Machine-Level Representation of Programs: Procedures, Recursion, Data

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April 3, 2023

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Announcements

Class session plan

- Monday, 4/3: Arrays and data structures in assembly. (Book chapter 3.8)

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Procedures and function calls

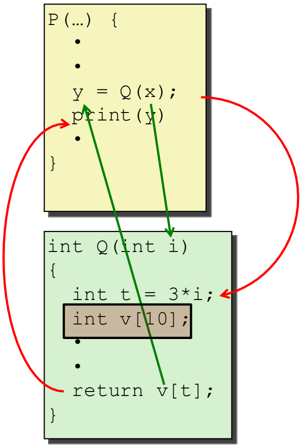
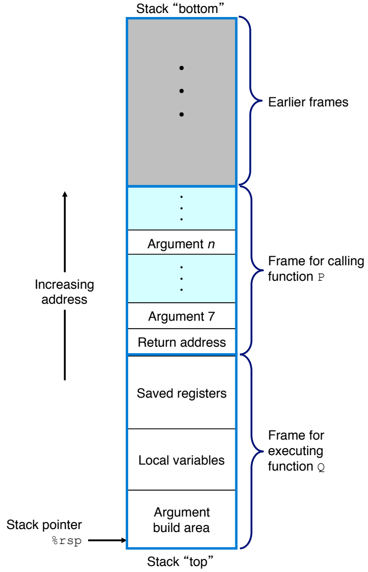


Figure: Steps of a C function call. Image credit CS:APP

To create the abstraction of functions, need to:

- Transfer control to function and back
- Transfer data to function (parameters)
- transfer data from function (return type)

Memory stack frames



Structure of stack for currently executing function Q()

- P() calls Q(). P() is the caller function. Q() is the callee function.

Stack instructions: `push src` and `pop dest`

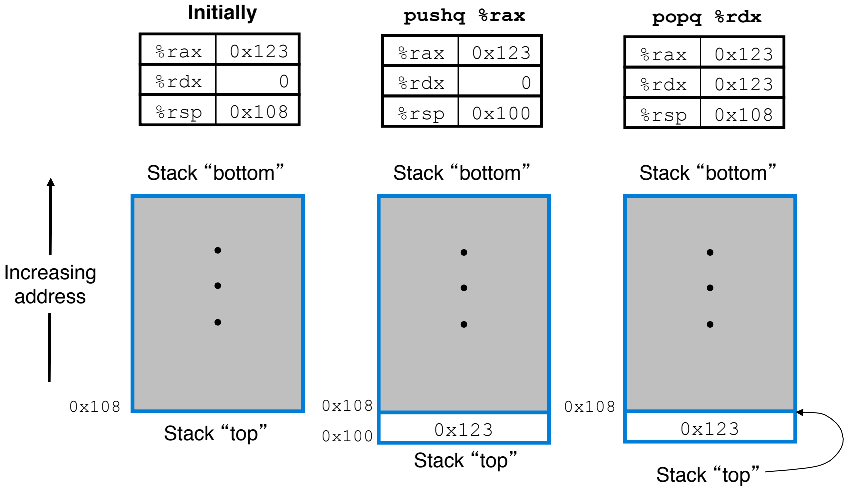


Figure: x86-64 offers dedicated instructions to work with stack in memory. In addition to moving data, the updating of %rsp is implied. Image credit: CS:APP.

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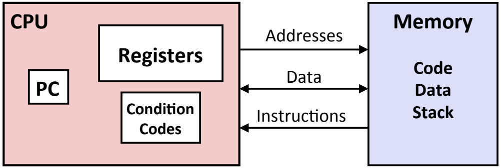
CPU and memory state in support of procedures and functions

Carnegie Mellon

Assembly/Machine Code View



Programmer-Visible State

- **PC: Program counter**
  - Address of next instruction
  - Called "RIP" (x86-64)
- **Register file**
  - Heavily used program data
- **Condition codes**
  - Store status information about most recent arithmetic or logical operation
  - Used for conditional branching

- **Memory**
  - Byte addressable array
  - Code and user data
  - Stack to support procedures

Bryant and O'Hallaron, Computer Systems: A Programmer's Perspective, Third Edition

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Relevant state in CPU:

- %rip register / instruction pointer / program counter
- %rsp register / stack pointer

Relevant state in Memory:

- Stack

Procedure call and return: `call` and `ret`

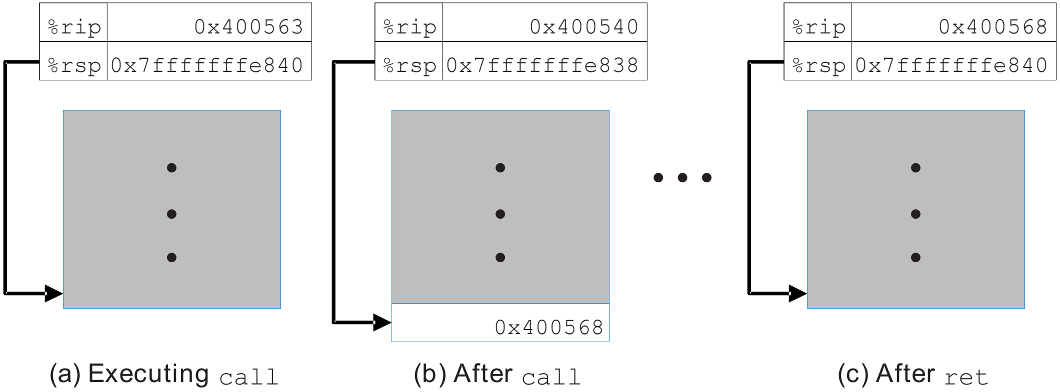

Figure: Effect of `call 0x400540` instruction and subsequent return. `call` and `ret` instructions update the instruction pointer, the stack pointer, and the stack to create the procedure / function call abstraction. Image credit: CS:APP.

Example in GDB

```c
#include <stdio.h>

int return_neg_one() {
  return -1;
}

int main() {
  int num = return_neg_one();
  printf("%d", num);
  return 0;
}
```

```
return_neg_one:
    movl $-1, %eax
    ret
main:
    subq $8, %rsp
    movl $0, %eax
    call return_neg_one
    movl %eax, %edx
```

Compile, and then run it in GDB:

`gdb return`

In GDB, see evolution of %rip, %rsp, and stack:

- `(gdb) layout split`
- `(gdb) break return_neg_one`
- `(gdb) info stack`
- `(gdb) print /a $rip`
- `(gdb) print /a $rsp`
- `(gdb) x /a $rsp`

Step past return instruction, and inspect again:

- `(gdb) stepi`
- `(gdb) info stack`

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Procedures and function calls: Transferring data

For purposes of this class, the Bomb Lab, and the CS:APP textbook, we study the x86-64 Linux Application Binary Interface (ABI). Would be different on ARM or in Windows. So, don't memorize this, but it is helpful for PA4 Lab.

Passing parameters

Parameter	Register / stack	Subset registers	Mnemonic[1]
1st	%rdi	%edi, %di	Diane's
2nd	%rsi	%esi, %si	silk
3rd	%rdx	%edx, %dx, %dl	dress
4th	%rcx	%ecx, %cx, %cl	cost
5th	%r8	%r8d	$8
6th	%r9	%r9d	9
7th and beyond	Stack		

[1] http://csappbook.blogspot.com/2015/08/dianes-silk-dress-costs-89.html

PA4 Defusing a Binary Bomb: `sscanf();`

```
int sscanf (
    const char *str, // 1st arg, %rdi
    const char *format, // 2nd arg, %rsi
    ...
)
```

Procedures and function calls: Transferring data

Passing function return data

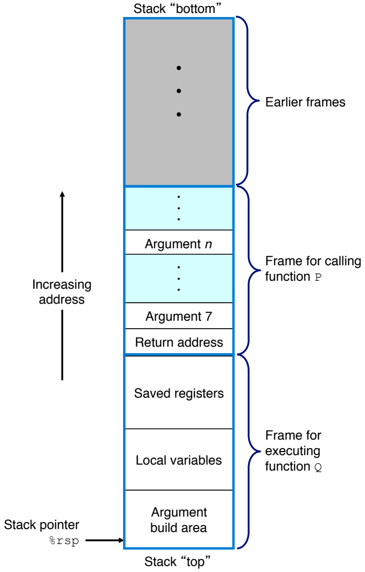
Function return data is passed via:

- the 64-bit %rax register
- the 32-bit subset %eax register

Example from textbook slides on assembly procedures

Slides 33 through 38.

Data transferred via memory



Structure of stack for currently executing function Q()

- P() calls Q(). P() is the caller function. Q() is the callee function.

Example from textbook slides on assembly procedures

Slides 40 through 44.

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`3_recursion.c`: Putting it all together to support recursion

Discussion points

- Use info stack, info args in GDB to see recursion depth
- Difference between compiling with and without -g for debugging information.
- Memory costs of recursion.
- Compilers can recognize tail recursive calls to reduce memory use. Enabled with -foptimize-sibling-calls, -O2, -O3, and -Os.