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Integrating the Web of Things with Solid: Architecture, Benefits, and Real-World Application

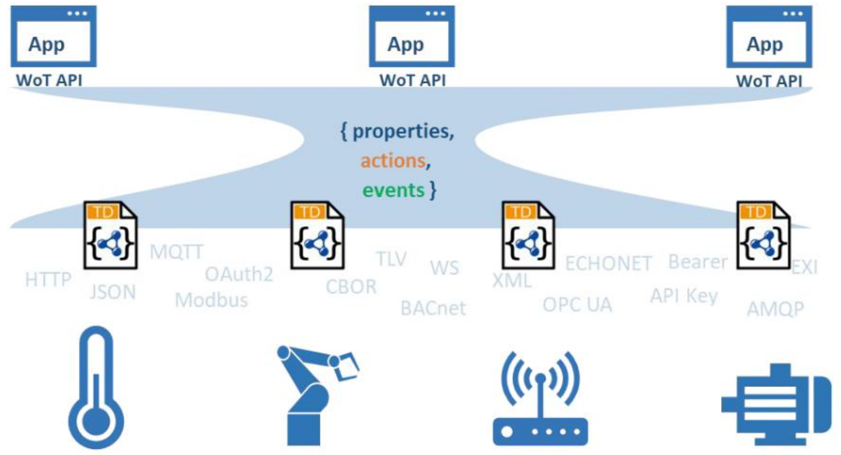
Michael Freund

Agenda

Web of Things (WoT)

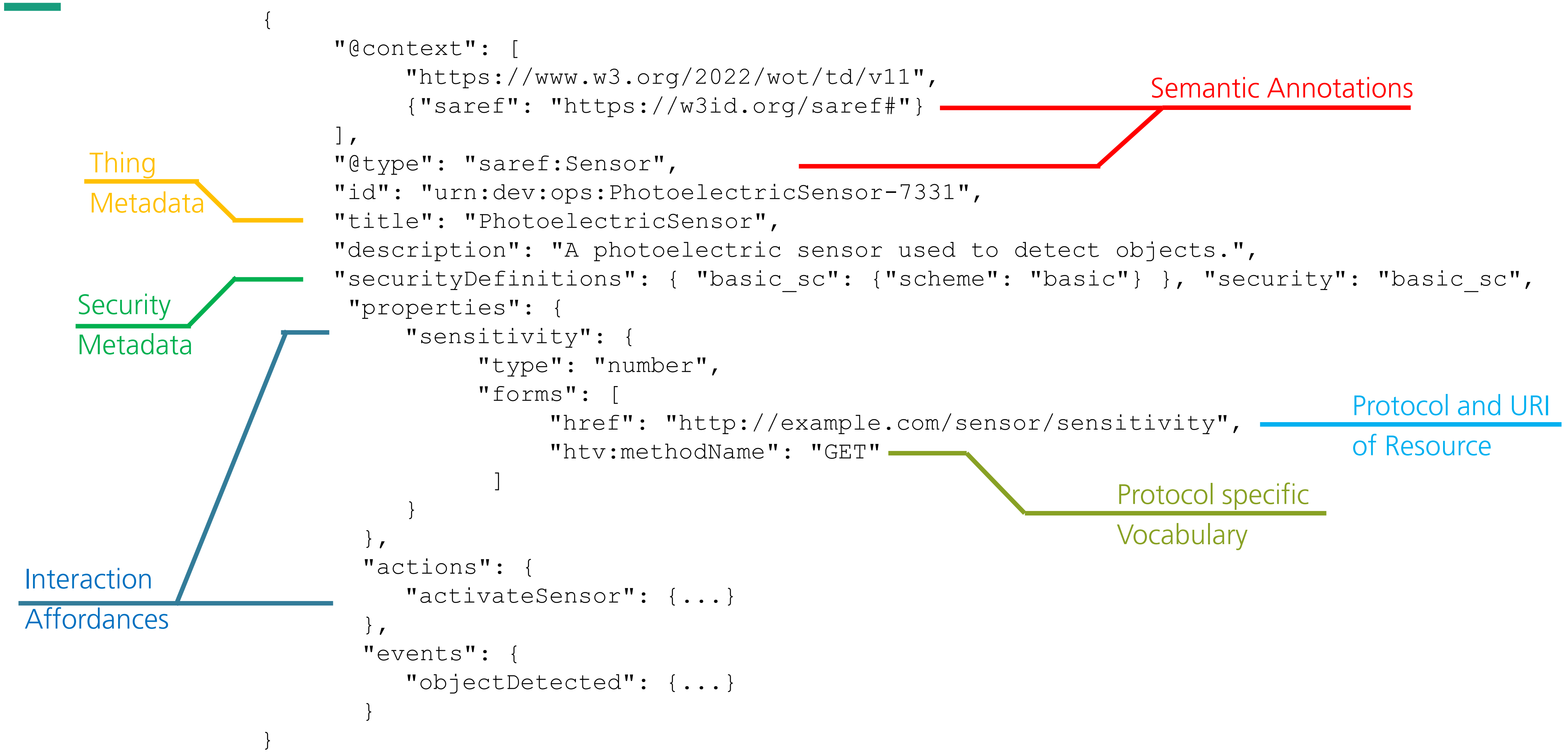
What is the WoT about?

The WoT is about describing any kind of API for IoT devices using any protocol, with a Thing Description (TD) as an abstraction.
A TD is a semantic interface description in RDF serialized in JSON-LD.



Aguzzi, C. & Korkan, E. (2023). "Quick Intro to WoT". *TPAC 2023*.
Kaebisch, S., McCool, M., Korkan, E., Kamiya, T., Charpenay, V., Kovatsch, M. (2023). "Web of Things (WoT) Thing Description 1.1.".

Web of Things (WoT)



```
{
     "@context": [
          "https://www.w3.org/2022/wot/td/v11",
          {"saref": "https://w3id.org/saref#"}
     ],
     "@type": "saref:Sensor",
     "id": "urn:dev:ops:PhotoelectricSensor-7331",
     "title": "PhotoelectricSensor",
     "description": "A photoelectric sensor used to detect objects.",
     "securityDefinitions": { "basic_sc": {"scheme": "basic"} }, "security": "basic_sc",
      "properties": {
          "sensitivity": {
               "type": "number",
               "forms": [
                    "href": "http://example.com/sensor/sensitivity",
                    "htv:methodName": "GET"
                ]
          }
       },
       "actions": {
          "activateSensor": {...}
       },
       "events": {
          "objectDetected": {...}
       }
}
```

Aguzzi, C. & Korkan, E. (2023). "Quick Intro to WoT". *TPAC 2023*.
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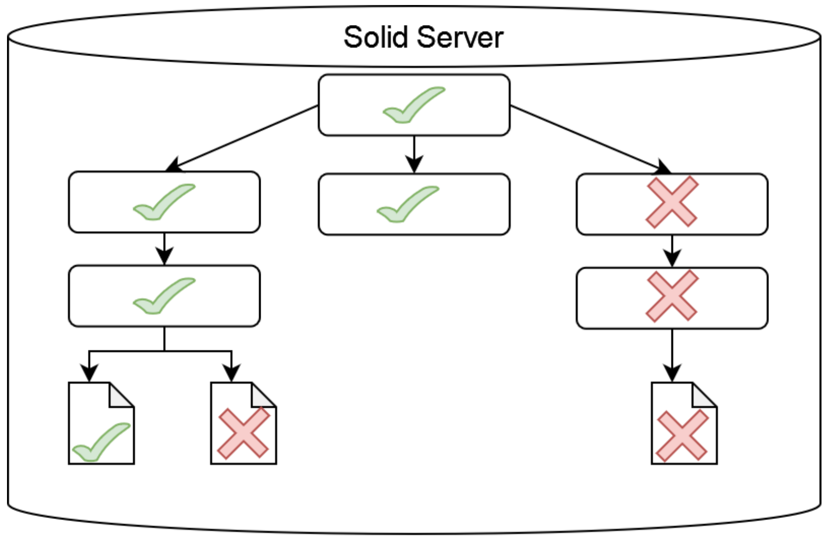
Solid

What is Solid about?

Solid is a set of specifications that enable a secure, decentralized, access-controlled Web data storage based on open standards such as the Linked Data Platform, HTTP, and RDF. The fundamental architectural design principle of Solid is the separation of data (storage) and applications (apps).



Capadisli, S., Berners-Lee, T., Verborgh, R., Kjernsmo, K. (2022). "Solid Protocol".
Sambra, A., Mansour, E., Hawke, S., et al. (2016). "Solid: A Platform for Decentralized Social Applications Based on Linked Data".

WoT and Solid

Goal

- Long-term IoT data storage for continuous analysis and monitoring
- Fine-grained access control to enable participation by internal and external stakeholders while maintaining privacy and security

Initial Situation

- Individual IoT devices and composite systems produce dynamic data at runtime and have associated static data
- But have limited computing power, memory, and power to run
- As a result, data can not be made available to stakeholders on the devices themselves

Challenge

1. Data needs to be offloaded to other components of the system
2. Storage components must provide fine-grained access control to manage data as multiple stakeholders are involved

Fries, J., Freund, M., & Harth, A. (2023). "A Solid Architecture for Machine Data Exchange with Access Control". *SWoCoT'23: 1st International Workshop on Semantic Web on Constrained Things.*

WoT and Solid

Users & Stakeholders

- Access data via a HTTP and RDF based Solid interface

Solid Server

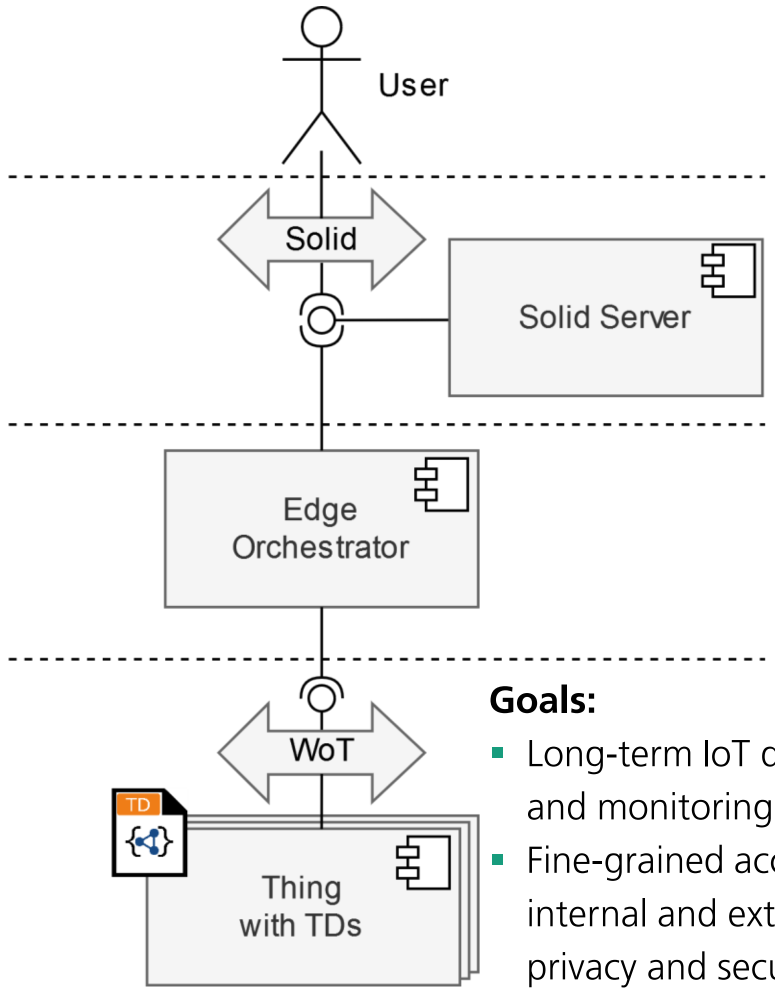
- Unconstrained
- Stores static and dynamic device data in RDF
- Hosts task queue accessible by users via HTTP

Orchestrator

- Edge device constrained in storage
- Orchestrator maps data fetched during orchestration to RDF
- Orchestrator pushes RDF data to Solid
- Orchestrator is a client, Solid Server and Things are servers

Things

- Constrained in energy, computation, and storage
- IoT devices described with a Thing Description



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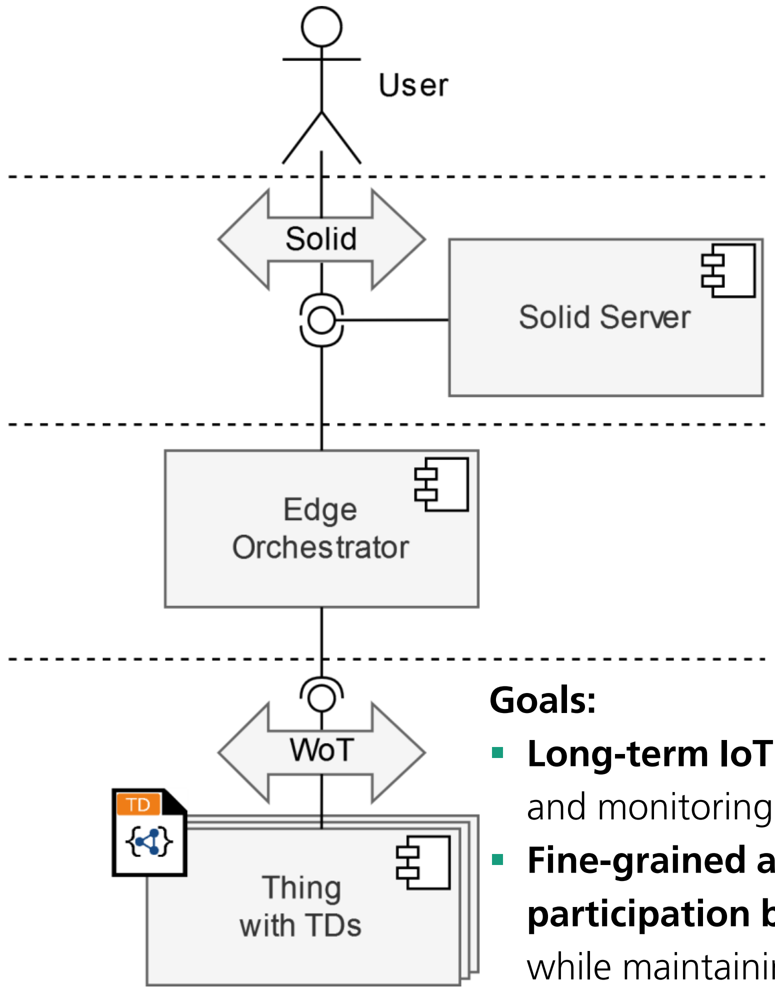

Goals:

- **Long-term IoT data storage** for continuous analysis and monitoring
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Motivation

How to effectively integrate applications?

- Applications dealing with IoT devices and data have different requirements

Latency-sensitive Applications

- Implement feedback loops
- Need near real-time access to most recent data
- Send control commands to devices
- Typically access data at the edge near devices

Data-intensive Applications

- Support high-level business decisions and process orchestration
- Perform long-term data analysis or machine learning
- Need access to significant amounts of historical data
- Typically use data stored in the cloud

Freund, M., Fries, J., Dorsch, R., Schiller, P., & Harth, A. (2023). WoT2Pod: An Architecture enabling an Edge-to-Cloud Continuum. *13th International Conference on the Internet of Things 2023*.

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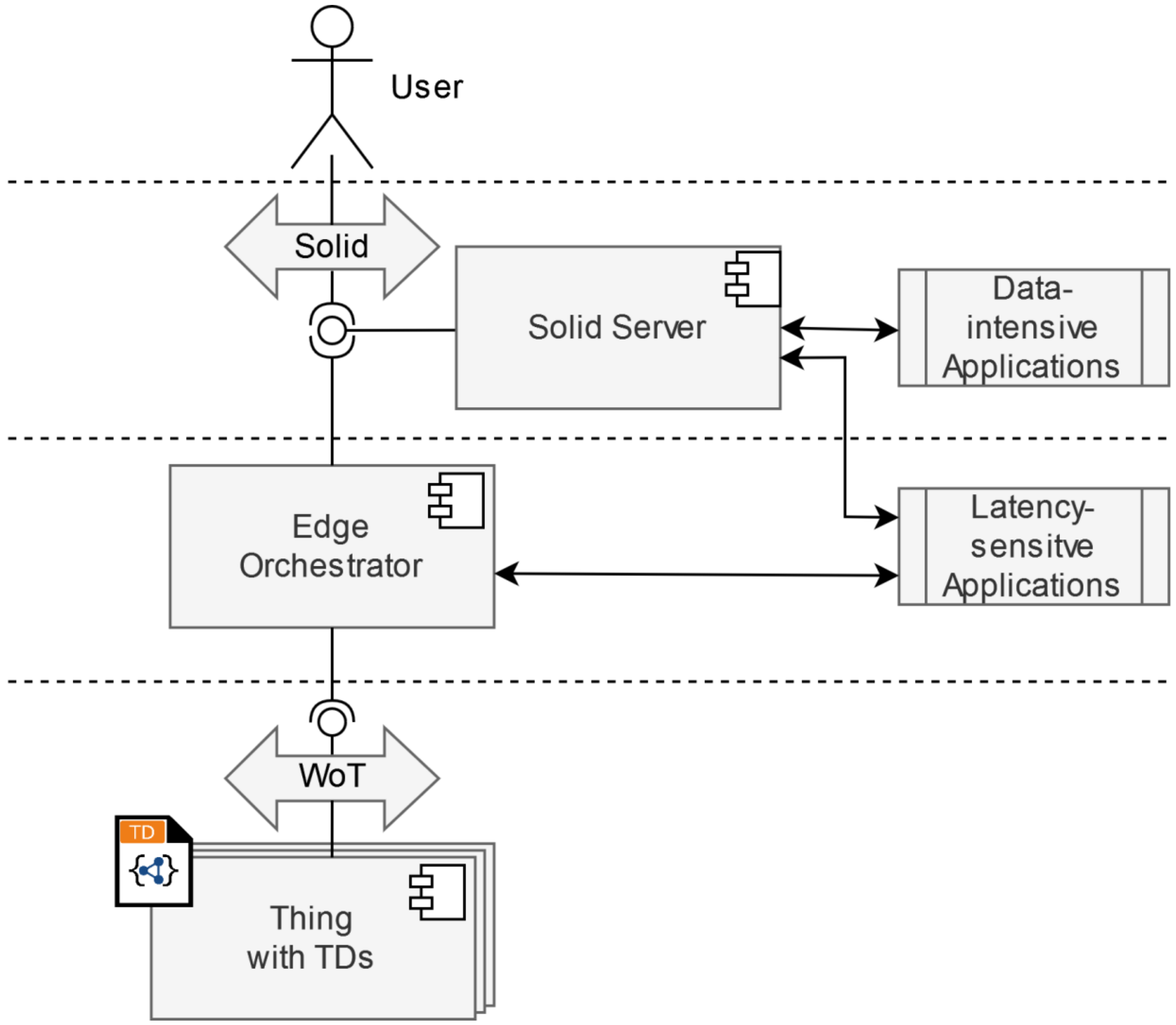
WoT and Solid

Integrating Applications: Challenges

- To enable access of data at the edge, we need a server
- To allow easier application development we need a uniform API at the edge and the cloud

Integrating Applications: Our Solutions

- Edge Orchestrator sets up the API structure and spawns Mediators



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WoT and Solid

Integrating Applications: Challenges

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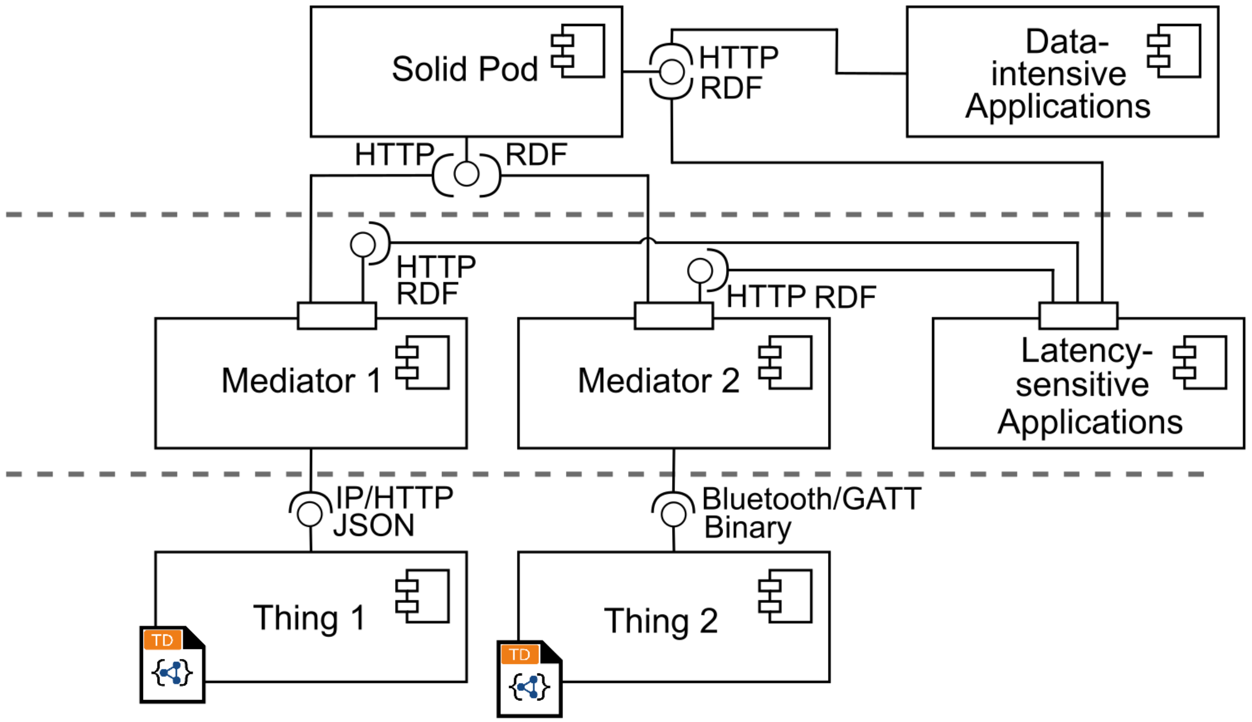
Integrating Applications: Our Solutions

- Edge Orchestrator sets up the API structure and spawns Mediators
- Introduce a Mediator as new component:
  - Maps different data encodings to RDF
  - Maps different protocols to HTTP
  - Implemented as Servient (Server & Client)

  → Acts like a digital replica of the Thing with dynamic data



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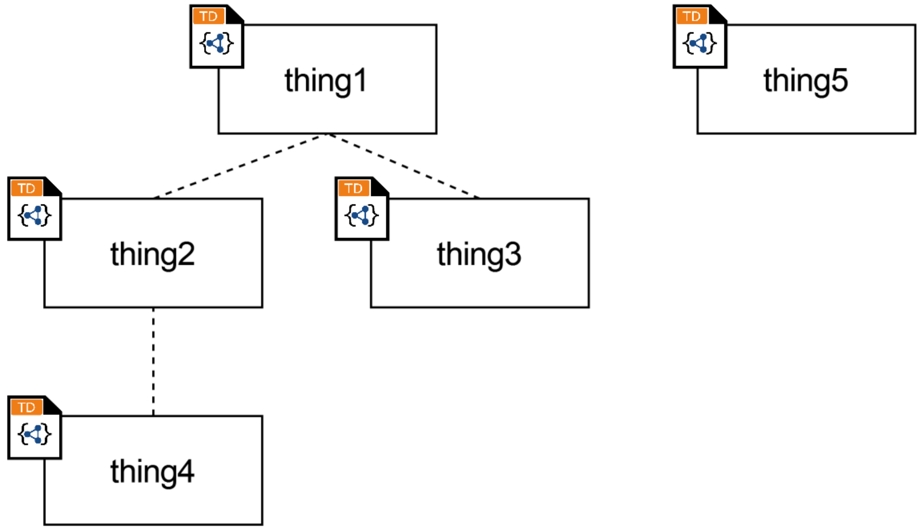
Generating a uniform API

Creating a uniform API structure



→ Thing 5:

base_uri/thing5/

→ Thing 4:

base_uri/thing1/thing2/thing4/

- Edge Orchestrator discovers all Things and creates based on the Thing hierarchy an API
- Thing hierarchy is derived from semantic annotations in Thing Descriptions

(1) Generate a tree structure by creating TreeNode instances

(2) Establish the tree's hierarchy by setting up parent-child relations between TreeNodes guided by sosa:hosts and sosa:isHostedBy

(3) Generate URIs for each tree node by traversing the tree mirroring the position of each node inside the tree.

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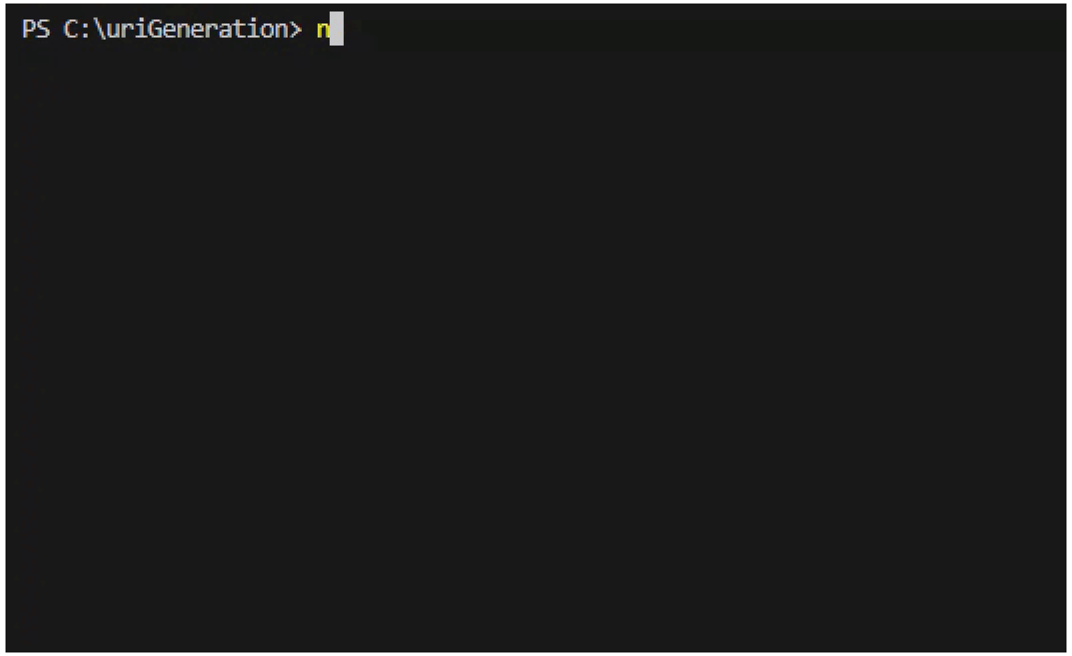

```
PS C:\uriGeneration> n
```

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Generating a uniform API

Mapping different protocols to HTTP

- Not all applications support all protocols (e.g., BLE requires hardware)

- Protocol mapping based on the Web of Things abstraction using protocol bindings
- Use the WoT methods as intermediary representation

WoT Operation	GATT Method
readProperty	Read
writeProperty	Write w/o Response
InvokeAction	Write w/ Response
subscribeEvent	Notify

WoT Operation	HTTP Method
readProperty	GET
writeProperty	PUT
InvokeAction	POST
subscribeEvent	GET

Freund, M., Dorsch, R., & Harth, A. (2022). "Applying the Web of Things Abstraction to Bluetooth Low Energy Communication". *Connected World & Semantic Interoperability Workshop 2022.*

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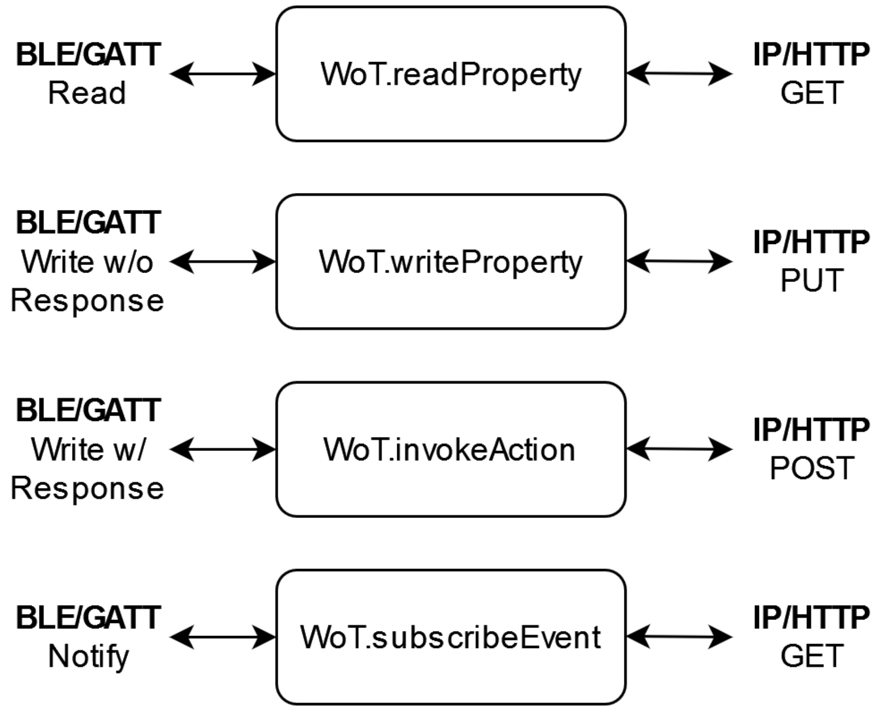

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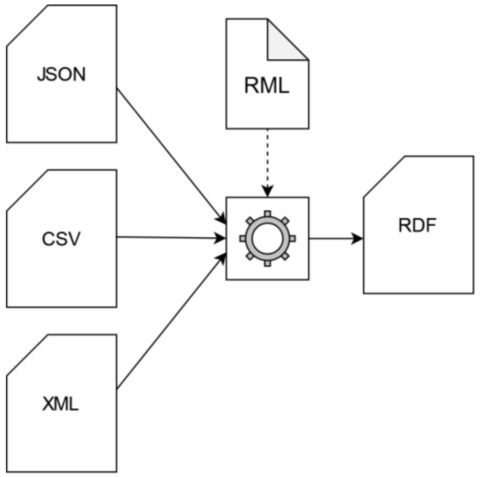
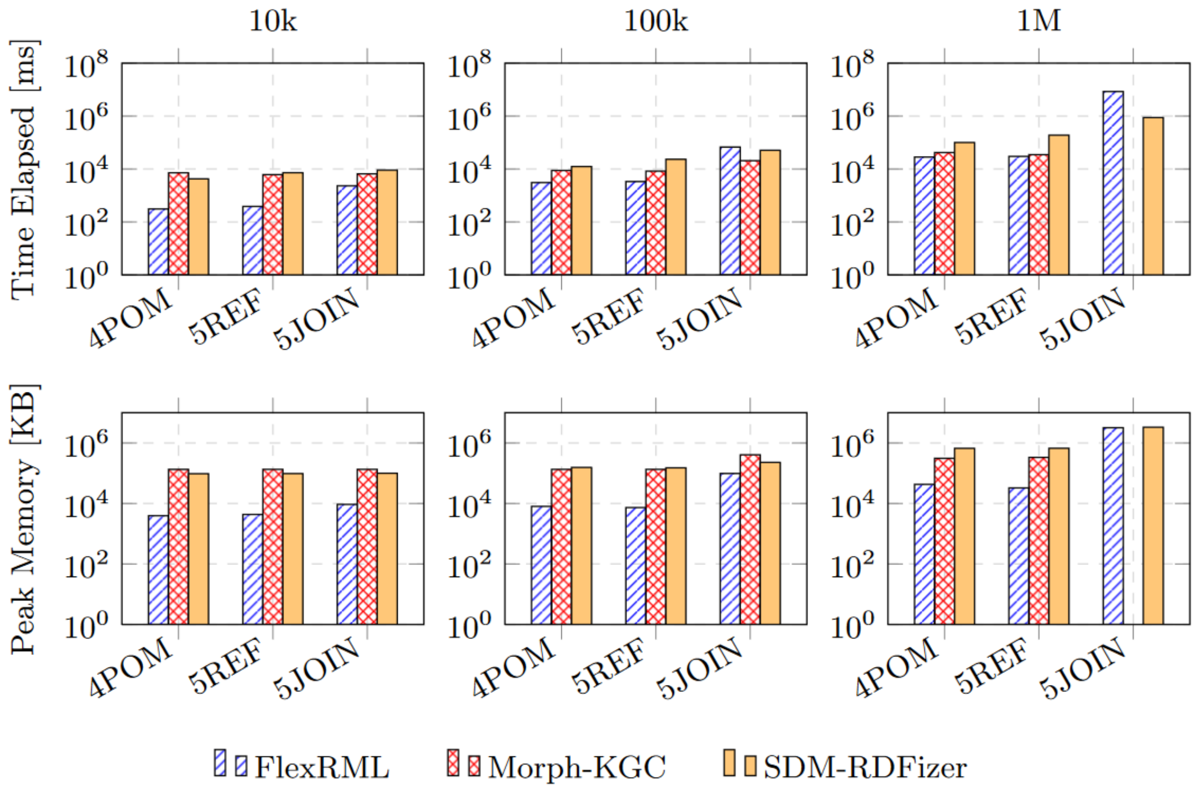
Generating a uniform API

Mapping different data encodings to RDF

- Mappings should be easy adjustable at runtime
- Describe mapping using the RDF Mapping Language (RML)
- RML is a declarative mapping language
- For mapping execution, we use FlexRML



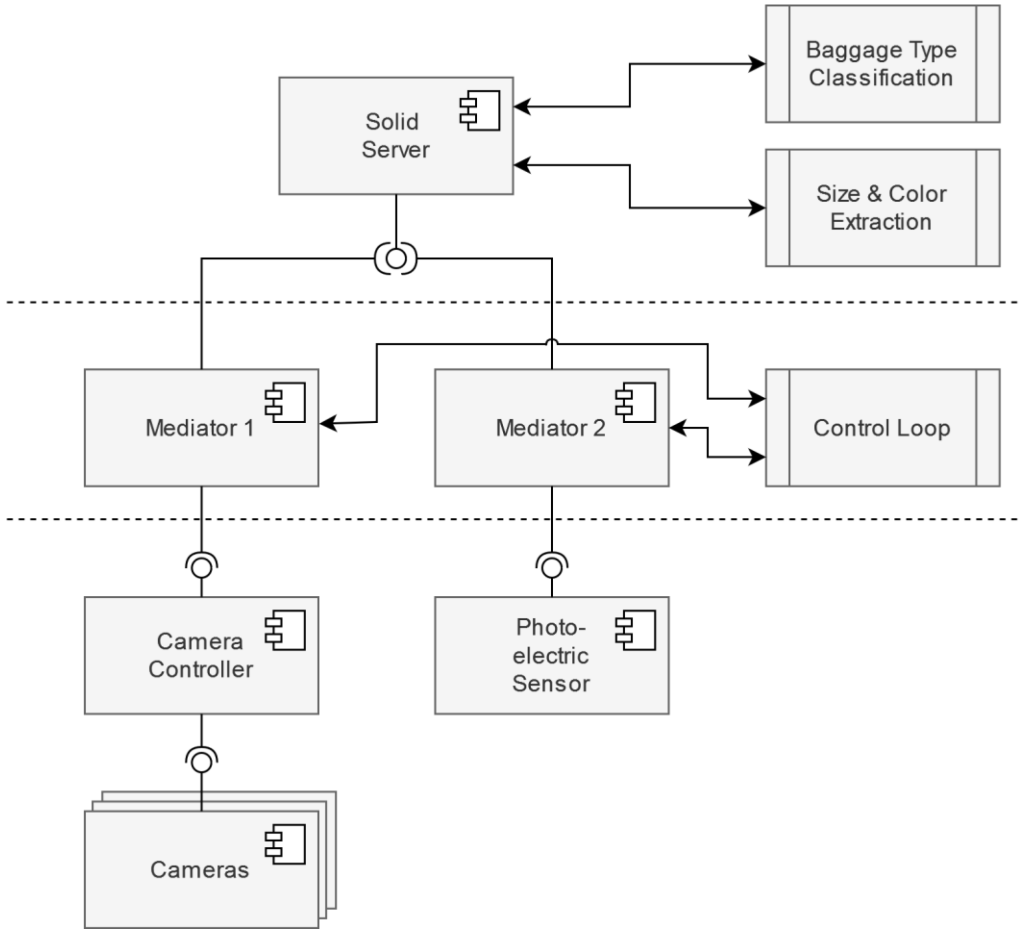


Freund, M., Schmid, S., Dorsch, R., & Harth, A. (2024). "FlexRML: A Flexible and Memory Efficient Knowledge Graph Materializer.". *European Semantic Web Conference 2024.*

Real-world Deployment

Goal: Take pictures of luggage and extract features

- Our prototype is installed at a check-in counter at Munich Airport
  - Devices:
    - 3 RGB-D Intel Realsense D435i Cameras with a Camera Controller
    - A Photoelectric Sensor
  - Edge:
    - An Edge PC hosting the Orchestrator and 2 Mediators
  - Cloud:
    - Community Solid Server



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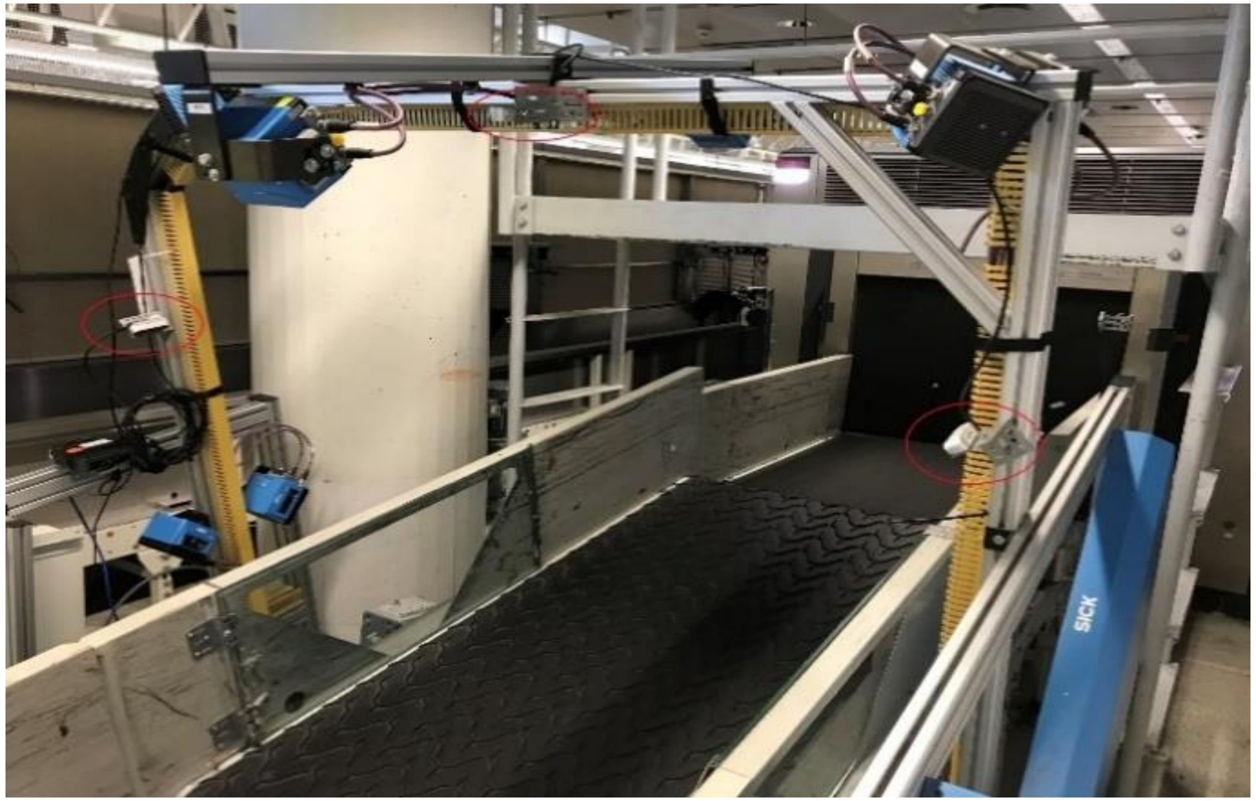

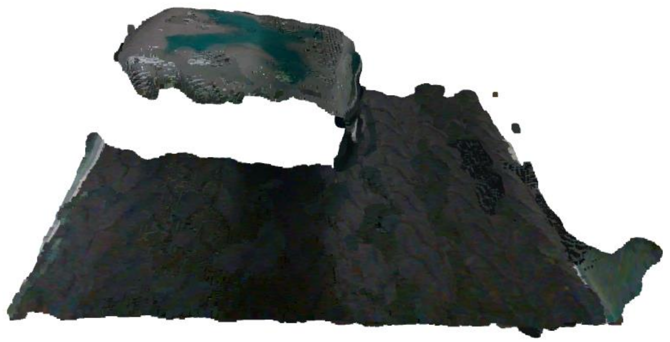

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Real-world Deployment

Data in Solid

```
<#image1> a prov:Entity;
         dc:format "image/png"; dc:creator <#cam37>;
         prov:generatedAtTime "2023-12-14T11:54:01"^^xsd:dateTime;
         dc:source <http://munich-airport.de/cam37/20240114/150340.png>.

<#cam37> a sosa:Sensor;
         sosa:observers <#baggageTop>;
         rdfs:label "Camera 37";
         sosa:isHostedBy <platform1>.

<#baggageTop> a sosa:ObservableProperty;
         rdfs:label "Top view of transported baggage.".

<#imageProcessingAgent> a prov:Agent;
         rdfs:label "Image Processing Agent".

<#imageProcessingActivity> a prov:Activity;
         prov:wasAssociatedWith <#imageProcessingAgent>;
         prov:used <#image1>.

<#processedData20231214115401876282> a prov:Entity;
         prov:wasGeneratedBy <#imageProcessingActivity>;
         :baggageHeight "0.1"^^xsd:decimal; :color "FF0000".
```

Freund, M., Rott, J., Dorsch, R., & Harth, A. (2024). "FAIR Internet of Things Data: Enabling Process Optimization at Munich Airport". *European Semantic Web Conference 2024.*

Conclusion

Initial Goals

- Long-term IoT data storage for continuous analysis and monitoring
- Fine-grained access control to enable participation by internal and external stakeholders while maintaining privacy and security

Combining WoT and Solid

- IoT devices using various data encodings and communication protocols can be integrated (WoT)
- Data and metadata are stored with fine grained access control to involve stakeholders (Solid)
- Enable development of applications (Uniform API)
  - Require only support for HTTP and RDF
  - Data can be accessed in the cloud and the edge by only changing the base IP

Fraunhofer Institute for Integrated Circuits IIS

Contact

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