Buffers

- In circuits where a logic gate has to drive a large capacitive load, buffers are often used to improved performance
- Buffers can be created with different amounts of drive capability (depending on the size of the transistors used to construct them)
  - Larger transistors => more current handling capability
  - A common use of a buffer is to control a light-emitting diode (LED)
- Buffers have greater fan-out than other (regular) logic gates
Buffers

A non-inverting buffer

An inverting buffer

Tri-state Buffers (Gates)

- A tri-state buffer (gate) has
  - One input \( (x) \)
  - One output \( (f) \)
  - One control input \( (e) \)

\[ f = x \text{ if } e = 1 \]

A tri-state buffer
Tri-state Buffers (Gates)

- When \( e = 1 \), the buffer drives the value of \( x \) onto \( f \), causing \( f = x \)
- When \( e = 0 \), the buffer is completely disconnected from the output \( f \)

Equivalent circuit

\[
\begin{align*}
\text{e=0} & \quad \begin{array}{c}
\text{x} \\
\rightarrow
\end{array} & \quad \begin{array}{c}
f \\
\rightarrow
\end{array} \\
\text{e=1} & \quad \begin{array}{c}
\text{x} \\
\rightarrow
\end{array} & \quad \begin{array}{c}
f \\
\rightarrow
\end{array}
\end{align*}
\]

- In truth table form,

<table>
<thead>
<tr>
<th>( e )</th>
<th>( x )</th>
<th>( f )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>( Z )</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>( Z )</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
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<tr>
<td>1</td>
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<td>1</td>
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</tbody>
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- For the rows where \( e = 0 \), the output is denoted by the logic value \( Z \)
- This \( Z \) is called the high-impedance state
- The name tri-state derives from the fact that there are two normal states for a logic signal (0 and 1) and \( Z \) represents a third state that has no output
Four type of tri-state buffers

- There are four possible configurations of tri-state buffers
  - based on two types of outputs
    - Inverting and non-inverting outputs
  - and two types of control signals ($e$)
    - Active high and active low enables
- Active low enables implies the output is active ($f=x$) when the enable is low ($e=0$)
**Tri-state buffer application**

- Note the outputs of the tri-state gates are wired together
  - This is possible only because we know that (in this configuration) one or the other of the tri-state gates will be in the high impedance (Z) state
  - This type of wired connection is not possible with ordinary logic gates

<table>
<thead>
<tr>
<th>s</th>
<th>x1</th>
<th>x2</th>
<th>f</th>
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</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
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**Transmission gate**

- A *transmission gate* acts as a switch, connecting an input (x) to an output (f)
  - Commonly used to implement XOR gate and multiplexer circuits

<table>
<thead>
<tr>
<th>s</th>
<th>f</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Z</td>
</tr>
<tr>
<td>1</td>
<td>x</td>
</tr>
</tbody>
</table>
Multiplexer with transmission gates

XOR with transmission gates