Formally Secure Compilation of Compartmentalized C Programs

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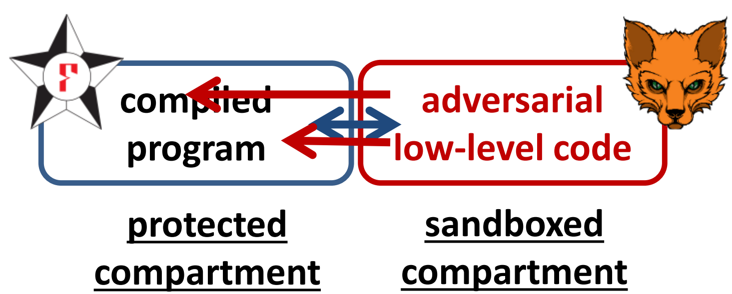
Secure Compilation of Secure Source Programs

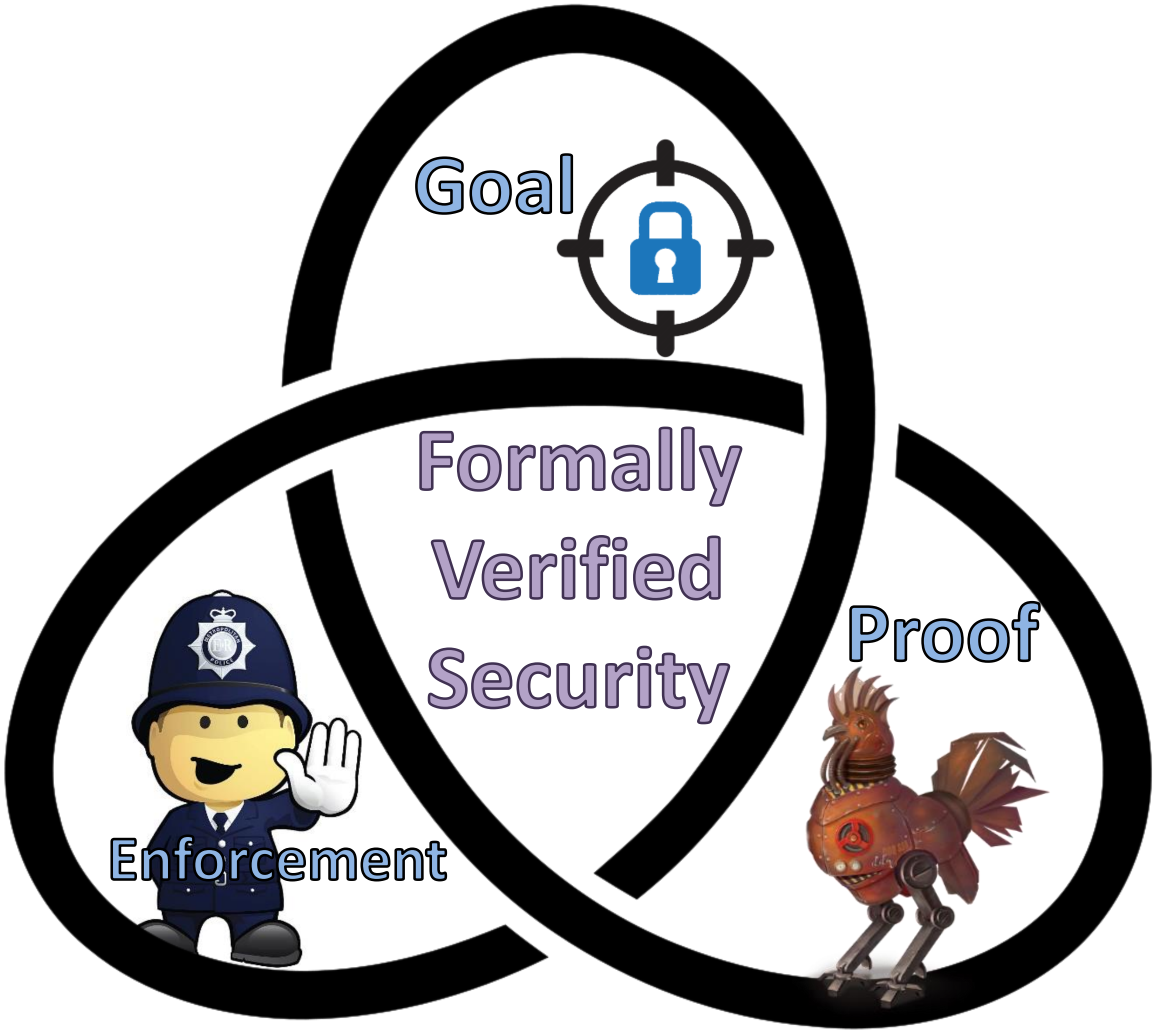
- **Suppose we have a secure source program ...**
  - For instance formally verified in F* [POPL'16,'17,'18,'20, ICFP'17,'19, ...]
  - e.g. EverCrypt verified crypto library, shipping in Firefox, Linux Kernel, ...
  - e.g. simple verified web server, linking with unverified libraries [arXiv'23]
- **What happens when we compile such a verified program and link it with adversarial low-level code?**
  - low-level code that can be buggy, vulnerable, compromised, malicious
  - **currently: all guarantees are lost, lower-level attacks become possible**
  - **secure compilation: protect the source abstractions all the way down**



Secure Compilation of Vulnerable Source Programs

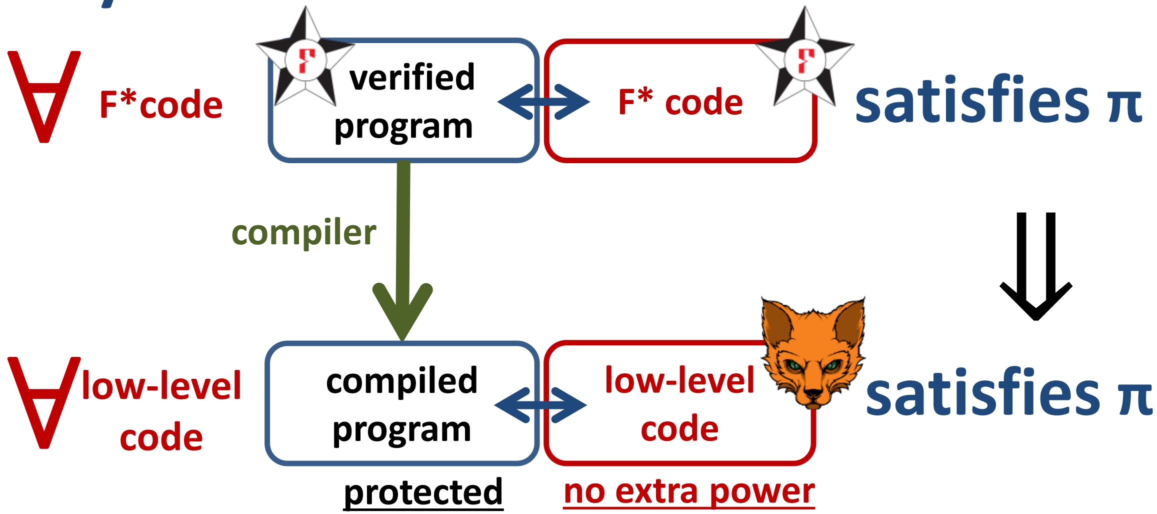
- **Insecure languages like C enable devastating vulnerabilities**
- **Mitigate vulnerabilities by compartmentalizing the program**
- **We don't know which compartments will be compromised**
  - protect vulnerable C compartments from each other
- **We don't know when a compartment will be compromised**
  - every compartment should receive protection until compromised

Secure Compilation is for us an instance of ...



1. Security Goal

∀ security property π



Where π can e.g. be "the web server's private key is not leaked"

We explored many classes of properties one can preserve this way:

Journey Beyond Full Abstraction [CSF'19, ESOP'20, TOPLAS'21]

More interesting definition for vulnerable C compartments [CSF'16, CCS'18]

2. Security Enforcement

Large subset of C with compartments

CompCert verified C compiler extended with compartments

RISC-V ASM with compartments

magically secure semantics

Software-Fault Isolation

vanilla ASM

Done for simplified languages, yet to be ported to RISC-V

Micro-Policies: ASM with programmable tags

[POPL'14, S&P'15, ASPLOS'15, POST'18, CCS'18, CSF'23]

[PriSC'23, ongoing]

CHERI RISC-V capability machine

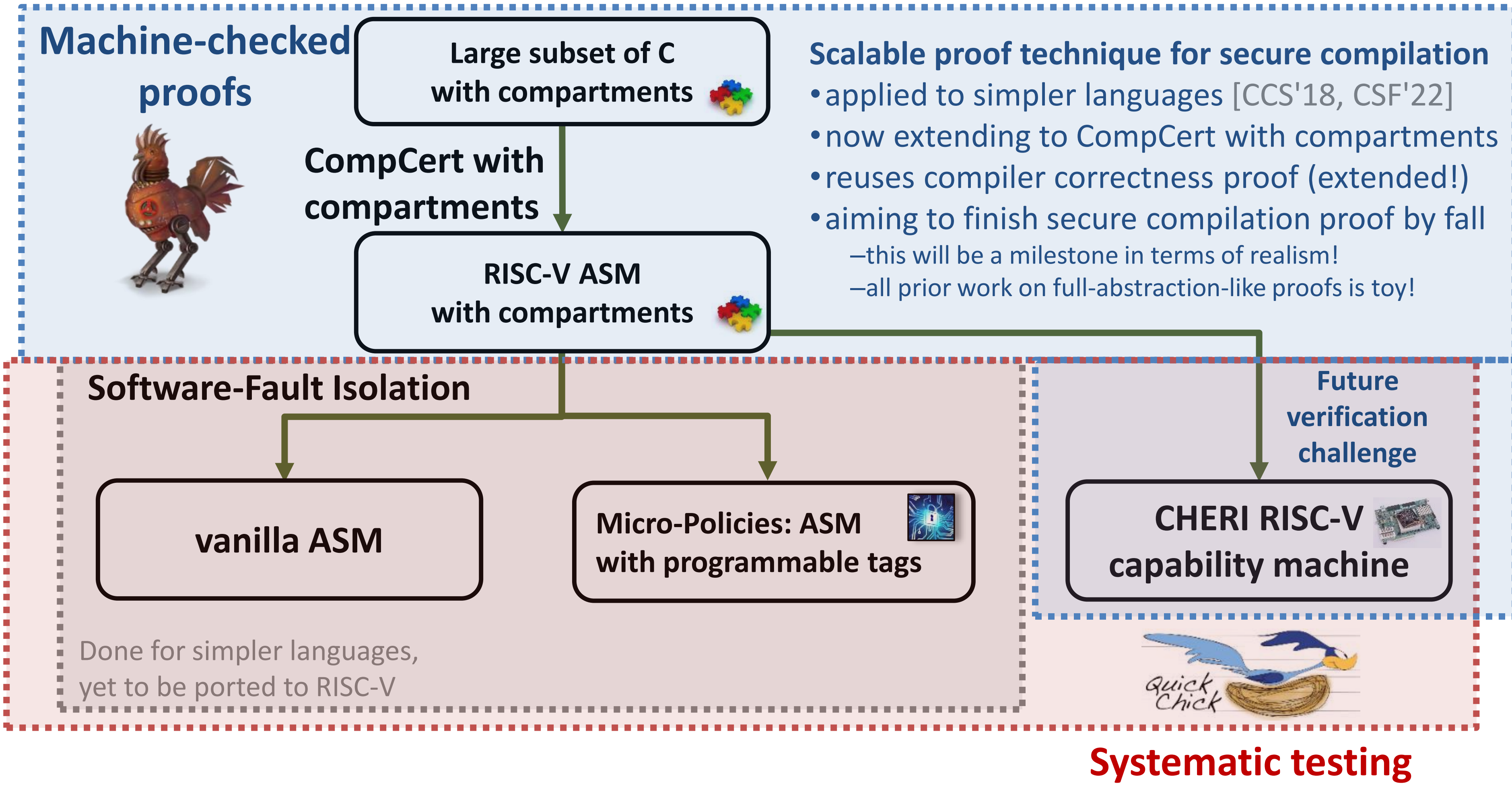
(inspiration for ARM Morello)

Hardware-accelerated enforcement

3. Security Proofs

- **Proving mathematically that our compilation chains achieve secure compilation**
  - such proofs generally **very difficult and tedious**
    - wrong conjectures for full abstraction have survived for decades
    - 250 pages of proof on paper for toy compiler
  - we propose **more scalable proof techniques** [CCS'18, CSF'22]
  - **machine-checked proofs** in the Coq and F* proof assistants
  - **systematic testing** to find wrong conjectures early [POPL'17, ICFP'13, ITP'15, JFP'16]

Testing and Proving Secure Compilation in Coq



Future Plans on Formally Secure Compilation

SPECTRE

Stronger Security Goals

Preserve data confidentiality
against micro-architectural side-channel attacks,
for arbitrary compartmentalized programs in F*, C, or Wasm
(not only constant time crypto code)

Realistic Enforcement

ARM Morello
capability machine

Capability passing

Better Proof Techniques

Verify capability backend