Structs and I/O
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"

```c
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

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

```c
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

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

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

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

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

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

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

```c
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

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

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

```c
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) );
}
```

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

```c
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)

```c
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
What is wrong with the following code?

```c
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

<table>
<thead>
<tr>
<th>UNSAFE</th>
<th>Safer alternative</th>
</tr>
</thead>
<tbody>
<tr>
<td>atoi</td>
<td>strtol</td>
</tr>
<tr>
<td>atof</td>
<td>strtod</td>
</tr>
<tr>
<td>gets</td>
<td>fgets</td>
</tr>
<tr>
<td>strcat</td>
<td>strncat</td>
</tr>
<tr>
<td>strcpy</td>
<td>snprintf</td>
</tr>
</tbody>
</table>

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

```c
#include <stdio.h>

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

    while (/* TODO: Implement cat functionality */ ) {
        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

Defined in header `<stdio.h>`

```c
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

```c
#include <stdio.h>

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

    while (1) {
        printf("%s", buffer);
    }

    return 0;
}
```
#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;
}
Simple “cat” program

```
#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;
}
```
#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;
}
#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