Agda Backends: A survey and a UHC backend prototype

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- Why dependent types?

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- ```
  head :: forall a . List a -> a
  head (x:xs) = x
  head [] = error "something␣went␣wrong..."
  ```
  ```

Agda Introduction

- Why dependent types?
- ```
  head :: forall a . List a -> a
  head (x:xs) = x
  head [] = error "something went wrong..."
  ```
- Runtime crashes are possible in Haskell!
  ```

Agda Introduction

- How to make sure at compile time that this doesn't happen?
- We need to encode the length of lists in the type

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```
data Nat : Set where
  zero : Nat
  succ : Nat → Nat
```

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- We need to encode the length of lists in the type

```
data Nat : Set where
   zero : Nat
   succ : Nat → Nat
data Vec : (A : Set) → (n : Nat) → Set where

   nil  : ∀ {A} → Vec A zero
   cons : ∀ {A n} → A → Vec A n → Vec A (succ n)
```

Agda Introduction - Cont.

We can now write the head function in Agda

head1 : $\forall \{A\ n\} \rightarrow$ Vec $A\ n \rightarrow A$
head1 (cons $x\ xs$) $= x$
head1 nil $=$????

Agda Introduction - Cont.

We can now write the head function in Agda

$\text{head1} : \forall \{A\ n\} \to \text{Vec}\ A\ n \to A$
$\text{head1}\ (\text{cons}\ x\ xs) = x$
$\text{head1}\ \text{nil} = ????$

This will not type check!

Agda Introduction - Cont.

We can now write the head function in Agda

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$\text{head1}\ (\text{cons}\ x\ xs) = x$
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This will not type check!

$\text{head2} : \forall \{A\ n\} \to \text{Vec}\ A\ (\text{succ}\ n) \to A$
$\text{head2}\ (\text{cons}\ x\ xs) = x$

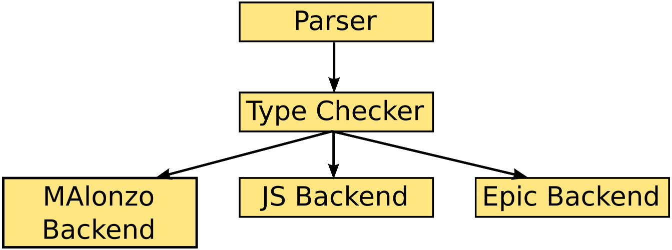
The typechecker now knows that the nil-case cannot happen!

Agda Characteristics

- Single language for programs, specifications and proofs
- Typechecking requires evaluation

- Values can be used as types
- Functions need to be total

Agda Architecture



MAlonzo backend

MAlonzo backend

- Targets Haskell
- Maintained

MAlonzo - Code Generation

```
vecToStr : ∀ {A m} → (A → String)
  → Vec A m → String
vecToStr f [] = ""
vecToStr f (x :: xs) = ", " ++ ((f x)
  ++ (vecToStr f xs))
```

MAlonzo - Code Generation

```
d55 v0 v1 v2 v3
  = MAlonzo.RTE. mazCoerce
      (d_1_55 (MAlonzo.RTE. mazCoerce v0)
         (MAlonzo.RTE. mazCoerce v1)
         (MAlonzo.RTE. mazCoerce v2)
         (MAlonzo.RTE. mazCoerce v3))
  where d_1_55 v0 v1 v2 (C51 v3 v4 v5)
          = MAlonzo.RTE. mazCoerce
              (d33 (MAlonzo.RTE. mazCoerce ",␣")
                 (MAlonzo.RTE. mazCoerce
  (d33 (MAlonzo.RTE. mazCoerce (v2 (MAlonzo.RTE. mazCoerce v4)))
     (MAlonzo.RTE. mazCoerce
        (d55 (MAlonzo.RTE. mazCoerce v0) (MAlonzo.RTE. mazCoerce v3)
           (MAlonzo.RTE. mazCoerce v2)
           (MAlonzo.RTE. mazCoerce v5))))))
        d_1_55 v0 v1 v2 v3 = MAlonzo.RTE.mazIncompleteMatch name55
```

MAlonzo - Code Generation

- Produces 'strange' haskell code
- Relies on GHC for optimization
- But generated code is not always suited for optimization!
- Can lead to size blow-up
  - 84 lines Agda - 250'000 lines Haskell - 300 Mb executable (CITE)

MAlonzo - FFI

- Provides simple FFI to haskell
- Very limited
  - No class support
  - Can't export Agda datatypes
  - Not automatic

MAlonzo - FFI

```
{-# IMPORT Data.List #-}

data List : (A : Set) -> Set where
  nil : ∀ {A} → List A
  cons : ∀ {A} → A → List A → List A
{-# COMPILED_DATA List Data.List nil cons #-}

postulate
  head : ∀ {A} → List A -> A
{-# COMPILED head Data.List.head #-}
```

JS backend

JS backend

- Targets Javascript
- Not maintained
- Very similar to MAlonzo

Epic backend

Epic backend

- Targets Epic
- Not maintained

Epic

- Untyped-lambda calculus with some extensions
- Intended as building block for compilers
- Also not maintained

Epic Language

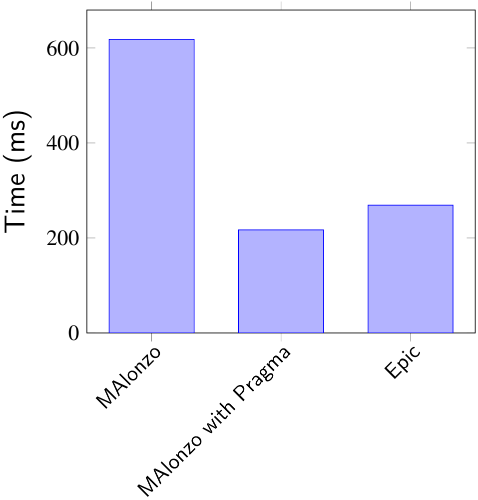
Epic Language			
t	$::=$	x	Variable
	$\mid$	$t\ \vec{t}$	Application
	$\mid$	$\lambda x \to t$	Abstraction
	$\mid$	Con $i\ \vec{t}$	Constructor application
	$\mid$	if t then t else t	if-then-else
	$\mid$	case t of $\vec{alt}$	Case expression
	$\mid$	let $x = t$ in t	Let expression
	$\mid$	lazy t	Suspended term
	$\mid$	i	Integer constants

Optimizations

Primitive Data - Nat

- ```
  data Nat : Set where
    zero : Nat
    succ : Nat -> Nat
  {-# BUILTIN NATURAL Nat #-}
  ```
- Naive translation is horribly slow
- Can be transformed into arbitrary precision Integers
- Automatic detection of Nat-like datatypes in Epic backend
  ```

Primitive Data - Performance



Smashing

- Consider the following Agda Code:

$$\text{data Equality } \{A : \text{Set}\}\ (x : A) : A -> \text{Set where}$$
$$\quad \text{refl} : \text{Equality}\ x\ x$$
$$\text{plusAssoc} : (n\ m\ k : \text{Nat})$$
$$\quad \to \text{Equality}\ (n + (m + k))\ ((n + m) + k)$$
$$\text{plusAssoc zero}\ m\ k = \text{refl}$$
$$\text{plusAssoc}\ (\text{suc}\ n)\ m\ k = \text{cong suc}\ (\text{plusAssoc}\ n\ m\ k)$$

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- But it will always return the same value.

Smashing

- Consider the following Agda Code:

```
data Equality {A : Set} (x : A) : A −> Set where
   refl : Equality x x
 plusAssoc : (n m k : Nat)
   → Equality (n + (m + k)) ((n + m) + k)
plusAssoc zero m k = refl
plusAssoc (suc n) m k = cong suc (plusAssoc n m k)
```

- The above definition of plusAssoc is linear in it's input.
- But it will always return the same value.
- We can just replace the body by the refl constructor at runtime.

Comparison

	MAlonzo (HS)	Epic	Javascript
Forcing	No	Yes	No
Erasure	No	Yes	No
Smashing	No	Yes	Yes
Primitive Data	Nat only	Yes	Nat only
Maintained	Yes	No	No
User Documentation	Usable	Bad	Bad

How to fix these issues?

- How can we solve this problem?

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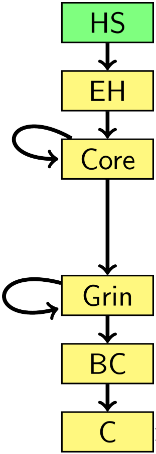
- How can we solve this problem?
- Let's write another backend :-)
- What would be a good target language?
- Untyped, functional, maintained
- UHC Core fits that bill!

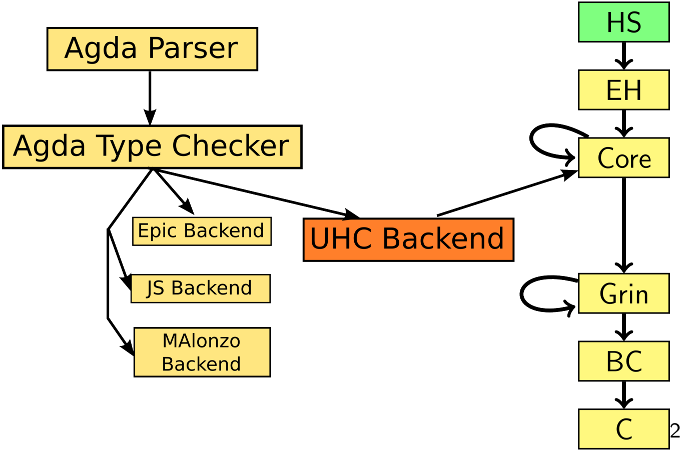
UHC Compiler



[1]

[1] Dijkstra, Fokker, and Swierstra, 2009.

UHC Backend



[2]

[2] Dijkstra et al., 2009.

UHC Backend

- Idea: Take Agda Epic backend and combine it with UHC
- A lot of the Epic backend can be reused

Epic vs UHC Core

Epic Language			UHC Core		
t	$::=$	x	t	$::=$	x
	$\mid$	$t\ \vec{t}$		$\mid$	$t\ t$
	$\mid$	$\lambda x \rightarrow t$		$\mid$	$\lambda x \rightarrow t$
	$\mid$	$\mathsf{Con}\ i\ \vec{t}$		$\mid$	$\mathsf{Con}\ i\ \vec{t}$
	$\mid$	$\mathsf{if}\ t\ \mathsf{then}\ t\ \mathsf{else}\ t$			
	$\mid$	$\mathsf{case}\ t\ \mathsf{of}\ \vec{alt}$		$\mid$	$\mathsf{case}\ t\ \mathsf{of}\ \vec{alt}$
	$\mid$	$\mathsf{let}\ x = t\ \mathsf{in}\ t$		$\mid$	$\mathsf{let}\ x = t\ \mathsf{in}\ t$
				$\mid$	$\mathsf{let!}\ x = t\ \mathsf{in}\ t$
	$\mid$	$\mathsf{lazy}\ t$			
	$\mid$	i		$\mid$	i

UHC Backend - Challenges

- Agda is a moving target
- UHC Core was not intended as public API
- Undocumented assumptions inside UHC

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```
case x of
  []     -> a
  (x:xs) -> b
```

is not the same as

```
case x of
  (x:xs) -> b
  []     -> a
```

UHC Backend - What works?

- (Dependent) dataypes, functions
- Compiling single Agda modules
- Agda - Haskell FFI, but involves manual work

Demonstration

UHC Backend - Future work

- Support whole Agda language
  - Multiple modules
  - Complete IO bindings
  - Agda Standard Library
- Optimizations
- Improve Agda - Haskell FFI
- Contracts for FFI
- Agda support for Cabal

Thank you!

Questions?

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