CSCE 314
Programming Languages
Haskell 101
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Historical Background

1930s:

Alonzo Church develops the lambda calculus, a simple but powerful theory of functions.
Historical Background

1950s:

John McCarthy develops Lisp, the first functional language, with some influences from the lambda calculus, but retaining variable assignments.
Historical Background

1960s:

Peter Landin develops ISWIM, the first pure functional language, based strongly on the lambda calculus, with no assignments.
Historical Background

1970s:

John Backus develops FP, a functional language that emphasizes higher-order functions and reasoning about programs.
Historical Background

1970s:

Robin Milner and others develop ML, the first modern functional language, which introduced type inference and polymorphic types.
Historical Background

1970s – 1980s:

David Turner develops a number of lazy functional languages, culminating in the Miranda system.
An international committee of researchers initiates the development of Haskell, a standard lazy pure functional language.
Historical Background

2003: The committee publishes the Haskell 98 report, defining a stable version of the language.

Since then highly influential in language research and fairly widely used in commercial software. For example, Facebook’s anti-spam programs, and Cardano, a cryptocurrency introduced in Sep. 2017, are written in Haskell.
Haskell is a Lazy Pure Functional Language
“Haskell is a **Lazy** Pure Functional Language”

Lazy programming language only evaluates arguments when strictly necessary, thus, (1) avoiding unnecessary computation and (2) ensuring that programs terminate whenever possible. For example, given the definitions

\[
\text{omit } x = 0 \\
\text{keep\_going } x = \text{keep\_going } (x+1)
\]

what is the result of the following expression?

\[
\text{omit } (\text{keep\_going } 1)
\]
“Haskell is a Lazy Pure Functional Language”

Pure functional language, as with mathematical functions, prohibits side effects (or at least they are confined):

- Immutable data: Instead of altering existing values, altered copies are created and the original is preserved, thus, there’s no destructive assignment:
  
  $$a = 1; a = 2; \quad -- \text{illegal}$$

- Referential transparency: Expressions yield the same value each time they are invoked; helps reasoning. Such expression can be replaced with its value without changing the behavior of a program, for example,
  
  $$y = f \cdot x \quad \text{and} \quad g = h \cdot y \cdot y$$

  then, replacing the definition of g with $$g = h \cdot (f \cdot x) \cdot (f \cdot x)$$ will get the same result (value).
"Haskell is a Lazy Pure Functional Language"

Functional language supports the functional programming style where the basic method of computation is application of functions to arguments. For example, in C,

```c
int s = 0;
for (int i=1; i <= 100; ++i)  s = s + i;
```

the computation method is **variable assignment**

In Haskell,

```haskell
sum [1..100]
```

the computation method is **function application**
Features of Functional Languages

- Higher-order functions are functions that take other functions as their arguments. E.g.,
  > map reverse ["abc","def"]
  ["cba","fed"]

- Purity – prohibits side effects
  (Expressions may result in some actions in addition to return values, such as changing state and I/O; these actions are called side effects)

- Recursion – the canonical way to iterate in functional languages
A Taste of Haskell

\[
\begin{align*}
f \; [] &= [] \\
f \; (x:xs) &= f \; ys \; ++ \; [x] \; ++ \; f \; zs \\
\text{where} \\
ys &= [a \mid a \leftarrow xs, a \leq x] \\
zs &= [b \mid b \leftarrow xs, b > x]
\end{align*}
\]
void f(int xs[], int first, int last)
{
    int mid;
    if (first < last)
    {
        mid = partition(xs, first, last);
        f(xs, first, mid);
        f(xs, mid+1, last);
    }
    return;
}

int partition(int xs[], int first, int last)
{
    int k = xs[first];
    int i = first-1;
    int j = last+1;
    int temp;
    do {
        do { j--; } while (k<xs[j]);
        do { i++; } while (k>xs[i]);
        if (i<j) { temp=xs[i]; xs[i]=xs[j]; xs[j]=temp; }
    } while (i<j);
    return j;
}
Recursive function execution:
Other Characteristics of Haskell

- Statically typed
- Type inference
- Rich type system
- Succinct, expressive syntax yields short programs
- Indentation matters
- Capitalization of names matters
Using GHC and GHCi

- From a shell window, the compiler is invoked as
  > ghc myfile.hs
  > ghci (or as > ghc --interactive)
- For multi-file programs, use --make option
- GHCi operates on an eval-print-loop:

  ```
  > sqrt (3^2 + 4^2)
  5.0
  >
  ```

  User types in a Haskell expression
  The interpreter evaluates it and prints out the result
  Waits for the next expression

- Efficient edit-compile-run cycle, e.g., using Emacs with haskell-mode
  (https://github.com/serras/emacs-haskell-tutorial/blob/master/tutorial.md) helps indenting, debugging, jumping to an error, etc.
Using GHCi

- Useful basic GHCi commands:
  - `:?`   Help! Show all commands
  - `:load test` Open file test.hs or test.lhs
  - `:reload` Reload the previously loaded file
  - `:main a1 a2` Invoke main with command line args a1 a2
  - `:!`   Execute a shell command
  - `:edit name` Edit script name
  - `:edit` Edit current script
  - `:type expr` Show type of expr
  - `:quit` Quit GHCi

- Commands can be abbreviated. E.g., `:r` is `:reload`

- At startup, the definitions of the “Standard Prelude” are loaded
The Standard Prelude

Haskell comes with a large number of standard library functions. In addition to the familiar numeric functions such as + and *, the library also provides many useful functions on lists.

-- Select the first element of a list:

\[ \texttt{> head } [1,2,3,4,5] \]
\[ 1 \]

-- Remove the first element from a list:

\[ \texttt{> tail } [1,2,3,4,5] \]
\[ [2,3,4,5] \]
-- Select the nth element of a list:

```
> [1,2,3,4,5] !! 2
3
```

-- Select the first n elements of a list:

```
> take 3 [1,2,3,4,5]
[1,2,3]
```

-- Remove the first n elements from a list:

```
> drop 3 [1,2,3,4,5]
[4,5]
```

-- Append two lists:

```
> [1,2,3] ++ [4,5]
[1,2,3,4,5]
```
-- Reverse a list:
> reverse [1,2,3,4,5] [5,4,3,2,1]

-- Calculate the length of a list:
> length [1,2,3,4,5] 5

-- Calculate the sum of a list of numbers:
> sum [1,2,3,4,5] 15

-- Calculate the product of a list of numbers:
> product [1,2,3,4,5] 120
Functions (1)

- Function and parameter names must start with a lower case letter, e.g., myFun1, arg_x, personName, etc. (By convention, list arguments usually have an _ suffix on their name, e.g., xs, ns, nss, etc.)

- Functions are defined as equations:
  
  square x = x * x     add x y = x + y

- Once defined, apply the function to arguments:
  
  > square 7     > add 2 3
  49             5

  In C, these calls would be square(7); and add(2,3);

- Parentheses are often needed in Haskell too

  > add (square 2) (add 2 3)

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Functions (2)

- Function application has the highest precedence
  square 2 + 3 means (square 2) + 3 not square (2+3)

- Function call associates to the left and is by pattern matching (first one to match is used)

- Function application operator $ has the lowest precedence and is used to rid of parentheses
  sum ([1..5] ++ [6..10]) -> sum $ [1..5] ++ [6..10]

- Combinations of most symbols are allowed as operator
  x @#$%^&*-+@#$% y = "What on earth?" 😊

  Another (more reasonable) example:
  x +/- y = (x+y, x-y)
  > 10 +/- 1
  (11,9)
Function Application

In **mathematics**, function application is denoted using parentheses, and multiplication is often denoted using juxtaposition or space.

\[ f(a,b) + c \cdot d \]

Apply the function \( f \) to \( a \) and \( b \), and add the result to the product of \( c \) and \( d \).

In **Haskell**, function application is denoted using space, and multiplication is denoted using \( \ast \).

\[ f \ a \ b + c \ast d \]

As previously, but in Haskell syntax.
Examples

**Mathematics**

- \( f(x) \)
- \( f(x, y) \)
- \( f(g(x)) \)
- \( f(x, g(y)) \)
- \( f(x)g(y) \)

**Haskell**

- \( f \ x \)
- \( f \ x \ y \)
- \( f \ (g \ x) \)
- \( f \ x \ (g \ y) \)
- \( f \ x \ * \ g \ y \)
Evaluating Functions (1)

Think of evaluating functions as substitution and reduction

\[
\text{add } x \ y = x + y; \quad \text{square } x = x \times x
\]

\[
\text{add} \ (\text{square} \ 2) \ (\text{add} \ 2 \ 3)
\]

— apply \ square

\[
\text{add} \ (2 \times 2) \ (\text{add} \ 2 \ 3)
\]

— apply \ *

\[
\text{add} \ 4 \ (\text{add} \ 2 \ 3)
\]

— apply inner \ add

\[
\text{add} \ 4 \ (2 + 3)
\]

— apply \ +

\[
\text{add} \ 4 \ 5
\]

— apply \ add

\[
4 + 5
\]

— apply \ +

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Evaluating Functions (2)

- There are many possible orders to evaluate a function
  head (1:(reverse [2,3,4,5])) → apply reverse → apply head → ... many steps omitted here → head ([1,5,4,3,2]) → apply head → 1

- In a pure functional language, evaluation order does not affect the value of the computation

- It can, however, affect the amount of computation and whether the computation terminates or not (or fails with a run-time error)

- Haskell evaluates a function’s argument lazily
  “Call-by-name” – only apply a function if its value is needed, and “memoize” what’s already been evaluated
Haskell Scripts

A Haskell program consists of one or more scripts.
A script is a text file comprising a sequence of definitions, where new functions are defined.
By convention, Haskell scripts usually have a .hs suffix on their filename. This is not mandatory, but is useful for identification purposes.

Loading new script causes new definitions to be in scope:
Prelude> :l test.hs
[1 of 1] Compiling Main    ( test.hs, interpreted )
Ok, modules loaded: Main.
*Main>
My First Script

When developing a Haskell script, it is useful to keep two windows open, one running an editor for the script, and the other running GHCi:

Start an editor, type in the following two function definitions, and save the script as test.hs:

```hs
double x = x + x
quadruple x = double (double x)
```

In another window start up GHCi with the new script:

```
% ghci test.hs
```

Now both the standard library and the file test.hs are loaded, and functions from both can be used:

```
> quadruple 10
40
> take (double 2) [1,2,3,4,5,6]
[1,2,3,4]
```
Leaving GHCi open, return to the editor, add the following definitions, and resave:

```
factorial n = product [1..n]
average ns = sum ns `div` length ns
```

Note:
- `div` is enclosed in back quotes, not forward
- `x `f` y` is syntactic sugar for `f x y`
- Any function with two or more arg.s can be used as an infix operator (enclosed in back quotes)
- Any infix operator can be used as a function (enclosed in parentheses), e.g., `(+) 10 20`

GHCi does not automatically detect that the script has been changed, so a `reload` command must be executed before the new definitions can be used:

```
> :r
  ( test.hs, interpreted )
> factorial 10
3628800
> average [1,2,3,4,5]
3
```
The Layout Rule

- Layout of a script determines the structure of definitions
- Commonly use layouts instead of braces and semicolons (which are still allowed and can be mixed with layout)
- Each definition must begin in precisely the same column:

\[
\begin{align*}
    a &= 10 \\
    b &= 20 \\
    c &= 30 \\
\end{align*}
\]

\[
\begin{align*}
    a &= 10 \\
    b &= 20 \\
    c &= 30 \\
\end{align*}
\]

\[
\begin{align*}
    a &= 10 \\
    b &= 20 \\
    c &= 30 \\
\end{align*}
\]

\[
\begin{align*}
    a &= b + c \\
    \text{where} \\
    b &= 1 \\
    c &= 2 \\
    d &= a \times 2
\end{align*}
\]

\[
\begin{align*}
    a &= b + c \\
    \text{where} \\
    \{b = 1; \\
    c = 2\} \\
    d &= a \times 2
\end{align*}
\]
Exercises

(1) Try out the codes in slides 15–24 using GHCi.

(2) Fix the syntax errors in the program below, and test your solution using GHCi.

```
N = a 'div' length xs
   where
       a = 10
       xs = [1,2,3,4,5]
```

```
n = a `div` length xs
   where
       a = 10
       xs = [1,2,3,4,5]
```
(3) Show how the library function `last` that selects the last element of a list can be defined using the functions introduced in this lecture.

\[
\text{last } xs = \text{head } (\text{reverse } xs)
\]

(4) Can you think of another possible definition?

\[
\text{last } xs = xs \text{ !! } (\text{length } xs - 1)
\]

(5) Similarly, show how the library function `init` that removes the last element from a list can be defined in two different ways.

\[
\text{init } xs = \text{take } (\text{length } xs - 1) \; xs
\]

\[
\text{init } xs = \text{reverse } (\text{tail } (\text{reverse } xs))
\]