COS320: Compiling Techniques

Zak Kincaid

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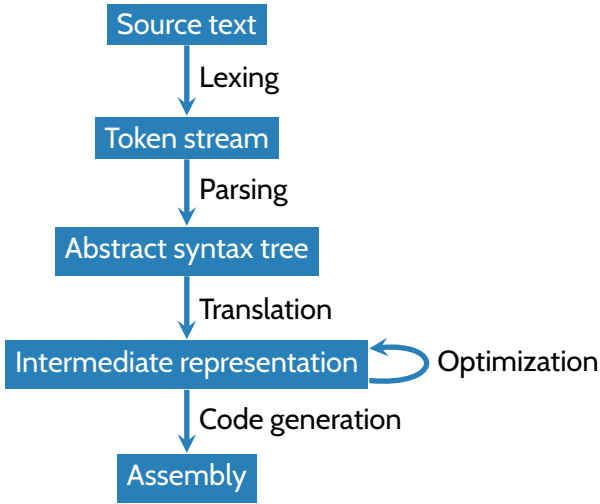
Compiler phases (simplified)



Today: x86Lite

X86

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  - 8-, 16-, 32-, 64-bit values, floats, …
  - Hundreds or thousands of instructions (depending on how they're counted)
  - Variable-length encoding for instructions (1-17 bytes)

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- X86lite is a simple subset, still suitable as a compilation target
  - Values are 64-bit integers
  - About 20 instructions
  - Fixed-length encoding for instructions

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  - `rcx`: counter register for strings & loops
  - `rdx`: data register for I/O
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- `rip`: "virtual" register, points to current instruction
  - `rip` is manipulated only by indirect jumps and return

Anatomy of an x86lite progam

```
factorial:
    cmpq    %rdi, $0
    je      .L4
    movq    $1, %rax
    movq    $0, %rdx
.L3:
    imulq   %rdx, %rax
    addq    $1, %rdx
    cmpq    %rdx, %rdi
    jne     .L3
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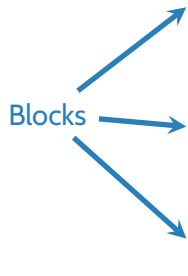


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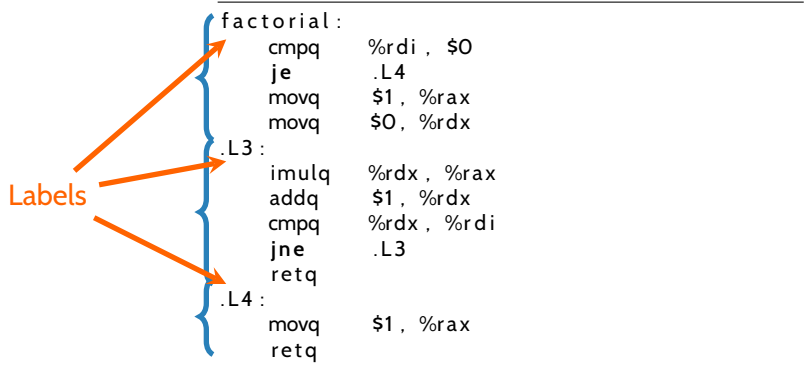

X86Lite instructions

- Instruction = opcode + operand list
  - AT&T syntax: `movq $42, %rax` stores the number 42 in `rax`
    - `$` prefix denotes immediate (constant)
    - `%` prefix denotes register
    - `q` suffix denote quadword
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- Opcodes (**full specification on course webpage**)
  - Arithmetic: `addq`, `imulq`, `subq`, `negq`, `incq`, `decq`
  - Logic: `andq`, `orq`, `notq`, `xorq`
  - Bit-manipulation: `sarq`, `shlq`, `shrq`, `setb`
  - Data-movement: `leaq`, `movq`, `pushq`, `popq`
  - Control flow: `cmpq` `jmp`, `callq`, `retq`, `j CC`

X86Lite Operands

- `Imm` ("immediate") 64-bit literal signed integer
  - `42`, `0x3de7`
- `Lbl` ("label") symbolic machine address (to be resolved by assembler/linker/loader)
  - `_factorial`, `.L2`
- `Reg` ("register")
  - `%rax`, `%r04`
- `Ind` ("indirect") memory address
  - `(%rax)`, `-8(%rbp)`

X86 Addressing

- Three components of an indirect address: Disp(Base, Index, Scale)
  - Base: a machine address stored in a register
  - Index & Scale: a variable offset from the base (not in x86lite)
  - Disp: displacement/offset (optional)
- Refers to the location **Mem**[Base+ Index * Scale + Disp]
  - `movq (%rsp), %rax` retrieves **Mem**[rsp] and stores it in rax
  - `movq -8(%rsp), %rax` retrieves **Mem**[rsp - 8] and stores it in rax
  - `movq %rax, (%rsp)` stores value of rax in **Mem**[rsp].

Control flow

- Three condition flags:
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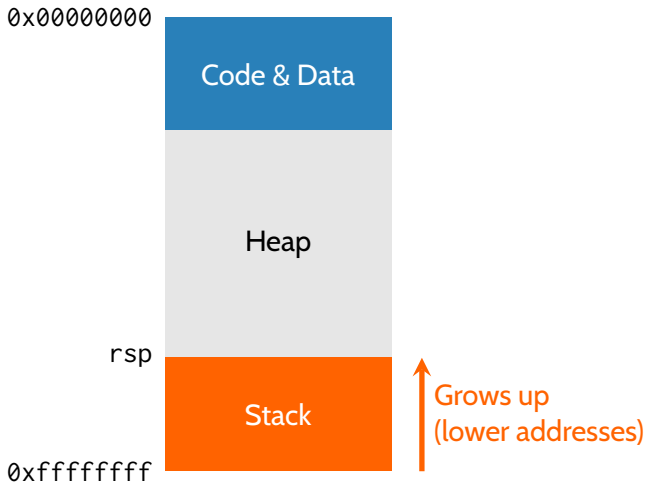
- Instruction `cmpq SRC1, SRC2`: compute `SRC2-SRC1` and set flags
- Instruction `j CC SRC`: jump if to `SRC` if condition code `CC` is set
  - `e` ("equality"): `ZF` set
  - `ne` ("inequality"): `ZF` clear
  - `g` ("greater than"): `SF` clear and `ZF` clear
  - `l` ("less than"): `SF` not equal to `OF`
  - `ge` ("greater than or equal"): `SF` clear
  - `le` ("less than or equal"): `SF` not equal to `OF` or `ZF` set

Conventions

Memory layout



Stack operations

- `%rsp`: pointer to the top of the stack
- `pushq SRC`
  ```
  rsp := rsp - 8
  Mem[rsp] := SRC
  ```
- `popq DEST`
  ```
  DEST := Mem[rsp]
  rsp := rsp + 8
  ```
- `callq SRC`
  ```
  pushq rip
  rip := SRC
  ```
- `retq`
  ```
  popq rip
  ```

Calling conventions

- Implementation of function calls is up to the compiler
  - How are parameters passed?
  - How is return value passed back?
  - How is the return address stored?
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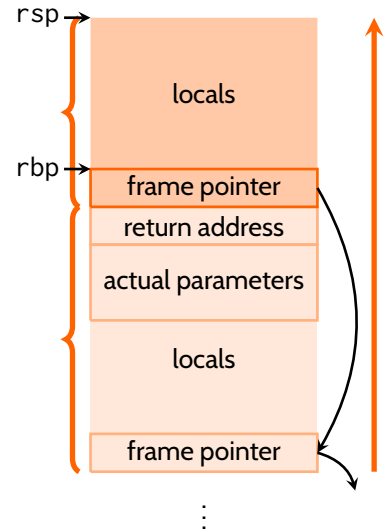
  - Which registers is a function allowed to change?
- A *calling convention* is a contract that specifies the structure of the stack and the interface between function *caller* and *callee*
- Useful to standardize on a single convention across the whole system
  - cdecl ("C declaration") is the standard on x86

The call stack

- Function calls are implemented using a *stack* of **activation records** (aka **stack frames**)
- Each activation record contains:
  - Frame pointer (start address of previous frame)
  - Local variables
- Except for current frame, also contains:
  - Actual parameters (arguments)
  - Return address



cdecl caller protocol

Suppose we call function with parameters v_1, ..., v_n

1. Save caller-save registers, if needed (`rax`, `rcx`, `rdx`)
2. Store first six actual parameters $v_1, \ldots, v_6$ in `rdi`, `rsi`, `rdx`, `rcx`, `r08`, `r09`
3. Push v_n,...,v_7
   - nth actual parameter is located at **Mem**`[rbp + 8*(n-5)]`
4. Use `callq` to jump to the code for `f` (& push return address)

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After call:

1. De-allocate pushed actual parameters
2. Restore caller-save registers, if needed (`rax`, `rcx`, `rdx`)

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On exit:

1. Store return value in `rax`
2. Deallocate local storage
3. Restore previous `rbp`

```c
long factorial(long n) {
  long i;
  long result = 1;
  for (i = 1; i < n; i++) {
    result *= i;
  }
  return result;
}
```

```
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