Compiling with Effects and Handlers

A New Compiler Architecture

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TU Delft

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1. Why write compilers differently?
2. What are effects and handlers?
3. How to compile with effects and handlers?

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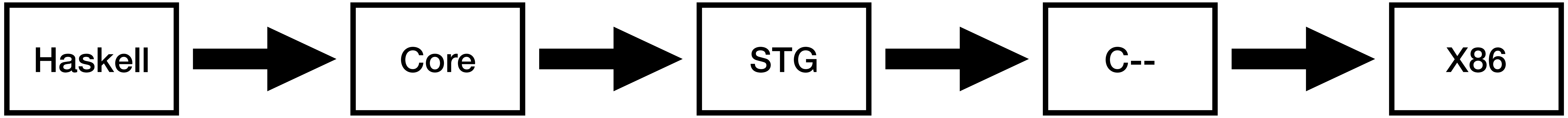
Goal: Modularity

- Most existing compilers (such as GHC) are monolithic
- Modularity could improve:
  - Maintenance
  - Extensibility
  - Understanding (reasoning)

A New Compiler Architecture

Inspired by nanopass compilers



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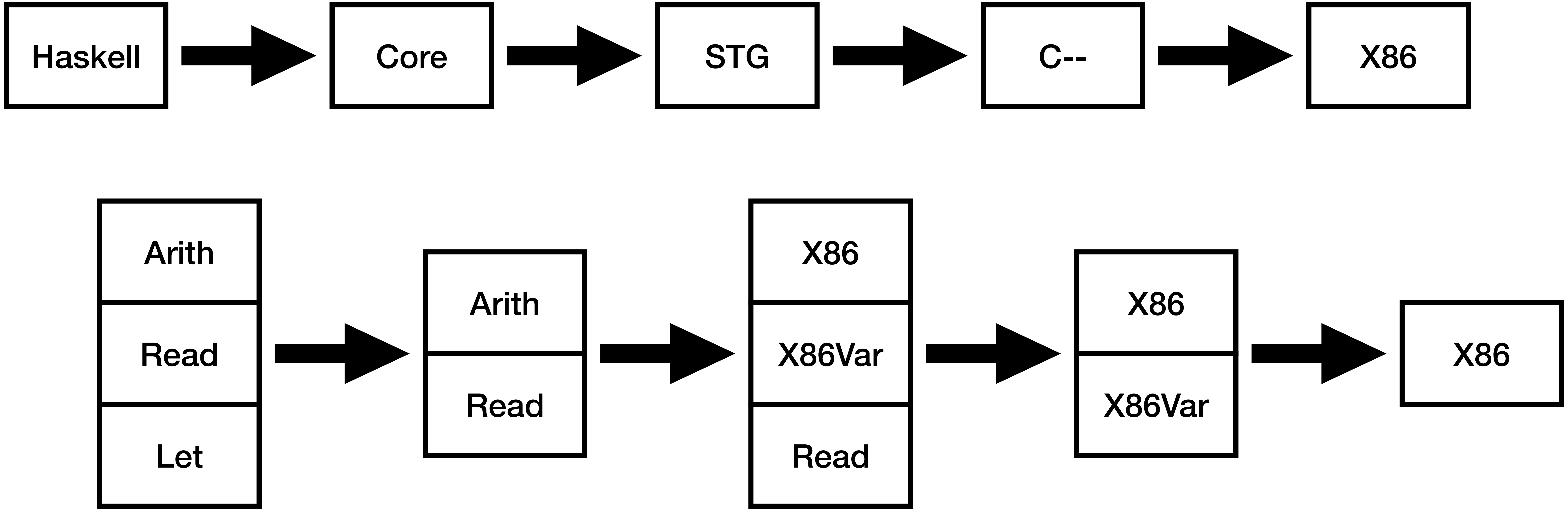

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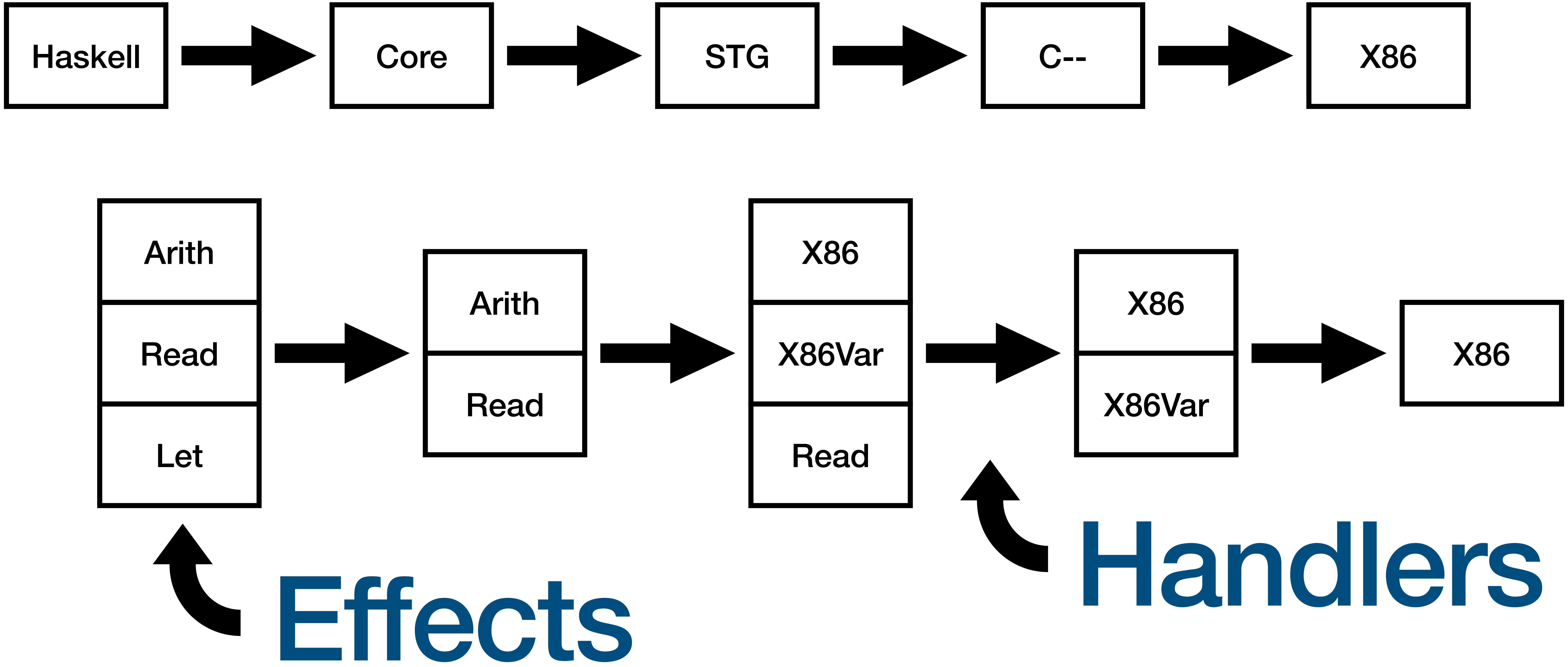

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Effects and Handlers

- Historically,
    - an improvement upon Moggi’s work on monads and monad transformers
    - avoiding the need for lifting functions
- Practically,
    - a set of **abstract operations** forming an interface
    - with the superpower to **manipulate control-flow**
    - and a mechanism to give **concrete meaning** to these abstract operations

Examples

Maybe

```haskell
data Maybe a
  = Nothing | Just a


instance Monad Maybe where
  Just x >>= k = k x
  Nothing >>= k = Nothing
  return x = Just x
```

Examples

Maybe

```
data Maybe a
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```

```
instance Monad Maybe where
  Just x >>= k = k x
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```

```
effect Abort where
  abort : m a
```

```
handle
  abort k -> Nothing
  return x -> Just x
```

Examples

State

```
data State s a
  = MkState (s → a × s)


instance Monad (State s) where
  MkState p >>= k = MkState \s →
    let (x, s’) = p s in
    let MkState q = k x in
    q s’
  return x = MkState \s → (x, s)
```

Examples

State

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```

```
effect State s where
  get : m s
  put : s → m ()

handle [s := s0]
  get      k s → k s s
  (put s’) k s → k () s’
  (return x) s → (x, s)
```

1. Why write compilers differently?
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3. How to compile with effects and handlers?

A Simple Language

```
effect Arith v where
  int : Integer → m v
  add : v × v   → m v

effect Read v where
  read : m v

effect Let v where
  let  : m v × (v → m v)
    → m v
```

A Simple Language

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effect Arith v where
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```

```
⟦n⟧           = int n
⟦e₁ + e₂⟧     = do x ← ⟦e₁⟧
                   y ← ⟦e₂⟧
                   add x y

⟦read⟧        = read


⟦let x = e₁ in e₂⟧ = let  ⟦e₁⟧ \x →  ⟦e₂⟧
```

X86

```
effect X86 where
  imm   : Integer  → m v
  reg   : Register → m v
  deref : Register × Integer → m v
  movq  : v × v    → m ()
  addq  : v × v    → m ()
  callq : Label    → m ()
```

```
effect X86Var where
  x86var : m v
```

Compiling Let, Arith, Read

```
handle
  (let e f) k → do
    x ← e
    z ← f x
    k z
```

```
handle
  (int n) k → do
    x ← imm n
    z ← x64var
    movq x z
    k z
  (add x y) k → do
    z ← x64var
    movq y z
    addq x z
    k z
```

```
handle
  read k → do
    callq _read_int
    x ← reg %rax
    z ← x64var
    movq x z
    k z
```

Stack Allocation

```
handle [n := 1]
  x64var k n → do
    z ← deref %rbp (-8 * n)
    k z (n + 1)
```

Pretty Printing

```
handle
  (imm n)     k → k (showInt n)
  (reg r)     k → k (showReg n)
  (deref r i) k → k (showInt i ++ “(“ ++ showReg r ++ “)”)
  (movq x y)  k → “movq “ ++ x ++ “, “ ++ y ++ “\n” ++ k ()
  (addq x y)  k → “addq “ ++ x ++ “, “ ++ y ++ “\n” ++ k ()
  (callq l)   k → “callq “ ++ l ++ “\n” ++ k ()
```

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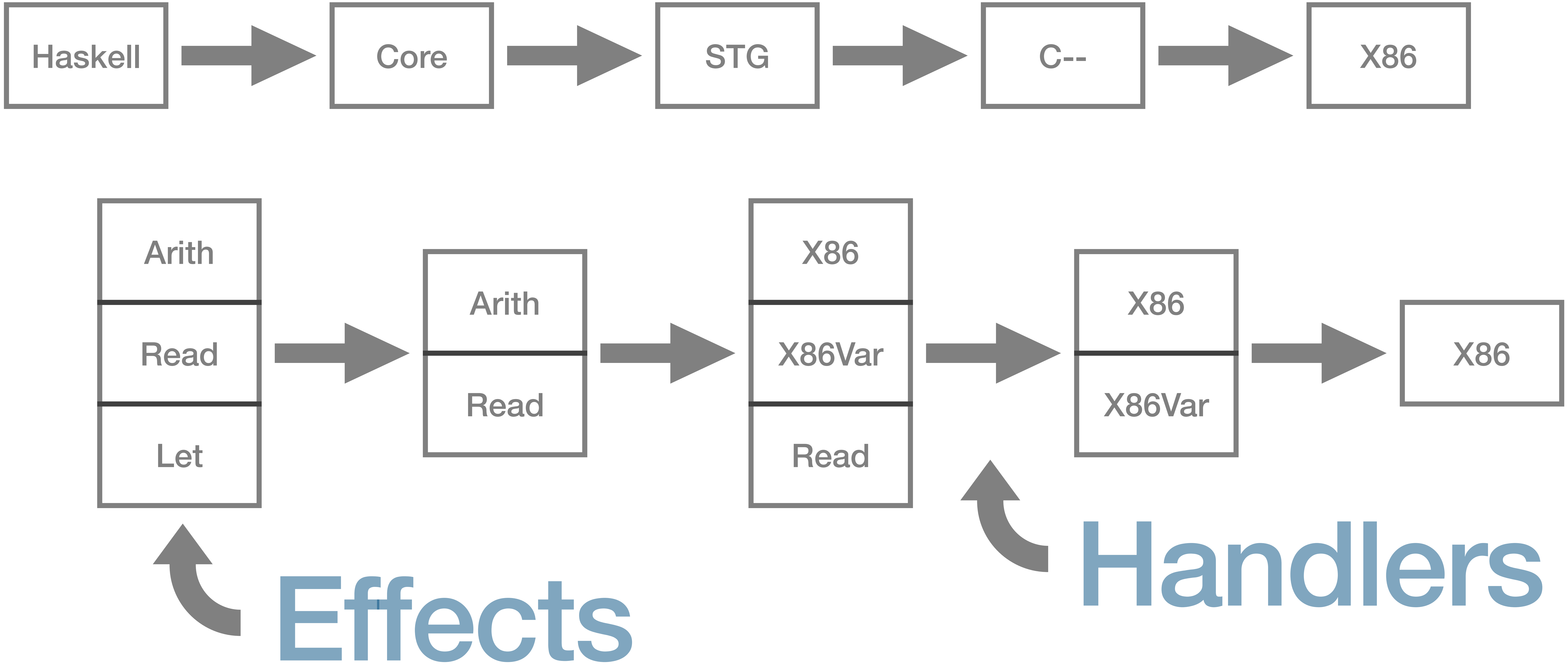
Haskell
Core
STG
C--
X86
Arith
Read
Let
Arith
Read
X86
X86Var
Read
X86
X86Var
X86
Effects
Handlers