Outline

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0) Course Info
1) Introduction
2) Data Preparation and Cleaning
3) Schema matching and mapping
4) Virtual Data Integration
5) **Data Exchange**
6) Data Warehousing
7) Big Data Analytics
8) Data Provenance

5. Data Exchange

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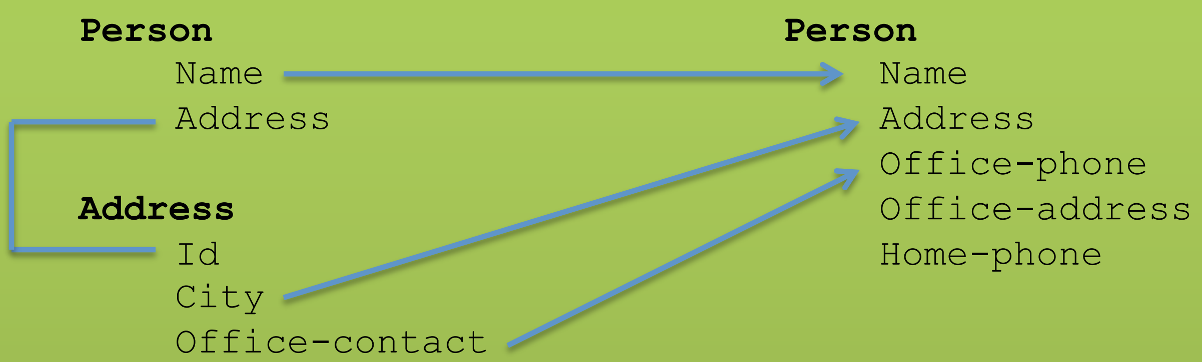
- **Virtual Data Integration**
  - Never materialize instances for the global schema
  - Data of global schema only “visible” through queries
- **Data Exchange**
  - Materialize instance of global instance
    - We call it the “target schema”
  - Based on information from an instance of the local schema
    - We call this the “source schema”

- **Data Exchange Problem Statement**
- **Input:**
  - Given a **source** and a **target schema**
  - + instance of the source schema
  - + set of schema mappings (here st-tgds)
- **Output:**
  - Instance of the target schema that fulfills constraints

5. Data Exchange

Example: Types of Matching



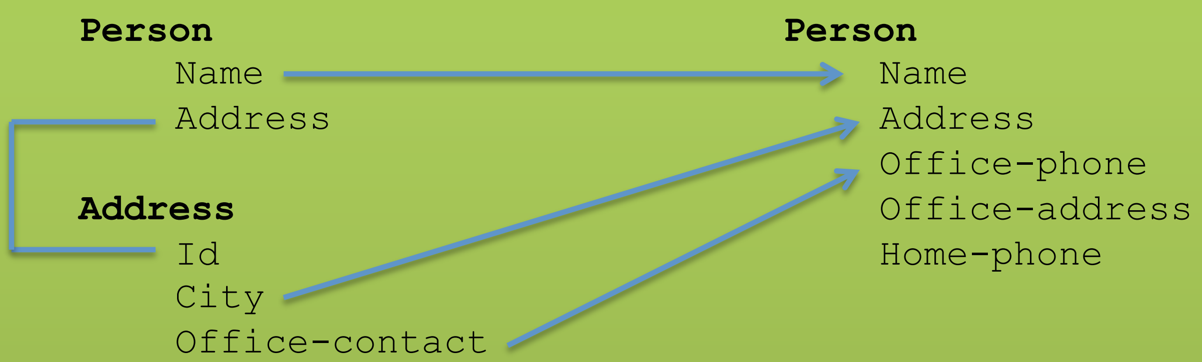
Name	Address
Peter	1
Alice	3
Bob	3

Id	City	Office-contact
1	Chicago	(312) 123 4343
2	Chicago	(312) 555 7777
3	New York	(465) 123 1234

$$\forall x, y, z, a : Person(x, y) \land Address(y, z, a) \rightarrow \exists b, c : Person(x, z, a, b, c)$$

5. Data Exchange

Example: Types of Matching



Name	Address
Peter	1
Alice	2
Bob	3

Id	City	Office-contact
1	Chicago	(312) 123 4343
2	Chicago	(312) 555 7777
3	New York	(465) 123 1234

Name	Address	Office-phone	Office-address	Home-phone
Peter	Chicago	(312) 123 4343		
Alice	Chicago	(312) 555 7777		
Bob	New York	(465) 123 1234		

Definition: Data Exchange Setting

Data Exchange setting is a tuple (**S**,**T**,**I**,**Σ**)

- Schema **S**
- Schema **T**
- Instance **I** of **S**
- Mappings **Σ** from **S** to **T**

5.1 Data Exchange Solutions

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Definition: Data Exchange Solution

Given data exchange setting is a tuple (**S,T,I,Σ**)

- Find instance **J** of **T** so that **(I,J)** fulfills mappings **Σ**
- **J** uses values from a **universe U** and set of **labeled nulls N**

5.1 Data Exchange Solutions

Example: Solutions

Person Name Address

Person Name Address

Name	Address
Peter	1
Alice	2
Bob	3

ntact

Id	City	Office-contact
1	Chicago	(312) 123 4343
2	Chicago	(312) 555 7777
3	New York	(465) 123 1234

$$\forall x, y, z, a : Person(x, y) \wedge Address(y, z, a) \rightarrow \exists b, c : Person(x, z, a, b, c)$$

Can we come up with a solution?

5.1 Data Exchange Solutions

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Example: Solutions

Person
Name
Address

Person
Name
Address

Name	Address
Peter	1
Alice	2
Bob	3

ntact

Id	City	Office-contact
1	Chicago	(312) 123 4343
2	Chicago	(312) 555 7777
3	New York	(465) 123 1234

$$\forall x, y, z, a : Person(x, y) \wedge Address(y, z, a) \rightarrow \exists b, c : Person(x, z, a, b, c)$$

Name	Address	Office-phone	Office-address	Home-phone
Peter	Chicago	(312) 123 4343	NULL	NULL
Alice	Chicago	(312) 555 7777	NULL	NULL
Bob	New York	(465) 123 1234	NULL	NULL

5.1 Number of Solutions

- **How many solutions exists?**
  - Depends on how whether we use existentially quantified variables in the mappings?
    - i.e., do we have attributes for which we have to invent values?
  - What attribute values do we allow?
    - Surely values from the source instance (active domain)
    - NULL?
      - Need multiple NULL values as placeholders for missing values that have to be the same
  - Note that this is the open-world assumption
    - there are infinitely many solutions (if domains infinite)

5.1 Number of Solutions

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- **Target instance domain**
  - Consider a **universe U**
    - Source instance can only use values from U
  - Consider an infinite **set N of labeled nulls**
    - Target instance can use these as placeholders for missing values

5.1 Data Exchange Solutions

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Example: Multiple Solutions

Name	Address	Office-phone	Office-address	Home-phone
Peter	Chicago	(312) 123 4343	X	Y
Alice	Chicago	(312) 555 7777	A	A
Bob	New York	(465) 123 1234	C	D

Id
City
Home-phone

Name	Address	Office-phone	Office-address	Home-phone
Peter	Chicago	(312) 123 4343	X	Y
Alice	Chicago	(312) 555 7777	A	A
Bob	New York	(465) 123 1234	C	D
Heinzbert	Pferdegert	111-222-3798	E	

Name	Address	Office-phone	Office-address	Home-phone
Peter	Chicago	(312) 123 4343	Hometown	111-322-3454
Alice	Chicago	(312) 555 7777	A	A
Bob	New York	(465) 123 1234	Other town	D

5.1 Certain answers (… again)

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- **Have multiple solutions**
  - Define certain answers for queries as before
  - Every tuple t so that t is in the result of query Q over any valid solution J
- **What's new?**
  - Want to materialize an instance so that computing certain answers over this instance is easy
    - Not immediately clear that this actually possible

5.1 Data Exchange Solutions

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Example: Solution generality

Name	Address	Office-phone	Office-address	Home-phone
Peter	Chicago	(312) 123 4343	X	Y
Alice	Chicago	(312) 555 7777	A	A
Bob	New York	(465) 123 1234	C	D

How general is solution (in terms of certain answers)?

Consider query

```
Q(n) :- P(n,a,op,oa,hp), oa = Hometown
```

Name	Address	Office-phone	Office-address	Home-phone
Peter	Chicago	(312) 123 4343	Hometown	111-322-3454
Alice	Chicago	(312) 555 7777	A	A
Bob	New York	(465) 123 1234	Other town	D

5.1 Universal solutions

- **Universal solution**
  - Want a solution that is as general as possible
  - We call such most general solutions universal solutions
  - How do we know whether it is most general
    - We can map the tuples in this solution to any other less general solution by replacing unspecified values (labelled nulls) with actual data values
- **Query answering with universal solutions**
  - For UCQs: run query over universal instance
  - Remove tuples with labelled nulls
  - Result are the certain answers!

5.1 Universal Solutions

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Definition: Homomorphism

A homomorphism **h** from instance **J** to instance **J'** maps the constants and nulls of **J** to the constants and nulls of **J'** and fulfills the following conditions**:**

- Constants are mapped onto themselves: **h(c) = c**
- Every tuple $\mathbf{R(a_1,\ldots,a_n)}$ in **J** is mapped to a tuple in **J'**:
  $\mathbf{R(a_1,\ldots,a_n)}$ in J -> $\mathbf{R(h(a_1), \ldots, h(a_n))}$ in **J'**

Definition: Universal solution

Given data exchange setting (**S,T,I,Σ**). An instance **J** of **T** is called an universal solution for a source instance **I** if it is a solution and for every other solution **J'** hold that

- There exists a homomorphism from **J** to **J'**

Example: Solution generality

Name	Address	Office-phone	Office-address	Home-phone
Peter	Chicago	(312) 123 4343	X	Y
Alice	Chicago	(312) 555 7777	A	A
Bob	New York	(465) 123 1234	C	D

How general is solution (in terms of certain answers)?

Consider query

```
Q(n) :- P(n,a,op,oa,hp), oa = Hometown
```

5.1 Data Exchange Solutions

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Example: Solution generality

Name	Address	Office-phone	Office-address	Home-phone
Peter	Chicago	(312) 123 4343	X	Y
Alice	Chicago	(312) 555 7777	A	A
Bob	New York	(465) 123 1234	C	D

Above is universal solution

How to map to below non-universal solution?
Replace generic labelled Nulls with values:
X -> Hometown, Y-> 111-322-3454, C -> other town,

Name	Address	Office-phone	Office-address	Home-phone
Peter	Chicago	(312) 123 4343	Hometown	111-322-3454
Alice	Chicago	(312) 555 7777	A	A
Bob	New York	(465) 123 1234	Other town	D

- **Note**
  - Schema mappings (st-tgds) are tuple-generating dependencies
  - What other tgd's do we know
    - Foreign keys
  - How did we solve violations to FKs?
    - **The chase!**
  - Chase produces universal solution!

5.2 Computing Solutions

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- **Can we use a database system to compute solutions?**
  - Yes, systems such as Clio generate queries that compute universal solutions!
    - SQL
    - Java
    - XSLT (for XML docs)

- **Generating Executable Transformations**
  - How to preserve semantics of labeled nulls
    - n = n' is true if we have the same labeled null only
    - n = n' if one is a constant and the other one is a labeled null

5.2 Skolem Functions

- **Skolem functions for labeled nulls**
  - For each existential variable in a tgd we create a new skolem function
  - What should be the arguments of the function?
    - Naïve: all universally quantified variables
    - Better: only relevant ones

5.2 Skolem Functions

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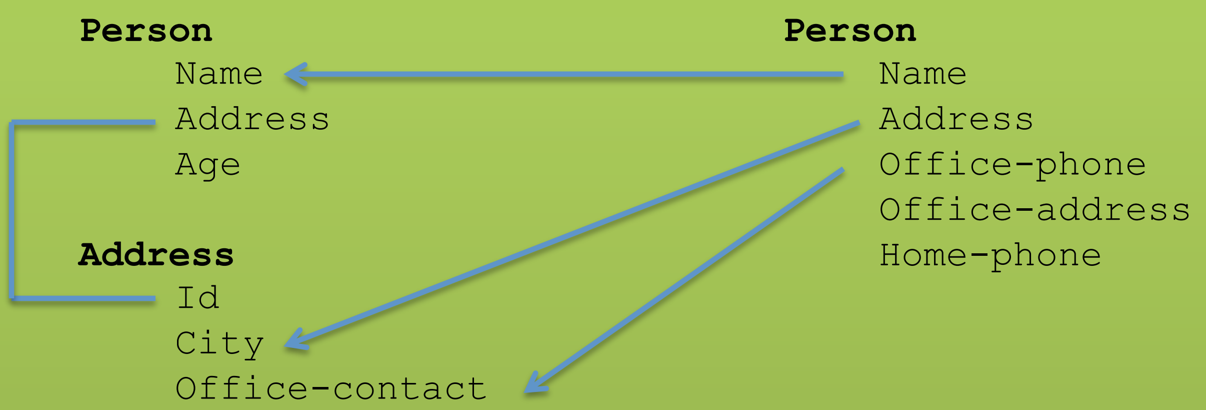
Example: Skolem Functions



5.2 Skolem Functions

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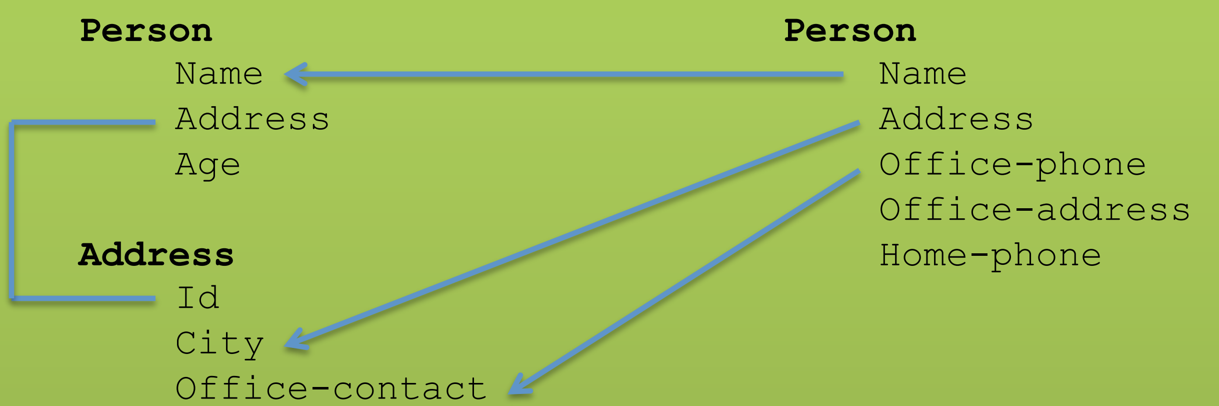
Example: Skolem Functions



$$\forall a, b, c, d, e : Person(a, b, c, d, e) \rightarrow \exists f, g Person(a, f, g) \wedge Address(f, b, c)$$

Introduce skolem function **sk1** and **sk2** for **f** and **g**.

What arguments to choose for **sk1** and **sk2**?

E.g.,, **f** should be fixed for a certain address and should not depend on the person.

5.2 Skolem Functions

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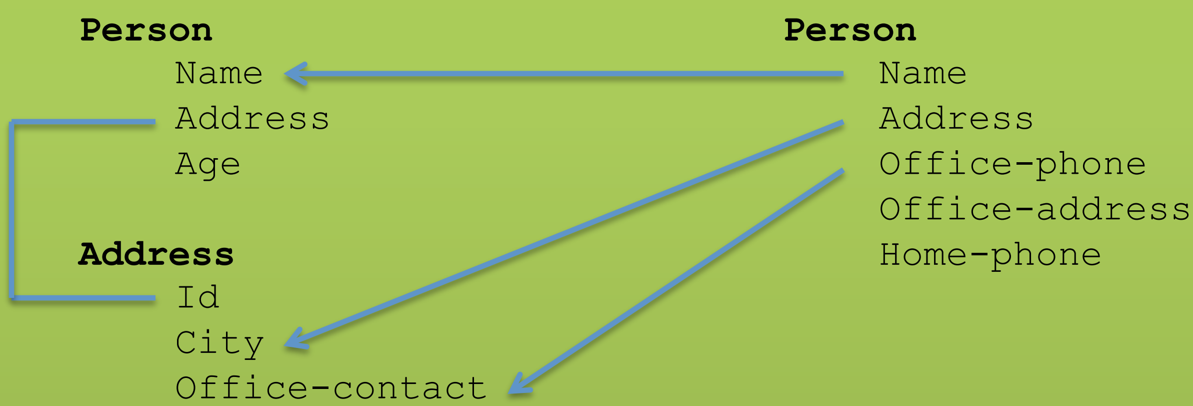
- **Clio Schema Graph Algorithm**
- **Nodes**
  - Create a graph with one node for every target attribute and one node for every target relation
  - Also add nodes for source attribute if they are copied to the target according to the mapping
- **Edges**
  - Edges between a relation and its attributes
  - Edges between target attributes that use the same variable
  - Edges between source attributes and target attributes if they use the same variable

5.2 Skolem Functions

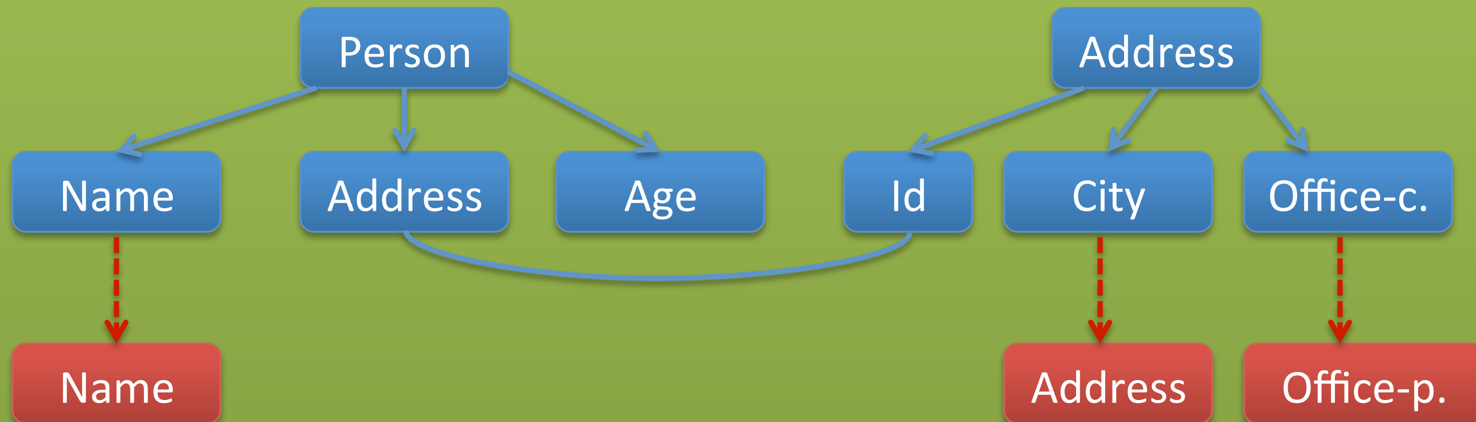
- **Clio Schema Graph Algorithm**
- **Annotations**
  - Annotate each target attribute connected to a source attribute with that source attribute
  - Propagate annotations according to the following rules
    - Propagate annotations from attributes to relations
    - Propagate annotations from relations to attributes
      - Only if attribute uses existentially quantified variable
    - Propagate annotations between target attributes connected by equality edges

5.2 Skolem Functions

Example: Skolem Functions



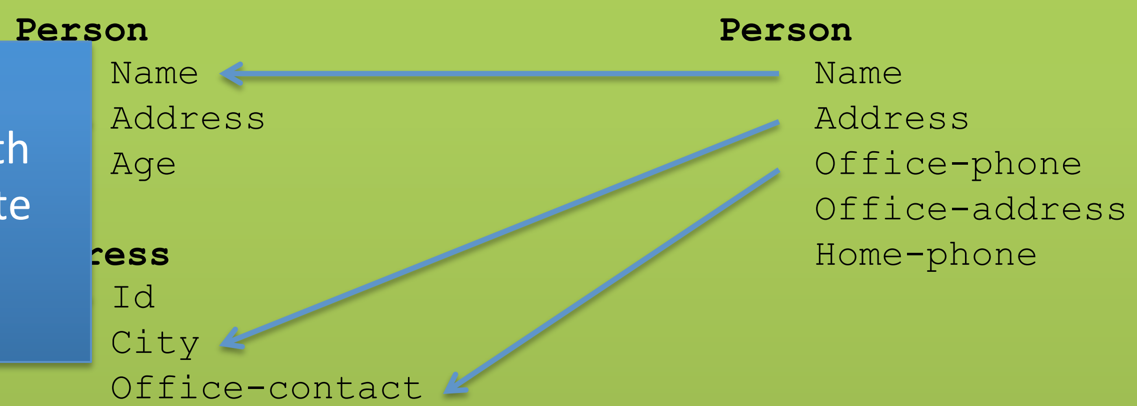
$$\forall a, b, c, d, e : Person(a, b, c, d, e) \rightarrow \exists f, g Person(a, f, g) \wedge Address(f, b, c)$$



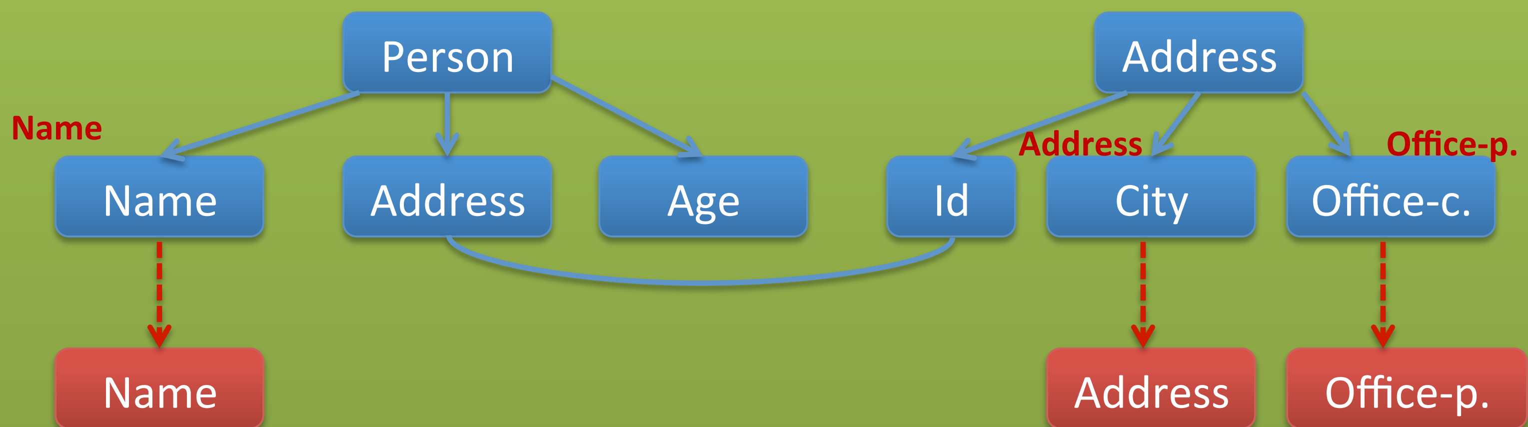
5.2 Skolem Functions

Example: Skolem Functions

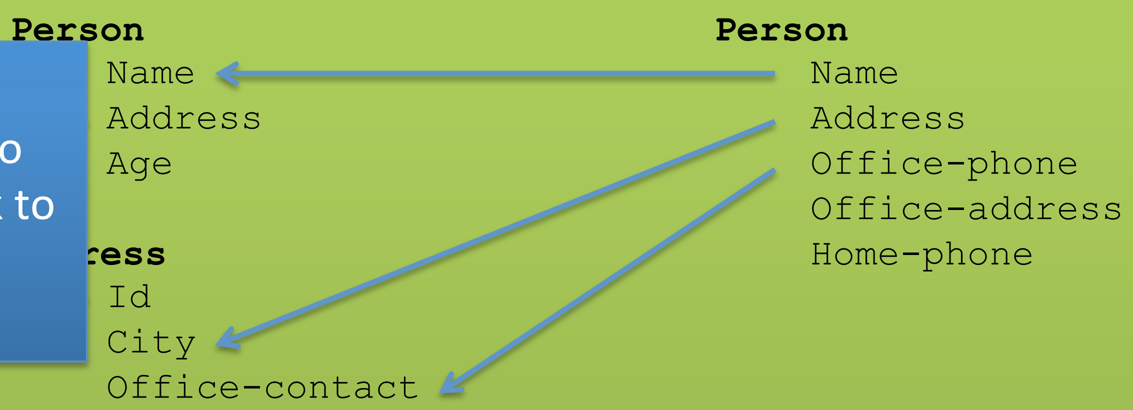
1) Initialize with source attribute names



$$\forall a, b, c, d, e : Person(a, b, c, d, e) \rightarrow \exists f, g Person(a, f, g) \wedge Address(f, b, c)$$

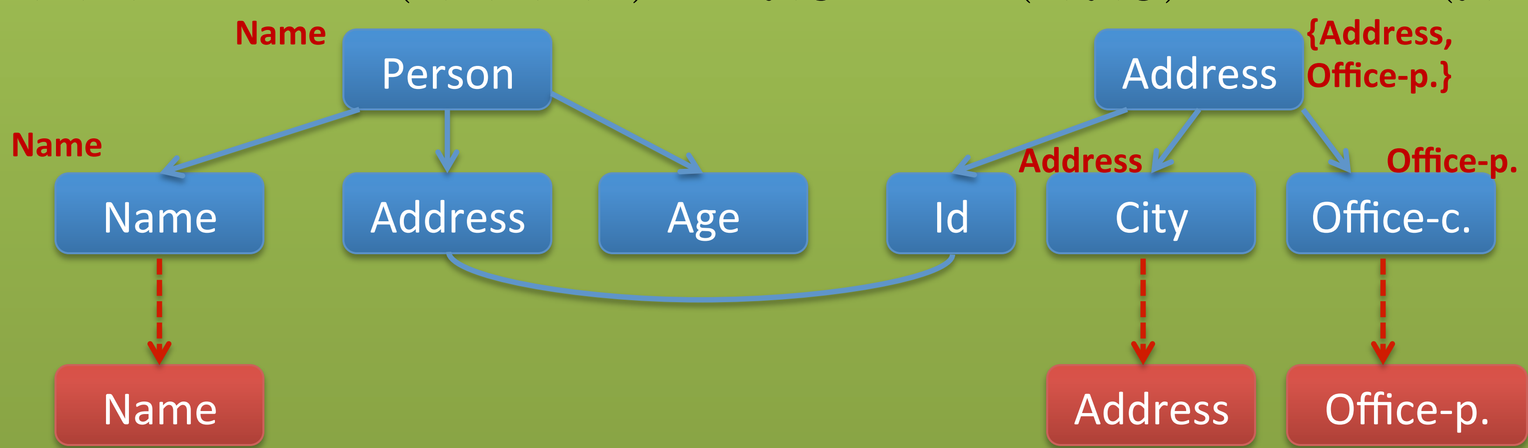


Example: Skolem Functions



2) Propagate to parent and back to children

$$\forall a, b, c, d, e : Person(a, b, c, d, e) \rightarrow \exists f, g Person(a, f, g) \wedge Address(f, b, c)$$



5.2 Skolem Functions

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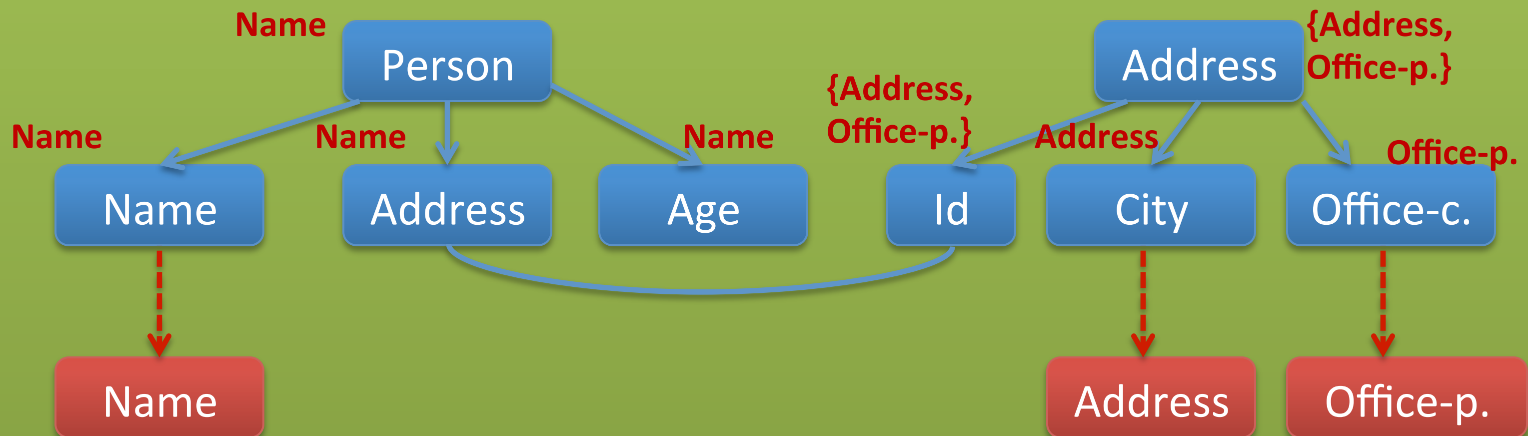
Example: Skolem Functions

2) Propagate to parent and back to children

```
Person                    Person
  Name                      Name
  Address                   Address
  Age                       Office-phone
                            Office-address
 ess                        Home-phone
  Id
  City
  Office-contact
```

$$\forall a, b, c, d, e : Person(a, b, c, d, e) \rightarrow \exists f, g Person(a, f, g) \wedge Address(f, b, c)$$

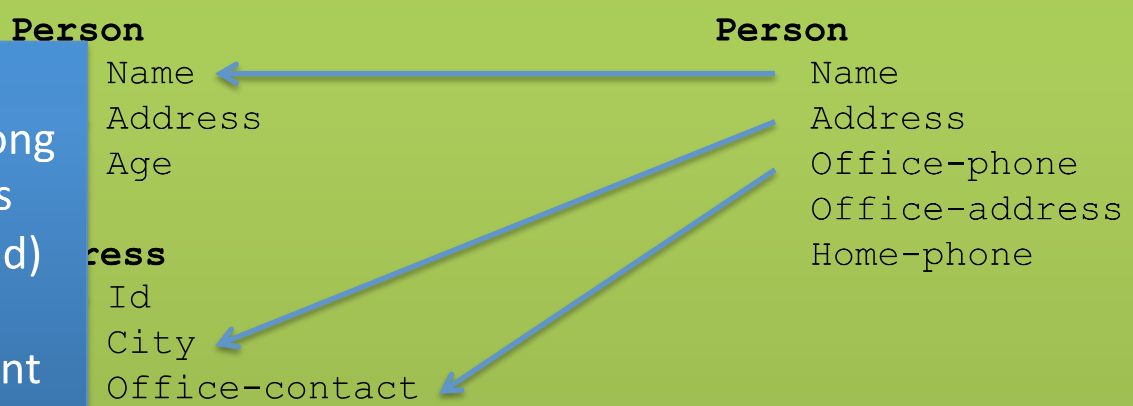


Example: Skolem Functions

3) Propagate along equality edges (here address=id)

…

Compute fixpoint



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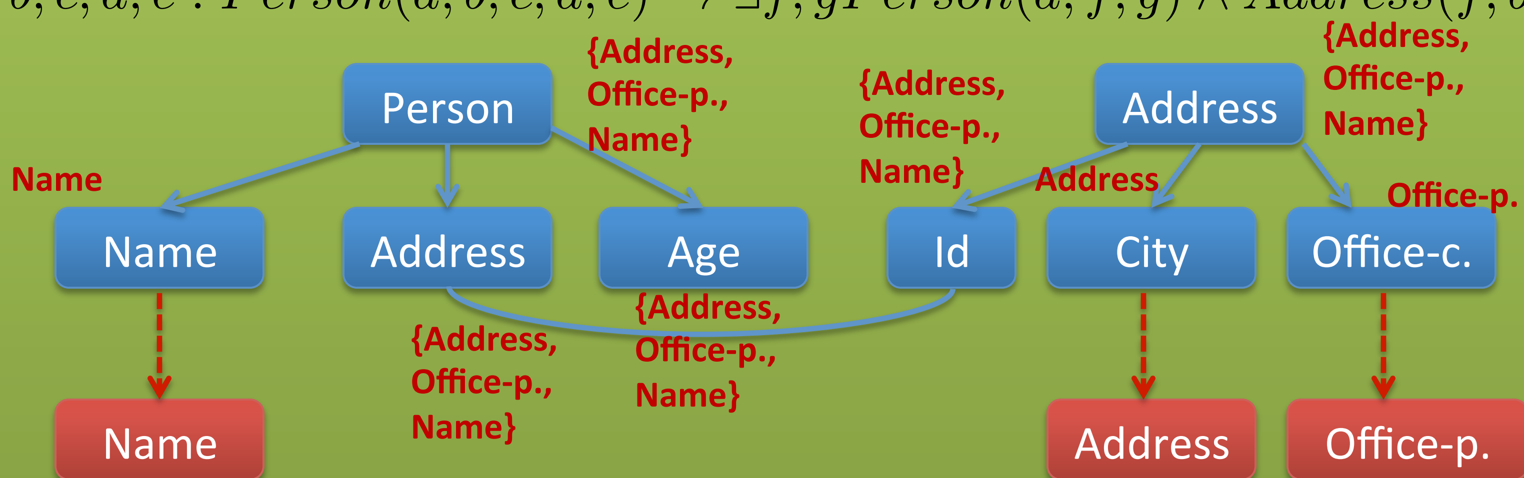

- **Clio Schema Graph Algorithm**
- **Skolem functions**
  - Derive skolem function arguments from the schema graph annotations of an element

Example: Skolem Functions

$$\forall a, b, c, d, e : Person(a, b, c, d, e) \rightarrow \exists f, g Person(a, f, g) \wedge Address(f, b, c)$$

For variable f (id, address) we assign sk1(a,b,c)
For variable g(age) we assign sk2(a,b,c)

5.2 Executable Transformations

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- **SQL Code Generation Example**
  - For each tgd mentioning a target relation R we generate a query fragment
  - All query fragments for R are "unioned" together
  - A query fragment is
    - A FROM and WHERE clause that is a direct translation of the LHS of a tgd into SQL
    - A SELECT clause corresponding the R atom in the RHS using attributes from the FROM clause can the skolem functions we have determined in the previous step

5.2 Executable Transformations

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Example: Skolem Functions

$$\forall a,b,c,d,e : Person(a,b,c,d,e) \rightarrow \exists f,g Person(a,f,g) \wedge Address(f,b,c)$$

<u>For Person atom in RHS:</u>

SELECT name,
    'SK1' || name || address || office-phone **AS** address,
    'SK2' || name || address || office-phone **AS** age
FROM Person

<u>For Address atom in RHS:</u>

SELECT 'SK1' || name || address || office-phone **AS** address,
    address AS city,
    office-phone AS office-contact
FROM Person

5.3 Recap Data Exchange Steps

- Schema Matching
- Generate Schema Mappings
  - Use constraints
- Generate Executable Transformations
  - SQL, XSLT, XQuery
  - Skolems for missing value
- Run Transformations over source instance to generate target instance
  - Universal solution

5.3 Comparison with virtual integration

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- Pay cost upfront instead of at query time
- Making decisions early vs. at query time
  - When generating a solution
  - Caution: bad decisions stick!
- **Universal solutions** allow efficient computation of certain types of queries using, e.g., SQL

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