CSE 303
Lecture 10

C memory model;
stack allocation

reading: *Programming in C* Ch. 11

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Lecture summary

- discuss ethics/society reading #3
- computer memory and addressing
- stack vs. heap
- pointers
- parameter passing
  - by value
  - by reference

Ethics/society reading #3

- Is DRM a hardware or software technology? What is one occasion in which you have run into DRM?
- Does DRM fundamentally conflict with fair use?
- Is DRM fair? If not, how can content creators ensure a suitable profit from their works without measures like DRM?

Memory hierarchy

CPU registers — a few bytes

L1/L2 cache (on CPU) — 1-4 MB

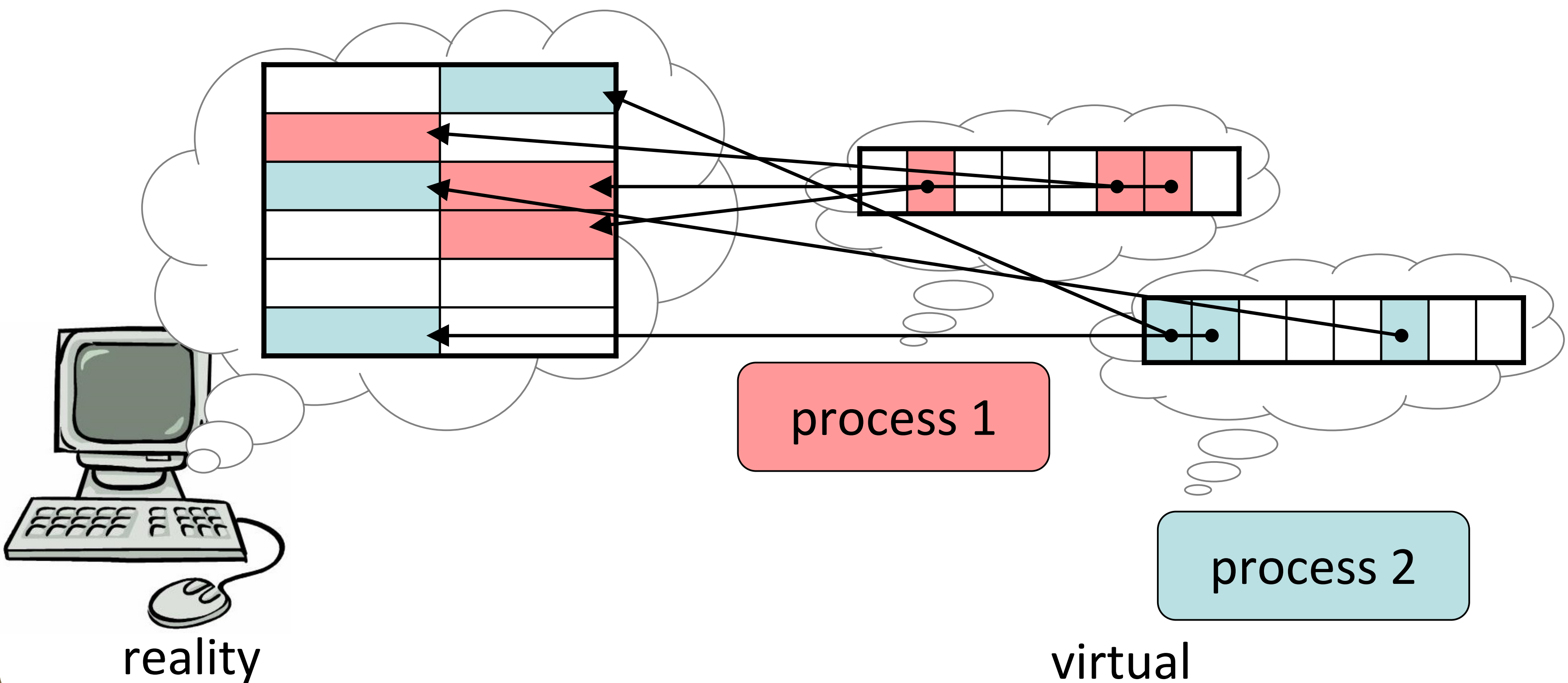
physical RAM (memory) — 1-2 GB

virtual RAM (on a hard disk) — 2-8 GB

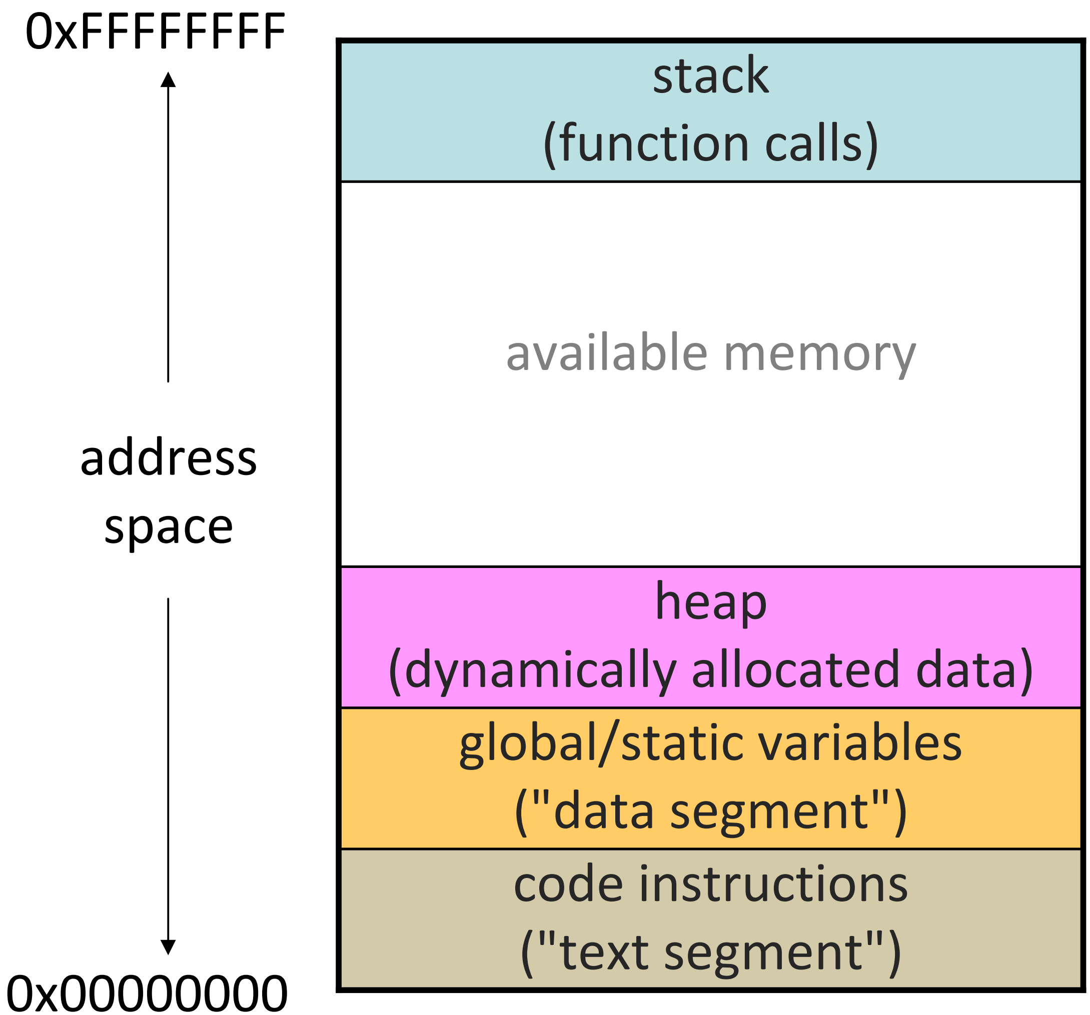
secondary/permanent storage
(hard disks, removable drives, network) — 500 GB

Virtual addressing

- each process has its own virtual address space of memory to use
  - each process doesn't have to worry about memory used by others
  - OS maps from each process's virtual addresses to physical addresses



Process memory layout



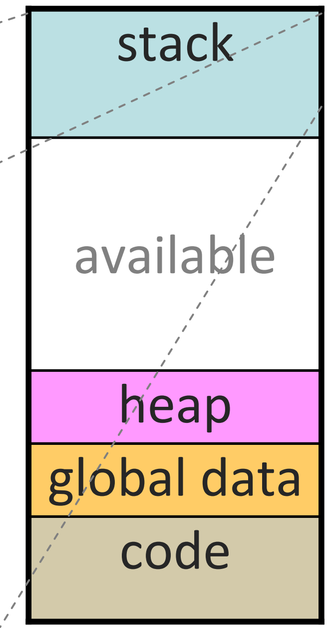
- when a process runs, its instructions/globals load into memory
- address space is like a huge array of bytes
  - total: 2^{32} bytes
  - each `int` = 4 bytes
- as functions are called, data goes on a **stack**
- dynamic data is created on a **heap**

Stack frames

- **stack frame** or **activation record**: memory for a function call
  - stores parameters, local variables, and **return address** to go back to

```
int f(int p1, int p2) {
    int x;
    int a[3];
    ...
    return x + y;
}
```

offset	contents
24	p2
20	p1
16	return address
12	a[2]
8	a[1]
4	a[0]
0	x



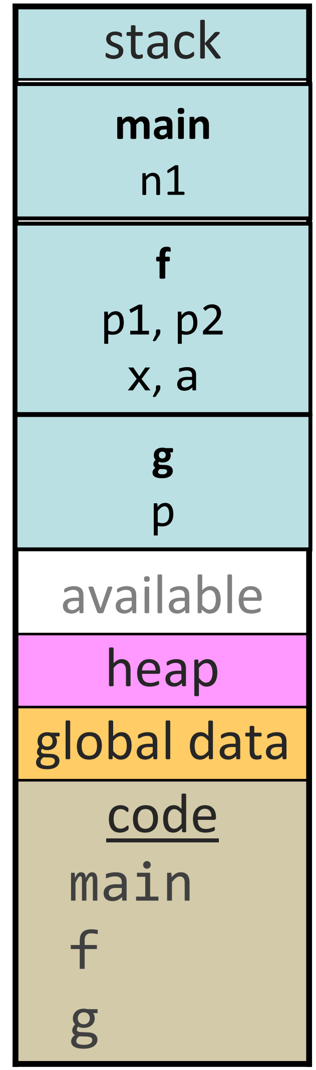
Tracing function calls

```
int main(void) {
    int n1 = f(3, -5);
    n1 = g(n1);
}

int f(int p1, int p2) {
    int x;
    int a[3];
    ...
    x = g(a[2]);

    return x + y;
}

int g(int param) {
    return param * 2;
}
```



The & operator

&*variable* produces ***variable***'s memory address

```
#include <stdio.h>

int main(void) {
    int x, y;
    int a[2];

    // printf("x is at %d\n", &x);
    printf("x    is at %p\n", &x);     // x    is at 0x0022ff8c
    printf("y    is at %p\n", &y);     // y    is at 0x0022ff88
    printf("a[0] is at %p\n", &a[0]);  // a[0] is at 0x0022ff80
    printf("a[1] is at %p\n", &a[1]);  // a[1] is at 0x0022ff84

    return 0;
}
```

- %p placeholder in `printf` prints a memory address in hexadecimal

OMG WTF BBQ

- array bounds are not enforced; can overwrite other variables

```
#include <stdio.h>

int main(void) {
    int x = 10, y = 20;
    int a[2] = {30, 40};

    printf("x = %d, y = %d\n", x, y);   // x = 10, y = 20

    a[2] = 999;   // !!!
    a[3] = 111;   // !!!
    printf("x = %d, y = %d\n", x, y);   // x = 111, y = 999

    return 0;
}
```

Segfault

- **segmentation fault** ("**segfault**"): A program crash caused by an attempt to access an illegal area of memory.

```
#include <stdio.h>

void f() {
    f();    // infinite recursion
}

int main(void) {
    f();
    return 0;
}
```

Output:

```
   Segmentation fault
```

```
#include <stdio.h>

int main(void) {
    int a[2];
    a[999999] = 12345;  //oob
    return 0;
}
```

Output:

```
   Segmentation fault
```

The sizeof operator

`sizeof(`***`type`***`)` or `(`***`variable`***`)` returns memory size in bytes

```
#include <stdio.h>

int main(void) {
    int x;
    int a[5];

    printf("int=%d, double=%d\n", sizeof(int), sizeof(double));
    printf("x    uses %d bytes\n", sizeof(x));
    printf("a    uses %d bytes\n", sizeof(a));
    printf("a[0] uses %d bytes\n", sizeof(a[0]));
    return 0;
}
```

Output:

```
int=4, double=8
x    uses 4 bytes
a    uses 20 bytes
a[0] uses 4 bytes
```

sizeof continued

- arrays passed as parameters do not remember their size

```
#include <stdio.h>

void f(int a[]);

int main(void) {
    int a[5];
    printf("a uses %d bytes\n", sizeof(a));
    f(a);
    return 0;
}

void f(int a[]) {
    printf("a uses %2d bytes in f\n", sizeof(a));
}
```

Output:

```
a uses 20 bytes
a uses  4 bytes in f
```

Pointers

```
type* name;                    // declare
type* name = address;          // declare/initialize
```

- **pointer**: A memory address that refers to another value.

```
int x = 42;
int* p;
p = &x;        // p stores address of x

printf("x  is %d\n",    x);   // x  is 42
printf("&x is %p\n", &x);   // &x is 0x0022ff8c
printf("p  is %p\n",  p);   // p  is 0x0022ff8c
```

- *caution*: declaring multiple pointers on one line is tricky:

```
int* p1, p2;    // incorrect =>  int* p1;  int p2;
int* p1, * p2;  // correct
```

Dereferencing pointers

```
*pointer                    // dereference
*pointer = value;           // dereference/assign
```

- **dereference**: To access the memory referred to by a pointer.

```
int x = 42;
int* p;
p = &x;       // p stores address of x

*p = 99;      // go to the int p refers to; set to 99

printf("x  is %d\n",    x);
```

Output:

```
x  is 99
```

* vs. &

- many students get * and & mixed up
  - & references (ampersand gets an address)
  - * dereferences (star follows a pointer)

```
int x = 42;
int* y = &x;
printf("x  is %d    \n",  x);    // x  is 42
printf("&x is %p\n", &x);        // &x is 0x0022ff8c
printf("y  is %p\n",  y);        // y  is 0x0022ff8c
printf("*y is %d    \n", *y);    // *y is 42
printf("&y is %p\n", &y);        // &y is 0x0022ff88
```

- What is *x ?

L-values and R-values

- **L-value**: Suitable for being on the *left*-side of an = assignment.
  - in other words, a valid memory address that can be stored into
- **R-value**: A value suitable for the *right*-side of an = assignment.

```
int x = 42;
int* p = &x;
```

- *L-values* : `x` or `*p` (store into x), `p` (changes what p points to)
  - not `&x`, `&p`, `*x`, `*(*p)`, `*12`
- *R-values* : `x` or `*p` (42), `&x` or `p` (`28fffc`), `&p` (`28fff8`)
  - not `&(&p)`, `&42`

Pass-by-value

- **value semantics**: Parameters' values are copied.
  - impossible to affect change on the original parameter variable

```
int main(void) {
    int a = 42, b = -7;
    swap(a, b);
    printf("a = %d, b = %d\n", a, b);
    return 0;
}

void swap(int a, int b) {
    int temp = a;
    a = b;
    b = temp;
}

Output:
a = 42, b = -7
```

Pass-by-reference

- **reference semantics**: Passed as references to / addresses of data.
  - can change the original parameter variable using the reference

```
int main(void) {
    int a = 42, b = -7;
    swap(&a, &b);
    printf("a = %d, b = %d\n", a, b);
    return 0;
}

void swap(int* a, int* b) {
    int temp = *a;
    *a = *b;
    *b = temp;
}

Output:
a = -7, b = 42
```