
# EECS 144/244
# Fundamental Algorithms for System Modeling, Analysis, and Optimization

## Lecture 2: Design approaches

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# State-of-the-art embedded systems

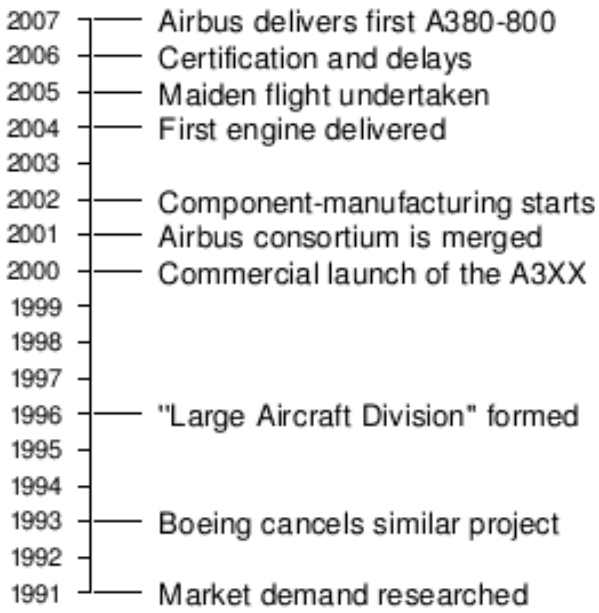
- Seem to fall under two distinct classes:

- Safety-critical (and for the most part dependable), but very expensive:
  - Satellites, airplanes, nuclear power plants, ...

- Cheap, but unreliable:
  - Consumer electronics, ...

# Safety-critical systems

- Airbus A380:
  - Development time: decades
  - Development cost: tens of billions




- Boeing 787
  - Development time: decades
    - Delays, delays … (first flight programmed initially for July 2007, finally done in December 2009)
    - Grounded for ~3 months in early 2013 due to battery problems
  - Cost: US$32 billion



Source: wikipedia

These systems are very expensive!

# Cheap systems

- Consumer electronics


These systems are not very dependable...

# Dependability & Affordability

- For future CPS we need both
- Safety critical systems => dependability
- Massively deployed => affordability

Our ultimate goal: how to achieve both?

# This course

- How can we design complex systems?
- *Fundamental Algorithms for System Modeling, Analysis, and Optimization*
- 3 elements:
  - Systems
    - System-oriented view: look at the system as a whole, then focus on its parts
  - Algorithms
    - Focus on computer-aided design techniques
  - Modeling, Analysis, and Optimization
    - Focus on **model-based design**

# SYSTEM DESIGN APPROACHES

# Approaches to system design (1)

- ***Trial-and-error*** approach:
  - Build prototype
  - Test it, find errors
  - Fix errors
  - Repeat
- Not good for dependability + affordability:
  - Too risky
  - Too costly
- Yet common...

# Design by trial-and-error

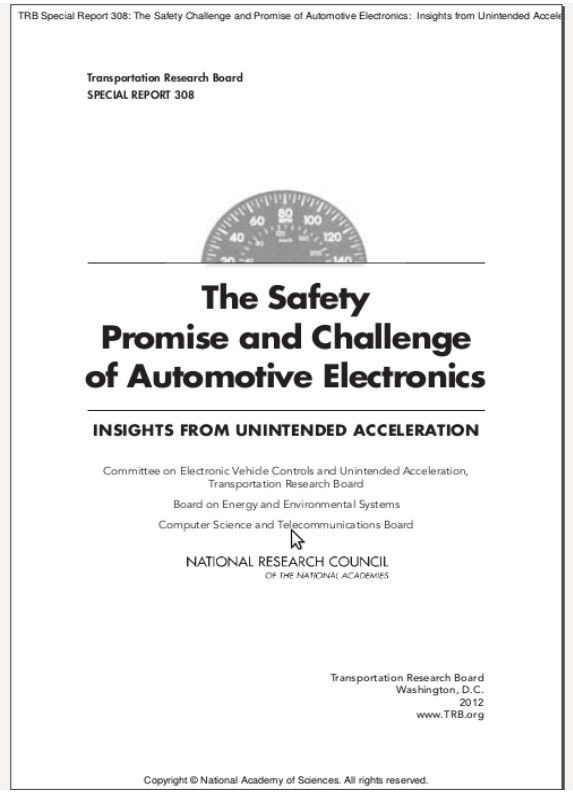
- Tacoma bridge:
http://www.youtube.com/watch?v=xox9BVSu7Ok&feature=related

# Design by trial-and-error

- Fukushima nuclear power plant:

# Design by trial-and-error

- Toyota unintended acceleration incidents
- Millions of cars recalled
- Cost: $ billions
- U.S. National Highway Transportation Safety Administration's (NHTSA) concluded that electronic throttle control systems were **not** the cause.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SPECIAL REPORT 308

**The Safety Promise and Challenge of Automotive Electronics**

**INSIGHTS FROM UNINTENDED ACCELERATION**

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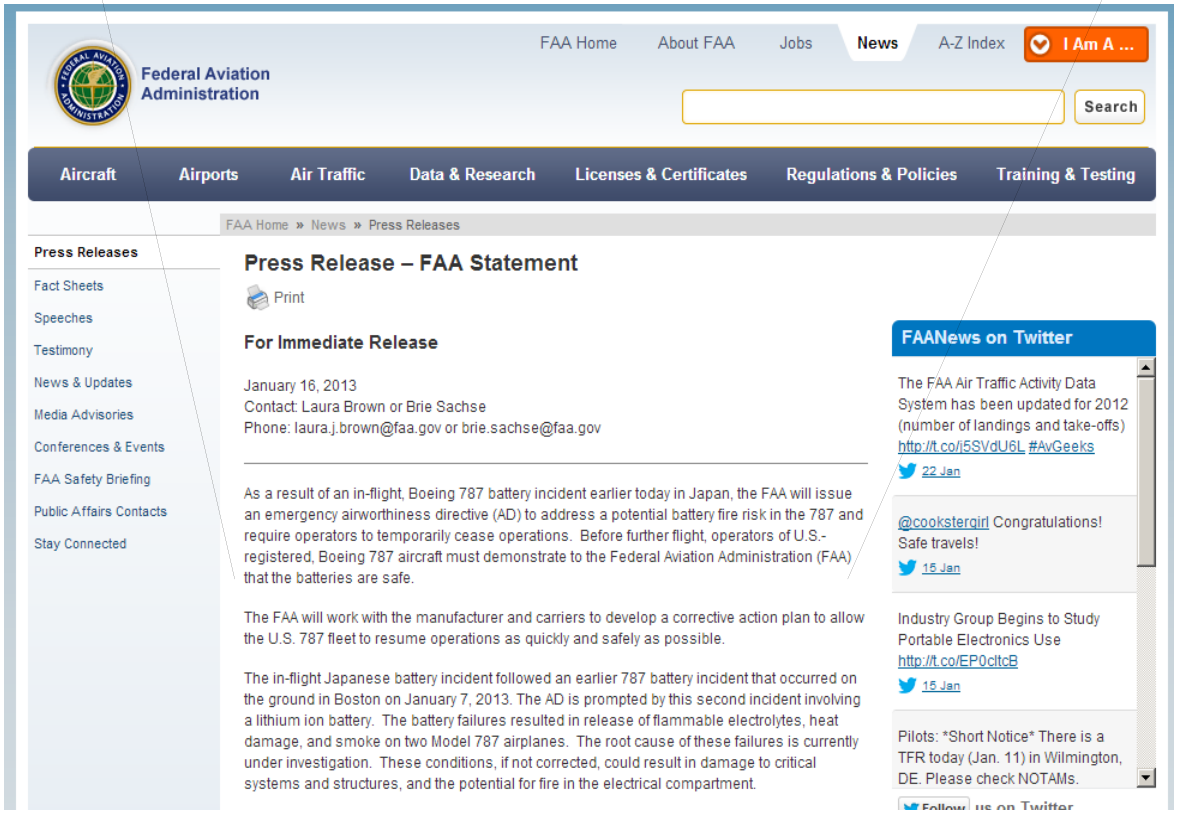
# Design by trial-and-error

- Boeing 787 grounded
- "*All-Nippon today announced it had canceled 320 flights, including 51 international flights, on 787s affecting a total of 46,800 passengers*" [San Jose Mercury News, 1/22/2013]
- FAA restriction finally lifted in April 2013.


*As a result of an in-flight, Boeing 787 battery incident earlier today in Japan, the FAA will issue an emergency airworthiness directive (AD) to address a potential battery fire risk in the 787 and require operators to temporarily cease operations.*
***Before further flight, operators of U.S.-registered, Boeing 787 aircraft must demonstrate to the Federal Aviation Administration (FAA) that the batteries are safe.***



# Design by trial-and-error

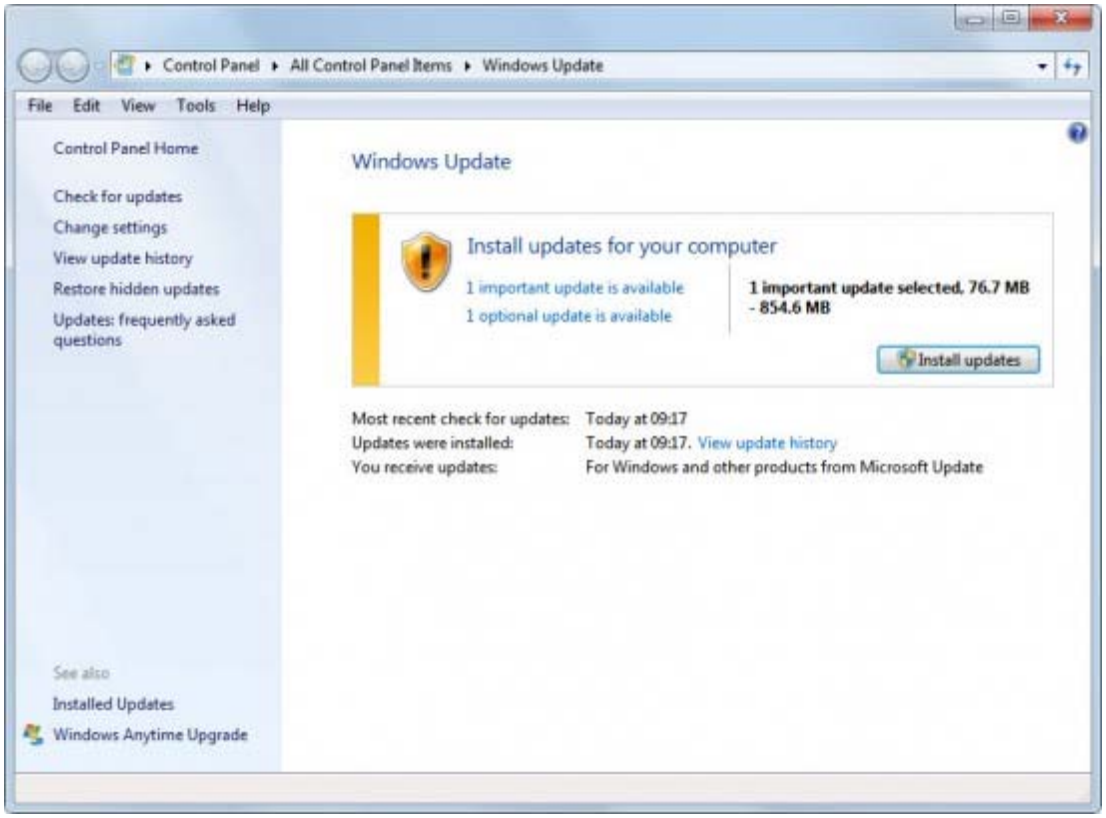
- Drugs (medical):
  - Theoretical candidates for “new chemical entity”: ~5000 – 10000
  - Of these, promising candidates on which lab/mice tests are run: ~250
  - Of these, ~10 qualify for tests on humans
  - Of these, ~20% make it to marketing
  - Source: http://en.wikipedia.org/wiki/Drug_development

# Design by trial-and-error

- Last but not least ...

# Design by trial-and-error

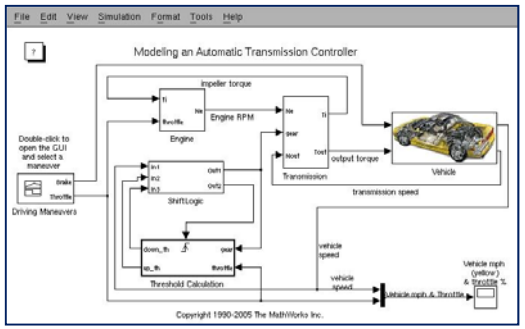
- Software!




# Approaches to system design (2)

- Rigorous, ***"model-based"*** design:
  - Build model ("executable specification") of system
    - before building the system itself
  - Analyze the model, find errors
  - Fix errors in the design (model)
  - Repeat until the design seems OK
  - Give models/specs to someone (or to a computer) to implement them
- Better for affordability:
  - Catch design errors early => easier / less costly to fix
- Better for dependability:
  - Sometimes can formally prove that design is correct
- Gaining acceptance in the industry

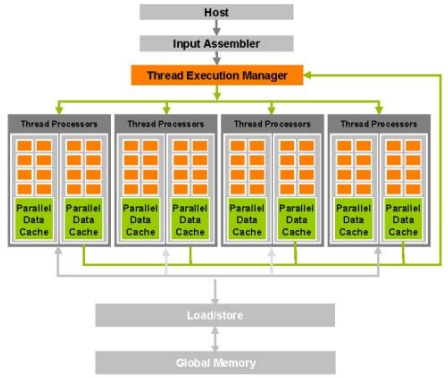
# The Elements of Model-Based Design




How to describe what we want?

Modeling

How to be sure that this is what we want?




Analysis

Implementation, Optimization

How to build it?
Automatically
Correct-by-construction

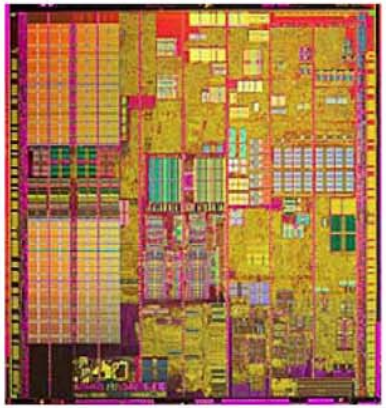
# From standard compilers ...

```
class HelloWorldApp {
  public static void
  main(String[] args) {
    System.out.println(
      "Hello World!");
  }
}
```

source code
(C, Java, …)

compiler

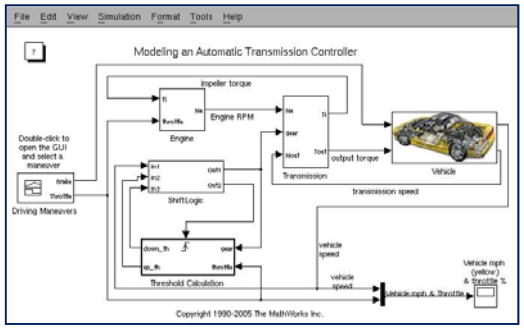
type checking, debugging, static analysis, …



machine code

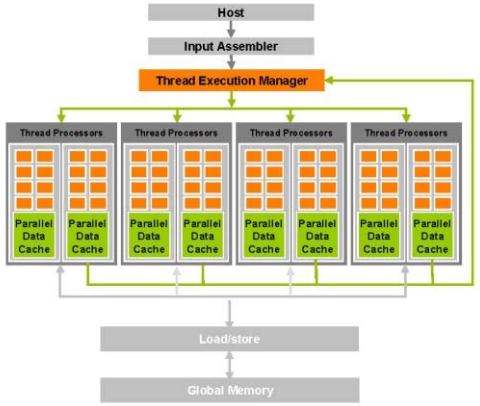
# … to system compilers

Vision: *modeling/simulation languages of today will become the **system-programming** languages of tomorrow*




Rich languages:
concurrency, time,
robustness, reliability,
energy, security, …

**system compiler**




Complex
execution platforms:
networked, distributed,
multicore, …

Powerful analyses:
model-checking, WCET analysis, schedulability,
performance analysis, reliability analysis, …

# Note

In real life, we need both MBD and trial-and-error methods.

Why?

1. We cannot trust our models 100%
2. All models are abstractions of reality. They make assumptions that need not hold.
   - E.g., road condition, weather condition, …
3. Analysis and optimization methods also have their limitations.
   - As we will see in this course.

# Model-based design is fine, but …

- There are many systems, of different kinds
- People have been designing these for decades
- Can we pretend to find a single design method that works for every kind of system?
- Of course not

# The thesis

Design is a SCIENCE:

- No matter what the application is, there are common features
- Foundational work in mathematical modeling, algorithms, methodologies

To demonstrate the value of design SCIENCE, apply the foundational work to a variety of areas from electronics, to automotive, to avionics, to intelligent buildings, to biological systems

**Raphael, The Athens School**

# Example of a successful model-based design flow

- RTL synthesis flow