

Introduction to Haskell

Functional programming in Haskell

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What is Haskell?

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Functional

- Functions as first-class citizens
- Higher order functions
- Declarative style

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- Equational reasoning
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- Infinite data structures
- Compositional programming style
- Tricky to evaluate complexity

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Statically typed

- “If a program compiles, it probably works”
- Expressive type system
- Type inference

Installing Haskell toolchain

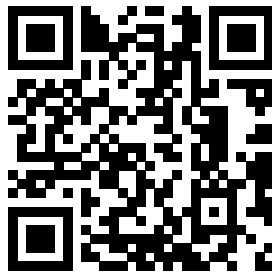
Official installer [GHCup](https://www.haskell.org/ghcup/)

- GHC (Glasgow Haskell Compiler)
- GHCi — interactive REPL-like environment
- HLS (Haskell Language Server) — integration with [editors](#)
- cabal and stack — tools for package management and development

```
$ ghc --version
```

```
The Glorious Glasgow Haskell Compilation System,  
version 9.4.8
```

Note: any version 9.x.x or above will be fine



<https://www.haskell.org/ghcup/>

Using GHCi

- `:?` — help
- `:quit` or `:q` — quit
- `:load` or `:l` — load module
- `:reload` or `:r` — reload modules
- `:info` or `:i` — information about identifier
- `:type` or `:t` — type of expression
- `:set` / `:unset` — set or unset options

```
$ ghci
GHCi, version 9.4.8:
https://www.haskell.org/ghc/ :? for help
ghci> 2
2
ghci> True
True
ghci> 'a'
'a'
ghci> "Hello"
"Hello"
ghci> [1,2,3]
[1,2,3]
ghci> (12, True)
(12, True)
ghci> :q
Leaving GHCi.
```


Evaluating expressions

Arithmetic

```
ghci> 2 + 3
5
ghci> 2 + 3 * 2
8
ghci> (-2) * 4
-8
ghci> 5.0 / 2.0
2.5
ghci> 5 `div` 2
2
ghci> 5 `mod` 2
1
```

Booleans and comparisons

```
ghci> True && False
False
ghci> True || False
True
ghci> not True
False
ghci> 5 == 2 + 3
True
ghci> 5 /= 2 + 3
False
ghci> True > False
True
```

Operators are functions

```
ghci> (+) 2 3
5
ghci> div 5 2
2
ghci> max 5 2
5
ghci> 5 `max` 2
5
```

Associativity and precedence

Symbolic operators

- Any non-alphanumeric identifier is considered operator and *infix* by default
- But can be made *prefix* by enclosing in parentheses
- Associativity and precedence must be explicitly specified

Alphanumeric functions

- Any alphanumeric identifier is *prefix* by default
- But can be made *infix* by enclosing in backticks
- Function application has highest precedence and always left-associative

```
ghci> 2 + (3 * 2)
8
ghci> :i (+)
type Num :: * -> Constraint
class Num a where
    (+) :: a -> a -> a
    ...
    -- Defined in `GHC.Num'
infixl 6 +
ghci> :i (*)
type Num :: * -> Constraint
class Num a where
    ...
    (*) :: a -> a -> a
    ...
    -- Defined in `GHC.Num'
infixl 7 *
```

Associativity and precedence

Symbolic operators

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- But can be made *prefix* by enclosing in parentheses
- Associativity and precedence must be explicitly specified

```
ghci> max 2 3 + 2
4
ghci> (max 2 3) + 2
4
ghci> max 2 (3 + 2)
5
ghci> min 4 (max 2 3)
3
```

Alphanumeric functions

- Any alphanumeric identifier is *prefix* by default
- But can be made *infix* by enclosing in backticks
- Function application has highest precedence and always left-associative

Lists and tuples

Lists

- *Homogeneous* linked lists
 - [] — empty list
 - (:) — constructor “cons”
 - (++) — concatenation
- Enumeration notation [1..10]

```
ghci> [1,2,3]
[1,2,3]
ghci> []
[]
ghci> 1 : []
[1]
ghci> [3,4] ++ [1,2]
[3,4,1,2]
ghci> 1 : 2 : 3 : []
[1,2,3]
ghci> 1 : 2 : 3 : [] == [1,2,3]
True
ghci> [1..5]
[1,2,3,4,5]
ghci> [1,3..10]
[1,3,5,7,9]
```

Lists and tuples

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- *Homogeneous* linked lists
 - `[]` — empty list
 - `(:)` — constructor “cons”
 - `(++)` — concatenation
- Enumeration notation `[1..10]`

Tuples

- Cartesian product of several types
- Except for pairs should not be used anywhere (Haskell provides better ways via custom data structures)
 - `fst` and `snd` are only for pairs

```
ghci> (1,2)
(1,2)
ghci> (True,2)
(True,2)
ghci> fst (True,2)
True
ghci> snd (True,2)
2
ghci> (True,[1,2],42)
(True,[1,2],42)
```

Strings

Strings are lists

- Strings are lists of Unicode characters¹
- Characters can be enumerated
- Strings can be compared lexicographically
- In real world more efficient implementations are used (see [text](#) and [bytestring](#))

¹Actually [Unicode code points](#)

```
ghci> 'a'
'a'
ghci> 'λ'
'\120582'
ghci> putStrLn "λ"
λ
ghci> "abc123"
"abc123"
ghci> ['a','b','c']
"abc"
ghci> 'a' : "bc" == "abc"
True
ghci> ['a'..'f']
"abcdef"
ghci> "Haskell" > "C++"
True
```

More functions

List functions

```
ghci> length "Haskell"
7
ghci> reverse "Haskell"
"lleksaH"
ghci> take 2 "Hello" ++ drop 5 "Haskell"
"Hell"
ghci> filter even [1..10]
[2,4,6,8,10]
ghci> sum (filter even [1..10])
30
ghci> map odd [1..5]
[True,False,True,False,True]
```

More functions

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ghci> map odd [1..5]
[True,False,True,False,True]
```

Anonymous functions¹

```
ghci> (\x -> 3 * x + 2) 2
8
ghci> map (\x -> 3 * x + 2) [1..5]
[5,8,11,14,17]
ghci> (\x y -> x + y) 2 3
5
ghci> zipWith (\x y -> x + y) [1..5] [6..10]
[7,9,11,13,15]
ghci> zipWith (+) [1..5] [6..10]
[7,9,11,13,15]
```

¹Also known as *lambda functions*

Inspecting types in GHCi

```
ghci> :t 'a'
'a' :: Char
ghci> :t True
True :: Bool
ghci> :t [True,False]
[True,False] :: [Bool]
ghci> :t (True,'a')
(True,'a') :: (Bool, Char)
ghci> :t ('a',True)
('a',True) :: (Char, Bool)
ghci> :t not
not :: Bool -> Bool
```

- :: reads as “has type”

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- `::` reads as “has type”

Parametric polymorphism

```
ghci> :t reverse
reverse :: [a] -> [a]
ghci> reverse [1,2,3]
[3,2,1]
ghci> reverse "Haskell"
"lleksaH"
ghci> :t fst
fst :: (a, b) -> a
```

- Lower-case identifiers in type signatures are *type variables*
- Concrete types always start with upper-case letter

Currying

- Functions with multiple parameters are always *curried*¹
 - Accept exactly one argument and return another function
- \rightarrow is *right-associative*, so following type signatures are the same

```
take :: Int -> [a] -> [a]
take :: Int -> ([a] -> [a])
```

- Allows *partial application* of function to the first argument(s)

```
ghci> :t take
take :: Int -> [a] -> [a]
ghci> :t take 2
take 2 :: [a] -> [a]
ghci> :t take 2 "abc"
take 2 "abc" :: [Char]
ghci> :t map
map :: (a -> b) -> [a] -> [b]
ghci> :t map (take 2)
map (take 2) :: [[a]] -> [[a]]
ghci> map (take 2) ["abc", "def"]
["ab", "de"]
```

¹This idea was first introduced by *Moses Schönfinkel* and then further developed and popularized by *Haskell Curry*

Overloading

- Type variables of polymorphic functions can have additional constraints¹ denoted by `=>` clause
- In that case we say that they are *overloaded*
- Overloaded functions use some specific API provided by those constraints in their implementation
- `Ord` means something *comparable*
- `Num` is any number-like type (`Int`, `Integer`, `Double`)
- `Foldable` is a generalization of any container-like type²

```
ghci> :t max
max :: Ord a => a -> a -> a
ghci> max "Haskell" "C++"
"Haskell"
ghci> max 3 5
5
ghci> :t (>)
(>) :: Ord a => a -> a -> Bool
ghci> :t (+)
(+) :: Num a => a -> a -> a
ghci> :t length
length :: Foldable t => t a -> Int
```

¹Such constraints are called *type classes* and we will encounter them a lot during semester

²For now consider it to be simply list type

Built-in types

- Numeric literals are overloaded
- We can explicitly specify type for any expression
- `Int` — fixed-precision integer type
 - Guaranteed to be at least $[-2^{29}, 2^{29} - 1]$ ¹, but usually is machine word sized
- `Integer` — arbitrary-precision integer type
 - Implemented internally via GNU Multiple Precision Arithmetic Library (GMP)²
- `Float` — single-precision floating point type
- `Double` — double-precision floating point type
- `Char` — Unicode code point (character)
- `()` — Unit type

¹See [Haskell 2010 Language Report, Section 6.4 Numbers](#)

²See [integer-gmp](#) package

```
ghci> :t 2
2 :: Num a => a
ghci> :t maxBound
maxBound :: Bounded a => a
ghci> maxBound
()
ghci> maxBound :: Int
9223372036854775807
ghci> maxBound :: Char
'\1114111'
ghci> 2^100
1267650600228229401496703205376
ghci> 2^100 :: Int
0
ghci> 2^100 :: Integer
1267650600228229401496703205376
```

Program structure

Modules

- Haskell program consists of *modules*
- Each module corresponds to single `.hs` or `.lhs` (*literate Haskell*) file
- Each module contains *declarations*:
 - Function declarations (*bindings*)
 - Type signatures
 - Fixity declarations (associativity and precedence of operators)
 - *Type declarations*
 - And many others...
- Order of declarations does not matter

Prelude

- Prelude is an implicitly imported module containing standard function and type declarations
- Most of the functions we have seen so far come from Prelude module
- Very little is actually built into Haskell language itself



<https://hackage.haskell.org/package/base-4.21.0.0/docs/Prelude.html>

Q&A