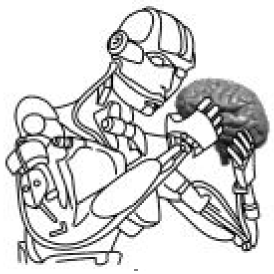
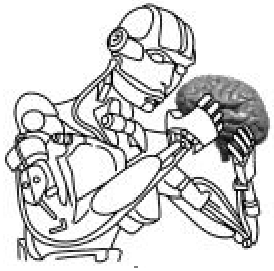
CS545 Lecture 16
Mobile Robotics



- Mobile Robots
  - Control Paradigms
  - Locomotion
  - Behavior-based robotics
- http://robotics.usc.edu/~aatrash/cs545

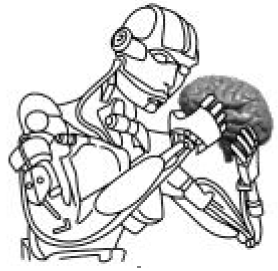
- Slides based on:
  - *Computational Principles of Mobile Robotics* – Gregory Dudek
  - *Probabilistic Robots* – Sebastian Thrun
  - *Behavior-based Robotics* – Ron Arkin
  - Presentation by Dieter Fox

Mobile Robots



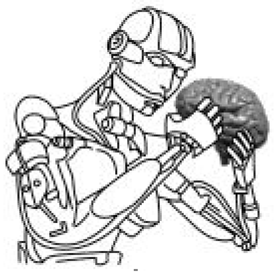
- Robots no longer restricted for factory settings
  - Entertainment, toys
  - Personal services
  - Medical
  - Industrial Automation (mining, harvesting)
  - Hazardous environments (space, underwater)
- Agents need to be mobile

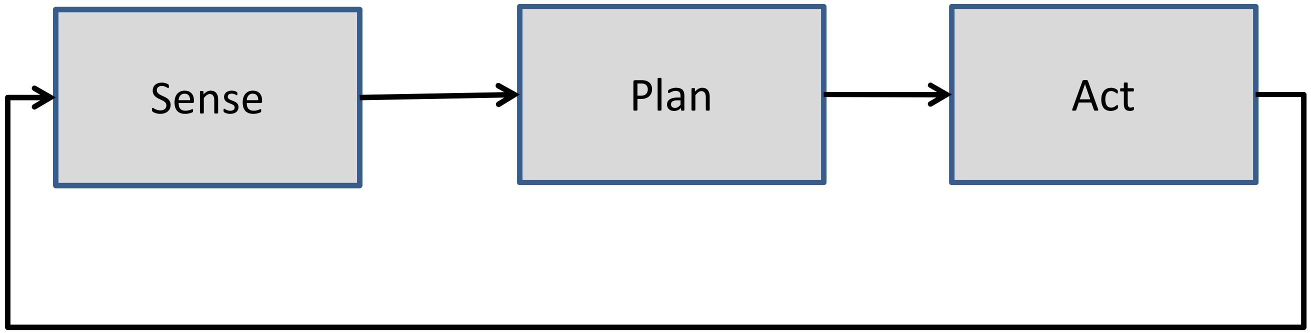
Shakey



- One of first general purpose robots
- Stanford Research Institute
- Use classical planning

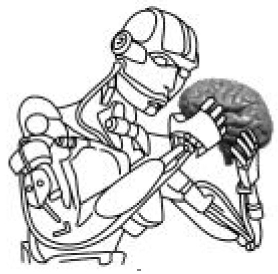
Classical Planning Paradigm

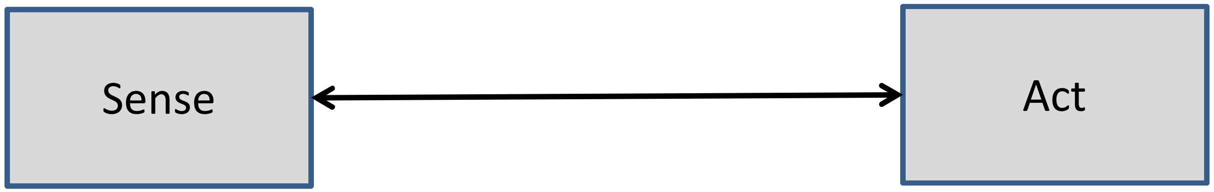




- Direct application of AI tech to robots
- STRIPS (Stanford Research Institute Problem Solver)
- Assumed perfect world. No noise
- SLOW!!!!

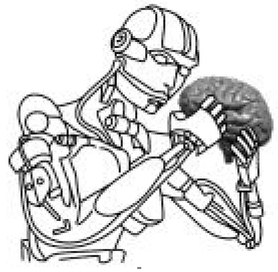
Reactive/Behavior-Based

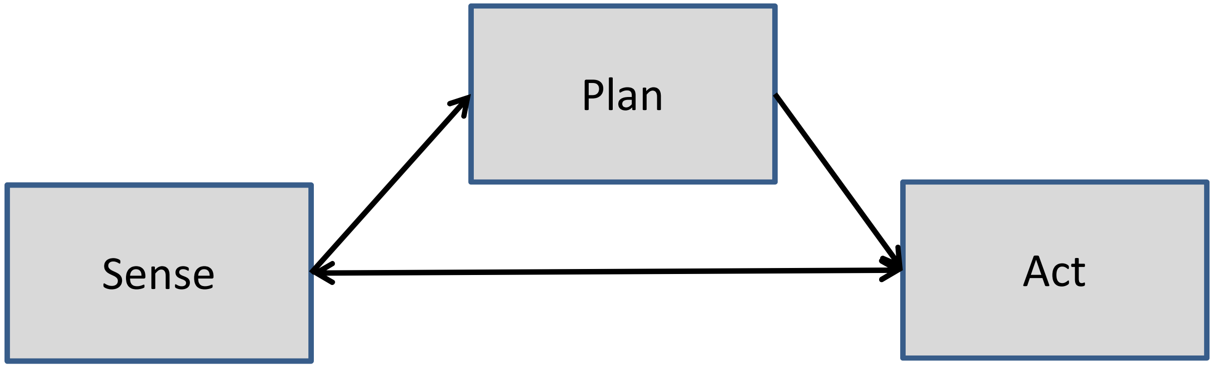




- No models/planning. “World is its own, best model”
- Based on biological systems
- Good for local decisions
- Many limitations

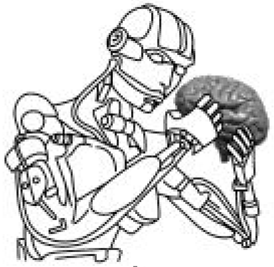
Hybrid





- Combination of other paradigms
  - Use planning components for slower long-term planning
  - Use reactive system for fast, local control

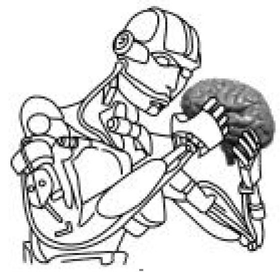
Probabilistic Robots

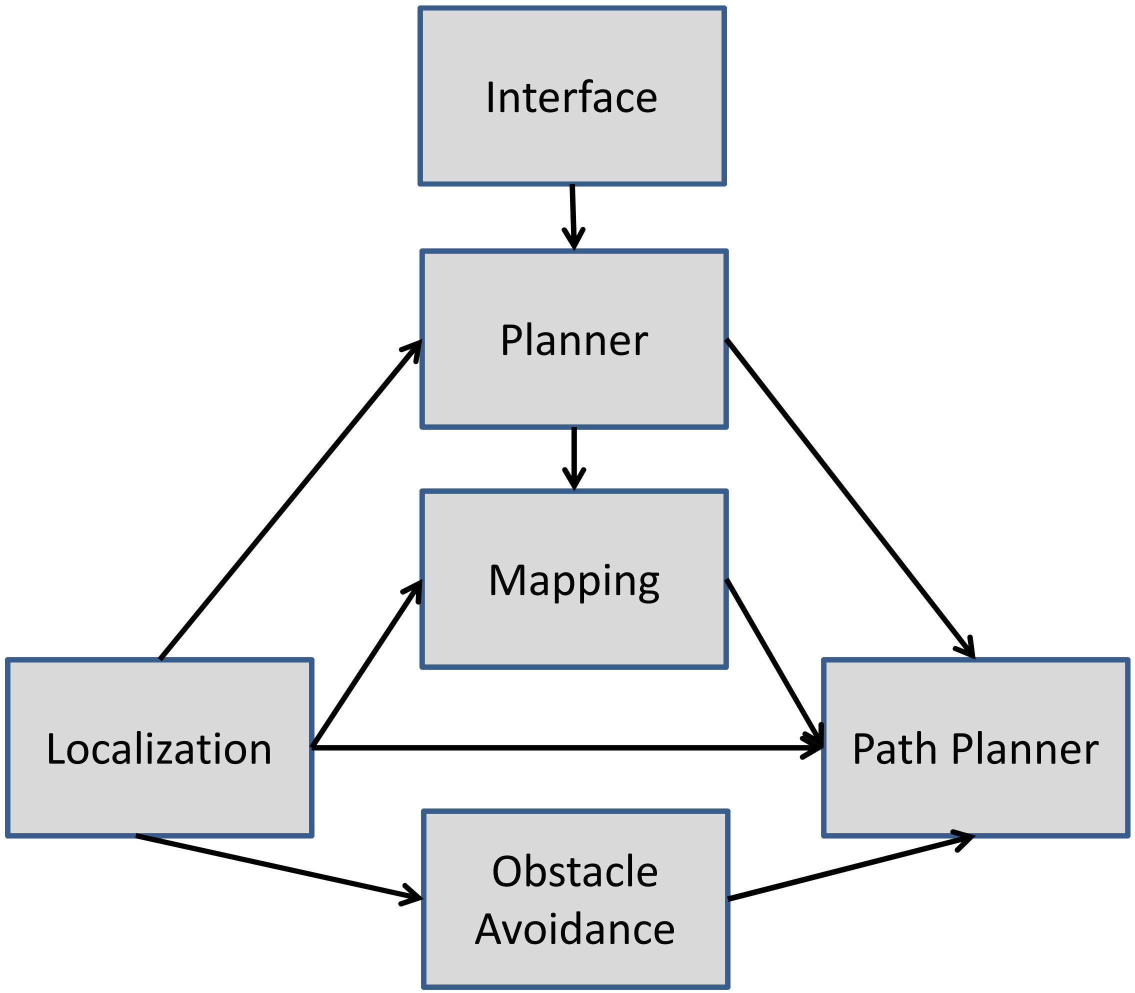


- Assume models and sensors are inaccurate
  - Sensors bad
  - Incomplete information
  - Motors not precise
- Integrate models and sensing
- Bayes Rule:

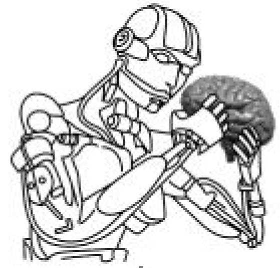
$$P(A|B) = \frac{P(B|A)P(B)}{P(A)}$$

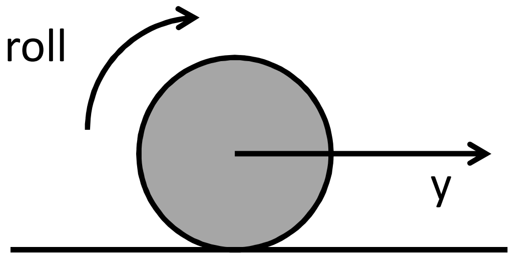
Control Architecture (Example)

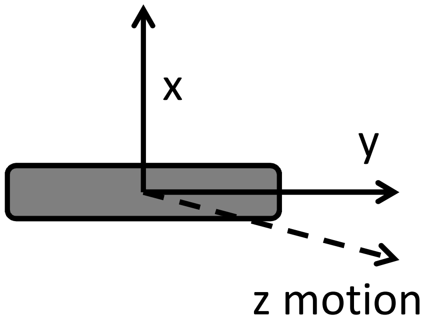




Locomotion

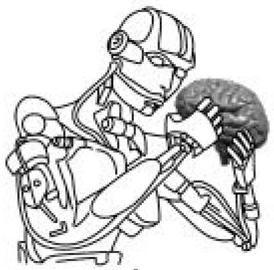




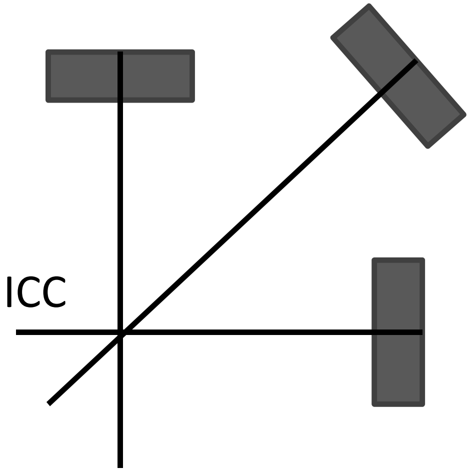


- Common Drives
  - Differential – rotation by speed of wheels
  - Synchronous – can steer wheels
  - Tracked – tanks
  - Car – Ackerman steering
- Holonomic vs. non-Holonomic

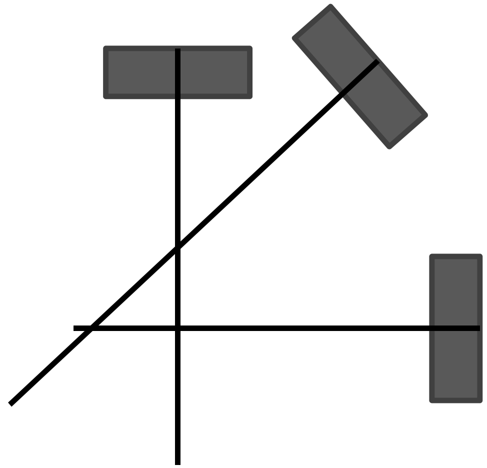
Instantaneous Center of Curvature



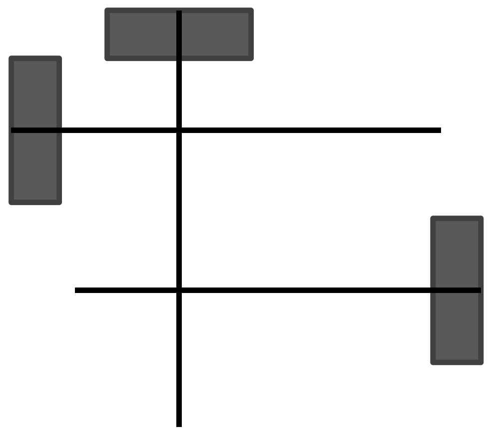
- Instantaneous Center of Curvature
  - Intersection of x-axis of wheels



Good!

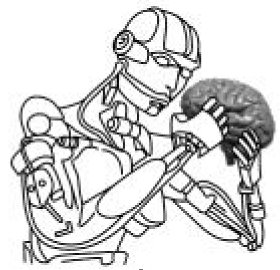


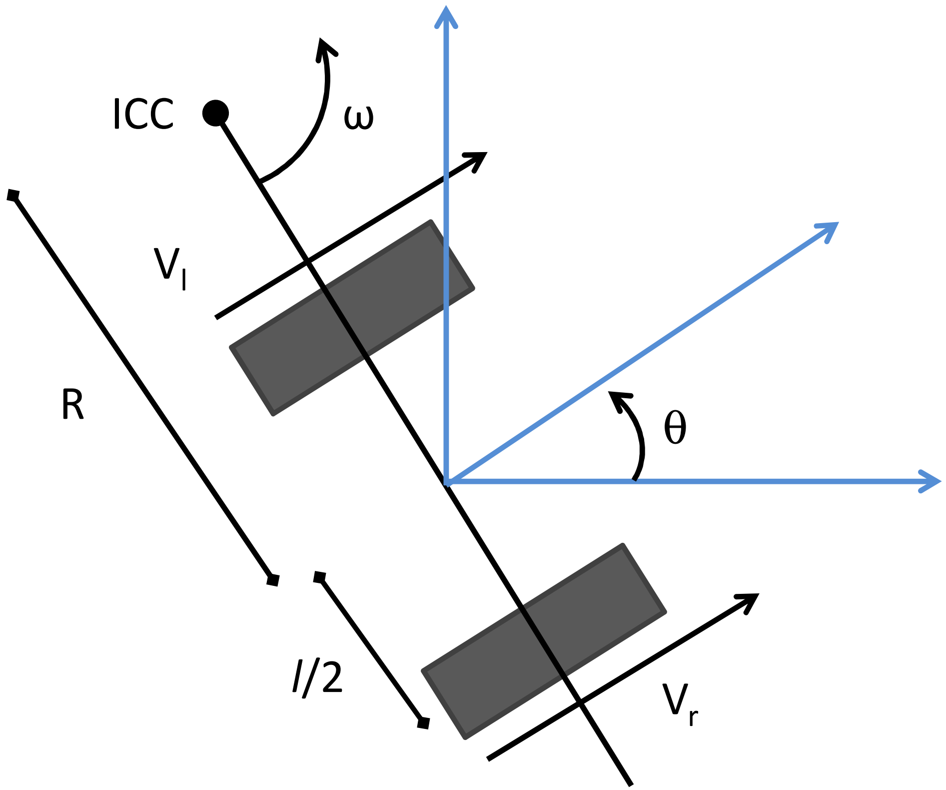
Bad!!!



Bad!!!

Differential Drives





$$\mathrm{ICC} = [x - R\sin\theta,\ y - R\cos\theta]$$

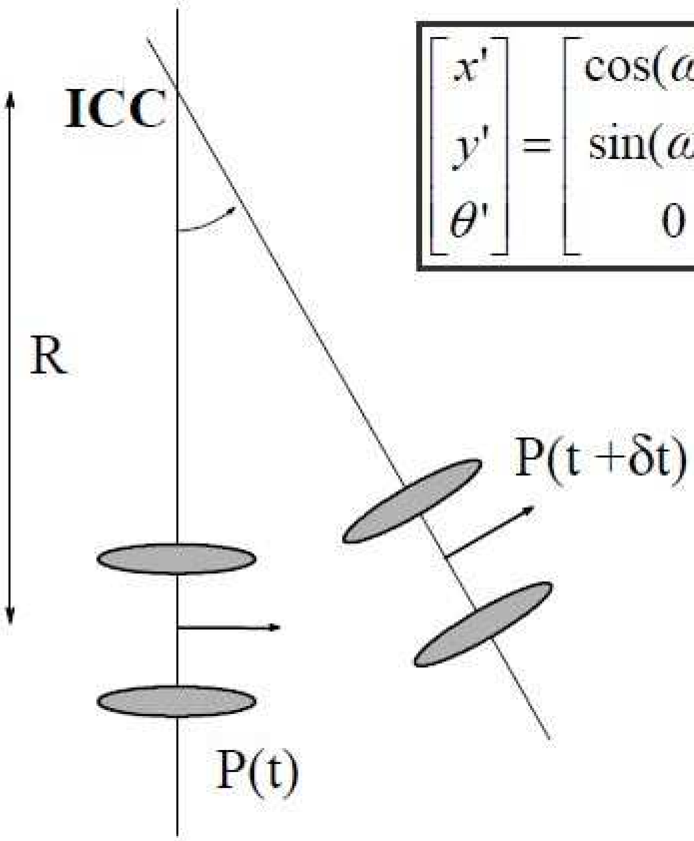
$$\omega(R + l/2) = v_r$$

$$\omega(R - l/2) = v_l$$

$$R = \frac{l}{2}\frac{(v_l + v_r)}{(v_r - v_l)}$$

$$\omega = \frac{v_r - v_l}{l}$$

Differential Drive



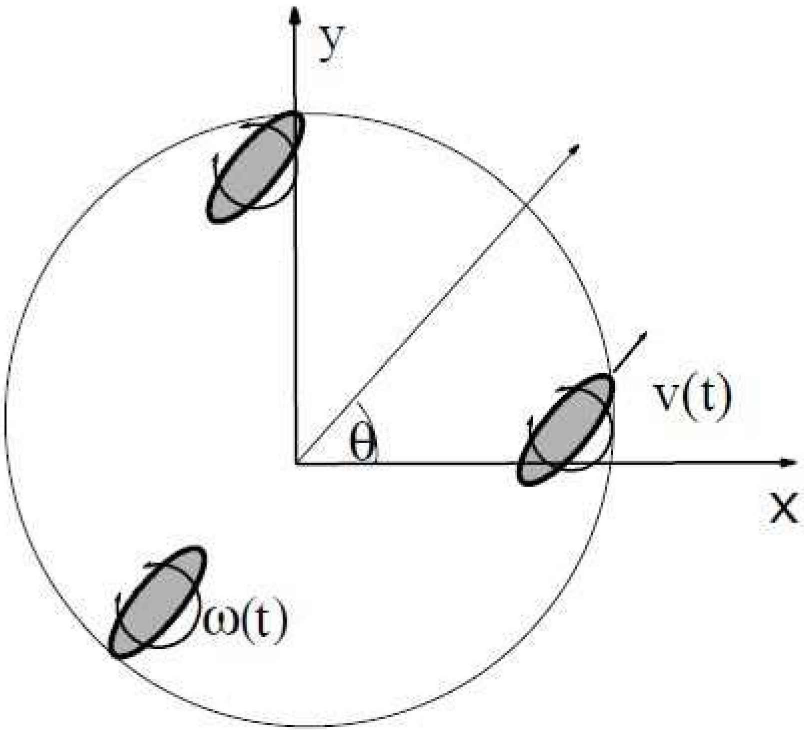
$$\begin{bmatrix} x' \\ y' \\ \theta' \end{bmatrix} = \begin{bmatrix} \cos(\omega\delta t) & -\sin(\omega\delta t) & 0 \\ \sin(\omega\delta t) & \cos(\omega\delta t) & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x - ICC_x \\ y - ICC_y \\ \theta \end{bmatrix} + \begin{bmatrix} ICC_x \\ ICC_y \\ \omega\delta t \end{bmatrix}$$

$$x(t) = \frac{1}{2}\int_0^t [v_r(t') + v_l(t')] \ \cos[\theta(t')]dt'$$

$$y(t) = \frac{1}{2}\int_0^t [v_r(t') + v_l(t')] \ \sin[\theta(t')]dt'$$

$$\theta(t) = \frac{1}{l}\int_0^t [v_r(t') - v_l(t')] \, dt'$$

Synchronous Drive

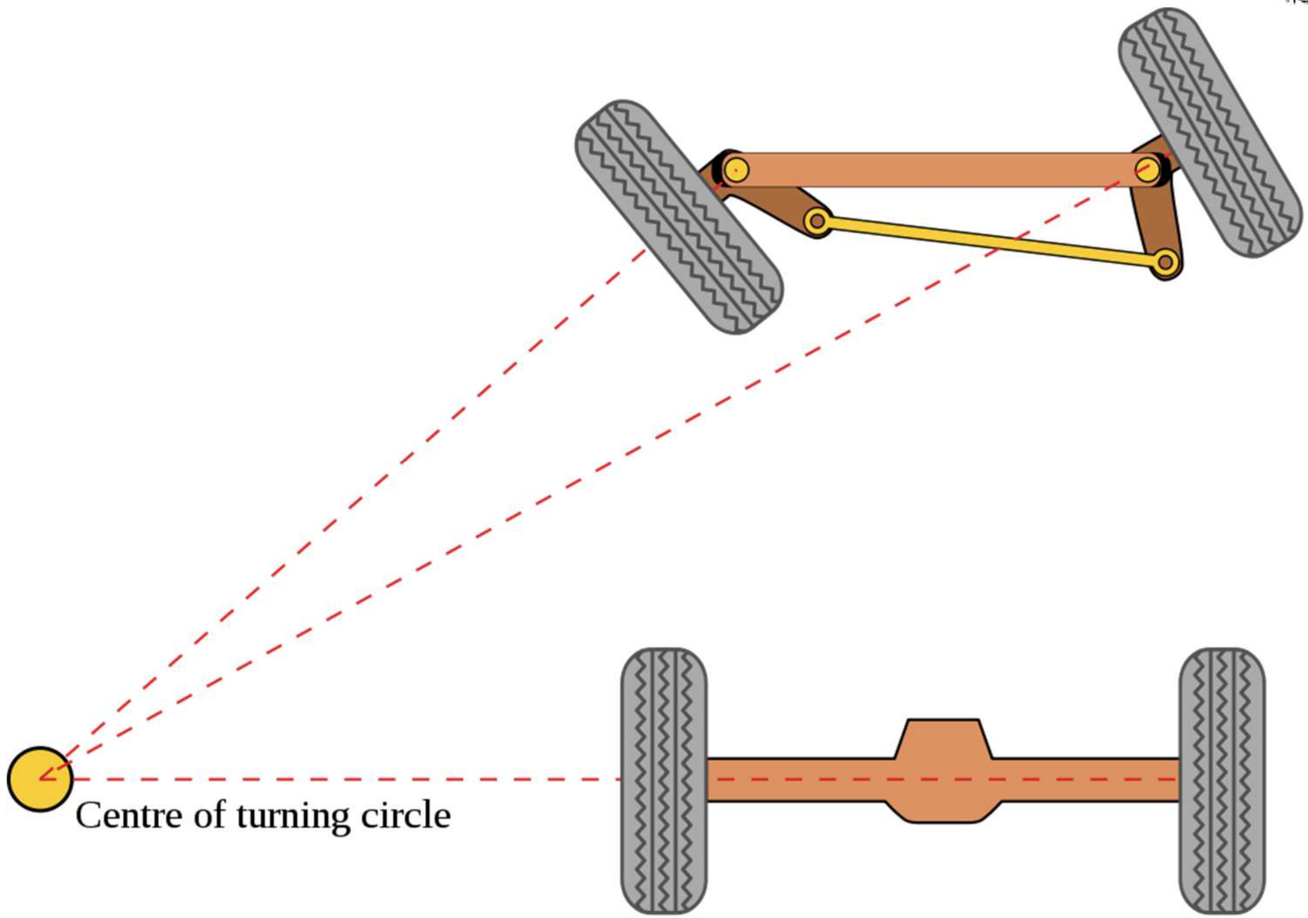


$$x(t) = \int_0^t v(t') \; \cos[\theta(t')] dt'$$

$$y(t) = \int_0^t v(t') \; \sin[\theta(t')] dt'$$

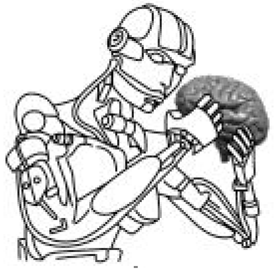
$$\theta(t) = \int_0^t \omega(t') \, dt'$$

Ackerman Steering (Kingpin Steering)



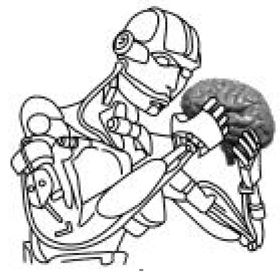
From wikipedia.org

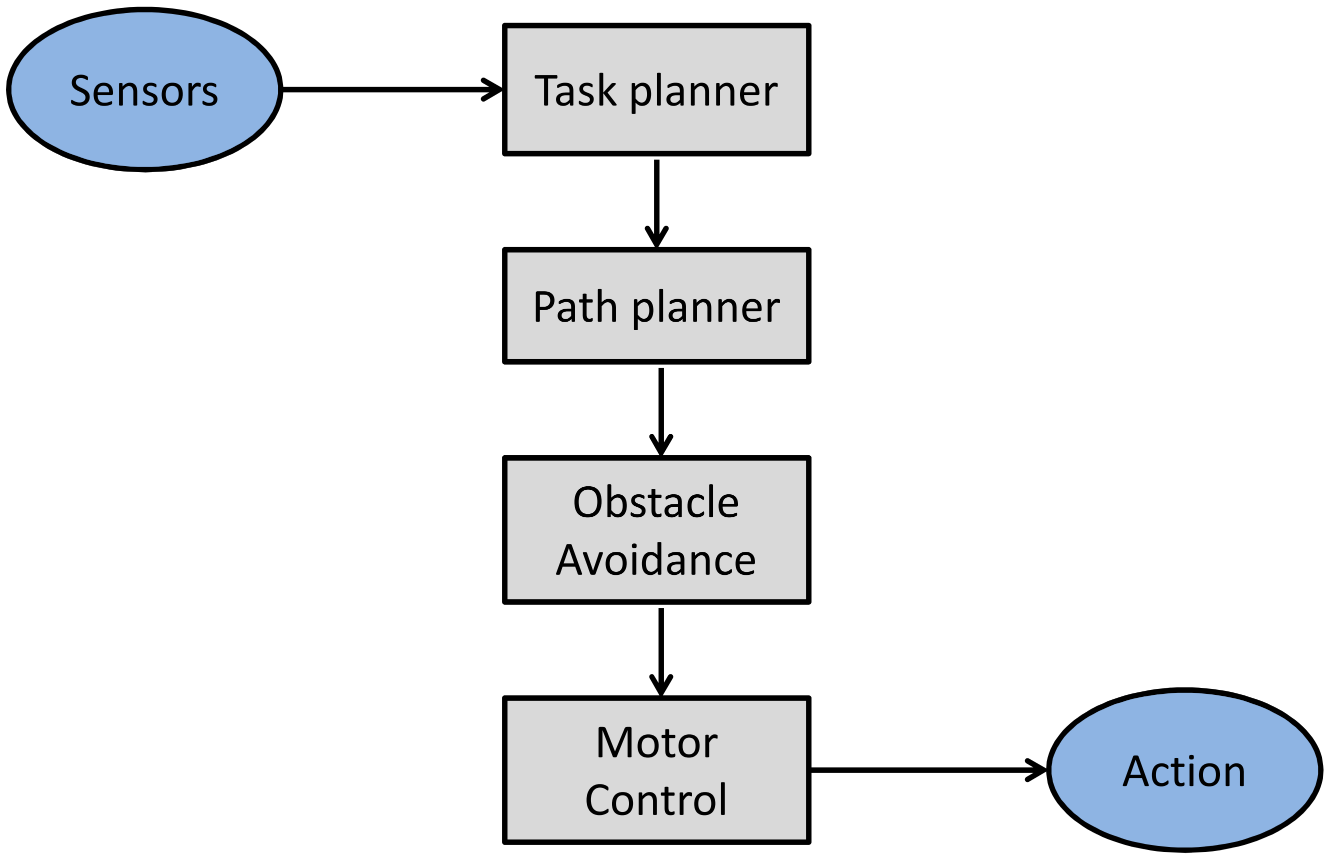
Other examples



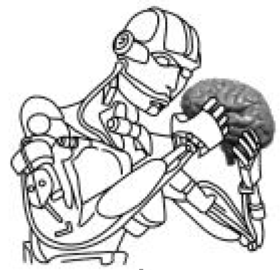
- Bicycle
- Tricycle

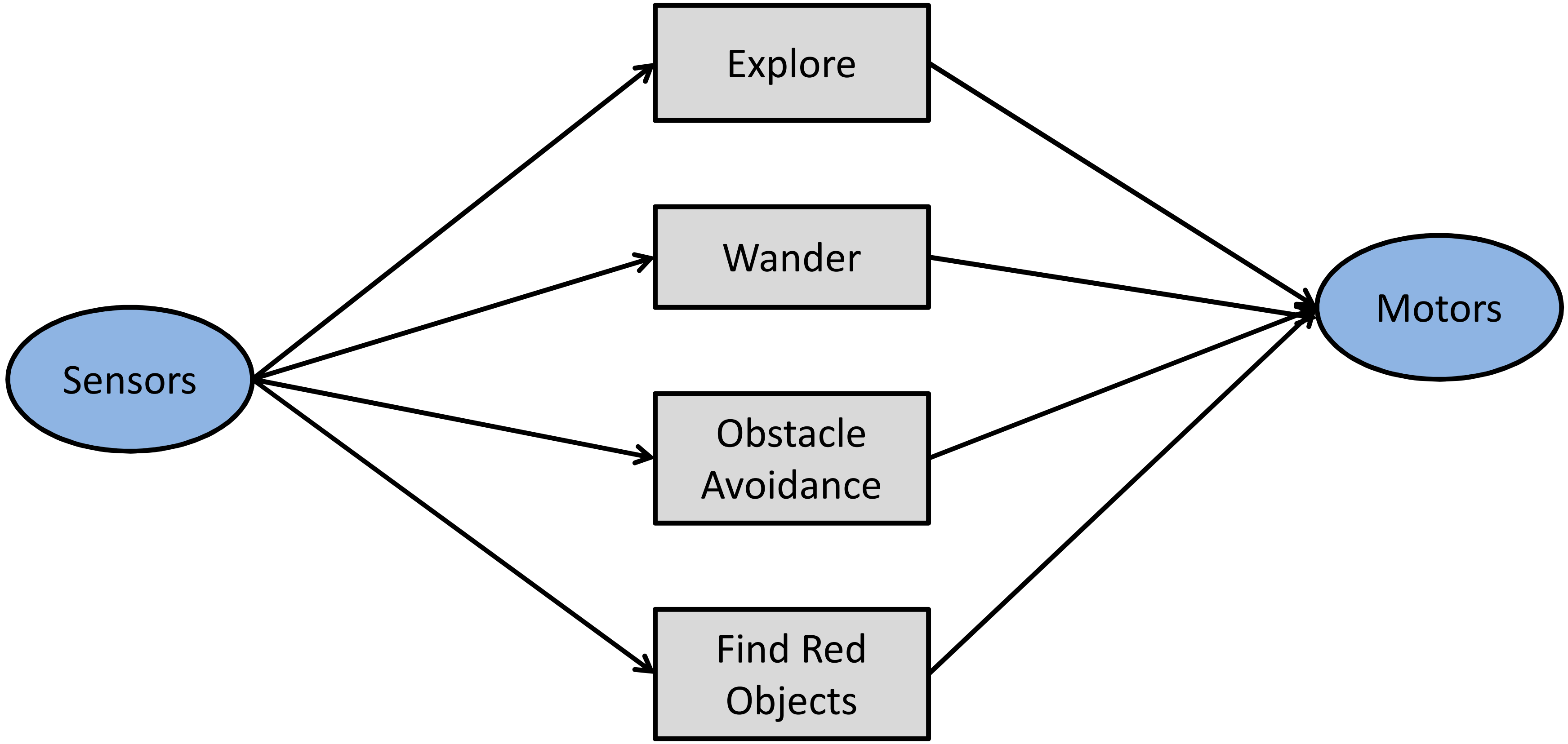
Classic Planning



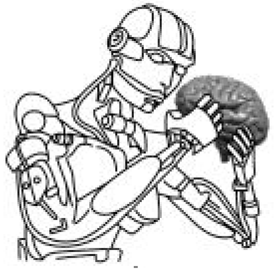


Behavior-based Robotics



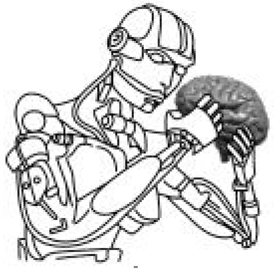


Behavior-based Robotics



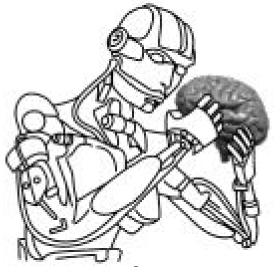
- Reactive systems
- No models. No memory
- Tight coupling between sensors and actuation
- Only local sensing/decision-making
- Based on biology

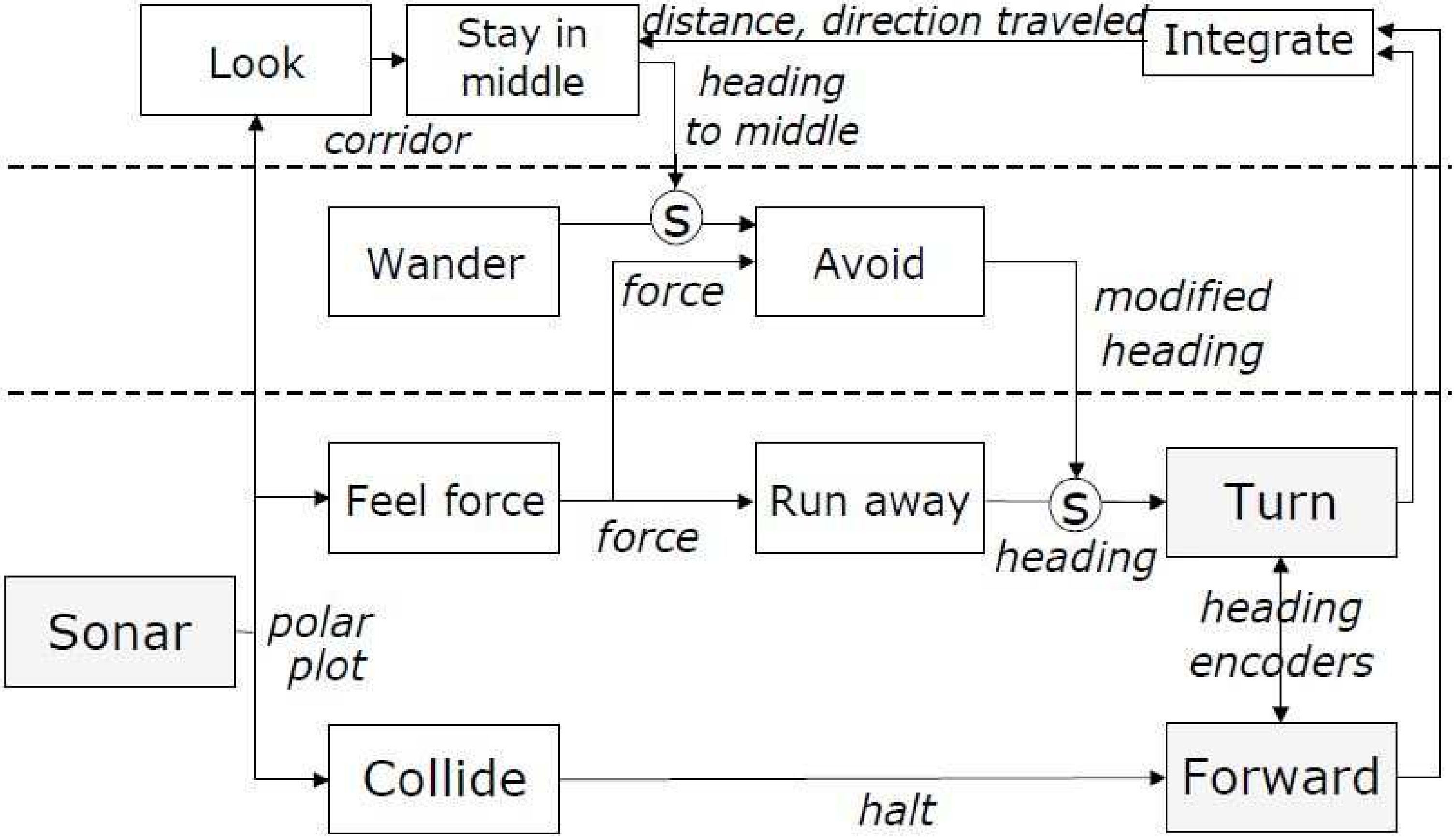
Behaviors



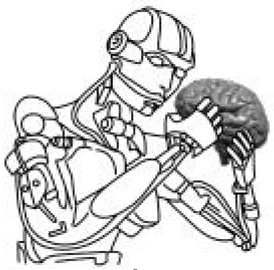
- Direct mapping from sensing to actuation
- Basic modules
  - Move Forward
  - Wander
  - FollowHallway
  - AvoidObstacles
- Networks of sensing and acting modules (Finite State Automata)
- Subsumption Architecture

Subsumption Architecture

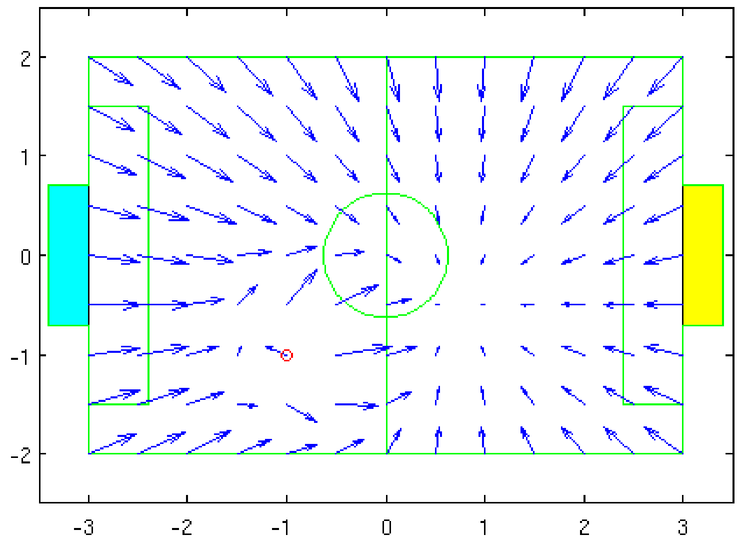




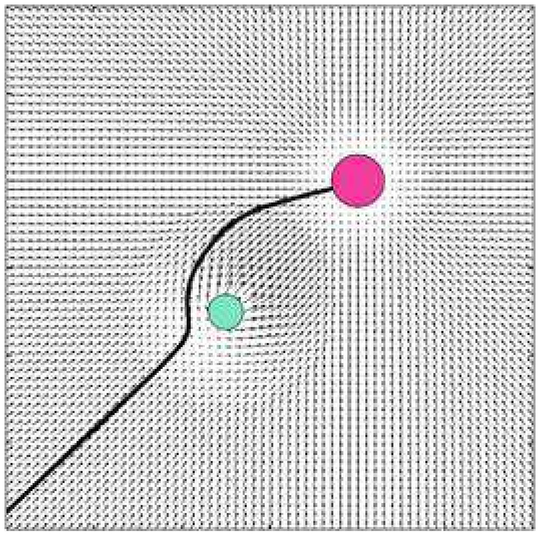
Potential Fields



- Treat robot as particle
- Environment generates potential field vectors
- Direct robot at each point
- Magnitude changes with distance

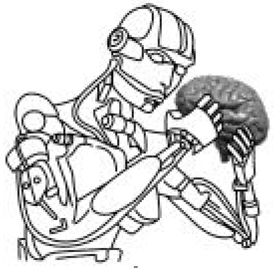


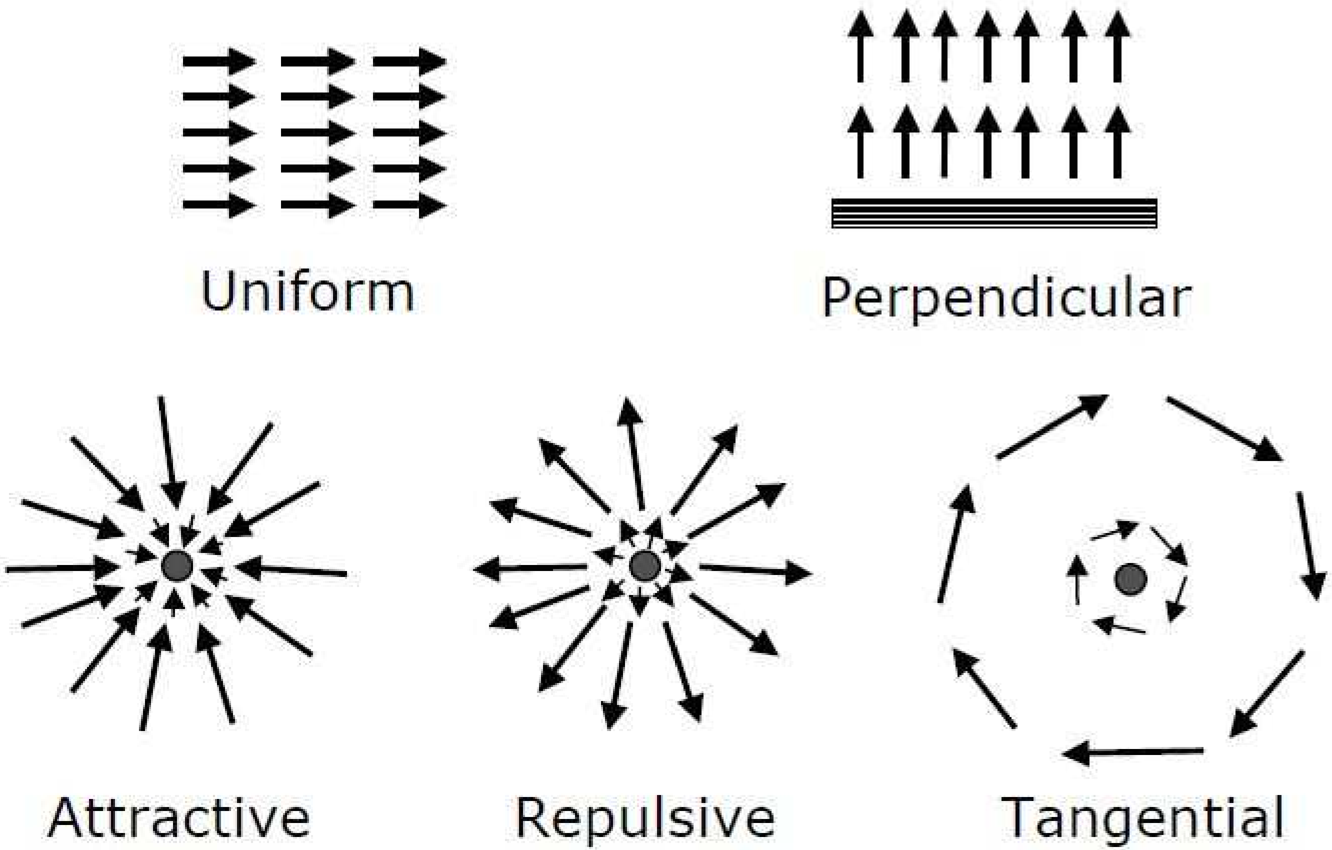
From UPenn



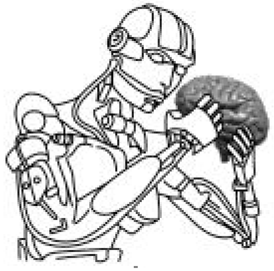
From McGill

Potential Fields



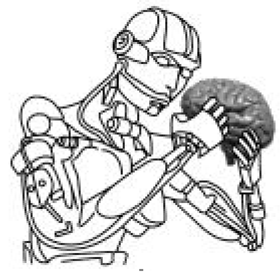


Potential Fields



- Obstacle Avoidance - Add repulsive forces around objects
- Wander – Add random field
- Follow Hallway – Two perpendicular forces and uniform force

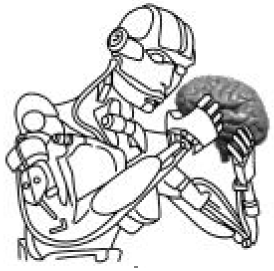
Characteristics



- Problems with local minima

- Require significant domain knowledge

Upcoming



- Next time: Tracking/Data Fusion
  - Kalman Filters
  - Extended Kalman Filters
  - Bayesian Filters
  - Particle Filters
- Later:
  - Optimal Control (Bellman, MDPs)
  - Adaptive Control
  - Probabilistic Robotics
  - Localization, Mapping