Knowledge Representation

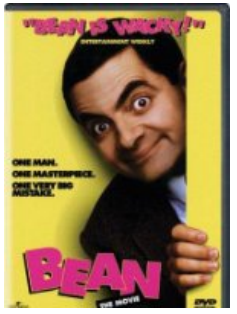
Fabian M. Suchanek

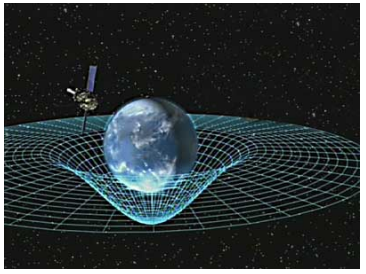
Overview

- Entities & Classes
- Relations
- Binary Relations
- Schema
- Knowledge Graphs
- N-ary Relations and Events
- Canonic Entities
- Reality

Entity

An entity (also: instance, resource)
is any particular object of the world
or imagination, be it abstract or concrete.

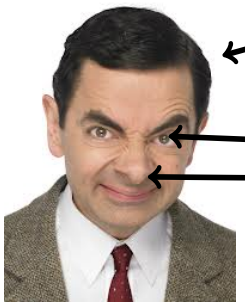




digressions>47

(The exact definition of “instance” is a philosophical conundrum. Don’t worry about it.)

Digression: Entities

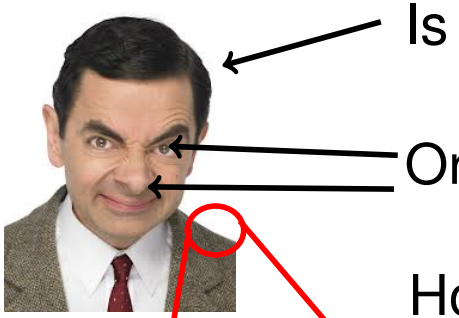


Is this an entity?

Or this?

How many entities are there?

Digression: Entities



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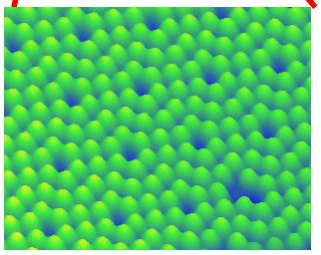


Isn’t everything just atoms?

Digression: Identity

Over time, all parts of a ship are replaced at some point of time.

Then, is it still the same ship?

see: Theseus's ship on Wikipedia

Digression: Identity

Over time, all parts of a ship are replaced at some point of time.
Then, is it still the same ship?

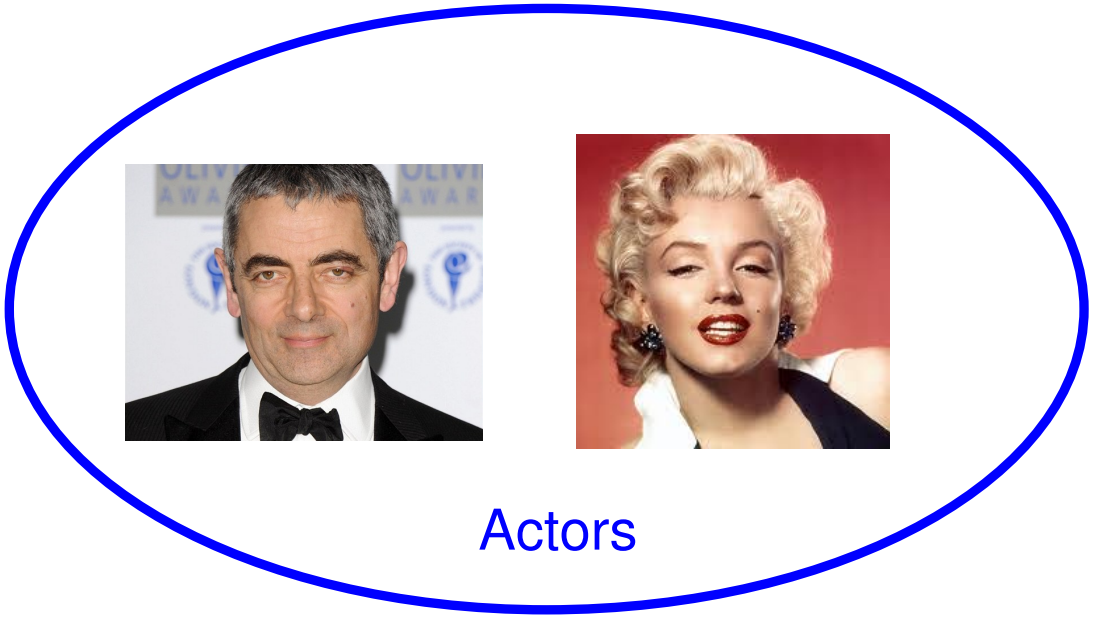
see: Theseus's ship on Wikipedia

Humans replace their cells every 7 years.

New York Times

Class

A class (also: concept) is a set of similar entities.



Cars

Cities

Rivers

Universities

Theories

...

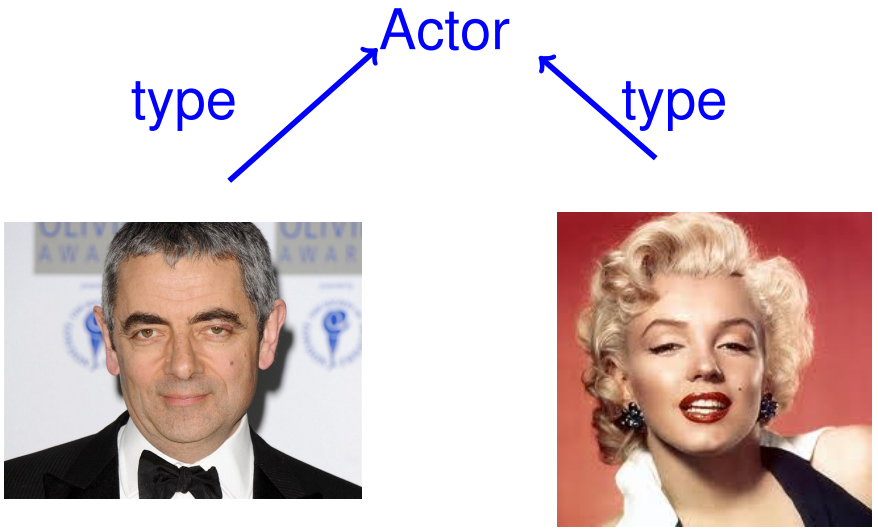
>instances

>instances,subclasses

(The exact definition of “class” is a philosophical conundrum, too)

Instance of a class

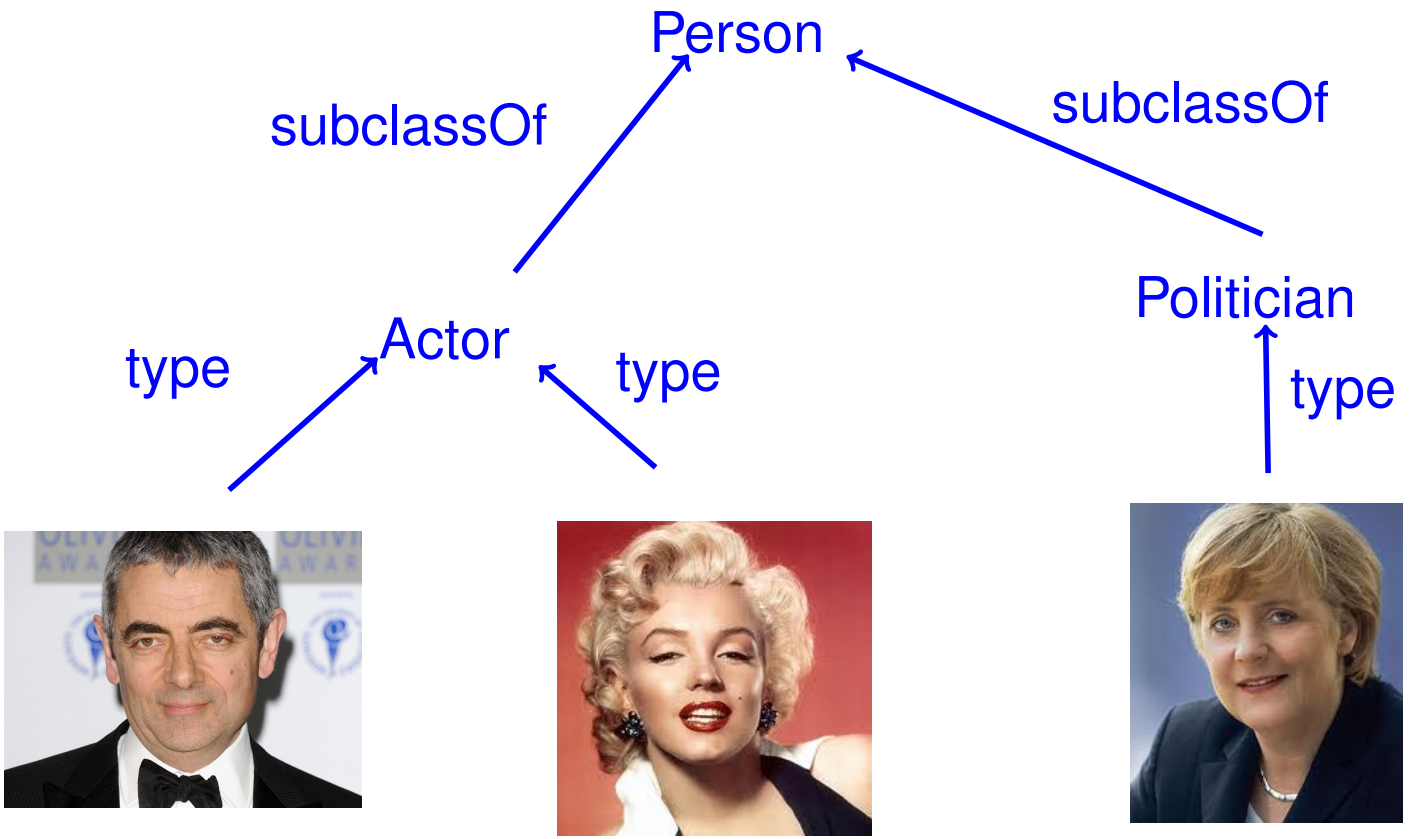
An entity is an instance of a class
(also: belongs to a class, has the type, is of the class),
if the entity is an element of that class.



Def: Subclass, Taxonomy

A class is a subclass of another class, if all instances of the first class are also instances of the second class.

A taxonomy is a hierarchy of classes.



Examples

iPhone -> smartphone

finger -> hand

apple -> orange

flower -> plant

Paris -> city

fruit -> food

France -> Europe

Paris -> France

city -> country

Examples

iPhone -> smartphone	subclass
finger -> hand	partof
apple -> orange	sibling
flower -> plant	subclass
Paris -> city	type
fruit -> food	subclass
France -> Europe	locatedIn
Paris -> France	locatedIn
city -> country	domain and range of “locatedIn”

Cheat Sheet

If we can say...	then...
• “a/an X”, “every X”	X is a class
• “Xs” (plural)	X is a class
• “This is X”	X is an instance of some class
• “X is a Y”	X is an instance of Y
• “Every X is a Y”	X is a subclass of Y

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Try it out: city, Elvis, Coli bacteria, Ford, time

>task

Task: Subclasses

Draw a picture of instances and subclasses in the animal kingdom.

How do you deal with “male” and “female”?

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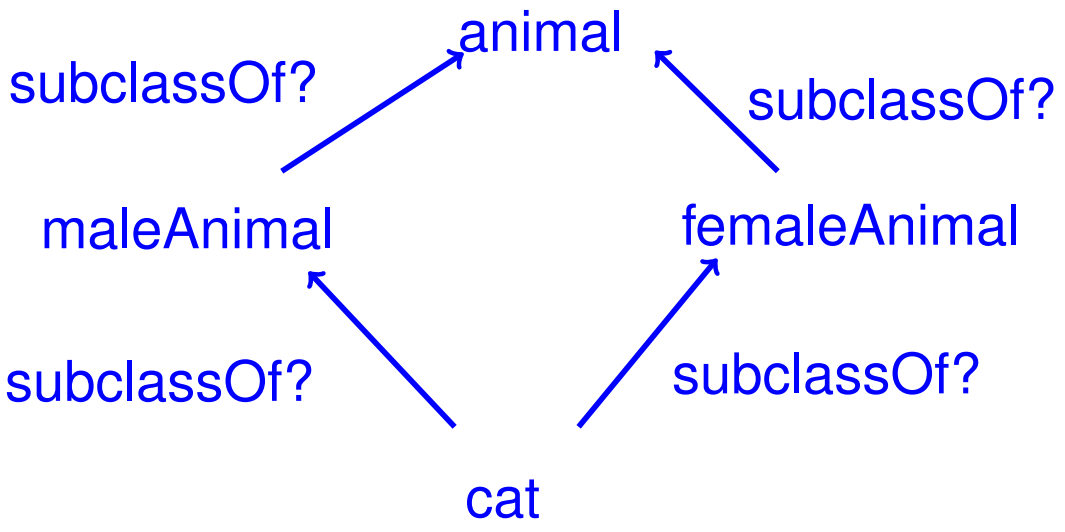


Intuition: Relations

A relation is like a table.

Relation “born”:

Person	City	Year
Atkinson	Consett	1955
Monroe	Los Angeles	1926
...		

Def:Relation

A relation (also: predicate) over classes is a subset of their cartesian product. The classes are called the domains of the relation.
The number of classes is called the arity of the relation.

$$R \subseteq C_1 \times C_2 \times ... \times C_n$$

$$born \subseteq person \times city \times year$$

$$born = \{< Atkinson, Consett, 1955 >,$$

$$< Monroe, LosAngeles, 1926 >, ...\}$$

>semantics
(tough stuff)

Digression: Semantics

A relation is any subset of the cartesian product. It does not have to correspond to a real-world relation. Its name is arbitrary.

$$born = \{< Atkinson, Consett, 1955 >,$$
$$< Monroe, LosAngeles, 1926 >, ...\}$$

Digression: Semantics

The semantics/denotation of a symbol is
the "meaning" of the symbol,
i.e., the real world entity or tuples.

$$\underbrace{D(Atkinson)}_{\text{Syntax}} = \underbrace{RowanAtkinson}_{\text{Semantics}}$$

$$D(born) = \{< x, y, z > | x was born in y in year z\}$$

Digression: Semantics

But these are again symbols.

$$D(born) = \{< x, y, z > | x was born in y in year z\}$$

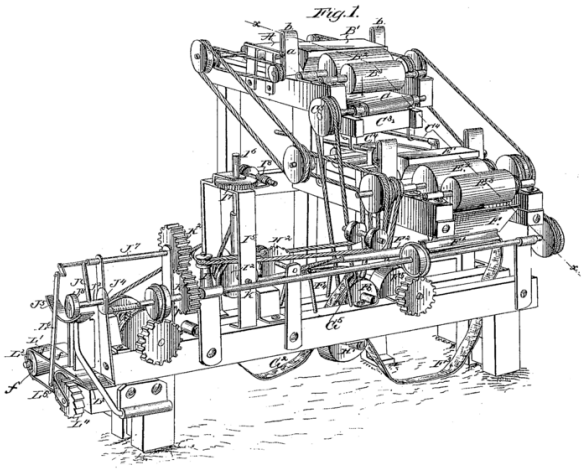
What is their semantics?

Digression: Semantics

$D(Atkinsonwasborninconsett)$

Digression: Semantics

$D(AtkinsonwasborninConsett)$



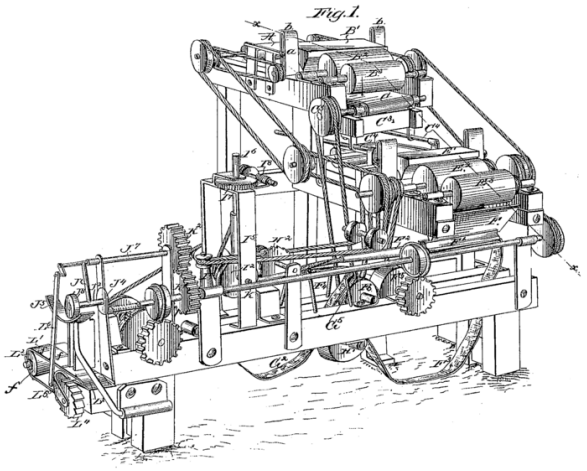
Linguistic parsing

+ Montague semantics

$= (\lambda xy < x, y > \in born)AtkinsonConsett$

Digression: Semantics

$D(Atkinsonwasborninconsett)$



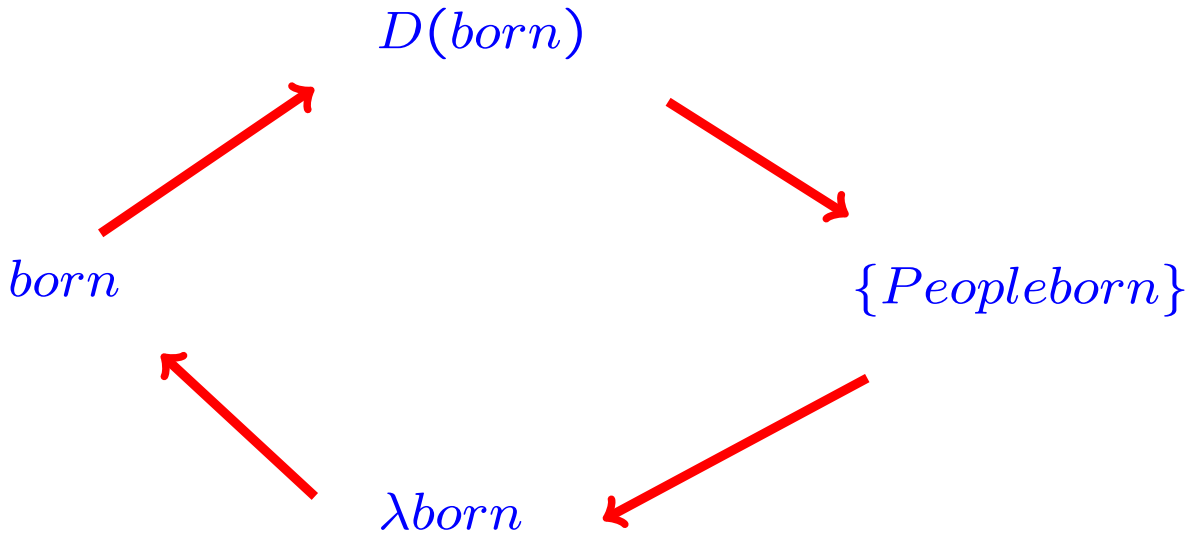
Linguistic parsing

+ Montague semantics

$= (\lambda xy < x, y > \in born)\, AtkinsonConsett$

$= < Atkinson, Consett > \in born$

Digression: Semantics



One man's semantics

is another man's syntax.

All we do is manipulating symbols.

There is no connection to the real world.

Def: Binary Relation, Triple

A binary relation is a relation of arity 2.

$$bornInCity \subseteq person \times city$$

For binary relations, the first class is called the domain and the second class is called the range.

An element of a binary relation is called a fact (or: triple), and we usually visualize it by an arrow:

$$bornInCity(Atkinson, Consett)$$

bornInCity

functions>3

The first argument of a fact is the subject, the second the object.

Def: Inverse

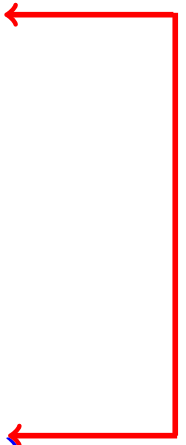
The inverse of a binary relation r is a relation r', such that $r'(x, y)$ iff $r(y, x)$.

$livesInCity \subseteq person \times city$

$livesInCity(Atkinson, Consett)$

$hasInhabitant \subseteq city \times person$

$hasInhabitant(Consett, Atkinson)$



inverses of each other

Def: Function

A function (also: functional relation) is a binary relation that has at most 1 object for each subject.

$$r\,functional \equiv \forall x : |\{y : r(x, y)\}| \leq 1$$

hasNationality

hasSpouse (in medieval ages)

hasNumberOfTeeth

Def:Inverse Functional Rel.

An inverse functional relation is a
relation whose inverse is functional.

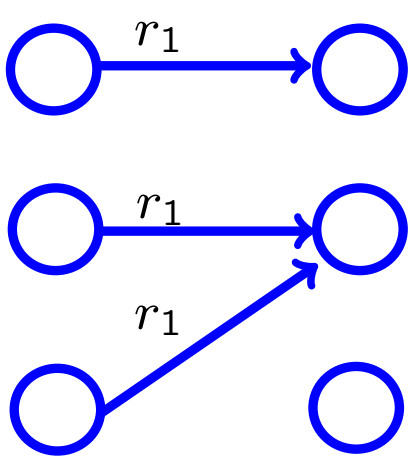
$$rinv.functional \equiv \forall y : |\{x : r(x, y)\}| \leq 1$$

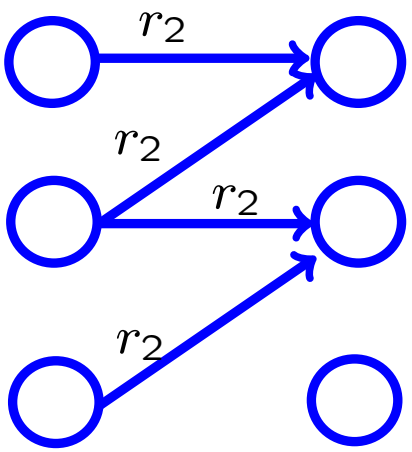
hasCitizen

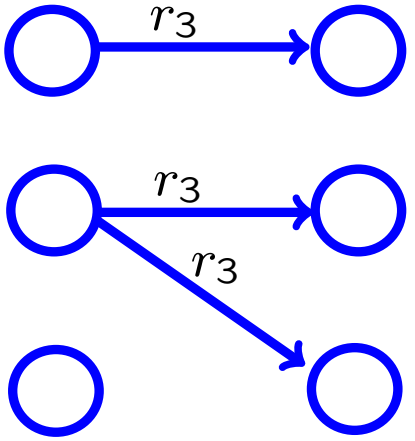
hasSpouse (in medieval ages)

Task: Functions

Which of the following relations are functional?







Digression: Equality

If two entities share the same object of an inverse functional relation, they are equal.

$$hasEmail(Bean, me@bean.com)$$

$$hasEmail(MrBean, me@bean.com)$$

$$\Rightarrow MrBean = Bean$$

$$born(Bean, 1955)$$

$$born(MrBean, 1955)$$ (Nothing follows)

Def: Name

A name (also: label) of an entity is a human-readable string attached to that entity.

Entity →

Name →

"Mr. Bean"

The entity is called the meaning of the name.

Label

label is a binary relation that holds between an entity and its name.

label → "Mr. Bean"

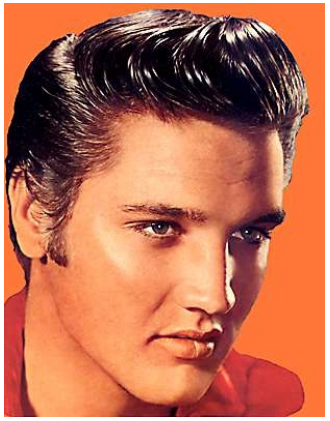
$$= label(MrBean, "Mr.Bean")$$

Def:Synonymy

If an entity has multiple names,

the names are called synonymous.

(The adjective for the names is “synonymous”, each name is a “synonym”, the phenomenon is called “synonymy”)



label → “The King”

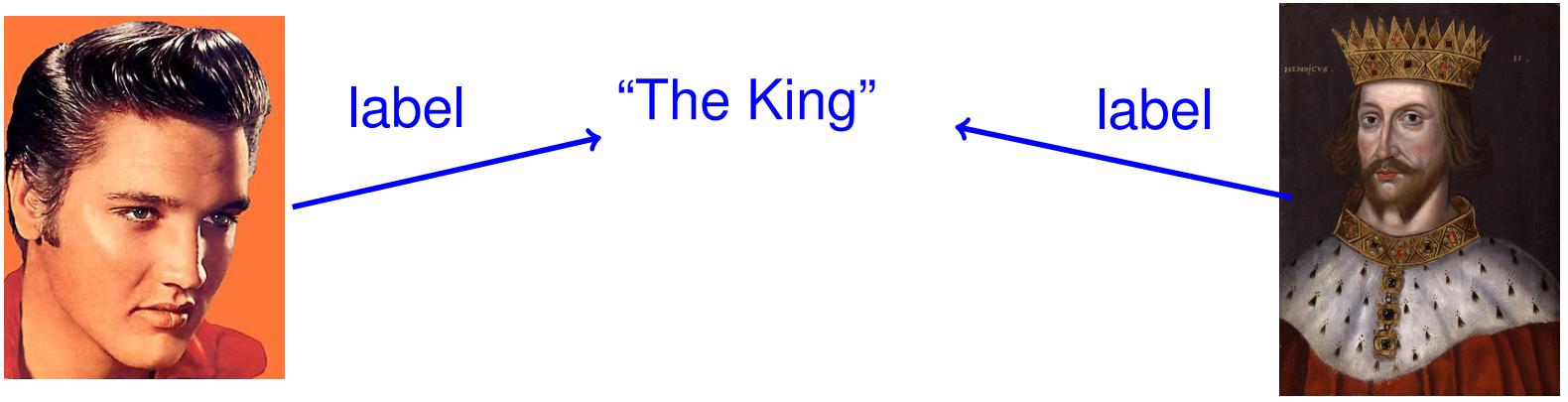
label → “Elvis”

Def:Ambiguity

If a name is attached to multiple entities,

the name is called ambiguous.

(The adjective for the names is “ambiguous”, the phenomenon is called “ambiguity”)



>classes
>Task

Task:Names

List some entities with their names,

some ambiguous names,

and some synonyms.

Classes as binary relations

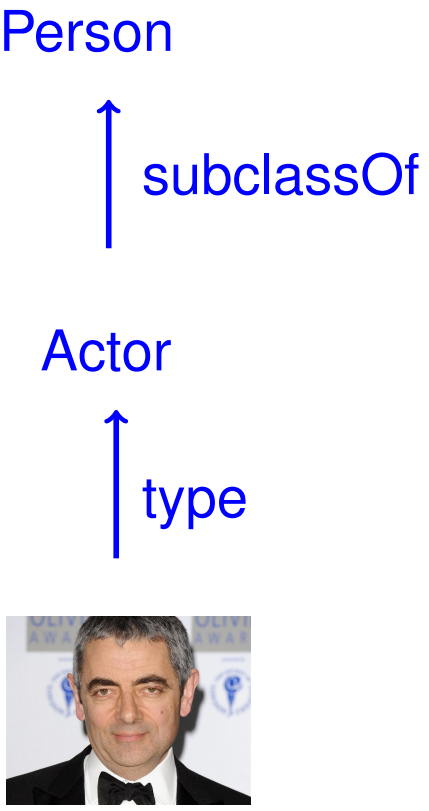
One way to represent a class is by the binary relations $type, subclassOf$.

$$type \subseteq entity \times class$$

$$type(Atkinson, actor)$$

$$subclassOf \subseteq class \times class$$

$$subclassOf(actor, person)$$



(Watch out: here, “entity” is the class of entities, “class” is the set of class names. See later in the lecture.)

Digression: Classes and Relations

A fact can be modeled as a class or as a relation.

type → woman

gender → female

type → singer

job → singer

>domain

Domains as binary relations

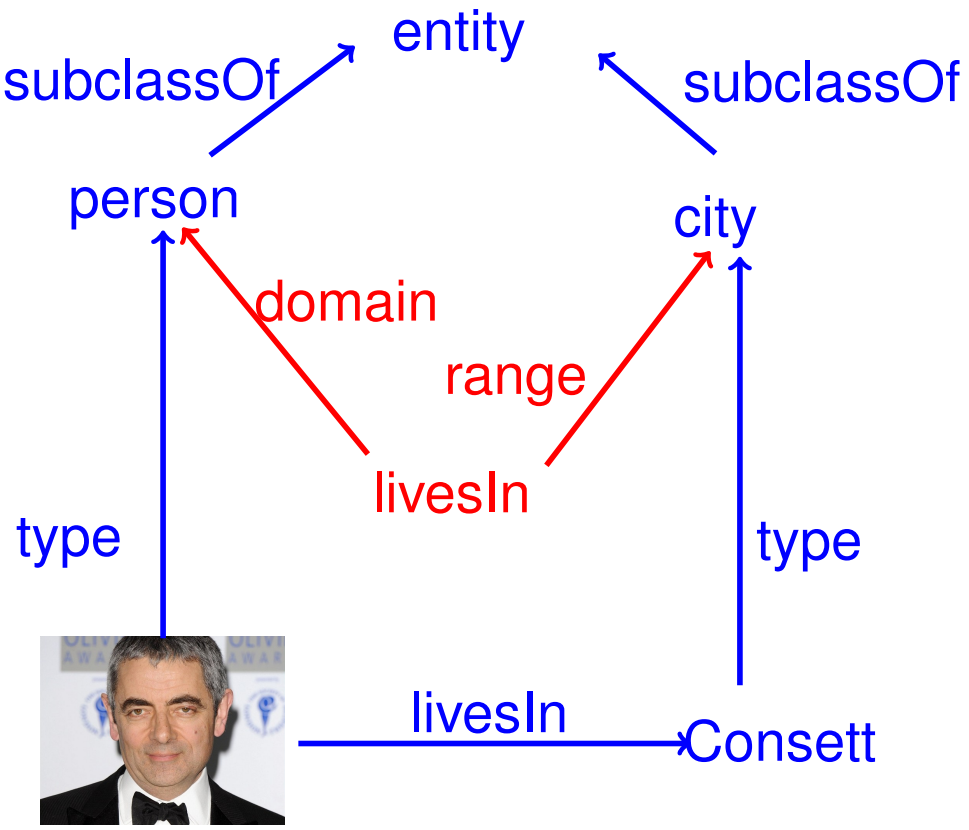
The domain and range of relations can be expressed by binary relations $domain$ and $range$.

$domain \subseteq relation \times class$

$domain(livesIn, person)$

$range \subseteq relation \times class$

$range(livesIn, city)$

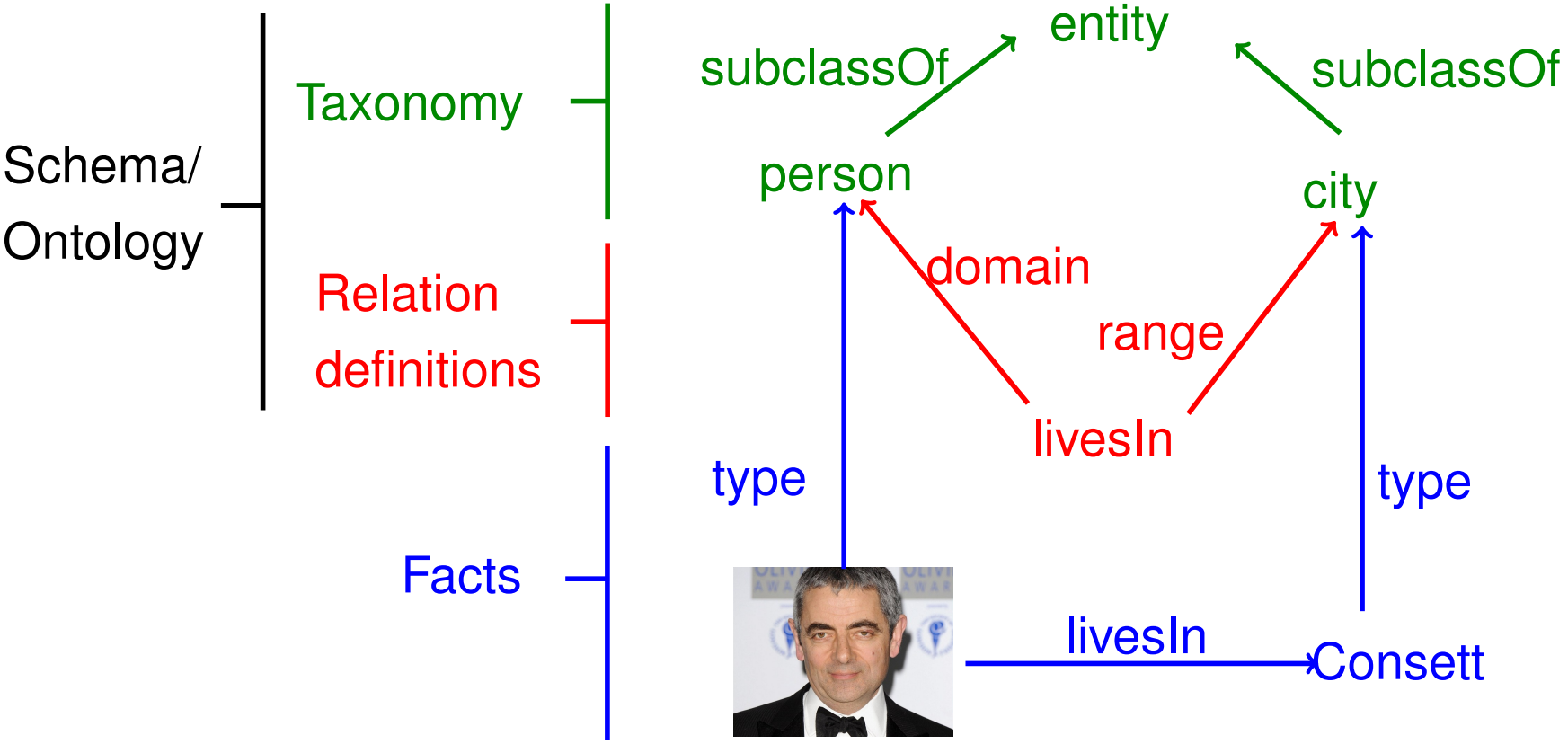


(Watch out: here, "relation" is the set of relation names. See later in this lecture.)

Def: Schema

A schema (or: ontology) consists of

- a taxonomy (= set of classes with their subclassOf-links)
- relation definitions (= a set of relations with domains and ranges)



Task: Schema

Define a schema for the domain of politics.

In that schema, express that Macron is the president
of France, Merkel is the chancellor of Germany,
and that Merkel loves Macron.

>meta
(tough stuff)

Digression: Task: Class entities

Draw a knowledge graph with the relations $domain$ and $range$.

Can $domain$ and $range$ appear as nodes?

Example: RDF

Digression: The problem with classes

type(class, class) “The class “class” is a class”

class $\in$ class ...in a naïve set-theoretical interpretation

class = {cars, frenchPeople, class, ...}

class = {cars, frenchPeople, {cars, frenchPeople, { cars, ...

Digression: Class Entity

A class entity is an entity that represents the class.

The class entity “Marianne”...

... represents the class (set) “French People”

$$frenchPeople = \{Hollande, Alizee, ...\}$$

Digression: The Class Class

"Class" is the class of all class entities.

class = {frenchPeople, class, ... }

class = {Marianne, Class, ...}

The set of instances

The class entity of this set of instances

This class can appear in relations

$$type \subseteq entity \times class$$

$$type = \{< Alizee, Marianne >, < actor, Class >, ...\}$$

The class entity that represents "frenchPeople"

Def: Knowledge Graph

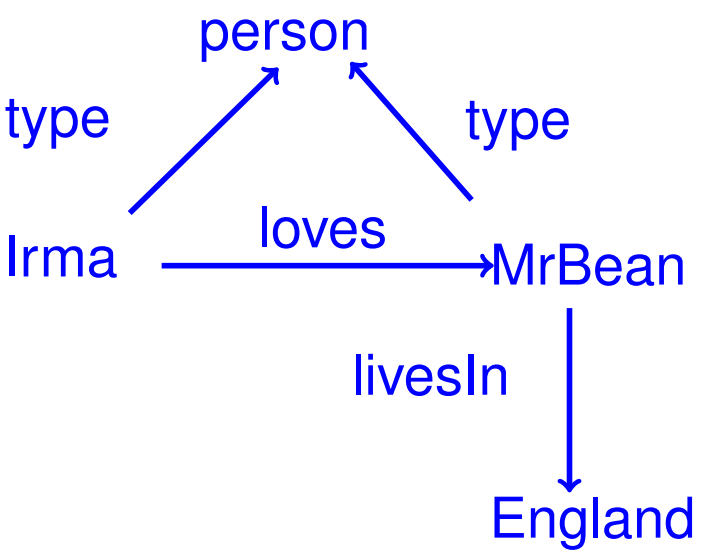
A knowledge graph (also: Entity-Relationship graph, Knowledge base, KB) is a directed labeled multi-graph that has an edge x->y with label r, iff r(x,y).

$loves(Irma, MrBean)$

$type(Irma, person)$

$type(MrBean, person)$

$livesIn(MrBean, England)$



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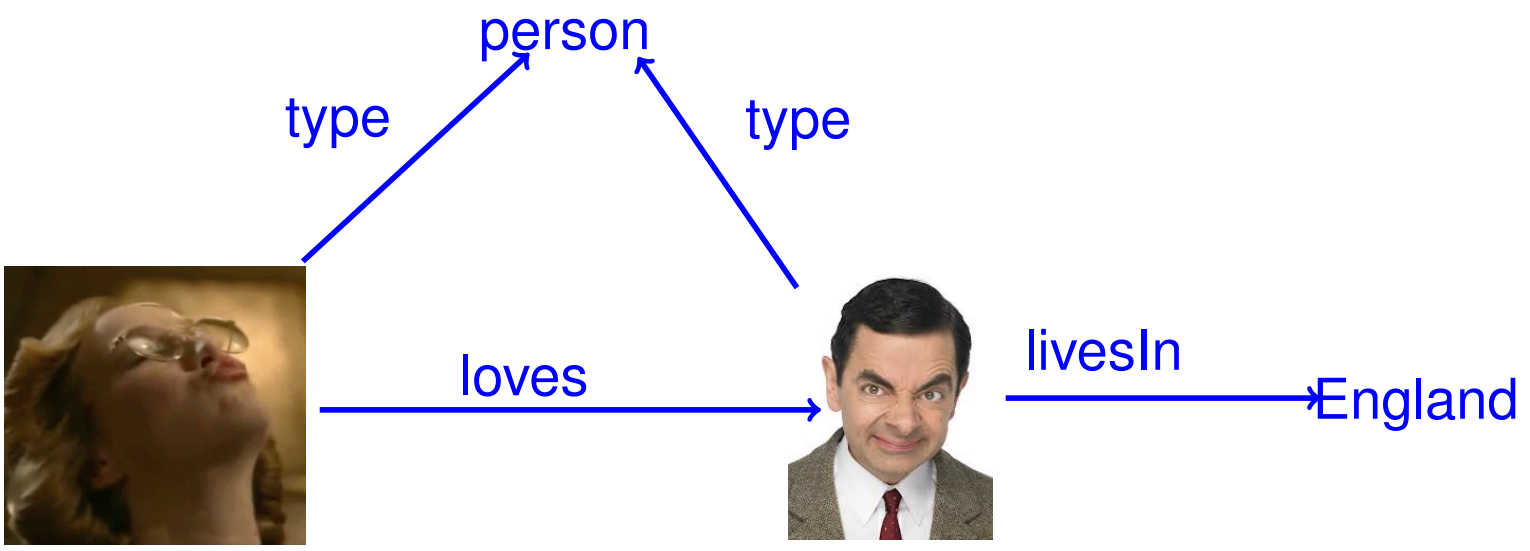


>triple store

Def: Triple Store

A triple store is a table that contains
a KB of binary relations in the form
of 3 columns: subject, relation, object.

Subject	Relation	Object
Irma	loves	MrBean
Irma	type	person

(The middle column is often called “Predicate”)

Fact Representations

Binary relations can be represented as

- relation

$$loves \subseteq person \times person$$

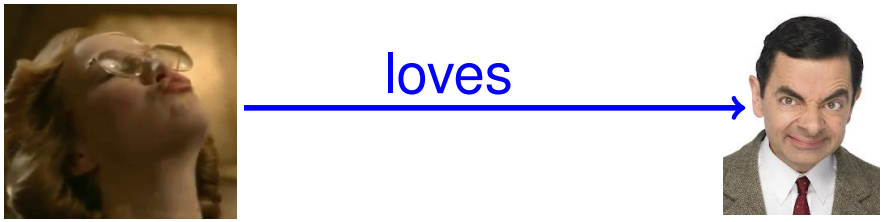
$$loves(Irma, MrBean)$$

- table

LOVES

Person	Person
Irma	MrBean

- graph



- triple store

Subject	Relation	Object
Irma	loves	MrBean

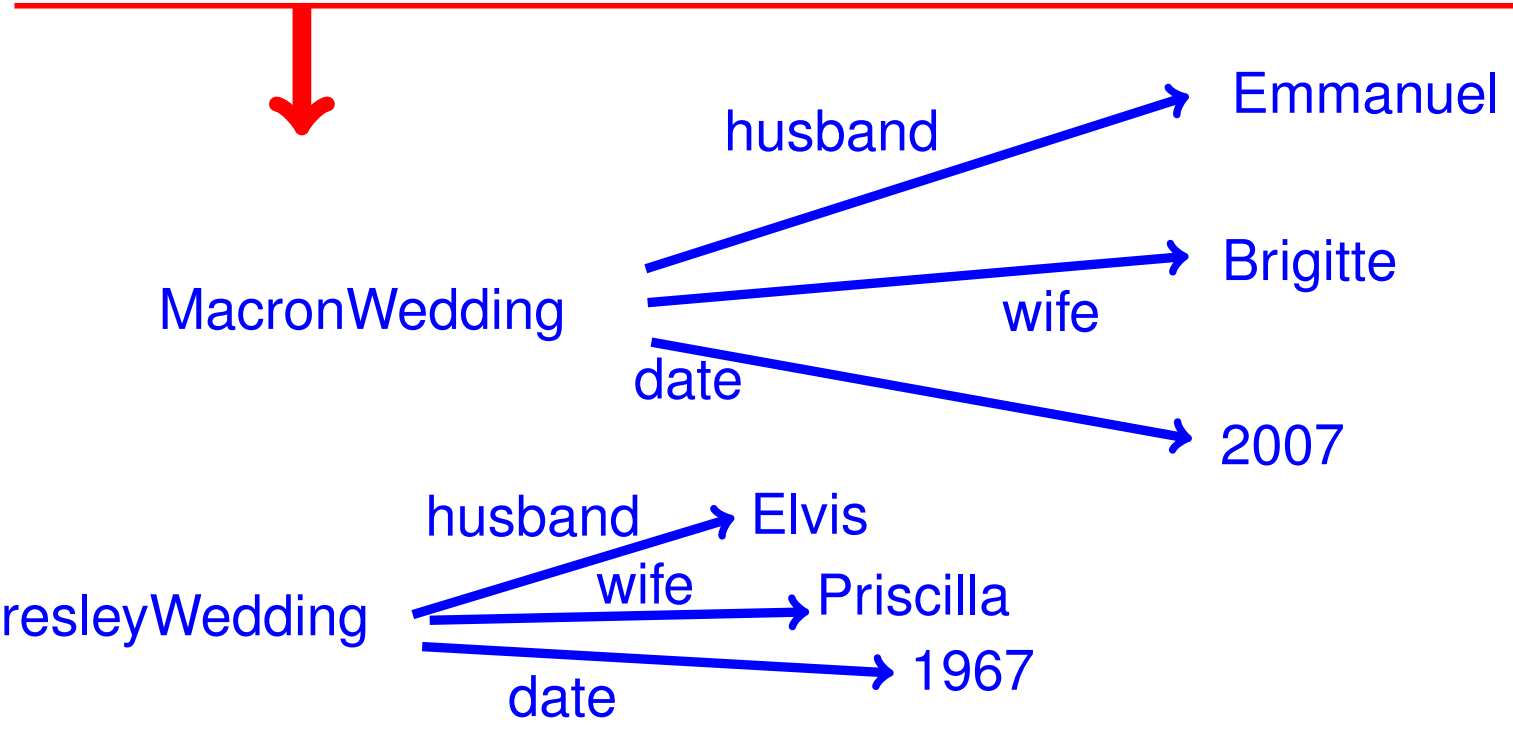
events>5

n-ary facts as binary facts

Every n-ary fact can be represented as binary facts.

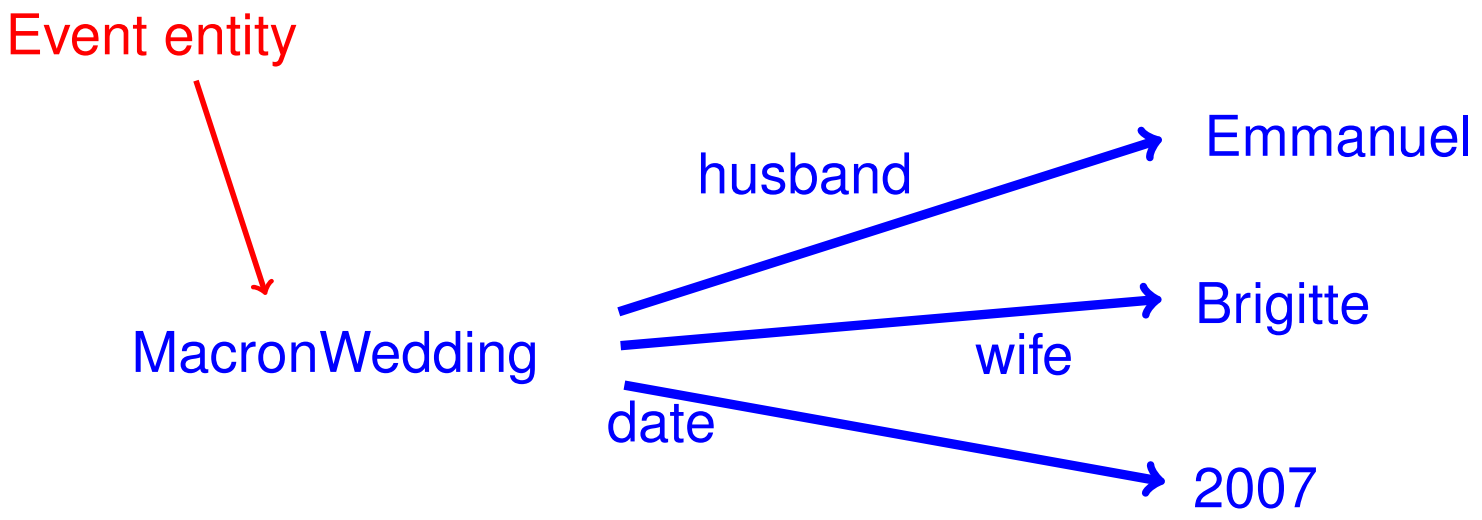
WEDDINGS

Husband	Wife	WeddingDate
Emmanuel	Brigitte	2007
Elvis	Priscilla	1967
...	...	...



Def: Event Entity

An event entity represents an n-ary fact.



>task

Task: Event Entities

Draw a knowledge graph for the following facts.

Irma loves Mr. Bean since 1955.

Mr. Bean drives with Irma to the cinema.

Irma and Mr. Bean watch “Titanic”.

The movie is about the trip of the ship “Titanic” from Europe to New York.

(There may be multiple solutions)

Binary relations are flexible

n-ary relations enforce the presence of all arguments:

born	Person	City	Year
	Atkinson	Consett	1955

Binary relations don't:

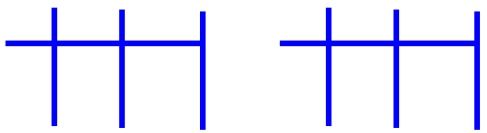



1955

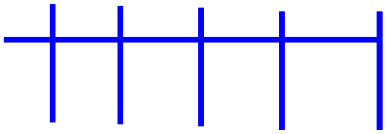

1955

Binary vs n-ary

Binary and n-ary relations can represent the same facts.



binary



n-ary

- more relations
- less arity
- more flexibility

- less relations
- more arity
- more control

Reify>63
Canonicity>73
Digression>77

Reified statements

A reified statement is an entity that represents a statement. This phenomenon is called reification.


UNIVERSITY OF OXFORD

THIS is to certify that

Ilya Pribylov

Templeton College

satisfied the Examiners for the Degree of

Master of Business Administration

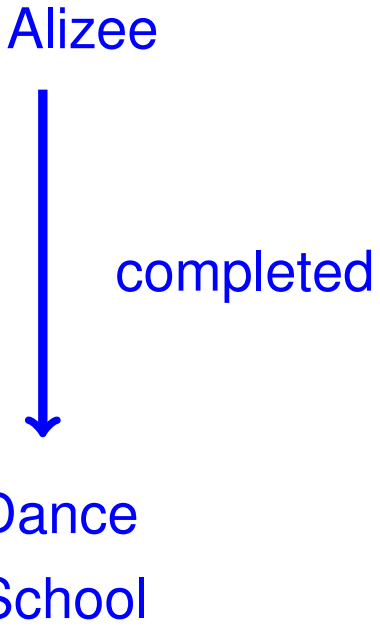
on 29 September 2006 and, having satisfied all the conditions prescribed by the Statutes of the University, was on 4 November 2006 admitted to the Degree of

Danse Classique

University Offices, Oxford. 7 December 2006

Registrar

represents



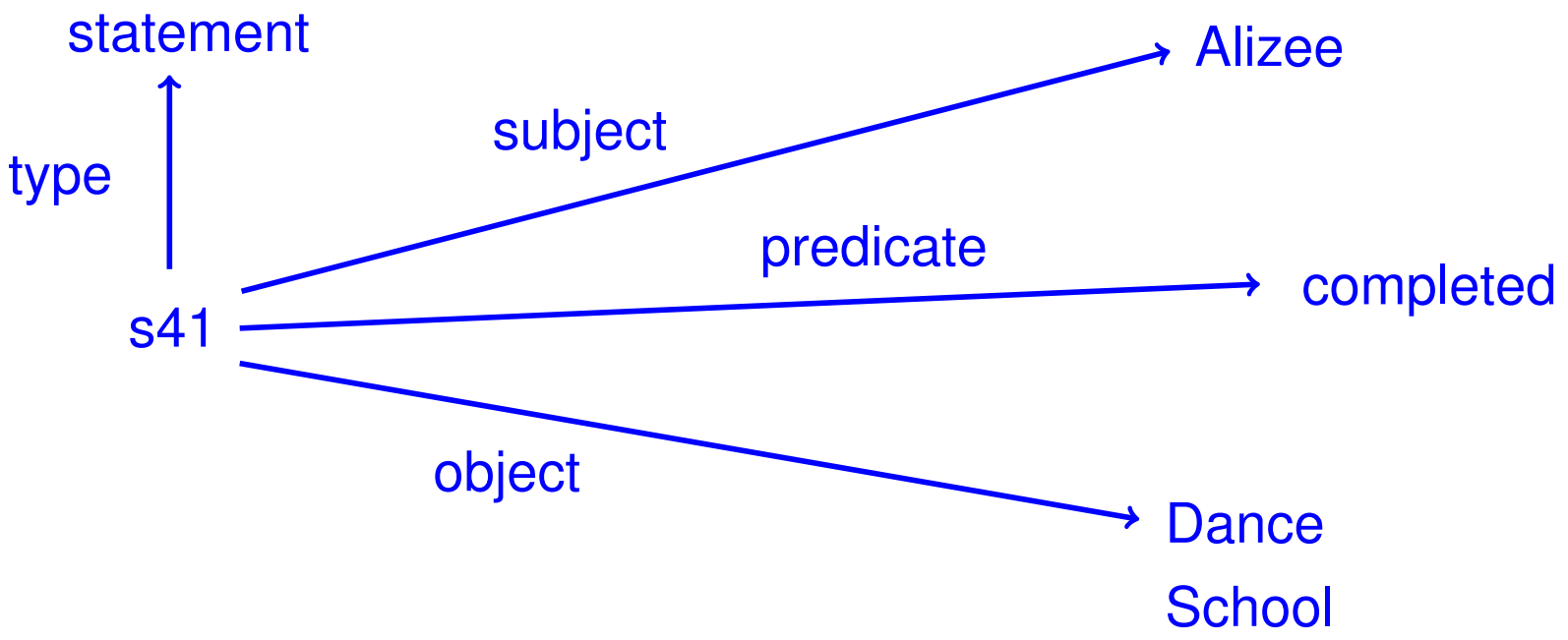
Reification Vocabulary

$statement$ = class of reified statements

$subject \subseteq statement \times entity$

$predicate \subseteq statement \times relation$

$object \subseteq statement \times entity$



Example: Reification

$hopes(Pierre, s42)$

$subject(s42, Alizee)$

$predicate(s42, type)$

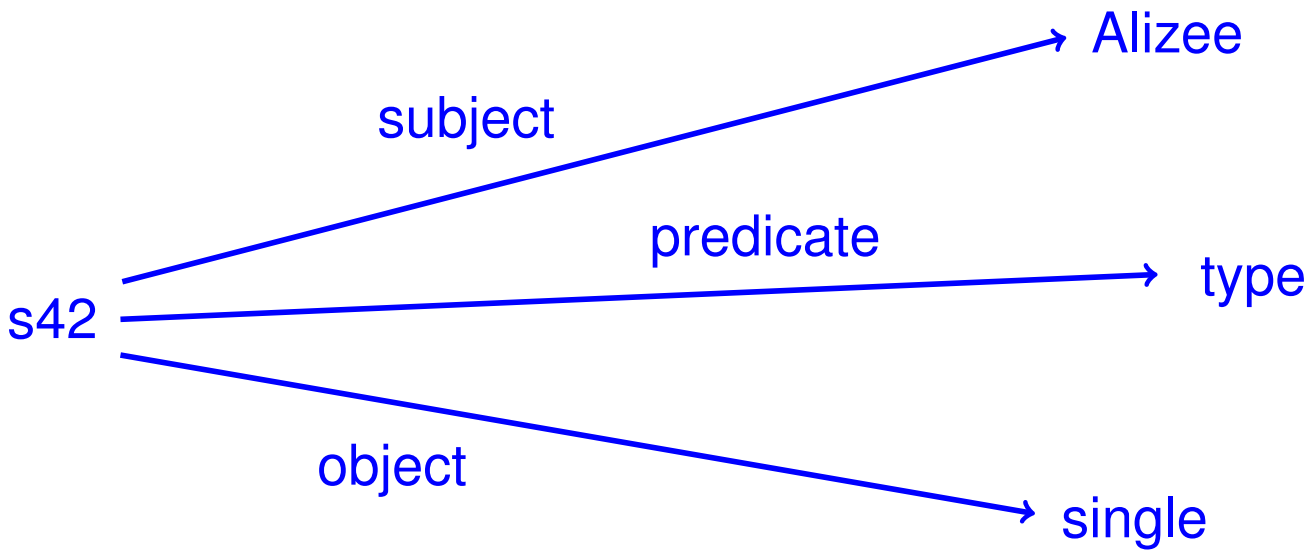
$object(s42, single)$

Simplified notation:

$$hopes(Pierre, type(Alizee, single))$$

Reification and Event Entities

The difference to event entities is that reified statements can be hypothetical (= not part of the KB).



Task>63
Canonicity>73
Digression>77

Task: Reification

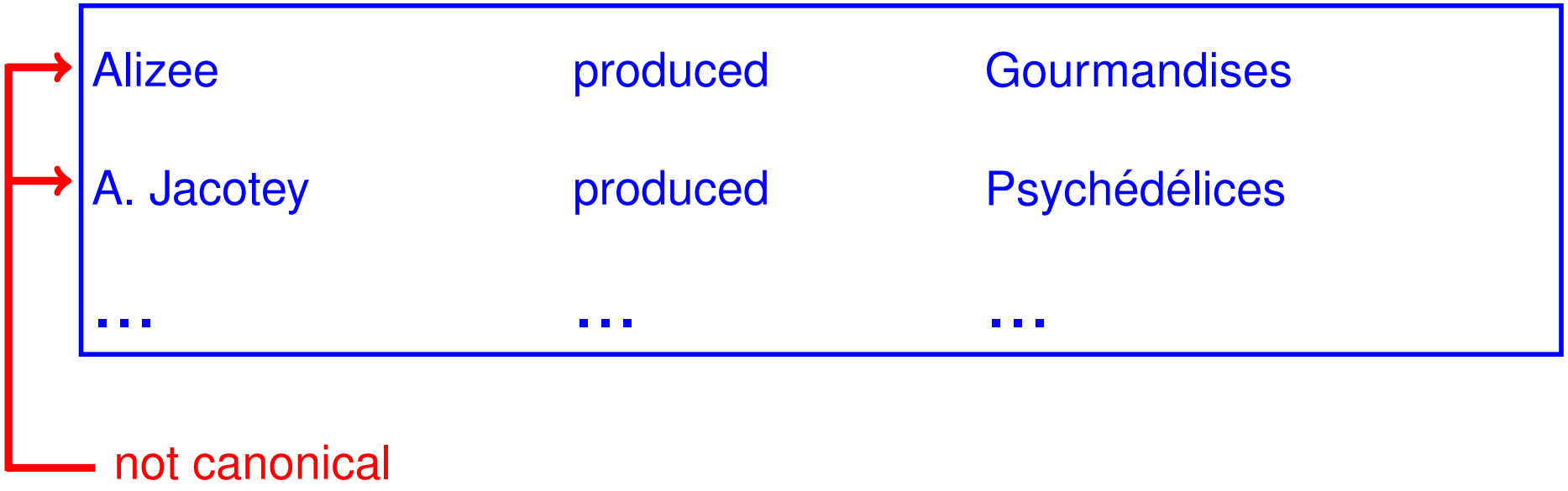
Write down a knowledge base

with some reified facts.

Can you reify facts that have reified arguments?

Def: Canonic Entities

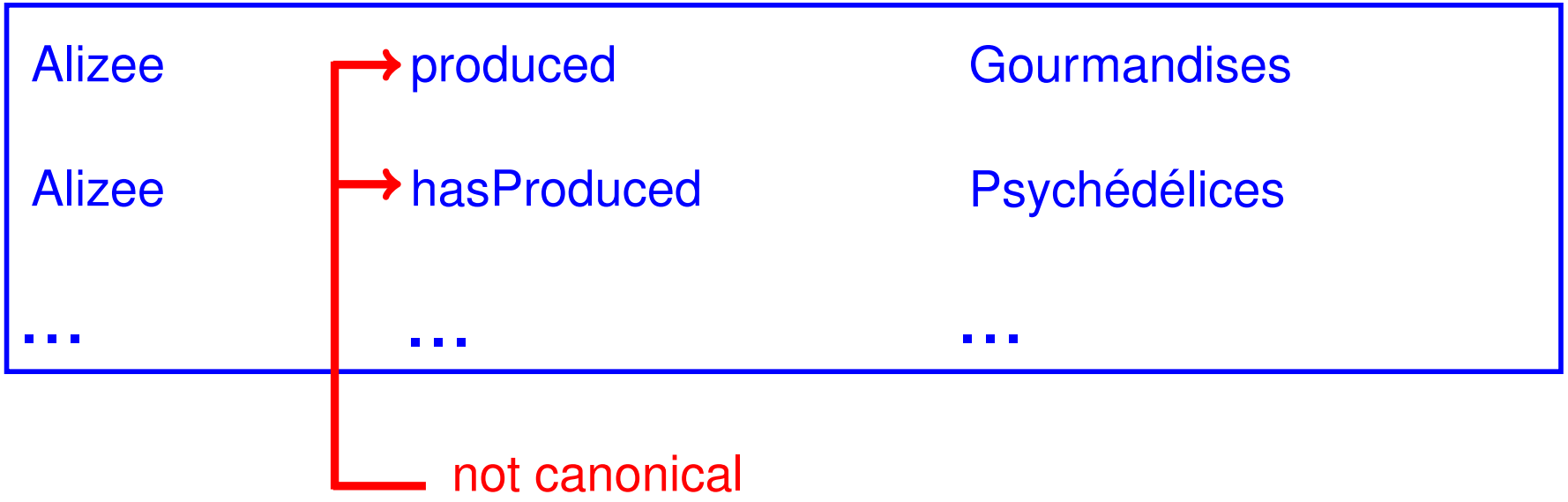
An entity is canonic in a KB, if there is no other entity in the KB that represents the same real-world object.



(Here, we distinguish exceptionally between an entity in the KB, and the real world object. This distinction is correct, but rarely necessary otherwise, which is why this lecture does not make the difference)

Def: Canonic Relations

An relation is canonic in a KB, if there is no other relation in the KB that represents the same real-world relation.

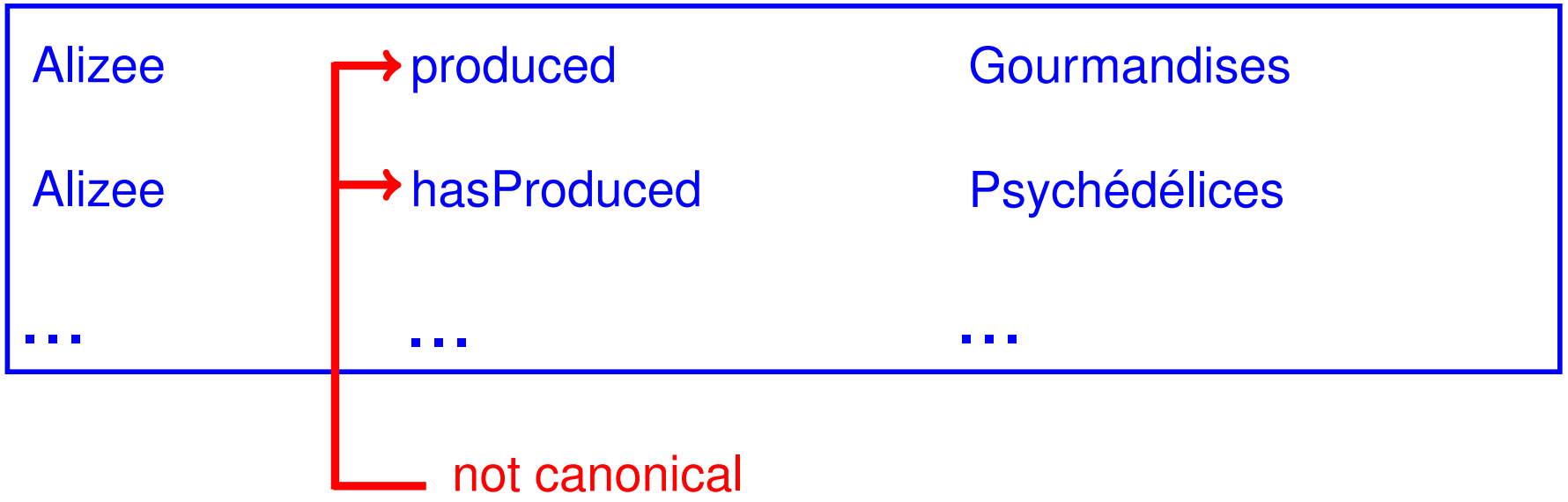


(Here, we distinguish exceptionally between a relation in the KB, and the real world relation. This distinction is correct, but rarely necessary otherwise, which is why this lecture does not make the difference)

Use of Canonicity

Canonicity is essential for

- counting
- answering queries
- constraint satisfaction



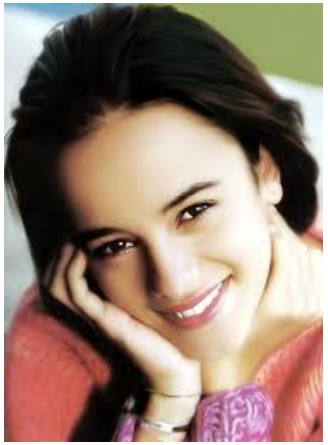
Canonicity and Names

A canonic entity can have multiple names.

Alizee	produced	Gourmandises
Alizee	produced	Psychédélices
Alizee	label	”Alizee”
Alizee	label	”A. Jacotey”
produced	label	”produced”
produced	label	”has produced”
…	…	…

Canonicity is not easy

Jacotey is considered one of the “100 Se
women of the world”. The singer said in
that Alizée is married, but she lives sepa



Example: Non-Canonicity

Open Information Extraction

"Tell me about Alizée"

Argument 1: Alizee Relation:

24 answers from **46 sentences**

is a french singer (8)

fakes urdukahaniustt 2006 (4)

was booed by some of the 3,400 fans (2)

is *French pop singer* (3)

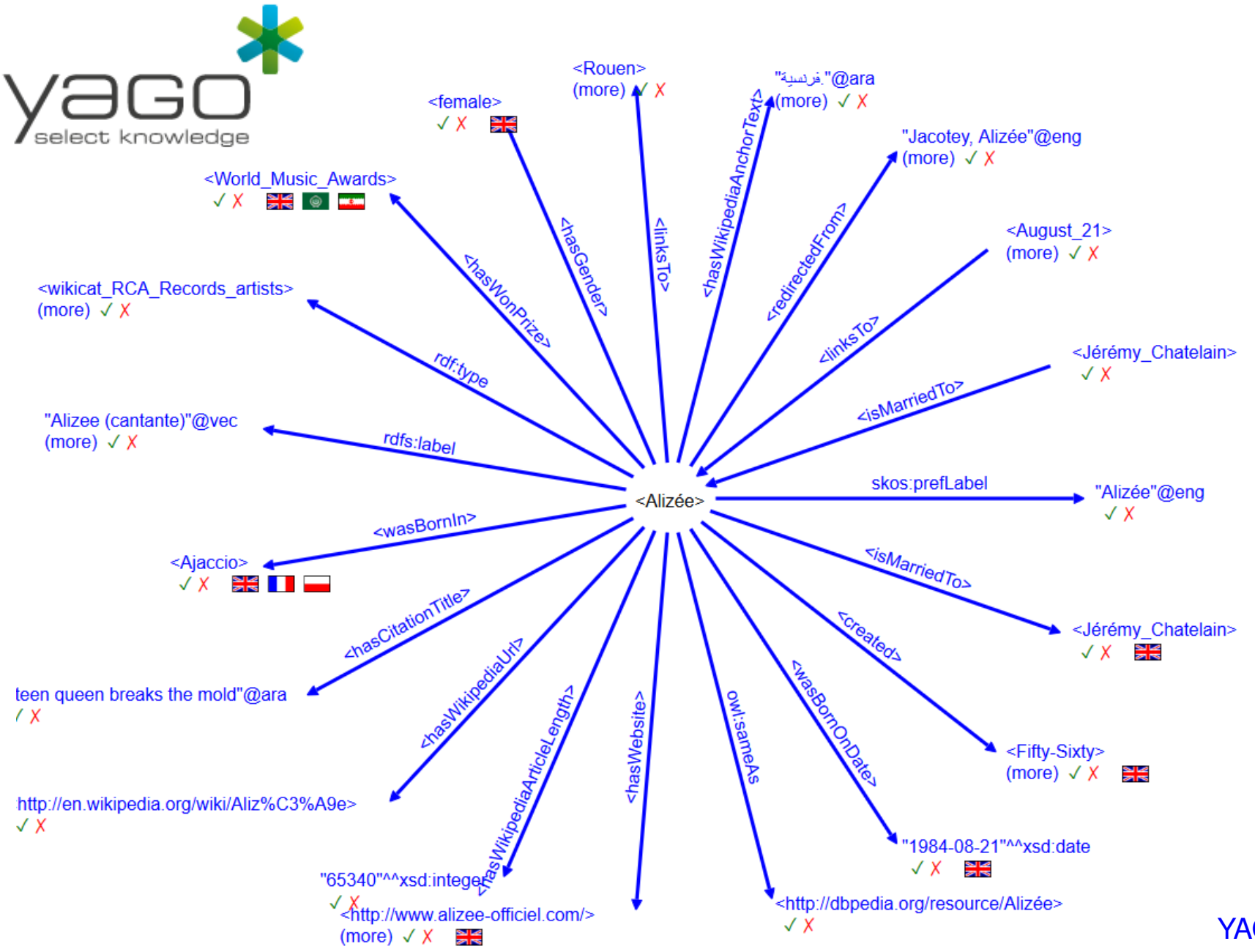
does a little strip-tease move (3)

near duplicates

not Alizee

not an entity

Example: Canonicity



Example: Non-Canonicity

Open Information Extraction

"Who built the pyramids?"

Argument 1: **Relation:** built

192 answers from **865 sentences**

all | person (29) | deceased person (16) | location (13) | monarch (12)

Egyptians (278) → correct

Pharaoh (41) → not bad

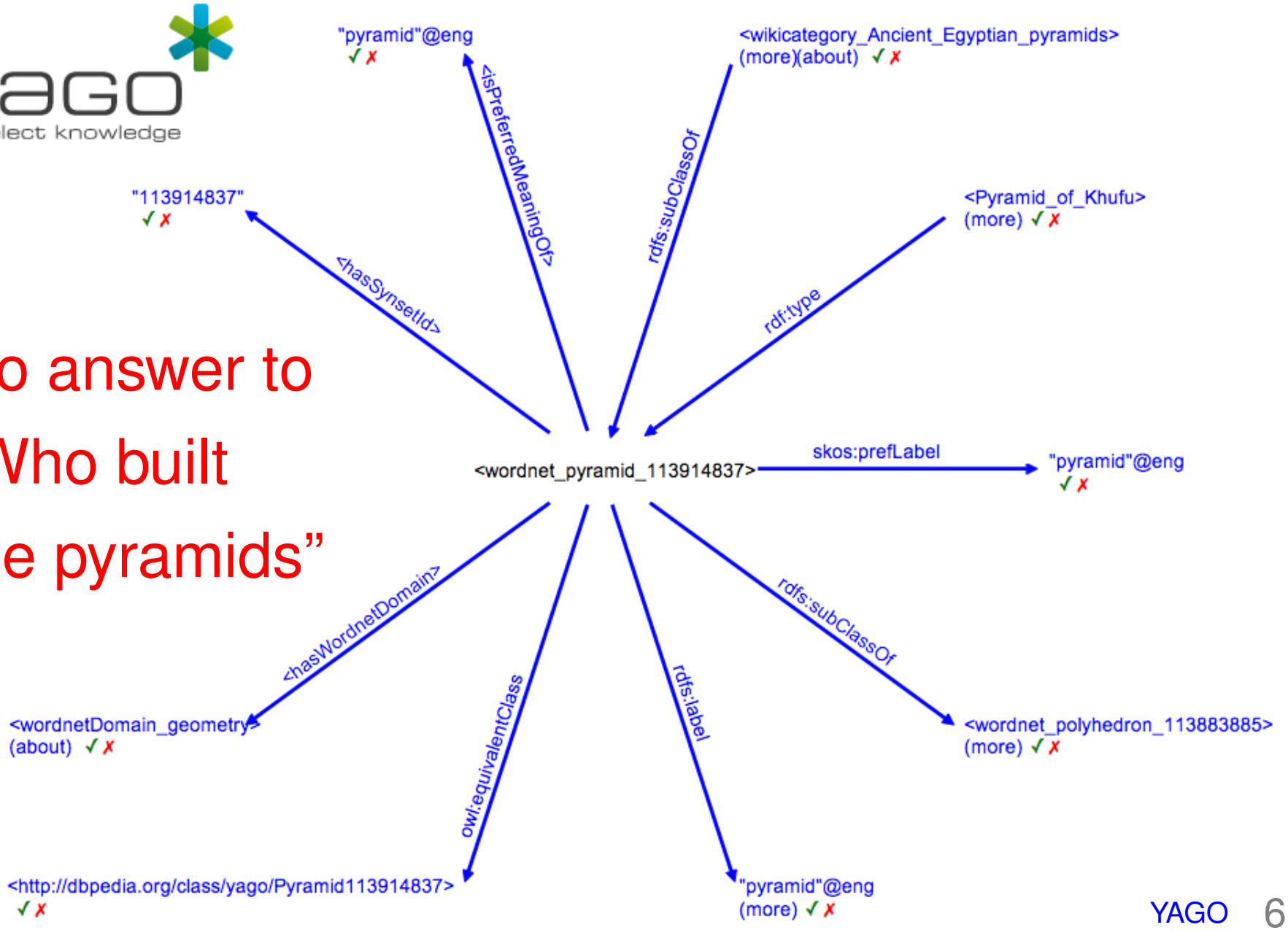
Aliens (35) → less likely

the Ancient Egyptians (31) → duplicate

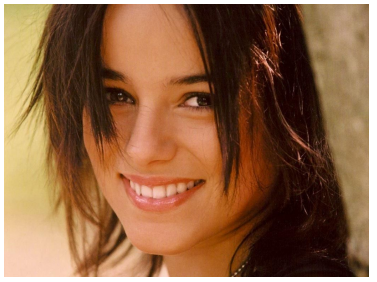
people (25)

correct, not bad → useful

Example: Canonicity



Canonicity as Trade-Off



non-canonic

canonic

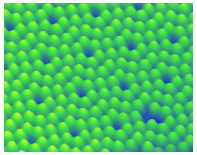
- easier to extract
- less easy to use
- more noise
- more data

- difficult to extract
- easy to use
- less noise
- less data

Digression: Reality

We model reality by a representation.






person

Alizée

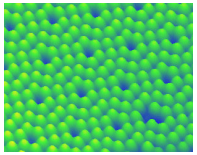
Monroe

female

Digression: Reality

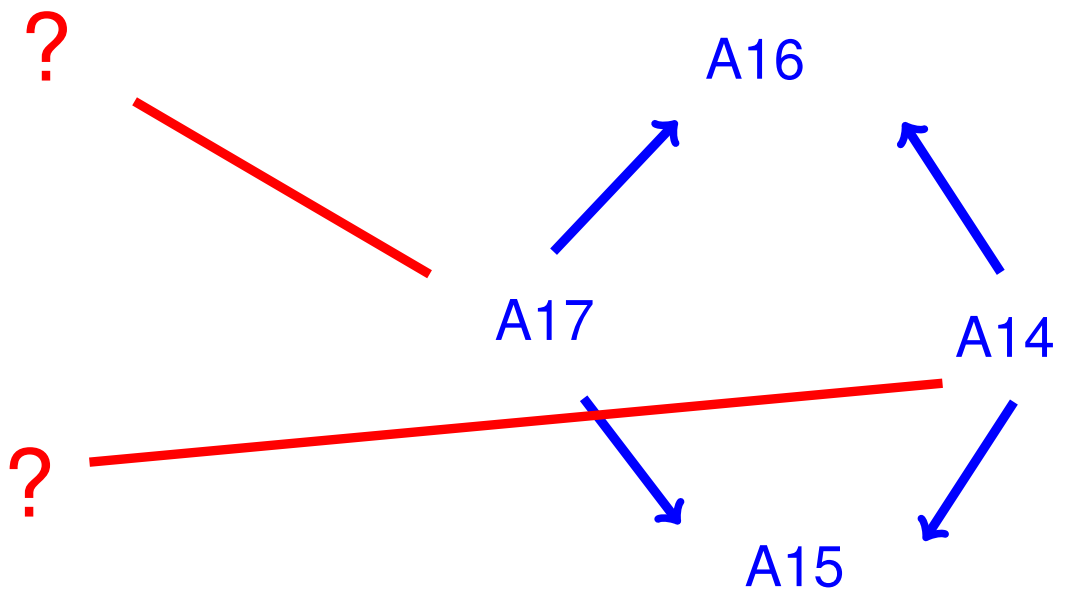
Our identifiers are arbitrary names.






Digression: Reality

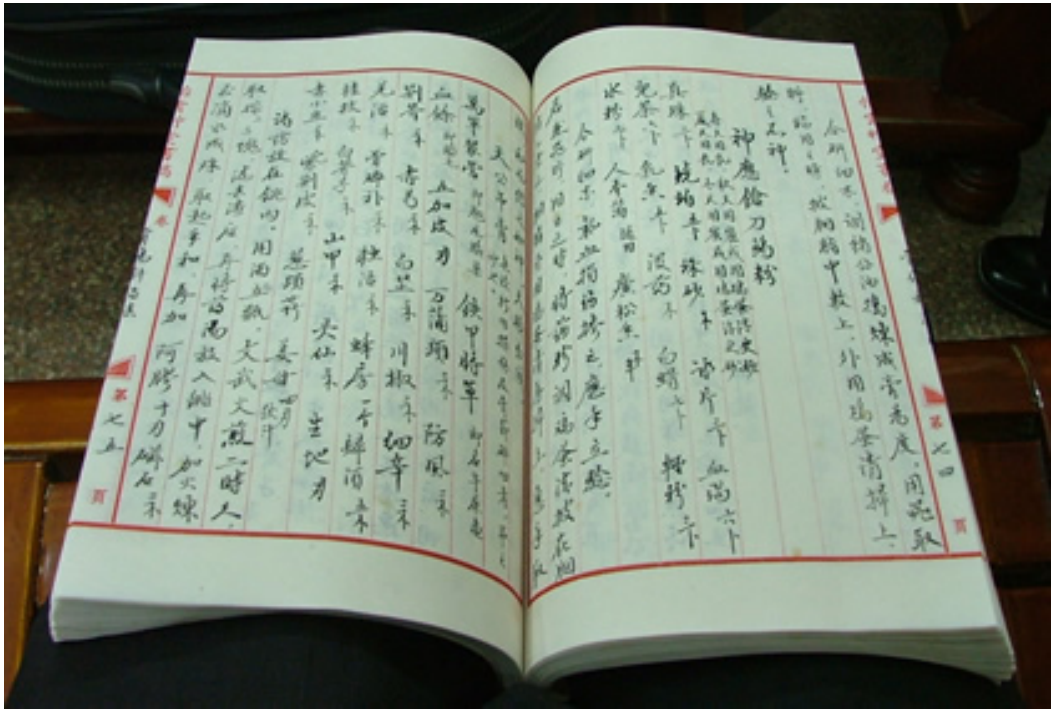
Can we reconstruct reality
from our model?



Digression: Reality

Most likely no: A Chinese dictionary

is a model of the world...



...yet, by reading it, you cannot learn Chinese.

->corpus

->character-encodings

->named-entity-recognition

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Mondays 19:30-21:30, in English

https://suchanek.name/dancing

References

The Knowledge Representation model we saw today is RDF without URIs:

RDF Primer

->corpus

->character-encodings

->named-entity-recognition