CS412/CS413

Introduction to Compilers

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Lecture 20: Stack Frames
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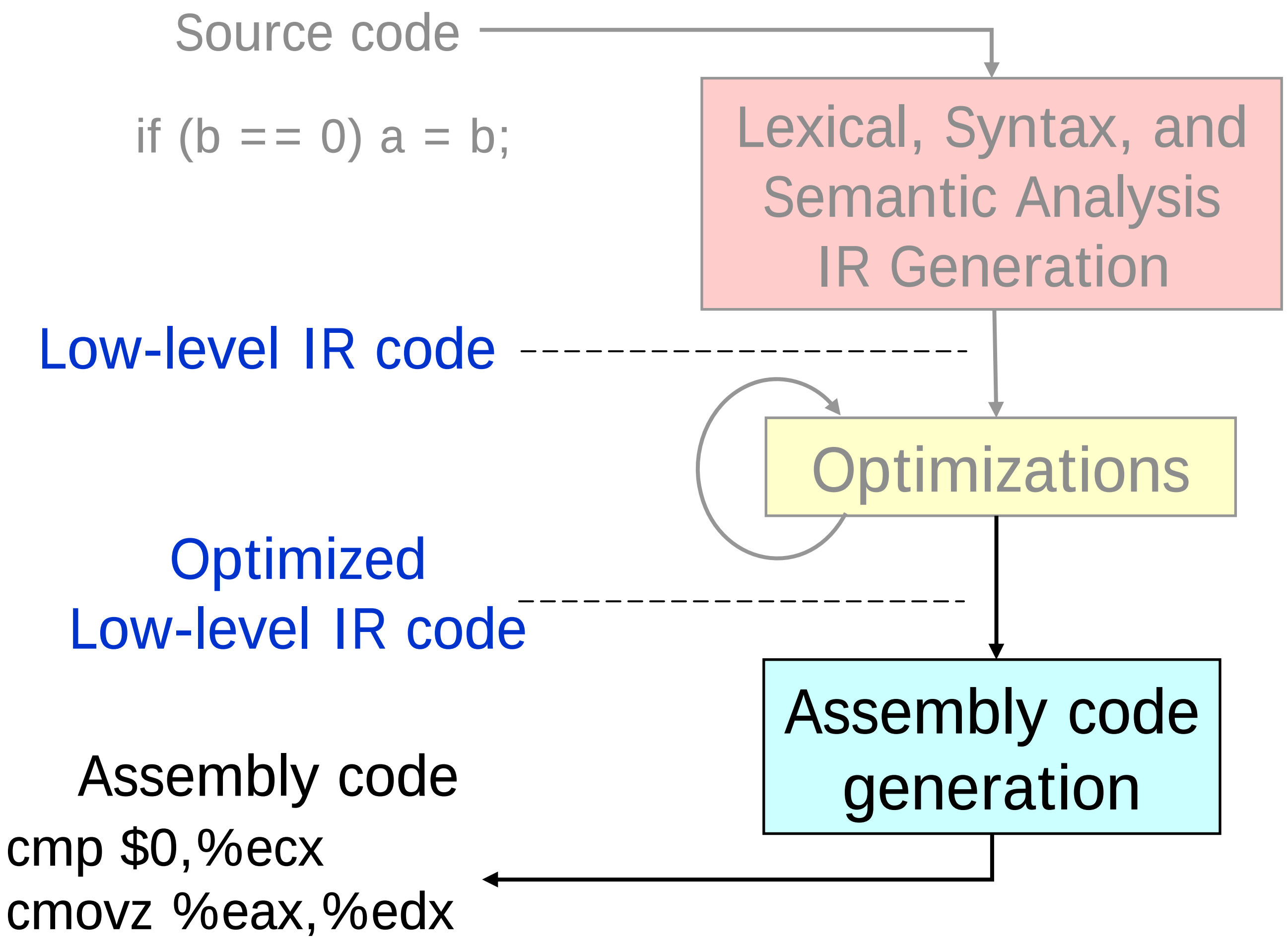
Where We Are



Source code
if (b == 0) a = b;
Lexical, Syntax, and Semantic Analysis IR Generation
Low-level IR code
Optimizations
Optimized Low-level IR code
Assembly code generation
Assembly code
cmp $0,%ecx
cmovz %eax,%edx

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

Low IR to Assembly Translation

- Calling sequences:
  - Translate function calls and returns into appropriate sequences that: 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

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

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

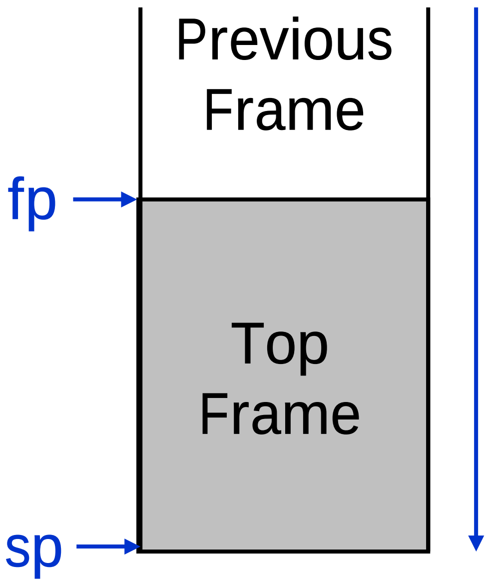
- Run-time stack of frames:
  - Push frame of f on stack when program calls f
  - Pop stack frame when f returns
  - Top frame = frame of currently executed function

- 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)



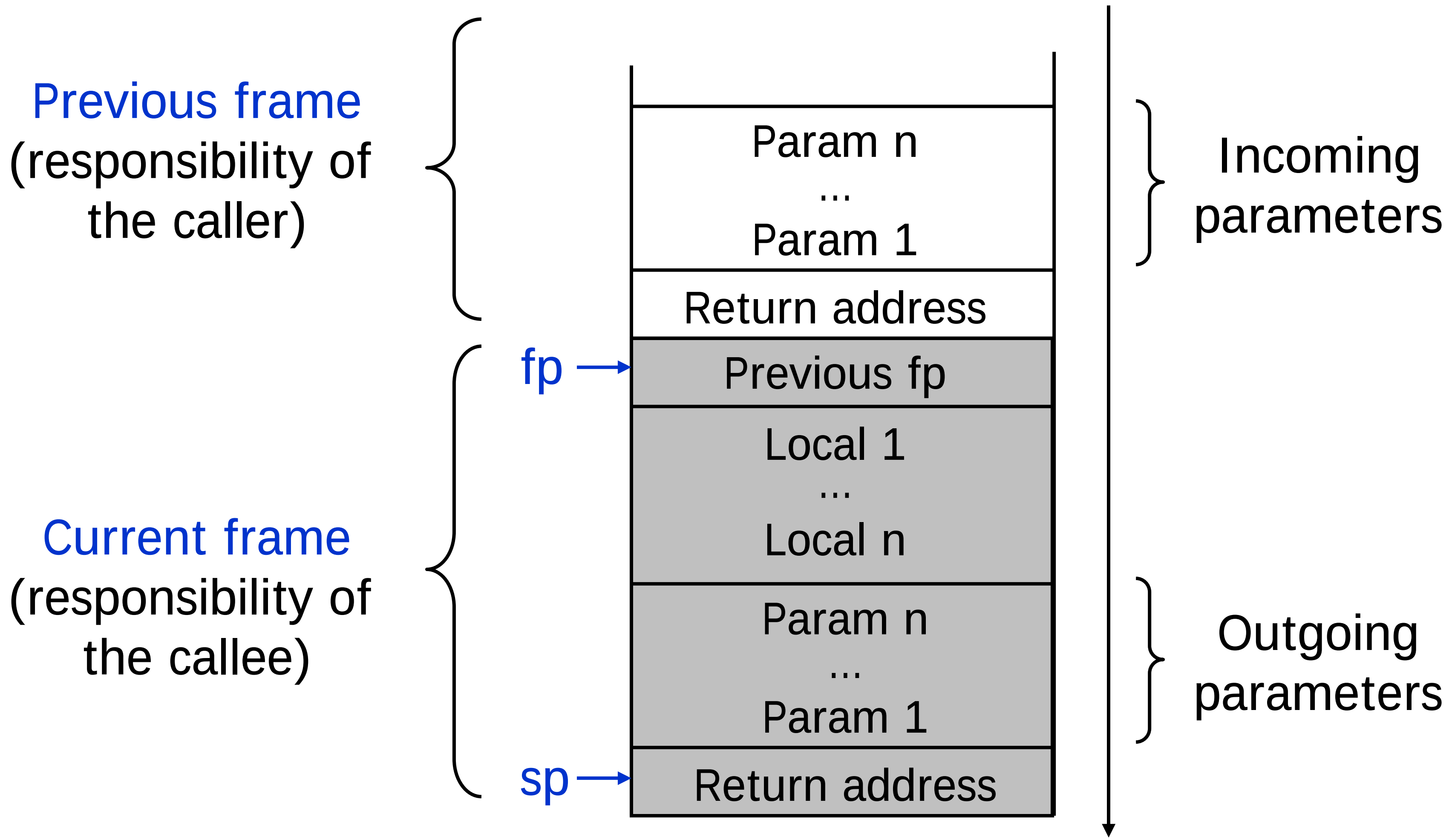
- When do we need two pointers?
  - If stack frame size not known at compile time
  - Example: alloca (dynamic allocation on stack)

Hardware Support

- Hardware provides:
  - Stack registers
  - Stack instructions

- 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



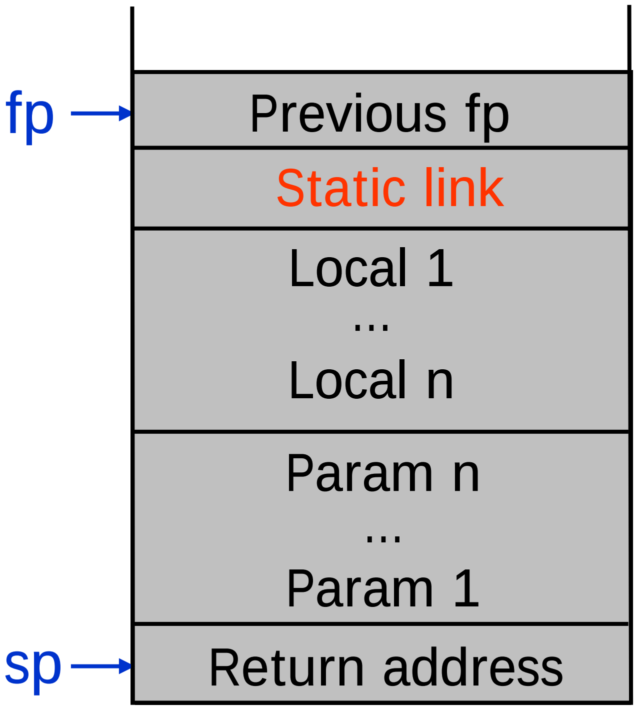
Static Links

- Problem for languages with nested functions (Pascal):

  How do we access local variables from other frames?

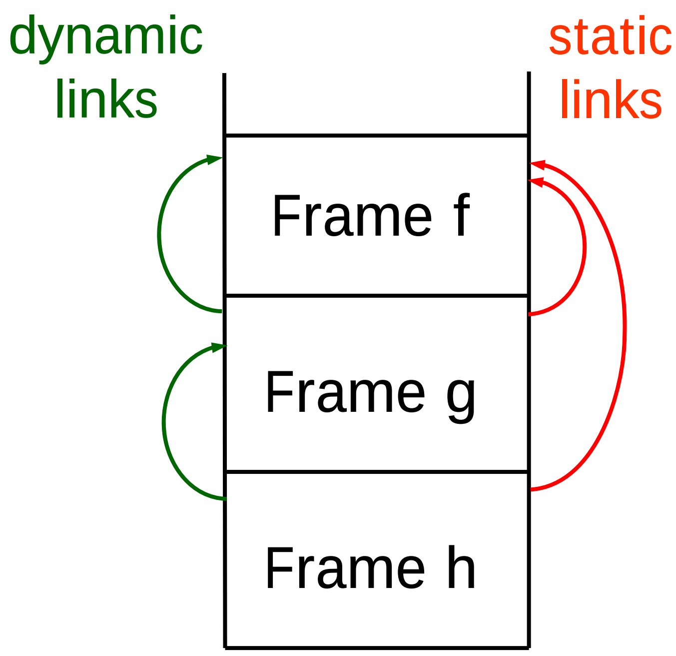
- Need a static link: a pointer to the frame of enclosing function

- Previous fp = dynamic link, i.e. pointer to the previous frame in the current execution



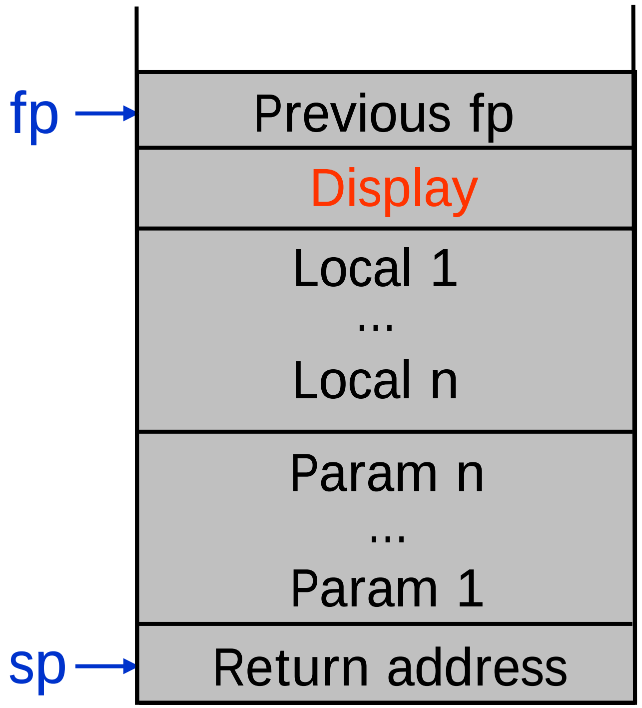
Example Nested Procedures

```
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
```



Display

- Unacceptable to have to chase down static chains to find frame containing non-local variable.
- A display is a linearization of the static chain copied into the local frame (or maintained globally) as an array.
- The pointer to the frame containing non-local variables at lexical level i is display[i].



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 that pushes values on stack:
  1. Before call instructions (caller responsibilities)
  2. At function entry (callee responsibilities)

- Generate code that 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 (or display) (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
  - Pop static link (or display) (if necessary)
  - 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 $5            // push second parameter
push $3            // push first 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:

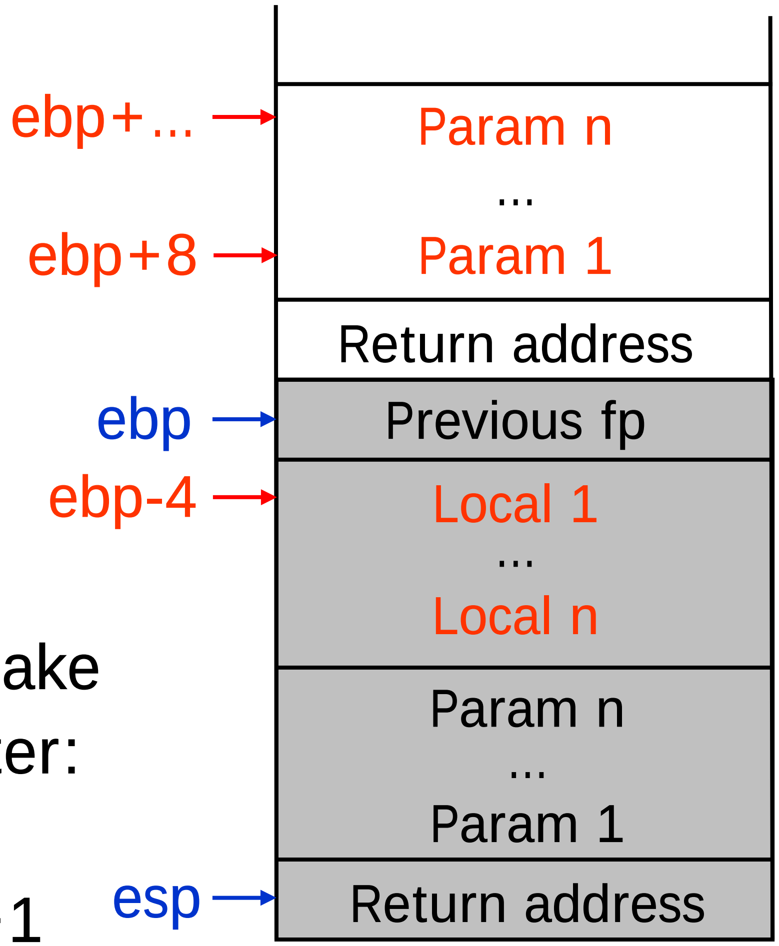
```
pop %ebx            // restore callee-saved registers
mov %ebp,%esp       // pop callee frame, including locals
pop %ebp            // restore old fp
ret                 // pop return address and jump
```

- 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:
  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



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 that hold their addresses
  - Therefore, they don’t explicitly occur in low-level code

Big Picture: Memory Layout