IA158 Real Time Systems

Tomáš Brázdil

Organization of This Course

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Evaluation:

- Homework project

  (have to do to be allowed to the exam)
- Oral exam

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Definition 3 (Real-time system)

A *real-time system* must deliver services in a timely manner.

Not necessarily fast, must satisfy some *quantitative* timing constraints

Real-time Embedded Systems

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(Few) Examples of Real-time Embedded Systems

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- Multimedia – multimedia center, videoconferencing
- ...

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- multimedia (on PC)
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There are embedded systems that are (possibly) not real-time

e.g. a weather station sends data once a day without any deadline – not really real-time system

Caveat: Aren't all systems real-time in a sense?

Characteristics of Real-Time Embedded Systems

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  - Serious consequences may result if services are not delivered on timely basis
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- reactive
  - Interact continuously with their environment (as opposed to information processing systems)

  ... “traditional” validation methods do not apply

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- We need a formal model and validation ...

- ... we need **predictable** behavior!
  It is difficult to obtain
  - caches, DMA, unmaskable interrupts
  - memory management
  - scheduling anomalies
  - difficult to compute worst-case execution time
  - ...

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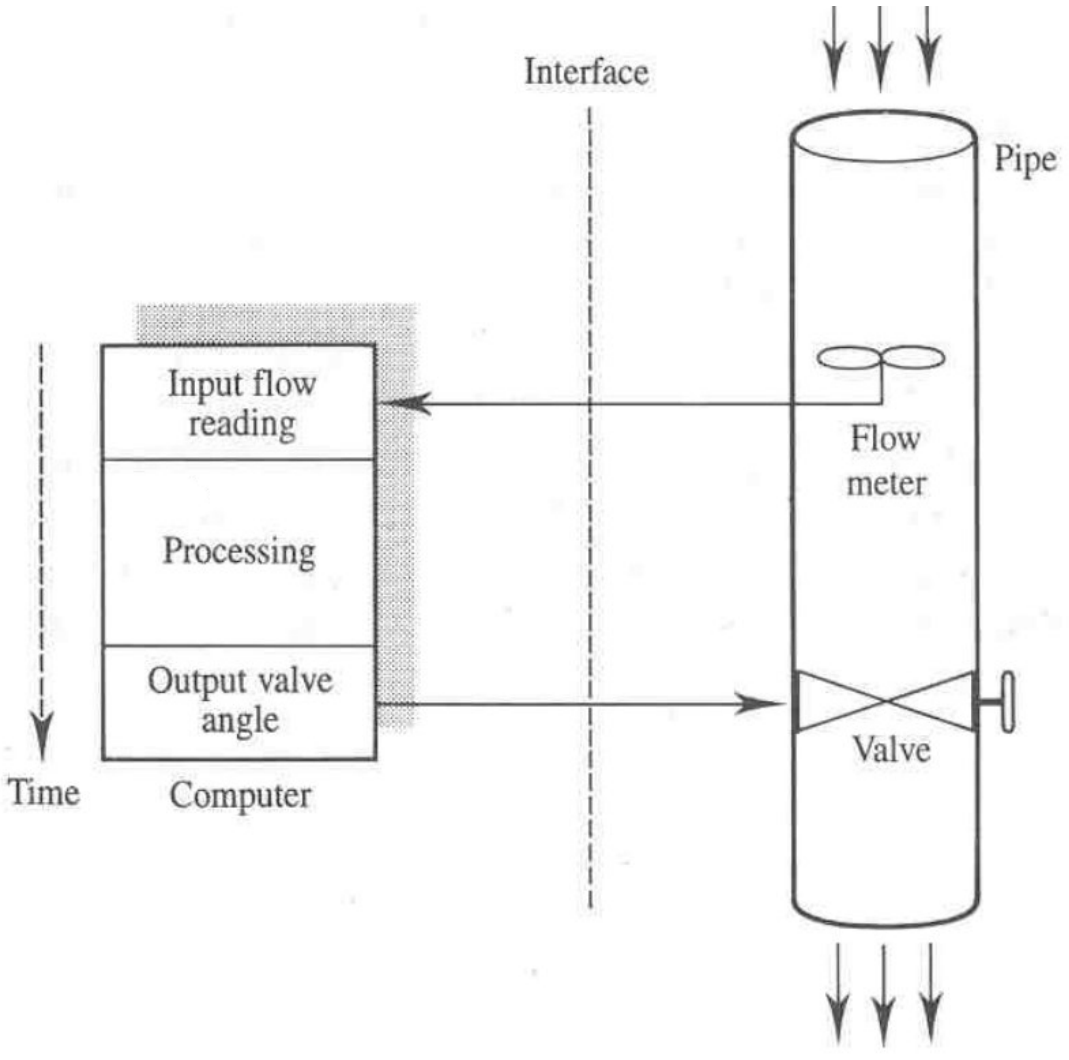
Many real-time systems combine "hard" and "soft" real-time tasks.

i.e. we optimize performance w.r.t. "soft" real-time tasks under the constraint that "hard" real-time tasks are finished before their deadlines

Examples of Real-Time Systems

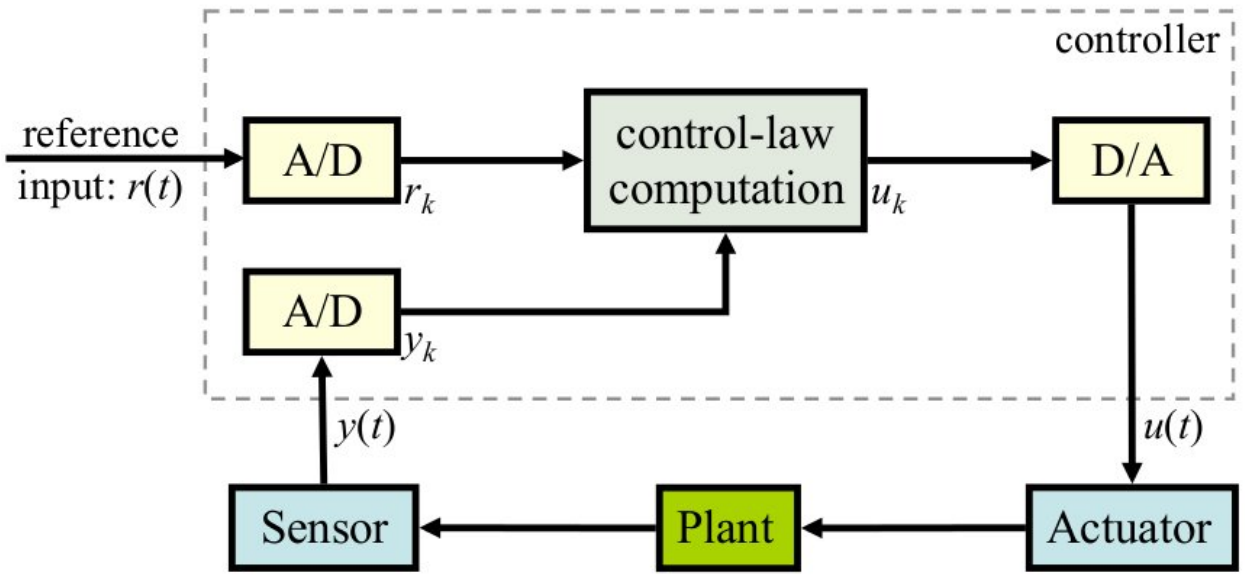
- Digital process control
  - anti-lock braking system
- Higher-level command and control
  - helicopter flight control
- Real-time databases
  - Stock trading systems

Digital Process Control



Computer controls the flow in the pipe in real-time

Digital Process Control



The controller (computer) controls the plant using the actuator (valve) based on sampled data from the sensor (flow meter)

- $y(t)$ – the measured state of the plant
- $r(t)$ – the desired state of the plant
- Calculate control output $u(t)$ as a function of $y(t), r(t)$
  e.g. $u_k = u_{k-2} + \alpha(r_k - y_k) + \beta(r_{k-1} - y_{k-1}) + \gamma(r_{k-2} - y_{k-2})$
  where α, β, γ are suitable constants

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- Pseudo-code for the controller:

  set timer to interrupt periodically with period T
  foreach timer interrupt **do**
  | analogue-to-digital conversion of $y(t)$ to get y_k
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- Effective control of the plant depends on:
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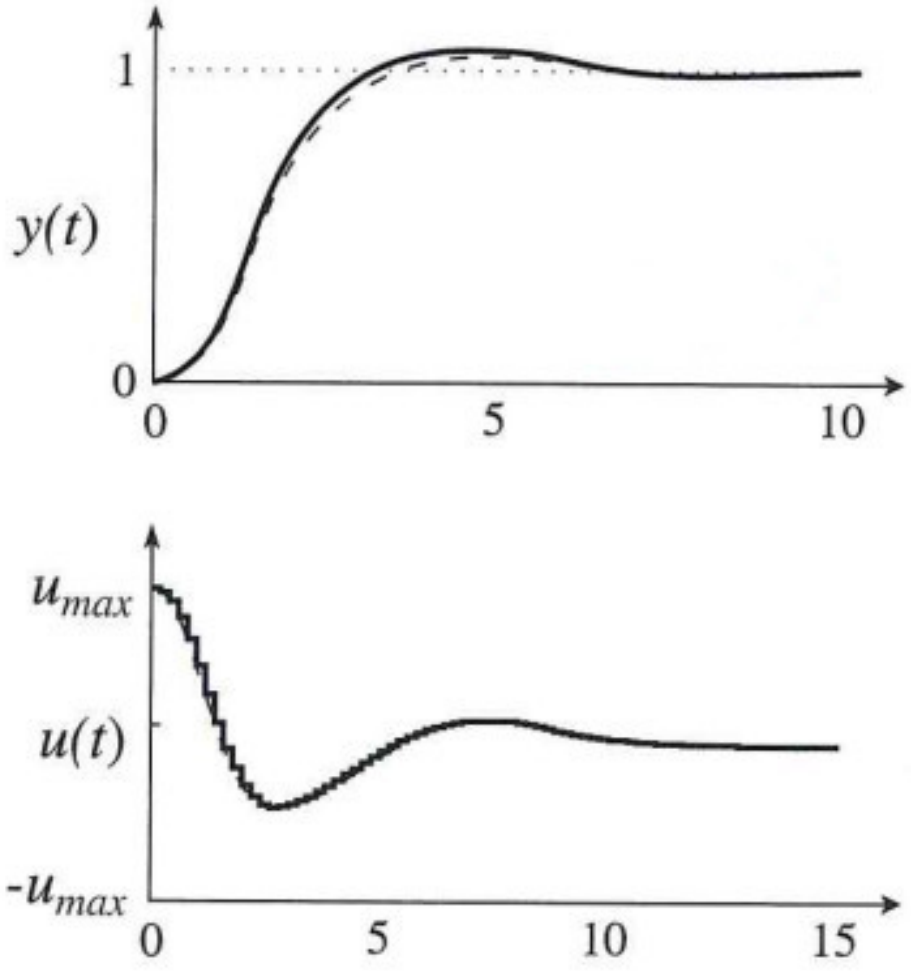
- T is the *sampling period*
  - Small T better approximates the analogue behavior
  - Large T means less processor-time demand

    ... but may result in unstable control

Example



$r(t) = 1$ for $t \geq 0$

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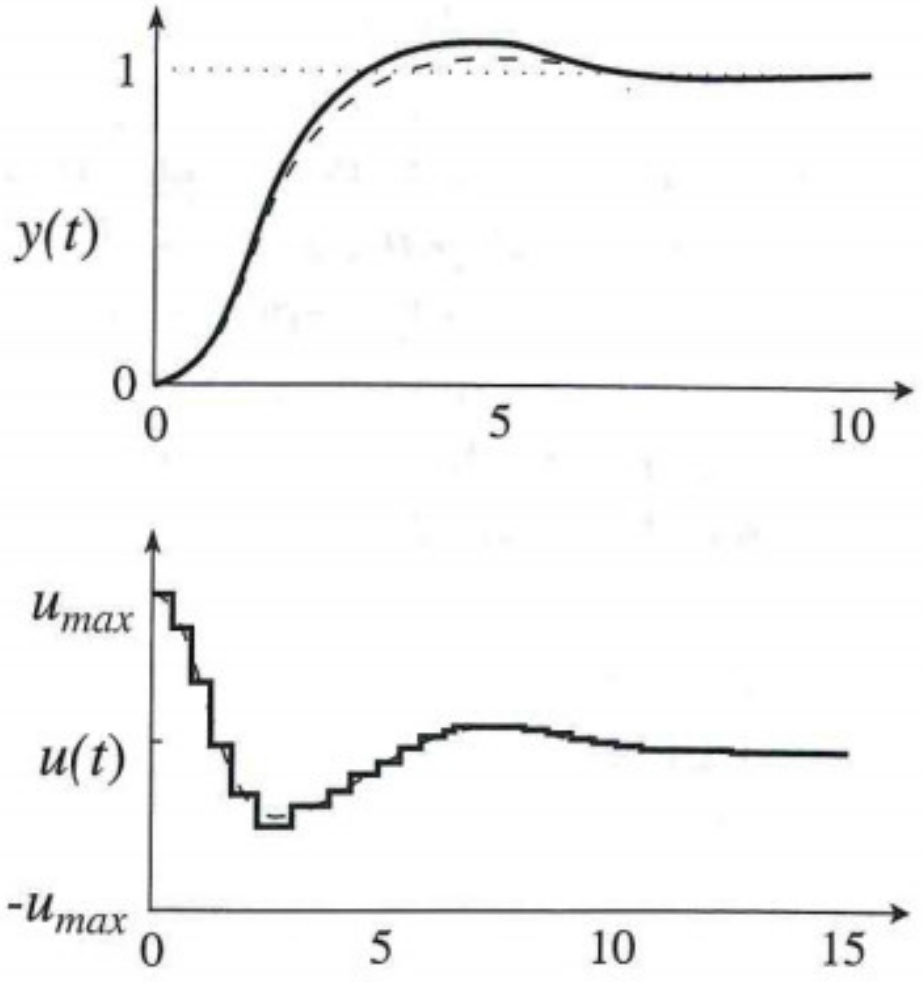

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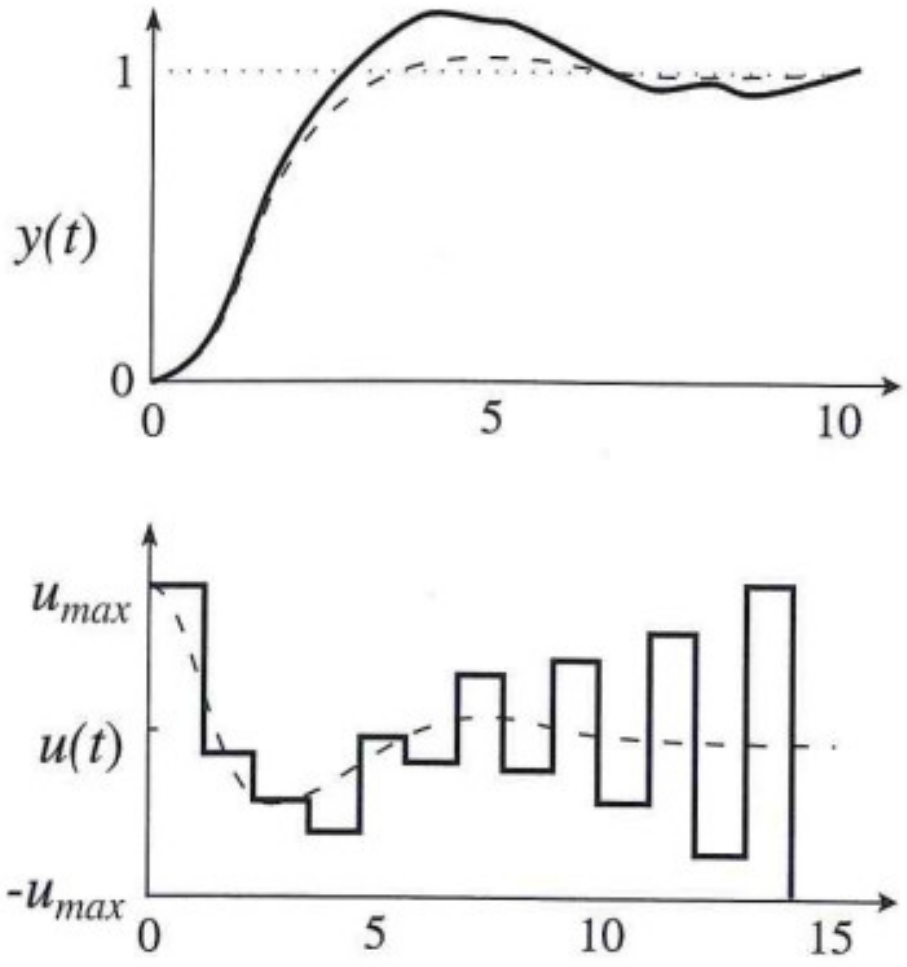

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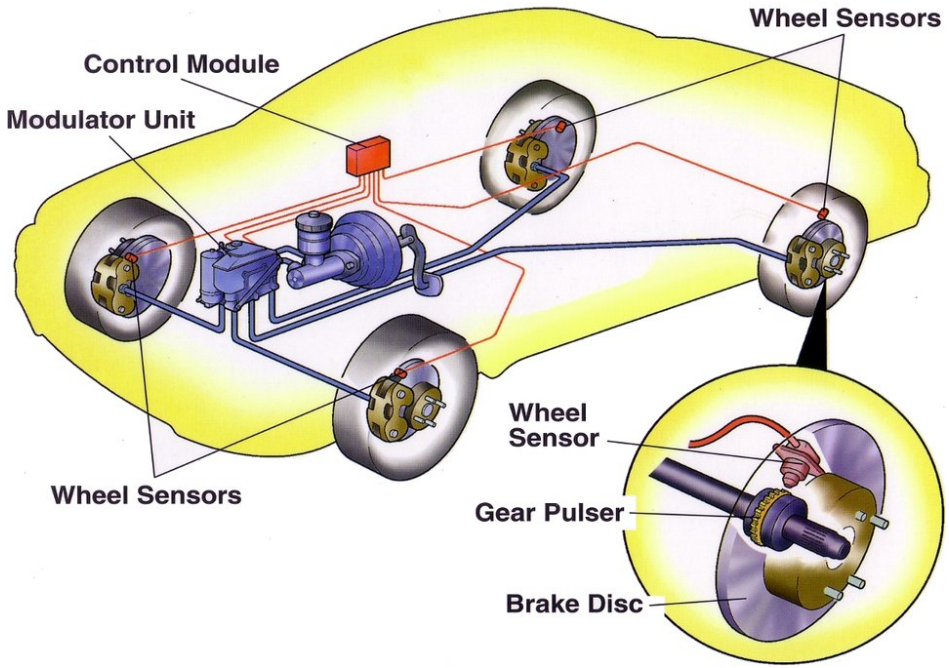
Anti-Lock Braking System



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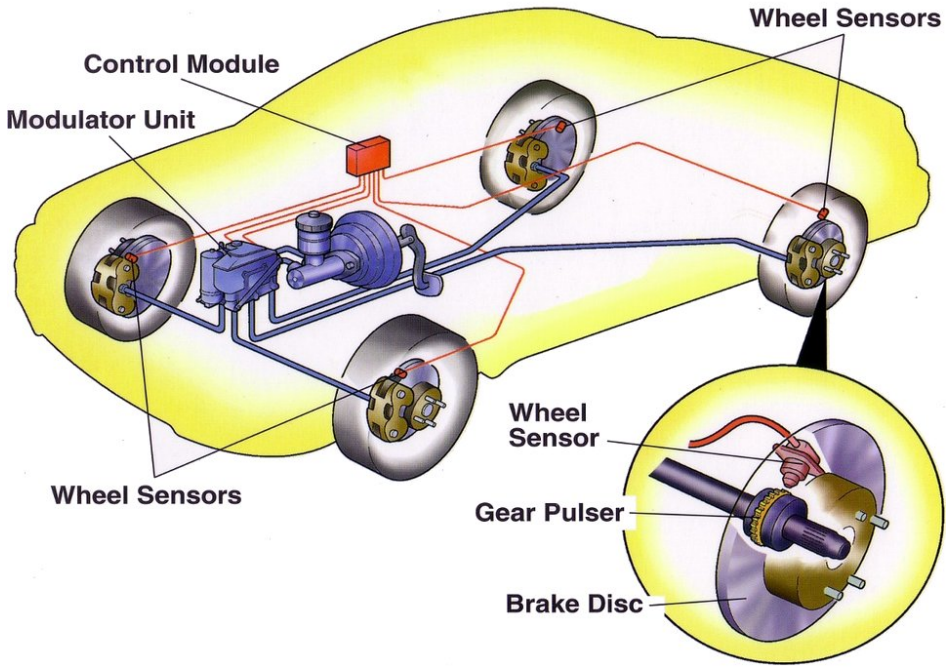

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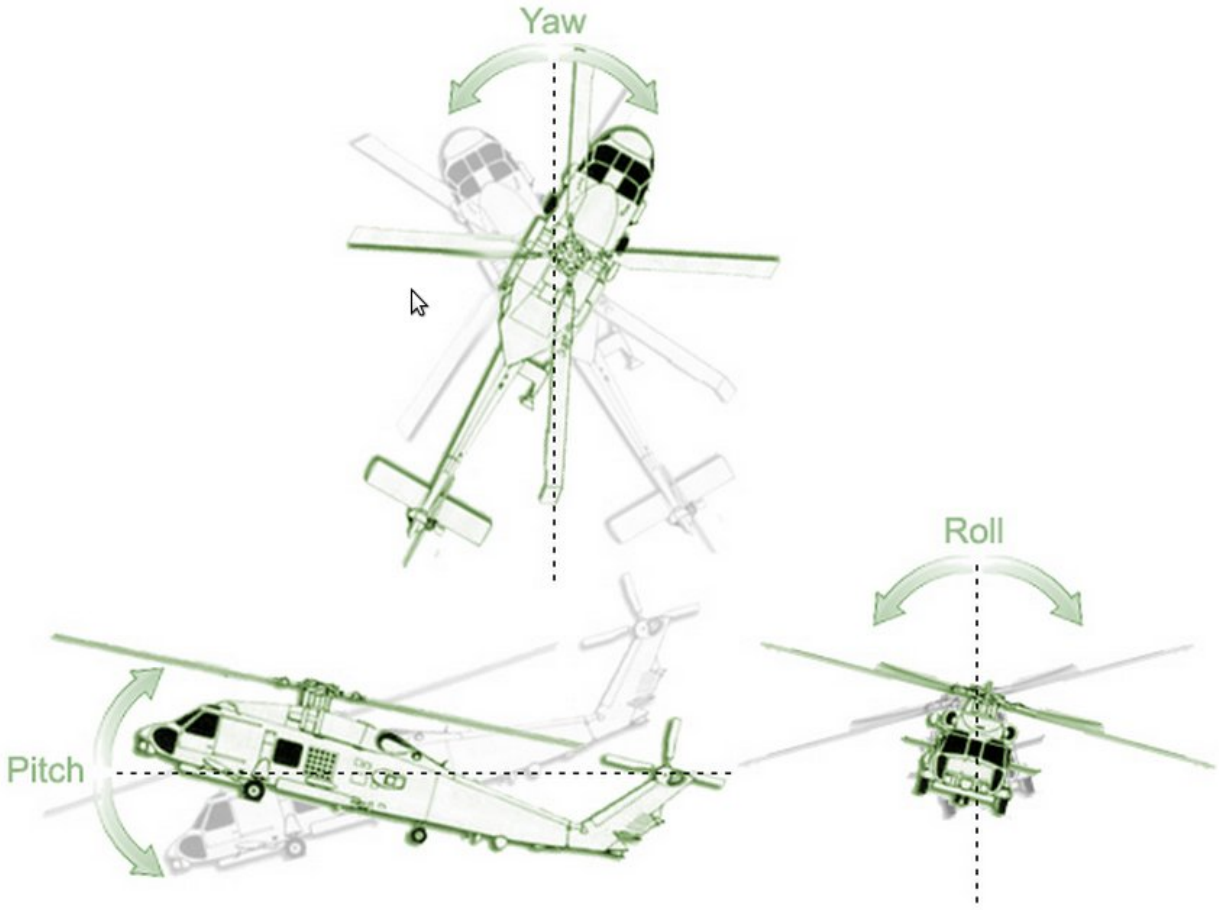
- If a rapid deceleration of a wheel is observed, the controller alternately
  - reduces pressure on the corresponding brake until acceleration is observed
  - then applies brake until deceleration is observed

Multi-Rate DPC – Helicopter Flight Control



There are also three velocity components

Two control loops: pilot's control (30Hz) and stabilization (90Hz)

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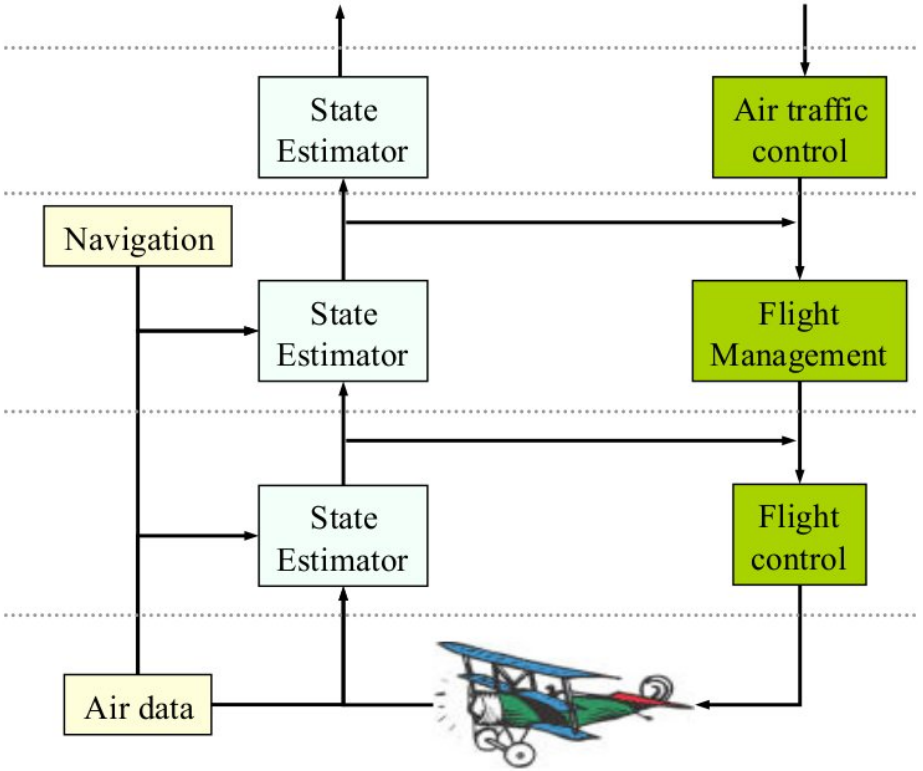
- Output commands
- Carry out built-in-test
- Wait until the beginning of the next cycle

Higher-Level Command and Control



Controllers organized into a hierarchy

- At the lowest level we place the digital control systems that operate on the physical environment
- Higher level controllers monitor the behavior of lower levels
- Time-scale and complexity of decision making increases as one goes up the hierarchy (from control to planning)

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- The temporal quality of data is quantified by *age of an image object*, i.e. the length of time since last update
- temporal consistency
  - absolute = max. age is bounded by a fixed threshold
  - relative = max. difference in ages is bounded by a threshold

    e.g. planning system correlating traffic density and flow of vehicles

Applications	Size	Ave. Resp. Time	Max Resp. Time	Abs. Cons.	Rel. Cons.
Air traffic control	20,000	0.50 ms	5.00 ms	3.00 sec.	6.00 sec.
Aircraft mission	3,000	0.05 ms	1.00 ms	0.05 sec.	0.20 sec.
Spacecraft control	5,000	0.05 ms	1.00 ms	0.20 sec.	1.00 sec.
Process control		0.80 ms	5.00 sec	1.00 sec.	2.00 sec

- Users of database compete for access – various models for trading consistency with time demands exist.

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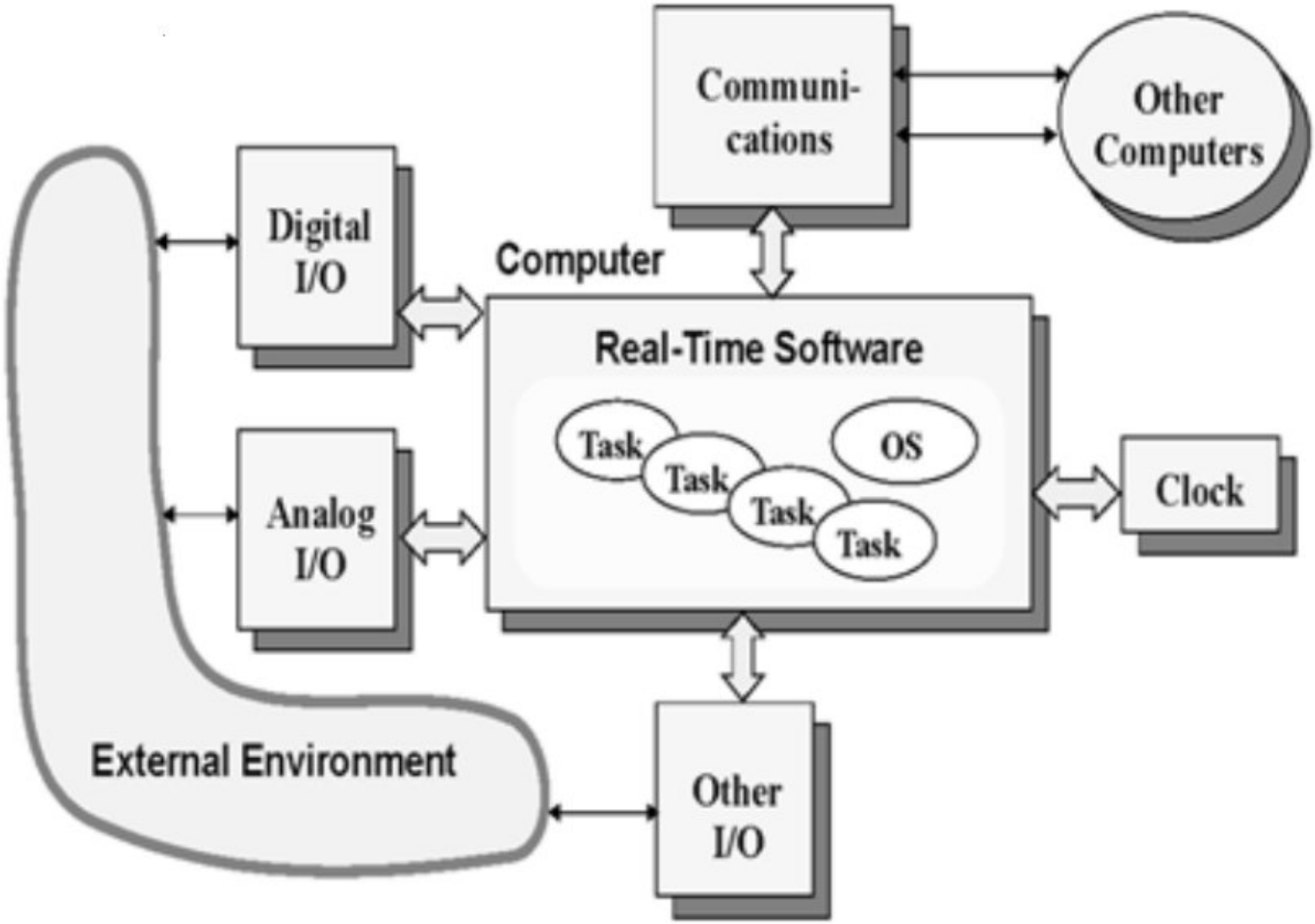
- Depending on the delay, the available price may be different from the limit

  successful stop orders depend on the timely delivery of stock trade data and the ability to trade on the changing prices in a timely manner

Structure of Real-Time (Embedded) Applications



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- Asynchronous and somewhat predictable
  - durations between consecutive executions of a task as well as demands in resources may vary considerably. These variations have either bounded range, or known statistics.

  e.g. radar signal processing, tracking

Types of Real-Time Systems

- The type of application affects how we schedule tasks and prove correctness
- It is easier to reason about applications that are more cyclic, synchronous and predictable
  - Many real-time systems are designed in this manner
  - Safe, conservative, design approach, if it works

Real-Time Systems Failures

- AT&T *long* distance calls
- Therac-25 medical accelerator disaster
- Patriot missile mistiming

AT&T Long Distance Calls

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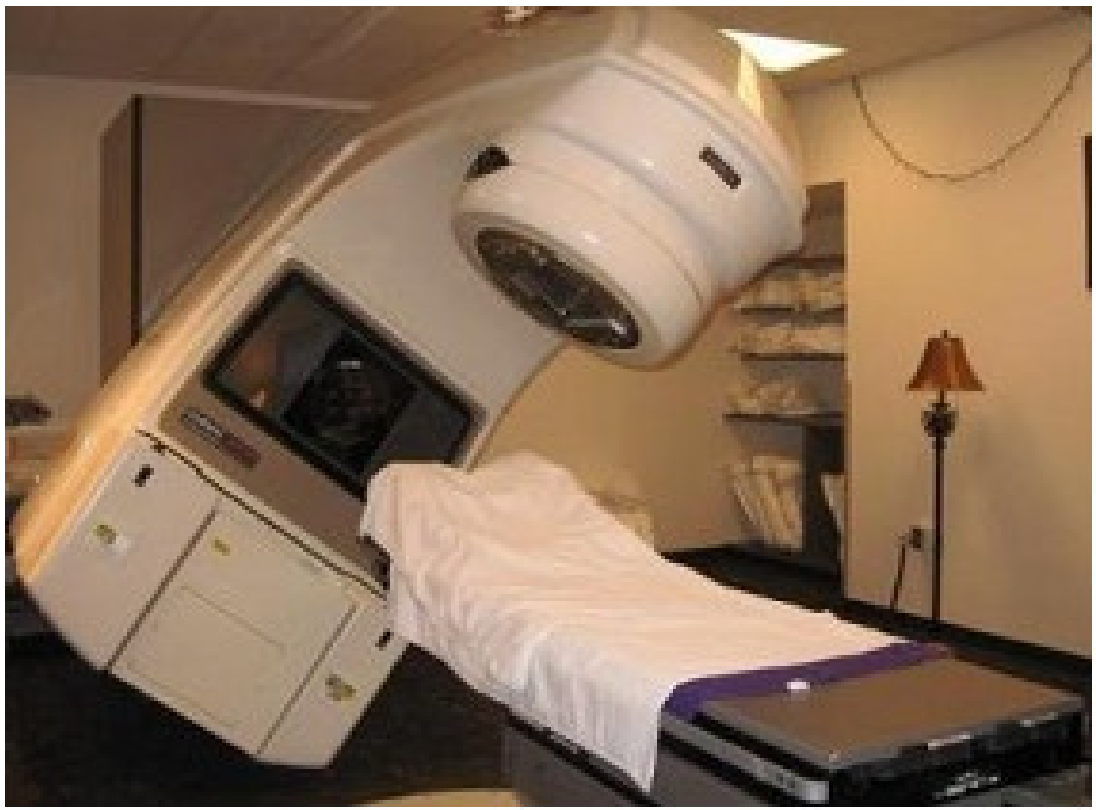
The reason for failure: The system was unable to react to closely timed messages

Therac-25 medical accelerator disaster

Therac-25 = a machine for radiotheratpy

- between 1985 and 1987 (at least) six accidents involving enormous radiation overdoses to patients
- Half of these patients died due to the overdoses



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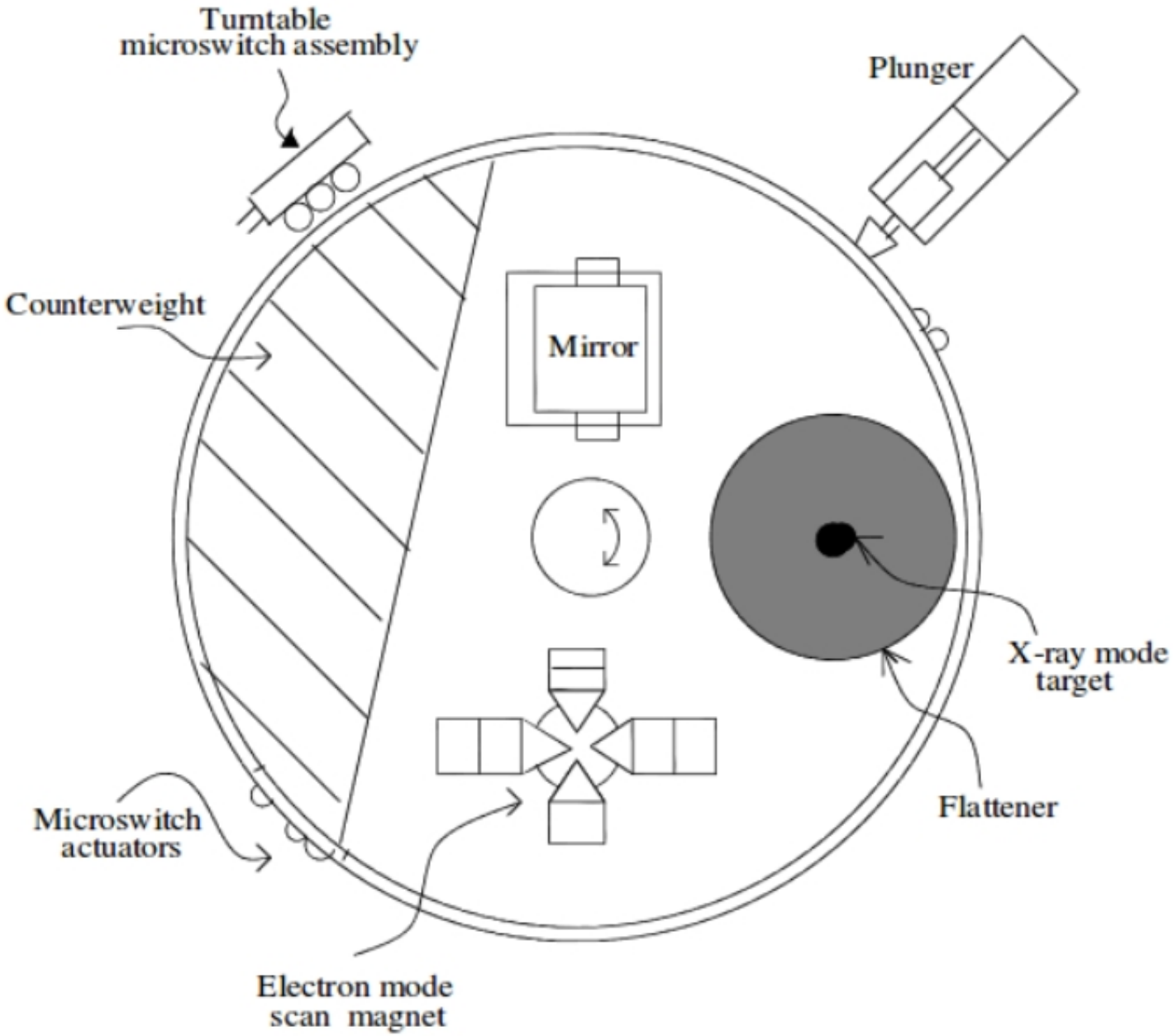
All devices placed on a turntable, supposed to be rotated to the correct position before the beam is started up

Therac-25 – turntable



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Software running several safety critical tasks in parallel!

Insufficient hardware protection (as opposed to previous models)!!

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Communication between tasks based on shared variables (without proper atomic test-and-set instructions)

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Patriot missile mistiming

vs

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- then the scud is intercepted

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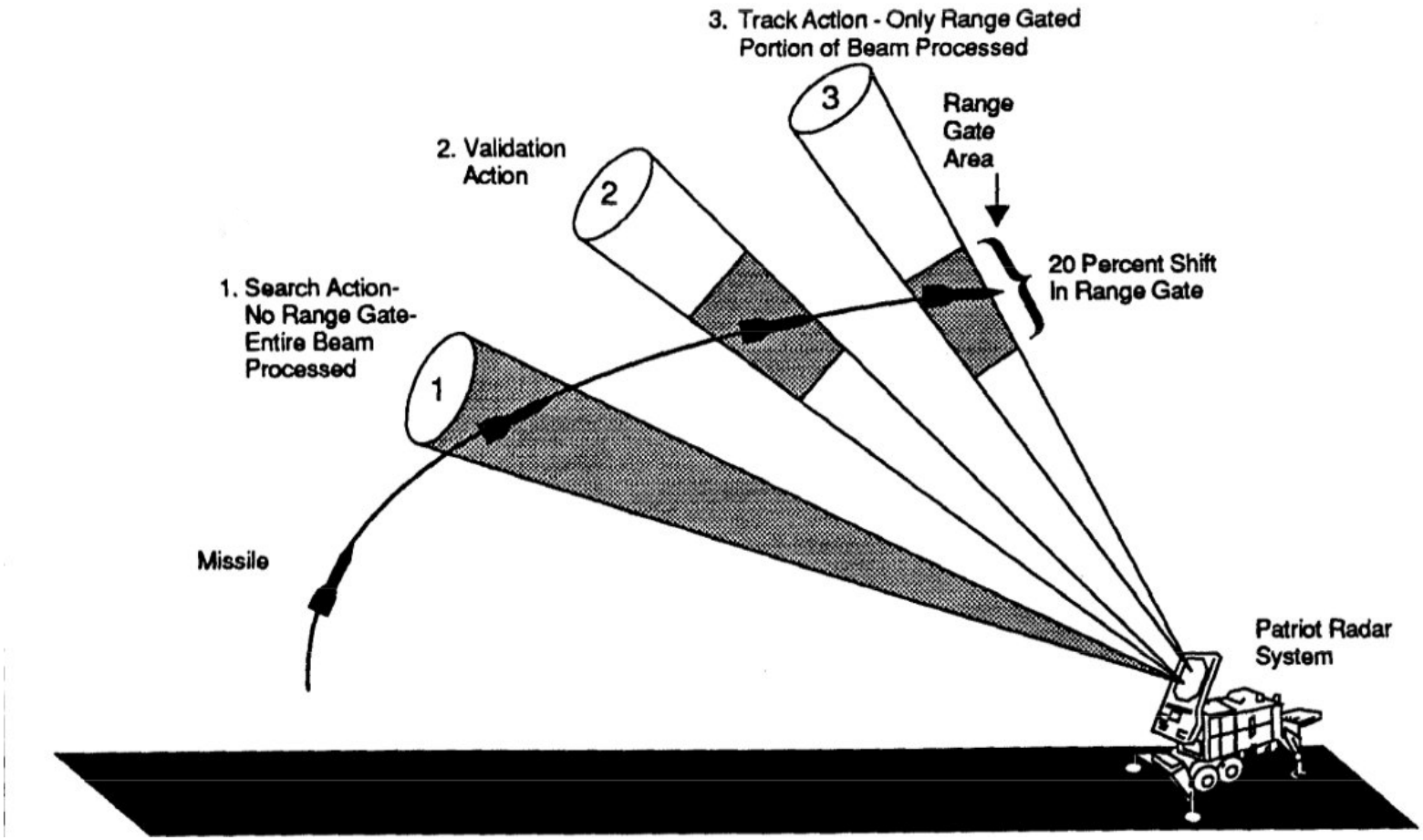

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As a result, the tracking gate looked into wrong area

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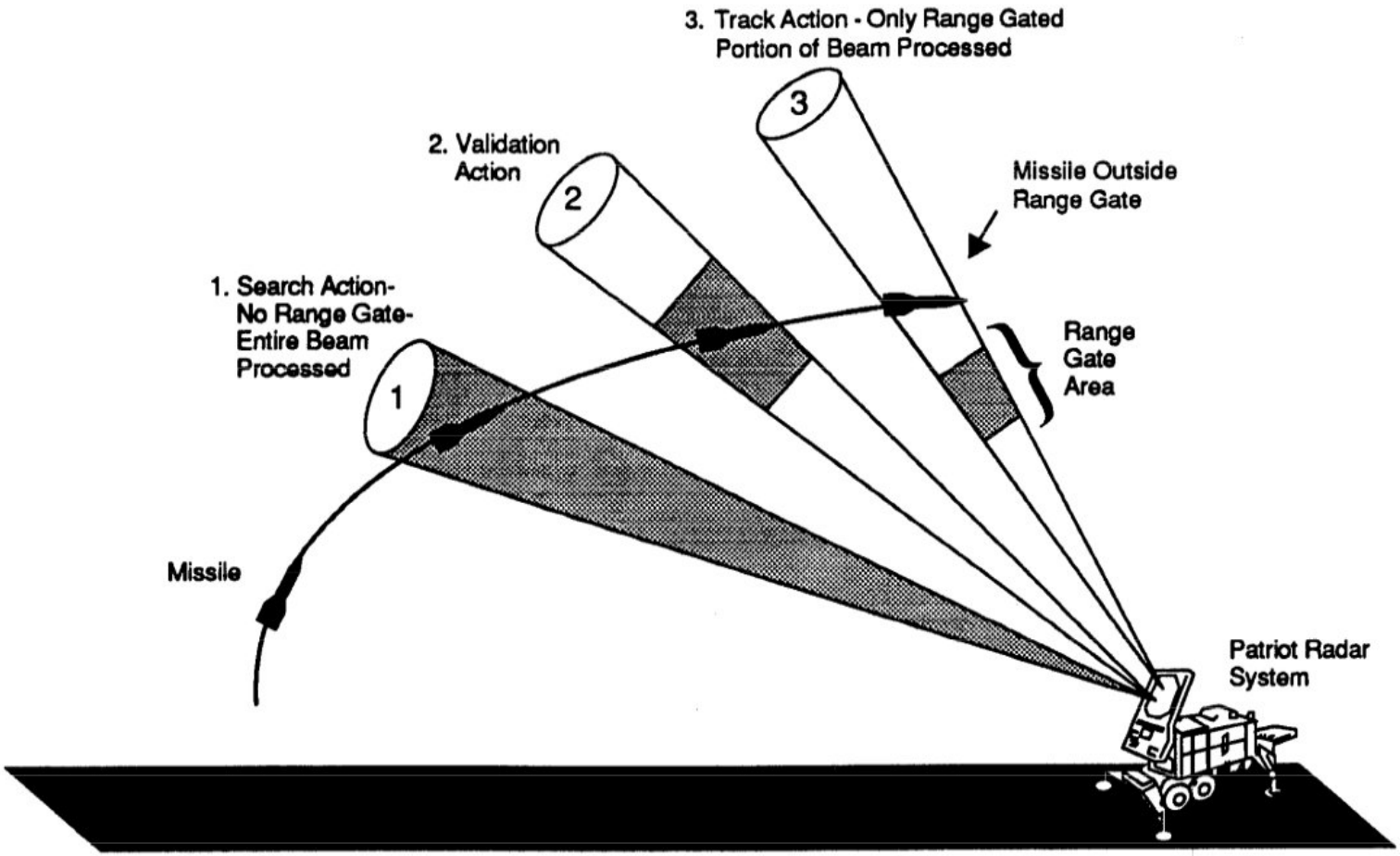

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- What happened:
  - Mission Elapsed Timer (MET), or clock, on Starliner was set to the wrong time and did not trigger the engines to fire correctly.
  - Other onboard systems compensated and it reached orbit, but had depleted so much fuel there was not enough to continue the journey.

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  - Time and priority driven
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  - Multi-processor (a bit)

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- A little bit on programming real-time systems
  - Real-time operating systems

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Example:

- 1 processor, one critical section shared by job 1 and job 3
- job 1: release time 1, computation time 4, deadline 8
- job 2: release time 1, computation time 2, deadline 5
- job 3: release time 0, computation time 3, deadline 4
- ...

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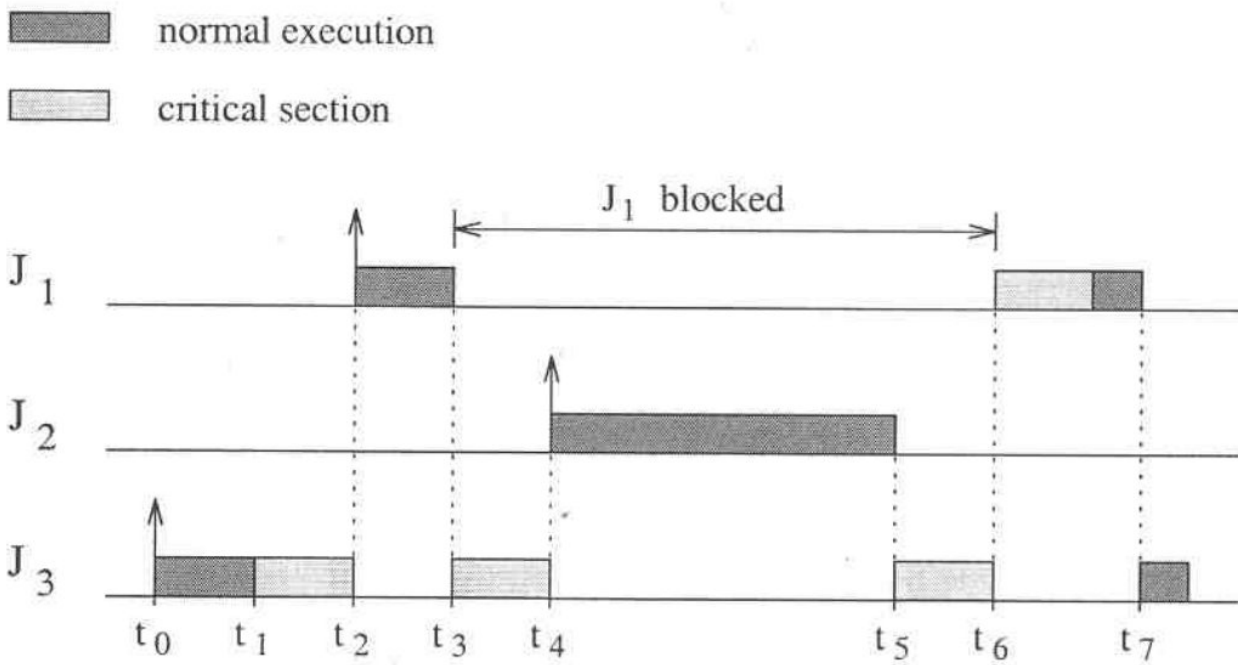
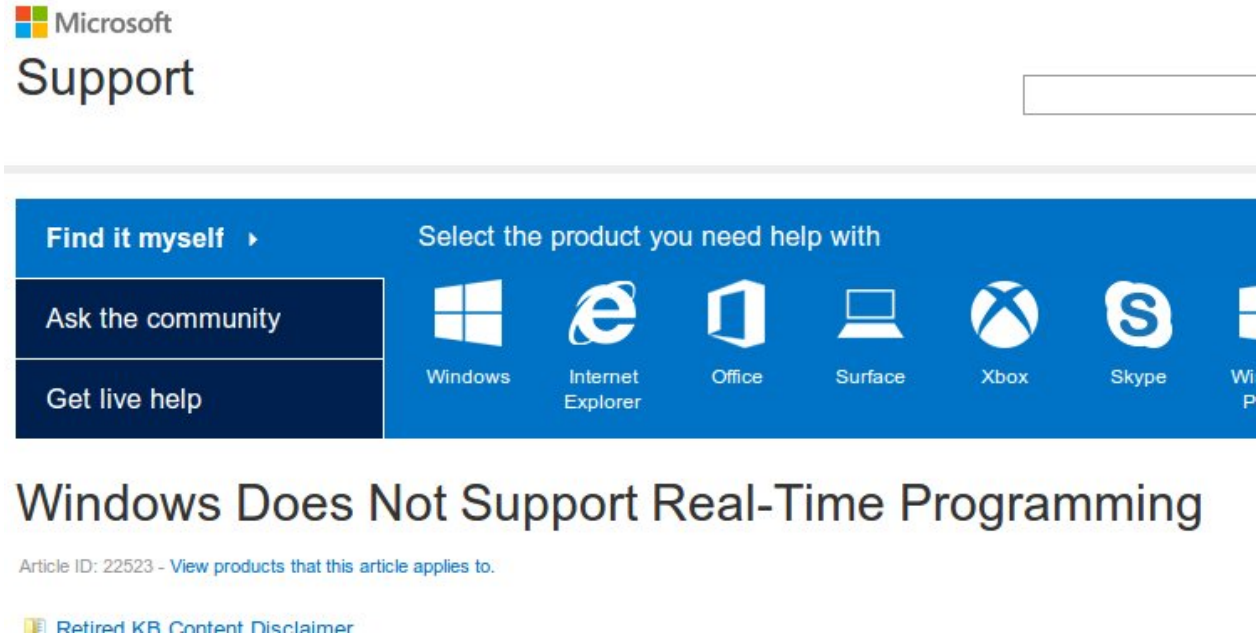


- We consider a formal model of systems with parallel jobs that possibly contend for shared resources

  consider periodic as well as aperiodic jobs
- Consider various algorithms that schedule jobs to meet their timing constraints

  offline and online algorithms, RM, EDF, etc.

Outline – Programming



Basic information about RTOS and RT programming languages

- RTOS – overview
  - real-time in non-real-time operating systems
  - **implementation of theoretical concepts in freeRTOS**
- RT in programming languages – short overview