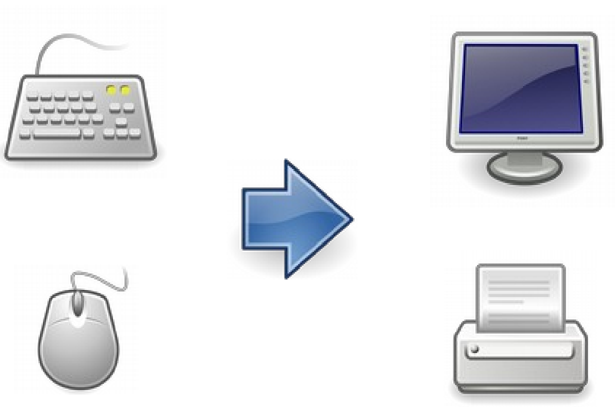
CS 261
Fall 2022

Mike Lam, Professor



Structs and I/O

Typedefs

- A `typedef` is a way to create a new type name
  - Basically a synonym for another type
  - Useful for shortening long types or providing more meaningful names
  - Names are usually postfixed with "`_t`"

```
typedef unsigned char byte_t;

byte_t b1, b2;
```

  - Use the `size_t` typedef (defined to be the same as `long unsigned int` in the stu headers) for non-negative sizes and counts

```
const size_t STR_SIZE = 1024;
```

Structs

- A `struct` contains a group of related sub-variables
  - New "kind" of type
  - Similar to classes from Java, but without methods and everything is “public”
  - Sub-variables are called fields
  - Struct variables are declared with `struct` keyword

```
struct vertex {
    double x;
    double y;
    bool visited;
};
```

```
int main()
{
    struct vertex p1;
    p1.x = 4.2;
    p1.y = 5.6;
    p1.visited = false;
}
```

```
double dist(struct vertex p1, struct vertex p2)
{
    return sqrt( (p1.x-p2.x)*(p1.x-p2.x) +
                 (p1.y-p2.y)*(p1.y-p2.y) );
}
```

Typedef structs

- Convention: create a typedef name for struct types
  - E.g., **`struct vertex -> vertex_t`**
  - More concise and readable
  - For projects, we'll provide structs and typedefs in headers

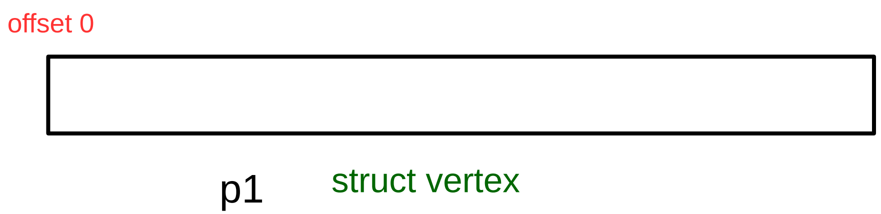
```
typedef struct vertex {
    double x;
    double y;
    bool visited;
} vertex_t;
```

```
int main()
{
    vertex_t p1;
    p1.x = 4.2;
    p1.y = 5.6;
    p1.visited = false;
}
```

```
double dist(vertex_t p1, vertex_t p2)
{
    return sqrt( (p1.x-p2.x)*(p1.x-p2.x) +
                 (p1.y-p2.y)*(p1.y-p2.y) );
}
```

Struct memory layout

- Fields are stored (mostly) contiguously in memory
  - Each field has a fixed offset from the beginning of the struct

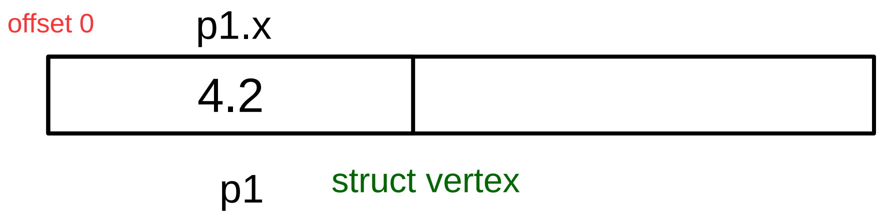



```
int main()
{
    vertex_t p1;
    p1.x = 4.2;
    p1.y = 5.6;
    p1.visited = false;
}
```

```
typedef struct vertex {
    double x;
    double y;
    bool visited;
} vertex_t;
```

Struct memory layout

- Fields are stored (mostly) contiguously in memory
  - Each field has a fixed offset from the beginning of the struct

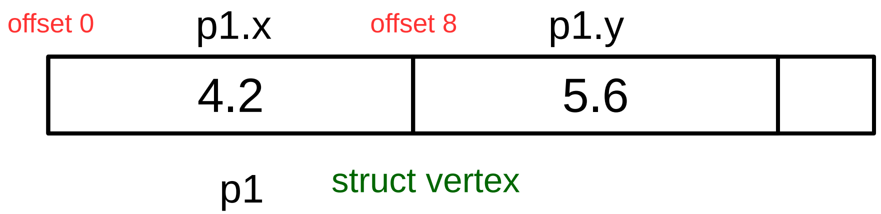



```
int main()
{
    vertex_t p1;
    p1.x = 4.2;
    p1.y = 5.6;
    p1.visited = false;
}
```

```
typedef struct vertex {
    double x;
    double y;
    bool visited;
} vertex_t;
```

Struct memory layout

- Fields are stored (mostly) contiguously in memory
  - Each field has a fixed offset from the beginning of the struct

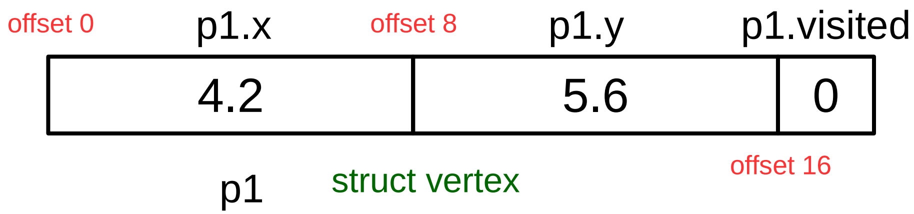



```
int main()
{
    vertex_t p1;
    p1.x = 4.2;
    p1.y = 5.6;
    p1.visited = false;
}
```

```
typedef struct vertex {
    double x;
    double y;
    bool visited;
} vertex_t;
```

Struct memory layout

- Fields are stored (mostly) contiguously in memory
  - Each field has a fixed offset from the beginning of the struct




```
int main()
{
    vertex_t p1;
    p1.x = 4.2;
    p1.y = 5.6;
    p1.visited = false;
}
```

```
typedef struct vertex {
    double x;
    double y;
    bool visited;
} vertex_t;
```

Struct memory layout

- Given the following code, how much space will be allocated for the "data" variable? Assume chars are one byte each and ints are four bytes each.

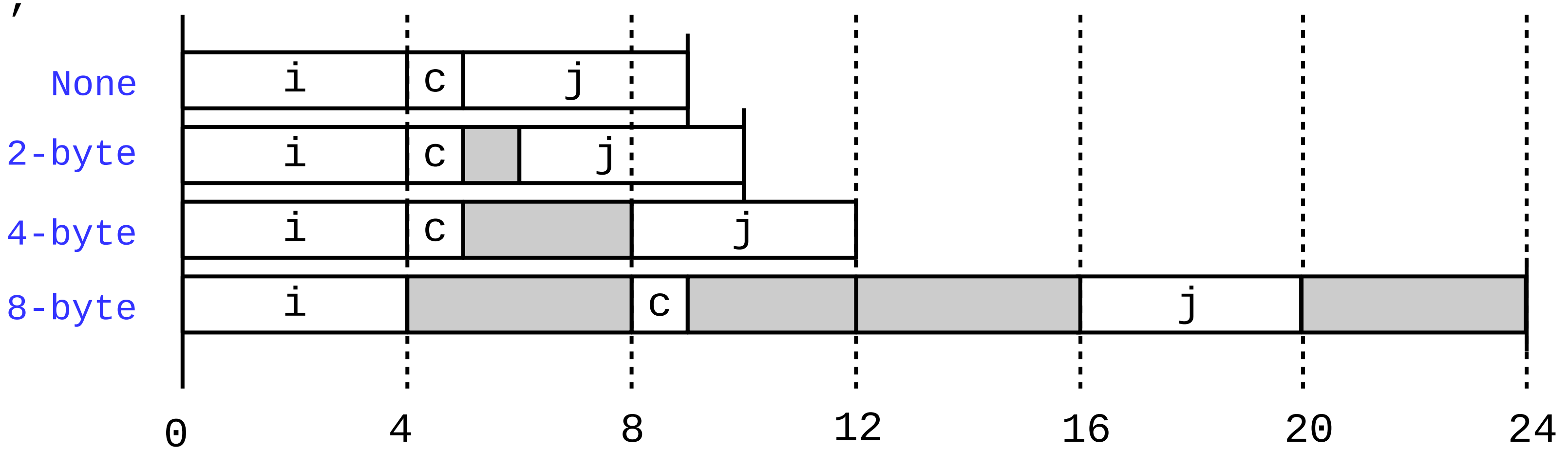
```
struct stuff {
    char a;
    char b;
    char c;
    int x;
} data;
```

  - A) 4 bytes
  - B) 7 bytes
  - C) 8 bytes
  - D) 16 bytes
  - E) There is not enough information to know.

Struct data alignment

- Alignment restrictions require addresses be *n*-divisible
  - E.g., 4-byte alignment means field offsets must be divisible by 4
  - Chosen by compiler based on hardware
  - Improves memory performance
  - Can be avoided in C using "`attribute (packed)`" (as in `elf.h`)

```
struct {
    int i;
    char c;
    int j;
} rec;
```



Function parameters

- In C, parameters are passed by value
  - Values are copied to a function-local variable at call time
  - Local changes are not visible to the caller unless returned
- It is expensive to pass large structs by value
  - Must copy the entire struct even if it is not all needed
  - Alternative: pass variables by reference using a pointer
  - Local changes **through the pointer** are visible to the caller
  - Local changes **to the pointer** are **not** visible to the caller
- Parameters can be passed as `const`
  - Shouldn't be changed by the function (checked by compiler)
  - Useful for ensuring you don't accidentally overwrite a by-reference parameter pointer

Struct pointers

- New "->" (arrow) operator dereferences a pointer to a struct and accesses a field in that struct

```
vertex_t v;
vertex_t *vp = &v;
(*vp).x = 1.0;          // set field "x"
vp->y = 2.0;            // set field "y"
```

```
typedef struct vertex {
    double x;
    double y;
    bool visited;
} vertex_t;
```

Faster!
(copy 8-byte pointer instead of 17-byte struct)

```
double dist(vertex_t *p1, vertex_t *p2)
{
    return sqrt( (p1->x – p2->x) * (p1->x - p2->x) +
                 (p1->y – p2->y) * (p1->y - p2->y) );
}
```

Aside: Enums

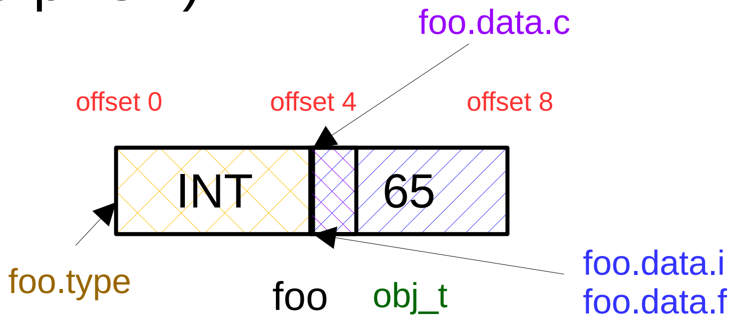
- An enumeration is a type where all values are listed
  - Declared in C using `enum` keyword
  - In C, the actual values are stored as integers
  - Can assign integer values if desired
  - Primary advantage: named constants

```
typedef enum {
   MON = 1, TUE, WED, THU, FRI, SAT, SUN
} day_t;

// essentially the same as: int midterm_day = 3;
day_t midterm_day = WED;
```

Aside: Unions

- A union is also a variable that can store data of different types
  - One “thing”, but it could be multiple sizes depending on what kind of “thing” it currently is (so context is even more important!)
  - All “fields” start at offset zero
  - Generally a bad idea! (circumvents the type system in C)
  - Can be used to do OOP in C (i.e., polymorphism)




```
typedef enum { CHAR, INT, FLOAT } objtype_t;

typedef struct {
    objtype_t type;
    union {
        char c;
        int i;
        float f;
    } data;
} obj_t;
```

```
obj_t foo;

foo.type = INT;
foo.data.i = 65;

printf(“%c”, foo.data.c);   ← VALID!
```

File I/O

- C standard library provides opaque file stream handles: `FILE*`
  - Internal representation is implementation-dependent
- File manipulation functions:
  - Open a file: `fopen`
    - Mode: read (‘`r`’), write (‘`w`’), append (‘`a`’)
  - Read a character: `fgetc`
  - Read a line of text: `fgets`
  - Read binary data: `fread`
  - Set current file position: `fseek`
  - Write formatted text: `fprintf`
  - Write binary data: `fwrite`
  - Close a file: `fclose`

These are all documented in the function reference (on website)

Standard I/O

- Standard "file" streams: `stdin`, `stdout`, `stderr` (type is `FILE*`)
  - Like `System.in`, `System.out`, and `System.err` in Java
  - Available to all programs; no need to open or close
  - Flushed when newline (‘`\n`’) encountered (included by `fgets`!)
  - Use CTRL-D to indicate end-of-file when typing input from the terminal
- Formatted input/output (`scanf` / `printf`)
  - Variable number of arguments (varargs)
  - Format string and type specifiers:
    - %d for signed int, %u for unsigned int
    - %c for chars, %s for C strings (`char *`, passing NULL is undefined behavior)
    - `%f` or %e for float, %x for hex, %p for pointer
    - Prepend ‘`l`’ for long or ‘`ll`’ for long long (e.g., `%lx` = long hex)
    - Include number for fixed-width field (e.g., `%20s` for a 20-character field)
    - Many more useful options; see documentation for details

Standard I/O

- What is wrong with the following code?

```
char buffer[20];

fgets(buffer, 30, stdin);
```

  - A) The buffer is not initialized before calling fgets.
  - B) The buffer is the wrong size.
  - C) The buffer size parameter is wrong.
  - D) The call to fgets has too few parameters.
  - E) There is nothing wrong with this code.

Security issues

- Input: beware of buffer overruns
  - Like carelessly copying strings, reading input improperly is a common source of security vulnerabilities
  - Best practice: declare a fixed-size buffer and use “safe” input functions (e.g., `fgets`)
  - You may NOT use unsafe functions in this course! (e.g., `gets`)
  - Here is a partial list of unsafe functions; see function reference on website for complete list

UNSAFE	Safer alternative
`atoi`	`strtol`
`atof`	`strtod`
`gets`	**`fgets`**
`strcat`	`strncat`
`strcpy`	`snprintf`

Be careful with code that you find online—never use code that you don't fully understand or that you haven’t verified to be safe.

Projects

- You are now a C programmer!
  - We have now covered all topics necessary for P0 and P1
  - There is certainly more to learn about C, but we have covered all the necessary topics for this course
  - References and resources on our website
  - Next time, we'll cover a few more useful things and some technicalities that we've glossed over
  - Now all you need is practice :)

Exercise

- Let's write a simple version of the 'cat' utility
  - Copy all text from standard in to standard out
    - No need to open/close a “real” file
  - Handle a line at a time
    - To reduce memory requirements
  - What is the basic form of our code?
    - What variable(s) will we need?

Simple “cat” program

```
#include <stdio.h>

int main (int argc, char **argv)
{
    const int BUF_SIZE = 1024;
    char buffer[BUF_SIZE];

    while (                                      ) {
        printf("%s", buffer);
    }

    return 0;
}
```

CS 261 C function reference:

w3.cs.jmu.edu/lam2mo/cs261/c_funcs.html

File I/O

- `FILE* fopen (char *filename, char *mode)`
  Open a file (modes: 'r', 'w', 'a')

- `int fgetc (FILE *stream)`
  Read a single character from a file

- `char* fgets (char *str, int count, FILE *stream)`
  Read a line of text from a file

- `int fscanf (FILE *stream, char *format, ...)`
  Read formatted data from a file (`scanf` assumes `stdin`)

- `size_t fread (void *buffer, size_t size, size_t count, FILE *stream)`
  Read (size x count) bytes from a file

- `int fseek (FILE *stream, long offset, int origin)`
  Set the current file position (origin: '`SEEK_SET`', '`SEEK_CUR`')

- `int fprintf (FILE *stream, char *format, ...)`
  Write formatted text to a file (`printf` assumes `stdout`)

- `size_t fwrite (void *buffer, size_t size, size_t count, FILE *stream)`
  Write (size x count) bytes to a file

- `int fclose (FILE *stream)`
  Close a file

Documentation

fgets

the 'restrict' keyword means "this is the only active pointer to this variable"

Defined in header <stdio.h>

```
char *fgets( char          *str, int count, FILE          *stream );   (until C99)
char *fgets( char *restrict str, int count, FILE *restrict stream );   (since C99)
```

Reads at most `count - 1` characters from the given file stream and stores them in the character array pointed to by `str`. Parsing stops if end-of-file occurs or a newline character is found, in which case `str` will contain that newline character. If no errors occur, writes a null character at the position immediately after the last character written to `str`.

The behavior is undefined if `count` is less than `1`.

Parameters

str - pointer to an element of a char array

count - maximum number of characters to write (typically the length of `str`)

stream - file stream to read the data from

Return value

`str` on success, null pointer on failure.

If the failure has been caused by end-of-file condition, additionally sets the *eof* indicator (see `feof()`) on `stream`. The contents of the array pointed to by `str` are not altered in this case.

If the failure has been caused by some other error, sets the *error* indicator (see `ferror()`) on `stream`. The contents of the array pointed to by `str` are indeterminate (it may not even be null-terminated).

Simple “cat” program

```
char *fgets( char *restrict str, int count, FILE *restrict stream );    (since C99)
```

Return value

`str` on success, null pointer on failure.

```
#include <stdio.h>

int main (int argc, char **argv)
{
    const int BUF_SIZE = 1024;
    char buffer[BUF_SIZE];

    while (                                        ) {
        printf("%s", buffer);
    }

    return 0;
}
```

Simple "cat" program

```
char *fgets( char *restrict str, int count, FILE *restrict stream );    (since C99)
```

```
#include <stdio.h>

int main (int argc, char **argv)
{
    const int BUF_SIZE = 1024;
    char buffer[BUF_SIZE];

    while (fgets(       ,          ,       ) != NULL) {
        printf("%s", buffer);
    }

    return 0;
}
```

Simple “cat” program

```
char *fgets( char *restrict str, int count, FILE *restrict stream );    (since C99)
```

```
#include <stdio.h>

int main (int argc, char **argv)
{
    const int BUF_SIZE = 1024;
    char buffer[BUF_SIZE];

    while (fgets(buffer,          ,        ) != NULL) {
        printf("%s", buffer);
    }

    return 0;
}
```

Simple "cat" program

```
char *fgets( char *restrict str, int count, FILE *restrict stream );    (since C99)
```

```
#include <stdio.h>

int main (int argc, char **argv)
{
    const int BUF_SIZE = 1024;
    char buffer[BUF_SIZE];

    while (fgets(buffer, BUF_SIZE,        ) != NULL) {
        printf("%s", buffer);
    }

    return 0;
}
```

Simple “cat” program

```
#include <stdio.h>

int main (int argc, char **argv)
{
    const int BUF_SIZE = 1024;
    char buffer[BUF_SIZE];

    while (fgets(buffer, BUF_SIZE, stdin) != NULL) {
        printf("%s", buffer);
    }

    return 0;
}
```

Exercise

- Write a program that reverses every line from standard in (`stdin`)
  - Reminder: to compile your program (after creating `rev.c`):

```
gcc -o rev rev.c
```

  - To test your program (after creating `input.txt`):

`./rev <input.txt` (or just `./rev` and type text followed by CTRL-D)

Hint: use `fgets()` to read the input a line at a time into a char array, printing the characters in reverse after reading each line

`char* fgets (char *str, int count, FILE *stream)`
Read a line of text input from a file (returns str, count is max chars)

`size_t strlen (char *str)`
Calculate the length of a null-terminated string

Sample input:

```
Hello, world!
My name is Bob.

ENOD
```

Sample output:

```
!dlrow ,olleH
.boB si eman yM

DONE
```