SEMANTICS-DRIVEN MIDDLEWARE LAYER FOR BUILDING OPERATION ANALYSIS IN LARGE-SCALE ENVIRONMENTS

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Outline

- **Introduction**
  - Facility management
  - Information systems in facility management
- **Motivation** and **Goals**
  - Use case: University campus of Masaryk University
- **Problem:** Automation data analysis
- **Method:** Automation data semantics and querying
- Results, Summary, Conclusions

Facility Management

- According to IFMA (International Facility management association): *„a profession that encompasses multiple disciplines to ensure functionality of the built environment by integrating people, place, process and technology*"
- FM ensures tasks, which are not part of organization's „core business"

IFMA™ International Facility Management Association

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IS in Facility Management

BIM

- BIM = Building Information Model
- Built environment, locations and devices
- Generally static data

CAFM

- CAFM = Computer Aided Facility Management Software
- Space management, Furniture, Maintenance, Energy management
- Dynamic data (e.g. financial, HR), uses BIM data
- Analysis & Reporting

BMS

- BMS = Building Management System
- Remote monitoring and control of building automation systems
- Recent (present) and historical data from sensors and other devices

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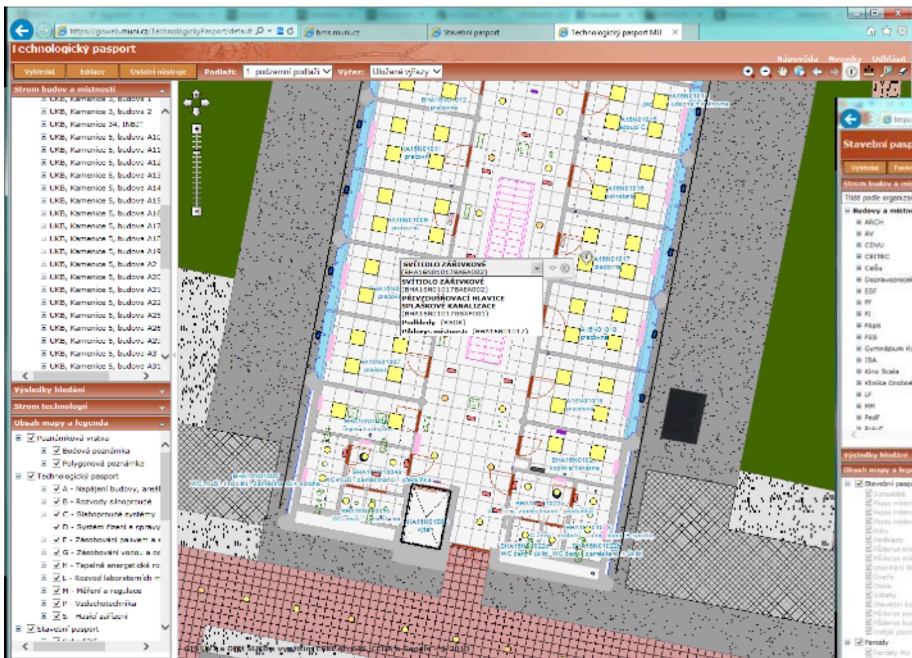
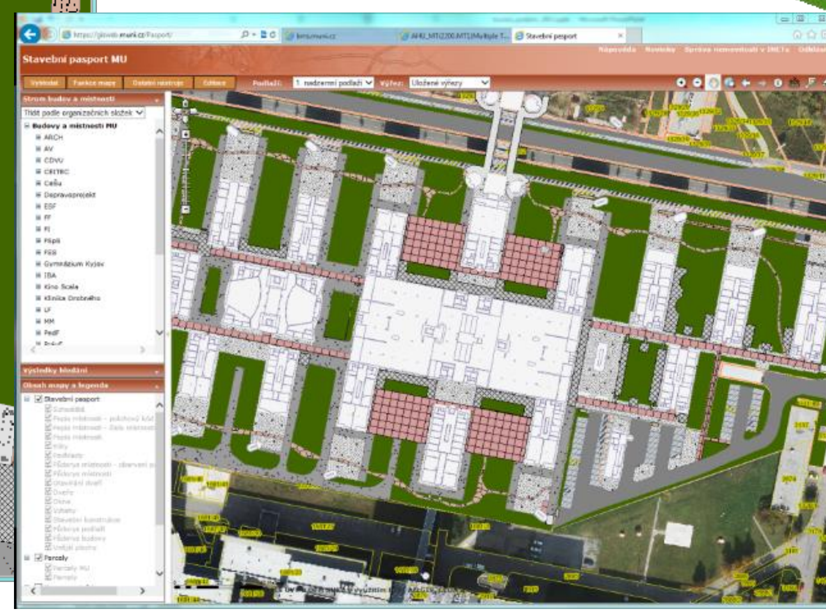
BIM – Building Information Model

- Digital representation of a building





Source: Authors

CAFM – Computer-Aided Facility Mgmt

- CAFM software supports:
  - Space management
  - Maintenance
  - Energy management
- Provides advanced analytical tools

Source: Archibus, Inc.

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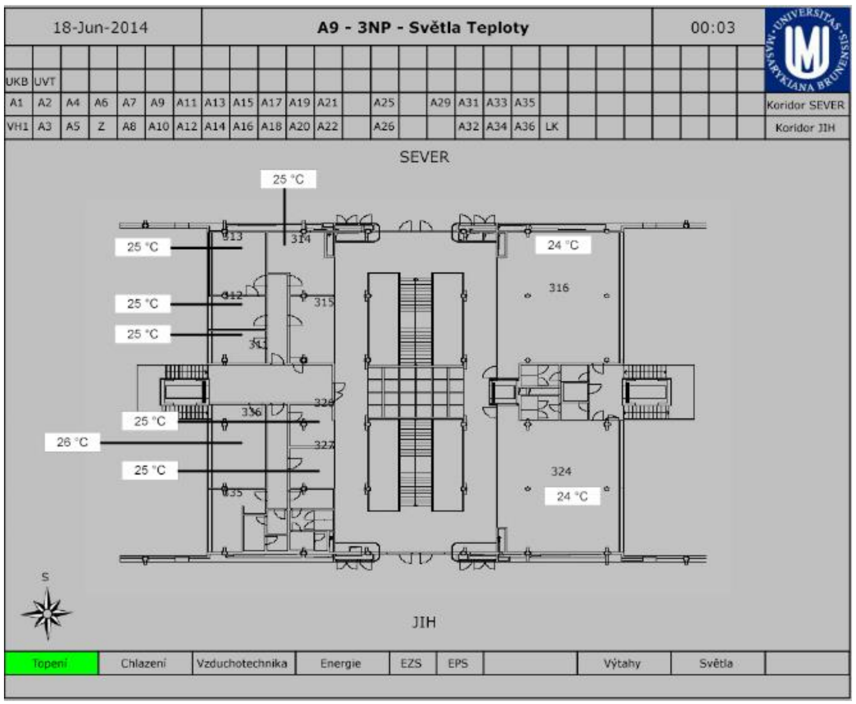
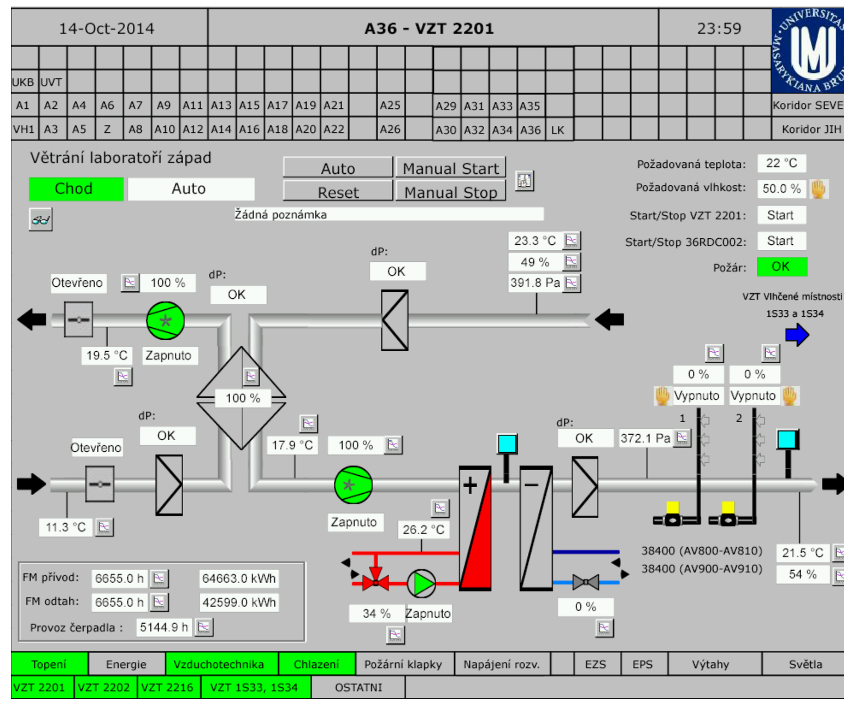
Smart buildings

- Devices in buildings connected to a network
  - Heaters
  - Air conditioning units (HVAC)
  - Lighting
  - Energy meters
  - ...
- Monitored and controlled remotely

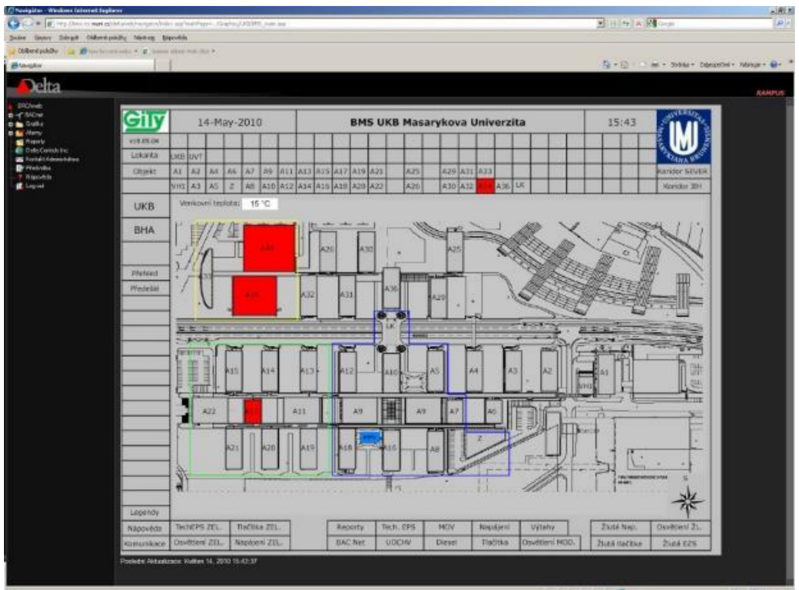
BMS – UI





Source: OFM SUKB MU

BMS – UI



Source: OFM SUKB MU

Motivation – Use case

- **Goal:** Examining building operation **performance** and **efficiency** using BMS data
- **Use case:** BMS of Masaryk University (40 buildings, 150 000 data points)


Source: muni.cz

Motivation – Analytical capabilities

BMS	CAFM
Sensor data	Financial data
High detail	Low detail
Recent data	Delayed data
Simple applications	Complex applications

How much does the electricity consumption differ across the campus?

How much energy is consumed by air conditioning?

What are the average room temperatures?

Problem – Complexity

- Application development tasks:
  - Data access (automation protocols, OLTP)
  - Data selection, grouping & aggregation
  - Analytical methods
  - User Interface

Problem – Unsuitable semantics

- Data points **identified by** network **address** in BMS
  - BACnet protocol: 25104.AI101
- Data point properties carry **limited semantics**:
  - Object type (Analog/Binary/..., Input/Output/Variable/...)
  - Engineering units
- **Missing relation** to the physical world:
  - Location
  - Source device
  - Measuring environment (air, water,...)
  - ...

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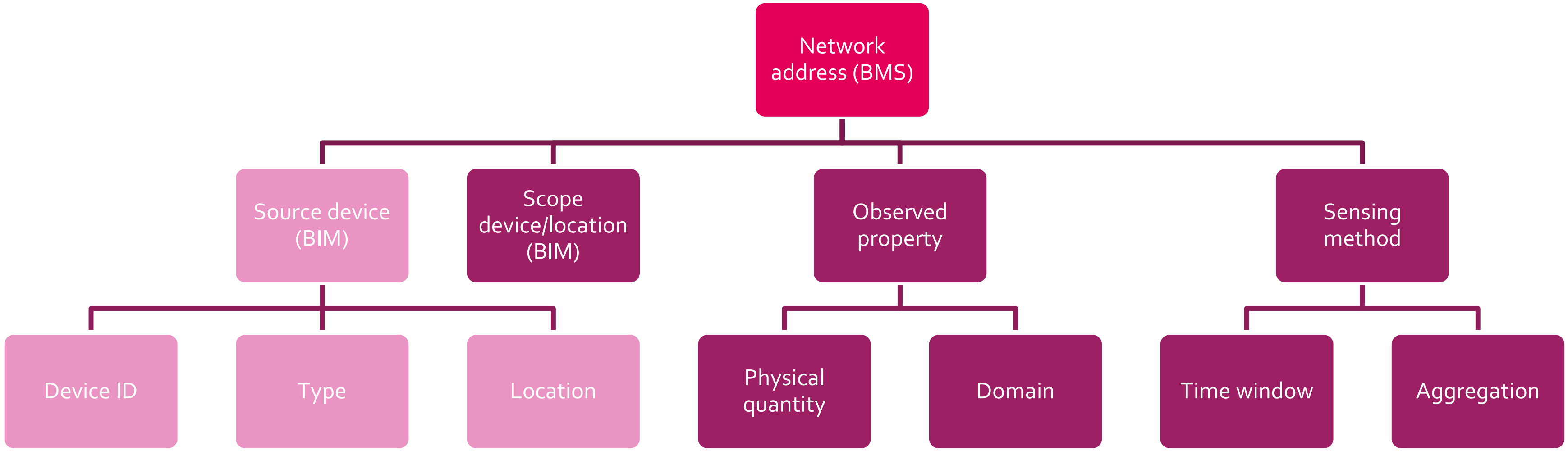
Aims & Methods – New semantics

- New approach to analysis of BMS data
  - Network **addresses are not used** as identifiers
  - Universal model relates **BMS** and **BIM** and also adds new information



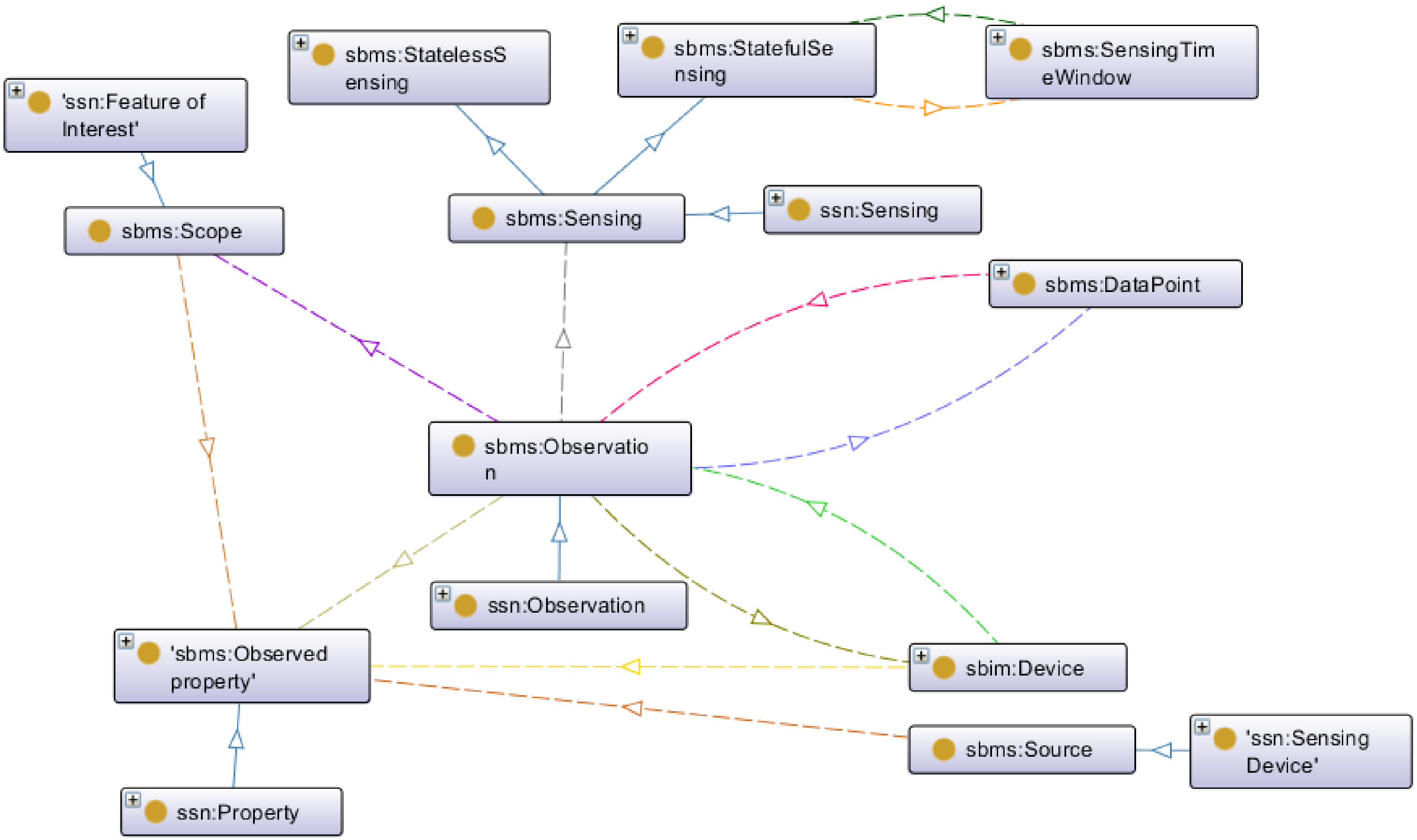
Aims & Methods – Ontology

- New semantics of BMS data can be described by **Ontology language**
- **OWL** –Web Ontology Language (W3C)
  - Designed for **Semantic web & Linked Data**
  - Based on **RDF** (Resource Definition Framework)
  - **„Subject-Predicate-Object"**

Aims & Methods – Ontology

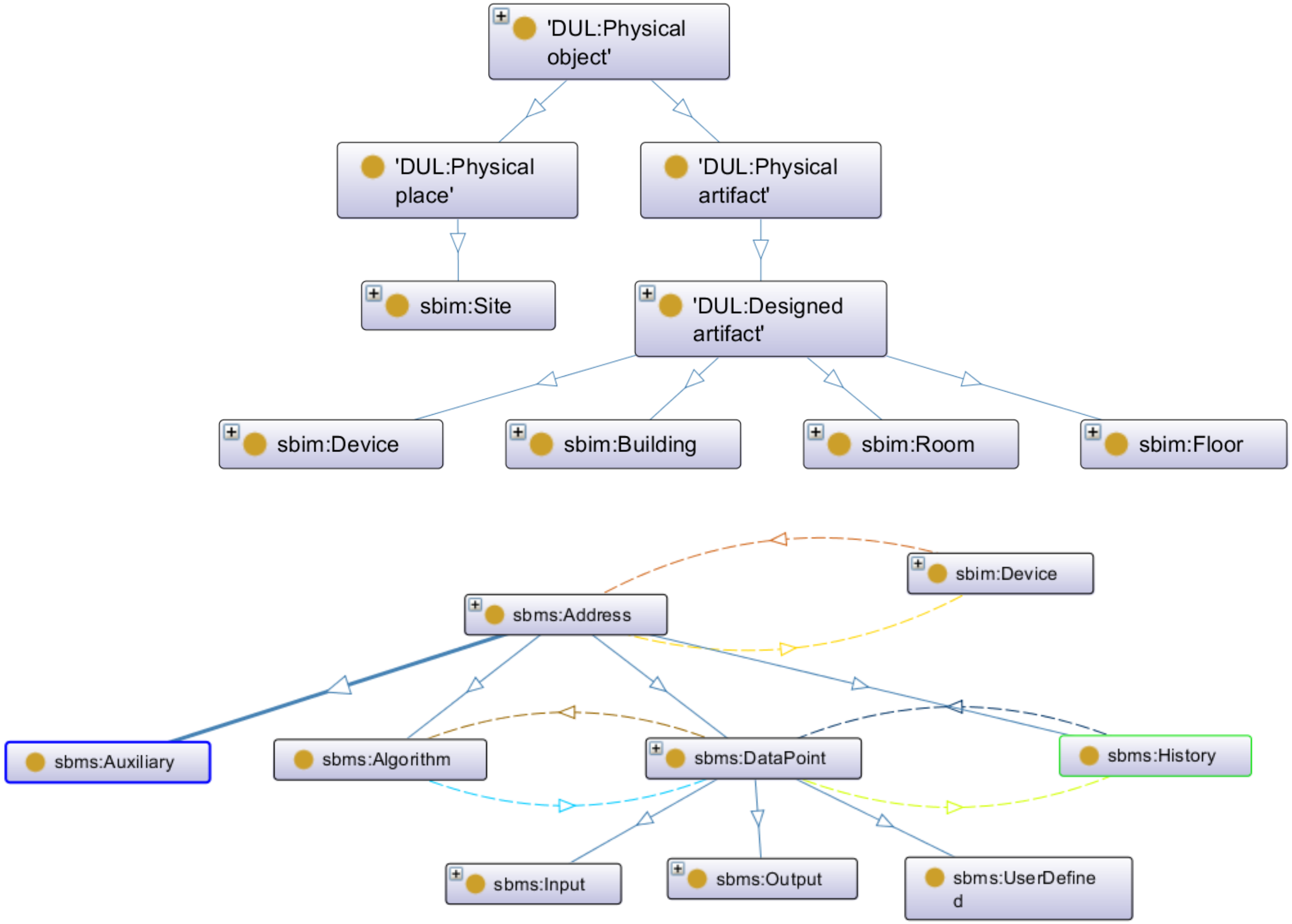
- Semantic Sensor Network ontology
  - Uses upper-level ontology (Dolce UltraLite)
  - **Stimulus-Sensor-Observation** Pattern
  - Adjustments/Extensions to SSN to meet domain specific requirements:
    - Representation of BIM elements
    - BMS Data points
    - Physical quantities
    - Sensing methods
    - Device types (adapted from IFC 4)

Aims & Methods – Ontology



Source: Authors

Aims & Methods – Ontology



Source: Authors

Aims & Methods – Ontology querying

- Ontology repositories can be queried using specialized query languages (**SPARQL**)

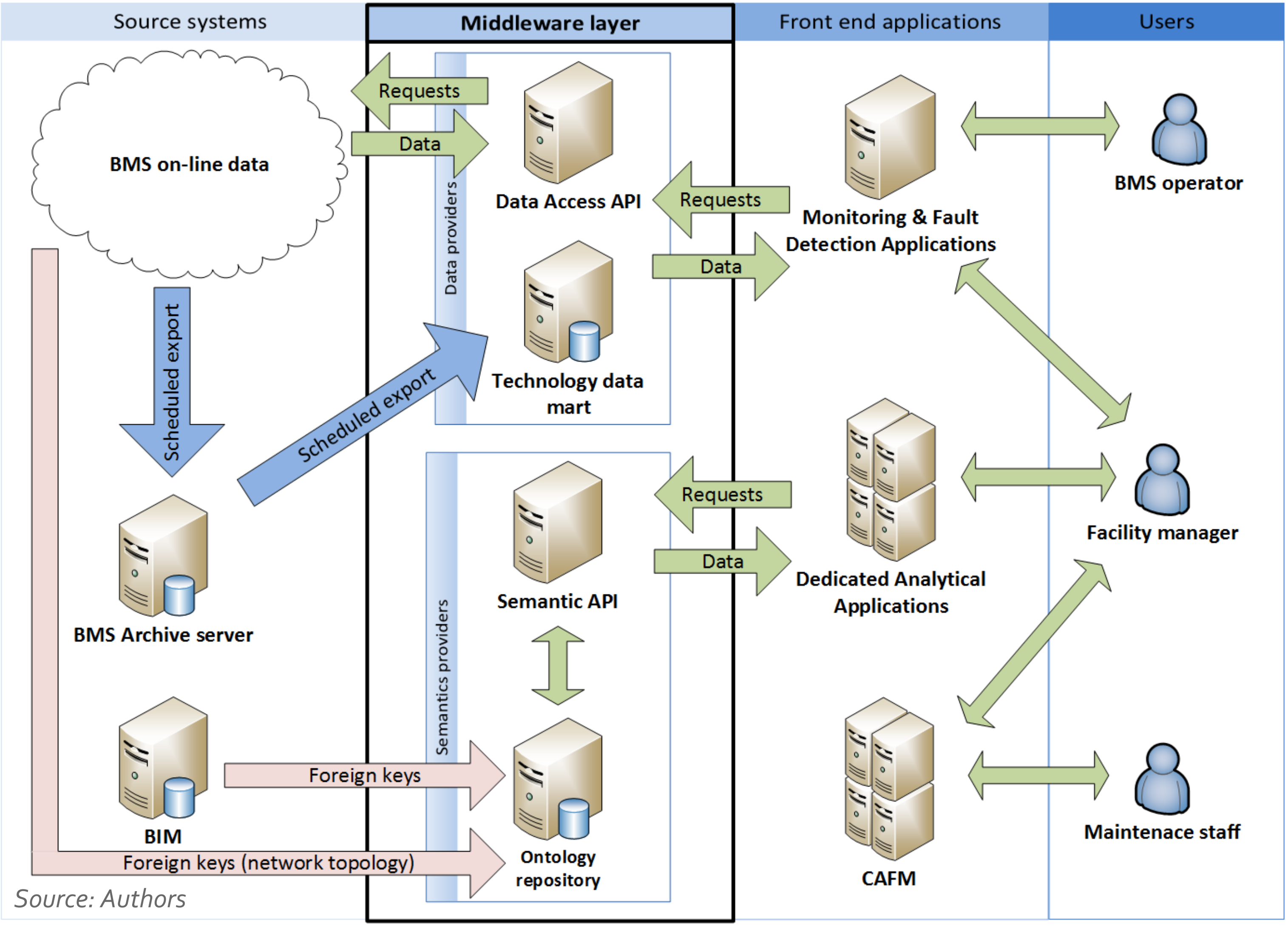
```
SELECT *

WHERE {
values ?bmsId { "2306.AI101" }
  ?dataPoint sbms:hasBMSId ?bmsId.
  ?dataPoint a ?dataPointClass.
  ?dataPointClass rdfs:subClassOf sbms:DataPoint.
  ?dataPoint sbms:expressesObservation ?observation.
  ?observation sbms:observedBy ?source.
  ?source sbim:hasBIMId ?sourceBIMId.
  ?source a ?sourceClass.
  ?sourceClass rdfs:subClassOf* sbim:Device.
  FILTER (not exists {?subtype rdfs:subClassOf ?sourceClass.
    FILTER (?subtype != ?sourceClass) } && ?sourceClass != sbms:Source).
  ?observation sbms:featureOfInterest ?scope.
  ?scope sbim:hasBIMId ?scopeBIMId.
  ?scope a ?scopeClass.
  ?scopeClass rdfs:subClassOf* dul:PhysicalObject.
  FILTER (not exists {?subtype rdfs:subClassOf ?scopeClass.
    FILTER (?subtype != ?scopeClass) } && ?scopeClass != sbms:Scope).
  ?observation sbms:sensingMethodUsed ?sensing.
  ?sensing a ?sensingClass.
  ?sensingClass rdfs:subClassOf* sbms:Sensing.
  FILTER not exists {?subtype rdfs:subClassOf ?sensingClass.
    FILTER (?subtype != ?sensingClass) }.
  OPTIONAL { ?sensing sbms:hasAggregationTimeWindow ?timeWindow }
  ?observation sbms:observedProperty ?property.
  ?property sbms:hasPhysicalQuality ?quality.
  ?property sbms:hasPropertyDomain ?propDomain.
}
```

Aims & Methods – APIs

- Simplification of application **development** & **integration**
- **Data access** APIs
- **Semantic** API
  - **Encapsulating** OWL & SPARQL
  - Domain-specific **operators** – aggregation, grouping & filtering according to:
    - Location
    - Source device
    - Observed property
    - …
  - Ready-to-use **functions** for frequent queries

Aims & Methods – Middleware layer



Source: Authors

Query examples

1. Semantic query

Location: *Campus Bohunice; Building A11*
Grouping: *Per floor*
Measured value: *Room temperature*
Source device: *Temperature sensor*
Data type: *Historical data*
Desired output: *Network address*

2. Semantic result

No1: {11400.TL5, 11500.TL5, 11600.TL1}
No2: {12100.TL5, 12300.TL3, 12400.TL5}
No3: {12500.TL1, 12600.TL1, 12800.TL1}

3. Data query

Data points: *Semantic result data*
Aggregate: *temporal AVG*
Period: *09/2014 – 1/2015*
Aggregation Window: *1 day*

4. Data result

No1: { {2014-09-01, 23.8}, {2014-09-02, 24.8}, {2014-09-03, 25.1}, {2014-09-04, 24.7}, …
No2: { … }
No3: { … }

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Query examples

1. Semantic query

Data type: *Input; Output; User defined value*
Influenced value: *Room temperature*
Influenced location: *Room 231 at building UCB-A11*
Desired output: *{Source device (with Location); Network address; Data type; Meaning (quantity) }*

2. Semantic result

{ Pump in UCB-A11-1S05, 10200.AO1, Output, Pump mode (on/off) }
{ Temperature sensor in UCB-A11-1S05, 10200.AI5, Input, Water temperature }
{ Application controller in UCB-A11-1S07, 10000.AV4, User defined value, Setpoint temperature }

3. Data query

Data points: *Semantic result data*
Aggregate: - *(present value)*

4. Data result

{ Pump in UCB-A11-1S05; ON }
{ TS in UCB-A11-1S05, 76,5 °C }
{ AC in UCB-A11-1S07, 22 °C }

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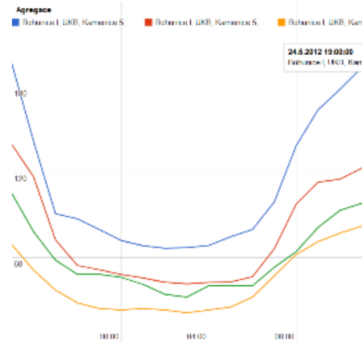
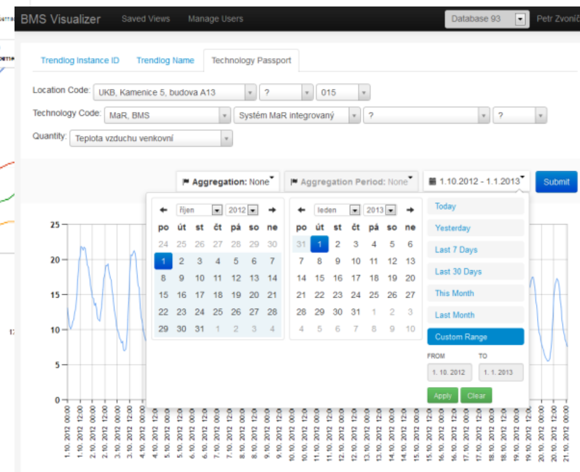
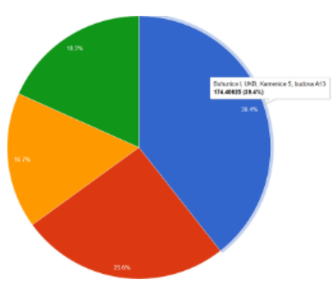
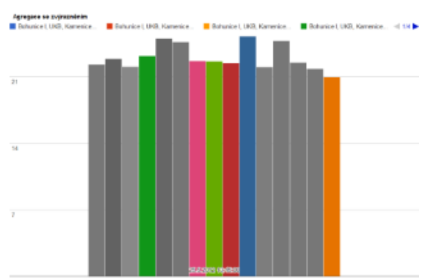
Results

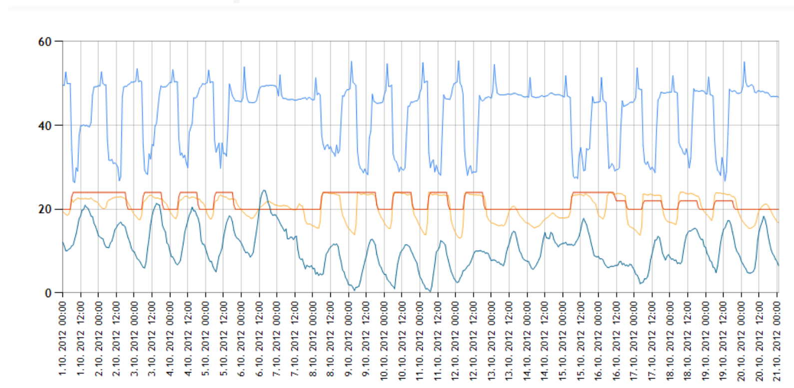
- Architecture design
- End-user applications
- Data access API
- Semantic model











Source: Authors, Petr Zvoníček, FI MU

Summary & Conclusion

- **Area:** Building operation analysis using data from automation systems
- **Aims:**
  - Provide new semantics to BMS data
  - Simplify development of analytical tools
- **Method:** Middleware layer
  - Semantic information – Integrating BMS and BIM
  - Data access
- **Evaluation:** Implementation of benchmarks defined in *EN 15 221: Facility Management*