

# Programming Language Concepts

## Binding and Scope

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# Outline

## 1 Abstraction

- Function and Procedure Abstractions
- Selector Abstraction
- Generic Abstraction
- Iterator Abstraction
- Iterator Abstraction

## 2 Abstraction Principle

## 3 Parameters

## 4 Parameter Passing Mechanisms

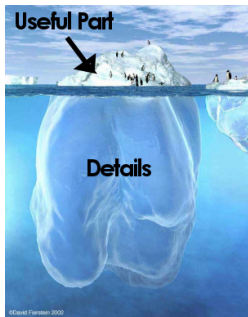
- Copy Mechanisms
- Binding Mechanisms
- Pass by Name

## 5 Evaluation Order

## 6 Infinite Values

## 7 Correspondence Principle

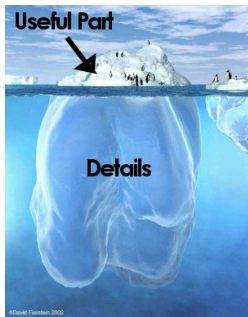
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- **Abstraction:** Make a program or design reusable by enclosing it in a body, hiding the details, and defining a mechanism to access it.
- Separating the usage and implementation of program segments.
- Vital large scale programming.

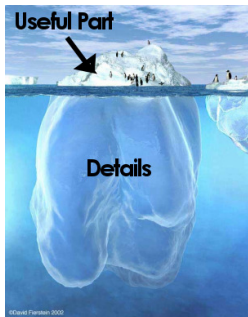
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  - User: “what does it do?”, Developer: “How does it do that?”
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- Abstraction philosophy: **Declare once, use many times!**
- **Code reusability** is the ultimate goal.
- Parameterization improves power of abstraction



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- Procedures are **abstractions over commands**
- Other type of abstractions possible?

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- User defined selectors on user defined structures?
- Example: Selector on a linked list:

```
struct List {
    int data;
    List *next;
    int & operator [] (int el) {
        int i; List *p = this;
        for (i = 1 ; i < el ; i++)
            p = p->next;      /* take the next element */
        return p->data;
    };
    ...
};
List h;
...
h[1] = h[2] + 1;
```

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```

- C++ allows overloading of `[]` operator for classes.

- Python `__setitem__ (k,v)` implements l-value, `__getitem__ (k)` r-value selector.

```
class BSTree:
    def __init__(self):
        self.node = None
    def __getitem__(self, key):
        if self.node == None:
            raise KeyError
        elif key < self.node[0]: return self.left[key]
        elif key > self.node[0]: return self.right[key]
        else: return self.node[1]
    def __setitem__(self, key, val):
        if self.node == None:
            self.node = (key, val)
            self.left = BSTree() # empty tree
            self.right = BSTree() # empty tree
        elif key < self.node[0]: self.left[key] = val
        elif key > self.node[0]: self.right[key] = val
        else: self.node = (key, val)

a = BSTree()
a["hello"] = 4
a["world"] = a["hello"] + 5
```

```

class BST {
    struct Node { string key; double val;
                 Node *left, *right; } *node;
public:
    BST() { node = NULL; };
    double & operator[] (const string &k) {
        Node **parent = NULL, *p = node, *newnode;
        while (p != NULL) {
            if (k < p->key) {
                parent = &p->left; p = p->left;
            } else if (k > p->key) {
                parent = &p->right; p = p->right;
            } else return p->val;
        }
        newnode = new Node;
        newnode->left = newnode->right = NULL;
        newnode->key = k;
        if (parent == NULL) node = newnode;
        else *parent = newnode;
        return newnode->val;
    }
};

BST a;
a["carrot"] = 3; a["onion"] = 4;
a["patato"] = a["onion"] + 2;

```

# Generic abstraction

- Same declaration pattern applied to different data types.
- **Abstraction over declaration.** A function or class declaration can be adapted to different types or values by using type or value parameters.

```
template <class T>
    class List {
        T content;
        List *next;
    public: List() { next=NULL };
        void add(T el) { ... };
        T get(int n) { ...};
    };

template <class U>
    void swap(U &a, U &b) { U tmp; tmp=a; a=b; b=tmp; }
...
List<int> a; List<double> b; List<Person> c;
int t,x; double v,y; Person z,w;
swap(t,x); swap(v,y); swap(z,w);
```

# Iterator abstraction

- Iteration over a user defined data structure. [Ruby](#) example:

```
class Tree
  def initialize(v)
    @value = v ; @left = nil ; @right = nil
  end
  def traverse
    @left.traverse {|v| yield v} if @left != nil
    yield @value           # block argument replaces
    @right.traverse {|v| yield v} if @right != nil
  end
end

a=Tree.new(3) ; l=[]
a.traverse { |node|      # yield param
  print node            # yield body
  l << node              # yield body
}
```



# Iterator abstraction

- Iteration over a user defined data structure. **Python** generator example:

```
class BSTree(object):
    def __init__(self):
        self.val = ()
    def inorder(self):
        if self.val == ():
            return
        else:
            for i in self.left.inorder():
                yield i
            yield self.val
            for i in self.right.inorder():
                yield i

v = BSTree()
...
for v in v.inorder():
    print v
```

# C++ iterators

- C++ Standard Template Library containers support **iterators**
- `begin()` and `end()` methods return iterators to start and end of the data structure
- Iterators can be dereferenced as `*iter` or `iter->member`.
- '+' operation on an iterator skips to the next value.

- ```
for (itttype it = a.begin(); it != a.end(); ++it) {
    // use *it or it->member it->method() in body
}
```

- C++11 added:

```
for (valtype & i : a ) {
    // use directly i as l-value or r-value.
}
```

This syntax is equivalent to:

```
for (itttype it = a.begin() ; it != a.end(); it++) {
    valtype & i = *it;
    // use directly i as l-value or r-value
}
```

# C++ iterators

```
template<class T> class List {
    struct Node { T val; Node *next;} *list;
public: List() { list = nullptr;}
    void insert(const T& v) { Node *newnode = new Node;
        newnode->next = list; newnode->val = v; list = newnode;}
    class Iterator {
        Node *pos;
    public: Iterator(Node *p) { pos = p;}
        T & operator*() { return pos->val; }
        void operator++() { pos = pos->next; }
        bool operator!=(const Iterator &it) { return pos != it.pos; }
    };
    Iterator begin() { Iterator it = Iterator(list); return it; }
    Iterator end() { Iterator it = Iterator(nullptr); return it; }
};

...
List<int> a;
// C++11 syntax below
for (int & i : a ) { i *= 2; cout << i << '\n'; }
for (const char * s : { "ankara", "istanbul", "izmir" }) {
    cout << s ; }
```

# Abstraction Principle

- If any programming language entity involves computation, it is possible to define an abstraction over it

| <b>Entity</b> | → | <b>Abstraction</b> |
|---------------|---|--------------------|
| Expression    | → | Function           |
| Command       | → | Procedure          |
| Selector      | → | Selector function  |
| Declaration   | → | Generic            |
| Command Block | → | Iterator           |

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- **Declaration part:** `abstraction_name(Fp1, Fp2, ..., Fpn)`  
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- **Parameter passing mechanisms**

# Parameter Passing Mechanisms

Programming language may support one or more mechanisms. 3 basic methods:

- 1 Copy mechanisms (assignment based)
- 2 Binding mechanisms
- 3 Pass by name (substitution based)

# Copy Mechanisms

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# Copy Mechanisms

- Function and procedure abstractions, assignment between actual and formal parameter:

- 1 Copy In:

On function call:  $Fp_i \leftarrow Ap_i$

- 2 Copy Out:

On function return:  $Ap_i \leftarrow Fp_i$

- 3 Copy In-Out:

On function call:  $Fp_i \leftarrow Ap_i$ , and

On function return:  $Ap_i \leftarrow Fp_i$



# Copy Mechanisms

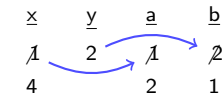
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  - 1 Copy In:  
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  - 2 Copy Out:  
On function return:  $Ap_i \leftarrow Fp_i$
  - 3 Copy In-Out:  
On function call:  $Fp_i \leftarrow Ap_i$ , and  
On function return:  $Ap_i \leftarrow Fp_i$
- C only allows copy-in mechanism. This mechanism is also called as **Pass by value**.

```

int x=1, y=2;
void f(int a, int b) {
    x += a+b;
    a++;
    b=a/2;
}
int main() {
    f(x,y);
    printf("x:%d, y:%d\n", x, y);
    return 0;
}

```

Copy In:



x:4, y:2

```

int x=1, y=2;
void f(int a, int b) {
    x += a+b;
    a++;
    b=a/2;
}
int main() {
    f(x,y);
    printf("x:%d, y:%d\n", x, y);
    return 0;
}

```

Copy Out:

| <u>x</u> | <u>y</u> | <u>a</u> | <u>b</u> |
|----------|----------|----------|----------|
| 1        | 2        | 0        | 0        |
| 1        | 0        | 1        | 0        |
| 1        |          |          |          |

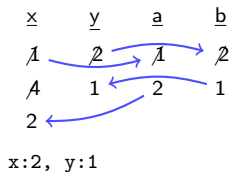
x:1, y:0

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int x=1, y=2;
void f(int a, int b) {
    x += a+b;
    a++;
    b=a/2;
}
int main() {
    f(x,y);
    printf("x:%d, y:%d\n", x, y);
    return 0;
}

```

### Copy In-Out:



# Binding Mechanisms

- Based on binding of the formal parameter variable/identifier to actual parameter value/identifier.
- Only one entity (value, variable, type) exists with more than one names.
  - 1 **Constant binding:** Formal parameter is constant during the function. The value is bound to actual parameter expression value.

Functional languages including Haskell uses this mechanism.
  - 2 **Variable binding:** Formal parameter variable is bound to the actual parameter variable. Same memory area is shared by two variable references.

Also known as **pass by reference**
- The other type and entities (function, type, etc) are passed with similar mechanisms.

```

int x=1, y=2;
void f(int a, int b) {
    x += a+b;
    a++;
    b=a/2;
}
int main() {
    f(x,y);
    printf("x:%d, y:%d\n", x, y);
    return 0;
}

```

Variable binding:

| x | y |
|---|---|
| 1 | 2 |
| 4 | 2 |
| 5 |   |

```

int x=1, y=2;
void f(int a, int b) {
    x += a+b;
    a++;
    b=a/2;
}
int main() {
    f(x,y);
    printf("x:%d, y:%d\n", x, y);
    return 0;
}

```

### Variable binding:

| f():a / | f():b / |
|---------|---------|
| x       | y       |
| 1       | 2       |
| 4       | 2       |
| 5       |         |

```
int x=1, y=2;
void f(int a, int b) {
    x += a+b;
    a++;
    b=a/2;
}
int main() {
    f(x,y);
    printf("x:%d, y:%d\n", x, y);
    return 0;
}
```

### Variable binding:

| x            | y            |
|--------------|--------------|
| <del>1</del> | <del>2</del> |
| 4            | 2            |
| 5            |              |
| x: 5, y:2    |              |



# Pass by name

- Actual parameter syntax replaces each occurrence of the formal parameter in the function body, then the function body evaluated.
- C macros works with a similar mechanism (by pre-processor)
- Mostly useful in theoretical analysis of PL's. Also known as **Normal order evaluation**
- Example (Haskell-like)

```
f x y = if (x<12) then x*x+y*y+x
      else x+x*x
```

Evaluation:  $f\ (3*12+7)\ (24+16*3) \mapsto \text{if } ((3*12+7)<12) \text{ then } (3*12+7)*(3*12+7)+(24+16*3)*(24+16*3)+(3*12+7) \text{ else } (3*12+7)+(3*12+7)*(3*12+7) \xrightarrow{*} \text{if } (43<12) \text{ then } \dots \mapsto \text{if } (\text{false}) \text{ then } \dots \mapsto (3*12+7)+(3*12+7)*(3*12+7) \xrightarrow{*} (3*12+7)+43*(3*12+7) \mapsto \dots \mapsto 1892$  (12 steps)

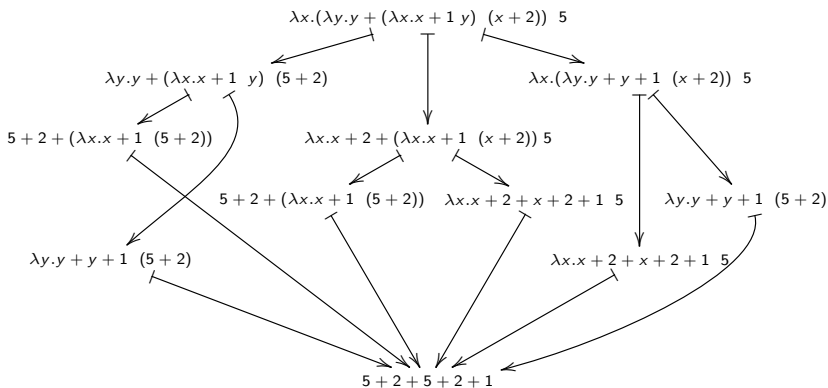
# Evaluation Order

- **Normal order evaluation** is mathematically natural order of evaluation.
- Most of the PL's apply **eager evaluation**: Actual parameters are evaluated first, then passed.

$f(3*12+7)(24+16*3) \mapsto f(36+7)(24+16*3) \xrightarrow{*} f\ 43\ 72 \mapsto \text{if } (43 < 12)$   
 $\text{then } 43*43+72*72+43 \text{ else } 43+43*43 \mapsto \text{if } (\text{false}) \text{ then } \dots \mapsto$   
 $43+43*43 \xrightarrow{*} 1892$  (8 steps)

- Consider “ $g \ x \ y = \text{if } x > 10 \text{ then } y \text{ else } x$ ” for  $g \ 2 \ (4/0)$
- Side effects are repeated in NOE.
- **Church–Rosser Property**: If an expression can be evaluated at all, it can be evaluated by consistently using normal-order evaluation. If an expression can be evaluated in several different orders (mixing eager and normal-order evaluation), then all of these evaluation orders yield the same result.

In  $\lambda$ -calculus, all orders reduce the same normal form.



- Haskell implements **Lazy Evaluation** order.
- Eager evaluation is faster than normal order evaluation but violates Church-Rosser Property. Lazy evaluation is as fast as eager evaluation but computes same results with normal order evaluation (unless there is a side effect)
- Lazy evaluation expands the expression as normal order evaluation however once it evaluates the formal parameter value other evaluations use previously found value:

```
f (3*12+7) (24+16*3)  $\mapsto$  if (x:(3*12+7)<12) then
x:(3*12+7)*x:(3*12+7)+y:(24+16*3)*y:(24+16*3)+x:(3*12+7) else
x:(3*12+7)+x:(3*12+7)*x:(3*12+7)  $\overset{*}{\mapsto}$  if (x:43<12) then
x:43*x:43+y:(24+16*3)*y:(24+16*3)+x:43 else x:43+x:43*x:43  $\mapsto$  if
(false) then ...  $\mapsto$  x:43+x:43*x:43  $\mapsto$  x:43+1849  $\mapsto$  1892 (7 steps)
```

# Lazy Evaluation

- Parameters are passed by name but compiler keeps evaluation state of them. Parameter value is store once it is evaluated. Further evaluations use that.
- Python implementation. First delay evaluation of expressions. Convert to functions:  
`exp`  $\rightarrow$  `lambda : exp`  
 $\eta$  expansion. Function version is also called `thunk`.
- Inside function, call these functions to evaluate the expression.

```
def E(thunk):
    if not hasattr(thunk, "stored"):
        thunk.stored = thunk()      # evaluate and store
    return thunk.stored             # use stored value

def f(x,y):
    if E(x) < 10:                    # call E() on all evaluations
        return E(x)*E(x)+E(y)
    else:
        return E(x)*E(x)+E(x)

f(lambda : 3*32+4, lambda: 4/0)    # call by converting to function
```

# Infinite Values

- Delayed evaluation in normal order or lazy evaluation enables working on infinite values:

```
take _ [] = []
take n (a:r) | n == 0 = []
               | otherwise = a : take (n-1) r
x = (1:2:x)
```

```
take 3 x  $\mapsto$  take 3 (1:2:x)  $\mapsto$  1:take (3-1) (2:x)  $\mapsto$ 
1:2:take (2-1) x  $\mapsto$  1:2:take 1 (1:2:x)  $\mapsto$  1:2:1:take (1-1) (2:x)  $\mapsto$ 
1:2:1:[]
```

- Programmers can take advantage of this. Construct an infinitely value, take as many as program needs. For example expand  $\pi$  in an infinite value, stop when desired resolution achieved.

# Correspondence Principle

## ■ Correspondence Principle:

For each form of declaration there exists a corresponding parameter mechanism.

## ■ C:

```
int a=p;           ↔ void f(int a) {
const int a=p;     ↔ void f(const int a) {
```

## ■ Pascal:

```
var a: integer; ↔ procedure f(a:integer) begin
const a:5;      ↔ ??? {
???            ↔ procedure f(var a:integer) begin
```

## ■ C++:

```
int a=p;           ↔ void f(int a) {
const int a=p;     ↔ void f(const int a) {
int &a=p;          ↔ void f(int &a) {
```