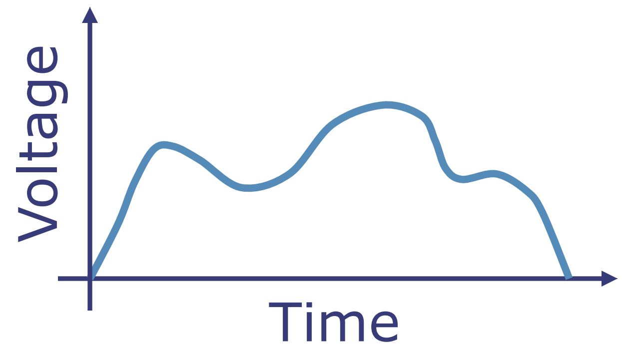
The Digital Abstraction

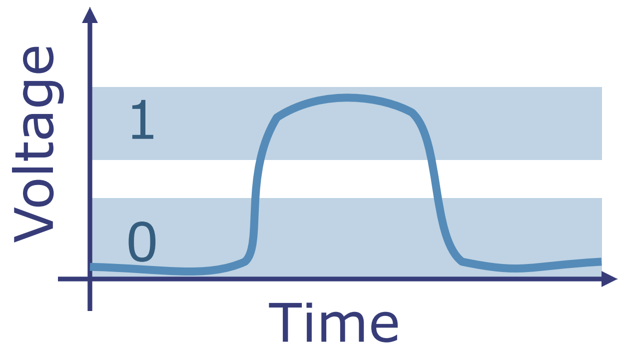
Building Digital Systems in an Analog World

Analog vs. Digital Systems

- Analog systems represent and process information using continuous signals
  - e.g., voltage, current, temperature, pressure, …



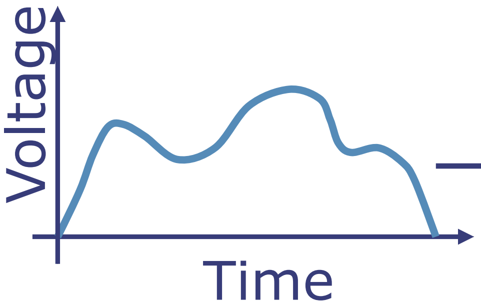
- Digital systems represent and process information using discrete symbols
  - Typically binary symbols (bits)
  - Encoded using ranges of a physical quantity (e.g., voltage)



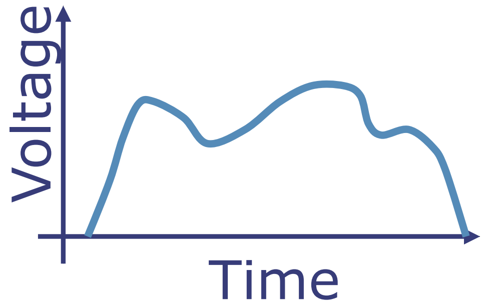
Digital systems tolerate noise

Example: Analog Audio Equalizer

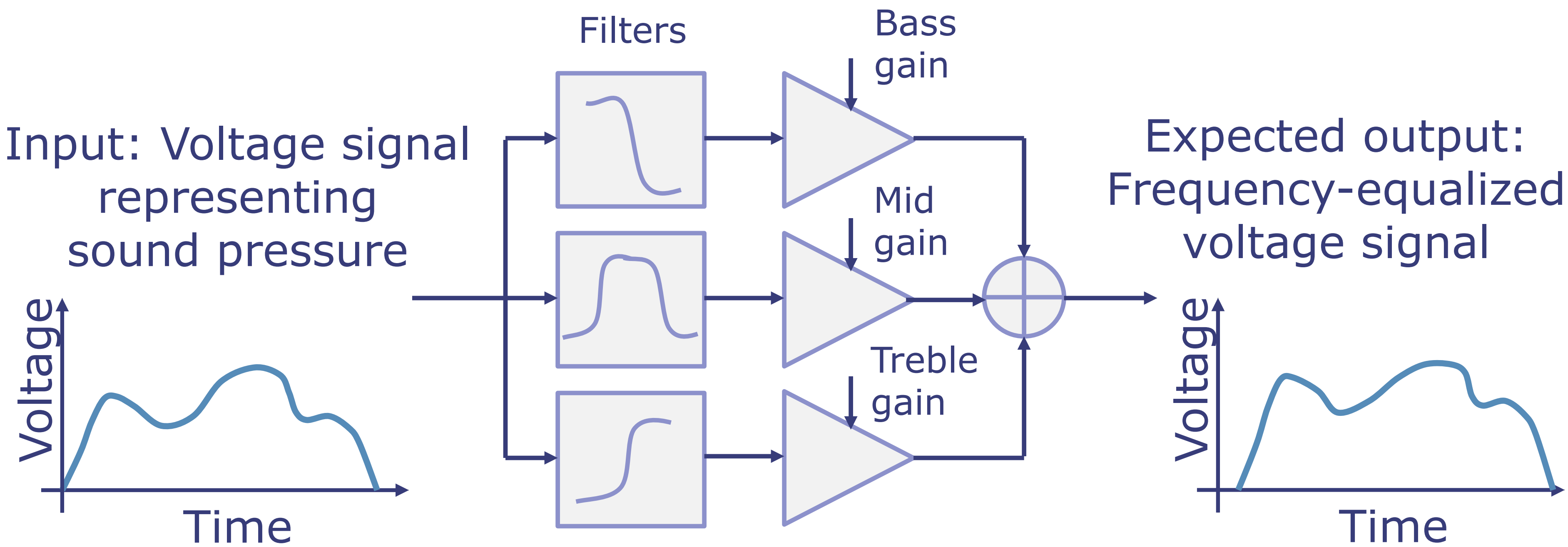
Input: Voltage signal representing sound pressure



Expected output: Frequency-equalized voltage signal



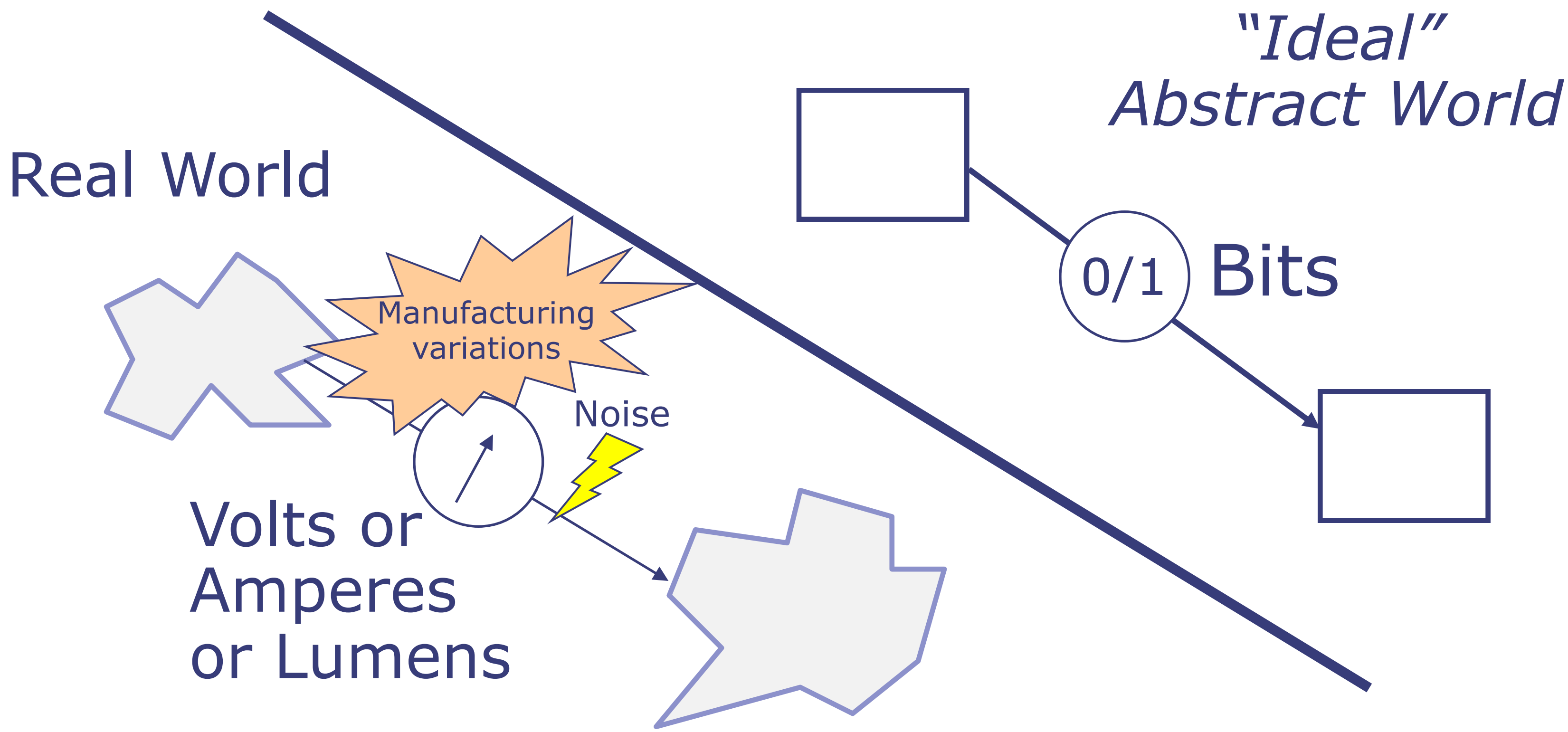
Example: Analog Audio Equalizer



Does output match expected output? *Not quite!*

Why or why not? *Noise*
Manufacturing variations
Components degrade over time
…

The Digital Abstraction

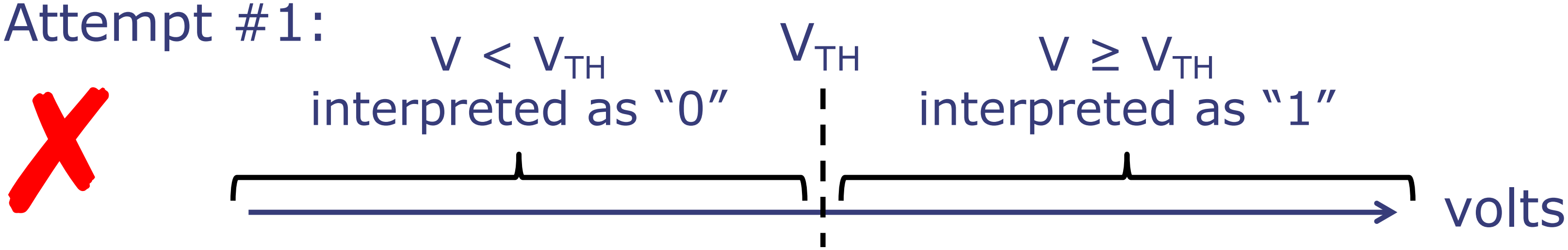


Keep in mind that the world is not digital, we would simply like to engineer it to behave that way. In the end we must use real physical phenomena to implement digital designs!

Using Voltages "Digitally"

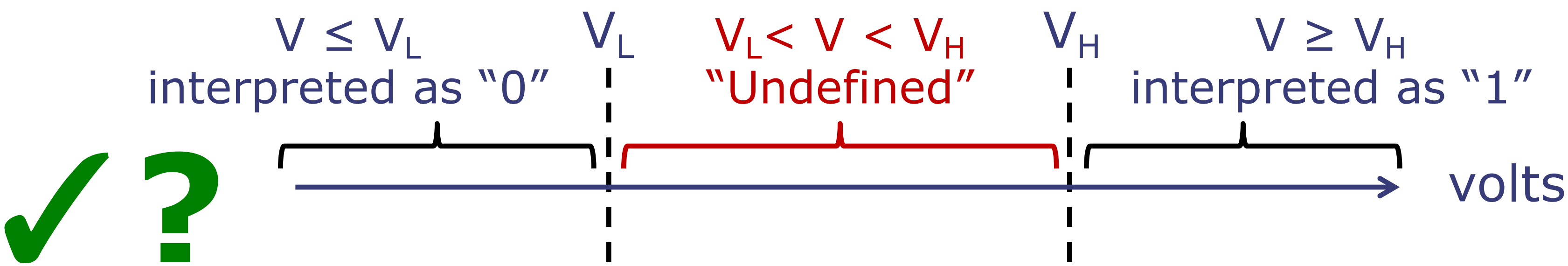
- Key idea: Encode two symbols, "0" and "1" (1 bit)
- Use the same convention for *every* component and wire in our digital system

Attempt #1:

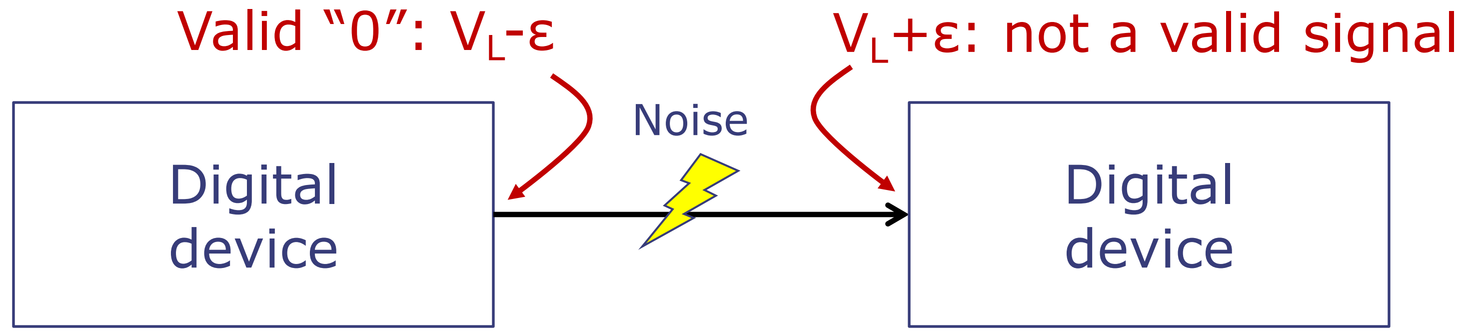


Not quite correct. Why? *Hard to distinguish* $V_{TH}-\varepsilon$ *from* $V_{TH}+\varepsilon$

Attempt #2:



Will This System Work?



Upstream device transmits a signal at V_L-ε, a valid "0". Noise on the wire causes the downstream device to receive V_L+ε, which is undefined.

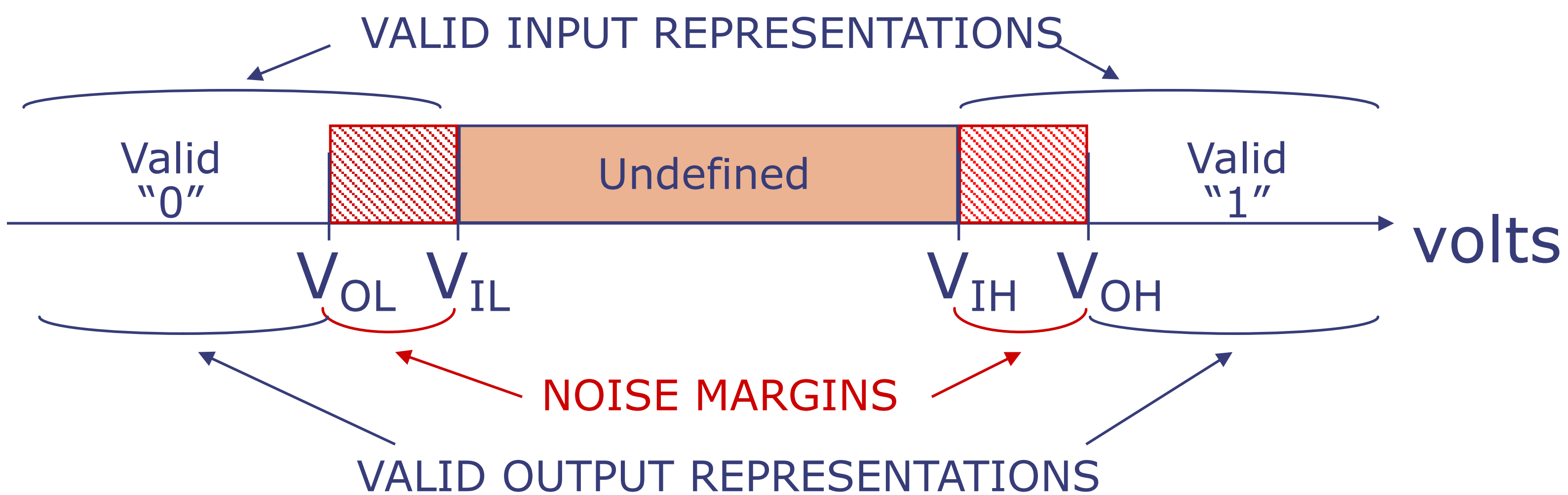
How can we address this?

Output voltages should use narrower ranges, so that signal will still be valid when it reaches an input even if there is noise.

Noise Margins

Proposed fix: Different specifications for inputs and outputs

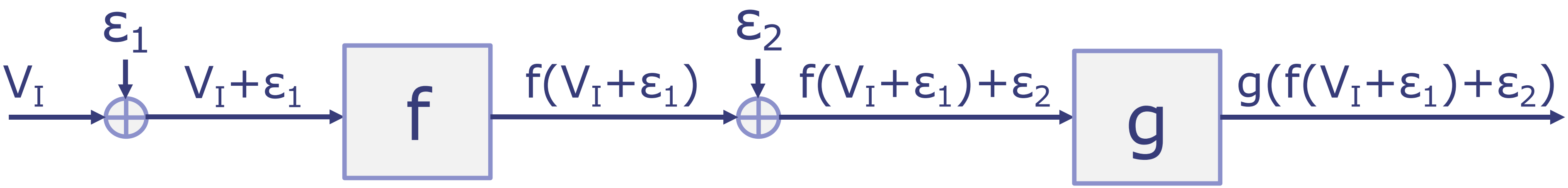
- Digital output: "0" ≤ V_{OL}, "1" ≥ V_{OH}
- Digital input: "0" ≤ V_{IL}, "1" ≥ V_{IH}
- **$V_{OL} < V_{IL} < V_{IH} < V_{OH}$**



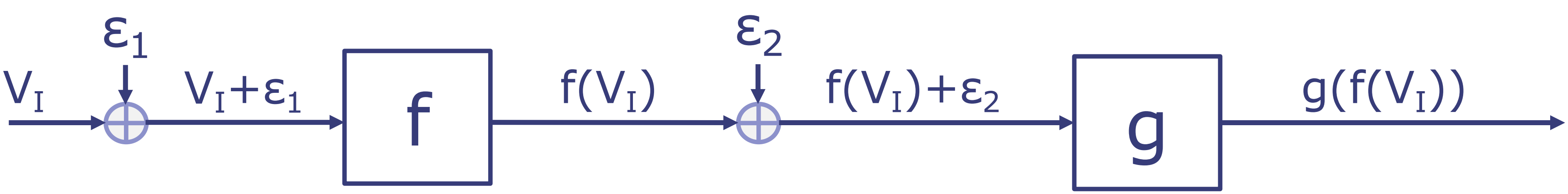
A digital device accepts marginal inputs and provides unquestionable outputs (to leave room for noise)

Digital Systems Fight Noise

Analog systems: Noise accumulates



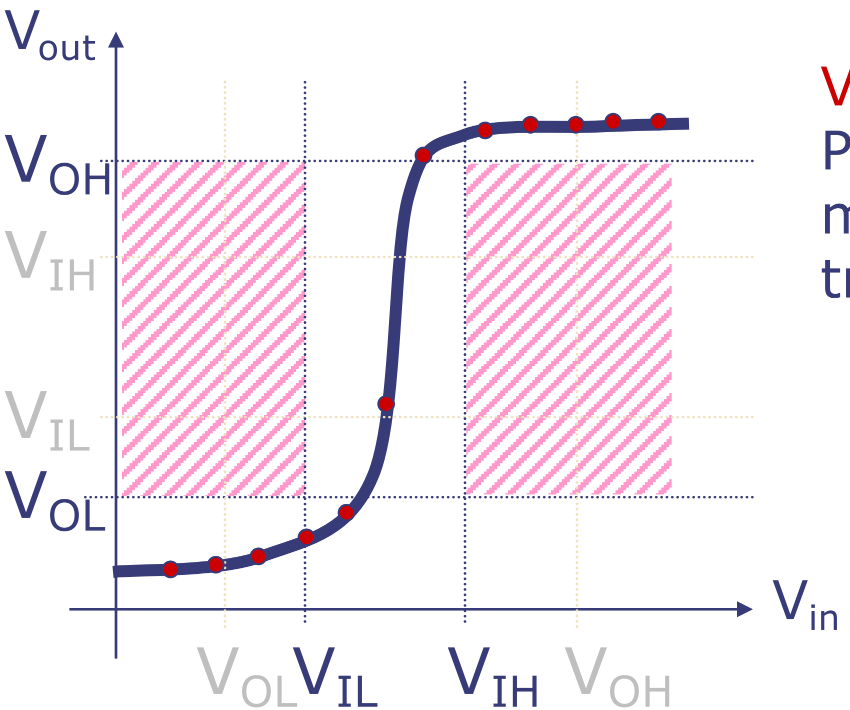
Digital systems: Noise is canceled at each stage



Intuitively, canceling noise requires *active components*, i.e., components that inject energy into the system

Voltage Transfer Characteristic

Buffer: A simple digital device that copies its input value to its output

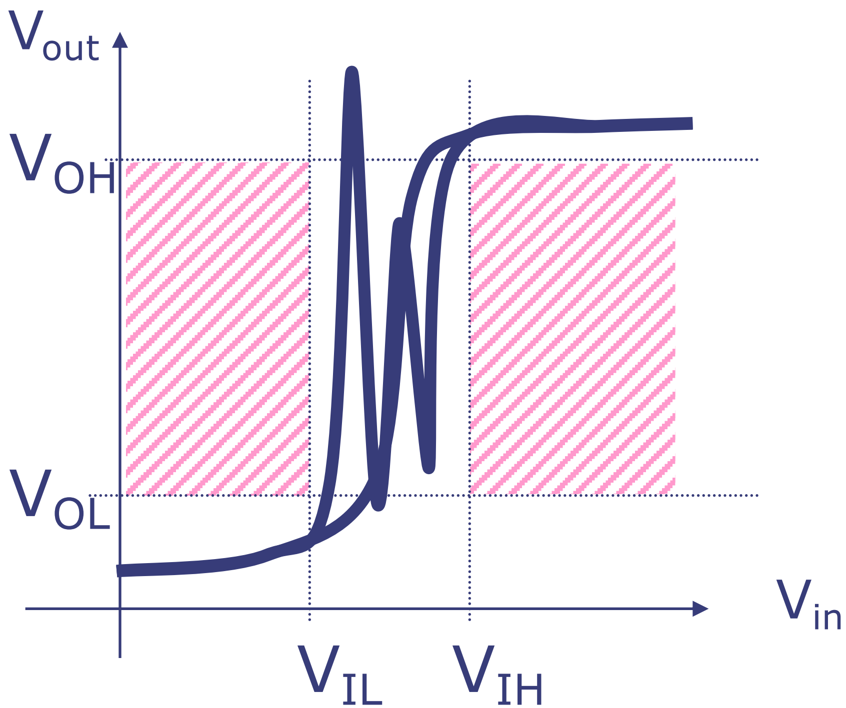


Voltage Transfer Characteristic (VTC): Plot of V_{out} vs. V_{in} where each measurement is taken after any transients have died out

Note: VTC does not tell you anything about how fast a device is — it measures static behavior, not dynamic behavior

VTC must avoid the shaded regions (aka "*forbidden zones*"), which correspond to *valid* inputs but *invalid* outputs

Voltage Transfer Characteristic



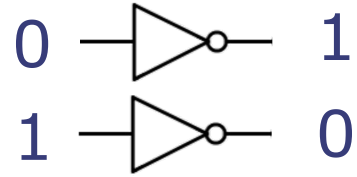
1) Note the center white region is taller than it is wide (V_{OH}-V_{OL} > V_{IH}-V_{IL}). Net result: device must have GAIN > 1 and thus be ACTIVE

2) Note the VTC can do anything when $V_{IL} < V_{IN} < V_{IH}$

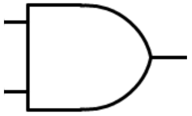
Types of Digital Circuits

- Combinational circuits
  - Do not have memory
  - Each output is a function of current input values
  - Examples:

Inverter



AND



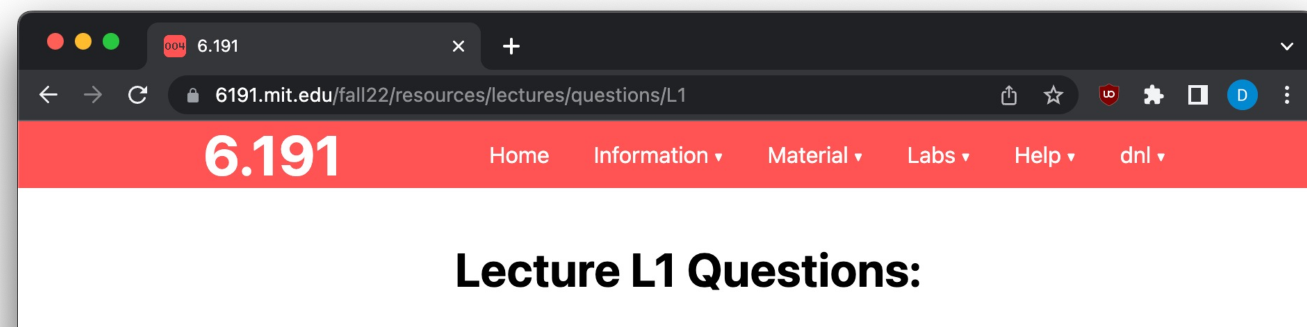
Output is 1 if both inputs are 1, 0 otherwise

- Sequential circuits
  - Have memory, i.e., *state*
  - Each output depends on current state + current inputs

Summary

- Digital systems tolerate noise
- Digital encoding
  - Valid voltage levels for representing "0" and "1"
  - Undefined range avoids mistaking "0" for "1" and vice versa
  - Noise margins require tougher standards for outputs than for inputs

- Complete post-lecture questions by 10am tomorrow
  - 6191.mit.edu > Material > Lectures > L1 questions



Thank you!

Next lecture:
Combinational Devices and Boolean Algebra