

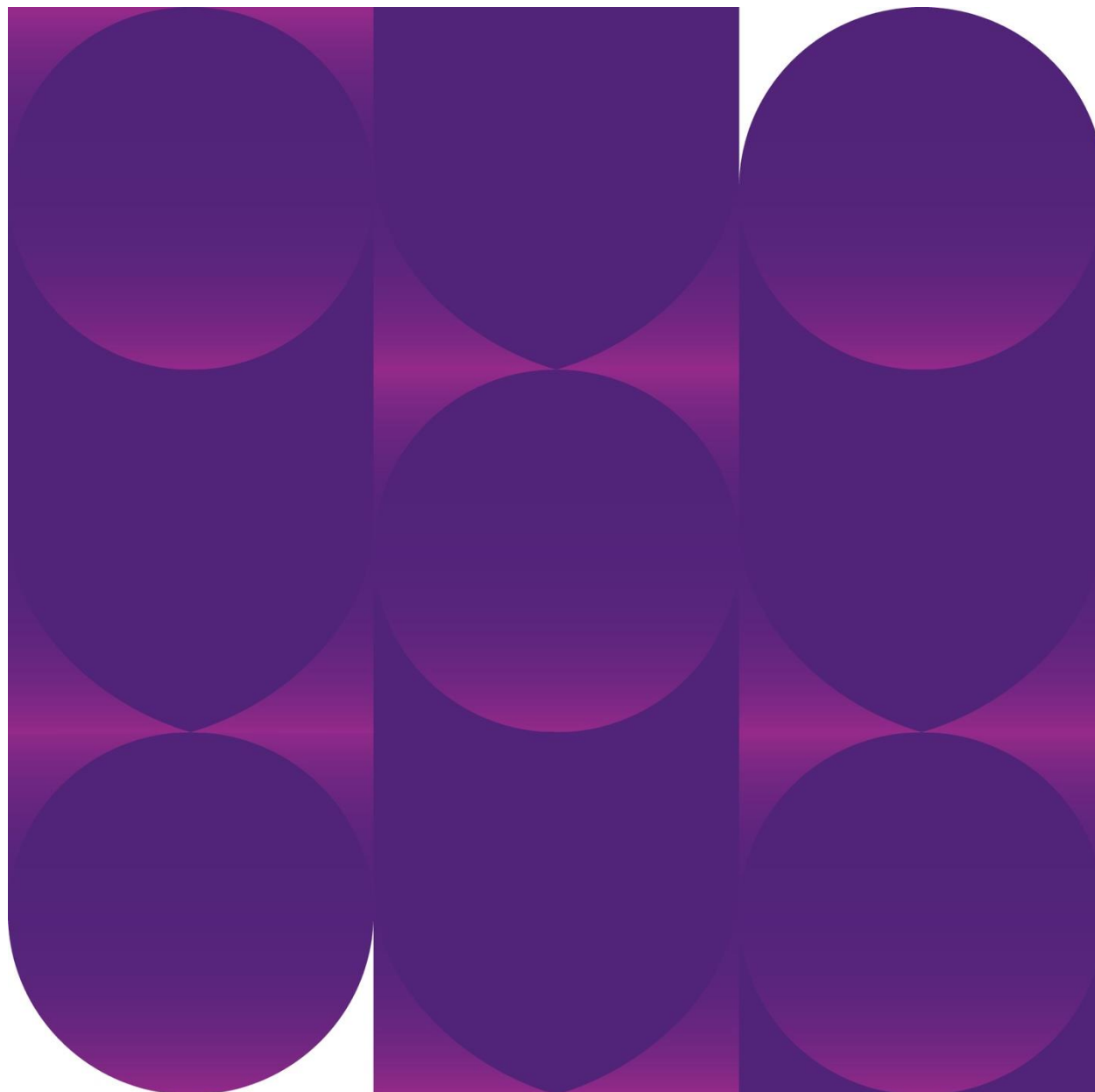
IROS 2026 Workshop on Intelligent Information
Gathering for Single and Multi-Robot Systems

We need to talk: Effective communication for collaborative MRS

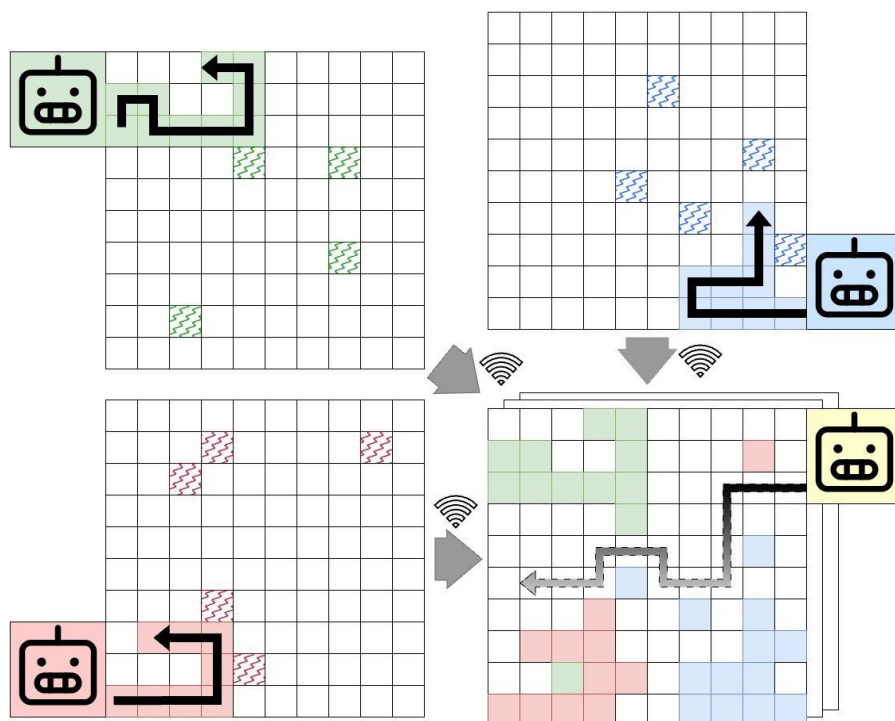
Jen Jen Chung

Nicholas Smith, Graeme Best

27 September 2026

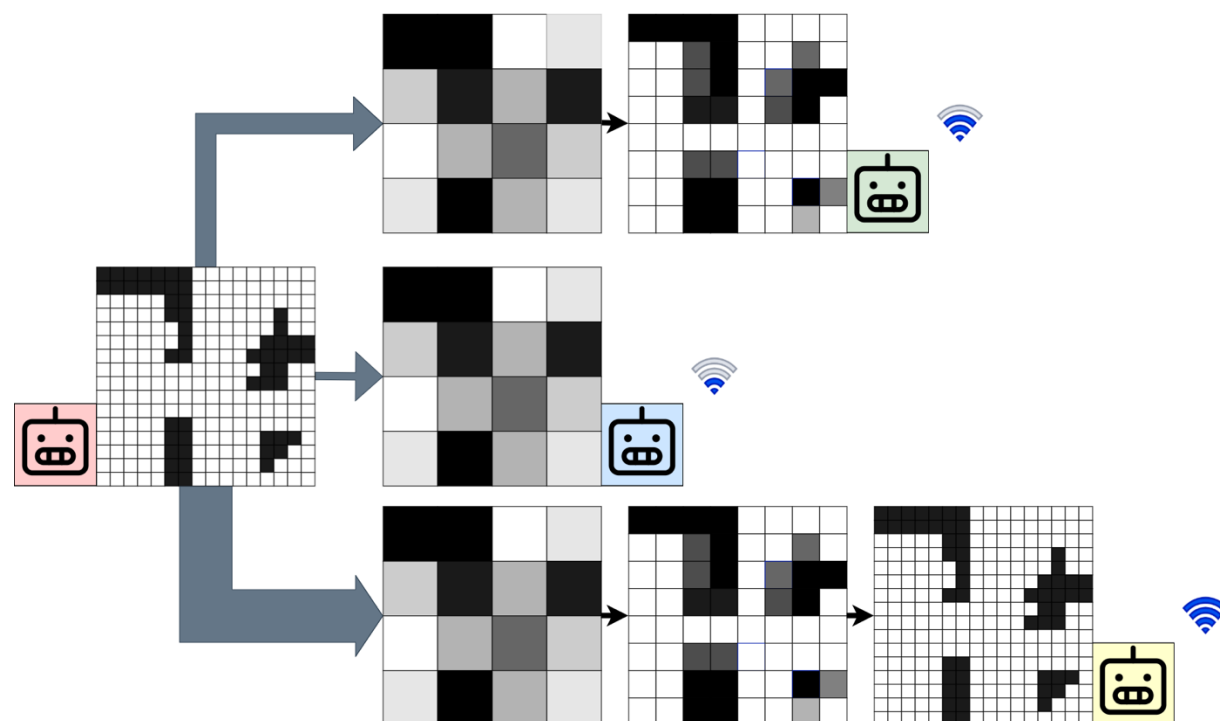


Resilient compression



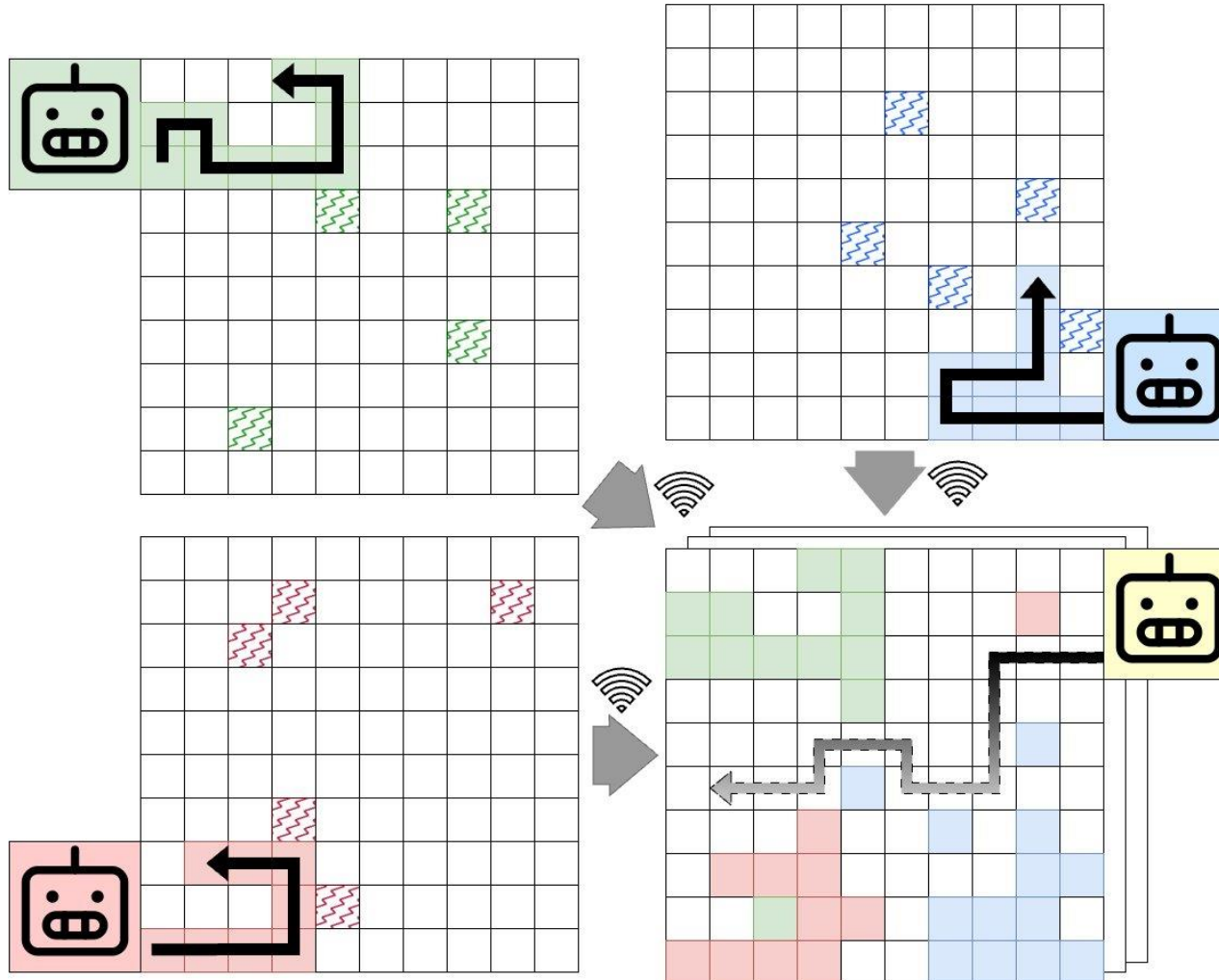
Smith et al., ICRA2026

Efficient streaming



Smith et al., under review

Collaborative exploration



Task:

- Efficient coverage with minimal overlap
- Distributed decision making
- Share observed map information

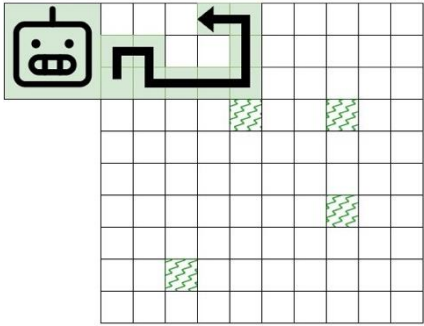
Challenge:

- Bandwidth limitations
- Network dropout

Insight:

- Treat grid maps as discrete sets
- Exploration as (approximate) set membership query

Encoding sets with Bloom filters

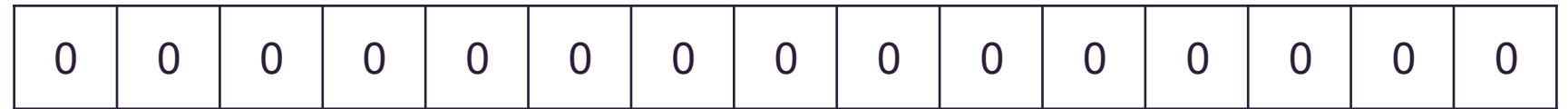


(0,7)

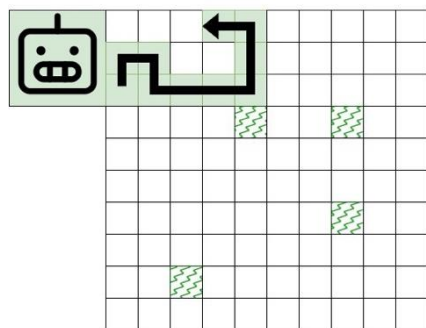
(0,8)

(1,7)

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-
-



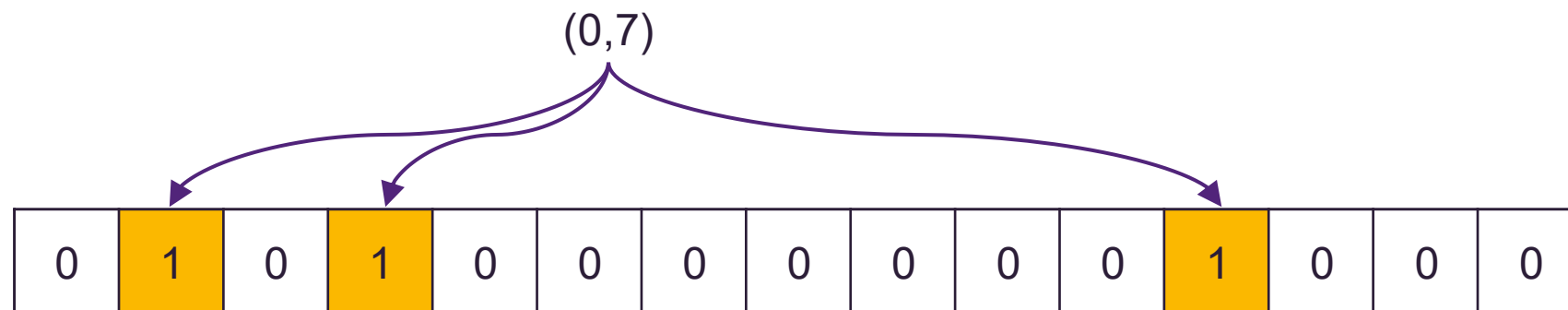
Encoding sets with Bloom filters



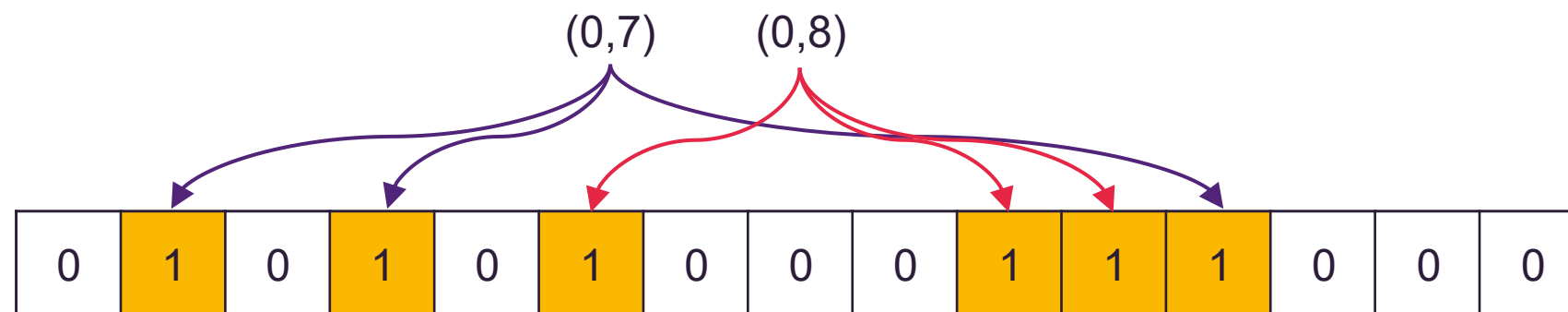
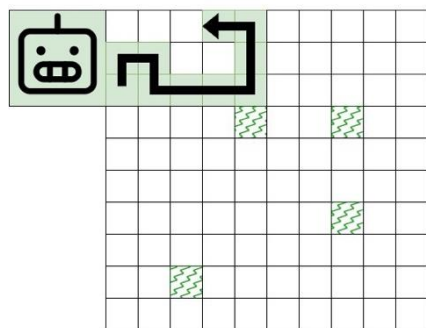
(0,8)

(1,7)

⋮

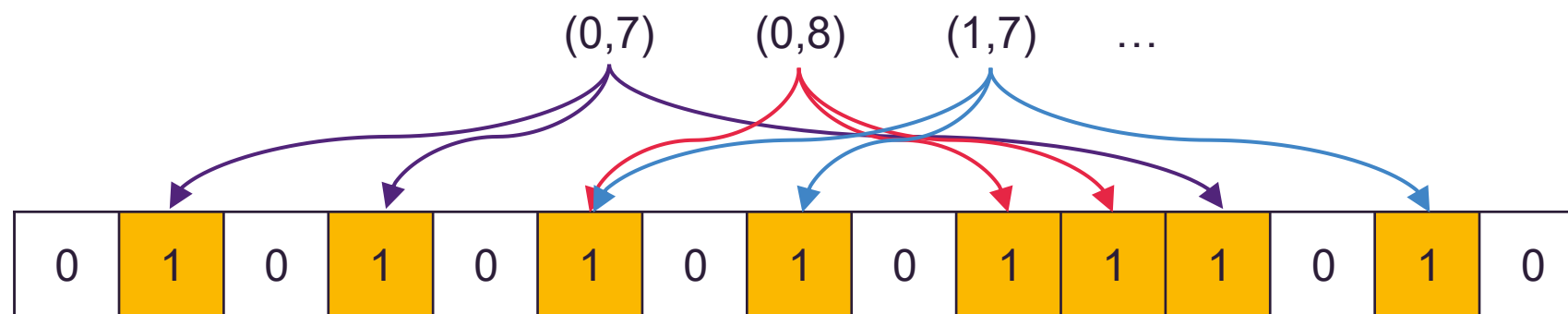
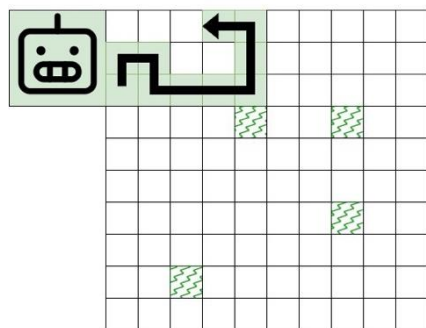


Encoding sets with Bloom filters

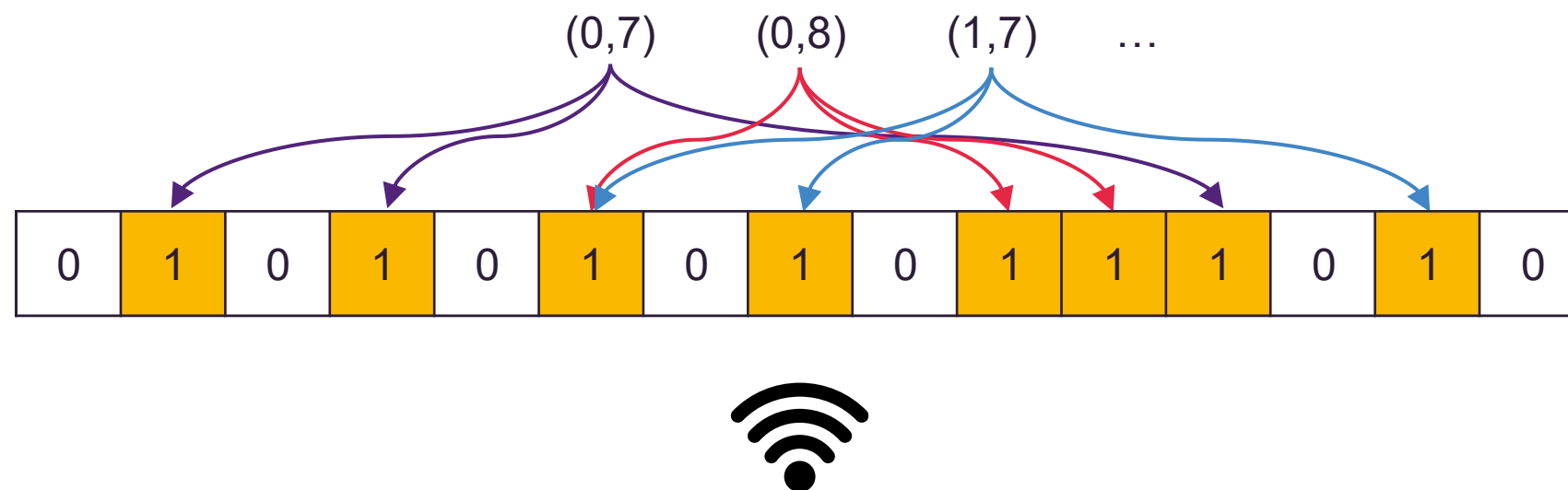
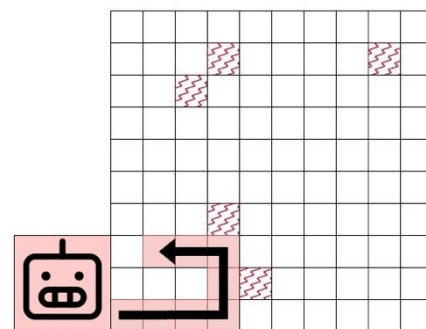
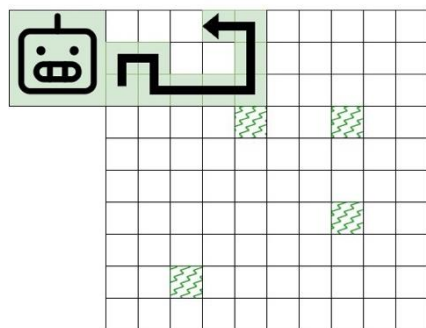


(1,7)
⋮

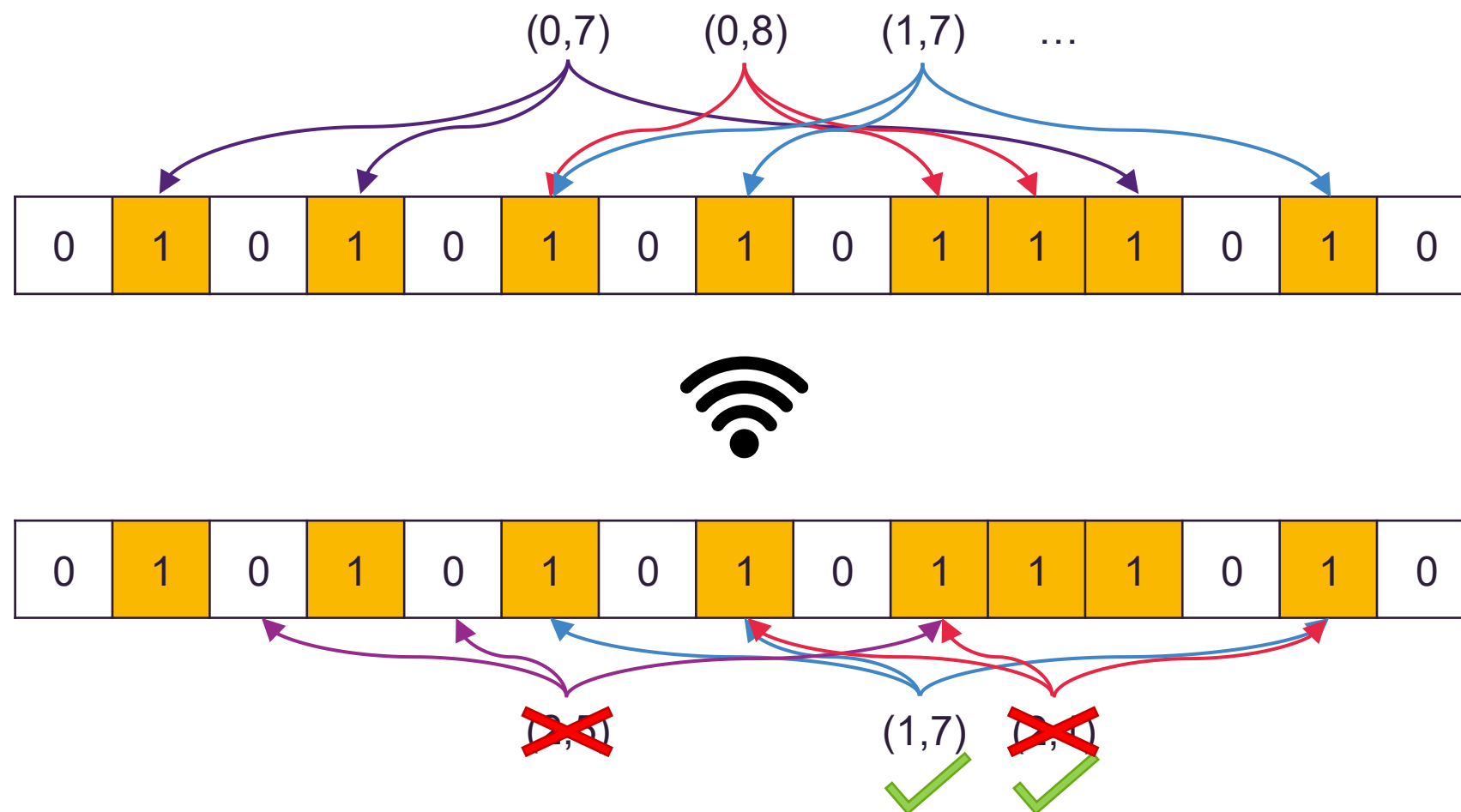
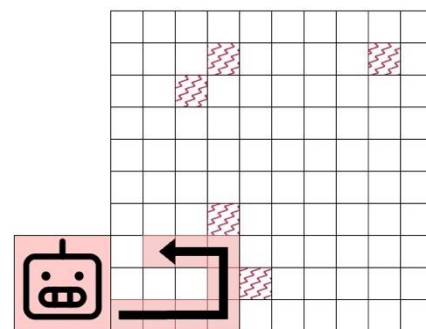
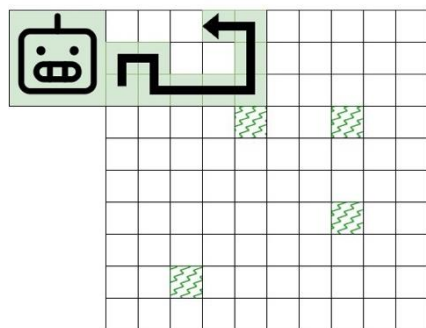
Encoding sets with Bloom filters



Encoding sets with Bloom filters

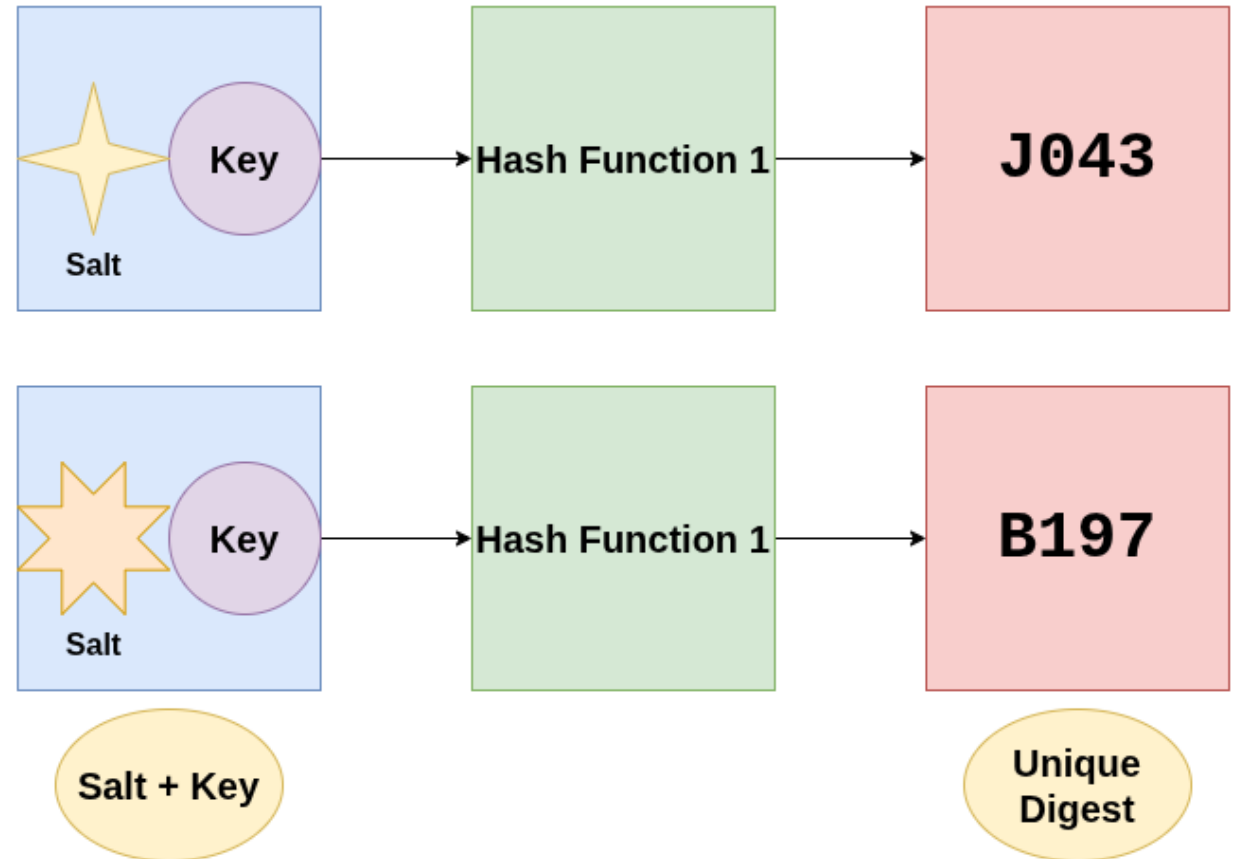


Encoding sets with Bloom filters



Salting: Making Bloom filters unique

- **Problem:** Hash functions are deterministic
- **Solution:** *Salting*
 - Add a known random value to input
 - Communicate salt value
- **Result:**
 - Decorrelates Bloom filters
 - Enables *Stacking*

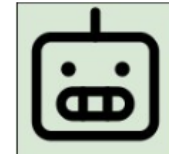


Stacking: Accumulating evidence

- **Problem:** Filters have false positives
- **Solution:** *Stacking*
 - Query across multiple independent Bloom filters
 - Compute likelihood of true positive
- **Result:**
 - Corroborated observations
 - Confidence thresholding

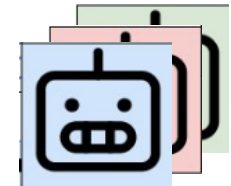
$$P_{obs_q} = \begin{cases} 0, & \text{if query returns negative,} \\ 1 - (e_{FPR})^{d_q}, & \text{otherwise,} \end{cases}$$

One robot

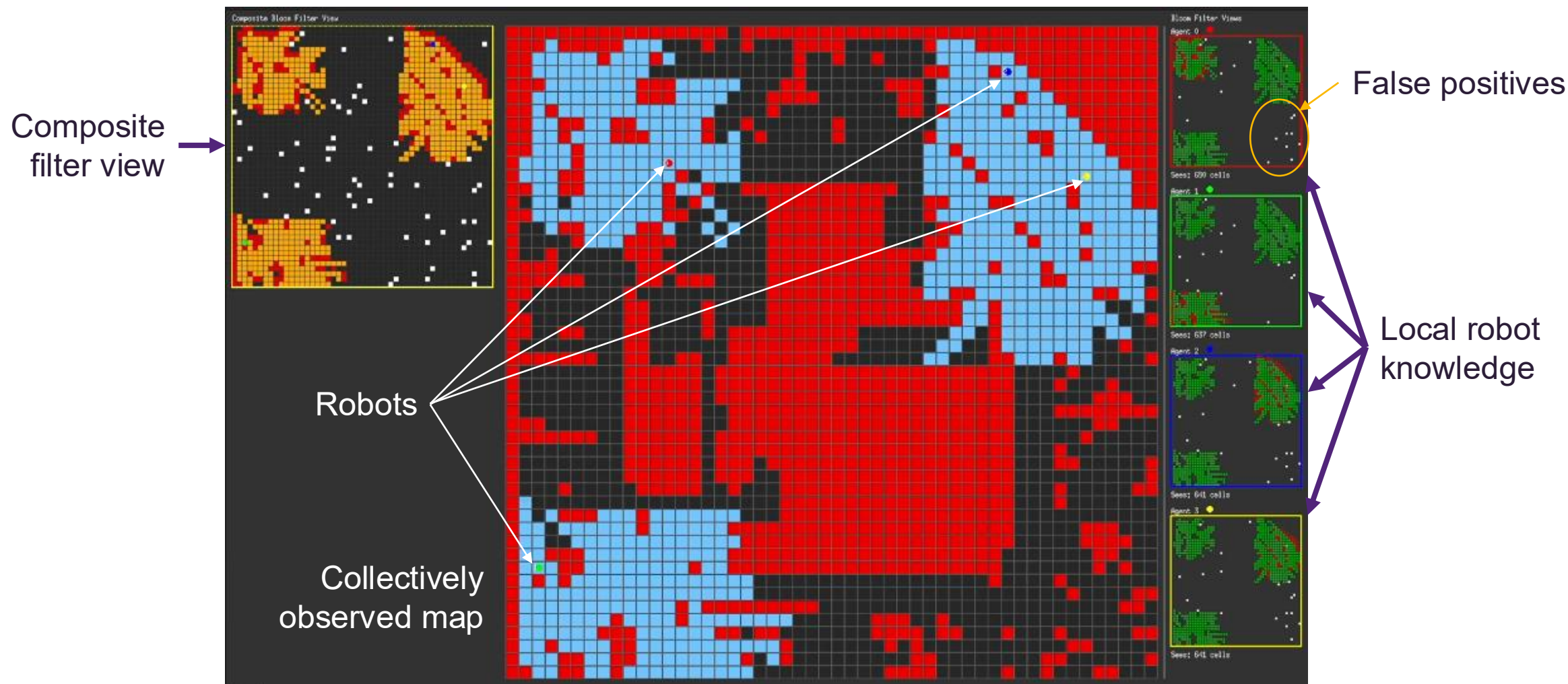


$$P_{obs} = 1 - \prod_{q \in \mathcal{R} \setminus r} (1 - P_{obs_q}) .$$

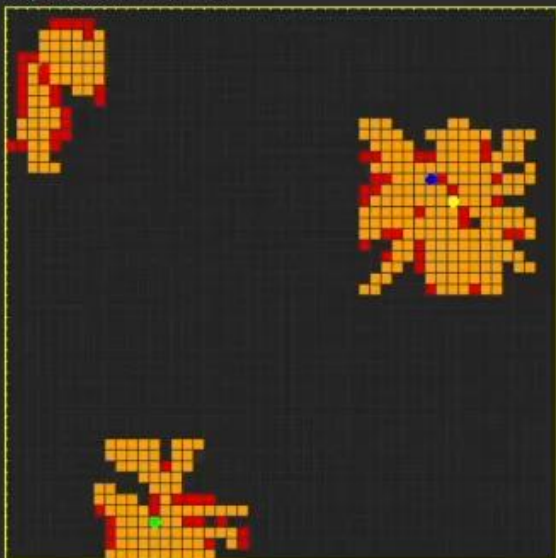
Multiple robots



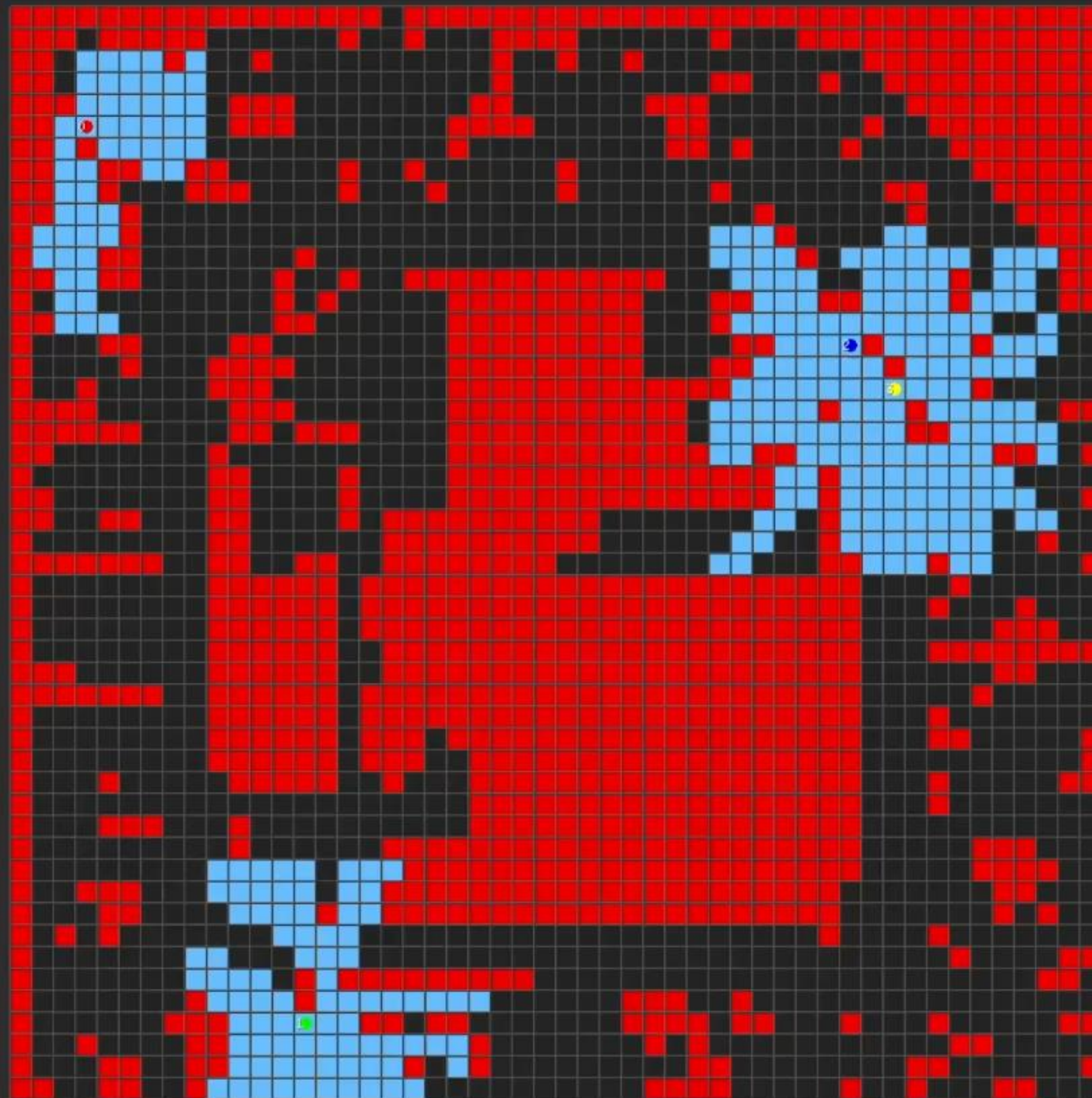
Collaborative exploration with Bloom filters



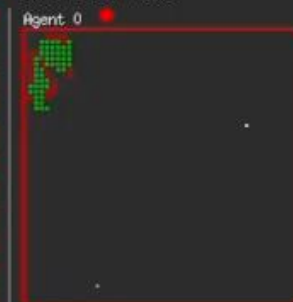
Composite Bloom Filter View



FP rate: 0.01



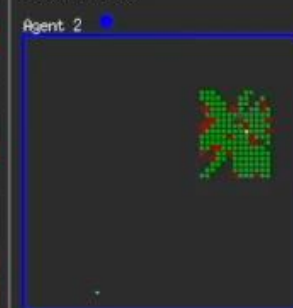
Bloom Filter Views



Sees: 53 cells



Sees: 83 cells

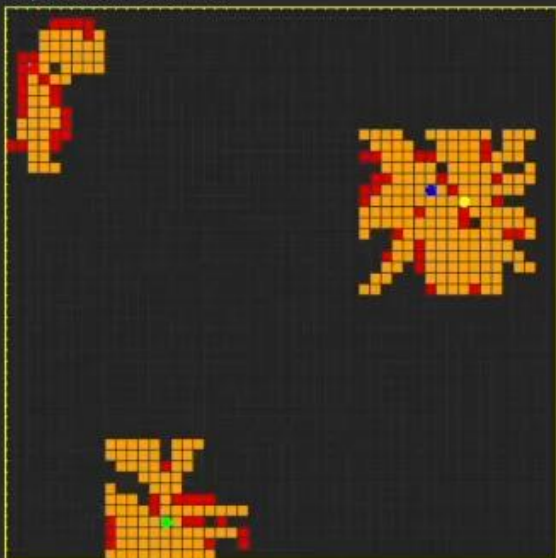


Sees: 141 cells

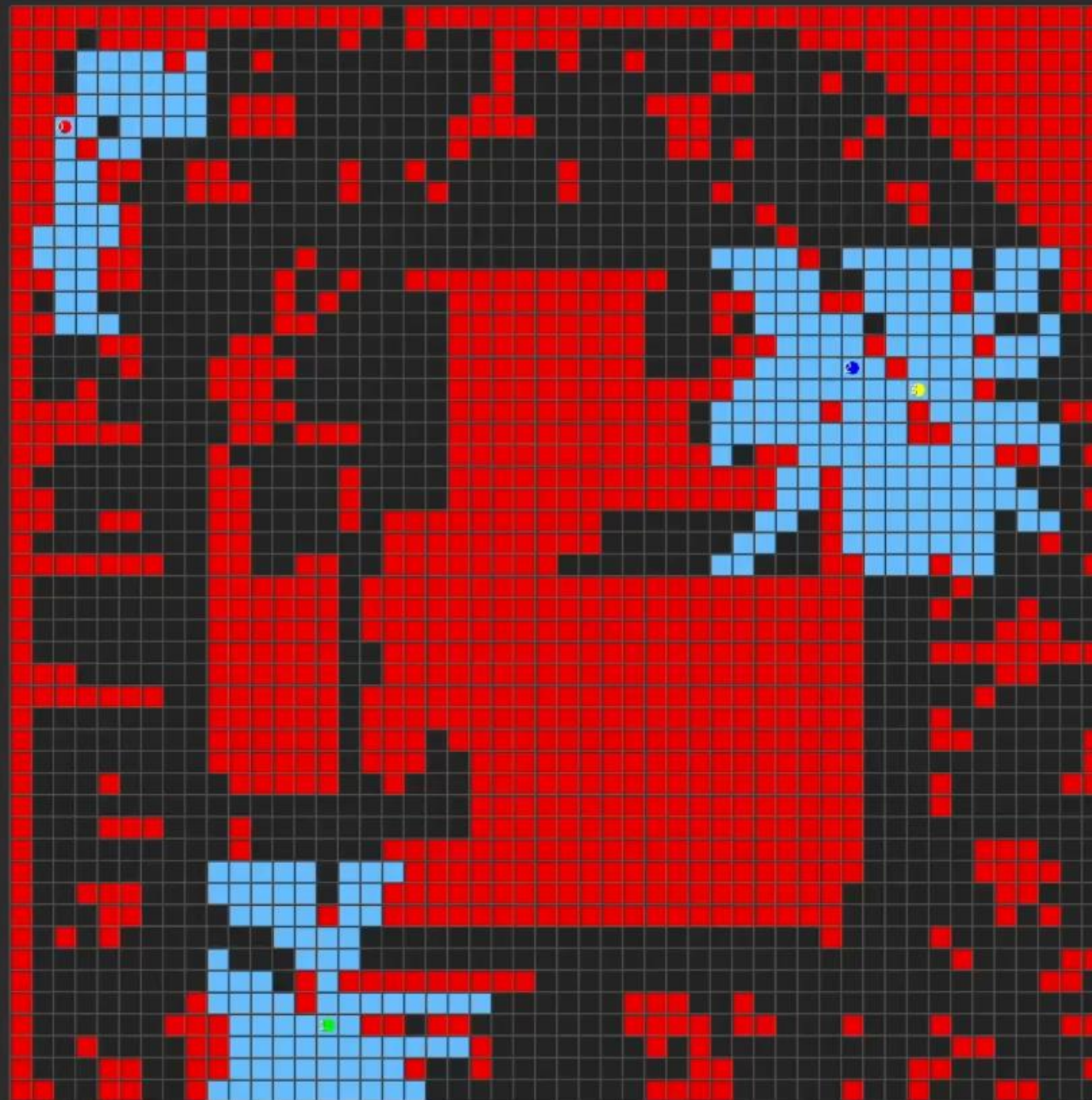


Sees: 117 cells

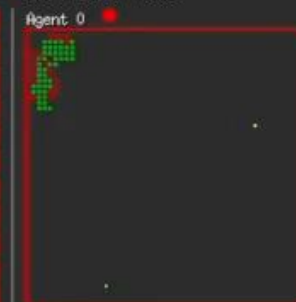
Composite Bloom Filter View



FP rate: 0.10



Bloom Filter Views



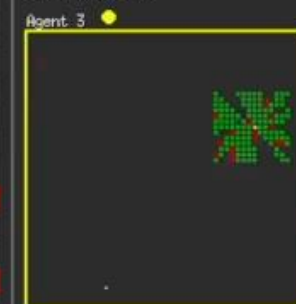
Sees: 47 cells



Sees: 80 cells



Sees: 126 cells

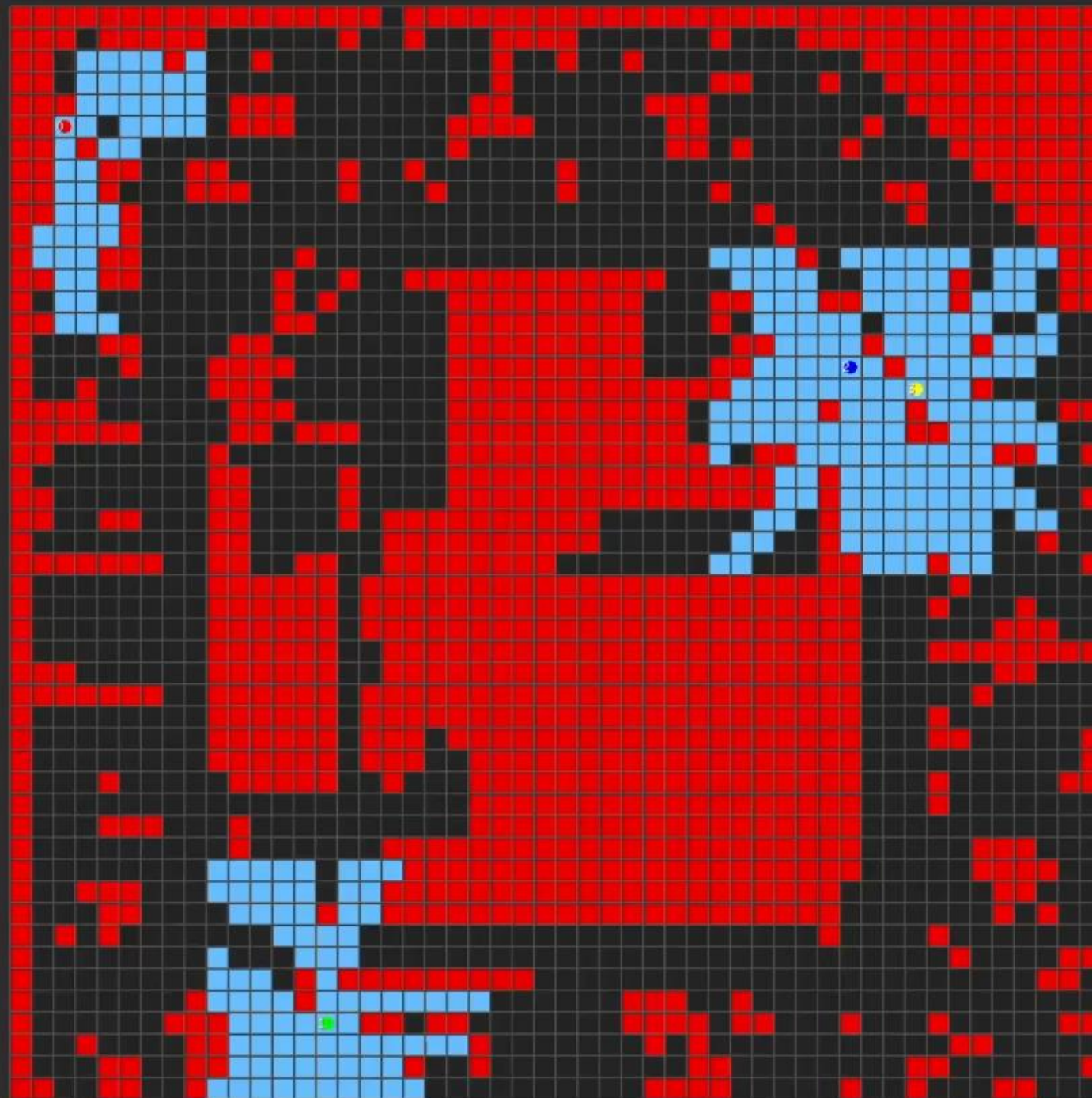


Sees: 117 cells

Composite Bloom Filter View



FP rate: 0.50



Bloom Filter Views



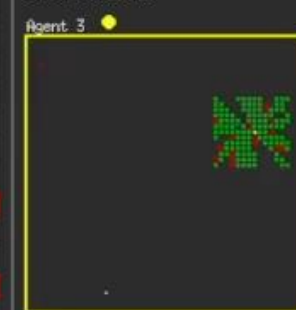
Sees: 47 cells



Sees: 80 cells



Sees: 126 cells

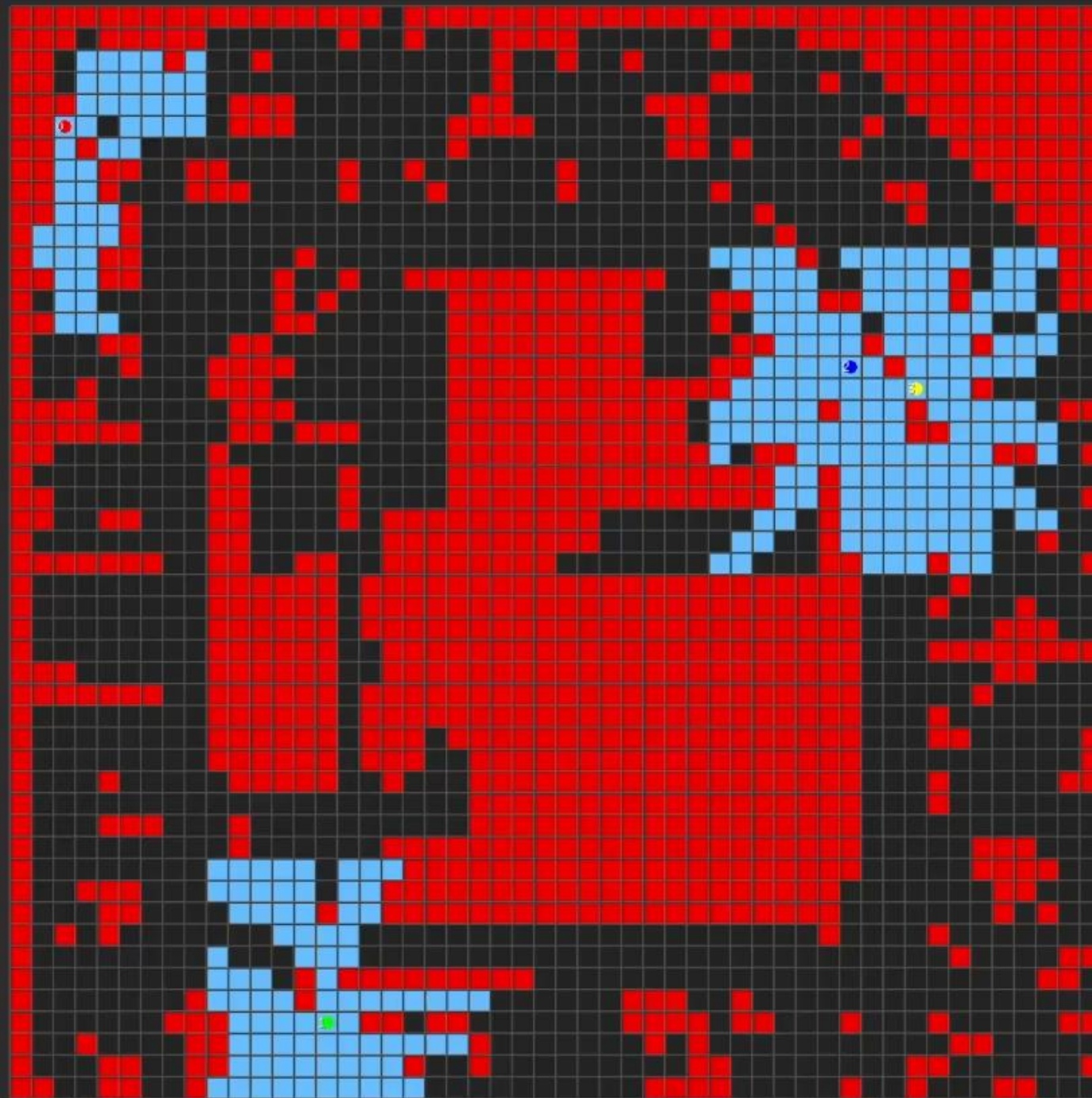


Sees: 117 cells

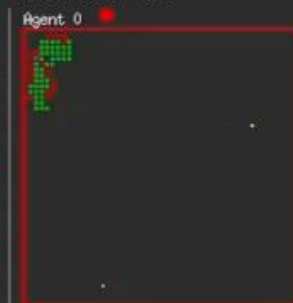
Composite Bloom Filter View



FP rate: 0.90



Bloom Filter Views



Sees: 47 cells



Sees: 80 cells



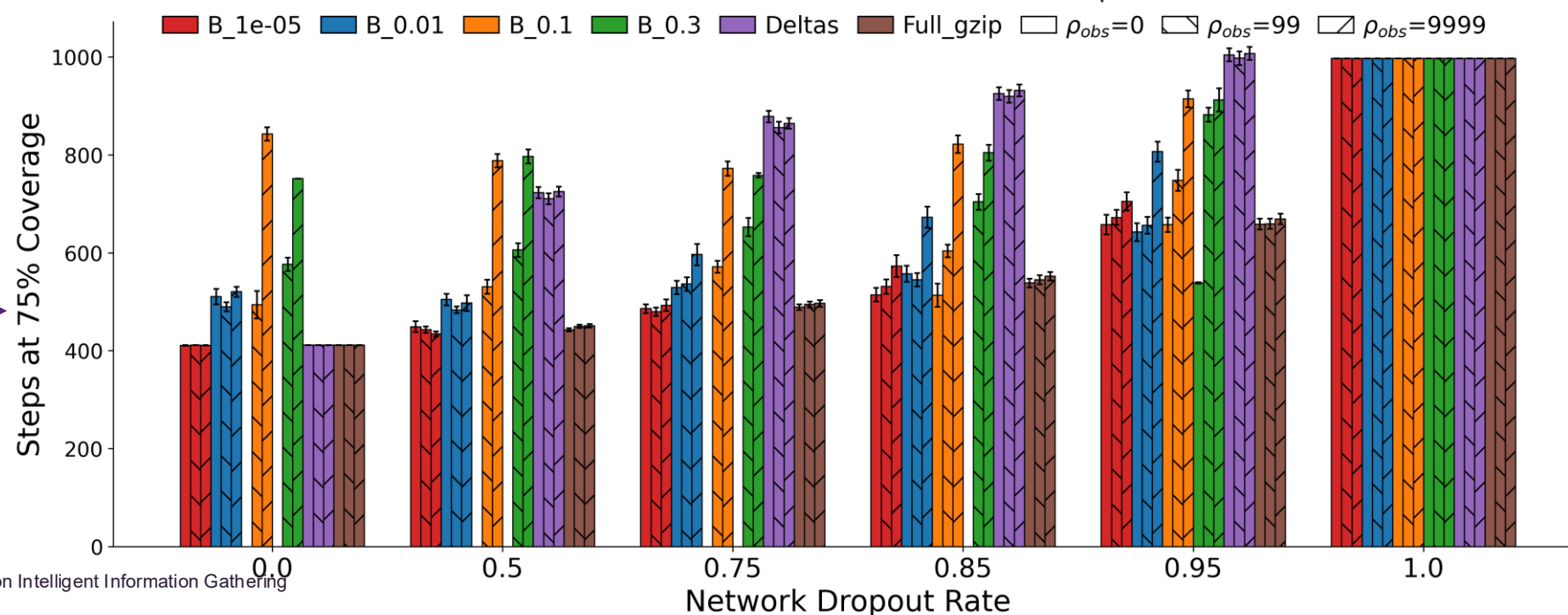
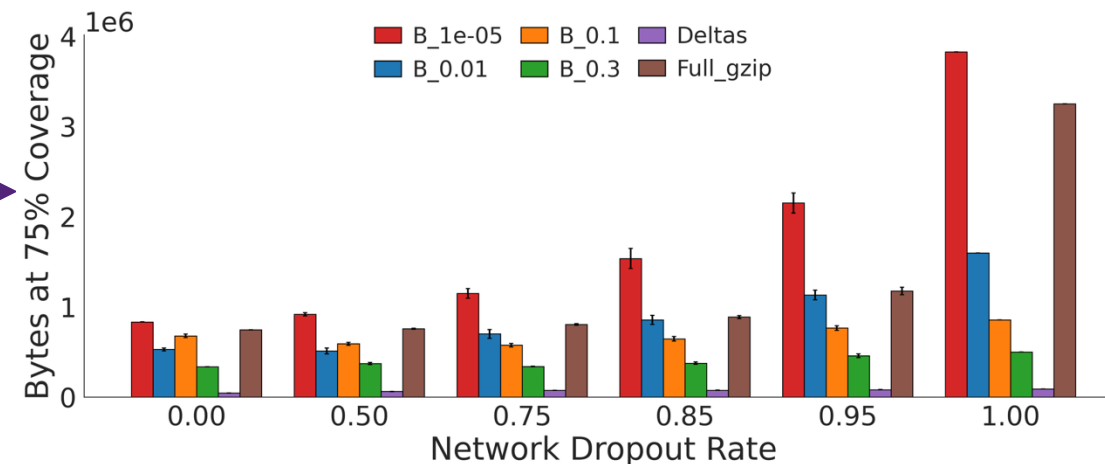
Sees: 126 cells



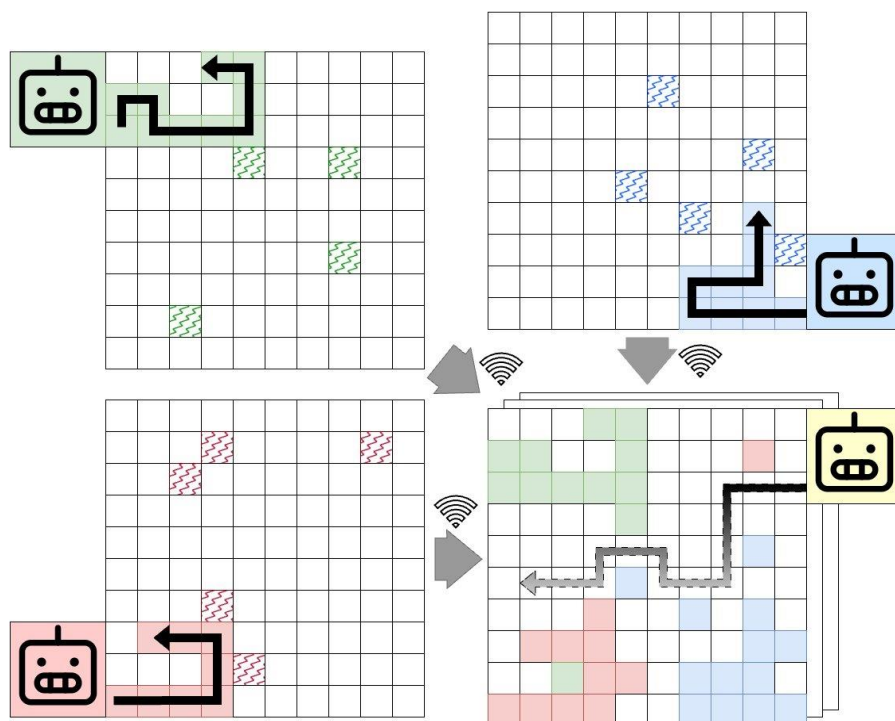
Sees: 117 cells

System resilience to dropout

Trade off **bandwidth requirements**
against **exploration speed**

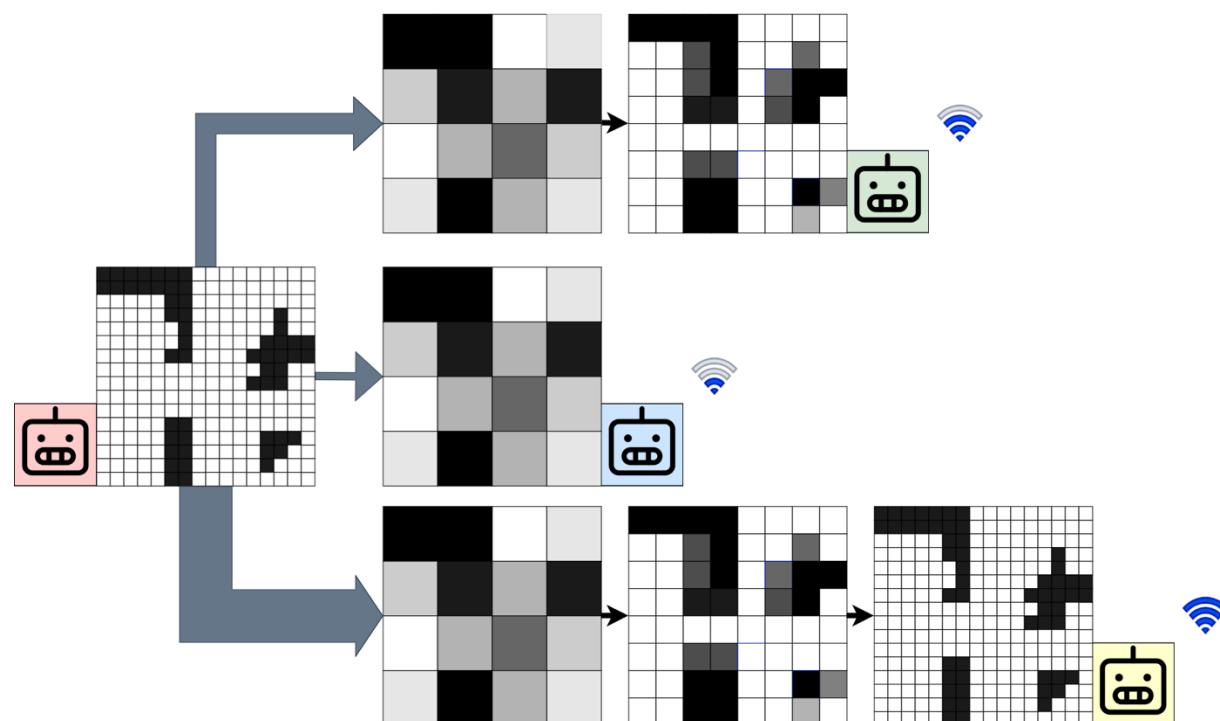


Resilient compression



Smith et al., ICRA2026

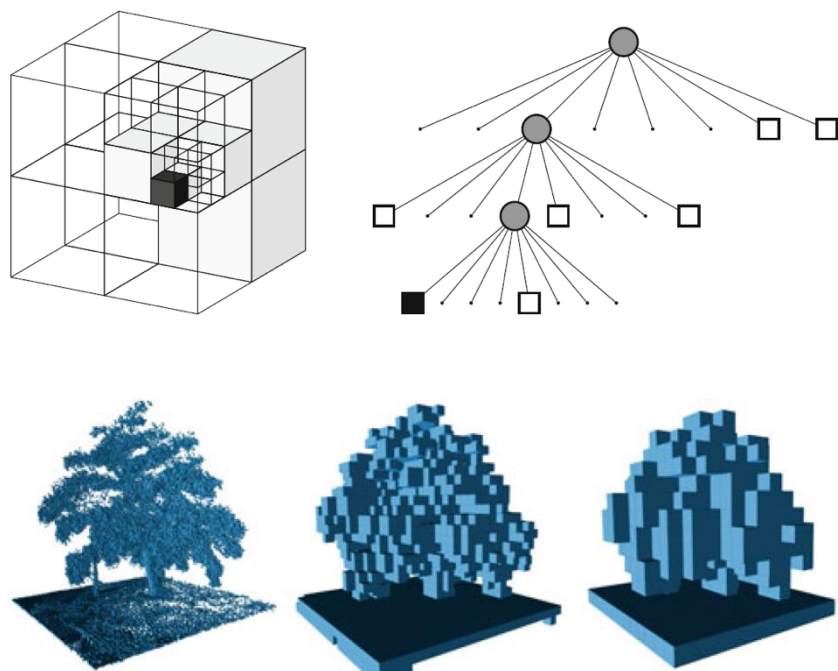
Efficient streaming



Smith et al., under review

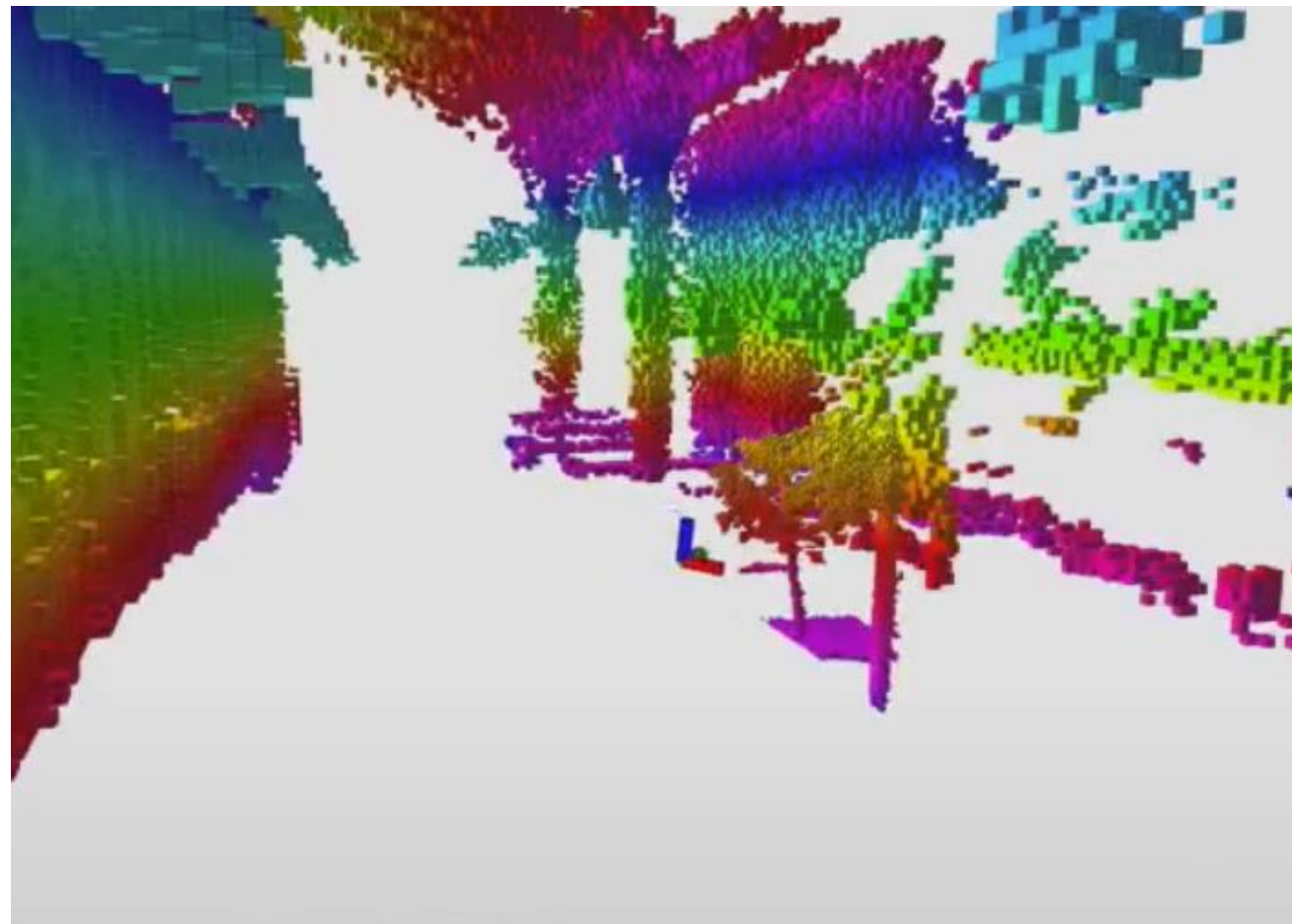
Multi-resolution map representations

Octomap



Hornung et al., AuRo2013

Wavemap



Reijgwart et al., RSS2023

Wavestream progressive level of detail

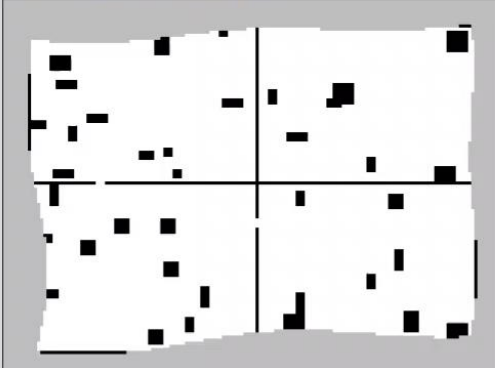
vxch visual test

1. Synthetic map
Width Height Seed

2. Encode with vxch
Haar levels Tile size (cells) Compression

3. Send bands over a simulated link
Bandwidth (kbps)

Sender -- ground truth map



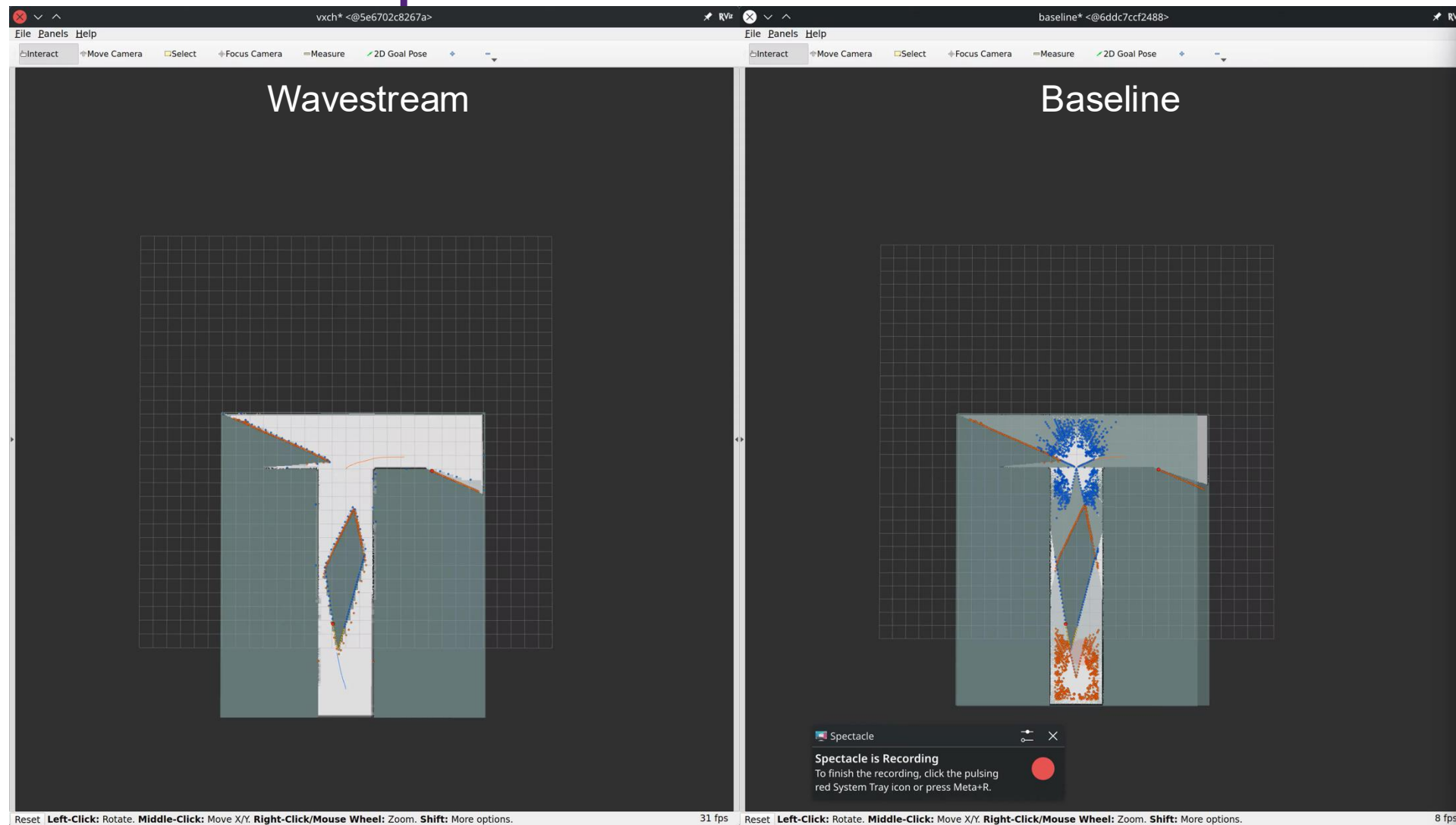
Receiver -- reconstruction so far



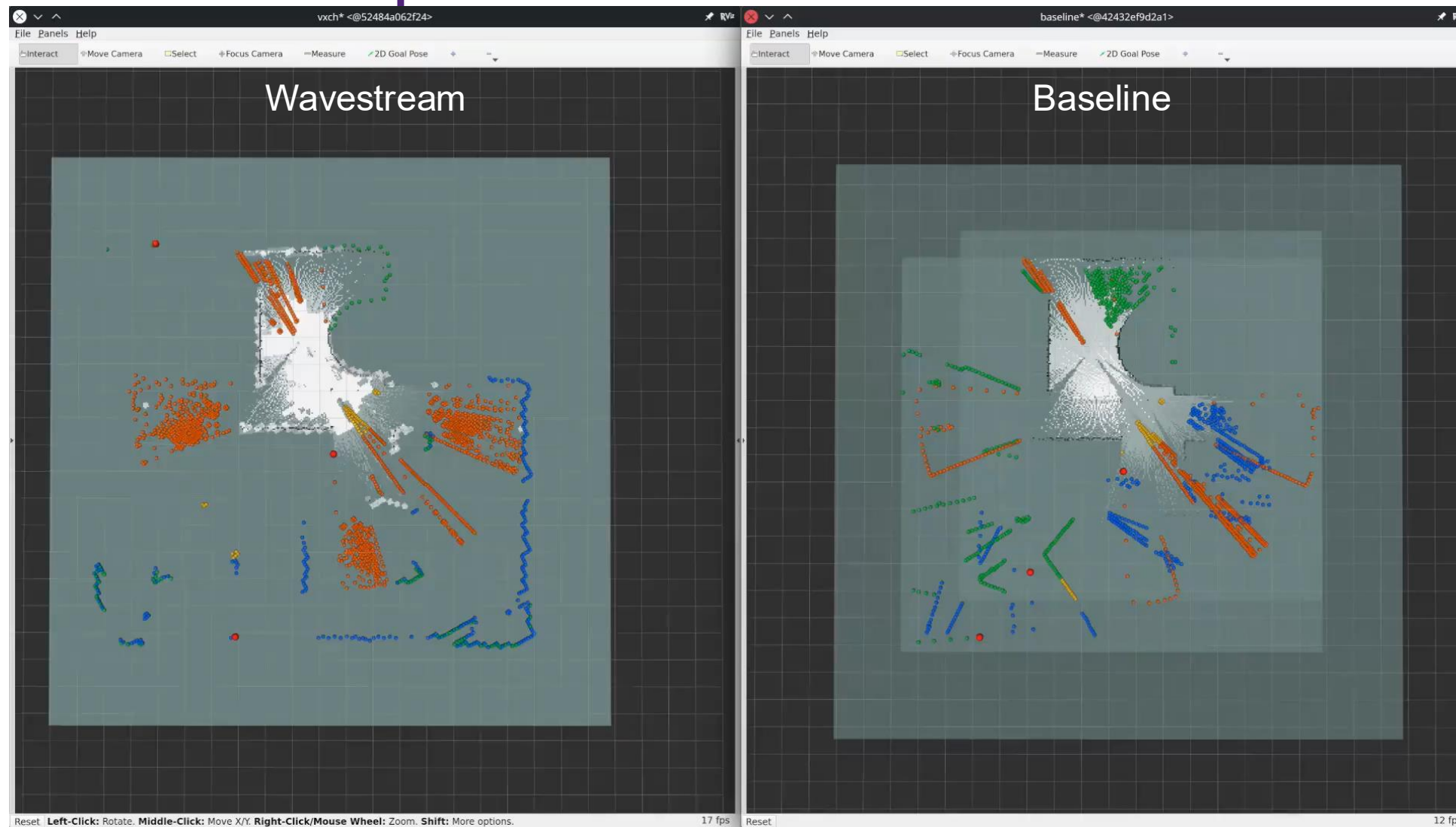
Sent 0/120 bands (0 B / 4.4 KB of encoded traffic, raw map = 18.8 KB, full vxch stream = 24% of raw)

```
tile(0,0) detail band 8: 416 B compressed (911 B raw) delivered after 3328 ms @ 1 kbps
tile(0,0) detail band 9: 589 B compressed (3.5 KB raw) delivered after 4712 ms @ 1 kbps
tile(0,0) detail band 10: 753 B compressed (14.4 KB raw) delivered after 6024 ms @ 1 kbps
Generated 160x120 map: 14208 free, 1127 occupied, 3865 unknown cells.
Encoded 20 tiles x 6 bands = 120 band messages queued. Full stream = 4.4 KB vs 18.8 KB raw (23%).
Generated 160x120 map: 13003 free, 1119 occupied, 5078 unknown cells.
Encoded 20 tiles x 6 bands = 120 band messages queued. Full stream = 4.4 KB vs 18.8 KB raw (24%).
```

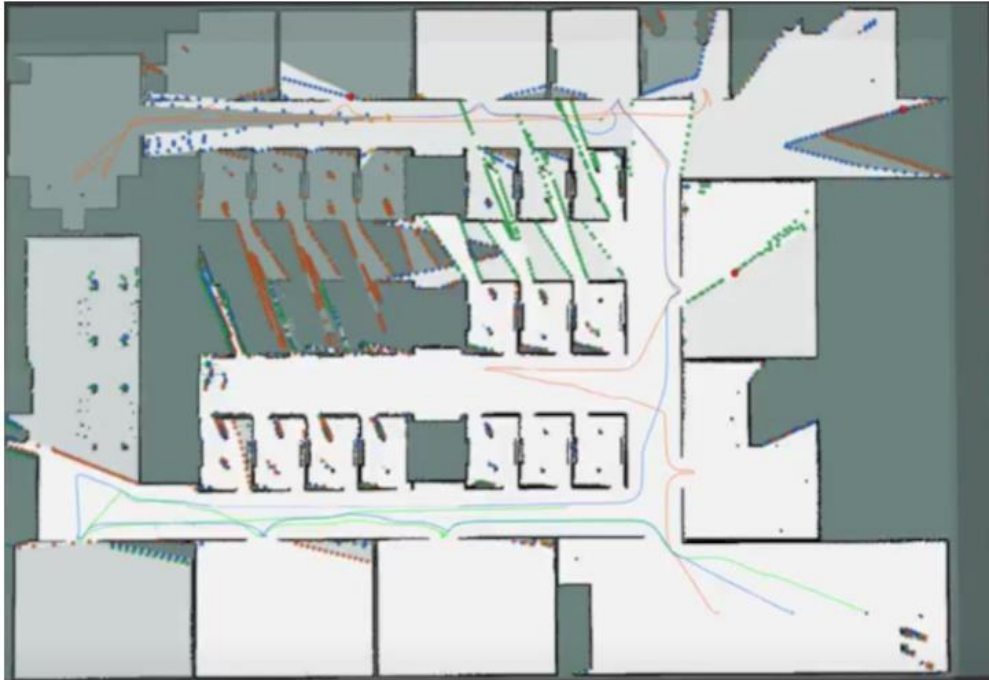
Collaborative exploration with Wavestream



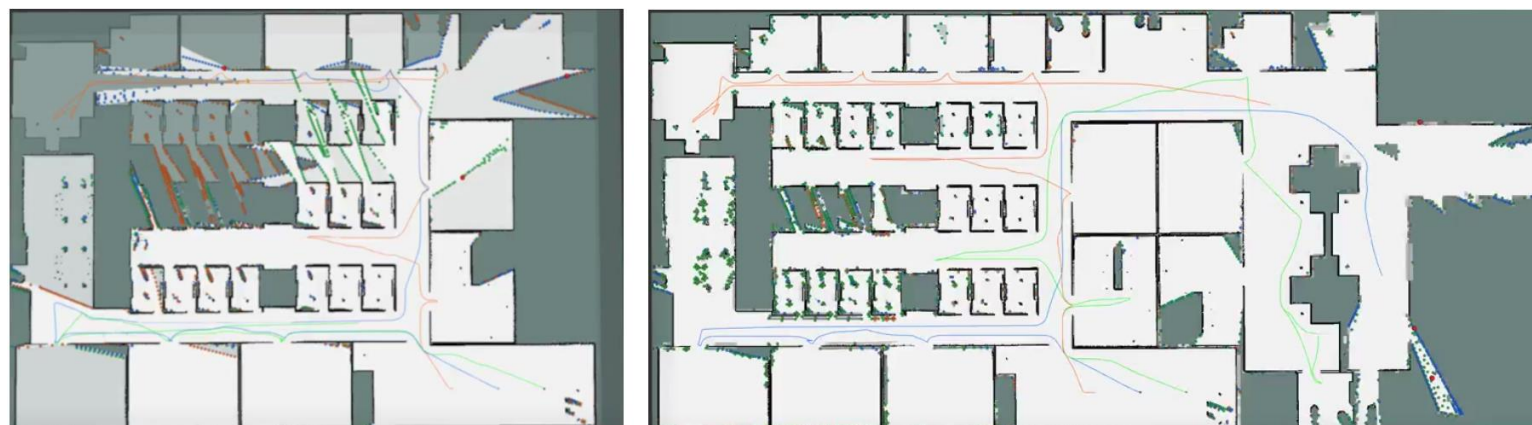
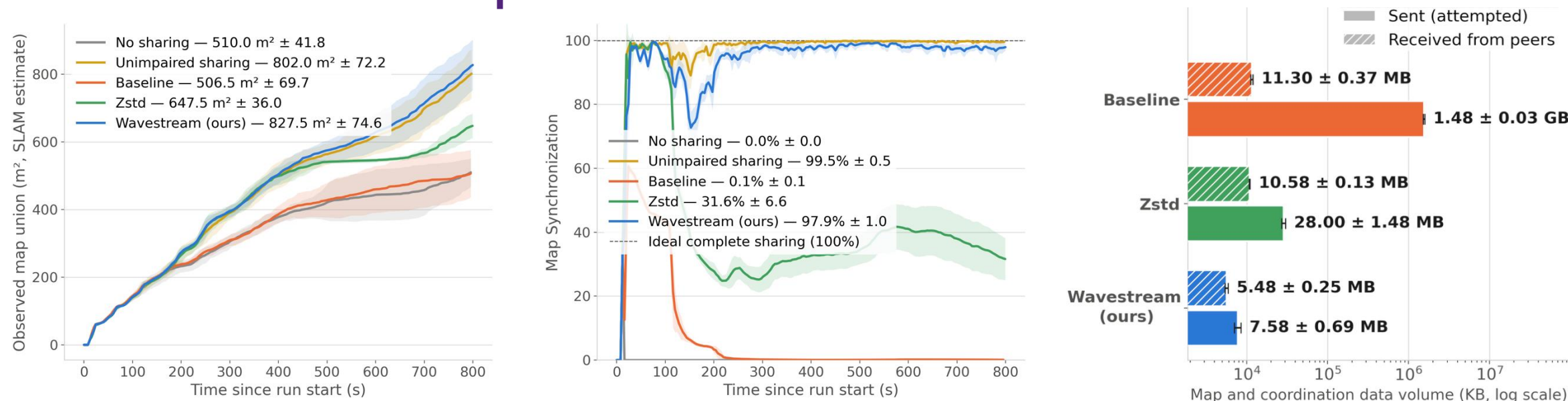
Collaborative exploration with Wavestream



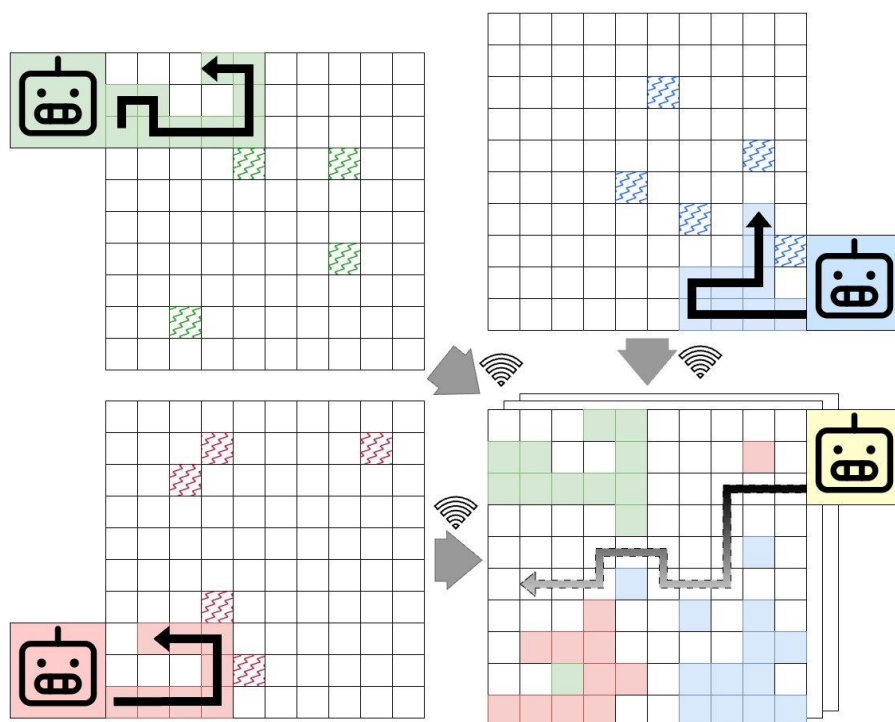
Collaborative exploration with Wavestream



Communication performance

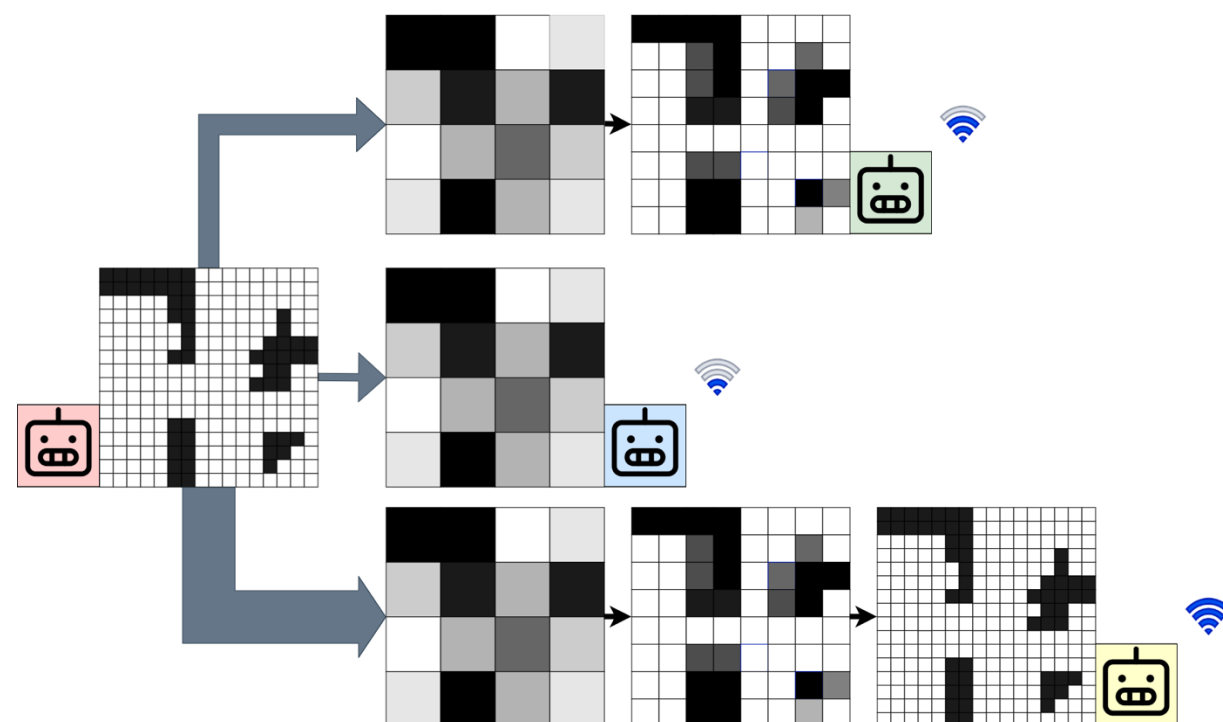


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