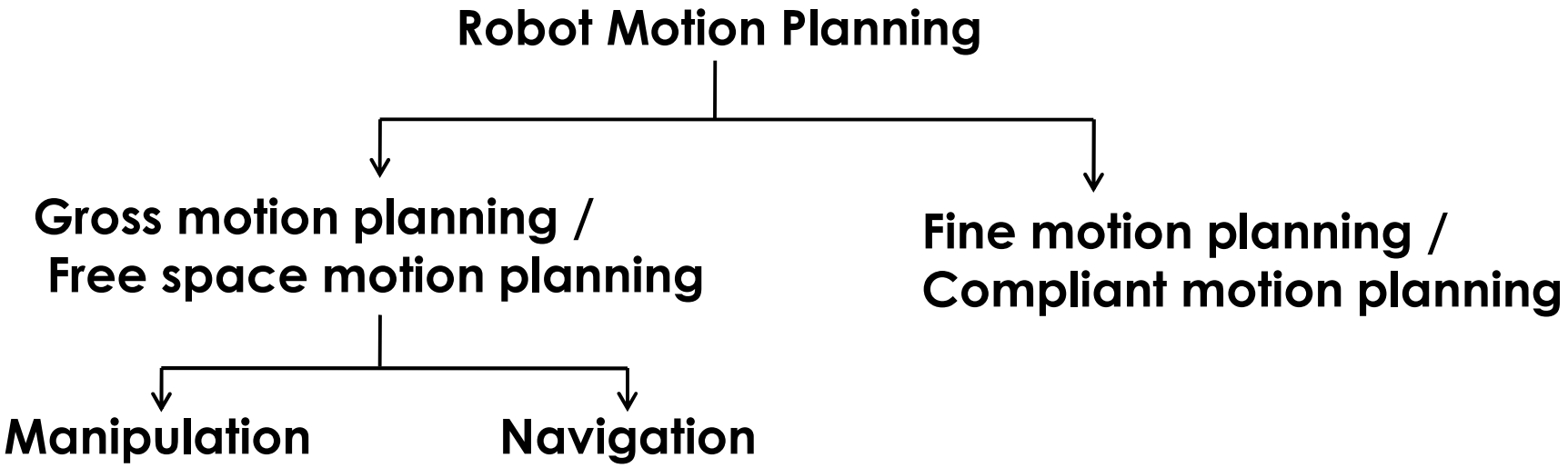
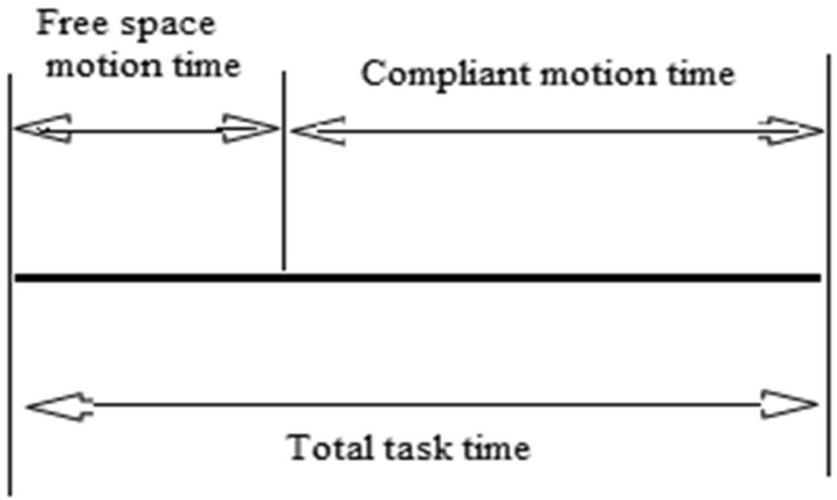
Robot Motion Planning

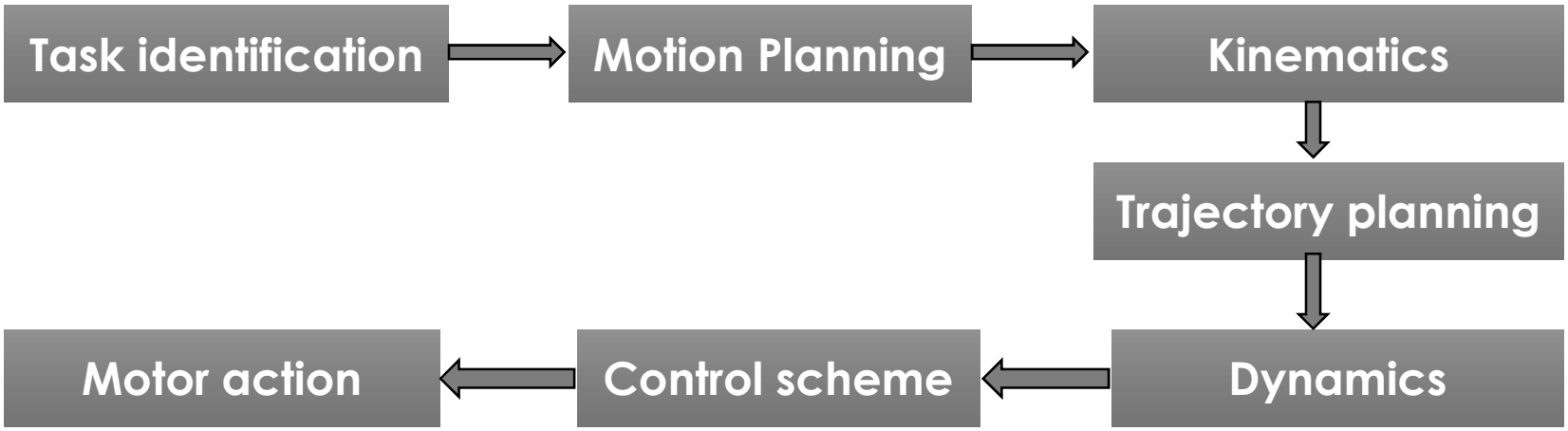
Aim

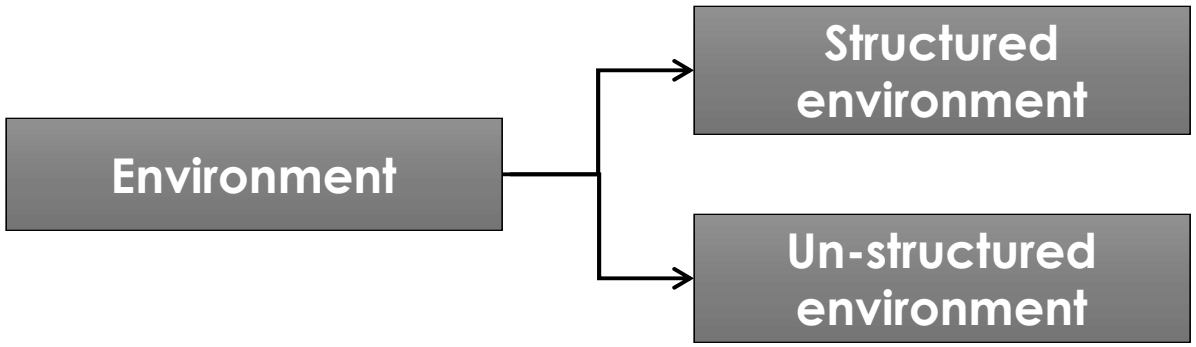
To determine the course of action/path while moving from an initial position to a final position.

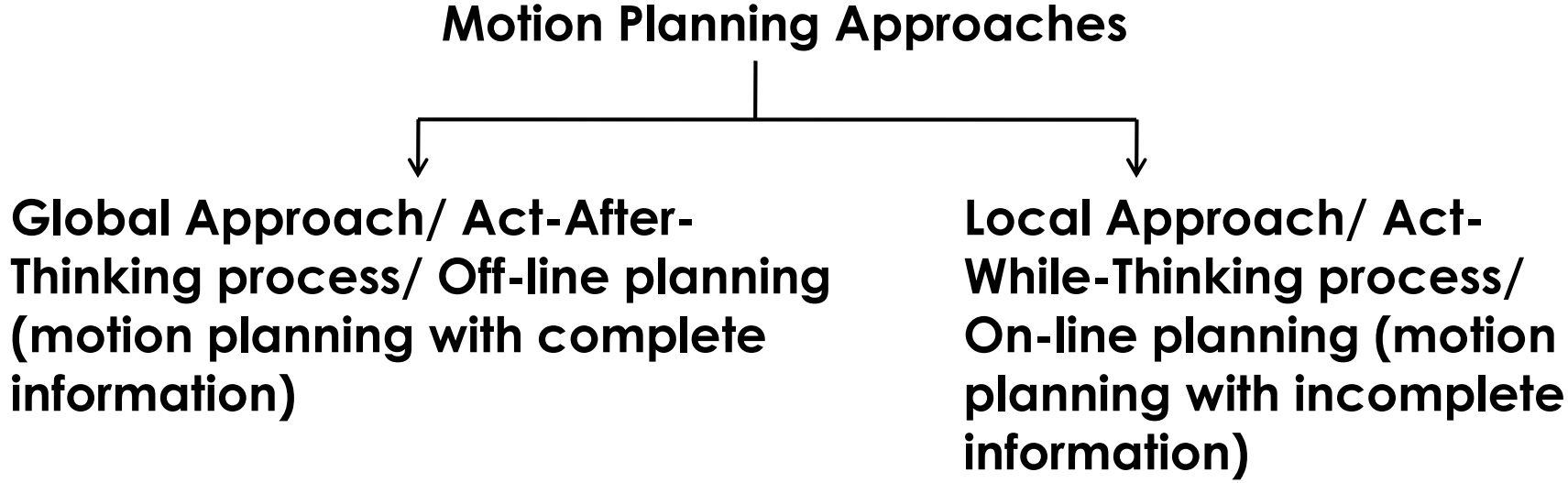

Robot Motion Planning
Gross motion planning /
Free space motion planning
Fine motion planning /
Compliant motion planning
Manipulation
Navigation

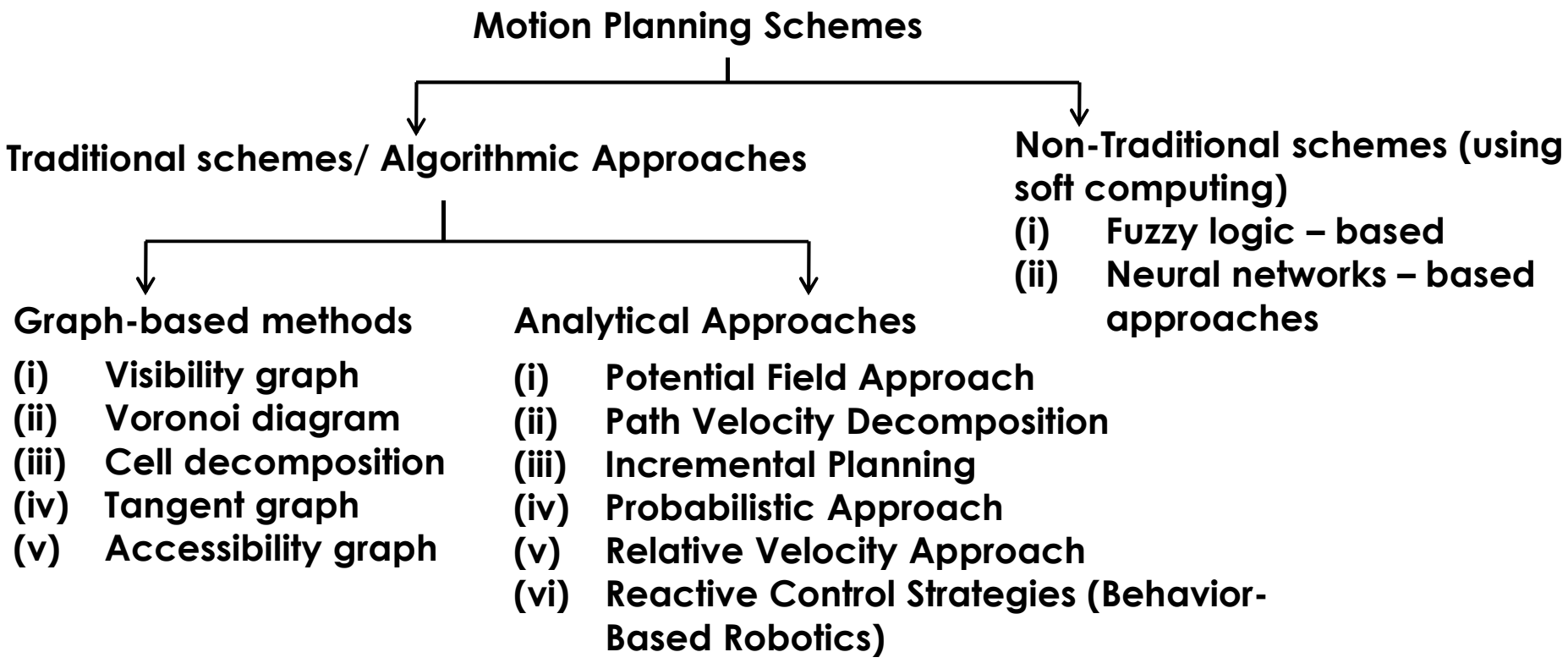

Free space
motion time
Compliant motion time
Total task time

Sequence of Robotic Action



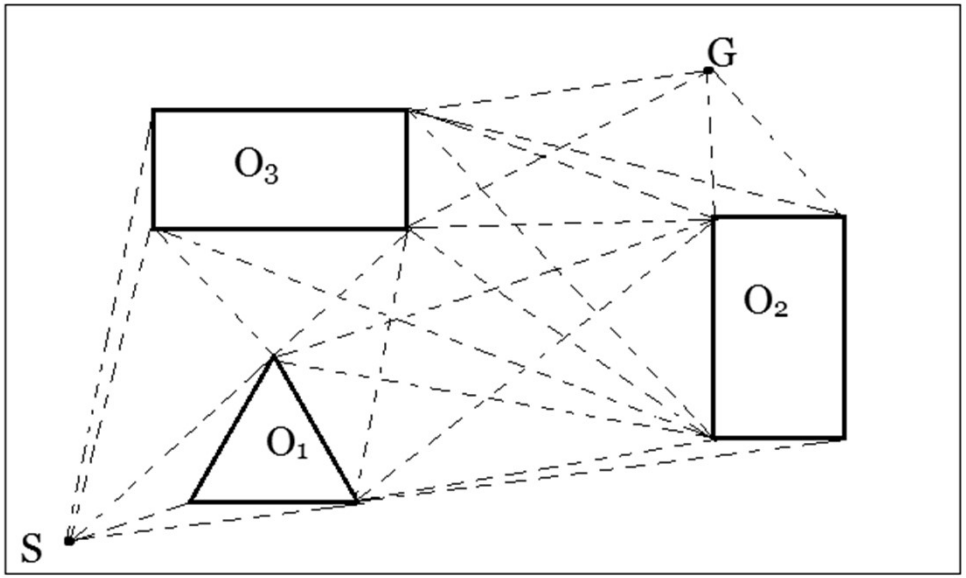

Environment
Structured environment
Un-structured environment


Motion Planning Approaches
Global Approach/ Act-After-Thinking process/ Off-line planning (motion planning with complete information)
Local Approach/ Act-While-Thinking process/ On-line planning (motion planning with incomplete information)


Motion Planning Schemes
Traditional schemes/ Algorithmic Approaches
Non-Traditional schemes (using soft computing)
(i) Fuzzy logic – based
(ii) Neural networks – based approaches
Graph-based methods
(i) Visibility graph
(ii) Voronoi diagram
(iii) Cell decomposition
(iv) Tangent graph
(v) Accessibility graph
Analytical Approaches
(i) Potential Field Approach
(ii) Path Velocity Decomposition
(iii) Incremental Planning
(iv) Probabilistic Approach
(v) Relative Velocity Approach
(vi) Reactive Control Strategies (Behavior-Based Robotics)

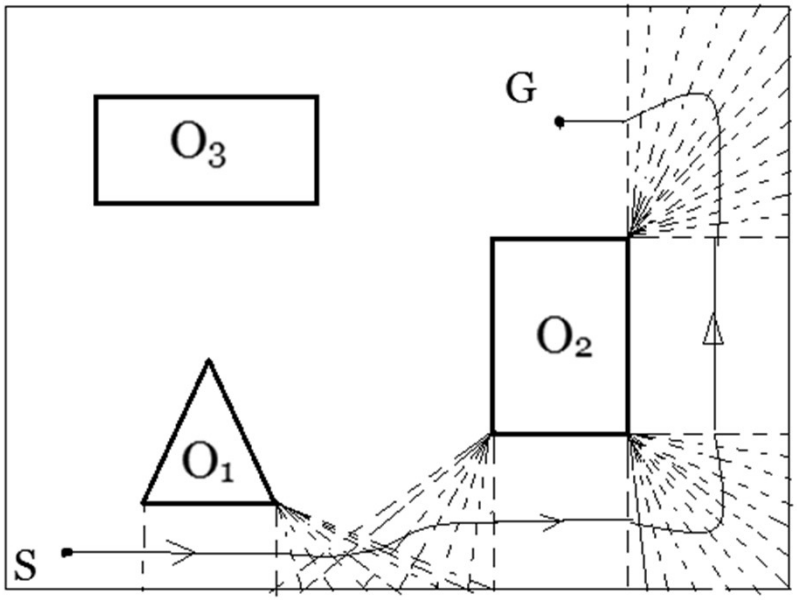
Visibility Graph (Nilsson 1969)

- It connects those vertices of obstacles, which are visible from one another.

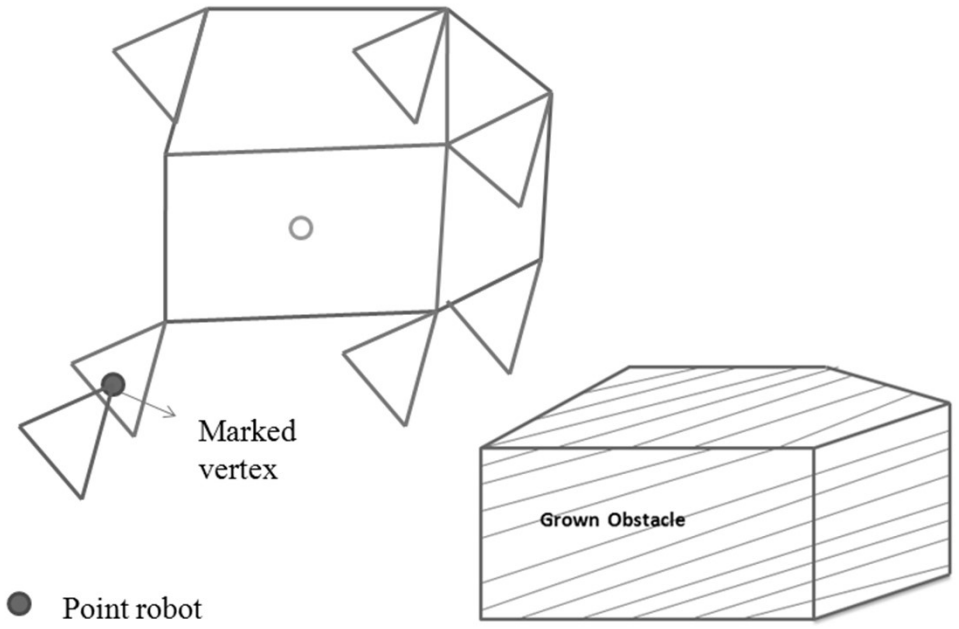


Voronoi Diagram (Dunlaing et al., 1986)

- Represents the locus of points those are equidistant from at least two of the boundaries (obstacle).

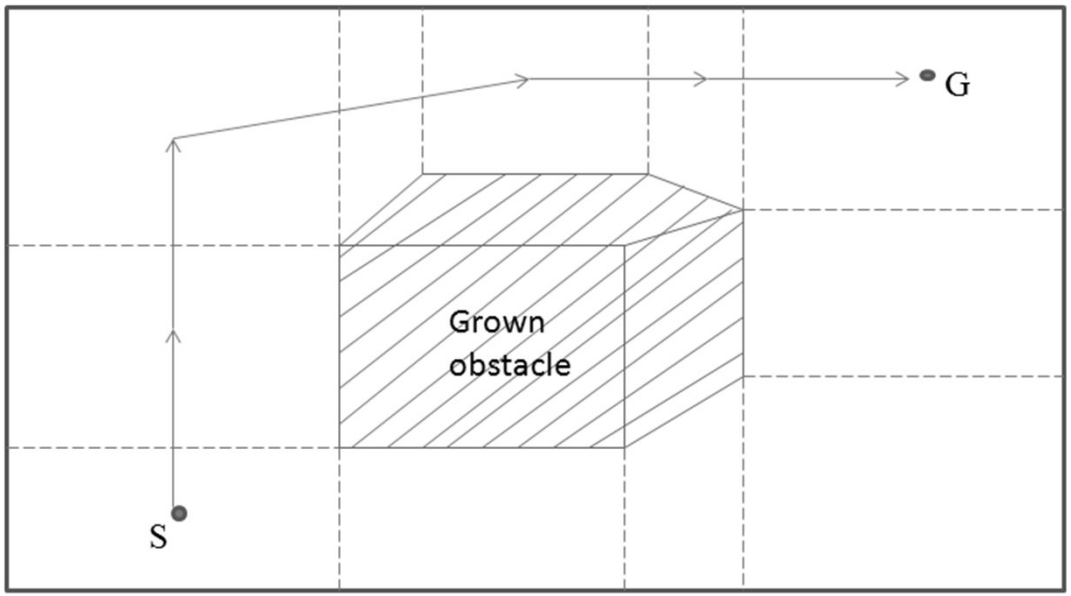


Cell Decomposition (Lozano Perez, 1983)
Configuration space (C-space)



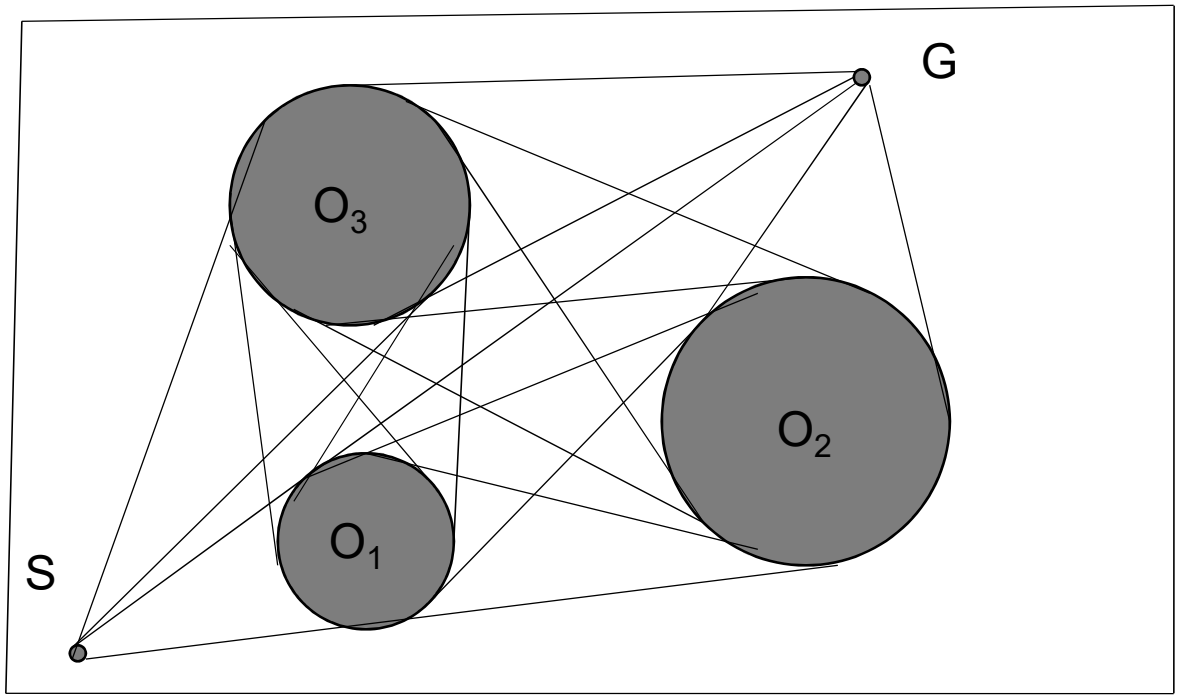
Cell Decomposition (contd.)

- **Robot's free area is divided into a number of small regions called cells. A connectivity graph is then constructed and searched.**



Tangent Graph (Liu & Arimoto 1991)

- Tangents are drawn from the starting point to the visible obstacle and then from one obstacle to another
- A path comprises of tangents and circular arcs
- Complexity: O (N^2), where N is the number of control points


G
O_3
O_2
O_1
S

Approaches to Solve Moving Obstacle Problems
Path Velocity Decomposition (Kant and Zucker, 1984)

This problem is decomposed into two sub-problems as follows:

(i) Path planning problem (PPP) – to plan a path to avoid collision with static obstacles

(ii) Velocity planning problem (VPP) – to plan the velocity of the robot along the above planned path to avoid collision with moving obstacles

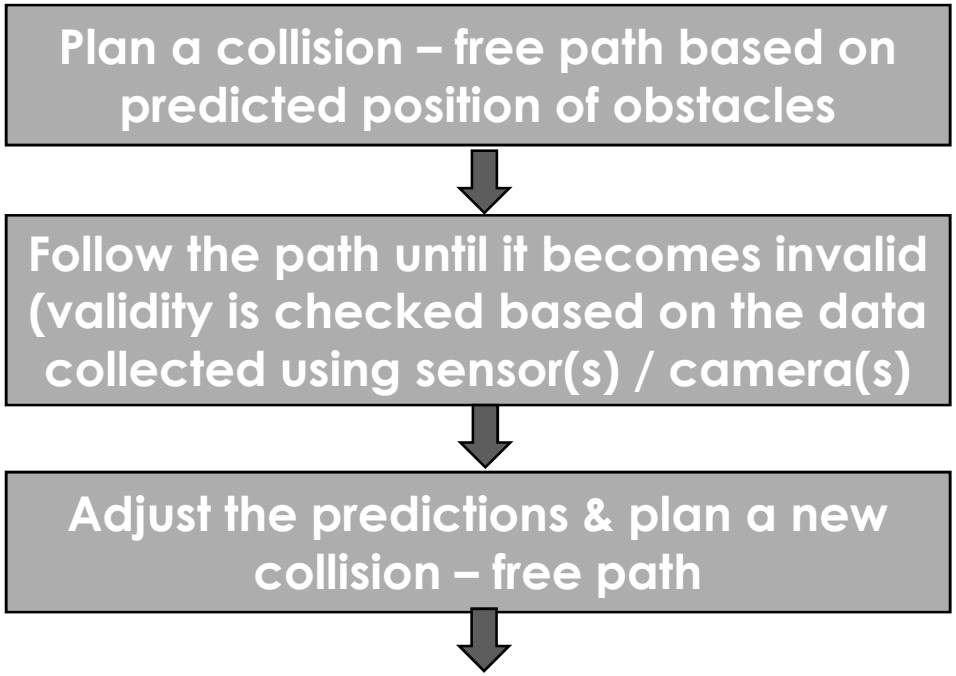
Drawbacks

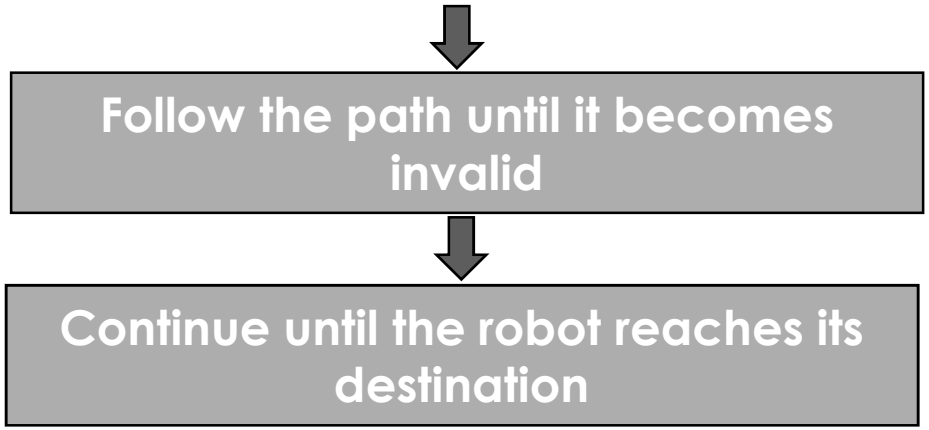
- **The path may not be always good, particularly when there are many obstacles**
- **As there is a sudden change of velocity of the robot, it will have jerky motion, which is not desirable.**

Accessibility Graph (Fujimura and samet, 1988)

- Generalization of the visibility graph
- At a particular instant of time, motion planning problem in dynamic environment is converted into find-path problem, which is solved using visibility graph
- In dynamic environment, visibility graph will go on changing.

Incremental Planning Scheme (Slack & Miller, 1987)




Follow the path until it becomes invalid
Continue until the robot reaches its destination

Relative Velocity Scheme

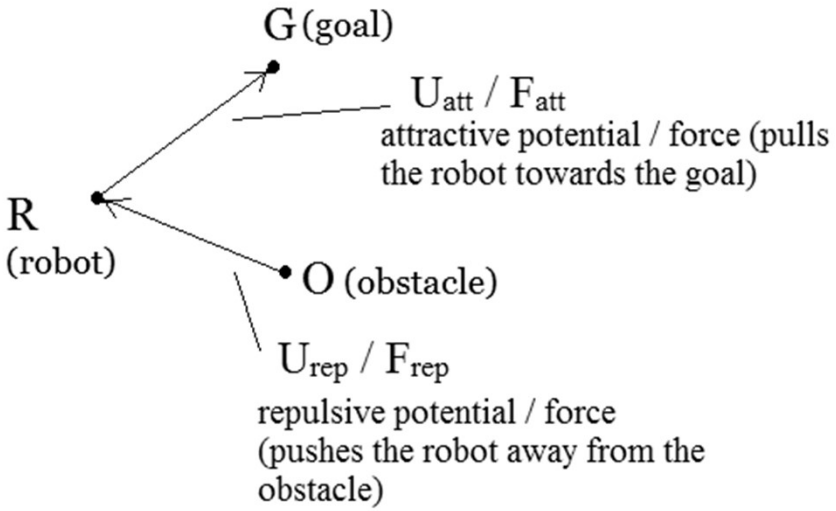
- **Consider relative velocity of the robot with respect to obstacles**

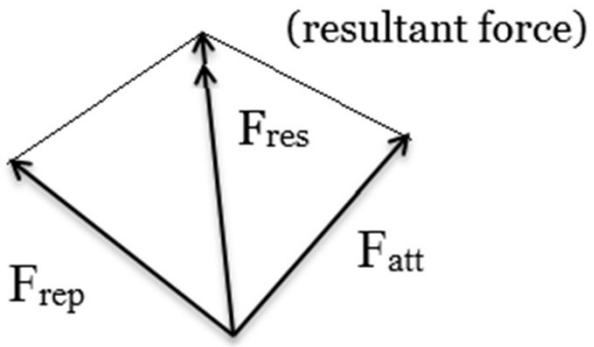
- **Dynamic motion planning problem is converted into several static problems**

- **Several static problems are then converted into a single problem by means of a vector transformation**

- **Set of velocity vectors are then computed, so that the robot avoids collision with all the moving obstacles**

Potential Field Approach (Khatib, 1986)



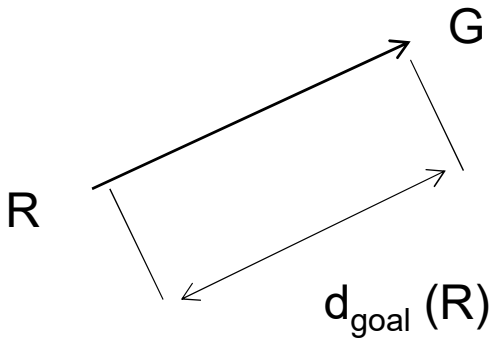


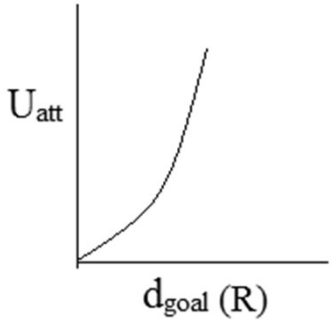
- **Speed of the robot α F_{res}**

- **Direction of movement of the robot is along the direction of resultant force**

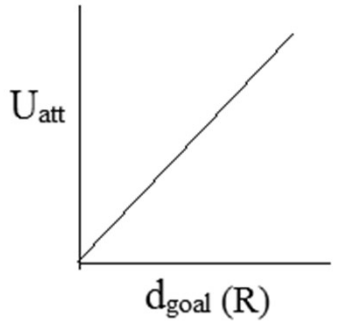
Attractive Potential

$$U_{att}(R) = \frac{1}{2}\xi d_{goal}^2(R), \text{ if parabolic}$$
$$= \xi d_{goal}(R), \text{ if conic-well}$$

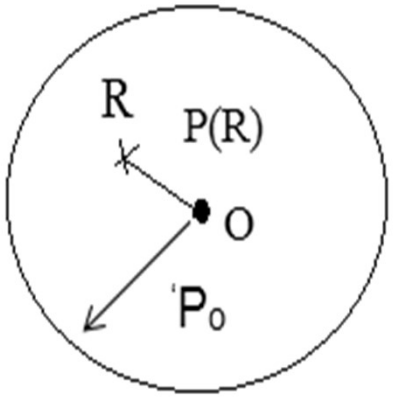




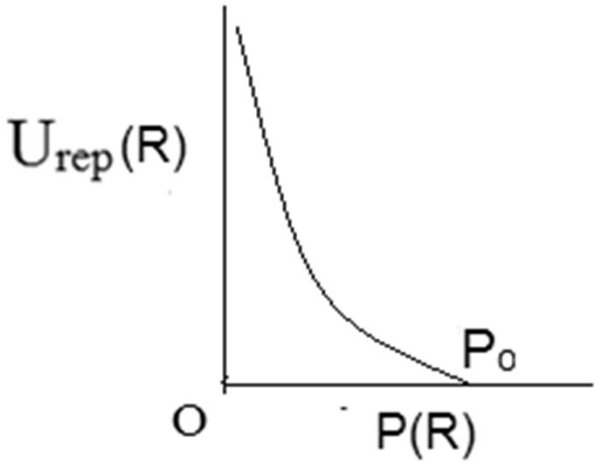
parabolic



Repulsive Potential



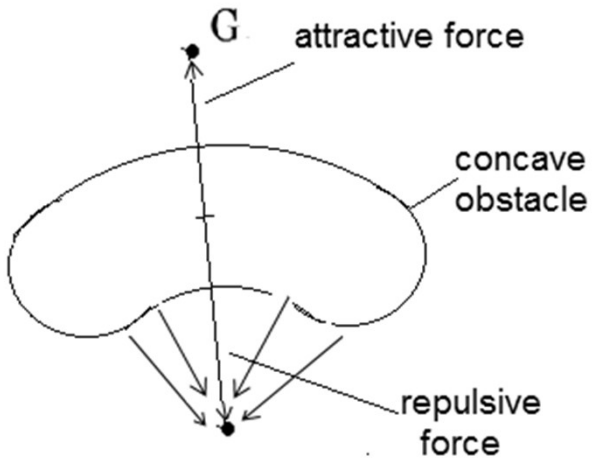
$$U_{rep}(R) = 0$$



$$U_{rep}(R) = \begin{cases} \frac{1}{2}\eta(\frac{1}{P(R)} - \frac{1}{P_o})^2, & \text{if } P(R) < P_o \\ 0, & \text{if } P(R) \geq P_o \end{cases}$$

Drawbacks

- **Solution depends on the chosen potential function**
- **Chance of local minima problem – when the attractive force is balanced by the repulsive force**



- **When the robot travels in a narrow corridor, it experiences repulsive forces simultaneously from the opposite sides, and consequently the motion becomes unstable**

- **Unable to find a path among closely spaced obstacles**

Reactive Control Strategy (Brooks, 1986)

- **Robotic action is decomposed into some independent primitive behaviours like move-to-goal, avoid-obstacle, etc.**
- **Basic behaviours are controlled at different layers of control architecture**
- **Basic behaviours are coordinated by a central mechanism (Behaviour-Based Robotics)**

Drawbacks

- **The behaviours are hard-wired, thus it is unable to handle behaviours which the programmer did not foresee beforehand**

- **The number of layers increases with the complexity of the problem. It requires a large amount of computer memory**

Computational Complexity

- **Canny and Reif (1987) –**

  Motion planning for a point robot among moving obstacles in 2D plane with bounded velocity is NP-hard.

- **Reif and Sharir (1985) –**

a) Motion planning among moving obstacles in 3-D space without velocity bound is NP-hard

b) Motion planning among moving obstacles in 3-D space with velocity bound is PSPACE-hard

Drawbacks of the Traditional Methods of Motion Planning

- **Traditional methods are computationally expensive even for a simple problem**
- **No versatile algorithm, which is applicable to all the problems**
- **As most of the algorithms do not have an optimization module, the generated path may not be optimal in any sense.**

So, there is still a need for the development of an efficient, versatile and computationally tractable algorithm for solving the motion planning problems of robots.