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

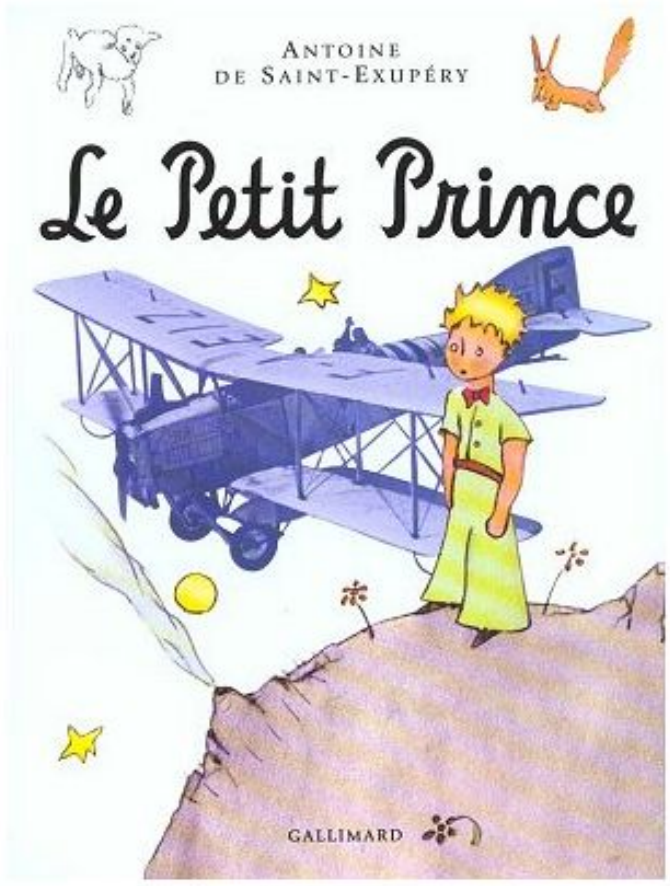
Xavier Leroy

Inria Paris-Rocquencourt

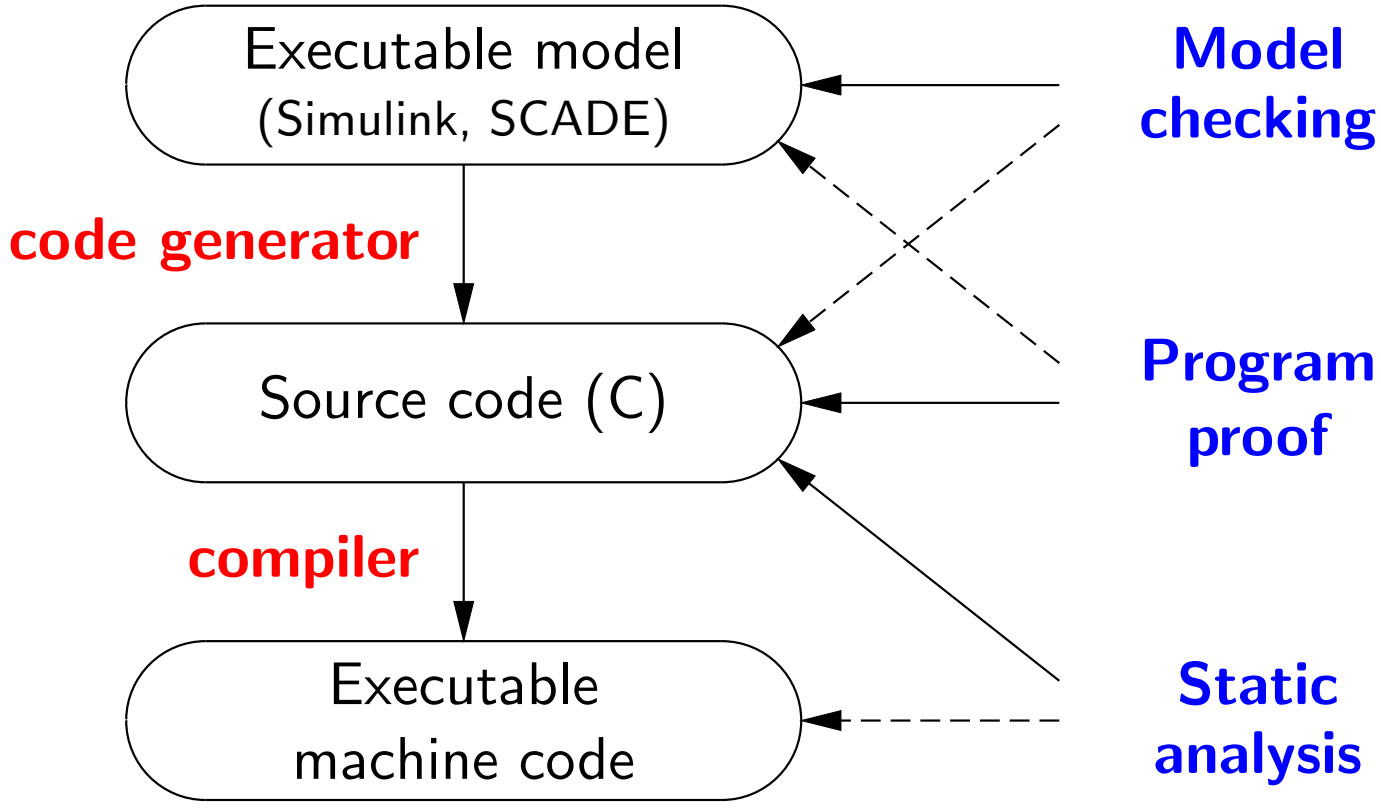
PiP 2014: Principles in Practice

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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when pitching your research to the critical software industry

"It's obviously the right thing to do."

(So you say. Have you ever built an airplane?)

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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.)

From unit tests. . .

```
double max(double x, double y)
{
    if (x >= y) return x; else return y;
}
```

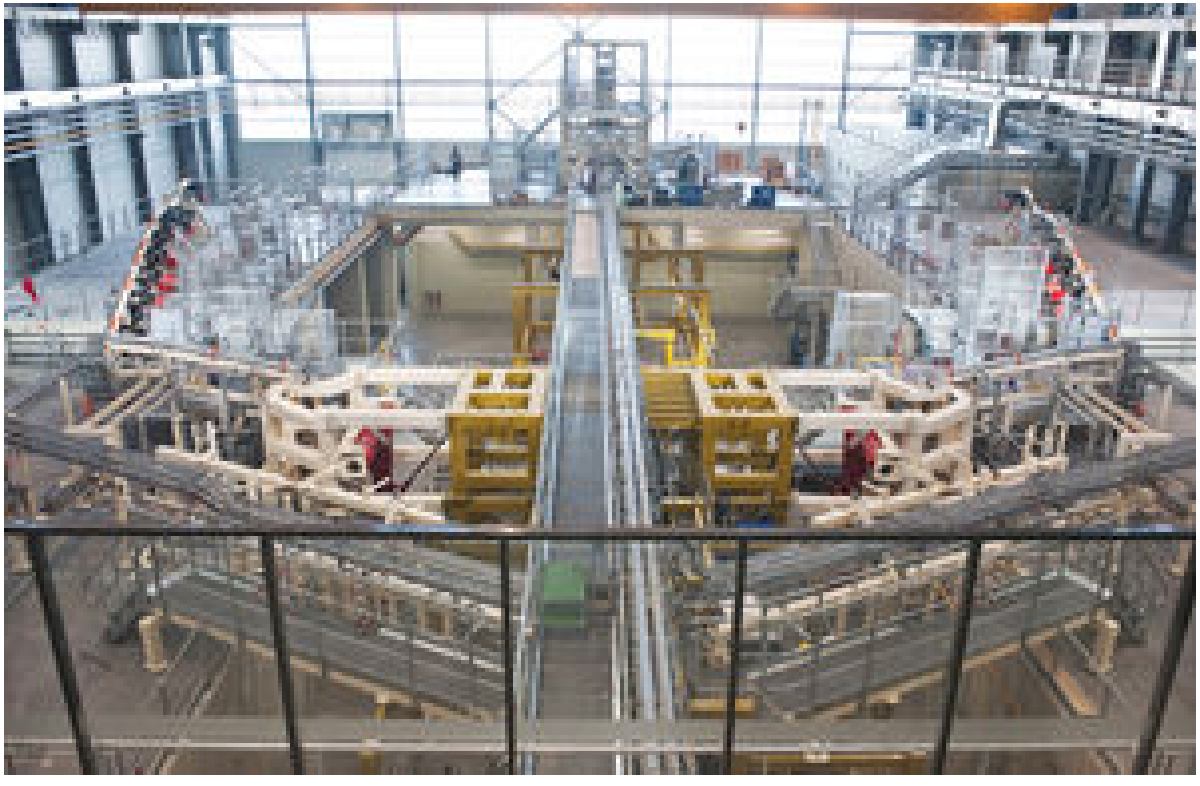
```
max(0,0) = 0
max(0,1) = 1
max(0,-1) = 0
max(0,3.14) = 3.14
max(0,inf) = inf
max(0,-inf) = 0
max(1,0) = 1
max(1,1) = 1
```

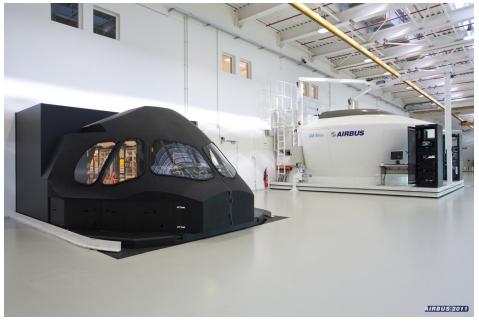
```
max(1,-1) = 1
max(1,3.14) = 3.14
max(1,inf) = inf
max(inf,0) = inf
max(inf,-inf) = inf
max(nan,0) = 0
max(0,nan) = nan
```

(Note: this is where Airbus uses Caveat for “unit proofs”.)

. . . to integration tests. . .

. . . to exploration on an Iron Bird. . .





. . . to test flights

Chronicle / Michael Macor

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"You'll get evidence that is complementary to testing."

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(We must sometimes react quicky, indeed.)

"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.

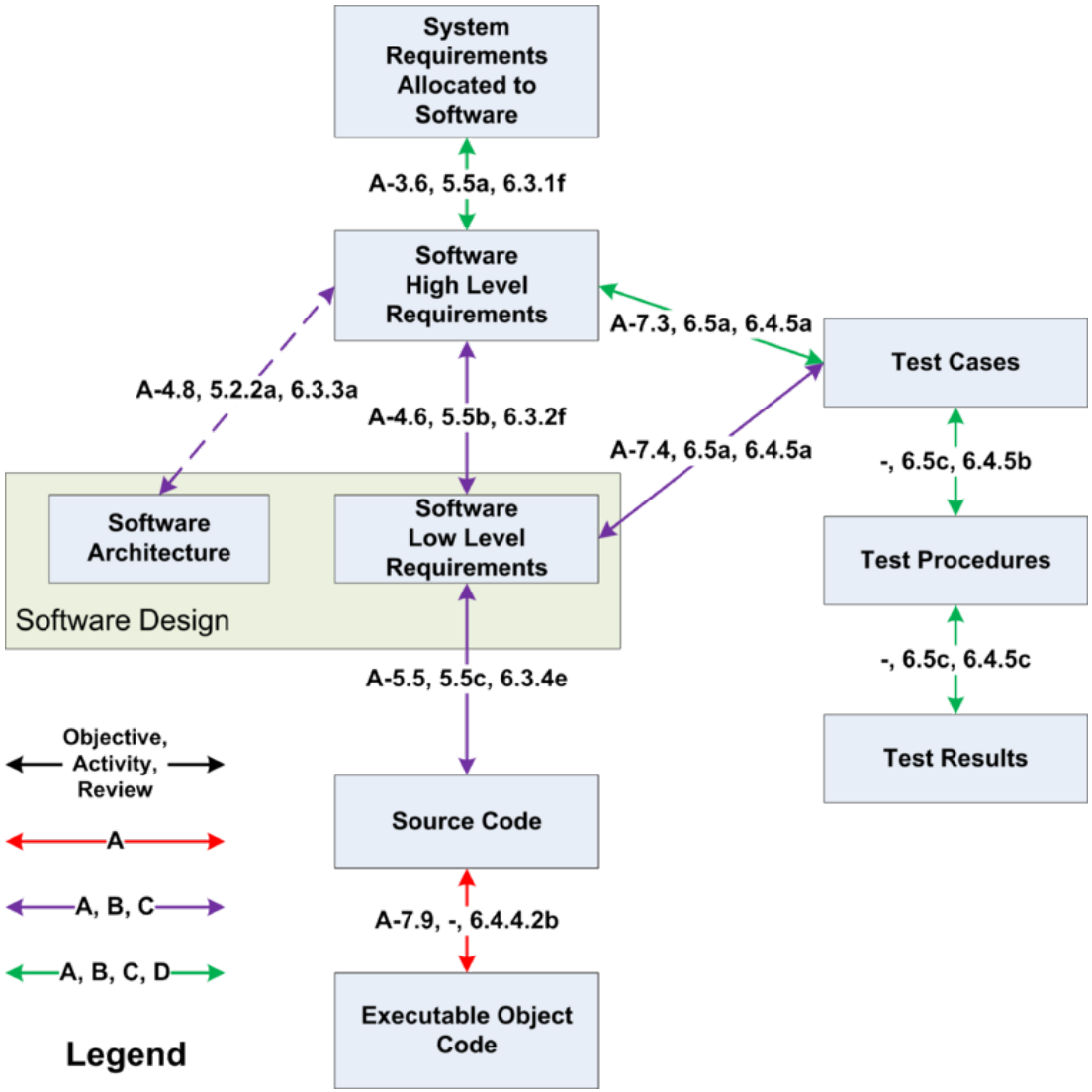
Certification

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?

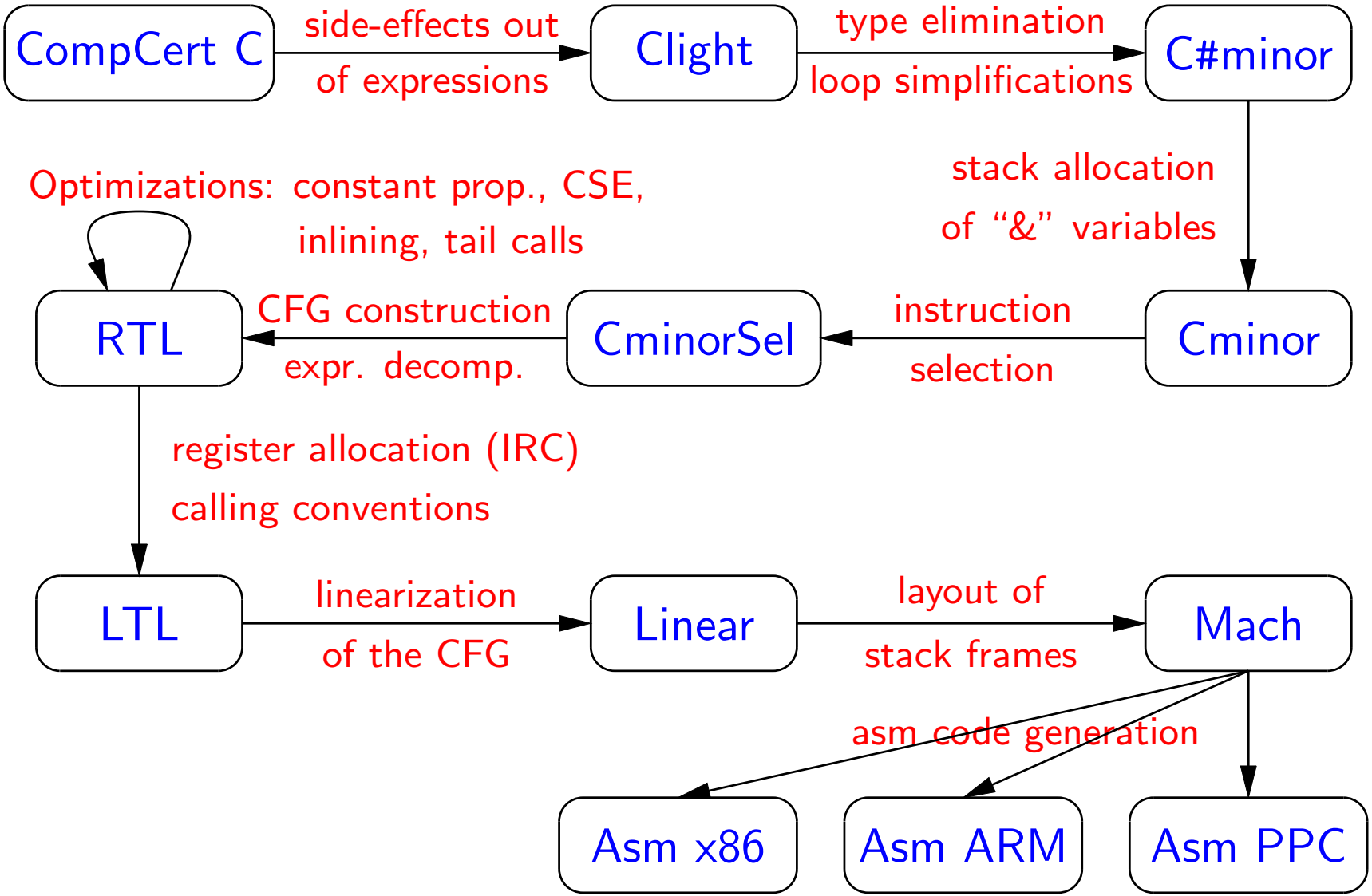
(A very hypothetical question: qualification of a C compiler has never been attempted before, and might not be economically viable.)

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.

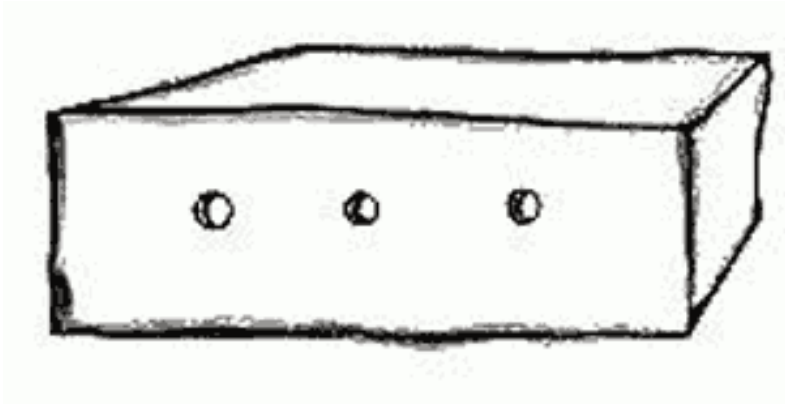
The formally-verified part of CompCert

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.)

"Draw me a compiler."



"The compiler is in this box."

Validating an operational semantics

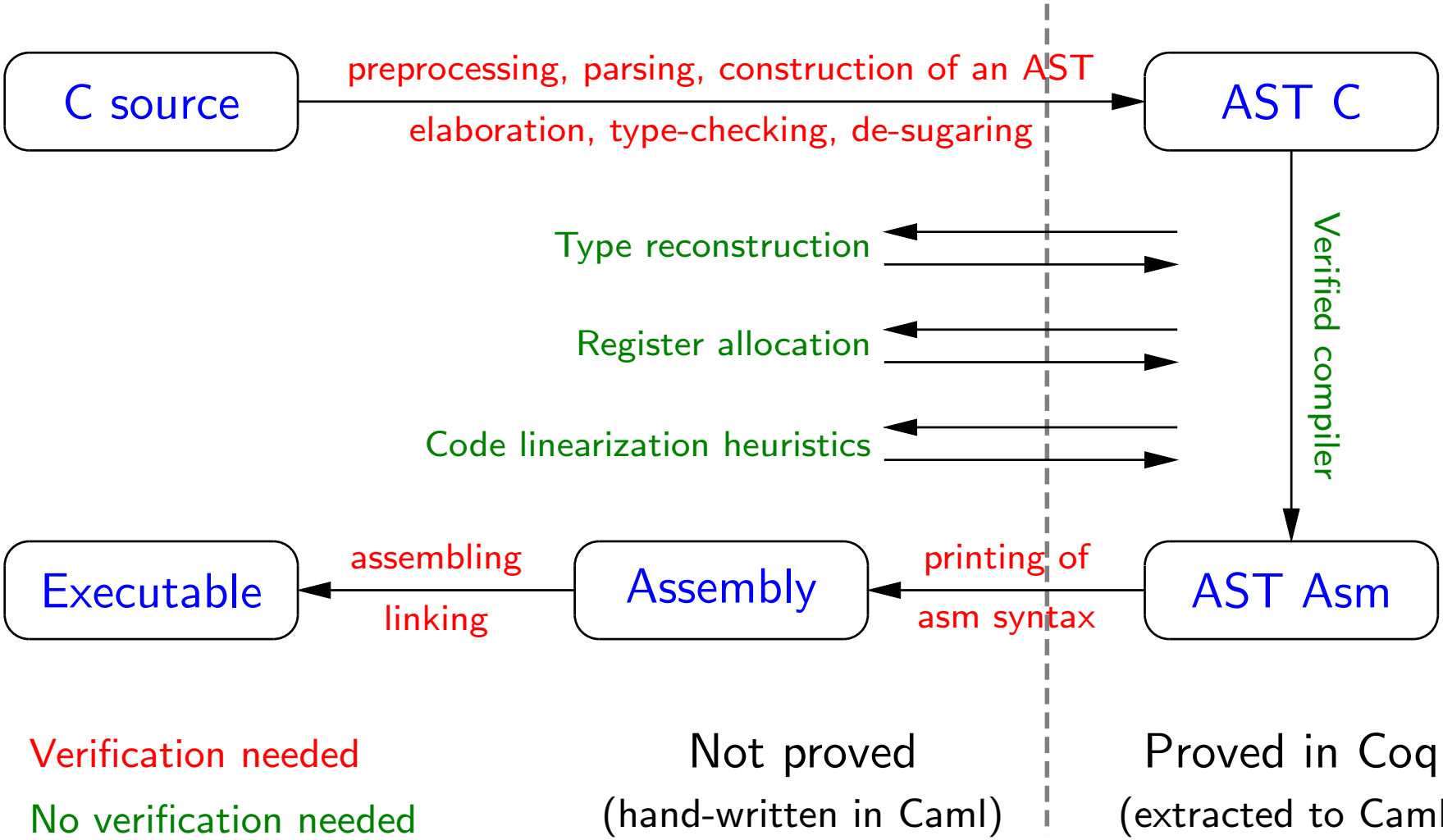
Most plausible approach: testing on an executable form of the semantics.

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

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vs.

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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!