Melocoton

A Program Logic for Verified Interoperability Between OCaml and C

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Multi-Language Programs Are Everywhere

NumPy

Python

C

Fortran

Firefox

C++

Rust

JavaScript

OpenSSL

Cryptography and SSL/TLS Toolkit

C

Bindings for:

- Rust
- Python
- OCaml
- Go
- ...

The Goal: Verifying Multi-Language Programs

How do we

verify functional correctness

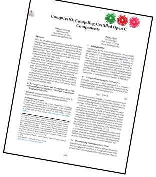
of programs written in

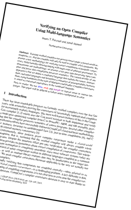
different languages?

Single-Language Functional Correctness

Hoare Logic for simple imperative languages.

Separation Logic for modularity and aliasing.





Multi-Language Functional Correctness

Existing work on Semantics and Logical Relations.

How do we prove functional correctness of individual, potentially unsafe programs?

A Multi-Language Program in OCaml and C

OCaml business logic

```
let main () =
  let r = ref 42 in
  hash_ref r; (*written in C*)
  print_int !r
```

C business logic

```
void hash_ptr(int * x) {
    // Implemented in OpenSSL
    // tedious to port to OCaml
}
```

OCaml glue code

```
external hash_ref
  : int ref -> unit
  = "caml_hash_ref"
```

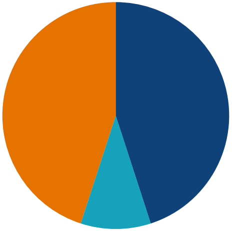
C glue code

```
value caml_hash_ref(value r) {
    int x = Int_val(Field(r, 0));
    hash_ptr(&x);
    Store_field(r, 0, Val_int(x));
    return Val_unit;
}
```

A Schematic Multi-Language Program

Most multi-language programs look like this:

OCaml business logic
oblivious of C



C business logic
oblivious of OCaml

glue code
where the languages actually interact

We Need to Reason Language-Locally!

Our Contribution: Melocoton

Common Approach: program logic on top of semantics, **but**

- **Language Interaction:** new semantics and logic for glue code
- **Language Locality:** embed existing semantics and logics

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*simplified/idealized versions of **OCaml** and **C**

Language Interaction: Different Views of the Same Data

OCaml glue code

```
external hash_ref
  : int ref -> unit
  = "caml_hash_ref"
```

C glue code

```
value caml_hash_ref(value r) {
    int x = Int_val(Field(r, 0));
    hash_ptr(&x);
    Store_field(r, 0, Val_int(x));
    return Val_unit;
}
```

How is **OCaml** data accessed from **C** glue code?

High-level **OCaml** values are accessed..
..through a low-level **block** representation.

Language Interaction: Semantics

High-level **OCaml** value	$\sim_{\mathtt{ML}}$	Low-level **block** representation
integers	$\sim_{\mathtt{ML}}$	integers
booleans	$\sim_{\mathtt{ML}}$	integers (0 or 1)
arrays, refs	$\sim_{\mathtt{ML}}$	blocks
pairs	$\sim_{\mathtt{ML}}$	blocks (of size 2)
lists	$\sim_{\mathtt{ML}}$	block-based linked lists

true $\sim_{\mathtt{ML}}$ $\mathit{1}$

$\ell \sim_{\mathtt{ML}} \gamma$

$\lambda_{\mathtt{ML+C}}$ **Semantics**

$$\sigma : \mathit{Heap}_{\mathtt{ML}} \rightleftarrows \zeta : \mathit{BlockHeap}$$

switch at the language barrier

Language Interaction: Program Logic, Take 1

all the $\ell \mapsto_{\mathrm{ML}} \vec{V}$

$\lambda_{\mathrm{ML+C}}$ **Program Logic**

all the $\gamma \mapsto_{\mathrm{blk}} \vec{v}$

$\lambda_{\mathrm{ML+C}}$ **Semantics**

$\sigma \; : \; Heap_{\mathrm{ML}}$ ⇄ $\zeta \; : \; BlockHeap$

ExtCall

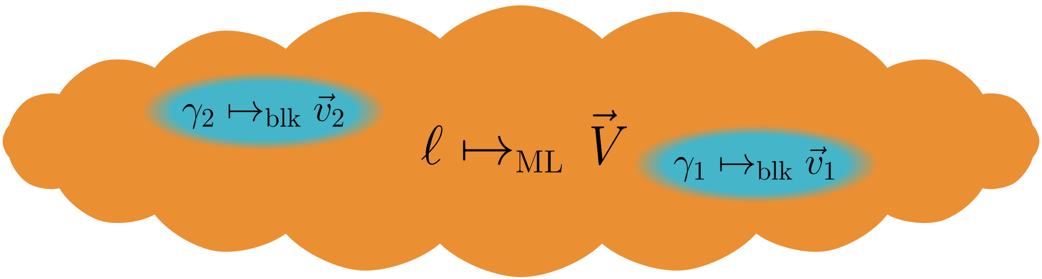
$$\frac{\{\text{all}\}\ \textbf{C}\text{ function body}\ \{\text{all}\}}{\{\text{all}\}\ \text{call into }\textbf{C}\ \{\text{all}\}}$$

Frame

$$\frac{\{P\}\ \text{call into }\textbf{C}\ \{Q\}}{\{\ell \mapsto_{\mathrm{ML}} \vec{V} * P\}\ \text{call into }\textbf{C}\ \{Q * \ell \mapsto_{\mathrm{ML}} \vec{V}\}}$$

Language Interaction: More Gradual Rules

OCaml points-tos *remain valid* when switching to **C**!



View Reconciliation Rules for Converting On-Demand:

$$\ell \mapsto_{\text{ML}} \vec{V} \;\Rrightarrow\!\ast\; \exists \gamma \vec{v}.\, \gamma \mapsto_{\text{blk}} \vec{v} * \ell \sim_{\texttt{ML}} \gamma * \vec{V} \sim_{\texttt{ML}} \vec{v}$$

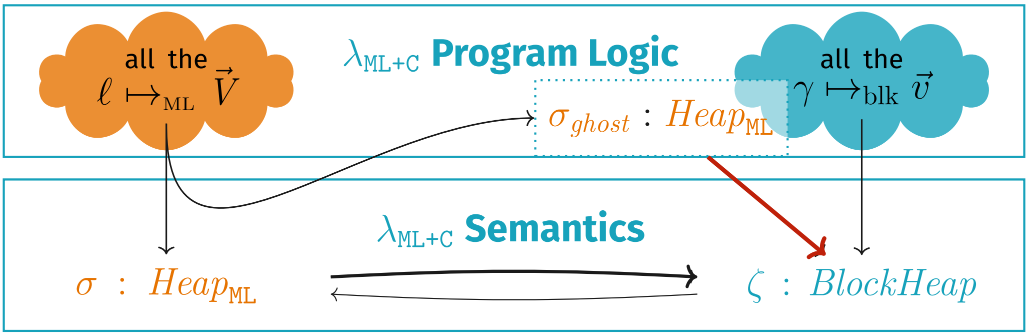
$$\vec{V} \sim_{\texttt{ML}} \vec{v} * \gamma \mapsto_{\text{blk}} \vec{v} \;\Rrightarrow\!\ast\; \exists \ell \;.\, \ell \mapsto_{\text{ML}} \vec{V} * \ell \sim_{\texttt{ML}} \gamma$$

Language Interaction: View Reconciliation

View Reconciliation Rules

$$\ell \mapsto_{\mathrm{ML}} \vec{V} \Rrightarrow\!\!\ast\ \exists \gamma \vec{v}.\ \gamma \mapsto_{\mathrm{blk}} \vec{v} * \ell \sim_{\mathtt{ML}} \gamma * \vec{V} \sim_{\mathtt{ML}} \vec{v}$$

$$\vec{V} \sim_{\mathtt{ML}} \vec{v} * \gamma \mapsto_{\mathrm{blk}} \vec{v} \Rrightarrow\!\!\ast\ \exists \ell.\ \ell \mapsto_{\mathrm{ML}} \vec{V} * \ell \sim_{\mathtt{ML}} \gamma$$



More in the paper …

- Language-local reasoning for **external calls**.
- Additional **OCaml FFI features**: garbage collection, registering roots, custom blocks, callbacks, etc.
- **Case studies** utilising all of these features.
- **Step-indexed logical relation** to prove OCaml type safety of external C functions.

Transfinite Iris

Our Contribution: Melocoton

Language Locality: Embed Existing Languages

OCaml Program Logic	$\lambda_{\text{ML+C}}$ **Program Logic** Glue Code Verification	C Program Logic
OCaml Semantics	$\lambda_{\text{ML+C}}$ **Semantics** Glue Code Semantics	C Semantics

Language Interaction: View Reconciliation Rules

$$\ell \mapsto_{\text{ML}} \vec{V} \;\Rrightarrow\!\!\ast\; \exists \gamma \vec{v}.\, \gamma \mapsto_{\text{blk}} \vec{v} * \ell \sim_{\text{ML}} \gamma * \vec{V} \sim_{\text{ML}} \vec{v}$$

$$\vec{V} \sim_{\text{ML}} \vec{v} * \gamma \mapsto_{\text{blk}} \vec{v} \;\Rrightarrow\!\!\ast\; \exists \ell .\, \ell \mapsto_{\text{ML}} \vec{V} * \ell \sim_{\text{ML}} \gamma$$

https://melocoton-project.github.io