LECTURE NOTES IN CIS300

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SECTION 2: C/C++ PROGRAMMING

REFERENCES

- "Unix Programming Tools", [link]
- Computer Systems: A Programmer's Perspective, Randal E. Bryant and David R. O'Hallaron, Chapter 1, [online pdf]

HELLOWORLD C

```c
#include <stdio.h> //include header file for preprocessing
int y = 3; //initializing a global variable
//extern int y; //declaring global  variable
int main() //defining main function
{
    int x = 0; //local var. (def. & init.), literal,
    printf("helloworld: y = %d\n",y); //function (invocation)
    return 0;
}
```

- `printf` is a function
  - the first argument is *format string*
- header files: `stdio.h`

LIFE CYCLE OF A VARIABLE/FUNCTION

	variable	function
declare	`extern int x;`	`void foo();`
define	`int x;`	`void foo(){}`
initialize	`int x=6;`	
reference	`y=x;x=1;`	`foo();` (invocation)
destroy		

COMPILATION & EXECUTION: BASICS

- GCC: GNU Compilation Collection
- In your terminal, run the following commands

```
gcc hello.c
./a.out
```

EXERCISES

- Write a C program that prints out your name. Compile and execute it in Ubuntu. Submit the C program to BB.
- Write a C program that computes the sum of 1,2,3,...,956. Compile and execute the program in Ubuntu. Submit the C program to BB.

GCC

COMPILATION (1)

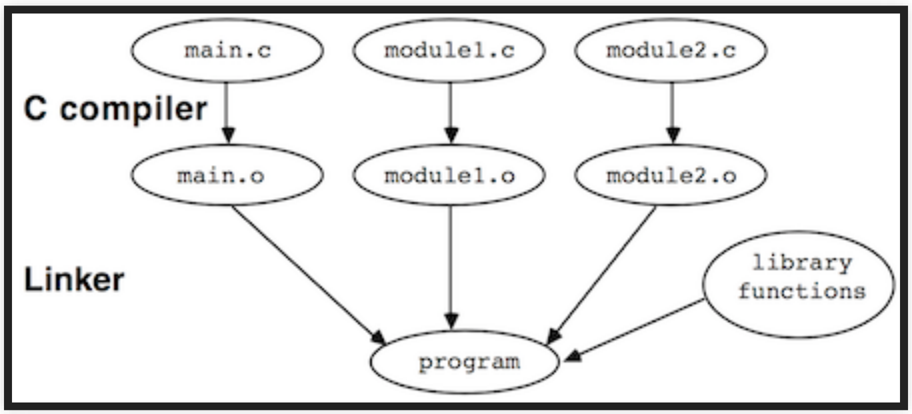
- Two steps of compilation:
  - *compiling*: text `.c` file to relocatable `.o` (object) file
  - *linking*: multiple relocatable `.o` files to one executable `.o` file
    - *symbol*: reference to link construct (declaration) in one `.o` file to construct (definition) in another `.o` file

COMPILATION (2)

```
gcc hello.c -o a.out
gcc -S hello.c -o hello.s #compiler
gcc -c hello.s -o hello.o #assembler
gcc hello.o -o a.out #linker
```

- `gcc` is a compilation system

1. **preprocessor**: from source file to source
2. **compiler**: from source to assembly file
   - *assembly file*
3. **assembler**: from assembly file to relocatable object file
4. **linker**: from multiple objects to an executable object


main.c
module1.c
module2.c
C compiler
main.o
module1.o
module2.o
Linker
library functions
program

Linker

COMPILING MULTIPLE C PROGRAMS

In `file1.c`:

```c
#include <stdio.h>
extern void foo();
int main(){
    printf("main();\n");
    foo();
}
```

In `file2.c`:

```c
#include <stdio.h>
void foo(){
    printf("foo();\n");
}
```

COMPILING MULTIPLE C PROGRAMS (2)

```
gcc file1.c file2.c
# try this?
gcc file1.c
gcc file2.c
```

COMPILING MULTIPLE C PROGRAMS (3)

```
gcc -c file1.c # compiler & assembler
gcc -c file2.c # compiler & assembler
gcc file1.o file2.o # linker
```

Or

```
gcc -S file1.c # compiler
gcc -c file1.s # assembler
gcc -S file2.c # compiler
gcc -c file2.s # assembler
gcc file1.o file2.o # linker
```

LINK LIBRARY FILES

```
gcc -S file1.c # compiler
gcc -c file1.s # assembler
gcc file1.o file2.o # linker
```

```
mv file2.o ../libfile2.a
gcc file1.o ../libfile2.a # linker
gcc file1.o -L.. file2.o # linker
gcc file1.c -L.. file2.o # linker
```

- Gcc flag: `-Ldir` `-lmylib` for library to link

INCLUDE HEADER FILE

In `header1.h`:

```
extern void foo();
```

In `file11.c`:

```
#include <stdio.h>
#include "header1.h"
int main(){
    printf("main();\n");
    foo();
}
```

```
gcc file11.c file2.c
```

INCLUDE HEADER FILE (2)

Header file in another directory

```
mv header1.h ..
#will the following work?
gcc file11.c file2.c
gcc -I .. file11.c file2.c
```

- Gcc flag for searching header file: `-I path`
  - `path` is where the header file is

GCC FLAGS (SUMMARY)

- `-c` for specifying using gcc as a compiler
- `-o` for specifying the name of output file
- `-Ldir -lmylib` for linking a library
  - search library file `dir/libmylib.a` for sovling symbols (functions, global variables) when linking
- `-I` for `#include`
  - header file (storing declarations)
- `-Wall`, w for warning
- `-g` for debug (later): `gcc -g file1.c file2.c`
- ref [link]

EXERCISE

- Write two C files:
  - `filea.c` defines functions `main()` and `bar()`
  - `fileb.c` defines function `foo()`
  - function `main()` calls `foo()`
  - function `foo()` calls `bar()`
  - Compile your program.
  - Submit the program and commands to BB.

MAKE AND MAKEFILE

DOWNLOAD COURSE REPO.

To download course repository, type the following commands

```
sudo apt-get update
sudo apt-get upgrade
sudo apt-get install git
git clone https://github.com/SUCourses/cis300-18spring.git
```

MAKEFILE: DEPENDENCY RULES

- `make` is a tool for project management in shell
- `Makefile` is the configuration file that tells `make` what to do
- A `Makefile` consists of a series of dependency rules
- Each dependency. rule expresses IFTTT logic (if-this-then-that)

```
target: files/objects
(tab)commands
```

There is a **tab** before the commands

HELLOWORLD `MAKEFILE`

In `Makefile` (related files are in dir. `demos/mar7`)

```
all:
    gcc file1.c file2.c
```

To run it, type following command in a terminal

```
make
```

(Try change `file.c`, and `make` it again).

`MAKEFILE` OF MULTIPLE RULES

```
c:
    gcc file1.c file2.c

exec: c
    ./a.out

clean:
    rm *.o *.out
```

Note there are empty lines btwn. two rules.

USE `MAKEFILE` TO LINK (1)

Recall how to run compiler, assembler and linker

```
gcc -c file1.c # compiler & assembler
gcc -c file2.c # compiler & assembler
gcc file1.o file2.o # linker
```

USE `MAKEFILE` TO LINK (2)

A `Makefile` can easily manage different "targets" - It does compiling, assembling and linking separately

```
link: file1.o file2.o
    gcc file1.o file2.o

file1.o: file1.c
    gcc -c file1.c

file2.o: file2.c
    gcc -c file2.c
```

```
make
make
```

USE `MAKEFILE` TO LINK (3)

Use a default rule to compile individual C file

```
link: file1.o file2.o
    @gcc file1.o file2.o
```

```
make
make
```

- `@` used to hide the command in printout.

`MAKEFILE`: USING VARIABLES

```
SRCS = file1.c file2.c
OBJS = $(SRCS:.c=.o)
CFLAGS = -g -Iheaders
#LDFLAGS = -L. -lxxx

link: $(OBJS)
	$(CC) $(LDFLAGS) $(OBJS)
```

`MAKEFILE`: USING VARIABLES (2)

- A Makefile variable is a text string
- There're standard variables
  - `CC` is equal to `gcc` (the compiler)
  - `OBJS = $(SRCS:.c=.o)`:
    - This incantation says that the object files have the same name as the .c files, but with .o extension
  - `LDFLAGS` is the linker flag of library search path (`-L`)
  - `CFLAGS` is the default compiling flags

EXERCISE

1. Write a `Makefile` such that `make` always clean .o files, recompiles all .c files and executes the new .o file.
2. Write a `Makefile` such that `make link` will compile a `file.c` file against a library file `libxxx.a`

GDB

REFERENCES

- "Reviewing gcc, make, gdb, and Linux Editors", [pdf]
- "Unix Programming Tools", [link]

A BUGGY C PROGRAM

```c
#include<stdio.h> //printf
int array_stack[] = {0,1,2};
int main(){
  int sum; // local variable
  for(int i=0; i<=3; i++){
    sum += array_stack[i];
  }
  printf("sum = %d\n", sum);
  return 0;
}
```

USE GDB TO FIND BUG

- Installing gdb
  - on MacOS: [youtu.be/Vj33vsrDkE80]
  - on Ubuntu: `sudo apt-get install gdb`
- Compile: `gcc -g`
- Run gdb: `gdb a.out`

GDB COMMAND: CONTROL EXECUTION

- CPU executes a C program, statement by statement
- Breakpoint is a GDB mechanism to control where CPU should pause execution
  - `break/b` is a GDB command to set breakpoint.
  - `break/b file:n`|`fn`|`file:fn`: breakpoint can be file:line number (`n`), function name or file:function name.
  - `disable/enable/delete` are GDB commands to disable/enable/delete a breakpoint
  - `disable/enable/delete i`: i is the index of breakpoint

GDB COMMAND: CONTROL EXECUTION (2)

- Stepping is a GDB mechanism to control the CPU execution step by step.
  - `run/r`: start to run the program until next breakpoint or the end of program.
  - `next/n`: run just the next statement (step over a function call)
  - `continue/c`: continue the execution until the next breakpoint

GDB COMMAND: EXAMINE RUNTIME

- Examine runtime data
  - `print v`/`p v`: print variable `v`
- Examine code (with `gcc -g`)
  - `list`/`l`
- Examine execution environment: e.g. stack (later)

GDB COMMANDS

functionality	commands
breakpoints	`b`,`disable/enable/delete breakpoi`
stepping	`r`,`s`,`n`,`c`,`finish`,`return`
examine_data	`p/i v`,`display/undisplay`,`watch`,`set`
examine_code	`list`
examine_stack	`bt`,`where`,`info`,`up/down`,`frame`
misc.	`editmode vi`, `b fn if expression`, `h` disassembler, `shell cmd`

DEMO

- Debug the following program using gdb

```
#include<stdio.h> //printf
int array_stack[] = {0,1,2};
int main(){
  int sum; // local variable
  for(int i=0; i<=3; i++){
    sum += array_stack[i];
  }
  printf("sum = %d\n", sum);
  return 0;
}
```

EXERCISE

- Exercise: Debug the following program using gdb, upload the correct program to BB.

```c
#include<stdio.h>
int main() {
    int x = 5;
    int y = 3;
    int z = x - y;
    int a = x * y;
    int b = a - 7*z;
    b--;
    int c = z + y;
    int d = c / b;
    int e = a + 12;
    int f = e - b;
    printf("%d\n",f);
}
```

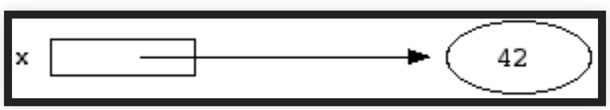
POINTER IN C

REFERENCES

- Pointer Basics: [http://cslibrary.stanford.edu/106/]
- Point fun with Binky: [http://cslibrary.stanford.edu/104/]

C POINTER

- A C pointer is a C variable that stores the reference to something.
  - "something", called pointee, is usually another variable.
- In the figure below, a pointer variable named `x` stores a reference to a "pointee" variable of value `42`.



pointer pointee

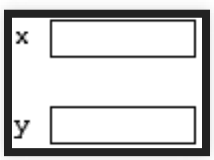
POINTER OPERATIONS

- Definition/initialization: `int *p1 = p2;`
- Assignment: `p1 = p2;`
- Dereference: `*p = 3`
- Get reference of: `&a`
  - get the *address* (memory location) of variable a

```
#include<stdio.h>
int main(){
    int a = 10;
    int * p = & a;
    int b = *p;
    printf("a=%d,b=%d,*p=%d,p=%p\n",a,b,*p,p);
}
```

BINKY'S CODE (1)

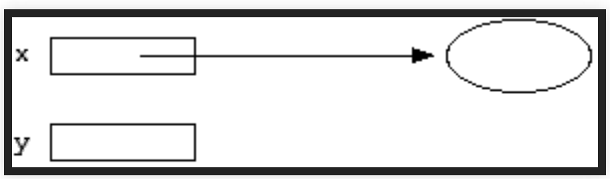
```
void main() {
    int*    x;  // Allocate the pointers x and y
    int*    y;  // (but not the pointees)
}
```



Allocate pointer

BINKY'S CODE (2)

```
void main() {
    int*    x;  // Allocate the pointers x and y
    int*    y;  // (but not the pointees)
    x = malloc(sizeof(int));    // Allocate an int pointee,
                                // and set x to point to it
}
```



Allocate pointee

BINKY'S CODE (3)

```
void main() {
    int*    x;  // Allocate the pointers x and y
    int*    y;  // (but not the pointees)
    x = malloc(sizeof(int));    // Allocate an int pointee,
                                // and set x to point to it
    *x = 42;    // Dereference x to store 42 in its pointee
}
```

Dereference pointer

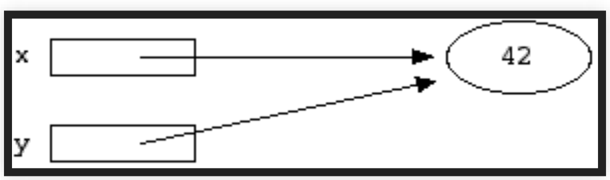
BINKY'S CODE (4)

```
void main() {
    int*    x;  // Allocate the pointers x and y
    int*    y;  // (but not the pointees)
    x = malloc(sizeof(int));    // Allocate an int pointee,
                                // and set x to point to it
    *x = 42;    // Dereference x to store 42 in its pointee
    *y = 13;    // CRASH -- y does not have a pointee yet
}
```

Dereference failure

BINKY'S CODE (5)

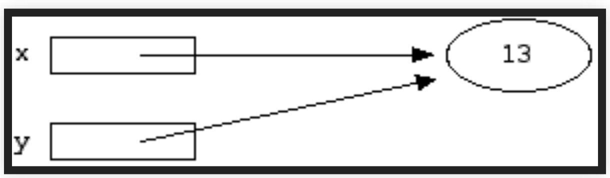
```
void main() {
    int*    x;  // Allocate the pointers x and y
    int*    y;  // (but not the pointees)
    x = malloc(sizeof(int));    // Allocate an int pointee,
                                // and set x to point to it
    *x = 42;    // Dereference x to store 42 in its pointee
    *y = 13;    // CRASH -- y does not have a pointee yet
    y = x;      // Pointer assignment sets y to point to x's pointee
}
```



Pointer assignment

BINKY'S CODE (6)

```
void main() {
    int*    x;  // Allocate the pointers x and y
    int*    y;  // (but not the pointees)
    x = malloc(sizeof(int));    // Allocate an int pointee,
                                // and set x to point to it
    *x = 42;    // Dereference x to store 42 in its pointee
    *y = 13;    // CRASH -- y does not have a pointee yet
    y = x;      // Pointer assignment sets y to point to x's pointee
    *y = 13;    // Dereference y to store 13 in its (shared) pointee
}
```



Deference pointer

LIFE CYCLE OF A `C` POINTER

	pointer	variable	fur
declare	`extern int * p`	`extern int x`	`vo`
define	`int *p;`	`int x`	`vo`
initialize	`int *p=&a;`	`int x=6`	
	`int*q=malloc(7)`		
(de)reference	`*p=x;x=*p`	`y=x`	`fo`
destroy	`delete p`		

EXERCISE

- Do the following to complete the code snippet at the bottom. Then compile and execute your program. Submit the completed program to BB.
  1. define two pointers `p1` and `p2`, both pointing to variable `x`.
  2. Use `p1` to update `x`'s value to 5.
  3. Then use `p2` to read the value of variable `x` and `printf` it on terminal.

```
#include<stdio.h>
int main(){
    int x = 4;
    // To complete the program below:


}
```

C POINTER AND DATA TYPES

DATA TYPE

- C is a typed language
- Data type in C determines:
  - How much space to allocate for storing a variable in memory
  - How to interpret bit-string stored in the memory
  - How to carry out the arithmetic on primitive types

PRIMITIVE TYPES

- types: signed, unsigned, long long, float, char

type	signed	unsigned	short	long long	float	char
`sizeof()`	4	4	2	8	4	1

- unsigned: a 32-bit unsigned integer, value from 0 to $2^{32} - 1$.
- signed: a 32-bit signed integer, value from -2^{31} to $2^{31} - 1$.
  - first bit determines whether negative
- Typecasting: convert the type of a variable.
  - `int x = 1; double f = (double) x;`

DEMO 1: TYPE INTERPRETATION

```
#include<stdio.h>
int main(){
  unsigned int u = 2147483649;
  int v = (int) u;
  printf("unsigned vs signed: %ud,%d\n",u,v);

  int i=1;
  float f = (float) i;
  printf("float vs int: %f,%d\n",f/3,i/3);
}
```

DEMO 2: DATA TYPE SIZE

```
#include<stdio.h>
int main(){
    signed int a;
  unsigned int b;
  short c;
  long long d;
  float e;
  char f;
  printf("signed int: %lu\n", sizeof(a));
  printf("unsigned int: %lu\n", sizeof(b));
  printf("short: %lu\n", sizeof(c));
  printf("long long: %lu\n", sizeof(d));
  printf("float: %lu\n", sizeof(e));
  printf("char: %lu\n", sizeof(f));
  return 0;
}
```

POINTER AND ARRAY

- An array in C stores a list of elements in adjacent memory locations.
- Use pointer to access array element
  - Pointer type: `char *`, `int *`
  - Pointer arithmetic:
    - `int * p = array; p += 1;`
    - `int pp = array; pp += sizeof(int);`

```
#include<stdio.h>
int main(){
    int a[] = {2,1,0};
    int *b = a; // b points to the first element in a
    unsigned long c = (unsigned long)a;//long
    for (int i=0; i<3; i++){
        printf("%d,%d,%d,%d,%d\n",a[i],*(b+i),*(a+i),b[i],*((int *)(c
    }
}
```

FUNCTION POINTER

- Two classes of pointers
- Data pointer: pointer to variable, array
- Code pointer: function pointer

```c
#include <stdio.h>  /* for printf */
// https://en.wikipedia.org/wiki/Function_pointer
double cm_to_inches(double cm) {
  return cm / 2.54;
}
int main(void) {
  double (*func1)(double) = cm_to_inches;
  printf("%f\n", func1(15.0));
  return 0;
}
```

EXERCISE

1. Write a C program that defines function `void foo(void)` and `int bar(long x)`. Call these two functions through function pointers. Upload your program to BB.
2. Complete the following program that scans the array using index `long_index`. Upload your program to BB.

```
#include<stdio.h>
int main(){
    int a[] = {7,9,6};
    unsigned long long_index = (unsigned long)a;
    for(int i=0; i<3; i++){
        printf("%d,",*(int *)(long_index));
        long_index += XXX;// fill out XXX
    }
}
```

FILE I/O

REFERENCES

- "Advance Programming in the Unix Environment" (APUE), Chapter 3.1-3.8 [link]

INTRODUCTION

- Five functions: `open`, `read`, `write`, `lseek`, `close`
- They are unbuffered IO in the sense that each call (`read`) invokes a syscall.
    - Unbuffered IO functions are not ISO C, but part of POSIX.1.
- Atomic functions over shared resources.

FILE DESCRIPTORS

- All open files are referred to by file descriptors.
- A file descriptor is a non-negative integer.
- FD is returned by `open` or `creat`, and is used as argument to `read` or `write`.
- 0 is FD for stdin, 1 is the FD for stdout, 2 is FD of stderr.

OPEN

Open a file

```
#include <fcntl.h>
int open(const char * pathname, int oflag, ...);
//returns: file descriptor if OK, -1 on error
```

- `oflag` takes one of three mandatory values and OR with optional values.
  - mandatory: `O_RDONLY`, `O_WRONLY`, `O_RDWR`
  - optional:
    - `O_CREAT`: Create a file if it doesn't exist
    - `O_TRUNC`: Truncate a file to zero if it exists and if it is opened for write-only or read-write
- the file descriptor returned is the lowest-numbered unused descriptor.

CREAT

Create a file

```
#include <fcntl.h>
int creat(const char * pathname, mode_t mode);
//returns: file descriptor opened for write-only if OK, -1 on error
//equiv. to
open(pathname, O_WRONLY | O_CREAT | O_TRUNC, mode);
```

CLOSE

Close a file

```
#include <unistd.h>
int close(int fd);
//return: 0 if OK, -1 on error
```

LSEEK

- Every open file has a "current file offset"
- `Read` and `write` starts at the offset and cause it to increment by the number of bytes read/written.

```
#include <unistd.h>
off_t lseek(int fd, off_t offset, int whence);
//Returns: new file offset if OK, 1 on error
```

- whence:
  - `SEEK_SET`: set offset to be `offset` plus the beginning of the file.
  - `SEEK_CUR`: set offset to `offset` plus the current value.
  - `SEEK_END`: set offset to be file size plus `offset`

READ AND WRITE

```c
#include <unistd.h>
ssize_t read(int fd, void *buf, size_t nbytes);
//Returns: number of bytes read, 0 if end of file, 1 on error
```

- It requests to read `nbytes` bytes from `fd` and stores them in `buf`.
- If the read is successful, it returns the actual number of bytes read.
- If the end of a file is reached, it returns 0

```c
#include <unistd.h>
ssize_t write(int fd, const void *buf, size_t nbytes);
//Returns: number of bytes written if OK, 1 on error
```

- It requests to write `nbytes` bytes to `fd` from `buf`.

SEEKABLE FILES

```
#include<unistd.h>
#include<stdio.h>
#include<stdlib.h>

int main(void){
    if (lseek(STDIN_FILENO, 0, SEEK_CUR) == -1)
        printf("cannot seek\n");
    else
        printf("seek OK\n");
    exit(0);
}
```

```
> ./a.out
> ./a.out < file #redirection is seekable
> cat file | ./a.out #pipe file is not seekable
```

CREAT FILE WITH A HOLE

- header.h

```
#include<stdio.h>
#include<unistd.h> //lseek, STDIN_FILENO
#include<stdlib.h>
#include <fcntl.h>
#define FILE_MODE (S_IRUSR | S_IWUSR | S_IRGRP | S_IROTH)
void err_sys(const char* x) {
    perror(x);
    exit(1);
}
```

```c
#include "header.h"
char buf1[] = "abcdefghij";
char buf2[] = "ABCDEFGHIJ";
int main(void){
 int fd;
 if ((fd = creat("file.hole", FILE_MODE)) < 0)
  err_sys("creat error");
 if (write(fd, buf1, 10) != 10)
  err_sys("buf1 write error");/* offset now = 10 */
 //comment out the following two lines, get a file file.nohole
 if (lseek(fd, 16384, SEEK_SET) == -1)
  err_sys("lseek error"); /* offset now = 16384 */
 if (write(fd, buf2, 10) != 10)
  err_sys("buf2 write error");/* offset now = 16394 */
 exit(0);
}
```

```
> cat file.hole
> cat file.nohole
> ls -ls file.hole file.nohole
> od -c file.hole
> od -c file.nohole
```

EXERCISE

- Write a C program that does the same thing to the following shell script. Upload your code to BB.

```
touch file1.txt
echo "Alice" >> file1.txt
cat file1.txt
```

Hint: to print a char array `buf`, `printf("%s\n", buf);`

FILE I/O (2)

`read` AND `write` (CONT'ED)

- Demo1: Copy text from stdin to stdout
    - `header.h`

```
#include<stdio.h>
#include<unistd.h> //lseek, STDIN_FILENO
#include<stdlib.h>
#include <fcntl.h>
#define FILE_MODE (S_IRUSR | S_IWUSR | S_IRGRP | S_IROTH)
void err_sys(const char* x) {
    perror(x);
    exit(1);
}
```

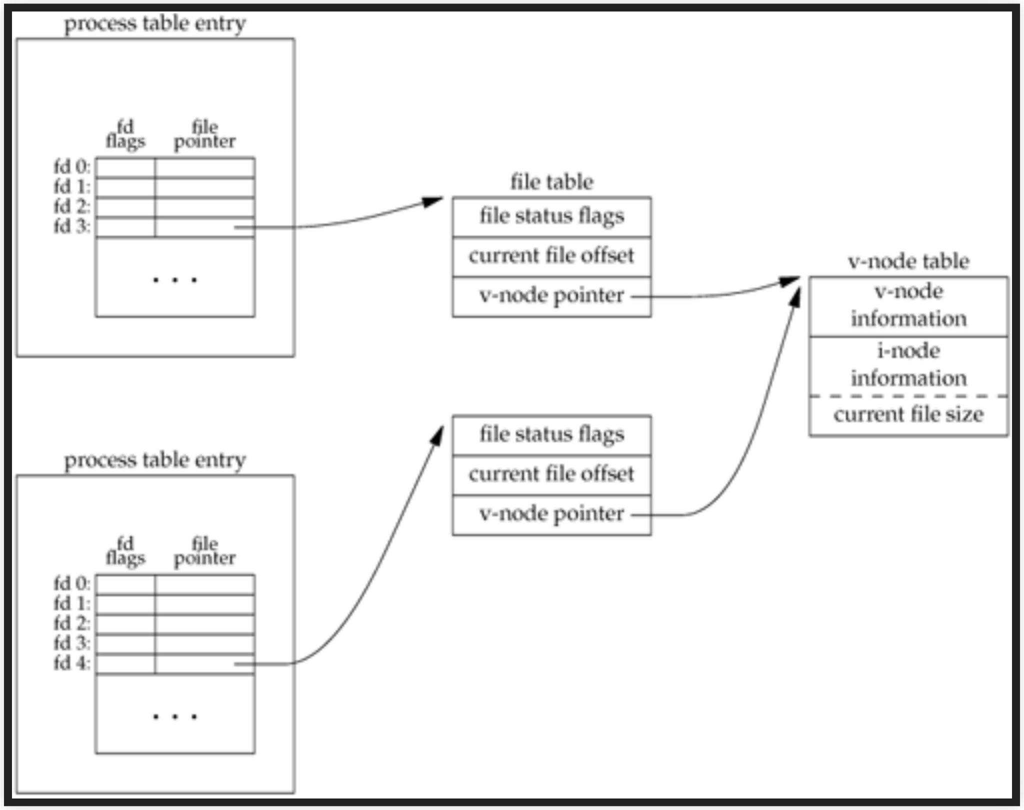
```c
#include "header.h"
#define BUFFSIZE 4096
int main(void){
    int n;
    char buf[BUFFSIZE];

    while ((n = read(STDIN_FILENO, buf, BUFFSIZE)) > 0)
        if (write(STDOUT_FILENO, buf, n) != n)
            err_sys("write error");

    if (n < 0)
        err_sys("read error");
    exit(0);
}
```

FILE SHARING & ATOMIC OPERATIONS

- An open file can be shared among multiple processes
- There are operations that are safe in multi-processing environment (atomic operations)
  - File `append`
  - `pread`/`pwrite` function
  - `sync`, `fsync`



File kernel representation and sharing

FILE APPEND

- Two ways to append text to a file: `lseek/write` and `O_APPEND`.
  - `lseek/write` is not safe in shared files.
  - `O_APPEND` is safe.

```
if (lseek(fd, 0L, SEEK_END) < 0) /* position to EOF */
    err_sys("lseek error");
if (write(fd, buf, 100) != 100) /* and write */
    err_sys("write error");
```

```
open(pathname, O_WRONLY | ... | O_APPEND, mode);
```

PREAD/PWRITE FUNCTION

- `pread` and `pwrite` functions: do seek and perform I/O atomically.
  - Calling `pread`/`pwrite` is equivalent to calling `lseek` followed by a call to `read`/`write`. There is no way to interrupt `lseek` and `read`/`write`.

```
#include <unistd.h>
ssize_t pread(int filedes, void *buf, size_t nbytes, off_t offset);
// Returns: number of bytes read, 0 if end of file, 1 on error

ssize_t pwrite(int filedes, const void *buf, size_t nbytes, off_t of
//Returns: number of bytes written if OK, 1 on error
```

SYNC, FSYNC

- Traditional UNIX system has a page cache in the kernel that queues data writes before the buffer overflows and it flushes data to disk.
- `sync/fsync` ensures consistency of the file system on disk with the contents of the buffer cache.
- The `sync` function simply queues all the modified block buffers for writing and returns; it does not wait for the disk writes to take place.
- The function `fsync` waits for the disk writes to complete before returning. The intended use of fsync is database applications that need be sure that the modified blocks have been written to the disk.

FCNTL

- The `fcntl` function reads/changes the properties of an open file.

```
#include <fcntl.h>
int fcntl(int filedes, int cmd, ... /* int arg */ );
//Returns: depends on cmd if OK (see following), 1 on error
```

DEMO2: PRINT FLAGS FOR SPECIFIED DESCRIPTOR

- see `demos/apr16/demo2.c`

```
#include "header.h"
int main(int argc, char *argv[]) {
    int val;
    if (argc != 2)
        err_quit("usage: a.out <descriptor#>");
    if ((val = fcntl(atoi(argv[1]), F_GETFL, 0)) < 0)
        err_sys("fcntl error for fd %d", atoi(argv[1]));
    switch (val & O_ACCMODE) {
    case O_RDONLY:
        printf("read only");
        break;
    case O_WRONLY:
        printf("write only");
        break;
    case O_RDWR:
        printf("read write");
```

```
./a.out 0 < /dev/tty
./a.out 1 > temp.foo; cat temp.foo
./a.out 2 2>> temp.foo
```

```
./a.out 5 5<> temp.foo
```

`5<>temp.foo` opens file `temp.foo` for read/write on file descriptor 5

STAT

- `stat` shell command
- `stat` returns information about a named file.
- `fstat` returns information about the open file by descriptor.

```
#include <sys/stat.h>

int stat(const char *restrict pathname, struct stat *restrict buf);
int fstat(int fd, struct stat *buf);
//All three return: 0 if OK, 1 on error
```

FILE TYPES

- Regular file: The most common file type, which contains data of some form.
- Directory file: file that contains the names of other files and pointers to information on these files.
- Block special file: file providing buffered I/O access in fixed-size units to devices such as disk drives.
- Character special file: file providing unbuffered I/O access in variable-sized units to devices.
- FIFO: file used for communication between processes, such as named pipe.
- Socket: file used for network communication between processes.
- Symbolic link: file that points to another file.

DEMO3: PRINT FILE TYPES

```c
int main(int argc, char *argv[]) {
    int i;
    struct stat buf;
    char *ptr;

    for (i = 1; i < argc; i++) {
         printf("%s: ", argv[i]);
         if(lstat(argv[i], &buf) < 0) {
            err_ret("lstat error");
            continue;
         }
         if (S_ISREG(buf.st_mode))
            ptr = "regular";
         else if (S_ISDIR(buf.st_mode))
            ptr = "directory";
         else if (S_ISCHR(buf.st_mode))
```

```
>./a.out /etc/passwd
/etc/passwd: regular
>./a.out .
.: directory
>./a.out /dev/disk0
/dev/disk0: block special
>./a.out /dev/io8log
/dev/io8log: character special
```

EXERCISE

- Write a C program to simulate `echo` command
  - Hint: use `read`/`write` file IO functions.