Naming, Twinning, and Observing — Towards Scalable, Reliable, and Resilient Cyber-Physical Systems Spanning Administrative and Geographic Boundaries

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Introduction

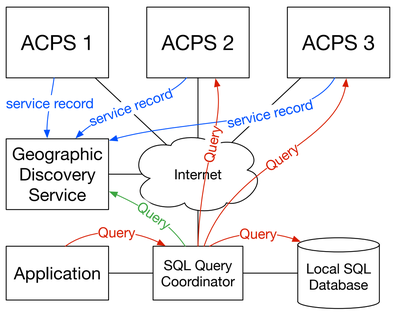
Broadly, our project aims to identify, design, and evaluate the missing technology for CPS' scalable across administrative and geographic boundaries.

Fundamental Challenges

1. Naming and name resolution of CPS devices
2. Scalable directory architecture for CPS metadata
3. Storage and query processing for sensor data
4. Fine-grained federated access control mechanism

Sensor Data Storage and Query Processing

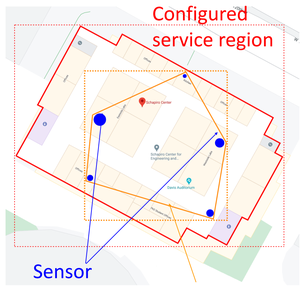
- Sensor data storage across **autonomous cyber-physical systems** (ACPS)
- Geographically bounded by a **service region**
- Described by a **service descriptor**
- Query processing architecture based on SQL Spatial




```
SELECT
    measurements.timestamp     AS 'Time',
    measurements.data::numeric AS 'PM2.5'
FROM
    measurements, openstreetmap
WHERE
    ST_Contains(openstreetmap.bounds, measurements.location)
    AND openstreetmap.name      = 'Morningside Heights'
    AND measurements.quantity   = 'PM2.5'
    AND measurements.timestamp > "2020-01-01'
ORDER BY timestamp
```

"Return the measurements ordered from January 1st, 2020 until now from all PM2.5 sensors within the Morningside Heights neighborhood."

```
[ "@type": "ServiceDescriptor",
  "@context": "https://schema.org/Syn
  "displayName": "IRT Lab Sensors",
  "lastUpdated": "<ISO timestamp>",
  "expires": "<ISO timestamp>",
  "coverageRegion": {
      "type": "Polygon",
      "bbox": [-10.0, -10.0, 10.0, 10
      "coordinates": [] },
  "private": false,
  "contact": "wss://as-123.example.co
```

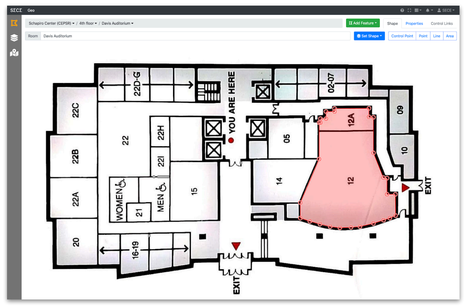


Geospatial Naming Architecture and Resolver

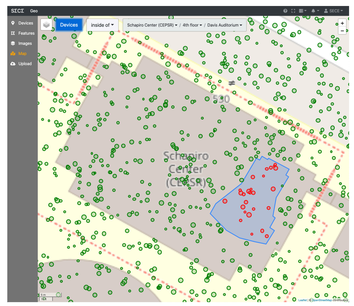
Approach

1. Combine public (OpenStreetMap) and private (floorplans) information into a **database of geographic features**
   - areas, POIs, ways, buildings, …
   - floors, apartments, rooms, …
2. Determine **location uncertainty area for CPS devices**
   - GPS, Wi-Fi/cellular/LoRa triangulation, manual, …
3. Name & **resolve** CPS **devices** based **on** **device type** and geographic **feature relationship**
4. Example: "inside('Davis Auditorium') & isa('thermometer')"

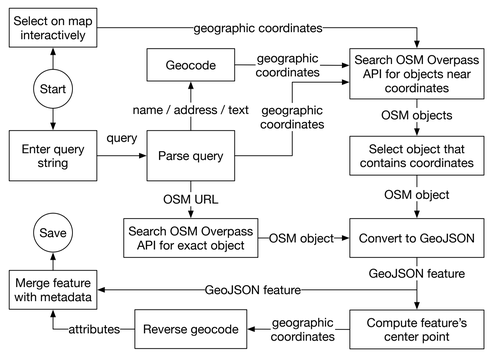
Web-based geographic feature editor



IoT device digital twins



Geospatial data processing architecture

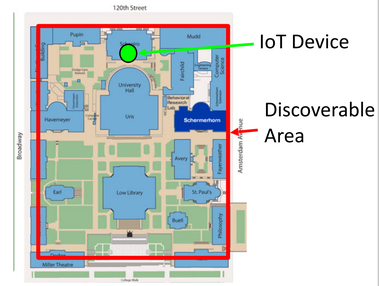


Examples of supported geographic naming predicates

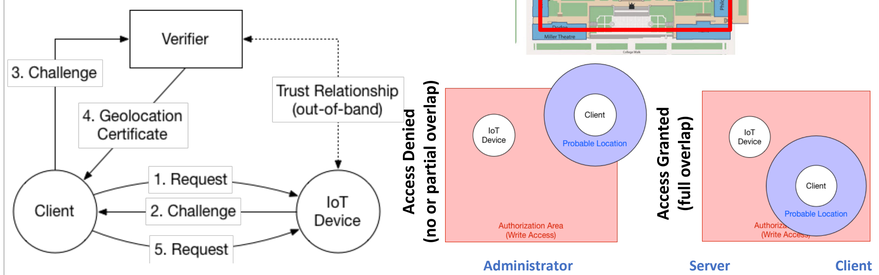
- all inside, one inside, around, along
- within X meters, nearest neighbor
- indoor, outdoor, on grass
- at the intersection of

Access Control for Proposed System

- Access control policies based on geospatial relationships
  - People can control light switches in the same room
  - Discoverable on campus
- Integrate attribute-based rules
  - Define more complex policies
  - Fine-grained and manageable

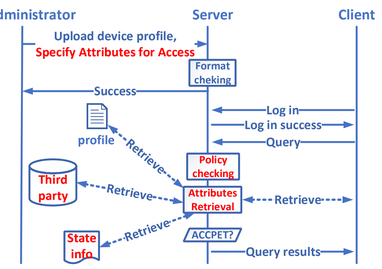


System Architecture



Objectives

- Federated attributes provision
- Various attributes
- Customized policies
- Multiple administrative domains



Retrieve attributes from different sources

Broader Impact

- Make building management easier
  - Digital twins of smart buildings
  - Resilient, reliable, scalable
- Education and outreach
  - Supports 2 PhD students
  - Supports 2 REU students in 2021
  - Possible outreach to larger CU community (in progress)

Source: https://www.securityindustry.org/

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