

# TDDDD07 – Real-time Systems

## Lecture 9: Dependability and Design

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# Dependability topics



Lectures 7 - 9 cover theory and practical examples

- Basic notions of dependability and redundancy in fault-tolerant systems
- Fault tolerance:
  - Relating faults/redundancy to distributed systems from lectures 4-6
  - Relating timing and fault tolerance

Lecture 8: Adds industrial perspective

Lecture 9: Fault prevention and design aspects

# Treatment of faults

- Recall: four approaches for treating faults in dependable systems
- This lecture:
  1. Fault prevention
  2. Fault removal
  3. Fault tolerance
  4. Fault forecasting

# Reading Material

- Ch. 15.1-15.4, 15.7 B&W or Ch. 5.2-5.3 in Carlsson et al.
- Section 5.1 and 5.3 of article by Avezienis et al. 2004
- Platform-independent design: Huang et al. 2003
- UML-MARTE: Weissnegger et al. 2015

# Why dependability-by-design is important (and hard)

# System Requirements

- Functional requirements
  - Describe the main objectives of the system, referred to as “correct service” earlier
- Extra-functional requirements
  - Cover other requirements not relating to main function, in particular dependability, acceptable frequency and severity of service failures
  - Also called non-functional properties (NFP), e.g. Timeliness, availability, energy efficiency
- Let’s start with one that we studied in this course...

# Design for timeliness

## Basic approach:

- define end-to-end deadlines
- define deadlines for individual tasks
- ascertain (worst case) execution/communication time for each task/message
- document assumptions/restrictions
- Prove/show that implementation satisfies requirements



So, what is so hard about this?



# Layers of design

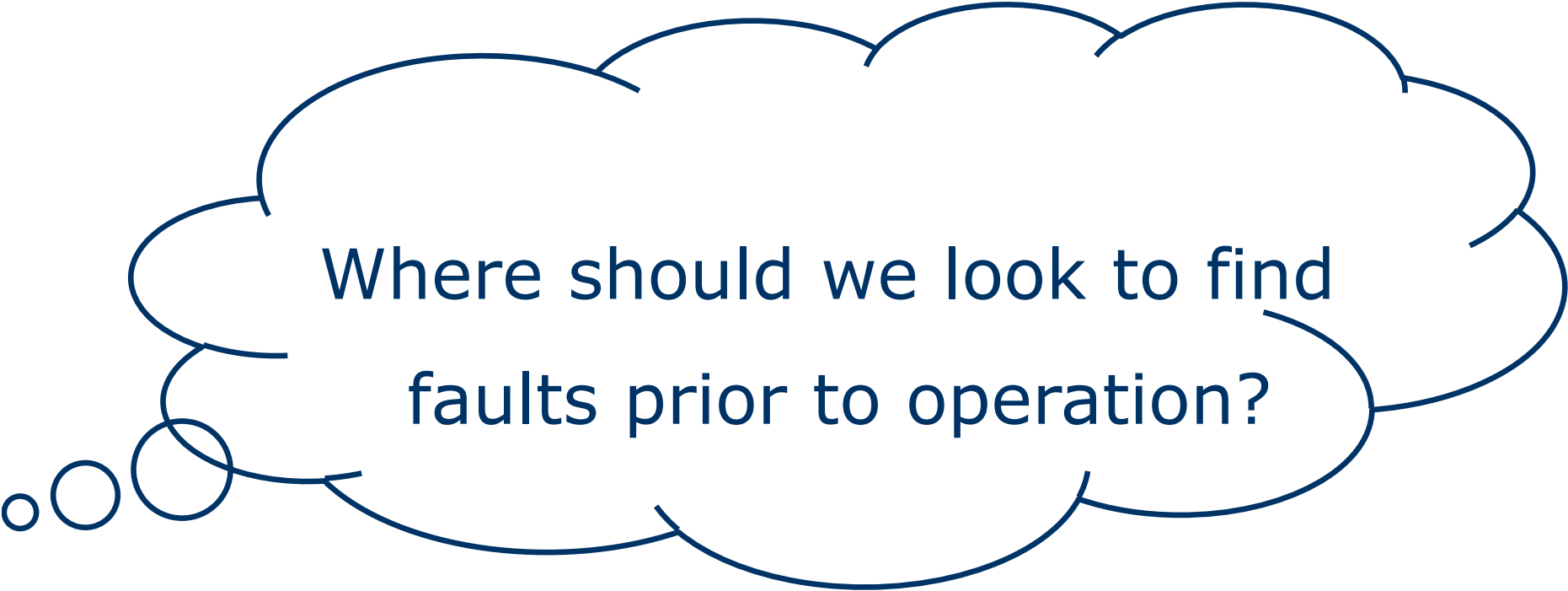
Application modelling support

Programming environment support

System software support  
(kernels, communication protocols)

Hardware support

# Fault prevention/removal



Where should we look to find faults prior to operation?

# Historical snapshots

- Hardware design
  - 1970's Dedicated hardware
  - 1980's Microcomputers & ASICS
  - 1990's High performance Microcomputers, FPGAs, MEMs
  - 2000's SoCware, Multicore
- Earlier predictable hardware is replaced with components that are complex to analyse (caches, pipelines, accelerators)

# Layers of design

Application modelling support

Programming environment support

**System software support (kernels)**

Hardware support

# Historical snapshots

- OS Scheduling principles
  - 1970's Fixed priority scheduling
  - 1980's Multiprocessor, Dynamic
  - 1990's Incorporating shared resources
  - 2000's Load variations, Multicore scheduling
- OS interfaces to optimise memory management e.g. prefetching instructions to boost performance, Virtualisers in cloud platforms

# Layers of design

Application modelling support

Programming environment support

System software support (kernels)

Hardware support

# Historical snapshots

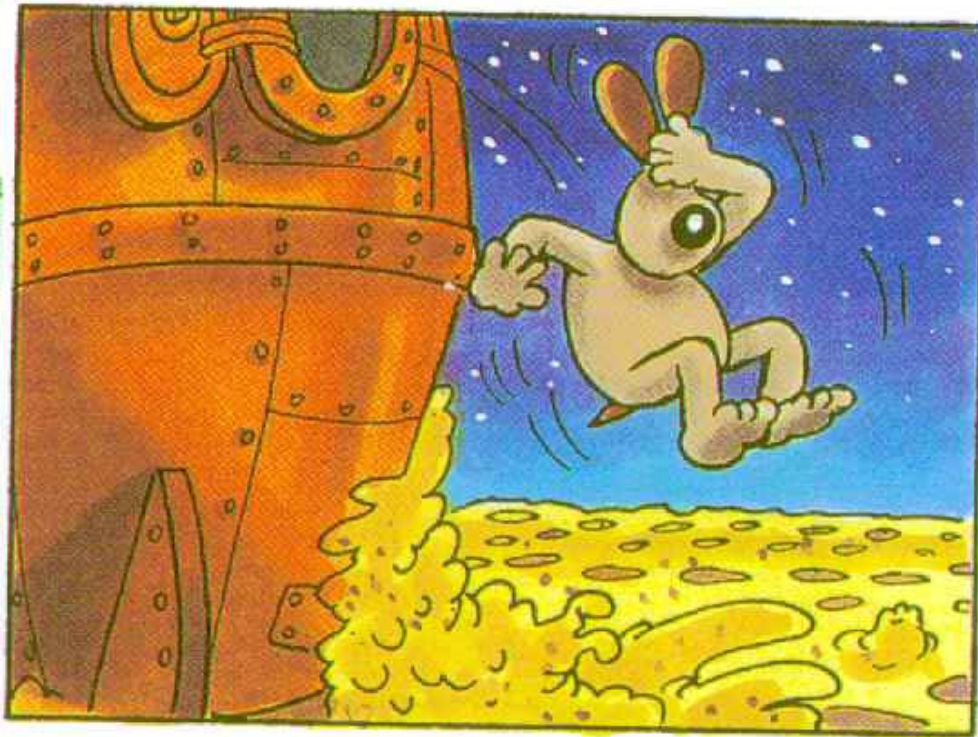
- Programming environments
  - 1970's "High" level programming
  - 1980's Real-time specific: Ada
  - 1990's OO languages, languages with formal semantics
  - 2000's Software libraries (reuse), AUTOSAR components in automotive
- Today: Data-driven, machine learning



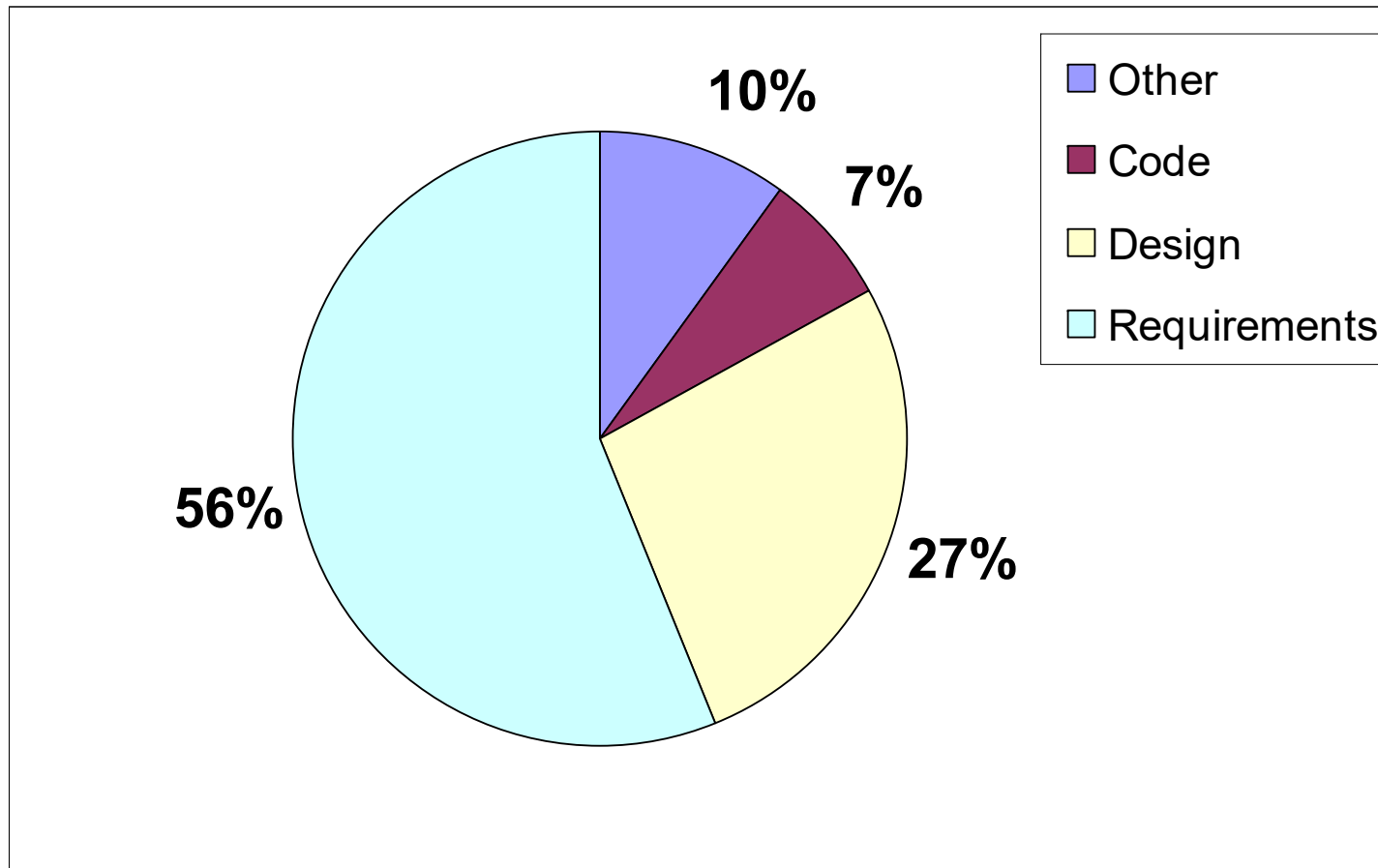
Engineers: Fool me once,  
shame on you – fool me  
twice, shame on me



Software developers: Fool me N times, who cares, this is complex and anyway no one expects software to work...



# Software: where do we find faults?



[Cooling 2003]

# Testing is not enough...

If a test fails, what was the cause?

- Undocumented assumptions on operational conditions, external impact?
- Wrong program code?
- Unexpected impact of OS? Scheduling?
- Virtualiser overhead?
- Hardware timing dependencies?
- Embedded test code affecting timing?

# Platform-independent design

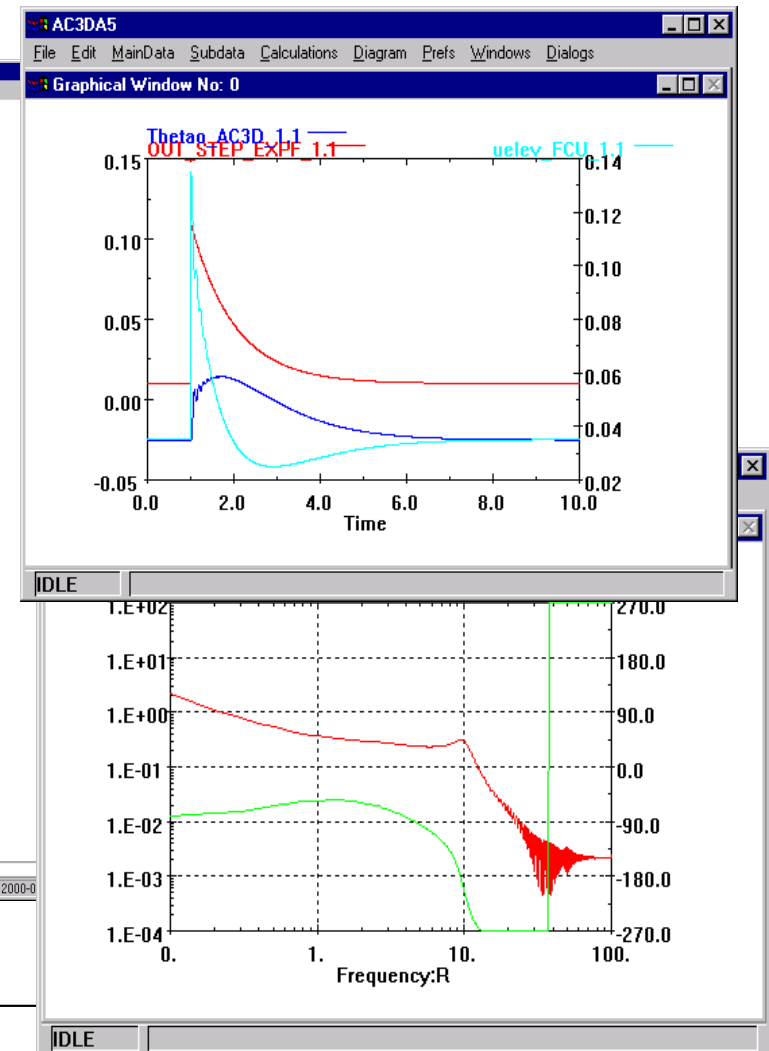
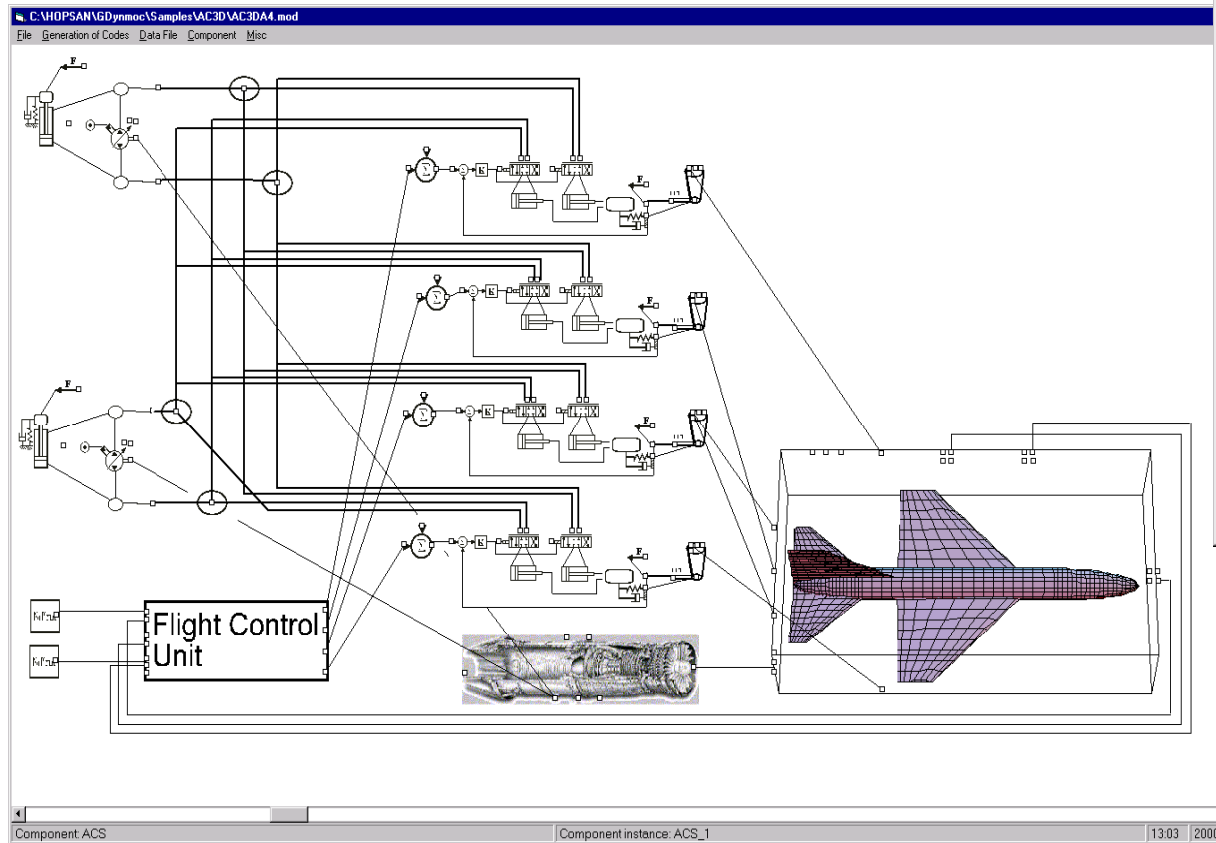


Eliminating “butterfly effect”  
means trying to isolate the  
impacts of different layers

# Back to basics

- define end-to-end deadlines
  - Model the environment!
- define deadlines for individual tasks
  - Specify system decomposition!
- ascertain (worst case) execution/communication time for each task/message
  - Assume hardware/bus characteristics!
- document assumptions/restrictions
  - Model, model, model!
- Prove/show that implementation satisfies requirements
  - Analyse models, then test implementation!

# Non-digital hardware



# An engineering discipline

Using mathematics can never be wrong!

# Model-based development (MBD)



# Model-based development

- In software-intensive systems
  - Models as “higher level” programs
- Idea: use models to analyse the design, automatically generate code from the model!
- Adequate support for modularisation: Well-tested libraries with well-defined interfaces

# Layers of design

Application modelling support

Programming environment support

System software support (kernels)

Hardware support

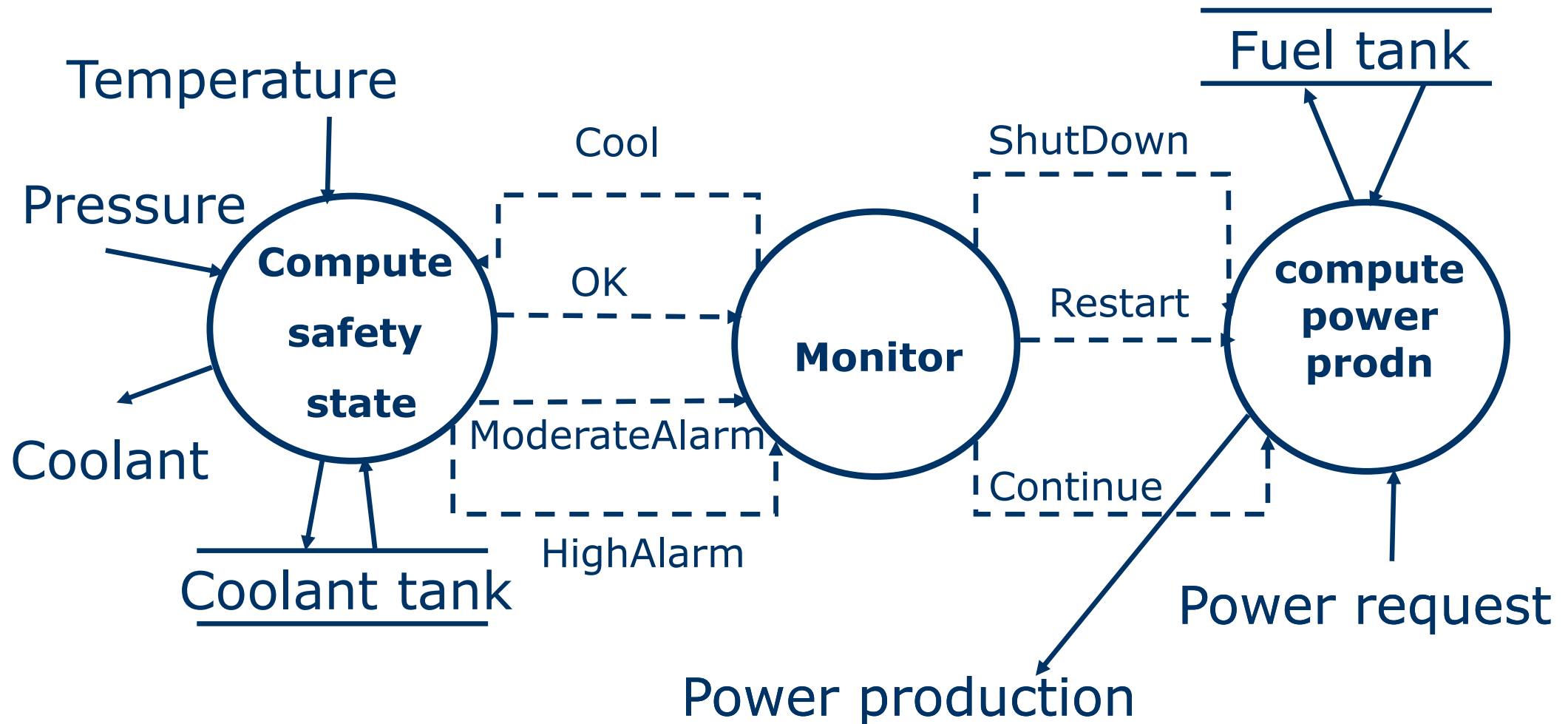
# Historical snapshots

- Mathematical modelling & analysis tools
  - 1970's Sequential systems
  - 1980's Concurrent/Distributed systems
  - 1990's Timed models, Combining discrete & continuous, UML
  - 2000's Incorporation in tools: MBD (domain-specific or universal)
- Today: Models in learning-based systems, explainable AI

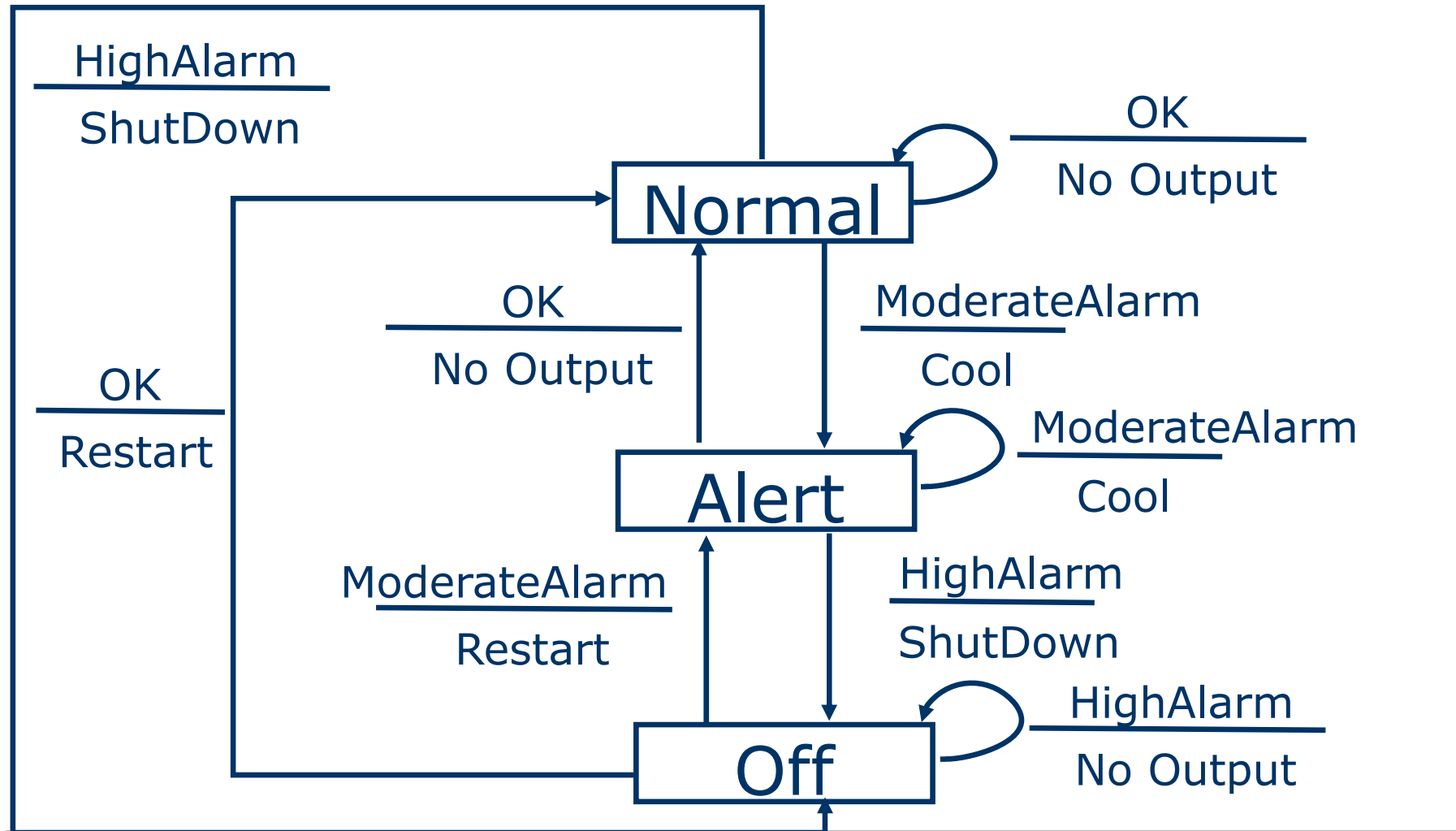
# UML standard

- UML 2.0 models components with required and provided interfaces
- Family of modelling techniques that are a further development of languages in early 80's, for example: Ward & Mellor Diagrams
- Next two slides from an example  
[Heitmeyer and Mandrioli, Wiley, 1996]


# Power plant: Functional part & safety part



# Monitor state machine



# Fault prevention and removal



What do we want to do with models once we create them?



# Advances in 2000's

- Tools to model digital hardware and software components, support for *functional analysis by*
  - Simulations
- Theory:
  - Formal verification of functional properties
  - Semi-automatic code generation

# Simulations of a model

Need a unique interpretation:

- The language should have (standard) operational semantics to enable “execution” of the model
- The language should be platform-independent

# Simulations

What do they show?



# Formal proofs

- Can be used to **Prove** that *specific* bad things *never* happen
- **Create counterexamples**, identify (design) faults that lead to demonstrated bad things
  - debugging the design
- Can be automated, but suffer from combinatorial explosion

# Useful approaches

- Smart data structures for efficient representation of state space
- Smart deduction engines (satisfiability checkers) that find proofs fast
- Smart abstractions of the design to capture the essential properties
  - Synchronous languages (e.g. Esterel, Lustre), used for Airbus 320 software

# Historical snapshots

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# Adding time to UML

- Still in progress...
- No industry-wide tool support
- Recent development: UML profile for Real-time and Embedded Systems (MARTE)
- Meta-models for a class of systems with timing and performance parameters<sup>oo</sup>

See case study in the  
Weissnegger et al. paper

Questions?

[www.ida.liu.se/~TDDD07](http://www.ida.liu.se/~TDDD07)