The Stack & Procedures

CSE 351 Winter 2022

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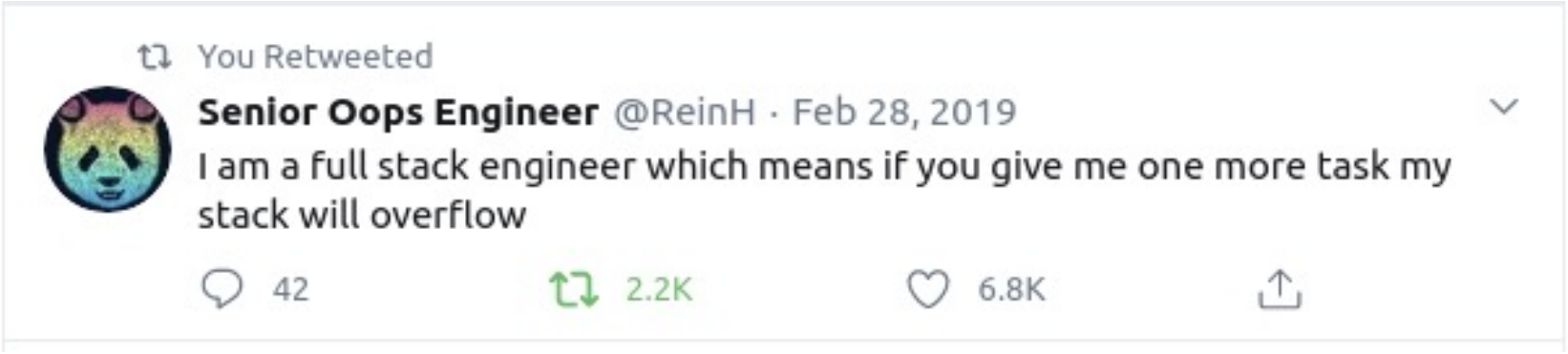


Relevant Course Information

- Lab 2 due next Friday (2/4)
  - Can start in earnest after today's lecture!
  - GDB tutorial and phase 1 walkthrough in section tomorrow
- Midterm (take home, 2/9—2/11)
  - Make notes and use the midterm reference sheet
  - Form study groups and look at past exams!
  - Socio-technical content **is** fair game

x86 Control Flow

- Condition codes
- Conditional and unconditional branches
- Loops
- **Switches**

```
long switch_ex
    (long x, long y, long z)
{
    long w = 1;
    switch (x) {
        case 1:
            w = y*z; break;
        case 2:
            w = y/z;
        /* Fall Through */
        case 3:
            w += z;  break;
        case 5:
        case 6:
            w -= z;  break;
        case 7:
            w = y%z; break;
        default:
            w = 2;
    }
    return w;
}
```

Switch Statement Example

- Multiple case labels
  - Here: 5 & 6
- Fall through cases
  - Here: 2
- Missing cases
  - Here: 4

- Implemented with:
  - *Jump table*
  - *Indirect jump instruction*

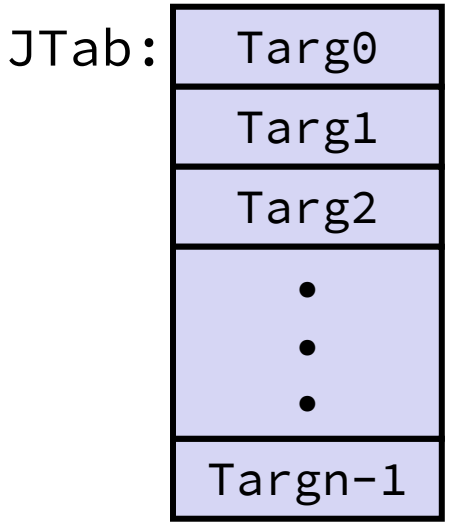
https://godbolt.org/z/Y9Kerb

Jump Table Structure

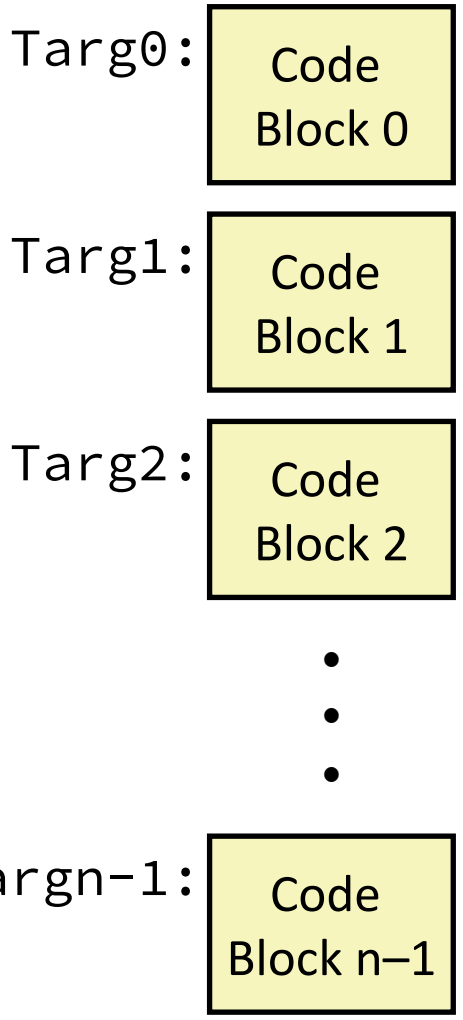
Switch Form

```
switch (x) {
  case val_0:
    Block 0
  case val_1:
    Block 1
    • • •
  case val_n-1:
    Block n–1
}
```

Jump Table



Jump Targets



Approximate Translation

```
target = JTab[x];
goto target;
```

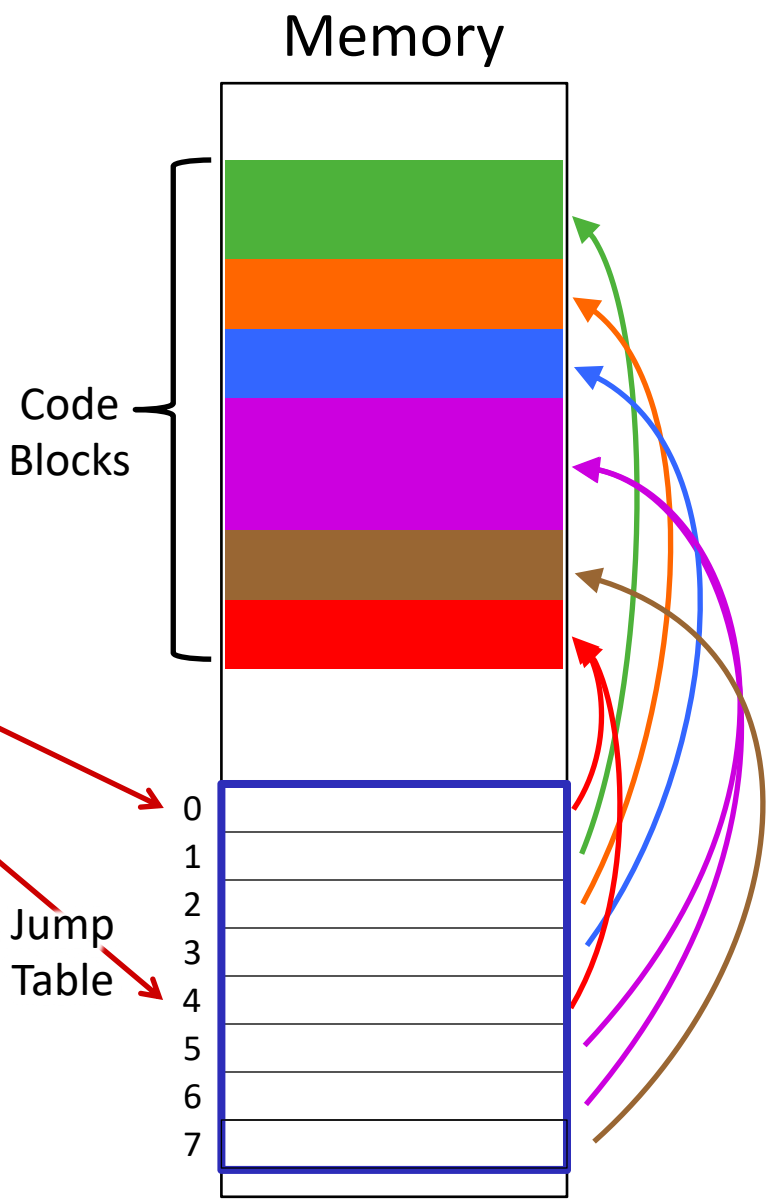
Jump Table Structure

C code:

```
switch (x) {
  case 1: <code> break;
  case 2: <code>
  case 3: <code> break;
  case 5:
  case 6: <code> break;
  case 7: <code> break;
  default: <code>
}
```

Use the jump table when x ≤ 7:

```
if (x <= 7)
  target = JTab[x];
  goto target;
else
  goto default;
```



Switch Statement Example

```
long switch_ex(long x, long y, long z)
{
    long w = 1;
    switch (x) {
      . . .
    }
    return w;
}
```

Register	Use(s)
%rdi	1st argument (x)
%rsi	2nd argument (y)
%rdx	3rd argument (z)
%rax	return value

Note compiler chose to not initialize w

```
switch_ex:
    movq    %rdx, %rcx
    cmpq    $7, %rdi        # x:7
    ja      .L9             # default
    jmp     *.L4(,%rdi,8)   # jump table
```

Take a look!
https://godbolt.org/z/Y9Kerb

jump **a**bove – unsigned > catches negative default cases

Switch Statement Example

```
long switch_ex(long x, long y, long z)
{
    long w = 1;
    switch (x) {
      . . .
    }
    return w;
}
```

```
switch_ex:
    movq    %rdx, %rcx
    cmpq    $7, %rdi        # x:7
    ja      .L9             # default
    jmp     *.L4(,%rdi,8)   # jump table
```

Indirect jump

Jump table

```
.section    .rodata
  .align 8
.L4:
  .quad    .L9    # x = 0
  .quad    .L8    # x = 1
  .quad    .L7    # x = 2
  .quad    .L10   # x = 3
  .quad    .L9    # x = 4
  .quad    .L5    # x = 5
  .quad    .L5    # x = 6
  .quad    .L3    # x = 7
```

Assembly Setup Explanation

- Table Structure
  - Each target requires 8 bytes (address)
  - Base address at `.L4`

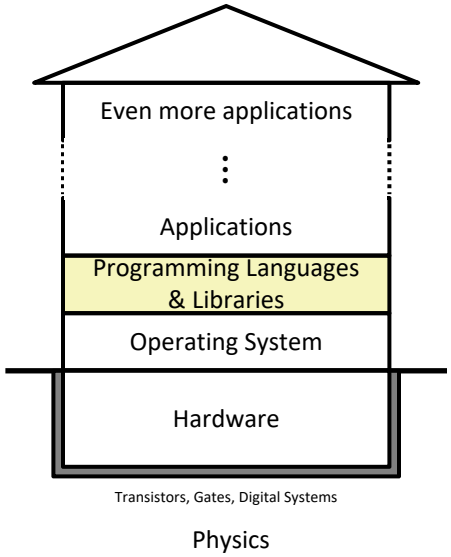
Jump table

```
.section    .rodata
  .align 8
.L4:
  .quad    .L9    # x = 0
  .quad    .L8    # x = 1
  .quad    .L7    # x = 2
  .quad    .L10   # x = 3
  .quad    .L9    # x = 4
  .quad    .L5    # x = 5
  .quad    .L5    # x = 6
  .quad    .L3    # x = 7
```

- Direct jump: `jmp .L9`
  - Jump target is denoted by label `.L9`
- Indirect jump: `jmp *.L4(,%rdi,8)`
  - Start of jump table: `.L4`
  - Must scale by factor of 8 (addresses are 8 bytes)
  - Fetch target from effective address `.L4 + x*8`
    - Only for $0 \le x \le 7$

The Hardware/Software Interface

- Topic Group 2: **Programs**
  - x86-64 Assembly, **Procedures**, **Stacks**, Executables



- How are programs created and executed on a CPU?
  - How does your source code become something that your computer understands?
  - How does the CPU organize and manipulate local data?

Reading Review

- Terminology:
  - Stack, Heap, Static Data, Literals, Code
  - Stack pointer (`%rsp`), `push`, `pop`
  - Caller, callee, return address, `call`, `ret`
    - Return value: `%rax`
    - Arguments: `%rdi`, `%rsi`, `%rdx`, `%rcx`, `%r8`, `%r9`
  - Stack frames and stack discipline

- Questions from the Reading?

Review Questions

- How does the stack change after executing the following instructions?

```
pushq %rbp
subq  $0x18, %rsp
```

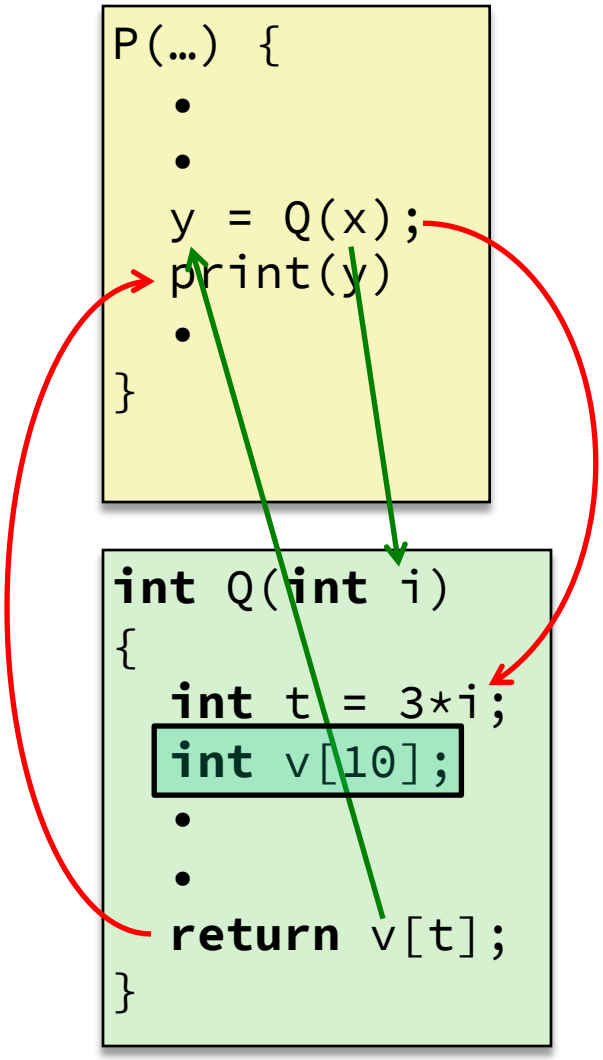
- For the following function, which registers do we know *must* be used?

```
void* memset(void* ptr, int value, size_t num);
```

Mechanisms required for *procedures*

1) Passing control
   - To beginning of procedure code
   - Back to return point
2) Passing data
   - Procedure arguments
   - Return value
3) Memory management
   - Allocate during procedure execution
   - De-allocate upon return

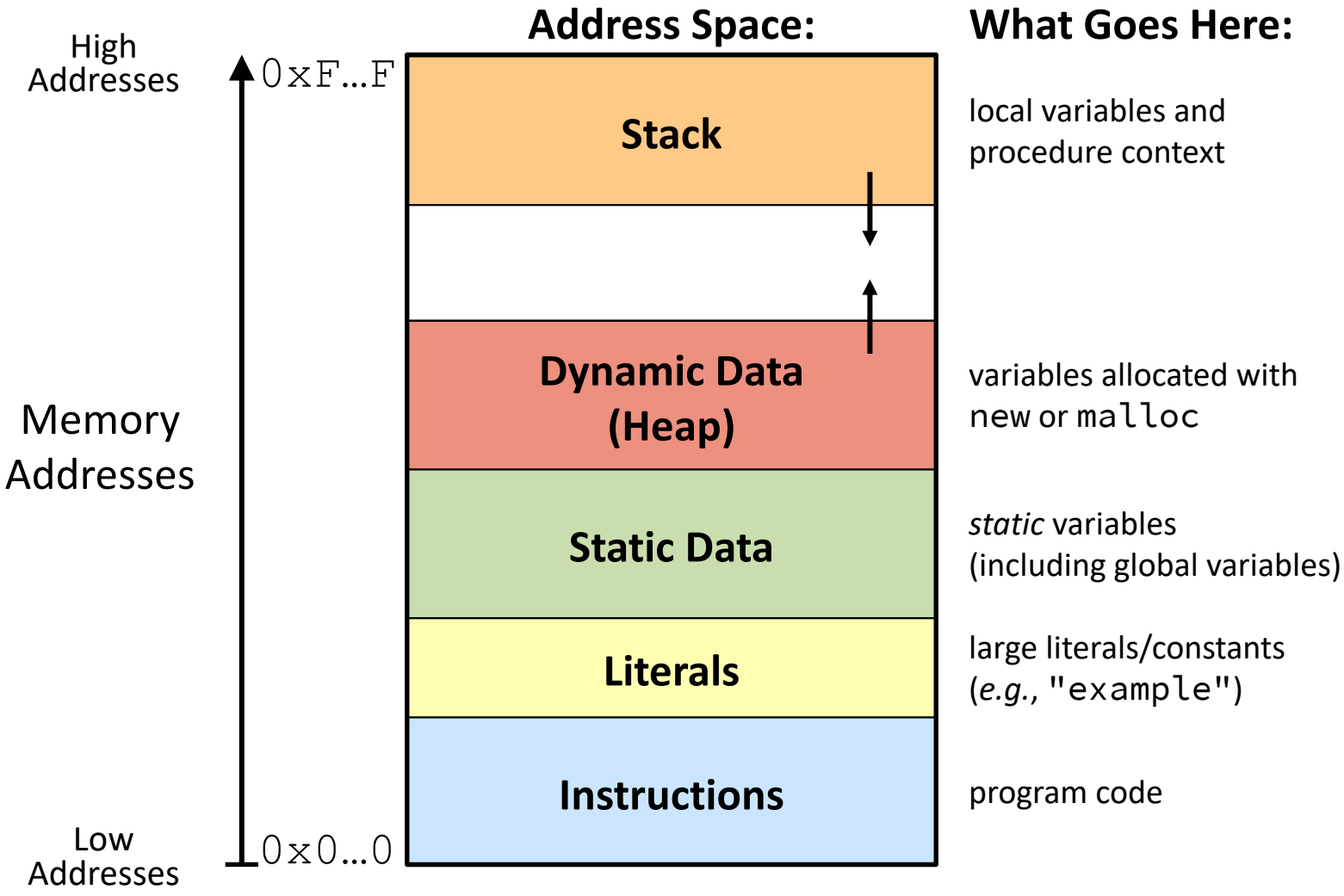
❖ All implemented with machine instructions!
   - An x86-64 procedure uses only those mechanisms required for that procedure



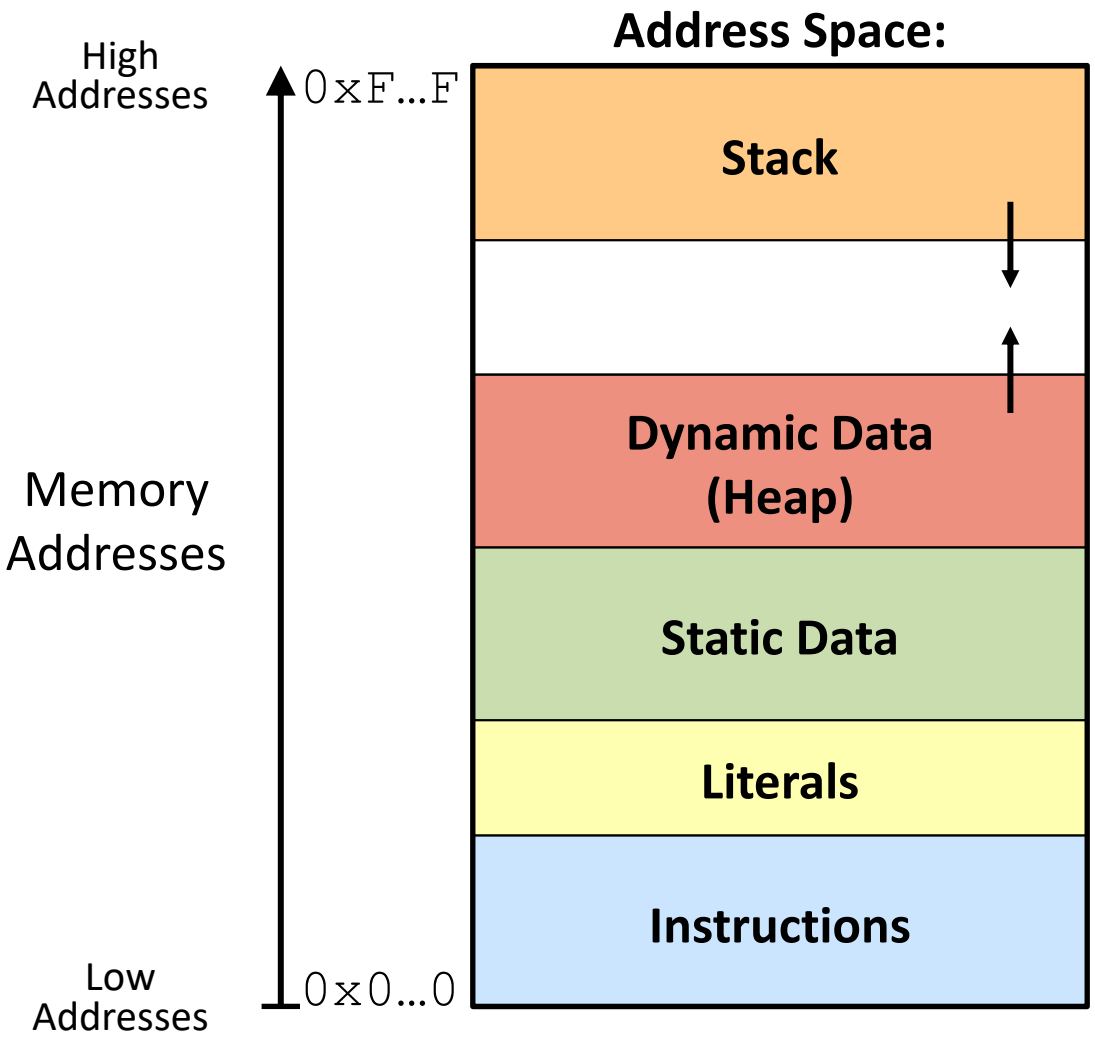
Procedures

- **Stack Structure**
- Calling Conventions
  - Passing control
  - Passing data
  - Managing local data
- Register Saving Conventions
- Illustration of Recursion

Simplified Memory Layout (Review)



Memory Management



Who's Responsible:

Managed "automatically" (by compiler/assembly)

Managed "dynamically" (by programmer)

Managed "statically" (initialized when process starts)

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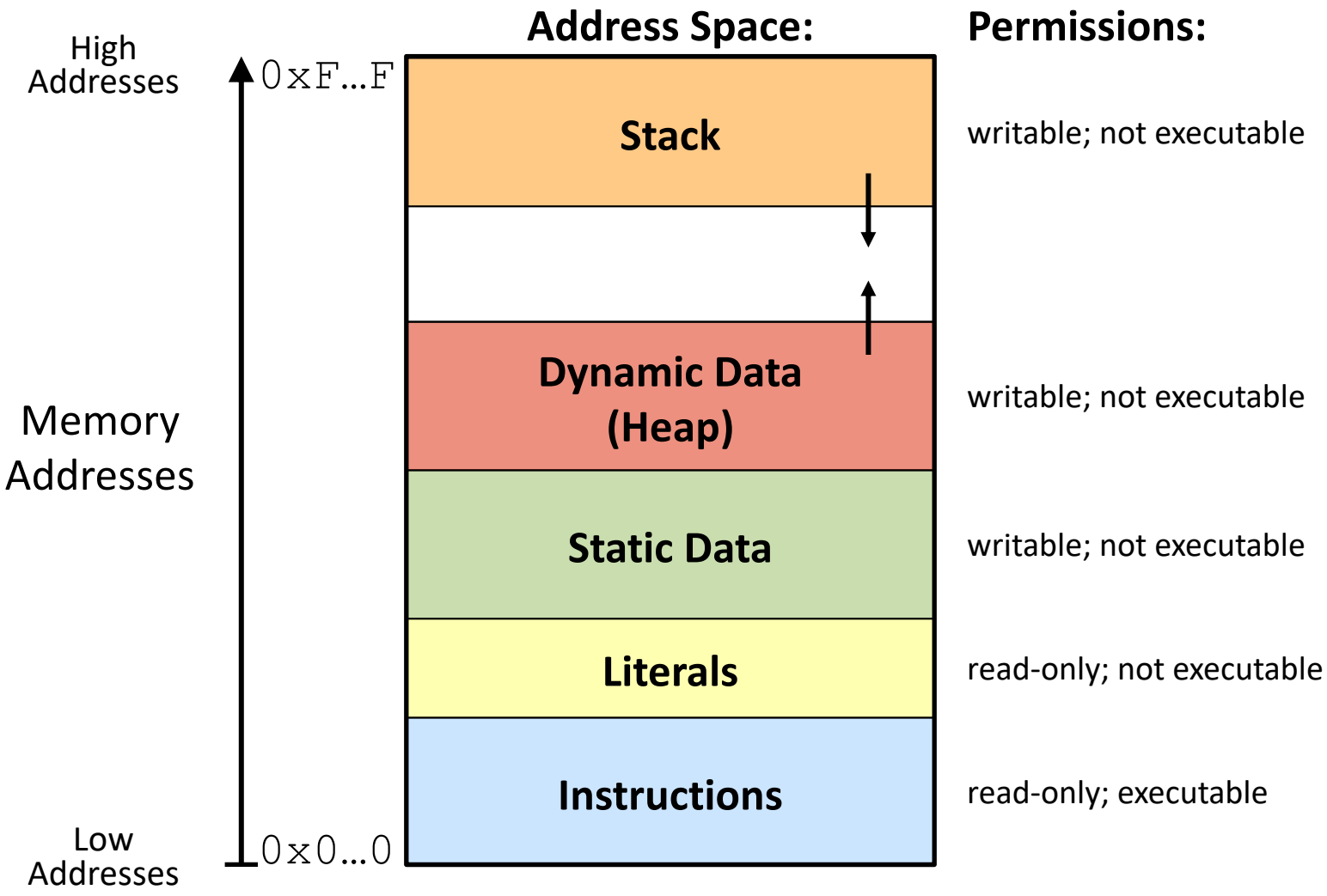
Managed "statically" (initialized when process starts)

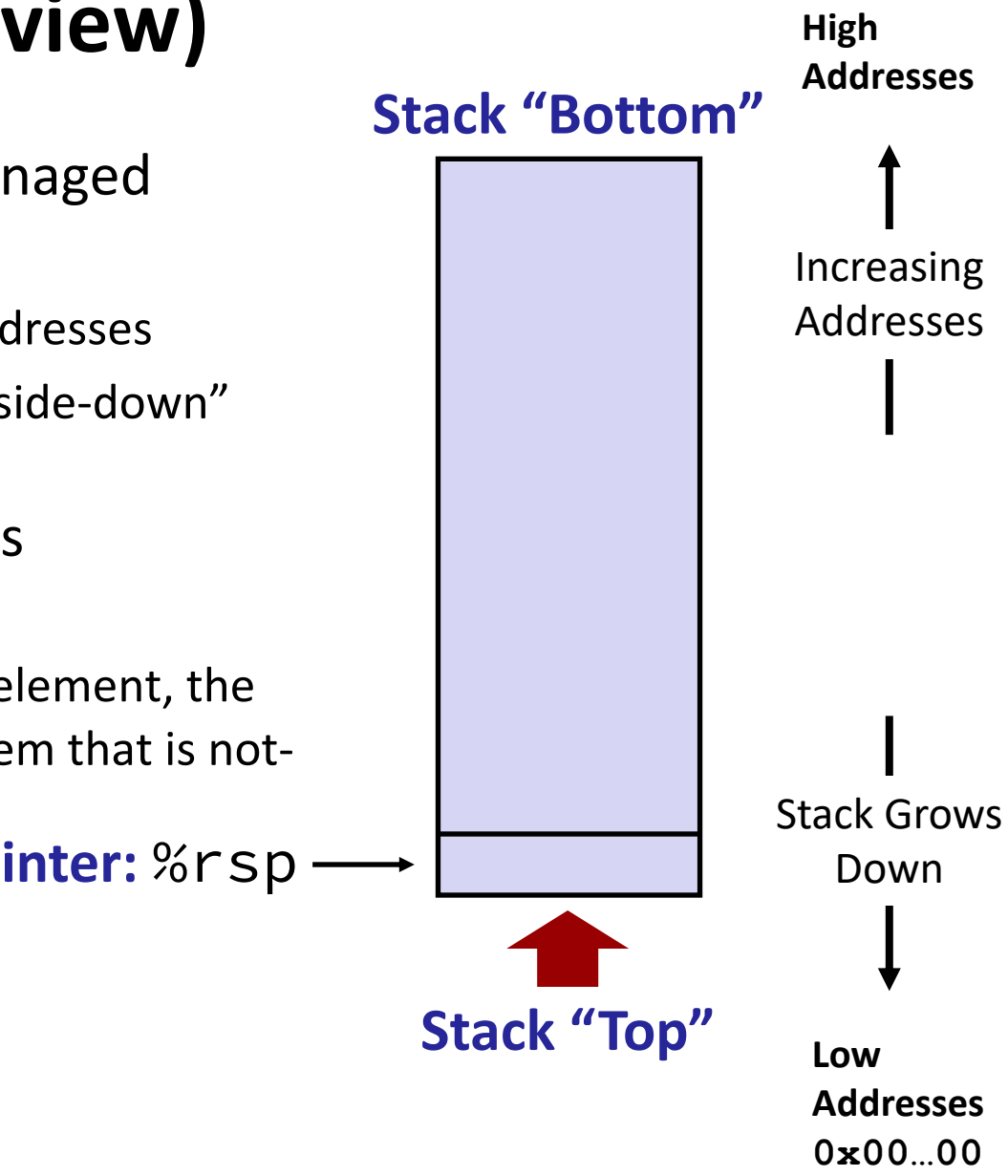
Memory Permissions



- Segmentation fault: impermissible memory access

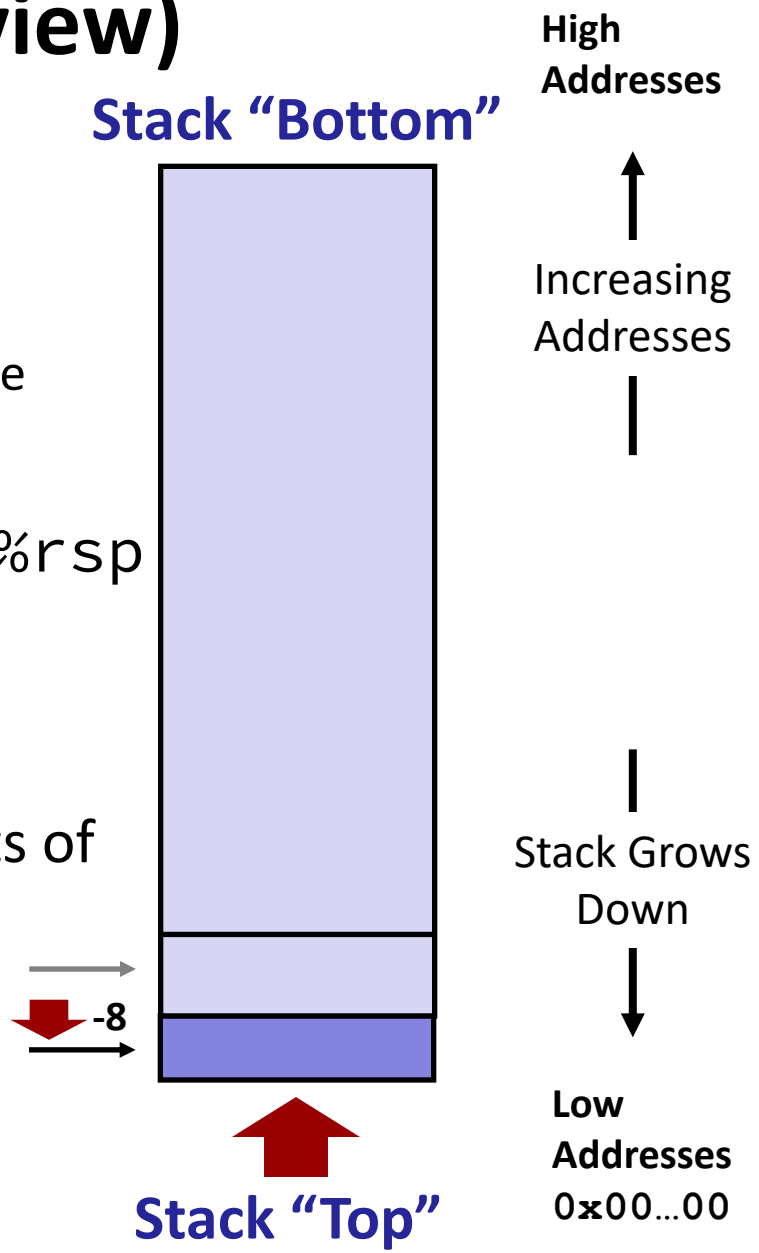
x86-64 Stack (Review)

- Region of memory managed with stack "discipline"
  - Grows toward lower addresses
  - Customarily shown "upside-down"
- Register `%rsp` contains *lowest* stack address
  - `%rsp` = address of *top* element, the most-recently-pushed item that is not-yet-popped



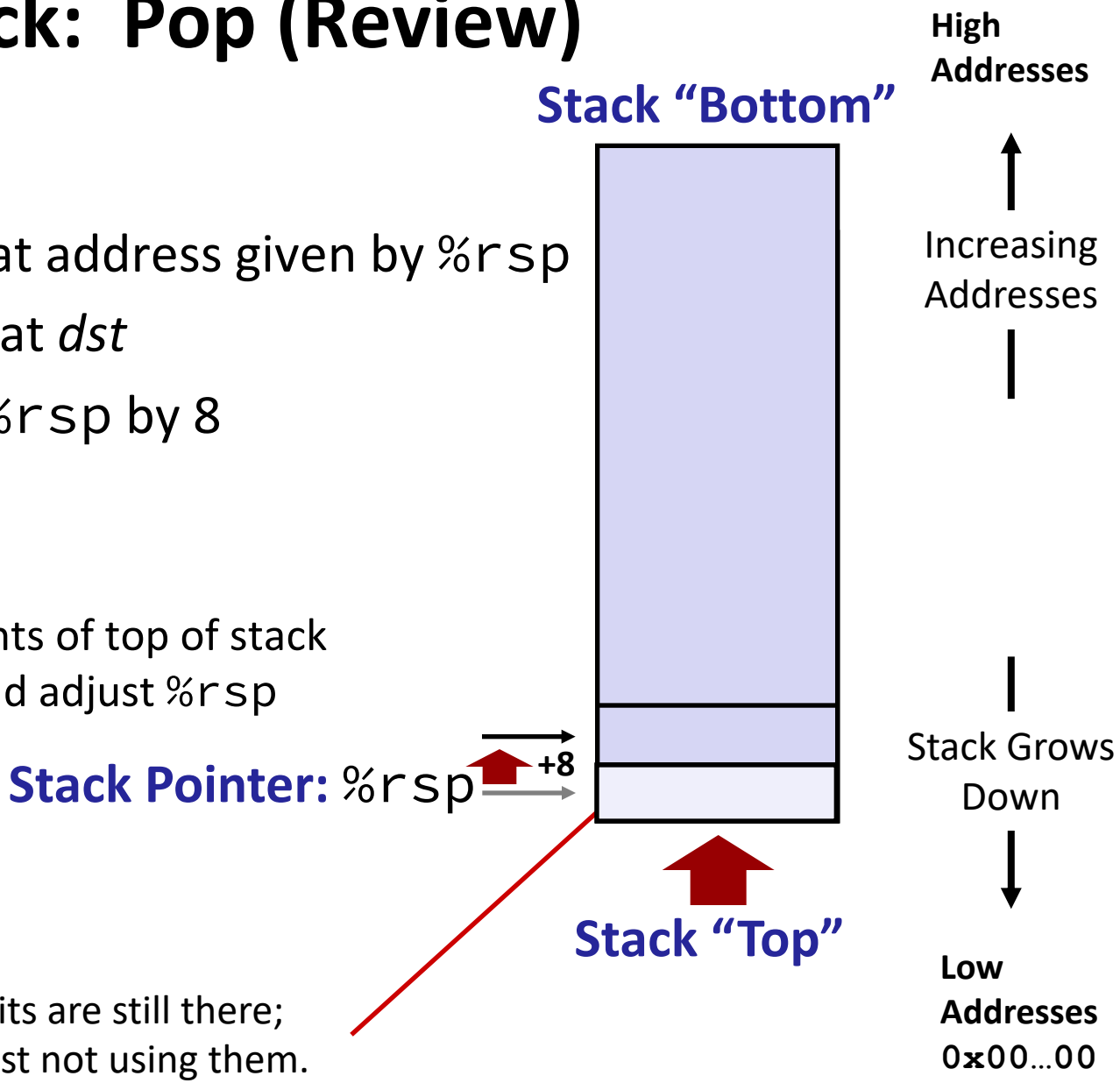
x86-64 Stack: Push (Review)

- `pushq` *src*
  - Fetch operand at src
    - Src can be reg, memory, immediate
  - ***Decrement*** `%rsp` by 8
  - Store value at address given by `%rsp`
- Example:
  - **`pushq %rcx`**
  - Adjust `%rsp` and store contents of `%rcx` on the stack



x86-64 Stack: Pop (Review)

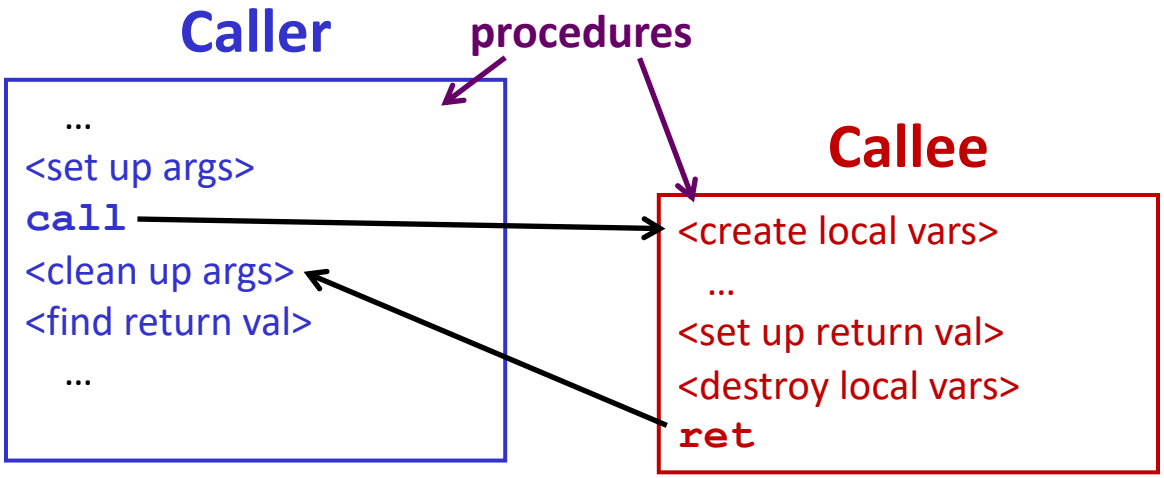
- `popq` *dst*
  - Load value at address given by `%rsp`
  - Store value at *dst*
  - ***Increment*** `%rsp` by 8
- Example:
  - **`popq %rcx`**
  - Stores contents of top of stack into `%rcx` and adjust `%rsp`



Procedures

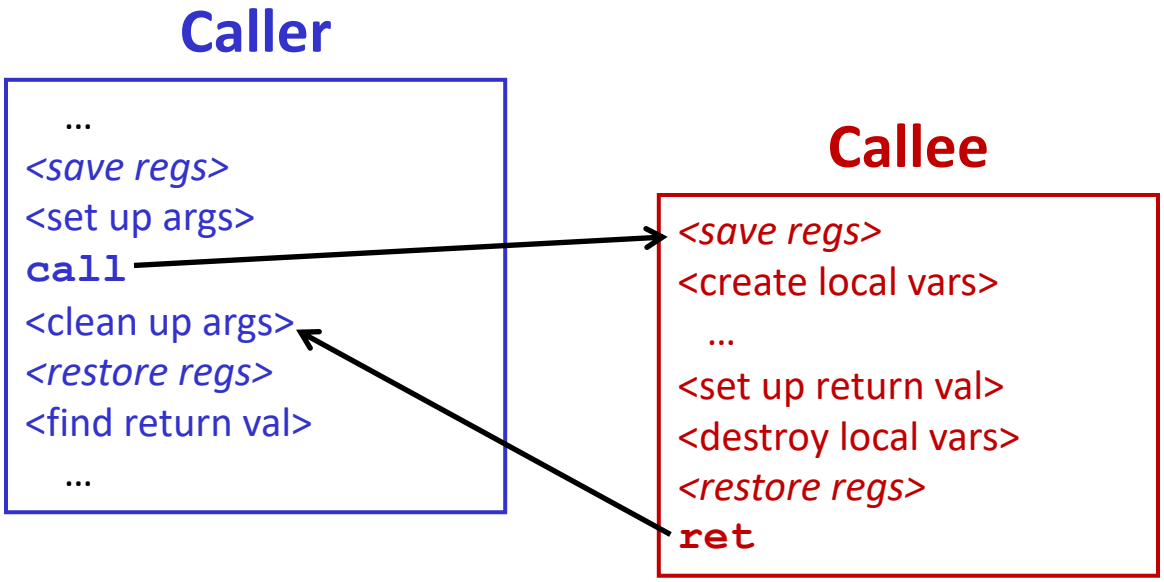
- Stack Structure
- **Calling Conventions**
  - **Passing control**
  - Passing data
  - Managing local data
- Register Saving Conventions
- Illustration of Recursion

Procedure Call Overview



- **Callee** must know where to find args
- **Callee** must know where to find *return address*
- **Caller** must know where to find *return value*
- **Caller** and **Callee** run on same CPU, so use the same registers
  - How do we deal with register reuse?
- Unneeded steps can be skipped (*e.g.*, no arguments)

Procedure Call Overview



- The *convention* of where to leave/find things is called the calling convention (or procedure call linkage)
  - Details vary between systems
  - We will see the convention for x86-64/Linux in detail
  - What could happen if our program didn't follow these conventions?