Hack Your Language!

CSE401 Winter 2016

Introduction to Compiler Construction

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Lecture 4: Iterators and Coroutines

Comprehensions
Lazy Iterators
Coroutines

Announcements

Sign up on Piazza if you haven't

Makeup lecture on Friday 2:30pm-3:50pm

- Same room (here!)
- Will be audio recorded

Section tomorrow

Permanent OHs posted on website

Today

- Comprehensions
- Composing iterators
- Lazy iterators
- Intro to coroutines

Reading

Required:

- Chapter on coroutines from the Lua textbook (http://www.lua.org/pil/)

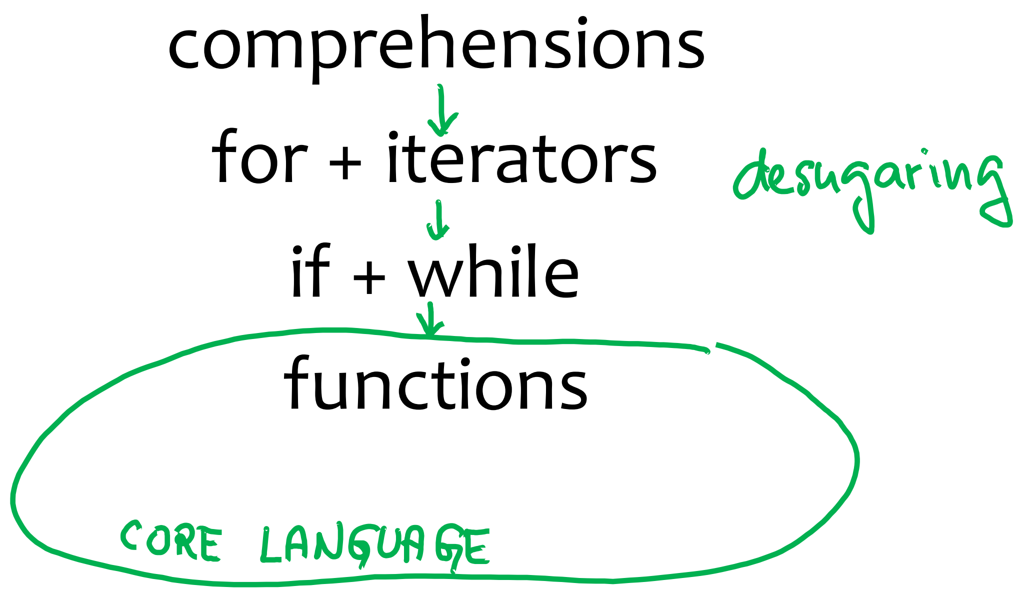
Recommended:

- Python generators are coroutines, actually

Fun:

- More applications of coroutines are in *Revisiting Coroutines*

Our abstraction stack is growing nicely



Comprehensions

Comprehensions

A *map* operation over anything that is iterable.

```
[toUpperCase(v) for v in elements([“a”,“b”])]
-->
[“A”, “B”]
```

General syntax:

[***E1*** for ***ID*** in ***E2***]

Can E1, E2 be comprehension expressions?

Where is variable *ID* visible? In E1, E2 or both?

Comprehensions

Desugaring this example:

```
    [toUpperCase(v) for v in elements(list)]
```

--->

```
    $1 = []
    for v in elements(list) { append($1, toUpperCase(v)) }
    $1
```

Your homework: write a general desugar rule

Must work work on nested comprehensions

```
mat = [[1, 2, 3],  // 2D matrix
       [4, 5, 6],
       [7, 8, 9],
      ]
print [[row[i] for row in mat]
               for i in [0, 1, 2]
      ]
--> [[1, 4, 7], [2, 5, 8], [3, 6, 9]]
```

"To avoid apprehension when nesting list comprehensions, read from right to left"

Compositions of iterators

Iterators can be composed

A simple example: convert characters to uppercase

```
def lst = [“a”, “b”, “c”]
for c in toUpCsIt(asArray(lst)) {
    print c
}
```

Exercise 1. Write `toUpCsIt`

```
function toUpCsIt(it) {
    function () {
        def c = it()
        if (c) { toUpperCase(c) }
        else { null }
}  }
```

(see note on next slide)

Modularity via high-order functions

Instead, use *map* (functional programming); a list comprehension; or the pipes-and-filters pattern. In either case, no code is specific to `ToUpperCase`:

1. `map(toUpperCase, lst)`
2. `[toUpperCase(c) for c in lst]`
3. `consumer(filter(toUpperCase, producer()))`

Lazy iterators

A motivating example

Find the best first move in Scrabble given some time:

```
s = [‘a‘,‘f‘,...]          // 7 letter tiles
for p in permgen(s) {
    for s in subsets(p) {
      if (legalWord(s, wordDict)) {
           // check score of s
           // exit when out if time
        }
    }
}
```

Print all permutations of a list

```
def permgen(a,n=len(a)) {
  if (n <= 1) {
    print(a)
  } else {
   for i in iter(n) {
     a[n],a[i] = a[i],a[n]
     permgen(a,n-1)
     a[n],a[i] = a[i],a[n]
}   } }
permgen(["a","b","c"])
```

[a, b, c], 3

[c, b, a], 2

[b, c, a], 1

[c, b, a], 1

“b c a”

“c b a”

[c, b, a], 2

[b, c, a], 1

[c, b, a], 1

Now let's try to wrap permgen in an iterator

We want to be able to write this code

```
for p in permIterator(list) {
   if (condition(p))
         print p    // print a subset of permutations
}
```

Don’t need to iterate over all permutations

We may want to print just the first legal word

```
def s = legalWord(permIterator(ltrs), myDict)
def word = s()
if (word) print word
```

legalWord may iterate only over some permutations, so let’s not compute and store all $O(2^n)$ of them in a list. Let’s compute them **lazily**, as needed by the caller of the permutation iterator

An incorrect attempt at permgen iterator

```
def permIterator(lst) {
   def permgen(a,n=len(a)) {
         if (n = 1) {
               return a           // was print(a)
         } else {
               for i in iter(n) {
                     a[n],a[i] = a[i],a[n]
                     permgen(a,n-1)
                     a[n],a[i] = a[i],a[n]
   }     }     }
   function () { permgen(lst) }   // the iterator
}
```

What is our stumbling block?

The call stack in `for p in permIterator(lst) {S(p)}` when permgen attempts to pass a permutation to for:

```
inside while loop
iterator
permgen(n)
…
permgen(1)
```

Why can't permgen pass the permutation to iterator?

- it would need to return all the way to top of recursion
- this would force it to lose all context
- context = the value of `i` for each recursion level

Solution and lessons

Rewriting permgen *to be resumable*

Replacing recursion with a loop forces us to maintain the context (a distinct copy of i for each level of recursion).

The code is significantly harder to write and read.

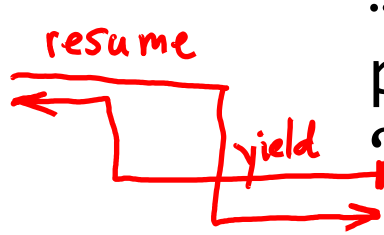
We need something like a goto

Idea: Jump from permgen to the while loop and back,

preserving permgen context on its call stack

Two execution contexts, each with own stack:

while call stack	**permgen call stack**
`inside while loop`	`permgen(n)`
`iter-function`	…
`“call” permgen`	`permgen(1)`
	`“return” to while`



Coroutines

Coroutines == cooperating “threads”

Cooperating =

- one thread of control (one Program Counter)
- coroutines themselves decide when control is transferred between them
  - as opposed to an OS scheduler deciding when to preempt the running thread and transfer control (as in timeslicing)
  - hence also known as “green threads”
- transfer done with a yield statement

many flavors of coroutines exist

We will cover Lua’s asymmetric coroutines

Asymmetric Coroutines

Asymmetric: notion of master vs. slave

symmetric coros. can be implemented on top of asymmetric

Benefits of asymmetric coroutines:

- easier to understand for the programmer because from the master the transfer looks like an ordinary call

- easier to implement (you'll do it in PA2)

Asymmetric Coroutines

Three constructs:

`co=create_coroutine(body)`	create a coroutine co is a handle
`resume(co, arg)`	call/resume a coroutime
`yield(arg)`	return to master, who can resume

Body is a closure

Example (no values passed)

```
var co = create_coroutine(
    function(){
       print(1)
       yield
       print(2)
       yield
       print(3)
}
)
resume(co) -->
resume(co) -->
resume(co) -->
resume(co) -->
```

Body of coroutine (a closure)

Example (yield passes values to master)

```
var co = create_coroutine(function(){
     yield(1)
     yield(2)
     yield(3)
})

print(resume(co)) -->
print(resume(co)) -->
print(resume(co)) -->
print(resume(co)) -->
resume(co) -->
```

Example (pass values to initial yield)

```
var co = create_coroutine(function(x){
     print(x)
     yield()
})

resume(co, 1) -->
resume(co) -->
```

Test yourself

```
var co = create_coroutine(function(x){
     print("1", x)
     print("2", yield())
})

resume(co, "hello") -->
resume(co, "world") -->
```

Iterator factory for permgen

```
var permgen(a, n=len(a)) {
  if (n <= 1) { yield(a) } /* used to be print(a) */
  else {
    for i=1 to n {
      a[n],a[i] = a[i],a[n]
      permgen(a,n-1)
      a[n],a[i] = a[i],a[n]
}     }     }
var permIterator(lst) {
   var co = coroutine(
               function(l) { permgen(l); null }
                 )
   function () { resume(co, lst) }
}
```

This is known as the **wrap** pattern in Lua

Applications of coroutines

What can we do with coroutines

Define control abstractions impossible with functions:

- lazy iterators
- push or pull producer-consumer patterns
- bactracking
- regexes
- exceptions

We will see some of these in lecture and PA

Stackful vs. stackless coroutines

Python generators

Python generators are coroutines with a limitation:

yield must occur in the body of the coroutine

That is, the call stack must be empty

Consumer-Producer Pattern

Create a dataflow on streams

Process the values from permgen

We can apply operations :

```
for v in toUppercaseF(permgen(...)) { process(v) }
```

How to create “filters” like `toUpperCaseF`?

A filter element of the pipeline

```
var filter(ant, f)
    var co = coroutine(function() {
        while (True) {
            --resume antecessor to obtain value
            var x=ant()
            -- yield transformed value
            yield(f(x))
    }    }
    function() { resume(co,0) }
}
f1 = function(x) { ... }
f2 = function(x) { ... }
consumer(filter(filter(producer(), f1), f2))
```

How to implement such pipelines

Producer-consumer patter: often a pipeline structure

- producer → filter → consumer
- All we need to say in code is

```
consumer(filter(producer()))
```

Producer-driven (push) or consumer-driven (pull)

- This decides who initiates resume(). In pull, the consumer resumes to producer who yields datum to consumer.

Each of producer, consumer, filter is a coroutine

- Who initiates resume is the main coroutine.
- In `for x in producer`, the main coroutine is the `for` loop.

Summary

Coroutines allow powerful control abstractions

- iterators but also backtracking, which we'll cover soon

You will implement coroutines in PA2

- we'll describe the implementation next time

What you need to know

- Iterators
- Programming with coroutines
- Write push and pull producer-consumer patterns

Acknowledgements

Our course language, including its coroutines, are modeled after Lua, a neat extensible language.

Many examples in this lecture come from *Programming in Lua*, a great book. Read the 1st edition on the web but consider buying the 3rd edition.

http://www.lua.org/pil/

Coroutine examples are from *Revisiting Coroutines*.