

Relations and Functions

- A relation R from a set A to a set B is a subset of $A \times B$ obtained by describing a relationship between the first element a and the second element b of the ordered pairs in $A \times B$. That is, $R \subseteq \{(a, b) \in A \times B, a \in A, b \in B\}$
- The domain of a relation R from set A to set B is the set of all first elements of the ordered pairs in R .
- The range of a relation R from set A to set B is the set of all second elements of the ordered pairs in R . The whole set B is called the co-domain of R . $\text{Range} \subseteq \text{Co-domain}$
- A relation R in a set A is called an empty relation, if no element of A is related to any element of A . In this case, $R = \emptyset \subset A \times A$

Example: Consider a relation R in set $A = \{3, 4, 5\}$ given by $R = \{(a, b): a^b < 25, \text{ where } a, b \in A\}$. It can be observed that no pair (a, b) satisfies this condition. Therefore, R is an empty relation.

- A relation R in a set A is called a universal relation, if each element of A is related to every element of A . In this case, $R = A \times A$

Example: Consider a relation R in the set $A = \{1, 3, 5, 7, 9\}$ given by $R = \{(a, b): a + b \text{ is an even number}\}$.

Here, we may observe that all pairs (a, b) satisfy the condition R . Therefore, R is a universal relation.

- Both the empty and the universal relation are called trivial relations.
- A relation R in a set A is called reflexive, if $(a, a) \in R$ for every $a \in R$.

Example: Consider a relation R in the set A , where $A = \{2, 3, 4\}$, given by $R = \{(a, b): a^b = 4, 27 \text{ or } 256\}$. Here, we may observe that $R = \{(2, 2), (3, 3), \text{ and } (4, 4)\}$. Since each element of R is related to itself (2 is related 2, 3 is related to 3, and 4 is related to 4), R is a reflexive relation.

- A relation R in a set A is called symmetric, if $(a_1, a_2) \in R \Rightarrow (a_2, a_1) \in R, \forall (a_1, a_2) \in R$

Example: Consider a relation R in the set A , where A is the set of natural numbers, given by $R = \{(a, b): 2 \leq ab < 20\}$. Here, it can be observed that $(b, a) \in R$ since $2 \leq ba < 20$ [since for natural numbers a and b , $ab = ba$]

Therefore, the relation R is symmetric.

- A relation R in a set A is called transitive, if $(a_1, a_2) \in R$ and $(a_2, a_3) \in R \Rightarrow (a_1, a_3) \in R$ for all $a_1, a_2, a_3 \in A$

Example: Let us consider a relation R in the set of all subsets with respect to a universal set U given by $R = \{(A, B): A \text{ is a subset of } B\}$

Now, if A, B , and C are three sets in R , such that $A \subset B$ and $B \subset C$, then we also have $A \subset C$. Therefore, the relation R is a symmetric relation.

- A relation R in a set A is said to be an equivalence relation, if R is altogether reflexive, symmetric, and transitive.

Example: Let (a, b) and (c, d) be two ordered pairs of numbers such that the relation between them is given by $a + d = b + c$. This relation will be an equivalence relation. Let us prove this.

(a, b) is related to (a, b) since $a + b = b + a$. Therefore, R is reflexive.

If (a, b) is related to (c, d) , then $a + d = b + c \Rightarrow c + b = d + a$. This shows that (c, d) is related to (a, b) . Hence, R is symmetric.

Let (a, b) is related to (c, d) ; and (c, d) is related to (e, f) , then $a + d = b + c$ and $c + f = d + e$. Now, $(a + d) + (c + f) = (b + c) + (d + e) \Rightarrow a + f = b + e$. This shows that (a, b) is related to (e, f) . Hence, R is transitive.

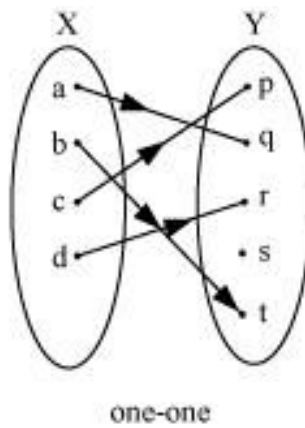
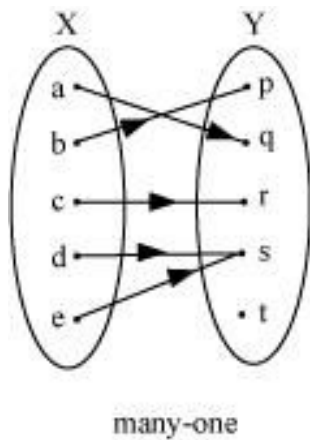
Since R is reflexive, symmetric, and transitive, R is an equivalence relation.

- Given an arbitrary equivalence relation R in an arbitrary set X , R divides X into mutually disjoint subsets A_i called partitions or subdivisions of X satisfying:
 - All elements of A_i are related to each other, for all i .
 - No element of A_i is related to any element of A_j , $i \neq j$
 - $\cup A_j = X$ and $A_i \cap A_j = \emptyset$, $i \neq j$

The subsets A_i are called equivalence classes.

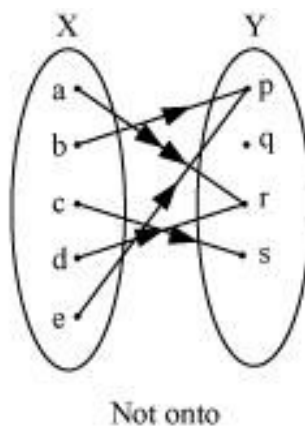
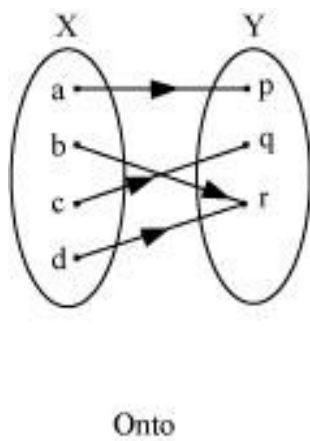
- A function f from set X to Y is a specific type of relation in which every element x of X has one and only one image y in set Y . We write the function f as $f: X \rightarrow Y$, where $f(x) = y$
- A function $f: X \rightarrow Y$ is said to be one-one or injective, if the image of distinct elements of X under f are distinct. In other words, if $x_1, x_2 \in X$ and $f(x_1) = f(x_2)$, then $x_1 = x_2$. If the function f is not one-one, then f is called a many-one function.

The one-one and many-one functions can be illustrated by the following figures:

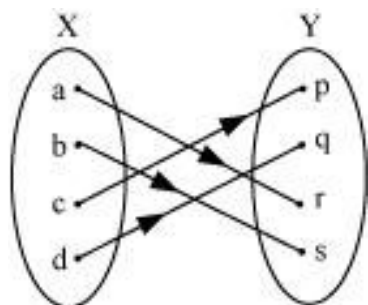


- A function $f: X \rightarrow Y$ can be defined as an onto (surjective) function, if $\forall y \in Y$, there exists $x \in X$ such that $f(x) = y$.

The onto and many-one (not onto) functions can be illustrated by the following figures:



- A function $f: X \rightarrow Y$ is said to be bijective, if it is both one-one and onto. A bijective function can be illustrated by the following figure:



Example: Show that the function $f: \mathbf{R} \rightarrow \mathbf{N}$ given by $f(x) = x^3 - 1$ is bijective.

Solution:

Let $x_1, x_2 \in \mathbf{R}$

For $f(x_1) = f(x_2)$, we have

$$x_1^3 - 1 = x_2^3 - 1$$

$$\Rightarrow x_1^3 = x_2^3$$

$$\Rightarrow x_1 = x_2$$

Therefore, f is one-one.

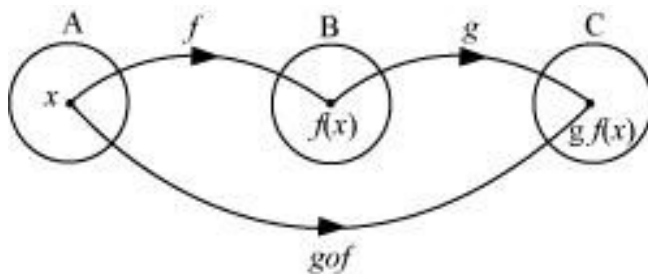
Also, for any y in $\mathbf{N}$, there exists $\sqrt[3]{y+1}$ in $\mathbf{R}$ such that

$$f\left(\sqrt[3]{y+1}\right) = \left(\sqrt[3]{y+1}\right)^3 - 1 = y.$$

Therefore, f is onto.

Since f is both one-one and onto, f is bijective.

- **Composite function:** Let $f: A \rightarrow B$ and $g: B \rightarrow C$ be two functions. The composition of f and g , i.e. $g \circ f$, is defined as a function from A to C given by $g \circ f(x) = g(f(x))$, $\forall x \in A$



Example: Find $g \circ f$ and $f \circ g$, if $f: \mathbf{R} \rightarrow \mathbf{R}$ and $g: \mathbf{R} \rightarrow \mathbf{R}$ are given by $f(x) = x^2 - 1$ and $g(x) = x^3 + 1$.

Solution:

$$g \circ f(x) = g(f(x))$$

$$= g(x^2 - 1)$$

$$= (x^2 - 1)^3 + 1$$

$$= x^6 - 1 - 3x^4 + 3x^2 + 1$$

$$= x^2(x^4 - 3x^2 + 3)$$

$$f \circ g(x) = f(g(x))$$

$$= f(x^3 + 1)$$

$$= (x^3 + 1)^2 - 1$$

$$= x^6 + 2x^3 + 1 - 1$$

$$= x^3(x^3 + 2)$$

- A function $f: X \rightarrow Y$ is said to be invertible, if there exists a function $g: Y \rightarrow X$ such that $g \circ f = I_X$ and $f \circ g = I_Y$. In this case, g is called inverse of f and is written as $g = f^{-1}$
- A function f is invertible, if and only if f is bijective.

Example: Show that $f: \mathbf{R}^+ \cup \{0\} \rightarrow \mathbf{N}$ defined as $f(x) = x^3 + 1$ is an invertible function. Also, find f^{-1} .

Solution:

Let $x_1, x_2 \in \mathbf{R}^+ \cup \{0\}$ and $f(x_1) = f(x_2)$

$$\therefore x_1^3 + 1 = x_2^3 + 1$$

$$\Rightarrow x_1^3 = x_2^3$$

$$\Rightarrow x_1 = x_2$$

Therefore, f is one-one.

Also, for any y in $\mathbf{N}$, there exists $\sqrt[3]{y-1} \in \mathbf{R}^+ \cup \{0\}$ such that $f(\sqrt[3]{y-1}) = y$.
 $\therefore f$ is onto.

Hence, f is bijective.

This shows that, f is invertible.

Let us consider a function $g: \mathbf{N} \rightarrow \mathbf{R}^+ \cup \{0\}$ such that $g(y) = \sqrt[3]{y-1}$

Now,

$$g \circ f(x) = g(f(x)) = g(x^3 + 1) = \sqrt[3]{(x^3 + 1) - 1} = x$$

$$f \circ g(y) = f(g(y)) = f(\sqrt[3]{y-1}) = (\sqrt[3]{y-1})^3 + 1 = y$$

Therefore, we have

$$g \circ f(x) = I_{\mathbb{R}^+ \cup \{0\}} \text{ and } f \circ g(y) = I_{\mathbb{N}}$$

$$\therefore f^{-1}(y) = g(y) = 3\sqrt{y-1}$$

- **Relation:** A relation R from a set A to a set B is a subset of the Cartesian product $A \times B$, obtained by describing a relationship between the first element x and the second element y of the ordered pairs (x, y) in $A \times B$.
- The image of an element x under a relation R is y , where $(x, y) \in R$
- **Domain:** The set of all the first elements of the ordered pairs in a relation R from a set A to a set B is called the domain of the relation R .
- **Range and Co-domain:** The set of all the second elements in a relation R from a set A to a set B is called the range of the relation R . The whole set B is called the co-domain of the relation R . $\text{Range} \subseteq \text{Co-domain}$

Example: In the relation X from $\mathbf{W}$ to $\mathbf{R}$, given by $X = \{(x, y): y = 2x + 1; x \in \mathbf{W}, y \in \mathbf{R}\}$, we obtain $X = \{(0, 1), (1, 3), (2, 5), (3, 7) \dots\}$. In this relation X , domain is the set of all whole numbers, i.e., domain = $\{0, 1, 2, 3 \dots\}$; range is the set of all positive odd integers, i.e., range = $\{1, 3, 5, 7 \dots\}$; and the co-domain is the set of all real numbers. In this relation, 1, 3, 5 and 7 are called the images of 0, 1, 2 and 3 respectively.

- The total number of relations that can be defined from a set A to a set B is the number of possible subsets of $A \times B$.

If $n(A) = p$ and $n(B) = q$, then $n(A \times B) = pq$ and the total number of relations is 2^{pq} .