Compiling a secure variant of C to capabilities

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Dagstuhl Seminar on Secure Compilation

How to keep C variables in RAM in a secure way?

Your intentions may be noble, but they are also misguided. The short answer is that there's really no way to do what you want on a *general purpose* system (i.e. commodity processors/motherboard and general-purpose O/S).

https://stackoverflow.com/questions/16500549/how-to-keep-c-variables-in-ram-securely

No data isolation in C

Data isolation is needed to be able to reason about security invariants.

C semantics does not require any isolation guarantee.

Data isolation?

We mean private state.

Only specific functions should be given access to specific pieces of data.

A programmer may rely on isolation to reason about security while still using untrusted libraries.

Example I

Private state in a C program

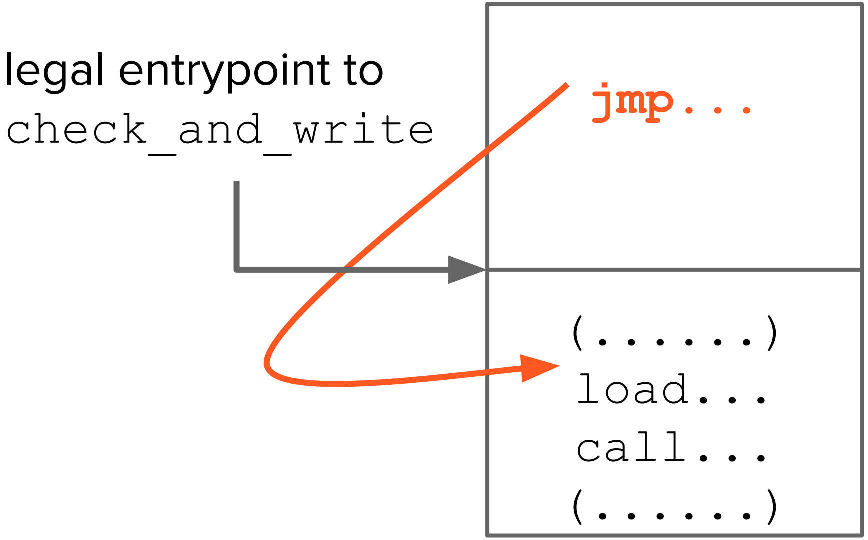
Safe fine-grained sharing while still maintaining the privacy of access to **b**:

```
int a;
int b;  //private variable

int f() {
    context_f(&a);
    ...
```

Example II

Private state in a C program,
control flow violation




```c
int secret;

// check then write secret
int check_and_write(t* f)
{
    if (check(f)) {
        write(f, secret);
    }
}
```

Approach

1. C-like language with **module isolation**

2. Compile this language to a **capability machine model**.

3. **Prove** that this translation is secure (**fully abstract**).

A secure variant of C

or a restricted subset of C

Modules as units of isolation

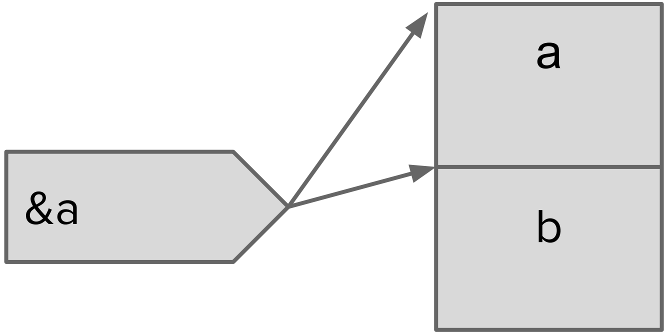
Functions within a module can access its global variables.

Jumping into the middle of functions is prohibited by design.

A variant of Clight, with regards to how we represent spatial memory safety

Example I revisited

- Compile pointers as capabilities.
- Sharing a pointer corresponds to sharing a restricted capability.



Safe fine-grained sharing while still maintaining the privacy of access to **b**:

```
int a;
int b;  //private variable

int f() {
    context_f(&a);
    ...
```

Example II revisited

- CHERI also features code capabilities.
- But it offers more..

- Sealed capabilities authorize access to code and data only by means of a trusted calling mechanism.
- The calling mechanism manages a trusted call stack.

```
int secret;

// check then write secret
int check_and_write(t* f)
{

    if (check(f)) {

        write(f, secret);

    }

}
```

Fully-abstract translation

Color code

Source

Target

Fully-abstract Translation $\downarrow$

$\forall P_1\, P_2$

$\forall C_S.\ C_S[P_1] \approx C_S[P_2]$

$\leftrightarrow$

$\forall C_T.\ C_T[P_1\downarrow] \approx C_T[P_2\downarrow]$

P_i: source program

$P_i\downarrow$: compiled program

Two arbitrary programs are equivalent iff their translations are equivalent

Preservation of contextual equivalence

$\forall P_1\, P_2$

$\quad \forall C_S.\; C_S[P_1] \approx C_S[P_2]$

$\rightarrow$

$\quad \forall C_T.\; C_T[P_1{\downarrow}] \approx C_T[P_2{\downarrow}]$

P_i: source program

$P_i{\downarrow}$: compiled program

Contextually-equivalent source programs remain so after translation.

Back-translation to prove preservation

$\forall P_1 P_2$

$\exists C_T. C_T[P_1{\downarrow}] \nsimeq C_T[P_2{\downarrow}]$

$\rightarrow$

$\exists C_S. C_S[P_1] \nsimeq C_S[P_2]$

P_i: source program

$P_i{\downarrow}$: compiled program

A distinguishing target context should exist only if there were a source one.

Traces soundness, then back-translation

$\forall P_1\ P_2$

$\exists C_T.\ C_T[P_1{\downarrow}] \not\approx C_T[P_2{\downarrow}]$

$\rightarrow$

$Tr(P_1{\downarrow}) \not\approx_{TR} Tr(P_2{\downarrow})$

$\rightarrow$

$\exists C_S.\ C_S[P_1] \not\approx C_S[P_2]$

P_i: source program

$P_i{\downarrow}$: compiled program

Abstracting target equivalence

by introducing trace equivalence

A trace semantics captures the interaction of a component.

Trace actions record sandbox switching and the status of shared memory.

Two compiled programs that have equal sets of traces are proved to be contextually equivalent.

Trace label example

`“call? f(5), M, alloc”`

Actions are calls or returns.

Argument values and shared memory

Allocator status is also observable

Conclusion and Future

- **Translate fully-abstractly** a C-like source language to a target language that abstracts the capability instruction set.

- Source-to-source transformation that **automates the initialization of sandboxes**

- Work on Compositional CompCert -- or a similar infrastructure for fully-abstract compilation proofs?

Thanks!

Questions and comments

References

1. https://www.cl.cam.ac.uk/research/security/ctsrd/pdfs/20140114-ctsrd-pimeeting.pdf
2. http://www.cl.cam.ac.uk/techreports/UCAM-CL-TR-907.pdf
3. Blazy, Sandrine, and Xavier Leroy. "Mechanized semantics for the Clight subset of the C language." *Journal of Automated Reasoning* 43.3 (2009): 263-288.
4. Watson, Robert NM, et al. "Cheri: A hybrid capability-system architecture for scalable software compartmentalization." *Security and Privacy (SP), 2015 IEEE Symposium on*. IEEE, 2015.
5. Abadi, Martín. "Protection in programming-language translations." *Secure Internet programming*. Springer, Berlin, Heidelberg, 1999. 19-34.
6. Abadi, Martın, Cédric Fournet, and Georges Gonthier. "Secure implementation of channel abstractions." *Information and Computation* 174.1 (2002): 37-83.