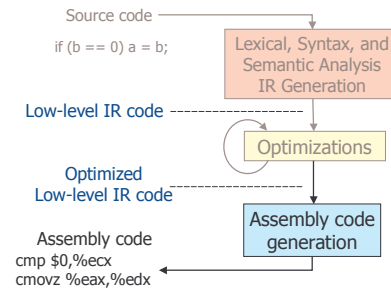


CS412/413

Introduction to Compilers Radu Rugina

Lecture 19: Stack Frames
12 Mar 04

Where We Are



CS 412/413 Spring 2004

Introduction to Compilers

2

Assembly vs. Low IR

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

CS 412/413 Spring 2004

Introduction to Compilers

3

Low IR to Assembly Translation

- **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
- **Variables:**
 - Translate accesses to specific kinds of variables (globals, locals, arguments, etc)
 - **Register Allocation:** map the variables to registers
- **Instruction set:**
 - Account for differences in the instruction set
 - **Instruction selection:** map sets of low level IR instructions to instructions in the target machine

CS 412/413 Spring 2004

Introduction to Compilers

4

x86 Quick Overview

- **Few registers:**
 - General purpose 32bit: eax, ebx, ecx, edx, esi, edi
 - Also 16-bit: ax, bx, etc., and 8-bit: al, ah, bl, bh, etc.
 - Stack registers: esp, ebp
- **Many instructions:**
 - Arithmetic: add, sub, inc, mod, idiv, imul, etc.
 - Logic: and, or, not, xor
 - Comparison: cmp, test
 - Control flow: jmp, jcc, jecz
 - Function calls: call, ret
 - Data movement: mov (many variants)
 - Stack manipulations: push, pop
 - Other: lea

CS 412/413 Spring 2004

Introduction to Compilers

5

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

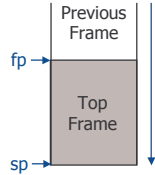
CS 412/413 Spring 2004

Introduction to Compilers

6

Stack Pointers

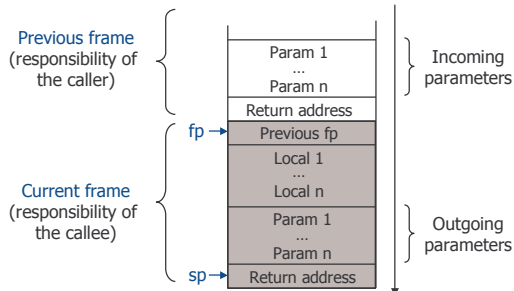
- Usually run-time stack grows downwards
 - Address of top of stack decreases
- Values on current frame (i.e. frame on top of stack) accessed using two pointers:
 - Stack pointer (sp): points to frame top
 - Frame pointer(fp): points to frame base
 - Variable access: use offset from fp (sp)
- When do we need two pointers?
 - If stack frame size not known at compile time
 - Example: `alloca` (dynamic allocation on stack)



Hardware Support

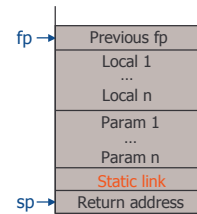
- Hardware provides:
 - Stack registers
 - Stack instructions
- X86 Registers and instructions for stack manipulation:
 - Stack pointer register: `esp`
 - Frame pointer register: `ebp`
 - Push instructions: `push`, `pusha`, etc.
 - Pop instructions: `pop`, `popa`, etc.
 - Call instruction: `call`
 - Return instruction: `ret`

Anatomy of a Stack Frame



Static Links

- Problem for languages with nested functions (Pascal):
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

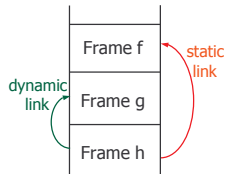


Example Nested Procedures

```

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

CS 412/413 Spring 2004

Introduction to Compilers

13

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

CS 412/413 Spring 2004

Introduction to Compilers

14

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

CS 412/413 Spring 2004

Introduction to Compilers

15

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
```

CS 412/413 Spring 2004

Introduction to Compilers

16

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
```

CS 412/413 Spring 2004

Introduction to Compilers

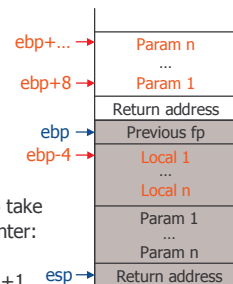
17

Accessing Stack Variables

- To access stack variables: use offsets from fp
- **Example:**

```
8(%ebp) = parameter 1
12(%ebp) = parameter 2
-4(%ebp) = local 1
```
- Translate low-level code to take into account the frame pointer:


```
a = p+1
=> -4(%ebp) = 16(%ebp)+1
```



CS 412/413 Spring 2004

Introduction to Compilers

18

Accessing Other Variables

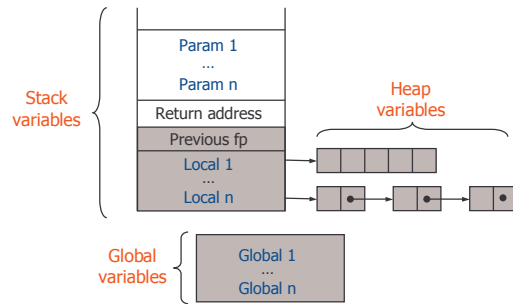
- **Global variables**
 - Are statically allocated
 - Their addresses can be statically computed
 - Don't need to translate low IR
- **Heap variables**
 - Are unnamed locations
 - Can be accessed only by dereferencing variables which hold their addresses
 - Therefore, they don't explicitly occur in low-level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

CS 412/413 Spring 2004

Introduction to Compilers

19

Big Picture: Memory Layout



CS 412/413 Spring 2004

Introduction to Compilers

20