

An Overview of Haskell

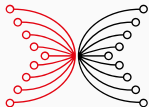
Haskell and Cryptocurrencies

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INPUT | OUTPUT

Goals

- What is Haskell?
- Provide a few examples of Haskell.
- Explain what makes Haskell unique.
- Pose a few programming tasks.

What is Haskell?

Haskell History

- Designed by a committee to create a standard **lazy and functional** language.
- Haskell 1.0 Report released 1990.
- Several iterations up to Haskell 98, released 1999.
- Minor revision of standard in Haskell 2010.
- A lot of development since then, but primarily outside of the standard, in the **Glasgow Haskell Compiler** (GHC).

Haskell Features

- functional
- statically typed
- algebraic datatypes
- type inference and polymorphism
(Damas-Hindley-Milner type system)
- type classes
- explicit effects (often called *pure*)
- lazy evaluation

Haskell Features

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(Damas-Hindley-Milner type system)
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Datatypes and functions

A type for “block chains”

```
data Chain =  
    GenesisBlock  
  | Block Chain Txs  
type Txs = Int
```

Terminology:

A type for “block chains”

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data Chain =  
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- datatype

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- (data) constructor

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- (data) constructor
- constructor arguments / fields

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Terminology:

- datatype
- (data) constructor
- constructor arguments / fields
- type synonym

Example chains

```
chain1 =  
  Block GenesisBlock 2  
chain2 =  
  Block chain1 4
```

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```
chain2' =  
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Terminology:

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Terminology:

- binding

Example chains

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```

```
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  Block chain1 4
```

```
chain2' =  
  Block (Block GenesisBlock 2) 4
```

Terminology:

- binding
- left hand side

Example chains

```
chain1 =
```

```
Block GenesisBlock 2
```

```
chain2 =
```

```
Block chain1 4
```

```
chain2' =
```

```
Block (Block GenesisBlock 2) 4
```

Terminology:

- binding
- right hand side
- left hand side

Example chains

```
chain1 =  
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```

```
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```

```
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  Block (Block GenesisBlock 2) 4
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Terminology:

- binding
- left hand side
- right hand side
- expression

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```

```
chain2 =  
  Block chain1 4
```

```
chain2' =  
  Block (Block GenesisBlock 2) 4
```

Terminology:

- binding
- right hand side
- left hand side
- expression

Example chains

```
chain1 =  
  Block GenesisBlock 2
```

```
chain2 =  
  Block chain1 4
```

```
chain2' =  
  Block (Block GenesisBlock 2) 4
```

Terminology:

- binding
- left hand side
- right hand side
- expression

Determine the length of a block chain

```
chainLength GenesisBlock = 0  
chainLength (Block c _) = chainLength c + 1
```

Determine the length of a block chain

```
chainLength :: Chain -> Int
chainLength GenesisBlock = 0
chainLength (Block c _)   = chainLength c + 1
```

Determine the length of a block chain

```
chainLength :: Chain -> Int  
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Terminology:

- type signature (optional)

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- equations / cases

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- left hand sides

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Terminology:

- type signature (optional)
- equations / cases
- left hand sides
- patterns

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Terminology:

- type signature (optional)
- equations / cases
- left hand sides
- patterns
- right hand sides

Determine the length of a block chain

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```

Terminology:

- type signature (optional)
- equations / cases
- left hand sides
- patterns
- right hand sides
- recursive call

Determine the length of a block chain

```
chainLength :: Chain -> Int
chainLength GenesisBlock = 0
chainLength (Block c _)  = chainLength c + 1
```

```
data Chain =
    GenesisBlock
  | Block Chain Tx
type Tx = Int
```

Evaluation in GHCi

```
GHCi> 1 + 1
```

```
2
```

```
GHCi> chainLength chain1
```

```
1
```

```
GHCi> chainLength chain1 + 1
```

```
2
```

```
GHCi> chainLength chain2
```

```
2
```

```
GHCi> chainLength chain1 == chainLength chain2
```

```
False
```

Evaluation step by step

```
chainLength chain2
```

Evaluation step by step

```
chainLength chain2  
= chainLength (Block chain1 4)
```


Evaluation step by step

```
chainLength chain2  
= chainLength (Block chain1 4)  
= chainLength chain1 + 1
```

Evaluation step by step

```
chainLength chain2  
= chainLength (Block chain1 4)  
= chainLength chain1 + 1  
= chainLength (Block GenesisBlock 2) + 1
```

Evaluation step by step

```
chainLength chain2  
= chainLength (Block chain1 4)  
= chainLength chain1 + 1  
= chainLength (Block GenesisBlock 2) + 1  
= (chainLength GenesisBlock + 1) + 1
```

Evaluation step by step

```
chainLength chain2  
= chainLength (Block chain1 4)  
= chainLength chain1 + 1  
= chainLength (Block GenesisBlock 2) + 1  
= (chainLength GenesisBlock + 1) + 1  
= (0 + 1) + 1
```

Evaluation step by step

```
chainLength chain2
= chainLength (Block chain1 4)
= chainLength chain1 + 1
= chainLength (Block GenesisBlock 2) + 1
= (chainLength GenesisBlock + 1) + 1
= (0 + 1) + 1
= 1 + 1
```

Evaluation step by step

```
chainLength chain2
= chainLength (Block chain1 4)
= chainLength chain1 + 1
= chainLength (Block GenesisBlock 2) + 1
= (chainLength GenesisBlock + 1) + 1
= (0 + 1) + 1
= 1 + 1
= 2
```

Evaluation step by step

```
chainLength chain2
= chainLength (Block chain1 4)
= chainLength chain1 + 1
= chainLength (Block GenesisBlock 2) + 1
= (chainLength GenesisBlock + 1) + 1
= (0 + 1) + 1
= 1 + 1
= 2
```

Also known as **equational reasoning**.

Currying

Testing for a particular block

```
hasBlock x GenesisBlock = False
hasBlock x (Block c t)   =
  x == t || hasBlock x c
```

The operator `||` implements *logical disjunction* (“or”).

Testing in GHCi

```
chain1 =  
    Block GenesisBlock 2  
chain2 =  
    Block chain1 4
```

```
GHCi> hasBlock 4 chain1  
False  
GHCi> hasBlock 4 chain2  
True
```

Currying

The (inferred) type of `hasBlock` is

```
GHCi> :t hasBlock  
hasBlock :: TxS -> Chain -> Bool
```

Currying

The (inferred) type of `hasBlock` is

```
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hasBlock :: TxS -> Chain -> Bool
```

```
hasBlock          :: TxS -> (Chain -> Bool)  
hasBlock 4        ::          Chain -> Bool  
(hasBlock 4) chain2 ::          Bool
```

Curried functions and operators

```
(||) :: Bool -> Bool -> Bool  
(&&) :: Bool -> Bool -> Bool  
Block :: Chain -> TxS -> Chain
```

Curried functions and operators

```
(||)  :: Bool -> Bool -> Bool
(&&)  :: Bool -> Bool -> Bool
Block :: Chain -> Txs -> Chain
```

Operators are just identifiers:

```
True || False      -- symbolic infix
(||) True False     -- symbolic prefix
Block chain1 4      -- alphanumeric prefix
chain1 `Block` 4    -- alphanumeric infix
```

Operator priorities

```
GHCi> :i (||)
(||) :: Bool -> Bool -> Bool
      -- Defined in 'GHC.Classes'
infixr 2 ||
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Defining a symbolic version of 'Block':

```
(|>) :: Chain -> Txs -> Chain
(|>) = Block
infixl 5 |>
```


Operator priorities

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GHCi> :i (||)
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      -- Defined in 'GHC.Classes'
infixr 2 ||
```

Defining a symbolic version of 'Block':

```
(|>) :: Chain -> Txs -> Chain
(|>) = Block
infixl 5 |>
```

```
chain2'' :: Chain
chain2'' = GenesisBlock |> 2 |> 4
```

Higher-order functions

Finding a block with a property

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Let's model a property as a function of type `Txs -> Bool`.

Finding a block with a property

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```
hasBlockProp :: (Txs -> Bool) -> Chain -> Bool
hasBlockProp prop GenesisBlock = False
hasBlockProp prop (Block c t)   =
    prop t || hasBlockProp prop c
```

Anonymous functions and operator sections

```
GHCi> hasBlockProp (\ x -> x > 10) chain2
False
GHCi> hasBlockProp even chain2
True
GHCi> hasBlockProp (\ x -> 4 == x) chain2
True
```

Anonymous functions and operator sections

```
GHCi> hasBlockProp (\ x -> x > 10) chain2  
False  
GHCi> hasBlockProp even chain2  
True  
GHCi> hasBlockProp (\ x -> 4 == x) chain2  
True
```

```
GHCi> hasBlockProp (> 10) chain2  
False  
GHCi> hasBlockProp (4 ==) chain2  
True
```

Several styles to write one function

```
hasBlockProp :: (Txs -> Bool) -> Chain -> Bool
hasBlockProp prop GenesisBlock = False
hasBlockProp prop (Block c t)   =
    prop t || hasBlockProp prop c
```

vs.

```
hasBlockProp :: (Txs -> Bool) -> Chain -> Bool
hasBlockProp = \ prop chain ->
    case chain of
        GenesisBlock -> False
        Block c t     -> prop t || hasBlockProp prop c
```


Similarity of functions / type-directed programming

```
chainLength :: Chain -> Int
chainLength GenesisBlock = 0
chainLength (Block c _)  = chainLength c + 1
```

```
hasBlock :: Txs -> Chain -> Bool
hasBlock x GenesisBlock = False
hasBlock x (Block c t)  =
  x == t || hasBlock x c
```

```
hasBlockProp :: (Txs -> Bool) -> Chain -> Bool
hasBlockProp prop GenesisBlock = False
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```

Types, overloading and polymorphism

```
hasBlockProp ::  
hasBlockProp prop GenesisBlock = False  
hasBlockProp prop (Block c t)  =  
  prop t || hasBlockProp prop c
```

Type inference

```
hasBlockProp :: ... -> ... -> ...  
hasBlockProp prop GenesisBlock = False  
hasBlockProp prop (Block c t)  =  
  prop t || hasBlockProp prop c
```

- Two arguments.

Type inference

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hasBlockProp :: ... -> ... -> Bool
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- Two arguments.
- Result of first case is `False`.

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- Pattern for second arg in first case is `GenesisBlock`.

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- We know `t :: Tx` due to the type of `Block`.

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- Result of first case is `False`.
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- We know `t :: Txs` due to the type of `Block`.
- We know `prop :: Txs -> Bool` due to `prop t || ...`.

(Parametric) Polymorphism

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data Chain =  
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(Parametric) Polymorphism

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data Chain =  
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```

Abstract from the type of transactions:

```
data Chain txs =  
    GenesisBlock  
  | Block (Chain txs) txs
```

Polymorphic types

```
GenesisBlock :: Chain txs  
Block :: Chain txs -> txs -> Chain txs
```

Polymorphic types

```
GenesisBlock :: Chain txs  
Block :: Chain txs -> txs -> Chain txs
```

```
chainLength :: Chain txs -> Int  
hasBlockProp :: (txs -> Bool) -> Chain txs -> Bool
```

These work for any choice of type `txs` !

Overloading

```
hasBlock x GenesisBlock = False  
hasBlock x (Block c t)  =  
  x == t || hasBlock x c
```

Not entirely independent of the type of `x` and `t`.

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(==) :: Eq a => a -> a -> Bool
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```
(==) :: Eq a => a -> a -> Bool
```

This type has a (class) constraint.

It works for any choice of type `a` that is in the `Eq` class.

Overloading

```
hasBlock :: Eq txs => txs -> Chain txs -> Bool
hasBlock x GenesisBlock = False
hasBlock x (Block c t)   =
  x == t || hasBlock x c
```

Not entirely independent of the type of `x` and `t`.

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(==) :: Eq a => a -> a -> Bool
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Chains vs. Lists

Polymorphic chains are quite similar to built-in lists:

```
GenesisBlock :: Chain txs
Block        :: Chain txs -> txs -> Chain txs
[]           :: [a]
(:)         :: a -> [a] -> [a]
```

Chains vs. Lists

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GenesisBlock :: Chain txs
Block        :: Chain txs -> txs -> Chain txs
[]           :: [a]
(:)         :: a -> [a] -> [a]
```

```
anotherChain :: Chain Int
anotherChain =
  Block (Block GenesisBlock 1) 2
```

```
aList :: [Int]
aList = 2 : (1 : [])
```

Syntactic sugar for lists

These are all equivalent:

```
2 : (1 : [])
```

```
2 : 1 : []
```

```
[2, 1]
```

Syntactic sugar for lists

These are all equivalent:

```
2 : (1 : [])  
2 : 1 : []  
[2, 1]
```

Lists of characters are called strings:

```
type String = [Char]
```

These are all equivalent for strings:

```
'x' : 'y' : []  
['x', 'y']  
"xy"
```

Overloaded length

Corresponds to `chainLength`:

```
length :: Foldable t => t a -> Int
```

Here, `Foldable`

- is another type class
- contains container types, such as lists

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Here, `Foldable`

- is another type class
- contains container types, such as lists

Specializations:

```
length :: [a] -> Int  
length :: [Int] -> Int  
length :: String -> Int
```

Other functions on lists

```
elem :: (Eq a, Foldable t) => a -> t a -> Bool  
any  :: Foldable t => (a -> Bool) -> t a -> Bool
```

Specializations:

```
elem :: (Eq a) => a -> [a] -> Bool  
elem :: Txs -> [Txs] -> Bool  
any  :: (a -> Bool) -> [a] -> Bool  
any  :: (Txs -> Bool) -> [Txs] -> Bool
```

Various other predefined functions

```
reverse :: [a] -> [a]
(++)    :: [a] -> [a] -> [a]
filter  :: (a -> Bool) -> [a] -> [a]
map     :: (a -> b) -> [a] -> [b]
```


Various other predefined functions

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reverse :: [a] -> [a]
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```

```
id      :: a -> a
const   :: a -> b -> a
```

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reverse :: [a] -> [a]
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map     :: (a -> b) -> [a] -> [b]
```

```
id      :: a -> a
const   :: a -> b -> a
```

```
(+)     :: Num a => a -> a -> a
(/)     :: Fractional a => a -> a -> a
(<=)    :: Ord a => a -> a -> Bool
```

Various other predefined functions

```
reverse :: [a] -> [a]  
(++)    :: [a] -> [a] -> [a]  
filter  :: (a -> Bool) -> [a] -> [a]  
map      :: (a -> b) -> [a] -> [b]
```

```
id       :: a -> a  
const    :: a -> b -> a
```

```
(+)      :: Num a => a -> a -> a  
(/)      :: Fractional a => a -> a -> a  
(<=)     :: Ord a => a -> a -> Bool
```

```
show     :: Show a => a -> String
```

Some important type classes

`Eq`

for types that support an equality test

`Ord`

for types that can be compared

`Num`

for numeric types

`Fractional`

for fractional numeric types

`Show`

for types that have a representation as string

`Read`

for types that can be parsed from strings

`Enum`

for types that can be enumerated

`Bounded`

for types that have a smallest and largest value

`Foldable`

for container types

Deriving instances

For some classes, we can automatically derive instances¹:

```
data Chain txs =  
    GenesisBlock  
  | Block (Chain txs) txs  
deriving (Eq, Show, Foldable)
```

¹For `Foldable`, a language extension is required.

Deriving instances

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```
data Chain txs =  
    GenesisBlock  
  | Block (Chain txs) txs  
deriving (Eq, Show, Foldable)
```

Generally, we have to manually provide **instance** declarations.

¹For **Foldable**, a language extension is required.

Explicit effects

Pure functions

- Function results depend only on their inputs.
- Functions have no side effects.

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Side effects are expressed by the `IO` type:

```
f :: Int -> Int      -- result depends only on argument  
g :: Int -> IO Int   -- result is not an Int , but an action
```

Reading a file from disk

```
readFile :: FilePath -> IO String  
type FilePath = String
```

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type FilePath = String
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The following is not type correct:

```
lengthOfFile file =  
    length (readFile file) -- type error!
```

Reading a file from disk

```
readFile :: FilePath -> IO String  
type FilePath = String
```

The following is not type correct:

```
lengthOfFile file =  
    length (readFile file) -- type error!
```

This is correct:

```
lengthOfFile :: FilePath -> IO Int  
lengthOfFile file =  
    length <$> readFile file
```

Constructing complex IO actions

```
(<$>) :: (a -> b) -> IO a -> IO b  
(>>)  :: IO a -> IO b -> IO b  
(<*>) :: IO (a -> b) -> IO a -> IO b  
(>>=) :: IO a -> (a -> IO b) -> IO b
```

(These all have more general types, but that does not matter now.)

No escape

- Results that depend on effects have an **IO** marker in their types.
- We cannot² lie about this.
- Effectful programs have stronger requirements than non-effectful ones.
- Encourages a programming style that separates effectful wrapper from pure kernels.

²not easily

Lazy evaluation

Building a chain

```
build :: Int -> Chain Int
build n =
  if n <= 0
    then GenesisBlock
    else Block (build (n - 1)) n
```


Building a chain

```
build :: Int -> Chain Int
build n =
  if n <= 0
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```

```
GHCi> build 2
Block (Block GenesisBlock 1) 2
```

Building a long chain

This takes a while:

```
GHCi> length (build 10000000)  
10000000
```

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What about this?

```
GHCi> hasBlockProp even (build 10000000)
```

Building a long chain

This takes a while:

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GHCi> length (build 10000000)  
10000000
```

What about this?

```
GHCi> hasBlockProp even (build 10000000)  
True
```

This is nearly immediate.

Multiple options to reduce

```
hasBlockProp even (build 10000000)
```

Multiple options to reduce

```
hasBlockProp even (build 10000000)
= hasBlockProp even
  (if 10000000 <= 0
   then GenesisBlock
   else Block (build (10000000 - 1)) 10000000
  )
```

Multiple options to reduce

```
hasBlockProp even (build 10000000)
= hasBlockProp even
  (if 10000000 <= 0
    then GenesisBlock
    else Block (build (10000000 - 1)) 10000000
  )
= hasBlockProp even
  (if False
    then GenesisBlock
    else Block (build (10000000 - 1)) 10000000
  )
```

Multiple options to reduce

```
hasBlockProp even (build 10000000)
= hasBlockProp even
  (if 10000000 <= 0
    then GenesisBlock
    else Block (build (10000000 - 1)) 10000000
  )
= hasBlockProp even
  (if False
    then GenesisBlock
    else Block (build (10000000 - 1)) 10000000
  )
= hasBlockProp even
  (Block (build (10000000 - 1)) 10000000)
```


Multiple options to reduce

```
hasBlockProp even (build 10000000)
= hasBlockProp even
  (if 10000000 <= 0
    then GenesisBlock
    else Block (build (10000000 - 1)) 10000000
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= hasBlockProp even
  (if False
    then GenesisBlock
    else Block (build (10000000 - 1)) 10000000
  )
= hasBlockProp even
  (Block (build (10000000 - 1)) 10000000)
```

Multiple options to reduce

```
hasBlockProp even (build 10000000)
= hasBlockProp even
  (if 10000000 <= 0
    then GenesisBlock
    else Block (build (10000000 - 1)) 10000000
  )
= hasBlockProp even
  (if False
    then GenesisBlock
    else Block (build (10000000 - 1)) 10000000
  )
= hasBlockProp even
  (Block (build (10000000 - 1)) 10000000)
```

```
= hasBlockProp even  
  (Block (build (100000000 - 1)) 100000000)
```

```
= hasBlockProp even  
  (Block (build (10000000 - 1)) 10000000)  
= even 10000000  
  || hasBlockProp even (build (10000000 - 1))
```

```
= hasBlockProp even  
  (Block (build (10000000 - 1)) 10000000)  
= even 10000000  
  || hasBlockProp even (build (10000000 - 1))  
= True  
  || hasBlockProp even (build (10000000 - 1))
```

```
= hasBlockProp even  
  (Block (build (10000000 - 1)) 10000000)  
= even 10000000  
  || hasBlockProp even (build (10000000 - 1))  
= True  
  || hasBlockProp even (build (10000000 - 1))  
= True
```

Lazy evaluation

- The leftmost outermost expressions are reduced.
- Expressions are only evaluated when needed.
- This implies we can work with potentially infinite values.
- More importantly, it allows for better separation of concerns and the definition of “control-flow constructs”.
- The disadvantage is that it becomes more difficult to reason about performance.

Summary

What we have seen

- Being able to define higher-order functions easily is a feature all functional languages share.
- Polymorphism, data types and pattern matching are common to statically typed functional languages.
- Type classes are rather unique to Haskell, but other languages have other features instead.
- Explicit effects and lazy evaluation make Haskell truly special (although some languages derived from Haskell take a similar approach).

What is next?

We will focus on two fundamental points of Haskell programming:

- How to define datatypes.
- How datatypes shape functions
(**type-directed programming**).