# Programming Language Concepts
# Subroutines

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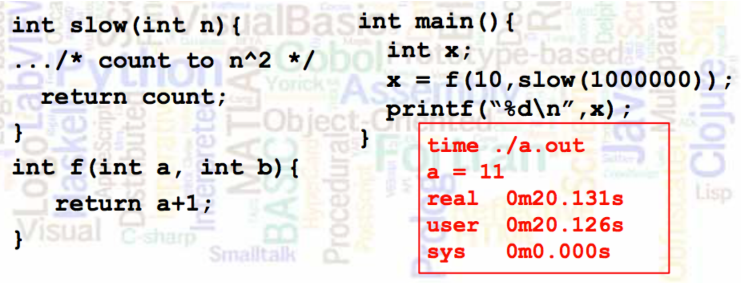
24 March, 2023

# Parameter Evaluation

“Applicative Order” evaluation:

– arguments evaluated before the function call. “Eager” evaluation.



```
int slow(int n){
.../* count to n^2 */
  return count;
}
int f(int a, int b){
   return a+1;
}
```

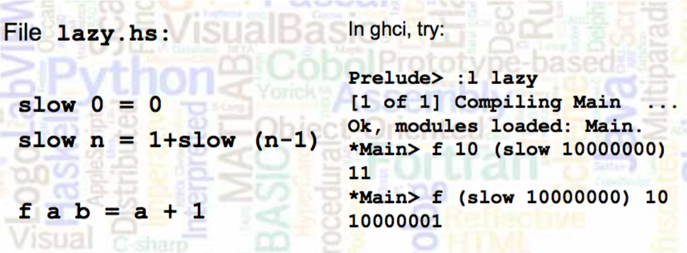
```
int main(){
  int x;
  x = f(10,slow(1000000));
  printf(“%d\n”,x);
}
```

```
time ./a.out
a = 11
real   0m20.131s
user   0m20.126s
sys    0m0.000s
```

# Parameter Evaluation

"Normal Order" evaluation:

– arguments are not evaluated until they are needed (possibly never).



File **lazy.hs:**

```haskell
slow 0 = 0
slow n = 1+slow (n-1)

f a b = a + 1
```

In ghci, try:

```
Prelude> :l lazy
[1 of 1] Compiling Main   ...
Ok, modules loaded: Main.
*Main> f 10 (slow 10000000)
11
*Main> f (slow 10000000) 10
10000001
```

# Parameter Evaluation

“Lazy” evaluation:

- arguments are evaluated at most once (possibly never).
- Even though we used a Haskell example to illustrate “normal order”, it is more accurate to call Haskell’s evaluation order “lazy’.’
- In normal order, a parameter could be evaluated more than once (i.e., evaluated each time it appears in the function).

# Closures

Parameter passing: by value, by reference, or by closure (a reference to a subroutine with its referencing environment).

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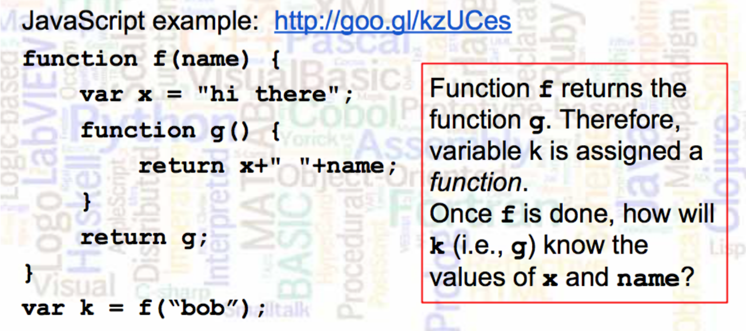
- In languages that support "first-class functions", a function may be a return value from another function; a function may be assigned to a variable.
- This raises some issues regarding scope.

# Closures

http://goo.gl/kzUCes



JavaScript example: http://goo.gl/kzUCes

```
function f(name) {
    var x = "hi there";
    function g() {
        return x+" "+name;
    }
    return g;
}
var k = f(“bob”);
```

Function **f** returns the function **g**. Therefore, variable k is assigned a *function*.
Once **f** is done, how will **k** (i.e., **g**) know the values of **x** and **name**?

# Closures

**One solution** (NOT the one used by JavaScript!):

use the most recently-declared values of variables “name” and “x”.
– This is called “*shallow binding*.” Common in dynamically-scoped languages.

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**Another solution** (used by JavaScript and most other statically-scoped languages):

bind the variables that are in the environment where the function is defined.
– This is an illustration of “deep binding” and the combination of the function and its defining environment is called a closure.

# Exceptions

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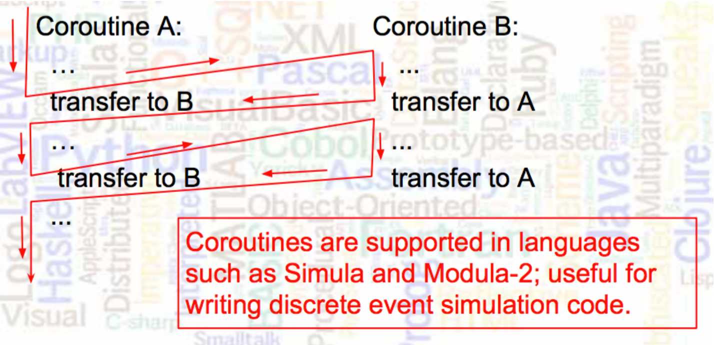
See `Exc.java` in the class activity17 repo.

# Coroutines

- A **coroutine** is a function that can be suspended and resumed.
- Several coroutines can be active at once, transferring control back and forth between them.

# Coroutines



Coroutine A:

…

transfer to B

…

transfer to B

…

Coroutine B:

…

transfer to A

…

transfer to A

Coroutines are supported in languages such as Simula and Modula-2; useful for writing discrete event simulation code.

# Generators in Python

Many other languages have features that allow the implementation of coroutines (even if they are not “built in” to the language).
– Python has generator functions:

```
>>> def gen99():
 ...   for i in range(100):
 ...      yield i # NOTE: not \return i"
 >>> a = gen99() # call the function just once
 >>> next(a)
 0
 >>> next(a)
 1
```

# Generators in Python

```
>>> next(a)
   2
   >>> for i in range(10):
   ...   print next(a),
   ...
   3 4 5 6 7 8 9 10 11 12
   >>> for i in range(10):
   ...   print next(a),
   ...
   13 14 15 16 17 18 19 20 21 22
```

# Generators in Python

- Several generators can be active at the same time; see sample program `gen.py` in the activity17 repository.
- This isn't precisely a coroutine example (we don't have "call" and "response" directly transferring back and forth).
- See `https://docs.python.org/3/library/asyncio-task.html` ("Tasks and coroutines", Python 3.5 documentation) intersection.

# Subroutines: Concepts

- Parameter passing (e.g., pass by value, pass by reference)
- Special syntax (default values, named parameters)
- Mechanisms for function calls (activation record stack, static and dynamic pointers, calling sequences)
- Parameter evaluation (applicative, normal, lazy)
- Closures
- Exceptions
- Coroutines