CS 314 Principles of Programming Languages

Lecture 13: Names, Scopes and Bindings

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Review: Names, Scopes and Binding

What's in a name? — Each name "means" something!

- Denotes a programming language construct
- Has associated "attributes"
  Examples: type, memory location, read/write permission, storage class, access restrictions.
- Has a meaning
  Examples: represents a semantic object, a type description, an integer value, a function value, a memory address.

Review: Names, Bindings and Memory

Bindings – Association of a name with the thing it "names" (e.g., a name and a memory location, a function name and its "meaning", a name and a value)

- **Compile time**: during compilation process - static (e.g.: macro expansion, type definition)
- **Link time**: separately compiled modules/files are joined together by the linker (e.g: adding the standard library routines for I/O (stdio.h), external variables)
- **Run time**: when program executes - dynamic

Compiler needs bindings to know meaning of names during translation (and execution).

Review: Binding Time - Choices

- **Early binding** times — more efficient (faster) at run time
- **Late binding** times — more flexible (postpone binding decision until more "information" is available)
- Examples of static binding (early):
  - functions in C
  - types in C
- Examples of dynamic binding (late):
  - virtual methods in Java
  - dynamic typing in Javascript, Scheme

Note: dynamic linking is somewhat in between static and dynamic binding; the function signature has to be known (static), but the implementation is linked and loaded at run time (dynamic).

Review: How to Maintain Bindings

- Symbol table: maintained by compiler during compilation
- Referencing Environment: maintained by compiler-generated-code during program execution

Question:

- How long do bindings last for a name hold in a program?
- What initiates a binding?
- What ends a binding?

Scope of a binding: the part of the in which the binding is active.

Review: Scope Example

Nested Subroutines (Algol 60, Ada, ML, Common Lisp, Python, ….)

```
program L;
        var n: char;          {n declared in L}
        procedure W;
        begin
                write (n);    {n referenced in W}
        end;
        procedure D;
                var n: char;  {n declared in D}
        begin
                n := ‘D’;     {n referenced in D}
                W
        end;
begin
        n := ‘L’;             {n referenced in L}
        W;
        D
end
```

Scope Example

Nested Subroutines (Algol 60, Ada, ML, Common Lisp, Python, ….)

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Lexical Scope

- Non-local variables are associated with declarations at *compile* time
- Find the smallest block syntactically enclosing the reference and containing a declaration of the variable
- Example:
    - The reference to n in W is associated with two different declarations at two different times
    - The output is?

L

Calling Chain:

$$L \Rightarrow W$$

$$L \Rightarrow D \Rightarrow W$$

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```

Dynamic Scope

- Non-local variables are associated with declarations at *run* time
- Find the most recent, currently active run-time stack frame containing a declaration of the variable
- Example:
  - The reference to n in W is associated with two different declarations at two different times
  - The output is ?

L

```
program L;
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        n := ‘L’;   {n referenced in L}
        W;
        D
end
```

Context of Procedures

Two contexts

- *static* placement in source code (same for each invocation)
- *dynamic* run-time stack context (different for each invocation)

Scope Rules:

Each variable reference must be associated with a single declaration.

Two choices:

1. Use static and dynamic context: *lexical scope*
2. Use dynamic context: *dynamic scope*
    - Easy for variables declared locally, and same for *lexical* and *dynamic* scoping
    - Harder for variables not declared locally and not same for *lexical* and *dynamic* scoping

Review: Access to Non-Local Data(Lexical Scoping)

Two important steps

1. *Compile-time*: How do we map a name into a (level, offset) pair?
   We use a block structured symbol table (**compile time**)
   - When we look up a name, we want to get the most recent declaration for the name
   - The declaration may be found in the current procedure or in any ancestor procedure
2. *Run-time*: Given a (level, offset) pair, what’s the address?
   - Two classical approaches:
     - ⇒ access link (*static link*)
     - ⇒ display

Lexical Scoping

Symbol table generated at compile time matches declarations and occurrences.
⇒ Each name can be represented as a pair (nesting_level, local_index).

```
Program
  x, y: integer   // declarations of x and y
  Procedure B     // declaration of B
      y, z: real  // declaration of y and z
      begin
        ...
        y = x + z // occurrences of y, x, and z
        if (...) call B // occurrence of B
      end
  Procedure C     // declaration of C
      x: real
      begin
        ...
        call B // occurrence of B
      end
  begin
  ...
  call C     // occurrence of C
  call B     // occurrence of B
end
```

```
Program
  (1,1), (1,2): integer   // declarations of x and y
  Procedure (1,3)    // declaration of B
      (2,1), (2,2): real  // declaration of y and z
      begin
        ...
        (2,1) = (1,1) + (2,2) // occurrences of y, x, and z
        if (...) call (1,3) // occurrence of B
      end
  Procedure (1,4)    // declaration of C
      (2,1): real
      begin
        ...
        call (1,3) // occurrence of B
      end
  begin
  ...
  call (1,4)     // occurrence of C
  call (1,3)     // occurrence of B
end
```

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     ⇒ access link (*static link*)

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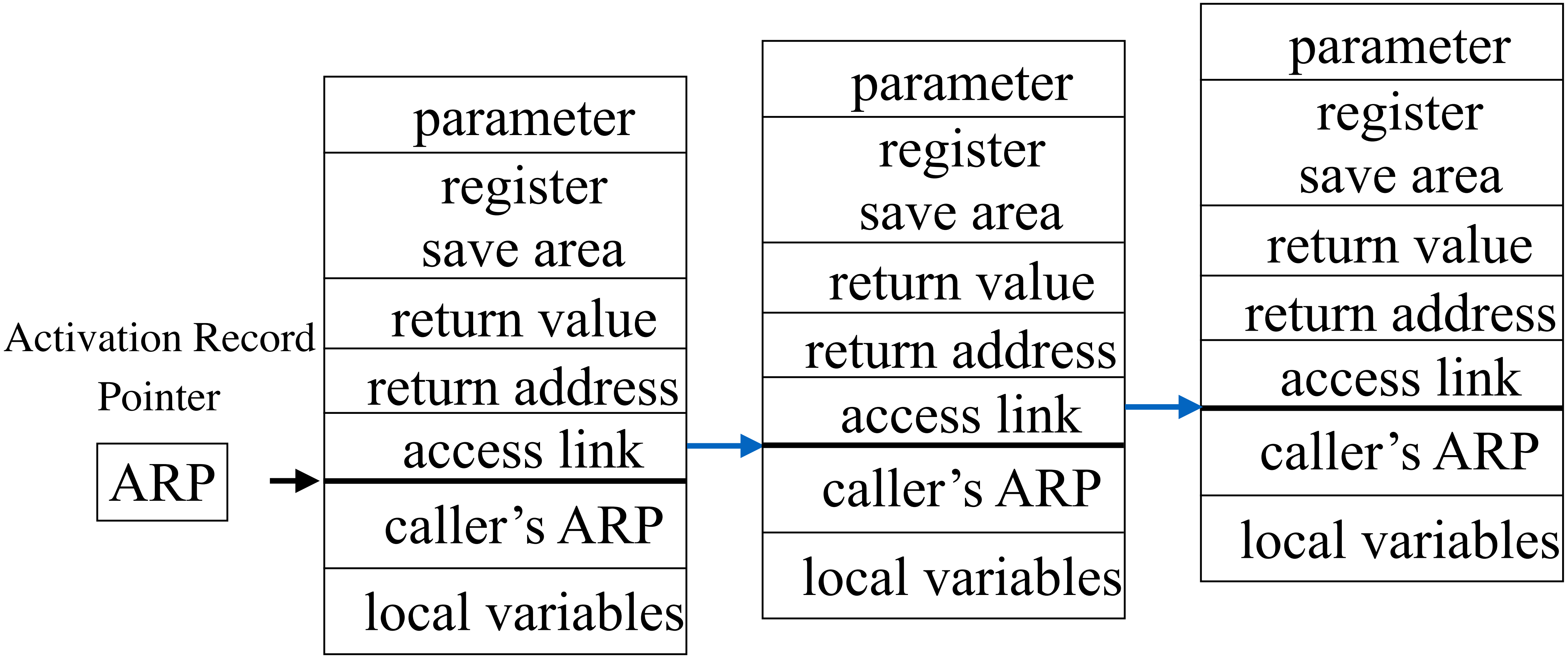
Access to Non-Local Data(Lexical Scoping): Access Link

Using access links (static links)

- Each AR has a pointer to most recent AR of immediate lexical ancestor
- Lexical ancestor does not need to be the caller



Activation Record Pointer

ARP

parameter
register save area
return value
return address
access link
caller’s ARP
local variables

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Example: reference to <p, 16> runs up access link to p

Cost of access link is proportional to lexical distance

Access to Non-Local Data(Lexical Scoping)

What code do we need to generate for this statement:

$$(2,1) = (1,1) + (2,2)$$

What do we know?

- Assume the nesting level of the statement is **level 2**
- Register r_0 contains the current FP (frame pointer)
- **(2, 1) and (2, 2) are local variables**, so they are allocated in the activation record that current FP points to.
  (1, 1) is an non-local variable.
- Two new instructions:

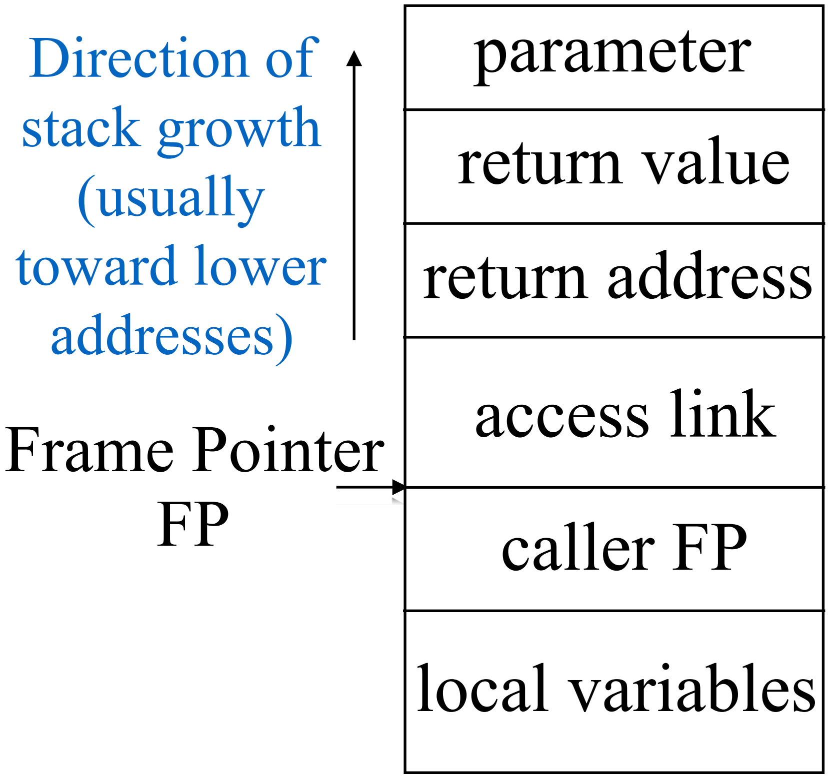
LOAD R_x, R_y means $R_x \leftarrow MEM(R_y)$

STORE R_x, R_y means $MEM(R_x) \leftarrow R_y$

Access to Non-Local Data(Lexical Scoping)

What code do we need to generate for statement (∗)?

$$(2,1) = (1,1) + (2,2)$$



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(1,1)  LOADI r1, #4      // offset of local variable (1,1) in frame
       LOADI r2, #-4     // offset of access link in frame (bytes)
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       LOAD r4 r3        // get access link
       ADD r5 r4 r1      // address of local variable (1,1) in frame
       LOAD r6 r5        // get content of variable (1,1)
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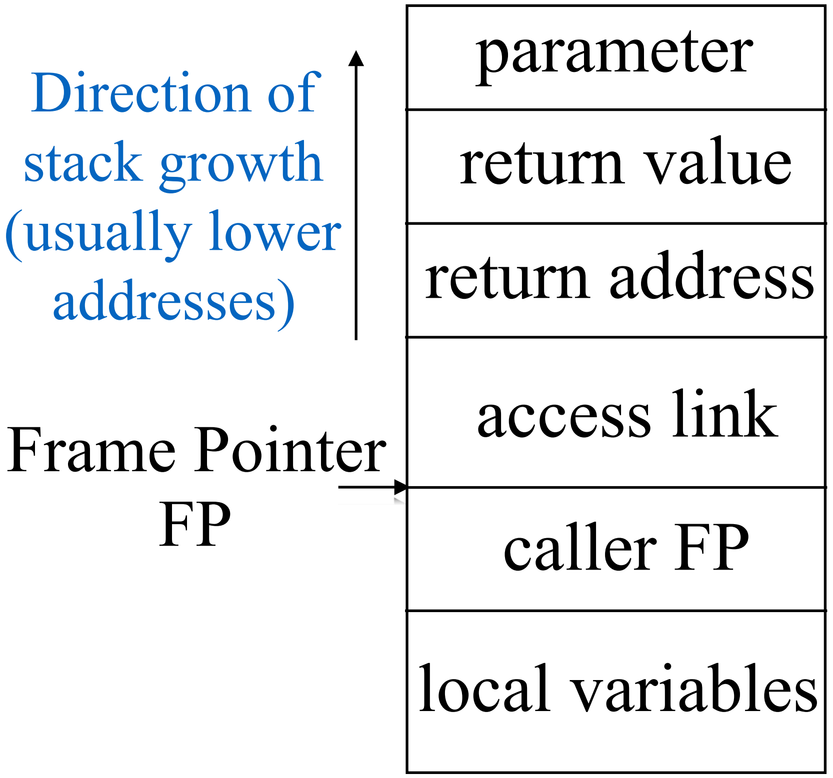

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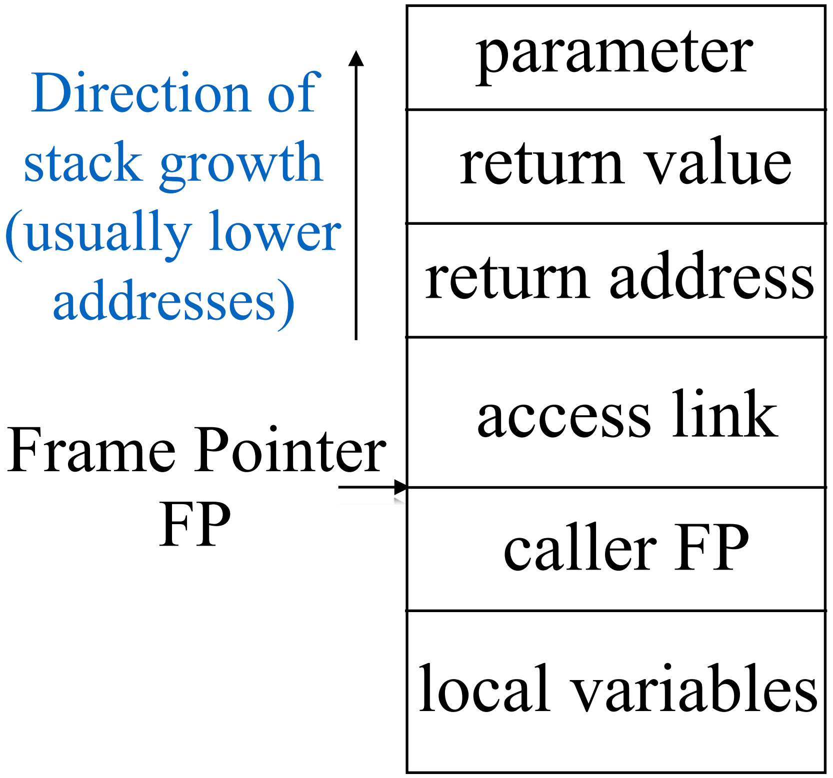

Direction of stack growth (usually lower addresses)

Frame Pointer FP

parameter

return value

return address

access link

caller FP

local variables

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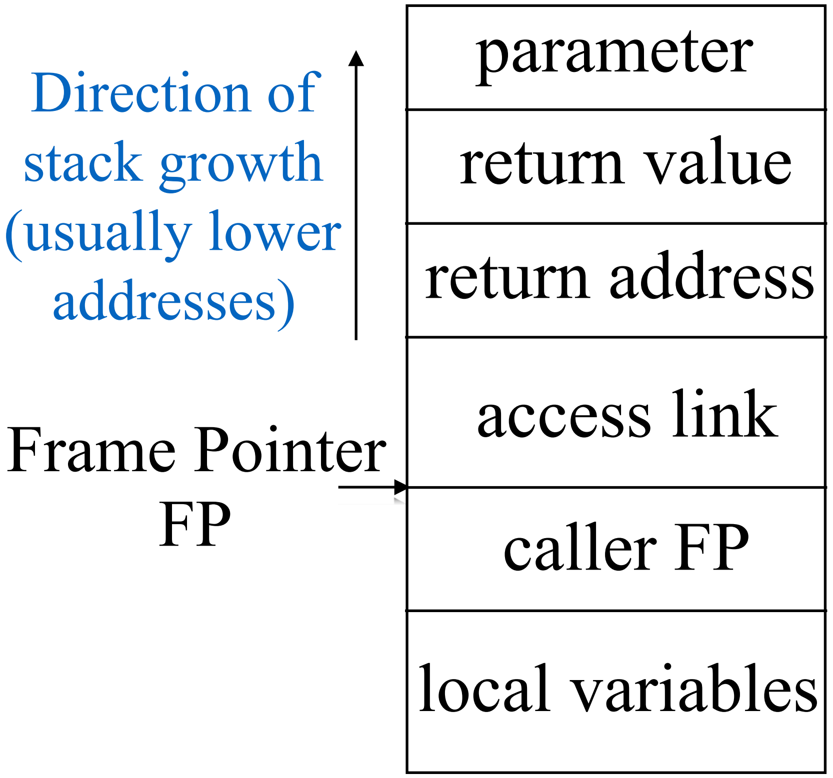

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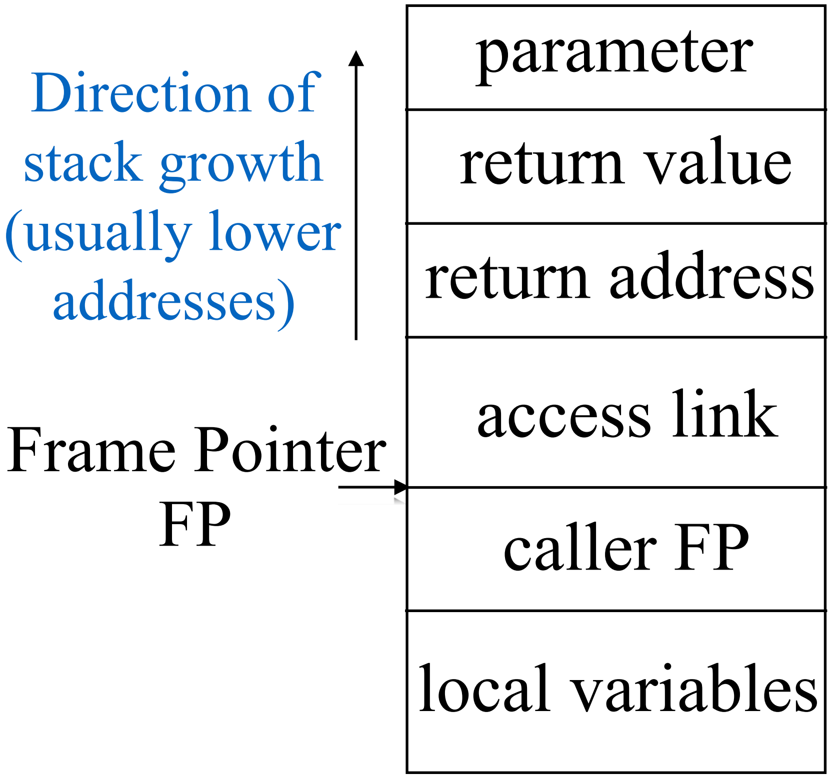

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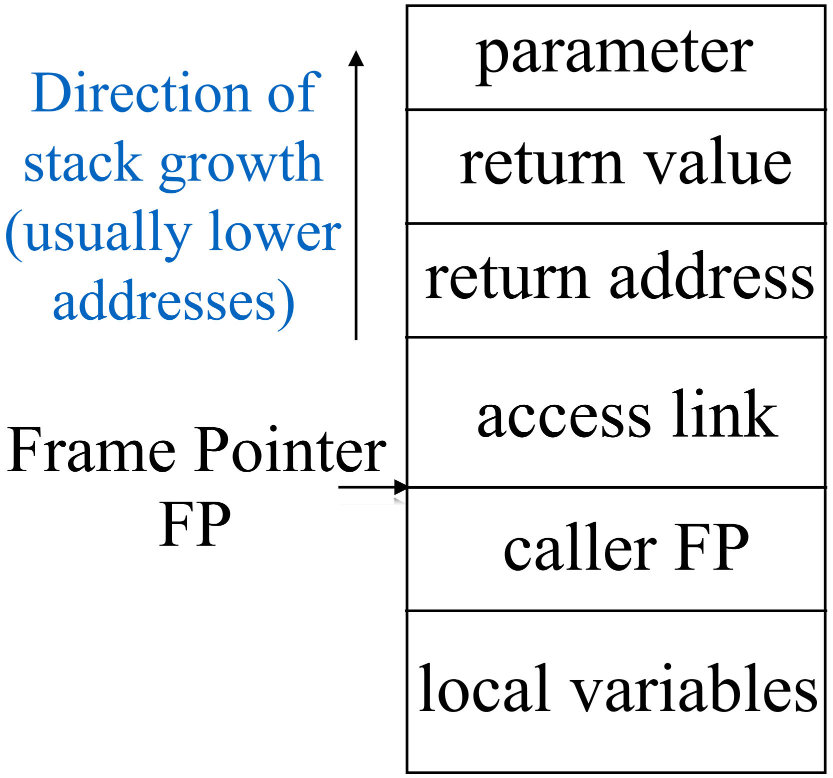

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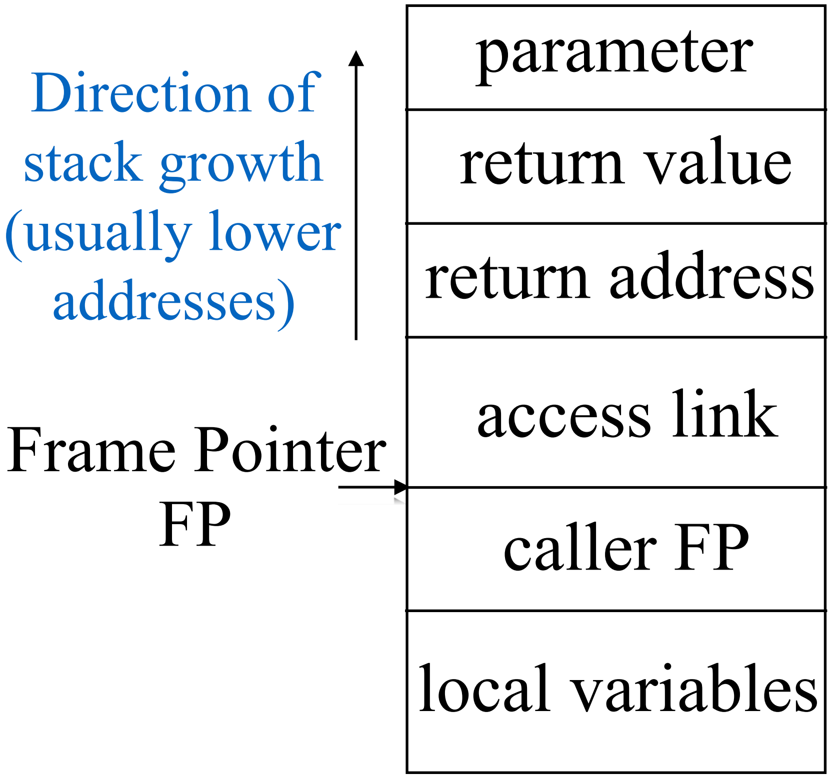

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(2,2)  LOADI r7 #8      // offset of local variable (2,2) in frame
       ADD r8 r0 r7     // address of local variable (2,2)
       LOAD r9 r8       // get content of variable (2, 2)
```

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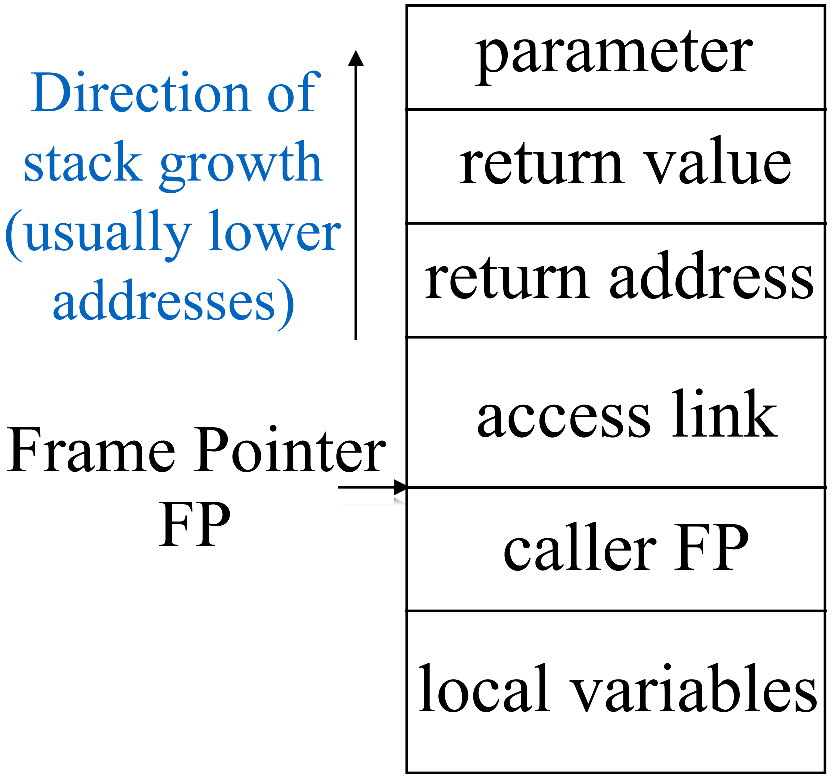

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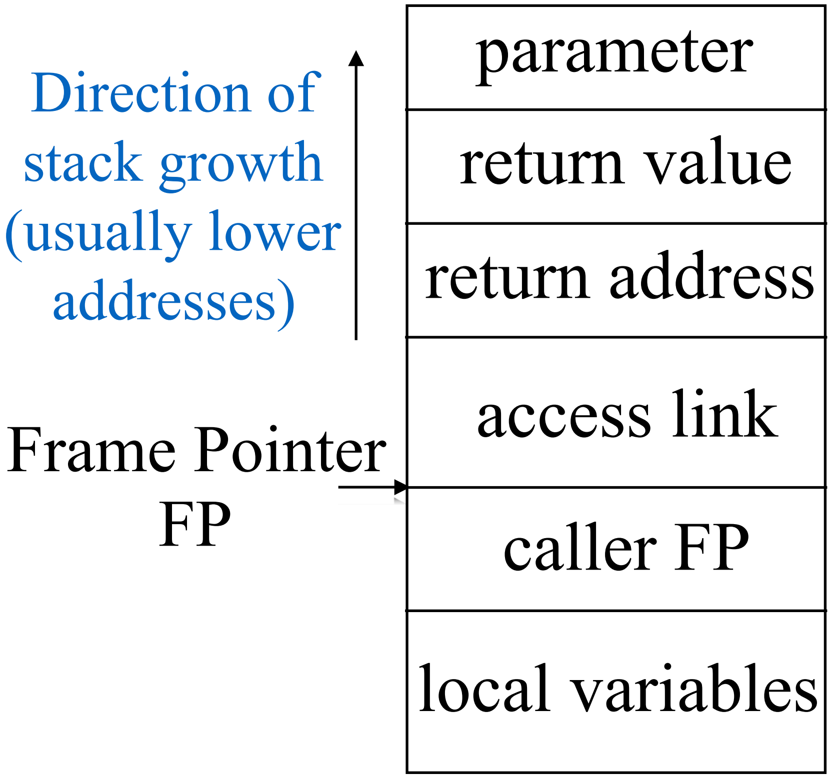

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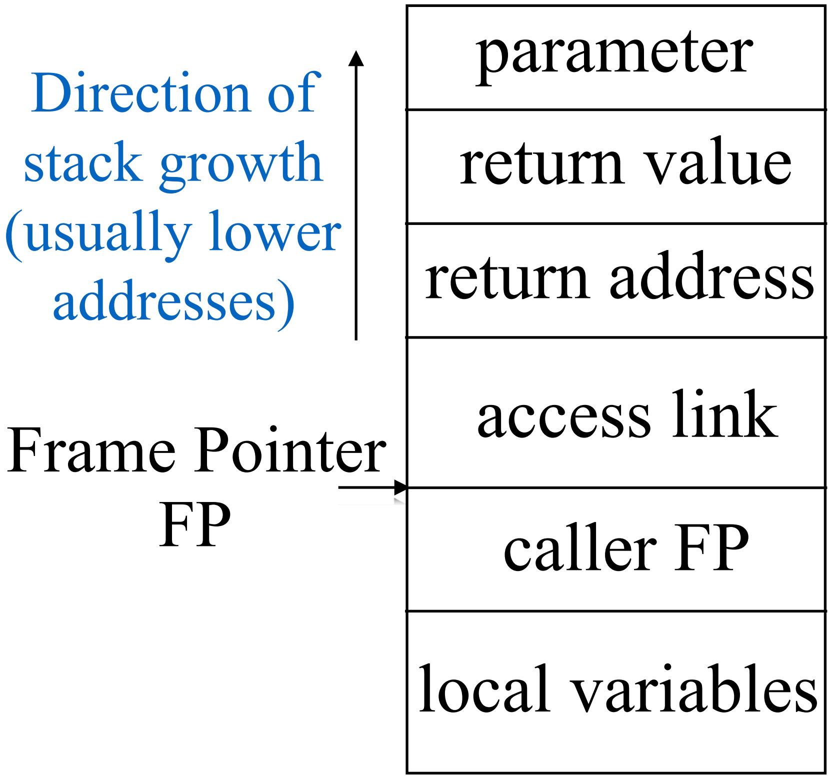

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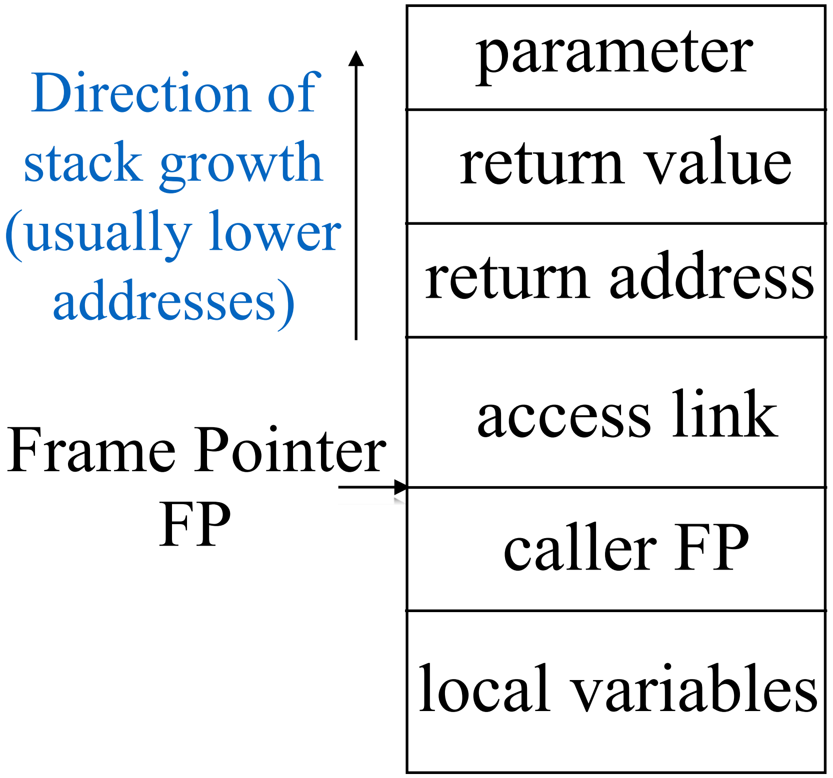

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  +    ADD r10 r6 r9     // (1,1) + (2,2)
(2,1)  LOADI r11 #4      // offset of local variable (2,1) in frame
       ADD r12 r0 r11    // address of local variable (2,1)
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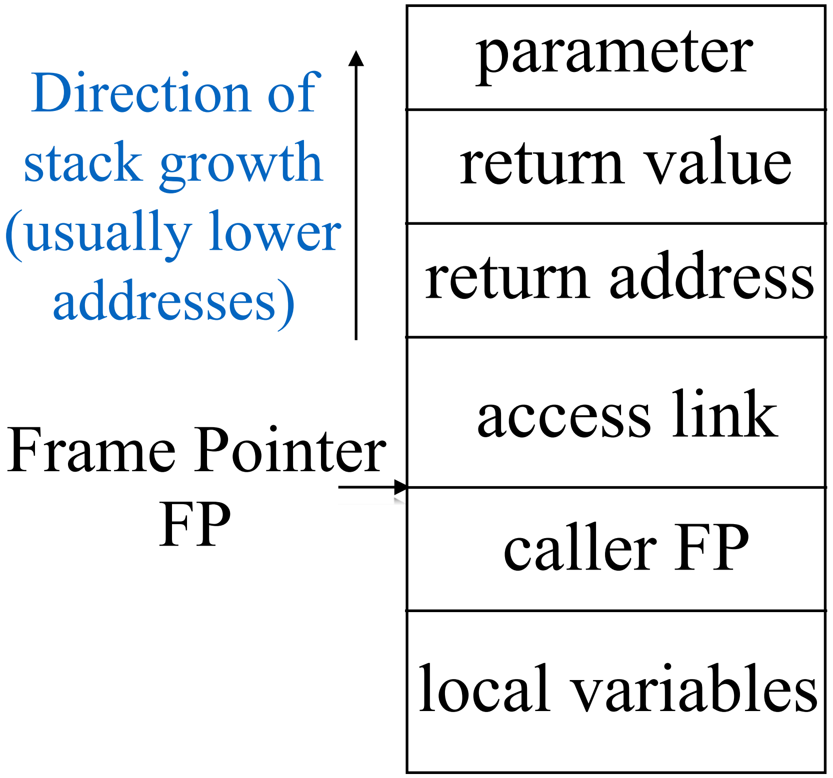

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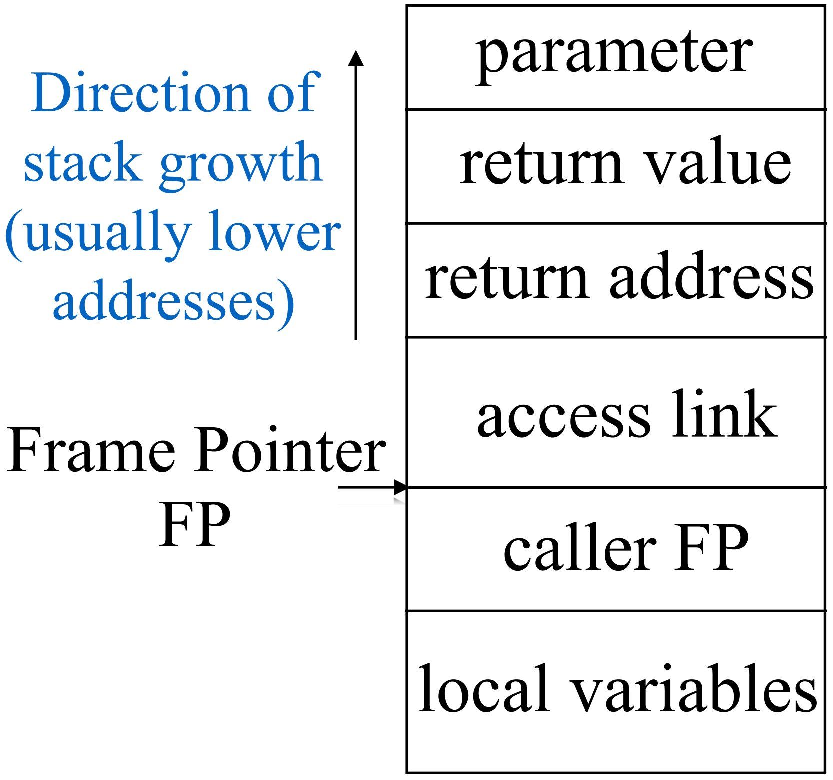

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       ADD r12 r0 r11    // address of local variable (2,1)
  =    STORE r12 r10     // (2,1) = (1,1) + (2,2)
```

Next Lecture

Things to do:

- Read Scott, Chapter 3.1 - 3.4, Chapter 9.1 - 9.3 (4th Edition) or Chapter 8.1 - 8.3 (3rd Edition)
- Read ALSU, Chapter 7.1 - 7.3 (2nd Edition).