Section 5: Procedures & Stacks

- Stacks in memory and stack operations
- The stack used to keep track of procedure calls
- Return addresses and return values
- Stack-based languages
- The Linux stack frame
- Passing arguments on the stack
- Allocating local variables on the stack
- Register-saving conventions
- Procedures and stacks on x64 architecture

x86-64 Procedure Calling Convention

- **Doubling of registers makes us less dependent on stack**
  - Store argument in registers
  - Store temporary variables in registers

- **What do we do if we have too many arguments or too many temporary variables?**

x86-64 64-bit Registers: Usage Conventions

%rax	Return value
%rbx	Callee saved
%rcx	Argument #4
%rdx	Argument #3
%rsi	Argument #2
%rdi	Argument #1
%rsp	Stack pointer
%rbp	Callee saved

%r8	Argument #5
%r9	Argument #6
%r10	Caller saved
%r11	Caller Saved
%r12	Callee saved
%r13	Callee saved
%r14	Callee saved
%r15	Callee saved

Revisiting swap, IA32 vs. x86-64 versions

```
swap:
    pushl %ebp
    movl %esp,%ebp
    pushl %ebx

    movl 12(%ebp),%ecx
    movl 8(%ebp),%edx
    movl (%ecx),%eax
    movl (%edx),%ebx
    movl %eax,(%edx)
    movl %ebx,(%ecx)

    movl -4(%ebp),%ebx
    movl %ebp,%esp
    popl %ebp
    ret
```

Set Up

Body

Finish

```
swap (64-bit long ints):
    movq    (%rdi), %rdx
    movq    (%rsi), %rax
    movq    %rax, (%rdi)
    movq    %rdx, (%rsi)
    ret
```

- **Arguments passed in registers**
  - First (**`xp`**) in **`%rdi`**, second (**`yp`**) in **`%rsi`**
  - 64-bit pointers
- **No stack operations required (except `ret`)**
- **Avoiding stack**
  - Can hold all local information in registers

X86-64 procedure call highlights

- **Arguments (up to first 6) in registers**
  - Faster to get these values from registers than from stack in memory
- **Local variables also in registers (if there is room)**
- **`callq` instruction stores 64-bit return address on stack**
  - Address pushed onto stack, decrementing %rsp by 8
- **No frame pointer**
  - All references to stack frame made relative to %rsp; eliminates need to update %ebp/%rbp, which is now available for general-purpose use
- **Functions can access memory up to 128 bytes beyond %rsp: the "red zone"**
  - Can store some temps on stack without altering %rsp
- **Registers still designated "caller-saved" or "callee-saved"**

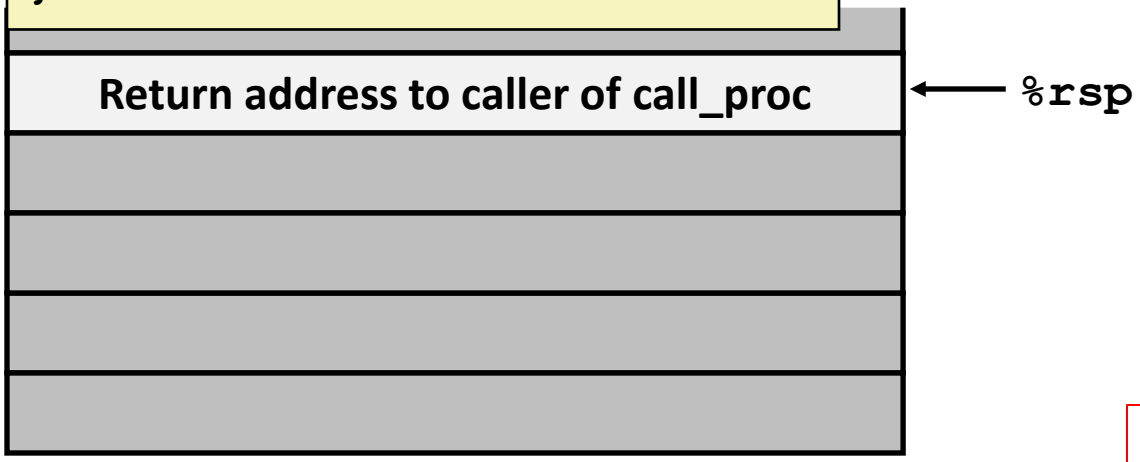
x86-64 Stack Frames

- **Often (ideally), x86-64 functions need no stack frame at all**
  - Just a return address is pushed onto the stack when a function call is made
- **A function *does* need a stack frame when it:**
  - Has too many local variables to hold in registers
  - Has local variables that are arrays or structs
  - Uses the address-of operator (&) to compute the address of a local variable
  - Calls another function that takes more than six arguments
  - Needs to save the state of callee-save registers before modifying them

Example

```
long int call_proc()
{
  long  x1 = 1;
  int   x2 = 2;
  short x3 = 3;
  char  x4 = 4;
  proc(x1, &x1, x2, &x2,
       x3, &x3, x4, &x4);
  return (x1+x2)*(x3-x4);
}
```

```
call_proc:
  subq  $32,%rsp
  movq  $1,16(%rsp)
  movl  $2,24(%rsp)
  movw  $3,28(%rsp)
  movb  $4,31(%rsp)
  • • •
```



NB: Details may vary depending on compiler.

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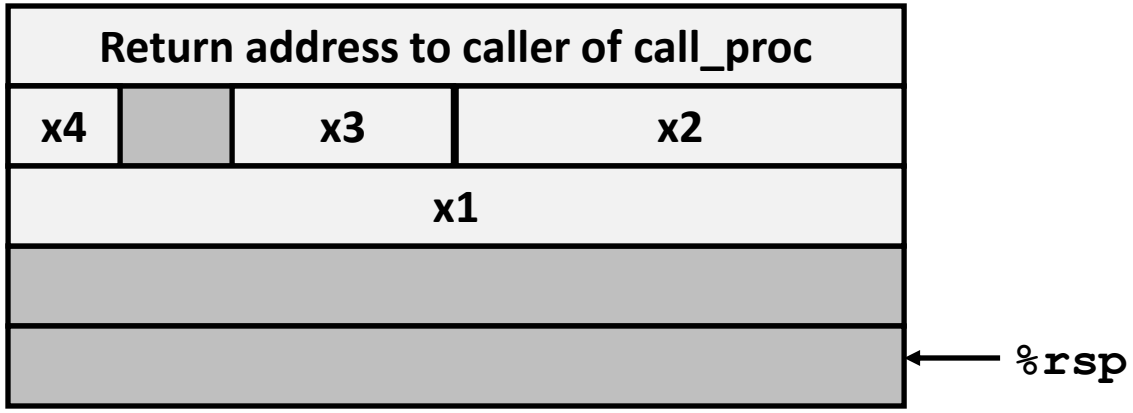

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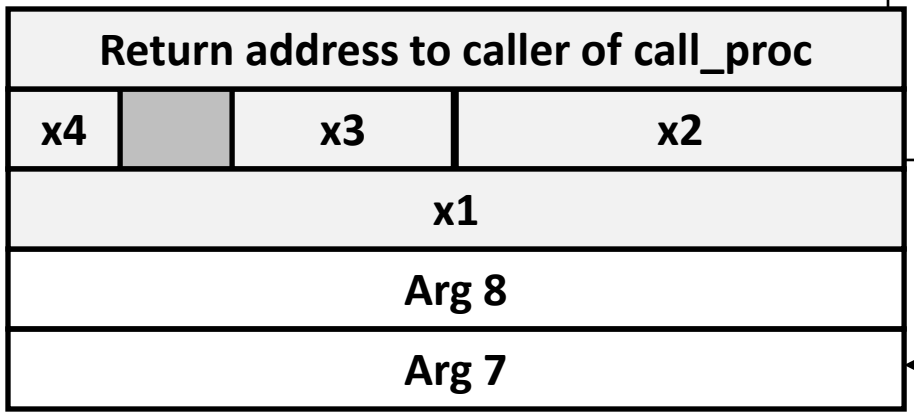
```

```
call_proc:
  • • •
  movq   $1,%rdi
  leaq   16(%rsp),%rsi
  movl   $2,%edx
  leaq   24(%rsp),%rcx
  movl   $3,%r8d
  leaq   28(%rsp),%r9
  movl   $4,(%rsp)
  leaq   31(%rsp),%rax
  movq   %rax,8(%rsp)
  call   proc
  • • •
```



Arguments passed in (in order):
rdi, rsi, rdx, rcx, r8, r9, then stack

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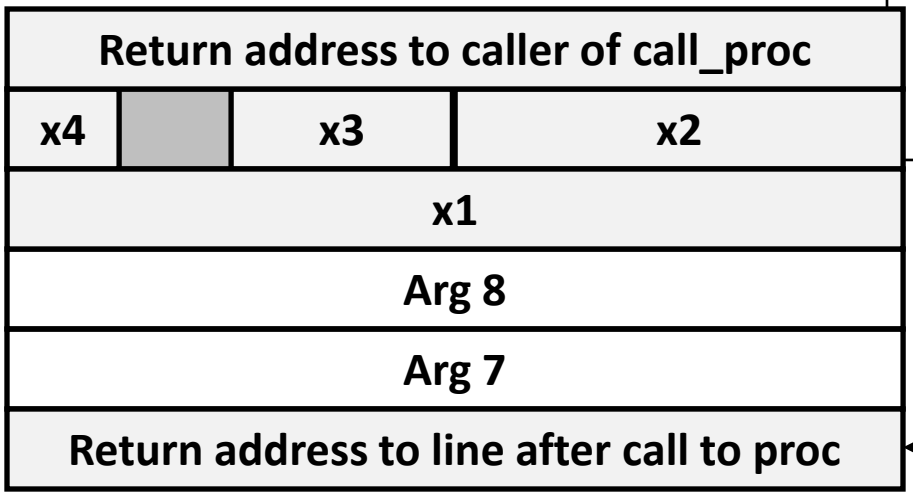

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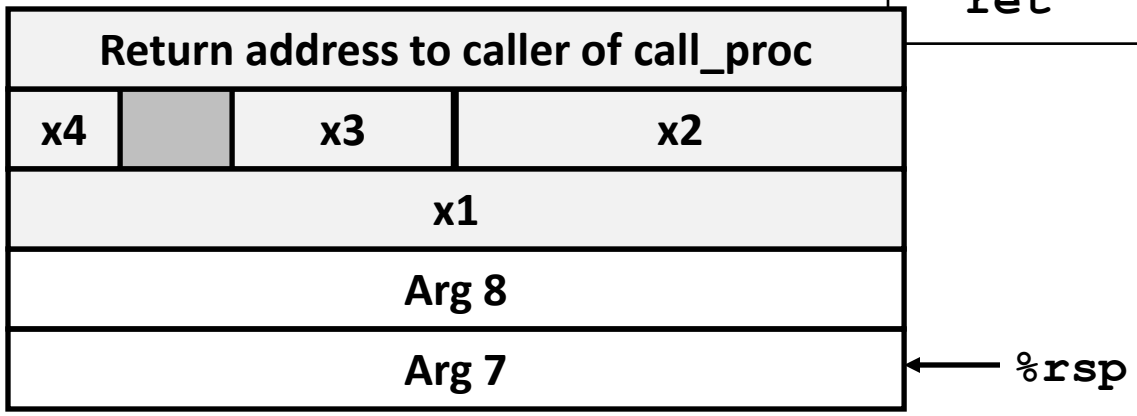
}
```

```
call_proc:
  • • •
  movswl 28(%rsp),%eax
  movsbl 31(%rsp),%edx
  subl   %edx,%eax
  cltq
  movslq 24(%rsp),%rdx
  addq   16(%rsp),%rdx
  imulq  %rdx,%rax
  addq   $32,%rsp
  ret
```



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  imulq  %rdx,%rax
  addq   $32,%rsp
  ret
```

Return address to caller of call_proc ← %rsp

x86-64 Procedure Summary

- **Heavy use of registers (faster than using stack in memory)**
  - Parameter passing
  - More temporaries since more registers
- **Minimal use of stack**
  - Sometimes none
  - When needed, allocate/deallocate entire frame at once
  - No more frame pointer: address relative to stack pointer
- **More room for compiler optimizations**
  - Prefer to store data in registers rather than memory
  - Minimize modifications to stack pointer