CSc 372 — Comparative Programming Languages

13 : Haskell — Lazy Evaluation

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1 Lazy evaluation

- Haskell evaluates expressions using a technique called *lazy evaluation*:
  1. No expression is evaluated until its value is needed.
  2. No shared expression is evaluated more than once; if the expression is ever evaluated then the result is shared between all those places in which it is used.
- Lazy functions are also called *non-strict* and evaluate their arguments *lazily* or *by need*.
- C functions and Java methods are *strict* and evaluate their arguments *eagerly*.

2 Don't Evaluate Until Necessary

- The first of these ideas is illustrated by the following function:

```
ignoreArgument x = "I didn't evaluate x"
```

- Since the result of the function `ignoreArgument` doesn't depend on the value of its argument `x`, that argument will not be evaluated:

```
$ hugs +s
> ignoreArgument (1/0)
I didn't evaluate x
(246 reductions, 351 cells)
```

3 Don't Evaluate Until Necessary...

- The function *seq* forces *strict evaluation* when that is necessary:

```
> seq ignoreArgument (1/0)
Inf
(32 reductions, 78 cells)
```

4 Evaluate Shared Expressions Once

- The second basic idea behind lazy evaluation is that no shared expression should be evaluated more than once.
- For example, the following two expressions can be used to calculate $3 * 3 * 3 * 3$:

```
$ hugs +s
> square*square where square = 3*3
81
(30 reductions, 67 cells)
> (3*3)*(3*3)
81
(34 reductions, 45 cells)
```

5 Evaluate Shared Expressions Once...

- Notice that the first expression requires fewer reduction than the second.
- A *reduction* is the basic step of evaluating a Haskell expression, by applying a function to its argument.

6 Saving Reductions

- Consider these sequences of reductions:

```
square * square where square = 3 * 3
   -- calculate the value of square by
   -- reducing 3*3==>9 and replace each
   -- occurrence of square with this result
   ==> 9 * 9
   ==> 81

(3 * 3) * (3 * 3)   -- evaluate first (3*3)
   ==> 9 * (3 * 3)  -- evaluate second (3*3)
   ==> 9 * 9
   ==> 81
```

- Lazy evaluation means that only the minimum amount of calculation is used to determine the result of an expression.

7 Taking the Minimum

- Consider the task of finding the smallest element of a list of integers.

```
> minimum [100,99..1]
1
(2355 reductions, 3211 cells)
```

- `[100,99..1]` denotes the list of integers from 1 to 100 arranged in decreasing order.
- Instead, we could first sort and then take the head of the result:

```
> :load List
> sort [100,99..1]
[1, 2, 3, 4, 5, 6, 7, 8, ..., 99, 100]
(3430 reductions, 8234 cells)
```

8 Taking the Minimum...

- However, thanks to lazy evaluation, calculating just the first element of the sorted list actually requires less work in this particular case than the first solution using `minimum`:

```
> head (sort [100,99..1])
1
(1877 reductions, 3993 cells)

> minimum [100,99..1]
1
(2355 reductions, 3211 cells)
```

9 Infinite data structures

- Lazy evaluation makes it possible for functions in Haskell to manipulate 'infinite' data structures.
- The advantage of lazy evaluation is that it allows us to construct infinite objects piece by piece as necessary
- The function `ones` below generates an infinite list of 1s:

```
ones = 1 :  ones

> take 10 ones
[1,1,1,1,1,1,1,1,1,1,1]
(277 reductions, 389 cells)
```

10 Infinite data structures...

- Consider the following function which can be used to produce infinite lists of integer values:

```
countFrom n = n :  countFrom (n+1)

> countFrom 1
[1, 2, 3, 4, 5, 6, 7, 8,^CInterrupted!]
```

11 Infinite data structures...

- For practical applications, we are usually only interested in using a finite portion of an infinite data structure.
- We can find the sum of the integers 1 to 10:

```
> sum (take 10 (countFrom 1))
55
(278 reductions, 440 cells)
```

- `take n xs` evaluates to a list containing the first `n` elements of the list `xs`.

12 Infinite data structures...

- Infinite data structures enable us to describe an object without being tied to one particular application of that object.
- The following definitions for infinite list of powers of two [1, 2, 4, 8, ...]:

```
powersOfTwo = 1 :  map double powersOfTwo
         where double n = 2*n

> take 10 powersOfTwo
[1,2,4,8,16,32,64,128,256,512]
```

13 Infinite data structures...

- `xs!!n` evaluates to the n:th element of the list `xs`.
- We can define a function to find the nth power of 2 for any given integer n:

```
powersOfTwo = 1 :  map (*2) powersOfTwo

twoToThe n = powersOfTwo !!  n

> twoToThe 5
32
```

14 Fibonacci

- Here's a definition of a function that generates an infinite list of all the fibonacci numbers:

```
fib = 1:1:  [a+b | (a,b) <- zip fib (tail fib)]
> take 10 fib
[1,1,2,3,5,8,13,21,34,55]
```

15 Acknowledgements

- These slides were derived mostly from the Gofer manual.

  Functional programming environment, Version 2.20
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- We're using **hugs** here rather than **ghci** since **ghci** doesn't have an easy way to show number of reductions.