The Logic Road to Software Homologation

II UB International PhD in Law Conference

Joost J. Joosten et al.

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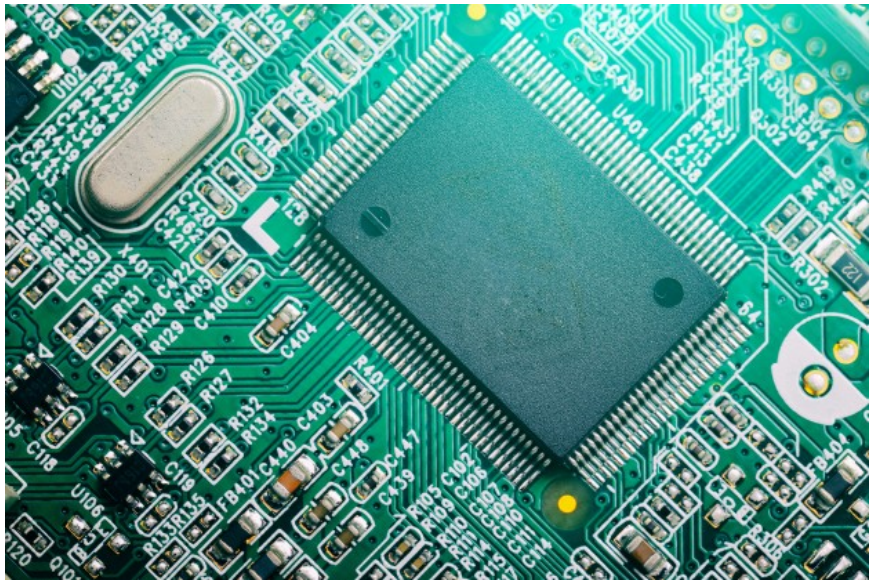
The Formal Verification Team:
The team is constituted in the University of Barcelona, and works conjointly with Formal Vindications S.L.
Júlia Pla Bauçà, Guillem Muñoz Mayoral, Gina Garcia Tarrach, Eric Sancho Adamson and Aleix Solé Sánchez have contributed to the making of these slides.

Project funded by the "Ministry of Science, Innovation and Universities", the "State Agency for Research" and the "European Regional Development Fund" (ERDF)

We become more and more dependent on automatised/digitalised processes. For example:

1. Electronic devices used in hospitals,
2. bureaucracy: institutions and companies,
3. the Paris metro system,
4. finance and the stock market,
5. access to press items about world events,
6. natural catastrophe prediction,
7. scientific research: gamma-ray detectors, electronic microscopes,



- hardware bugs are rare but do occur
- 2012 AMD CPU error : about a billion dollor loss;
- 2018: intel and AMD: Meltdown and spectre: various law suits going on

- On June 4, 1996, the maiden flight of the European Ariane 5 launcher crashed about 40 seconds after takeoff

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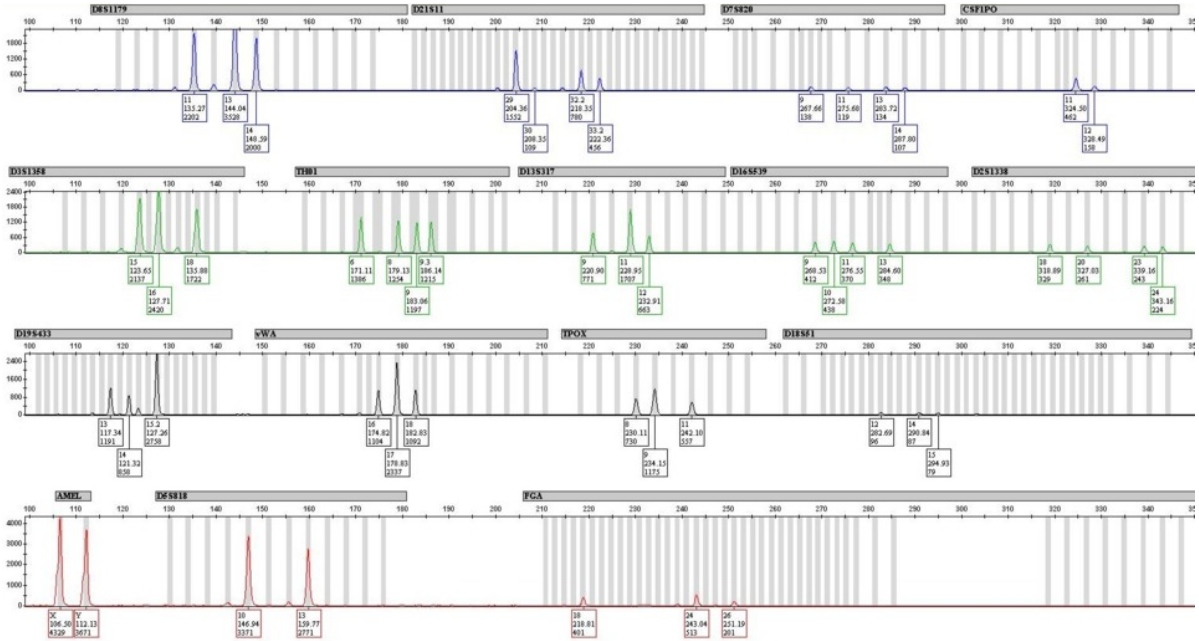
- Media reports indicated that the amount lost was half a billion dollars – uninsured
- A costly software error!

1994: A Chinook Mk2 helicopter which went into service despite a series of failures involving its safety-critical engine control system, whose failure was mortal for 29 people, suspected to be caused by the known software failure.

How was this software developed?

- Legal examples concerning unreliable software:
  - In three cases, judges from USA have petitioned to **make the software open to the public** from proprietary DNA comparing software, due to some unreliable results:



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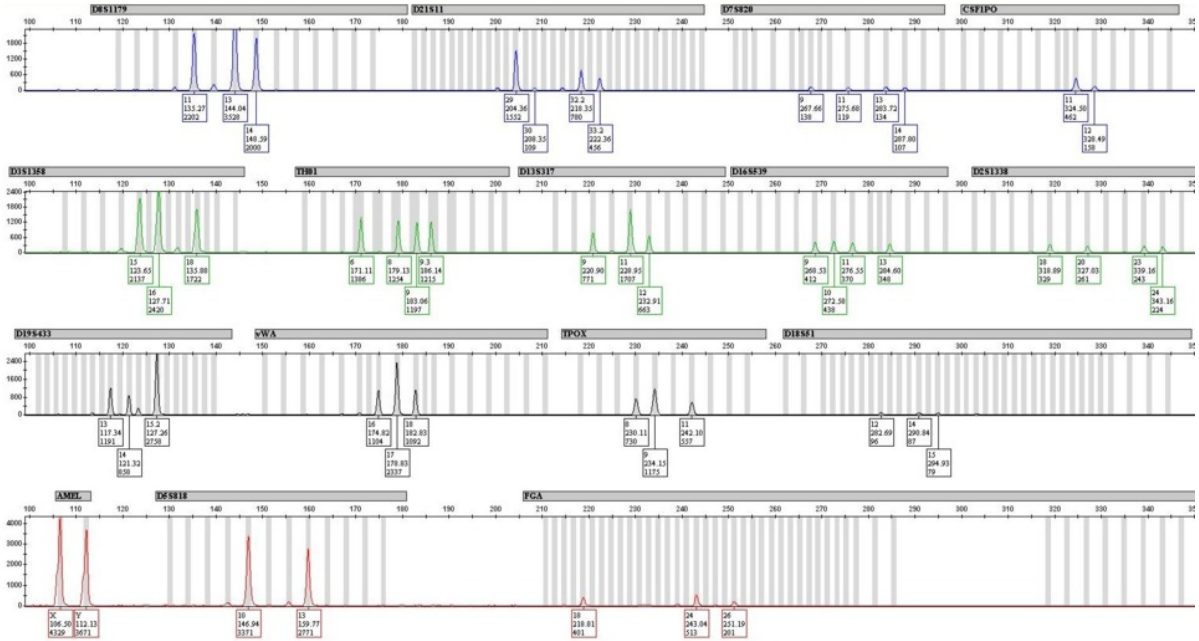

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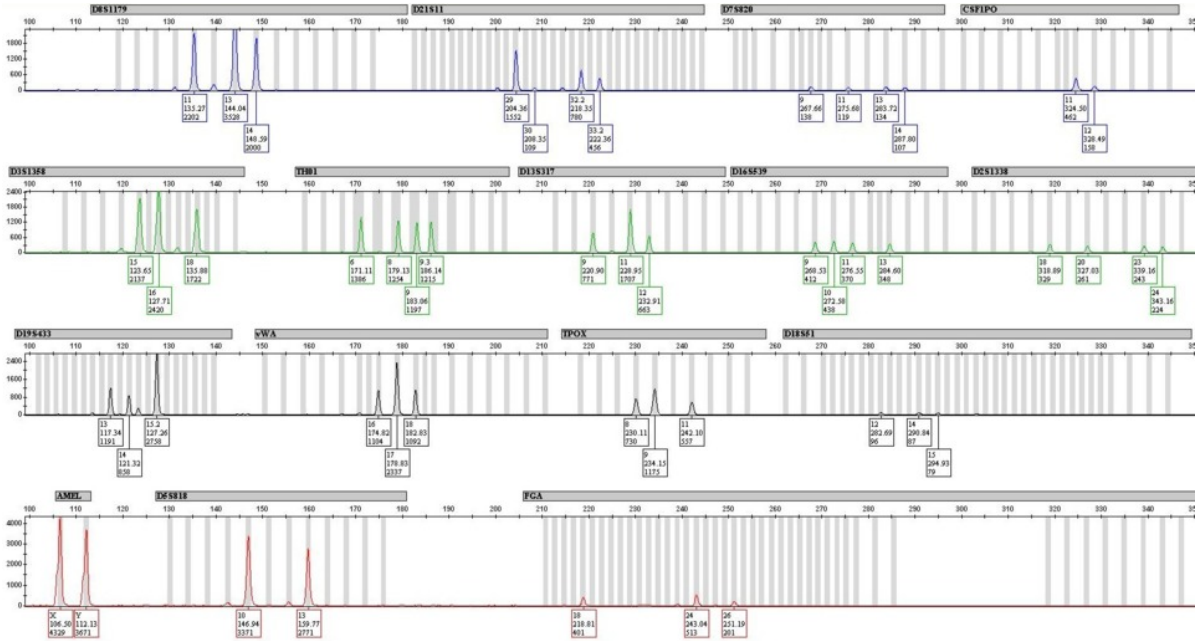

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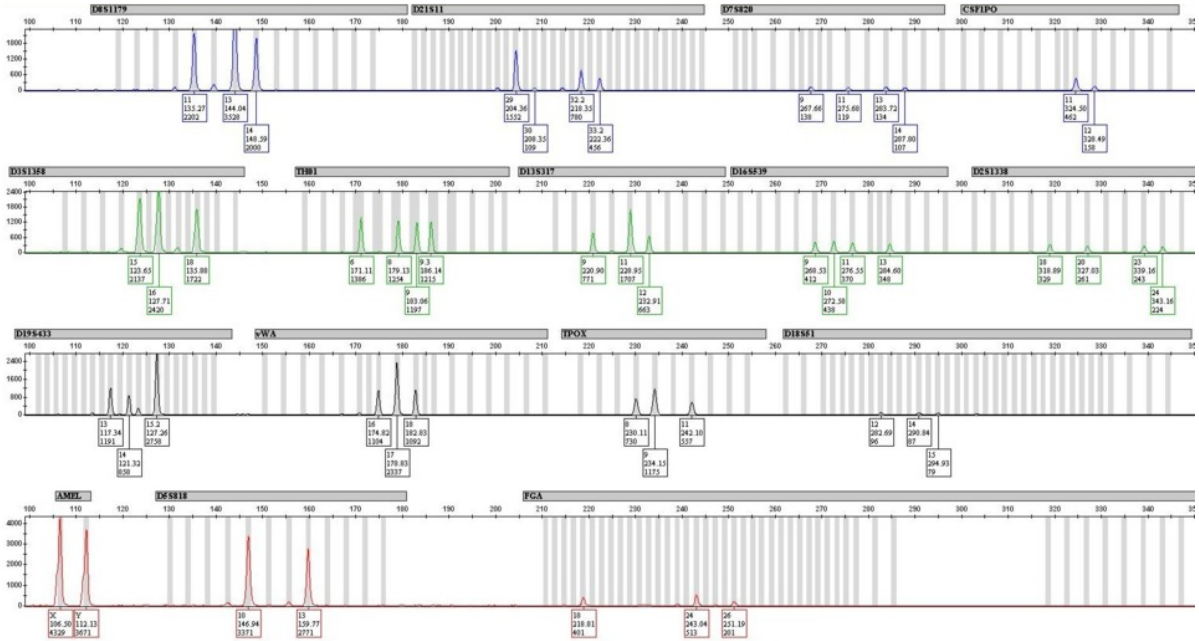
    - STRmix
    - FST
    - TrueAllele (still proprietary)



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  - In this case, in Miami, the fact that a mother had searched the word "chloroform" online **84 times** was used conclusively as evidence in an infanticide case.
  - The software had counted 84 times **instead of 1**, due to an error. **The programmer apologized**.

- In Valladolid, the court sentenced that a fine was not to be issued in virtue of the software involved **is not homologated**.

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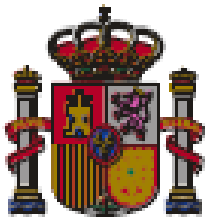
- N. Sentence: 30/2019, CONTENCIOSO/ADMTVO court. N. 4 of Valladolid (Spain)



infracción imputada y sancionada en cuanto que no se han incumplido los tiempos de descanso semanales.

En segundo lugar considera que los hechos denunciados no están suficientemente probados a efectos de poderlos considerar constitutivos de la infracción sancionada. En este apartado señala que el tacógrafo del que se han obtenido datos tiene una programación o configuración de fábrica que adolece de errores y que hace que sus resultados no sean fiables ni ciertos. No se trata de una avería o de un mal funcionamiento sino de errores de fabricación, configuración y/o programación llamando la atención sobre la falta de homologación del tacógrafo y, especialmente, del software utilizado dentro del mismo. A lo anterior añade que no consta, y por lo tanto falta, la homologación del software utilizado por las autoridades para obtener y procesar los datos registrados en el tacógrafo.

Se acepta lo alegado por la parte demandante en lo que se refiere a la ausencia de prueba de cargo suficiente respecto al software utilizado por la autoridad correspondiente para obtener los datos registrados en el tacógrafo por lo que, sin necesidad de analizar el resto de la fundamentación jurídica

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- To become a practicing lawyer in Spain you have 4 years of study, 2 years of specialisation (Master's degree), an exam to affiliate with the Bar, 18 month of induction period, and another exam to confirm one has received the appropriate knowledge, including the full memorization of the Spanish constitution.

- Required preparation to become a programmer: There exist 4 year bachelor's degrees, 2 year professional training courses, online courses, or even one can be self-taught.

  Anyone can become a programmer!

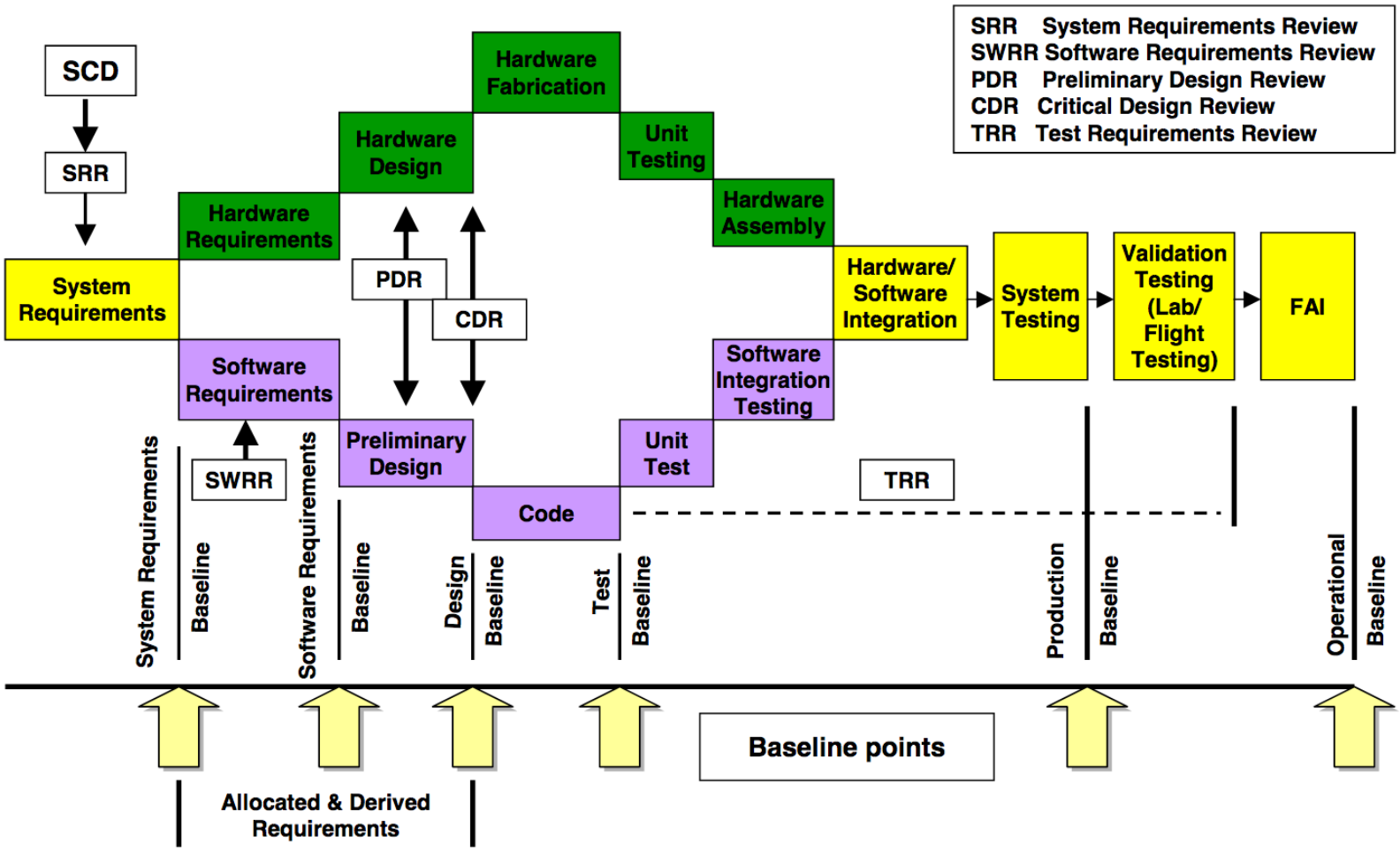
Do we need standards?

The highest standard for verification used in developing aviation software in the European Union is specified within various protocols DO-178B (ED-12B), DO-178C and DO-333. It roughly consists of:

1. Development plan,
2. (non-formal) verification plan,
3. plan for quality testing,
4. plan for configuration.

Development Process Model

(1 of 4)



Key ingredients:

- be careful;
- have lots of sanity checks;
- in many stages of the process;
- do lots of testing.

Can we do any better?

Is there no way to ***know*** that a program is correct, rather than having much circumstantial evidence?

industry	fault density Error for Kloc
Automotive	3
Aviation	1
Shuttle	0.1
Traditional	200
Agile	22

http://leanagilepartners.com/publications.html

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Is there no way to ***know*** that a program is correct, rather than having much circumstantial evidence?

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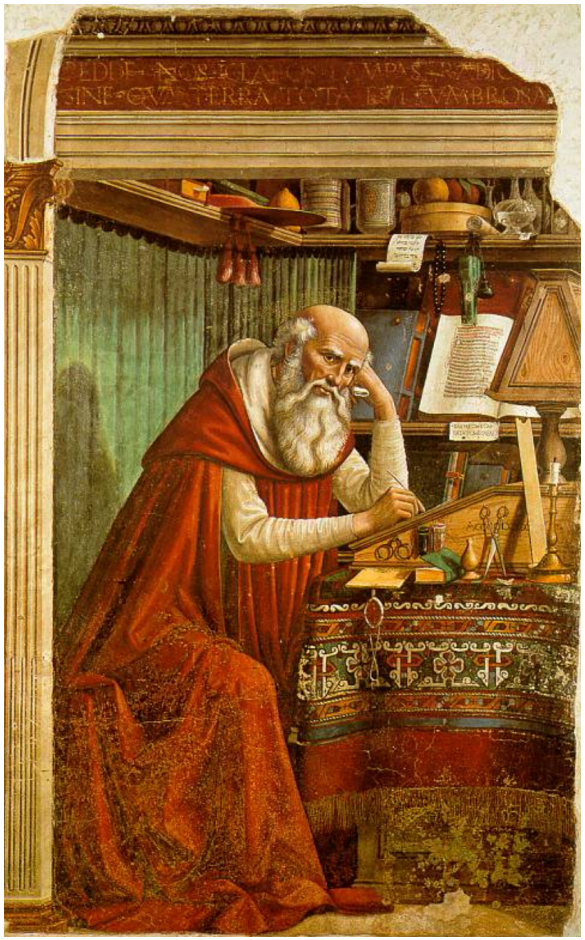
- From Gospel of John (1:1)

- "Logos" had many meanings:
- number
- esteem
- spoken word
- word as container of thought
- content of thought
- Spirit
- reason

Saint Jerome chose to use "Word" for "Logos" in his Vulgata Bible translation from the fourth century.

Stoic predominant reading: "logos spermatikos": the generative principle of the Universe which creates and takes back all things.



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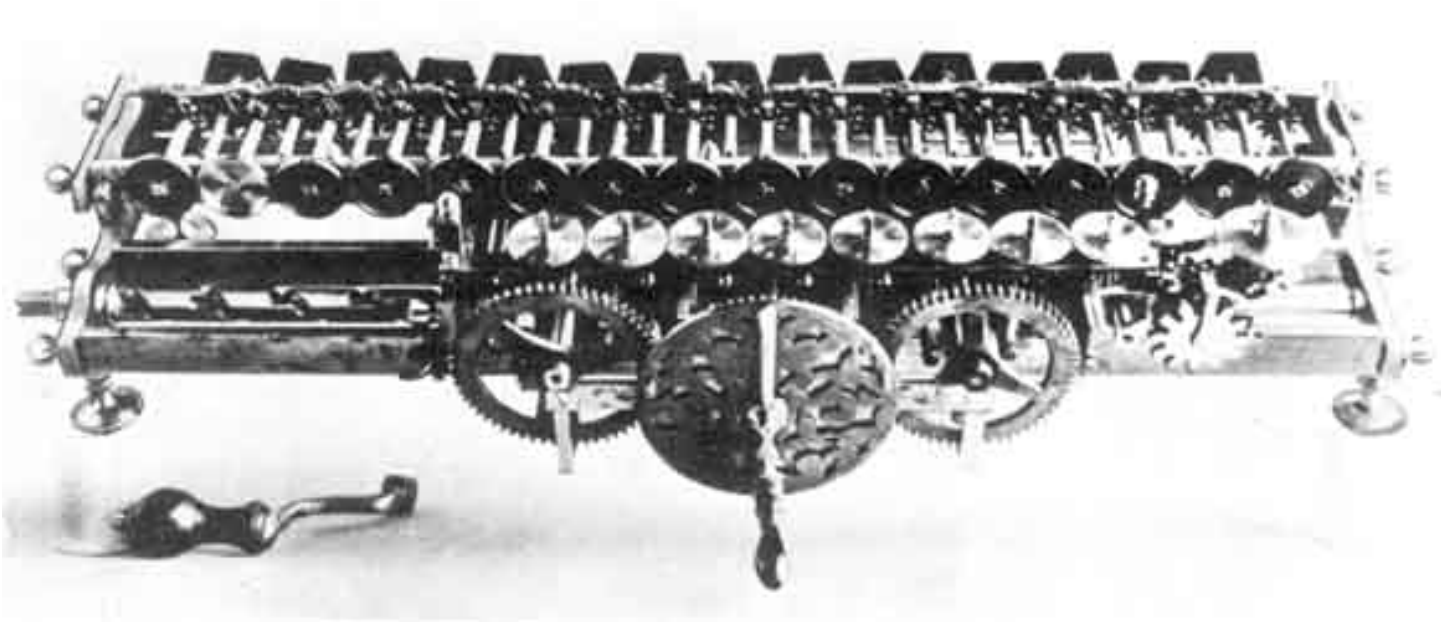
- Logic: the art of valid reasoning

Gottfried Leibniz (1646-1716)

"The only way to rectify our reasonings is to make them as tangible as those of the Mathematicians, so that we can find our error at a glance, and when there are disputes among persons, we can simply say: Let us calculate [calculemus], without further ado, to see who is right."

Leibniz' Step Reckoner (1671) could add, multiply, calculate square roots, etc.



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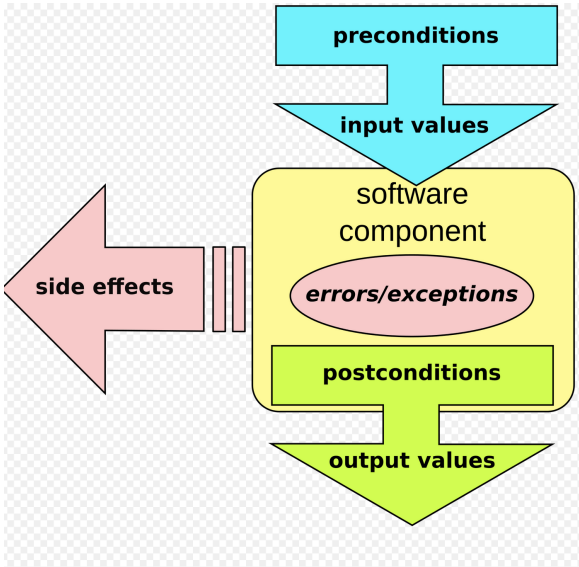
- But still, there is a huge gap between the preciseness in mathematics and in real life



- Edsger Dijkstra: Weakest Precondition
- Hoare Logic
- Design by Contract

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- constructive logic does not validate the *excluded middle* $p \vee \neg p$

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- If we trust the proof assistant we can say that the extracted software has **ZERO ERRORS**

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Specification of sorting function

```
Definition is_sorting_function (f : list nat -> list nat) : Prop :=
  forall (w : list nat),
    permutation w (f w) /\ sorted (f w).
```

Never mind . . .

Definition of sorted

```
Inductive sorted : list nat -> Prop :=
  | sorted_nil : sorted nil
  | sorted_singleton : forall n : nat, sorted [n]
  | sorted_full :
    forall (n m : nat) (w : list nat),
      n <= m ->
      sorted (m :: w) ->
      sorted (n :: m :: w).
```

Definition of permutation

```
Definition permutation (w w' : list nat) :=
  forall n : nat, (number_occurrences n w) = (number_occurrences n w').
```

Definition of number of occurrences

```
Fixpoint number_occurrences (n : nat) (w : list nat) : nat :=
  match w with
    | nil => 0
    | m :: w' =>
      if m == n then
        S (number_occurrences n w')
      else
        number_occurrences n w'
  end.
```

We can now define a particular function insertion_sort

Insertion sort

```
Fixpoint insertion_sort (w : list nat) : list nat :=
  match w with
  | nil => nil
  | n :: tl => insert n (insertion_sort tl)
  end.
```

Insertion

```
Fixpoint insert (n : nat) (w : list nat) : list nat :=
  match w with
  | nil => n :: nil
  | m :: w' =>
    if n <= m then
      n :: m :: w'
    else
      m :: (insert n w')
  end.
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- The programming team has full legal coverage
- The program is as good as its specification is

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- In the early days it was only used for high risk projects
- Metro system of Paris runs without an actual driver!
- The list of companies involved is ever growing (Escher Technologies, Intel, AMD, Precision Design Technology)

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- Interested: many, like Facebook, Google, Bitcoin, Automated Driving, Aviation, Volkswagen, etc.

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- A consortium University of Barcelona, Formal Vindications S.L. and Guretruck S.L. develops legal formally verified software for tachographs
- The project is funded through the Generalitat, The Spanish Ministry of Science, Innovation and Universities and European Regional Development Funds (ERDF = FEDER) for about one million euro.

'If we desire respect for the law, we must first make the law respectable'.

Louis D. Brandeis, Cleveland Hill

'If we desire algorithmic implementation of a law, we must first make that law computable'.

JjJ

A computable law should have

- clear delimitation of applicability;
- in particular: unambiguous input specification;
- property of being itself unambiguous;
- algorithmic precision: no arbitrary choices left to the engineers;
- certain logical requirements:
  - Consistency;
  - Completeness;
- reflections on physical limits;
- reflections on computational limits;
- mathematically clean properties.

Regulation (EU) 2016/799 lays down the requirements for the construction, testing, installation, operation and repair of tachographs —digital devices which record the activities of road transport drivers.

We analyse Requirements (51) and (52) of the regulation with the goal of identifying problematic behaviour.

Tachographs are required to output one activity per minute.

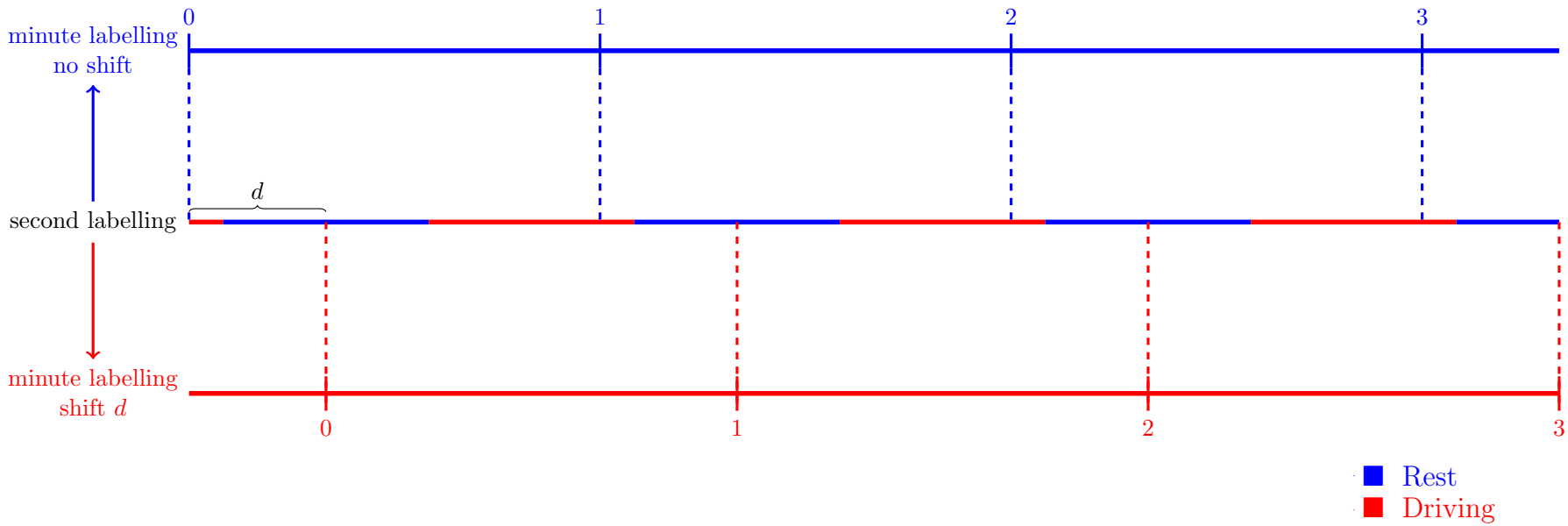
Requirements (51) and (52) are meant to prescribe how to label minutes according to the recorded labelling of seconds.

(51) Given a calendar minute, if DRIVING is registered as the activity of both the immediately preceding and the immediately succeeding minute, the whole minute shall be regarded as DRIVING.

(52) Given a calendar minute that is not regarded as DRIVING according to requirement 051, the whole minute shall be regarded to be of the same type of activity as the longest continuous activity within the minute (or the latest of the equally long activities).

A mathematical analysis reveals:

1. The order should be **first apply (52)** and **next apply (51)**;
2. The law is **not shift-invariant**



So, using one clock the tachograph says you have been driving all the time

using another clock with a couple of seconds of difference the tachograph says you have been resting all the time

- Is it bad that the law is **not shift-invariant**?
- English: "Given a calendar minute";
- The Spanish version says *un minuto cualquiera*, “any minute”;
- the Italian says *un intervallo di un minuto*, “an interval of a minute”;
- And actually, the law prescribes usage of UTC (including leap-seconds)
- But in practice everyone uses UT1 (currently 27 seconds of difference with UTC)
- Guretruck SL and Formal Vindications SL have found differences in real driver files of up to 8% caused by using UT1 instead of UTC

Conclusions

1. Legal/critical software should contain ZERO errors
2. The only way to achieve this is using verified software (strong homolgation)
3. But the laws that are amenable to this should be computable
4. Having good mathematical, legal, and computational properties
5. Law and mathematical logic: a long-lasting marriage?

THANK YOU FOR YOUR ATTENTION!!!