

Chapter 3

Arithmetic for Computers

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HW#1 & Project #1

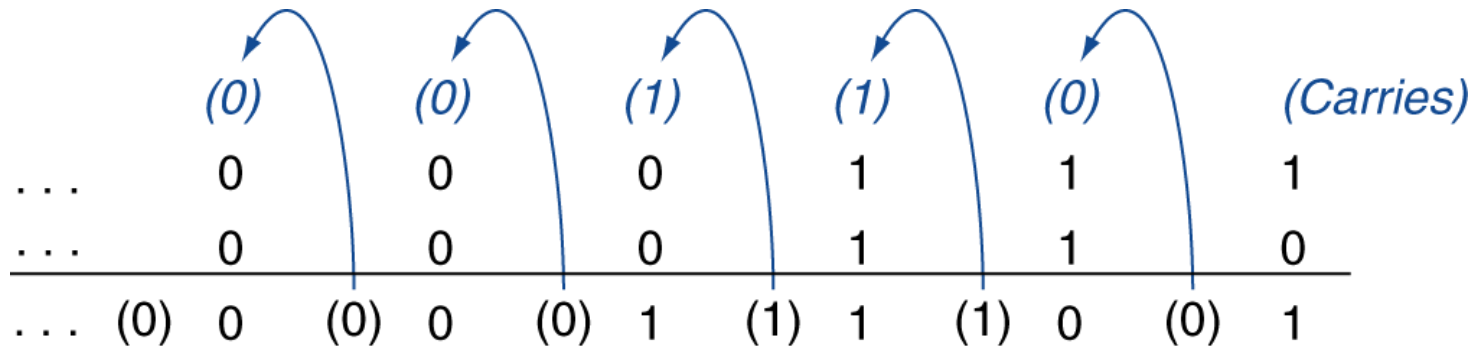
- Programming merge sort in MIPS assembly
 - Due on Sept. 28 (Fri.)
- Project#1: installing simplescalar simulator
 - Due on Oct. 5 (Fri.)

Arithmetic for Computers

- Operations on integers
 - Addition and subtraction
 - Multiplication and division
 - Dealing with overflow
- Floating-point real numbers
 - Representation and operations

Integer Addition

■ Example: $7 + 6$



■ Overflow if result out of range

- Adding +ve and -ve operands, no overflow
- Adding two +ve operands
 - Overflow if result sign is 1
- Adding two -ve operands
 - Overflow if result sign is 0

Integer Subtraction

- Add negation of second operand
- Example: $7 - 6 = 7 + (-6)$

+7:	0000 0000 ... 0000 0111
-6:	1111 1111 ... 1111 1010
<hr/>	
+1:	0000 0000 ... 0000 0001

- Overflow if result out of range
 - Subtracting two +ve or two -ve operands, no overflow
 - Subtracting +ve from -ve operand
 - Overflow if result sign is 0
 - Subtracting -ve from +ve operand
 - Overflow if result sign is 1

Dealing with Overflow

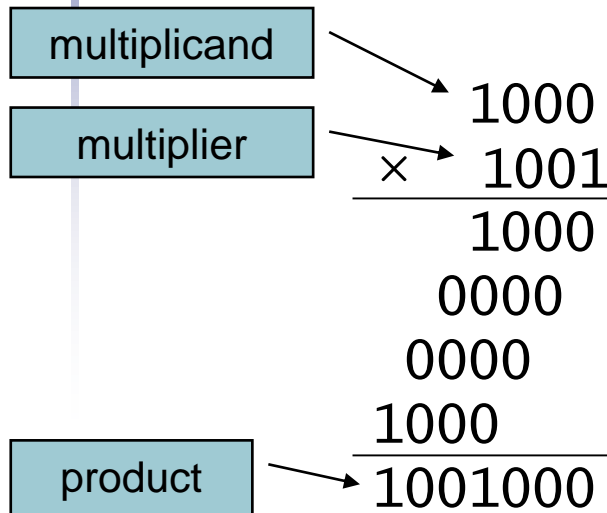
- Some languages (e.g., C) ignore overflow
 - Use MIPS `addu`, `addui`, `subu` instructions
- Other languages (e.g., Ada, Fortran) require raising an exception
 - Use MIPS `add`, `addi`, `sub` instructions
 - On overflow, invoke exception handler
 - Save PC in exception program counter (EPC) register
 - Jump to predefined handler address
 - `mfc0` (move from coprocessor reg) instruction can retrieve EPC value, to return after corrective action

Arithmetic for Multimedia

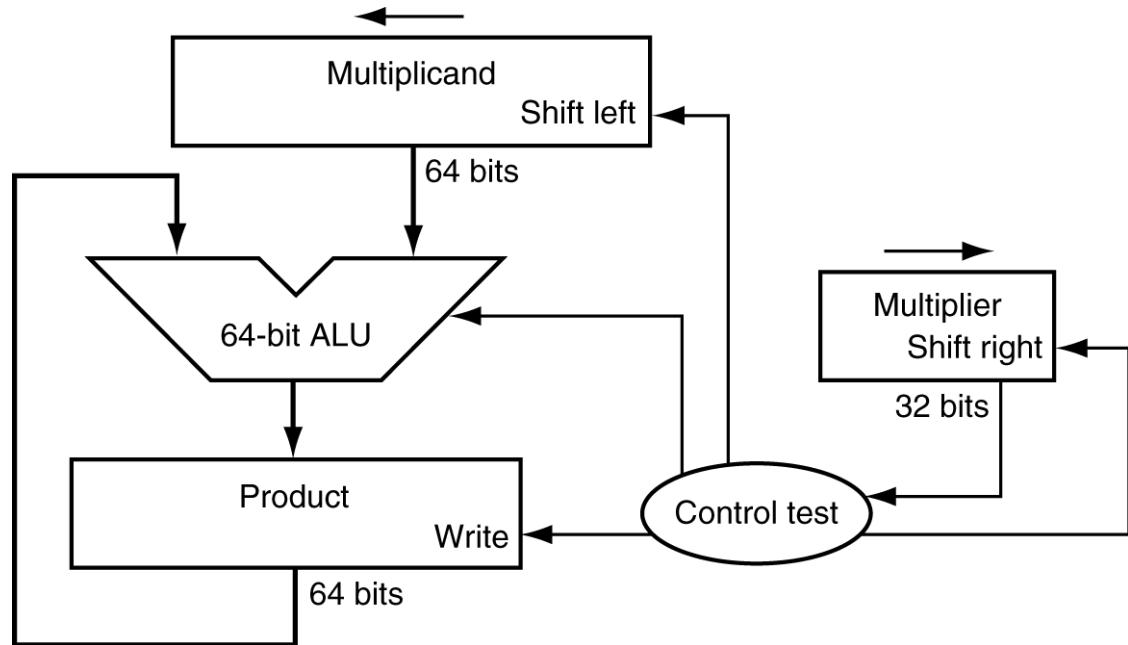
- Graphics and media processing operates on vectors of 8-bit and 16-bit data
 - Use 64-bit adder, with partitioned carry chain
 - Operate on 8×8 -bit, 4×16 -bit, or 2×32 -bit vectors
 - SIMD (single-instruction, multiple-data)
- Saturating operations
 - On overflow, result is largest representable value
 - c.f. 2s-complement modulo arithmetic
 - E.g., clipping in audio, saturation in video

Multiplication

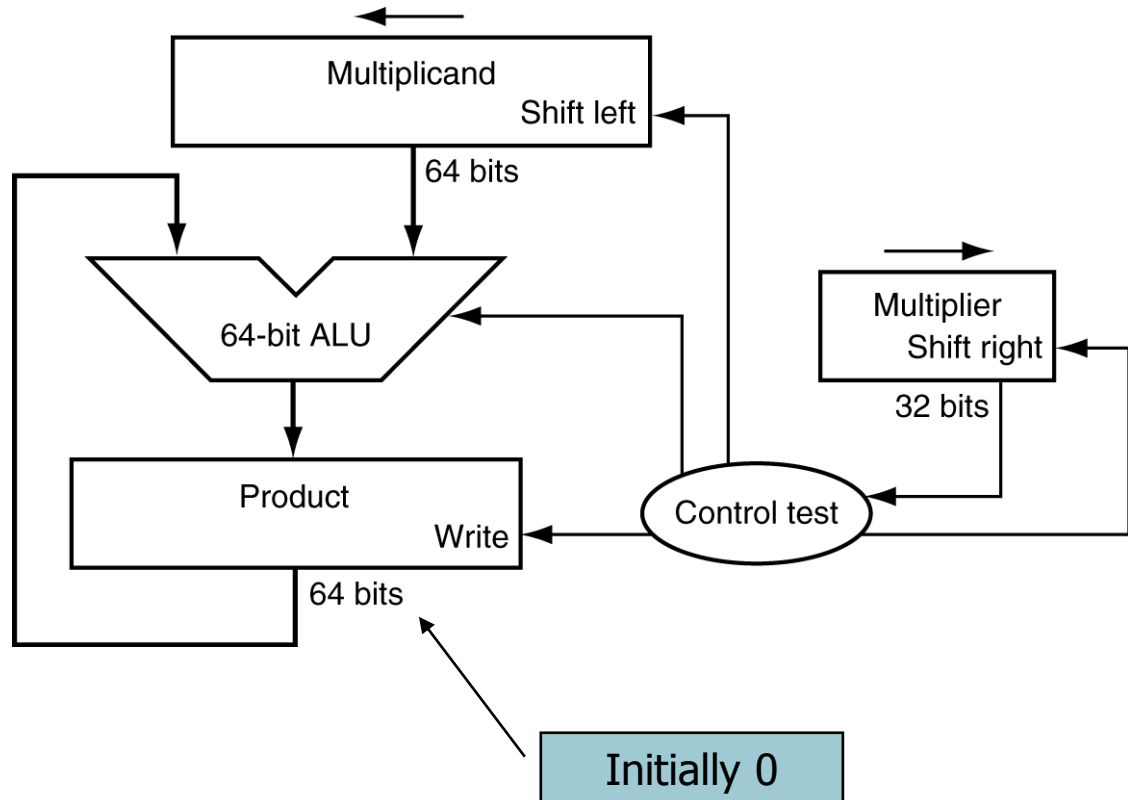
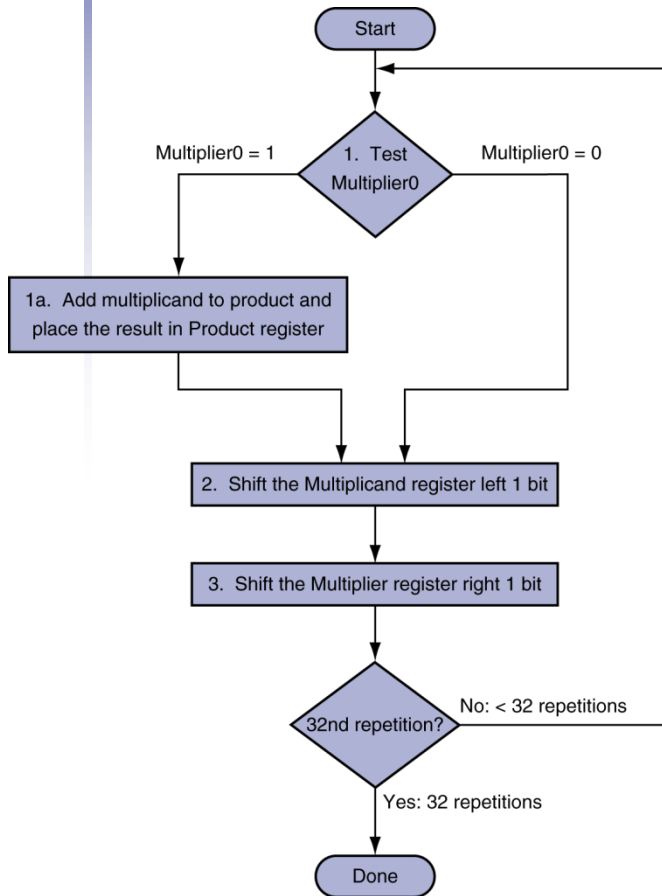
- Start with long-multiplication approach



Length of product is the sum of operand lengths



Multiplication Hardware

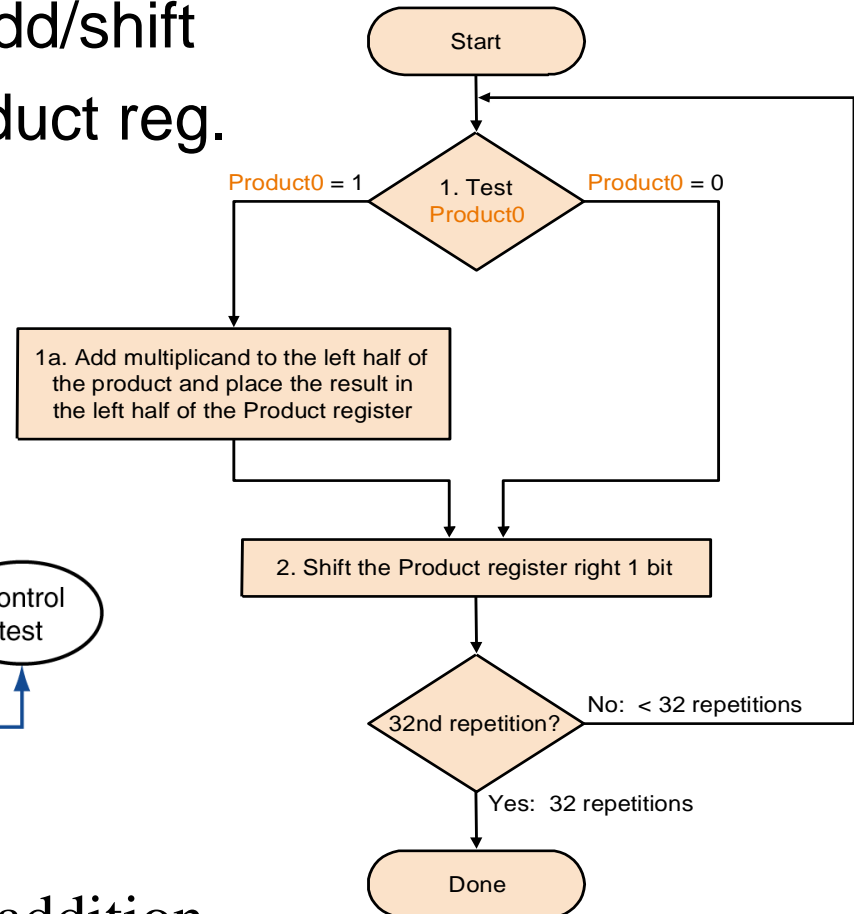
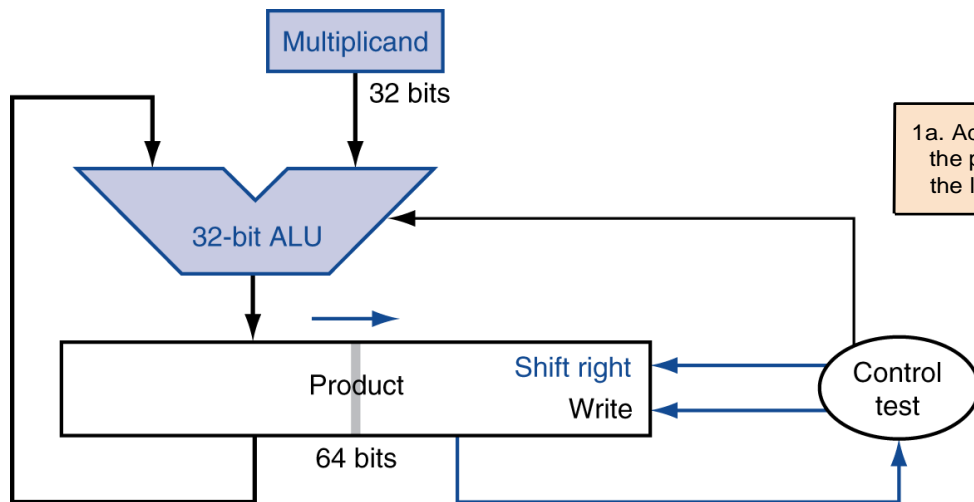


Example: (4-bit) $0010_2 \times 0011_2 = 00000110_2$

Iteration	Step	Multiplier	Multiplicand	Product
0	Initial Steps	0011	0000 0010	0000 0000
1	1a → LSB multiplier = 1	0011	0000 0010	$\rightarrow +$ 0000 0010
	2 → Shift Mcand left	--	0000 0100	0000 0010
	3 → shift Multiplier right	0001	0000 0100	0000 0010
2	1a → LSB multiplier = 1	0001	0000 0100	$\rightarrow +$ 0000 0110
	2 → Shift Mcand left	--	0000 1000	0000 0110
	3 → shift Multiplier right	0000	0000 1000	0000 0110
3	1 → LSB multiplier = 0	0000	0000 1000	0000 0110
	2 → Shift Mcand left	--	0001 0000	0000 0110
	3 → shift Multiplier right	0000	0001 0000	0000 0110
4	1 → LSB multiplier = 0	0000	0001 0000	0000 0110
	2 → Shift Mcand left		0010 0000	0000 0110
	3 → shift Multiplier right	0000	0010 0000	0000 0110

Optimized Multiplier

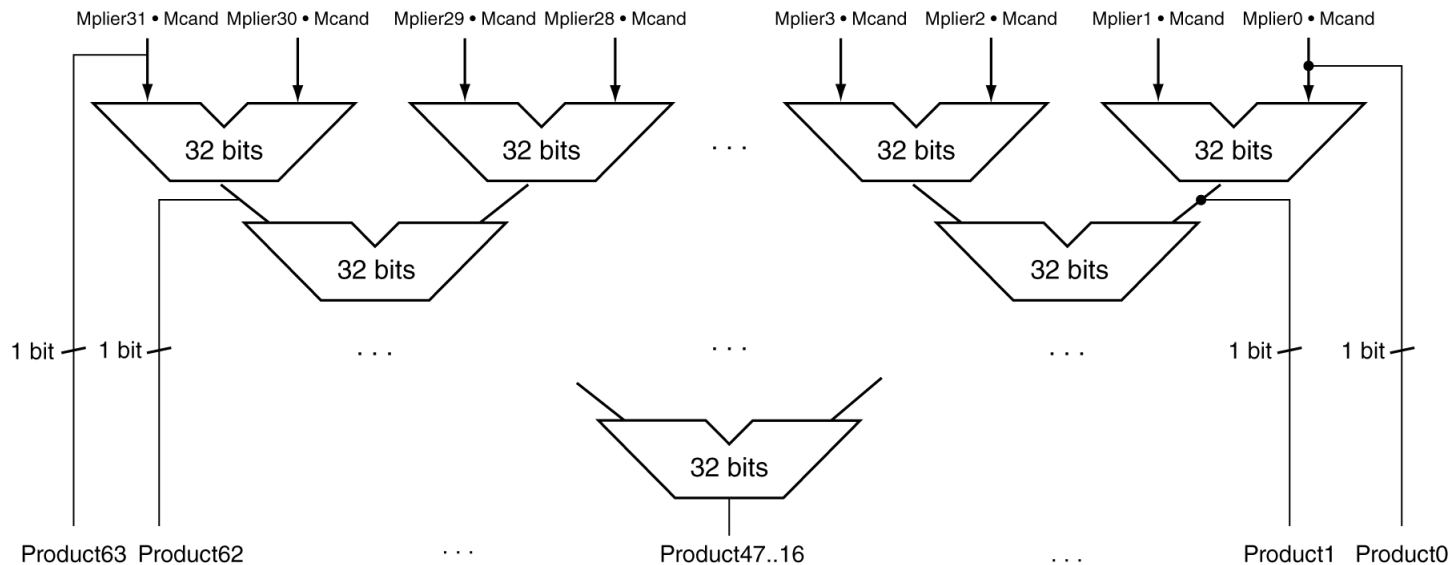
- Perform steps in parallel: add/shift
- Multiflier in right half of product reg.



- One cycle per partial-product addition
 - That's ok, if frequency of multiplications is low

Faster Multiplier

- Uses multiple adders
 - Cost/performance tradeoff

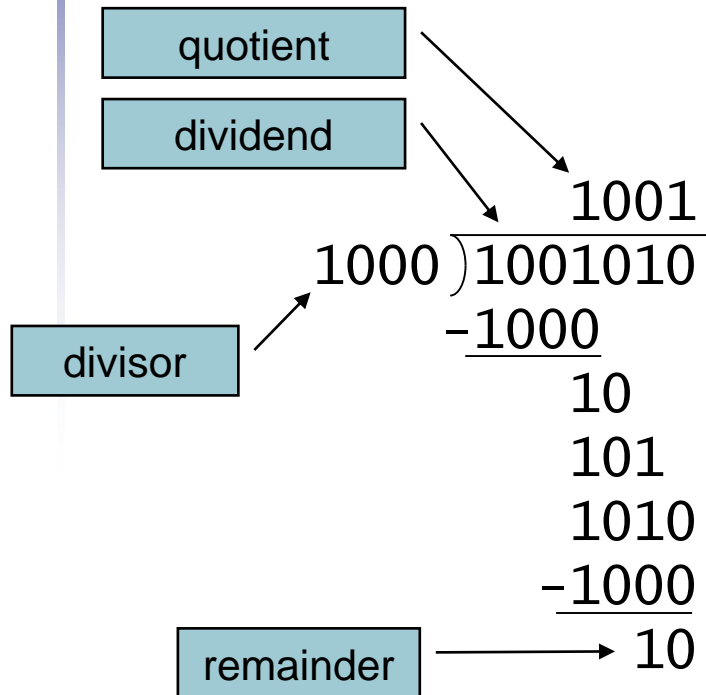


- Can be pipelined
 - Several multiplication performed in parallel

MIPS Multiplication

- Two 32-bit registers for product
 - HI: most-significant 32 bits
 - LO: least-significant 32-bits
- Instructions
 - `mult rs, rt` / `multu rs, rt`
 - 64-bit product in HI/LO
 - `mfhi rd` / `mflo rd`
 - Move from HI/LO to rd
 - Can test HI value to see if product overflows 32 bits

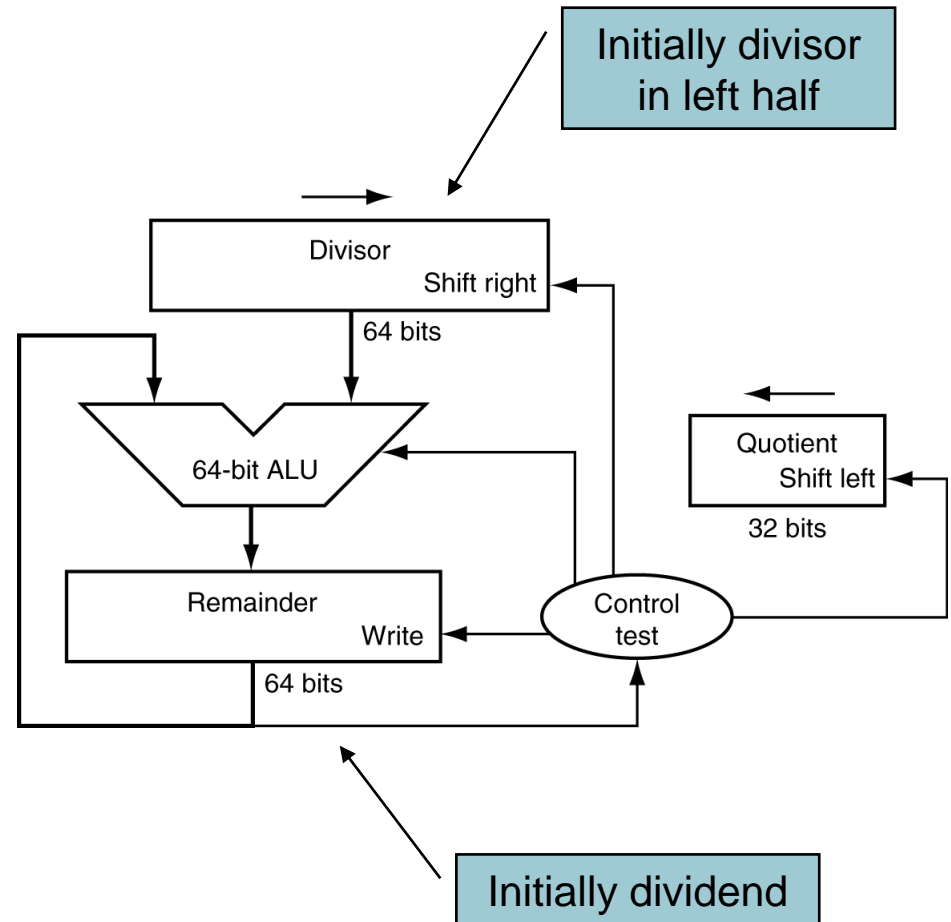
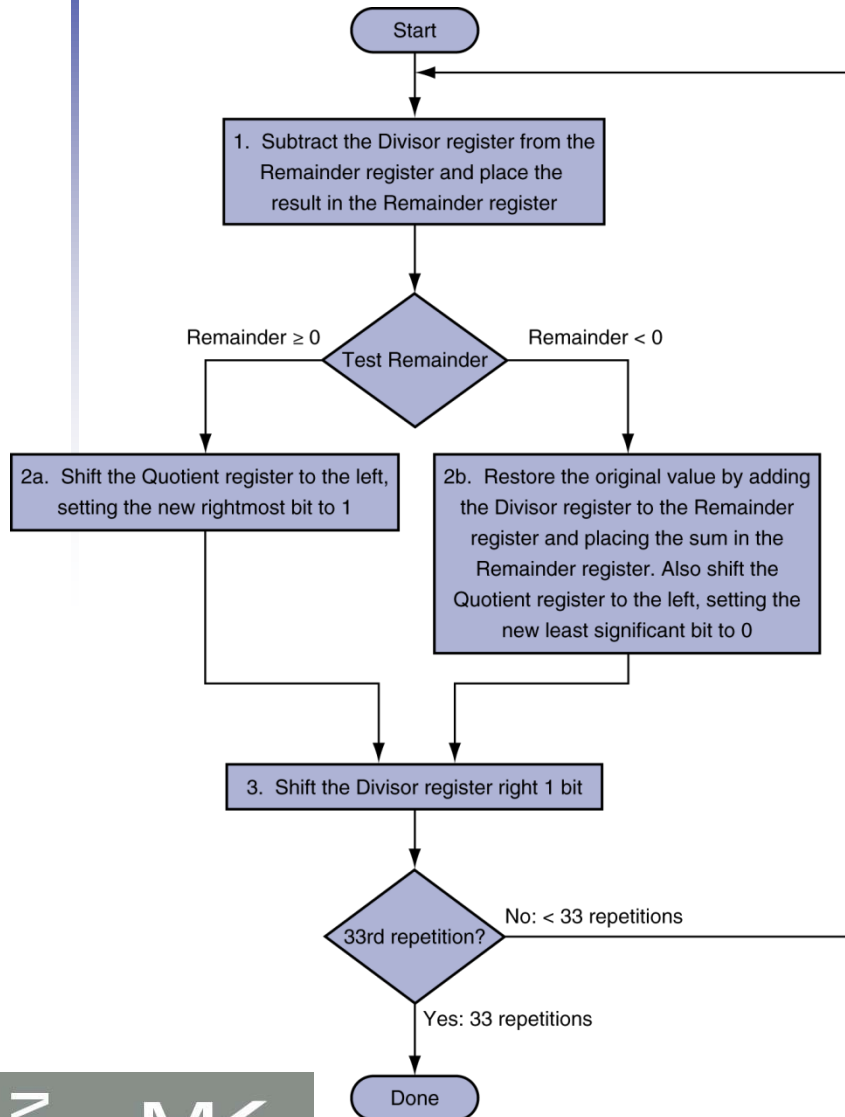
Division



n-bit divisor yields *n*-bit quotient and remainder

- Check for 0 divisor
- Long division approach
 - If divisor \leq dividend bits
 - 1 in quotient and subtract
 - Otherwise
 - 0 in quotient and bring down next dividend bit
- Restoring division
 - Do the subtract, and if remainder goes < 0 , add divisor back
- Signed division
 - Divide using absolute values
 - Adjust sign of quotient and remainder as required

Division Hardware

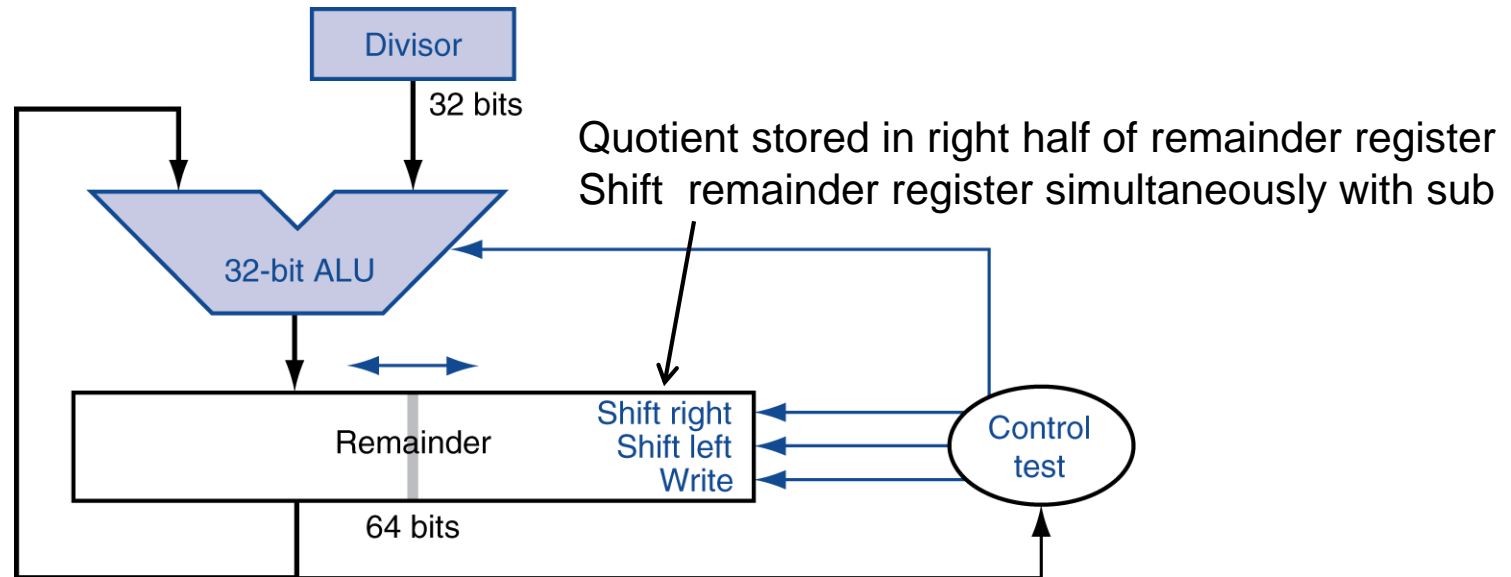


Dividing 0000 0111 by 0010

Iteration	Step	Quotient	Divisor	Remainder
0	Initial values	0000	0010 0000	0000 0111
1	1: Rem = Rem - Div	0000	0010 0000	①110 0111
	2b: Rem < 0 \Rightarrow +Div, sll Q, Q0 = 0	0000	0010 0000	0000 0111
	3: Shift Div right	0000	0001 0000	0000 0111
2	1: Rem = Rem - Div	0000	0001 0000	①111 0111
	2b: Rem < 0 \Rightarrow +Div, sll Q, Q0 = 0	0000	0001 0000	0000 0111
	3: Shift Div right	0000	0000 1000	0000 0111
3	1: Rem = Rem - Div	0000	0000 1000	①111 1111
	2b: Rem < 0 \Rightarrow +Div, sll Q, Q0 = 0	0000	0000 1000	0000 0111
	3: Shift Div right	0000	0000 0100	0000 0111
4	1: Rem = Rem - Div	0000	0000 0100	①000 0011
	2a: Rem \geq 0 \Rightarrow sll Q, Q0 = 1	0001	0000 0100	0000 0011
	3: Shift Div right	0001	0000 0010	0000 0011
5	1: Rem = Rem - Div	0001	0000 0010	①000 0001
	2a: Rem \geq 0 \Rightarrow sll Q, Q0 = 1	0011	0000 0010	0000 0001
	3: Shift Div right	0011	0000 0001	0000 0001

FIGURE 3.10 Division example using the algorithm in Figure 3.9. The bit examined to determine the next step is circled in color.

Optimized Divider



- One cycle per partial-remainder subtraction
- Looks a lot like a multiplier!
 - Same hardware can be used for both

MIPS Division

- Use HI/LO registers for result
 - HI: 32-bit remainder
 - LO: 32-bit quotient
- Instructions
 - `div rs, rt` / `divu rs, rt`
 - No overflow or divide-by-0 checking
 - Software must perform checks if required
 - Use `mfhi`, `mflo` to access result