Programming Paradigms

Lecture 7:

Control Flow (Part 2)

Prof. Dr. Michael Pradel

Software Lab, University of Stuttgart

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Wake-up Exercise

What does this Java function return?

```
boolean callMe() {
    try {
        return true;
    } finally {
        return false;
    }
}
```

https://ilias3.uni-stuttgart.de/vote/0ZT9

Wake-up Exercise

What does this Java function return?

```
boolean callMe() {
    try {
        return true;
    } finally {
        return false;
    }
}
```

Result: false

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Wake-up Exercise

What does this Java function return?

```
boolean callMe() {
    try {
        return true;
    } finally {
        return false;
    }
}
```

Finally blocks are always executed, even after a return

But: Avoid returning in a finally block

Result: false

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Overview

- **Expression Evaluation**
- **Structured and Unstructured Control Flow**
- **Selection** ←
- **Iteration**
- **Recursion**

Selection

- **Branch that depends on a condition**
- **Different syntactic variants**
  - If-else statements (sometimes with else-if)
  - Case/switch statements

If Statements

Syntactic variants across PLs

Algol 60 and its descendants:

```
if (A == B) then ...
else if (A == C) then ...
else ...
```

Bash

```
If [ $A = $B ]
then ...
elif [ $A = $C ]
then ...
else ...
fi
```

Lisp and its descendants:

```
(cond
  ((= A B)
    (...))
  ((= A C)
    (...))
  (T
    (...))
)
```

Compilation of If Statements

```
if ((A > B) and (C > D)) or
   (E ≠ F) then
      then_clause
else
      else_clause
```

- short-circuited evaluation
- fall-through to same cases

```
      r1 := A
      r2 := B
      if r1 <= r2 goto L4
      r1 := C
      r2 := D
      if r1 > r2 goto L1
L4:   r1 := E
      r2 := F
      if r1 = r2 goto L2
L1:   then_clause
      goto L3
L2:   else_clause
L3:
```

Case/Switch Statements

Many conditions that compare the same expression to different compile-time constants

```
-- Ada syntax
case ... -- potentially complicated expression
if
  when 1       => clause_A
  when 2 | 7   => clause_B
  when 3..5    => clause_C
  when 10      => clause_D
  when others  => clause_E
end case;
```

Case/Switch Statements

Many conditions that compare the same expression to different compile-time constants

```
-- Ada syntax
case ... -- potentially complicated expression
if
   when 1        => clause_A
   when 2 | 7    => clause_B
   when 3..5     => clause_C
   when 10       => clause_D
   when others   => clause_E
end case;
```

Labels **Arms**

Compilation of Case/Switch Statements

(calculate controlling expression)

```
    r1 := ...
    if r1 ≠ 1  goto L1
    clause_A
    goto L6
L1: if r1 = 2  goto L2
    if r1 ≠ 7  goto L3
L2: clause_B
    goto L6
L3: if r1 < 3  goto L4
    if r1 > 5  goto L4
    clause_C
    goto L6
L4: if r1 ≠ 10 goto L5
    clause_D
    goto L6
L5: clause_E
L6:
```

Jump Table-based Compilation

```
T:  &L1          (expression = 1)
    &L2
    &L3
    &L3
    &L3
    &L5
    &L2
    &L5
    &L5
    &L4          (expression 10)
L6: r1 := ...    (evaluate expression)
    if r1 < 1  goto L5
    if r1 > 10 goto L5
    r1 := r1 - 1
    r1 := T[r1]
    goto * r1
```

advantage:
constant-time jump
to right arm

Variations Across PLs

- **Case/switch varies across PLs**
  - What values are allowed in labels?
  - Are ranges allowed?
  - Do you need a default arm?
  - What happens if the value does not match?

Fall-Through Case/Switch

C/C++/Java

- Each expression needs its own label (no ranges)
- Control flow "falls through", unless stopped by `break` statement

```
switch ( /* expression */ ) {
   case 1: clause_A
           break;
   case 2:
   case 7: clause_B
           break;
   case 3:
   case 4:
   case 5: clause_C
           break;
   case 10: clause_D
           break;
   default: clause_E
           break;
}
```

Quiz: Switch/Case

What does the following C++ code print?

```
int x = 3;
switch (x)
{
  case 1: { x += x; }
  case 3: { x += x; }
  case 5: { x += x; }
  default: { x += 5; }
}
std::cout << x;
```

https://ilias3.uni-stuttgart.de/vote/0ZT9

Quiz: Switch/Case

What does the following C++ code print?

```
int x = 3;
switch (x)
{
  case 1: { x += x; }
  case 3: { x += x; }
  case 5: { x += x; }
  default: { x += 5; }
}
std::cout << x;
```

Each of these is executed (because no `break` statement)

Result: 17

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Overview

- **Expression Evaluation**
- **Structured and Unstructured Control Flow**
- **Selection**
- **Iteration** ←
- **Recursion**

Iteration

- **Essential language construct**
  - Otherwise: Amount of work done is linear to program size
- **Two basic forms of loops**
  - Enumeration-controlled:
    Once per value in finite set
  - Logically controlled:
    Until Boolean expression is false

Enumeration-controlled Loops

- **Most simple form: Triple of**
  - Initial value
  - Bound
  - Step size

Fortran 90:

```
do i = 1, 10, 2
   ...
enddo;
```

Modula-2:

```
FOR i := 1 TO 10 BY 2 DO
   ...
END
```

Enumeration-controlled Loops

- **Most simple form: Triple of**
  - Initial value
  - Bound
  - Step size

Fortran 90:

```
do i = 1, 10, 2
   ...
enddo;
```

Modula-2:

```
FOR i := 1 TO 10 BY 2 DO
   ...
END
```

Iterations with i = 1, 3, 5, 7, 9

Semantic Variants

Different PLs offer different variants

- Can you leave the loop in the middle?
- Can you modify the loop variable?
- Can you modify the values used to compute the loop bounds?
- Can you read the loop variable in/after the loop?

Iterators

- **Special enumeration-controlled loop: Iterates through any kind of set/sequence of values**
  - E.g., nodes of a tree or elements of a collection
- **Decouples two algorithms**
  - How to enumerate the values
  - How to use the values
- **Three flavors**
  - “True” iterators, iterator objects, first-class functions

"True" Iterators

- **Subroutine with `yield` statements**
  - Each `yield` "returns" another element
- **Popular, e.g., in Python, Ruby, and C#**
- **Used in a `for` loop**
  - Example (Python):

```
# range is a built-in iterator
for i in range(first, last, step):
    ...
```

Example: Binary Tree

```
class BinTree:
    def __init__(self, data):
        self.data = data
        self.lchild = self.rchild = None

    # other methods: insert, delete lookup, ...

    def preorder(self):
        if self.data is not None:
            yield self.data
        if self.lchild is not None:
            for d in self.lchild.preorder():
                yield d
        if self.rchild is not None:
            for d in self.rchild.preorder():
                yield d
```

Iterator Objects

- **Regular object with methods for**
  - Initialization
  - Generation of next value
  - Test for completion
- **Popular, e.g., in Java and C++**
- **Used in `for` loop**

```
for (Iterator i = c.iterator(); i.hasNext(); ) {
    ... = i.next();
}
```

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Iterator Objects

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- **Popular, e.g., in Java and C++**
- **Used in `for` loop**

```
for (Iterator i = c.iterator(); i.hasNext(); ) {
    ... = i.next();
}
```

Since Java 5

```
for (Element e : c) {
    ...
}
```

Example: Binary Tree

```
class BinTree<T> implements Iterable<T> {
    BinTree<T> left; BinTree<T> right; T val;

    // other methods: insert, delete, lookup

    public Iterator<T> iterator() {
        return new TreeIterator(this);
    }
    private class TreeIterator implements Iterator<T> {
        public boolean hasNext() {
            ... // check if there is another element
        }
        public T next() {
            ... // return the next element
        }
        public void remove() {
            throw new UnsupportedOperationException();
}}}
```

Iterating with First-Class Functions

- **Two functions**
  - One function about what to do for each element
  - Another function that calls the first function for each element
- **Example (Scheme):**

```
(define uptoby
  (lambda (low high step f)
    (if (<= low high)
      (begin
        (f low)
        (uptoby (+ low step) high step f))
      '())))
```

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```

Defines a function with four arguments

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```
(define uptoby
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    (if (<= low high)
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        (f low)
        (uptoby (+ low step) high step f))
      '())))
```

Calls `f` with the next element

Iterating with First-Class Functions

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- **Example (Scheme):**

```
(define uptoby
  (lambda (low high step f)
    (if (<= low high)
      (begin
        (f low)
        (uptoby (+ low step) high step f))
      '())))
```

Recursively calls `uptoby` to handle the remaining elements

Iterating with First-Class Functions (2)

- **Originally, proposed in functional languages**
- **Nowadays, available in many modern PLs through libraries**
  - E.g., Java

```
mySet.stream().filter(e -> e.someProp > 5)
```

  - E.g., JavaScript

```
myArray.filter(e => e.someProp > 5)
```

Iterating with First-Class Functions (2)

- **Originally, proposed in functional languages**
- **Nowadays, available in many modern PLs through libraries**
  - E.g., Java

```
mySet.stream().filter(e -> e.someProp > 5)
```

Iterates through all elements and returns a filtered subset

  - E.g., JavaScript

```
myArray.filter(e => e.someProp > 5)
```

Iterating with First-Class Functions (2)

- **Originally, proposed in functional languages**
- **Nowadays, available in many modern PLs through libraries**
  - E.g., Java

```
mySet.stream().filter(e -> e.someProp > 5)
```

Boolean function that decides which elements to keep

  - E.g., JavaScript

```
myArray.filter(e => e.someProp > 5)
```

Logically Controlled Loops

Whether to continue to iterate decided through a Boolean expression

- Pre-test:
```
while (cond) {
   ...
}
```
- Mid-test:
```
for (;;) {
   ...
   if (cond) break
}
```
- Post-test:
```
do {
   ...
} while (cond)
```

Quiz: Iteration

Which of the following statements is true?

- Iterators are a form of logically controlled loops.
- A “true” iterator yields one element each time it is called.
- Iterator objects have a method that yields another element each time it is called.
- Iterating with first-class functions does not require a for-loop.

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Quiz: Iteration

Which of the following statements is true?

- ~~Iterators are a form of logically controlled loops.~~
- ~~A “true” iterator yields one element each time it is called~~.
- Iterator objects have a method that yields another element each time it is called.
- Iterating with first-class functions does not require a for-loop.

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Overview

- Expression Evaluation
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- Selection
- Iteration
- Recursion ←

Recursion

- **Equally powerful as iteration**
- **Most PLs allow both recursion and iteration**
  - Iteration: More natural in imperative PLs (because the loop body typically updates variables)
  - Recursion: More natural in functional PLs (because the recursive function typically doesn't update any non-local variables)

Efficiency

Naively written or naively compiled recursive functions: Less efficient than equivalent iterative code

- Reason: New allocation frame for each call
- Example: Compute $\sum_{low \leq i \leq high} f(i)$ in Scheme

```
(define sum
  (lambda (f low high)
    (if (= low high)
      (f low)
      (+ (f low) (sum f (+ low 1) high)))))
```

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```

Then and else branches

Efficiency

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- Example: Compute $\sum_{low \leq i \leq high} f(i)$ in Scheme

```
(define sum
  (lambda (f low high)
    (if (= low high)
      (f low)
      (+ (f low) (sum f (+ low 1) high)))))
```

Recursive call

Tail Recursion

Recursive call is the last statement before the function returns

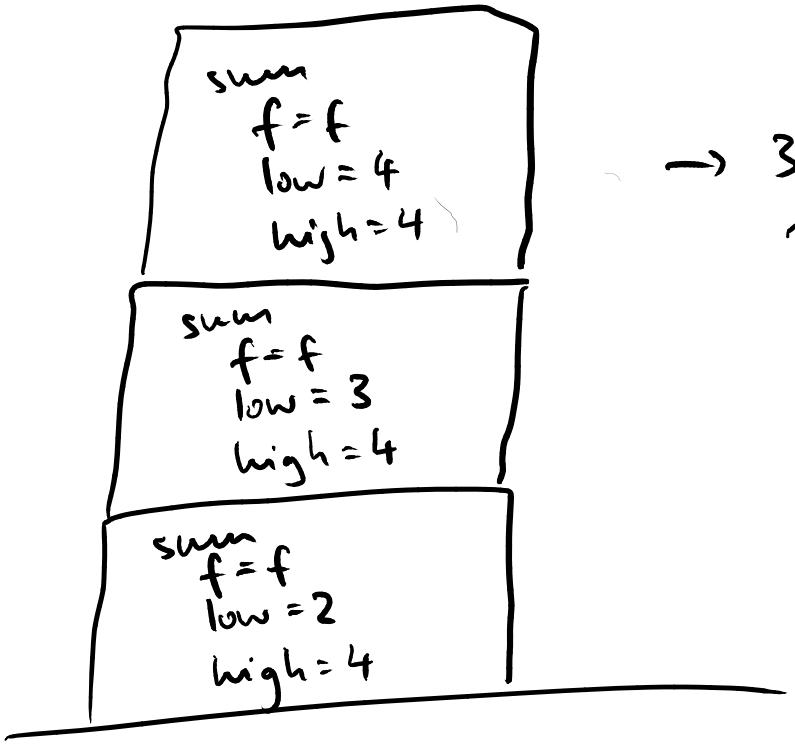
- Compiled code can reuse same allocation frame
- Revised example:

```
(define sum
  (lambda (f low high subtotal)
    (if (= low high)
      (+ subtotal (f low))
      (sum f (+ low 1) high (+ subtotal (f low))))))
```

Example: Summation

(sum f 2 4)

Naive implementation

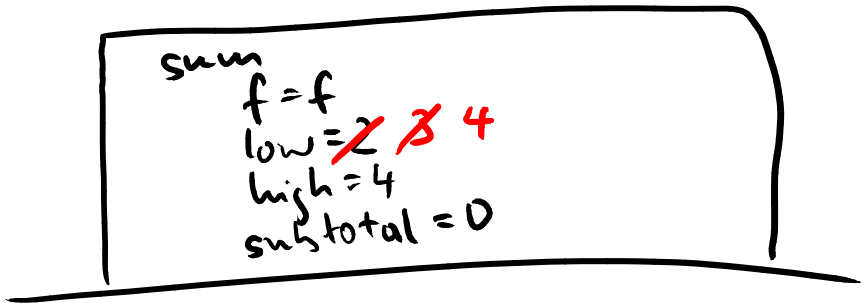


→ 3 allocation frames

(sum f 2 4 0)

Tail-recursive implementation

→ reusing a single allocation frame



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