Developing Software Rigorously: Introduction and Motivation[1]

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[1] Many slides borrowed from J. R. Abrial and M. Butler

Take notes

TECHNOLOGY

To Remember a Lecture Better, Take Notes by Hand

Students do worse on quizzes when they use keyboards in class.

Renato Ganoza

Picture & headline © *The Atlantic*

https://www.theatlantic.com/technology/archive/2014/05/to-remember-a-lecture-better-take-notes-by-hand/361478/

I will make notes / slides available *after* the lectures
I will ask you to work during the lectures

Plan

- Three-hour lectures: three 50-minute sections with ten-minute breaks.
  - Worked well in previous years.
- Course: two parts.
- Homework + term project with presentation.
- Final exam for those who **choose not** to do HW + project.
- Hands-on.

Purpose of the course

- To give you some insights about modelling and formal reasoning
- To show that programs can be *correct by construction*
- To show that modelling can be made practical
- To illustrate this approach with many examples

What you will learn

By the end of the course you should be comfortable with:

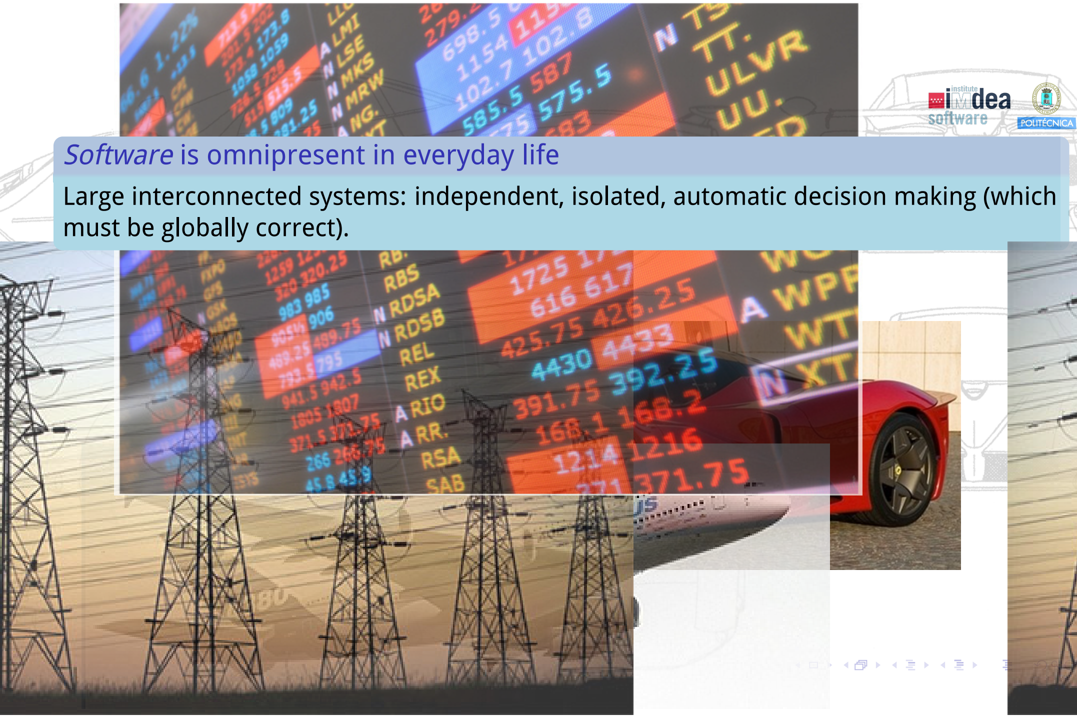
- Modelling (versus programming)
- Abstraction and refinement
- Some mathematical techniques used to reason about programs
- The practice of proving as a means to construct (provably) correct programs
- The usage of some tools to help in the above

Software is omnipresent in everyday life

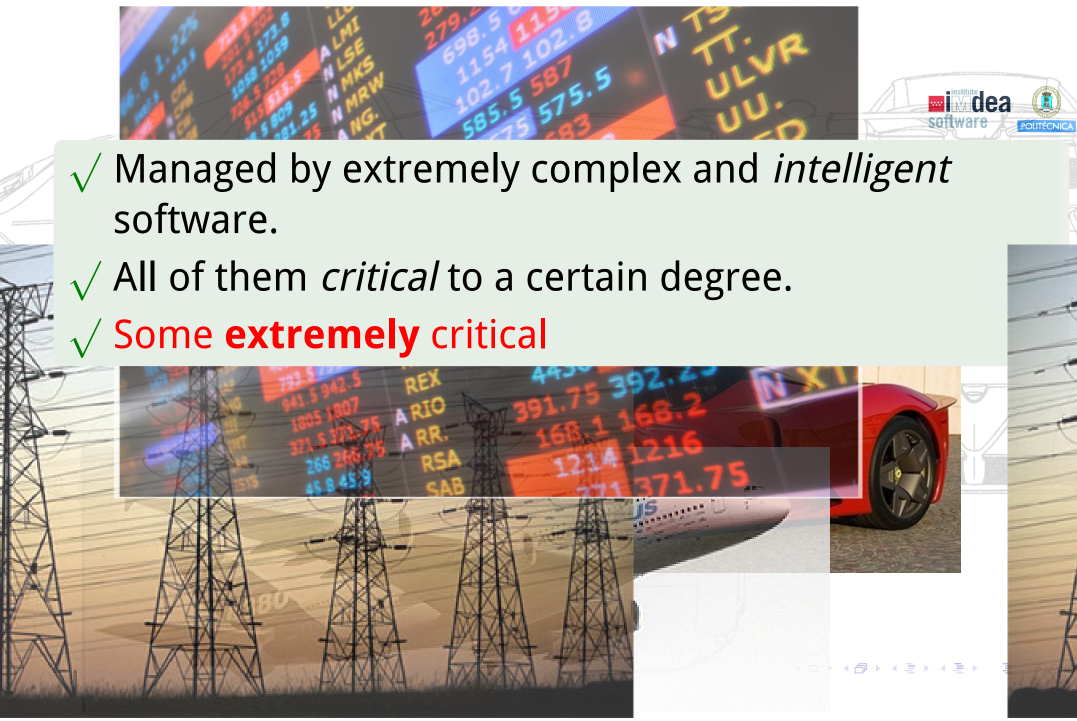
Today's car: typically 100+ microprocessors, 100 M. lines of code, 20.000 programmer years.

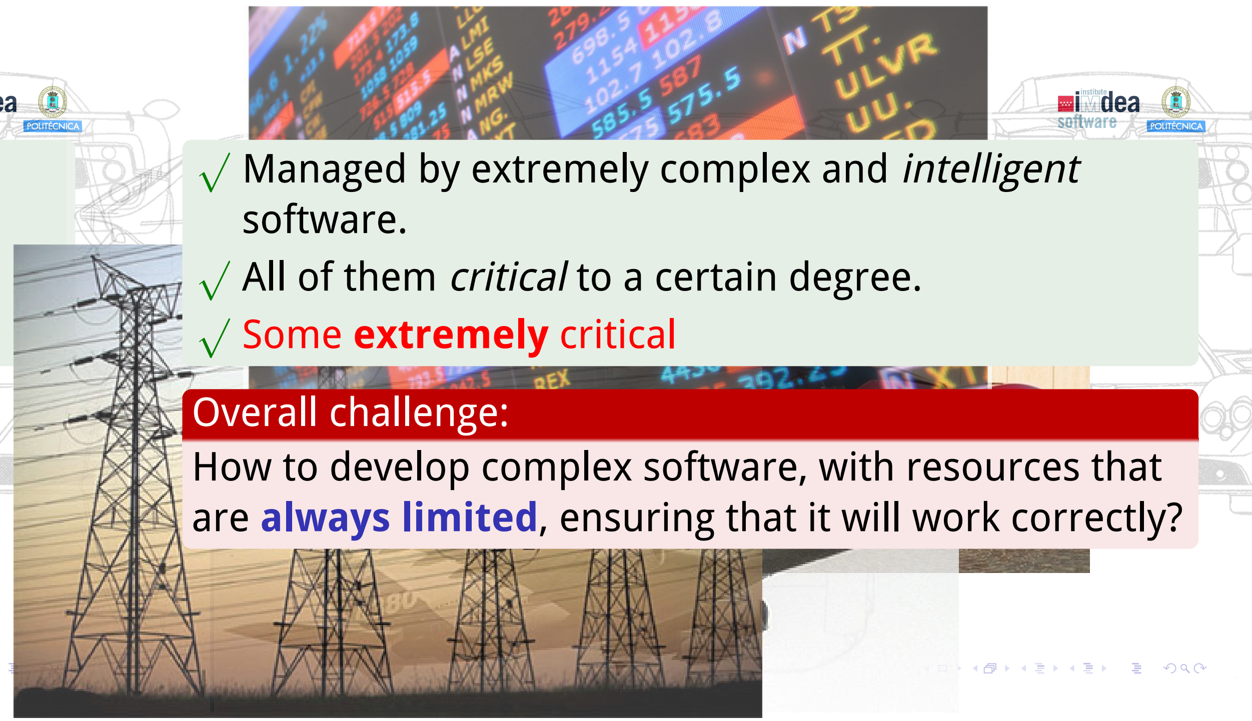
Software is omnipresent in everyday life

Plane: computers manage controls, calculate routes, ...


Software is omnipresent in everyday life
Large interconnected systems: independent, isolated, automatic decision making (which must be globally correct).


Software is omnipresent in everyday life
Cell phones (from O.S. to compression algorithms to user interfaces).
HDTV (routing, encoding and decoding), Netflix, ...
Buying and selling on the Internet (web interfaces, databases, encryption).
Stock market (algorithmic trading, high frequency trading).
Skype, Whatsapp, AirBnB, idealista, GroupOn, FB, Steam, Spotify, E-Banking, Google Maps / Waze, Uber / Lyft, ...


√ Managed by extremely complex and *intelligent* software.
√ All of them *critical* to a certain degree.
√ Some **extremely** critical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Overall challenge:
How to develop complex software, with resources that are **always limited**, ensuring that it will work correctly?

Growth in complexity and expectations

- Processes managed by computing systems increasingly complex.
- Same software is to run in several platforms.
- Computing systems interact more and more with other systems.
- They should stay autonomous for longer.
- They become reactive.

Then and now

Yesterday	Today	Tomorrow
It's nice that I can see my account through my web browser!		

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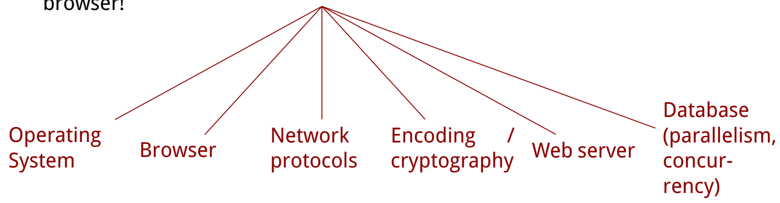

Then and now

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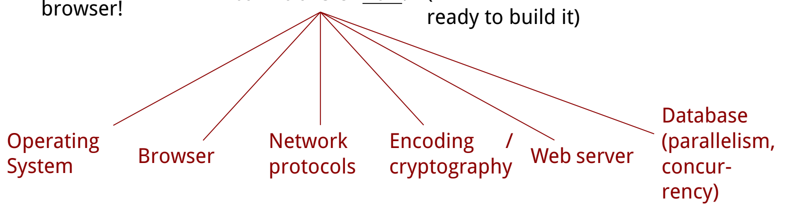
Tomorrow

?

(but we need to be ready to build it)



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(Only showing some types of problems)

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July 16, 2012: Skype bug sends messages to unintended recipients.

July 13, 2012: Apple's "in-app purchase" service for iOS bypassed by Russian hacker.

July 13, 2012: German security experts find major flaw in credit card terminals.

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July 12, 2012: Hackers expose 453,000 credentials allegedly taken from Yahoo service.

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July 7, 2012: Still infected, 300,000 PCs to lose Internet access.

July 6, 2012: Apple fixes App Store DRM error, crash-free downloads resume.

July 5, 2012: "Find and Call" app becomes first trojan to appear on iOS App Store.

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Just two weeks

The Ariane 5 incident

Example: effect of a *single* overflow

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- June 4, 1996: After launch, the Ariane 5 rocket exploded.
- This was its maiden voyage.
- It flew for about 37 Sec only in Kourou's sky.
- No injury in the disaster.

The story

- Normal behavior of the launcher for 36 Sec after lift-off
- Failure of both Inertial Reference Systems almost simultaneously
- Strong pivoting of the nozzles of the boosters and Vulcan engine
- Self-destruction at an altitude of 4000 m (1000 m from the pad)

More details

- Both inertial computers failed because of overflow on one variable
- This caused a software exception that stopped these computers
- These computers sent post-mortem info through the bus
- Normally, main computer receives velocity info through the bus
- The main computer was confused and pivoted the nozzles

More details

- The faulty program was working correctly on Ariane 4
- The faulty program was not tested for A5 (since it worked for A4)
- But the velocity of Ariane 5 was far greater than that of Ariane 4
- That caused the overflow in one variable
- The faulty program happened to be useless for Ariane 5

Messages

- Clear, up to date, realistic requirements
- Relationship requirements / programs
- Proof that programs were built according to requirements

Note: we will not deal with requirement engineering, *which is related and very interesting in itself.*

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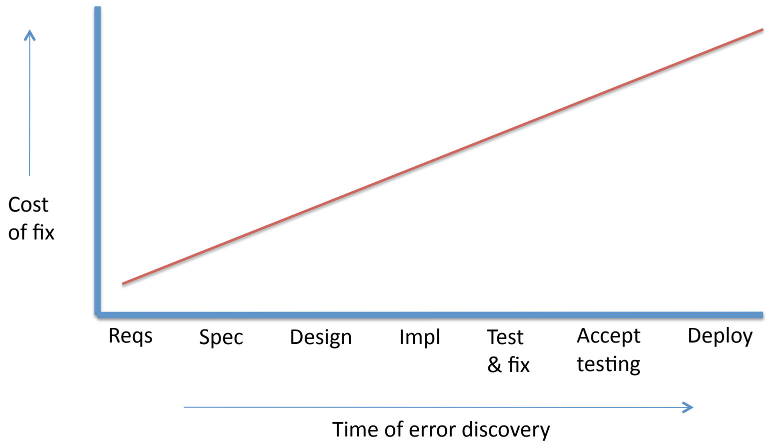
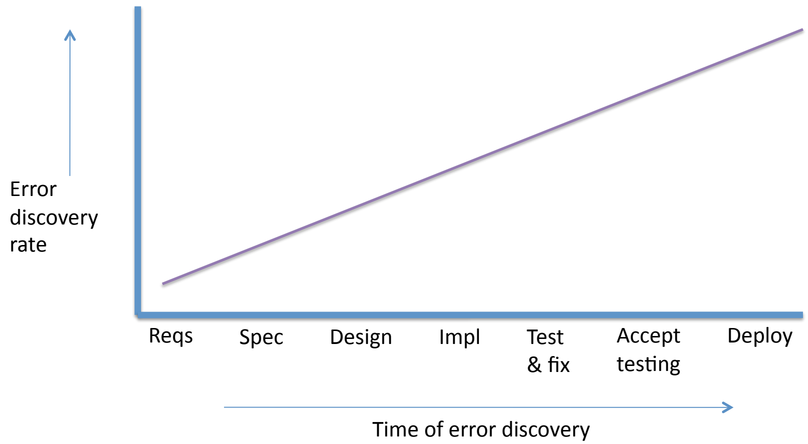
. . . in a way that is (a) dependable and (b) cost-effective?

Cost of error fixes

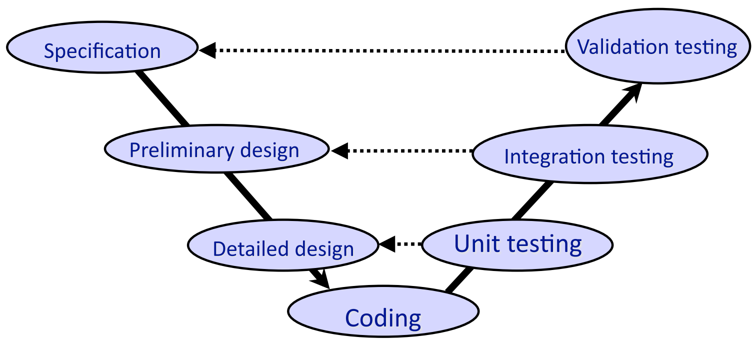


Rate of error discovery



The V model

When are errors discovered in the V Model?



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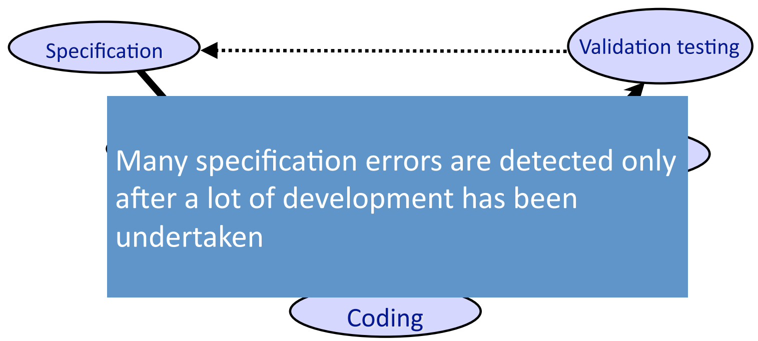

Some sources of errors

- Lack of precision
  - Ambiguities
  - Inconsistencies
- Too much complexity
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Some preventive measures

- Early stage analysis
  - Precise descriptions of intent
  - Amenable to analysis by tools
  - Identify and fix ambiguities and inconsistencies as early as possible
- Mastering complexity
  - Encourage abstraction
  - Focus on what a system does
  - Early focus on key / critical features
  - Incremental analysis and design

Formal methods

- Rigorous techniques for formulation and analysis of systems
- They facilitate:
  - Clear specifications (contract)
  - Rigorous validation and verification

If we do not capture precisely what a system ought to do, there is little chance that we may really decide whether it fits the bill

Validation: does the contract specify the right system?

- Answered informally

Verification: does the finished product satisfy the contract?

- Can be answered formally

Specifications and the real world?

How can specifications be used?

- Use a specification to build tests
- Use a specification to check that a program computes what it should (verification, model checking)
- Use a specification to compute (functional / logic / equational programming)
- Use specifications to drive the generation of a program (correctness by construction, automatic code generation)

How can guarantees be given?

- Enlightened management: of little help.
- Convincing arguments beyond any reasonable doubt:
  - Formal basis.
  - Proofs based on rigorous methods.
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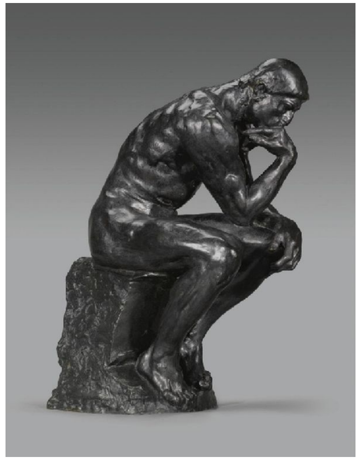
- Carefully prove that programs will behave as expected.
- For **every** single program?



It's too difficult for humans to do!

- Methodologies
- Mechanization
- Automation
- Computer-aided software development
  - Correctness by construction
  - Automatic analysis
  - Verification (model checking, deductive verification)
  - Automated testing

A basic property: termination

- Termination is often expected.
- How easy is it to decide whether a program terminates?

```
input n;

while n > 1 do
    if n mod 2 = 0 then
        n:= n / 2
    else
        n:= 3*n + 1
    end if
end while
```

Question: will it finish for any input value `n`?

A specification example

```
procedure whatAmI(A: Array)
   repeat
     swapped := false
     for i := 1 to length(A) - 1 do
       if A[i-1] > A[i] then
         swap(A[i-1], A[i])
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- Can we use specifications to derive a correct sorting program?

Jean-Raymond Abrial.
Faultless systems: Yes we can!
IEEE Computer, 42(9):30–36, 2009.

Jean-Raymond Abrial.
Modeling in Event-B - System and Software Engineering.
Cambridge University Press, 2010.