Poll Everywhere

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About where are you on Homework 1?

A. Haven't started yet
B. Working on Part A (LinkedList)
C. Working on Part B (HashTable)
D. Finished or about finished
E. Prefer not to say

Notes:

- ✓ Don't wait – Part B is longer and harder than Part A
- ✓ OH get crowded – come prepared to describe your incorrect behavior and what you think the issue is and what you've tried

Linking, File I/O

CSE 333 Spring 2021

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Administrivia

- Exercise 3 posted Wednesday, due Monday (4/12)

- Homework 1 due next Thursday (4/15)
  - Watch that `HashTable` doesn't violate the modularity of `LinkedList`
  - Watch for pointer to local (stack) variables
  - ***Draw memory diagrams!***
  - Use a debugger (*e.g.*, `gdb`) and valgrind
    - Fill out your bug journal as you go!
  - Please leave "`STEP #`" markers for graders!
  - Late days: don't tag `hw1-final` until you are really ready
  - Extra Credit: if you add unit tests, put them in a new file and adjust the Makefile

Preprocessor Tricks: Macros

- You can pass arguments to macros

```
#define ODD(x) ((x) % 2 != 0)

void foo() {
  if ( ODD(5) )
    printf("5 is odd!\n");
}
```

cpp

```
void foo() {
  if ( ((5) % 2 != 0) )
    printf("5 is odd!\n");
}
```

treated as just text

- Beware of operator precedence issues!
  - Use parentheses

```
#define ODD(x) ((x) % 2 != 0)
#define WEIRD(x) x % 2 != 0

ODD(5 + 1);

WEIRD(5 + 1);
```

cpp

```
((5 + 1) % 2 != 0);

5 + 1 % 2 != 0;
```

Preprocessor Tricks: Defining Tokens

- Besides `#define`s in the code, preprocessor values can be given as part of the `gcc` command:

```
bash$ gcc -Wall -g -DTRACE -o ifdef ifdef.c
```

-D define
-U undefine

- assert can be controlled the same way – defining `NDEBUG` causes assert to expand to "empty"
  - It's a macro – see `assert.h`

```
bash$ gcc -Wall -g -DNDEBUG -o faster useassert.c
```

Preprocessor Tricks: Conditional Compilation

#ifdef = "if defined"
#ifndef = "if not defined"

- You can change what gets compiled
  - In this example, `#define TRACE` before `#ifdef` to include debug **`printf`**s in compiled code

```
#ifdef TRACE
#define ENTER(f) printf("Entering %s\n", f);
#define EXIT(f)  printf("Exiting  %s\n", f);
#else
#define ENTER(f)
#define EXIT(f)
#endif

// print n
void pr(int n) {
  ENTER("pr");
  printf("\n = %d\n", n);
  EXIT("pr");
}
```

ifdef.c

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What will happen when we try to compile and run?

```
bash$ gcc -Wall -DFOO -DBAR -o condcomp condcomp.c
bash$ ./condcomp
```

FOO and BAR are defined

A. Output "333"

B. Output "334"

C. Compiler message about EVEN

D. Compiler message about BAZ

E. We're lost…

```
#ifdef FOO        <- yes
#define EVEN(x) !(x%2)
#endif
#ifndef DBAR      <- no
#define BAZ 333
#endif

int main(int argc, char** argv) {
  int i = EVEN(42) + BAZ;
  printf("%d\n",i);
  return EXIT_SUCCESS;
}
```

EVEN(42) evaluates to !0 = 1; BAZ = 333

Lecture Outline

- **Visibility of Symbols**
  - `extern`, `static`
- File I/O with the C standard library

Namespace Problem

- If we define a global variable named "counter" in one C file, is it visible in a different C file in the same program?
  - Yes, if you use *external linkage*
    - The name "counter" refers to the same variable in both files
    - The variable is *defined* in one file and *declared* in the other(s)
    - When the program is linked, the symbol resolves to one location
  - No, if you use *internal linkage*
    - The name "counter" refers to a different variable in each file
    - The variable must be *defined* in each file
    - When the program is linked, the symbols resolve to two locations

External Linkage

	declaration	definition	initialization	
int x;	✓	✓		x ?
int x = 0;	✓	✓	✓	x 0
extern int x;	✓			
extern int x = 1;	✓	✓	✓	x 1

- `extern` makes a *declaration* of something externally-visible
  - Works slightly differently for variables and functions…

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

// A global variable, defined and
// initialized here in foo.c.
// It has external linkage by
// default.
int counter = 1;

int main(int argc, char** argv) {
  printf("%d\n", counter);
  bar();
  printf("%d\n", counter);
  return EXIT_SUCCESS;
}
```

foo.c

```c
#include <stdio.h>

// "counter" is defined and
// initialized in foo.c.
// Here, we declare it, and
// specify external linkage
// by using the extern specifier.
extern int counter;

void bar() {
  counter++;
  printf("(b): counter = %d\n",
         counter);
}
```

bar.c

Internal Linkage

- `static` (in the global context) restricts a definition to visibility within that file

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

// A global variable, defined and
// initialized here in foo.c.
// We force internal linkage by
// using the static specifier.
static int counter = 1;

int main(int argc, char** argv) {
  printf("%d\n", counter);
  bar();
  printf("%d\n", counter);
  return EXIT_SUCCESS;
}
```

foo.c

```c
#include <stdio.h>

// A global variable, defined and
// initialized here in bar.c.
// We force internal linkage by
// using the static specifier.
static int counter = 100;

void bar() {
  counter++;
  printf("(b): counter = %d\n",
         counter);
}
```

bar.c

Function Visibility

bar.c

```
// By using the static specifier, we are indicating
// that foo() should have internal linkage.  Other
// .c files cannot see or invoke foo().
static int foo(int x) {
  return x*3 + 1;
}

// Bar is "extern" by default.  Thus, other .c files
// could declare our bar() and invoke it.
int bar(int x) {
  return 2*foo(x);
}
```

bar() can invoke foo() because in same file

main.c

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

extern int bar(int x); // "extern" is default, usually omit
int main(int argc, char** argv) {
  printf("%d\n", bar(5));
  return EXIT_SUCCESS;
}
```

not explicitly needed, but indicates that definition is elsewhere

Linkage Issues

- Every global (variables and functions) is `extern` by default
  - Unless you add the `static` specifier, if some other module uses the same name, you'll end up with a collision!
    - Best case: compiler (or linker) error
    - Worst case: stomp all over each other

- It's good practice to:
  - Use `static` to "defend" your globals
    - Hide your private stuff!
  - Place external declarations in a module's header file
    - Header is the public specification

Static Confusion…

- C has a *different* use for the word "`static`": to create a persistent *local* variable
  - The storage for that variable is allocated when the program loads, in either the `.data` or `.bss` segment (Static Data)
  - Retains its value across multiple function invocations

```
void foo() {
  static int count = 1; // persists
  printf("foo has been called %d times\n", count++);
}

void bar() {
  int count = 1;  // re-initialized each time
  printf("bar has been called %d times\n", count++);
}

int main(int argc, char** argv) {
  foo(); foo(); bar(); bar(); return EXIT_SUCCESS;
}
```

1 times 2 times 1 times 1 times

static_extent.c

Additional C Topics

- Teach yourself!
  - man pages are your friend!
  - String library functions in the C standard library
    - `#include <string.h>`
      - strlen(), strcpy(), strdup(), strcat(), strcmp(), strchr(), strstr(), …
    - `#include <stdlib.h>` or `#include <stdio.h>`
      - atoi(), atof(), sprint(), sscanf()
  - How to declare, define, and use a function that accepts a variable-number of arguments (`varargs`)
  - `unions` and what they are good for
  - `enums` and what they are good for
  - Pre- and post-increment/decrement
  - Harder: the meaning of the "`volatile`" storage class

Lecture Outline

- Visibility of Symbols
  - `extern`, `static`
- **File I/O with the C standard library**

This is essential material for the next part of the project (hw2)!

File I/O

- We'll start by using C's standard library
  - These functions are part of `glibc` on Linux
  - They are implemented using Linux system calls (POSIX)

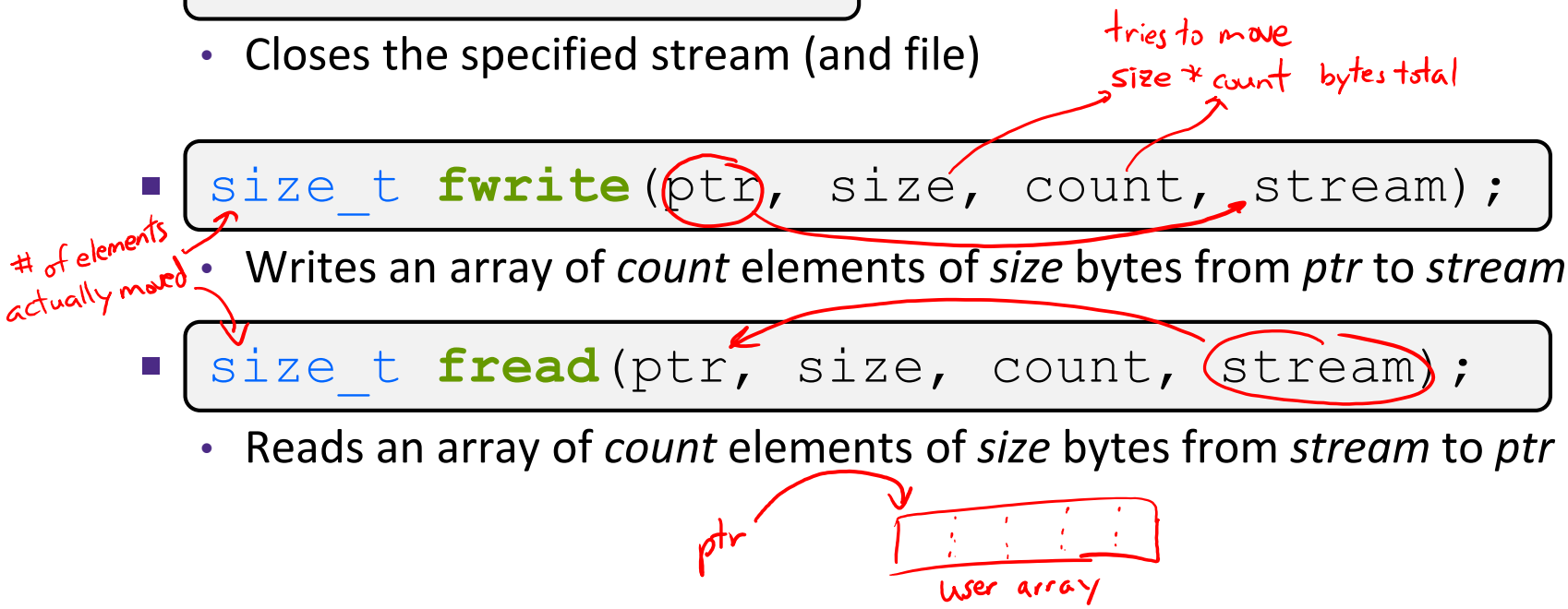
- C's `stdio` defines the notion of a stream
  - A sequence of characters that flows **to** and **from** a device
    - Can be either *text* or *binary*; Linux does not distinguish
  - Is *buffered* by default; `libc` reads ahead of your program
  - Three streams provided by default: `stdin`, `stdout`, `stderr`
    - You can open additional streams to read and write to files
  - C streams are manipulated with a `FILE*` pointer, which is defined in `stdio.h`

C Stream Functions (1 of 2)

- Some stream functions (complete list in `stdio.h`):
  - NULL if error!
  - `FILE* fopen(filename, mode);`
    - Opens a stream to the specified file in specified file access mode
  - `int fclose(stream);`
    - Closes the specified stream (and file)
  - `int fprintf(stream, format, ...);`
    - Writes a formatted C string
      - `printf(...);` is equivalent to `fprintf(stdout, ...);`
  - `int fscanf(stream, format, ...);`
    - Reads data and stores data matching the format string

C Stream Functions (2 of 2)

- Some stream functions (complete list in `stdio.h`):
  - `FILE* fopen(filename, mode);`
    - Opens a stream to the specified file in specified file access mode
  - `int fclose(stream);`
    - Closes the specified stream (and file)
  - `size_t fwrite(ptr, size, count, stream);`
    - Writes an array of *count* elements of *size* bytes from *ptr* to *stream*
  - `size_t fread(ptr, size, count, stream);`
    - Reads an array of *count* elements of *size* bytes from *stream* to *ptr*



C Stream Error Checking/Handling

- Some error functions (complete list in `stdio.h`):
  - `int ferror(stream);`
    - Checks if the error indicator associated with the specified stream is set
  - `int clearerr(stream);`
    - Resets error and EOF indicators for the specified stream
  - `void perror(message);`
    - Prints `message` followed by an error message related to `errno` to `stderr`

global var

extra info!

error message

① `fprintf(stderr, ... );` // single, known cause

② `perror("my error msg");` // multiple possible causes

C Streams Example

cp_example.c

```
#include <stdio.h>
#include <stdlib.h>
#include <errno.h>
#define READBUFSIZE 128

int main(int argc, char** argv) {
  FILE *fin, *fout;
  char readbuf[READBUFSIZE];
  size_t readlen;

  if (argc != 3) {
    fprintf(stderr, "usage: ./cp_example infile outfile\n");
    return EXIT_FAILURE;        // defined in stdlib.h
  }

  // Open the input file
  fin = fopen(argv[1], "rb");  // "rb" -> read, binary mode
  if (fin == NULL) {
    perror("fopen for read failed");
    return EXIT_FAILURE;
  }

  ...
```

stream variables

arbitrarily-sized buffer

prints to console, even if you pipe program output

file must exist when reading

prints extra info on source of error

C Streams Example

cp_example.c

```
int main(int argc, char** argv) {

  ...   // previous slide's code

  // Open the output file
  fout = fopen(argv[2], "wb");  // "wb" -> write, binary mode
  if (fout == NULL) {
    perror("fopen for write failed");
    fclose(fin);
    return EXIT_FAILURE;
  }

  // Read from the file, write to fout
  while ((readlen = fread(readbuf, 1, READBUFSIZE, fin)) > 0) {
    // Test to see if we encountered an error while reading
    if (ferror(fin)) {
      perror("fread failed");
      fclose(fin);
      fclose(fout);
      return EXIT_FAILURE;
    }
    ...   // next slide's code
}
```

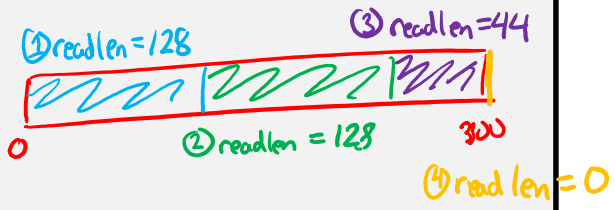
when writing, file created if it doesn't exist

make sure to clean up for every exit path!

# of bytes actually read

(check if error on input stream)

for file of size 300 bytes, fread called 4 times:



C Streams Example

cp_example.c

```
int main(int argc, char** argv) {

  ...   // two slides ago's code

  ...   // previous slide's code

    if (fwrite(readbuf, 1, readlen, fout) < readlen) {
      perror("fwrite failed");
      fclose(fin);
      fclose(fout);
      return EXIT_FAILURE;
    }
  }

  fclose(fin);
  fclose(fout);

  return EXIT_SUCCESS;
}
```

return value from fread

something wrong if didn't write all requested bytes

close streams when done with them!

Extra Exercise #1

- Modify the linked list code from Lecture 4 Extra Exercise #3
  - Add static declarations to any internal functions you implemented in `linkedlist.h`
  - Add a header guard to the header file

Extra Exercise #2

- Write a program that:
  - Uses `argc`/`argv` to receive the name of a text file
  - Reads the contents of the file a line at a time
  - Parses each line, converting text into a `uint32_t`
  - Builds an array of the parsed `uint32_t`'s
  - Sorts the array
  - Prints the sorted array to `stdout`

- Hint: use `man` to read about `getline`, `sscanf`, `realloc`, and `qsort`

```
bash$ cat in.txt
1213
3231
000005
52
bash$ ./extra1 in.txt
5
52
1213
3231
bash$
```

Extra Exercise #3

- Write a program that:
  - Loops forever; in each loop:
    - Prompt the user to input a filename
    - Reads a filename from `stdin`
    - Opens and reads the file
    - Prints its contents to `stdout` in the format shown:

```
00000000 50 4b 03 04 14 00 00 00 00 00 9c 45 26 3c f1 d5
00000010 68 95 25 1b 00 00 25 1b 00 00 0d 00 00 00 43 53
00000020 45 6c 6f 67 6f 2d 31 2e 70 6e 67 89 50 4e 47 0d
00000030 0a 1a 0a 00 00 00 0d 49 48 44 52 00 00 00 91 00
00000040 00 00 91 08 06 00 00 00 c3 d8 5a 23 00 00 00 09
00000050 70 48 59 73 00 00 0b 13 00 00 0b 13 01 00 9a 9c
00000060 18 00 00 0a 4f 69 43 43 50 50 68 6f 74 6f 73 68
00000070 6f 70 20 49 43 43 20 70 72 6f 66 69 6c 65 00 00
00000080 78 da 9d 53 67 54 53 e9 16 3d f7 de f4 42 4b 88
00000090 80 94 4b 6f 52 15 08 20 52 42 8b 80 14 91 26 2a
000000a0 21 09 10 4a 88 21 a1 d9 15 51 c1 11 45 45 04 1b
... etc ...
```

- Hints:
  - Use `man` to read about `fgets`
  - Or, if you're more courageous, try `man 3 readline` to learn about `libreadline.a` and Google to learn how to link to it