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
Historical Background

1987:

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?

```plaintext
omit (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,

  \[ y = f \; x \quad \text{and} \quad g = h \; y \; y \]

  then, replacing the definition of \( g \) with \( g = h \; (f \; x) \; (f \; x) \) 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

\[
f \; [\;] \; = \; [\;]
\]
\[
f \; (x:xs) \; = \; f \; ys \; ++ \; [x] \; ++ \; f \; zs
\]
where
\[
ys \; = \; [a \mid a \leftarrow xs, \; a \; \leq \; x]
\]
\[
zs \; = \; [b \mid b \leftarrow xs, \; b \; > \; x]
\]
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:

\[ f\{3,2,4,1,5\} \]

\[ f\{2,1\} \quad \text{++} \quad [3] \quad \text{++} \quad f\{4,5\} \]

\[ f\{1\} \quad \text{++} \quad [2] \quad \text{++} \quad f\{\} \]

\[ f\{\} \quad \text{++} \quad [4] \quad \text{++} \quad f\{5\} \]

\[ [1] \]

\[ [] \]

\[ [] \]

\[ [] \]

\[ [5] \]
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:

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

-- Remove the first element from a list:

```
> 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 \_s suffix on their name, e.g., xs, ns, nss, etc.)

- Functions are defined as equations:
  square \( x = x \times x \)     \( \text{add} \ x \ y = x + y \)

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

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

- Parentheses are often needed in Haskell too
  \> \text{add} \ (\text{square} \ 2) \ (\text{add} \ 2 \ 3)
  9
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 $*$

$$f \ a \ b + c*d$$

As previously, but in Haskell syntax
<table>
<thead>
<tr>
<th>Mathematics</th>
<th>Haskell</th>
</tr>
</thead>
<tbody>
<tr>
<td>$f(x)$</td>
<td>$f \ x$</td>
</tr>
<tr>
<td>$f(x,y)$</td>
<td>$f \ x \ y$</td>
</tr>
<tr>
<td>$f(g(x))$</td>
<td>$f \ (g \ x)$</td>
</tr>
<tr>
<td>$f(x,g(y))$</td>
<td>$f \ x \ (g \ y)$</td>
</tr>
<tr>
<td>$f(x)g(y)$</td>
<td>$f \ x \ * \ g \ y$</td>
</tr>
</tbody>
</table>
Evaluating Functions (1)

Think of evaluating functions as substitution and reduction

```
add x y = x + y;  square x = x * x
add (square 2) (add 2 3)
  — apply square
add (2 * 2) (add 2 3)
  — apply *
add 4 (add 2 3)
  — apply inner add
add 4 (2 + 3)
  — apply +
add 4 5
  — apply add
4+5
  — apply +
9
```
Evaluating Functions (2)

- There are many possible orders to evaluate a function:
  head (1:(reverse [2,3,4,5]))
  -- apply reverse
  -- ... 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-need” – 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`:

```haskell
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:

\[
\text{factorial } n = \text{product } [1..n] \\
\text{average } ns = \text{sum } ns \ `\text{div}\` \text{length } ns
\]

Note:

- `\text{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 `\text{reload}` command must be executed before the new definitions can be used:

```
> :r
Reading file "test.hs"
> 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:

```
| a = 10   | a = 10   | a = 10   |
| b = 20   | b = 20   | b = 20   |
| c = 30   | c = 30   | c = 30   |
```

- implicit grouping by layout

```
| a = b + c where b = 1  |
| c = 2  d = a * 2       |
```

- explicit grouping by braces and semicolons

```
| a = b + c where {b = 1; c = 2} |
| d = a * 2                       |
```
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.

\[
N = a \div \text{length } xs \\
\text{where} \\
a = 10 \\
xs = [1,2,3,4,5]
\]

\[
n = a \ `\div` \text{length } xs \\
\text{where} \\
a = 10 \\
xs = [1,2,3,4,5]
\]
(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.

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

(4) Can you think of another possible definition?

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

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

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