Rigorous Software Development
An introduction

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Outline

1. Context and Motivations

2. Formal Software Engineering and Software Verification

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An appetizer

Software and cathedrals are much the same. First we build them, then we pray.
Sam Redwine, at the 4th International Software Process Workshop - 1988

The Formal Methods Approach:

Aide toi, et le ciel t'aidera!
Jean de La Fontaine - Le chartier embourbé. Livre VI - Fable 18.

... That is what this short introduction is about.

Main reference for this lecture

Rigorous Software Development, A Practical Introduction to Program Verification
Series: Undergraduate Topics in Computer Science.
Almeida, J.B., Frade, M.J., Pinto, J.S., Melo de Sousa, S.,
Springer Verlag, 1st Edition., 2011, XIII, 307 p. 52 illus.
Softcover, ISBN 978-0-85729-017-5

Our Focus

Reliability as Fault Avoidance and not Fault Tolerance

Introduction to the methods and tools that provide means to design Information and Computer Systems (ICS) that are functionally and logically correct.

modern ICS = new challenges

$\left\{\begin{array}{l}\textbf{reliability}\\ \textbf{correctness}\\ \textbf{security}\\ \textbf{safety}\\ \textbf{robustness}\\ \textbf{etc...}\end{array}\right.$ as a central challenge to the design of modern ICS.

- was and still is a central issue in the design of safety critical systems.
- The *reliability* quest lies at the foundations of Computer Science. Establishing its rigorous and complete foundations is a debate as old as Computer Science itself, indeed older ... (but Computer Science is a very young discipline).

facts from classical software engineering

Dysfunctions are expensive

- ICS maintenance $= \frac{2}{3}$ of total costs;
- Dealing with dysfunctions or bugs $=$ 20 times more expensive after than before production.
- Apart from these software life cycle considerations, it is well known that bugs can have deep impact in the customers' trust (e.g Pentium bug) or financial losses (IBM vs FAA), letting aside human life losses (e.g. Therac 25) or ICS where bugs are simply unacceptable.

more facts...

About 16 years ago, W. Gibbs said:

Despite 50 years of progress, the software industry remains years – perhaps decades – short of the mature engineering discipline required to meet the needs of an information-age society.

in: Trends in Computing: Software's Chronic Crisis - Scientific American - 1994.

Past? Provocation?

Unfortunately no. See for instance the usual *software equation*:

Software in the market = bug report channel

Solution?

Unfortunately,

There is no definite solution!

Nevertheless, there are satisfactory solutions:

Reshape and Adapt the software life cycle in order to include **reliability** as a central requirement.

$\Downarrow$

Common Criteria (EAL 5-7), Cenelec / IEC 61508 (Safety Integrity Level 3 and 4), DO-178B (Design Assurance Level A and B).

(rel)ease

Solution?

Unfortunately,

There is no definite solution!

Nevertheless, there are satisfactory solutions:

integration and use of:

- Tests and Simulation
- Formal Methods

Tests and Simulation

Main Principle

For a given **model** of the target ICS, **provide** a set of input data that are **representative** and **compare** the output answer with the expected result.

But, good tests are rare:

exhaustiveness: in the general case, impossible (the set of possible values is possibly infinite)

representativeness: in the general case, problems occur when unexpected values are given as input.

Tests and Simulation

An illustrative example (From J. Harrison Lectures):

Littlewood proved, in 1914 a surprising result: the function

$$\pi(n) - li(n)$$

where

$$li(n) = \int_0^n \frac{du}{ln(u)} \quad \text{and} \quad \pi(n) = \text{number of primes} \leq n$$

changes its sign infinitely. Surprising? yes, because despite intensive (manual) tests (up to 10^{10}, before the computer era), no sign changes were detected until this proof.

A general definition

The term Formal Methods (FM) refers to the use of mathematical modelling, calculation and prediction in the specification, design, analysis and assurance of computer systems and software. The reason it is called formal methods rather than mathematical modelling of software is to highlight the character of the mathematics involved.

J. Rushby, Formal Methods and their Role in the Certification of Critical Systems - SRI - 1995.

The use of formal methods for software and hardware design is motivated by the expectation that, as in other engineering disciplines, performing appropriate mathematical analyses can contribute to the reliability and robustness of a design.

from wikipedia.

In a broad sense, FM is intended to be for ICS engineering what physics is already for aerospace engineering.

Formal Methods

Some properties

exhaustiveness: **Formal** reasoning over the **possibly infinite** set of values.

rigour: well established mathematical foundations

adequacy: provided tools and techniques are evaluated as adequate means for providing **evidences of reliability** (see for instance the ISO standard Common Criteria for the security of ICS)

Some considerations

Tests vs. FM

- (Edsger W. Dijkstra):

  > *Program testing can be a very effective way to show the presence of bugs, but is hopelessly inadequate for showing their absence.*

- But, Formal Methods only prove what can be (indeed, what is) carefully stated (D. Knuth):

  > *Beware of bugs in the above code; I have only proved it correct, not tried it.*

- Thus, (D. Syme & A. Gordon):

  > *if you specify you must test.*

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The main issue

Formal Methods intend to provide means to:

ensure that a given ICS has a given (adequate) behaviour

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Central notion of $\left\{ \begin{array}{l} - \textbf{model} \\ - \textbf{specification} \end{array} \right.$ to bring the object under study to mathematics (logic, algebra, etc...).

The main issue

Formal Methods intend to provide means to:

ensure that a given ICS has a given (adequate) behaviour

In practice: this central issue is divided into two sub-problems

evidences of behaviour: How to ensure/verify the expected behaviour at the specification level.

model against code:

1. How to obtain, from a well behaved model, a program with the same behaviour?
2. or, provided code and specification, how to ensure that both share the same behaviour/properties?

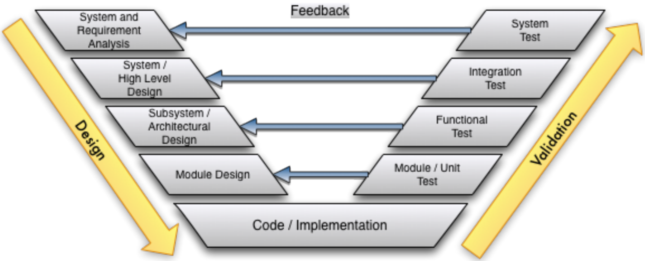
Classical vs. Formal Software Engineering

Software Life Cycle: The classics...

- Waterfall (Boehm, 1977)
- V, Spiral, etc...

Semi-formal Methods:

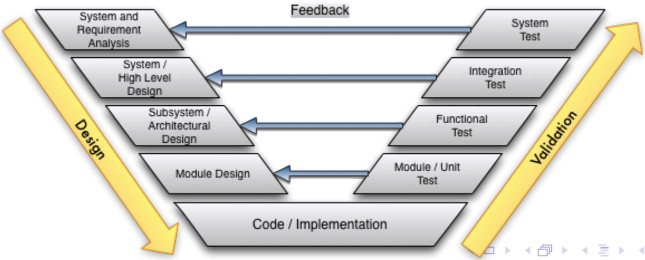
- SA, SADT, SSADM, MERISE, UML, etc...
- Deep System Analysis, but do not provide strong evidence w.r.t. reliability requirements
- Nevertheless, positive contributions.



Classical vs. Formal Software Engineering

Development Process and Requirements

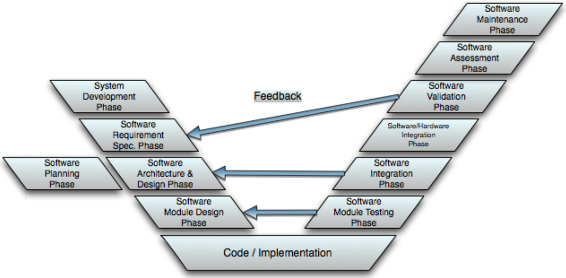
- Design:
  Each step: a more finely grained look at the system than the previous step.
  Requirements of the previous step must be refined. The new requirements should reflect the upper stage requirements.
  Each stage: should produce reports/outputs that form the basis of the next stage and of corresponding validation step.
- Validation:
  Should give an answer (hopefully positive) to the challenges stated by the related design stage reports.
  Essentially based on tests and simulation in a controlled environment



Classical vs. Formal Software Engineering

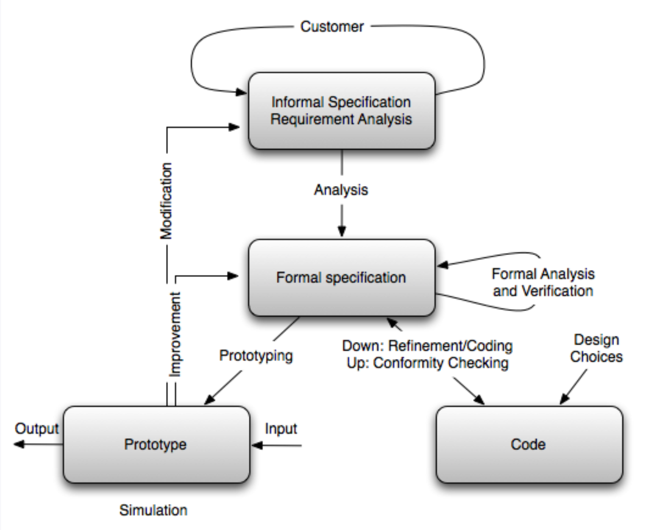
Development Process and Requirements

- Several (safety/reliability/security based) software standard **highly recommend** the use of mathematically based tools and methodologies to ensure the absence of determined errors: DO-178B, EN 50128 (see figure), GalileoSW, IEC 61508.
- The ISO/IEC-15408 Common Criteria (for the security of IT) indeed **requires** the use of such tools for the highest certifications.



Formal Software Development in a picture

Balzer Software Life cycle



Formal Software Development vs Formal Modeling

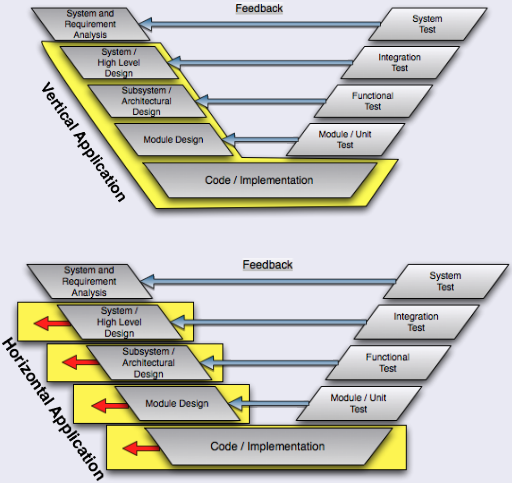
At this point we should stress that one can roughly divide the formal methods tools into two main families:

1. System Validation/Verification Tools: Horizontal application of the Balzer Life Cycle
2. Correct by Construction approach: Downward application of the Balzer Life Cycle

The former clearly provide means to address only the first sub-problem (with very specialized techniques and tools), while the second intend cover the whole issue.

Formal Software Development in a picture

Applied Balzer Software Life cycle



Pragmatical considerations on the application of FM

Are the FM tools ready to be used by the ICS industry?

- Tools maturity and usability: from my own experience, there is a real (and constant) improvement
- Does a software company need to have FM experts in order to use FM? yes, at least one.
- Does the FM expert need to have a PhD in order to successfully apply FM? No (personal experience).
- FM tools still have problems to cope with modularity and scalability (size, etc...)...
- But, Formal Verification "tours de force" (e.g. works from Leroy, Barthe, Klein, Cousot, Nipkow, ...) are increasingly frequent...

1000000 of Verified lines of code: You can't say any more it can't be done! Here, we've done it! (Jim Woodcok - Formal Verification of Software)

Pragmatical considerations on the application of FM

Is the ICS industry ready to use FM ?

- First. ICS industry should realize that FM are not a product (as anti-viruses).
- (This is in fact happening (or already the case) in several ICS key area)
- But ICS industry already has ICS development process and does not want to lose it.
- Thus, adopting FM *implies* reshape and adapt the in-house ICS design "savoir-faire".
- $\Longrightarrow$ FM tools should take the Balzer life-cycle into consideration

- ICS standards about security and reliability *recommend* nowadays the use of FM for the highest levels of certification.
- Shift paradigm: next versions of these standard (that really rule Critical system industry) are willing to require the use of FM.
- notable exception : Common Criteria, that already *requires*.
- lack of specialists, IVV is a emerging market.

Pragmatical considerations on the application of FM

What is to be formally specified and verified?

- Formal Specification and Verification are far from easy (and are not cheap, but the real cost has to be considered in the long term)
- General practice: determine the critical parts of the ICS to be verified. Apply FM on these parts