Analog and Digital Computers

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Classification and Definitions

- All computers are divided in two broad categories: analog and digital
- In an *analog* computer, each number is represented by a measurable physical quantity assuming a continuous range of values
- In a *digital* computer, each number is represented as a sequence of digits that represent values from a finite set

Basic Arithmetic Operations

- Analog computer (the *differential analyzer*):
  1. *$(x \pm y)/2$*
  2. Integration (the Stieltjes integral)
- Digital computer:
  1. Addition *$(x+y)$*
  2. Subtraction *$(x-y)$*
  3. Multiplication *$(x*y)$*
  4. Division *(x/y)*

Representation of Digits

- A group of 3 two-valued (binary) markers yields $2^3=2*2*2=8$ combinations (*octal* digits). Decimal digits 8 and 9 are not used.
- A group of 4 two-valued (binary) markers yields $2^4=2*2*2*2=16$ combinations (*hexadecimal* digits). The extra digits are denoted as A (10), B (11), C (12), D (13), E (14), and F (15).

Basic Components of Digital Computers

- Electromechanical relays
- Vacuum tubes
- Crystal diodes
- Ferromagnetic cores
- ***Transistors*** (nowadays, *VLSI circuits* are made of them, as you may recall)

Addition and Subtraction in Binary

```
 1   11     ←carry                    1    ←carry
  10011        →        1+2+16 =    19
+ 11001        →        1+8+16 =  + 25
 101100        →        4+8+32 =    44

   1  1     ←borrow
   10101                1+4+16 =    21
-   1011                1+2+ 8  =  - 11
    1010                 2+8    =    10
```

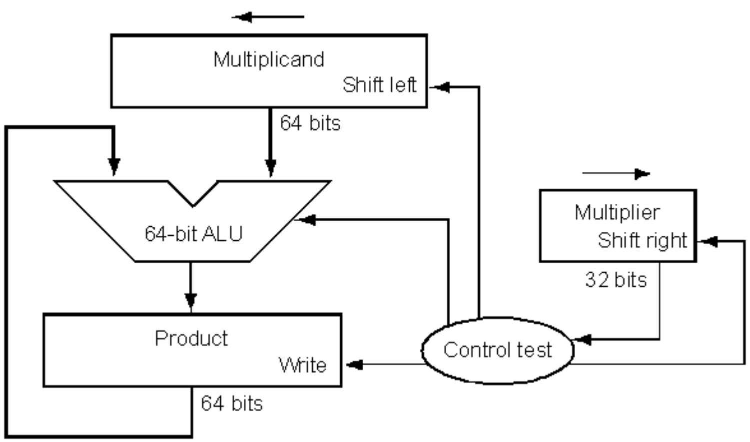
Multiplication

- More complicated than addition
  - accomplished via shifting and addition
- More time and more area
- Let's look at 3 versions based on a gradeschool algorithm

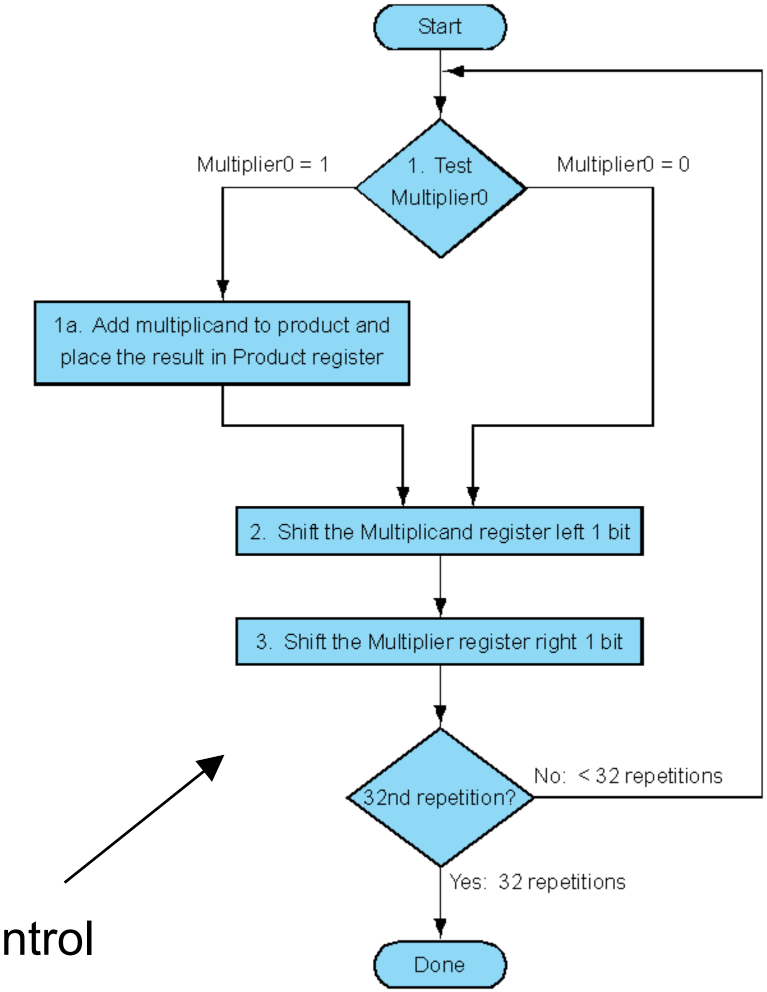
```
      0010   (multiplicand)
  __x_1011   (multiplier)
```

- Negative numbers: convert and multiply
  - there are better techniques, we won’t look at them

Multiplication: Implementation



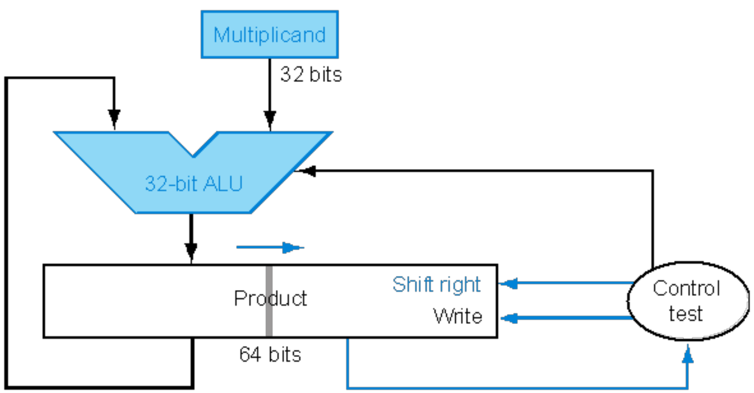
Datapath

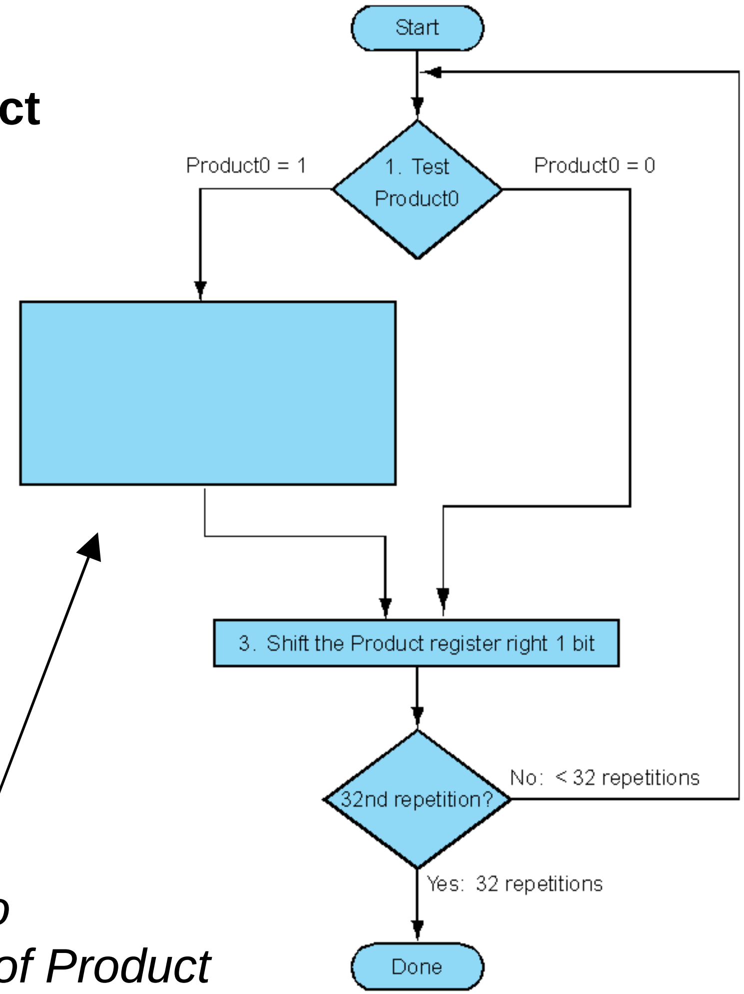


Control

Improved Version

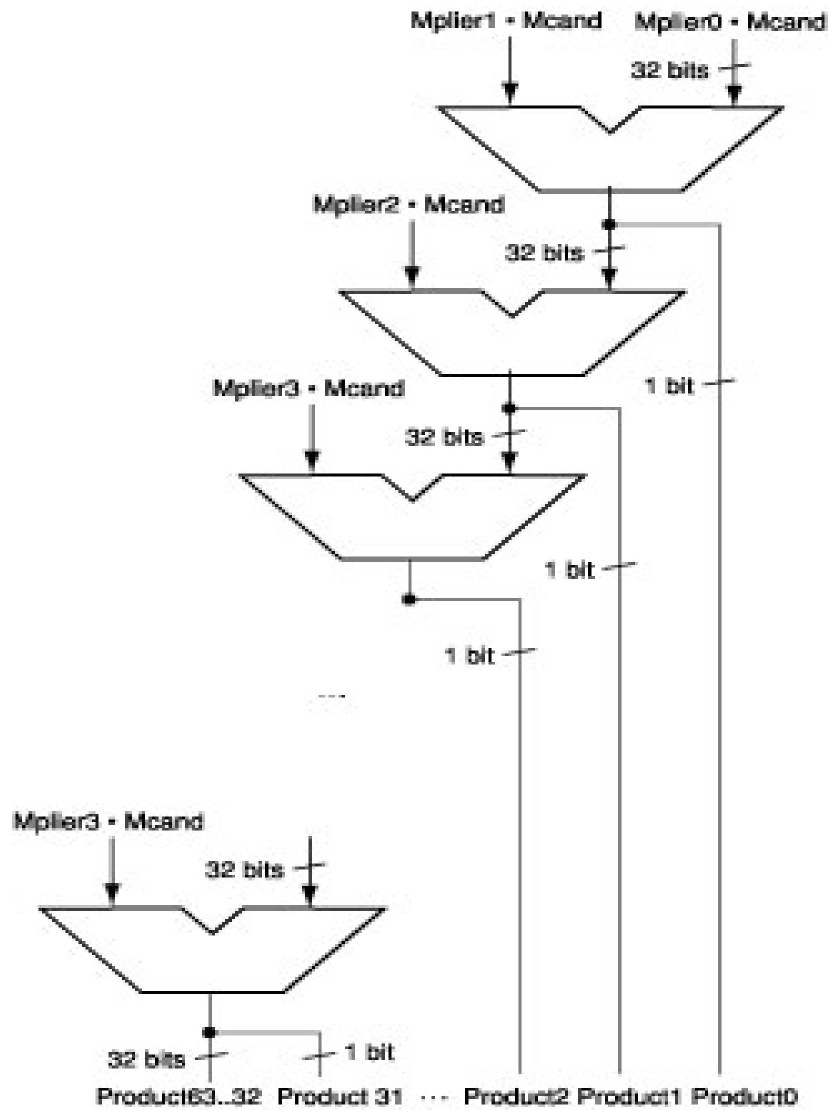
- **Multiplier starts in right half of product**





Add multiplicand to
The left-hand half of Product
(need a 65th bit for overflow)

Final Version: Fast Multiplication



Logical Control

- John von Neumann: “Beyond the capability to execute the basic operations singly, a computing machine must be able to perform them according to the sequence…”

Control in Analog Computers

- By cogwheel connections
- By electrical follower-arrangements (“selsyns”)
- By electrical “plugged” connections controlled by logical tapes via electromechanical relays

One Organ for Each Basic Operation

- Analog computers must have enough organs for each basic operation
- John von Neumann: "…in digital machines there is uniformly only one organ for each basic operation."
- But then we need *memory registers* to store the results of these operations!

Control Sequence Points

- This is an (obsolete) form of plugged control for digital computers
- Each control sequence point is connected to:
  - One of the basic operation organs
  - Memory registers for input and output
  - One or more “successor” control sequence points
- “Branching points”