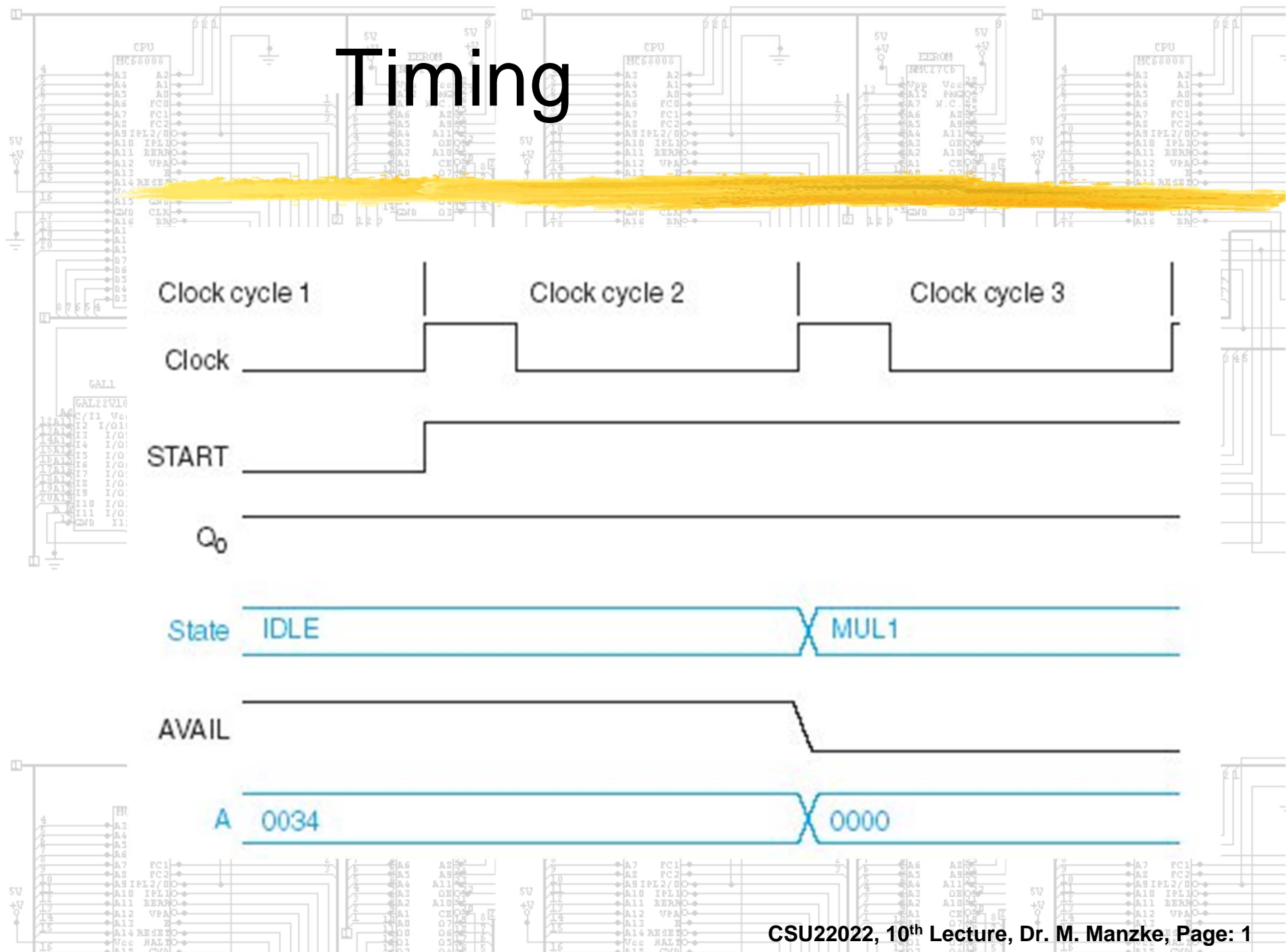


# Timing



# Control Unit Design

▶ Two contrasting approaches to control unit design have evolved:

▶ Hard-wired

▶ Micro-coded

# Example

▶ We will consider a shift-and-add multiply circuit as an example of each design approach.

▶ If **A** and **B** are n-bit unsigned integers.

▶ To compute their product **P**:

$$P = A \times B$$

Product = Multiplier  $\times$  Multiplicand

# Bit Products

► We can generate the bit products:

$$P_i \quad i=0, n-1$$

$$P_i = a_i \times B = \begin{cases} 0 & \text{if } a_i=0 \\ B & \text{if } a_i=1 \end{cases} = a_i \wedge B$$

$$PP_j = \sum_{i=0}^j P_i \times 2^i = P_j \times 2^j + PP_{j-1}$$

$$P = PP_{n-1}$$

# Hand Multiplication

23

19

10111

10011

10111

10111

00000

00000

10111

437

110110101

Multiplicand

Multiplier

←  $P_0$

←  $P_1 \times 2^1$

←  $P_2 \times 2^2$

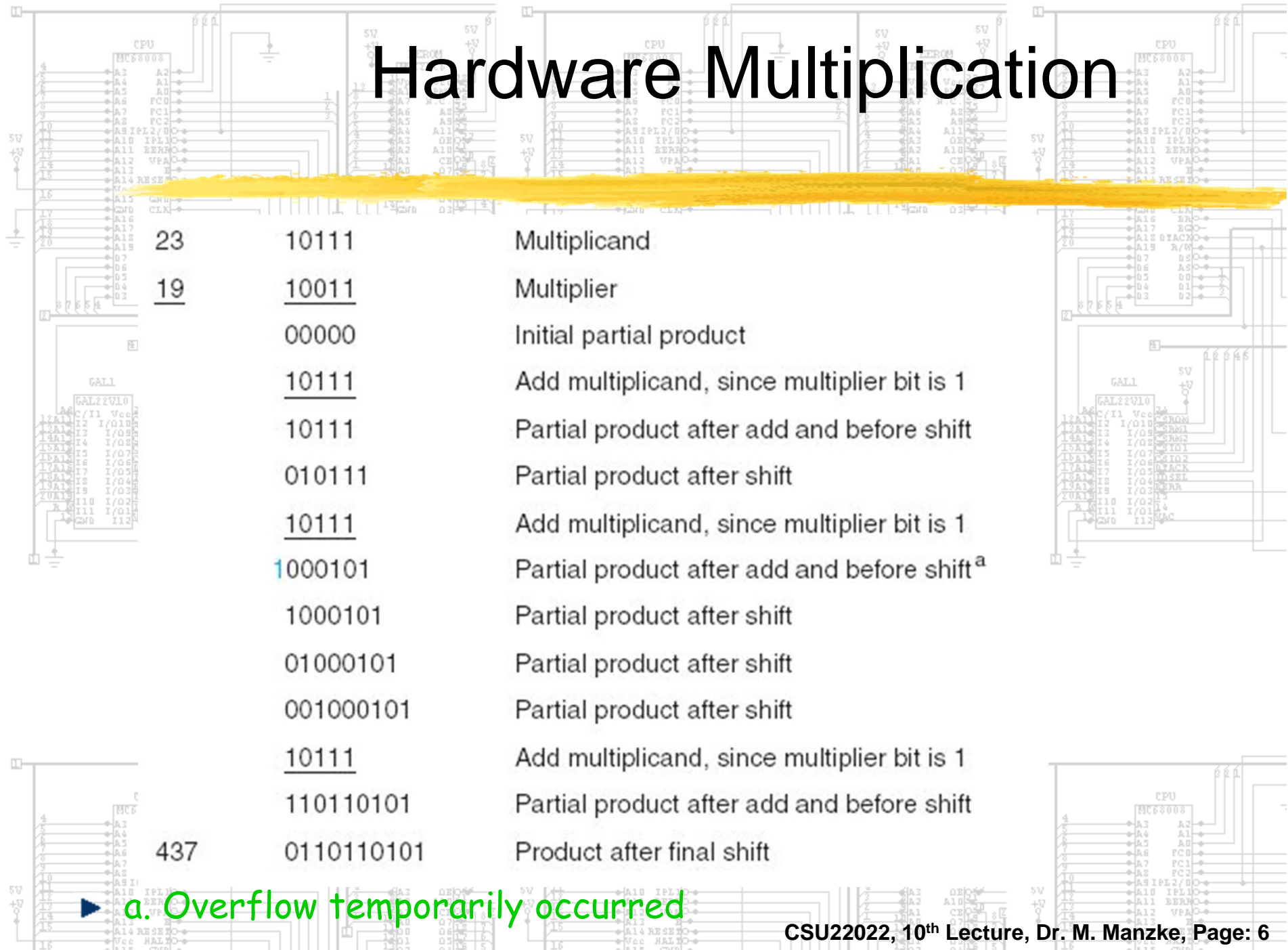
←  $P_3 \times 2^3$

←  $P_4 \times 2^4$

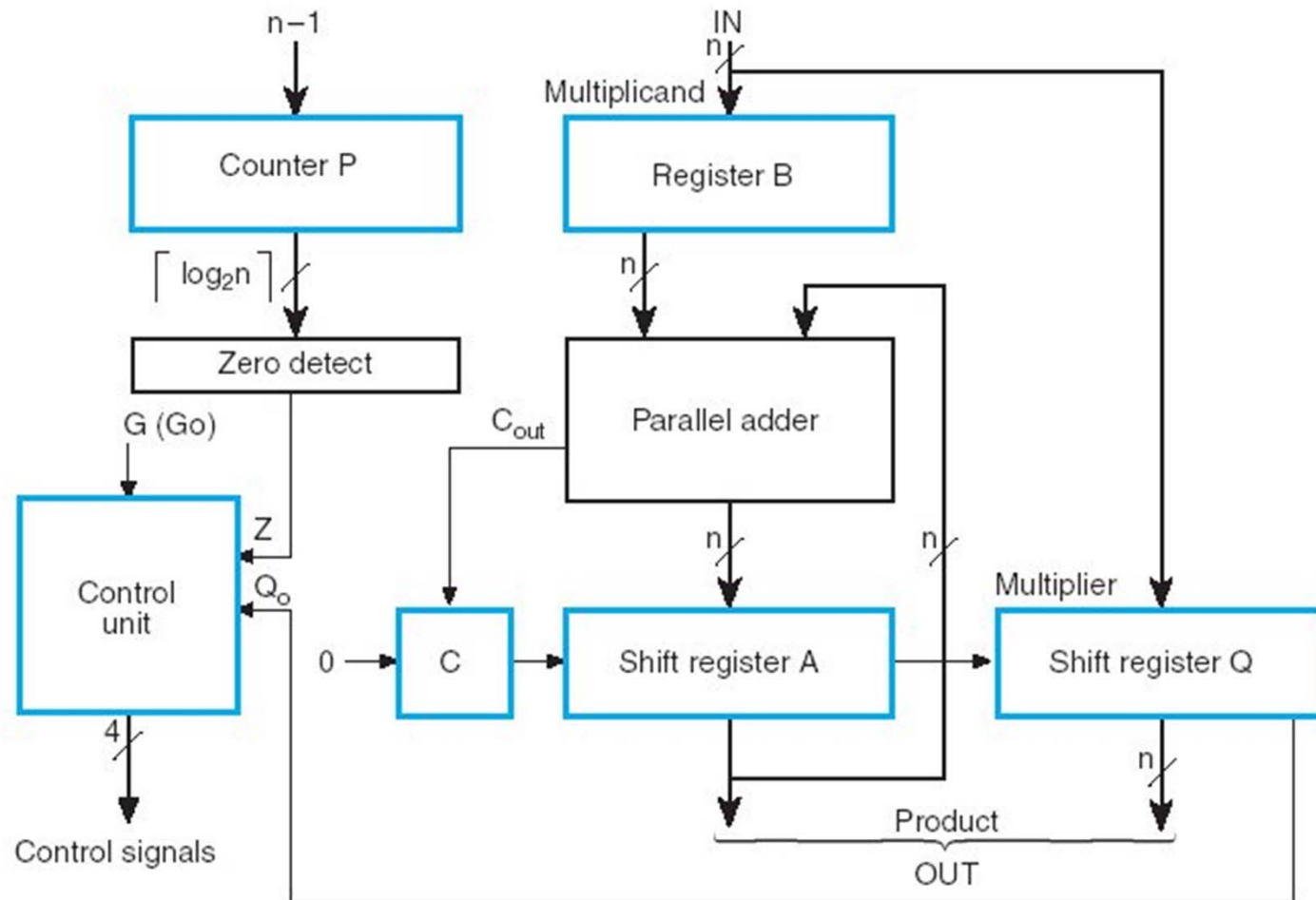
Product



# Hardware Multiplication



# Binary Multiplier Diagram



# Binary Multiplier

▶ The figure on the previous slide shows:

▶ Datapath

▶ Status signals **Z** and **Q<sub>0</sub>**

▶ External Input

▶ **G** = Go

▶ Output



# Binary Multiplier ASM

