Programming Language Concepts

Binding and Scope

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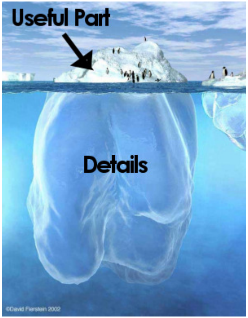
Outline

Abstraction



- Iceberg: Details at the bottom, useful part at the top of the ocean. Animals do not care about the bottom.
- User: "how do I use it?", Developer: "How do I make it work?"
- User: "what does it do?", Developer: "How does it do that?

- 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.

- Abstraction is possible in any discipline involving design:
- radio tuner. Adjustment knob on a radio is an abstraction over the tuner element, frequency selection.
- An ATM is an abstraction over complicated set of bank transaction operations.
- Programming languages can be considered as abstraction over machine language.
- ...

Purpose

- Details are confusing
- Details may contain more error
- Repeating same details increase complexity and errors
- Abstraction philosophy: Declare once, use many times!
- Code reusability is the ultimate goal.
- Parameterization improves power of abstraction

Function and procedure abstractions

- The computation of an expression is the detail (algorithm, variables, etc.)
- Function call is the usage of the detail
- Functions are abstractions over expressions
- `void` functions of C or procedure declarations of some languages
- No value but contains executable statements as detail.
- Procedures are abstractions over commands
- Other type of abstractions possible?

Selector abstraction

- arrays: `int a[10][20]; a[i]=a[i]+1;`
- `[..]` operator selects elements of an array.
- 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;
```

- 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 (ittype 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 (ittype 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

Entity		**Abstraction**
Expression	$\rightarrow$	Function
Command	$\rightarrow$	Procedure
Selector	$\rightarrow$	Selector function
Declaration	$\rightarrow$	Generic
Command Block	$\rightarrow$	Iterator

Parameters

- Many purpose and behaviors in order to take advantage of "declare once use many times".
- **Declaration part:** `abstraction_name(`$\texttt{Fp}_1$`, `$\texttt{Fp}_2$`, ..., `$\texttt{Fp}_n$`)`
  Use part: `abstraction_name(`$\texttt{Ap}_1$`, `$\texttt{Ap}_2$`, ..., `$\texttt{Ap}_n$`)`
- Formal parameters: identifiers or constructors of identifiers (patterns in functional languages)
- Actual parameters: expression or identifier based on the type of the abstraction and parameter
- Question: How actual and formal parameters relate/communicate?
- Programming language design should answer
- 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

- 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: $Ap_i \leftarrow Fp_i$
- 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	y	a	b
~~1~~	2	~~1~~	~~2~~
4		2	1

```
x:4, y:2
```

Copy Out:

x	y	a	b
~~1~~	~~2~~	~~0~~	~~0~~
~~1~~	0	1	0
1			

```
x:1, y:0
```

Copy In-Out:

x	y	a	b
~~1~~	~~2~~	~~1~~	~~2~~
~~4~~	1	2	1
2			

```
x:2, y:1
```

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:

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

```
x: 5, y:2
```

Pass by name

- Actual parameter syntax replaces each occurence 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
```

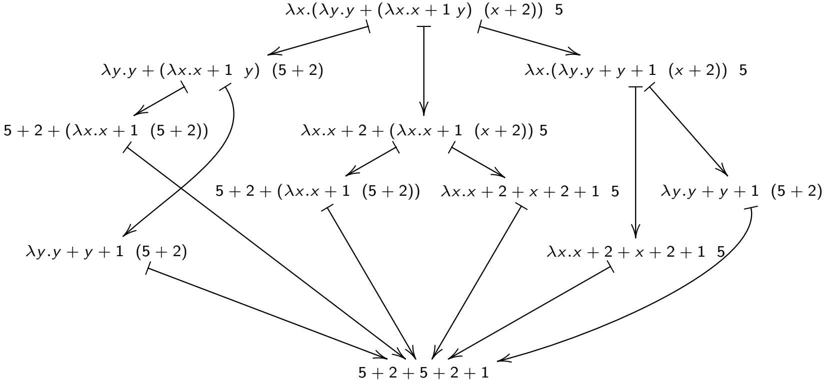
Evaluation: `f (3*12+7) (24+16*3)` $\mapsto$ `if ((3*12+7)<12) then (3*12+7)*(3*12+7)+(24+16*3)*(24+16*3)+(3*12+7) else (3*12+7)+(3*12+7)*(3*12+7)` $\overset{*}{\mapsto}$ `if (43<12) then ...` $\mapsto$ `if (false) then ...` $\mapsto$ `(3*12+7)+(3*12+7)*(3*12+7)` $\overset{*}{\mapsto}$ `(3*12+7)+43*(3*12+7)` $\mapsto$ `...` $\mapsto$ `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)` $\overset{*}{\mapsto}$ `f 43 72` $\mapsto$ `if (43<12) then 43*43+72*72+43 else 43+43*43` $\mapsto$ `if (false) then ...` $\mapsto$ `43+43*43` $\overset{*}{\mapsto}$ `1892` (8 steps)
- Consider "`g x y= if x>10 then y 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 λ-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

  η 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 ↦ take 3 (1:2:x) ↦ 1:take (3-1) (2:x) ↦
1:2:take (2-1) x ↦ 1:2:take 1 (1:2:x) ↦ 1:2:1:take (1-1) (2:x) ↦
1:2:1:[]

- Programmers can take advantage of this. Construct an infitely value, take as many as program needs. For example expand π 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;`	$\leftrightarrow$	`void f(int a) {`
`const int a=p;`	$\leftrightarrow$	`void f(const int a) {`

- Pascal:

`var a: integer;`	$\leftrightarrow$	`procedure f(a:integer) begin`
`const a:5;`	$\leftrightarrow$	`??? {`
`???`	$\leftrightarrow$	`procedure f(var a:integer) begin`

- C++:

`int a=p;`	$\leftrightarrow$	`void f(int a) {`
`const int a=p;`	$\leftrightarrow$	`void f(const int a) {`
`int &a=p;`	$\leftrightarrow$	`void f(int &a) {`