Intel Labs Haskell Research Compiler

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An alternative Haskell compiler that:

- uses GHC as frontend;
- does whole program compilation;
- achieves overall performance parity with GHC+LLVM;
- is significantly better for some programs;
- does automatic SIMD vectorization for Intel CPUs.

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- has a set of different design decisions;
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We re-purposed an existing FL compiler and runtime that:

- has a set of different design decisions;
- makes an interesting comparison to GHC.

Known Limitations:

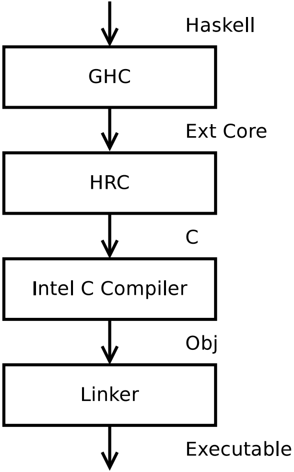
- No lightweight threads, sparks, or STM (easy);
- No exception re-throw for thunks (fixable);
- No asynchronous exceptions (hard).

Functionality

HRC is highly compatible to GHC:

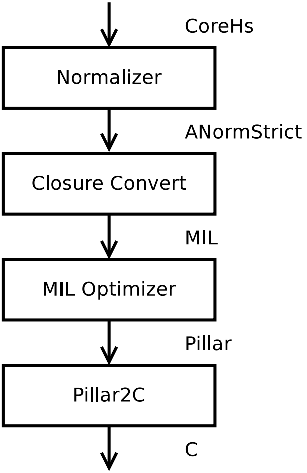
- Modified GHC and base libraries to handle differences;
- Modified Vector library to use initializing writes;
- Modified Cabal to compile for HRC;
- Little or no modifications to most other libraries.

Compilation Process



Inside HRC Pipeline

CoreHs	functional, non-strict
ANormStrict	ANF, strict explicit thunk/eval
MIL	CFG/SSA based high-level object
Pillar	inspired by C−− variant of C



Comparison to GHC

GHC		HRC	
Desugaring Type analysis Core-to-Core transformation			
STG	Functional, object memory model, optimized for currying and thunks	MIL	CFG/SSA based, object memory model, conventional
Cmm	CFG blocks, low-level types, and custom calling convention	Pillar	C types, C calling convention meta and GC support
LLVM or NCG	Portable LLVM bitcode, or direct assembly generation	Intel C/C++ Compiler	Portable C code compiled to assembly
Runtime and GC	Optimized for currying and thunks	Runtime and GC	Conventional

MIL

- High level object model with low level control flow
- Leveraging immutability and memory safety
- Data flow and control flow analysis
- Inter- and intra- procedural optimizations
- Representation/contification/loop/thunk optimizations
- SIMD auto vectorization

Immutable Array

GHC creates an immutable array by:

- creating a mutable array;
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HRC separates array creation and initialization, with primitives to:

- create immutable array
- do initializing writes
- read

Programmers must ensure:

- an array field is written to before it is read;
- a field is never written to more than once.

Walkthrough by Example

$$\begin{aligned}
&\text{odd, even} :: \text{Int} \rightarrow \text{Bool}\\
&\text{odd } \mathsf{0} = \text{False}\\
&\text{odd } \mathsf{n} = \text{even } (\mathsf{n} - \mathsf{1})\\
\\
&\text{even } \mathsf{0} = \text{True}\\
&\text{even } \mathsf{n} = \text{odd } (\mathsf{n} - \mathsf{1})
\end{aligned}$$

GHC Core

```
even :: (Int → Bool) =
  \ (n :: Int) →
      %case n %of (_ :: Int)
        {I# (n1 :: Int#) →
           %case n1 %of (n2 :: Int#)
             {(0 :: Int#) → True;
              %_ → odd (I# (n2 − (1 :: Int#)))}};

odd :: (Int → Bool) =
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ANormStrict

```
even = %thunk
  %let f = \n →
    %let n0 = %eval n
    %in %case n0 of
        {I# n1 → %case n1 of
          {0 → %eval True;
           _ → %let u = %let v = %let w = 1
                                 %in n1 − w
                             i = %eval I#
                         %in i v
                     t = %thunk u
                     g = %eval odd
                 %in g t}}
  %in f;
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  %in f;
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ANormStrict (closure converted)

```
even = %thunk <I#, True, odd;>
  %let  f  = \<I#, True, odd; n> →
    %let  n0 = %eval n
    %in %case n0 of
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                                     %in  n1 − w
                                 i  = %eval I#
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MIL

```
f_code =
  Code(CcClosure(lv_I#, lv_True, lv_odd); n)
  {
     L0():     n0 ← Eval(n) ⇒ L1
     L1():     Case tagof(n0) { U32(0) ⇒ L2() }
     L2():     n1 = SumProj(n0.U32(0).0)
               Case n1 { S32(0) ⇒ L8() Default ⇒ L3() }
     L3():     v = SInt32Minus(n1, 1)
               i ← Eval(lv_I#) ⇒ L4
     L4():     u ← CallClos(i) (v) ⇒ L5
     L5():     t = ThunkMkVal(u)
               g ← Eval(lv_odd) ⇒ L6
     L6():     c ← CallClos(g) (t) ⇒ L7
     L7():     Goto L10(c)
     L8():     b ← Eval(lv_True) ⇒ L9
     L9():     Goto L10(b)
     L10(r):   Return(r)
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MIL (after Rep optimization)

```
f_code =
  Code(CcCode; n)
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    L0():   even = SInt32Eq (n, 0)
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            odd = SInt32Eq(v, 0)
            Case odd  { True ⇒ L3() False ⇒ L2() }
    L2():   w  = SInt32Minus(v, 1)
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    L4():    Return(gv_True)
  }
```

MIL (after contification)

```
f_code =
  Code(CcCode; n)
  {
    L0():   Goto L1(n)
    L1(u):  even = SInt32Eq(u, 0)
            Case even { True ⇒ L5() False ⇒ L2() }
    L2():   v = SInt32Minus(u, 1)
            odd = SInt32Eq(v, 0)
            Case odd  { True ⇒ L4() False ⇒ L3() }
    L3():   w = SInt32Minus(v, 1)
            Goto L1(w)
    L4():   Return(gv_False)
    L5():   Return(gv_True)
  }
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MIL (after arithmetic simplification)

```
f_code =
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    L1(u):   even = SInt32Eq(u, 0)
             Case even { True ⇒ L5() False ⇒ L2() }
    L2():    odd = SInt32Eq(u, 1)
             Case odd  { True ⇒ L4() False ⇒ L3() }
    L3():    w = SInt32Minus(u, 2)
             Goto L1(w)
    L4():    Return(gv_False)
    L5():    Return(gv_True)
  }
```

Benchmarking

40+ benchmark programs:

- a mixed set of programs from nofib benchmark suite;
- performance oriented programs using array libraries.

Sequential performance is measured by compiling and running on 2.7GHz Xeon machine (32-bit Windows) with:

- standard GHC 7.6.1
- GHC 7.6.1 + LLVM 2.9
- HRC with modified GHC 7.6.1 + Intel C/C++ compiler.

Benchmark Result

HRC is at parity to GHC+LLVM, which is 10% faster than GHC.

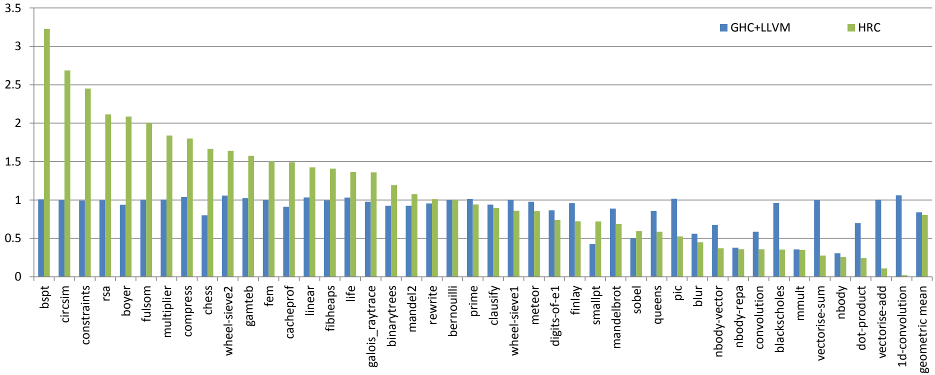

Figure: Kernel Execution Time Relative to GHC (smaller is better)

Benchmark Result (selected)

Performance oriented program with a numeric computation kernel using arrays.

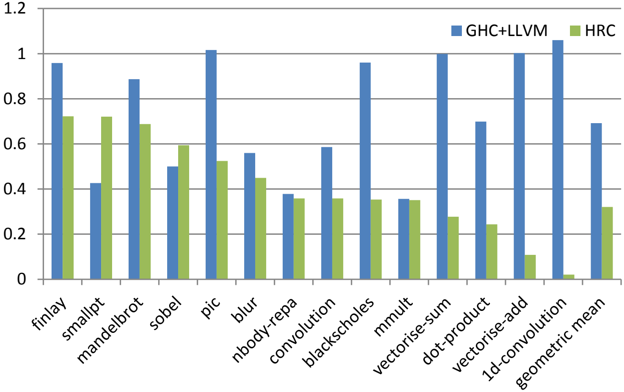

Figure: Kernel Execution Time Relative to GHC (smaller is better)

Performance

For GHC:

- GHC is better at executing lazy code and curried functions.
- GHC's object representation and GC are better suited to typical Haskell programs.

For HRC:

- HRC focuses on optimizing strict programs with hot loops.
- HRC benefits significantly from the elimination of thunks, boxes and branches.

Take Aways

- Reusing GHC is a big win (Core: easy, library: a bit work)
- Novel MIL design choices:
  - Low-level control with high-level object.
  - Immutable array with initializing writes.
- Eliminating thunks is critical to performance.
- Penalty of not using a specialized runtime.
- Compilation through C has overhead, but not as significant.

References

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