When Good Components Go Bad

What are the security guarantees of compartmentalization?

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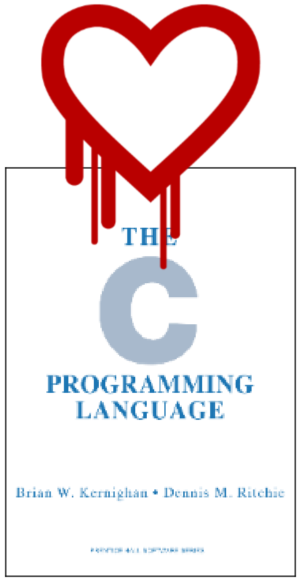
HOPE Project

Devastating low-level vulnerabilities

- **Languages like C/C++ sacrifice security for efficiency**
  - **type and memory unsafe**:
    - e.g. any buffer overflow is catastrophic
  - **root cause**, working on fixes, but it's challenging:
    - efficiency
    - precision
    - scalability
    - backwards compatibility
    - deployment



Compartmentalization = Practical mitigation

- **Main idea:**
  - break up security-critical applications into **mutually distrustful components** with clearly specified privileges
- **Enforce components can only interact in a safe way**:
  - component separation, call-return discipline, ...
- **... by building secure compilation chain:**
  - compiler, linker, loader, runtime, system, hardware
- **... targeting various mechanisms:**
  - **tagged architecture (micro-policies)**
  - **software fault isolation (SFI)**
  - hardware enclaves (SGX)
  - capability machines (CHERI)

What are the security guarantees of compartmentalization?

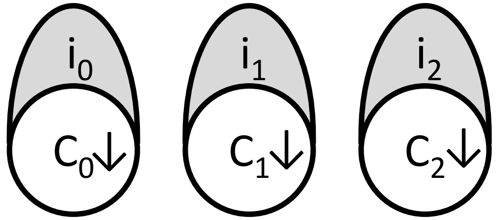
Challenge

- **Source reasoning**
  = want compartmentalization to enable reasoning formally about security with respect to source language semantics
- **Undefined behavior**
  = can't be expressed at all by source language semantics!
- **Many different examples in a usual C compiler**
  - **out of bounds array accesses**
  - **use after frees and double frees**
  - **invalid unchecked casts**
  - **(often even) signed integer overflows,**
  - **...**

Restricting undefined behavior

- **Limit spatial scope** of undefined behavior
  - **mutually-distrustful components**
    - **each component protected from all the others,**
      in particular from already compromised components
- **Limit temporal scope** of undefined behavior
  - **dynamic compromise**
    - **each component gets guarantees**
      as long as it has not encountered undefined behavior
    - i.e. the mere existence of vulnerabilities doesn't immediately make a component compromised

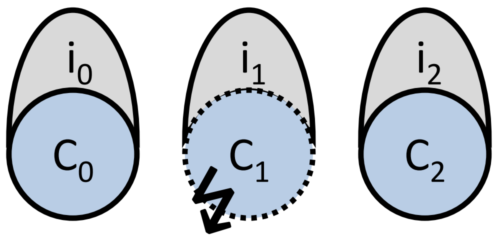
∀attack trace t, if



$\rightsquigarrow t$ then

∃ a **dynamic compromise scenario** explaining t in source language
... for instance:

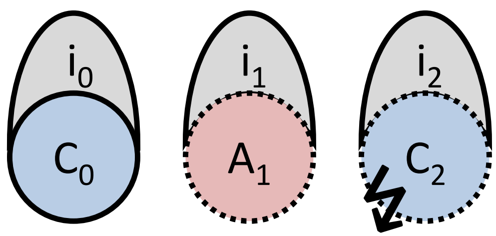
(0)



$\rightsquigarrow^* m_1;\mathrm{Undef}(C_1)$

$\leq$

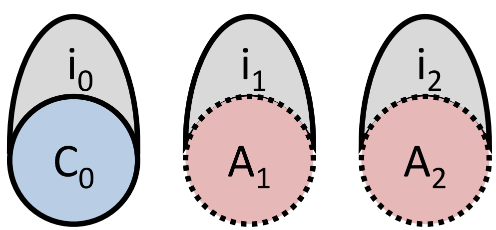
(1) $\exists A_1.$



$\rightsquigarrow^* m_2;\mathrm{Undef}(C_2)$

$\leq$

(2) $\exists A_2.$



$\rightsquigarrow t$

Building secure compilation chain

(mostly) **Verified** in Coq

Compartmentalized unsafe source

Buffers, procedures, components interacting via **strictly enforced interfaces**

↓

Compartmentalized abstract machine

Simple RISC abstract machine with **build-in compartmentalization**

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Micro-policy machine | **Bare-bone machine** (software fault isolation)

Systematically tested (with QuickChick)

When Good Components Go Bad (arXiv:1802.00588)