Dealing with Time in Combinational Circuits

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How Fast Does an Electrical Signal Travel

- Electrical signals travel through a wire at roughly 50% to 99% of the speed of light depending on the insulation on the wire
  - See **Speed of electricity** and **Velocity factor** in Wikipedia
  - Speed of light is ~300,000 kilometers per second
  - So, electrical signals in a wire travel ~0.984 to ~0.492 feet per nanosecond (nanosecond = a billionth of a second)
- Grace Hopper and a wire “nanosecond”
- However, signals travel much slower through an active device such as a logic gate

What is a **Gate Delay**?

- A **gate delay** is the time required for a change to the inputs of a gate to be reflected in the new stable state of that gate's output(s)

- For each family of gates, a simplified and uniform **gate delay** is specified by the **Greek letter tau**, **τ**

- Because gate delays dominate timing in our circuits, we will ignore the speed of travel of electrical signals in wires/traces

Circuit Model, Net, Timing Waveform

- In our simplified model, all points in a circuit that are connected by a wire are immediately at the same potential and are referred to as a **net**
  - Therefore, a net represents an electrical signal in a circuit and each net encompasses all *connected* inputs, connection points, and outputs.

- The state of all nets in a circuit over time is often used to demonstrate the response of a circuit to a change in inputs
  - A graphical representation of the state of all nets in a circuit over time is called a **Timing Waveform**

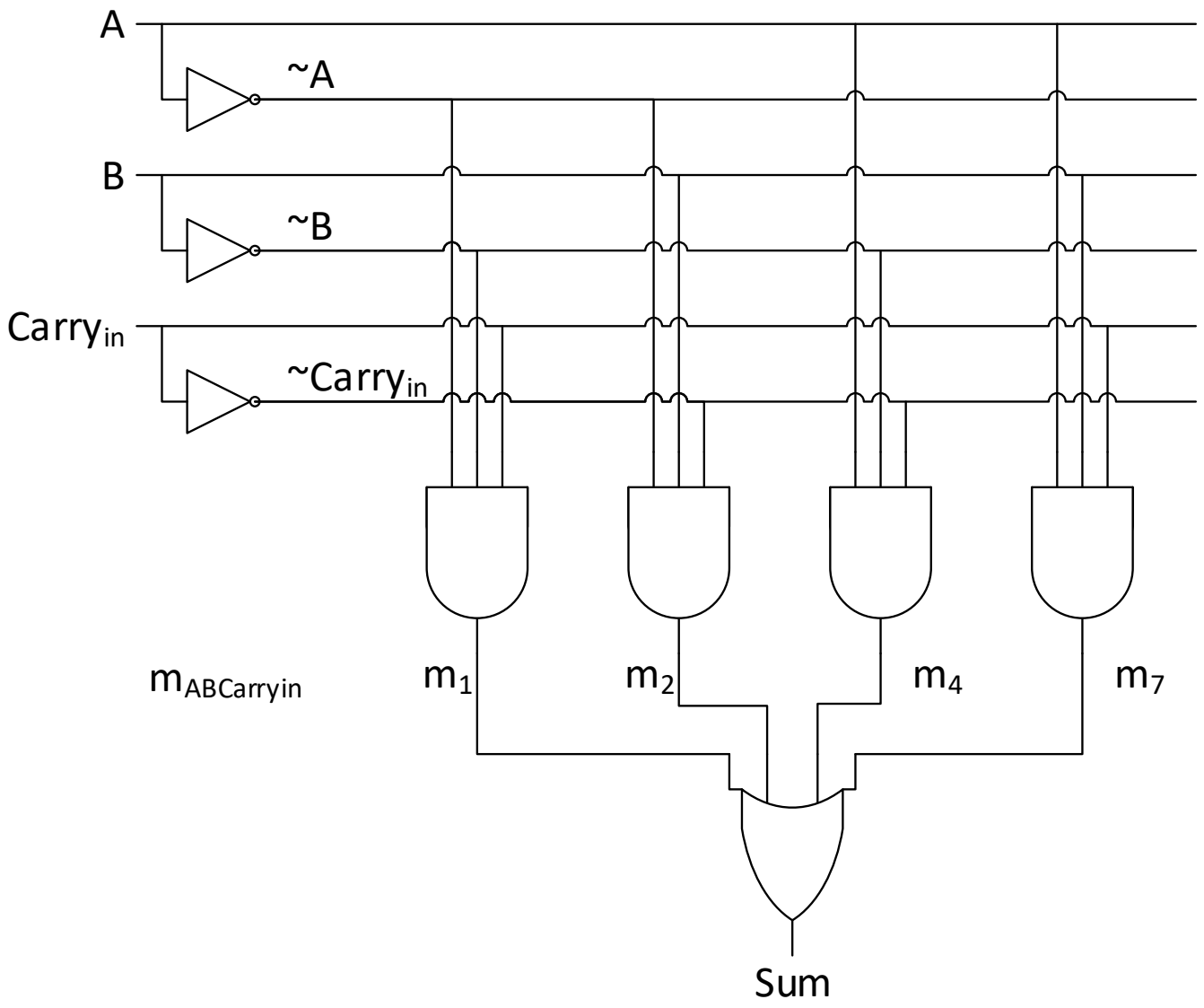
Timing Waveform

- To reflect the state of all parts of a circuit over time, we will draw a timing waveform for every net in a circuit

- The x-axis will represent time from left to right
- Each net will be present on the y-axis
  - Each net will be higher on the y-axis to represent a 1 and lower on the y-axis to represent a 0
  - A net can also be represented in an uncertain state using cross-hatching

- An example circuit and timing waveform for that circuit follows

Circuit to Generate Sum for Full Adder



Timing Waveform Diagram