CSc 520 — Principles of Programming Languages

31 : Control Structures — Iterators

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1 Iterators

- `FOR`-loops are typically used to iterate over some range of enumerable values.
- `Iterators` are used to iterate over an **abstraction**, such as the elements of a list, the nodes of a tree, the edges of a graph, etc.
- For example,

```
for n := tree_nodes_in_inorder(T) do
   print n
end
```

Iterators in Java

2 Iterators in Java

- In object-oriented languages it is typical to create an **enumeration object** `i` which contains the current state of the iteration:

```
LinkedList<String> L = new LinkedList<String>();
L.add("Bebe");
L.add("Wendy");
L.add("Nelly");

Iterator<String>  i = L.iterator();
while (i.hasNext()) {
   String c = i.next();
   System.out.println(c);
}
```

- This is not as clean as in languages with built-in support for iterators.

3 Java 1.5 extended `for`-loop

- As of Java 1.5, the `for`-loop has been augmented so you can say

```
LinkedList<String> L = new LinkedList<String>();
L.add("Bebe");
L.add("Wendy");
L.add("Nelly");
for (String c : L)
   System.out.println(c);
```

- However, this is just syntactic sugar for calls to the `Iterator` class.

4 Java 1.5 extended `for`-loop

- You can tell that this is just syntactic sugar by looking at the bytecode the compiler generates (use `javap -c Iter`):

```
29: aload_1
30: invokevirtual #8;       // LinkedList.iterator:
33: astore_2
34: aload_2
35: invokeinterface #9,1;  // java/util/Iterator.hasNext
40: ifeq 63
43: aload_2
44: invokeinterface #10,1; // java/util/Iterator.next
49: checkcast #11;         // java/lang/String
52: astore_3
53: getstatic #12;         // java/lang/System.out
56: aload_3
57: invokevirtual #13;     // java/io/PrintStream.println
60: goto 34
```

Ruby iterators

5 Blocks

- Let's write a simple Ruby for loop to search through an array looking for a particular value:

```
$flock = ["huey","dewey","louie"]

def isDuck?(name)
   for i in 0...$flock.length
      if $flock[i] == name then
         return true
      end
   end
   return false
end

puts isDuck?("dewey"), isDuck?("donald")
```

6 Iterators

- Ruby's *iterators* are an easier way to do this.
- The `Array` class implements a method `find` that iterates through the array.

```
def isDuck?(name)
   $flock.find do |x|
      x == name
   end
end

puts isDuck?("dewey")
puts isDuck?("donald")
```

7 Yield

- A block is enclosed within { } or `do...end`. Arguments to the block (there can be more than one) are given within `|...|`.
- A block is passed to a method by giving it after the list of "normal" parameters.
- The method invokes the block by using `yield`.
- `yield` can take an argument which the method passed back to the block.

8 Yield...

```
def triplets()
   yield "huey"
   yield "dewey"
   yield "louie"
end

triplets() {|d| puts d}

triplets() do |d|
  puts d
end
```

9 Factorial

- Here's the factorial function, as an iterator.

```
def fac(n)
   f = 1
   for i in 1..n
     f *= i
     yield f
   end
end

fac(5) {|f| puts f}
```

10 Passing arguments

- `yield` can pass more than one value to the block.

```
def fac(n)
   f = 1
   for i in 1..n
     f *= i
     yield i,f
   end
end

fac(5) do |i,x|
   puts "#{i}! = #{x}"
end
```

11 Nesting iterators

- Iterators can be nested.

```
fac(3) do |i,x|
   fac(3) do |j,y|
      puts "#{i}! * #{j}! = #{x*y}"
```

```
   end
end
```

12 Scope

- A local variable which is active when the block is started up, can be accessed (and modified) within the block.

```
def sumfac(n)
   y = 0
   fac(n) do |i,x|
      y = y + x
   end
   return y
end

puts sumfac(5)
```

13 Implementing `Array#find`

- We can implement our own `find` method:

```
def find(arr)
   for i in 0..arr.length
      if yield arr[i] then return true end
   end
   return false
end

puts find($flock) {|x| x=="dewey"}
puts find($flock) {|x| x=="donald"}
```

14 `Array#collect`

- `collect` applies the block to every element of an array, creating a new array. This is similar to Haskell's `map`.

```
$flock = ["huey","dewey","louie"]
$flock.each {|x| puts x}

puts $flock.collect {|x| x.length}
puts $flock.collect do |x|
   "junior woodchuck, General " + x
end
```

15 `Array#inject`

- `inject(init)` is similar to Haskell's `foldl`.
- `inject()` without an argument is like Haskell's `foldl1`, i.e. it uses the first element of the array as the starting value.

```
x = $flock.inject("") do |elmt,total|
   total = elmt + " " + total
end
puts x

x = $flock.inject() do |elmt,total|
   total = elmt + " " + total
end
puts x
```

Icon Generators

16 Icon Generators

Procedures are really generators; they can return 0, 1, or a sequence of results. There are three cases

`fail` The procedure fails and generates no value.

`return e` The procedure generates one value, `e`.

`suspend e` The procedure generates the value `e`, and makes itself ready to possibly generate more values.

```
procedure To(i,j)
   while i <= j do {
      suspend i
      i+:= 1
   }
end
```

17 Example

```
procedure To(i,j)
   while i <= j do {
      suspend i
      i+:= 1
   }
end

procedure main()
   every k := To(1,3) do
      write(k)
end
```

18 simple.icn

```
procedure P()
   suspend 3
   suspend 4
   suspend 5
end

procedure main()
   every k := P() do
      write(k)
end
```

19 simple.icn...

```
> setenv TRACE 100
> simple
             :       main()
simple.icn   :    8  | P()
simple.icn   :    2  | P suspended 3
3
simple.icn   :    9  | P resumed
simple.icn   :    3  | P suspended 4
4
simple.icn   :    9  | P resumed
simple.icn   :    4  | P suspended 5
5
simple.icn   :    9  | P resumed
simple.icn   :    5  | P failed
simple.icn   :   10  main failed
```

Iterators in CLU

20 CLU-Style Iterators

- Iterators were pioneered by CLU, a (dead) class-based language from MIT.

```
setsum = proc(s:intset) returns(int)
   sum :  int := 0
   for e:int in intset$elmts(s) do
      sum := sum + e
   end
   return sum
end setsum
```

21 CLU-style Iterators...

- Procedure `setsum` computes the sum of the elements in a set of integers.
- `setsum` iterates over an instance of the abstract type `intset` using the `intset$elmts` iterator.
- Each time around the loop, `intset$elmts` yields a new element, suspends itself, and returns control to the loop body.

22 CLU-style Iterators...

```
intset = cluster is create,elmts,...
   rep = array[int]
   elmts = iter(s:cvt) yields(int)
      i :  int := rep$low(s)
      while i <= rep$high(s) do
         yield (s[i])
         i = i + 1
      end
   end elmts
end intset
```

23 CLU-style Iterators...

- A CLU `cluster` is a typed module; a C++ class, but without inheritance.
- CLU makes a clear distinction between the abstract type (the cluster as seen from the outside), and its representation (the cluster from the inside). The **rep** clause defines the relationship between the two.

24 CLU-style Iterators...

```
elmts = iter(s:cvt) yields(int)
   i :  int := rep$low(s)
   while i <= rep$high(s) do
      yield (s[i])
      i = i + 1
   end
end elmts
```

25 CLU-style Iterators...

- **s:cvt** says that the operation converts its argument from the abstract to the representation type.
- `rep$low` and `rep$high` are the bounds of the array representation.
- `yield` returns the next element of the set, and then suspends the iterator until the next iteration.
- Iterators may be nested and recursive.

26 CLU-style Iterators...

```
array = cluster [t:  type] is ...
   elmts = iter(s:array[t]) yields(t)
      for i:int in int$from_to(
            array[t]$low(a),
            array[t]$high(a)) do
         yield (a[i])
      end
   end elmts
end array
elmts = iter(s:cvt) yields(int)
   for i:int in array$elmts(s) do
      yield (i)
   end
end elmts
```

27 CLU-style Iterators...

- Iterators may invoke other iterators.
- CLU supports constrained generic clusters (like Ada's generic packages, only better).

28 CLU Iterators — Example A

- Here's an example of a CLU iterator that generates all the integers in a range:

```
for i in from_to_by(first,last,step) do
   ...
end
```

29 CLU Iterators — Example A...

```
from_to_by = iter(from,to,by:int) yields(int)
   i : int := from
   if by> 0 then
      while i <= to do
         yield i
         i +:= by
      end
   else
      while i >= to do
         yield i
         i +:= by
      end
   end
```

30 CLU Iterators — Example B

- Here's an example of a CLU iterator that generates all the binary trees of n nodes.

```
for t: bin_tree in bin_tree$tree_gen(n) do
   bin_tree$print(t)
end
```

31 CLU Iterators — Example B...

```
bin_tree = cluster ...
   node = record [left,right : bin_tree]
   rep  = variant [some : node, empty : null]
   ...
   tree_gen = iter (k : int) yields (cvt)
      if k=0 then
         yield red$make_empty(nil)
      else
         for i:int in from_to(1,k) do
            for l : bin_tree in tree_gen(i-1) do
              for r : bin_tree in tree_gen(k-i) do
                 yield rep$make_some(node${l,r})
              end
            end
      end
   end tree_gen
   ...
end
```

Implementing Iterators

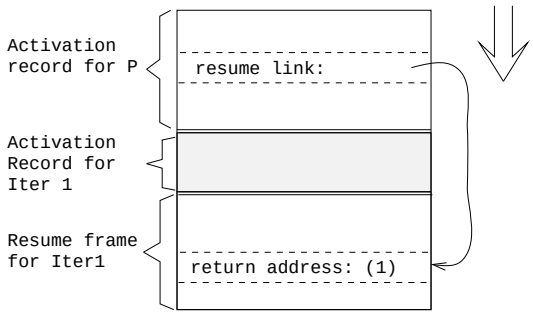
32 Iterator Implementation

```
Iter1 = iter ( ...  )
  ...  yield x
  (1) ...
  end
end Iter1
P = proc ( ...  )
  for i in Iter1(...)  do
    S
  end
end P
```

33 Iterator Implementation

- Calling an iterator is the same as calling a procedure. Arguments are transferred, an activation record is constructed, etc.
- Returning from an iterator is also the same as returning from a procedure call.

34 Iterator Implementation...



35 Iterator Implementation...

- When an iterator yields an item, its activation record remains on the stack. A new activation record (called a **resume frame**) is added to the stack.
- The resume frame contains information on how to resume the iterator. The **return address**-entry in the resume frame contains the address in the iterator body where execution should continue when the iterator is resumed.

36 Nested Iterators

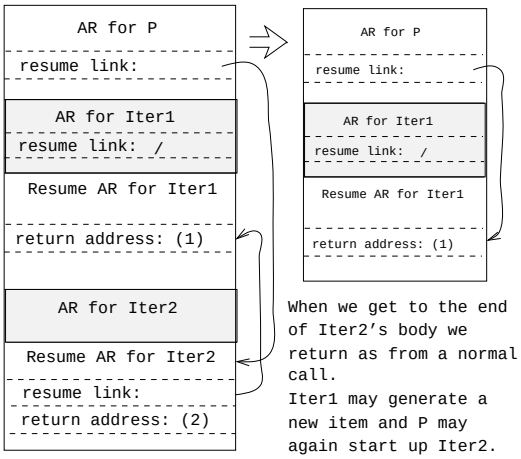
```
for i in Iter1(...)  do
   for j in Iter2(...)  do
      S
```

```
    end
  end
```

37 Nested Iterators...

- Since iterators may be nested, a procedure may have several resume-frames on the stack.
- A new resume frame is inserted **first** in the procedure's **iterator chain**.
- At the end of the **for**-loop body we resume the **first** iterator on the iterator chain:
  1. The first resume frame is unlinked.
  2. We jump to the address contained in the removed frame's return address entry.

38 Nested Iterators...



39 Simpler Iterator Implementation

```
Iter = iter ( ...  )
   while ...  do
      yield x
   end
end

begin
   for i in Iter(...)  do
      print(i);
   end
end
```

$\Downarrow$

40 Simpler Iterator Implementation...

```
PROCEDURE Iter (
   Success, Fail :  LABEL;
```

```
   VAR Resume :  LABEL; VAR Result :  T);
BEGIN
   WHILE ...  DO
      ResumeLabel:
      Result := x;
      Resume := ADDR(ResumeLabel);
      GOTO Success
   END;
   GOTO Fail;
END
```

41 Simpler Iterator Implementation...

```
VAR Result :  T;
VAR Resume :  LABEL;
BEGIN
   Iter(ADDR(SuccesLabel), ADDR(FailLabel),
         Resume, Result);
   SuccessLabel:
   WRITE Result;
   GOTO Resume;
   FailLabel:
END;
```

Summary

42 Readings and References

1. **Read Scott, pp. 278–284, 135CD-136CD**.
2. Russell R. Atkinson, Barbara H. Liskov, and Robert W. Scheifler: *Aspects of Implementing CLU*, Proceedings ACM National Conference, pp. 123–129, Dec, 1978.
3. Murer, Omohundro, Szyperski: *Sather Iters: Object-Oriented Iteration Abstraction*: `ftp://ftp.icsi.berkeley.edu/pub/techreports/1993/tr-93-045.ps.gz`
4. Todd A. Proebsting: *Simple Translation of Goal-Directed Evaluation*, PLDI'97, pp. 1–6. This paper describes an efficient implementation of Icon iterators.

43 Summary

- Sather (a mini-Eiffel) has adopted an iterator concept similar to CLU's, but tailored to OO languages.
- Iterators function (and can be implemented as) coroutines. Smart compilers should, however, take care to implement "simple" iterators in a more direct way (See the Sather paper).
- Inline expansion of iterators may of course be helpful, but the same caveats as for expansion of procedures apply: code explosion, cache overflow, extra compilation dependencies.