ROBOTICS AND INTELLIGENCE SYSTEMS

Undergraduate course (Spring 2020)

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Part of the Lecture

- Robotics
  - Autonomous control
  - Mechanism, planning and navigation
  - Sensoring
- Autonomous Robots
  - Robot Mechanism
  - Navigation
  - Sensor-driven
- Intelligent Robots
  - Intelligent systems
  - Learning Robots

ROBOTICS

HMI
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A Brief History of Robotics

- Mechanical Automata
  - Ancient Greece & Egypt
    - Water powered for ceremonies
  - 14^{th} – 19^{th} century Europe
    - Clockwork driven for entertainment
- Motor driven Robots
  - 1928: First motor driven automata
  - 1961: Unimate
    - First industrial robot
  - 1967: Shakey
    - Autonomous mobile research robot
  - 1969: Stanford Arm
    - Dextrous, electric motor driven robot arm

Maillardet's Automaton

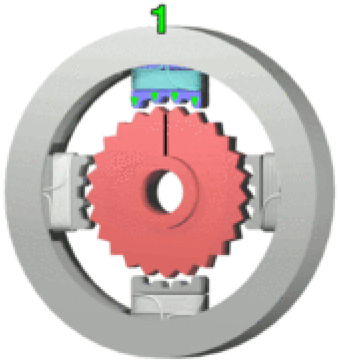
Unimate

Robot Accessories

- Actuators :
  - Actuators are the muscles of the manipulators.
  - Common types: servomotors, stepper motors, pneumatic cylinders.
- Sensors :
  - Sensors are used to collect information about the internal state of the robot or to communicate with the outside environment.
  - Robots are often equipped with external sensory devices: vision system, touch, tactile, sound, balancing sensors, GPS …
- Controller :
  - The controller receives data from the computer,
  - Controls the motions of the actuator and coordinates these motions with the sensory feedback information.

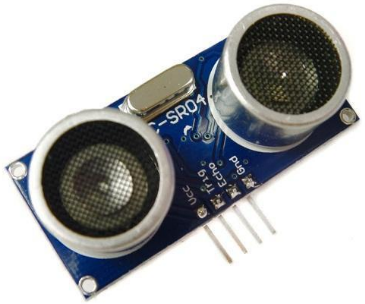
Actuator

- Servomotors
  - Precise control of angular position
  - Sensor for feedback
- Stepper motor
  - DC electric motor divides full rotation into number of equal steps
- Pneumatic cylinder (air cylinder)
  - Produces liner movement



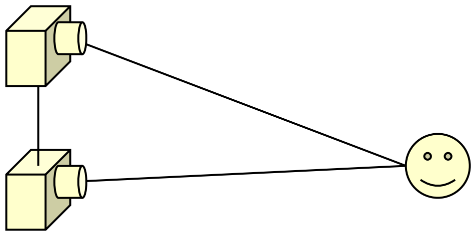
Proximity Sensors

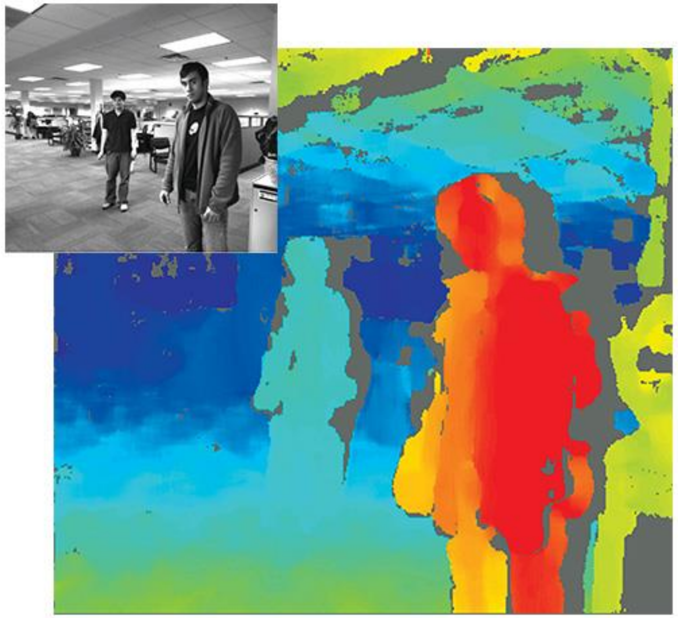
- Proximity sensors: measure the distance or location of objects in the environment.
  - Infrared sensors: measure the amount of infrared light the object reflects back to the robot
  - Ultrasonic sensors (sonars): measure the time that an ultrasonic signal takes until it returns to the robot
  - Laser range finders:
    - measuring either the time a laser beam to be reflected back to the robot
    - where the laser hits the object



Vision and Depth Sensors

- Computer Vision
- Depth Sensors:
  - Stereo vision systems provide complete location information using triangulation





  - However, computer vision is very complex
    - Correspondence problem makes stereo vision even more difficult

Controllers

Phidgets Servo 1-Motor Controller

Arduino Uno R3 Microcontroller

Pixhawk flight controller

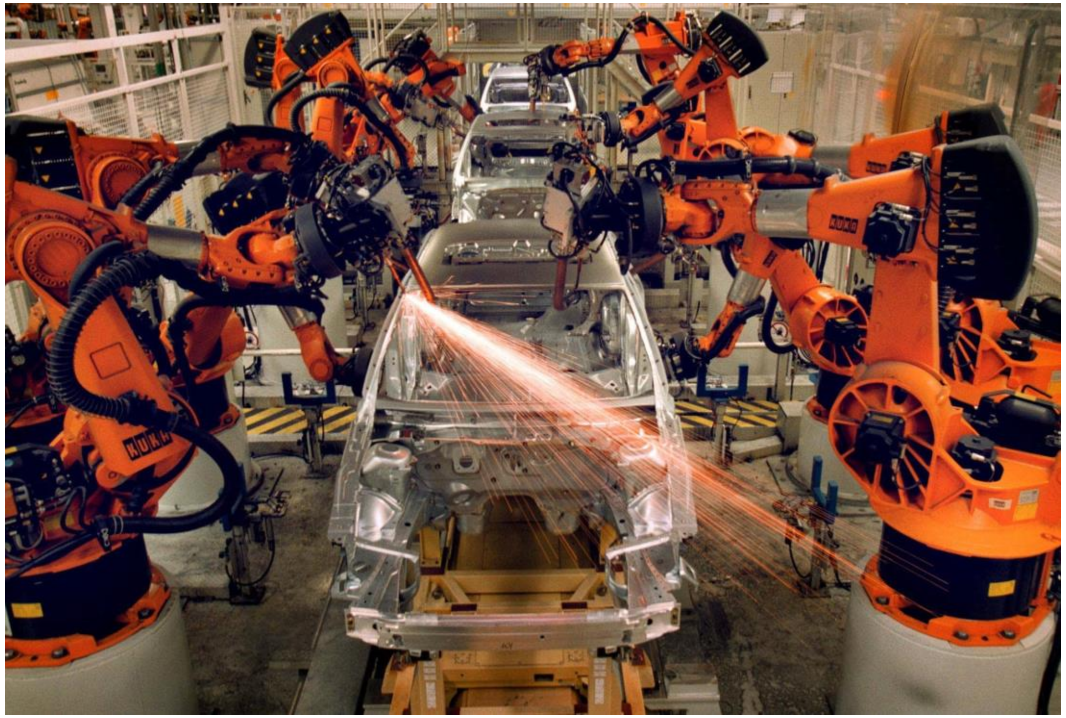
AUTONOMOUS ROBOTS

Autonomous Robots

- The control of autonomous robots involves a number of subtasks
  - Understanding and modeling of the mechanism
    - Kinematics, Dynamics, and Odometry
  - Reliable control of the actuators
    - Closed-loop control
  - Generation of task-specific motions
    - Path planning
  - Integration of sensors
    - Selection and interfacing of various types of sensors
  - Coping with noise and uncertainty
    - Filtering of sensor noise and actuator uncertainty
  - Creation of flexible control policies
    - Control has to deal with new situations

Traditional Industrial Robots

- Traditional industrial robot control uses robot arms and largely pre-computed motions
  - Programming using “teach box”
  - Repetitive tasks
  - High speed
  - Few sensing operations
  - High precision movements
  - Pre-planned trajectories and task policies
  - No interaction with humans

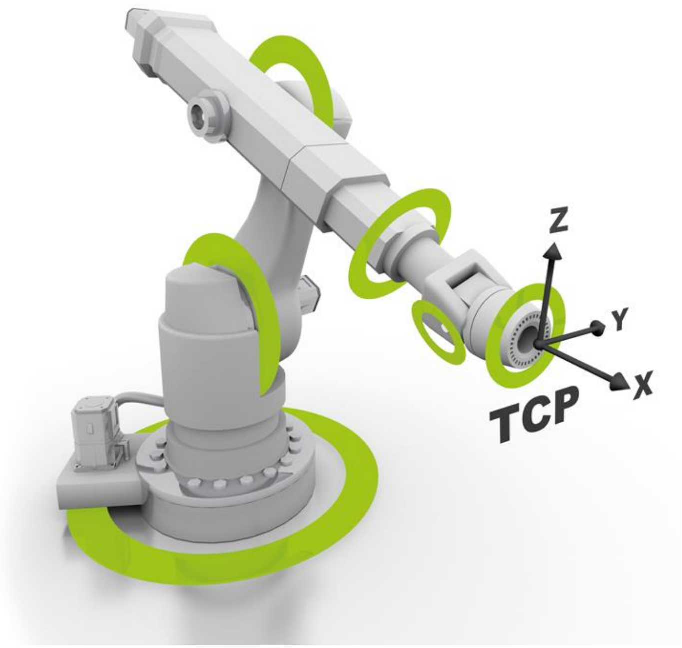


Autonomous Robot Control

- To control robots to perform tasks autonomously a number of tasks have to be addressed:
  - Modeling of robot mechanisms
    - Kinematics, Dynamics
  - Robot sensor selection
    - Active and passive proximity sensors
  - Low-level control of actuators
    - Closed-loop control
  - Control architectures
    - Traditional planning architectures
    - Behavior-based control architectures
    - Hybrid architectures

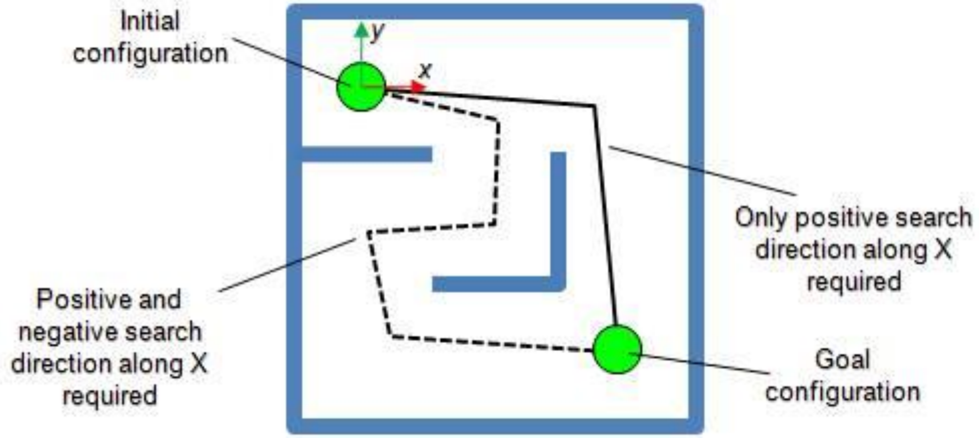
Modeling the Robot Mechanism

- Forward kinematics describes how the robots joint angle configurations translate to locations in the world
- Inverse kinematics computes the joint angle configuration necessary to reach a particular point in space.
- Jacobians calculate how the speed and configuration of the actuators translate into velocity of the robot



Robot Navigation

- Path planning addresses the task of computing a trajectory for the robot such that it reaches the desired goal without colliding with obstacles
  - Optimal paths are hard to compute in particular for robots that can not move in arbitrary directions (i.e. nonholonomic robots)
  - Shortest distance paths can be dangerous since they always graze obstacles
  - Paths for robot arms have to take into account the entire robot (not only the end effector)



Sensor-Driven Robot Control

- To accurately achieve a task in an intelligent environment, a robot has to be able to react dynamically to changes ion its surrounding
  - Robots need sensors to perceive the environment
  - Most robots use a set of different sensors
    - Different sensors serve different purposes
  - Information from sensors has to be integrated into the control of the robot

INTELLIGENT ROBOTS

Problems

- Traditional programming techniques: lack key capabilities necessary in intelligent environments
  - Only limited on-line sensing
  - No incorporation of uncertainty
  - No interaction with humans
  - Reliance on perfect task information
  - Complete re-programming for new tasks

What are Systems?

- Assemblages of parts with structure, connectivity, and behavior
- Modules that relate to each other
- Interacting entities with common goals
- Objects with defined boundaries within some environment
- Objects that respond to inputs from externalities
- Objects that create outputs to externalities

Intelligent System

- Systems that
  - Perform useful functions driven by desired goals and current knowledge
  - Emulate biological and cognitive processes
  - Process information to achieve objectives
  - Learn by example or from experience
  - Adapt functions to a changing environment
- Learning: Data + Insight -> Knowledge

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Requirements for Robots in Intelligent Environments

- Human-Robot Interfaces
  - Use of robots in smart homes can not require extensive user training
  - Commands to robots should be natural for inhabitants
- Autonomy and Adaptation
  - Robots have to be capable of achieving task objectives without human input
  - Robots have to be able to make and execute their own decisions based on sensor information
  - Robots have to be able to adjust to changes in the environment

Human-Robot Interaction

- Personal service robot
  - Controlled and used by untrained users
    - Intuitive, easy to use interface
    - Interface has to “filter” user input
  - Receive only intermittent commands
    - Robot requires autonomous capabilities
    - User commands can be at various levels of complexity
    - Control system merges instructions and autonomous operation
  - Interact with a variety of humans
    - Humans have to feel “comfortable” around robots
    - Robots have to communicate intentions in a natural way

Command Input

- Graphical programming interfaces
  - Users construct policies form elemental blocks
  - Requires substantial understanding of the robot
- Deictic (pointing) interfaces
  - Humans point at desired targets in the world or
  - Target specification on a computer screen
  - How to interpret human gestures ?
- Voice recognition
  - Humans instruct the robot verbally
  - Problems:
    - Speech recognition is very difficult
    - Robot actions corresponding to words has to be defined

Robot-Human Interaction

- He robot has to be able to communicate its intentions to the human
  - Output has to be easy to understand by humans
  - Robot has to be able to encode its intention
  - Interface has to keep human's attention without annoying her
- Robot communication devices:
  - Easy to understand computer screens
  - Speech synthesis
  - Robot "gestures"

Adaptation and Learning for Robots

- Intelligent Environments are non-stationary and change frequently, requiring robots to adapt
  - Adaptation to changes in the environment
  - Learning to address changes in inhabitant preferences
- Robots in intelligent environments can frequently not be pre-programmed
  - The environment is unknown
  - The list of tasks that the robot should perform might not be known beforehand
  - Different users have different preferences

Adaptation and Learning In Autonomous Robots

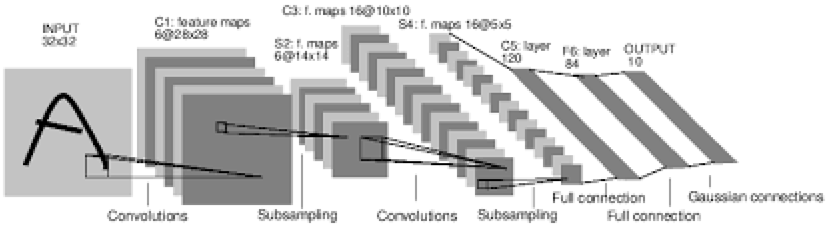
- Learning to interpret sensor information
  - Recognizing objects in the environment is difficult
  - Sensors provide prohibitively large amounts of data
  - Programming of all required objects is generally not possible
- Learning new strategies and tasks
  - New tasks have to be learned on-line in the home
  - Different inhabitants require new strategies even for existing tasks
- Adaptation of existing control policies
  - User preferences can change dynamically
  - Changes in the environment have to be reflected

Learning Approaches for Robot Systems

- Supervised learning by teaching
  - Robots can learn from direct feedback from the user that indicates the correct strategy
    - The robot learns the exact strategy provided by the user
- Learning from demonstration (Imitation)
  - Robots learn by observing a human or a robot perform the required task
    - The robot has to be able to “understand” what it observes and map it onto its own capabilities
- Learning by exploration
  - Robots can learn autonomously by trying different actions and observing their results
    - The robot learns a strategy that optimizes reward

Learning Sensory Patterns

- Learning to Identify Objects
  - How can a particular object be recognized ?
    - Programming recognition strategies is difficult because we do not fully understand how we perform recognition
    - Learning techniques permit the robot system to form its own recognition strategy
  - Supervised learning can be used by giving the robot a set of pictures and the corresponding classification
    - Neural networks
    - Decision trees

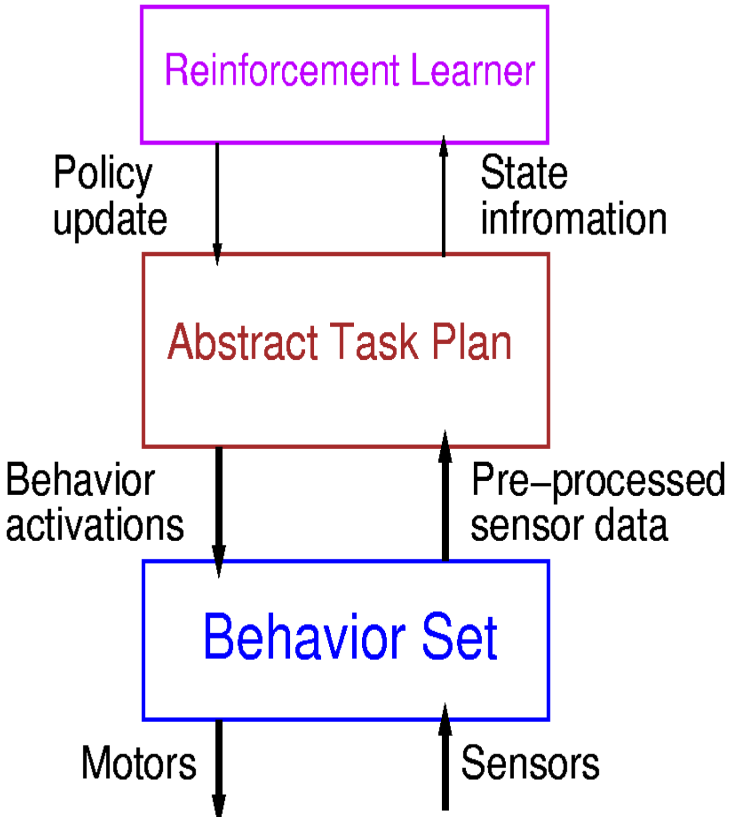


Learning Task Strategies by Experimentation

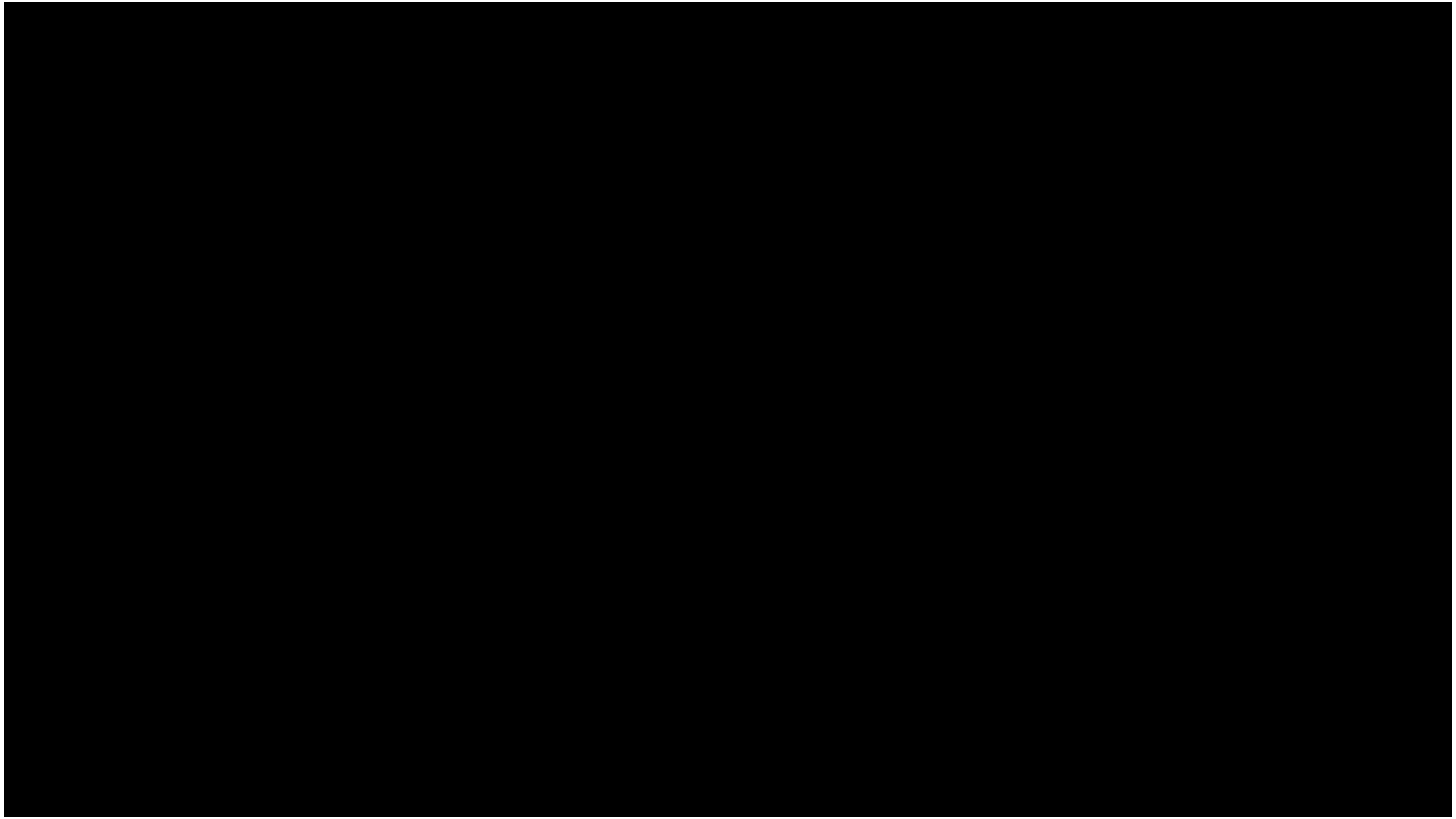
- Autonomous robots have to be able to learn new tasks even without input from the user
  - Learning to perform a task in order to optimize the reward the robot obtains (Reinforcement Learning)
    - Reward has to be provided either by the user or the environment
      - Intermittent user feedback
      - Generic rewards indicating unsafe or inconvenient actions or occurrences
    - The robot has to explore its actions to determine what their effects are
      - Actions change the state of the environment
      - Actions achieve different amounts of reward
    - During learning the robot has to maintain a level of safety

Example: Reinforcement Learning in a Hybrid Architecture

- Policy Acquisition Layer
  - Learning tasks without supervision
- Abstract Plan Layer
  - Learning a system model
  - Basic state space compression
- Reactive Behavior Layer
  - Initial competence and reactivity



Example Task: Learning to Walk



https://www.youtube.com/watch?v=gn4nRCC9TwQ

Conclusion

- Robot Systems in these environments need particular capabilities:
  - Autonomous control systems
  - Simple and natural human-robot interface
  - Adaptive and learning capabilities
  - Robots have to maintain safety during operation
- Task:
  - Controlling program
  - Learning to understand environment and human interaction
  - Learning to act (advanced)