Session 3 – Robotics and Autonomous Agents

Dr Claire Rocks C.L.Rocks@warwick.ac.uk

Agenda

- What is a mobile robot?
- How do they get information about their environment?
- How can they use that to create maps?
- Once they have a map, how do they find a path through?
- Introduce the lab

What is a robot?

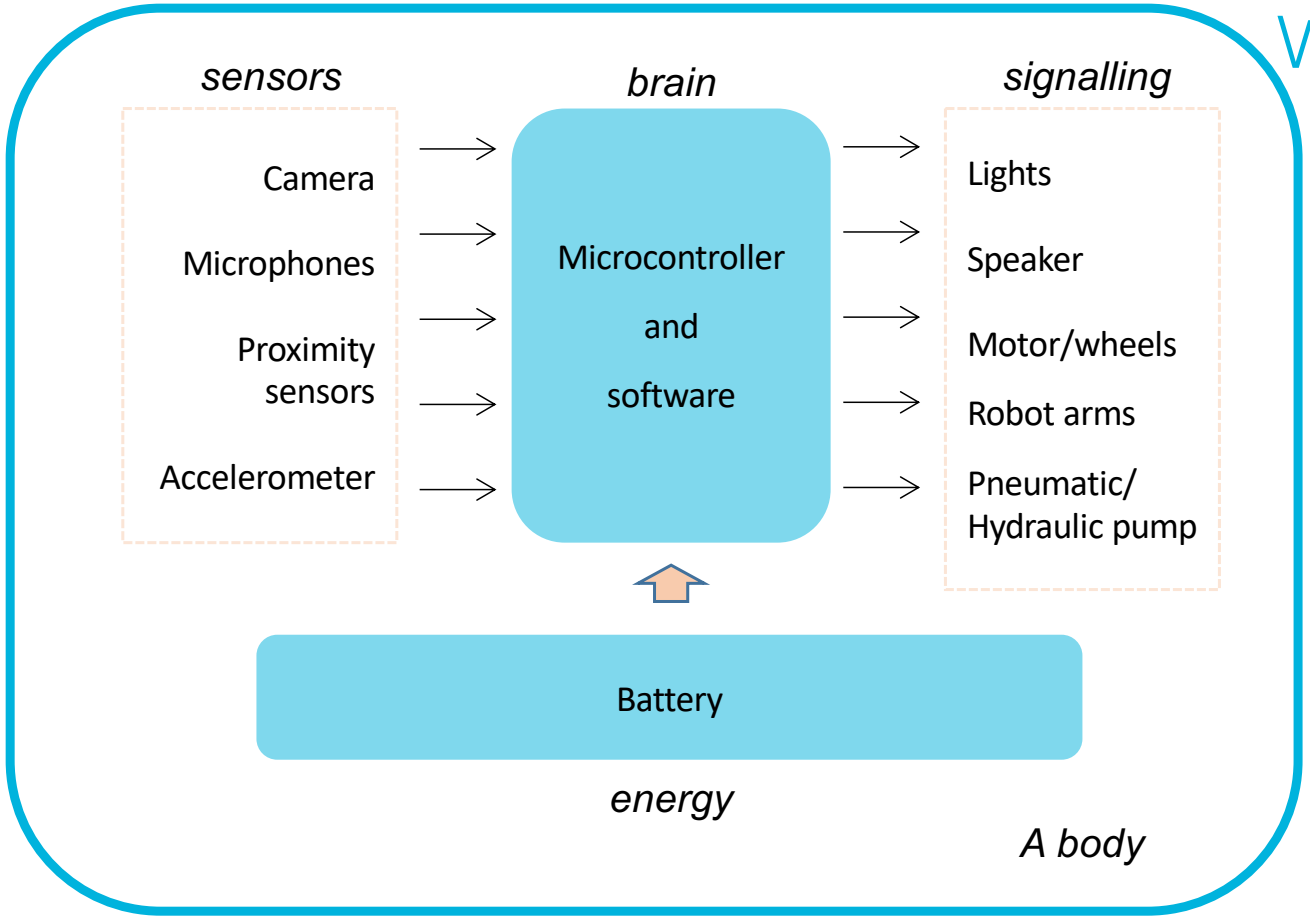
What is a robot?

WARWICK

A robot is:

1. An artificial device that can sense its environment and act purposefully in it
2. An embodied artificial intelligence
3. A machine that can autonomously carry out useful work

Alan Winfield, Robotics: a very short introduction


sensors
brain
signalling
Camera
Microphones
Proximity sensors
Accelerometer
Microcontroller and software
Lights
Speaker
Motor/wheels
Robot arms
Pneumatic/ Hydraulic pump
Battery
energy
A body

Task

- Chat to the person next to you to answer the following question:

Why do robots need sensors?

Why do robots need sensors?

WARWICK

To measure parameters of

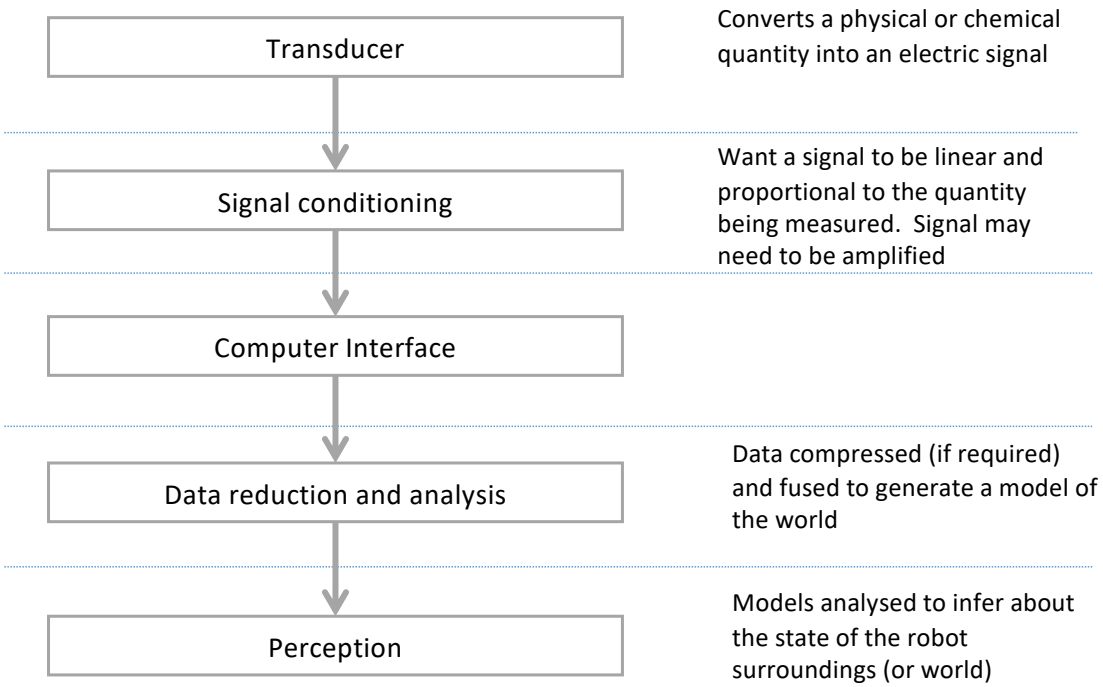
- The robot, and
- The environment

For various purposes such as control, monitoring, inspection and modelling

Increasing the sensor capability could

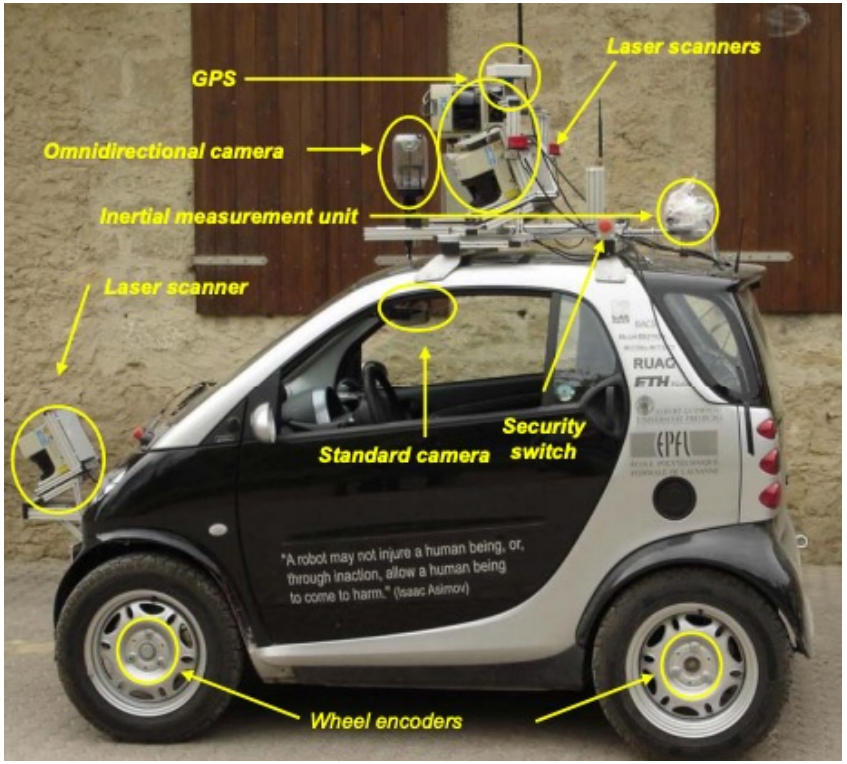
- Increase flexibility
- Save time
- Increase productivity
- Increase safety

The sensing process



Commonly used sensors

- Wheel/motor ecoders
- Heading sensors
- Accelerometers
- Inertial Measurement Unit
- Light and temperature sensors
- Touch sensors
- Proximity
- **Range sensors**
- Beacons/GPS
- Vision Sensors

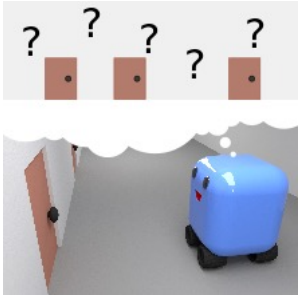


Task

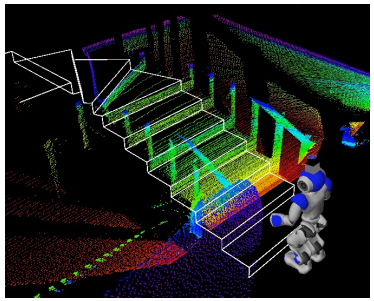
- An autonomous unmanned security car is to patrol the University Campus.
- In groups of 3-4 discuss the following:
  - What internal and external parameters do you think the autonomous unmanned security car would need to monitor and why?
    - Can you take a guess at the sensors it would need to use?
- Feedback to the group

Fundamental Questions

Where am I?



Where am I going?



How should I get there?

Robot Human Interactions

- All real robots interact with humans to an extent. However the amount of interaction varies, and this reflects the extent to which a robot works for itself or relies on us.

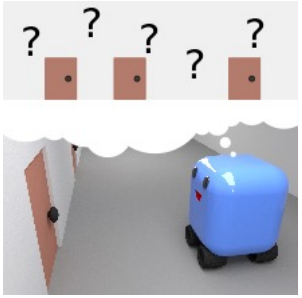
Increasing human input

Autonomous | Commanded | Remote-controlled

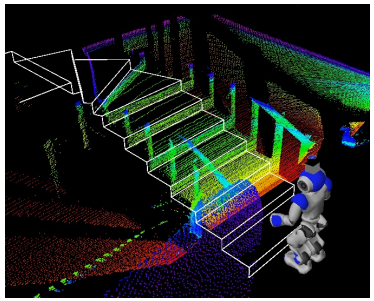
- Difference between autonomy and automatic
- Dynamic autonomy
- Autonomy and Intelligence are not the same thing…

Fundamental Questions

Where am I?



Where am I going?



How should I get there?

This is hard!!

- World is uncertain, complex and dynamic
- Sensor measurements are noisy
- Control inputs are noisy

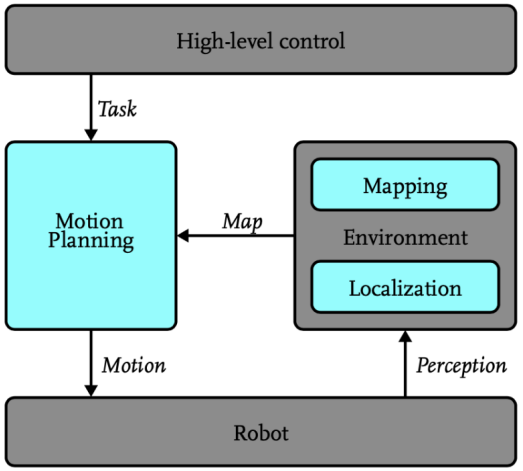
Moravec wrote, “It is comparatively easy to make computers exhibit adult level performance on intelligence tests or playing checkers, and difficult or impossible to give them the skills of a one-year-old when it comes to perception and mobility.”

The Motion Planning Problem

- Find a motion from a starting position to a goal position while safely avoiding any obstacles
- A key component in the navigation stack of a robot

Given an initial pose (position and orientation) and a goal pose of a robot, find a path (in the form of a continuous sequence of robot poses:

- that do not collide or contact with any obstacle
- that will allow the robot to move from its starting pose to its goal pose
- and report failure if such a path does not exist



Dense Metric Maps

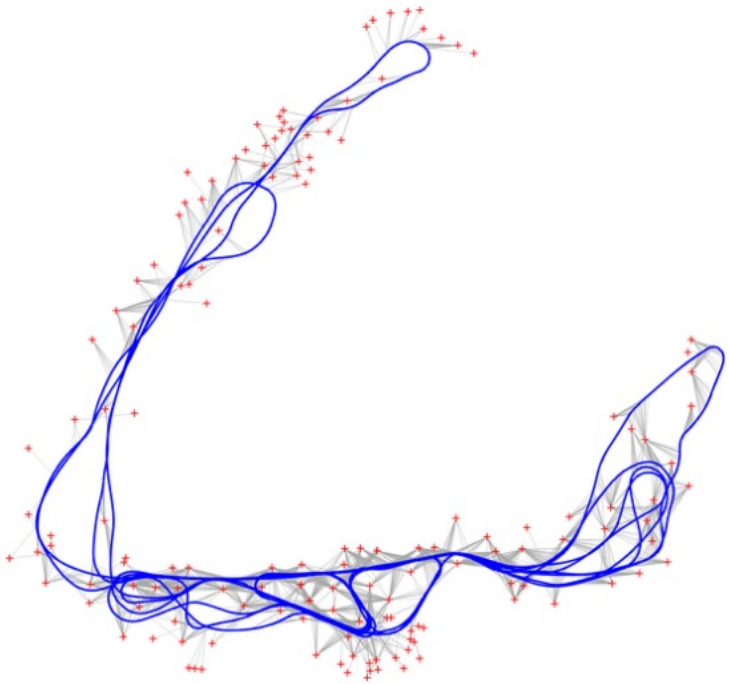
- A metric representation (or metric map) is a symbolic structure that encodes the geometry of the environment
- Dense representations attempt to provide high-resolution models of the geometry
- These models are more suitable for obstacle avoidance, or for visualisation and rendering
- Visually pleasant, also need a large amount of data

Dense map of an office
(produced by ElasticFusion [2])

[2] Thomas Whelan, Stefan Leutenegger, Renato F. Salas-Moreno, Ben Glocker, Andrew J. Davison: ElasticFusion: Dense SLAM Without A Pose Graph. Robotics: Science and Systems 2015

Feature-based Metric Maps

- Feature-based metric maps represent the scene as a set of sparse landmarks corresponding to identifiable features in the environment (e.g., lines, corners, interest points)

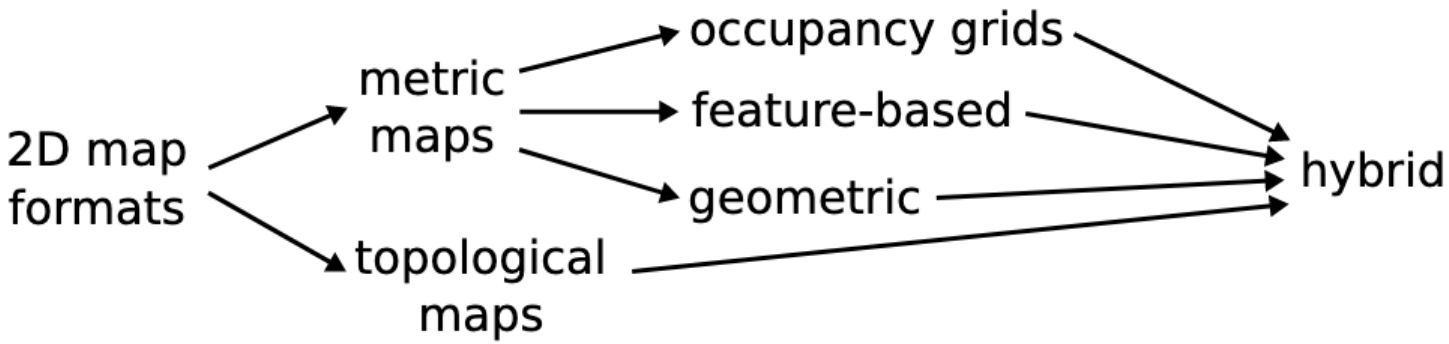


Topological Maps

- Topological maps drops the metric information
- Only leverages place recognition to build a graph in which the nodes represent distinguishable "places", while edges denote reachability among places
- Not suitable for tasks such as obstacle avoidance
- Can add local metric information to the edges

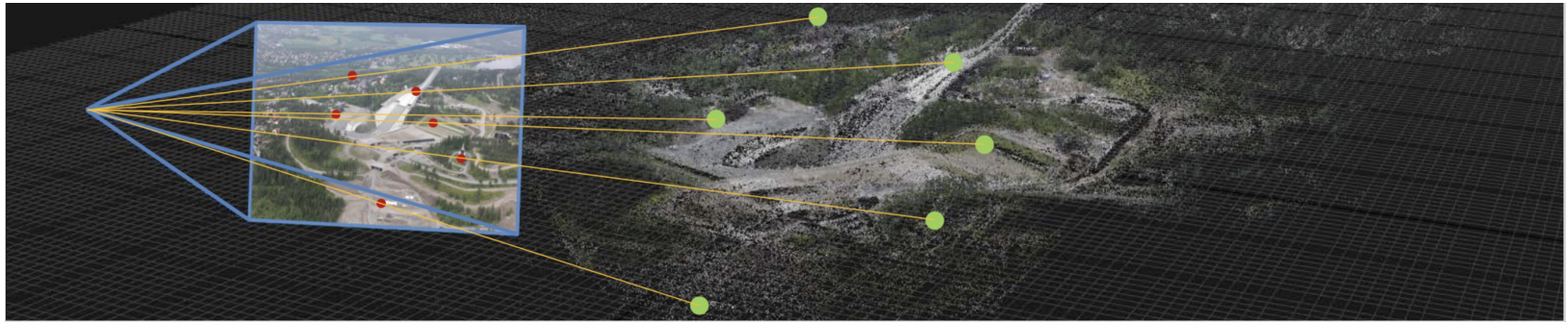
Topological maps in
COLD-TopoMaps Dataset [3]

[3] K. Zheng, A. Pronobis and R. P. N. Rao. Learning {G}raph-{S}tructured {S}um-{P}roduct {N}etworks for Probabilistic Semantic Maps. Proceedings of the 32nd AAAI Conference on Artificial Intelligence (AAAI), 2018


2D map formats
metric maps
topological maps
occupancy grids
feature-based
geometric
hybrid

Simultaneous Localisation and Mapping

- The SLAM Problem
  - A fundamental problem in mobile robotics, and providing some solutions is one of the main successes of probabilistic robotics
  - A robot with sensors moves through a previously unknown, static environment, mapping it and calculating its own motion at the same time.



Simultaneous Localisation and Mapping

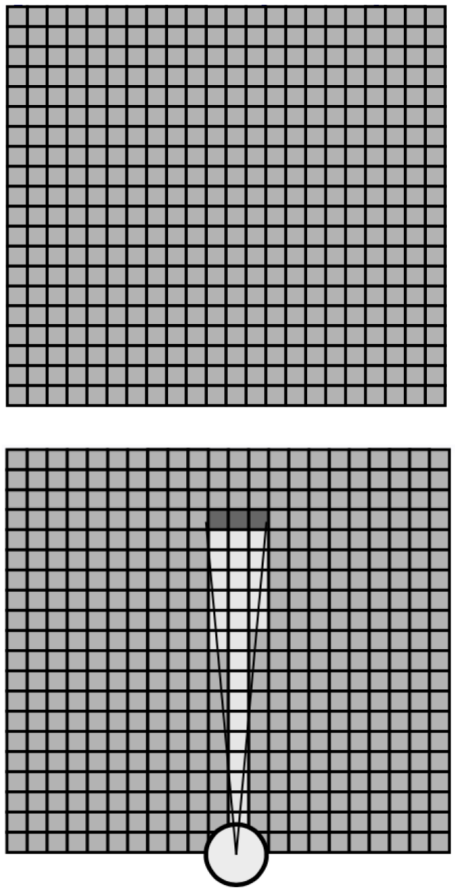
- We need SLAM:
  - When a robot must be truly autonomous (no human input)
  - When little or nothing is known in advance about the environment (don't have a map)
  - When we can't place or use infrastructure such as artificial beacons, or GPS
  - And when the robot actually needs to know where it is

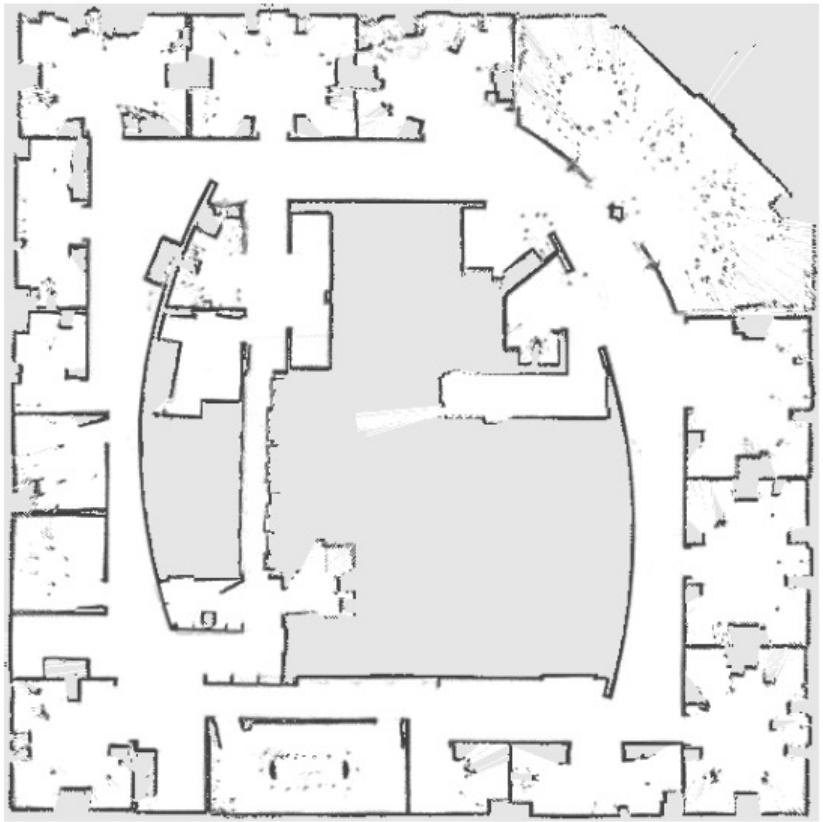
- In SLAM:
  - We build a map incrementally
  - And localise the robot with respect to that map as it grows

How do you represent the robot's map in the code?

Occupancy Grid Representation

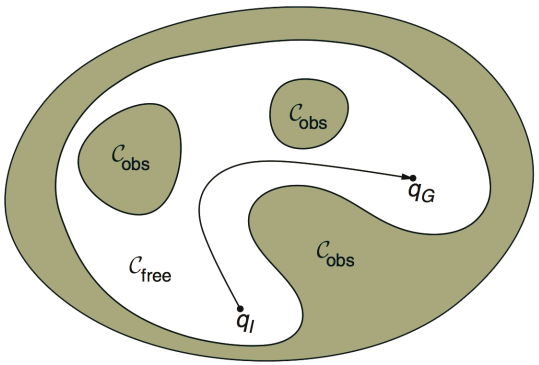
- Use Grid to Represent an Area on the Ground
  - Choose a suitable square grid cell size
- For Each Cell
  - Store and update a probability of occupancy $P(O_i)$ that it is occupied by an obstacle
- Greyscale Visualisation
  - From black for *occupied*, to white for *empty*, while intermediate values are shades of grey





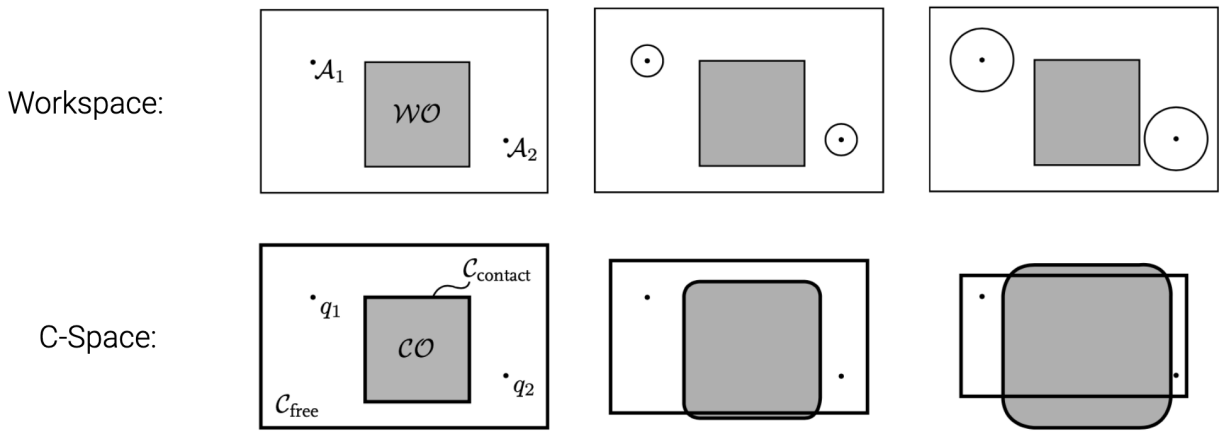
Configuration Space

- The Robot in the World (Workspace)
  - To solve the motion planning problem, we need to position the robot in an appropriate space
  - Every point of the robot needs to be specified the space to ensure no possible collision
  - We can transform the robot and the obstacles in the workspace into the configuration space (C-Space)
- The Configuration Space
  - The space of all legal configurations of the robot
  - Regardless the geometry of the robot



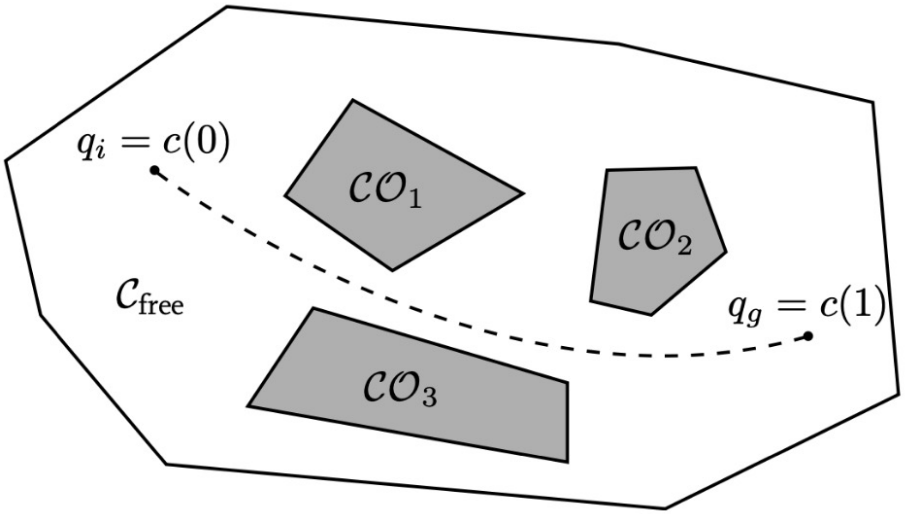
Configuration Space

- C-Space Transformation
  - Two robot locations A_1 and A_2 in the workspace
  - Two robot configurations q_1 and q_2 in the C-Space
  - WO: Obstacle region in workspace; CO: Obstacle region transformed into C-Space
  - C_{free} : free configuration space; $C_{contact}$: the contact space

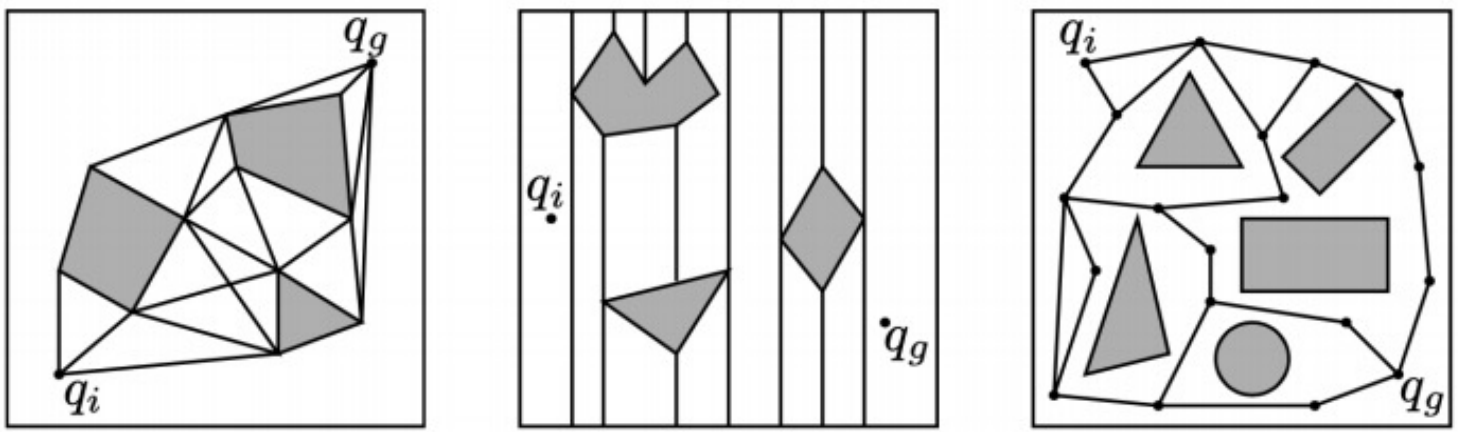


Configuration Space

- Planning a Path in C free
  - Within the C-Space, the robot can be viewed as a point
  - Path planning can be done for this point in the C-Space



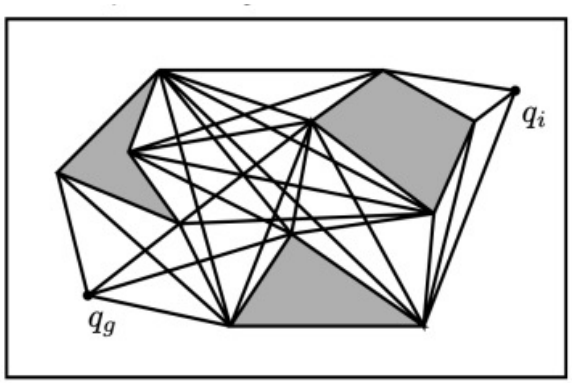
Finding paths through C-Space



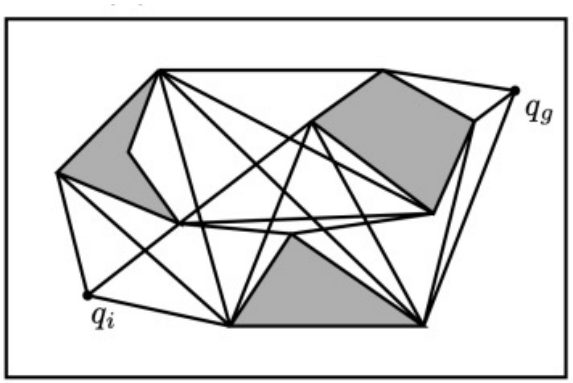
Roadmap Cell Decomposition Sampling-based

Roadmaps

- Can be Constructed by Various Methods
  - **Visibility Graph**
  - Vonoroi Diagrams

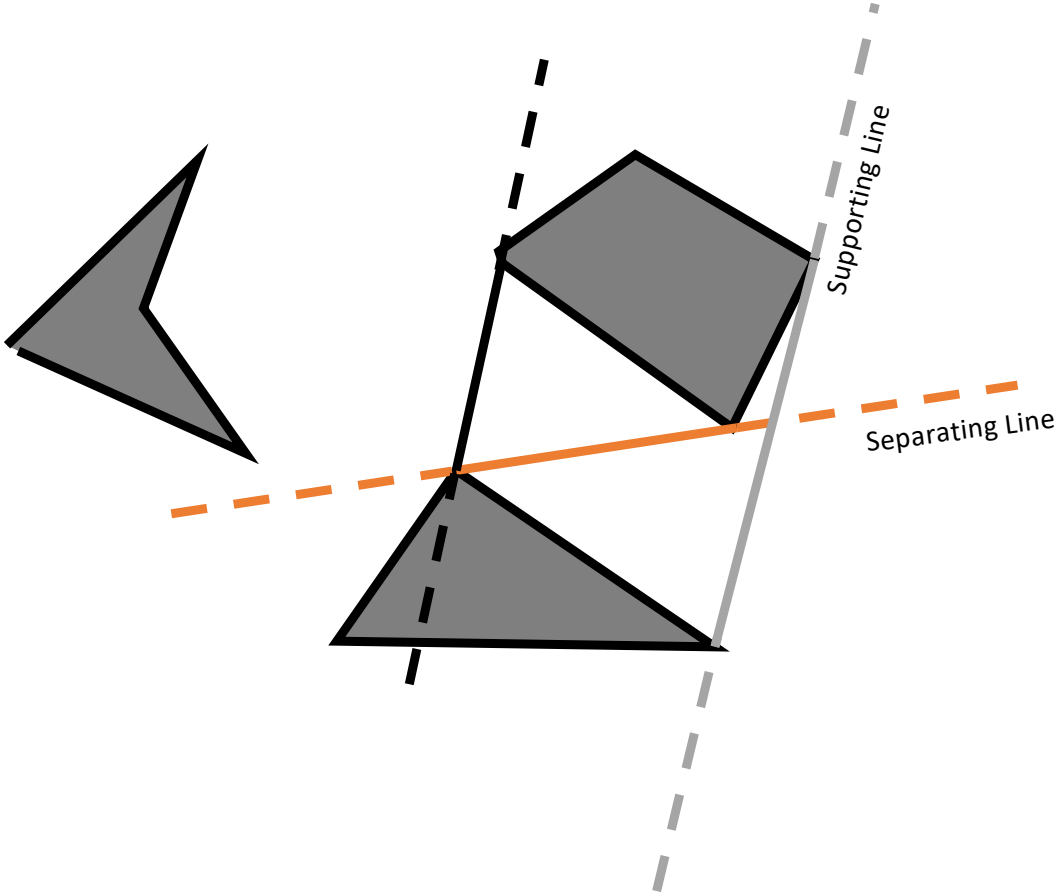


A Visibility Graph



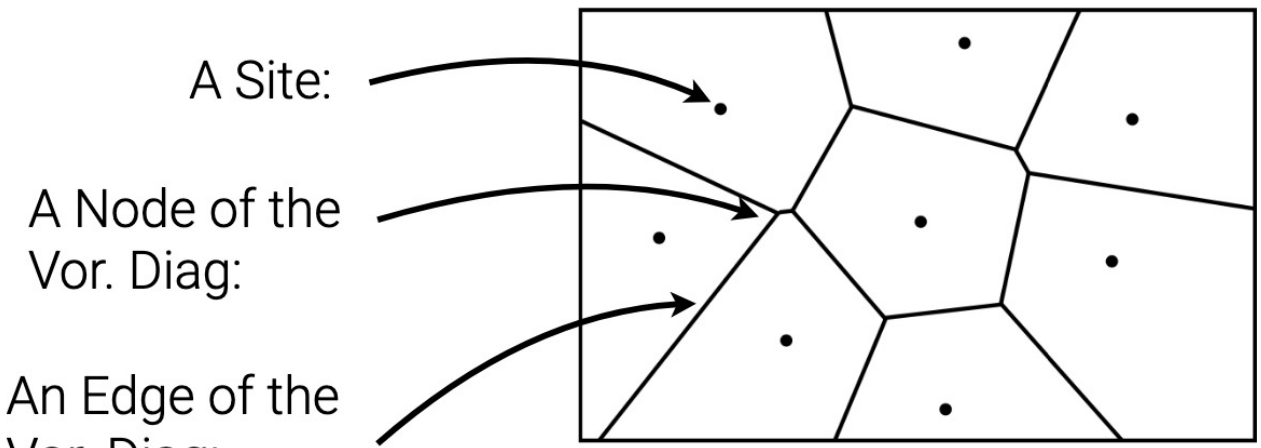
A Reduced Visibility Graph

Supporting and Separating Lines

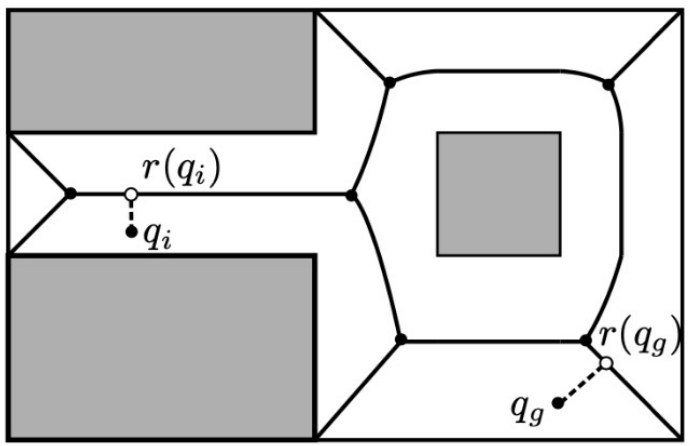


Roadmaps

- Can be Constructed by Various Methods
  - Visibility Graph
  - **Vonoroi Diagrams**



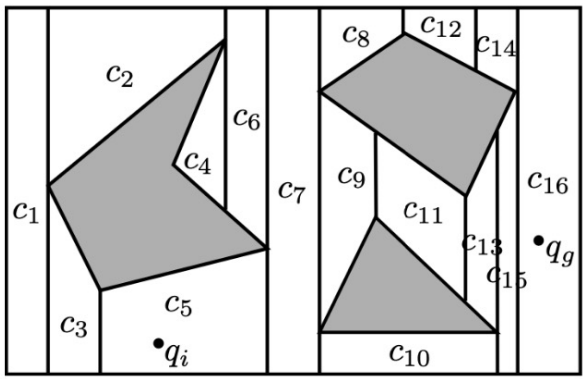
An Original Vor. Diagram



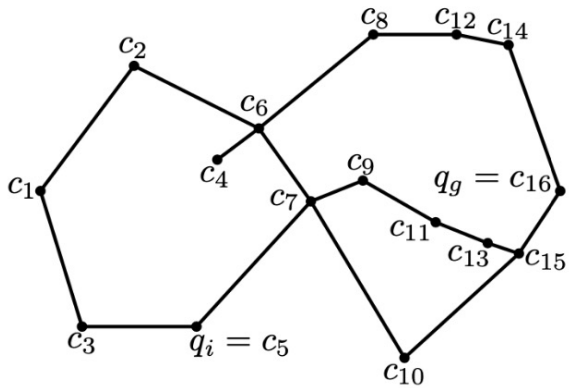
An Generalised Vor. Diagram

Exact Cell Decomposition

- Decompose Configuration Space C into
  - Discrete a
- Trapezoidi
  - 2D C-Spa
  - Vertical/H
    node of c



A Trapezoidial Decomposition



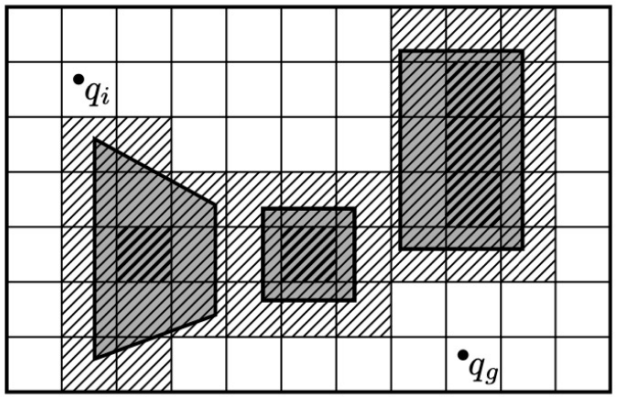
The Connectivity Graph

; a

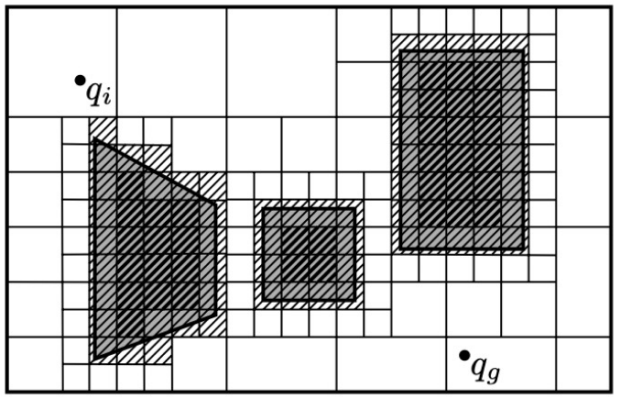
- A path can be found from the associated connectivity graph

Approximate Cell Decomposition

- Decompose Configuration Space C into
  - A grid of cells with predefined shape and size
  - Samples the workspace, and identify:
    - Free cells
    - Mixed cells
    - Occupied cells
  - Connectivity Graphs Built upon Free and Mixed Cells



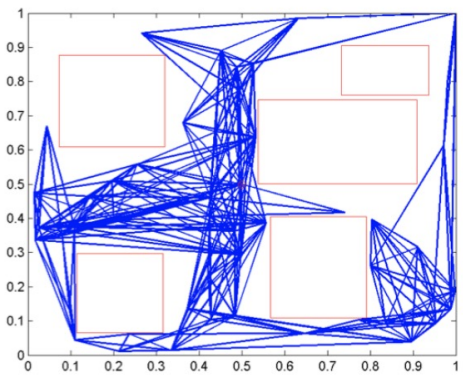
Approximate Decomposition



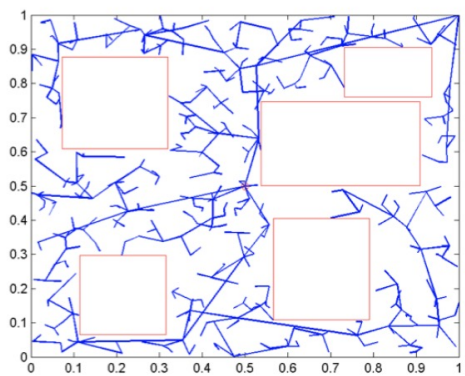
Adaptive Decomposition

Sampling-based approaches

- Sampling C, and connecting those samples to solve the motion planning problem
  - Two main approaches:
    - Probabilistic Roadmap
    - Single-query planners



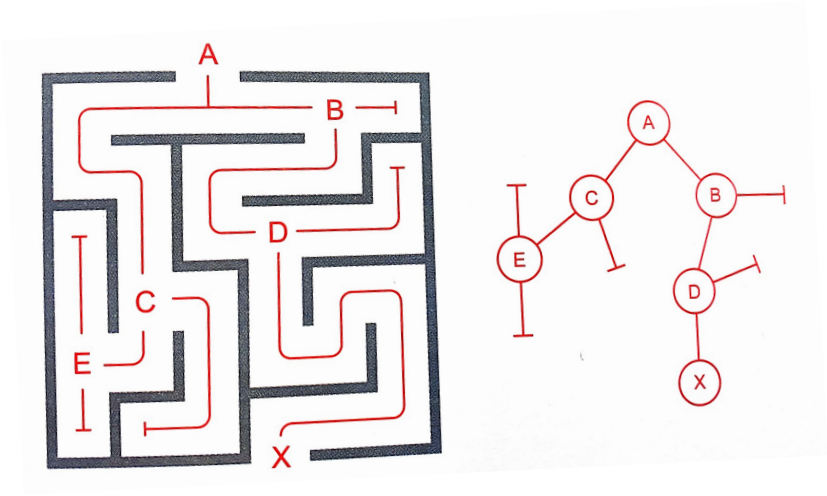
Probabilistic Roadmap



Rapid-exploring Random Tree

Connectivity Graphs

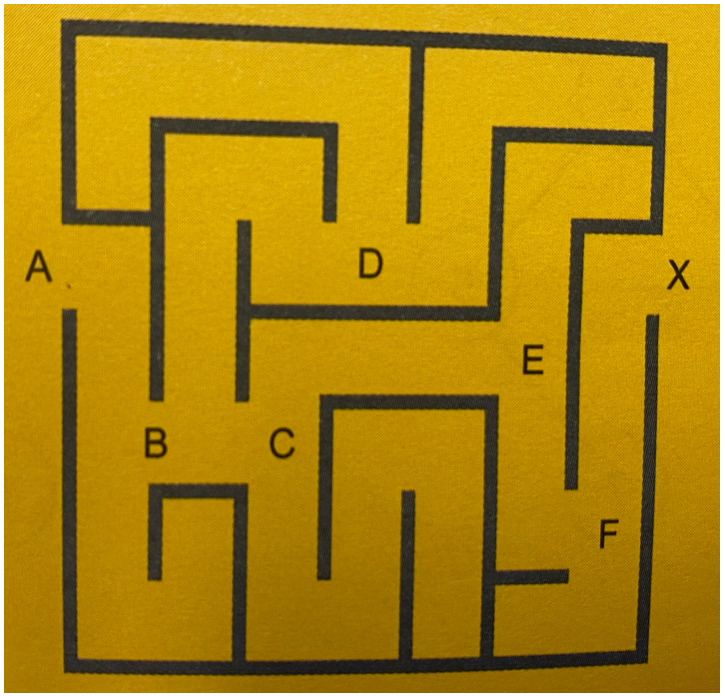
- A graph models a set of connections
- They are made up of nodes and edges
- A node can be connected to many other nodes, those nodes are called its neighbours
- Can be used to model paths through mazes – junctions where there is a choice of route are modelled as nodes
- **Is there a path between nodes?**
- **What is the shortest path?**



Task

- In pairs, draw the graph representing the following maze.

  Draw in the dead ends

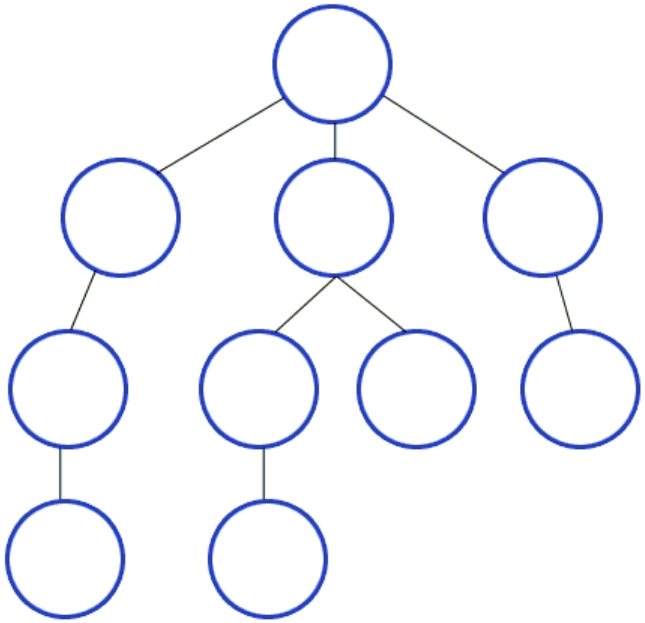


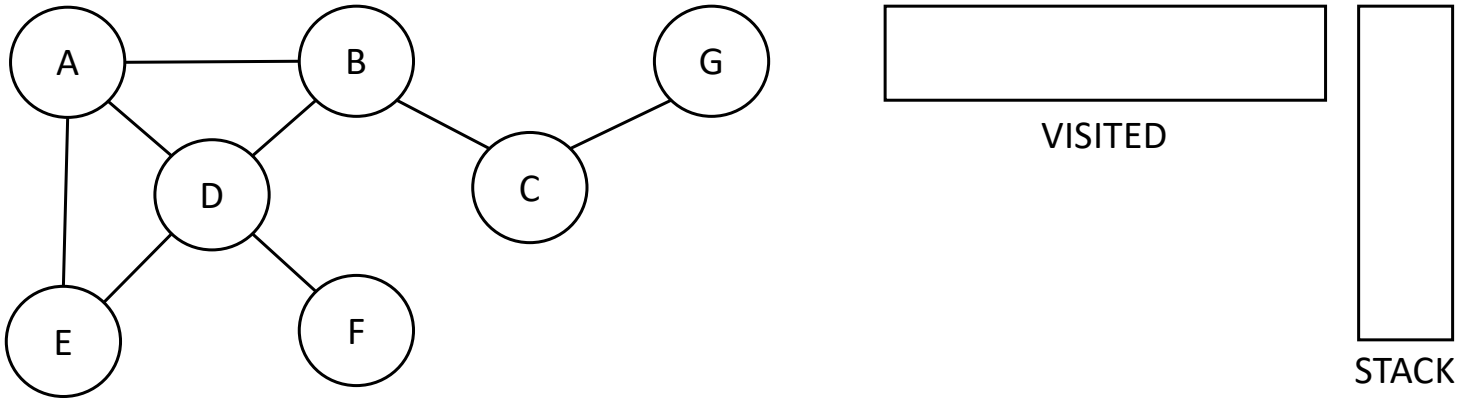
Search Algorithms

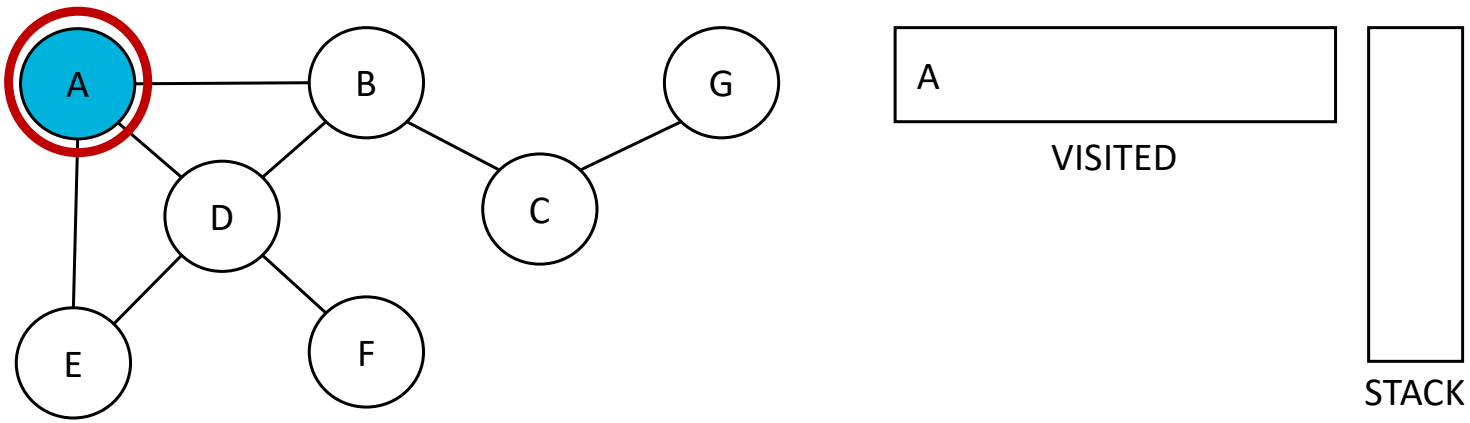
- Given the C-Space Representation (a connectivity graph), search for a solution
- Different Types of Search Algorithms
  - **Uninformed search -** no additional information about the distance from the current state to the goal.
    - **Examples: Depth First Search and Breadth-First Search.**
  - Informed search – has additional information about the distance from the current state to the goal

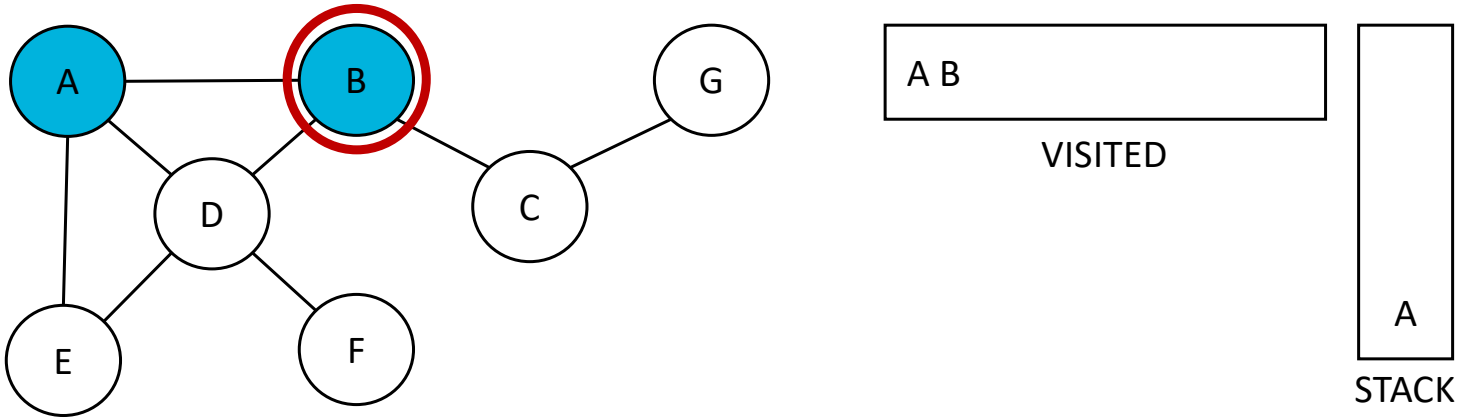
Depth First Search

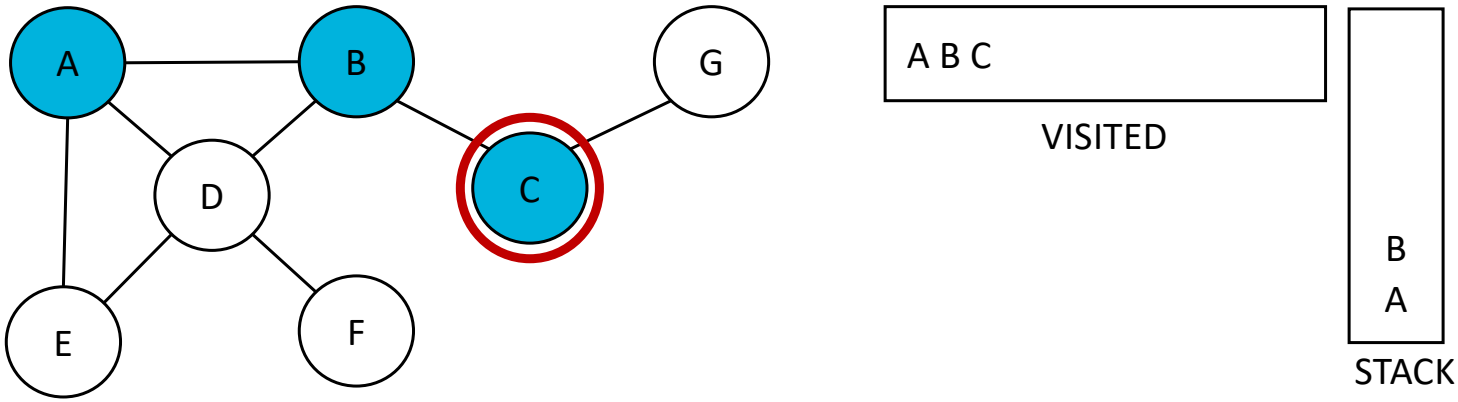
- Explores as far into the graph as possible before backtracking to visit unvisited nodes
- Often implemented using a recursive algorithm
- Uses a stack - LIFO

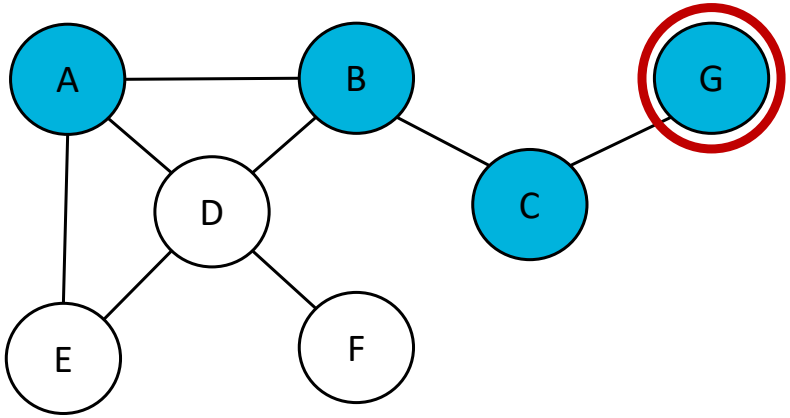



A
B
G
D
C
E
F
VISITED
STACK


A
B
G
D
C
E
F
A
VISITED
STACK


A
B
G
D
C
E
F
A B
VISITED
A
STACK


A
B
G
D
C
E
F
A B C
VISITED
B
A
STACK

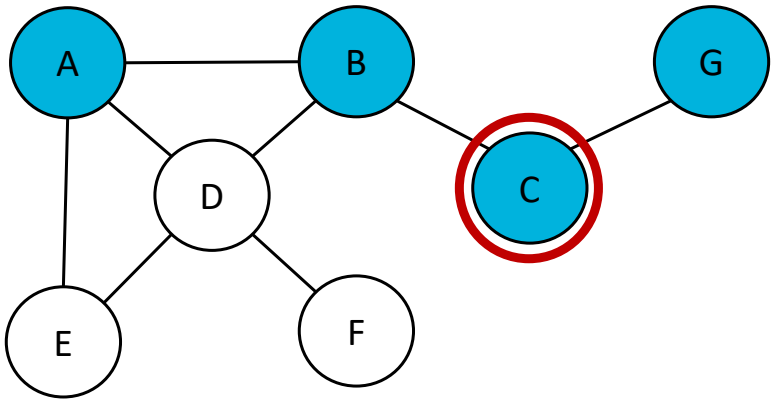


A B C G

VISITED

C
B
A

STACK

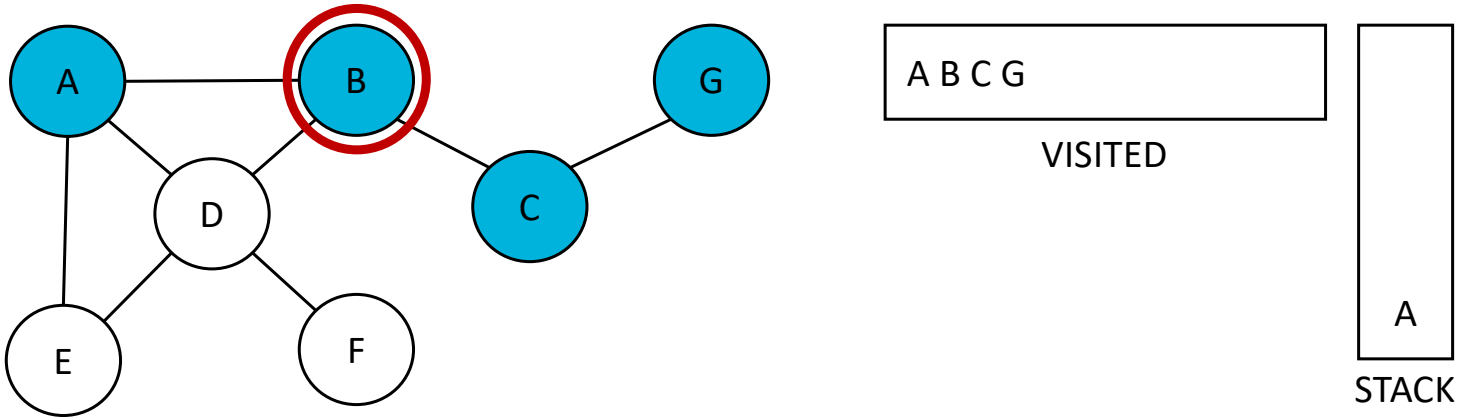


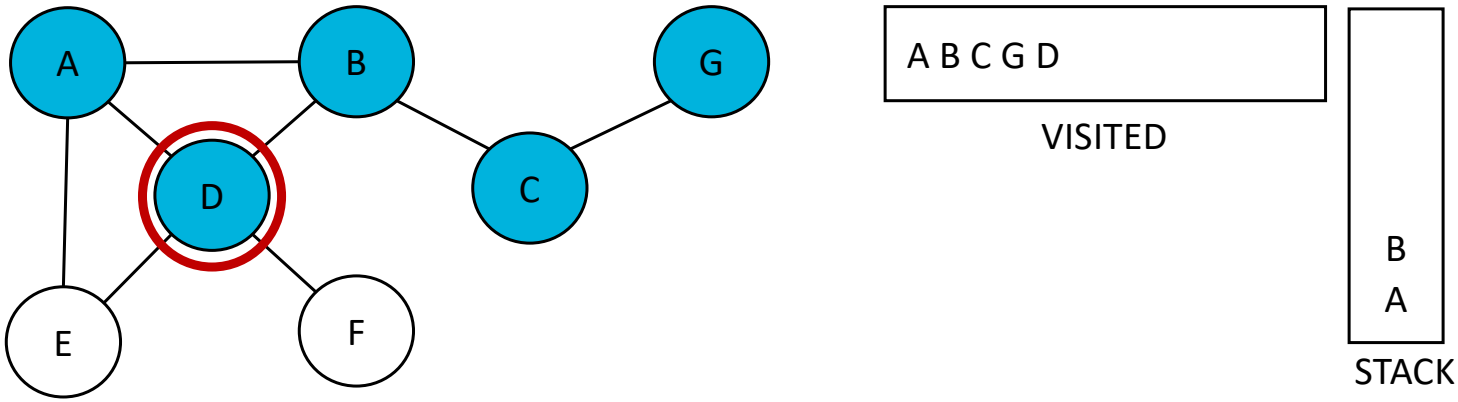
A B C G

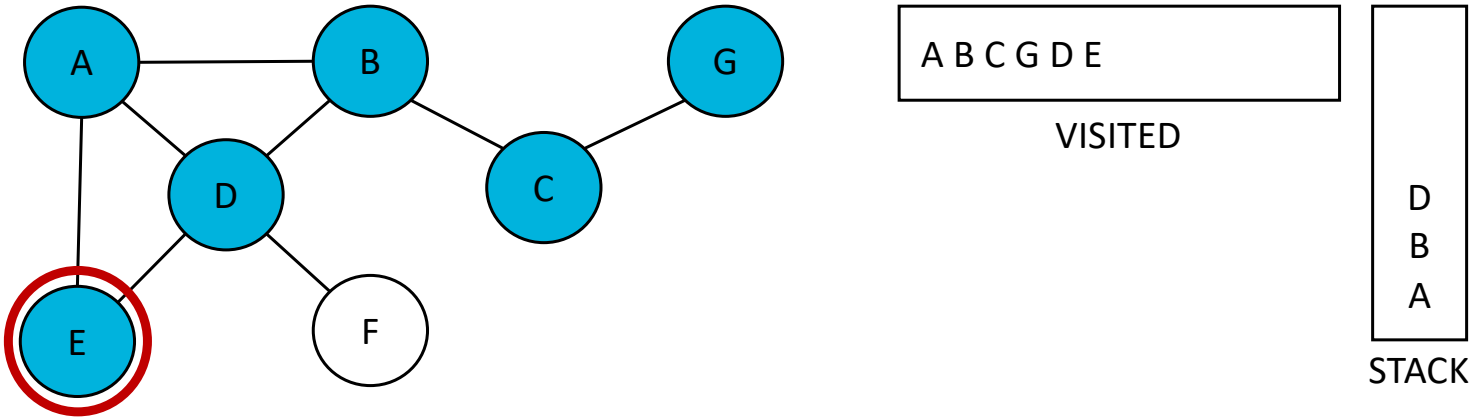
VISITED

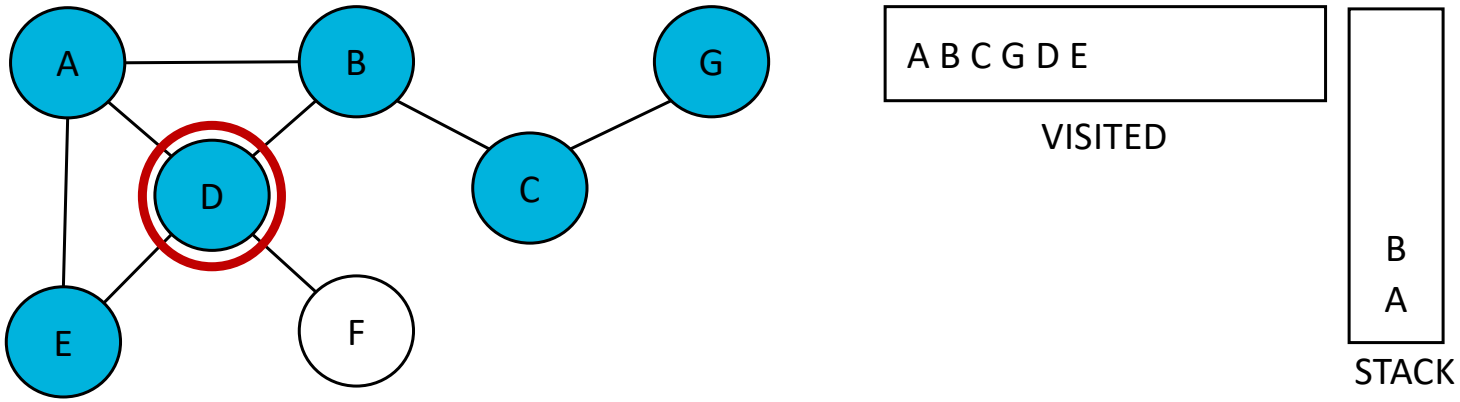
B
A

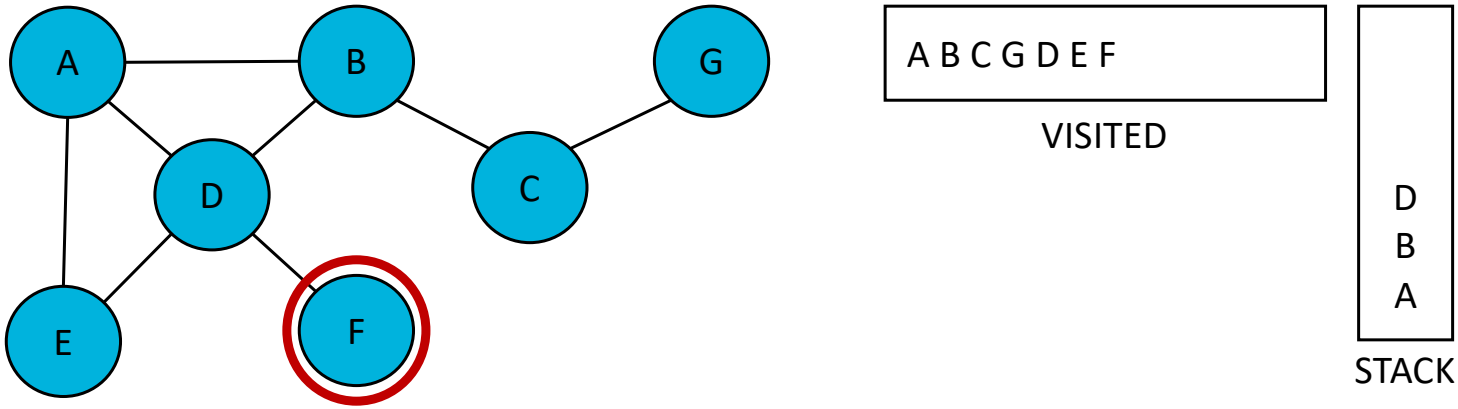
STACK

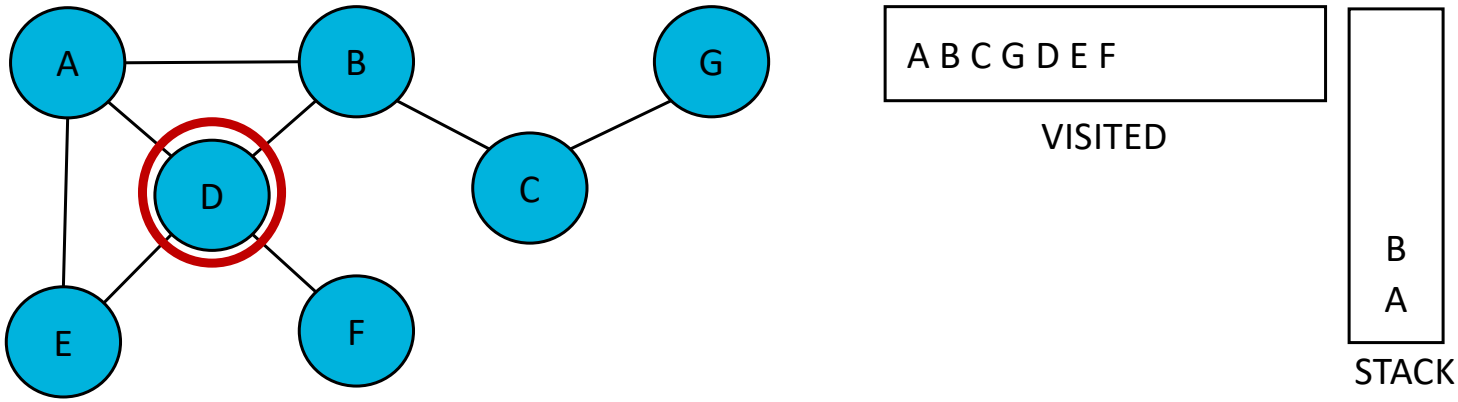

A
B
G
D
C
E
F
A B C G
VISITED
A
STACK

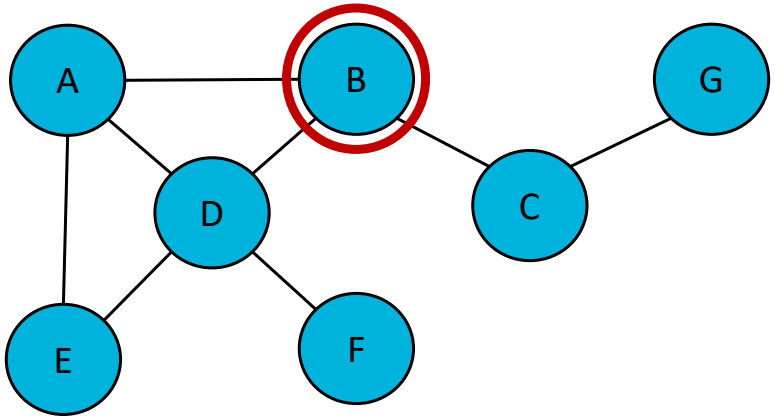

A
B
G
D
C
E
F
A B C G D
VISITED
B
A
STACK


A
B
G
D
C
E
F
A B C G D E
VISITED
D
B
A
STACK


A
B
G
D
C
E
F
A B C G D E
VISITED
B
A
STACK


A
B
G
D
C
E
F
A B C G D E F
VISITED
D
B
A
STACK


A
B
G
D
C
E
F
A B C G D E F
VISITED
B
A
STACK

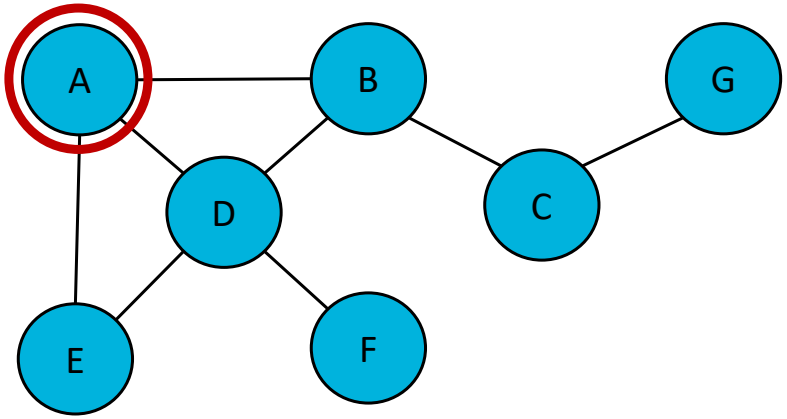


A B C G D E F

VISITED

A

STACK



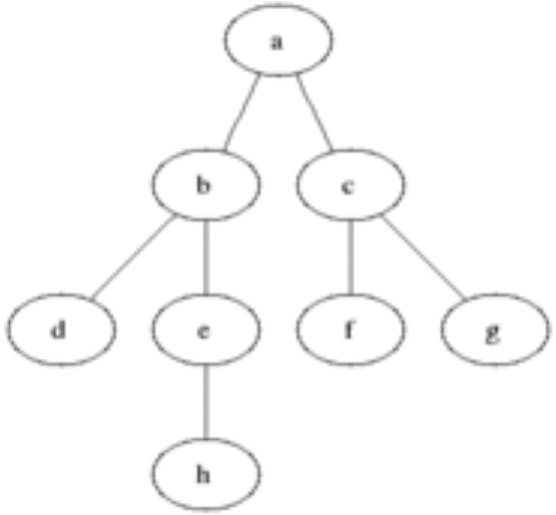
A B C G D E F

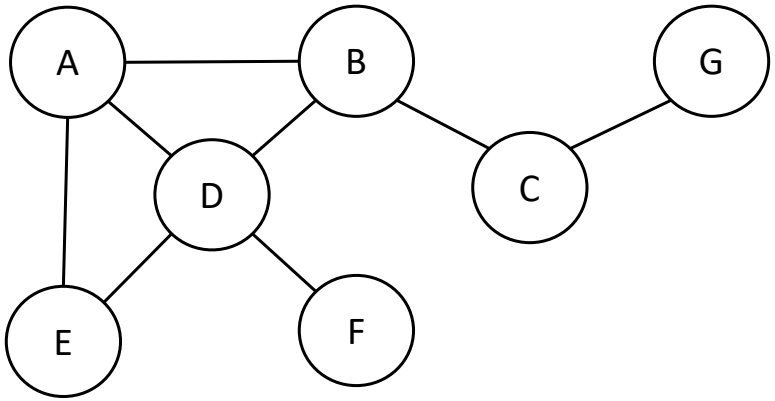
VISITED

STACK

Breadth first search

- Visits the nodes closest to the starting point first
- A queue – (FIFO) - is used to keep track of the nodes to visit

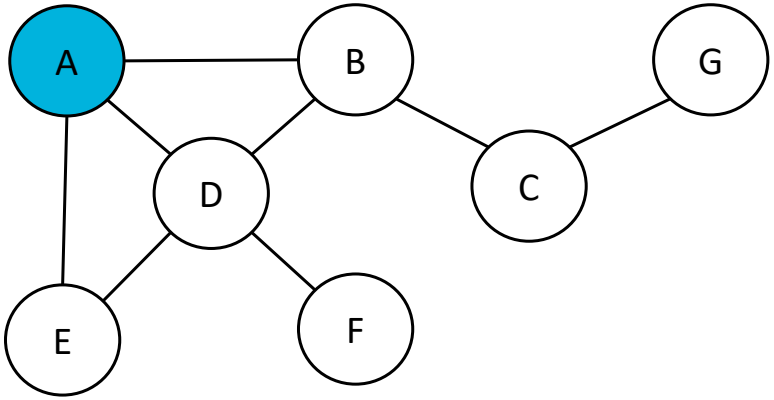




VISITED

A

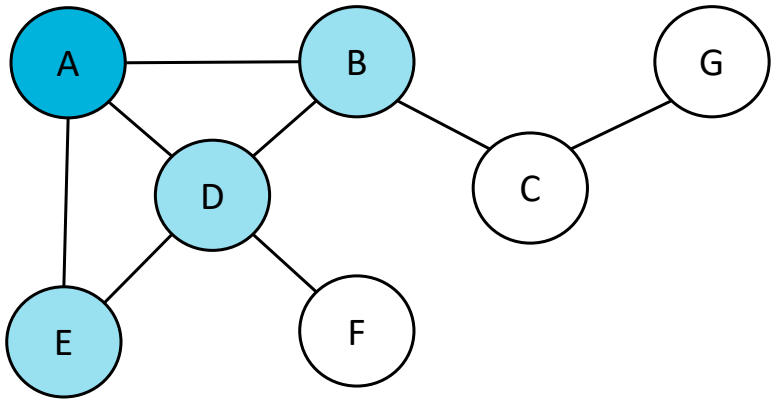
QUEUE



A

VISITED

QUEUE

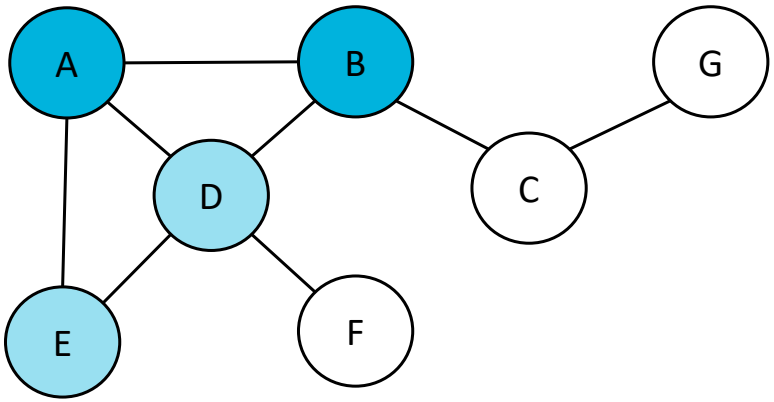


A

VISITED

B D E

QUEUE

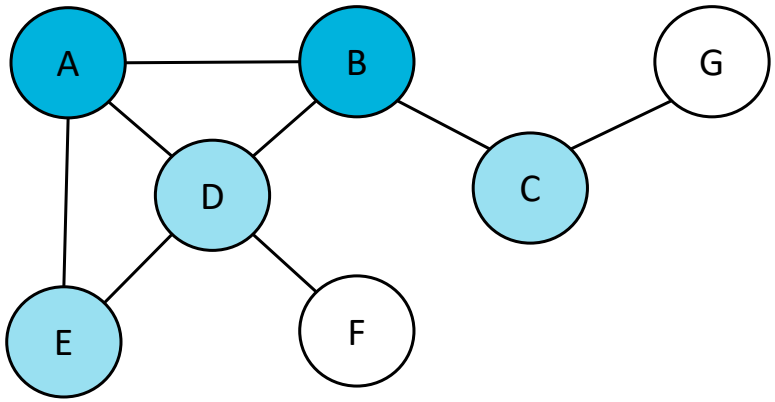


A B

VISITED

D E

QUEUE

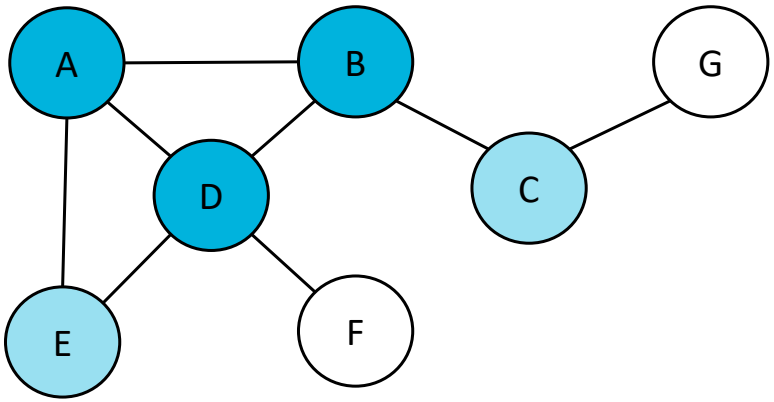


A B

VISITED

D E C

QUEUE

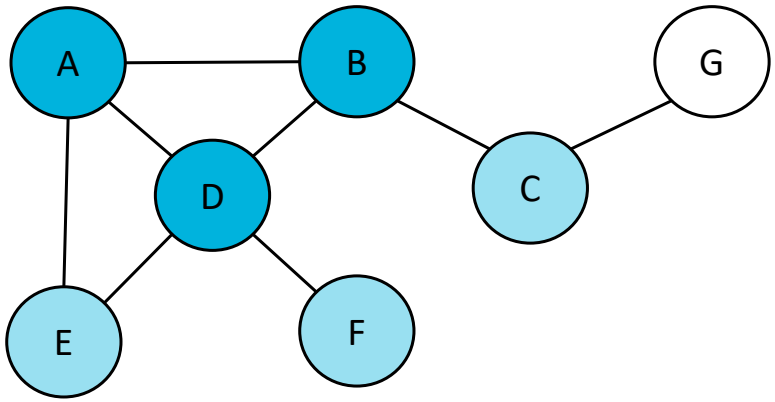


A B D

VISITED

E C

QUEUE

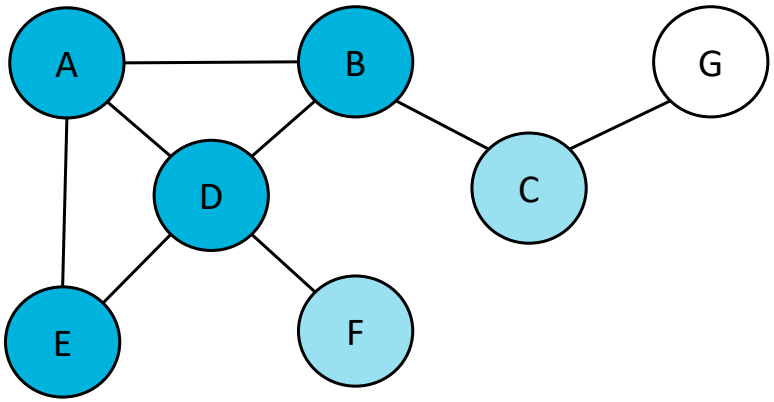


A B D

VISITED

E C F

QUEUE

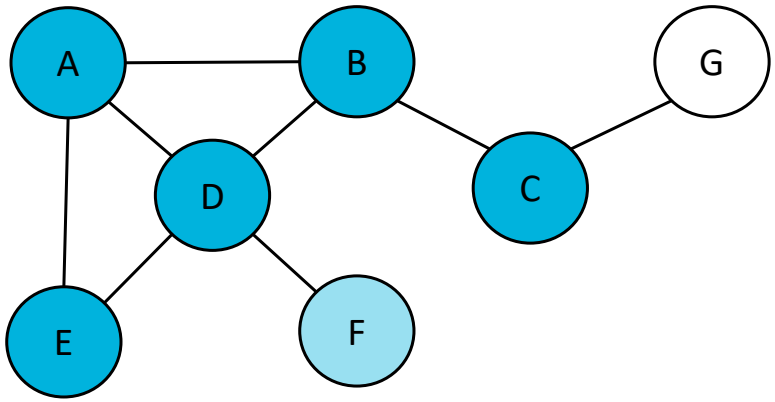


A B D E

VISITED

C F

QUEUE

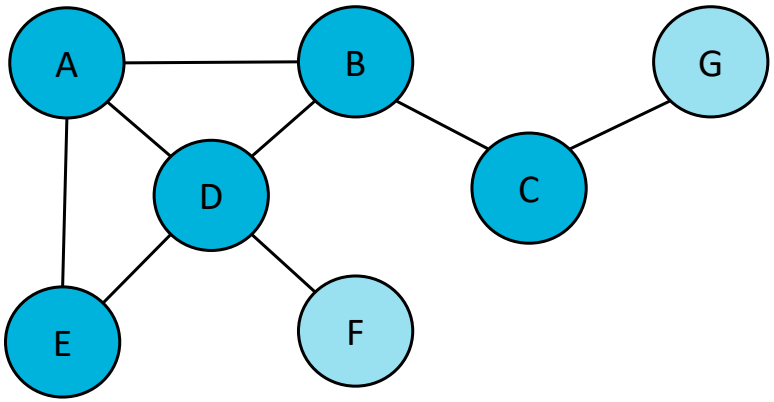


A B D E C

VISITED

F

QUEUE

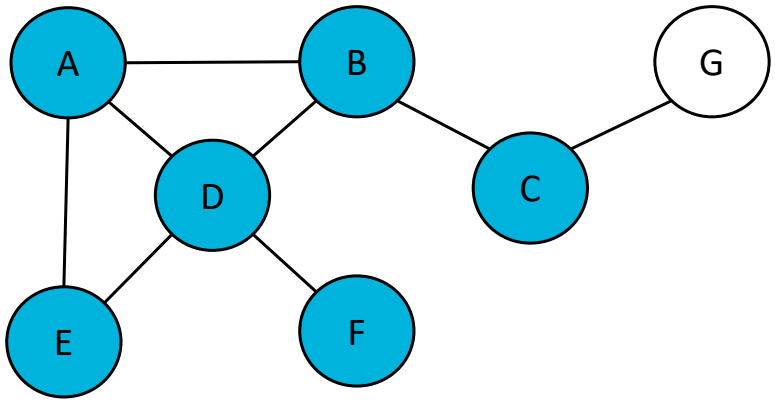


A B D E C

VISITED

F G

QUEUE

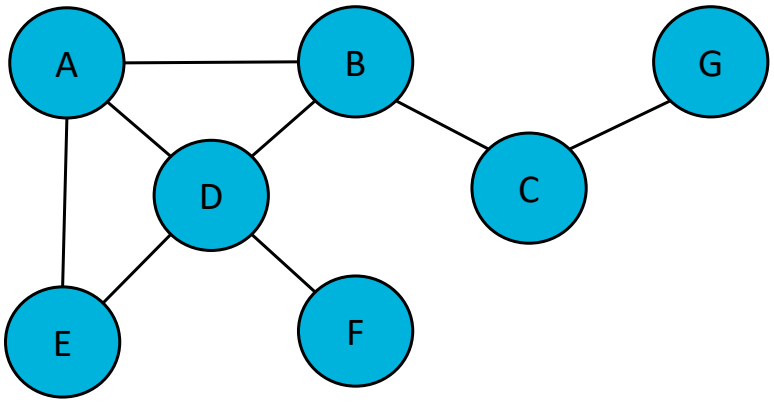


A B D E C F

VISITED

G

QUEUE



A B D E F G

VISITED

QUEUE

Summary

- What is a mobile robot?
- How do they get information about their environment?
- How can they use that to create maps?
- Once they have a map, how do they find a path through?
- We be doing some of this in the lab tomorrow

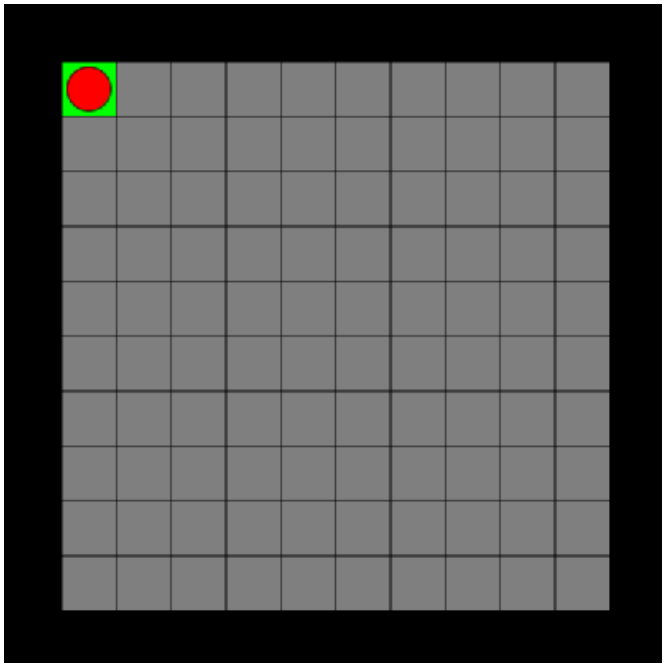
The robot lab

- Working in pairs
- Your robot is part of a search and rescue mission. It needs to get to the victims located at the Goal. Once it has found the victims, it should lead them to safety via the fastest route.

2 steps

1. Explore the world and build the map in simulation
2. Use the map to provide waypoints to a real robot

Initially, we don’t know much…



```
maze = {
     {1,1,1,1,1,1,1,1,1,1,1,1},
     {1,2,4,4,4,4,4,4,4,4,4,1},
     {1,4,4,4,4,4,4,4,4,4,4,1},
     {1,4,4,4,4,4,4,4,4,4,4,1},
     {1,4,4,4,4,4,4,4,4,4,4,1},
     {1,4,4,4,4,4,4,4,4,4,4,1},
     {1,4,4,4,4,4,4,4,4,4,4,1},
     {1,4,4,4,4,4,4,4,4,4,4,1},
     {1,4,4,4,4,4,4,4,4,4,4,1},
     {1,4,4,4,4,4,4,4,4,4,4,1},
     {1,4,4,4,4,4,4,4,4,4,4,1},
     {1,1,1,1,1,1,1,1,1,1,1,1}
  };
```

```
0 = unoccupied
1 = occupied
2 = starting cell
3 = goal
4 = unknown
```

Maze | Library | Robot

```java
class Robot {

  Library lib = new Library();
  int current_x = 1;
  int current_y = 1;

  int[] checkNeighbours(int current_x, int current_y) {
    return lib.checkNeighbours(current_x, current_y);
  }

  void moveNorth() {
    if (!(lib.checkNeighbours(current_x, current_y)[0] == 1))
      current_y -= 1;
  }

  void draw() {
    fill(255, 0, 0);
    ellipse(robot.current_x*cellWidth+cellWidth/2,
            robot.current_y*cellWidth+cellWidth/2,
            cellWidth-10, cellWidth-10);
  }
}
```

This will return and array called neighbours with 4 elements, [?, ?, ?, ?].

- [0] will store a 0, 1, 2 or 3 depending on the cell to the North
- [1] will store a 0, 1, 2 or 3 depending on the cell to the South
- [2] will store a 0, 1, 2 or 3 depending on the cell to the East
- [3] will store a 0, 1, 2 or 3 depending on the cell to the West

The 0, 1, 2, or 3 stored in the array represent the following:

- 0 - Unoccupied
- 1 - Occupied
- 2 - Starting cell
- 3 - Goal

This checks the neighbours of the current cell and then checks that the first element in that array, [0], is not equal to 1 (its the ! that makes the check NOT equal to).

If the element is not equal to 1 then we can move north by subtracting y from the current element, current_y -= 1

Maze | Library | Robot

```java
int h = 0;
int w = 0;
int cellWidth;
int[][] maze;
Robot robot;

Library lib;
void setup() {
  frameRate(10);
  size(600, 600);
  robot = new Robot();
  lib = new Library();
  h = lib.getHeight();
  w = lib.getWidth();

  cellWidth = width/w;

  //initialise maze as unknown
  maze = new int[h][w];
  for (int i=0; i<h; i++) {
    for (int j=0; j<w; j++) {
      maze[i][j] = 1;
    }
  }

  //set special cases
  //walls around the edge
  for (int i=1; i<h-1; i++) {
    for (int j=1; j<w-1; j++) {
      maze[i][j] = 4;
    }
  }

  //set start node
  maze[1][1] = 2;
}
```

Sets the frame rate

Sets the size of the drawing canvass

Used when drawing the grid

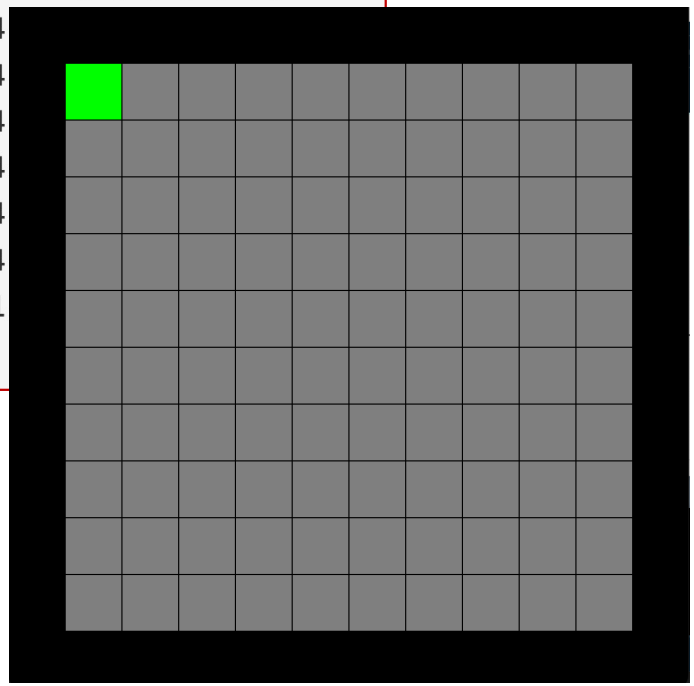
```java
maze = {
     {1,1,1,1,1,1,1,1,1,1,1,1},
     {1,2,4,4,4,4,4,4,4,4,4,1},
     {1,4,4,4,4,4,4,4,4,4,4,1},
     {1,4,4,4,4,4,4,4,4,4,4,1},
     {1,4,4,4,4,4,4,4,4,4,4,1},
     {1,4,4,4,4,4,4,4,4,4,4,1},
     {1,4,4,4,4,4,4,4,4,4,4,1},
     {1,4,4,4,4,4,4,4,4,4,4,1},
     {1,4,4,4,4,4,4,4,4,4,4,1},
     {1,4,4,4,4,4,4,4,4,4,4,1},
     {1,4,4,4,4,4,4,4,4,4,4,1},
     {1,1,1,1,1,1,1,1,1,1,1,1}
  };
```

Maze | Library | Robot

```java
void draw() {
  //draw the maze
  drawMaze();
  //draw the robot in the maze
  robot.draw();

  // Write your code here

  //check the neighbours at the robots current location
  //update your represntation of the environment
  // Move to new position if valid
}

void drawMaze() {
  for (int i=0; i<h; i++) {
    for (int j=0; j<w; j++) {
      switch(maze[j][i]) {
      case 0:
        fill(255, 255, 255);
        break;
      case 1:
        fill(0);
        break;
      case 2:
        fill(0, 255, 0);
        break;
      case 3:
        fill(255, 0, 0);
        break;
      case 4:
        fill(127);
        break;
      }

      rect(j*cellWidth, i*cellWidth, cellWidth, cellWidth);
    }
```

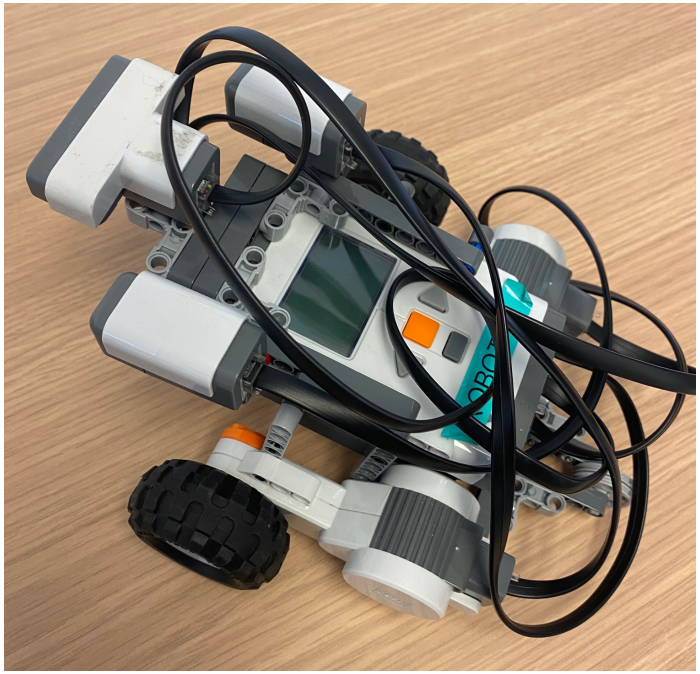
Draws the maze

```java
maze = {
     {1,1,1,1,1,1,1,1,1,1,1,1},
     {1,2,4,4,4,4,4,4,4,4,4,1},
     {1,4,4,4,4,4,4,4,4,4,4,1},
     {1,4,4,4,4,4,4,4,4,4,4,1},
     {1,4,4,4,4,4,4,4,4,4,4,1},
     {1,4,4,4,4
     {1,4,4,4,4
     {1,4,4,4,4
     {1,4,4,4,4
     {1,4,4,4,4
     {1,4,4,4,4
     {1,1,1,1,1
  };
```



Moving it to the robot

- Using LeJOS – lets us program the robot in Java
- Extract the waypoints from the grid map –> upload them to the robot



The Robot Class

```java
import lejos.nxt.*;
import lejos.robotics.navigation.*;

class Robot {
  private DifferentialPilot pilot;
  private Navigator navbot;

  public Robot() {
    //set up the robot
    pilot = new DifferentialPilot(5.0, 17.5, Motor.B, Motor.C);
    //set up the navigator
    navbot = new Navigator(pilot);
    pilot.setTravelSpeed(30); // cm per second
    pilot.setRotateSpeed(45); // degrees per second
  }

  public void moveTo(int x, int y) {
    navbot.goTo(x, y);
    while(navbot.isMoving()){}
  }
}

```

The Main Class

```java
import lejos.nxt.*;
import lejos.robotics.navigation.*;

public class RobotLab {

  public static void main(String[] args) {

    //set up the robot

    Robot robot;
    robot = new Robot();

    // write code to move the robot
    //e.g. robot.moveTo(20, 20);

    //press F9 to compile and upload the code to the robot

  }//end class main
}//end RobotLabDFS

```