## Fundamentals of Database Systems COMPSCI 351

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# Relational Query Languages: Algebra

"Stand firm in your refusal to remain conscious during algebra. In real life, I assure you, there is no such thing as algebra."

— Fran Lebowitz

#### Consider our database schema from before

- MOVIE(title, year, country, run\_time, genre), DIRECTOR(id, title, year)
- Person(id, first\_name, last\_name, year\_born), Actor(id, title, year, role)

#### Consider our database schema from before

- MOVIE(title, year, country, run\_time, genre), DIRECTOR(id, title, year)
- Person(id, first\_name, last\_name, year\_born), Actor(id, title, year, role)

#### Query in English

What are the movies directed by 'Akira Kurosawa'?

#### Consider our database schema from before

- MOVIE(title, year, country, run\_time, genre), DIRECTOR(id, title, year)
- Person(id, first\_name, last\_name, year\_born), Actor(id, title, year, role)

#### Query in English

What are the movies directed by 'Akira Kurosawa'?

#### SQL

FROM MOVIE m, DIRECTOR d, PERSON p

,

#### Consider our database schema from before

- MOVIE(title, year, country, run\_time, genre), DIRECTOR(id, title, year)
- Person(id, first\_name, last\_name, year\_born), Actor(id, title, year, role)

#### Query in English

What are the movies directed by 'Akira Kurosawa'?

#### **SQL**

FROM MOVIE m, DIRECTOR d, PERSON p
WHERE m.title=d.title AND m.year=d.year AND

 $\label{eq:did_p.id_AND_p.first_name} $$ d.id=p.id_AND_p.first_name='Akira'_AND_p.last_name='Kurosawa';$ 

#### Consider our database schema from before

- MOVIE(title, year, country, run\_time, genre), DIRECTOR(id, title, year)
- Person(id, first\_name, last\_name, year\_born), Actor(id, title, year, role)

#### Query in English

What are the movies directed by 'Akira Kurosawa'?

#### **SQL**

SELECT m.title, m.year

FROM MOVIE m, DIRECTOR d, PERSON p
WHERE m.title=d.title AND m.year=d.year AND

did-nid AND n first name-'Akira' AND n

 $d.id = p.id \ AND \ p.first\_name = 'Akira' \ AND \ p.last\_name = 'Kurosawa';$ 

#### Consider our database schema from before

- MOVIE(title, year, country, run\_time, genre), DIRECTOR(id, title, year)
- Person(id, first\_name, last\_name, year\_born), Actor(id, title, year, role)

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- MOVIE(title, year, country, run\_time, genre), DIRECTOR(id, title, year)
- Person(id, first\_name, last\_name, year\_born), Actor(id, title, year, role)

#### Query in English

What are the movies directed by 'Akira Kurosawa'?

#### Consider our database schema from before

- MOVIE(title, year, country, run\_time, genre), DIRECTOR(id, title, year)
- Person(id, first\_name, last\_name, year\_born), Actor(id, title, year, role)

#### Query in English

What are the movies directed by 'Akira Kurosawa'?

#### Relational algebra

Movie Director Person

#### Consider our database schema from before

- MOVIE(title, year, country, run\_time, genre), DIRECTOR(id, title, year)
- Person(id, first\_name, last\_name, year\_born), Actor(id, title, year, role)

#### Query in English

What are the movies directed by 'Akira Kurosawa'?

#### Relational algebra

Movie ⋈ Director ⋈ Person

#### Consider our database schema from before

- MOVIE(title, year, country, run\_time, genre), DIRECTOR(id, title, year)
- Person(id, first\_name, last\_name, year\_born), Actor(id, title, year, role)

#### Query in English

What are the movies directed by 'Akira Kurosawa'?

#### Relational algebra

 $\sigma_{\mathsf{first\_name}=\mathsf{'Akira'}}(\mathsf{MOVIE} \bowtie \mathsf{DIRECTOR} \bowtie \mathsf{PERSON})$ 

#### Consider our database schema from before

- MOVIE(title, year, country, run\_time, genre), DIRECTOR(id, title, year)
- Person(id, first\_name, last\_name, year\_born), Actor(id, title, year, role)

#### Query in English

What are the movies directed by 'Akira Kurosawa'?

#### Relational algebra

 $\sigma_{\mathsf{last\_name}='\mathsf{Kurosawa'}}(\sigma_{\mathsf{first\_name}='\mathsf{Akira'}}(\mathsf{Movie}\bowtie\mathsf{Director}\bowtie\mathsf{Person}))$ 

#### Consider our database schema from before

- MOVIE(title, year, country, run\_time, genre), DIRECTOR(id, title, year)
- Person(id, first\_name, last\_name, year\_born), Actor(id, title, year, role)

#### Query in English

What are the movies directed by 'Akira Kurosawa'?

#### Relational algebra

 $\pi_{\mathsf{title},\mathsf{year}}(\sigma_{\mathsf{last\_name}=\mathsf{'Kurosawa'}}(\sigma_{\mathsf{first\_name}=\mathsf{'Akira'}}(\mathsf{MOVIE}\bowtie\mathsf{DIRECTOR}\bowtie\mathsf{PERSON})))$ 

## Algebras

An algebra is given by a set A and a set of operations on A

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#### In Relational Algebra

- A is the set of possible relations
- The partial operations on A
  - $\hookrightarrow$  take either 1 or 2 relations as input and
  - $\hookrightarrow$  produce another relation as output

## Algebras

An algebra is given by a set A and a set of operations on A

#### In Relational Algebra

- *A* is the set of possible relations
- The partial operations on A
  - → take either 1 or 2 relations as input and
  - → produce another relation as output

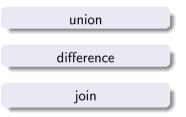
For a relation r let #r denote its set of attributes over which r is defined

## Operations of Relational Algebra

constant selection

projection

renaming



## Attribute Selection

Attribute selection  $\sigma_{A=B}$ 

### **Attribute Selection**

#### Attribute selection $\sigma_{A=B}$

• takes a single relation r with  $A, B \in \#r$ , and produces

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#### Attribute selection $\sigma_{A=B}$

- takes a single relation r with  $A, B \in \#r$ , and produces
- the relation  $\sigma_{A=B}(r) = \{t \mid t \in r \land t(A) = t(B)\}$  over #r



Evaluate $\sigma_{ ext{m.title}= ext{d.title}}$ on the following relation $r$						
m.title	m.country	d.name	d.title			
The Seven Samurai	Japan	Akira Kurosawa	The Seven Samurai			
The Seven Samurai	Japan	Francis F. Coppola	The Godfather			
The Godfather	USA	Akira Kurosawa	The Seven Samurai			
The Godfather	USA	Francis F. Coppola	The Godfather			

	$\sigma_{m.title}$	$_{\rm e=d.title}(r)$		
m.title	m.country	d.name	d.title	

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The Seven Samurai	Japan	Francis F. Coppola	The Godfather		
The Godfather	USA	Akira Kurosawa	The Seven Samurai		
The Godfather	USA	Francis F. Coppola	The Godfather		

$\sigma_{m.title=d.title}(r)$				
m.title	m.country	d.name	d.title	

Evaluate $\sigma_{ m m.title=d.title}$ on the following relation $r$					
m.title	m.country	d.name	d.title		
The Seven Samurai	Japan	Akira Kurosawa	The Seven Samurai		
The Seven Samurai	Japan	Francis F. Coppola	The Godfather		
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					_

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The Godfather	USA	Akira Kurosawa	The Seven Samurai		
The Godfather	USA	Francis F. Coppola	The Godfather		

$\sigma_{\sf m.title=d.title}(r)$				
m.title	m.country	d.name	d.title	
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The Godfather	USA	Francis F. Coppola	The Godfather			

	$\sigma_{m.t}$	$_{ m citle}=$ d $_{ m title}(r)$	
m.title	m.country	d.name	d.title
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	The Seven Samurai	Japan	Akira Kurosawa	The Seven Samurai		
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	The Godfather	USA	Akira Kurosawa	The Seven Samurai		
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$\sigma_{\sf m.title=d.title}(r)$					
m.title	m.country	d.name	d.title		
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The Godfather	USA	Akira Kurosawa	The Seven Samurai		
The Godfather	USA	Francis F. Coppola	The Godfather		

$\sigma_{ m m.title=d.title}(r)$					
m.title	m.country	d.name	d.title		
The Seven Samurai	Japan	Akira Kurosawa	The Seven Samurai		

Evaluate $\sigma_{ exttt{m.title}= exttt{d.title}}$ on the following relation $r$					
m.title	m.country	d.name	d.title		
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The Seven Samurai	Japan	Francis F. Coppola	The Godfather		
The Godfather	USA	Akira Kurosawa	The Seven Samurai		
The Godfather	USA	Francis F. Coppola	The Godfather		

$\sigma_{\sf m.title=d.title}(r)$					
m.title	m.country	d.name	d.title	_	
The Seven Samurai	Japan	Akira Kurosawa	The Seven Samurai		
The Godfather	USA	Francis F. Coppola	The Godfather		

## **Constant Selection**

Constant selection  $\sigma_{A=c}$  with  $c \in dom(A)$ 

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• takes a single relation r with  $A \in \#r$ , and produces

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- takes a single relation r with  $A \in \#r$ , and produces
- a relation  $\sigma_{A=c}(r) = \{t \mid t \in r \land t(A) = c\}$  over #r

Evaluate $\sigma_{ extsf{d.name}=' ext{Akira Kurosawa}'}$ on the following relation $r$					
m.title	m.country	d.name	d.title		
The Seven Samurai	Japan	Akira Kurosawa	The Seven Samurai		
The Godfather	USA	Francis F. Coppola	The Godfather		

		$\sigma_{\sf d.name='Aki}$	ra Kurosawa' $(r)$		
-	m.title	m.country	d.name	d.title	

Evaluate $\sigma_{\sf d}$	l.name='Akira K	<sub>urosawa'</sub> on the followin	ig relation <i>r</i>
m.title	m.country	d.name	d.title
The Seven Samurai	Japan	Akira Kurosawa	The Seven Samurai
The Godfather	USA	Francis F. Coppola	The Godfather

		$\sigma_{\sf d.name='Aki}$	ra Kurosawa' $(r)$		
-	m.title	m.country	d.name	d.title	
_				_	

Evaluate $\sigma_{ m c}$	l.name='Akira K	<sub>urosawa'</sub> on the followin	g relation <i>r</i>
m.title	m.country	d.name	d.title
The Seven Samurai	Japan	Akira Kurosawa	The Seven Samurai
The Godfather	USA	Francis F. Coppola	The Godfather

	$\sigma_{\sf d.name='Aki}$	ra Kurosawa' (r)	
m.title	m.country	d.name	d.title

Evaluate $\sigma_{ m c}$	l.name='Akira K	<sub>urosawa'</sub> on the followin	ng relation <i>r</i>
m.title	m.country	d.name	d.title
The Seven Samurai	Japan	Akira Kurosawa	The Seven Samurai
The Godfather	USA	Francis F. Coppola	The Godfather

	$\sigma_{\sf d.name='}$	Akira Kurosawa' $(r)$	
m.title	m.country	d.name	d.title
The Seven Samurai	Japan	Akira Kurosawa	The Seven Samurai

Evaluate $\sigma_{ m c}$	l.name='Akira K	<sub>urosawa'</sub> on the followin	ng relation <i>r</i>
m.title	m.country	d.name	d.title
The Seven Samurai	Japan	Akira Kurosawa	The Seven Samurai
The Godfather	USA	Francis F. Coppola	The Godfather

$\sigma$ d.name $=$ 'Akira Kurosawa' $(r)$				
m.title	m.country	d.name	d.title	
The Seven Samurai	Japan	Akira Kurosawa	The Seven Samurai	

Evaluate $\sigma_{\sf d}$	l.name='Akira K	<sub>urosawa'</sub> on the followin	g relation <i>r</i>
m.title	m.country	d.name	d.title
The Seven Samurai	Japan	Akira Kurosawa	The Seven Samurai
The Godfather	USA	Francis F. Coppola	The Godfather

	$\sigma_{\sf d.name='}$	Akira Kurosawa' $(r)$	
m.title	m.country	d.name	d.title
The Seven Samurai	Japan	Akira Kurosawa	The Seven Samurai

Evaluate $\sigma_{ m c}$	l.name='Akira K	<sub>urosawa'</sub> on the followin	ng relation <i>r</i>
m.title	m.country	d.name	d.title
The Seven Samurai	Japan	Akira Kurosawa	The Seven Samurai
The Godfather	USA	Francis F. Coppola	The Godfather

	$\sigma_{\sf d.name='}$	Akira Kurosawa' $(r)$	
m.title	m.country	d.name	d.title
The Seven Samurai	Japan	Akira Kurosawa	The Seven Samurai

# Projection

Projection  $\pi_{A_1,...,A_k}$ 

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• takes a single relation r with  $A_1, \ldots, A_k \in \#r$  as input, and produces

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- takes a single relation r with  $A_1, \ldots, A_k \in \#r$  as input, and produces
- relation  $\pi_{A_1,\ldots,A_k}(r)=\{t\mid \exists t'\in r\forall i\in\{1,\ldots,k\}t(A_i)=t'(A_i)\}$  over  $\{A_1,\ldots,A_k\}$

Evaluate	$\pi_{m.title,m.cou}$	<sub>ntry</sub> on the following r	elation <i>r</i>
m.title	m.country	d.name	d.title
The Seven Samurai	Japan	Akira Kurosawa	The Seven Samurai
The Seven Samurai	Japan	Francis F. Coppola	The Godfather
The Godfather	USA	Akira Kurosawa	The Seven Samurai
The Godfather	USA	Francis F. Coppola	The Godfather
	m.title The Seven Samurai The Seven Samurai The Godfather	m.title m.country The Seven Samurai Japan The Seven Samurai Japan The Godfather USA	The Seven Samurai Japan Akira Kurosawa The Seven Samurai Japan Francis F. Coppola The Godfather USA Akira Kurosawa

$\pi_{m.title,m.country}(r)$		
	m.title	m.country

Evaluate	$\pi_{m.title,m.cou}$	<sub>ntry</sub> on the following re	elation <i>r</i>
m.title	m.country	d.name	d.title
The Seven Samurai	Japan	Akira Kurosawa	The Seven Samurai
The Seven Samurai	Japan	Francis F. Coppola	The Godfather
The Godfather	USA	Akira Kurosawa	The Seven Samurai
The Godfather	USA	Francis F. Coppola	The Godfather

$\pi$ m.title,m.co	$_{ m untry}(r)$	
m.title	m.country	

Evaluate	$\pi$ m.title,m.cou	<sub>ntry</sub> on the following re	elation <i>r</i>
m.title	m.country	d.name	d.title
The Seven Samurai	Japan	Akira Kurosawa	The Seven Samurai
The Seven Samurai	Japan	Francis F. Coppola	The Godfather
The Godfather	USA	Akira Kurosawa	The Seven Samurai
The Godfather	USA	Francis F. Coppola	The Godfather

m.title m.country

Evaluate	$\pi_{m.title,m.cou}$	<sub>ntry</sub> on the following re	elation <i>r</i>
m.title	m.country	d.name	d.title
The Seven Samurai	Japan	Akira Kurosawa	The Seven Samurai
The Seven Samurai	Japan	Francis F. Coppola	The Godfather
The Godfather	USA	Akira Kurosawa	The Seven Samurai
The Godfather	USA	Francis F. Coppola	The Godfather

$\frac{\pi_{m.title,m.country}(r)}{m.title}$	
m.title The Seven Samurai	m.country Japan

Evaluate	$\pi$ m.title,m.cou	<sub>ntry</sub> on the following re	elation <i>r</i>
m.title	m.country	d.name	d.title
The Seven Samurai	Japan	Akira Kurosawa	The Seven Samurai
The Seven Samurai	Japan	Francis F. Coppola	The Godfather
The Godfather	USA	Akira Kurosawa	The Seven Samurai
The Godfather	USA	Francis F. Coppola	The Godfather

$\pi_{\text{m.title,m.country}}(r)$	
m.title	m.country
The Seven Samurai	Japan

Evaluate	$\pi$ m.title,m.cou	<sub>ntry</sub> on the following re	elation <i>r</i>
m.title	m.country	d.name	d.title
The Seven Samurai	Japan	Akira Kurosawa	The Seven Samurai
The Seven Samurai	Japan	Francis F. Coppola	The Godfather
The Godfather	USA	Akira Kurosawa	The Seven Samurai
The Godfather	USA	Francis F. Coppola	The Godfather

$\pi_{m.title,m.co}$	$t_{country}(r)$
m.title	m.country
The Seven Samui	rai Japan

Evaluate	$\pi_{m.title,m.cou}$	<sub>ntry</sub> on the following re	elation <i>r</i>
m.title	m.country	d.name	d.title
The Seven Samurai	Japan	Akira Kurosawa	The Seven Samurai
The Seven Samurai	Japan	Francis F. Coppola	The Godfather
The Godfather	USA	Akira Kurosawa	The Seven Samurai
The Godfather	USA	Francis F. Coppola	The Godfather

$\pi_{m.title,m.countr}$	$r_{y}(r)$
m.title	m.country
The Seven Samurai	Japan

	Evaluate	$\pi$ m.title,m.cou	<sub>ntry</sub> on the following re	elation <i>r</i>
-	m.title	m.country	d.name	d.title
	The Seven Samurai	Japan	Akira Kurosawa	The Seven Samurai
	The Seven Samurai	Japan	Francis F. Coppola	The Godfather
	The Godfather	USA	Akira Kurosawa	The Seven Samurai
	The Godfather	USA	Francis F. Coppola	The Godfather

$\pi_{m.title,m.counti}$	<sub>'y</sub> (r)
m.title	m.country
The Seven Samurai	Japan

Evaluate	$\pi_{m.title,m.cou}$	<sub>ntry</sub> on the following re	elation <i>r</i>
m.title	m.country	d.name	d.title
The Seven Samurai	Japan	Akira Kurosawa	The Seven Samurai
The Seven Samurai	Japan	Francis F. Coppola	The Godfather
The Godfather	USA	Akira Kurosawa	The Seven Samurai
The Godfather	USA	Francis F. Coppola	The Godfather

$\pi$ m.title,m.countr	$\pi_{m.title,m.country}(r)$	
m.title	m.country	
The Seven Samurai	Japan	
The Godfather	USA	

Evaluate	$\pi_{m.title,m.cou}$	<sub>ntry</sub> on the following re	elation <i>r</i>
m.title	m.country	d.name	d.title
The Seven Samurai	Japan	Akira Kurosawa	The Seven Samurai
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The Godfather	USA	Francis F. Coppola	The Godfather

$\pi_{m.title,m.country}(r)$	
m.title	m.country
The Seven Samurai	Japan
The Godfather	USA

Evaluate	$\pi_{m.title,m.cou}$	<sub>ntry</sub> on the following re	elation <i>r</i>
m.title	m.country	d.name	d.title
The Seven Samurai	Japan	Akira Kurosawa	The Seven Samurai
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$\pi$ m.title,m.count	$\pi_{m.title,m.country}(r)$	
m.title	m.country	
The Seven Samurai	Japan	
The Godfather	USA	

Evaluate $\pi_{m.title,m.country}$ on the following relation $r$							
m.title	m.country	d.name	d.title				
The Seven Samurai	Japan	Akira Kurosawa	The Seven Samurai				
The Seven Samurai	Japan	Francis F. Coppola	The Godfather				
The Godfather	USA	Akira Kurosawa	The Seven Samurai				
The Godfather	USA	Francis F. Coppola	The Godfather				

$\pi$ m.title,m.countr	$\pi_{m.title,m.country}(r)$		
m.title	m.country		
The Seven Samurai	Japan		
The Godfather	USA		

Simply changes some attribute names without changing the relation

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Renaming  $\delta_{A_1 \mapsto B_1, \dots, A_k \mapsto B_k}$  with  $dom(B_i) = dom(A_i)$  for  $i = 1, \dots, k$ 

Simply changes some attribute names without changing the relation

Renaming 
$$\delta_{A_1 \mapsto B_1, \dots, A_k \mapsto B_k}$$
 with  $dom(B_i) = dom(A_i)$  for  $i = 1, \dots, k$ 

• takes relation r with  $A_1, \ldots, A_k \in \#r$  and  $B_1, \ldots, B_k \notin \#r - \{A_1, \ldots, A_k\}$ , and

© Professor Sebastian Link

Simply changes some attribute names without changing the relation

#### Renaming $\delta_{A_1 \mapsto B_1, \dots, A_k \mapsto B_k}$ with $dom(B_i) = dom(A_i)$ for $i = 1, \dots, k$

- takes relation r with  $A_1, \ldots, A_k \in \#r$  and  $B_1, \ldots, B_k \notin \#r \{A_1, \ldots, A_k\}$ , and
- produces relation

$$\delta_{A_1 \mapsto B_1, \dots, A_k \mapsto B_k}(r) = \{t \mid \exists t' \in r \forall i \in \{1, \dots, k\} t(B_i) = t'(A_i) \land \forall C \in \#r - \{A_1, \dots, A_k\} t(C) = t'(C)\}$$

over 
$$(\#r - \{A_1, \dots, A_k\}) \cup \{B_1, \dots, B_k\}$$

#### Evaluate $\delta_{\text{m.title}} \rightarrow \text{title}, \text{m.country} \rightarrow \text{country}$ on the following relation r

m.title	m.country
The Seven Samurai	Japan
The Godfather	USA

Evaluate $\delta_{m.title \mapsto title, m.country \mapsto country}$	on the	following	relation	t
--	--------	-----------	----------	---

m.title	m.country
The Seven Samurai	Japan
The Godfather	USA

Evaluate $\delta_{ m m.til}$	wing relation <i>r</i>		
m.title		m.country	
The Seven Samur		Japan	
	The Godfather	USA	

Evaluate $\delta_{m.ti}$	tle→title,m.country→country	on the follow	wing relation <i>r</i>
	m.title	m.country	
	The Seven Samurai	Japan	
	The Godfather	USA	

titlecountryThe Seven SamuraiJapanThe GodfatherUSA	$\delta_{\sf m.tit}$	:le⊢→title,m.country⊢→	$_{country}(r)$
•		title	country
The Godfather USA	The S	Seven Samurai	Japan
	Th	ne Godfather	USA

Evaluate $\delta_{\text{m.title} \mapsto \text{title}, \text{m.country} \mapsto \text{country}}$	on	the	following	relation	r
--	----	-----	-----------	----------	---

m.title	m.country
The Seven Samurai	Japan
The Godfather	USA

# $\delta_{ ext{m.title} ightarrow ext{title}, ext{m.country} ightarrow ext{country}}(r)$ title country The Seven Samurai Japan The Godfather USA

#### Union

#### Union ∪

- takes two relations r and s with #r = #s, and produces
- the relation that is the set union  $r \cup s$  over #r = #s

© Professor Sebastian Link

#### Evaluate $\sigma_{\sf Country='New\ Zealand'}(r) \cup \sigma_{\sf Country='Japan'}(r)$ on the following relation r

title	year	country	run_time	genre
13 Assassins	2010	Japan	126	Drama
La dolce vita	1960	Italy	174	Classic
Mana Waka	1937	New Zealand	85	History
Nosferatu	1922	Germany	80	Horror



$\sigma$ Country='New Zealand' $(r)\cup\sigma$ Country='Japan' $(r)$					
title	year	country	run_time	genre	

#### Evaluate $\sigma_{\sf Country='New\ Zealand'}(r) \cup \sigma_{\sf Country='Japan'}(r)$ on the following relation r

title	year	country	run_time	genre
13 Assassins	2010	Japan	126	Drama
La dolce vita	1960	Italy	174	Classic
Mana Waka	1937	New Zealand	85	History
Nosferatu	1922	Germany	80	Horror

	$\sigma_{Count}$	ry='New Zealan	$_{d'}(r)$	
title	year	country	run_time	genre



$\sigma$ Country='New Zealand' $(r)\cup\sigma$ Country='Japan' $(r)$					
title	year	country	run_time	genre	

#### Evaluate $\sigma_{\mathsf{Country}='\mathsf{New}\ \mathsf{Zealand'}}(r) \cup \sigma_{\mathsf{Country}='\mathsf{Japan'}}(r)$ on the following relation r

title	year	country	run_time	genre
13 Assassins	2010	Japan	126	Drama
La dolce vita	1960	Italy	174	Classic
Mana Waka	1937	New Zealand	85	History
Nosferatu	1922	Germany	80	Horror

	$\sigma$ Country='New Zealand' $(r)$					
title	year	country	run_time	genre		

	$\sigma_{ extsf{Country='Japan'}}(r)$					
-	title	year	country	run_time	genre	-
	13 Assassins	2010	Japan	126	Drama	

$\sigma$ Country='New Zealand' $(r)$ $\cup$ $\sigma$ Country='Japan' $(r)$					
title	year	country	run_time	genre	

#### Evaluate $\sigma_{\mathsf{Country}='\mathsf{New}\ \mathsf{Zealand'}}(r) \cup \sigma_{\mathsf{Country}='\mathsf{Japan'}}(r)$ on the following relation r

title	year	country	run_time	genre
13 Assassins	2010	Japan	126	Drama
La dolce vita	1960	Italy	174	Classic
Mana Waka	1937	New Zealand	85	History
Nosferatu	1922	Germany	80	Horror

$\sigma$ Country='New Zealand' $(r)$					
title	year	country	run_time	genre	

$\sigma_{Country='Japan'}(r)$				
title	year	country	run_time	genre
13 Assassins	2010	Japan	126	Drama

$\sigma$ Country='New Zealand' $(r)\cup\sigma$ Country='Japan' $(r)$					
title	year	country	run_time	genre	

## Evaluate $\sigma_{\mathsf{Country}='\mathsf{New}\ \mathsf{Zealand'}}(r) \cup \sigma_{\mathsf{Country}='\mathsf{Japan'}}(r)$ on the following relation r

title	year	country	run_time	genre
13 Assassins	2010	Japan	126	Drama
La dolce vita	1960	Italy	174	Classic
Mana Waka	1937	New Zealand	85	History
Nosferatu	1922	Germany	80	Horror

	$\sigma_{Count}$	ry='New Zealan	$_{d'}(r)$	
title	year	country	run_time	genre

		$\sigma_{Cour}$	ntry='Japan'	(r)		
-	title	year	country	run_time	genre	
	13 Assassins	2010	Japan	126	Drama	

## Evaluate $\sigma_{\sf Country='New\ Zealand'}(r) \cup \sigma_{\sf Country='Japan'}(r)$ on the following relation r

title	year	country	run_time	genre
13 Assassins	2010	Japan	126	Drama
La dolce vita	1960	Italy	174	Classic
Mana Waka	1937	New Zealand	85	History
Nosferatu	1922	Germany	80	Horror

	$\sigma_{Coul}$	ntry='New Zealand'	(r)	
title	year	country	run_time	genre
Mana Waka	1937	New Zealand	85	History

$\sigma_{Country='Japan'}(r)$					
title	year	country	run_time	genre	
13 Assassins 2010 Japan 126 Drama					

## Evaluate $\sigma_{\mathsf{Country}='\mathsf{New}\ \mathsf{Zealand'}}(r) \cup \sigma_{\mathsf{Country}='\mathsf{Japan'}}(r)$ on the following relation r

title	year	country	run_time	genre
13 Assassins	2010	Japan	126	Drama
La dolce vita	1960	Italy	174	Classic
Mana Waka	1937	New Zealand	85	History
Nosferatu	1922	Germany	80	Horror

	$\sigma_{Coul}$	ntry='New Zealand'	(r)	
title	year	country	run_time	genre
Mana Waka	1937	New Zealand	85	History

$\sigma_{Country='Japan'}(r)$				
title	year	country	run_time	genre
13 Assassins	2010	Japan	126	Drama

## Evaluate $\sigma_{\mathsf{Country}='\mathsf{New}\ \mathsf{Zealand'}}(r) \cup \sigma_{\mathsf{Country}='\mathsf{Japan'}}(r)$ on the following relation r

title	year	country	run_time	genre
13 Assassins	2010	Japan	126	Drama
La dolce vita	1960	Italy	174	Classic
Mana Waka	1937	New Zealand	85	History
Nosferatu	1922	Germany	80	Horror

$\sigma_{Country='New\ Zealand'}(r)$							
title	year	country	run_time	genre			
Mana Waka	1937	New Zealand	85	History			

$\sigma_{Country=^{\scriptscriptstyle{'}}Japan^{\scriptscriptstyle{'}}}(r)$						
title	year	country	run_time	genre	-	
13 Assassins	2010	Japan	126	Drama		

title year country run_time genre	$\sigma$ Country='New Zealand' $(r)$ $\cup$ $\sigma$ Country='Japan' $(r)$							
	title	year	country	run_time	genre			

Evaluate $\sigma_{Country='New}$ Zealand' $(r)\cup\sigma_{Country='Japan'}(r)$ on the following relative	ation <i>r</i>

title	year	country	run_time	genre
13 Assassins	2010	Japan	126	Drama
La dolce vita	1960	Italy	174	Classic
Mana Waka	1937	New Zealand	85	History
Nosferatu	1922	Germany	80	Horror

$\sigma$ Country='New Zealand' $(r)$								
titl	e	year	country	run_time	genre			
Mana \	Waka 1937	Waka 1937 New Zeala	Waka 1937 New Zealand	1937 New Ze	85	History		

$\sigma_{Country=^{'}Japan'}(r)$						
title	year	country	run_time	genre	-	
13 Assassins	2010	Japan	126	Drama		

Country= New Zealand (1) Country= Japan (1)								
title	genre							
13 Assassins	2010	Japan	126	Drama				
Mana Waka	1937	New Zealand	85	History				

Evaluate $\sigma_{Country='New}$ Zealand' (	(r)	$) \cup \sigma_{Country='Japan'}$	(r)	) on	the	following	relation	r
---	-----	-----------------------------------	-----	------	-----	-----------	----------	---

title	year	country	run_time	genre
13 Assassins	2010	Japan	126	Drama
La dolce vita	1960	Italy	174	Classic
Mana Waka	1937	New Zealand	85	History
Nosferatu	1922	Germany	80	Horror

$\sigma$ Country='New Zealand' $(r)$							
title	year	country	run_time	genre			
Mana Waka	1937	New Zealand	85	History			

$\sigma_{Country='Japan'}(r)$						
title year country run_time ger						
13 Assassins	2010	Japan	126	Drama		

Country= New Zealand (1) Country= Japan (1)						
title	year	country	run_time	genre		
13 Assassins	2010	Japan	126	Drama		
Mana Waka	1937	New Zealand	85	History		

## Difference

### Difference –

• takes two relations r and s with #r = #s, and produces the relation that

### Difference

### Difference -

- ullet takes two relations r and s with #r = #s, and produces the relation that
- is the set difference  $r s = \{t \mid t \in r \land t \notin s\}$  over #r = #s



Evaluate $r - \sigma_{Country='Italy'}(r)$	over the following relation <i>r</i>

title	year	country	$run\_time$	genre
13 Assassins	2010	Japan	126	Drama
La dolce vita	1960	Italy	174	Classic
Mana Waka	1937	New Zealand	85	History
Nosferatu	1922	Germany	80	Horror

### $\sigma_{\mathsf{Country}='\mathsf{Italy}'}(r)$

title	year	country	run_time	genre

## $r - \sigma_{\mathsf{Country}='\mathsf{Italy}'}(r)$

title	year	country	run_time	genre

Evaluate $r - \sigma_{\text{County}=\text{Haly}}(r)$ over the following relation $r$					
title	year	country	run_time	genre	
13 Assassins	2010	Japan	126	Drama	
La dolce vita	1960	Italy	174	Classic	
Mana Waka	1937	New Zealand	85	History	
Nosferatu	1922	Germany	80	Horror	

$\sigma_{Country='Italy'}(r)$					
title	year	country	run_time	genre	
title	year	Country	run_time	genre	

$\mathit{r} - \sigma_{Country='ltaly'}(\mathit{r})$						
title	year	country	run_time	genre		

Evaluate $r - \sigma_{Country='Italy'}(r)$	over the following relation <i>r</i>

title	year	country	run_time	genre
13 Assassins	2010	Japan	126	Drama
La dolce vita	1960	Italy	174	Classic
Mana Waka	1937	New Zealand	85	History
Nosferatu	1922	Germany	80	Horror

### $\sigma_{\mathsf{Country}='\mathsf{Italy'}}(r)$

title	year	country	run_time	genre

## $r - \sigma_{\mathsf{Country}='\mathsf{Italy}'}(r)$

title	year	country	run_time	genre

Evaluate $r - \sigma_{\sf Country='Italy'}(r)$ over the following relation $r$							
	* Country=	italy (1)	8				
title	year	country	run_time	genre			
13 Assassins	2010	Japan	126	Drama			
La dolce vita	1960	Italy	174	Classic			
Mana Waka	1937	New Zealand	85	History			
Nosferatu	1922	Germany	80	Horror			

$\sigma_{Country='Italy'}(r)$					
title	year	country	run_time	genre	

	r –	$\sigma_{Country='Italy'}$	r)	
title	year	country	run_time	genre

Evaluate $r - \sigma_{Country = Halp}(r)$ over the following relation $r$				
title	year	country	run_time	genre
13 Assassins	2010	Japan	126	Drama
La dolce vita	1960	Italy	174	Classic
Mana Waka	1937	New Zealand	85	History
Nosferatu	1922	Germany	80	Horror

title	year	country	run_time	genre	
La dolce vita	1960	Italy	174	Classic	

	r –	$\sigma_{Country='Italy'}$	r)	
title	year	country	run_time	genre

Evaluate $r - \sigma_{Country='Italy'}(r)$	) ove	the	following	relation <i>r</i>
--	-------	-----	-----------	-------------------

title	year	country	$run\_time$	genre
13 Assassins	2010	Japan	126	Drama
La dolce vita	1960	Italy	174	Classic
Mana Waka	1937	New Zealand	85	History
Nosferatu	1922	Germany	80	Horror

### $\sigma_{\mathsf{Country}='\mathsf{Italy'}}(r)$

title	year	country	run_time	genre
La dolce vita	1960	Italy	174	Classic

### $r - \sigma_{\mathsf{Country}='\mathsf{Italy'}}(r)$

titl	e ye	ar count	try run_	time genre
+1+1	O 1/6	ar count	run run	time genre
LILI	e ye	ai couiii	iy run_	Lillie gelli

Evaluate $r - \sigma_{Country='Italy'}$	[r]	over the	following	relation r	
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title	year	country	run_time	genre
13 Assassins	2010	Japan	126	Drama
La dolce vita	1960	Italy	174	Classic
Mana Waka	1937	New Zealand	85	History
Nosferatu	1922	Germany	80	Horror

### $\sigma_{\mathsf{Country}='\mathsf{Italy}'}(r)$

title	year	country	run_time	genre
La dolce vita	1960	Italy	174	Classic

## $r - \sigma_{\mathsf{Country}='\mathsf{Italy'}}(r)$

title year country run_time genr	title year country run_time g
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Evaluate $r - \sigma_{Country='Italy'}(r)$	) ove	the	following	relation <i>r</i>
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title	year	country	$run\_time$	genre
13 Assassins	2010	Japan	126	Drama
La dolce vita	1960	Italy	174	Classic
Mana Waka	1937	New Zealand	85	History
Nosferatu	1922	Germany	80	Horror

### $\sigma_{\mathsf{Country}='\mathsf{Italy}'}(r)$

title	year	country	run_time	genre
La dolce vita	1960	Italy	174	Classic

### $r - \sigma_{\text{Country}='|\text{Italy}'}(r)$

titic	year	eountry ,	Tuni-time	801110
title	year	country	run_time	genre

Nosferatu

1922

Evaluate $r - \sigma_{Country='Italy'}(r)$ over the following relation $r$							
title	vear	country	run_time	genre			
13 Assassins	2010		126	Drama			
		Japan					
La dolce vita	1960	Italy	174	Classic			
Mana Waka	1937	New Zealand	85	History			

Germany

80

Horror

	<i>O</i> C <sub>0</sub>	untry='Italy'(「	)		
title	year	country	run_time	genre	
La dolce vita	1960	Italy	174	Classic	

r –	$\sigma_{Country='Italy'}$	r)	
year	country	run_time	genre
			year country run_time

Evaluate $r-\sigma_{Country='Italy'}($	r)	over the following relation $r$
--	----	---------------------------------

title	year	country	$run_time$	genre
13 Assassins	2010	Japan	126	Drama
La dolce vita	1960	Italy	174	Classic
Mana Waka	1937	New Zealand	85	History
Nosferatu	1922	Germany	80	Horror

## $\sigma_{\mathsf{Country}='\mathsf{Italy'}}(r)$

title	year	country	run_time	genre
La dolce vita	1960	Italy	174	Classic

### $r - \sigma_{\mathsf{Country} = \mathsf{'Italy'}}(r)$

title	year	country	run_time	genre
13 Assassins	2010	Japan	126	Drama

Evaluate $r-\sigma_{Country='Italy'}(r)$	over the following relation $r$

title	year	country	$run_time$	genre
13 Assassins	2010	Japan	126	Drama
La dolce vita	1960	Italy	174	Classic
Mana Waka	1937	New Zealand	85	History
Nosferatu	1922	Germany	80	Horror

### $\sigma_{\mathsf{Country}='\mathsf{Italy}'}(r)$

title	year	country	run_time	genre
La dolce vita	1960	ltaly	174	Classic

#### $r - \sigma_{\mathsf{Country} = \mathsf{'Italy'}}(r)$

title	year	country	run_time	genre
13 Assassins	2010	Japan	126	Drama

Evaluate $r - \sigma_{\sf Country='Italy'}(r)$	over the following relation $r$

title	year	country	run_time	genre
13 Assassins	2010	Japan	126	Drama
La dolce vita	1960	Italy	174	Classic
Mana Waka	1937	New Zealand	85	History
Nosferatu	1922	Germany	80	Horror

### $\sigma_{\mathsf{Country}='\mathsf{Italy}'}(r)$

title	year	country	run_time	genre
La dolce vita	1960	ltaly	174	Classic

#### $r - \sigma_{\mathsf{Country} = \mathsf{'Italy'}}(r)$

title	year	country	run_time	genre
13 Assassins	2010	Japan	126	Drama

Evaluate $r-\sigma_{\sf Country='Italy'}$	(r)	) over the following relation $r$	
---	-----	-----------------------------------	--

title	year	country	$run\_time$	genre
13 Assassins	2010	Japan	126	Drama
La dolce vita	1960	Italy	174	Classic
Mana Waka	1937	New Zealand	85	History
Nosferatu	1922	Germany	80	Horror

## $\sigma_{\mathsf{Country}='\mathsf{Italy'}}(r)$

title	year	country	run_time	genre
La dolce vita	1960	ltaly	174	Classic

#### $r - \sigma_{\mathsf{Country} = '\mathsf{Italy'}}(r)$

title	year	country	run_time	genre
13 Assassins	2010	Japan	126	Drama

Evaluate $r-\sigma_{\sf Country='Italy'}$	(r)	) over the following relation $r$	
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title	year	country	$run\_time$	genre
13 Assassins	2010	Japan	126	Drama
La dolce vita	1960	Italy	174	Classic
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Nosferatu	1922	Germany	80	Horror

### $\sigma_{\mathsf{Country}='\mathsf{Italy}'}(r)$

title	year	country	run_time	genre
La dolce vita	1960	Italy	174	Classic

#### $r - \sigma_{\mathsf{Country} = '\mathsf{Italy'}}(r)$

title	year	country	run_time	genre
13 Assassins	2010	Japan	126	Drama
Mana Waka	1937	New Zealand	85	History

Evaluate $r-\sigma_{\sf Country='Italy'}$	(r)	over the	following	relation <i>r</i>
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title	year	country	$run\_time$	genre
13 Assassins	2010	Japan	126	Drama
La dolce vita	1960	Italy	174	Classic
Mana Waka	1937	New Zealand	85	History
Nosferatu	1922	Germany	80	Horror

### $\sigma_{\mathsf{Country}='\mathsf{Italy}'}(r)$

title	year	country	run_time	genre
La dolce vita	1960	Italy	174	Classic

#### $r - \sigma_{\mathsf{Country} = '\mathsf{Italy'}}(r)$

title	year	country	run_time	genre
13 Assassins	2010	Japan	126	Drama
Mana Waka	1937	New Zealand	85	History

Evaluate $r-\sigma_{\sf Country='Italy'}$	(r)	) over the following relation $r$	
---	-----	-----------------------------------	--

title	year	country	run_time	genre
13 Assassins	2010	Japan	126	Drama
La dolce vita	1960	Italy	174	Classic
Mana Waka	1937	New Zealand	85	History
Nosferatu	1922	Germany	80	Horror

## $\sigma_{\mathsf{Country}='\mathsf{Italy'}}(r)$

title	year	country	run_time	genre
La dolce vita	1960	Italy	174	Classic

#### $r - \sigma_{\mathsf{Country}='\mathsf{Italy'}}(r)$

title	year	country	run_time	genre
13 Assassins	2010	Japan	126	Drama
Mana Waka	1937	New Zealand	85	History
Nosferatu	1922	Germany	80	Horror

Evaluate $r-\sigma_{Country='Italy'}($	r)	over the following relation $r$
--	----	---------------------------------

title	year	country	run_time	genre
13 Assassins	2010	Japan	126	Drama
La dolce vita	1960	Italy	174	Classic
Mana Waka	1937	New Zealand	85	History
Nosferatu	1922	Germany	80	Horror

## $\sigma_{\mathsf{Country}='\mathsf{Italy'}}(r)$

title	year	country	run_time	genre
La dolce vita	1960	ltaly	174	Classic

### $r - \sigma_{\mathsf{Country}='\mathsf{Italy'}}(r)$

title	year	country	run_time	genre
13 Assassins	2010	Japan	126	Drama
Mana Waka	1937	New Zealand	85	History
Nosferatu	1922	Germany	80	Horror

## Natural Join

## (Natural) join ⋈

ullet takes two relations r and s as input, and

## Natural Join

## (Natural) join ⋈

- takes two relations r and s as input, and
- produces the relation

$$r\bowtie s=\{t\mid \exists t_1\in r, t_2\in s(\forall A\in \#r(t(A)=t_1(A))\land \forall B\in \#s(t(B)=t_2(B)))\}$$

over  $\#r \cup \#s$ 



title	year	$run_{-}time$	genre
13 Assassins	2010	126	Drama
Mana Waka	1937	85	History
Nosferatu	1922	80	Horror

id	title	year	role
2	13 Assassins	2010	Shinzaemon Shimada
4	La dolce vita	1960	Marcello Rubini
8	Nosferatu	1922	Graf Orlock
8	Nosferatu	1922	Nosferatu

title	year	run_time	genre	id	role

		Evaluate	$r \bowtie s$	over	the	following re	elation	s r and s
					id	title	vear	rol
title	year	run₋time	genre				,	
13 Assassins	2010	126	Drama	_	2	13 Assassins	2010	Shinzaemor
		120			4	La dolce vita	1960	Marcello
Mana Waka	1937	85	History					
					8	Nosferatu	1922	Graf O
Nosferatu	1922	80	Horror		0	N £ +	1000	NI C-

id	title	year	role
2	13 Assassins	2010	Shinzaemon Shimada
4	La dolce vita	1960	Marcello Rubini
8	Nosferatu	1922	Graf Orlock
8	Nosferatu	1922	Nosferatu

		r	⊠ <i>5</i>			
title	year	run_time	genre	id	role	

Evaluate $r \bowtie s$	over the	following	relations	r an	d <i>s</i>
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title	year	$run\_time$	genre
13 Assassins	2010	126	Drama
Mana Waka	1937	85	History
Nosferatu	1922	80	Horror

id	title	year	role
2	13 Assassins	2010	Shinzaemon Shimada
4	La dolce vita	1960	Marcello Rubini
8	Nosferatu	1922	Graf Orlock
8	Nosferatu	1922	Nosferatu

title	year	run_time	genre	id	role
13 Assassins	2010	126	Drama	2	Shinzaemon Shimada

title	year	run_time	genre
13 Assassins	2010	126	Drama
Mana Waka	1937	85	History
Nosferatu	1922	80	Horror

id	title	year	role
2	13 Assassins	2010	Shinzaemon Shimada
4	La dolce vita	1960	Marcello Rubini
8	Nosferatu	1922	Graf Orlock
8	Nosferatu	1922	Nosferatu

title	year	run_time	genre	id	role
13 Assassins	2010	126	Drama	2	Shinzaemon Shimada

title	year	$run\_time$	genre
13 Assassins	2010	126	Drama
Mana Waka	1937	85	History
Nosferatu	1922	80	Horror

id	title	year	role
2	13 Assassins	2010	Shinzaemon Shimada
4	La dolce vita	1960	Marcello Rubini
8	Nosferatu	1922	Graf Orlock
8	Nosferatu	1922	Nosferatu

title	year	run_time	genre	id	role
13 Assassins	2010	126	Drama	2	Shinzaemon Shimada

title	year	$run_{-}time$	genre
13 Assassins	2010	126	Drama
Mana Waka	1937	85	History
Nosferatu	1922	80	Horror

id	title	year	role
2	13 Assassins	2010	Shinzaemon Shimada
4	La dolce vita	1960	Marcello Rubini
8	Nosferatu	1922	Graf Orlock
8	Nosferatu	1922	Nosferatu

title	year	run_time	genre	id	role
13 Assassins	2010	126	Drama	2	Shinzaemon Shimada

Evaluate	$r \bowtie s$ over	the following	relations <i>i</i>	and s
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title	year	$run_{-}time$	genre
13 Assassins	2010	126	Drama
Mana Waka	1937	85	History
Nosferatu	1922	80	Horror

id	title	year	role
2	13 Assassins	2010	Shinzaemon Shimada
4	La dolce vita	1960	Marcello Rubini
8	Nosferatu	1922	Graf Orlock
8	Nosferatu	1922	Nosferatu

title	year	run_time	genre	id	role
13 Assassins	2010	126	Drama	2	Shinzaemon Shimada

Evaluate $r \bowtie s$ over the following	wing relations $r$ and $s$
---	----------------------------

year	$run_{-}time$	genre
2010	126	Drama
1937	85	History
1922	80	Horror
	2010 1937	2010 126 1937 85

id	title	year	role
2	13 Assassins	2010	Shinzaemon Shimada
4	La dolce vita	1960	Marcello Rubini
8	Nosferatu	1922	Graf Orlock
8	Nosferatu	1922	Nosferatu

title	year	run_time	genre	id	role
13 Assassins	2010	126	Drama	2	Shinzaemon Shimada

Evaluate $r \bowtie s$	over the	following	relations	r an	d <i>s</i>
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title	year	$run_{-}time$	genre
13 Assassins	2010	126	Drama
Mana Waka	1937	85	History
Nosferatu	1922	80	Horror

id	title	year	role
2	13 Assassins	2010	Shinzaemon Shimada
4	La dolce vita	1960	Marcello Rubini
8	Nosferatu	1922	Graf Orlock
8	Nosferatu	1922	Nosferatu

title	year	run_time	genre	id	role
13 Assassins	2010	126	Drama	2	Shinzaemon Shimada

title	year	$run_{-}time$	genre
13 Assassins	2010	126	Drama
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id	title	year	role
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8	Nosferatu	1922	Nosferatu

title	year	run_time	genre	id	role
13 Assassins	2010	126	Drama	2	Shinzaemon Shimada

Evaluate $r \bowtie s$ over the following relations $r$ are
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Mana Waka	1937	85	History
Nosferatu	1922	80	Horror

id	title	year	role
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### Intersection $\cap$

- takes two relations r and s with #r = #s, and
- ullet produces the set intersection  $r\cap s=\{t\mid t\in r\land t\in s\}$  over  $\#r\cup \#s$  as output

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### Cross-product $\times$

- takes two relations r and s with schemata  $\#r \cap \#s = \emptyset$ , and
- produces the relation

$$r \times s = \{t \mid \exists t_1 \in r, t_2 \in s \forall A \in \#r(t(A) = t_1(A) \land \forall B \in \#s(t(B) = t_2(B)))\}$$

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### **GENIUS Question**

Why is this operation redundant?

## Relational Algebra as a Query Language

Use operations of relational algebra to define a query language

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Use operations of relational algebra to define a query language

### For given database schema ${\cal S}$

- ullet all our queries Q will be defined over  ${\mathcal S}$
- in(Q) = S for all our queries Q
- out(Q) = ans(Q), i.e., a single (answer) relation schema

### Remarks

### Notation

- use db to denote an S-database
- for each  $R \in \mathcal{S}$ , use db(R) to denote the R-relation in db

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- use db to denote an S-database
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### Note for equations in the definitions on the next pages

- left hand side refers to syntactic expression of the query language,
- right hand side contains Relational Algebra operations from before

# The Query Language $\mathcal{L}_{\mathsf{ALG}}$ of Relational Algebra (1)

### Each relation schema $R \in \mathcal{S}$ is a query in $\mathcal{L}_{\mathsf{ALG}}$

- with answer schema R, and the query mapping
- defined by q(R)(db) = db(R)

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### Each pair (A:c) with $c \in dom(A)$ is a query in $\mathcal{L}_{\mathsf{ALG}}$

- with answer schema  $\{A\}$ , and the query mapping
- defined by  $q(A : c)(db) = \{(A : c)\}$

# The Query Language $\mathcal{L}_{ALG}$ of Relational Algebra (2)

For each query  $Q \in \mathcal{L}_{ALG}$  and attributes  $A, B \in ans(Q)$  the expression  $\sigma_{A=B}(Q)$  is also a query in  $\mathcal{L}_{ALG}$ 

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For each query  $Q \in \mathcal{L}_{ALG}$ , any attribute  $A \in ans(Q)$  and any constant  $c \in dom(A)$  the expression  $\sigma_{A=c}(Q)$  is also a query in  $\mathcal{L}_{ALG}$ 

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## The Query Language $\mathcal{L}_{ALG}$ of Relational Algebra (3)

For each query  $Q \in \mathcal{L}_{ALG}$  and attributes  $A_1, \ldots, A_k \in ans(Q)$  the expression  $\pi_{A_1, \ldots, A_k}(Q)$  is also a query in  $\mathcal{L}_{ALG}$ 

- with answer schema  $\{A_1, \ldots, A_k\}$ , and the query mapping
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For each query  $Q \in \mathcal{L}_{ALG}$ , any attributes  $A_1, \ldots, A_k \in ans(Q)$  and attributes  $B_1, \ldots, B_k \notin ans(Q) - \{A_1, \ldots, A_k\}$  with  $dom(A_i) = dom(B_i)$  the expression  $\delta_{A_1 \mapsto B_1, \ldots, A_k \mapsto B_k}(Q)$  is also a query in  $\mathcal{L}_{ALG}$ 

- with answer schema  $(ans(Q) \{A_1, \ldots, A_k\}) \cup \{B_1, \ldots, B_k\}$ , and
- the query mapping defined by

$$q(\delta_{A_1\mapsto B_1,...,A_k\mapsto B_k}(Q))(db) = \delta_{A_1\mapsto B_1,...,A_k\mapsto B_k}(q(Q)(db))$$

## The Query Language $\mathcal{L}_{ALG}$ of Relational Algebra (4)

For any queries  $Q_1,Q_2\in\mathcal{L}_{\mathsf{ALG}}$  with  $\mathit{ans}(Q_1)=\mathit{ans}(Q_2)$  the expression  $Q_1\cup Q_2$  is also a query in  $\mathcal{L}_{\mathsf{ALG}}$ 

- ullet with answer schema  $ans(Q_1)$ , and the query mapping
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- with answer schema  $ans(Q_1)$ , and the query mapping
- defined by  $q(Q_1 Q_2)(db) = q(Q_1)(db) q(Q_2)(db)$

# The Query Language $\mathcal{L}_{ALG}$ of Relational Algebra (5)

## For any queries $Q_1,Q_2\in\mathcal{L}_{\mathsf{ALG}}$ the expression $Q_1\bowtie Q_2$ is also a query in $\mathcal{L}_{\mathsf{ALG}}$

- ullet with answer schema  $ans(Q_1)\cup ans(Q_2)$ , and the query mapping
- ullet defined by  $q(Q_1 \bowtie Q_2)(db) = q(Q_1)(db) \bowtie q(Q_2)(db)$

Movie					
title	year	country	run_time	genre	
Inglorious Basterds	2009	USA	153	Drama	
Django Unchained	2012	USA	165	Drama	
Ex-machina	2015	USA	108	Drama	

	DIRECTOR	
id	title	year
1	Django Unchained	2012
1	Inglorious Basterds	2009
5	Ex-machina	2015

_			ERSON	
	id	first_name	last_name	year_born
	1	Quentin	Tarantino	1963
	2	Jamie	Foxx	1967
	3	Brad	Pitt	1963
	4	Christoph	Waltz	1956
	5	Alex	Garland	1970
	6	Alicia	Vikander	1988

PERSON

ACTOR					
id	title	year	role		
2	Django Unchained	2012	Django		
3	Inglorious Basterds	2009	Lt Aldo Raine		
4	Inglorious Basterds	2009	Col Hans Landa		
4	Django Unchained	2012	Dr King Schultz		
6	Ex-machina	2015	Ava		

#### Actors appearing in all movies directed by Quentin Tarantino

 $\pi_{\mathsf{id},\mathsf{title},\mathsf{year}}(\mathsf{ACTOR}) \div \pi_{\mathsf{title},\mathsf{year}}(\mathsf{MOVIE} \bowtie \mathsf{DIRECTOR} \bowtie \sigma_{\mathsf{first\_name}='\mathsf{Quentin'}}(\sigma_{\mathsf{last\_name}='\mathsf{Tarantino'}}(\mathsf{PERSON})))$ 

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2012	USA	165	Drama			
2015	USA	108	Drama			
	year 2009 2012	year country 2009 USA 2012 USA	year country run_time 2009 USA 153 2012 USA 165			

Director		
title	year	
Django Unchained	2012	
Inglorious Basterds	2009	
Ex-machina	2015	
	title Django Unchained Inglorious Basterds	

id	first_name	last_name	year_born
1	Quentin	Tarantino	1963
2	Jamie	Foxx	1967
3	Brad	Pitt	1963
4	Christoph	Waltz	1956
5	Alex	Garland	1970
6	Alicia	Vikander	1988

PERSON

title	year	
Django Unchained	2012	
Inglorious Basterds	2009	
Inglorious Basterds	2009	
Django Unchained	2012	
Ex-machina	2015	
	Django Unchained Inglorious Basterds Inglorious Basterds Django Unchained	Django Unchained 2012 Inglorious Basterds 2009 Inglorious Basterds 2009 Django Unchained 2012

#### Actors appearing in all movies directed by Quentin Tarantino

 $\pi_{\mathsf{id},\mathsf{title},\mathsf{year}}(\mathsf{ACTOR}) \div \pi_{\mathsf{title},\mathsf{year}}(\mathsf{MOVIE} \bowtie \mathsf{DIRECTOR} \bowtie \sigma_{\mathsf{first\_name}='\mathsf{Quentin'}}(\sigma_{\mathsf{last\_name}='\mathsf{Tarantino'}}(\mathsf{PERSON})))$ 

title	year
Inglorious Basterds	2009
Diango Unchained	2012

	AOVIE		
year	country	run_time	genre
2009	USA	153	Drama
2012	USA	165	Drama
2015	USA	108	Drama
	year 2009 2012	year country 2009 USA 2012 USA	year         country         run_time           2009         USA         153           2012         USA         165

		Director	
-	id	title	year
-	1	Django Unchained	2012
	1	Inglorious Basterds	2009
	5	Ex-machina	2015
_			

		. Litaboli	
id	first_name	last_name	year_born
1	Quentin	Tarantino	1963
2	Jamie	Foxx	1967
3	Brad	Pitt	1963
4	Christoph	Waltz	1956
5	Alex	Garland	1970
6	Alicia	Vikander	1988

PERSON

	Ac	TOR	
id	title	year	
2	Django Unchained	2012	
3	Inglorious Basterds	2009	
4	Inglorious Basterds	2009	
4	Django Unchained	2012	
6	Ex-machina	2015	

#### Actors appearing in all movies directed by Quentin Tarantino

 $\pi_{\mathsf{id},\mathsf{title},\mathsf{year}}(\mathsf{ACTOR}) \div \pi_{\mathsf{title},\mathsf{year}}(\mathsf{MOVIE} \bowtie \mathsf{DIRECTOR} \bowtie \sigma_{\mathsf{first\_name}='\mathsf{Quentin'}}(\sigma_{\mathsf{last\_name}='\mathsf{Tarantino'}}(\mathsf{PERSON})))$ 

title	year
Inglorious Basterds	2009
Django Unchained	2012

MOVIE				
title	year	country	run_time	genre
Inglorious Basterds	2009	USA	153	Drama
Django Unchained	2012	USA	165	Drama
Ex-machina	2015	USA	108	Drama

	Director	
id	title	year
1	Django Unchained	2012
1	Inglorious Basterds	2009
5	Ex-machina	2015

id	first_name	last_name	year_born
1	Quentin	Tarantino	1963
2	Jamie	Foxx	1967
3	Brad	Pitt	1963
4	Christoph	Waltz	1956
5	Alex	Garland	1970
6	Alicia	Vikander	1988

PERSON

	Ac	TOR	
id	title	vear	-
2	Django Unchained	2012	1
3	Inglorious Basterds	2009	
4	Inglorious Basterds	2009	
4	Django Unchained	2012	
6	Ex-machina	2015	

#### Actors appearing in all movies directed by Quentin Tarantino

 $\pi_{\mathsf{id},\mathsf{title},\mathsf{year}}(\mathsf{ACTOR}) \div \pi_{\mathsf{title},\mathsf{year}}(\mathsf{MOVIE} \bowtie \mathsf{DIRECTOR} \bowtie \sigma_{\mathsf{first\_name}='\mathsf{Quentin'}}(\sigma_{\mathsf{last\_name}='\mathsf{Tarantino'}}(\mathsf{PERSON})))$ 

title	year	
Inglorious Basterds	2009	
Django Unchained	2012	

	AOVIE		
year	country	run_time	genre
2009	USA	153	Drama
2012	USA	165	Drama
2015	USA	108	Drama
	year 2009 2012	year country 2009 USA 2012 USA	year         country         run_time           2009         USA         153           2012         USA         165

	DIRECTOR	
id	title	year
1	Django Unchained	2012
1	Inglorious Basterds	2009
5	Ex-machina	2015

id	first_name	last_name	year_born
1	Quentin	Tarantino	1963
2	Jamie	Foxx	1967
3	Brad	Pitt	1963
4	Christoph	Waltz	1956
5	Alex	Garland	1970
6	Alicia	Vikander	1988

PERSON

id	title	year	
2	Django Unchained	2012	
3	Inglorious Basterds	2009	
4	Inglorious Basterds	2009	
4	Django Unchained	2012	
6	Ex-machina	2015	

#### Actors appearing in all movies directed by Quentin Tarantino

 $\pi_{\mathsf{id},\mathsf{title},\mathsf{year}}(\mathsf{ACTOR}) \div \pi_{\mathsf{title},\mathsf{year}}(\mathsf{MOVIE} \bowtie \mathsf{DIRECTOR} \bowtie \sigma_{\mathsf{first\_name}='\mathsf{Quentin'}}(\sigma_{\mathsf{last\_name}='\mathsf{Tarantino'}}(\mathsf{PERSON})))$ 

title	year
Inglorious Basterds	2009
Diango Unchained	2012

	N	AOVIE .		
title	year	country	run_time	genre
Inglorious Basterds	2009	USA	153	Drama
Django Unchained	2012	USA	165	Drama
Ex-machina	2015	USA	108	Drama

		Director	
i	d	title	year
	1	Django Unchained	2012
	1	Inglorious Basterds	2009
	5	Ex-machina	2015

		Littoon	
id	first_name	last_name	year_born
1	Quentin	Tarantino	1963
2	Jamie	Foxx	1967
3	Brad	Pitt	1963
4	Christoph	Waltz	1956
5	Alex	Garland	1970
6	Alicia	Vikander	1988

PERSON

id	title	year	
2	Django Unchained	2012	
3	Inglorious Basterds	2009	
4	Inglorious Basterds	2009	
4	Django Unchained	2012	
6	Ex-machina	2015	

#### Actors appearing in all movies directed by Quentin Tarantino

 $\pi_{\mathsf{id},\mathsf{title},\mathsf{year}}(\mathsf{ACTOR}) \div \pi_{\mathsf{title},\mathsf{year}}(\mathsf{MOVIE} \bowtie \mathsf{DIRECTOR} \bowtie \sigma_{\mathsf{first\_name}='\mathsf{Quentin'}}(\sigma_{\mathsf{last\_name}='\mathsf{Tarantino'}}(\mathsf{PERSON})))$ 

title	year
Inglorious Basterds	2009
Diango Unchained	2012

Movie				
year	country	run_time	genre	
2009	USA	153	Drama	
2012	USA	165	Drama	
2015	USA	108	Drama	
	year 2009 2012	year country 2009 USA 2012 USA	year         country         run_time           2009         USA         153           2012         USA         165	

	Director	
id	title	year
1	Django Unchained	2012
1	Inglorious Basterds	2009
5	Ex-machina	2015

id	first_name	last_name	year_born
1	Quentin	Tarantino	1963
2	Jamie	Foxx	1967
3	Brad	Pitt	1963
4	Christoph	Waltz	1956
5	Alex	Garland	1970
6	Alicia	Vikander	1988

PERSON

	Ac	TOR	
id	title	year	
2	Django Unchained	2012	
3	Inglorious Basterds	2009	
4	Inglorious Basterds	2009	
4	Django Unchained	2012	
6	Ex-machina	2015	

#### Actors appearing in all movies directed by Quentin Tarantino

 $\pi_{\mathsf{id},\mathsf{title},\mathsf{year}}(\mathsf{ACTOR}) \div \pi_{\mathsf{title},\mathsf{year}}(\mathsf{MOVIE} \bowtie \mathsf{DIRECTOR} \bowtie \sigma_{\mathsf{first\_name} = '\mathsf{Quentin'}}(\sigma_{\mathsf{last\_name} = '\mathsf{Tarantino'}}(\mathsf{PERSON})))$ 

title	year
Inglorious Basterds	2000
Django Unchained	2012

V	10VIE		
year	country	run_time	genre
2009	USA	153	Drama
2012	USA	165	Drama
2015	USA	108	Drama
	year 2009 2012	2009 USA 2012 USA	year         country         run_time           2009         USA         153           2012         USA         165

	Director		
id	title	year	
1	Django Unchained	2012	
1	Inglorious Basterds	2009	
5	Ex-machina	2015	

1         Quentin         Tarantino         1963           2         Jamie         Foxx         1967           3         Brad         Pitt         1963           4         Christoph         Waltz         1956           5         Alex         Garland         1970           6         Alicia         Vikander         1988	id	first_name	last_name	vear_born
2         Jamie         Foxx         1967           3         Brad         Pitt         1963           4         Christoph         Waltz         1956           5         Alex         Garland         1970	1			
4 Christoph Waltz 1956 5 Alex Garland 1970	2		Foxx	
5 Alex Garland 1970	3	Brad	Pitt	1963
	4	Christoph	Waltz	1956
6 Alicia Vikander 1988	5	Alex	Garland	1970
	6	Alicia	Vikander	1988

PERSON

		Ac	TOR	
	id	title	year	-
	2	Django Unchained	2012	-
	3	Inglorious Basterds	2009	
	4	Inglorious Basterds	2009	
	4	Django Unchained	2012	
	6	Ex-machina	2015	_
_				

#### Actors appearing in all movies directed by Quentin Tarantino

 $\pi_{\mathsf{id},\mathsf{title},\mathsf{year}}(\mathsf{ACTOR}) \div \pi_{\mathsf{title},\mathsf{year}}(\mathsf{MOVIE} \bowtie \mathsf{DIRECTOR} \bowtie \sigma_{\mathsf{first\_name}='\mathsf{Quentin'}}(\sigma_{\mathsf{last\_name}='\mathsf{Tarantino'}}(\mathsf{PERSON})))$ 

title	year	
Inglorious Basterds	2009	
Django Unchained	2012	

genre	run_time	year	title
Drama	153	2009	Inglorious Basterds
Drama	165	2012	Django Unchained
Drama	108	2015	Ex-machina

		DIRECTOR	
i	d	title	year
	1	Django Unchained	2012
	1	Inglorious Basterds	2009
	5	Ex-machina	2015
_			

id	first_name	last_name	year_born
1	Quentin	Tarantino	1963
2	Jamie	Foxx	1967
3	Brad	Pitt	1963
4	Christoph	Waltz	1956
5	Alex	Garland	1970
6	Alicia	Vikander	1988

PERSON

		Ac	TOR	
-	id	title	year	_
_	2	Django Unchained	2012	_
	3	Inglorious Basterds	2009	
	4	Inglorious Basterds	2009	
	4	Django Unchained	2012	
	6	Ex-machina	2015	
_				

#### Actors appearing in all movies directed by Quentin Tarantino

 $\pi_{\mathsf{id},\mathsf{title},\mathsf{year}}(\mathsf{ACTOR}) \div \pi_{\mathsf{title},\mathsf{year}}(\mathsf{MOVIE} \bowtie \mathsf{DIRECTOR} \bowtie \sigma_{\mathsf{first\_name}='\mathsf{Quentin'}}(\sigma_{\mathsf{last\_name}='\mathsf{Tarantino'}}(\mathsf{PERSON})))$ 

title	year
Inglorious Basterds	2009
Django Unchained	2012

MOVIE			
year	country	run_time	genre
2009	USA	153	Drama
2012	USA	165	Drama
2015	USA	108	Drama
	year 2009 2012	2009 USA 2012 USA	year         country         run_time           2009         USA         153           2012         USA         165

	Director	
id	title	year
1	Django Unchained	2012
1	Inglorious Basterds	2009
5	Ex-machina	2015

id	first_name	last_name	vear_born
1	Quentin	Tarantino	1963
2	Jamie	Foxx	1967
3	Brad	Pitt	1963
4	Christoph	Waltz	1956
5	Alex	Garland	1970
6	Alicia	Vikander	1988

PERSON

id	title	year	
2	Django Unchained	2012	
3	Inglorious Basterds	2009	
4	Inglorious Basterds	2009	
4	Django Unchained	2012	
6	Ex-machina	2015	

#### Actors appearing in all movies directed by Quentin Tarantino

 $\pi_{\mathsf{id},\mathsf{title},\mathsf{year}}(\mathsf{ACTOR}) \div \pi_{\mathsf{title},\mathsf{year}}(\mathsf{MOVIE} \bowtie \mathsf{DIRECTOR} \bowtie \sigma_{\mathsf{first\_name} = '\mathsf{Quentin'}}(\sigma_{\mathsf{last\_name} = '\mathsf{Tarantino'}}(\mathsf{PERSON})))$ 

title	year
Inglorious Basterds	2009
Django Unchained	2012

MOVIE			
year	country	run_time	genre
2009	USA	153	Drama
2012	USA	165	Drama
2015	USA	108	Drama
	year 2009 2012	2009 USA 2012 USA	year         country         run_time           2009         USA         153           2012         USA         165

	Director	
id	title	year
1	Django Unchained	2012
1	Inglorious Basterds	2009
5	Ex-machina	2015

1         Quentin         Tarantino         1963           2         Jamie         Foxx         1967           3         Brad         Pitt         1963           4         Christoph         Waltz         1956           5         Alex         Garland         1970           6         Alicia         Vikander         1988	id	first_name	last_name	vear_born
2         Jamie         Foxx         1967           3         Brad         Pitt         1963           4         Christoph         Waltz         1956           5         Alex         Garland         1970	1			
4 Christoph Waltz 1956 5 Alex Garland 1970	2		Foxx	
5 Alex Garland 1970	3	Brad	Pitt	1963
	4	Christoph	Waltz	1956
6 Alicia Vikander 1988	5	Alex	Garland	1970
	6	Alicia	Vikander	1988

PERSON

	-1-1		
id	title	year	
2	Django Unchained	2012	
3	Inglorious Basterds	2009	
4	Inglorious Basterds	2009	
4	Django Unchained	2012	
6	Ex-machina	2015	

#### Actors appearing in all movies directed by Quentin Tarantino

 $\pi_{\mathsf{id},\mathsf{title},\mathsf{year}}(\mathsf{ACTOR}) \div \pi_{\mathsf{title},\mathsf{year}}(\mathsf{MOVIE} \bowtie \mathsf{DIRECTOR} \bowtie \sigma_{\mathsf{first\_name}='\mathsf{Quentin'}}(\sigma_{\mathsf{last\_name}='\mathsf{Tarantino'}}(\mathsf{PERSON})))$ 

title	year
Inglorious Basterds	2009
Django Unchained	

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na
na

	DIRECTOR	
id	title	year
1	Django Unchained	2012
1	Inglorious Basterds	2009
5	Ex-machina	2015

id	first_name	last_name	year_born
1	Quentin	Tarantino	1963
2	Jamie	Foxx	1967
3	Brad	Pitt	1963
4	Christoph	Waltz	1956
5	Alex	Garland	1970
6	Alicia	Vikander	1988

PERSON

	Ac	TOR	
id	title	year	
2	Django Unchained	2012	
3	Inglorious Basterds	2009	
4	Inglorious Basterds	2009	
4	Django Unchained	2012	
6	Ex-machina	2015	

#### Actors appearing in all movies directed by Quentin Tarantino

 $\pi_{\mathsf{id},\mathsf{title},\mathsf{year}}(\mathsf{ACTOR}) \div \pi_{\mathsf{title},\mathsf{year}}(\mathsf{MOVIE} \bowtie \mathsf{DIRECTOR} \bowtie \sigma_{\mathsf{first\_name}='\mathsf{Quentin'}}(\sigma_{\mathsf{last\_name}='\mathsf{Tarantino'}}(\mathsf{PERSON})))$ 

title	ye
	, .
Inglorious Baste	erds 20
Django Unchai	ned 20

## Database schema from before

- MOVIE(title, year, country, run\_time, genre), DIRECTOR(id, title, year)
- Person(id, first\_name, last\_name, year\_born), Actor(id, title, year, role)

## In English, what are the results of the following queries?

•  $\pi_{\mathsf{title},\mathsf{year}}(\sigma_{\mathsf{last\_name}='\mathsf{Nicholson'}}(\sigma_{\mathsf{first\_name}='\mathsf{Jack'}}(\mathsf{Movie}\bowtie\mathsf{Actor}\bowtie\mathsf{Person})))$ 

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#### Database schema from before

- MOVIE(title, year, country, run\_time, genre), DIRECTOR(id, title, year)
- Person(id, first\_name, last\_name, year\_born), Actor(id, title, year, role)

## In English, what are the results of the following queries?

•  $\pi_{\text{title,year}}(\sigma_{\text{last\_name}='\text{Nicholson'}}(\sigma_{\text{first\_name}='\text{Jack'}}(\text{MOVIE} \bowtie \text{ACTOR} \bowtie \text{PERSON})))$ In which movies did 'Jack Nicholson' act?

#### Database schema from before

- MOVIE(title, year, country, run\_time, genre), DIRECTOR(id, title, year)
- Person(id, first\_name, last\_name, year\_born), Actor(id, title, year, role)

## In English, what are the results of the following queries?

- $\pi_{\text{title,year}}(\sigma_{\text{last\_name}='\text{Nicholson'}}(\sigma_{\text{first\_name}='\text{Jack'}}(\text{MOVIE} \bowtie \text{ACTOR} \bowtie \text{PERSON})))$ In which movies did 'Jack Nicholson' act?
- $\pi_{\text{first\_name}, \text{last\_name}}(((\text{MOVIE} \sigma_{\text{country}='\text{USA'}}(\text{MOVIE})) \sigma_{\text{country}='\text{UK'}}(\text{MOVIE})) \bowtie DIRECTOR \bowtie PERSON)$

#### Database schema from before

- MOVIE(title, year, country, run\_time, genre), DIRECTOR(id, title, year)
- Person(id, first\_name, last\_name, year\_born), Actor(id, title, year, role)

## In English, what are the results of the following queries?

- $\pi_{\text{title,year}}(\sigma_{\text{last\_name}='\text{Nicholson'}}(\sigma_{\text{first\_name}='\text{Jack'}}(\text{MOVIE} \bowtie \text{ACTOR} \bowtie \text{PERSON})))$ In which movies did 'Jack Nicholson' act?
- $\pi_{\text{first\_name}, \text{last\_name}}(((\text{MOVIE} \sigma_{\text{country}='\text{USA'}}(\text{MOVIE})) \sigma_{\text{country}='\text{UK'}}(\text{MOVIE})) \bowtie DIRECTOR \bowtie PERSON)$

What are the names of people who directed movies not produced in the USA and not produced in the UK?

## Database schema from before

- MOVIE(title, year, country, run\_time, genre), DIRECTOR(id, title, year)
- Person(id, first\_name, last\_name, year\_born), Actor(id, title, year, role)

## In English, what are the results of the following queries?

•  $\pi_{\emptyset}(\sigma_{\mathsf{role}='\mathsf{James}\;\mathsf{Bond'}}(\mathsf{ACTOR})\bowtie \mathsf{MOVIE})$ 

## Database schema from before

- MOVIE(title, year, country, run\_time, genre), DIRECTOR(id, title, year)
- Person(id, first\_name, last\_name, year\_born), Actor(id, title, year, role)

## In English, what are the results of the following queries?

•  $\pi_{\emptyset}(\sigma_{\mathsf{role}='\mathsf{James\ Bond'}}(\mathsf{ACTOR})\bowtie \mathsf{MOVIE})$ Is there a movie in which the role 'James Bond' occurred?

## Database schema from before

- MOVIE(title, year, country, run\_time, genre), DIRECTOR(id, title, year)
- Person(id, first\_name, last\_name, year\_born), Actor(id, title, year, role)

## In English, what are the results of the following queries?

- $\pi_{\emptyset}(\sigma_{\mathsf{role}='\mathsf{James\ Bond'}}(\mathrm{ACTOR})\bowtie\mathrm{MOVIE})$ Is there a movie in which the role 'James Bond' occurred?
- $\pi_{\mathsf{first\_name},\mathsf{last\_name}}(((\pi_{\mathsf{id}}(\mathsf{DIRECTOR}) \pi_{\mathsf{id}}(\mathsf{ACTOR})) \bowtie \mathsf{DIRECTOR}) \bowtie \mathsf{Movie} \bowtie \delta_{\mathsf{id} \mapsto \mathsf{aid}}(\mathsf{ACTOR} \bowtie \mathsf{PERSON}))$

## Database schema from before

- MOVIE(title, year, country, run\_time, genre), DIRECTOR(id, title, year)
- Person(id, first\_name, last\_name, year\_born), Actor(id, title, year, role)

## In English, what are the results of the following queries?

- $\pi_{\emptyset}(\sigma_{\mathsf{role}='\mathsf{James\ Bond'}}(\mathrm{ACTOR})\bowtie\mathrm{MOVIE})$ Is there a movie in which the role 'James Bond' occurred?
- $\pi_{\mathsf{first\_name},\mathsf{last\_name}}(((\pi_{\mathsf{id}}(\mathsf{DIRECTOR}) \pi_{\mathsf{id}}(\mathsf{ACTOR})) \bowtie \mathsf{DIRECTOR}) \bowtie \mathsf{Movie} \bowtie \delta_{\mathsf{id} \mapsto \mathsf{aid}}(\mathsf{ACTOR} \bowtie \mathsf{PERSON}))$

What are the names of actors appearing in movies directed by non-actors?

## Database schema from before

- MOVIE(title, year, country, run\_time, genre), DIRECTOR(id, title, year)
- Person(id, first\_name, last\_name, year\_born), Actor(id, title, year, role)

What are the roles played by actors appearing in those movies that were the only ones directed by some director?

• Directors who directed at least two movies (same director, different movies):

## Database schema from before

- MOVIE(title, year, country, run\_time, genre), DIRECTOR(id, title, year)
- Person(id, first\_name, last\_name, year\_born), Actor(id, title, year, role)

- Directors who directed at least two movies (same director, different movies):
  - $Q_1 = \text{DIRECTOR} \bowtie \delta_{\text{title} \rightarrow \text{title',vear} \rightarrow \text{vear'}}(\text{DIRECTOR})$

## Database schema from before

- MOVIE(title, year, country, run\_time, genre), DIRECTOR(id, title, year)
- Person(id, first\_name, last\_name, year\_born), Actor(id, title, year, role)

- Directors who directed at least two movies (same director, different movies):
  - $Q_1 = \text{DIRECTOR} \bowtie \delta_{\text{title} \rightarrow \text{title'}, \text{year} \rightarrow \text{year'}}(\text{DIRECTOR})$
  - $Q_2 = \sigma_{\mathsf{title}=\mathsf{title'}}(\sigma_{\mathsf{year}=\mathsf{year'}}(Q_1))$

## Database schema from before

- MOVIE(title, year, country, run\_time, genre), DIRECTOR(id, title, year)
- Person(id, first\_name, last\_name, year\_born), Actor(id, title, year, role)

- Directors who directed at least two movies (same director, different movies):
  - $Q_1 = \text{DIRECTOR} \bowtie \delta_{\text{title} \rightarrow \text{title'}, \text{year} \rightarrow \text{year'}}(\text{DIRECTOR})$
  - $Q_2 = \sigma_{\mathsf{title}=\mathsf{title'}}(\sigma_{\mathsf{year}=\mathsf{year'}}(Q_1))$
  - $ullet Q_3 = \pi_{\mathsf{id},\mathsf{title},\mathsf{year}}(Q_1 Q_2)$

#### Database schema from before

- MOVIE(title, year, country, run\_time, genre), DIRECTOR(id, title, year)
- Person(id, first\_name, last\_name, year\_born), Actor(id, title, year, role)

- Directors who directed at least two movies (same director, different movies):
  - $Q_1 = \text{DIRECTOR} \bowtie \delta_{\text{title} \rightarrow \text{title',vear} \rightarrow \text{vear'}}(\text{DIRECTOR})$
  - $Q_2 = \sigma_{\mathsf{title}=\mathsf{title'}}(\sigma_{\mathsf{year}=\mathsf{year'}}(Q_1))$
  - $Q_3 = \pi_{\mathsf{id},\mathsf{title},\mathsf{year}}(Q_1 Q_2)$
- Directors who directed only one movie:

## Database schema from before

- MOVIE(title, year, country, run\_time, genre), DIRECTOR(id, title, year)
- Person(id, first\_name, last\_name, year\_born), Actor(id, title, year, role)

- Directors who directed at least two movies (same director, different movies):
  - $Q_1 = \text{DIRECTOR} \bowtie \delta_{\text{title} \mapsto \text{title'}, \text{year} \mapsto \text{year'}}(\text{DIRECTOR})$
  - $Q_2 = \sigma_{\text{title=title'}}(\sigma_{\text{year=year'}}(Q_1))$
  - $Q_3 = \pi_{\text{id.title.vear}}(Q_1 Q_2)$
- Directors who directed only one movie:

$$Q_4 = \text{Director} - Q_3$$

## Database schema from before

- MOVIE(title, year, country, run\_time, genre), DIRECTOR(id, title, year)
- Person(id, first\_name, last\_name, year\_born), Actor(id, title, year, role)

# What are the roles played by actors appearing in those movies that were the only ones directed by some director?

- Directors who directed at least two movies (same director, different movies):
  - $Q_1 = \text{DIRECTOR} \bowtie \delta_{\text{title} \rightarrow \text{title}', \text{year} \rightarrow \text{year}'}(\text{DIRECTOR})$
  - $Q_2 = \sigma_{\mathsf{title}=\mathsf{title'}}(\sigma_{\mathsf{year}=\mathsf{year'}}(Q_1))$
  - $Q_3 = \pi_{\text{id.title.vear}}(Q_1 Q_2)$
- Directors who directed only one movie:

$$Q_4 = \text{Director} - Q_3$$

• Roles in movies whose director only directed that movie:

## Database schema from before

- MOVIE(title, year, country, run\_time, genre), DIRECTOR(id, title, year)
- Person(id, first\_name, last\_name, year\_born), Actor(id, title, year, role)

# What are the roles played by actors appearing in those movies that were the only ones directed by some director?

- Directors who directed at least two movies (same director, different movies):
  - $Q_1 = \text{DIRECTOR} \bowtie \delta_{\text{title} \rightarrow \text{title}', \text{year} \mapsto \text{year}'}(\text{DIRECTOR})$
  - $ullet Q_2 = \sigma_{\mathsf{title} = \mathsf{title'}}(\sigma_{\mathsf{year} = \mathsf{year'}}(Q_1))$
  - $Q_3 = \pi_{\text{id.title.vear}}(Q_1 Q_2)$
- Directors who directed only one movie:

$$Q_4 = \text{Director} - Q_3$$

• Roles in movies whose director only directed that movie:

$$Q_5 = \pi_{\text{role}}(\delta_{\text{id} \mapsto \text{aid}}(ACTOR) \bowtie Q_4)$$

MOVIE			
year	country	run_time	genre
2009	USA	153	Drama
2012	USA	165	Drama
2015	USA	108	Drama
	year 2009 2012	year country 2009 USA 2012 USA	year         country         run_time           2009         USA         153           2012         USA         165

	DIRECTOR	
id	title	year
1	Django Unchained	2012
1	Inglorious Basterds	2009
5	Ex-machina	2015

id	first_name	last_name	year_born
1	Quentin	Tarantino	1963
2	Jamie	Foxx	1967
4	Christoph	Waltz	1956
5	Alex	Garland	1970
6	Alicia	Vikander	1988

PERSON

	AC	TOR	
id	title	year	role
2	Django Unchained	2012	Django
4	Inglorious Basterds	2009	Col Hans Landa
4	Django Unchained	2012	Dr King Schultz
6	Ex-machina	2015	Āva

#### Directors with at least two movies

 $Q_3 = \pi_{\mathrm{id,title,year'}}(\mathrm{DIRECTOR} \bowtie \delta_{\mathrm{title} \mapsto \mathrm{title'}, \mathrm{year} \mapsto \mathrm{year'}}(\mathrm{DIRECTOR})) - \sigma_{\mathrm{title} = \mathrm{title'}}(\sigma_{\mathrm{year} = \mathrm{year'}}(\mathrm{DIRECTOR} \bowtie \delta_{\mathrm{title} \mapsto \mathrm{title'}, \mathrm{year} \mapsto \mathrm{year'}}(\mathrm{DIRECTOR}))))$ 

MOVIE				
title	year	country	run_time	genre
Inglorious Basterds	2009	USA	153	Drama
Django Unchained	2012	USA	165	Drama
Ex-machina	2015	USA	108	Drama

	Director		
id	title	year	
1	Django Unchained	2012	
1	Inglorious Basterds	2009	
5	Ex-machina	2015	

id	first_name	last_name	year_born
1	Quentin	Tarantino	1963
2	Jamie	Foxx	1967
1	Christoph	Waltz	1956
5	Alex	Garland	1970
6	Alicia	Vikander	1988

id	title	year	role
2	Django Unchained	2012	Django
4	Inglorious Basterds	2009	Col Hans Landa
4	Django Unchained	2012	Dr King Schultz
6	Ex-machina	2015	Ava

#### Directors with at least two movies

 $Q_3 = \pi_{id,title,year}((\texttt{DIRECTOR} \bowtie \delta_{title \rightarrow title',year \rightarrow year'}(\texttt{DIRECTOR})) - \sigma_{title = title'}(\sigma_{year = year'}(\texttt{DIRECTOR} \bowtie \delta_{title \rightarrow title',year \rightarrow year'}(\texttt{DIRECTOR}))))$ 

id	title	year	title'	year'
1	Django Unchained	2012	Django Unchained	2012
1	Inglorious Basterds	2009	Inglorious Basterds	2009
1	Django Unchained	2012	Inglorious Basterds	2009
1	Inglorious Basterds	2009	Django Unchained	2012
5	Ex-machina	2015	Ex-machina	2015

MOVIE						
title	year	country	run_time	genre		
Inglorious Basterds	2009	USA	153	Drama		
Django Unchained	2012	USA	165	Drama		
Ex-machina	2015	USA	108	Drama		

	Director	
id	title	year
1	Django Unchained	2012
1	Inglorious Basterds	2009
5	Ex-machina	2015

id	first_name	last_name	year_born
1	Quentin	Tarantino	1963
2	Jamie	Foxx	1967
4	Christoph	Waltz	1956
5	Alex	Garland	1970
6	Alicia	Vikander	1988

ACTOR					
id	title	year	role		
2	Django Unchained	2012	Django		
4	Inglorious Basterds	2009	Col Hans Landa		
4	Django Unchained	2012	Dr King Schultz		
6	Ex-machina	2015	Āva		

#### Directors with at least two movies

 $Q_3 = \pi_{\mathsf{id},\mathsf{title},\mathsf{year}}((\mathsf{DIRECTOR} \bowtie \delta_{\mathsf{title} \mapsto \mathsf{title}',\mathsf{year} \mapsto \mathsf{year}'}(\mathsf{DIRECTOR})) - \sigma_{\mathsf{title} = \mathsf{title}'}(\sigma_{\mathsf{year} = \mathsf{year}'}(\mathsf{DIRECTOR} \bowtie \delta_{\mathsf{title} \mapsto \mathsf{title}',\mathsf{year} \mapsto \mathsf{year}'}(\mathsf{DIRECTOR}))))$ 

id	title	year	title'	year'
1	Django Unchained	2012	Django Unchained	2012
1	Inglorious Basterds	2009	Inglorious Basterds	2009
1	Django Unchained	2012	Inglorious Basterds	2009
1	Inglorious Basterds	2009	Django Unchained	2012
5	Ex-machina	2015	Ex-machina	2015

	10	TOVIE		
title	year	country	run_time	genre
Inglorious Basterds	2009	USA	153	Drama
Django Unchained	2012	USA	165	Drama
Ex-machina	2015	USA	108	Drama

title	1,024
	year
Unchained	2012
ous Basterd	s 2009
machina	2015
	ous Basterd -machina

id	first_name	last_name	year_born
1	Quentin	Tarantino	1963
2	Jamie	Foxx	1967
4	Christoph	Waltz	1956
5	Alex	Garland	1970
6	Alicia	Vikander	1988

id	title	year	role
2	Django Unchained	2012	Django
4	Inglorious Basterds	2009	Col Hans Landa
4	Django Unchained	2012	Dr King Schultz
6	Ex-machina	2015	Ava

#### Directors with at least two movies

 $\textit{Q}_{3} = \pi_{id, title, year}((\texttt{DIRECTOR} \bowtie \delta_{title \mapsto title', year \mapsto year'}(\texttt{DIRECTOR})) - \sigma_{title = title'}(\sigma_{year = year'}(\texttt{DIRECTOR} \bowtie \delta_{title \mapsto title', year \mapsto year'}(\texttt{DIRECTOR}))))$ 

id	title	year	title'	year'
1	Django Unchained	2012	Inglorious Basterds	2009
1	Inglorious Basterds	2009	Django Unchained	2012

	10	TOVIE		
title	year	country	run_time	genre
Inglorious Basterds	2009	USA	153	Drama
Django Unchained	2012	USA	165	Drama
Ex-machina	2015	USA	108	Drama

	DIRECTOR	
id	title	year
1	Django Unchained	2012
1	Inglorious Basterds	2009
5	Ex-machina	2015

id	first_name	last_name	year_born
1	Quentin	Tarantino	1963
2	Jamie	Foxx	1967
4	Christoph	Waltz	1956
5	Alex	Garland	1970
6	Alicia	Vikander	1988

PERSON

	110	1011	
id	title	year	role
2	Django Unchained	2012	Django
4	Inglorious Basterds	2009	Col Hans Landa
4	Django Unchained	2012	Dr King Schultz
6	Ex-machina	2015	Āva

#### Directors with at least two movies

 $Q_3 = \pi_{\mathsf{id},\mathsf{title},\mathsf{vear}}((\mathsf{DIRECTOR} \bowtie \delta_{\mathsf{title} \mapsto \mathsf{title}',\mathsf{vear} \mapsto \mathsf{vear}'}(\mathsf{DIRECTOR})) - \sigma_{\mathsf{title} = \mathsf{title}'}(\sigma_{\mathsf{vear} = \mathsf{vear}'}(\mathsf{DIRECTOR} \bowtie \delta_{\mathsf{title} \mapsto \mathsf{title}',\mathsf{vear} \mapsto \mathsf{vear}'}(\mathsf{DIRECTOR}))))$ 

title vear

- Diango Unchained 2012
- Inglorious Basterds 2009

	1/	TOVIE		
title	year	country	run_time	genre
Inglorious Basterds	2009	USA	153	Drama
Django Unchained	2012	USA	165	Drama
Ex-machina	2015	USA	108	Drama

Director			
id	title	year	
1	Django Unchained	2012	
1	Inglorious Basterds	2009	
5	Ex-machina	2015	

id	first_name	last_name	year_born
1	Quentin	Tarantino	1963
2	Jamie	Foxx	1967
4	Christoph	Waltz	1956
5	Alex	Garland	1970
6	Alicia	Vikander	1988

PERSON

d	title	year	role
2	Django Unchained	2012	Django
4	Inglorious Basterds	2009	Col Hans Landa
4	Django Unchained	2012	Dr King Schultz
6	Ex-machina	2015	Äva

#### Directors with at least two movies

 $Q_3 = \pi_{\mathsf{id},\mathsf{title},\mathsf{vear}}((\mathsf{DIRECTOR} \bowtie \delta_{\mathsf{title} \mapsto \mathsf{title}',\mathsf{vear} \mapsto \mathsf{vear}'}(\mathsf{DIRECTOR})) - \sigma_{\mathsf{title} = \mathsf{title}'}(\sigma_{\mathsf{vear} = \mathsf{vear}'}(\mathsf{DIRECTOR} \bowtie \delta_{\mathsf{title} \mapsto \mathsf{title}',\mathsf{vear} \mapsto \mathsf{vear}'}(\mathsf{DIRECTOR}))))$ 

title vear

- Diango Unchained 2012
- Inglorious Basterds 2009

Movie			
year	country	run_time	genre
2009	USA	153	Drama
2012	USA	165	Drama
2015	USA	108	Drama
	year 2009 2012	year country 2009 USA 2012 USA	year         country         run_time           2009         USA         153           2012         USA         165

	Director			
id	title	year		
1	Django Unchained	2012		
1	Inglorious Basterds	2009		
5	Ex-machina	2015		

id	first_name	last_name	year_born
1	Quentin	Tarantino	1963
2	Jamie	Foxx	1967
4	Christoph	Waltz	1956
5	Alex	Garland	1970
6	Alicia	Vikander	1988

Person

ACTOR				
id	title	year	role	
2	Django Unchained	2012	Django	
4	Inglorious Basterds	2009	Col Hans Landa	
4	Django Unchained	2012	Dr King Schultz	
6	Ex-machina	2015	Āva	

### Directors with only one movie

 $Q_4 = \text{Director} - Q_3$ 

MOVIE			
year	country	run_time	genre
2009	USA	153	Drama
2012	USA	165	Drama
2015	USA	108	Drama
	year 2009 2012	year country 2009 USA 2012 USA	year country run_time 2009 USA 153 2012 USA 165

	Director					
-	id title year					
_	1	Django Unchained	2012			
	1	Inglorious Basterds	2009			
	5	Ex-machina	2015			

id	first_name	last_name	year_born
1	Quentin	Tarantino	1963
2	Jamie	Foxx	1967
4	Christoph	Waltz	1956
5	Alex	Garland	1970
6	Alicia	Vikander	1988

PERSON

	AC	TOR	
id	title	year	role
2	Django Unchained	2012	Django
4	Inglorious Basterds	2009	Col Hans Landa
4	Django Unchained	2012	Dr King Schultz
6	Ex-machina	2015	Ava

### Directors with only one movie

 $Q_4 = \text{Director} - Q_3$ 

#### $Q_3$ =Directors with at least two movies

id	title	year
1	Django Unchained	2012
1	Inglorious Basterds	2009

	MOVIE				
-	title	vear	country	run_time	genre
	Inglorious Basterds	2009	USA	153	Drama
	Django Unchained	2012	USA	165	Drama
	Ex-machina	2015	USA	108	Drama

Director			
id	title	year	
1	Django Unchained	2012	
1	Inglorious Basterds	2009	
5	Ex-machina	2015	

id	first_name	last_name	year_born
1	Quentin	Tarantino	1963
2	Jamie	Foxx	1967
4	Christoph	Waltz	1956
5	Alex	Garland	1970
6	Alicia	Vikander	1988

PERSON

ACTOR				
id	title	year	role	
2	Django Unchained	2012	Django	
4	Inglorious Basterds	2009	Col Hans Landa	
4	Django Unchained	2012	Dr King Schultz	
6	Ex-machina	2015	Āva	

#### Directors with only one movie

 $Q_4 = \text{DIRECTOR} - Q_3$ 

#### $Q_3$ =Directors with at least two movies

id	title	year
1	Django Unchained	2012
1	Inglorious Basterds	2009

#### Directors with only one movie

id	title	year
1	Django Unchained	2012
1	Inglorious Basterds	2009
5	Ex-machina	2015

	N	TOVIE		
title	year	country	run_time	genre
Inglorious Basterds	2009	USA	153	Drama
Django Unchained	2012	USA	165	Drama
Ex-machina	2015	USA	108	Drama

Director				
id	title	year		
1	Django Unchained	2012		
1	Inglorious Basterds	2009		
5	Ex-machina	2015		

id	first_name	last_name	year_born
1	Quentin	Tarantino	1963
2	Jamie	Foxx	1967
4	Christoph	Waltz	1956
5	Alex	Garland	1970
6	Alicia	Vikander	1988

	Ac	TOR	
id	title	year	role
2	Django Unchained	2012	Django
4	Inglorious Basterds	2009	Col Hans Landa
4	Django Unchained	2012	Dr King Schultz
6	Ex-machina	2015	Āva

#### Directors with only one movie

$$Q_4 = \text{DIRECTOR} - Q_3$$

Q	3=Di	rectors with at least t	wo movie	es .
	id	title	year	
	1	Django Unchained	2012	
	1	Inglorious Basterds	2009	

id title year		Directors with only one movie				
	_	id	title	year		
5 Ex-machina 2015		5	Ex-machina	2015		

	N	TOVIE		
title	vear	country	run_time	genre
Inglorious Basterds	2009	USA	153	Drama
Django Unchained	2012	USA	165	Drama
Ex-machina	2015	USA	108	Drama

Director				
id	title	year		
1	Django Unchained	2012		
1	Inglorious Basterds	2009		
5	Ex-machina	2015		

id	first_name	last_name	year_born
1	Quentin	Tarantino	1963
2	Jamie	Foxx	1967
4	Christoph	Waltz	1956
5	Alex	Garland	1970
6	Alicia	Vikander	1988

Actor				
id	title	year	role	
2	Django Unchained	2012	Django	
4	Inglorious Basterds	2009	Col Hans Landa	
4	Django Unchained	2012	Dr King Schultz	
6	Ex-machina	2015	Ava	

#### Directors with only one movie

 $Q_4 = \text{DIRECTOR} - Q_3$ 

Q	$Q_3=$ Directors with at least two movies					
	id	title	year			
	1	Django Unchained	2012			
	1	Inglorious Basterds	2009			

Directors with only one movie				
id	title	year		
5	Ex-machina	2015		

		MOVIE		
title	year	country	run_time	genre
Inglorious Basterds	2009	USA	153	Drama
Django Unchained	2012	USA	165	Drama
Ex-machina	2015	USA	108	Drama
Django Unchained	2012	USA	165	I

	DIRECTOR			
id	title	year		
1 Django Unchained		2012		
1	Inglorious Basterds	2009		
5	Ex-machina	2015		

id	first_name	last_name	year_born
1	Quentin	Tarantino	1963
2	Jamie	Foxx	1967
4	Christoph	Waltz	1956
5	Alex	Garland	1970
6	Alicia	Vikander	1988

PERSON

		ACTOR	
id	title	year	role
2	Django Unchained	2012	Django
4	Inglorious Basterds	2009	Col Hans Landa
4	Django Unchained	2012	Dr King Schultz
6	Ex-machina	2015	Ava

#### Roles in movies whose director only directed that movie

$$Q_5 = \pi_{\mathsf{role}}(\delta_{\mathsf{id} \mapsto \mathsf{aid}}(\operatorname{ACTOR}) \bowtie Q_4)$$

	AOVIE		
year	country	run_time	genre
2009	USA	153	Drama
2012	USA	165	Drama
2015	USA	108	Drama
	year 2009 2012	year country 2009 USA 2012 USA	year         country         run_time           2009         USA         153           2012         USA         165

Director				
id	title	year		
1	Django Unchained	2012		
1	Inglorious Basterds	2009		
5	Ex-machina	2015		

id	first_name	last_name	year_born
1	Quentin	Tarantino	1963
2	Jamie	Foxx	1967
4	Christoph	Waltz	1956
5	Alex	Garland	1970
6	Alicia	Vikander	1988

id	title	year	role
2	Django Unchained	2012	Django
4	Inglorious Basterds	2009	Col Hans Landa
4	Django Unchained	2012	Dr King Schultz
6	Ex-machina	2015	Āva

### Roles in movies whose director only directed that movie

$$Q_5 = \pi_{\mathsf{role}}(\delta_{\mathsf{id} \mapsto \mathsf{aid}}(\mathsf{ACTOR}) \bowtie Q_4)$$

#### $Q_4$ =Directors with only one movie

id	title	year
5	Ex-machina	2015

V	AOVIE		
year	country	run_time	genre
2009	USA	153	Drama
2012	USA	165	Drama
2015	USA	108	Drama
	year 2009 2012	2009 USA 2012 USA	year         country         run_time           2009         USA         153           2012         USA         165

	Director	
id	title	year
1	Django Unchained	2012
1	Inglorious Basterds	2009
5	Ex-machina	2015

id	first_name	last_name	year_born
1	Quentin	Tarantino	1963
2	Jamie	Foxx	1967
4	Christoph	Waltz	1956
5	Alex	Garland	1970
6	Alicia	Vikander	1988

$\delta_{id \mapsto aid}(\operatorname{ACTOR})$						
aid	title	year	role			
2	Django Unchained	2012	Django			
4	Inglorious Basterds	2009	Col Hans Landa			
4	Django Unchained	2012	Dr King Schultz			
6	Ex-machina	2015	Āva			

#### Roles in movies whose director only directed that movie

$$Q_5 = \pi_{\text{role}}(\delta_{\text{id} \mapsto \text{aid}}(ACTOR) \bowtie Q_4)$$

#### $Q_4$ =Directors with only one movie

id	title	year
5	Ex-machina	2015

	<u>(</u>	<i>?</i> 5			
aid	title	year	role	id	
6	Ex-machina	2015	Ava	5	

Movie					
title	year	country	run_time	genre	
Inglorious Basterds	2009	USA	153	Drama	
Django Unchained	2012	USA	165	Drama	
Ex-machina	2015	USA	108	Drama	

		Director	
_	id	title	year
_	1	Django Unchained	2012
	1	Inglorious Basterds	2009
	5	Ex-machina	2015
_			

id	first_name	last_name	year_born
1	Quentin	Tarantino	1963
2	Jamie	Foxx	1967
4	Christoph	Waltz	1956
5	Alex	Garland	1970
6	Alicia	Vikander	1988

		Actor		
id	title	year	role	
2	Django Unchained	2012	Django	
4	Inglorious Basterds	2009	Col Hans Landa	
4	Django Unchained	2012	Dr King Schultz	
6	Ex-machina	2015	Ava	

#### Roles in movies whose director only directed that movie

$$Q_5 = \pi_{\mathsf{role}}(\delta_{\mathsf{id} \mapsto \mathsf{aid}}(\mathsf{Actor}) \bowtie Q_4)$$

#### Q<sub>4</sub>=Directors with only one movie

id	title	year
5	Ex-machina	2015

$Q_5$	
role	
Ava	

MOVIE				
title	year	country	run_time	genre
Inglorious Basterds	2009	USA	153	Drama
Django Unchained	2012	USA	165	Drama
Ex-machina	2015	USA	108	Drama

	DIRECTOR	
id	title	year
1	Django Unchained	2012
1	Inglorious Basterds	2009
5	Ex-machina	2015

id	first_name	last_name	year_born
L	Quentin	Tarantino	1963
	Jamie	Foxx	1967
4	Christoph	Waltz	1956
5	Alex	Garland	1970
6	Alicia	Vikander	1988

		Actor	
id	title	year	role
2	Django Unchained	2012	Django
4	Inglorious Basterds	2009	Col Hans Landa
4	Django Unchained	2012	Dr King Schultz
6	Ex-machina	2015	Ava

#### Roles in movies whose director only directed that movie

$$Q_5 = \pi_{\mathsf{role}}(\delta_{\mathsf{id} \mapsto \mathsf{aid}}(\mathsf{ACTOR}) \bowtie Q_4)$$

### Q<sub>4</sub>=Directors with only one movie

id	title	year	
5	Ex-machina	2015	

$Q_5$	
role	
Ava	

### Database schema from before

- MOVIE(title, year, country, run\_time, genre), DIRECTOR(id, title, year)
- Person(id, first\_name, last\_name, year\_born), Actor(id, title, year, role)

What are the roles played by actors appearing in *only* those movies that were the only ones directed by some director?

• Actors of movies directed by a director who has directed more than one movie:

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### Database schema from before

- MOVIE(title, year, country, run\_time, genre), DIRECTOR(id, title, year)
- Person(id, first\_name, last\_name, year\_born), Actor(id, title, year, role)

What are the roles played by actors appearing in *only* those movies that were the only ones directed by some director?

• Actors of movies directed by a director who has directed more than one movie:

$$Q_7 = \pi_{\mathsf{aid}}(\delta_{\mathsf{id} \mapsto \mathsf{aid}}(\operatorname{ACTOR}) \bowtie Q_3)$$

### Database schema from before

- MOVIE(title, year, country, run\_time, genre), DIRECTOR(id, title, year)
- Person(id, first\_name, last\_name, year\_born), Actor(id, title, year, role)

# What are the roles played by actors appearing in *only* those movies that were the only ones directed by some director?

• Actors of movies directed by a director who has directed more than one movie:

$$Q_7 = \pi_{\mathsf{aid}}(\delta_{\mathsf{id} \mapsto \mathsf{aid}}(\operatorname{ACTOR}) \bowtie Q_3)$$

• Actors only appearing in movies which were the only ones directed by the director:

### Database schema from before

- MOVIE(title, year, country, run\_time, genre), DIRECTOR(id, title, year)
- Person(id, first\_name, last\_name, year\_born), Actor(id, title, year, role)

# What are the roles played by actors appearing in *only* those movies that were the only ones directed by some director?

• Actors of movies directed by a director who has directed more than one movie:

$$Q_7 = \pi_{\mathsf{aid}}(\delta_{\mathsf{id} \mapsto \mathsf{aid}}(\operatorname{ACTOR}) \bowtie Q_3)$$

• Actors only appearing in movies which were the only ones directed by the director:

$$Q_8 = \pi_{\mathsf{aid}}(\delta_{\mathsf{id} \mapsto \mathsf{aid}}(\operatorname{ACTOR})) - Q_7$$

### Database schema from before

- MOVIE(title, year, country, run\_time, genre), DIRECTOR(id, title, year)
- Person(id, first\_name, last\_name, year\_born), Actor(id, title, year, role)

# What are the roles played by actors appearing in *only* those movies that were the only ones directed by some director?

- Actors of movies directed by a director who has directed more than one movie:
  - $\mathit{Q}_7 = \pi_{\mathsf{aid}}(\delta_{\mathsf{id} \mapsto \mathsf{aid}}(\operatorname{ACTOR}) \bowtie \mathit{Q}_3)$
- Actors only appearing in movies which were the only ones directed by the director:  $Q_8 = \pi_{\text{aid}}(\delta_{\text{id} \mapsto \text{aid}}(A_{\text{CTOR}})) Q_7$
- Roles only appearing in movies which were the only ones directed by the director:

### Database schema from before

- MOVIE(title, year, country, run\_time, genre), DIRECTOR(id, title, year)
- Person(id, first\_name, last\_name, year\_born), Actor(id, title, year, role)

# What are the roles played by actors appearing in *only* those movies that were the only ones directed by some director?

- Actors of movies directed by a director who has directed more than one movie:
  - $Q_7 = \pi_{\mathsf{aid}}(\delta_{\mathsf{id} \mapsto \mathsf{aid}}(\operatorname{ACTOR}) \bowtie Q_3)$
- Actors only appearing in movies which were the only ones directed by the director:
- $Q_8 = \pi_{\text{aid}}(\delta_{\text{id} \mapsto \text{aid}}(Actor)) Q_7$  Roles only appearing in movies which were the only ones directed by the director:
  - $Q = \pi_{\text{role}}(\delta_{\mathsf{id} \mapsto \mathsf{aid}}(\operatorname{ACTOR}) \bowtie Q_8)$

# Summary for Relational Algebra

- The relational model has brought forward simple and powerful query languages
- The operators in relational algebra include:
  - attribute and constant selection
  - projection and renaming
  - set union and difference
  - natural join
- Relational algebra expressions suggest an ordering on the operations
- It is possible to describe an algebra expression that produces the same result with the operators in a different order
  - This is used in query optimization
- Relational algebra operators are executed by the DBMS
  - see Figure for DBMS Architecture