Implementation of a Pragmatic Translation from Haskell into Isabelle/HOL

Patrick Bahr
pa-ba@arcor.de

NICTA

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Outline

1. Introduction

2. Existing Implementation

3. Extensions to the Implementation
    - Translating Further Language Features
    - Useful Techniques

4. Summary

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Motivation

seL4

- Prototype implementation in Haskell.
- Executable model in Isabelle/HOL for verification.

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No Theorem Prover for Haskell

- Haskell allows easy reasoning about its semantics.
- no theorem prover to automate this

Isabelle/HOL as Target Language

Benefits

- automated translation is simpler
- resulting translation is close to original Haskell code
- reasoning in HOL is easier (than in HOLCF)

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Drawbacks

- translation is not complete
- translation is not sound
- issues:
  - comprehensive language features (e.g. type system)
  - non-strictness

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Design of the Implementation

The translation is performed in six steps:

- Parsing
- Preprocessing
- Analysis
- Conversion
- Adaption
- Printing

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Preprocessing

- Guards are transformed into if-then-else expressions.
- Local function definitions are transformed into top-level function definitions.
- As-patters are transformed into additional nested pattern matches.
- Keywords and identifiers defined in the Isabelle/HOL library are renamed.

Conversion

- Definitions are reordered according to their dependencies.
- Haskell syntax trees are translated into Isabelle/HOL syntax trees.

Translation in a (Very Small) Nutshell

function bindings ↦ **`fun`**

simple pattern bindings ↦ **`definition`**

data type declarations ↦ **`datatype`**

type class declararions ↦ **`class`**

instance declarations ↦ **`instantiation`**

Issues of the Implementation

Things that are not Supported

- data types with field labels
- closures of local function definitions
- constructor type classes (+ multi-parameter type classes)
- irrefutable patterns

Things that Go Wrong

- Dependencies on data types are ignored.
- The translation of as-patterns is unsound.

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Our Contributions

- translation of data types with labelled fields
- translation of closures
- heuristic to translate monadic programs
- infrastructure to customise the translation
- dependencies on type definitions are respected
- sound translation of as-patterns*
- testing framework

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▸ Jump to Details
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▸ Skip Details

Data Types with Labelled Fields

Haskell

```
data MyRecord = A { aField1 :: Int,
                    aField2 :: String,
                    common  :: Char }
              | B { bField1 :: Bool,
                    bField2 :: Int,
                    bField3 :: Int,
                    common  :: Char }
              | C Bool Bool String
```

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Isabelle/HOL

```
datatype MyRecord = A int string char
                  | B bool int int char
                  | C bool bool string
```

Fields as Selection Functions

```
primrec aField1 :: "MyRecord => int"
where
  "aField1 (A x _ _) = x"

primrec common :: "MyRecord => char"
where
  "common (B _ _ _ x) = x"
| "common (A _ _ x) = x"

     ⋮
```

Related Syntax

Construction

Haskel

```
constr :: MyRecord
constr = A{ aField1 = 1, common = '2'}
```

Related Syntax

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```
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Isabelle/HOL

```
definition constr :: "MyRecord"
where
  "constr = A 1 arbitrary CHR ''2''"
```

Related Syntax

Updates

Haskel

```
update :: MyRecord -> MyRecord
update x = x{aField2 = "foo"}
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Isabelle/HOL

```
fun update :: "MyRecord => MyRecord"
where
  "update x = (case x of
                   A v1 v2 v3
                     => A v1 ''foo'' v3
                 | _ => arbitrary)"
```

Related Syntax

Pattern Matching

Haskel

```
pattern :: MyRecord -> Int
pattern A{aField1 = val} = val
pattern B{bField3 = val} = val
pattern (C v1 v2 v3) = 1
```

Related Syntax

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Isabelle/HOL

```
fun pattern :: "MyRecord => int"
where
  "pattern A val _ _ = val"
| "pattern B _ _ val _ = val"
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- functions can be defined locally using `where` and `let`
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But

- Locally defined function can refer to free variables only bound in the local context.
  $\Rightarrow$ Closure
- The transformation has to make the environment of the closure explicit.

An Example

Haskell Definition of Several Closures

```
func x y = sum x + addToX y   -- closure:
    where addToX y = x + y    --  x
          addToY x = x + y    --  y (+ x)
          w = addToY x
          sum y = w + y       --  x (+ y)
```

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```

Transformed Top-level Definitions

```
  addToX' x y = x + y
  addToY' (_, y) x = x + y
  sum' env y = let (x, _) = env
                   w      = addToY' env x
               in w + y
```

An Example

The Final Result

```
addToX' x y = x + y
addToY' (_, y) x = x + y
sum' env y = let (x, _) = env
                 w      = addToY' env x
             in w + y
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An Example

The Final Result

```
addToX' x y = x + y
addToY' (_, y) x = x + y
sum' env y = let (x, _) = env
                 w      = addToY' env x
              in w + y

func x y = let addToX = addToX' x
               addToY = addToY' (x, y)
               sum    = sum' (x, y)
               w      = addToY x
            in sum x + addToX y
```

Coping with Large Data Types

Dealing with syntax trees ⇒ dealing with large data types.

Data Types Defining Haskell Syntax Trees

- 500 lines of Haskell code
- 51 data types
- “largest” data type contains 45 constructors

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- If you have to write it you only want to write it once!

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  ⇒ **Generic Programming + Code Generation**
- If you have to write it you only want to write it once!

  ⇒ **Modularity**

Testing with QuickCheck

QuickCheck

- allows to specify and test algebraic properties
- needs generators that produce random test data
- tests properties by generating a value for each universally quantified element
- uses type system to get the right generator for each type

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Generators for Data Types

- randomly choose a constructor,
- generate values for the argument of the constructor, and
- combine the results

Template Haskell

Extension to Haskell that allows to generate Haskell code at compile time.

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Using Template Haskell to Define Test Data Generators

We implemented a library of Template Haskell functions that allow

- to define most generators in one line, and
- to customise the defined generators.

Generic Programming

“Scrap Your Boilerplate”

Problem Addressed by SYB

- traverse a data structure to transform or query it
- only a few parts of the data structure are relevant

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Example

- compute free variables of an expression
- transform `where` clauses into `let` expressions

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Example

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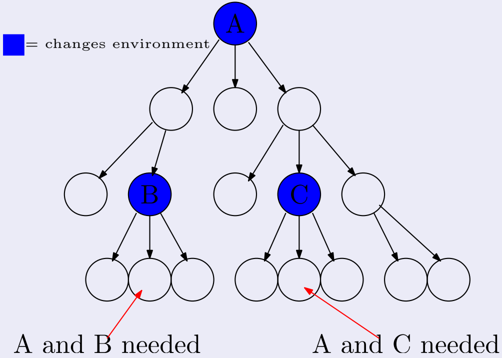
Difficulties when Applying SYB in our Setting

- often context information is necessary
- We want to define a piece of context information only once.

Environments

Data Structure as a Tree



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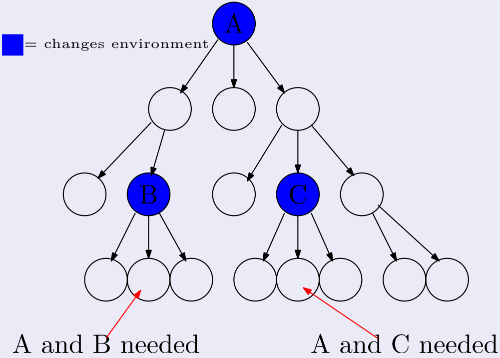

Defining Environments by `a -> (e -> e)`

- a is the type of the current node
- e is the type of the environment

Extending SYB by Environment Propagation

Extension to SYB

- allows to define environments
- allows to combine environments
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Generalisation of Environment Propagation

- non-uniform propagation
- monadic computations to define an environment

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Loose Ends

- circular dependencies between modules
- applying the translation to seL4.

Thank you!