PURDUE UNIVERSITY®

CS 50011: Introduction to Systems II

Lecture 4: Programs and Processes

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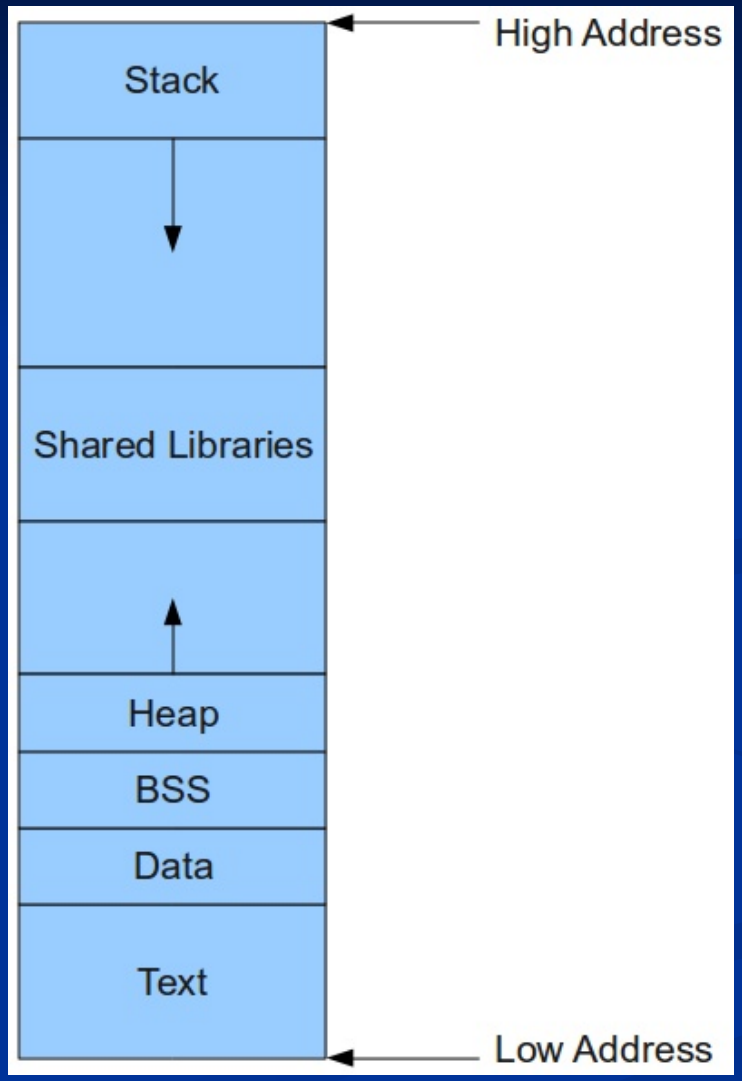
Lecture 05

- Program layout and segments
- The stack
- Calling conventions

Program vs. process

- A program is an executable file that contains a set of instructions
  - Usually stored on disk or other secondary storage
- A process is a program in execution
  - It resides, at least partially, in memory

Process memory layout



32-bit vs 64-bit

- 32-bit systems usually have shared libraries at the lowest address, followed by the text segment
- Starting addresses differ
  - Text or code usually starts 0x400000 on 64-bit, 0x8047000 on 32-bit

Text segment

- Also called the code segment
- Contains actual program instructions and any statically linked libraries
- Often read only and executable
  - Self-modifying code

Data segment

- Initialized global variables and static strings

Demo

- hello.c

```
#include <unistd.h>
int main(int argc, char *argv[])
{
  int ret = 0xbeefbeef;
  ret = write(1, "Hello\n", 6);
  return 0;
}
```

```
$ gcc -masm=intel -S hello.c
$ objdump -M intel -Dl a.out
```

BSS

- Block started by segment
- Holds uninitialized global variables
  - By C convention are initialized automatically to 0

Heap

- Dynamically allocated memory
  - i.e., obtained via `malloc()`
- Grows upward as memory is requested
  - Upward → increasing addresses

Stack

- Holds temporary, or automatic, variables
- Arguments passed during a function call
- Information needed to return to a previous point in the program
- Grows downward (decreasing addresses)

Stack

- A stack is a very common data structure used in programs and architectures
- Stacks are generally LIFO queues
  - Last in, first out
- Two operations
  - PUSH – add something to the stack
  - POP – retrieve the most recent item

x86_64 hardware support

- RBP, base pointer
- RSP, stack pointer, points to next available address
- PUSH and POP instructions
  - Automatically decrement/increment RSP by 8

Function calls

- CALL
- RET

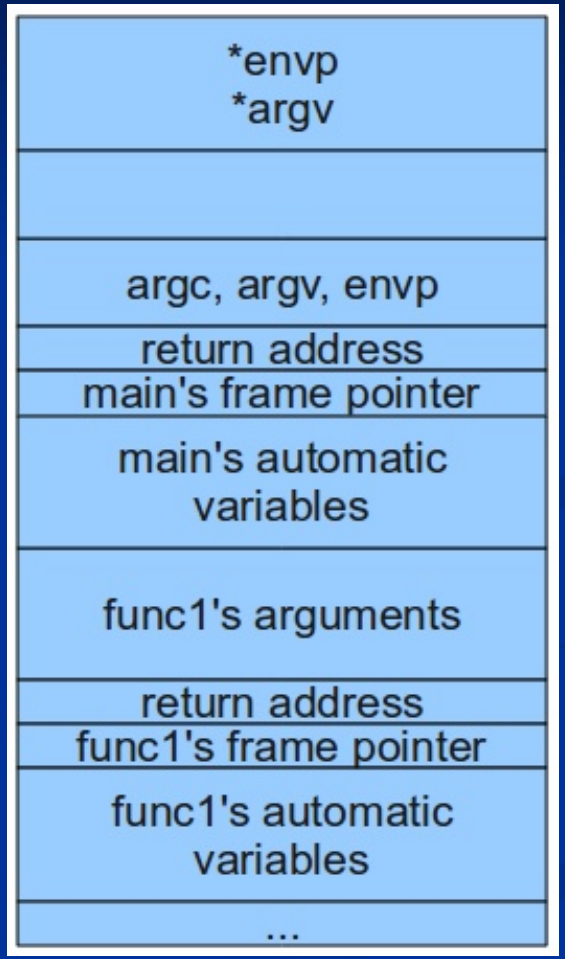
Base pointer

- Represents currently active region of the stack
- Used in combination with an offset to reference all local variables
  - Accesses are relative to RBP
- RBP updated any time a function is called or returns

Stack frame

- Frame is pushed on function call
- Popped on function return
- Contains data for function calls
  - Parameters
  - Return address
  - Return value
  - Automatic (local) variables
- Structure is defined by calling convention

General stack frame layout



Stack frames form a linked list

- RBP always points to the start of the previous stack frame
  - Which contains. … the previous RBP

Register preservation

- Functions share one set of registers
- Calling convention dictates how they are shared
  - Caller-saved: the calling function is responsible for saving them

```
void foo() {
  // push regs
  bar();
  // pop regs
}
```

- Callee-saved: the called function is responsible for saving and restoring

```
void bar() {
  // push regs
  do_things;
  // restore regs
  return;
}
```

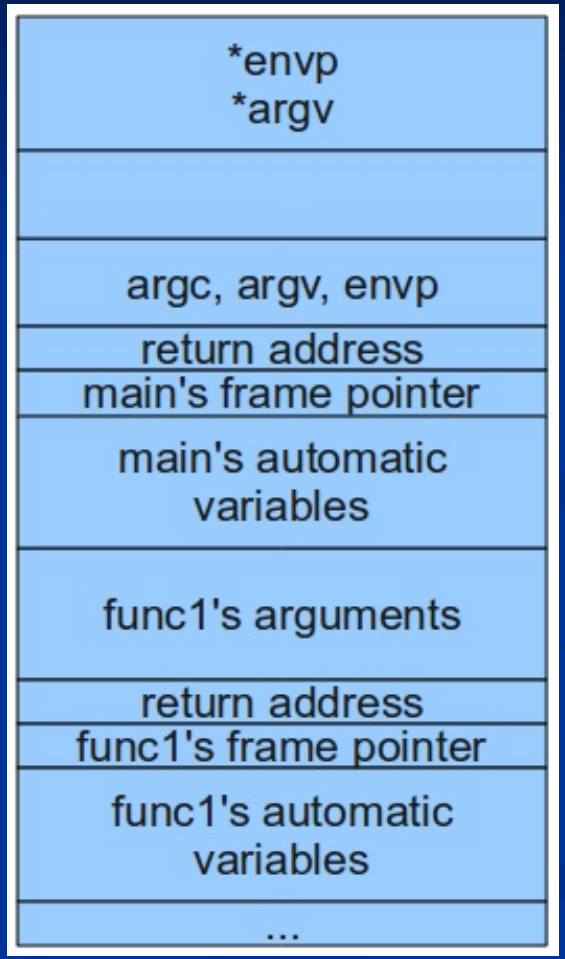
Calling conventions

- Dictate how registers are shared
- How the stack is managed when a function is called
  - Return address location
  - RBP, etc
- Also dictate how a process interacts with the kernel

cdecl - “C declaration”

- Function parameters pushed onto stack right to left
- RAX for (primitive) return values
- Caller-saved stack

General stack frame layout again



How did we get here?

- Arguments to func1() were pushed onto the stack
- func1() was called
- RBP was pushed onto the stack
- RSP was moved to RBP
- Space for local variables was allocated
- Local variables set to initial values
  - If provided

Interacting with the kernel

System V AMD64 ABI

- Used on Solaris, Linux, FreeBSD, and macOS
- RDI, RSI, RDX, RCX, R8, and R9
  - integer or pointer arguments
  - R10 instead of RCX for kernel
- XMM0-7
  - Floating point
- Additional arguments on the stack
- Return value in RAX and RDX

- Callee must save and restore RBP, RBX, R12-R15 if used
  - Not for system calls
- Lots of details
  - http://refspecs.linuxbase.org/elf/x86-64-abi-0.99.pdf

Example

Questions?