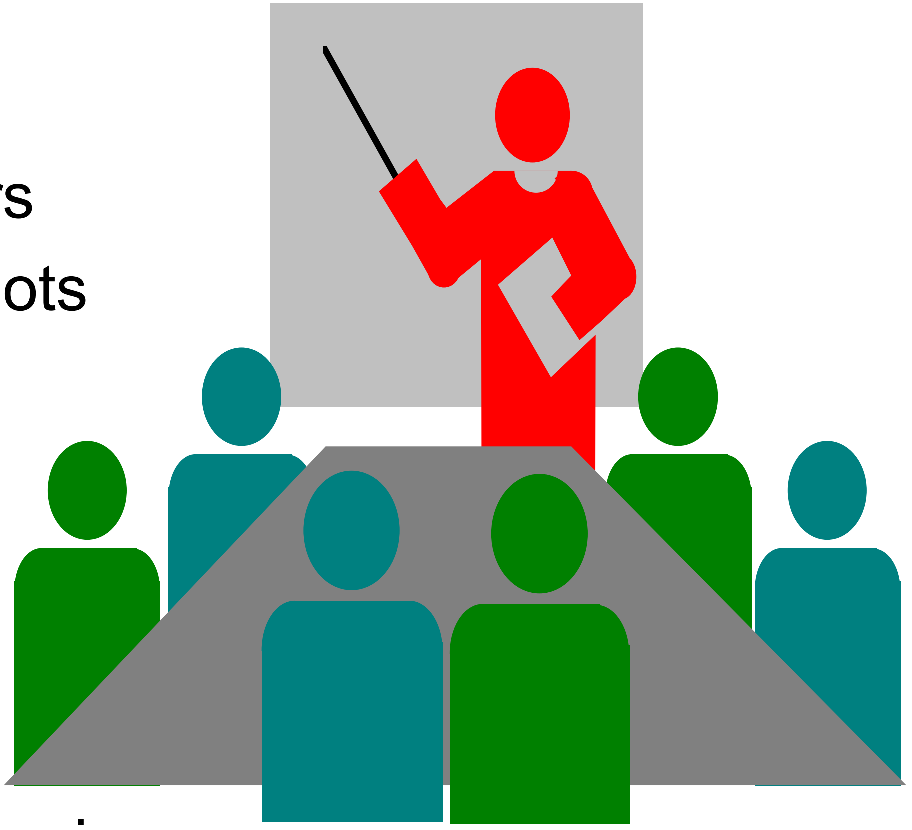
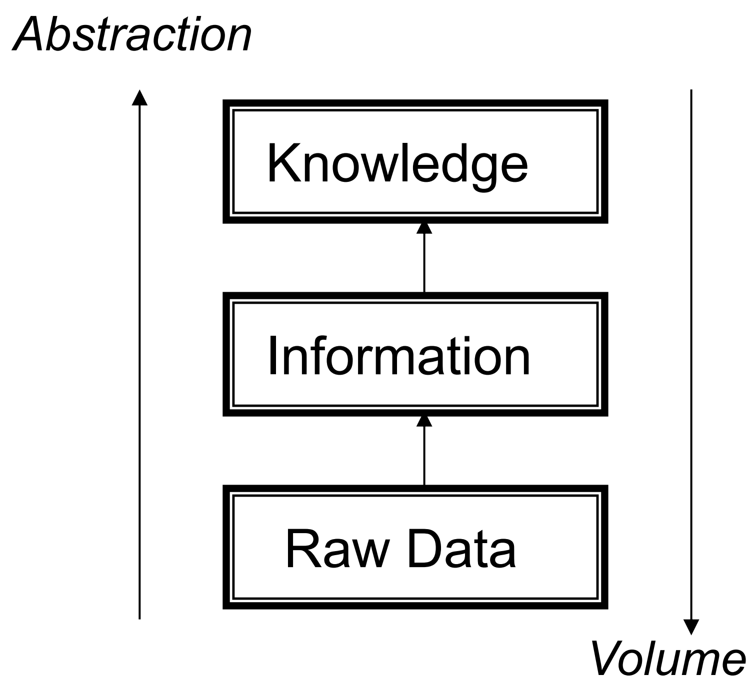
Topic 8: Knowledge Representation - Mapping



8.1 Introduction

8.1.1 What is knowledge?

- Knowledge is information in context, organised for solving real problems.
- Knowledge involves using information intelligently.



Controversy views:

- *Behaviour-based approach*

  The use of symbolic representational knowledge is a burden for efficient and reactive control of a robot.

- *Planning-based approach*

  The strong form of representational knowledge is needed for robots to become intelligent and do something useful.

Note: Traditional AI is distinguished from behaviour-based systems along the knowledge representation front.

8.1.2 Knowledge for Robot Behaviours

8.1.2 Knowledge for robot behaviours:

- **Environment correlation**

-- A knowledge representation must relate to with the external world to be useful.

-- The characteristics of the relationship including:

short term or long term → *knowledge persistence*

metric or relational → *knowledge correlation*

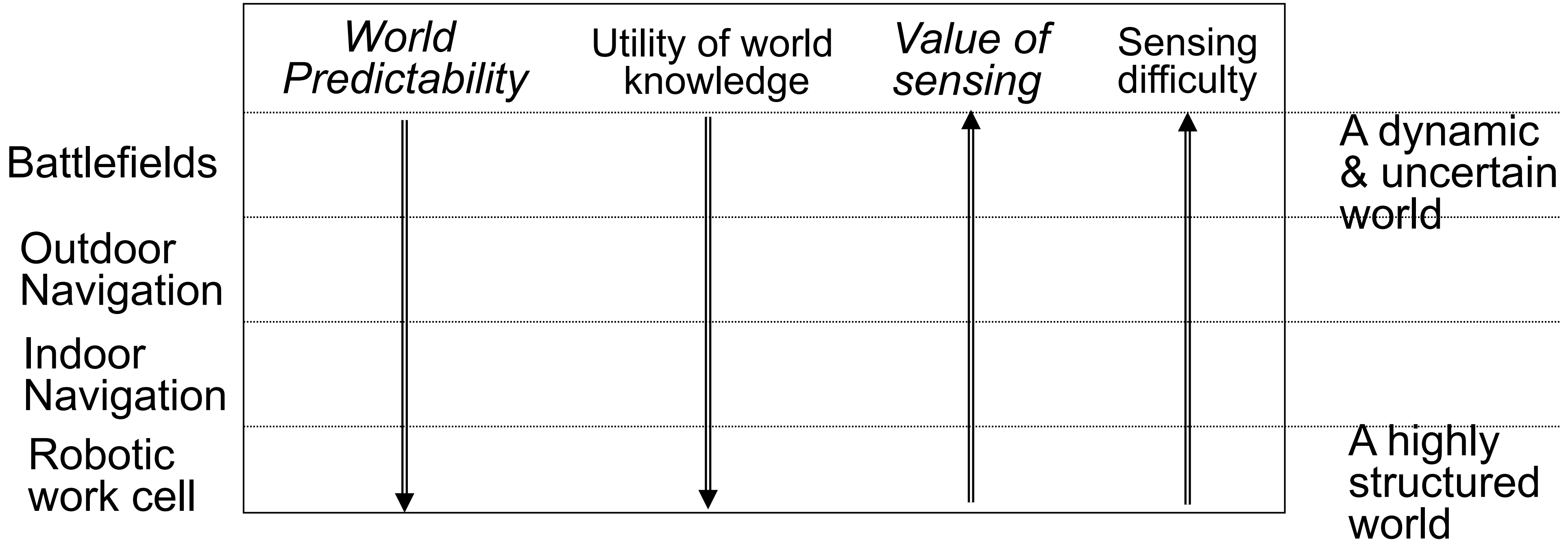
- **Predictive ability**

-- A pure reactive approach does not need to predict.

-- It is worthwhile to provide knowledge representations to encode useful information that is accurate and reliable.

-- The predictive ability enables a robot to justify whether the sensed information is accurate and timely.

8.1.2 Knowledge for Robot Behaviours



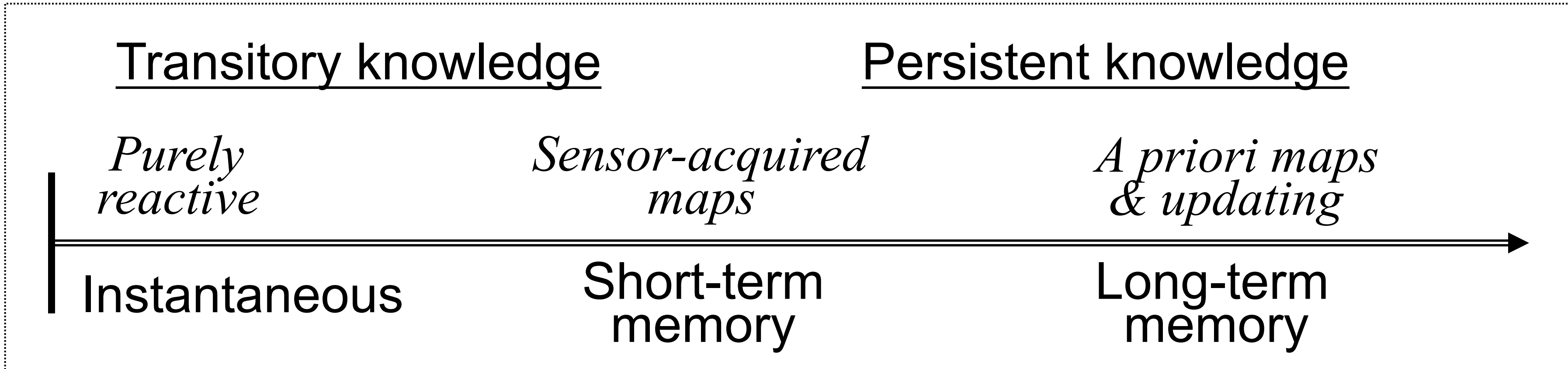
- Whenever the world changes rapidly, stored knowledge becomes potentially obsolete quickly.
- It is important to maintain an accurate correlation between the robot's knowledge representations and the external world.

8.2 Knowledge Representation for Robots

8.2.1 Typical types of knowledge for robots:

- *Spatial world knowledge* -- an understanding of the navigable space and structure surrounding the robot, including two main forms: *qualitative or quantitative.*
- *Object knowledge* -- categories of things within the real world
- *Perceptual knowledge* -- information regarding how to sense the environment under various circumstances
- *Behaviour knowledge* -- understand how to react in different situation
- *Ego knowledge* -- limits on the abilities of the robot's actions within the world (i.e. speed, fuel, etc.) and on sensor models
- *Intentional knowledge* -- information regarding the robot's goals and intended actions within the environment - a plan of action.

8.2.2 Transitory and Persistent Knowledge



Time Horizon

- All intelligent systems must use knowledge to accomplish their goals.
- To be truly intelligent, the knowledge usage must be efficient & effective.
- Transitory (fades) knowledge is dynamically required as robots move through the world, stored in the short-term memory.
- Persistent knowledge involves a priori information about the robot's environment & updated information, stored in the long-term memory.

8.2.3 Knowledge Representations

1. *Short-term behaviour memory*

-- It provides knowledge on a need-to-know basis.
-- It is action-oriented knowledge representation.

2. A priori map-based long-term representations

-- It is normally generated from floor plans or external map of the environment,
gathered independently of the robotic agent.
-- It may be inaccurate and untimely.

3. Sensor-derived long-term cognitive maps

-- Information is directly perceived from the environment, used to construct a standalone world model.
-- The model is continuously updated and modified attempting to maintain a close correlation with the real world.

8.2.4 Neural Cognitive Robots

Neural Cognitive Robot

Learning, Memory and Intelligence

8.3 Short-Term Memory Map

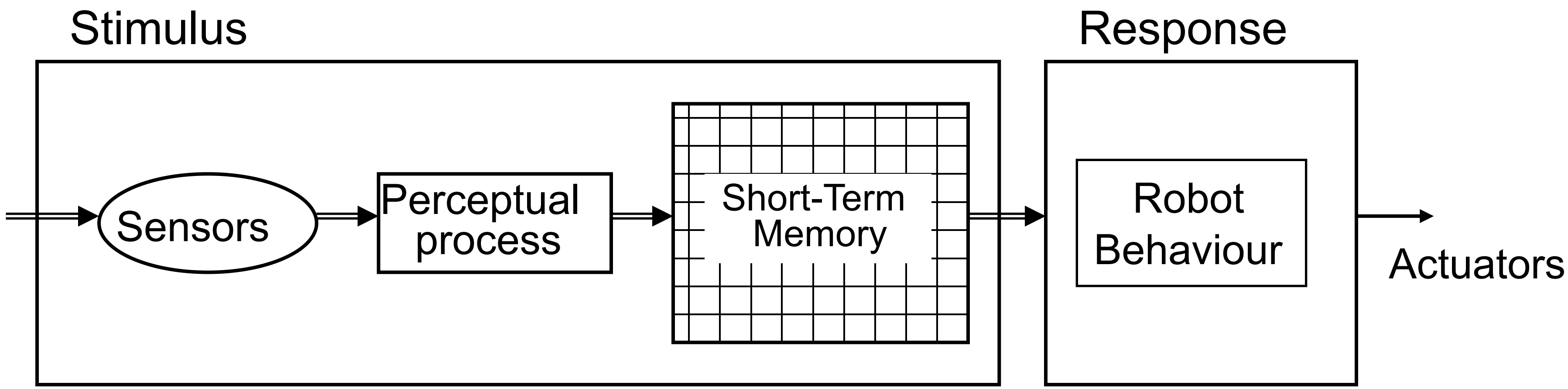
Short-Term Memory (STM) Map

-- It reduces the need for frequent sensor sampling.
-- It provides recent information to guide the robot.
-- It is normally limited within the surrounding of the robot.

General characteristics:

- It supports a single behaviour in behavioural control systems.
- It directly feeds the behaviour, serves as a buffer and translator between sensory data and the behaviour.
- It is transitory: the representations are constructed and used while the robot is in the environment, and then discarded.
- It is well suited for a dynamic and unknown environment where obstacles may change overtime.
- ***Grid representations*** are commonly used in STMs.

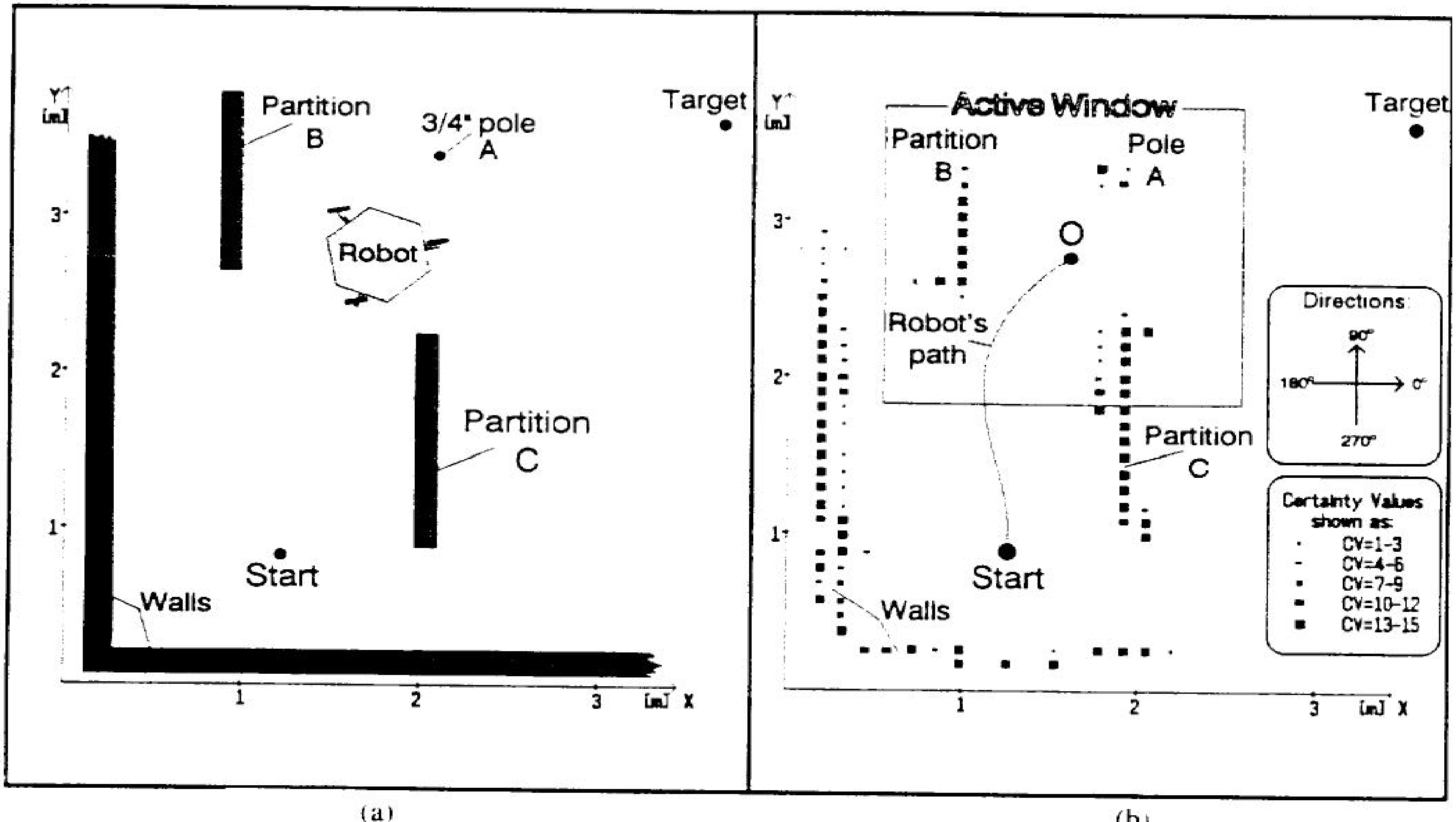
8.3 Short-Term Memory Map



Short-Term Behavioural Memory

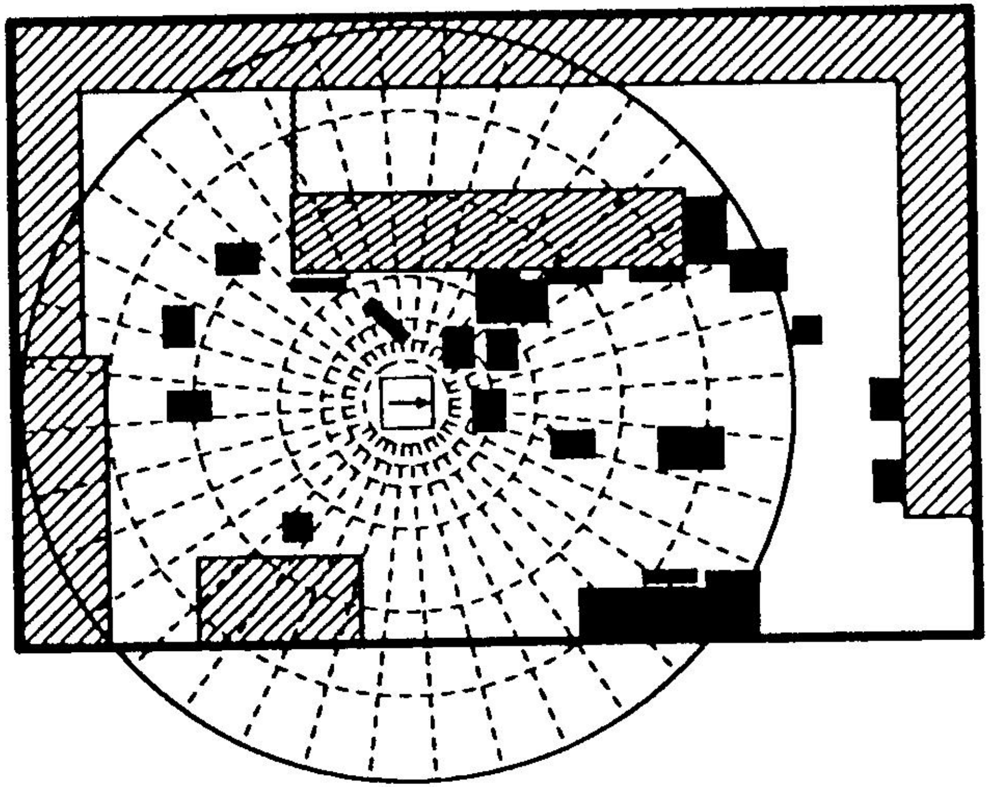
- ***Resolution***: is the amount of area each grid covers (an inch or a meter).
- ***Shape***: most frequently square, but may in other forms such as radial sectors.
- ***Uniformity***: the grid cells have the same size, or may vary in size, such as quad-trees which are formed through the recursive decomposition of free space.

8.4 Short-Term Memory Map

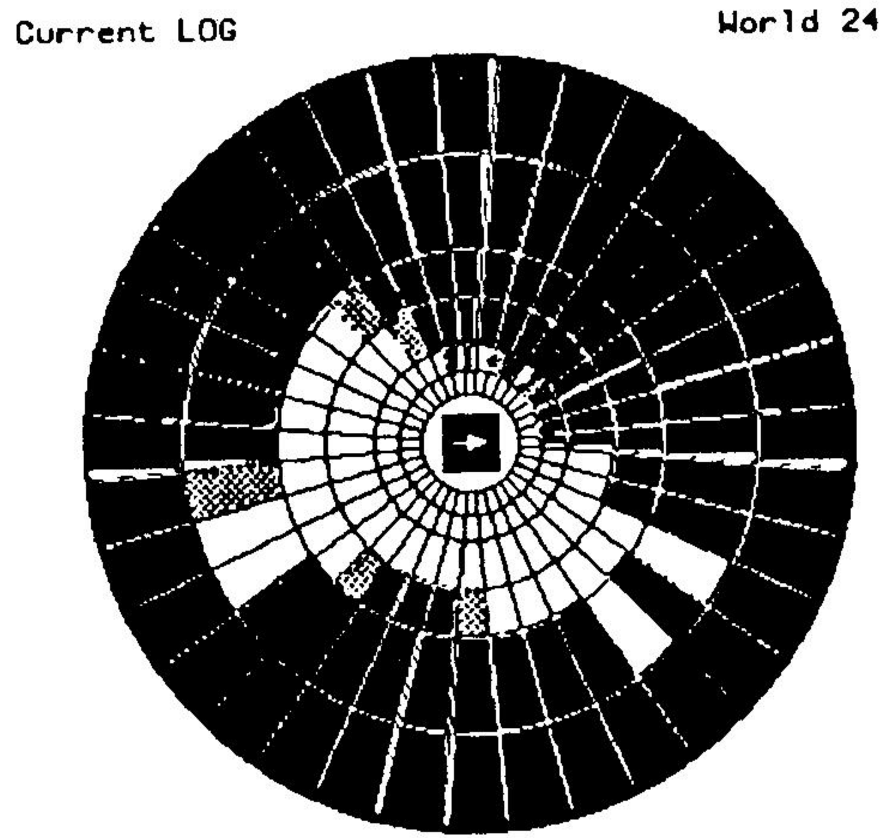


Regular grid based STM

8.3 Short-Term Memory Map



A typical environment



STM in the sector format

8.4 Long-Term Memory Map

It is used to store persistent information regarding the environment, typically encoded in one of two forms:

- ***Quantitative form***: in which absolute measurements and coordinate systems (x, y) are used to represent information regarding the world.
- ***Qualitative form***: in which salient features and their relationships with the world are represented, e.g. "turn left at the 2nd door", or "continue moving until you see the sign".

Two generating methods

- A priori map-derived representations in LTM (*Long-Term Memory Map*)
- Sensor-derived cognitive maps in LTM (*Long-Term Memory Map*)

8.4.1 A Priori Map-derived LTM

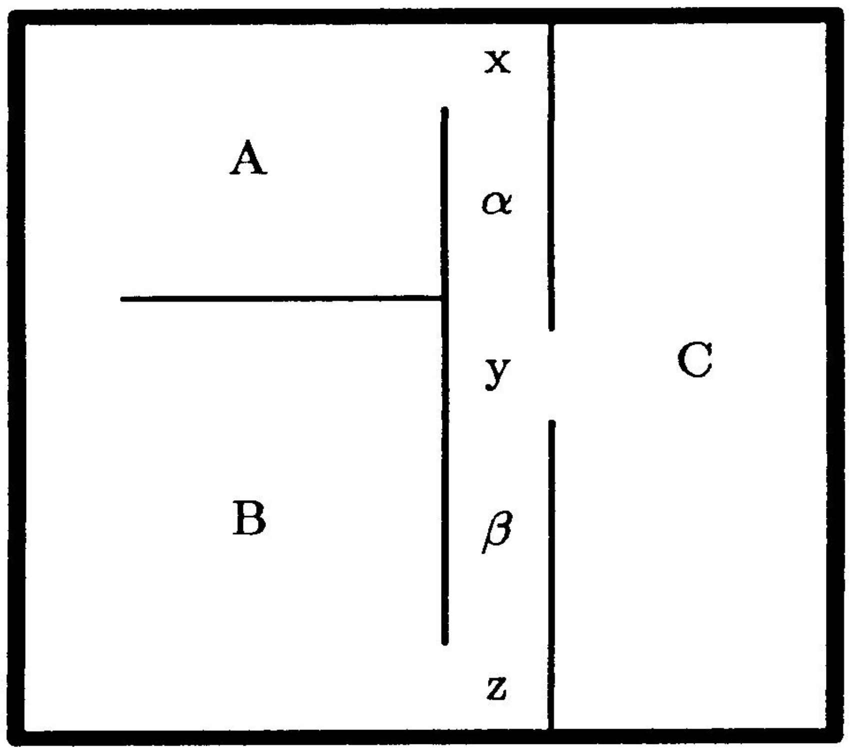
- It is easily constructed from data available in the GSA (*Geographical Survey Agency*).
- Precompiled sources of information may be used, such as blueprints, floor plans and roadmaps.

However

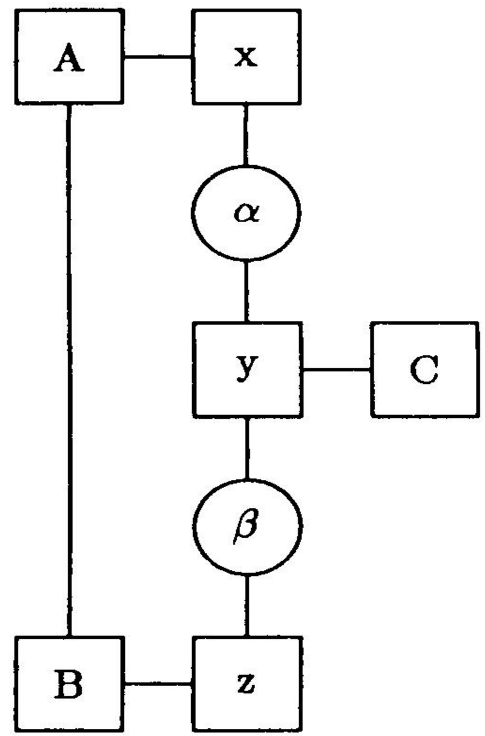
- Errors may be introduced in the process of encoding the new data.
- The data may be relatively old than current sensor readings.
- The frame of reference may be incompatible with the robot's point of view.
- It is mainly used to provide guidance for a robot to operate in a new environment.

8.4.1 A Priori Map-derived LTM

Topologic Representation

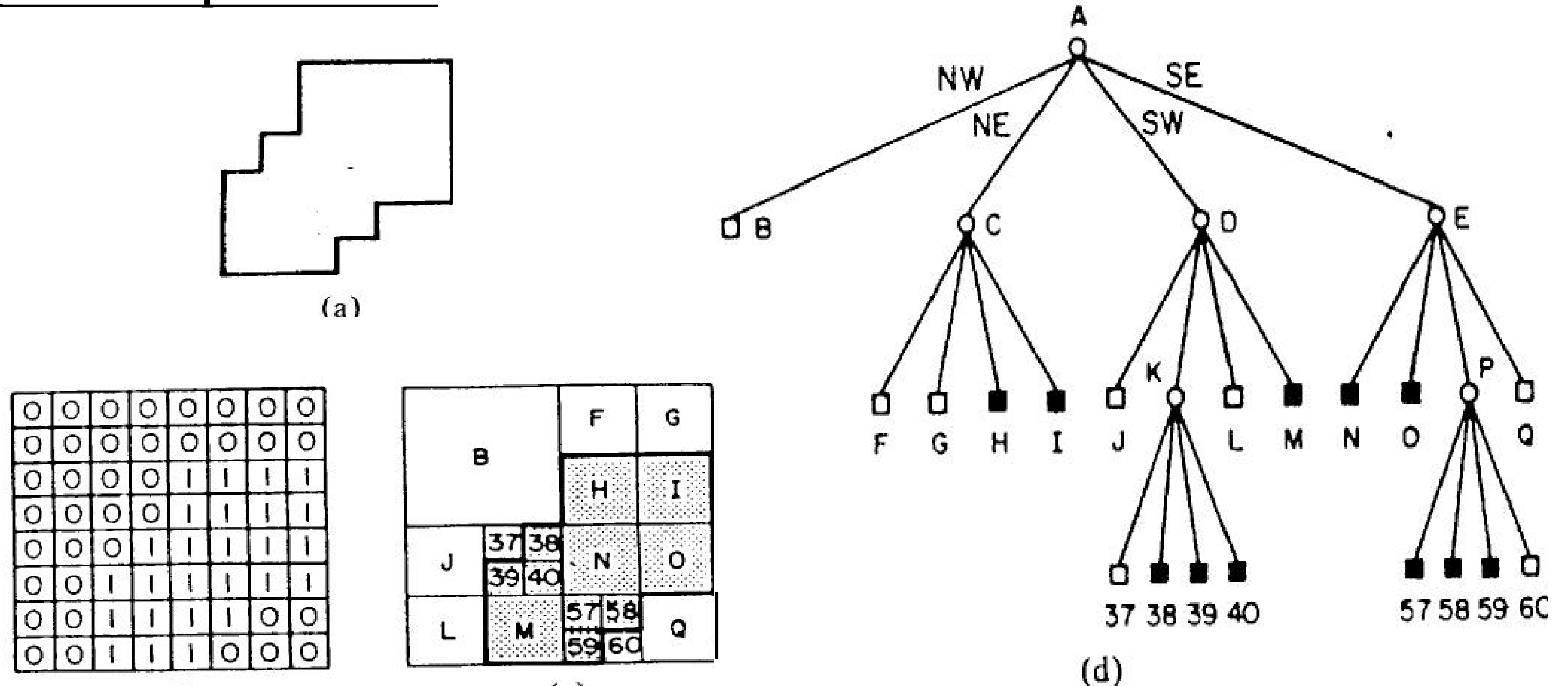


A typical environment



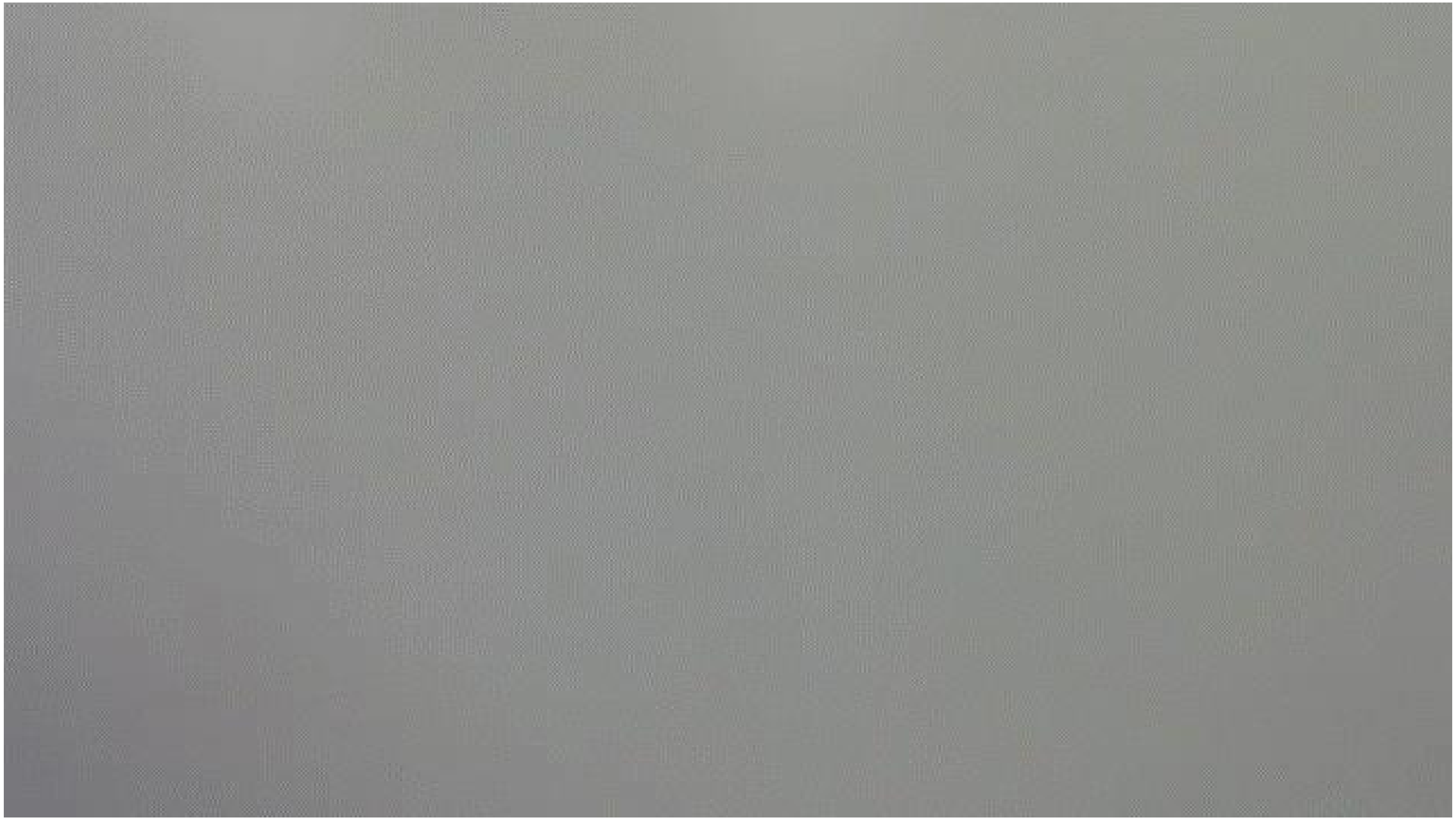
Its topologic map

Quadtree representation

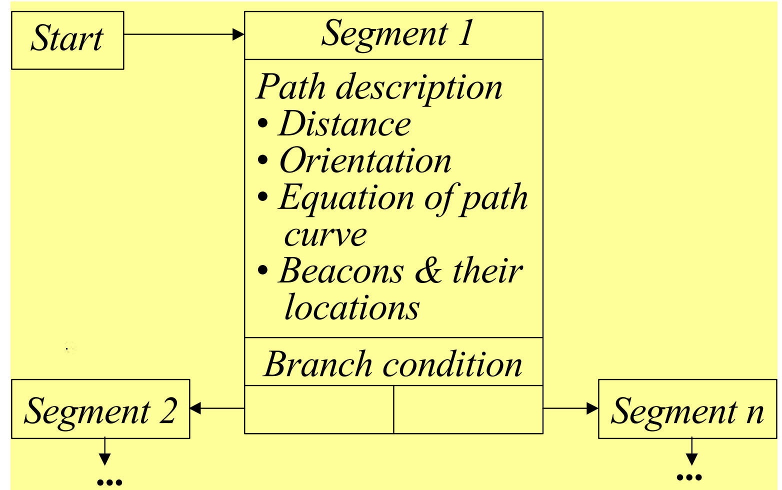


(a) (b) (c) (d)

8.4.1 A Priori Map-derived LTM

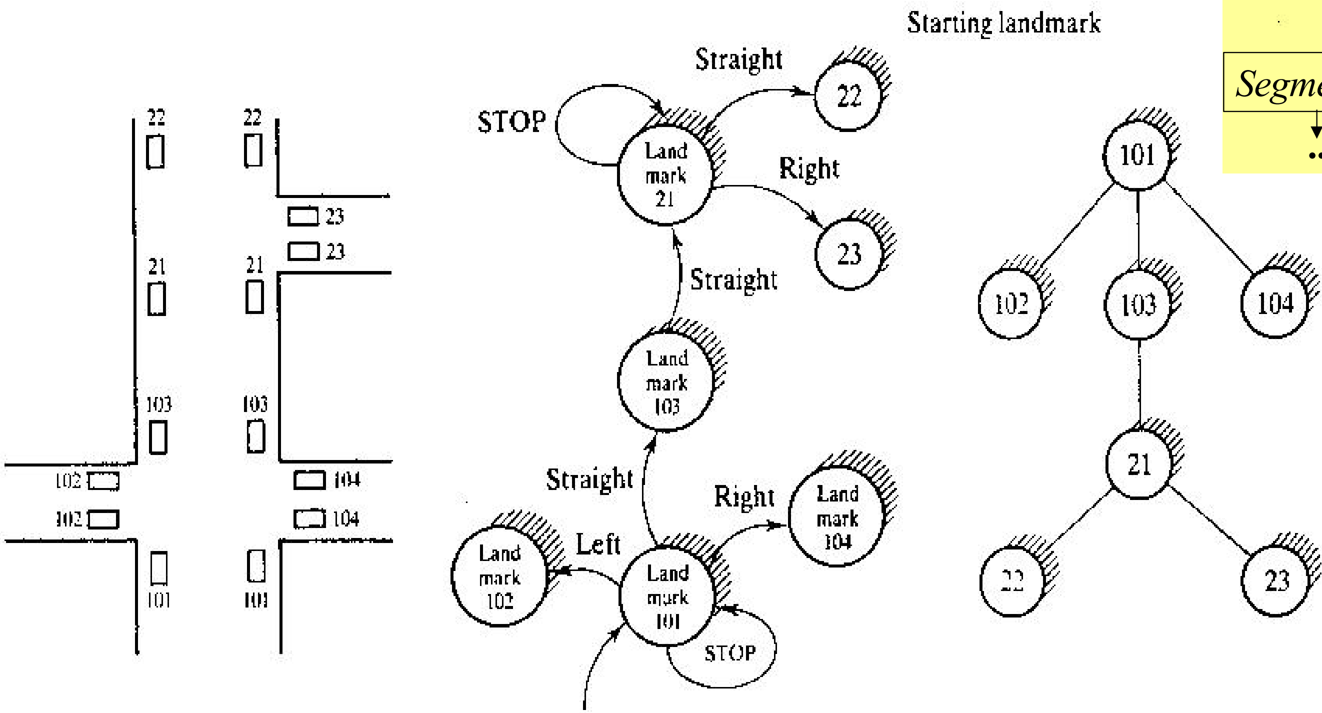


8.4.1 A Priori Map-derived LTM



Path or Landmark representation

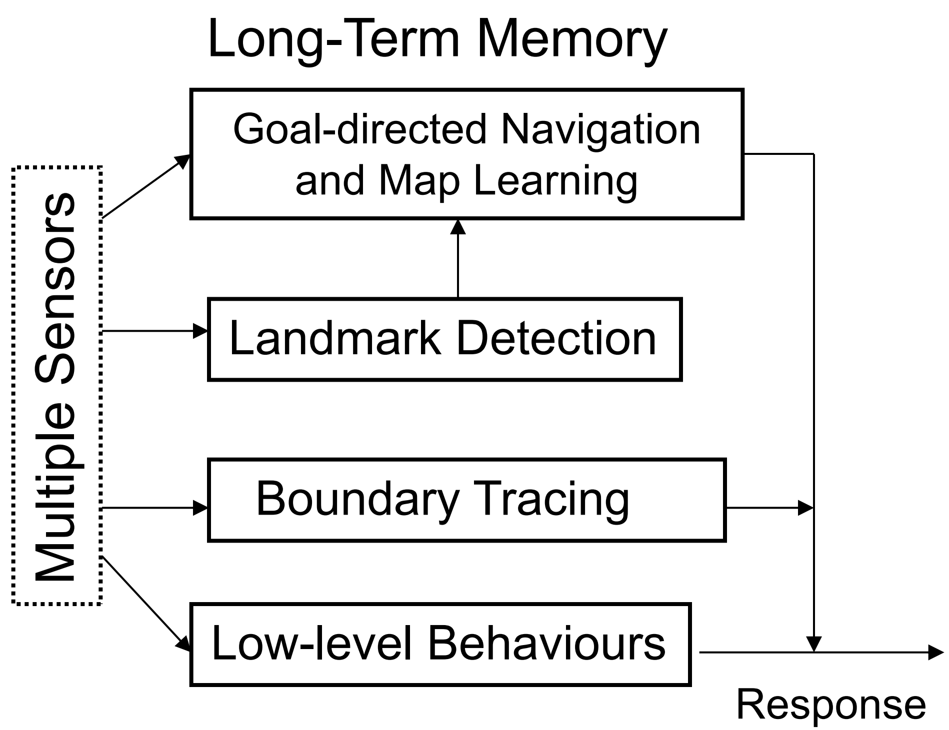
- Landmarks are represented by notes in the graph, and streets connect these landmarks by arcs. More details can be seen from the following figure.



- A priori-map-derived LTM can be represented by data structures as shown above. LTM links the start point to Segment 1, and then links to other segments one by one.

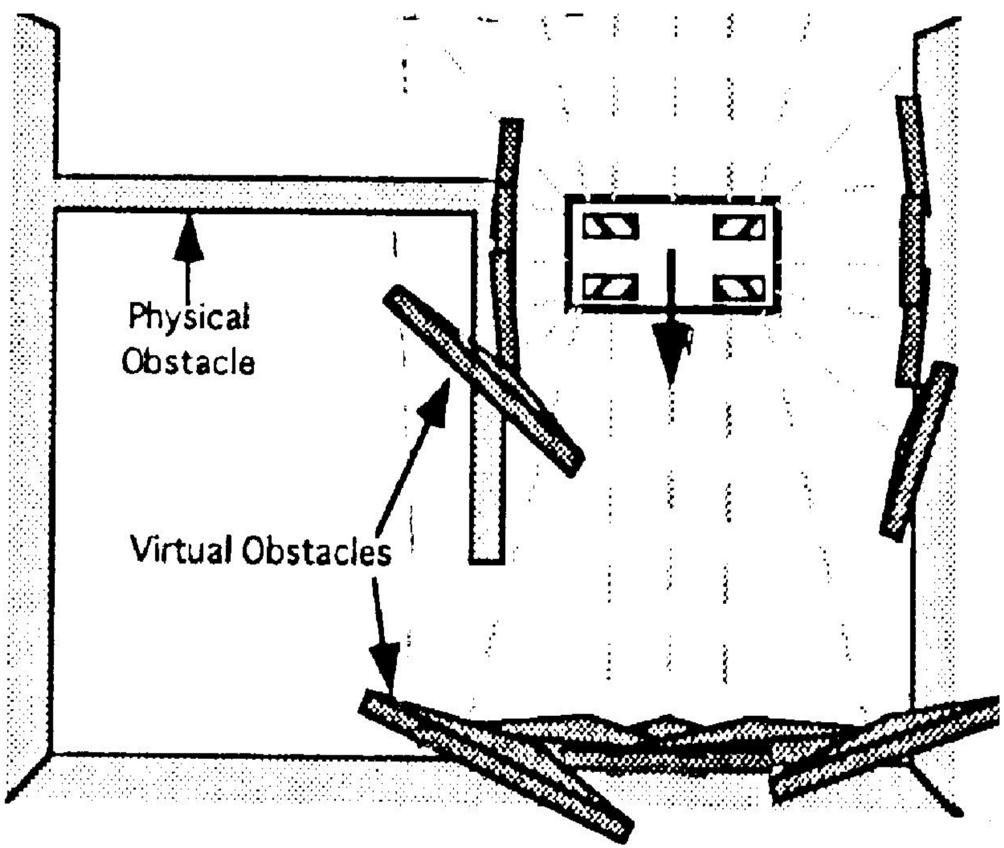
8.4.2 Sensor-derived LTM

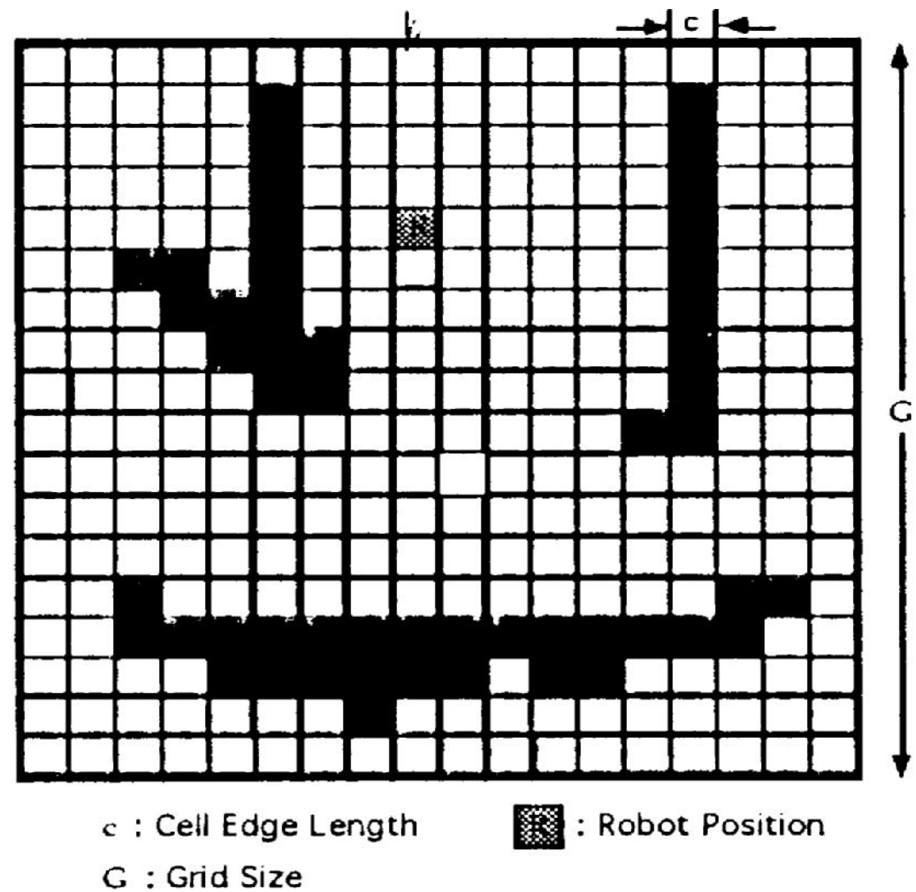
- Sensor-derived maps provide information directly gleaned from the robot's experiences within the real world.
- The notion of *distinctive places* is used in a qualitative representation.
- Distinctive places is stored in the robot's LTM, updated by new sensor readings.
- Distinctive places serve as landmarks for locating a mobile robot in the environment.



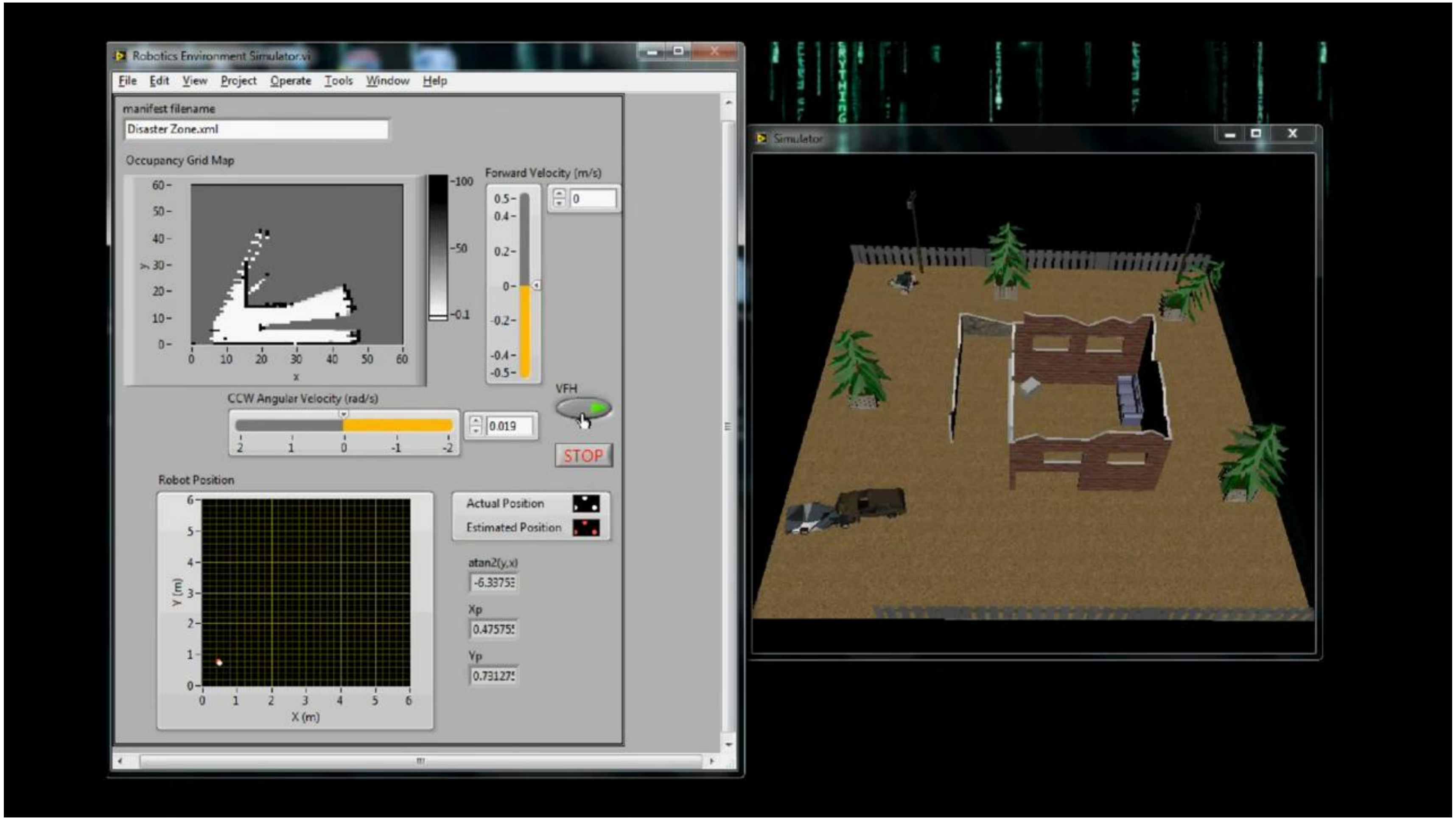
8.4.2 Sensor-derived LTM

Regular Grid Representation





8.4.2 Sensor-derived LTM



8.5 Map Building Process

- Map building converts a local or robot centred sensor observations into a global map based on the robot location.
- The more often the robot is able to locate itself, the more accurate the global map can be produced.
- Concurrent map-building and localisation becomes necessary.

Feature based

Metric based

One of most common data structures used to present metric maps is the *occupancy grids: Two dimensional array regular grids*
a high resolution (5-9cm per grid element)

8.5 Map Building Process

Robotic survey

8.5 Map Building Process

Building Occupancy Grid Map

- The great accuracy is obtained in occupancy grids by fusing multiple uncertain sensor readings together.
- To build a global grid map, there are three methods:

-- Bayesian method:

Probabilistic sensor models + Bayes updating rule

-- DS (*Dempster-Shafer*) method:

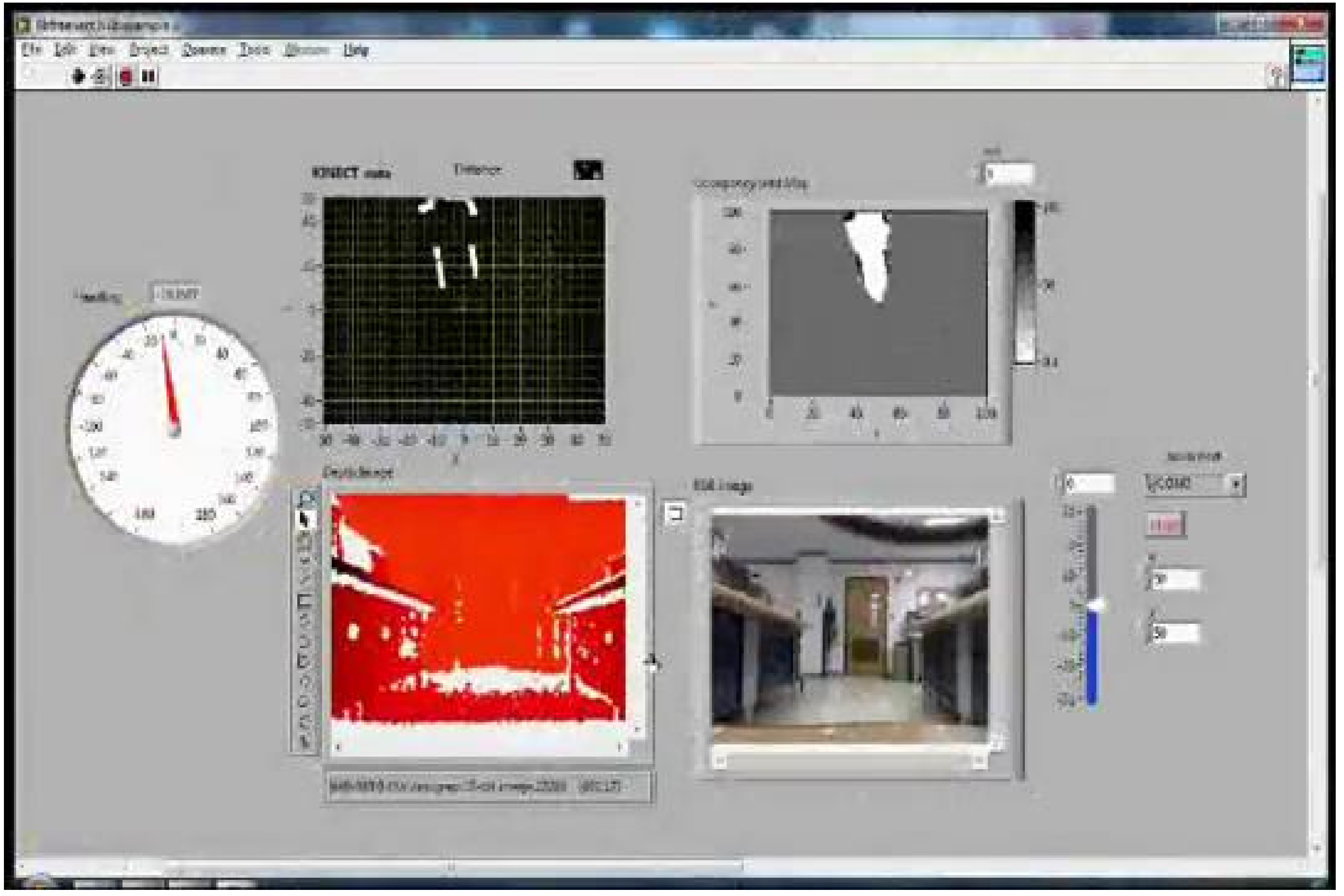
Possibilistic sensor models + Shafer belief functions & Dempster's rule

-- HIMM (*Histogrammic in Motion Mapping)* method:

Ad hoc sensor models + Heuristic updating rule

8.5 Map Building Process

Building an occupancy grid map using IMU & Kinect



8.6 Simultaneous Localisation And Mapping

8.6.1 What is SLAM?

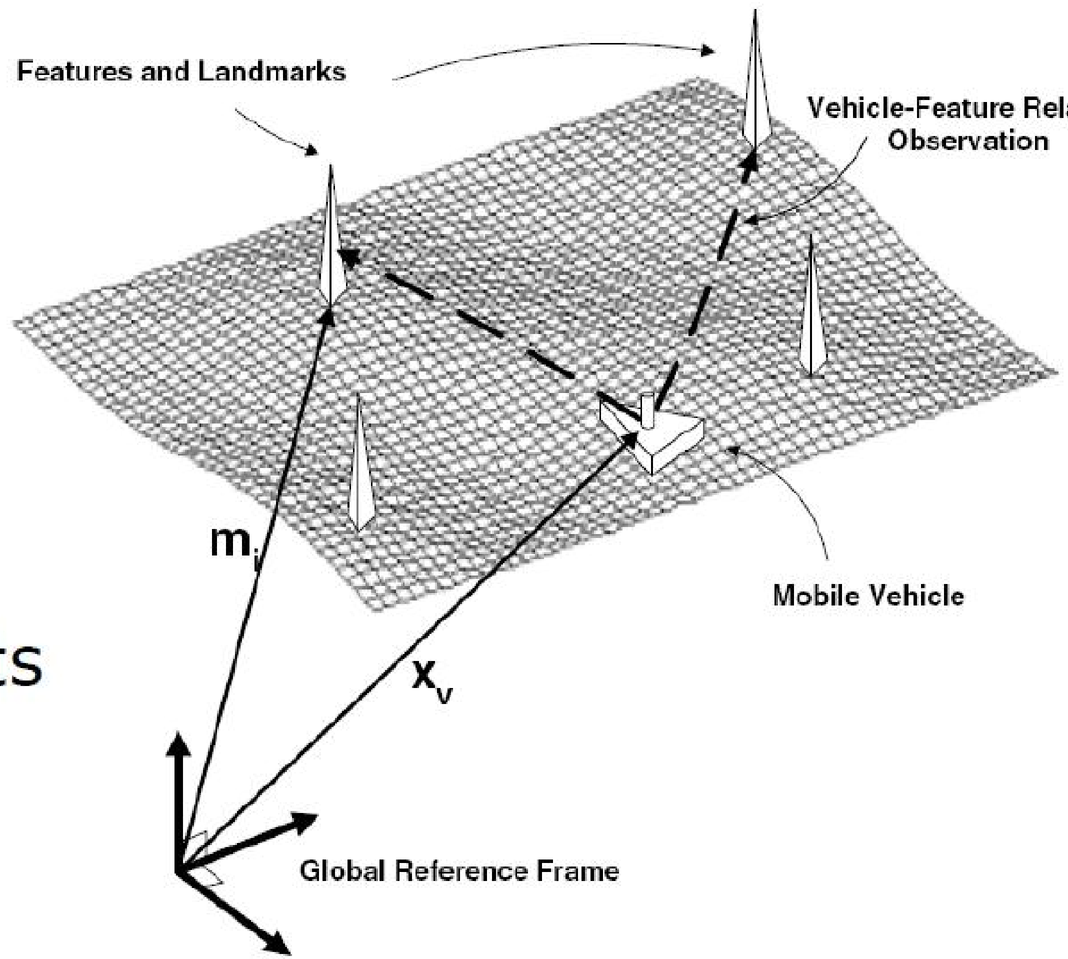
- Estimate the robot pose and the map of the environment at the same time.
- SLAM is hard as it is "Chicken and Egg problem":
  - A map is needed for localization, and
  - A good pose estimate is needed for mapping.

8.6.2 History of SLAM

- SLAM is key for robots operated in unknown environments.
- Large variety of different SLAM approaches have been developed.
- The majority of SLAM approaches uses probabilistic concepts.

8.6.3 Feature based SLAM

- **Absolute** robot poses
- **Absolute** landmark positions
- But only **relative** measurements of landmarks



8.6.3 Feature based SLAM

Given:

- The robot's controls

$$U_{1:k} = \{u_1, u_2, \ldots, u_k\}$$

- Relative observations

$$Z_{1:k} = \{z_1, z_2, \ldots, z_k\}$$

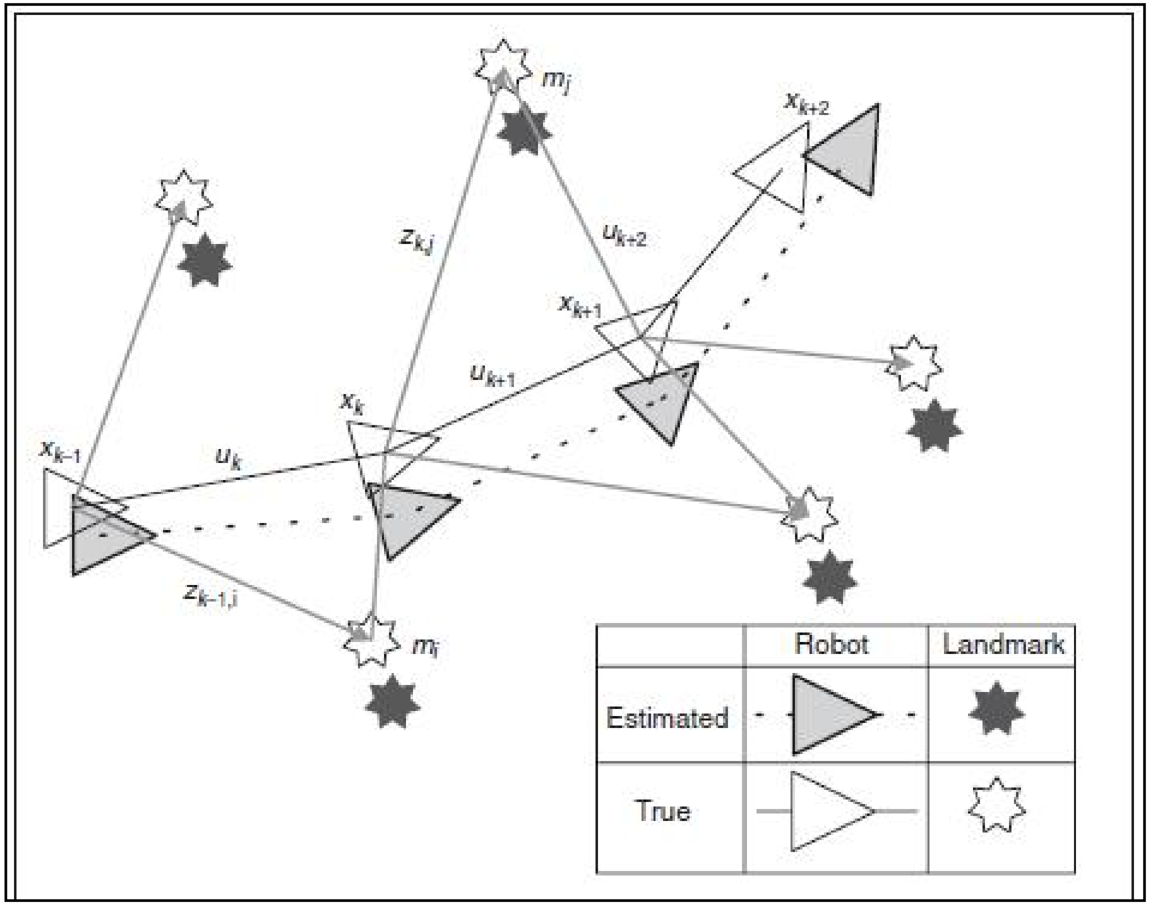
Wanted:

- Map of features

$$m = \{m_1, m_2, \ldots, m_n\}$$

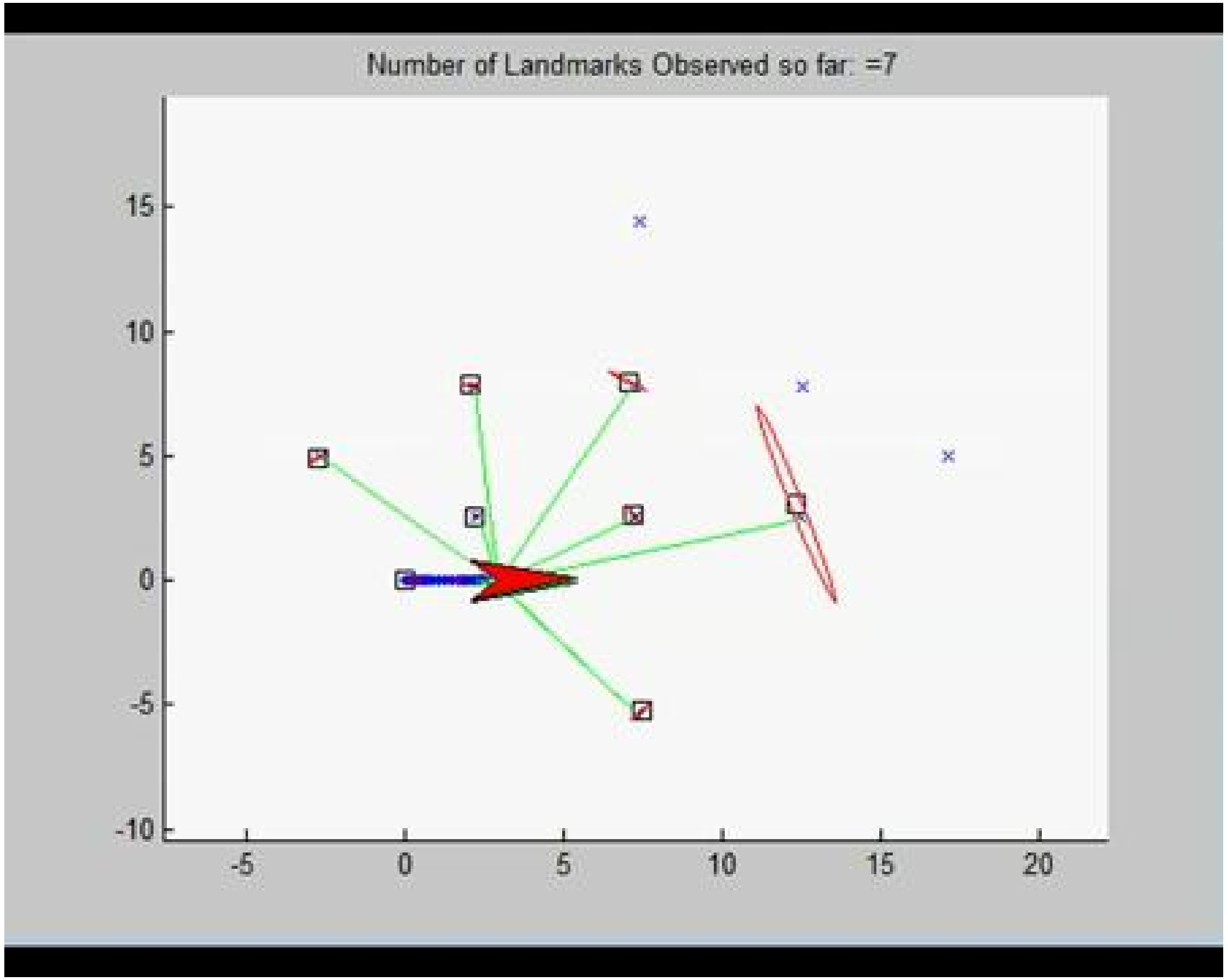
- Path of the robot

$$X_{1:k} = \{x_1, x_2, \ldots, x_k\}$$



8.6.3 Feature based SLAM

Feature based SLAM algorithm



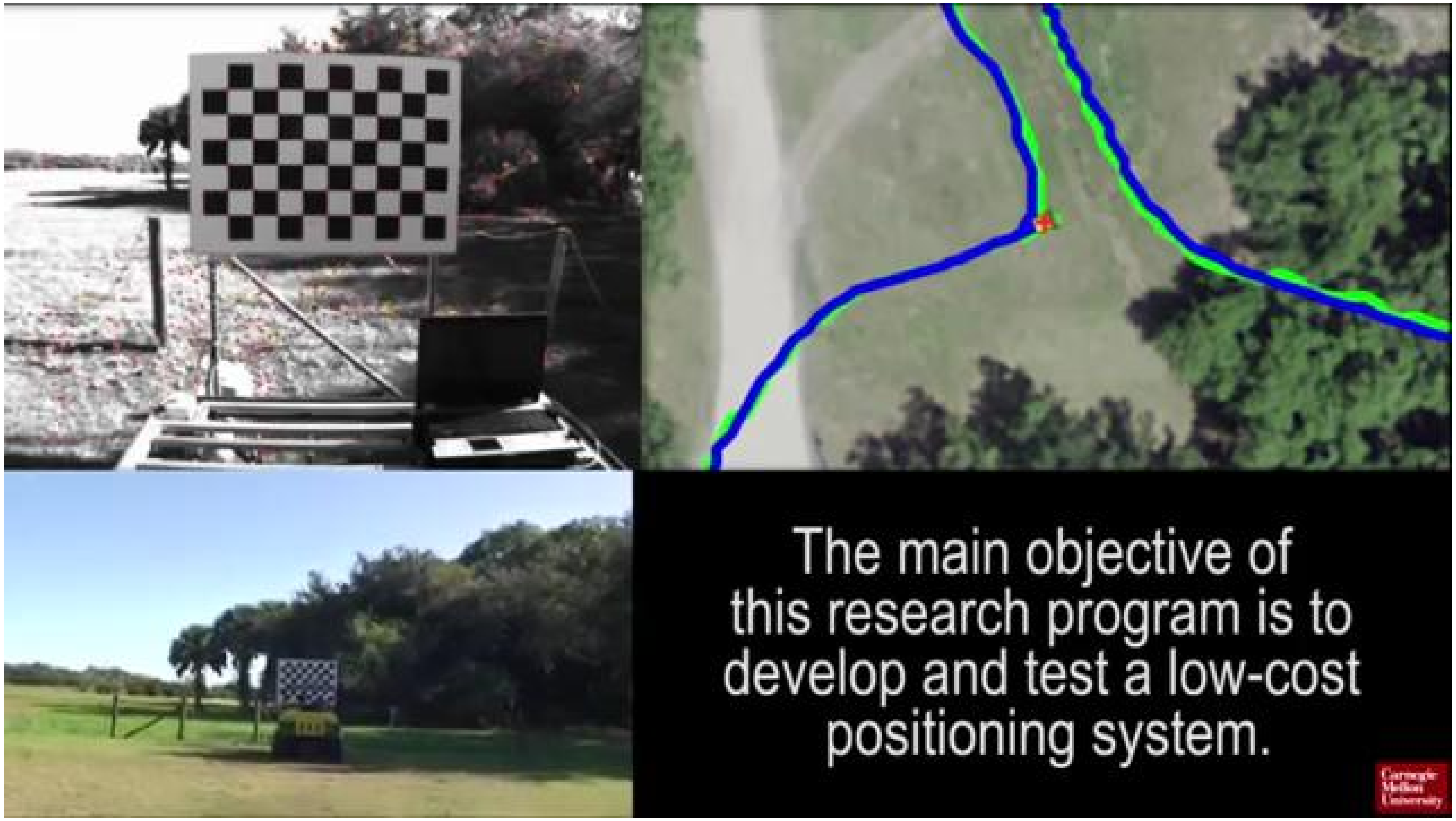
8.6.4 Biologically inspired SLAM

Context

- Most robotic mapping systems have traditionally used highly accurate, expensive laser range finders
- In this demonstration, we show that a cheap webcamera provides enough information to map a large and challenging environment
- We use a biologically inspired mapping system, RatSLAM, to map an entire suburb.

8.6.5 SLAM in Crops Farming

It is relied on Visual odometry and inertial navigation.



8.7 Conclusions

- Short-term Memory (STM).
  - A STM extends behavioural control beyond the robot's immediate range and reduces the demand for frequent sampling.
  - Grid-based representations are used for both STM, including either regular or sector-based.
- Long-term Memory (LTM)
  - LTM representations are either metric or qualitative.
  - Distinctive places are central to the use of sensor-derived LTMs.
- Qualitative maps support general navigational capabilities such as reaching to a goal, avoiding obstacles, etc.
- Priori map-derived maps are based on the data that comes from the existing maps, blueprints, floor plan, etc.
- SLAM plays a key role in the real-world navigation of mobile robots.