

Grid Cell-Inspired Fragmentation and Recall for Efficient Map Building



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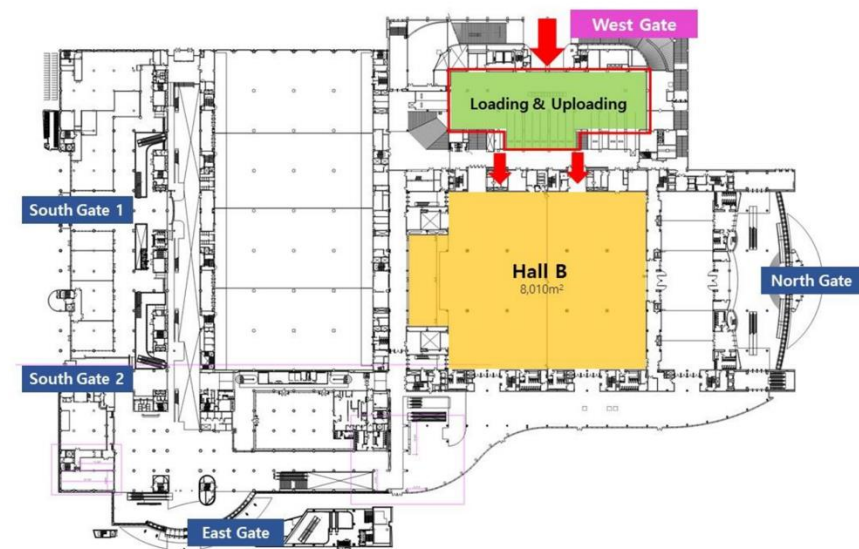
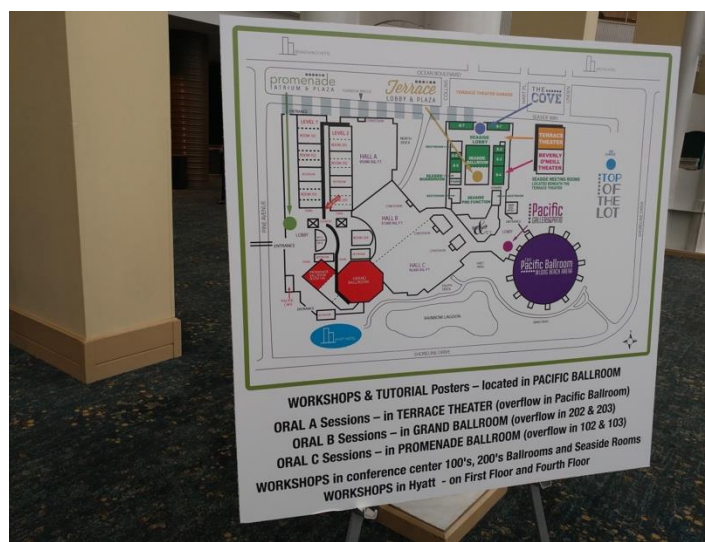


Pulkit Agrawal

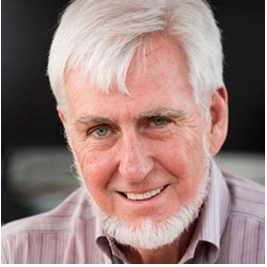


Ila Fiete

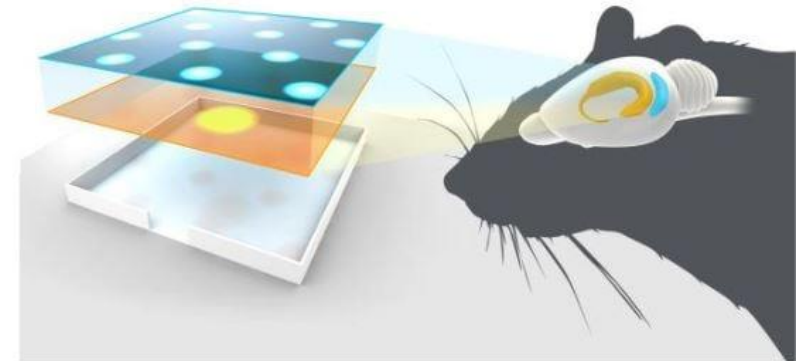
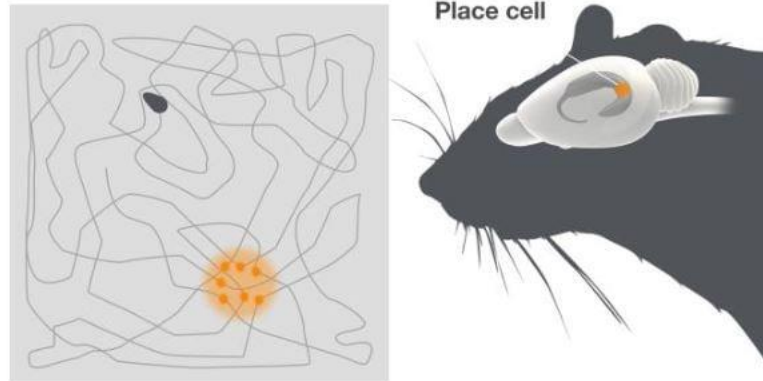
Conferences are held in various locations and usually very complex



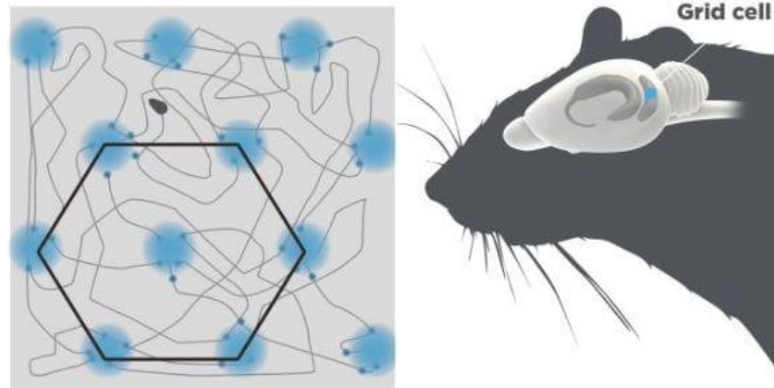
Place Cell and Grid Cell



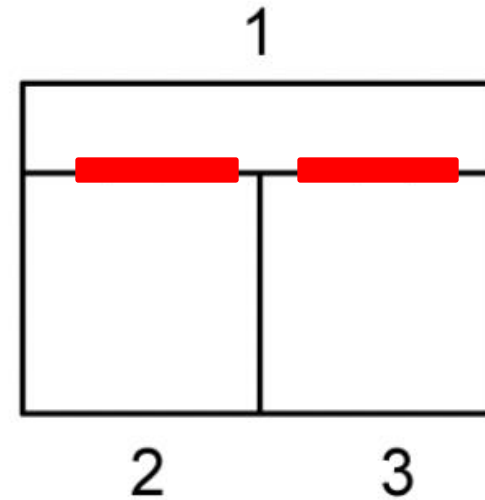
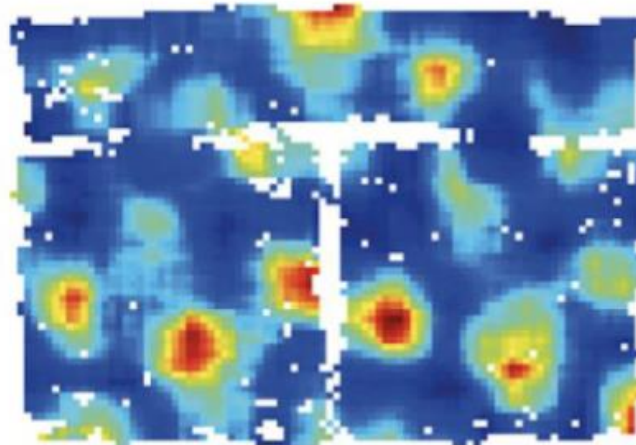
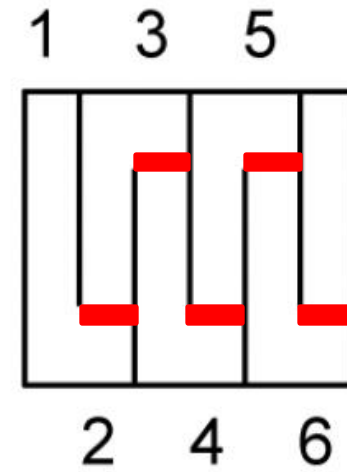
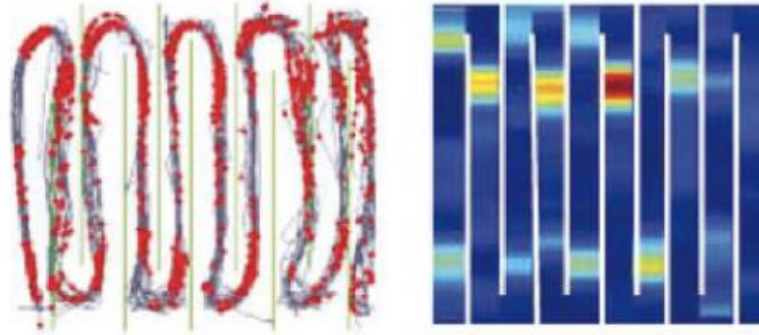
John O'Keefe



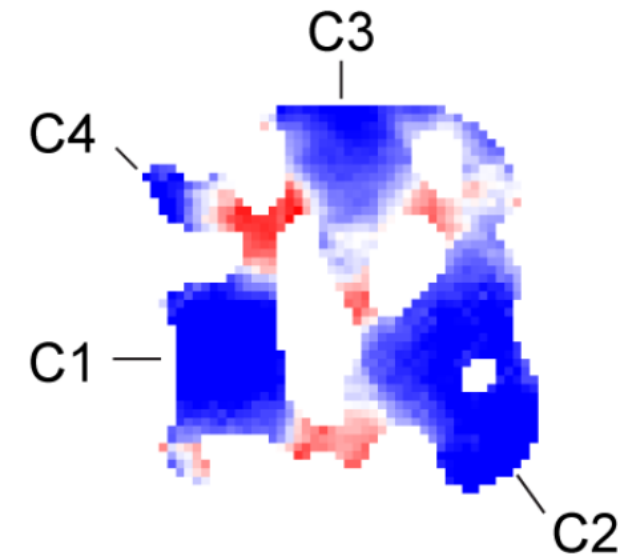
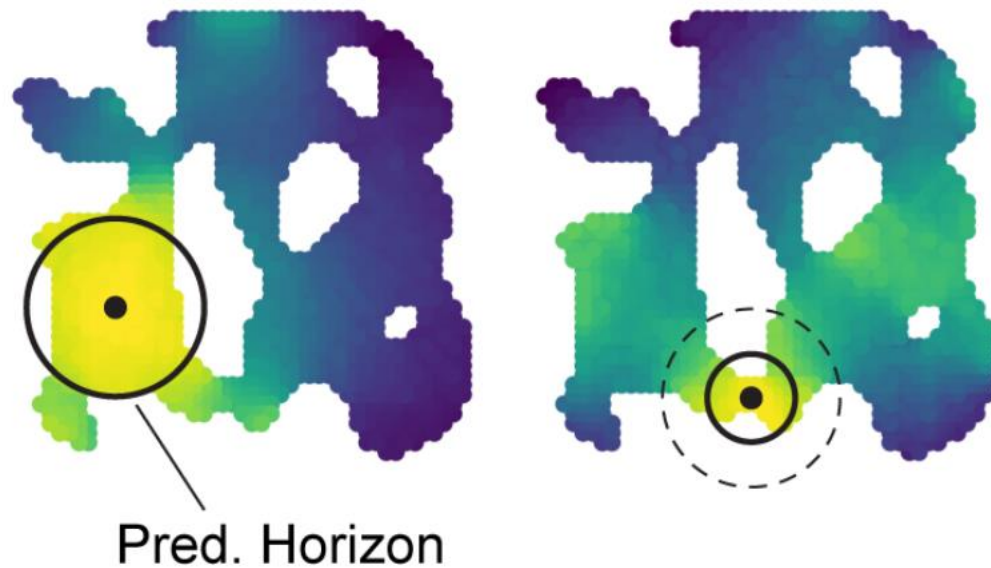
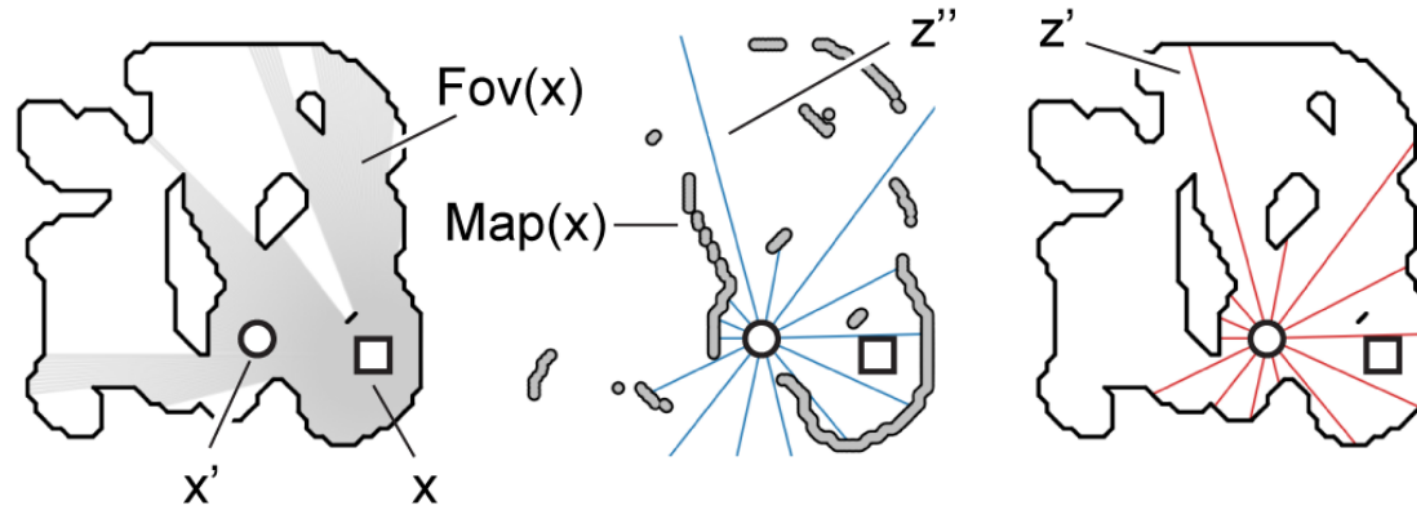
May-Britt & Edvard I.
Moser



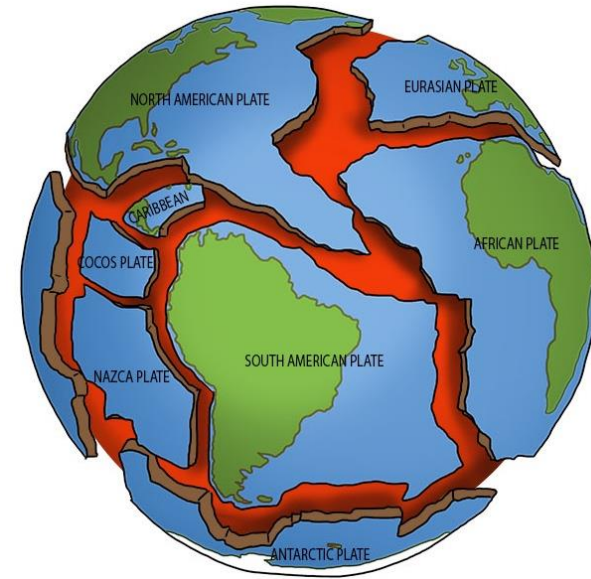
Remapping



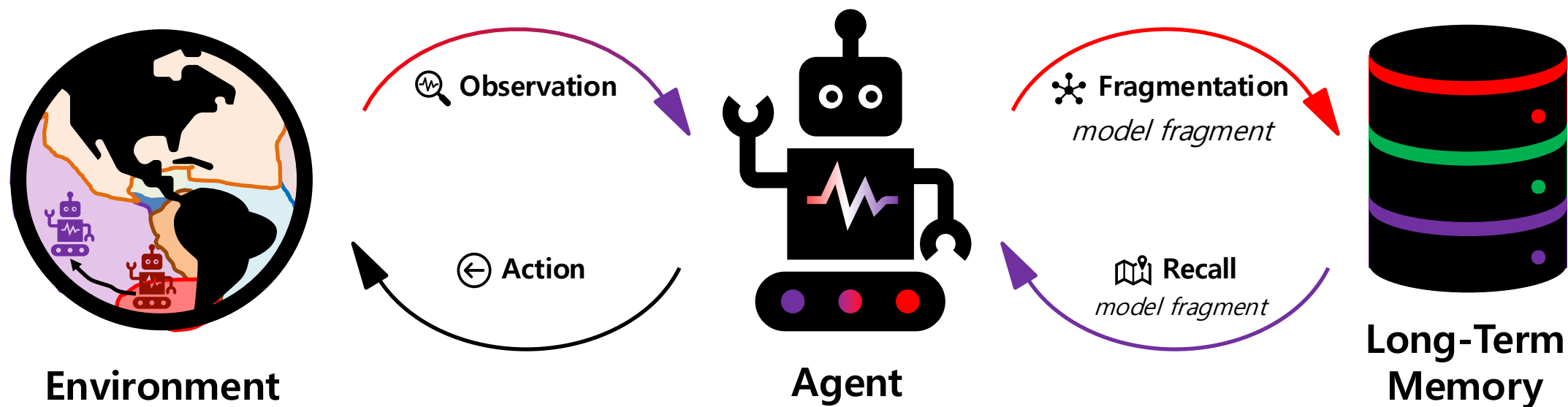
Where does the remapping happen?



Fragmentation



Overall Framework



Why Fragmentation and Recall?

- **By Fragmentation**

- We can divide one big problem into multiple subproblem.
- Since the problem set size is reduced, we can use a local model that is expertized in each sub set.

- **By Recall**

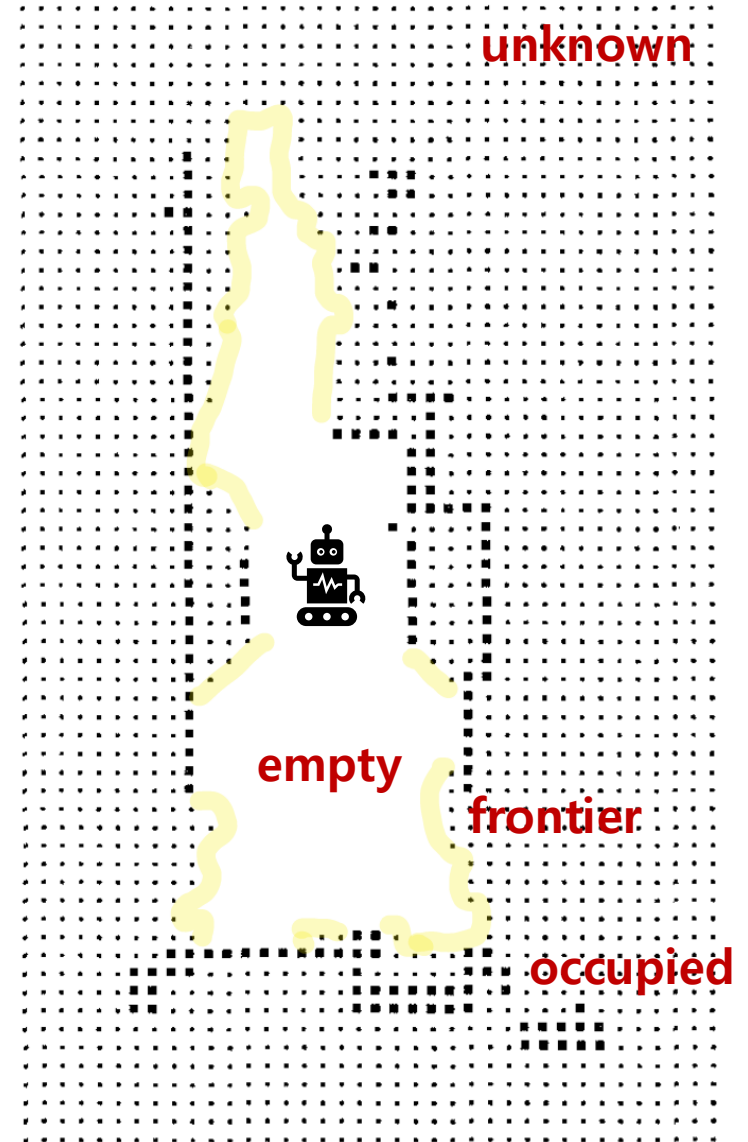
- We can use memorized information without forgetting.

Simultaneous Localization and Mapping (SLAM)

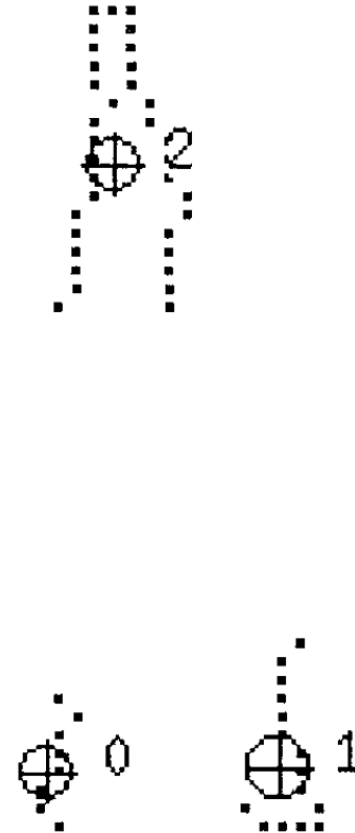
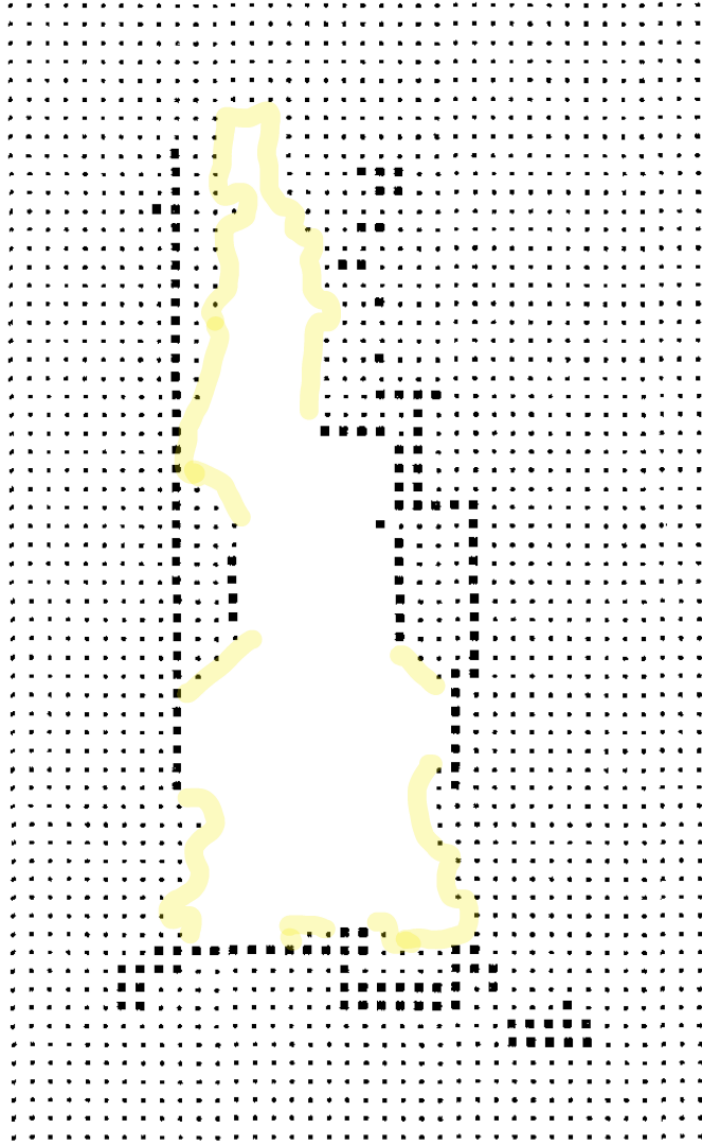


Cell Type in the Occupancy Grid

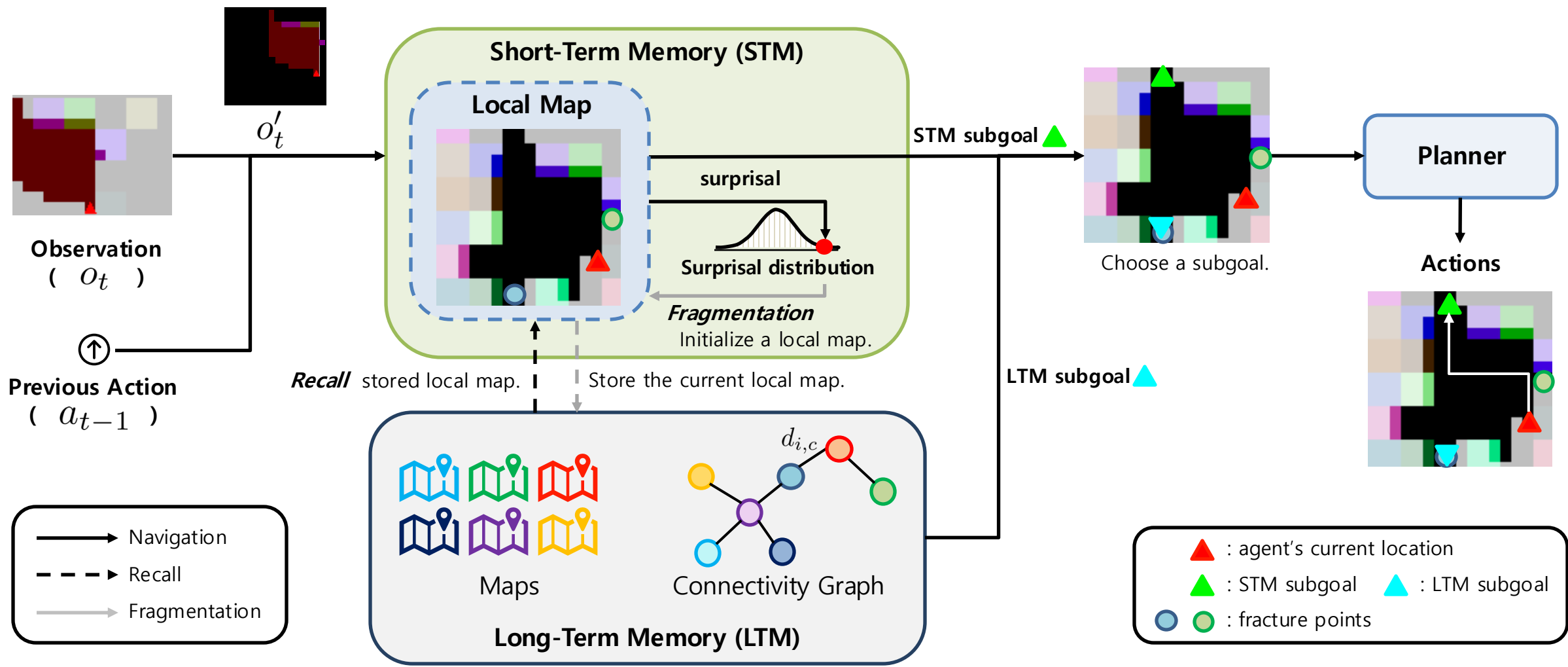
- Known Cell
 - Occupied Cell
 - Unoccupied (empty) Cell
- Unknown Cell
 - Frontier



Frontier: boundary between known and unknown cells



Fragmentation and Recall in Map Building (FARMap)



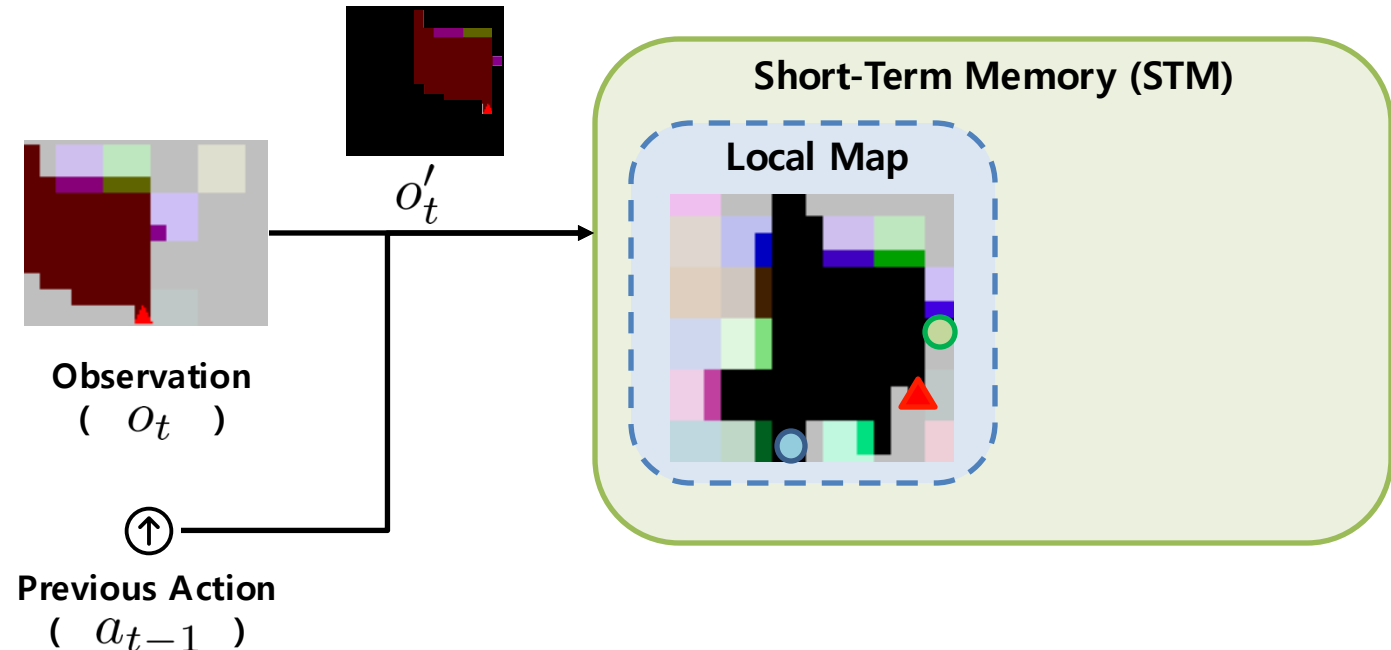
Short-Term Memory (STM)

- Short-Term Memory builds a local predictive map.
- The map is defined as temporally decaying trace of recent sensory observations.

$$\mathbf{M}_{t,C}^{\text{cur}} = \gamma \cdot \mathbf{M}_{t-1,C}^{\text{cur}} + (1 - \gamma) \cdot o'_{t,C}$$

γ : discount factor

o'_t : spatially transformed
current observation.



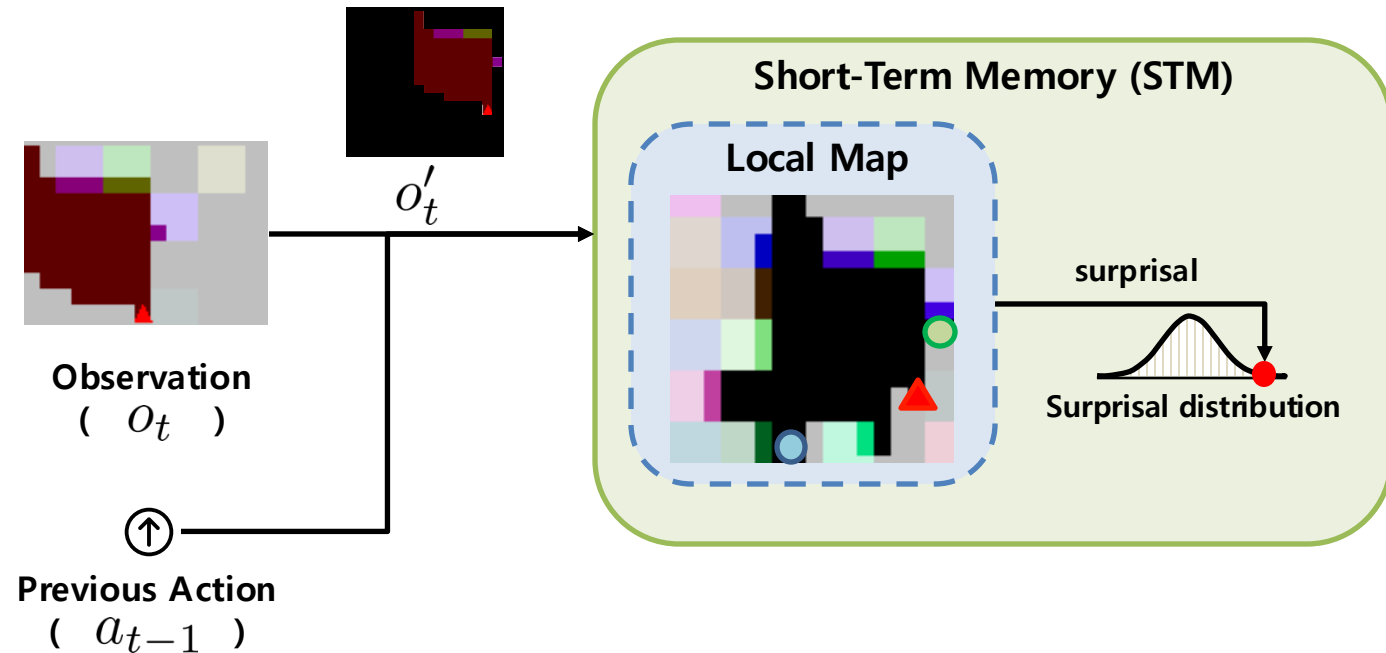
Confidence and Surprisal

- Confidence at time t is defined as average confidence of visible cells:

$$c_t = \frac{\mathbf{M}_{t-1,C}^{\text{cur}} \cdot o'_{t,C}}{\|o'_{t,C}\|_1}$$

- Surprisal is defined as

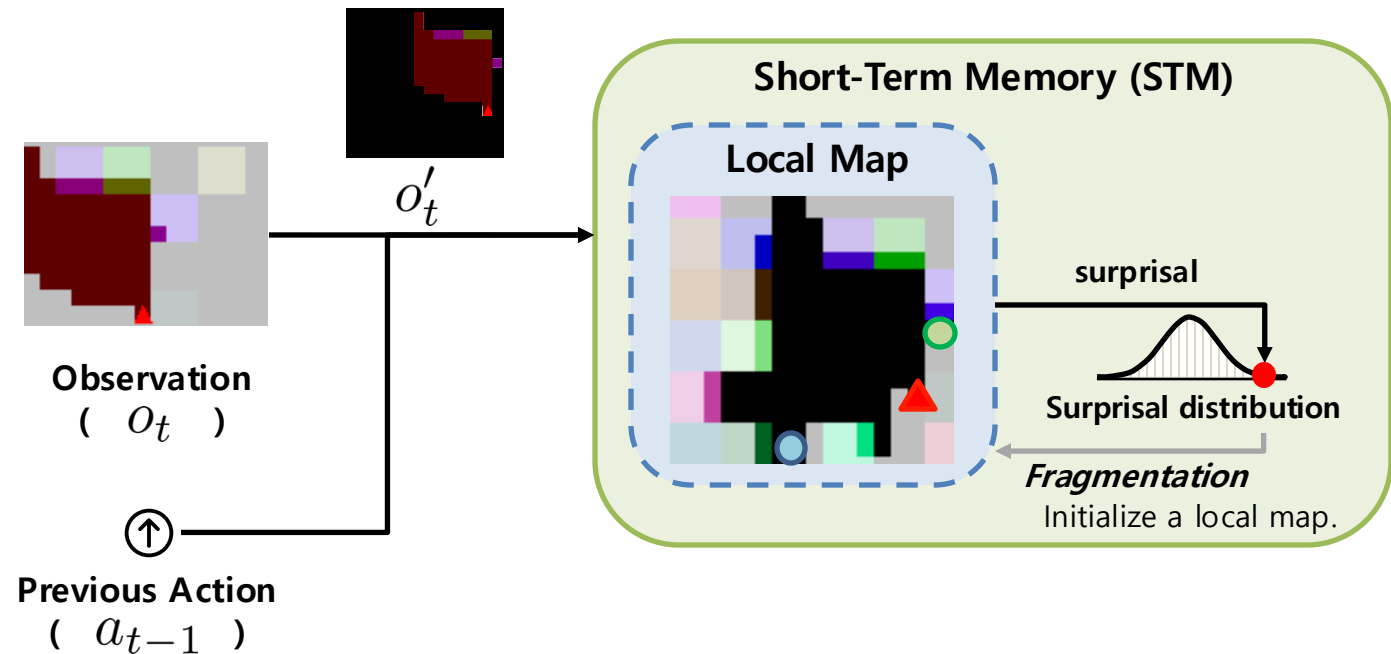
$$s_t = 1 - c_t$$



Fragmentation

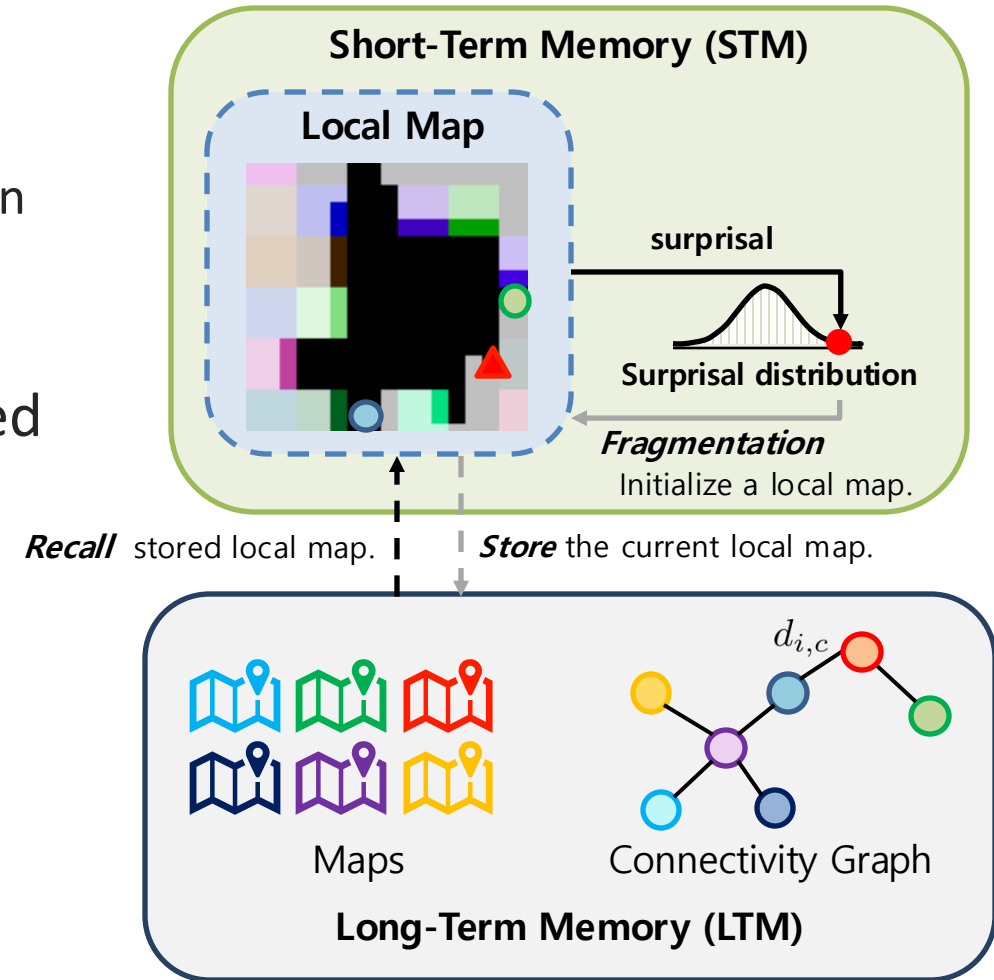
- We calculate running average and standard deviation of surprisal in the local map.
- If z-score for the current surprisal is bigger than a threshold, the fragmentation happens.

$$\frac{s_t - \mu_t}{\sigma_t} > \rho$$



Long-Term Memory (LTM)

- Store – when the fragmentation event happens.
 - Local map
 - the ratio of the number of frontier and the number of known cells in the map
- Recall – when the agent approaches to the fragmented location (overlap with another local map)
 - Recall corresponding local map.
 - Store current local map in LTM.



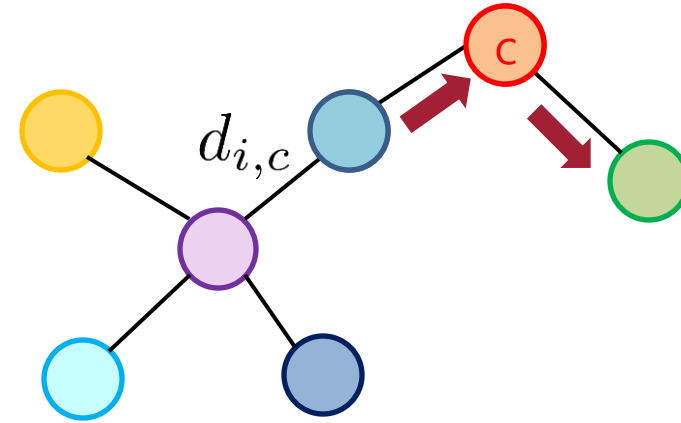
Subgoal

- Two sources of subgoal; STM and LTM.
- From the current local map, the agent sets frontier-based subgoal.
- By using connectivity graph of maps in LTM, the agent decides that which local region is less explored.

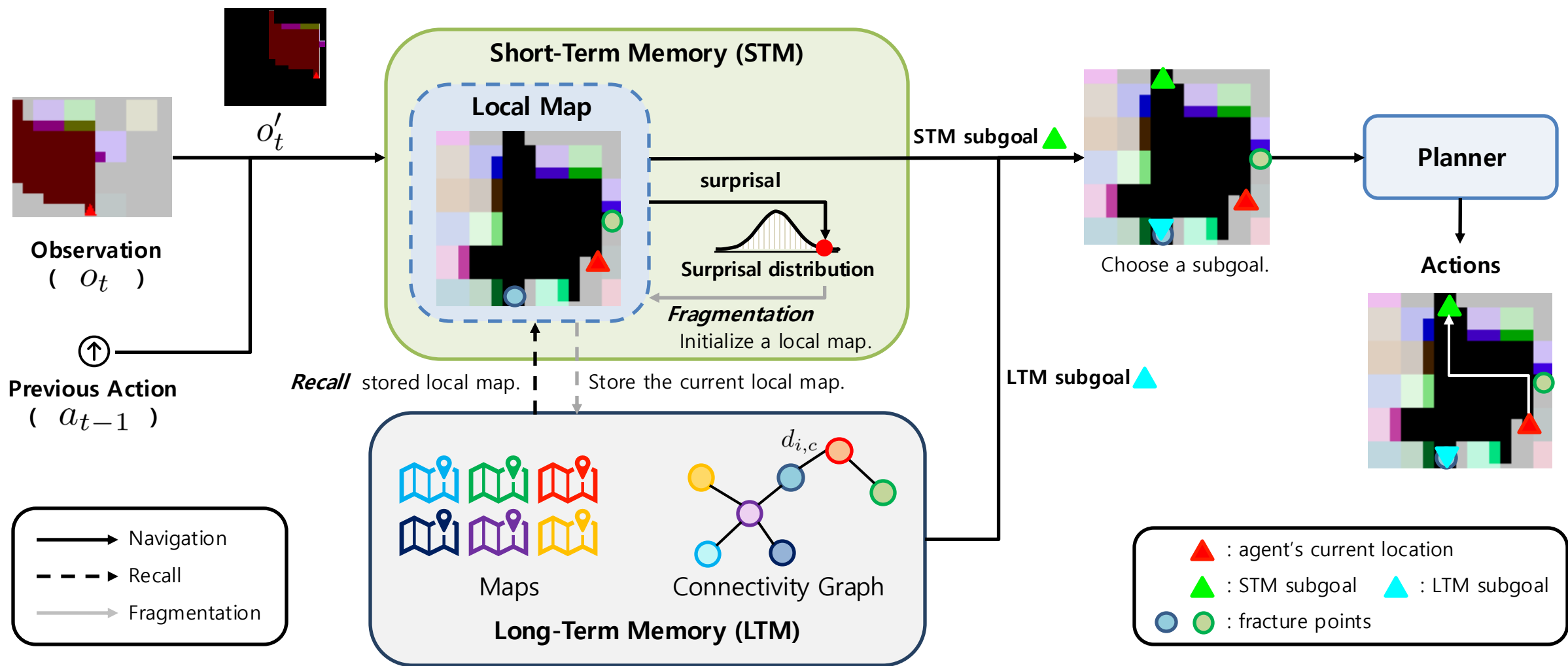
Subgoal from LTM

- Subgoal is defined as fragmentation location between the current local map and less explored local map which is defined as

$$g = \arg \max_i \frac{q_i}{d_{i,c} + \epsilon}$$



- If $g = c$ (current local map), stay in the current map
o.w. set subgoal to fragmentation location between the current local map and local map g
- $d_{i,c}$: the distance between the agent and local map
- q_c : (the number of frontiers) / (the number of known (empty + occupied))
- ϵ : hyper-parameter – preference to not stay in the current region

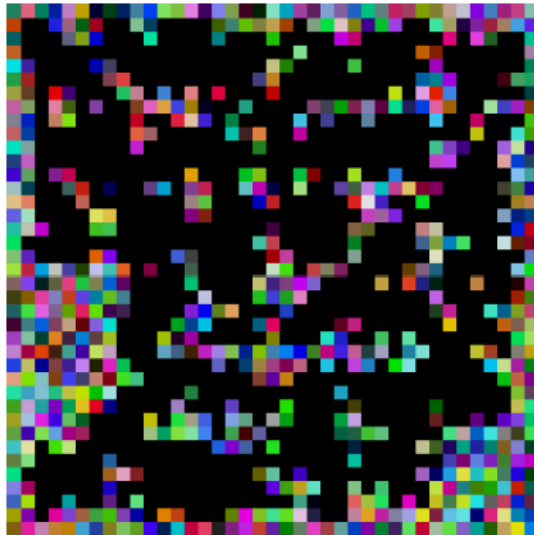


Procedurally-Generated Environments

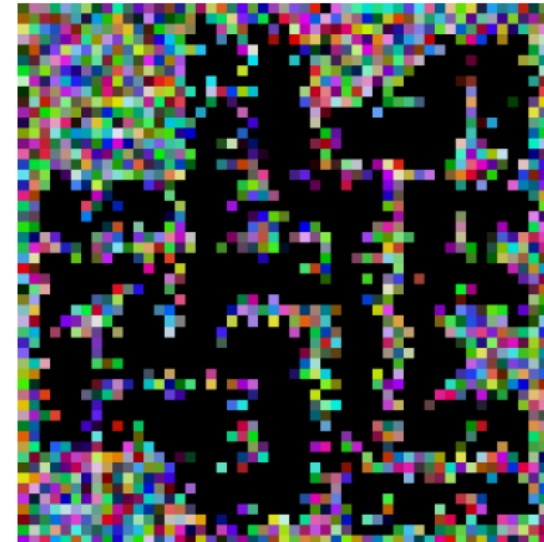
- 1500 environments
 - 300 maps with 5 different colors and starting locations.
 - Depending on the size of environment, we divide into three groups; small, medium, large.



(b) Small (size: 3249)



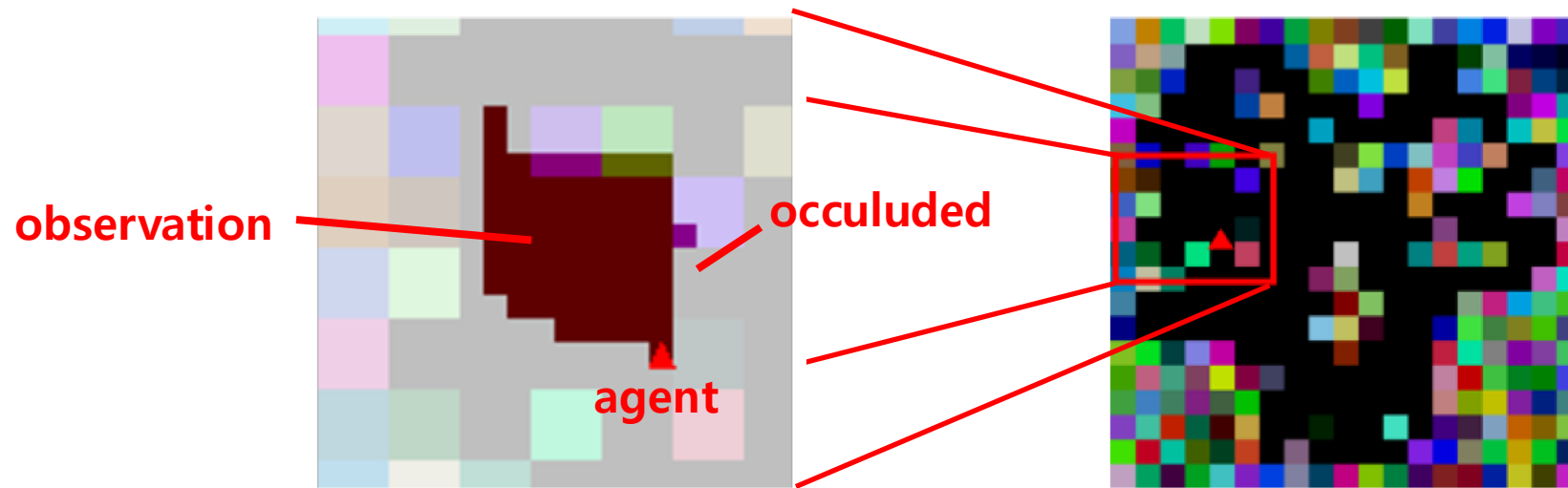
(c) Medium (size: 13689)



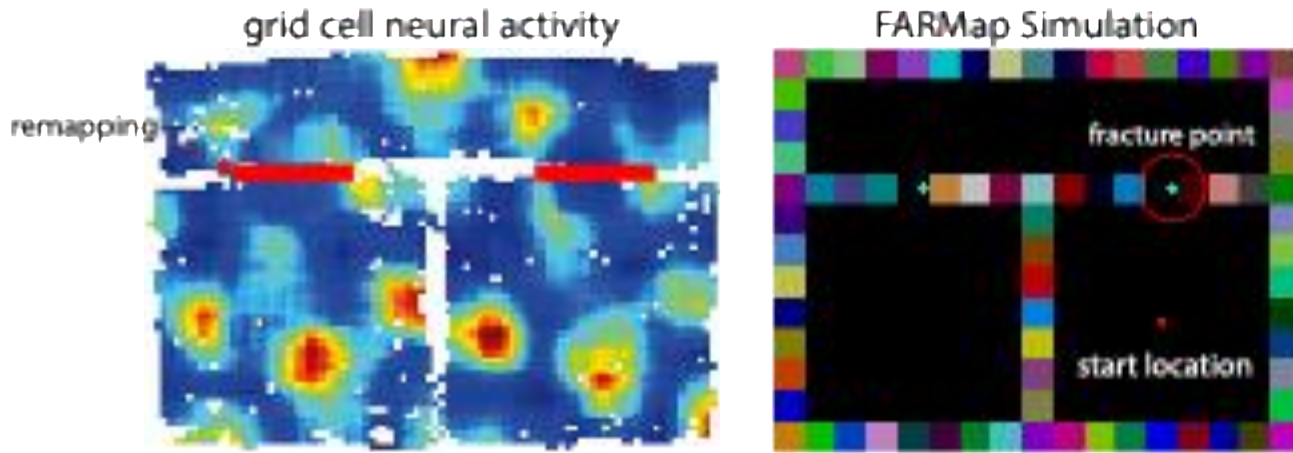
(d) Large (size: 23868)

Observation

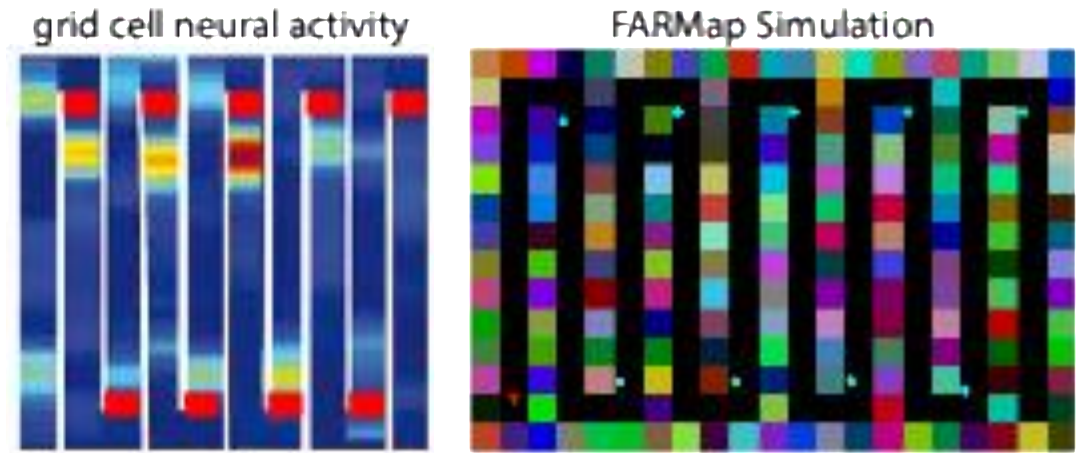
- Egocentric restricted field of view (130 degree) with occlusion.



FARMap Fragments where actual Remapping happens

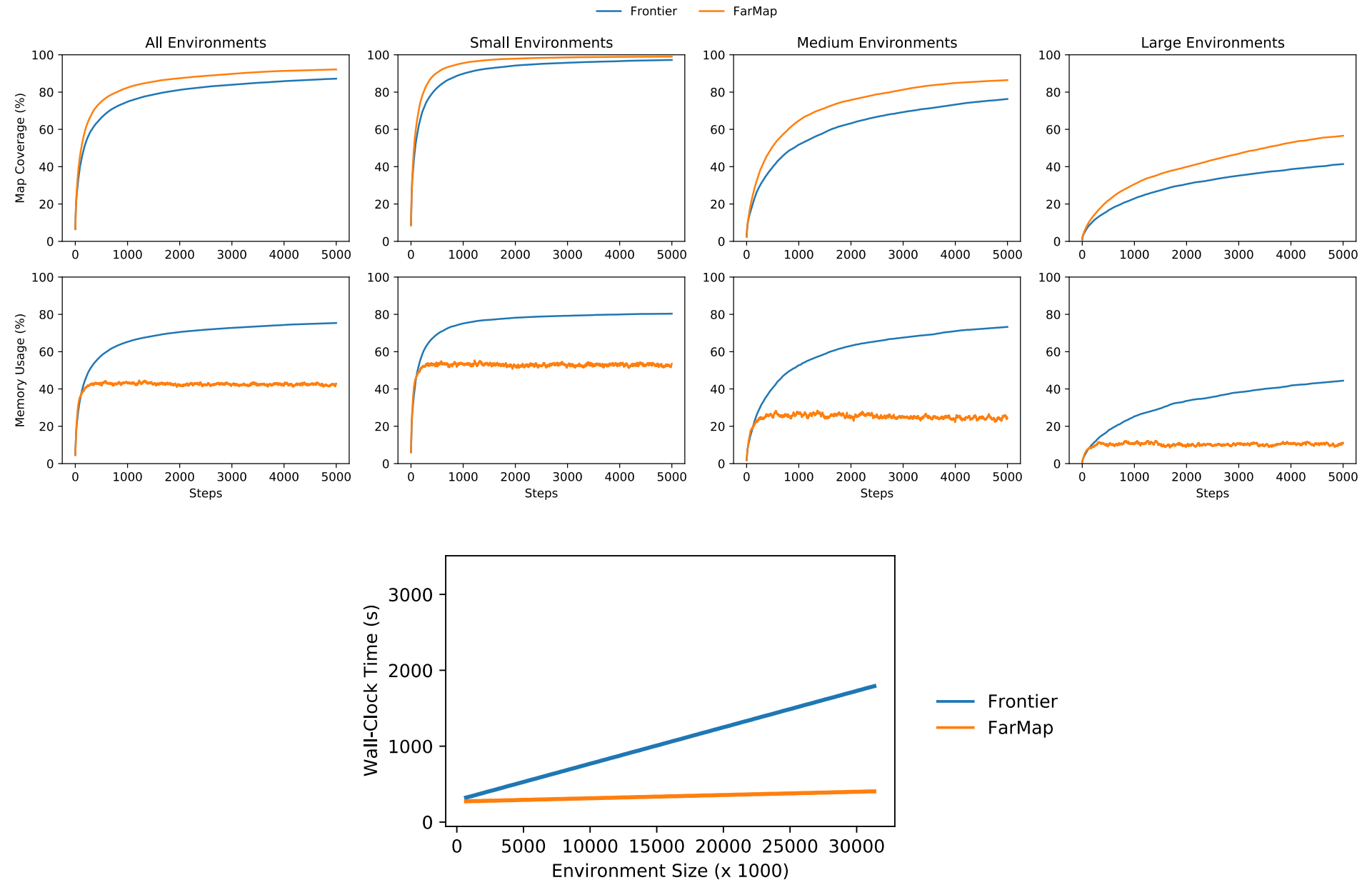


(a) Carpenter et al. (2015)



(b) Derdikman et al. (2009)

FARMap achieves better performance with less memory & wall-clock time



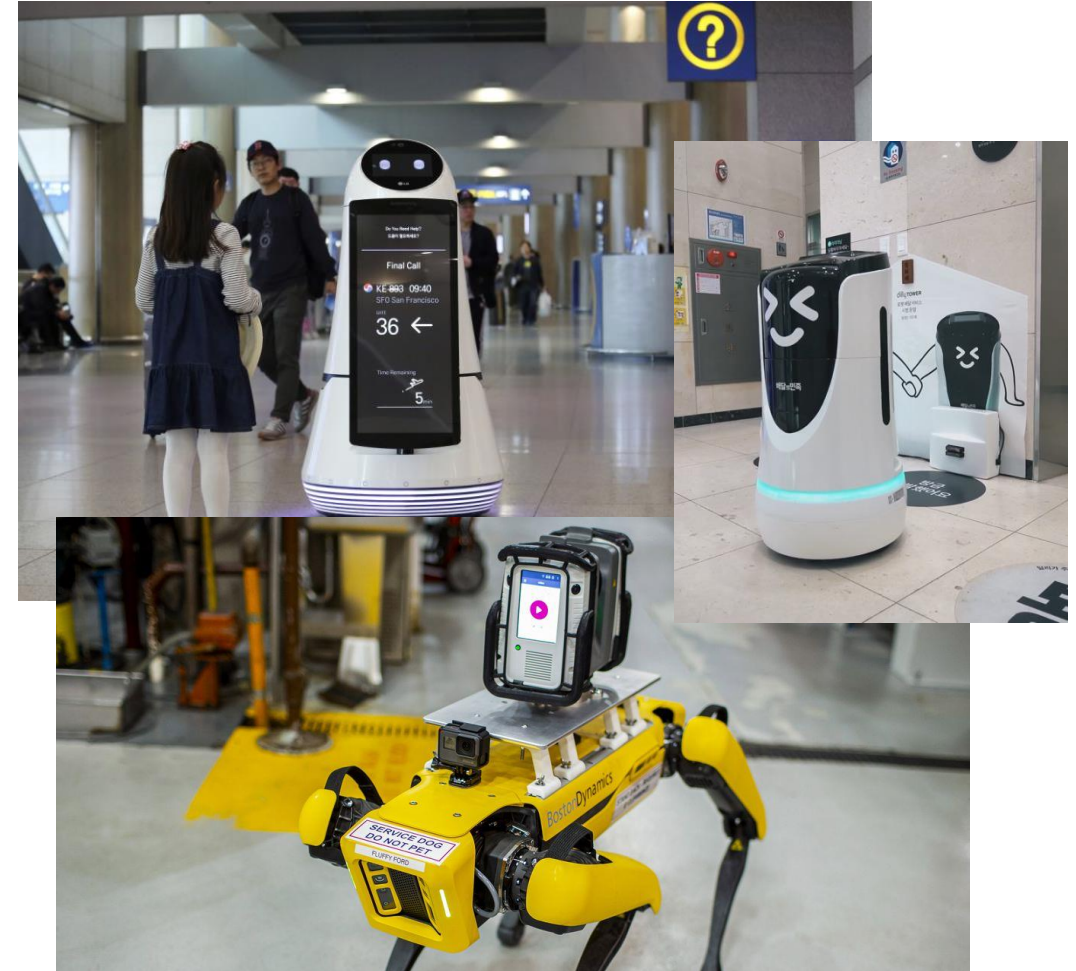
Where can we use FarMap?



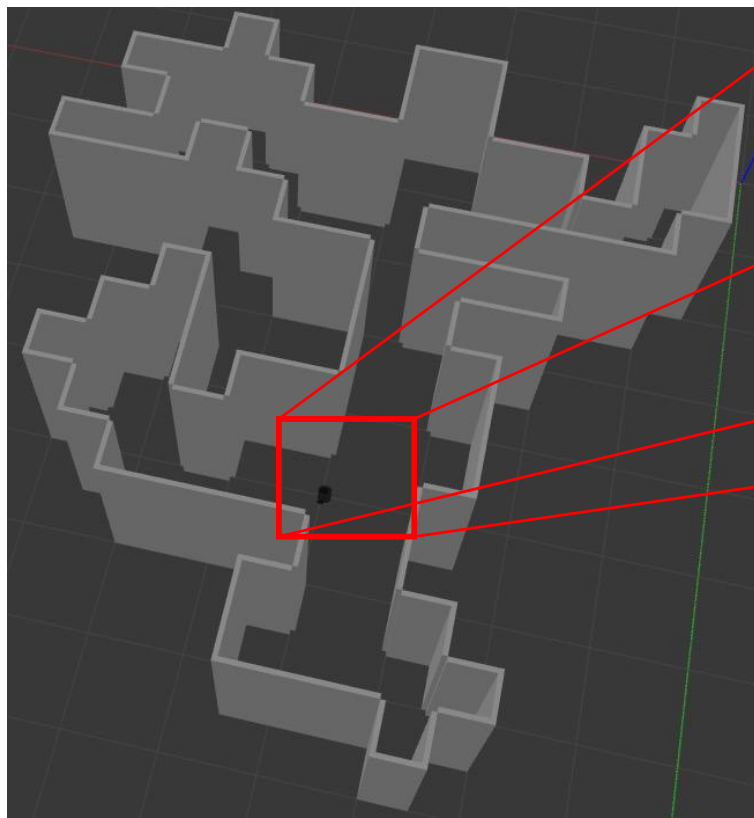
Processor	Radiation-hardened central processor with PowerPC 750 Architecture: a BAE RAD 750 Operates at up to 200 megahertz speed, 10 times the speed in Mars rovers Spirit and Opportunity's computers
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Memory	2 gigabytes of flash memory (~8 times as much as Spirit or Opportunity) 256 megabytes of dynamic random access memory
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<https://mars.nasa.gov/msl/spacecraft/rover/brains/>



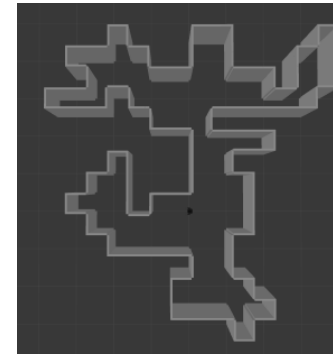
FarMap in Robot Operating System (ROS)



Environment



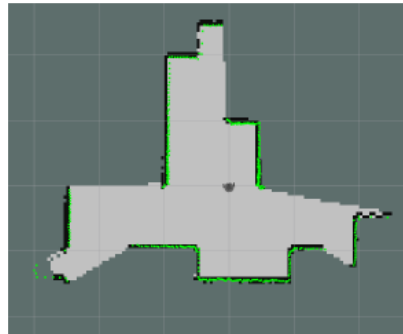
Agent
(turtlebot)



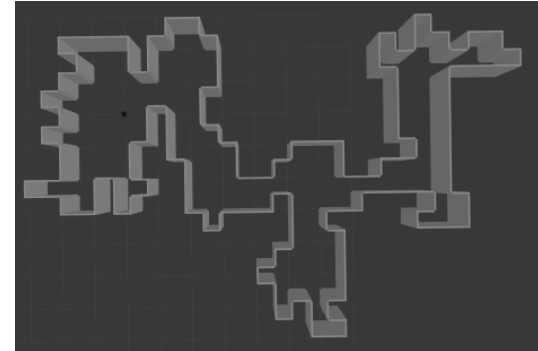
Environment 1



AWS Office



Observation



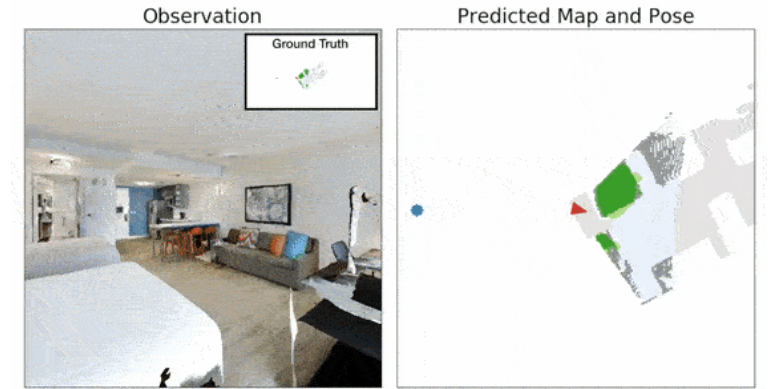
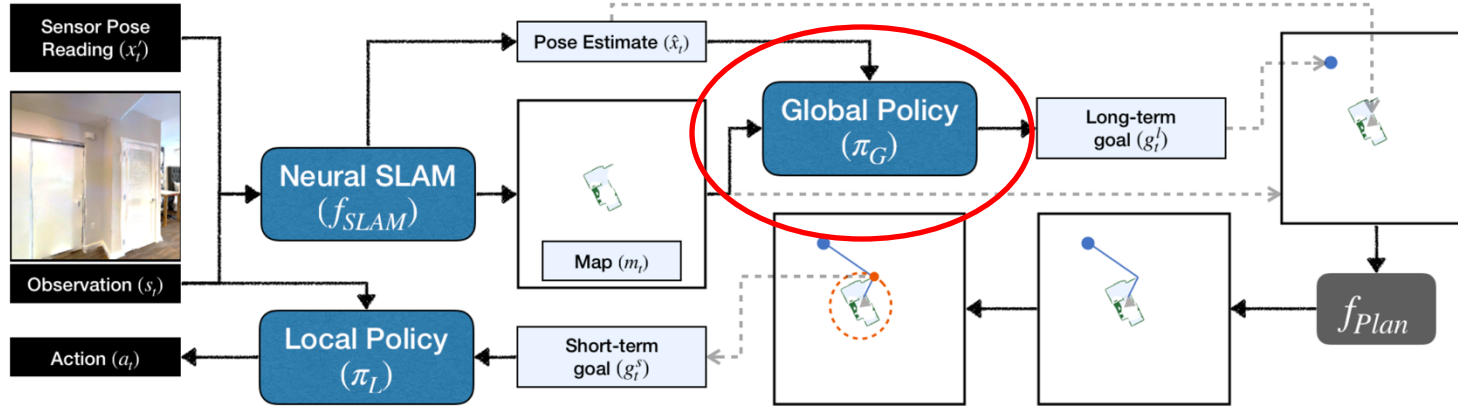
Environment 2



American

Model	Environment 1		Environment 2		AWS Office (Erdogan, 2019)		American (Shen et al., 2021)	
	Coverage (k)	Memory (k)	Coverage (k)	Memory (k)	Coverage (k)	Memory (k)	Coverage (k)	Memory (k)
Frontier	7.0 (\pm 1.4)	20.5 (\pm 1.0)	8.3 (\pm 0.6)	32.8 (\pm 34.4)	38.2 (\pm 30.0)	48.1 (\pm 20.8)	13.8 (\pm 3.1)	11.0 (\pm 2.1)
FARMap	7.7 (\pm 1.0)	20.1 (\pm 2.4)	8.3 (\pm 0.1)	23.0 (\pm 8.6)	57.0 (\pm 4.7)	66.0 (\pm 14.3)	15.8 (\pm 4.2)	10.6 (\pm 3.7)

With Neural SLAM in Habitat Simulation



Model	% Cov.	Cov. (m ²)
Neural SLAM (Chaplot et al., 2020)	0.818	64.795
Neural SLAM w/o global policy + Frontier	0.733	58.103
Neural SLAM w/o global policy + FARMap	0.833	66.012

Summary

- We proposed Fragmentation-and-Recall framework for map building (FARMap)
- The fracture points match with the actual neuroscience experiments.
- FARMap explores a new environment faster with less memory compared to the baseline.
- FARMap can be combined with other spatial exploration methods.