

# Monday October 11

Logical operators aka propositional connectives

<b>Conjunction</b>	AND	$\wedge$	<code>\land</code>	2 inputs	Evaluates to $T$ exactly when <b>both</b> inputs are $T$
<b>Exclusive or</b>	XOR	$\oplus$	<code>\oplus</code>	2 inputs	Evaluates to $T$ exactly when <b>exactly one</b> of inputs is $T$
<b>Disjunction</b>	OR	$\vee$	<code>\lor</code>	2 inputs	Evaluates to $T$ exactly when <b>at least one</b> of inputs is $T$
<b>Negation</b>	NOT	$\neg$	<code>\lnot</code>	1 input	Evaluates to $T$ exactly when its input is $F$

Truth tables: Input-output tables where we use  $T$  for 1 and  $F$  for 0.

Input		Output		
$p$	$q$	<b>Conjunction</b> $p \wedge q$	<b>Exclusive or</b> $p \oplus q$	<b>Disjunction</b> $p \vee q$
$T$	$T$	$T$	$F$	$T$
$T$	$F$	$F$	$T$	$T$
$F$	$T$	$F$	$T$	$T$
$F$	$F$	$F$	$F$	$F$
				

Input	Output
$p$	<b>Negation</b> $\neg p$
$T$	$F$
$F$	$T$
	

Input			Output	
$p$	$q$	$r$	$(p \wedge q) \oplus ((p \oplus q) \wedge r)$	$(p \wedge q) \vee ((p \oplus q) \wedge r)$
$T$	$T$	$T$		
$T$	$T$	$F$		
$T$	$F$	$T$		
$T$	$F$	$F$		
$F$	$T$	$T$		
$F$	$T$	$F$		
$F$	$F$	$T$		
$F$	$F$	$F$		

Given a truth table, how do we find an expression using the input variables and logical operators that has the output values specified in this table?

*Application:* design a circuit given a desired input-output relationship.

Input		Output	
$p$	$q$	$mystery_1$	$mystery_2$
$T$	$T$	$T$	$F$
$T$	$F$	$T$	$F$
$F$	$T$	$F$	$F$
$F$	$F$	$T$	$T$

Expressions that have output  $mystery_1$  are

Expressions that have output  $mystery_2$  are

**Definition** An expression built of variables and logical operators is in **disjunctive normal form** (DNF) means that it is an OR of ANDs of variables and their negations.

**Definition** An expression built of variables and logical operators is in **conjunctive normal form** (CNF) means that it is an AND of ORs of variables and their negations.

*Extra example:* An expression that has output ? is:

Input			Output
$p$	$q$	$r$	$?$
$T$	$T$	$T$	$T$
$T$	$T$	$F$	$T$
$T$	$F$	$T$	$F$
$T$	$F$	$F$	$T$
$F$	$T$	$T$	$F$
$F$	$T$	$F$	$F$
$F$	$F$	$T$	$T$
$F$	$F$	$F$	$F$

## Review: Week 3 Monday

1. (a) Consider the logic circuit



For which of the following settings(s) of input values is the output  $y_1 = 0$ ? (Select all and only those that apply.)

- i.  $x_1 = 0, x_2 = 0, x_3 = 0$ , and  $x_4 = 0$
- ii.  $x_1 = 1, x_2 = 1, x_3 = 1$ , and  $x_4 = 1$
- iii.  $x_1 = 1, x_2 = 0, x_3 = 0$ , and  $x_4 = 1$
- iv.  $x_1 = 0, x_2 = 0, x_3 = 1$ , and  $x_4 = 1$

- (b) Consider the logic circuits



For which of the following settings(s) of input values do the outputs of these circuits have the same value, i.e.  $y_1 = z_1$ ? (Select all and only those that apply.)

- i.  $x_1 = 1, x_2 = 1$
- ii.  $x_1 = 1, x_2 = 0$
- iii.  $x_1 = 0, x_2 = 1$
- iv.  $x_1 = 0, x_2 = 0$

2. For each of the following compound propositions, determine if it is in DNF, CNF, both, or neither.

- (a)  $(x \vee y \vee z) \wedge (x \wedge \neg y \wedge z)$
- (b)  $\neg(x \wedge y \wedge z) \wedge \neg(\neg x \wedge y \wedge \neg z)$

# Wednesday October 13

**Proposition:** Declarative sentence that is true or false (not both).

**Propositional variable:** Variable that represents a proposition.

**Compound proposition:** New proposition formed from existing propositions (potentially) using logical operators. *Note:* A propositional variable is one example of a compound proposition.

**Truth table:** Table with one row for each of the possible combinations of truth values of the input and an additional column that shows the truth value of the result of the operation corresponding to a particular row.

**Logical equivalence :** Two compound propositions are **logically equivalent** means that they have the same truth values for all settings of truth values to their propositional variables.

**Tautology:** A compound proposition that evaluates to true for all settings of truth values to its propositional variables; it is abbreviated  $T$ .

**Contradiction:** A compound proposition that evaluates to false for all settings of truth values to its propositional variables; it is abbreviated  $F$ .

**Contingency:** A compound proposition that is neither a tautology nor a contradiction.

Label each of the following as a tautology, contradiction, or contingency.

$$p \wedge p$$

$$p \oplus p$$

$$p \vee p$$

$$p \vee \neg p$$

$$p \wedge \neg p$$

*Extra Example:* Which of the compound propositions in the table below are logically equivalent?

Input		Output				
$p$	$q$	$\neg(p \wedge \neg q)$	$\neg(\neg p \vee \neg q)$	$(\neg p \vee q)$	$(\neg q \vee \neg p)$	$(p \wedge q)$
$T$	$T$					
$T$	$F$					
$F$	$T$					
$F$	$F$					

Input		Output				
$p$	$q$	Conjunction $p \wedge q$	Exclusive or $p \oplus q$	Disjunction $p \vee q$	Conditional $p \rightarrow q$	Biconditional $p \leftrightarrow q$
$T$	$T$	$T$	$F$	$T$	$T$	$T$
$T$	$F$	$F$	$T$	$T$	$F$	$F$
$F$	$T$	$F$	$T$	$T$	$T$	$F$
$F$	$F$	$F$	$F$	$F$	$T$	$T$
		" $p$ and $q$ "	" $p$ xor $q$ "	" $p$ or $q$ "	"if $p$ then $q$ "	" $p$ if and only if $q$ "

The only way to make the conditional statement  $p \rightarrow q$  false is to \_\_\_\_\_

The **hypothesis** of  $p \rightarrow q$  is \_\_\_\_\_ The **antecedent** of  $p \rightarrow q$  is \_\_\_\_\_

The **conclusion** of  $p \rightarrow q$  is \_\_\_\_\_ The **consequent** of  $p \rightarrow q$  is \_\_\_\_\_

The **converse** of  $p \rightarrow q$  is \_\_\_\_\_

The **inverse** of  $p \rightarrow q$  is \_\_\_\_\_

The **contrapositive** of  $p \rightarrow q$  is \_\_\_\_\_

We can use a recursive definition to describe all compound propositions that use propositional variables from a specified collection. Here's the definition for all compound propositions whose propositional variables are in  $\{p, q\}$ .

Basis Step:  $p$  and  $q$  are each a compound proposition  
Recursive Step: If  $x$  is a compound proposition then so is  $(\neg x)$  and if  $x$  and  $y$  are both compound propositions then so is each of  $(x \wedge y)$ ,  $(x \oplus y)$ ,  $(x \vee y)$ ,  $(x \rightarrow y)$ ,  $(x \leftrightarrow y)$

Order of operations (Precedence) for logical operators:

Negation, then conjunction / disjunction, then conditional / biconditionals.

Example:  $\neg p \vee \neg q$  means  $(\neg p) \vee (\neg q)$ .

## (Some) logical equivalences

*Can replace  $p$  and  $q$  with any compound proposition*

$$\neg(\neg p) \equiv p$$

**Double negation**

$$p \vee q \equiv q \vee p$$

$$p \wedge q \equiv q \wedge p$$

**Commutativity** Ordering of terms

$$(p \vee q) \vee r \equiv p \vee (q \vee r)$$

$$(p \wedge q) \wedge r \equiv p \wedge (q \wedge r)$$

**Associativity** Grouping of terms

$$p \wedge F \equiv F$$

$$p \vee T \equiv T$$

$$p \wedge T \equiv p$$

$$p \vee F \equiv p$$

**Domination** aka short circuit evaluation

$$\neg(p \wedge q) \equiv \neg p \vee \neg q$$

$$\neg(p \vee q) \equiv \neg p \wedge \neg q$$

**DeMorgan's Laws**

$$p \rightarrow q \equiv \neg p \vee q$$

$$p \rightarrow q \equiv \neg q \rightarrow \neg p$$

**Contrapositive**

$$\neg(p \rightarrow q) \equiv p \wedge \neg q$$

$$\neg(p \leftrightarrow q) \equiv p \oplus q$$

$$p \leftrightarrow q \equiv q \leftrightarrow p$$

*Extra examples:*

$p \leftrightarrow q$  is not logically equivalent to  $p \wedge q$  because \_\_\_\_\_

$p \rightarrow q$  is not logically equivalent to  $q \rightarrow p$  because \_\_\_\_\_

## Review: Week 3 Wednesday

1. For each of the following propositions, indicate exactly one of:

- There is no assignment of truth values to its variables that makes it true,
- There is exactly one assignment of truth values to its variables that makes it true, or
- There are exactly two assignments of truth values to its variables that make it true, or
- There are exactly three assignments of truth values to its variables that make it true, or
- *All* assignments of truth values to its variables make it true.

(a)  $x \wedge y \wedge (x \vee y)$

(b)  $\neg x \wedge y \wedge (x \vee y)$

(c)  $x \wedge \neg y \wedge (x \wedge y)$

(d)  $\neg x \wedge (y \vee \neg y)$

(e)  $x \wedge (y \vee \neg x)$

For each of the following propositions, indicate exactly one of:

- 2.
- There is no assignment of truth values to its variables that makes it true,
  - There is exactly one assignment of truth values to its variables that makes it true, or
  - There are exactly two assignments of truth values to its variables that make it true, or
  - There are exactly three assignments of truth values to its variables that make it true, or
  - *All* assignments of truth values to its variables make it true.

(a)  $(p \leftrightarrow q) \oplus (p \wedge q)$

(b)  $(p \rightarrow q) \vee (q \rightarrow p)$

(c)  $(p \rightarrow q) \wedge (q \rightarrow p)$

(d)  $\neg(p \rightarrow q)$

# Friday October 15

## Common ways to express logical operators in English:

**Negation**  $\neg p$  can be said in English as

- Not  $p$ .
- It's not the case that  $p$ .
- $p$  is false.

**Conjunction**  $p \wedge q$  can be said in English as

- $p$  and  $q$ .
- Both  $p$  and  $q$  are true.
- $p$  but  $q$ .

**Exclusive or**  $p \oplus q$  can be said in English as

- $p$  or  $q$ , but not both.
- Exactly one of  $p$  and  $q$  is true.

**Disjunction**  $p \vee q$  can be said in English as

- $p$  or  $q$ , or both.
- $p$  or  $q$  (inclusive).
- At least one of  $p$  and  $q$  is true.

**Conditional**  $p \rightarrow q$  can be said in English as

- if  $p$ , then  $q$ .
- $p$  is sufficient for  $q$ .
- $q$  when  $p$ .
- $q$  whenever  $p$ .
- $p$  implies  $q$ .
- $q$  follows from  $p$ .
- $p$  is sufficient for  $q$ .
- $q$  is necessary for  $p$ .
- $p$  only if  $q$ .

**Biconditional**

- $p$  if and only if  $q$ .
- $p$  iff  $q$ .
- If  $p$  then  $q$ , and conversely.
- $p$  is necessary and sufficient for  $q$ .





### Consistency:

1. Translate to symbolic compound propositions

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## Review: Week 3 Friday

1. Express each of the following sentences as compound propositions, using the given propositions.
  - (a) “If you try to run Zoom while your computer is running many applications, the video is likely to be choppy and laggy.”  $t$  is “you run Zoom while your computer is running many applications”,  $c$  is “the video is likely to be choppy”,  $g$  is “the video is likely to be laggy”
    - i.  $t \rightarrow (c \wedge g)$
    - ii.  $(c \wedge g) \rightarrow t$
    - iii.  $(c \wedge g) \leftrightarrow t$
    - iv.  $t \oplus (c \wedge g)$
  - (b) “To connect wirelessly on campus without logging in you need to use the UCSD-Guest network.”  $c$  is “connect wirelessly on campus”,  $g$  is “logging in”, and  $u$  is “use UCSD-Guest network”.
    - i.  $c \wedge \neg g \wedge u$
    - ii.  $(c \wedge \neg g) \vee u$
    - iii.  $(c \wedge \neg g) \oplus u$
    - iv.  $(c \wedge \neg g) \rightarrow u$
    - v.  $u \rightarrow (c \wedge \neg g)$
    - vi.  $u \leftrightarrow (c \wedge \neg g)$

For each of the following system specifications, identify the compound propositions that give their translations to logic and then determine if the translated collection of compound propositions is consistent.

2. (a) Specification: If the computer is out of memory, then network connectivity is unreliable. No disk errors can occur when the computer is out of memory. Disk errors only occur when network connectivity is unreliable.  
Translation:  $M$  = “the computer is out of memory”;  $N$  = “network connectivity is unreliable”;  $D$  = “disk errors can occur”.

i.

$$\neg M \rightarrow N$$

$$\neg D \rightarrow M$$

$$D \rightarrow N$$

ii.

$$M \rightarrow \neg N$$

$$\neg D \wedge M$$

$$N \rightarrow D$$

iii.

$$M \rightarrow N$$

$$M \rightarrow \neg D$$

$$\neg N \rightarrow \neg D$$

(b) Specification: Whether you think you can, or you think you can't - you're right. <sup>1</sup>

Translation:  $T$  = "you think you can";  $C$  = "you can".

i.

$$\begin{aligned}T &\rightarrow C \\ \neg T &\rightarrow \neg C\end{aligned}$$

ii.

$$\begin{aligned}T &\wedge C \\ \neg T &\wedge \neg C\end{aligned}$$

iii.

$$\begin{aligned}T &\rightarrow \neg T \\ C &\rightarrow \neg C\end{aligned}$$

(c) Specification: A secure password must be private and complicated. If a password is complicated then it will be hard to remember. People write down hard-to-remember passwords. If a password is written down, it's not private. The password is secure.

Translation:  $S$  = "the password is secure";  $P$  = "the password is private";  $C$  = "the password is complicated";  $H$  = "the password is hard to remember";  $W$  = "the password is written down".

i.

$$\begin{aligned}\neg(P \wedge C) &\rightarrow \neg S \\ C &\rightarrow H \\ W &\wedge H \\ W &\rightarrow \neg P \\ S\end{aligned}$$

ii.

$$\begin{aligned}(P \wedge C) &\rightarrow S \\ C &\rightarrow H \\ W &\rightarrow H \\ W &\rightarrow P \\ S\end{aligned}$$

iii.

$$\begin{aligned}S &\rightarrow (P \wedge C) \\ C &\rightarrow H \\ H &\rightarrow W \\ W &\rightarrow \neg P \\ S\end{aligned}$$

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<sup>1</sup>Henry Ford