

Rechnerarchitektur Serie 3

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1 Theorie-Teil

1.1 Aufgabe 1

	t	$Freq$	CPI	$Freq * CPI$	CPI	$Freq * CPI$	CPI	$Freq * CPI$
<i>ALU</i>	$5nsec$	25%	2	0.5	2	0.5	1	0.25
<i>LOAD</i>	$10nsec$	25%	4	1.0	6	1.5	4	1.0
<i>STORE</i>	$7.5nsec$	25%	3	0.75	3	0.75	1	0.75
<i>Branch</i>	$7.5nsec$	25%	3	0.75	3	0.75	1	0.75
				3.0		3.5		2.75

1. Eine Maschine, die für die LOAD Instruktion 6 Taktzyklen braucht, ist also $3.5/3.0 - 1 = 16.7\%$ langsamer.
2. Eine CPU, bei der die ALU doppelt so schnell arbeitet, ist also $2.75/3.0 - 1 = 8.3\%$ schneller.

1.2 Aufgabe 2

1. Darauf kann die Rücksprungadresse für die Vortsetzung der Programmbearbeitung gespeichert werden.
2. Darauf können die Aufrufparameter gelegt werden, damit sie von der Subroutine gelesen werden können.

1.3 Aufgabe 3

Damit der Overflow behandelt werden kann:

<i>VorzeichenA</i>	<i>VorzeichenB</i>	<i>Binvert</i>	<i>Carryout</i>	<i>Vorz.Result.</i>	<i>Korr.Vorz.Res.</i>	<i>Overflow</i>
0	0	0	0	0	0	0
0	0	1	0	1	0	1
0	1	0	0	1	1	0
0	1	1	1	0	0	0
1	0	0	0	1	1	0
1	0	1	1	0	0	0
1	1	0	1	0	1	1
1	1	1	1	1	1	0

Die ersten 5 Argumente werden für die Overflowdetection gebraucht. Ist das B invert Bit nicht gleich dem Carry out Bit, so gibt es einen Overflow. (Bei ALU31, da da die Vorzeichen abgespeichert sind)

1.4 Aufgabe 4

- Beim slt-Befehl wird $a - b$ gerechnet. Falls $a - b < 0$ erhält man im Vorzeichenbit (ALU31) eine 1.
- Die ALU unterstützt diesen Befehl, indem sie das Set des ALU31 Bits mit dem Less des ALU0 Bits verbindet. Alle anderen Less sind 0;

1.5 Aufgabe 5

Listing 1: MIPS push und pop

```
1 # Push und pop auf dem Stack. $sp bezeichnet den Stackpointer.
2 push:
3     subi $sp $sp 4
4     sw   $t0 0($sp)
5
6 pop:
7     lw   $t0 0($sp)
8     addi $sp $sp 4
```

1.6 Aufgabe 6

Listing 2: loadi

```
1 # obere 16 Bits mittels LUI in Register $0 laden und dann dieses Register mit
   ORI und den unteren 16 Bits verknüpfen:
2 lui $s0 $upperConstBits
3 ori $s0 $s0 $lowerConstBits
```

1.7 Aufgabe 7

<i>Befehl</i>	<i>Ainvert</i>	<i>Binvert</i>	<i>Operation</i>
<i>and</i>	0	0	00
<i>or</i>	0	0	01
<i>add</i>	0	0	10
<i>subtract</i>	0	1	10
<i>slt</i>	0	1	11
<i>nor</i>	1	1	00

and Mit dem Opcode 00 wird der erste Eingang des Operationsmuxes (das AND-Gatter) angesteuert, und somit muss A und B nicht invertiert werden.

or Gleich wie oben. Mit dem Opcode 01 kann direkt der zweite Eingang des Operationsmuxes (das OR-Gatter) angesteuert werden, und somit müssen A und B wiederum nicht invertiert werden.

add Wiederum kann mit dem Opcode 10 der dritte Eingang des Operationsmuxes (Addition) angesteuert werden, und A und B müssen wiederum nicht invertiert werden.

subtract Wenn man b negiert (also invertiert) kann man einfach noch eine Addition ausführen (Opcode 10)

slt Es wird wieder $a - b$ gerechnet (siehe subtract). Also B invertieren. Falls B grösser als A ist, soll das 31ste Bit den Wert 1 haben, welcher ebenfalls aufs erste Bit zurückgeführt wird. Damit kann man beim Operationsmux den vierten Eingang (Opcode 11) wählen, und erhält nun als Ausgabe eine 1, falls B grösser als A ist und sonst eine 0.

nor Da $aNORb = not aANDnot b$ ist, kann man A und B invertieren und das AND-Gatter (Opcode 00) anlegen.

2 Programmierteil

Listing 3: compile.c

```
1  /* TODO: Task (b) Please fill in the following lines, then remove this line.
2   *
3  * author(s):   Dominik Bodenmann
4  *              Orlando Signer
5  * modified:    2010-01-07
6   *
7  */
8
9  #include <stdlib.h>
10 #include <stdio.h>
11 #include "memory.h"
12 #include "mips.h"
13 #include "compiler.h"
14
15 int main ( int argc, char** argv ) {
16     /* TODO: Task (c) implement main */
17     if (argc != 3) {
18         printf("usage: <%s> expression filename\n", argv[0]);
19         return EXIT_FAILURE;
20     }
21     char * expression = argv[1];
22     char * filename = argv[2];
23     compiler(expression, filename);
24     return EXIT_SUCCESS;
25 }
```

Listing 4: mips.c

```

1  /* TODO: Task (b) Please fill in the following lines, then remove this line.
2   *
3   * author(s):   Dominik Bodenmann
4   *              Orlando Signer
5   * modified:    2010-01-07
6   *
7   */
8
9  #include <stdarg.h>
10 #include <stdlib.h>
11 #include <stdio.h>
12 #include <string.h>
13
14 #include "mips.h"
15 #include "memory.h"
16
17 /* The "Hardware" */
18 word registers[REGISTER_COUNT];
19 word pc;
20
21 /* To stop the MIPS machine */
22 int doRun;
23
24 /* In case you want to watch the machine working */
25 int verbose = FALSE;
26
27 /* Operation and function dispatcher */
28 Operation operations[OPERATION_COUNT];
29 Function functions[FUNCTION_COUNT];
30
31 /* ===== */
32 /* Some useful helpers */
33
34 void error(const char *functionName, const char *fileName, int lineNumber,
35           char *message, ...) {
36     /* TODO: Task (e) implement error */
37     printf("%s in %s, line %i: %s\n", functionName, fileName, lineNumber,
38           message);
39
40     exit(EXIT_FAILURE);
41 }
42
43 /* Assembles the given parts of an I-type instruction into a single word*/
44 word create_itype_hex(unsigned short immediate, unsigned short rt, unsigned
45                      short rs, unsigned short opcode) {
46     return immediate + (rt << 16) + (rs << 21) + (opcode << 26);
47 }
48
49 /* Assembles the given parts of an J-type instruction into a single word*/
50 word create_jtype_hex(unsigned long address, unsigned short opcode) {

```

```

50     return address + (opcode << 26);
51 }
52
53 /* Assembles the given parts of an R-type instruction into a single word */
54 word create_rtype_hex(unsigned short funct, unsigned short shamt, unsigned
    short rd, unsigned short rt, unsigned short rs, unsigned short opcode) {
55     return funct + (shamt << 6) + (rd << 11) + (rt << 16) + (rs << 21) + (opcode
        << 26);
56 }
57
58 /* Extends a 16 bit halfword to a 32 bit word with the value of the most
    significant bit */
59 word signExtend(halfword value) {
60     return (value ^ 0x8000) - 0x8000;
61 }
62
63
64 /* Extends a 16 bit halfword to a 32 bit word by adding leading zeros */
65 word zeroExtend(halfword value) {
66     return (value | 0x00000000);
67 }
68
69 /* To make some noise */
70 void printInstruction(Instruction *i) {
71     Operation o = operations[i->i.opcode];
72     Function f;
73     switch (o.type) {
74         case iType:
75             printf("%-4s %02i=0x%08ux, %02i=0x%08ux, 0x%04x\n", o.name, i->i.
                rt, registers[i->i.rt], i->i.rs, registers[i->i.rs], i->i.
                immediate );
76             break;
77         case jType:
78             printf("%-4s 0x%08x\n", o.name, i->j.address);
79             break;
80         case rType:
81             f = functions[i->r.funct];
82             printf("%-4s %02i=0x%08ux, %02i=0x%08ux, %02i=0x%08ux, 0x%04x\n",
                f.name, i->r.rd, registers[i->r.rd], i->r.rs, registers[i->r.
                rs], i->r.rt, registers[i->r.rt], i->r.shamt);
83             break;
84         case specialType:
85             printf("%-4s\n", o.name);
86             break;
87     }
88 }
89
90
91 /* ===== */
92 /* Initialize and run */
93
94 void assignOperation(unsigned short opCode, const char name[OP_NAME_LENGTH
    +1], char type, void (*operation)(Instruction*)) {
95     strcpy(operations[opCode].name, name);

```

```

96     operations[opCode].type=type;
97     operations[opCode].operation = operation;
98 }
99
100 void assignFunction(unsigned short funct, const char name[FUNC_NAME_LENGTH
    +1], void (*function)(Instruction*)) {
101     strcpy(functions[funct].name, name);
102     functions[funct].function = function;
103 }
104
105 /* Initialize the "hardware" and operation and function dispatcher */
106 void initialize() {
107     int i;
108     /* Initialize operations */
109     for (i=0; i<OPERATION_COUNT; ++i) {
110         assignOperation(i, "ndef", specialType, &undefinedOperation);
111     }
112     assignOperation(OC_ZERO, "zero", rType, &opCodeZeroOperation);
113     /* To stop the MIPS machine */
114     assignOperation(OC_STOP, "stop", specialType, &stopOperation);
115
116     assignOperation(OC_ADDI, "addi", iType, &mips_addi);
117     assignOperation(OC_LUI, "lui", iType, &mips_lui);
118     assignOperation(OC_LW, "lw", iType, &mips_lw);
119     assignOperation(OC_ORI, "ori", iType, &mips_ori);
120     assignOperation(OC_SW, "sw", iType, &mips_sw);
121
122     /* Initialize operations with OpCode = 0 and corresponding functions */
123     for (i=0; i<FUNCTION_COUNT; ++i) {
124         assignFunction(i, "ndef", &undefinedFunction);
125     }
126     assignFunction(FC_ADD, "add", &mips_add);
127     assignFunction(FC_DIV, "div", &mips_div);
128     assignFunction(FC_MULT, "mult", &mips_mult);
129     assignFunction(FC_SUB, "sub", &mips_sub);
130
131     initializeMemory();
132
133     /* Initialize registers */
134     for (i=0; i<REGISTER_COUNT; ++i) {
135         registers[i]= 0;
136     }
137
138     /* Stack pointer */
139     SP=65535;
140
141     /* Initialize program counter */
142     pc = 0;
143
144     /* Yes, we want the machine to run */
145     doRun = TRUE;
146
147 }
148

```

```

149  /* Fetch and execute */
150  void run() {
151      while (doRun) {
152          /* Fetch Instruction*/
153          word w = loadWord(pc);
154          Instruction *instruction = (Instruction *) &w;
155          pc += 4;
156          /* Execute Instruction*/
157          operations[instruction->i.opcode].operation(instruction);
158          /* In case you want to watch the machine */
159              if (verbose) {
160                  printInstruction(instruction);
161              }
162      }
163  }
164
165
166  /* ===== */
167  /* "Special" operations --- only for "internal" usage */
168
169  /* To deal with "undefined" behaviour */
170  void undefinedOperation(Instruction *instruction) {
171      ERROR("Unknown opcode: %x", instruction->i.opcode);
172  }
173
174  /* To deal with "undefined" behaviour */
175  void undefinedFunction(Instruction *instruction) {
176      ERROR("Unknown funct: %x", instruction->r.funct);
177  }
178
179  /* To deal with operations with opcode = 0 */
180  void opCodeZeroOperation(Instruction *instruction) {
181      functions[instruction->r.funct].function(instruction);
182  }
183
184  /* To stop the machine */
185  void stopOperation(Instruction *instruction) {
186      doRun = FALSE;
187  }
188
189  /* =====
190      */
191
192  /* ADD */
193  void mips_add(Instruction *instruction) {
194      InstructionTypeR r = instruction->r;
195      registers[r.rd] = (signed)registers[r.rs] + (signed)registers[r.rt];
196  }
197
198  /* ADDI */
199  void mips_addi(Instruction *instruction) {
200      InstructionTypeI i = instruction->i;
201      registers[i.rt] = (signed)registers[i.rs] + (signed)signExtend(i.immediate)
202          ;

```



```

201 }
202
203 /* DIV --- Warning: actual DIV is a bit more complicated*/
204 void mips_div(Instruction *instruction) {
205     InstructionTypeR r = instruction->r;
206     registers[r.rd] = (signed)registers[r.rs] / (signed)registers[r.rt];
207 }
208
209 /* LUI */
210 void mips_lui(Instruction *instruction) {
211     InstructionTypeI i = instruction->i;
212     registers[i.rt] = i.immediate << 16;
213 }
214
215 /* LW */
216 void mips_lw(Instruction *instruction) {
217     InstructionTypeI i = instruction->i;
218     registers[i.rt] = loadWord(registers[i.rs] + (signed)signExtend(i.immediate
219 ));
220
221 /* MULT --- Warning: actual MULT is a bit more complicated */
222 void mips_mult(Instruction *instruction) {
223     InstructionTypeR r = instruction->r;
224     registers[r.rd] = (signed)registers[r.rs] * (signed)registers[r.rt];
225 }
226
227 /* ORI */
228 void mips_ori(Instruction *instruction) {
229     InstructionTypeI i = instruction->i;
230     registers[i.rt] = registers[i.rs] | zeroExtend(i.immediate);
231 }
232
233 /* SUB */
234 void mips_sub(Instruction *instruction) {
235     InstructionTypeR r = instruction->r;
236     registers[r.rd] = (signed)registers[r.rs] - (signed)registers[r.rt];
237 }
238
239 /* SW */
240 void mips_sw(Instruction *instruction) {
241     InstructionTypeI i = instruction->i;
242     storeWord(registers[i.rt], registers[i.rs] + (signed)signExtend(i.immediate
243 ));

```

Listing 5: memory.c

```

1  /* TODO: Task (b) Please fill in the following lines, then remove this line.
2  *
3  * author(s):   Dominik Bodenmann
4  *              Orlando Signer
5  * modified:    2010-01-07
6  *
7  */
8
9  #include <stdlib.h>
10 #include <stdio.h>
11 #include <string.h>
12 #include <time.h>
13 #include "memory.h"
14
15 MemoryRegion * memoryRegions[MEMORY_REGION_SIZE];
16 FILE * outputStream;
17
18 void emptyMemoryRegionInitializer() {}
19
20 /* =====
21    */
22 /* DEFAULT MEMORY */
23 byte defaultMemoryData[RAM_SIZE];
24
25 void defaultMemoryInitializer() {
26     int i;
27     for (i=0; i<RAM_SIZE; ++i) {
28         defaultMemoryData[i] = 0;
29     }
30 }
31
32 void defaultMemoryWriteHandler(word address, byte value) {
33     defaultMemoryData[address] = value;
34 }
35
36 byte defaultMemoryReadHandler(word address) {
37     return defaultMemoryData[address];
38 }
39
40 MemoryRegion defaultMemory = {
41     0,
42     RAM_SIZE-1,
43     &defaultMemoryInitializer,
44     &defaultMemoryWriteHandler,
45     &defaultMemoryReadHandler
46 };
47
48 /* NEW Macro */
49 /* =====
50    */
51 /* printf memory */

```

```

51 void fprintfMemoryRegionInitializer() {
52     outputStream = stdout;
53 }
54
55 void fprintfMemoryWriteHandler(word address, byte value) {
56     fprintf(outputStream, "%c", value);
57 }
58
59 byte fprintfMemoryReadHandler(word address) {
60     /* ignore reads, only used to output */
61     return 0;
62 }
63
64 MemoryRegion fprintfMemory = {
65     FPRINTF_MEMORY_LOCATION,
66     FPRINTF_MEMORY_LOCATION,
67     &fprintfMemoryRegionInitializer,
68     &fprintfMemoryWriteHandler,
69     &fprintfMemoryReadHandler
70 };
71
72 /* =====
73     */
74     /* time memory */
75 void timeMemorWriteHandler(word address, byte value) {}
76
77 byte timeMemoryReadHandler(word address) {
78     return clock() * 1000 / CLOCKS_PER_SEC;
79 }
80
81 MemoryRegion timeMemory = {
82     TIME_MEMORY_LOCATION,
83     TIME_MEMORY_LOCATION,
84     &emptyMemoryRegionInitializer,
85     &timeMemorWriteHandler,
86     &timeMemoryReadHandler
87 };
88
89 /* =====
90     */
91 int checkMemoryRegionOverlap(MemoryRegion *region) {
92     int i;
93     for (i=0; i<MEMORY_REGION_SIZE; ++i) {
94         if (!memoryRegions[i]) {
95             break;
96         }
97         if (((memoryRegions[i]->min >= region->min) && ( region->min <=
memoryRegions[i]->max))
98             || ((memoryRegions[i]->min >= region->max) && (region->max <=
memoryRegions[i]->max))) {
99             return FALSE;
100         }

```

```

101     }
102     return TRUE;
103 }
104
105 int memoryRegionCounter = 0;
106
107 void registerMemoryRegion(MemoryRegion *region) {
108     if (checkMemoryRegionOverlap(region)) {
109         memoryRegions[memoryRegionCounter] = region;
110         memoryRegionCounter++;
111         region->initialize();
112     } else {
113         ERROR("Overlapping memory regions");
114     }
115 }
116
117 void initializeMemory() {
118     int i;
119     memoryRegionCounter = 0;
120     for (i=0; i<MEMORY_REGION_SIZE; ++i) {
121         memoryRegions[i] = NULL;
122     }
123     registerMemoryRegion(&defaultMemory);
124     registerMemoryRegion(&fprintfMemory);
125     registerMemoryRegion(&timeMemory);
126 }
127
128 /* MEMORY FUNCTIONS =====
129    */
130
131 /* Load a file to memory */
132 void loadFile(char* filename) {
133     /* TODO: Task (d) implement loadFile */
134     int i;
135     FILE *file;
136     char *buffer = 0;
137     long length;
138     byte* ram;
139
140     // Reading the file in the buffer
141     file = fopen(filename, "rb");
142     if (file) {
143         fseek (file, 0, SEEK_END);
144         length = ftell (file);
145         fseek (file, 0, SEEK_SET);
146         buffer = malloc (length);
147         if (buffer)
148             fread (buffer, 1, length, file);
149     }
150     fclose(file);
151
152     // Create store characters in the memory
153     if (buffer) {
154         ram = defaultMemoryData;

```

```

154         for (i = 0; i < length; i++) {
155             *ram = (unsigned) buffer[i];
156             ram += 1;
157         }
158     }
159 }
160
161 /* =====
162     */
163 MemoryRegion* getMemoryRegion(word location) {
164     int i;
165     MemoryRegion *memoryRegion = NULL;
166     for (i=0; i<MEMORY_REGION_SIZE && !memoryRegion; ++i) {
167         if (memoryRegions[i] && memoryRegions[i]->min <= location &&
168             memoryRegions[i]->max >= location) {
169             memoryRegion = memoryRegions[i];
170         }
171         if (!memoryRegion) {
172             ERROR("Invalid memory access at 0x%x", (int) location);
173         }
174         return memoryRegion;
175     }
176
177
178     /* Store a word to memory */
179     void storeWord(word w, word location) {
180         MemoryRegion *memoryRegion = getMemoryRegion(location);
181         memoryRegion->write(location, (w >> (8*3)) & 0xFF);
182         memoryRegion->write(location+1, (w >> (8*2)) & 0xFF);
183         memoryRegion->write(location+2, (w >> (8*1)) & 0xFF);
184         memoryRegion->write(location+3, (w >> (8*0)) & 0xFF);
185     }
186
187     /* Load a word from memory */
188     word loadWord(word location) {
189         MemoryRegion *memoryRegion = getMemoryRegion(location);
190         word w = 0;
191         w += (memoryRegion->read(location) << (8*3));
192         w += (memoryRegion->read(location+1) << (8*2));
193         w += (memoryRegion->read(location+2) << (8*1));
194         w += (memoryRegion->read(location+3) << (8*0));
195         return w;
196     }

```