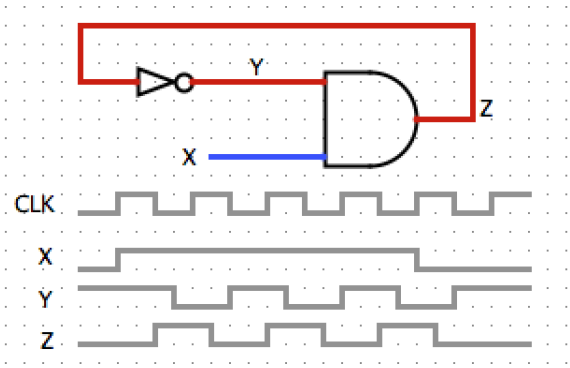
Circuit Delay

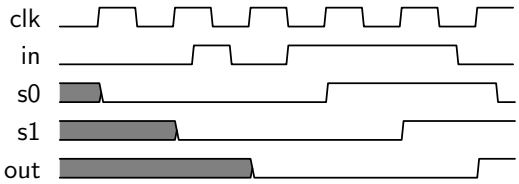
1. Assume that the clock period is 20ns, the inverter in the network below has a propagation delay of 5 ns and the AND gate has a propagation delay of 10 ns. Draw a timing diagram for the network showing X, Y, and Z. Assume that X is initially 0, Y is initially 1, X becomes 1 for 80 ns, and then X is 0 again. Fill out the timing diagram for the circuit below:



State

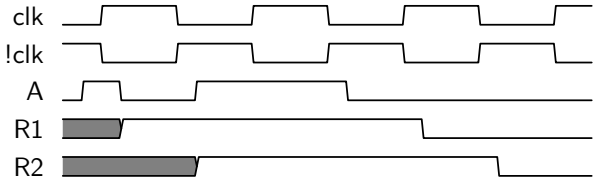
1. Fill out the timing diagram for the circuit below:

```
   +---+    +---+    +---+
IN-|D Q|-s0-|D Q|-s1-|D Q|--Out
   +-^-+    +-^-+    +-^-+
     |        |        |
CLK--+--------+--------+
```



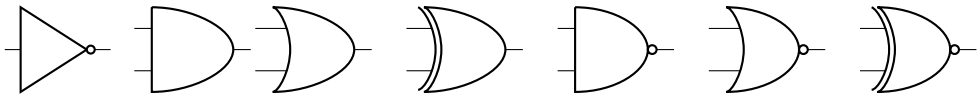
2. Fill out the timing diagram for the circuit below:

```
   +---+    +---+
A--|D Q|-R1-|D Q|-R2--
   +-^-+    +-^-+
     |        |
CLK--+---|>o--+
```



Logic Gates

1. Label the following logic gates:



Solution: not, and, or, xor, nand, nor, xnor

2. Convert the following to boolean expressions:
   (a) NAND

   Solution: $\bar{A}\bar{B} + \bar{A}B + A\bar{B}$

   (b) XOR

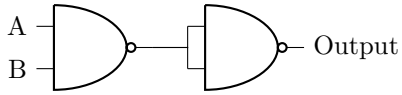
   Solution: $\bar{A}B + A\bar{B}$

   (c) XNOR

   Solution: $\bar{A}\bar{B} + AB$

3. Create an AND gate using only NAND gates. (Can NAND gate implement ANY Boolean function by itself?)

Solution:



4. How many different two-input logic gates can there be? How many n-input logic gates?

Solution: A truth table with n inputs has 2^n rows. Each logic gate has a 0 or a 1 at each of these rows. Imagining a function as a 2^n-bit number, we count 2^{2^n} total functions, or 16 in the case of n = 2.

Boolean Logic

$1 + A = 1$	$A + \bar{A} = 1$	$A + AB = A$	$(A + B)(A + C) = A + BC$
$0B = 0$	$B\bar{B} = 0$	$A + \bar{A}B = A + B$	
DeMorgan's Law:	$\overline{AB} = \bar{A} + \bar{B}$	$\overline{A + B} = \bar{A}\bar{B}$	

1. Minimize the following boolean expressions:

   (a) Standard: $(A + B)(A + \bar{B})C$

   Solution:

   $$(AA + A\bar{B} + AB + B\bar{B})C = (A + A(\bar{B} + B))C = AC \tag{1}$$

   (b) Grouping & Extra Terms: $\bar{A}\bar{B}\bar{C} + \bar{A}B\bar{C} + AB\bar{C} + A\bar{B}\bar{C} + ABC + A\bar{B}C$

   Solution:

   $$\begin{aligned} \bar{A}\bar{C}(\bar{B} + B) + A\bar{C}(B + \bar{B}) + AC(B + \bar{B}) & \quad (2) \\ = \bar{A}\bar{C} + A\bar{C} + AC & \quad (3) \\ = \bar{A}\bar{C} + A\bar{C} + A\bar{C} + AC & \quad (4) \\ = (\bar{A} + A)\bar{C} + A(\bar{C} + C) & \quad (5) \\ = A + \bar{C} & \quad (6) \end{aligned}$$

   (c) DeMorgan's: $\overline{A(\bar{B}\bar{C} + BC)}$

   Solution:

   $$\begin{aligned} \overline{A(\bar{B}\bar{C} + BC)} &= \bar{A} + \overline{\bar{B}\bar{C} + BC} & (7) \\ &= \bar{A} + \overline{\bar{B}\bar{C}}\,\overline{BC} & (8) \\ &= \bar{A} + (B + C)(\bar{B} + \bar{C}) & (9) \\ &= \bar{A} + B\bar{C} + \bar{B}C & (10) \end{aligned}$$