How to Use Mathematics to Write Better Programs

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Bugs are annoying

Bugs are annoying

Therac-25: The killing radiation therapy machine

People got hurt

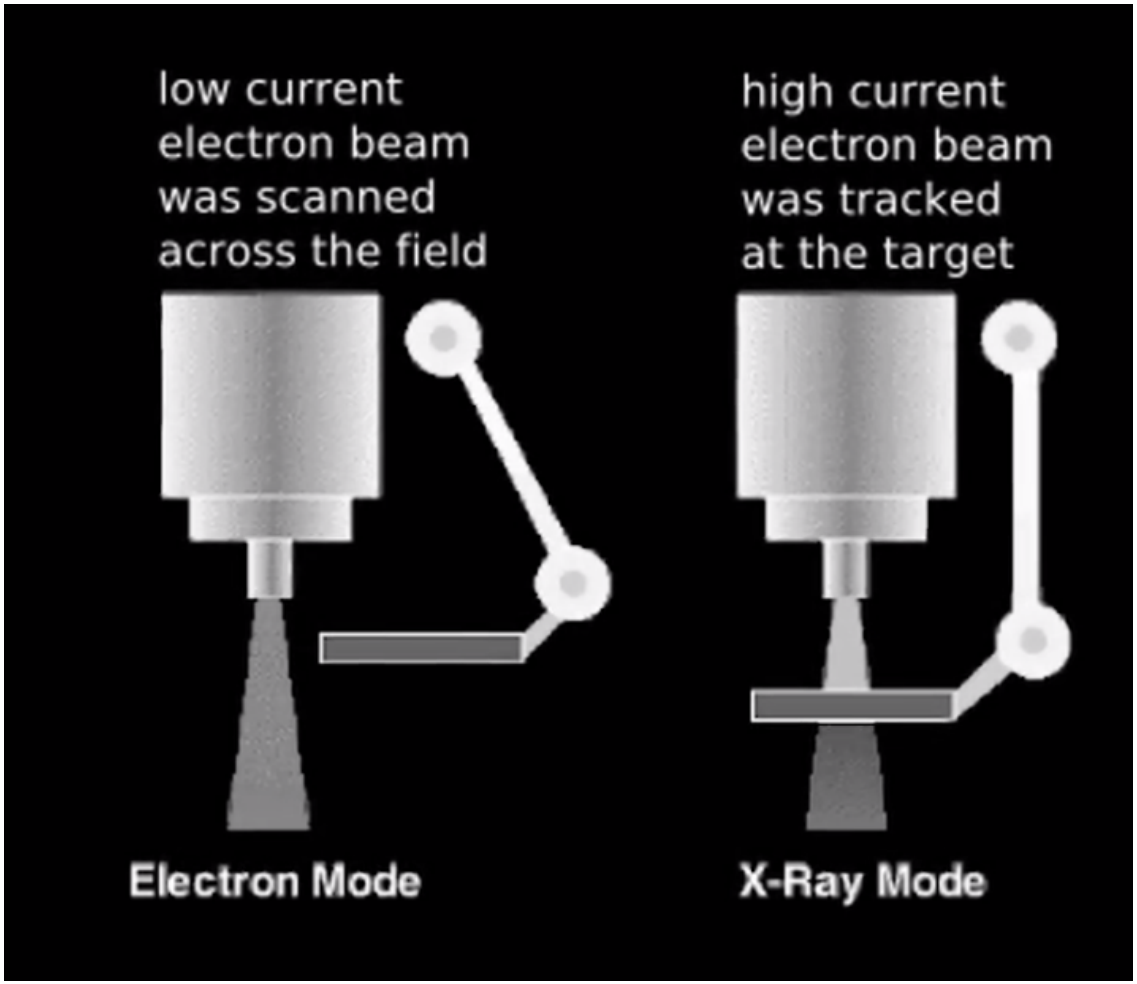
- At least 6 accidents between 1985 and 1987, 3 died later

Malfunction messages

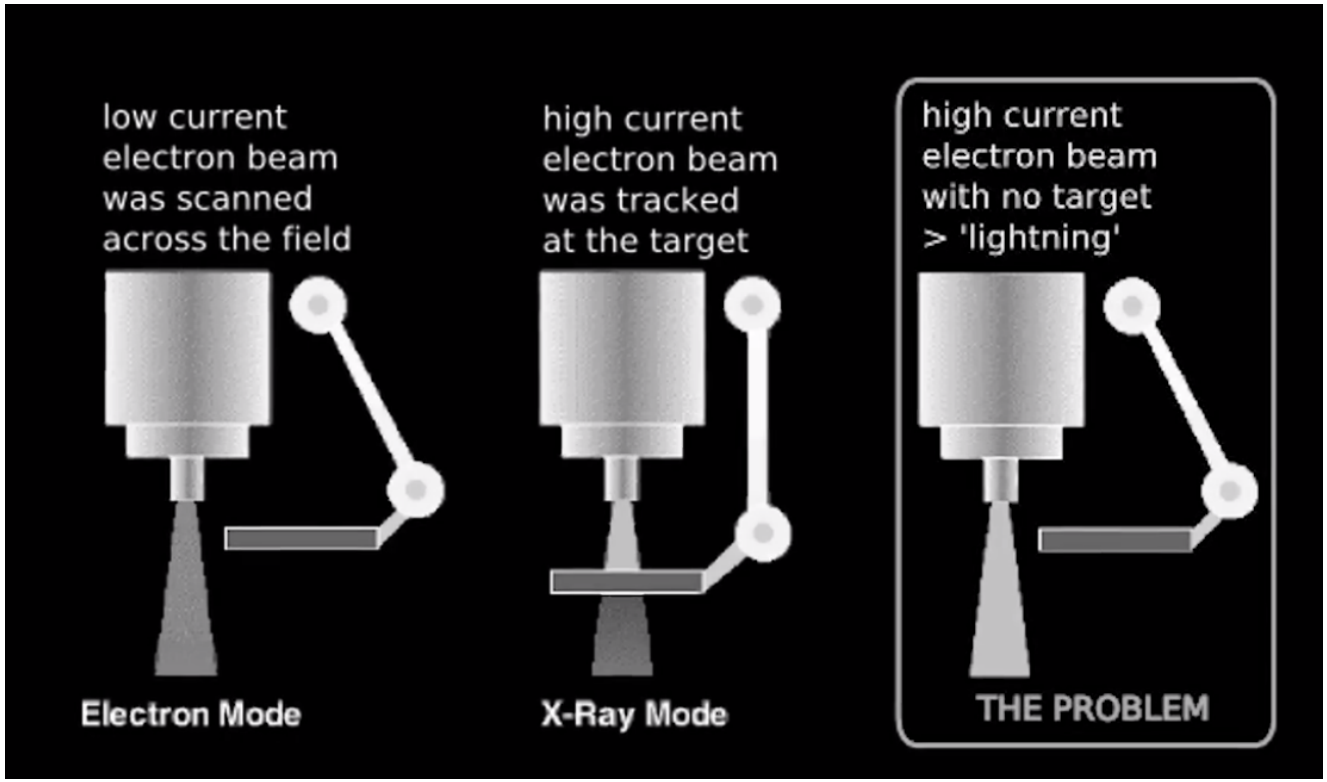
- Malfunction messages from 1 to 64, with no extra information

The machine a bug

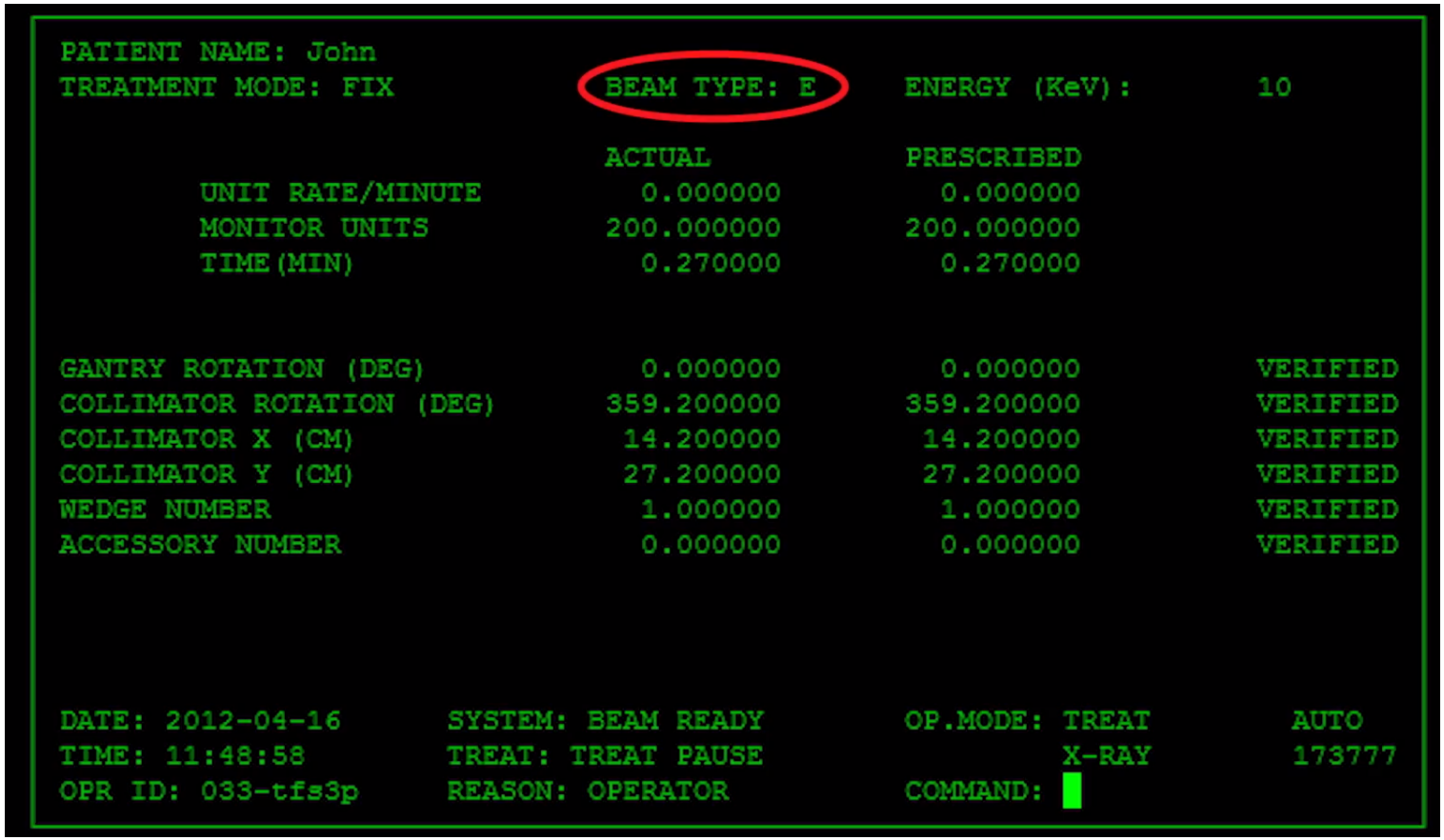
- The machine had three modes: field light, direct electron beam, x-ray



The machine a bug



How to cause the bug

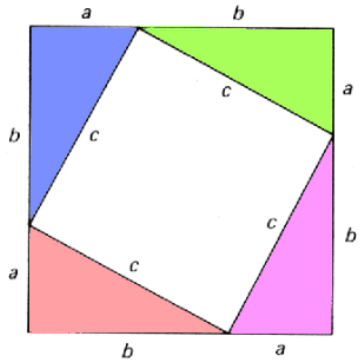


How to write software that don't cause catastrophic failures?

- Formal Methods!
- There are many techniques: static analysis, model checking and formal proving

What is to prove something?

- Establishing mathematical facts that are universally true
- You know some: Pythoragoras theorem: $\forall abc.c^2 = a^2 + b^2$



Two ways to calculate this area:

1. $(a+b)(a+b) = a^2 + ab + ab + b^2$
2. $4(ab)/2 + c^2$
   they should be the same!
   $a^2 + ab + ab + b^2 = 4(ab)/2 + c^2$
   $a^2 + b^2 = c^2$
3. How can you be sure that there is no mistake in the proof?

Proof assistants

- Proof assistants: programs that verify if your proof is correct!
  - We trust the verifier!
- I use a proof assistant called Isabelle/HOL to verify programs
- How my research works:
  1. I write a specification of the program: what it should do, and what it should not do
  2. I write the program
  3. I write a proof that the program respects the specification
     - Usually this requires writing many other auxiliary proofs

Examples!

- Pythagoras
- Sorting

This is a real job!

- TLA+/TLC: Amazon AWS, Intel, Microsoft...
- Coq (CompCert): Airbus
- Isabelle/HOL (seL4): Defense Advanced Research Projects Agency (DARPA)
- Formal methods companies: Absint, Trustworthy Systems
- Apple: `https://jobs.apple.com/en-us/details/200343072/formal-verification-engineer`

Thank you!

- Questions?