A Manufacturer-Agnostic Automation Framework for SPM

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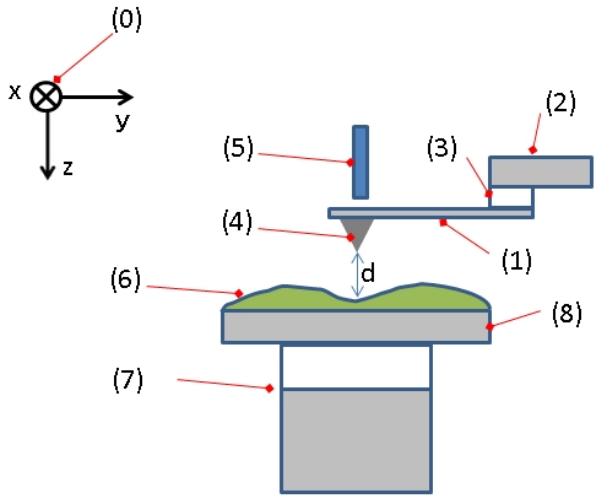
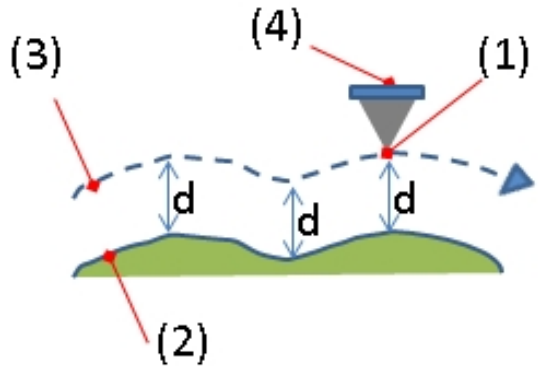
Outline

SPM Basics

- An **atomically-sharp tip** is **scanned** above a **surface** measuring properties.
  - Allows spatial imaging, spectroscopic analysis, sample manipulation.
- Usable on various surfaces, only require **relatively flat** sample ($\sim 5\mu m$).



Typical AFM Configuration, Tom Toyosaki, Wikimedia Commons.



Schematics of AFM topographic image forming, Tom Toyosaki, Wikimedia Commons.

Challenges and Automation

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Challenges for Wider Adoption

1. Preparing, running, and analyzing requires significant **domain knowledge**.
2. Running an experiment requires **constant user attention**.
3. **Statistical** understanding is **limited** by the researcher's **decisions**.

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Automation Prior Art

- **Conditioning** of the **tip** for proper surface characterization.
- **Structure classification**, for **where to scan** next.
- **Bayesian/Active Learning** for statistical decision making.

A Remaining Limitation

Many SPM systems allow custom scripts to run an experiment. But:

- Scripts written for a **specific** SPM system **cannot be re-used** on others.
- While **decoupling** is possible, it is **rarely** a **priority** for researchers.

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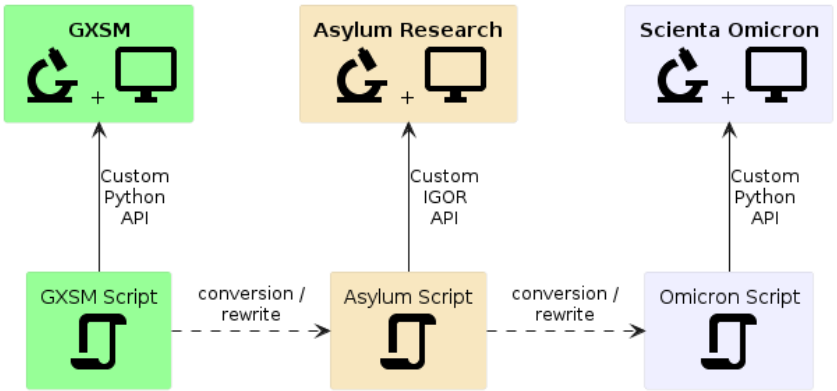

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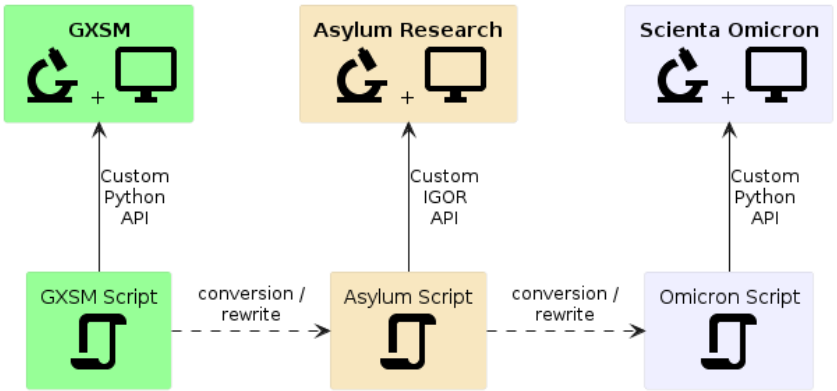

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Goals, Scope, and Design Characteristics

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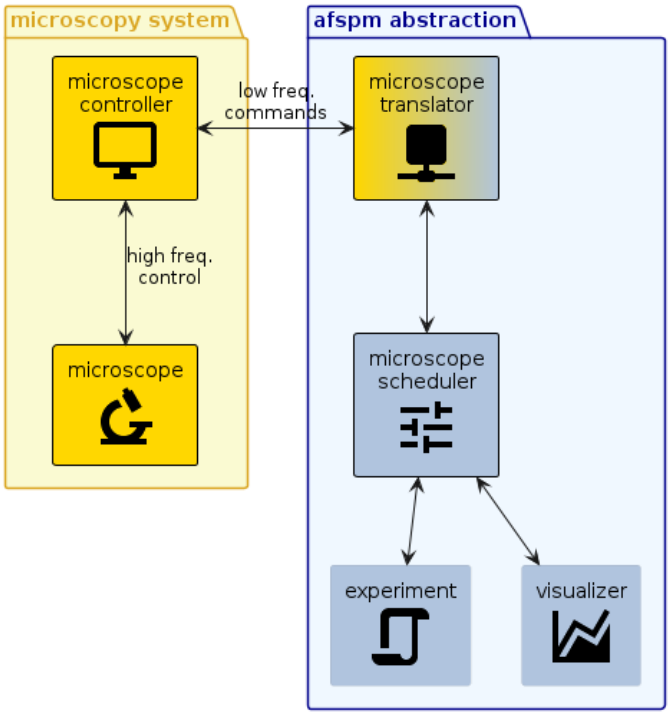
Design Characteristics

- **Standalone components** that each 'do one thing and do it well' (nodes).
- They communicate over **'pipes'** via generic **schemas**.
- It is easy to **split up** components among **different** computing **devices**.

Principal Components



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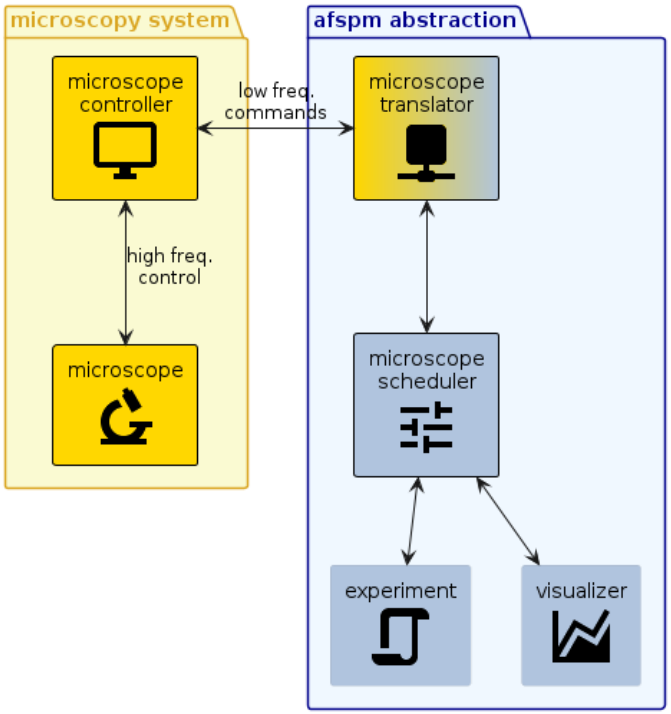
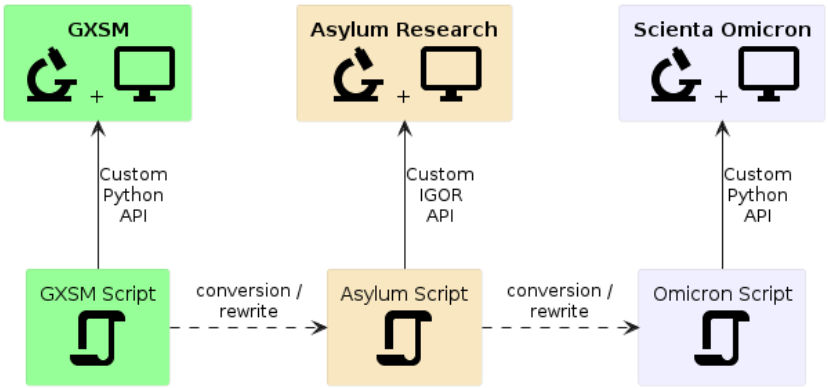


Any experiment must contain:

- **Microscope Translator**: translates between afspm-generic and microscope-specific.
- **Microscope Scheduler**: mediates control between components and translator and caches data.

Scripting with / without afspm



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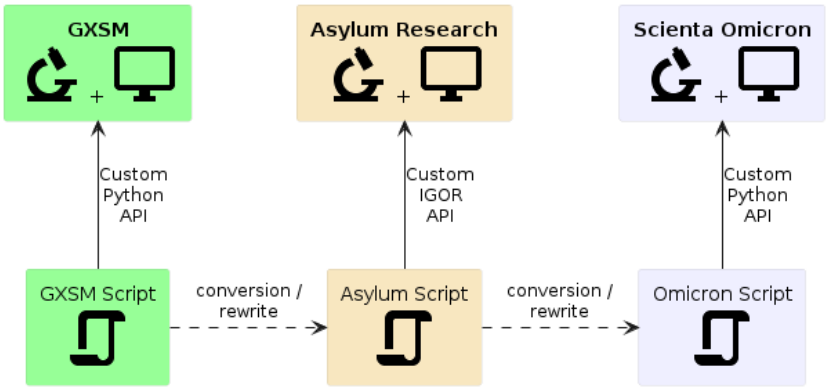

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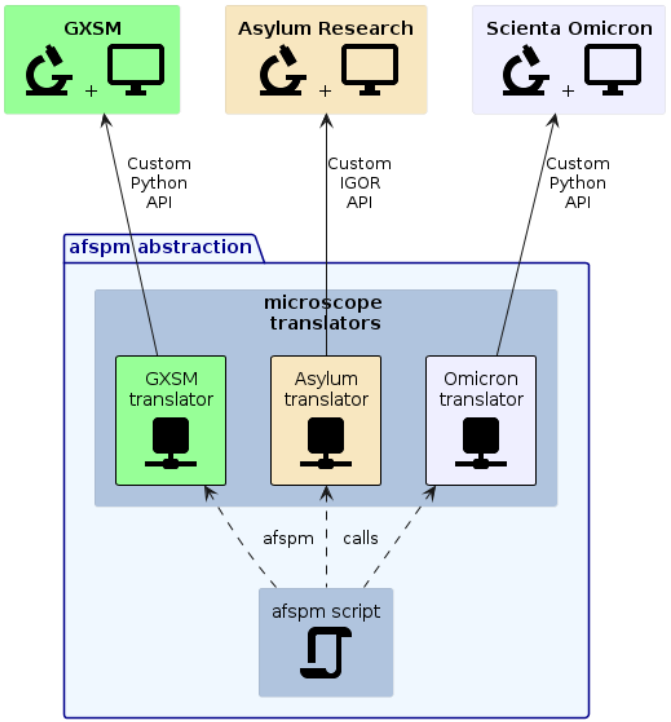
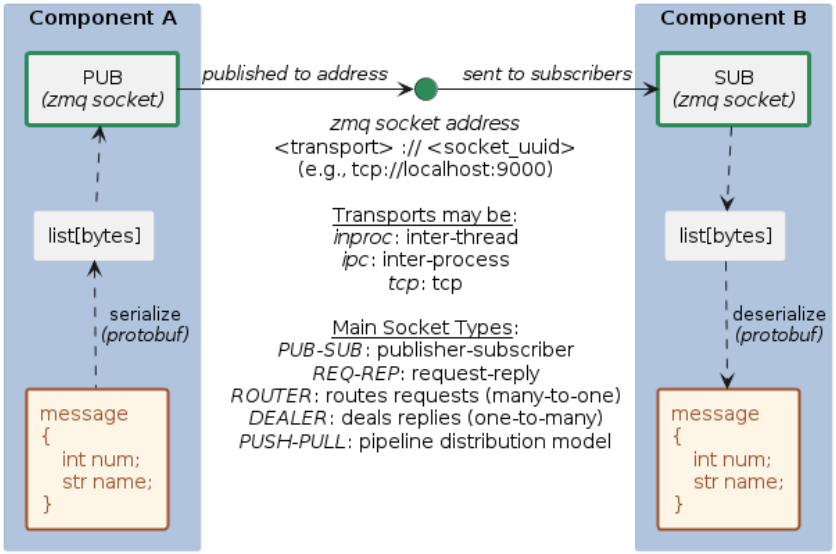


Approach Taken by afspm

Communication Protocol



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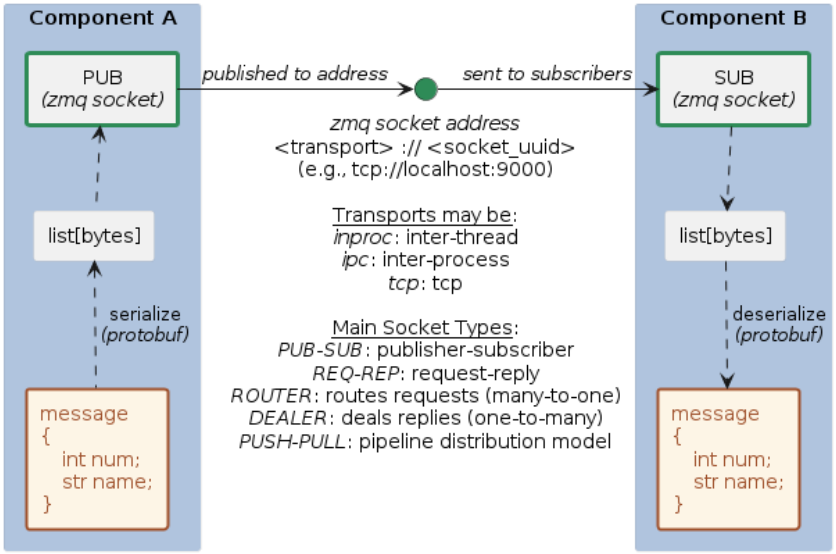

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Translates data structures into a format that can be stored/communicated.
`Google Protocol Buffers`: avoids schema violations, extra error handling.

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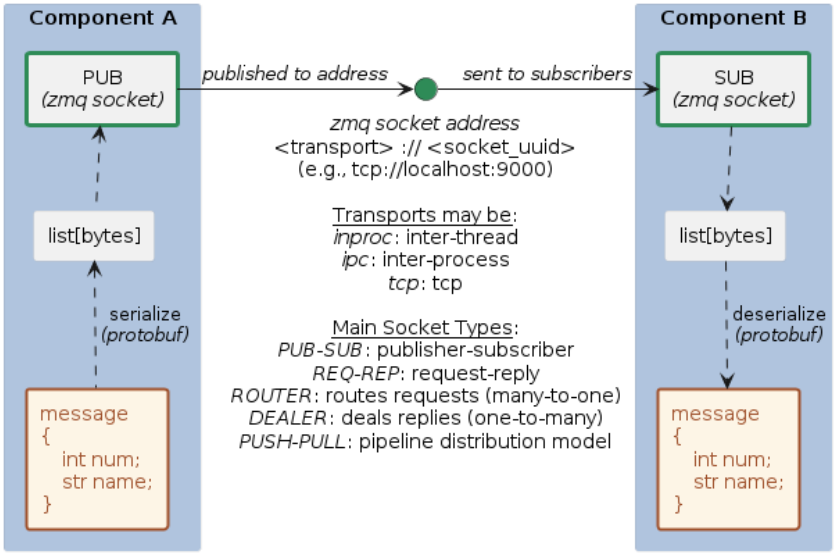

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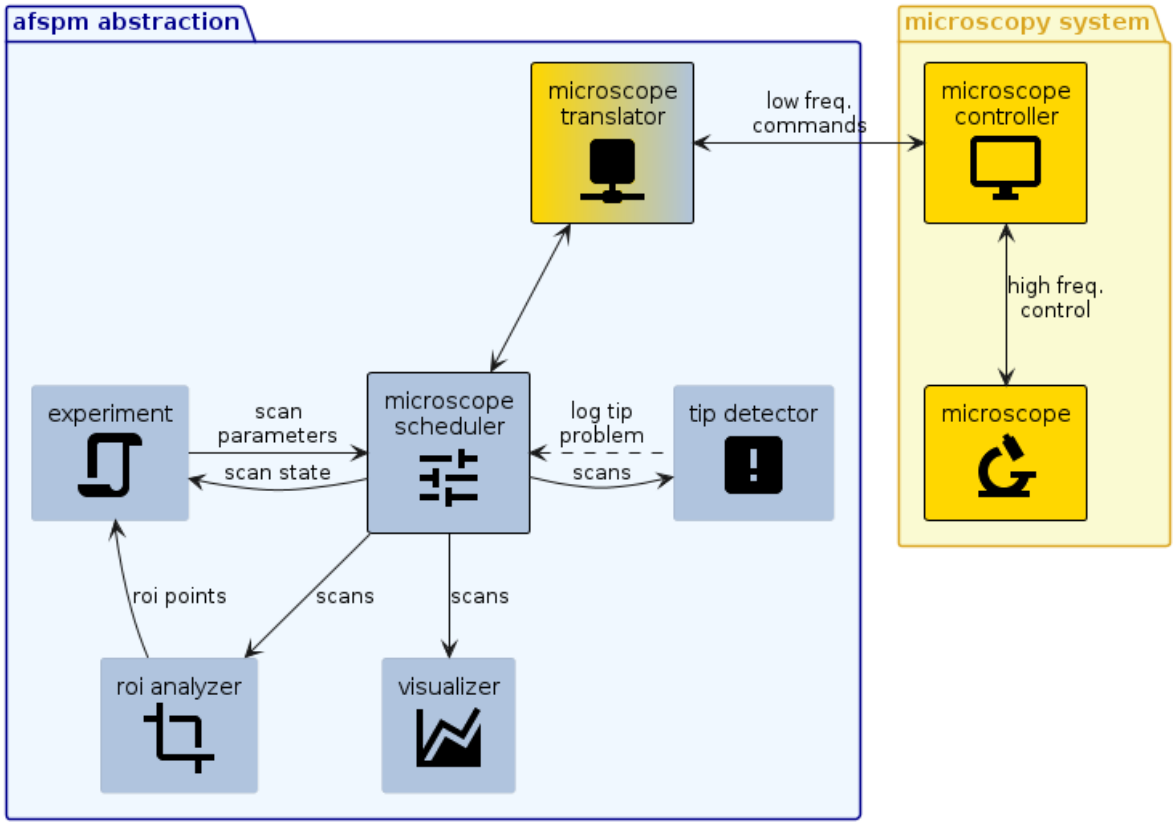
Data Transmission Protocol

Handles sending of data between 'sockets' via common 'nodes'.
`ZeroMQ`: abstracts away transports used, handles common roadblocks.

Example


afspm abstraction
microscopy system
microscope translator
low freq. commands
microscope controller
high freq. control
microscope
experiment
scan parameters
scan state
microscope scheduler
log tip problem
scans
tip detector
roi points
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scans
roi analyzer
visualizer

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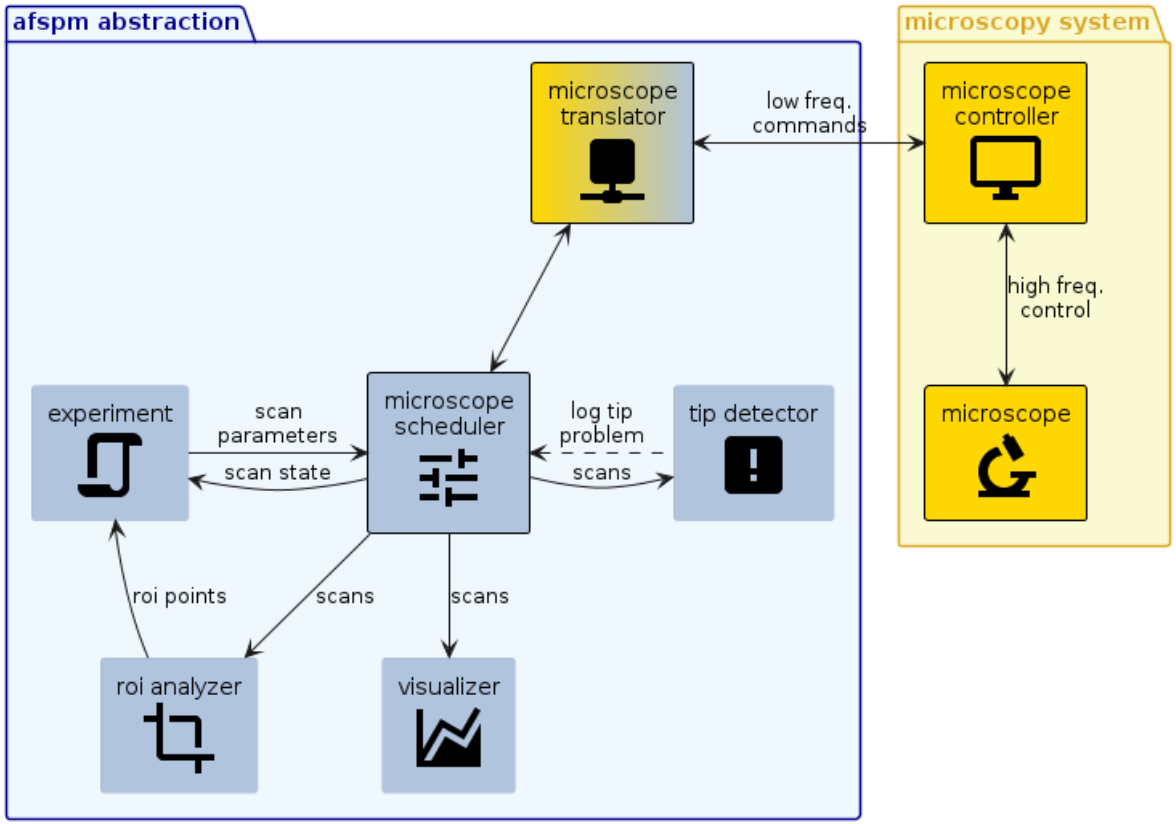

- **ROI Analyzer** reviews scans for interesting regions.
- **Experiment** switches between scanning a large region or a suggested ROI.
- **Tip Detector** evaluates the state of the tip, logs problem if deemed poor.
- **Visualizer** visualizes what is being scanned.

Our publisher-subscriber, control-request world

*We **subscribe** to events published by the SPM and **request** actions of it.*

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Publisher-Subscriber Path

- The SPM **publishes** messages types when its 'state' changes.
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- Messages may be **cached** by the Scheduler, to send to new components.

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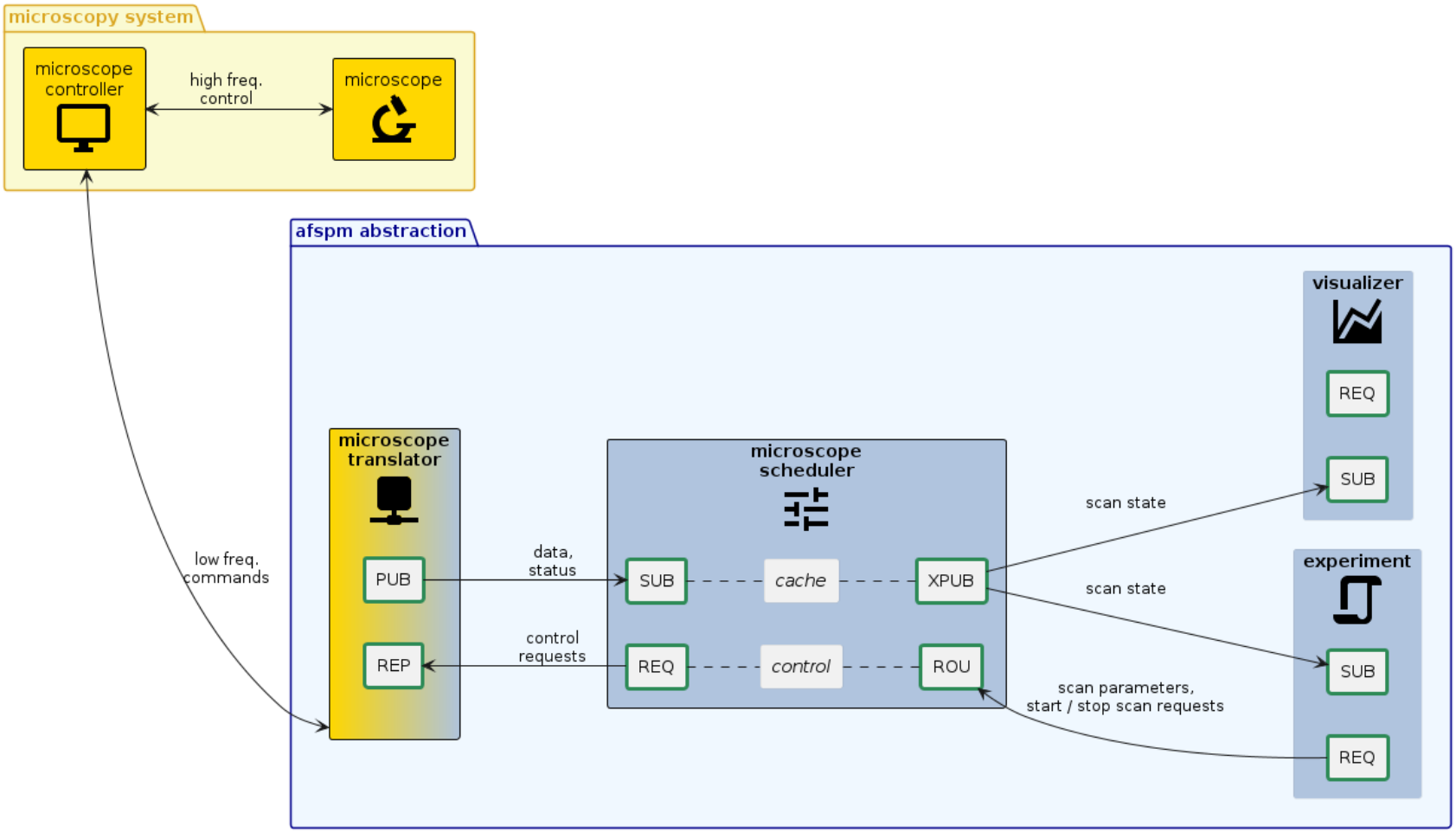
Control Path

- Components send **requests** to the SPM and receive **responses**.
- The Scheduler **routes** control to the SPM (one component at a time).
- Components not in control may flag **problems** – control is dropped.
  - A user may **manually** fix a problem and unflag the problem.
  - A component that **fixes** a flagged problem can grab control.

afspm: Detailed View



Publisher-Subscriber Path

```
message DataAspects {
  optional Size2u shape = 1;
  optional string units = 2;
}

message SpatialAspects {
  optional Rect2d roi = 1;
  optional string units = 2;
}

message ScanParameters2d {
  optional SpatialAspects spatial = 1;
  optional DataAspects data = 2;
}
```

2D Scan Parameters Schema

```
message Scan2d {
  optional ScanParameters2d params = 1;
  optional google.protobuf.Timestamp timestamp = 2;
  optional string channel = 3;
  optional string filename = 5;
  repeated double values = 4;
}
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2D Scan Schema

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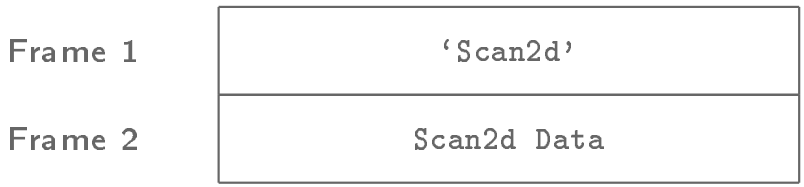

Message Format

Control Path

```
enum ControlRequest {
  REQ_UNDEFINED = 0;
  REQ_START_SCAN = 1;      // [...]
  REQ_REQUEST_CTRL = 4;    // [...]
  REQ_ADD_EXP_PRBLM = 6;   // [...]
  REQ_SET_CONTROL_MODE = 8;
}
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Control Request Schema

```
enum ControlResponse {
  REP_SUCCESS = 0;
  REP_FAILURE = 1;              // [...]
  REP_NO_RESPONSE = 3;          // [...]
  REP_NOT_FREE = 7;             // [...]
  REP_PARAM_NOT_SUPPORTED = 9; // [...]
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Control Response Schema

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Control Response Schema

```
enum ExperimentProblem {
  EP_NONE = 0;
  EP_TIP_SHAPE_CHANGED = 1;
  EP_DEVICE_MALFUNCTION = 2;
  EP_FEEDBACK_NON_OPTIMAL = 3;
}
```

Experiment Problem Schema

```
enum ControlMode {
  CM_UNDEFINED = 0;
  CM_MANUAL = 1;
  CM_AUTOMATED = 2;
  CM_PROBLEM = 3;
}
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Control Mode Schema

Control Path

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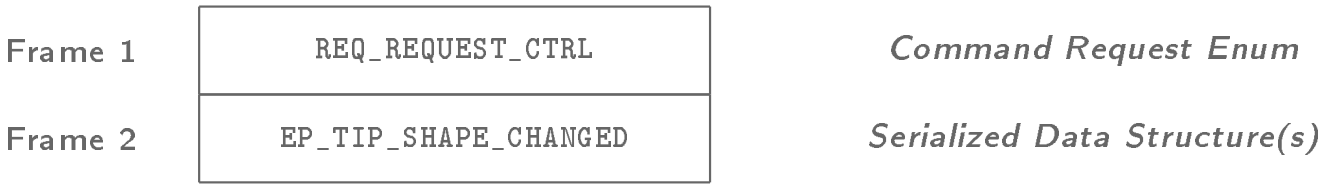

Message Format

Spawning, Monitoring, and the Config File

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- We can spawn different components on different computers.
  - The 'spawn' command allows indication of which components to spawn.

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Monitoring

- The parent process monitors spawned components for heartbeats.
- If a process has not 'beat' in a timeframe, it is killed and respawned.
- Then the caching logic chosen is important – must be able to run.

Sample Config File

```
# --- URLs --- #
pub_url = "tcp://127.0.0.1:9000"
psc_url = "tcp://127.0.0.1:9001"

server_url = "tcp://127.0.0.1:6666"
router_url = "tcp://127.0.0.1:6667"
# [...]
exp_scan_res = [256, 256]
# [...]
```

General Variables

```
# ----- PubSub ----- #
[translator_pub]
class = 'afspm.io.pubsub.publisher.Publisher'
url = 'pub_url'
# [...]
[experiment_sub]
class = 'afspm.io.pubsub.subscriber.Subscriber'
sub_url = 'psc_url'
# [...]
```

Intermediary Classes

```
[translator]
component = true
class = 'afspm.components.microscope.translators.gxsm.translator.GxsmTranslator'
publisher = 'translator_pub'
control_server = 'translator_server'
# [...]
```

Config Components

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Custom Messages

- Any user may create custom messages or expand existing ones.

The End

Let us know what you think and help us make it better.

afspm on github