ANNA+ Programming Card

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| --- | --- | --- | --- |
| ***Opcode*** | ***Op*** | ***Operands*** | ***Description*** |
| 0000 | add | *Rd Rs1 Rs2* | Two's complement addition: R(*Rd*)  R(*Rs1*) + R(*Rs2*) |
| 0000 | sub | *Rd Rs1 Rs2* | Two's complement subtraction: R(*Rd*)  R(*Rs1*) – R(*Rs2*) |
| 0000 | and | *Rd Rs1 Rs2* | Bitwise and operation: R(*Rd*)  R(*Rs1*) & R(*Rs2*) |
| 0000 | or | *Rd Rs1 Rs2* | Bitwise or operation: R(*Rd*)  R(*Rs1*) | R(*Rs2*) |
| 0000 | not | *Rd Rs1* | Bitwise not operation: R(*Rd*)  ~R(*Rs1*) |
| 0000 | mul | *Rd Rs1 Rs2* | Two's complement multiplication: R(*Rd*)  R(*Rs1*) × R(*Rs2*) |
| 0000 | div | *Rd Rs1 Rs2* | Two's complement integer division: R(*Rd*)  R(*Rs1*) ÷ R(*Rs2*) |
| 0000 | mod | *Rd Rs1 Rs2* | Two's complement modulus: R(*Rd*)  R(*Rs1*) % R(*Rs2*) |
| 0001 | jalr | *Rd Rs1* | Jumps to the address stored in register *Rd* and stores PC + 1 in register *Rs1*. |
| 0010 | in | *Rd* | Input instruction: R(*Rd*)  input |
| 0011 | out | *Rd* | Output instruction: output  R(*Rd*). If *Rd* is r0, halts the processor (see halt). |
| 0011 | outn | *Rd* | Prints the integer value R(*Rd*) to STDOUT. |
| 0011 | outs | *Rd* | Prints the NUL-terminated string at M[R(*Rd*)] to STDOUT. |
| 0100 | addi | *Rd Rs1 Imm6* | Add immediate: R(*Rd*)  R(*Rs1*) + *Imm6* |
| 0101 | shf | *Rd Rs1 Imm6* | Bit shift. The contents of *Rs1* are shifted left (if *Imm6* is positive) or right with zero extension (if *Imm6* is negative). The shift amount is abs(*Imm6*); the result is stored in R(*Rd)*. |
| 0110 | lw | *Rd Rs1 Imm6* | Loads word from memory using the effective address computed by adding *Rs1* with the signed immediate: R(*Rd*)  M[R(*Rs1*) + *Imm6*] |
| 0111 | sw | *Rd Rs1 Imm6* | Stores word into memory using the effective address computed by adding Rs1 with the signed immediate: M[R(*Rs1*) + *Imm6*]  R(*Rd*) |
| 1000 | lli | *Rd Imm8* | The lower bits (7-0) of *Rd* are copied from *Imm8*. The upper bits (15-8) of *Rd* are equal to bit 7 of *Imm8* (sign extension). |
| 1001 | lui | *Rd Imm8* | The upper bits (15- 8) of *Rd* are copied from Imm8. The lower bits (7-0) of *Rd* are unchanged. |
| 1010 | beq | *Rd Imm8* | If R(*Rd*) = 0, then branch is taken with indirect target of PC + 1 + *Imm8* as next PC. Immediate is a signed value. |
| 1011 | bne | *Rd Imm8* | If R(*Rd*) ≠ 0, then branch is taken with indirect target of  PC + 1 + *Imm8* as next PC. Immediate is a signed value. |
| 1100 | bgt | *Rd Imm8* | If R(*Rd*) > 0, then branch is taken with indirect target of  PC + 1 + *Imm8* as next PC. Immediate is a signed value. |
| 1101 | bge | *Rd Imm8* | If R(*Rd*) ≥ 0, then branch is taken with indirect target of PC + 1 + *Imm8* as next PC. Immediate is a signed value. |
| 1110 | blt | *Rd Imm8* | If R(*Rd*) < 0, then branch is taken with indirect target of  PC + 1 + *Imm8* as next PC. Immediate is a signed value. |
| 1111 | ble | *Rd Imm8* | If R(*Rd*) ≤ 0, then branch is taken with indirect target of PC + 1 + *Imm8* as next PC. Immediate is a signed value. |
| Pseudo-Ops | br | *Imm8* | Assembles as beq r0 *Imm8* to always branch. |
| halt |  | Assembles as out r0 instruction (0x3000) that halts the processor. |
| jmp | *Rd* | Assembles as jalr *Rd* r0 to perform a jump. |
| lwi | *Rd Imm16* | Assembles lli and lui instructions to load *Imm16* into R(*Rd*). Can be used with labels. |
| mov | *Rd Rs1* | Assembles as add *Rd* *Rs1* r0 to execute R(*Rd*)  R(*Rs1*) |
| push | *Rsp Rs1* | Assembles sw and addi instructions to push R(*Rs1*) to M(*Rsp*) and decrement R(*Rsp*). |
| pop | *Rsp Rd* | Assembles addi and lw instructions to increment R(*Rsp*) then pop M(*Rsp*) to R(*Rd*). |
| Assembler Directives | .halt |  | Assembler directive that emits an out instruction (0x3000) that halts the processor. (Supported for backward compatibility; use halt pseudo-op instead.) |
| .fill | *Imm16* | Fills next memory locations with the specified values. Immediate is a signed value. |
| .frame | *String* | Defines stack frames (activation records) for function. See the ANNA Guide for more information. |
| .org | *Imm16* | Assembly continues at the address indicated. |
| .def | *Imm16* | Sets the specified label to the value indicated. Must specify a label with this directive. Similar to .fill except that .def does not write any data to memory. |
| .cstr | *String* | Fills next memory locations with a NUL-terminated string, one character per memory word. |
| .ralias | *A Rn* | Creates an alias *A* for register *n*. The alias must start with an r. |

# Registers

* Represented by fields *Rd*, *Rs1*, and *Rs2.*
* A register can be any value from: r0, r1, r2, r3, r4, r5, r6, r7.
* Register r0 is always zero. Writes to register r0 are ignored.

# Immediates

* Represented by fields *Imm6*, *Imm8*, and *Imm16*. The number refers to the size of the immediate in bits.
* Immediates are represented using decimal values, hexadecimal values, or labels. Hexadecimal values must start with '0x' and labels must be preceded with '&'.
* The immediate fields represent a signed value. The immediate field for lui is specified using a signed value but the sign is irrelevant as the eight bits are copied directly into the upper eight bits of the destination register.
* Labels refer to the address of the label. If a label is used in a branch, the proper PC-relative offset is computed and used as the immediate.

**Comments**

* A comment begins with a pound sign '#' and continues until the following newline.

# Labels

* Label definitions consist of a string of letters, digits, and underscore characters followed by a colon. The colon is not part of the label name.
* A label definition must precede an instruction on the same line.
* A label may only be defined once in a program. Only one label is allowed per instruction. The instruction must appear on the same line as the label.

# Instruction Formats

Instructions adhere to one of the following three instruction formats:

**R-type** (add, sub, and, or, not, jalr, in, out)

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| 15 12 | 11 9 | | 8 6 | | 5 3 | 2 0 | |
| Opcode | *Rd* | | *Rs1* | | *Rs2* | Function code\* | |
| \*Function codes for opcode 0000: add (000), sub (001), and (010), or (011), not (100),  jalr , in, out do not use the function; each has a unique opcode. | | | | | | | |
| **I6-type** (addi, shf, lw, sw) | | | | | | | |
| 15 12 | 11 | 9 | 8 6 | | 5 |  | 0 |
| Opcode | *Rd* |  | *Rs1* | | *Imm6* |  |  |
| **I8-type** (lli, lui, beq, bne, bgt, bge, blt, ble) | | | | | | | |
| 15 12 | 11 9 | | 8 | 7 |  | | 0 |
| Opcode | *Rd* | | Unused | *Imm8* |  | |  |

# ANNA Calling Convention

* The start of the stack is at address 0x8000. The program is responsible for initializing the stack and frame pointers at the beginning of the program.
* Register usage:
  + r4: return value after a function call.
  + r5: return address at the beginning of the function call.
  + r6: frame pointer throughout the program
  + r7: stack pointer throughout the program

* All parameters must be stored on the stack (registers are not used).
* The return value is stored in r4 (stack is not used).
* Caller must save values in r1-r5 they want retained after a function (caller save registers).
  + The return address in r5 is treated like any other caller save register.

* All activation records have the same ordering.
  + Function parameters are pushed onto the stack, accessed via FP+*n*.
  + First entry (offset 0) is for the previous frame pointer
  + Next entry (offset -1) is for return address
  + Remaining entries are used for local variables and temporary values (order left up to programmer).
* Activation record for “main” only has local variables and temporary values.
  + No previous frame
  + No parameters
* Alternatively, global variables may be stored in regular memory as labels on .fill directives.

# ANNA Heap Management

* Dynamic memory in ANNA is simplified – only allocations (no deallocations).
* Heap management table is implemented using a single pointer called heapPtr: it points to the next free word in memory.
* Heap is placed at the very end of the program:

# heap section

heapPtr: .fill &heap

heap: .fill 0