# Design of Real-Time Software

## Introduction

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# Overview

- Real-Time Systems
  - Definition
  - Examples
  - Components
- Specification aspects

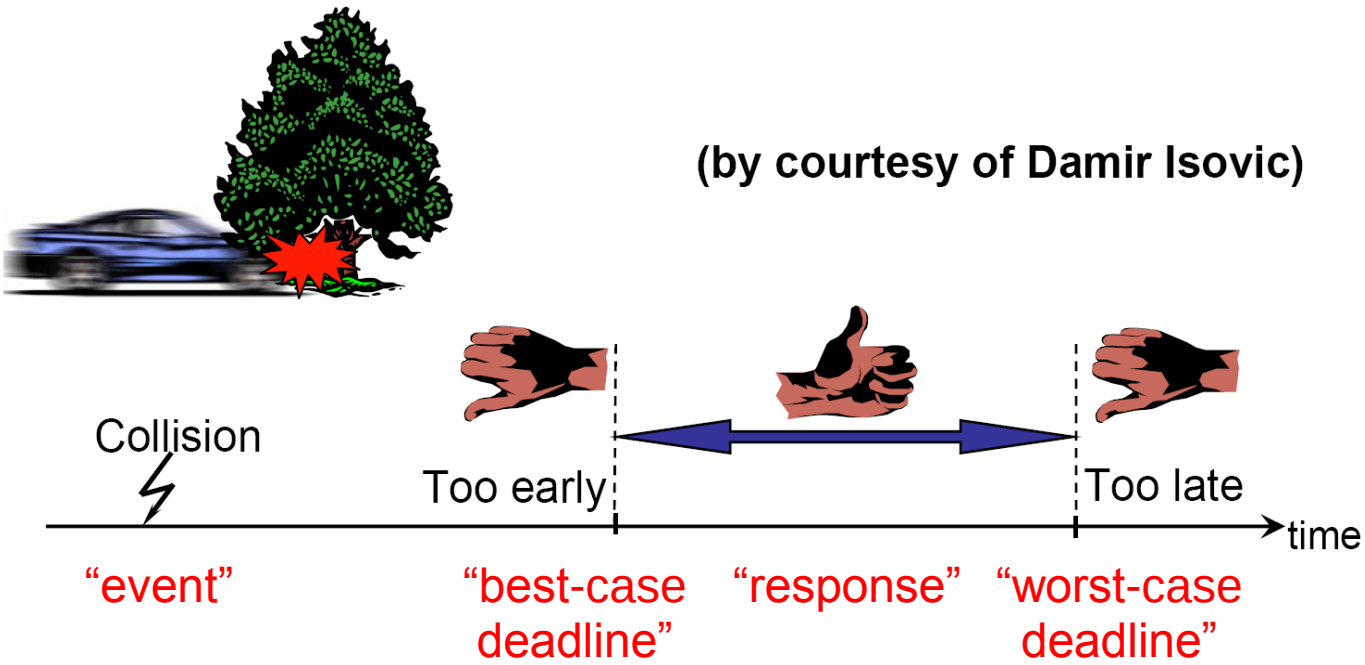
# Real-time systems

- **Definition:** a system in which correct operation depends not only on logical results of computation of values *but also on the time these results are produced*
  - *Stankovic in Byte, '92*

- Hence, *performance* plays a role....
- .... though not just high, but *predictable*!

# Predictable versus fast

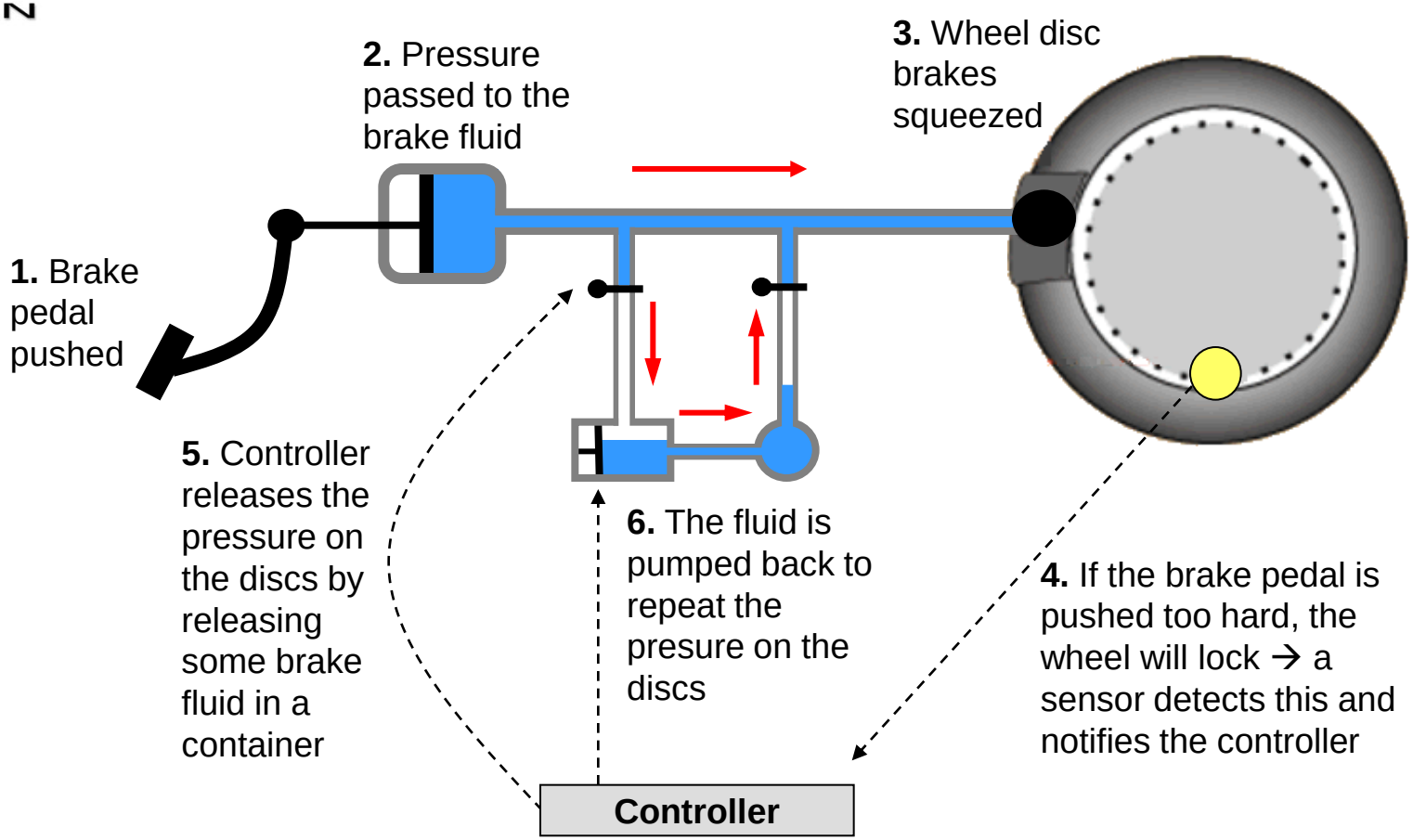
- Example: inflation of an air bag




– Conclusions:
  1. real-time ≠ fast
  2. real time: fulfill individual timing requirements

# Example: Anti-lock Braking System (ABS)

(by courtesy of Damir Isovic)

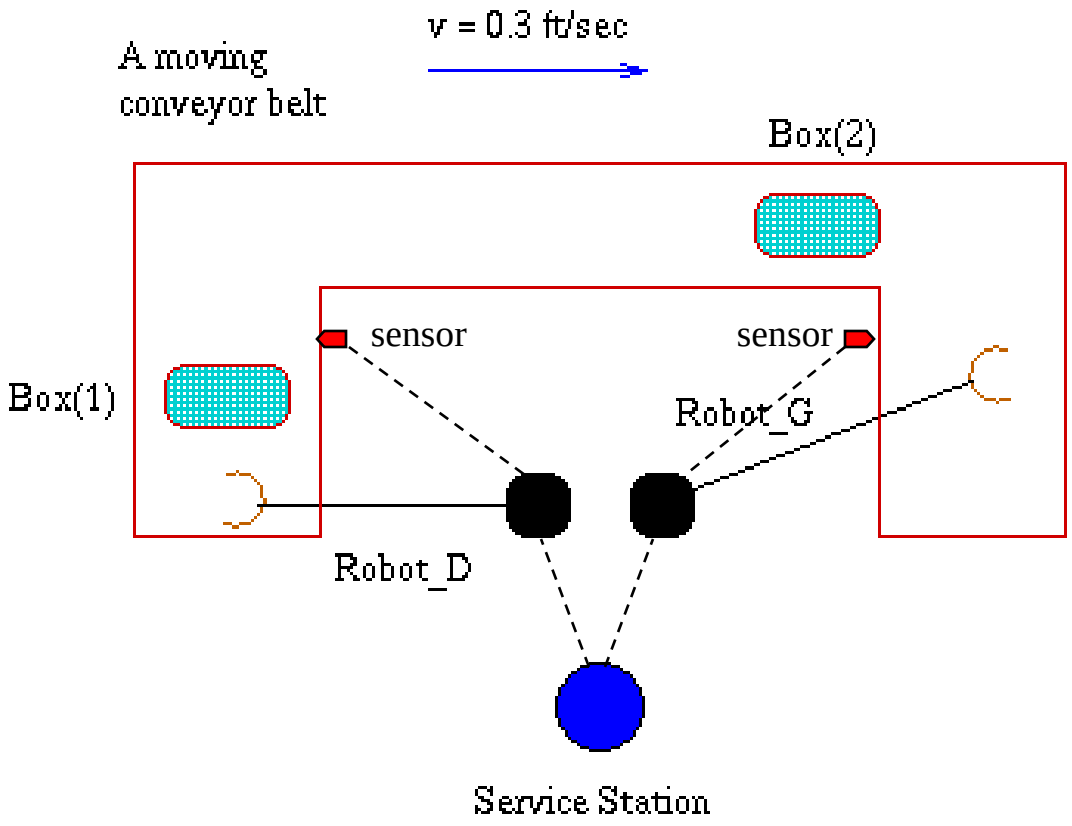



**7.** Entire process is repeated about 15 times/sec

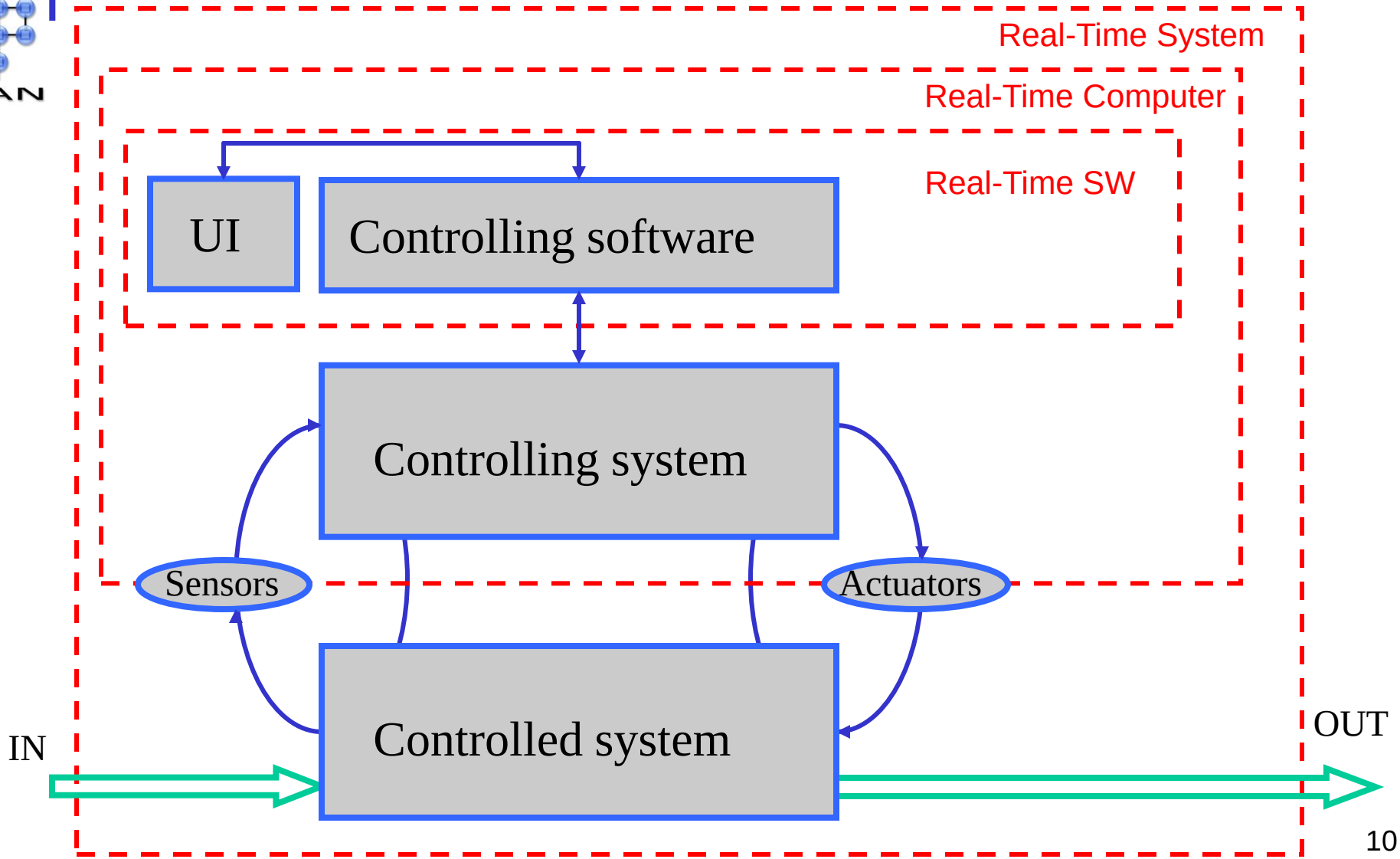
# Example: ABS – cnt'd

- Electronic system:
  - *controller*: requires an ECU;
  - *sensor*:
    - detects that the wheel will lock;
    - either generates an interrupt or is "readable"
  - *actuator*: release and repeat the pressure on the discs
- Distributed:
  - controller, sensors, and actuators at different locations;
  - requires wires or a "network";
- Embedded and invisible to the driver

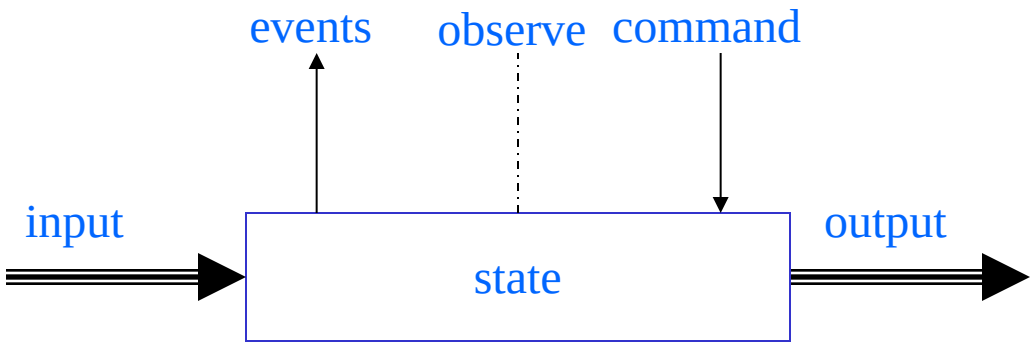
# Example: robots at conveyor belt




# RT(C)S components

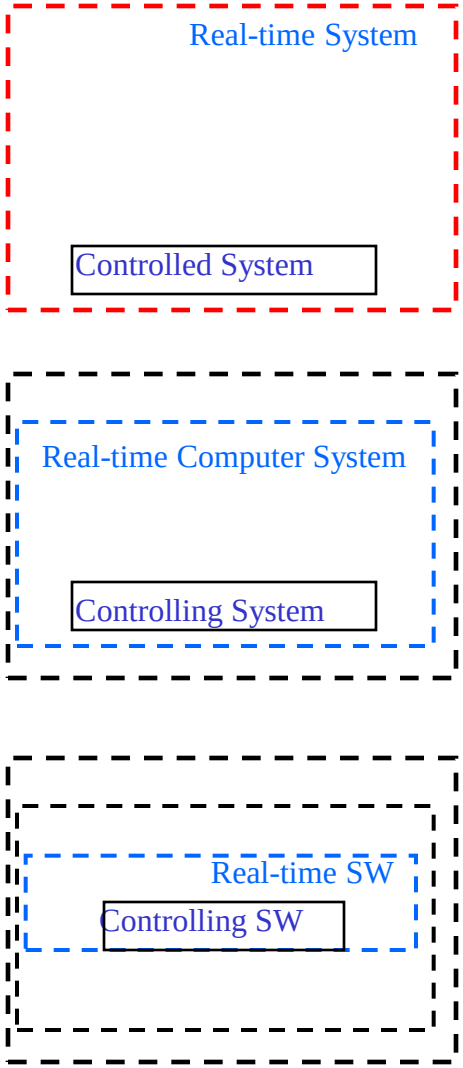


# RT(C)S components (cnt'd)




- Terminals (sensors, actuators) are modelled inside a computer as a component
- Three interface elements for control (though not all parts need to be there at any time)
  - sensor related:
    1. events
    2. observe (internal state)
  - actuator related:
    3. command
- Control 'steers' the data streams

# Top down refinement




- Requirement spec → Design
- Derived requirement spec → Design
- Derived requirement spec → Design

# Overview

- Real-Time Systems
- Specification aspects
  - Functional behaviour
  - Timeliness; constraints derived from
    - functional specification of the system
    - design choices of the system
  - Physical constraints and boundary conditions
    - distribution, concurrency
    - resources
    - size, power
  - Dependability
    - Availability, Reliability
    - Safety, Security
    - Predictability

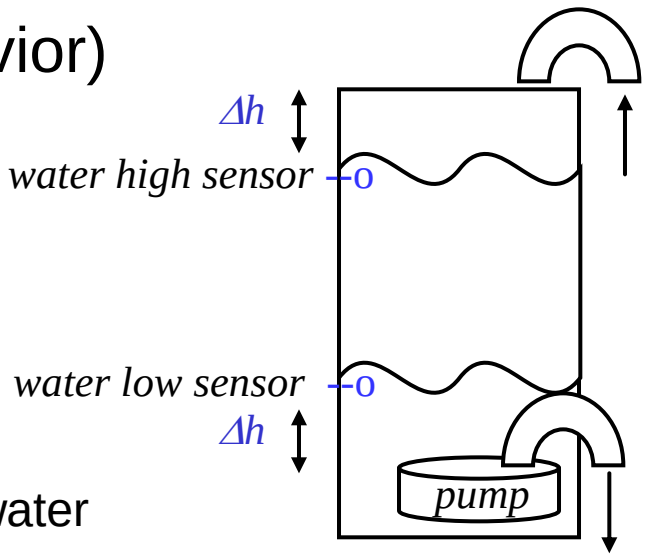
# Functional behaviour

- Top level description of functionality of (controlled) *system.* E.g.,
  - The items that go on the conveyor belt must be painted
  - The temperature must remain between 300K and 301K
  - *K* items must be packed in each box
  - The traffic light system operates according to the rules
  - The video is displayed smoothly, with the highest possible quality
- *Basis for the relation between (sensor) input and (actuator) output*

# Timeliness

- *Derived* constraints on *controlling system* (from functional behaviour) are determined by design choices in the *system*
  - "Not more that 5% of the paint is wasted"
    - opening the faucet must be precise enough w.r.t. speed of conveyor belt:
  - "Variations in temperature are within 0.05K"
    - response must be quick enough w.r.t. possible variations in environment and size and thermal isolation of system
  - "*K* items must be packed in each box"
    - response must be quick enough w.r.t. transport speed of items to pick one
- System design choices (decisions)
  - speed of conveyor belt (following productivity requirements)
  - size and thermal isolation
  - transport speed of items

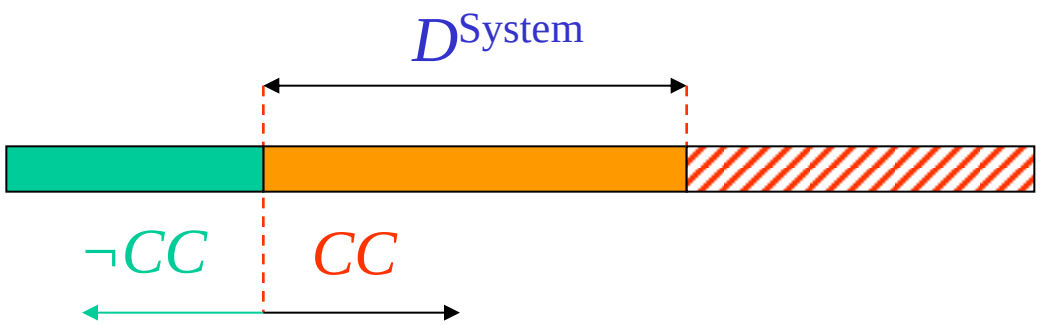
# Example: Water vessel




- Requirements (functional behavior)
  - Vessel should not overflow
  - Pump should not run dry
- Properties
  - Pump
    - states:
      - *off*: limited influx $\Phi_{in} > 0$ of water
      - *on*: limited outflux $\Phi_{out} > 0$ of water
    - operations: *start* and *stop*
  - Sensors
    - placed $\Delta h$ from critical levels
    - readable, i.e. no trigger
- *Derived* timing requirement:
  - $D^{System}$ time units needed for a level change $\Delta h$ (for both pump *off* and pump *on*)

# Water vessel: solution

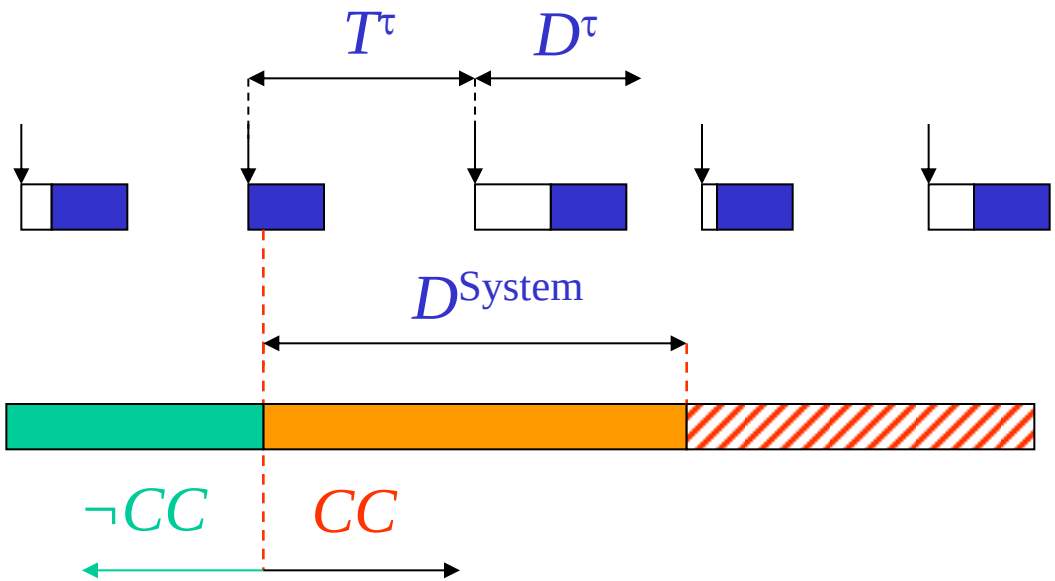
- *System specification*: *event* or critical condition $CC$
  - water above (/below) water high (/low) sensor
  - upon occurrence, a *response* is required within $D^{System}$ time




- *Design: time*-triggered (i.e. *polling*), periodic task $\tau$:
  - period $T^{\tau}$;
  - deadline $D^{\tau}$;
  - actions:
    - read sensors (to detect $CC$)
    - water above high sensor: *start* pump
    - water below low sensor: *stop* pump

# Water vessel: solution

- Schedulability conditions:
  - general: $T^{\tau} + D^{\tau} \leq D^{System}$
  - for $D^{\tau} = T^{\tau}$: $2*T^{\tau} \leq D^{System}$




- Note: *independent* of the scheduling algorithm!

# Physical constraints

- *Environment of the RTCS is given: the controlled system*
  - though it may be part of the RTS design cycle
- Environment dictates part of the RTCS architecture
  - distribution, several distinct locations
  - concurrency
    - respond to *simultaneous* events
    - control *concurrent* physical processes
    - interconnect medium
  - embedding
    - limitations in resources: size, power, communication, memory
    - choice of processor or controller
    - software difficult to access

# Dependability

- Availability:
  - probability of the system being ready to use
- Reliability:
  - expected time until not being available
- Safety:
  - catastrophic states not reachable
- Security:
  - protection of system assets
- Predictability
  - fixed and known system performance
  - ...under varying circumstances
- Maintainability: ease of repair, update etc.

# Predictability

- Essential ingredient for real-time systems

- The predictability is endangered by
  - anomalies of the hardware and system software
    - use of DMA that locks the bus
    - cache behaviour
    - interrupts
    - memory management
  - constraints (dependencies between tasks)
    - concurrency control: locking of resource
    - precedence constraints
  - absence of transparency in high level languages
    - dynamic variables, garbage collection (memory management)
    - repetition, recursion