Rigorous Development: An Introduction [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.

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

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 for reasoning on 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.

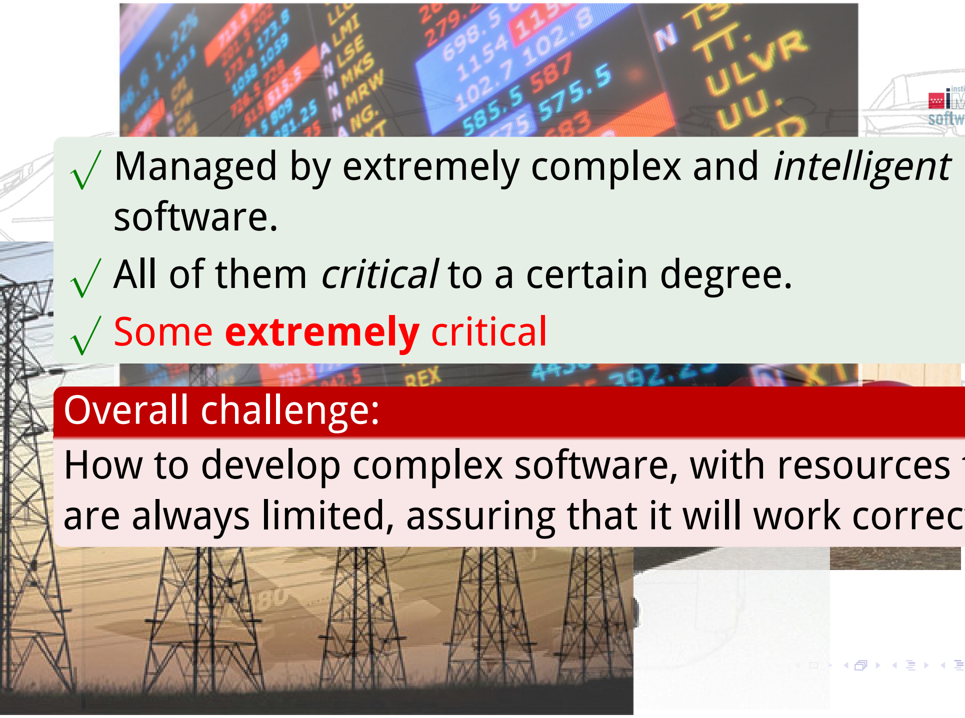
Software is omnipresent in everyday life

- Cell phones (from O.S. to compression algorithms to user interfaces).
- HDTV (routing, encoding and decoding)... Netflix!
- Buy and sell 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, assuring that it will work correctly?

Growth in Complexity and Expectations

- Processes managed by computing systems increasingly complex.
- Same software is to run in more platforms.
- Computing systems to 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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- Browser
- Network protocols
- Encoding / cryptography
- Web server
- Database (parallelism, concurrency)

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(but we need to be ready to build it)

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(Only showing some types of problems)

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iOS, Mac app crashes linked to botched FairPlay DRM.

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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.

July 12, 2012: Mountain Lion (Mac OS X version) sends some 64-bit Macs to sleep (related to graphics drivers).

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.

July 5, 2012: iOS, Mac app crashes linked to botched FairPlay DRM.

Just two weeks

The Ariane 5 Incident

Example: effect of a *single* integer 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 is 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 was built according to requirements

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

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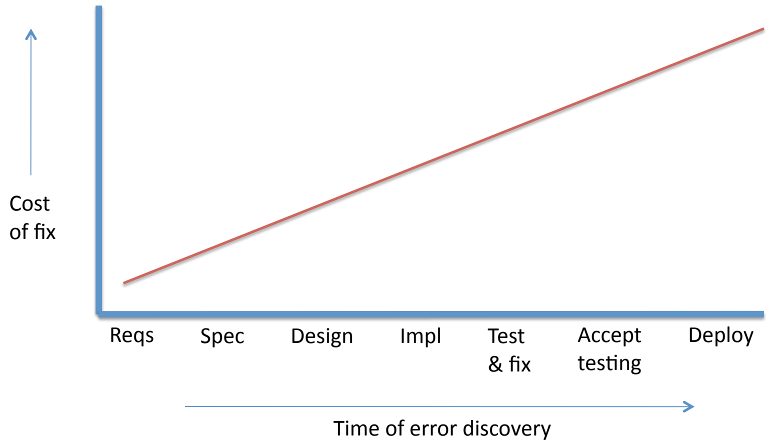
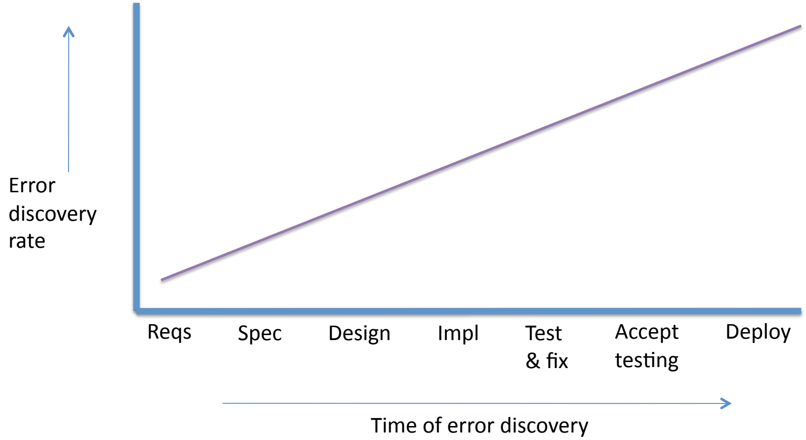
...in a way that is (a) dependable and (b) cost-effective?

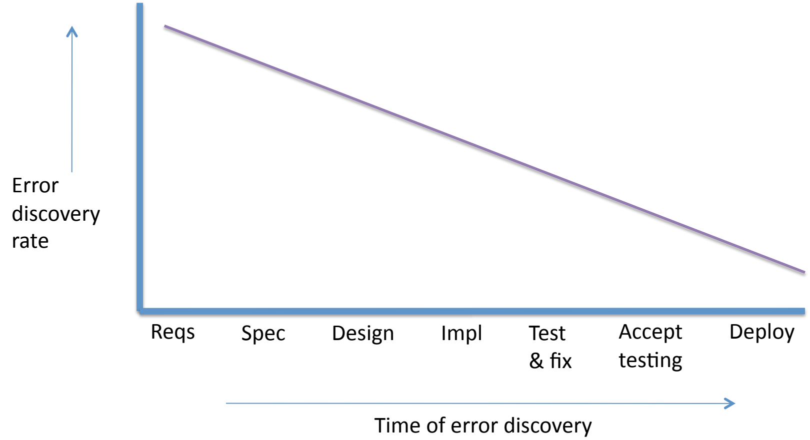
Cost of error fixes



Rate of error discovery

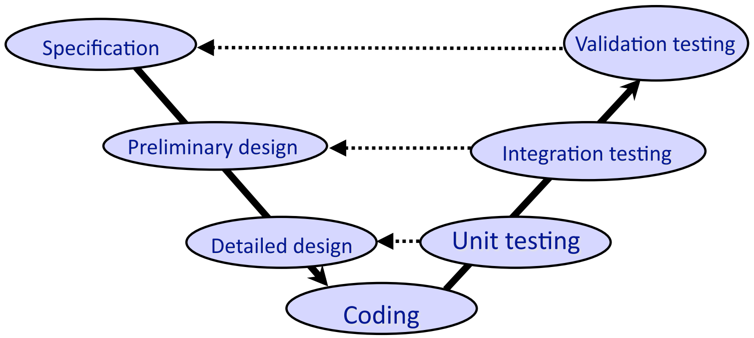


Reverse error identification rate!



The V model

When are errors discovered in the V Model?



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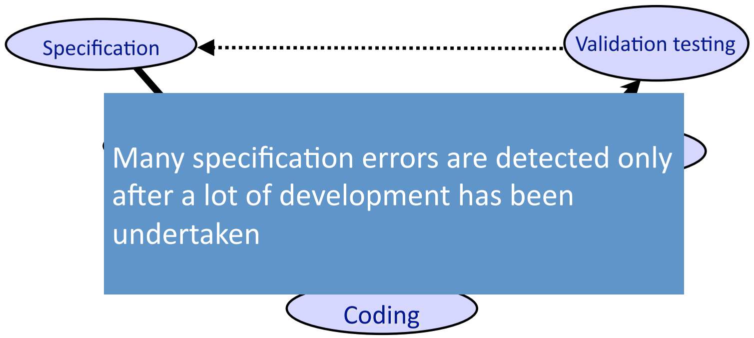

Many specification errors are detected only after a lot of development has been undertaken

Some sources of errors

- Lack of precision
  - Ambiguities
  - Inconsistencies
- Too much complexity
  - Complexity of requirements
  - Complexity of operating environment
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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

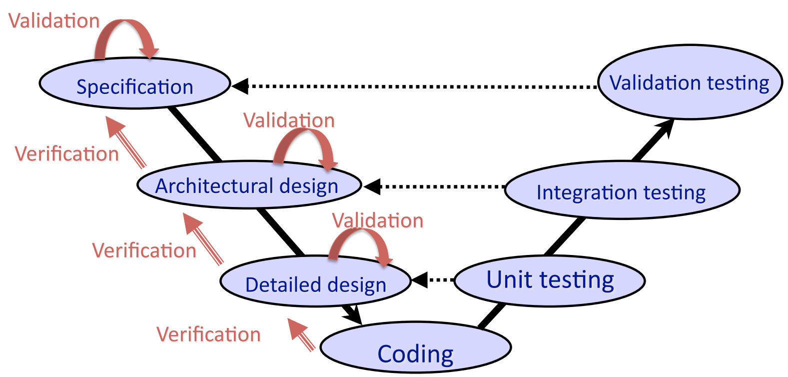
Validation: does the contract specify the right system?

- Answered informally

Verification: does the finished product satisfy the contract?

- Can be answered formally

Early stage analysis



Specifications and Programs

How can we relate specifications and computations?

- 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 generate the program (automatic code generation, correctness by construction)

How Can Guarantees be Given?

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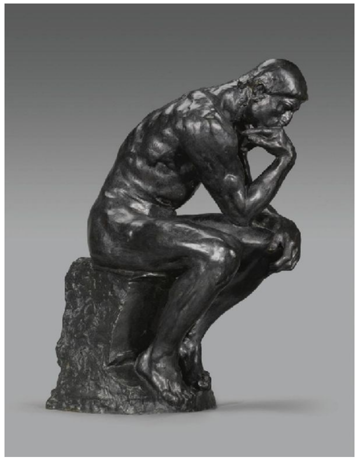
- Carefully prove that programs will behave as expected.
- For **every** single program?



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 Termination Problem: Collatz's Conjecture

This is just a humbling example. Not terribly useful by itself, but illustrative.

```
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?
Note: termination is often a basic property!

A Specification Example

```
procedure whoAmI(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])
         swapped := true
       end if
     end for
   until not swapped
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- What does this program do?

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- What does this program do?
- Can you specify the property that characterizes a sorted array?
- Can we prove that, after executing the code above, array A meets that property?

- 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.