Hochschule
Bonn-Rhein-Sieg
University of Applied Sciences

b-it Bonn-Aachen International Center for Information Technology

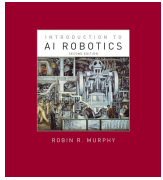
Institute for AI and Autonomous Systems

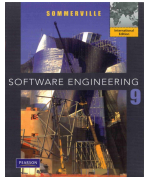
(Robot) Software Architectures

An Overview

Dr. Alex Mitrevski
Master of Autonomous Systems

Structure





- Software architecture fundamentals
- Robot architecture types
- System architecture modelling

Software Architecture Fundamentals

What is an Architecture?

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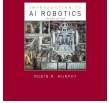
An architecture is a description of a system, namely its design and operation, at a given level of abstraction

Architecture Abstraction Levels



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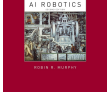

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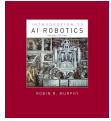

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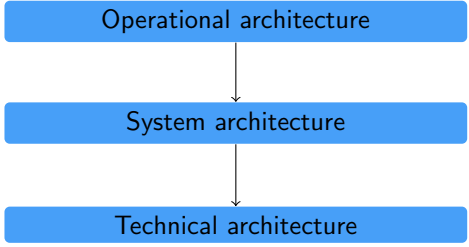

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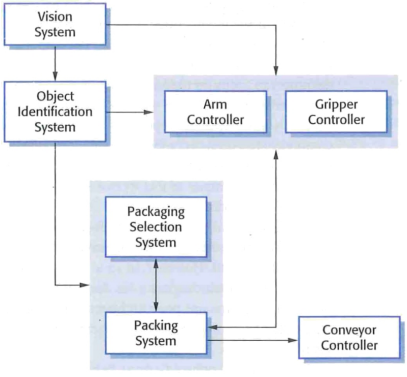

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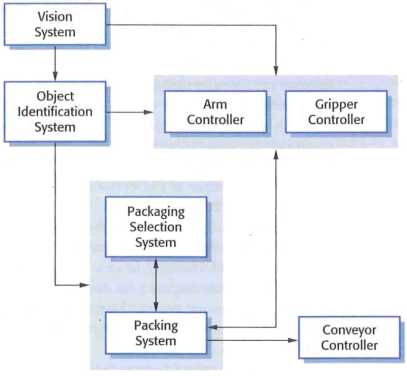

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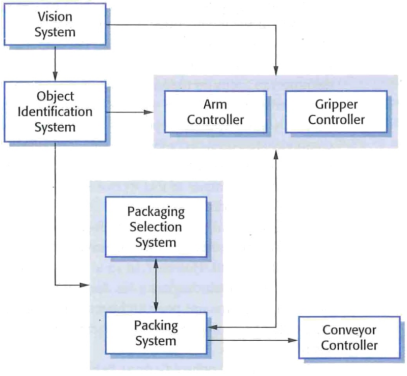

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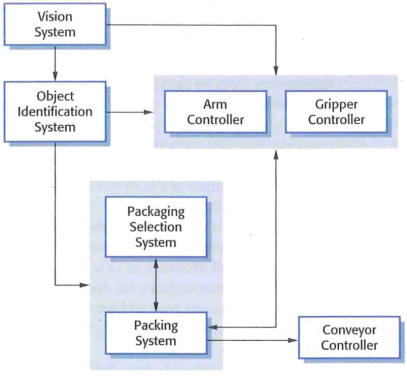

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Objectives of System Architectures

Common system understanding

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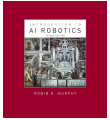
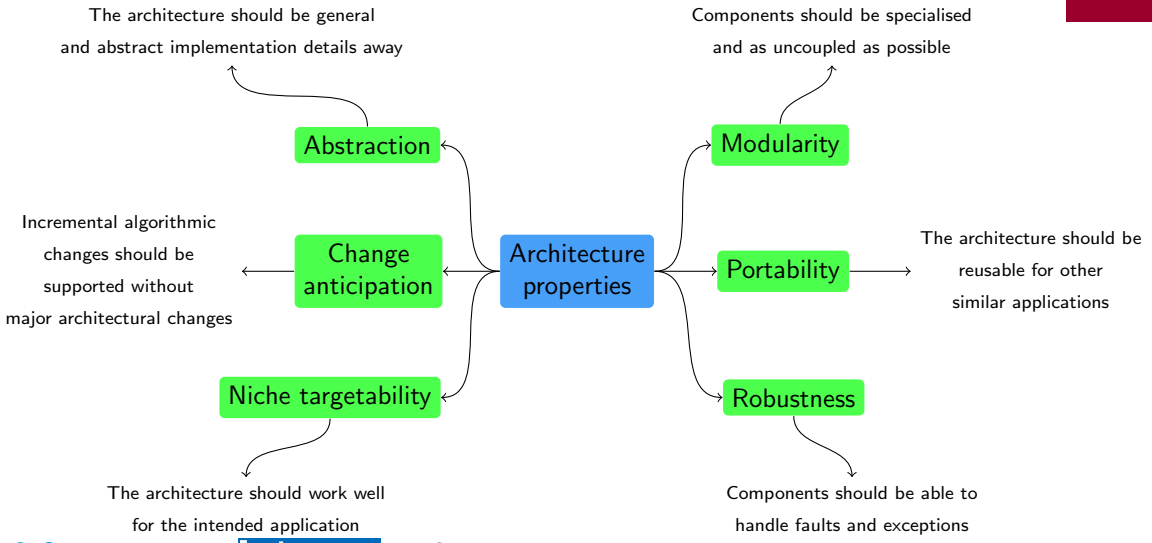
Simplified communication

An explicit representation of a software architecture (e.g. in terms of a visual diagram) can serve as a means of communication with stakeholders

General Properties of (Robot) Software Architectures





Robot Architecture Types

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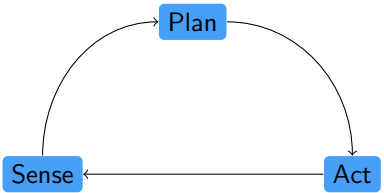
- The development of robot architectures is an evolving process, where **insights from older architectures are used to define new, improved architectures**

Sense-Plan-Act Paradigm



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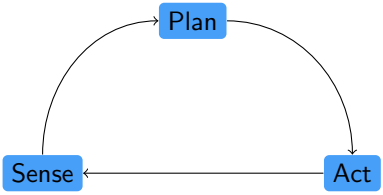

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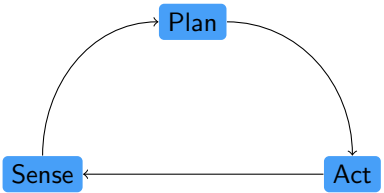

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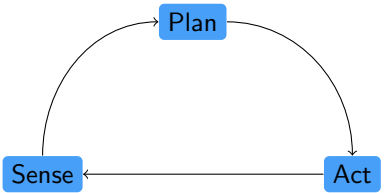

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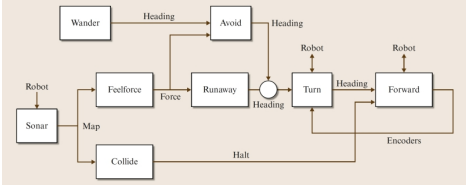
The sense-plan-act paradigm models a robot's decision-making process as a continuous loop of perceiving its environment (sensing), interpreting the information to create plans (planning), and executing actions (acting)

Behaviour-Based Architectures

- In the sense-plan-act paradigm, the action execution process is performed without taking sensor information into account — **problematic if quick reactions are needed**



Subsumption example

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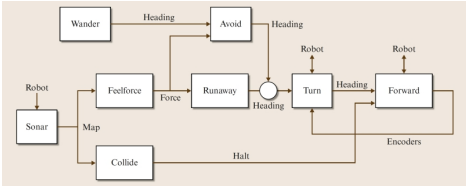

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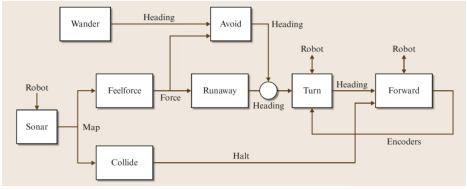

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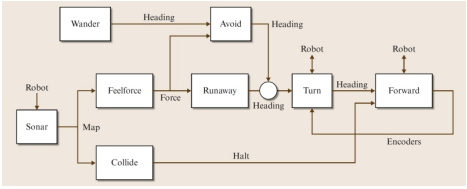

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Behaviour-based architectures organise the operation of a robot into specialised behaviours that can be composed to perform complex operations

Three-Tier (3T) Architectures

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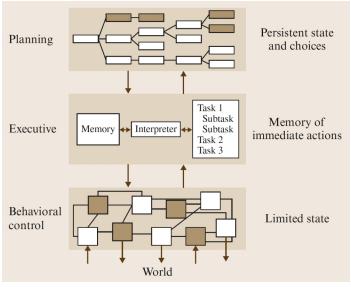

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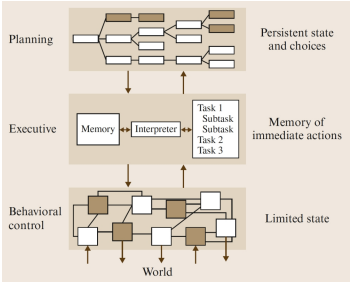

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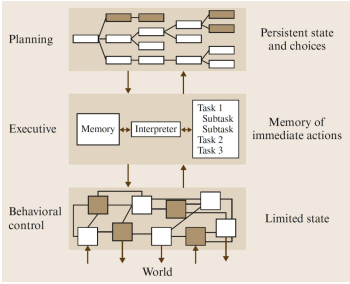

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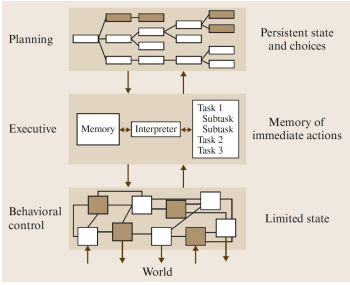

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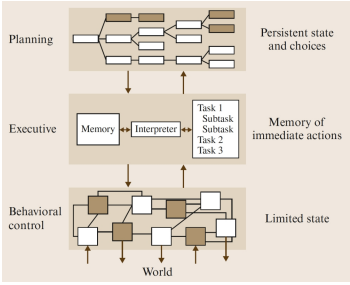

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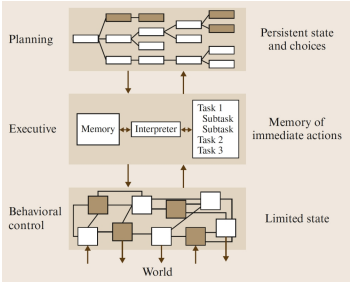

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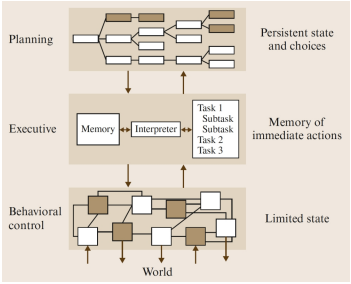

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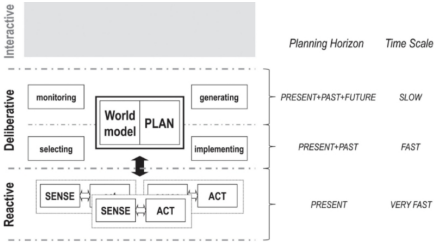
A 3T architecture hierarchically decomposes different robot operation into three layers that perform planning, execution management, and environment interpretation and control

Hybrid Interactive Architecture



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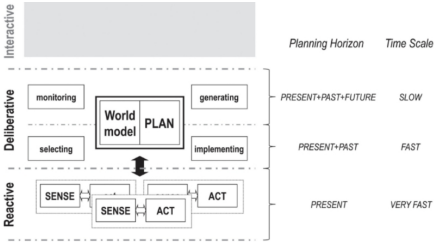

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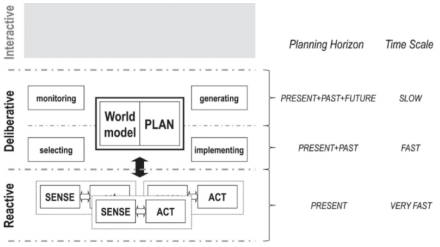

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- A prototypical example of such an architecture that includes **deliberative, reactive, as well as interactive elements** is illustrated on the left

Cognitive Architectures

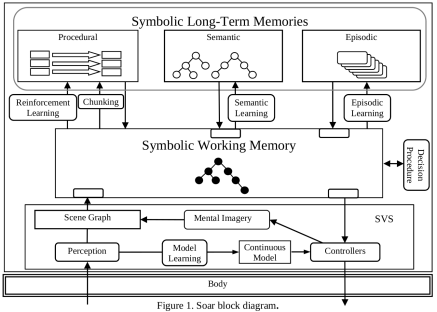

Figure 1. Soar block diagram.

J. E. Laird, K. R. Kinkade, S. Mohan, and J. Z. Xu, "Cognitive Robotics Using the Soar Cognitive Architecture," in *Cognitive Robotics Workshop at the 26th AAAI Conf. Artificial Intelligence*, 2012.

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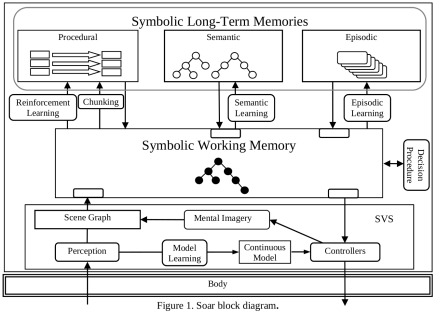

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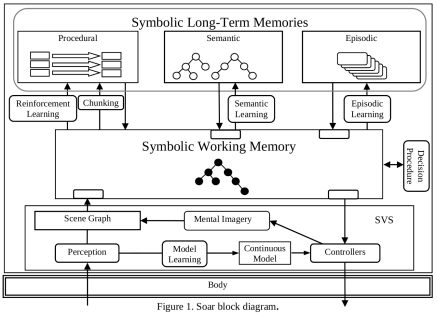

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- A variety of cognitive architectures exist, which **typically emphasise different aspects of intelligence** (e.g. affect or continual learning)

Cognitive Architectures

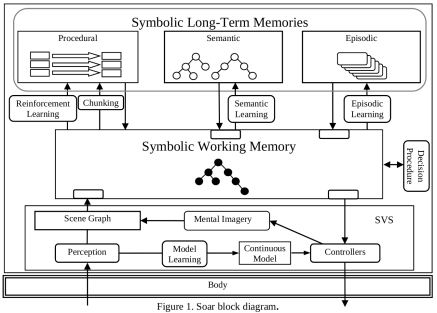

Figure 1. Soar block diagram.

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- Unlike typical agent architectures that are not concerned with biological plausibility, some robot architectures model aspects that are typical for biological systems (e.g. long- and short-term memory)
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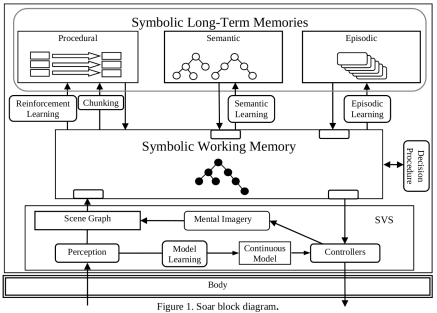

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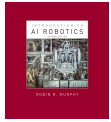
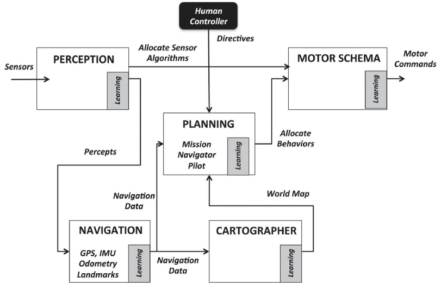
A cognitive architecture is a model inspired by natural intelligence or directly models aspects thereof

Prototypical Robot System Architecture



At a system level, most robot architectures typically include at least the following five components:

- **Perception**: Takes care of sensor data processing and information extraction
- **Navigation**: Performs path planning and trajectory execution
- **Cartographer**: Collects information about the environment (maintains a world model)
- **Planning**: Generates high-level task plans and monitors their execution
- **Motor schema**: Performs reactive selection of motor action and takes care of their execution



System Architecture Modelling

Architectural Modelling Standards

Not all architectural models are equally useful

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- Architecture modelling paradigms and tools have evolved over many years of developing complex systems; through these efforts, certain **de facto discipline-agnostic modelling standards have been accepted**
- On the following few slides, we will take a closer look at one widely accepted modelling paradigm — the Unified Modelling Language (UML)

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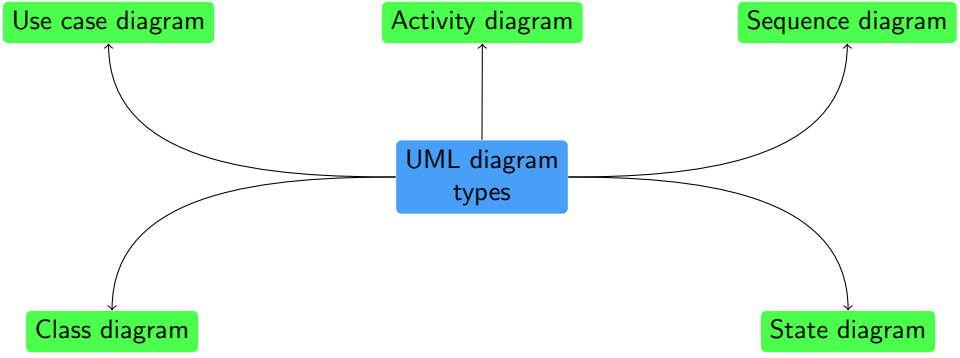
- UML includes **different diagram types**, each of which focuses on modelling a specific aspect of a system and its interaction with the external world
- UML diagrams can be used for different purposes, such as **idea brainstorming with stakeholders, system documentation**, but also for **automatic code generation** (in the context of model-driven engineering)

UML Diagram Types



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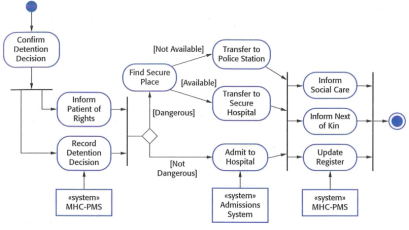
- Use case diagrams can be useful during the requirement elicitation process

Activity Diagram

- The objective of an activity diagram is to show **the flow of activities in a certain process**



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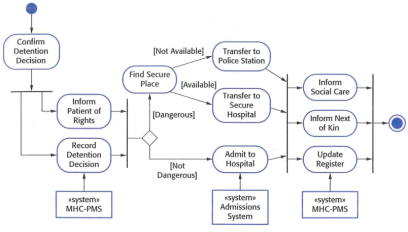

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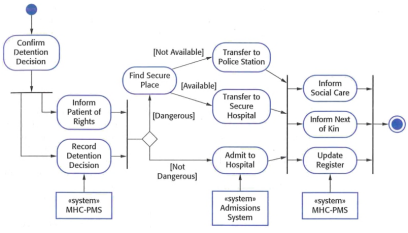

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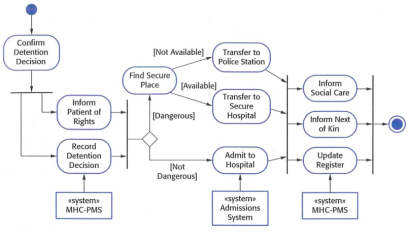

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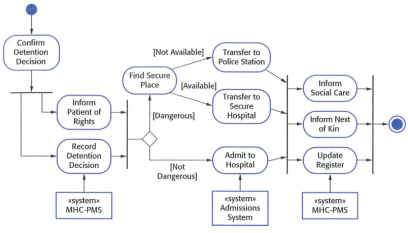

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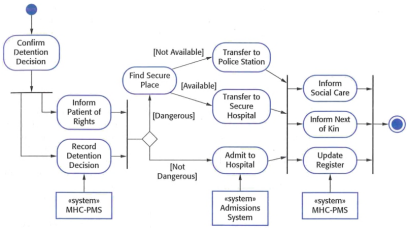

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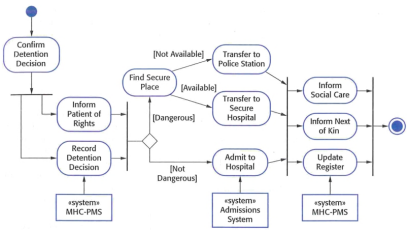

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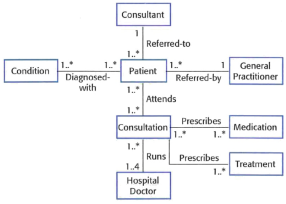
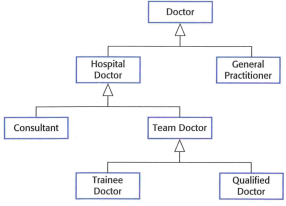
- The **Business Process Model and Notation (BPMN)** is a similar graphical representation that is sometimes used instead of UML activity diagrams

Class Diagram



Class diagram illustrating associations between classes



Class diagram representing generalisation relations between classes

- The purpose of a class diagram is to show **the relation between different system components**, which are modelled as classes that interact with each other

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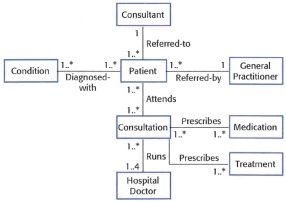

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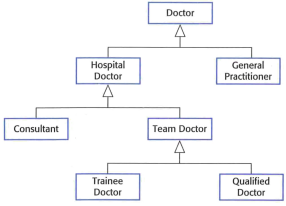

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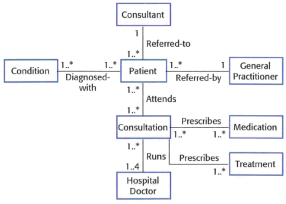

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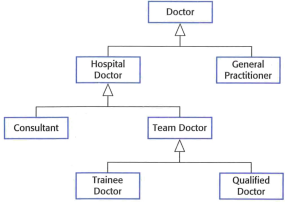

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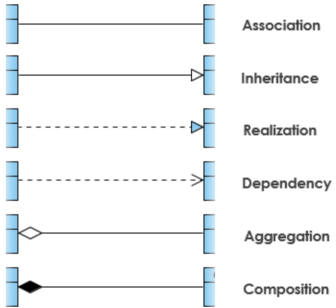
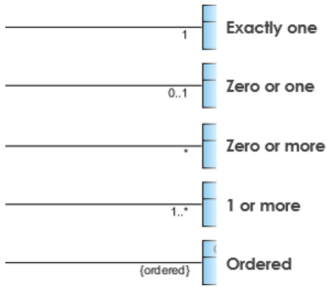
- A class diagram **hides the implementation details of classes**, but **includes details about how exactly classes are related to each other**

Class Diagram Relation Types

- UML class diagrams allow showing different types of relations between classes through various relation types
- Relationships between classes can also have explicit cardinalities (as illustrated on the previous slide)



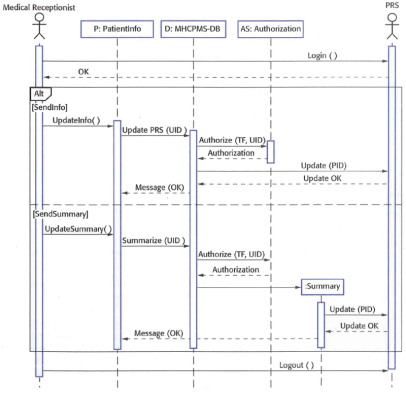
Relation types



Cardinality types

https://www.visual-paradigm.com/guide/uml-unified-modeling-language/uml-class-diagram-tutorial/

Sequence Diagram



- To model concrete data flow in a system, sequence diagrams can be used

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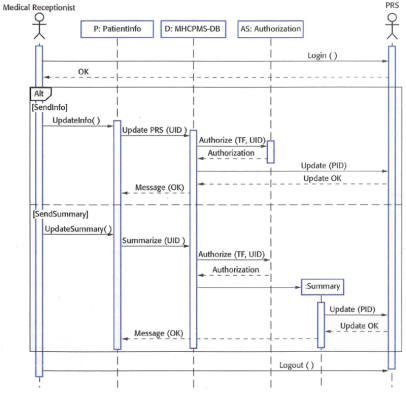

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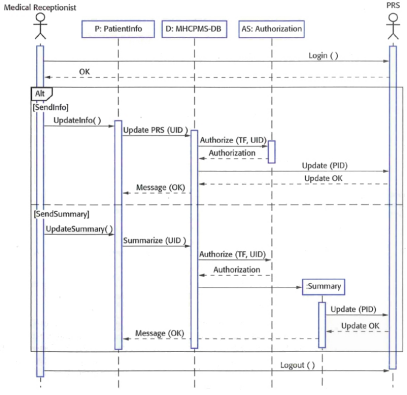

- To model concrete data flow in a system, sequence diagrams can be used
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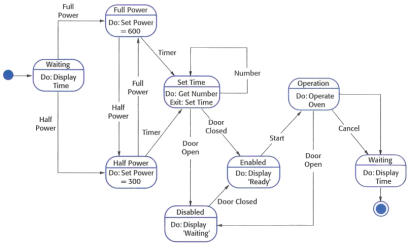
- Typically, sequence diagrams illustrate a complete interaction that is initiated by or involves a user

State Diagram



- In robotics, we typically care about **the current state of the robot and the transitions as a result of the robot's actions**; thus, behaviours are often represented using state-based paradigms, such as state machines or behaviour trees

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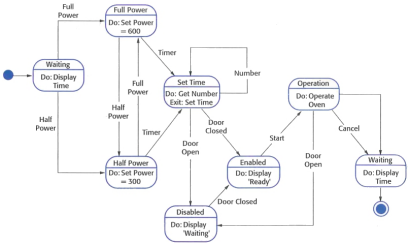

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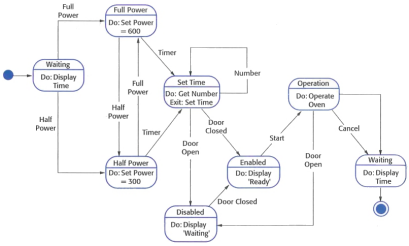

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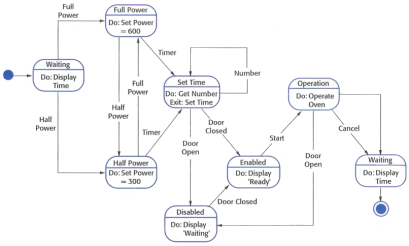

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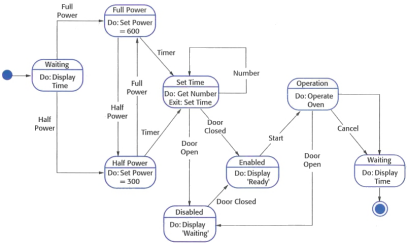

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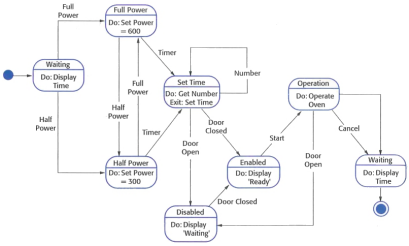

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  - Circles have the same semantics as in activity diagrams

Summary

- Architectures represent an abstraction of the design and operation of a system, and can be done at different abstraction levels
- Software architectures model the component design of a system as well as the interaction between system components
- There are various operational architectures used in robotics, such as sense-plan-act, behaviour-based, three-tier, hybrid, and cognitive architectures
- UML is a de facto standard notation for system and component modelling, which includes multiple diagram types, such as use case, activity, class, sequence, and state diagrams