

CS 202(-002) Lecture 4

Announcement

- Quiz 2 on 09/18/2025 (not 09/16)
- Quiz 1
 - Answers online, scores on BRIGHTSPACE
 - Might be helpful to review material on pointers & references.
 - ↳ K&R
- THE STACK IS IN MEMORY!
EVERYTHING IN MEMORY HAS AN ADDRESS!

LAST CLASS

- KERNEL, USER MODE
- TRAPS
- SHELL, THE BEGINNINGS

TODAY

- SHELL
 - A last bit of processes
 - CONCURRENCY
- SHOULD LOOK FAMILIAR

```
16
17     while (1) {
18         write(1, "$ ", 2);
19         readcommand(command, args); // parse input
20         if ((pid = fork()) == 0) // child?
21             execve(command, args, 0);
22         else if (pid > 0) // parent?
23             wait(0); //wait for child
24         else
25             perror("failed to fork");
26     }
```

1 : File descriptor

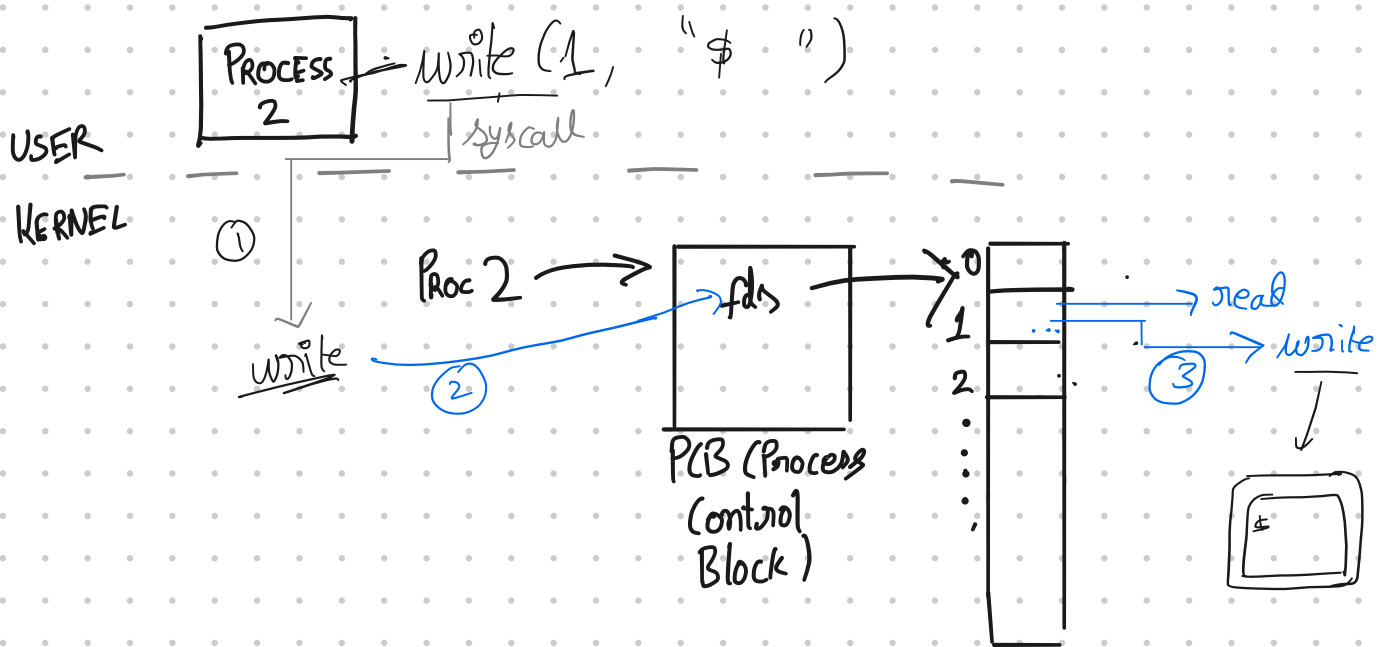
↳ How the program refers to a previously opened file

```
int fd = open("...", mode);
```

1 is a special file descriptor

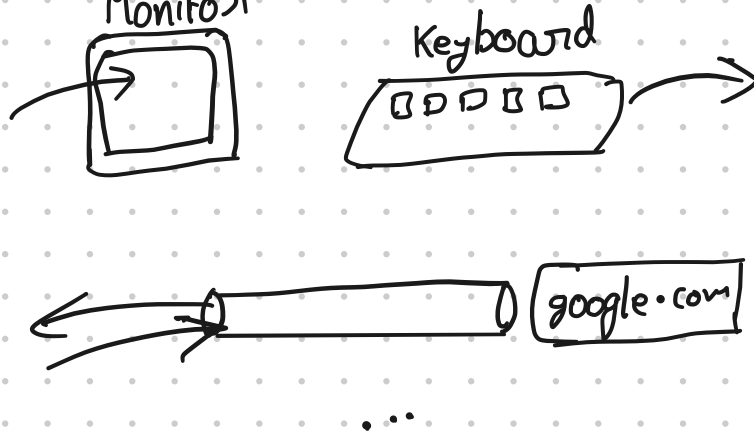
↳ standard. out (stdout)

} More below



★ Same thing happens when you call `printf(...)` → ... → `write(1, ...)`

Unix abstraction: everything* is a file



PROGRAM DOES NOT NEED TO KNOW WHAT TYPE OF FILE
IT IS READING OR WRITING FROM
↳ BUT SOME OPS MIGHT
PRODUCE ERRORS.

ONE CASE WHERE THIS HELPS

$\$./outputs-lots \xrightarrow{\text{Output to } f}$

Can now edit f to see list.

$\$./outputs-lots | \text{sort } -n | \text{uniq } -c$
↑
Pipe output

Compose programs

- What is happening under the hood

① - Output to screen $\leftarrow$ file

$\hookrightarrow$ stdout

$\rightarrow$ File descriptor 1 (STDOUT_FILENO)

- Input $\leftarrow$ file

$\hookrightarrow$ stdin

$\rightarrow$ FD: 0 (STDIN_FILENO)

- Errors $\leftarrow$ file

$\hookrightarrow$ stderr

$\rightarrow$ FD: 2 ...

② execv DOES NOT CLEAR FILE DESCRIPTORS

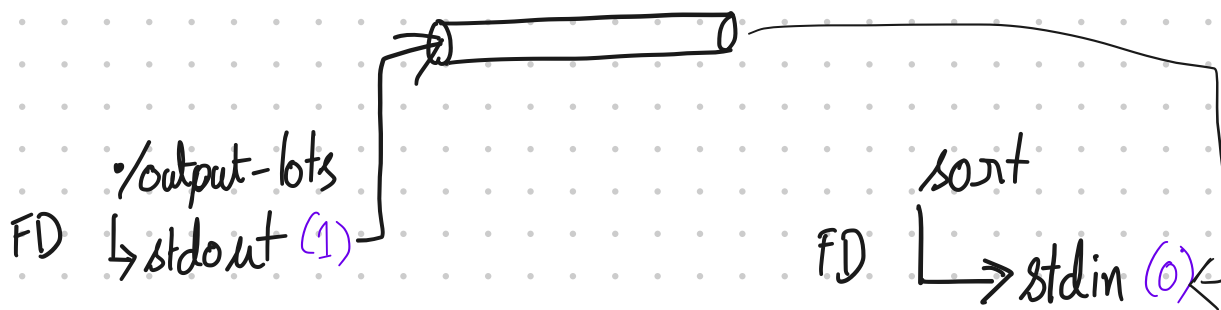
\$./outputs-lots > out

```
while (1) {
    write(1, "$ ", 2);
    readcommand(command, args); // parse input
    if ((pid = fork()) == 0) { // child?
        if (output_redirected) {
            close(1);
            open(redirect_file, O_CREAT | O_TRUNC | O_WRONLY, 0666);
        }
        // when command runs, fd 1 will refer to the redirected file
        execve(command, args, 0);
    } else if (pid > 0) { // parent?
    }
```

→ Replace file descriptor 1

\$./output-lots | sort -n

① Create a PIPE (a special type of file)



Things that matter

- File descriptors
- Stdout, in, err are files
- Allows programs to be chained
- fork, exec, wait.

Concurrency

Threads: Remember the process abstract machine

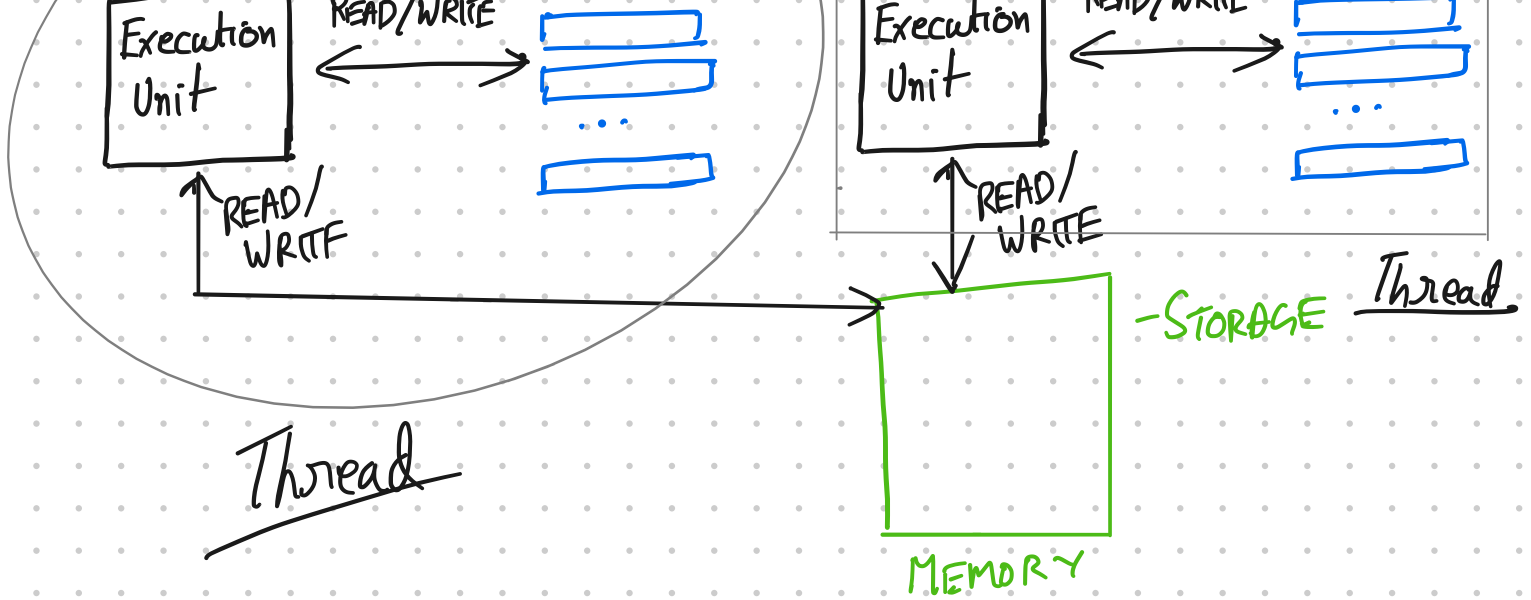
REGISTERS



REGISTERS



READ/WRITE



- Allow things to execute CONCURRENTLY
- Each thread gets
 - Its own set of registers
 - Its own stack
- All threads have access to all of the process memory

Qo Can thread t1 access a location in thread t2's stack?

Interface

man 2 wait

Create tid thread - create (void (*fn)(void*), void*)

Exit void thread_exit()

Wait void thread_join(tid id)

+

Synchronization Primitives

uint64_t x = 3;

t1

void t1() {

① $x = x * 2;$

② $x = x + 7$

}

t2

void t2() {

① $x = x + 6;$

② $x = x * 3;$

}

a
6

i
12

b
19

ii
57

i

a

b

ii

i
9

a
18

ii
54

b
61

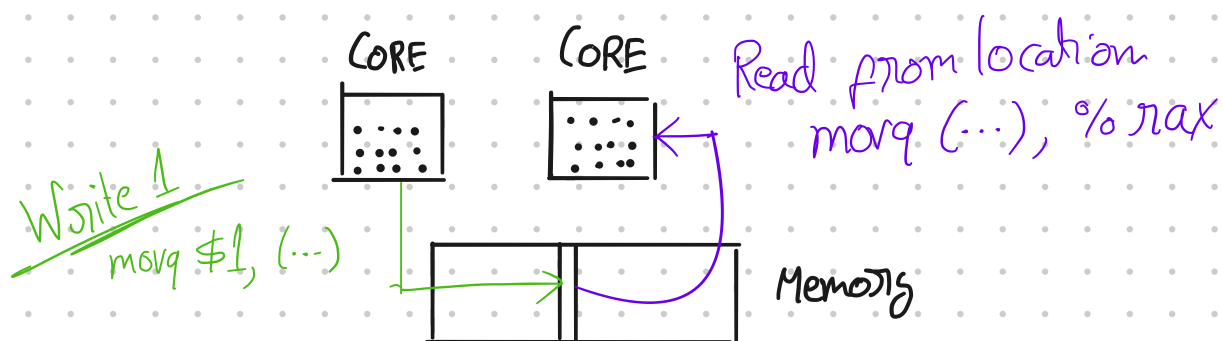


1. Ordering dictates behavior

↳ But some behaviors are not correct.

2. Hardware makes matters worse.

- Memory models.



C0

$x = 1$

$y = 1$

$z = 1$

C1

$a = z + 1$

$b = x + 1$

Don't worry too much about mem. models.
Going to assume sequential consistency for now.

Goal in this class

↳ Use some synchronization primitives

to build CORRECT concurrent programs.

- What is correct?
- What is a synchronization primitive?

Aug 31, 2025 12:51

handout02.txt

Page 1/4

1 CS 202, Spring 2023
2 Handout 2 (Class 4)

3
4 The handout is meant to:

5 --illustrate how the shell itself uses syscalls
6
7 --communicate the power of the fork()/exec() separation
8
9 --give an example of how small, modular pieces (file descriptors,
10 pipes, fork(), exec()) can be combined to achieve complex behavior
11 far beyond what any single application designer could or would have
12 specified at design time. (We will not cover pipes in lecture today.)
13

14
15 1. Pseudocode for a very simple shell

```
16     while (1) {
17         write(1, "$ ", 2);
18         readcommand(command, args); // parse input
19         if ((pid = fork()) == 0) // child?
20             execve(command, args, 0);
21         else if (pid > 0) // parent?
22             wait(0); //wait for child
23         else
24             perror("failed to fork");
25     }
26
```

27
28 2. Now add two features to this simple shell: output redirection and
29 backgrounding

30
31 By output redirection, we mean, for example:

32 \$ ls > list.txt

33 By backgrounding, we mean, for example:

34 \$ myprog &
35 \$

```
36  
37     while (1) {
38         write(1, "$ ", 2);
39         readcommand(command, args); // parse input
40         if ((pid = fork()) == 0) { // child?
41             if (output_redirected) {
42                 close(1);
43                 open(redirect_file, O_CREAT | O_TRUNC | O_WRONLY, 0666);
44             }
45             // when command runs, fd 1 will refer to the redirected file
46             execve(command, args, 0);
47         } else if (pid > 0) { // parent?
48             if (foreground_process) {
49                 wait(0); //wait for child
50             }
51         } else {
52             perror("failed to fork");
53         }
54     }
55
```

Aug 31, 2025 12:51

handout02.txt

Page 2/4

56 3. Another syscall example: pipe()

57
58 The pipe() syscall is used by the shell to implement pipelines, such as
59 \$ ls | sort | head -4
60 We will see this in a moment; for now, here is an example use of
61 pipes.
62

63 // C fragment with simple use of pipes

```
64  
65     int fdarray[2];
66     char buf[512];
67     int n;
68  
69     pipe(fdarray);
70     write(fdarray[1], "hello", 5);
71     n = read(fdarray[0], buf, sizeof(buf));
72     // buf[] now contains 'h', 'e', 'l', 'l', 'o'
73
```

74 4. File descriptors are inherited across fork

75 // C fragment showing how two processes can communicate over a pipe

```
76  
77     int fdarray[2];
78     char buf[512];
79     int n, pid;
80  
81  
82     pipe(fdarray);
83     pid = fork();
84     if (pid > 0) {
85         write(fdarray[1], "hello", 5);
86     } else {
87         n = read(fdarray[0], buf, sizeof(buf));
88     }
89
```

Aug 31, 2025 12:51

handout02.txt

Page 3/4

```

90 5. Putting it all together: implementing shell pipelines using
91 fork(), exec(), and pipe().
92
93
94 // Pseudocode for a Unix shell that can run processes in the
95 // background, redirect the output of commands, and implement
96 // two element pipelines, such as "ls | sort"
97
98 void main_loop() {
99
100     while (1) {
101         write(1, "$ ", 2);
102         readcommand(command, args); // parse input
103         if ((pid = fork()) == 0) { // child?
104             if (pipeline_requested) {
105                 handle_pipeline(left_command, right_command)
106             } else {
107                 if (output_redirected) {
108                     close(1);
109                     open(redirect_file, O_CREAT | O_TRUNC | O_WRONLY, 0666);
110                 }
111                 exec(command, args, 0);
112             }
113         } else if (pid > 0) { // parent?
114             if (foreground_process) {
115                 wait(0); // wait for child
116             }
117         } else {
118             perror("failed to fork");
119         }
120     }
121 }
122
123 void handle_pipeline(left_command, right_command) {
124
125     int fdarray[2];
126
127     if (pipe(fdarray) < 0) panic ("error");
128     if ((pid = fork ()) == 0) { // child (left end of pipe)
129
130         dup2 (fdarray[1], 1); // make fd 1 the same as fdarray[1],
131                             // which is the write end of the
132                             // pipe. implies close (1).
133
134         close (fdarray[0]);
135         close (fdarray[1]);
136         parse(command1, args1, left_command);
137         exec (command1, args1, 0);
138     } else if (pid > 0) { // parent (right end of pipe)
139
140         dup2 (fdarray[0], 0); // make fd 0 the same as fdarray[0],
141                             // which is the read end of the pipe.
142                             // implies close (0).
143
144         close (fdarray[0]);
145         close (fdarray[1]);
146         parse(command2, args2, right_command);
147         exec (command2, args2, 0);
148     } else {
149         printf ("Unable to fork\n");
150     }
151 }
152

```

Aug 31, 2025 12:51

handout02.txt

Page 4/4

```

152
153 6. Commentary
154
155 Why is this interesting? Because pipelines and output redirection
156 are accomplished by manipulating the child's environment, not by
157 asking a program author to implement a complex set of behaviors.
158 That is, the *identical code* for "ls" can result in printing to the
159 screen ("ls -l"), writing to a file ("ls -l > output.txt"), or
160 getting ls's output formatted by a sorting program ("ls -l | sort").
161
162 This concept is powerful indeed. Consider what would be needed if it
163 weren't for redirection: the author of ls would have had to
164 anticipate every possible output mode and would have had to build in
165 an interface by which the user could specify exactly how the output
166 is treated.
167
168 What makes it work is that the author of ls expressed their
169 code in terms of a file descriptor:
170     write(1, "some output", byte_count);
171 This author does not, and cannot, know what the file descriptor will
172 represent at runtime. Meanwhile, the shell has the opportunity, *in
173 between fork() and exec()*, to arrange to have that file descriptor
174 represent a pipe, a file to write to, the console, etc.

```

Aug 31, 2025 12:51

our_head.c

Page 1/1

```

1  /*
2  * our_head.c -- a C program that prints the first L lines of its input,
3  *   where L defaults to 10 but can be specified by the caller of the
4  *   program.
5  *
6  *   (This program is inefficient and does not check its error
7  *   conditions. It is meant to illustrate filters aka pipelines.)
8  */
9  #include <stdlib.h>
10 #include <unistd.h>
11 #include <stdio.h>
12
13 int main(int argc, char** argv)
14 {
15     int i = 0;
16     int nlines;
17     char ch;
18     int ret;
19
20     if (argc == 2) {
21         nlines = atoi(argv[1]);
22     } else if (argc == 1) {
23         nlines = 10;
24     } else {
25         fprintf(stderr, "usage: our_head [nlines]\n");
26         exit(1);
27     }
28
29     for (i = 0; i < nlines; i++) {
30
31         do {
32
33             /* read in the first character from fd 0 */
34             ret = read(0, &ch, 1);
35
36             /* if there are no more characters to read, then exit */
37             if (ret == 0) exit(0);
38
39             write(1, &ch, 1);
40
41         } while (ch != '\n');
42     }
43
44     exit(0);
45 }
46

```

Aug 31, 2025 12:51

our_yes.c

Page 1/1

```

1  /*
2  * our_yes.c -- a C program that prints its argument to the screen on a
3  *   new line every second.
4  *
5  */
6  #include <stdlib.h>
7  #include <string.h>
8  #include <unistd.h>
9  #include <stdio.h>
10
11 int main(int argc, char** argv)
12 {
13     char* repeated;
14     int len;
15
16     /* check to make sure the user gave us one argument */
17     if (argc != 2) {
18         fprintf(stderr, "usage: our_yes string_to_repeat\n");
19         exit(1);
20     }
21
22     repeated = argv[1];
23
24     len = strlen(repeated);
25
26     /* loop forever */
27     while (1) {
28
29         write(1, repeated, len);
30
31         write(1, "\n", 1);
32
33         sleep(1);
34     }
35
36 }

```

Aug 31, 2025 12:51

handout03.txt

Page 1/4

```

1 CS 202, Spring 2023
2 Handout 3 (Class 4)
3
4 1. Example to illustrate interleavings: say that thread tid1 executes f()
5 and thread tid2 executes g(). (Here, we are using the term "thread"
6 abstractly. This example applies to any of the approaches that fall
7 under the word "thread".)
8
9 a. [this is pseudocode]
10
11     int x;
12
13     int main(int argc, char** argv) {
14
15         tid tid1 = thread_create(f, NULL);
16         tid tid2 = thread_create(g, NULL);
17
18         thread_join(tid1);
19         thread_join(tid2);
20
21         printf("%d\n", x);
22     }
23
24     void f()
25     {
26         x = 1;
27         thread_exit();
28     }
29
30     void g()
31     {
32         x = 2;
33         thread_exit();
34     }
35
36
37     What are possible values of x after tid1 has executed f() and tid2 has
38     executed g()? In other words, what are possible outputs of the
39     program above?
40
41
42
43 b. Same question as above, but f() and g() are now defined as
44 follows:
45
46     int y = 12;
47
48     f() { x = y + 1; }
49     g() { y = y * 2; }
50
51     What are the possible values of x?
52
53
54
55 c. Same question as above, but f() and g() are now defined as
56 follows:
57
58     int x = 0;
59     f() { x = x + 1; }
60     g() { x = x + 2; }
61
62     What are the possible values of x?
63

```

Aug 31, 2025 12:51

handout03.txt

Page 2/4

```

64 2. Linked list example
65
66     struct List_elem {
67         int data;
68         struct List_elem* next;
69     };
70
71     List_elem* head = 0;
72
73     insert(int data) {
74         List_elem* l = new List_elem;
75         l->data = data;
76         l->next = head;
77         head = l;
78     }
79
80     What happens if two threads execute insert() at once and we get the
81     following interleaving?
82
83     thread 1: l->next = head
84     thread 2: l->next = head
85     thread 2: head = l;
86     thread 1: head = l;
87

```

Aug 31, 2025 12:51

handout03.txt

Page 3/4

```

88 3. Producer/consumer example:
89
90  /*
91   "buffer" stores BUFFER_SIZE items
92   "count" is number of used slots. a variable that lives in memory
93   "out" is next empty buffer slot to fill (if any)
94   "in" is oldest filled slot to consume (if any)
95   */
96
97   void producer (void *ignored) {
98       for (;;) {
99           /* next line produces an item and puts it in nextProduced */
100          nextProduced = means_of_production();
101          while (count == BUFFER_SIZE)
102              ; // do nothing
103          buffer [in] = nextProduced;
104          in = (in + 1) % BUFFER_SIZE;
105          count++;
106      }
107  }
108
109  void consumer (void *ignored) {
110      for (;;) {
111          while (count == 0)
112              ; // do nothing
113          nextConsumed = buffer[out];
114          out = (out + 1) % BUFFER_SIZE;
115          count--;
116          /* next line abstractly consumes the item */
117          consume_item(nextConsumed);
118      }
119  }
120
121  /*
122   what count++ probably compiles to:
123   reg1 <-- count      # load
124   reg1 <-- reg1 + 1    # increment register
125   count <-- reg1      # store
126
127   what count-- could compile to:
128   reg2 <-- count      # load
129   reg2 <-- reg2 - 1    # decrement register
130   count <-- reg2      # store
131  */
132
133  What happens if we get the following interleaving?
134
135   reg1 <-- count
136   reg1 <-- reg1 + 1
137   reg2 <-- count
138   reg2 <-- reg2 - 1
139   count <-- reg1
140   count <-- reg2
141

```

Aug 31, 2025 12:51

handout03.txt

Page 4/4

```

142
143 4. Some other examples. What is the point of these?
144
145 [From S.V. Adve and K. Gharachorloo, IEEE Computer, December 1996,
146 66-76. http://rsim.cs.uiuc.edu/~sadve/Publications/computer96.pdf]
147
148 a. Can both "critical sections" run?
149
150     int flag1 = 0, flag2 = 0;
151
152     int main () {
153         tid id = thread_create (p1, NULL);
154         p2 (); thread_join (id);
155     }
156
157     void p1 (void *ignored) {
158         flag1 = 1;
159         if (!flag2) {
160             critical_section_1 ();
161         }
162     }
163
164     void p2 (void *ignored) {
165         flag2 = 1;
166         if (!flag1) {
167             critical_section_2 ();
168         }
169     }
170
171 b. Can use() be called with value 0, if p2 and p1 run concurrently?
172
173     int data = 0, ready = 0;
174
175     void p1 () {
176         data = 2000;
177         ready = 1;
178     }
179
180     int p2 () {
181         while (!ready) {}
182         use(data);
183     }
184
185 c. Can use() be called with value 0?
186
187     int a = 0, b = 0;
188
189     void p1 (void *ignored) { a = 1; }
190
191     void p2 (void *ignored) {
192         if (a == 1)
193             b = 1;
194     }
195
196     void p3 (void *ignored) {
197         if (b == 1)
198             use (a);
199     }

```