11. Low Level File Input / Output
ENEE 140

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Today's Lecture

- Where we've been
  - Scalar data types
  - Arrays and strings
  - Functions
  - Random number generation
  - Control flow
  - Structuring complex programs
  - Formatted and character file I/O
- Where we're going today
  - Low Level File Input/Output
- Where we're going next
  - Sorting

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Review: Nested Loops

- You can nest loops

```
for (i=1; i<=3; i++) {
 for (j=1; j<=3; j++) {
    printf("%dx%d=%2d\t", i, j, i*j);
 }
 printf("\n");    // ready for next line
}
```

- Output

```
1x1= 1  1x2= 2    1x3= 3
2x1= 2  2x2= 4    2x3= 6
3x1= 3  3x2= 6    3x3= 9
```

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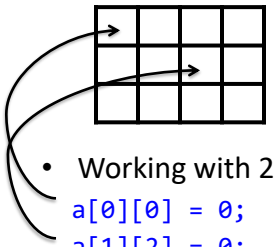
Two-Dimensional Arrays

- Two-dimensional arrays

`int a[3][4];` int array with 3 rows and 4 columns (12 elements)

  - Think of this as 3 arrays with 4 elements each



- Working with 2D arrays

`a[0][0] = 0;` access element on first row and first column

`a[1][2] = 0;` access element on row 1 and column 2

`a[0][4] = 0;` error: index out of bounds

`a[3][0] = 0;` error: index out of bounds

  - Use 2D arrays to represent matrices

- Arrays with 3, 4, 5, etc. dimensions

`int a[2][3][4];` 3D array with 24 elements

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Review: Binary Representation

- Numbers in base B $N = \sum n_i \cdot B^i$
- Examples
  - Binary (base 2): digits 0 and 1
    - $0011_2 = 1*2 + 1 = 3_{10}$
  - Octal (base 8): digits 0, 1, 2, 3, 4, 5, 6, 7
    - $14_8 = 1*8 + 4 = 12_{10}$
- Geeky joke:
  - *Why do programmers confuse Halloween and Christmas?*

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Review: Bitwise Operations

- Operators for manipulating bits:
  - & bitwise AND
  - | bitwise OR
  - ^ bitwise XOR (exclusive OR)
  - << left shift
  - >> right shift
  - ~ flip all bits (unary)
- Common usage: bit masks
  - `a = a & 1;` set all but lowest order bit to 0
  - `a = a | 1;` set lowest order bit to 1;
  - `b = (a>>2) & 1;` find value of bit b2 from b31 … b3 b2 b1 b0

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High Level and Low Level I/O

- We've seen: high level I/O
  `FILE *file;` can call `fopen, fscanf, getc, ungetc`, etc. on `file`
- `FILE*` operations are implemented using low-level file access facilities provided by the UNIX system interface
  - The FILE data structure maintains a buffer of bytes
  - `ungetc()` pushes back a character into the buffer
    - Needed for implementing `fscanf()`
  - The buffer also helps performance
- Low level I/O
  - Key difference: no `ungetc` => no formatted I/O
  - Low-level I/O functions read and write raw bytes

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File Descriptors

- Instead of a `FILE*`, the UNIX system interface represents files with a non-negative integer identifier
  - This integer is called a **file descriptor**
  - The `open()` function returns a file descriptor
- Three file descriptors are open when a program starts
  - `0`: standard input (stdin)
  - `1`: standard output (stdout)
  - `2`: standard error (stderr)

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Low Level File I/O

- Functions for low-level file I/O manipulate file descriptors

```
#include <fcntl.h>
#include <unistd.h>

char buffer[N];                              data buffer
int fd1 = open("file1.txt", O_RDONLY);       open fd1 for reading
int n_read =                                 returns num. bytes read
 read(fd1, buffer, sizeof(buffer));          read up to N bytes into buffer

int fd2 = open("file2.txt", O_WRONLY);       open fd2 for writing
int n_written =                              returns num. bytes written
 write(fd2, buffer, sizeof(buffer));         write up to N bytes from buffer
```

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Some Functions for Low-Level I/O

`int open(const char *pathname, int flags, mode_t mode);`

- Opens a file and returns a file descriptor
- `flags` must include one of `O_RDONLY`, `O_WRONLY`, or `O_RDWR`
- `flags` may also be bitwise-or'd with `O_APPEND` (write after end of file), `O_TRUNC` (if file exists, discard current data), `O_CREAT` (create the file if it doesn't exist), and a few others (full list in man page)
- `mode` must be provided with `O_CREAT` and specifies the file permissions (e.g. `0600` for giving RW permissions to the file owner)

`int creat(const char *pathname, mode_t mode);`

- Equivalent to `open()` with `O_CREAT|O_WRONLY|O_TRUNC` for flags

`FILE *fdopen(int fd, const char *mode);`

- Associates a `FILE*` stream to an existing file descriptor

`int unlink(const char *pathname);`

- Deletes a file from the filesystem

`off_t lseek(int fd, off_t offset, int whence);`

- Changes position in file

`int close(int fd);`

- Closes the file associated with fd

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errno

- We've seen:
  `perror(msg);` prints a message describing the error after msg
- You can also handle errors programmatically

```
#include <errno.h>
…                          some I/O code that may encounter errors

if (errno == EACCES)
  …                        handle "Permission denied" error
```

- The value of the `errno` variable is the last error that occurred
  - Only meaningful if checked after the function call that encountered the error
  - Manual pages for most functions specify possible values for `errno`
- **Good programming practice: check the return values of all the functions you invoke – an error may have occurred!**

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Unions

- Composite type that stores variables of different types in the same memory location

```
union {
  int i;
  float f;
} u;
u.i = 1;          assign value to int component of u
u.f = 2.0;        overwrites u.i
```

- **Avoid unions!**

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Review of Lecture

- What did we learn?

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Next Steps

- Next lecture
  - Sorting
- Assignments for this week
  - Try to understand how the shellsort implementation from **K&R Chapter 3.5** works; read **Chapter 5.11** for how to use the library function qsort()
  - No quiz
  - Weekly challenge: **selection_sort.c**
  - Homework: `lab11.pdf` (on http://ter.ps/enee140), due on Friday at 11:59 pm

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