

# ANNA+ Programming Card

<i>Opcode</i>	<i>Op</i>	<i>Operands</i>	<i>Description</i>
0000	add	$Rd\ Rs_1\ Rs_2$	Two's complement addition: $R(Rd) \leftarrow R(Rs_1) + R(Rs_2)$
0000	sub	$Rd\ Rs_1\ Rs_2$	Two's complement subtraction: $R(Rd) \leftarrow R(Rs_1) - R(Rs_2)$
0000	and	$Rd\ Rs_1\ Rs_2$	Bitwise and operation: $R(Rd) \leftarrow R(Rs_1) \& R(Rs_2)$
0000	or	$Rd\ Rs_1\ Rs_2$	Bitwise or operation: $R(Rd) \leftarrow R(Rs_1)   R(Rs_2)$
0000	not	$Rd\ Rs_1$	Bitwise not operation: $R(Rd) \leftarrow \sim R(Rs_1)$
0001	jalr	$Rd\ Rs_1$	Jumps to the address stored in register $Rd$ and stores $PC + 1$ in register $Rs_1$ .
0010	in	$Rd$	Input instruction: $R(Rd) \leftarrow \text{input}$
0011	out	$Rd$	Output instruction: $\text{output} \leftarrow R(Rd)$ . If $Rd$ is <code>r0</code> , halts the processor (see <code>.halt</code> ).
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	$Rd\ Rs_1\ Imm6$	Add immediate: $R(Rd) \leftarrow R(Rs_1) + Imm6$
0101	shf	$Rd\ Rs_1\ Imm6$	Bit shift. The contents of $Rs_1$ are shifted left (if $Imm6$ is positive) or right with zero extension (if $Imm6$ is negative). The shift amount is $\text{abs}(Imm6)$ ; the result is stored in $R(Rd)$ .
0110	lw	$Rd\ Rs_1\ Imm6$	Loads word from memory using the effective address computed by adding $Rs_1$ with the signed immediate: $R(Rd) \leftarrow M[R(Rs_1) + Imm6]$
0111	sw	$Rd\ Rs_1\ Imm6$	Stores word into memory using the effective address computed by adding $Rs_1$ with the signed immediate: $M[R(Rs_1) + Imm6] \leftarrow R(Rd)$
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 $R(Rd) \neq 0$ , 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 <i>Rd Imm8</i>	If $R(Rd) \geq 0$ , then branch is taken with indirect target of $PC + 1 + Imm8$ as next PC. Immediate is a signed value.
1110	blt <i>Rd Imm8</i>	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 <i>Rd Imm8</i>	If $R(Rd) \leq 0$ , then branch is taken with indirect target of $PC + 1 + Imm8$ as next PC. Immediate is a signed value.
Pseudo-Ops	lwi <i>Rd Imm16</i>	Assembles <code>lwi</code> and <code>lui</code> instructions to load <i>Imm16</i> into $R(Rd)$ . Can be used with labels.
	mov <i>Rd Rs1</i>	Assembles <code>add Rd Rs1 r0</code> to execute $R(Rd) \leftarrow R(Rs1)$
	push <i>Rsp Rs1</i>	Assembles <code>sw</code> and <code>addi</code> instructions to push $R(Rs1)$ to $M(Rsp)$ and decrement $R(Rsp)$ .
	pop <i>Rsp Rd</i>	Assembles <code>addi</code> and <code>lw</code> instructions to increment $R(Rsp)$ then pop $M(Rsp)$ to $R(Rd)$ .
Assembler Directives	.halt	Assemble directive that emits an <code>out</code> instruction (0x3000) that halts the processor.
	.fill <i>Imm16</i>	Fills next memory locations with the specified values. Immediate is a signed value.
	.org <i>Imm16</i>	Assembly continues at the address indicated.
	.def <i>Imm16</i>	Sets the specified label to the value indicated. Must specify a label with this directive.
	.cstr <i>String</i>	Fills next memory locations with a NUL-terminated string, one character per memory word.

## 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		<i>Rd</i>		<i>Rs1</i>		<i>Rs2</i>		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		<i>Rd</i>		<i>Rs1</i>		<i>Imm6</i>	

### I8-type (lli, lui, beq, bne, bgt, bge, blt, ble)

15	12	11	9	8	7	0
Opcode		<i>Rd</i>		Unused	<i>Imm8</i>	

## 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
```