COMPUTER SYSTEMS ORGANIZATION

ALU Design -- Spring 2012 -- IIIT-H -- Suresh Purini

MIPS Architecture

- Introduced in 1981(by John Hennessy & Co. in Stanford University).
- Initially a 32-bit processor. 64-bit versions available from1991 onwards.
- ISA follows RISC philosophy
- 32-bit (4 GB) Address Space
- 31 General Purpose Registers (No condition code register, like CPSR in ARM)
- Load-Store Architecture
- Only few addressing modes
  - Register, immediate, register+offset, pc-relative addressing in branch instructions.

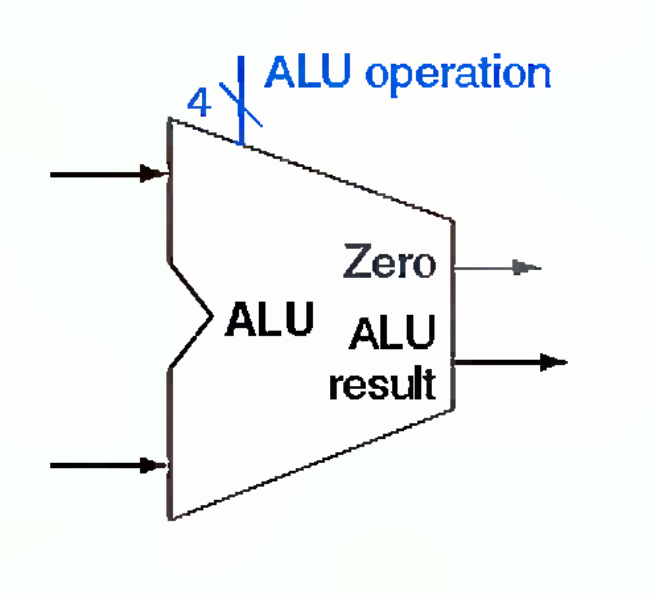
MIPS ISA

Our Focus: How to implement the following 8 instructions of MIPS ?

Instructions	Functionality
lw r_1 , 24(r_2)	$r_1 = mem[r_2 + 24]$
sw r_1 , 24(r_2)	$mem[r_2 + 24] = r_1$
add r_1, r_2 , r_3	$r_1 = r_2 + r_3$ (signed)
sub r_1, r_2 , r_3	$r_1 = r_2 - r_3$ (signed)
and r_1, r_2 , r_3	$r_1 = r_2 \& r_3$
or r_1, r_2 , r_3	$r_1 = r_2 \mid r_3$
slt r_1, r_2 , r_3	if $r_2 < r_3$ then $r_1 = 1$ else $r_1 = 0$ (signed)
beq r_1, r_2, 25	if $r_1 == r_2$ then pc = pc + 4 + 100

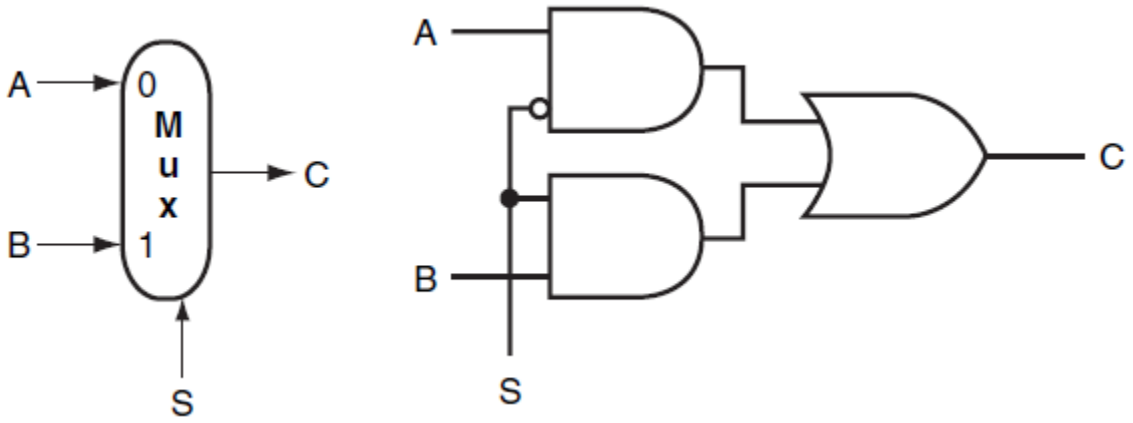
Designing a 32-bit ALU

Idea: Build the 32-bit ALU using 32 1-bit ALU



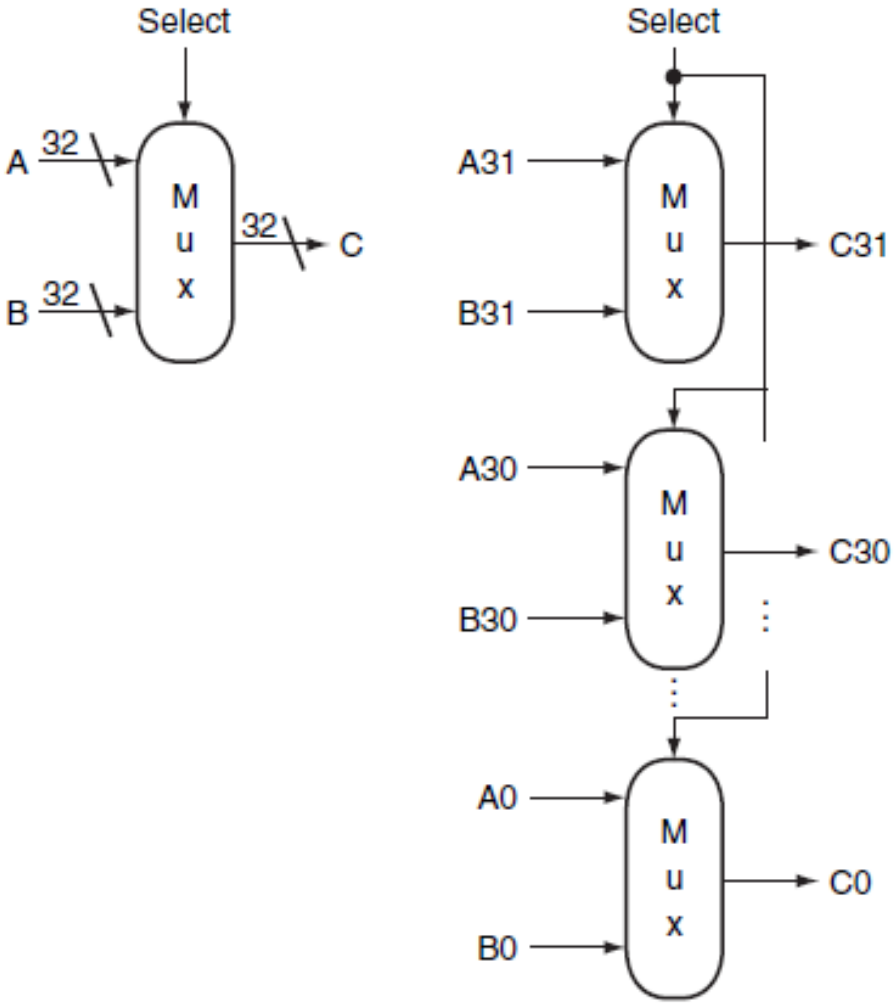
Review: Multiplexor

- A 2-to-1 multiplexor.



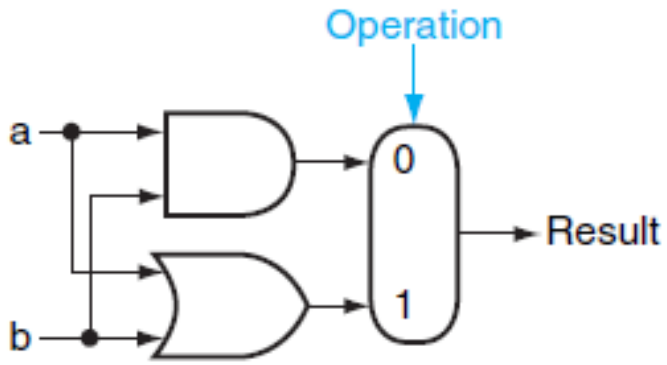
- How to use a multiplexer to build an ALU?

A 32-bit wide 2-to-1 Multiplexor

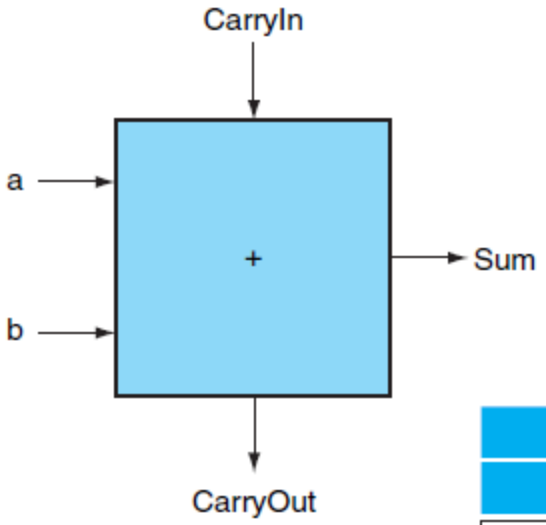


1-bit ALU

- A 1-bit ALU that can perform AND/OR operation.



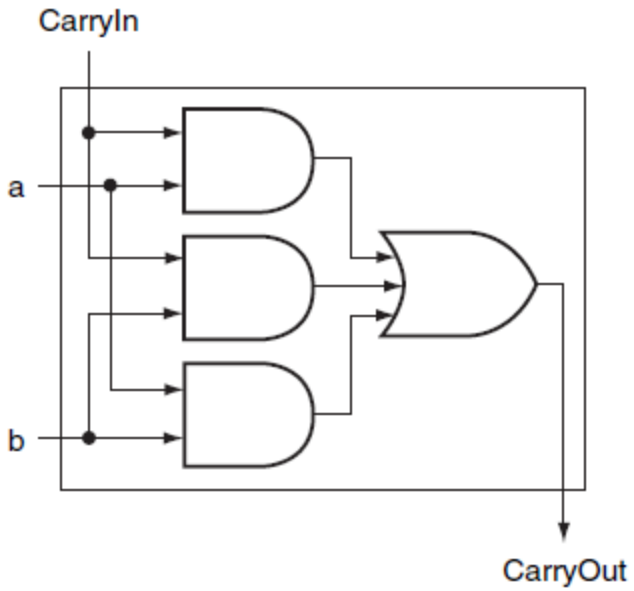
1-bit Addition Operation



Inputs			Outputs		Comments
a	b	CarryIn	CarryOut	Sum	
0	0	0	0	0	$0 + 0 + 0 = 00_{two}$
0	0	1	0	1	$0 + 0 + 1 = 01_{two}$
0	1	0	0	1	$0 + 1 + 0 = 01_{two}$
0	1	1	1	0	$0 + 1 + 1 = 10_{two}$
1	0	0	0	1	$1 + 0 + 0 = 01_{two}$
1	0	1	1	0	$1 + 0 + 1 = 10_{two}$
1	1	0	1	0	$1 + 1 + 0 = 10_{two}$
1	1	1	1	1	$1 + 1 + 1 = 11_{two}$

1-bit Addition Operation

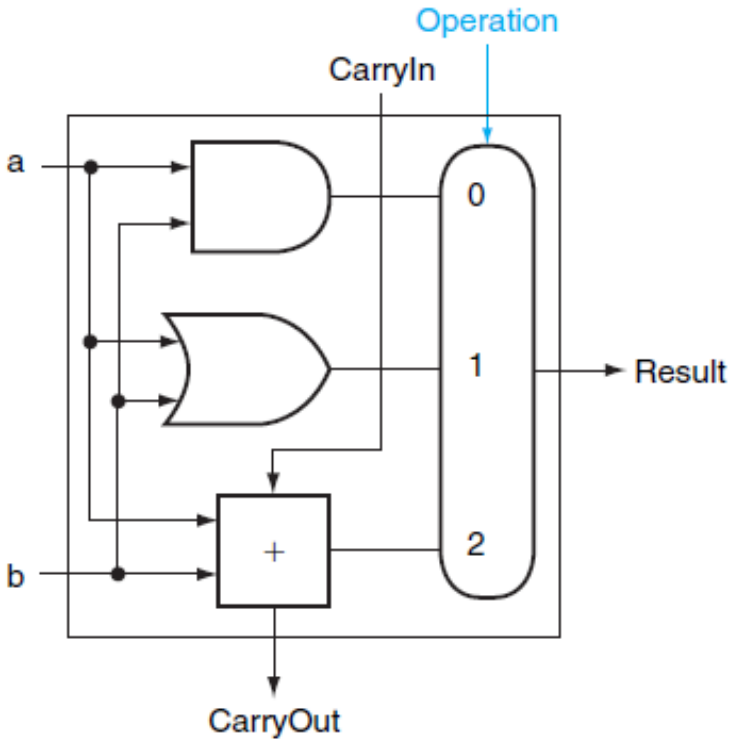
$$\text{CarryOut} = (b \cdot \text{CarryIn}) + (a \cdot \text{CarryIn}) + (a \cdot b)$$



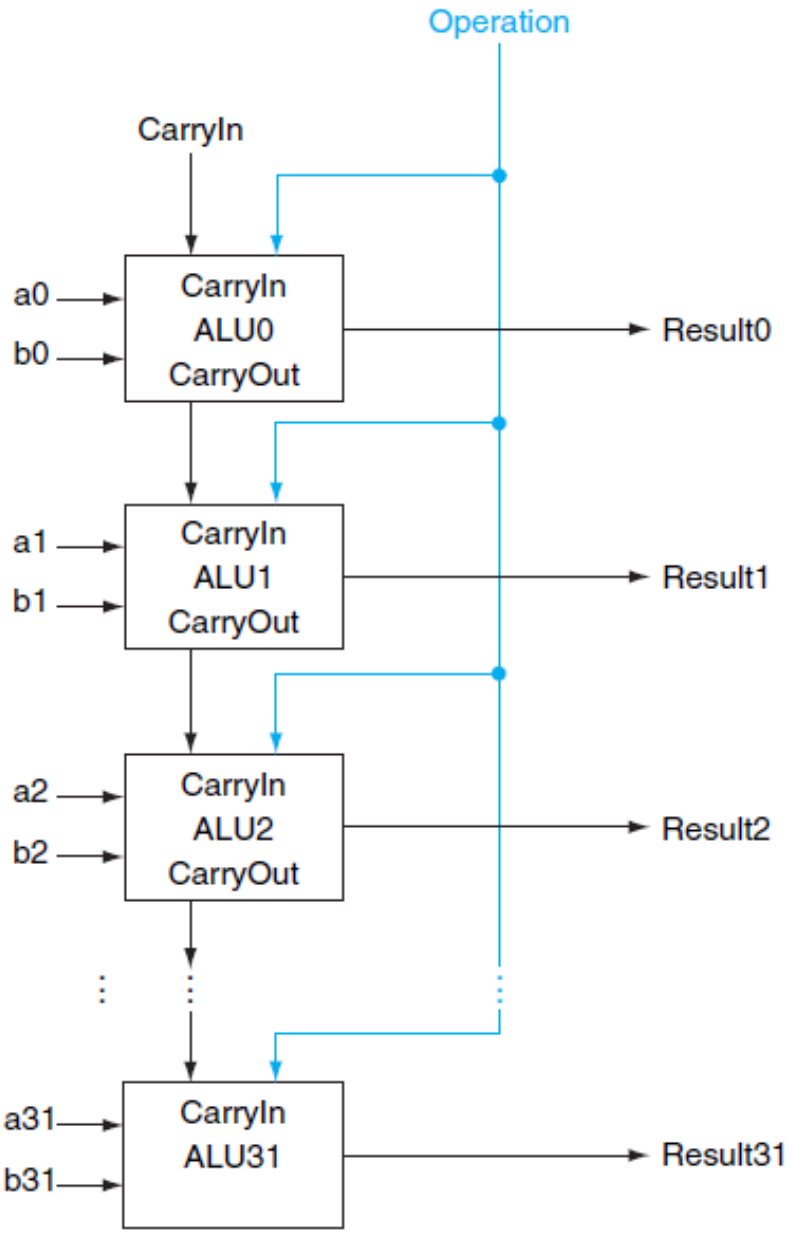
$$\text{Sum} = (a \cdot \overline{b} \cdot \overline{\text{CarryIn}}) + (\overline{a} \cdot b \cdot \overline{\text{CarryIn}}) + (\overline{a} \cdot \overline{b} \cdot \text{CarryIn}) + (a \cdot b \cdot \text{CarryIn})$$

1-bit ALU

- A 1-bit ALU that can perform AND, OR and Addition.

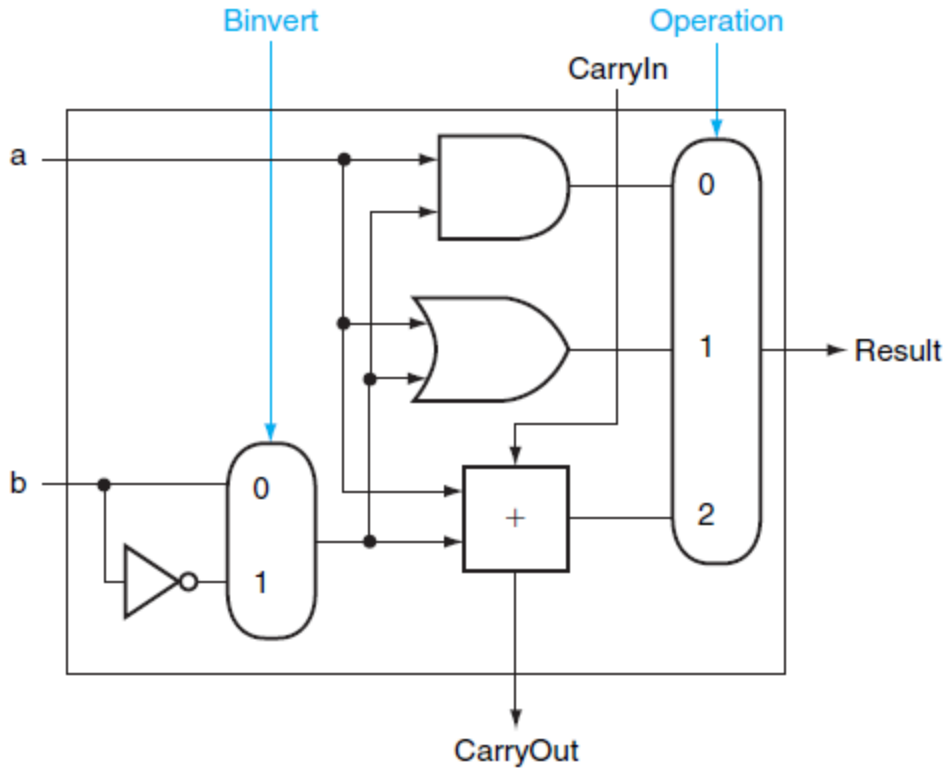


32-bit ALU


Operation
CarryIn
a0
b0
CarryIn
ALU0
CarryOut
Result0
a1
b1
CarryIn
ALU1
CarryOut
Result1
a2
b2
CarryIn
ALU2
CarryOut
Result2
a31
b31
CarryIn
ALU31
Result31

1-bit ALU

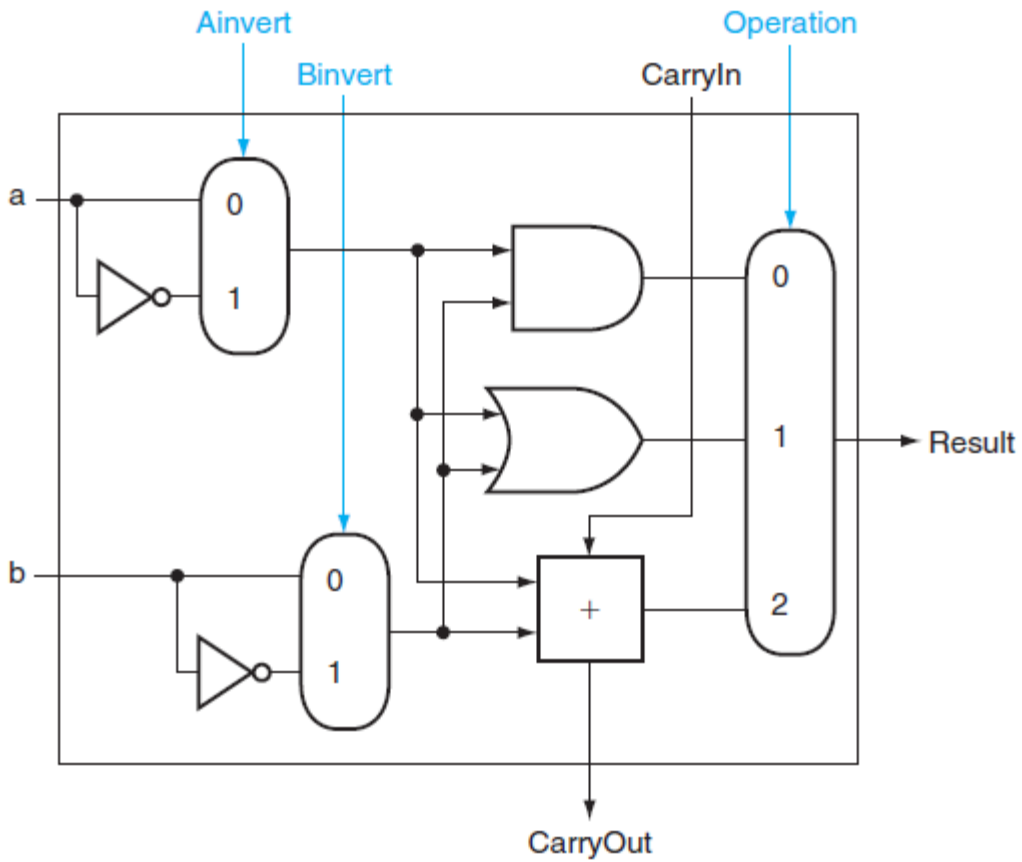
- A 1-bit ALU that can perform AND, OR, ADD (a, b or a, b')



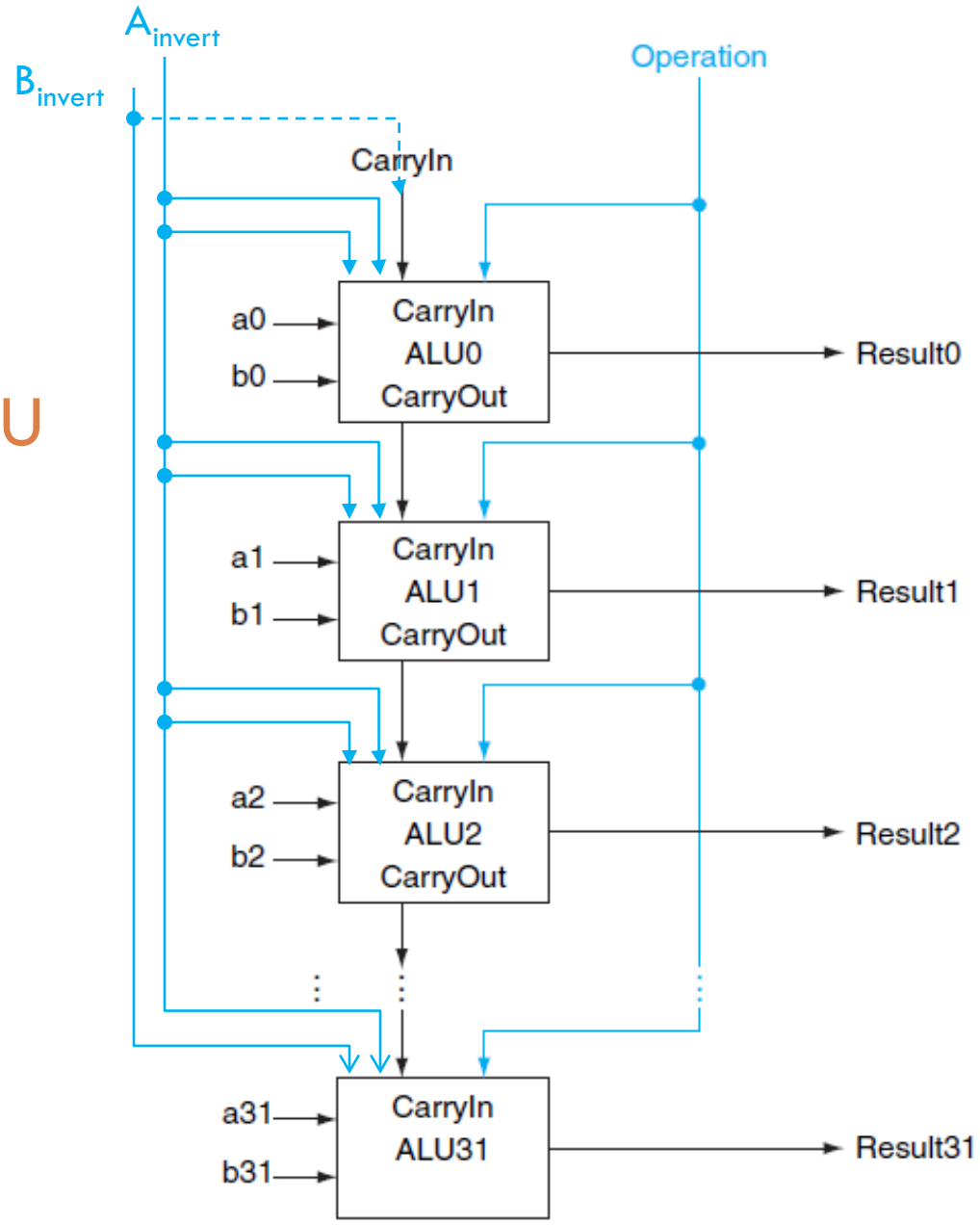
Can you think of how to build 32-bit ALU that can do subtraction also using 32 of these 1-bit ALUs?

1-bit ALU

- A 1-bit that can perform AND, OR, NOR and ADD

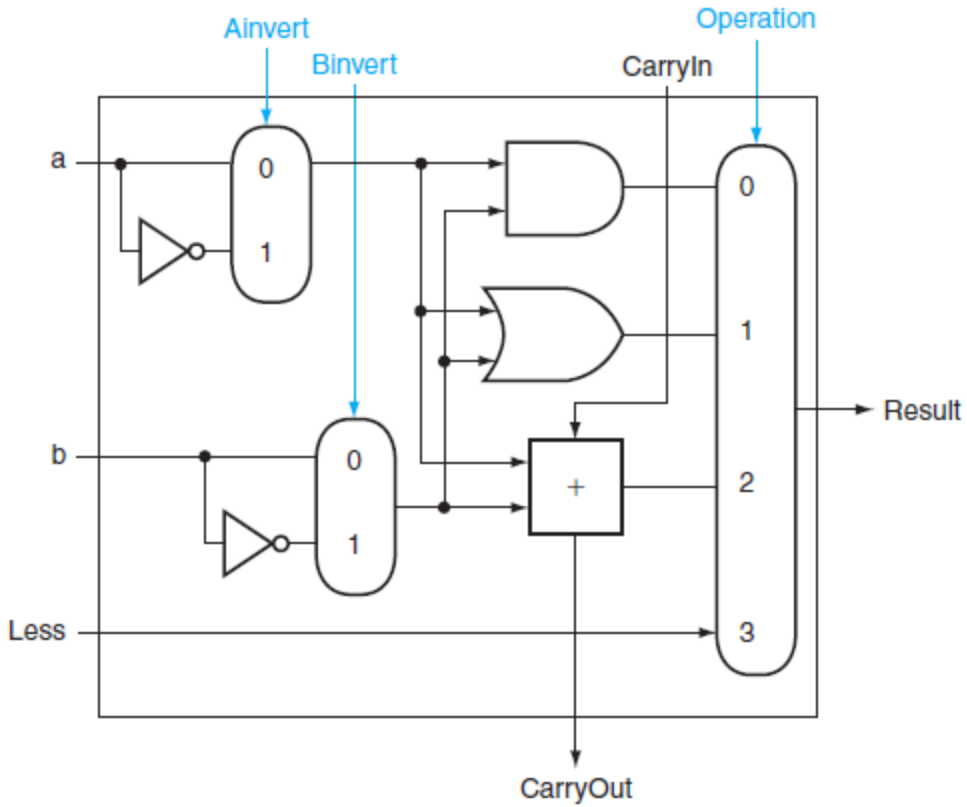


32-bit ALU


A invert
B invert
Operation
CarryIn
a0
b0
CarryIn
ALU0
CarryOut
Result0
a1
b1
CarryIn
ALU1
CarryOut
Result1
a2
b2
CarryIn
ALU2
CarryOut
Result2
a31
b31
CarryIn
ALU31
Result31

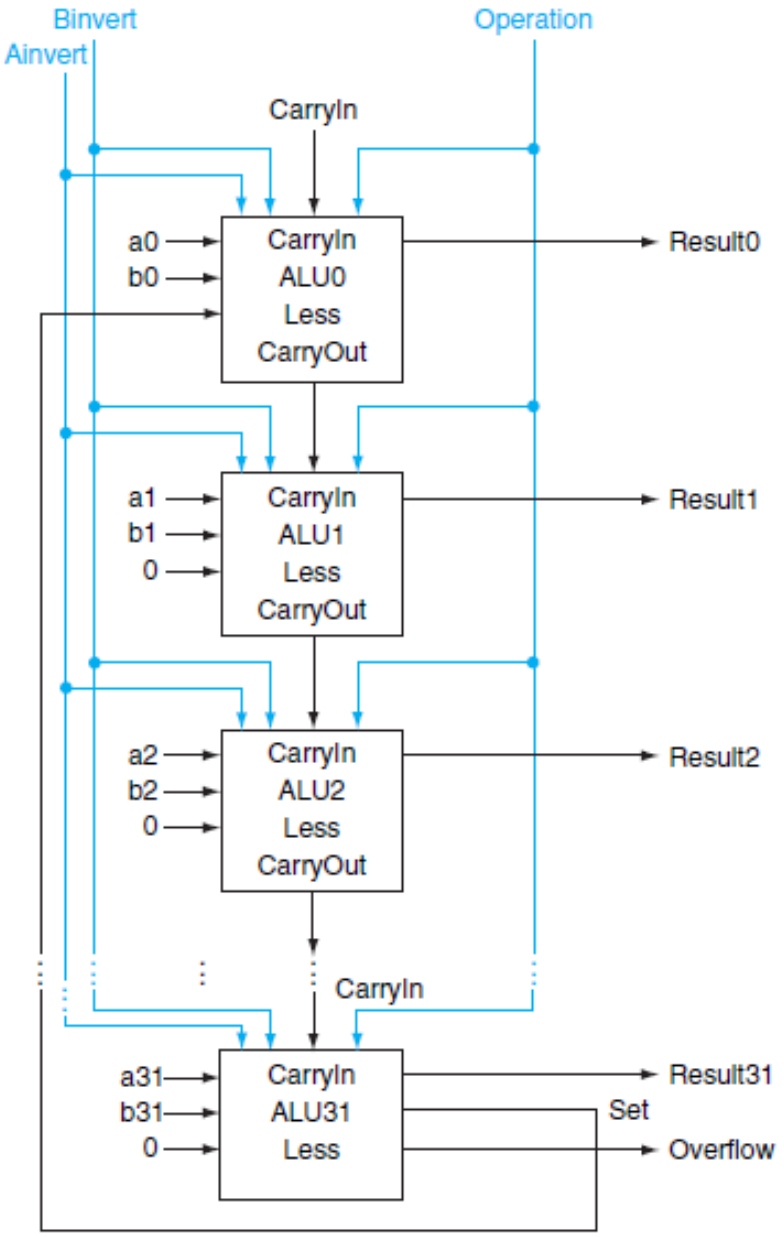
Supporting slt Instruction

- Hardwire Less input to 0 for the higher 31 bits of the ALU.
- How to compare and the LSB ($Less_0$) of ALU?



Does this ALU takes care of the slt instruction?

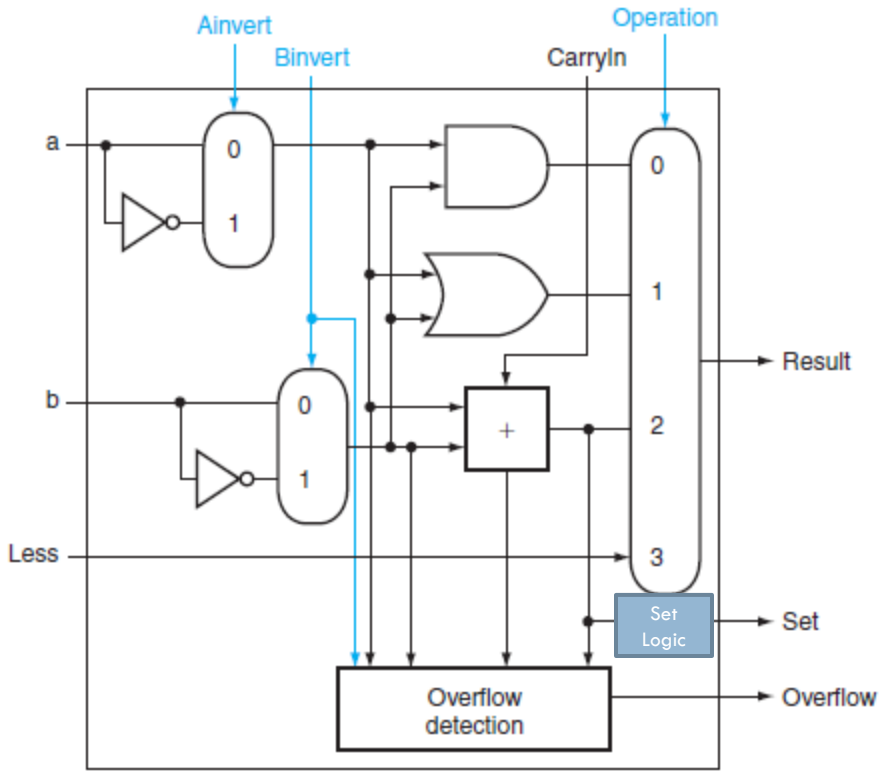
a_{31}	b_{31}	Set
0	0	MSB
0	1	0
1	0	1
1	1	MSB



ALU-31

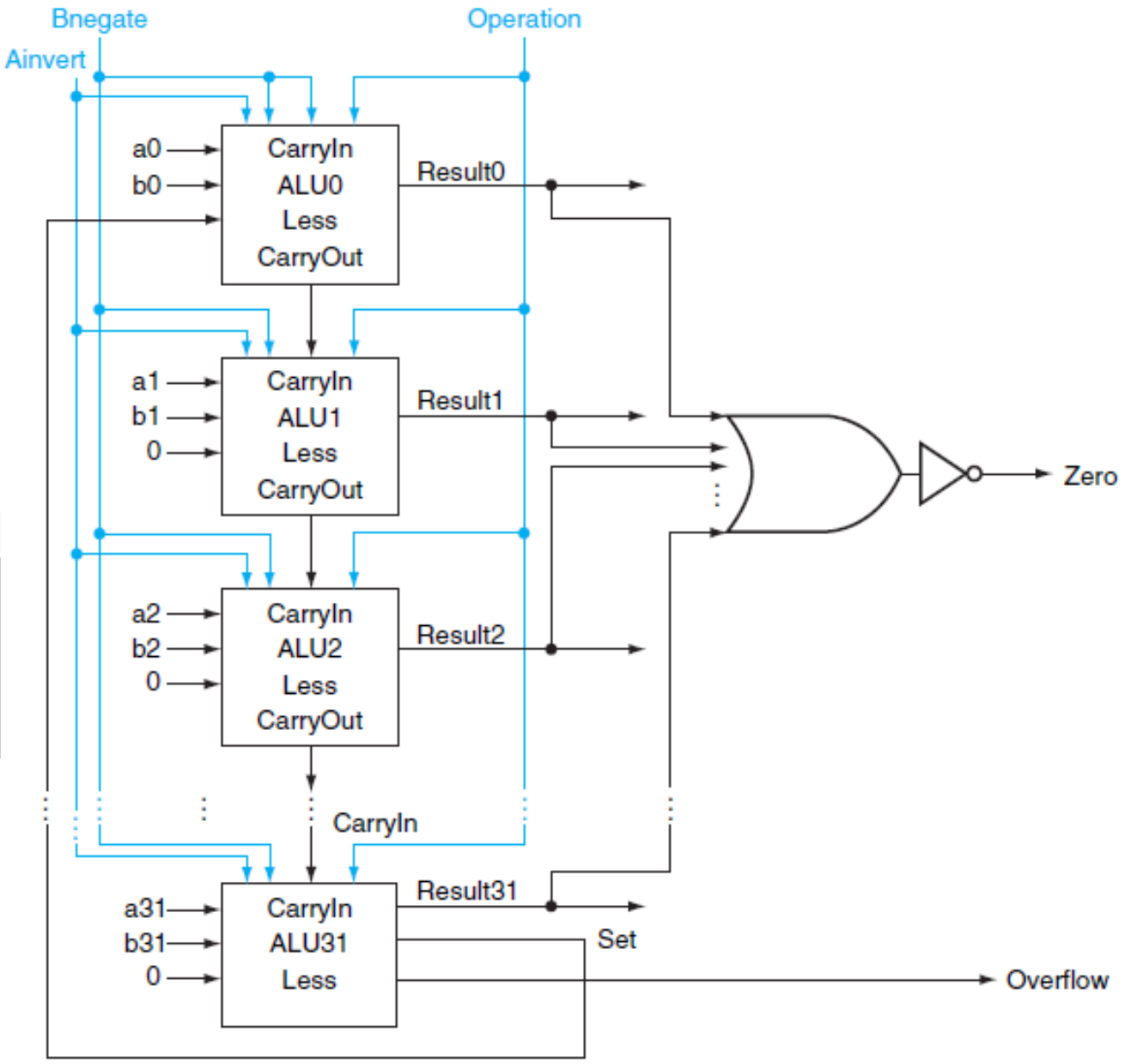
- Can you come up with overflow detection logic for signed numbers?

a_{31}	b_{31}	Set
0	0	MSB
0	1	0
1	0	1
1	1	MSB



32-bit ALU with Zero Flag Logic

ALU control lines	Function
0000	AND
0001	OR
0010	add
0110	subtract
0111	set on less than
1100	NOR



Final Block Diagram of 32-bit ALU