Next Generation User Interfaces

Indoor Positioning and Location Awareness

Maxim Van de Wynckel

Indoor Positioning System

OpenHPS

"*An indoor positioning system (IPS) is a network of devices used to locate people or objects where GPS and other satellite technologies lack precision or fail entirely, such as inside multistory buildings, airports, alleys, parking garages, and underground locations.*"

- Wikipedia (2022)

- (image) Bonkers.io (2018)

Location Awareness

OpenHPS

"*Location awareness refers to devices that can passively or actively determine their location.*"

- Wikipedia (2022)

Contextual Location Awareness

OpenHPS

Using the location of a person or asset as contextual information for **implicit human-computer interaction**.

NOTE: You will see implicit human-computer interaction in a later lecture

Use Cases

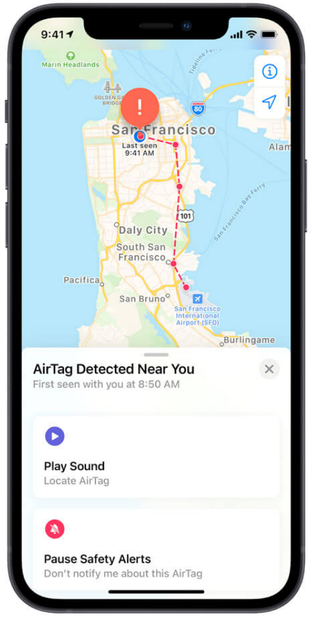
Indoor Navigation

- Gatwick Airport Limited (2017)

Use Cases ...

Asset Tracking

- Track the location of expensive items
- Material resource planning
- Personnel tracking



- LetsGoDigital (2021)

- Favendo (2022)

Use Cases ...

OpenHPS

Implicit Interaction

- Home automation
- Resource assigning
- Machine learning recommendations

Use Cases ...

Autonomous Robots

- Jim Martin (2019)

Positioning Technologies

OpenHPS

- RF-based (Wi-Fi, Bluetooth, UWB)
- Sound-based (Ultrasound beacons, ambient noise)
- Camera-based (VSLAM, MTMC, VLC)
- Inertial Measurement Unit (IMU-based) (acceleration, velocity, geomagnetic)
- *Many more ...*

Positioning Algorithms

OpenHPS

- Fingerprinting (k-NN, affinity propagation, clustering, ...)
- Mathematical (triangulation, multilateration, ...)
- Dead reckoning
- Sensor fusion (complementary filters, probabilistic, ...)
- Cartographing
- *Many more ...*

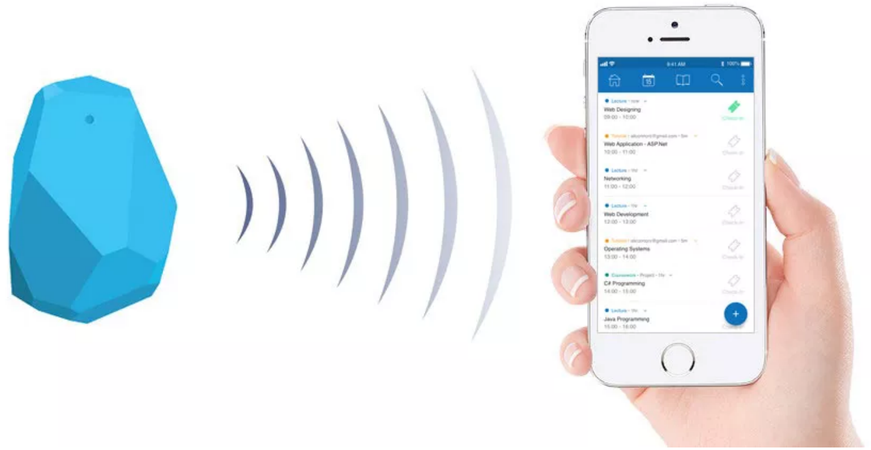
Bluetooth beacons

OpenHPS

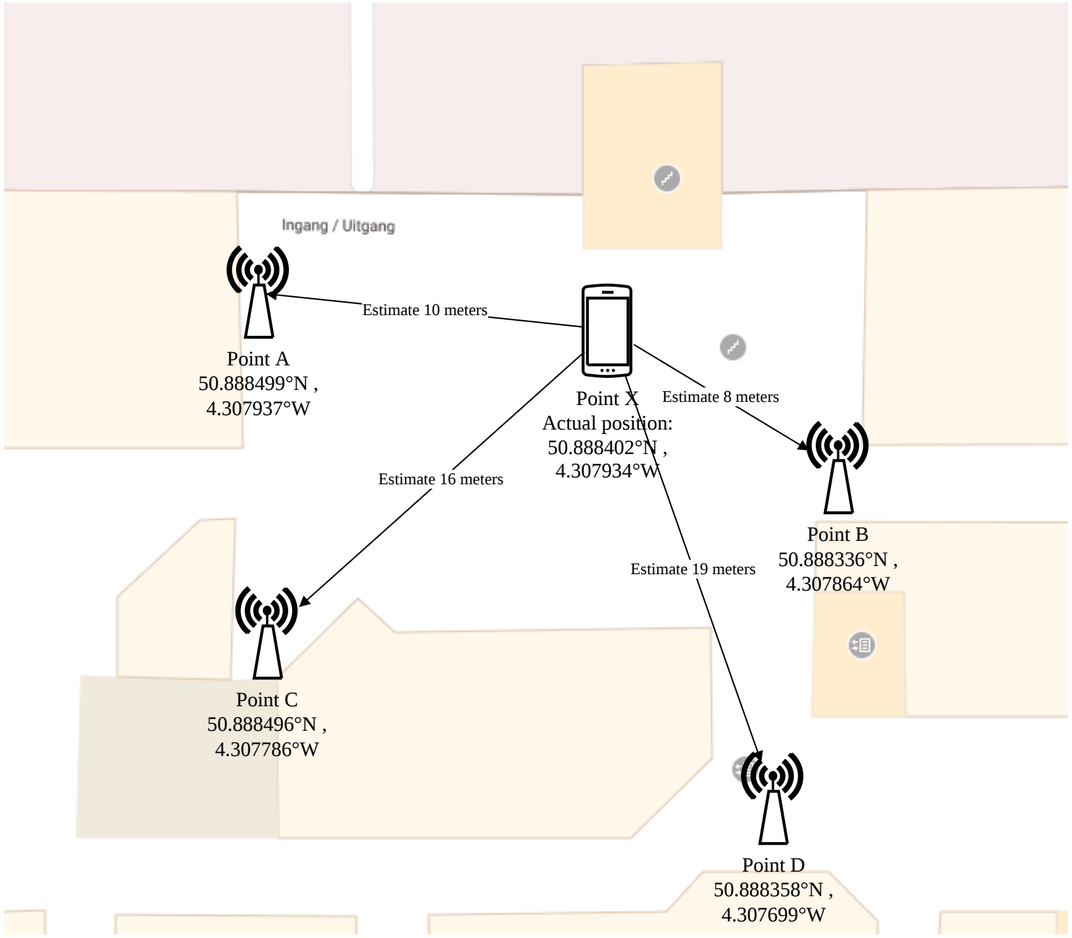
A small (battery powered) device that sends out a BLE advertisement in a fixed interval. The received signal strength is used to esimate the linear distance.

Algorithms:

- Fingerprinting
- Multilateration, Cell-Identification

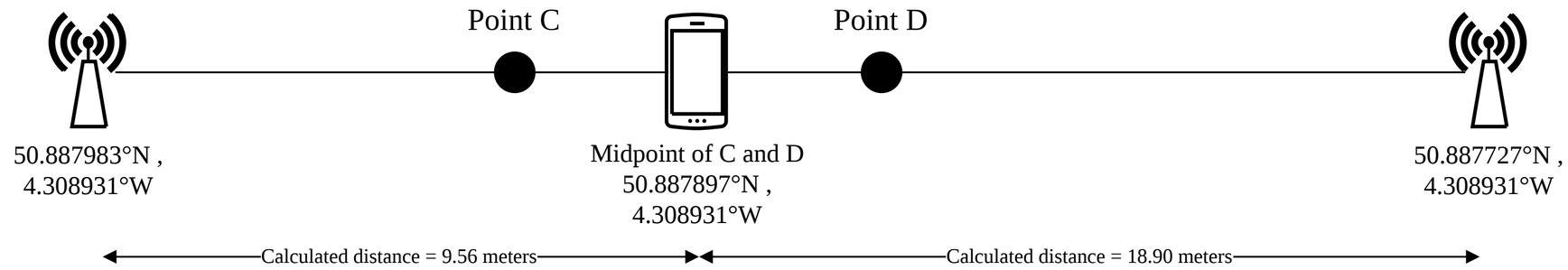


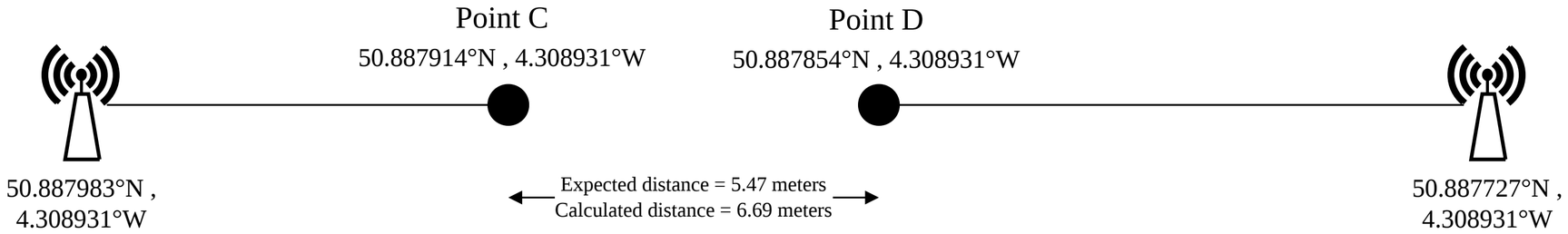
Multilateration (>3 transmitters)



- Van de Wynckel, Maxim (2019)

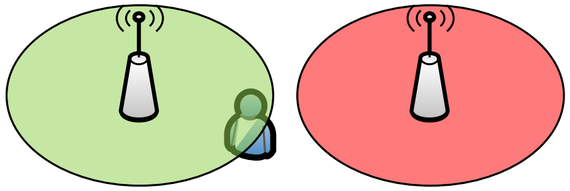
Multilateration (2 transmitters)

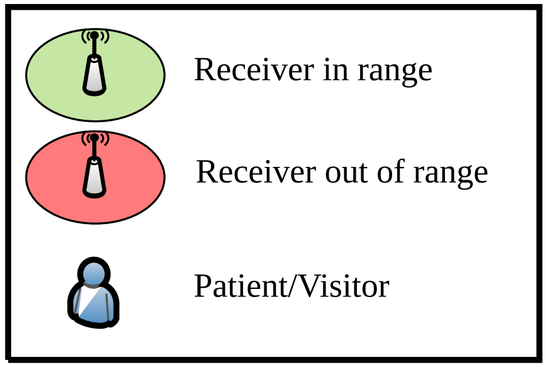


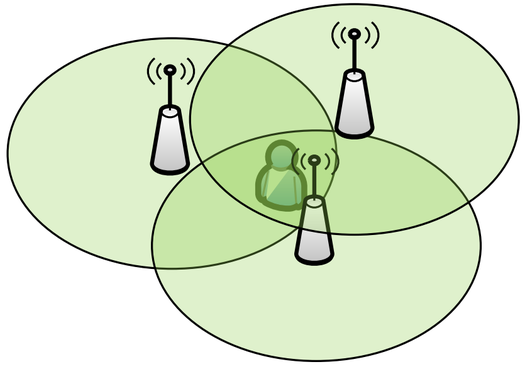


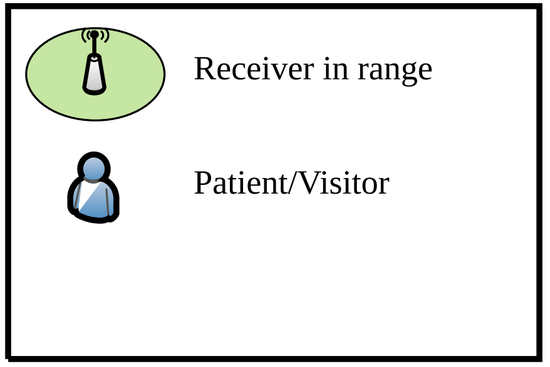
- Van de Wynckel, Maxim (2019)

Cell-Identification (1 transmitter)









- Van de Wynckel, Maxim (2019)

Ultra wideband

OpenHPS

A small (battery powered) device that sends out an RF signal over a large band (6 - 8 GHz), allowing the use of Time of Flight (ToF) for determining the distance to centimeter precision. More power consumption than BLE.

Algorithms:

- Multilateration

Wi-Fi access points

OpenHPS

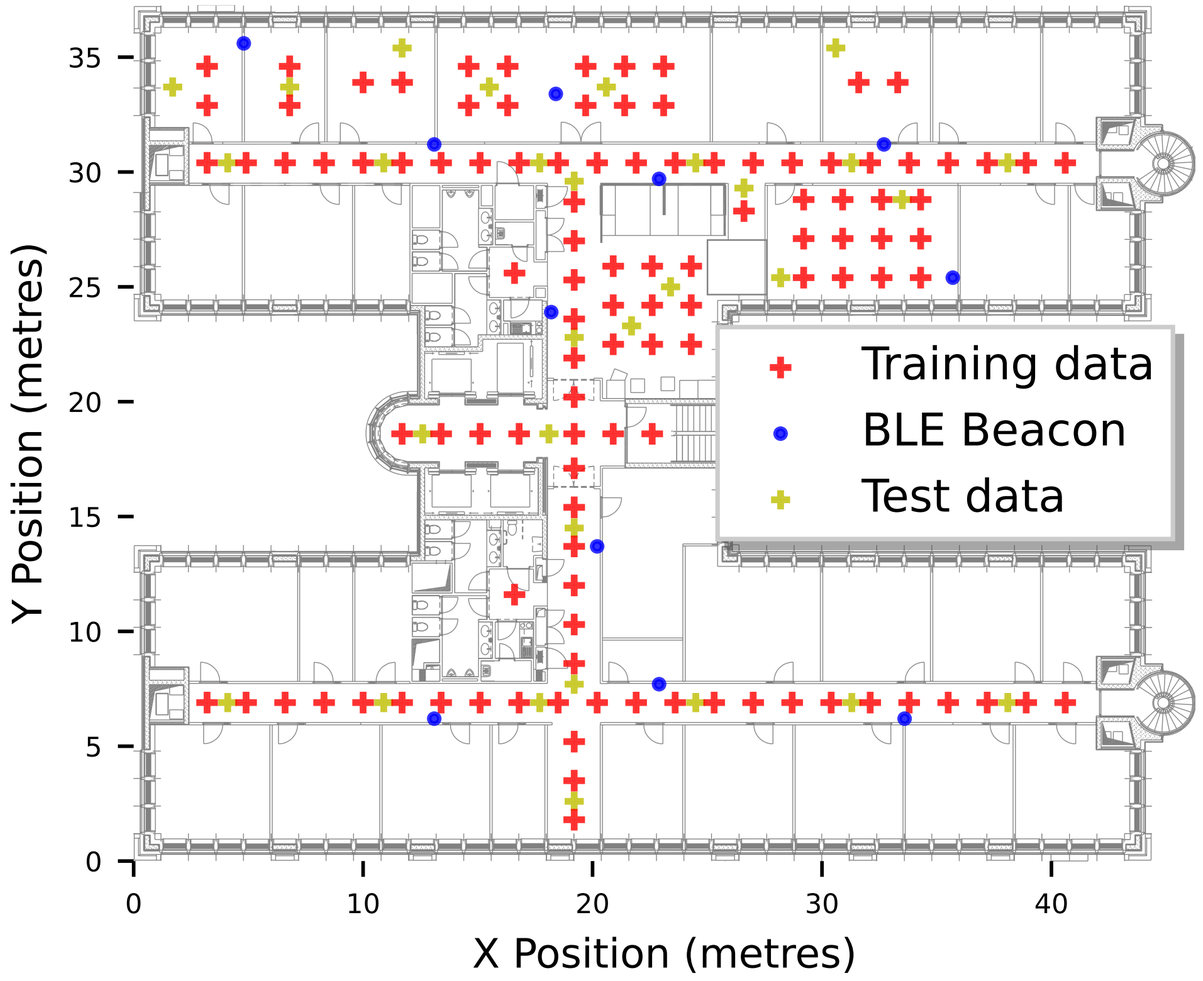
Existing Wi-Fi infrastructure to predict the position based on the signal strength or Time of Flight (ToF) on supported access points.

Algorithms:

- Fingerprinting
- Multilateration

Fingerprinting

OpenHPS



- Van de Wynckel, Maxim & Signer, Beat (2021)

Fingerprinting ...

OpenHPS

```
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```

- Van de Wynckel, Maxim & Signer, Beat (2021)

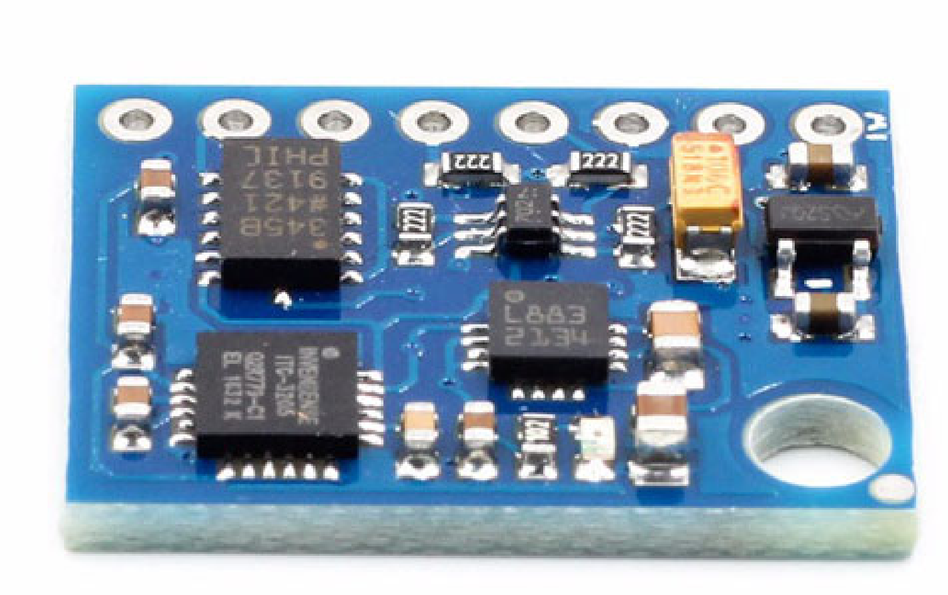
Inertial Measurement Unit (IMU sensor)

OpenHPS

Accelerometer, gyroscope and magnetometer to determine the orientation, linear and angular velocity. Optionally can contain a barometer.

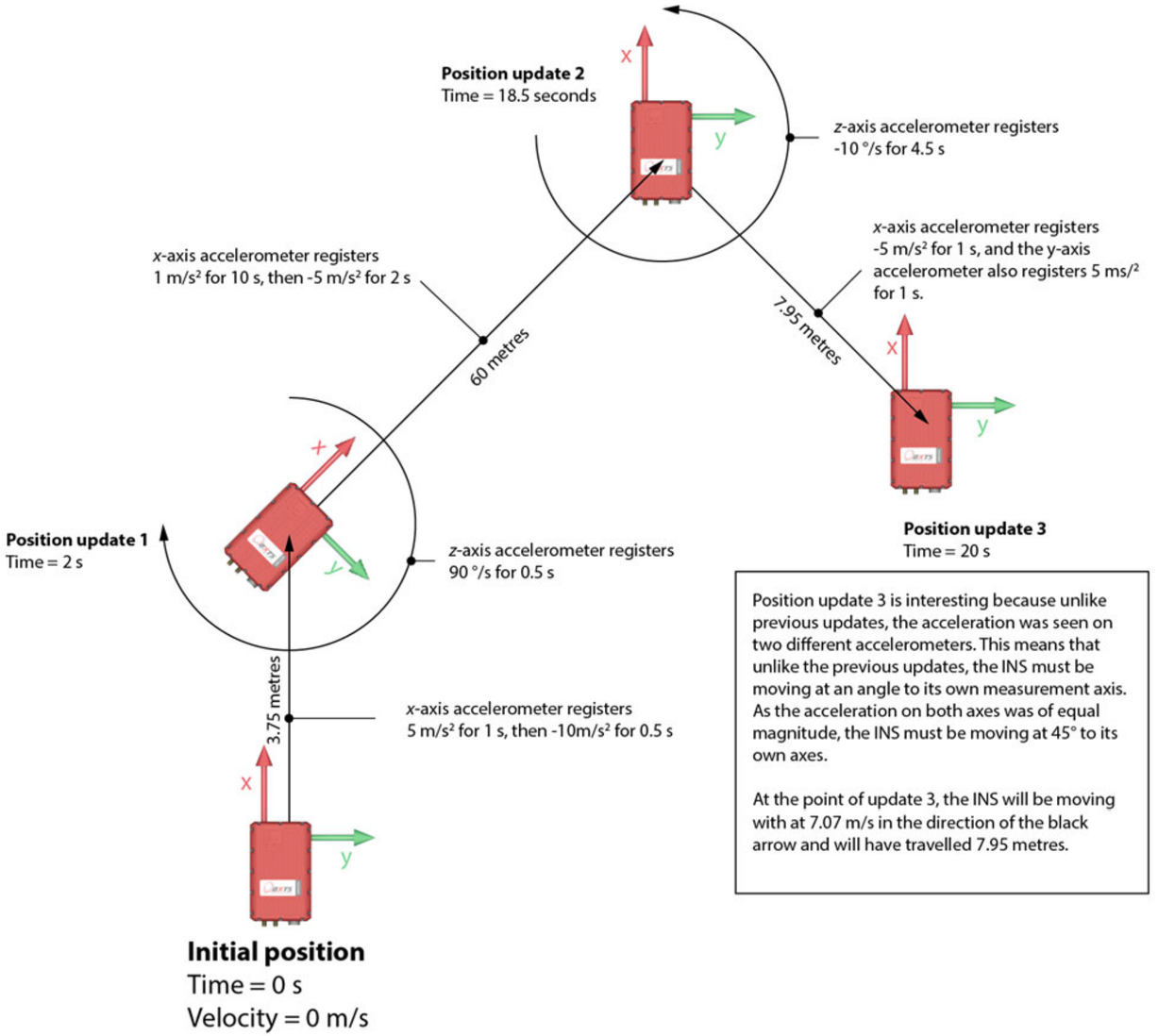
Algorithms:

- Dead reckoning (raw, pedometer)
- Geomagnetic fingerprinting



Dead Reckoning

OpenHPS



What is OpenHPS?

OpenHPS

An Open Source Hybrid Positioning System

OpenHPS

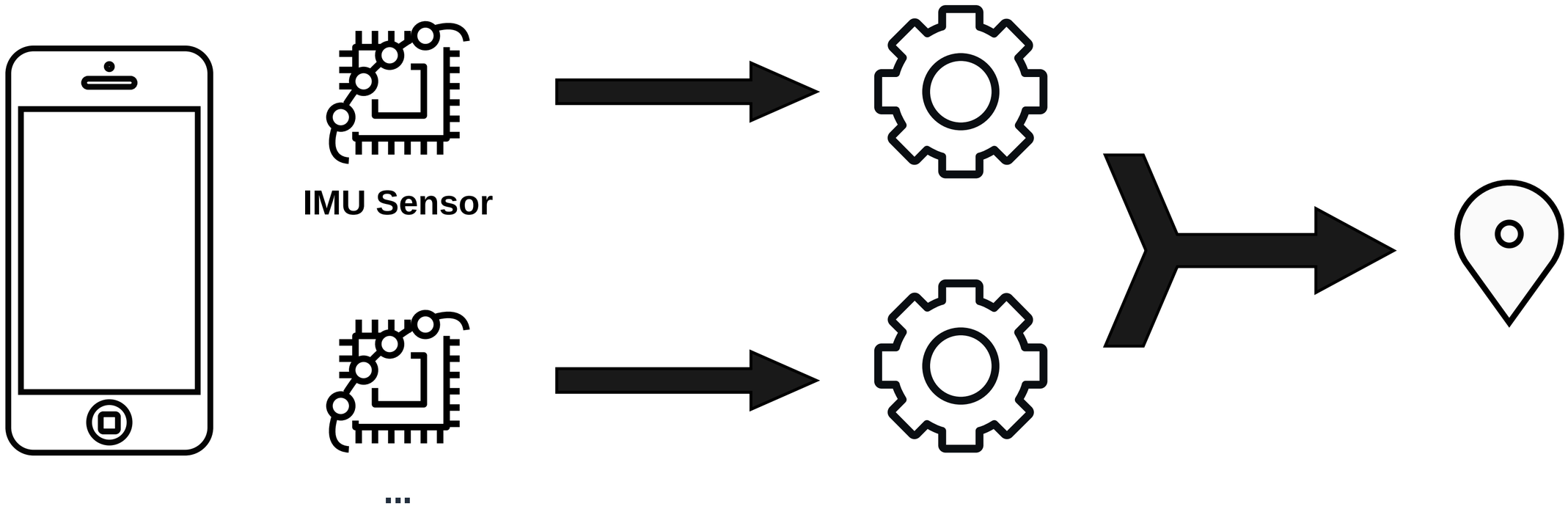
OpenHPS

An Open Source Hybrid Positioning System

- Any technology
- Any algorithm
- Various use cases
- Flexible processing and output
  - Prefer accuracy over battery consumption, reliability, ...
- Aimed towards developers and researchers

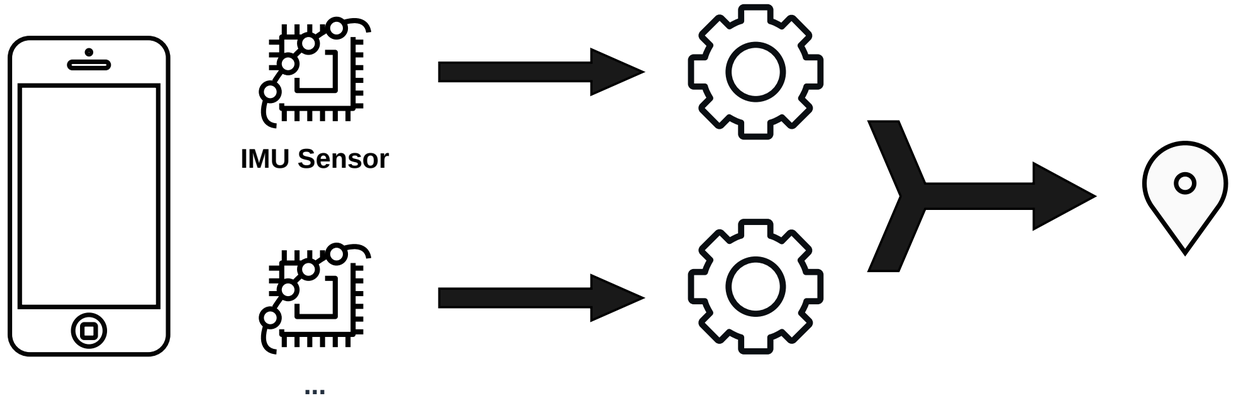
Process Network Design

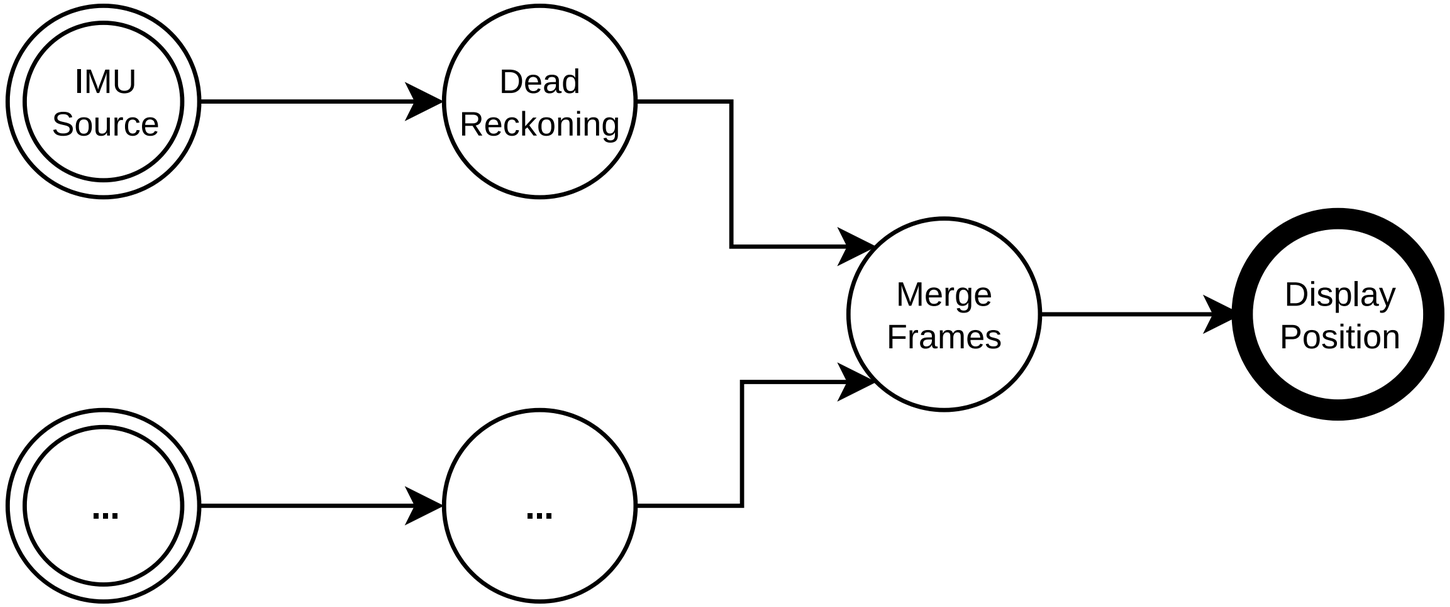
OpenHPS



Process Network Design ...

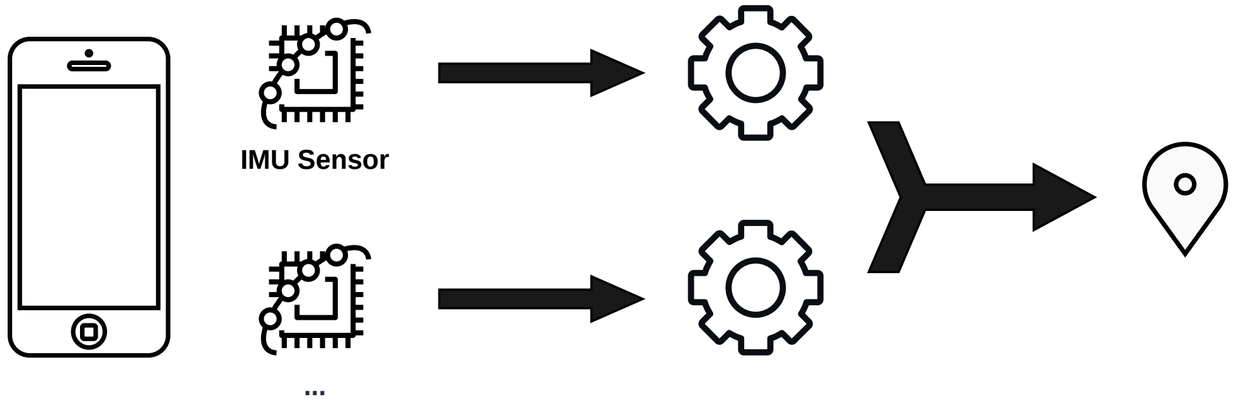
OpenHPS

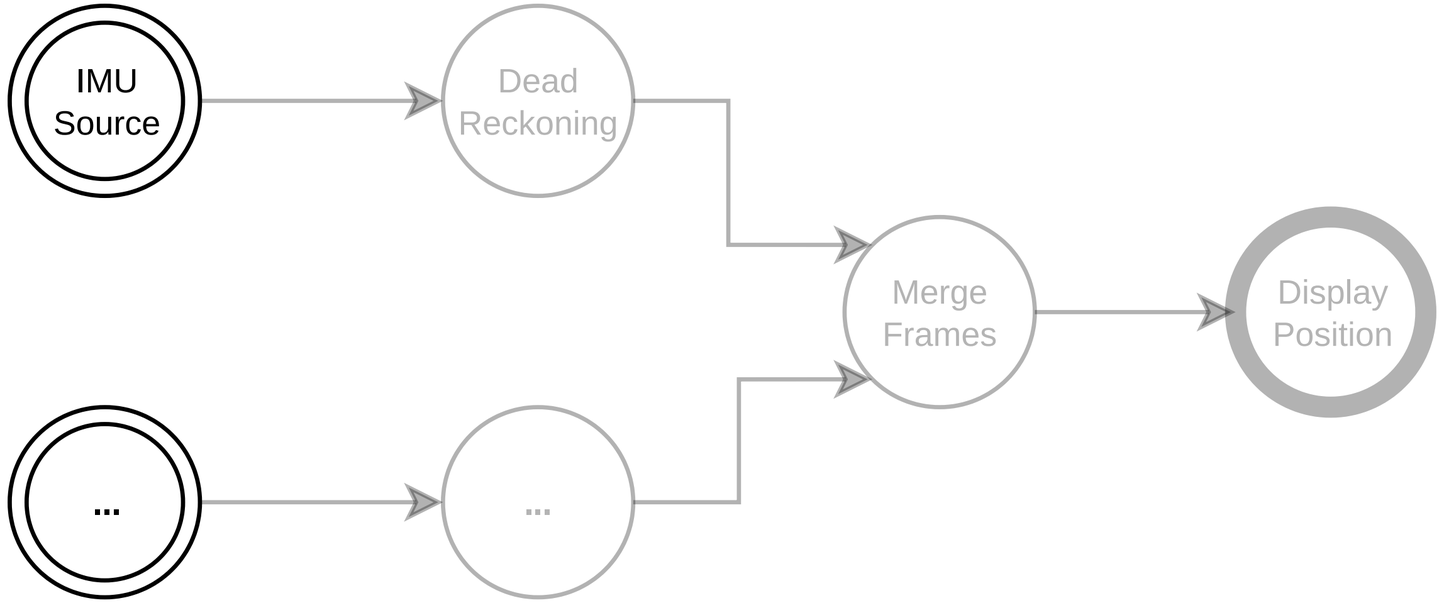




Process Network Design ...

OpenHPS





Process Network Design ...

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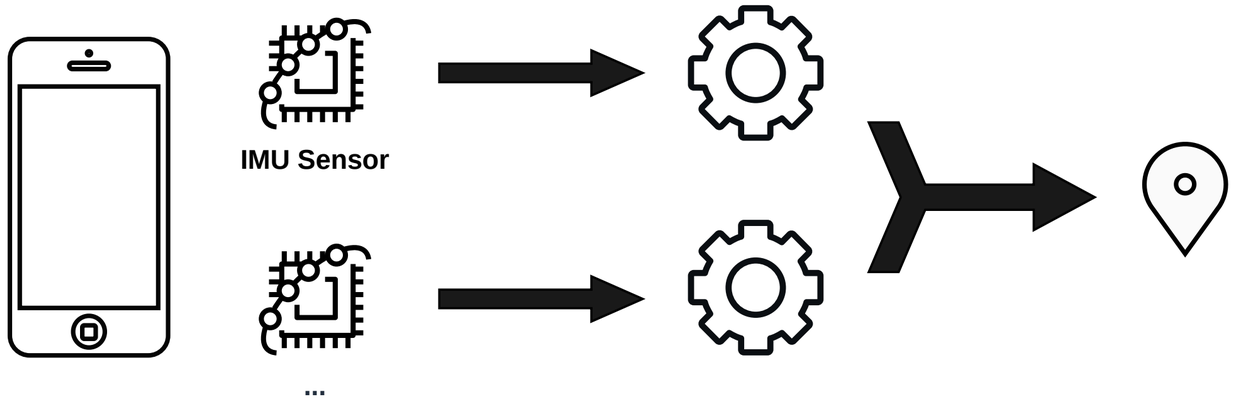
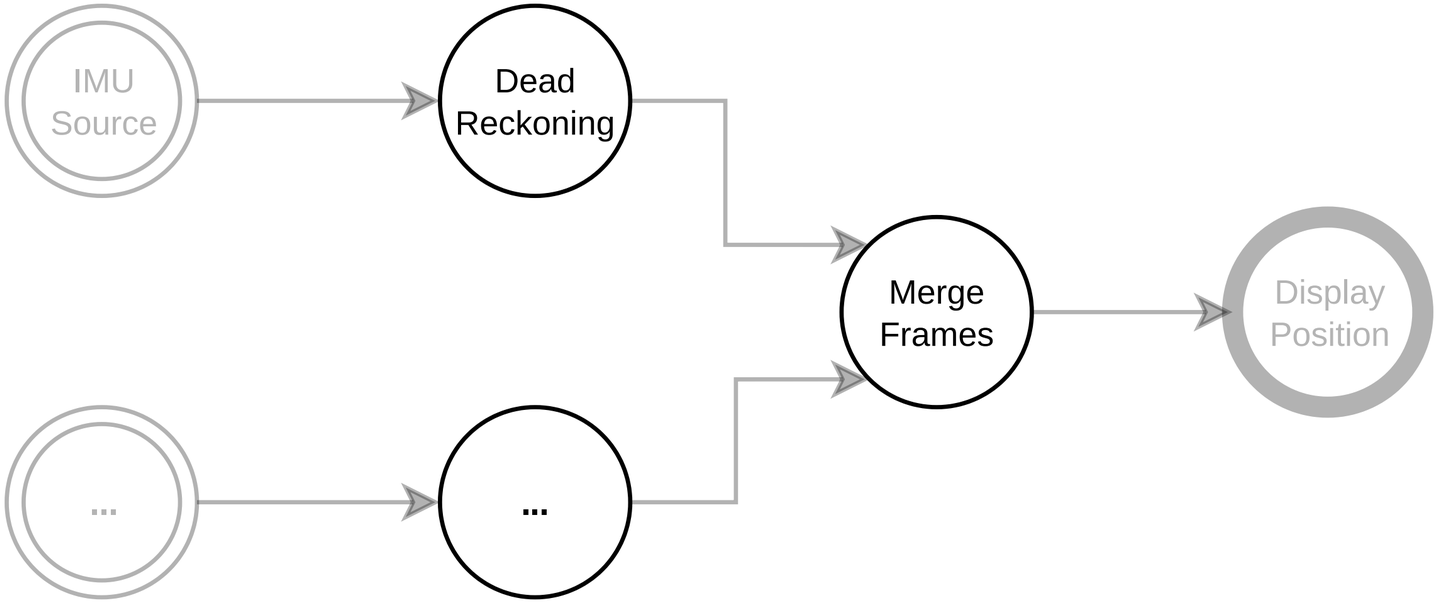
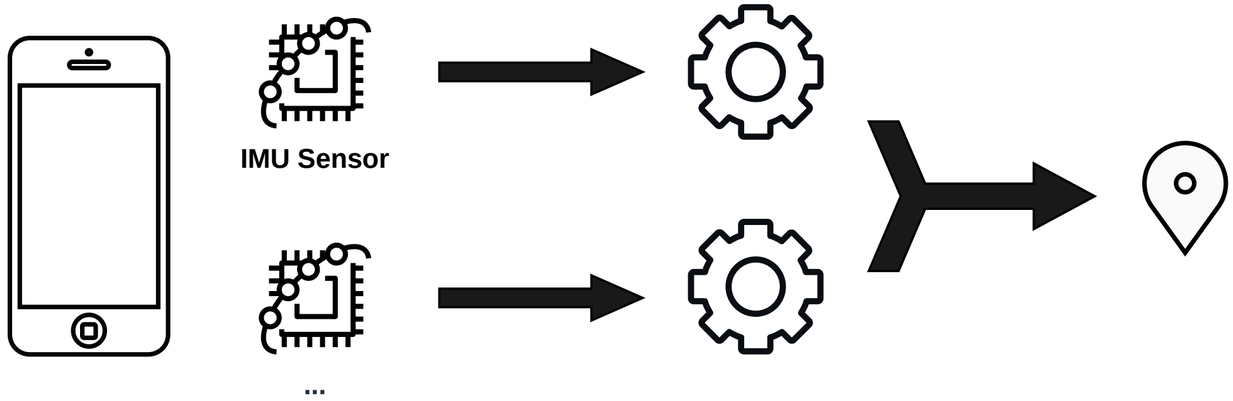
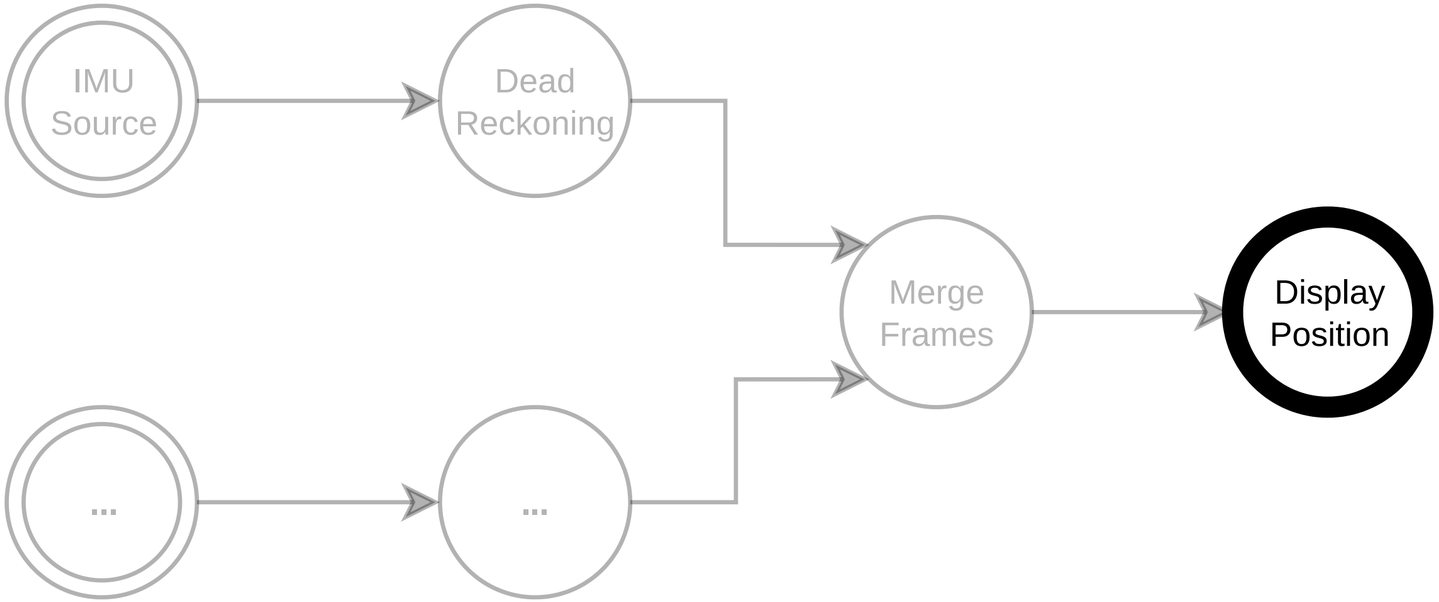




Process Network Design ...

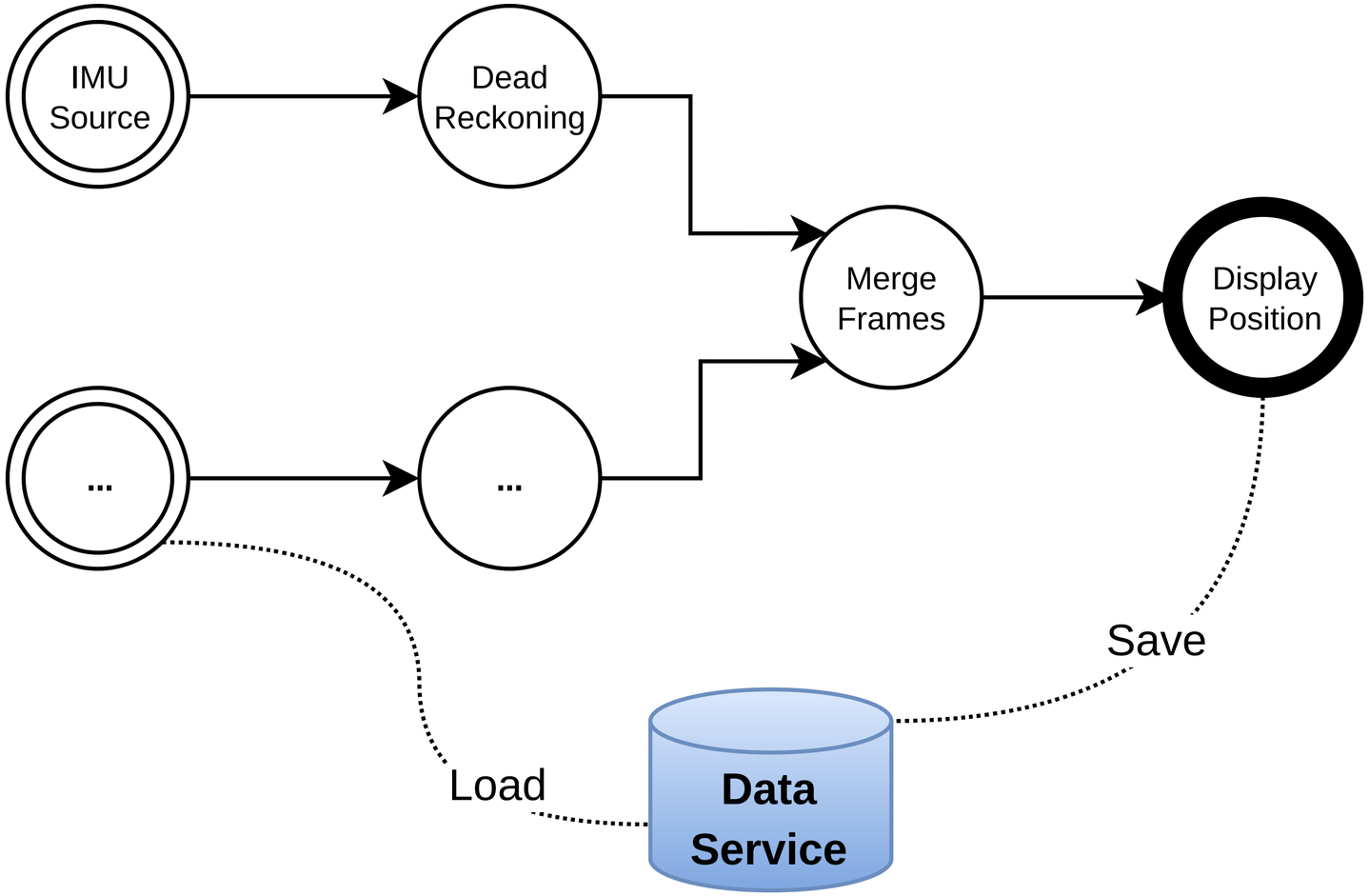
OpenHPS





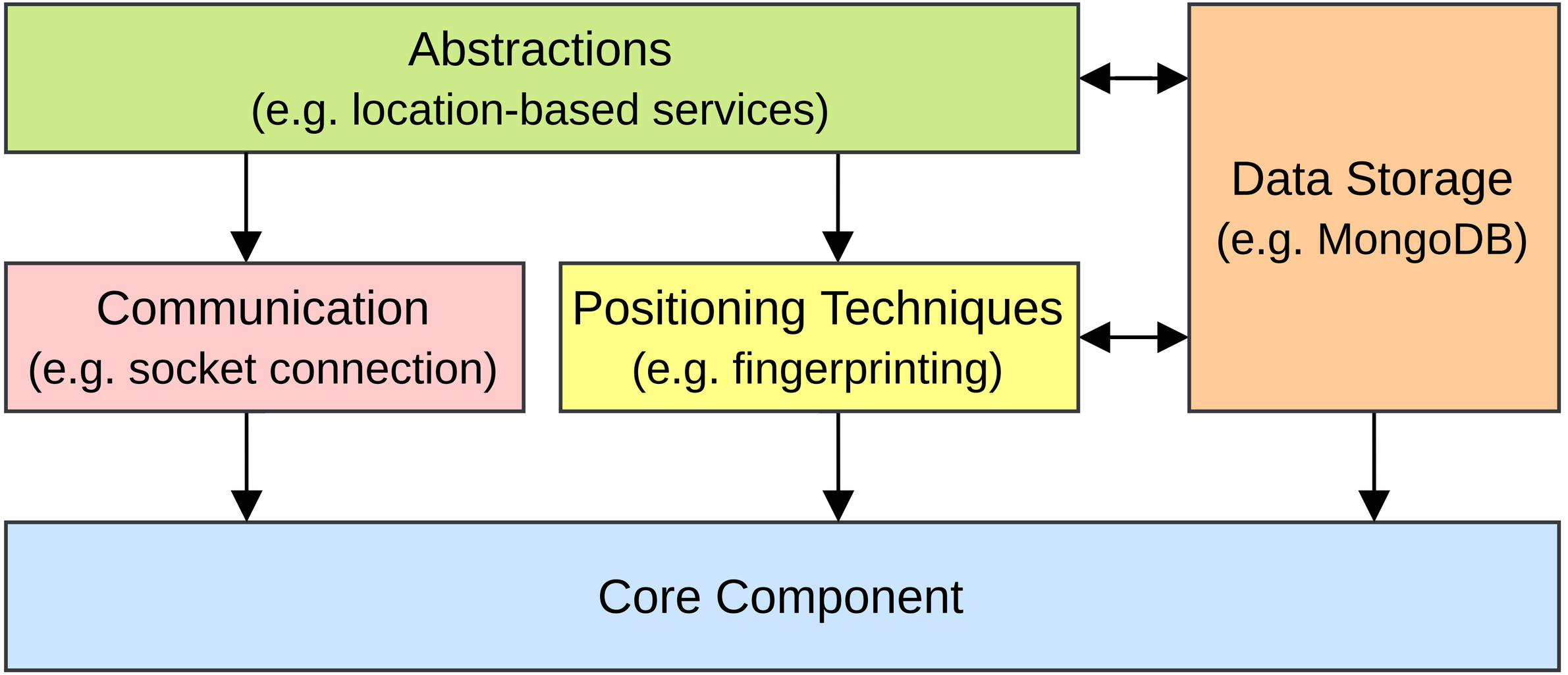
Process Network Design ...

OpenHPS



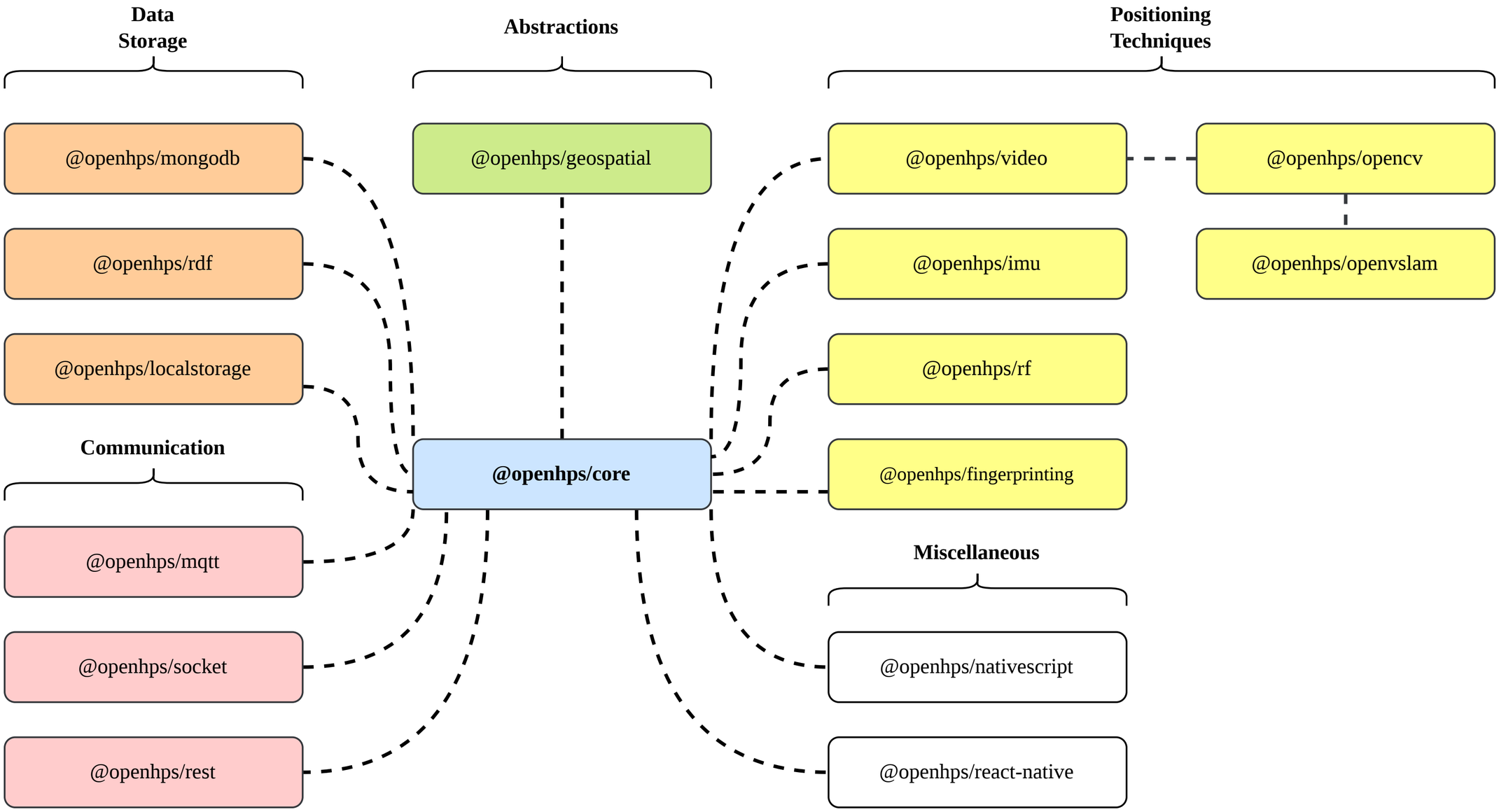
Modularity

OpenHPS



Modularity ...

OpenHPS



Modularity ...

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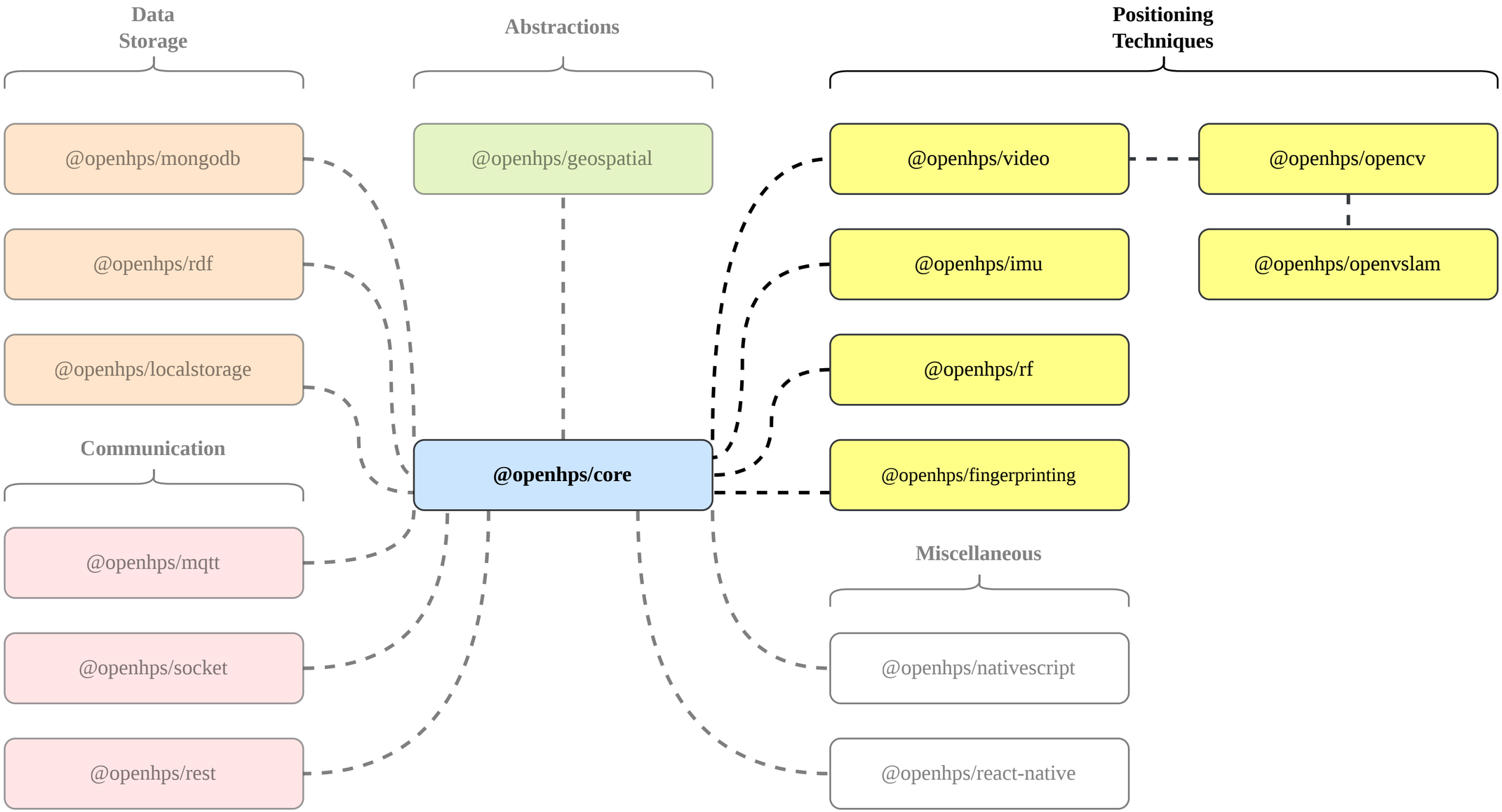

Modularity ...

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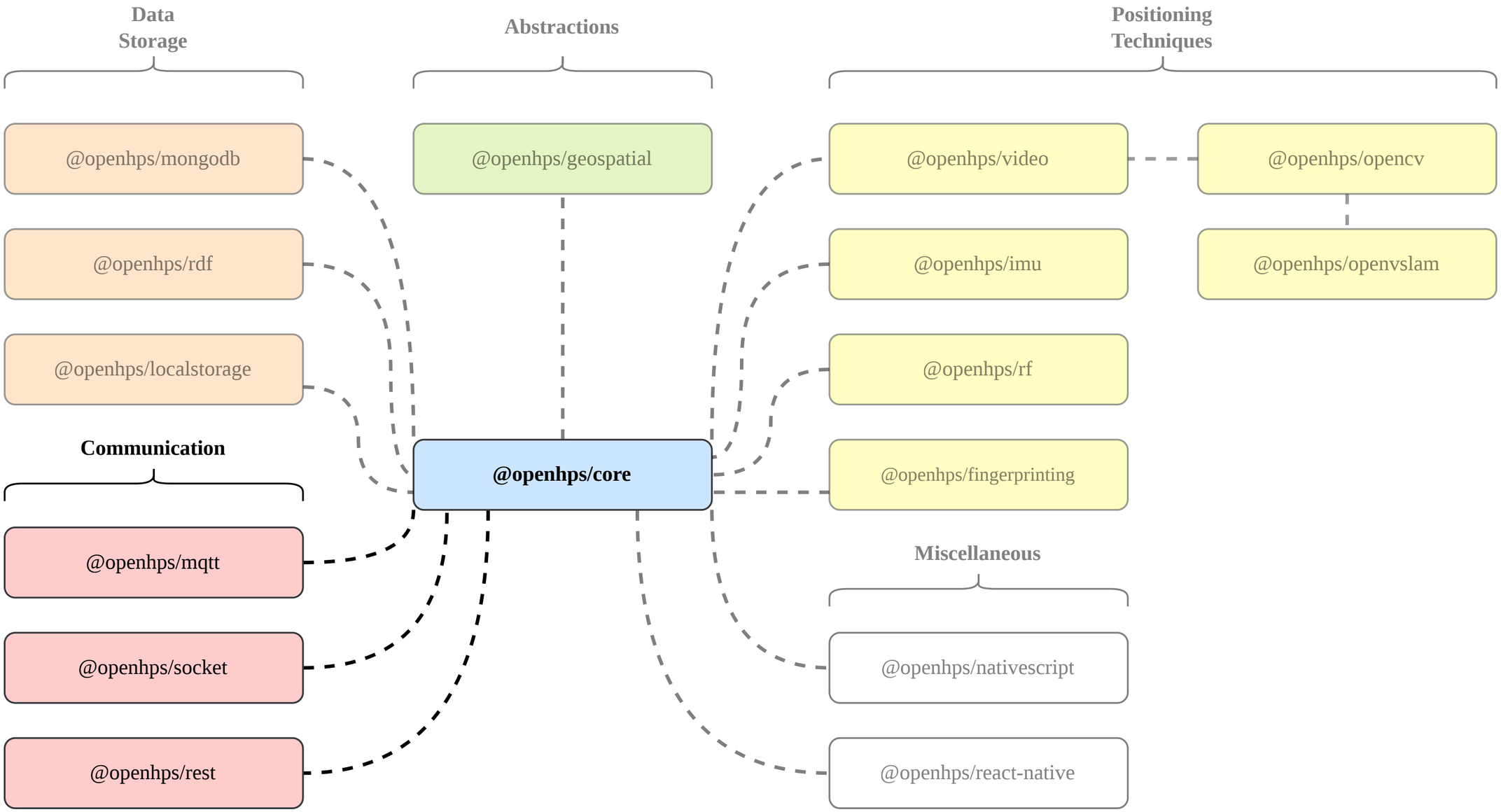

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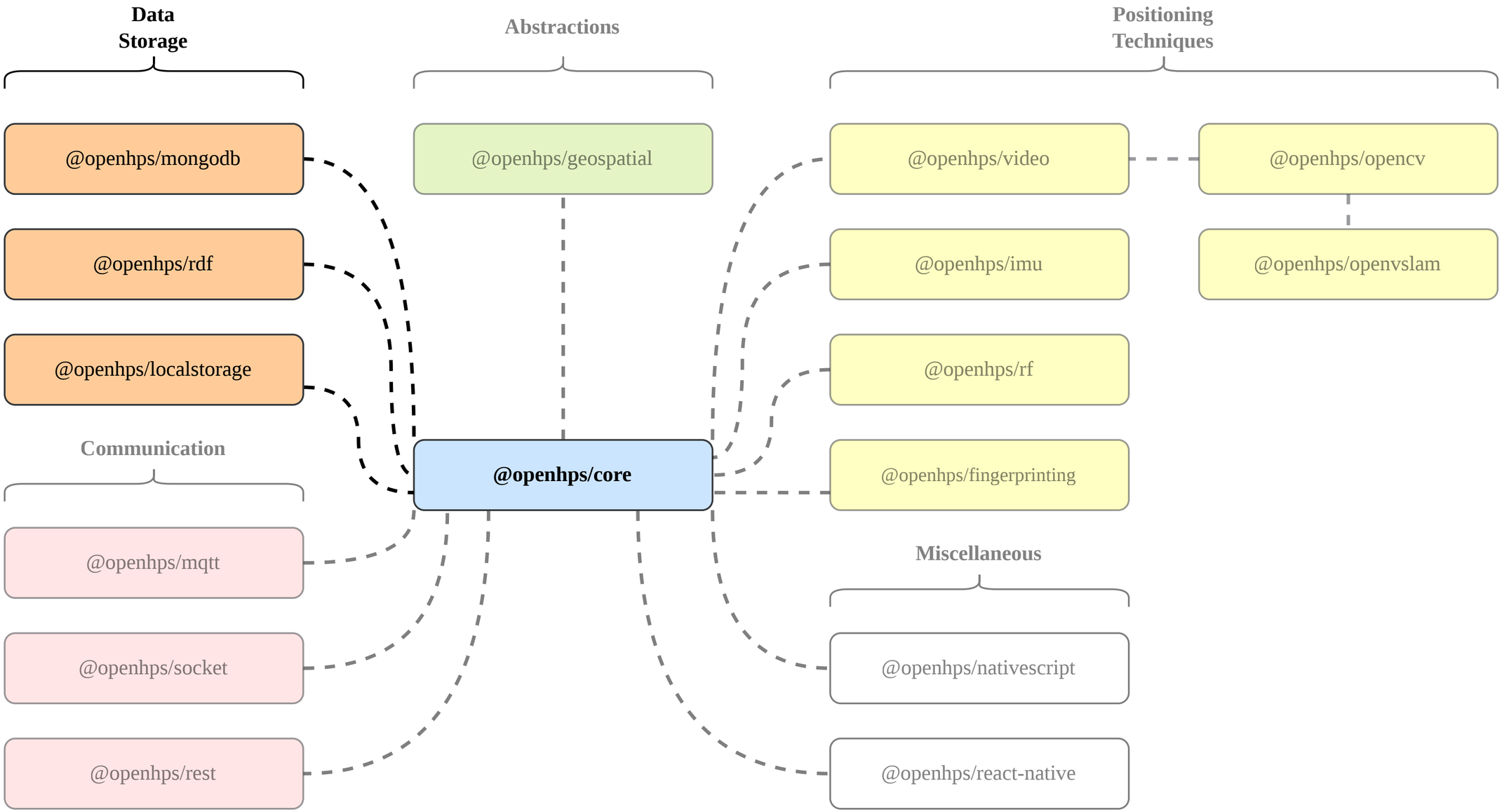

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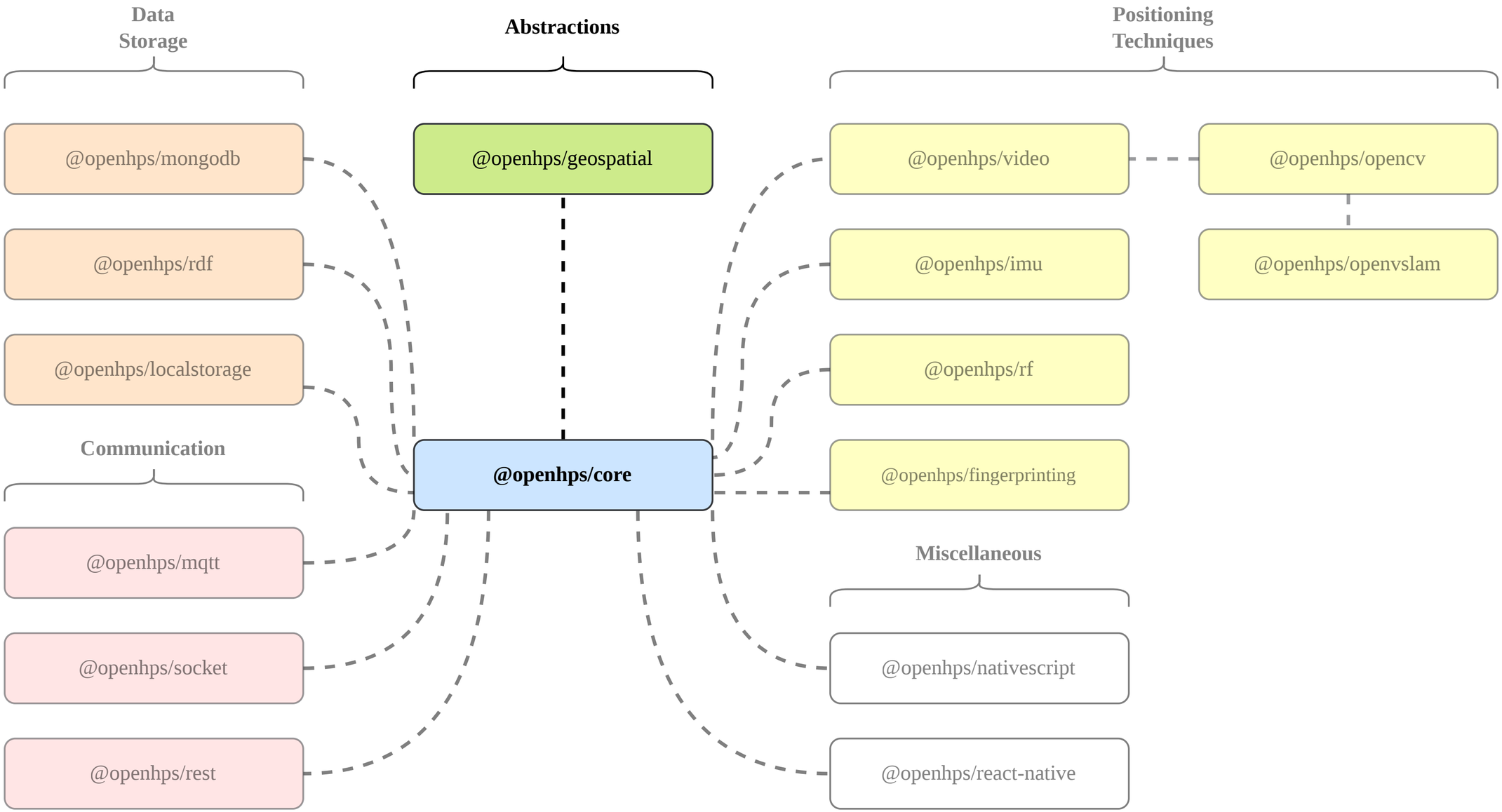
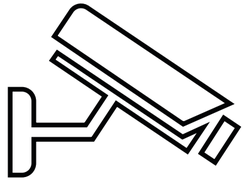
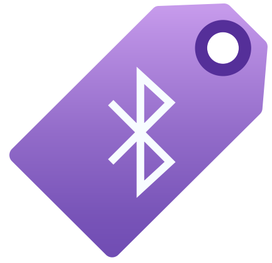
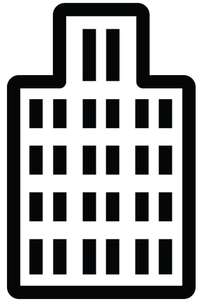


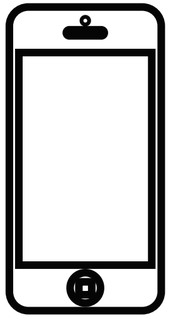
Data Processing

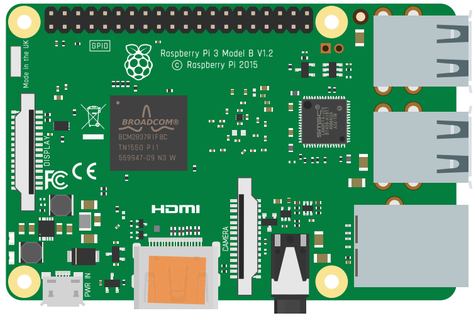
OpenHPS

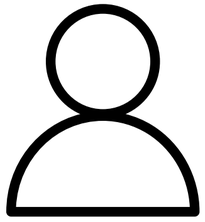


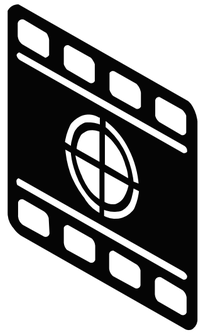






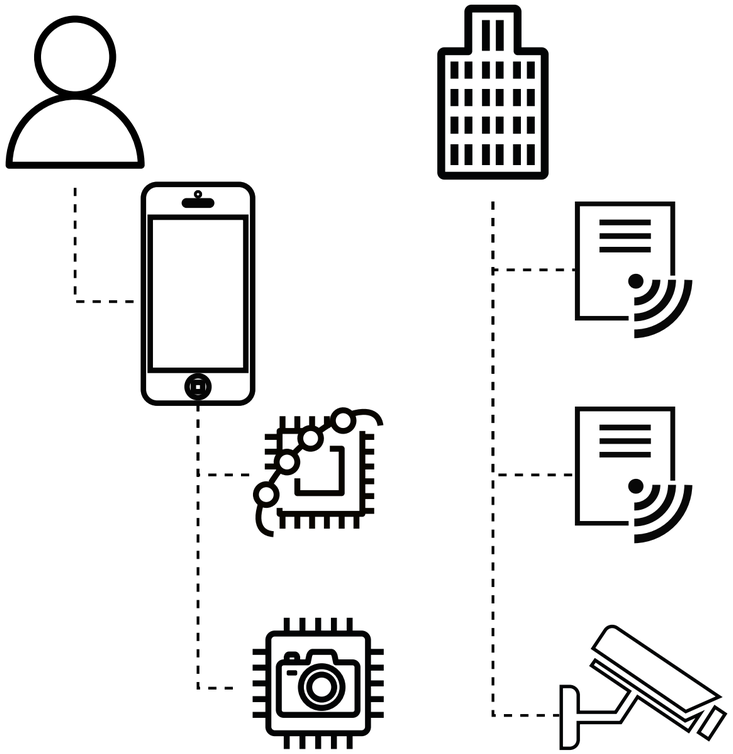






DataObject

OpenHPS



```
// Data object for the person we are tracking
const me = new DataObject("mvdewync@vub.be");
me.displayName = "Maxim Van de Wynckel";

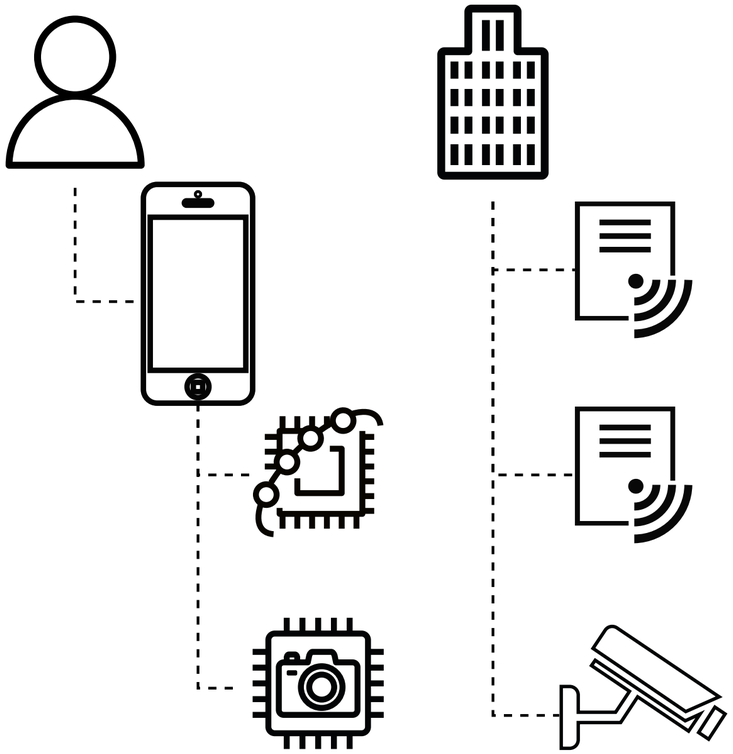
// Phone belonging to the person
const phone = new DataObject()
phone.displayName = "Maxim's Phone";
phone.setParent(me);

// Watch belonging to the person
const watch = new DataObject();
watch.displayName = "Maxim's Android Watch";
watch.setParent(me);

// IP camera identified by MAC
const camera = new CameraObject("80:bb:7c:37:0e:02");
camera.width = 1980;
camera.height = 1024;
camera.fps = 30;
camera.setPosition(/* ... */);
```

DataObject

OpenHPS



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const camera = new CameraObject("80:bb:7c:37:0e:02");
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camera.height = 1024;
camera.fps = 30;
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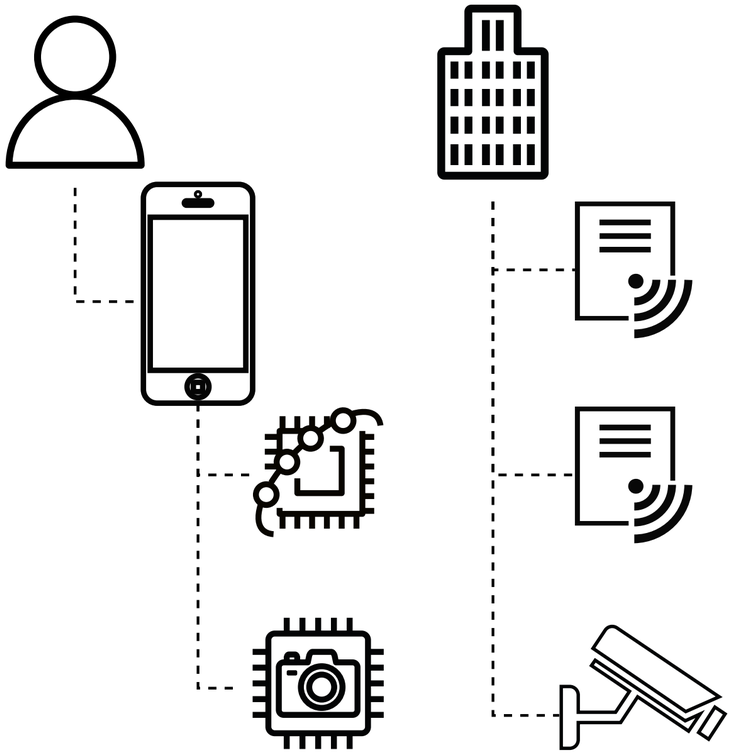
DataObject

OpenHPS



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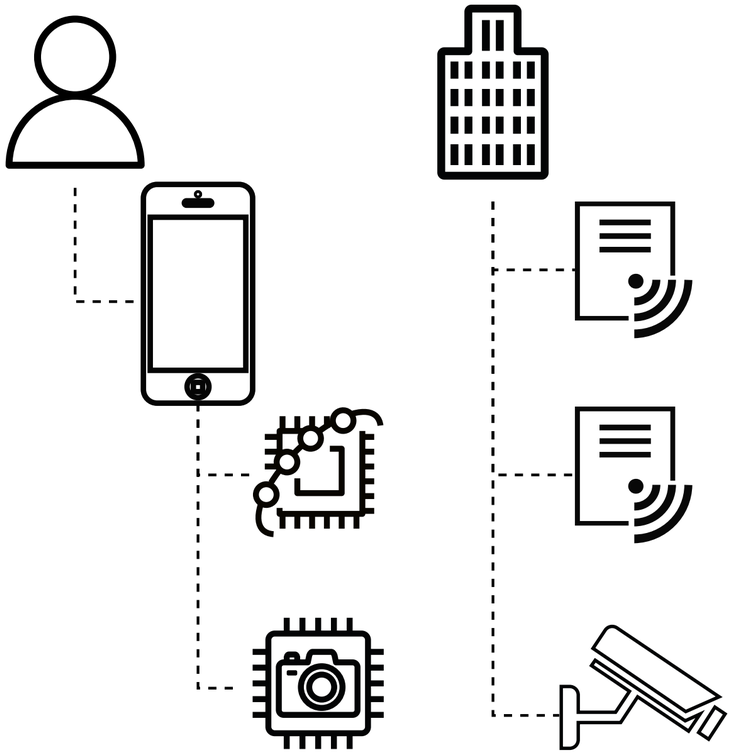
phone.displayName = "Maxim's Phone";
phone.setParent(me);

// Watch belonging to the person
const watch = new DataObject();
watch.displayName = "Maxim's Android Watch";
watch.setParent(me);

// IP camera identified by MAC
const camera = new CameraObject("80:bb:7c:37:0e:02");
camera.width = 1980;
camera.height = 1024;
camera.fps = 30;
camera.setPosition(/* ... */);
```

DataObject

OpenHPS



```
// Data object for the person we are tracking
const me = new DataObject("mvdewync@vub.be");
me.displayName = "Maxim Van de Wynckel";

// Phone belonging to the person
const phone = new DataObject();
phone.displayName = "Maxim's Phone";
phone.setParent(me);

// Watch belonging to the person
const watch = new DataObject();
watch.displayName = "Maxim's Android Watch";
watch.setParent(me);

// IP camera identified by MAC
const camera = new CameraObject("80:bb:7c:37:0e:02");
camera.width = 1980;
camera.height = 1024;
camera.fps = 30;
camera.setPosition(/* ... */);
```

Absolute and Relative Positions

OpenHPS

Absolute

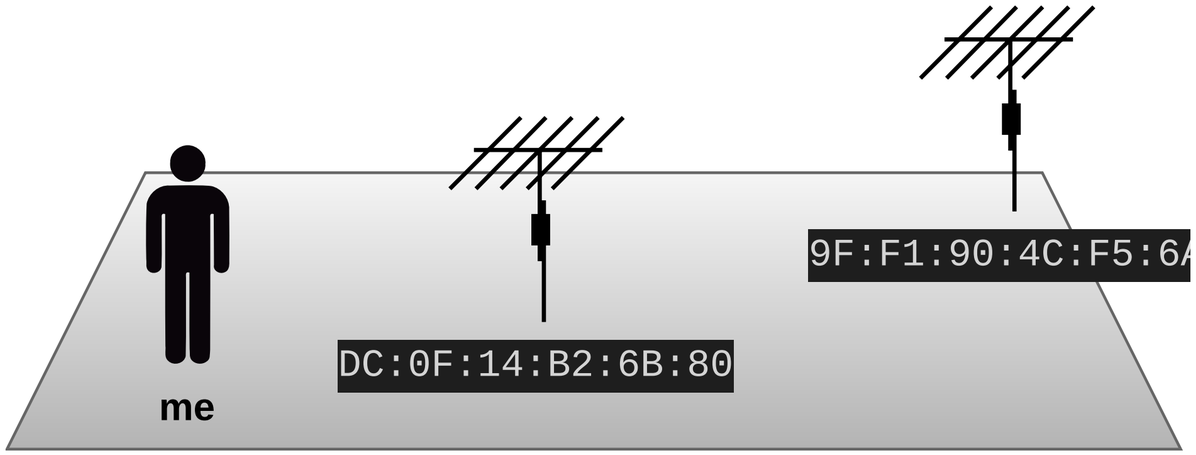
- 2D, 3D, geographical, ...
- Within a reference space

Relative

- Distance, angle, velocity, ...
- Relative to another *object*

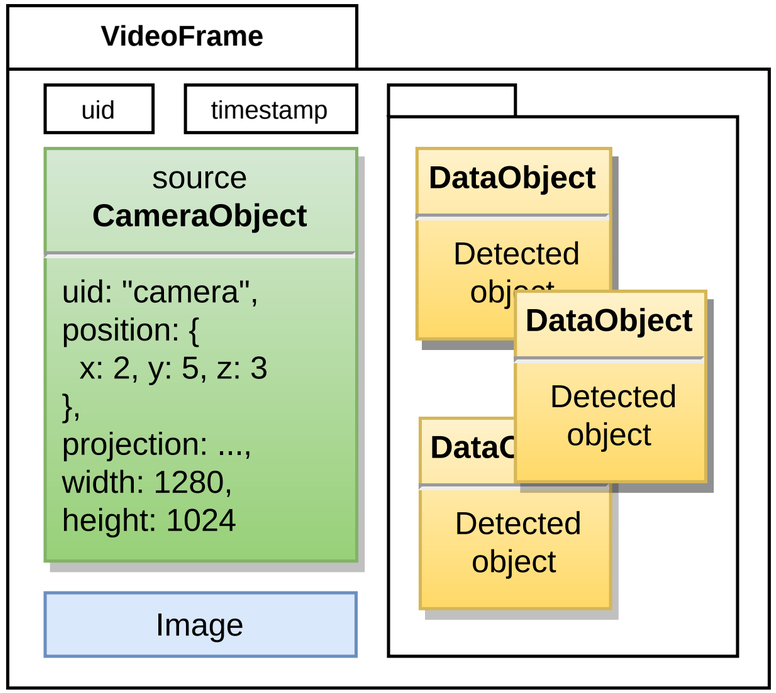
```
// Absolute geographical position
me.setPosition(new GeographicalPosition(
    50.8204, 4.3921
));

// Relative position(s) to another object
me.addRelativePosition(new RelativeDistance(
    "9F:F1:90:4C:F5:6A", 5.2, LengthUnit.METER
));
me.addRelativePosition(new RelativeDistance(
    "DC:0F:14:B2:6B:80", 1.4, LengthUnit.METER
));
```



DataFrame

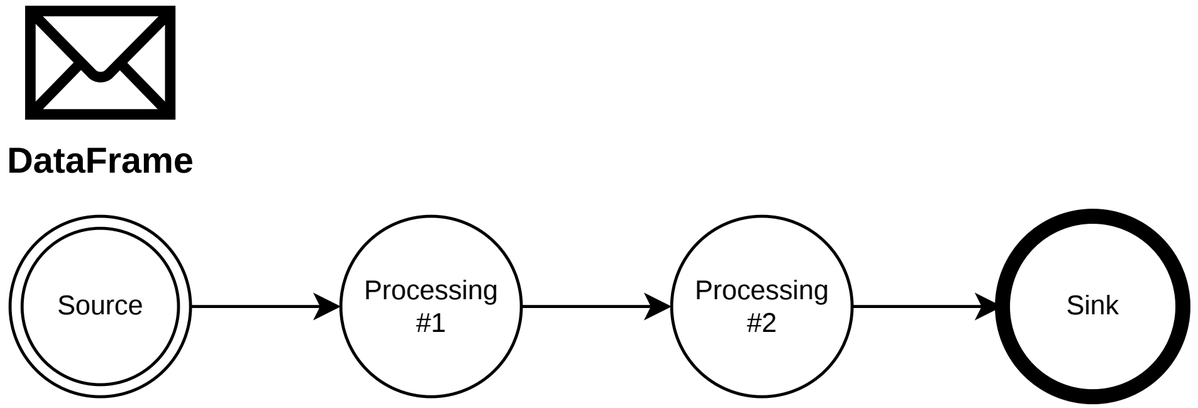
OpenHPS




```
// Sensor that captured the frame
const camera = new CameraObject();

// Create a new frame
const frame = new VideoFrame();
frame.source = camera;
frame.image = myImage;

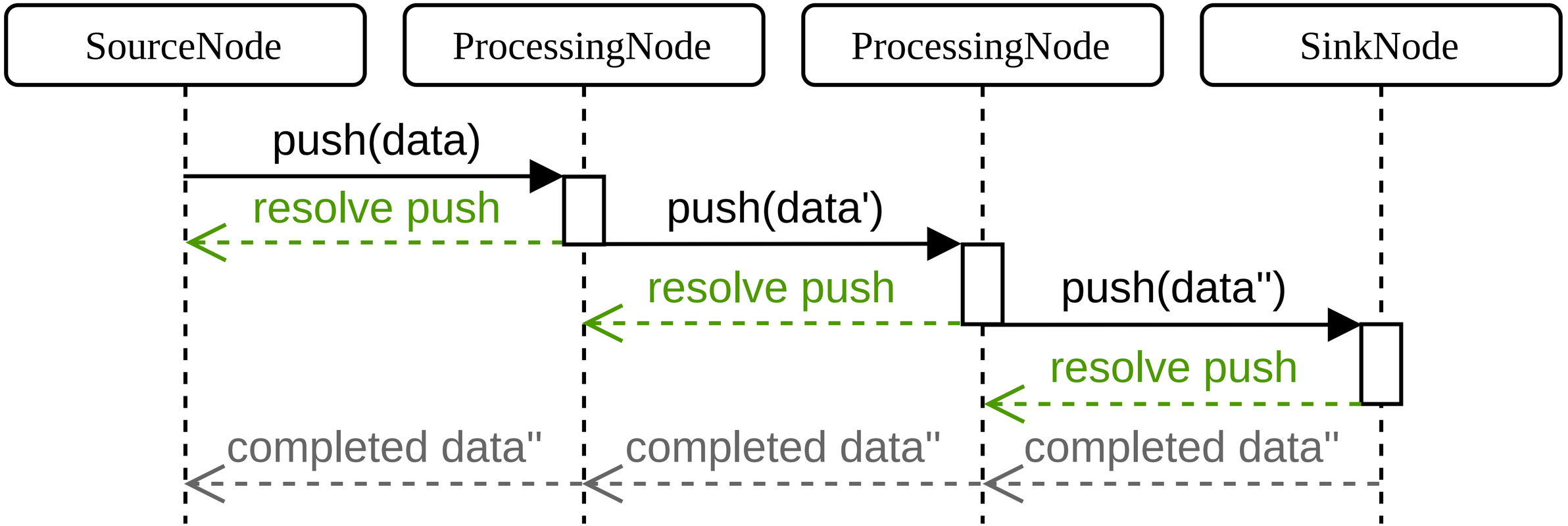
// Add detected objects to frame
frame.addObject(/* ... */);
frame.addObject(/* ... */);
frame.addObject(/* ... */);
```



DataFrame ...

OpenHPS

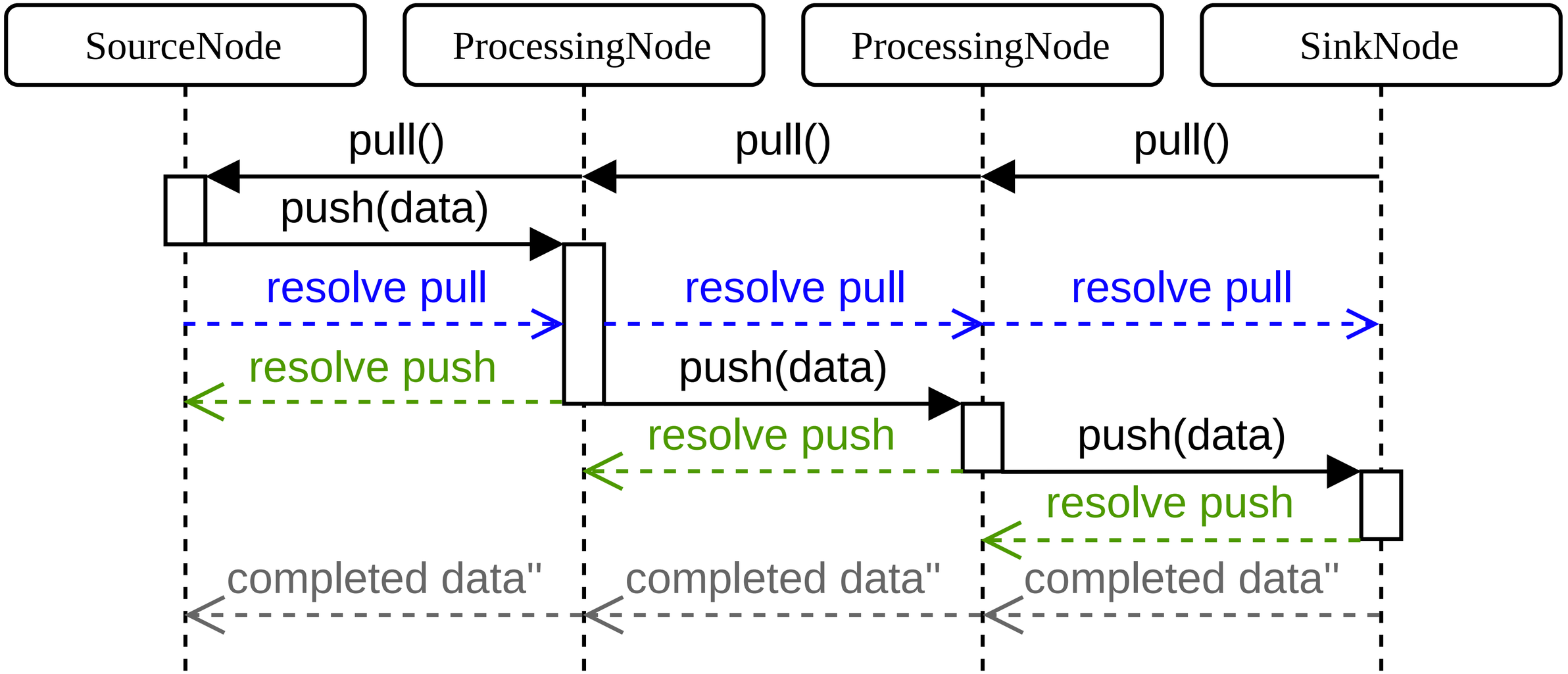
Pushing Data



DataFrame ...

OpenHPS

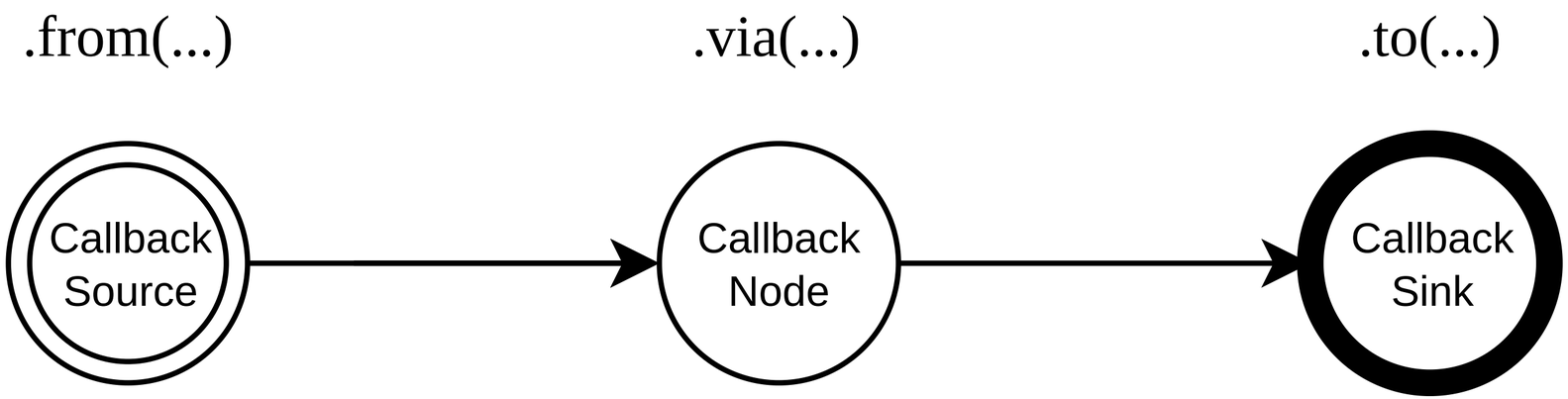
Pulling Data



Positioning Model

OpenHPS

```
ModelBuilder.create()
    .from(new CallbackSourceNode(() => {
        const myObject = new DataObject("mvdewync");
        const frame = new DataFrame();
        frame.addObject(myObject);
        return frame;
    }))
    .via(new CallbackNode((frame: DataFrame) => { /* ... */ }))
    .to(new CallbackSinkNode((frame: DataFrame) => { /* ... */ }))
    .build().then((model: Model) => { /* ... */ });
```



Exercises Dataset

OpenHPS

OpenHPS Fingerprinting Dataset Overview

The OpenHPS fingerprinting dataset of March 2021 contains **110 training** and **30 test** locations in **4 different orientations**. We collected information on Wi-Fi access point signal strengths, **11 BLE beacons** and IMU data at a requested refresh rate of 50Hz. More information about the contents of the dataset can be found here.

BLE Beacons Train Data Test Data

Out dataset is recorded on Sunday the 7th of March 2021 in the building: "Pleinlaan 9" on the third floor.

Wireless Access Points

Our dataset captures signal strength from **220** wireless access points. Based on the SSID before anonymisation, we identified **199** access points to be stable (university network, department network, ...). Other (unstable) access points were identified as hotspots, printers and unknown company networks inside the same building.

ID	SSID_ID	FREQUENCY	STABLE
WAP_001	1	2,452	1
WAP_002	1	5,180	1
WAP_003	2	2,432	0
WAP_004	3	2,462	0
WAP_005	4	2,462	1
WAP_006	5	5,220	1
WAP_007	6	5,180	1
WAP_008	6	5,220	1
WAP_009	7	2,412	1
WAP_010	6	5,220	1

OpenHPS OpenHPS Fingerprinting Dataset Overview

Observable

Exercise 1 - Multilateration

OpenHPS

Question 1

Create a new Bluetooth beacon object with the ID column as its uid and an absolute 3d position for the X, Y and Z coordinates. Return the beacon object in this function.

Question 2

Create a relative position for the rssi and beacon Use the RelativeRSSI class in combination with a new BLEObject that uses the beacon name as its UID

Exercise 1 ...

OpenHPS

Question 3

Convert the RSSI to a distance using log distance propagation Assume we have a calibrated received signal strength of -69 at 1 meter distance. Play around with the environment factor to see what works best.

Question 4

Use the RSSI converted to a distance (from question 2) to calculate the position with multilateration.

Exercise 2 - Fingerprinting

OpenHPS

Question 1

Create a fingerprint service that will store the scene analysis. Experiment with the default RSSI value and grouping

Question 2

Create a KNN fingerprinting node to convert sensor data to a position. Experiment with the parameters to obtain a better result.

Exercise 3 - Location Awareness

OpenHPS

Question 1

Load the spaces/features defined in our dataset (spaces.geo.json). The file is already loaded as the variable GEOJSON_FEATURES.

Question 2

Emit the event of entering and exiting a space This event should only trigger when you enter a new space. The 'enterspace' event should only trigger when you enter a new space. The 'exitspace' event should only trigger when you leave a space.