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Seminar 55: True Building Controls Interoperability: New digital solutions enabled by proposed ASHRAE standards 223P and 231P

Digitizing the delivery of controls and analytics through the proposed ASHRAE standards 223p and 231p

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Learning Objectives

- Learn about the key features of the upcoming interoperability ASHRAE standards 223p and 231p.
- Understand how these two standards will be integrated and synergize with ASHRAE 135 (BACnet) and Guideline 36 (Best in class control sequences).
- Learn about practical examples of the implementation of these standards in real buildings.
- Explore opportunities to use these standards in your products, services or workflows.

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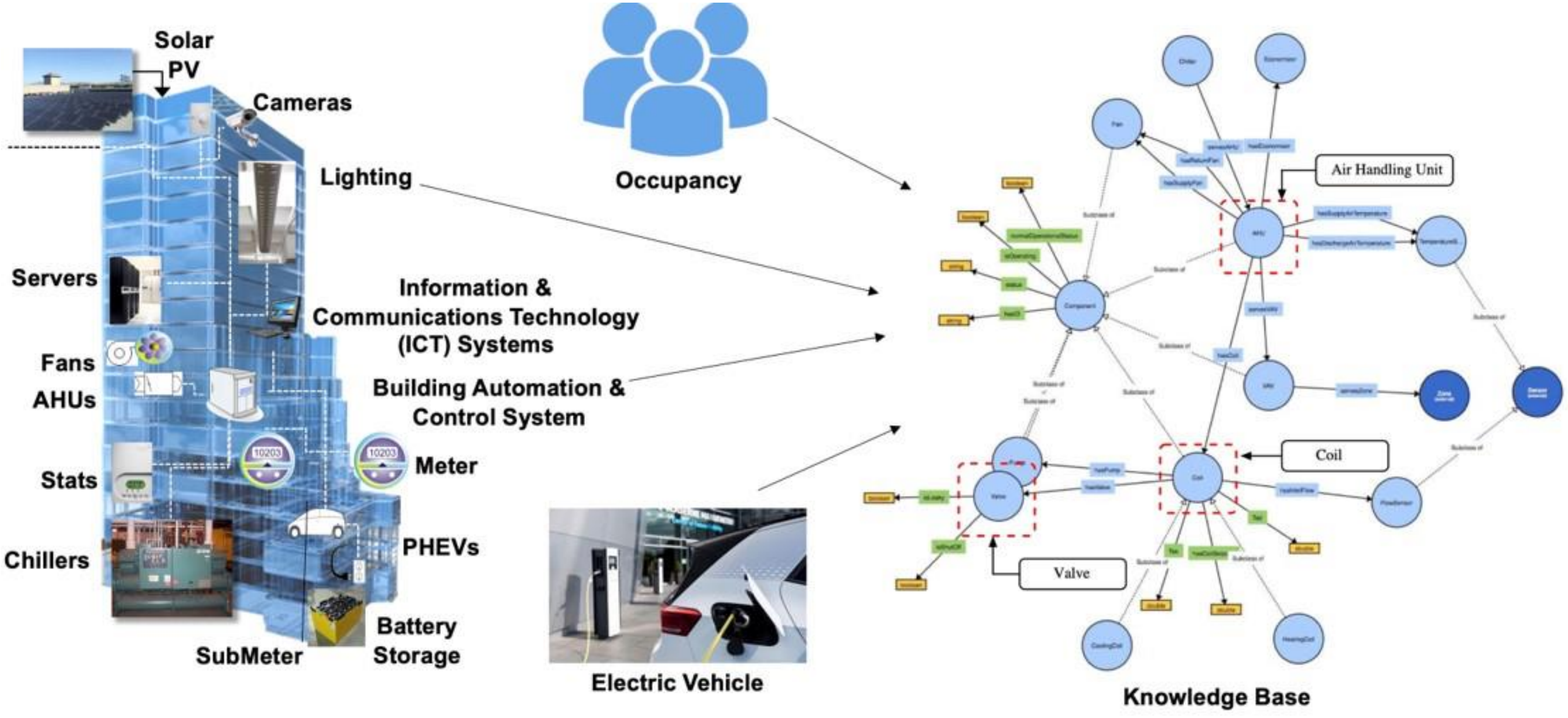
Outline/Agenda

- What is 223P?
- Modeling a simple HVAC system
- 223P provides context for data
- Example FDD application

What is ASHRAE 223P?

ASHRAE 223P standard defines concepts and methodologies to create interoperable, **machine-readable semantic models** for representing building information for analytics, control, and automation.



- Control
- Energy Auditing
- Fault Detection and Diagnostics
- Commissioning
- Smart Grid Interactions
- **ASHRAE 231P**

Physical, logical systems ← represents ← **Semantic Model** ← access ← **Applications**

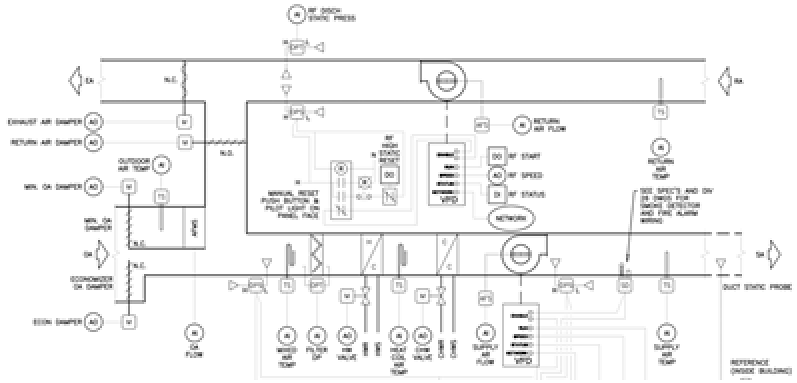
Framing the Problem

- **Applications** define data, system requirements using convention-driven, but non-standard language
  - *Example (right): point lists from ASHRAE Guideline 36*

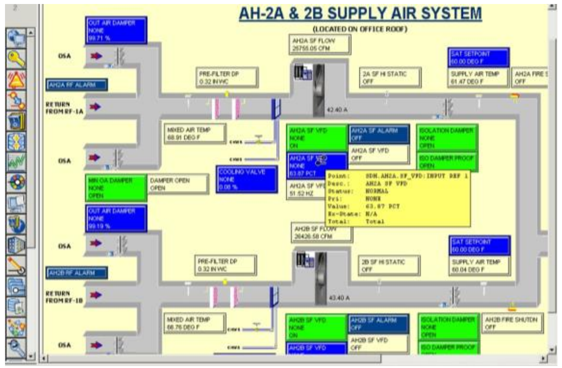
- Necessary data is spread over many (potentially) noisy, non-standard, and possibly non-digital sources

4.2 VAV Terminal Unit with Reheat

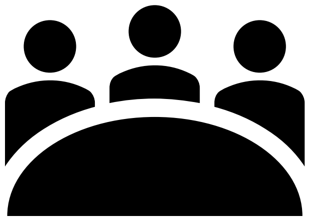
Required?	Description	Type	Device
R	VAV box damper position	AO OR two DOs	Modulating actuator OR Floating actuator
R	Heating signal	AO OR two DOs	Modulating valve OR Floating actuator OR Modulating electric heating coil
R	Discharge airflow	AI	DP transducer connected to flow sensor
R	Discharge air temperature (DAT)	AI	Duct temperature sensor (probe or averaging at designer's discretion)
R	Zone temperature	AI	Room temperature sensor
A	Local override (if applicable)	DI	Zone thermostat override switch
A	Occupancy sensor (if applicable)	DI	Occupancy sensor
A	Window switch (if applicable)	DI	Window switch
A	Zone temperature setpoint adjustment (if applicable)	AI	Zone thermostat adjustment
A	Zone CO_2 level (if applicable)	AI	Room CO_2 sensor



Mechanical Diagrams: human-readable but non-standard



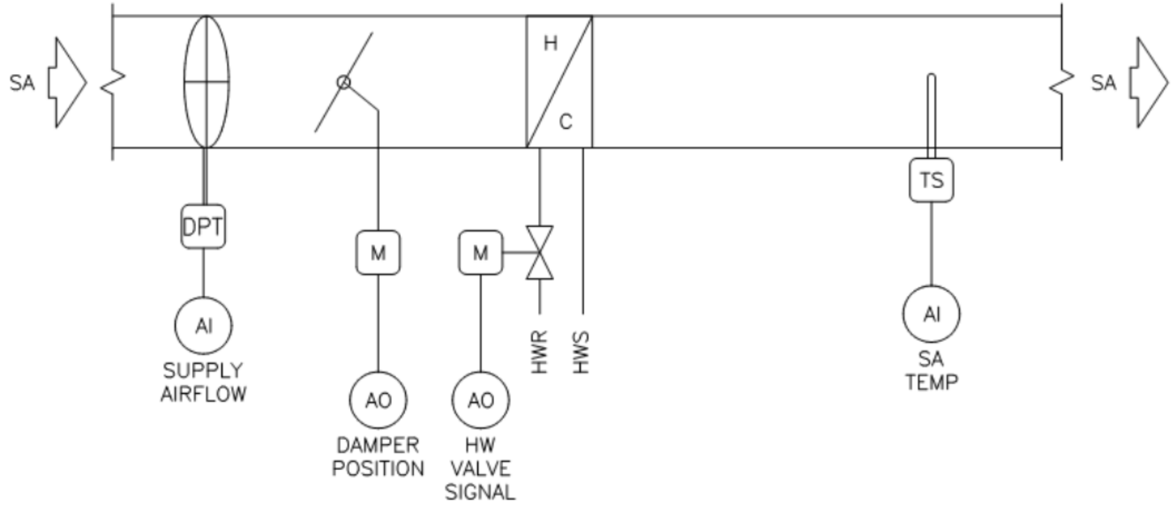
BMS labels and graphics: undocumented naming conventions



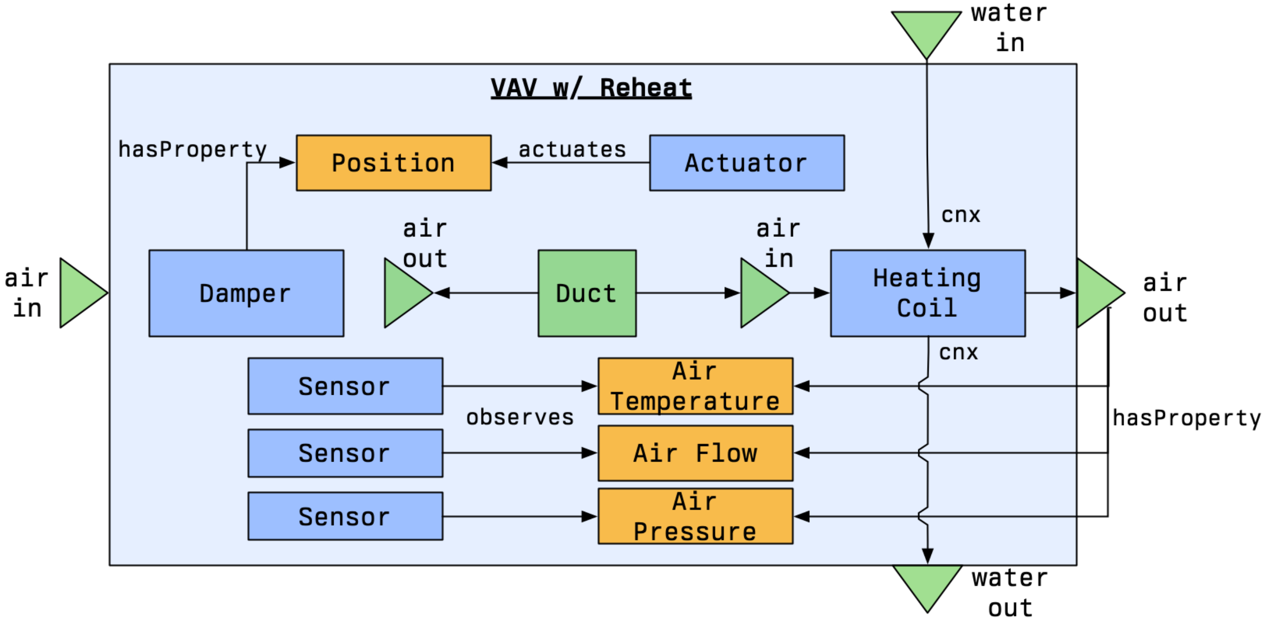
Facility managers, maintenance staff, and others hold implicit knowledge

Ontologies and Semantic Models

- A **semantic model** is a digital graph-based representation of a building
  - *Entities*: equipment, sensors, actuators, properties, connections
  - Includes useful attributes of these entities
  - Models how entities relate to each other and compose into systems



VAV with Reheat Mechanical Diagram

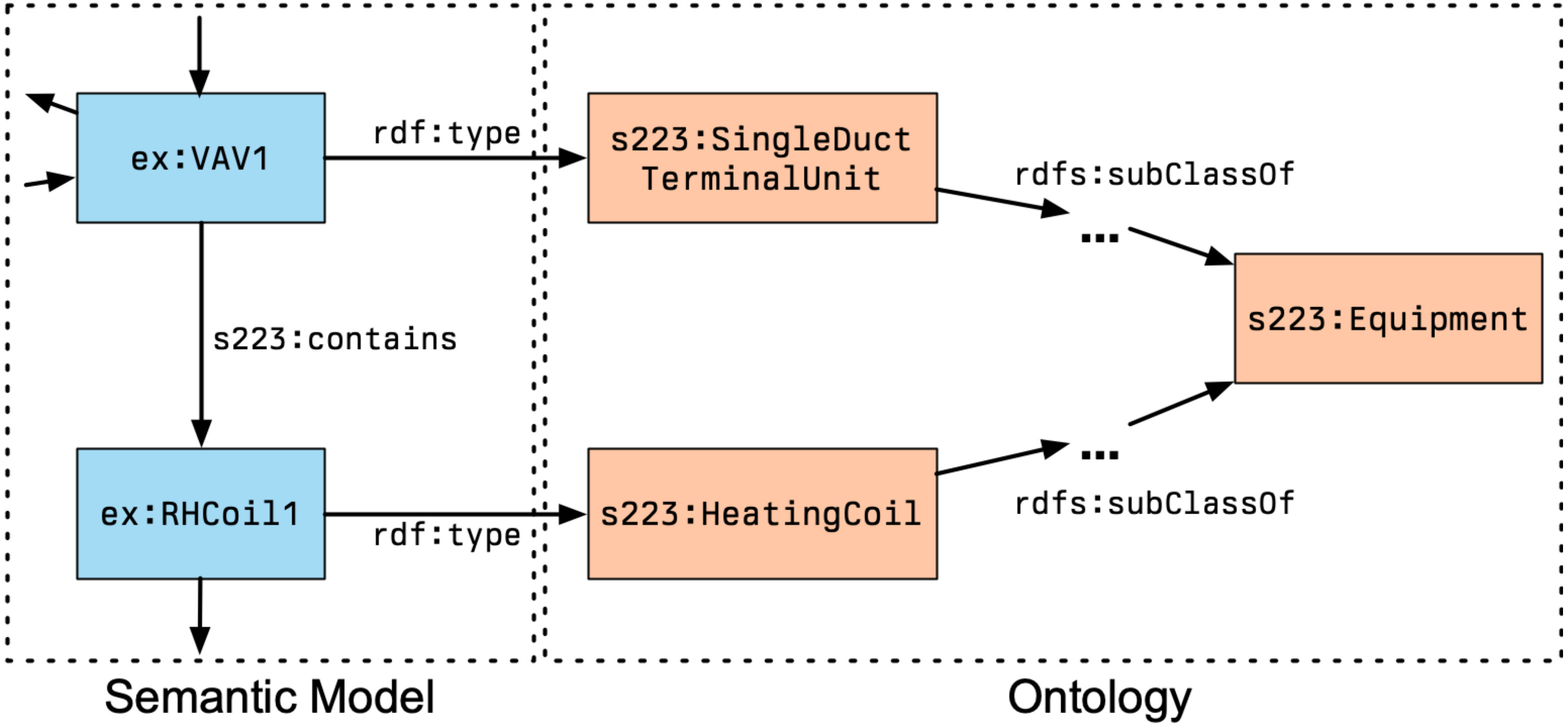


Graphical representation of 223P model

Ontologies and Semantic Models

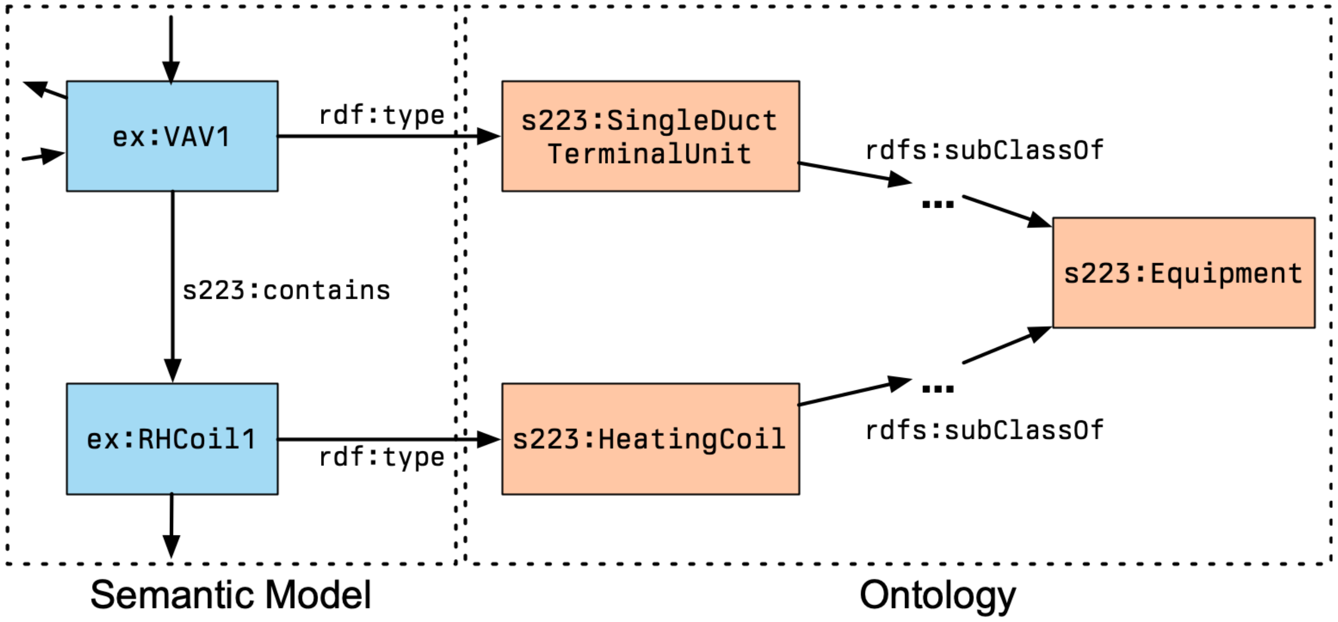
- ASHRAE 223P is an **ontology**
  - Formal definition of directed, labeled graph data structure
  - Analogous to a schema (think XML, databases, etc)
- Provides structure to semantic models, enabling
  - Automated verification/validation of semantic models
  - (Semi-)automated configuration of applications
  - (Semi-)automated creation and maintenance of semantic models
- Builds on open standards
  - **RDF (Resource Description Framework):** W3C standard for directed graphs
  - **SPARQL**: W3C standard query language for graphs
  - **SHACL**: W3C standard constraint language for graph validation

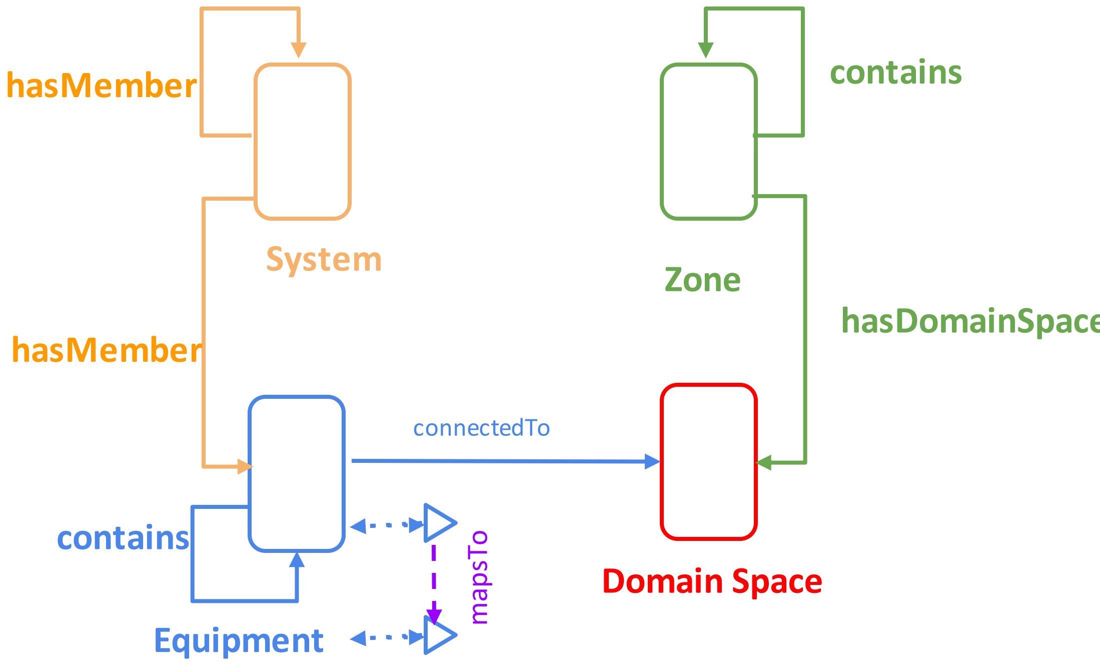
What's in a 223P Model?



- A semantic model is a graph containing labeled **nodes** and **edges** representing **entities** and their **relationships**
  - "Type" of an entity (tells applications what properties, etc to expect)
  - How entities are connected
  - Available sensors, actuators, BMS points
  - etc

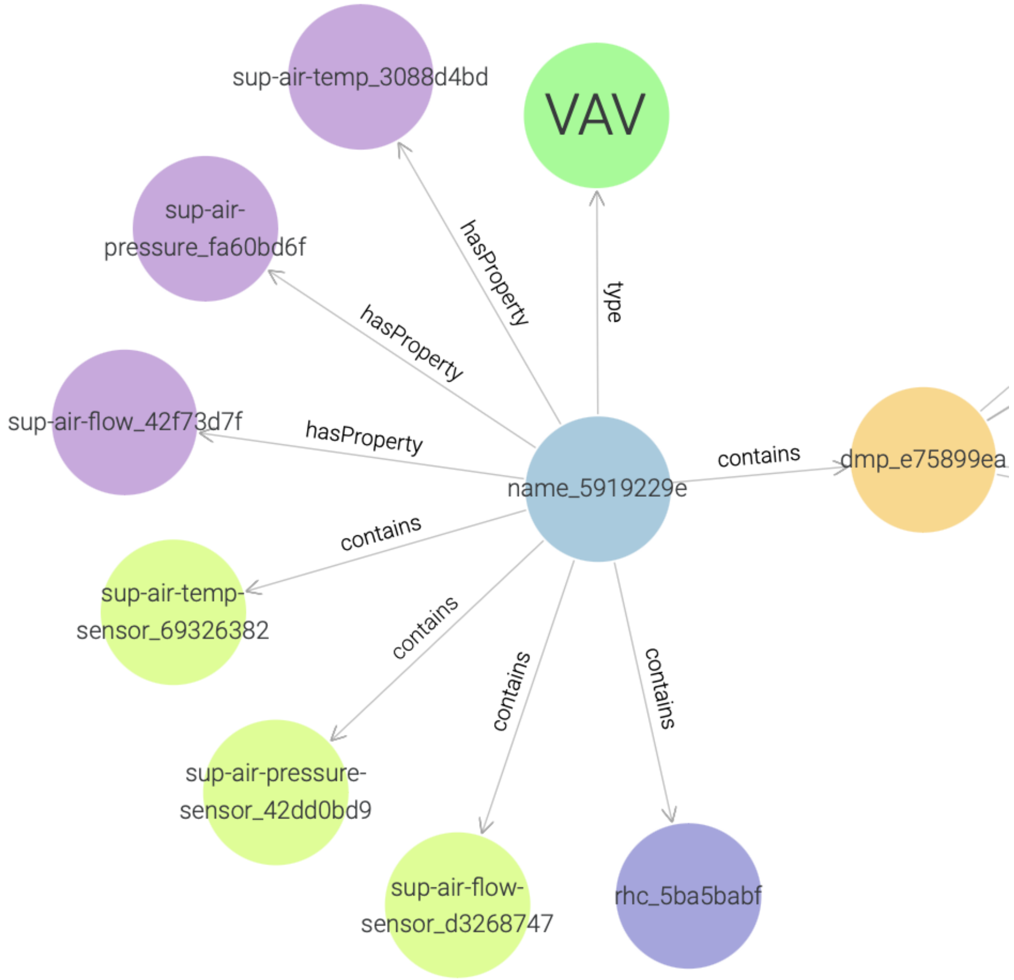
What's in the 223P Ontology?





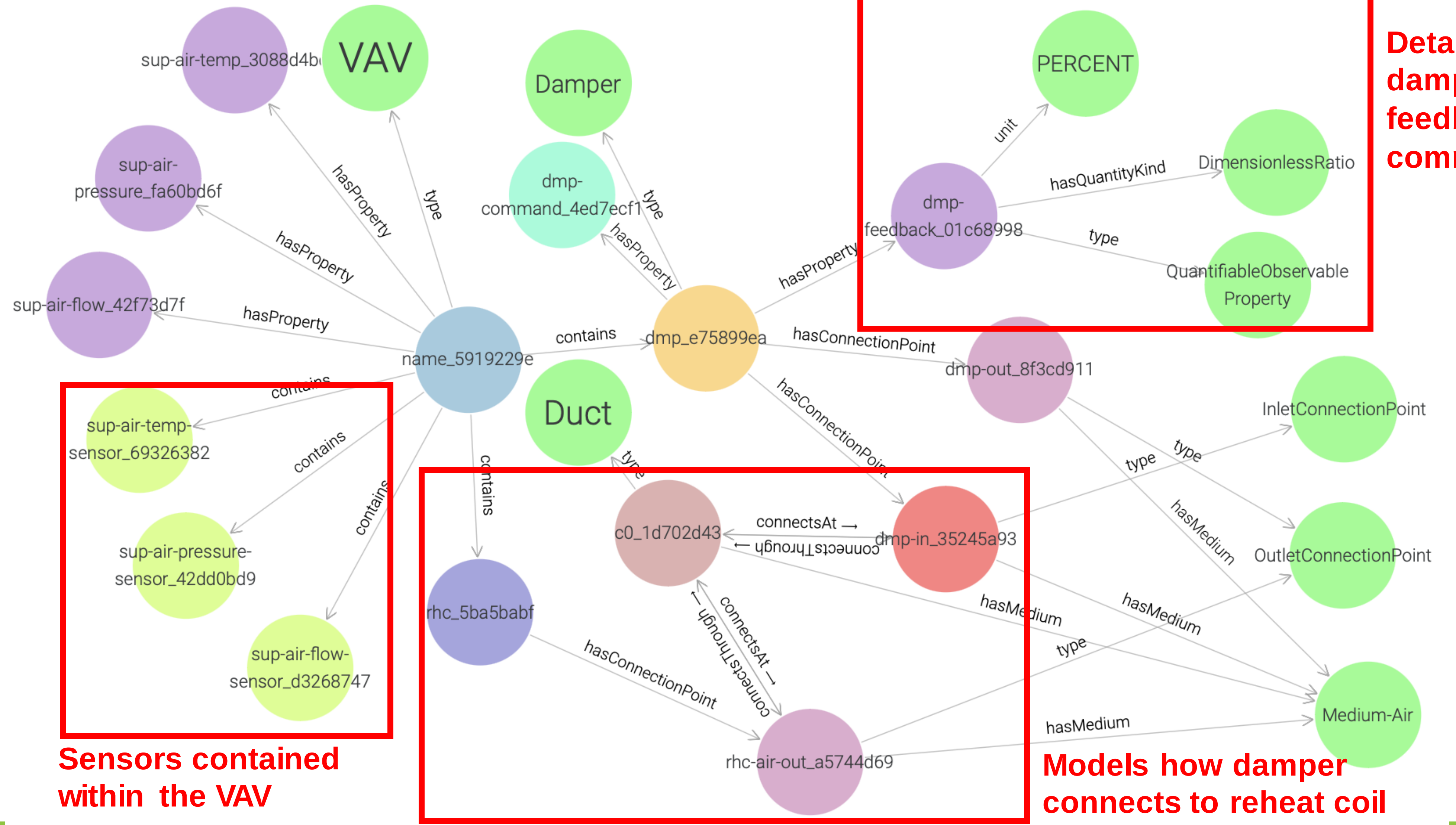
- **The 223P ontology is also a graph**
- Defines what relationships different types of entities can have
- Defines inference rules for generating new information about the model
- Includes constraints to ensure *consistency* in modeling and therefore *interoperability*

Example: VAV with Reheat



- *Name_5919229e* is the name of our RVAV
- **contains** relationship models internal equipment
  - Damper and reheat coil
  - Multiple sensors (air temp, pressure, flow)
- **hasProperty** relationship models properties which can be observed/actuated
- **type** relationship tells us which 223P class this entity is

Example: VAV with Reheat

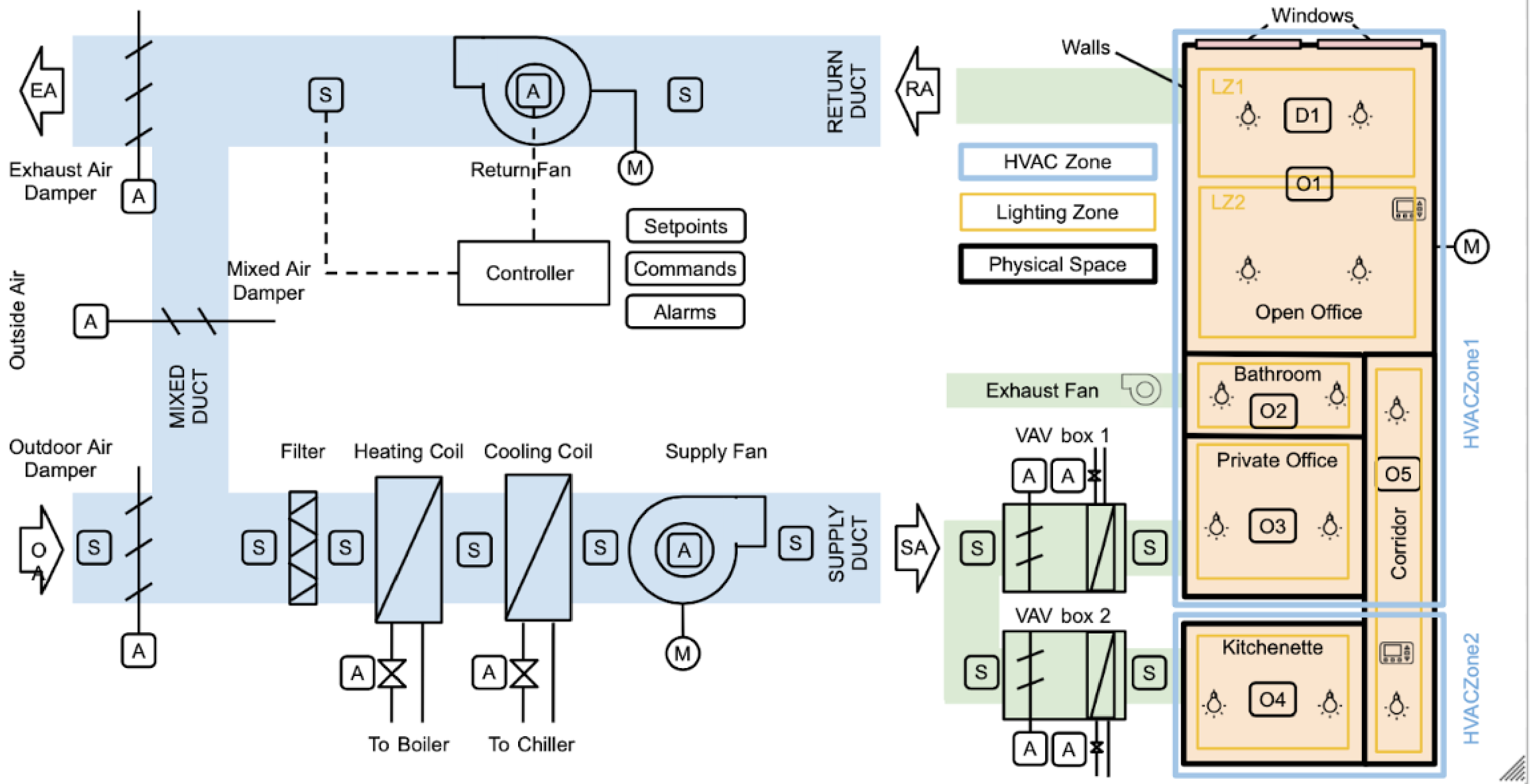


Details on damper feedback command

Sensors contained within the VAV

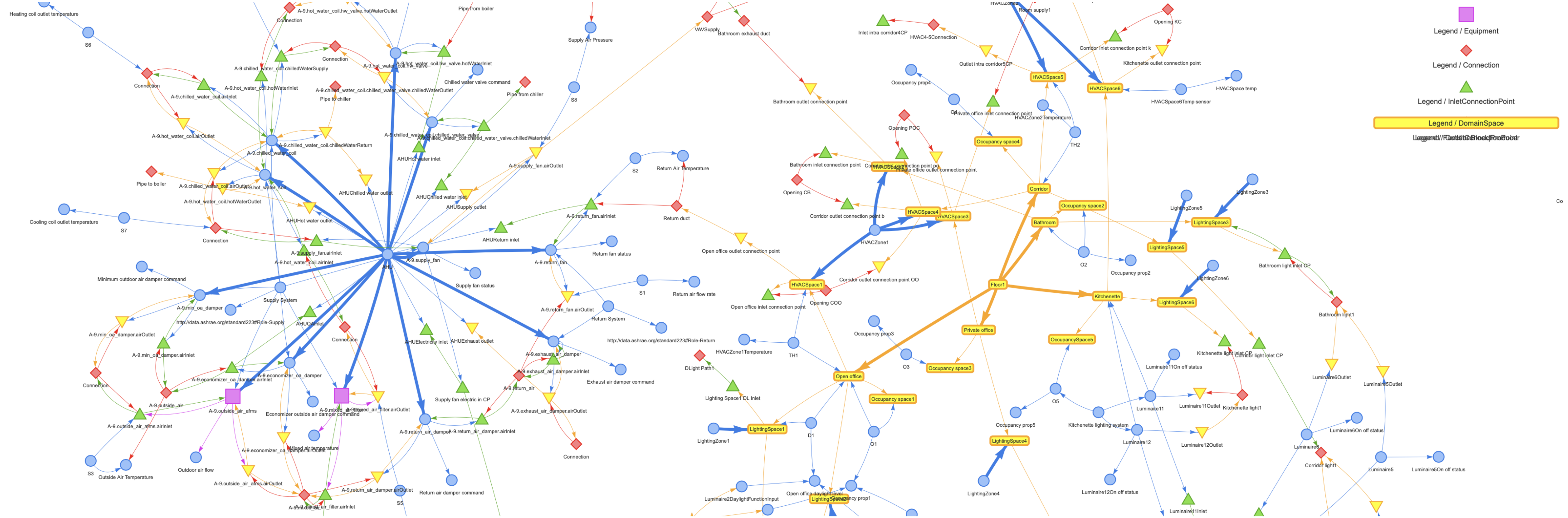
Models how damper connects to reheat coil

Example: Multi-zone AHU



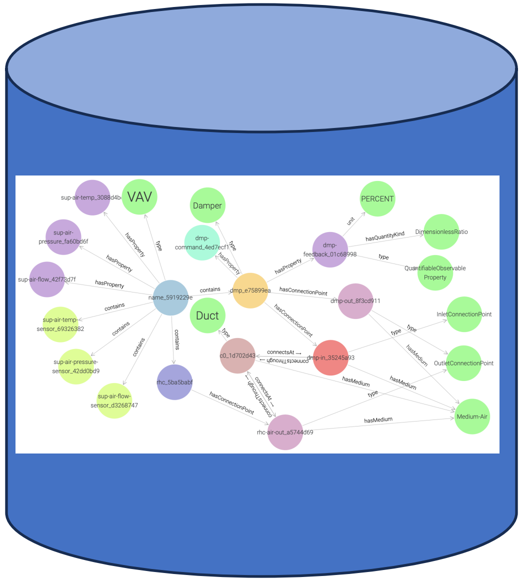
Notes: DaylightSensor1 (D1) is an input to the control for LightingZone1 (LZ1); OccSensor1 (O1) is an input to the control for LightingZone1 (LZ1) and LightingZone2 (LZ2)

Example: Multi-zone AHU



Note that this is a different visualization tool! Building on open standards like RDF makes it possible to use many different pieces of software

Asking questions about our model



Semantic model stored in graph database

- **SPARQL queries** retrieve information from semantic models
- Example: retrieving all temperature sensors and where they observe temperature

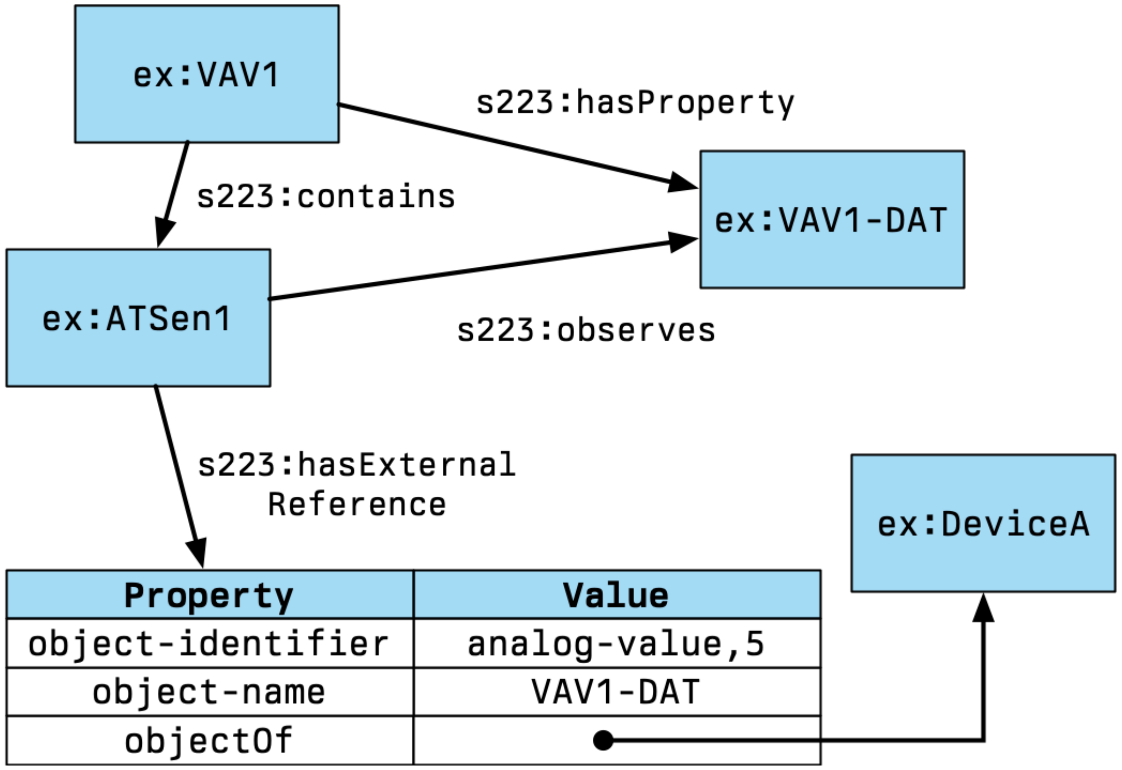
```
SELECT ?sensor ?location WHERE {
    ?sensor rdf:type/rdfs:subClassOf* s223:Sensor .
    ?sensor s223:observes ?property .
    ?property qudt:hasQuantityKind quantitykind:Temperature .
    ?sensor s223:hasObservationLocation ?location
}
```

?sensor	?location
sup-air-temp-sensor_69326382	vav_out_name_a871635f
rhc-ret-water-temp-sensor_40bc	rhc-valve-in_5060b895

From our earlier VAV Reheat example

Using queries to build applications

- *First question*: how to find the actual data?
  - Solution: **External References**
- External References are 223P entities which contain the necessary properties required to retrieve data
  - From a timeseries database…
  - From a BACnet object…
  - From a Modbus register…
  - etc



Using queries to build applications

- Example: Fault Condition from ASHRAE Guideline 36
  - Low Mixed Air Temperature detection for single zone VAVs

FC #2 (omit if no MAT sensor)	**Equation**	$MAT_{AVG} + \varepsilon_{MAT} < \min[(RAT_{AVG} - \varepsilon_{RAT}), (OAT_{AVG} - \varepsilon_{OAT})]$
	Description	MAT too low; should be between OAT and RAT
	Possible Diagnosis	RAT sensor error MAT sensor error OAT sensor error

- Use a SPARQL query to
  a) identify all locations in the model (building) where this rule can run
  b) retrieve the data necessary to run the rule
- Write the rule itself in the Python programming language

Example FDD rule application

FC #2 (omit if no MAT sensor)	**Equation**	$MAT_{AVG} + \varepsilon_{MAT} < \min[(RAT_{AVG} - \varepsilon_{RAT}), (OAT_{AVG} - \varepsilon_{OAT})]$
	Description	MAT too low; should be between OAT and RAT
	Possible Diagnosis	RAT sensor error MAT sensor error OAT sensor error

Need to find:

- Mixed air temperature
- Return air temperature
- Outside air temperature

```
PREFIX s223: <http://data.ashrae.org/standard223#>
PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX qudt: <http://qudt.org/schema/qudt/>
PREFIX quantitykind: <http://qudt.org/vocab/quantitykind/>
PREFIX bacnet: <http://data.ashrae.org/bacnet/2020#>

SELECT ?oat ?oatId ?mat ?matId ?rat ?ratId ?inst WHERE {
    ?ahu rdf:type s223:AirHandlingUnit .
    ?bacnet a bacnet:BACnetDevice ;
        bacnet:device-instance ?inst .
    # Outside Air Temperature Sensor
    ?oat rdf:type s223:Sensor ;
         s223:observes ?outsideAir .
    ?outsideAir rdf:type s223:QuantifiableObservableProperty ;
        s223:hasAspect s223:Role-Outside ;
        qudt:hasQuantityKind quantitykind:Temperature ;
        s223:hasExternalReference/bacnet:object-identifier ?oatId .

    # Mixed Air Temperature Sensor
    ?mat rdf:type s223:Sensor ;
         s223:observes ?mixedAir .
    ?mixedAir rdf:type s223:QuantifiableObservableProperty ;
        s223:hasAspect s223:Role-Mixed ;
        qudt:hasQuantityKind quantitykind:Temperature ;
        s223:hasExternalReference/bacnet:object-identifier ?matId .

    # Return Air Temperature Sensor
    ?rat rdf:type s223:Sensor ;
         s223:observes ?returnAir .
    ?returnAir rdf:type s223:QuantifiableObservableProperty ;
        s223:hasAspect s223:Role-Return ;
        qudt:hasQuantityKind quantitykind:Temperature ;
        s223:hasExternalReference/bacnet:object-identifier ?ratId .
}
```


```
SELECT ?oat ?oatId ?mat ?matId ?rat ?ratId ?inst WHERE {
    ?ahu rdf:type s223:AirHandlingUnit .
    ?bacnet a bacnet:BACnetDevice ;
        bacnet:device-instance ?inst .
    # Outside Air Temperature Sensor
    ?oat rdf:type s223:Sensor ;
         s223:observes ?outsideAir .
    ?outsideAir rdf:type s223:QuantifiableObservableProperty ;
        s223:hasAspect s223:Role-Outside ;
        qudt:hasQuantityKind quantitykind:Temperature ;
        s223:hasExternalReference/bacnet:object-identifier ?oatId .
```


SPARQL query retrieves names and BACnet object IDs for all sensors

Example FDD rule application

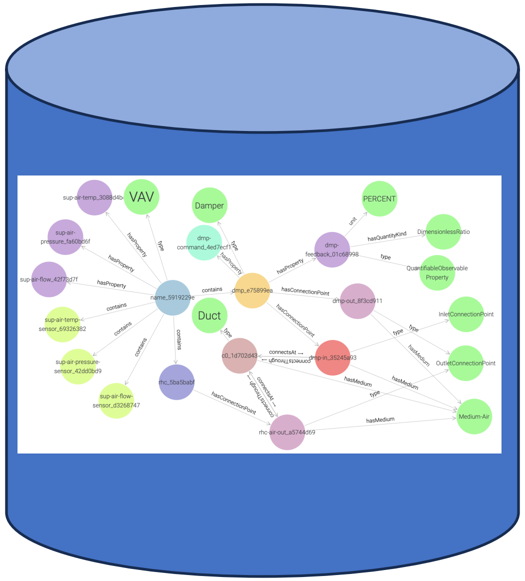
```
PREFIX s223: <http://data.ashrae.org/standard223#>
PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX qudt: <http://qudt.org/schema/qudt/>
PREFIX quantitykind: <http://qudt.org/vocab/quantitykind/>
PREFIX bacnet: <http://data.ashrae.org/bacnet/2020#>

SELECT ?oat ?oatId ?mat ?matId ?rat ?ratId ?inst WHERE {
    ?ahu rdf:type s223:AirHandlingUnit .
    ?bacnet a bacnet:BACnetDevice ;
        bacnet:device-instance ?inst .
    # Outside Air Temperature Sensor
    ?oat rdf:type s223:Sensor ;
         s223:observes ?outsideAir .
    ?outsideAir rdf:type s223:QuantifiableObservableProperty ;
        s223:hasAspect s223:Role-Outside ;
        qudt:hasQuantityKind quantitykind:Temperature ;
        s223:hasExternalReference/bacnet:object-identifier ?oatId .

    # Mixed Air Temperature Sensor
    ?mat rdf:type s223:Sensor ;
         s223:observes ?mixedAir .
    ?mixedAir rdf:type s223:QuantifiableObservableProperty ;
        s223:hasAspect s223:Role-Mixed ;
        qudt:hasQuantityKind quantitykind:Temperature ;
        s223:hasExternalReference/bacnet:object-identifier ?matId .

    # Return Air Temperature Sensor
    ?rat rdf:type s223:Sensor ;
         s223:observes ?returnAir .
    ?returnAir rdf:type s223:QuantifiableObservableProperty ;
        s223:hasAspect s223:Role-Return ;
        qudt:hasQuantityKind quantitykind:Temperature ;
        s223:hasExternalReference/bacnet:object-identifier ?ratId .
}
```

Execute query against semantic model



ahu	inst	matId
urn:ex/single-zone-ahu	123	analog-value,6

oatId	ratId
analog-value,5	analog-value,7

Query Results

- Now we have all the information necessary to read live data from our BACnet network!
- External references also let us read data out of databases, etc

Example FDD rule application

FC #2 (omit if no MAT sensor)	**Equation**	$MAT_{AVG} + \varepsilon_{MAT} < \min[(RAT_{AVG} - \varepsilon_{RAT}), (OAT_{AVG} - \varepsilon_{OAT})]$
	Description	MAT too low; should be between OAT and RAT
	Possible Diagnosis	RAT sensor error MAT sensor error OAT sensor error

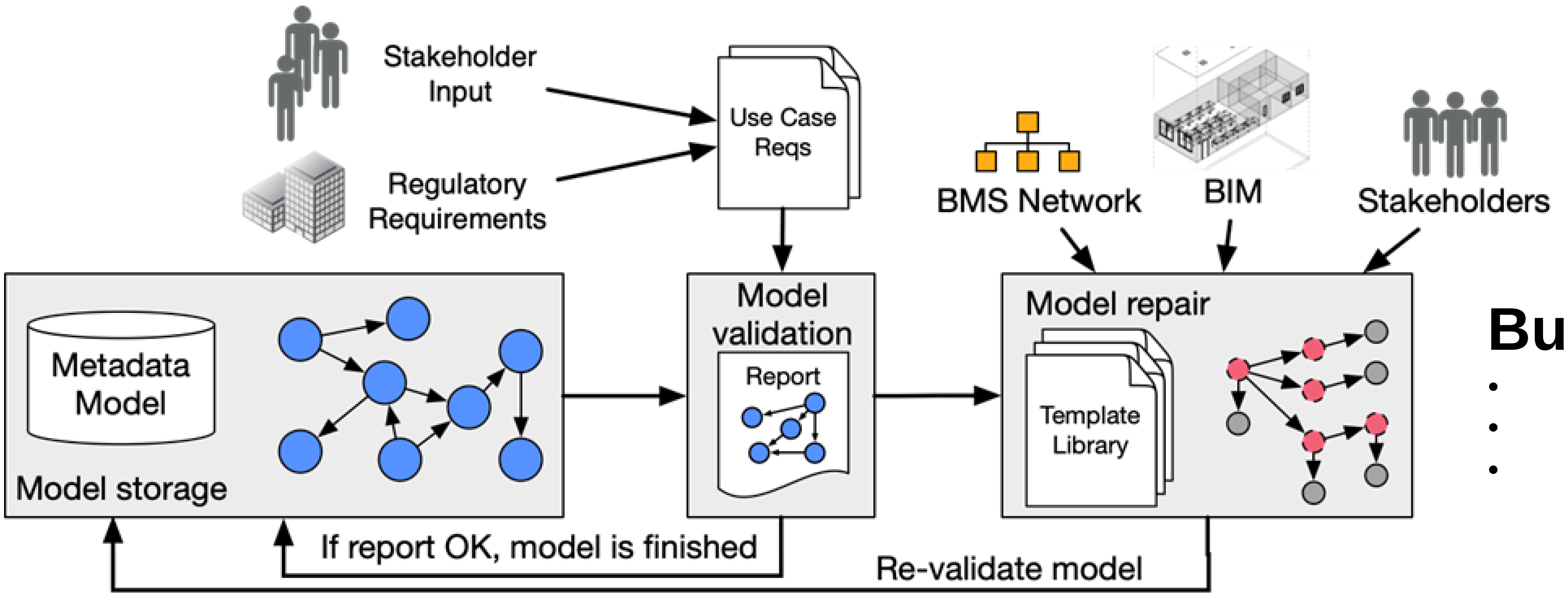
- Write out FDD rule as a Python function
- Use query results to generate a dataset with the correct column names
- Run the function!

```
def run_fc2(df):
    """
    Check MAT + ε_MAT < min[(RAT − ε_RAT), (OAT − ε_OAT)] at each timestamp and
    print out the timestamps where the inequality is true.
    """
    # Assuming ε values as constants, they can be changed as per actual values
    epsilon_MAT = epsilon_RAT = epsilon_OAT = 1
    # List to store timestamps where the inequality holds true
    timestamps_where_true = []
    # Iterate over the dataframe
    for index, row in df.iterrows():
        # Check the inequality condition for each row
        if row['mat'] + epsilon_MAT < min(row['rat'] - epsilon_RAT, row['oat'] - epsilon_OAT):
            timestamps_where_true.append(index)
    # Print out the timestamps
    for timestamp in timestamps_where_true:
        print(f"Fault condition true at: {timestamp}")
```

[19]:
```
run_fc2(df)
```

```
Fault condition true at: 2023-01-01 06:30:00
Fault condition true at: 2023-01-01 08:30:00
Fault condition true at: 2023-01-01 09:45:00
```

Open-Source Software for 223P Semantic Models



BuildingMOTIF

- Open source, BSD-licensed
- Developed by NREL
- Available on GitHub

- Incorporate formal use case requirements into iterative workflow
- Ensure that delivered metadata model fulfills all use cases
- Automate / simplify authoring through templates, imports from other sources
- Generate SPARQL queries from application requirements

Conclusion

- ASHRAE 223P models buildings, their assets, and data sources as a directed graph
- Applications, such as FDD suites and control sequences, can query 223P models for useful configuration information
- ASHRAE 223P provides a standardized framework for data interoperability, allowing the software applications to exchange information seamlessly.

Questions?

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