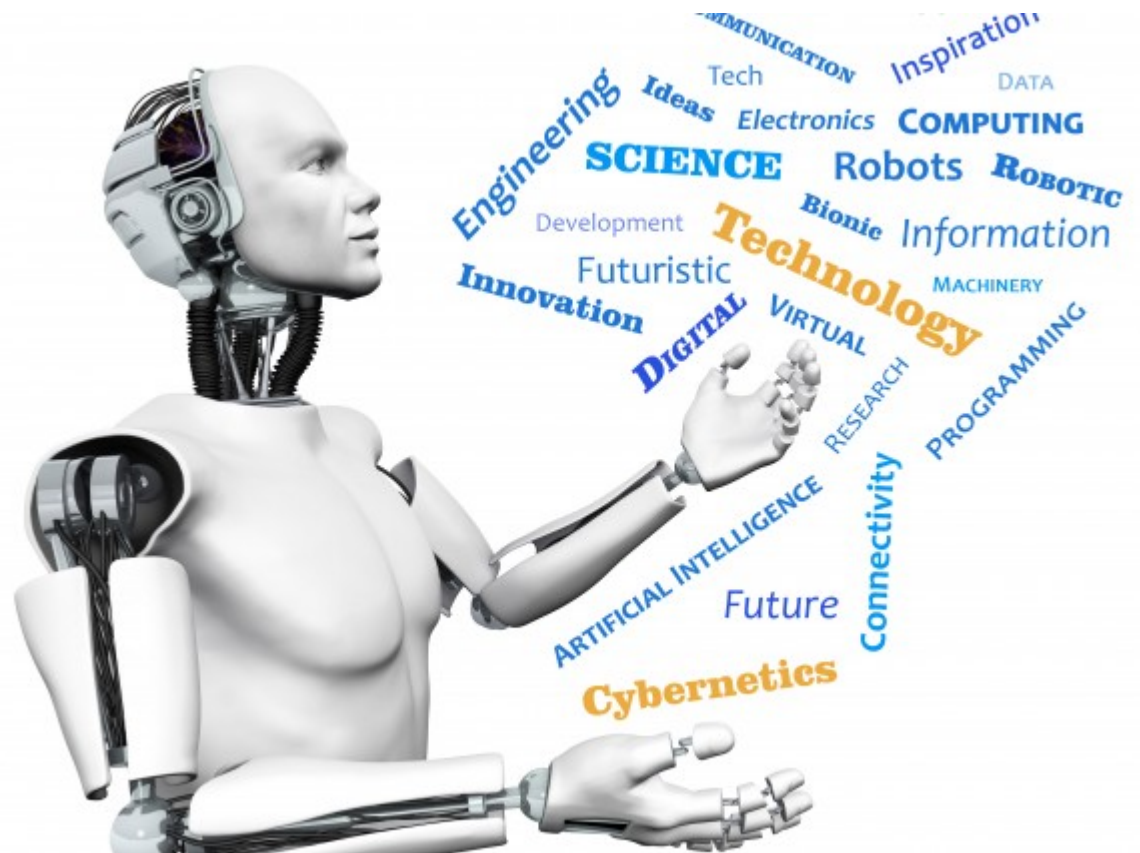


15-494/694: Cognitive Robotics

Dave Touretzky

Lecture 8:
Review, and SLAM



Kinematics Again

- Why we need a kinematics engine (Tower of Hanoi demo).
- But we need path planning too.

Kinematics Review

- What is a kinematic chain?

Kinematics Review

- What is a kinematic chain?
 - An alternating sequence of joints and links.
 - The transformation between reference frame i and reference frame $i+1$ is described by DH parameters.

Kinematics Review (2)

- What defines a reference frame?

Kinematics Review (2)

- What defines a reference frame?
 - An origin (x,y,z) and a 3D orientation.
 - The orientation can be described in terms of a 3D rotation matrix.
 - We could also use Euler angles, or a quaternion.

Kinematics Review (3)

- Why do we need a dummy joint between the head reference frame and the camera reference frame?

Kinematics Review (3)

- Why do we need a dummy joint between the head reference frame and the camera reference frame?
 - The four DH parameters for one joint don't provide enough degrees of freedom to let us control both the orientation and the origin of the new reference frame.
 - The dummy joint adds four additional degrees of freedom.

Kinematics Review (4)

- How do we move from the joint i reference frame to the link i reference frame?

Kinematics Review (4)

- How do we move from the joint i reference frame to the link i reference frame?
 - Use `joint.apply_q()` to apply the rotation.

Kinematics Review (4)

- How do we move from the joint i reference frame to the link i reference frame?
 - Use `joint.apply_q()` to apply the rotation.
- How do we move from the link i reference frame to the joint $i+1$ reference frame?

Kinematics Review (4)

- How do we move from the joint i reference frame to the link i reference frame?
 - Use `joint.apply_q()` to apply the rotation.
- How do we move from the link i reference frame to the joint $i+1$ reference frame?
 - Apply the (constant) transformation matrix described by the DH parameters.

Particle Filter Review

- What are the results of each of the following choices of sensor model?
 - Distance only; one landmark.
 - Distance only; two landmarks.
 - Bearing only; one landmark.
 - Bearing only; two landmarks.
 - Distance plus bearing; one landmark.
 - Distance plus bearing; two landmarks.
 - Non-point landmarks (cubes).
 - Non-point landmarks (ArUco markers).

How To Build A World Map

- SLAM: Simultaneous Localization and Mapping algorithm.
- Each particle stores:
 - a hypothesis about the robot's location
 - a hypothesis about the map, e.g., a set of landmark identities and locations.
- Particles score well if:
 - Landmark locations match the sensor values predicted by the robot's location.
- Robot location is jittered by the motion model. This jitters the landmark locations.

First SLAM Video

- SLAM works well even when landmarks are ambiguous, such as identical markers.
- Reason: updating the particle weights based on sensor readings after movement applies strong constraints on possible robot locations.

Brenner's Particle Filter Course

- Part A: introduce robot, odometry, laser scanner as distance sensor.
- Part B: using laser sensor data to estimate landmark positions.
- Part C: Bayes filter: predict (motion model) and correct (sensor model).
- Part D: Kalman filter (Bayes with gaussian noise model) and Extended Kalman Filter (arbitrary noise model; approximate with Taylor series). Error ellipses.

Brenner's Particle Filter Course

- Part E: particle filters (non-parametric alternative to EKF; arbitrary distributions including multi-modal).

SLAM:

- Part F: EKF SLAM: use EKF for both position and landmarks.
- Part G: Particle SLAM: use particle filter for position and EKF for landmarks.

The cozmo-tools Particle Filter

- Defined in `cozmo_fsm/particle.py`
 - Versions with and without SLAM
 - Default is `SLAMParticleFilter`
 - Uses walls defined by ArUco markers as landmarks, but you can control this.

```
robot.world.particle_filter
```

```
p0 = robot.world.particle_filter.particles[0]
```

```
p0.landmarks
```

Representation of a Landmark

Assume the robot is seeing Wall 1.

```
wall1 = p0.landmarks['Wall-1']
```

- `wall1[0]` is a column vector $[x,y]^T$ giving the position of the landmark on the map.
- `wall1[1]` is the landmark's orientation, `theta`.
- `wall1[2]` is the covariance matrix Σ used in the EKF update equation.

How Do We Display the Map?

- Every particle has a weight.
- Use the map from the most highly weighted particle.
- This means the map will sometimes “jump” to a new configuration if the highest weighted particle changes.