

Topic 5: Activation Records

COS 320

Compiling Techniques

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The Stack

The Stack

- Used to hold local variables.
- Large array which typically grows downwards in memory toward lower addresses, shrinks upwards.
- Push(r1):

```
stack_pointer--;  
M[stack_pointer] = r1;
```
- r1 = Pop():

```
r1 = M[stack_pointer];  
stack_pointer++;
```
- Previous activation records need to be accessed, so push/pop not sufficient.
 - Treat stack as array with index off of `stack_pointer`.
 - Push and pop entire activation records.

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- Modern imperative programming languages typically have *local* variables.
 - Created upon entry to function.
 - Destroyed when function returns.
- Each invocation of a function has its own *instantiation* of local variables.
 - Recursive calls to a function require several instantiations to exist simultaneously.
 - Functions return only after all functions it calls have returned \Rightarrow last-in-first-out (LIFO) behavior.
 - A LIFO structure called a *stack* is used to hold each instantiation.
- The portion of the stack used for an invocation of a function is called the function's *stack frame* or *activation record*.

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Example

Consider:

```
let  
  function g(x:int) =  
    let  
      var y := 10  
    in  
      x + y  
    end  
  function h(y:int):int =  
    y + g(y)  
in  
  h(4)  
end
```

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Example

Step 1: $h(4)$ called

Chunk of memory allocated on the stack in order to hold local variables of h . The activation record (or stack frame) of h is pushed onto the stack.

Stack	
Frame for h	$y=4$

Step 2: $g(4)$ called

Activation record for g allocated (pushed) on stack.

Stack	
Frame for h	$y=4$
Frame for g	$x=4$ $y=10$

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Recursive Example

Can have multiple stack frames for same function (different invocations) on stack at any given time due to recursion.

Consider:

```
let
  function fact(n:int):int =
    if n = 0 then 1
    else n * fact(n - 1)
in
  fact(3)
end
```

Step 1: Record for $fact(3)$ pushed on stack.

Stack	
Frame for fact	$n=3$

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Example

Step 3: $g(4)$ returns with value 14

Activation record for g deallocated (popped) from stack.

Stack	
Frame for h	$y=4$ $rv = 14$

Step 4: $h(4)$ returns with value 18

Activation record for h deallocated (popped) from stack. Stack now empty.

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Recursive Example

Step 2: Record for $fact(2)$ pushed on stack.

Stack	
Frame for fact	$n=3$
Frame for fact	$n=2$

Step 3: Record for $fact(1)$ pushed on stack.

Stack	
Frame for fact	$n=3$
Frame for fact	$n=2$
Frame for fact	$n=1$

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Recursive Example

Step 4: Record for `fact(0)` pushed on stack.

Stack Frame for fact	n=3
Stack Frame for fact	n=2
Stack Frame for fact	n=1
Stack Frame for fact	n=0

Step 5: Record for `fact(0)` popped off stack, 1 returned.

Step 6: Record for `fact(1)` popped off stack, 1 returned.

Step 7: Record for `fact(2)` popped off stack, 2 returned.

Step 8: Record for `fact(3)` popped off stack, 3 returned. Stack now empty.

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Functional Languages

In some functional languages (such as ML, Scheme), local variables cannot be stored on stack.

```
fun f(x) =  
  let  
    fun g(y) = x + y  
  in  
    g  
  end
```

Consider:

```
- val z = f(4)  
- val w = z(5)
```

Assume variables are stack-allocated.

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Functional Languages

Step 1: `f(4)` called.

Frame for `f(4)` pushed, `g` returned, frame for `f(4)` popped.

Stack Frame for f	x=4
-------------------------	-----

Stack empty.

Step 3: `z(5)` called

Stack Frame for z	y=5
-------------------------	-----

Memory location containing `x` has been deallocated!

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Functional Languages

Combination of nested functions and functions returned as results (higher-order functions):

- Requires local variables to remain in existence even after enclosing function has been returned.
- Activation records must be allocated on heap, not stack.

Concentrate on languages which use stack.

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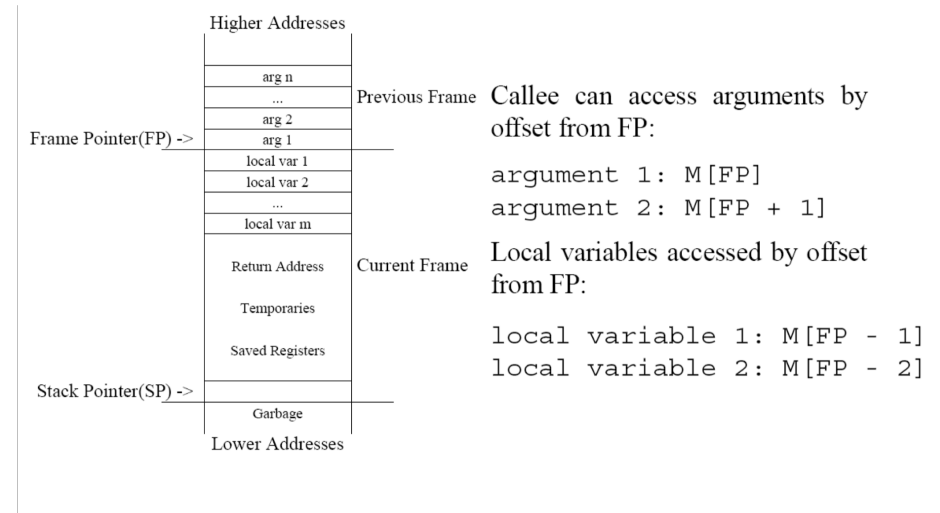
Stack Frame Organizations

How is data organized in stack frame?

- Compiler can use any layout scheme that is convenient.
- Microprocessor manufactures specify “standard” layout schemes used by all compilers.
 - Sometimes referred to as *Calling Conventions*.
 - If all compilers use the same calling conventions, then functions compiled with one compiler can call functions compiled with another.
 - Essential for interaction with OS/libraries.

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Typical Stack Frame

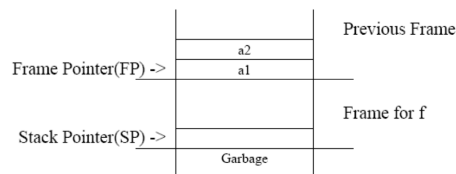


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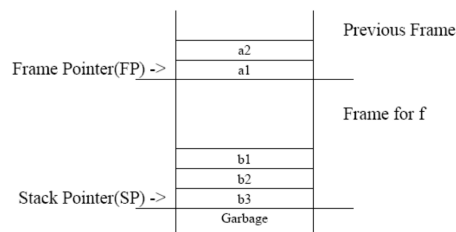
Stack Frame Example

Suppose $f(a1, a2)$ calls $g(b1, b2, b3)$

Step 1:



Step 2:

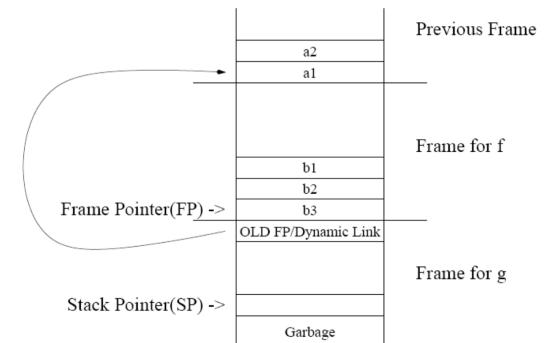


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Stack Frame Example

Suppose $f(a1, a2)$ calls $g(b1, b2, b3)$

Step 3:



Dynamic link (AKA Control link) points to the activation record of the caller.

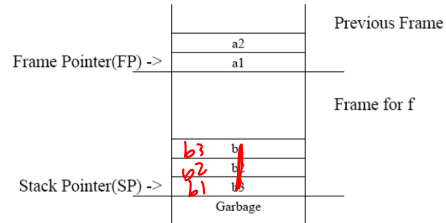
- Optional if size of caller activation record is known at compile time.
- Used to restore stack pointer during return sequence.

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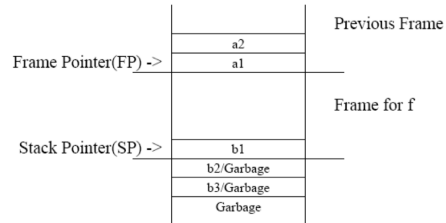
Stack Frame Example

Suppose $f(a_1, a_2)$ calls $g(b_1, b_2, b_3)$, and returns.

Step 4



Step 5



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Parameter Passing

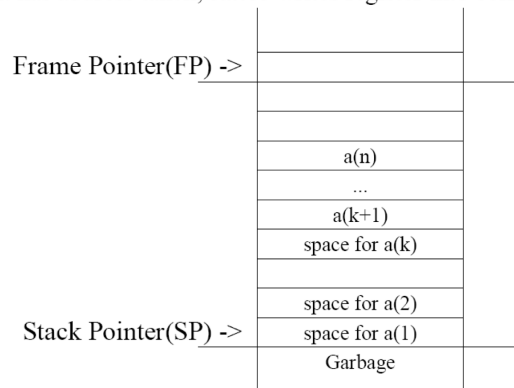
$f(a_1, a_2, \dots, a_n)$

- Registers are faster than memory.
- Compiler should keep values in register whenever possible.
- Modern calling convention: rather than placing a_1, a_2, \dots, a_n on stack frame, put a_1, \dots, a_k ($k = 4$) in registers $r_p, r_{p+1}, r_{p+2}, r_{p+3}$ and $a_{k+1}, a_{k+2}, a_{k+3}, \dots, a_n$.
- If $r_p, r_{p+1}, r_{p+2}, r_{p+3}$ are needed for other purposes, callee function must save incoming argument(s) in stack frame.
- C language allows programmer to take address of formal parameter and guarantees that formals are located at consecutive memory addresses.
 - If address argument has address taken, then it must be written into stack frame.
 - Saving it in “saved registers” area of stack won’t make it consecutive with memory resident arguments.
 - Space must be allocated even if parameters are passed through register.

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Parameter Passing

If register argument has address taken, *callee* writes register into corresponding space.



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Registers

Registers hold:

- Some Parameters
- Return Value
- Local Variables
- Intermediate results of expressions (temporaries)

Stack Frame holds:

- Variables passed by reference or have their address taken (&)
- Variables that are accessed by procedures nested within current one.
- Variables that are too large to fit into register file.
- Array variables (address arithmetic needed to access array elements).
- Variables whose registers are needed for a specific purpose (parameter passing)
- *Spilled* registers. Too many local variables to fit into register file, so some must be stored in stack frame.

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Compilers typically place variables on stack until it can determine whether or not it can be promoted to a register (e.g. no references).

The assignment of variables to registers is done by the *Register Allocator*.

Return Address and Return Value

A called function must be able to return to calling function when finished.

- Return address is address of instruction following the function call.
- Return address can be placed on stack or in a register.
- The *call* instruction in modern machines places the return address in a designated register.
- This return address is written to stack by callee function in non-leaf functions.

Return value is placed in designated register by callee function.

Register state for a function must be saved before a callee function can use them.

Calling convention describes two types of registers.

- *Caller-save* registers are the responsibility of the calling function.
 - Caller-save register values are saved to the stack by the calling function if they will be used after the call.
 - The callee function can use caller-save registers without saving their original values.
- *Callee-save* registers are the responsibility of the called function.
 - Callee-save register values must be saved to the stack by called function before they can be used.
 - The caller (calling function) can assume that these registers will contain the same value before and after the call.

Placement of values into callee-save vs. caller-save registers is determined by the register allocator.

Frame Resident Variables

- A variable *escapes* if:
 - it is passed by reference,
 - its address is taken, or
 - it is accessed from a nested function.
- Variables cannot be assigned a location at declaration time.
 - Escape conditions not known.
 - Assign provisional locations, decide later if variables can be promoted to registers.
- *escape* set to true by default.

Static Links

In languages that allow nested functions (e.g. Tiger), functions must access outer function's stack frame.

```
let
  function f():int = let
    var a:=5
    function g(y:int):int = let
      var b:=10
      function h(z:int):int =
        if z > 10 then h(z / 2)
        else z + b * a
      in
        y + a + h(16)
      end
    in
      g(10)
    end
  in f() end
```

\leftarrow b, a of outer fn

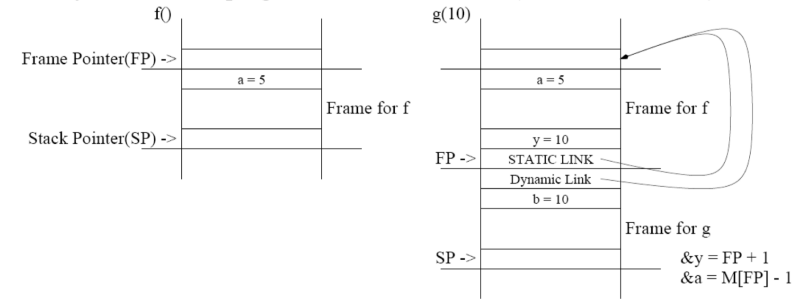
\leftarrow a of outer fn

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Static Links

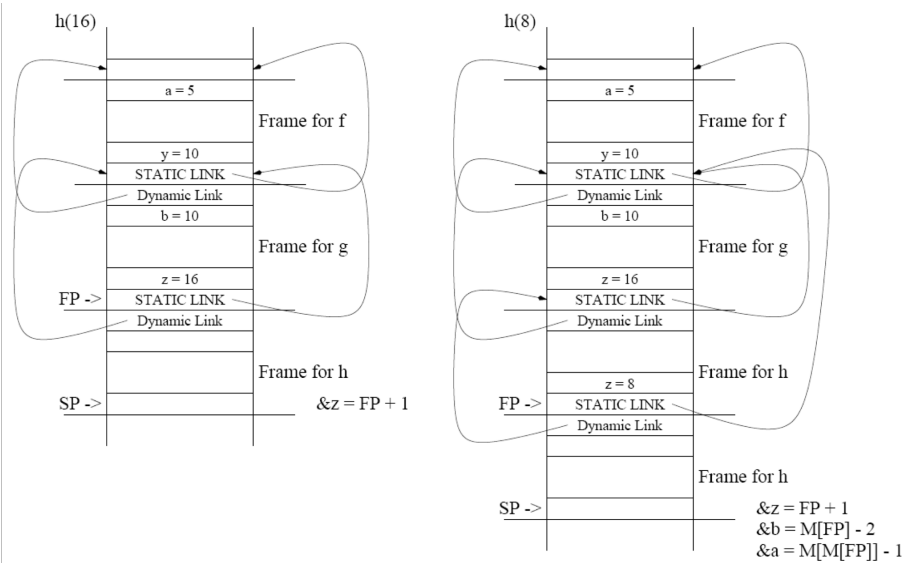
Solution:

Whenever f is called, it is passed pointer to most recent activation record of g that immediately encloses f in program text \Rightarrow Static Link (AKA Access Link).



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Static Links



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Static Links

- Need a chain of indirect memory references for each variable access.
- Number of indirect references = difference in nesting depth between variable declaration function and use function.

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