CC6202-1
La Web de Datos
Primavera 2016

Lecture 4: Web Ontology Language (I)

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PREVIOUSLY ON
“LA WEB DE DATOS”

(1) Data, (2) Rules/Ontologies, (3) Query,

INPUT: "$(x$,partOf,$y)$"

DATA:

`http://ex.org/Ireland`

Ireland 

(Ireland,partOf,Europe)
(Ireland,a,Country)
(Ireland,capital,Dublin)

`http://ex.org/Dublin`

Dublin 

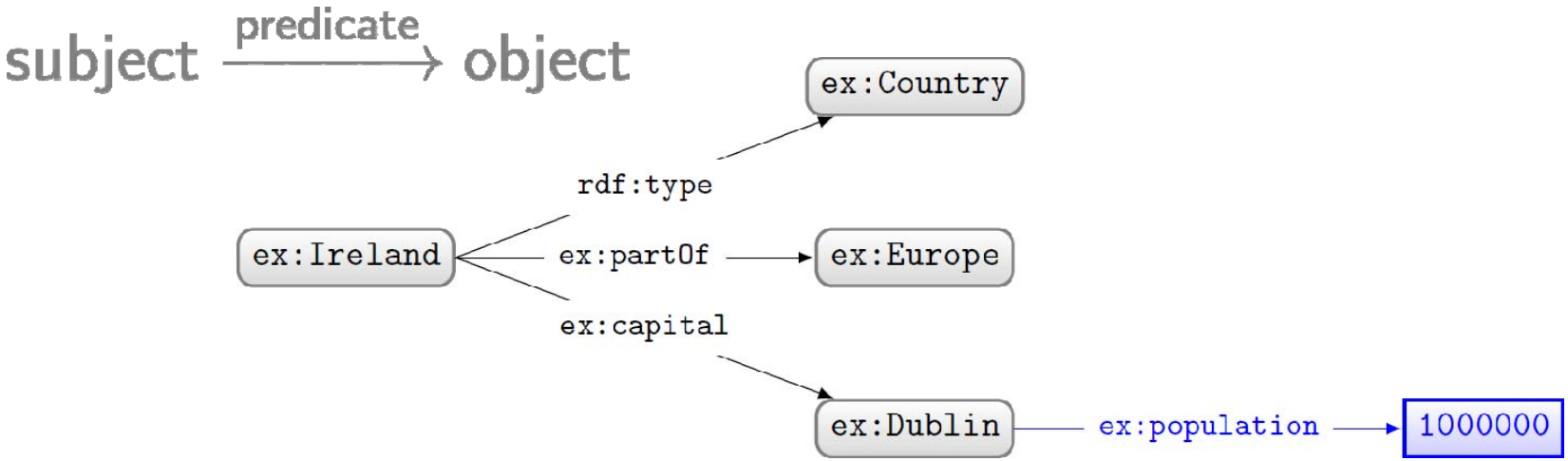
(Dublin,population,1000000)

RULES: $(a, \text{capital}, b) \rightarrow (b, \text{partOf}, a)$
$(c, \text{partOf}, d), (d, \text{partOf}, e) \rightarrow (c, \text{partOf}, e)$

OUTPUT: $\{(x \mapsto \text{Ireland}, y \mapsto \text{Europe}), (x \mapsto \text{Dublin}, y \mapsto \text{Ireland})$
$(x \mapsto \text{Dublin}, y \mapsto \text{Europe})\}$

RDF: Resource Description Framework

subject	*predicate*	*object*
ex:Ireland	ex:partOf	ex:Europe
ex:Ireland	rdf:type	ex:Country
ex:Ireland	ex:capital	ex:Dublin
ex:Dublin	ex:population	1,000,000



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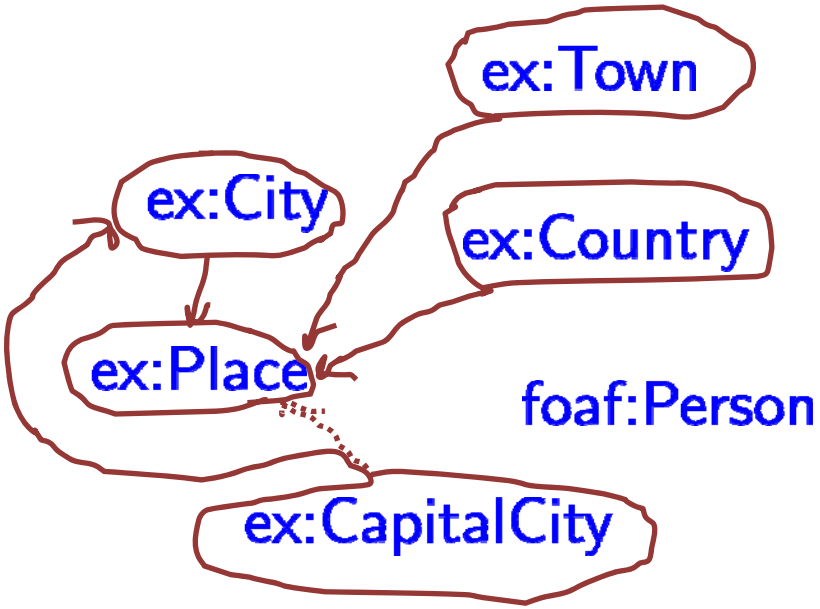
$(x \mapsto \text{Dublin}, y \mapsto \text{Europe})\}$

Class hierarchy

- Class *c1* is a sub-class of Class *c2*
  - If (x,rdf:type,*c1*) then (x,rdf:type,*c2*),

Example: if ex:CapitalCity *sub-class of* ex:City
and if (ex:Dublin,rdf:type,ex:CapitalCity)
then (ex:Dublin,rdf:type,ex:City)

Which classes would be sub-classes of each other?

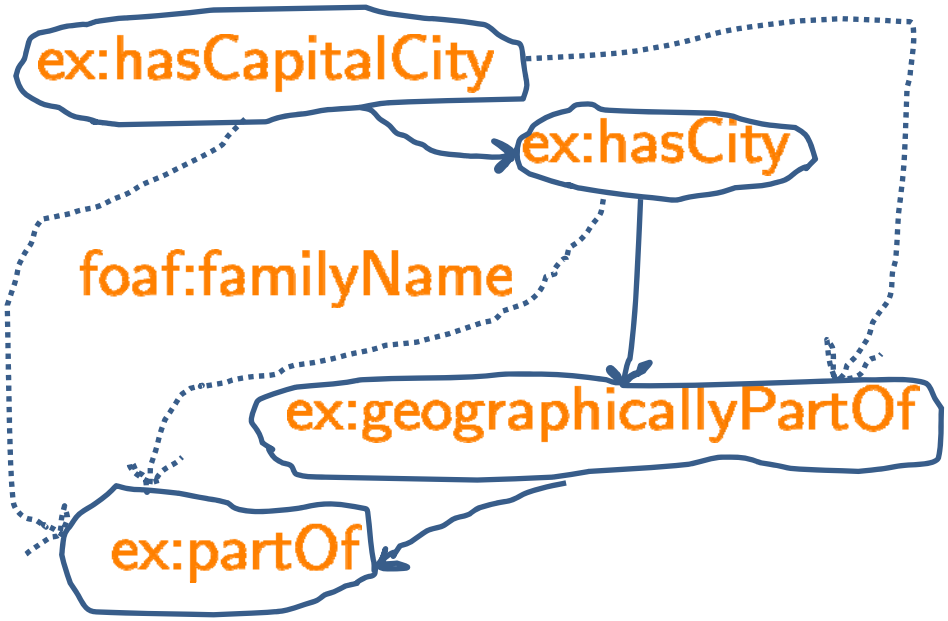


Property hierarchy

- Property *p1* is a sub-property of *p2*
  - If (x,*p1*,y) then (x,*p2*,y)

Example: if `ex:hasCapitalCity` *sub-property of* `ex:hasCity`
and if `(ex:Ireland,ex:hasCapitalCity,ex:Dublin)`
then `(ex:Ireland,ex:hasCity,ex:Dublin)`

Which properties would be sub-properties of each other?

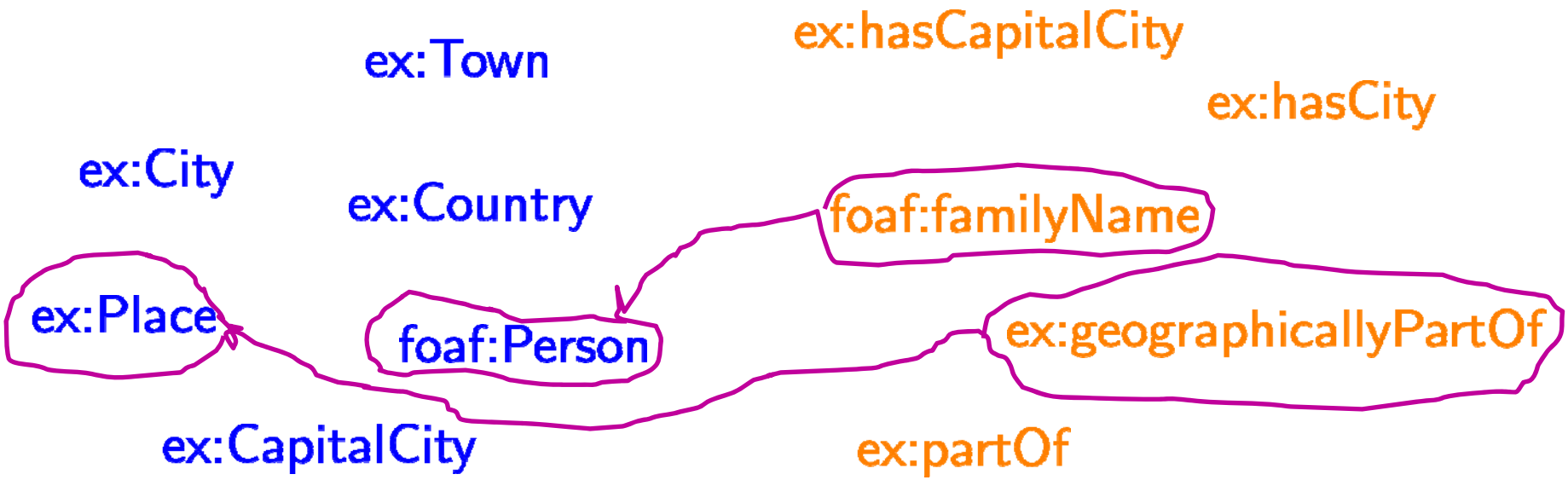


Domain of properties

- Property *p* has domain class *c*
  - If (x,*p*,y) then (x,rdf:type,*c*)

Example: if `foaf:familyName` *has domain* `foaf:Person`
and if (`ex:Aidan`,`foaf:familyName`,"Hogan")
then (`ex:Aidan`,`rdf:type`,`foaf:Person`)

Which properties would have which classes as domain?

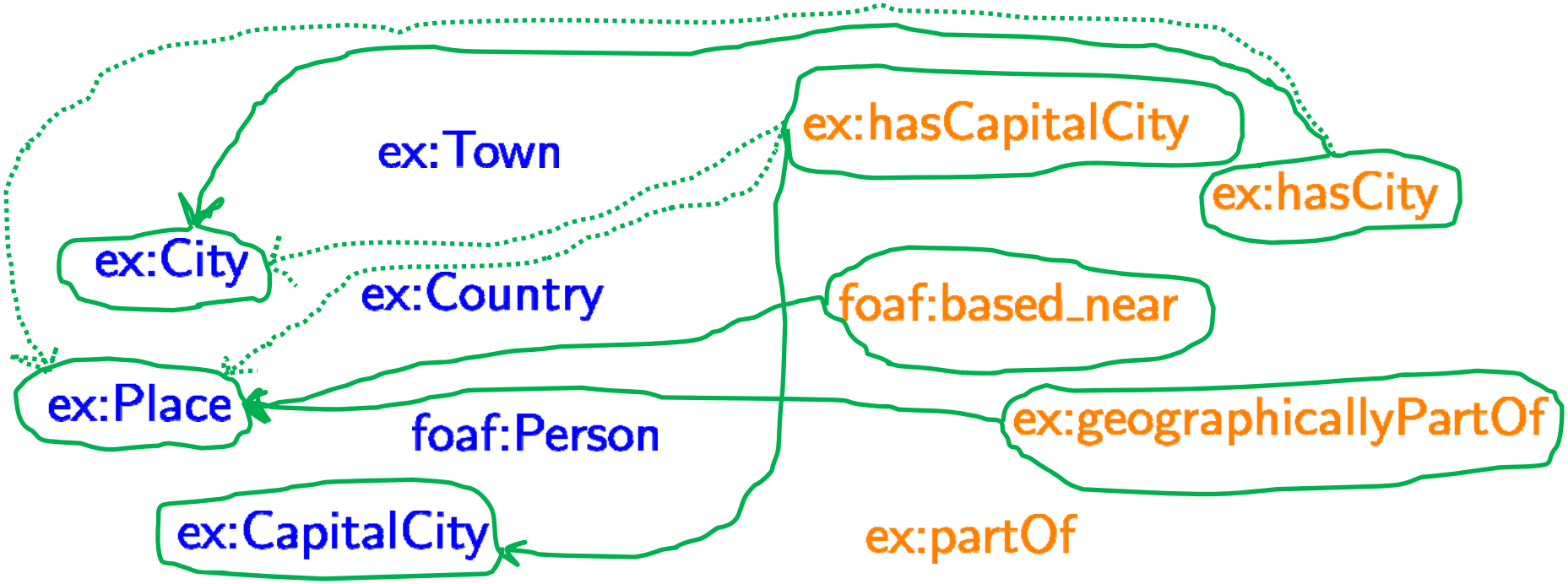


Range of properties

- Property *p* has range class *c*
  - If `(x,p,y)` then `(y,rdf:type,c)`

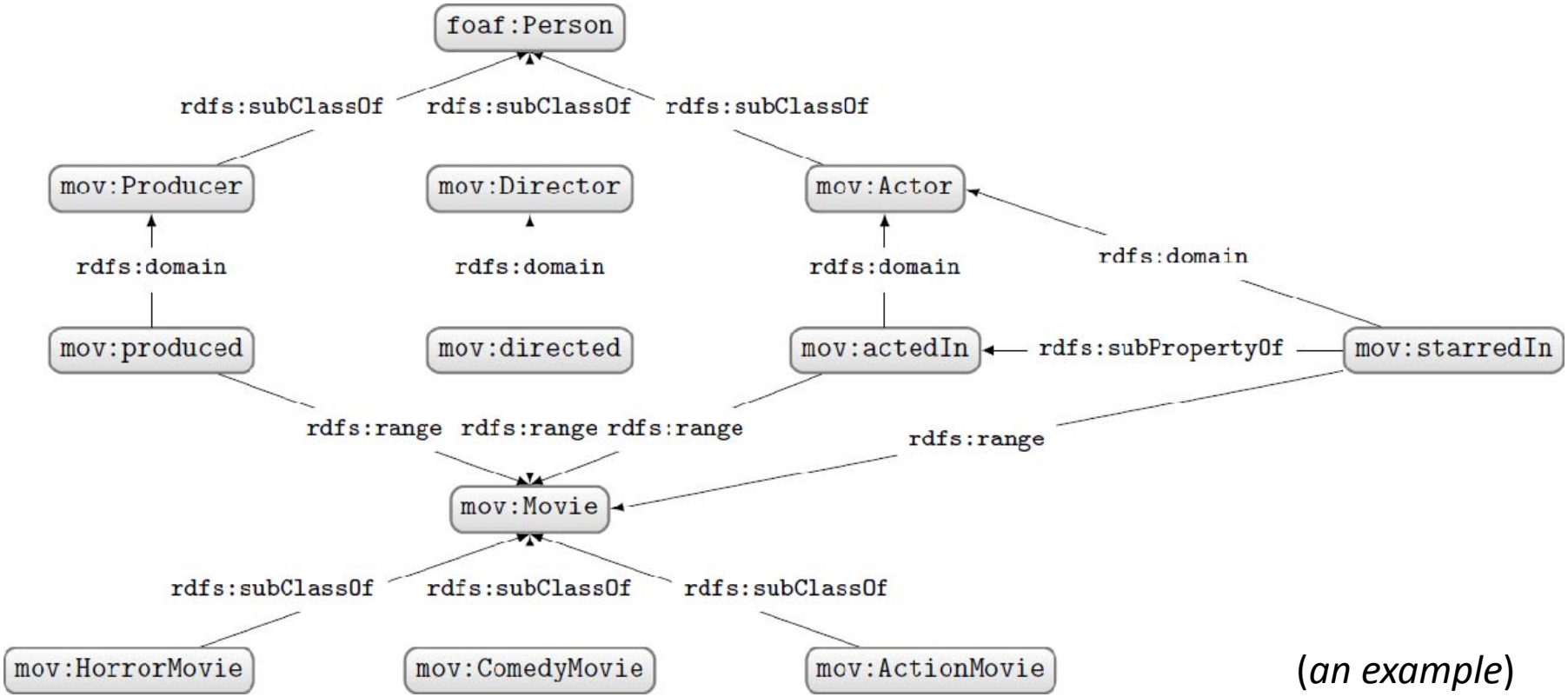
Example: if `ex:hasCity` *has range* `ex:City`
and if `(ex:Ireland,ex:hasCity,ex:Dublin)`
then `(ex:Dublin,rdf:type,ex:City)`

Which properties would have which classes as range?



RDF Schema …

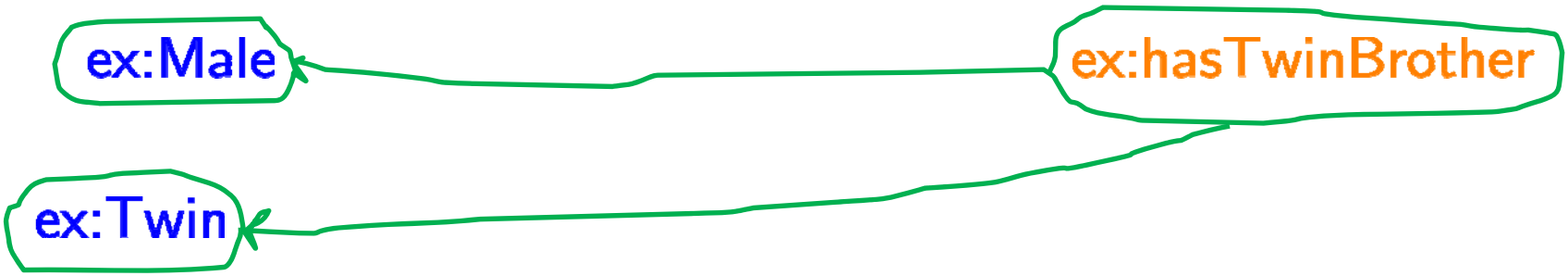
Let's model an RDF Schema for Movies, including different types of movies, some different types of people involved, and how they are related.



(*an example*)

On a side note

- A property can have multiple domains or ranges



TODAY’S TOPIC …

(1) Data, **(2) Rules/Ontologies,** (3) Query

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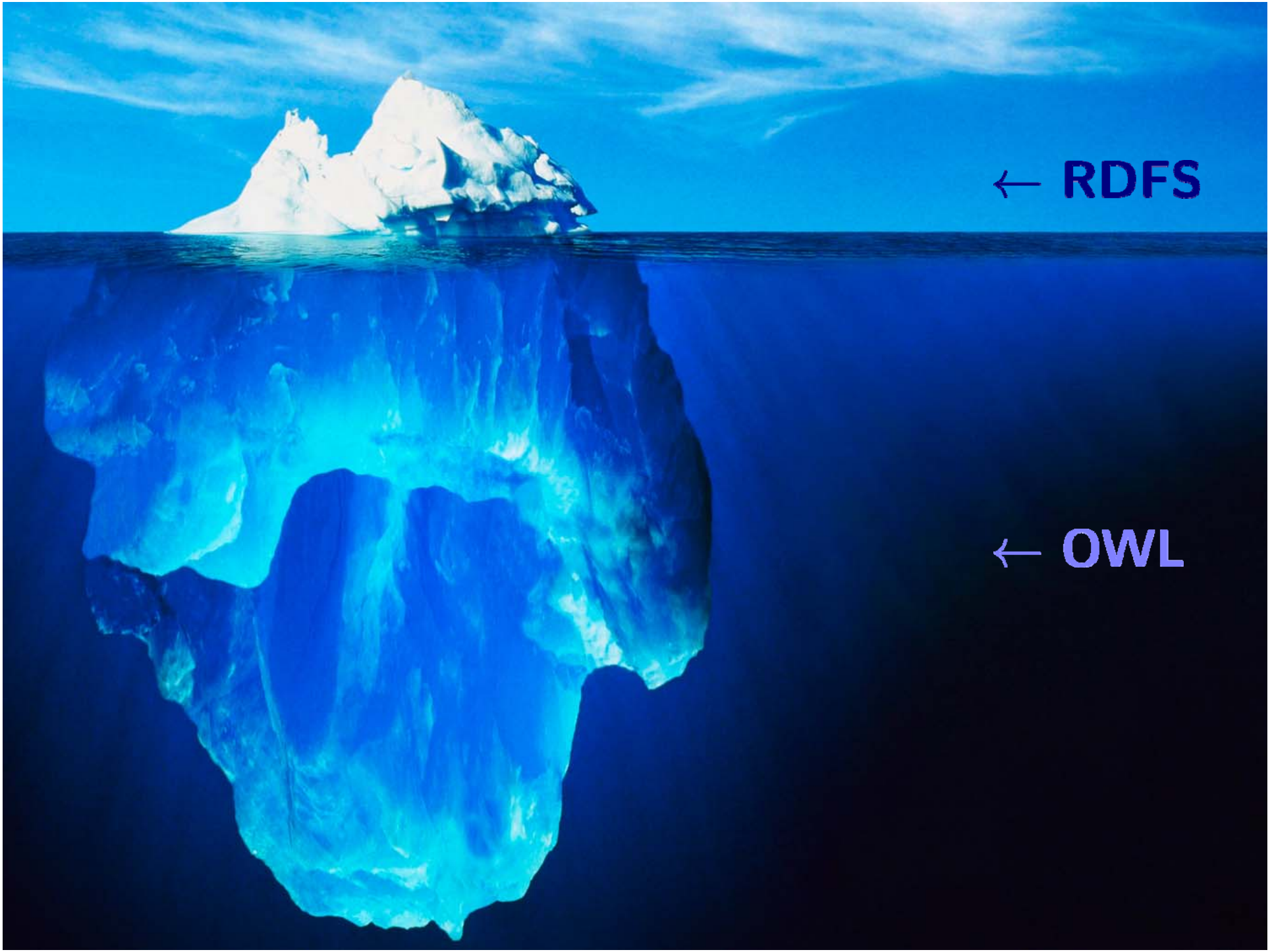
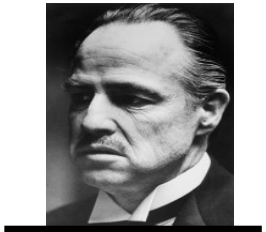

← RDFS
← OWL

LET’S DIVE INTO OWL

A special family …


ex:Vito


ex:Carmela


ex:Sonny


ex:Connie


ex:Fredo


ex:Michael


ex:Vincent

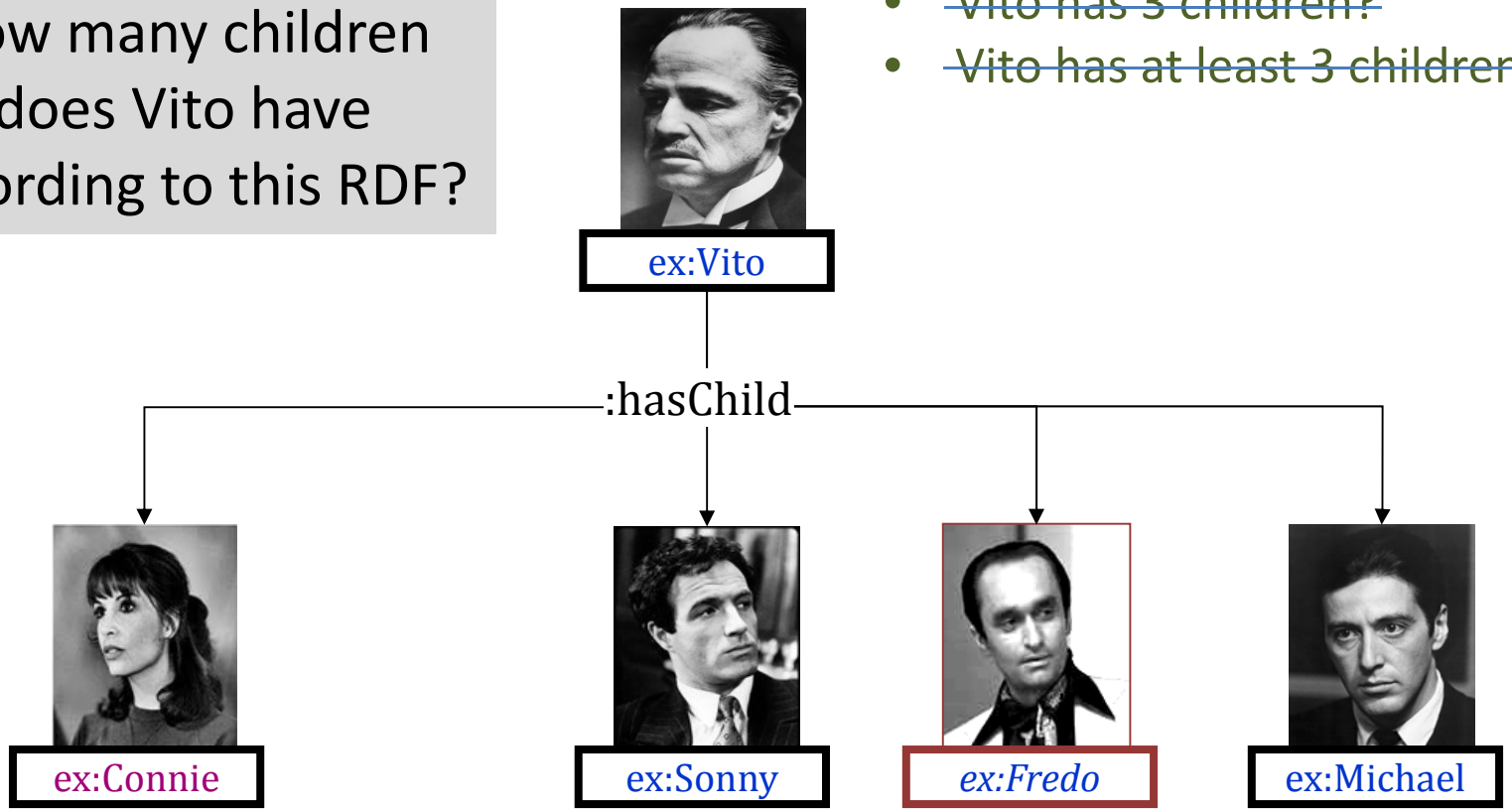

ex:Mary

FIRST SOME PRELIMINARIES

Open World Assumption (OWA)

How many children does Vito have according to this RDF?

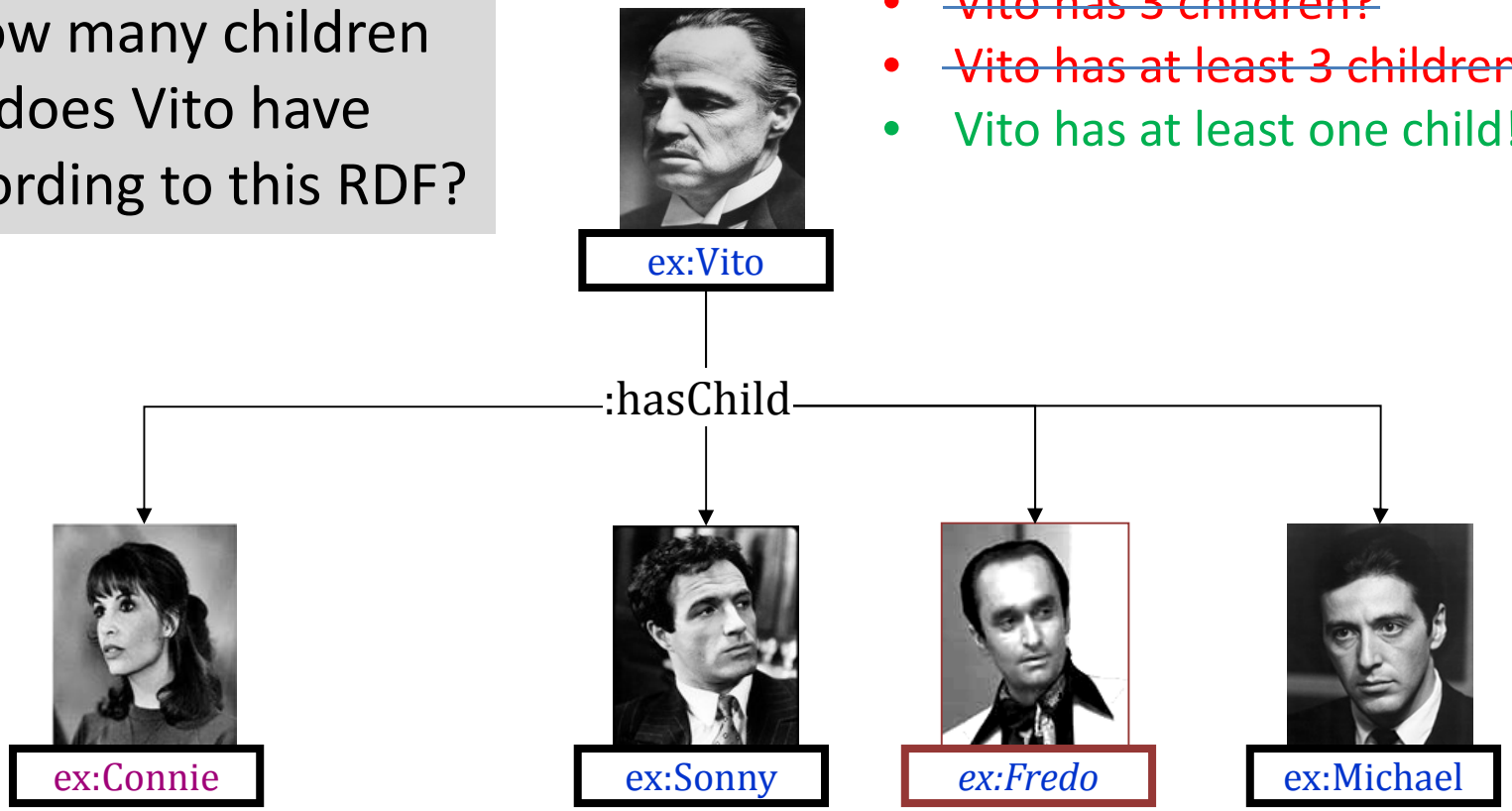
- ~~Vito has 3 children?~~
- ~~Vito has at least 3 children?~~




```
ex:Vito :hasChild ex:Connie, ex:Sonny, ex:Michael .
ex:Vito :hasChild ex:Fredo .
... ?
```

No Unique Name Assumption (No UNA)

How many children does Vito have according to this RDF?



- ~~Vito has 3 children?~~
- ~~Vito has at least 3 children?~~
- Vito has at least one child!

```
ex:Vito :hasChild ex:Connie, ex:Sonny, ex:Michael .
ex:Vito :hasChild ex:Fredo .
... ?
```

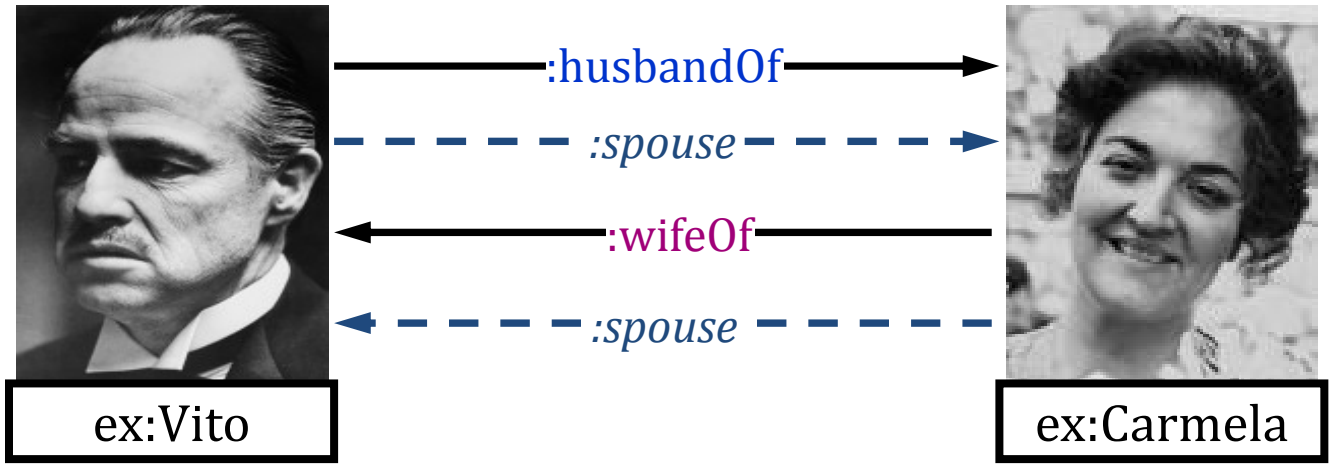
… in words

- RDF(S) and OWL:
  - Take an Open World Assumption:
    - Anything not known is not assumed to be false, simply unknown
    - Without further information, Vito may have children that we don't know about!
  - Do not take a Unique Name Assumption:
    - Two or more IRIs may refer to the same thing!
    - Without further information, the IRIs we know to be Vito's children may refer to one thing in the real-world!

Why might this be important for the Web?

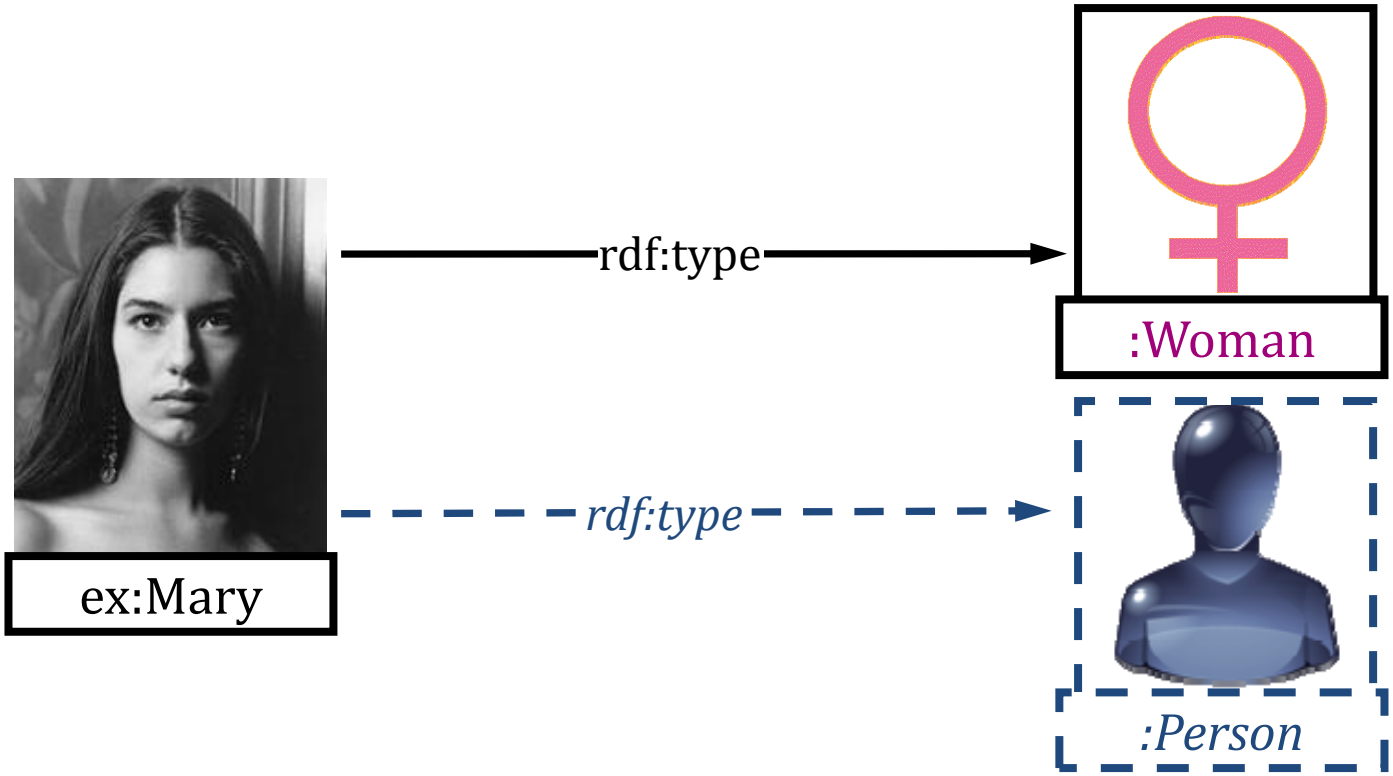
LET’S START WITH SOME RDFS …

rdfs:subPropertyOf



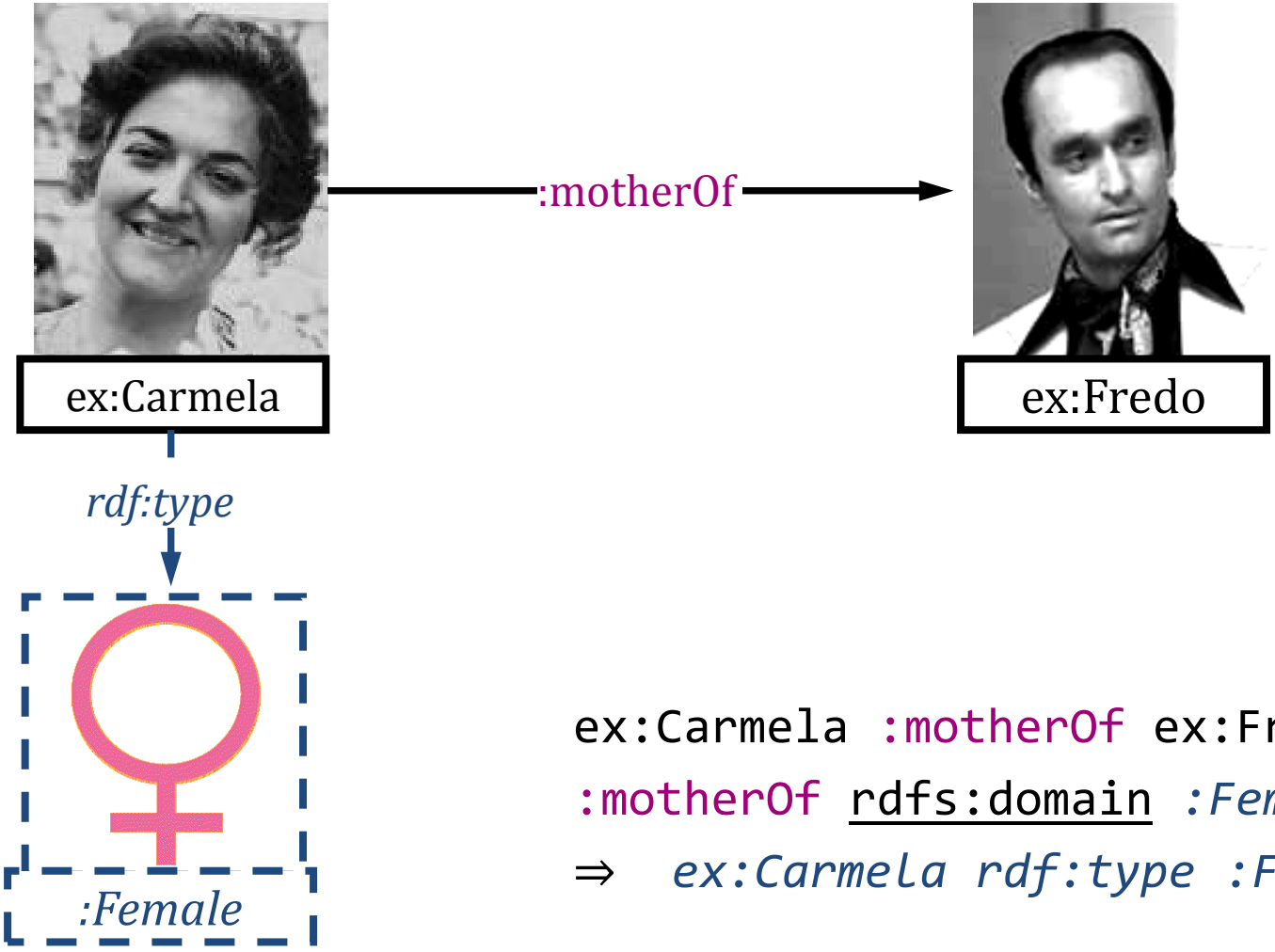

```
ex:Vito :husbandOf ex:Carmela .
:husbandOf rdfs:subPropertyOf :spouse .
⇒  ex:Vito :spouse ex:Carmela .

ex:Carmela :wifeOf ex:Vito .
:wifeOf rdfs:subPropertyOf :spouse .
⇒  ex:Carmela :spouse ex:Vito .
```

rdfs:subClassOf



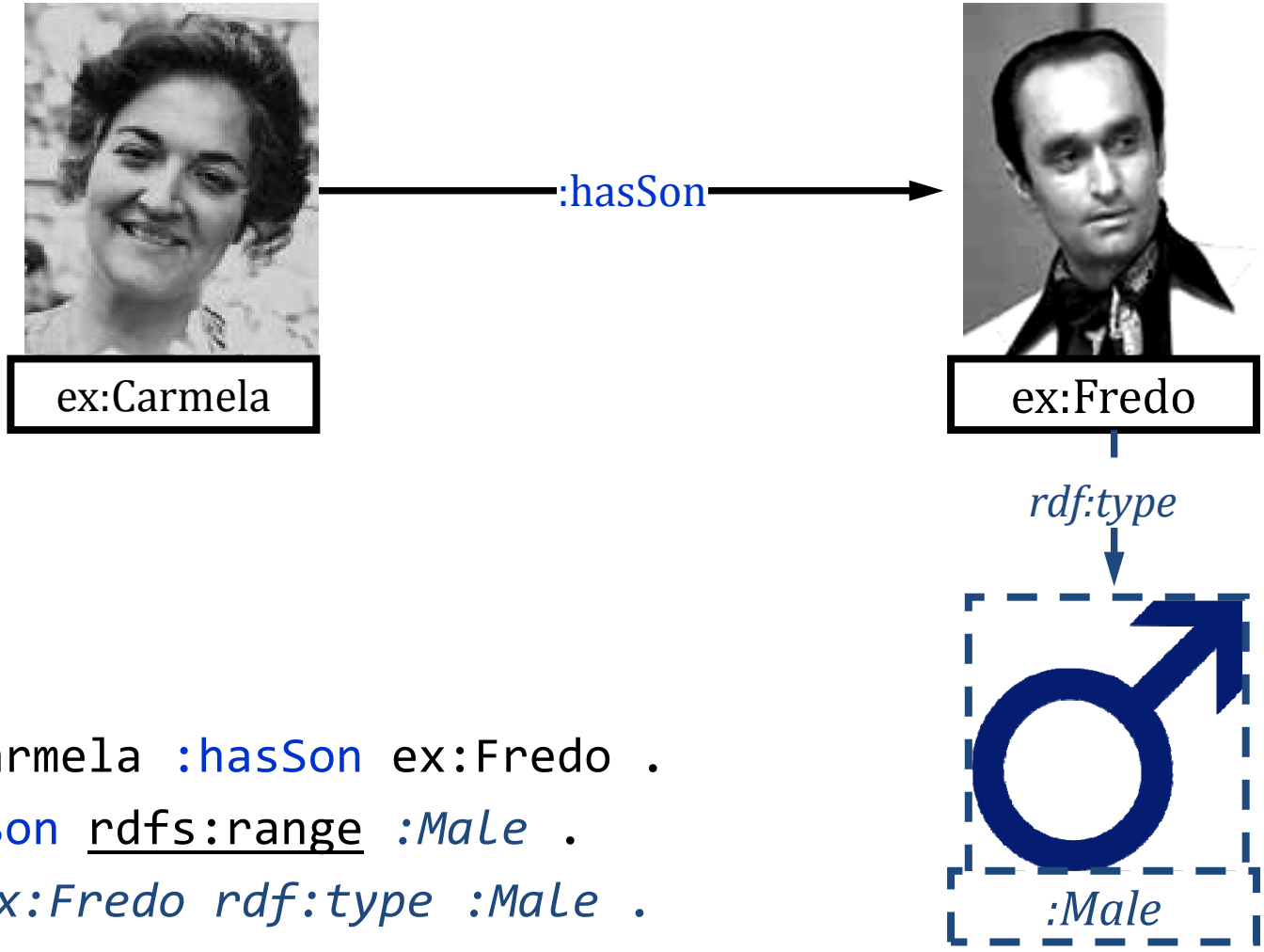

```
ex:Mary rdf:type :Woman .
:Woman rdfs:subClassOf :Person .
⇒  ex:Mary rdf:type :Person .
```

rdfs:domain




```
ex:Carmela :motherOf ex:Fredo .
:motherOf rdfs:domain :Female.
⇒  ex:Carmela rdf:type :Female .
```

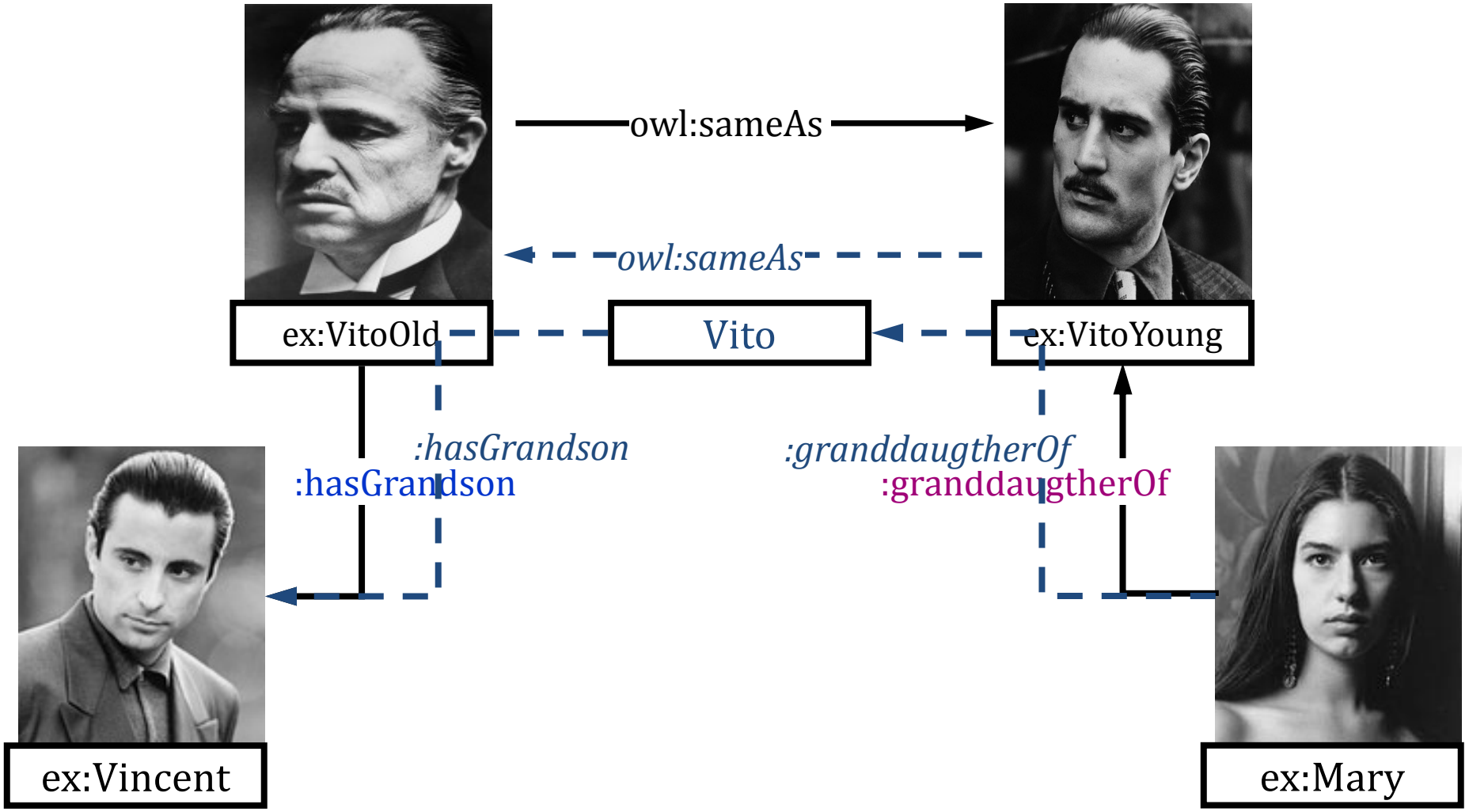
rdfs:range




```
ex:Carmela :hasSon ex:Fredo .
:hasSon rdfs:range :Male .
⇒  ex:Fredo rdf:type :Male .
```

(IN)EQUALITY IN OWL …

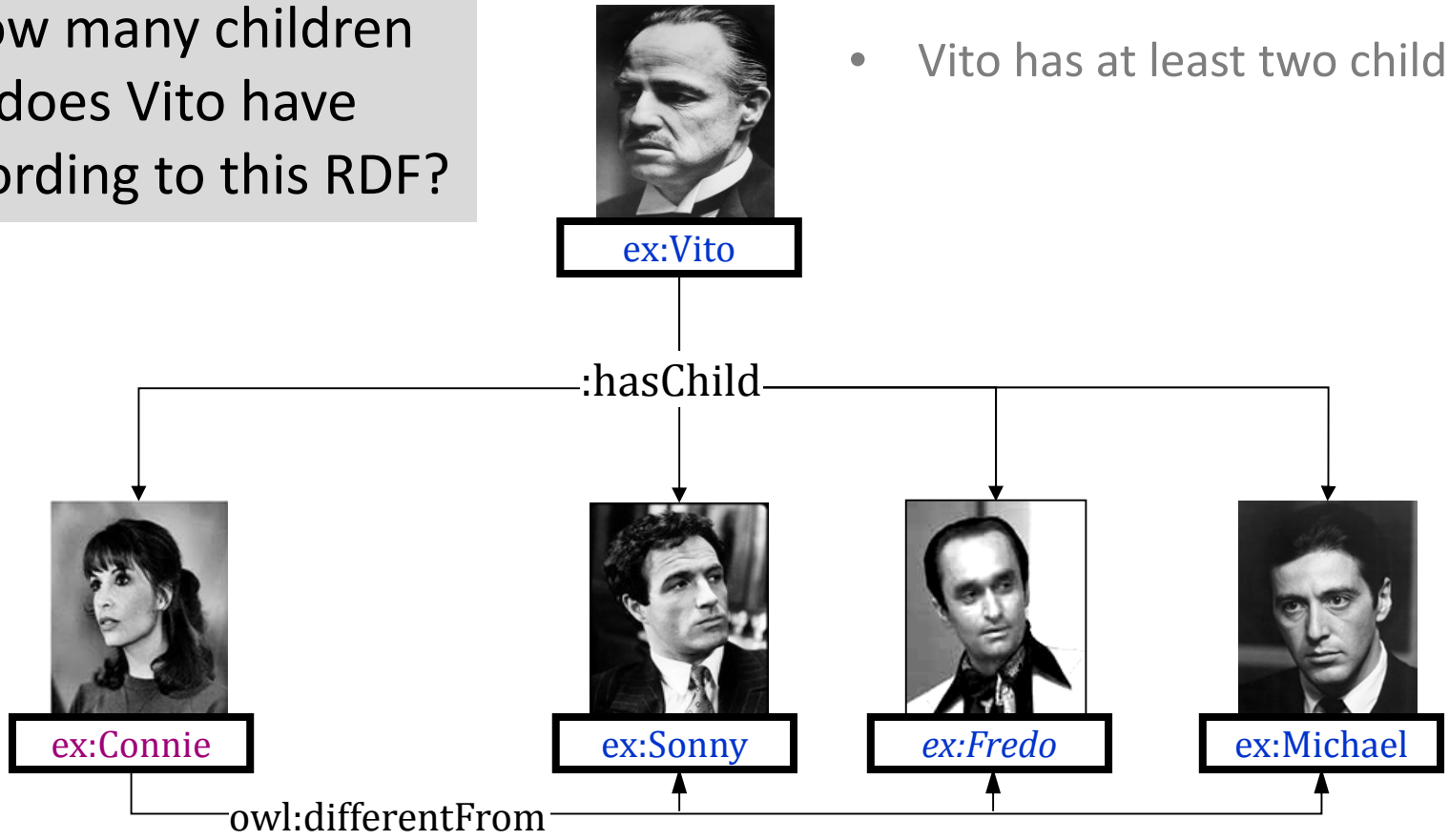
owl:sameAs




```
ex:VitoOld owl:sameAs ex:VitoYoung .
```

owl:differentFrom

How many children does Vito have according to this RDF?

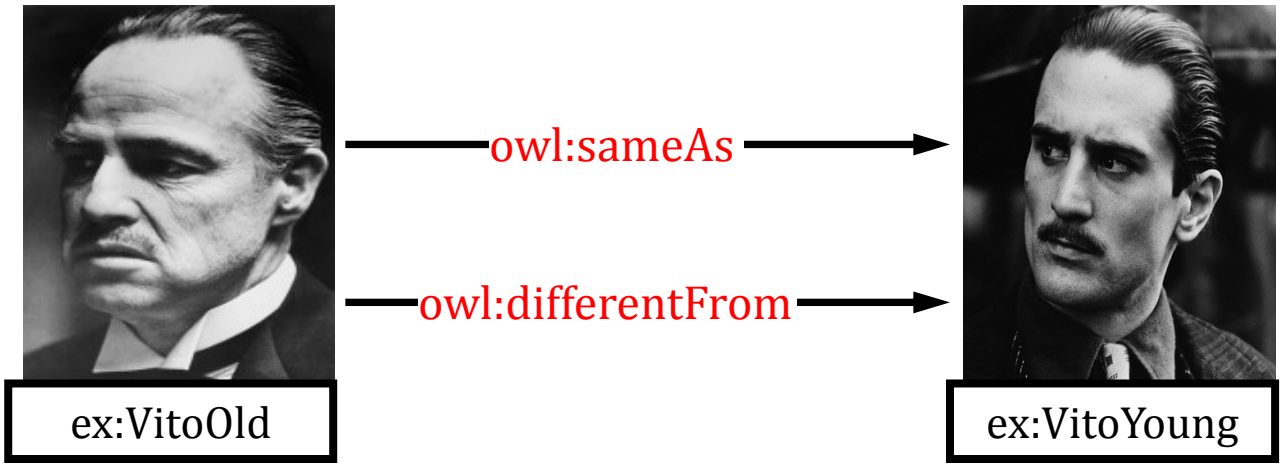


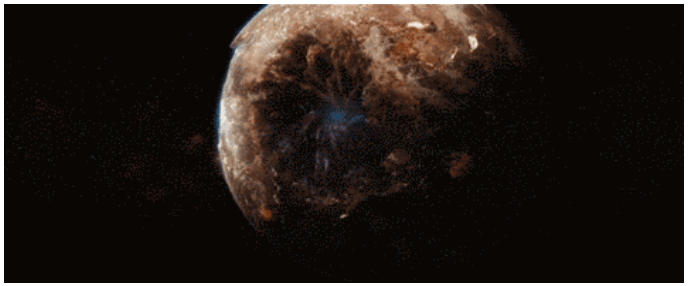
- Vito has at least two children!

```
ex:Vito :hasChild ex:Connie, ex:Sonny, ex:Michael, ex:Fredo .
ex:Connie owl:differentFrom ex:Sonny, ex:Michael, ex:Fredo .
```

Inconsistency in OWL …

- Contradictory statements



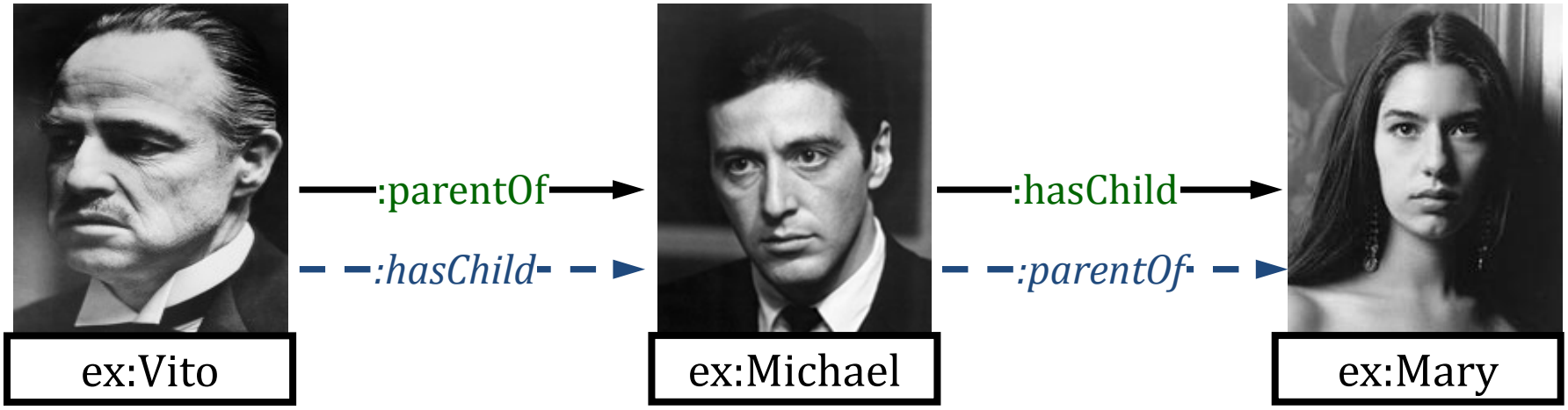


```
ex:VitoOld owl:sameAs ex:VitoYoung .
ex:VitoOld owl:differentFrom ex:VitoYoung .
```

⇒ *FALSE*

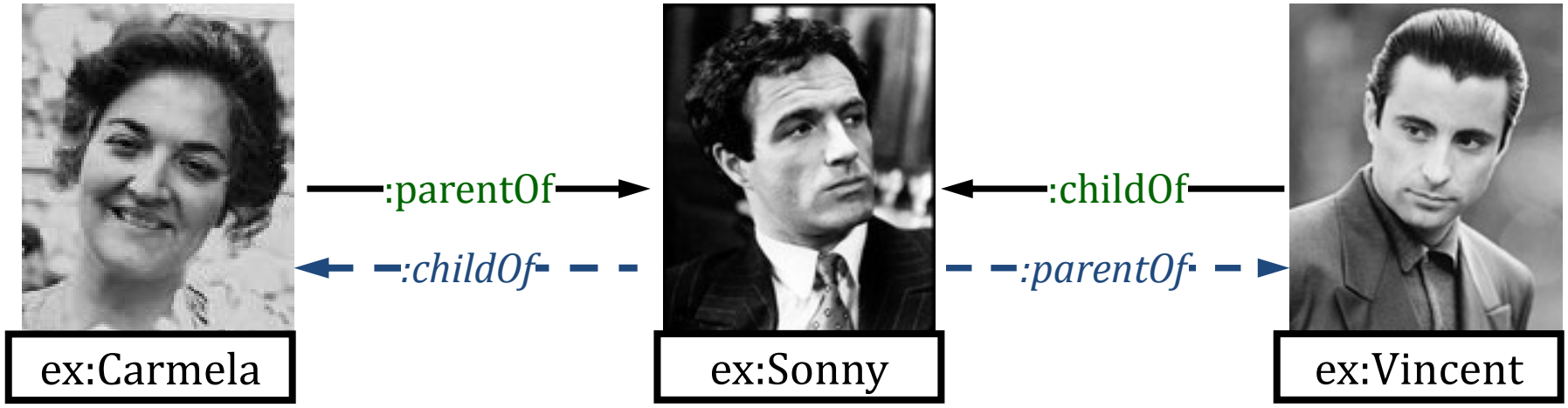
PROPERTY AXIOMS IN OWL …

owl:equivalentProperty



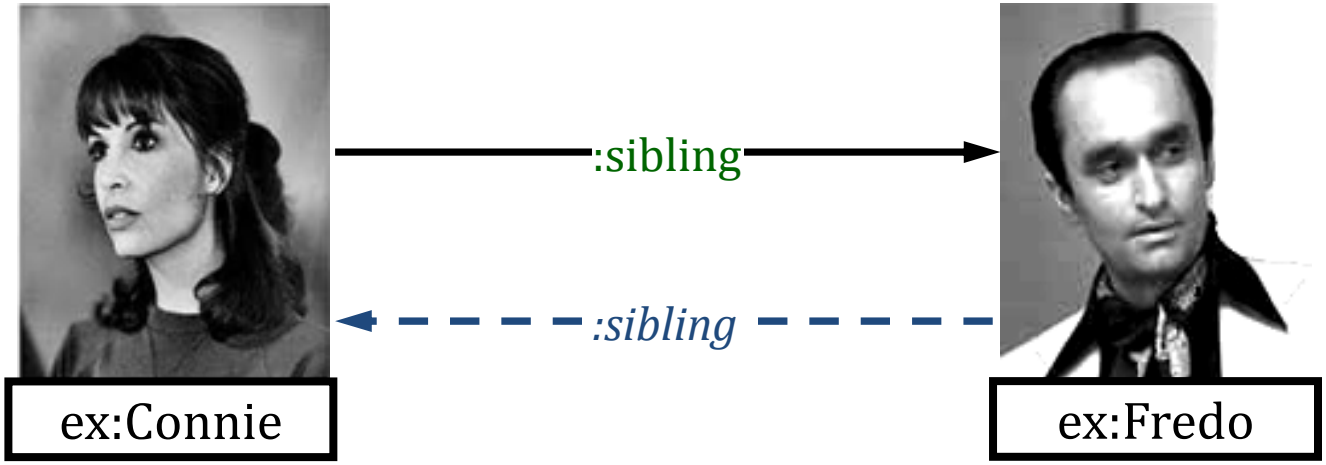

```
ex:Vito :parentOf ex:Michael .
ex:Michael :hasChild ex:Mary .
:parentOf owl:equivalentProperty :hasChild .
⇒  ex:Vito :hasChild ex:Michael .
⇒  ex:Michael :parentOf ex:Mary .
```

owl:inverseOf



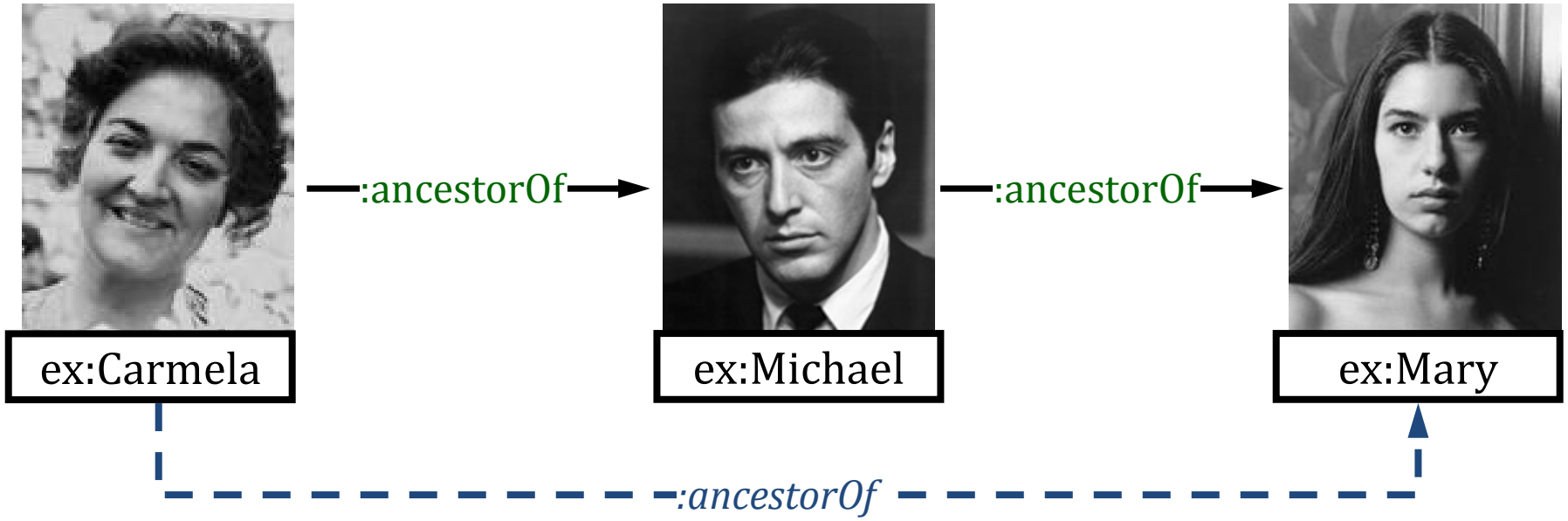

```
ex:Carmela :parentOf ex:Sonny .
ex:Vincent :childOf ex:Sonny .
:parentOf owl:inverseOf :childOf .
⇒  ex:Sonny :parentOf ex:Vincent .
⇒  ex:Sonny :childOf ex:Carmela .
```

owl:SymmetricProperty




```
ex:Connie :sibling ex:Fredo .
:sibling rdf:type owl:SymmetricProperty .
⇒  ex:Fredo :sibling ex:Connie .
```

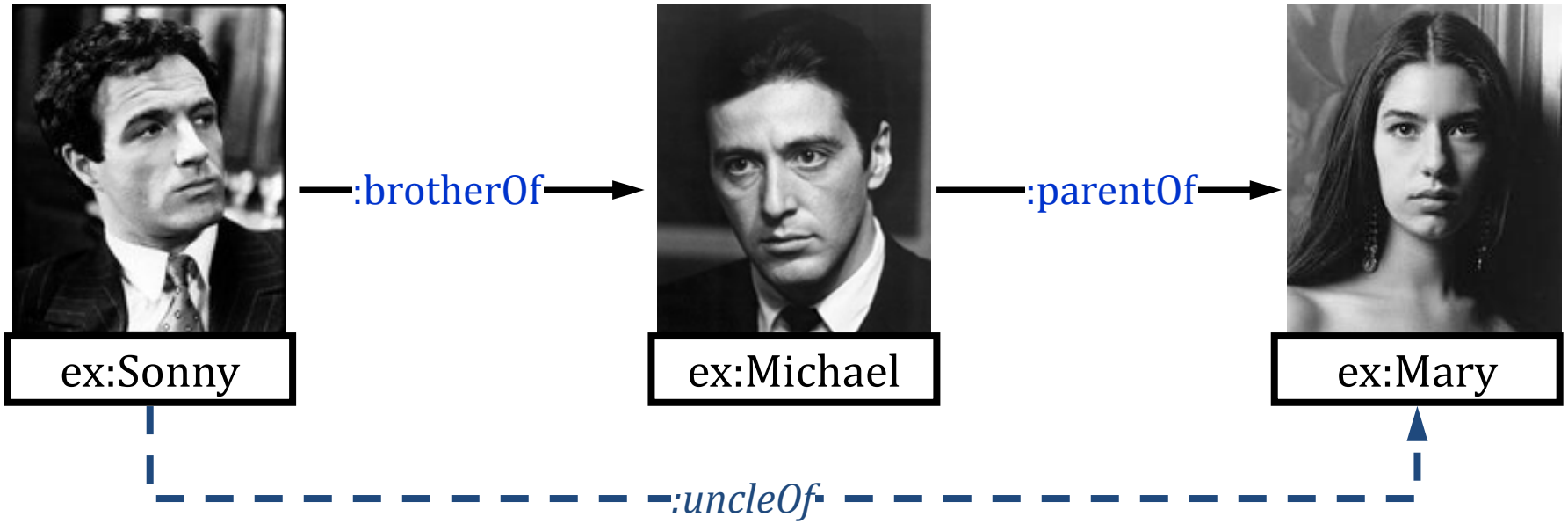
owl:TransitiveProperty




```
ex:Carmela :ancestorOf ex:Michael .
ex:Michael :ancestorOf ex:Mary .
:ancestorOf rdf:type owl:TransitiveProperty .
⇒  ex:Carmela :ancestorOf ex:Mary .
```

owl:propertyChainAxiom

Means new to OWL version 2.0!

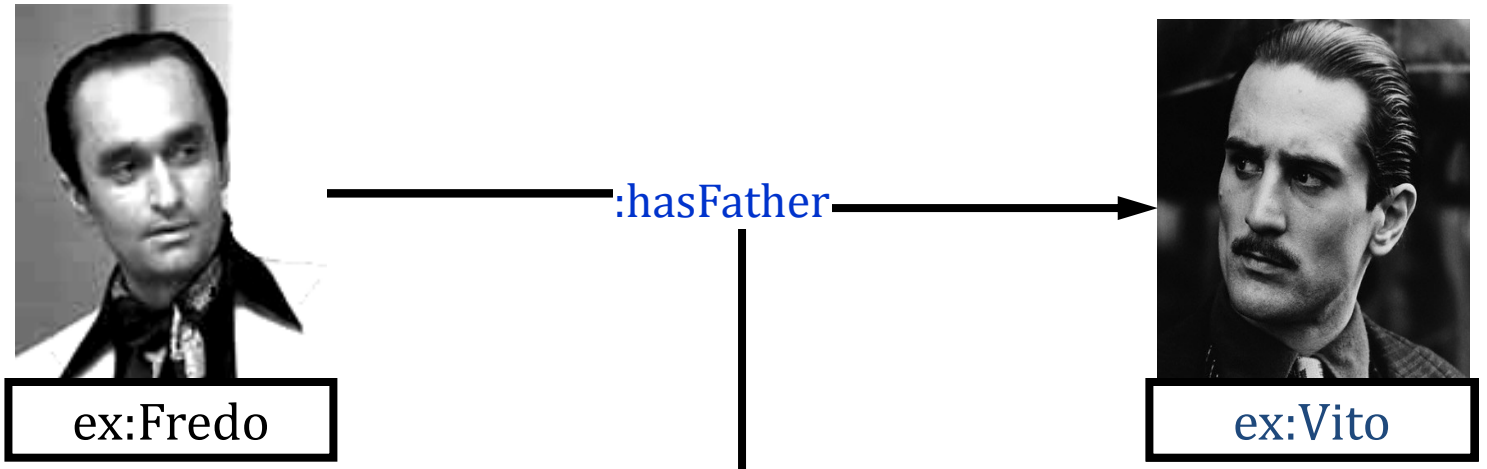



```
ex:Sonny :brotherOf ex:Michael .
ex:Michael :parentOf ex:Mary .
:uncleOf owl:propertyChainAxiom (:brotherOf :parentOf) .
⇒  ex:Sonny :uncleOf ex:Mary .
```

owl:ReflexiveProperty


```
:similarTo rdf:type owl:ReflexiveProperty .
⇒ ex:Connie :similarTo ex:Connie .
ex:Freddie :similarTo ex:Freddie .
(everything :similarTo itself)
```

owl:FunctionalProperty

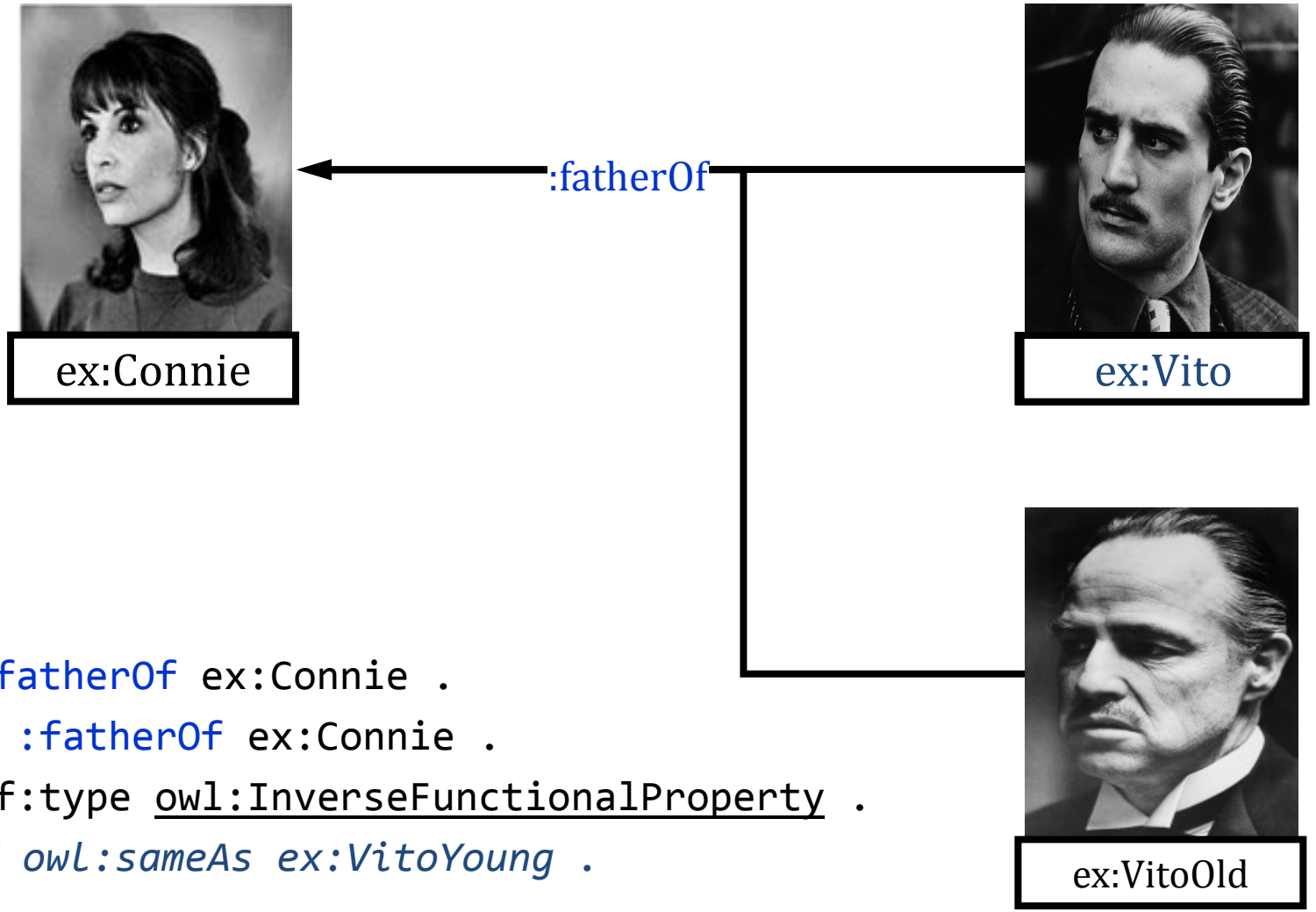



```
ex:Fredo :hasFather ex:VitoOld .
ex:Fredo :hasFather ex:VitoYoung .
:hasFather rdf:type owl:FunctionalProperty .
⇒ ex:VitoOld owl:sameAs ex:VitoYoung .
```

Aside: Be careful what you define …

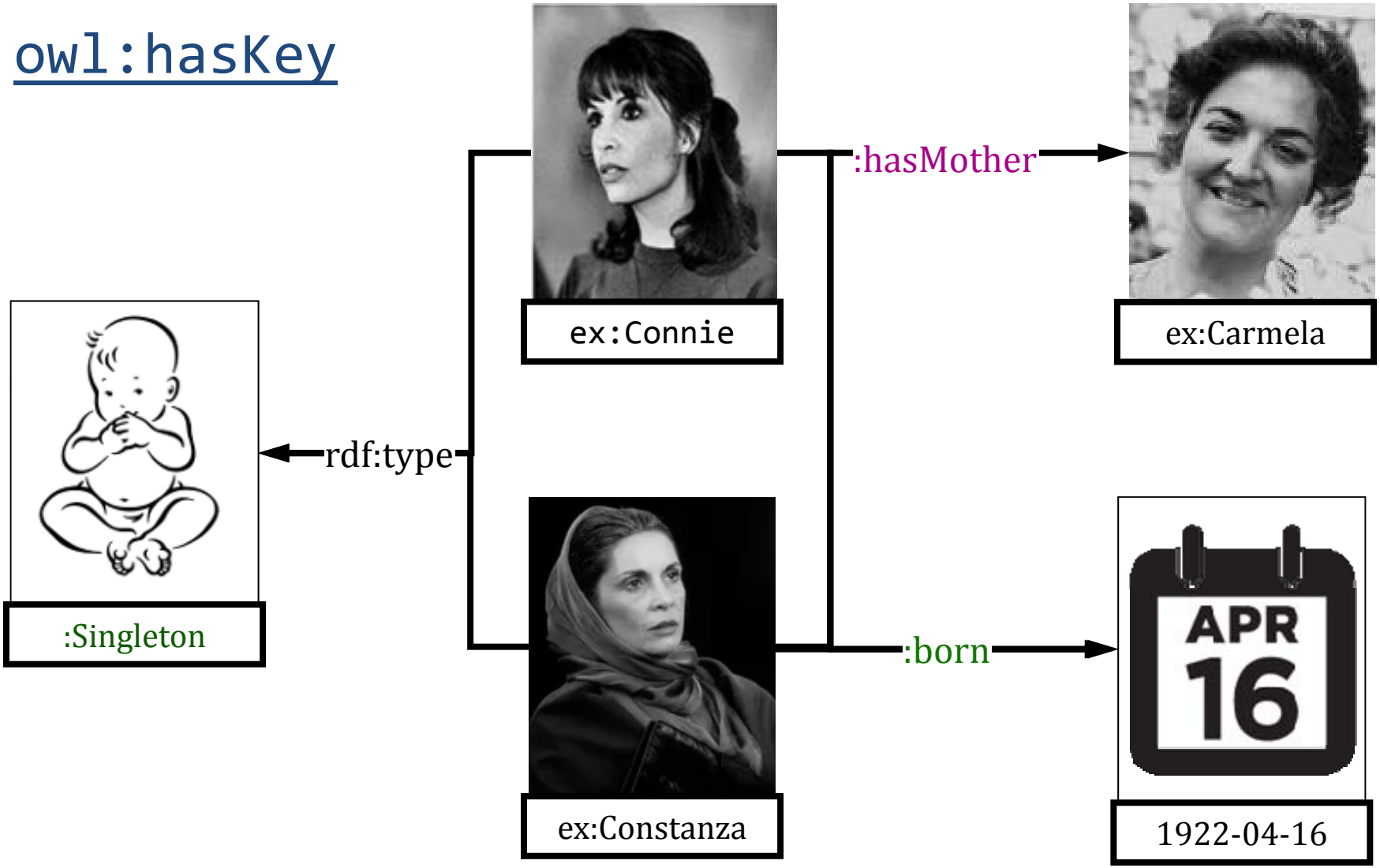
- Tom Hagen, the adopted son of Vito
  - Maybe he has two fathers?
  - We probably meant *biologicalFather*, etc.
- Likewise there may be exceptions to other claims made here (which take an overly simplified view of the world)

owl:InverseFunctionalProperty



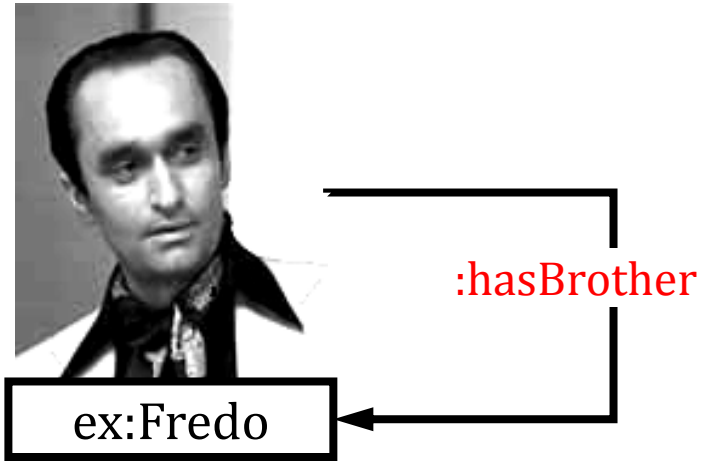

```
ex:VitoOld :fatherOf ex:Connie .
ex:VitoYoung :fatherOf ex:Connie .
:fatherOf rdf:type owl:InverseFunctionalProperty .
⇒ ex:VitoOld owl:sameAs ex:VitoYoung .
```

owl:hasKey



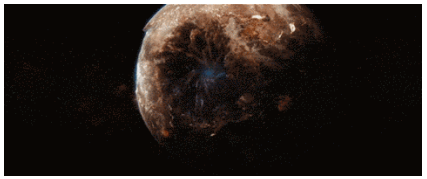

```
ex:Connie a :Singleton ; :hasMother ex:Carmela ; :born “1922-04-16”^^xsd:date .
ex:Constanza a :Singleton ; :hasMother ex:Carmela ; :born “1922-04-16”^^xsd:date .
:Singleton owl:hasKey ( :hasMother :born ) .
⇒ ex:Connie owl:sameAs ex:Constanza .
```

owl:IrreflexiveProperty

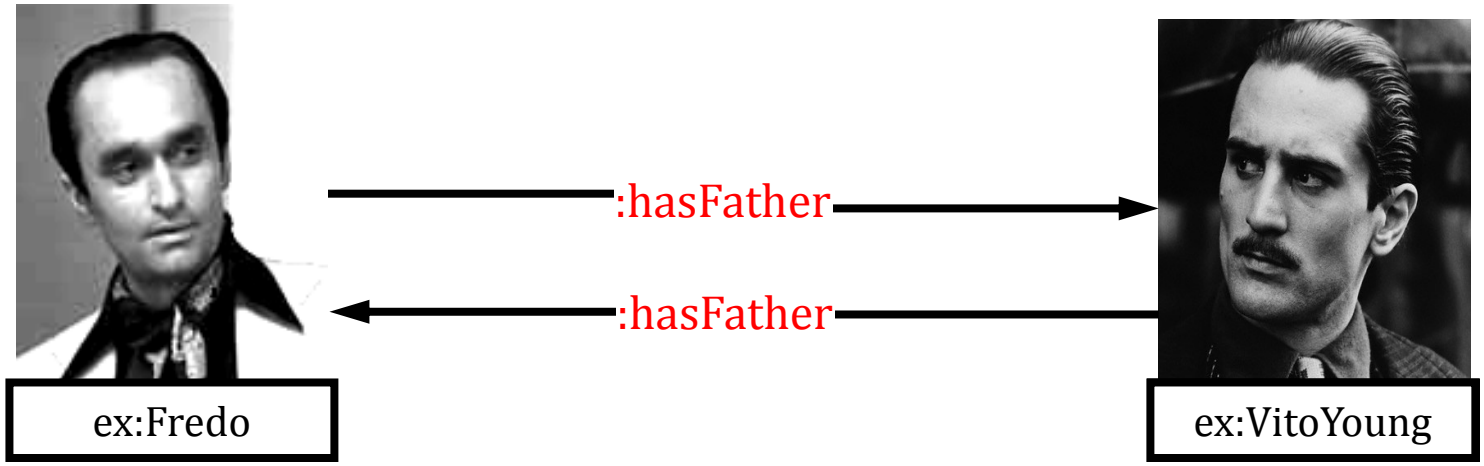



```
ex:Fredo :hasBrother ex:Fredo .
:hasBrother rdf:type owl:IrreflexiveProperty .
```

⇒ *FALSE*

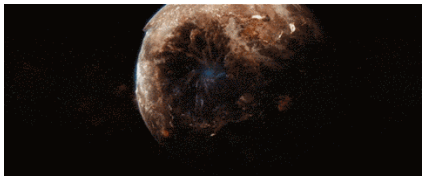


owl:AsymmetricProperty

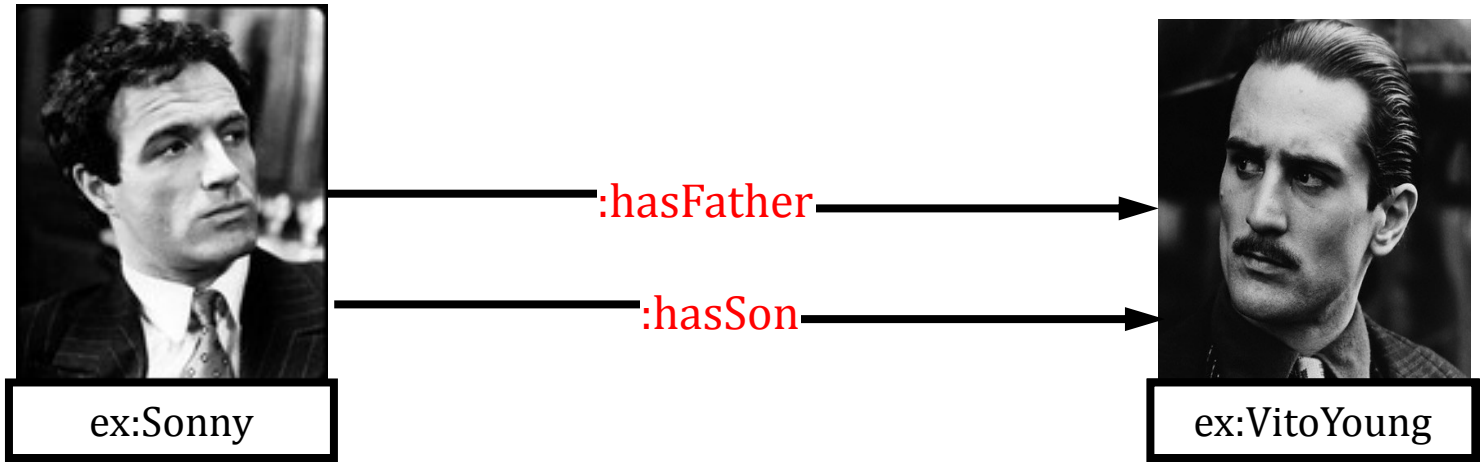



```
ex:Fredo :hasFather ex:VitoYoung .
ex:VitoYoung :hasFather ex:Fredo .
:hasFather rdf:type owl:AsymmetricProperty .
```

⇒ *FALSE*

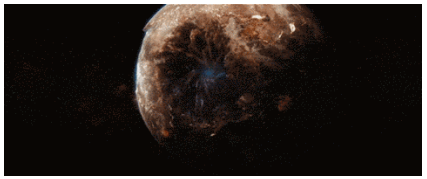


owl:disjointPropertyWith

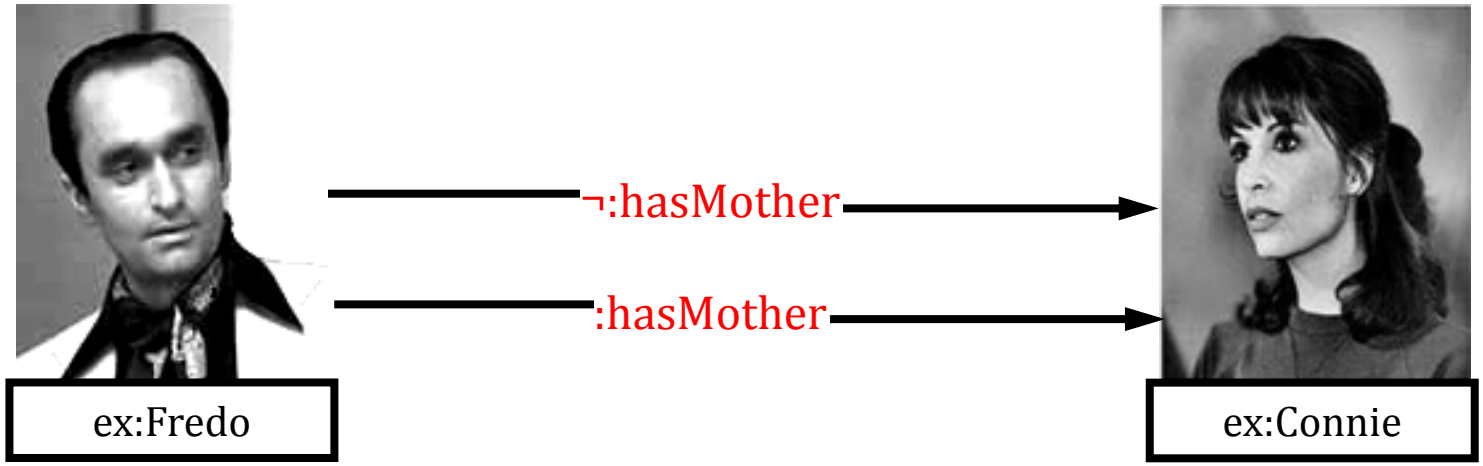



```
ex:Sonny :hasFather ex:VitoYoung .
ex:VitoYoung :hasSon ex:Sonny .
:hasSon owl:disjointPropertyWith :hasFather .
```

⇒ *FALSE*

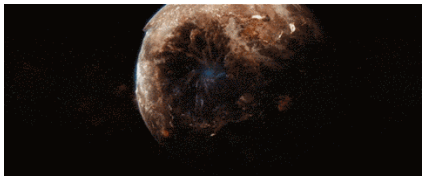


Negative property assertions




```
[] owl:sourceIndividual ex:Fredo ;
   owl:assertionProperty :hasMother ;
   owl:targetIndividual ex:Connie .
ex:Fredo :hasMother ex:Connie .
```

⇒ *FALSE*



Recap OWL property axioms

What would be the `owl:inverseOf` the property `:fatherOf`?

Name an `owl:SymmetricProperty` for family relations?

Name an `owl:TransitiveProperty` for family relations?

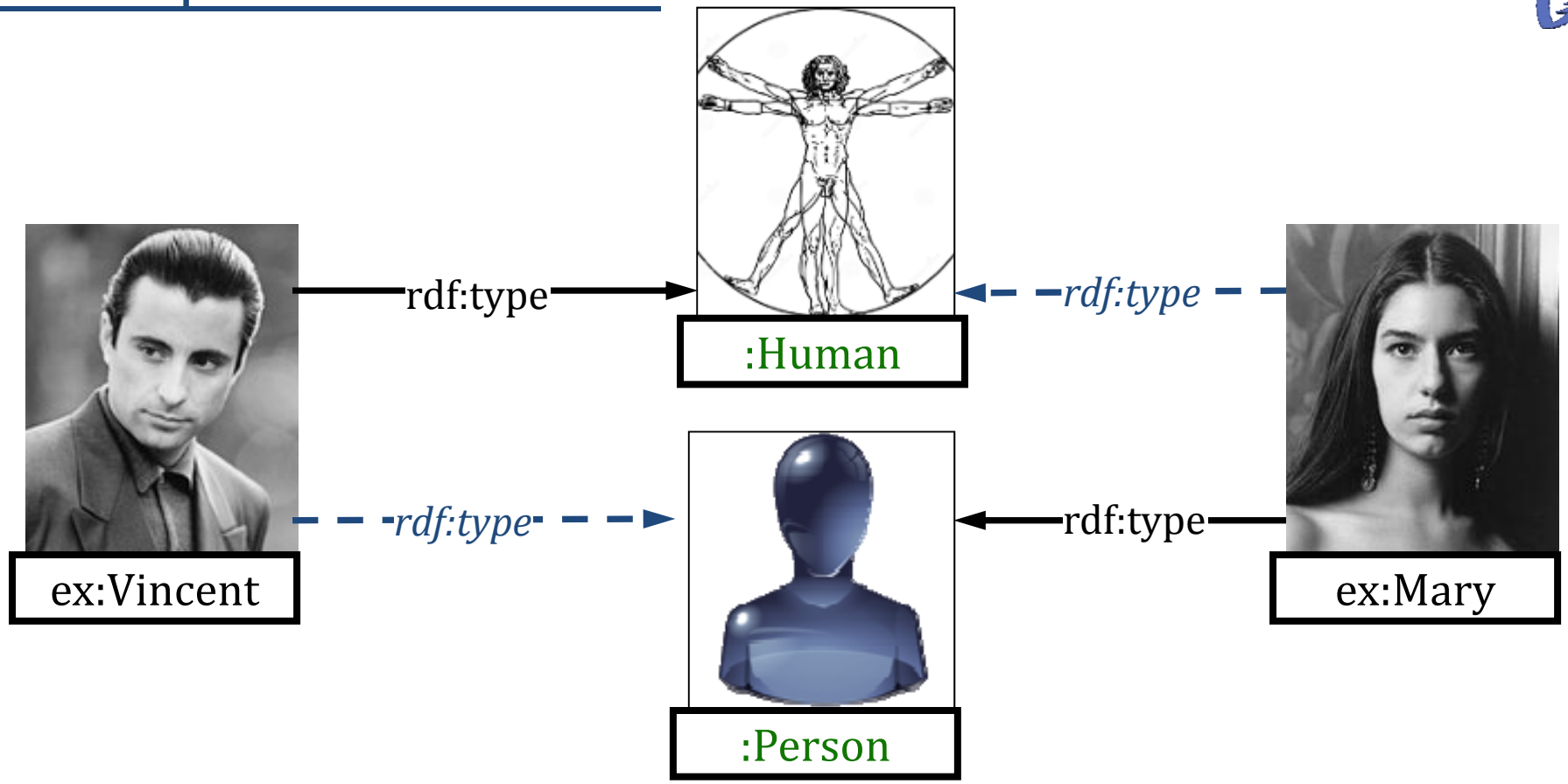
Give an `owl:propertyChainAxiom` for `:hasNiece`?

Name an `owl:AsymmetricProperty` for family relations?

Name an `owl:FunctionalProperty` for family relations?

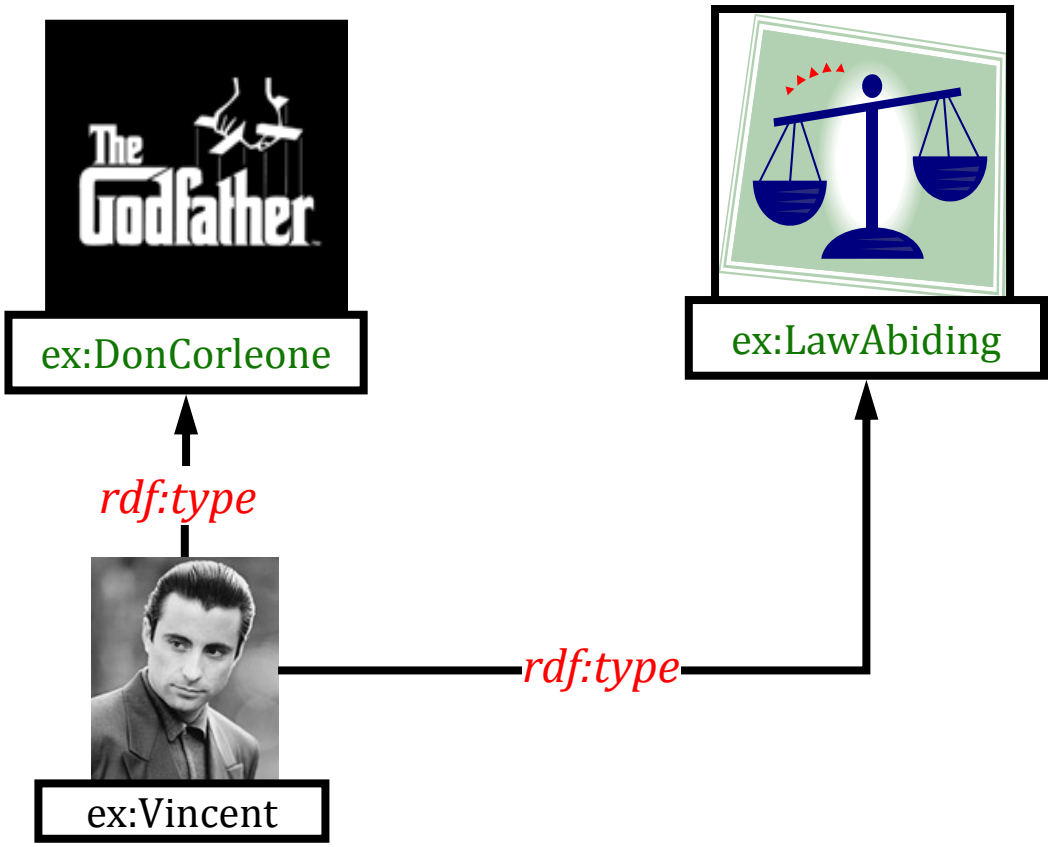
CLASS AXIOMS IN OWL

owl:equivalentClass




```
ex:Vincent rdf:type :Human .
ex:Mary rdf:type :Person .
:Human owl:equivalentClass :Person .
⇒ ex:Vincent rdf:type :Person .
ex:Mary rdf:type :Human .
```

owl:disjointWith

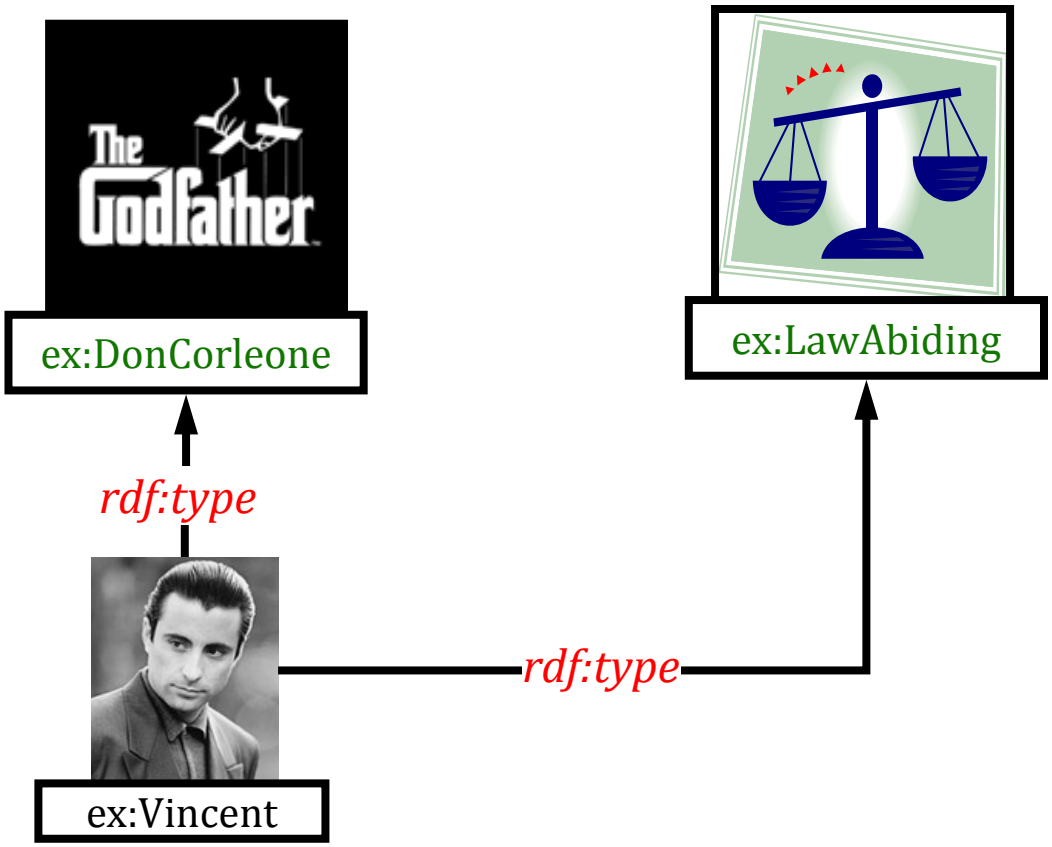


ex:Vincent rdf:type ex:DonCorleone , ex:LawAbiding .

ex:DonCorleone owl:disjointWith ex:LawAbiding .

⇒ *FALSE*

owl:disjointWith

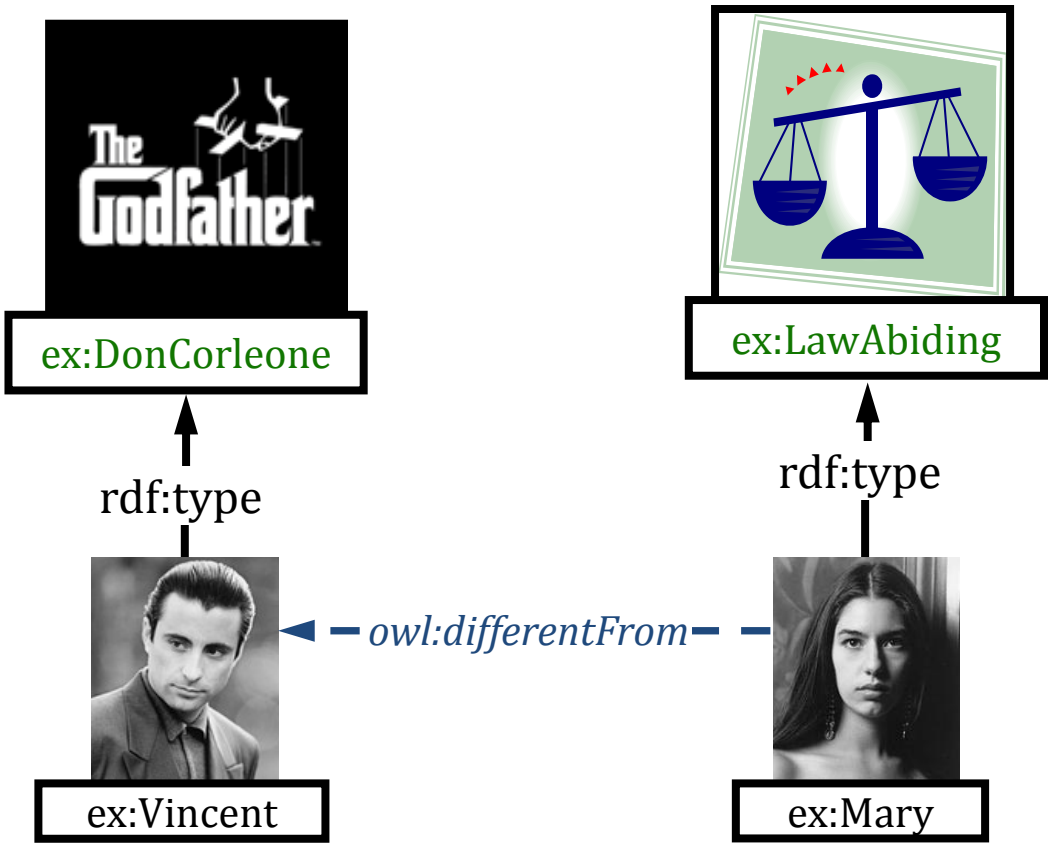


ex:Vincent rdf:type ex:DonCorleone , ex:LawAbiding .

ex:DonCorleone owl:disjointWith ex:LawAbiding .

⇒ *FALSE*

owl:disjointWith (ii)




```
ex:Vincent rdf:type ex:DonCorleone .
ex:Mary rdf:type ex:LawAbiding .
ex:DonCorleone owl:disjointWith ex:LawAbiding .
⇒ ex:Mary owl:differentFrom ex:Vincent .
```

CLASS DEFINITIONS IN OWL

Things start to get a little more “tricky”

- Property axioms say something about properties
- Class axioms say something about classes
- Class definitions define new classes
    - e.g., the class of humans with at least one human child
  - often these classes are not named, but a class axiom is used to relate them to a named class
    - e.g., the class of human parent is equivalent to the class of humans with at least one human child
    - e.g., the class of human mother is a sub-class of the class of humans with at least one human child
- Will become more clear ☺

Some basic Description Logics symbols

- Description Logics (DL) a theory underlying OWL
- '≡' for equivalent class or property

  `:Person ≡ :Human`

  `:hasChild ≡ :parentOf`
- '⊑' for sub-class or sub-property

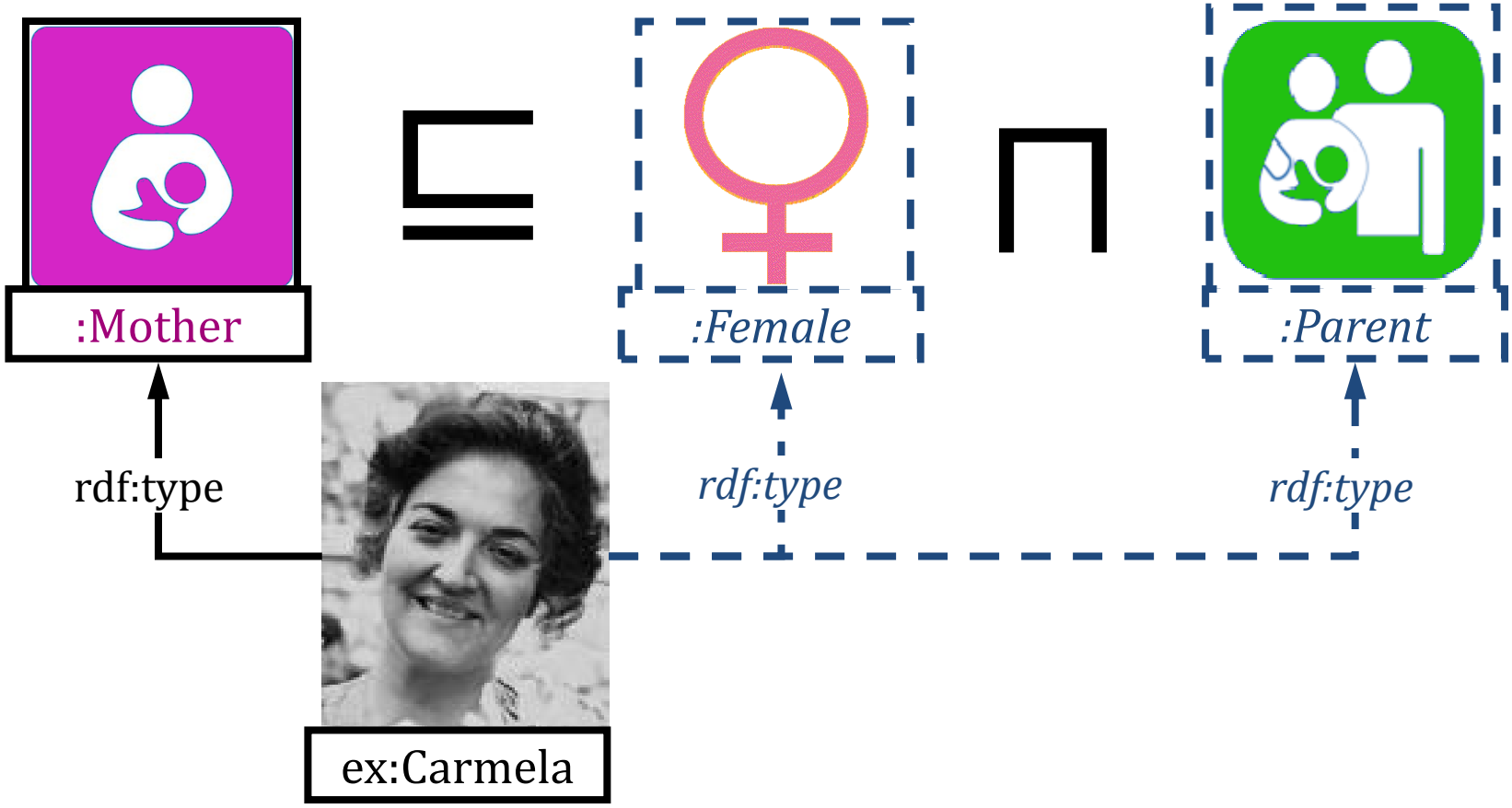
  `:Woman ⊑ :Person`

  `:hasSon ⊑ :hasChild`

Some built in classes and properties

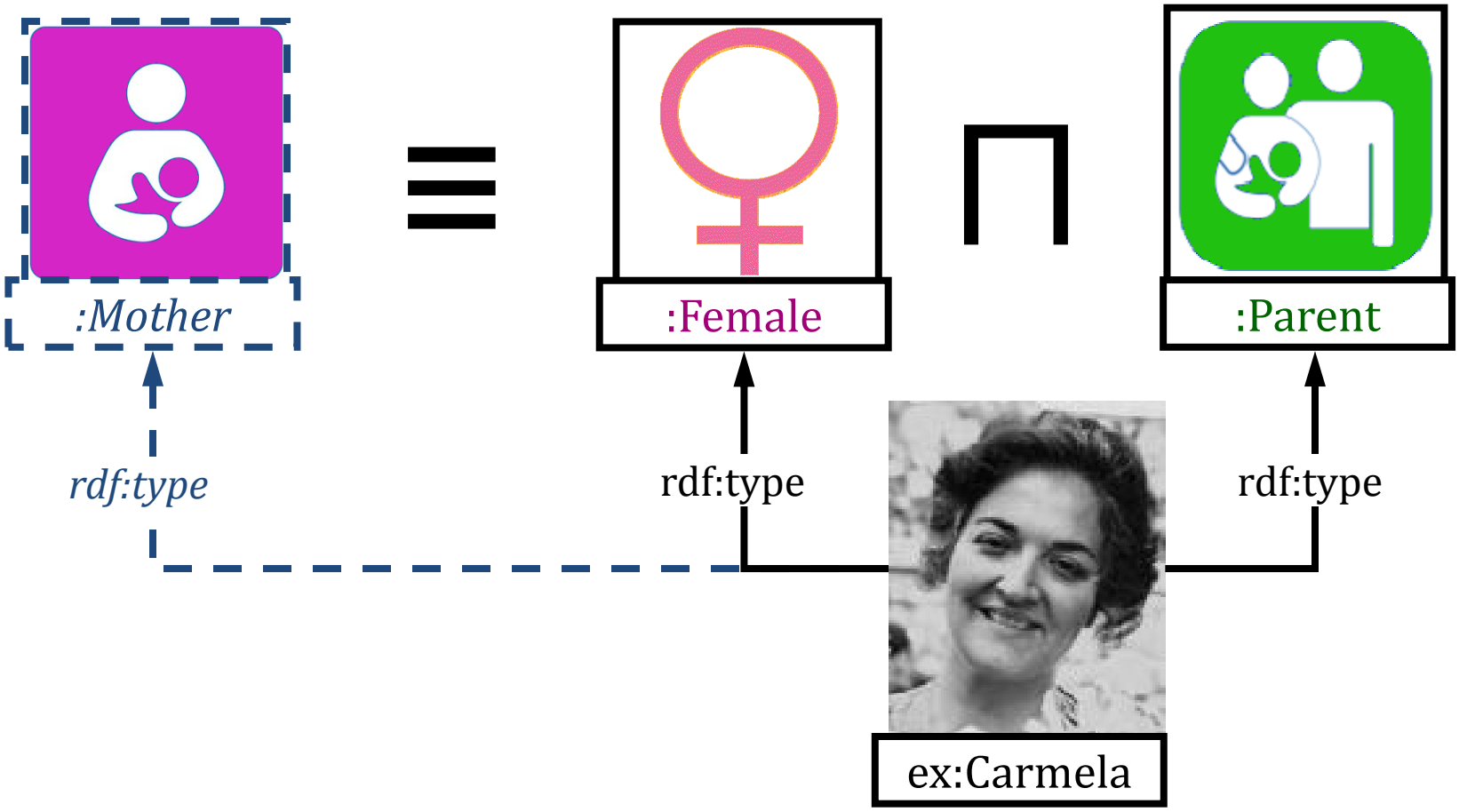
- `owl:Thing`: the class of "everything"
  - Relation to `rdfs:Resource` is complicated … let's not get into that now ☺
  - Symbol: '⊤'
- `owl:Nothing`: the empty class
  - Symbol: '⊥'

owl:intersectionOf (⊓) [i]



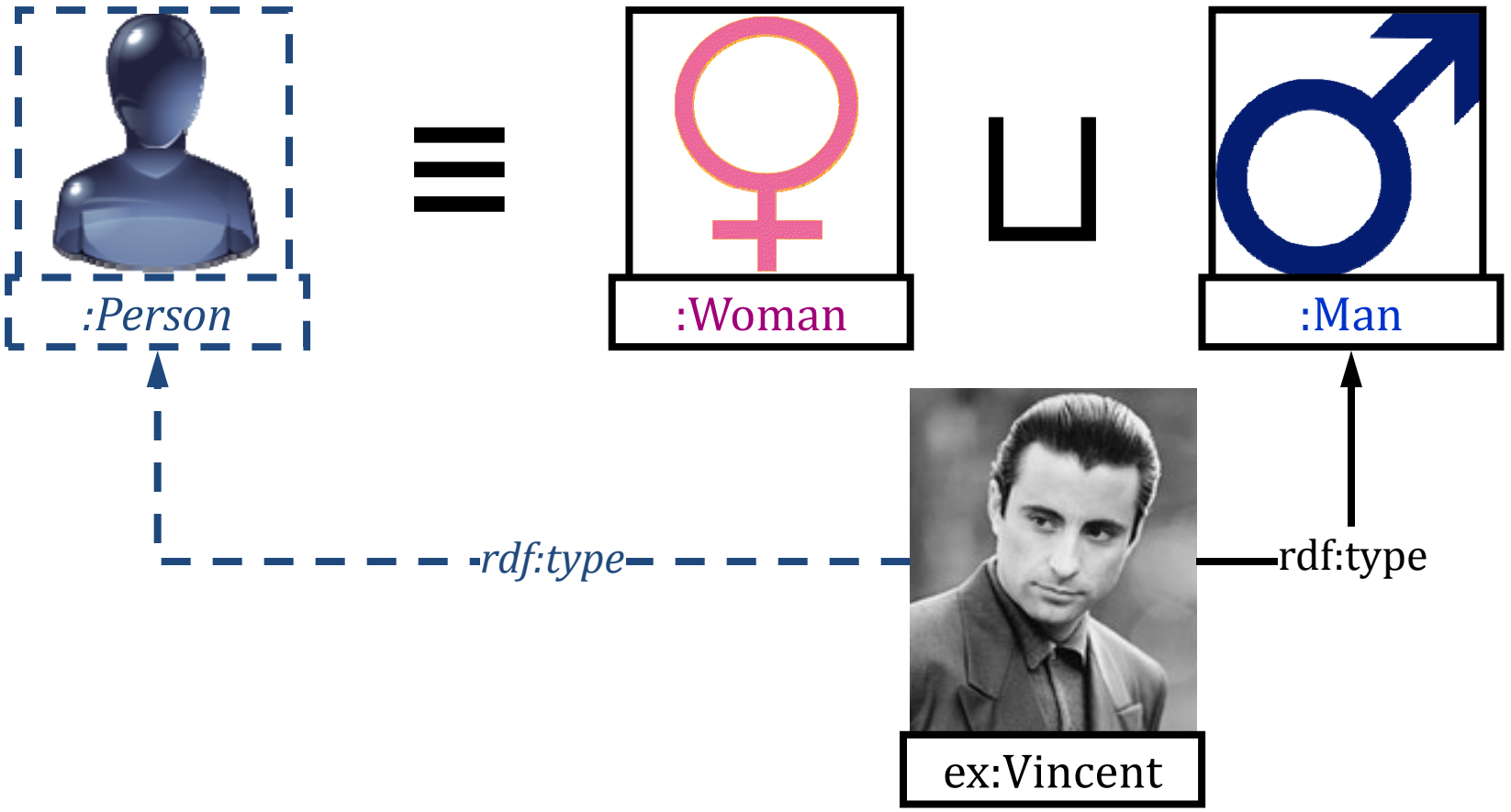

```
ex:Carmela rdf:type :Mother .
:Mother rdfs:subClassOf [ owl:intersectionOf ( :Female :Parent ) ]
⇒ ex:Carmela rdf:type :Female, :Parent .
```

owl:intersectionOf (⊓) [ii]



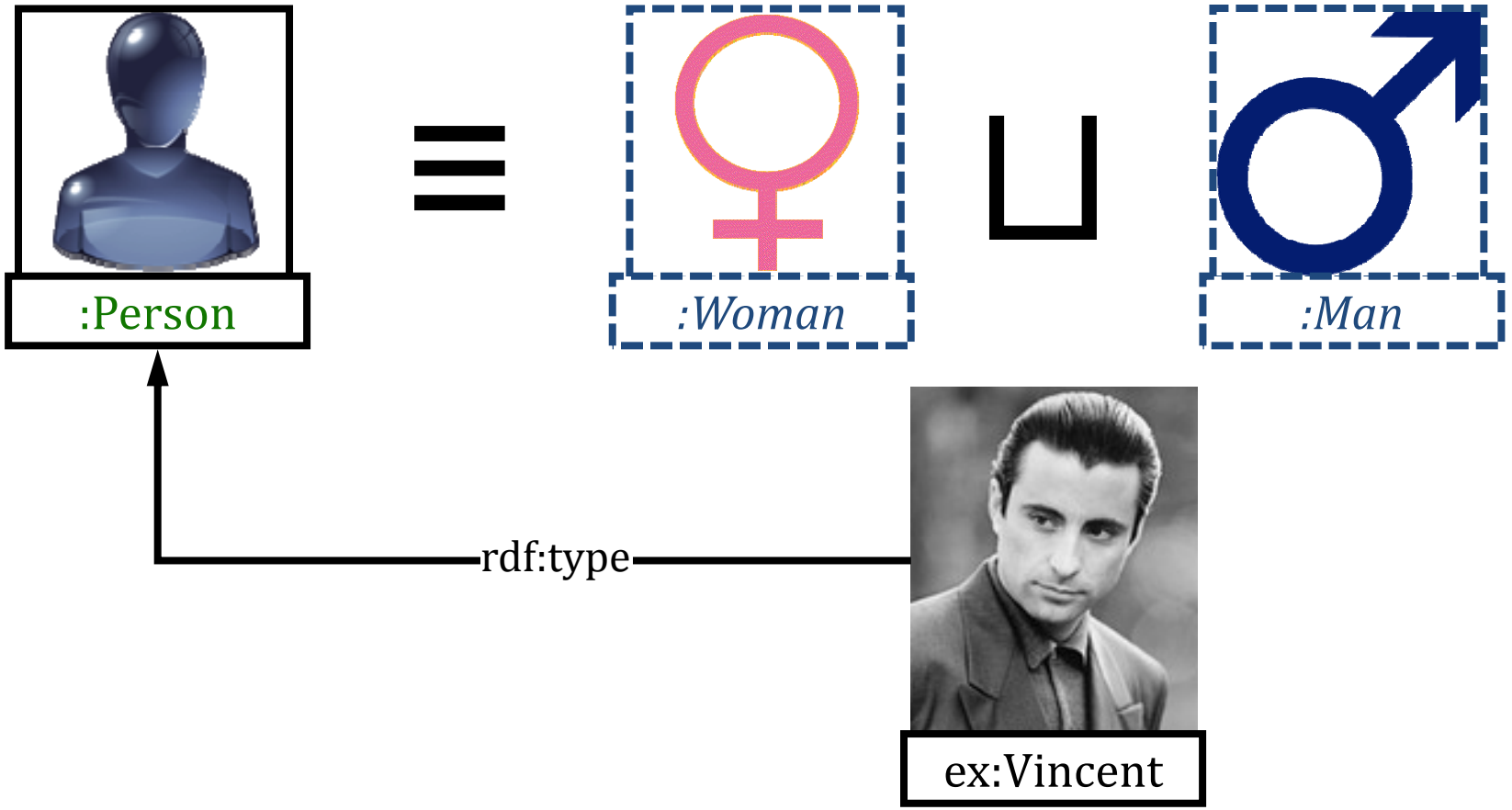

```
ex:Carmela rdf:type :Female , :Parent .
:Mother owl:equivalentClass [ owl:intersectionOf ( :Female :Parent ) ]
⇒ ex:Carmela rdf:type :Mother .
```

owl:unionOf (⊔)




```
ex:Vincent rdf:type :Man .
:Person owl:equivalentClass [ owl:unionOf ( :Woman :Man ) ]
⇒  ex:Vincent rdf:type :Person .
```

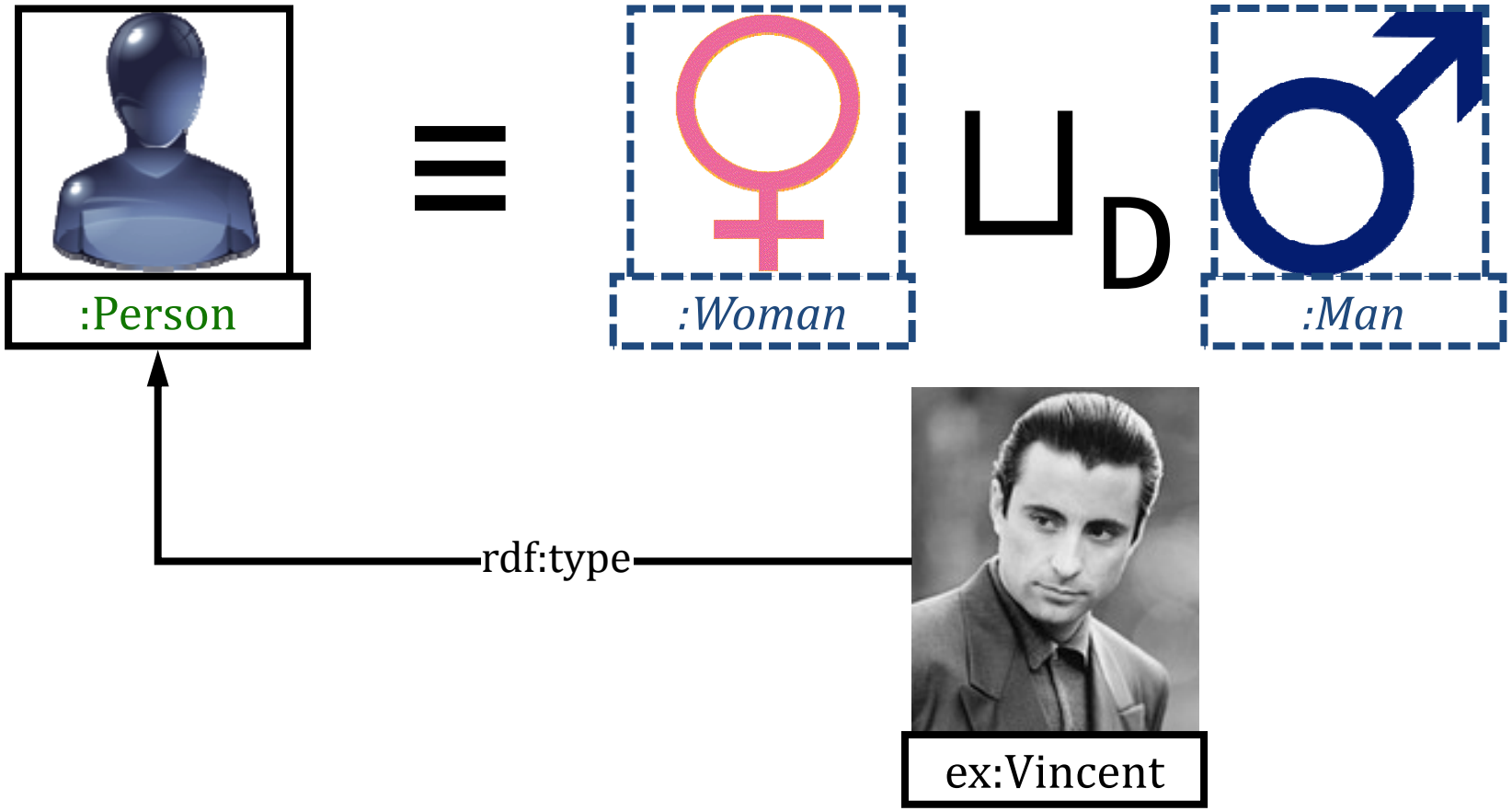
owl:unionOf (⊔) [ii]




```
ex:Vincent rdf:type :Person .
:Person owl:equivalentClass [ owl:unionOf ( :Woman :Man ) ]
```

⇒ … ex:Vincent must be either of type *:Woman* or *:Man* **(or both)**

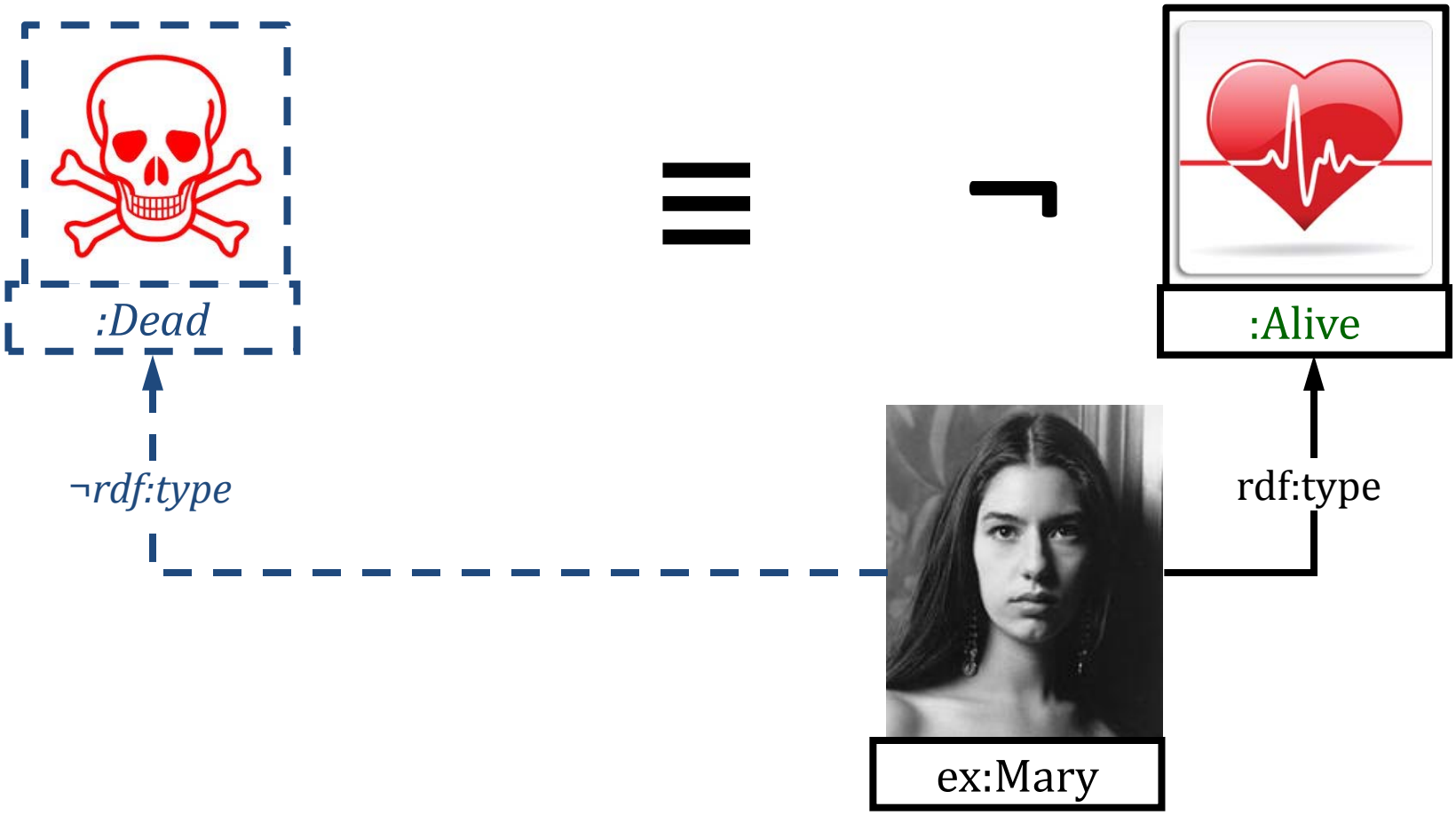
owl:disjointUnionOf ($\sqcup_D$)




```
ex:Vincent rdf:type :Person .
:Person owl:equivalentClass [ owl:disjointUnionOf ( :Woman :Man ) ]
```

⇒ … ex:Vincent must be either of type *:Woman* or *:Man* **(not both) (?!)**

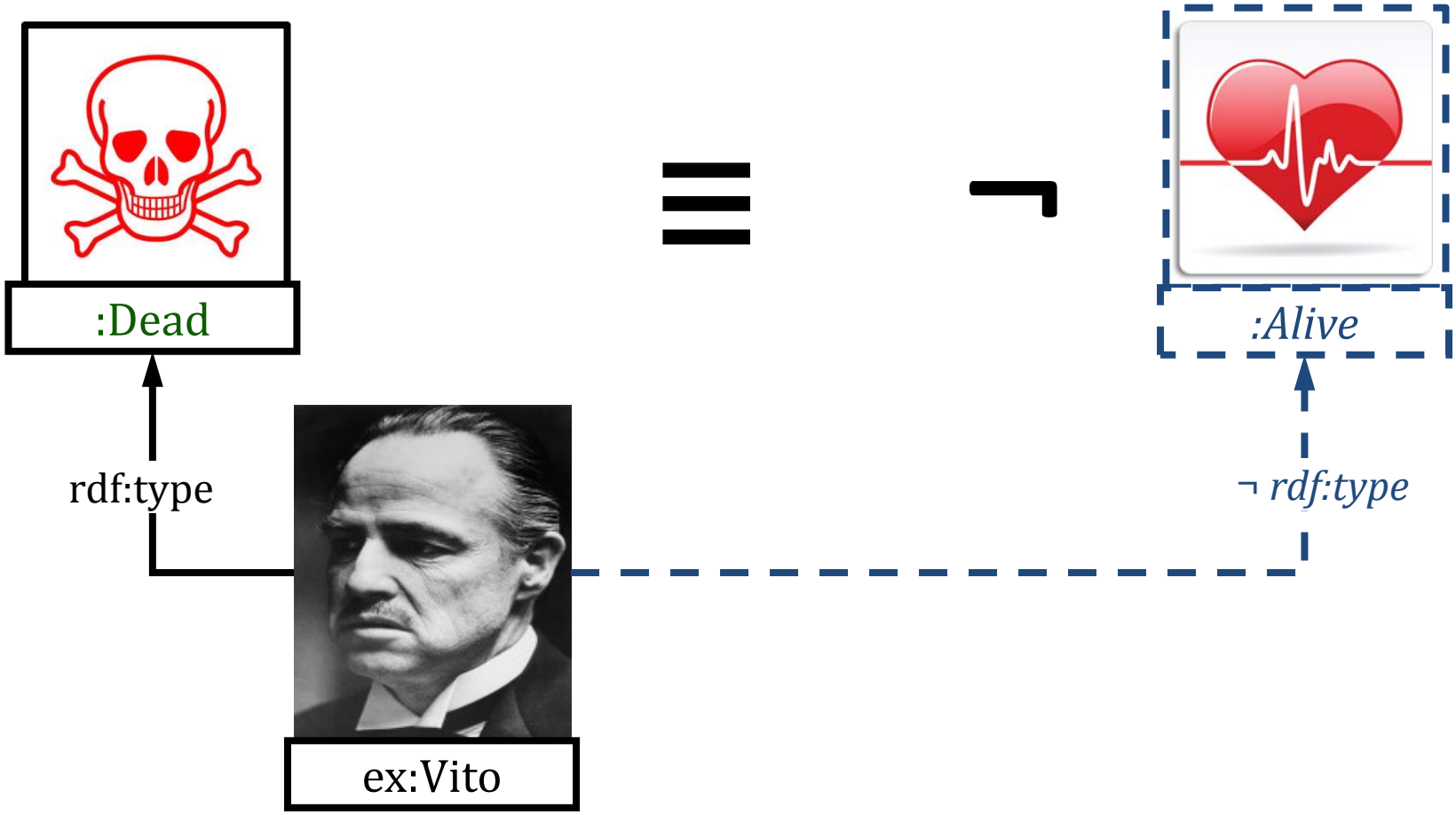
owl:complementOf (¬) [i]




```
ex:Mary rdf:type :Alive .
:Dead owl:equivalentClass [ owl:complementOf :Alive ]
⇒ [] owl:sourceIndividual ex:Mary ; owl:targetProperty
   rdf:type ; owl:targetIndividual :Dead .
```

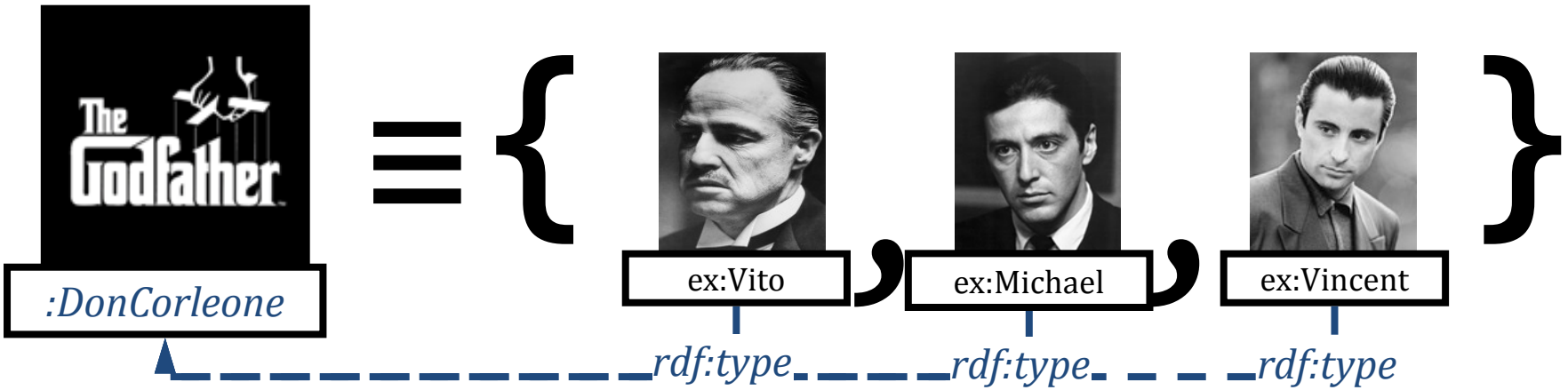

WARNING
SPOILER
ALERT

owl:complementOf (¬) [ii]



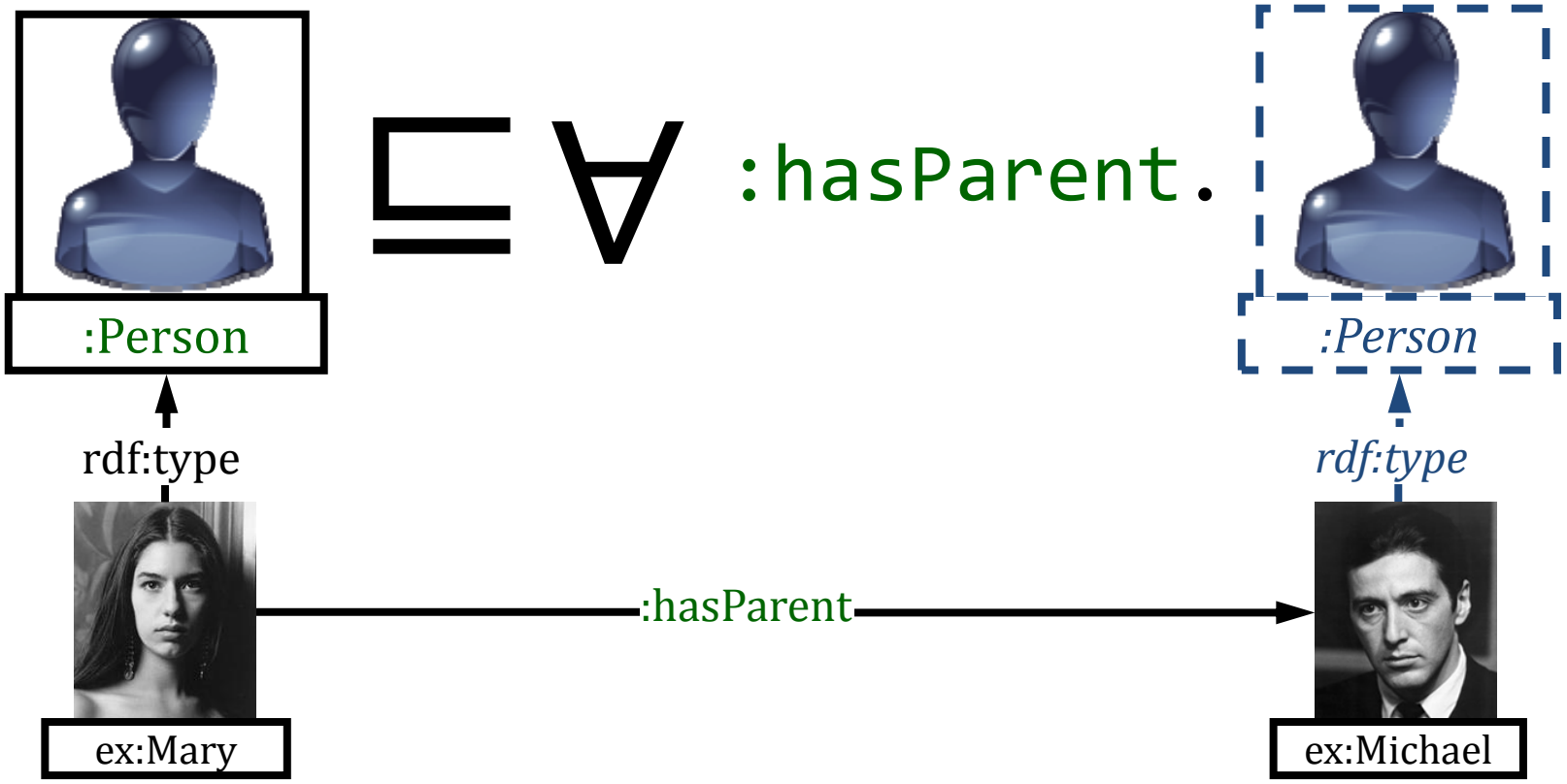

```
ex:Vito rdf:type :Dead .
:Dead owl:equivalentClass [ owl:complementOf :Alive ]
⇒ [] owl:sourceIndividual ex:Vito ; owl:targetProperty
   rdf:type ; owl:targetIndividual :Alive .
```

owl:oneOf ({})



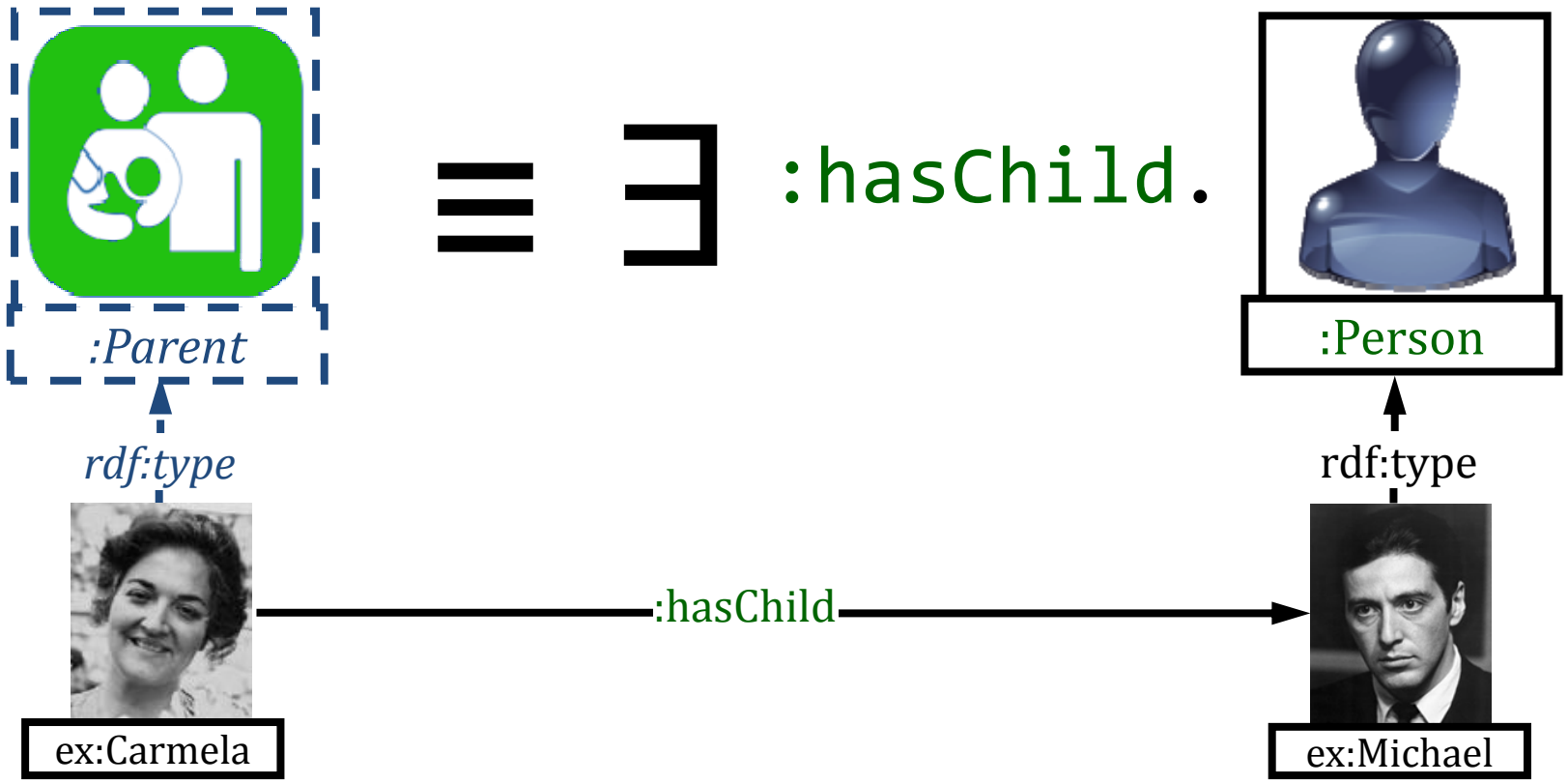

```
:DonCorleone owl:equivalentClass
   [ owl:oneOf (ex:Vito ex:Michael ex:Vincent) ]
⇒ ex:Vito rdf:type :DonCorleone .
⇒ ex:Michael rdf:type :DonCorleone .
⇒ ex:Vincent rdf:type :DonCorleone .
```

owl:allValuesFrom (∀)



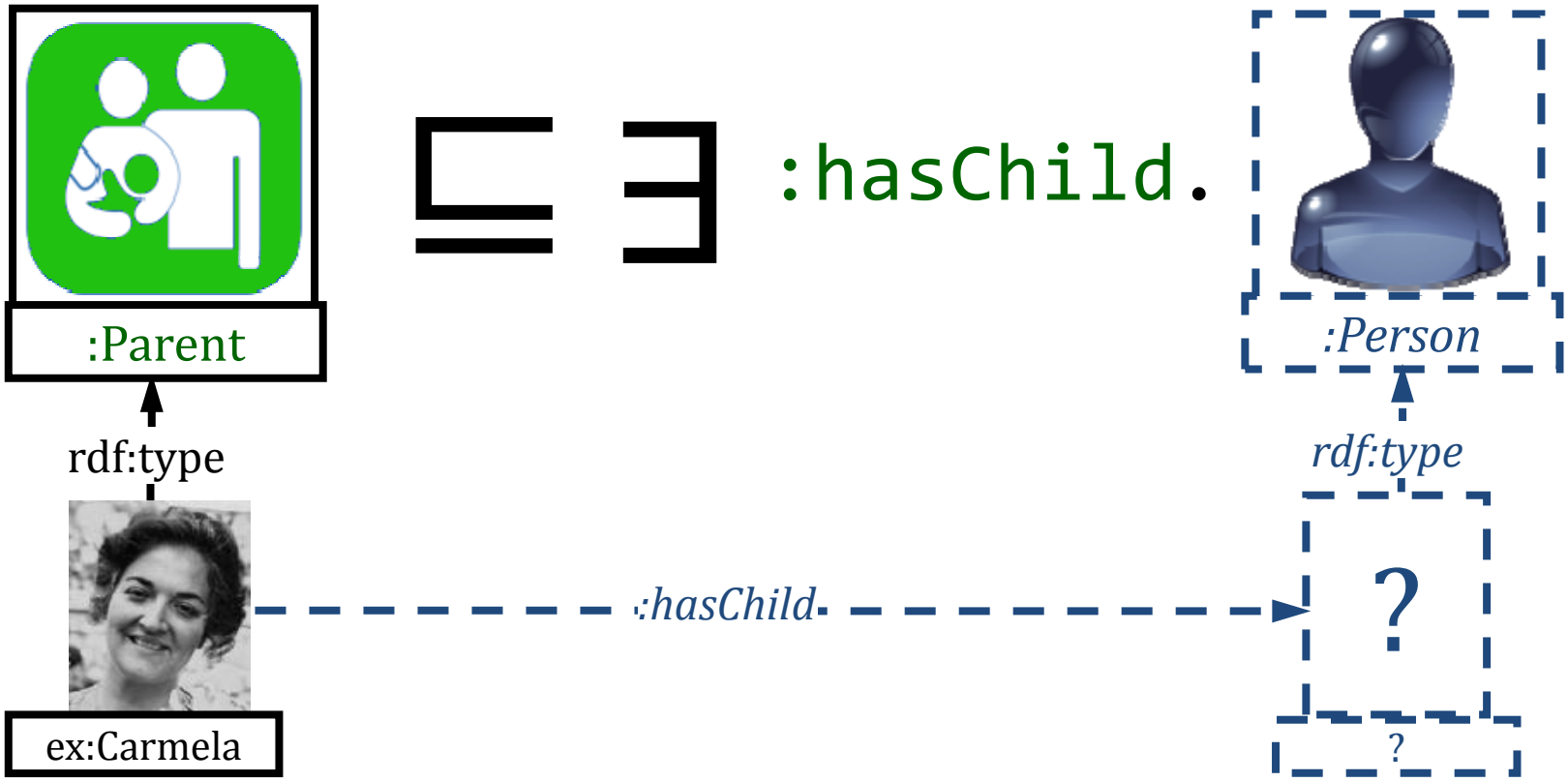

```
ex:Mary rdf:type :Person ; :hasParent ex:Michael .
:Person rdfs:subClassOf
  [ owl:allValuesFrom :Person ; owl:onProperty :hasParent ]
⇒  ex:Michael rdf:type :Person .
```

owl:someValuesFrom (∃) [i]



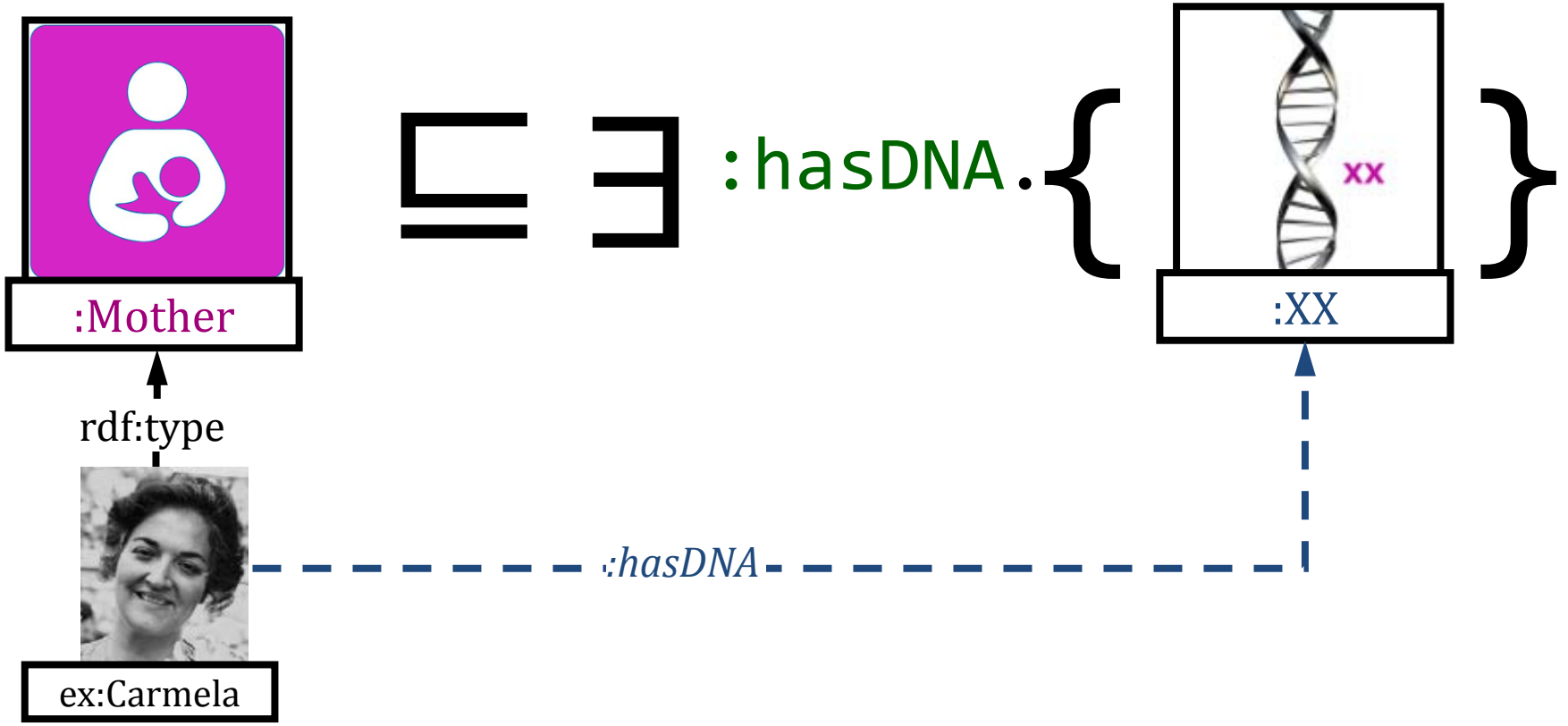

```
ex:Carmela :hasChild ex:Michael . ex:Michael rdf:type :Person .
:Parent owl:equivalentClass
  [ owl:someValuesFrom :Person ; owl:onProperty :hasChild ]
⇒  ex:Carmela rdf:type :Parent .
```

owl:someValuesFrom (∃) [ii]



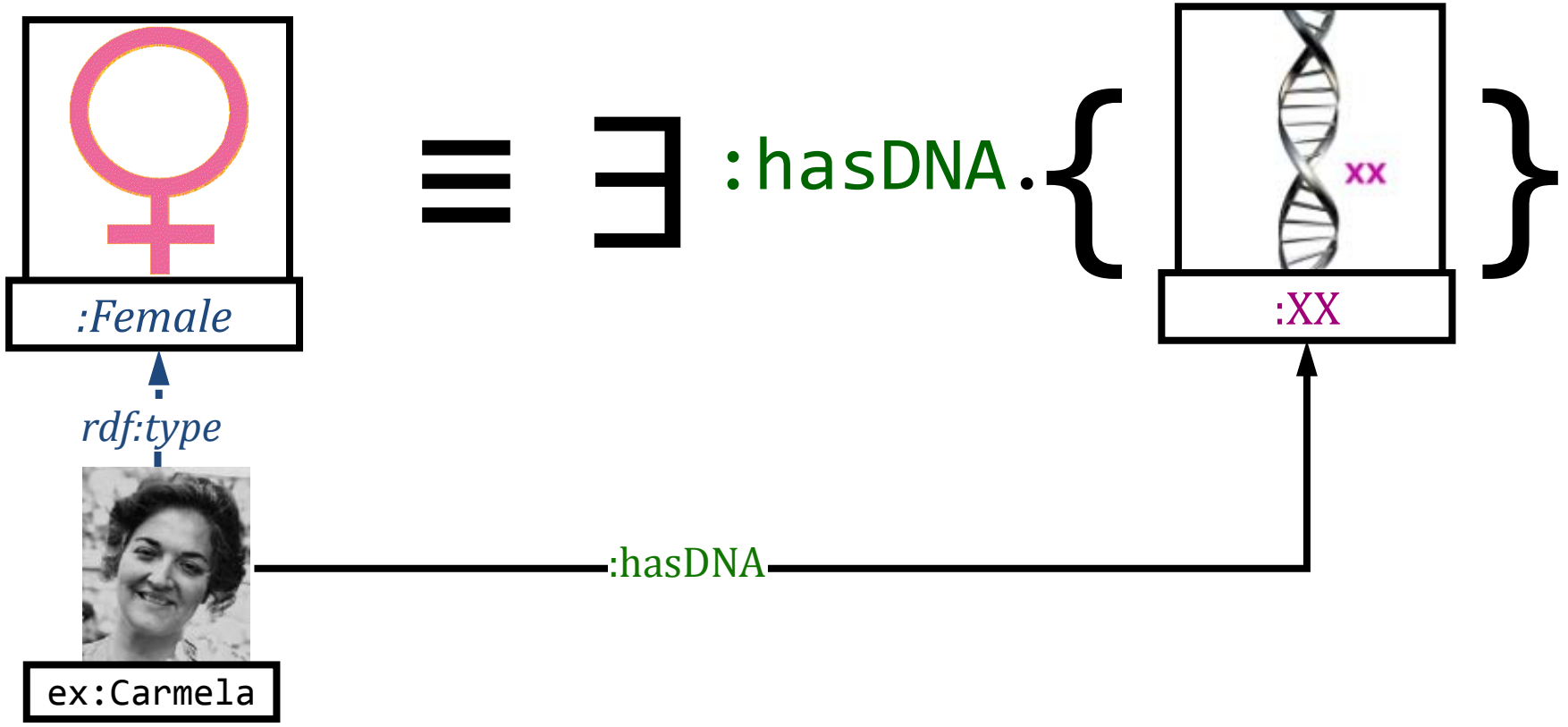

```
ex:Carmela rdf:type :Parent .
:Parent rdfs:subClassOf
  [ owl:someValuesFrom :Person ; owl:onProperty :hasChild ] .
⇒  ex:Mary :hasChild _:someone . _:someone rdf:type :Person .
```

owl:hasValue (∃P.{x}) [i]



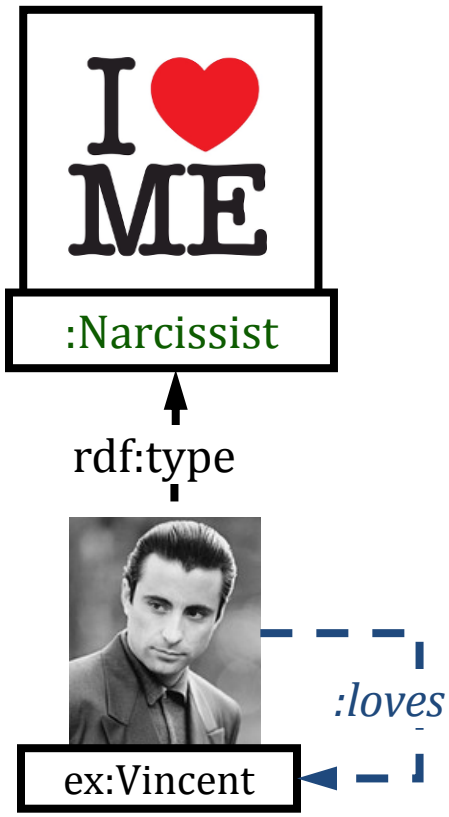

```
ex:Carmela rdf:type :Mother .
:Mother rdfs:subClassOf
  [ owl:hasValue :XX ; owl:onProperty :hasDNA ]
⇒  ex:Carmela :hasDNA :XX .
```

owl:hasValue (∃P.{x}) [ii]




```
ex:Carmela :hasDNA :XX .
:Female owl:equivalentClass
  [ owl:hasValue :XX ; owl:onProperty :hasDNA ]
⇒  ex:Carmela rdf:type :Female .
```

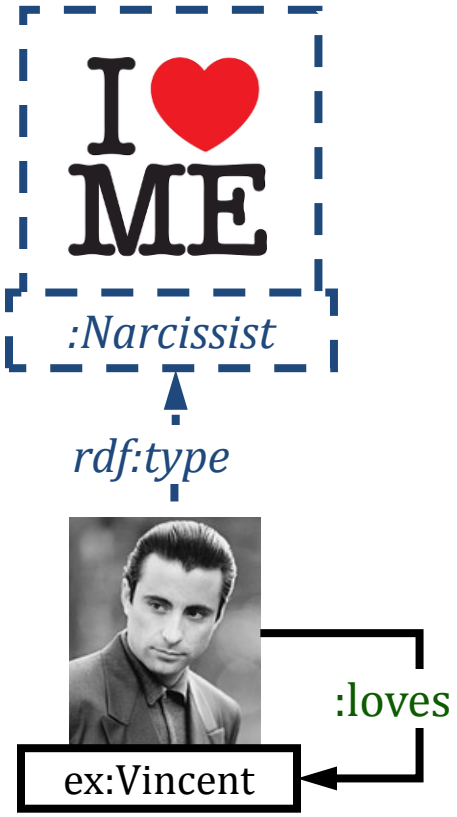
owl:hasSelf (Self) [i]



$\sqsubseteq$ Self(*:loves*)

```
ex:Vincent rdf:type :Narcissist .
:Narcissist rdfs:subClassOf
  [ owl:hasSelf true ; owl:onProperty :loves ]
⇒  ex:Vincent :loves ex:Vincent .
```

owl:hasSelf (Self) [ii]



≡ Self(:loves)

```
ex:Vincent :loves ex:Vincent .
:Narcissist owl:equivalentClass
  [ owl:hasSelf true ; owl:onProperty :loves ]
⇒  ex:Vincent rdf:type :Narcissist .
```

Cardinality restrictions (≥, ≤,=)

- Define a class with a given number of values for a property:
  - Exact:
    - `:Person ⊑ =2 (:hasParent)`
    - `:Parent rdfs:subClassOf [ owl:cardinality 2 ; owl:onProperty :hasParent ] .`
  - Max:
    - `:Monogamist ⊑ ≤ 1 (:currentSpouse)`
    - `:Monogamist rdfs:subClassOf [ owl:maxCardinality 1 ; owl:onProperty :currentSpouse ] .`
  - Min:
    - `:Parent ≡ ≥ 1 (:hasChild)`
    - `:Parent owl:equivalentClass [ owl:minCardinality 1 ; owl:onProperty :hasChild ] .`

Qualified cardinality restrictions (≥, ≤,=)

- Define a class with a given number of values from a given class for a property:
  - Exact:
    - `:Person ≡ =2 (:hasParent.Person)`
    - `:Parent owl:equivalentClass [ owl:qualifiedCardinality 2 ; owl:onProperty :hasParent ; owl:onClass :Person ] .`
    - Now the values in question must be people!
  - Analogous versions of Max and Min.

Recap OWL class axioms/definitions

A class `:HumanParent` might be equivalent to the `owl:unionOf` which classes?

What is the difference/relation between `owl:complementOf` and `owl:disjointWith`

Give an example use of `owl:allValuesFrom` for family relations

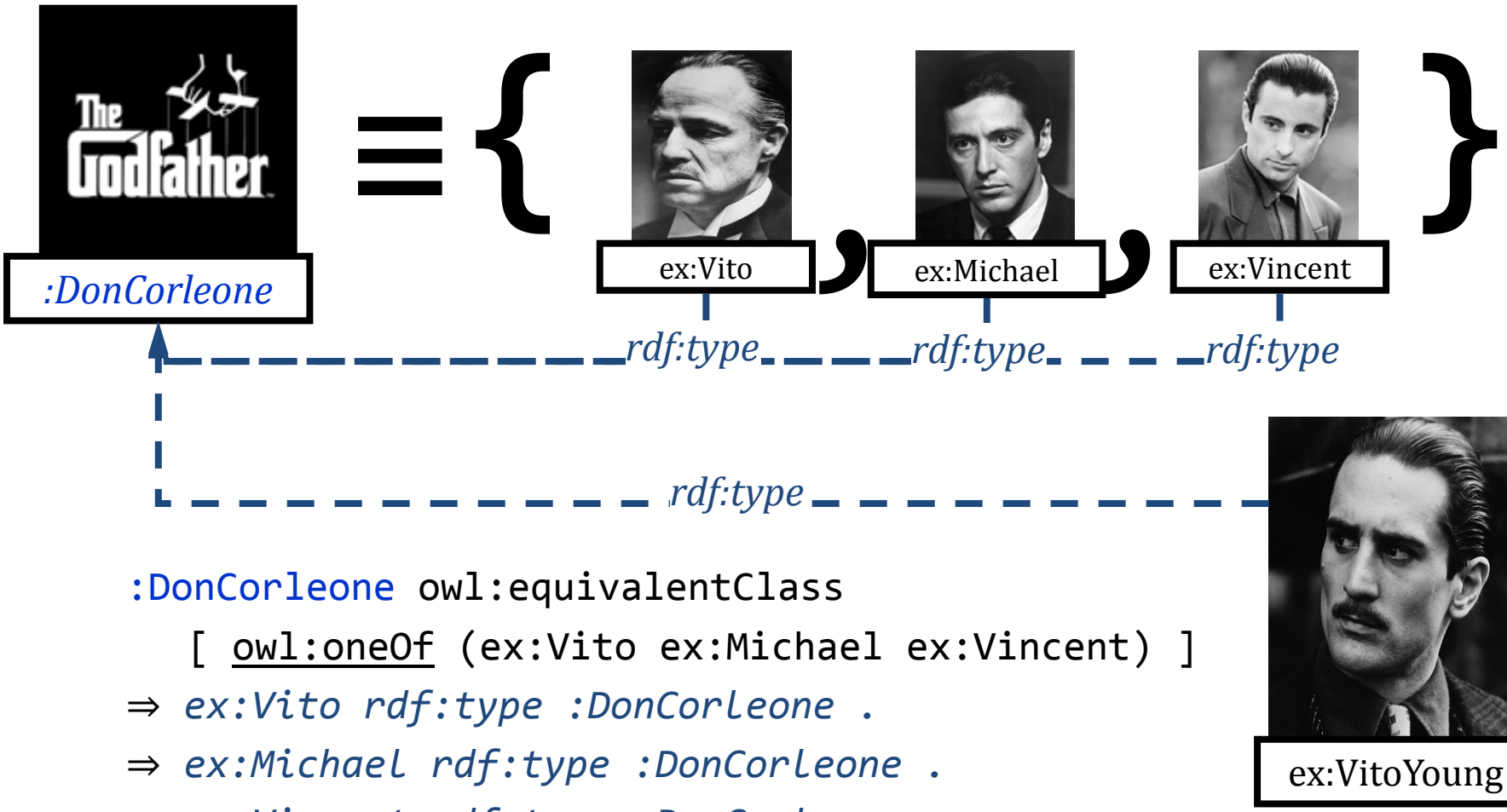
$A \sqsubseteq (B \sqcap \exists P.C)$?

Give an example use of `owl:someValuesFrom` for `:Uncle`.

How might we codify the semantics of a class `:OnlyChild` in OWL?

How might we codify the semantics of a class `:InSameSexMarriage` in OWL?

Slides are examples, not definitions




```
:DonCorleone owl:equivalentClass
   [ owl:oneOf (ex:Vito ex:Michael ex:Vincent) ]
⇒ ex:Vito rdf:type :DonCorleone .
⇒ ex:Michael rdf:type :DonCorleone .
⇒ ex:Vincent rdf:type :DonCorleone .
⇒ … ex:VitoYoung must be the same as one of the three dons!
```

RECAP

(1) Data, **(2) Rules/Ontologies,** (3) Query

INPUT: "$(x$,partOf,$y)$"

DATA:

`http://ex.org/Ireland`

Ireland

(Ireland,partOf,Europe)
(Ireland,a,Country)
(Ireland,capital,Dublin)

`http://ex.org/Dublin`

Dublin

(Dublin,population,1000000)

RULES: $(a, \text{capital}, b) \rightarrow (b, \text{partOf}, a)$
$(c, \text{partOf}, d), (d, \text{partOf}, e) \rightarrow (c, \text{partOf}, e)$

OUTPUT: $\{(x \mapsto \text{Ireland}, y \mapsto \text{Europe}), (x \mapsto \text{Dublin}, y \mapsto \text{Ireland})$
$(x \mapsto \text{Dublin}, y \mapsto \text{Europe})\}$

RDF(S)/OWL: OWA, no UNA

- RDF(S)/OWL
  - Take an Open World Assumption
  - Do not take a Unique Name Assumption
  - On the Web:
    - information is incomplete
    - having one name for everything would require too much coordination

OWL Features: (In)Equality

- `owl:sameAs`: two names refer to same thing
- `owl:differentFrom`: two names refer to different things

OWL Features: Property Axioms

- `owl:equivalentProperty`: two properties are synonymous
- `owl:inverseOf`: two properties synonymous but in opposite directions
- `owl:SymmetricProperty`: properties that always hold in both directions; i.e., if (a,P,b) then (b,P,a)
- `owl:TransitiveProperty`: if (a,P,b) and (b,P,c) then (a,P,c)

OWL Features: Property Axioms

- `owl:propertyChainAxiom`: define a property as a chain of other properties
- `owl:ReflexiveProperty`: a class of properties that relate everything to itself
- `owl:FunctionalProperty`: if (a,P,x) and (b,P,x) then x = y
- `owl:InverseFunctionalProperty`: if (x,P,a) and (y,P,a) then x = y
- `owl:hasKey`: define complex keys for instances of a given class

OWL Features: Property Axioms

- `owl:IrreflexiveProperty`: can never relate x to x
- `owl:AsymmetricProperty`: can never relate x to y and y to x
- `owl:disjointPropertyWith`: two properties that can never relate the same two things
- Negative property assertions: say that something is false

OWL Features: Class Axioms

- `owl:equivalentClass`: relates two classes that are synonymous
- `owl:disjointWith`: relates two classes that cannot share any instances

OWL Features: Class Definitions

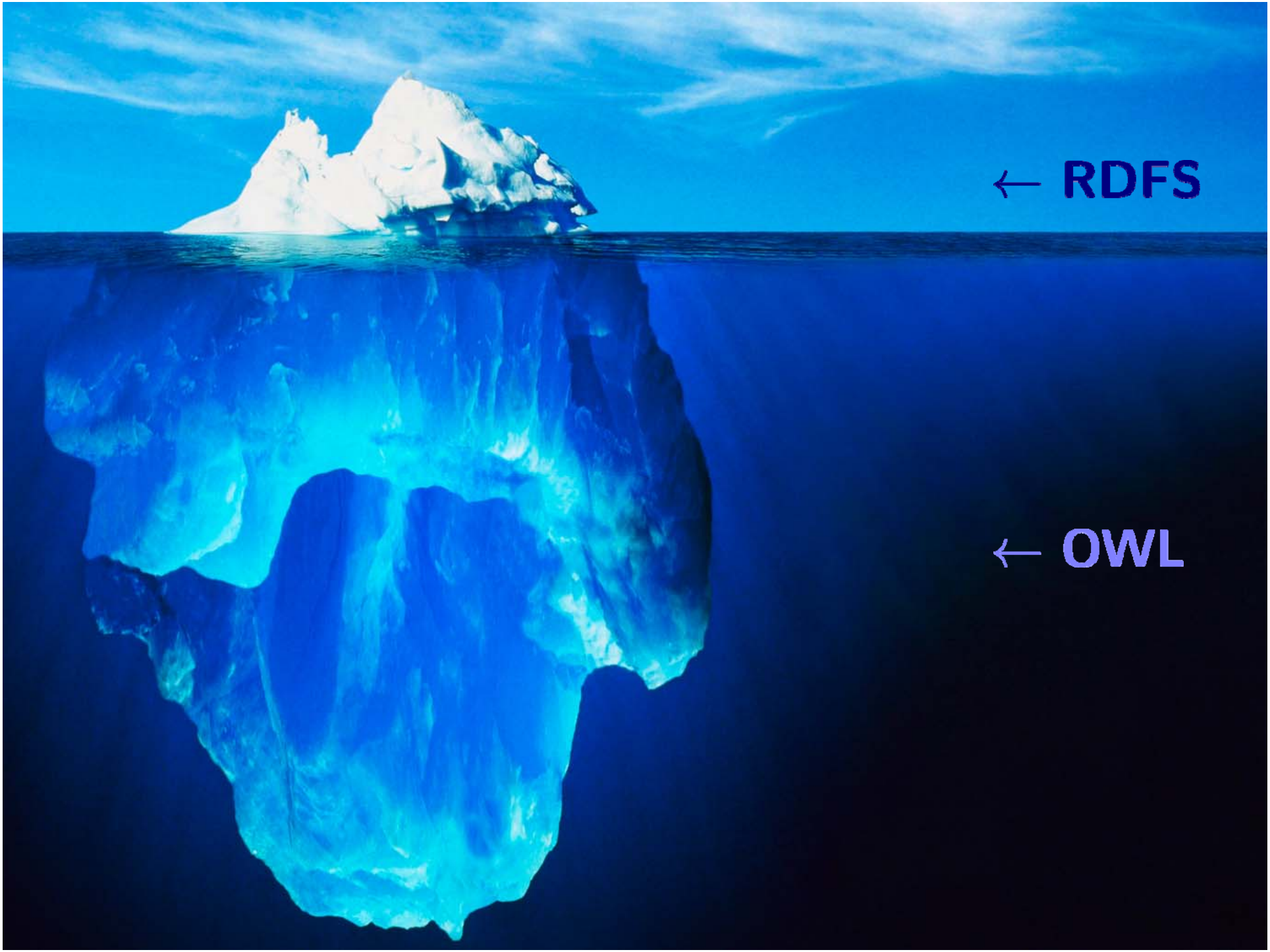
- `owl:unionOf`: defines a class that's the union of one or more other classes
- `owl:intersectionOf`: defines a class that's the intersection of one or more other classes
- `owl:complementOf`: defines a class that's the complement of another class
- `owl:oneOf`: defines a class by enumerating precisely all of its instances

OWL Features: Class Definitions

- `owl:allValuesFrom`: defines a class that contains all things that have values for a given property that are all of a certain type
- `owl:someValuesFrom`: defines a class that contains all things that have at least one value for a given property of a certain type
- `owl:hasValue`: defines a class that contains all things that have a specific value for a given property
- `owl:hasSelf`: defines a class that contains all things that have themself as a value for a given property
- Cardinality restrictions define classes with a given number of values for a property
- Qualified cardinality restrictions define classes with a given number of values for a property in a given class

Some Description Logic symbols

- ⊑: sub-class/-property
- ≡: equivalent class/property
- ⊔: union
- ⊓: intersection
- ⊤: top (class of everything)
- ⊥: bottom (empty class)
- ∃: exists (`someValuesFrom`/`hasValue`)
- ∀: for all (`allValuesFrom`)
- ¬: not (complement, negation)
- ⁻ (superscript minus): inverse property
- {}: enumeration (`owl:oneOf`)
- Self, Trans, Dom, etc.: where symbols not available


← RDFS
← OWL

Questions?