
# Architecture and interaction

## ST5 Autonomous robotics

Francis Colas

2022-10-07

# Introduction

## Path-planning and navigation

- based on perception
- go to a given place, while avoiding obstacles
- exploration

## Remaining questions

- where to go?
- what to do?
- how to execute?

## Decision

- higher-level planning
- decide on a list of simpler actions

# Introduction

## Human-robot interaction

- specific challenges
- perception, control
- communication

## Execution

- coordination of actions
- control architecture

## Aim of the session

- task planning
- control architecture
- human-robot interaction

# 01

# Task planning

# Task planning

## Main issue

- difficulty of programming complex tasks

## General idea

- decompose complex tasks into simpler actions
- handle dependencies and prerequisites
- find valid list of actions

## Approach

- formal description of world and actions (domain)
- specification of current state and goal (problem)
- graph search

# Knowledge representation

## Formal description

- robot and its evolution
- objects and environment and their evolution
- robot actions

## Formal languages

- different choices
- based on logic (predicates, propositional, order-1...)

# Planning Domain Definition Language

## Take a ball – definitions

```
(define (domain gripper-strips)
    (:predicates (room ?r)
                 (ball ?b)
                 (gripper ?g)
                 (at-robby ?r)
                 (at ?b ?r)
                 (free ?g)
                 (carry ?o ?g))
    ...
)
```

# PDDL example

## Take a ball – actions

```
(define (domain gripper-strips)
    ...
    (:action move
     :parameters (?from ?to)
     :precondition (and (room ?from) (room ?to)
                        (at-robby ?from))
     :effect (and (at-robby ?to)
                  (not (at-robby ?from))))
    (:action pick
     :parameters (?obj ?room ?gripper)
     :precondition (and (ball ?obj) (room ?room) (at ?obj, ?room)
                        (gripper ?gripper) (at-robby ?room)
                        (free ?gripper))
     :effect (and (carry ?obj ?gripper) (not (at ?obj ?room))
                  (not (free ?gripper))))
    ...
)
```

# PDDL example

## Take a ball – problem

```
(define (problem strips-gripper1)
    (:domain gripper-strips)
    (:objects room1 room2 ball1 ball2 hand)
    (:init (room room1)
           (room room2)
           (ball ball1)
           (ball ball2)
           (gripper hand)
           (at-robby room1)
           (free hand)
           (at ball1 room1)
           (at ball2 room1))
    (:goal (at ball1 room2)))
```

# High-level planning

## Solving principles

- forward chaining:
  - generate deduction graph starting from initial state
- backward chaining:
  - same, but starting from goal
- mixed forward and backward approaches

## Take a ball?

## Take a ball

```
((pick  ball1 room1 hand)
 (move room1 room2)
 (drop  ball1 room2 hand))
```

# Conclusion on high-level planning

## Knowledge representation

- abstract description
- formal language
- *symbol grounding* problem

## Planning

- definition of a problem in a domain
- planning as inference

## Probabilistic planning

- handle uncertainty
- planning as probabilistic inference
- Markov Decision Processes (MDPs)
- Partially-Observable Markov Decision Processes (POMDPs)

# 02

# Control architecture

# Control architecture

## Need

- integration of perception, decision, and action
- integration of several levels
  - task planning
  - motion planning
  - obstacle avoidance
  - motor control...
- various time scales
  - real time
  - millisecond
  - second
  - a few minutes...

# Structural principles

## Structural principles

- modularity
  - complexity reduction
  - specialized algorithms for particular roles
- hierarchy
  - behavior layers more and more complex
  - difficult to specify
- concurrence
  - perception and action in parallel
  - high-level planning and reaction unexpected events
- communication
  - synchronous or asynchronous
  - message-passing, remote procedure call, shared memory

# Deliberative

## Sense-plan-act

- architecture of Shakey (60's)
- sensors used for perception
- world modeling for planning
- plan for execution
- sense-plan-act-repeat

## Limitations

- monolithic loop
- open-loop control
- execution of an obsolete plan

# Behavior-based

## Subsumption architecture

- subsumption: concept inclusion/generalization
- set of behaviors
- organized in layers
- upper layers can inhibit lower layers

## Behaviors

- finite-state automata
- between sensors and actuators

## Limitations

- no memory nor representation
- complicated system of behavior inhibition

# Subsumption architecture (1/2)

## Brooks's example (1986)

7 reason about behavior of objects

6 plan changes to the world

5 identify objects

4 monitor changes

3 build maps

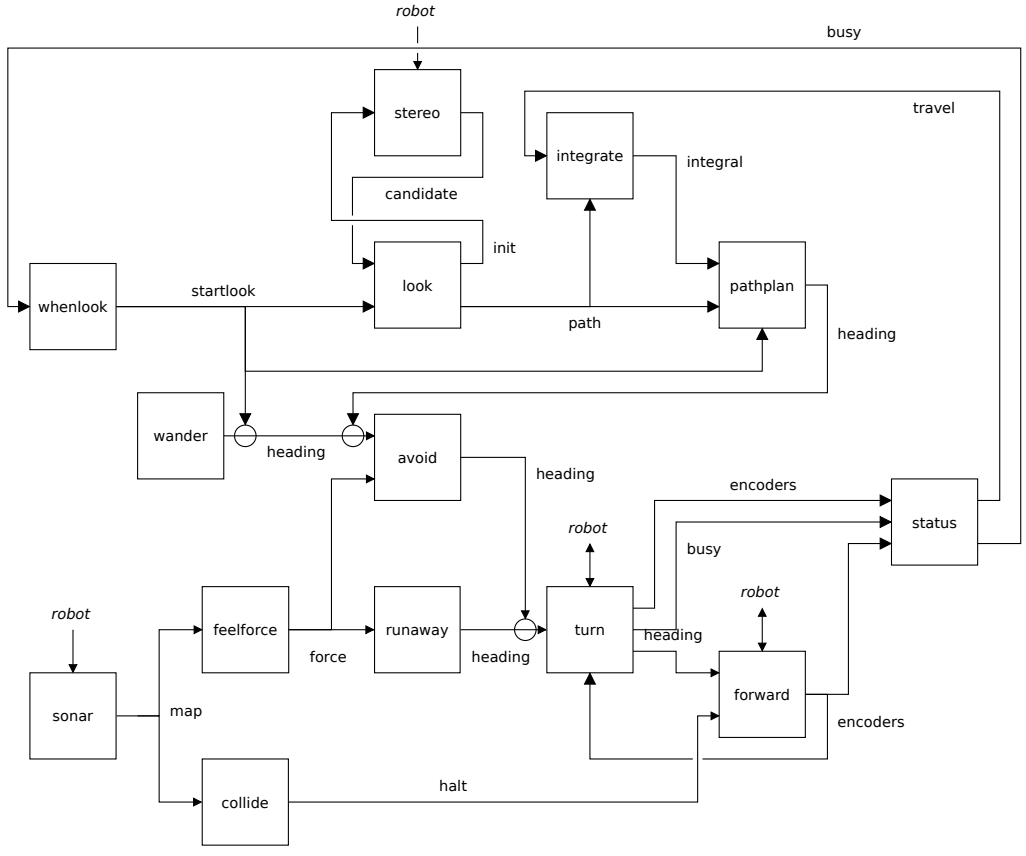
2 explore

1 wander

0 avoid objects

# Subsumption architecture (2/2)

## Brooks' example (1986)




Levels 0, 1, and 2: explore

# Layered architectures

## Layers

- behaviors and representations
- behavior
  - goal from upper layer
  - commands to lower layer
- representation
  - monitoring of lower layer
  - abstract data for upper layer
- upper layers at lower frequencies

# Layered architectures

## Three-tier architecture

- planning
  - handle high-level goals
  - maintains an abstract representation
- executive
  - task decomposition
  - monitoring and synchronization of tasks
  - manage resources
  - instantaneous memory
- behaviors
  - reactive or limited states
  - interaction between sensors and actuators

# Conclusion on control architecture

## Sense-Plan-Act

- deliberative
- slow and rigid
- top-down approach

## Subsumption

- behavior-based
- complex design and no (or limited) memory
- bottom-up approach

## Layered architectures

- behaviors and representations
- reactive and deliberative

# Conclusion on control architecture

## Typology

- deliberative: think, then act
- reactive: don't think, (re)act
- behavior-based: think the way you act
- hybrid: think and act concurrently

# 03

# Human-Robot Interaction (HRI)

# Human-robot interaction

## Human-Robot Interaction (HRI)

- security
- physical interaction
- communication
- acceptability

# Security

## Space sharing

- industrial robots in cages
- some tasks require space sharing
- needs for intrinsic security

## Collision

- reduce gravity of impact
  - lower speed, mass, and inertia
  - *compliance*
- collision detection
  - estimate external torque
  - torque error
- reaction strategies
  - stop the robot
  - gravity compensation
  - admittance control


Sami Haddadin

`https://youtu.be/dnUwqngH0bM`

# Physical interaction

## Physical interaction

- more than simply space sharing
- joint task achievement: assembly

## Approaches

- intelligent assistance systems:
  - crane or gantry with interaction forces
- force amplification
  - exoskeleton
  - industry or rehabilitation
- cobots (collaborative robots)
  - robot restriction in a sub part of workspace
  - fine human control

Comau AURA

Estimation of what the human is doing.

# Human-robot communication

## Human-robot communication

- robot for non-experts
- natural communication

## Multimodal communication

- verbal
- non-verbal: gestures, expressions, posture...

## Complementary communication

- regulate conversation
- show one's state: pointing, attention, emotions...
- illustrate

Leonardo robot

Estimation of what the human is communicating.

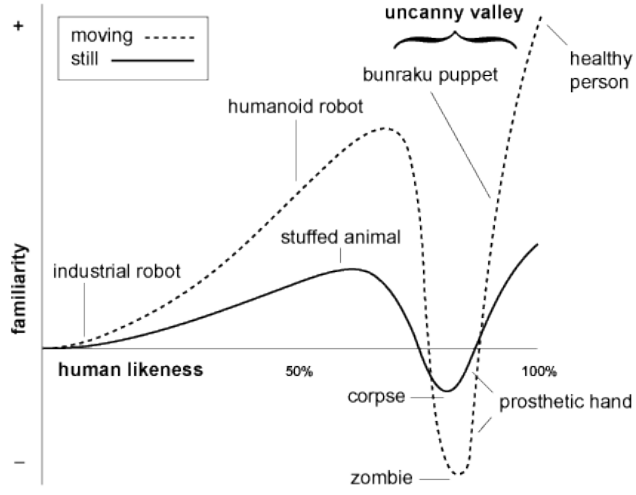
# Acceptability

## Acceptability

- robots can help
- only when accepted
- user studies
- worries
  - aspect
  - understanding
  - societal impacts...

## Uncanny valley

- not totally human-looking
- negative emotional response
- loss of empathy
- stronger when in motion




uncanny valley (Mori)

# 04

# Conclusion

# Conclusion

## High-level function

- need a high-level representation of actions and states
- reasoning at this level
- integration with low-level
- control architecture

## Human-robot interaction

- security
- physical interaction
- communication
- acceptability
- human estimation

# Bibliography


## STRIPS and PDDL

- Fikes and Nilsson, *STRIPS: A New Approach to the Application of Theorem Proving to Problem Solving*, AI, 1971.
- McDermott *et al.*, *PDDL – The Planning Domain Definition Language*, Yale CVC, 1998.
- Fox and Long, *PDDL2.1: An Extension to PDDL for Expressing Temporal Planning Domains*, JAIR, 2003.

## Subsumption

- Brooks, *A robust layered control system for a mobile robot*, RA, 1986.

# Bibliography

## Intrinsic security


- Haddadin *et al.*, *Collision detection and reaction: a contribution to safe physical human-robot interaction*, IROS 2008.


## Social robotics


- Dautenhahn, *Socially intelligent robots: dimensions of human-robot interaction*, Phil. Trans. R. Soc. B, 2007.


## Books


- Siciliano *et al.*, *Springer Handbook of Robotics*, 2nd ed., Springer, 2016.


Thanks for your attention

Questions?