CS412/413

Introduction to Compilers

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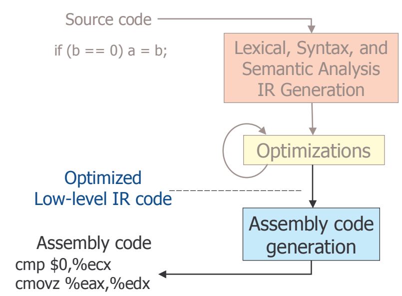
Lecture 27: Stack Frames

2 Apr 03

Where We Are



Assembly vs. Low IR

- Assembly code:
  - Finite set of registers
  - Variables in memory
  - Variables accessed differently: global, local, heap, args, etc.
  - Uses a run-time stack
  - Calling sequences: special sequences of instructions for function calls and returns
  - Instruction set of target machine
  - Special instructions for accessing the run-time stack
- Low IR code:
  - Variables (and temporaries)
  - No run-time stack
  - No calling sequences
  - Some abstract set of instructions

Low IR to Assembly Translation

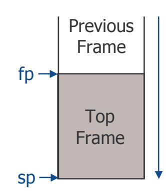
- Variables:
  - Register Allocation: map the variables to registers
  - Translate accesses to specific kinds of variables (globals, locals, arguments, etc)
- Calling sequences:
  - Translate function calls and returns into appropriate sequences which: pass parameters, save registers, and give back return values
  - Consists of push/pop operations on the run-time stack
- Instruction set:
  - Account for differences in the instruction set
  - Instruction selection: map sets of low level IR instructions to instructions in the target machine

Run-Time Stack

- A frame (or activation record) for each function execution
  - Represents execution environment of the function
  - Includes: local variables, parameters, return value, etc.
  - Different frames for recursive function invocations
- Run-time stack of frames:
  - Push frame of f on stack when program calls f
  - Pop stack frame when f returns
  - Top frame = frame of currently executed function
- This mechanism is necessary to support recursion
  - Different activations of the same recursive function have different stack frames

Stack Pointers

- Usually run-time stack grows downwards
  - Address of top of stack decreases
- Values on current frame (i.e. frame on top of stack) accessed using two pointers:
  - Stack pointer (sp): points to frame top
  - Frame pointer(fp): points to frame base
  - Variable access: use offset from fp (sp)

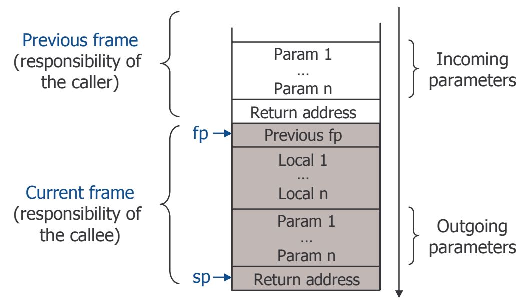


- When do we need two pointers?
  - If stack frame size not known at compile time
  - Example: alloca (dynamic allocation on stack)

Hardware Support

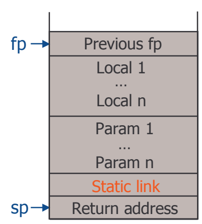
- Hardware provides:
  - Stack registers
  - Stack instructions
- Pentium:
  - Register for stack pointer: esp
  - Register for frame pointer: ebp
  - Push instructions: push, pusha, etc.
  - Pop instructions: pop, popa, etc
  - Call instruction: call
  - Return instruction: ret

Anatomy of a Stack Frame



Static Links

- Problem for languages with nested functions (Pascal, ML): How do we access local variables from other frames?
- Need a static link: a pointer to the frame of enclosing function
- Previous fp = dynamic link, I.e. pointer to the previous frame in the current execution



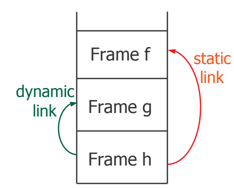
Example Nested Procedures

```
procedure f(i : integer)
  var a : integer;

  procedure h(j : integer)
      begin a = j end

  procedure g(k : integer)
      begin h(k*k) end

  begin g(i+2) end
```



Saving Registers

- Problem: execution of invoked function may overwrite useful values in registers
- Generated code must:
  - Save registers when function is invoked
  - Restore registers when function returns
- Possibilities:
  - Callee saves and restores registers
  - Caller saves and restores registers
  - … or both

Calling Sequences

- How to generate the code that builds the frames?
- Generate code which pushes values on stack:
  1. Before call instructions (caller responsibilities)
  2. At function entry (callee responsibilities)
- Generate code which pops values from stack:
  3. After call instructions (caller responsibilities)
  4. At return instructions (callee responsibilities)
- Calling sequences = sequences of instructions performed in each of the above 4 cases

Push Values on Stack

- Code before call instruction:
  - Push caller-saved registers
  - Push each actual parameter (in reverse order)
  - Push static link (if necessary)
  - Push return address (current program counter) and jump to caller code
- Prologue = code at function entry
  - Push dynamic link (i.e. current fp)
  - Old stack pointer becomes new frame pointer
  - Push local variables
  - Push callee-saved registers

Pop Values from Stack

- Epilogue = code at return instruction
  - Pop (restore) callee-saved registers
  - Restore old stack pointer (pop callee frame!)
  - Pop old frame pointer
  - Pop return address and jump to that address
- Code after call
  - Pop (restore) caller-saved registers
  - Pop parameters from the stack
  - Use return value

Example: Pentium

- Consider call foo(3, 5), %ecx caller-saved, %ebx callee-saved, no static links, result passed back in %eax
- Code before call instruction:

```
push %ecx       // push caller saved registers
push $3         // push first parameter
push $5         // push second parameter
call _foo       // push return address and jump to callee
```

- Prologue:

```
push %ebp       // push old fp
mov %esp, %ebp  // compute new fp
sub $12, %esp   // push 3 integer local variables
push %ebx       // push callee saved registers
```


Example: Pentium

- Epilogue:

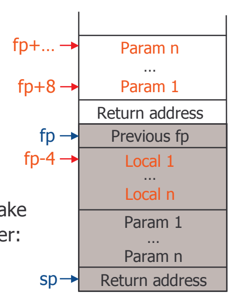
```
pop %ebx        // restore callee-saved registers
mov %ebp,%esp   // pop callee frame, including locals
pop %ebp        // restore old fp
ret             // pop return address and jump
```

- Code after call instruction:

```
add $8,%esp     // pop parameters
pop %ecx        // restore caller-saved registers
```


Accessing Stack Variables

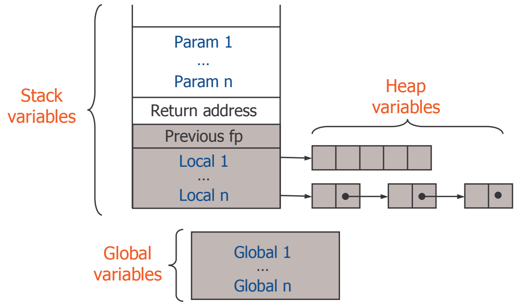
- To access stack variables: use offsets from fp
- Example:
  [fp+8] = parameter 1
  [fp+12] = parameter 2
  [fp-4] =local 1
- Translate low-level code to take into account the frame pointer:
  a = p+1
  => [fp-4] = [fp+16] + 1



Accessing Other Variables

- Global variables
  - Are statically allocated
  - Their addresses can be statically computed
  - Don't need to translate low IR
- Heap variables
  - Are unnamed locations
  - Can be accessed only by dereferencing variables which hold their addresses
  - Therefore, they don't explicitly occur in low-level code

Big Picture: Memory Layout



Run-time Support

- Code to maintain stack frames = run-time mechanism
- Array bounds checks: if v holds the address of an array element, insert array bounds checking code for v before each load (…=v[i]) or store (v[i] = …)
- Garbage collection: insert code which automatically deallocates heap objects when they are no longer referenced