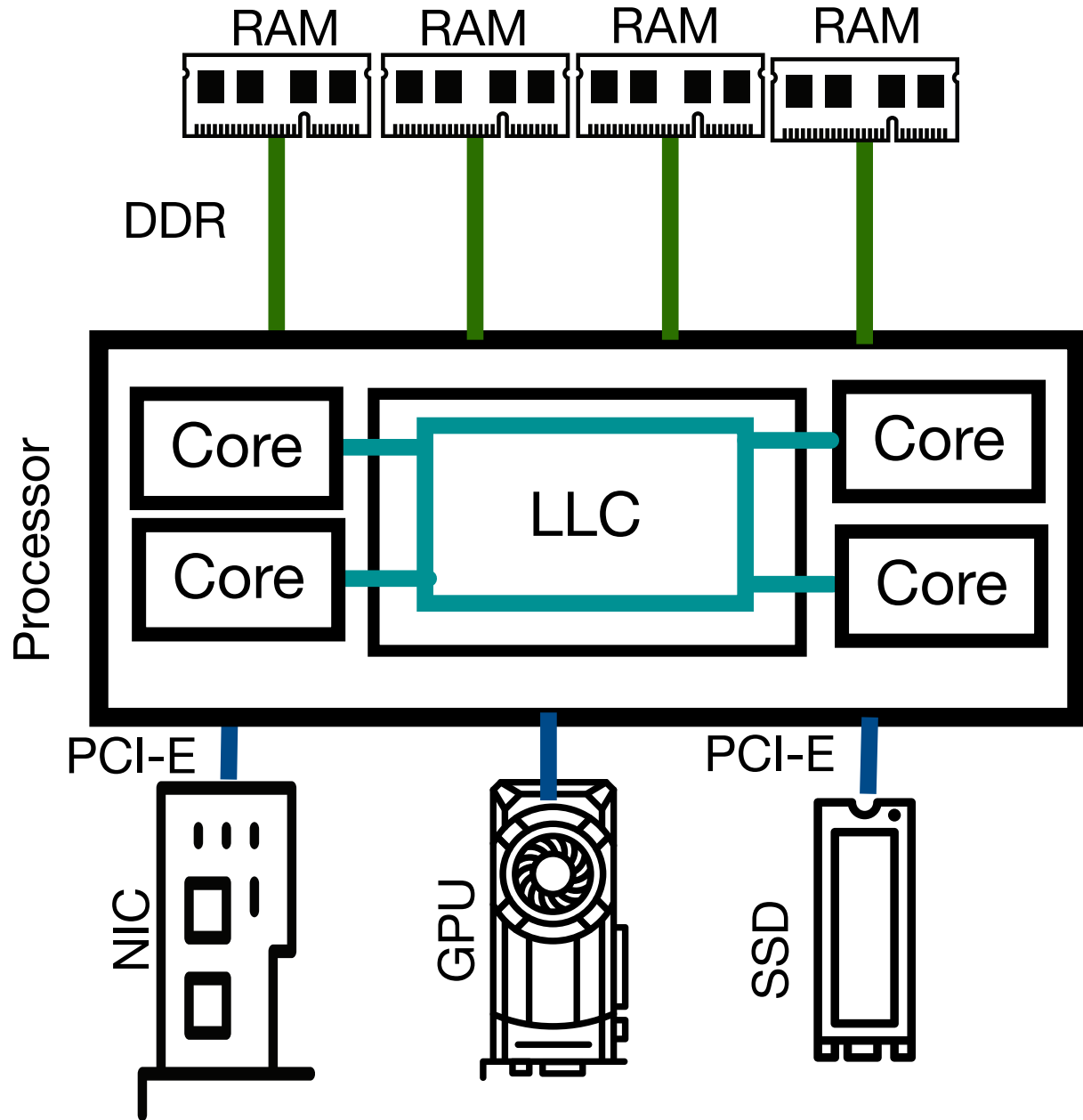


# Machine



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```

1 CS 202, Spring 2021
2 Handout 10 (Class 16)
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
14    Figures 36.5 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 510 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 }
73

```

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```

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         return ch;
189     }

```

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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 'cpos', which should be between 0
199     //     and 80 * 25.
200
201     void console_show_cursor(int cpos) {
202         if (cpos < 0 || cpos > CONSOLE_ROWS * CONSOLE_COLUMNS) {
203             cpos = 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

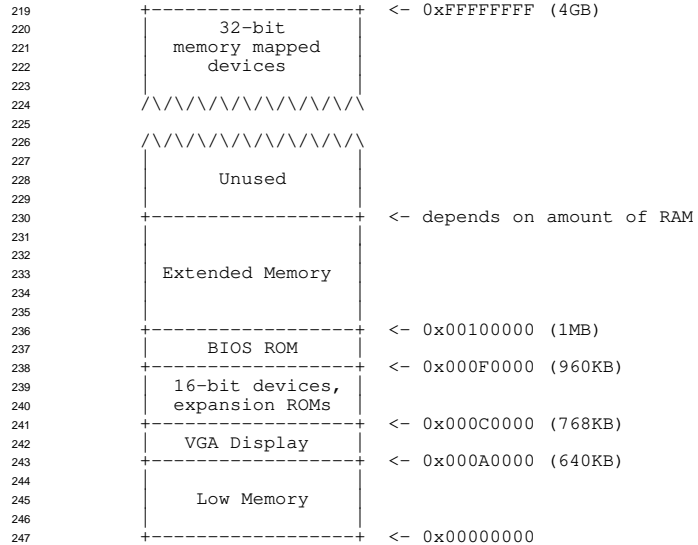
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## 215 3. Memory-mapped I/O

216

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

218



225

226 [Credit to Frans Kaashoek, Robert Morris, and Nickolai Zeldovich for  
227 this picture]

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}

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

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

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

261 This is an excerpt from lib.c; notice how it uses the address  
262 "console":

```
264 /*
265  * prints a character to the console at the specified
266  * cursor position in the specified color.
267  * Question: what is going on in the check
268  *     if (c == '\n')
269  * ?
270  * Hint: '\n' is "C" for "newline" (the user pressed enter).
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     if (c == '\n') {
278         int pos = (cp->cursor - console) % 80;
279         for (; pos != 80; pos++) {
280             *cp->cursor++ = ' ' | color;
281         }
282     } else {
283         *cp->cursor++ = c | color;
284     }
285 }
```