Activation Records/Stack Frames

COS 320

Compiler Implementation

Princeton University
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Prof. David August (guest)

Activation Records (ARs)

- Modern imperative PLs typically have *local* variables
  - Created upon call to function (or entry to region of code)
  - Destroyed upon return of function (or exit of region of code)
- Each invocation has own *instance* of locals
  - Recursive calls require several instances to exist simultaneously
  - Function instance dies only after all callees have died (LIFO)
  - Need LIFO structure to hold each instance: Stack
- The portion of "The Stack" used for an invocation of a function is called the *stack frame* or *activation record*
- *Callee/Caller* terminology?

The Stack

- Essentially:
  - A large (resizable) array
  - Grows downward (upward) in memory addresses
  - Shrinks upward (downward)
- **`push(r1):`**

```
stack_pointer--;
M[stack_pointer] = r1;
```

- **`r1 = pop():`**

```
r1 = M[stack_pointer];
stack_pointer++;
```

- Notes:
  - Push and pop entire activation records?
  - Previous activation records need to be accessed? Implications?

Stack Frame Example

```
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
```


Recursive Example

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

What about Functional Languages?

Some functional PLs (ML, Scheme) cannot use a 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.

Functional Languages

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

1. Requires locals to remain after enclosing function returns
2. Activation records must be allocated on heap, not stack

Concentrate on languages using the stack…

Prof. Walker adds:

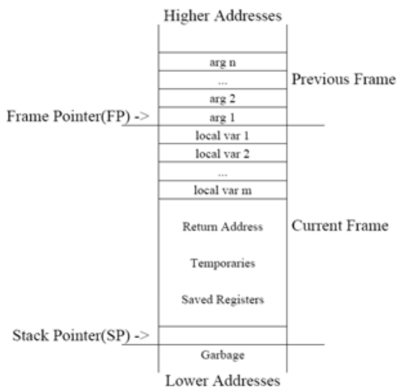
Comment that I already talked about closure conversion, which deals with the problem of creating "activation records" (closures) for ML-style nested functions (or at least reduces it to the problem of creating activation records for C).

Stack Frame Organization

- In isolation, compiler can use any layout scheme
- Microprocessor manufacturers specify standards
  - Called: Calling Conventions
  - Allows code from different compilers to work together
  - Essential for library interaction

Typical Calling Convention

- *Frame Pointer* points to top (bottom) of previous frame
- *Stack Pointer* points to slot above (below) current frame



Callee can access arguments by offset from FP:

```
argument 1: M[FP]
argument 2: M[FP + 1]
```

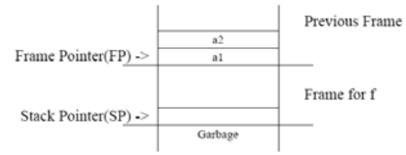
Local variables accessed by offset from FP:

```
local variable 1: M[FP - 1]
local variable 2: M[FP - 2]
```

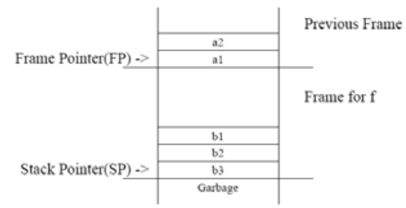

Stack Frame Example

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

Step 1:



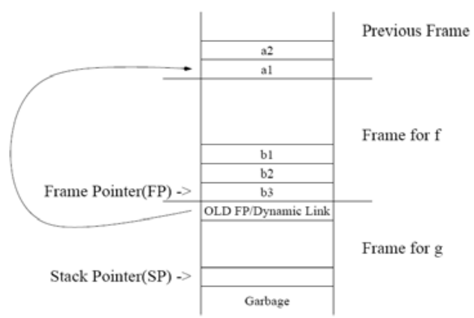
Step 2:



Stack Frame Example

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

Step 3:



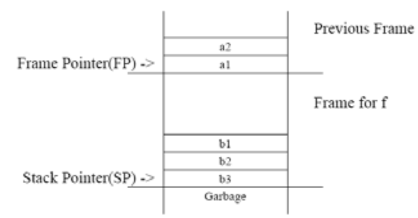
Dynamic Link (AKA Control Link) points to AR of the caller

- Optional if size of caller AR is static and known
- Used to restore stack pointer during return sequence

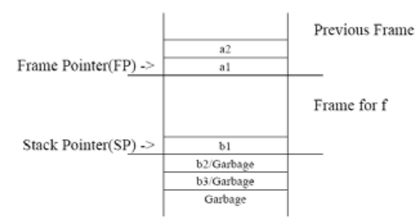
Stack Frame Example

Suppose `f(a1, a2)` calls `g(b1, b2, b3)`, and returns.

Step 4



Step 5



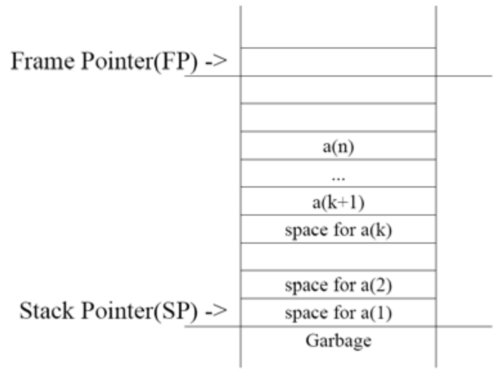
Parameter Passing

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

- Registers are faster than memory.
- Compiler should keep values in register whenever possible.
- Modern calling convention: rather than placing $a_1, a_2, \ldots, a_n$ on stack frame, put $a_1, \ldots, a_k$ ($k = 4$) in registers $r_p, r_{p+1}, r_{p+2}, r_{p+3}$ and $a_{k+1}, a_{k+2}, a_{k+2}, \ldots, a_n$.
- 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.

Parameter Passing

If register argument has address taken,
callee materializes it on the stack



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.

Registers

- Compilers typically place a variable 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*

Registers

Register's value must be saved before callee can reuse

Calling convention defines two types of registers:

- *Caller-save registers* are responsibility of the caller
  - Caller-save register values saved only if used after call/return
  - The callee function can use caller-saved registers with concern
- *Callee-save register* are the responsibility of the callee
  - Values must be saved by callee before they can be used
  - Caller can assume that these registers will be restored

Allocation of variables to callee-saved vs. caller-saved done by register allocator

Return Address and Return Value(s)

Return Address:

- A called function must be able to return to caller
- Return address is address of instruction following call
- Return address can be placed on the stack or register
- A call instruction (if present in ISA) places return address in a designated register
- The return address is written to stack by callee in non-leaf functions

Return Value is placed in designated register or on stack

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

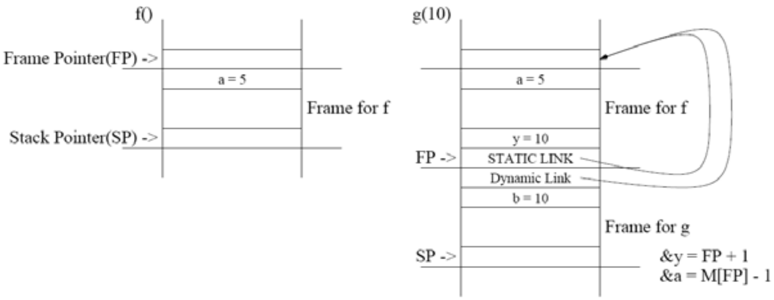
Static Links

In languages that allow nested functions,
functions must access other function's stack frame.

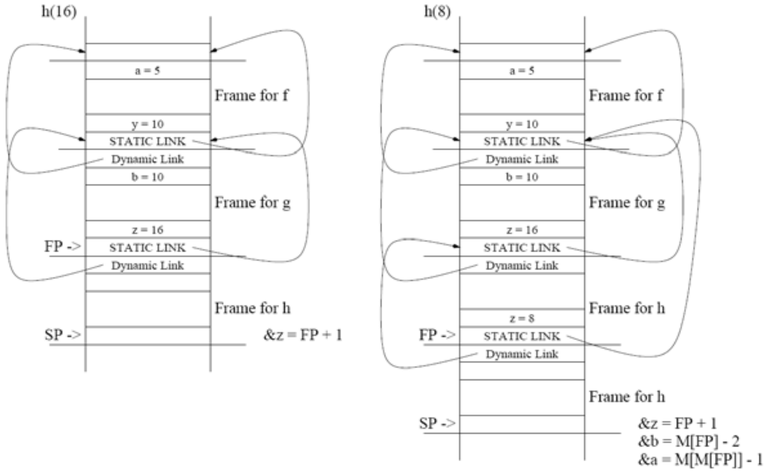
```
let
  function f():int = let
      var a:=5
      function g(y:int):int = let
          var b:=10
          function h(z:int):int =
            if z > 10 then h(z / 2)
            else z + b * a          <- b, a of outer fn
        in
          y + a + h(16)             <- a of outer fn
        end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

Static Links

Whenever f is called, it is passed a pointer to most recent AR of g that immediately encloses f in program text → Static Link (AKA Access Link)



Static Links



Static Links

- Need a chain of indirect memory references for each variable access
  - Example: `M[M[M[FP]]]`
- Number of indirect references = difference in nesting depth between variable declaration function and use function