26120 ?

$$\{[mnr] \mid \exists nam, sem([mnr, nam, sem] \in student) \wedge \forall lnr, gr([mnr, lnr, gr] \in examine \rightarrow gr = 2)\}$$

$\exists nam, sem: [mnr, nam, sem] \in student?$ ✓

Comparison: Tuple and Domain Relational Calculus

Example (semantics domain relational calculus)

student		
matrNr	name	Sem
26120	Fichte	10
29555	Feuerbach	2
28106	Carnap	3
27550	Schopenhauer	6

examine		
matrNr	lecNr	grade
28106	5041	2
27550	5001	2
28106	5001	2
26120	5001	2
27550	4052	1
25403	5001	1

result
matrNr
26120 ?

$$\{[mnr] \mid \exists nam, sem([mnr, nam, sem] \in student) \land \forall lnr, gr([mnr, lnr, gr] \in examine \rightarrow gr = 2)\}$$

$\exists nam, sem: [mnr, nam, sem] \in student?$ ✓

$\forall lnr, gr \ldots ?$

Comparison: Tuple and Domain Relational Calculus

Example (semantics domain relational calculus)

student

matrNr	name	Sem
26120	Fichte	10
29555	Feuerbach	2
28106	Carnap	3
27550	Schopenhauer	6

examine

matrNr	lecNr	grade
28106	5041	2
27550	5001	2
28106	5001	2
26120	5001	2
27550	4052	1
25403	5001	1

result

matrNr
26120 ?

$$\{[mnr] \mid \exists nam, sem([mnr, nam, sem] \in student) \wedge \forall lnr, gr([mnr, lnr, gr] \in examine \rightarrow gr = 2)\}$$

$\exists nam, sem\colon [mnr, nam, sem] \in student?$ ✓

$\forall lnr, gr \ldots ?\ lnr = \text{'a'},\ gr = \text{'b'}$

Comparison: Tuple and Domain Relational Calculus

Example (semantics domain relational calculus)

student

matrNr	name	Sem
26120	Fichte	10
29555	Feuerbach	2
28106	Carnap	3
27550	Schopenhauer	6

examine

matrNr	lecNr	grade
28106	5041	2
27550	5001	2
28106	5001	2
26120	5001	2
27550	4052	1
25403	5001	1

result

matrNr
26120 ?

$$\{[mnr] \mid \exists nam, sem([mnr, nam, sem] \in student) \wedge \forall lnr, gr([mnr, lnr, gr] \in examine \rightarrow gr = 2)\}$$

$\exists nam, sem\colon [mnr, nam, sem] \in student?$ ✓

$\forall lnr, gr \ldots ?\ lnr = \text{'a'},\ gr = \text{'b'}$ ✓

Comparison: Tuple and Domain Relational Calculus

Example (semantics domain relational calculus)

student		
matrNr	name	Sem
26120	Fichte	10
29555	Feuerbach	2
28106	Carnap	3
27550	Schopenhauer	6

examine		
matrNr	lecNr	grade
28106	5041	2
27550	5001	2
28106	5001	2
26120	5001	2
27550	4052	1
25403	5001	1

result
matrNr
26120 ?

$$\{[mnr] \mid \exists nam, sem([mnr, nam, sem] \in student) \land \forall lnr, gr([mnr, lnr, gr] \in examine \rightarrow gr = 2)\}$$

$\exists nam, sem: [mnr, nam, sem] \in student?$ ✓

$\forall lnr, gr \ldots ?$ $lnr =$ 'a', $gr =$ 'b' ✓ $lnr = 4052$, $gr = 1$ ✓

Comparison: Tuple and Domain Relational Calculus

Example (semantics domain relational calculus)

student

matrNr	name	Sem
26120	Fichte	10
29555	Feuerbach	2
28106	Carnap	3
27550	Schopenhauer	6

examine

matrNr	lecNr	grade
28106	5041	2
27550	5001	2
28106	5001	2
26120	5001	2
27550	4052	1
25403	5001	1

result

matrNr
26120 ?

$$\{[mnr] \mid \exists nam, sem([mnr, nam, sem] \in student) \wedge \forall lnr, gr([mnr, lnr, gr] \in examine \rightarrow gr = 2)\}$$

$\exists nam, sem\colon [mnr, nam, sem] \in student?$ ✓

$\forall lnr, gr \ldots ?$ $lnr =$ 'a', $gr =$ 'b' ✓ $lnr = 4052$, $gr = 1$ ✓ ...

Comparison: Tuple and Domain Relational Calculus

Example (semantics domain relational calculus)

student

matrNr	name	Sem
26120	Fichte	10
29555	Feuerbach	2
28106	Carnap	3
27550	Schopenhauer	6

examine

matrNr	lecNr	grade
28106	5041	2
27550	5001	2
28106	5001	2
26120	5001	2
27550	4052	1
25403	5001	1

result

matrNr
26120 ?

$$\{[mnr] \mid \exists nam, sem([mnr, nam, sem] \in student) \land \forall lnr, gr([mnr, lnr, gr] \in examine \rightarrow gr = 2)\}$$

$\exists nam, sem\colon [mnr, nam, sem] \in student?$ ✓

$\forall lnr, gr \ldots ?$ $\quad \ldots$ $lnr = 5001,\ gr = 2$

Comparison: Tuple and Domain Relational Calculus

Example (semantics domain relational calculus)

student

matrNr	name	Sem
26120	Fichte	10
29555	Feuerbach	2
28106	Carnap	3
27550	Schopenhauer	6

examine

matrNr	lecNr	grade
28106	5041	2
27550	5001	2
28106	5001	2
26120	5001	2 ✓
27550	4052	1
25403	5001	1

result

matrNr
26120 ?

$$\{[mnr] \mid \exists nam, sem([mnr, nam, sem] \in student) \land \forall lnr, gr([mnr, lnr, gr] \in examine \rightarrow gr = 2)\}$$

$\exists nam, sem : [mnr, nam, sem] \in student?$ ✓

$\forall lnr, gr \ldots ?$ $\quad \ldots \; lnr = 5001, \; gr = 2$

Comparison: Tuple and Domain Relational Calculus

Example (semantics domain relational calculus)

student		
matrNr	name	Sem
26120	Fichte	10
29555	Feuerbach	2
28106	Carnap	3
27550	Schopenhauer	6

examine		
matrNr	lecNr	grade
28106	5041	2
27550	5001	2
28106	5001	2
26120	5001	2 ✓
27550	4052	1
25403	5001	1

result
matrNr
26120 ?

$$\{[mnr] \mid \exists nam, sem([mnr, nam, sem] \in student) \land \forall lnr, gr([mnr, lnr, gr] \in examine \rightarrow gr = 2)\}$$

$\exists nam, sem\colon [mnr, nam, sem] \in student?$ ✓

$\forall lnr, gr \ldots ?$ $\quad \ldots\ lnr = 5001,\ gr = 2$

Comparison: Tuple and Domain Relational Calculus

Example (semantics domain relational calculus)

student		
matrNr	name	Sem
$\boxed{26120}$	$\boxed{\text{Fichte}}$	$\boxed{10}$
29555	Feuerbach	2
28106	Carnap	3
27550	Schopenhauer	6

examine		
matrNr	lecNr	grade
28106	5041	2
27550	5001	2
28106	5001	2
26120	5001	2 ✓
27550	4052	1
25403	5001	1

result
matrNr
26120 ?

$$\{[mnr] \mid \exists nam, sem([mnr, nam, sem] \in student) \wedge \forall lnr, gr([mnr, lnr, gr] \in examine \rightarrow gr = 2)\}$$

$\exists nam, sem\colon [mnr, nam, sem] \in student?$ ✓

$\forall lnr, gr \ldots ?$ $\quad \ldots\ lnr = 5001,\ gr = 2$ ✓

Comparison: Tuple and Domain Relational Calculus

Example (semantics domain relational calculus)

student

matrNr	name	Sem
26120	Fichte	10
29555	Feuerbach	2
28106	Carnap	3
27550	Schopenhauer	6

examine

matrNr	lecNr	grade
28106	5041	2
27550	5001	2
28106	5001	2
26120	5001	2 ✓
27550	4052	1
25403	5001	1

result

matrNr
26120 ✓

$$\{[mnr] \mid \exists nam, sem([mnr, nam, sem] \in student) \land \forall lnr, gr([mnr, lnr, gr] \in examine \rightarrow gr = 2)\}$$

$\exists nam, sem\colon [mnr, nam, sem] \in student?$ ✓

$\forall lnr, gr \ldots ?$ $\quad \ldots$ $lnr = 5001,\ gr = 2$ ✓ $\Rightarrow$ ✓

Comparison: Tuple and Domain Relational Calculus

Example (semantics domain relational calculus)

student

matrNr	name	Sem
26120	Fichte	10
29555	Feuerbach	2
28106	Carnap	3
27550	Schopenhauer	6

examine

matrNr	lecNr	grade
28106	5041	2
27550	5001	2
28106	5001	2
26120	5001	2
27550	4052	1
25403	5001	1

result

matrNr
26120 ✓
29555 ?

$$\{[mnr] \mid \exists nam, sem([mnr, nam, sem] \in student) \wedge \forall lnr, gr([mnr, lnr, gr] \in examine \rightarrow gr = 2)\}$$

Comparison: Tuple and Domain Relational Calculus

Example (semantics domain relational calculus)

student

matrNr	name	Sem
26120	Fichte	10
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examine

matrNr	lecNr	grade
28106	5041	2
27550	5001	2
28106	5001	2
26120	5001	2
27550	4052	1
25403	5001	1

result

matrNr
26120 ✓
29555 ?

$$\{[mnr] \mid \exists nam, sem([mnr, nam, sem] \in student) \land \forall lnr, gr([mnr, lnr, gr] \in examine \rightarrow gr = 2)\}$$

$\exists nam, sem\colon [mnr, nam, sem] \in student?$

Comparison: Tuple and Domain Relational Calculus

Example (semantics domain relational calculus)

student

matrNr	name	Sem
26120	Fichte	10
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examine

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28106	5041	2
27550	5001	2
28106	5001	2
26120	5001	2
27550	4052	1
25403	5001	1

result

matrNr
26120 ✓
29555 ?

$$\{[mnr] \mid \exists nam, sem([mnr, nam, sem] \in student) \land \forall lnr, gr([mnr, lnr, gr] \in examine \rightarrow gr = 2)\}$$

$\exists nam, sem: [mnr, nam, sem] \in student?$ ✓

Comparison: Tuple and Domain Relational Calculus

Example (semantics domain relational calculus)

student

matrNr	name	Sem
26120	Fichte	10
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result

matrNr
26120 ✓
29555 ?

$$\{[mnr] \mid \exists nam, sem([mnr, nam, sem] \in student) \wedge \forall lnr, gr([mnr, lnr, gr] \in examine \rightarrow gr = 2)\}$$

$\exists nam, sem\colon [mnr, nam, sem] \in student?$ ✓

$\forall lnr, gr \ldots ?$

Comparison: Tuple and Domain Relational Calculus

Example (semantics domain relational calculus)

student		
matrNr	name	Sem
26120	Fichte	10
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examine		
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$\forall lnr, gr \ldots ? \ldots$ ✓

Comparison: Tuple and Domain Relational Calculus

Example (semantics domain relational calculus)

student		
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examine		
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$\exists nam, sem : [mnr, nam, sem] \in student?$ ✓

$\forall lnr, gr \ldots ? \ldots$ ✓ $\Rightarrow$ ✓

Comparison: Tuple and Domain Relational Calculus

Example (semantics domain relational calculus)

student

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29555 ✓
28106 ?

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Comparison: Tuple and Domain Relational Calculus

Example (semantics domain relational calculus)

student

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examine

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28106	5041	2
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matrNr
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28106 ?

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$\exists nam, sem\colon [mnr, nam, sem] \in student?$ ✓

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$\forall lnr, gr \ldots ?$

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28106 ?

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$\forall lnr, gr \ldots ? \ldots$ ✓

Comparison: Tuple and Domain Relational Calculus

Example (semantics domain relational calculus)

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matrNr	lecNr	grade
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matrNr
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29555 ✓
28106 ?

$$\{[mnr] \mid \exists nam, sem([mnr, nam, sem] \in student) \wedge$$
$$\forall lnr, gr([mnr, lnr, gr] \in examine \rightarrow gr = 2)\}$$

$\exists nam, sem : [mnr, nam, sem] \in student?$ ✓

$\forall lnr, gr \ldots ? \ldots$ ✓

Comparison: Tuple and Domain Relational Calculus

Example (semantics domain relational calculus)

student

matrNr	name	Sem
26120	Fichte	10
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28106	Carnap	3
27550	Schopenhauer	6

examine

matrNr	lecNr	grade
28106	5041	2 ✓
27550	5001	2
28106	5001	2 ✓
26120	5001	2
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25403	5001	1

result

matrNr
26120 ✓
29555 ✓
28106 ?

$$\{[mnr] \mid \exists nam, sem([mnr, nam, sem] \in student) \wedge$$
$$\forall lnr, gr([mnr, lnr, gr] \in examine \rightarrow gr = 2)\}$$

$\exists nam, sem: [mnr, nam, sem] \in student?$ ✓

$\forall lnr, gr \ldots ? \ldots$ ✓

Comparison: Tuple and Domain Relational Calculus

Example (semantics domain relational calculus)

student

matrNr	name	Sem
26120	Fichte	10
29555	Feuerbach	2
28106	Carnap	3
27550	Schopenhauer	6

examine

matrNr	lecNr	grade
28106	5041	2 ✓
27550	5001	2
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26120	5001	2
27550	4052	1
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result

matrNr
26120 ✓
29555 ✓
28106 ?

$$\{[mnr] \mid \exists nam, sem([mnr, nam, sem] \in student) \wedge \forall lnr, gr([mnr, lnr, gr] \in examine \rightarrow gr = 2)\}$$

$\exists nam, sem\colon [mnr, nam, sem] \in student?$ ✓

$\forall lnr, gr \ldots ? \ldots$ ✓

Comparison: Tuple and Domain Relational Calculus

Example (semantics domain relational calculus)

student

matrNr	name	Sem
26120	Fichte	10
29555	Feuerbach	2
$\boxed{28106}$	$\boxed{\text{Carnap}}$	$\boxed{3}$
27550	Schopenhauer	6

examine

matrNr	lecNr	grade
28106	5041	2 ✓
27550	5001	2
28106	5001	2 ✓
26120	5001	2
27550	4052	1
25403	5001	1

result

matrNr
26120 ✓
29555 ✓
28106 ✓

$$\{[mnr] \mid \exists nam, sem([mnr, nam, sem] \in student) \land \forall lnr, gr([mnr, lnr, gr] \in examine \rightarrow gr = 2)\}$$

$\exists nam, sem\colon [mnr, nam, sem] \in student?$ ✓

$\forall lnr, gr \ldots ? \ldots$ ✓ $\Rightarrow$ ✓

Comparison: Tuple and Domain Relational Calculus

Example (semantics domain relational calculus)

student

matrNr	name	Sem
26120	Fichte	10
29555	Feuerbach	2
28106	Carnap	3
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examine

matrNr	lecNr	grade
28106	5041	2
27550	5001	2
28106	5001	2
26120	5001	2
27550	4052	1
25403	5001	1

result

matrNr
26120 ✓
29555 ✓
28106 ✓
27550 ?

$$\{[mnr] \mid \exists nam, sem([mnr, nam, sem] \in student) \wedge \\ \forall lnr, gr([mnr, lnr, gr] \in examine \rightarrow gr = 2)\}$$

Comparison: Tuple and Domain Relational Calculus

Example (semantics domain relational calculus)

student

matrNr	name	Sem
26120	Fichte	10
29555	Feuerbach	2
28106	Carnap	3
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examine

matrNr	lecNr	grade
28106	5041	2
27550	5001	2
28106	5001	2
26120	5001	2
27550	4052	1
25403	5001	1

result

matrNr
26120 ✓
29555 ✓
28106 ✓
27550 ?

$$\{[mnr] \mid \exists nam, sem([mnr, nam, sem] \in student) \wedge \forall lnr, gr([mnr, lnr, gr] \in examine \rightarrow gr = 2)\}$$

$\exists nam, sem\colon [mnr, nam, sem] \in student?$

Comparison: Tuple and Domain Relational Calculus

Example (semantics domain relational calculus)

student

matrNr	name	Sem
26120	Fichte	10
29555	Feuerbach	2
28106	Carnap	3
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examine

matrNr	lecNr	grade
28106	5041	2
27550	5001	2
28106	5001	2
26120	5001	2
27550	4052	1
25403	5001	1

result

matrNr
26120 ✓
29555 ✓
28106 ✓
27550 ?

$$\{[mnr] \mid \exists nam, sem([mnr, nam, sem] \in student) \land \forall lnr, gr([mnr, lnr, gr] \in examine \rightarrow gr = 2)\}$$

$\exists nam, sem: [mnr, nam, sem] \in student?$ ✓

Comparison: Tuple and Domain Relational Calculus

Example (semantics domain relational calculus)

student

matrNr	name	Sem
26120	Fichte	10
29555	Feuerbach	2
28106	Carnap	3
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examine

matrNr	lecNr	grade
28106	5041	2
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result

matrNr
26120 ✓
29555 ✓
28106 ✓
27550 ?

$$\{[mnr] \mid \exists nam, sem([mnr, nam, sem] \in student) \land \forall lnr, gr([mnr, lnr, gr] \in examine \rightarrow gr = 2)\}$$

$\exists nam, sem\colon [mnr, nam, sem] \in student?$ ✓

$\forall lnr, gr \ldots ?$

Comparison: Tuple and Domain Relational Calculus

Example (semantics domain relational calculus)

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matrNr	name	Sem
26120	Fichte	10
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28106	Carnap	3
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examine

matrNr	lecNr	grade
28106	5041	2
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26120	5001	2
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matrNr
26120 ✓
29555 ✓
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27550 ?

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Comparison: Tuple and Domain Relational Calculus

Example (semantics domain relational calculus)

student

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26120	Fichte	10
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examine

matrNr	lecNr	grade
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matrNr
26120 ✓
29555 ✓
28106 ✓
27550 ?

$$\{[mnr] \mid \exists nam, sem([mnr, nam, sem] \in student) \land \forall lnr, gr([mnr, lnr, gr] \in examine \rightarrow gr = 2)\}$$

$\exists nam, sem\colon [mnr, nam, sem] \in student$? ✓

$\forall lnr, gr \ldots ? \ldots$ ✓

Comparison: Tuple and Domain Relational Calculus

Example (semantics domain relational calculus)

student		
matrNr	name	Sem
26120	Fichte	10
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examine		
matrNr	lecNr	grade
28106	5041	2
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26120	5001	2
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result
matrNr
26120 ✓
29555 ✓
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$$\{[mnr] \mid \exists nam, sem([mnr, nam, sem] \in student) \land$$
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$\exists nam, sem\colon [mnr, nam, sem] \in student?$ ✓

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FAKULTÄT FÜR INFORMATIK
Faculty of Informatics

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result

matrNr
26120 ✓
29555 ✓
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$$\{[mnr] \mid \exists nam, sem([mnr, nam, sem] \in student) \land$$
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$\exists nam, sem\colon [mnr, nam, sem] \in student?$ ✓

$\forall lnr, gr \ldots ? \ldots$ ✓

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28106	5041	2
27550	5001	2 ✓
28106	5001	2
26120	5001	2
27550	4052	1 ✗
25403	5001	1

result

matrNr
26120 ✓
29555 ✓
28106 ✓
27550 ?

$$\{[mnr] \mid \exists nam, sem([mnr, nam, sem] \in student) \land \forall lnr, gr([mnr, lnr, gr] \in examine \rightarrow gr = 2)\}$$

$\exists nam, sem\colon [mnr, nam, sem] \in student?$ ✓

$\forall lnr, gr \ldots ? \ldots$ ✓

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matrNr
26120 ✓
29555 ✓
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27550 ?

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$\exists nam, sem\colon [mnr, nam, sem] \in student?$ ✓

$\forall lnr, gr \ldots ? \ldots$ ✓ ✗

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result
matrNr
26120 ✓
29555 ✓
28106 ✓
27550 ✗

$$\{[mnr] \mid \exists nam, sem([mnr, nam, sem] \in student) \land \forall lnr, gr([mnr, lnr, gr] \in examine \rightarrow gr = 2)\}$$

$\exists nam, sem: [mnr, nam, sem] \in student?$ ✓

$\forall lnr, gr \ldots ? \ldots$ ✓ ✗ $\Rightarrow$ ✗

Comparison: Tuple and Domain Relational Calculus

Example (semantics domain relational calculus)

student

matrNr	name	Sem
26120	Fichte	10
29555	Feuerbach	2
28106	Carnap	3
27550	Schopenhauer	6

examine

matrNr	lecNr	grade
28106	5041	2
27550	5001	2
28106	5001	2
26120	5001	2
27550	4052	1
25403	5001	1

result

matrNr
26120 ✓
29555 ✓
28106 ✓

$$\{[mnr] \mid \exists nam, sem([mnr, nam, sem] \in student) \land \forall lnr, gr([mnr, lnr, gr] \in examine \rightarrow gr = 2)\}$$

Safe Expressions and Expressive Power of Query Languages

Safe Expressions in the Relational Calculus

"A query in the relational calculus is safe, if its result depends only on values that occur in the data base or in the query, but not on the domain."

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Example (unsafe queries)

$R(A)$

$$\{t \mid \neg(t \in R)\} \qquad \{[a] \mid \neg([a] \in R)\}$$

Safe Expressions in the Tuple Relational Calculus

in some cases queries specify an infinite set of results:

Example

$$\{n \mid \neg(n \in \mathit{professor})\}$$

results in all tuples that do not occur in the relation professor. We can think of infinitely many such tuples.

Safe Expressions in the Tuple Relational Calculus

Definition (domain of an expression)

The domain of a formula contains

- all constants occurring in the formula and
- all attribute values of relations that are referenced in the formula.

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Definition (safe expressions)

An expression in the tuple relational calculus is safe if the result of the expression is a subset of the domain.

Safe Expressions in the Domain Relational Calculus

in some cases queries might result in an infinite set of results

Example

$$\{[p, n, r, o] \mid \neg([p, n, r, o] \in \mathit{professor})\}$$

results in all tuples that do not occur in the relation professor; we can think of infinitely many such tuples

Safe Expressions in the Domain Relational Calculus

Definition (safe expressions)

an expression

$$\{[x_1, x_2, \ldots, x_n] \mid P(x_1, x_2, \ldots, x_n)\}$$

is safe if:

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- for each subformula $\exists x P_1(x)$: if the constant c satisfies $P(c)$, then c is contained in the domain of P_1
- for each subformula $\forall x P_1(x)$: satisfied if and only if $P_1(x)$ is satisfied for all values in the domain of P_1

(2. and 3. are satisfied in the tuple relational calculus automatically!)

Expressive Power of the Query Languages

The three languages

- relational algebra,
- tuple relational calculus, restricted to safe expressions and
- domain relational calculus, restricted to safe expressions

are equally expressive.

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important: SQL is equally expressive as well (with some specific restrictions)

Learning Objectives

- What are the differences between the relational algebra and the relational calculus?
- What does it mean for a language to be relationally complete?
- What are the differences between tuple relational calculus and domain relational calculus?
- How do expressions in tuple resp. domain relational calculus look like?
- What are safe expressions in the relational calculus?