Linear capabilities for fully abstract compilation of separation-logic-verified code

Thomas Van Strydonck Dominique Devriese Frank Piessens

KU Leuven

thomas.vanstrydonck@cs.kuleuven.be

July 20, 2018

Linear capabilities for
fully abstract compilation of
separation-logic-verified code

Overview

1. Full abstraction

2. Full abstraction for verified code

3. Compilation by example

4. Conclusion and future work

Outline

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2. Full abstraction for verified code
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Full abstraction (FA)

Intuition

Attacking the compiled code is as hard as attacking the source code

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Definition of FA

$=$ reflection and preservation of contextual equivalence $\simeq_{ctx}$

$$s \simeq_{ctx} s' \Leftrightarrow [\![s]\!] \simeq_{ctx} [\![s']\!]$$
$$\text{where } x \simeq_{ctx} x' \equiv \forall C : C[x] \Downarrow \Leftrightarrow C[x'] \Downarrow$$

$\supseteq$ preservation of integrity and confidentiality properties

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$\supseteq$ preservation of integrity and confidentiality properties

Methodology: Change the source code by $[\![\cdot]\!]$ + prove FA

$\Rightarrow$ Change does not alter security aspects

eg. CFI, notion of private fields, ...

Outline

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2. Full abstraction for verified code

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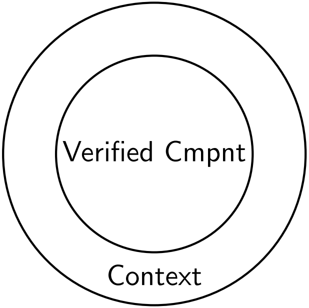
4. Conclusion and future work

Problem: Preserving verification during compilation

- Separation logic in verification tools
  - Sound
  - Modular
- **Problem**: guarantees *lost* in untrusted context
- **Solution**: compiler enforces separation logic contracts

  FA is exactly what we need!



Linear capabilities for
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Separation Logic

- Substructural logic (linear aspects)
- Program verification
  - Sound
  - Modular
- Contract-based, eg. :

```
void p(int x,int *data)
//@pre data ↦ _ * x > 0;
//@post data ↦ x;
{*data = x}
```

Notation:

- $*$, $\mapsto$ (resource: permission)
- @pre/post: contract
  Consume/produce
- Array resource notation:
  $\mapsto[a_1, \ldots, a_n]$

- Hoare-logic-style program proofs: $\Rightarrow \{P\}\ c\ \{Q\}$
  Functions: $\{@pre\}\ BODY\ \{@post\}$

Motivating example

	Verified Component	Context Declaration

Source	`void f(int* a)`
	`//@pre n: a ↦ [0]`
	`//@post n : a ↦ [1]`
	`{`
	`   id(a);`
	`   a[0]=1;`
	`}`
		`void id(int* a)`
		`//@pre n: a ↦ [0]`
		`//@post n : a ↦ [0]`

- SOA: compilers erase contracts
- Untrusted function *id* can:
  - Overread/-write using *a*, copy *a*
  - Not satisfy postcondition (eg. $a[0] = 2$)
- **NOT fully abstract!**

The compiler

Source language

- Regular verified C code
- *Separation logic* annotated

Target language

- Regular unverified C code
- **Language enhancement to allow full abstraction???**

No assembly hassle in C, but still unsafe (powerful attacker).

What (language) enhancements do we need?

	Verified Component	Context Declaration

Source	`void f(int* a)`
	`//@pre n: a ↦ [0]`
	`//@post n : a ↦ [1]`
	`{`
	`  id(a);`
	`  a[0]=1;`
	`}`
		`void id(int* a)`
		`//@pre n: a ↦ [0]`
		`//@post n : a ↦ [0]`

Recall, *id* can:

- Overread/-write using a, copy a
  - $\Rightarrow$ **Capabilities** implement POLA
  - $\Rightarrow$ **Linear Capabilities** prevent copying
- Not satisfy postcondition (eg. $a[0] = 2$)
  - $\Rightarrow$ **Checking functions aka. stubs**

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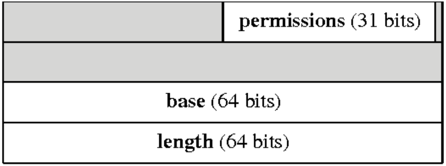
(Linear) Capabilities

Capability:

- Unforgeable memory pointer
- Grants permissions on memory region
- Fine-grained memory protection
- Capability machines (ex CHERI)



Linear Capability:

- Linearity = one-use! cfr e.g. Linear Logic
- Non-copyable $\Rightarrow$ callees cannot keep copies
- Intuitive: separation logic is linear

Goal: proving that contracts are compiled away safely by proving full abstraction

Source language

- Regular verified C code
- *Separation logic* annotated
  - e.g. VeriFast syntax for concreteness

FA!

Target language

- Regular unverified C code
- Support for *capabilities*
  - CHERI-inspired
  - Linear capabilities

Related work (Agten et al.)

- Different hardware primitives
  $\Rightarrow$ Less fine-grained
- Integrity, *not* confidentiality

Outline

Compilation: Intuition

- Resources reified into linear capabilities
  - Behave linearly
  - Contain all permissions
  - This is why we **name** heap resources!
- Original pointers become addresses
  - Regular ints[1]
  - Lose all permission
  - Kept for address operations

```
//{c1: n ↦ [1,2,3]}
n: int*
```

⬇

```
c1: int* (linear)
 n: int
```

$\Rightarrow$ *Separation-logic-proof-directed*:

- **proof of** input program used as input
- compiled operations on resources, eg. $a[0] \Rightarrow_{[\![\cdot]\!]} n[0]$

[1] This is a slight simplification

Motivating example: overread/overwrite/copy

	Verified Component	Context Declaration

Source	`void f(int* a)`
	`//@pre n: a ↦ [0]`
	`//@post n : a ↦ [1]`
	`{`
	`  id(a);`
	`  a[0]=1;`
	`}`
		`void id(int* a)`
		`//@pre n: a ↦ [0]`
		`//@post n : a ↦ [0]`

Target	`int* f(int a,int* n)`
	`{`
	`  n = id(a,n);`
	`  n[0]=1;`
	`  return n;`
	`}`
		`int* id(int a,int* n)`

Prevented by: Linear capabilities + Proof-directed-compilation

Motivating example: postcondition

	Stub	Context Declaration

Source		`void id(int* a)`
		`//@pre n: a ↦ [0]`
		`//@post n : a ↦ [0]`

Target	`int* id_stub(int a,int* n)`
	`{`
	`  n = id(a,n);`
	`  assert(a == addr(n));`
	`  assert(len(n) == 1);`
	`  assert(n[0] == 0);`
	`  return n;`
	`}`
		`int* id(int a,int* n)`

Prevented by: stub

Outline

Conclusion

- Compiler from verified C to unverified C with (linear) capabilities
- **Proven**: Full Abstraction

Fully abstractly compiling Rust (IDEA STAGE)

- Ownership and borrowing; linear aspects
  $\Rightarrow$ Compile borrows to linear capabilities
- Start from λ_{Rust} in RustBelt