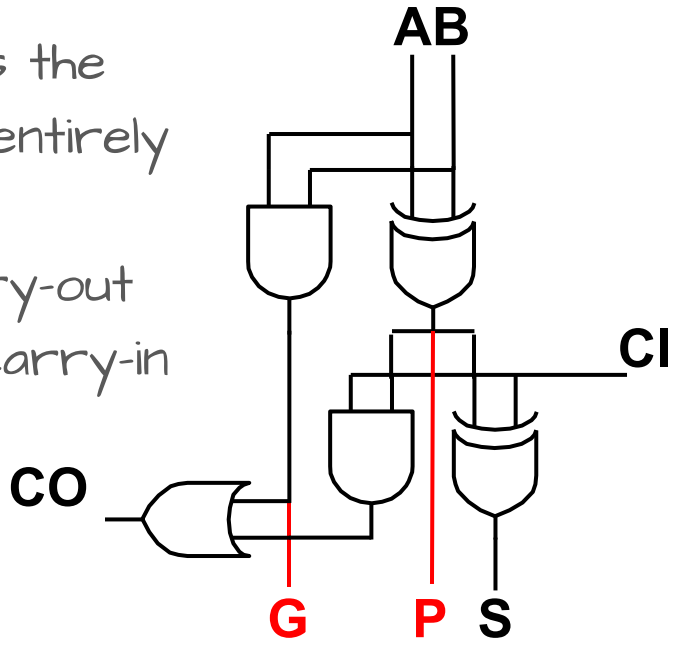
We can add "much" faster

Using more gates we can speed up adding considerably if we add 2 "free" extra outputs from our adder

- P, Propagate, means the carry-out depends entirely on the carry-in
- G, generates a carry-out regardless of the carry-in

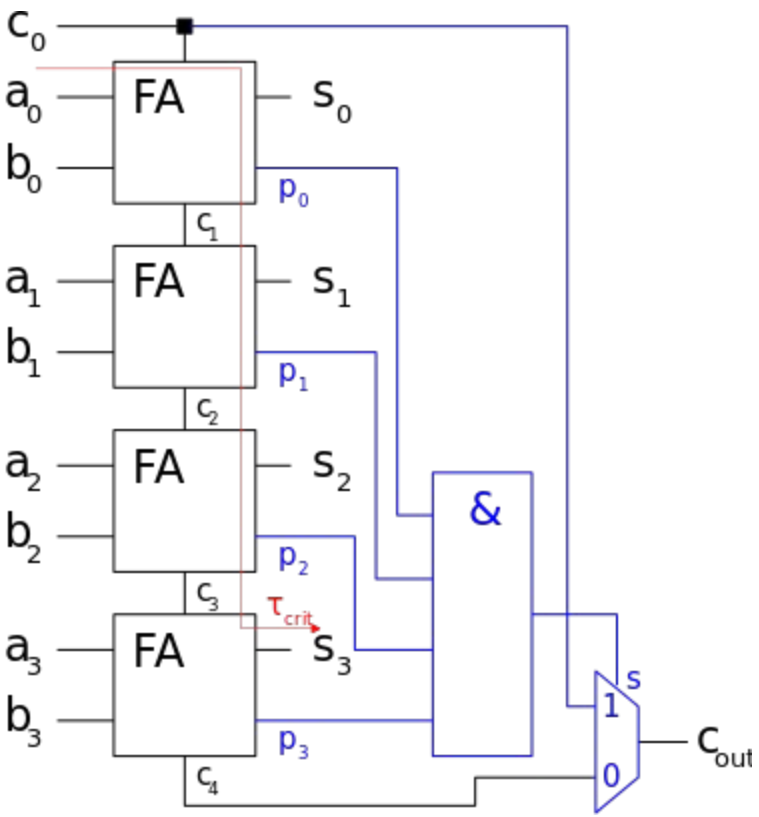


C_i	A	B	C_o	S
0	0	0	0	0
0	0	1	0	1
0	1	0	0	1
0	1	1	1	0
1	0	0	0	1
1	0	1	1	0
1	1	0	1	0
1	1	1	1	1

Carry-skip adders

If all full adders in a contiguous block have their Propagate true, then the incoming carry-in can "skip" over the entire block!

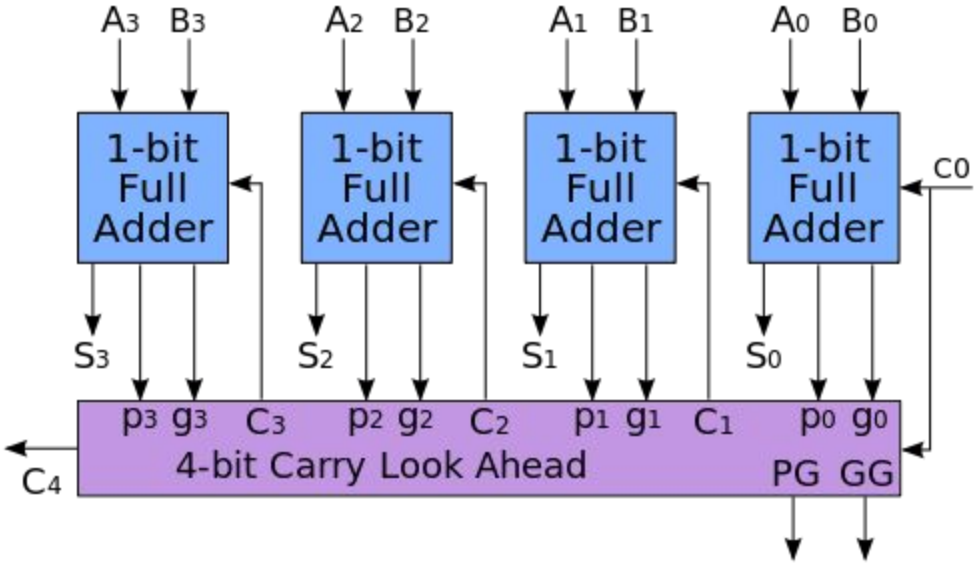
Requires extra AND gates and a MUX, but reduces the worst case add-time



Full Carry-Lookahead

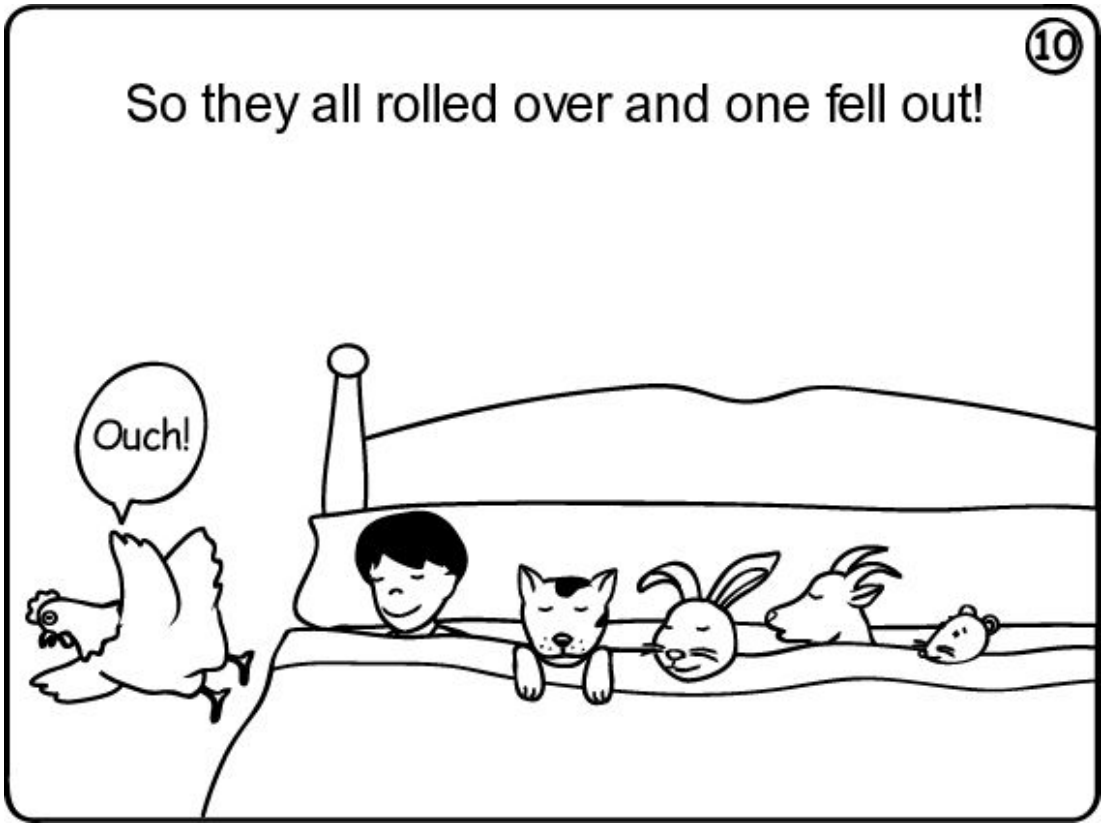
The fastest adders use full carry look-ahead.

- Given the Ps and Gs of a block, one can simultaneously compute the carry-ins for all bits as well as the block using the 3-level SOP methods discussed last lecture.



- Results in an $\Theta(\log_2(N))$, T_{pd} , like an N-input AND gate, using ≈2x more gates

An Arithmetic Logic UNIT



- Shifts of shifts
- Boolean logic
- An ALU

Shifting Logic

Shifting is a common operation that is applied to groups of bits. Shifting is used for alignment, selecting parts of a word, as well as for arithmetic operations.

X << 1 is approx the same as 2*X

X >> 1 can be the same as X/2

For example:

$X = 00010100_2 = 20_{10}$

Left Shift:

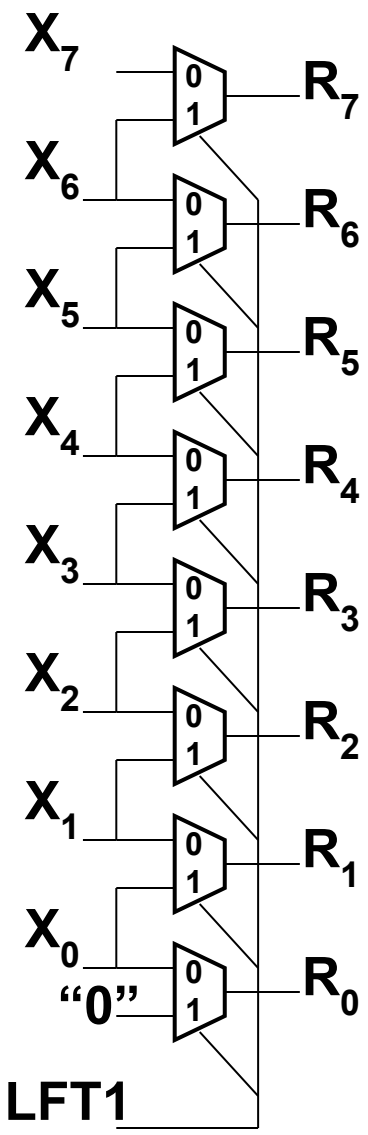
$(X << 1) = 00101000_2 = 40_{10}$

Right Shift:

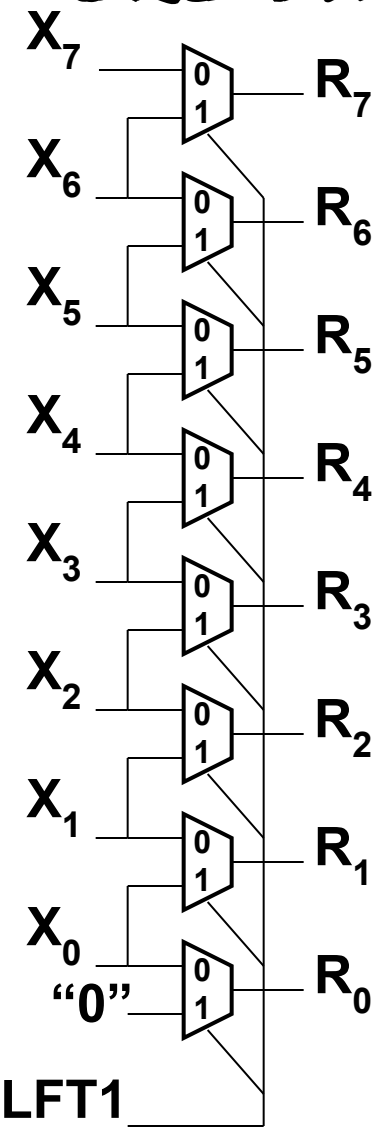
$(X >> 1) = 00001010_2 = 10_{10}$

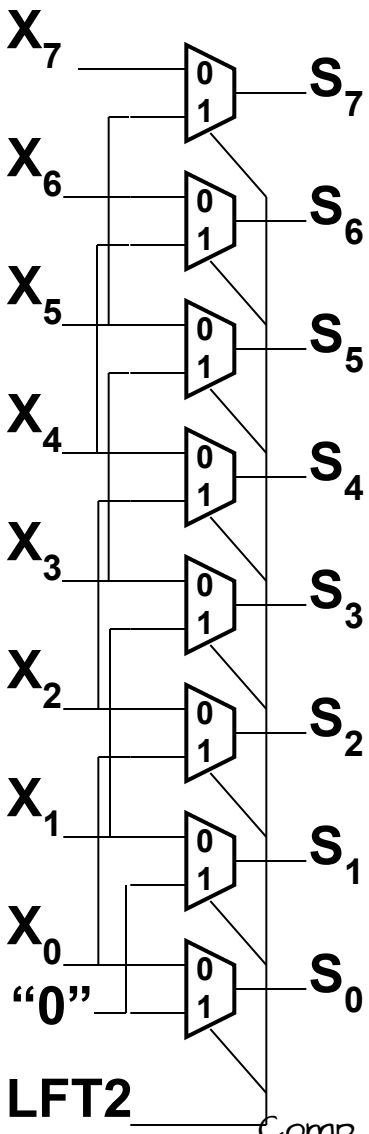
Signed or "Arithmetic" Right Shift:

$(-X >> 1) = (11101100_2 >> 1) = 11110110_2 = -10_{10}$



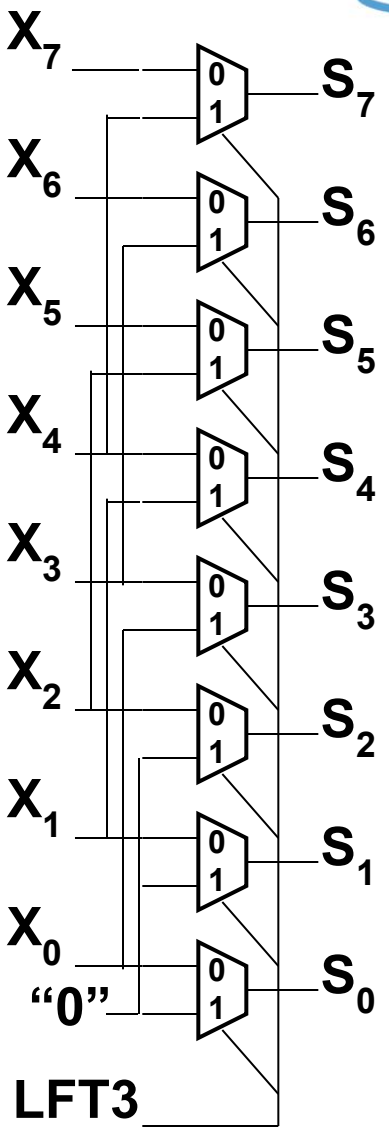
More Shifting



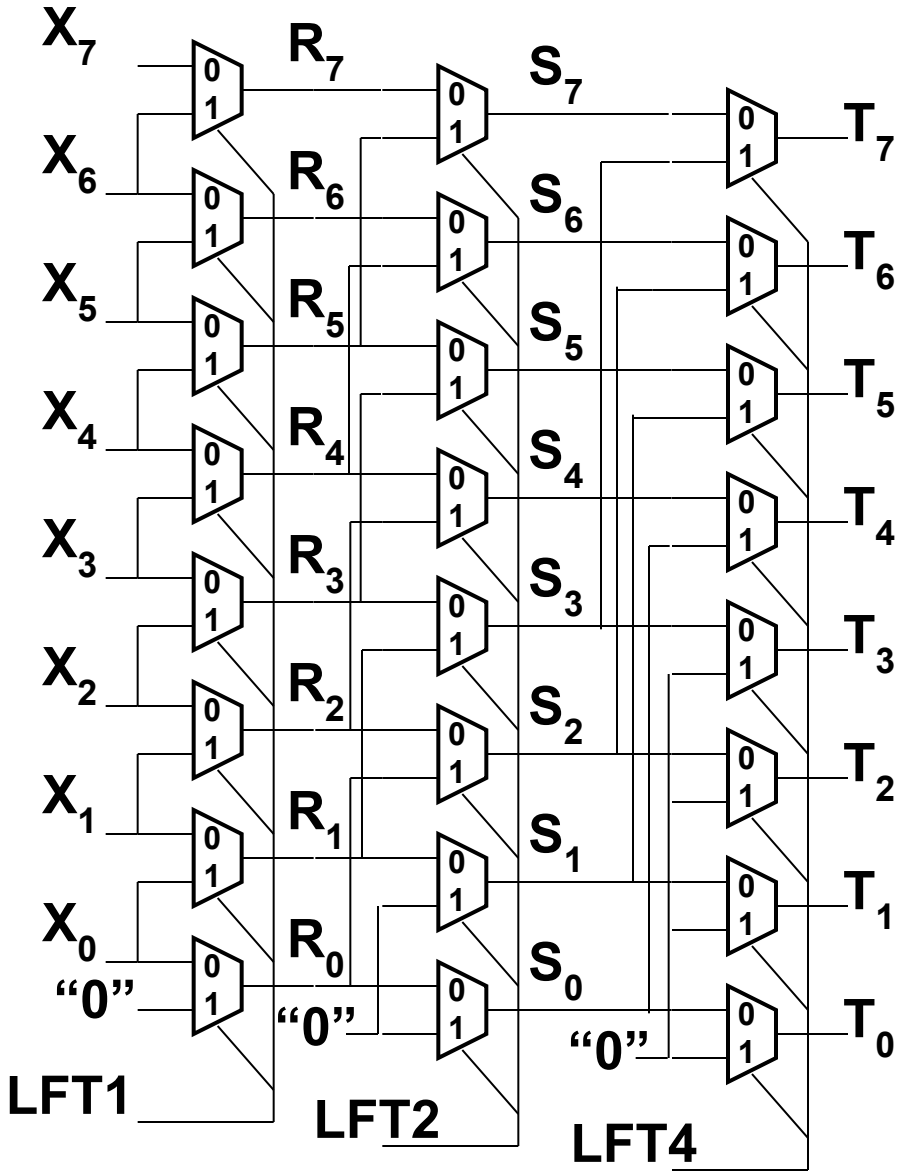


Using the same basic idea we can build left shifters of arbitrary shift amounts using muxes.

Each shift amount requires its own set of muxes.



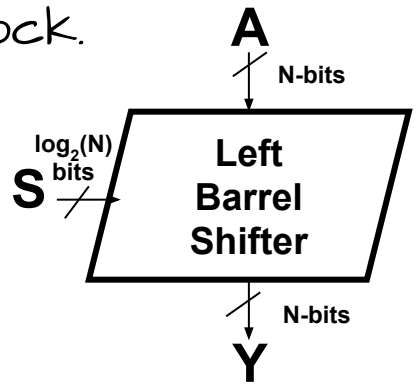
Barrel Shifting



If we connect our "shift-left-two" shifter to the output of our "shift-left-one" we can shift by 0, 1, 2, or 3 bits.

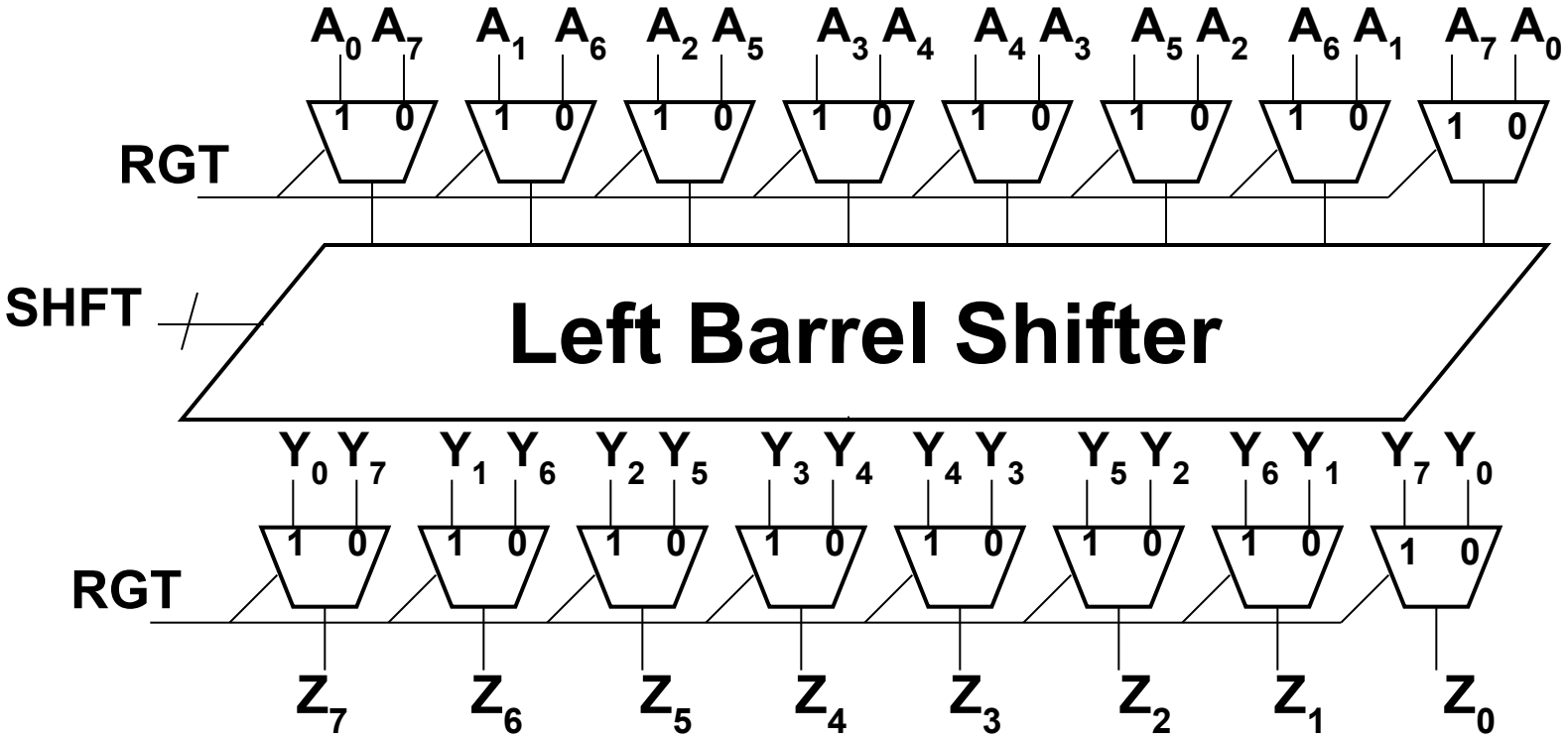
And, if we add one more "shift-left-4" shifter we can do any shift up to 7 bits!

So, let's put a box around it and call it a new functional block.

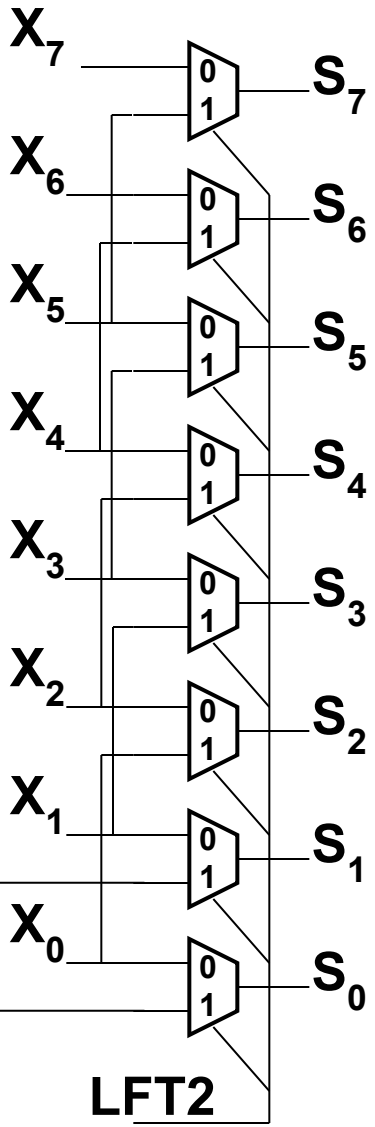


Adding a Twist

It would be straightforward to construct a "right barrel shifter" unit. However, a simple trick that enables a "left barrel shifter" to do both.

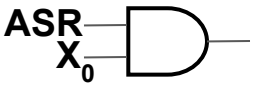


Rotate and Arithmetic shifts



The basics are the same for logical and arithmetic shifts except instead of shifting in zeros for the vacated bits on arithmetic shifts, you shift in copies of X_0. For rotates, you shift in the bits from the other end.

This adds two control lines, ASR, and ROT, which are shared amongst all of the LFTx units.



Bitwise Logical Operations

We need to perform logical operations, or **Booleans**, on groups of bits. Which ones?

ANDing is used for "masking" off groups of bits.
ex. 10101110 & 00001111 = 00001110 (mask selects last 4 bits)

ORing is used for "setting" groups of bits.
ex. 10101110 | 00001111 = 10101111 (1's set last 4 bits)

EORing is used for "complementing" groups of bits.
ex. 10101110 ^ 00001111 = 10100001 (complement last 4 bits)

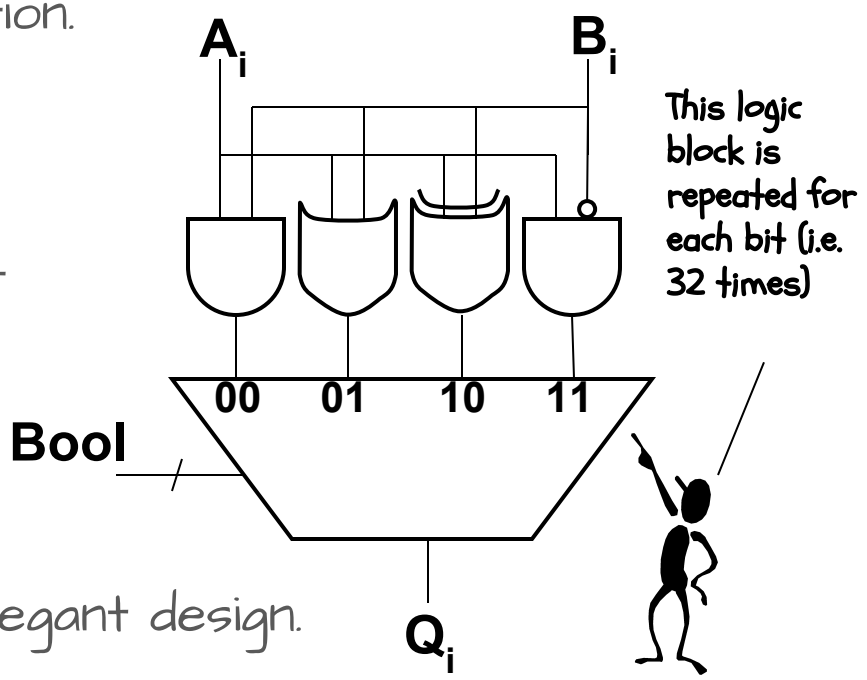
BICing is used to "clear" groups of bits (BIC = bit clear).
ex. 10101110 & ~(00001111) = 01010000 (1's clear)

Boolean Unit (The obvious way)

It is simple to build up a Boolean unit using primitive gates and a mux to select the function.

Since there is no interconnection between bits, this unit can be simply replicated at each position. The cost is about 7 gates per bit. One for each primitive function, and approx 3 for the 4-input mux.

This is a straightforward, but not elegant design.



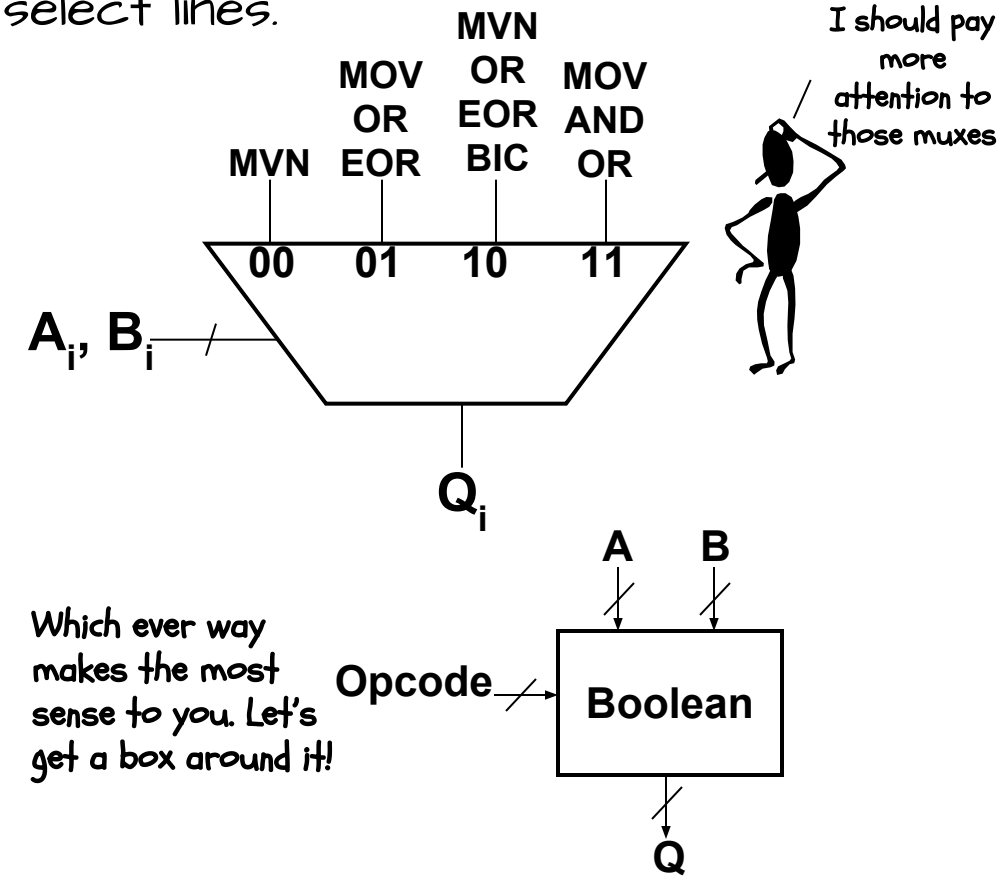
Cooler Bools

We can better leverage a MUX's capabilities in our Boolean unit design, by connecting the bits to the select lines.

Why is this better?

While it might take a little logic to decode the truth table inputs, you only have to do it once, independent of the number of bits.

BTW, it also handles the MOV and MVN cases.



Decoding the Booleans and others

It may seem a little tedious, but all the controls that we need can be derived from the ARM OpCode encodings.

The 'X's in the truth table are "don't cares" they provide flexibility in the implementation.

Opcode	Code				00	01	10	11	Sub	Rsb	Math
AND	0	0	0	0	0	0	0	1	X	X	0
EOR	0	0	0	1	0	1	1	0	X	X	0
SUB	0	0	1	0	X	X	X	X	1	0	1
RSB	0	0	1	1	X	X	X	X	0	1	1
ADD	0	1	0	0	X	X	X	X	0	0	1
ADC	0	1	0	1	X	X	X	X	0	0	1
SBC	0	1	1	0	X	X	X	X	1	0	1
RSC	0	1	1	1	X	X	X	X	0	1	1
TST	1	0	0	0	0	0	0	1	X	X	0
TEQ	1	0	0	1	0	1	1	0	X	X	0
CMP	1	0	1	0	X	X	X	X	1	0	1
CMN	1	0	1	1	X	X	X	X	0	0	1
ORR	1	1	0	0	0	1	1	1	X	X	0
MOV	1	1	0	1	0	1	0	1	X	X	0
BIC	1	1	1	0	0	0	1	0	X	X	0
MVN	1	1	1	1	1	0	1	0	X	X	0

An ALU, at last

We give the "Math Center" of a computer a special name--the Arithmetic Logic Unit (ALU). For us, it just a big box of gates!