Compartmentalizing Formally Secure Compilation

Cătălin Hriţcu

Inria Paris

https://secure-compilation.github.io

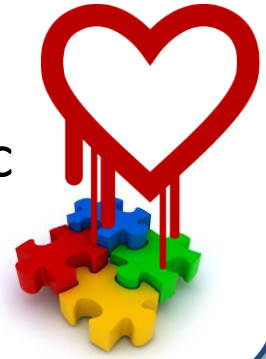
Secure compilation has various goals

- **Preventing low-level attacks and Enabling source-level security reasoning**
  - by compartmentalizing compilation
- **Making the source language safer**
  - memory and type safety, less/no undefined behavior
- **Making it easier to express security intent**
  - marking secrets, specifying security properties
- **Making exploits more difficult**
  - CFI, CPI, stack protection, randomization, diversity

Devastating low-level attacks

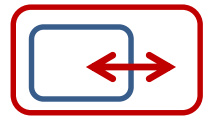
Part 2: give meaning to mitigation (protected components)

inherently insecure languages like C/C++



- **e.g. memory unsafe**: any buffer overflow is catastrophic allowing remote attackers to gain complete control
- ~100 different **undefined behaviors** in usual C compiler

insecure interoperability with lower-level code

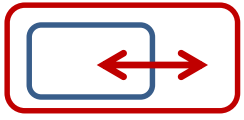


- even code in **more secure languages (Java, OCaml, Rust)** has to interoperate with **low-level code (C, C++, ASM)**
- **insecure interoperability:** all source-level guarantees lost

Part 1: formalize what it means to solve this problem

Part 1 of 2

Secure Interoperability with Lower-Level Code



Carmine Abate
Inria Paris

Rob Blanco
Inria Paris

Deepak Garg
MPI-SWS

Cătălin Hriţcu
Inria Paris

Jérémy Thibault
Inria Paris

Marco Patrignani
CISPA
Stanford

Journey Beyond Full Abstraction:

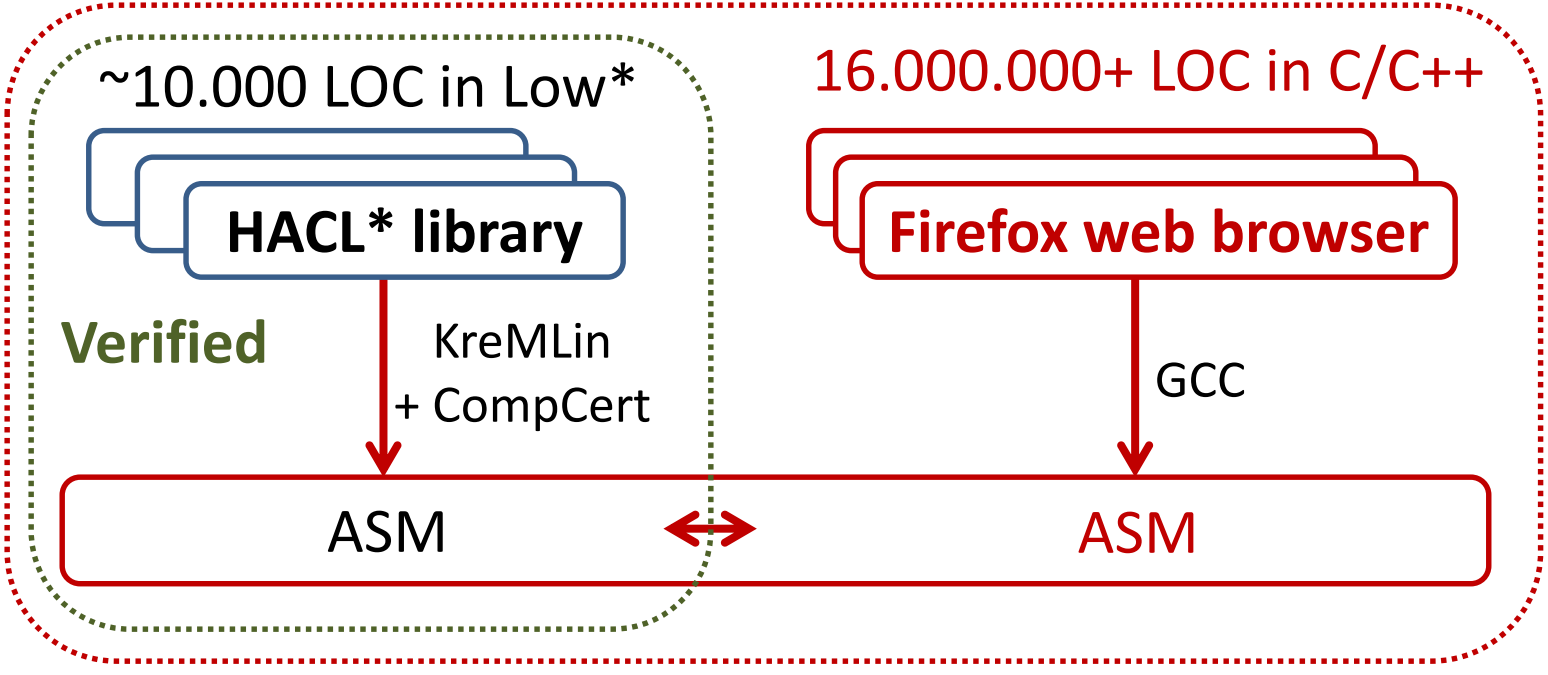
Exploring Robust Property Preservation for Secure Compilation

https://arxiv.org/abs/1807.04603

Good programming languages provide helpful abstractions for writing more secure code

- e.g. **HACL*** and **miTLS** written in **Low*** which provides:
  - **low-level abstractions associated with safe C programs**
    - structured control flow, procedures, abstract memory model
  - **higher-level abstractions associated with ML-like languages**
    - modules, interfaces, and parametric polymorphism
  - **most features of verification systems like Coq and Dafny**
    - effects, dependent types, logical pre- and post-conditions
  - **patterns specific to cryptographic code**
    - abstract types and interfaces for mitigating side-channel attacks

Abstractions not enforced when linking with adversarial low-level code



Insecure interoperability: compromised (or malicious) application linking in miTLS can easily **read and write miTLS's data and code**, **jump to arbitrary instructions**, **smash the stack**, ...

Secure compilation

- **Protect source-level abstractions**
  even against linked adversarial low-level code
- **Enable source-level security reasoning**
  - even **adversarial target-level context cannot break security properties of compiled program** any more than some source-level context could
  - **no "low-level" attacks**

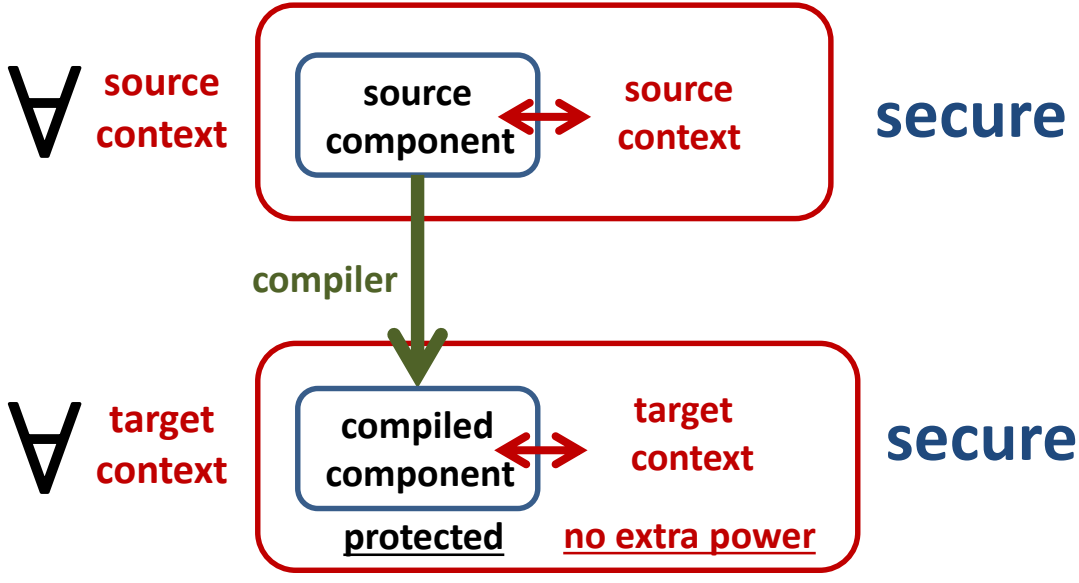
Three important concerns for secure compilation

1. **What are we trying to achieve?** ← **this course mostly focused on 1**
   - Identifying and formalizing secure compilation criteria and attacker models

(does touch on 2+3 a bit too)

2. **How can we achieve it efficiently?**
   - compartmentalization can be achieved using: OS processes, software-fault isolation, hardware enclaves, tagged architectures, capability machines
3. **How can prove it effectively?**
   - e.g. (bi)simulations, logical relations, game semantics, ...

Source-level security reasoning

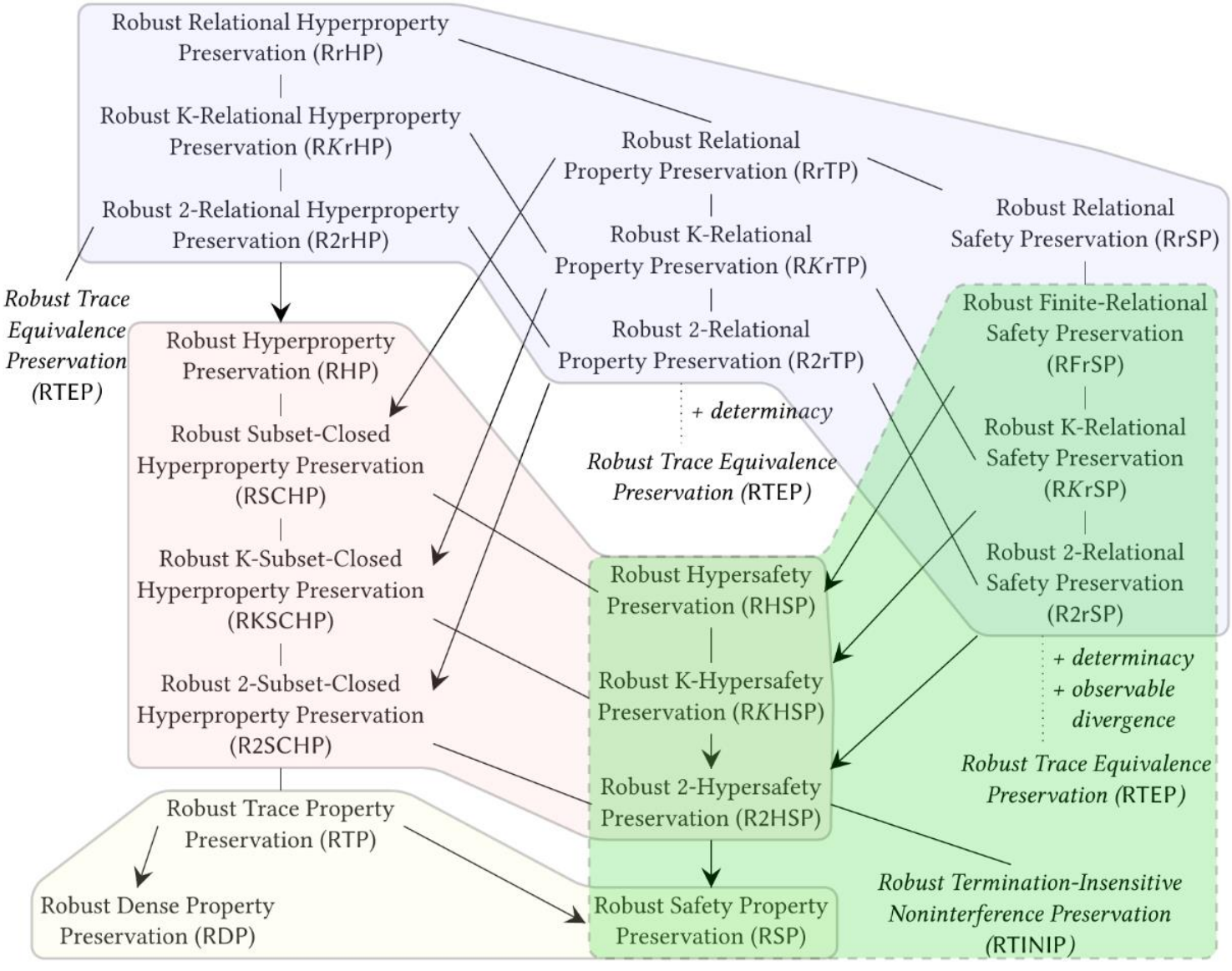


But what does "secure" mean?

What security properties should we preserve?

- **We explored a large space of security properties**
- **Studied preserving various classes of ...**
  - **trace properties** (safety, liveness)
  - **hyperproperties** (e.g. noninterference)
  - **relational hyperproperties** (e.g. trace equivalence)

  ... against adversarial target-level contexts
- **No "one-size-fits-all solution"**
  - e.g. full abstraction does **not** imply the other criteria we study
  - **stronger** criteria are **harder** to achieve and prove, both challenging



More secure

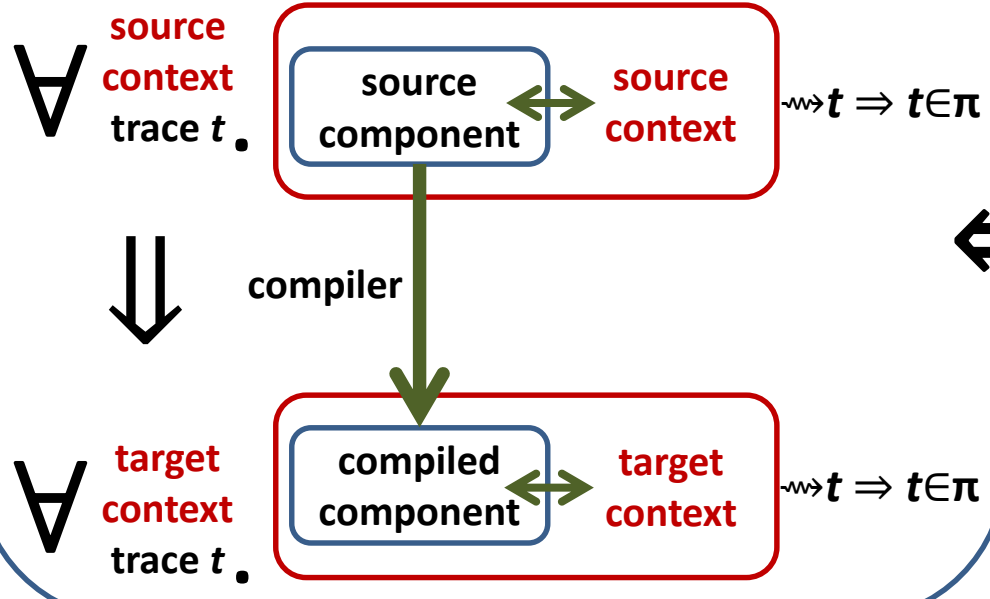
More efficient
Easier to prove

Robust Trace Property Preservation

property-based characterization

∀source component.

∀π trace property.

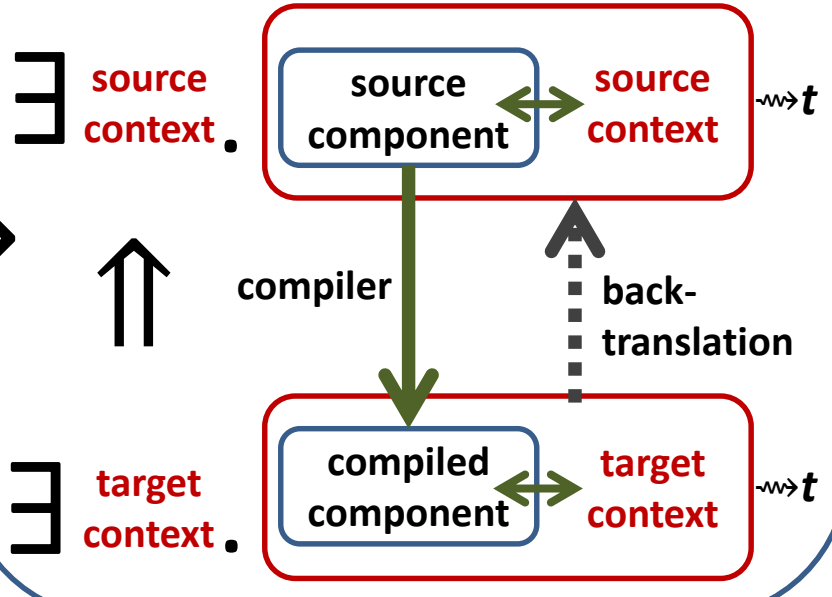


preservation of **robust** satisfaction

property-free characterization

∀source component.

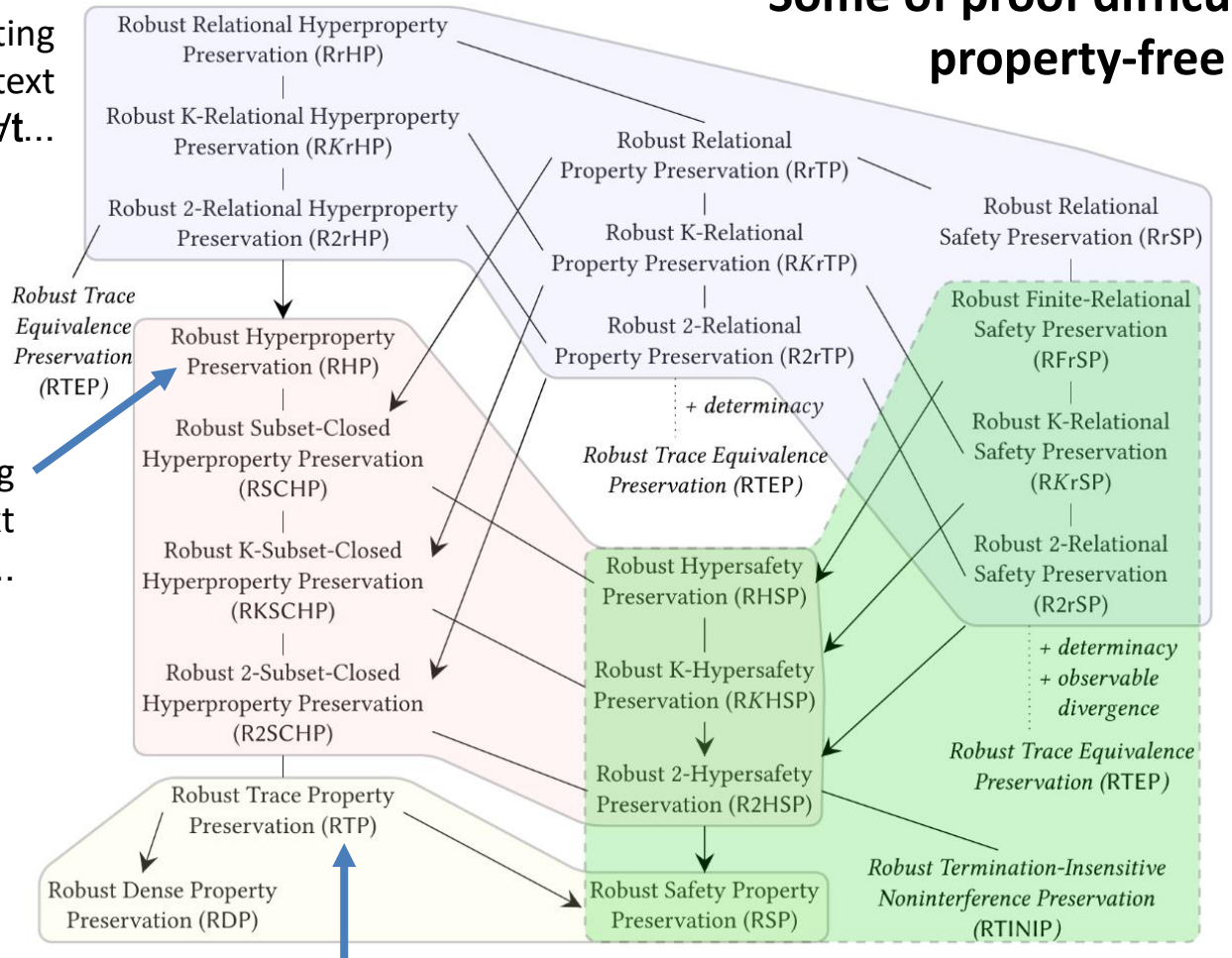
∀(bad attack) trace *t*.



how one can prove it

Some of proof difficulty is manifest in property-free characterization

back-translating context
$\forall C_T \exists C_S \forall P \forall t$...



back-translating
prog & context
$\forall P \forall C_T \exists C_S \forall t$...

back-translating
finite set of
finite trace prefixes
$\forall k \forall P_1..P_k \forall C_T$
$\forall m_1..m_k \exists C_S$...

back-translating
prog & context & trace
$\forall P \forall C_T \forall t \exists C_S$...

back-translating
finite trace prefix
$\forall P \forall C_T \forall m \leq t \exists C_S$...

Summarizing recent results [arXiv:1807.04603]

- **Mapped the space of secure compilation criteria** based on robust "property" preservation
  - **Property-free characterizations** and **implications** in Coq
  - **Separation results** (e.g. robust safety/liveness preservation strictly weaker than robust trace property preservation)
  - **Collapse** between preserving all hyperproperties and preserving just hyperliveness
- Showed that **even strongest criterion is achievable**
  - for simple translation from a statically to a dynamically typed language with first-order functions and I/O

Some open problems

- **Practically achieving**
  secure interoperability with lower-level code
  - **More realistic languages and secure compilation chains**
  - Achieve **robust noninterference preservation** in realistic attacker model **with side-channels**
  - **Efficient enforcement mechanisms**
- **Scalable proof techniques for other criteria**
  - robust (hyper)liveness preservation (possible?)
- **Proving robust satisfaction for source programs**
  - partial semantics, program logics, logical relations, ...

Where is full abstraction?

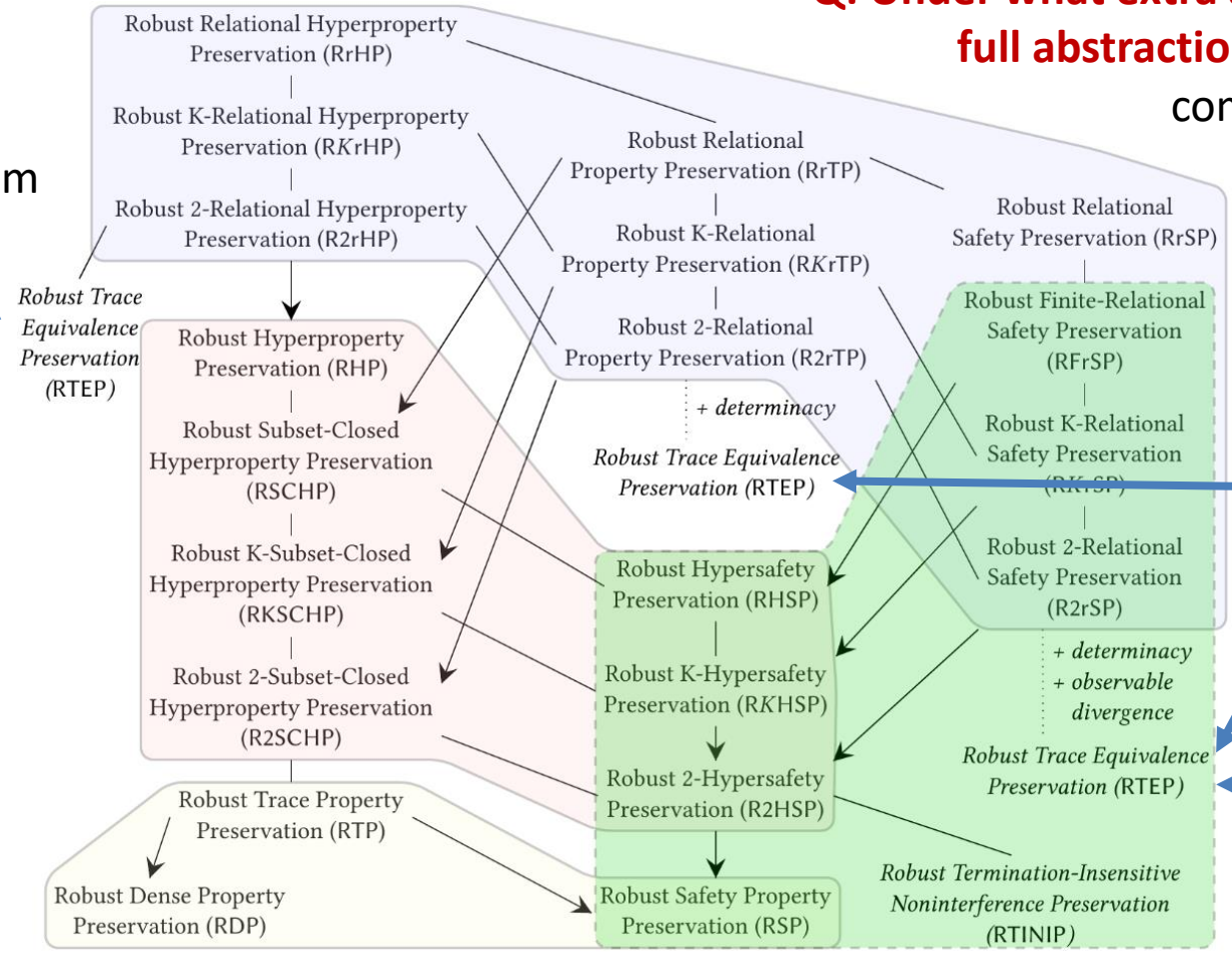
Q: Under what extra assumptions does full abstraction imply anything?

compiler correctness not enough!

with internal nondeterminism

without internal nondeterminism

divergence finitely observable



Wrapping up the intro

- **1. Secure interoperability with lower-level code**
  - **exploring a continuum, security vs efficiency tradeoff**

- **We're hiring! now!**
  - **PostDocs, Young Researchers,** Interns, PhD students

Plan for the rest of this course

- **0. Compiler correctness**
  - as Trace Property Preservation
- **1. Secure interoperability with lower-level code**
  - Secure 2-Compartmentalizing Compilation as **Robust** Property Preservation
  - Property ∈ **Trace Properties**, Hyperproperties, Relational ...
- **2. Secure compilation despite dynamic compromise**
  - Compartmentalizing Compilation for **Unsafe Languages**
  - Restricting the temporal + spatial scope of **undefined behavior**


And pay no attention to the little man behind the curtain...