Lecture 13: ALUs, Adders

- Today's topics:
  - ALU wrap-up
  - Carry-lookahead adder

.align 0

.align 2

Thurs – FSMs – example probs

↳ on midterm, only easy qs on FSM

Midterm - incl everything until Thurs 2/23

On Thurs - email practice midterm

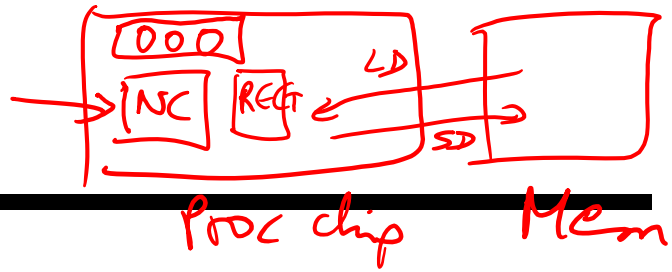
3 sheets of ~~notes~~ paper (front + back) + Green sheet

calculators ok

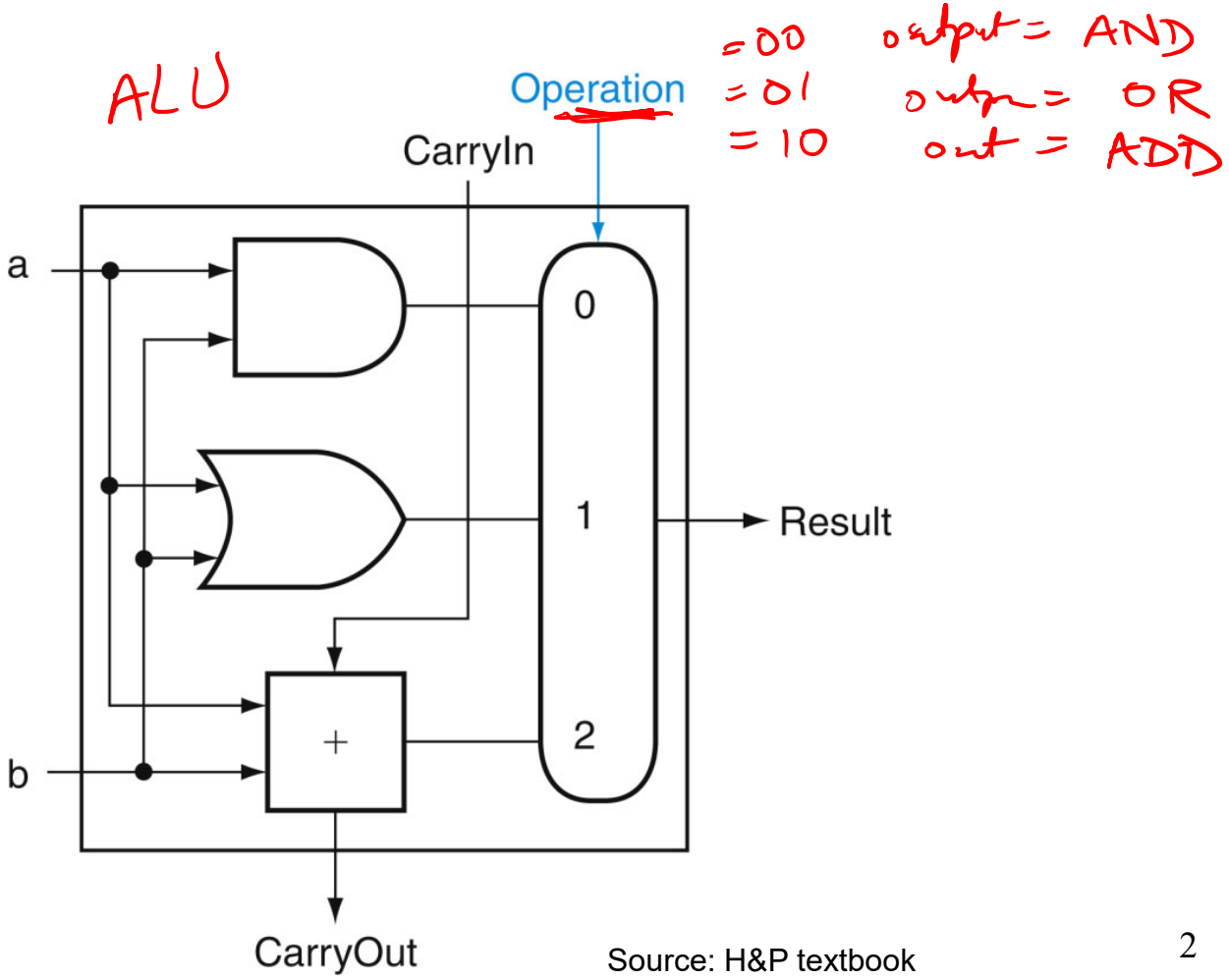
Tue - Review session

$$\frac{(1.0 + 1.2 + 3.4)}{3} \times 0.2\,ns$$

1-Bit ALU with Add, Or, And

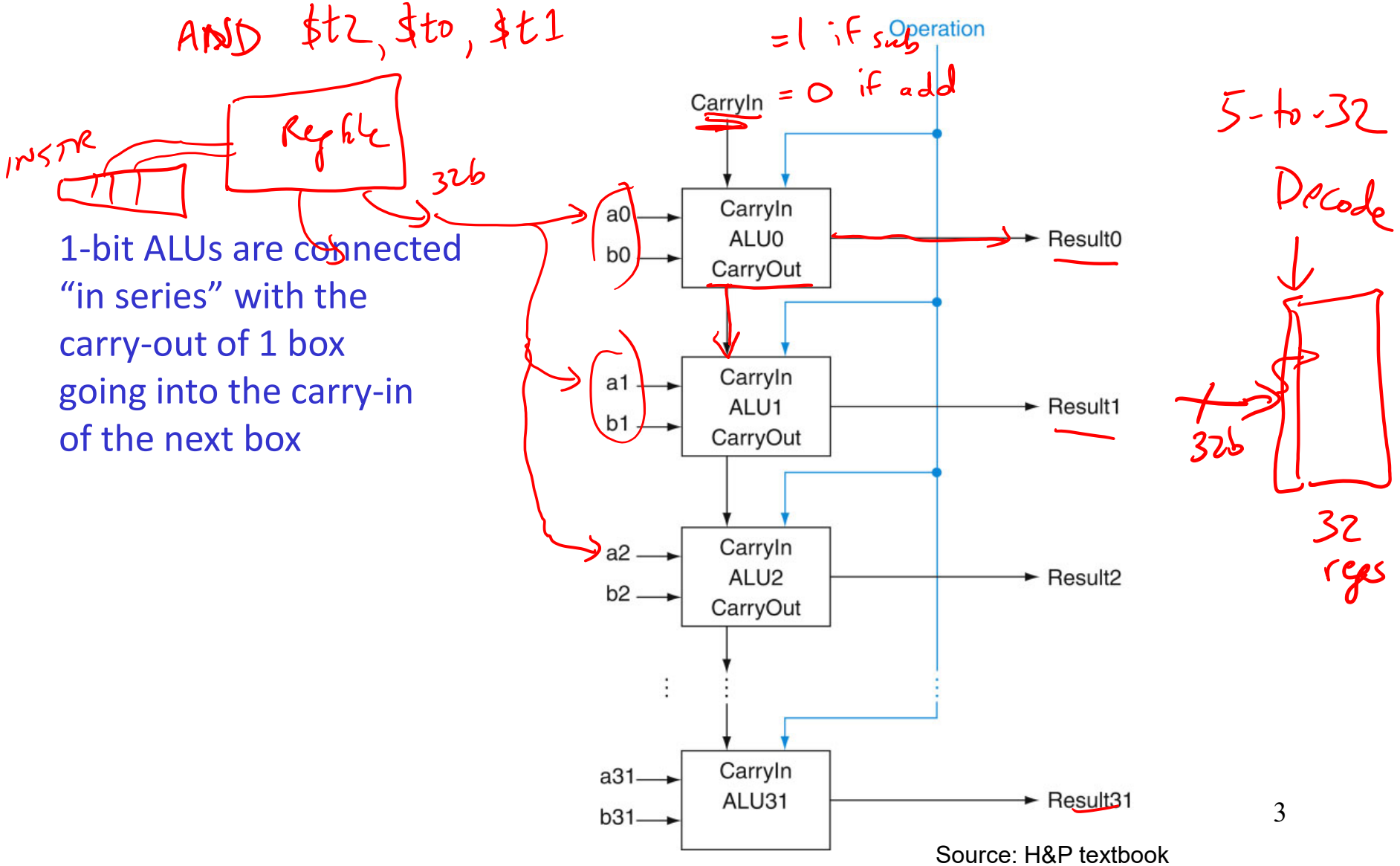


- Multiplexor selects between Add, Or, And operations



Source: H&P textbook

32-bit Ripple Carry Adder



Source: H&P textbook

Incorporating Subtraction

$a - b$

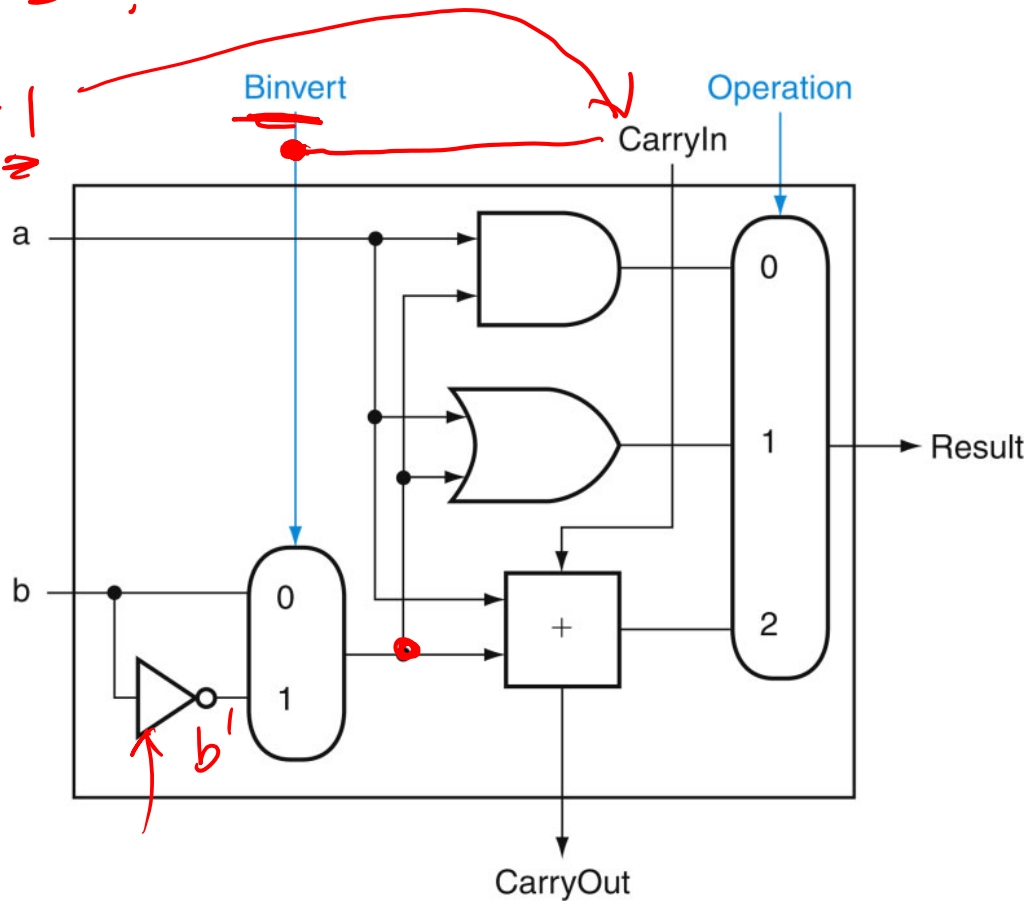
$a + (-b)$

$b \rightarrow -b$?

$b \rightarrow b' + 1$

Must invert bits of B and add a 1

- Include an inverter
- CarryIn for the first bit is 1
- The CarryIn signal (for the first bit) can be the same as the Binvert signal

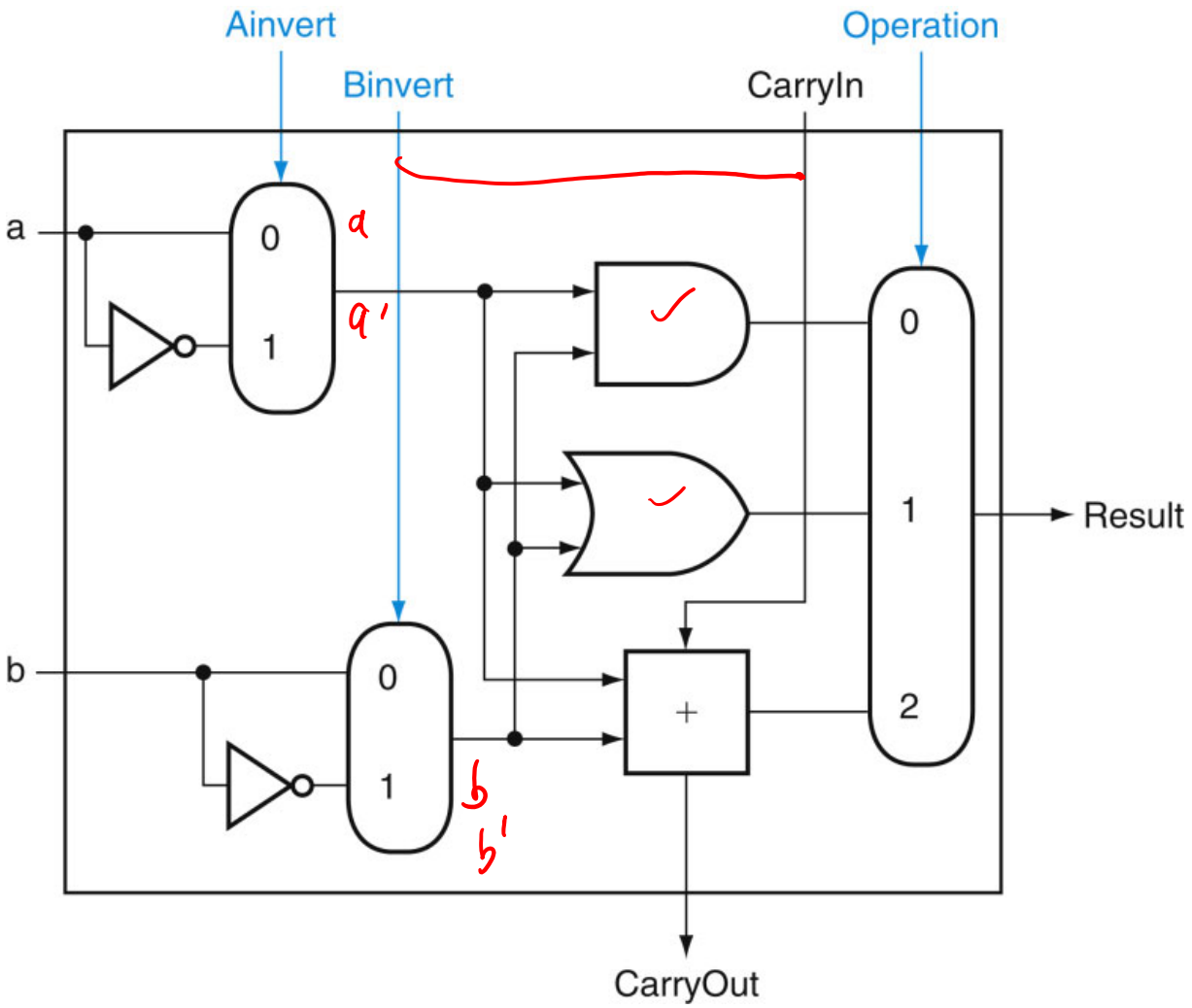


Source: H&P textbook

Incorporating NOR and NAND

$a' \cdot b' = \overline{a+b}$ = NOR

$a' + b' = \overline{a \cdot b}$ = NAND

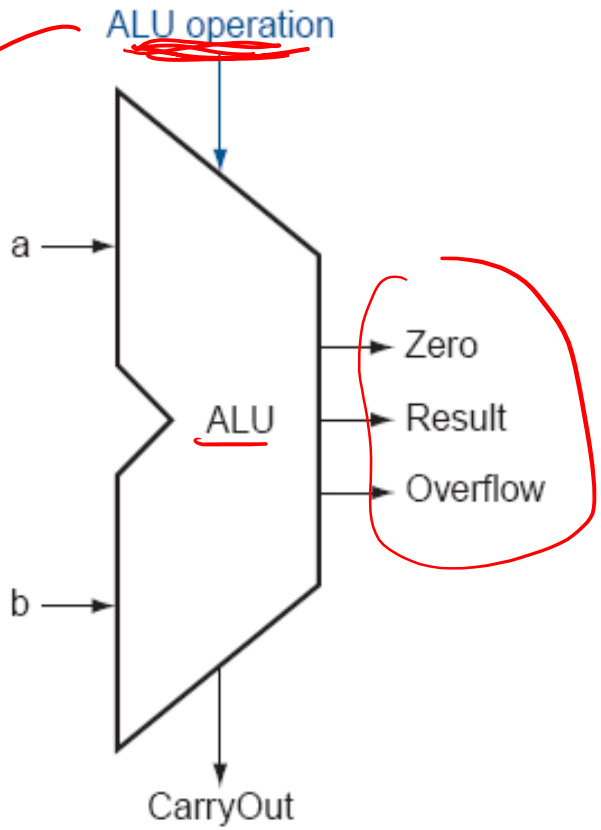


Source: H&P textbook

Control Lines

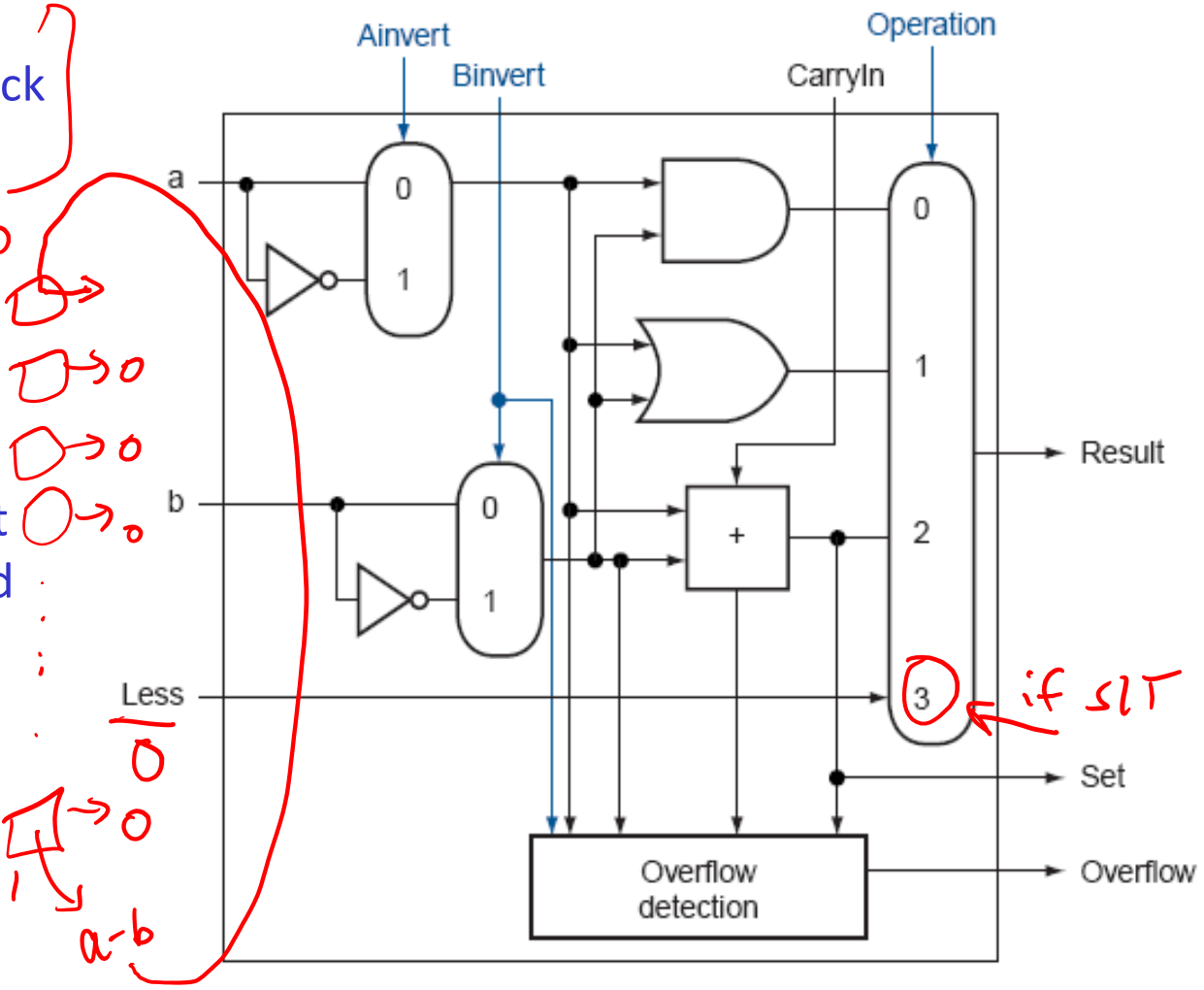
What are the values of the control lines and what operations do they correspond to?

	Ai	Bn	Op
AND	0	0	00
OR	0	0	01
Add	0	0	10
Sub	0	1	10
NAND	1	1	01
NOR	1	1	00



Incorporating slt

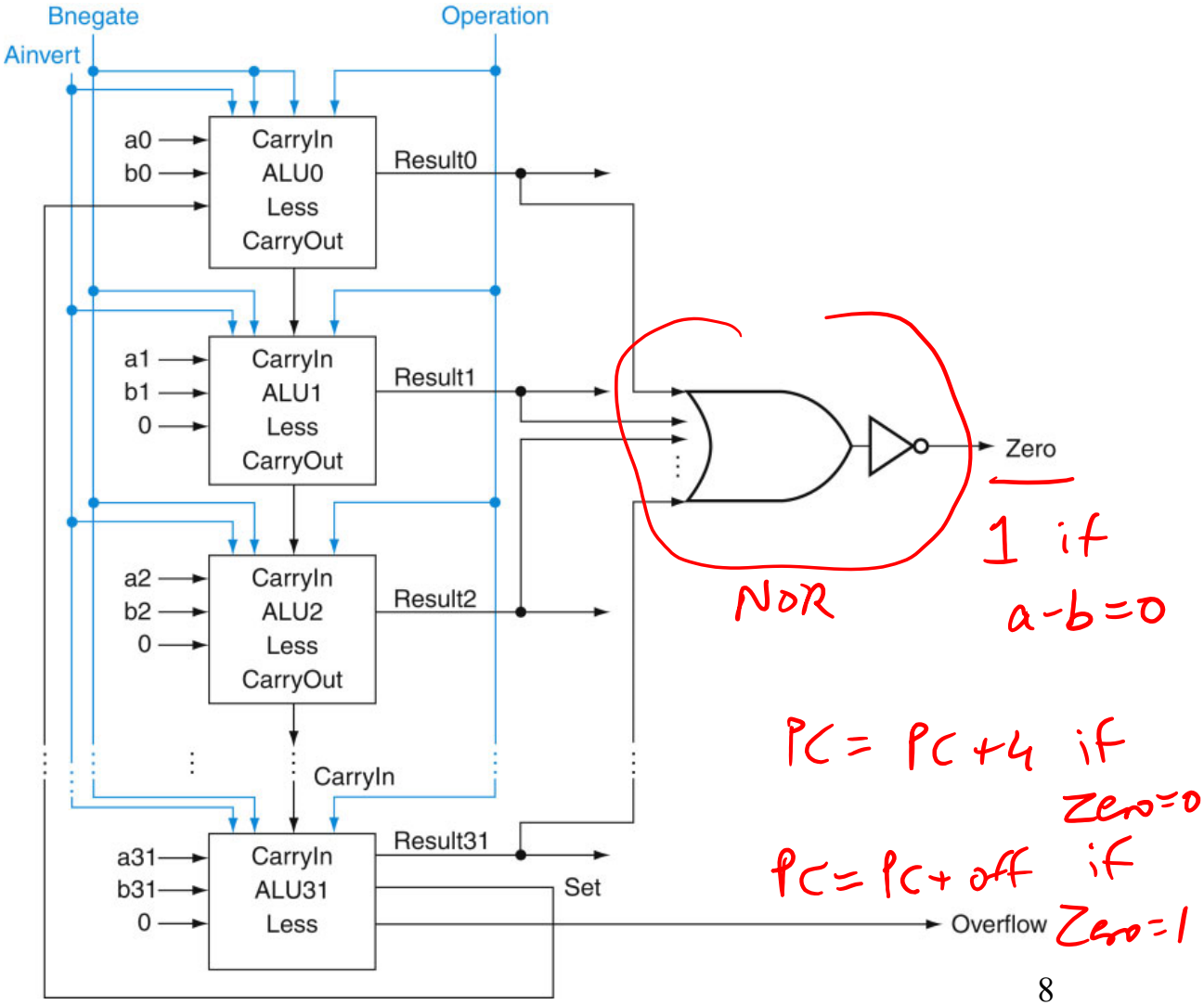
- Perform a – b and check the sign
- New signal (Less) that is zero for ALU boxes 1-31
- The 31st box has a unit to detect overflow and sign – the sign bit serves as the Less signal for the 0th box



Source: H&P textbook

Incorporating beq

- Perform a – b and confirm that the result is all zero's



Source: H&P textbook

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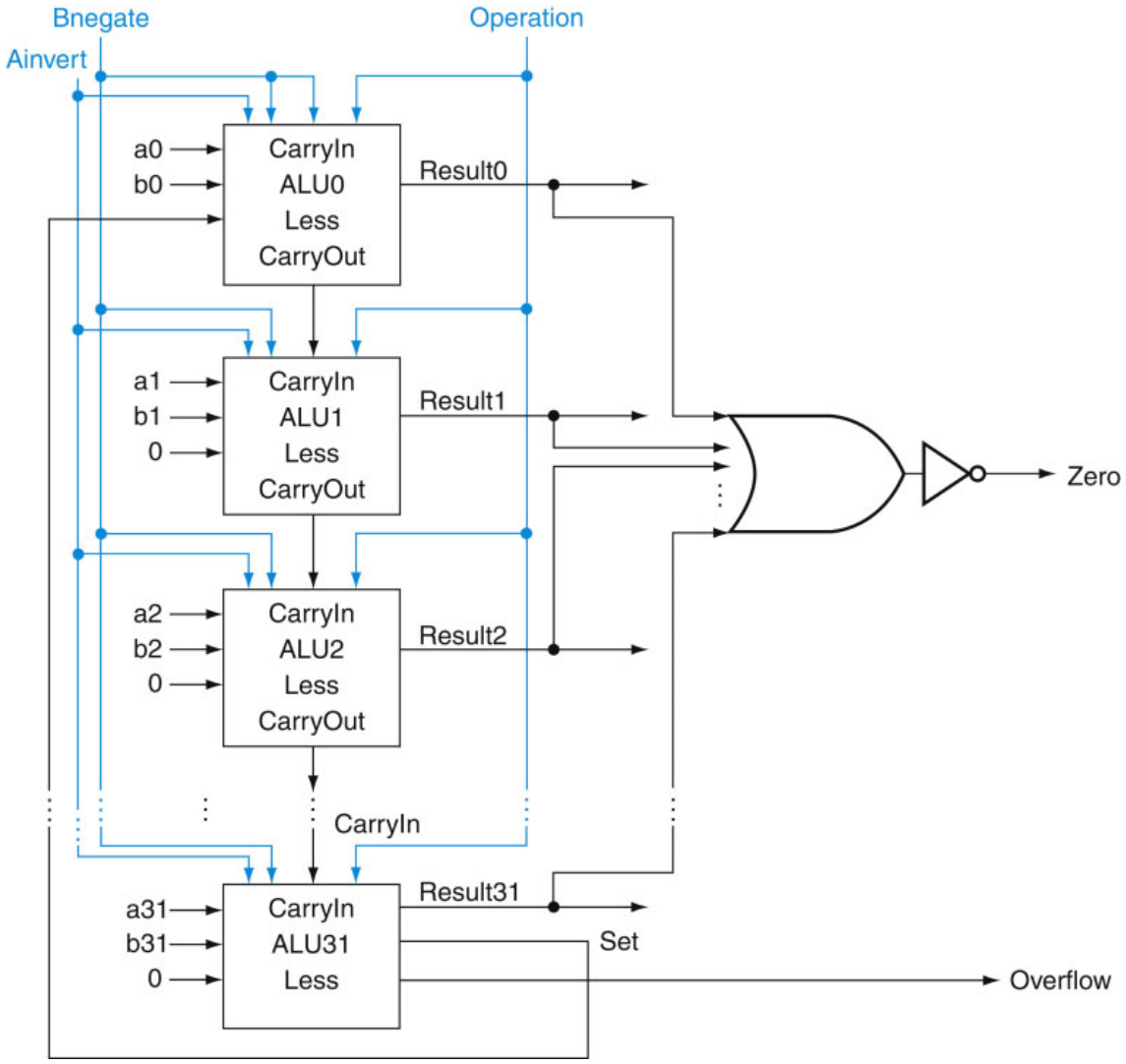

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Control Lines

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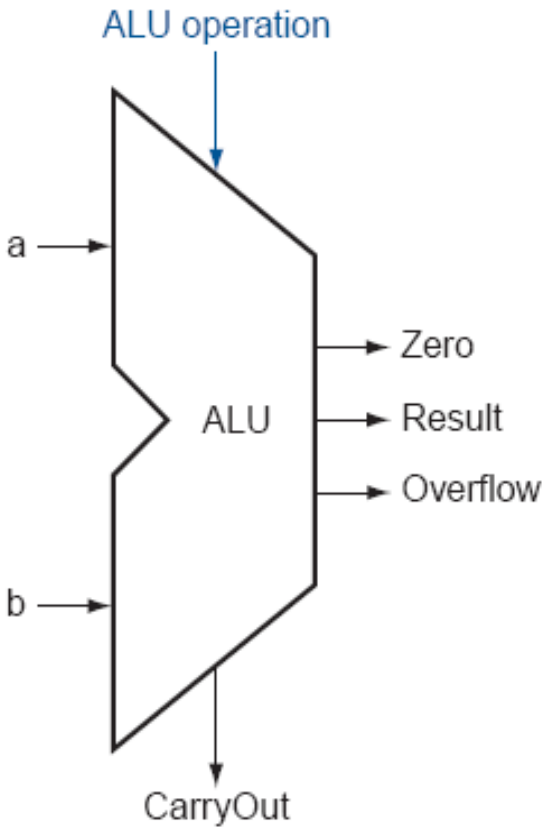
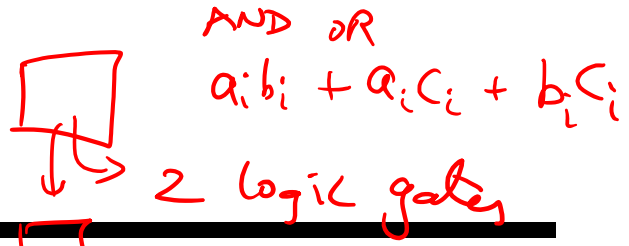
OR	0	0	01
Add	0	0	10
Sub	0	1	10
NOR	1	1	00
NAND	1	1	01
SLT	0	1	11
BEQ	0	1	10



Source: H&P textbook

Speed of Ripple Carry



- The carry propagates thru every 1-bit box: each 1-bit box sequentially implements AND and OR – total delay is the time to go through 64 gates!
- We've already seen that any logic equation can be expressed as the sum of products – so it should be possible to compute the result by going through only 2 gates!
- Caveat: need many parallel gates and each gate may have a very large number of inputs – it is difficult to efficiently build such large gates, so we'll find a compromise:
  - moderate number of gates
  - moderate number of inputs to each gate
  - moderate number of sequential gates traversed

Computing CarryOut

CarryIn1 = b0.CarryIn0 + a0.CarryIn0 + a0.b0

CarryIn2 = b1.CarryIn1 + a1.CarryIn1 + a1.b1

= b1.b0.c0 + b1.a0.c0 + b1.a0.b0 +
a1.b0.c0 + a1.a0.c0 + a1.a0.b0 + a1.b1

…

CarryIn32 = a really large sum of really large products

expo terms (sum-of-prod)

- Potentially fast implementation as the result is computed by going thru just 2 levels of logic – unfortunately, each gate is enormous and slow

Generate and Propagate

Equation re-phrased:

$C_{i+1} = a_i.b_i + a_i.C_i + b_i.C_i$

$= (a_i.b_i) + (a_i + b_i).C_i$

Generate Propagate

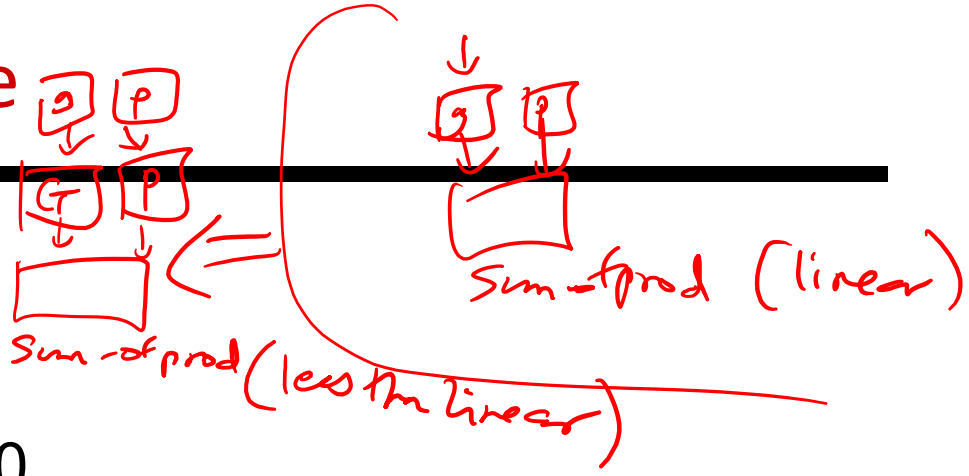
Stated verbally, the current pair of bits will *generate* a carry if they are both 1 and the current pair of bits will *propagate* a carry if either is 1

Generate signal = $a_i.b_i$

Propagate signal = $a_i + b_i$

Therefore, $C_{i+1} = G_i + P_i . C_i$

Generate and Propagate



$c1 = g0 + p0.c0$

$c2 = g1 + p1.c1$

$\quad = g1 + p1.g0 + p1.p0.c0$

$c3 = g2 + p2.g1 + p2.p1.g0 + p2.p1.p0.c0$

$c4 = g3 + p3.g2 + p3.p2.g1 + p3.p2.p1.g0 + p3.p2.p1.p0.c0$

C32

Super-generate G

32 terms

Super-prop P

Either,

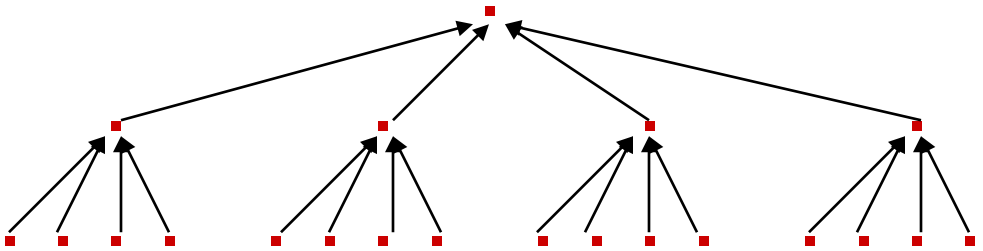
- a carry was just generated, or
- a carry was generated in the last step and was propagated, or
- a carry was generated two steps back and was propagated by both the next two stages, or
- a carry was generated N steps back and was propagated by every single one of the N next stages

Divide and Conquer

- The equations on the previous slide are still difficult to implement as logic functions – for the 32nd bit, we must AND every single propagate bit to determine what becomes of c0 (among other things)

- Hence, the bits are broken into groups (of 4) and each group computes its group-generate and group-propagate

- For example, to add 32 numbers, you can partition the task as a tree



P and G for 4-bit Blocks

- Compute P0 and G0 (super-propagate and super-generate) for the first group of 4 bits (and similarly for other groups of 4 bits)

  P0 = p0.p1.p2.p3

  G0 = g3 + g2.p3 + g1.p2.p3 + g0.p1.p2.p3

- Carry out of the first group of 4 bits is

  C1 = G0 + P0.c0

  C2 = G1 + P1.G0 + P1.P0.c0

  C3 = G2 + (P2.G1) + (P2.P1.G0) + (P2.P1.P0.c0)

  C4 = G3 + (P3.G2) + (P3.P2.G1) + (P3.P2.P1.G0) + (P3.P2.P1.P0.c0)

  carry out from 16th bit

- By having a tree of sub-computations, each AND, OR gate has few inputs and logic signals have to travel through a modest set of gates (equal to the height of the tree)

Example

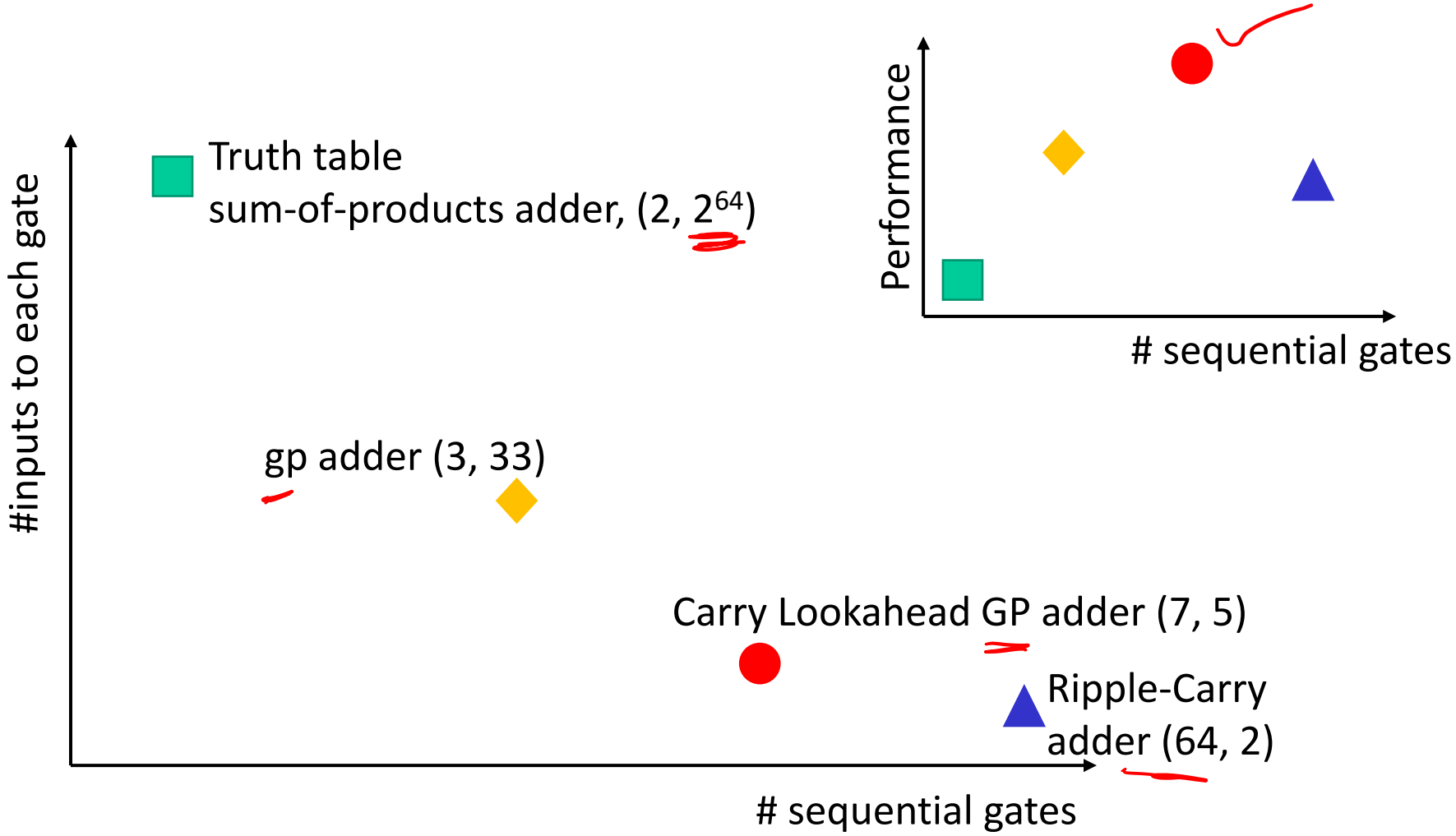
Add					
	A	0001	1010	0011	0011
	B	1110	0101	1110	1011
	g	0000	0000	0010	0011
	p	1111	1111	1111	1011
	P	1	1	1	0
	G	0	0	1	0

16 b inputs

Gen

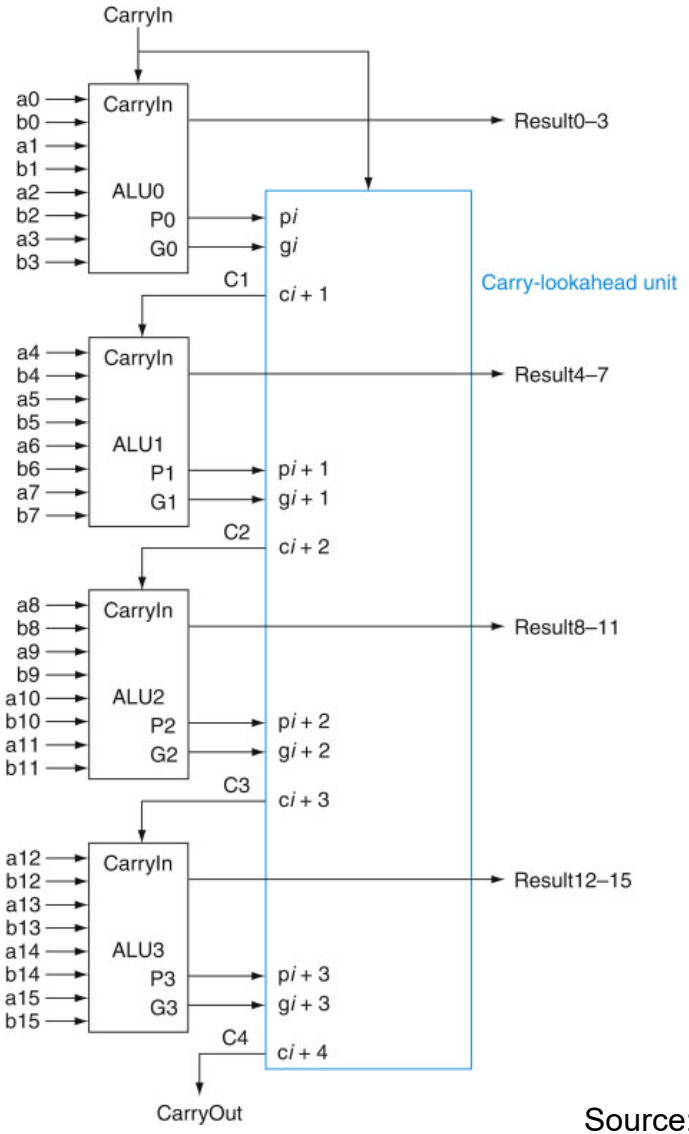
C4 = 1

Trade-Off Curve



Carry Look-Ahead Adder

- 16-bit Ripple-carry takes 32 steps
- This design takes how many steps?
  4 sequential steps



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