A practical approach to ontology-enabled control systems for astronomical instrumentation.

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KATHOLIEKE UNIVERSITEIT
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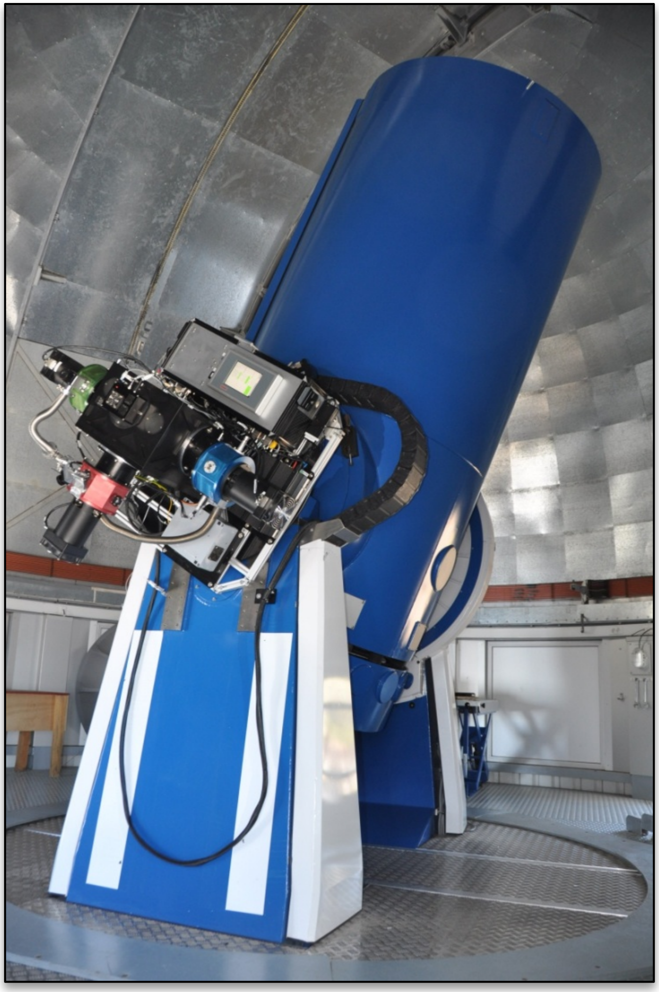
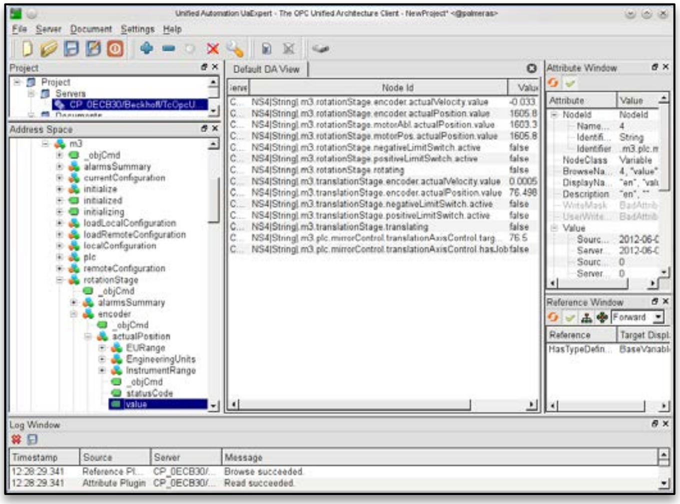
Introduction

- MAIA: Mercator Advanced Imager for Asteroseismology
- Three-channel astronomical imager

Introduction

- PLC for controlling the instrument
- OPC UA for remote operation





```
Project
  Servers
    CP_0ECB30/Beckhoff/TcOpcU...
  Documents
```

```
m3
  _objCmd
  alarmsSummary
  currentConfiguration
  initialize
  initialized
  initializing
  loadLocalConfiguration
  loadRemoteConfiguration
  localConfiguration
  plc
  remoteConfiguration
  rotationStage
    _objCmd
    alarmsSummary
    encoder
      _objCmd
      actualPosition
        EURange
        EngineeringUnits
        InstrumentRange
        _objCmd
        statusCode
        value
```

Serve	Node Id	Valu
C...	NS4|String|.m3.rotationStage.encoder.actualVelocity.value	-0.033
C...	NS4|String|.m3.rotationStage.encoder.actualPosition.value	1605.8
C...	NS4|String|.m3.rotationStage.motorAbl.actualPosition.value	1603.3
C...	NS4|String|.m3.rotationStage.motorPos.actualPosition.value	1605.8
C...	NS4|String|.m3.rotationStage.negativeLimitSwitch.active	false
C...	NS4|String|.m3.rotationStage.positiveLimitSwitch.active	false
C...	NS4|String|.m3.rotationStage.rotating	false
C...	NS4|String|.m3.translationStage.encoder.actualVelocity.value	0.0005
C...	NS4|String|.m3.translationStage.encoder.actualPosition.value	76.498
C...	NS4|String|.m3.translationStage.negativeLimitSwitch.active	false
C...	NS4|String|.m3.translationStage.positiveLimitSwitch.active	false
C...	NS4|String|.m3.translationStage.translating	false
C...	NS4|String|.m3.plc.mirrorControl.translationAxisControl.targ...	76.5
C...	NS4|String|.m3.plc.mirrorControl.translationAxisControl.hasJob	false

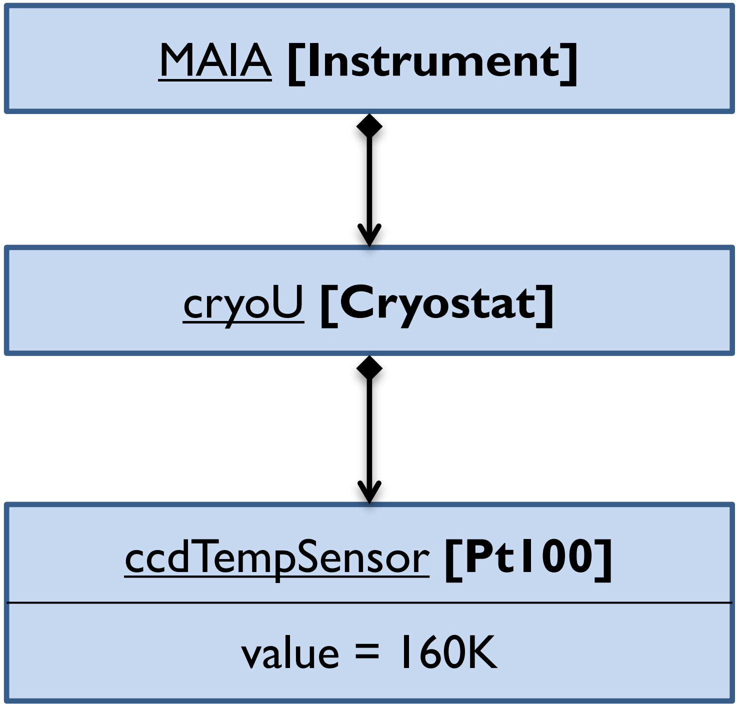
Attribute	Value
NodeId	NodeId
Name...	4
Identifi...	String
Identifier	.m3.plc.m
NodeClass	Variable
BrowseNa...	4, "value"
DisplayNa...	"en", "valu
Description	"en", ""
WriteMask	BadAttrib
UserWrite...	BadAttrib
Value	
Sourc...	2012-06-0
Server...	2012-06-0
Sourc...	0
Server...	0

Reference	Target Displ
HasTypeDefin...	BaseVariabl

Timestamp	Source	Server	Message
12:28:29.341	Reference Pl...	CP_0ECB30/...	Browse succeeded.
12:28:29.341	Attribute Plugin	CP_0ECB30/...	Read succeeded.

Problem

- Interface to the rest of the control system: object-oriented



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READ(MAIA.cryoU.ccdTempsensor.value)
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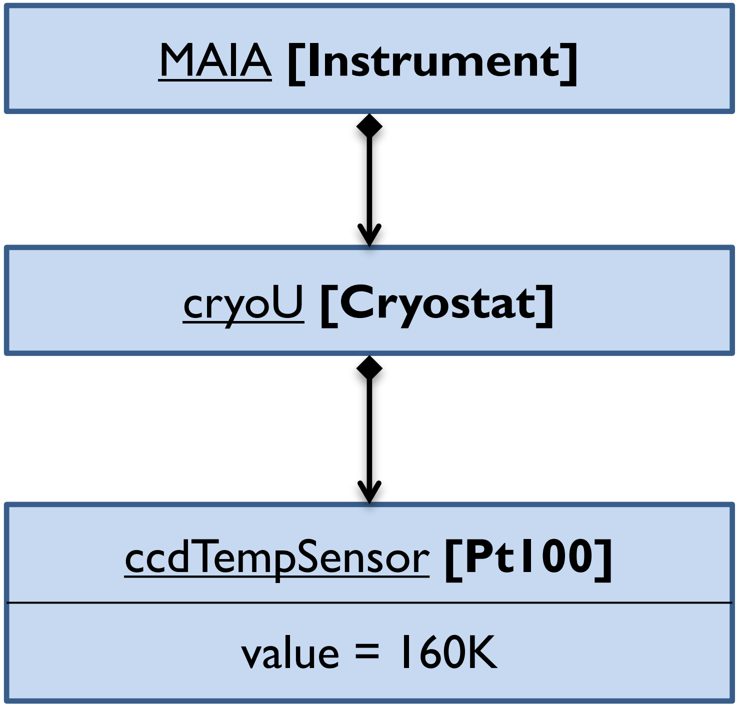

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  - Also model the detector
  - Change the sensor name
- The system has not changed, but the model has (twice!)
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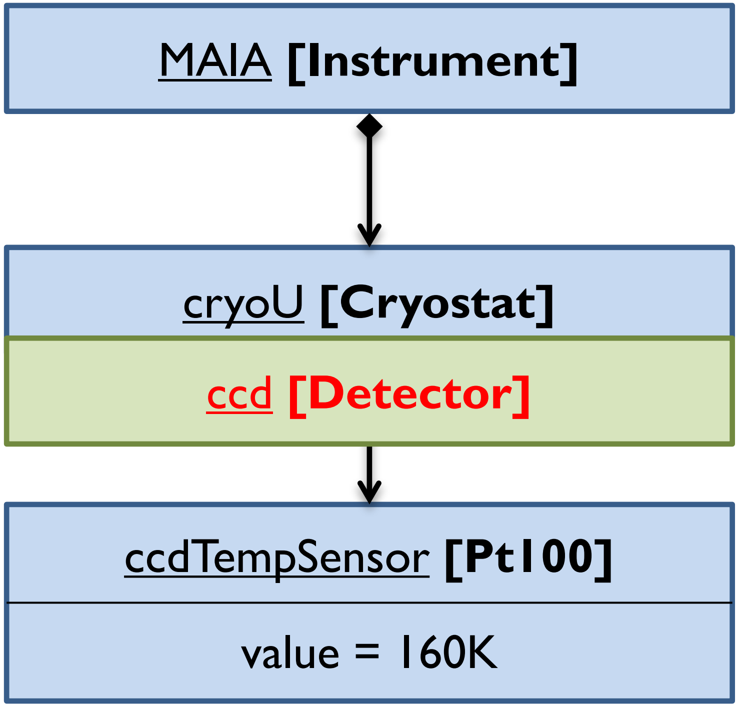

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Prototype implementation

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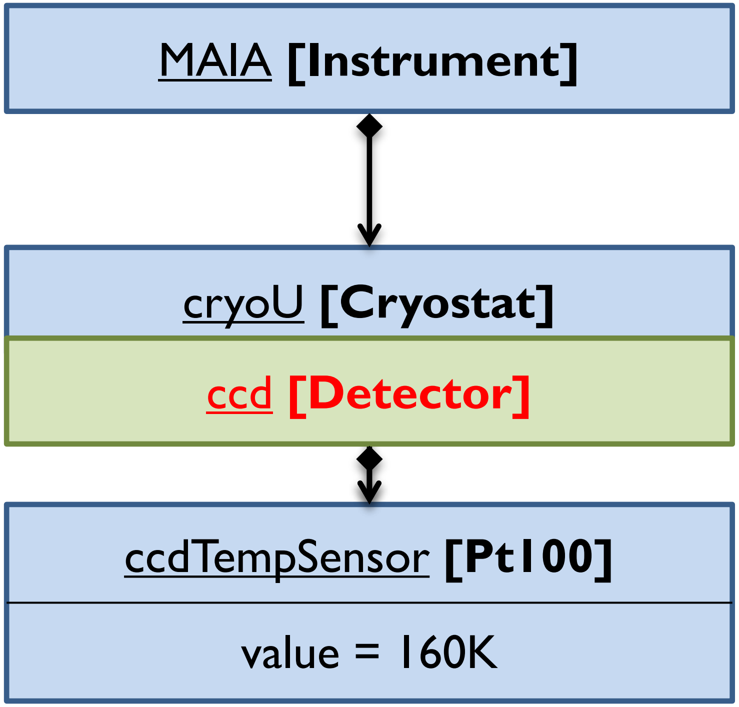

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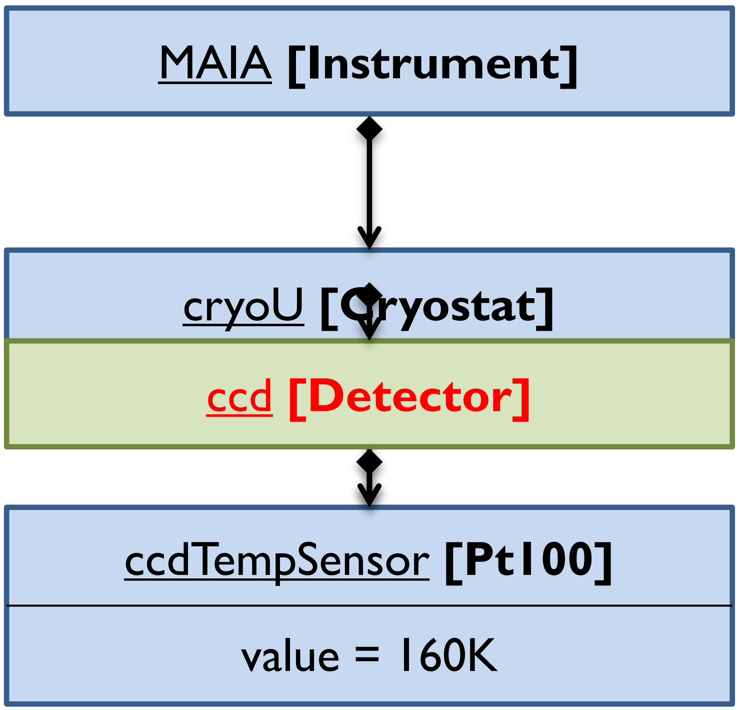

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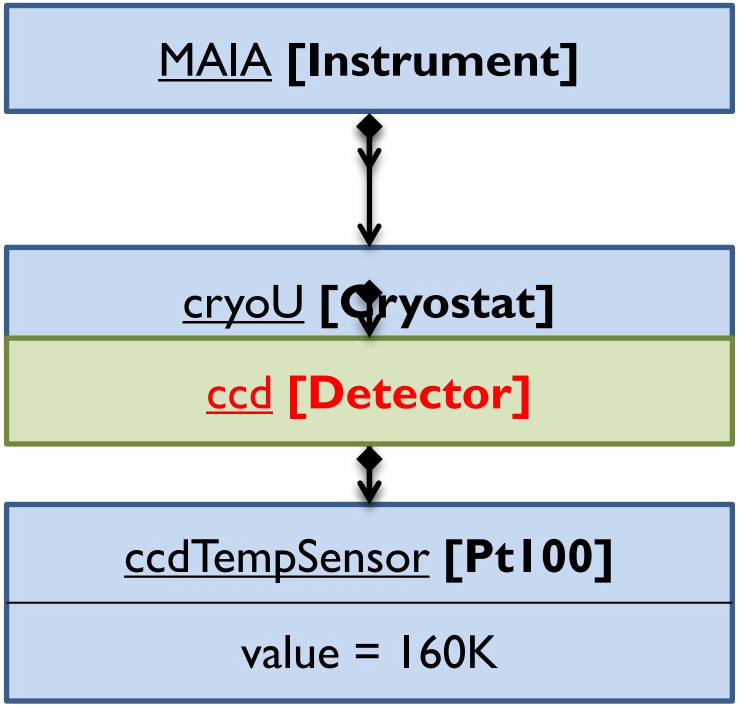

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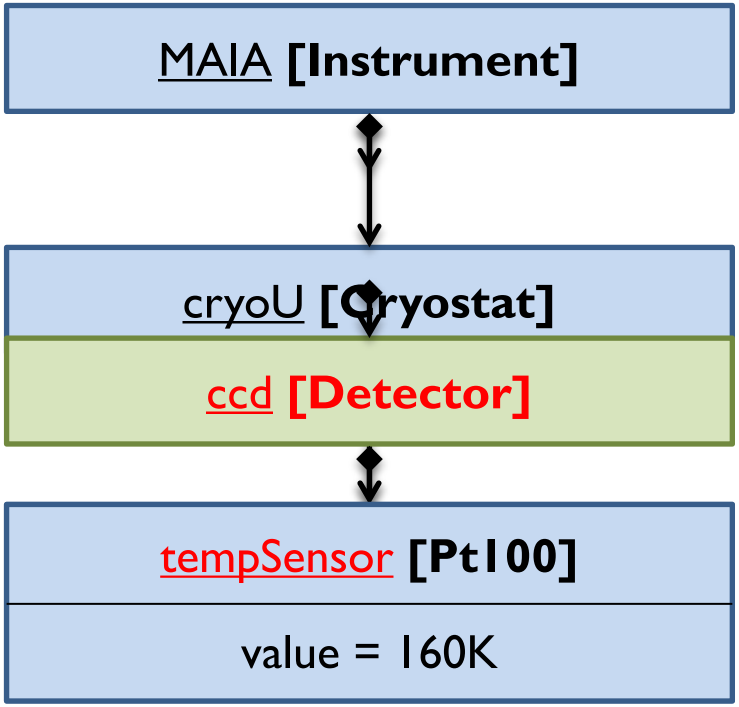

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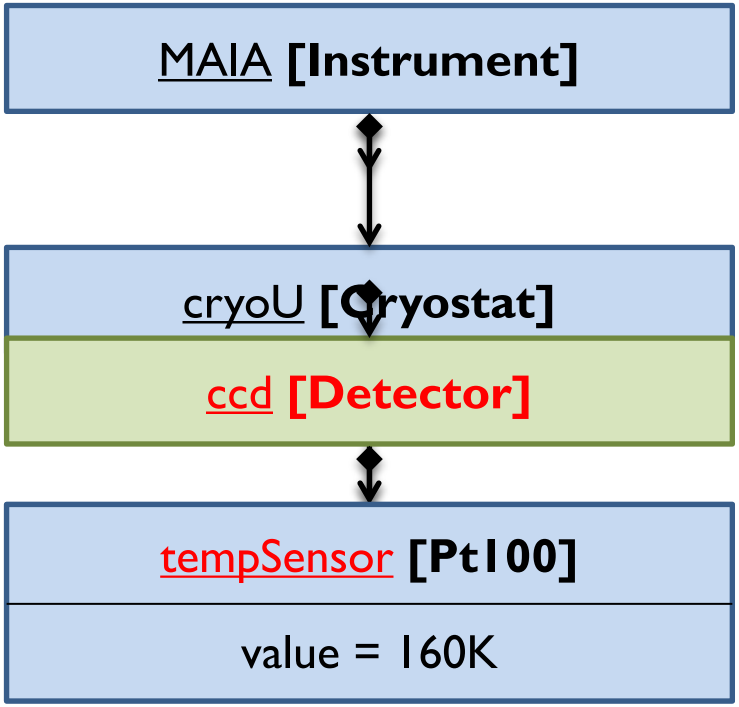

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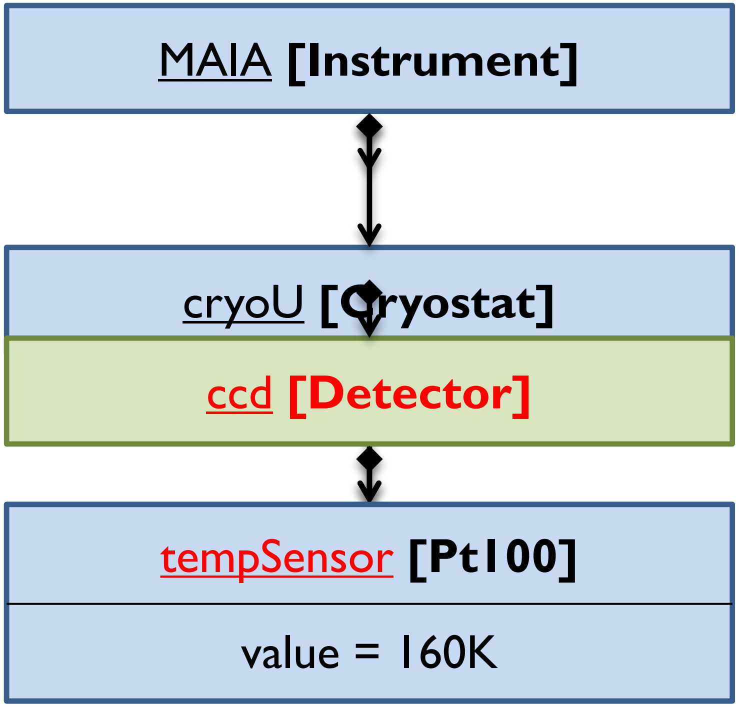

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Ontologies

Ontologies

- Formal representation of knowledge
  - … as a set of **concepts within a domain**
  - … and the **relationships** between pairs of concepts
- Suppose we want to create an ontology about electronics:
  - Namespace
    - **URI:** http://www.icalepcs2013.org/ontologies/electronics
    - **Prefix:** elec
  - Concepts
    - **Classes:** *Sensor*, *Pt100*, *Detector*, *Power*, *PowerSupply*, …
    - **Instances:** *THREE_PHASE_POWER*
    - **Relations:** *senses*, *isSensedBy*, *powers*, *isPoweredBy*, …
  - Facts
    - *Pt100* is a subclass of *Sensor*
    - *THREE_PHASE_POWER* is an instance of *Power*
    - *senses* is a relation with *Sensor* as its domain
    - Any *Sensor* *senses* at least one *Thing*

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MAIA revisited

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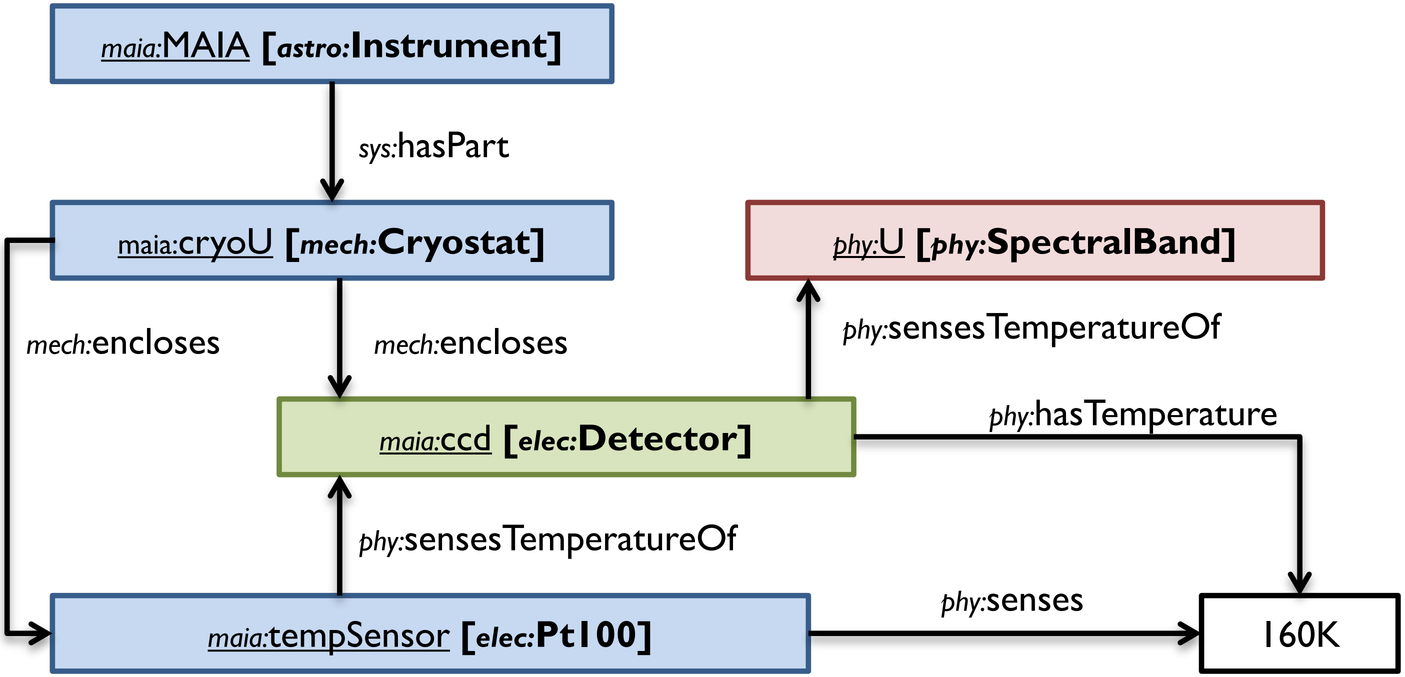

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160K

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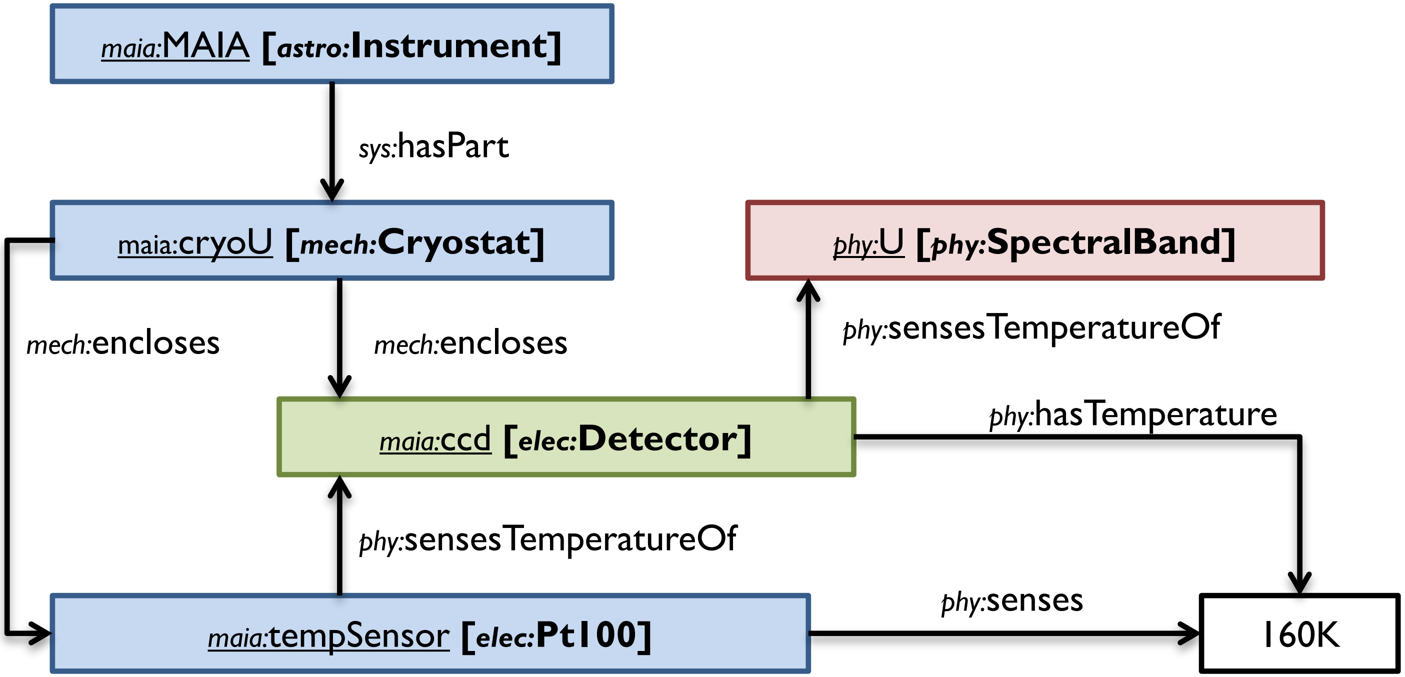
General “engineering” ontologies

- classes
- relations
- some instances



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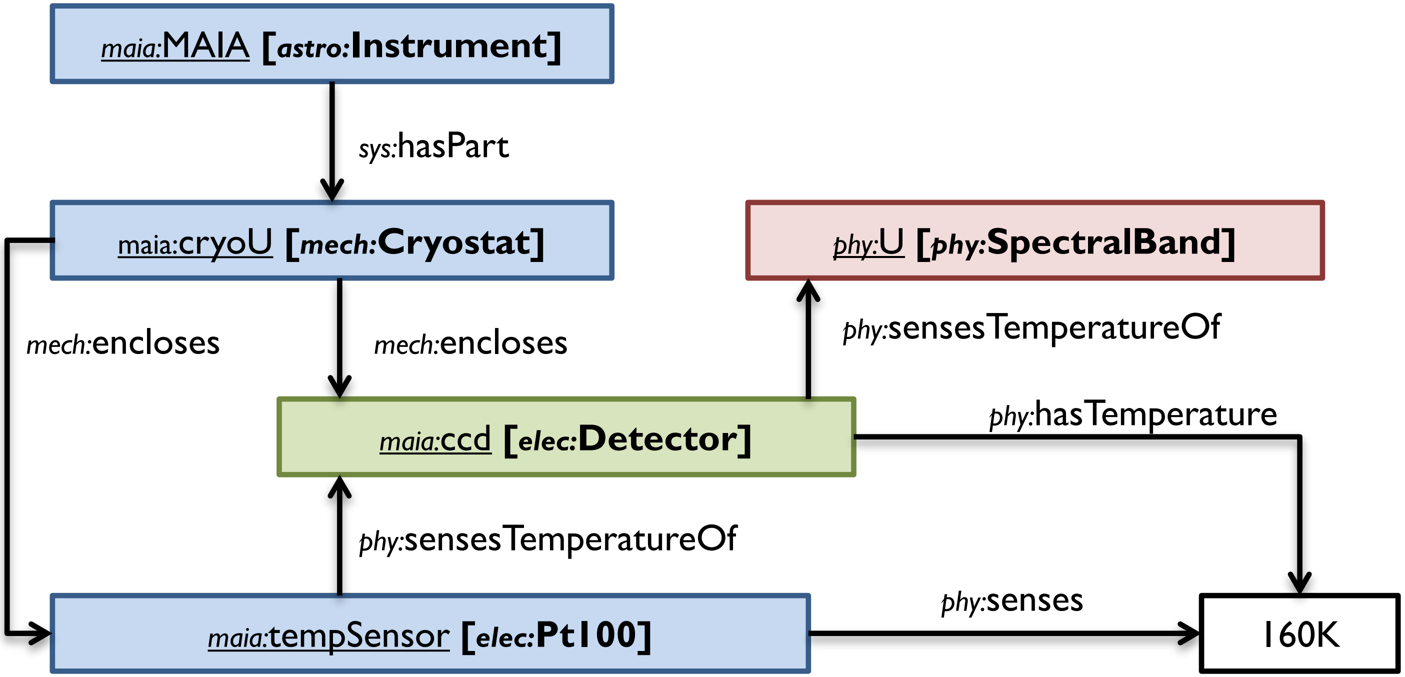

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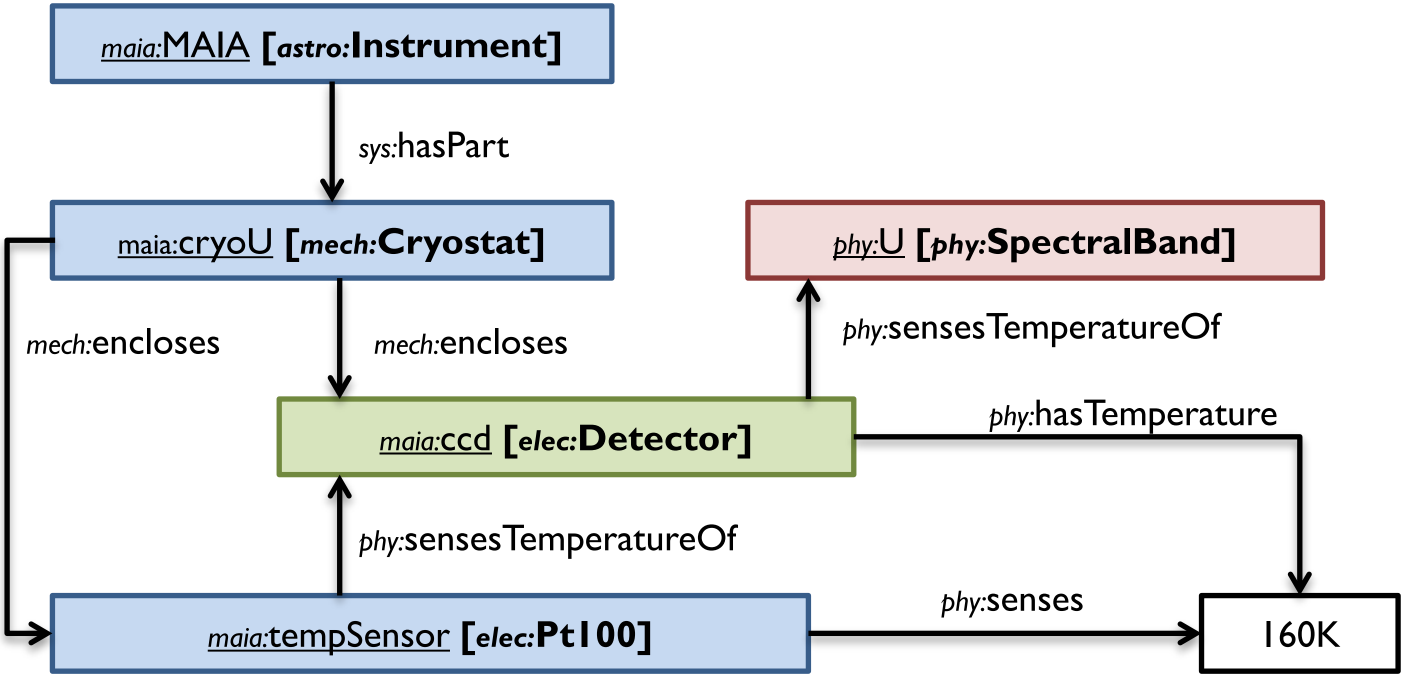

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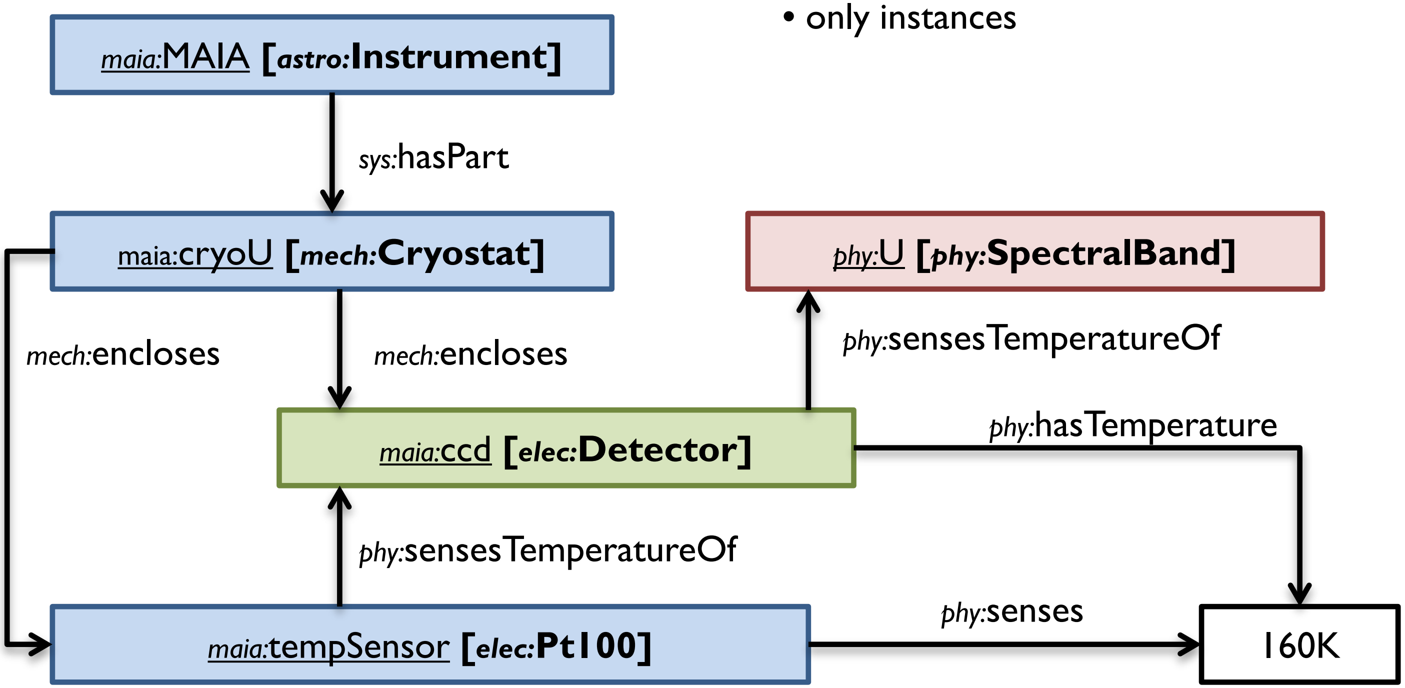

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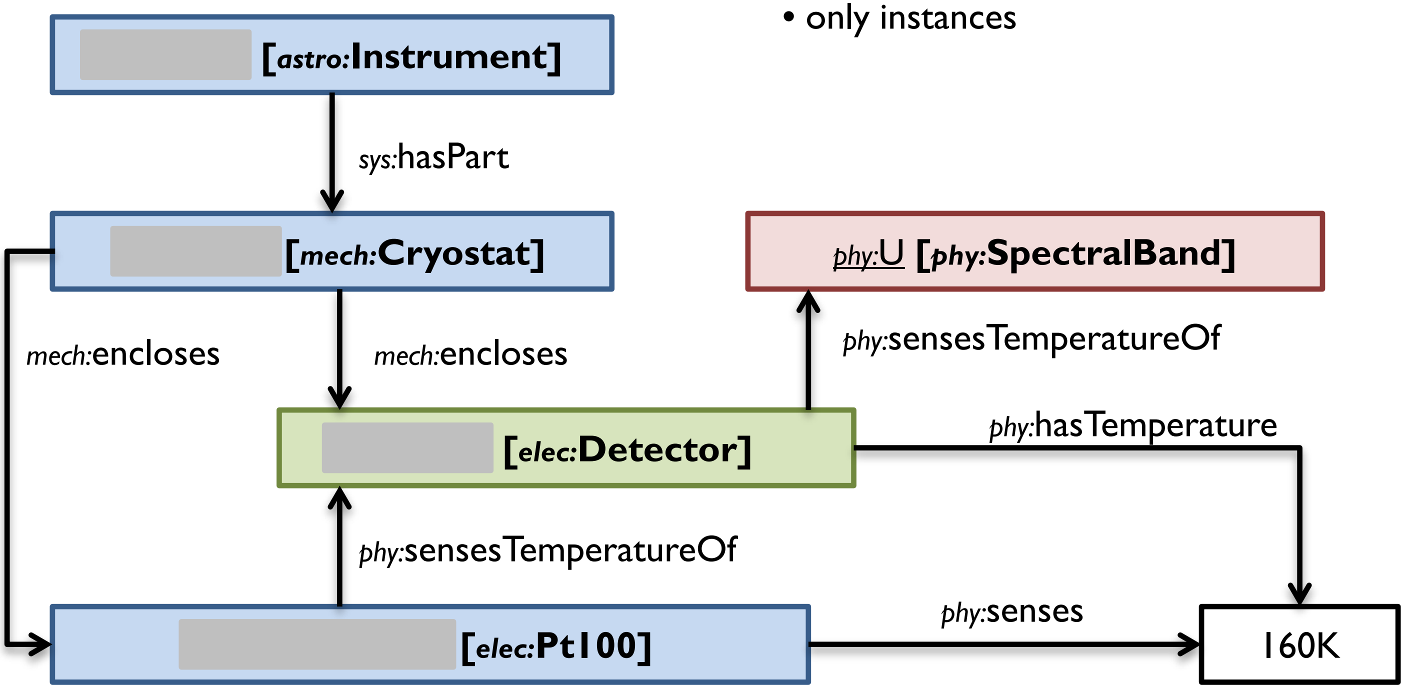

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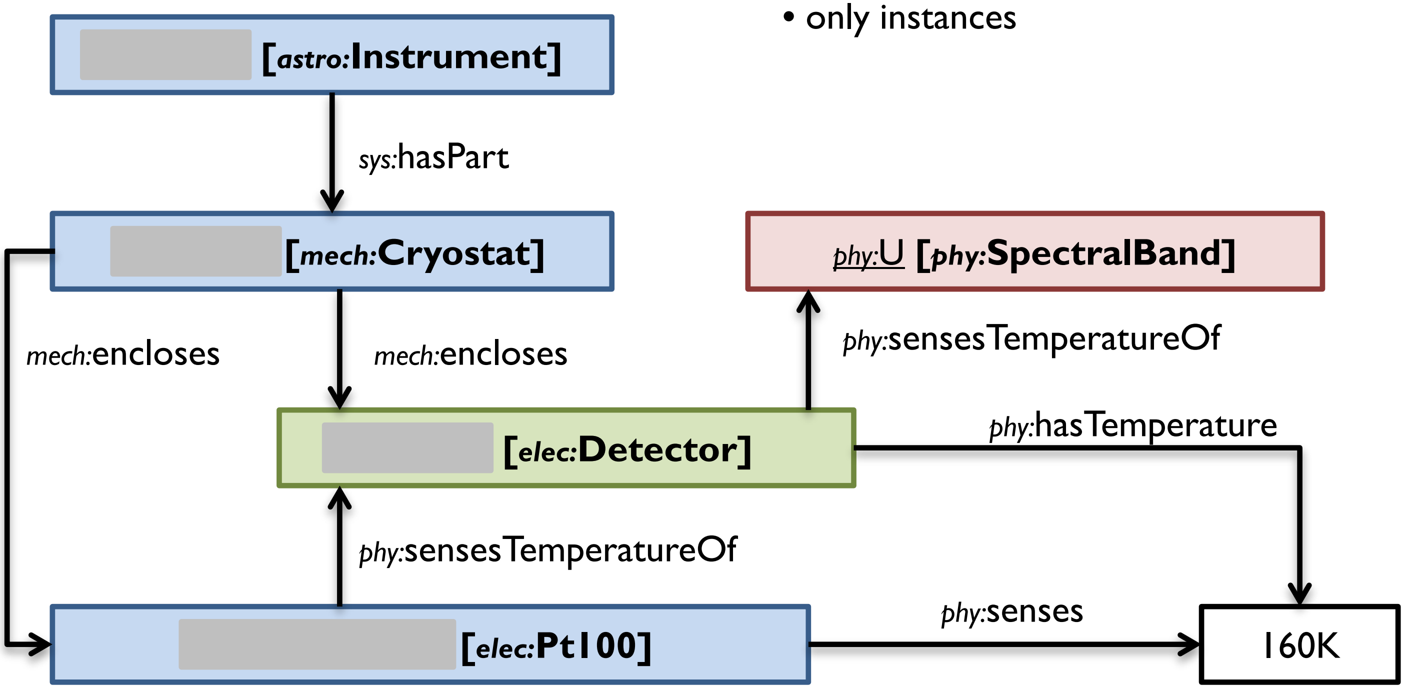
provide context to



Implementations

Semantic Web

Implementations

- Semantic Web standards
  - Designed to add semantics to the huge amount of syntactic information on the WWW

Semantic Web

- Quick summary:
  - **RDF** (Resource Description Framework)
    - Defines basic data model: *subject – predicate – object* "triples"
    - E.g. `elec:THREE_PHASE_POWER – rdf:type – elec:Power`
  - **RDF-S** (RDF-Schema)
    - Extends RDF so basic ontologies can be built
    - E.g. `elec:Pt100 – rdfs:subClassOf – elec:Sensor`
  - **OWL** (Web Ontology Language)
    - Extends RDF-S to build more advanced ontologies
    - E.g. `elec:senses – owl:inverseOf – elec:isSensedBy`
  - **SWRL** (Semantic Web Rule Language)
    - Even more expressive power
    - Not a standard
    - Need to be careful …

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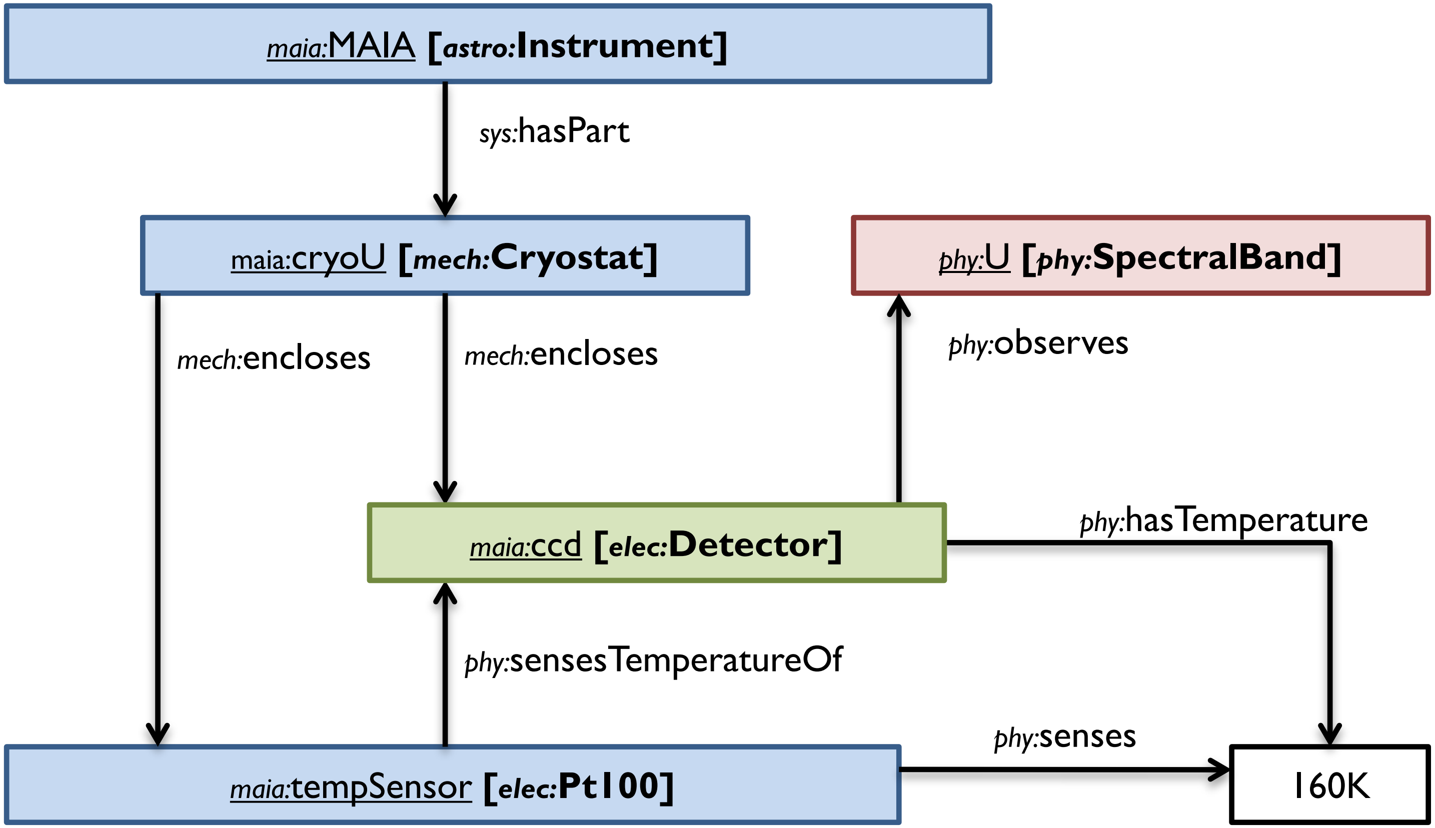

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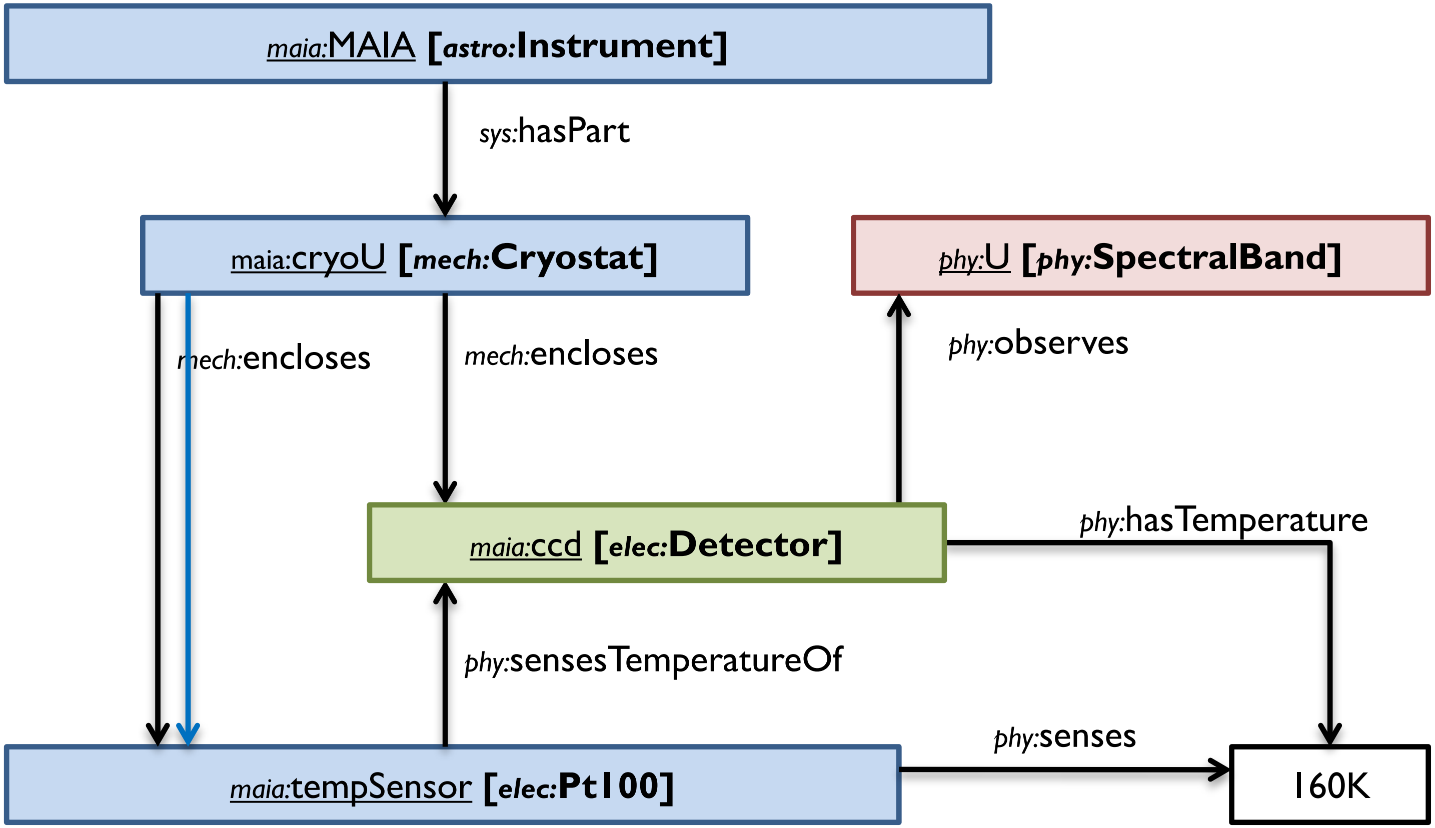

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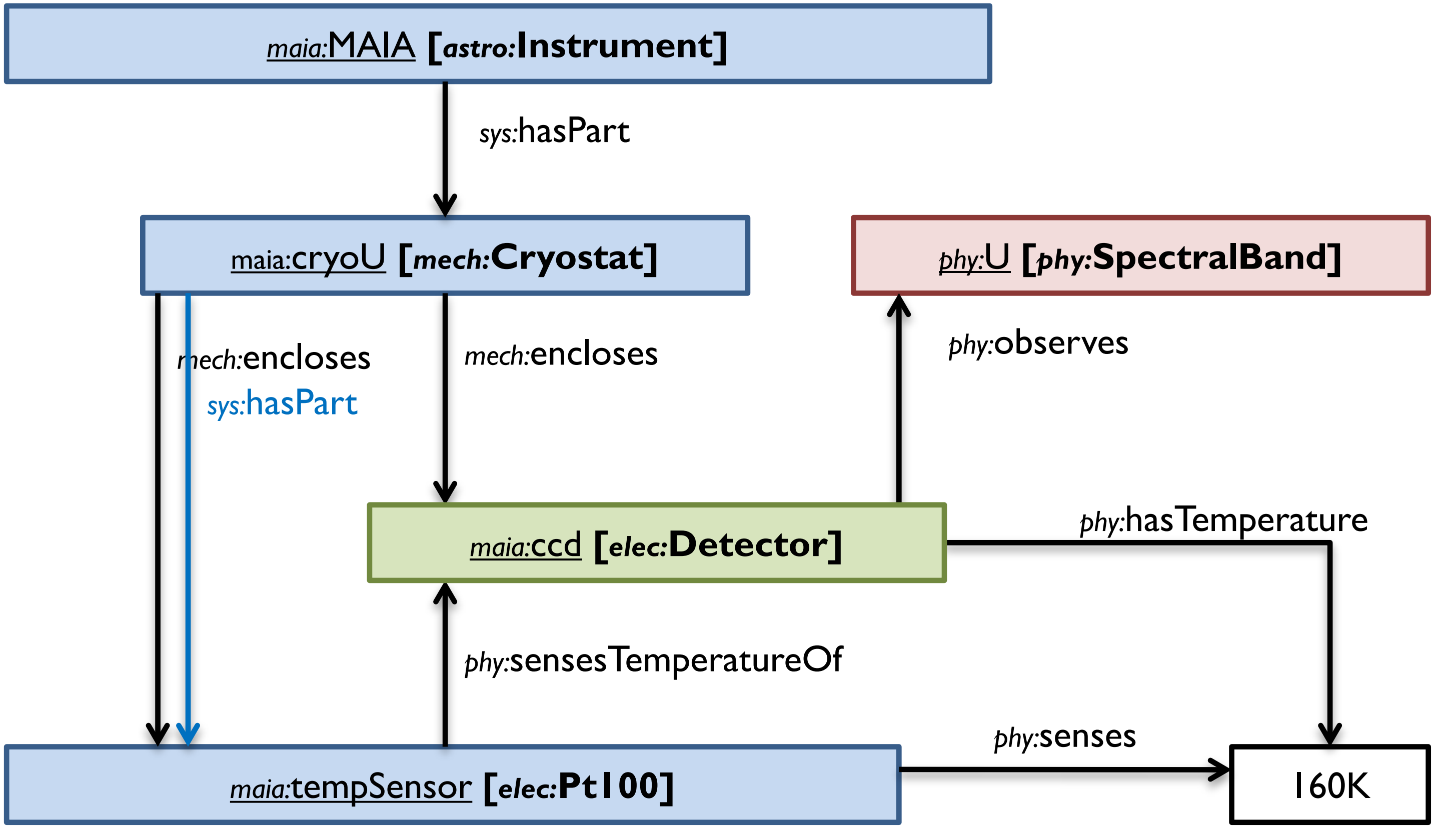

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160K

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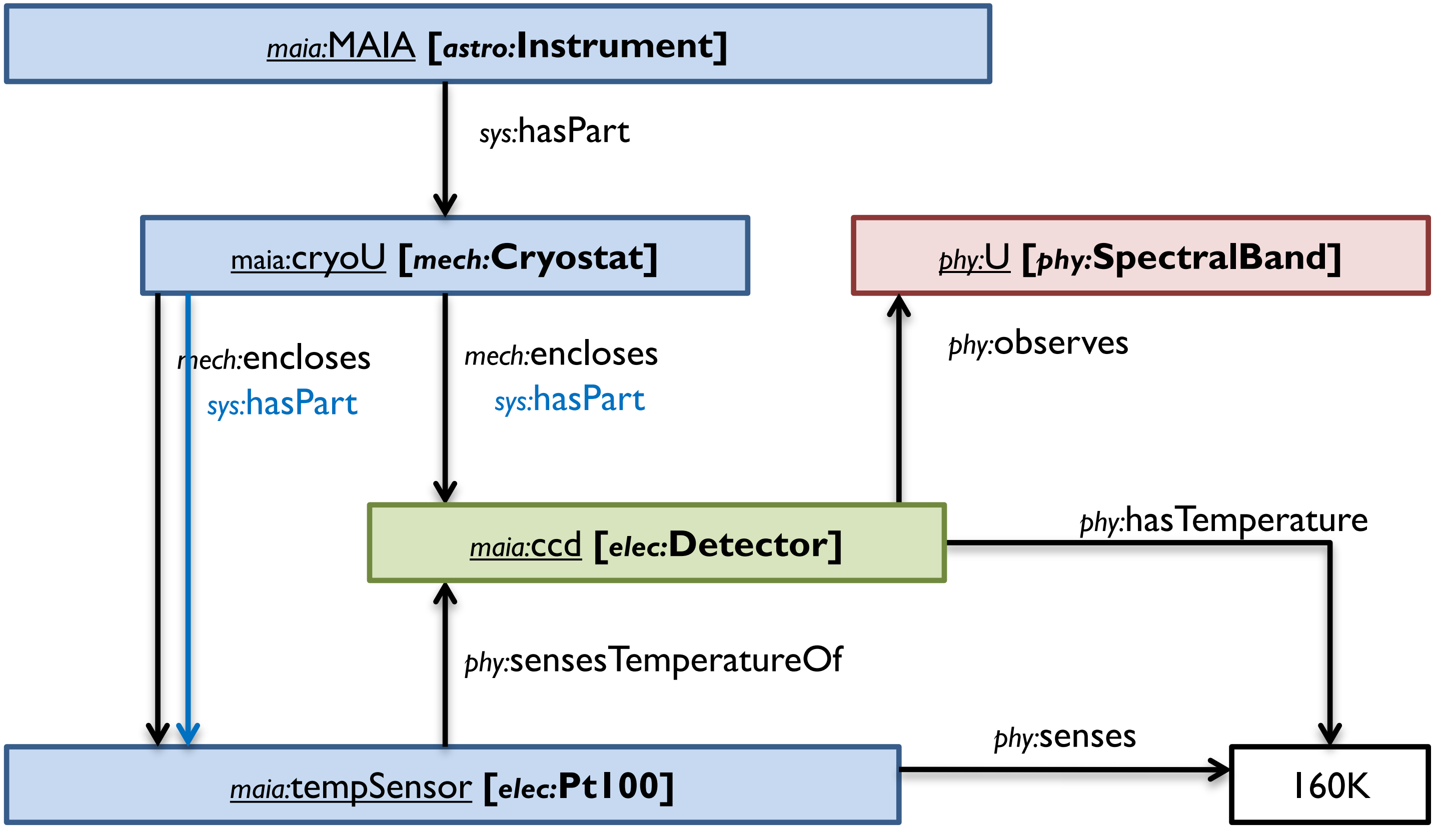

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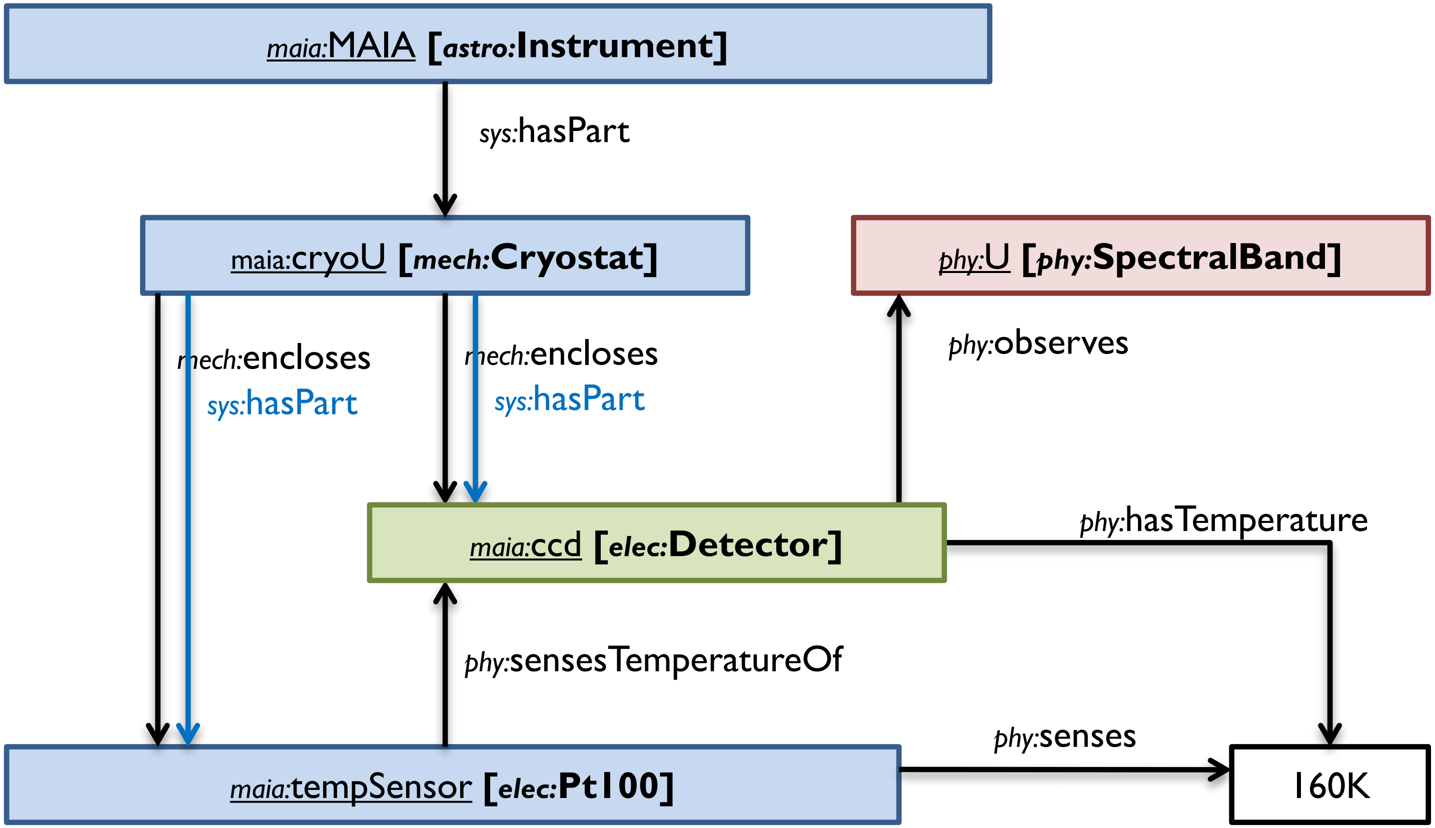

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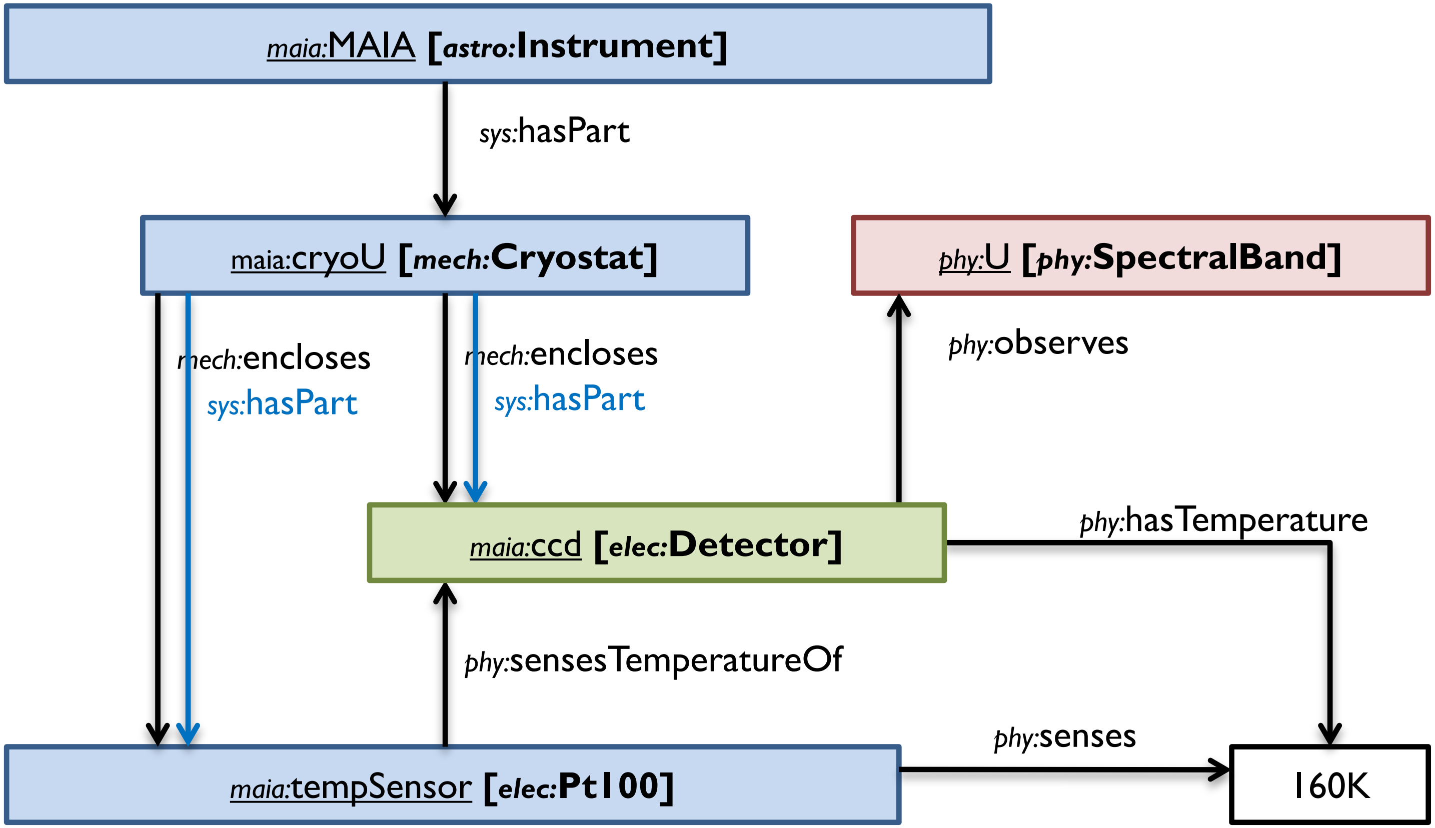

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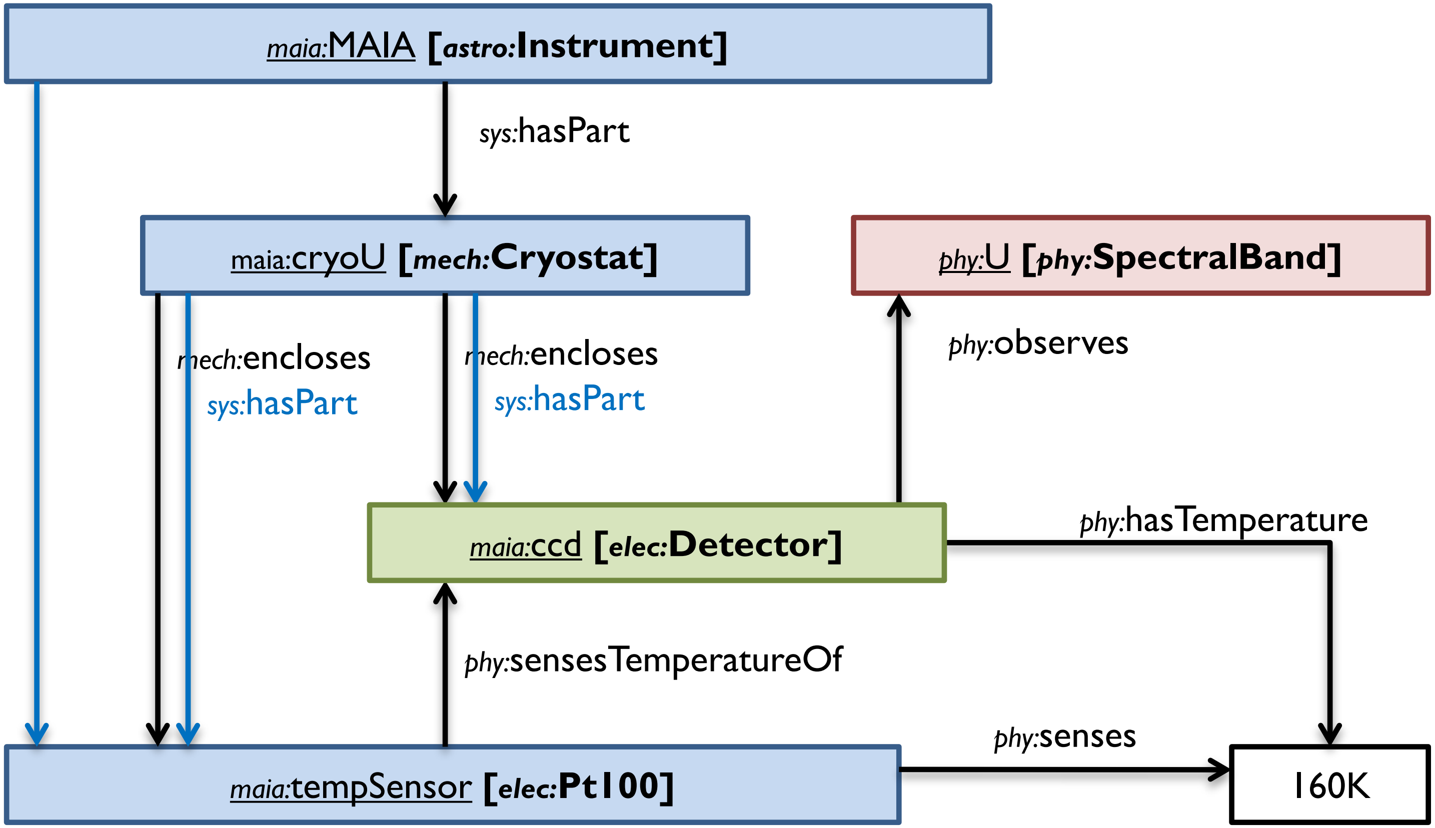
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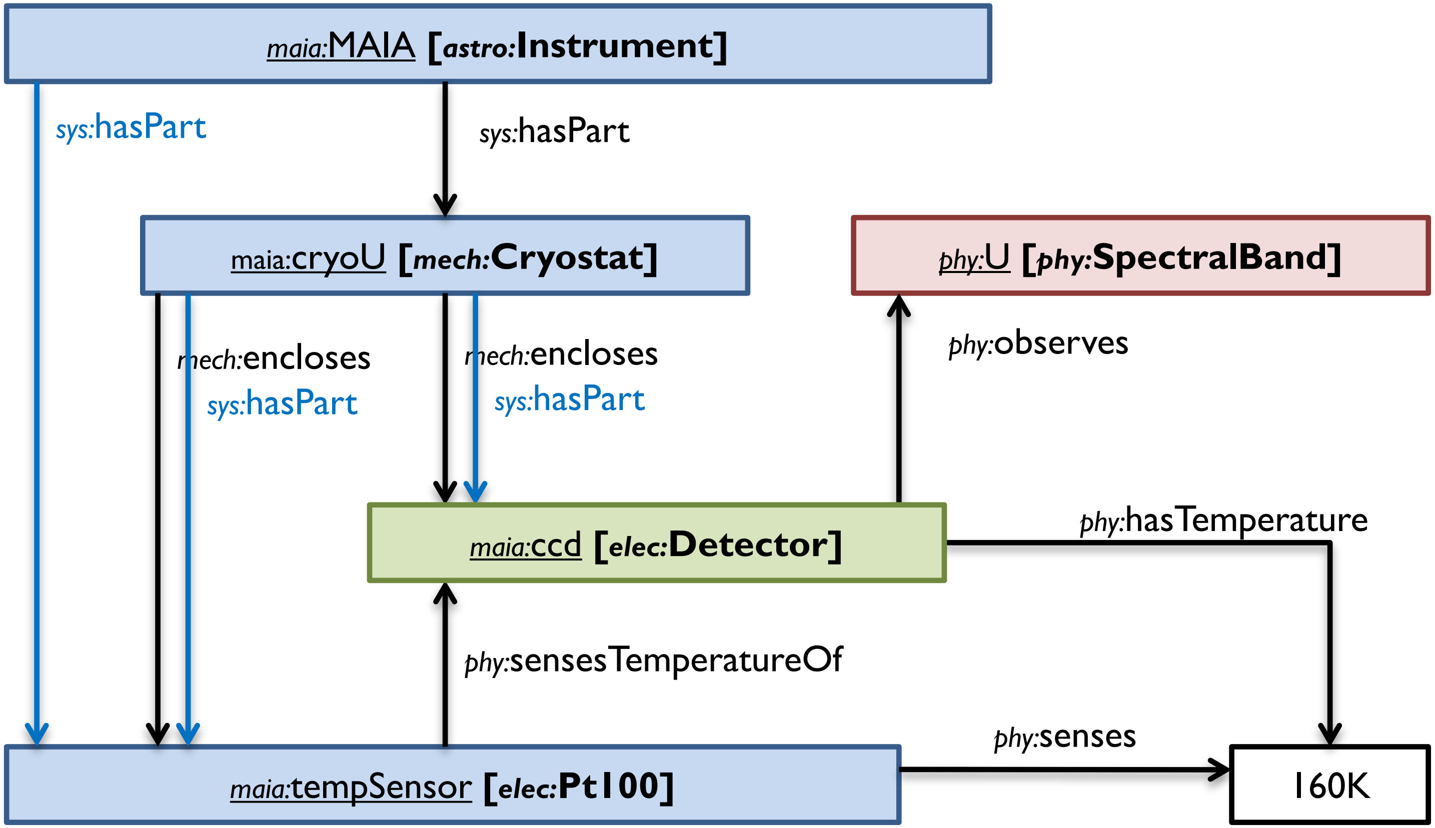

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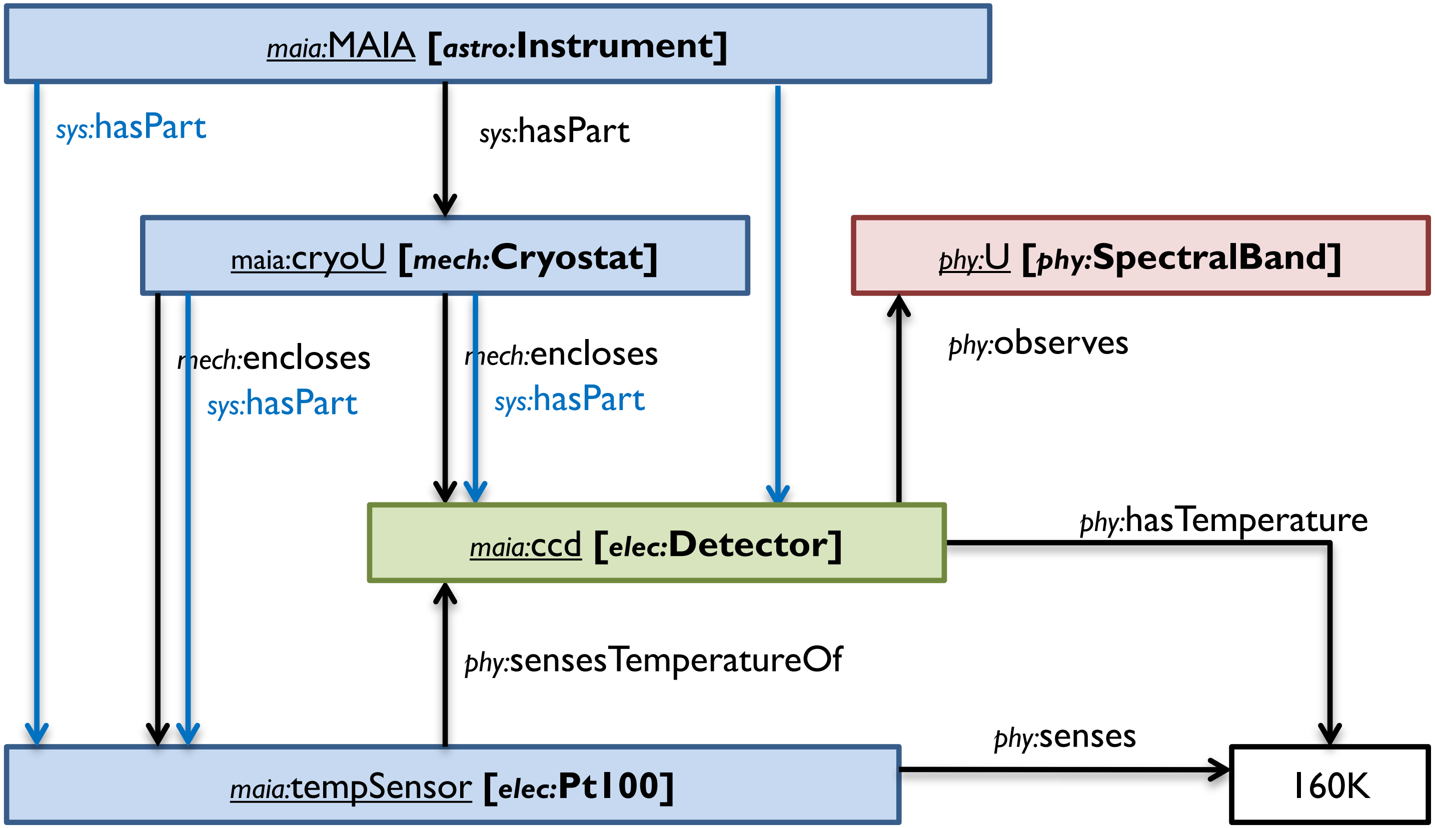

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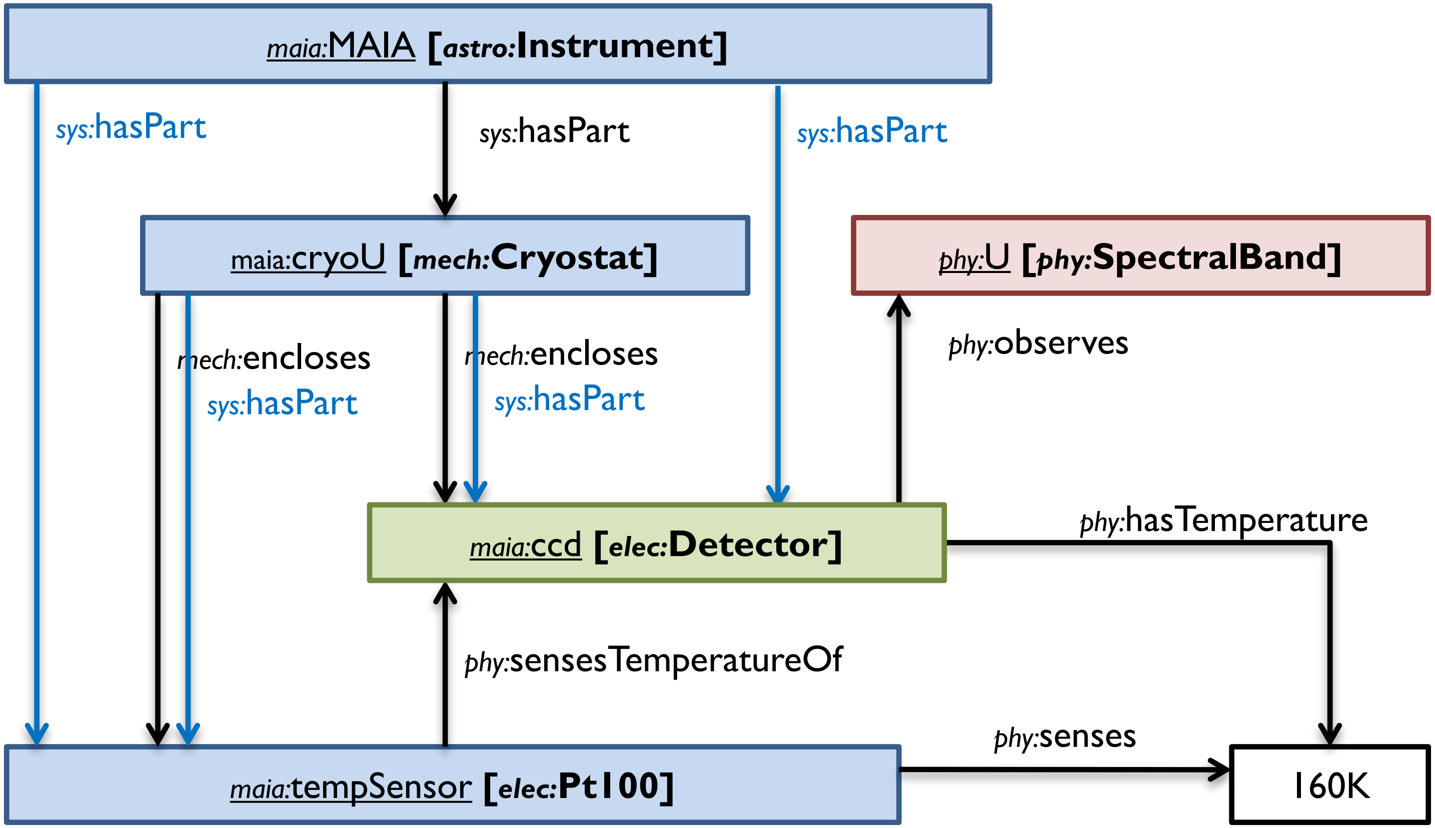

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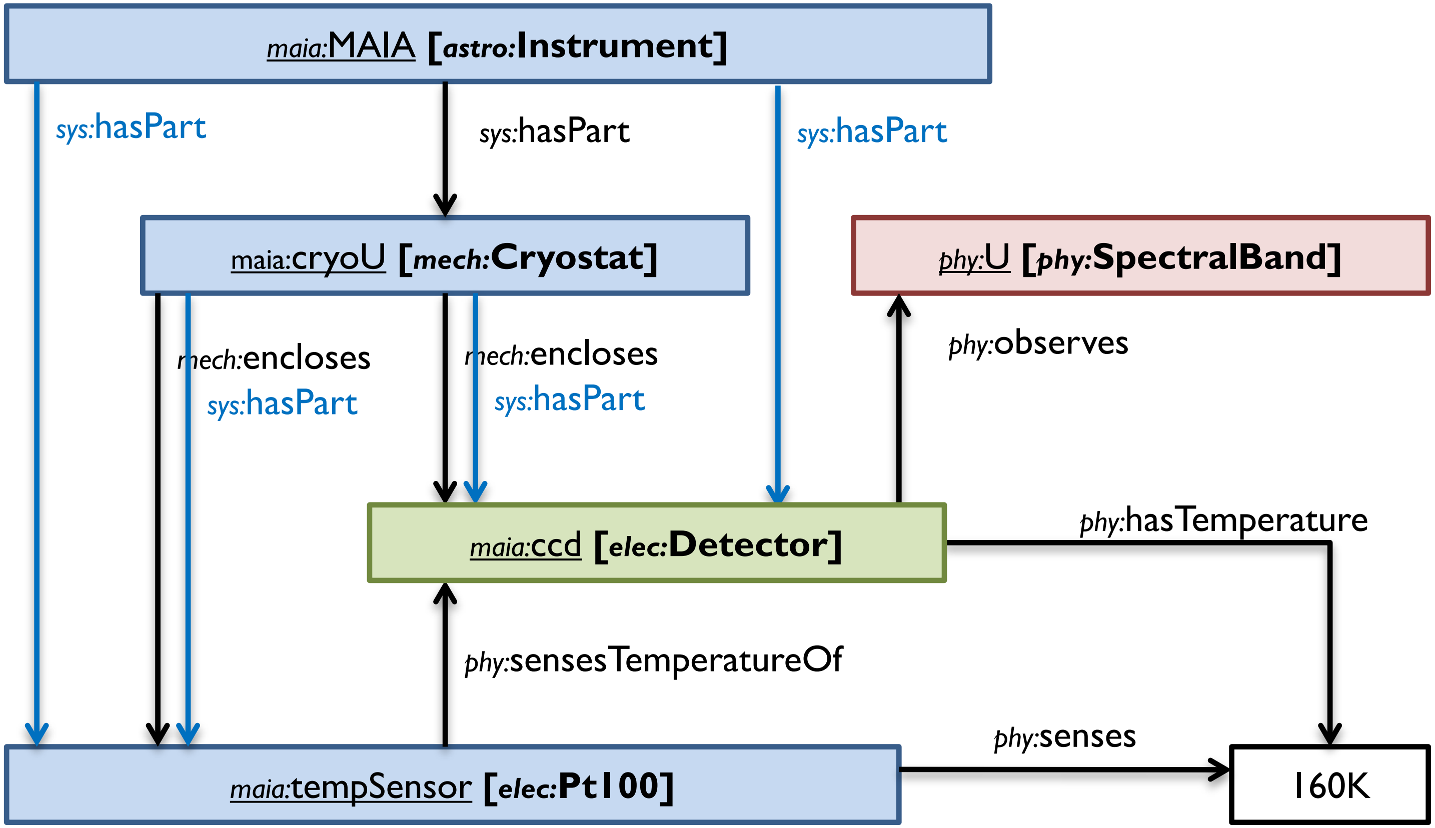
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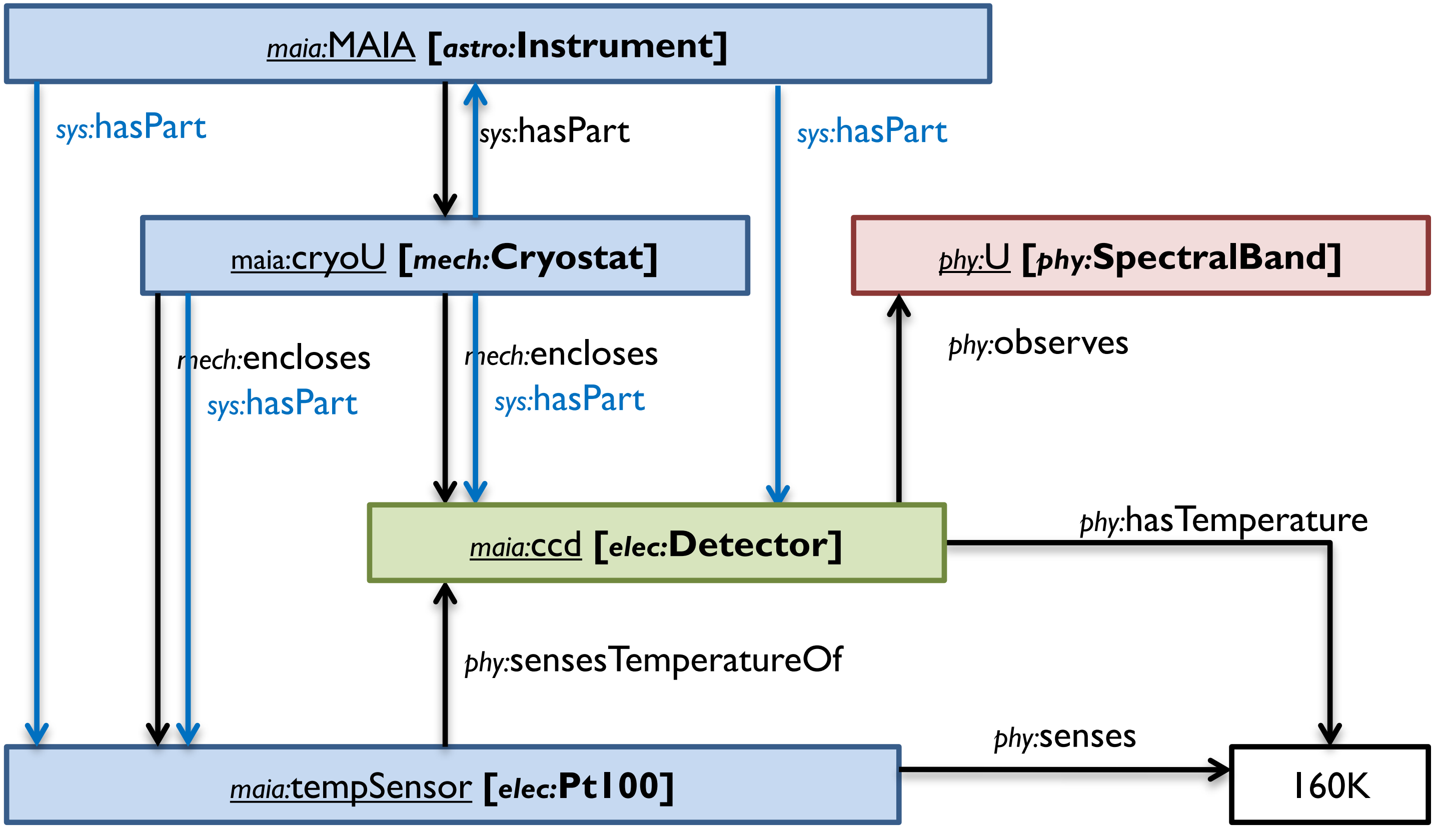
*phy:*U [*phy:*SpectralBand]
*mech:*encloses
*sys:*hasPart
*mech:*encloses
*sys:*hasPart
*phy:*observes
*maia:*ccd [*elec:*Detector]
*phy:*hasTemperature
*phy:*sensesTemperatureOf
*phy:*senses
*maia:*tempSensor [*elec:*Pt100]
160K

• *mech:*encloses	*rdfs:*subPropertyOf	*sys:*hasPart
• *sys:*hasPart	*rdf:*type	*owl:*TransitiveProperty

MAIA revisited



*maia:*MAIA [*astro:*Instrument]

*sys:*hasPart

*sys:*hasPart

*sys:*hasPart

*maia:*cryoU [*mech:*Cryostat]

*phy:*U [*phy:*SpectralBand]

*mech:*encloses

*sys:*hasPart

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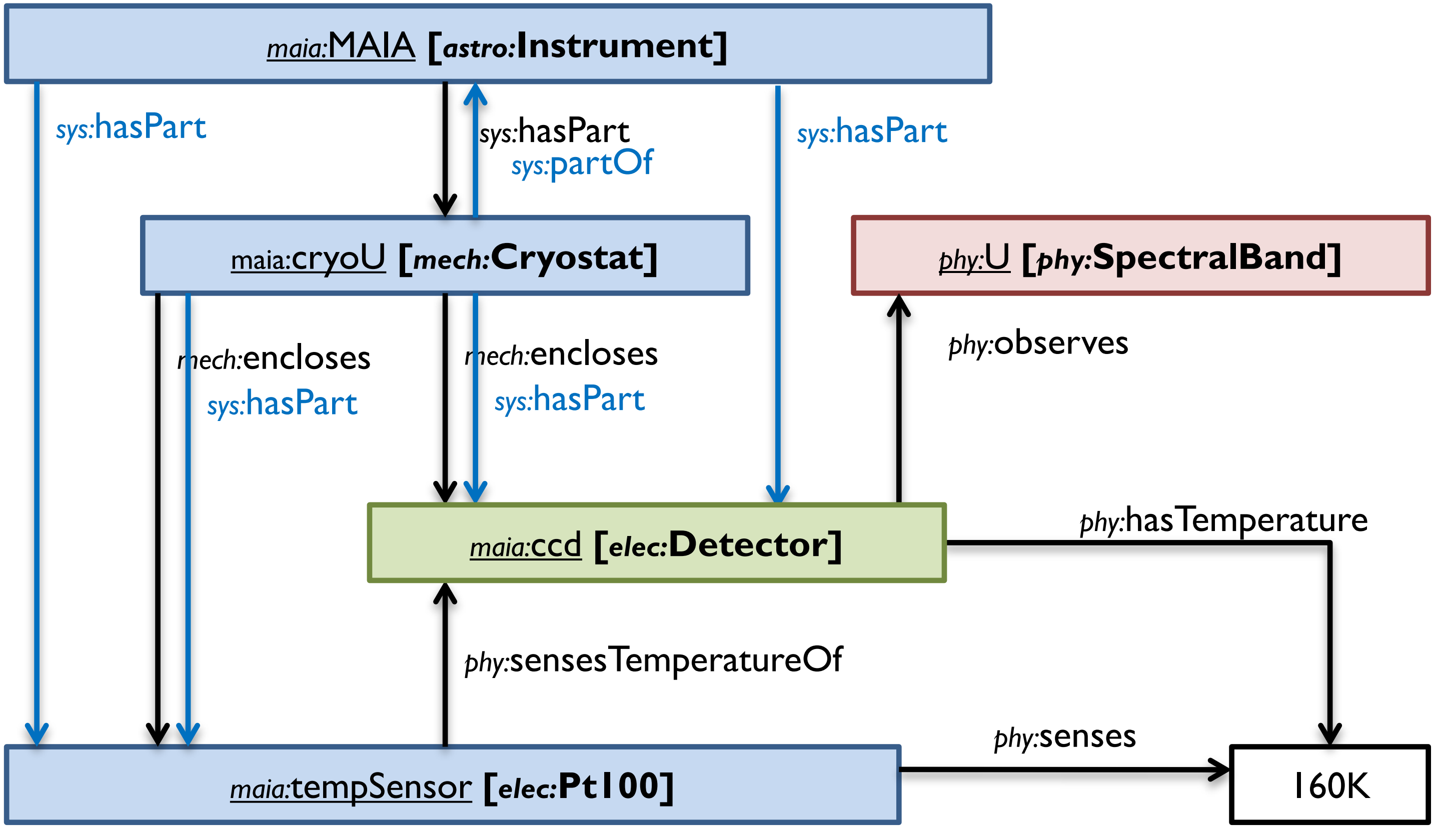

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*sys:*partOf
*sys:*hasPart
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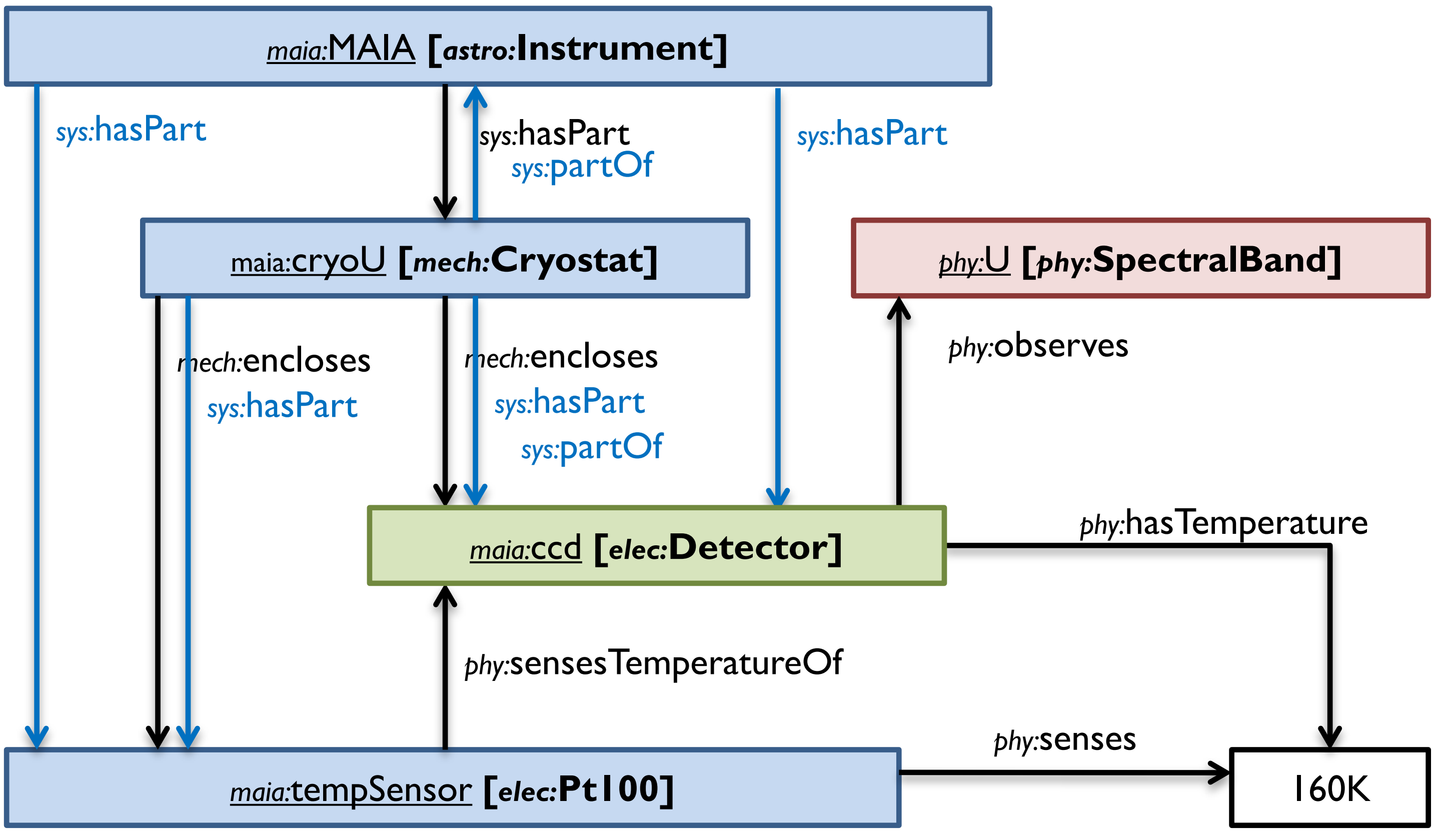

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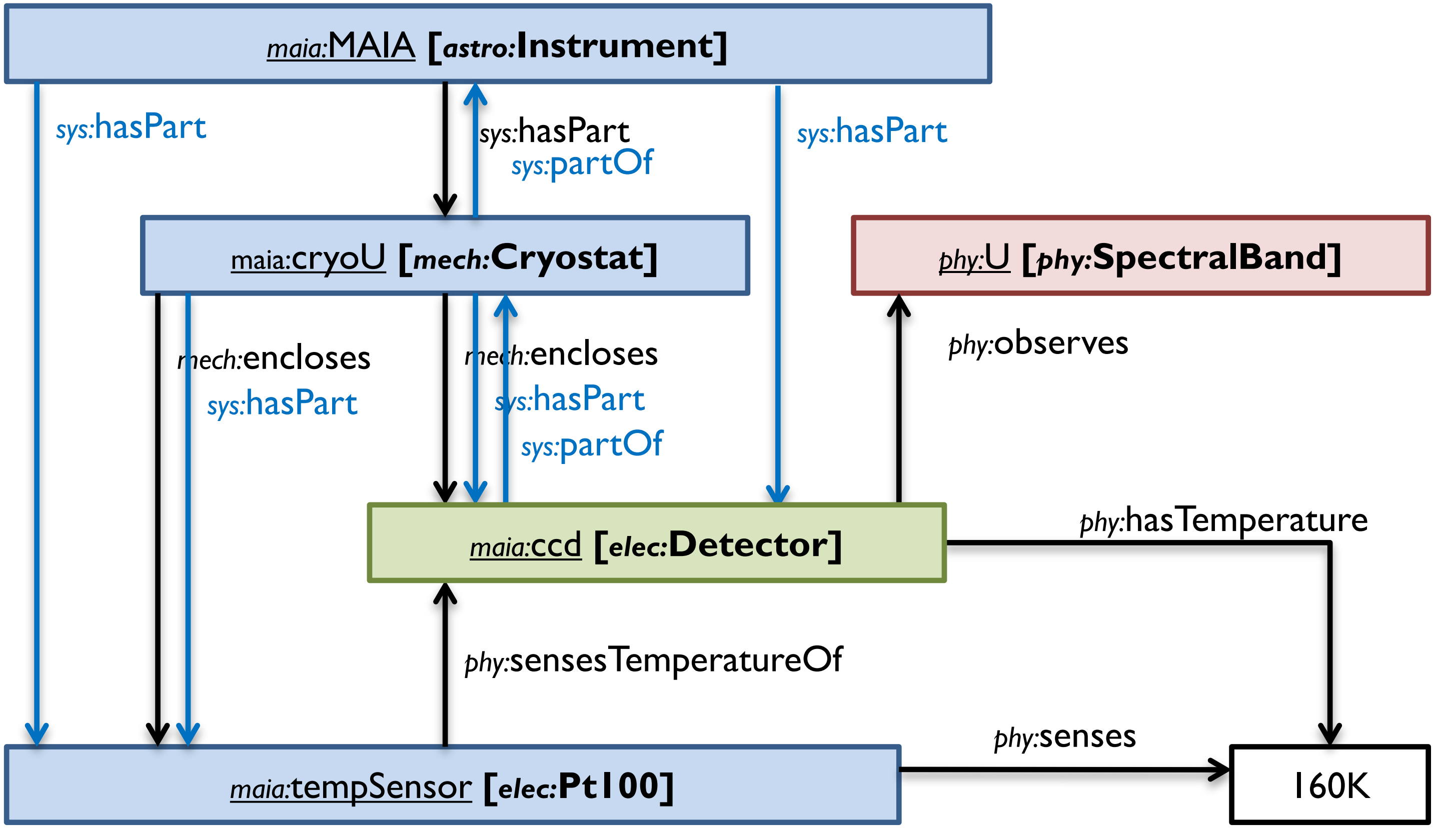
MAIA revisited



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*maia:*tempSensor [*elec:*Pt100]

160K

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*sys:*hasPart

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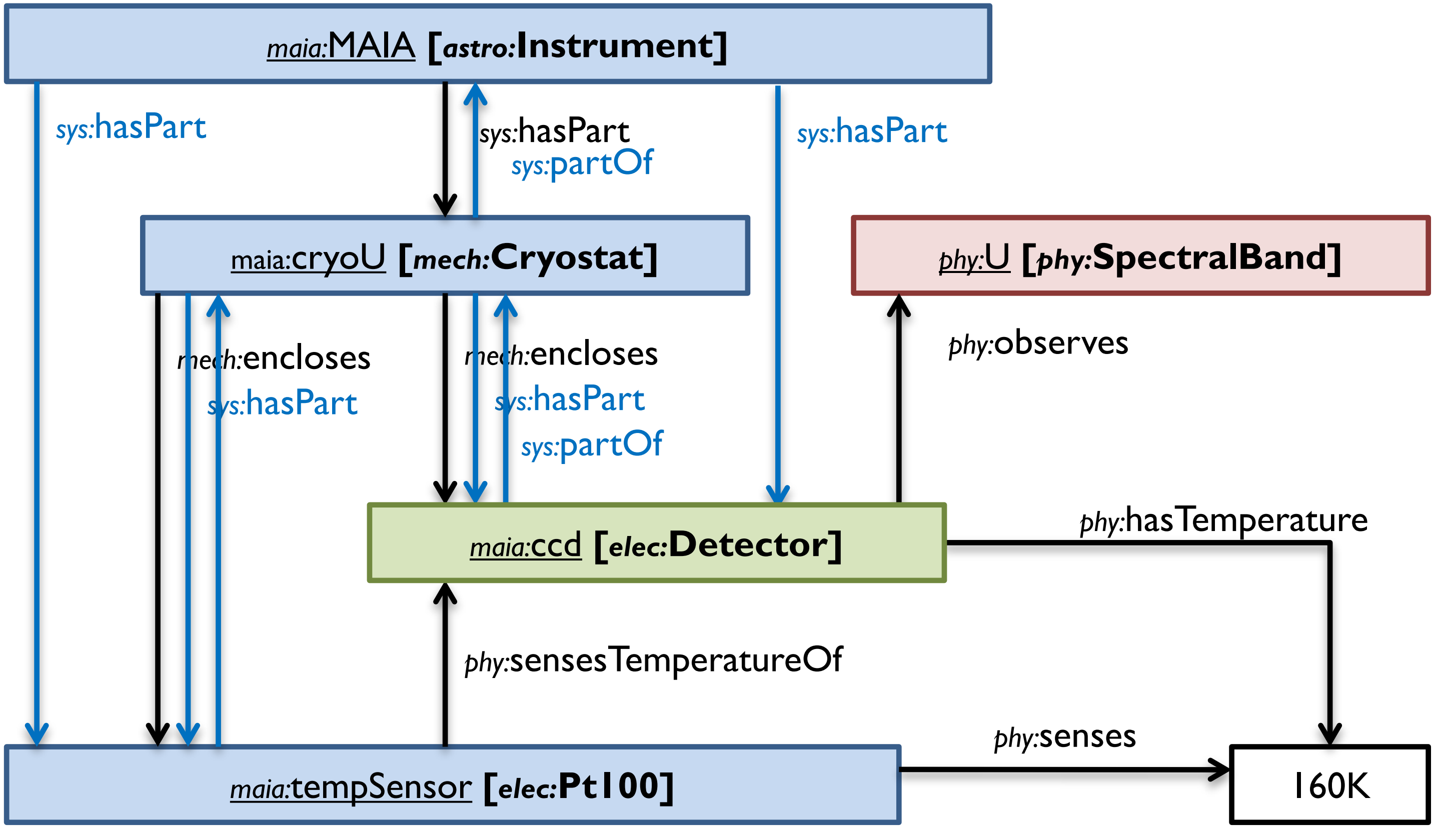
MAIA revisited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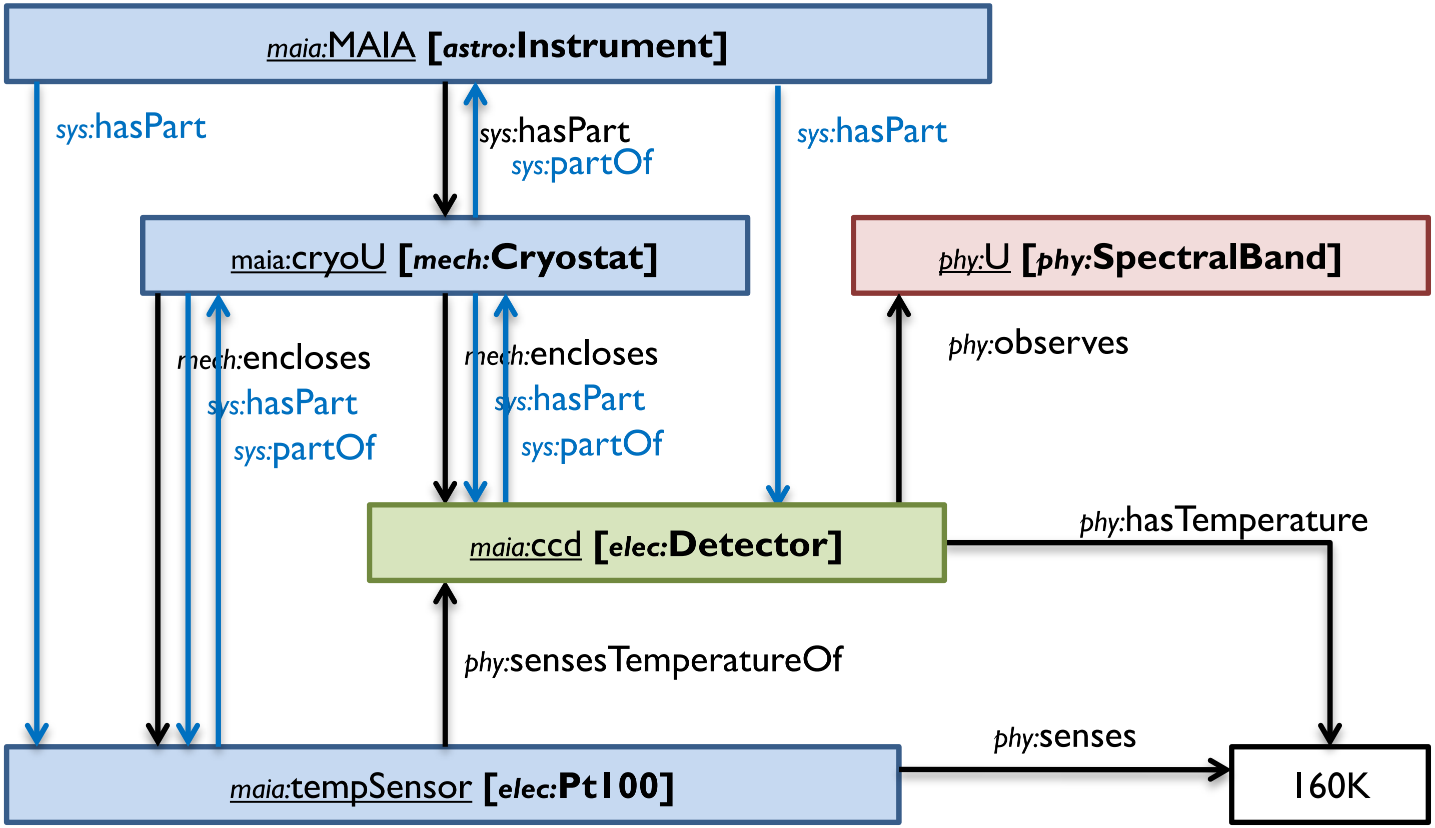

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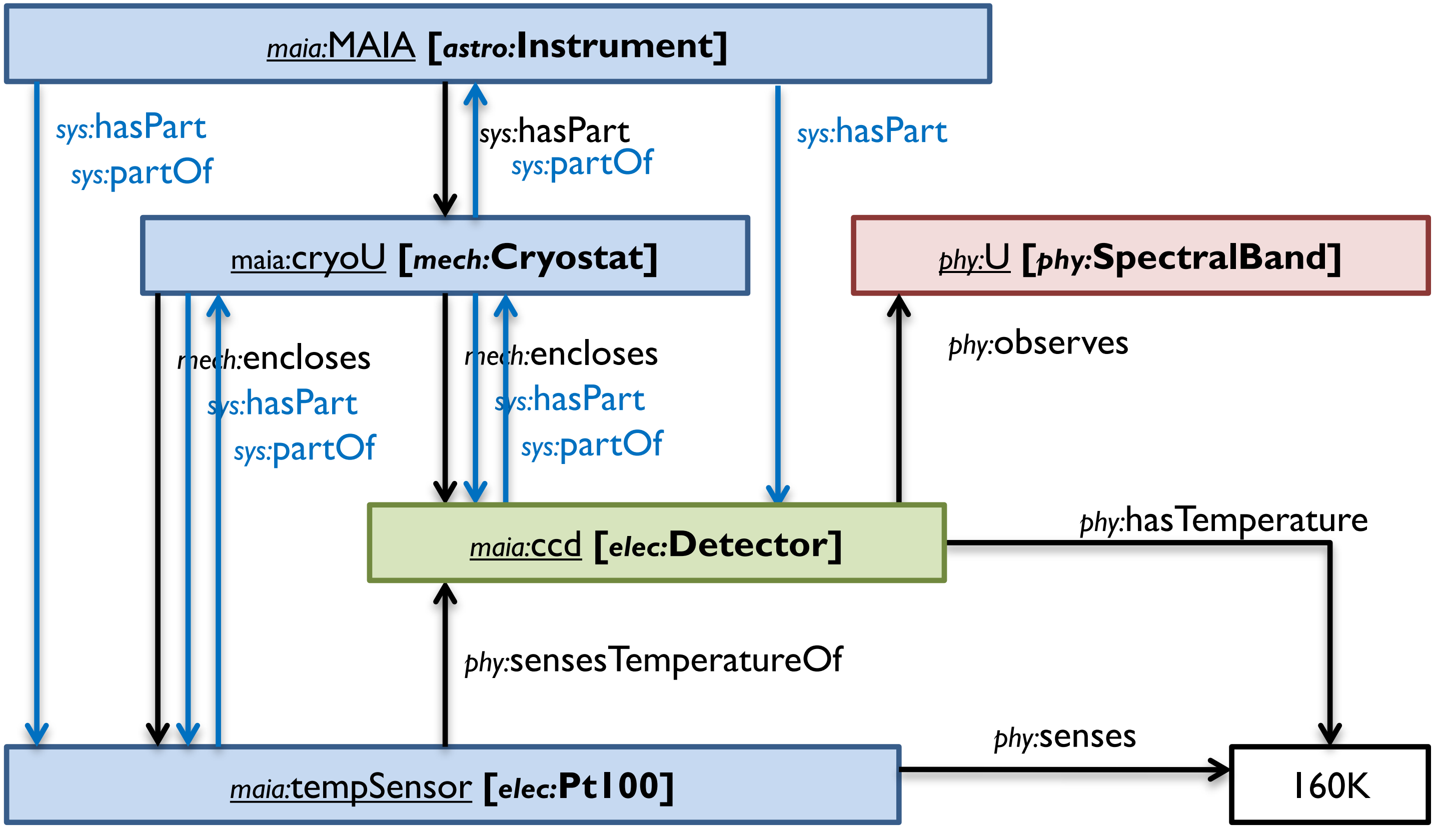
MAIA revisited



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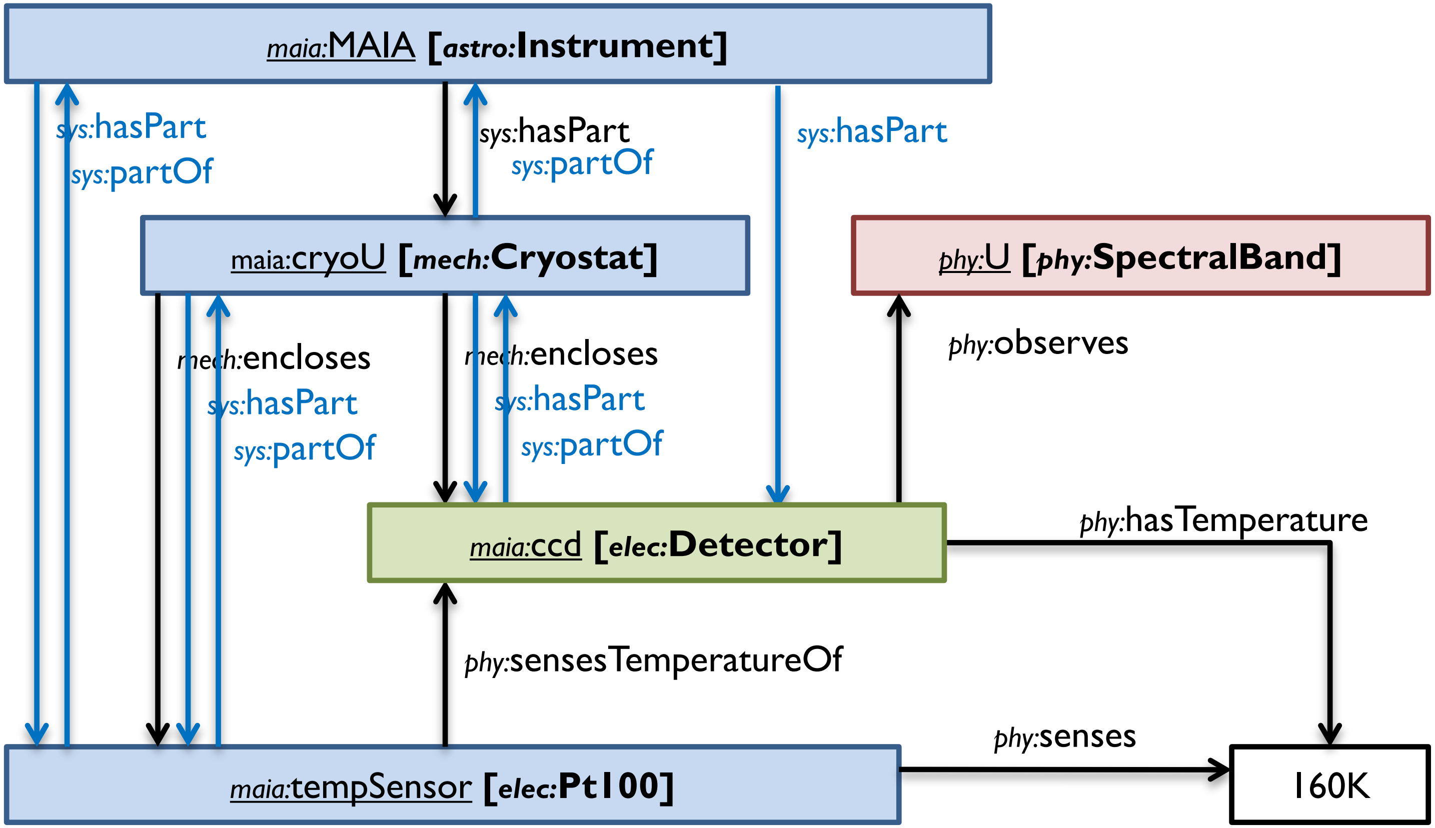

• mech:encloses	rdfs:subPropertyOf	sys:hasPart
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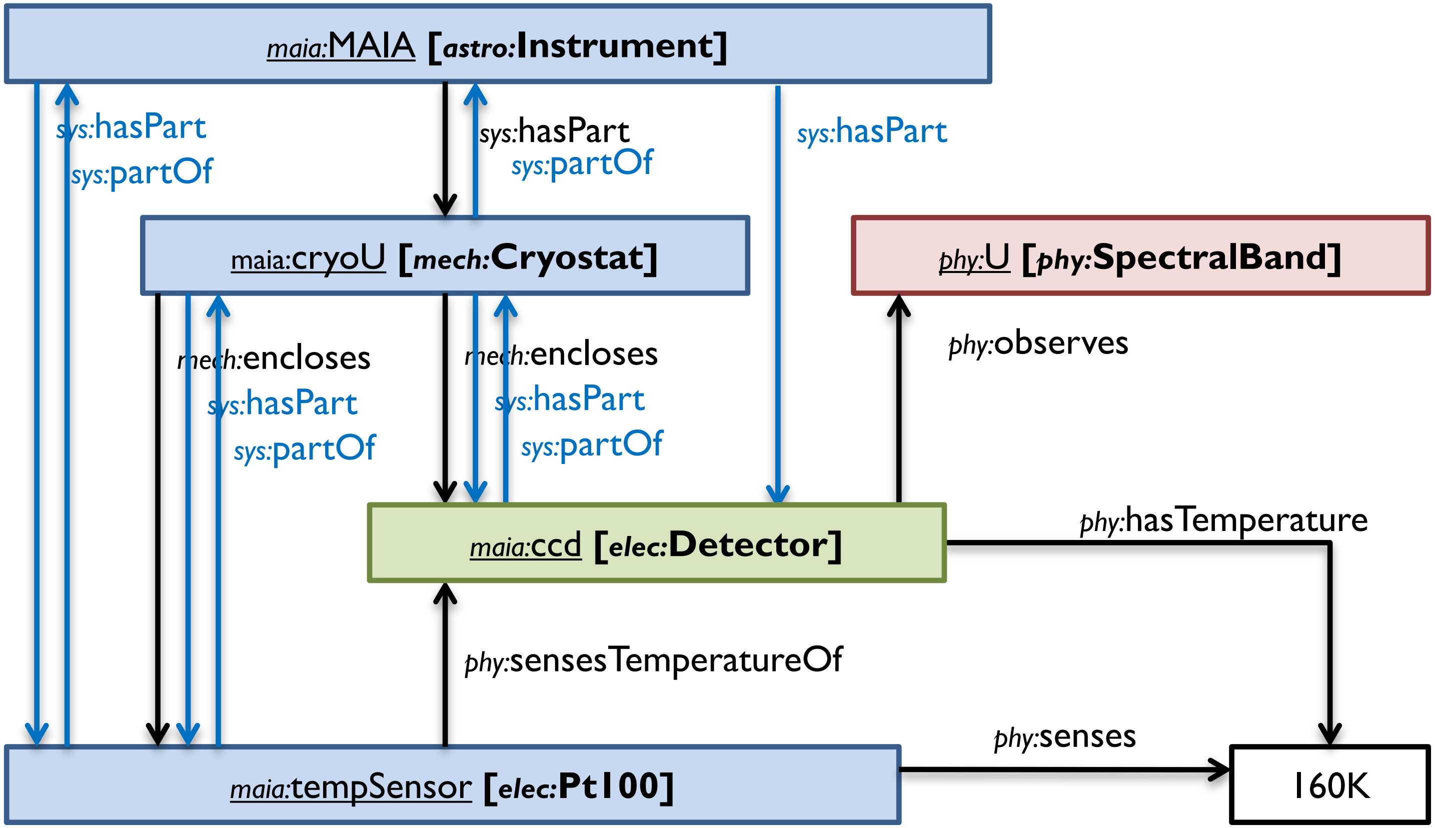
MAIA revisited



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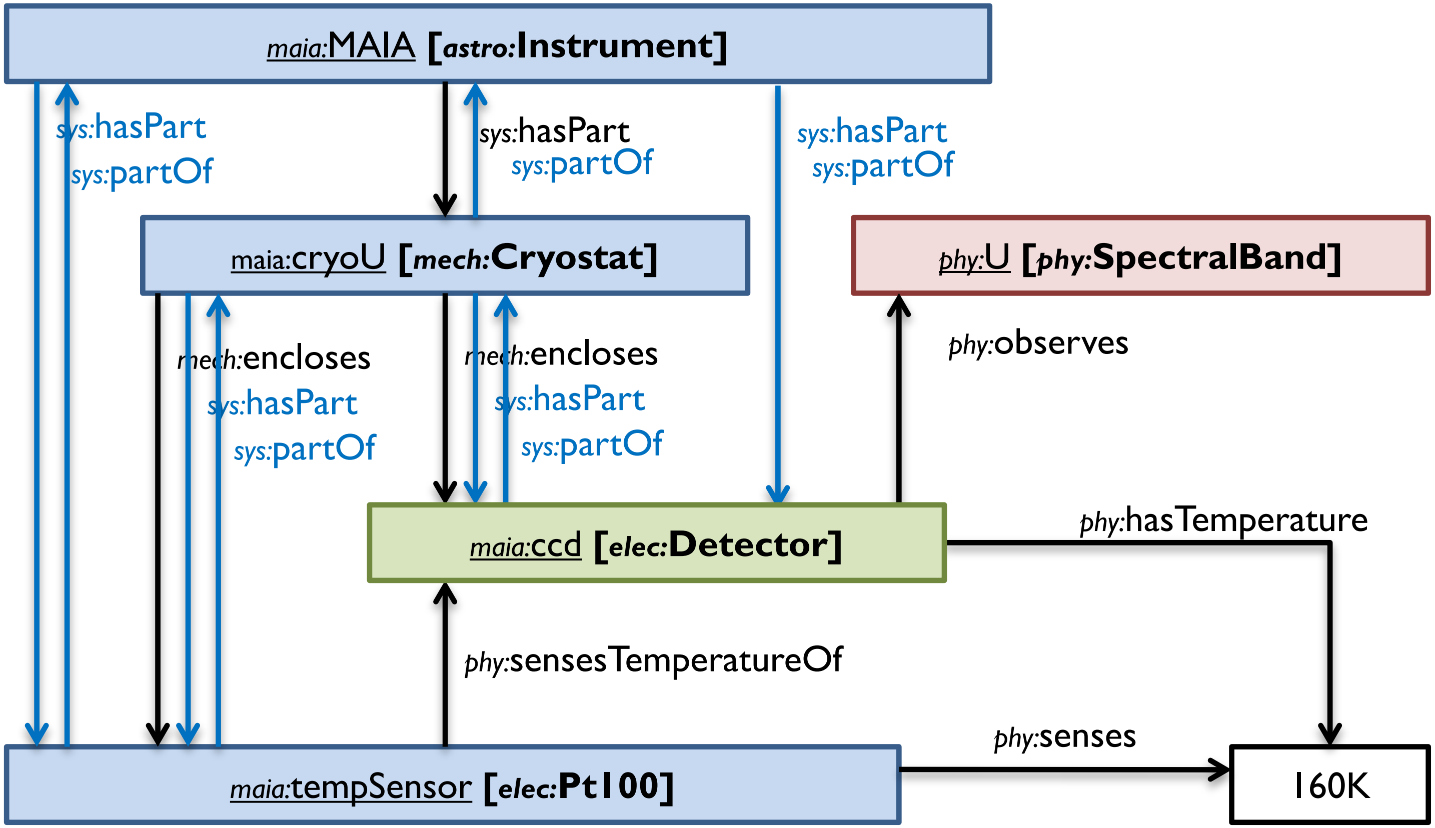
• *sys:*hasPart	*owl:*inverseOf	*sys:*partOf

MAIA revisited



maia:MAIA [astro:Instrument]

sys:hasPart

sys:partOf

sys:hasPart

sys:partOf

sys:hasPart

sys:partOf

maia:cryoU [mech:Cryostat]

phy:U [phy:SpectralBand]

mech:encloses

sys:hasPart

sys:partOf

mech:encloses

sys:hasPart

sys:partOf

phy:observes

maia:ccd [elec:Detector]

phy:hasTemperature

phy:sensesTemperatureOf

phy:senses

maia:tempSensor [elec:Pt100]

160K

• mech:encloses	rdfs:subPropertyOf	sys:hasPart
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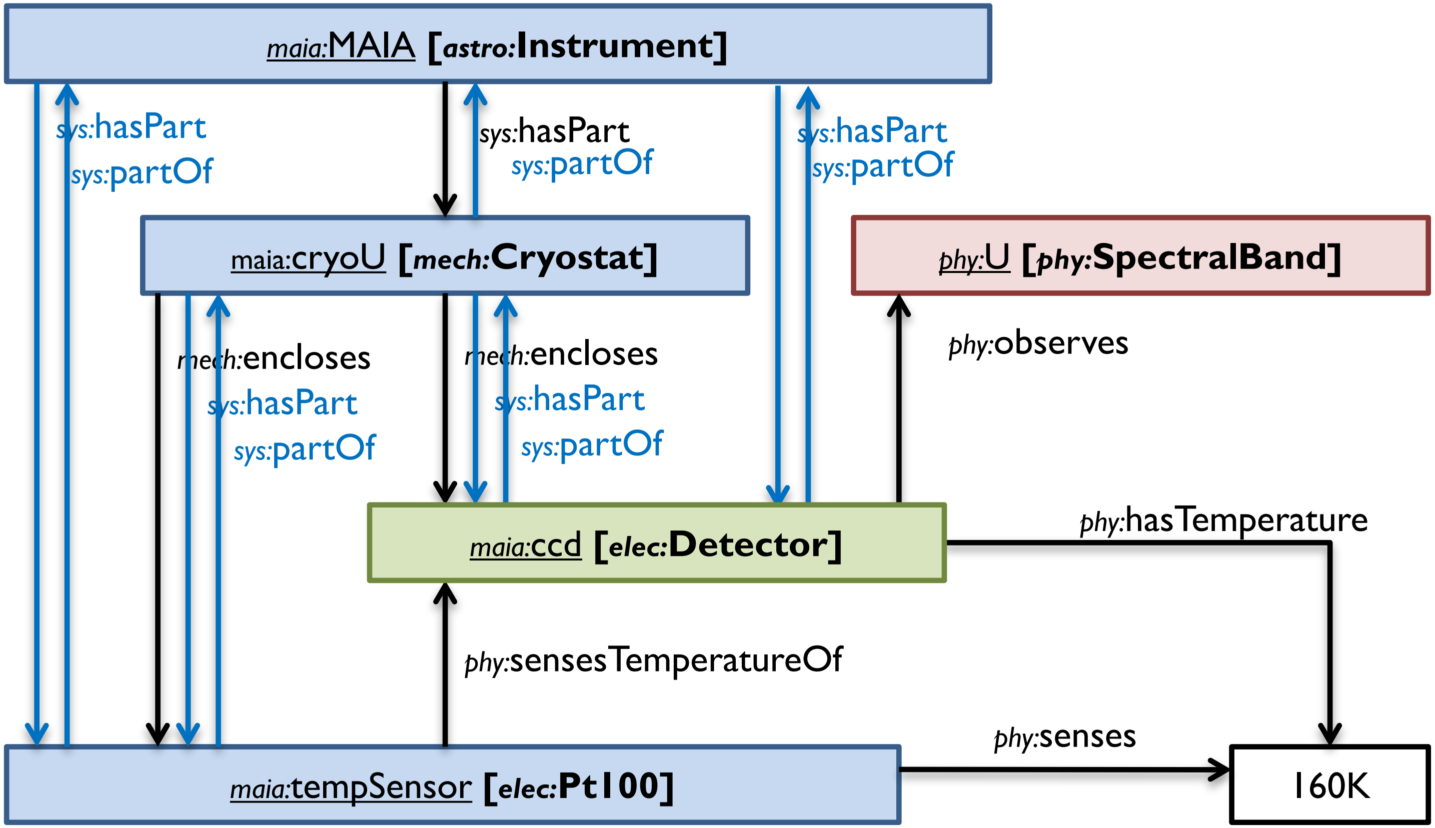
MAIA revisited



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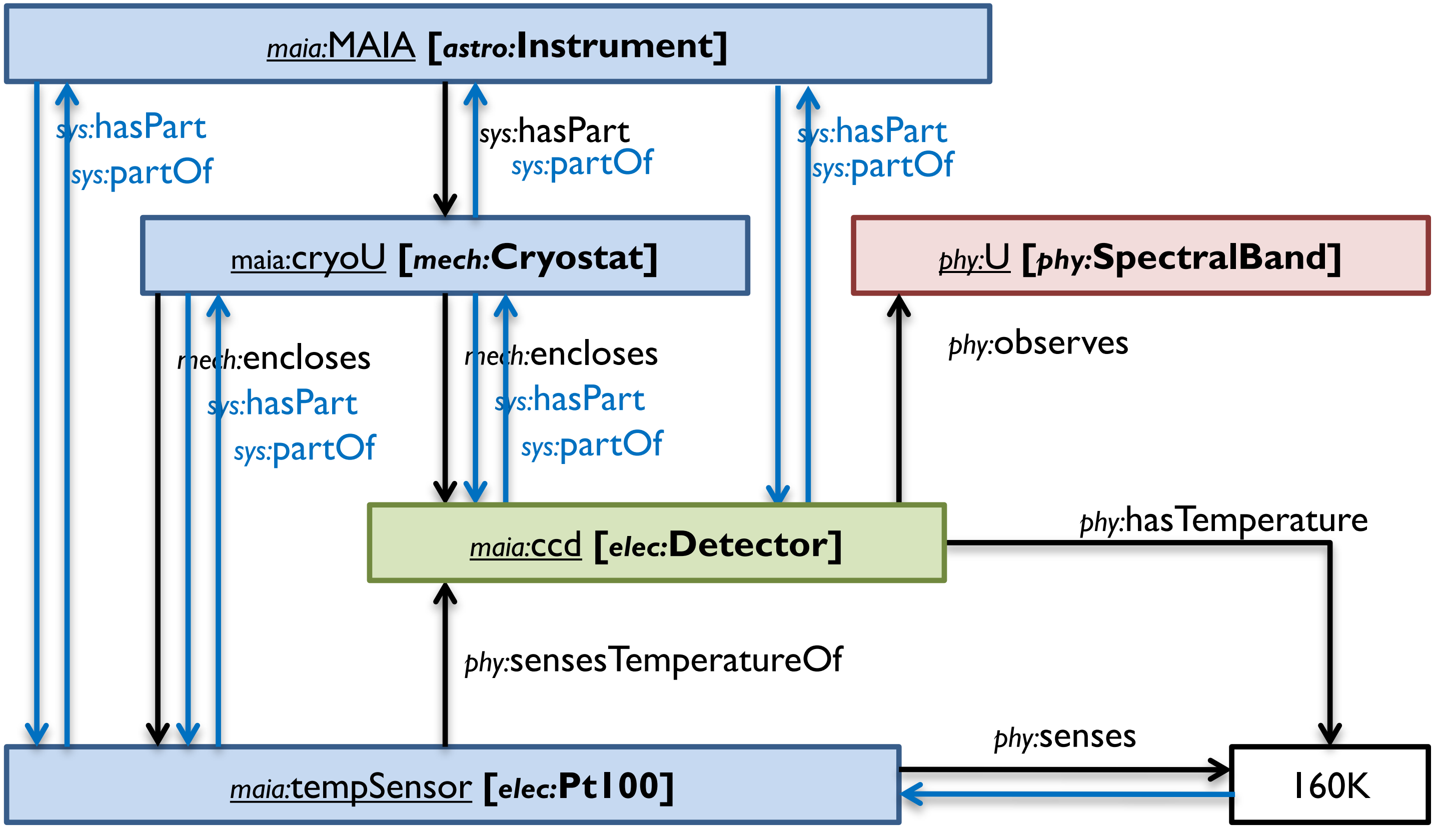

maia:MAIA [astro:Instrument]

sys:hasPart

sys:partOf

sys:hasPart

sys:partOf

sys:hasPart

sys:partOf

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phy:U [phy:SpectralBand]

mech:encloses

sys:hasPart

sys:partOf

mech:encloses

sys:hasPart

sys:partOf

phy:observes

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phy:senses

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160K

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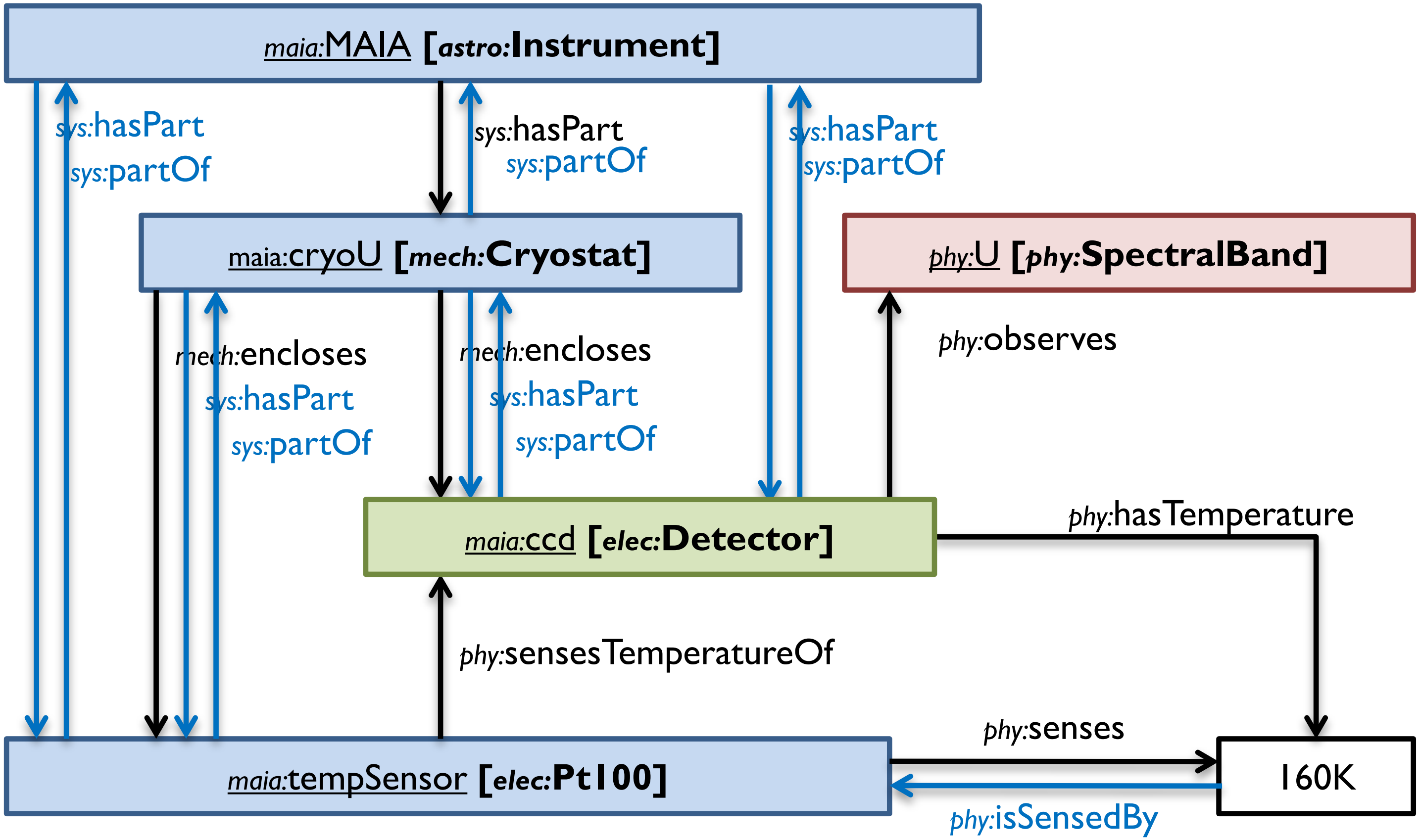
• sys:hasPart	owl:inverseOf	sys:partOf

MAIA revisited



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*sys:*partOf

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*sys:*hasPart

*sys:*partOf

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*mech:*encloses

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*phy:*senses

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160K

*phy:*isSensedBy

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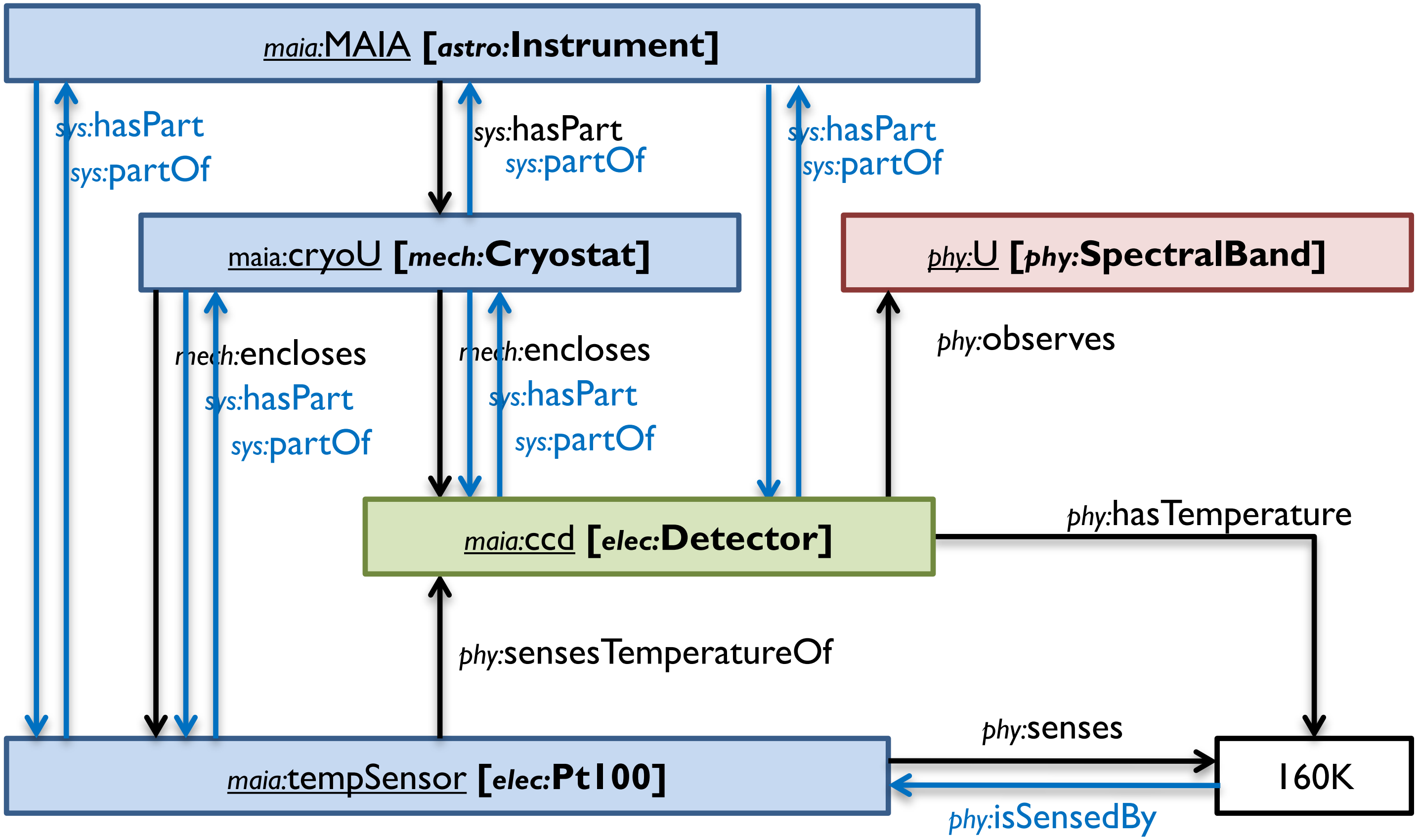
MAIA revisited



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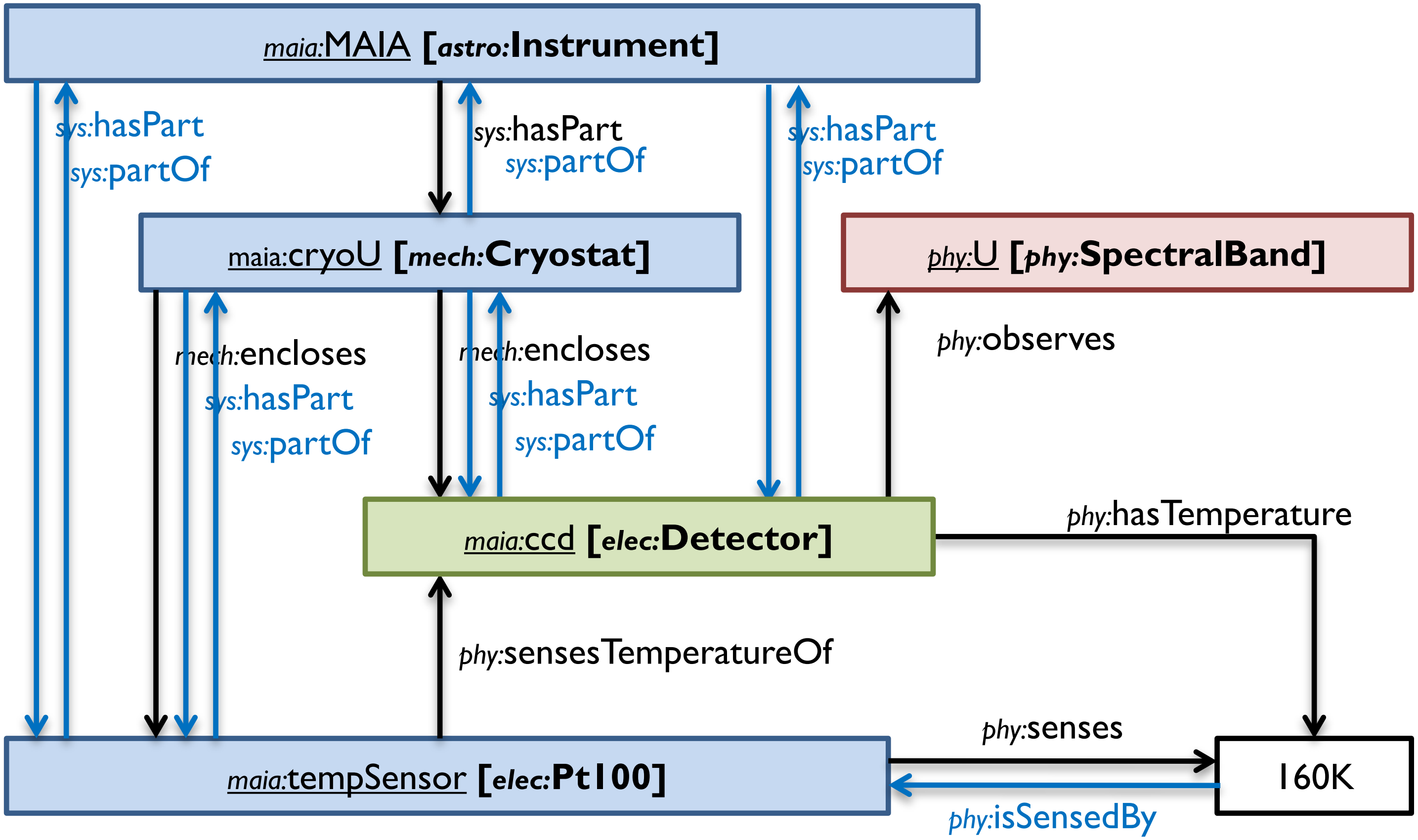

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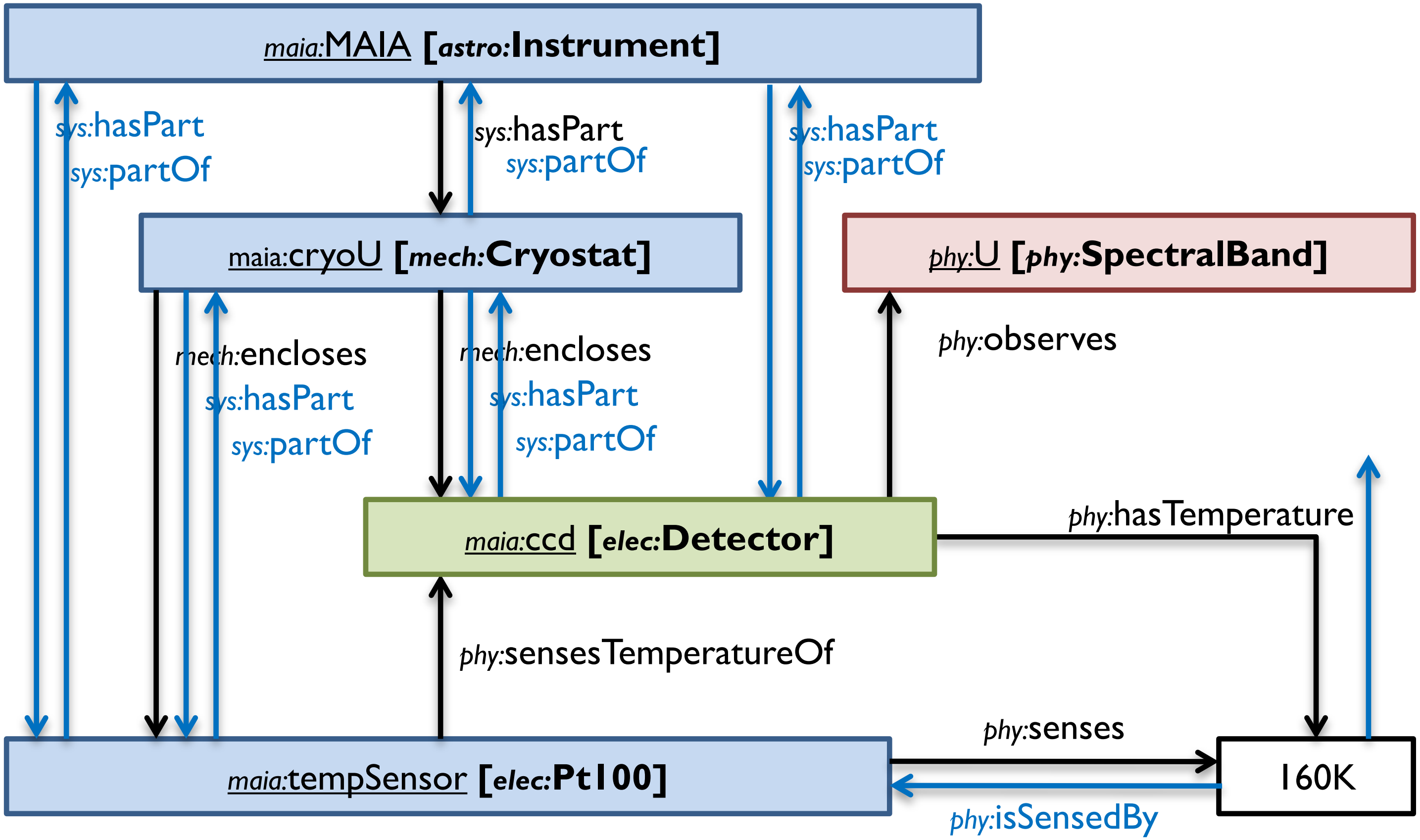
• *phy:*hasTemperature	*rdfs:*range	*phy:*Temperature

MAIA revisited



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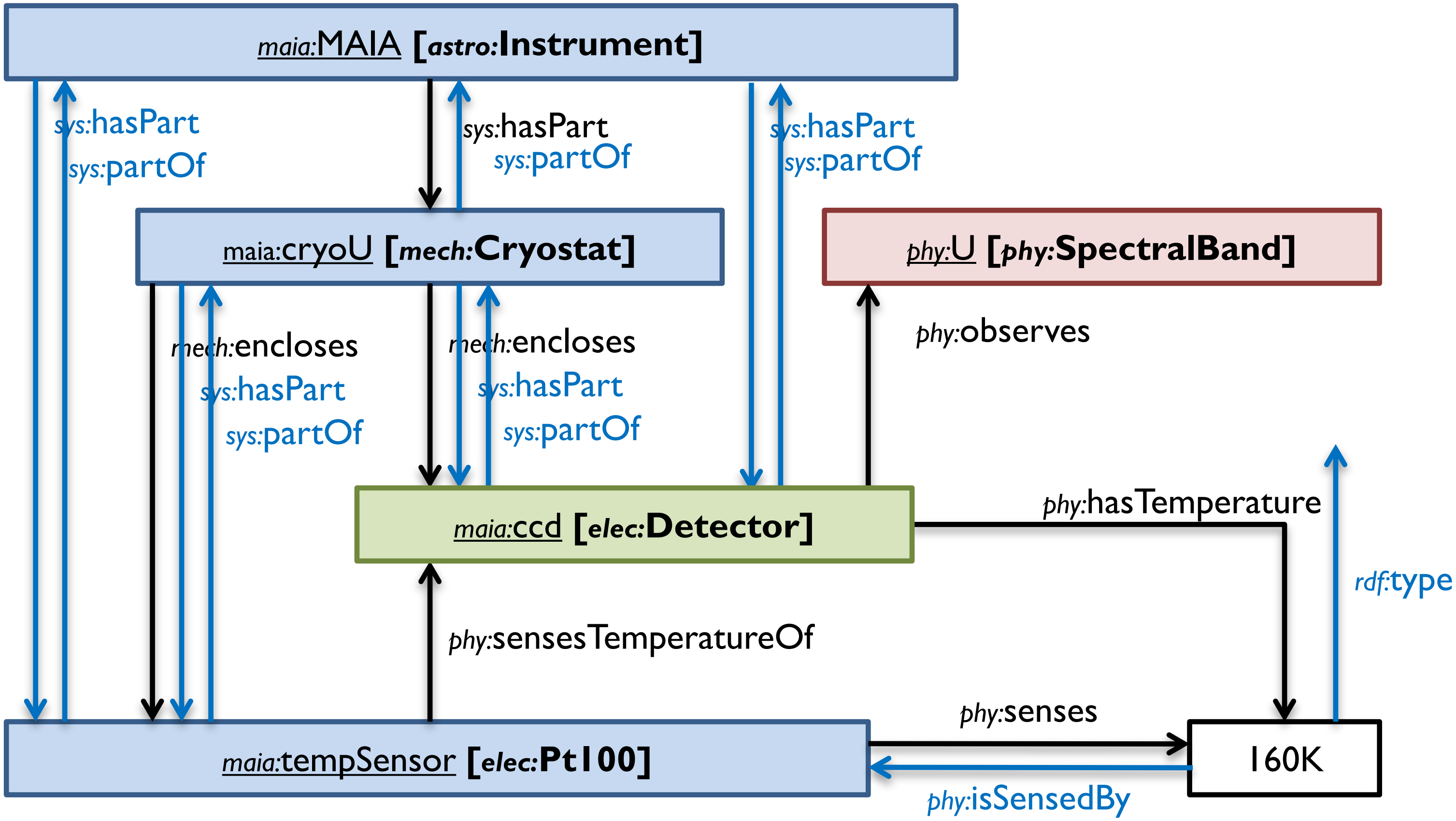
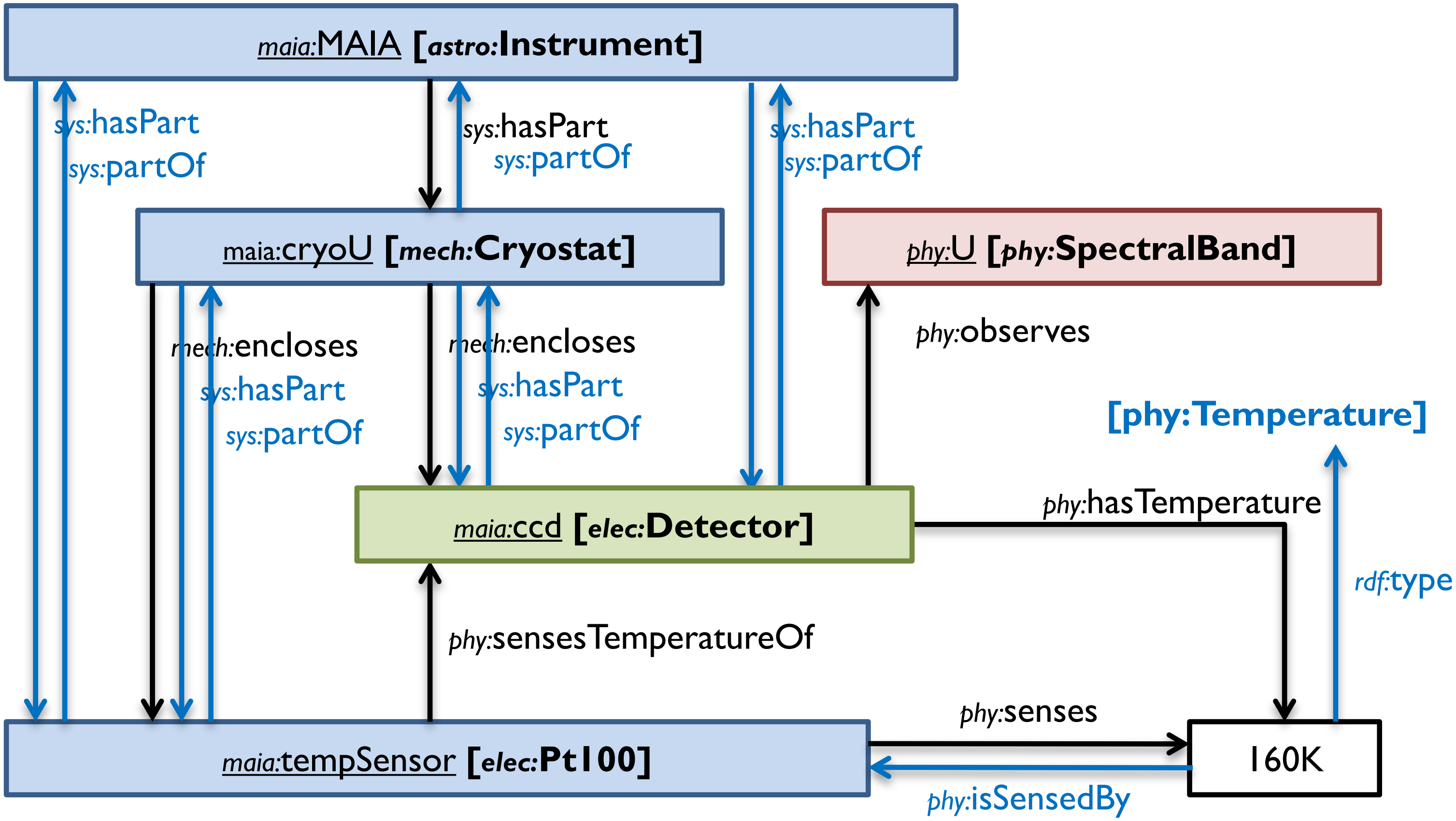
• *phy:*hasTemperature	*rdfs:*range	*phy:*Temperature

MAIA revisited



• *mech*:encloses	*rdfs*:subPropertyOf	*sys*:hasPart
• *sys*:hasPart	*rdf*:type	*owl*:TransitiveProperty
• *sys*:hasPart	*owl*:inverseOf	*sys*:partOf
• *phy*:senses	*owl*:inverseOf	*phy*:isSensedBy
• *phy*:hasTemperature	*rdfs*:range	*phy*:Temperature

MAIA revisited



*maia:*MAIA [*astro:*Instrument]

*maia:*cryoU [*mech:*Cryostat]

*phy:*U [*phy:*SpectralBand]

*maia:*ccd [*elec:*Detector]

*maia:*tempSensor [*elec:*Pt100]

160K

[phy:Temperature]

*sys:*hasPart

*sys:*partOf

*mech:*encloses

*phy:*observes

*phy:*hasTemperature

*rdf:*type

*phy:*sensesTemperatureOf

*phy:*senses

*phy:*isSensedBy

• *mech:*encloses	*rdfs:*subPropertyOf	*sys:*hasPart
• *sys:*hasPart	*rdf:*type	*owl:*TransitiveProperty
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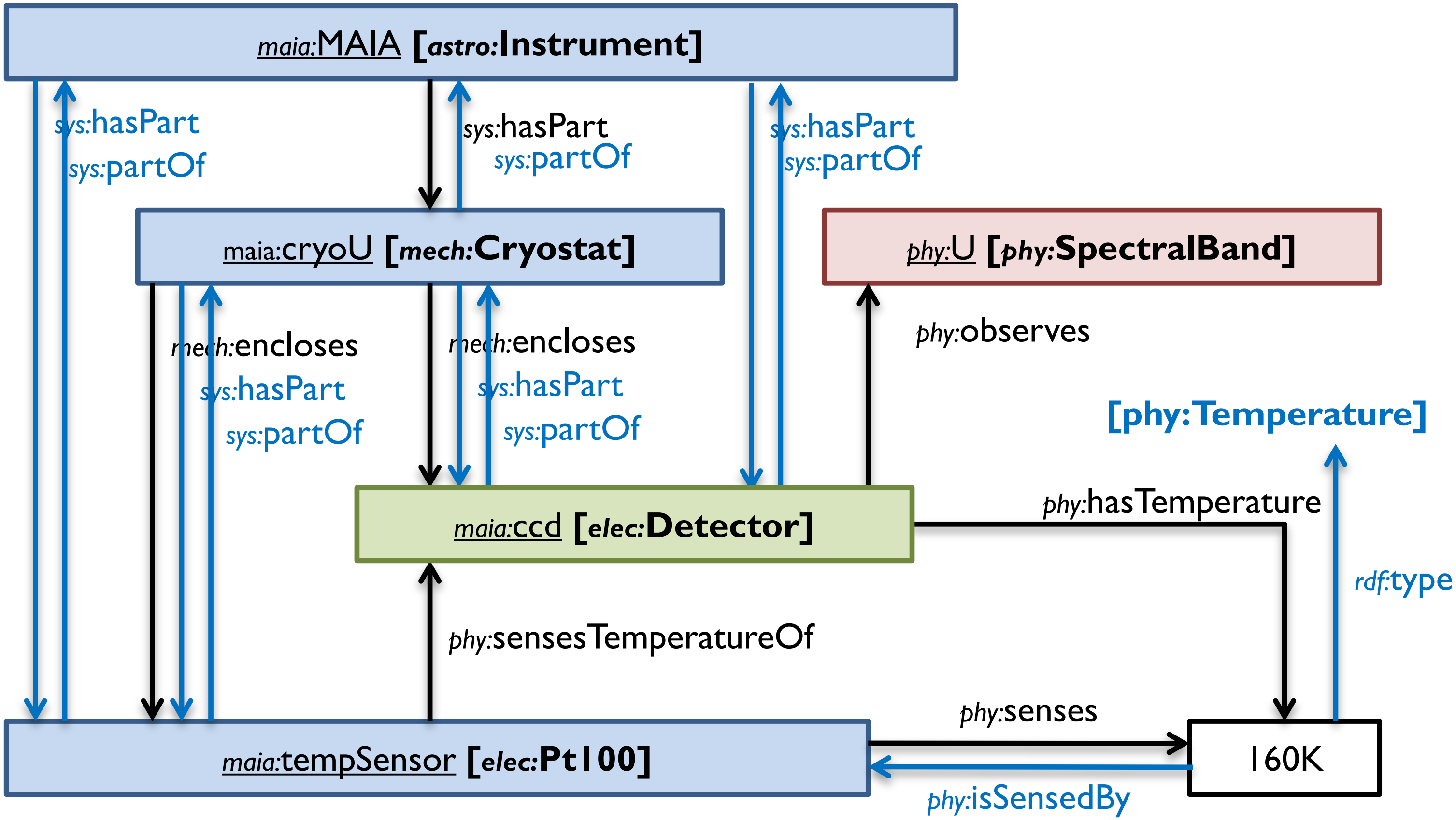
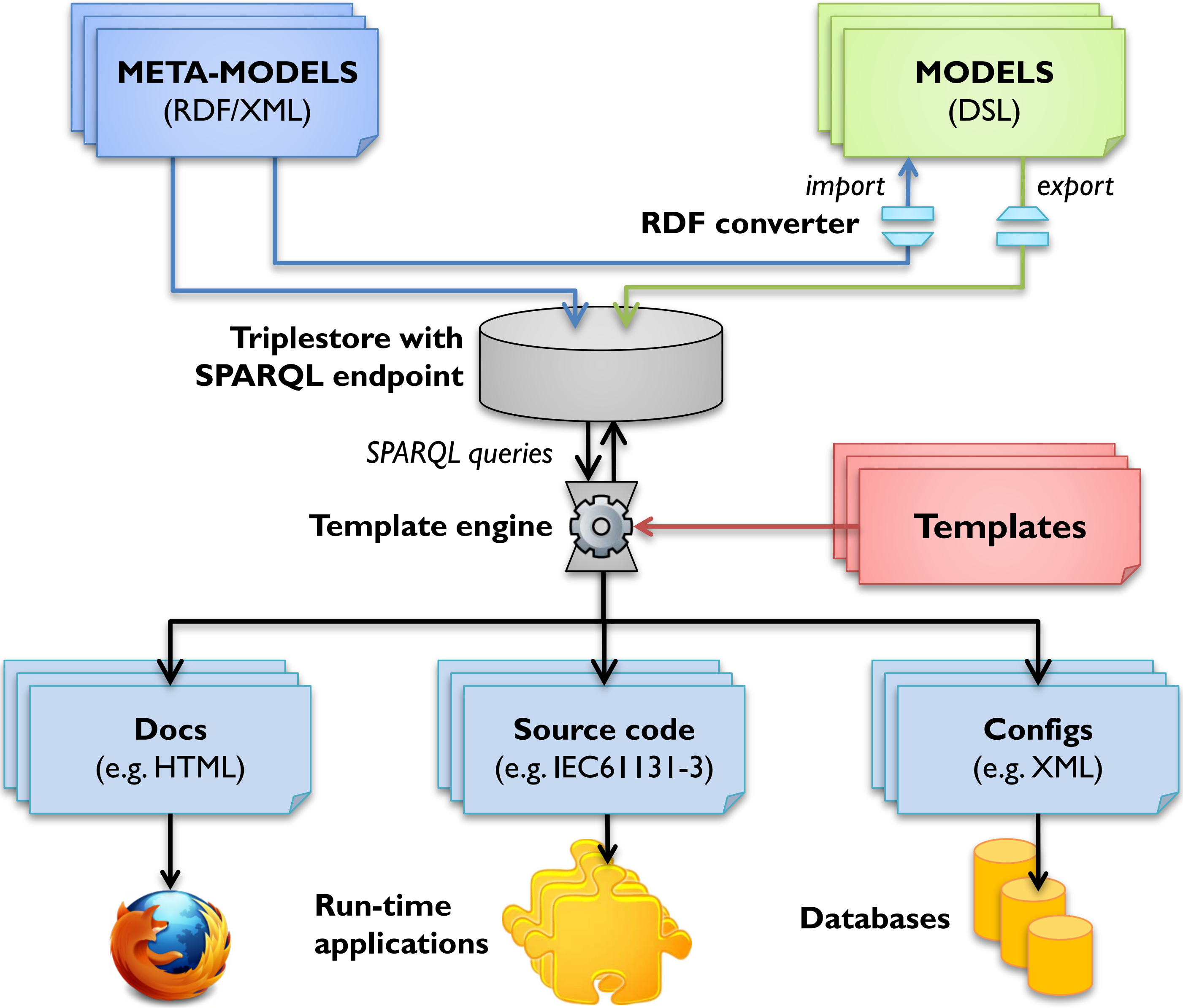
• *phy:*hasTemperature	*rdfs:*range	*phy:*Temperature

MAIA revisited



```
query  =   SELECT      ?value
           WHERE  {  ?det     sys:partOf                maia:Maia      .
                     ?det     phy:observes              phy:U          .
                     ?det     phy:hasTemperature        ?t             .
                     ?t       phy:hasValue              ?value         }
READ(query)
```

Prototype implementation



Prototype implementation

META-MODELS
(RDF/XML)

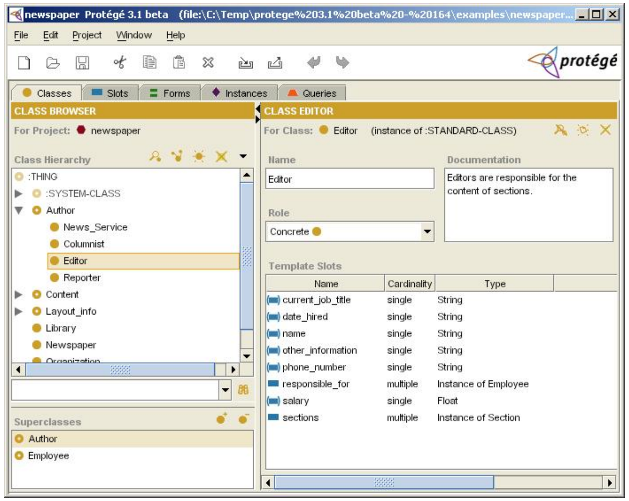
MODELS
(DSL)

import

export

- “Engineering ontologies”
- Provide the context
- “Heavy-weight” ontologies
- Most appropriate tool: ontology editor

http://protege.stanford.edu


newspaper Protégé 3.1 beta (file:\C:\Temp\protege%203.1%20beta%20-%20164\examples\newspaper...
File
Edit
Project
Window
Help
protégé
Classes
Slots
Forms
Instances
Queries

CLASS BROWSER

For Project: newspaper

Class Hierarchy

- :THING
- :SYSTEM-CLASS
- Author
  - News_Service
  - Columnist
  - Editor
  - Reporter
- Content
- Layout_info
- Library
- Newspaper
- Organization

Superclasses

- Author
- Employee

CLASS EDITOR

For Class: Editor (instance of :STANDARD-CLASS)

Name: Editor

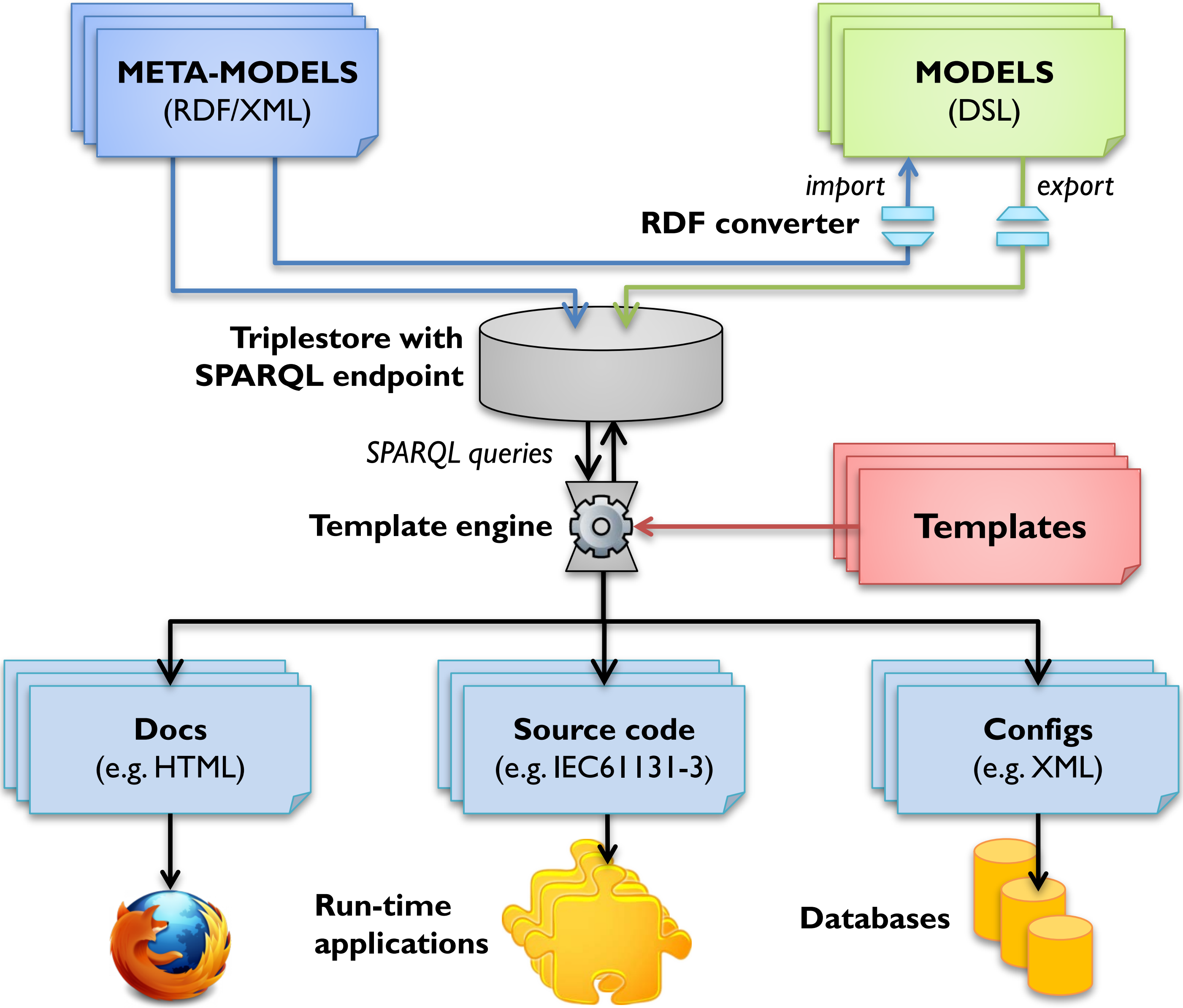
Documentation: Editors are responsible for the content of sections.

Role: Concrete

Template Slots

Name	Cardinality	Type
current_job_title	single	String
date_hired	single	String
name	single	String
other_information	single	String
phone_number	single	String
responsible_for	multiple	Instance of Employee
salary	single	Float
sections	multiple	Instance of Section

Prototype implementation



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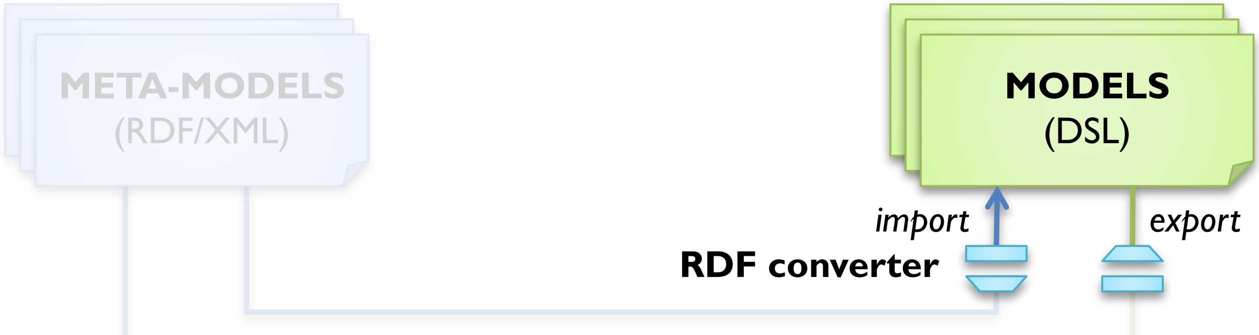

- Project specific ontologies
- Less heavy-weight (only instances)
- “Ontoscript” (internal DSL based on Coffeescript)

→ http://github.com/WimPessemier/ontoscript
→ http://github.com/WimPessemier/rdfconvert

```
MODEL “http://www.icalepcs2013.org/maia” : “maia”
# imports
maia.IMPORT_METAMODEL “http://www.icalepcs2013.org/physics”        : “phy”
maia.IMPORT_METAMODEL “http://www.icalepcs2013.org/electronics”    : “elec”
maia.IMPORT_MODEL     “http://www.icalepcs2013.org/physics-extras” : “phyx”

maia.ADD phyx.CreateTemperature(phy.Kelvin) “ccdTemp” # macro call

maia.ADD elec.Pt100 “tempSensor” : [
           phy.senses maia.ccdTemp
           # add more knowledge...
]
```

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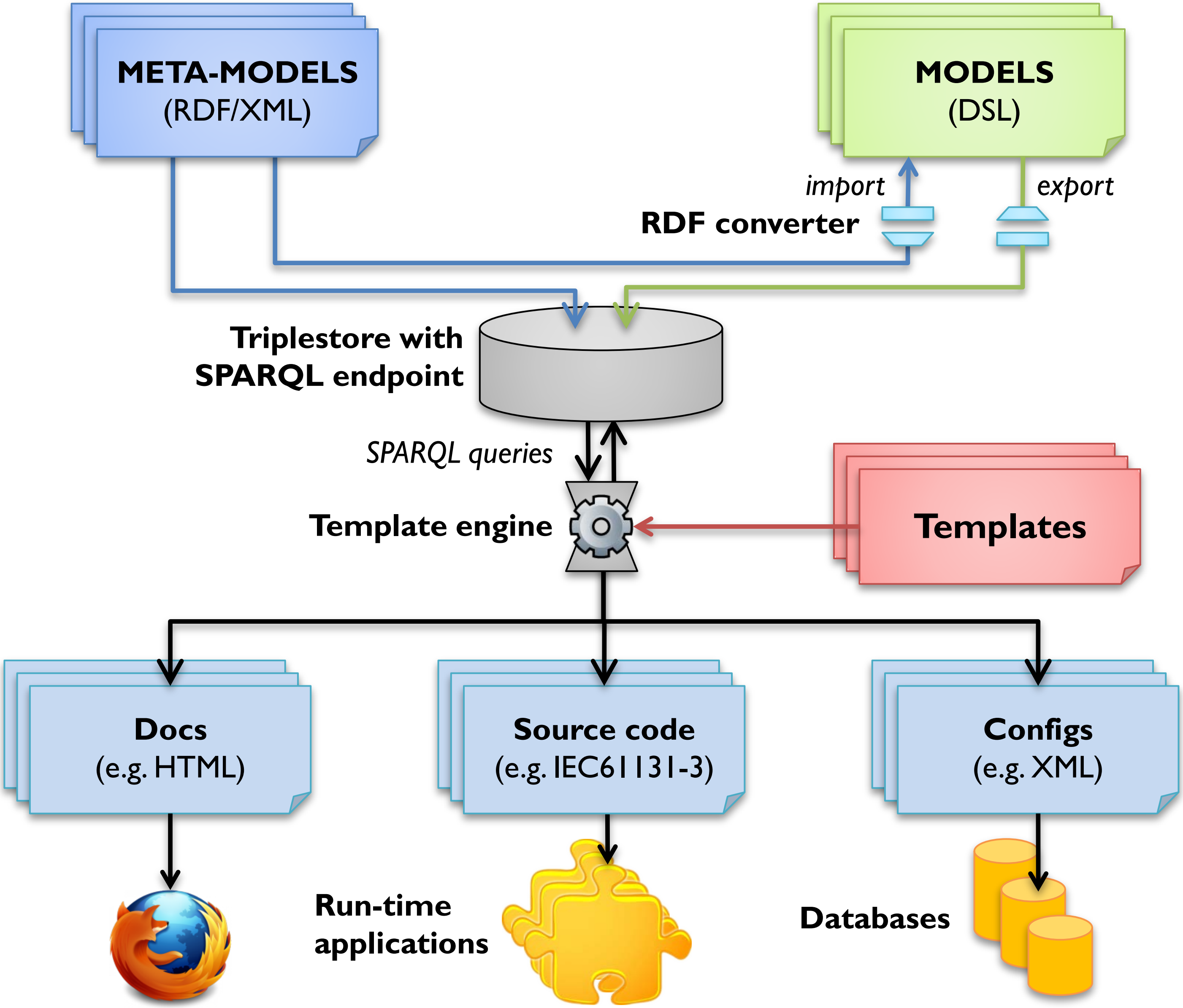

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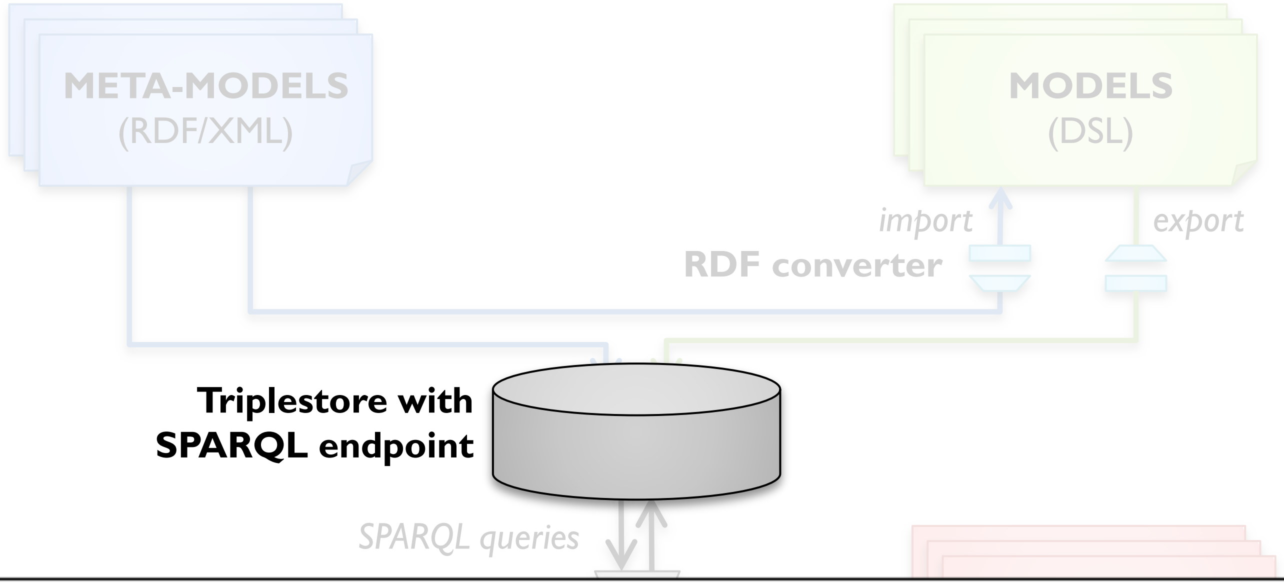
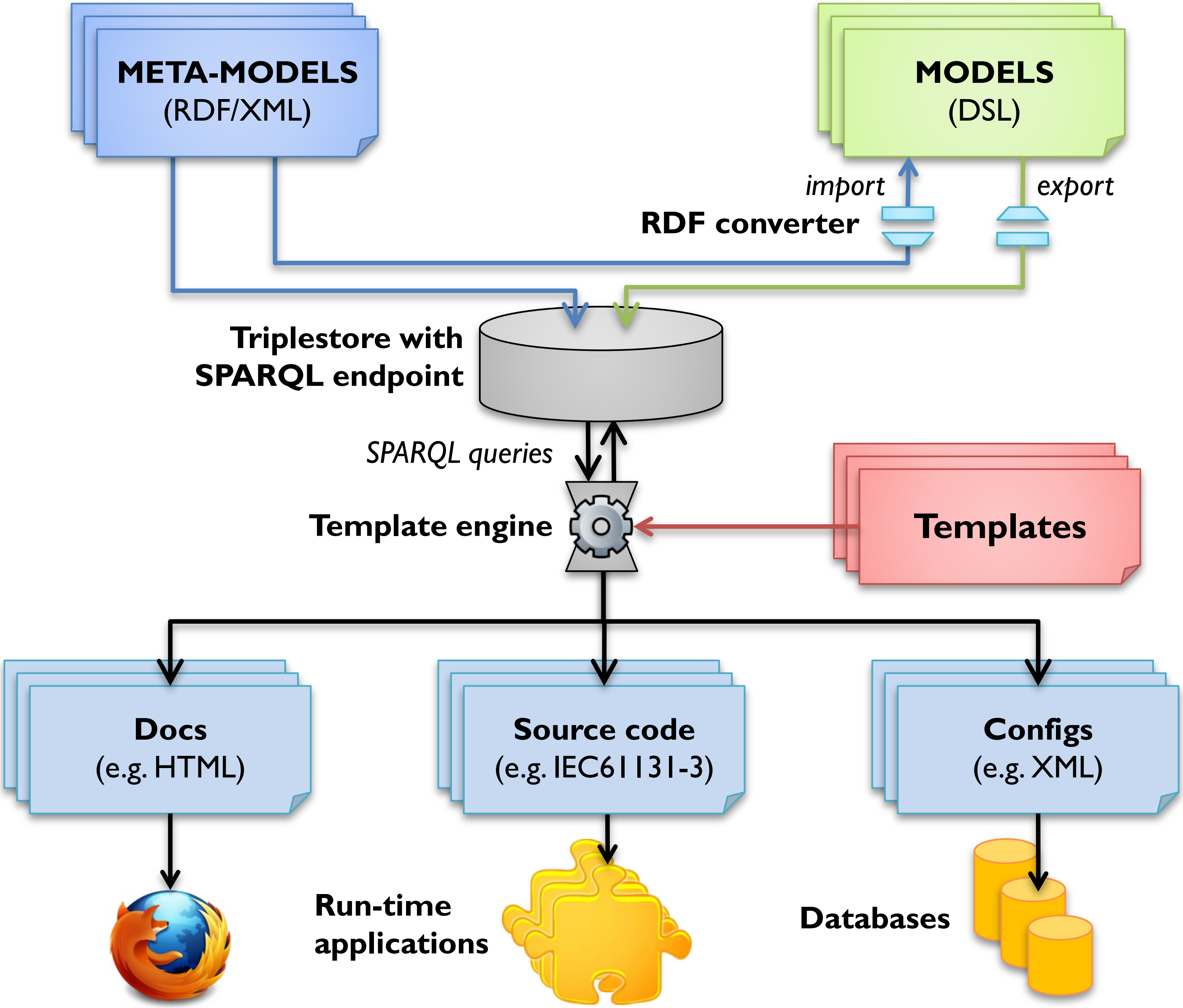


- Database of RDF triples
- Off-the-shelf
- Comes with built-in reasoner and SPARQL endpoint
- E.g. Stardog (comes with Pellet reasoner)

  → http://stardog.com

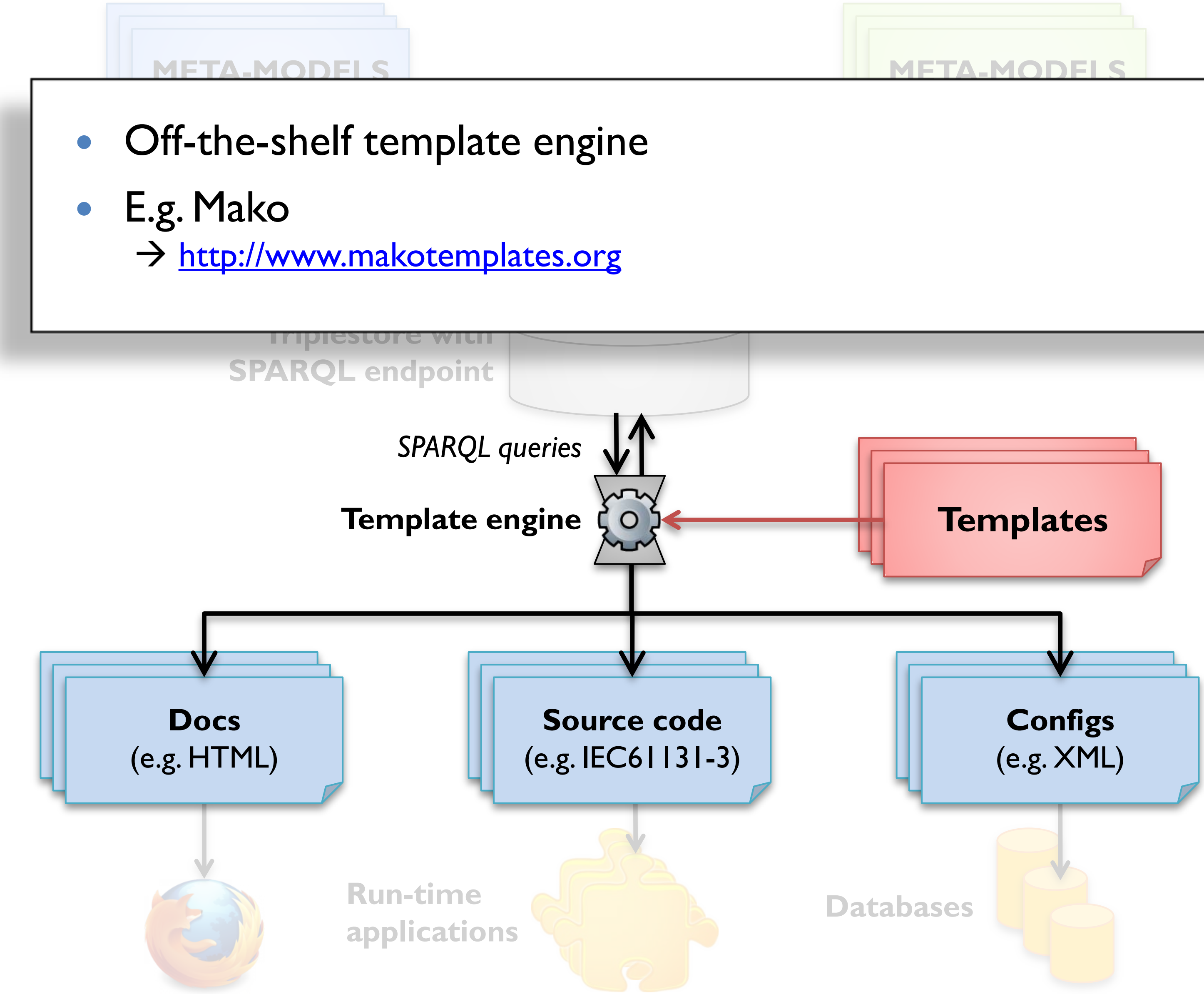
Stardog

Prototype implementation



Prototype implementation

- Off-the-shelf template engine
- E.g. Mako
  → http://www.makotemplates.org



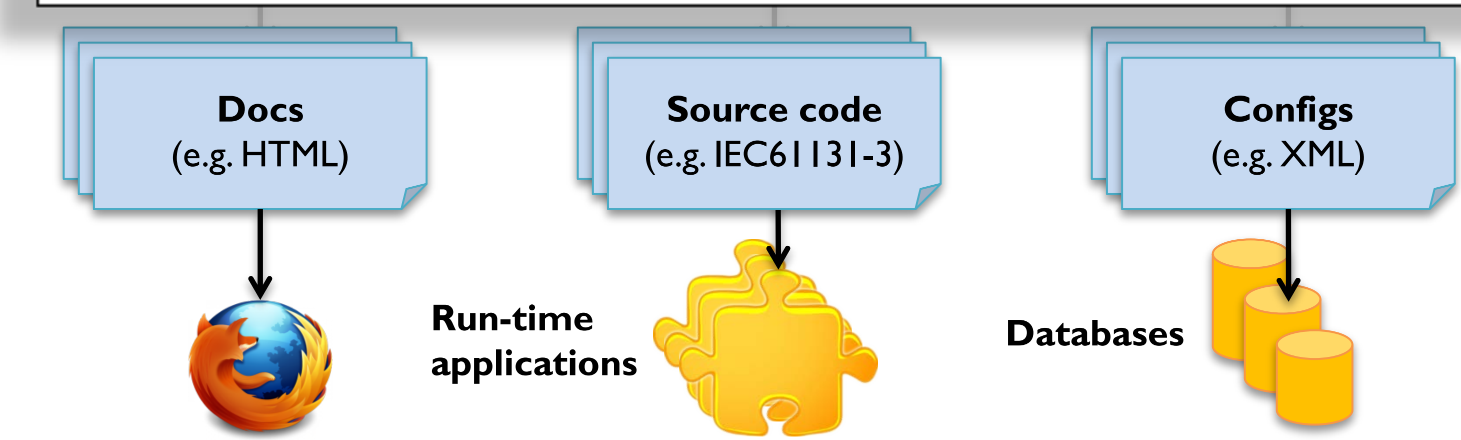
Prototype implementation

- Queries are performed by the template system ➔ knowledge is used when the artifacts are generated

```
<% results = sparql.simpleQuery("""
SELECT ?svrUri ?nsIdx ?id WHERE {
  ?det     astro:observes            astro:U      .
  ?det     phy:hasTemperature        ?temp        .
  ?temp    opcua:hasExpandedNodeId   ?nodeId      .
  ?nodeId  opcua:hasServerUri        ?svrUri      .
  ?nodeId  opcua:hasNamespaceIndex   ?nsIdx       .
  ?nodeId  opcua:hasIdentifier       ?id   } """) %>

def getUTemperatures():
  addresses = []
  % for r in results:
  addresses.append(Address(
    NodeId(${r.nsIdx},"${r.id}"),"${r.svrUri}"))
  % endfor
  return UAF_client.read(addresses)
```

* OPC UA Framework (UAF): http://github.com/uaf



Docs
(e.g. HTML)

Source code
(e.g. IEC61131-3)

Configs
(e.g. XML)

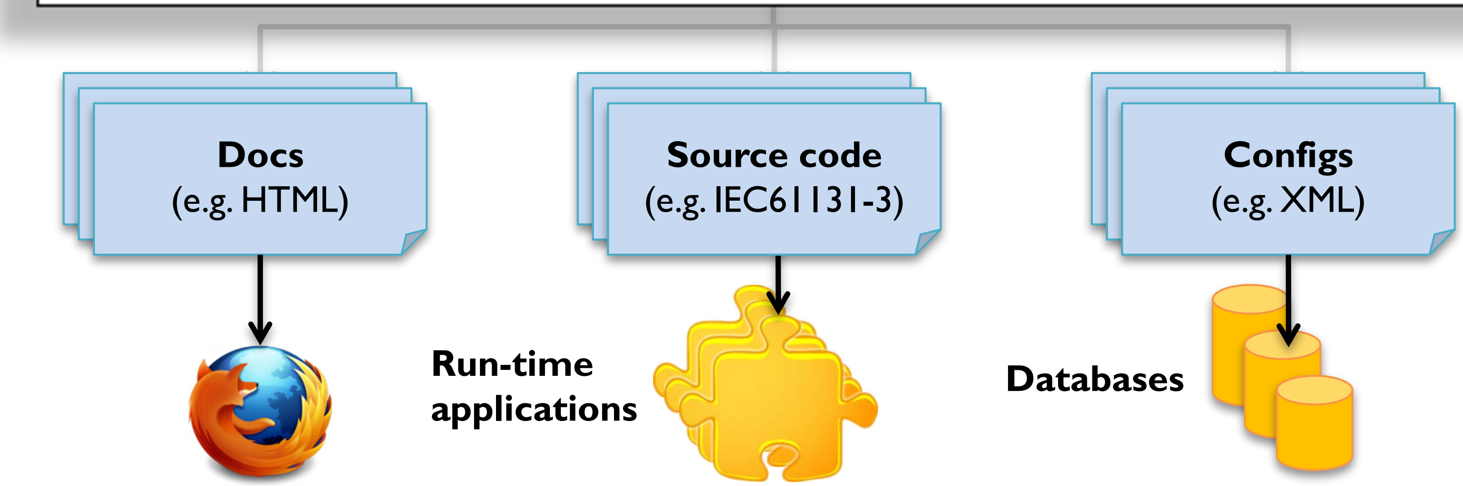
Run-time applications

Databases

Prototype implementation

- Queries can also be performed at run-time!
  - Semantic Web technology (http, slow)
  - OPC UA (binary, fast)

Feature	Sem. web	OPC UA
Complex graphs	✓	✓
URI-qualified nodes and references	✓	✓
Reading, writing, querying, ...	✓	✓
Communication paradigm	Sync	Sync + Async
Communication protocol	Slow (http)	Fast (binary)



Docs
(e.g. HTML)

Source code
(e.g. IEC61131-3)

Configs
(e.g. XML)

Run-time applications

Databases

Conclusions

- Object-oriented models/interfaces are evil
  - They cannot express the rich context of multi-disciplinary distributed applications - such as control systems - accurately.

- Semantic models/interfaces are less evil
  - They can express this information much more accurately
  - Tools and languages (OWL, DSLs, OPC UA) are available!

- Prototype will be tested on MAIA soon!

→ Thanks for your attention!