MOBILE ROBOTS 9– SLAM

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EPFL

2025-2026

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Simultaneous Localisation and Mapping (SLAM)

SLAM

Can a robot placed at an unknown location in an unknown environment incrementally build a consistent map of this environment while simultaneously determining its location within the map?

YES: this is called *Simultaneous Localisation and Mapping* (SLAM)

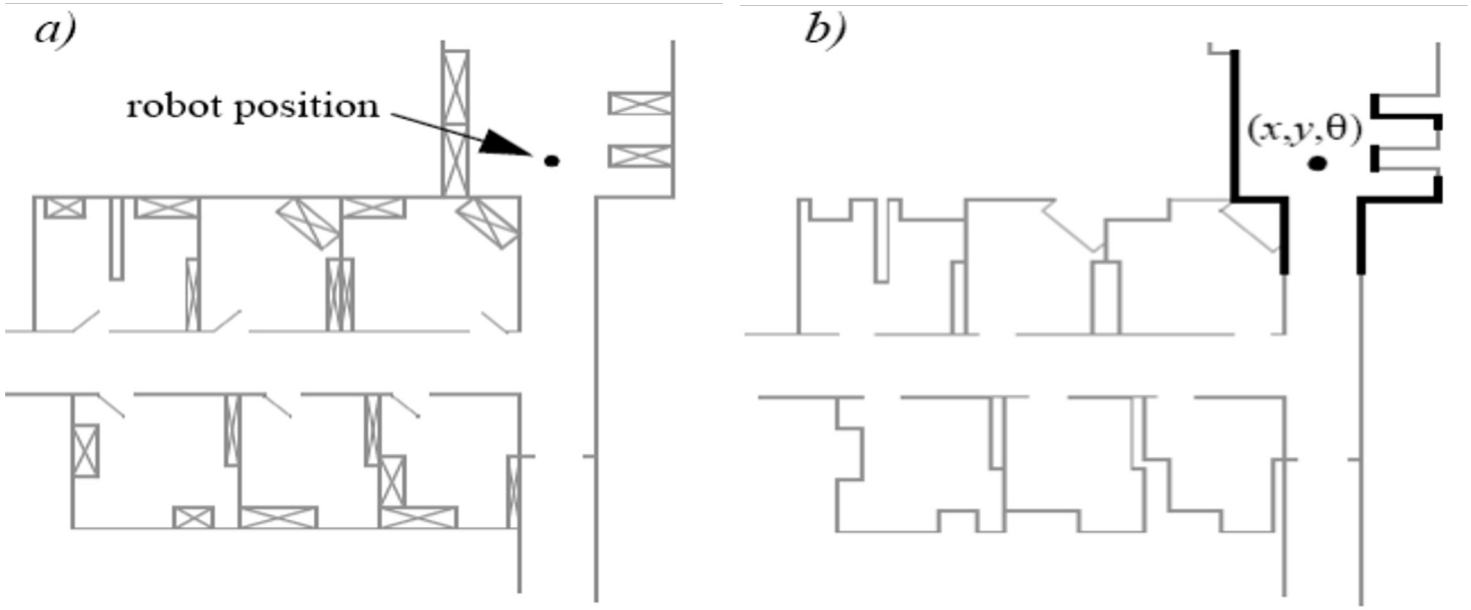
Sensors?

- Lidar
- 2D Cameras
- Depth cameras

Map Types

a) Real map with walls, doors and furniture.

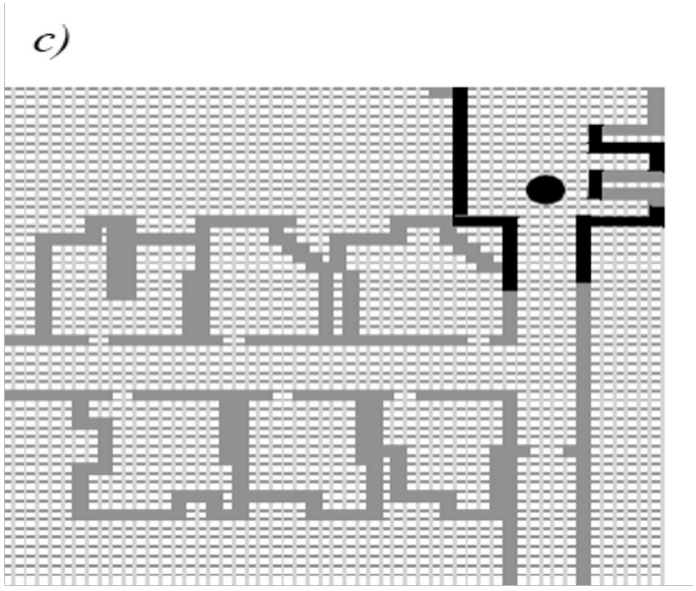
b) Line-based map: example ~100 lines with two parameters.

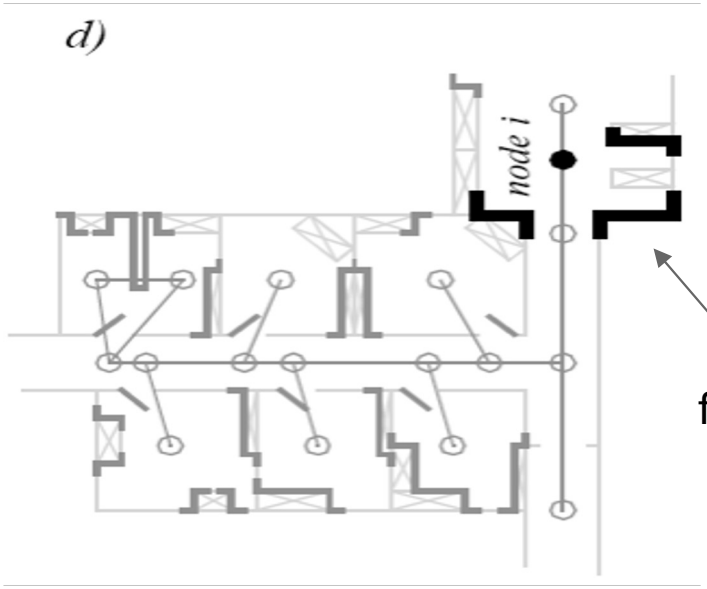


Map Types

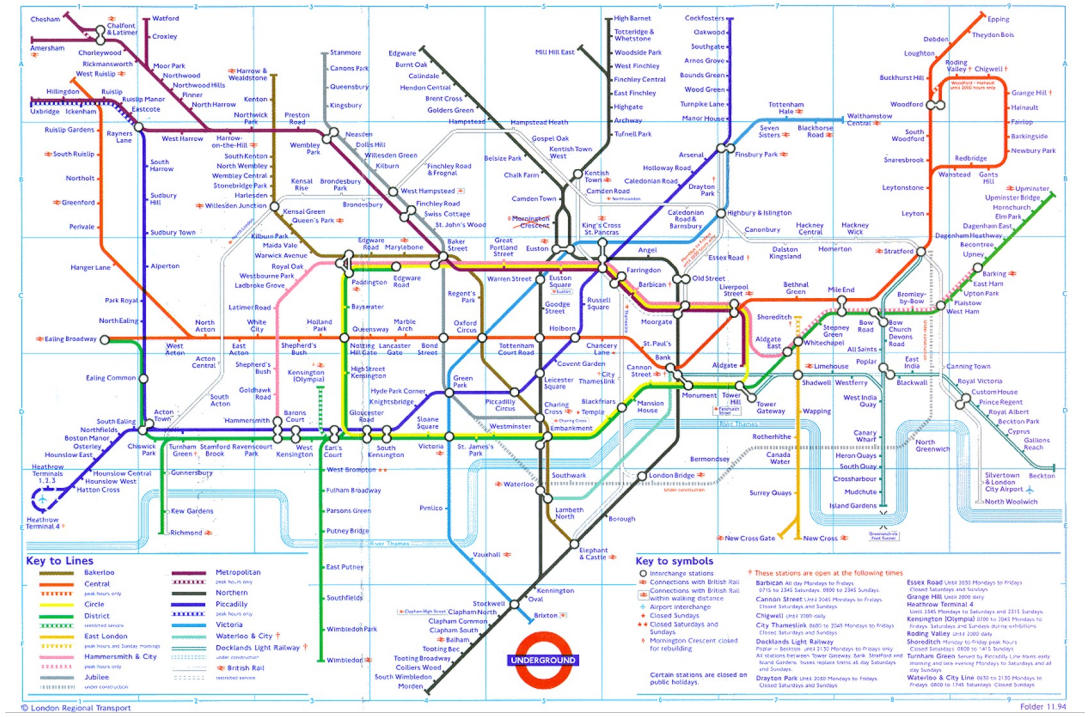
c) Occupancy grid map: example below ~3000 grid cells of 50 x 50cm.

d) Topological map e.g. using features and local paths between nodes: example ~18 nodes and 50 features.

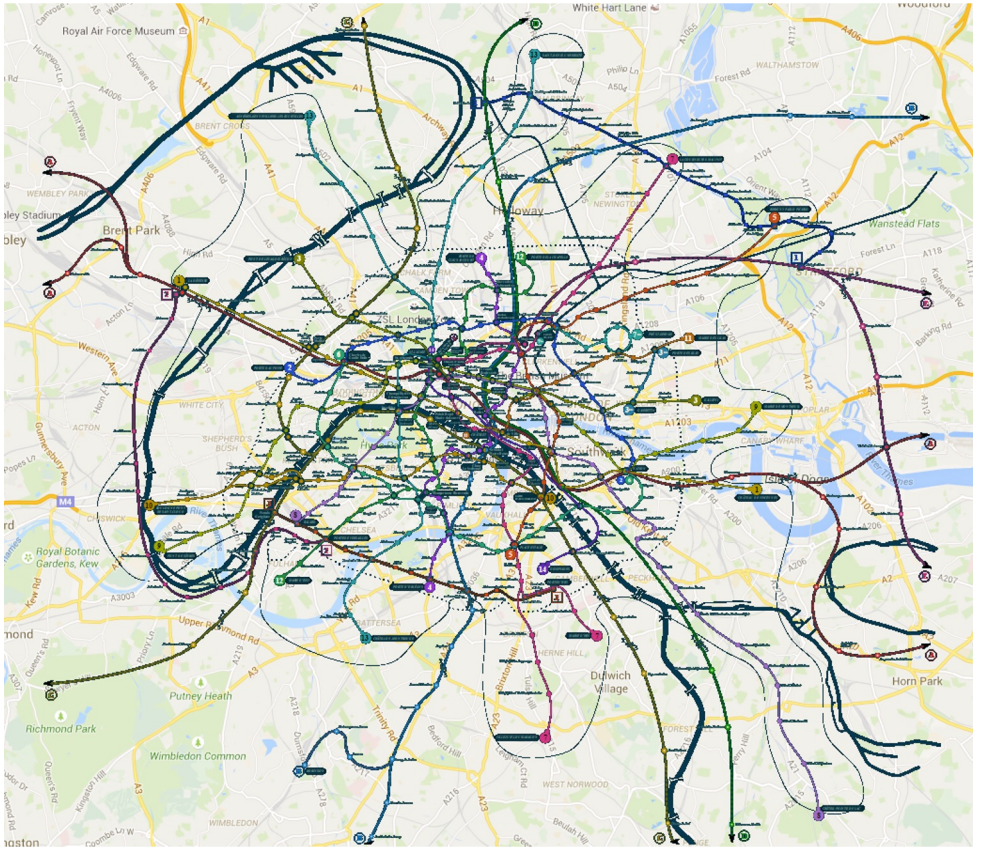




Maps - Example : London Metro



Topological map



Geographic map

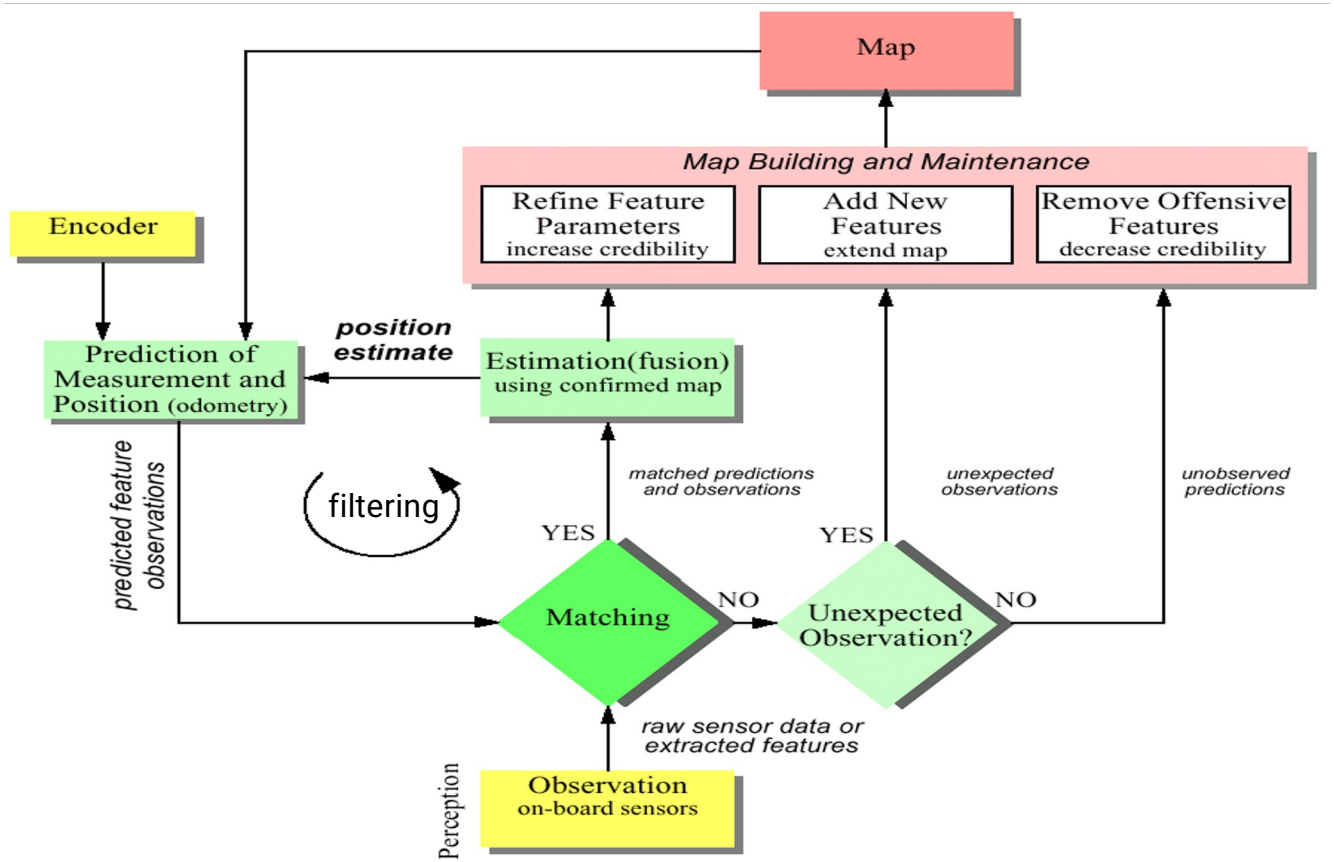
SLAM – Map Building and Maintenance

Unexpected observations will cause the creation of new features in the map.

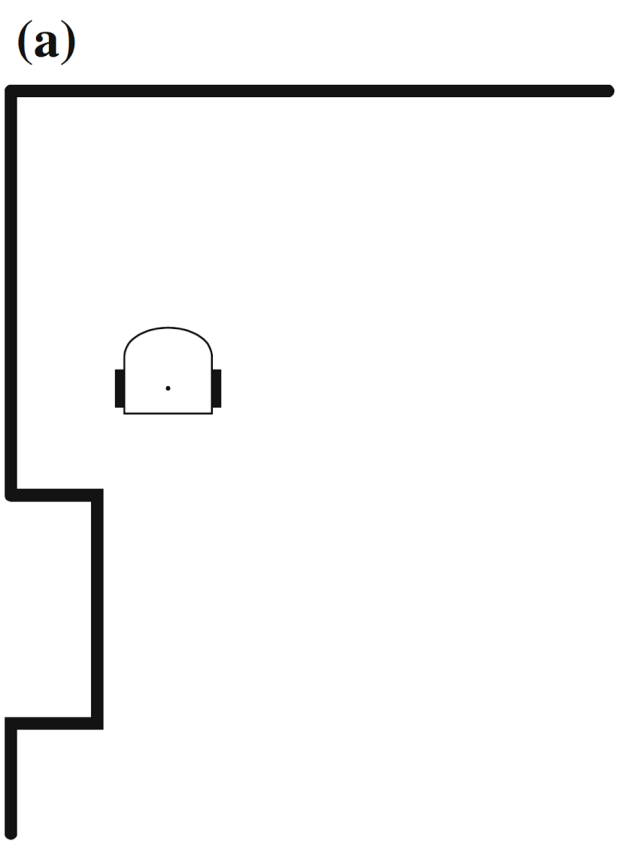
Unobserved measurement predictions may induce the removal of features from the map.

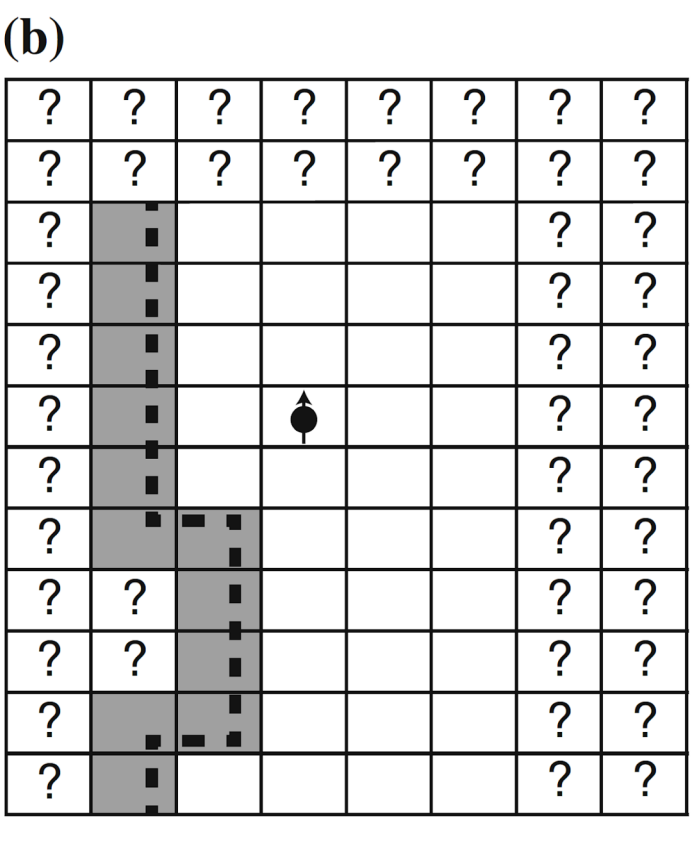
Each feature has varying degrees of probability that it is indeed part of the environment.

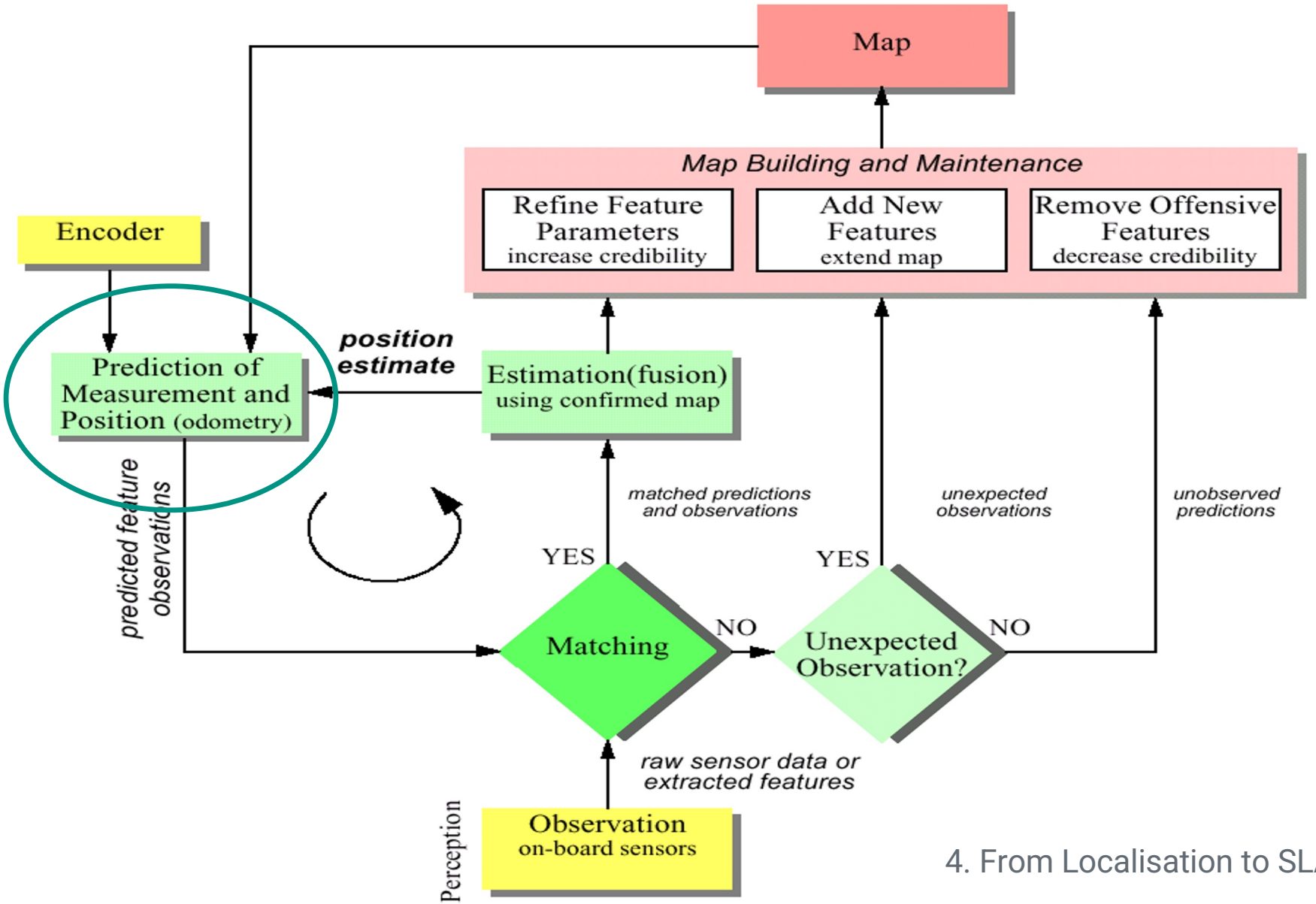
This forms a stochastic map represented by the state vector and a **covariance matrix** containing all cross-correlations, which must be updated at each cycle.



Example : Situation



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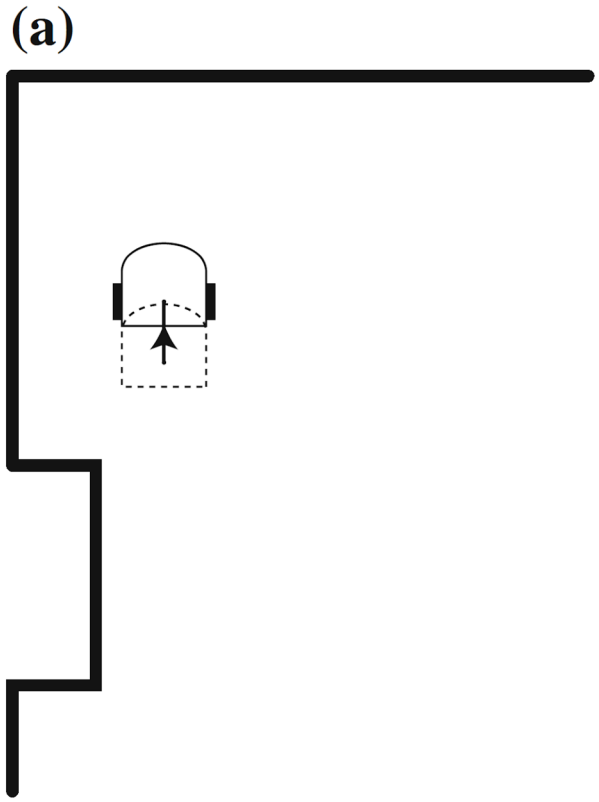
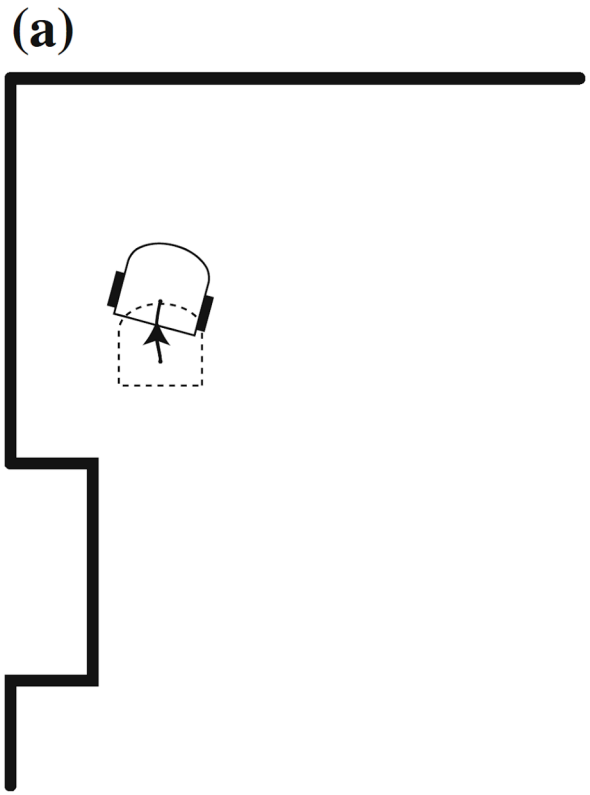
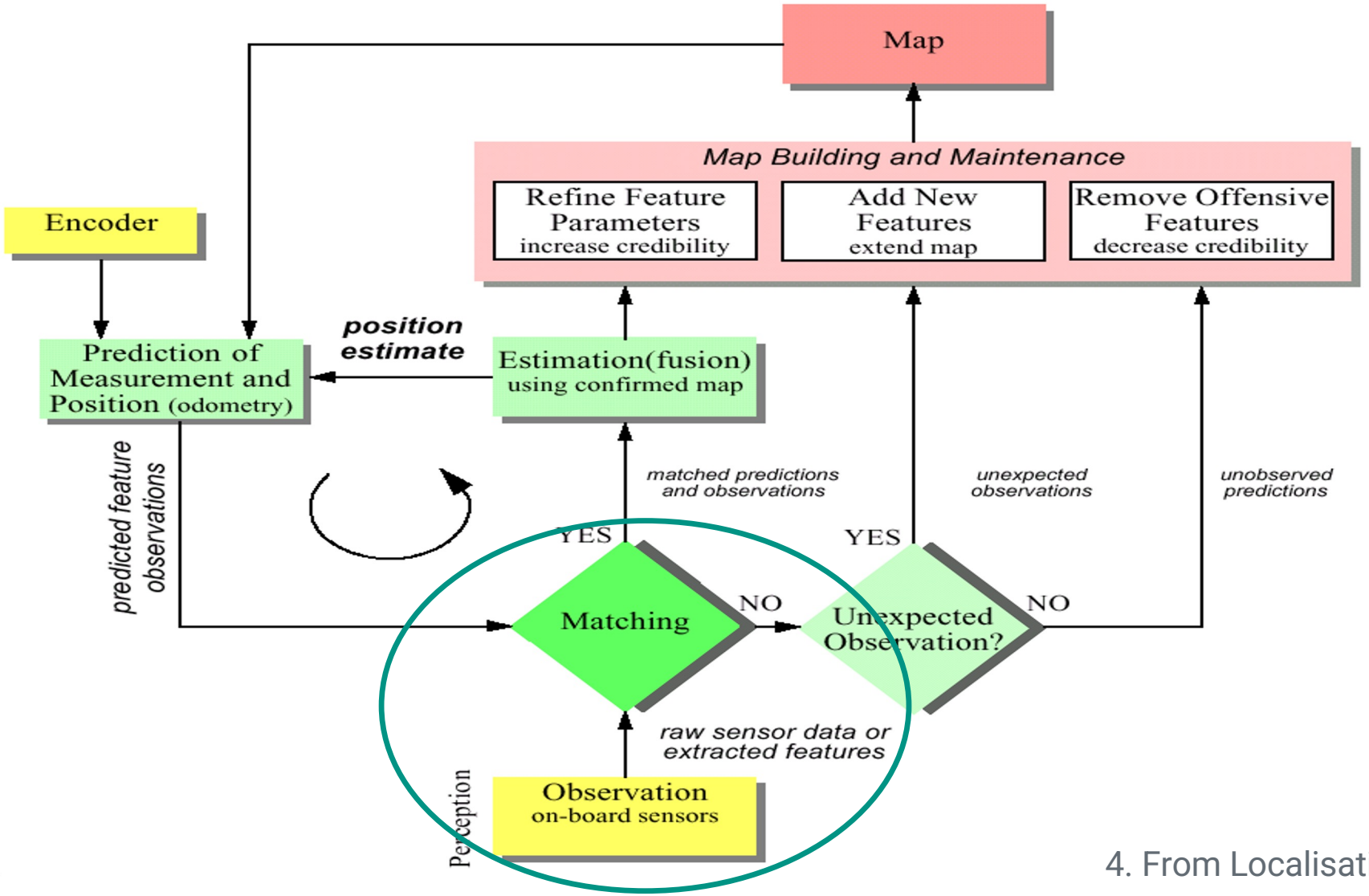
Map Building and Maintenance
Refine Feature Parameters
increase credibility
Add New Features
extend map
Remove Offensive Features
decrease credibility
Encoder
Prediction of Measurement and Position (odometry)
position estimate
Estimation(fusion)
using confirmed map
predicted feature observations
matched predictions and observations
unexpected observations
unobserved predictions
YES
YES
Matching
NO
Unexpected Observation?
NO
raw sensor data or extracted features
Perception
Observation
on-board sensors

Example : Move and Prediction



Example : Real Situation

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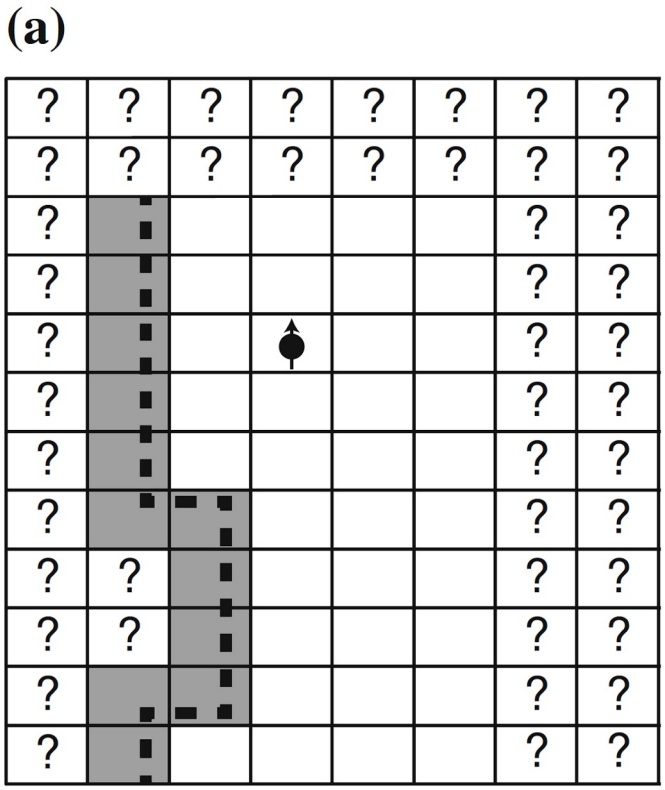
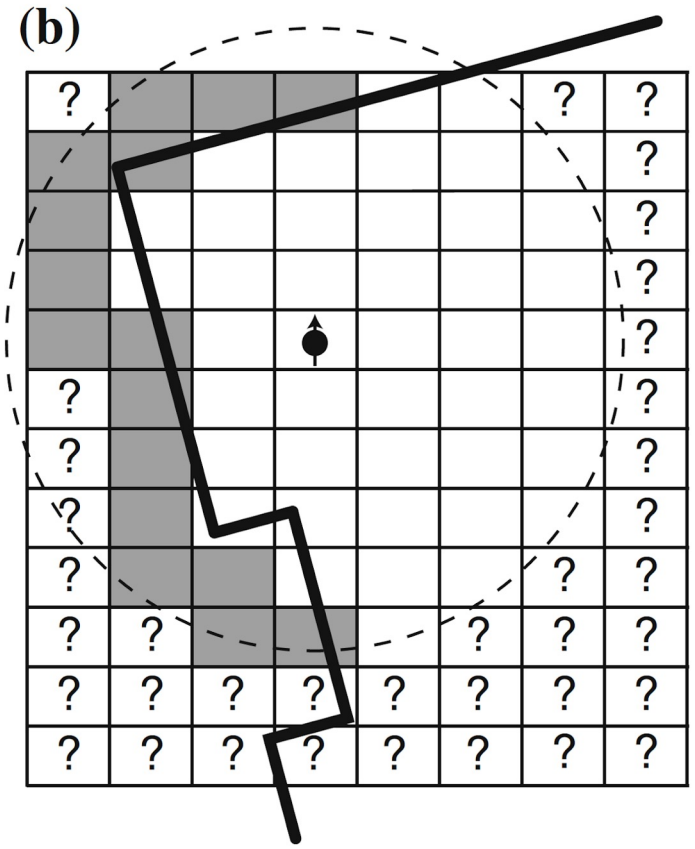
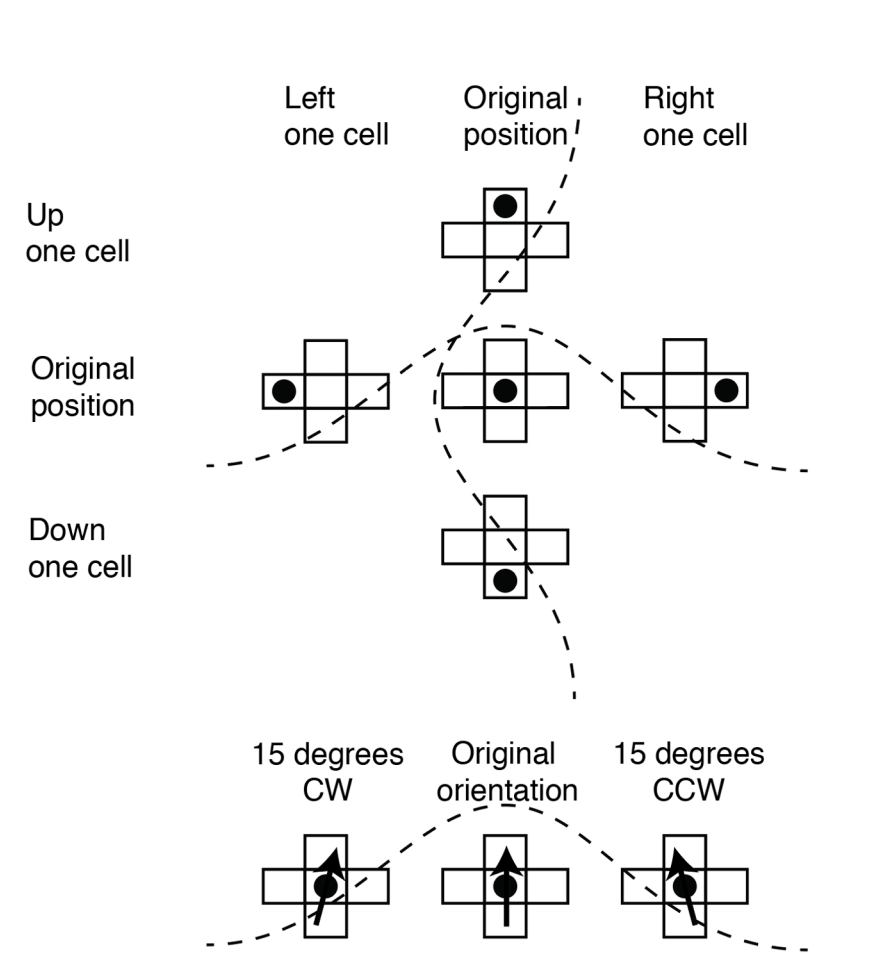
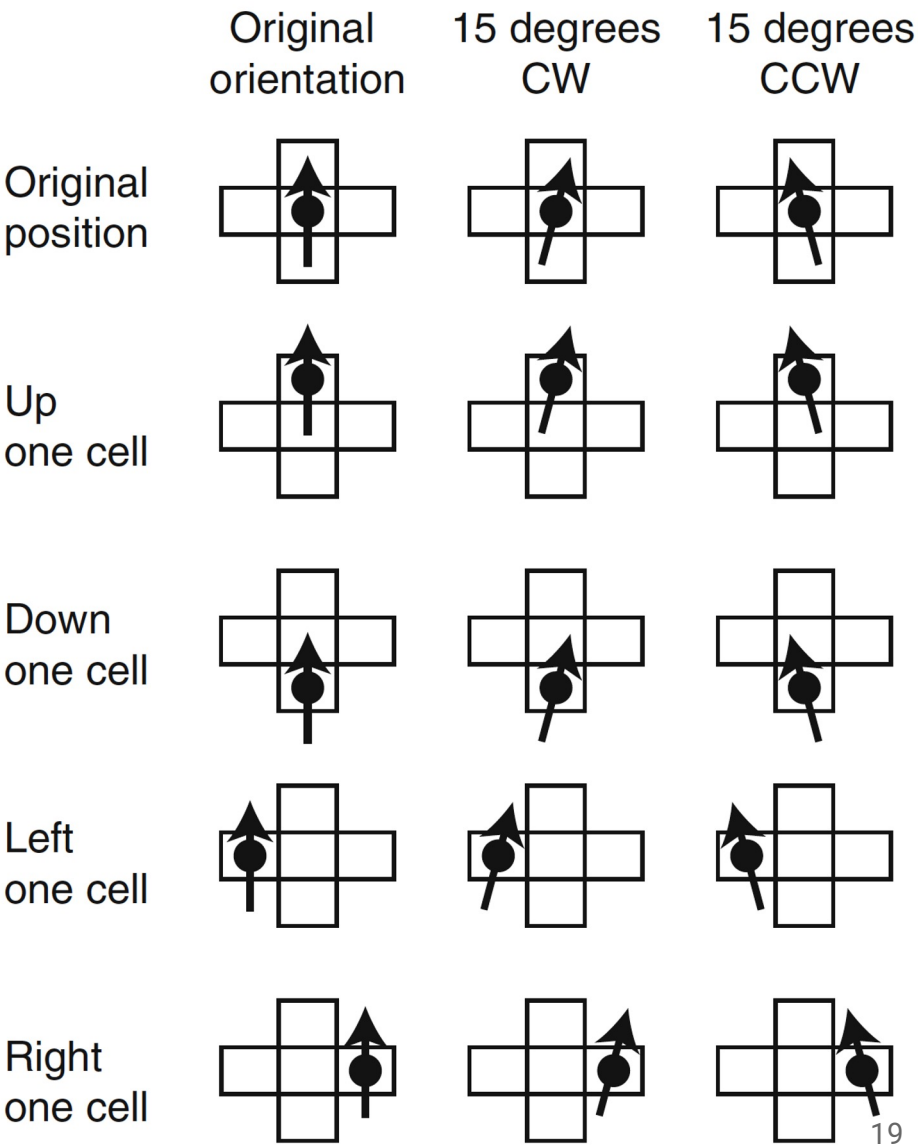
Example : Prediction vs. Observation



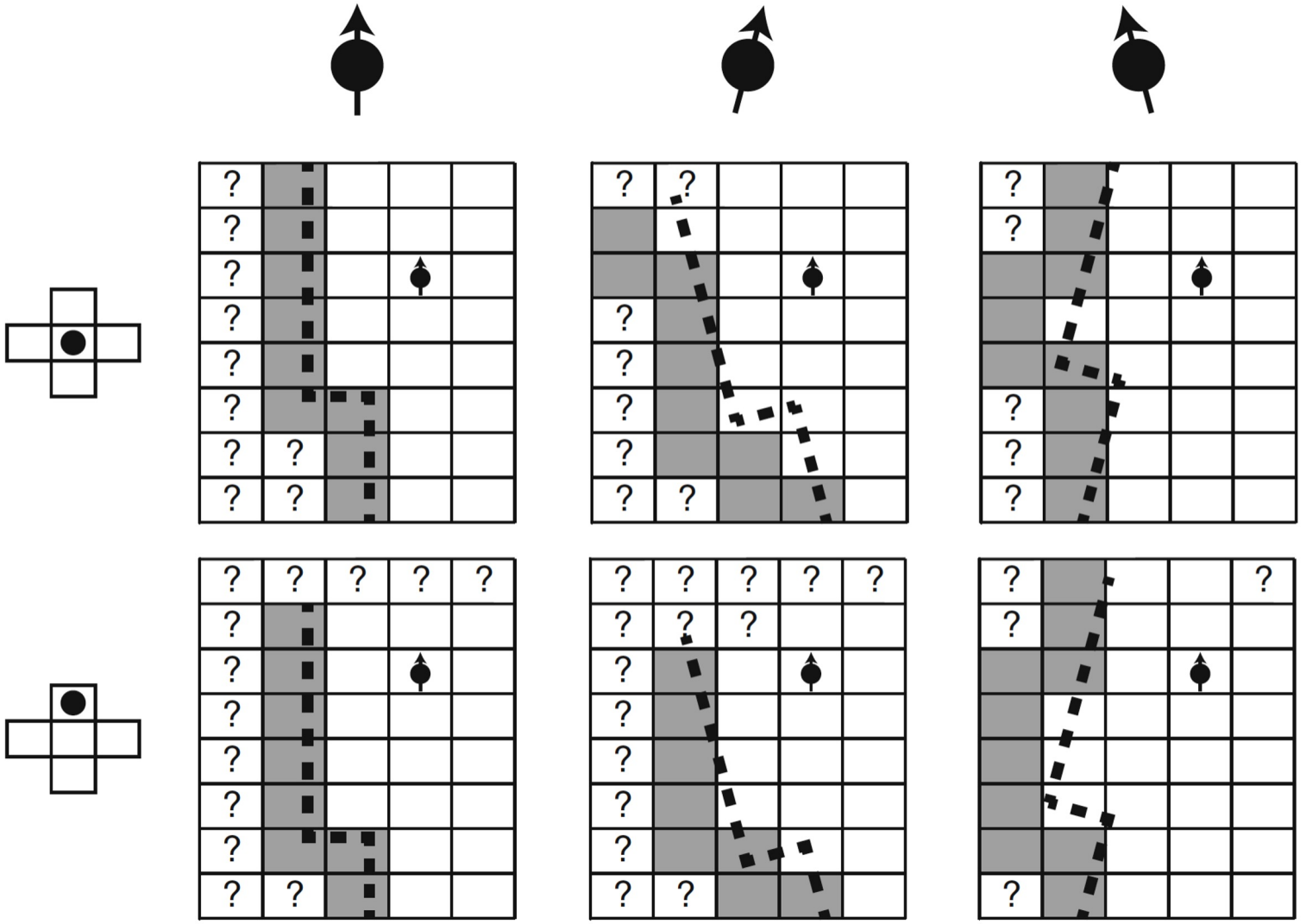


Example: Close Poses

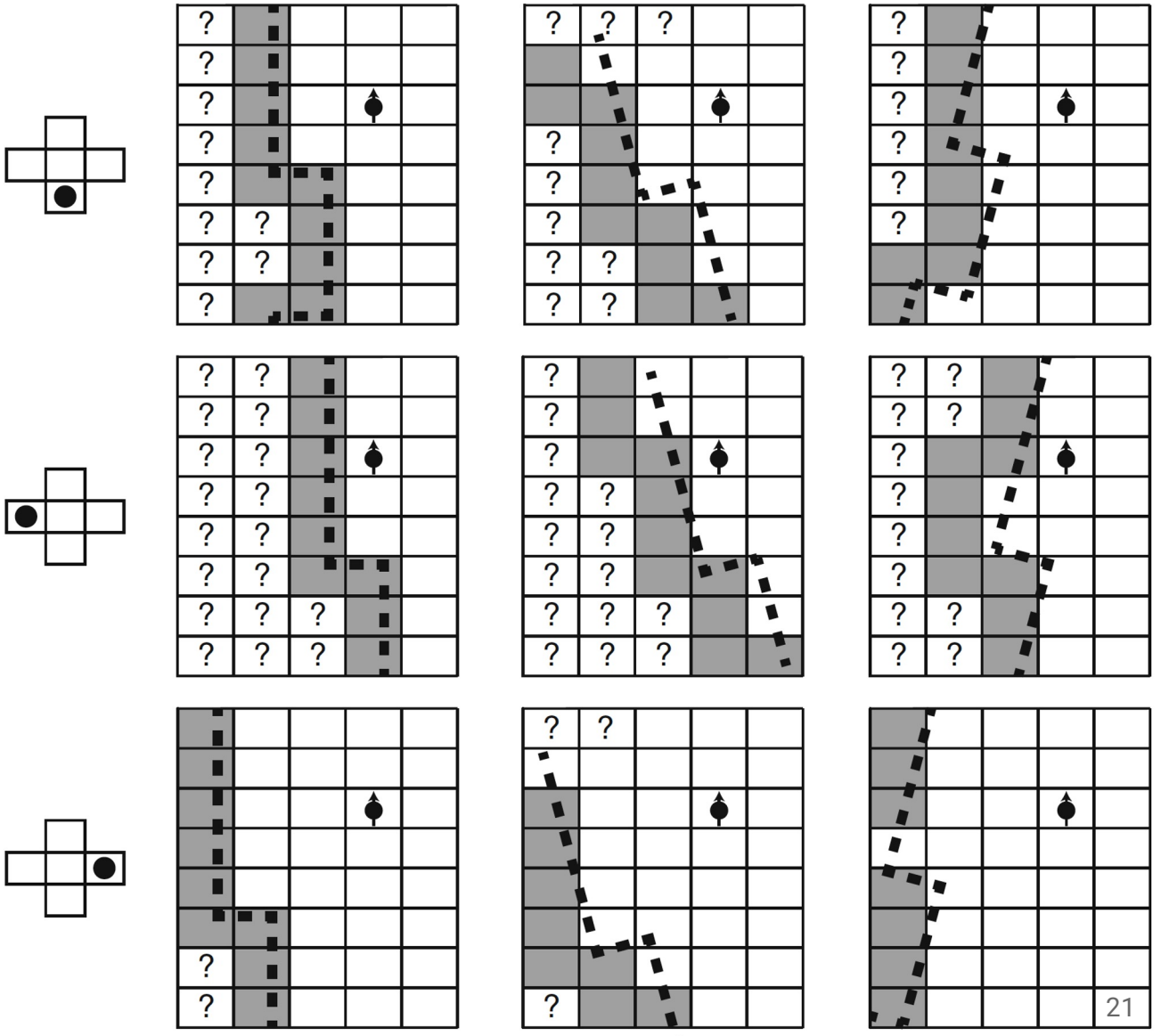




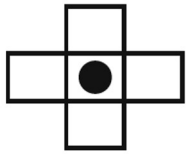
Example : Predictions



Example : Predictions



Example: Fit Prediction – Observation



0	1	-1	-1	-1
0	1	-1	-1	-1
0	1	-1	-1	-1
0	1	-1	-1	-1
0	1	-1	-1	-1
0	1	1	-1	-1
0	0	1	-1	-1
0	0	1	-1	-1

x

1	-1	-1	-1	-1
1	-1	-1	-1	-1
1	1	-1	-1	-1
0	1	-1	-1	-1
0	1	-1	-1	-1
0	1	-1	-1	-1
0	1	1	-1	-1
0	0	1	1	-1

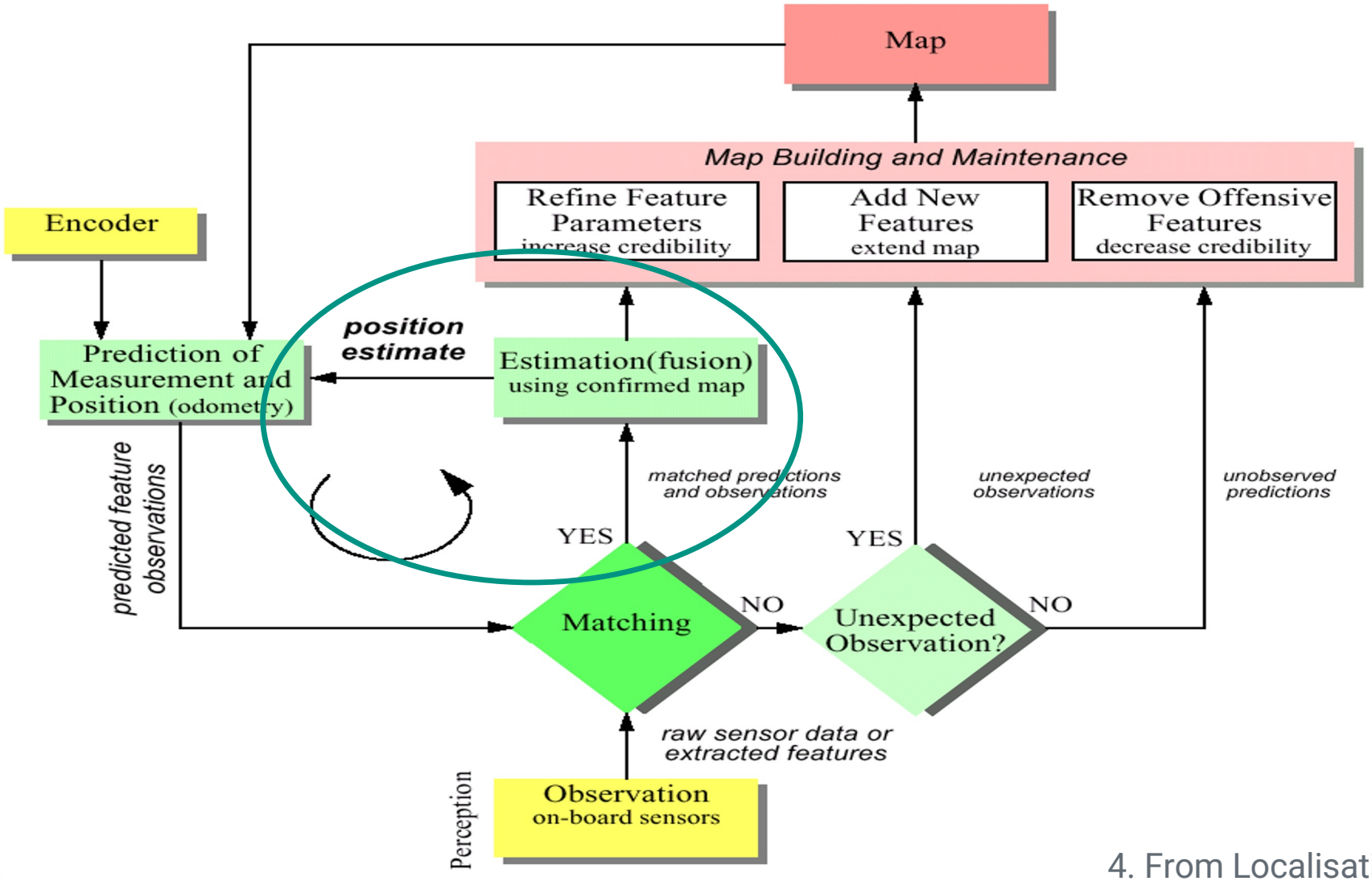
=

0	-1	1	1	1
0	-1	1	1	1
0	1	1	1	1
0	1	1	1	1
0	1	1	1	1
0	1	-1	1	1
0	0	1	1	1
0	0	1	-1	1

Example: Fit Prediction – Observation

Table 9.1 Similarity $\mathcal{S}$ of the sensor-based map with the current map

	Intended orientation	15° CW	15° CCW
Intended position	22	**32**	20
Up one cell	23	25	16
Down one cell	19	28	21
Left one cell	6	7	18
Right one cell	22	18	18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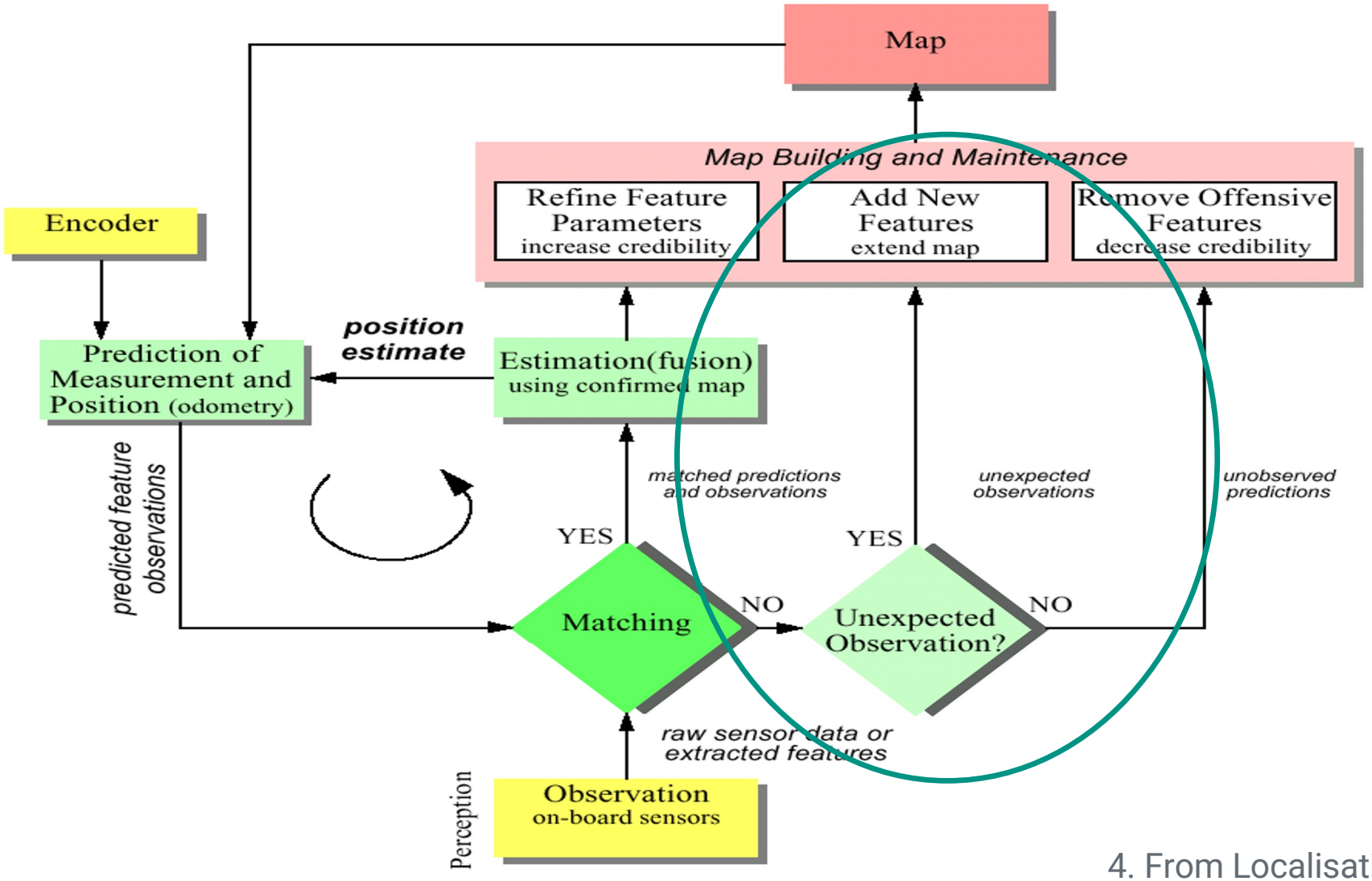
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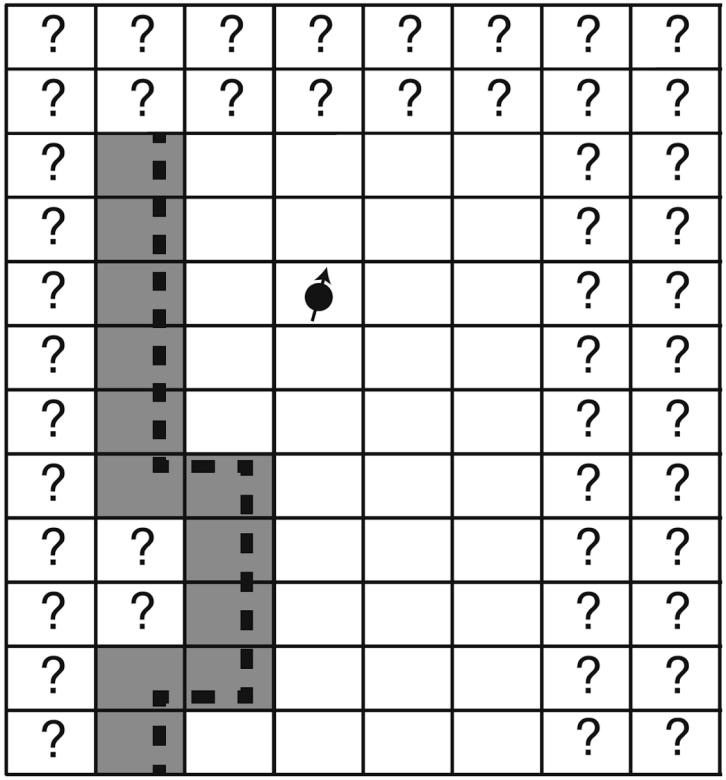
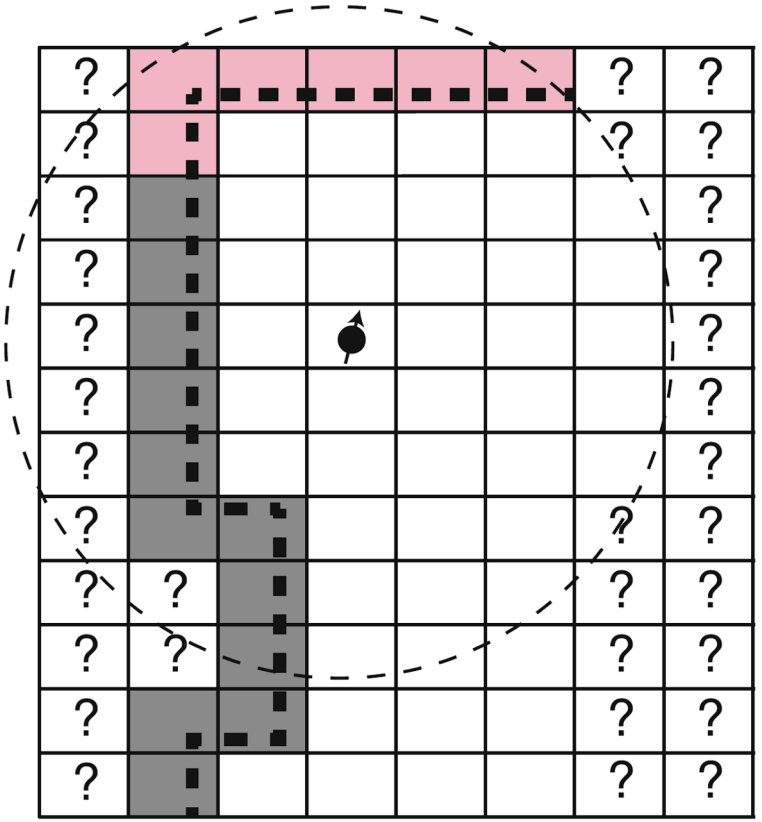
Features Matching





APPLICATION: 3D MODELING

SLAM – Different Approaches

- Volumetric Versus Feature-Based
  - Volumetric has sufficient information to allows rendering of the environment
  - Feature-Based use only some features, no rendering possible
- Topological Versus Metric
  - Topological only considers the relation between positions
  - Metric adds metric information
- Static Versus Dynamic
  - Most of the literature assumes static environments, without changes over time.

SLAM – Different Approaches

- Active Versus Passive
  - In active approach the robot moves to optimize the map construction. Most approaches are passive, based on pure observation.

- Single-Robot Versus Multi-Robot
  - Multi-robot approaches can be based on local communication for better scalability, for instance (distributed system)

Active Map Building : Exploration

- Free center of the map: low obstacles occupancy probabilities (0. 1 or 0. 2).
- Three known obstacles, characterized by high occupancy probabilities (0. 9 or 1. 0).
- Unknown cells elsewhere.
- Frontier cells are free cell that is adjacent (left, right, up, down) to one or more unknown cells. The set of frontier cells is called the frontier (red lines).

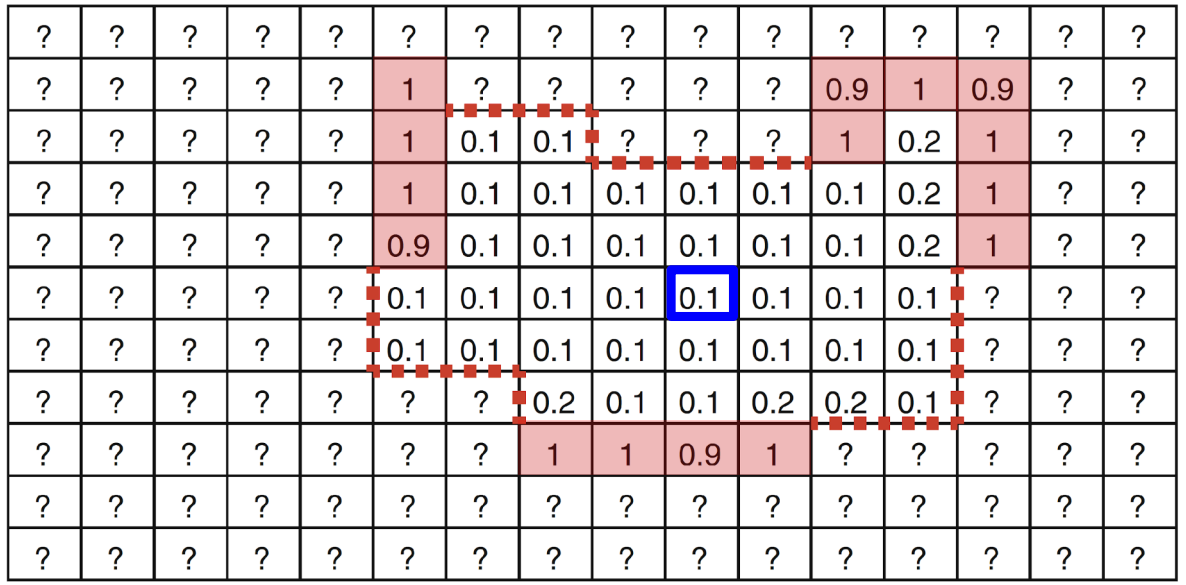
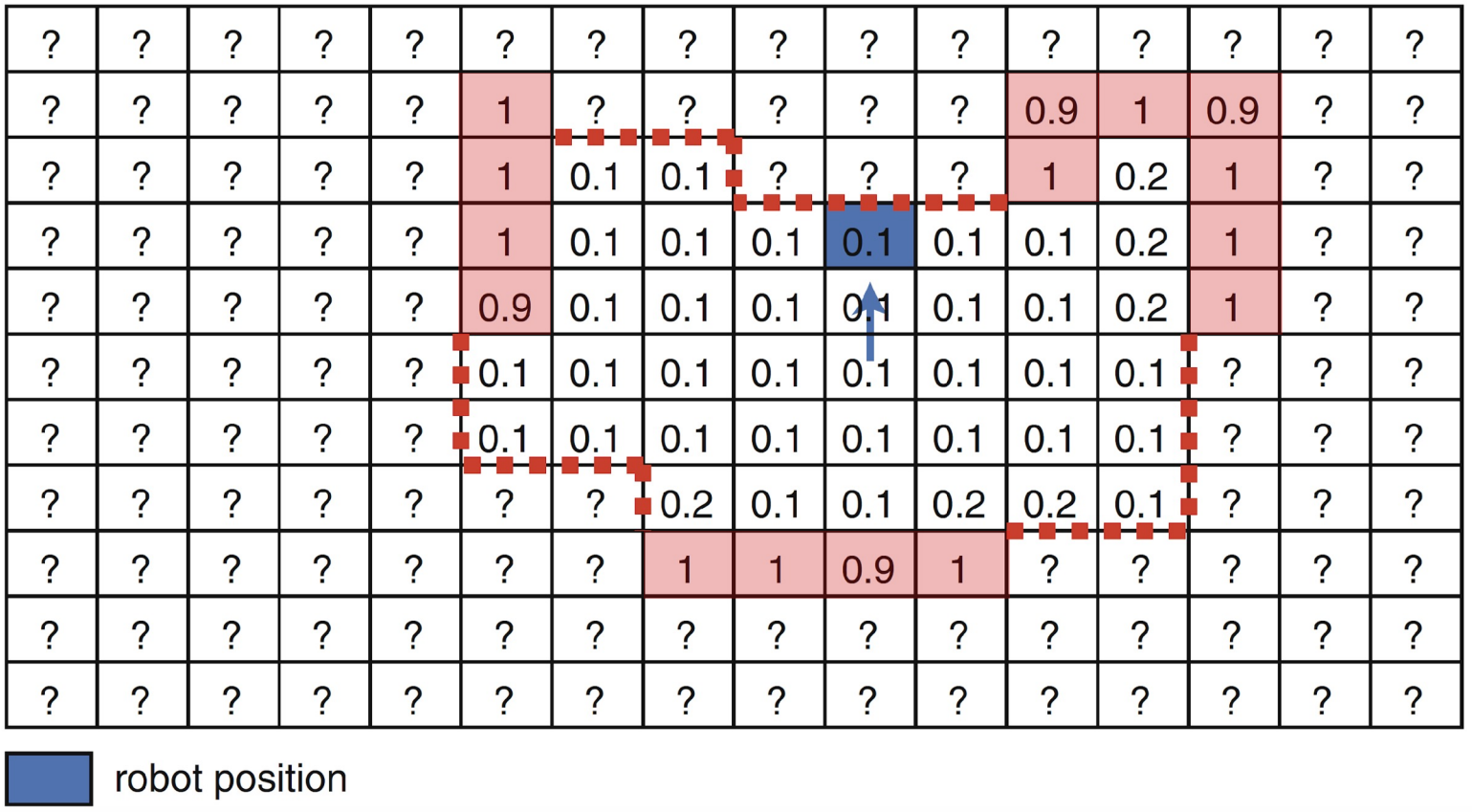


Fig. 9.4 Grid map of an environment with occupancy probabilities

Active Map Building : Exploration

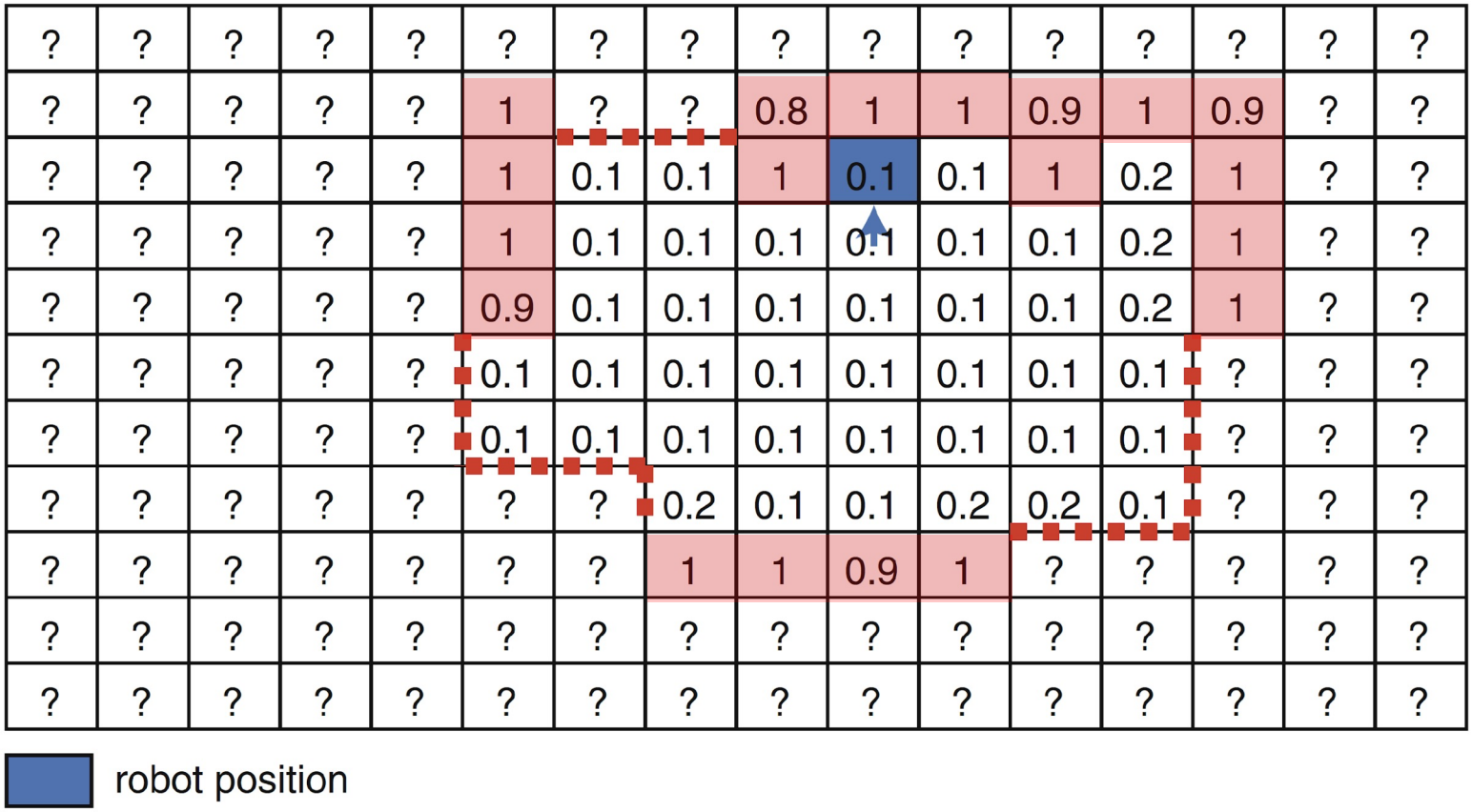


Active Map Building : Exploration

?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?
?	?	?	?	?	1	?	?	?	?	?	0.9	1	0.9	?	?
?	?	?	?	?	1	0.1	0.1	1	0.1	0.1	1	0.2	1	?	?
?	?	?	?	?	1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	1	?	?
?	?	?	?	?	0.9	0.1	0.1	0.1	0.1	0.1	0.1	0.2	1	?	?
?	?	?	?	?	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	?	?	?
?	?	?	?	?	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	?	?	?
?	?	?	?	?	?	?	0.2	0.1	0.1	0.2	0.2	0.1	?	?	?
?	?	?	?	?	?	?	1	1	0.9	1	?	?	?	?	?
?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?
?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?

robot position

Active Map Building : Exploration



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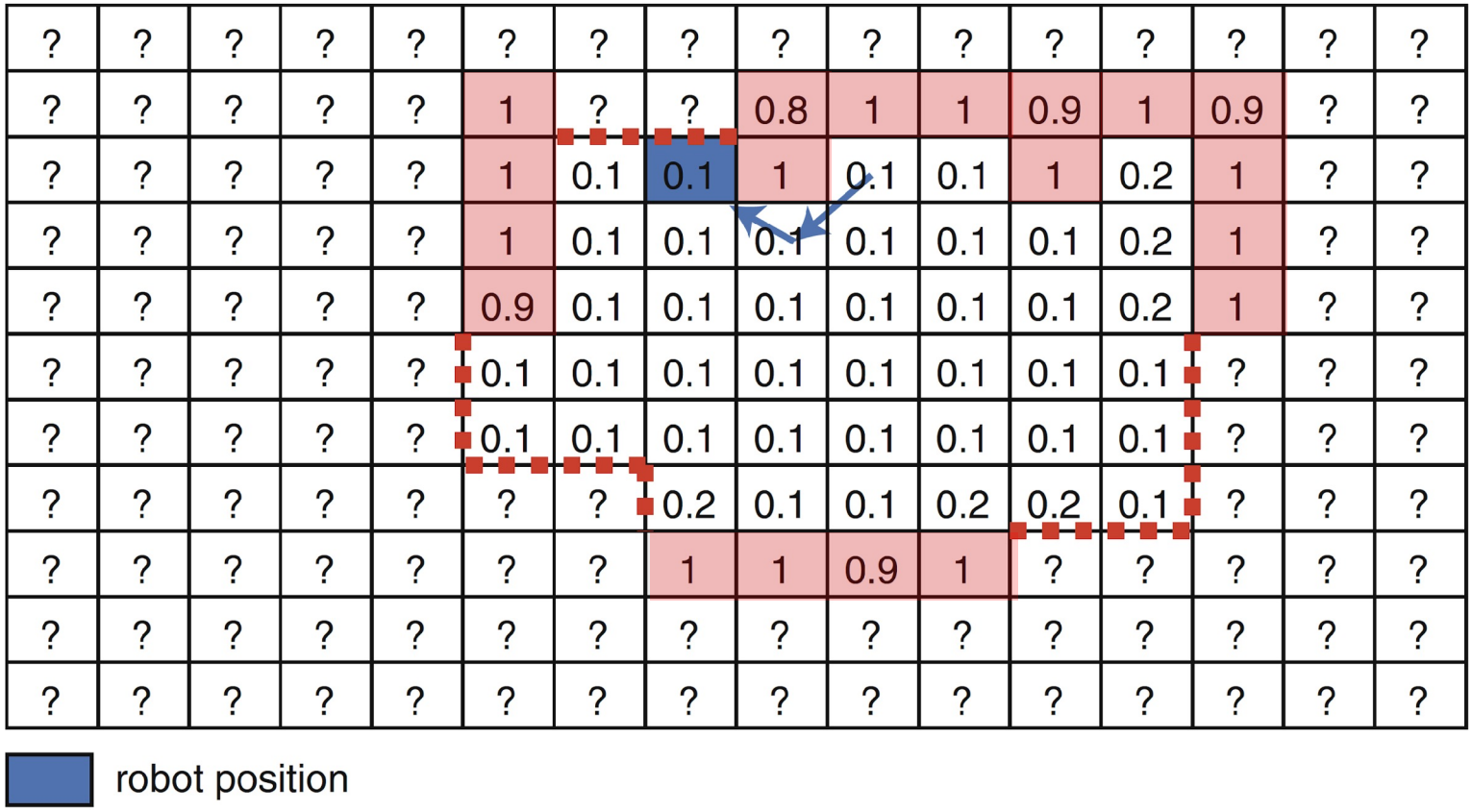
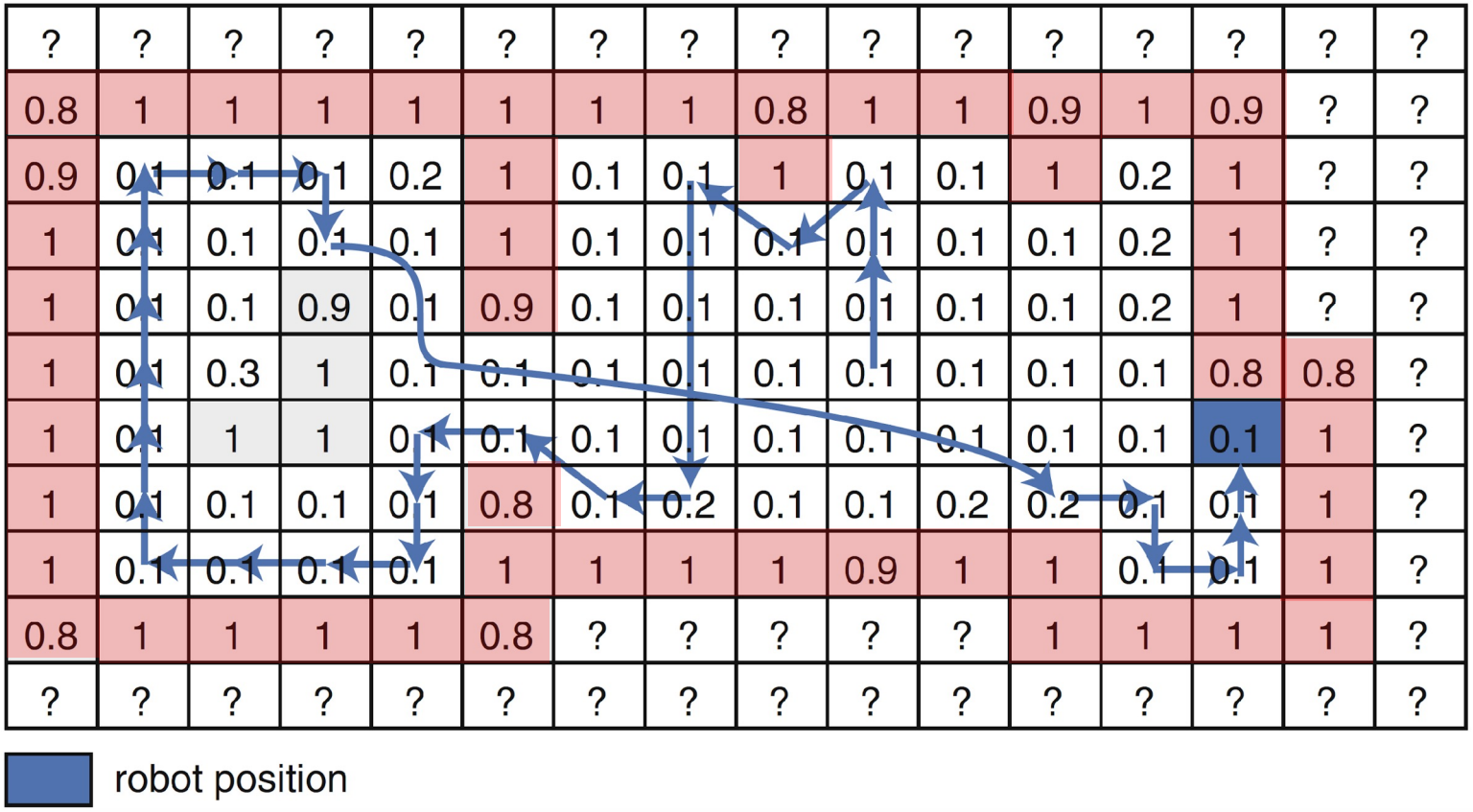


Active Map Building : Exploration



Exploration Criteria

You are here

Frontier cells

The criteria can be changed:

- the closest cell
- the higher number of unknown adjacent cells