CS 453/698: Software and Systems Security

Module: Background

Lecture: Abstractions in OS, PL, and SE

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Outline

Layered abstraction

Modern computing systems are among the most complex systems ever built.

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One of the key engineering techniques that enables the construction of such complex systems is the use of layered abstractions:

- the system is designed as a stack of layers, where
- each layer hides implementation details of lower layers.

The hello-world example

```
#include <stdio.h>

int main(void) {
    printf("Hello World");
    return 0;
}
```

The hello-world example

```c
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Compile:

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cc hello-world.c
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Q: What happens behind the scenes exactly?

Von Neumann architecture

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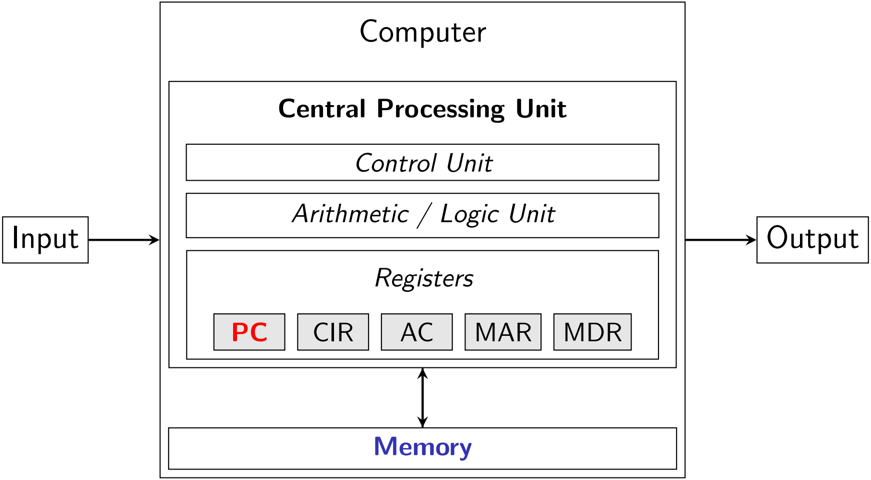

Program the low-level machine

Suppose there is a CPU instruction called `output <char>`, with opcode `0B <char>`, which sends a single character `<char>` to the output device.

Q: How to display "Hello World" in the output device?

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`output <char>`, with opcode `0B <char>`,
which sends a single character `<char>` to the output device.

Q: How to display "Hello World" in the output device?

A: This is a multi-step process:

Step 1: Find a suitable memory location (e.g., address `0x0010`)

Step 2: Put the following bytes into this memory location

```
0B 48 // ASCII code for 'H'
0B 65 // ASCII code for 'e'
...
0B 64 // ASCII code for 'd'
```

Step 3: Put value `0x0010` into the PC register.

A simplified view of compilation and loading

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- getting the bytes `0B 48 0B 65 ... 0B 64` from source code as **compilation**, and
- the rest as **loading**, including
  1. Find a suitable memory location (e.g., address `0x0010`)
  2. Put the bytes `0B 48 0B 65 ... 0B 64` into this memory location
  3. Put value `0x0010` into the `PC` register.

Reality is more complicated

However, in reality, things are way more complicated. But the operating system, compiler, and software engineering practices abstract the complications away.

Outline

A simple C program

```c
#include <stdio.h>
#include <string.h>

int main(void) {
  int pass = 0;
  char buff[8];

  printf("Enter the password: ");
  gets(buff);

  if(strcmp(buff, "warriors")) {
    printf("Wrong password\n");
  } else {
    printf("Correct password\n");
    pass = 1;
  }

  if(pass) {
    printf ("Root privileges granted\n");
  }
  return 0;
}
```

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  return 0;
}
```

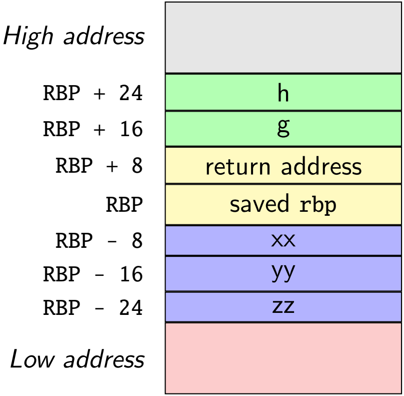
Try with

`gcc -m64 -fno-stack-protector`

And password "golden-hawks"

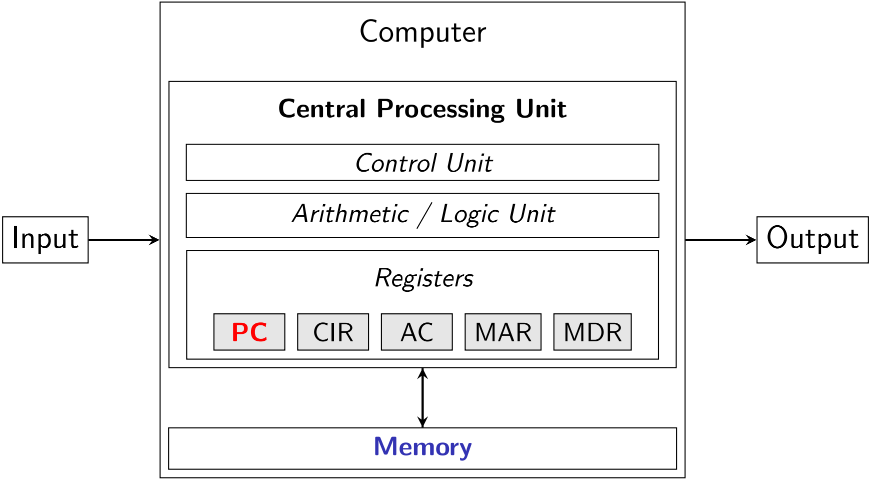
Stack layout (Linux x86-64 convention)

```c
long foo(
    long a, long b, long c,
    long d, long e, long f,
    long g, long h)
{
    long xx = a * b * c;
    long yy = d + e + f;
    long zz = bar(xx, yy, g + h);
    return zz + 20;
}
```



Argument a to `f` passed by registers.

Von Neumann architecture



Implications of the Von Neumann architecture

- Code and data reside in the same memory space and can be addressed in a unified way
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- Code and data reside in the same memory space and can be addressed in a unified way
  - If you manage to get the PC register to point to a memory address contains your logic, you have effectively hijacked the control flow.
- There is only one unified memory. It is the job of the compiler / programming language / runtime to find a way to utilize the memory efficiently.
  - Variables declared in a program (e.g., `int i = 0;`) need to be mapped to an address in the memory, and the mapping logic needs to be (ideally) consistent on the same architecture.

Definition: memory

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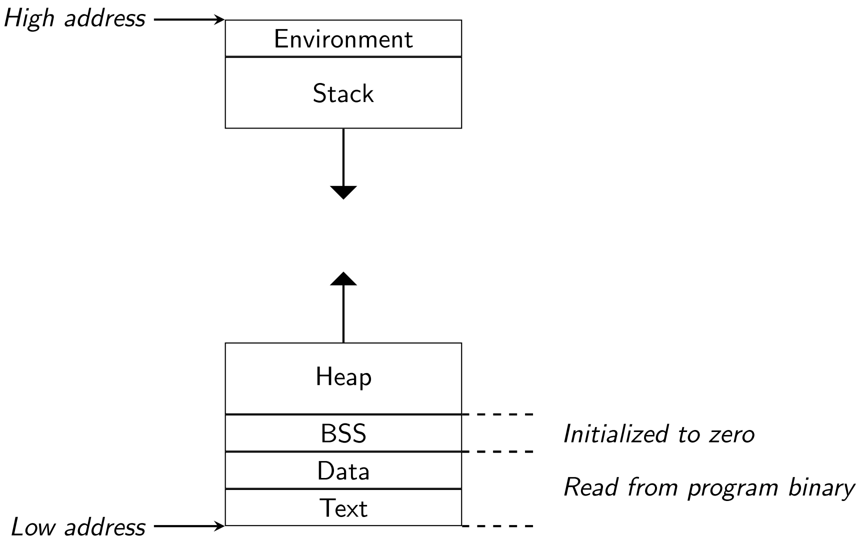
A: Four types of memory on a conceptual level:

- Text (where program code is initially loaded to)
- Stack
- Heap
- Global (a.k.a., static)

Memory layout (Linux x86-64 convention)



Example

```c
#include <stdlib.c>

//! where is this variable hosted?
const char *HELLO = "hello";

//! where is this variable hosted?
long counter;

void main() {
    //! where is this variable hosted?
    int val;

    //! where is this variable hosted?
    //! where is its content allocated?
    char *msg = malloc(120);

    //! what is freed here?
    free(msg);

    //! what is freed here (at end of function)?
}

//! what is freed here (at end of execution)?
```

Example (and answers)

```c
#include <stdlib.c>

// this is in the data section
const char *HELLO = "hello";

// this is in the BSS section
long counter;

void main() {
    // this is in the stack memory
    int val;

    // the msg pointer is in the stack memory
    // the msg content is in the heap memory
    char *msg = malloc(120);

    // msg content is explicitly freed here
    free(msg);

    // the val and msg pointer is implicitly freed here
}

// the global memory is only destroyed on program exit
```

What is heap and why do we need it?

In C/C++, the heap is used to manually allocate (and free) new regions of process memory during program execution.

Heap vs stack

```c
typedef struct Response {
  int status;
  char message[40];
} response_t;

response_t *say_hello() {
  response_t* res =
    malloc(sizeof(response_t));
  if (res != NULL) {
    res->status = 200;
    strncpy(res->message, "hello", 6);
  }
  return res;
}
void send_back(response_t *res) {
  // implementation omitted
}
void process() {
  response_t *res = say_hello();
  send_back(res);
  free(res);
}
```

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void send_back(response_t *res) {
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}
void process() {
  struct Response res;
  say_hello(&res);
  send_back(&res);
}
```

A stack-based implementation of (roughly) the same functionality

⟨ End ⟩