# How much is a mechanized proof worth, certification-wise?

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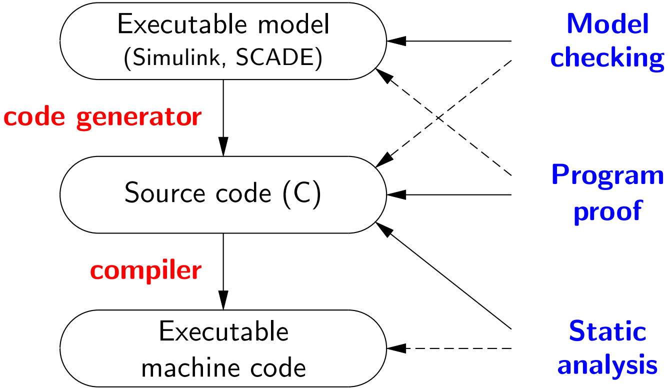
# In this talk. . .

Some feedback from the aircraft industry concerning the potential usefulness of the CompCert formally-verified C compiler.

# The initial plan




"Pitch" CompCert and its proof as a radical way to

- establish confidence in the C→asm compilation process;
- preserve guarantees obtained by C-level formal verification.

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"You'll get stronger guarantees this way than by testing."

*(Our avionics software has no known flaws.)*
*(Besides, we perfected testing to an art.)*

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"You could gain performance by using better algorithms
that you could not test well enough."

*(We have performance issues, indeed.)*

# Things you will hear

## when pitching your research to the critical software industry

*Maybe your stuff has some value.*
*But do you have a certification plan?*

Huh? It's proved in Coq!

*A formal verification is not a certification.*

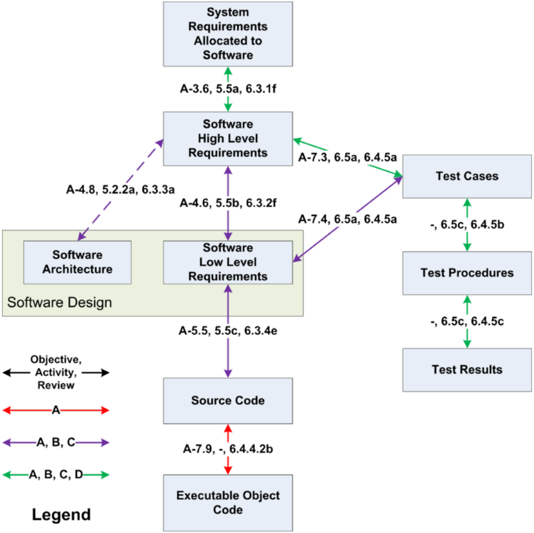
# Certification


Awarded by certification authorities (FAA, EASA) following domain-specific regulations, e.g. DO-178C for avionics (*Software Considerations in Airborne Systems and Equipment Certification*).

DO-178C specifies:

- several levels of assurance;
- the corresponding requirements to meet;
- the verification activities to conduct;
- but not any particular technology (prog. lang., tools, etc).

# DO-178C process and traceability



# Verification techniques

Three major kinds:

- Reviews (qualitative)
- Analyses (quantitative)
- Testing.

Analyses welcome maths & physics:

- High levels: aerodynamics, control theory.
- Low levels: use of software verification tools
  (e.g. static analyzers, deductive program provers).

But: tools must be qualified to get certification credit.

# Tool qualification (DO-330)

Purpose: obtain appropriate assurance that the tools are at least as dependable as the manual processes that they are replacing.

- Criteria 1: a tool whose output is part of the airborne software and thus could insert an error.
- Criteria 2: a tool that automates verification processes and thus could fail to detect an error, and whose output is used to justify the elimination or reduction of other verification or development processes.
- Criteria 3: a tool that could fail to detect an error.

Determines how stringent the tool qualification is:

| | **Criteria** | | |
|---|---|---|---|
| **Software Level** | **1** | **2** | **3** |
| A | TQL-1 | TQL-4 | TQL-5 |
| B | TQL-2 | TQL-4 | TQL-5 |
| C | TQL-3 | TQL-5 | TQL-5 |
| D | TQL-4 | TQL-5 | TQL-5 |

# How much is CompCert's proof worth, certification/qualification-wise?

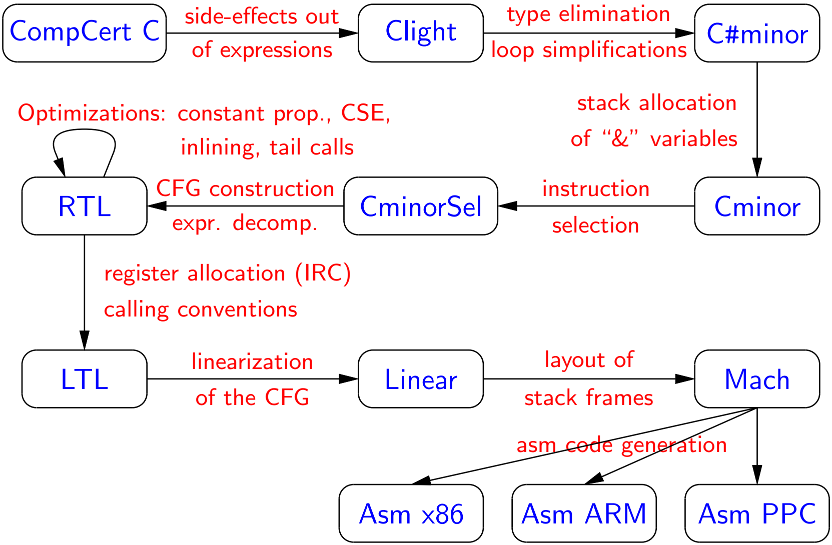
(A very hypothetical question: qualification of a C compiler has never been attempted before, and might not be economically viable.)

At first sight, a plausible match:

| | | |
|---|---|---|
| Coq specifications | $\approx$ | parts of the high-level requirements |
| Coq functions | $\approx$ | parts of the low-level requirements |
| Coq proofs | $\approx$ | automated verification activity |

But this leaves many things unaccounted for. . .

# The formally-verified part of CompCert



# The formally-verified part of CompCert

The high-level specifications comprise:

- Operational semantics of CompCert C (big, complex)
- Operational semantics of PowerPC Asm (large, simple)
- The statement of semantic preservation: simulation diagram or (simpler) inclusion between whole-program behaviors.
- Supporting theories: machine integers, floats, memory model, I/O model.

# The formally-verified part of CompCert

Thanks to the proof, no need to talk about:

- Intermediate languages.
- Compilation algorithms.
- Optimizations and their supporting static analyses.

(Note: optimizations, being context-dependent, cannot be validated by traditional testing.)

# Validating an operational semantics

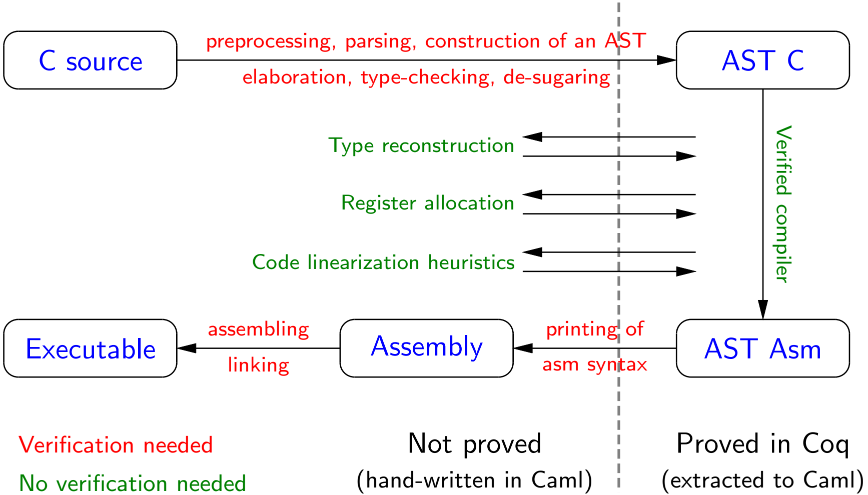
Most plausible approach: testing on an executable form of the semantics.

The CompCert C reference interpreter:
Coq functions that are proved equivalent to one-step transitions.
(Approach suggested by Brian Campbell.)

Other techniques: PLT Redex, Ott, Jakarta, ...

Example of use: 3-way differential random testing with Csmith
(CompCert interpreter / CompCert compiler / GCC).
(But: no value for certification.)

# The full CompCert compiler



# What to do with the unproved parts?

Assembly and linking:

- An unverified validation tool that matches the ELF executable against the Asm AST.

From C source to CompCert C AST:

- Testing? (mostly compositional transformations)
- Proving more things? (e.g. lexing and parsing)
- Lack of high-level formal specifications.

# When spec = implementation...

Example: interpreting the "tag soup" (G. Necula).

```
volatile long unsigned inline long static * const f(void)
{ ... }
```

$\rightarrow$

Function declaration:

name: `f`
storage class: `static`
inline: `true`
result type: `TPtr(TInt(IULongLong, volatile), const)`
parameters: none
varargs: no
body: ...

# Trusting Coq

As a verification tool:

- The “de Bruijn” architecture is appreciated (production of independently-checkable proof terms).
- Multiple independent checkers would be a big plus (e.g. `coqchk` that works and is developed independently).

As a code generation tool: (extraction)

- Highly suspect.
- Manual review of extracted Caml code probably needed.

Doubts on the OCaml compiler and runtime:

- A simplified version used in Scade KCG6, passed level-A qualification.
- Multiple implementations could help (e.g. OCamlJava, F#).

# Various cognitive dissonances

DO-178 traceability $=$ refinement $\wedge$ no additional functionality.

vs.

Soundness proofs cannot show that no dead code was introduced.

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Good mathematical style: define things then immediately prove some properties about them.

vs.

Orthodox V&V practice: development and verification are distinct activities, preferably done by different teams.

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Rome wasn't built in a day. Keep bringing nice stones!