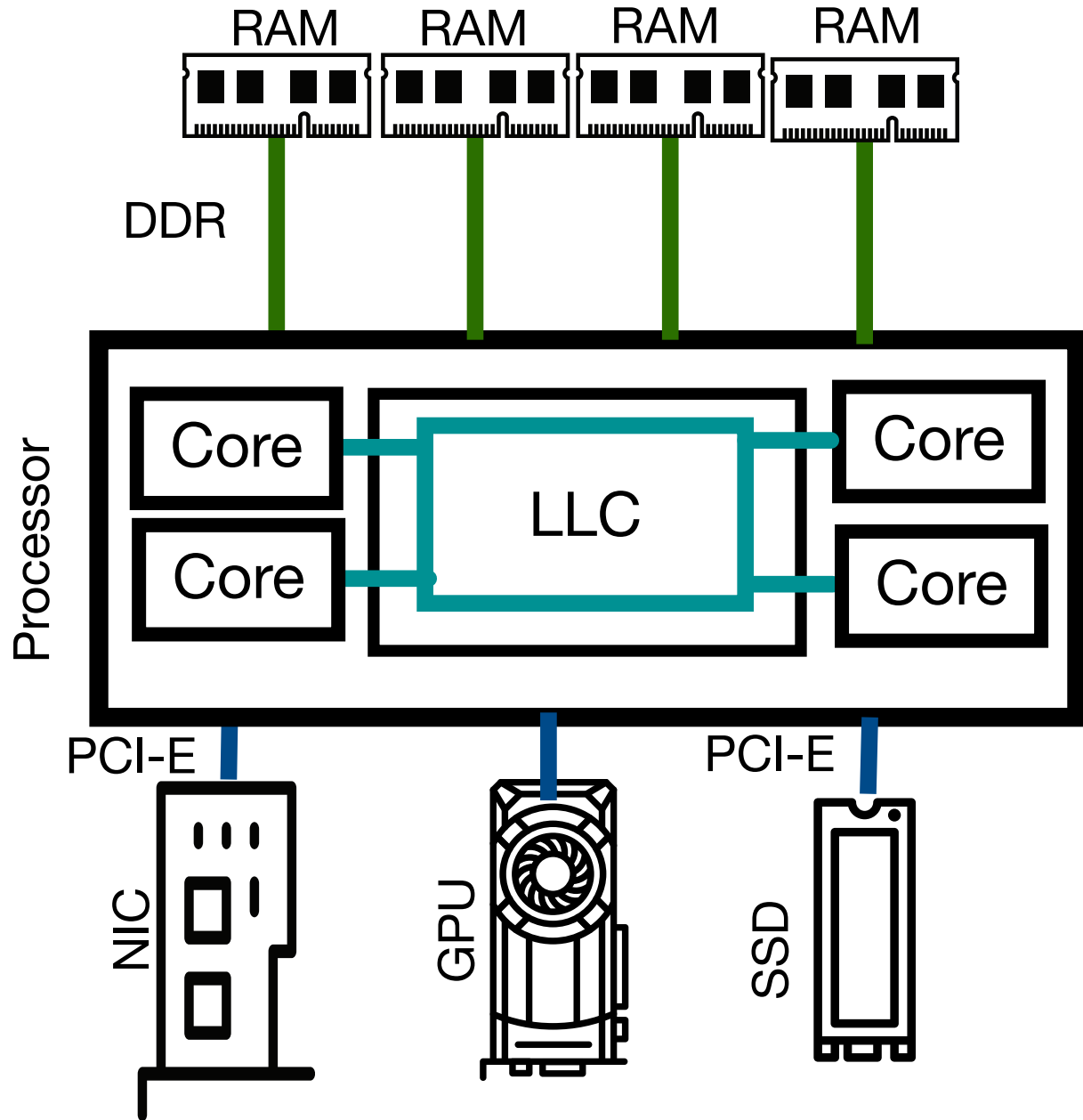


Machine



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```

1 CS 202, Spring 2020
2 Handout 9 (Class 14)
3
4 1. Example use of I/O instructions: boot loader
5
6     Below is the WeensyOS boot loader
7
8     It may be helpful to understand the overall picture
9
10    This code demonstrates I/O, specifically with the disk: the
11    bootloader reads in the kernel from the disk.
12
13    See the functions boot_waitdisk() and boot_readsect(). Compare to Figures 36
14    .5 and 36.6 in OSTEP.
15
16    /* boot.c */
17    #include "x86-64.h"
18    #include "elf.h"
19
20    // boot.c
21    //
22    // WeensyOS boot loader. Loads the kernel at address 0x40000 from
23    // the first IDE hard disk.
24    //
25    // A BOOT LOADER is a tiny program that loads an operating system into
26    // memory. It has to be tiny because it can contain no more than 512 bytes
27    // of instructions: it is stored in the disk's first 512-byte sector.
28    //
29    // When the CPU boots it loads the BIOS into memory and executes it. The
30    // BIOS initializes devices and CPU state, reads the first 512-byte sector of
31    // the boot device (hard drive) into memory at address 0x7C00, and jumps to
32    // that address.
33    //
34    // The boot loader is contained in bootstart.S and boot.c. Control starts
35    // in bootstart.S, which initializes the CPU and sets up a stack, then
36    // transfers here. This code reads in the kernel image and calls the
37    // kernel.
38    //
39    // The main kernel is stored as an ELF executable image starting in the
40    // disk's sector 1.
41
42    #define SECTORSIZE      512
43    #define ELFHDR          ((elf_header*) 0x10000) // scratch space
44
45    void boot(void) __attribute__((noreturn));
46    static void boot_readsect(uintptr_t dst, uint32_t src_sect);
47    static void boot_readseg(uintptr_t dst, uint32_t src_sect,
48                             size_t filesz, size_t memsz);
49
50    // boot
51    // Load the kernel and jump to it.
52    void boot(void) {
53        // read 1st page off disk (should include programs as well as header)
54        // and check validity
55        boot_readseg((uintptr_t) ELFHDR, 1, PAGESIZE, PAGESIZE);
56        while (ELFHDR->e_magic != ELF_MAGIC) {
57            /* do nothing */
58        }
59
60        // load each program segment
61        elf_program* ph = (elf_program*) ((uint8_t*) ELFHDR + ELFHDR->e_phoff);
62        elf_program* eph = ph + ELFHDR->e_phnum;
63        for (; ph < eph; ++ph) {
64            boot_readseg(ph->p_va, ph->p_offset / SECTORSIZE + 1,
65                        ph->p_filesz, ph->p_memsz);
66        }
67
68        // jump to the kernel
69        typedef void (*kernel_entry_t)(void) __attribute__((noreturn));
70        kernel_entry_t kernel_entry = (kernel_entry_t) ELFHDR->e_entry;
71        kernel_entry();
72    }

```

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```

73
74
75 // boot_readseg(dst, src_sect, filesz, memsz)
76 // Load an ELF segment at virtual address `dst` from the IDE disk's sector
77 // `src_sect`. Copies `filesz` bytes into memory at `dst` from sectors
78 // `src_sect` and up, then clears memory in the range
79 // `[dst+filesz, dst+memsz)`.
80 static void boot_readseg(uintptr_t ptr, uint32_t src_sect,
81                          size_t filesz, size_t memsz) {
82     uintptr_t end_ptr = ptr + filesz;
83     memsz += ptr;
84
85     // round down to sector boundary
86     ptr &= ~(SECTORSIZE - 1);
87
88     // read sectors
89     for (; ptr < end_ptr; ptr += SECTORSIZE, ++src_sect) {
90         boot_readsect(ptr, src_sect);
91     }
92
93     // clear bss segment
94     for (; end_ptr < memsz; ++end_ptr) {
95         *(uint8_t*) end_ptr = 0;
96     }
97 }
98
99
100 // boot_waitdisk
101 // Wait for the disk to be ready.
102 static void boot_waitdisk(void) {
103     // Wait until the ATA status register says ready (0x40 is on)
104     // & not busy (0x80 is off)
105     while ((inb(0x1F7) & 0xC0) != 0x40) {
106         /* do nothing */
107     }
108 }
109
110
111 // boot_readsect(dst, src_sect)
112 // Read disk sector number `src_sect` into address `dst`.
113 static void boot_readsect(uintptr_t dst, uint32_t src_sect) {
114     // programmed I/O for "read sector"
115     boot_waitdisk();
116     outb(0x1F2, 1); // send `count = 1` as an ATA argument
117     outb(0x1F3, src_sect); // send `src_sect`, the sector number
118     outb(0x1F4, src_sect >> 8);
119     outb(0x1F5, src_sect >> 16);
120     outb(0x1F6, (src_sect >> 24) | 0xE0);
121     outb(0x1F7, 0x20); // send the command: 0x20 = read sectors
122
123     // then move the data into memory
124     boot_waitdisk();
125     insl(0x1F0, (void*) dst, SECTORSIZE/4); // read 128 words from the disk
126 }
127
128

```

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```

129 2. Two more examples of I/O instructions
130
131     (a) Reading keyboard input
132
133     The code below is an excerpt from WeensyOS's k-hardware.c
134
135     This reads a character typed at the keyboard (which shows up on the
136     "keyboard data port" (KEYBOARD_DATAREG)).
137
138     /* Excerpt from WeensyOS x86-64.h */
139     // Keyboard programmed I/O
140     #define KEYBOARD_STATUSREG    0x64
141     #define KEYBOARD_STATUS_READY 0x01
142     #define KEYBOARD_DATAREG     0x60
143
144     int keyboard_readc(void) {
145         static uint8_t modifiers;
146         static uint8_t last_escape;
147
148         if ((inb(KEYBOARD_STATUSREG) & KEYBOARD_STATUS_READY) == 0) {
149             return -1;
150         }
151
152         uint8_t data = inb(KEYBOARD_DATAREG);
153         uint8_t escape = last_escape;
154         last_escape = 0;
155
156         if (data == 0xE0) { // mode shift
157             last_escape = 0x80;
158             return 0;
159         } else if (data & 0x80) { // key release: matters only for modifier ke
160             ys
161                 int ch = keymap[(data & 0x7F) | escape];
162                 if (ch >= KEY_SHIFT && ch < KEY_CAPSLOCK) {
163                     modifiers &= ~(1 << (ch - KEY_SHIFT));
164                 }
165                 return 0;
166             }
167
168             int ch = (unsigned char) keymap[data | escape];
169
170             if (ch >= 'a' && ch <= 'z') {
171                 if (modifiers & MOD_CONTROL) {
172                     ch -= 0x60;
173                 } else if (!(modifiers & MOD_SHIFT) != !(modifiers & MOD_CAPSLOCK))
174                 {
175                     ch -= 0x20;
176                 }
177             } else if (ch >= KEY_CAPSLOCK) {
178                 modifiers ^= 1 << (ch - KEY_SHIFT);
179                 ch = 0;
180             } else if (ch >= KEY_SHIFT) {
181                 modifiers |= 1 << (ch - KEY_SHIFT);
182                 ch = 0;
183             } else if (ch >= CKEY(0) && ch <= CKEY(21)) {
184                 ch = complex_keymap[ch - CKEY(0)].map[modifiers & 3];
185             } else if (ch < 0x80 && (modifiers & MOD_CONTROL)) {
186                 ch = 0;
187             }
188
189             return ch;
190         }

```

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```

190
191     (b) Setting the cursor position
192
193     The code below is also excerpted from WeensyOS's k-hardware.c. It
194     uses I/O instructions to set a blinking cursor in the upper left of
195     the screen.
196
197     // console_show_cursor(cpos)
198     //     Move the console cursor to position 'cpo', which should be between 0
199     //     and 80 * 25.
200
201     void console_show_cursor(int cpos) {
202         if (cpo < 0 || cpo > CONSOLE_ROWS * CONSOLE_COLUMNS) {
203             cpo = 0;
204         }
205
206         outb(0x3D4, 14); // Command 14 = upper byte of position
207         outb(0x3D5, 0 / 256); // row 0
208         outb(0x3D4, 15); // Command 15 = lower byte of position
209         outb(0x3D5, 0 % 256); // column 0
210     }
211
212
213
214

```

215 3. Memory-mapped I/O

216

217 a. Here is a 32-bit PC's physical memory map:

218

219 +-----+ <- 0xFFFFFFFF (4GB)

220 32-bit
221 memory mapped
222 devices

223 /\ /\ /\ /\ /\ /\ /\ /\

224

225 /\ /\ /\ /\ /\ /\ /\ /\

226

227 Unused

228

229 <- depends on amount of RAM

230

231 Extended Memory

232

233 BIOS ROM <- 0x00100000 (1MB)

234

235 <- 0x000F0000 (960KB)

236

237 16-bit devices,
238 expansion ROMs

239

240 <- 0x000C0000 (768KB)

241

242 VGA Display <- 0x000A0000 (640KB)

243

244 Low Memory

245

246 <- 0x00000000

247

248 [Credit to Frans Kaashoek, Robert Morris, and Nickolai Zeldovich for
249 this picture]

250

251

252 b. Loads and stores to the device memory "go to hardware".

253

254 An example is in the console printing code from WeensyOS. Here is an
255 excerpt from link/shared.ld:

256

257 /* Compare the address below to the map above. */
258 PROVIDE(console = 0xB8000);

259

260

261 /*
262 * prints a character to the console at the specified
263 * cursor position in the specified color.

264

265 * Question: what is going on in the check
266 * if (c == '\n')

267

268 * ?
269 * Hint: '\n' is "C" for "newline" (the user pressed enter).

270

271 /*
272 static void console_putc(printer* p, unsigned char c, int color) {
273 console_printer* cp = (console_printer*) p;
274 if (cp->cursor >= console + CONSOLE_ROWS * CONSOLE_COLUMNS) {
275 cp->cursor = console;

276

277 }
278 if (c == '\n') {
279 int pos = (cp->cursor - console) % 80;

280

281 for (; pos != 80; pos++) {
282 *cp->cursor++ = ' ' | color;

283

284 }
285 } else {
286 *cp->cursor++ = c | color;

287

288 }
289 }

290

291

292

293

294