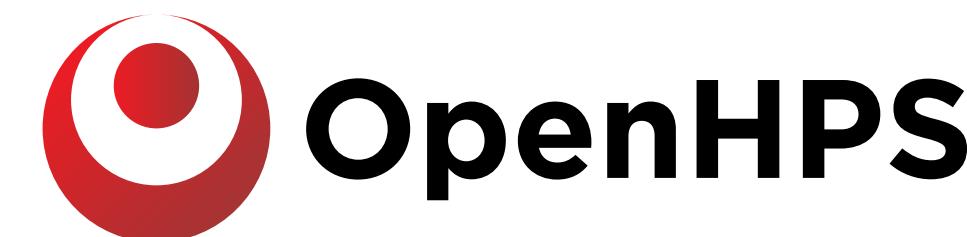


# Rapid Prototyping of a Positioning System Using the OpenHPS Framework

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Maxim Van de Wynckel

*Web & Information Systems Engineering Lab*  
*Vrije Universiteit Brussel*



# Positioning System



*"A positioning system is a mechanism for determining the position of an object in space."*

*- Wikipedia (2022)*

# Positioning System



*"A positioning system is a mechanism for determining the position of an **object** in **space**."*

- Wikipedia (2022)

## Object

What are you tracking? A person, an asset or a phone?

## Space

Outdoor, indoor, under water or on a table?

# Use Cases

- ▶ **Navigation**

*Navigate a person from point A to point B*

- ▶ **Tracking**

*Asset tracking, customer tracking, tracking items on a table*

- ▶ **Location Awareness**

*Trigger an action whenever a specific person is in a room*

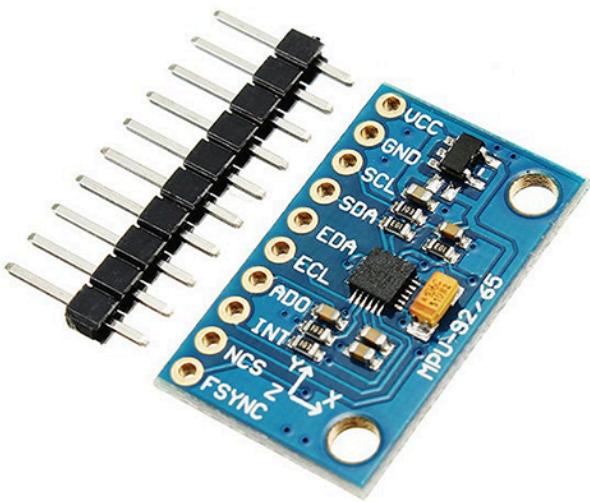
- ▶ **Mapping**

*Geospatial mapping of an environment*

# Technologies

*Technologies used to obtain sensor data for positioning*

- ▶ Camera (stereoscopic, monocular, omnidirectional)
- ▶ Beacons (ultrawideband, Bluetooth, ultrasound)
- ▶ LIDAR
- ▶ Inertial measurement unit (IMU)
- ▶ Visible light communication
- ▶ ...



# Algorithms

*Algorithms used to process sensor data*

- ▶ Lateration
- ▶ Proximity positioning
- ▶ Signal propagation
- ▶ Fingerprinting
- ▶ Computer vision
- ▶ Dead reckoning
- ▶ Sensor fusion
- ▶ ...



# Open Source Solutions



- ▶ AnyPlace <https://anyplace.cs.ucy.ac.cy/>
- ▶ FIND <https://github.com/schollz/find3>
- ▶ IndoorLocation <https://github.com/IndoorLocation>
- ▶ Navigine <https://github.com/Navigine>
- ▶ RedPin <http://redpin.org/>
- ▶ Traccar <https://github.com/traccar>
- ▶ TraceMeNow <https://isislab-unisa.github.io/trace-me-now>

## An Open Source Hybrid Positioning System

 DOCS BLOG GITHUB

### Documentation

Introduction  
Installation  
Modules

### Basic Concepts

Data Object

#### Data Frame

Creating data frames  
Creating a custom data frame

Standard Units

Position and Orientation

Reference Space

Positioning Model

Source Node

Processing Node

Sink Node

Services

### Advanced Concepts

Remote Service  
Threading

### Miscellaneous

Examples

## Data Frame

Data frames are envelopes that are transmitted and processed through a positioning model. These frames are created by source nodes (e.g. sensors) and contain one or more data objects needed to process the frame.

A frame should contain a single reading of a sensor (such as an image of a video stream or current acceleration) and not permanent or calculated information.

The diagram illustrates three types of Data Frames:

- VideoDataFrame:** Contains a source CameraObject (uid: "camera", position: {x: 2, y: 5, z: 3}, projection: ..., width: 1280, height: 1024) and a detected object (uid: "image", position: {x: 1, y: 0}).
- IMUDataFrame:** Contains a source DataObject (uid: "imu", position: {x: 0, y: 0, linearVelocity: {x: 1, y: 0}}) and multiple detected objects (uid: "acceleration", position: {x: 0, y: 0}, uid: "sensorFrequency", position: {x: 0, y: 0}).
- RFDataFrame:** Contains a source RFRReceiverObject (uid: "wifiscanner", relativePositions: [{obj: "AP1", distance: 5}, {obj: "AP2", distance: 8}]) and two detected objects (uid: "AP1", position: {x: 0, y: 0}, uid: "AP2", position: {x: 15, y: 3}).

### Creating data frames

OpenHPS is a framework that processes sensor information to retrieve a position for one or more data objects. These objects are contained within an envelope called a data frame.

```
import { DataObject, DataFrame } from '@openhps/core';

const myObject = new DataObject("bsigner", "Beat Signer");
const frame = new DataFrame();
frame.addObject(myObject);

(method) DataFrame.addObject(object: DataObject): void
```

A basic data frame supports the addition of objects. Extended versions of this basic data frame also add additional sensor data.

### Creating a custom data frame

Similar to data objects, decorators have to be used to indicate a serializable data frame.

```
import {
  DataFrame,
```

License Apache 2.0

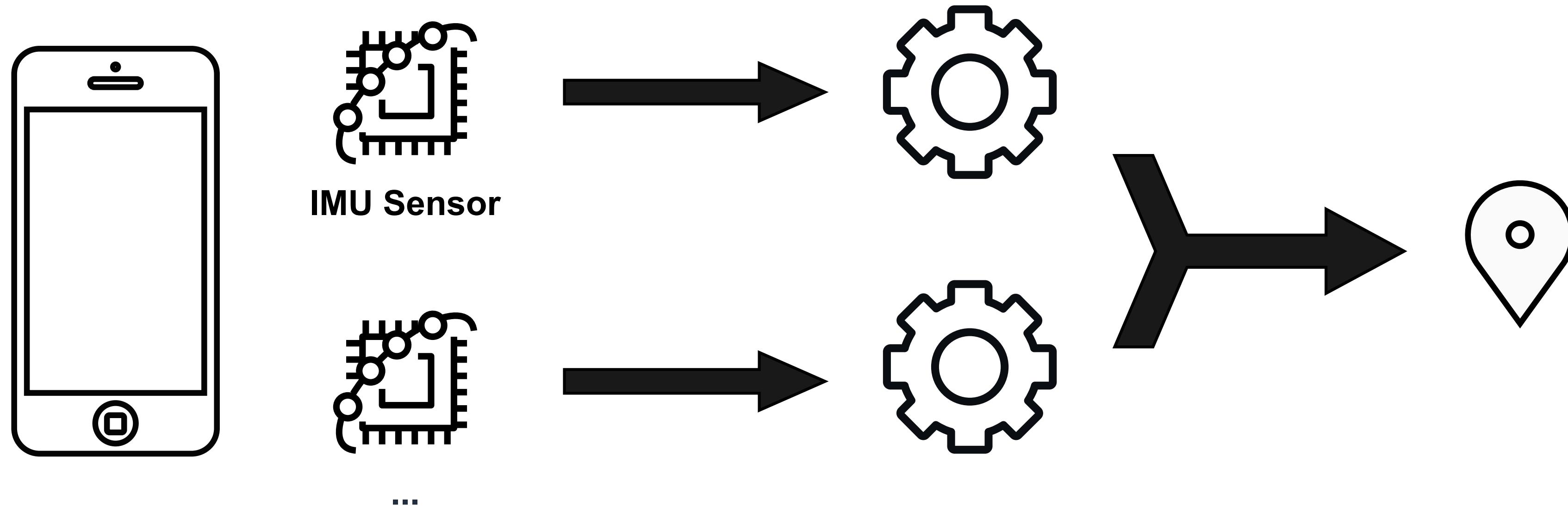
Built With TypeScript

Website [openhps.org](http://openhps.org)

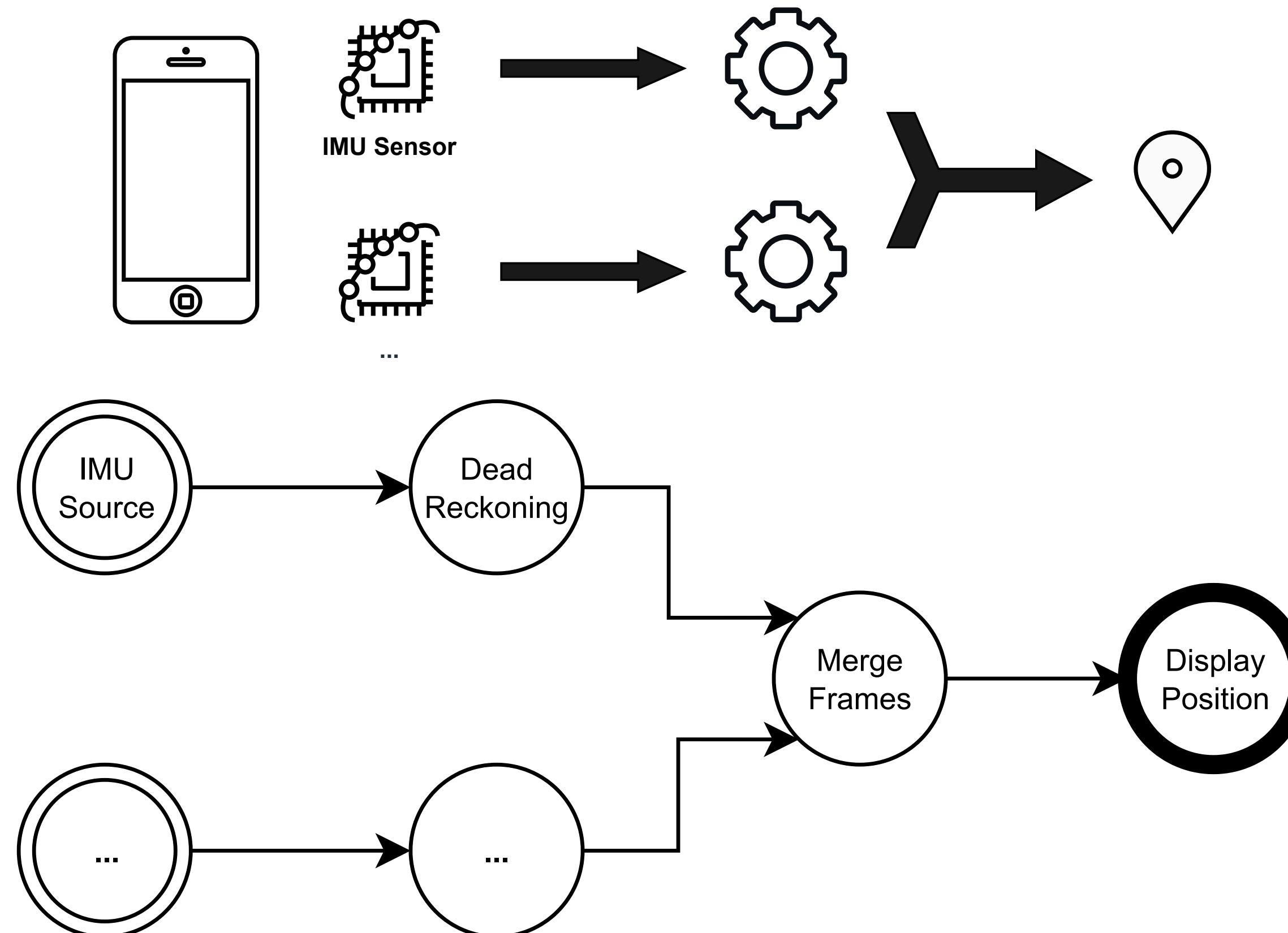
## An Open Source Hybrid Positioning System

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

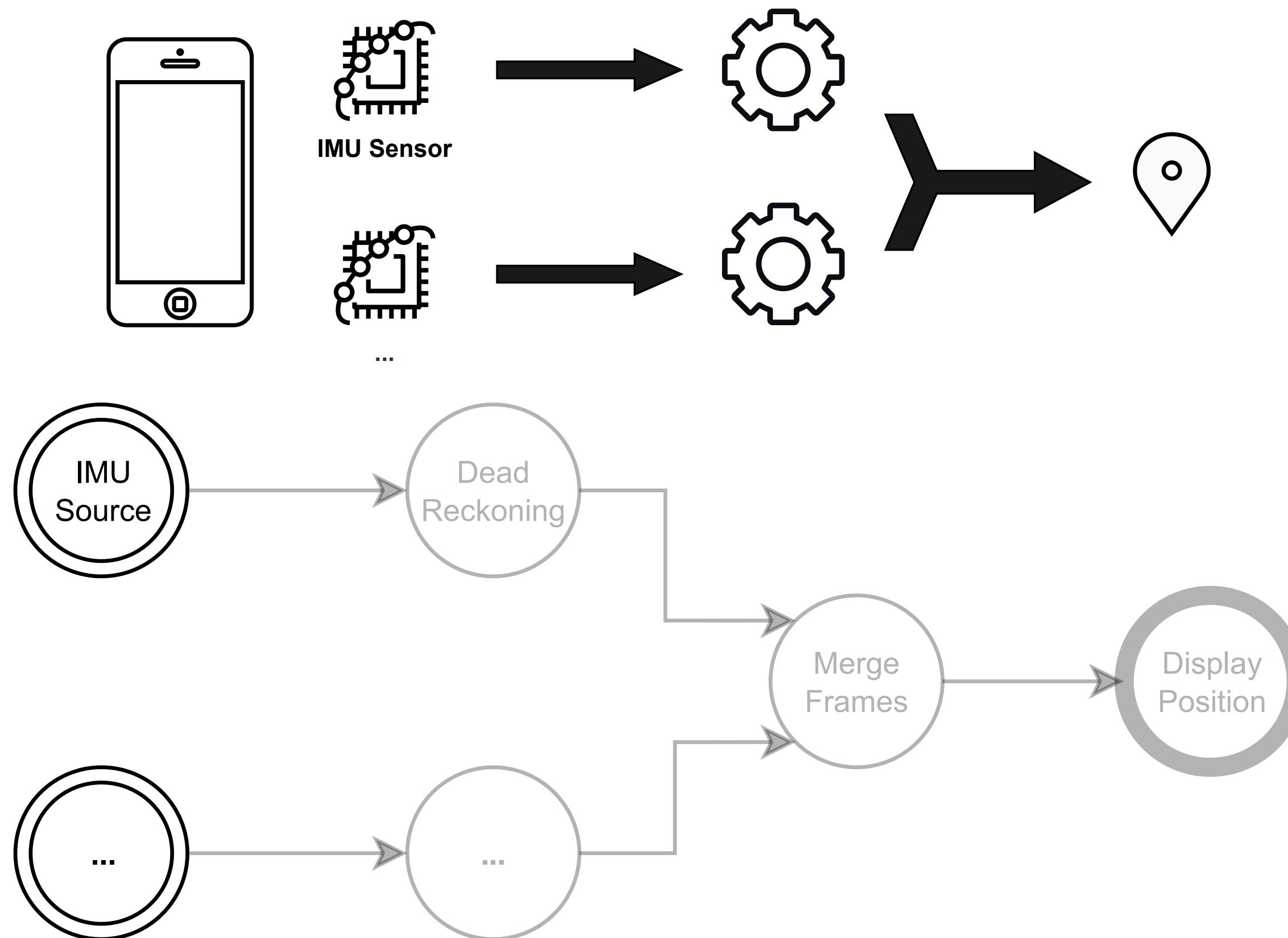
# Process Network Design



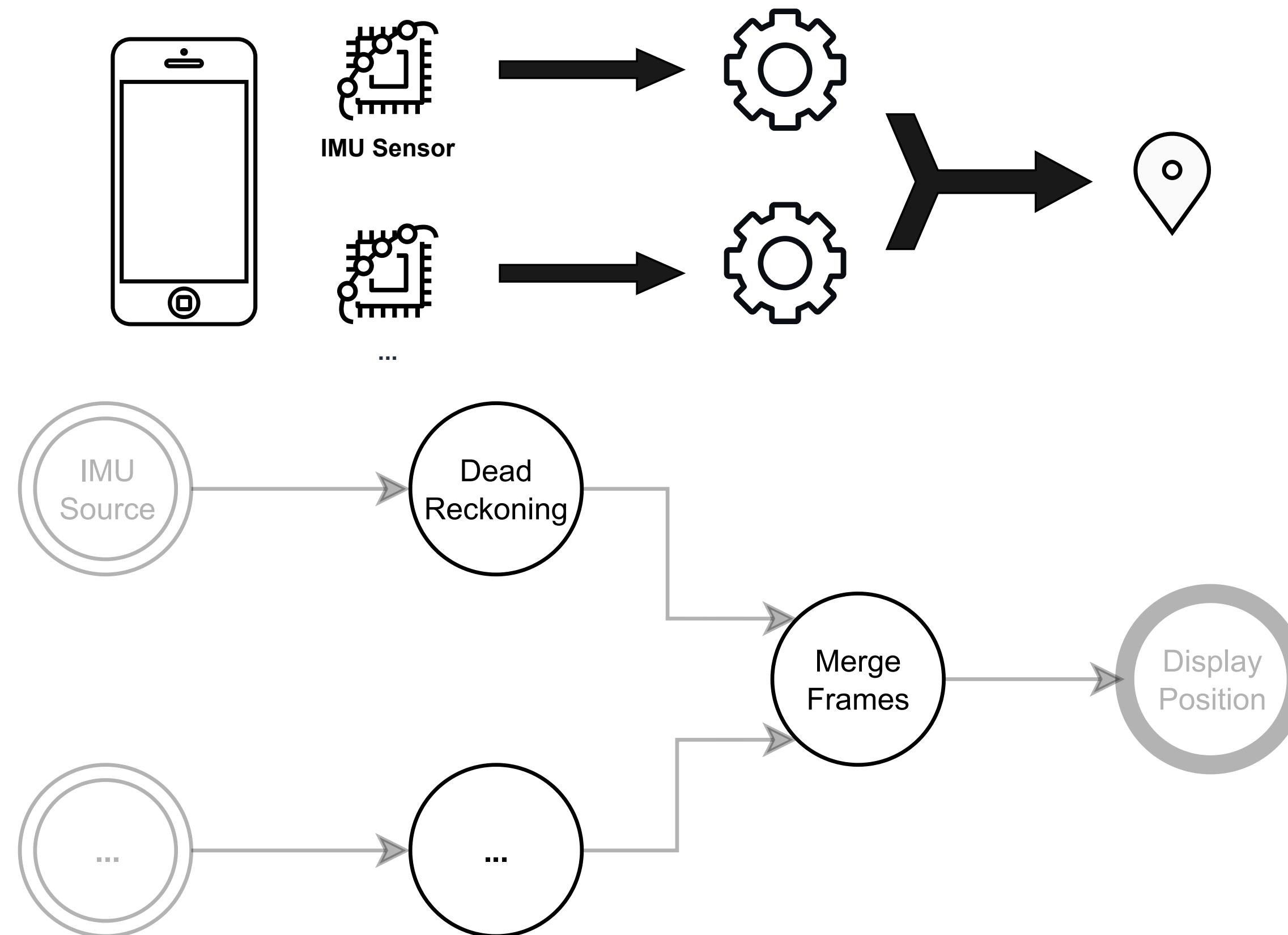
# Process Network Design ...



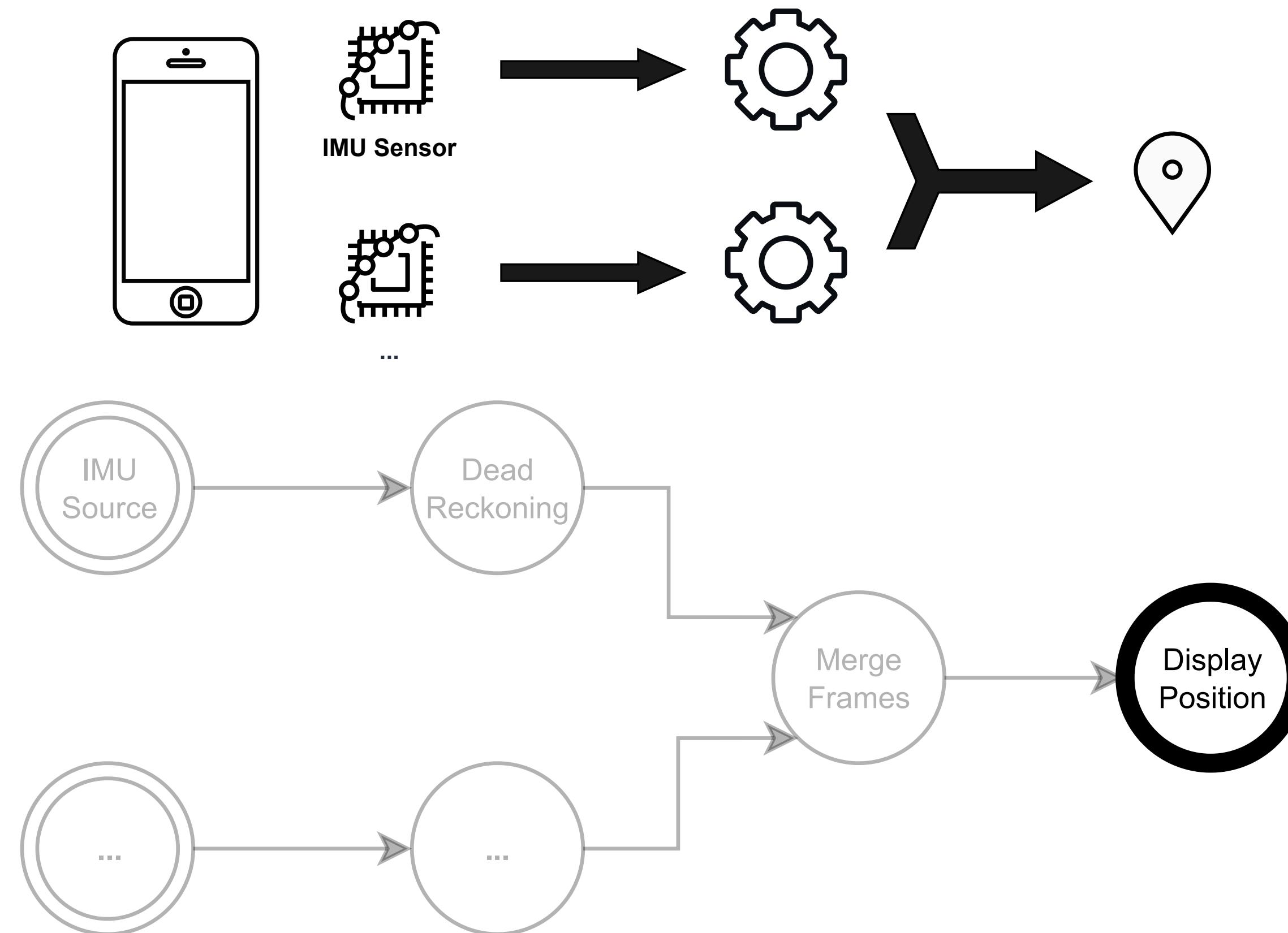
# Process Network Design ...



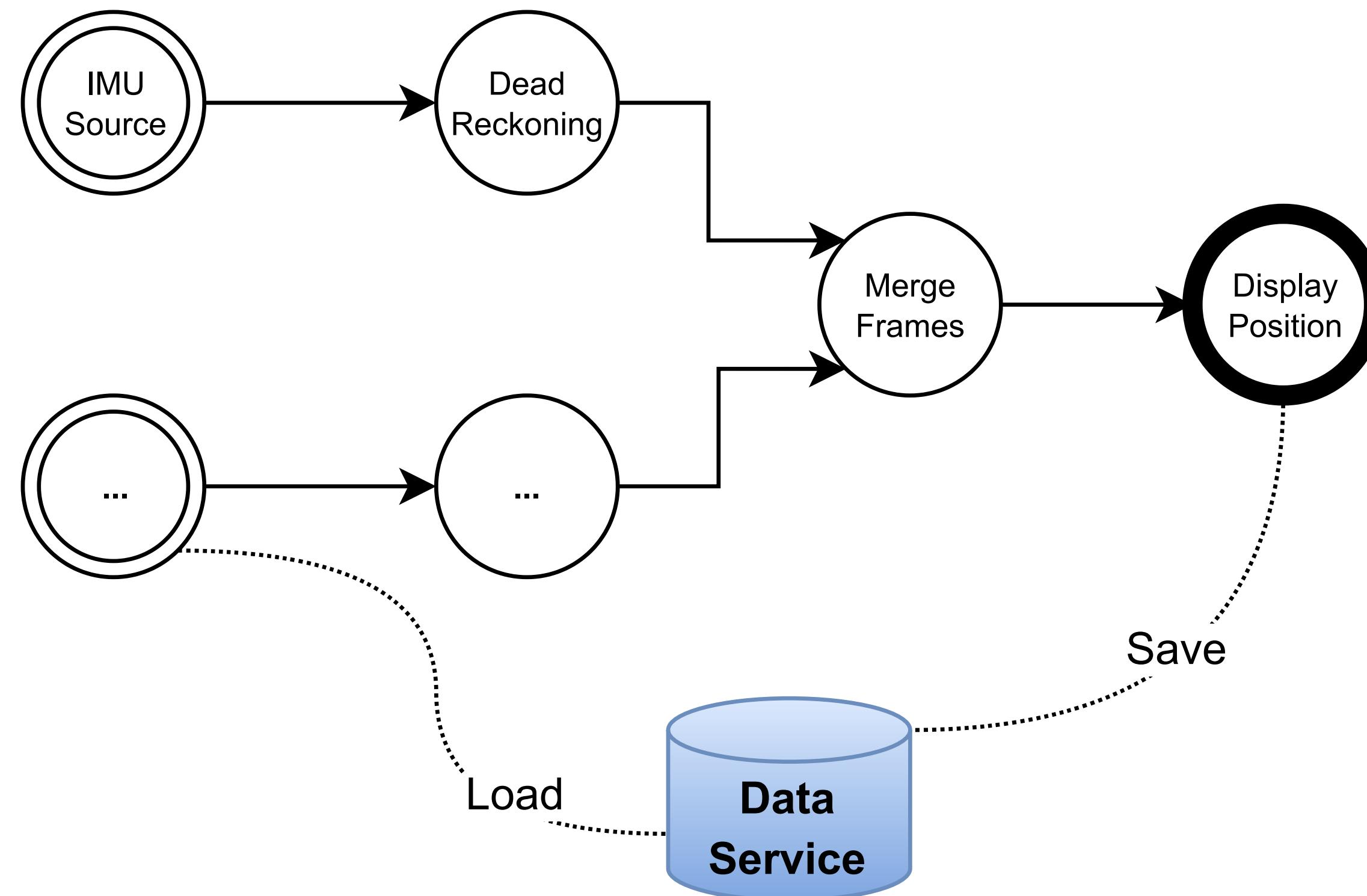
# Process Network Design ...



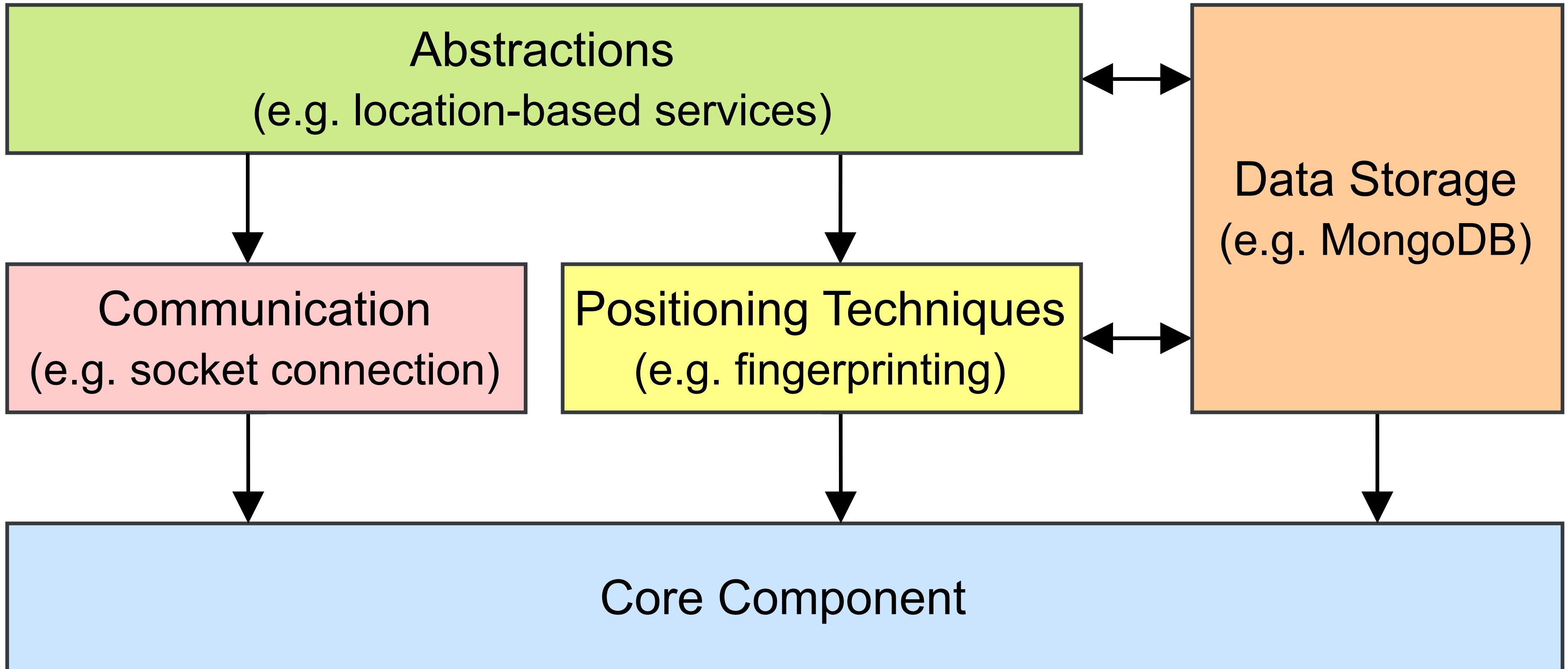
# Process Network Design ...



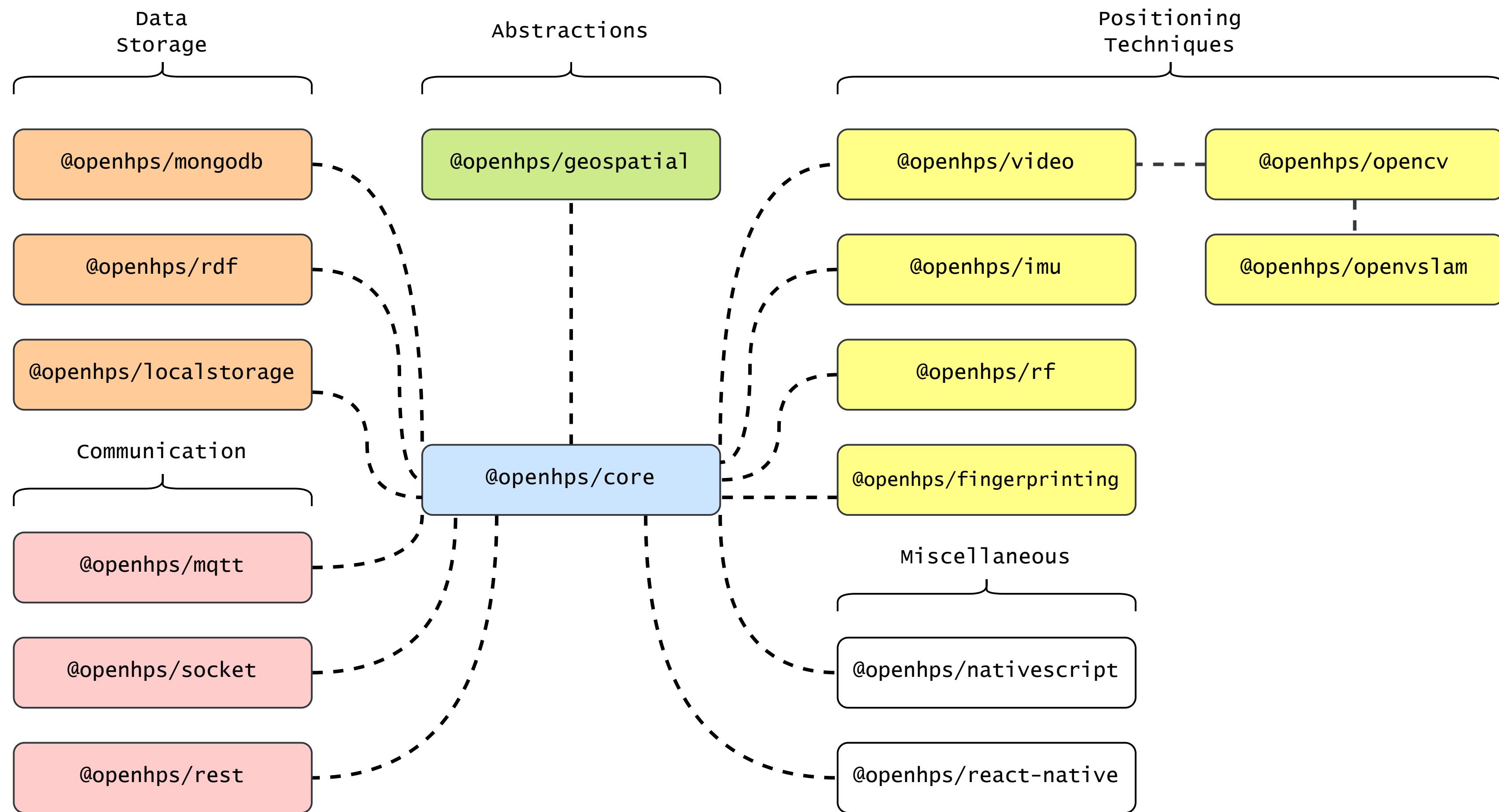
# Process Network Design ...



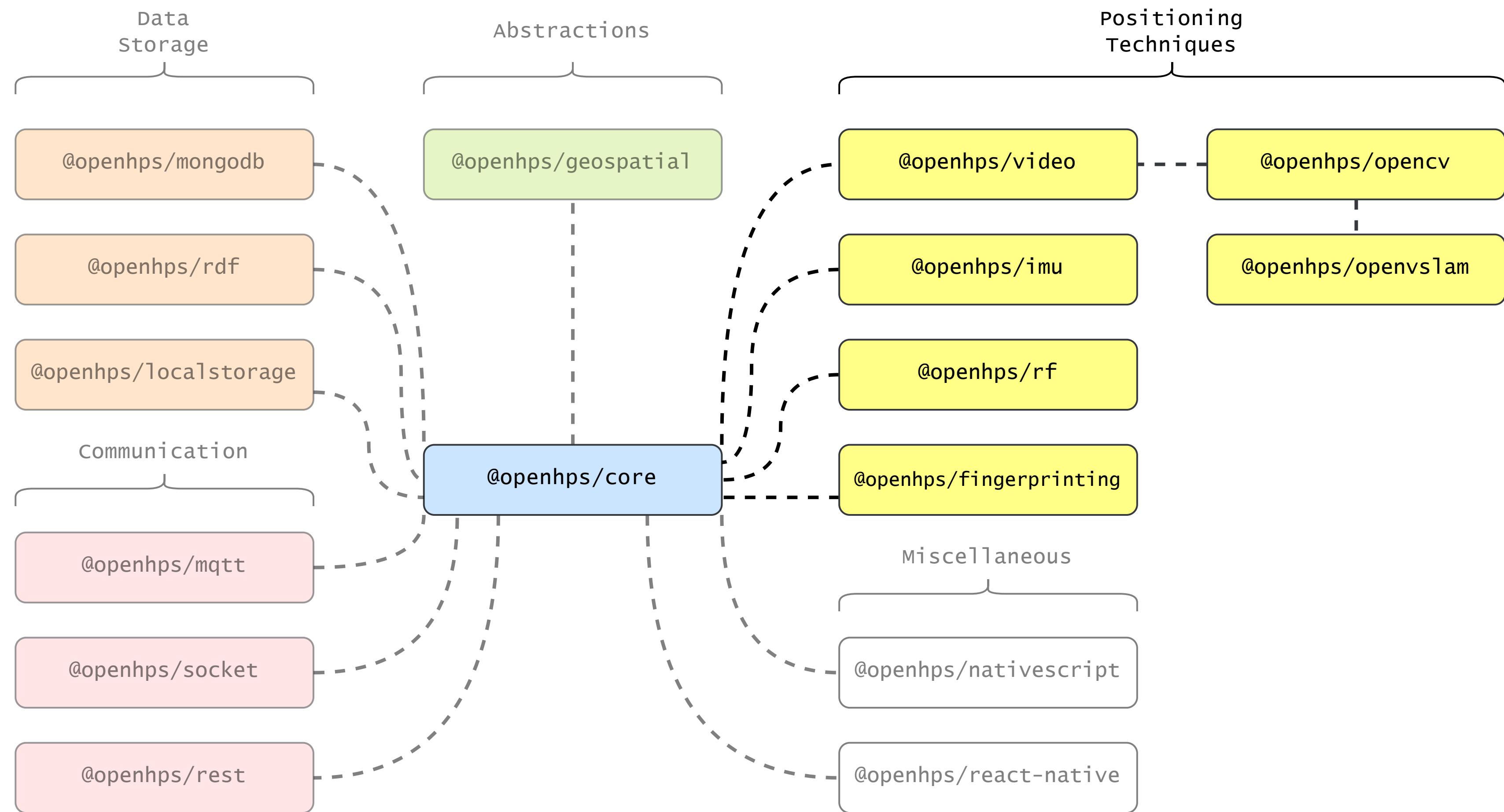
# Modularity



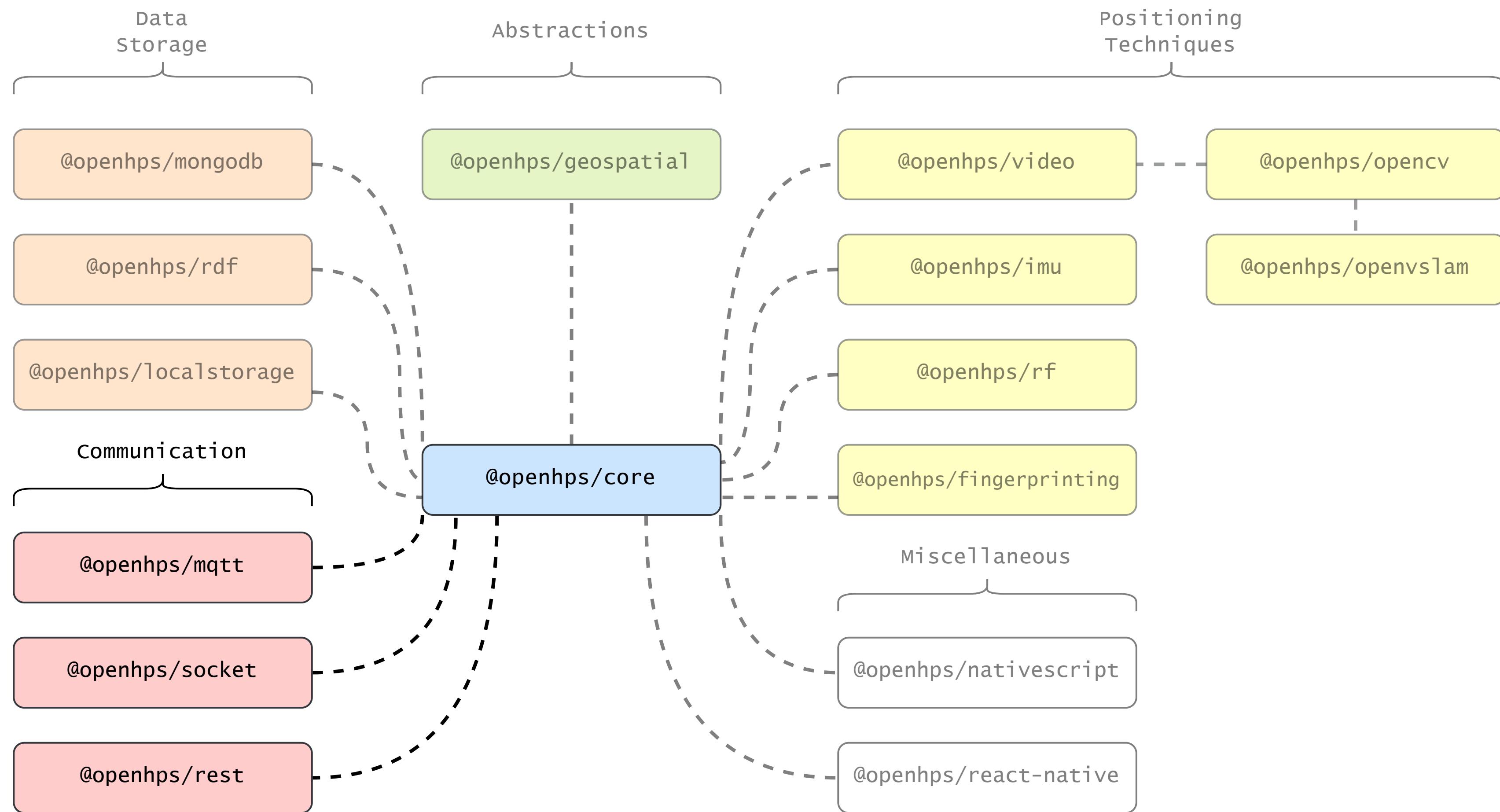
# Modularity ...



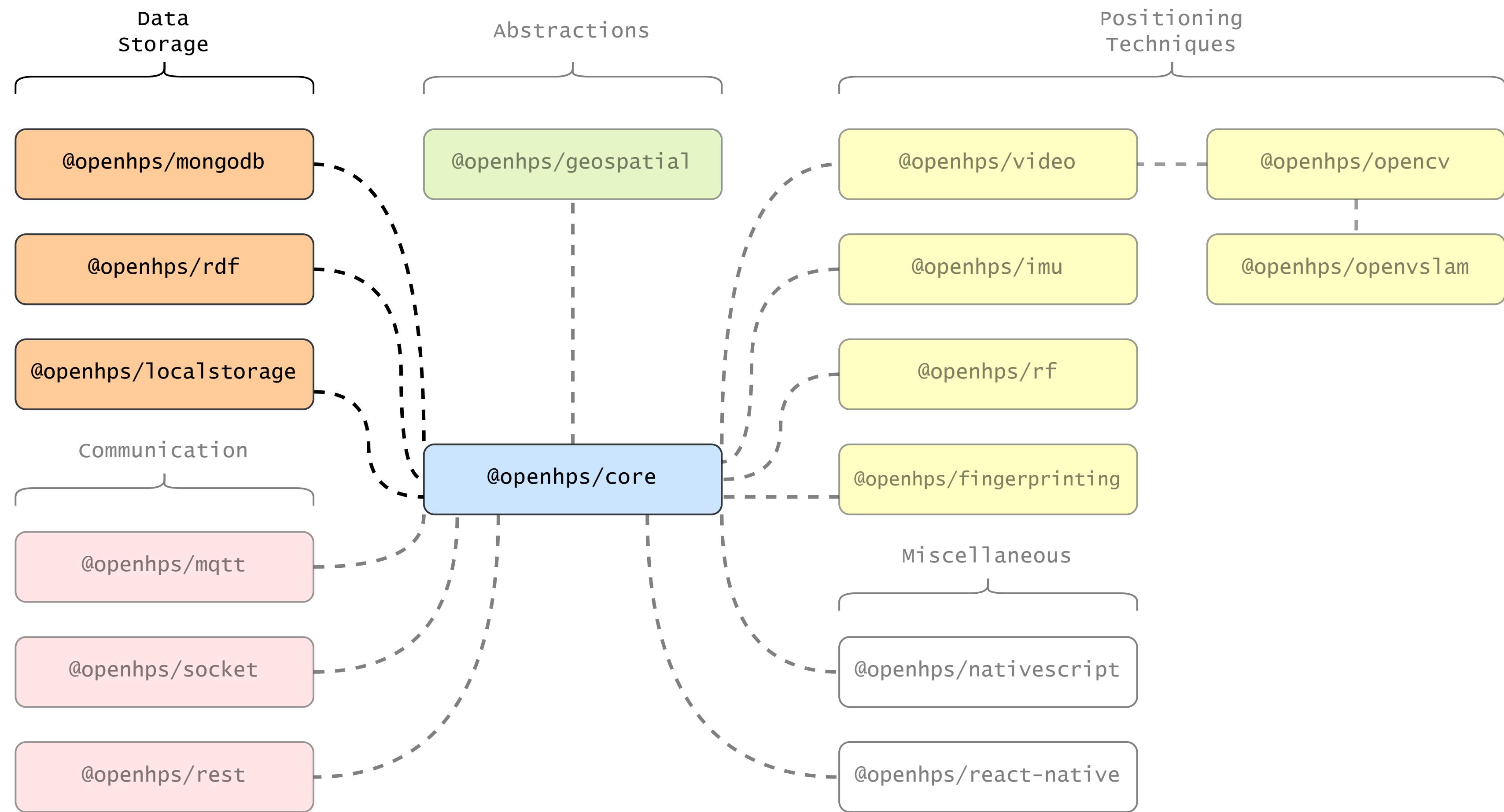
# Modularity ...



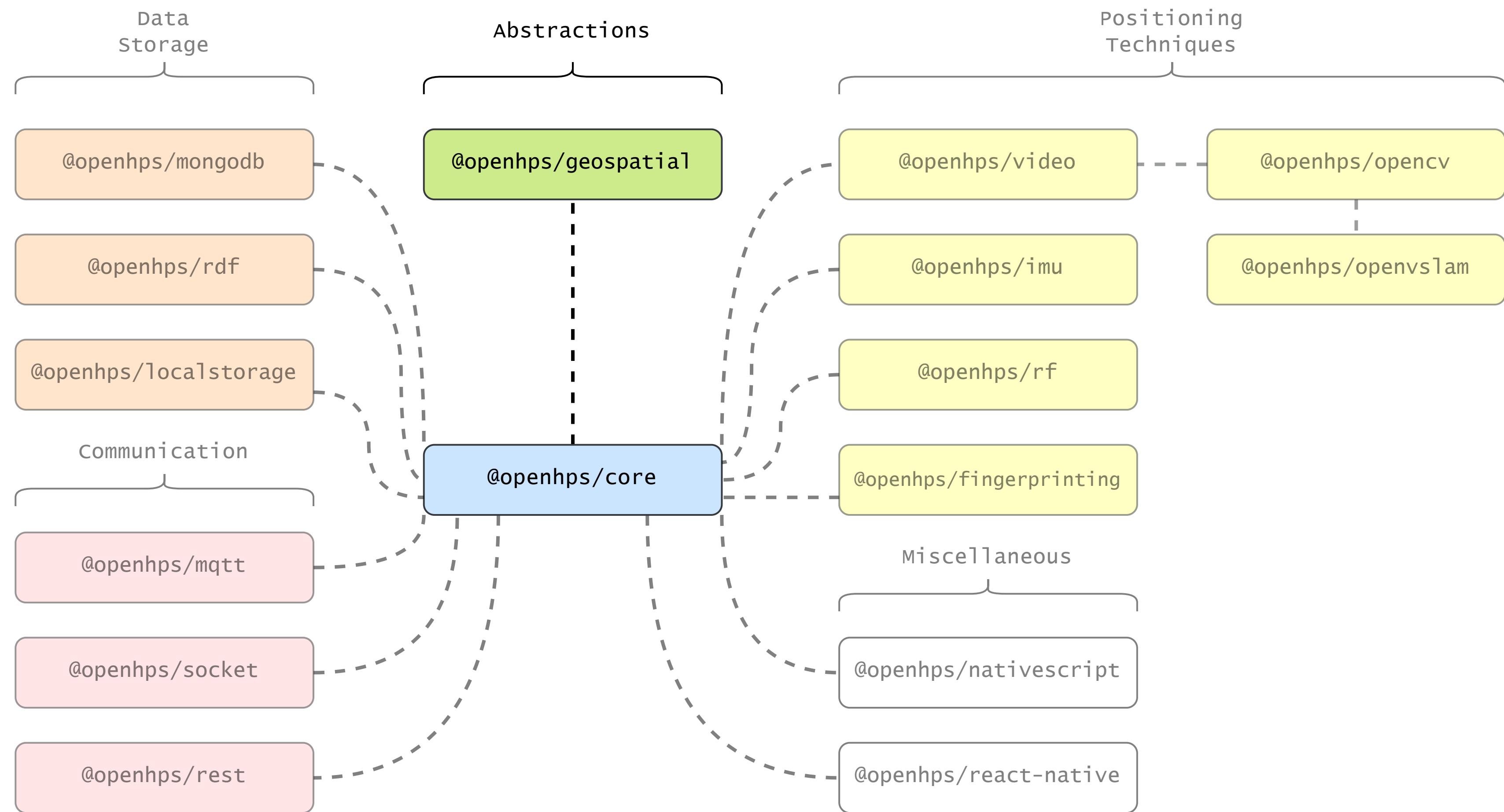
# Modularity ...



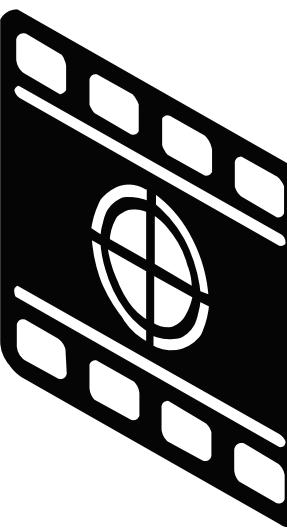
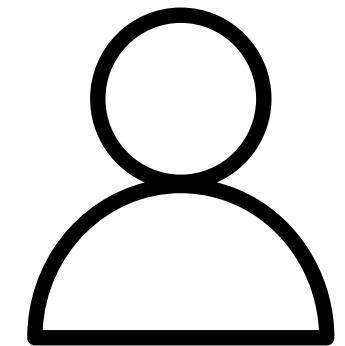
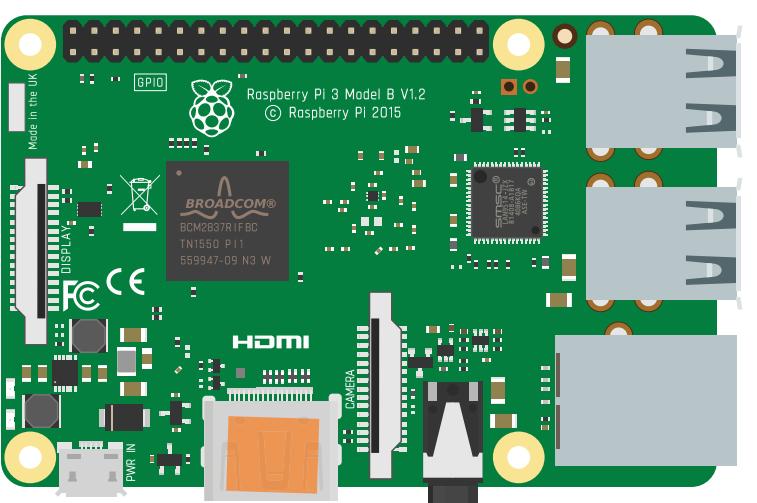
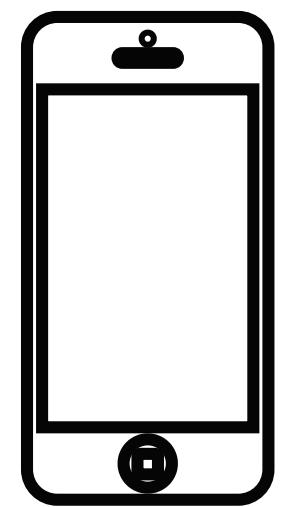
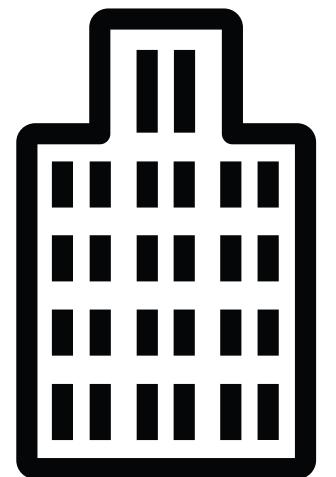
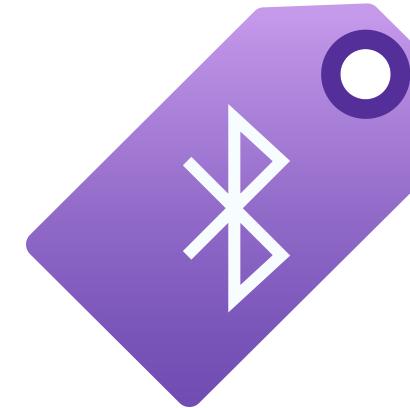
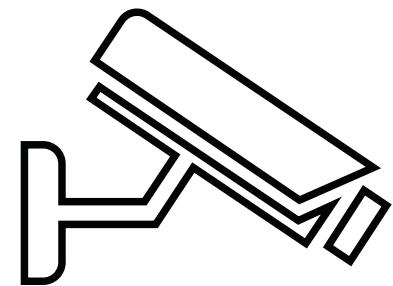
# Modularity ...



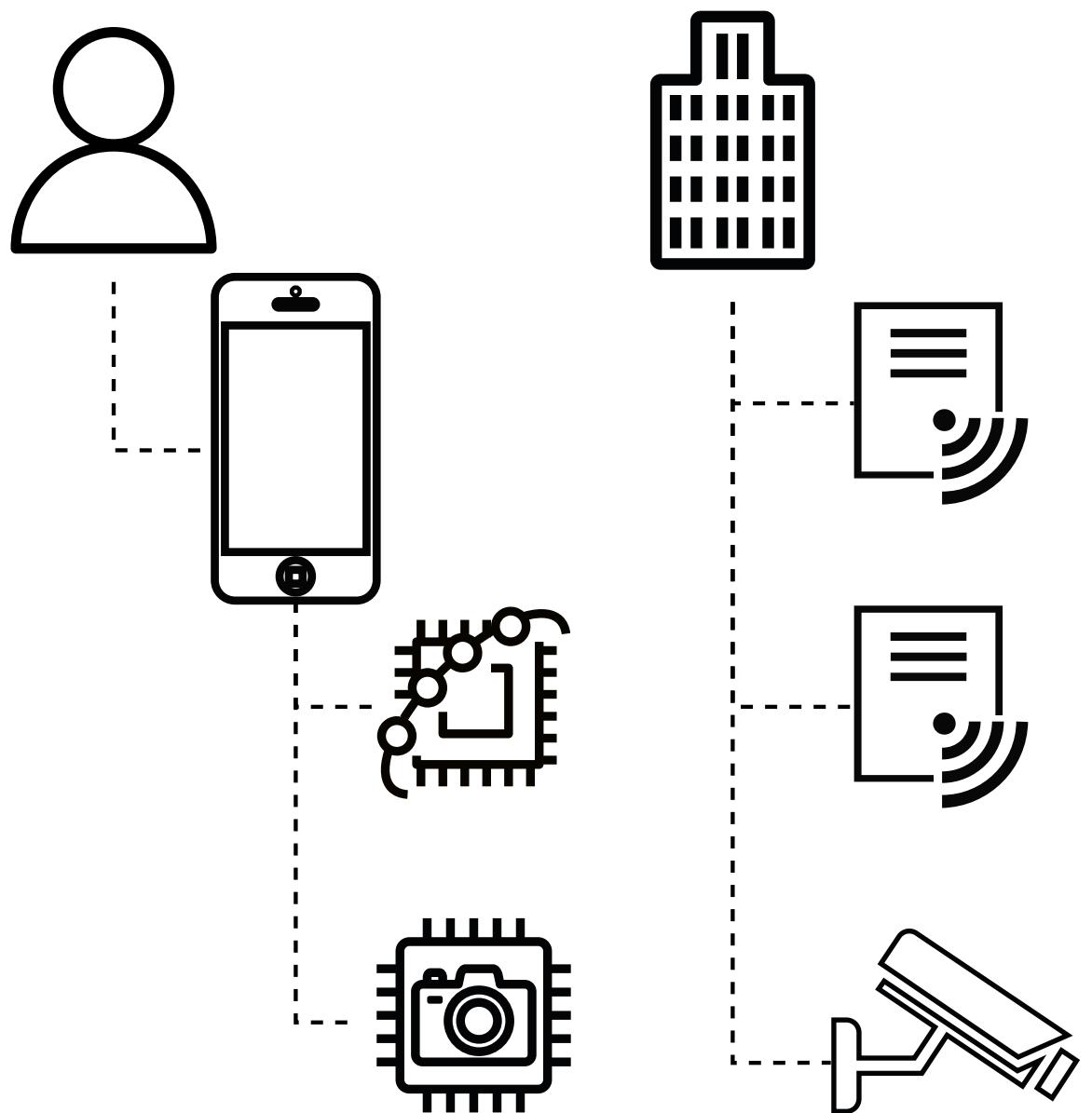
# Modularity ...



# Data Processing



# DataObject



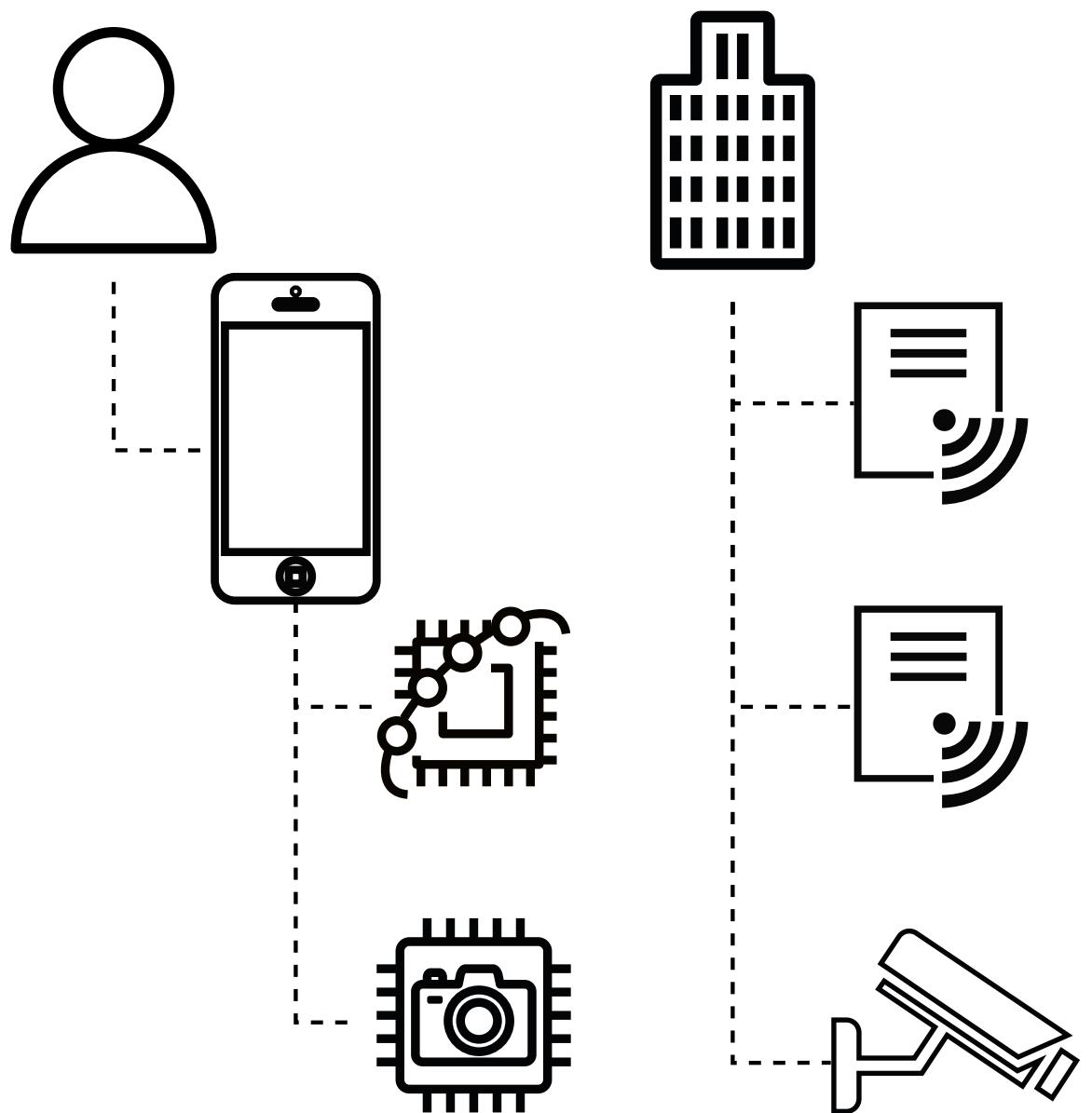
```
// Data object for the person we are tracking
const me = new DataObject("mvdewync@vub.be");
me.displayName = "Maxim Van de Wynckel";

// 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



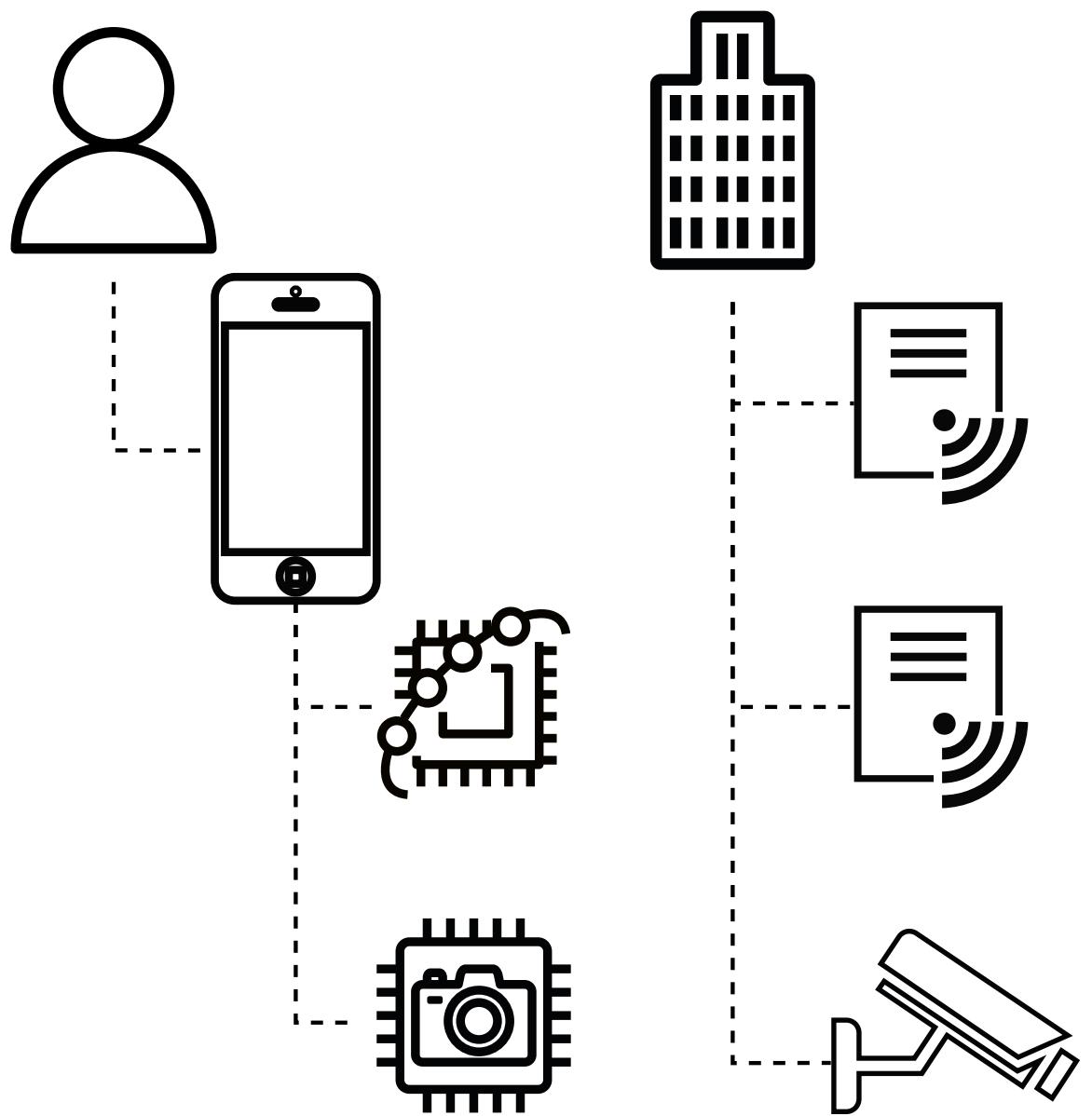
```
// Data object for the person we are tracking
const me = new DataObject("mvdewync@vub.be");
me.displayName = "Maxim Van de Wynckel";

// 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



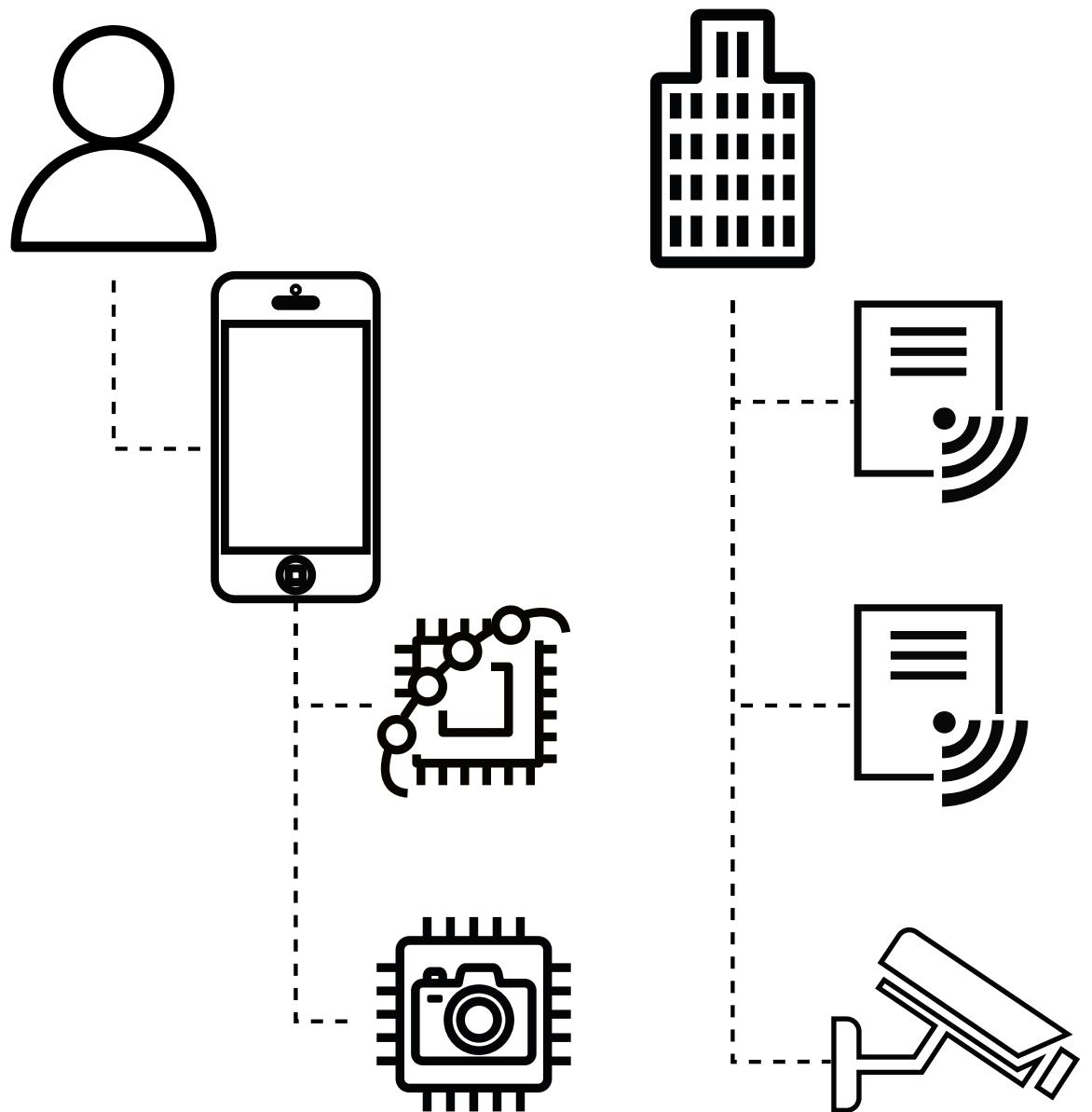
```
// Data object for the person we are tracking
const me = new DataObject("mvdewync@vub.be");
me.displayName = "Maxim Van de Wynckel";

// 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



```
// 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

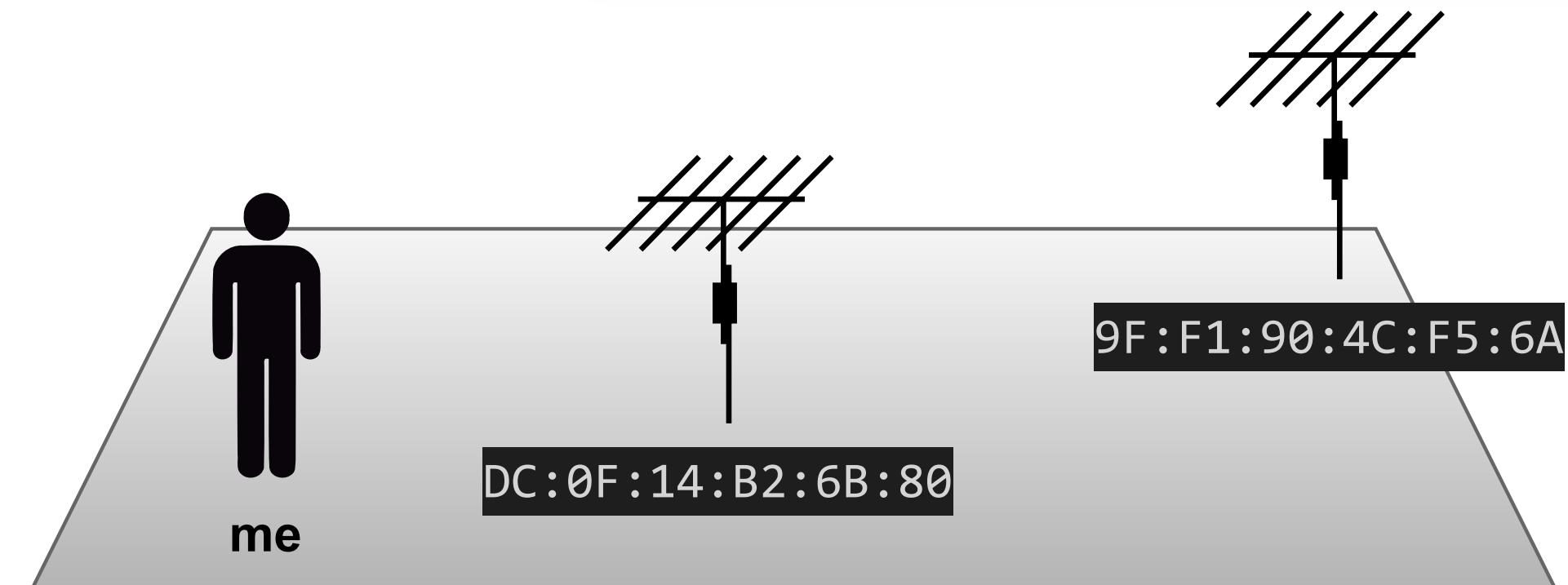
## Absolute

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

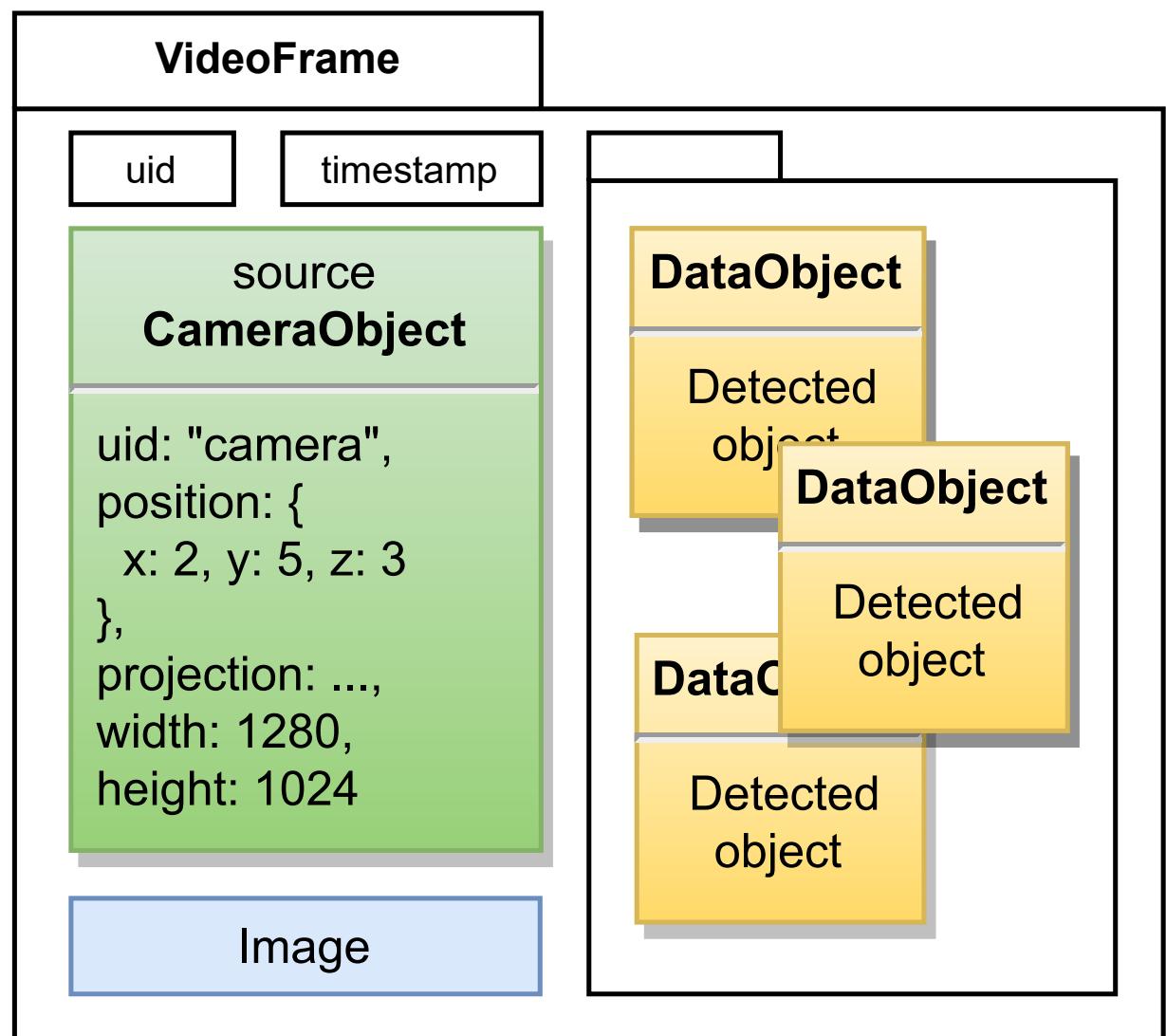
## Relative

- ▶ 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  
));
```



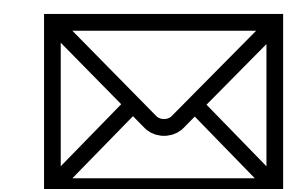
# DataFrame



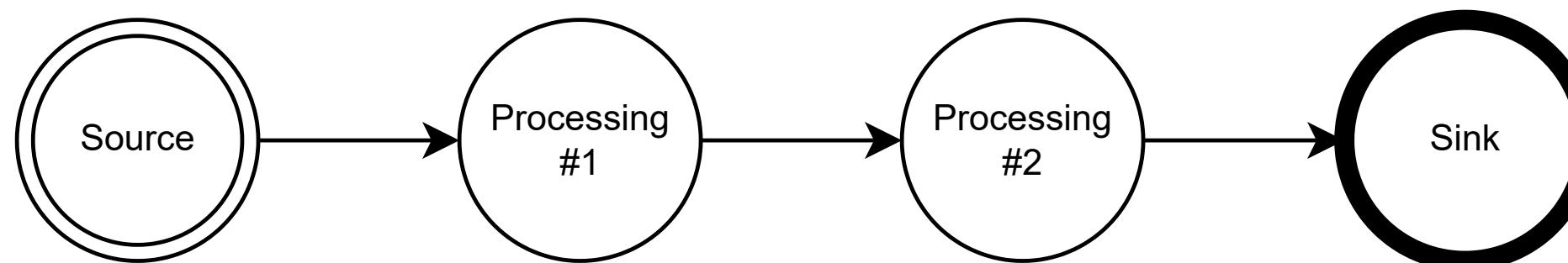
```
// Sensor that captured the frame
const camera = new CameraObject();

// 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(/* ... */);
```

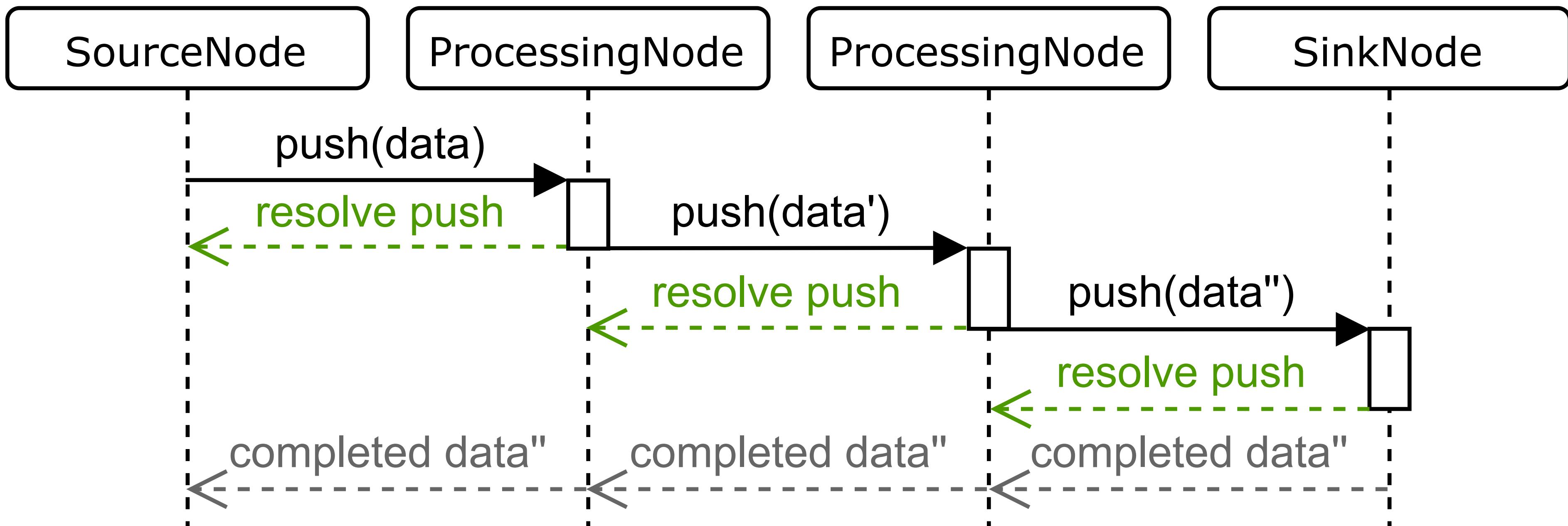


**DataFrame**



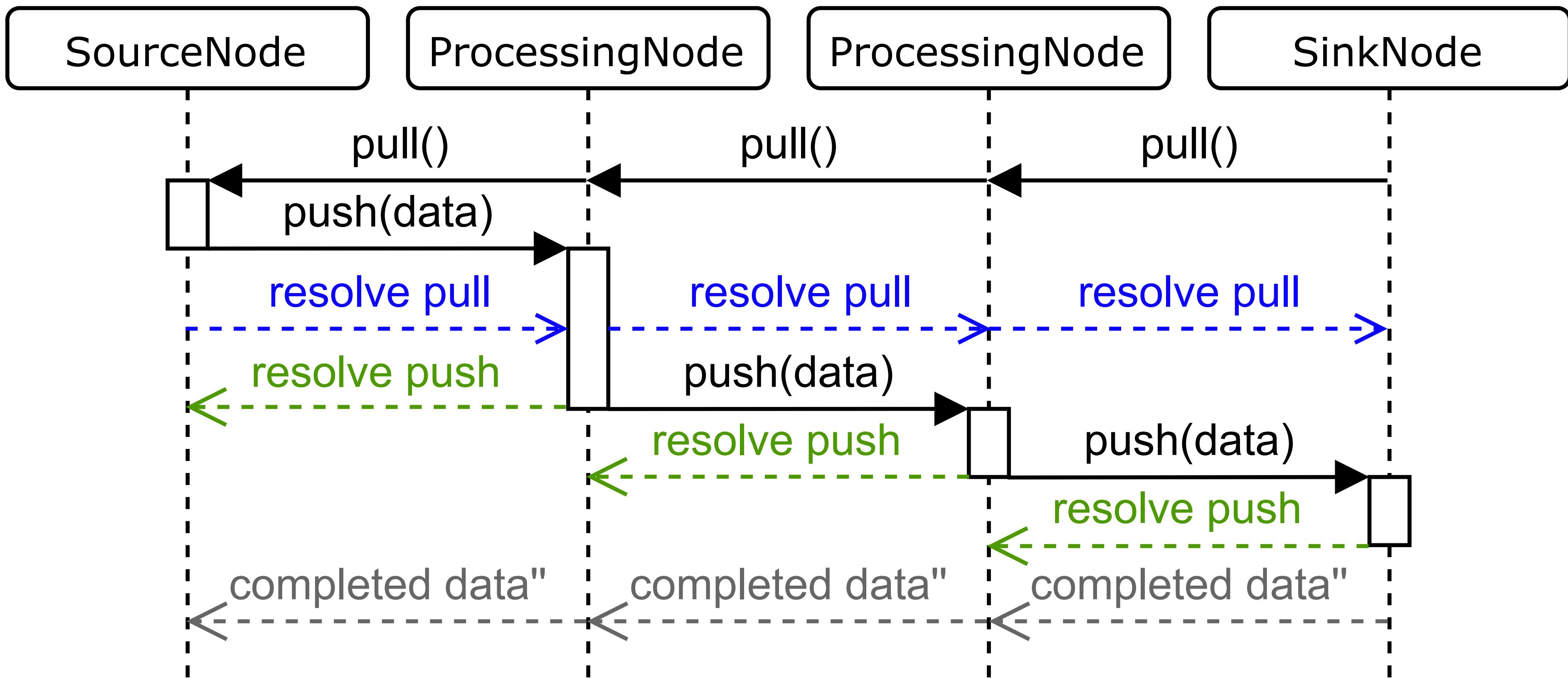
# DataFrame ...

## Pushing Data



# DataFrame ...

# Pulling Data



# Positioning Model

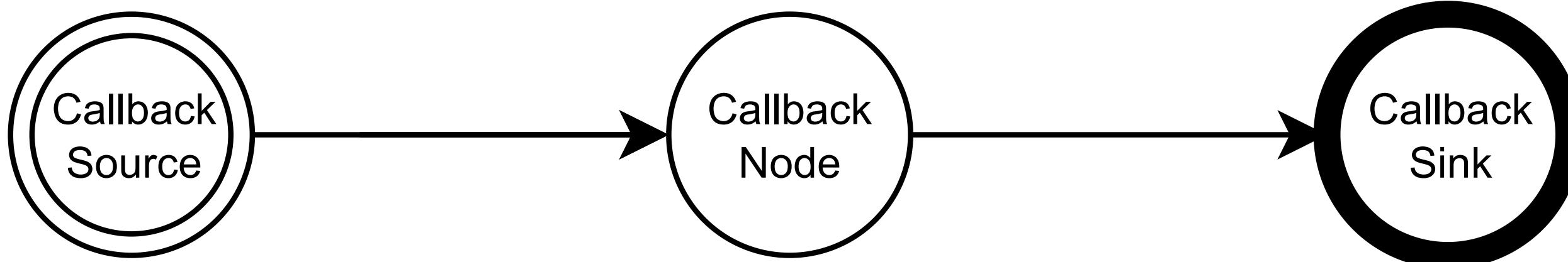


```
ModelBuilder.create()
  .from(new CallbackSourceNode(() => {
    const myObject = new DataObject("mvdewync");
    const frame = new DataFrame();
    frame addObject(myObject);
    return frame;
}))
  .via(new CallbackNode((frame: DataFrame) => { /* ... */ }))
  .to(new CallbackSinkNode((frame: DataFrame)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

.from(...)

.via(...)

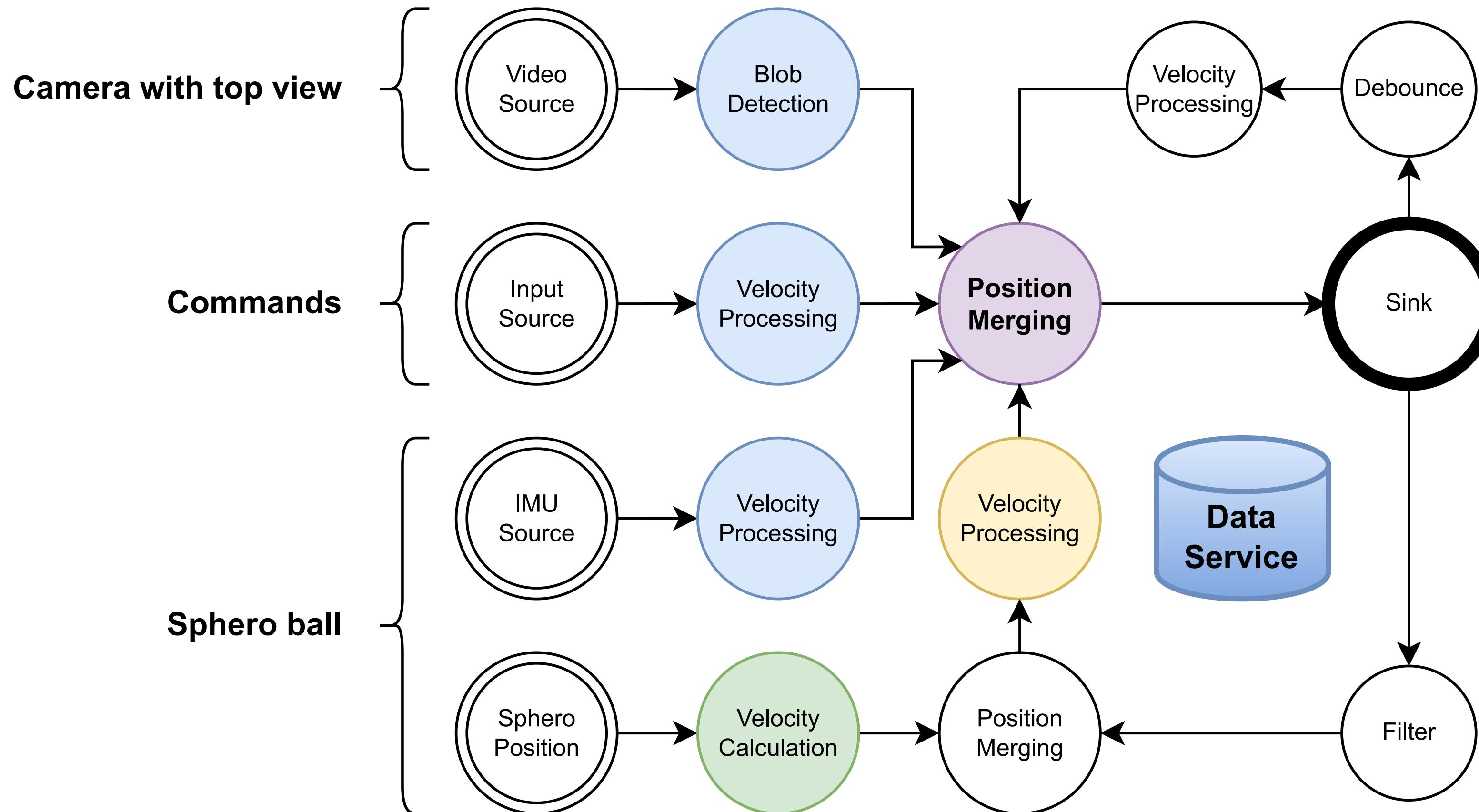
.to(...)



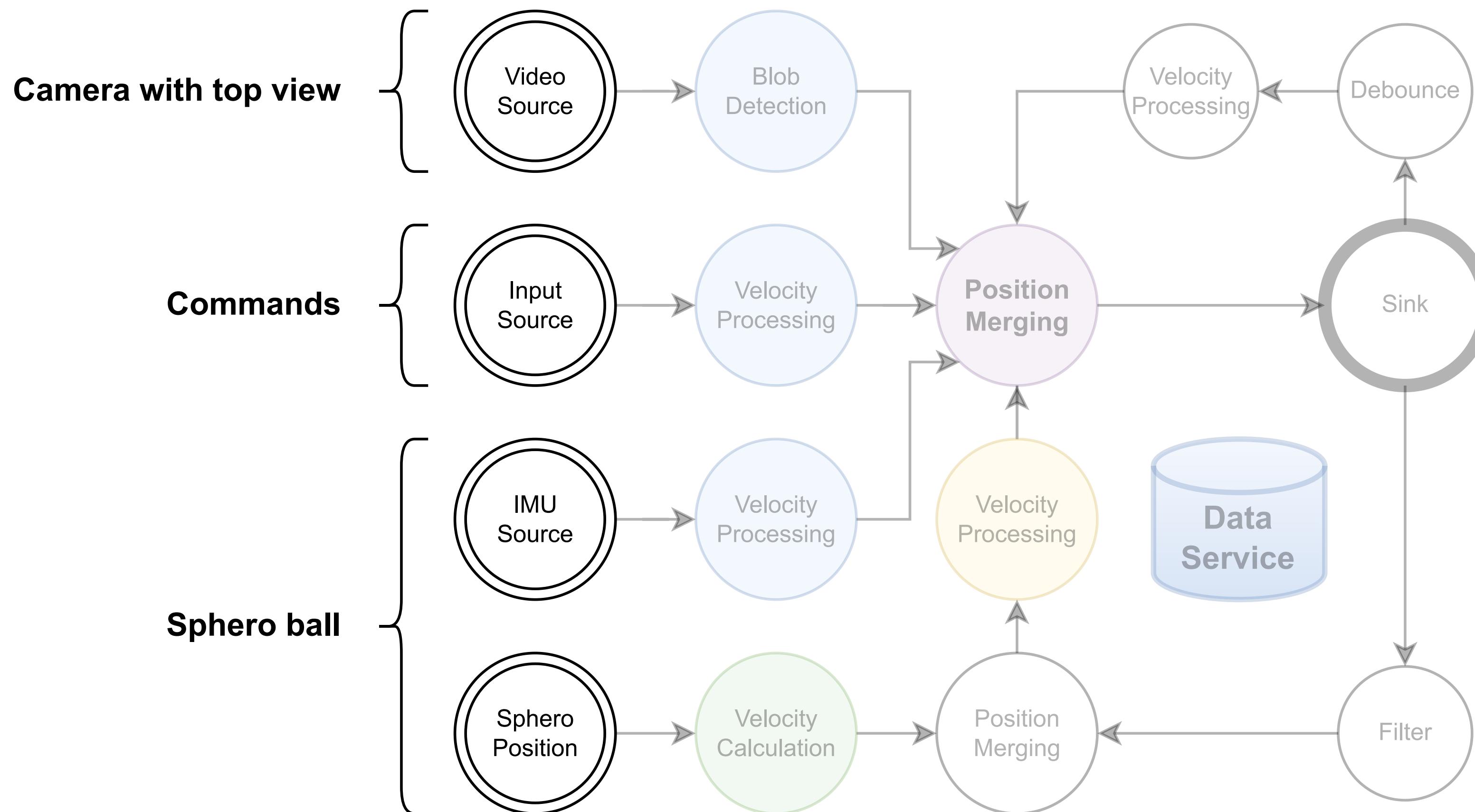
# Example



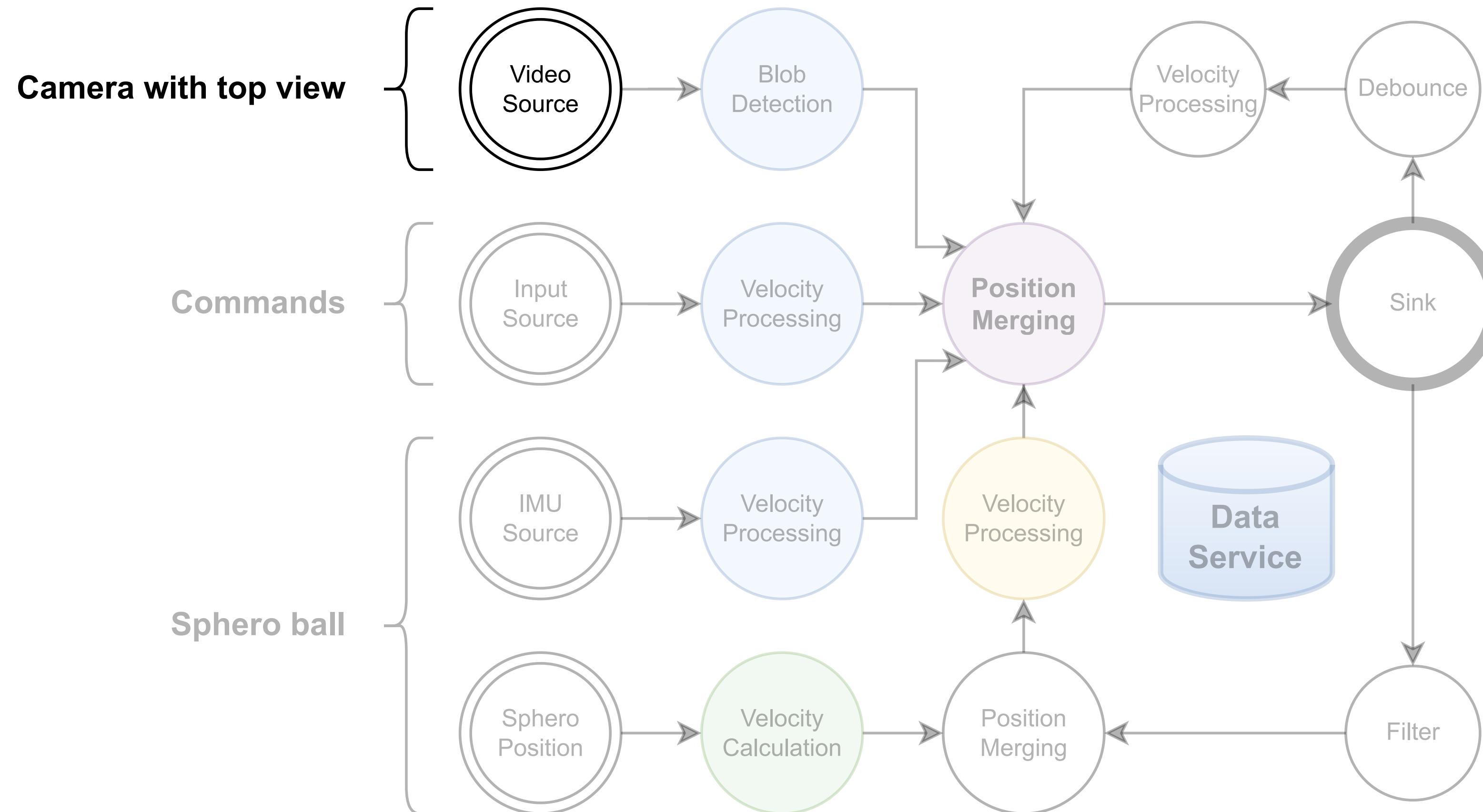
# Example ...



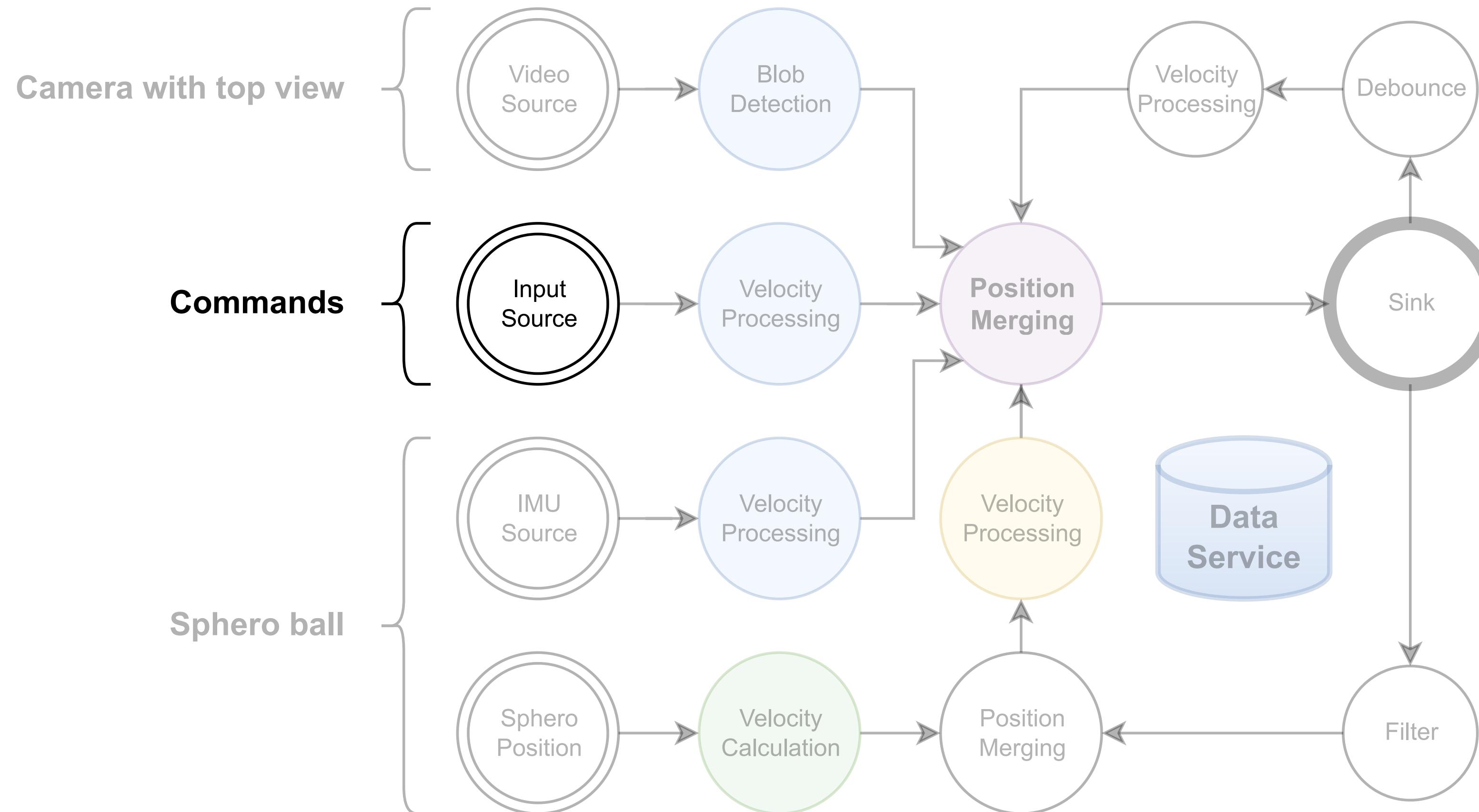
# Example ...



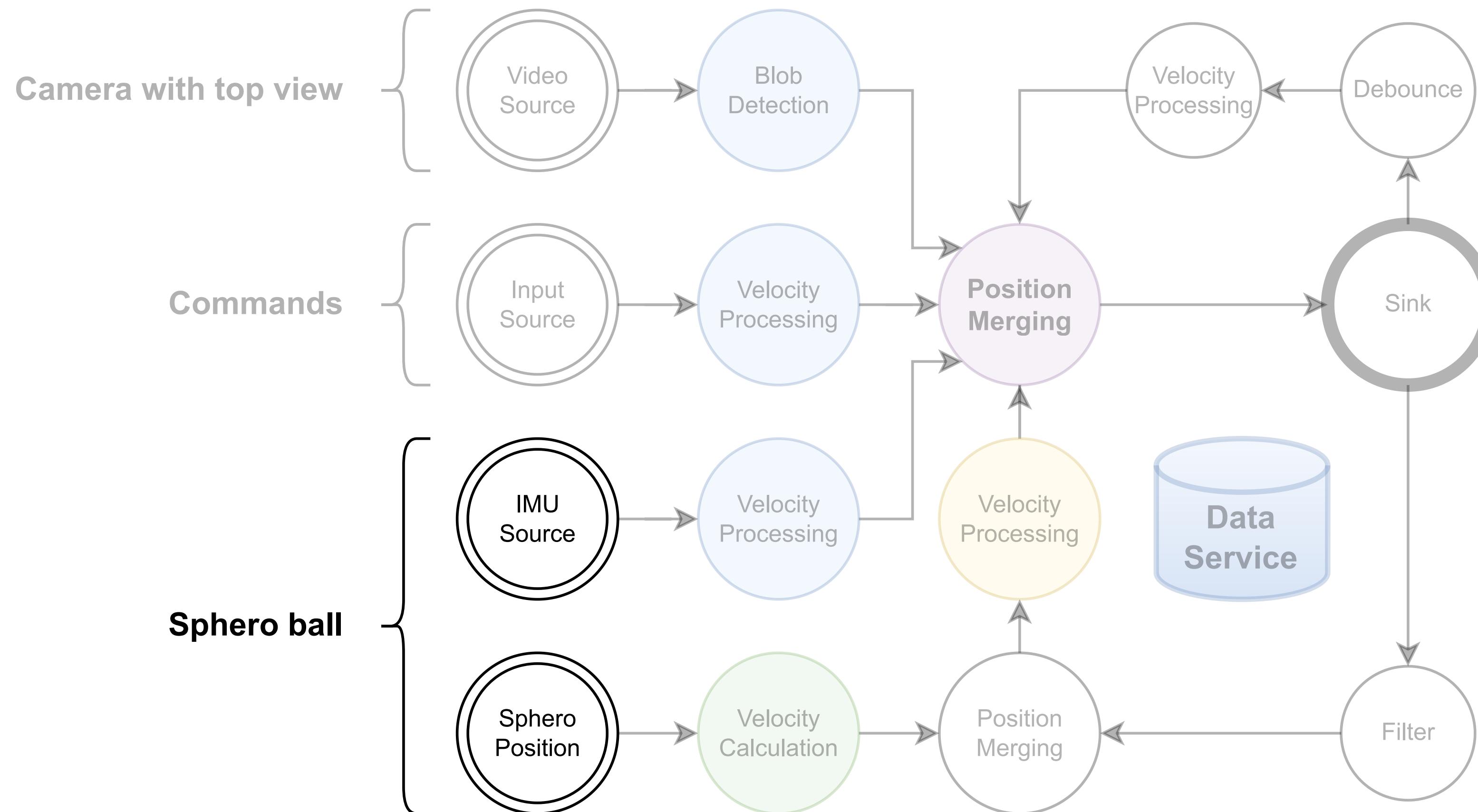
# Example ...



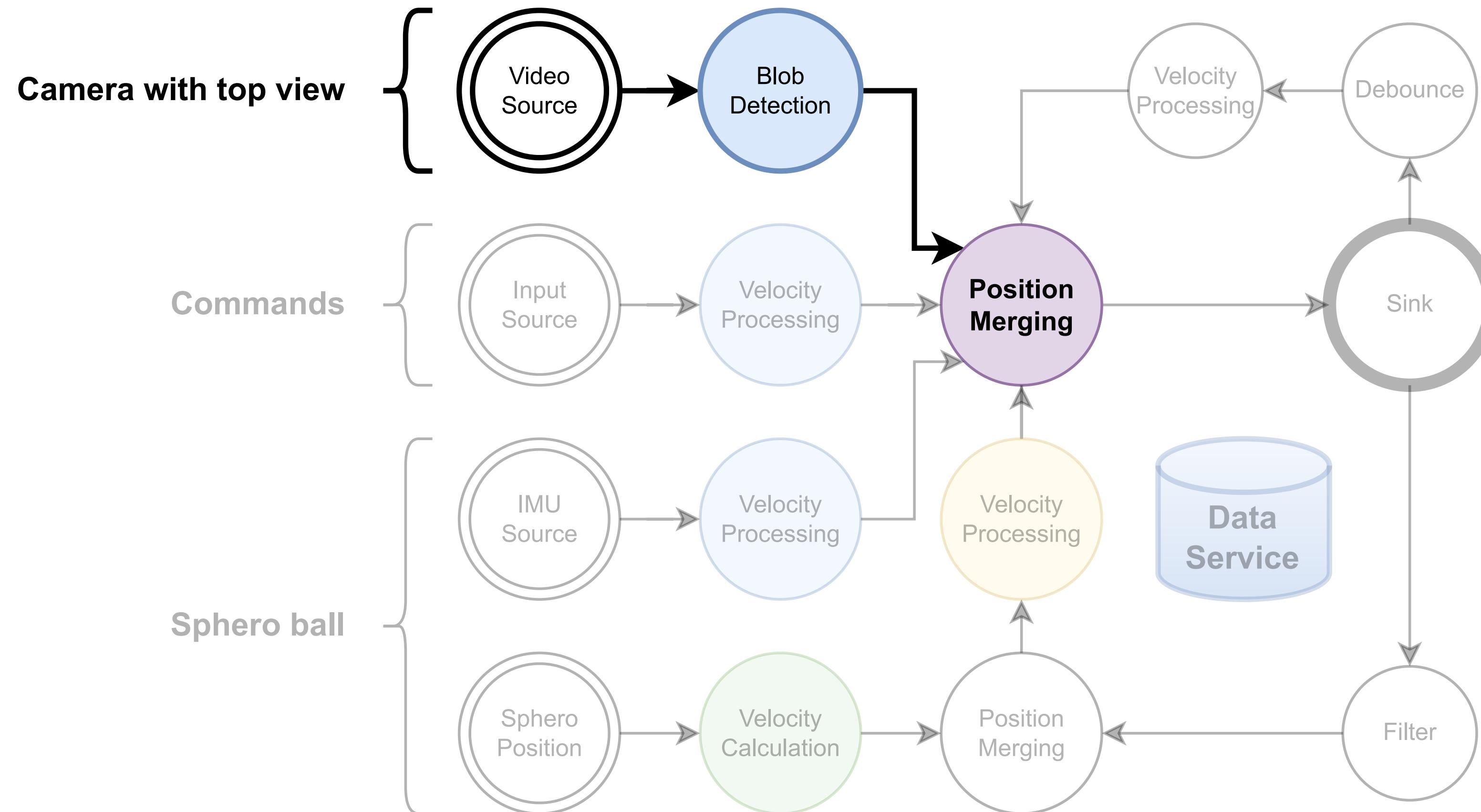
# Example ...



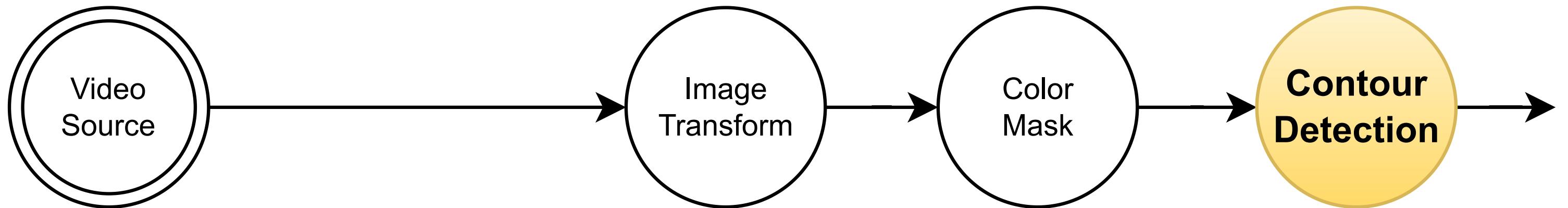
# Example ...



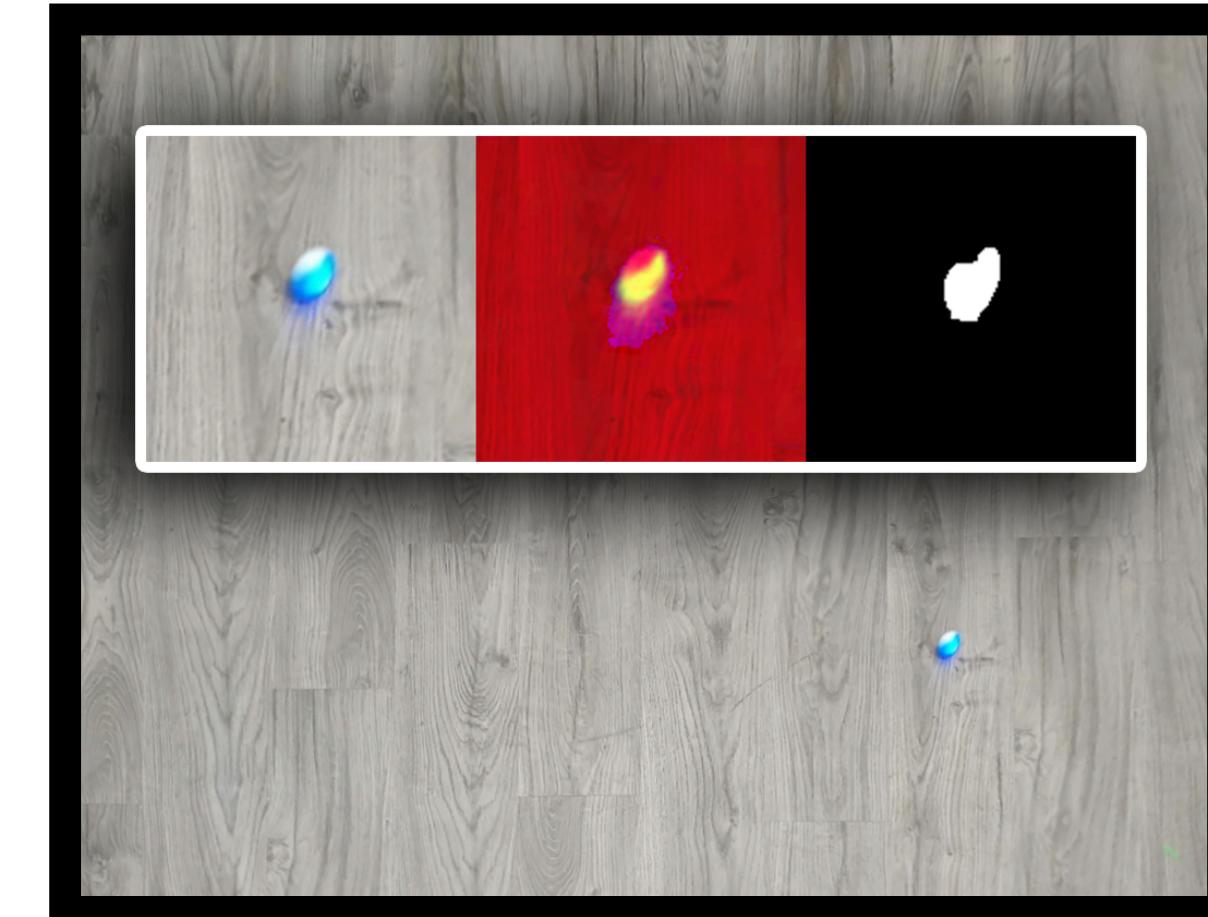
# Example ...



# Example ...

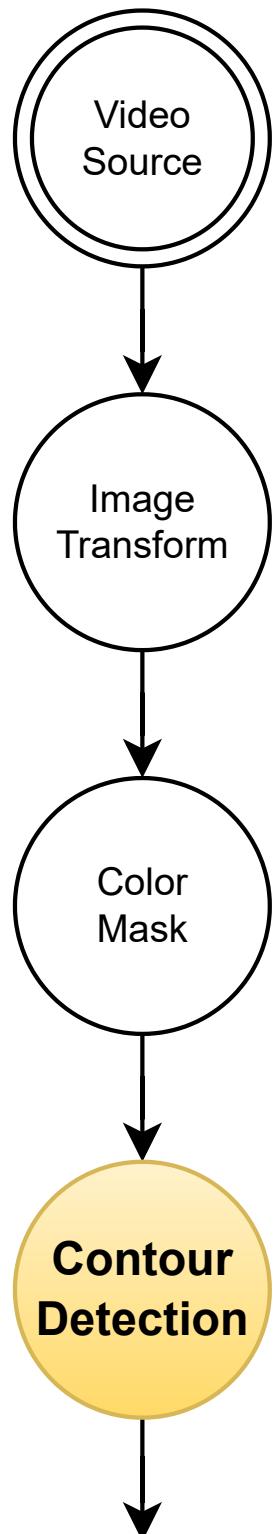


Original



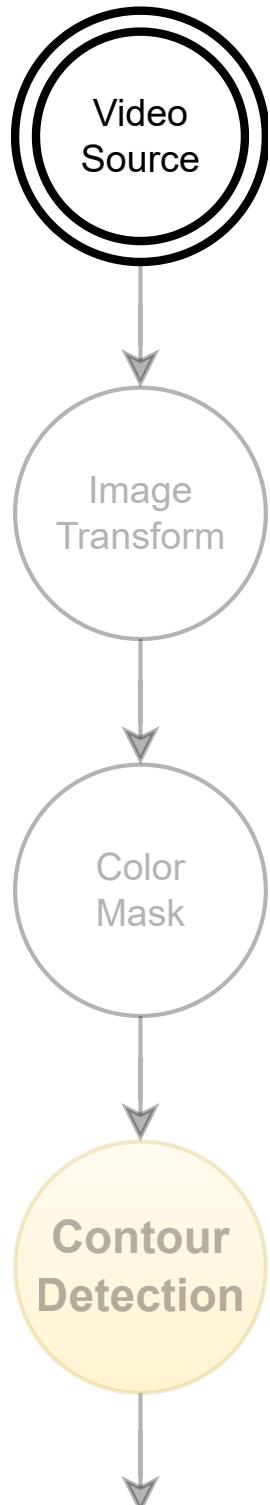
Transformed  
& Mask

# Example ...



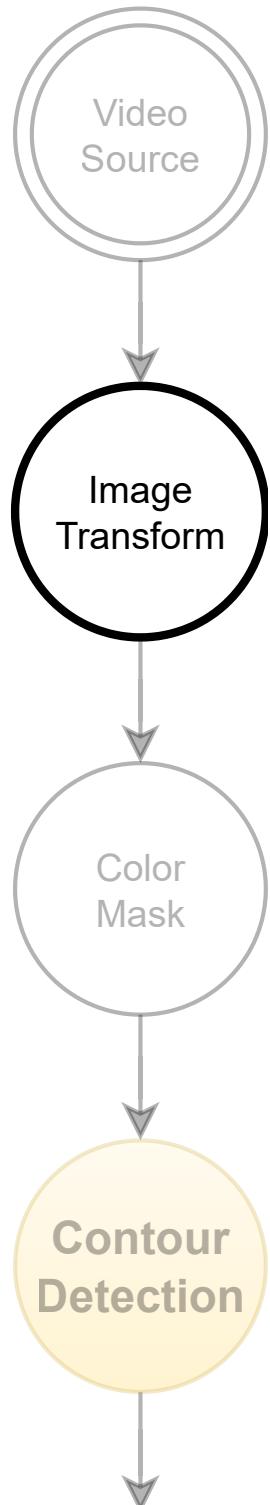
```
GraphBuilder.create()
    .from(new VideoSource({
        autoPlay: true,
        fps: 30,
        throttleRead: true,
        source: new CameraObject("sphero_video")
    }).load("/dev/video2"))
    .via(new ImageTransformNode({
        src: [
            new OpenCV.Point2(307, 120),
            new OpenCV.Point2(1473, 87),
            new OpenCV.Point2(1899, 891),
            new OpenCV.Point2(20, 1024),
        ],
        height: 800,
        width: 1040
    }))
    .via(new ColorMaskProcessing({
        minRange: [90, 50, 50],
        maxRange: [140, 255, 255]
    }))
    .via(new ContourDetectionNode()) // Custom
    .to();
```

# Example ...



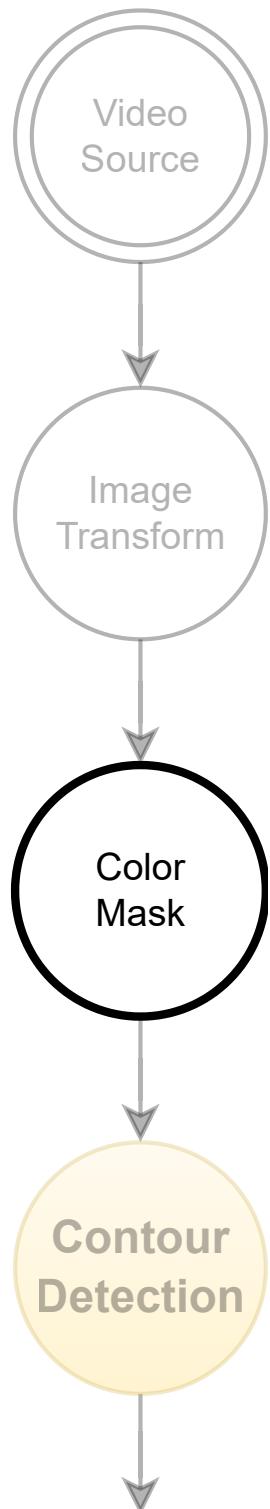
```
GraphBuilder.create()
    .from(new VideoSource({
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        fps: 30,
        throttleRead: true,
        source: new CameraObject("sphero_video")
    }).load("/dev/video2"))
    .via(new ImageTransformNode({
        src: [
            new OpenCV.Point2(307, 120),
            new OpenCV.Point2(1473, 87),
            new OpenCV.Point2(1899, 891),
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        ],
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        minRange: [90, 50, 50],
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# Example ...



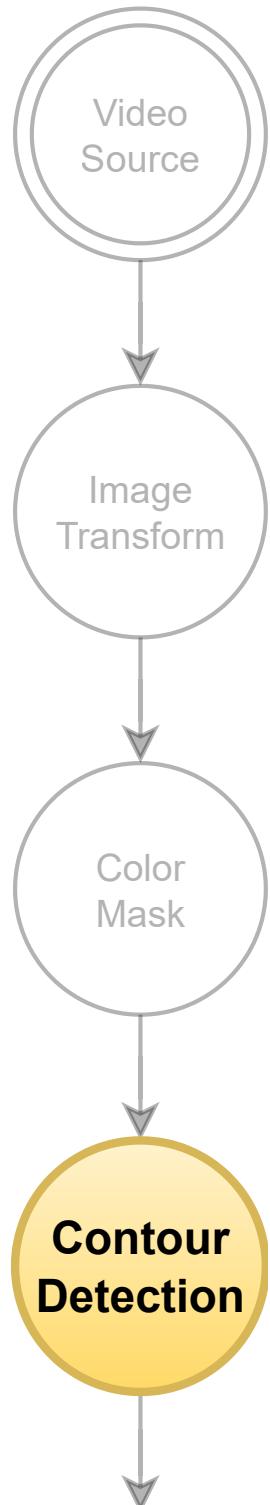
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    }).load("/dev/video2"))
    .via(new ImageTransformNode({
        src: [
            new OpenCV.Point2(307, 120),
            new OpenCV.Point2(1473, 87),
            new OpenCV.Point2(1899, 891),
            new OpenCV.Point2(20, 1024),
        ],
        height: 800,
        width: 1040
    }))
    .via(new ColorMaskProcessing({
        minRange: [90, 50, 50],
        maxRange: [140, 255, 255]
    }))
    .via(new ContourDetectionNode()) // Custom
    .to();
```

# Example ...



```
GraphBuilder.create()
    .from(new VideoSource({
        autoPlay: true,
        fps: 30,
        throttleRead: true,
        source: new CameraObject("sphero_video")
    }).load("/dev/video2"))
    .via(new ImageTransformNode({
        src: [
            new OpenCV.Point2(307, 120),
            new OpenCV.Point2(1473, 87),
            new OpenCV.Point2(1899, 891),
            new OpenCV.Point2(20, 1024),
        ],
        height: 800,
        width: 1040
    }))
    .via(new ColorMaskProcessing({
        minRange: [90, 50, 50],
        maxRange: [140, 255, 255]
    }))
    .via(new ContourDetectionNode()) // Custom
    .to();
```

# Example ...



```
GraphBuilder.create()
    .from(new VideoSource({
        autoPlay: true,
        fps: 30,
        throttleRead: true,
        source: new CameraObject("sphero_video")
    }).load("/dev/video2"))
    .via(new ImageTransformNode({
        src: [
            new OpenCV.Point2(307, 120),
            new OpenCV.Point2(1473, 87),
            new OpenCV.Point2(1899, 891),
            new OpenCV.Point2(20, 1024),
        ],
        height: 800,
        width: 1040
    }))
    .via(new ColorMaskProcessing({
        minRange: [90, 50, 50],
        maxRange: [140, 255, 255]
    }))
    .via(new ContourDetectionNode()) // Custom
    .to();
```

# OpenCV: Contour Detection



```
class ContourDetectionNode extends ProcessingNode<VideoFrame> {
    process(frame: VideoFrame): Promise<VideoFrame> {
        return new Promise((resolve) => {
            let contours = frame.image.findContours(
                OpenCV.RETR_EXTERNAL, OpenCV.CHAIN_APPROX_SIMPLE);
            if (contours.length >= 1) {
                // Sort contours by area and select largest area as 'ball'
                contours = contours.sort((a, b) => a.area - b.area);
                const m = contours[0].moments();
                const center = new OpenCV.Vec2(m.m10 / m.m00, m.m01 / m.m00);
                // Use the center as the 2D pixel position
                const position = new Absolute2DPosition(center.x, center.y);
                position.unit = LengthUnit.CENTIMETER;
                position.accuracy = Math.sqrt(contours[0].area);
                frame addObject(new DataObject("ball").setPosition(position));
            }
            resolve(frame);
        });
    }
}
```

# OpenCV: Contour Detection

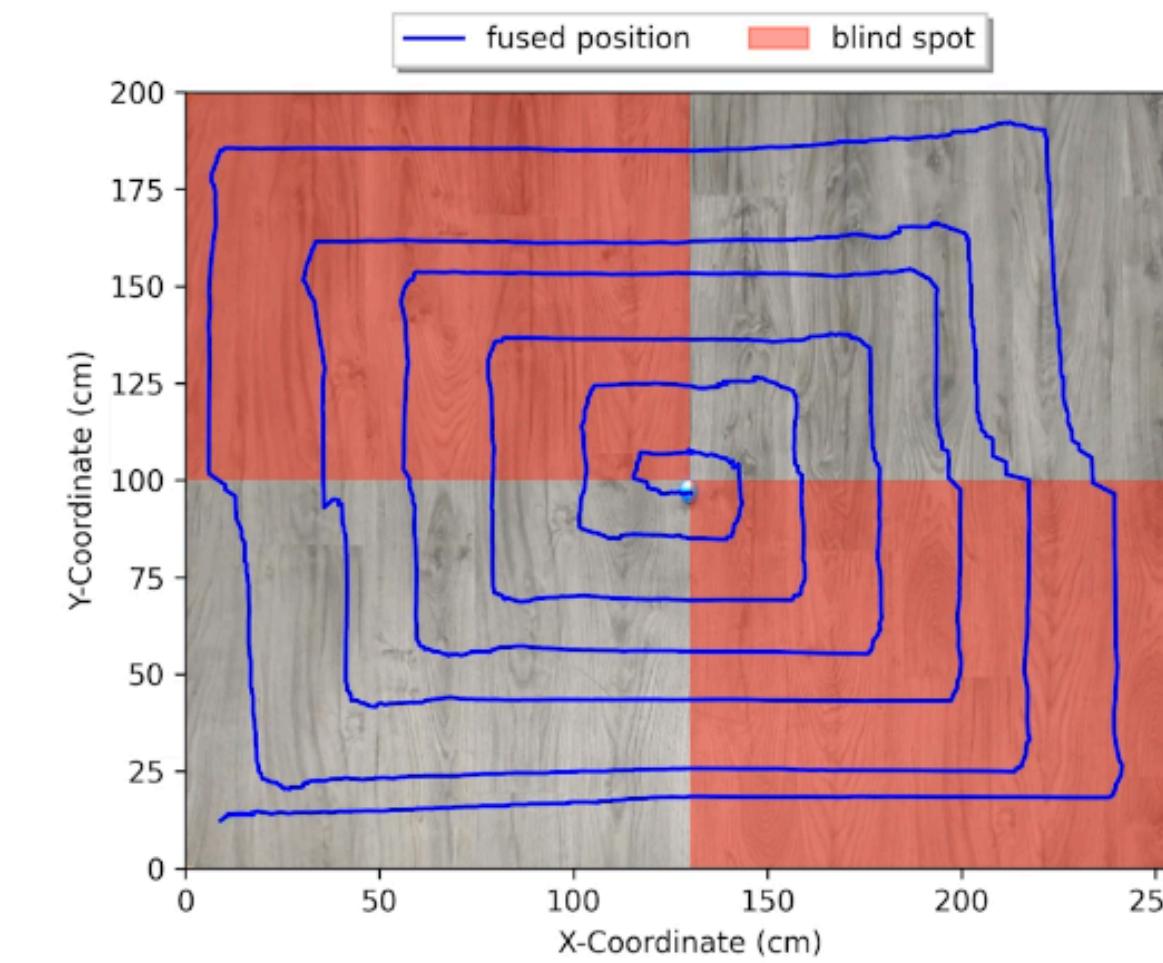
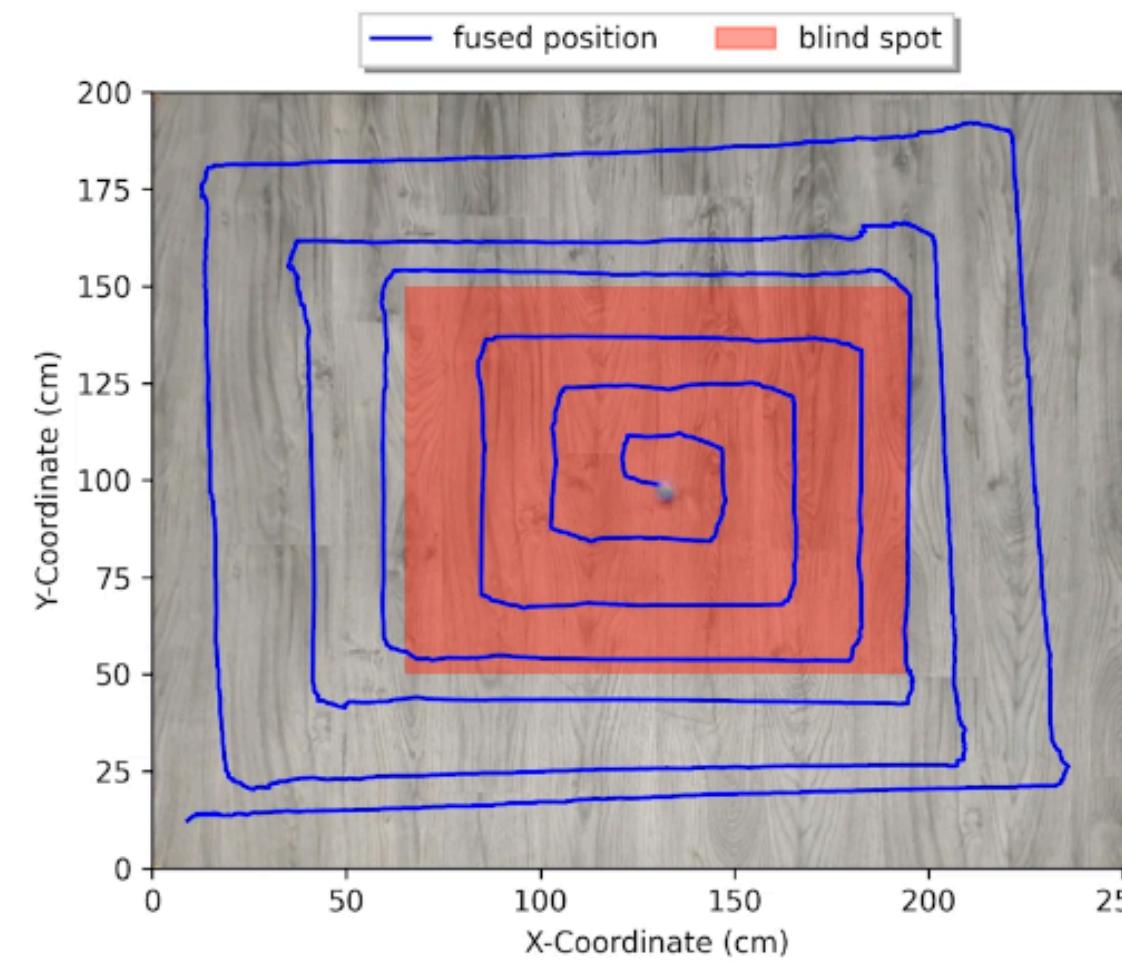
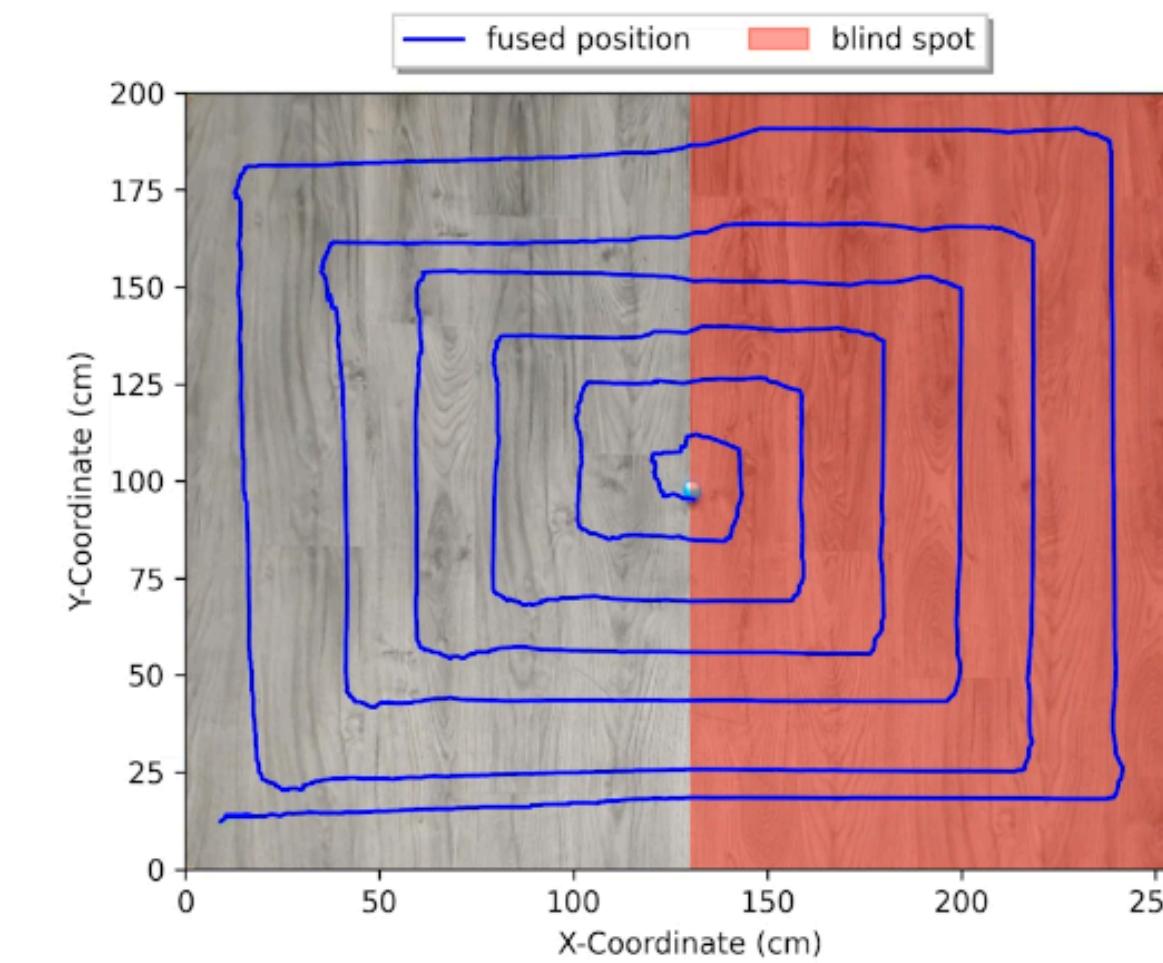
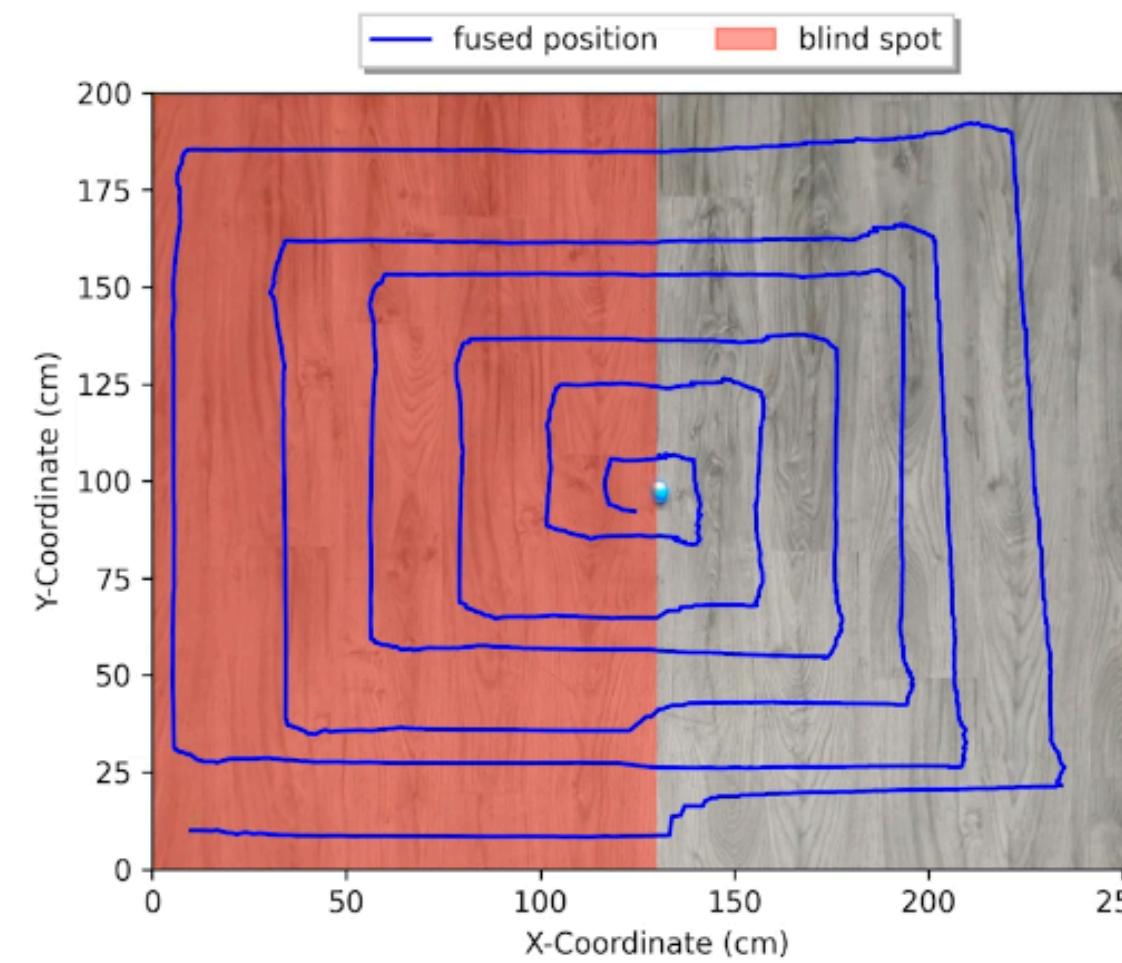


```
class ContourDetectionNode extends ProcessingNode<VideoFrame> {
    process(frame: VideoFrame): Promise<VideoFrame> {
        return new Promise((resolve) => {
            let contours = frame.image.findContours(
                OpenCV.RETR_EXTERNAL, OpenCV.CHAIN_APPROX_SIMPLE);
            if (contours.length >= 1) {
                // Sort contours by area and select largest area as 'ball'
                contours = contours.sort((a, b) => a.area - b.area);
                const m = contours[0].moments();
                const center = new OpenCV.Vec2(m.m10 / m.m00, m.m01 / m.m00);
                // Use the center as the 2D pixel position
                const position = new Absolute2DPosition(center.x, center.y);
                position.unit = LengthUnit.CENTIMETER;
                position.accuracy = Math.sqrt(contours[0].area);
                frame addObject(new DataObject("ball").setPosition(position));
            }
            resolve(frame);
        });
    }
}
```

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```
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                const m = contours[0].moments();
                const center = new OpenCV.Vec2(m.m10 / m.m00, m.m01 / m.m00);
                // Use the center as the 2D pixel position
                const position = new Absolute2DPosition(center.x, center.y);
                position.unit = LengthUnit.CENTIMETER; // Convert later
                position.accuracy = Math.sqrt(contours[0].area);
                frame addObject(new DataObject("ball").setPosition(position));
            }
            resolve(frame);
        });
    }
}
```



# Contributing and Future Work

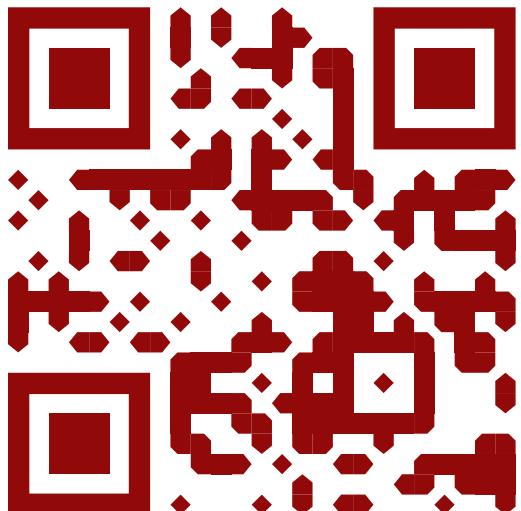


- ▶ Positioning algorithms
- ▶ Process network communication
- ▶ Bindings to other systems
- ▶ (UI) abstractions for end-user authoring
- ▶ Documentation and examples
- ▶ Calibration and set-up utilities

# Resources and Links



-  <https://openhps.org>
-  <https://github.com/OpenHPS>
-  <https://npmjs.com/org/openhps>
-  <https://twitter.com/OpenHPS>



Maxim Van de Wynckel  
<mvdewync@vub.be>