Running Haskell on the CLR

“but does it run on Windows?”

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Don't get your hopes up!

Don't get your hopes up!

```
module Main where

foreign import ccall "primAddInt" (+) :: Int → Int → Int

inc :: Int → Int
inc x = x + 1

data List = Nil | Cons Int List

length :: List → Int
length Nil = 0
length (Cons x xs) = inc (length xs)

five :: List
five = Cons 1 (Cons 2 (Cons 3 (Cons 4 (Cons 5 Nil))))

main = length five
```

Why target the CLR?

Why target the CLR?

A lot of presence.

- Multiple versions of Windows desktops.
- OS X and Linux desktops, through Mono.
- Web browsers, through Silverlight and Moonlight.
- Mobile devices:
  - Windows Mobile.
  - Mono on the iPhone and Android.
- In the cloud!
  - Windows Azure: Distributed computation environment.

Why target the CLR?

Rich environment.

- Interop with other languages.
- Access a huge set of libraries.
- Provide libraries developed in Haskell.

What is the CLR?

Common Language Runtime / Mono Project

- Stack-based virtual machine.
- First-class support for classes with methods.
- Basic operations for reference types and value types.
- Type safe: operations must match the exact type.
- Dynamic casting is allowed.
- Executes Common Intermediate Language (CIL).
- CIL has a concrete syntax.
  - ilasm
  - ildasm / monodis

What is the CLR?

```
.class private Test extends [mscorlib] System.Object
  {
    .method private static void Main () cil managed
    {
      .entrypoint
      .locals init (int32 x)
      ldc_i4 2
      stloc 0
      ldc_i4 3
      ldloc 0
      add
      call void class [mscorlib] System.Console :: WriteLine (int32)
      ret
    }
}
```

Architecture of .NET backend

```
$ bin/8/ehc -ccil Test.hs
```

Architecture of .NET backend

```
$ bin/8/ehc -ccil Test.hs
$ ls
Test.hs Test.il
```

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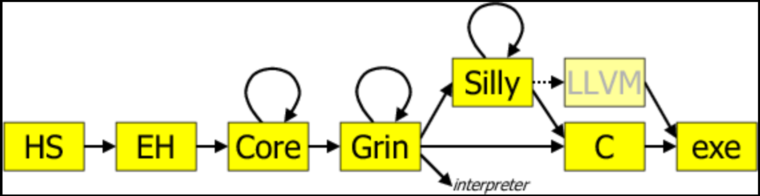
$ ls
Test.exe Test.hs Test.il
```

Architecture of .NET backend

```
$ bin/8/ehc -ccil Test.hs
$ ls
Test.hs Test.il
$ ilasm Test.il
$ ls
Test.exe Test.hs Test.il
$ mono Test.exe
42
```

Architecture of .NET backend



Architecture of .NET backend

Haskell package language-cil.

Abstract syntax for the Common Intermediate Language.

With build functions and pretty printer for concrete syntax.

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Haskell package language-cil.

Abstract syntax for the Common Intermediate Language.

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Future:

- Support all CIL constructs
- Parser for concrete syntax
- Analysis functions
- Release on Hackage

Philosophy on the Runtime System

How to treat the RTS?

- As an abstract machine?
- Use it for what it was designed

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- As an abstract machine?
  - simulate virtual memory
  - simulate registers
  - simulate functions and function calls
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  - build strongly typed objects
  - use inheritance
  - use method calling conventions
  - interop with other languages

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  - interop with other languages

Look at the what other languages do (F#).

Philosophy on the Runtime System

Some questions

$$\textbf{data}\ List = Nil \mid Cons\ Int\ List$$

Philosophy on the Runtime System

Some questions

$$\textbf{data}\ List = Nil \mid Cons\ Int\ List$$

What is the type of List?

What are the types of Nil and Cons?

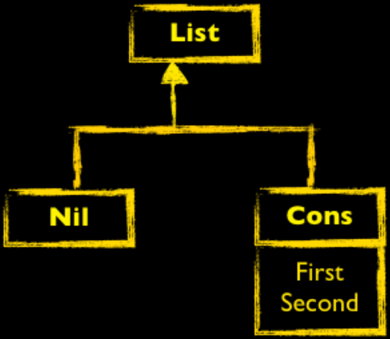
How do we handle do thunks and partial applications?

And what about updates?

Philosophy on the Runtime System

Some questions

$$\textbf{data}\ List = Nil \mid Cons\ Int\ List$$



Philosophy on the Runtime System

Some questions

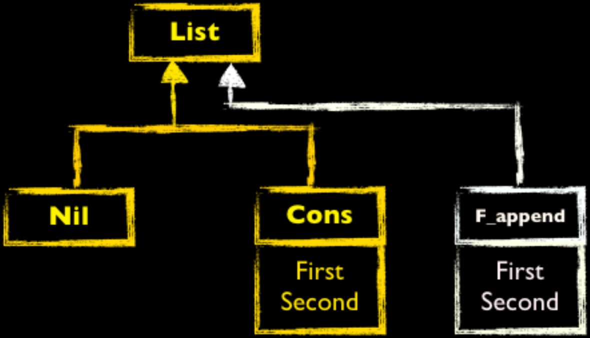
$\textbf{data}\ \mathit{List} = \mathit{Nil} \mid \mathit{Cons}\ \mathit{Int}\ \mathit{List}$

$\mathit{Cons}\ 1\ (\mathit{xs}\ \text{`}\mathit{append}\text{`}\ \mathit{ys})$

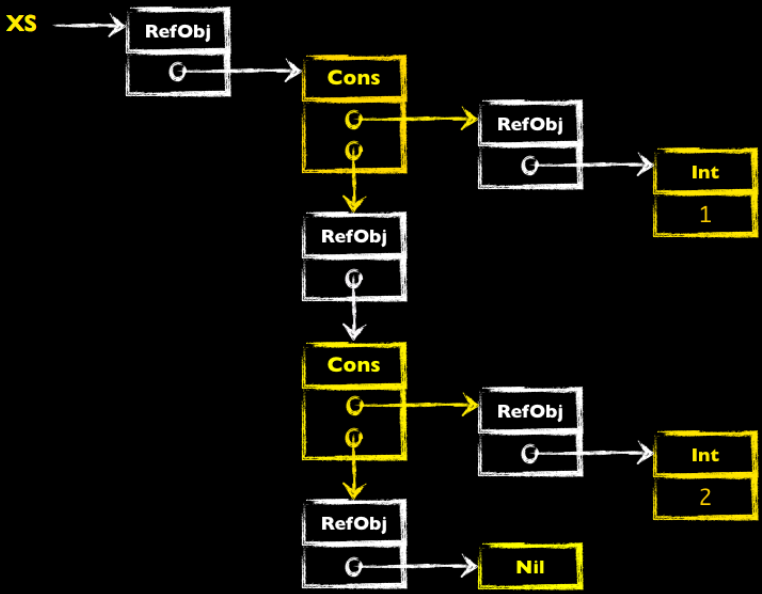
Philosophy on the Runtime System

Some questions

$$\textbf{data}\ List = Nil \mid Cons\ Int\ List$$



$$\mathsf{xs} = [1, 2]$$


XS
RefObj
Cons
RefObj
Int
1
RefObj
Cons
RefObj
Int
2
RefObj
Nil

Code generation

- Generate code from GRIN
- Direct translation of GRIN constructs

Code generation

Sequence

Evaluate $expr$ and bind the result to x.

$$expr; \lambda x \rightarrow \ldots length\ x \ldots$$

Code generation

Sequence

Evaluate $expr$ and bind the result to x.

$$expr; \lambda x \rightarrow ...length\ x\ ...$$

expr

Code generation

Sequence

Evaluate $expr$ and bind the result to x.

$$expr; \lambda x \to \ldots length\ x \ldots$$

```
expr
STLOC x
```

Code generation

Sequence

Evaluate *expr* and bind the result to x.

$$expr; \lambda x \rightarrow ...length\ x...$$

```
expr
STLOC x
...
LDLOC x
CALL length(object)
...
```

Code generation

Case

Match a tag variable against different alternatives.

$$\begin{array}{l} \textbf{case}\ \mathit{tag}\ \textbf{of} \\ \quad \mathit{CNil} \rightarrow \ldots \\ \quad \mathit{CCons} \rightarrow \ldots \end{array}$$

Code generation

Case

Match a tag variable against different alternatives.

$$\begin{array}{l}\textbf{case}\ \mathit{tag}\ \textbf{of}\\ \quad \mathit{CNil} \rightarrow \ldots\\ \quad \mathit{CCons} \rightarrow \ldots\end{array}$$

tag

Code generation

Case

Match a tag variable against different alternatives.

> **case** *tag* **of**
> *CNil* $\longrightarrow$ ...
> *CCons* $\longrightarrow$ ...

```
tag
L1:
  DUP
  ISINST CNil
  BRFALSE L2
  POP
  ...
L2:
```

Code generation

Store

Store a value on the heap and return a pointer to it.

> *store val*

Code generation

Store

Store a value on the heap and return a pointer to it.

store val

```
val
NEWOBJ RefObj::.ctor(object)
```

Code generation

Store

Store a value on the heap and return a pointer to it.

store val

val
NEWOBJ RefObj::.ctor(object)
All our values are already stored on the heap, so we only have to create a pointer.

Code generation

Update

Update the value pointed to by pointer x with val.

update x val

```
LDLOC x
val
STFLD RefObj::Value
```

Code generation

Fetch 0

Fetch the tag of a node, following pointer x.

$$\textit{fetch } x\ [0]$$

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```
LDLOC x
LDFLD RefObj::Value
```

Code generation

Fetch 0

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$$\textit{fetch}\ x\ [0]$$

LDLOC x
LDFLD RefObj::Value

We have no representation for stand-alone tags. We use the complete node.

Code generation

Fetch n

Fetch the first field of a node, following pointer x.

$$fetch\ x\ [1]$$

Code generation

Fetch n

Fetch the first field of a node, following pointer x.

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LDLOC x
LDFLD RefObj::Value
LDFLD Int/Int::Value

Code generation

Fetch n

Fetch the first field of a node, following pointer x.

$$\mathit{fetch}\ x\ [1]$$

LDLOC x
LDFLD RefObj::Value
LDFLD Int/Int::Value

Uh oh! We have to know the class.

Code generation

Fetch n – Class information

Fortunately, GRIN stores this information for us:

$$GrExpr\_FetchField\ x\ 1\ (Just\ (GrTag\_Con\ \{1,1\}\ 0\ Int))$$

Phew.

Code generation

Binding multiple variables

However:

$$
\begin{array}{l}
...; \lambda x \rightarrow \\
inc\ x; \lambda(y\ z) \rightarrow \\
\ ...
\end{array}
$$

Code generation

Binding multiple variables

However:

$$...; \lambda x \rightarrow$$
$$inc\ x; \lambda(y\ z) \rightarrow$$
$$...$$

- We have to extract the first field to bind to z.

Code generation

Binding multiple variables

However:

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...
\end{array}
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- We have to extract the first field to bind to z.
- We need the class information for this.
  LDFLD ?/?::Value

Code generation

Binding multiple variables

However:

$$...; \lambda x \rightarrow$$
$$inc\ x; \lambda(y\ z) \rightarrow$$
$$...$$

- We have to extract the first field to bind to z.
- We need the class information for this.
  LDFLD ?/?::?

Code generation

Binding multiple variables

However:

$$\ldots; \lambda x \rightarrow$$
$$inc\ x; \lambda(y\ z) \rightarrow$$
$$\ldots$$

- We have to extract the first field to bind to z.
- We need the class information for this.
  LDFLD ?/?::?
- But we don't know what y is!

Code generation

Types!

We need the possible tags of every variable, so we can figure out which class to use.

Basically type (tag) inferencing. A lot of work!

Code generation

Types!

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Basically type (tag) inferencing. A lot of work!

Fortunately, the heap points-to analysis does this already.

Heap points-to analysis

The analysis gives us, for each variable, what kind of values it can contain.

Example:

$$\begin{aligned}
&\mathit{fetch}\ T\ 1; x \longrightarrow \\
&\mathit{inc}\ x \qquad ; \lambda(y\ z) \longrightarrow \\
&\mathit{update}\ T\ (x\ y)
\end{aligned}$$

T is a thunk here.

Heap points-to analysis

$$\begin{array}{l} \textit{fetch}\ T\ 1; x \rightarrow \\ \textit{inc}\ x \quad ; \lambda(y\ z) \rightarrow \\ \textit{update}\ T\ (x\ y) \end{array}$$

Variables:

T	Pointer	[13,14]
inc	Node	[(CInt, [Basic])]
x	Pointer	[13,14]
y	Tag	CInt
z	Basic	

Heap:

13	Node	[(CInt, [Basic])]
14	Node	[(CInt, [Basic]),(Finc, [Pointer [13,14]])]

Future work

Obvious enhancements

- stloc x, ldloc x
- more stack focussed code
  - Silly-like
  - tail calls!
- remove RefObj indirection
- use value types
- more polymorphic code
  - inline unboxed values

Future work

More 'out there' stuff

Simon Peyton Jones on Haskell for CLR:

- Generate IL
  - Runtime representation for thunks
- Interop with .NET libraries
  - No foreign import ... for everything
- Other GHC primitives:
  - the I/O monad
  - arbitrary precision arithmetic
  - concurrency
  - exceptions
  - finalisers
  - stable pointers
  - Software transactional memory
- Existing libraries

In conclusion

We think our runtime representation is workable.

We have an interesting prototype that shows this.

There's much work still to be done...

EOF