LOCALIZATION

- General control scheme for mobile robot systems
- Odometry or dead reckoning
- Map based localization
- Probabilistic map based localization
- SLAM
- Mathematical formulation of slam

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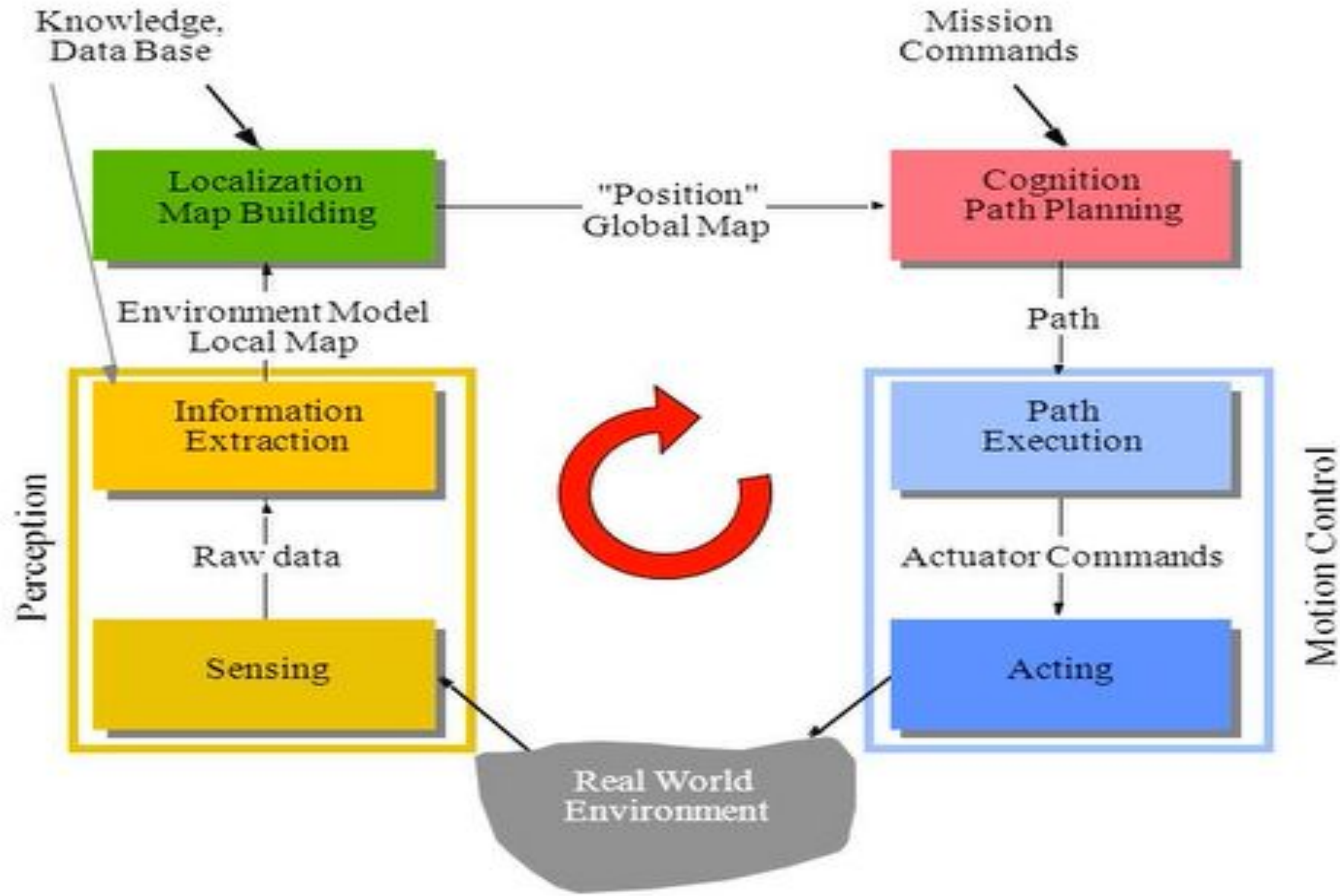
GENERAL CONTROL SCHEME FOR MOBILE ROBOT SYSTEMS



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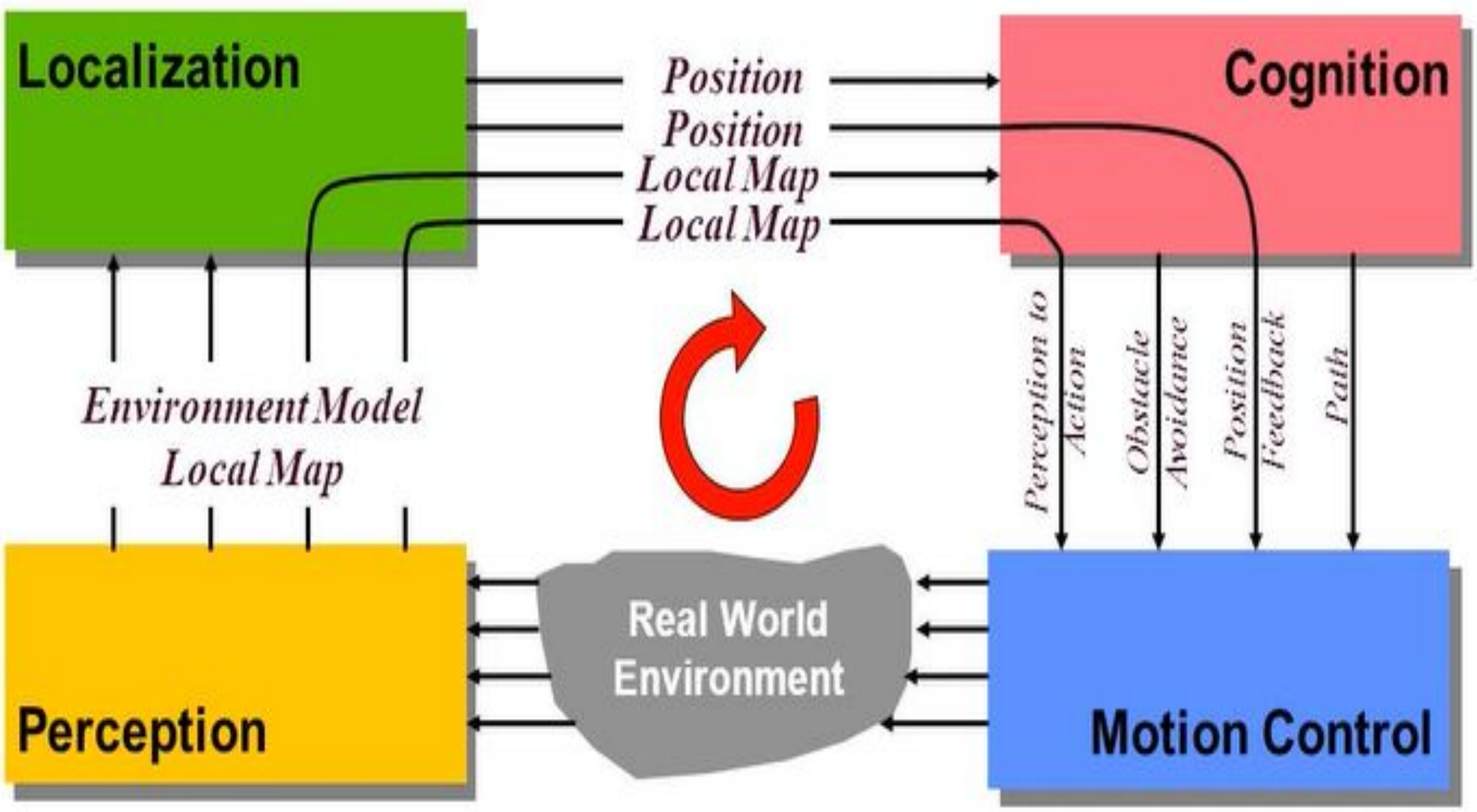

localization

- Localization requires the perception.
- So, the sensors get the data, sensors will collect the data and that data will be processed with the information available with the robot either the map is given or the map is created and based on that it do the localization.
  - Mobile Robot Localization
- Odometry – Dead reckoning
  - Map based localization
    - Markov localization
    - Kalman Filter
  - Autonomous map building
    - SLAM

1.ODOMETRY OR DEAD RECKONING

- Localization method is called odometry or dead reckoning
  - The robot uses its sensors and get the position and orientation, this is called odometry based localisation or a dead reckoning based localisation.
- The robot needs to know the x, y and θ and the odometry will provide you the velocity information.
  - The encoders attached to the robot will provide the velocity information and then the velocity information can be integrated to get the position information and the sensors can be used for getting the orientation.
    - compass to get the orientation
    - odometry to get the position.
- This method cannot be used for a long duration, because of the errors will accumulates.

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1.ODOMETRY OR DEAD RECKONING

inertial Measurement Unit (IMU):

An **IMU** typically contains **accelerometers** and **gyroscopes**, and sometimes **magnetometers**, which together help estimate the robot's **velocity**, **orientation**, and sometimes **position**.

Steps:

- **Accelerometers** measure the robot's acceleration in three dimensions. By integrating this acceleration over time, you can estimate the robot's velocity and position.
- **Gyroscopes** measure the robot's angular velocity (rate of rotation). By integrating the angular velocity, you can estimate changes in orientation (angle).
- **Magnetometers** can be used to determine the robot's orientation relative to the Earth's magnetic field, providing heading information, especially in situations where gyroscopes experience drift.

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1.ODOMETRY OR DEAD RECKONING

Visual Odometry:

Visual Odometry (VO) uses a camera to estimate the robot's motion by analyzing the movement of objects in the environment from consecutive camera frames. It can estimate both **position** and **orientation**.

Steps:

- A camera (monocular or stereo) captures images of the surroundings.
- Image processing algorithms track the displacement of features in the scene between consecutive images (using techniques like feature matching or optical flow).
- By analyzing these shifts, the robot can calculate the distance moved and the change in orientation between frames.

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2.MAP BASED LOCALIZATION

- Map based localization is a localization method by which we use the odometry information and the map information and then localize.
- In map based localisation we use the probabilistic localisation methods
  - Markov localisation
  - Kalman filter localisation.
- Both are map based localisation.
- So, We need to have the map information and the odometry information and the sensor information will be combined in order to get the localization of the robots.
- These are the algorithms which can be used for map based localisation.

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SLAM

- As the robot do the localization sometimes their map may not be available, so in that case the robot needs to create a map of the environment as it do the localisation.
- And this is known as simultaneous localisation and mapping or slam.
- So, the robot will be able to create a map and localise itself
within the map simultaneously.
- The robot does not know the map in advance, but using the sensor information it will try to create a map and then using the algorithms it will try to localise itself within the map that is basically known as slam.

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Simultaneous Localization and Mapping (SLAM):

SLAM is a method that allows a robot to build a map of its environment while simultaneously estimating its own position and orientation within that map. SLAM is used when the robot does not have prior knowledge of the environment.

Steps:

- **Sensor Inputs**: SLAM can use various sensors, such as LIDAR, cameras, or ultrasonic sensors, to measure the environment.
- **Mapping**: SLAM algorithms build a map of the environment by tracking features or landmarks as the robot moves.
- **Localization**: Simultaneously, the robot estimates its position and orientation in the map using the sensor data and the previous map, correcting errors as new data is received.

Types of SLAM:

- **LIDAR-based SLAM**: Uses LIDAR for precise distance measurements to build an accurate 2D or 3D map of the environment.
- **Visual SLAM**: Uses cameras to create a map and estimate the robot's position, typically by detecting and tracking visual features.
- **Extended Kalman Filter (EKF) SLAM**: Uses an estimation technique (Kalman Filter) to estimate both the robot's position and the map of the environment.

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PROBABILISTIC MAP BASED LOCALIZATION.

- In the probabilistic map based localization, we use the odometry, but we try to minimize the odometric error by some methods.
- In a known-location, the robot will be able to move based on the odometry, but after a certain moment the robot will get very uncertain about its position.
- So, in the probabilistic map based localization, we update the position using an observation of its environment by using a camera or some other sensor to observe the surroundings of the robot.
- And then use that information along with the map information and using that information we try to update the robot position.

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PROBABILISTIC MAP BASED LOCALIZATION.

- Information collected from the odometry, and the information collected from the sensors will be fused to get a better estimate of the robot.
- At every stage we will try to reduce the error in the estimated position.
- If the error is increasing we will try to use the information from other sensors and then reduce it to a smaller value.
- And again if it is increasing then again we will try to bring it down.
- So, the estimated error will be much less compared to the odometry alone.
- Then, we use a fusion algorithm to get the better estimate of the robot position.

PROBABILISTIC MAP BASED LOCALIZATION.

- So, at every stage, we will try to at this stage if this is the estimated position using odometry.
- We will try to use the information from the sensors and then reduce it to a smaller value.
- And again this will actually go up, and then again we will try to bring it down, and we will try to bring it down.
- So, the error estimated error will be much less compared to the odometry alone localization.
- So, that is basically the map based localization.

AUTONOMOUS MAP BUILDING

- when the robot is going to an unknown area then the robot will not have the map of an environment.
- So, in that case the robot needs to do the localisation at the same time it has to do the map building.
- This is basically known as autonomous map building and then localizing itself that is the simultaneous localisation and mapping.
- If the map is known, then the robot can do the localisation using the Kalman filter or other methods, but when the map is not there it would not be able to use kalman filter method.

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SLAM

- Starting from an arbitrary initial point, a mobile robot should be able to autonomously explore the environment with its onboard sensors, gain knowledge about it, interpret the scene, build an appropriate map and localize itself relative to this map.
- SLAM- Simultaneous localisation and mapping
- SLAM is a process by which a mobile robot can build a map of an environment and at the same time use this map to deduce its location.
- In SLAM, both the trajectory of the platform and the location of all landmarks are estimated online without the need for any a prior knowledge of location.

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1^{ST} STAGE

- Assume that the robots position is known and the initial position.
- The uncertainty about the current position is known then it starts with the current location and then it looks around and an object mo is located at some distance.

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1ST STAGE

- The robot collects the information and it will create a database and stores the measured distance between the object and the robot in the database.
- Then it will create a map from its current location.
- So, the current location is known.
- There is an uncertainty because at the beginning, the robot position is uncertain and the sensor usually is uncertain.
- So, there will be an error in the object position also.
- As the robot moves its uncertainty increases its position uncertainty increases because its only having the odometry.
- At every odometry calculation the uncertainty increases and the robot is very much uncertain about its position.
  So, that is why it is a large ellipse.

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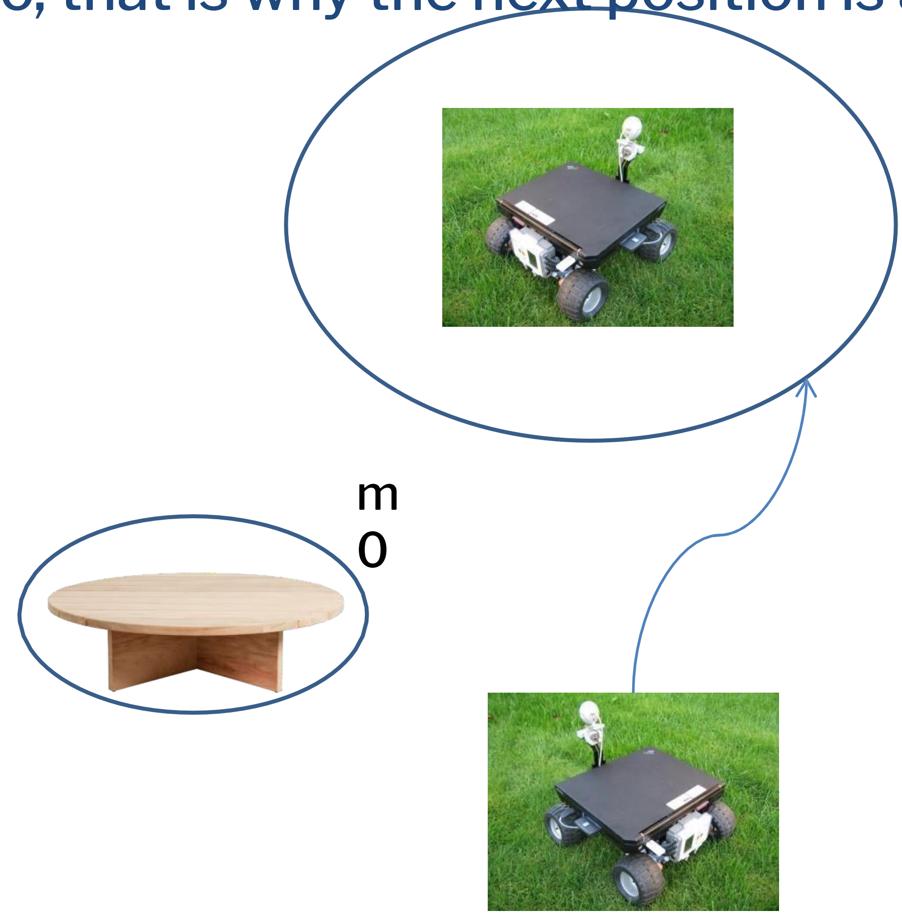
2ND STAGE

- At every odometry calculation the uncertainty increases and the robot is very much uncertain about its position.
  So, that is why the next position is a large ellipse.



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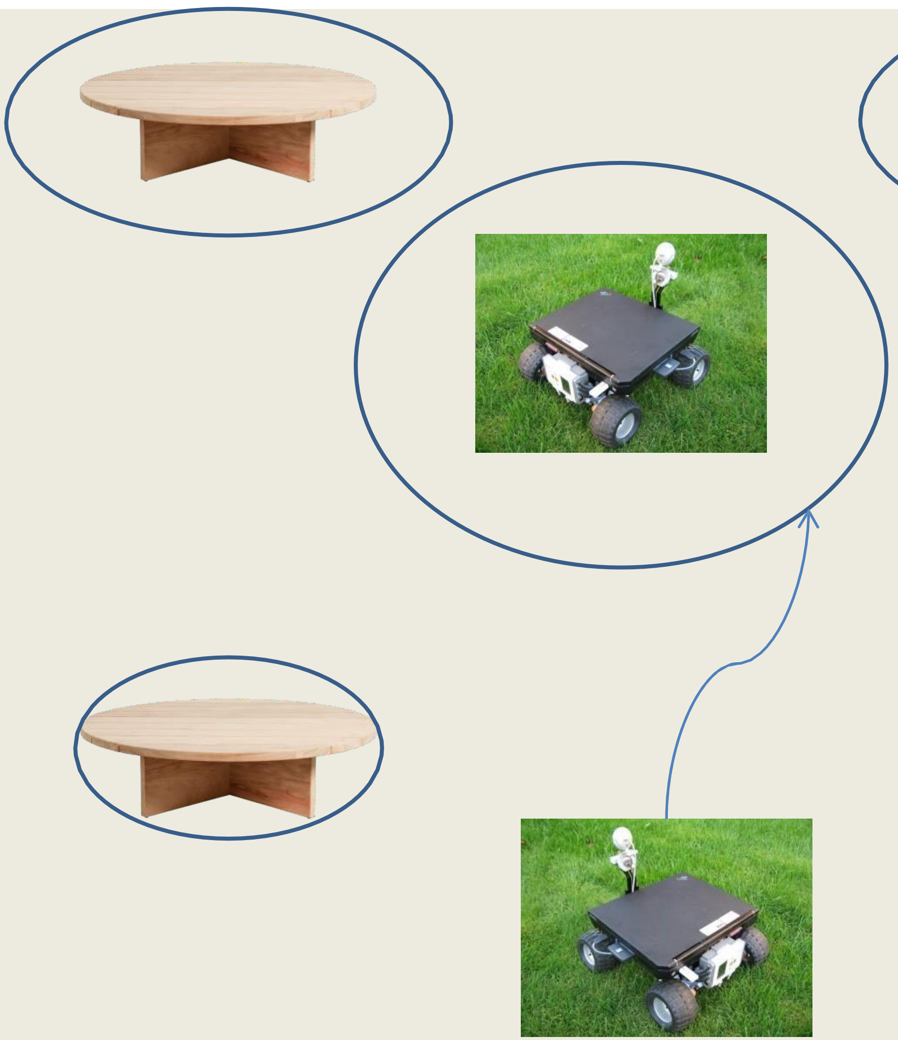
3RD STAGE



3RD STAGE

- Now the robot will see two objects.
- So, it will record the two objects distance from the robots current position.
- So the current position is updated on the database and the calculated position it is seeing two objects is also updated.
- And it just got uncertainty because the position is uncertain and the sensor uncertainty is there therefore, there will be large uncertainty in the object position.

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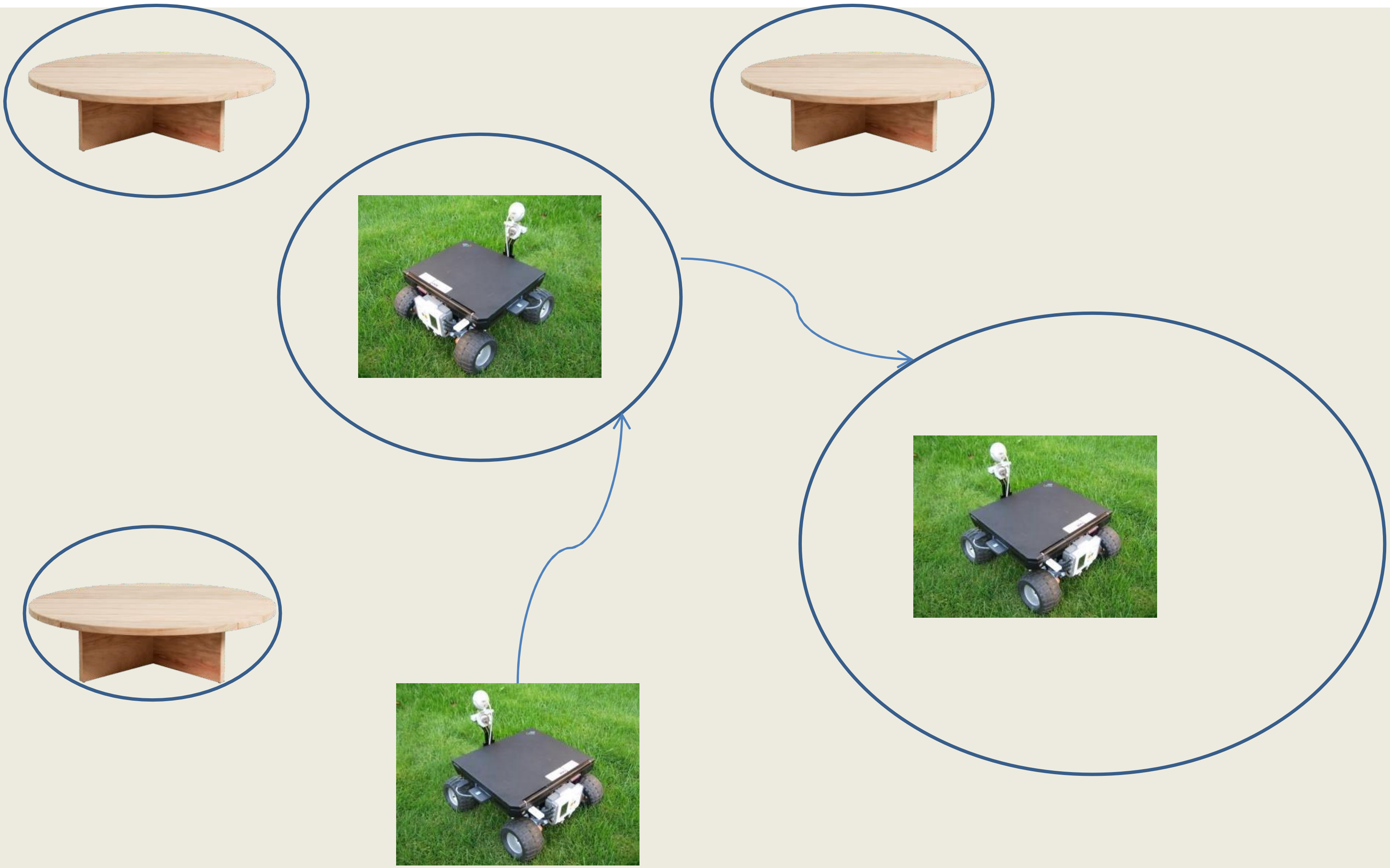
4TH STAG



4TH STAGE

- Its uncertainty is very huge because it has travelled all the distance.
- So, it has become highly uncertain about its position.

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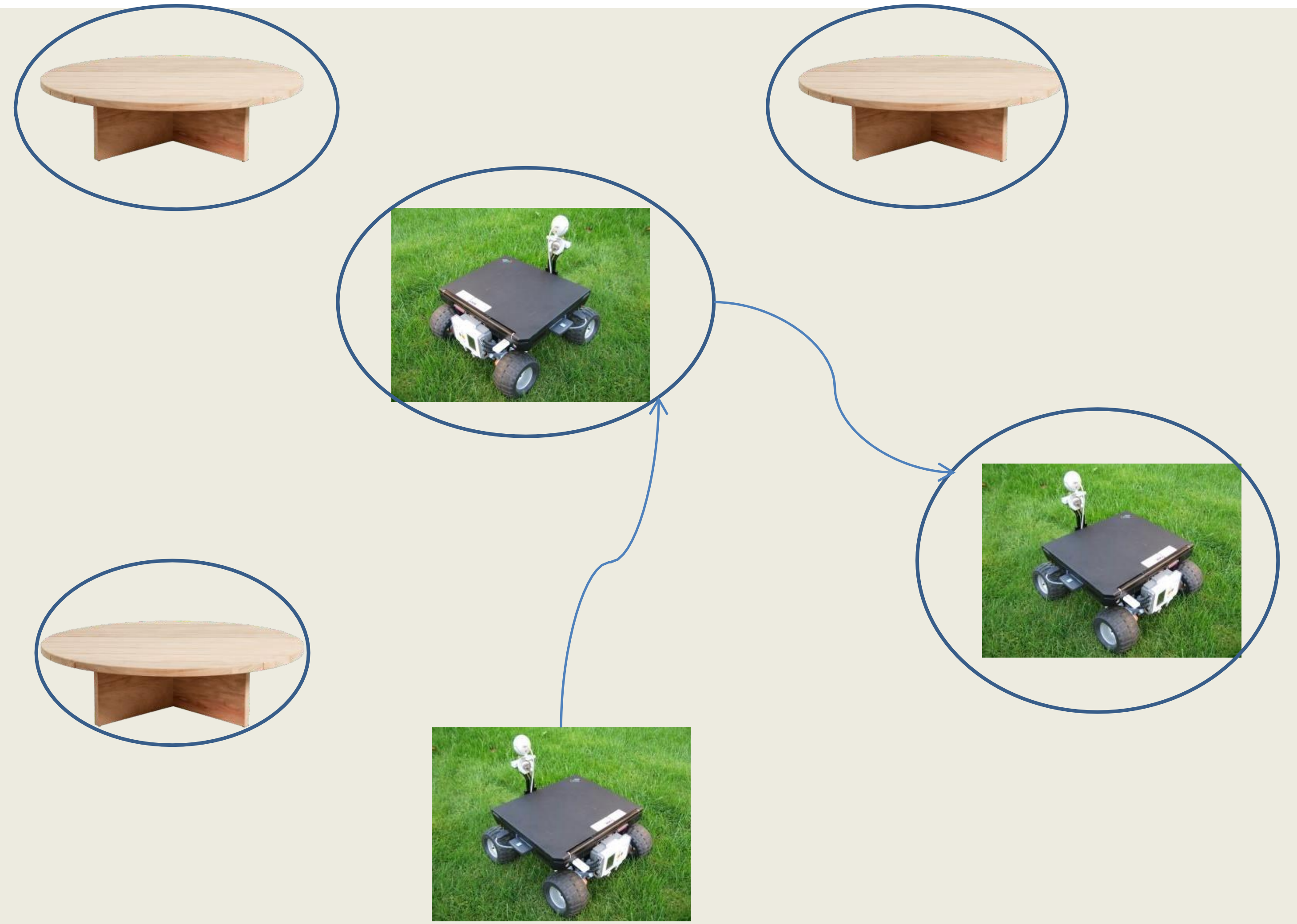
5TH STAGE



5^TH STAGE

- Then from this position it sees the same object.
- we have two observations for the same object - one from current position and one from initial position
- So there will be a difference or then it can calculate the position of the object from both positions.
- Because that information is already there in the map.
- This object is already there in the map and now the robot can actually use that information to recalculate its position using some kind of a data fusion and once it is done then the uncertainty will reduce drastically then the uncertainty in position will also come down drastically.

5TH STAGE

- Now, this uncertainty has come down because it has seen the same object, but the same feature it has seen and therefore, since it is already there in the database the robot will be able to use that information.
- Fuse these two information and then recalculate its position
- So, similarly it will be able to recalculate all positions.
- The robot keeps on moving and if it moves further it will see the something new and it will recalculate this position and record the position of the object new object based on the information.

5TH STAGE

- After going through many times the robot will be having a much more clarity on the objects in the arena.
- So, it will be creating a much better map and then it will be able to localize itself using the fusion method or some algorithms that we already use for localisation.

MATHEMATICAL FORMULATION OF SLAM

X_T ------------- Robot path

U_T ……………….Robot motion

M ……………………True map

Z_t ……………………. Observations in the sensor frame

The SLAM problem is recovering the model map M and robot path X from odometry U and observations Z

Online SLAM

$P(x_t, M|Z_t, U_T)$

- Xt will be the path of the robots
- It is a set of points
  - ie. x y and θ will be the parameters at every time t it will be finding out what is the new position that is basically the robot path.
- UT is the control input which is the robot motion control input
- M is the map of the environment the map which is being created by the robots
- ZT is the observation what the robot is seeing in the sensor frame.
- So, the SLAM problem is to recover the model map M and path X from odometry and observations. So, we have only odometry and observations.

- So, using this we try to create the map and get the path X.
- Create the map means actually making the map and get the path X means we are trying to find out the location of the robot.
- SLAM problem is basically recovering the model map and robot path from observations.
- The online SLAM is basically getting current position of the robot using the current map information and the control inputs.
- In offline SLAM we need to have the complete path identified at every point.