Probabilistic Ontology: Representation and Modeling Methodology

Como modelar e automatizar o conhecimento de especialistas: Estudos de caso de identificação de fraudes em licitações públicas e de terroristas e contrabando na costa americana

Dr. Rommel Novaes Carvalho | https://about.me/rommelnc

Dissertation Defense
PhD in Systems Engineering and Operations Research
George Mason University
06/28/2011

Ciclo de Palestras da CGU
Observatório da Despesa Pública
Ministério da Transparência, Monitoramento e CGU
13/01/2017

Agenda

- Introduction
  - Problem Statement
  - Contributions
- Representing Uncertainty in Semantic Technologies
- 1st Major Contribution: PR-OWL 2.0
- 2nd Major Contribution: Uncertainty Modeling Process for Semantic Technologies (UMP-ST)
- Conclusion

Introduction

Summary of Problems

- 1st major problem - Mapping/Types
  - Probabilistic web ontology language (PR-OWL) does not have a well-defined and complete integration between the deterministic and probabilistic parts of an ontology
- 2nd major problem - Methodology
  - Probabilistic languages for semantic technologies like PR-OWL lack a methodology for guiding the construction of models

Summary of Contributions

- For the 1st problem - Mapping/Types
  - Extended probabilistic web ontology language (PR-OWL)
    - Led the development of a proof of concept tool in collaboration with UnB [105]*
- For the 2nd problem - Methodology
  - Developed a methodology for modeling probabilistic ontologies (POs)
    - Created two use cases using the proposed methodology

*These numbers refer to the references in my dissertation

What’s the problem?

What's the problem?

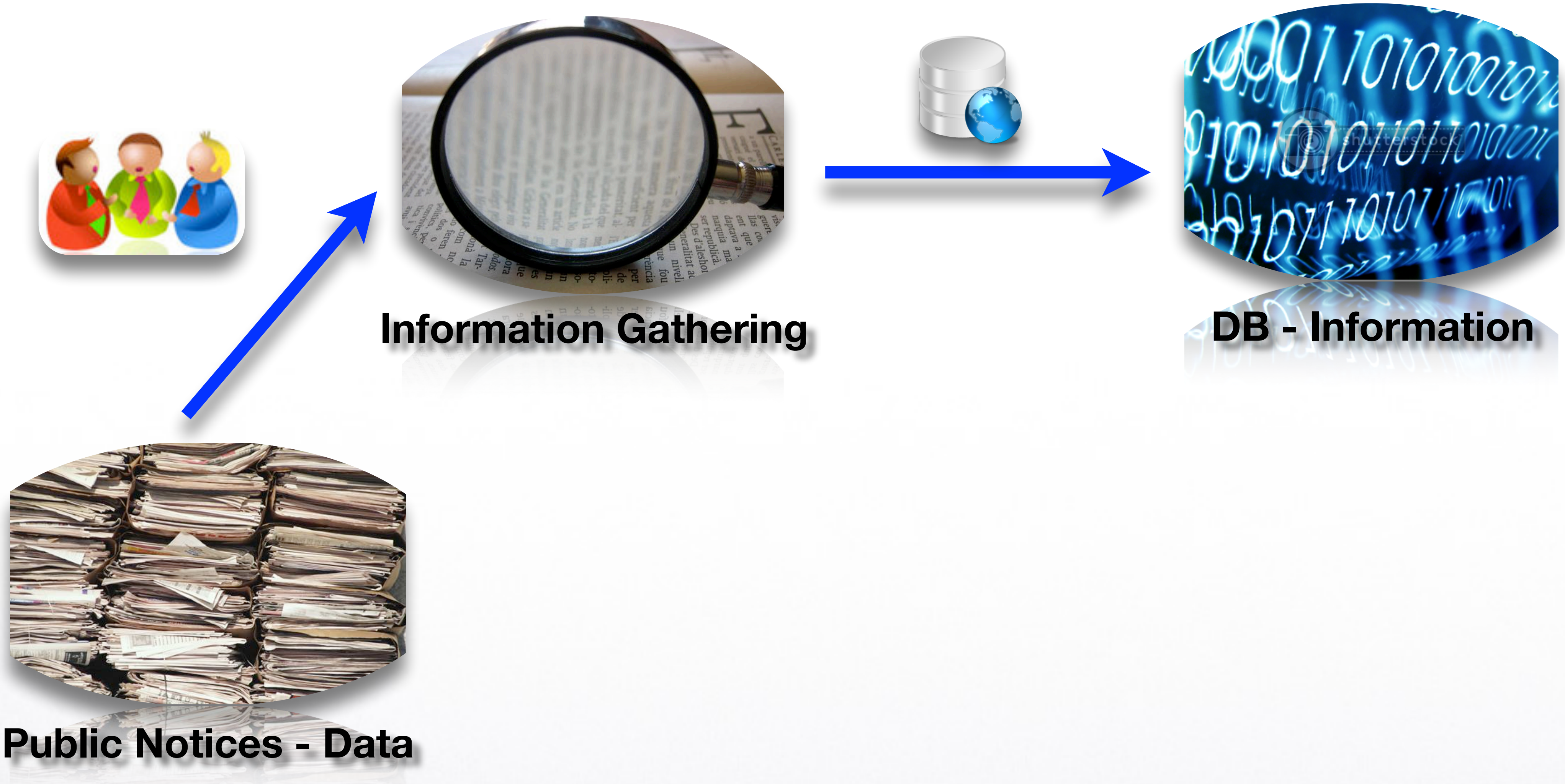
Public Notices - Data

What's the problem?

Information Gathering

Public Notices - Data

What's the problem?

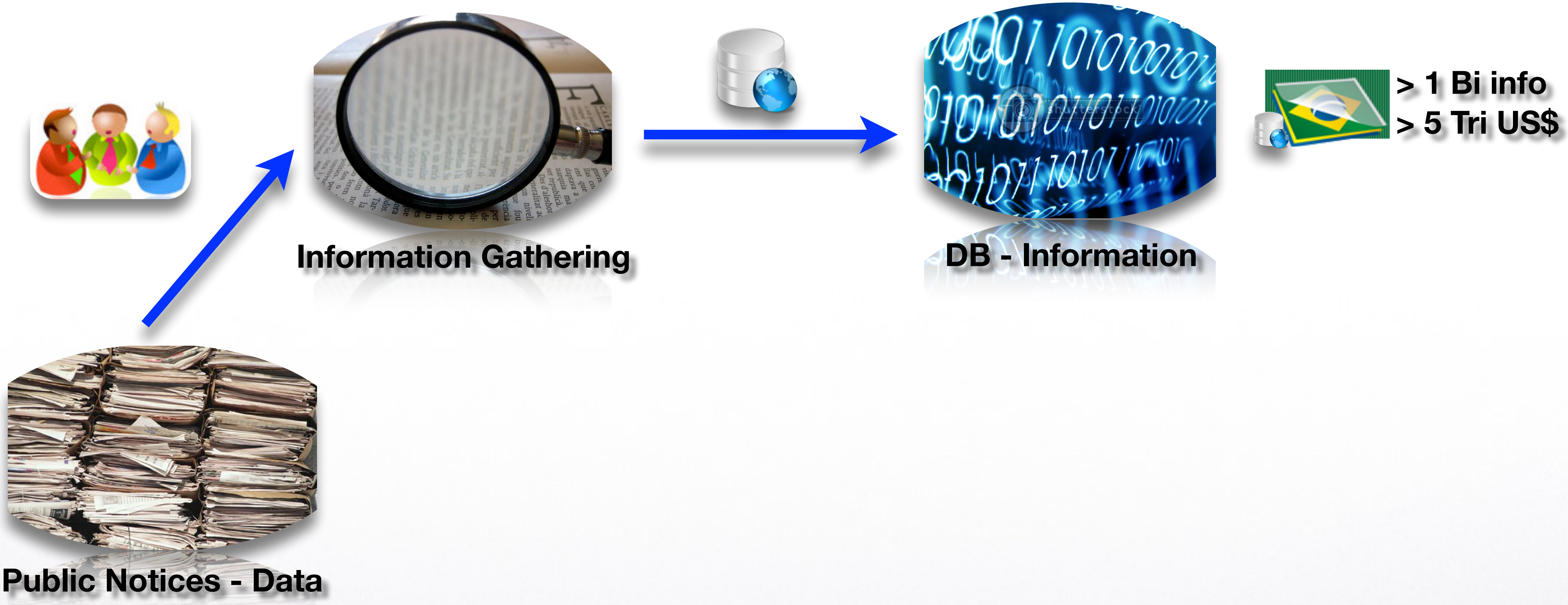


Information Gathering

DB - Information

Public Notices - Data

What's the problem?



Public Notices - Data

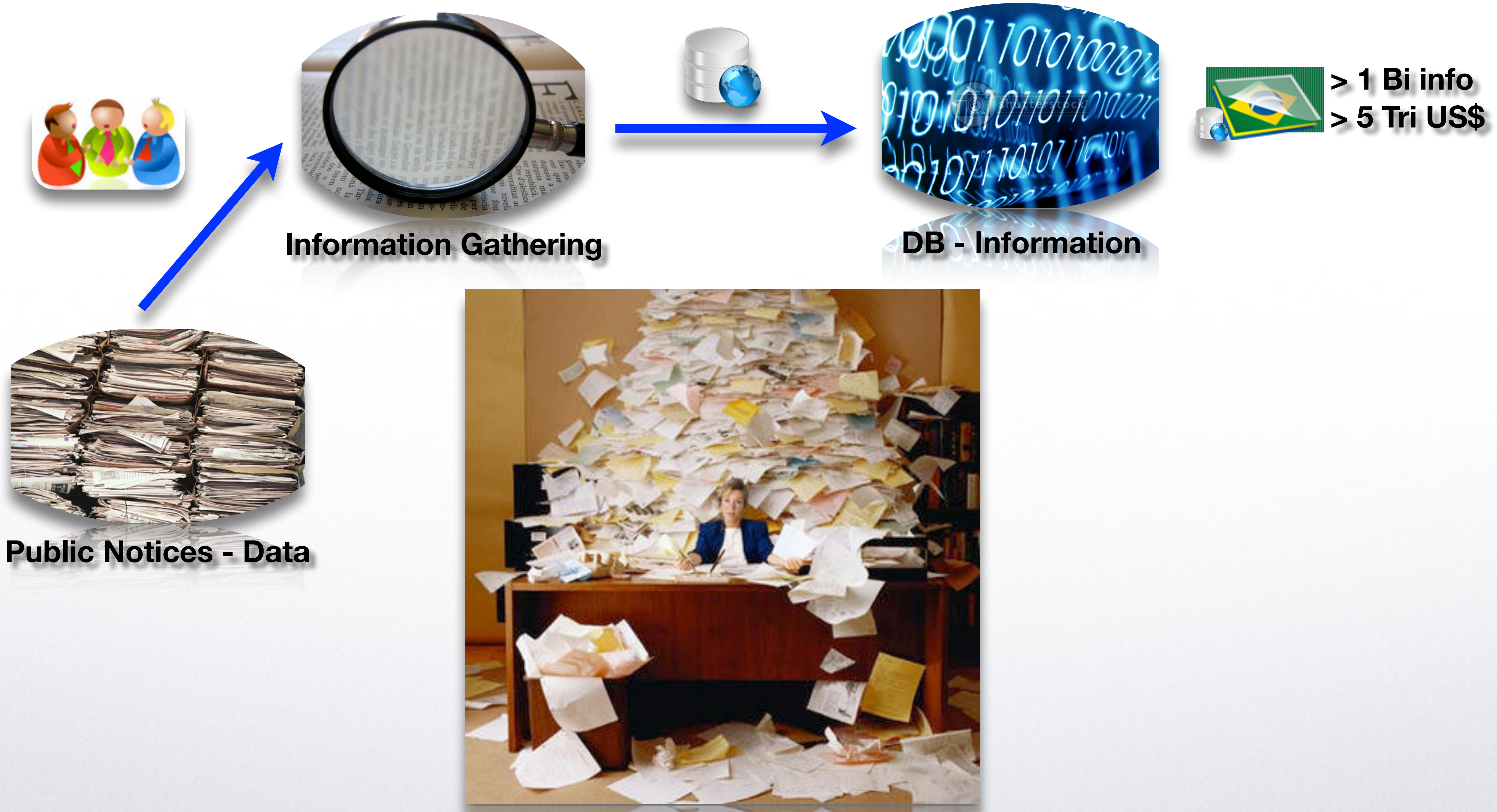
Information Gathering

DB - Information

> 1 Bi info

> 5 Tri US$

What's the problem?



Information Gathering

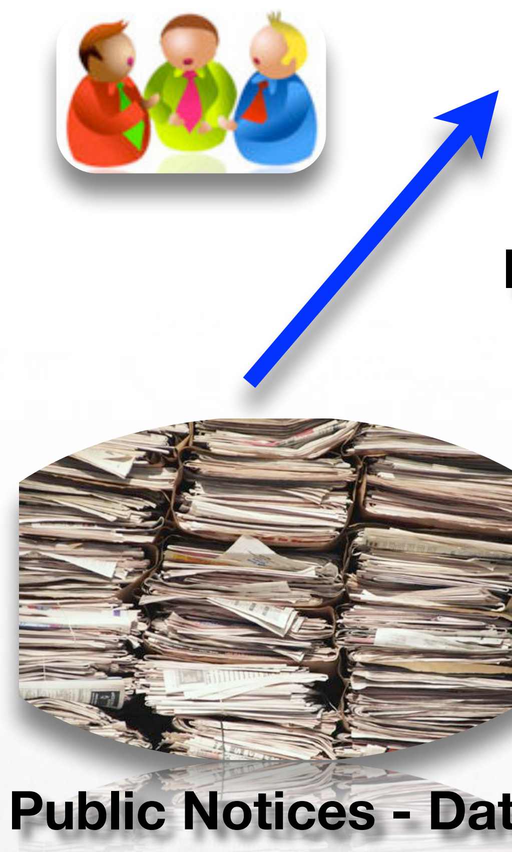
DB - Information

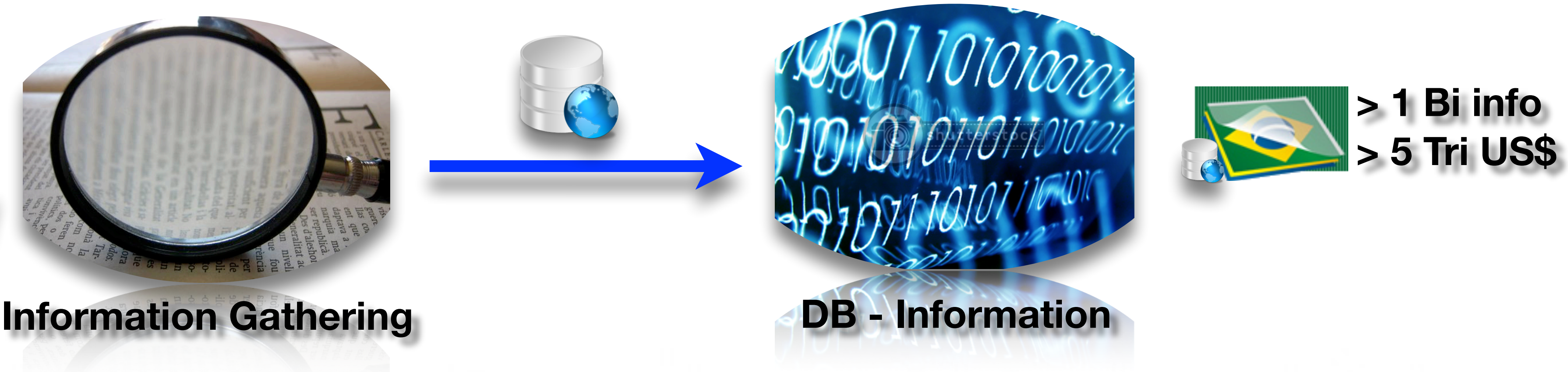
> 1 Bi info

> 5 Tri US$

Public Notices - Data

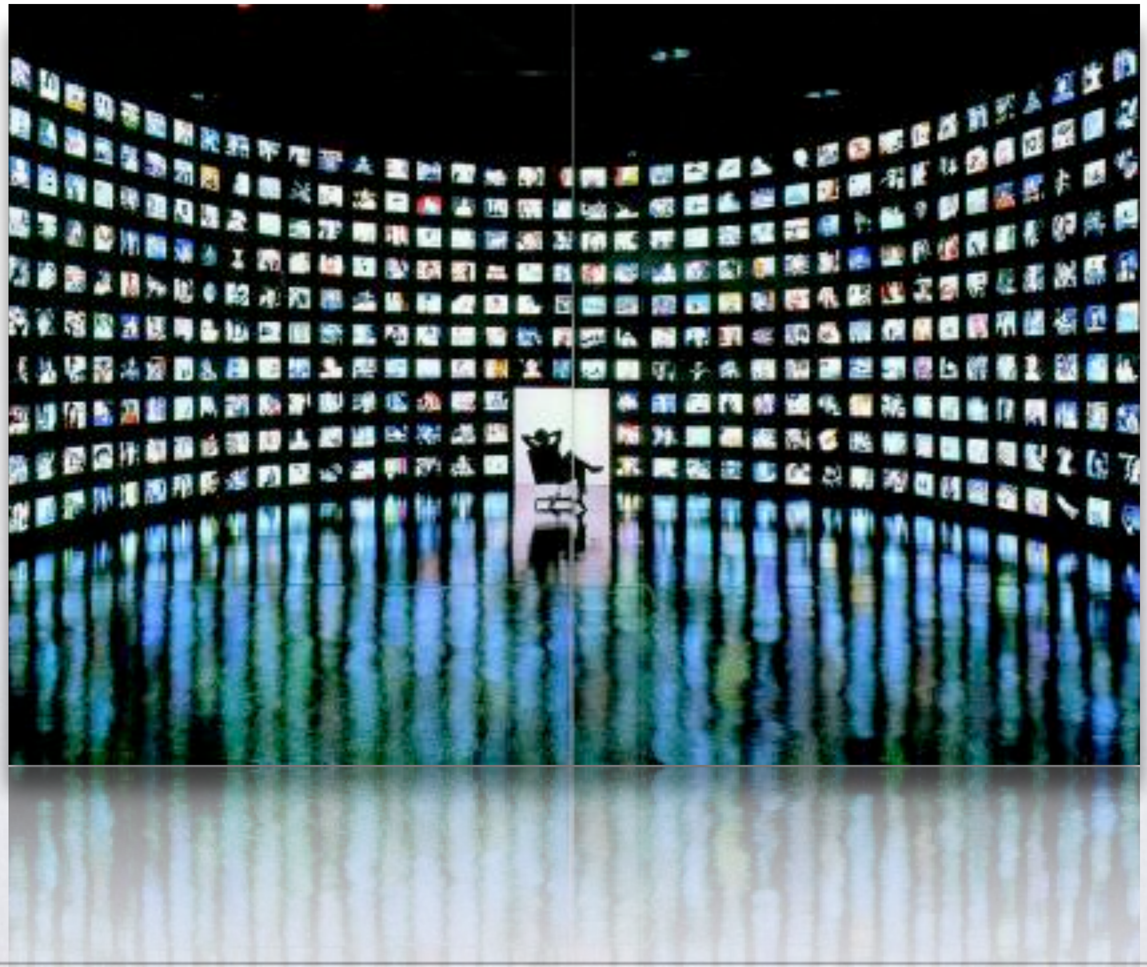
What's the problem?


Public Notices - Data

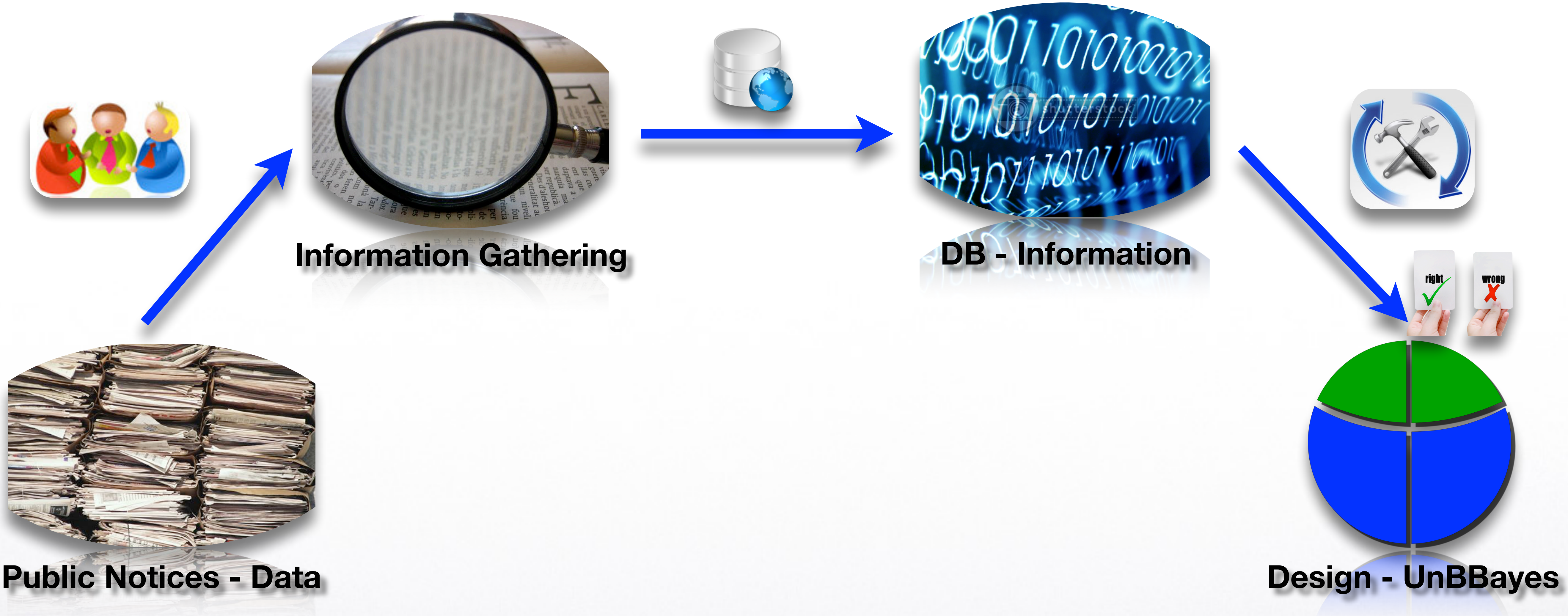

Information Gathering

DB - Information

> 1 Bi info
> 5 Tri US$



What’s the problem?



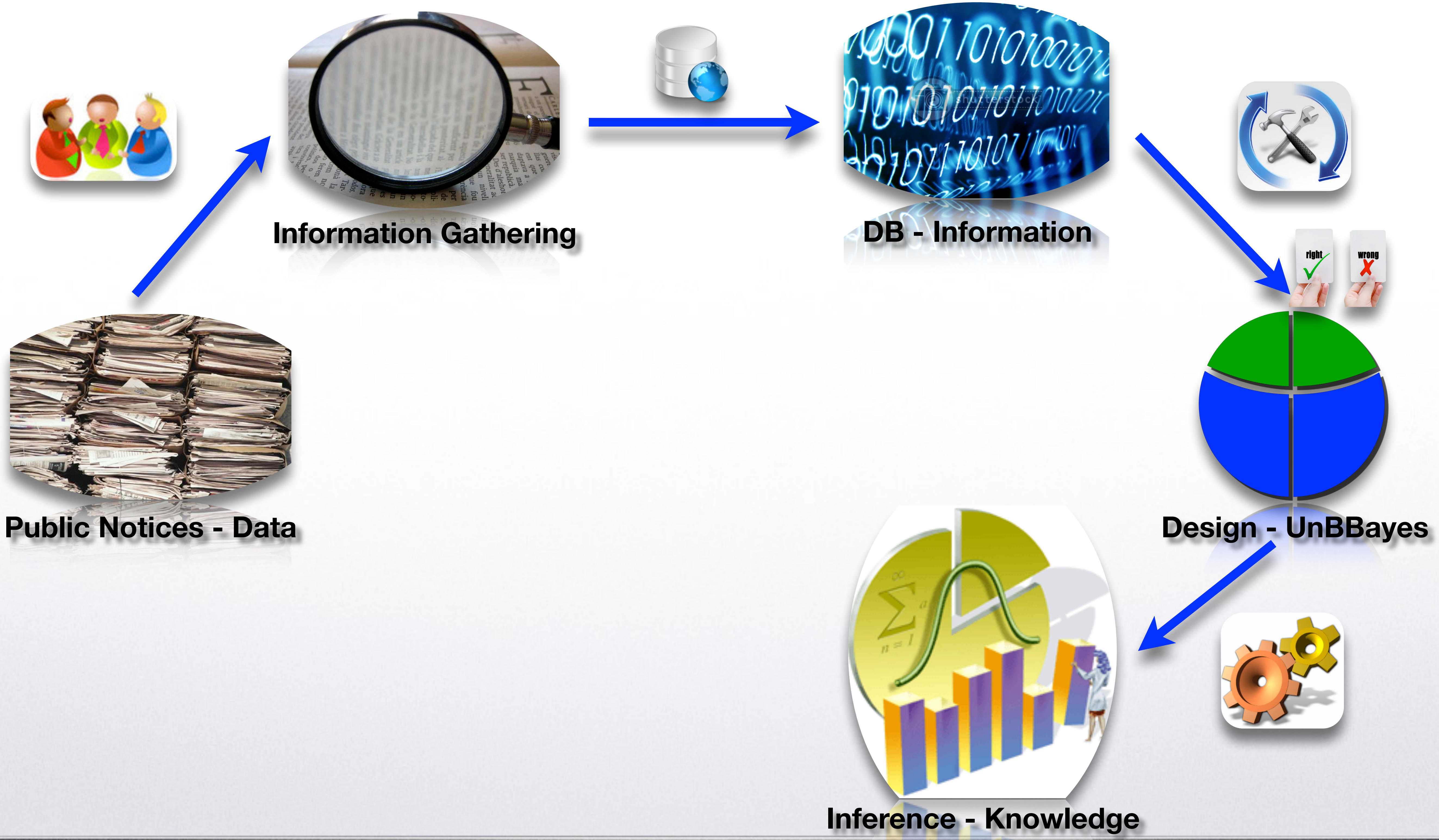
Public Notices - Data

Information Gathering

DB - Information

Design - UnBBayes

What's the problem?



Public Notices - Data

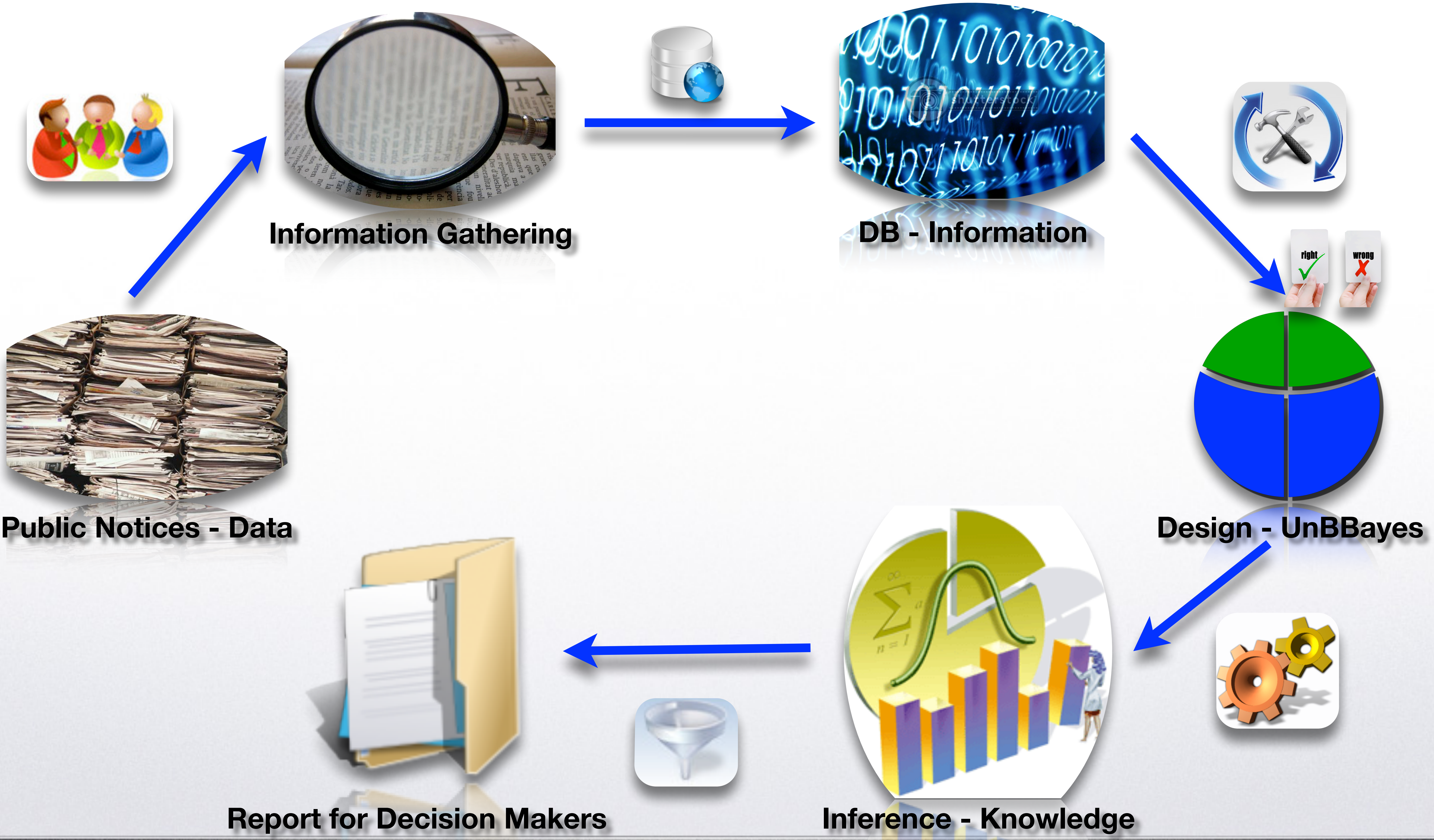
Information Gathering

DB - Information

Design - UnBBayes

Inference - Knowledge

What's the problem?


Public Notices - Data

Information Gathering

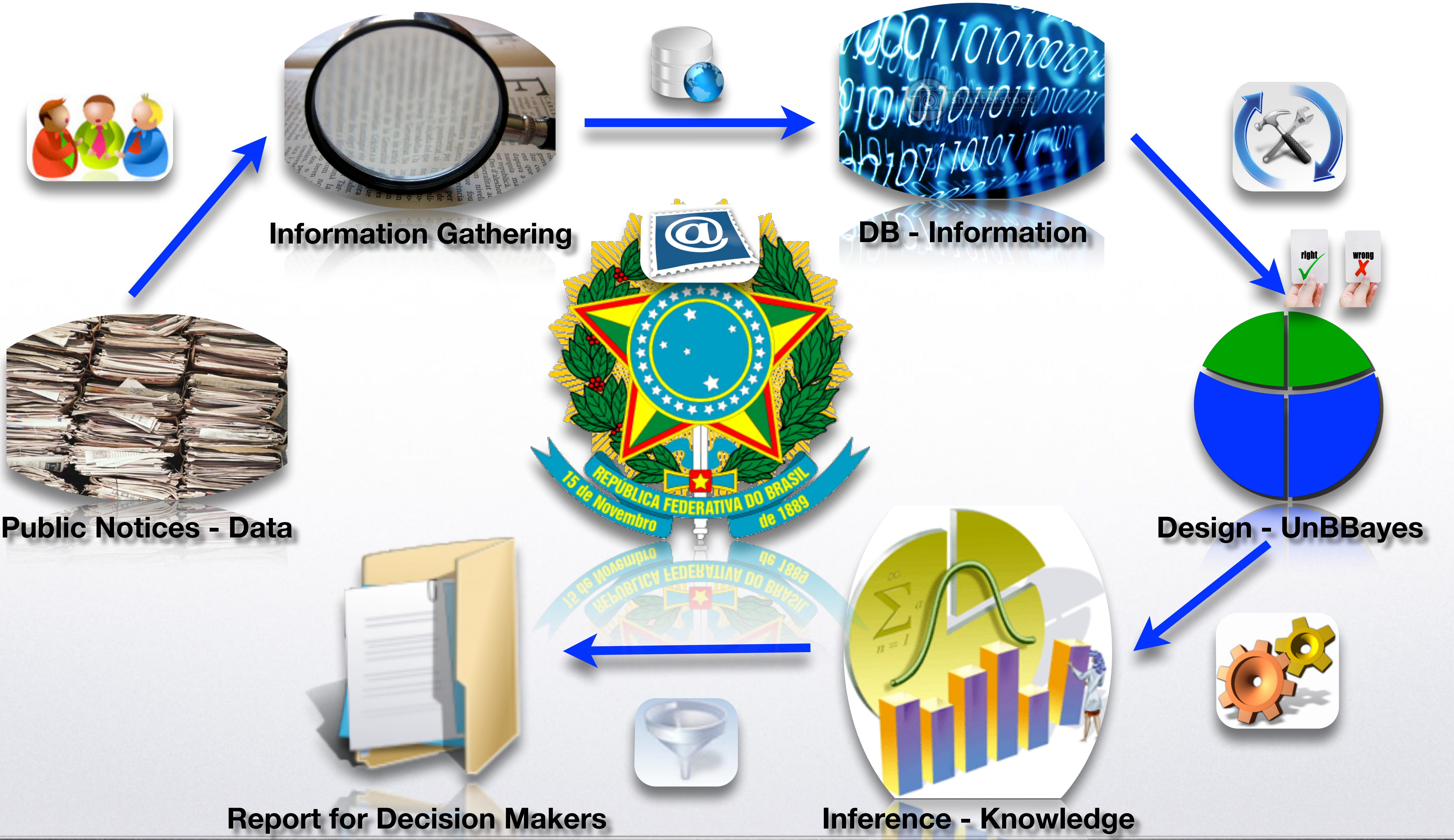
DB - Information

Design - UnBBayes

Inference - Knowledge

Report for Decision Makers

What's the problem?



Public Notices - Data

Information Gathering

DB - Information

Design - UnBBayes

Inference - Knowledge

Report for Decision Makers

Semantic Web

- Semantic Web (SW) is a web of data that can be processed by machines [45]
  - E.g., allow machines to differentiate between 3 pounds (price of product) and 3 pounds (weight of product)
- Change focus from data driven to knowledge driven
- The World Wide Web Consortium (W3C) states that ontologies provide the cement for building the SW [46]
  - Ontology: Taken from *Philosophy*, where it means a *systematic explanation of being*

Ontology

- An ontology is an explicit, formal knowledge representation that expresses knowledge about a domain of application. This includes:
  - Types of entities that exist in the domain;
  - Properties of those entities;
  - Relationships among entities;
  - Processes and events that happen with those entities;

  where the term entity refers to any concept (real or fictitious, concrete or abstract) that can be described and reasoned about within the domain of application [2].
- The Web Ontology Language (OWL)
  - Developed by the W3C
  - As a language to represent ontologies for the SW
  - Accepted as a W3C recommendation in 2004

Ontology

- An ontology is an explicit, formal knowledge representation that expresses knowledge about a domain of application. This includes:
  - Types of entities that exist in the domain; `Person, Procurement, Enterprise, ...`
  - Properties of those entities;
  - Relationships among entities;
  - Processes and events that happen with those entities;

  where the term entity refers to any concept (real or fictitious, concrete or abstract) that can be described and reasoned about within the domain of application [2].
- The Web Ontology Language (OWL)
  - Developed by the W3C
  - As a language to represent ontologies for the SW
  - Accepted as a W3C recommendation in 2004

Ontology

- An ontology is an explicit, formal knowledge representation that expresses knowledge about a domain of application. This includes:
  - Types of entities that exist in the domain; `Person, Procurement, Enterprise, ...`
  - Properties of those entities; `firstName, lastName, procurementNumber, ...`
  - Relationships among entities;
  - Processes and events that happen with those entities;

  where the term entity refers to any concept (real or fictitious, concrete or abstract) that can be described and reasoned about within the domain of application [2].

- The Web Ontology Language (OWL)
  - Developed by the W3C
  - As a language to represent ontologies for the SW
  - Accepted as a W3C recommendation in 2004

Ontology

- An ontology is an explicit, formal knowledge representation that expresses knowledge about a domain of application. This includes:
  - Types of entities that exist in the domain; `Person, Procurement, Enterprise, ...`
  - Properties of those entities; `firstName, lastName, procurementNumber, ...`
  - Relationships among entities; `motherOf, ownerOf, isFrontFor ...`
  - Processes and events that happen with those entities;

where the term entity refers to any concept (real or fictitious, concrete or abstract) that can be described and reasoned about within the domain of application [2].

- The Web Ontology Language (OWL)
  - Developed by the W3C
  - As a language to represent ontologies for the SW
  - Accepted as a W3C recommendation in 2004

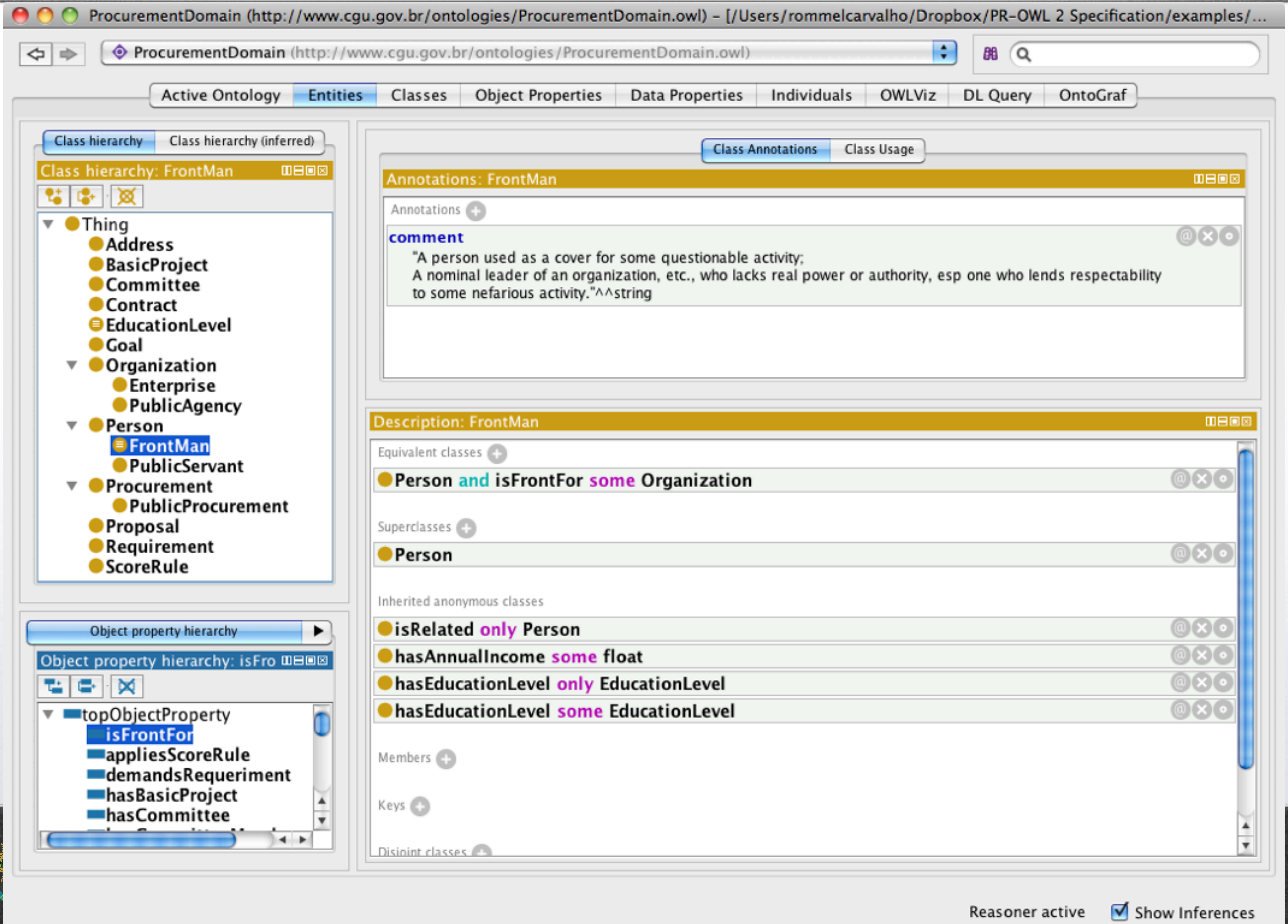
Ontology

- An ontology is an explicit, formal knowledge representation that expresses knowledge about a domain of application. This includes:
  - Types of entities that exist in the domain; `Person, Procurement, Enterprise, ...`
  - Properties of those entities; `firstName, lastName, procurementNumber, ...`
  - Relationships among entities; `motherOf, ownerOf, isFrontFor ...`
  - Processes and events that happen with those entities; `analyzing if requirements are met, choosing best proposal, ...`

  where the term entity refers to any concept (real or fictitious, concrete or abstract) that can be described and reasoned about within the domain of application [2].

- The Web Ontology Language (OWL)
  - Developed by the W3C
  - As a language to represent ontologies for the SW
  - Accepted as a W3C recommendation in 2004

Ontology in OWL



ProcurementDomain (http://www.cgu.gov.br/ontologies/ProcurementDomain.owl) - [/Users/rommelcarvalho/Dropbox/PR-OWL 2 Specification/examples/...

ProcurementDomain (http://www.cgu.gov.br/ontologies/ProcurementDomain.owl)

Class hierarchy: FrontMan

- Thing
  - Address
  - BasicProject
  - Committee
  - Contract
  - EducationLevel
  - Goal
  - Organization
    - Enterprise
    - PublicAgency
  - Person
    - FrontMan
    - PublicServant
  - Procurement
    - PublicProcurement
  - Proposal
  - Requirement
  - ScoreRule

Object property hierarchy: isFro

- topObjectProperty
  - isFrontFor
  - appliesScoreRule
  - demandsRequeriment
  - hasBasicProject
  - hasCommittee

Annotations: FrontMan

Annotations

comment
"A person used as a cover for some questionable activity;
A nominal leader of an organization, etc., who lacks real power or authority, esp one who lends respectability to some nefarious activity."^^string

Description: FrontMan

Equivalent classes

Person and isFrontFor some Organization

Superclasses

Person

Inherited anonymous classes

isRelated only Person

hasAnnualIncome some float

hasEducationLevel only EducationLevel

hasEducationLevel some EducationLevel

Members

Keys

Disjoint classes

Reasoner active ☑ Show Inferences

Uncertainty in the SW

- The community recognizes the need to represent and reason with uncertainty
- W3C created the URW3-XG in 2007
  - Concluded that standardized representations were needed [50]
- Probabilistic Web Ontology Language (PR-OWL) is a candidate language to represent probabilistic ontologies
  - Based on Multi-Entity Bayesian Network (MEBN) logic

Probabilistic Ontology

- A ontology is an explicit, formal knowledge representation that expresses knowledge about a domain of application. This includes:
  - Types of entities that exist in the domain; `Person, Procurement, Enterprise, ...`
  - Properties of those entities; `firstName, lastName, procurementNumber, ...`
  - Relationships among entities; `motherOf, ownerOf, isFrontFor ...`
  - Processes and events that happen with those entities; `analyzing if requirements are met, choosing better proposal, ...`

where the term entity refers to any concept (real or fictitious, concrete or abstract) that can be described and reasoned about within the domain of application [2].

Probabilistic Ontology

- A *probabilistic* ontology is an explicit, formal knowledge representation that expresses knowledge about a domain of application. This includes:
  - Types of entities that exist in the domain; `Person, Procurement, Enterprise, ...`
  - Properties of those entities; `firstName, lastName, procurementNumber, ...`
  - Relationships among entities; `motherOf, ownerOf, isFrontFor ...`
  - Processes and events that happen with those entities; `analyzing if requirements are met, choosing better proposal, ...`

where the term entity refers to any concept (real or fictitious, concrete or abstract) that can be described and reasoned about within the domain of application [2].

Probabilistic Ontology

- A *probabilistic* ontology is an explicit, formal knowledge representation that expresses knowledge about a domain of application. This includes:
  - Types of entities that exist in the domain; `Person, Procurement, Enterprise, ...`
  - Properties of those entities; `firstName, lastName, procurementNumber, ...`
  - Relationships among entities; `motherOf, ownerOf, isFrontFor ...`
  - Processes and events that happen with those entities; `analyzing if requirements are met, choosing better proposal, ...`
  - *Statistical regularities that characterize the domain;*
  - *Inconclusive, ambiguous, incomplete, unreliable, and dissonant knowledge related to entities of the domain;*
  - *Uncertainty about all the above forms of knowledge;*

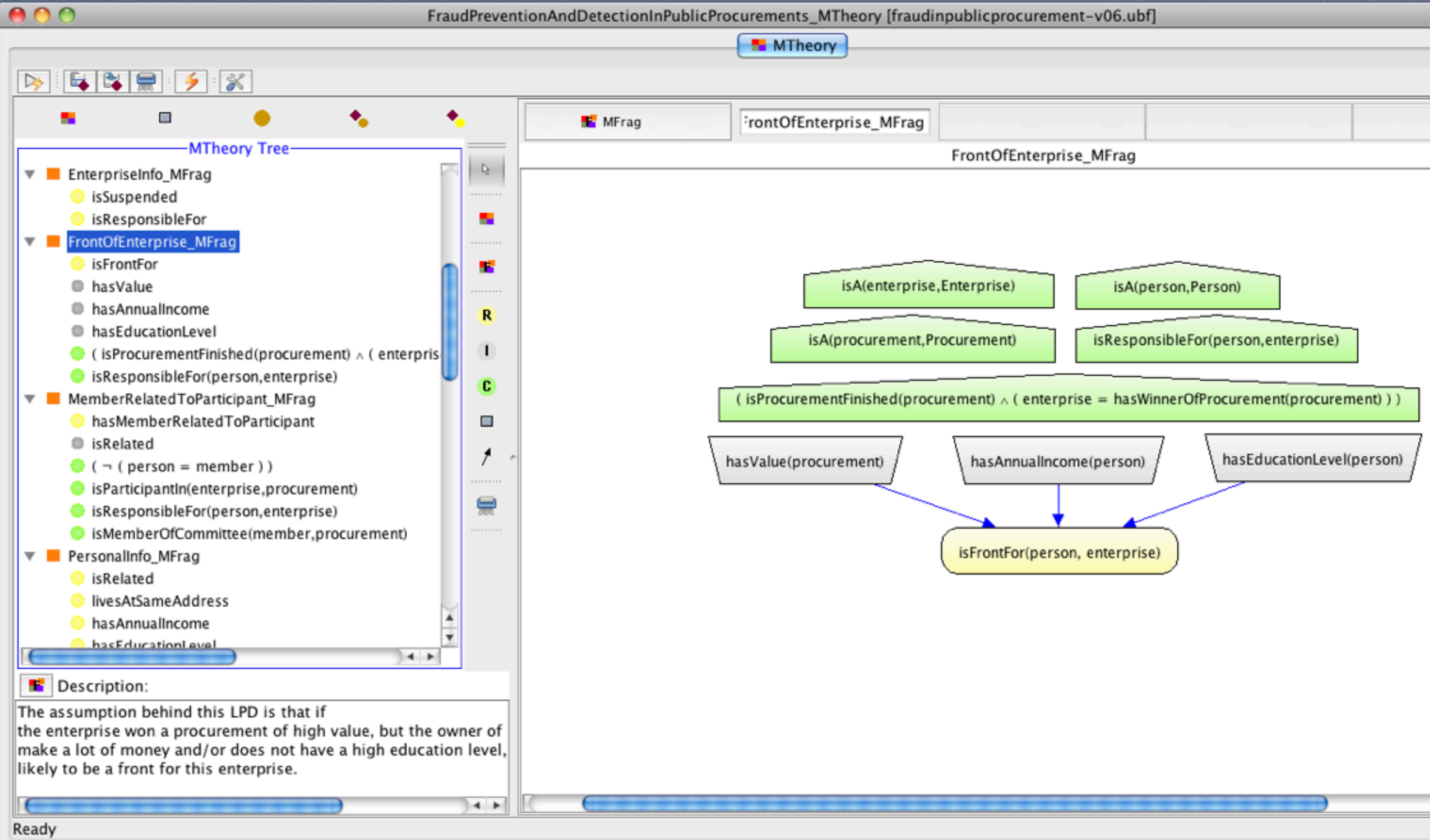
where the term entity refers to any concept (real or fictitious, concrete or abstract) that can be described and reasoned about within the domain of application [2].

Probabilistic Ontology

- A *probabilistic* ontology is an explicit, formal knowledge representation that expresses knowledge about a domain of application. This includes:
  - Types of entities that exist in the domain; `Person, Procurement, Enterprise, ...`
  - Properties of those entities; `firstName, lastName, procurementNumber, ...`
  - Relationships among entities; `motherOf, ownerOf, isFrontFor ...`
  - Processes and events that happen with those entities; `analyzing if requirements are met, choosing better proposal, ...`
  - *Statistical regularities that characterize the domain;*
  - *Inconclusive, ambiguous, incomplete, unreliable, and dissonant knowledge related to entities of the domain;*
  - *Uncertainty about all the above forms of knowledge;* `P(isFrontFor| valueOfProcurement = >1M, annualIncome = <10k) = 90%`

where the term entity refers to any concept (real or fictitious, concrete or abstract) that can be described and reasoned about within the domain of application [2].

Probabilistic Ontology in PR-OWL 1.0



FraudPreventionAndDetectionInPublicProcurements_MTheory [fraudinpublicprocurement-v06.ubf]

MTheory

MTheory Tree

- EnterpriseInfo_MFrag
  - isSuspended
  - isResponsibleFor
- FrontOfEnterprise_MFrag
  - isFrontFor
  - hasValue
  - hasAnnualIncome
  - hasEducationLevel
  - (isProcurementFinished(procurement) ∧ (enterpris
  - isResponsibleFor(person,enterprise)
- MemberRelatedToParticipant_MFrag
  - hasMemberRelatedToParticipant
  - isRelated
  - (¬ (person = member))
  - isParticipantIn(enterprise,procurement)
  - isResponsibleFor(person,enterprise)
  - isMemberOfCommittee(member,procurement)
- PersonalInfo_MFrag
  - isRelated
  - livesAtSameAddress
  - hasAnnualIncome
  - hasEducationLevel

Description:

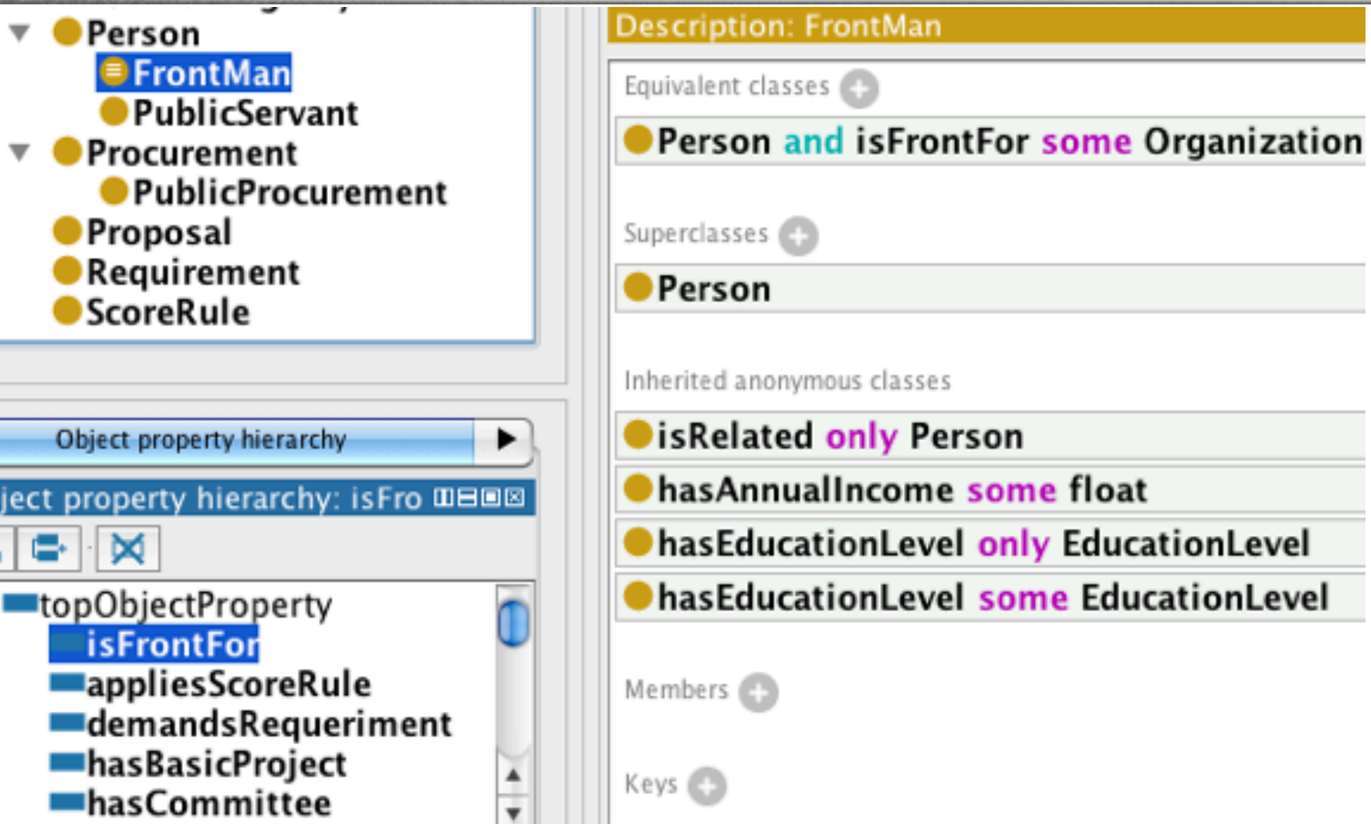
The assumption behind this LPD is that if
the enterprise won a procurement of high value, but the owner of
make a lot of money and/or does not have a high education level,
likely to be a front for this enterprise.

Ready

MFrag
FrontOfEnterprise_MFrag
FrontOfEnterprise_MFrag
R
I
C
isA(enterprise,Enterprise)
isA(person,Person)
isA(procurement,Procurement)
isResponsibleFor(person,enterprise)
(isProcurementFinished(procurement) ∧ (enterprise = hasWinnerOfProcurement(procurement)))
hasValue(procurement)
hasAnnualIncome(person)
hasEducationLevel(person)
isFrontFor(person, enterprise)

1st Problem - Mapping/Types

1st Problem - Mapping/Types



Description: FrontMan

Equivalent classes

Person and isFrontFor some Organization

Superclasses

Person

Inherited anonymous classes

isRelated only Person

hasAnnualIncome some float

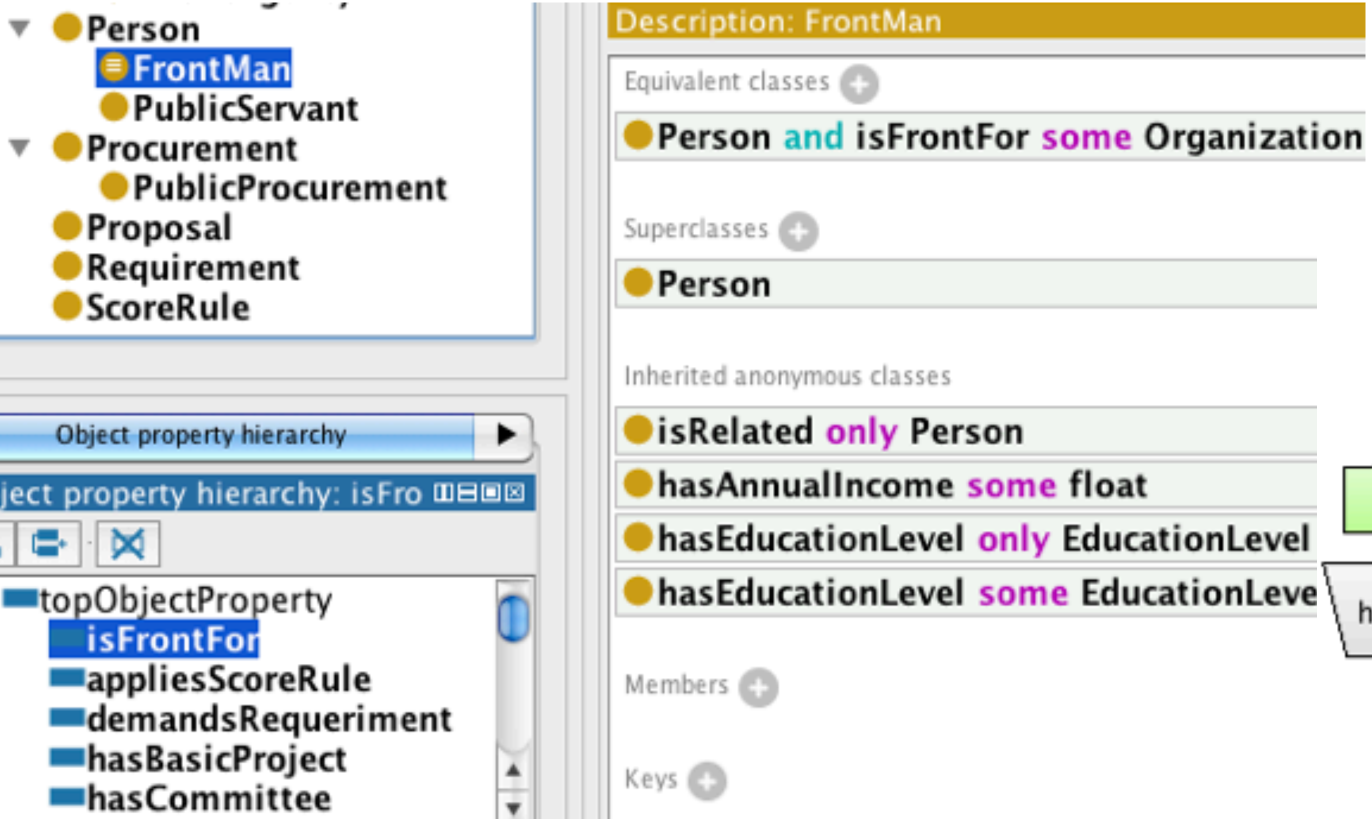
hasEducationLevel only EducationLevel

hasEducationLevel some EducationLevel

Members

Keys

1st Problem - Mapping/Types



- Person
  - FrontMan
  - PublicServant
- Procurement
  - PublicProcurement
- Proposal
- Requirement
- ScoreRule

Object property hierarchy ▶

ject property hierarchy: isFro

- topObjectProperty
  - isFrontFor
  - appliesScoreRule
  - demandsRequeriment
  - hasBasicProject
  - hasCommittee

Description: FrontMan

Equivalent classes

Person and isFrontFor some Organization

Superclasses

Person

Inherited anonymous classes

isRelated only Person

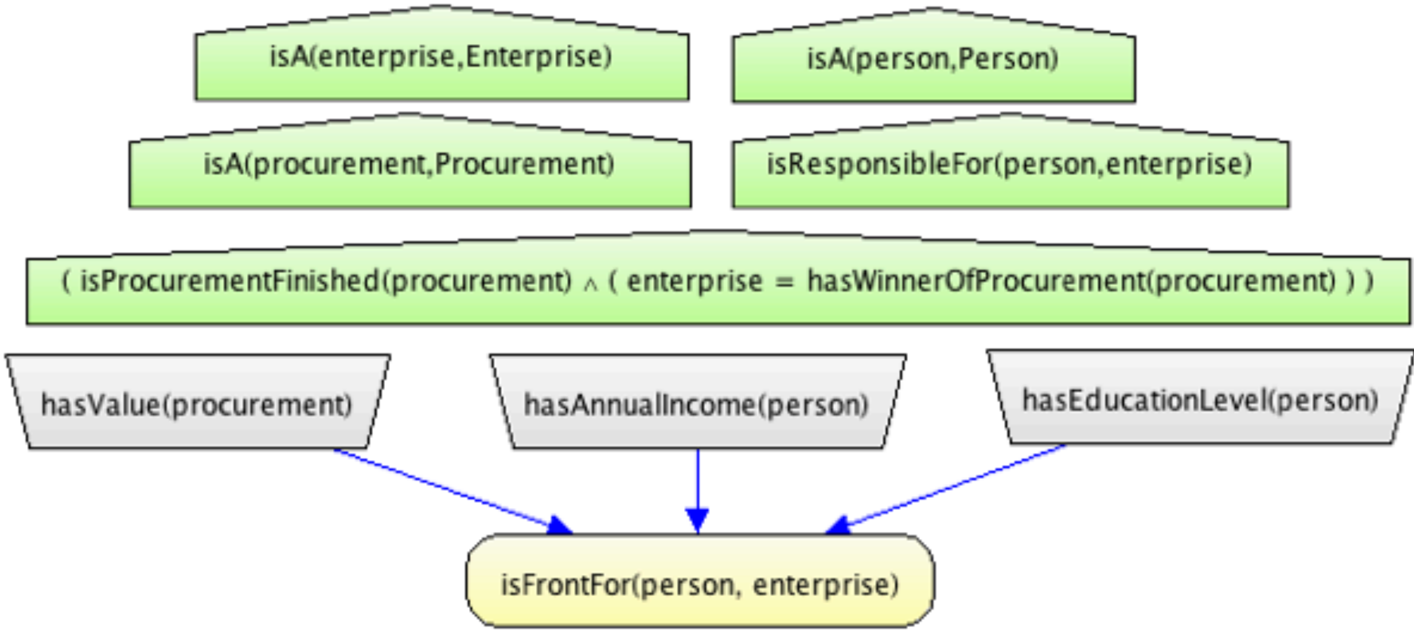
hasAnnualIncome some float

hasEducationLevel only EducationLevel

hasEducationLevel some EducationLeve

Members

Keys



isA(enterprise,Enterprise)

isA(person,Person)

isA(procurement,Procurement)

isResponsibleFor(person,enterprise)

(isProcurementFinished(procurement) ∧ (enterprise = hasWinnerOfProcurement(procurement)))

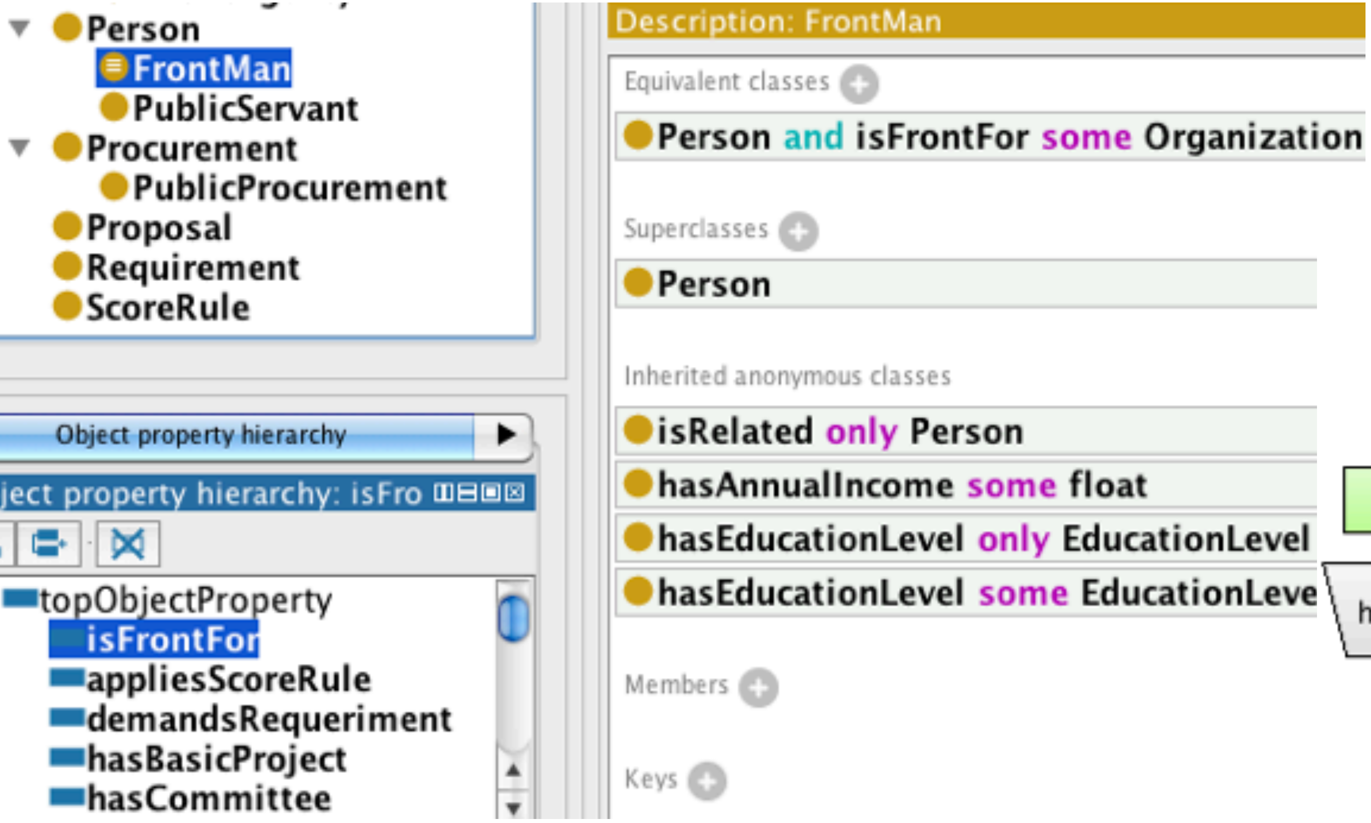
hasValue(procurement)

hasAnnualIncome(person)

hasEducationLevel(person)

isFrontFor(person, enterprise)

1st Problem - Mapping/Types



- Person
  - FrontMan
  - PublicServant
- Procurement
  - PublicProcurement
- Proposal
- Requirement
- ScoreRule

Object property hierarchy

ject property hierarchy: isFro

- topObjectProperty
  - isFrontFor
  - appliesScoreRule
  - demandsRequeriment
  - hasBasicProject
  - hasCommittee

Description: FrontMan

Equivalent classes

Person and isFrontFor some Organization

Superclasses

Person

Inherited anonymous classes

isRelated only Person

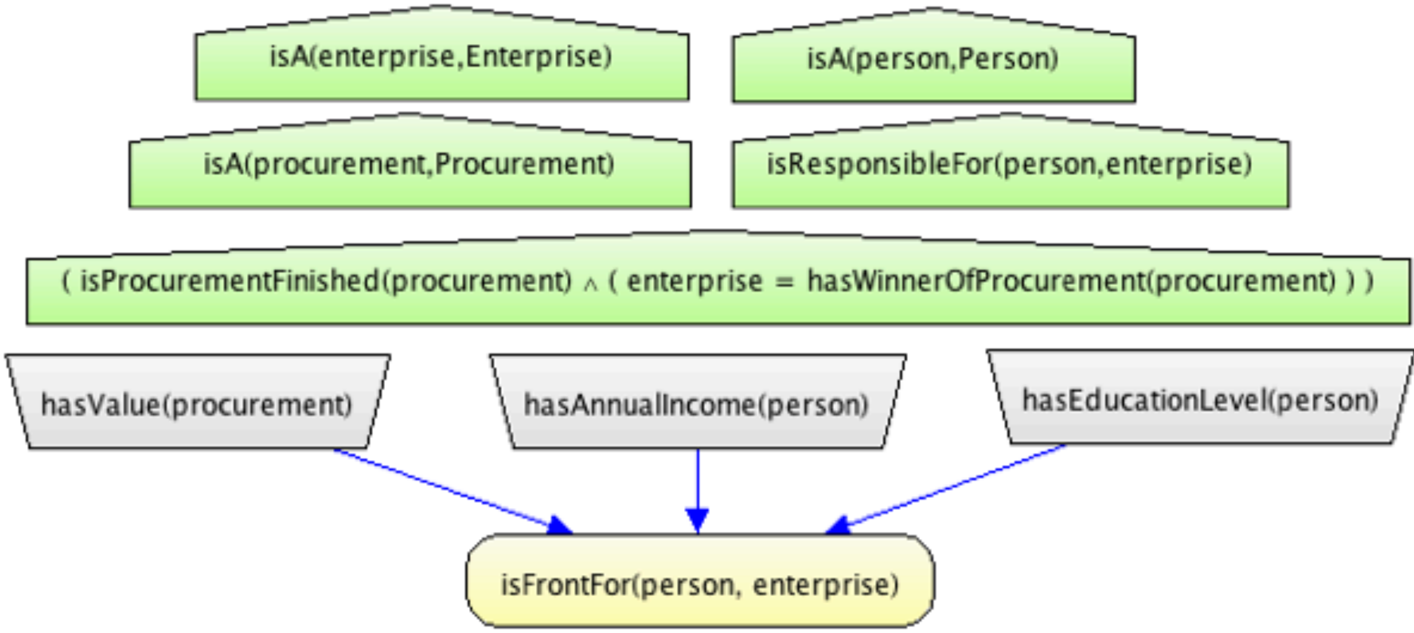
hasAnnualIncome some float

hasEducationLevel only EducationLevel

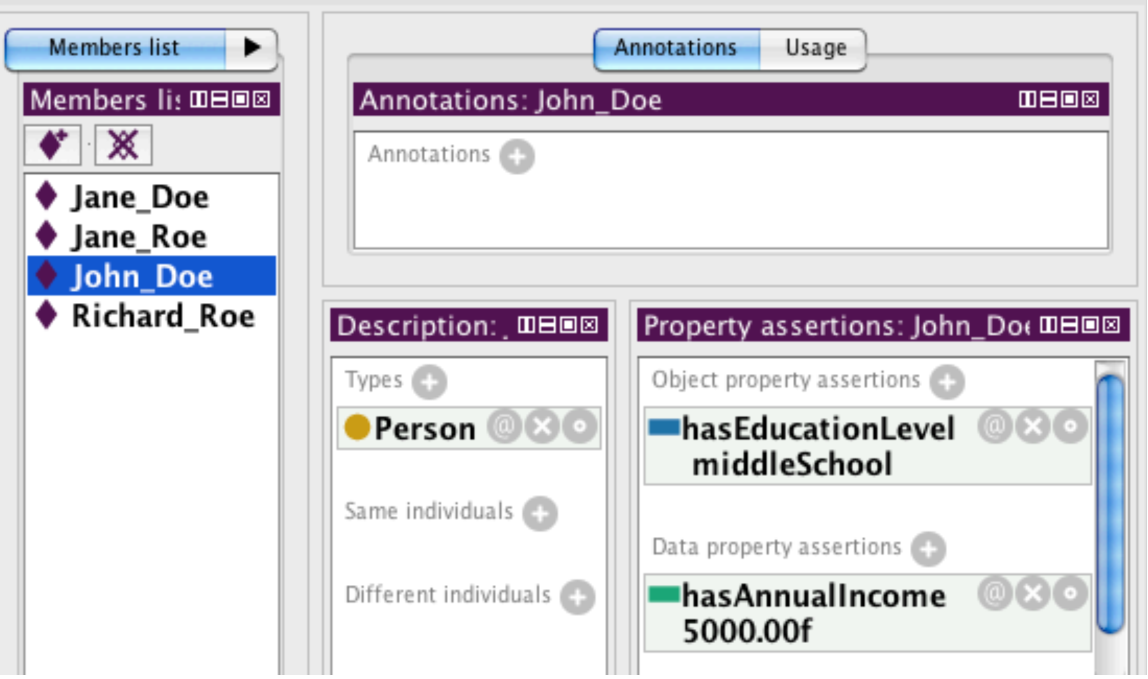
hasEducationLevel some EducationLeve

Members

Keys



isA(enterprise,Enterprise)
isA(person,Person)
isA(procurement,Procurement)
isResponsibleFor(person,enterprise)
(isProcurementFinished(procurement) ∧ (enterprise = hasWinnerOfProcurement(procurement)))
hasValue(procurement)
hasAnnualIncome(person)
hasEducationLevel(person)
isFrontFor(person, enterprise)



Members list

Members lis

- Jane_Doe
- Jane_Roe
- John_Doe
- Richard_Roe

Annotations | Usage

Annotations: John_Doe

Annotations

Description:

Types

Person

Same individuals

Different individuals

Property assertions: John_Do

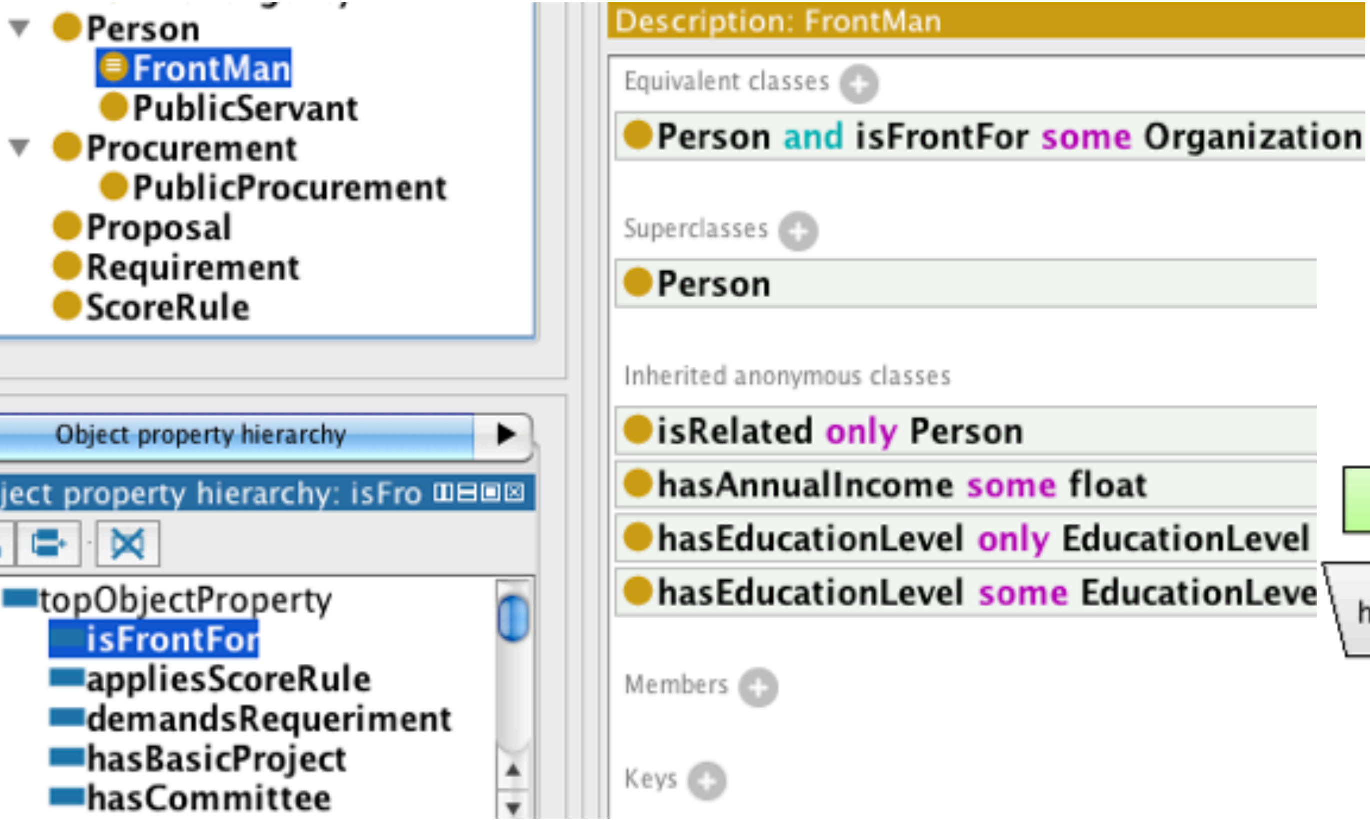
Object property assertions

hasEducationLevel middleSchool

Data property assertions

hasAnnualIncome 5000.00f

1st Problem - Mapping/Types



- Person
  - FrontMan
  - PublicServant
- Procurement
  - PublicProcurement
- Proposal
- Requirement
- ScoreRule

Description: FrontMan

Equivalent classes

Person and isFrontFor some Organization

Superclasses

Person

Inherited anonymous classes

isRelated only Person

hasAnnualIncome some float

hasEducationLevel only EducationLevel

hasEducationLevel some EducationLeve

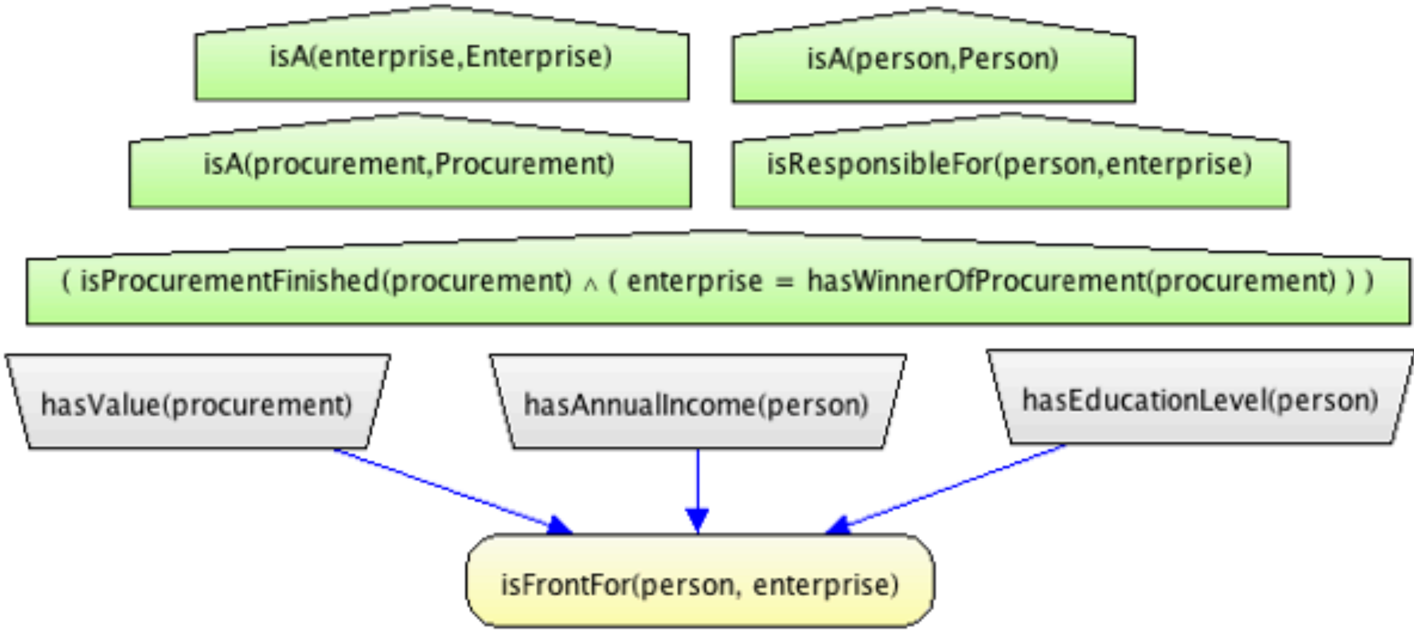
Members

Keys

Object property hierarchy

ject property hierarchy: isFro

- topObjectProperty
  - isFrontFor
  - appliesScoreRule
  - demandsRequeriment
  - hasBasicProject
  - hasCommittee



isA(enterprise,Enterprise)

isA(person,Person)

isA(procurement,Procurement)

isResponsibleFor(person,enterprise)

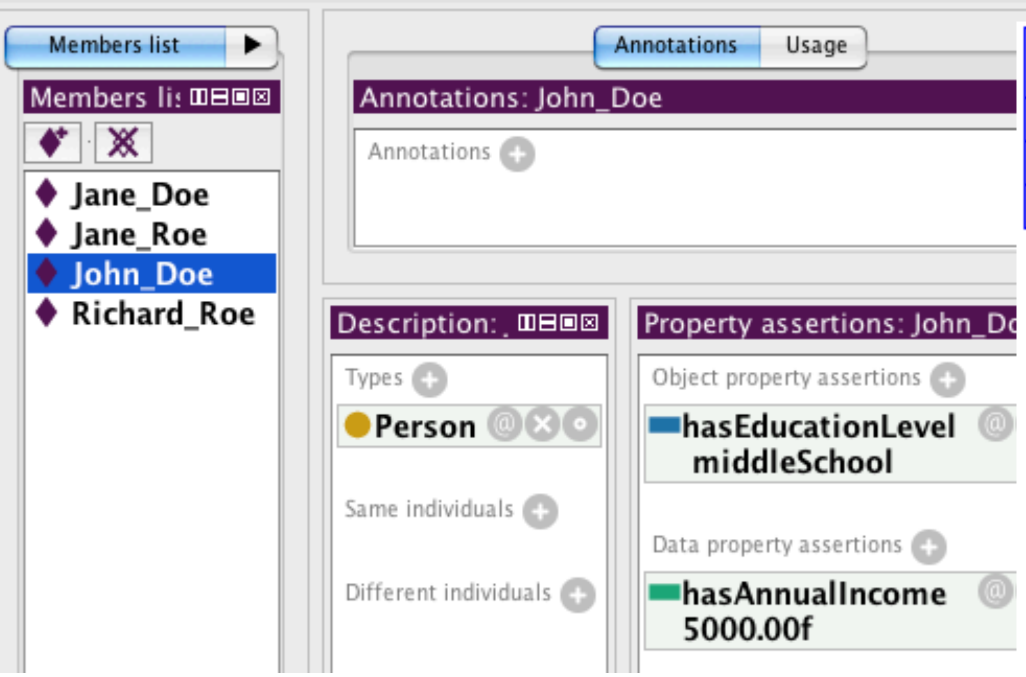
(isProcurementFinished(procurement) ∧ (enterprise = hasWinnerOfProcurement(procurement)))

hasValue(procurement)

hasAnnualIncome(person)

hasEducationLevel(person)

isFrontFor(person, enterprise)



Members list

Members li:

- Jane_Doe
- Jane_Roe
- John_Doe
- Richard_Roe

Annotations | Usage

Annotations: John_Doe

Annotations

Description:

Types

Person

Same individuals

Different individuals

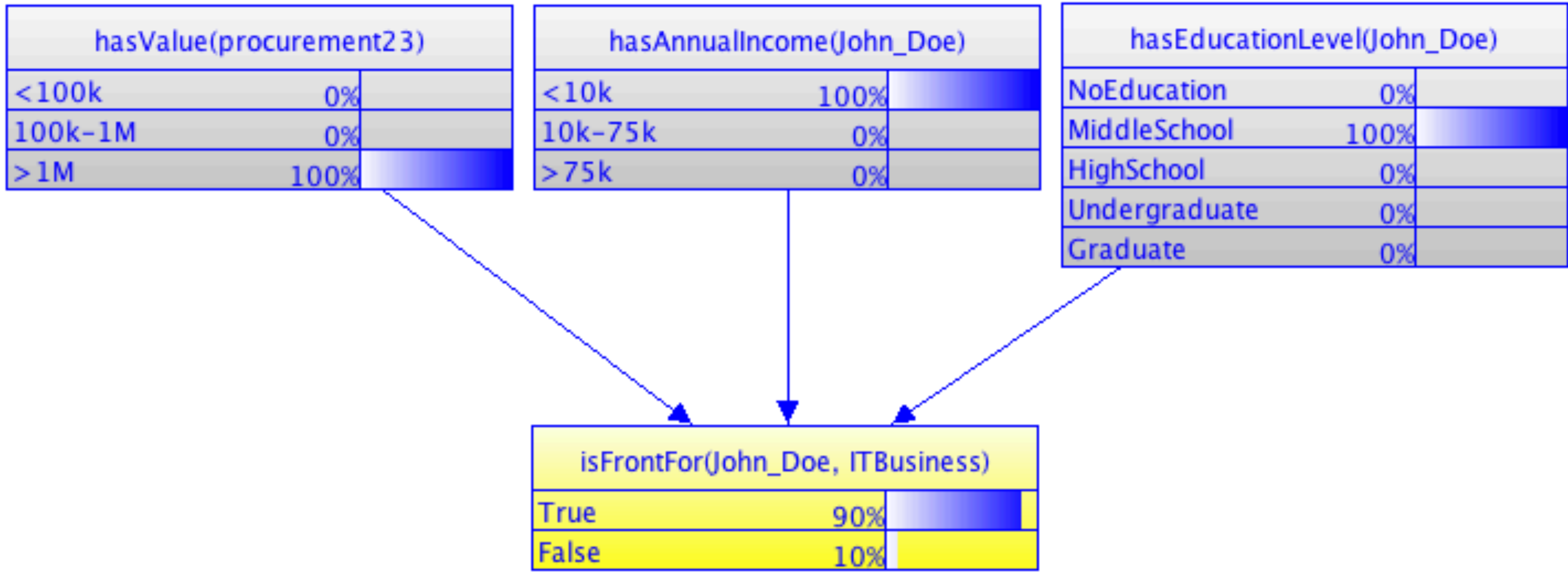
Property assertions: John_Do

Object property assertions

hasEducationLevel middleSchool

Data property assertions

hasAnnualIncome 5000.00f



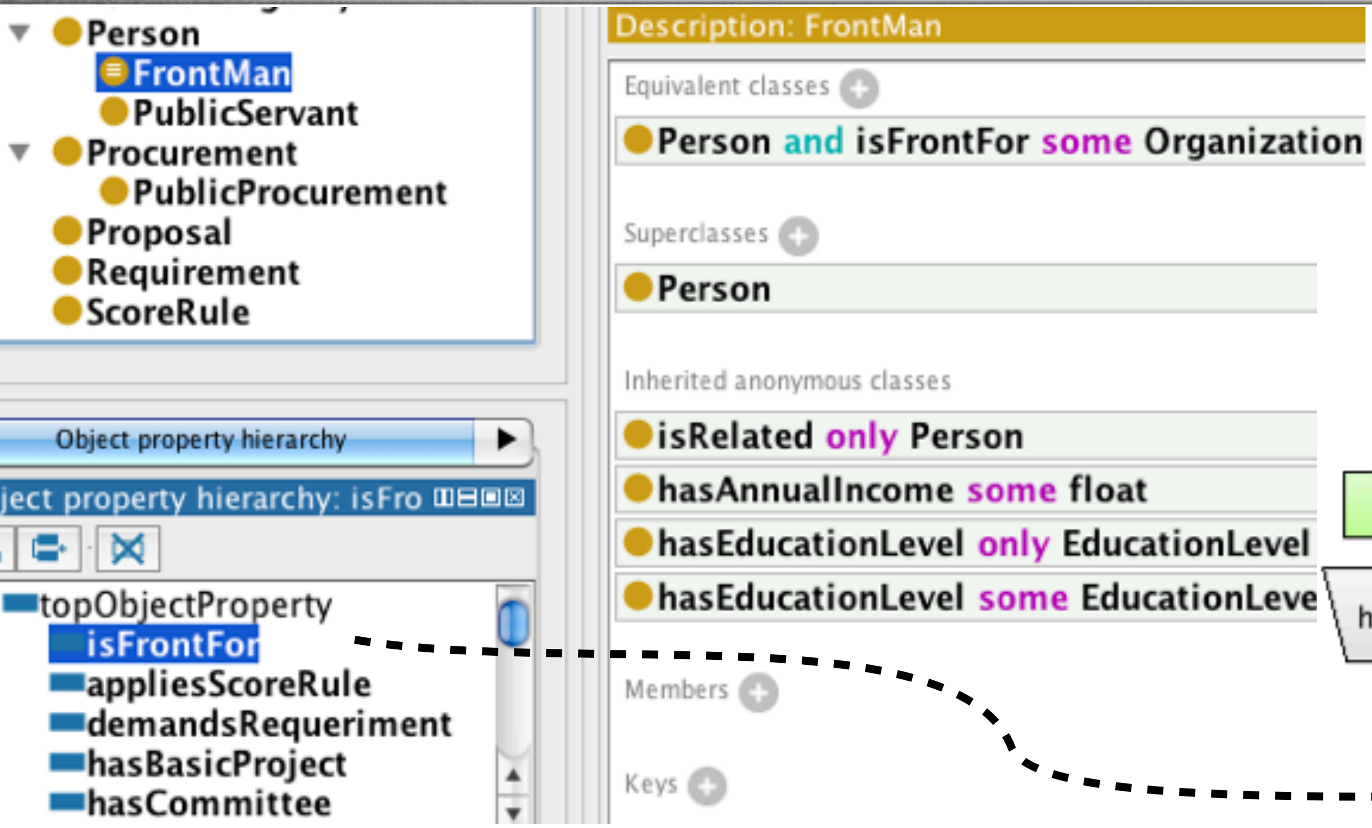
hasValue(procurement23)	
<100k	0%
100k-1M	0%
>1M	100%

hasAnnualIncome(John_Doe)	
<10k	100%
10k-75k	0%
>75k	0%

hasEducationLevel(John_Doe)	
NoEducation	0%
MiddleSchool	100%
HighSchool	0%
Undergraduate	0%
Graduate	0%

isFrontFor(John_Doe, ITBusiness)	
True	90%
False	10%

1st Problem - Mapping/Types



- Person
  - FrontMan
  - PublicServant
- Procurement
  - PublicProcurement
- Proposal
- Requirement
- ScoreRule

- topObjectProperty
  - isFrontFor
  - appliesScoreRule
  - demandsRequeriment
  - hasBasicProject
  - hasCommittee

Description: FrontMan

Equivalent classes

Person and isFrontFor some Organization

Superclasses

Person

Inherited anonymous classes

isRelated only Person

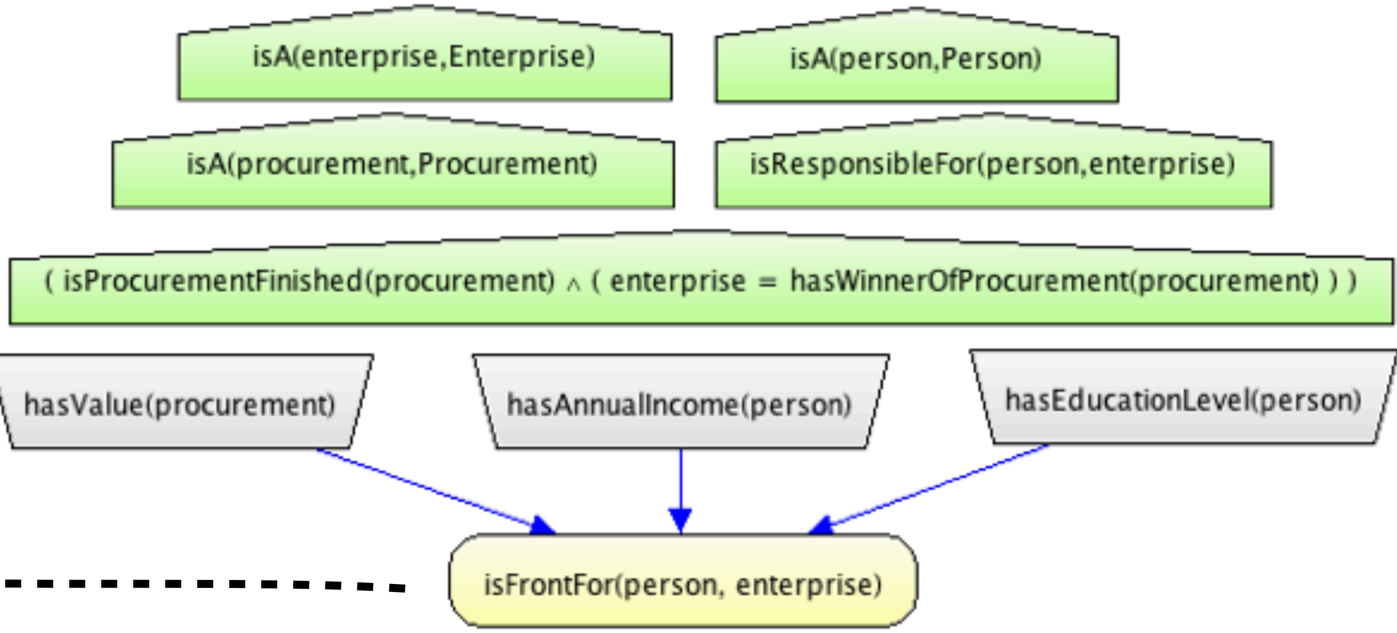
hasAnnualIncome some float

hasEducationLevel only EducationLevel

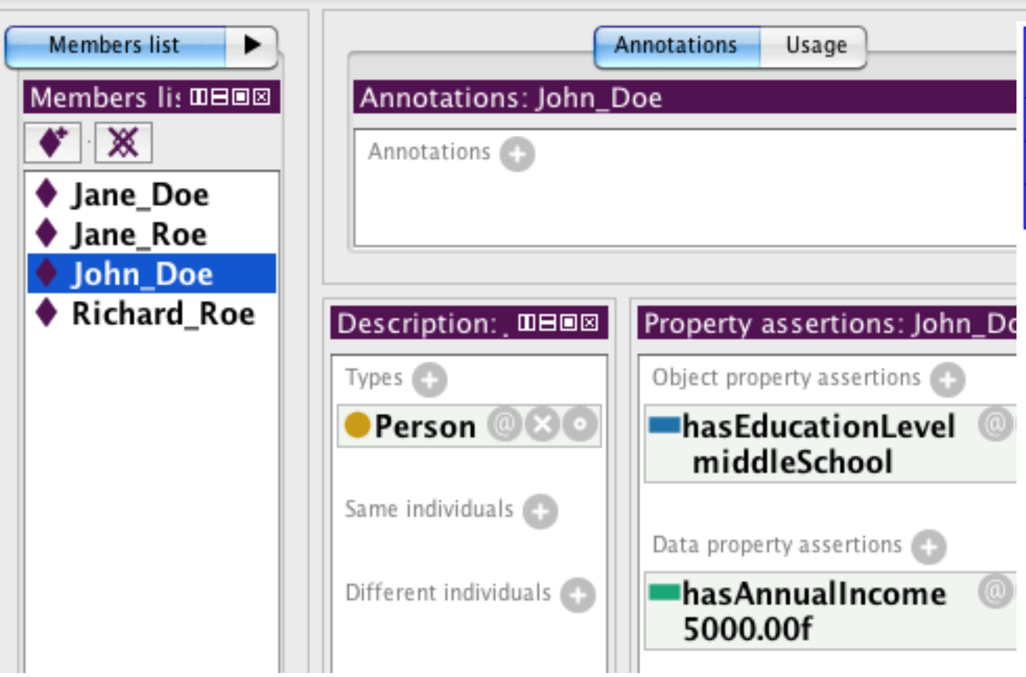
hasEducationLevel some EducationLeve

Members

Keys



isA(enterprise,Enterprise)
isA(person,Person)
isA(procurement,Procurement)
isResponsibleFor(person,enterprise)
(isProcurementFinished(procurement) ∧ (enterprise = hasWinnerOfProcurement(procurement)))
hasValue(procurement)
hasAnnualIncome(person)
hasEducationLevel(person)
isFrontFor(person, enterprise)



- Jane_Doe
- Jane_Roe
- John_Doe
- Richard_Roe

Annotations: John_Doe

Annotations

Description:

Types

Person

Same individuals

Different individuals

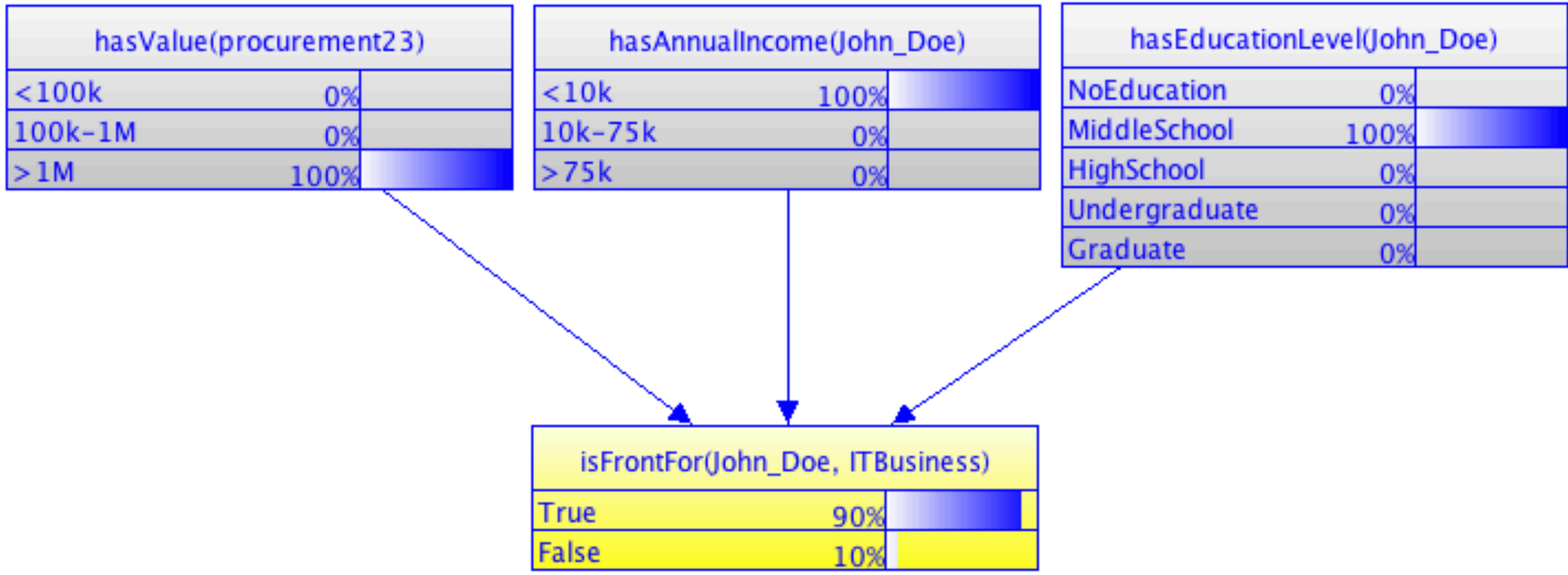
Property assertions: John_Do

Object property assertions

hasEducationLevel middleSchool

Data property assertions

hasAnnualIncome 5000.00f



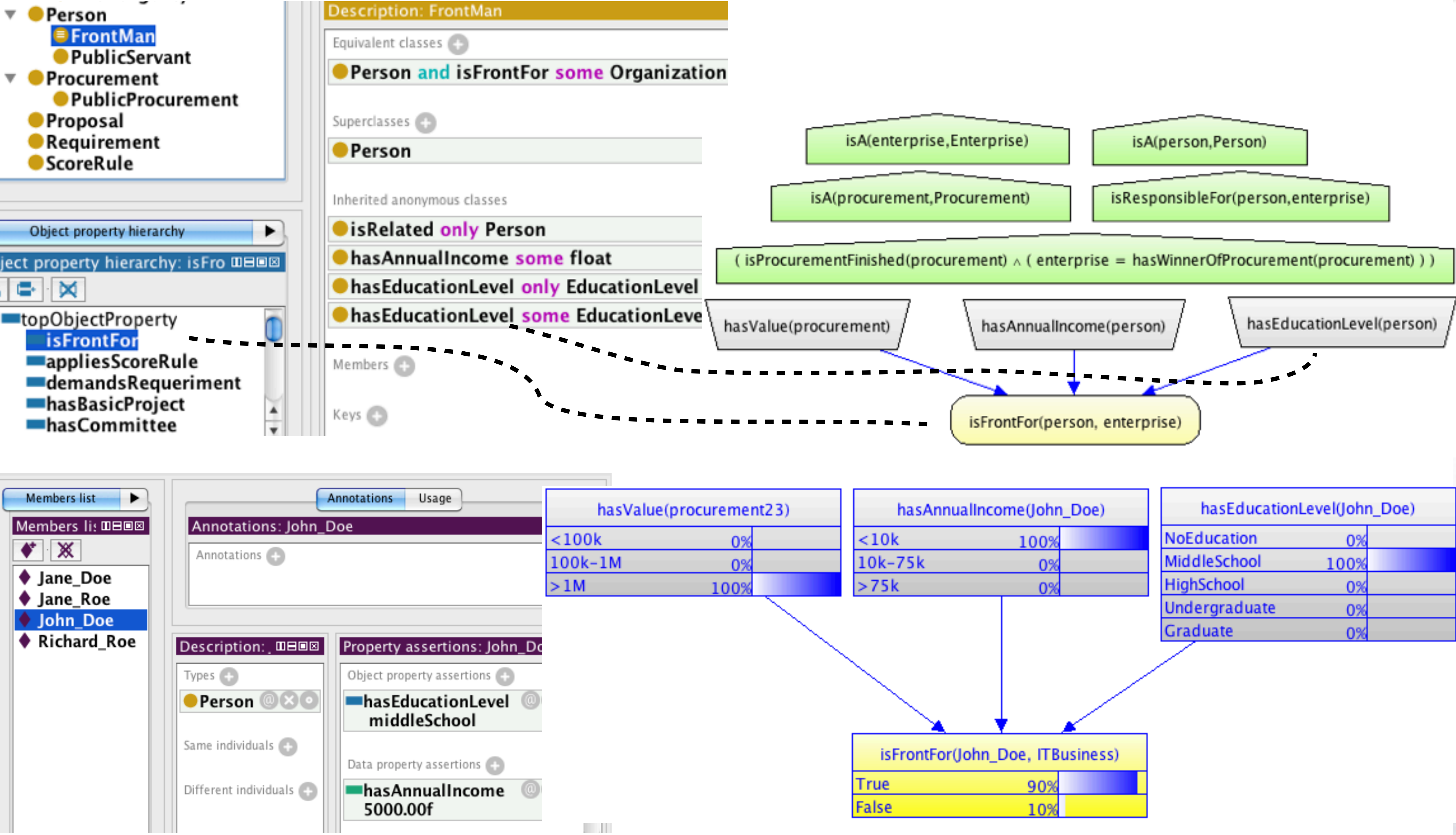
hasValue(procurement23)	
<100k	0%
100k-1M	0%
>1M	100%

hasAnnualIncome(John_Doe)	
<10k	100%
10k-75k	0%
>75k	0%

hasEducationLevel(John_Doe)	
NoEducation	0%
MiddleSchool	100%
HighSchool	0%
Undergraduate	0%
Graduate	0%

isFrontFor(John_Doe, ITBusiness)	
True	90%
False	10%

1st Problem - Mapping/Types



- Person
  - FrontMan
  - PublicServant
- Procurement
  - PublicProcurement
- Proposal
- Requirement
- ScoreRule

Description: FrontMan

Equivalent classes

Person and isFrontFor some Organization

Superclasses

Person

Inherited anonymous classes

isRelated only Person

hasAnnualIncome some float

hasEducationLevel only EducationLevel

hasEducationLevel some EducationLeve

Members

Keys

Object property hierarchy

ject property hierarchy: isFro

- topObjectProperty
  - isFrontFor
  - appliesScoreRule
  - demandsRequeriment
  - hasBasicProject
  - hasCommittee

Members list

Members li:

- Jane_Doe
- Jane_Roe
- John_Doe
- Richard_Roe

Annotations | Usage

Annotations: John_Doe

Annotations

Description: _

Types

Person

Same individuals

Different individuals

Property assertions: John_Do

Object property assertions

hasEducationLevel middleSchool

Data property assertions

hasAnnualIncome 5000.00f

isA(enterprise,Enterprise)
isA(person,Person)
isA(procurement,Procurement)
isResponsibleFor(person,enterprise)
(isProcurementFinished(procurement) ∧ (enterprise = hasWinnerOfProcurement(procurement)))
hasValue(procurement)
hasAnnualIncome(person)
hasEducationLevel(person)
isFrontFor(person, enterprise)

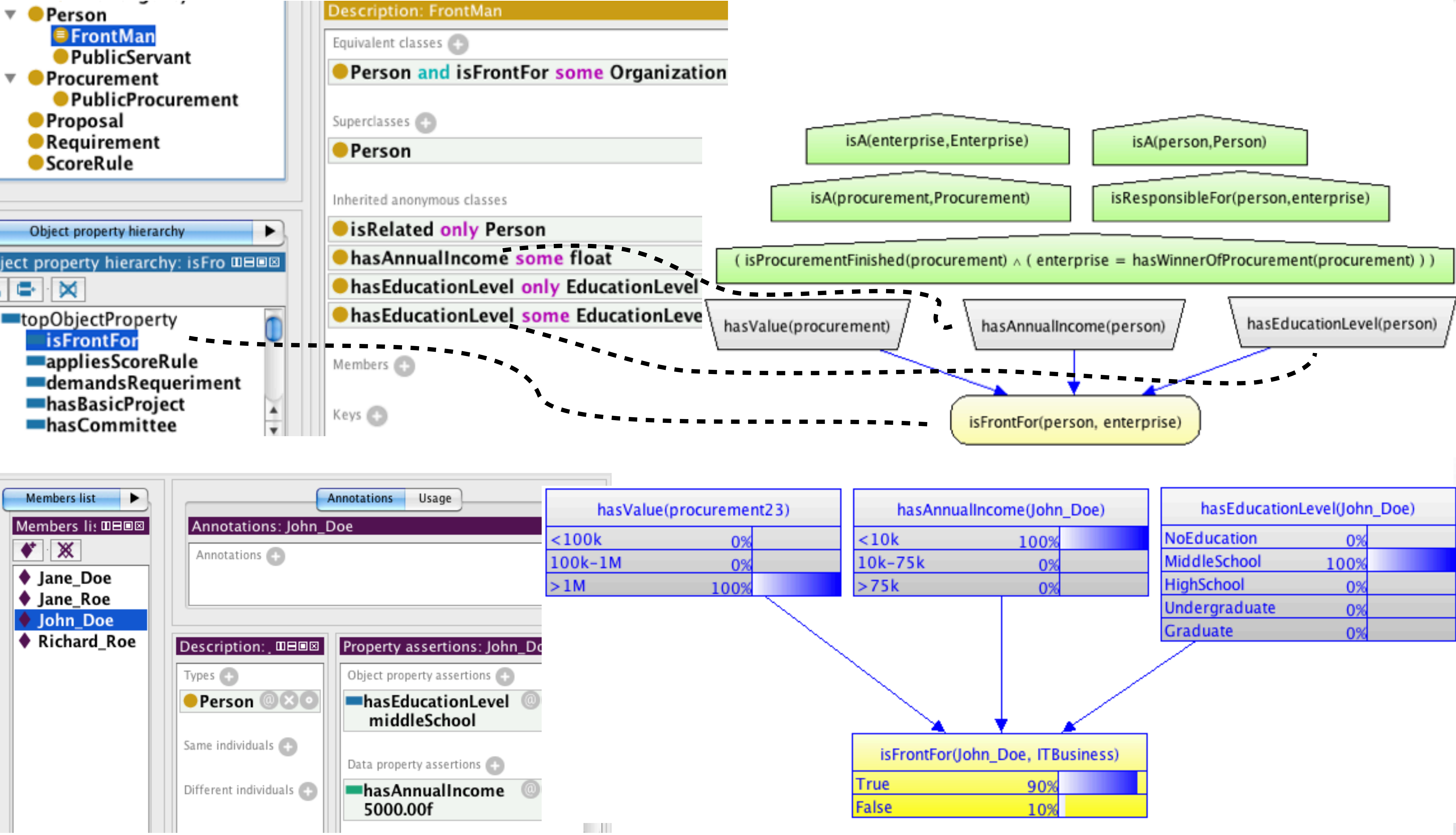
hasValue(procurement23)	
<100k	0%
100k-1M	0%
>1M	100%

hasAnnualIncome(John_Doe)	
<10k	100%
10k-75k	0%
>75k	0%

hasEducationLevel(John_Doe)	
NoEducation	0%
MiddleSchool	100%
HighSchool	0%
Undergraduate	0%
Graduate	0%

isFrontFor(John_Doe, ITBusiness)	
True	90%
False	10%

1st Problem - Mapping/Types



Person
FrontMan
PublicServant
Procurement
PublicProcurement
Proposal
Requirement
ScoreRule

Object property hierarchy

ject property hierarchy: isFro

topObjectProperty
isFrontFor
appliesScoreRule
demandsRequeriment
hasBasicProject
hasCommittee

Description: FrontMan

Equivalent classes
Person and isFrontFor some Organization

Superclasses
Person

Inherited anonymous classes
isRelated only Person
hasAnnualIncome some float
hasEducationLevel only EducationLevel
hasEducationLevel some EducationLeve

Members

Keys

isA(enterprise,Enterprise)
isA(person,Person)
isA(procurement,Procurement)
isResponsibleFor(person,enterprise)
(isProcurementFinished(procurement) ∧ (enterprise = hasWinnerOfProcurement(procurement)))
hasValue(procurement)
hasAnnualIncome(person)
hasEducationLevel(person)
isFrontFor(person, enterprise)

Members list

Members lis

Jane_Doe
Jane_Roe
John_Doe
Richard_Roe

Annotations | Usage

Annotations: John_Doe

Annotations

Description:

Types
Person

Same individuals

Different individuals

Property assertions: John_Do

Object property assertions
hasEducationLevel middleSchool

Data property assertions
hasAnnualIncome 5000.00f

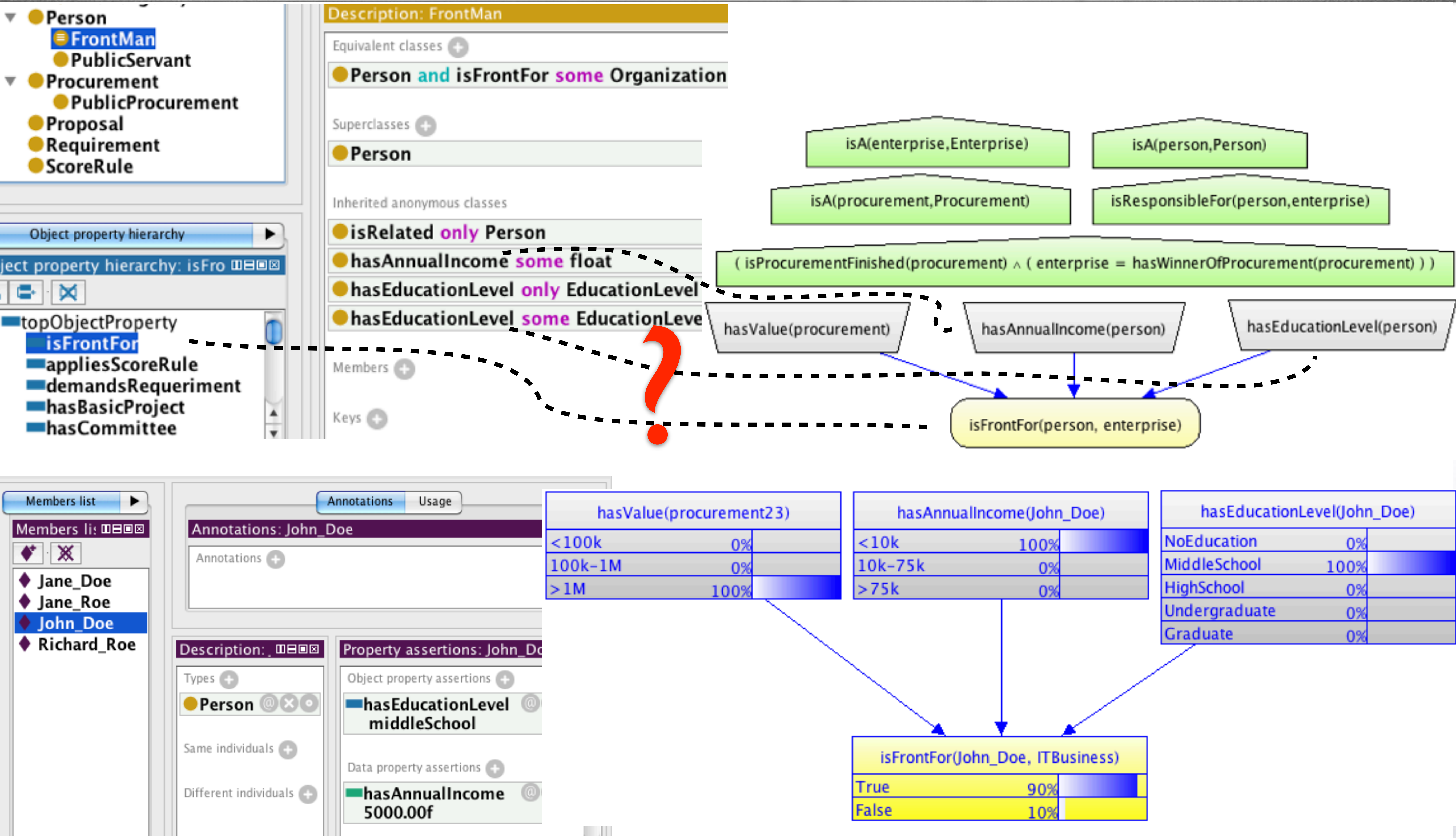
hasValue(procurement23)	
<100k	0%
100k-1M	0%
>1M	100%

hasAnnualIncome(John_Doe)	
<10k	100%
10k-75k	0%
>75k	0%

hasEducationLevel(John_Doe)	
NoEducation	0%
MiddleSchool	100%
HighSchool	0%
Undergraduate	0%
Graduate	0%

isFrontFor(John_Doe, ITBusiness)	
True	90%
False	10%

1st Problem - Mapping/Types



Person
FrontMan
PublicServant
Procurement
PublicProcurement
Proposal
Requirement
ScoreRule

Description: FrontMan

Equivalent classes
Person and isFrontFor some Organization

Superclasses
Person

Inherited anonymous classes
isRelated only Person
hasAnnualIncome some float
hasEducationLevel only EducationLevel
hasEducationLevel some EducationLeve

Members

Keys

Object property hierarchy

ject property hierarchy: isFro

topObjectProperty
isFrontFor
appliesScoreRule
demandsRequeriment
hasBasicProject
hasCommittee

isA(enterprise,Enterprise)
isA(person,Person)
isA(procurement,Procurement)
isResponsibleFor(person,enterprise)
(isProcurementFinished(procurement) ∧ (enterprise = hasWinnerOfProcurement(procurement)))
hasValue(procurement)
hasAnnualIncome(person)
hasEducationLevel(person)
isFrontFor(person, enterprise)
?

Members list

Members li:

Jane_Doe
Jane_Roe
John_Doe
Richard_Roe

Annotations | Usage

Annotations: John_Doe

Annotations

Description:

Types
Person

Same individuals

Different individuals

Property assertions: John_Do

Object property assertions
hasEducationLevel middleSchool

Data property assertions
hasAnnualIncome 5000.00f

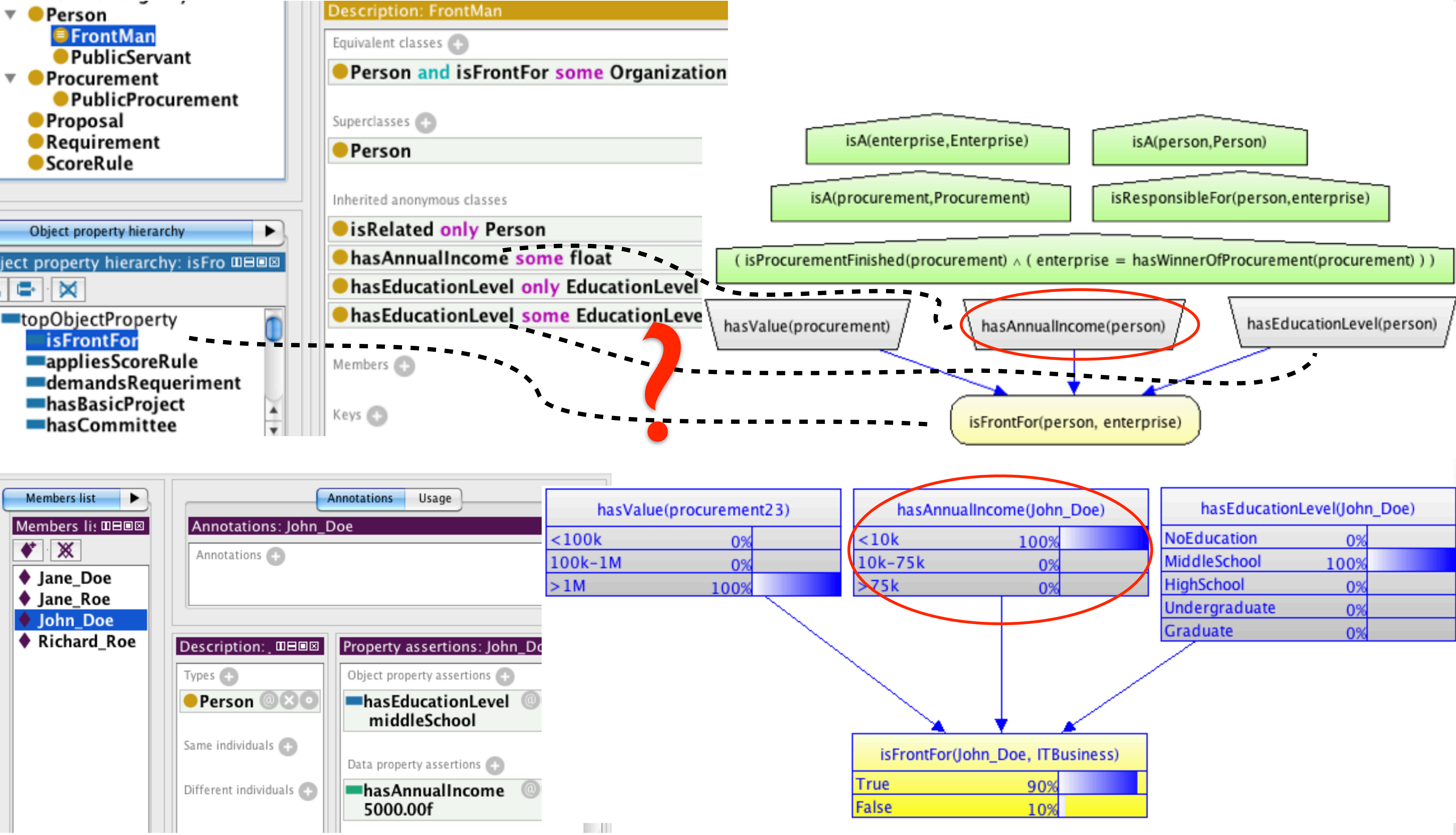
hasValue(procurement23)	
<100k	0%
100k-1M	0%
>1M	100%

hasAnnualIncome(John_Doe)	
<10k	100%
10k-75k	0%
>75k	0%

hasEducationLevel(John_Doe)	
NoEducation	0%
MiddleSchool	100%
HighSchool	0%
Undergraduate	0%
Graduate	0%

isFrontFor(John_Doe, ITBusiness)	
True	90%
False	10%

1st Problem - Mapping/Types



Person
FrontMan
PublicServant
Procurement
PublicProcurement
Proposal
Requirement
ScoreRule

Description: FrontMan

Equivalent classes

Person and isFrontFor some Organization

Superclasses

Person

Inherited anonymous classes

isRelated only Person

hasAnnualIncome some float

hasEducationLevel only EducationLevel

hasEducationLevel some EducationLeve

Members

Keys

Object property hierarchy

ject property hierarchy: isFro

topObjectProperty
isFrontFor
appliesScoreRule
demandsRequeriment
hasBasicProject
hasCommittee

isA(enterprise,Enterprise)
isA(person,Person)
isA(procurement,Procurement)
isResponsibleFor(person,enterprise)
(isProcurementFinished(procurement) ∧ (enterprise = hasWinnerOfProcurement(procurement)))
hasValue(procurement)
hasAnnualIncome(person)
hasEducationLevel(person)
isFrontFor(person, enterprise)
?

Members list

Members li:

Jane_Doe
Jane_Roe
John_Doe
Richard_Roe

Annotations | Usage

Annotations: John_Doe

Annotations

Description:

Types

Person

Same individuals

Different individuals

Property assertions: John_Dc

Object property assertions

hasEducationLevel middleSchool

Data property assertions

hasAnnualIncome 5000.00f

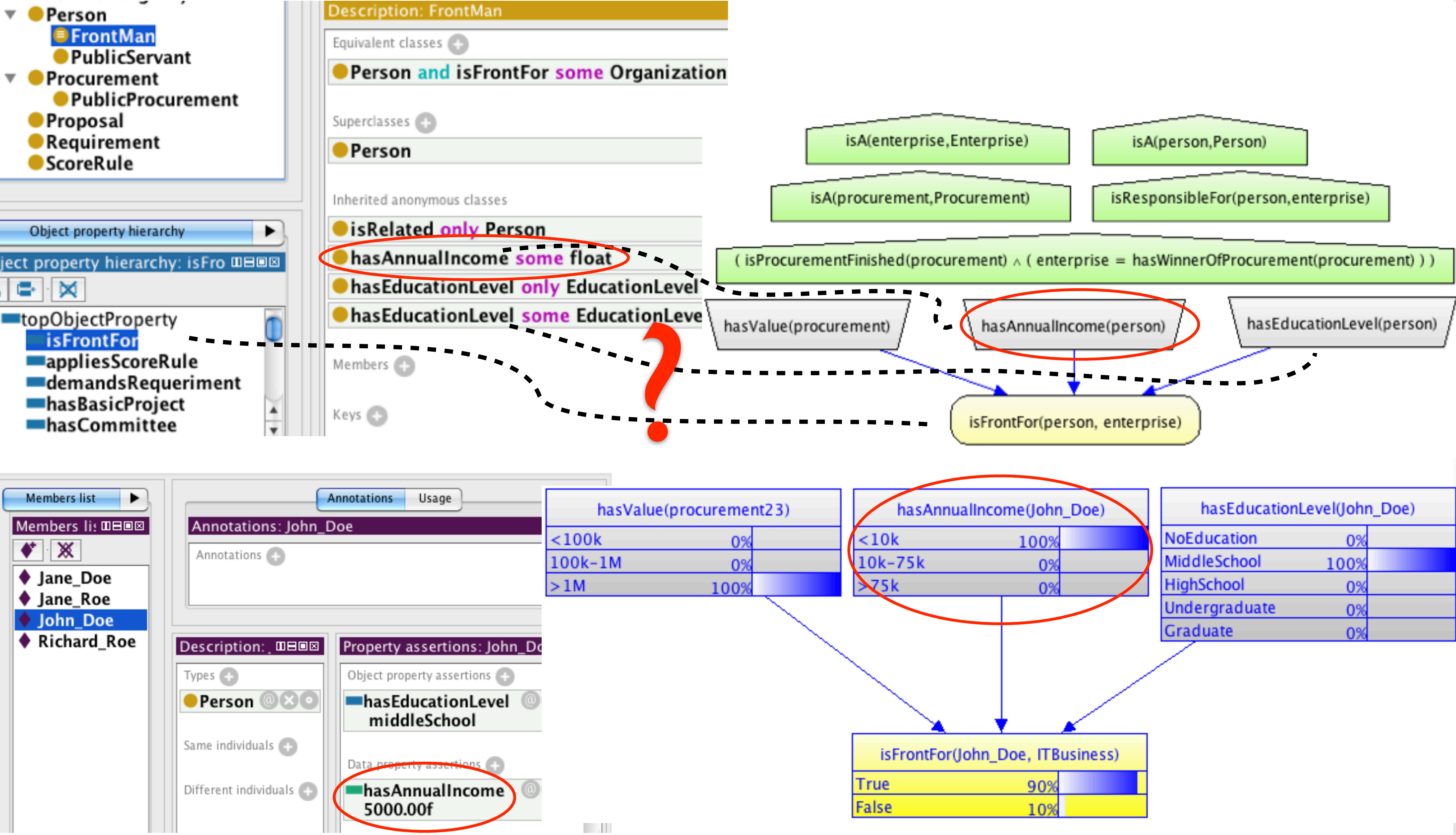
hasValue(procurement23)	
<100k	0%
100k-1M	0%
>1M	100%

hasAnnualIncome(John_Doe)	
<10k	100%
10k-75k	0%
>75k	0%

hasEducationLevel(John_Doe)	
NoEducation	0%
MiddleSchool	100%
HighSchool	0%
Undergraduate	0%
Graduate	0%

isFrontFor(John_Doe, ITBusiness)	
True	90%
False	10%

1st Problem - Mapping/Types



- Person
  - FrontMan
  - PublicServant
- Procurement
  - PublicProcurement
- Proposal
- Requirement
- ScoreRule

Object property hierarchy

ject property hierarchy: isFro

- topObjectProperty
  - isFrontFor
  - appliesScoreRule
  - demandsRequeriment
  - hasBasicProject
  - hasCommittee

Description: FrontMan

Equivalent classes

Person and isFrontFor some Organization

Superclasses

Person

Inherited anonymous classes

isRelated only Person

hasAnnualIncome some float

hasEducationLevel only EducationLevel

hasEducationLevel some EducationLeve

Members

Keys

?

isA(enterprise,Enterprise)
isA(person,Person)
isA(procurement,Procurement)
isResponsibleFor(person,enterprise)
(isProcurementFinished(procurement) ∧ (enterprise = hasWinnerOfProcurement(procurement)))
hasValue(procurement)
hasAnnualIncome(person)
hasEducationLevel(person)
isFrontFor(person, enterprise)

Members list

Members li:

- Jane_Doe
- Jane_Roe
- John_Doe
- Richard_Roe

Annotations | Usage

Annotations: John_Doe

Annotations

Description:

Types

Person

Same individuals

Different individuals

Property assertions: John_Do

Object property assertions

hasEducationLevel middleSchool

Data property assertions

hasAnnualIncome 5000.00f

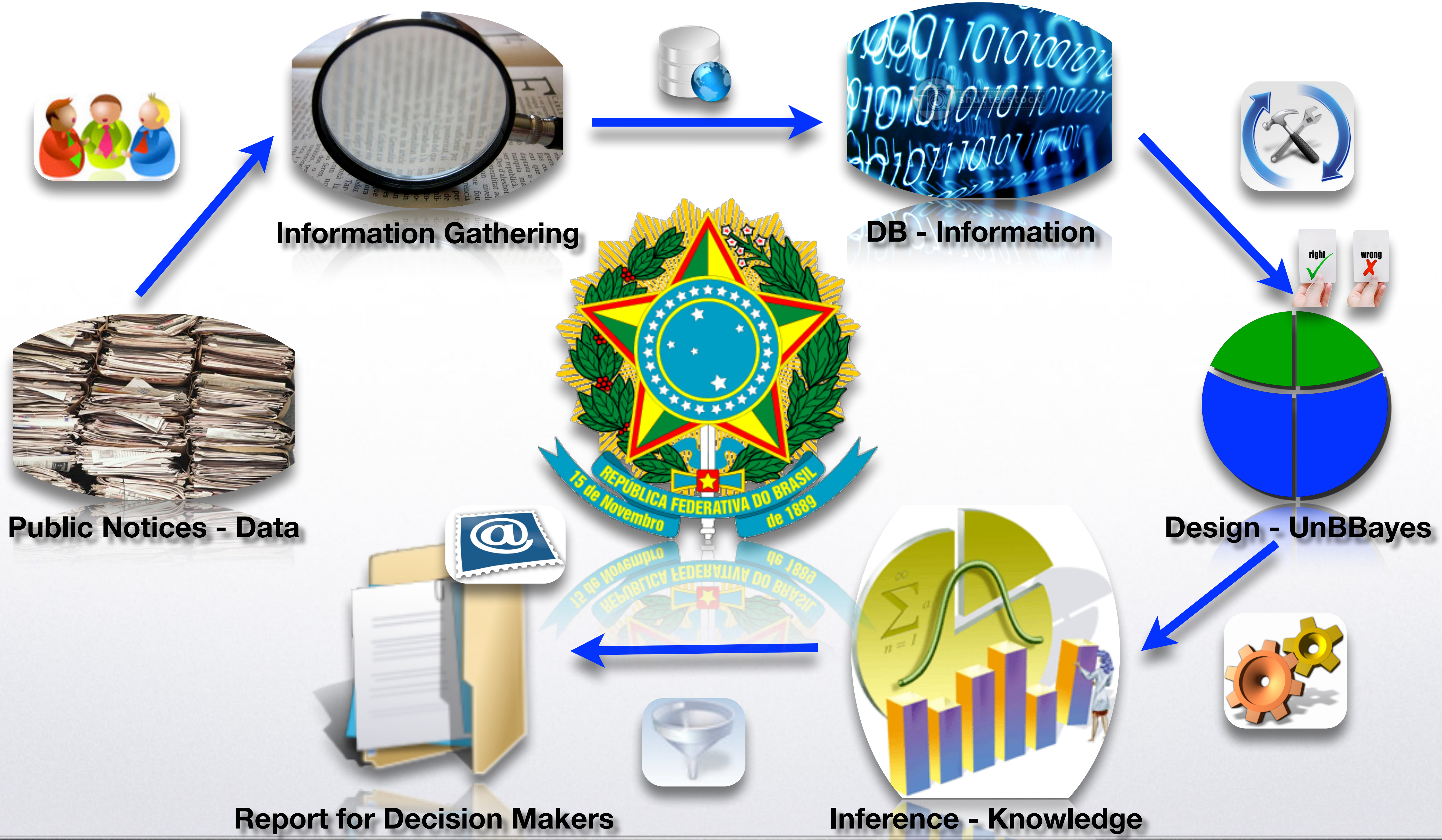
hasValue(procurement23)	
<100k	0%
100k-1M	0%
>1M	100%

hasAnnualIncome(John_Doe)	
<10k	100%
10k-75k	0%
>75k	0%

hasEducationLevel(John_Doe)	
NoEducation	0%
MiddleSchool	100%
HighSchool	0%
Undergraduate	0%
Graduate	0%

isFrontFor(John_Doe, ITBusiness)	
True	90%
False	10%

How to build Probabilistic Ontologies?



Public Notices - Data

Information Gathering

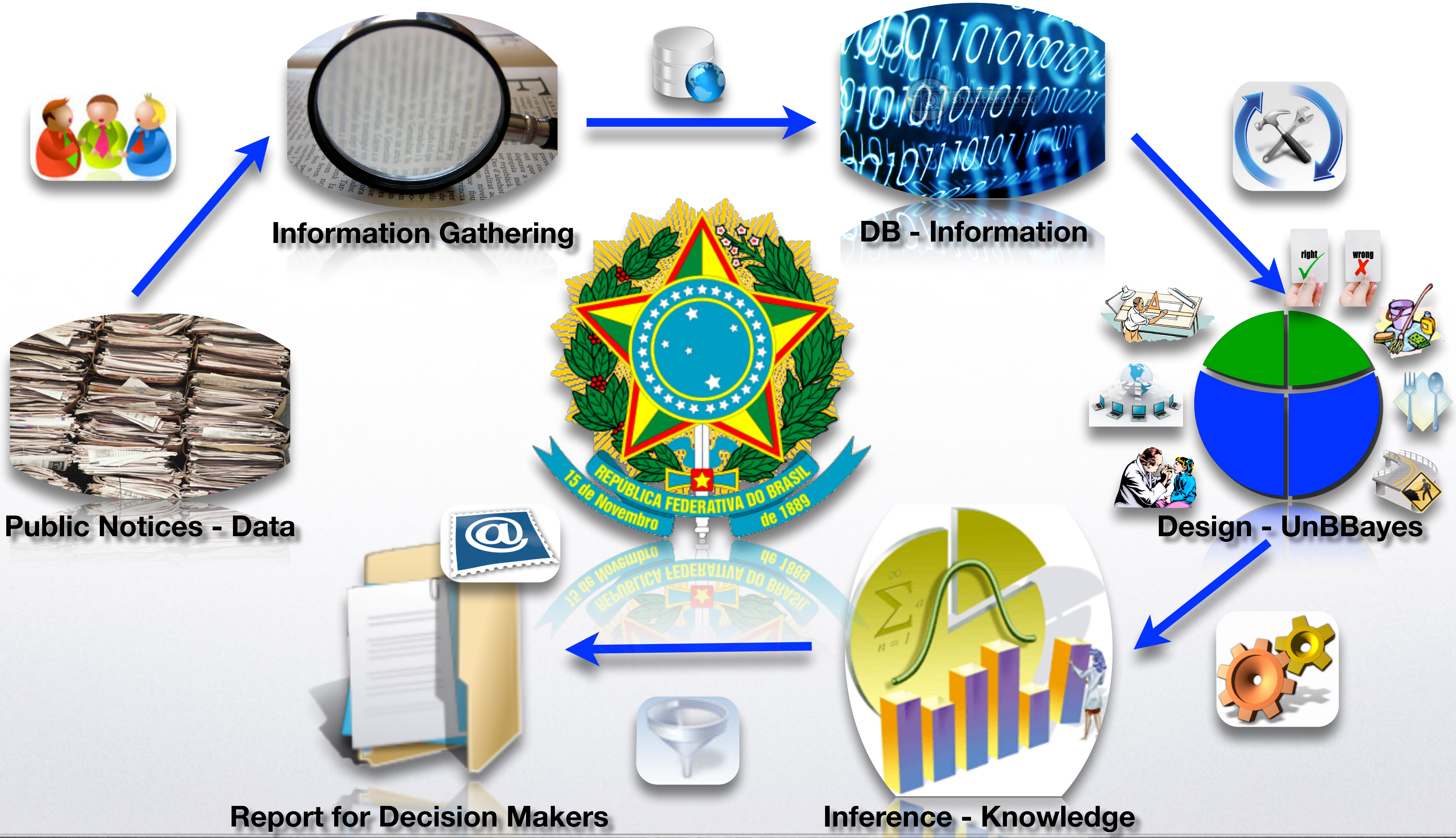
DB - Information

Design - UnBBayes

Inference - Knowledge

Report for Decision Makers

How to build Probabilistic Ontologies?



Public Notices - Data

Information Gathering

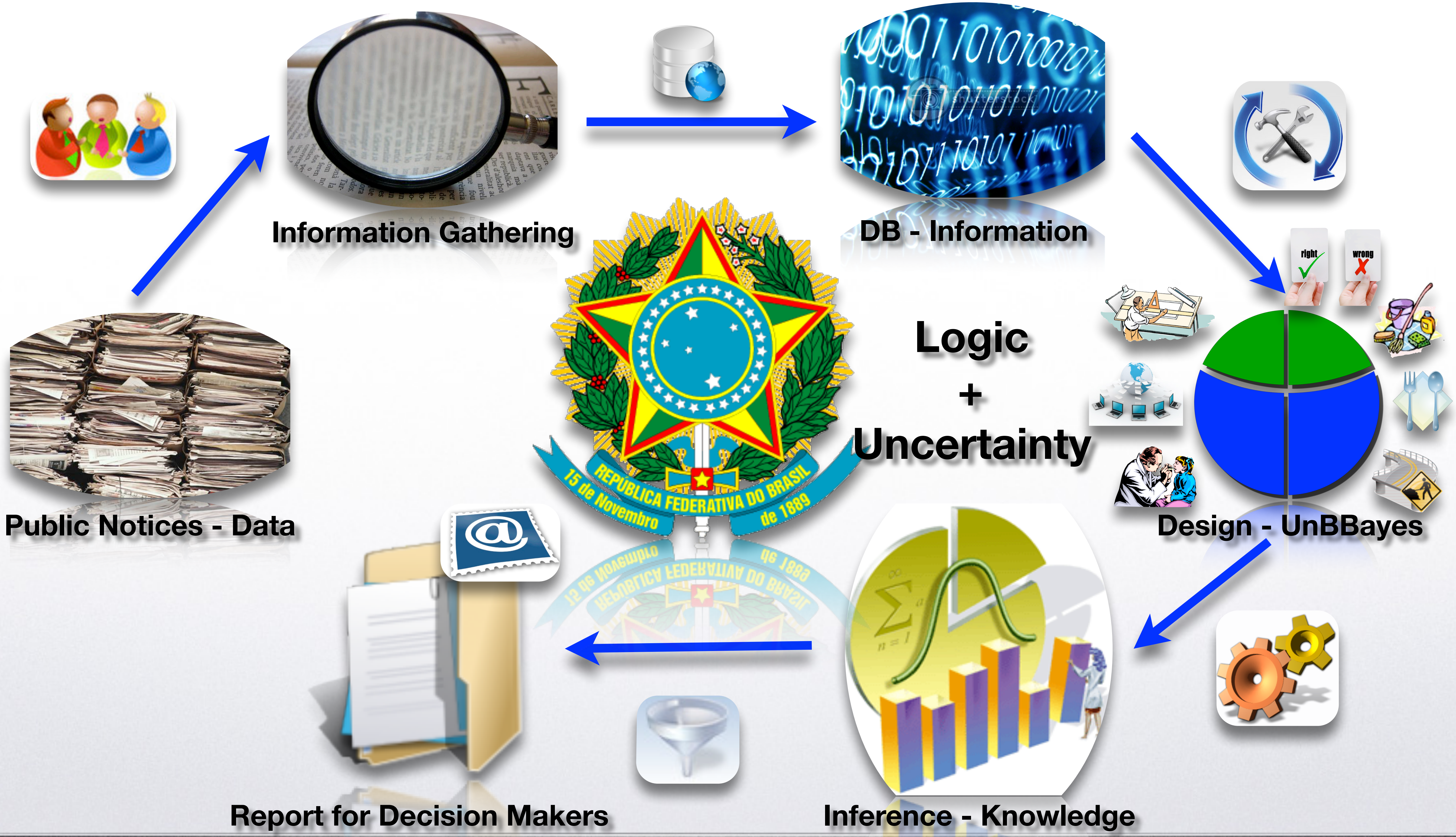
DB - Information

Design - UnBBayes

Inference - Knowledge

Report for Decision Makers

How to build Probabilistic Ontologies?



Public Notices - Data

Information Gathering

DB - Information

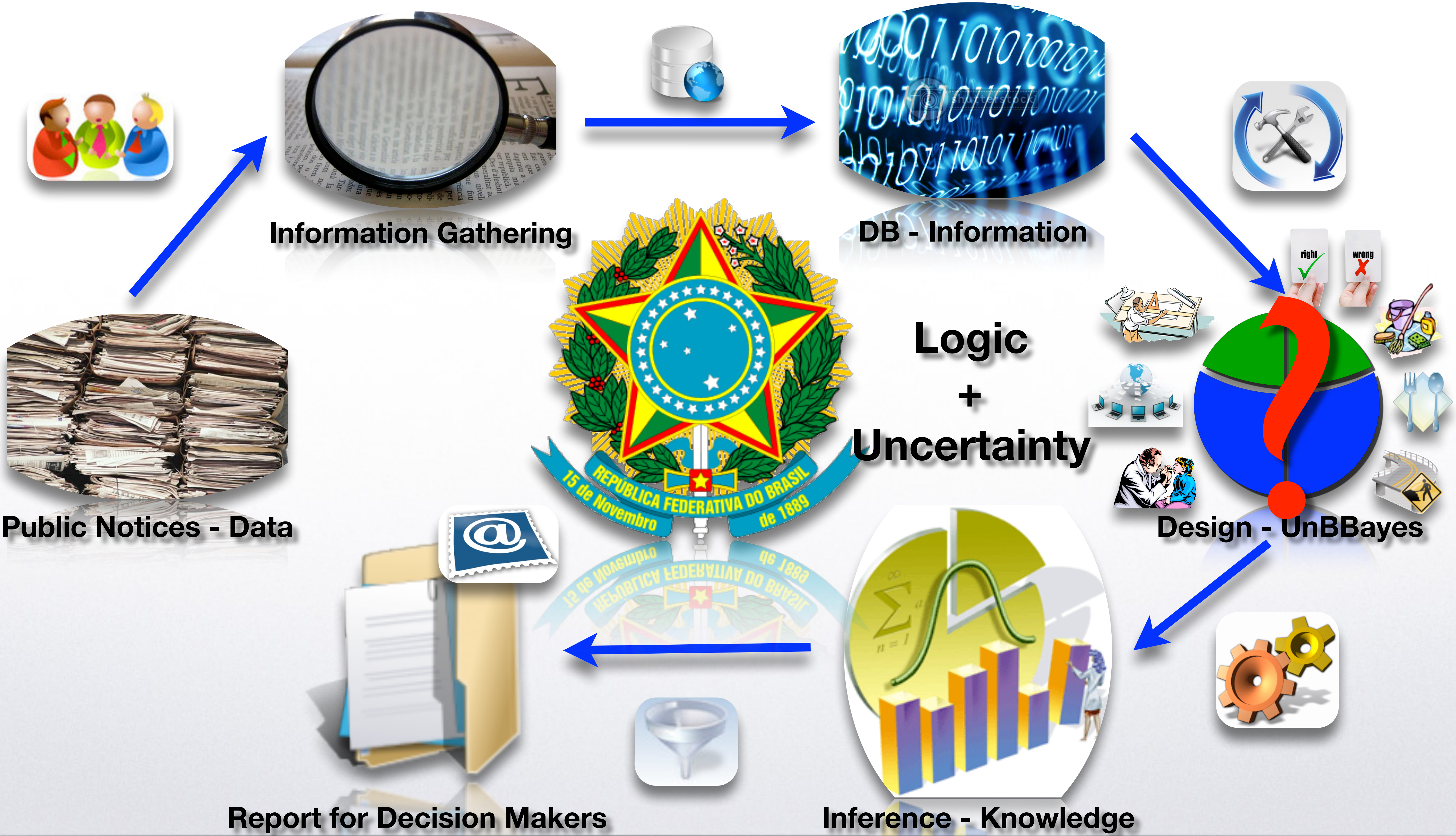
Design - UnBBayes

Inference - Knowledge

Report for Decision Makers

Logic
+
Uncertainty

How to build Probabilistic Ontologies?



Public Notices - Data

Information Gathering

DB - Information

Design - UnBBayes

Inference - Knowledge

Report for Decision Makers

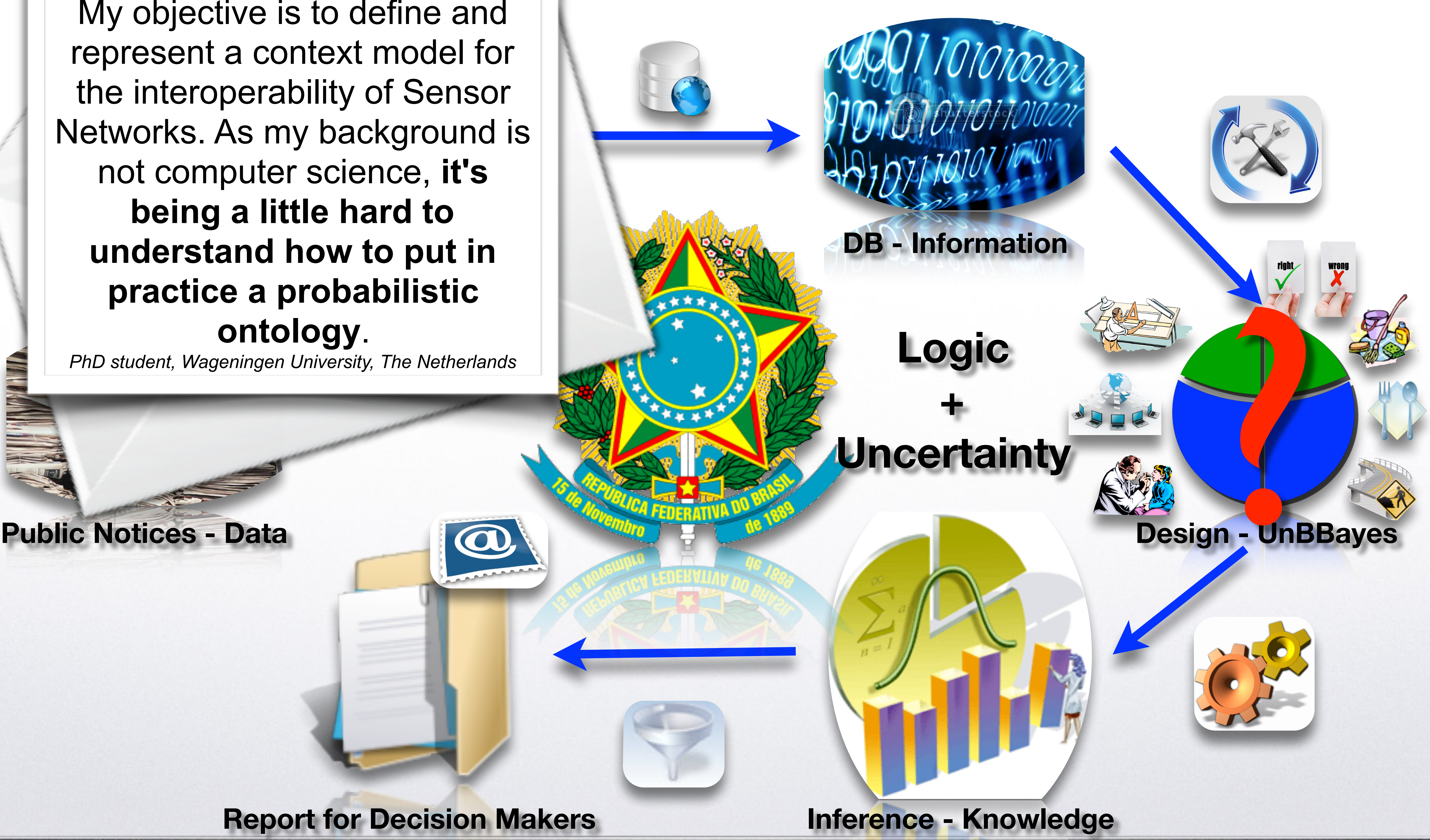
Logic

+

Uncertainty

Ho uild Probabilistic Ontologies?

> My objective is to define and represent a context model for the interoperability of Sensor Networks. As my background is not computer science, **it's being a little hard to understand how to put in practice a probabilistic ontology**.
>
> *PhD student, Wageningen University, The Netherlands*



DB - Information

Logic + Uncertainty

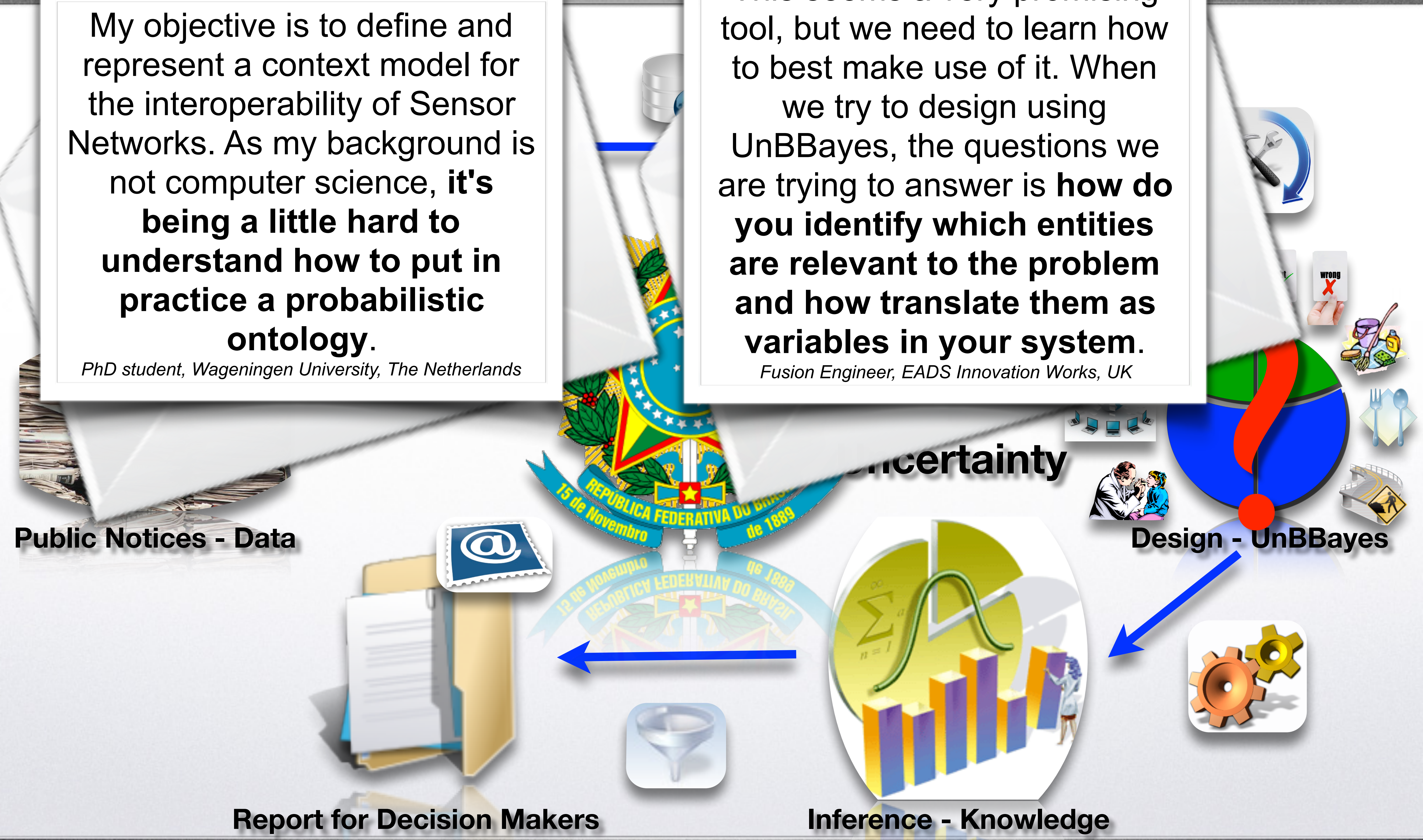
Design - UnBBayes

Inference - Knowledge

Report for Decision Makers

Public Notices - Data

Ho uild Probabilist logies?



> My objective is to define and represent a context model for the interoperability of Sensor Networks. As my background is not computer science, **it's being a little hard to understand how to put in practice a probabilistic ontology**.
>
> *PhD student, Wageningen University, The Netherlands*

> This seems a very promising tool, but we need to learn how to best make use of it. When we try to design using UnBBayes, the questions we are trying to answer is **how do you identify which entities are relevant to the problem and how translate them as variables in your system**.
>
> *Fusion Engineer, EADS Innovation Works, UK*

Ho… …uild Probabilist… …logies?

My objective is to define and represent a context model for the interoperability of Sensor Networks. As my background is not computer science, **it's being a little hard to understand how to put in practice a probabilistic ontology**

PhD student, Wageningen University, The Netherlands

This seems a very promising tool, but we need to learn how to best make use of it. When we try to design using UnBBayes, the questions we are trying to answer is **how do you identify which entities are relevant to the problem and how translate them as variables in your system**.

Fusion Engineer, EADS Innovation Works, UK

I am evaluating PR-OWL as a knowledge representation as well as reasoning formalism. **I'd like to explore if/how it can be used for applications using resource devices**.

PhD student, University of Texas at Arlington, USA

…certainty

Design - UnBBayes

Public Noti…

R…port for Decision Makers

Inference - Knowledge

Ho uild Probabilist logies?

My objective is to define and represent a context model for the interoperability of Sensor Networks. As my background is not computer science, **it's being a little hard to understand how to put in practice a probabilistic ontology.**

PhD student, Wageningen University, The Netherlands

This seems a very promising tool, but we need to learn how to best make use of it. When we try to design using UnBBayes, the questions we are trying to answer is **how do you identify which entities are relevant to the problem and how translate them as variables in your system.**

Fusion Engineer, EADS Innovation Works, UK

I am evaluating PR-OWL as a knowledge representation as well as reasoning formalism. **I'd like to explore if/how it can be used for applications using resource devices.**

PhD student, University of Texas at Arlington, USA

Why use these variables? Why they are connected in such a way? How do you choose what type of variable it is?

Fusion Engineer, EADS Innovation Works, UK

Public Noti

R port for Decision Makers

Inference - Knowledge

Ho… …logies?

My objective is … represent a c… the int… Network… not c… be… un… pr…

PhD stude…

…mising … how … hen

One thing which might be beyond the scope of this tutorial is a write-up about "Art of Modeling with MEBN". Both narration and the resultant MEBN help in understanding the problem, but **how one reach from a problem description to a MEBN at times is not very clear**. ... So when it comes to MEBN, how one decides about the context nodes, input nodes and resident nodes? Most of the times it might be pretty obvious but sometimes it is not very clear why certain nodes are modeled as input nodes in a fragment when they could also be modeled as context nodes, etc. **Should we follow an object-oriented approach when identifying important entities or should we think in terms of predicate logic, etc.? As a modeler what drives our thinking process?**

Professor, Institute of Business Administration, Pakistan

…riables? …ected in … do you …ype of …it is?

…novation Works, UK

Public Noti…

R…po… …r Decision Makers

Inference - Knowledge

2nd Problem - Methodology

- There is now substantial literature about
  - what PR-OWL is [2, 4, 5],
  - how to implement it [6-9], and
  - where it can be used [10-15]
- There is an emerging literature on ontology engineering [4, 28]
- But, little has been written about
  - ***how to model a probabilistic ontology***
- This lack of methodology is not only associated with PR-OWL
  - OntoBayes [30], BayesOWL [31], P-SHIF(**D**) and P-SHOIN(**D**) [32], Markov Logic Network [33], Bayesian Logic [63], and Probabilistic Relational Models [64], amongst others, do not have a methodology for creating models

Contributions

- For the 1st problem - Mapping/Types
  - Extended probabilistic web ontology language (PR-OWL) in order to:
    - Provide a mapping between deterministic knowledge and probabilistic knowledge
    - Allow reuse of existing types provided by OWL
  - Led the development of a proof of concept tool in collaboration with UnB [105]
- For the 2nd problem - Methodology
  - Developed a methodology for modeling probabilistic ontologies (POs)
    - Created two use cases using the proposed methodology

Representing Uncertainty in Semantic Technologies

Uncertainty in the SW

- Deterministic SW will either consider a statement to be true, false, or unknown
  - Shortcoming: no built-in support for uncertainty
- In open world partial (not complete) or approximate (not exact) information is more the rule than the exception

Uncertainty in the SW

- Deterministic SW will either consider a statement to be true, false, or unknown
  - Shortcoming: no built-in support for uncertainty
- In open world partial (not complete) or approximate (not exact) information is more the rule than the exception

```
∀x,y,z ((Mother(x,y) ∧ Mother(z,y)) ⇒ Sibling(x,z))
∀x,y (Sibling(x,y) ⇒ Related(x,y))
∀y∃x,z,r Committee(x,y)
       ∧ Participant(z,y) ∧ Responsible(r,z)
       ∧ Related(x,r) ⇒ ViolationOfLaw(y)
```

Uncertainty in the SW

- Deterministic SW will either consider a statement to be true, false, or unknown
  - Shortcoming: no built-in support for uncertainty
- In open world partial (not complete) or approximate (not exact) information is more the rule than the exception

```
Committee(John,procurement34)
Participant(ITBusiness,procurement34)
Responsible(Richard,ITBusiness)
```

```
∀x,y,z ((Mother(x,y) ∧ Mother(z,y)) ⇒ Sibling(x,z))

∀x,y (Sibling(x,y) ⇒ Related(x,y))

∀y∃x,z,r Committee(x,y)
       ∧ Participant(z,y) ∧ Responsible(r,z)
       ∧ Related(x,r) ⇒ ViolationOfLaw(y)
```

```
Mother(John,Jane)
Mother(Richard,Jane)
```

Uncertainty in the SW

- Deterministic SW will either consider a statement to be true, false, or unknown
  - Shortcoming: no built-in support for uncertainty
- In open world partial (not complete) or approximate (not exact) information is more the rule than the exception

```
∀x,y,z ((Mother(x,y) ∧ Mother(z,y)) ⇒ Sibling(x,z))

∀x,y (Sibling(x,y) ⇒ Related(x,y))

∀y∃x,z,r Committee(x,y)
       ∧ Participant(z,y) ∧ Responsible(r,z)
       ∧ Related(x,r) ⇒ ViolationOfLaw(y)
```

```
Committee(John,procurement34)
Participant(ITBusiness,procurement34)
Responsible(Richard,ITBusiness)
```

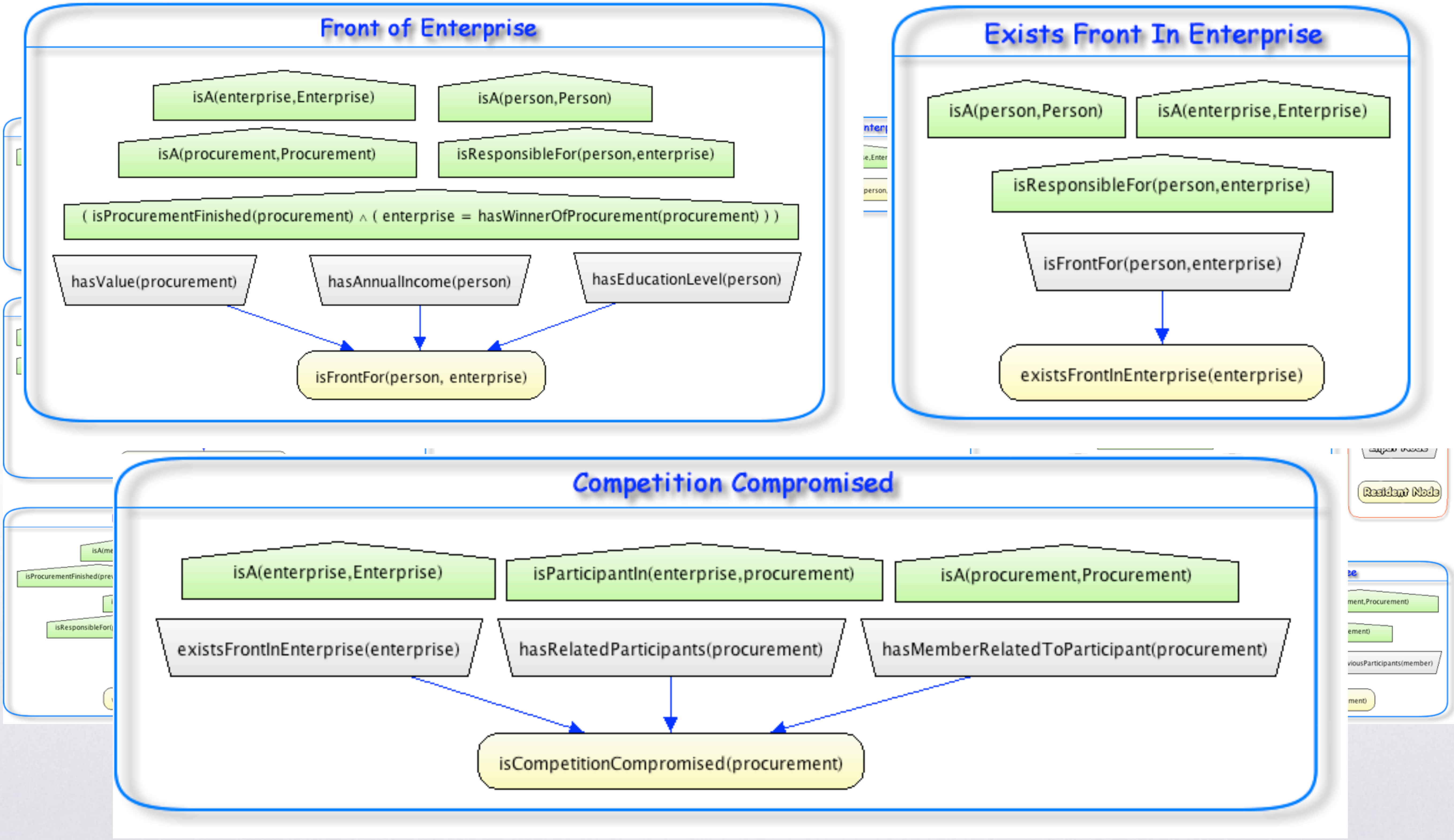
?

```
LivesAt(John,Address1)
LivesAt(Richard,Address1)
LastName(John,White)
LastName(Richard,White)
```

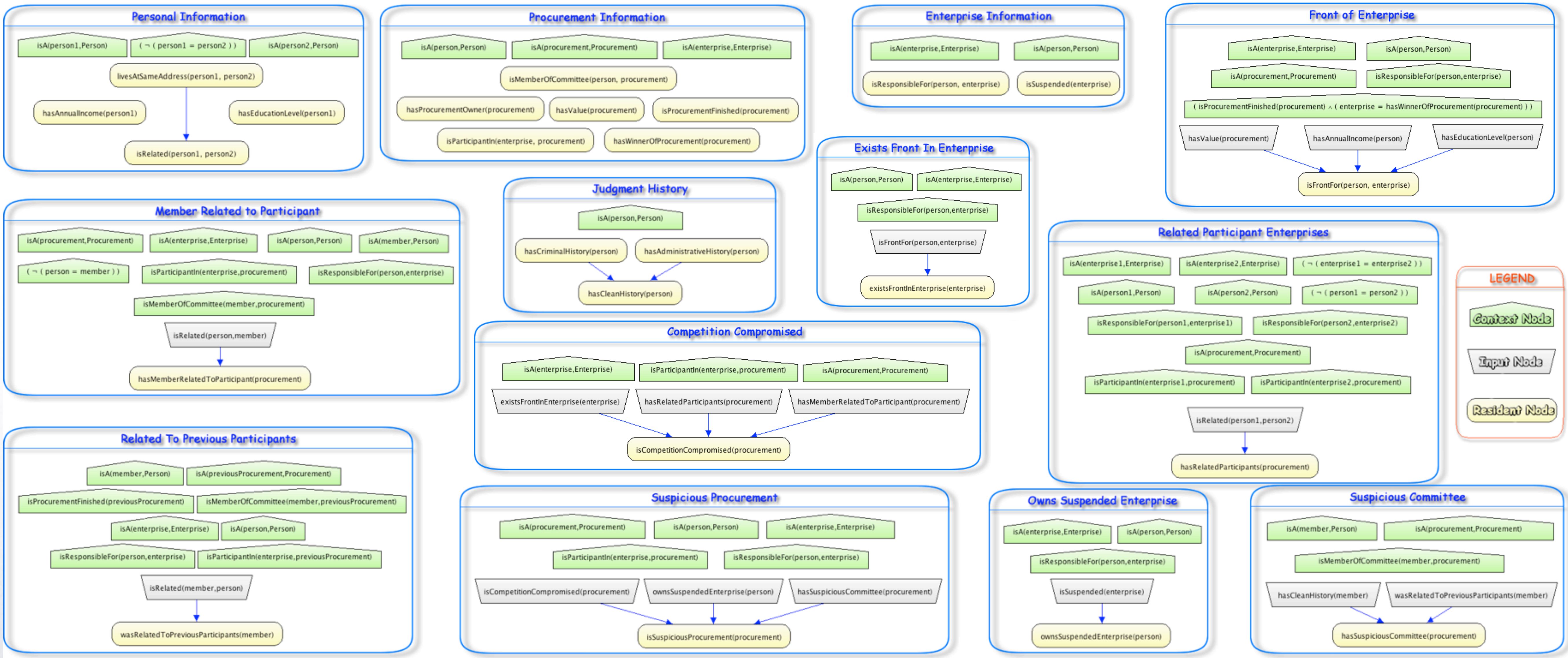
Uncertainty in the SW

- The community recognizes the need to represent and reason with uncertainty
- W3C created the URW3-XG in 2007
  - Concluded that standardized representations were needed [50]
- PR-OWL is a candidate language to represent probabilistic ontologies
  - Based on MEBN logic

MEBN


Front of Enterprise
isA(enterprise,Enterprise)
isA(person,Person)
isA(procurement,Procurement)
isResponsibleFor(person,enterprise)
(isProcurementFinished(procurement) ∧ (enterprise = hasWinnerOfProcurement(procurement)))
hasValue(procurement)
hasAnnualIncome(person)
hasEducationLevel(person)
isFrontFor(person, enterprise)
Exists Front In Enterprise
isA(person,Person)
isA(enterprise,Enterprise)
isResponsibleFor(person,enterprise)
isFrontFor(person,enterprise)
existsFrontInEnterprise(enterprise)
Competition Compromised
isA(enterprise,Enterprise)
isParticipantIn(enterprise,procurement)
isA(procurement,Procurement)
existsFrontInEnterprise(enterprise)
hasRelatedParticipants(procurement)
hasMemberRelatedToParticipant(procurement)
isCompetitionCompromised(procurement)
Resident Node

MEBN



Personal Information

isA(person1,Person)

(¬ (person1 = person2))

isA(person2,Person)

livesAtSameAddress(person1, person2)

hasAnnualIncome(person1)

hasEducationLevel(person1)

isRelated(person1, person2)

Procurement Information

isA(person,Person)

isA(procurement,Procurement)

isA(enterprise,Enterprise)

isMemberOfCommittee(person, procurement)

hasProcurementOwner(procurement)

hasValue(procurement)

isProcurementFinished(procurement)

isParticipantIn(enterprise, procurement)

hasWinnerOfProcurement(procurement)

Enterprise Information

isA(enterprise,Enterprise)

isA(person,Person)

isResponsibleFor(person, enterprise)

isSuspended(enterprise)

Front of Enterprise

isA(enterprise,Enterprise)

isA(person,Person)

isA(procurement,Procurement)

isResponsibleFor(person,enterprise)

(isProcurementFinished(procurement) ∧ (enterprise = hasWinnerOfProcurement(procurement)))

hasValue(procurement)

hasAnnualIncome(person)

hasEducationLevel(person)

isFrontFor(person, enterprise)

Member Related to Participant

isA(procurement,Procurement)

isA(enterprise,Enterprise)

isA(person,Person)

isA(member,Person)

(¬ (person = member))

isParticipantIn(enterprise,procurement)

isResponsibleFor(person,enterprise)

isMemberOfCommittee(member,procurement)

isRelated(person,member)

hasMemberRelatedToParticipant(procurement)

Judgment History

isA(person,Person)

hasCriminalHistory(person)

hasAdministrativeHistory(person)

hasCleanHistory(person)

Exists Front In Enterprise

isA(person,Person)

isA(enterprise,Enterprise)

isResponsibleFor(person,enterprise)

isFrontFor(person,enterprise)

existsFrontInEnterprise(enterprise)

Related Participant Enterprises

isA(enterprise1,Enterprise)

isA(enterprise2,Enterprise)

(¬ (enterprise1 = enterprise2))

isA(person1,Person)

isA(person2,Person)

(¬ (person1 = person2))

isResponsibleFor(person1,enterprise1)

isResponsibleFor(person2,enterprise2)

isA(procurement,Procurement)

isParticipantIn(enterprise1,procurement)

isParticipantIn(enterprise2,procurement)

isRelated(person1,person2)

hasRelatedParticipants(procurement)

Competition Compromised

isA(enterprise,Enterprise)

isParticipantIn(enterprise,procurement)

isA(procurement,Procurement)

existsFrontInEnterprise(enterprise)

hasRelatedParticipants(procurement)

hasMemberRelatedToParticipant(procurement)

isCompetitionCompromised(procurement)

LEGEND

Context Node

Input Node

Resident Node

Related To Previous Participants

isA(member,Person)

isA(previousProcurement,Procurement)

isProcurementFinished(previousProcurement)

isMemberOfCommittee(member,previousProcurement)

isA(enterprise,Enterprise)

isA(person,Person)

isResponsibleFor(person,enterprise)

isParticipantIn(enterprise,previousProcurement)

isRelated(member,person)

wasRelatedToPreviousParticipants(member)

Suspicious Procurement

isA(procurement,Procurement)

isA(person,Person)

isA(enterprise,Enterprise)

isParticipantIn(enterprise,procurement)

isResponsibleFor(person,enterprise)

isCompetitionCompromised(procurement)

ownsSuspendedEnterprise(person)

hasSuspiciousCommittee(procurement)

isSuspiciousProcurement(procurement)

Owns Suspended Enterprise

isA(enterprise,Enterprise)

isA(person,Person)

isResponsibleFor(person,enterprise)

isSuspended(enterprise)

ownsSuspendedEnterprise(person)

Suspicious Committee

isA(member,Person)

isA(procurement,Procurement)

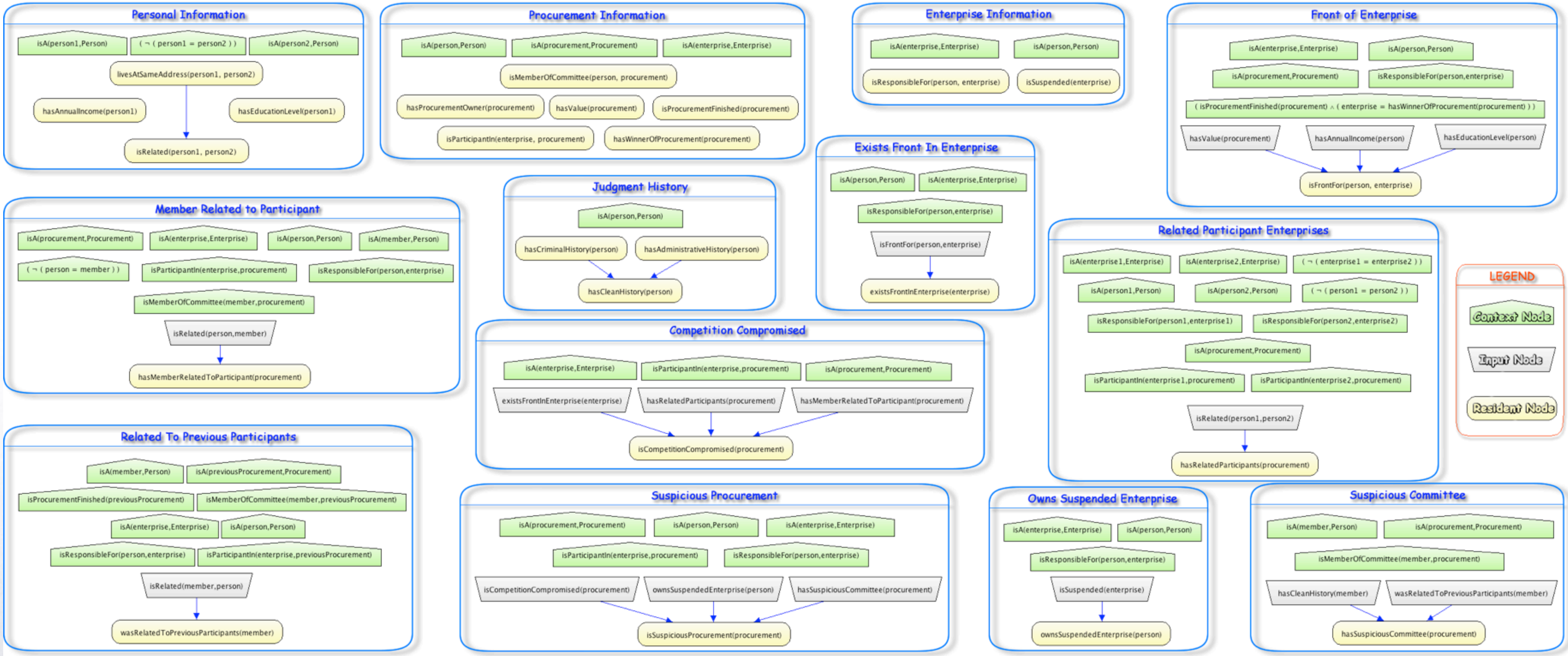
isMemberOfCommittee(member,procurement)

hasCleanHistory(member)

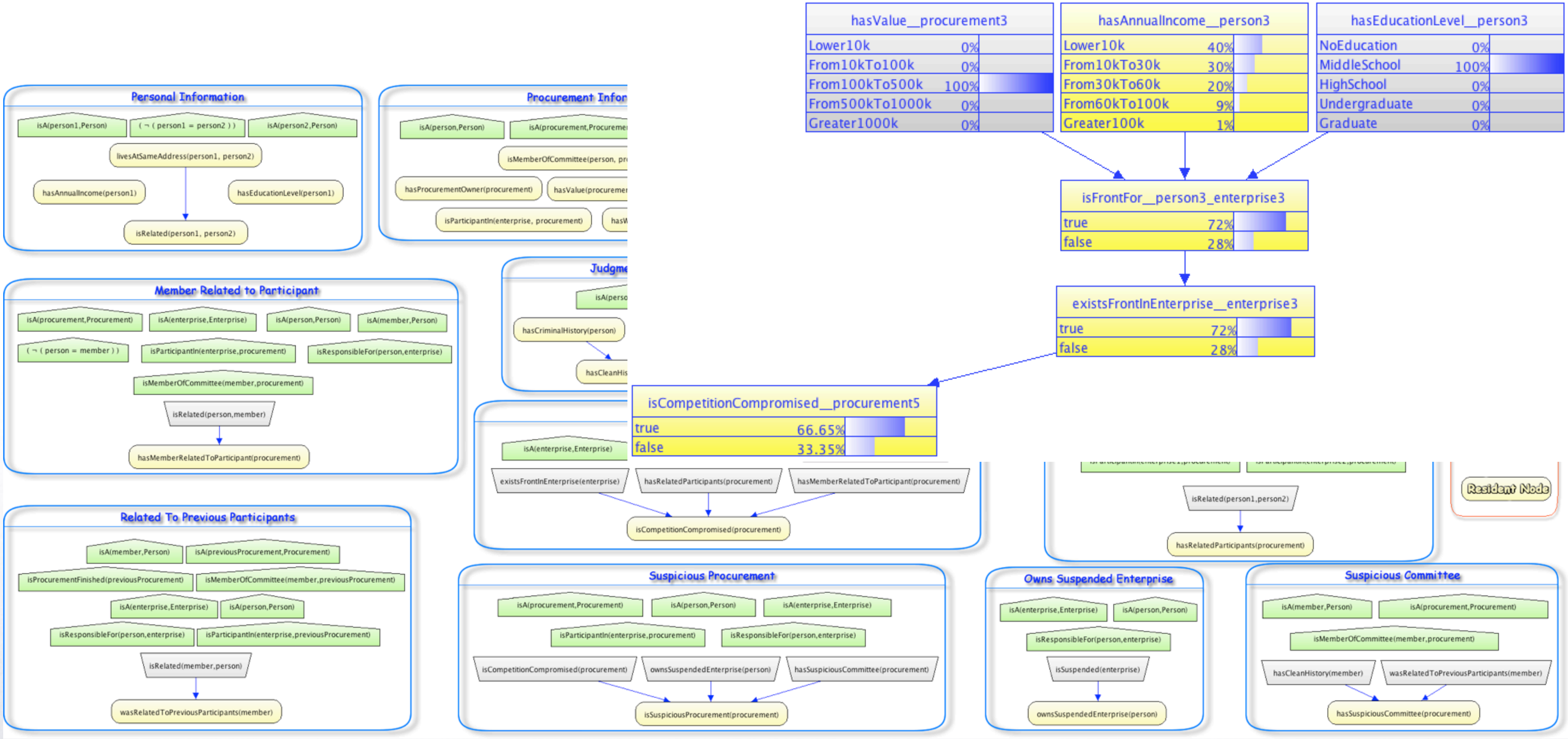
wasRelatedToPreviousParticipants(member)

hasSuspiciousCommittee(procurement)

Why MEBN?


Personal Information
isA(person1,Person)
(¬ (person1 = person2))
isA(person2,Person)
livesAtSameAddress(person1, person2)
hasAnnualIncome(person1)
hasEducationLevel(person1)
isRelated(person1, person2)
Procurement Information
isA(person,Person)
isA(procurement,Procurement)
isA(enterprise,Enterprise)
isMemberOfCommittee(person, procurement)
hasProcurementOwner(procurement)
hasValue(procurement)
isProcurementFinished(procurement)
isParticipantIn(enterprise, procurement)
hasWinnerOfProcurement(procurement)
Enterprise Information
isA(enterprise,Enterprise)
isA(person,Person)
isResponsibleFor(person, enterprise)
isSuspended(enterprise)
Front of Enterprise
isA(enterprise,Enterprise)
isA(person,Person)
isA(procurement,Procurement)
isResponsibleFor(person,enterprise)
(isProcurementFinished(procurement) ∧ (enterprise = hasWinnerOfProcurement(procurement)))
hasValue(procurement)
hasAnnualIncome(person)
hasEducationLevel(person)
isFrontFor(person, enterprise)
Member Related to Participant
isA(procurement,Procurement)
isA(enterprise,Enterprise)
isA(person,Person)
isA(member,Person)
(¬ (person = member))
isParticipantIn(enterprise,procurement)
isResponsibleFor(person,enterprise)
isMemberOfCommittee(member,procurement)
isRelated(person,member)
hasMemberRelatedToParticipant(procurement)
Judgment History
isA(person,Person)
hasCriminalHistory(person)
hasAdministrativeHistory(person)
hasCleanHistory(person)
Exists Front In Enterprise
isA(person,Person)
isA(enterprise,Enterprise)
isResponsibleFor(person,enterprise)
isFrontFor(person,enterprise)
existsFrontInEnterprise(enterprise)
Related Participant Enterprises
isA(enterprise1,Enterprise)
isA(enterprise2,Enterprise)
(¬ (enterprise1 = enterprise2))
isA(person1,Person)
isA(person2,Person)
(¬ (person1 = person2))
isResponsibleFor(person1,enterprise1)
isResponsibleFor(person2,enterprise2)
isA(procurement,Procurement)
isParticipantIn(enterprise1,procurement)
isParticipantIn(enterprise2,procurement)
isRelated(person1,person2)
hasRelatedParticipants(procurement)
LEGEND
Context Node
Input Node
Resident Node
Competition Compromised
isA(enterprise,Enterprise)
isParticipantIn(enterprise,procurement)
isA(procurement,Procurement)
existsFrontInEnterprise(enterprise)
hasRelatedParticipants(procurement)
hasMemberRelatedToParticipant(procurement)
isCompetitionCompromised(procurement)
Related To Previous Participants
isA(member,Person)
isA(previousProcurement,Procurement)
isProcurementFinished(previousProcurement)
isMemberOfCommittee(member,previousProcurement)
isA(enterprise,Enterprise)
isA(person,Person)
isResponsibleFor(person,enterprise)
isParticipantIn(enterprise,previousProcurement)
isRelated(member,person)
wasRelatedToPreviousParticipants(member)
Suspicious Procurement
isA(procurement,Procurement)
isA(person,Person)
isA(enterprise,Enterprise)
isParticipantIn(enterprise,procurement)
isResponsibleFor(person,enterprise)
isCompetitionCompromised(procurement)
ownsSuspendedEnterprise(person)
hasSuspiciousCommittee(procurement)
isSuspiciousProcurement(procurement)
Owns Suspended Enterprise
isA(enterprise,Enterprise)
isA(person,Person)
isResponsibleFor(person,enterprise)
isSuspended(enterprise)
ownsSuspendedEnterprise(person)
Suspicious Committee
isA(member,Person)
isA(procurement,Procurement)
isMemberOfCommittee(member,procurement)
hasCleanHistory(member)
wasRelatedToPreviousParticipants(member)
hasSuspiciousCommittee(procurement)

Why MEBN?



hasValue__procurement3	
Lower10k	0%
From10kTo100k	0%
From100kTo500k	100%
From500kTo1000k	0%
Greater1000k	0%

hasAnnualIncome__person3	
Lower10k	40%
From10kTo30k	30%
From30kTo60k	20%
From60kTo100k	9%
Greater100k	1%

hasEducationLevel__person3	
NoEducation	0%
MiddleSchool	100%
HighSchool	0%
Undergraduate	0%
Graduate	0%

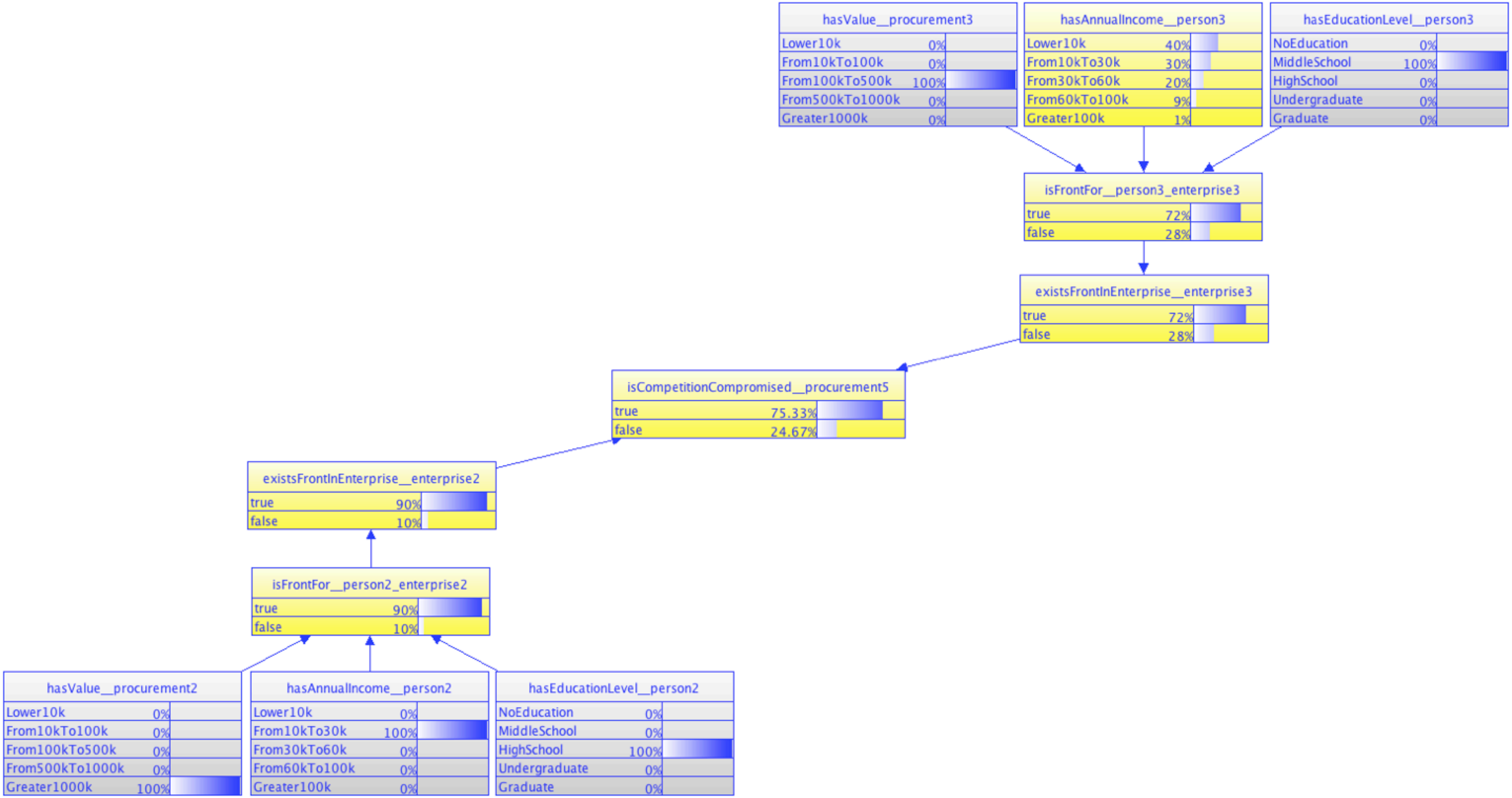
isFrontFor__person3_enterprise3	
true	72%
false	28%

existsFrontInEnterprise__enterprise3	
true	72%
false	28%

isCompetitionCompromised__procurement5	
true	66.65%
false	33.35%

Personal Information
isA(person1,Person)
(¬ (person1 = person2))
isA(person2,Person)
livesAtSameAddress(person1, person2)
hasAnnualIncome(person1)
hasEducationLevel(person1)
isRelated(person1, person2)
Procurement Infor
isA(person,Person)
isA(procurement,Procureme
isMemberOfCommittee(person, pr
hasProcurementOwner(procurement)
hasValue(procuremer
isParticipantIn(enterprise, procurement)
hasW
Judgme
isA(perso
hasCriminalHistory(person)
hasCleanHis
Member Related to Participant
isA(procurement,Procurement)
isA(enterprise,Enterprise)
isA(person,Person)
isA(member,Person)
(¬ (person = member))
isParticipantIn(enterprise,procurement)
isResponsibleFor(person,enterprise)
isMemberOfCommittee(member,procurement)
isRelated(person,member)
hasMemberRelatedToParticipant(procurement)
isA(enterprise,Enterprise)
existsFrontInEnterprise(enterprise)
hasRelatedParticipants(procurement)
hasMemberRelatedToParticipant(procurement)
isCompetitionCompromised(procurement)
isRelated(person1,person2)
hasRelatedParticipants(procurement)
Resident Node
Related To Previous Participants
isA(member,Person)
isA(previousProcurement,Procurement)
isProcurementFinished(previousProcurement)
isMemberOfCommittee(member,previousProcurement)
isA(enterprise,Enterprise)
isA(person,Person)
isResponsibleFor(person,enterprise)
isParticipantIn(enterprise,previousProcurement)
isRelated(member,person)
wasRelatedToPreviousParticipants(member)
Suspicious Procurement
isA(procurement,Procurement)
isA(person,Person)
isA(enterprise,Enterprise)
isParticipantIn(enterprise,procurement)
isResponsibleFor(person,enterprise)
isCompetitionCompromised(procurement)
ownsSuspendedEnterprise(person)
hasSuspiciousCommittee(procurement)
isSuspiciousProcurement(procurement)
Owns Suspended Enterprise
isA(enterprise,Enterprise)
isA(person,Person)
isResponsibleFor(person,enterprise)
isSuspended(enterprise)
ownsSuspendedEnterprise(person)
Suspicious Committee
isA(member,Person)
isA(procurement,Procurement)
isMemberOfCommittee(member,procurement)
hasCleanHistory(member)
wasRelatedToPreviousParticipants(member)
hasSuspiciousCommittee(procurement)

Why MEBN?



hasValue__procurement3	
Lower10k	0%
From10kTo100k	0%
From100kTo500k	100%
From500kTo1000k	0%
Greater1000k	0%

hasAnnualIncome__person3	
Lower10k	40%
From10kTo30k	30%
From30kTo60k	20%
From60kTo100k	9%
Greater100k	1%

hasEducationLevel__person3	
NoEducation	0%
MiddleSchool	100%
HighSchool	0%
Undergraduate	0%
Graduate	0%

isFrontFor__person3_enterprise3	
true	72%
false	28%

existsFrontInEnterprise__enterprise3	
true	72%
false	28%

isCompetitionCompromised__procurement5	
true	75.33%
false	24.67%

existsFrontInEnterprise__enterprise2	
true	90%
false	10%

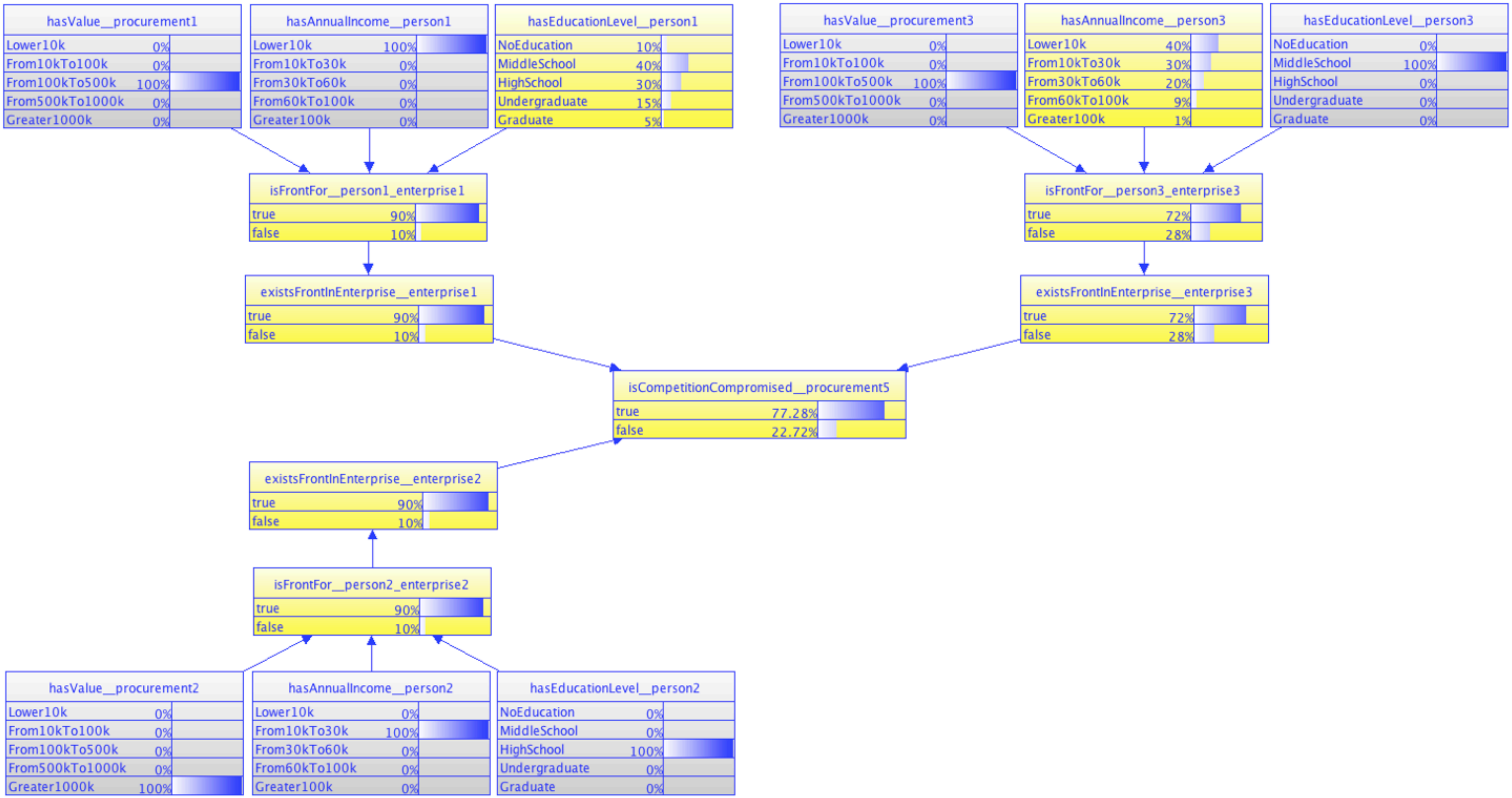
isFrontFor__person2_enterprise2	
true	90%
false	10%

hasValue__procurement2	
Lower10k	0%
From10kTo100k	0%
From100kTo500k	0%
From500kTo1000k	0%
Greater1000k	100%

hasAnnualIncome__person2	
Lower10k	0%
From10kTo30k	100%
From30kTo60k	0%
From60kTo100k	0%
Greater100k	0%

hasEducationLevel__person2	
NoEducation	0%
MiddleSchool	0%
HighSchool	100%
Undergraduate	0%
Graduate	0%

Why MEBN?



hasValue__procurement1	
Lower10k	0%
From10kTo100k	0%
From100kTo500k	100%
From500kTo1000k	0%
Greater1000k	0%

hasAnnualIncome__person1	
Lower10k	100%
From10kTo30k	0%
From30kTo60k	0%
From60kTo100k	0%
Greater100k	0%

hasEducationLevel__person1	
NoEducation	10%
MiddleSchool	40%
HighSchool	30%
Undergraduate	15%
Graduate	5%

hasValue__procurement3	
Lower10k	0%
From10kTo100k	0%
From100kTo500k	100%
From500kTo1000k	0%
Greater1000k	0%

hasAnnualIncome__person3	
Lower10k	40%
From10kTo30k	30%
From30kTo60k	20%
From60kTo100k	9%
Greater100k	1%

hasEducationLevel__person3	
NoEducation	0%
MiddleSchool	100%
HighSchool	0%
Undergraduate	0%
Graduate	0%

isFrontFor__person1_enterprise1	
true	90%
false	10%

isFrontFor__person3_enterprise3	
true	72%
false	28%

existsFrontInEnterprise__enterprise1	
true	90%
false	10%

existsFrontInEnterprise__enterprise3	
true	72%
false	28%

isCompetitionCompromised__procurement5	
true	77.28%
false	22.72%

existsFrontInEnterprise__enterprise2	
true	90%
false	10%

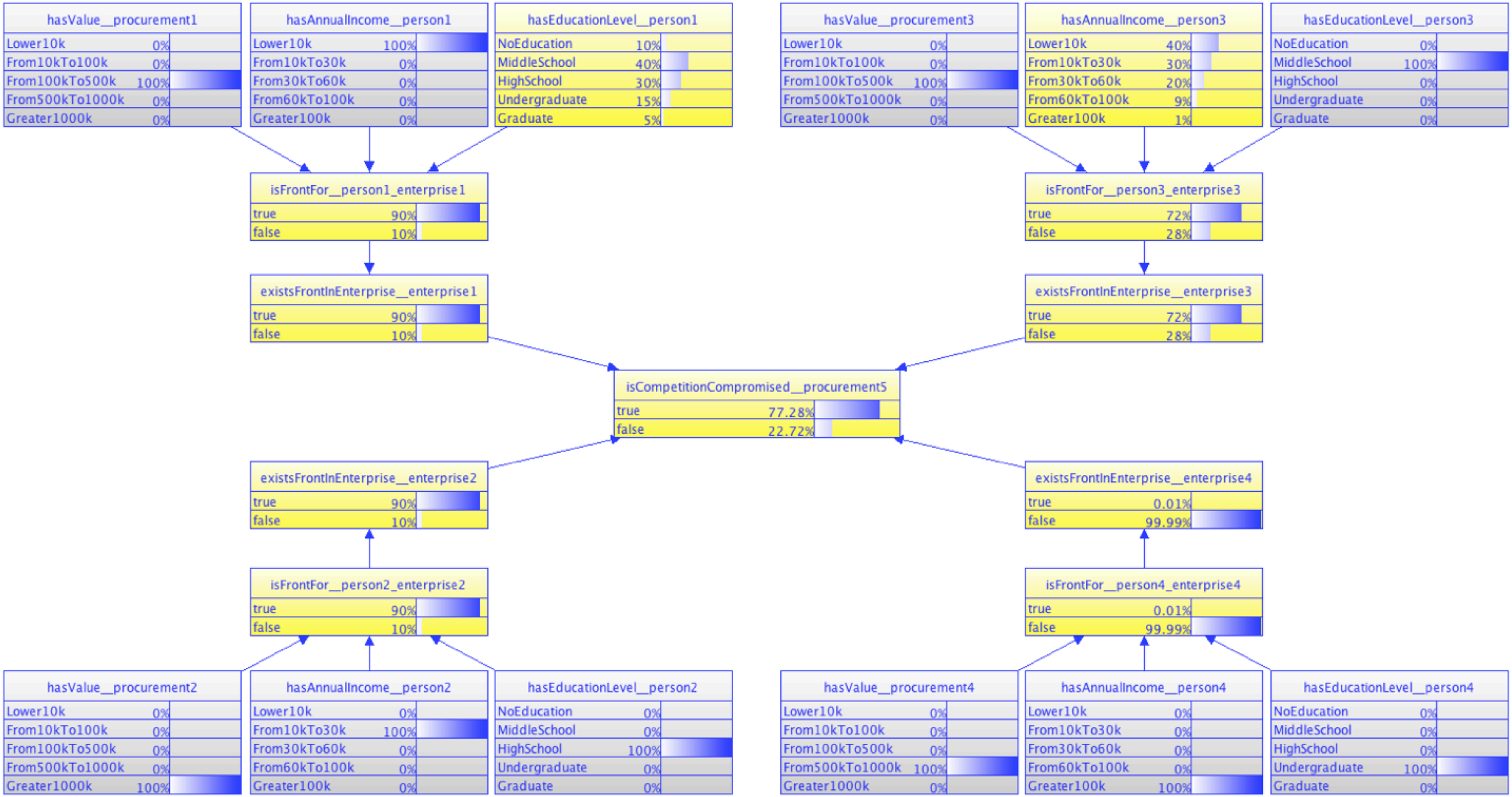
isFrontFor__person2_enterprise2	
true	90%
false	10%

hasValue__procurement2	
Lower10k	0%
From10kTo100k	0%
From100kTo500k	0%
From500kTo1000k	0%
Greater1000k	100%

hasAnnualIncome__person2	
Lower10k	0%
From10kTo30k	100%
From30kTo60k	0%
From60kTo100k	0%
Greater100k	0%

hasEducationLevel__person2	
NoEducation	0%
MiddleSchool	0%
HighSchool	100%
Undergraduate	0%
Graduate	0%

Why MEBN?



hasValue__procurement1	
Lower10k	0%
From10kTo100k	0%
From100kTo500k	100%
From500kTo1000k	0%
Greater1000k	0%

hasAnnualIncome__person1	
Lower10k	100%
From10kTo30k	0%
From30kTo60k	0%
From60kTo100k	0%
Greater100k	0%

hasEducationLevel__person1	
NoEducation	10%
MiddleSchool	40%
HighSchool	30%
Undergraduate	15%
Graduate	5%

hasValue__procurement3	
Lower10k	0%
From10kTo100k	0%
From100kTo500k	100%
From500kTo1000k	0%
Greater1000k	0%

hasAnnualIncome__person3	
Lower10k	40%
From10kTo30k	30%
From30kTo60k	20%
From60kTo100k	9%
Greater100k	1%

hasEducationLevel__person3	
NoEducation	0%
MiddleSchool	100%
HighSchool	0%
Undergraduate	0%
Graduate	0%

isFrontFor__person1_enterprise1	
true	90%
false	10%

isFrontFor__person3_enterprise3	
true	72%
false	28%

existsFrontInEnterprise__enterprise1	
true	90%
false	10%

existsFrontInEnterprise__enterprise3	
true	72%
false	28%

isCompetitionCompromised__procurement5	
true	77.28%
false	22.72%

existsFrontInEnterprise__enterprise2	
true	90%
false	10%

existsFrontInEnterprise__enterprise4	
true	0.01%
false	99.99%

isFrontFor__person2_enterprise2	
true	90%
false	10%

isFrontFor__person4_enterprise4	
true	0.01%
false	99.99%

hasValue__procurement2	
Lower10k	0%
From10kTo100k	0%
From100kTo500k	0%
From500kTo1000k	0%
Greater1000k	100%

hasAnnualIncome__person2	
Lower10k	0%
From10kTo30k	100%
From30kTo60k	0%
From60kTo100k	0%
Greater100k	0%

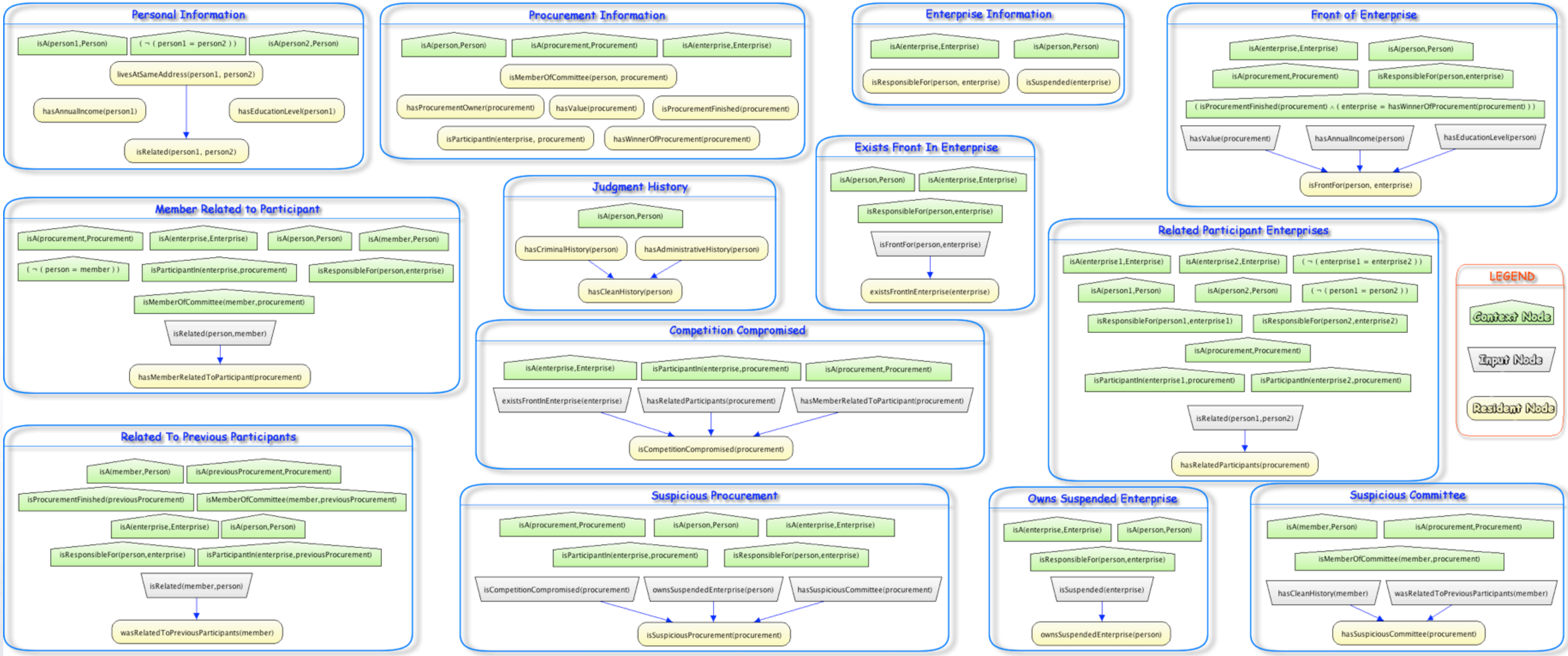
hasEducationLevel__person2	
NoEducation	0%
MiddleSchool	0%
HighSchool	100%
Undergraduate	0%
Graduate	0%

hasValue__procurement4	
Lower10k	0%
From10kTo100k	0%
From100kTo500k	0%
From500kTo1000k	100%
Greater1000k	0%

hasAnnualIncome__person4	
Lower10k	0%
From10kTo30k	0%
From30kTo60k	0%
From60kTo100k	0%
Greater100k	100%

hasEducationLevel__person4	
NoEducation	0%
MiddleSchool	0%
HighSchool	0%
Undergraduate	100%
Graduate	0%

PR-OWL 1.0



Personal Information

isA(person1,Person)
(¬ (person1 = person2))
isA(person2,Person)
livesAtSameAddress(person1, person2)
hasAnnualIncome(person1)
hasEducationLevel(person1)
isRelated(person1, person2)

Procurement Information

isA(person,Person)
isA(procurement,Procurement)
isA(enterprise,Enterprise)
isMemberOfCommittee(person, procurement)
hasProcurementOwner(procurement)
hasValue(procurement)
isProcurementFinished(procurement)
isParticipantIn(enterprise, procurement)
hasWinnerOfProcurement(procurement)

Enterprise Information

isA(enterprise,Enterprise)
isA(person,Person)
isResponsibleFor(person, enterprise)
isSuspended(enterprise)

Front of Enterprise

isA(enterprise,Enterprise)
isA(person,Person)
isA(procurement,Procurement)
isResponsibleFor(person,enterprise)
(isProcurementFinished(procurement) ∧ (enterprise = hasWinnerOfProcurement(procurement)))
hasValue(procurement)
hasAnnualIncome(person)
hasEducationLevel(person)
isFrontFor(person, enterprise)

Exists Front In Enterprise

isA(person,Person)
isA(enterprise,Enterprise)
isResponsibleFor(person,enterprise)
isFrontFor(person,enterprise)
existsFrontInEnterprise(enterprise)

Judgment History

isA(person,Person)
hasCriminalHistory(person)
hasAdministrativeHistory(person)
hasCleanHistory(person)

Member Related to Participant

isA(procurement,Procurement)
isA(enterprise,Enterprise)
isA(person,Person)
isA(member,Person)
(¬ (person = member))
isParticipantIn(enterprise,procurement)
isResponsibleFor(person,enterprise)
isMemberOfCommittee(member,procurement)
isRelated(person,member)
hasMemberRelatedToParticipant(procurement)

Related Participant Enterprises

isA(enterprise1,Enterprise)
isA(enterprise2,Enterprise)
(¬ (enterprise1 = enterprise2))
isA(person1,Person)
isA(person2,Person)
(¬ (person1 = person2))
isResponsibleFor(person1,enterprise1)
isResponsibleFor(person2,enterprise2)
isA(procurement,Procurement)
isParticipantIn(enterprise1,procurement)
isParticipantIn(enterprise2,procurement)
isRelated(person1,person2)
hasRelatedParticipants(procurement)

LEGEND

Context Node
Input Node
Resident Node

Competition Compromised

isA(enterprise,Enterprise)
isParticipantIn(enterprise,procurement)
isA(procurement,Procurement)
existsFrontInEnterprise(enterprise)
hasRelatedParticipants(procurement)
hasMemberRelatedToParticipant(procurement)
isCompetitionCompromised(procurement)

Related To Previous Participants

isA(member,Person)
isA(previousProcurement,Procurement)
isProcurementFinished(previousProcurement)
isMemberOfCommittee(member,previousProcurement)
isA(enterprise,Enterprise)
isA(person,Person)
isResponsibleFor(person,enterprise)
isParticipantIn(enterprise,previousProcurement)
isRelated(member,person)
wasRelatedToPreviousParticipants(member)

Suspicious Procurement

isA(procurement,Procurement)
isA(person,Person)
isA(enterprise,Enterprise)
isParticipantIn(enterprise,procurement)
isResponsibleFor(person,enterprise)
isCompetitionCompromised(procurement)
ownsSuspendedEnterprise(person)
hasSuspiciousCommittee(procurement)
isSuspiciousProcurement(procurement)

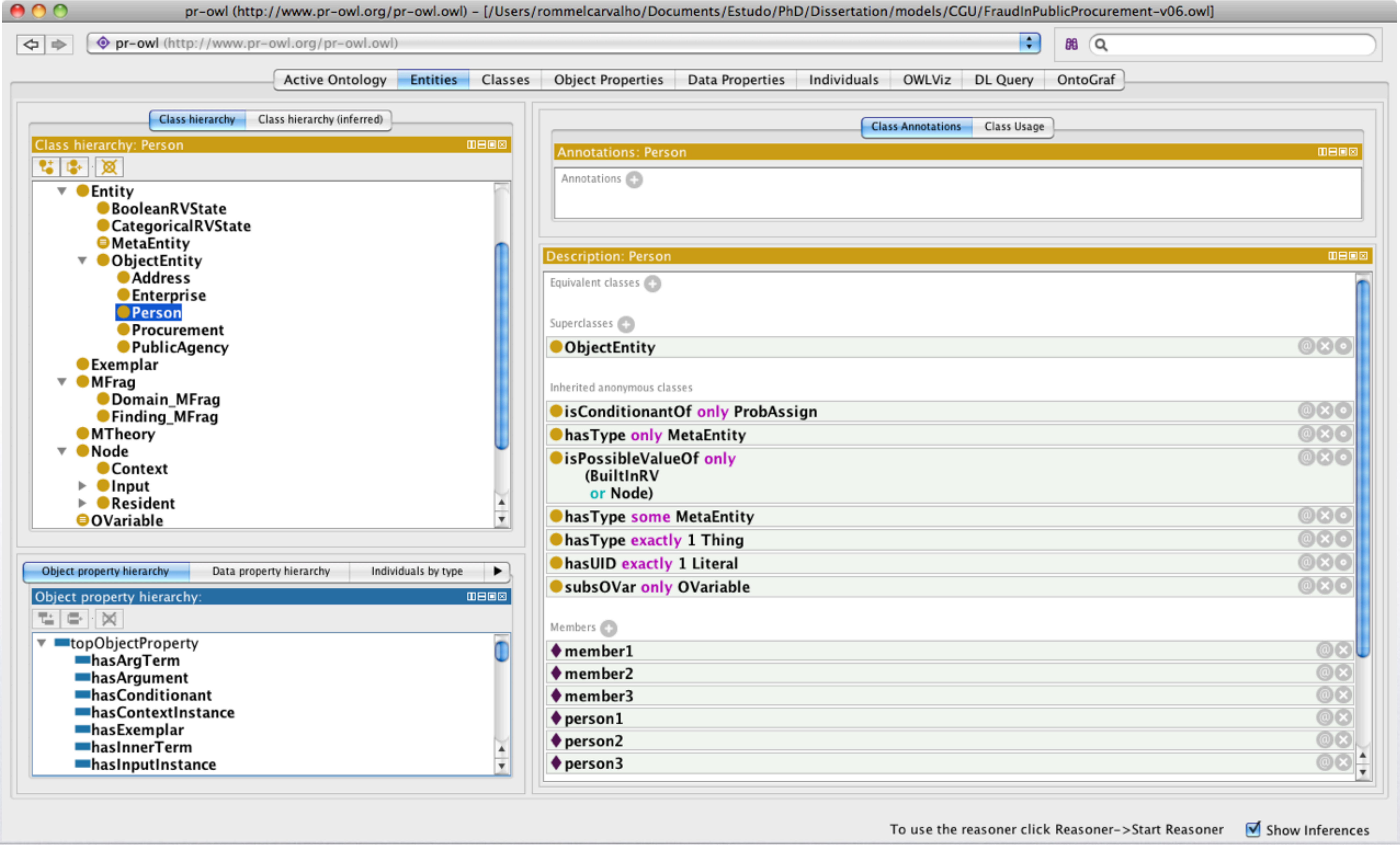
Owns Suspended Enterprise

isA(enterprise,Enterprise)
isA(person,Person)
isResponsibleFor(person,enterprise)
isSuspended(enterprise)
ownsSuspendedEnterprise(person)

Suspicious Committee

isA(member,Person)
isA(procurement,Procurement)
isMemberOfCommittee(member,procurement)
hasCleanHistory(member)
wasRelatedToPreviousParticipants(member)
hasSuspiciousCommittee(procurement)

PR-OWL 1.0



pr-owl (http://www.pr-owl.org/pr-owl.owl) – [/Users/rommelcarvalho/Documents/Estudo/PhD/Dissertation/models/CGU/FraudInPublicProcurement-v06.owl]

pr-owl (http://www.pr-owl.org/pr-owl.owl)

Class hierarchy: Person

- Entity
  - BooleanRVState
  - CategoricalRVState
  - MetaEntity
  - ObjectEntity
    - Address
    - Enterprise
    - Person
    - Procurement
    - PublicAgency
- Exemplar
- MFrag
  - Domain_MFrag
  - Finding_MFrag
- MTheory
- Node
  - Context
  - Input
  - Resident
- OVariable

Object property hierarchy:

- topObjectProperty
  - hasArgTerm
  - hasArgument
  - hasConditionant
  - hasContextInstance
  - hasExemplar
  - hasInnerTerm
  - hasInputInstance

Annotations: Person

Annotations

Description: Person

Equivalent classes

Superclasses

ObjectEntity

Inherited anonymous classes

isConditionantOf only ProbAssign

hasType only MetaEntity

isPossibleValueOf only
(BuiltInRV
or Node)

hasType some MetaEntity

hasType exactly 1 Thing

hasUID exactly 1 Literal

subsOVar only OVariable

Members

member1

member2

member3

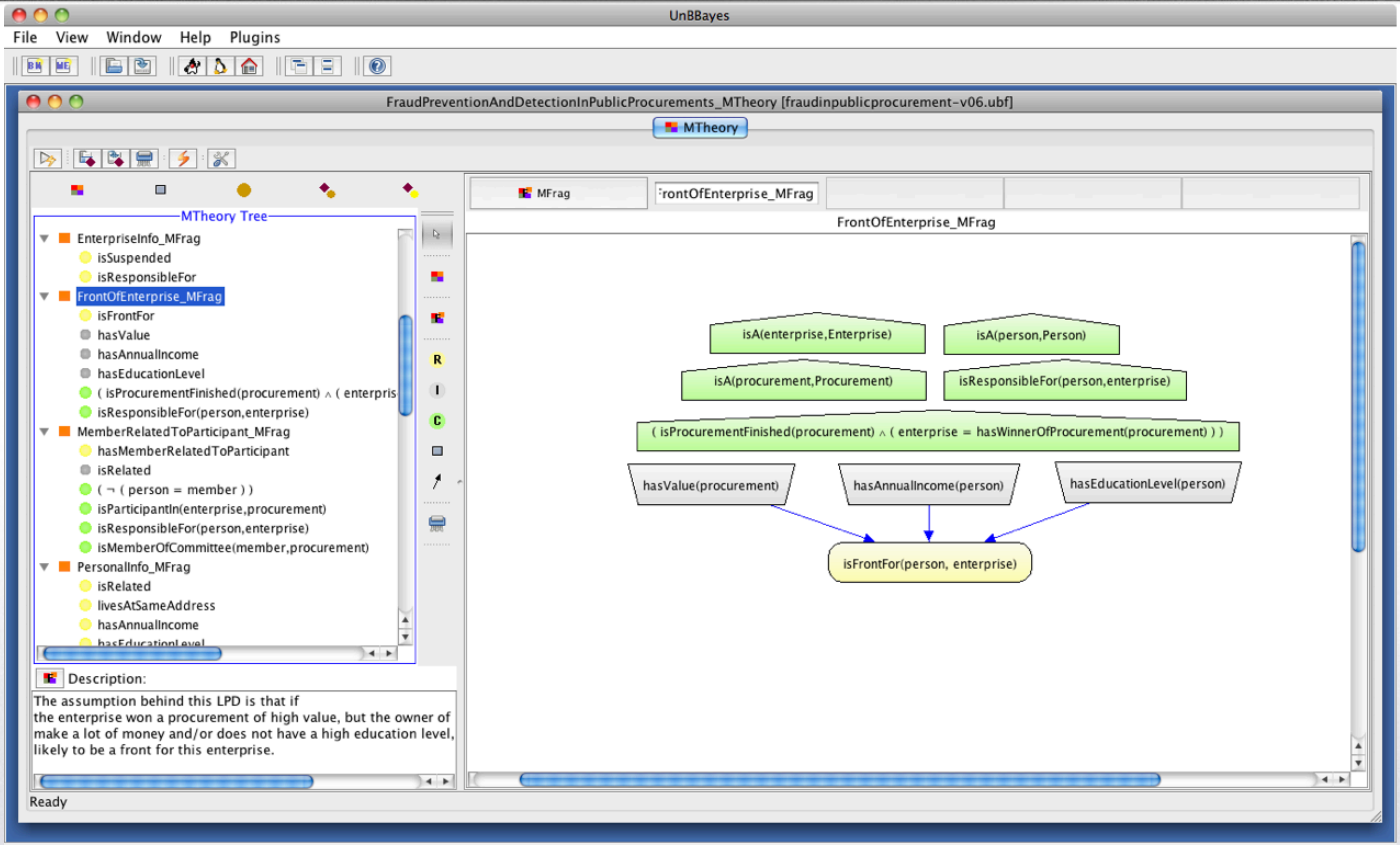
person1

person2

person3

To use the reasoner click Reasoner->Start Reasoner ☑ Show Inferences

UnBBayes - MEBN / PR-OWL 1.0

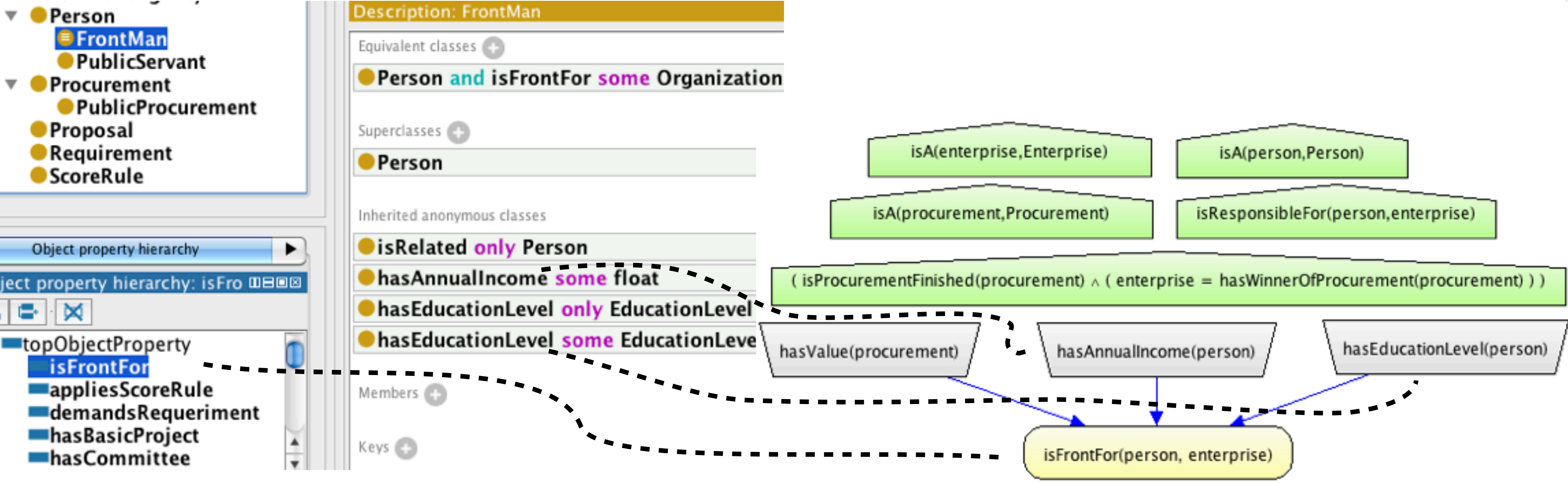

UnBBayes
File View Window Help Plugins
FraudPreventionAndDetectionInPublicProcurements_MTheory [fraudinpublicprocurement-v06.ubf]
MTheory
MTheory Tree
EnterpriseInfo_MFrag
isSuspended
isResponsibleFor
FrontOfEnterprise_MFrag
isFrontFor
hasValue
hasAnnualIncome
hasEducationLevel
(isProcurementFinished(procurement) ∧ (enterpris
isResponsibleFor(person,enterprise)
MemberRelatedToParticipant_MFrag
hasMemberRelatedToParticipant
isRelated
(¬ (person = member))
isParticipantIn(enterprise,procurement)
isResponsibleFor(person,enterprise)
isMemberOfCommittee(member,procurement)
PersonalInfo_MFrag
isRelated
livesAtSameAddress
hasAnnualIncome
hasEducationLevel
MFrag
FrontOfEnterprise_MFrag
FrontOfEnterprise_MFrag
R
I
C
isA(enterprise,Enterprise)
isA(person,Person)
isA(procurement,Procurement)
isResponsibleFor(person,enterprise)
(isProcurementFinished(procurement) ∧ (enterprise = hasWinnerOfProcurement(procurement)))
hasValue(procurement)
hasAnnualIncome(person)
hasEducationLevel(person)
isFrontFor(person, enterprise)
Description:
Ready

The assumption behind this LPD is that if
the enterprise won a procurement of high value, but the owner of
make a lot of money and/or does not have a high education level,
likely to be a front for this enterprise.

1st Major Contribution

PR-OWL 2.0

1st Problem - Mapping/Types



- Person
  - FrontMan
  - PublicServant
- Procurement
  - PublicProcurement
- Proposal
- Requirement
- ScoreRule

Object property hierarchy

ject property hierarchy: isFro

- topObjectProperty
  - isFrontFor
  - appliesScoreRule
  - demandsRequeriment
  - hasBasicProject
  - hasCommittee

Description: FrontMan

Equivalent classes

Person and isFrontFor some Organization

Superclasses

Person

Inherited anonymous classes

isRelated only Person

hasAnnualIncome some float

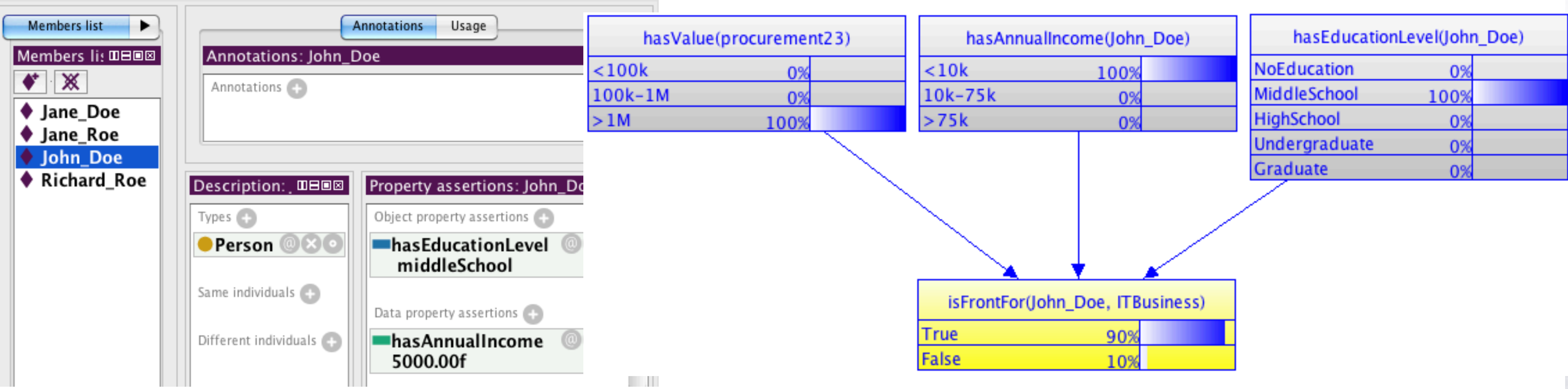
hasEducationLevel only EducationLevel

hasEducationLevel some EducationLeve

Members

Keys

isA(enterprise,Enterprise)
isA(person,Person)
isA(procurement,Procurement)
isResponsibleFor(person,enterprise)
(isProcurementFinished(procurement) ∧ (enterprise = hasWinnerOfProcurement(procurement)))
hasValue(procurement)
hasAnnualIncome(person)
hasEducationLevel(person)
isFrontFor(person, enterprise)



Members list

Members lis

- Jane_Doe
- Jane_Roe
- John_Doe
- Richard_Roe

Annotations | Usage

Annotations: John_Doe

Annotations

Description:

Types

Person

Same individuals

Different individuals

Property assertions: John_Do

Object property assertions

hasEducationLevel middleSchool

Data property assertions

hasAnnualIncome 5000.00f

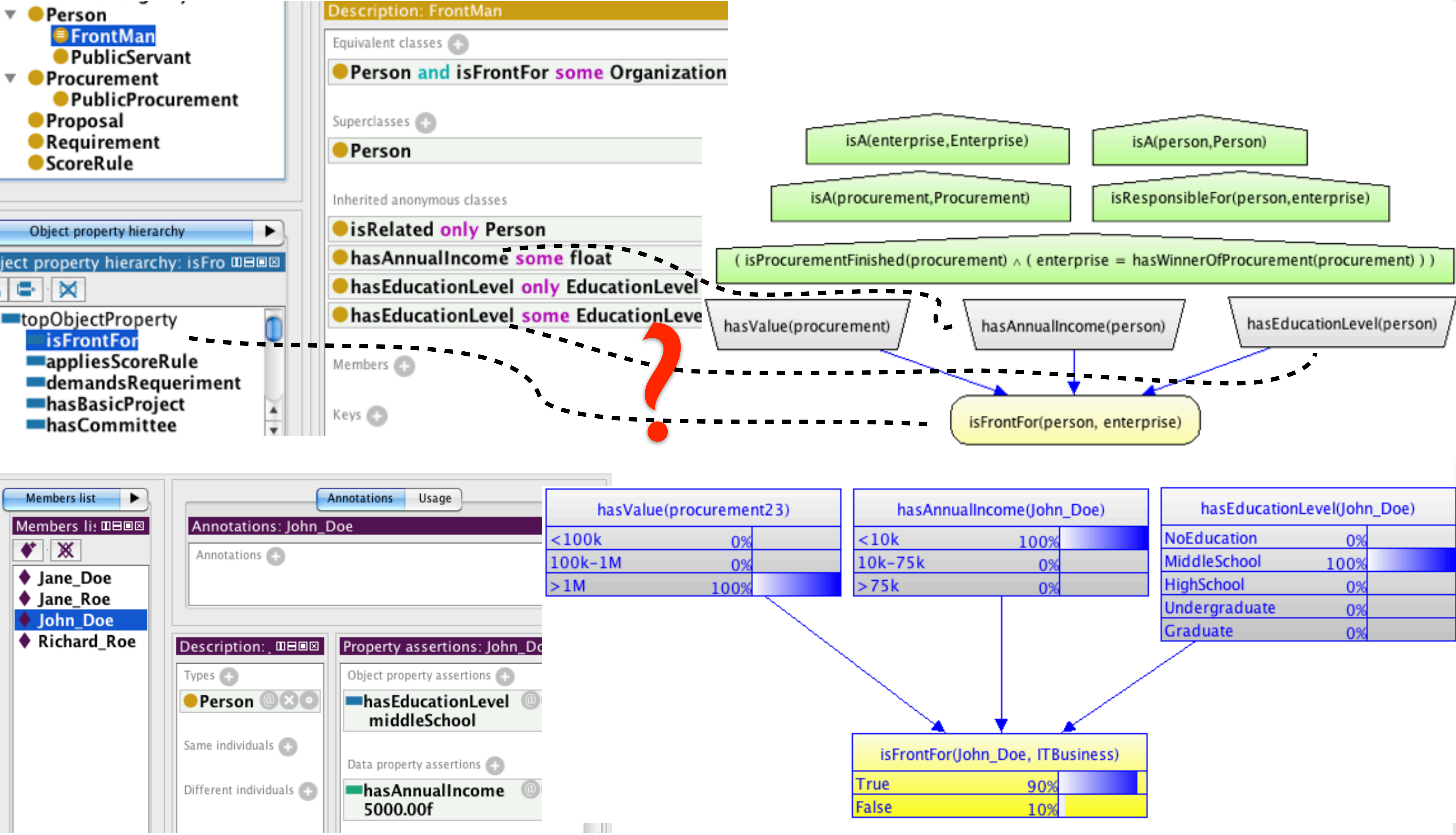
hasValue(procurement23)	
<100k	0%
100k-1M	0%
>1M	100%

hasAnnualIncome(John_Doe)	
<10k	100%
10k-75k	0%
>75k	0%

hasEducationLevel(John_Doe)	
NoEducation	0%
MiddleSchool	100%
HighSchool	0%
Undergraduate	0%
Graduate	0%

isFrontFor(John_Doe, ITBusiness)	
True	90%
False	10%

1st Problem - Mapping/Types



- ● Person
  - ● FrontMan
  - ● PublicServant
- ● Procurement
  - ● PublicProcurement
- ● Proposal
- ● Requirement
- ● ScoreRule

Description: FrontMan

Equivalent classes
- ● Person and isFrontFor some Organization

Superclasses
- ● Person

Inherited anonymous classes
- ● isRelated only Person
- ● hasAnnualIncome some float
- ● hasEducationLevel only EducationLevel
- ● hasEducationLevel some EducationLeve

Members

Keys

Object property hierarchy

ject property hierarchy: isFro

- topObjectProperty
  - isFrontFor
  - appliesScoreRule
  - demandsRequeriment
  - hasBasicProject
  - hasCommittee

Members list

Members lis

- ♦ Jane_Doe
- ♦ Jane_Roe
- ♦ John_Doe
- ♦ Richard_Roe

Annotations | Usage

Annotations: John_Doe

Annotations

Description:

Types
- ● Person

Same individuals

Different individuals

Property assertions: John_Do

Object property assertions
- hasEducationLevel middleSchool

Data property assertions
- hasAnnualIncome 5000.00f

isA(enterprise,Enterprise)
isA(person,Person)
isA(procurement,Procurement)
isResponsibleFor(person,enterprise)
(isProcurementFinished(procurement) ∧ (enterprise = hasWinnerOfProcurement(procurement)))
hasValue(procurement)
hasAnnualIncome(person)
hasEducationLevel(person)
isFrontFor(person, enterprise)
?

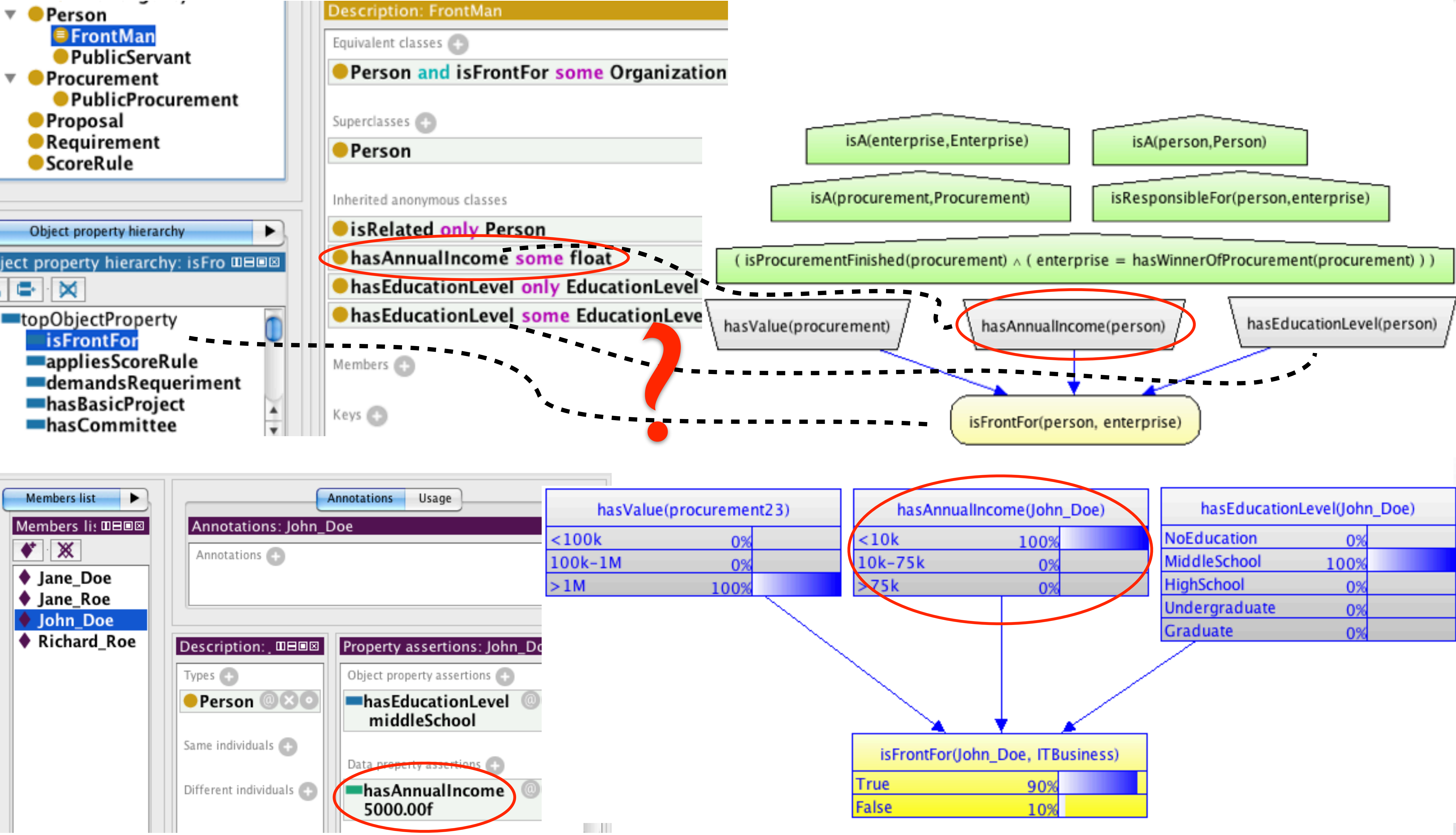
hasValue(procurement23)	
<100k	0%
100k-1M	0%
>1M	100%

hasAnnualIncome(John_Doe)	
<10k	100%
10k-75k	0%
>75k	0%

hasEducationLevel(John_Doe)	
NoEducation	0%
MiddleSchool	100%
HighSchool	0%
Undergraduate	0%
Graduate	0%

isFrontFor(John_Doe, ITBusiness)	
True	90%
False	10%

1st Problem - Mapping/Types



Person
FrontMan
PublicServant
Procurement
PublicProcurement
Proposal
Requirement
ScoreRule

Description: FrontMan

Equivalent classes

Person and isFrontFor some Organization

Superclasses

Person

Inherited anonymous classes

isRelated only Person

hasAnnualIncome some float

hasEducationLevel only EducationLevel

hasEducationLevel some EducationLeve

Members

Keys

Object property hierarchy

ject property hierarchy: isFro

topObjectProperty
isFrontFor
appliesScoreRule
demandsRequeriment
hasBasicProject
hasCommittee

isA(enterprise,Enterprise)

isA(person,Person)

isA(procurement,Procurement)

isResponsibleFor(person,enterprise)

(isProcurementFinished(procurement) ∧ (enterprise = hasWinnerOfProcurement(procurement)))

hasValue(procurement)

hasAnnualIncome(person)

hasEducationLevel(person)

isFrontFor(person, enterprise)

?

Members list

Members li

Jane_Doe
Jane_Roe
John_Doe
Richard_Roe

Annotations | Usage

Annotations: John_Doe

Annotations

Description:

Types

Person

Same individuals

Different individuals

Property assertions: John_Do

Object property assertions

hasEducationLevel middleSchool

Data property assertions

hasAnnualIncome 5000.00f

hasValue(procurement23)	
<100k	0%
100k-1M	0%
>1M	100%

hasAnnualIncome(John_Doe)	
<10k	100%
10k-75k	0%
>75k	0%

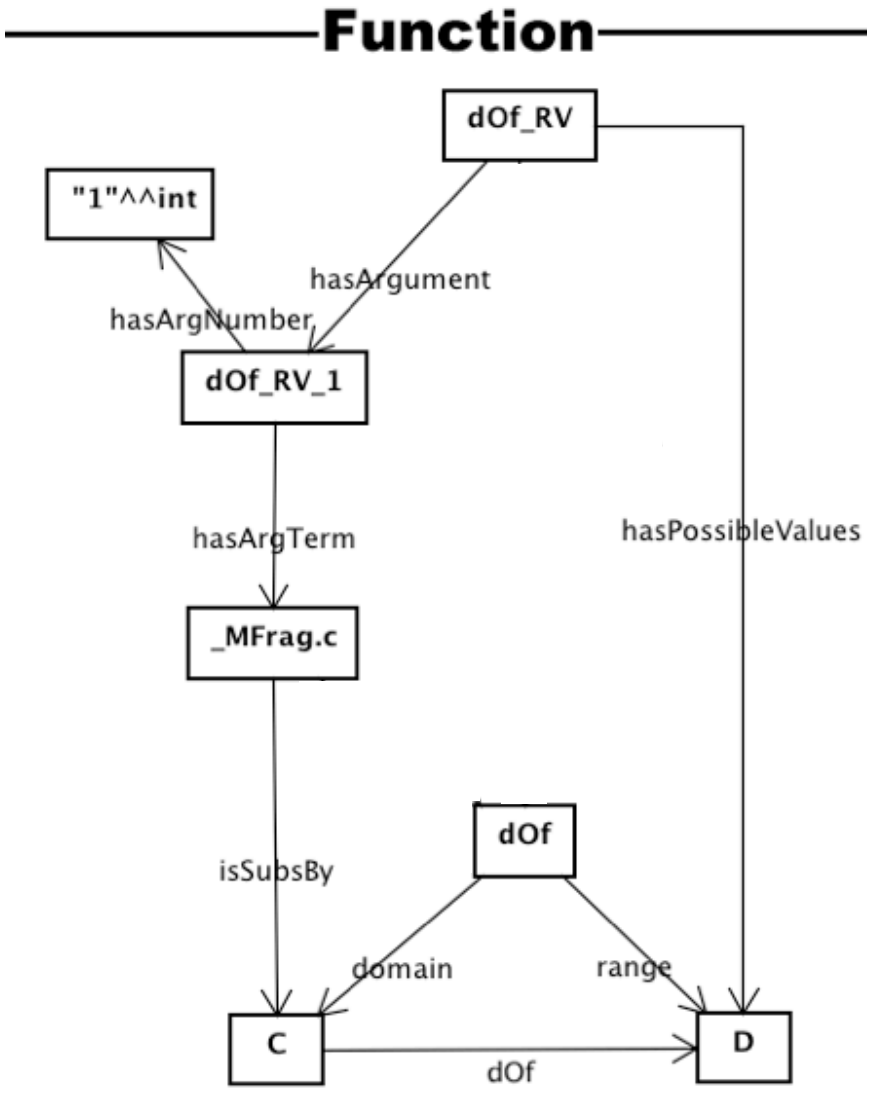
hasEducationLevel(John_Doe)	
NoEducation	0%
MiddleSchool	100%
HighSchool	0%
Undergraduate	0%
Graduate	0%

isFrontFor(John_Doe, ITBusiness)	
True	90%
False	10%

Mapping Schema

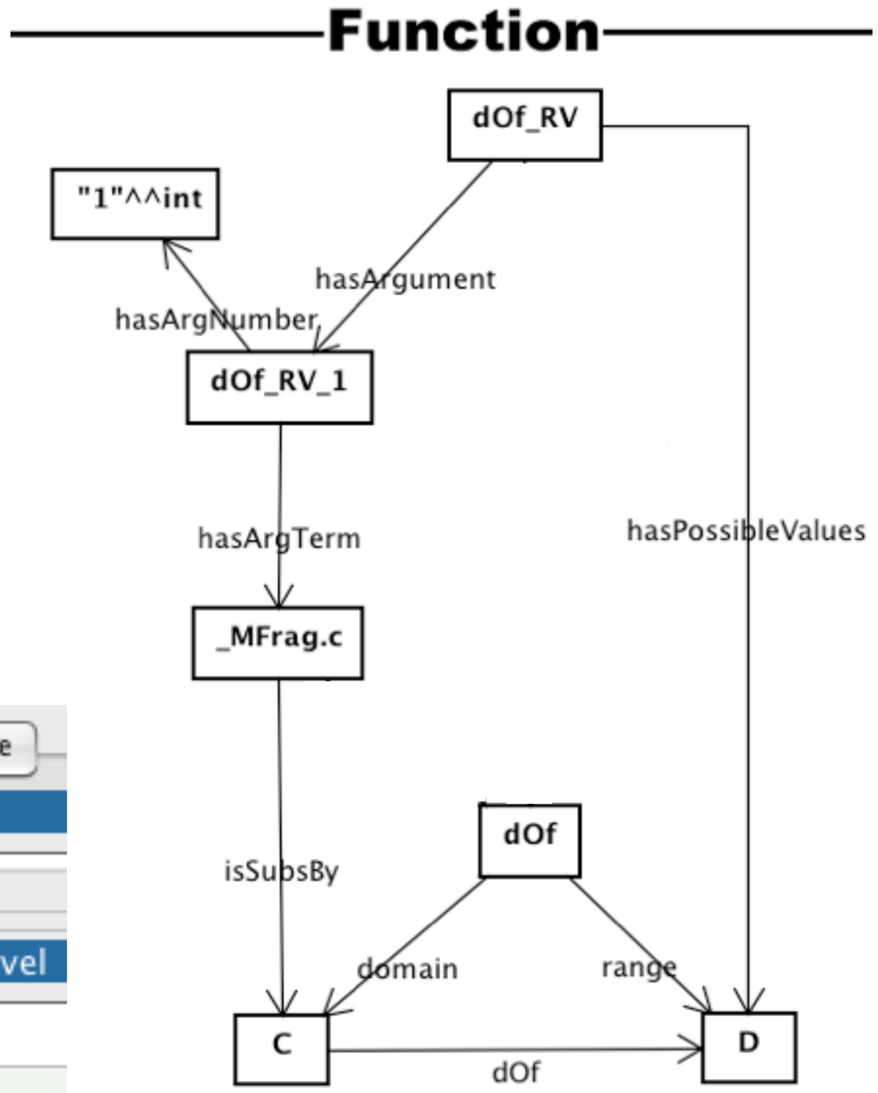
PR-OWL

OWL

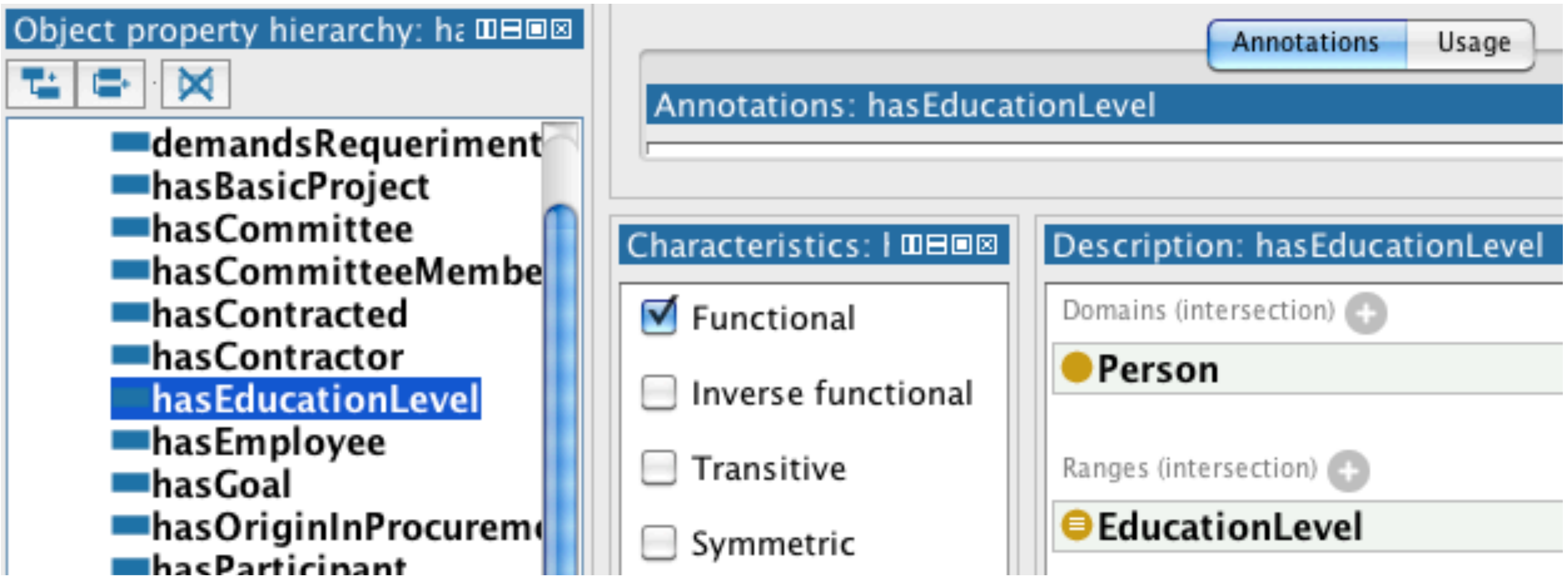


Mapping Schema

PR-OWL



OWL



Object property hierarchy: ha

- demandsRequeriment
- hasBasicProject
- hasCommittee
- hasCommitteeMembe
- hasContracted
- hasContractor
- hasEducationLevel
- hasEmployee
- hasGoal
- hasOriginInProcurem
- hasParticipant

Annotations | Usage

Annotations: hasEducationLevel

Characteristics: h

- ☑ Functional
- ☐ Inverse functional
- ☐ Transitive
- ☐ Symmetric

Description: hasEducationLevel

Domains (intersection)

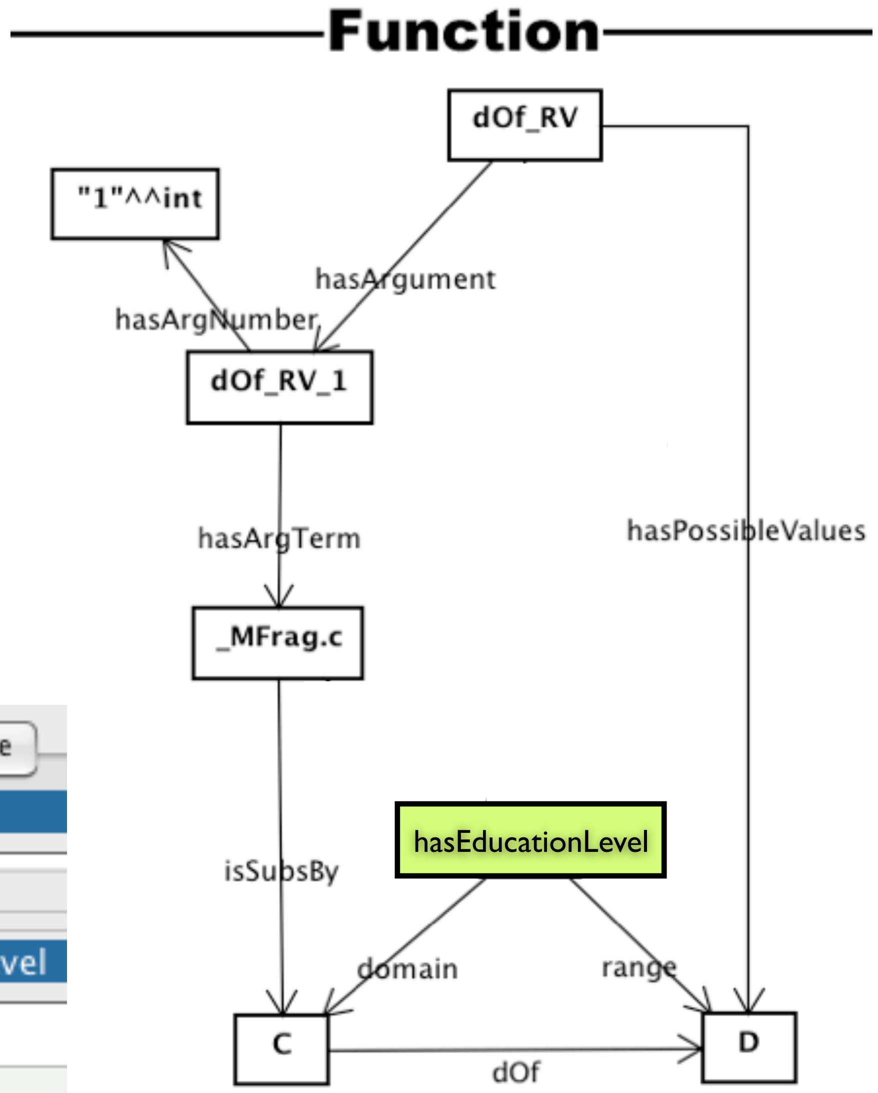
● Person

Ranges (intersection)

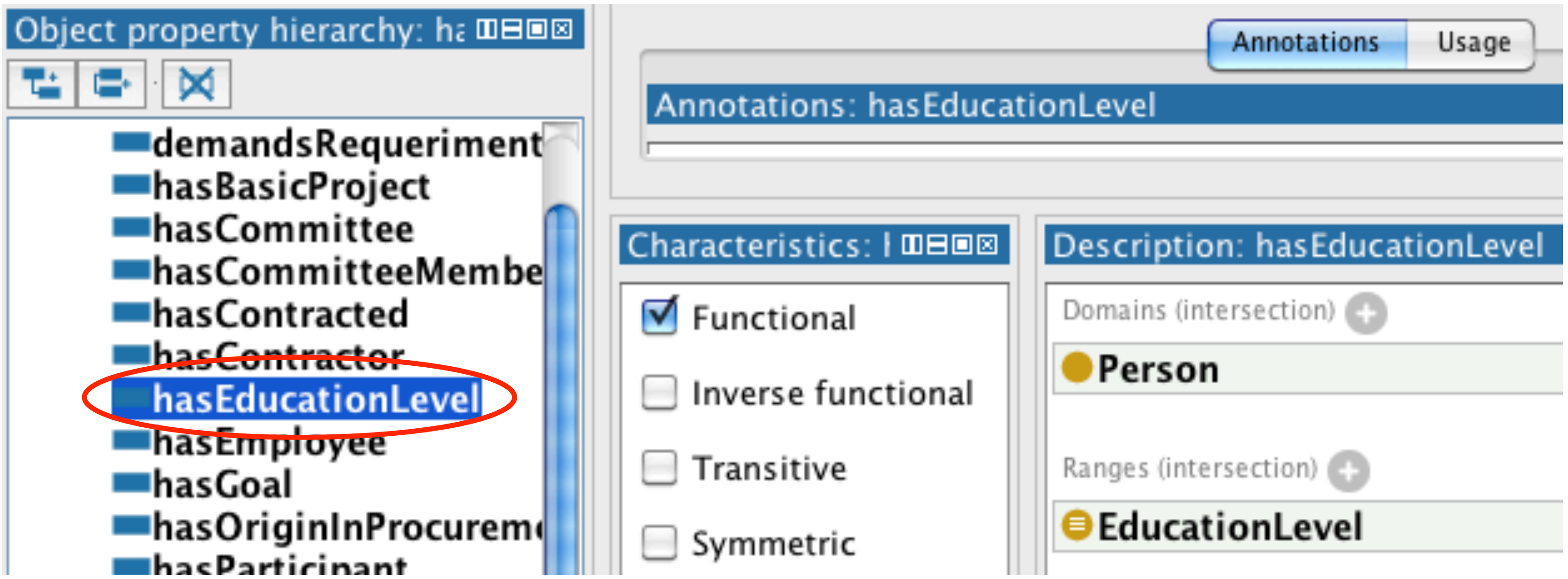
● EducationLevel

Mapping Schema

PR-OWL



OWL


Object property hierarchy: ha

- demandsRequeriment
- hasBasicProject
- hasCommittee
- hasCommitteeMembe
- hasContracted
- hasContractor
- hasEducationLevel
- hasEmployee
- hasGoal
- hasOriginInProcurem
- hasParticipant

Annotations: hasEducationLevel

Characteristics: h

☑ Functional

□ Inverse functional

□ Transitive

□ Symmetric

Description: hasEducationLevel

Domains (intersection)

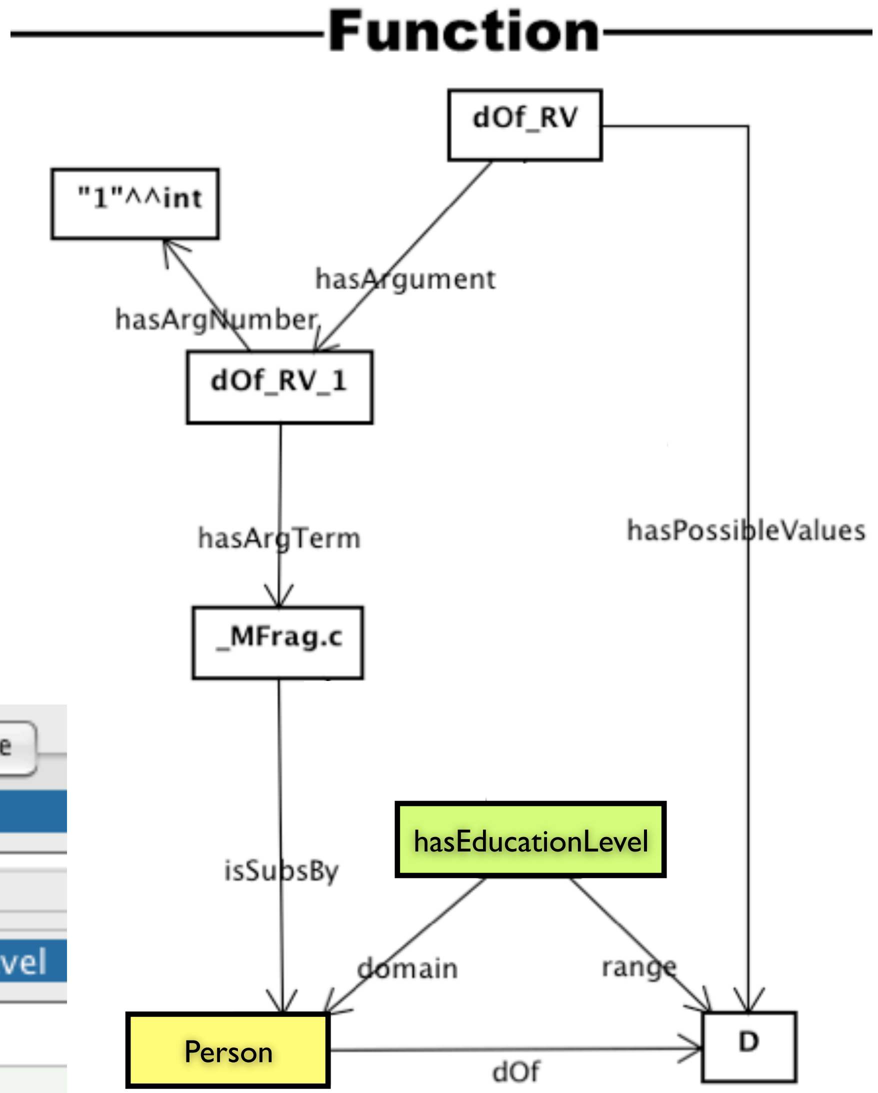
● Person

Ranges (intersection)

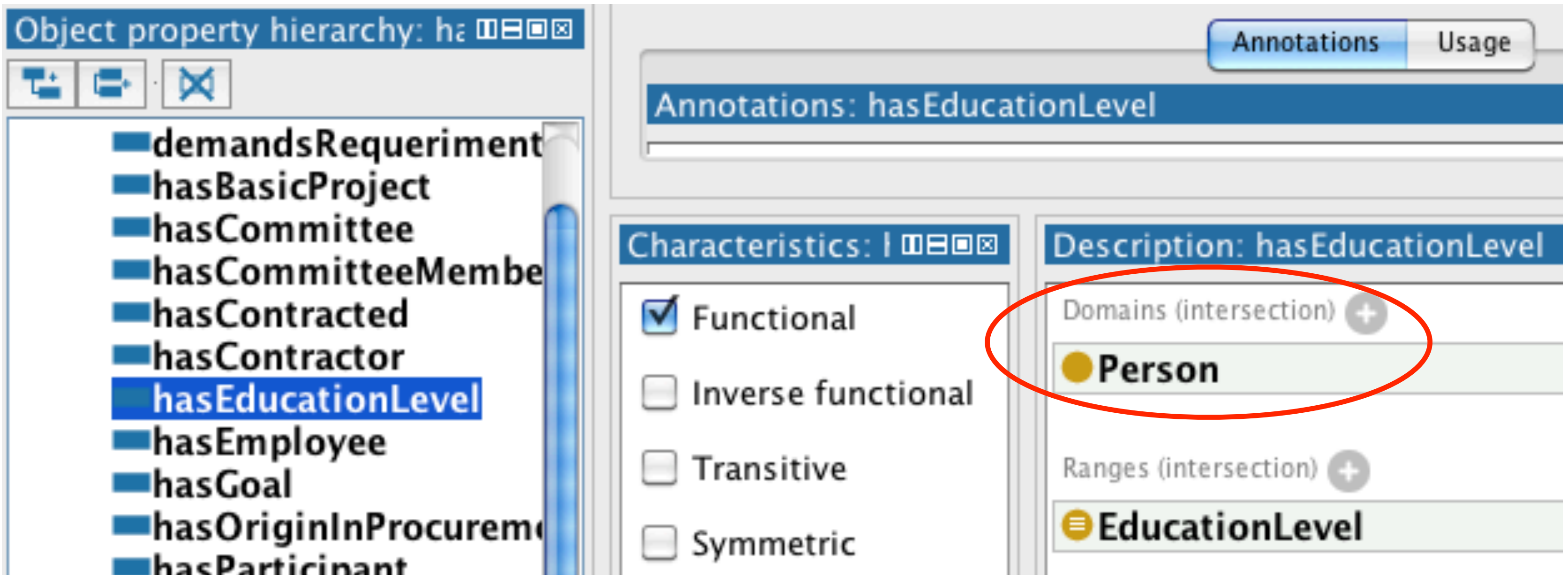
● EducationLevel

Mapping Schema

PR-OWL



OWL


Object property hierarchy: ha

- demandsRequeriment
- hasBasicProject
- hasCommittee
- hasCommitteeMembe
- hasContracted
- hasContractor
- hasEducationLevel
- hasEmployee
- hasGoal
- hasOriginInProcurem
- hasParticipant

Annotations | Usage

Annotations: hasEducationLevel

Characteristics: ł

☑ Functional

☐ Inverse functional

☐ Transitive

☐ Symmetric

Description: hasEducationLevel

Domains (intersection)

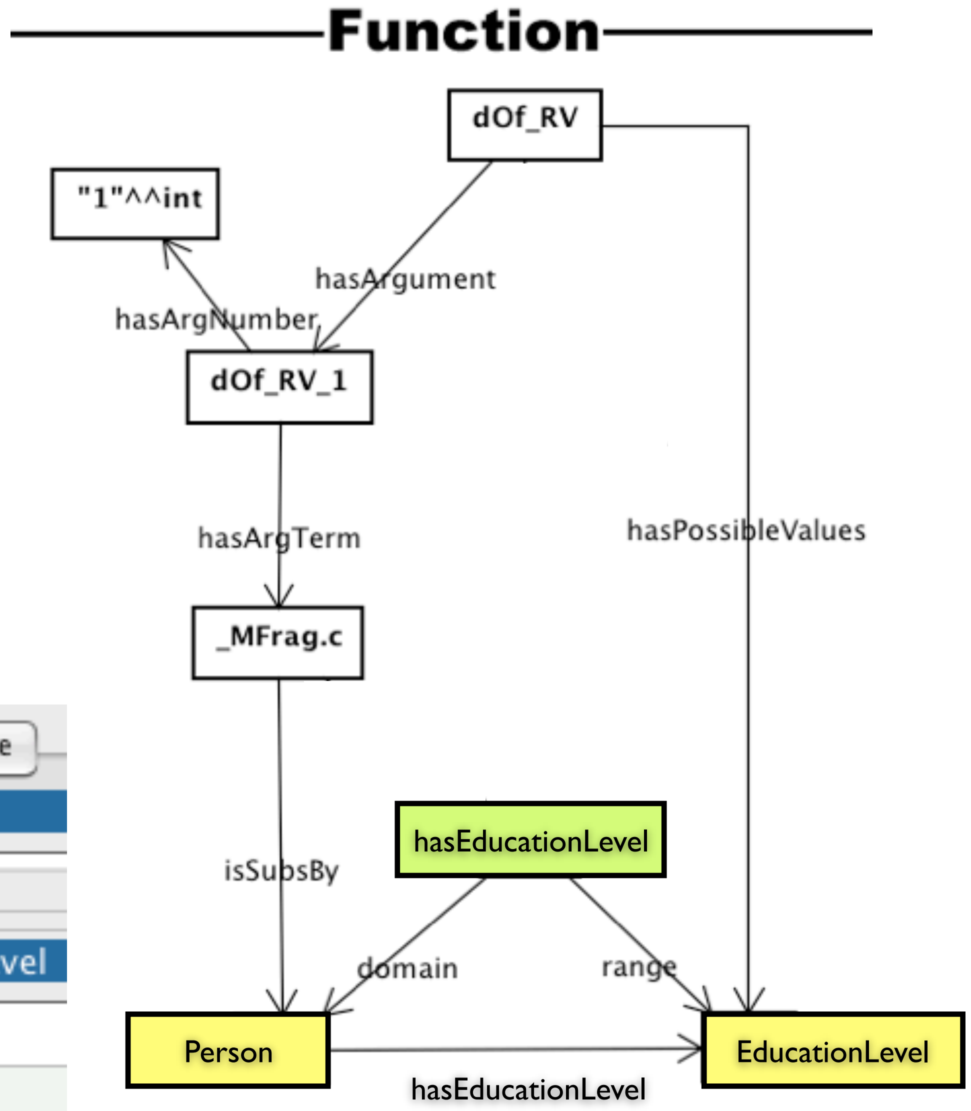
● Person

Ranges (intersection)

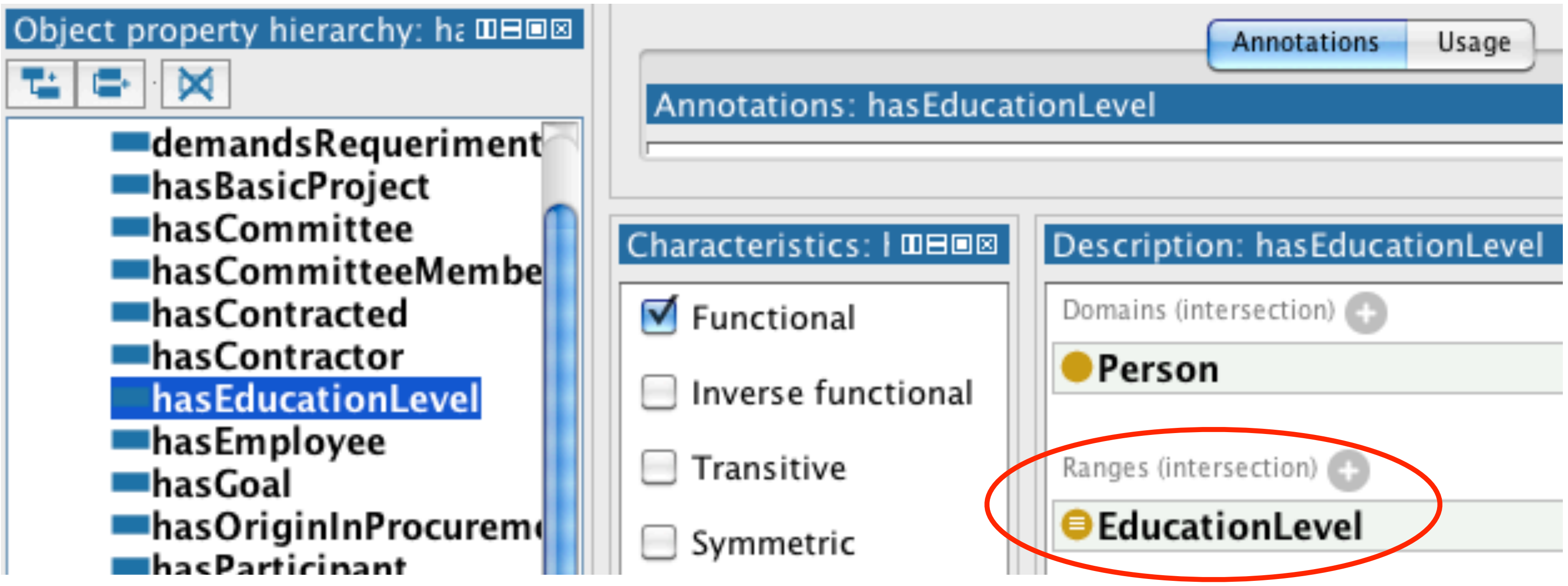
EducationLevel

Mapping Schema

PR-OWL



OWL


Object property hierarchy: ha

- demandsRequeriment
- hasBasicProject
- hasCommittee
- hasCommitteeMembe
- hasContracted
- hasContractor
- hasEducationLevel
- hasEmployee
- hasGoal
- hasOriginInProcureme
- hasParticipant

Annotations: hasEducationLevel

Characteristics: h

- ☑ Functional
- ☐ Inverse functional
- ☐ Transitive
- ☐ Symmetric

Description: hasEducationLevel

Domains (intersection)

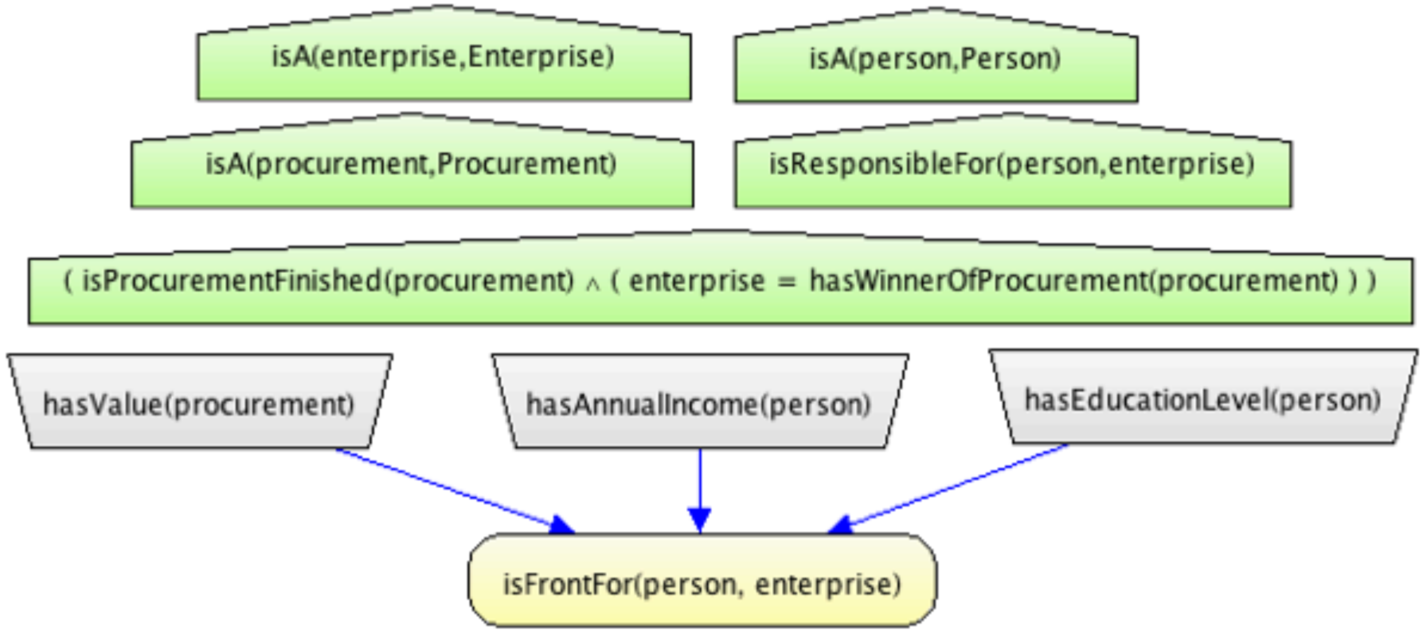
● Person

Ranges (intersection)

● EducationLevel

Mapping Schema

PR-OWL



isA(enterprise,Enterprise)

isA(person,Person)

isA(procurement,Procurement)

isResponsibleFor(person,enterprise)

(isProcurementFinished(procurement) ∧ (enterprise = hasWinnerOfProcurement(procurement)))

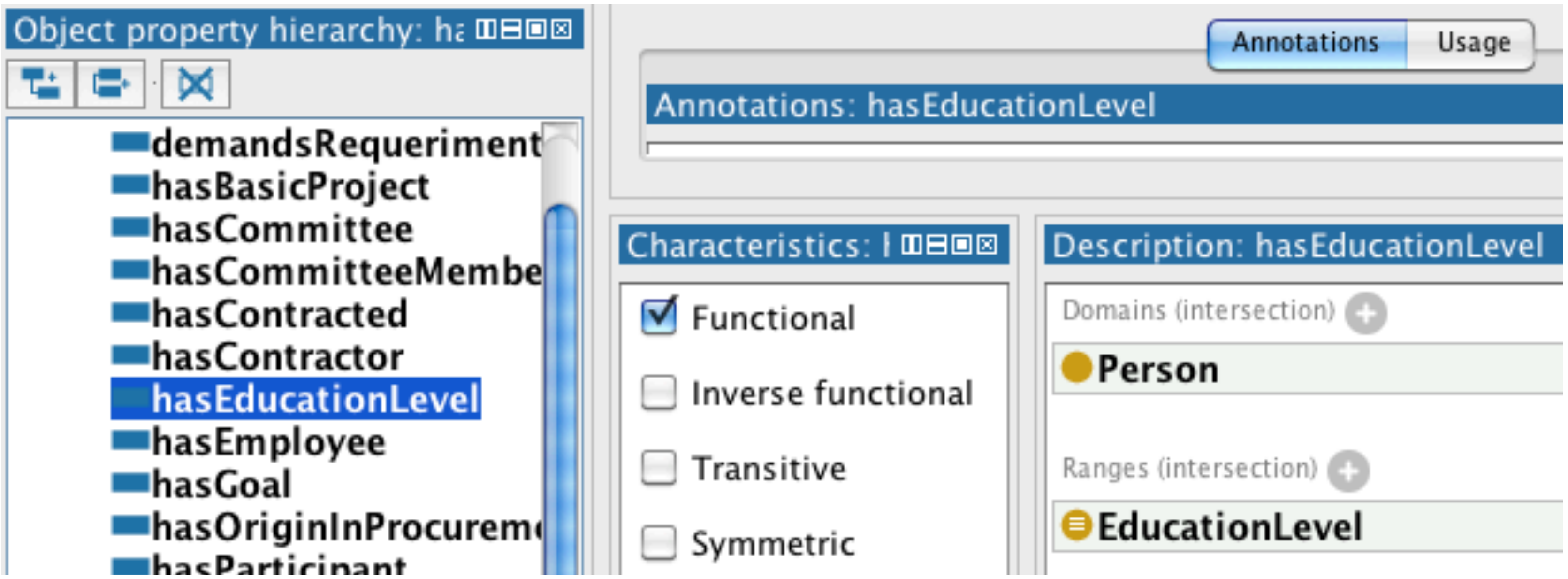
hasValue(procurement)

hasAnnualIncome(person)

hasEducationLevel(person)

isFrontFor(person, enterprise)

OWL



demandsRequeriment
hasBasicProject
hasCommittee
hasCommitteeMembe
hasContracted
hasContractor
hasEducationLevel
hasEmployee
hasGoal
hasOriginInProcurem
hasParticipant

Annotations: hasEducationLevel

Characteristics: I

☑ Functional

☐ Inverse functional

☐ Transitive

☐ Symmetric

Description: hasEducationLevel

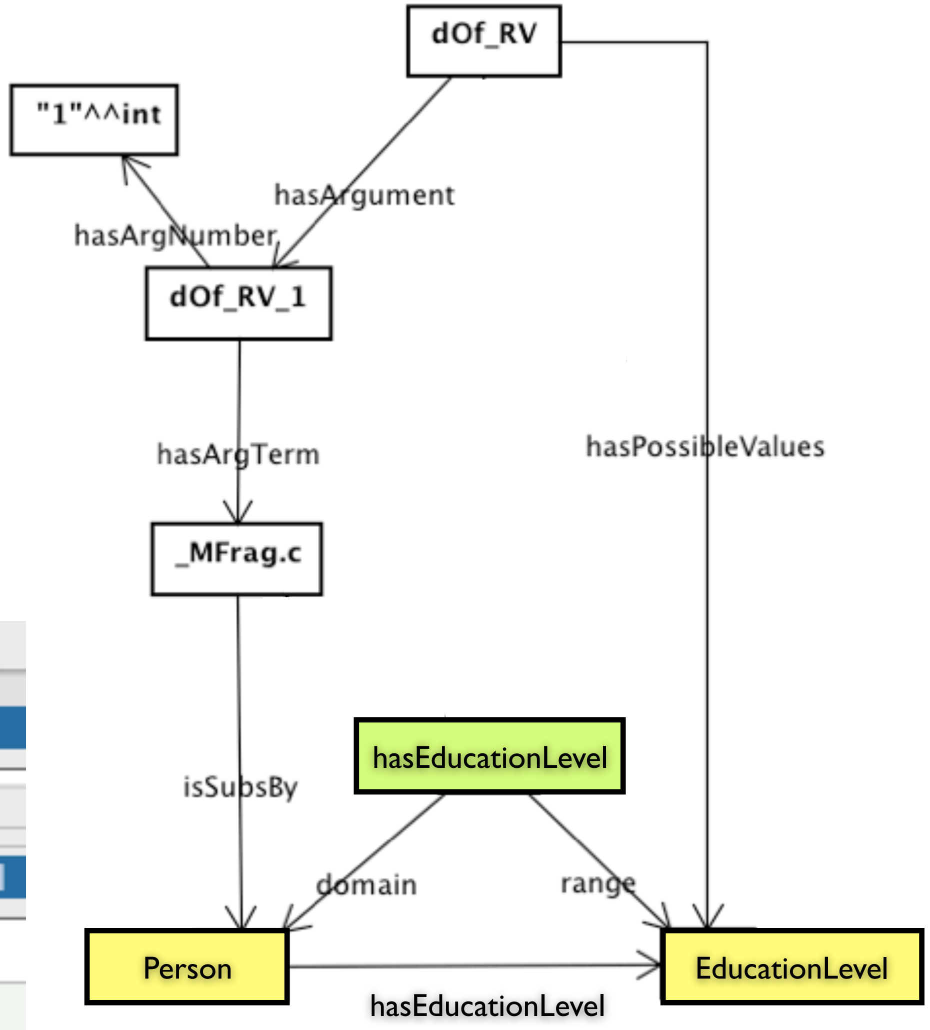
Domains (intersection)

● Person

Ranges (intersection)

● EducationLevel

Function



dOf_RV

"1"^^int

hasArgument

hasArgNumber

dOf_RV_1

hasArgTerm

hasPossibleValues

_MFrag.c

isSubsBy

hasEducationLevel

domain

range

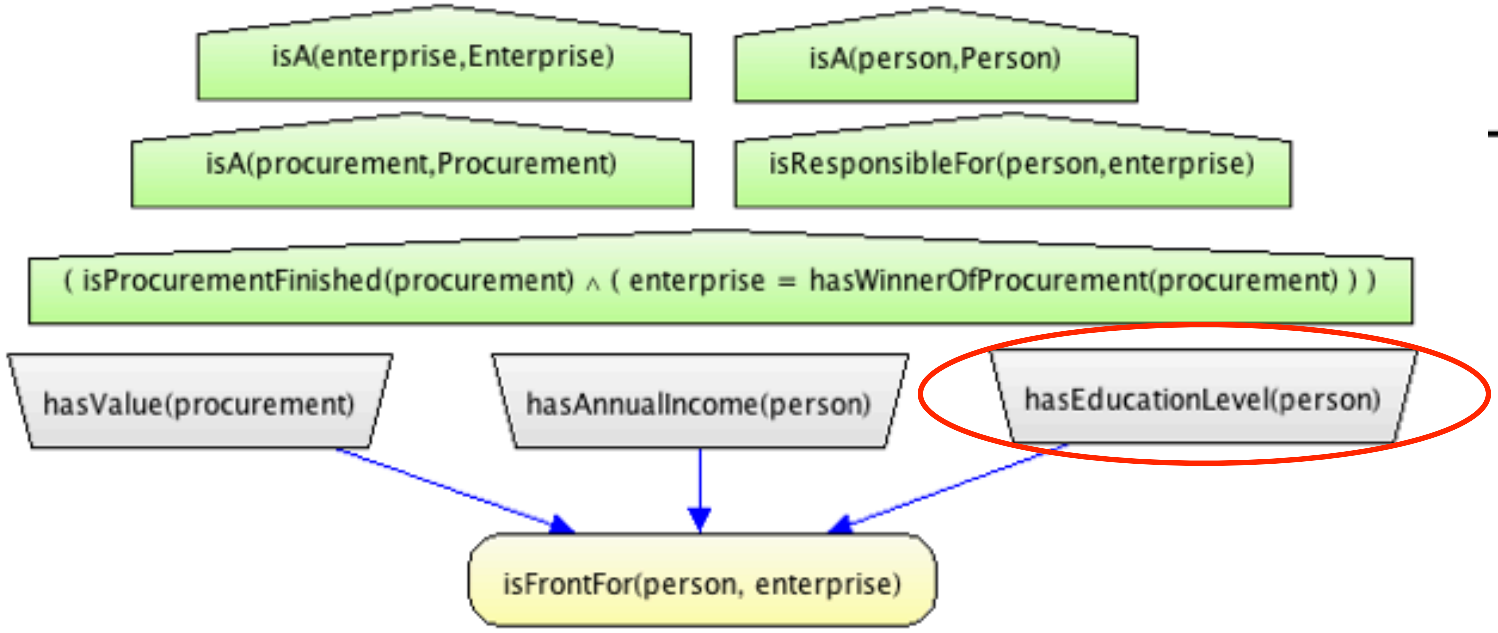
Person

EducationLevel

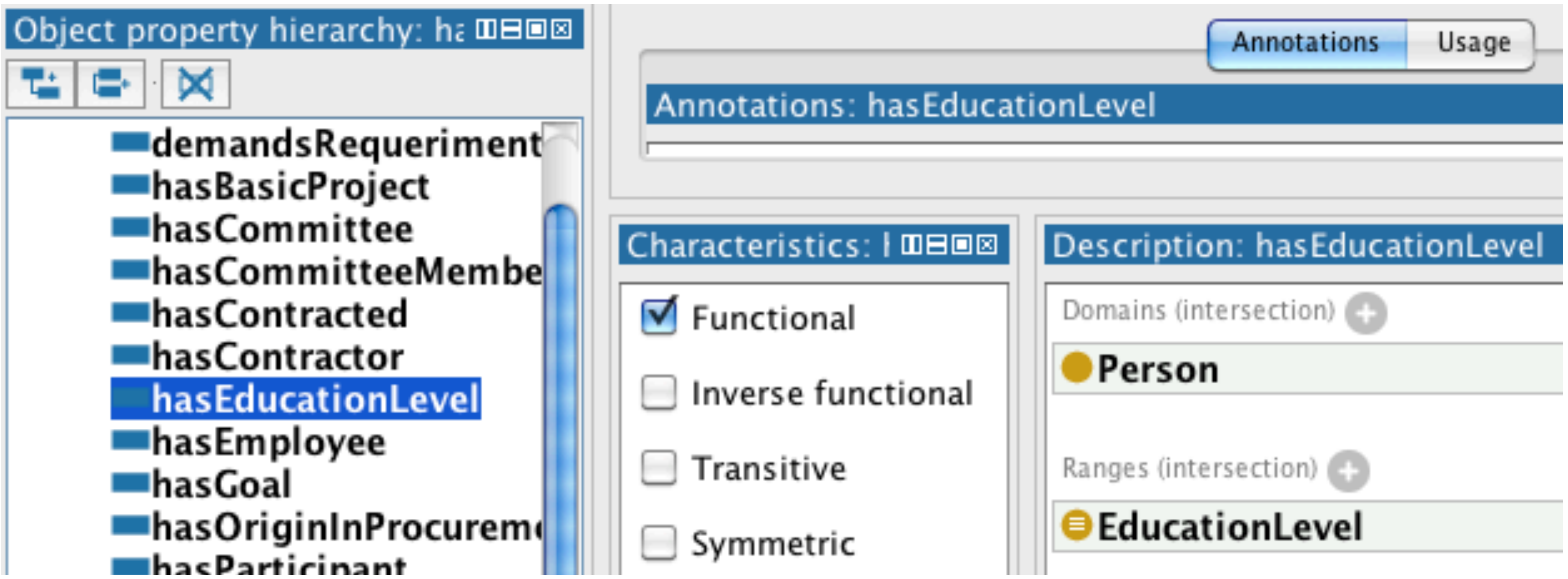
hasEducationLevel

Mapping Schema

PR-OWL


isA(enterprise,Enterprise)
isA(person,Person)
isA(procurement,Procurement)
isResponsibleFor(person,enterprise)
(isProcurementFinished(procurement) ∧ (enterprise = hasWinnerOfProcurement(procurement)))
hasValue(procurement)
hasAnnualIncome(person)
hasEducationLevel(person)
isFrontFor(person, enterprise)

OWL


Object property hierarchy: ha

demandsRequeriment
hasBasicProject
hasCommittee
hasCommitteeMembe
hasContracted
hasContractor
hasEducationLevel
hasEmployee
hasGoal
hasOriginInProcurem
hasParticipant

Annotations | Usage

Annotations: hasEducationLevel

Characteristics: I

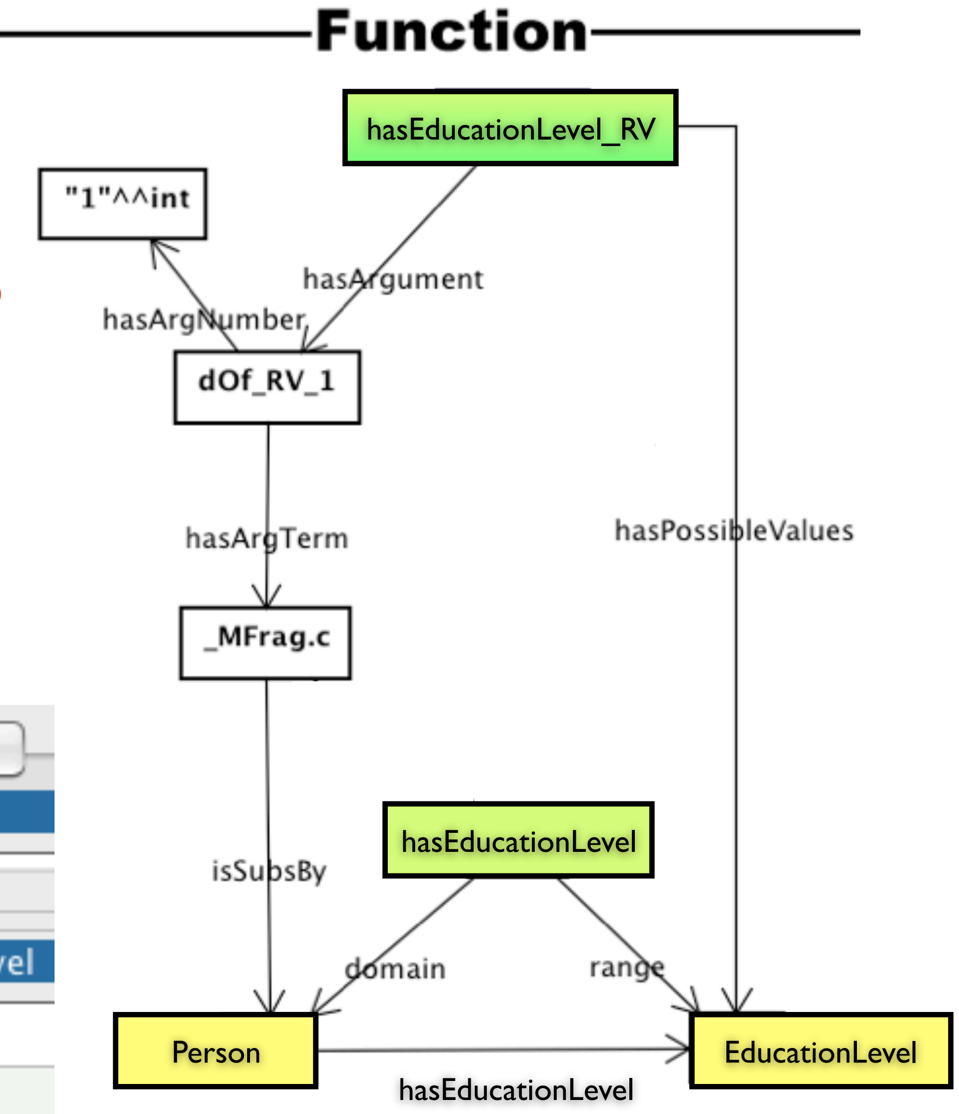
☑ Functional
☐ Inverse functional
☐ Transitive
☐ Symmetric

Description: hasEducationLevel

Domains (intersection)
● Person

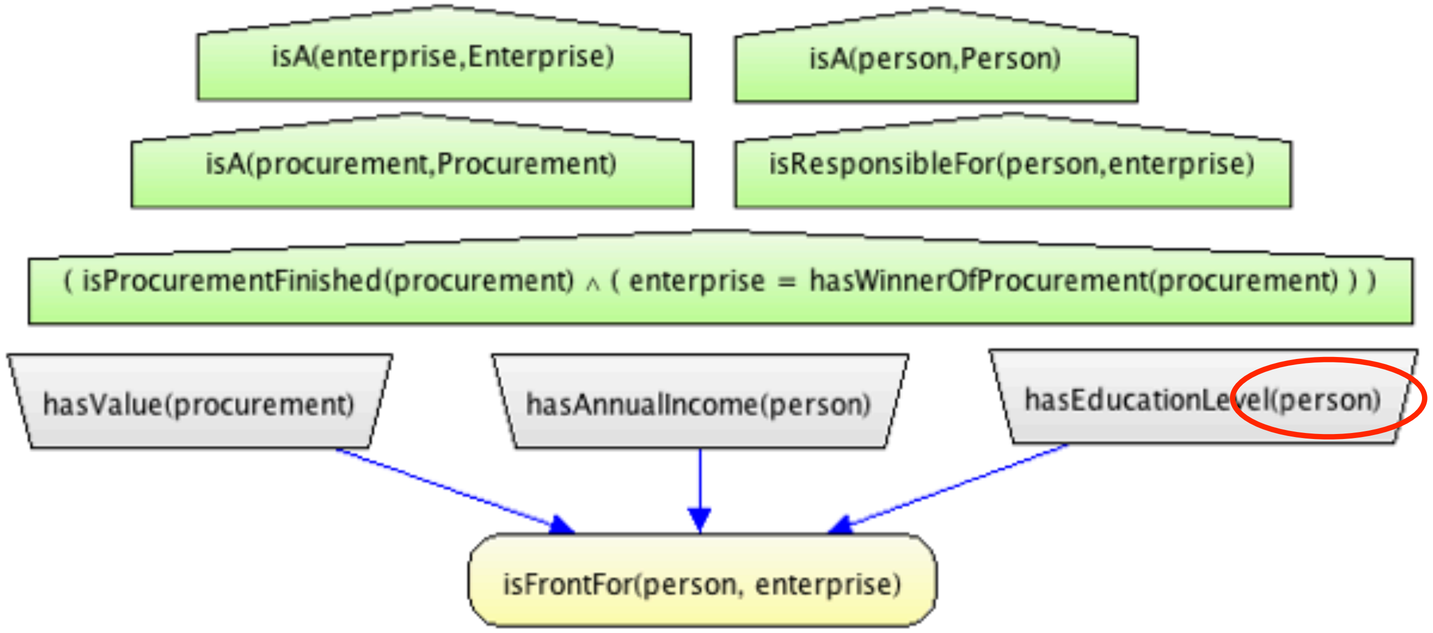
Ranges (intersection)
● EducationLevel

Function



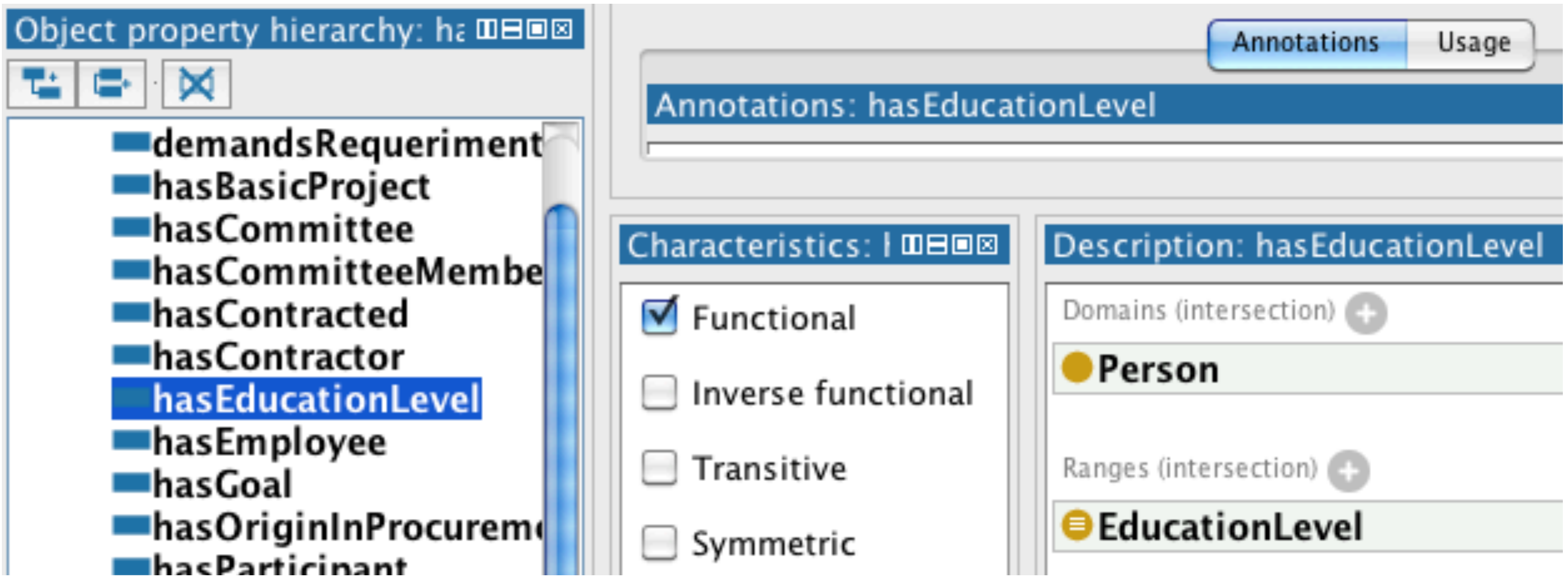
Mapping Schema

PR-OWL



isA(enterprise,Enterprise)
isA(person,Person)
isA(procurement,Procurement)
isResponsibleFor(person,enterprise)
(isProcurementFinished(procurement) ∧ (enterprise = hasWinnerOfProcurement(procurement)))
hasValue(procurement)
hasAnnualIncome(person)
hasEducationLevel(person)
isFrontFor(person, enterprise)

OWL



Object property hierarchy: ha

- demandsRequeriment
- hasBasicProject
- hasCommittee
- hasCommitteeMembe
- hasContracted
- hasContractor
- hasEducationLevel
- hasEmployee
- hasGoal
- hasOriginInProcurem
- hasParticipant

Annotations | Usage

Annotations: hasEducationLevel

Characteristics: I

- ☑ Functional
- □ Inverse functional
- □ Transitive
- □ Symmetric

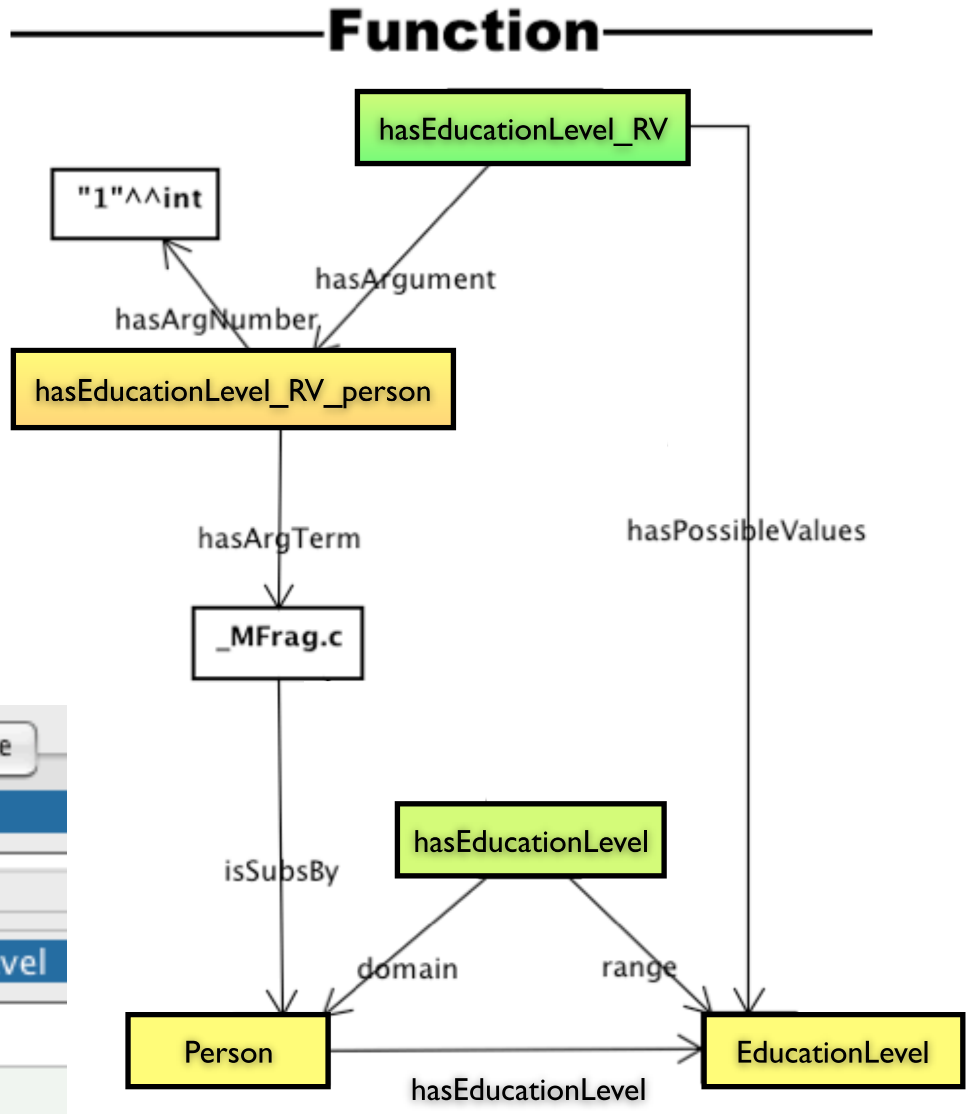
Description: hasEducationLevel

Domains (intersection)

● Person

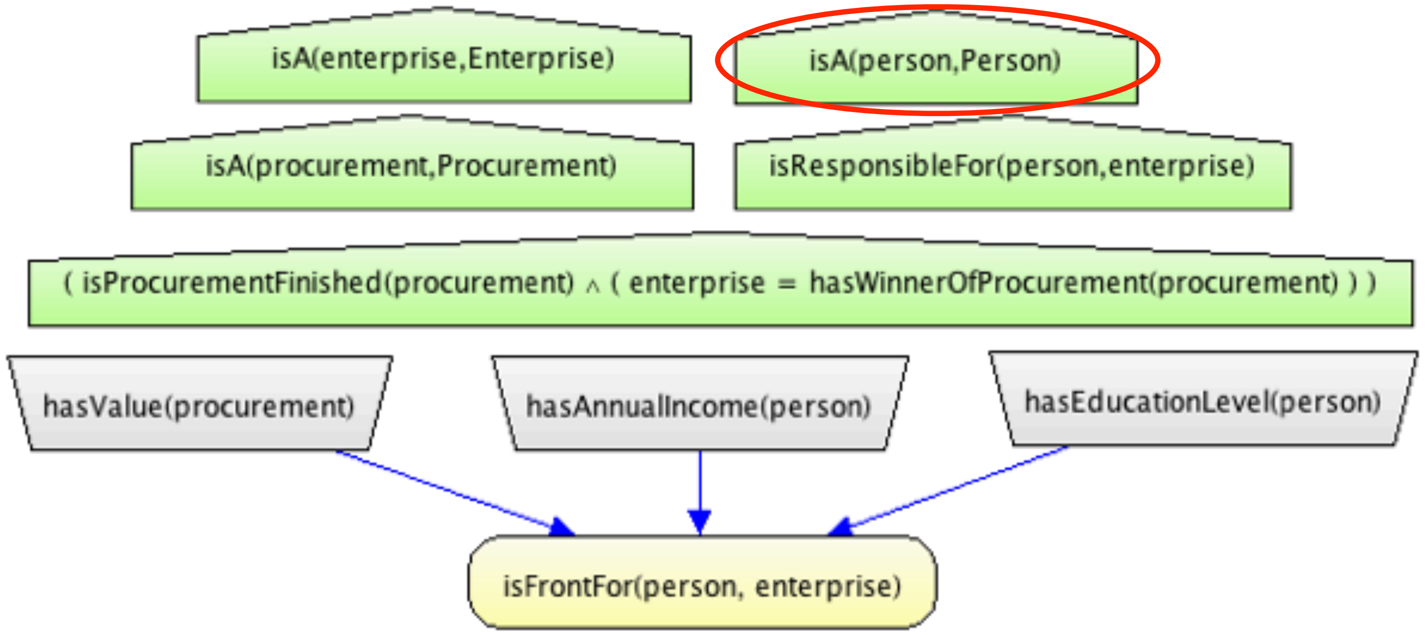
Ranges (intersection)

● EducationLevel

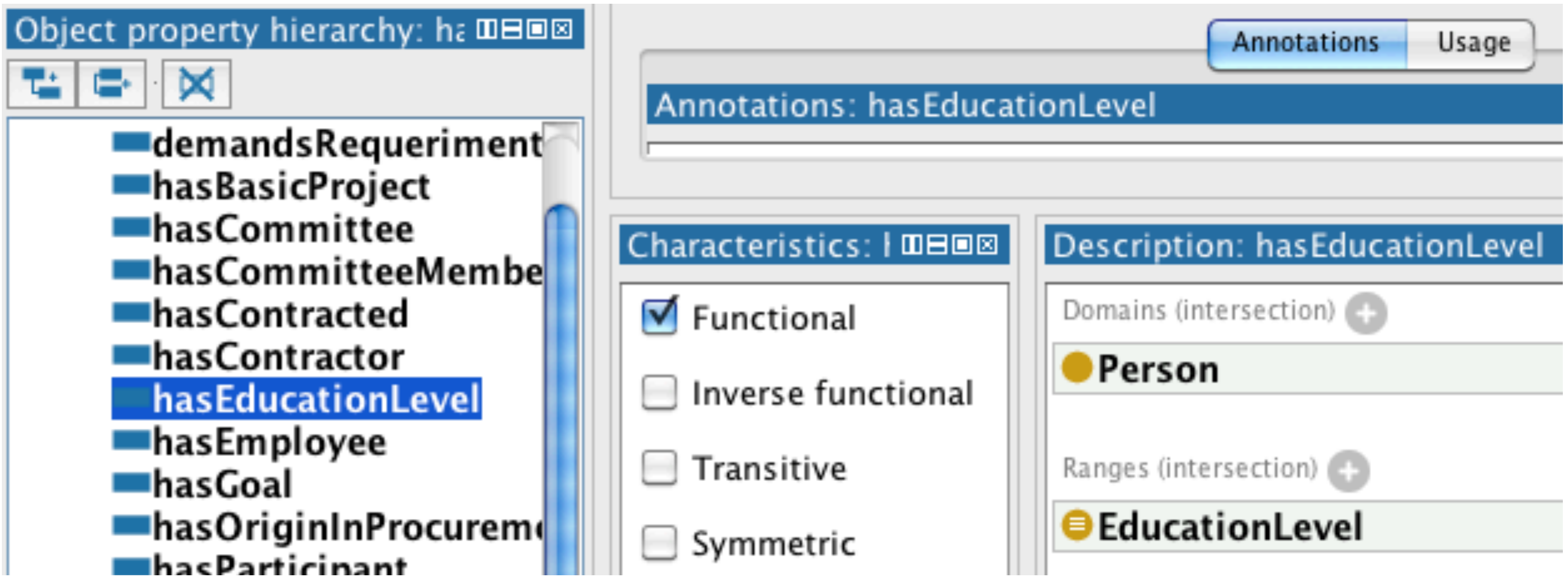


Mapping Schema

PR-OWL


isA(enterprise,Enterprise)
isA(person,Person)
isA(procurement,Procurement)
isResponsibleFor(person,enterprise)
(isProcurementFinished(procurement) ∧ (enterprise = hasWinnerOfProcurement(procurement)))
hasValue(procurement)
hasAnnualIncome(person)
hasEducationLevel(person)
isFrontFor(person, enterprise)

OWL



Object property hierarchy: ha

- demandsRequeriment
- hasBasicProject
- hasCommittee
- hasCommitteeMembe
- hasContracted
- hasContractor
- hasEducationLevel
- hasEmployee
- hasGoal
- hasOriginInProcureme
- hasParticipant

Annotations | Usage

Annotations: hasEducationLevel

Characteristics: I

☑ Functional

□ Inverse functional

□ Transitive

□ Symmetric

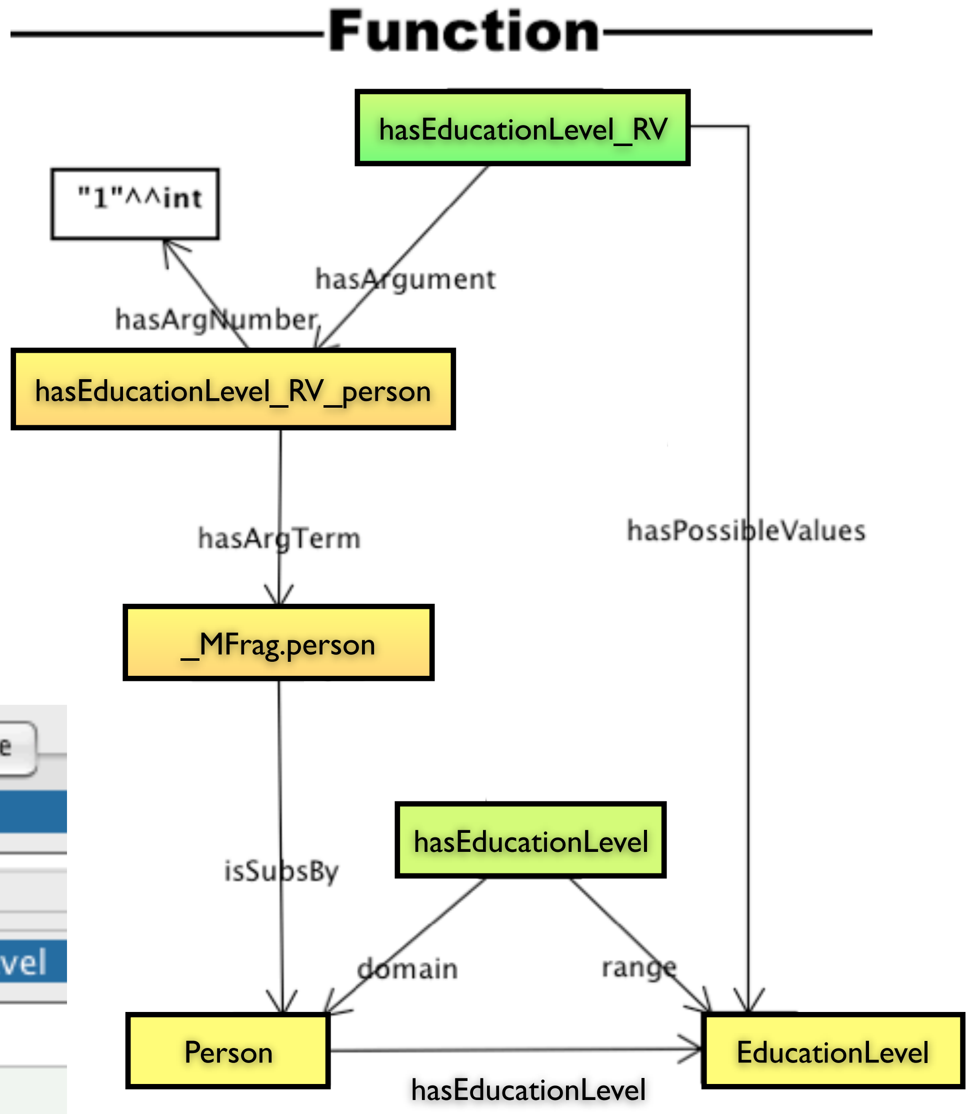
Description: hasEducationLevel

Domains (intersection)

Person

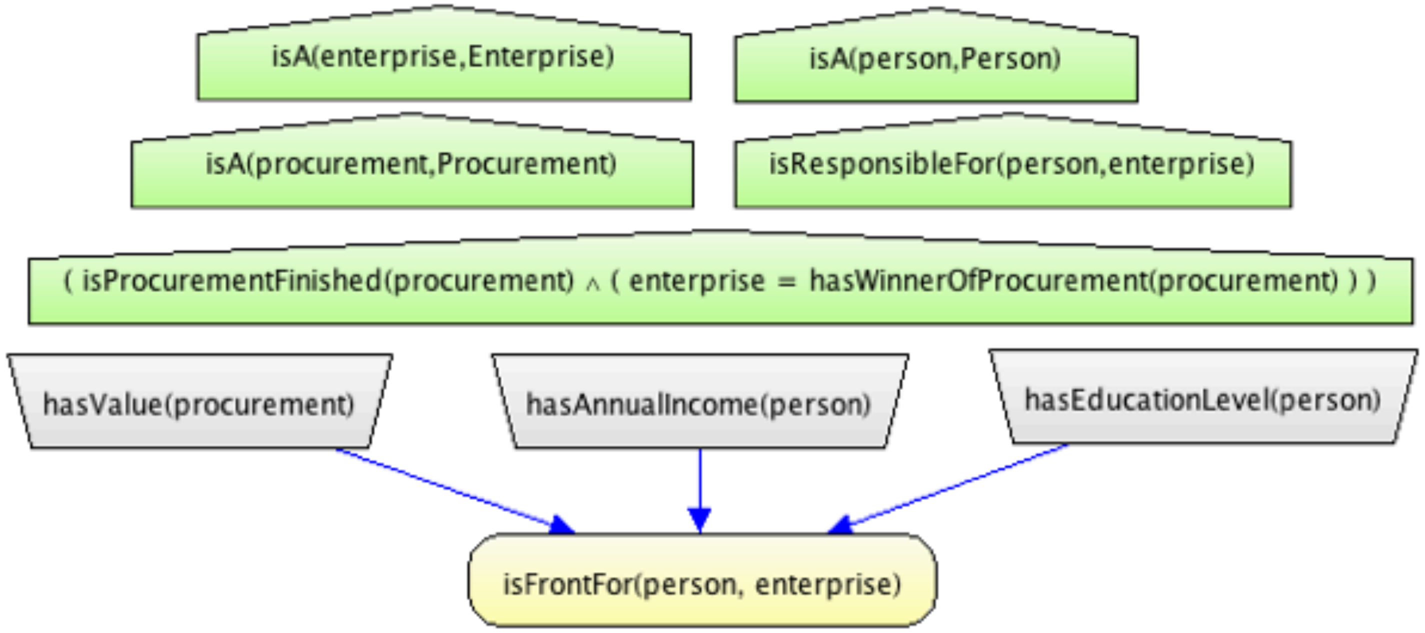
Ranges (intersection)

EducationLevel

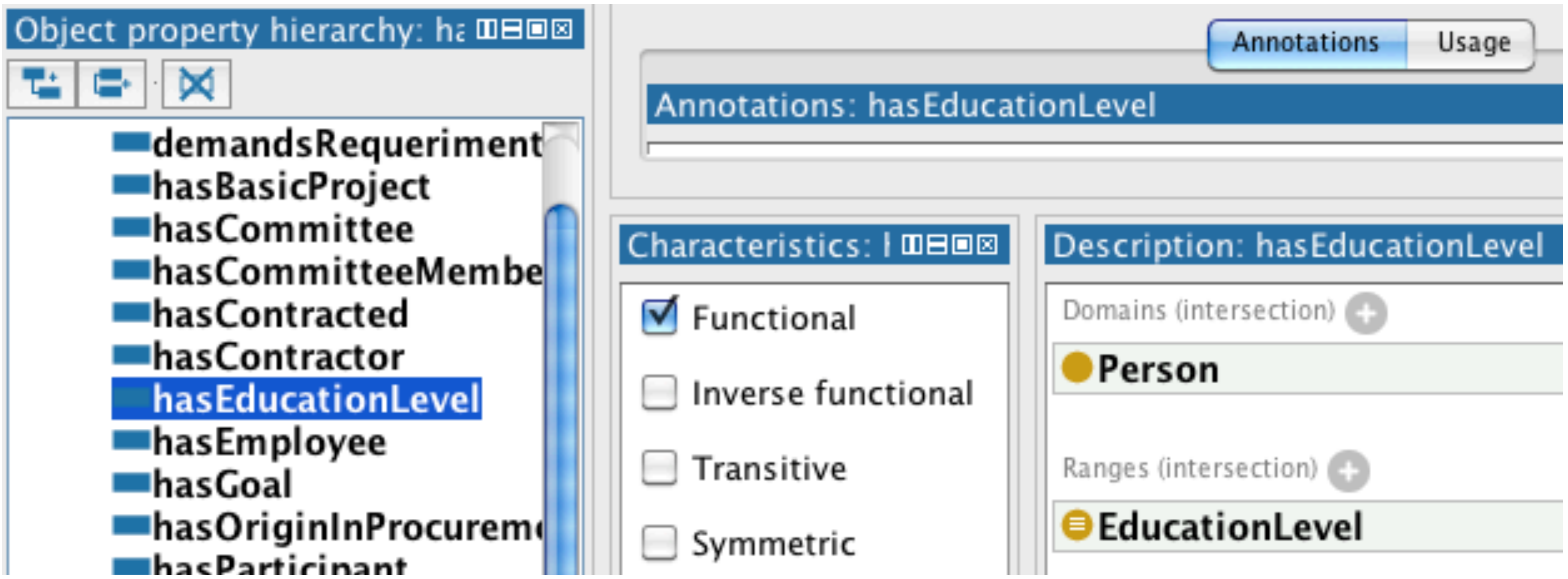


Mapping Schema

PR-OWL


isA(enterprise,Enterprise)
isA(person,Person)
isA(procurement,Procurement)
isResponsibleFor(person,enterprise)
(isProcurementFinished(procurement) ∧ (enterprise = hasWinnerOfProcurement(procurement)))
hasValue(procurement)
hasAnnualIncome(person)
hasEducationLevel(person)
isFrontFor(person, enterprise)

OWL



Object property hierarchy: ha

- demandsRequeriment
- hasBasicProject
- hasCommittee
- hasCommitteeMembe
- hasContracted
- hasContractor
- hasEducationLevel
- hasEmployee
- hasGoal
- hasOriginInProcurem
- hasParticipant

Annotations | Usage

Annotations: hasEducationLevel

Characteristics:

☑ Functional

☐ Inverse functional

☐ Transitive

☐ Symmetric

Description: hasEducationLevel

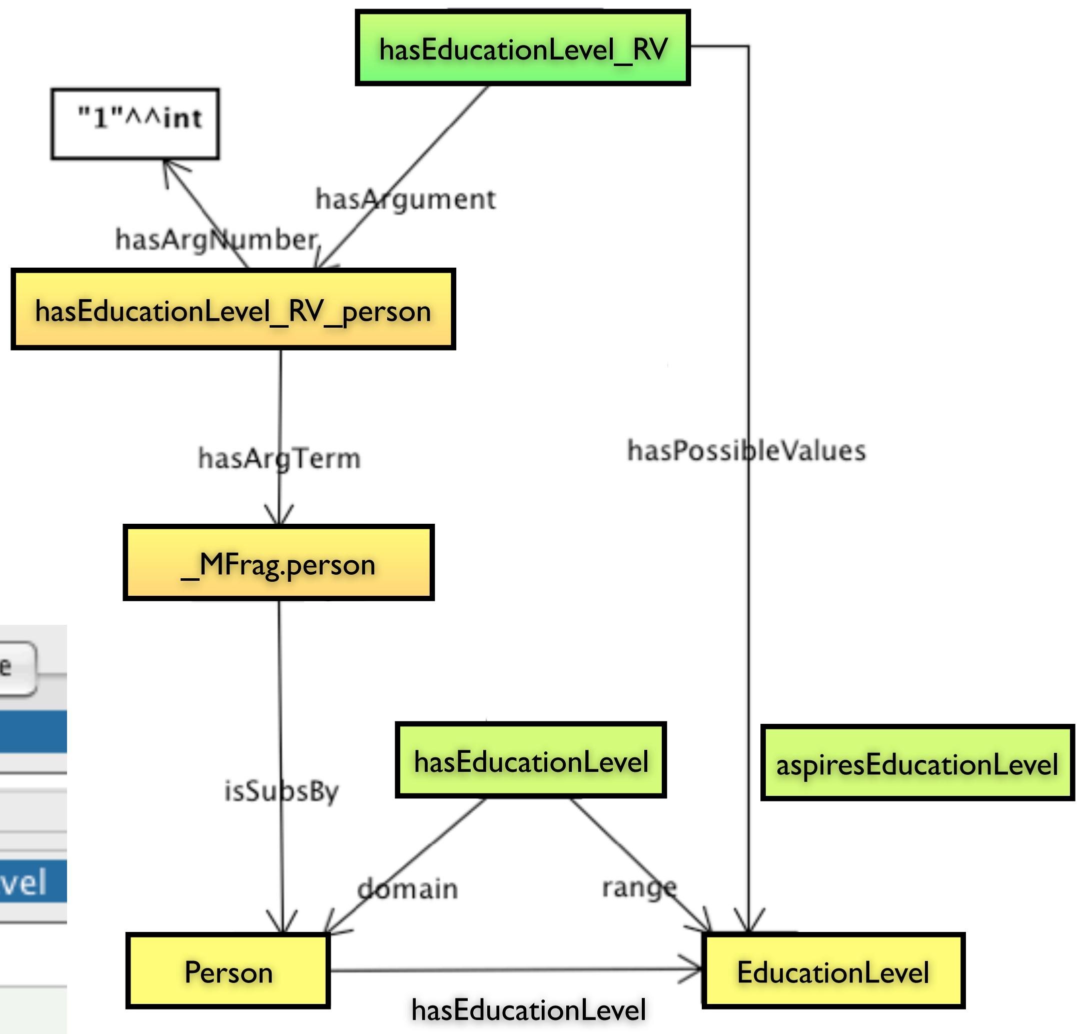
Domains (intersection)

● Person

Ranges (intersection)

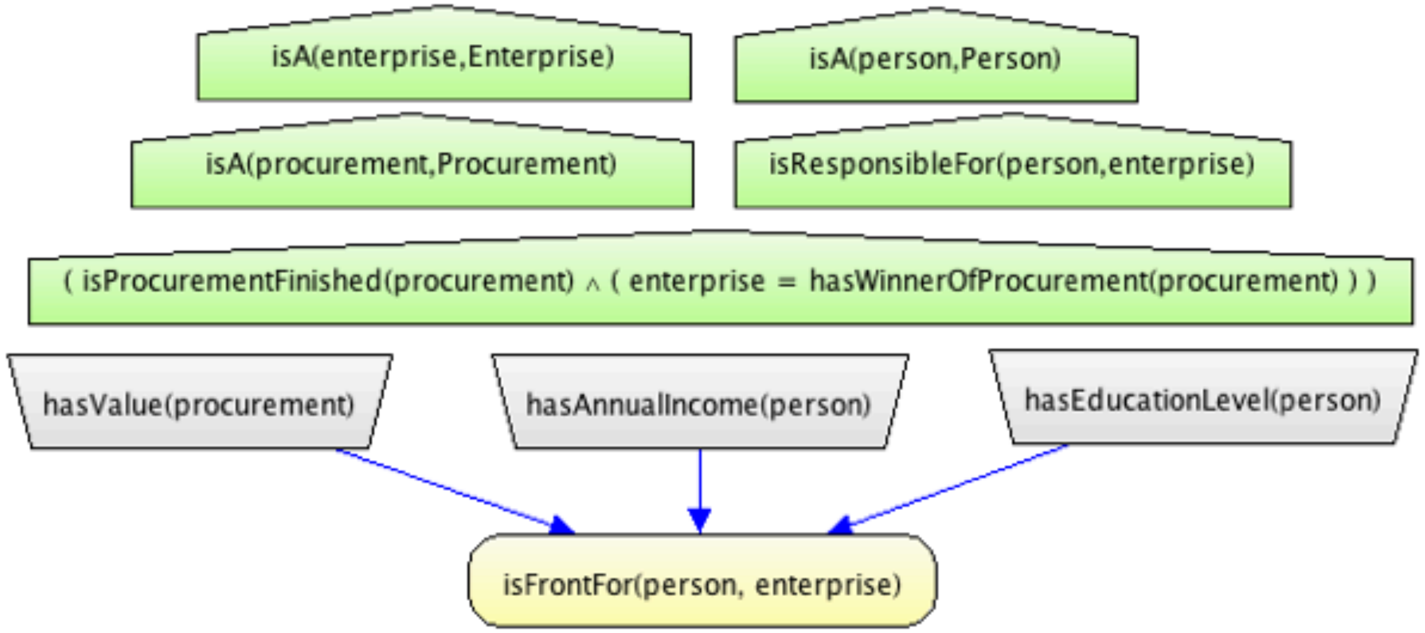
● EducationLevel

Function

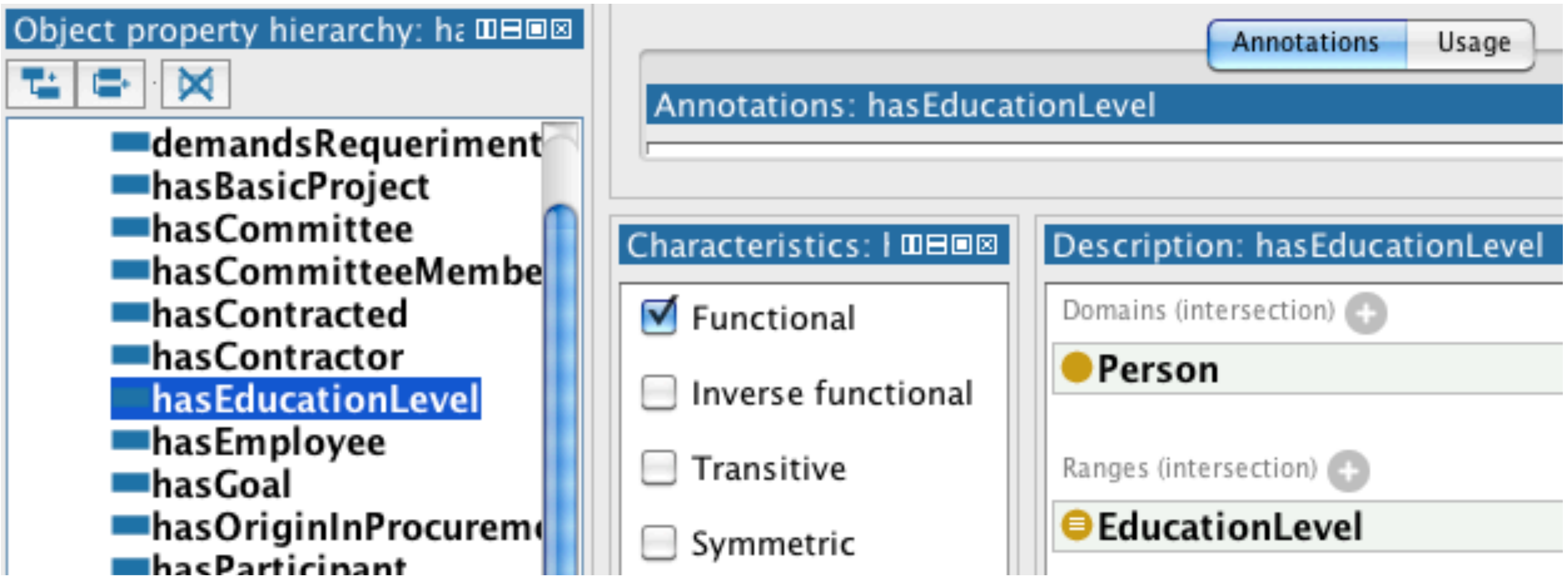


Mapping Schema

PR-OWL


isA(enterprise,Enterprise)
isA(person,Person)
isA(procurement,Procurement)
isResponsibleFor(person,enterprise)
(isProcurementFinished(procurement) ∧ (enterprise = hasWinnerOfProcurement(procurement)))
hasValue(procurement)
hasAnnualIncome(person)
hasEducationLevel(person)
isFrontFor(person, enterprise)

OWL


Object property hierarchy: ha

- demandsRequeriment
- hasBasicProject
- hasCommittee
- hasCommitteeMembe
- hasContracted
- hasContractor
- hasEducationLevel
- hasEmployee
- hasGoal
- hasOriginInProcurem
- hasParticipant

Annotations | Usage

Annotations: hasEducationLevel

Characteristics: h

☑ Functional

☐ Inverse functional

☐ Transitive

☐ Symmetric

Description: hasEducationLevel

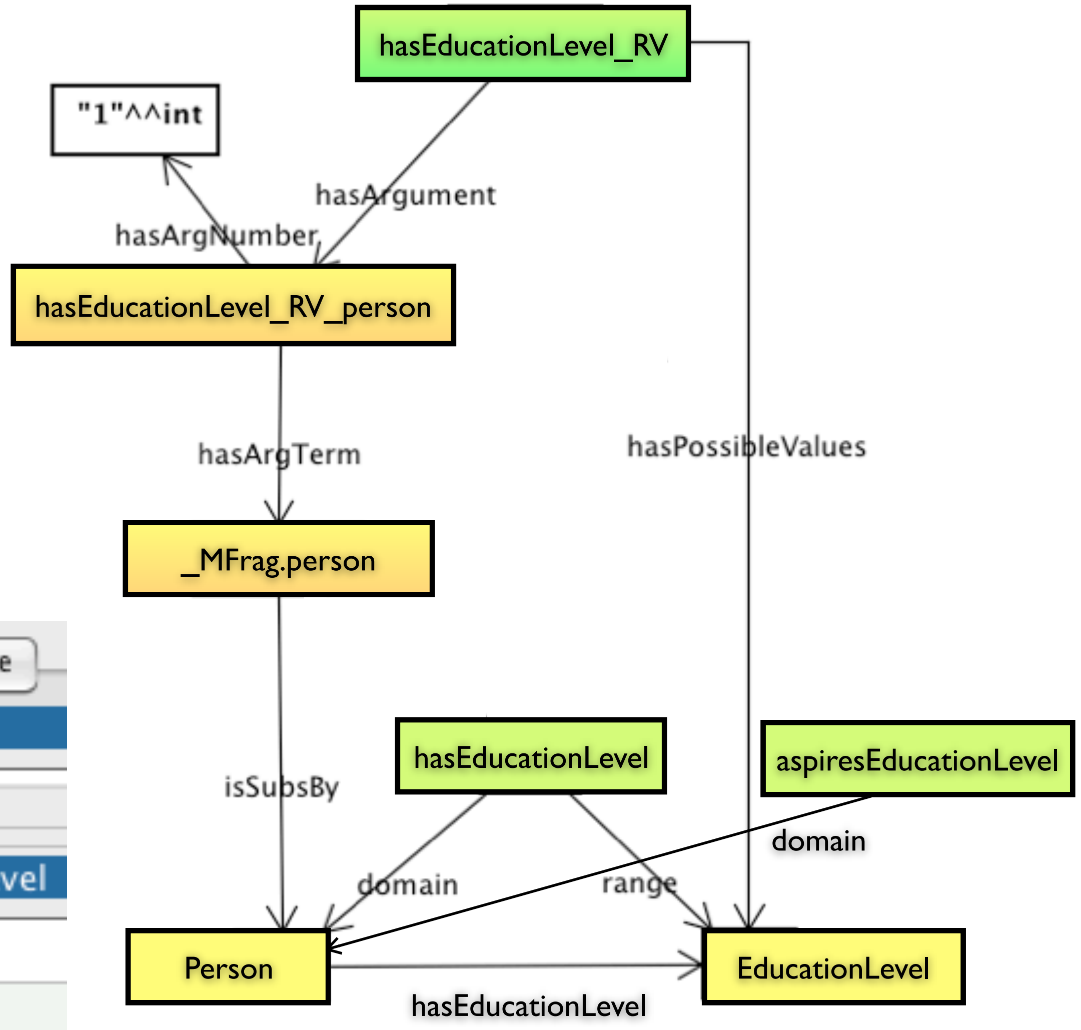
Domains (intersection)

● Person

Ranges (intersection)

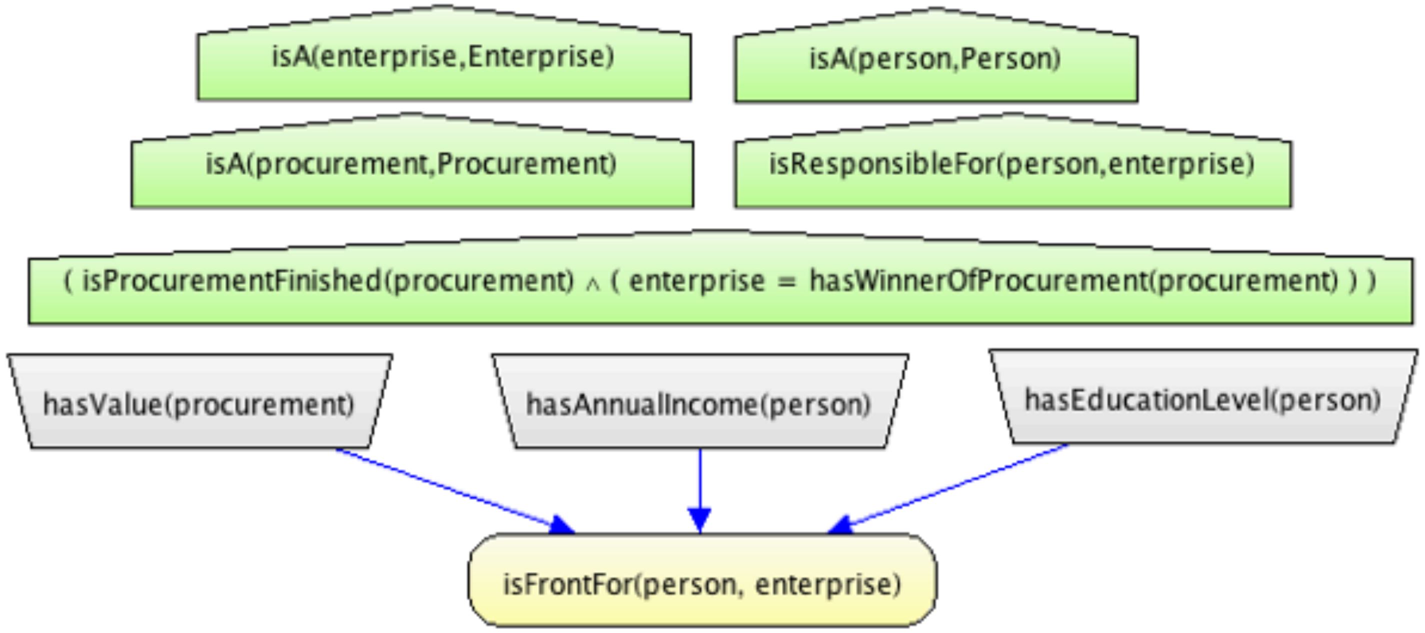
● EducationLevel

Function

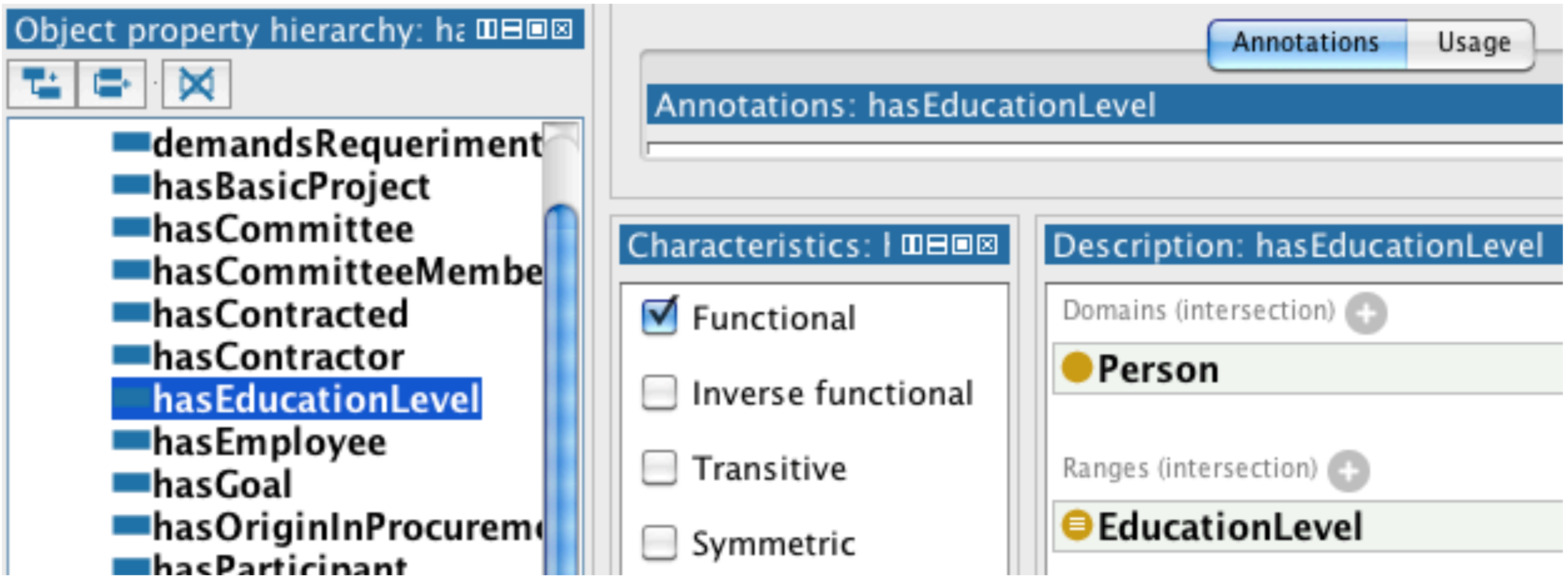


Mapping Schema

PR-OWL


isA(enterprise,Enterprise)
isA(person,Person)
isA(procurement,Procurement)
isResponsibleFor(person,enterprise)
(isProcurementFinished(procurement) ∧ (enterprise = hasWinnerOfProcurement(procurement)))
hasValue(procurement)
hasAnnualIncome(person)
hasEducationLevel(person)
isFrontFor(person, enterprise)

OWL



Object property hierarchy: ha

- demandsRequeriment
- hasBasicProject
- hasCommittee
- hasCommitteeMembe
- hasContracted
- hasContractor
- hasEducationLevel
- hasEmployee
- hasGoal
- hasOriginInProcurem
- hasParticipant

Annotations | Usage

Annotations: hasEducationLevel

Characteristics: I

☑ Functional

☐ Inverse functional

☐ Transitive

☐ Symmetric

Description: hasEducationLevel

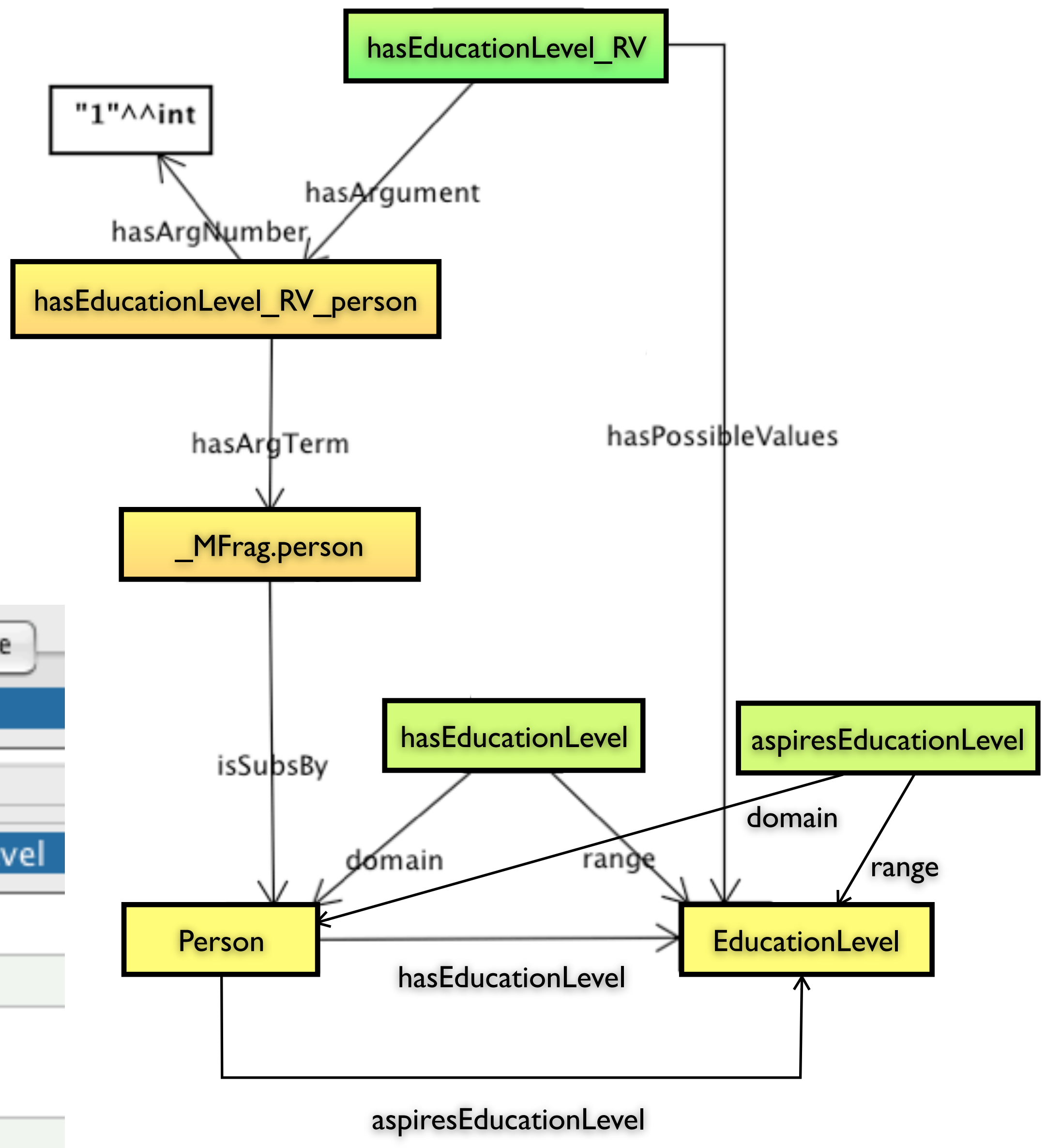
Domains (intersection)

● Person

Ranges (intersection)

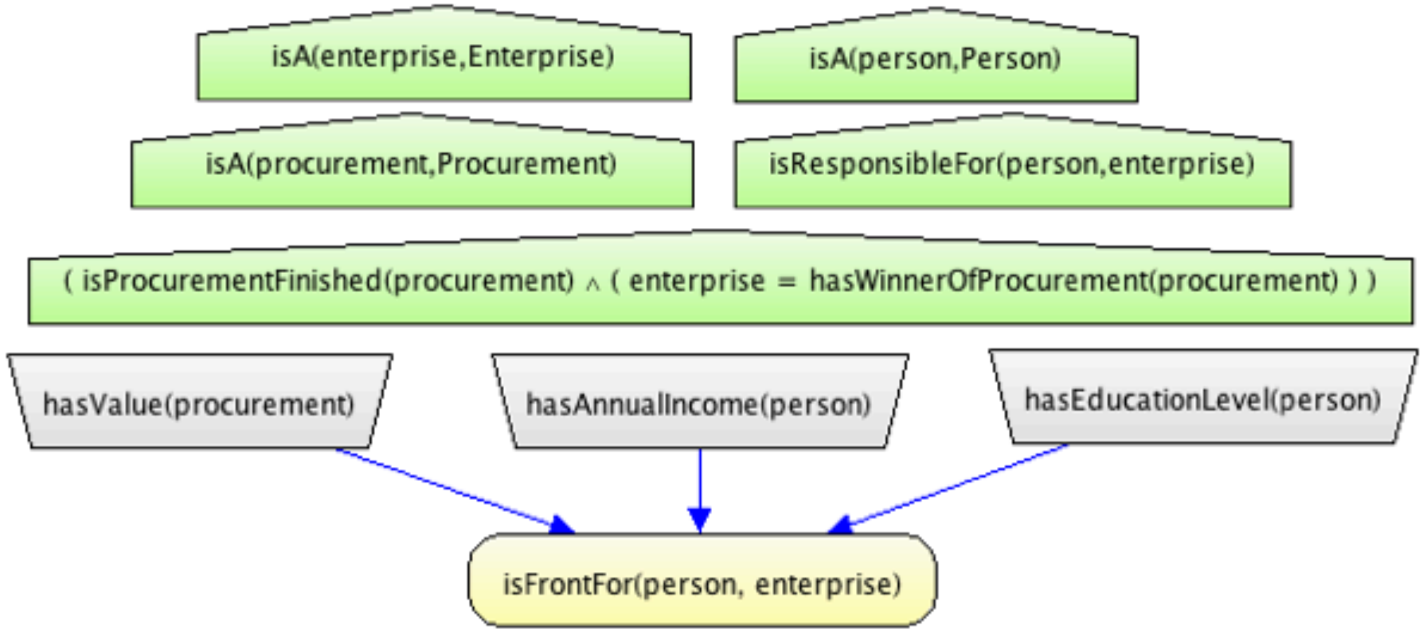
● EducationLevel

Function

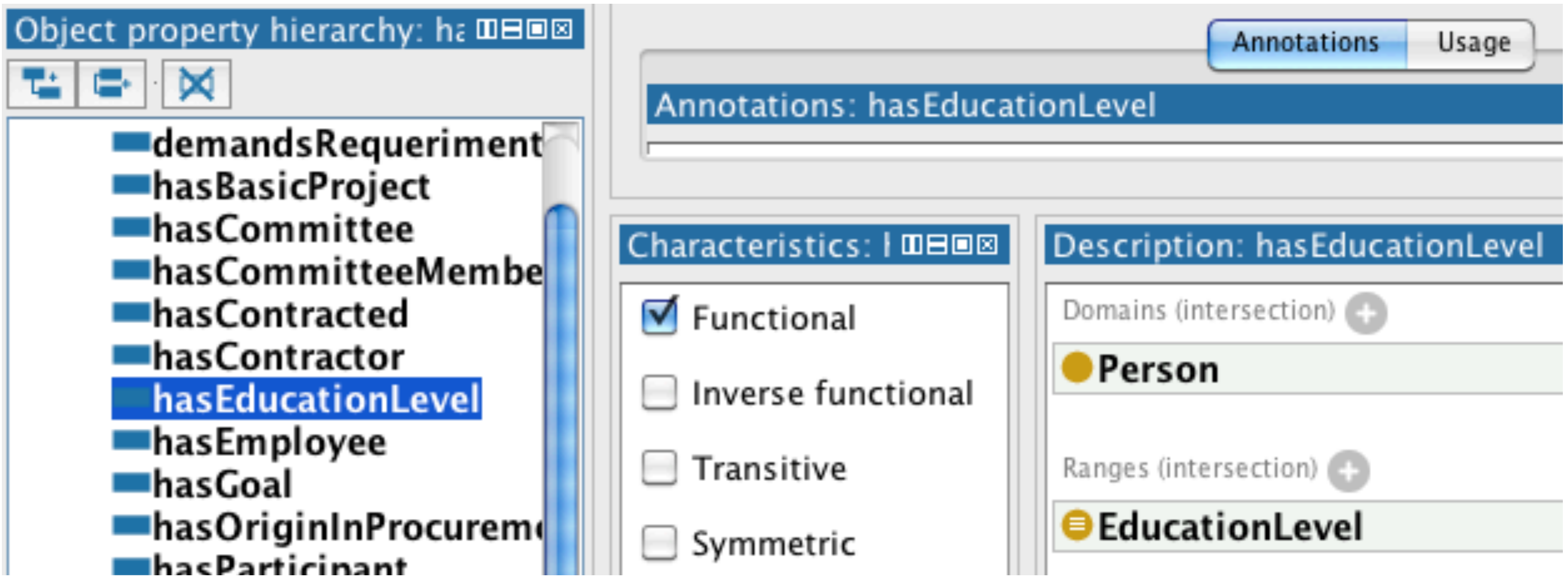


Mapping Schema

PR-OWL


isA(enterprise,Enterprise)
isA(person,Person)
isA(procurement,Procurement)
isResponsibleFor(person,enterprise)
(isProcurementFinished(procurement) ∧ (enterprise = hasWinnerOfProcurement(procurement)))
hasValue(procurement)
hasAnnualIncome(person)
hasEducationLevel(person)
isFrontFor(person, enterprise)

OWL


Object property hierarchy: ha

- demandsRequeriment
- hasBasicProject
- hasCommittee
- hasCommitteeMembe
- hasContracted
- hasContractor
- hasEducationLevel
- hasEmployee
- hasGoal
- hasOriginInProcureme
- hasParticipant

Annotations | Usage

Annotations: hasEducationLevel

Characteristics: I

☑ Functional

☐ Inverse functional

☐ Transitive

☐ Symmetric

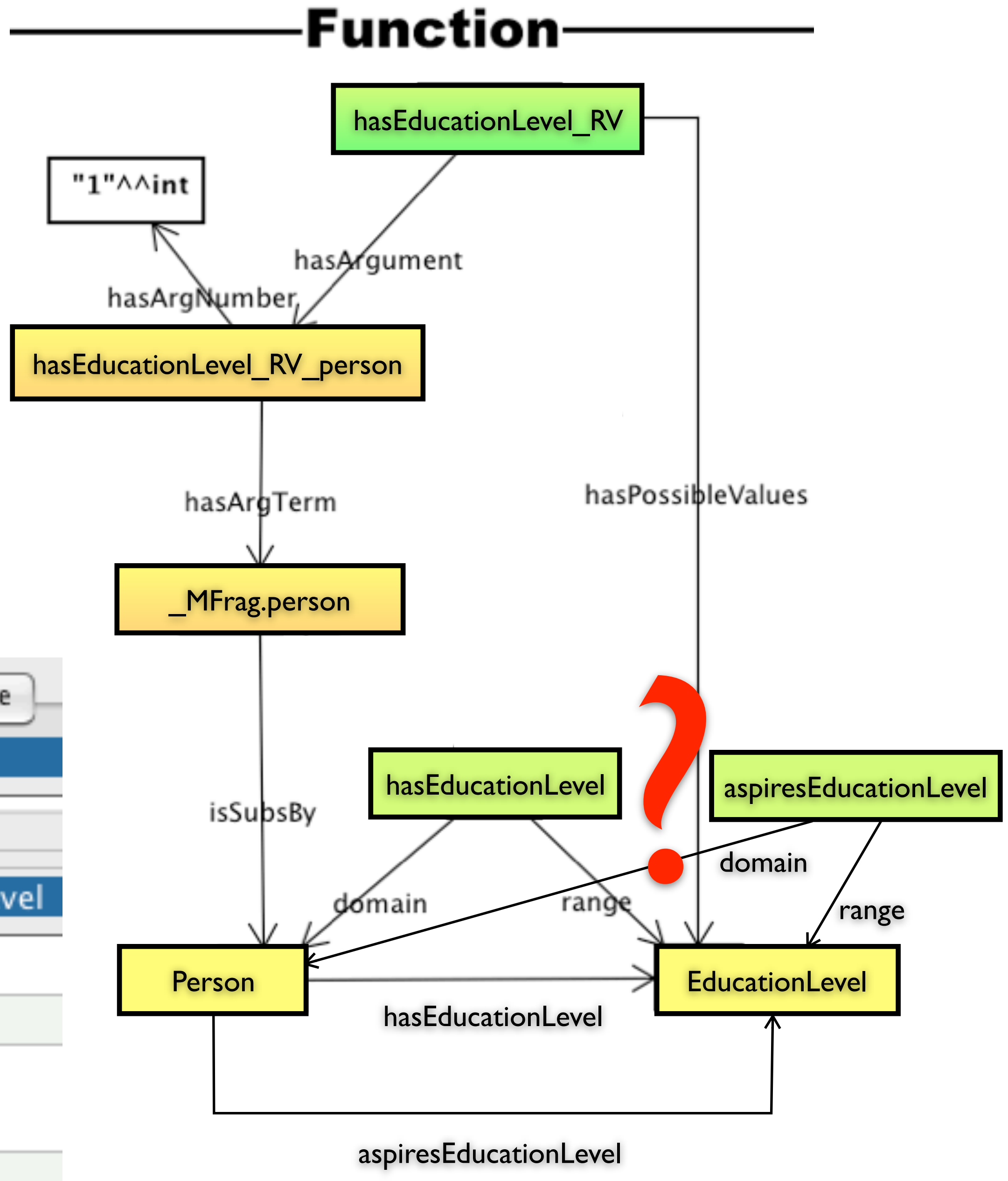
Description: hasEducationLevel

Domains (intersection)

● Person

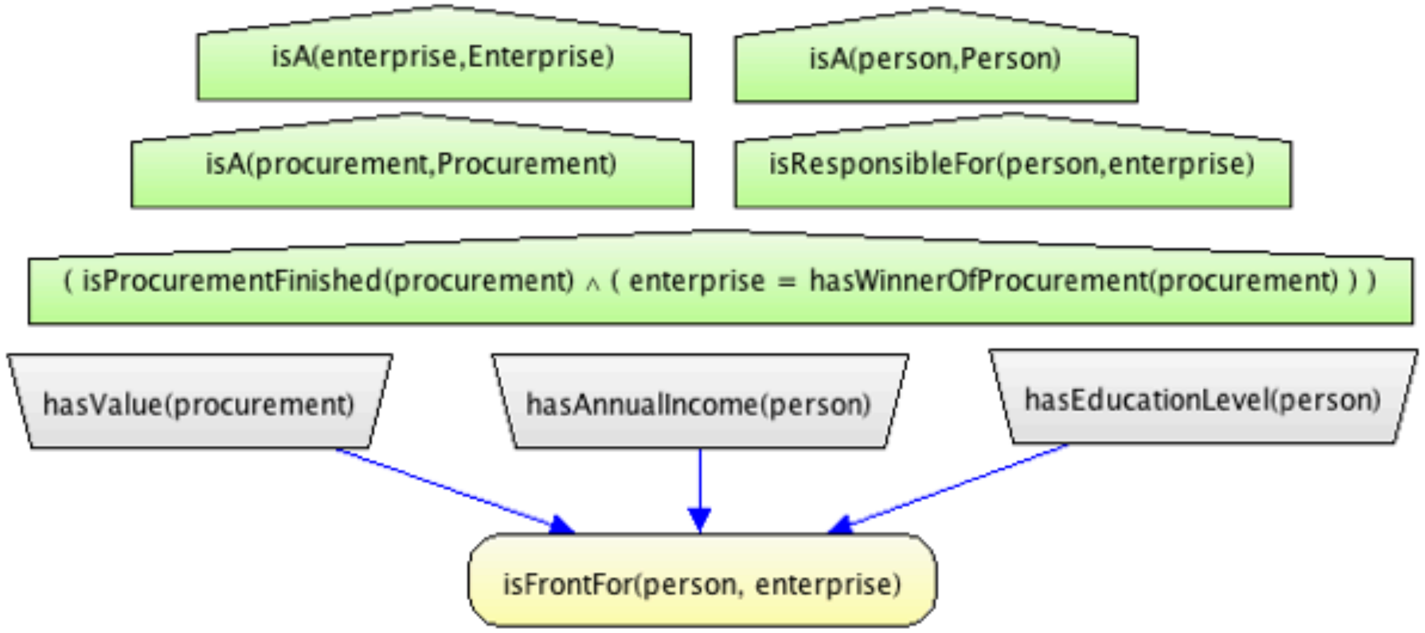
Ranges (intersection)

● EducationLevel

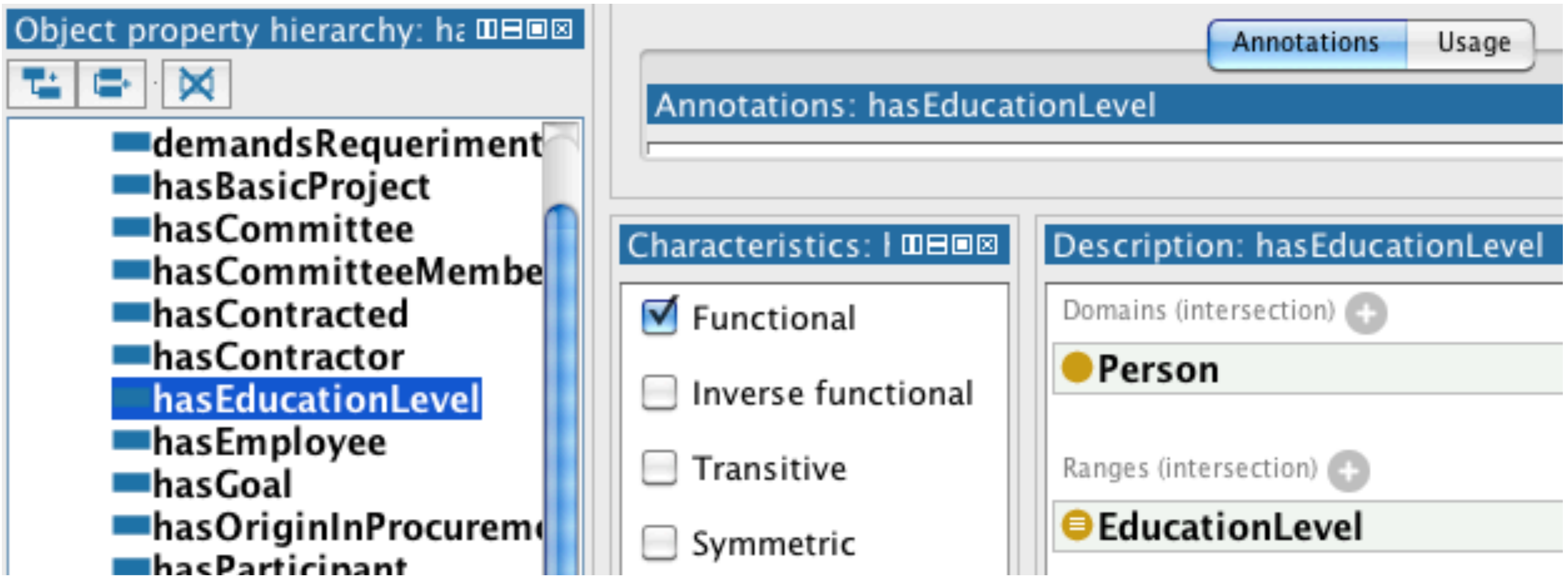


Mapping Schema

PR-OWL


isA(enterprise,Enterprise)
isA(person,Person)
isA(procurement,Procurement)
isResponsibleFor(person,enterprise)
(isProcurementFinished(procurement) ∧ (enterprise = hasWinnerOfProcurement(procurement)))
hasValue(procurement)
hasAnnualIncome(person)
hasEducationLevel(person)
isFrontFor(person, enterprise)

OWL


Object property hierarchy: ha

- demandsRequeriment
- hasBasicProject
- hasCommittee
- hasCommitteeMembe
- hasContracted
- hasContractor
- hasEducationLevel
- hasEmployee
- hasGoal
- hasOriginInProcurem
- hasParticipant

Annotations: hasEducationLevel

Characteristics: I

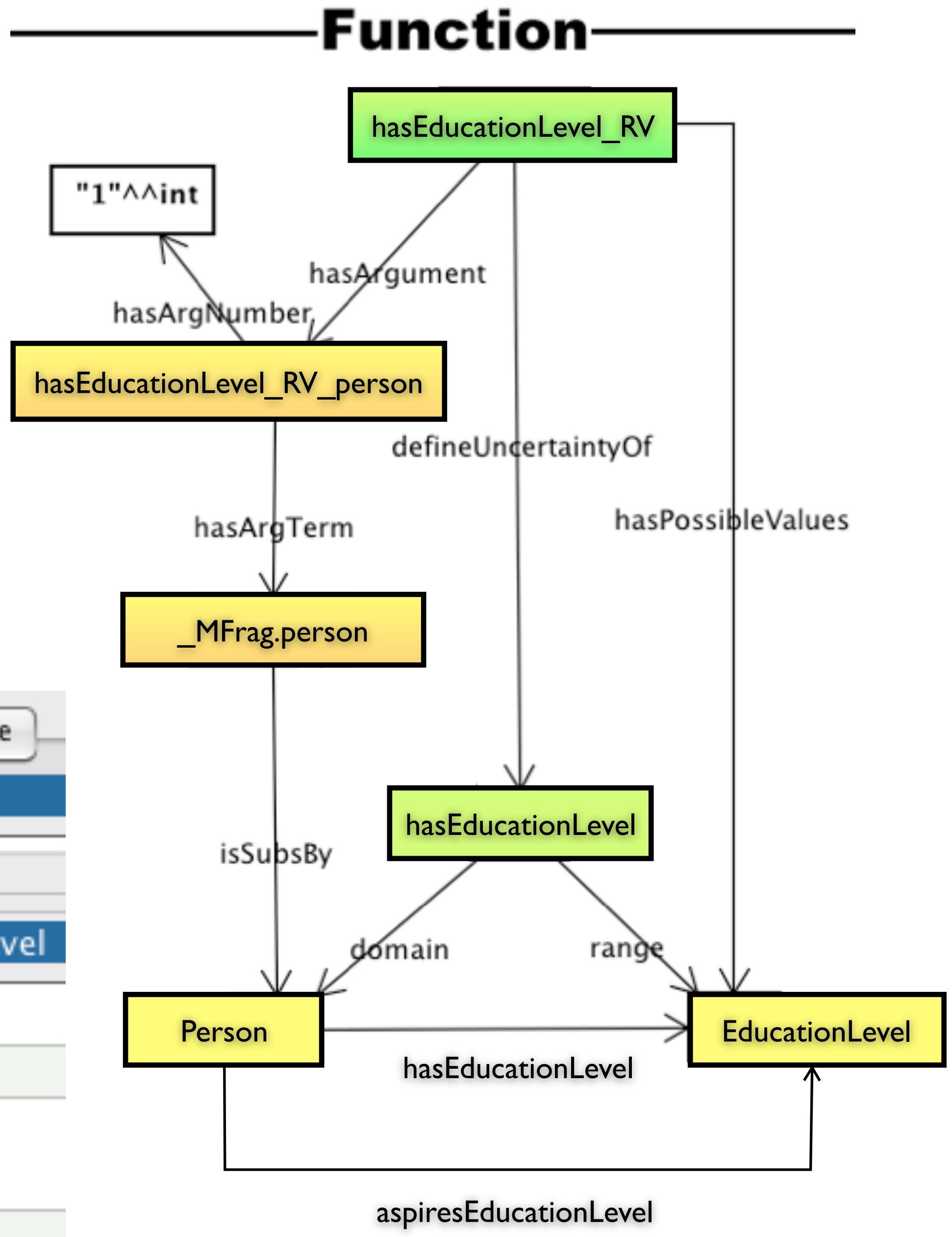
☑ Functional
☐ Inverse functional
☐ Transitive
☐ Symmetric

Description: hasEducationLevel

Domains (intersection)
● Person

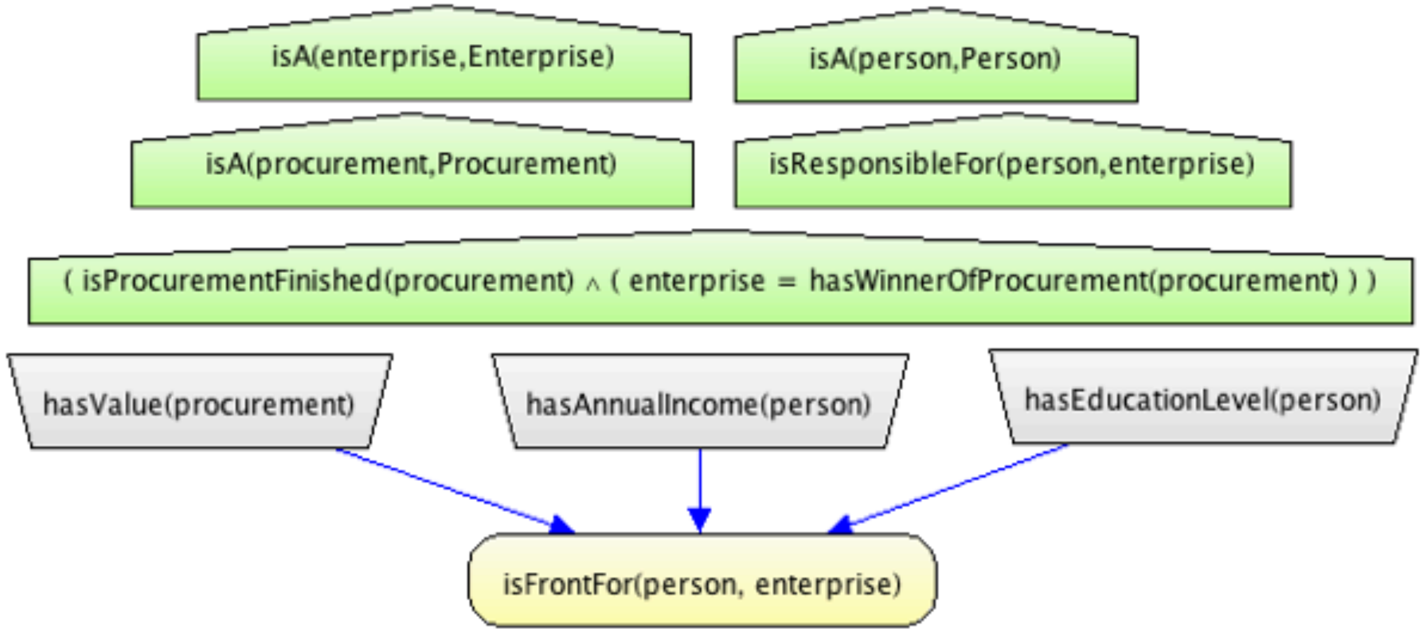
Ranges (intersection)
● EducationLevel

Function


hasEducationLevel_RV
"1"^^int
hasArgument
hasArgNumber
hasEducationLevel_RV_person
defineUncertaintyOf
hasPossibleValues
hasArgTerm
_MFrag.person
isSubsBy
hasEducationLevel
domain
range
Person
EducationLevel
hasEducationLevel
aspiresEducationLevel

Mapping Schema

PR-OWL



isA(enterprise,Enterprise)

isA(person,Person)

isA(procurement,Procurement)

isResponsibleFor(person,enterprise)

(isProcurementFinished(procurement) ∧ (enterprise = hasWinnerOfProcurement(procurement)))

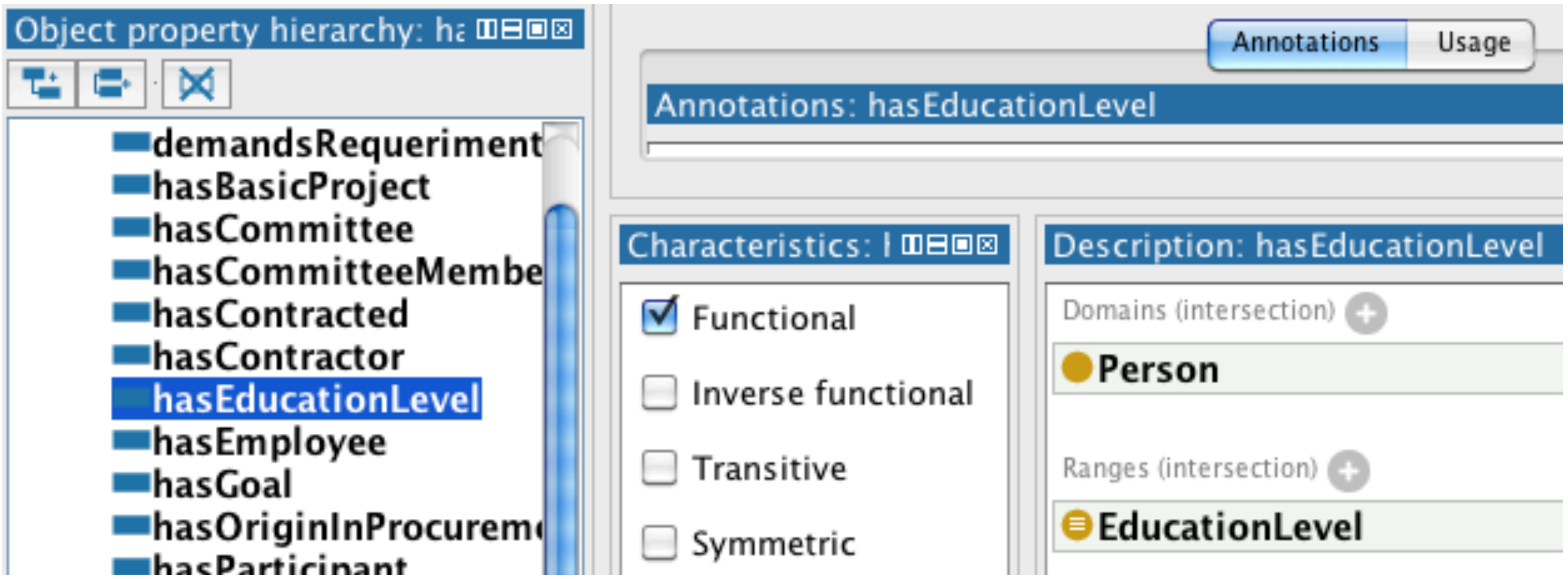
hasValue(procurement)

hasAnnualIncome(person)

hasEducationLevel(person)

isFrontFor(person, enterprise)

OWL



Object property hierarchy: ha

- demandsRequeriment
- hasBasicProject
- hasCommittee
- hasCommitteeMembe
- hasContracted
- hasContractor
- hasEducationLevel
- hasEmployee
- hasGoal
- hasOriginInProcurem
- hasParticipant

Annotations: hasEducationLevel

Characteristics: I

☑ Functional

□ Inverse functional

□ Transitive

□ Symmetric

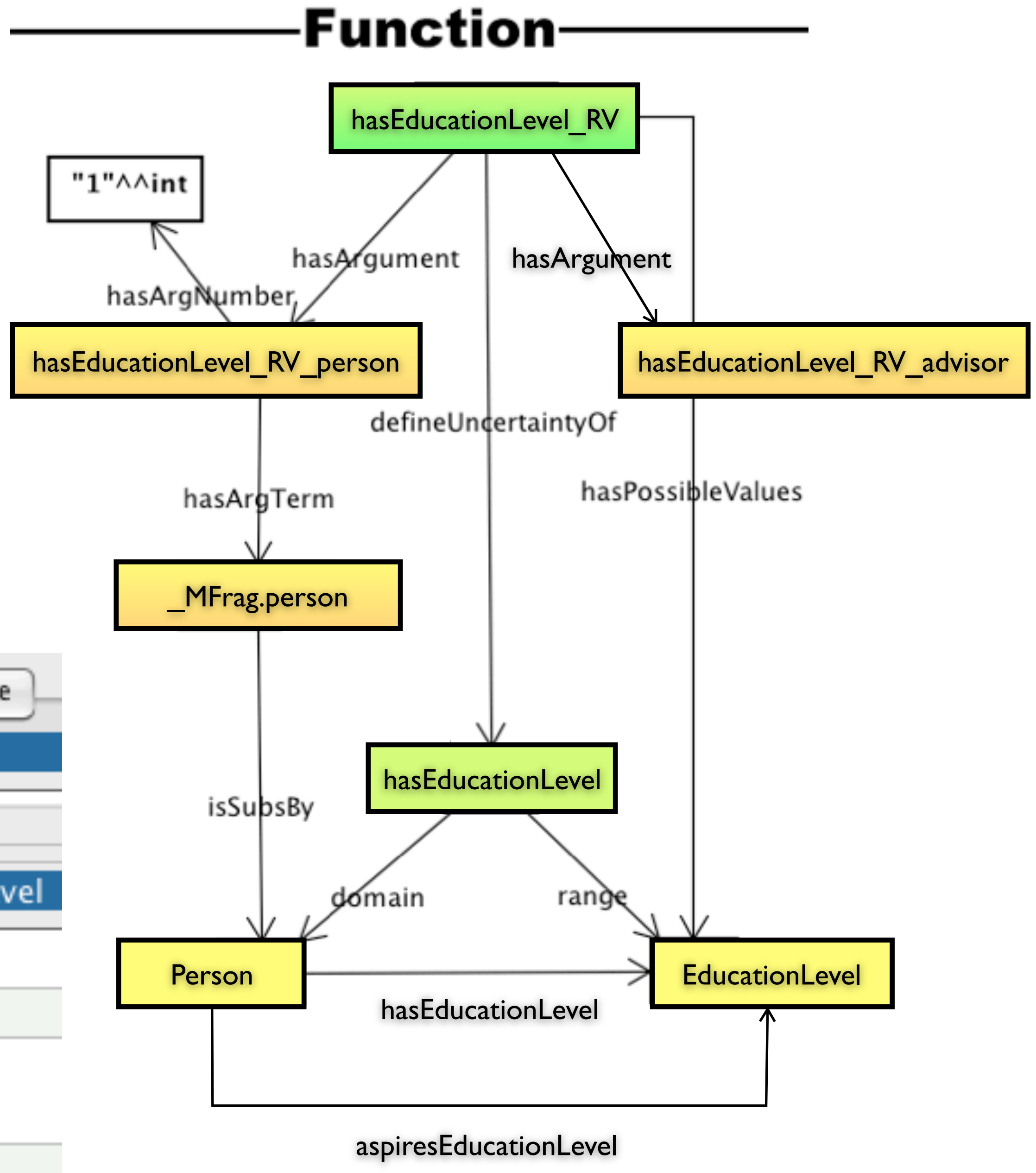
Description: hasEducationLevel

Domains (intersection)

Person

Ranges (intersection)

EducationLevel



Function

hasEducationLevel_RV

"1"^^int

hasArgument

hasArgument

hasArgNumber

hasEducationLevel_RV_person

hasEducationLevel_RV_advisor

defineUncertaintyOf

hasArgTerm

hasPossibleValues

_MFrag.person

hasEducationLevel

isSubsBy

domain

range

Person

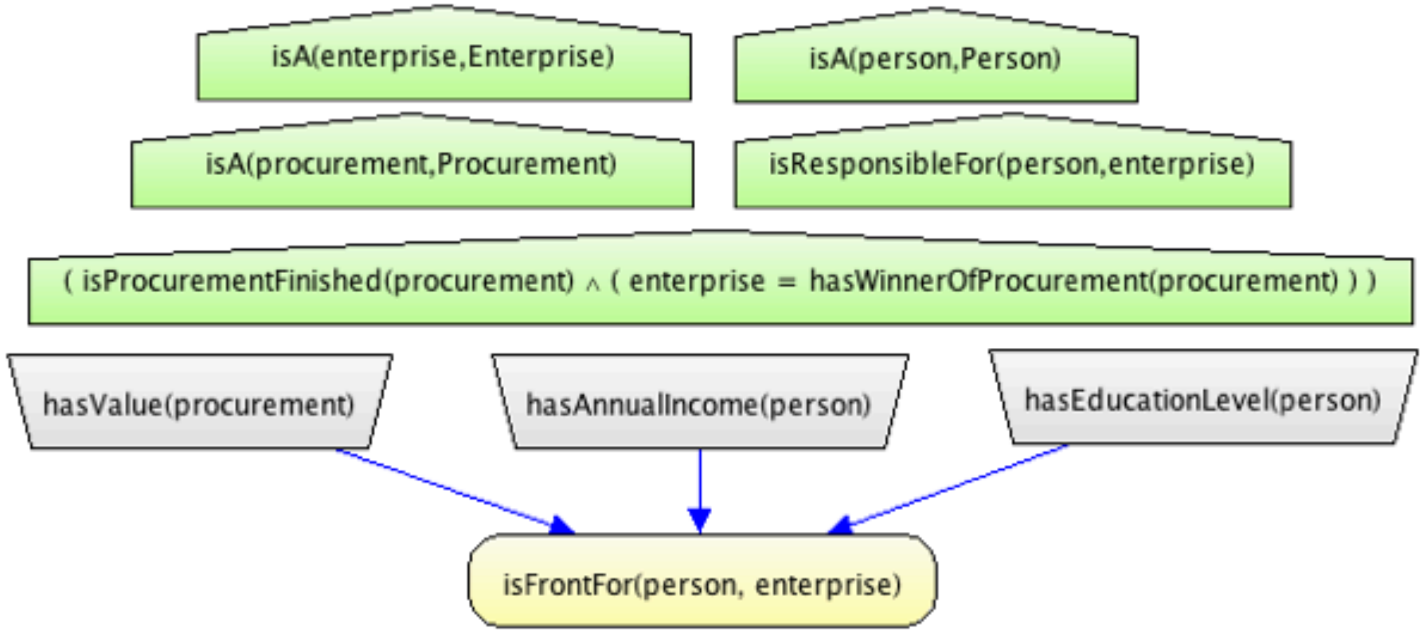
EducationLevel

hasEducationLevel

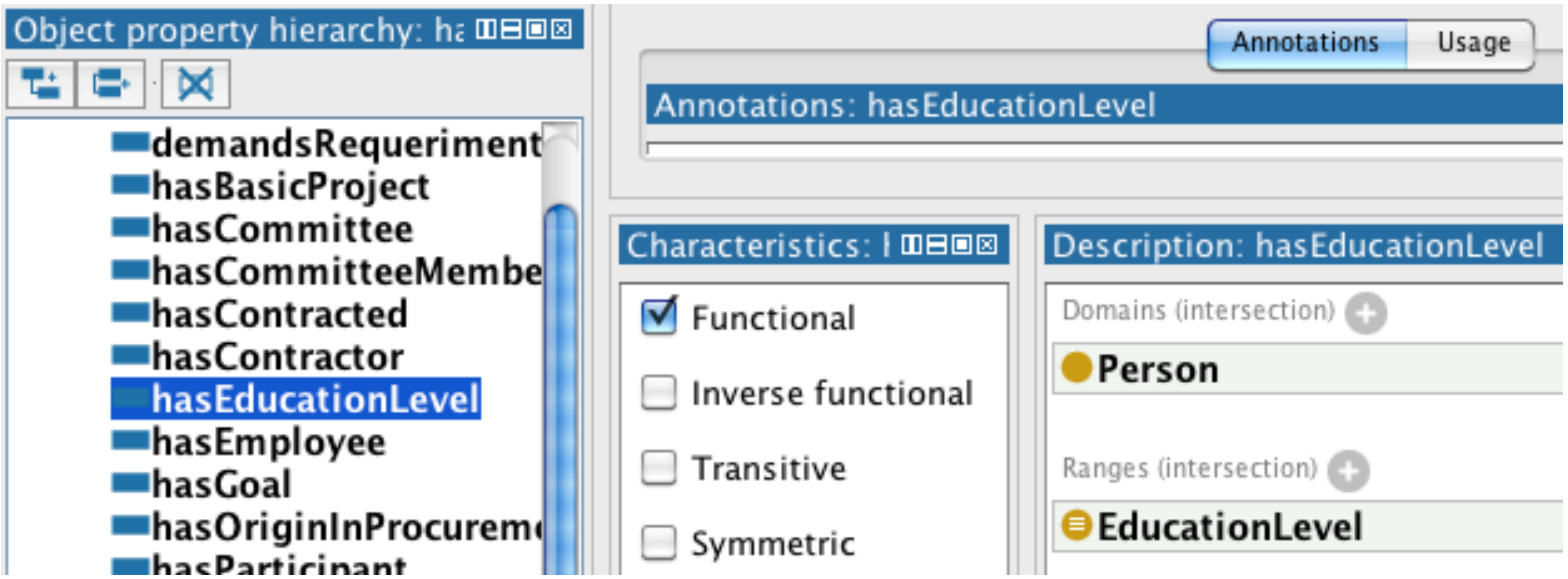
aspiresEducationLevel

Mapping Schema

PR-OWL


isA(enterprise,Enterprise)
isA(person,Person)
isA(procurement,Procurement)
isResponsibleFor(person,enterprise)
(isProcurementFinished(procurement) ∧ (enterprise = hasWinnerOfProcurement(procurement)))
hasValue(procurement)
hasAnnualIncome(person)
hasEducationLevel(person)
isFrontFor(person, enterprise)

OWL


Object property hierarchy: ha

- demandsRequeriment
- hasBasicProject
- hasCommittee
- hasCommitteeMembe
- hasContracted
- hasContractor
- hasEducationLevel
- hasEmployee
- hasGoal
- hasOriginInProcurem
- hasParticipant

Annotations | Usage

Annotations: hasEducationLevel

Characteristics: I

- ☑ Functional
- □ Inverse functional
- □ Transitive
- □ Symmetric

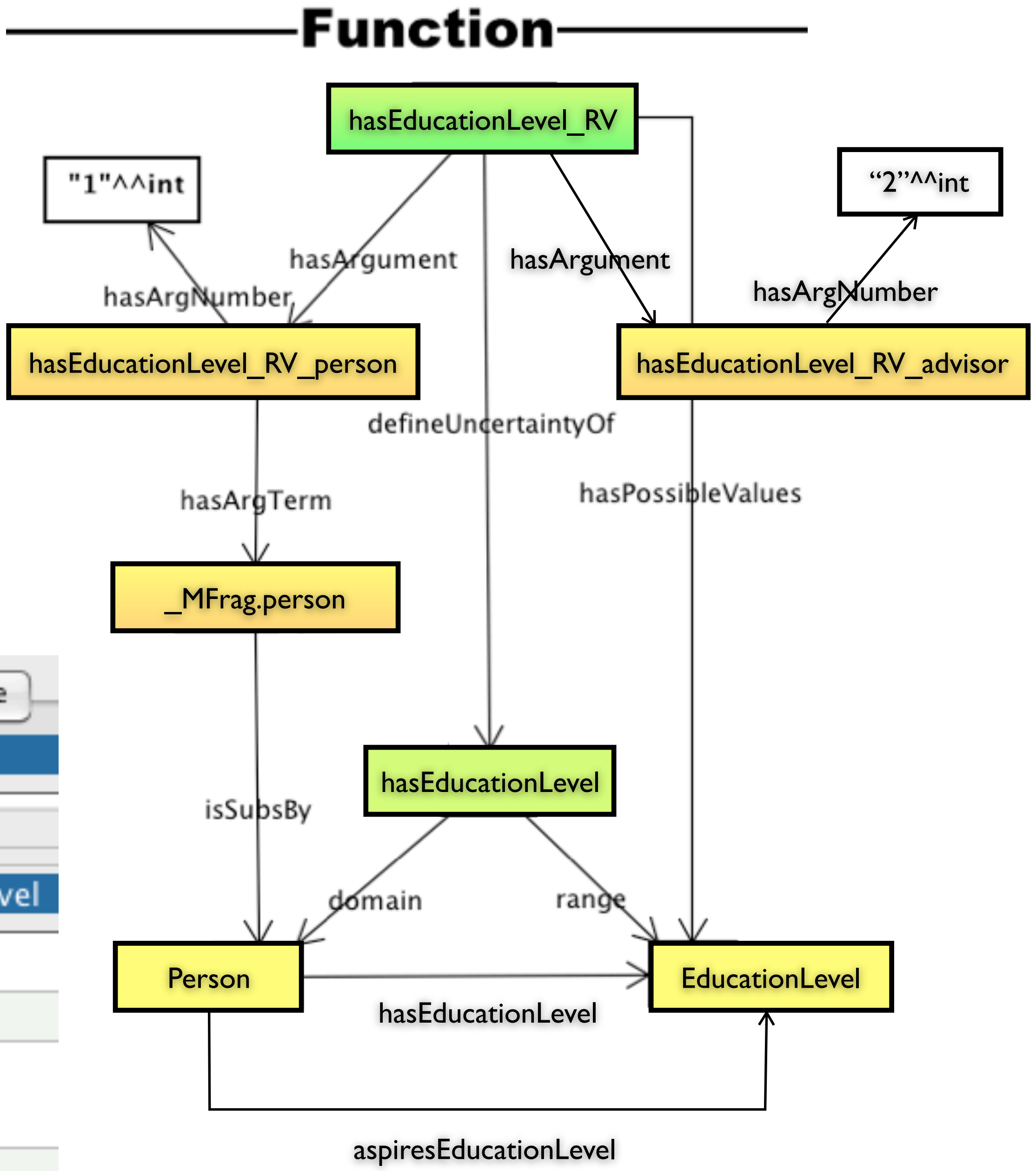
Description: hasEducationLevel

Domains (intersection)

● Person

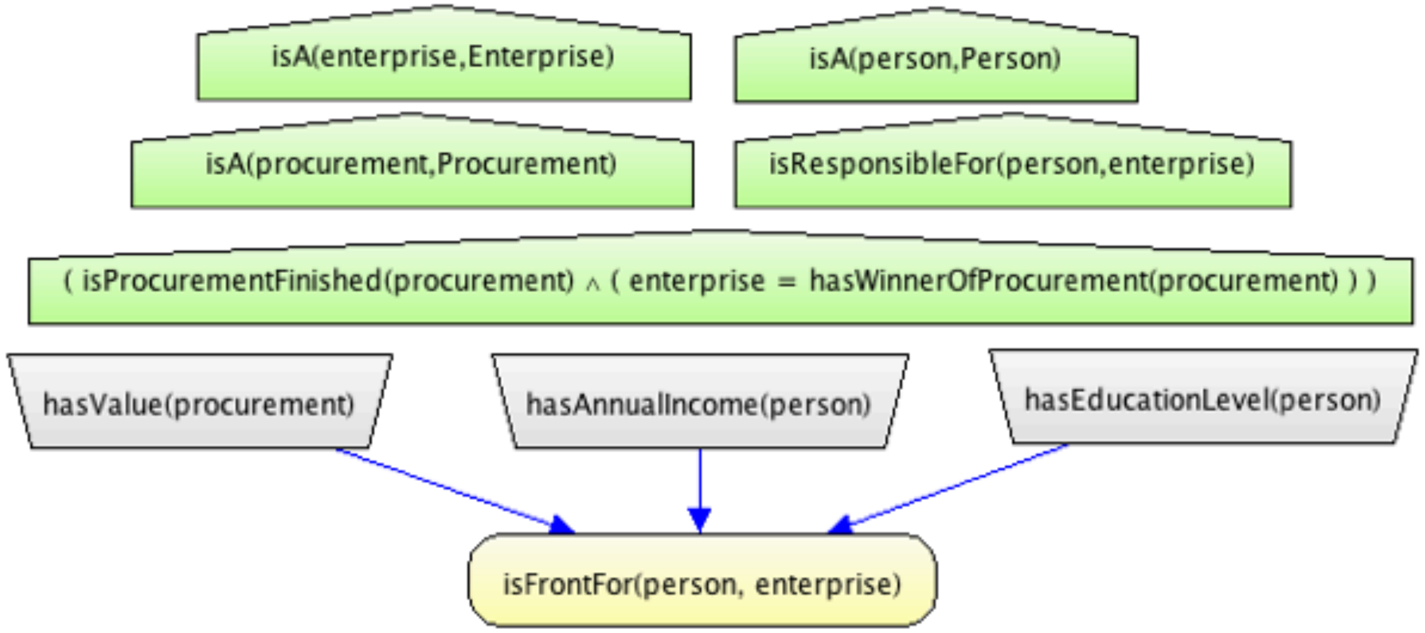
Ranges (intersection)

● EducationLevel

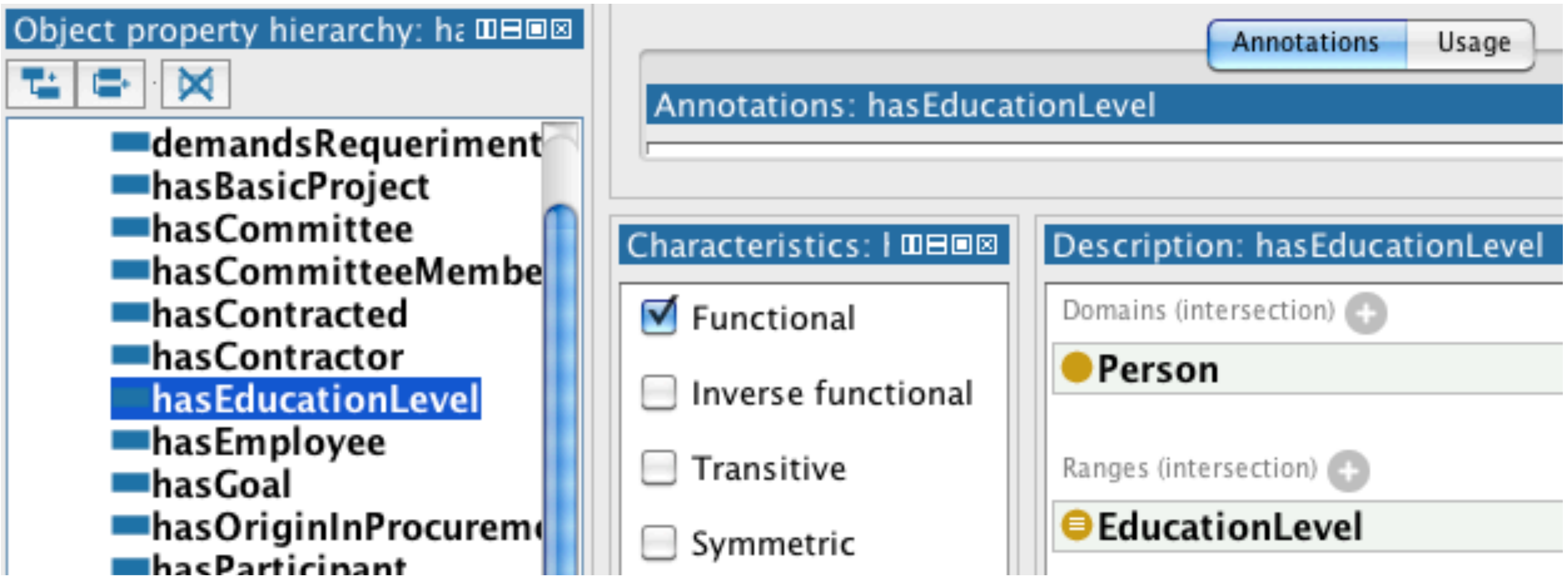


Mapping Schema

PR-OWL


isA(enterprise,Enterprise)
isA(person,Person)
isA(procurement,Procurement)
isResponsibleFor(person,enterprise)
(isProcurementFinished(procurement) ∧ (enterprise = hasWinnerOfProcurement(procurement)))
hasValue(procurement)
hasAnnualIncome(person)
hasEducationLevel(person)
isFrontFor(person, enterprise)

OWL


Object property hierarchy: ha

- demandsRequeriment
- hasBasicProject
- hasCommittee
- hasCommitteeMembe
- hasContracted
- hasContractor
- hasEducationLevel
- hasEmployee
- hasGoal
- hasOriginInProcurem
- hasParticipant

Annotations | Usage

Annotations: hasEducationLevel

Characteristics: l

☑ Functional

□ Inverse functional

□ Transitive

□ Symmetric

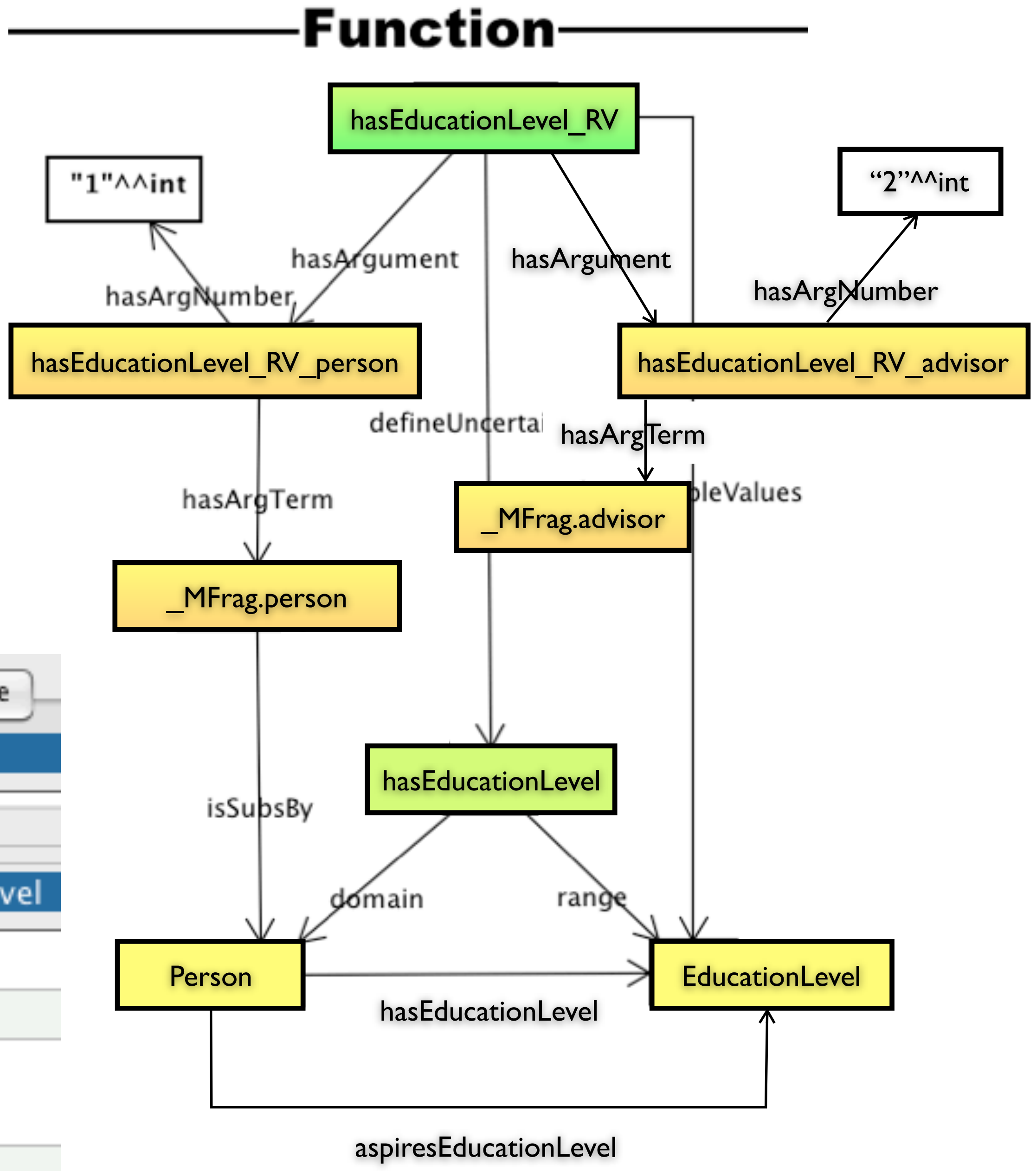
Description: hasEducationLevel

Domains (intersection)

● Person

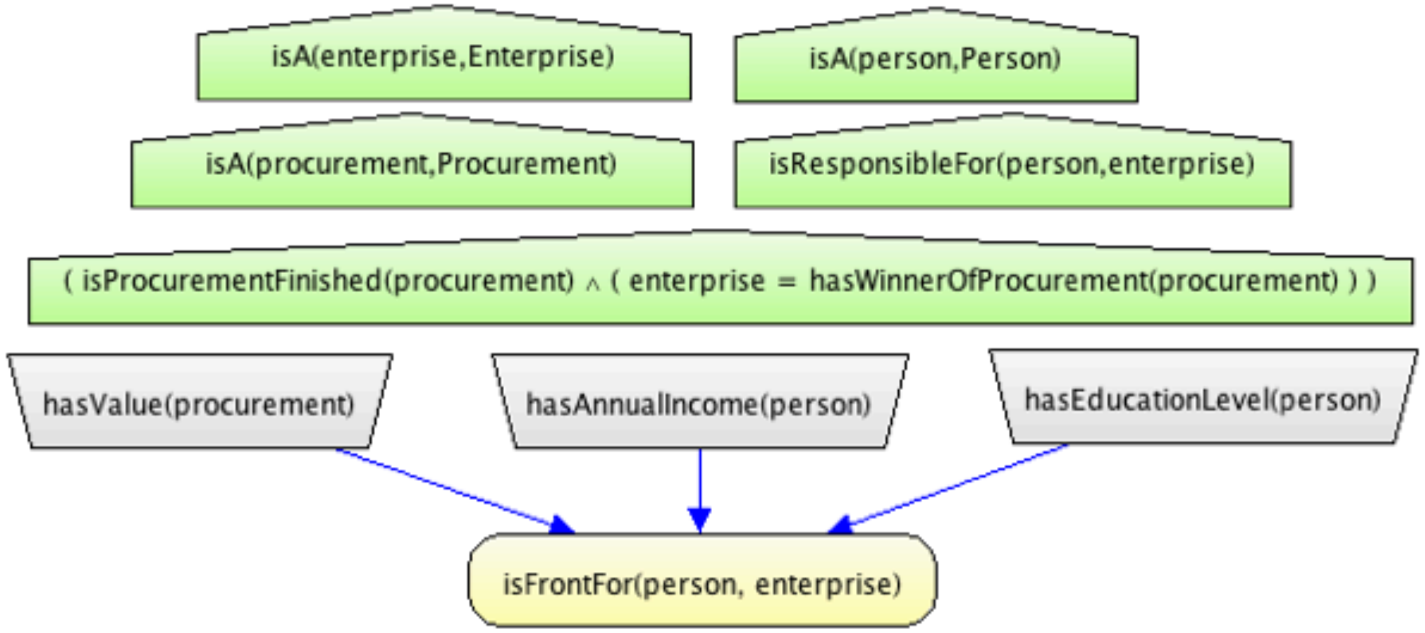
Ranges (intersection)

● EducationLevel



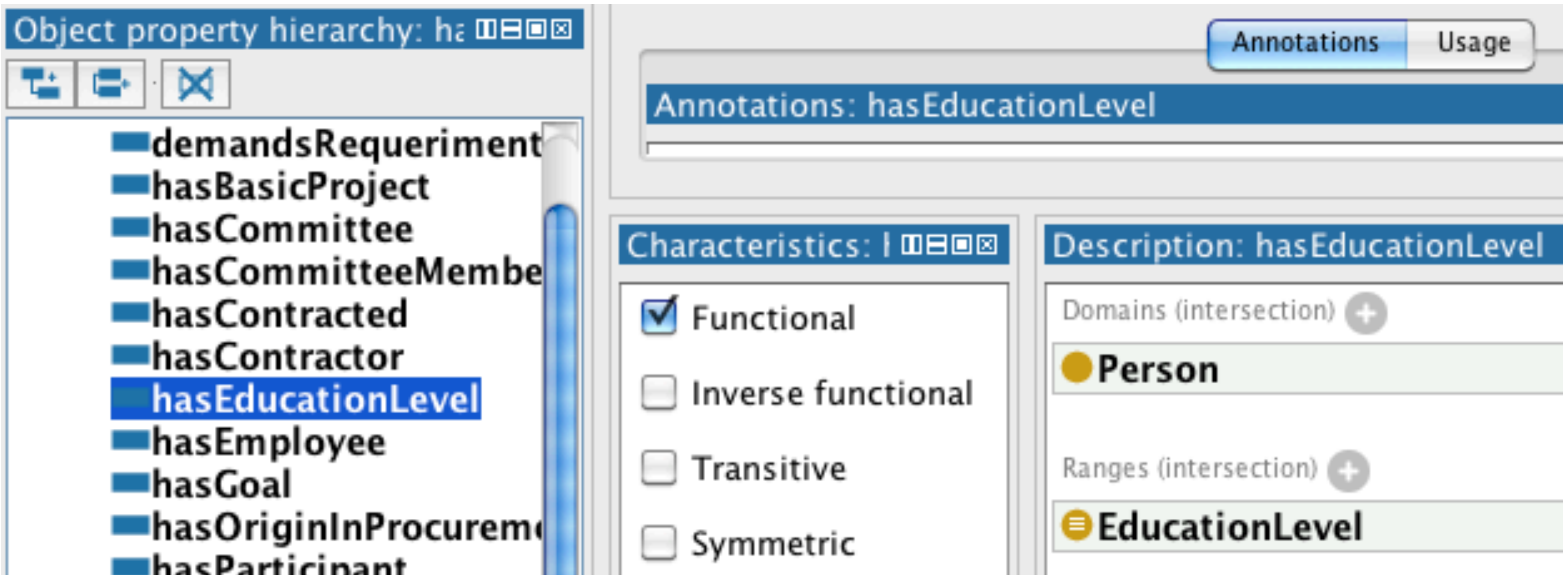
Mapping Schema

PR-OWL



isA(enterprise,Enterprise)
isA(person,Person)
isA(procurement,Procurement)
isResponsibleFor(person,enterprise)
(isProcurementFinished(procurement) ∧ (enterprise = hasWinnerOfProcurement(procurement)))
hasValue(procurement)
hasAnnualIncome(person)
hasEducationLevel(person)
isFrontFor(person, enterprise)

OWL



Object property hierarchy: ha

- demandsRequeriment
- hasBasicProject
- hasCommittee
- hasCommitteeMembe
- hasContracted
- hasContractor
- hasEducationLevel
- hasEmployee
- hasGoal
- hasOriginInProcureme
- hasParticipant

Annotations | Usage

Annotations: hasEducationLevel

Characteristics: I

☑ Functional

□ Inverse functional

□ Transitive

□ Symmetric

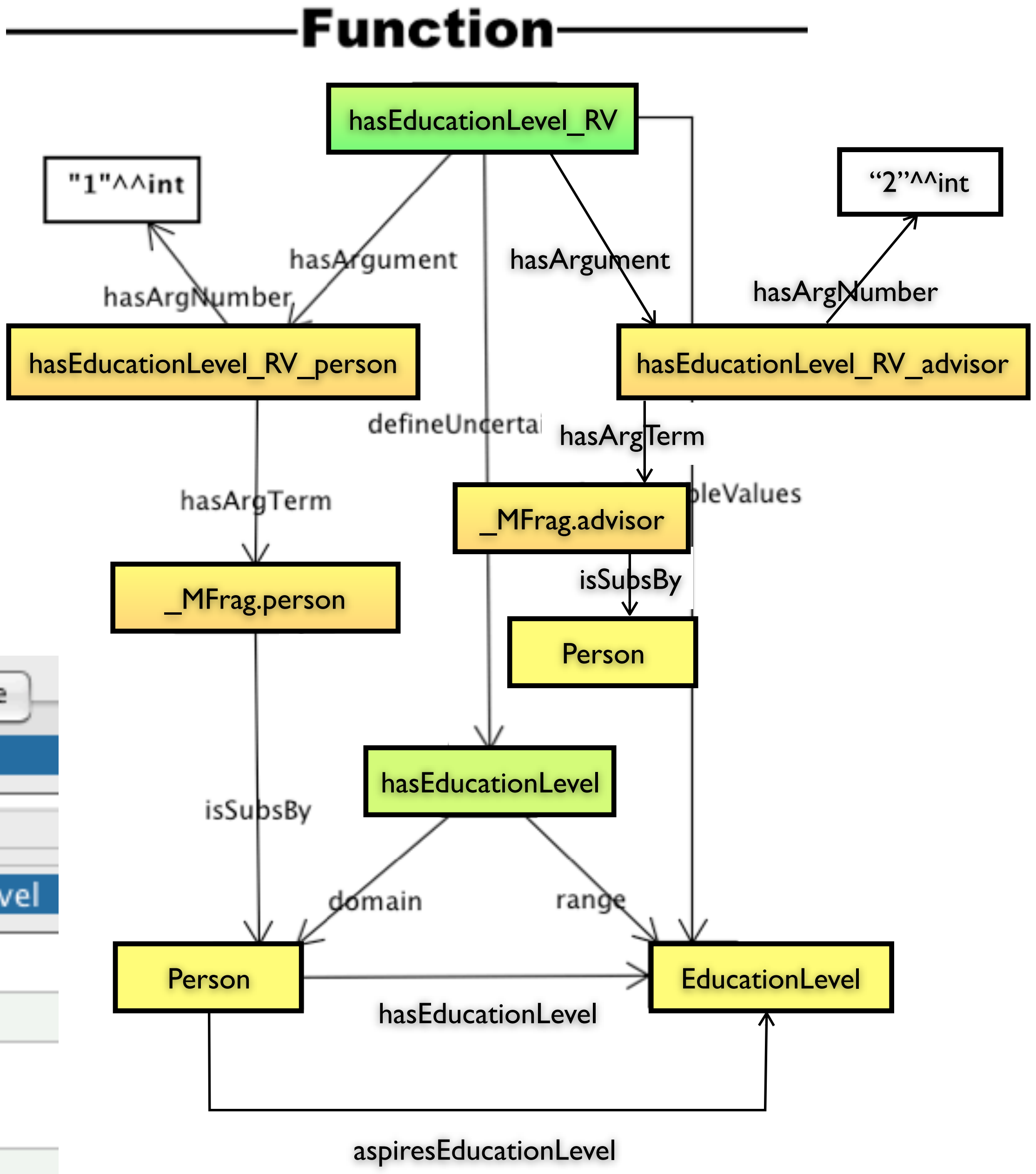
Description: hasEducationLevel

Domains (intersection)

● Person

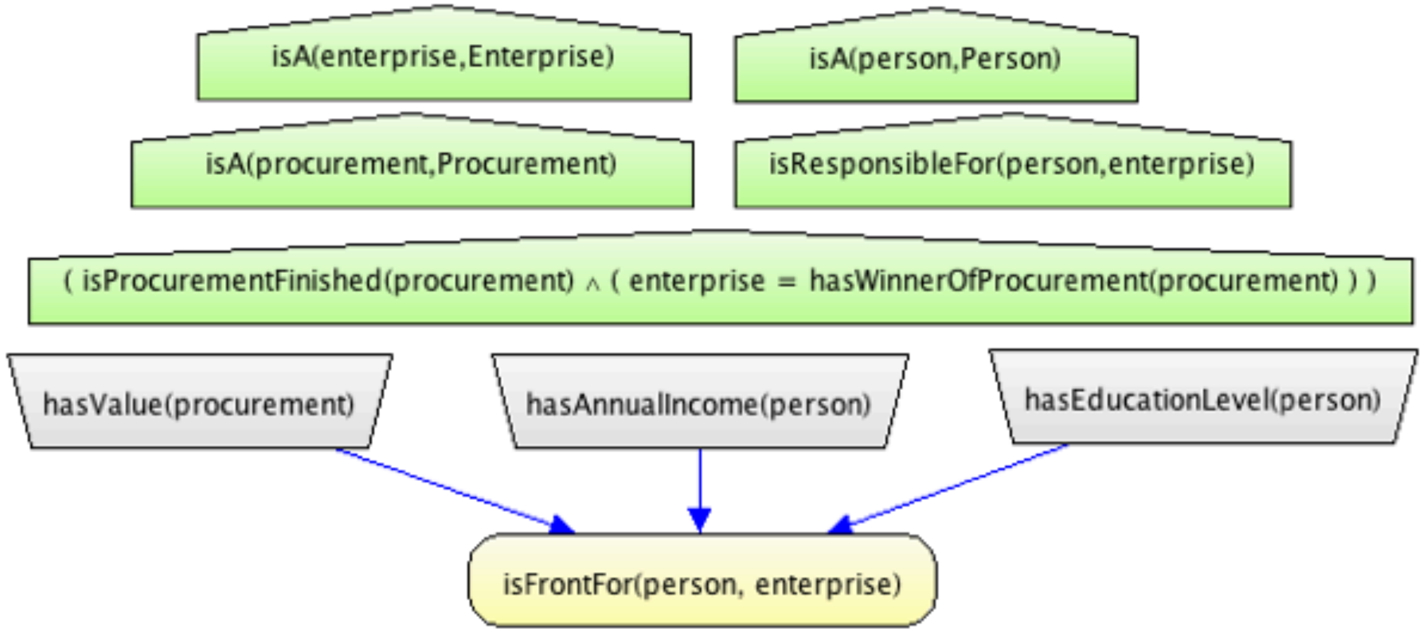
Ranges (intersection)

● EducationLevel

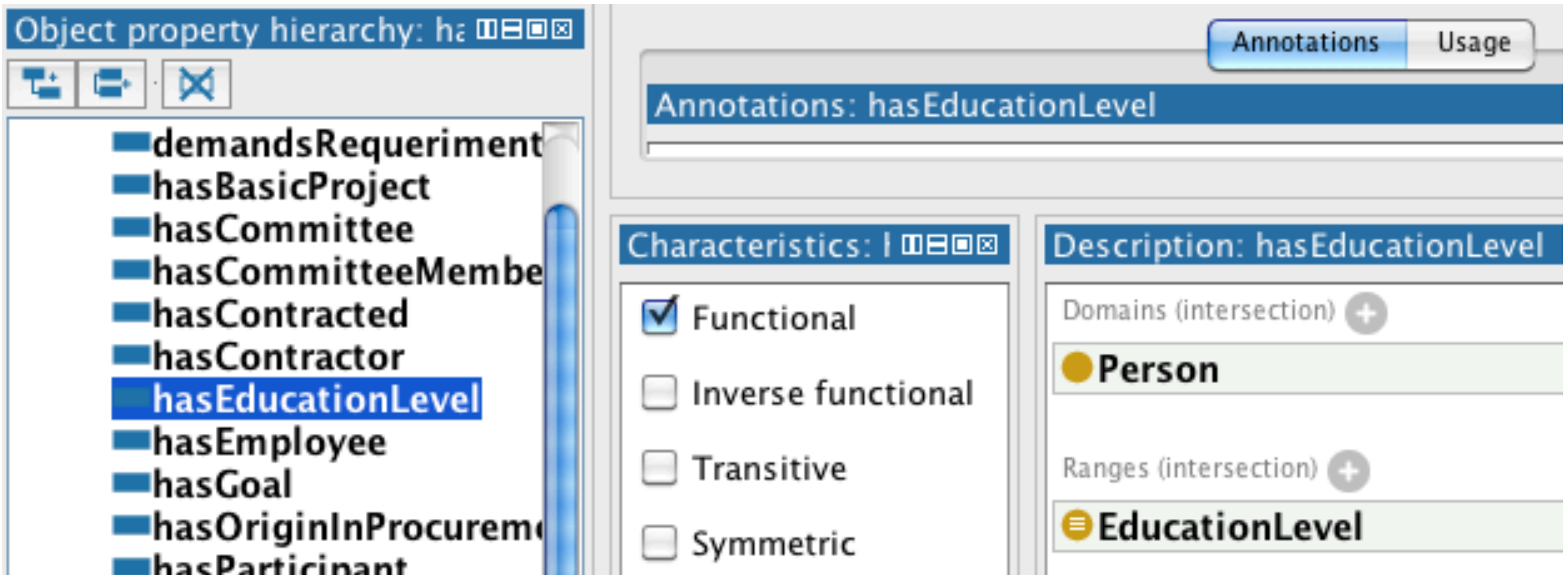


Mapping Schema

PR-OWL


isA(enterprise,Enterprise)
isA(person,Person)
isA(procurement,Procurement)
isResponsibleFor(person,enterprise)
(isProcurementFinished(procurement) ∧ (enterprise = hasWinnerOfProcurement(procurement)))
hasValue(procurement)
hasAnnualIncome(person)
hasEducationLevel(person)
isFrontFor(person, enterprise)

OWL


Object property hierarchy: ha

- demandsRequeriment
- hasBasicProject
- hasCommittee
- hasCommitteeMembe
- hasContracted
- hasContractor
- hasEducationLevel
- hasEmployee
- hasGoal
- hasOriginInProcureme
- hasParticipant

Annotations | Usage

Annotations: hasEducationLevel

Characteristics: l

☑ Functional

□ Inverse functional

□ Transitive

□ Symmetric

Description: hasEducationLevel

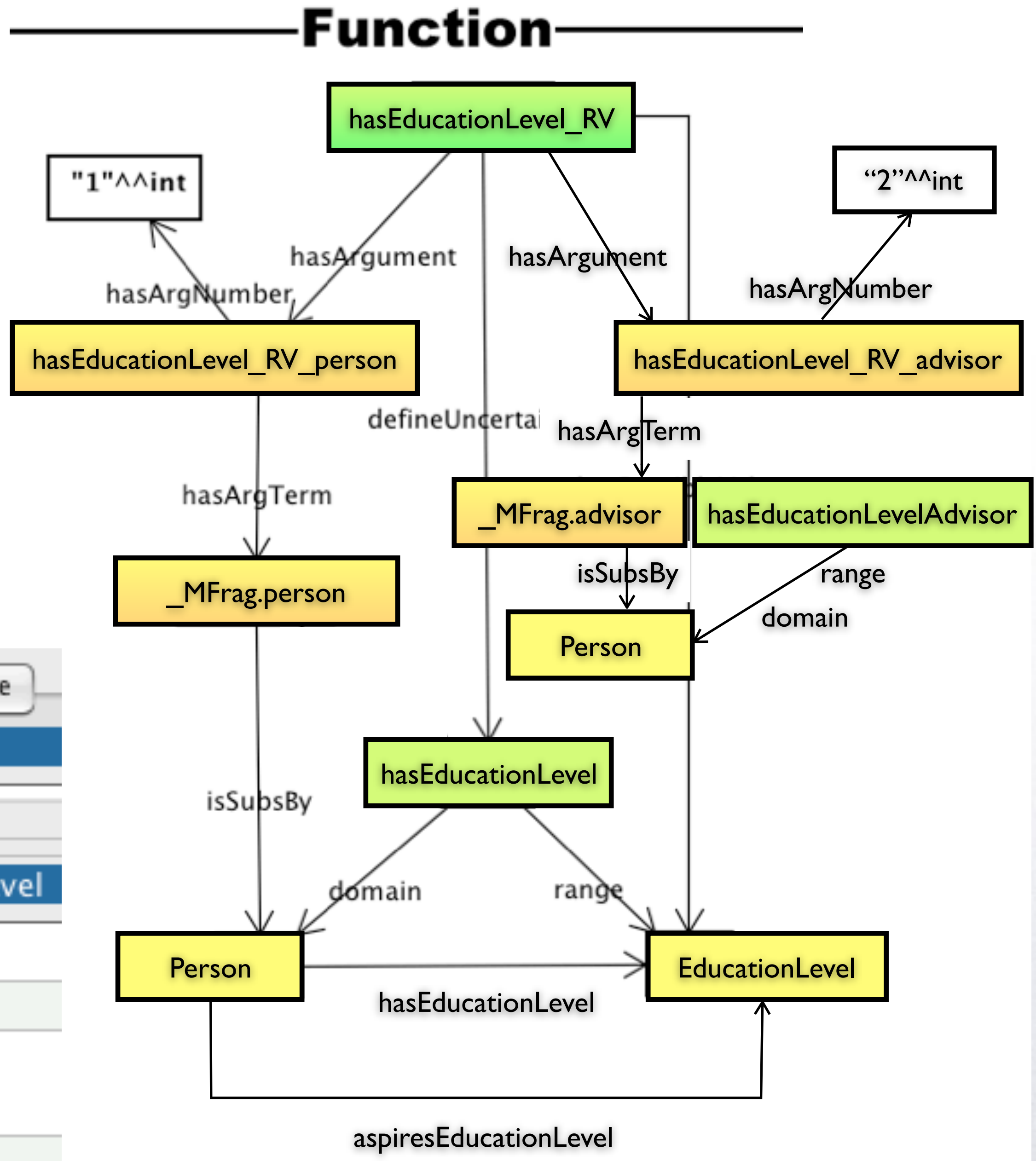
Domains (intersection)

● Person

Ranges (intersection)

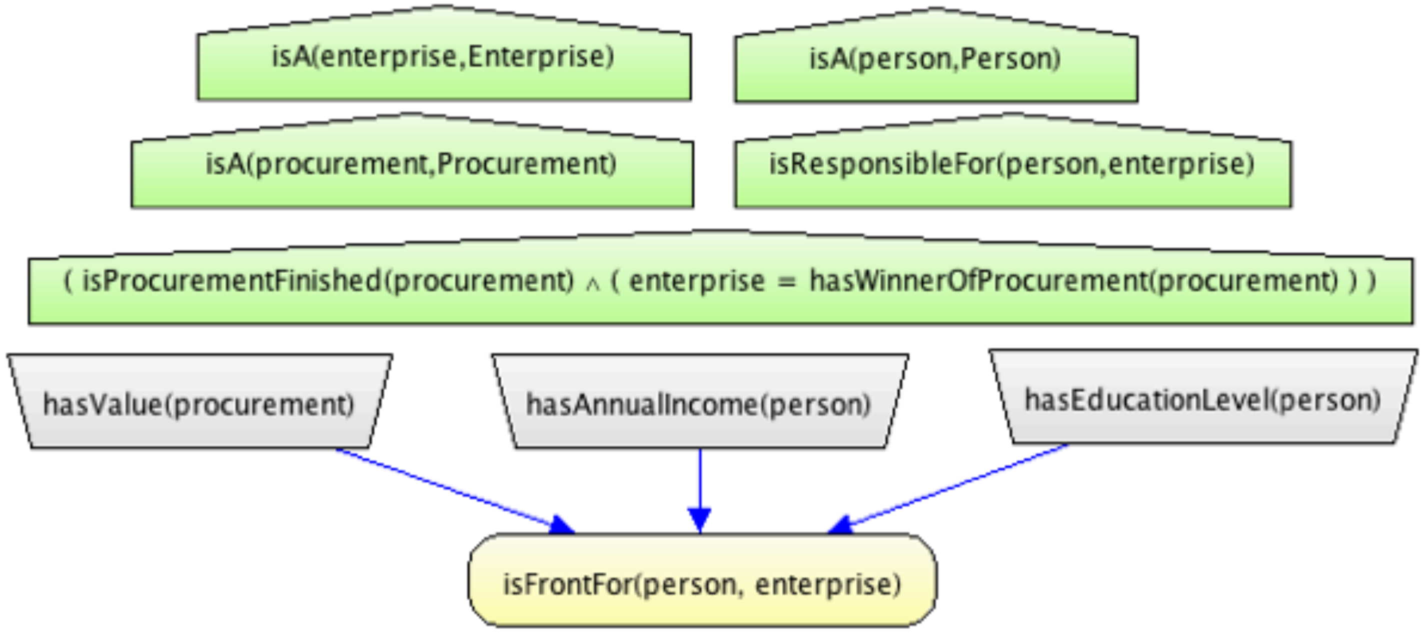
● EducationLevel

Function

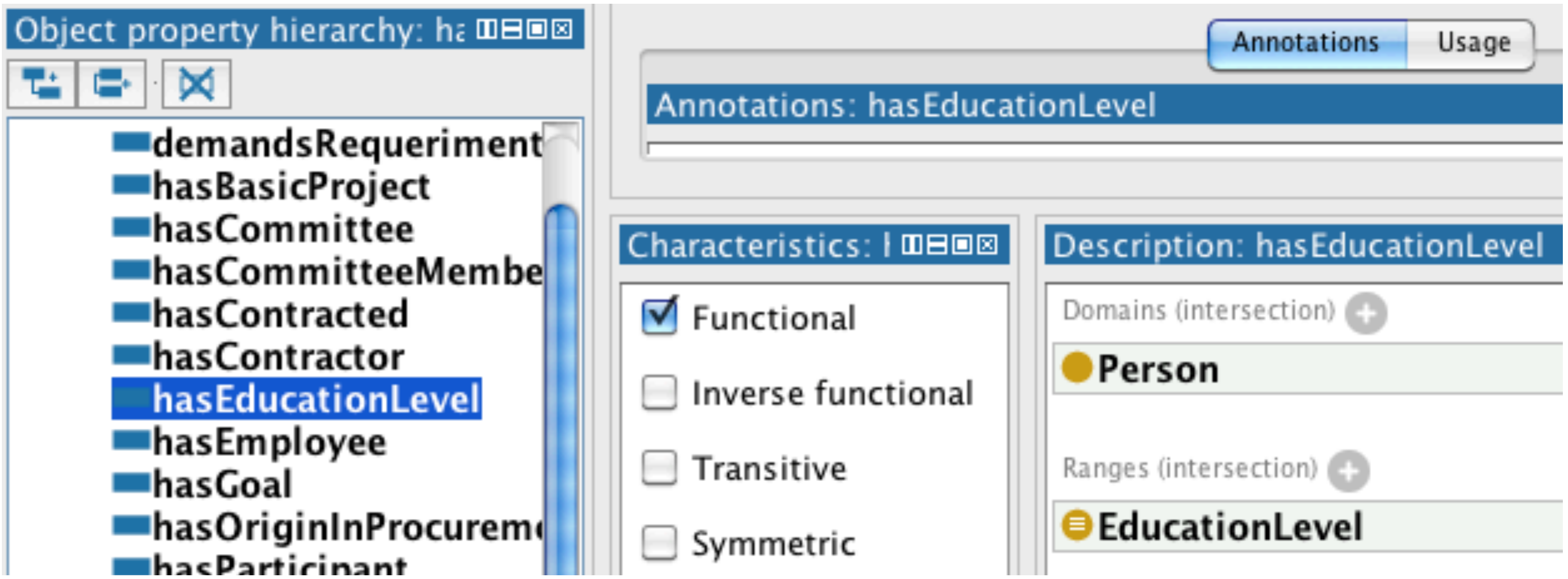


Mapping Schema

PR-OWL


isA(enterprise,Enterprise)
isA(person,Person)
isA(procurement,Procurement)
isResponsibleFor(person,enterprise)
(isProcurementFinished(procurement) ∧ (enterprise = hasWinnerOfProcurement(procurement)))
hasValue(procurement)
hasAnnualIncome(person)
hasEducationLevel(person)
isFrontFor(person, enterprise)

OWL



- demandsRequeriment
- hasBasicProject
- hasCommittee
- hasCommitteeMembe
- hasContracted
- hasContractor
- hasEducationLevel
- hasEmployee
- hasGoal
- hasOriginInProcureme
- hasParticipant

Annotations: hasEducationLevel

Characteristics: I

☑ Functional

☐ Inverse functional

☐ Transitive

☐ Symmetric

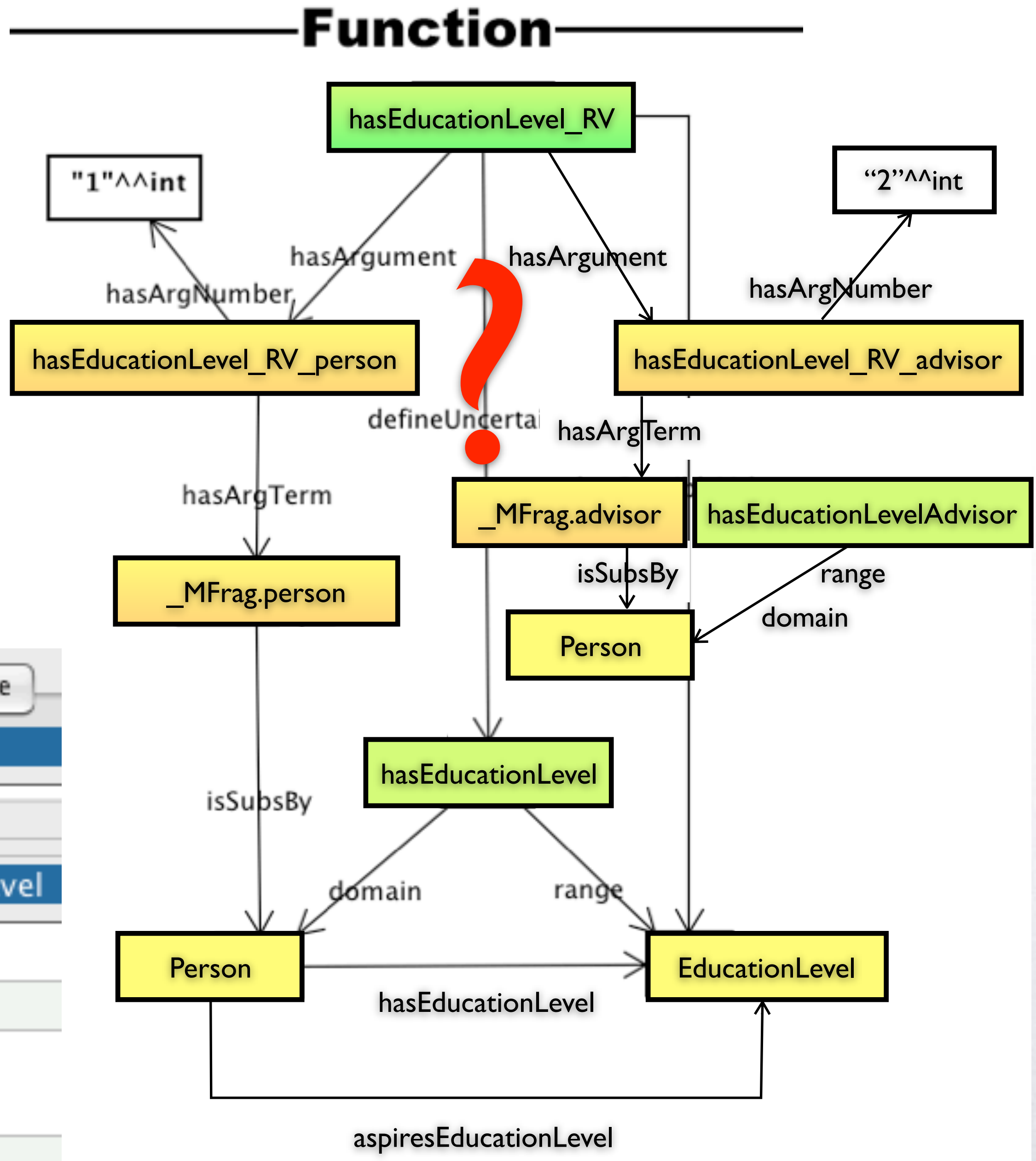
Description: hasEducationLevel

Domains (intersection)

● Person

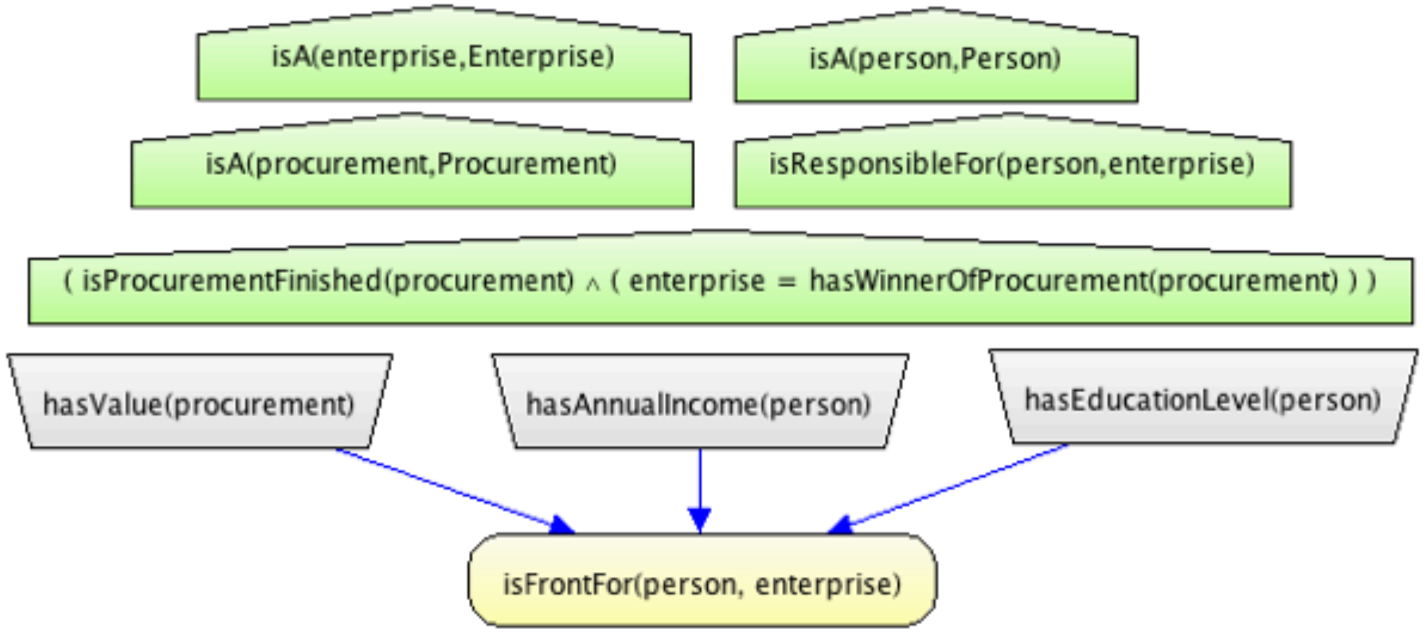
Ranges (intersection)

● EducationLevel



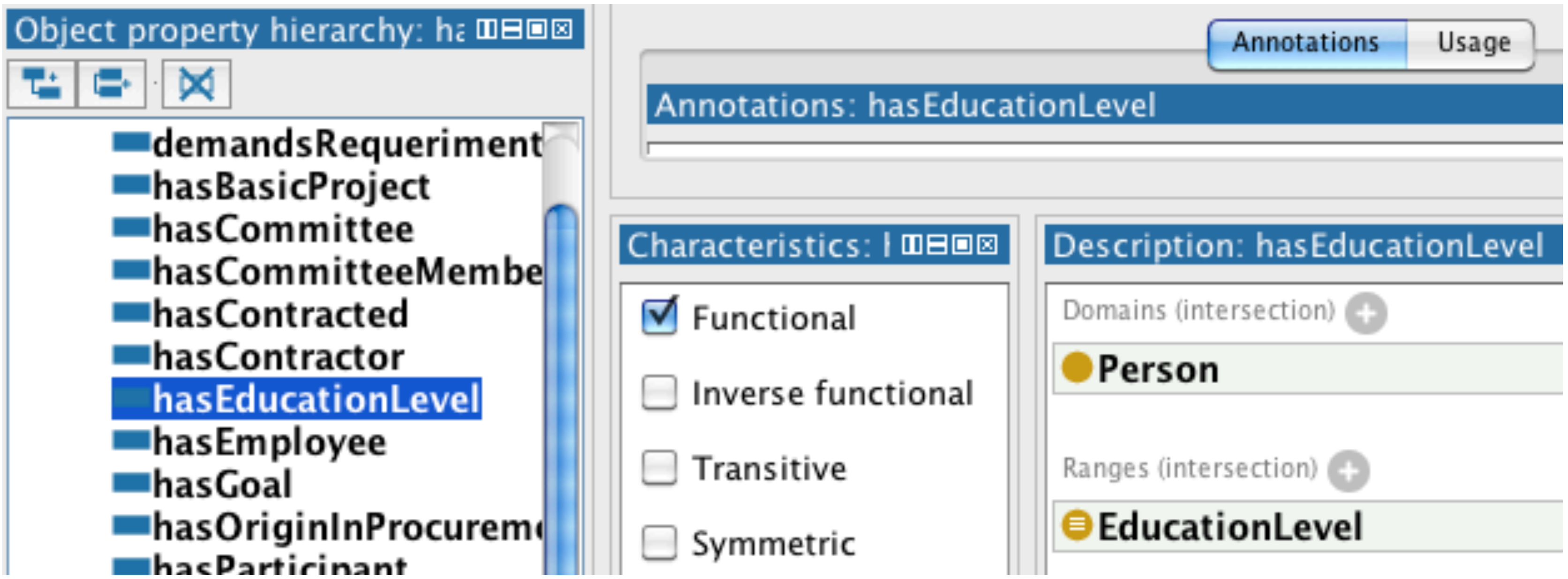
Mapping Schema

PR-OWL



isA(enterprise,Enterprise)
isA(person,Person)
isA(procurement,Procurement)
isResponsibleFor(person,enterprise)
(isProcurementFinished(procurement) ∧ (enterprise = hasWinnerOfProcurement(procurement)))
hasValue(procurement)
hasAnnualIncome(person)
hasEducationLevel(person)
isFrontFor(person, enterprise)

OWL



- demandsRequeriment
- hasBasicProject
- hasCommittee
- hasCommitteeMembe
- hasContracted
- hasContractor
- hasEducationLevel
- hasEmployee
- hasGoal
- hasOriginInProcureme
- hasParticipant

Annotations: hasEducationLevel

Characteristics: I

☑ Functional

□ Inverse functional

□ Transitive

□ Symmetric

Description: hasEducationLevel

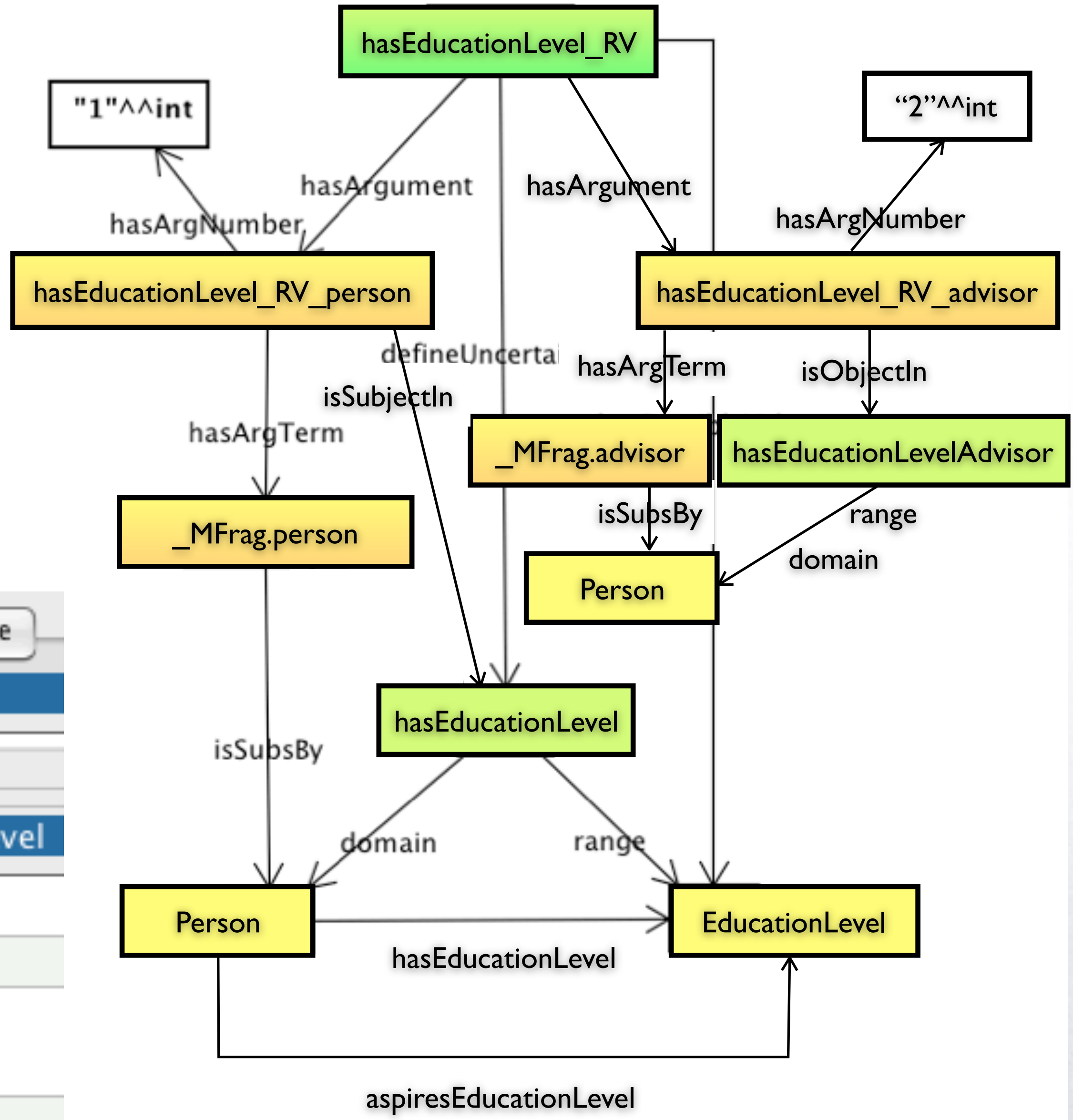
Domains (intersection)

● Person

Ranges (intersection)

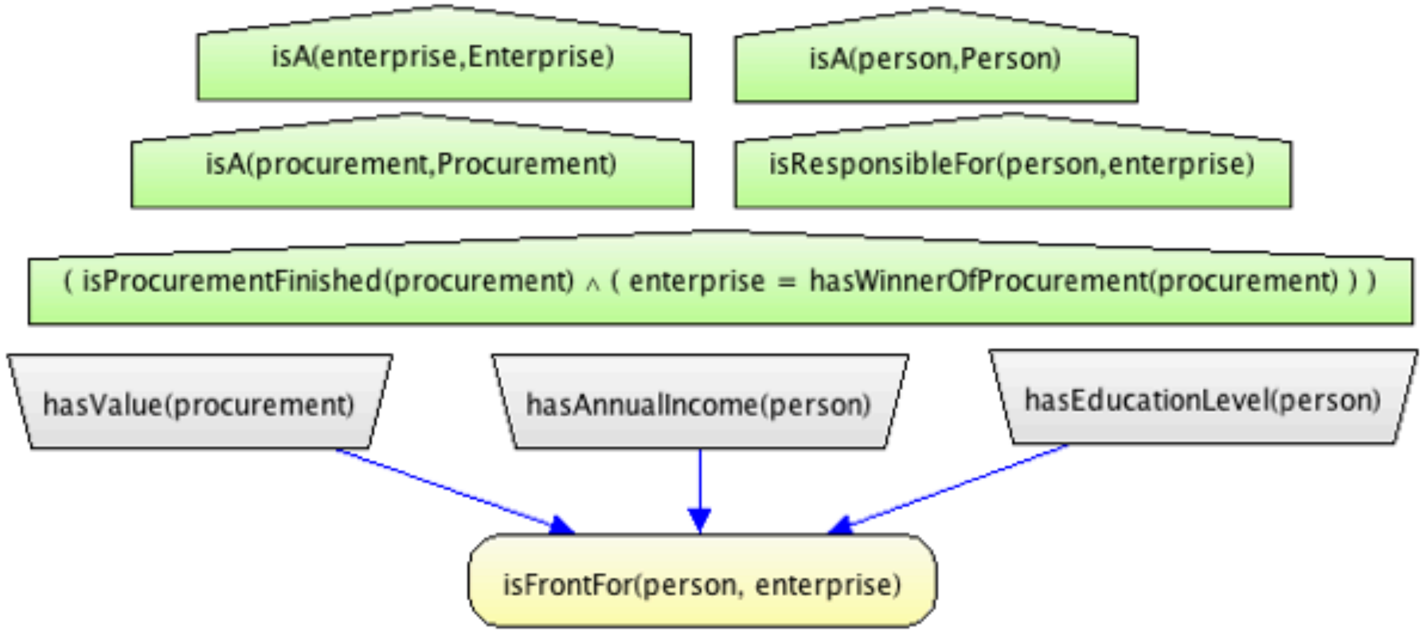
● EducationLevel

Function



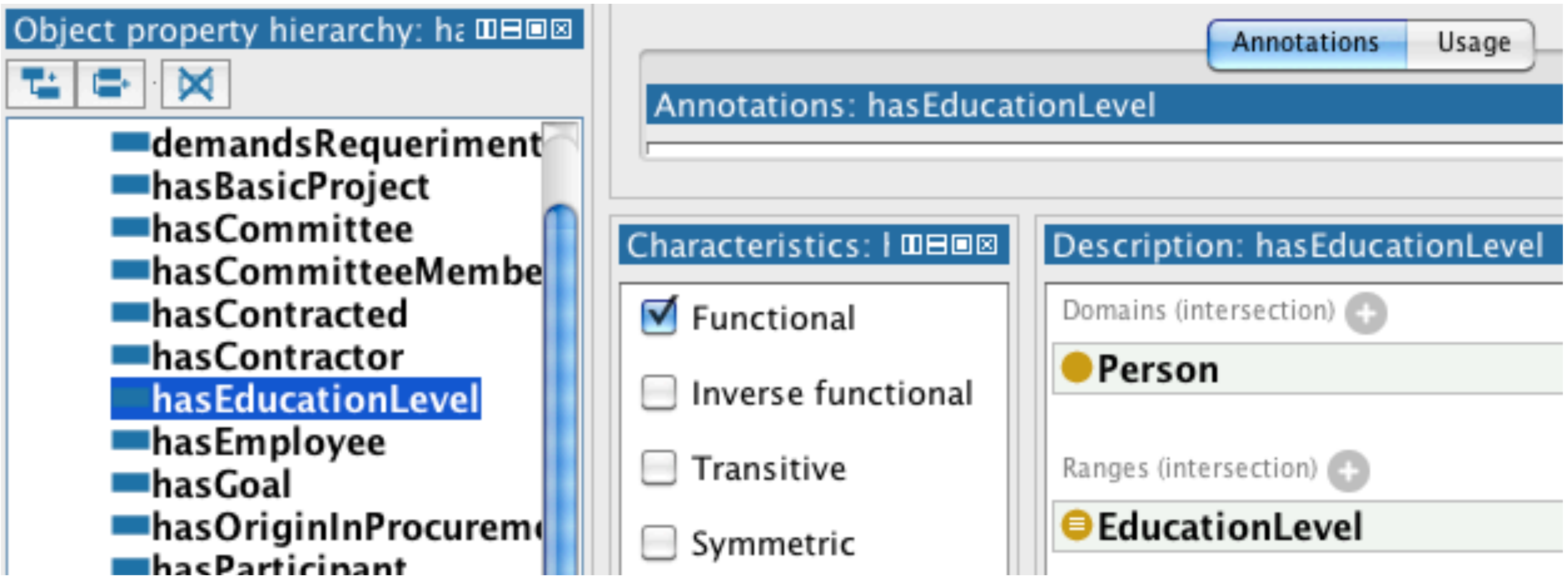
Mapping Schema

PR-OWL



isA(enterprise,Enterprise)
isA(person,Person)
isA(procurement,Procurement)
isResponsibleFor(person,enterprise)
(isProcurementFinished(procurement) ∧ (enterprise = hasWinnerOfProcurement(procurement)))
hasValue(procurement)
hasAnnualIncome(person)
hasEducationLevel(person)
isFrontFor(person, enterprise)

OWL



- demandsRequeriment
- hasBasicProject
- hasCommittee
- hasCommitteeMembe
- hasContracted
- hasContractor
- hasEducationLevel
- hasEmployee
- hasGoal
- hasOriginInProcurem
- hasParticipant

Annotations: hasEducationLevel

Characteristics: I

- ☑ Functional
- □ Inverse functional
- □ Transitive
- □ Symmetric

Description: hasEducationLevel

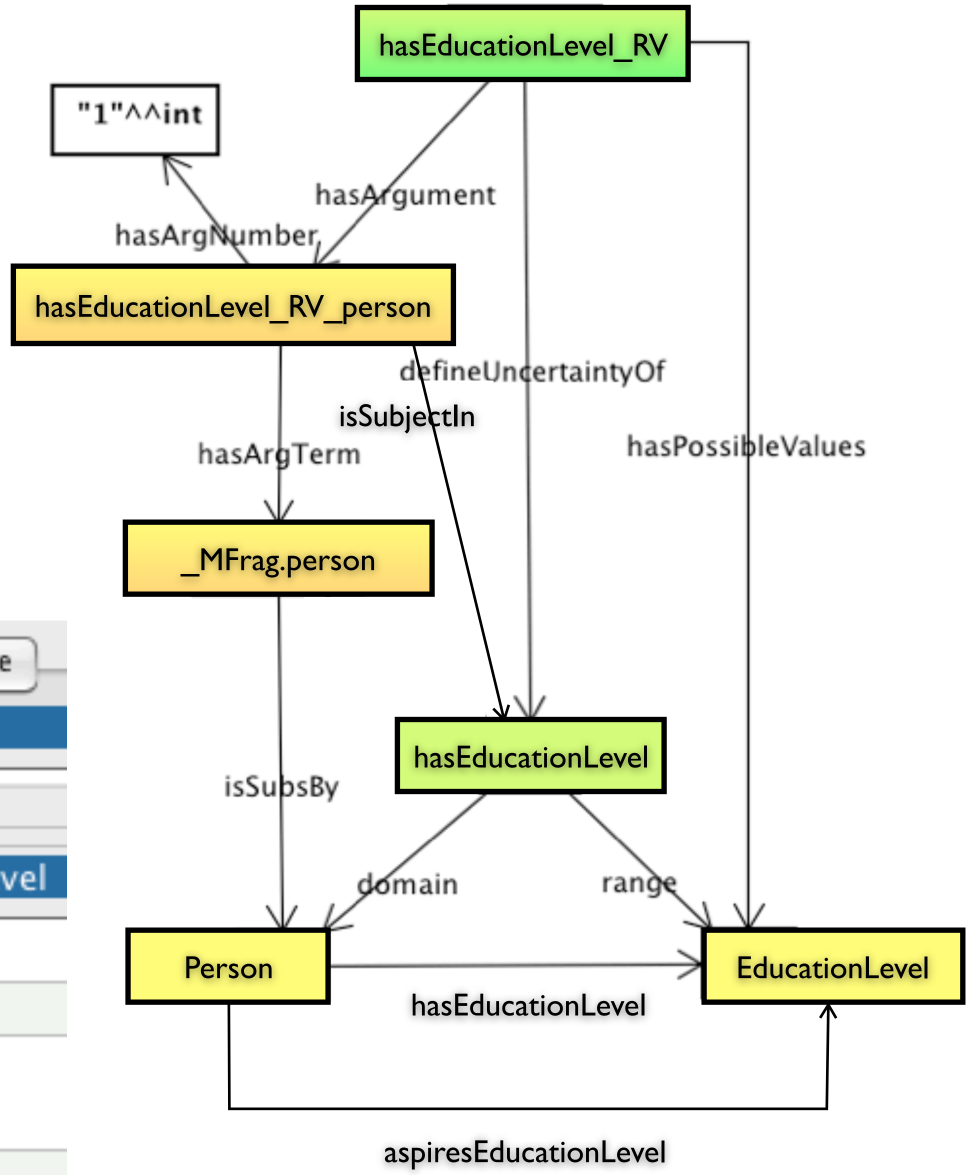
Domains (intersection)

● Person

Ranges (intersection)

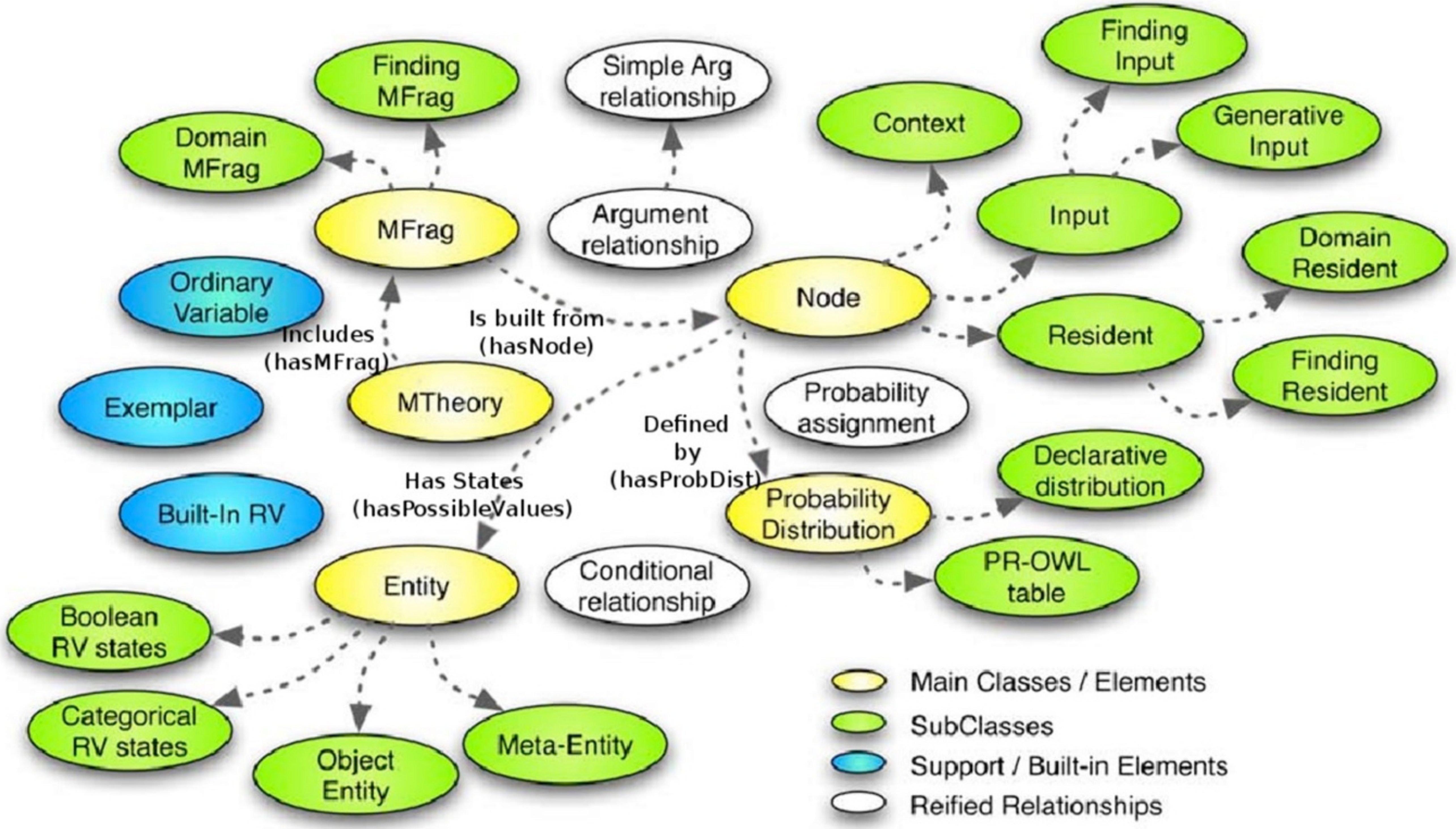
● EducationLevel

Function



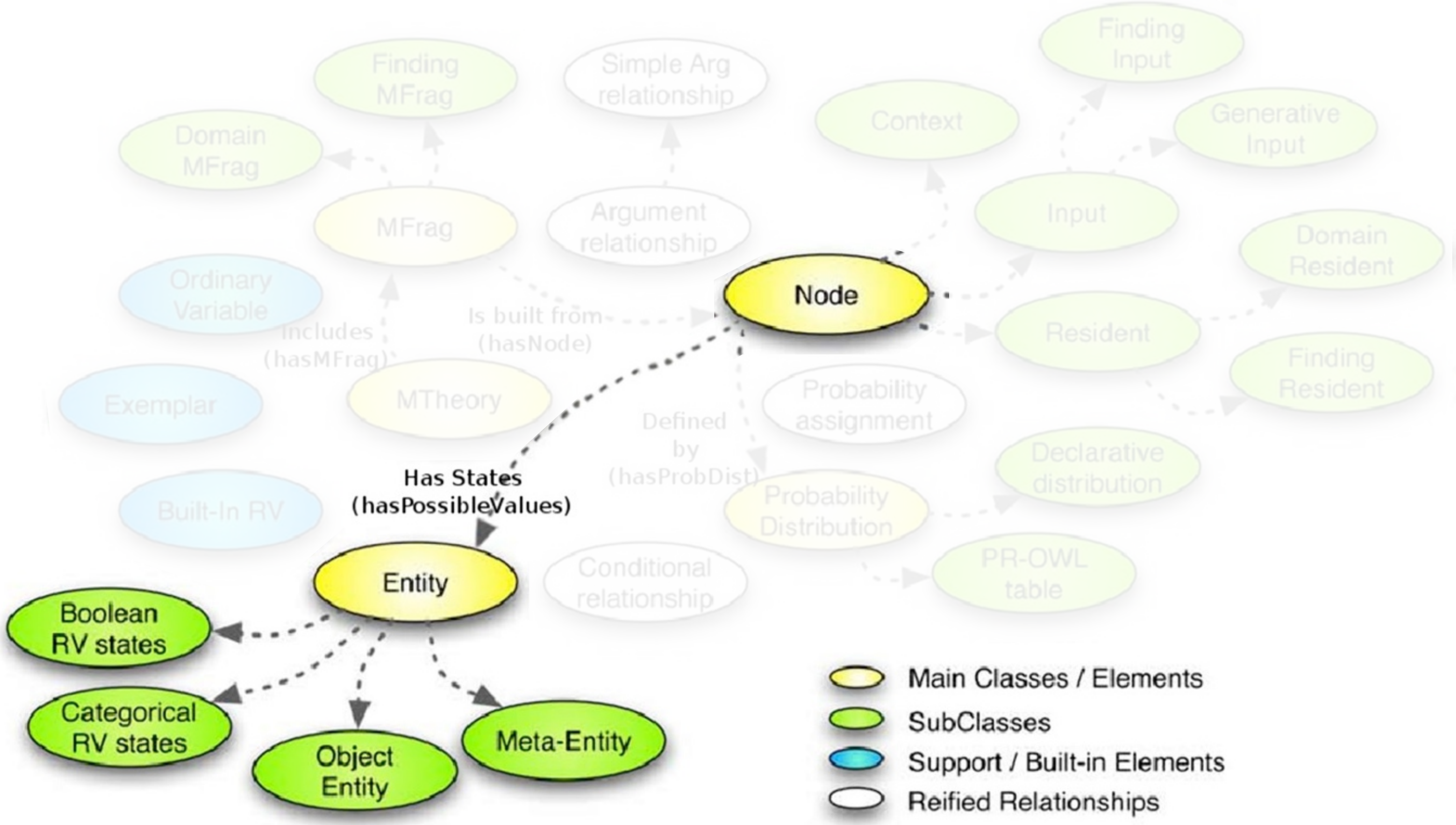
Using Existing Types

reproduced with permission from [2] - extended version



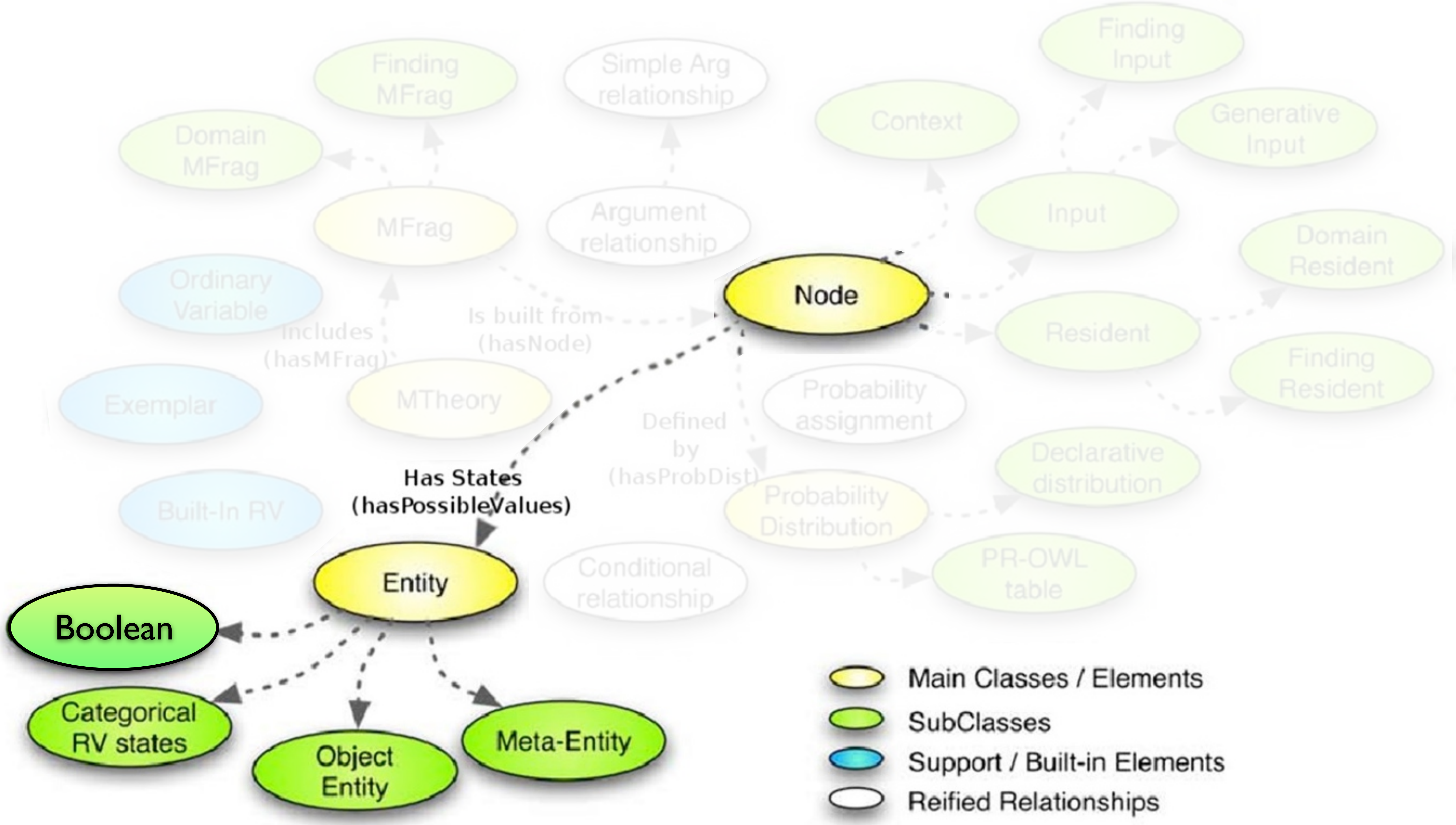
Using Existing Types

***reproduced with permission from [2] - extended version**



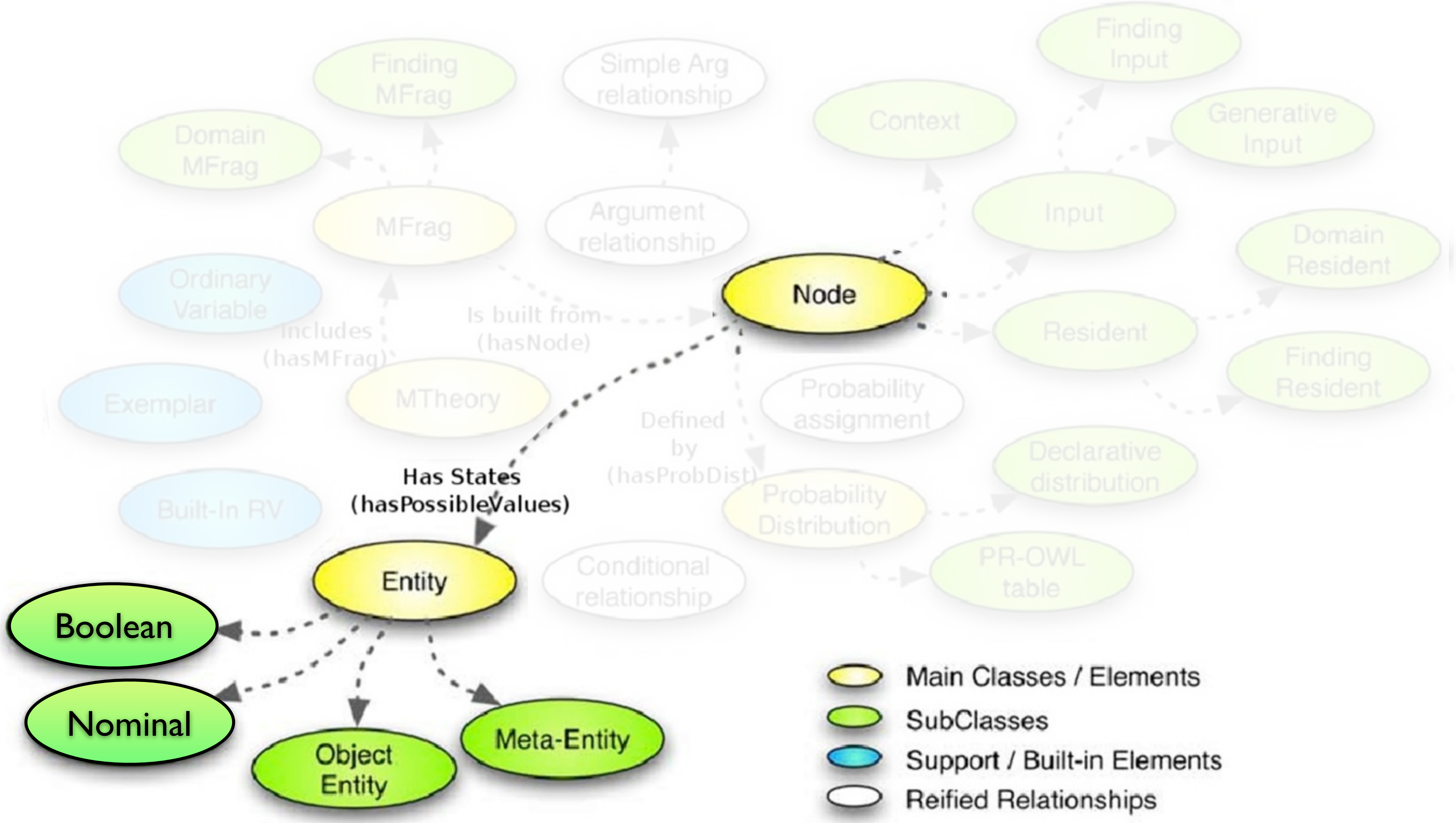
Using Existing Types

reproduced with permission from [2] - extended version



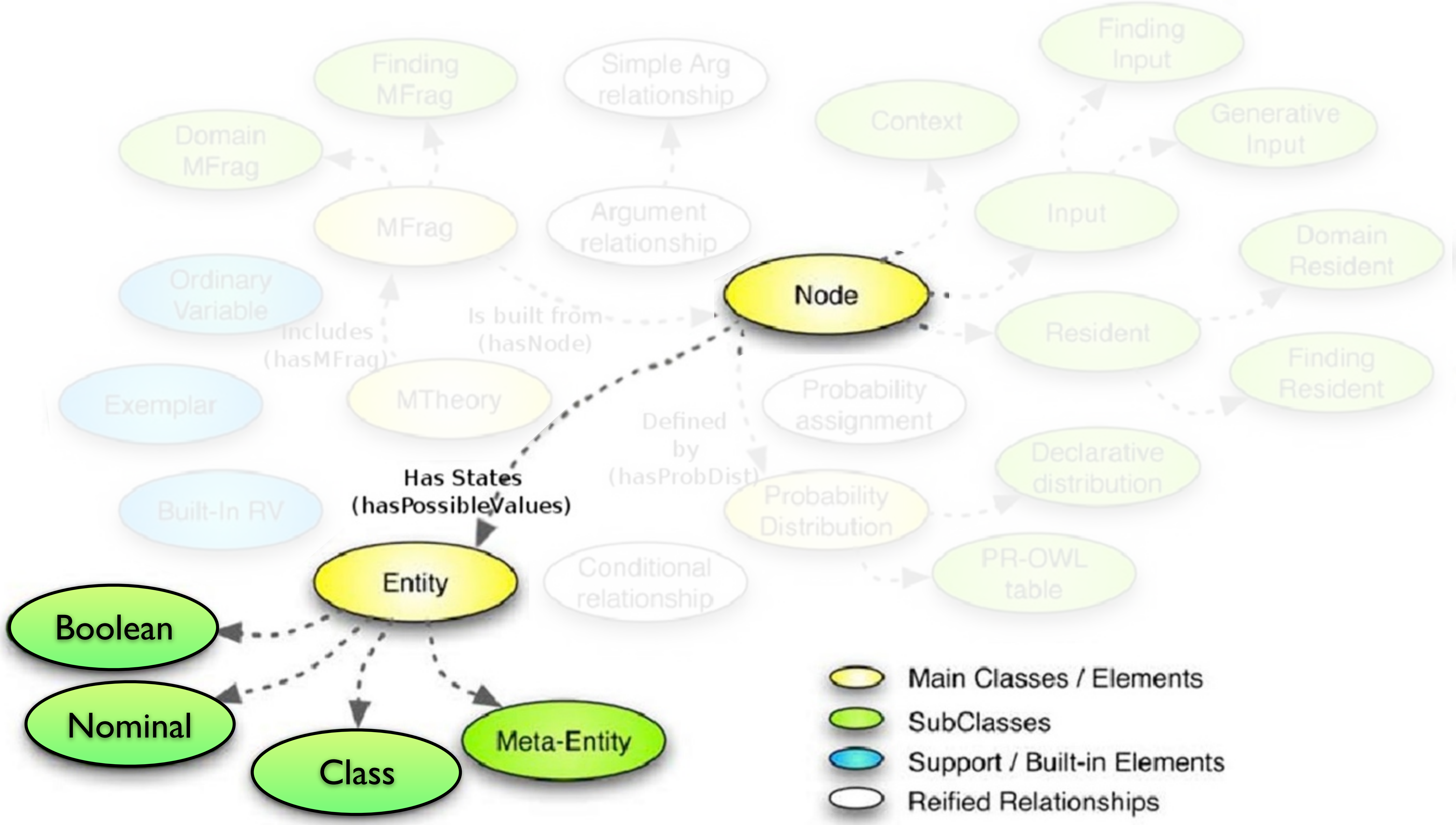
Using Existing Types

***reproduced with permission from [2] - extended version**



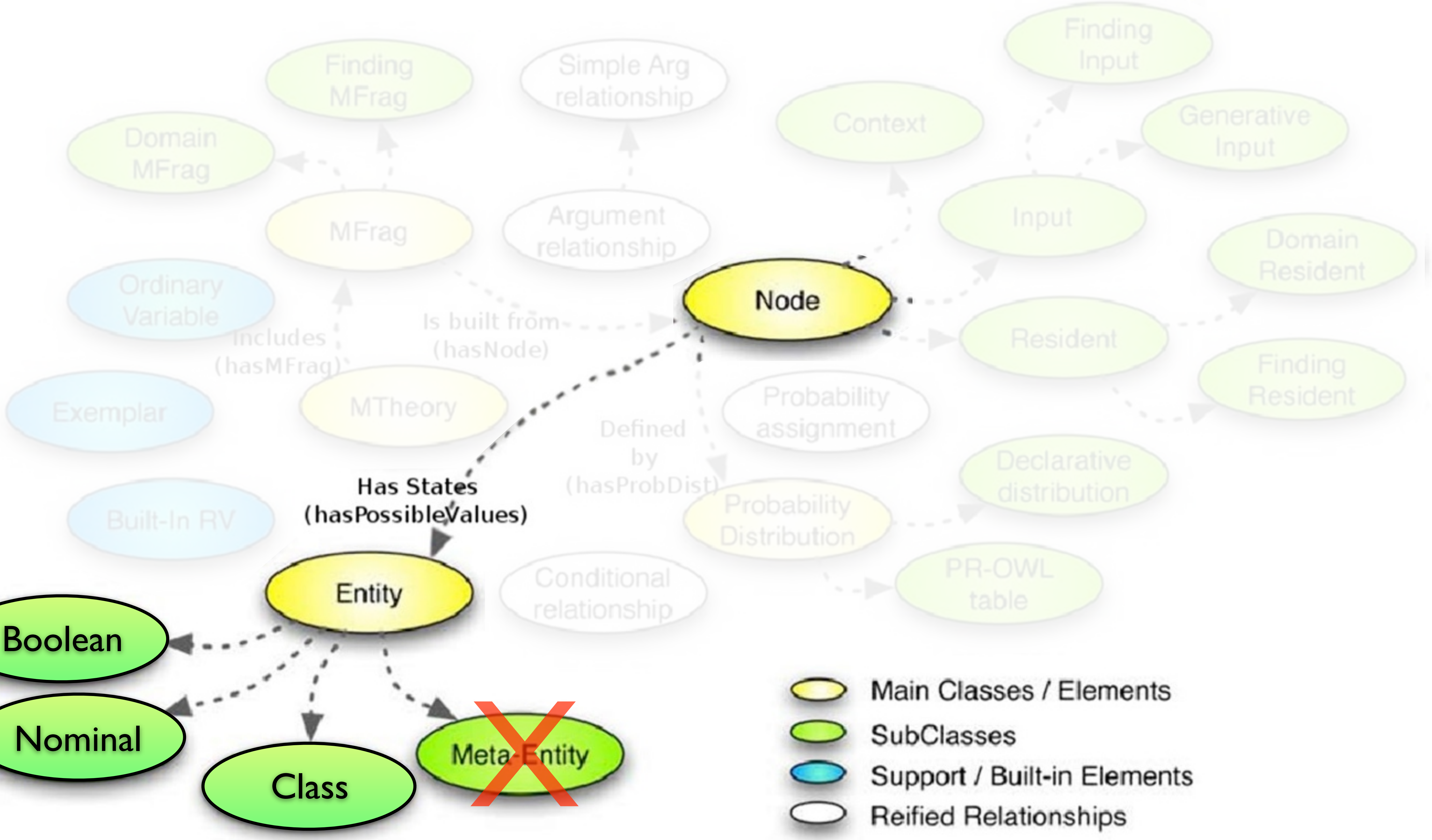
Using Existing Types

reproduced with permission from [2] - extended version



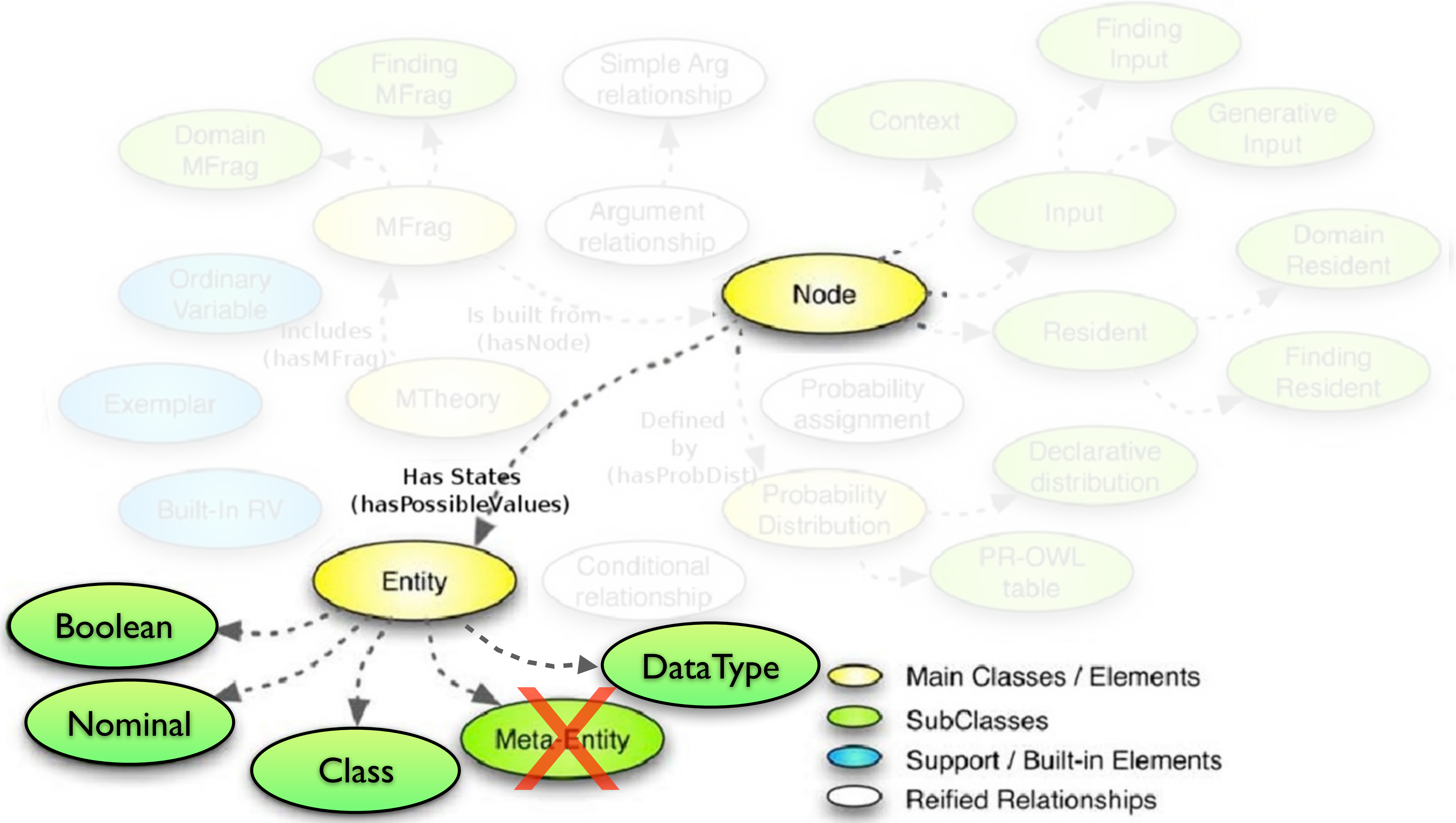
Using Existing Types

***reproduced with permission from [2] - extended version**



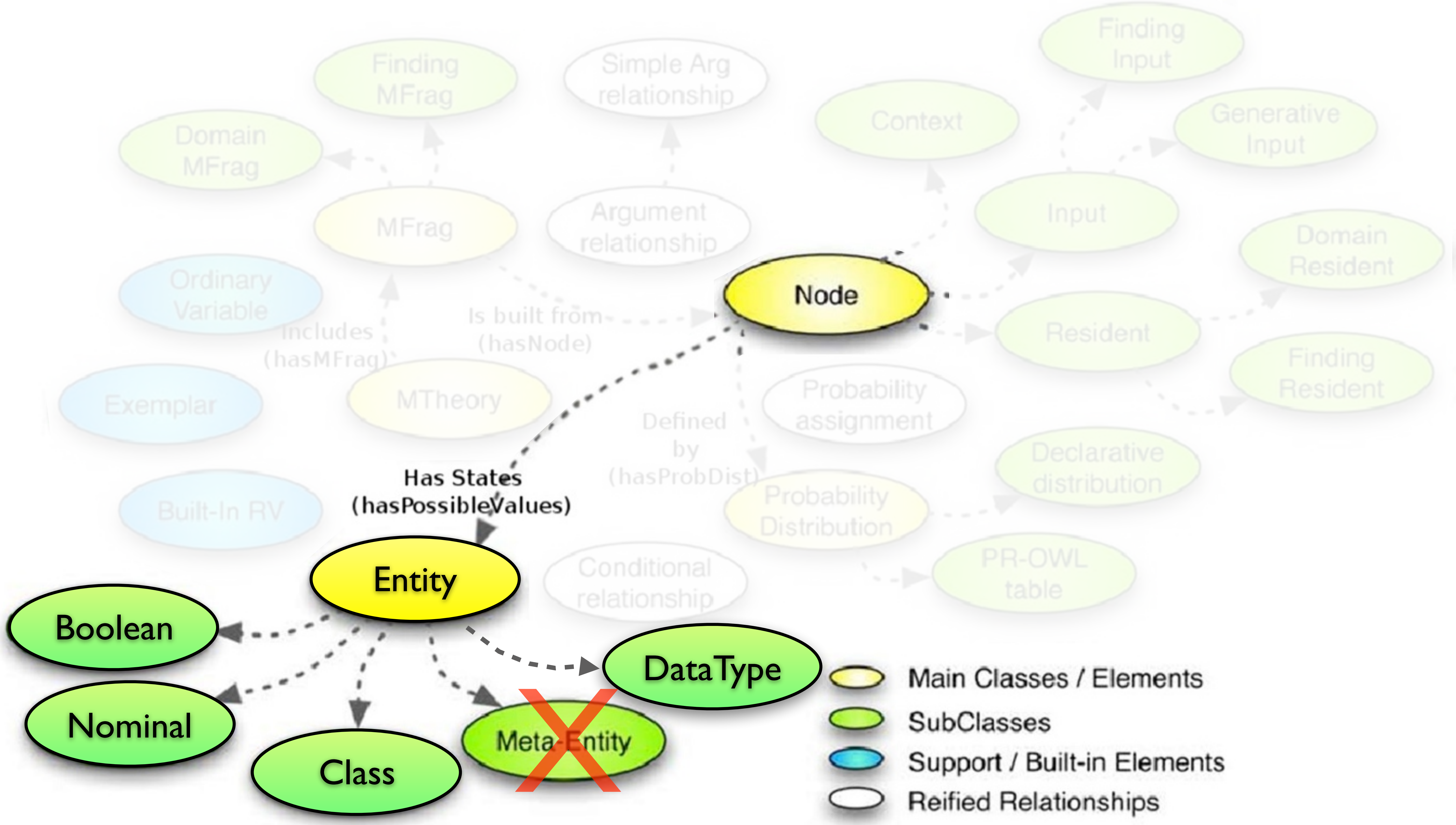
Using Existing Types

reproduced with permission from [2] - extended version

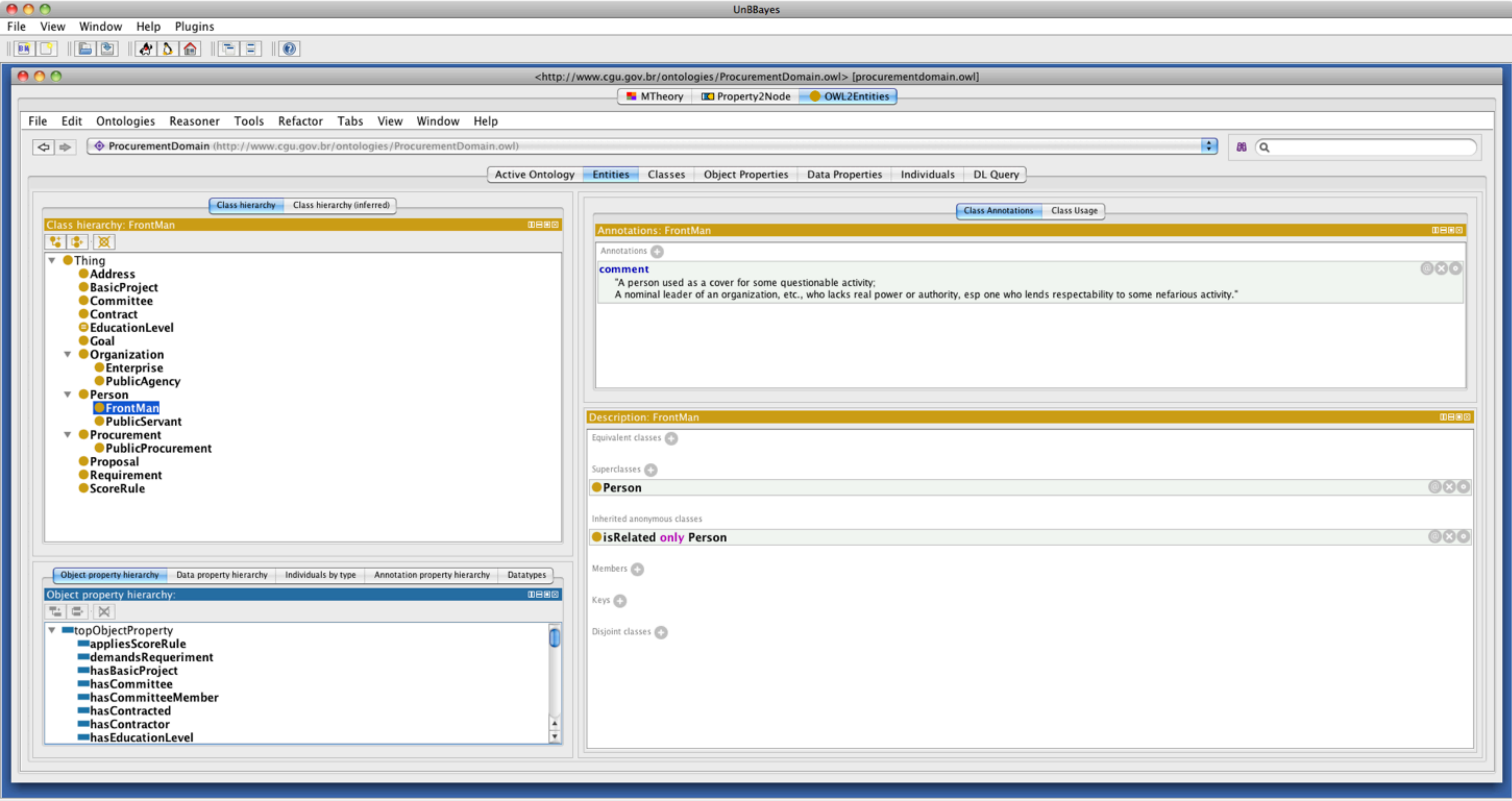


Using Existing Types

reproduced with permission from [2] - extended version



PR-OWL 2.0 - Proof of Concept


UnBBayes
File View Window Help Plugins
<http://www.cgu.gov.br/ontologies/ProcurementDomain.owl> [procurementdomain.owl]
MTheory
Property2Node
OWL2Entities
File Edit Ontologies Reasoner Tools Refactor Tabs View Window Help
ProcurementDomain (http://www.cgu.gov.br/ontologies/ProcurementDomain.owl)
Active Ontology
Entities
Classes
Object Properties
Data Properties
Individuals
DL Query
Class hierarchy
Class hierarchy (inferred)
Class hierarchy: FrontMan
Class Annotations
Class Usage
Annotations: FrontMan
Annotations
Description: FrontMan
Equivalent classes
Superclasses
Inherited anonymous classes
Members
Keys
Disjoint classes
Object property hierarchy
Data property hierarchy
Individuals by type
Annotation property hierarchy
Datatypes
Object property hierarchy:

- Thing
  - Address
  - BasicProject
  - Committee
  - Contract
  - EducationLevel
  - Goal
  - Organization
    - Enterprise
    - PublicAgency
  - Person
    - FrontMan
    - PublicServant
  - Procurement
    - PublicProcurement
  - Proposal
  - Requirement
  - ScoreRule

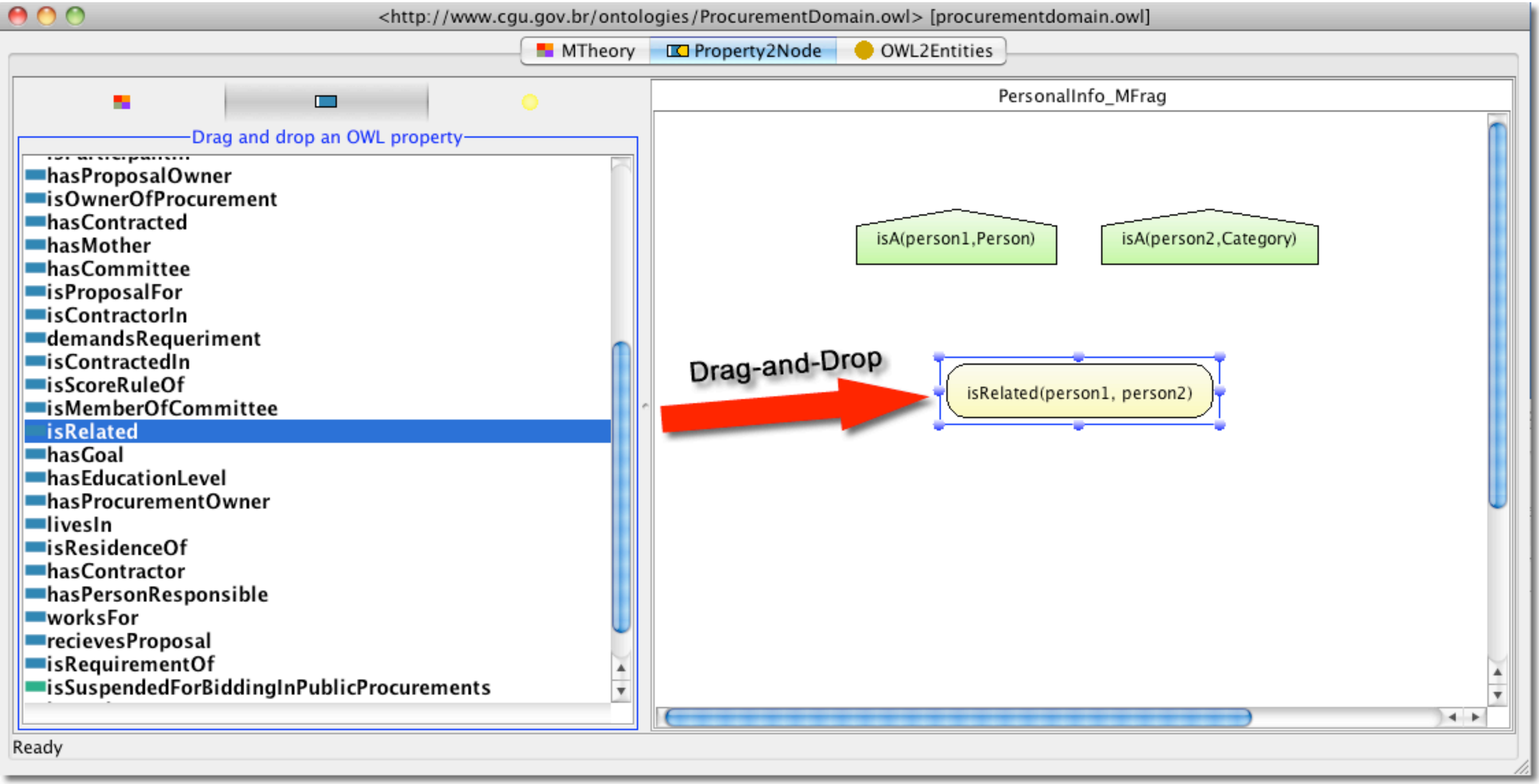
comment
"A person used as a cover for some questionable activity;
A nominal leader of an organization, etc., who lacks real power or authority, esp one who lends respectability to some nefarious activity."

Superclasses: Person

Inherited anonymous classes: isRelated only Person

- topObjectProperty
  - appliesScoreRule
  - demandsRequeriment
  - hasBasicProject
  - hasCommittee
  - hasCommitteeMember
  - hasContracted
  - hasContractor
  - hasEducationLevel

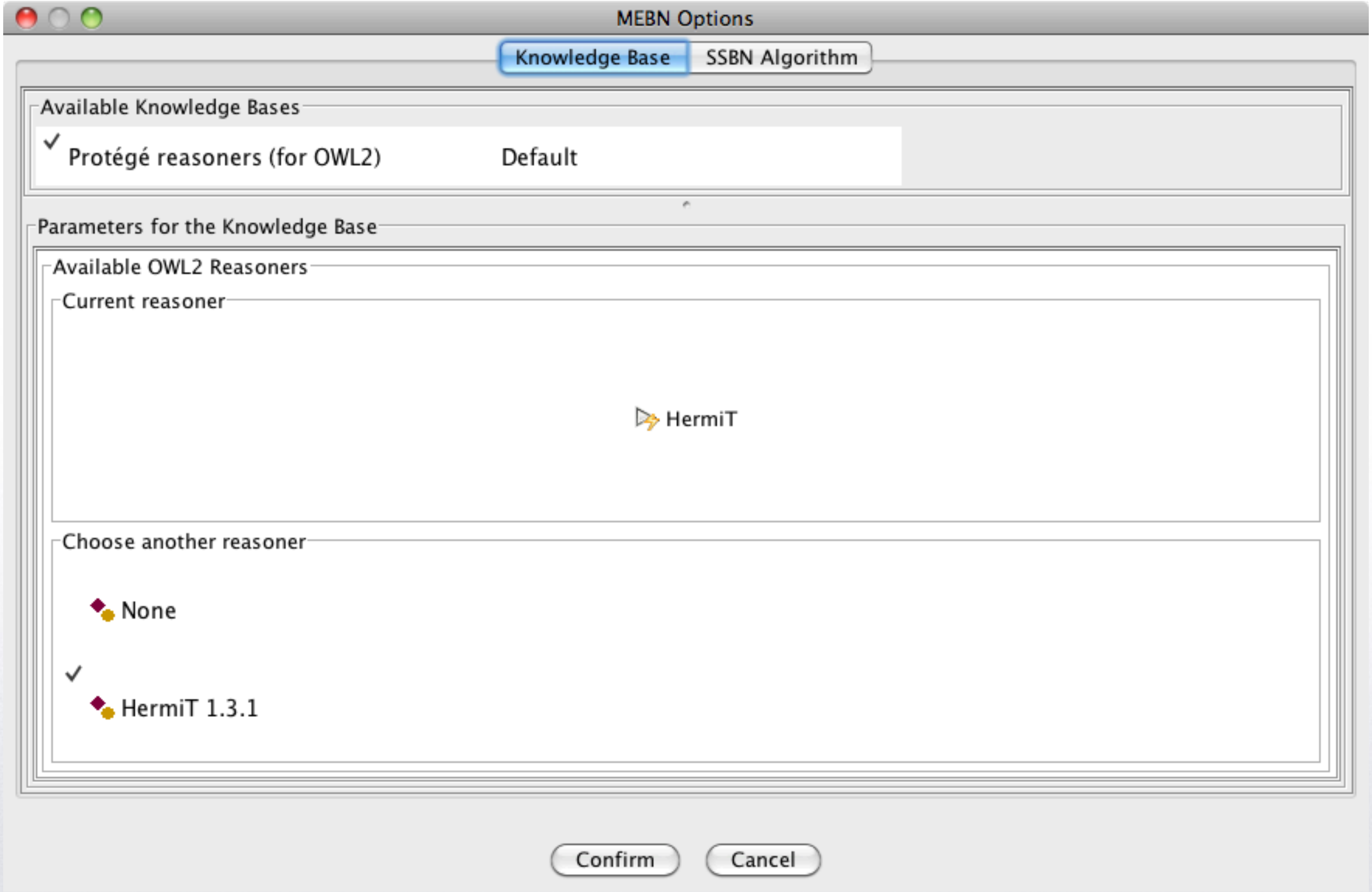
PR-OWL 2.0 - Proof of Concept



<http://www.cgu.gov.br/ontologies/ProcurementDomain.owl> [procurementdomain.owl]
MTheory
Property2Node
OWL2Entities
Drag and drop an OWL property
PersonalInfo_MFrag
isA(person1,Person)
isA(person2,Category)
Drag-and-Drop
isRelated(person1, person2)
Ready

- hasProposalOwner
- isOwnerOfProcurement
- hasContracted
- hasMother
- hasCommittee
- isProposalFor
- isContractorIn
- demandsRequeriment
- isContractedIn
- isScoreRuleOf
- isMemberOfCommittee
- isRelated
- hasGoal
- hasEducationLevel
- hasProcurementOwner
- livesIn
- isResidenceOf
- hasContractor
- hasPersonResponsible
- worksFor
- recievesProposal
- isRequirementOf
- isSuspendedForBiddingInPublicProcurements

PR-OWL 2.0 - Proof of Concept



MEBN Options

Knowledge Base | SSBN Algorithm

Available Knowledge Bases

✓ Protégé reasoners (for OWL2) Default

Parameters for the Knowledge Base

Available OWL2 Reasoners

Current reasoner

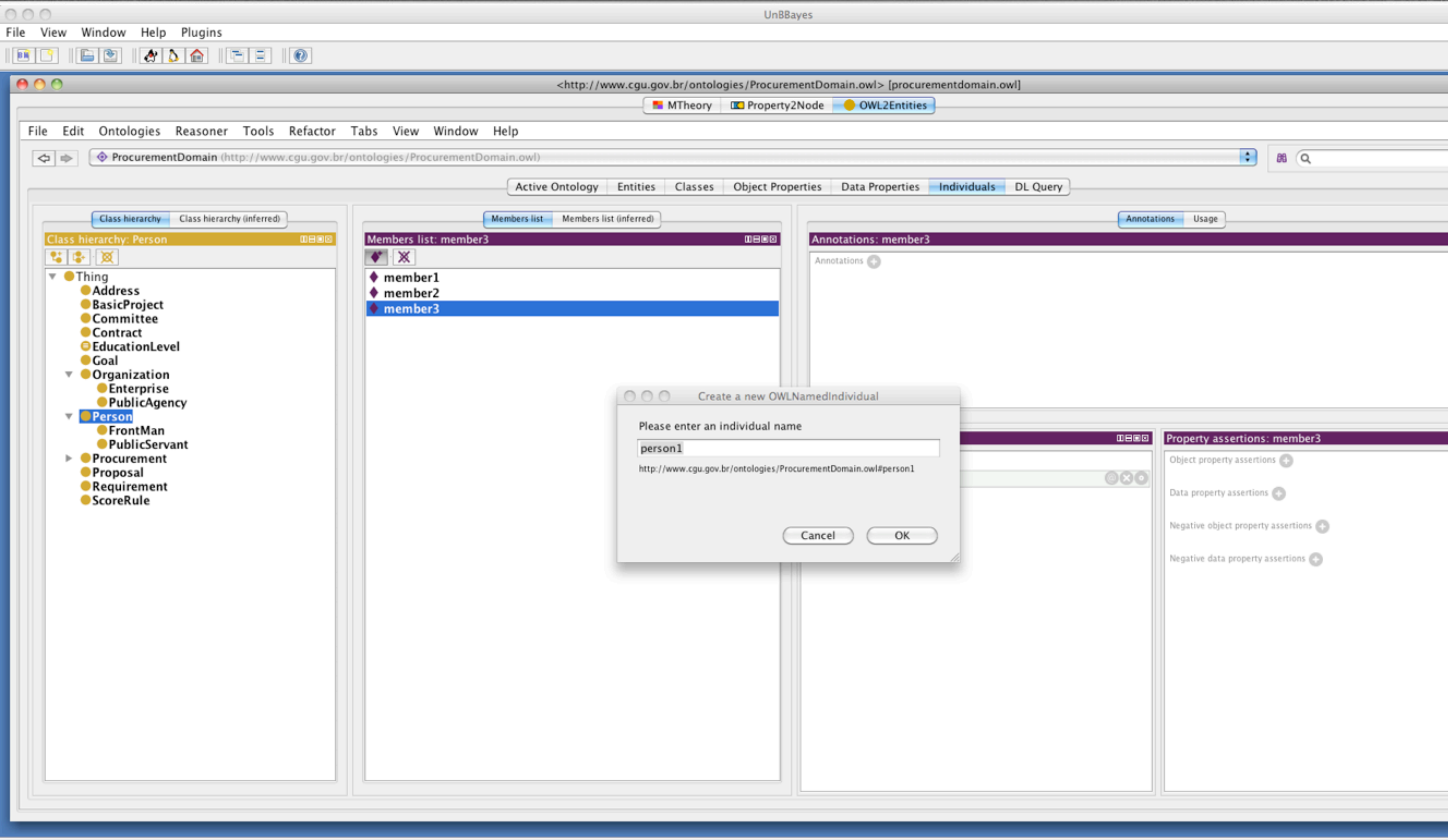
HermiT

Choose another reasoner

None

✓ HermiT 1.3.1

PR-OWL 2.0 - Proof of Concept


UnBBayes
File View Window Help Plugins
<http://www.cgu.gov.br/ontologies/ProcurementDomain.owl> [procurementdomain.owl]
MTheory
Property2Node
OWL2Entities
File Edit Ontologies Reasoner Tools Refactor Tabs View Window Help
ProcurementDomain (http://www.cgu.gov.br/ontologies/ProcurementDomain.owl)
Active Ontology
Entities
Classes
Object Properties
Data Properties
Individuals
DL Query
Class hierarchy
Class hierarchy (inferred)
Members list
Members list (inferred)
Annotations
Usage

Class hierarchy: Person

- Thing
  - Address
  - BasicProject
  - Committee
  - Contract
  - EducationLevel
  - Goal
  - Organization
    - Enterprise
    - PublicAgency
  - Person
    - FrontMan
    - PublicServant
  - Procurement
  - Proposal
  - Requirement
  - ScoreRule

Members list: member3

- member1
- member2
- member3

Annotations: member3

Annotations

Create a new OWLNamedIndividual

Please enter an individual name

person1

http://www.cgu.gov.br/ontologies/ProcurementDomain.owl#person1

Property assertions: member3

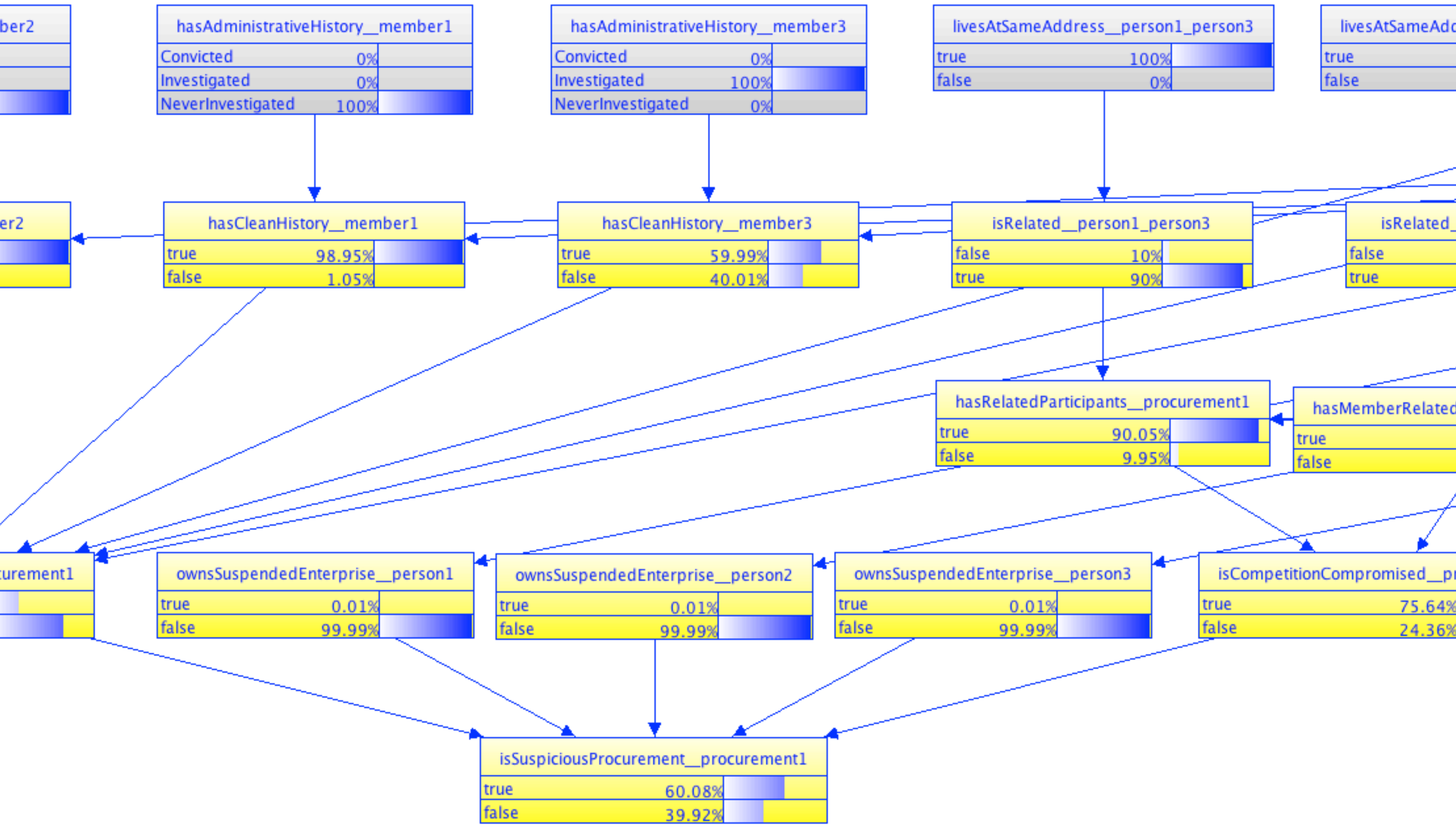
Object property assertions

Data property assertions

Negative object property assertions

Negative data property assertions

PR-OWL 2.0 - Proof of Concept



ber2

hasAdministrativeHistory__member1

Convicted	0%
Investigated	0%
NeverInvestigated	100%

hasAdministrativeHistory__member3

Convicted	0%
Investigated	100%
NeverInvestigated	0%

livesAtSameAddress__person1_person3

true	100%
false	0%

livesAtSameAdd

true
false

er2

hasCleanHistory__member1

true	98.95%
false	1.05%

hasCleanHistory__member3

true	59.99%
false	40.01%

isRelated__person1_person3

false	10%
true	90%

isRelated_

false
true

hasRelatedParticipants__procurement1

true	90.05%
false	9.95%

hasMemberRelated

true
false

curement1

ownsSuspendedEnterprise__person1

true	0.01%
false	99.99%

ownsSuspendedEnterprise__person2

true	0.01%
false	99.99%

ownsSuspendedEnterprise__person3

true	0.01%
false	99.99%

isCompetitionCompromised__pr

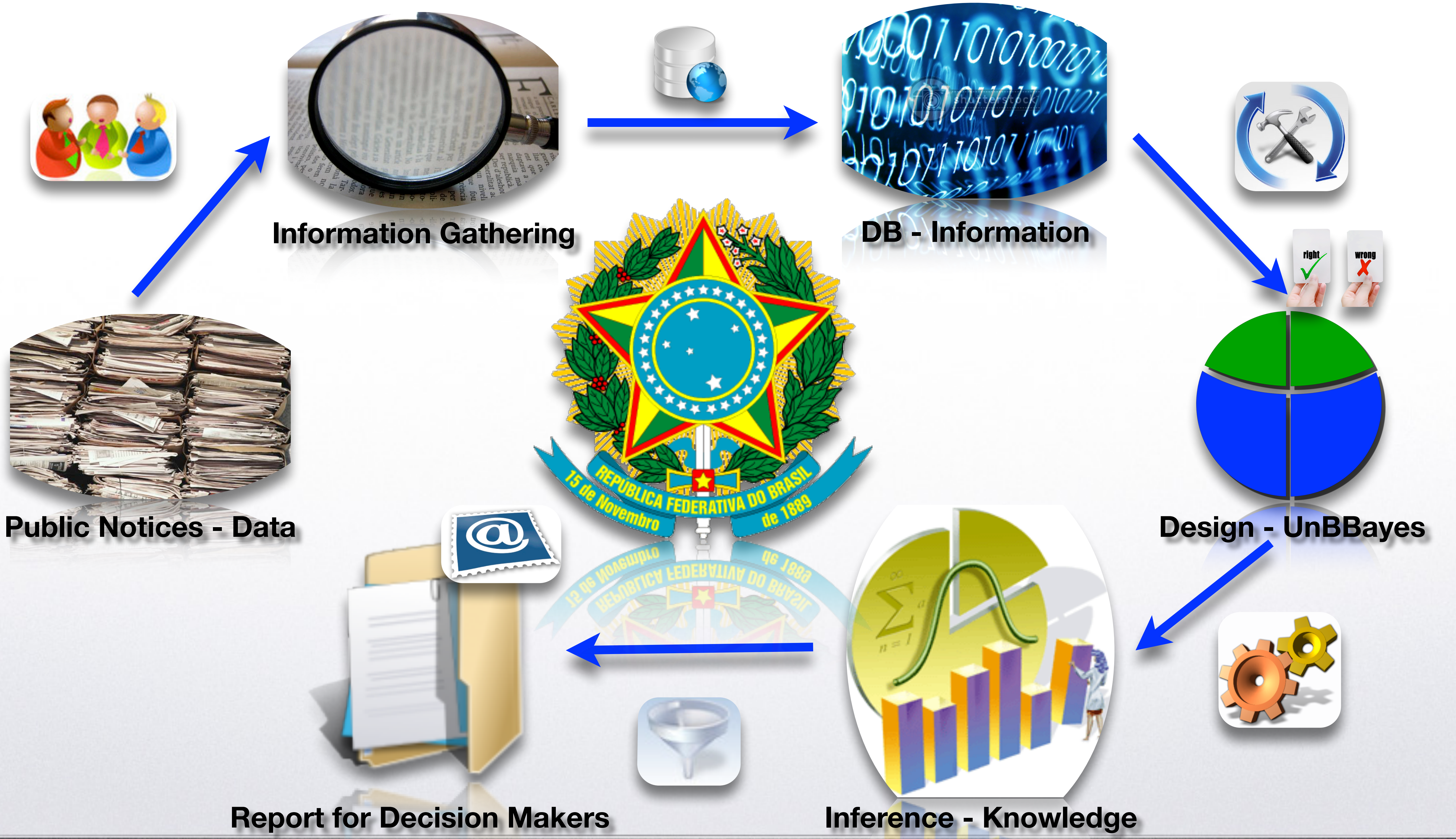
true	75.64%
false	24.36%

isSuspiciousProcurement__procurement1

true	60.08%
false	39.92%

2nd Major Contribution
Uncertainty Modeling Process for Semantic Technologies (UMP-ST)

How to build Probabilistic Ontologies?



Public Notices - Data

Information Gathering

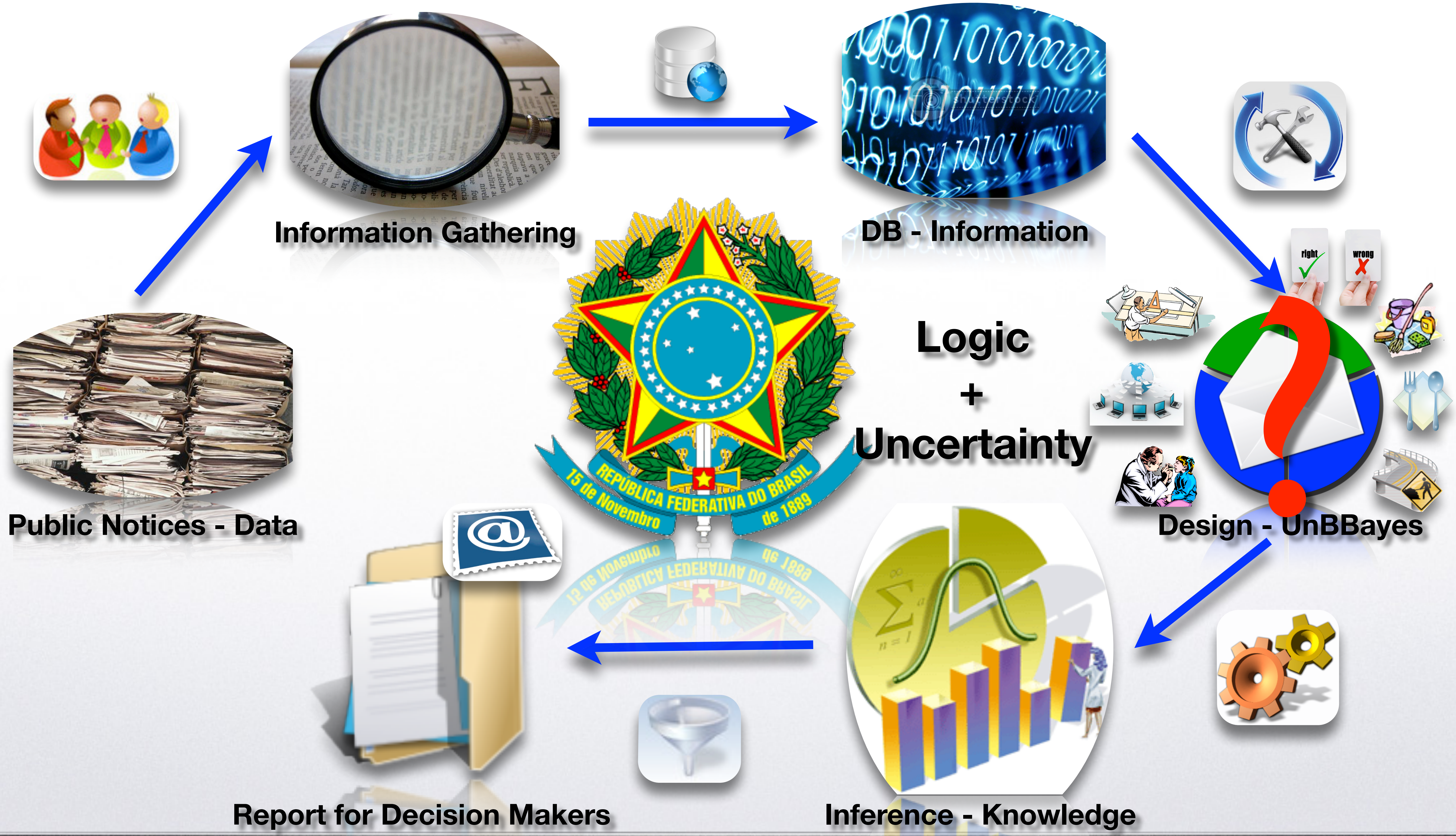
DB - Information

Design - UnBBayes

Inference - Knowledge

Report for Decision Makers

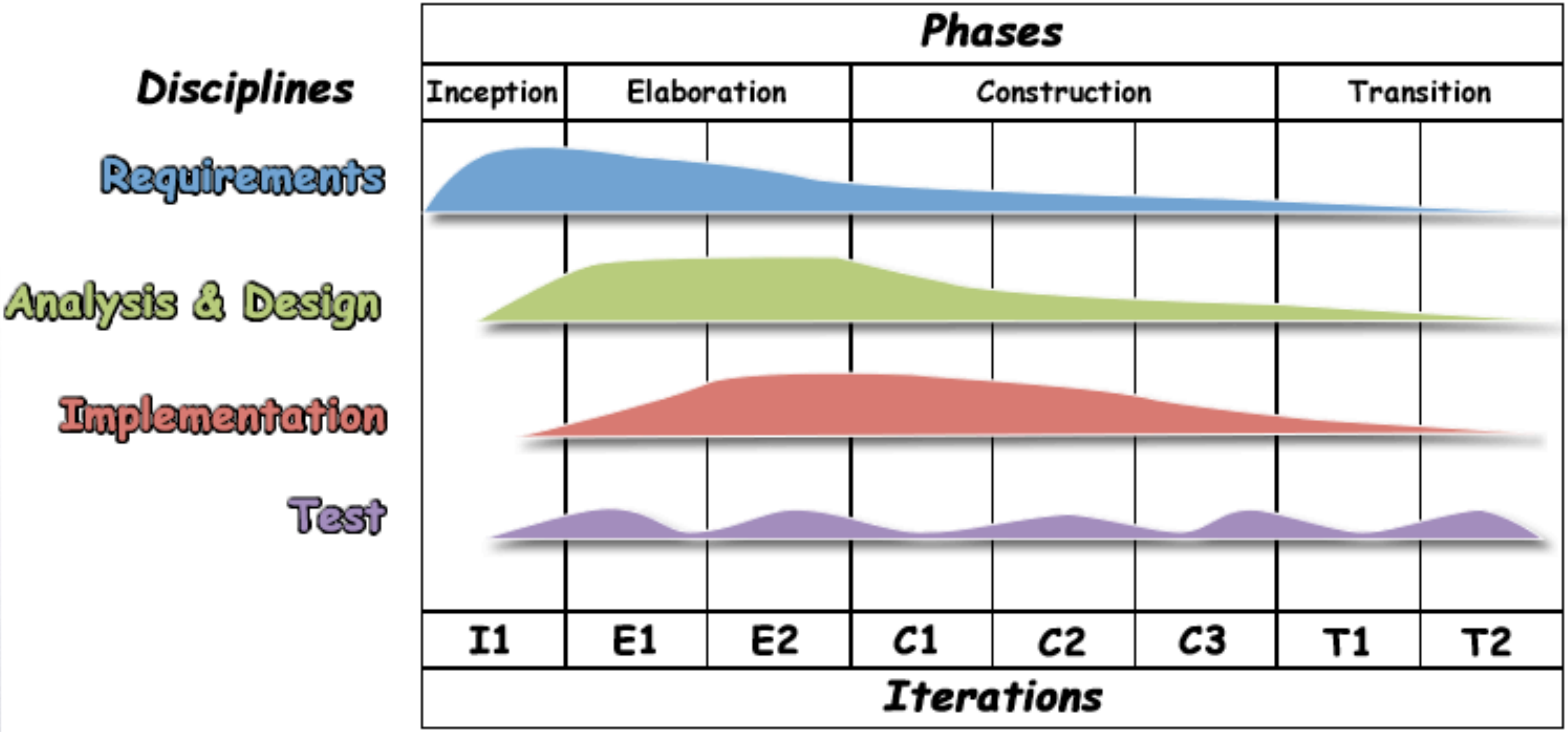
How to build Probabilistic Ontologies?



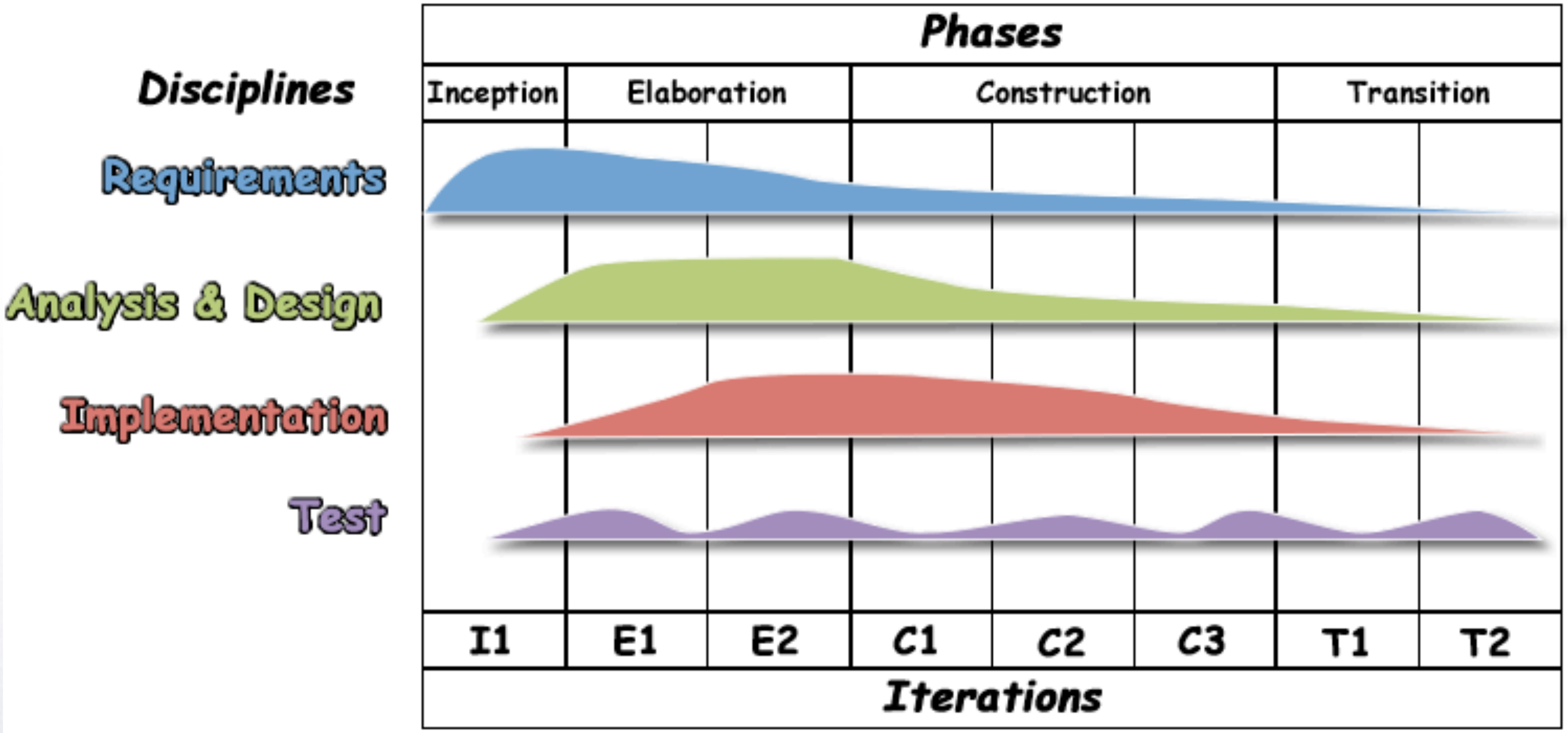
2nd Problem - Methodology

- There is now substantial literature about
  - what PR-OWL is [2, 4, 5],
  - how to implement it [6-9], and
  - where it can be used [10-15]
- There is an emerging literature on ontology engineering [4, 28]
- But, little has been written about
  - ***how to model a probabilistic ontology***
- This lack of methodology is not only associated with PR-OWL
  - OntoBayes [30], BayesOWL [31], P-SHIF(**D**) and P-SHOIN(**D**) [32], Markov Logic Network [33], Bayesian Logic [63], and Probabilistic Relation Models [64], amongst others, do not have a methodology for creating models

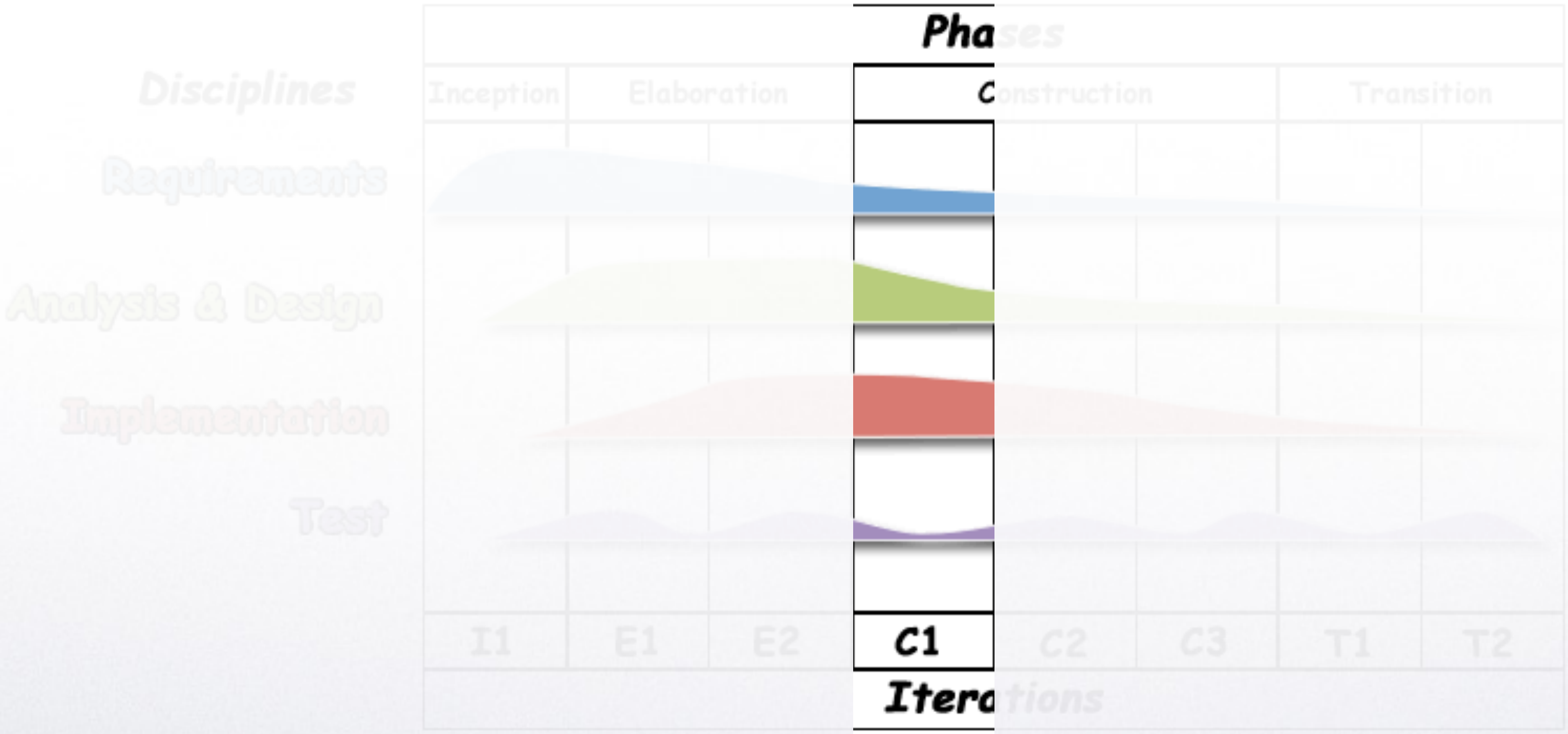
Methodology



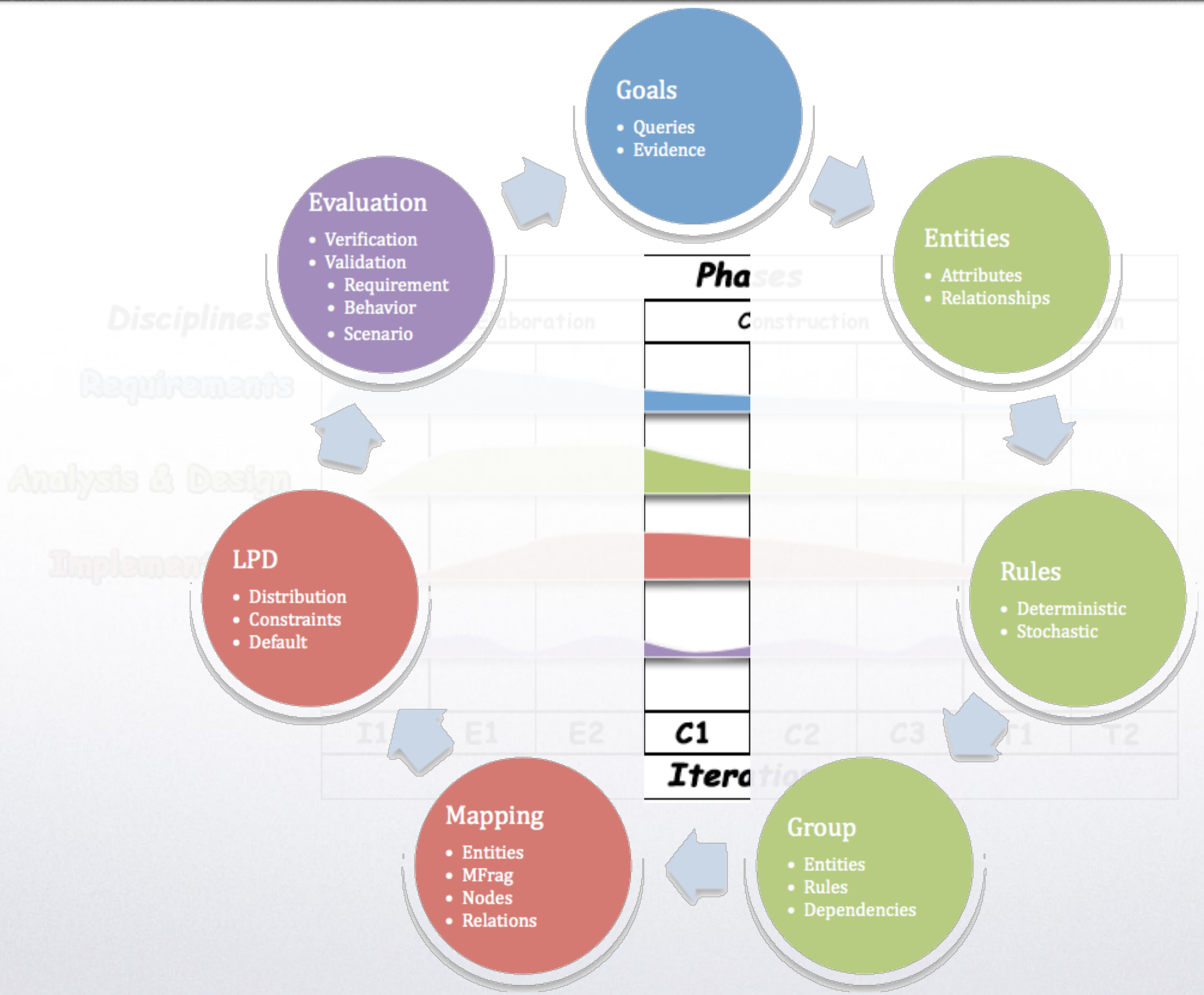
Modeling Cycle - Procurement Fraud



Modeling Cycle - Procurement Fraud



Modeling Cycle - Procurement Fraud



Goals
- Queries
- Evidence

Entities
- Attributes
- Relationships

Rules
- Deterministic
- Stochastic

Group
- Entities
- Rules
- Dependencies

Mapping
- Entities
- MFrag
- Nodes
- Relations

LPD
- Distribution
- Constraints
- Default

Evaluation
- Verification
- Validation
  - Requirement
  - Behavior
  - Scenario

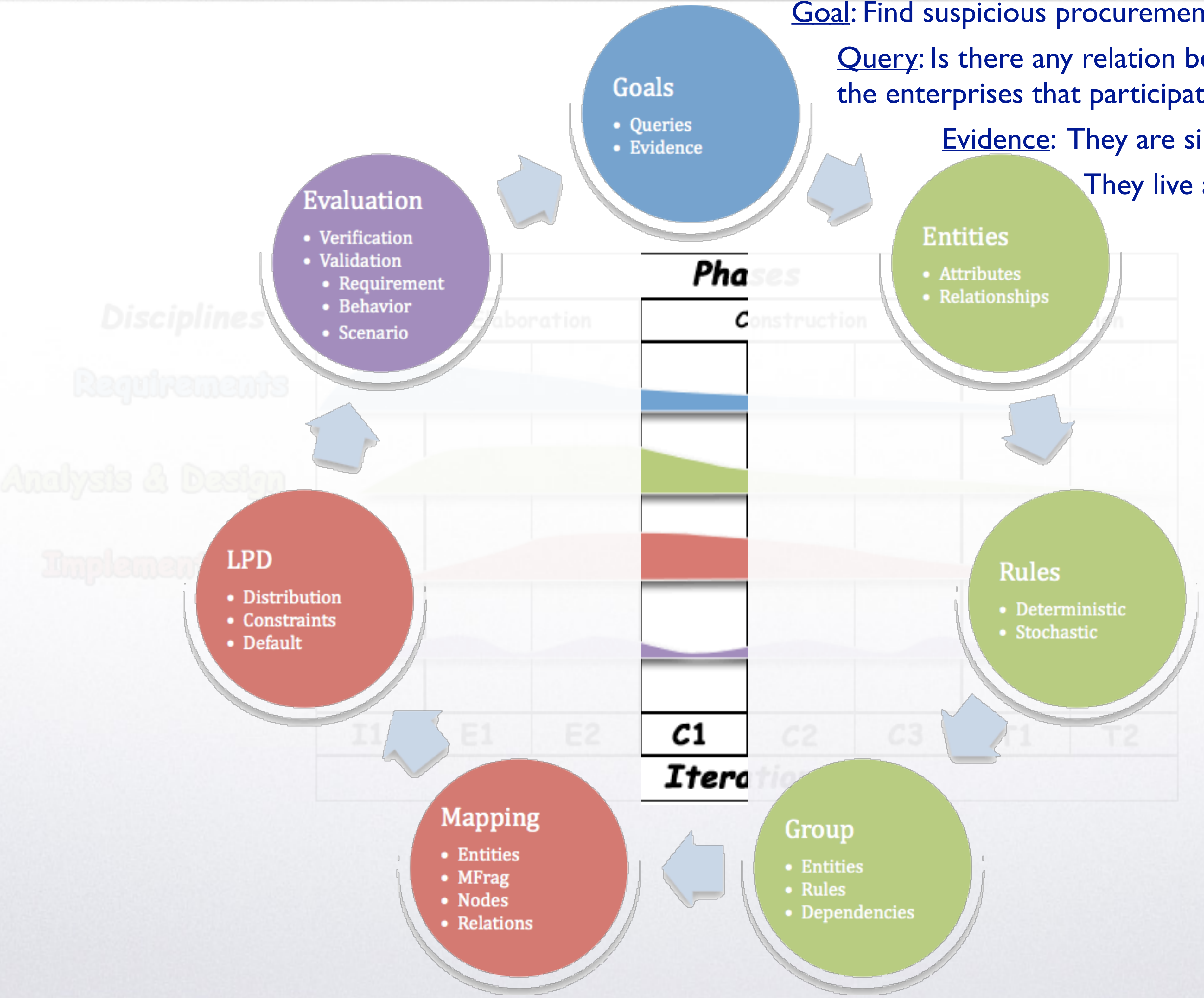
Modeling Cycle - Procurement Fraud

Goal: Find suspicious procurements

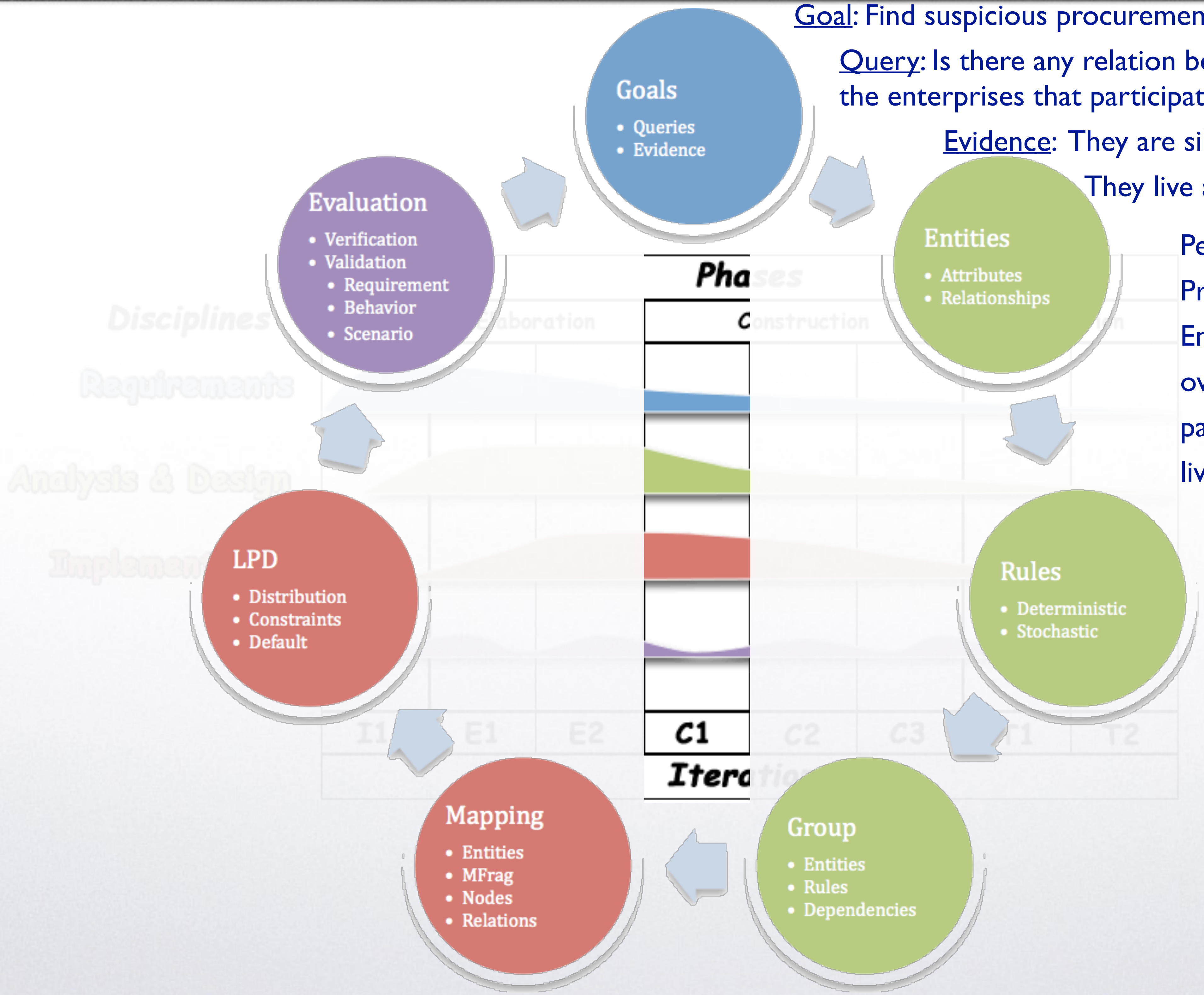
Query: Is there any relation between the committee and the enterprises that participated in the procurement?

Evidence: They are siblings

They live at the same address



Modeling Cycle - Procurement Fraud



Goal: Find suspicious procurements

Query: Is there any relation between the committee and the enterprises that participated in the procurement?

Evidence: They are siblings

They live at the same address

Person

Procurement

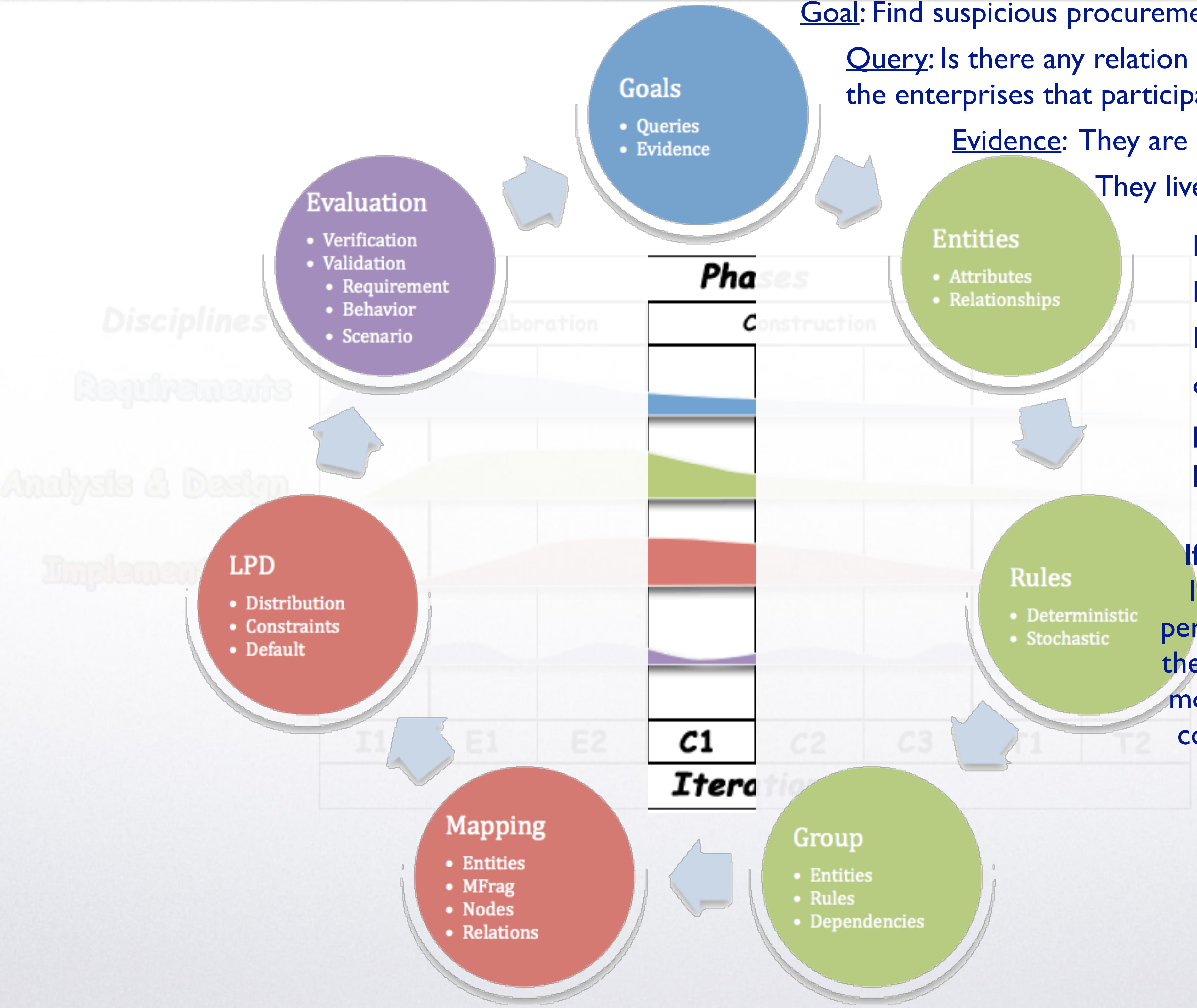
Enterprise

ownerOf

participatesIn

livesAt

Modeling Cycle - Procurement Fraud



Goals
- Queries
- Evidence

Entities
- Attributes
- Relationships

Rules
- Deterministic
- Stochastic

Group
- Entities
- Rules
- Dependencies

Mapping
- Entities
- MFrag
- Nodes
- Relations

LPD
- Distribution
- Constraints
- Default

Evaluation
- Verification
- Validation
  - Requirement
  - Behavior
  - Scenario

Goal: Find suspicious procurements

Query: Is there any relation between the committee and the enterprises that participated in the procurement?

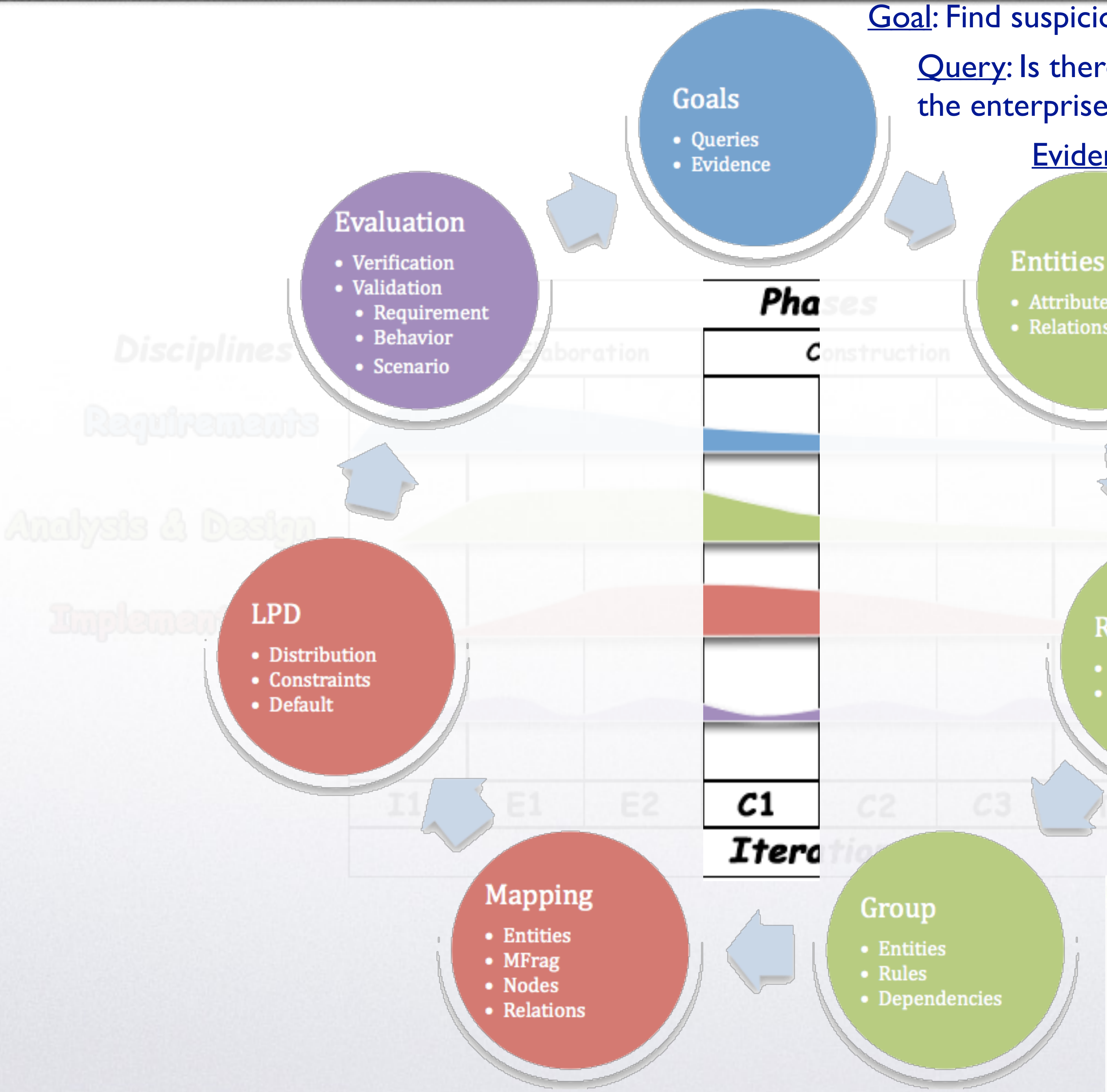
Evidence: They are siblings

They live at the same address

Person
Procurement
Enterprise
ownerOf
participatesIn
livesAt

If a member of the committee lives at the same address as a person responsible for a bidder in the procurement, a relationship is more likely to exist between the committee and the enterprises, which lowers competition.

Modeling Cycle - Procurement Fraud



Goal: Find suspicious procurements

Query: Is there any relation between the committee and the enterprises that participated in the procurement?

Evidence: They are siblings

They live at the same address

Person

Procurement

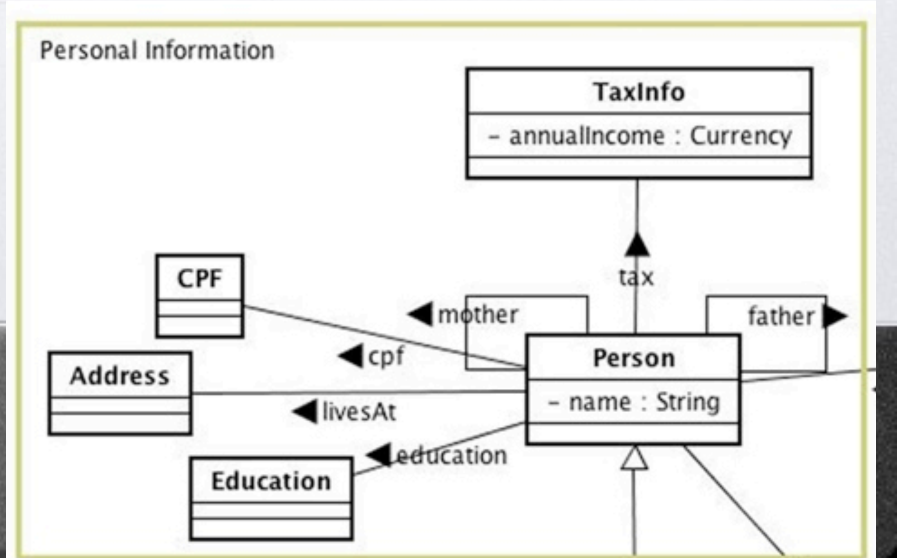
Enterprise

ownerOf

participatesIn

livesAt

If a member of the committee lives at the same address as a person responsible for a bidder in the procurement, a relationship is more likely to exist between the committee and the enterprises, which lowers competition.



Modeling Cycle - Procurement Fraud

Goal: Find suspicious procurements

Query: Is there any relation between the committee and the enterprises that participated in the procurement?

Evidence: They are siblings

They live at the same address

Person

Procurement

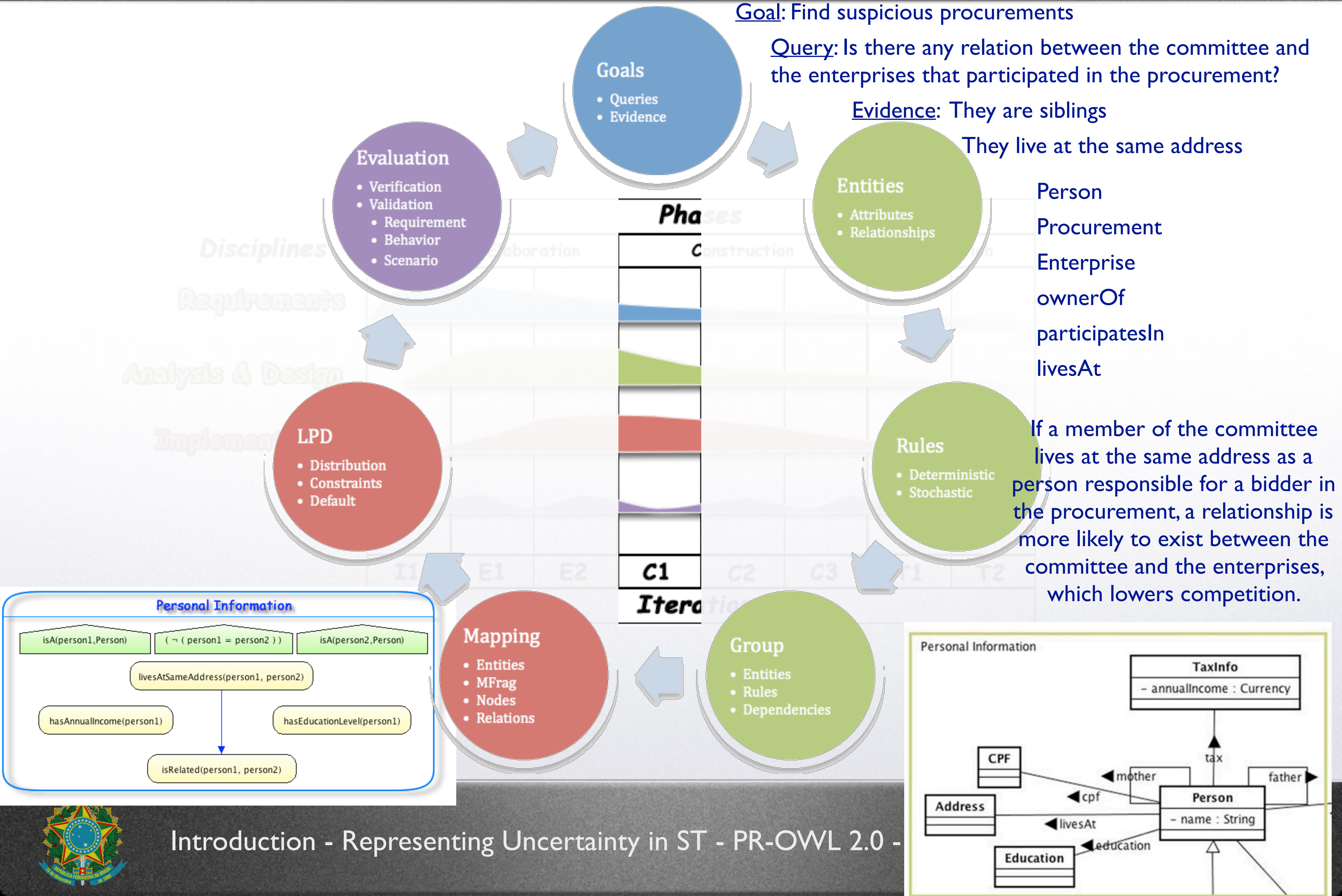
Enterprise

ownerOf

participatesIn

livesAt

If a member of the committee lives at the same address as a person responsible for a bidder in the procurement, a relationship is more likely to exist between the committee and the enterprises, which lowers competition.



Personal Information

isA(person1,Person)

(¬ (person1 = person2))

isA(person2,Person)

livesAtSameAddress(person1, person2)

hasAnnualIncome(person1)

hasEducationLevel(person1)

isRelated(person1, person2)

Personal Information

Modeling Cycle - Procurement Fraud

Goal: Find suspicious procurements

Query: Is there any relation between the committee and the enterprises that participated in the procurement?

Evidence: They are siblings

They live at the same address

Person

Procurement

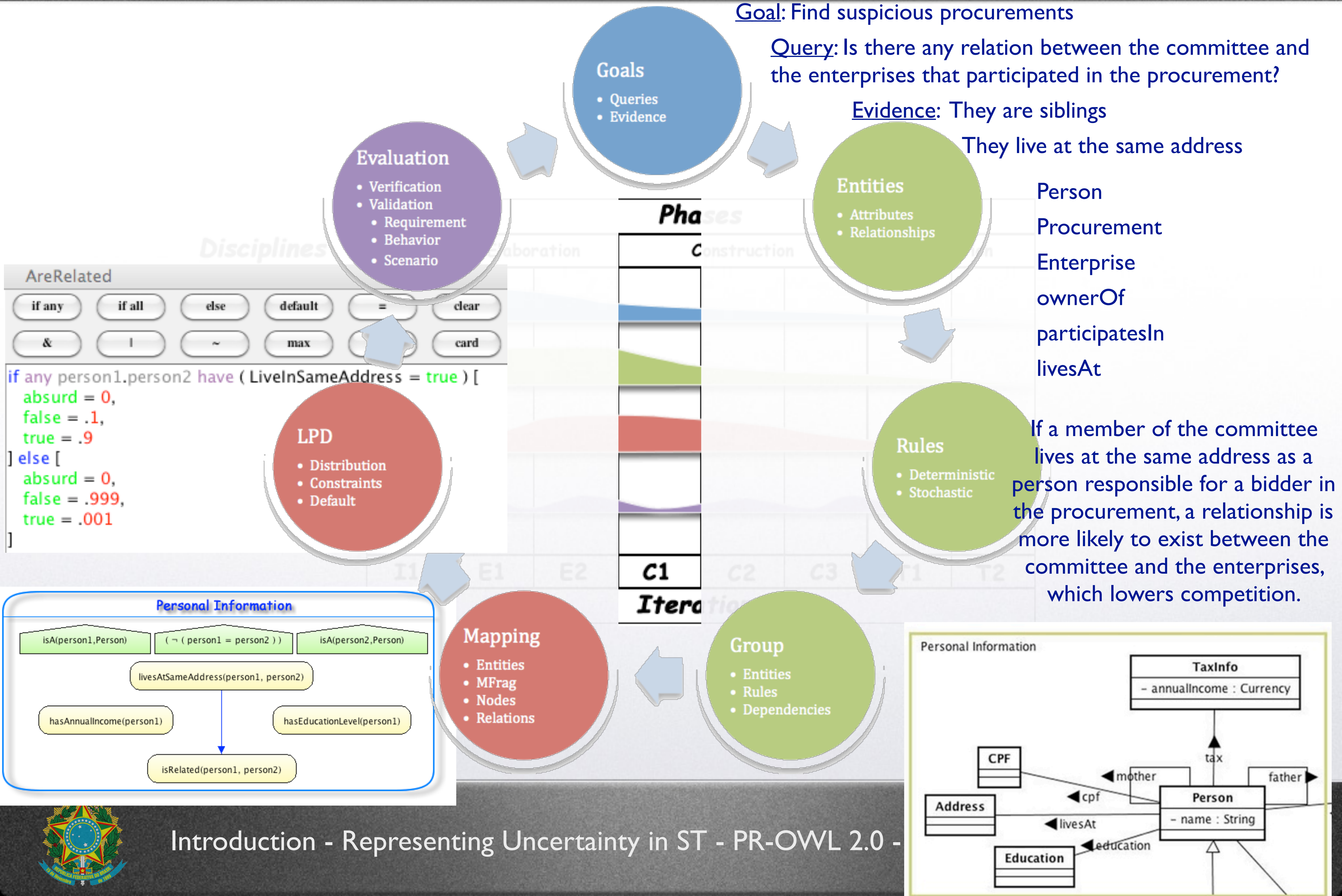
Enterprise

ownerOf

participatesIn

livesAt

If a member of the committee lives at the same address as a person responsible for a bidder in the procurement, a relationship is more likely to exist between the committee and the enterprises, which lowers competition.



```
if any person1.person2 have ( LiveInSameAddress = true ) [
  absurd = 0,
  false = .1,
  true = .9
] else [
  absurd = 0,
  false = .999,
  true = .001
]
```

Modeling Cycle - Procurement Fraud

Goal: Find suspicious procurements

Query: Is there any relation between the committee and the enterprises that participated in the procurement?

Evidence: They are siblings

They live at the same address

Person

Procurement

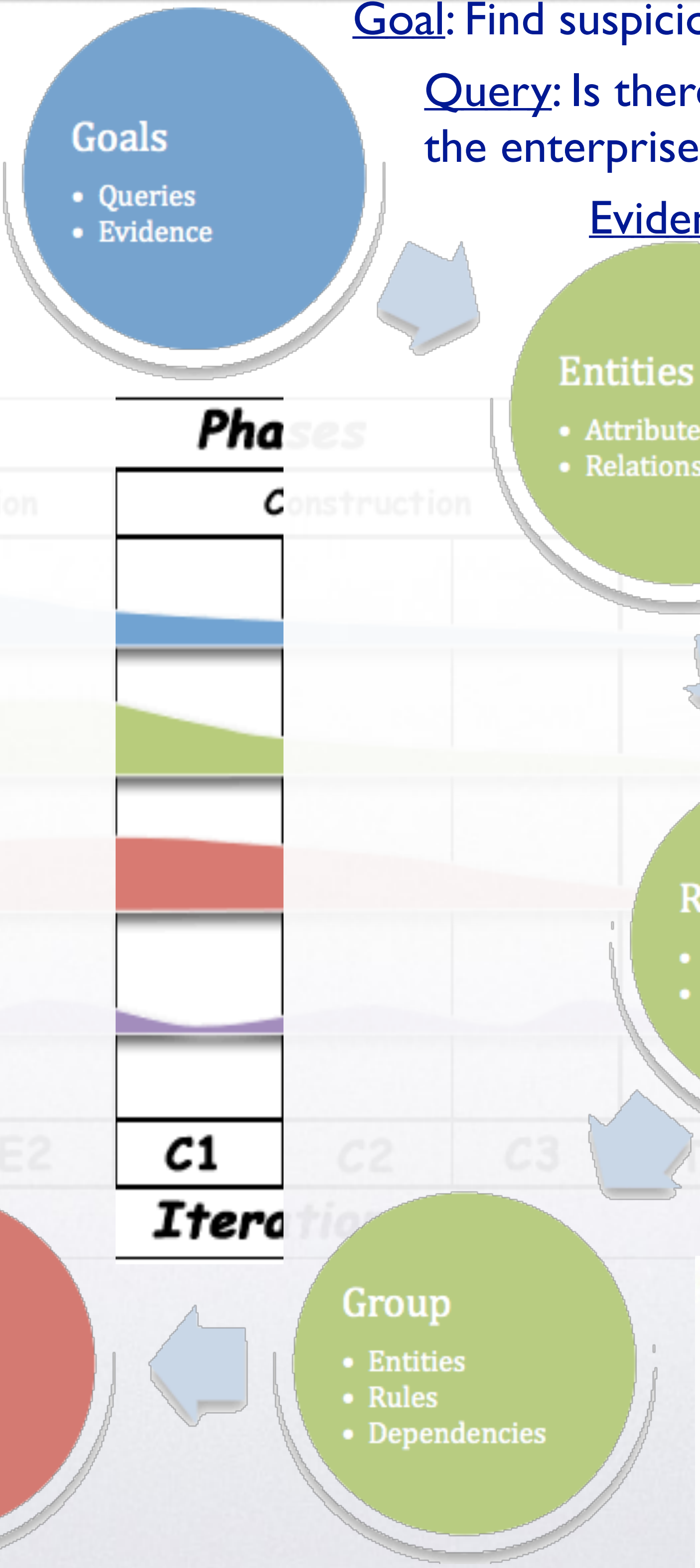
Enterprise

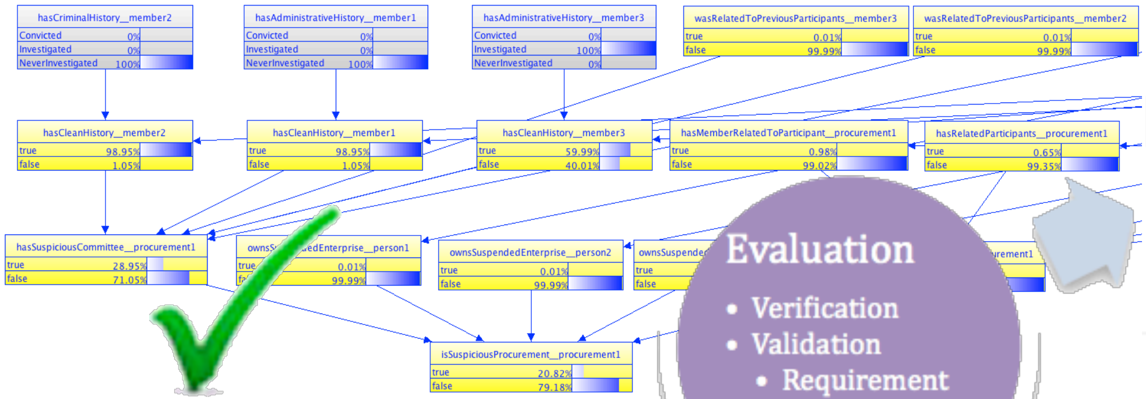
ownerOf

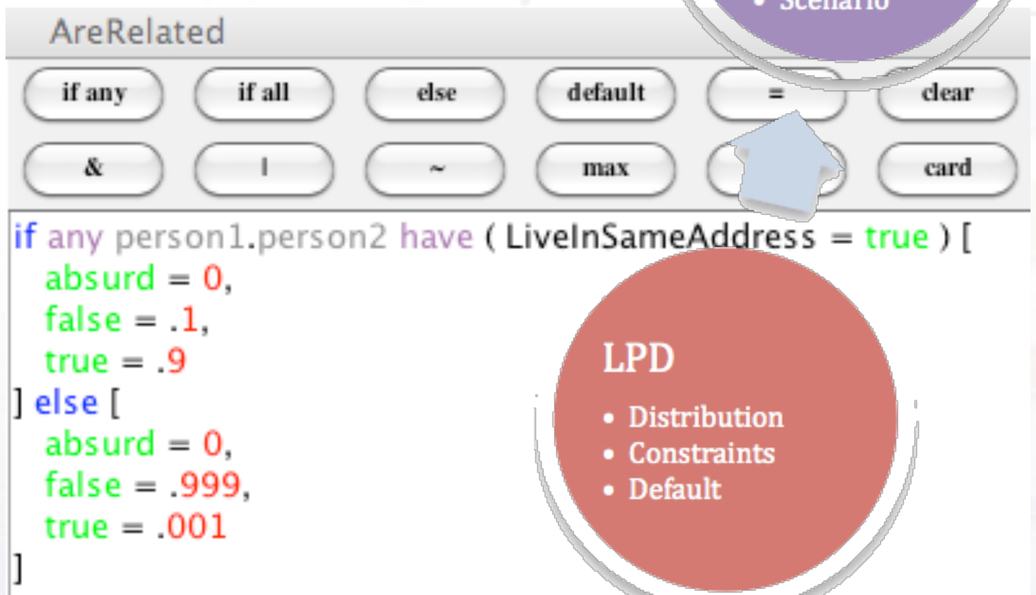
participatesIn

livesAt

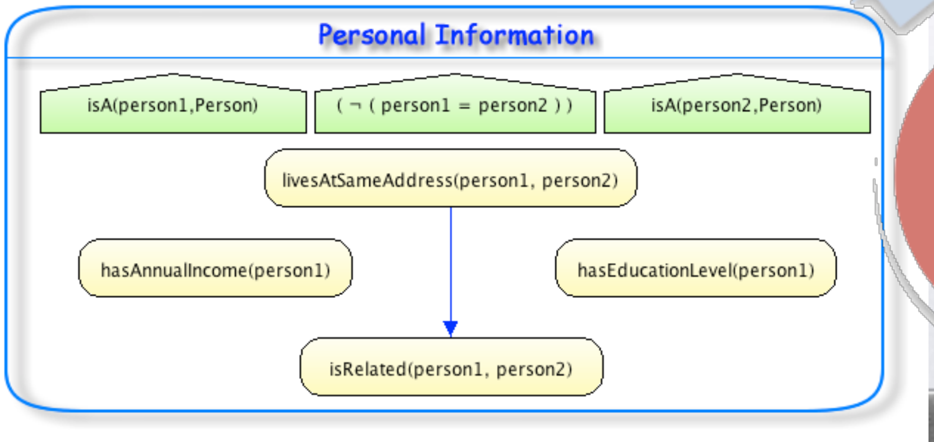
If a member of the committee lives at the same address as a person responsible for a bidder in the procurement, a relationship is more likely to exist between the committee and the enterprises, which lowers competition.

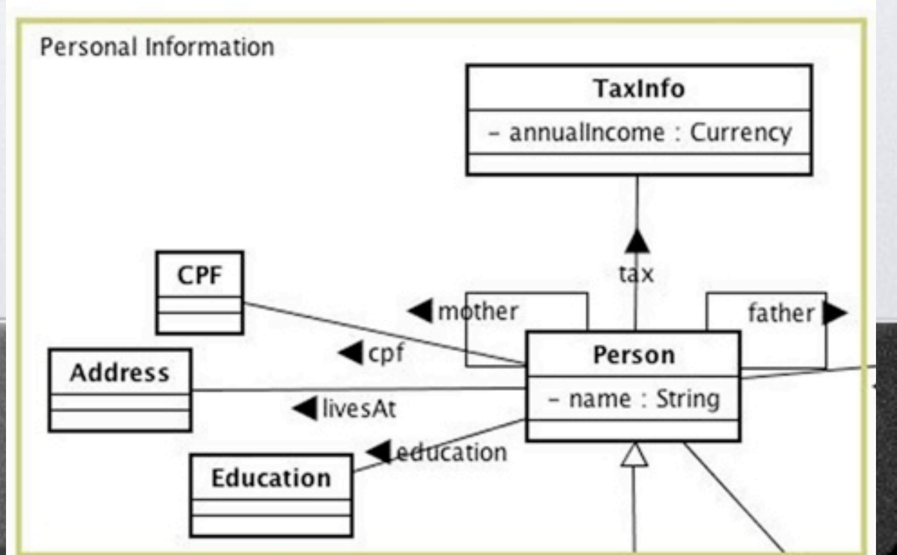






```
if any person1.person2 have ( LiveInSameAddress = true ) [
  absurd = 0,
  false = .1,
  true = .9
] else [
  absurd = 0,
  false = .999,
  true = .001
]
```


Personal Information
isA(person1,Person)
(¬ (person1 = person2))
isA(person2,Person)
livesAtSameAddress(person1, person2)
hasAnnualIncome(person1)
hasEducationLevel(person1)
isRelated(person1, person2)

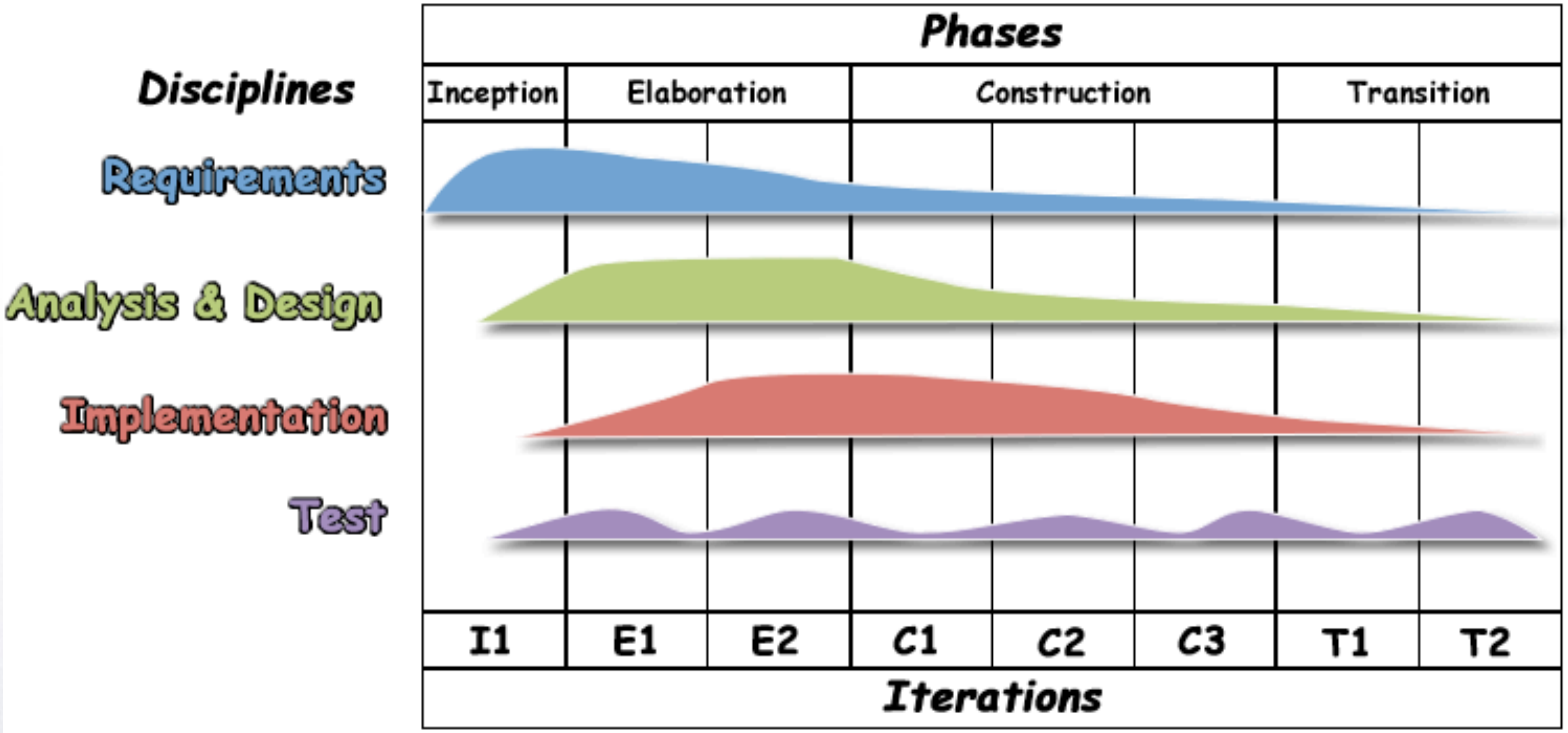


Evaluation - Procurement Fraud

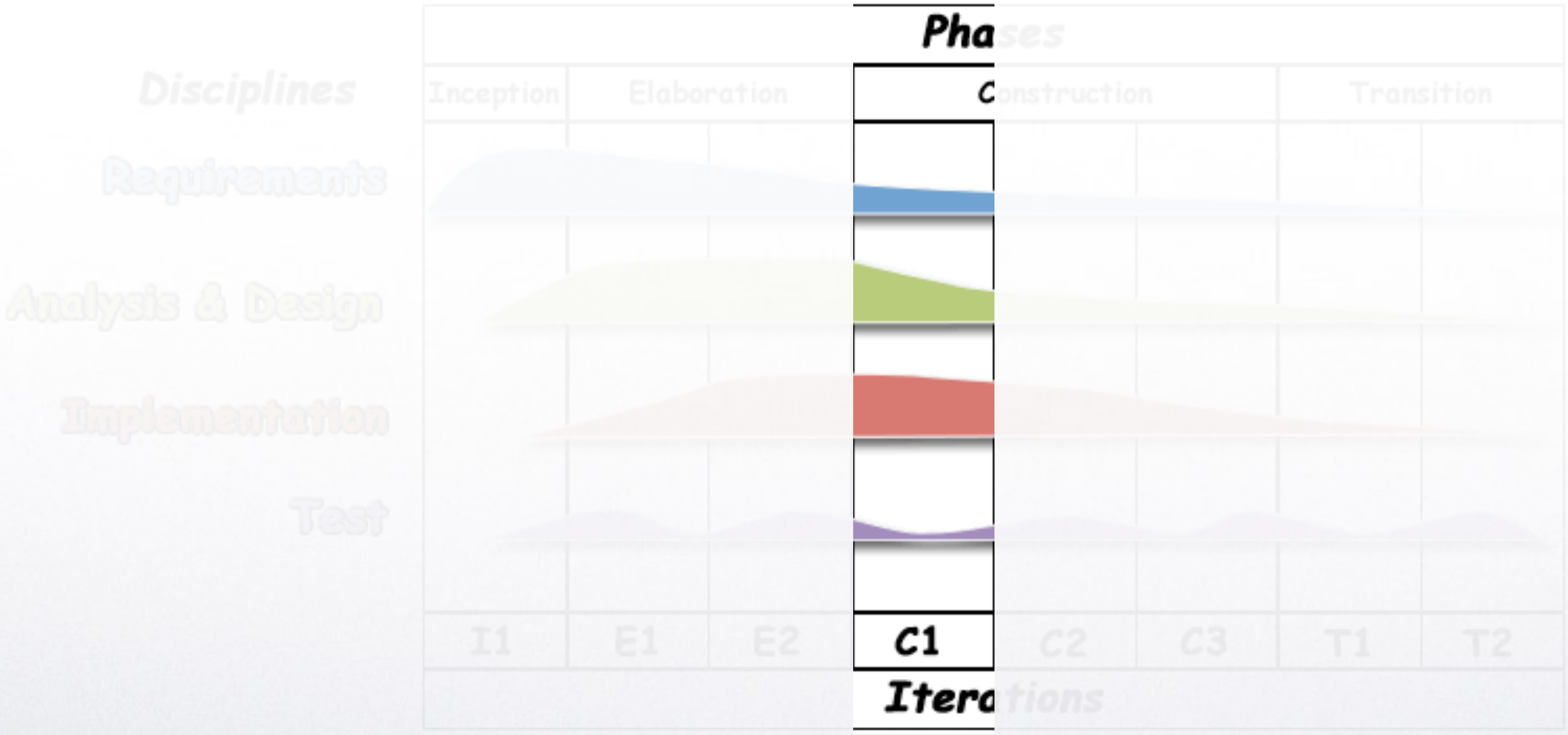
- Case-based evaluation (integration test / scenarios)

Scenario	Hypothesis (H)	Evidence (E)	Expected Result	Result
1	(a) isSuspiciousProcurement(procurement) (b) isSuspiciousCommittee(pro	...does not support hypothesis...	(a) Low probability that P(H = true | E) (b) Low probability that P(H = true | E)	(a) P(H = true | E) = 2.35% (b) P(H = true | E) = 2.33%
2	(a) isSuspiciousProcurement(procurement) (b) isSuspiciousCommittee(pro	...does and does not support hypothesis... ...conflicting information...	(a) 10% < P(H = true | E) < 50% (b) 10% < P(H = true | E) < 50%	(a) P(H = true | E) = 20.82% (b) P(H = true | E) = 28.95%
3	(a) isSuspiciousProcurement(procurement) (b) isSuspiciousCommittee(pro	...support hypothesis...	(a) P(H = true | E) > 50% (b) 10% < P(H = true | E) < 50%	(a) P(H = true | E) = 60.08% (b) P(H = true | E) = 28.95%

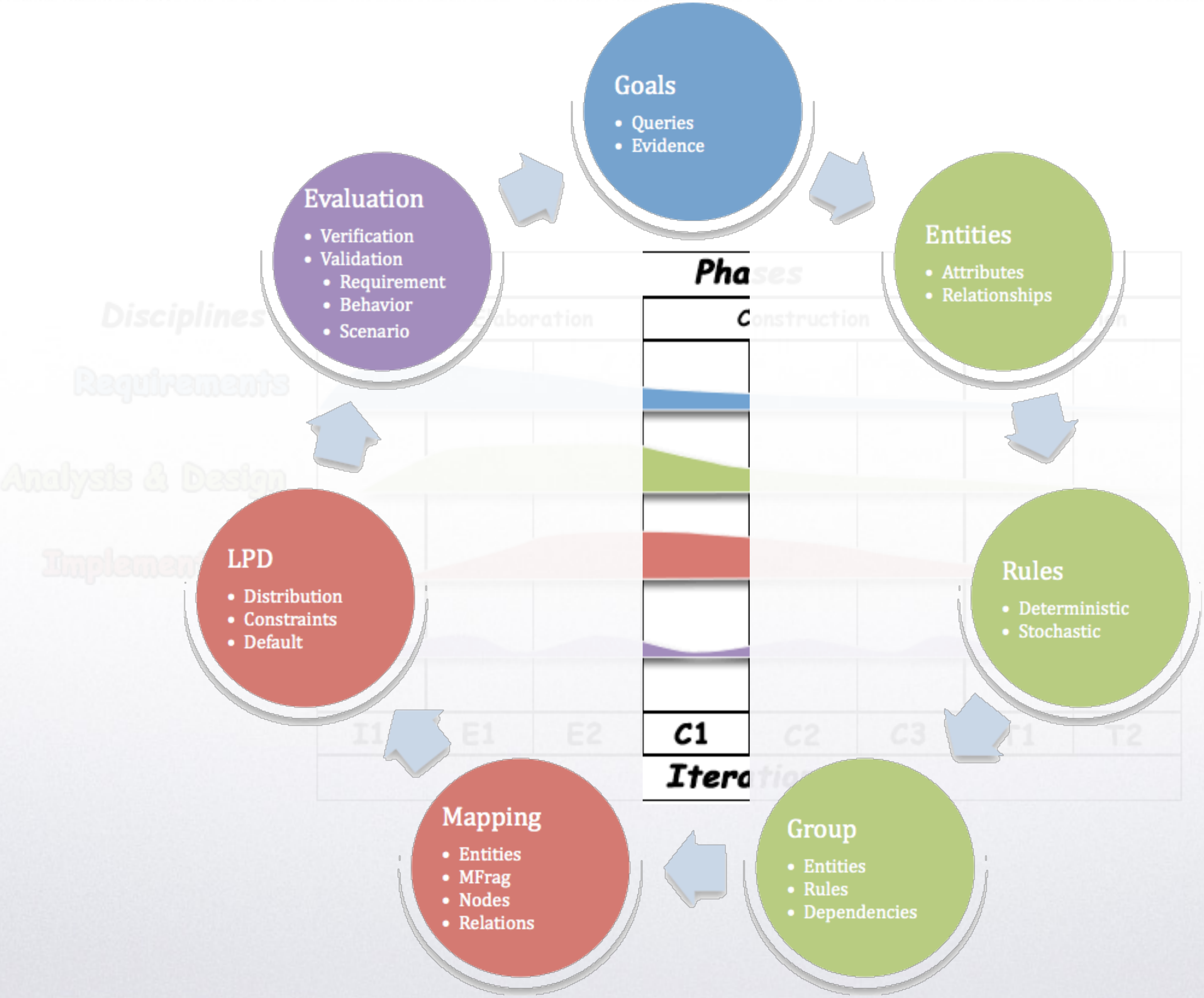
Modeling Cycle - MDA



Modeling Cycle - MDA



Modeling Cycle - MDA



Goals
- Queries
- Evidence

Entities
- Attributes
- Relationships

Rules
- Deterministic
- Stochastic

Group
- Entities
- Rules
- Dependencies

Mapping
- Entities
- MFrag
- Nodes
- Relations

LPD
- Distribution
- Constraints
- Default

Evaluation
- Verification
- Validation
  - Requirement
  - Behavior
  - Scenario

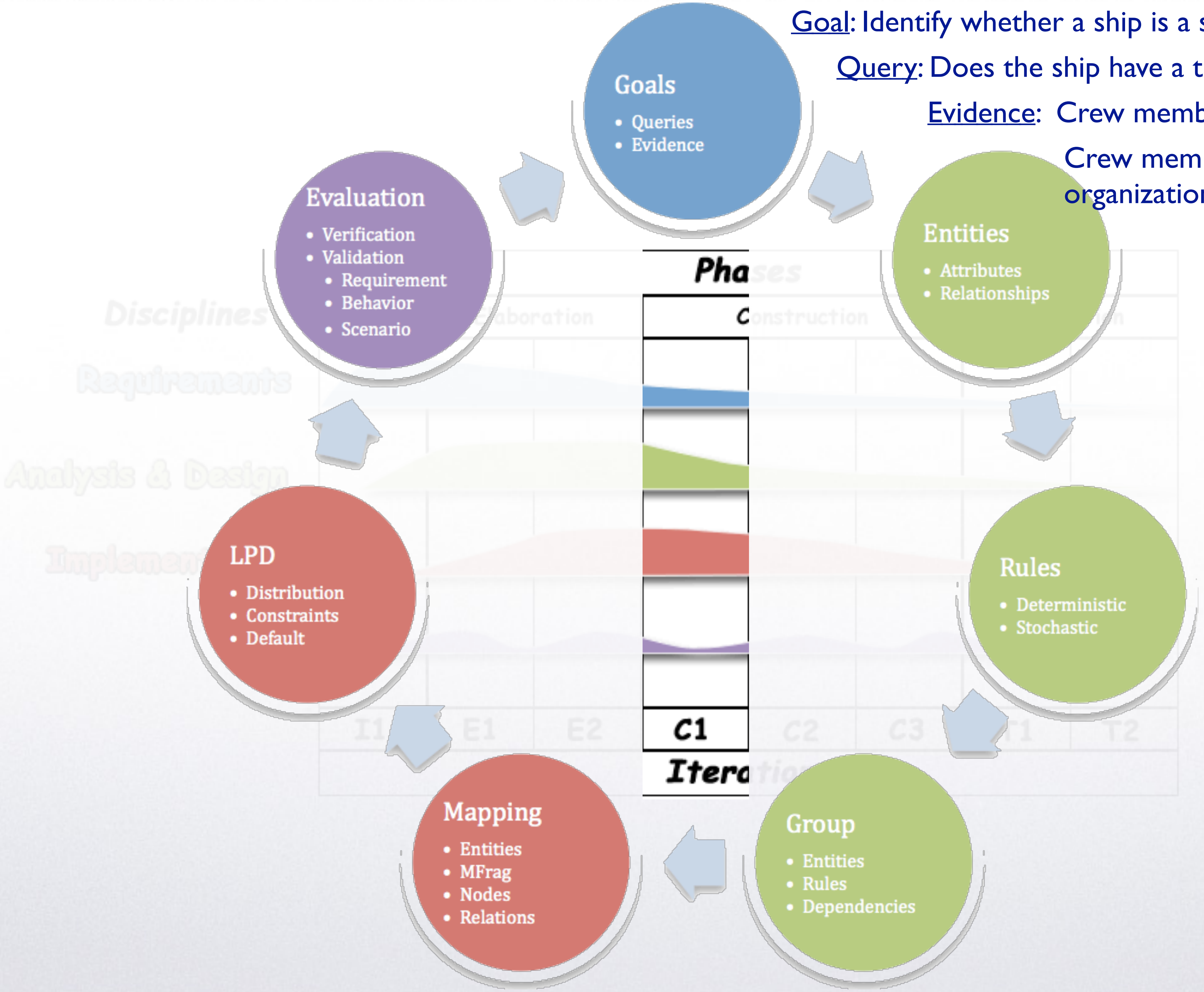
Modeling Cycle - MDA

Goal: Identify whether a ship is a ship of interest

Query: Does the ship have a terrorist crew member?

Evidence: Crew member related to any terrorist;

Crew member associated with terrorist organization



Goals
- Queries
- Evidence

Entities
- Attributes
- Relationships

Rules
- Deterministic
- Stochastic

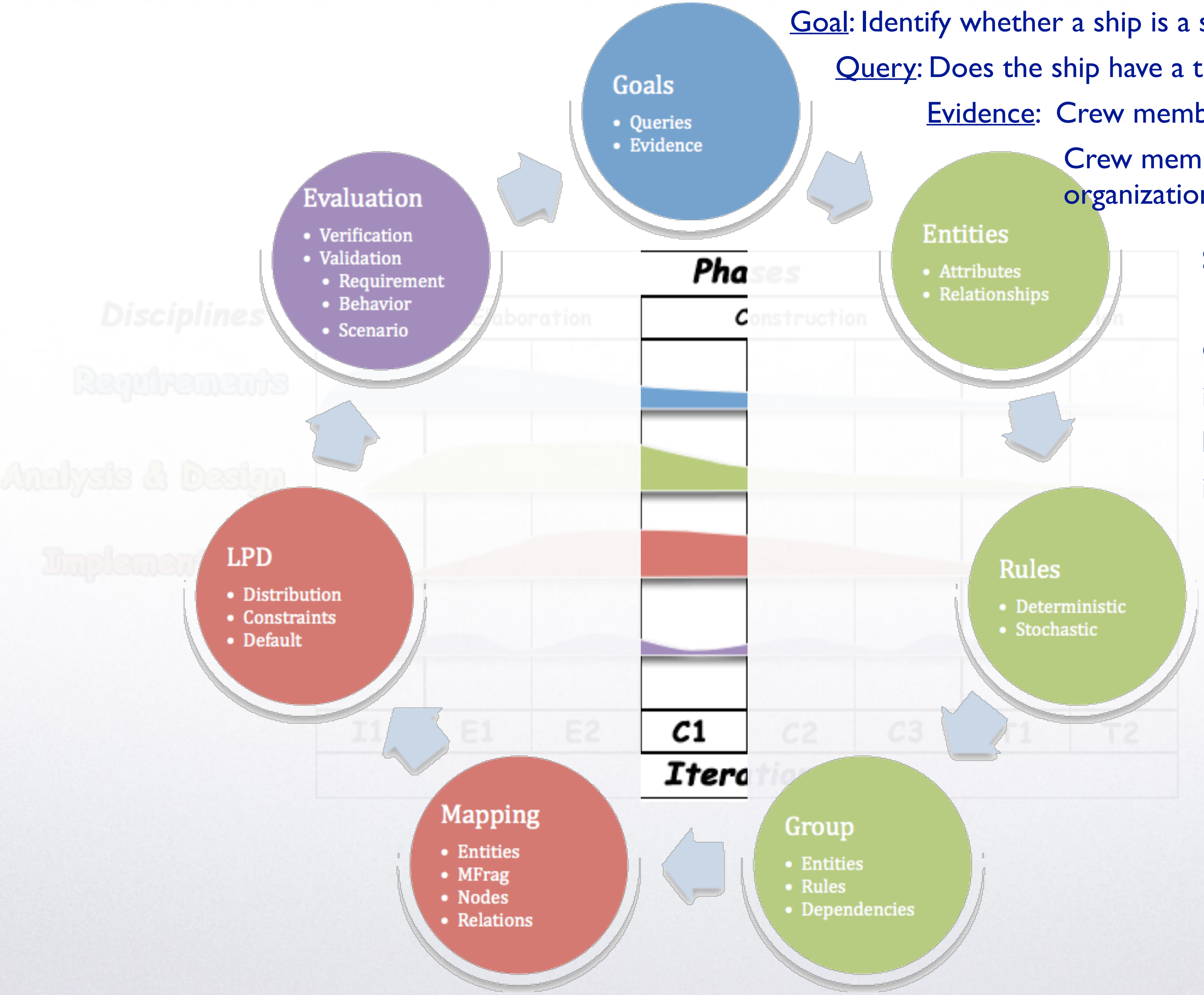
Group
- Entities
- Rules
- Dependencies

Mapping
- Entities
- MFrag
- Nodes
- Relations

LPD
- Distribution
- Constraints
- Default

Evaluation
- Verification
- Validation
  - Requirement
  - Behavior
  - Scenario

Modeling Cycle - MDA



Goal: Identify whether a ship is a ship of interest

Query: Does the ship have a terrorist crew member?

Evidence: Crew member related to any terrorist;

Crew member associated with terrorist organization

Ship

Person

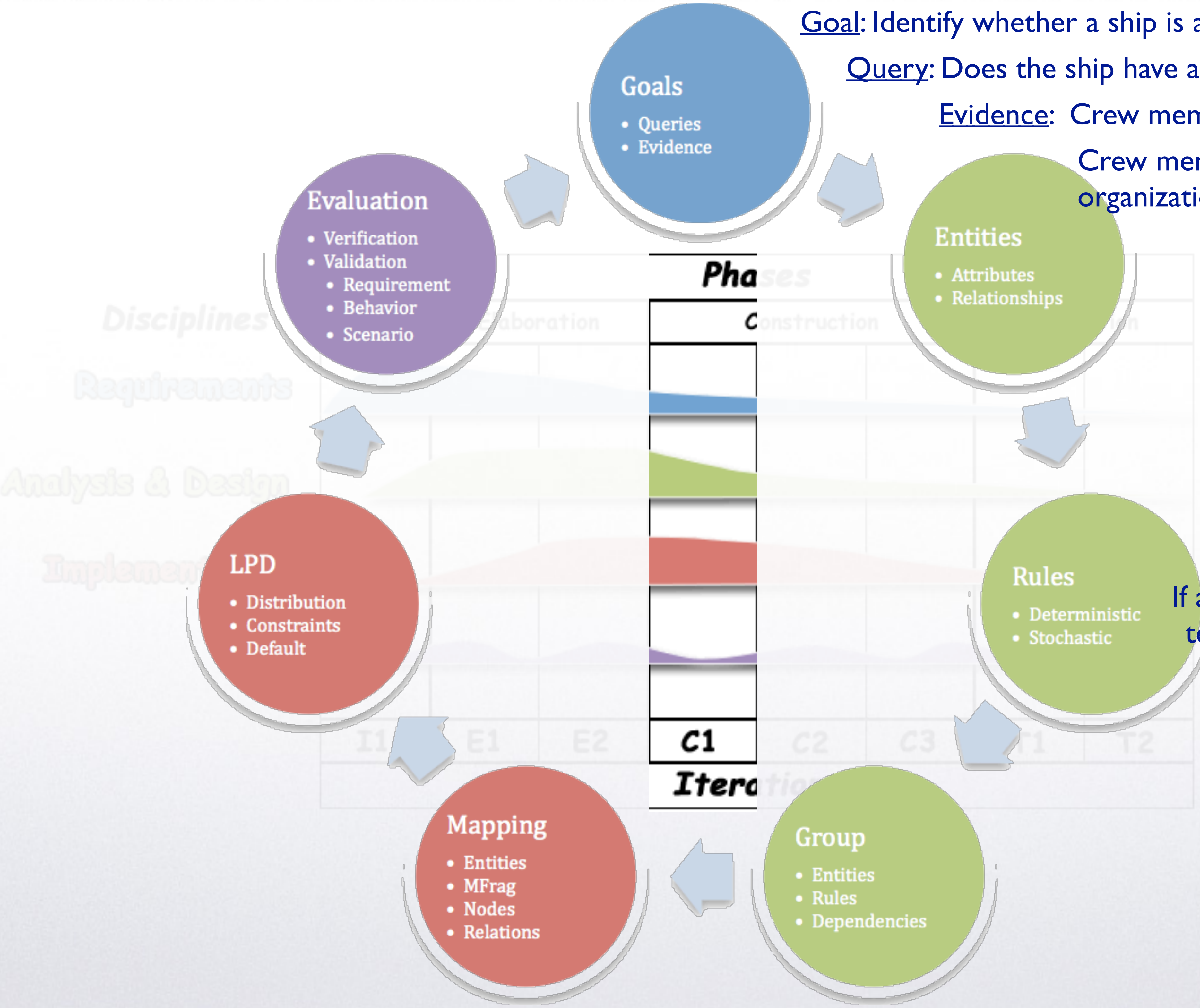
Organization

isTerroristPerson

hasCrewMember

isRelatedTo

Modeling Cycle - MDA



Goal: Identify whether a ship is a ship of interest

Query: Does the ship have a terrorist crew member?

Evidence: Crew member related to any terrorist;

Crew member associated with terrorist organization

Ship

Person

Organization

isTerroristPerson

hasCrewMember

isRelatedTo

If a crew member is related to a terrorist, then it is more likely that he is also a terrorist

Modeling Cycle - MDA

Goal: Identify whether a ship is a ship of interest

Query: Does the ship have a terrorist crew member?

Evidence: Crew member related to any terrorist;

Crew member associated with terrorist organization

Ship

Person

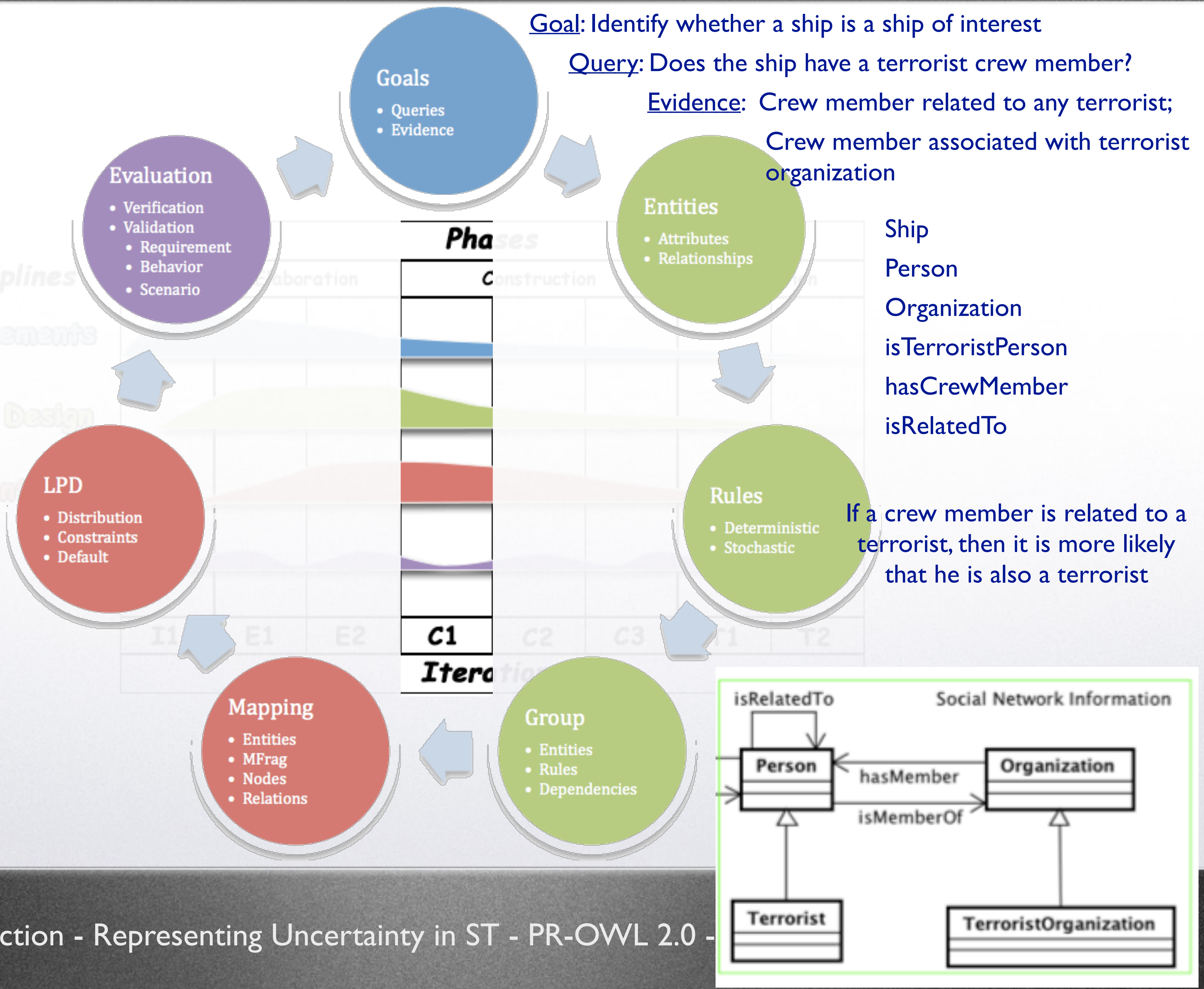
Organization

isTerroristPerson

hasCrewMember

isRelatedTo

If a crew member is related to a terrorist, then it is more likely that he is also a terrorist



Modeling Cycle - MDA

<u>Goal</u>: Identify whether a ship is a ship of interest

<u>Query</u>: Does the ship have a terrorist crew member?

<u>Evidence</u>: Crew member related to any terrorist;

Crew member associated with terrorist organization

Ship

Person

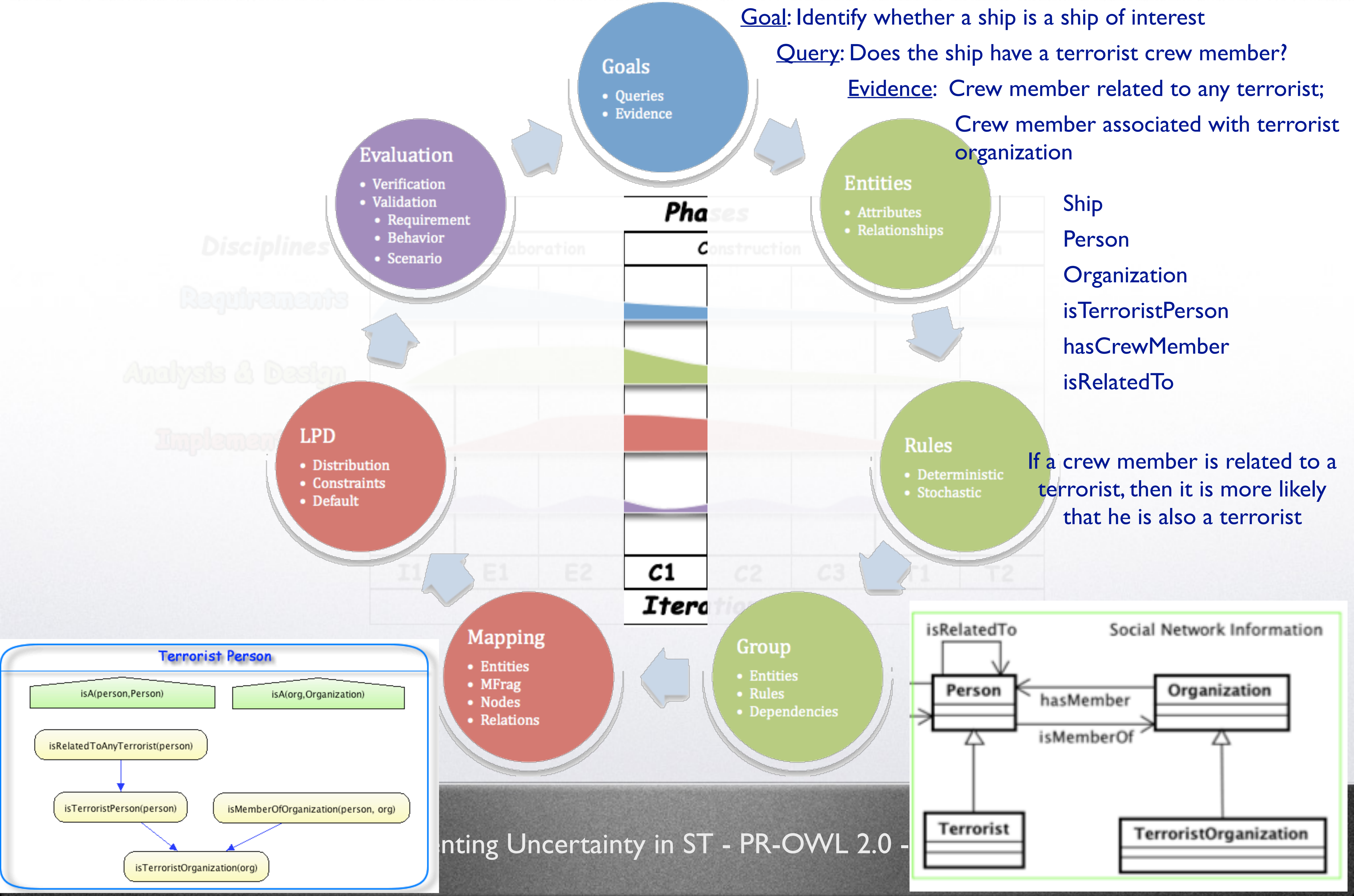
Organization

isTerroristPerson

hasCrewMember

isRelatedTo

If a crew member is related to a terrorist, then it is more likely that he is also a terrorist



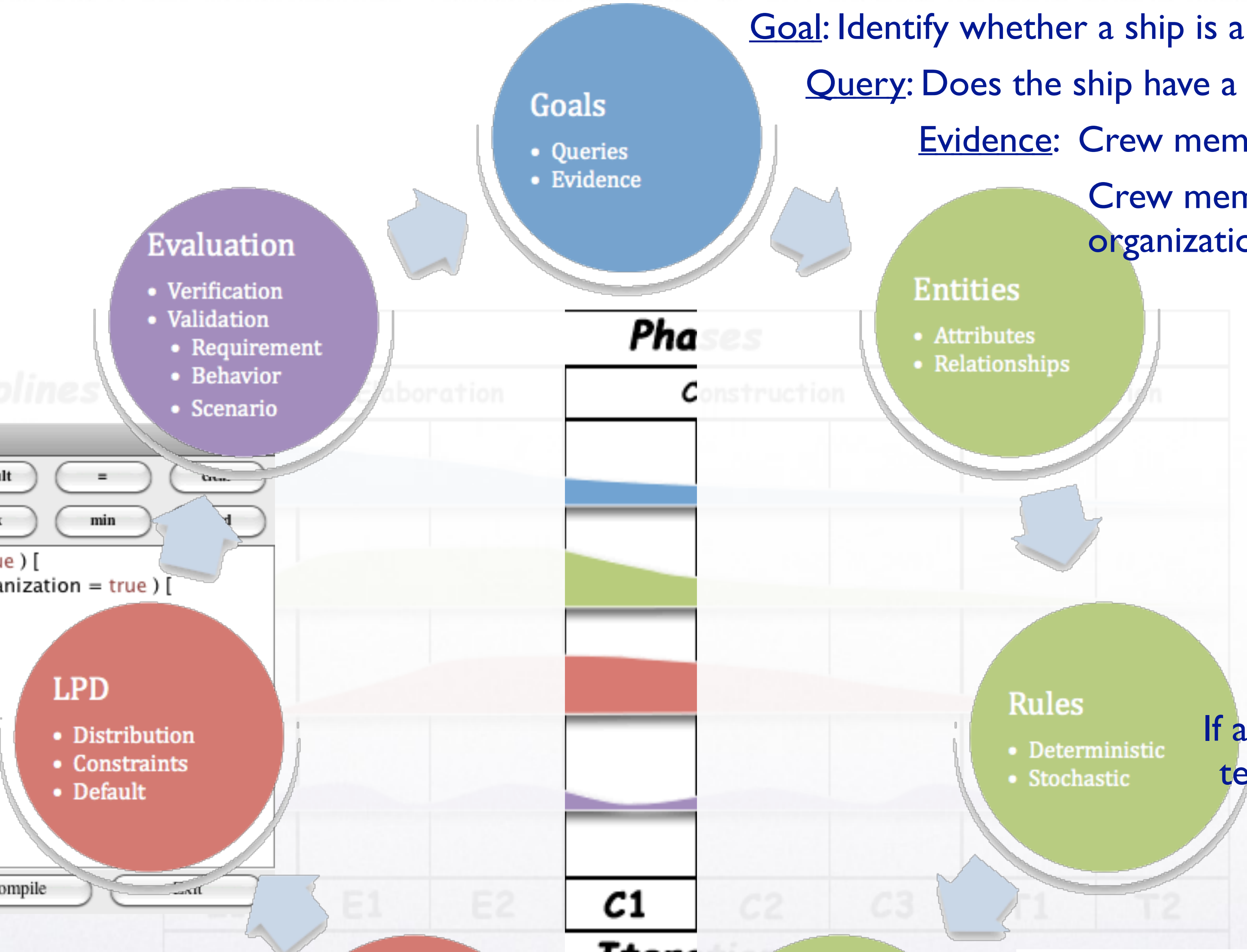
Modeling Cycle - MDA

Goal: Identify whether a ship is a ship of interest

Query: Does the ship have a terrorist crew member?

Evidence: Crew member related to any terrorist;

Crew member associated with terrorist organization



Ship

Person

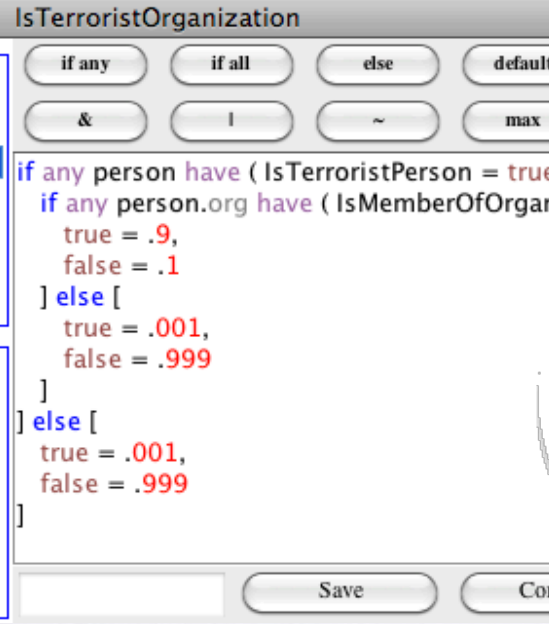
Organization

isTerroristPerson

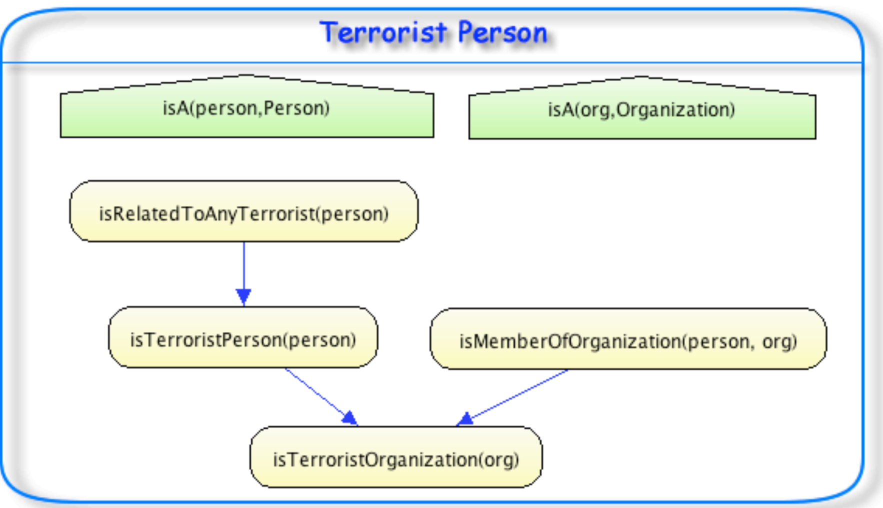
hasCrewMember

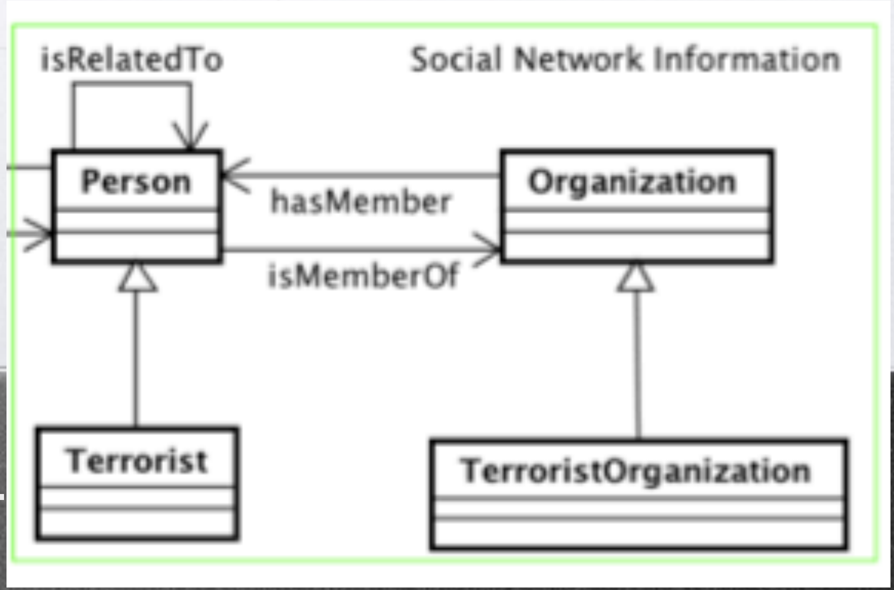
isRelatedTo

If a crew member is related to a terrorist, then it is more likely that he is also a terrorist

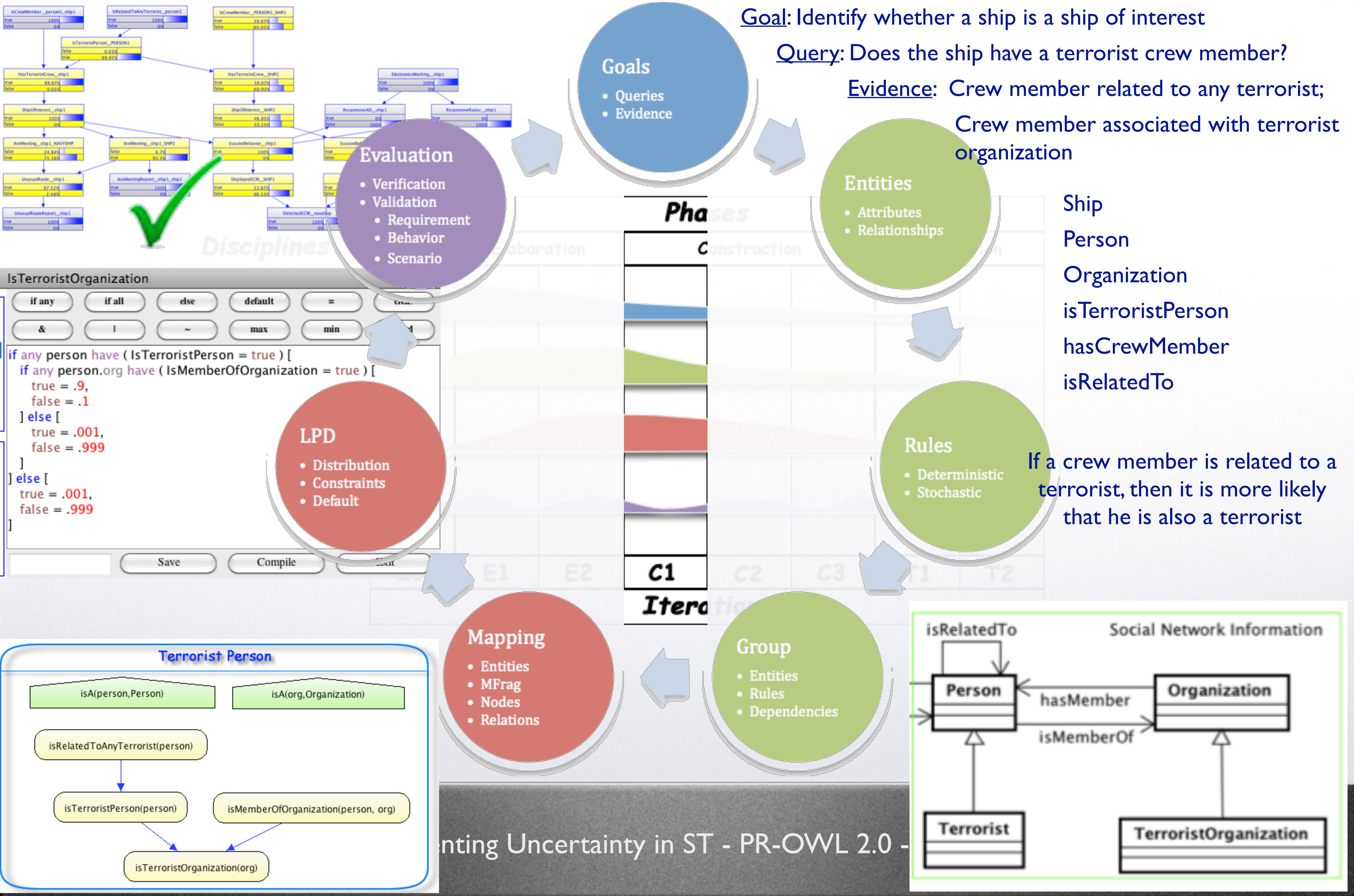


```
if any person have ( IsTerroristPerson = true ) [
  if any person.org have ( IsMemberOfOrganization = true ) [
    true = .9,
    false = .1
  ] else [
    true = .001,
    false = .999
  ]
] else [
  true = .001,
  false = .999
]
```


Terrorist Person
isA(person,Person)
isA(org,Organization)
isRelatedToAnyTerrorist(person)
isTerroristPerson(person)
isMemberOfOrganization(person, org)
isTerroristOrganization(org)



Modeling Cycle - MDA



Goal: Identify whether a ship is a ship of interest

Query: Does the ship have a terrorist crew member?

Evidence: Crew member related to any terrorist;

Crew member associated with terrorist organization

Ship

Person

Organization

isTerroristPerson

hasCrewMember

isRelatedTo

If a crew member is related to a terrorist, then it is more likely that he is also a terrorist

```
IsCrewMember__person1_ship1        true 100%     false 0%
IsRelatedToAnyTerrorist__person1   true 100%     false 0%
IsCrewMember__PERSON1_SHIP2        true 39.07%   false 60.93%
IsTerroristPerson__PERSON1         false 0.03%   true 99.97%
HasTerroristCrew__ship1            true 99.97%   false 0.03%
HasTerroristCrew__SHIP2            true 39.07%   false 60.93%
ElectronicsWorking__ship1          true 100%     false 0%
ShipOfInterest__ship1              true 100%     false 0%
ShipOfInterest__SHIP2              true 46.85%   false 53.15%
ResponsiveAIS__ship1               true 0%       false 100%
ResponsiveRadar__ship1             true 0%       false 100%
AreMeeting__ship1_NAVYSHIP         false 24.84%  true 75.16%
AreMeeting__ship1_SHIP2            false 6.7%    true 93.3%
EvasiveBehavior__ship1             true 100%     false 0%
UnusualRoute__ship1                true 97.52%   false 2.48%
AreMeetingReport__ship1_ship2      true 100%     false 0%
DeployedECM__SHIP1                 true 13.87%   false 86.13%
UnusualRouteReport__ship1          true 100%     false 0%
DetectedECM__navyShip              true 100%     false 0%
```

IsTerroristOrganization

```
if any person have ( IsTerroristPerson = true ) [
  if any person.org have ( IsMemberOfOrganization = true ) [
    true = .9,
    false = .1
  ] else [
    true = .001,
    false = .999
  ]
] else [
  true = .001,
  false = .999
]
```

Terrorist Person
isA(person,Person)
isA(org,Organization)
isRelatedToAnyTerrorist(person)
isTerroristPerson(person)
isMemberOfOrganization(person, org)
isTerroristOrganization(org)
isRelatedTo
Social Network Information
Person
hasMember
Organization
isMemberOf
Terrorist
TerroristOrganization

Evaluation - MDA

- Manual case-based evaluation
  - 4 major categories were defined:
    - A possible bomb plan using fishing ship;
    - A possible bomb plan using merchant ship;
    - A possible exchange illicit cargo using fishing ship;
    - A possible exchange illicit cargo using merchant ship.
  - 5 variations for each scenario:
    - "Sure" positive, "looks" positive, unsure, "looks" negative, and "sure" negative.
  - All 20 different scenarios were analyzed by the SME and were evaluated as reasonable results (what was expected).

Evaluation - MDA

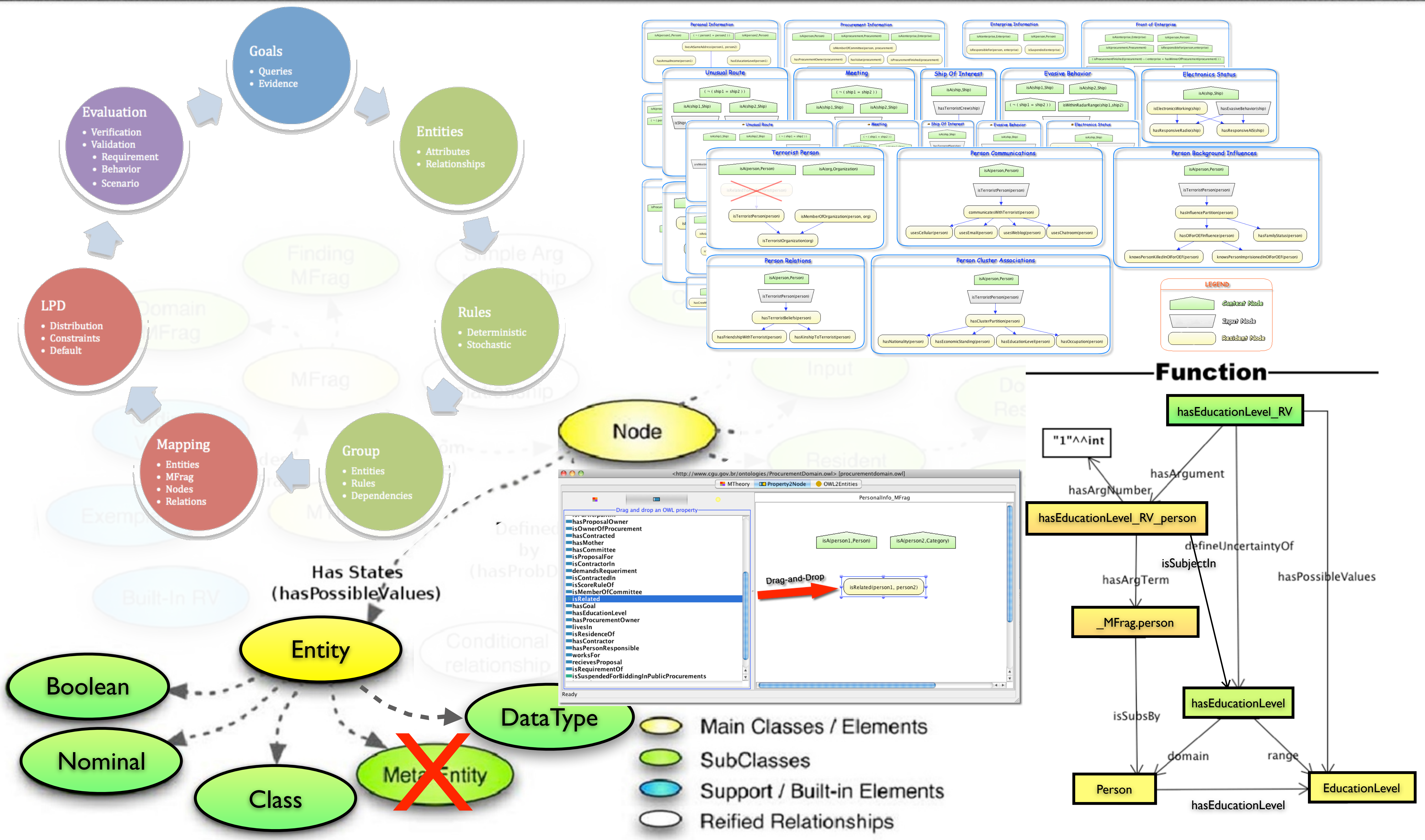
- Automatic case-based evaluation
  - Used simulation tool to generate ground truth
  - Generated reports based on simulated data
  - Inferred result and compared with ground truth
    - Confusion matrix with threshold of 50%

Inferred/ Real	≥ 50%	< 50%
TRUE	24	3
FALSE	11	577

Inferred/ Real	≥ 50%	< 50%
TRUE	88.89%	11.11%
FALSE	1.87%	98.13%

Conclusion

Contributions



<http://www.cgu.gov.br/ontologies/ProcurementDomain.owl> [procurementdomain.owl]

MTheory | Property2Node | OWL2Entities

Drag and drop an OWL property

- hasProposalOwner
- isOwnerOfProcurement
- hasContracted
- hasMother
- hasCommittee
- isProposalFor
- isContractorIn
- demandsRequeriment
- isContractedIn
- isScoreRuleOf
- isMemberOfCommittee
- isRelated
- hasGoal
- hasEducationLevel
- hasProcurementOwner
- livesIn
- isResidenceOf
- hasContractor
- hasPersonResponsible
- worksFor
- recievesProposal
- isRequirementOf
- isSuspendedForBiddingInPublicProcurements

PersonalInfo_MFrag

isA(person1,Person) isA(person2,Category)

Drag-and-Drop

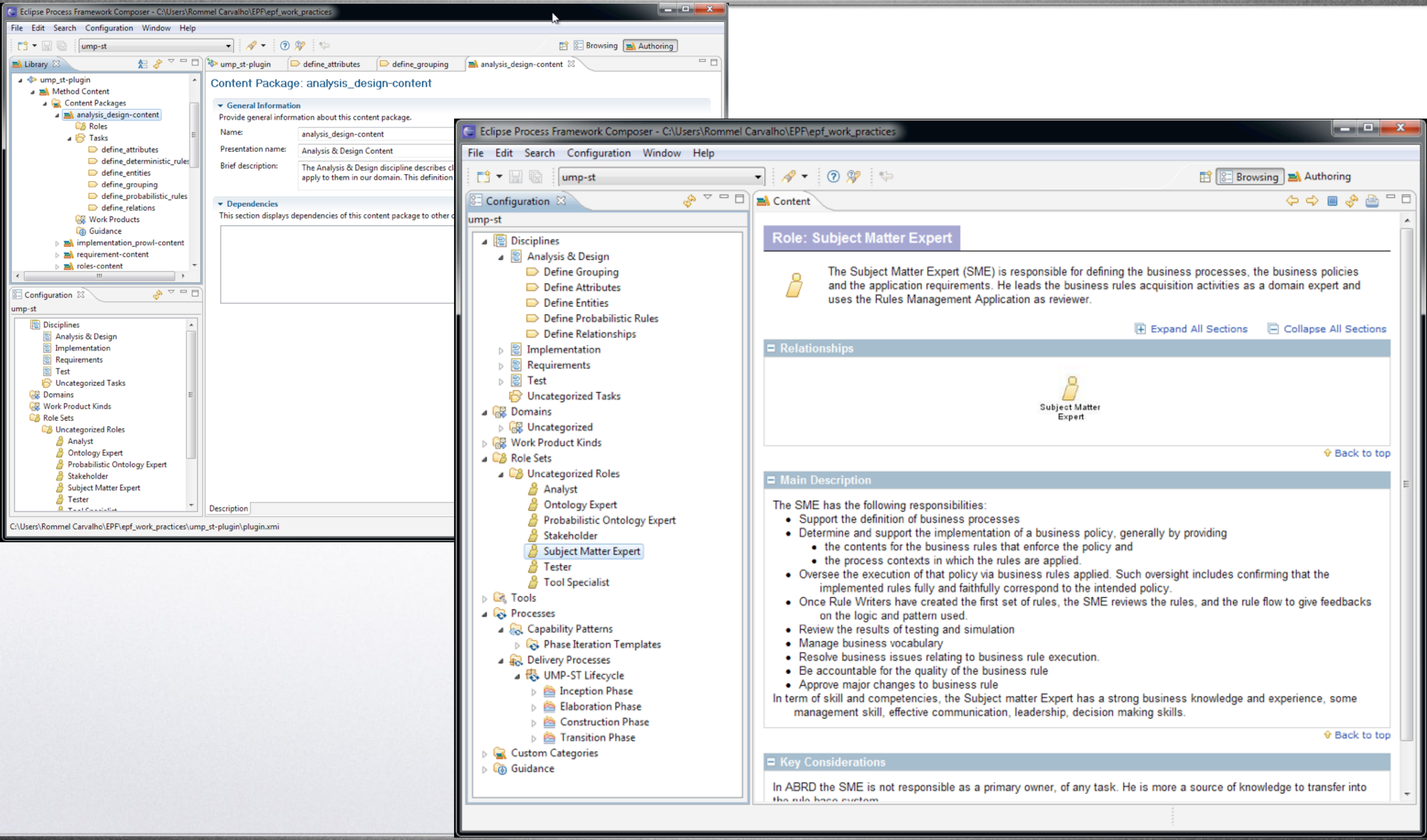
isRelated(person1, person2)

Ready

Future Work

- PR-OWL 2.0 implementation [105]
- UMP-ST implementation [122]
- Scalability (MEBN reasoning)
  - PR-OWL 2.0 sublanguages/complexity
- Learning (MEBN learning)
- RV "solved" by external tools
  - hasAnnualIncome(person) < 50,000.00
  - isShipLocatedInArea(ship, area)
  - sin(x)
  - linearEquationValue(m,b)

Future Work - EPF for UMP-ST



ump_st-plugin
- Method Content
  - Content Packages
    - analysis_design-content
      - Roles
      - Tasks
        - define_attributes
        - define_deterministic_rules
        - define_entities
        - define_grouping
        - define_probabilistic_rules
        - define_relations
      - Work Products
      - Guidance
    - implementation_prowl-content
    - requirement-content
    - roles-content

Content Package: analysis_design-content

General Information

Provide general information about this content package.

Name: analysis_design-content

Presentation name: Analysis & Design Content

Brief description: The Analysis & Design discipline describes cl apply to them in our domain. This definition

Dependencies

This section displays dependencies of this content package to other c

ump-st
- Disciplines
  - Analysis & Design
  - Implementation
  - Requirements
  - Test
  - Uncategorized Tasks
- Domains
- Work Product Kinds
- Role Sets
  - Uncategorized Roles
    - Analyst
    - Ontology Expert
    - Probabilistic Ontology Expert
    - Stakeholder
    - Subject Matter Expert
    - Tester

C:\Users\Rommel Carvalho\EPF\epf_work_practices\ump_st-plugin\plugin.xmi

ump-st
- Disciplines
  - Analysis & Design
    - Define Grouping
    - Define Attributes
    - Define Entities
    - Define Probabilistic Rules
    - Define Relationships
  - Implementation
  - Requirements
  - Test
  - Uncategorized Tasks
- Domains
  - Uncategorized
- Work Product Kinds
- Role Sets
  - Uncategorized Roles
    - Analyst
    - Ontology Expert
    - Probabilistic Ontology Expert
    - Stakeholder
    - Subject Matter Expert
    - Tester
    - Tool Specialist
- Tools
- Processes
  - Capability Patterns
    - Phase Iteration Templates
  - Delivery Processes
    - UMP-ST Lifecycle
      - Inception Phase
      - Elaboration Phase
      - Construction Phase
      - Transition Phase
- Custom Categories
- Guidance

Role: Subject Matter Expert

The Subject Matter Expert (SME) is responsible for defining the business processes, the business policies and the application requirements. He leads the business rules acquisition activities as a domain expert and uses the Rules Management Application as reviewer.

Relationships

Subject Matter Expert

Main Description

The SME has the following responsibilities:
- Support the definition of business processes
- Determine and support the implementation of a business policy, generally by providing
  - the contents for the business rules that enforce the policy and
  - the process contexts in which the rules are applied.
- Oversee the execution of that policy via business rules applied. Such oversight includes confirming that the implemented rules fully and faithfully correspond to the intended policy.
- Once Rule Writers have created the first set of rules, the SME reviews the rules, and the rule flow to give feedbacks on the logic and pattern used.
- Review the results of testing and simulation
- Manage business vocabulary
- Resolve business issues relating to business rule execution.
- Be accountable for the quality of the business rule
- Approve major changes to business rule

In term of skill and competencies, the Subject matter Expert has a strong business knowledge and experience, some management skill, effective communication, leadership, decision making skills.

Key Considerations

In ABRD the SME is not responsible as a primary owner, of any task. He is more a source of knowledge to transfer into the rule base system

Publications

Publications - Paper I

- Papers:
  1. R. N. Carvalho, R. Haberlin, P. C. G. Costa, K. B. Laskey, and K.-C. Chang, "Modeling a Probabilistic Ontology for Maritime Domain Awareness," in Proceedings of the 14th International Conference on Information **Fusion**, Chicago, USA, 2011.
  2. P. C. G. Costa, R. N. Carvalho, K. B. Laskey, and C. Y. Park, "Evaluating uncertainty representation and reasoning in HLF systems," in Proceedings of the 14th International Conference on Information **Fusion**, Chicago, USA, 2011.
  3. R.N. Carvalho, K.B. Laskey, and P.C.G. Costa, "PR-OWL 2.0 - Bridging the gap to OWL semantics," Proceedings of the 6th Uncertainty Reasoning for the Semantic Web (**URSW** 2010) on the 9th International Semantic Web Conference (ISWC 2010), Shanghai, China: 2010.
  4. R.N. Carvalho, P.C.G. Costa, K.B. Laskey, and K. Chang, "PROGNOS: Predictive Situational Awareness with Probabilistic Ontologies," Proceedings of the 13th International Conference on Information **Fusion**, Edinburgh, UK: 2010.
  5. R.N. Carvalho, K.B. Laskey, and P.C.G. Costa, "Compatibility Formalization Between PR-OWL and OWL," Proceedings of the First International Workshop on Uncertainty in Description Logics (**UniDL**) on Federated Logic Conference (FLoC) 2010, Edinburgh, UK: 2010.

Publications - Paper II

- Papers:

6. P.C.G. Costa, K. Chang, K.B. Laskey, and R.N. Carvalho, "High Level Fusion and Predictive Situational Awareness with Probabilistic Ontologies," Proceedings of the **AFCEA-GMU** C4I Center Symposium, George Mason University, Fairfax, VA, USA: 2010.

7. R.N. Carvalho, K.B. Laskey, P.C.G. Costa, M. Ladeira, L.L. Santos, and S. Matsumoto, "Probabilistic Ontology and Knowledge Fusion for Procurement Fraud Detection in Brazil," Proceedings of the 5th Uncertainty Reasoning for the Semantic Web (**URSW** 2009) on the 8th International Semantic Web Conference (ISWC 2009), Chantilly, Virginia, USA: 2009.

8. P.C.G. Costa, Kuo-Chu Chang, K. Laskey, and R.N. Carvalho, "A multi-disciplinary approach to high level fusion in predictive situational awareness," Proceedings of the 12th International Conference on Information **Fusion**, Seattle, Washington, USA: 2009, pp. 248-255.

9. R.N. Carvalho and KC. Chang, "A performance evaluation tool for multi-sensor classification systems," Proceedings of the 12th International Conference on Information **Fusion**, Seattle, Washington, USA: 2009, pp. 1123-1130.

***Best Student Paper Travel Award**

Publications - Book

- Book chapters:

1. R. N. Carvalho, K. B. Laskey, and P. C. G. da Costa, "PR-OWL 2.0 - Bridging the gap to OWL semantics," in Uncertainty Reasoning for the Semantic Web II: ISWC International Workshops, URSW 2008-2010, Revised Selected and Invited Papers, Springer-Verlag (Forthcoming).
2. R. N. Carvalho, S. Matsumoto, K. B. Laskey, P. C. G. da Costa, M. Ladeira, and L. Santos, "Probabilistic Ontology and Knowledge Fusion for Procurement Fraud Detection in Brazil," in Uncertainty Reasoning for the Semantic Web II: ISWC International Workshops, URSW 2008-2010, Revised Selected and Invited Papers, Springer-Verlag (Forthcoming).
3. S. Matsumoto, R. N. Carvalho, M. Ladeira, P. C. G. da Costa, L. Santos, D. Silva, M. Onishi, and E. Machado, "UnBBayes: a Java Framework for Probabilistic Models in AI," in Java in Academia and Research, iConcept Press (Forthcoming).
4. S. Matsumoto, R. N. Carvalho, P. C. G. da Costa, K. B. Laskey, L. L. Santos, and M. Ladeira, "Theres No More Need to be a Night OWL: on the PR-OWL for a MEBN Tool Before Nightfall," in Introduction to the Semantic Web: Concepts, Technologies and Applications, G. Fung, Ed. iConcept Press, 2011.
5. R.N. Carvalho, K.B. Laskey, P.C.G.D. Costa, M. Ladeira, L.L. Santos, and S. Matsumoto, "UnBBayes: Modeling Uncertainty for Plausible Reasoning in the Semantic Web," Semantic Web, INTECH, 2010, pp. 1-28.
6. R.N. Carvalho, M. Ladeira, L.L. Santos, S. Matsumoto, and P.C.G. Costa, "A GUI Tool for Plausible Reasoning in the SemanticWeb Using MEBN," Innovative Applications in Data Mining, Nadia Nedjah, Luiza de Macedo Mourelle, Janusz Kacprzyk, 2009, pp. 17-45.

Publications - Journal

- Journal papers:

1. R.N. Carvalho, K.B. Laskey, and P.C.G. Costa, "A Formal Definition for Probabilistic Ontology - PR-OWL 2.0," Journal of Web Semantics - **JWS** (Preparing).
2. R.N. Carvalho, K.B. Laskey, and P.C.G. Costa, "Uncertainty Modeling Process for Semantic Technologies," Journal of IEEE Transactions on Knowledge and Data Engineering - **TKDE** (Preparing).
3. R.N. Carvalho and KC Chang, "A Performance Evaluation Tool and Analysis for Multi-Sensor Classification Systems," Submitted to Journal of Advances in Information Fusion - **JAIF**, Oct., 2009 (accepted with conditions).

- Edited work:

4. F. Bobillo, R.N. Carvalho, P.C.G. Costa, C. d'Amato, N. Fanizzi, K.B. Laskey, K.J. Laskey, T. Lukasiewicz, T. Martin, M. Nickles, and M. Pool (editors), Proceedings of the 7th International Workshop on Uncertainty Reasoning for the Semantic Web (**URSW** 2011), Bonn, Germany, 2011, CEUR Workshop Proceedings, CEUR-WS.org: 2011 (Forthcoming).
5. F. Bobillo, R.N. Carvalho, P.C.G. Costa, C. d'Amato, N. Fanizzi, K.B. Laskey, K.J. Laskey, T. Lukasiewicz, T. Martin, M. Nickles, and M. Pool (editors), Proceedings of the 6th International Workshop on Uncertainty Reasoning for the Semantic Web (**URSW** 2010), Shanghai, China, November 2010, CEUR Workshop Proceedings, CEUR-WS.org: 2010.

Publications - Committee

- Participation in committees:

1. The 7th International Workshop on Uncertainty Reasoning for the SemanticWeb (URSW 2011)

    Program Committee

    Organizing Committee

2. The 6th International Workshop on Uncertainty Reasoning for the SemanticWeb (URSW 2010)

    Program Committee

    Organizing Committee

3. The 5th International Workshop on Uncertainty Reasoning for the SemanticWeb (URSW 2009)

    Program Committee

4. The 25th Conference on Uncertainty in Artificial Intelligence (UAI 2009)

    Co-reviewer

5. Journal of Tourism Management 2009

    Reviewer

Resultados

Quase 6 Anos Depois

- Evolução do UnBBayes:
  - https://sourceforge.net/projects/unbbayes/
- Uso na Indústria (e-mail que recebi):
  - "I have meaning to mail you for a long time now, things have been moving very fast. We are **using** the **Unbbayes** api for some of the data mining and research efforts here at **Verisign**. It is currently being used for purpose **classification** (bayes net) across **more than 120 million + domains** , The **accuracy** has been **so great** that we are planning to port some of the older algorithms to bayes nets. Given that the **data set is very huge** the **API performed very well** with a very small memory and CPU imprint . Do keep in touch. See ya.”
- Citações e novas publicações:
  - https://scholar.google.com.br/citations?user=XMPnxf8AAAAJ

Obrigado!