Examples for Programming Language Features

Ch 1 Preliminaries

1.3 Language Evaluation Criteria

1.3.3 Reliability

1.3.3.1 Type Checking

The following C program compiles and runs!

```
foo (float a) {
    printf (“a: %g and square(a): %g\n”, a, a*a);
}
main () {
    char z = ‘b’;
    foo(z);
}
```

Output is : `a: 98 and square(a): 9604`

Subscript range checking for arrays is a part of type checking, but it must be done in the **run-time**. Out-of-range subscript often cause errors that do not appear until long after actual violation.

```
#include <stdio.h>
foo (char s[])  {
    printf ("5th char in %s is %c\n", s, s[4]);
}

main () {
    char str[] = "abc";
    foo(str);
}
```

produces:

```
5th char in abc is }
```

Ch 3. Describing Syntax and Semantics

3.1. Formal Methods of Describing Syntax

Example: Python formal definition (https://docs.python.org/3/reference/simple_stmts.html)

Ch 5. Names, Bindings, and Scopes

5.4.2.1 Static Type Binding

In Perl, $x is a scalar, @x is an array, %x is a hash.

```
$x = 5;

print $x ."\n";

$x = "Hello";

print $x ."\n";

@x = ("Ali", "Ayse", "Can", "Canan");

print "$x \n";

print "@x \n";
```

```
5

Hello

Hello

Ali Ayse Can Canan
```

```
%data = ('A', 4.0, 'A-', 3.7, 'B+', 3.3, 'B', 3);

print "$data{'A-'}\n";
```

```
3.7
```

5.4.2.2. Dynamic Type Binding

Javascript uses dynamic type binding.

```
list = [2, 4.33, 6, 8]; list is a single dimensioned array.
list = 73                     list is a simple integer.
```

5.4.3.1. Static Variables

Ex in C:

```
int a = 5; // global static variable
int foo(){
  static int b = 10; // static variable, scope is only the function.
}
```

5.4.3.3. Explicit Heap-Dynamic Variables

Ex in C++

```
  int *intnode;  // create a pointer
  intnode = new int; // create the heap-dynamic variable
  delete intnode;  // deallocate the heap-dynamic variable
```

Ex in Java:

```
  Integer i = new Integer(5);
```

5.4.3.4 Implicit Heap-Dynamic Variables

Example in JavaScript:

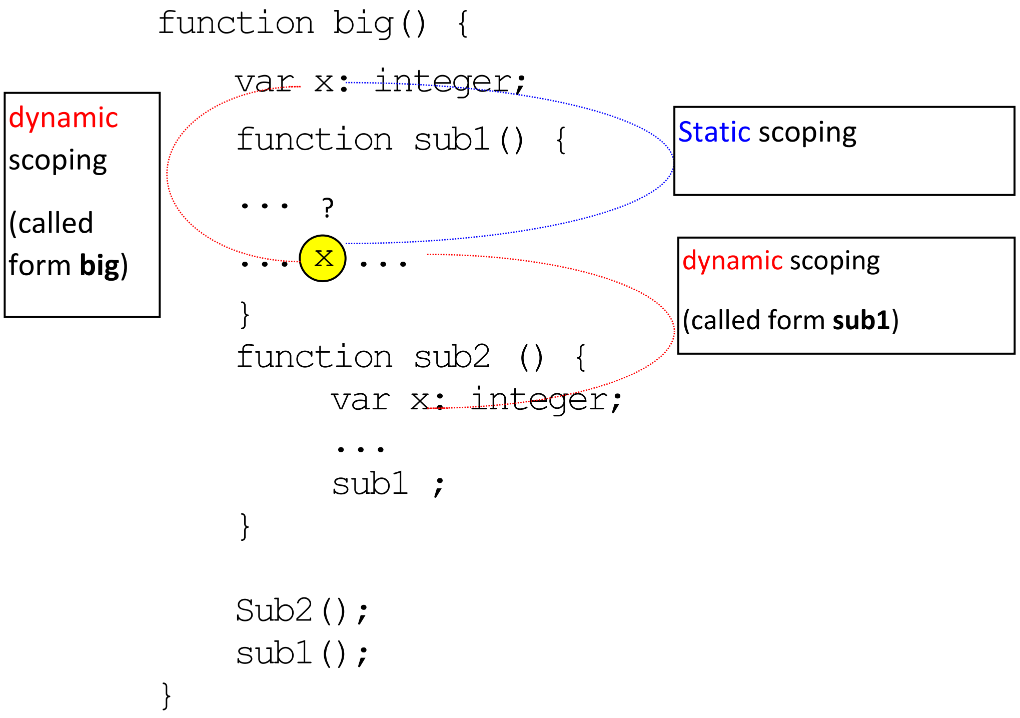
```
numbers = [3, 5, 7, 15];
```

5.4-Summary

C Example:

```
int a1[10];                 // static global variable.
static int a2 = 5;          // static global variable, initialized
void foo(){
  static int a3[10];        // static local array variable
  int a4[10];               // stack-dynamic variable
  int *a5 = (int *)malloc(10*sizeof(int));
                            // a5 (pointer) is stack-dynamic
                            // *a5 is explicit heap-dynamic
  ...
  free(a5);
}
```

5.5.6. Dynamic Scope



```
      function big() {
          var x: integer;
          function sub1() {
          ...  ?
          ... x ...
          }
          function sub2 () {
               var x: integer;
               ...
               sub1 ;
          }

          Sub2();
          sub1();
      }
```

dynamic scoping

(called form **big**)

Static scoping

dynamic scoping

(called form **sub1**)

5.8 Named Constants

Java and C++ allow dynamic binding of values to named constants.

Example in Java

```
import java.util.Scanner;
public class A {
   public static void main(String[] args) {
     Scanner kb = new Scanner(System.in);
     int a = kb.nextInt();
     final int b = a * 2;
     System.out.println(a+" "+b);
    }
}
```

6. Data Types

6.3.3 String Length Options

- **Limited dynamic length strings:** (C and C++)

Following are equivalent in C

```
char c[] = "abcd";

char c[50] = "abcd";

char c[] = {'a', 'b', 'c', 'd', '\0'};

char c[5] = {'a', 'b', 'c', 'd', '\0'};
```

6.4 Enumeration Types

- Example in C:

```
/* enumeration type in C */
main () {
 enum day {mo, tu, we, th, fr, sa, su};
 enum day today;
 today = th;
 if ((today == sa) || (today == su))
       printf (“weekend\n”);
 else printf (“weekday\n”);
}
```

6.5.3 Subscript Bindings and Array Categories

Heap-dynamic array: Similar to stack-dynamic array, but the size can change during the lifetime.

Advantage: the array can grow and shrink.

Example:

ArrayList in Java, List in python, Arrays in perl (dynamic-array.pl)

Python

```
>>> mylist = [2, 1.6, (3+5j), 'c', "a word"]
>>> print mylist
[2, 1.6, (3+5j), 'c', 'a word']
>>> x = (1+2j) * mylist[2]
>>> x
(-7+11j)
```

6.6 Associative Arrays

Provided in Perl (called hash) and Java.

- Indexed by keys
- The size can grow and shrink dynamically.

```
#!/usr/local/bin/perl

%notlar = ("Ali" => 95, "Veli" => 80, "Selami" => 95);
```

To print an entry:

```
print "Veli’nin notu $notlar{Veli}\n";
```

To add a new entry:

```
$notlar{"Hulki"} = 75;
```

To delete an entry:

```
delete $notlar{"Veli"};
```

To change an entry:

```
$notlar{"Veli"} = 82;
```

To go through the array:

```
foreach $anahtar (keys %notlar) {
 print "$anahtar $notlar{$anahtar}\n";
}
```

To empty the array:

```
%notlar = ();
```

6.8. Tuple Types

A tuple is a data type that is similar to a record, except that the elements are not named.

Ex: Python

```
>>> myTuple = (3, 5.8, 'apple')
>>> myTuple[1]
5.8
```

```
>>> myTuple[1] = 6.7
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
TypeError: 'tuple' object does not support item assignment
>>> myTuple = [3, 5.8, 'apple']    #Now, it is a list
>>> myTuple[1] = 6.7
>>> myTuple = (3, 5.8, 'apple')  # Back to tuple
>>> yourTuple = (1, 'pear')
>>> print myTuple + yourTuple
(3, 5.8, 'apple', 1, 'pear')
>>> print yourTuple
(1, 'pear')
>>> del yourTuple
>>> print yourTuple
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
NameError: name 'yourTuple' is not defined
```

List Types

Lists were first supported in Lisp and Scheme.

Ex: Python:

```
>>> myList = [1, 2.3, "three"]
>>> del myList[1]
>>> myList
[1, 'three']
>>> myList.insert(1,"orange")
>>> myList
[1, 'orange', 'three']
>>> myList.append("plum")
>>> myList
[1, 'orange', 'three', 'plum']
```

6.10. Union Types

A **union type** may store different type values at different times in the same location.

Type checking must be dynamic.

Example in C:

```
#include <stdio.h>
#include <string.h>
```

```
union Data {
  int i;
  float f;
  char str[20];
};

int main() {
  union Data data;
  data.i = 10;
  data.f = 220.5;
  strcpy( data.str, "C Programming");
  printf( "data.i : %d\n", data.i);
  printf( "data.f : %f\n", data.f);
  printf( "data.str : %s\n", data.str);
  return 0;
}
```

Generates the following output:

```
data.i : 1917853763
data.f : 4122360580327794860452759994368.000000
data.str : C Programming
```

Size of a variable of union type:

```
#include <stdio.h>
#include <string.h>

union Data {
  int i;
  float f;
  char str[20];
};

int main( ) {
  union Data data;
  printf("Memory size occupied by data: %d\n", sizeof(data));
  return 0;
}
```

Prints 20.

6.11.3.2. Lost heap-dynamic variables

C++ Example

```
void foo(){
  int * x = new int;
}
foo(); // no way to reach the allocated integer: memory leakage
```

C++ Example

```
int * x = new int;
x = new int;
// no way to reach the first allocated integer: memory leakage
```

7. Expressions and Assignment Statements

7.2.2.1 Side Effects

C Example

```
#include<stdio.h>
int foo(int *x) {
  *x = *x * 2;
  return *x;
}
int bar(int *x) {
  *x = *x * 3;
  return *x;
}

int main() {
  int n = 5;
  //  printf("result is %d\n",  foo(&n) + bar(&n)); // 40
  printf("result is %d\n",  bar(&n) + foo(&n));   // 45
}
```

7.5.2. Boolean Expressions

Python:

```
x < y < z is equivalent to x < y and y < z,
```

Falsy values:

Python: [], (), {}, "", range(0), set(), 0, 0.0, 0j, None, False

Javascript: [], "", 0, NaN, false, undefined

Truthy values: other values.

7.6 Short-Circuit Evaluation

Python

```
X or Y: If X is false then Y,
        else X
X and Y: If X is false, then X,
         else Y
not X:   if X is true then False,
         else True
>>> 0 or 'abc'
'abc'
>>> 1 or 'abc'
1
>>> 0 or '' or 'abc'
'abc'
>>> 'abc' and 'de'
'de'
```

9. Subprograms

9.2.3 Parameters

Python Example / positional parameter passing

```
def sum(x, y, z):
  return x + y + z
u = sum(a, b, c)
```

Python Example / positional with defaults

```
def sum(x, y, z=3):
  return x + y + z
u = sum(a, b)
u = sum(a, b, c)
```

Python Example / keyword based:

```
def sum(x, y, z=3):
  return x + y + z
u = sum(y=a, x=b)
u = sum(y=a, z=c, x=b)
```

Python Example / variable number of arguments:

```
def sum(x, y, *z):
  s = x + y
  for e in z:
    s = s + e
  return s
u = sum(a, b)
u = sum(a, b, c, 3, 5)
```

Python Example / variable number of arguments:

```
def sum(x, y, *z, **w):
  s = x + y
  for e in z:
    s = s + e
  for k,e in w.iteritems():
    s = s + e
  return s
u = sum(a, b)
u = sum(a, b, c, d, i=3, j=5)
```

Python Example / unpacking:

```
def sum(x, y, z, t):
  return x + y + z + t

v = [3, 5, 6, 8]
u = sum(*v) # same as sum(3, 5, 6, 8)
```

9.5.2 Parameter passing methods

The output of the program considering static scoping, sub-expression evaluation order of left-to-right, and:

- parameter passing with pass-by-value-result
- parameter passing with pass-by-reference
- parameter passing with pass-by-value

```
int y;
int z;
int foo(int x) {
  x = x + 5;
  y = x;
  x = x + 6;
  return y;
}

int bar(int x){
  y = foo(x) * x;
  return x;
}

void main(){
  y = 4;
  z = bar(y);
  print(y, z);
}
// Pass-by-value-result: 15 15
// Pass-by-reference: 225 225
// Pass-by-value: 36 4
```

9.5.2.5. Pass-by-name

Example in Scala

https://alvinalexander.com/source-code/scala/simple-scala-call-name-example

(Scala is a type-safe JVM language that incorporates both object oriented and functional programming)

9.6 Parameters That Are Subprograms

Python Example

```
def map(op, items):
  res = []
  for item in items:
    res.append(op(item))
  return res

def square(x):
  return x*x

def triple(x):
  return 3*x

print(map(square, [1, 2, 3])) # prints [1, 4, 9]
print(map(triple, [1, 2, 3])) # prints [3, 6, 9]
```

C++ Example

```
vector<int> map(int (*op)(int), vector<int> const & list){
  vector<int> res;
  for (int v: list){
    int mappedValue = (*op)(v);
    res.push_back(mappedValue);
  }
  return res;
}

int square(int x){
  return x*x;
}

int triple(int x){
  return 3*x;
}

vector<int> list = {1, 2, 3, 4};
vector<int> res = map(&square, list);
vector<int> res2 = map(&triple, list);
```

9.12. Closures

A JavaScript closure example:

http://dijkstra.cs.bilkent.edu.tr/~guvenir/closure.htm

Python Example:

```
def make_adder(x):
  def adder(y):
    return x+y # x is captured from y.
  return adder # make_adder returns inner function.

f = make_adder(3) # f is a function
print(f(5)) #prints 8
# 3 of the previous line is captured as x
```

C++ Example:

```
function<int(int)> make_adder(int x){
  auto adder = [=] (int y) {return x+y; };
  return adder;
}
auto adder = make_adder(3);
cout << adder(5);
```

9.13. Coroutines

Not exactly a full-coroutine implementation, but a similar feature in Python, “generators” example:

```
def genPairs(n):
  for i in range(0, n):
    for j in range(i+1, n):
      yield (i, j)

for p in genPairs(5):
  print(p)
```

10. Implementing Subprograms

10.2 Implementing “Simple” Subprograms

Example in Fortran

```
      INTEGER I,J
      COMMON I
      CALL X
      GOTO 10
   10 CONTINUE
      END
```

```
       SUBROUTINE X
       INTEGER K, J
       COMMON I
       K=5
       I=6
       J=I+K
       RETURN
       END
```

The translator performs the following bindings for the main program:

```
I ↔ d[COMMON, 0]
J ↔ d[MAIN,1]
10 ↔ c[MAIN,3]              CONTINUE statement
X ↔ c[X,0]                  first statement of X
```

And the following bindings for the subroutine X:

```
I ↔ d[COMMON, 0]
K ↔ d[X, 1]
J ↔ d[X, 2]
```

The linker then performs a further binding of addresses by combining the main program and the subroutine X.

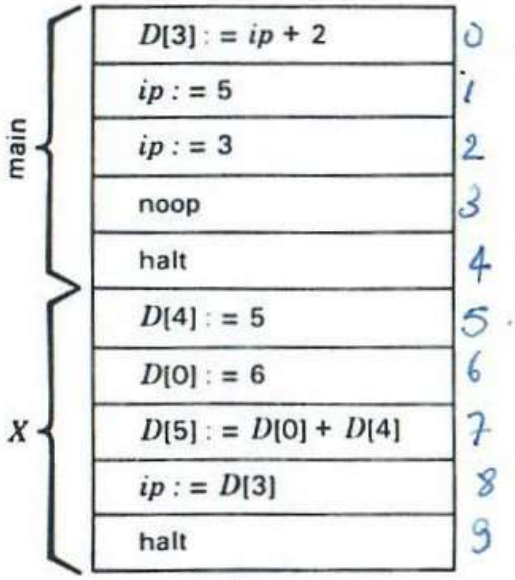
It produces the following bindings in the main program:

```
I ↔ D[0]
J ↔ D[2]
10 ↔ C[3]
X ↔ C[5]
```

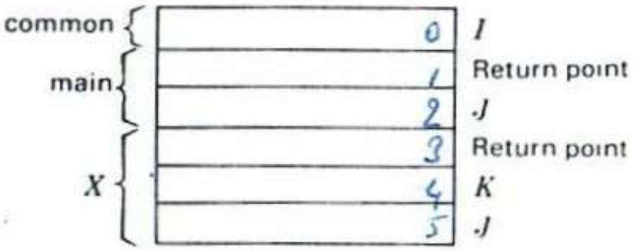
And the following bindings for X:

```
I ↔ D[0]
K ↔ D[4]
J ↔ D[5]
```

The contents of the memory will be as follows:

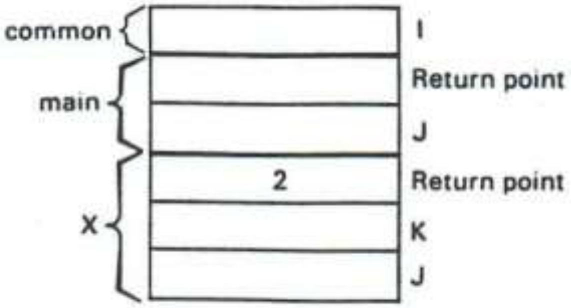


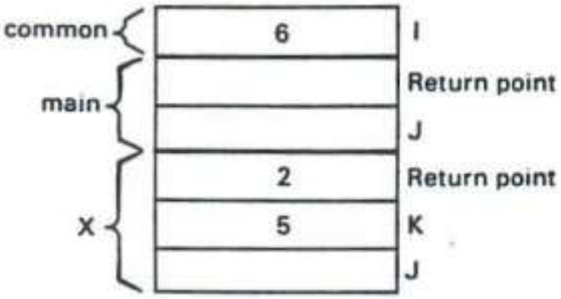
Code memory

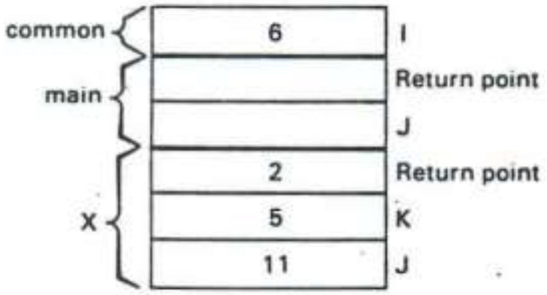


Data memory

The contents of the Data memory during the execution:







Static Chains

The most common way to implement static scoping in languages that support nested subprograms is static chaining.

A new pointer, called Static Link, is added to the Activation Record.

Static Link is sometimes called static scope pointer.

Static Link is used to access to nonlocal variables.

Static Chain is the chain of static Links.

When a reference is made to a nonlocal variable, the Activation Record instance is in the static chain.

How to find the ARI that contains the nonlocal variable?

Compiler can determine the distance of the ARI on the static chain.

Static_depth of a subprogram is the depth of nesting.

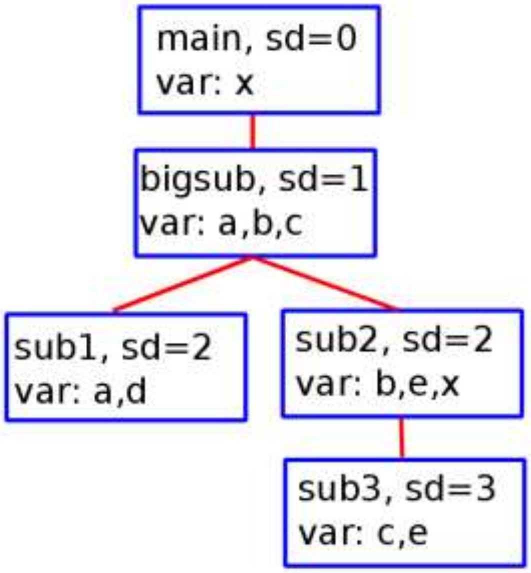
```
Static_depth(main) = 0.

Static depth(A) = 1 + static_depth(A's static parent).
```

Nesting_depth (chain_offset) of a variable:

```
static_depth(ARI of reference) - static_depth(ARI of delaration)
```

Then, address of a variable is represented by a pair
    (*chain_offset*, *local_offset*),

```
function main(){
   var x = 5;
   function bigsub() {
      var a, b, c;
      function sub1 {
         var a, d;
         a = b + c;
         ...
      }  // end of sub1
      function sub2(x) {
         var b, e;
         function sub3() {
            var c, e;
            ...
            sub1();
            ...
            e = b + a;
         } // end of sub3
         ...
         sub3();
         ...
         a = d + e;
      } // end of sub2
      ...
      sub2(7);
      ...
   } // end of bigsub
   ...
   bigsub();
   ...
} // end of main
```



Sequence of calls:

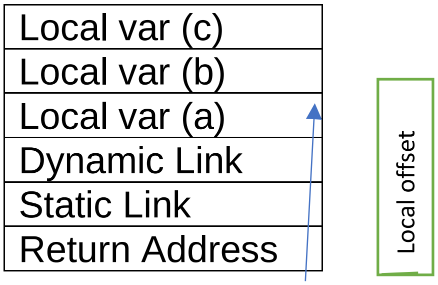
- main calls bigsub
- bigsub calls sub2
- sub2 calls sub3
- sub3 calls sub1

Activation Records:

main:

Local variable(x)

bigsub:



Local var (c)
Local var (b)
Local var (a)
Dynamic Link
Static Link
Return Address

`local_offset(a) = 3`

sub1:

Local var (d)
Local var (a)
Dynamic Link
Static Link
Return Address

sub2:

Local var (e)
Local var (b)
Parameter (x)
Dynamic Link
Static Link
Return Address

sub3:

Local var (e)
Local var (c)
Dynamic Link
Static Link
Return Address

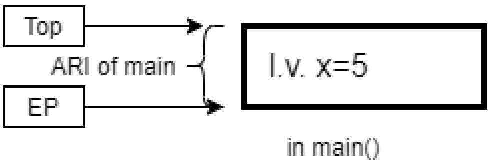
```
function main(){
```

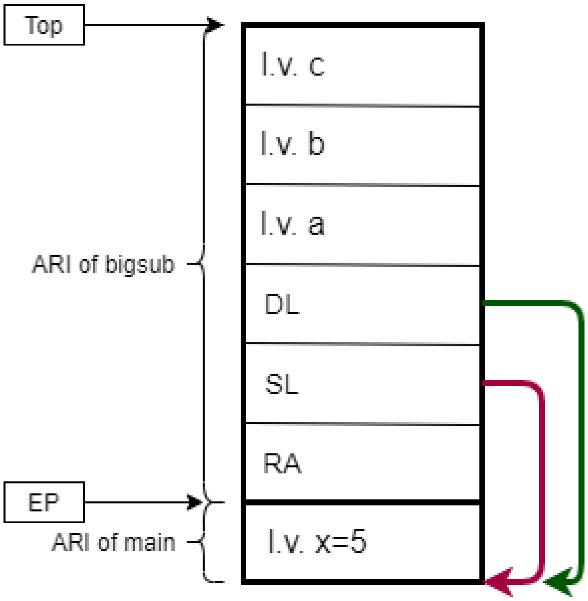
Chain_offset

local_offset

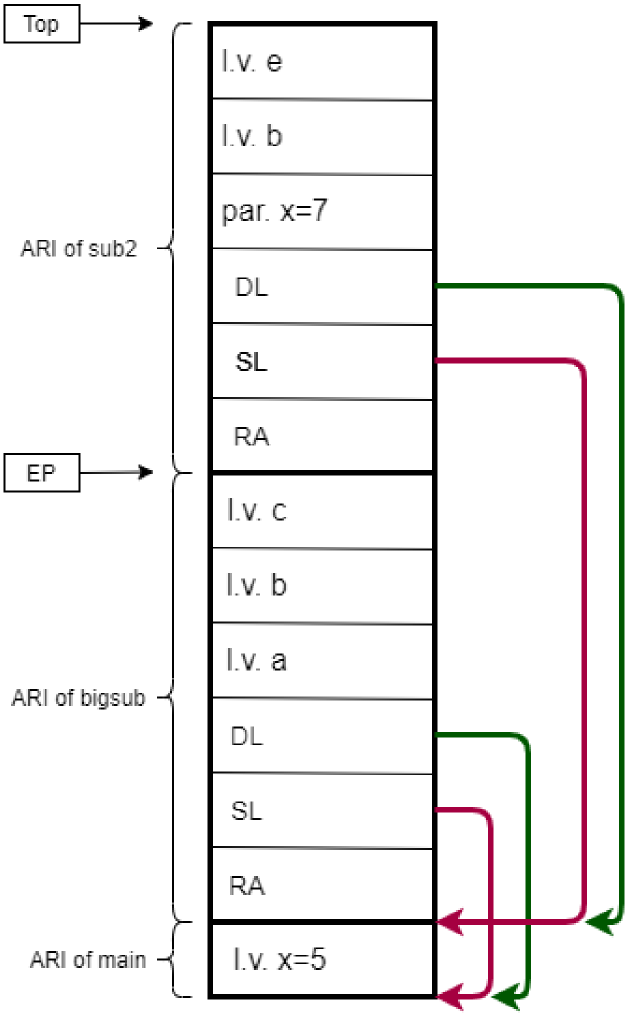
```
   var x = 5;
   function bigsub() {
      var a, b, c;
      function sub1() {
         var a, d;
         a = b + c; ←----------(0,3) = (1,4) + (1,5)
         ...
      }  // end of sub1
      function sub2(x) {
         var b, e;
         function sub3() {
            var c, e;
            ...
            sub1();
            ...
            e = b + a; ←-------(0,4) = (1,4) + (2,3)
         } // end of sub3 ...
         sub3();
         ...
         a = d + e;  ←---------(1,3) = d: ??? Error
      } // end of sub2
      ...
      sub2(7);
      ...
   } // end of bigsub
   ...
   bigsub();
   ...
} // end of main
```

Contents of the Runtime Stack:

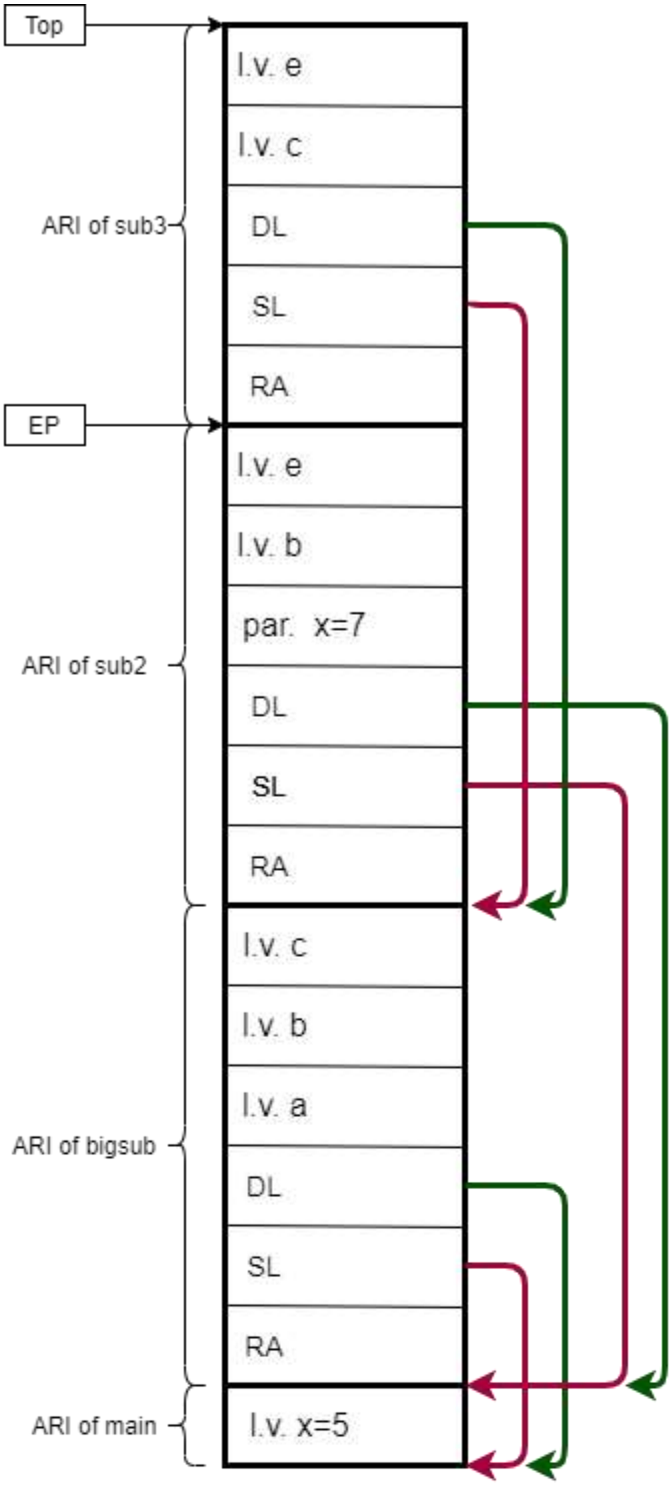




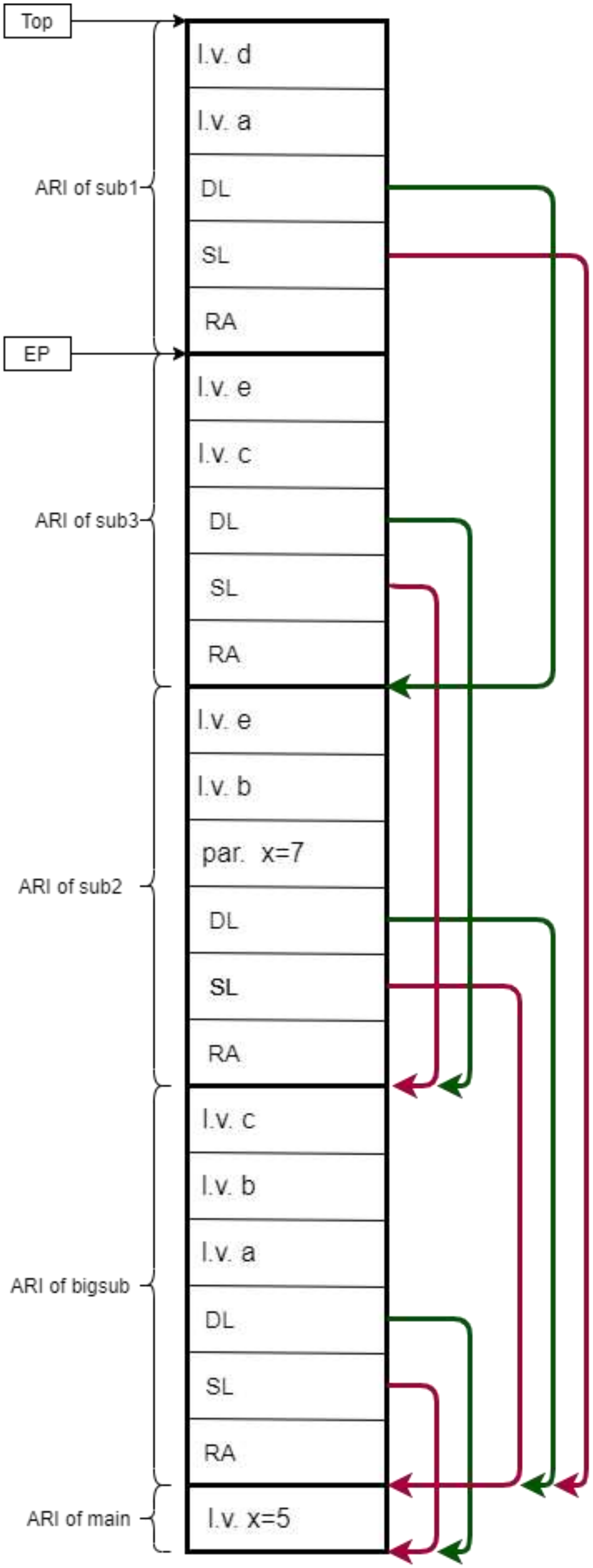
in bigub()



in sub2()


Top
EP
ARI of sub3
l.v. e
l.v. c
DL
SL
RA
ARI of sub2
l.v. e
l.v. b
par. x=7
DL
SL
RA
ARI of bigsub
l.v. c
l.v. b
l.v. a
DL
SL
RA
ARI of main
l.v. x=5

in sub3()


Top
EP
ARI of sub1
l.v. d
l.v. a
DL
SL
RA
ARI of sub3
l.v. e
l.v. c
DL
SL
RA
ARI of sub2
l.v. e
l.v. b
par. x=7
DL
SL
RA
ARI of bigsub
l.v. c
l.v. b
l.v. a
DL
SL
RA
ARI of main
l.v. x=5

in sub1()

How to maintain the static links?

Where should a Static Link point to when a new ARI is created?

It should point to the most recent ARI of the static parent.

How to find the most recent ARI of the static parent?

For example, when sub1() is called from sub3(), the ARI of sub1() should point to the ARI of bigsub(), which is the static parent of sub1().

Solution: Compiler computes: **nesting_depth(caller, called)**: as

Static_depth(caller) – static_depth (unit that declared called).

It the example above:

Caller: sub3

Callee: sub1

Static parent of Callee: bigsub

nesting_depth(sub3, sub1):

= Static_depth(sub3) - static_depth(unit that declared sub1)

= Static_depth(sub3) - static_depth(bigsub)

= 3 – 1

= 2.

So, SL of the ARI of sub1 should point to the 2nd ARI in the static chain.