Programming Languages

Storage Management

Janyl Jumadinova

March 15-17, 2023

Scope Rules

A **scope** is a program section of maximal size in which no bindings change, or at least in which no re-declarations are permitted.

Scope Rules

A **scope** is a program section of maximal size in which no bindings change, or at least in which no re-declarations are permitted.

In most languages with subroutines (functions, methods, procedures), we OPEN a new scope on subroutine entry:

- create bindings for new local variables,
- deactivate bindings for global variables that are re-declared (these variable are said to have a "hole" in their scope)
- make references to variables

Ways Around "Hole in Scope"

Some languages allow access to scopes that are "hidden" by new declarations. E.g., Java:

```
public class MyClass {
    private int x;
    // This creates a hole in the scope
    // of the instance variable x
    public void myMethod(int x) {
        x = 10; // Parameter x
        this.x = 20; // instance variable x
        ...
```

C++ has a similar construct.

Scope Rules

On subroutine exit:

- destroy bindings for local variables
- reactivate bindings for global variables that were deactivated

Sometimes the term "**elaboration**" is used for the process of allocating memory and creating bindings associated with a declaration.

Memory segments on the x86-32 architecture

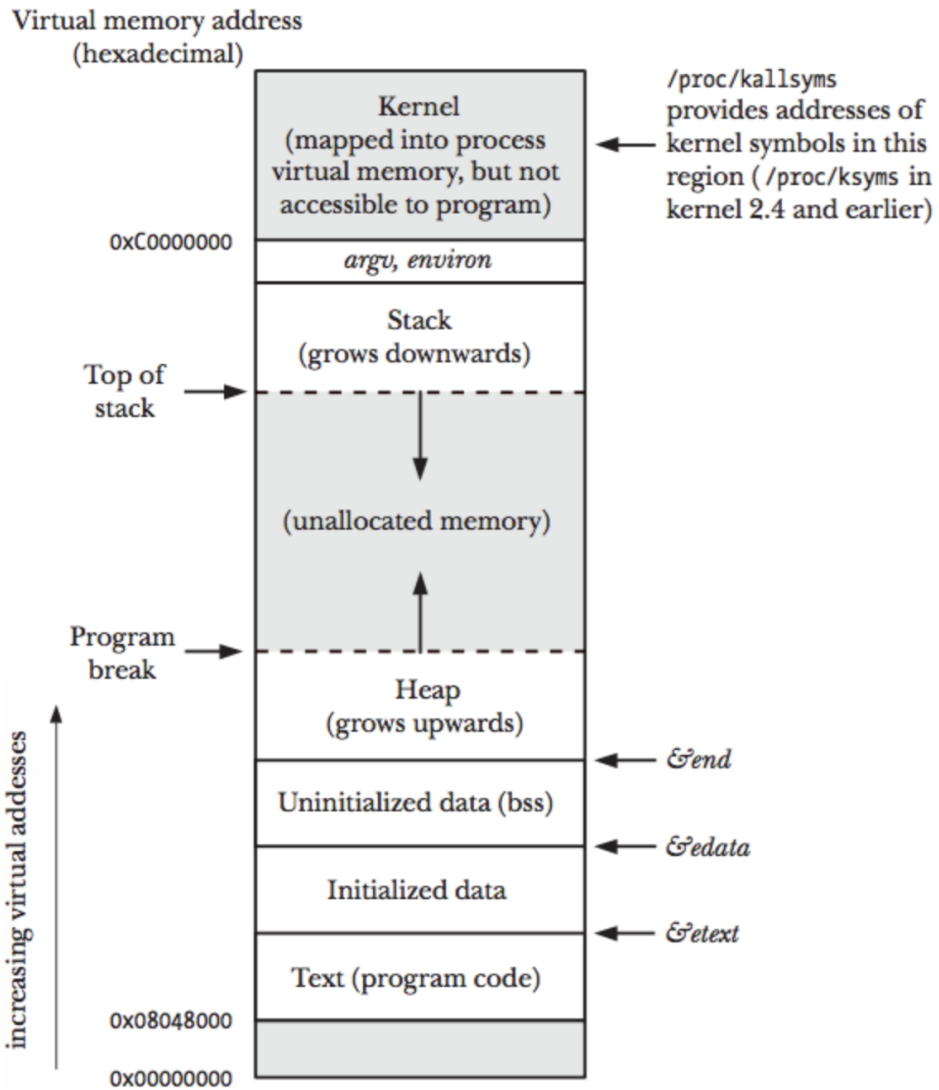


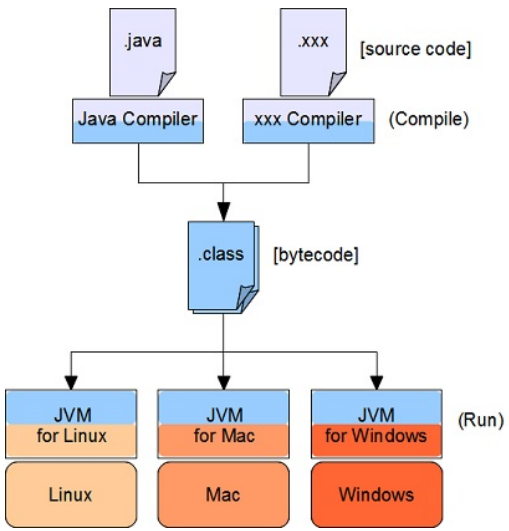
Image credit: https://notes.shichao.io/tlpi/ch6/

Java Example

```
public class Example {
    public static void main(String[] args) {
      int num1 = 1;
      int num2 = 3;
      int num = num1 + num2;
    }
}
```

Java Example

```
public class Example {
    public static void main(String[] args) {
      int num1 = 1;
      int num2 = 3;
      int num = num1 + num2;
    }
}
```



Ref: Dr. H. Yang

Java Bytecode Example

0: iconst_1: Push the integer constant 1 onto the operand stack

1: istore_1: Pop the top operand (an int value) and store it in local variable at index 1, which corresponds to variable num1

2: iconst_3: Push the integer constant 3 onto the operand stack

3: istore_2: Pop the top operand (an int value) and store it in local variable at index 2, which corresponds to variable num2

4. iload_1: Load the int value from local variable at index 1 and push it onto the operand stack

5. iload_2: Load the int value from local variable at index 2 and push it onto the operand stack

6. iadd: Pop the top two int values from the operand stack, add them, and push the result back onto the operand stack

7. istore_3: Pop the top operand int value and store it in local variable at index 3, which corresponds to variable num

8. istore_3: Return from the void main method

Jamboard example: Example.java bytecode

Elaboration Example

```
public class MyClass {
  private int a;
  public int getA() {
     return a;
  }
  public void setA(int x) {
     a = x;
  }
}
```

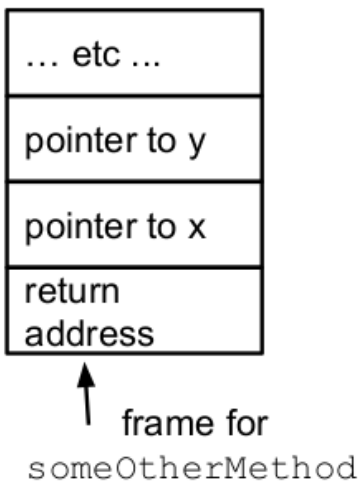
```
public void someOtherMethod() {

   MyClass x = new MyClass();

   MyClass y = new MyClass();
      …
}
```

Whenever **someOtherMethod** is invoked, a new activation record (frame) is created for **someOtherMethod** and the declarations of **x** and **y** are elaborated into locations in this frame; the names **x** and **y** are bound to these locations.

(NOTE: creation of the frame itself is an elaboration of the declaration of function **someOtherMethod**)



Elaboration Example

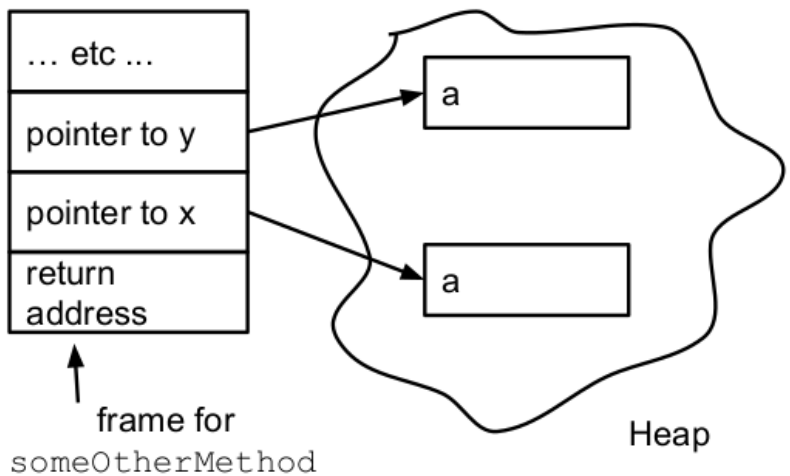
```
public class MyClass {
  private int a;
  public int getA() {
     return a;
  }
  public void setA(int x) {
     a = x;
  }
}
```

Furthermore, the declarations of the instance variable **a** are elaborated into memory locations in the heap and the names **x.a** and **y.a** are bound to these locations.

```
public void someOtherMethod() {

   MyClass x = new MyClass();

   MyClass y = new MyClass();
      ...
}
```



Heap Allocation (Dynamic allocation)

Example (Java):

```
int values[ ];
System.out.print("How big is the array? ");
int n = scan.nextInt();
values = new int[n];
```

Heap Allocation (Dynamic allocation)

Example (Java):

```
int values[ ];
System.out.print("How big is the array? ");
int n = scan.nextInt();
values = new int[n];
```

- No way to know at compile time how much space will be needed for the array "values" – determined at run time.
- So... how can we know how much memory to save on the stack?

Heap Allocation (Dynamic allocation)

Example (Java):

```
int values[ ];
System.out.print("How big is the array? ");
int n = scan.nextInt();
values = new int[n];
```

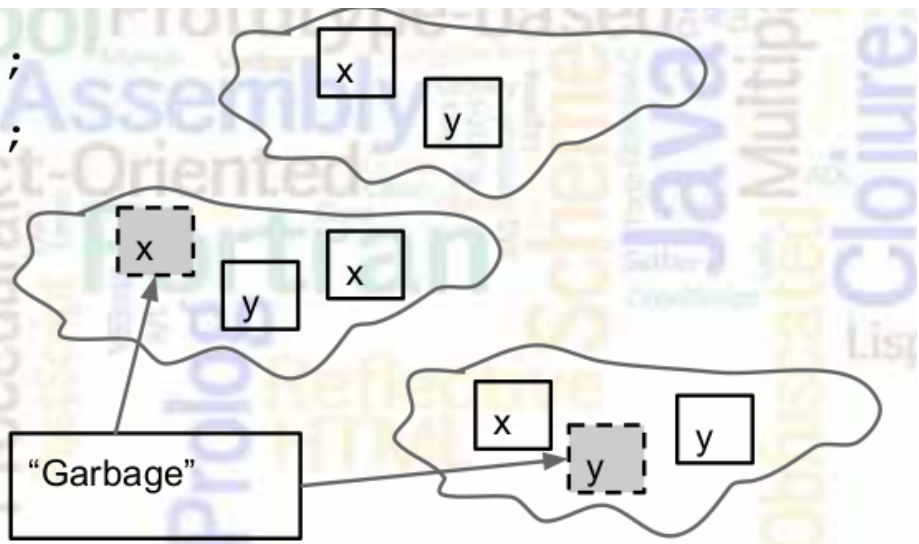
- No way to know at compile time how much space will be needed for the array "values" – determined at run time.
- So... how can we know how much memory to save on the stack? We can't!
- We must allocate it dynamically from a special memory area called the **heap**.

Heap Allocation

Stack grows and shrinks ("push" and "pop"); easy to generate code for this at compile time.

Heap: no pattern – no "last-in, first-out" or similar rule:

```
MyClass x = new MyClass();
MyClass y = new MyClass();
if (count == 10)
  x = new MyClass();
else
  y = new MyClass();
```

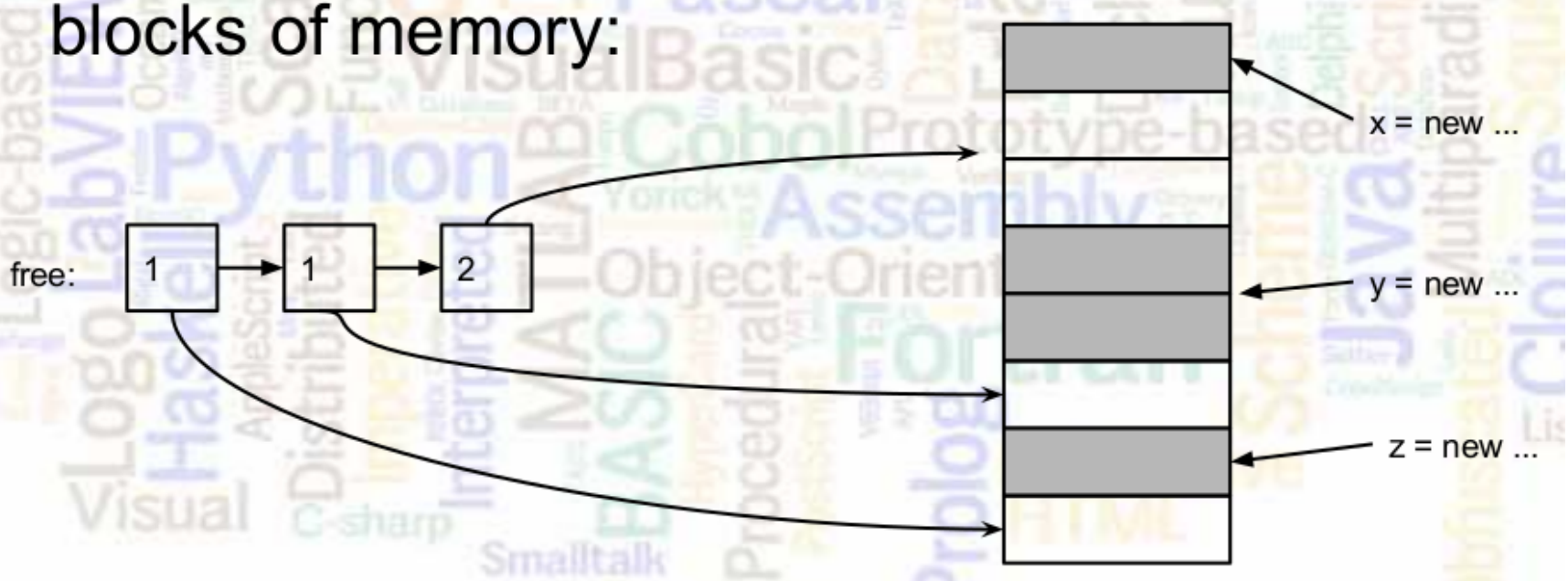


Heap Allocation

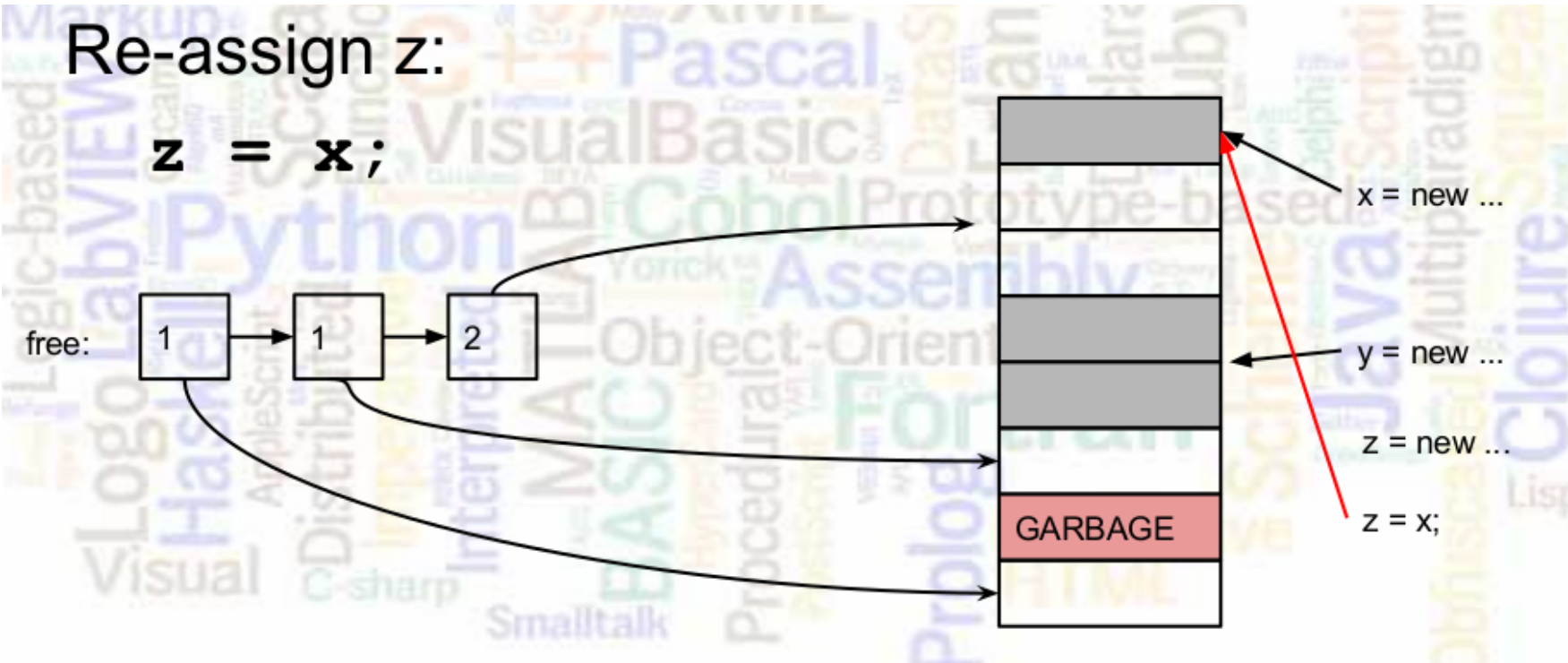
- Any time we use the “new” operator in Java, we allocate space from the heap.
- In C, use of the malloc function allocates from the heap.
- Harder to maintain than a stack; many techniques used.

Heap Allocation

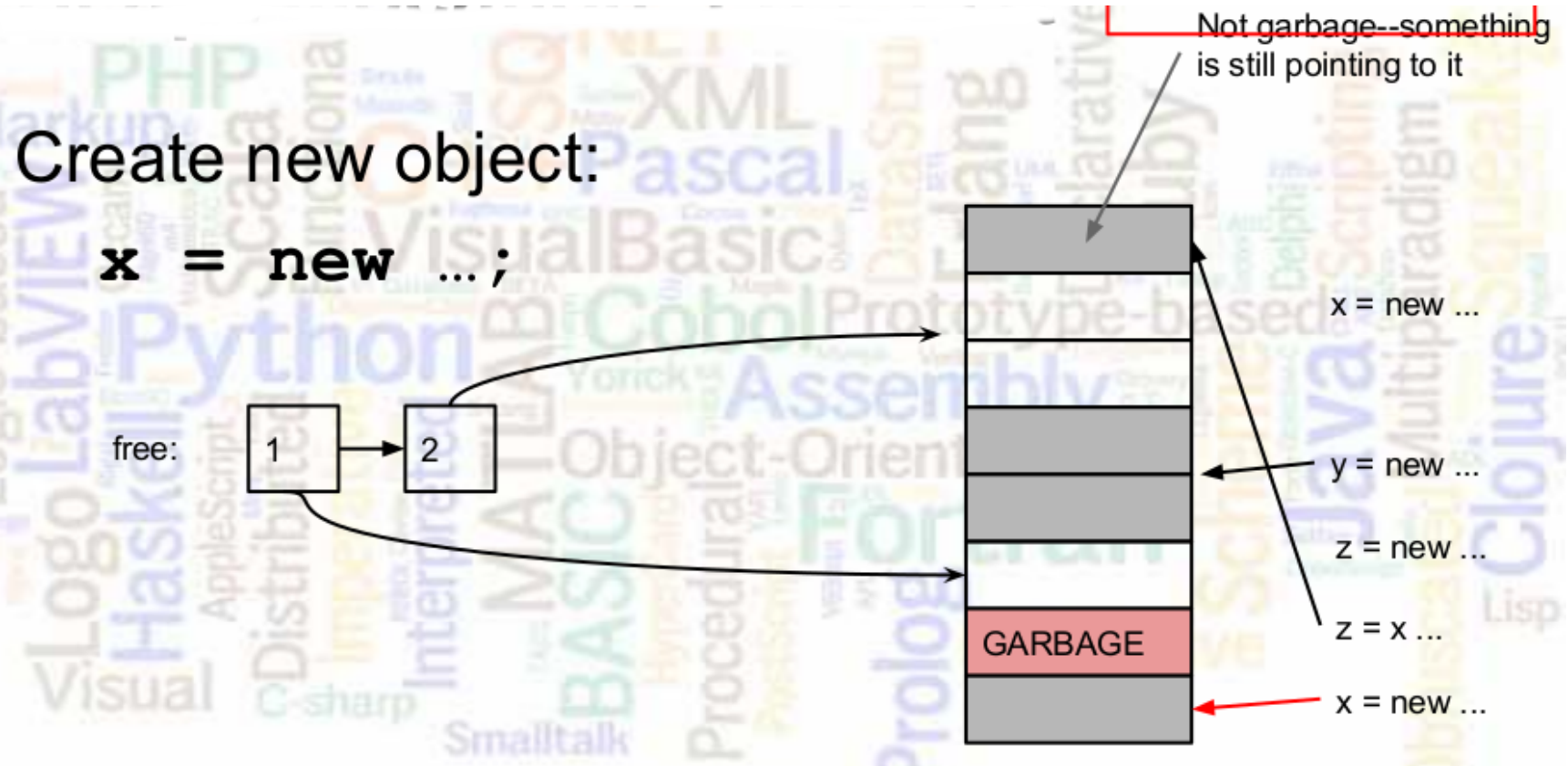
Simplest way to maintain heap--“free list” of blocks of memory:



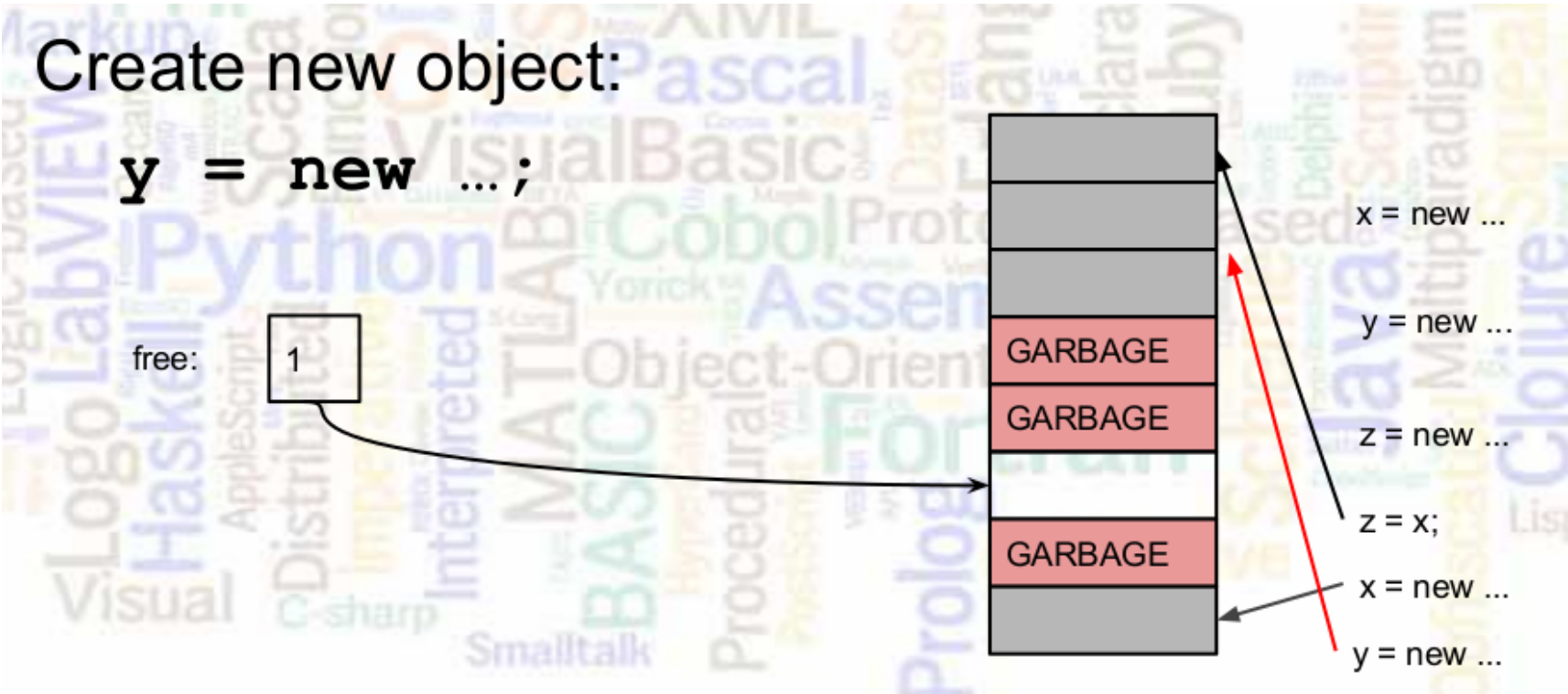
Heap Allocation



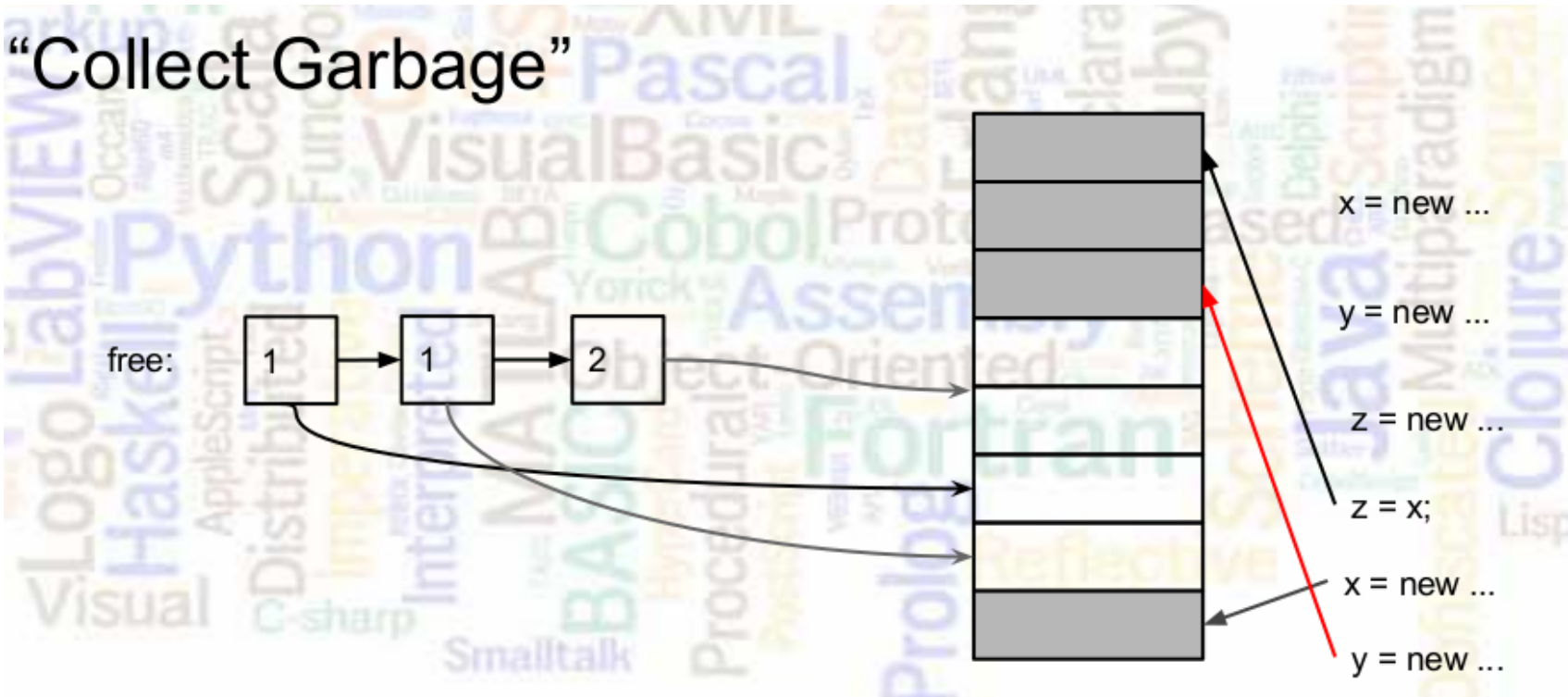
Heap Allocation



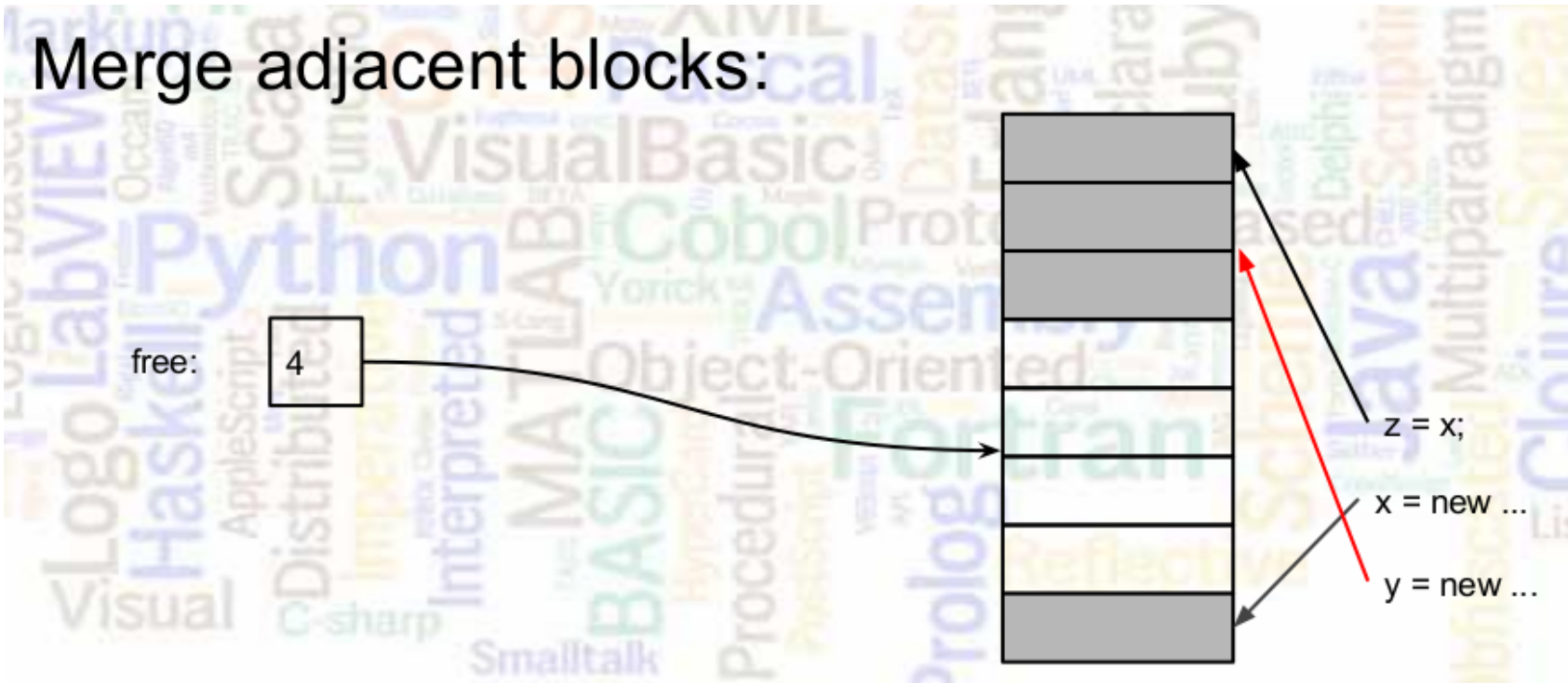
Heap Allocation



Heap Allocation



Heap Allocation



Which Block to Use from Free List?

1. First fit: take the first block in the free list that is big enough to satisfy the requested amount.
2. Best fit: take the smallest block in the free list that is big enough to satisfy the request.

Summary: Names, Scopes and Bindings

Binding

is an association between an attribute and an entity, such as between a variable and its type or value, or between an operation and a symbol.
static vs. dynamic

Summary: Names, Scopes and Bindings

Binding

is an association between an attribute and an entity, such as between a variable and its type or value, or between an operation and a symbol.
static vs. dynamic

Example: $count = count + 5;$

Summary: Names, Scopes and Bindings

Example: $count = count + 5$;
Some of the bindings and their binding times:

- The type of count is bound at compile time.
- The set of possible values of count is bound at compiler design time.
- The meaning of the operator symbol + is bound at compile time, when the types of its operands have been determined.
- The internal representation of the literal 5 is bound at compiler design time.
- The value of count is bound at execution time with this statement.

Example: Static vs. Dynamic Scoping

```
function big() {
  function sub1() {
    var x = 7;
    sub2();
  }
  function sub2() {
    var y = x;
  }
  var x = 3;
  sub1();
}
```

Under static scoping, the reference to the variable `x` in `sub2` is to the `x` declared in the procedure `big`.

Example: Static vs. Dynamic Scoping

```
function big() {
    function sub1() {
      var x = 7;
    }
    function sub2() {
      var y = x;
      var z = 3;
    }
    var x = 3;
}
```

Under dynamic scoping, the meaning of `x` may reference the variable from either declaration of `x`, depending on the calling sequence.

Summary: Names, Scopes and Bindings

How is scope implemented at execution time?

- Pointers on the activation record stack refer to surrounding scope.
- Static: "static link"– pointer to lexical parent (for nested functions).
- Dynamic: "dynamic link" – pointer to caller's stack frame.

Activity: Static chains in JavaScript and Scoping

1. Activity: Go to http://goo.gl/hcrqmE for a working version of Figure 3.5 below from Programming Language Pragmatics textbook.

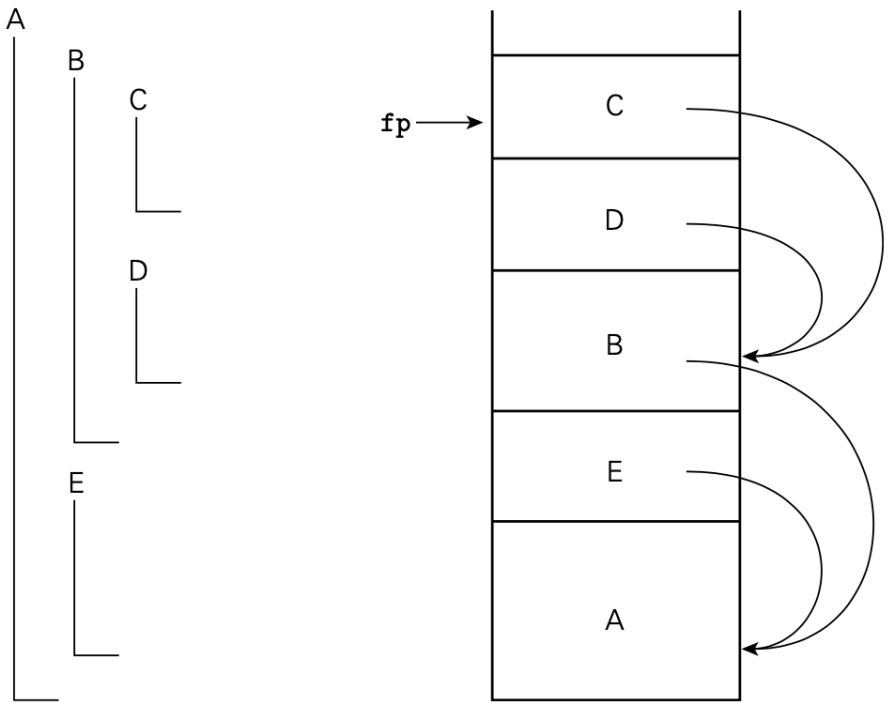


Figure 3.5 **Static chains.** Subroutines A, B, C, D, and E are nested as shown on the left. If the sequence of nested calls at run time is A, E, B, D, and C, then the static links in the stack will look as shown on the right. The code for subroutine C can find local objects at known offsets from the frame pointer. It can find local objects of the surrounding scope, B, by dereferencing its static chain once and then applying an offset. It can find local objects in B's surrounding scope, A, by dereferencing its static chain twice and then applying an offset.