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Code Generation

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Internals of The Code Generator

Imperative Code

Getting Rid of the Translation: Isabelle_LLVM

Getting Rid of the Translation and the Compiler: Targetting CakeML

Conclusion

Aim

- Generate code from an Isabelle function, with same behavior
- The code should perform reasonably
- The code should be reasonable
- The code should be correct (for some definition of correct)

3 Flavors of Code-Generation

- export existing functional HOL functions
  - How? Just write functions
- export HOL_Imperative functions in imperative code (using existing code generation)
  - How? Just write functions in the HOL_Imperative
  - Or use Sepref to synthesize the function from the non-determinism HOL
- export Isabelle_LLVM to generate (without using existing code generation)
  - How? Use the other Sepref to synthesize the function from the other non-determinism exception HOL

Key difference: Isabelle abstracts over the semantics of imperative code. So sometimes not matching, like arr[INT128_MAX].

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One Example

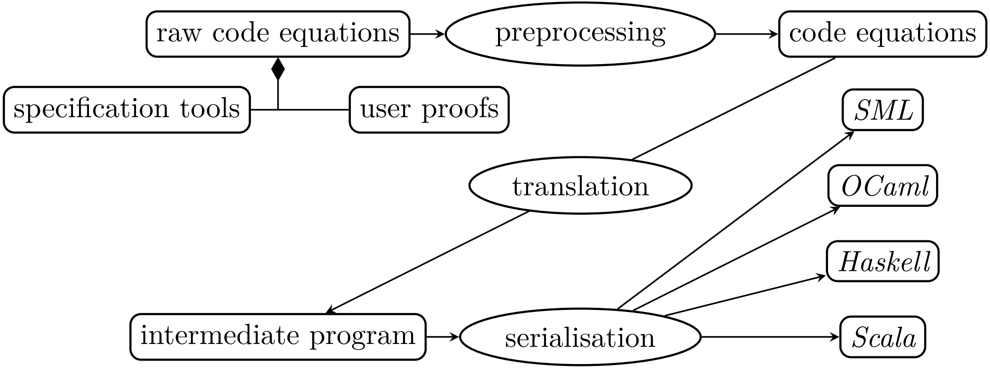
```
fun fib :: ‹nat ⇒ nat› where
  ‹fib 0 = 0› |
  ‹fib (Suc 0) = 1› |
  ‹fib (Suc (Suc n)) = fib (Suc n) + fib n›
```

```
export-code fib in SML
```

Now import HOL−Library.Code-Abstract-Nat or HOL−Library.Code-Binary-Nat and see the difference!

Internals of The Code Generator

General Infrastructure [Haftmann, PhD thesis]



raw code equations

preprocessing

code equations

specification tools

user proofs

translation

intermediate program

serialisation

SML

OCaml

Haskell

Scala

Dictionary Construction

```
fun test :: ‹'a :: order ⇒ 'a :: order ⇒ bool› where
  ‹test a b = (a < b)›
```

The translation becomes:

```
definition test-SML :: ‹'a  ⇒ 'a ⇒ bool› where
  ‹test-SML a b = (less-operator information-on-α a b)›
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and pass information-on-α to each function.

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Intermediate Language

The intermediate language has 4 constructors: datatypes, fun, class, and inst.

Correctness

Theorem

The translation is correct if for any input, it fails or yields a compatible output.

Pretty-Printing

Finally, translation to target language is so simple that it is trusted.

If:

- the code setup is correct
- you do not violate the assumptions of the code setup
- the semantic the developer has in mind matches the compiler semantic

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Calling the Code Generator

eval is actually calling the code generator...
And you assume that it is correct because you can use the result.
Lochbihler has found a bug in the word implementation [ITP'18].

Imperative Code

Modelization

Idea:

1. Program depends on a polymorphic heap where you can put content
2. heap operations are automatically mapped by the code generator.

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Code Generation

```
definition f :: ‹nat ⇒ -› where
‹f x = do {
  a ← Array.new x (5::nat);
  a ← Array.upd 1 2 a;
  x ← Array.nth a 1;
  (if x = 0 then return a else Array.upd 1 2 a)
}›
```

```
export-code f in SML-imp
  module-name F — Do not forget to name the target module, or you get a very weird error message.
```

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Most people generating efficient code use Sepref that can transform a functional code on list into an array.

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Sepref

Quick idea:

1. Annotate you program with assertion.
2. Let Sepref translate data structures and program flow into imperative code

```
term
 ‹g xs n = do {
    ASSERT (n ≤ length xs);
    return (xs ! n)
  }›
```

Compiler

Many SML compilers out there... but for imperative code you should use MLton.
I tried at some point IsaSAT in PolyML (like Isabelle), MLton, Scala, and OCaml.
MLton one order of magnitude faster.

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Getting Rid of the Translation: Isabelle_LLVM

What is the Idea? [Lammich, ITP 19]

Idea:

1. have a modelization of the LLVM IR semantics
2. let Sepref generate LLVM IR
3. trivial pretty-printer!

Drawbacks

But: LLVM IR is purely imperative, so instead map ((+) (1::'a)) create a constant map-add-1 with a loop.

Also: no GMP integers.

This change alone made my SAT solver twice as fast.

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There is no some parallelization based on splitting arrays into 2.

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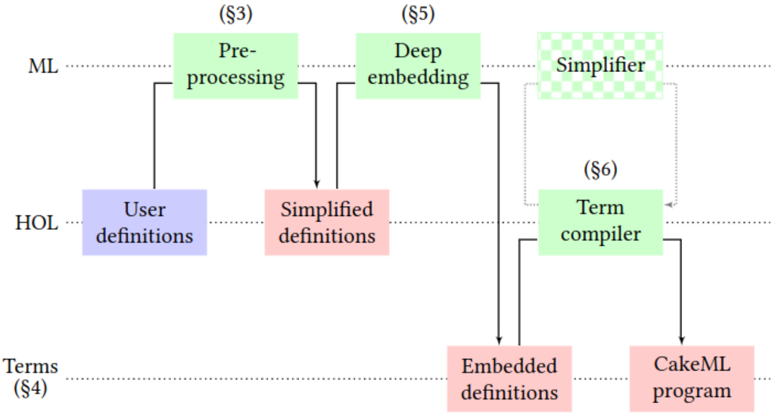
Getting Rid of the Translation and the Compiler: Ta

Idea [Hupel PhD thesis]

Verify the standard code generator approach.
And target the verified compiler CakeML, via Lem to translate the semantics.

Idea



green	implemented as part of this thesis (checkered: already available in Isabelle)
blue	specified by user
red	generated object

Issues

- Very slow
- No support for Imperative code
- no native types, like machine words

Conclusion