Functions

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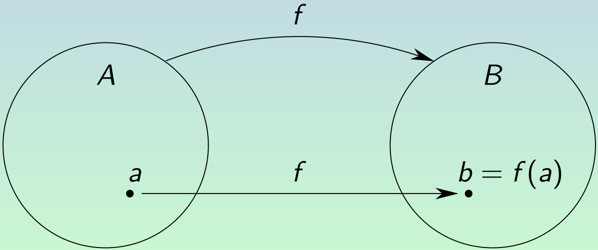
Definition: Function

Definition

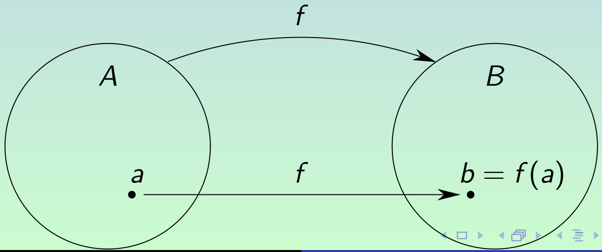
Let A and B be non empty sets. A **function** f from A to B is an assignment of *exactly one* element of B to each element of A. We write $f(a) = b$ if b is the *unique* element of B assigned by the function f to the element a of A. If f is a function from A to B, we write $f : A \rightarrow B$.



Definitions: Domain, Codomain, Image, Preimage and Range

Definition

If f is a function from A to B, we say that A is the **domain** of f and B is the **codomain** of f.
If $f(a) = b$, we say that b is the **image** of a and a is the **preimage** of b.
The **range** of f is the set of all images of elements of A.
Also, If f is a function from A to B, we say that f **maps** A to B.



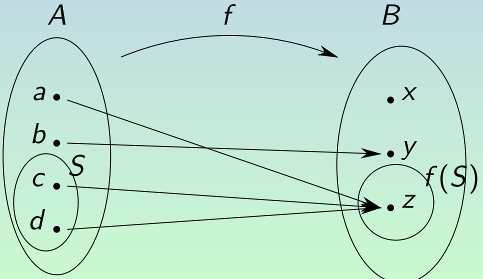
Definition: Image of a Subset

Definition

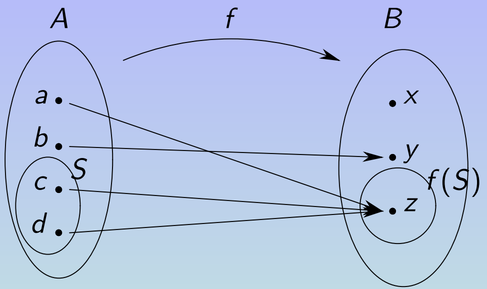
Let f be a function from the set A to the set B and let S be a subset of A. The **image** of S under the function f is the subset of B that consists of the images of the elements of S. We denote the image of S by $f(S)$, so

$$f(S) = \{t \in B \mid \exists s \in S \text{ with } (t = f(s))\}.$$

We also use the shorthand $f(S) = \{f(s) \mid s \in S\}$ to denote this set.



Example



- The domain of f is $A = \{a, b, c, d\}$.
- The codomain of f is $B = \{x, y, z\}$.
- $f(a) = z$.
- The image of a is z.
- The preimages of z are a, c and d.
- The range of f is $f(A) = \{y, z\} \subseteq B$.
- The image of the subset $S = \{c, d\} \subseteq A$ is $f(S) = \{z\} \subseteq B$.

Definition: One-To-One (Injective) Function

Definition

A function f from A to B is said to be **one-to-one**, or **injective**, if and only if $f(a) = f(b)$ implies that $a = b$ for all a and b in the domain A. A function is said to be an **injection** if it is injective.

By taking the contrapositive of the implication in this definition, a function is injective if and only if $a \neq b$ implies $f(a) \neq f(b)$.

Another way to understand it, a function is injective means that if an element of the codomain has a preimage, then it is a unique preimage.

Definition: Onto (Surjective) Function

Definition

A function f from A to B is called **onto**, or **surjective**, if and only if for every element $b \in B$ there is an element $a \in A$ with $f(a) = b$. A function f is called a **surjection** if it is surjective.

Another way to understand it, a function is surjective means that each element of the codomain has at least one preimage.

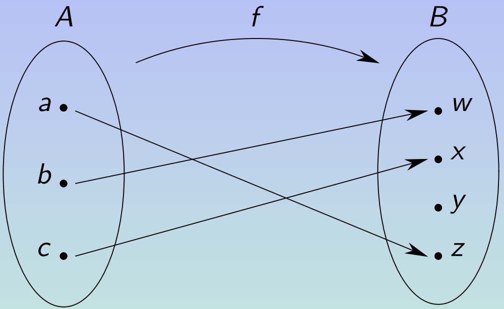
Definition: One-To-One Correspondence (Bijective) Function

Definition

The function f is a **one-to-one correspondence** if it is both one-to-one and onto.

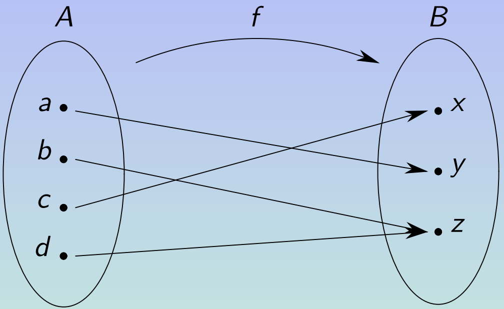
The function f is is said to be **bijective** if it is both injective and surjective. A function is said to be a **bijection** if it is bijective.

Example 1



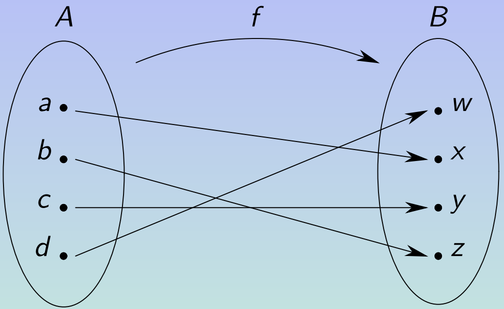
Is f injective?
Is f surjective?
Is f bijective?

Example 2



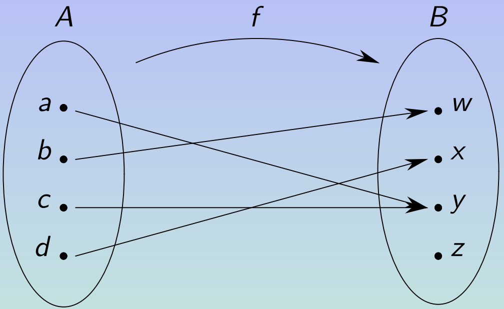
Is f injective?
Is f surjective?
Is f bijective?

Example 3



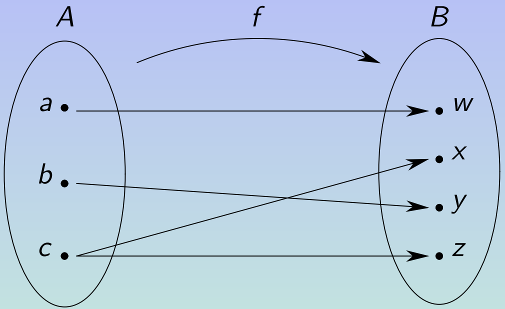
Is f injective?
Is f surjective?
Is f bijective?

Example 4



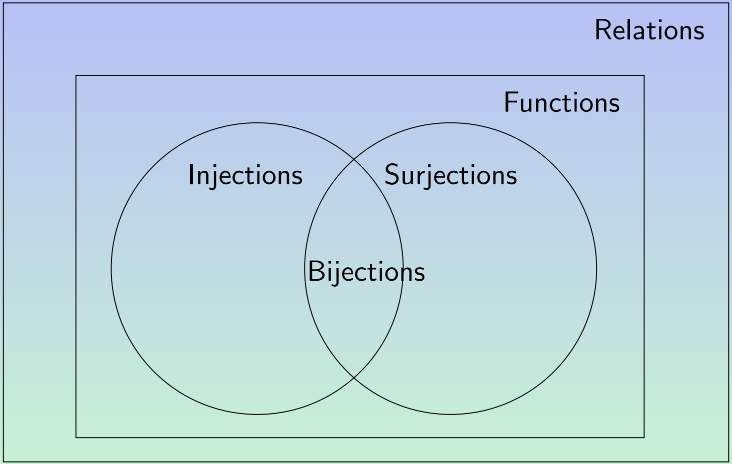
Is f injective?
Is f surjective?
Is f bijective?

Example 5



Is f injective?
Is f surjective?
Is f bijective?

Venn Diagram of Function Classification



Addition and Product of Functions

Definition

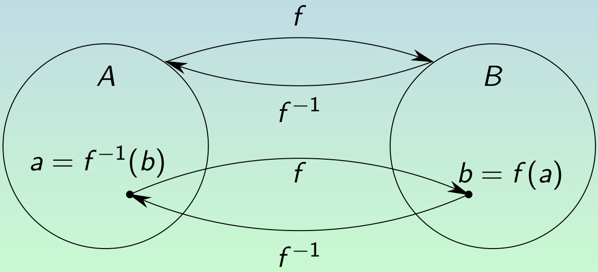
Let f_1 and f_2 be functions from A to $\mathbb{R}$. Then $f_1 + f_2$ and $f_1 f_2$ are also functions from A to $\mathbb{R}$ defined by

$$(f_1 + f_2)(x) = f_1(x) + f_2(x),$$
$$(f_1 f_2)(x) = f_1(x) f_2(x).$$

Definition: Inverse Function

Definition

Let f be a bijection from the set A to the set B. The **inverse function** of f is the function that assigns to an element b belonging to B the unique element a in A such that $f(a) = b$. The inverse function of f is denoted by f^{-1}. Hence, $f^{-1}(b) = a$ when $f(a) = b$. The inverse function is also a bijection.

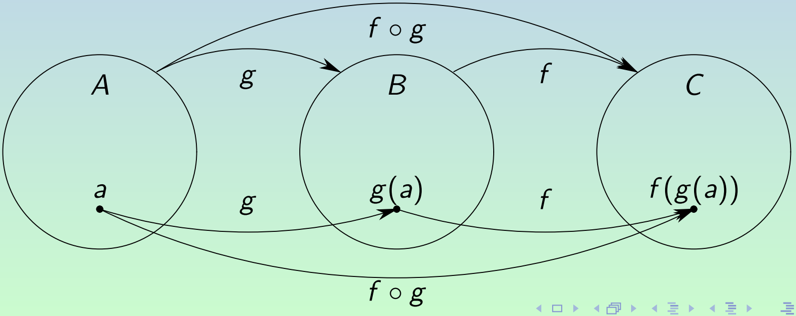


Definition: Composition of Functions

Definition

Let g be a function from the set A to the set B, and let f be a function from the set B to the set C. The **composition of the functions** f **and** g, denoted by $f \circ g$, is defined by

$$(f \circ g)(a) = f(g(a)).$$



Definition

The **factorial function** $f : \mathbb{N} \to \mathbb{Z}^+$, denoted by $f(n) = n!$ is the product of the first n positive integers, so

$$n! = 1 \times 2 \times 3 \times \cdots \times (n-1) \times n.$$

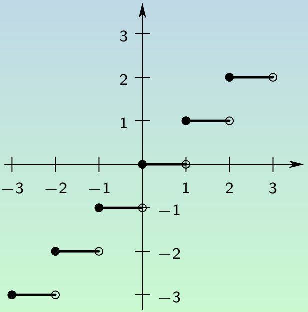
and $f(0) = 0! = 1$.

For example, $5! = 1 \times 2 \times 3 \times 4 \times 5 = 120$.
This function increases very fast.
$10! = 3628800$,
$20! = 2432902008176640000$,
$30! = 265252859812191058636308480000000$,
$40! = 815915283247897734345611269596115894272000000000$.
For n sufficiently large, $n!$ can be approximated by the Stirling's formula: $n! \approx \sqrt{2\pi n}\,(n/e)^n$.

Definition: Floor Function

Definition

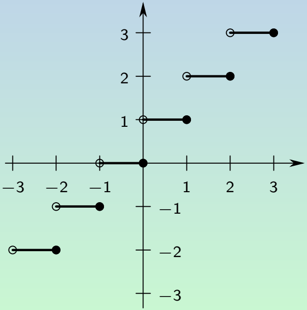
The **floor function** assigns to the real number x the largest integer that is less than or equal to x. The value of the floor function at x is denoted by $\lfloor x \rfloor$. The floor function is often also called the greatest integer function and also denoted by $[x]$.



Definition: Ceiling Function

Definition

The **ceiling function** assigns to the real number x the smallest integer that is greater than or equal to x. The value of the ceiling function at x is denoted by $\lceil x \rceil$.



Useful Properties of the Floor and Ceiling Functions

Let x be a real number and n be an integer.

- $\lfloor x \rfloor = n$ if and only if $n \leq x < n + 1$.
- $\lceil x \rceil = n$ if and only if $n - 1 < x \leq n$.
- $\lfloor x \rfloor = n$ if and only if $x - 1 < n \leq x$.
- $\lceil x \rceil = n$ if and only if $x \leq n < x + 1$.
- $x - 1 < \lfloor x \rfloor \leq x < \lceil x \rceil < x + 1$
- $\lfloor -x \rfloor = -\lceil x \rceil$
- $\lceil -x \rceil = -\lfloor x \rfloor$
- $\lfloor x + n \rfloor = \lfloor x \rfloor + n$
- $\lceil x + n \rceil = \lceil x \rceil + n$