

Abstract

In this pieces of notes, we will go through the concepts related to functions and the meaning of graphs of the functions.

Contents

1	Function and its graph	5
1.1	What is a Function?	5
1.1.1	Function as an input-output pair	6
1.1.2	Defining a function with variables	8
1.1.3	Domain, Codomain and Range	9
1.2	Graph of a function	11
1.2.1	Blobs-and-arrows diagram for discrete functions	11
1.2.2	The pairing table and xy-coordination	11
1.3	Fundamental properties of a graph	11
1.3.1	points lying on the graph	11
1.3.2	x-intercept	11
1.3.3	y-intercept	11
1.3.4	general intersection	11
1.4	Solving equations using graphs of functions	11
1.5	Transformation of functions	11
1.5.1	Translation	11
1.5.2	Dilation	11
1.6	Challenging questions	11
2	Linear functions	12
2.1	Fundamental concepts of points	12
2.1.1	Distance between two points	12
2.1.2	Mid-point and Division points	12
2.2	Different forms of a linear function	12
2.2.1	Slope of a line	12
2.2.2	Two-point form	12
2.2.3	Point-slope form	12
2.2.4	Slope-intercept form	12
2.2.5	General form	12

2.2.6	Special: Intercept-form	12
2.3	Parallel lines and Perpendicular lines	12
2.3.1	Point of intersection	12
2.3.2	Parallel lines	12
2.3.3	Perpendicular lines	12
2.3.4	Number of intersections	12
2.4	Angle of elevation and depression	12
2.5	Additional content: Point-line distance	12
2.6	Linear inequalities	13
2.6.1	One variable inequality	13
2.6.2	Two variable inequality	13
2.6.3	Linear programming	13
2.7	Challenging questions	13
3	Quadratic functions	14
3.1	Solving Quadratic Equations	14
3.1.1	The square-root method	14
3.1.2	General form and Completing the square method	14
3.1.3	The quadratic formula	14
3.2	Solvability of Quadratic Equations	14
3.2.1	Discriminant: the factor affecting solvability	14
3.2.2	Application of solvability	14
3.3	Relation between coefficients and roots	14
3.3.1	What does it mean by a root?	14
3.3.2	The Vieta formula	14
3.3.3	Forming quadratic equations with given roots	14
3.4	Vertex form of a quadratic function	14
3.4.1	Obtaining vertex form using Transformation	14
3.4.2	Relation between vertex form and general form	14
3.4.3	Opening direction	14
3.4.4	The axis of symmetry	14
3.4.5	The extremum of quadratic functions	14
3.5	Quadratic inequalities	14
3.5.1	Boolean algebra	14
3.5.2	Solving quadratic inequalities	14

3.6	Challenging questions	14
4	Polynomial functions	15
4.1	Arithmetic rules for polynomials	15
4.1.1	Addition, Subtraction and Multiplication	15
4.1.2	Division	15
4.2	Divisibility of polynomials	15
4.2.1	Division algorithm	15
4.2.2	Remainder Theorem	15
4.2.3	Factor Theorem and General Vieta formula	15
4.3	G.C.D. and L.C.M.	15
4.3.1	Greatest common divisor	15
4.3.2	Least common multiple	15
4.4	Positional notation	15
4.4.1	Binary, Octal, Decimal and Hexadecimal	15
4.4.2	Conversion between different bases	15
4.5	Challenging questions	15
5	Exponential and Logarithmic functions	16
5.1	Exponential functions	16
5.1.1	Law of Exponential algebra	16
5.1.2	Seeing surds as fractional exponents	16
5.1.3	Solving equations using exponentiation method	16
5.2	Logarithmic functions	16
5.2.1	What is Logarithm?	16
5.2.2	Law of Logarithmic algebra	16
5.2.3	Solving equations using Logarithmic method	16
5.3	Challenging questions	16
6	Sequence as a function of natural numbers	17
6.1	What is a sequence?	17
6.2	Arithmetic sequence	17
6.2.1	General form	17
6.2.2	Summation of arithmetic sequence	17
6.3	Geometric sequence	17

6.3.1	General form	17
6.3.2	Summation on Geometric sequence	17
6.3.3	Infinite sum of Geometric sequence	17
6.4	Additional content: Arithmetic-Geometric sequence	17
6.5	Challenging questions	17

1 Function and its graph

‘Functions describes the world!’, one Professor in Mathematics of Massachusetts Institute of Technology (a.k.a. MIT) said that. His speech was greatly influential, as I have never heard such conclusive thinking about functions. In fact, in the past few years, whenever I was studying in schools, my thought about functions is always only about projecting elements from one set to another set, but what he said had a big impact to my knowledge about functions.

What function talks about, is a subjection of one elements to one another. It can be thought of as a pointing action started from element A to element B , which not so far away, if we could think of subjecting a lot of, a bunch of, or a list of, whatever, objects from one collection to another collection, and they can all be matched under this pointing action, then it is a so-called function.

For example, in an Indian factory, the production of food undergoes many different process. Those can all be called functions. Let say a raw material comes to the factory first, it then be put to a machine to chop into many small pieces. It is the chopping function inside the factory. Next, the chopped material will be put into a pool of yellowish-brownish liquid and be stirred by dirty hands. It is the Mixing function in the factory. After that, the liquid will be drained on the dirty floor and be stepped on by Indian workers so that they can be smell freshed. It is the flavouring function in the factory. Finally, it will be sold to stores, which is the selling function.

Another example is what our body does. We eat and drink, going down the digestive system, and we sit on a toilet. Although we stupid human knows nothing about how the digestive system works, we could still name the conversion from food to poops a digestion, which means the digestive function representing the process in our body.

So we know that function as an english word represents the naming of a process of conversion, it is the time to explore how Math functions works.

1.1 What is a Function?

A function is defined as follow:

Definition 1.1 (Function). *Given an input x and an output y , a **function** is a relation between x and y so that we can write $y = f(x)$ to represent the relationship.*

Essential Practice 1.1.0.1. *Write down functions for the following input-output variables:*

1. u as input and v as output;
2. b as input and a as output;

3. n as input and 1 as output (which we call it a constant function);
4. x^2 as input and y as output;
5. xy as input and z as output;
6. 2^x as input and k as output;
7. \sqrt{p} as input and q as output;

Remark. It is notable that we may write functions as $y = g(x)$, $y = h(x)$, $y = d(x)$, ... as we want. The ‘naming’ of a function is always definitive and up to user’s construction.

We can also apply functions after functions. To do so, we have to talk about the following:

Definition 1.2 (Composite functions). Let f and g be functions such that f takes x as input and y as output, and g takes y as input and z as output. Then we can say there is a function h that takes x as input and z as output. In other words, h is a **composite function** such that $z = h(x) = g(f(x))$.

Essential Practice 1.1.0.2. Let f and g be functions such that $b = f(a)$, $c = g(b)$. Write a function for a as input and c as output.

1.1.1 Function as an input-output pair

We may now consider how functions carry things to things using arrow notations. We may use a stroked arrow \mapsto to emphasis the carrying process. Let’s take a look at the following examples.

Example. Given a function that undergoes the process of adding one to the given element. We can say

$$\dots, 1 \mapsto 2, 2 \mapsto 3, 3 \mapsto 4, \dots$$

In other words, we may write

$$x \mapsto x + 1$$

to generalize the process of adding one to the given element, which is how we usually write to describe any functions.

The example shows that we can generalize the process using algebraic notation, in which it is usually in the form of

$$x \mapsto f(x)$$

with the function f . It is equivalent to say that

$$\dots, 1 \mapsto f(1), 2 \mapsto f(2), \dots$$

but what's important is how explicit the mapping process is done. More examples could be viewed to familiarize with it.

Example. *To describe a function undergoes the process ‘multiplying the element by two and add one to it’, we may examine that*

$$\dots, 0 \mapsto 1, 1 \mapsto 3, 2 \mapsto 5, \dots$$

so that it is equivalent to write

$$x \mapsto 2x + 1$$

as a generalization of the function. It is equivalent to write $f(x) := 2x + 1$ to emphasis that we shall call the function f as a naming for the given process, as long as we can write

$$x \mapsto f(x), f(x) := 2x + 1$$

Essential Practice 1.1.1.1. *Examine the following functions from 0 to 3, and generalize the function using algebraic notation. You may either choose writing $x \mapsto \square$ directly or $x \mapsto f(x), f(x) := \square$.*

1. *Multiply the element by 3 and then add 2 to it.*
2. *Divide the element by 10 and then Subtract 7 from it.*
3. *Multiply the element by a and then add b to it.*
4. *Squaring the element.*
5. *Multiply 3 to the square of the element, an then add 5 to it.*
6. *Add 1 to the element first, then multiply the square of the result by 6, and then add 1 to it.*
7. *Subtract 8 from the element first, then divide the square of the result by 2, and then add 4 to it.*
8. *Subtract h from the element first, then multiply the square of the result by a , and then add k to it.*

It is notable that a function can only gives one output for each input, which makes the next page a fruitful discussion.

1.1.2 Defining a function with variables

So far, we have learnt how writing a generalization of a function is, and have we used algebraic notation to shorten the examination, one suggest we can always write algebraic notation for a function definition. In addition, we also find that a function cannot have more than one output, as we see functions as a pointing process from one element to another element. So we have the following definition:

Definition 1.3 (Function). A **function** f of x defines the pointing process $x \mapsto f(x)$ is a one-to-one pointing process, which can have only one output.

It is important to note that $f(x)$ is a function of x if and only if one x produce one $f(x)$. The x is called a *dummy variable*, which is a variable that can be changed all the time. For example, writing $f(y)$ or $g(z)$ still makes sense to say a function, but not of x .

From now on, we can determine whether a given relation is a function or not.

Example. Given the relation $y = mx + c$. Since one x can produce only one y , y is a function of x ; on the other hand, we also see one y produces only one x , so x is also a function of y .

Example. Given the relation $y = x^2$. Since one x can produce only one y , y is a function of x ; however, one y may produces more than one x , say if $y = 4$ then x can be 2 or -2 , so x is not a function of y .

Essential Practice 1.1.2.1. Determine whether the following given relation between x and y is a function of one another or not. Provide counterexample if it is not a function.

1. $y = -x$;
2. $y = 4x + 3$;
3. $y = \frac{1}{x}$;
4. $y = \frac{x}{6}$;
5. $y^2 = x$;
6. $y^2 = x^2$;
7. $y^3 = 4x^2 - 3$.

1.1.3 Domain, Codomain and Range

For explicit definition of a function, we need the following concepts to help with: *domain*, *codomain* and *range*.

A **domain** is where the input comes from, which is usually half-customized and half-restricted. For example, $f(x) = \frac{1}{x}$ can have input of negative real numbers, positive real numbers, any complex numbers except 0. This means that 0 is naturally restricted by the operation of $\frac{1}{x}$, but other than 0, we can choose freely our input from all complex numbers. Thus, the largest domain of $f(x) = \frac{1}{x}$ is all complex numbers except 0. However, it is not saying that the domain of $f(x) = \frac{1}{x}$ must be all complex numbers except 0, we can still put restrictions on our own, what means by customize, like all real numbers except 0 or all positive real numbers except 0 as its domain, is still a possible choice. Hence, we shall usually talk about the *greatest possible domain of a function* if we need to find the natural restrictions, and the *domain of a function* if we are going to define our source of input.

Essential Practice 1.1.3.1. Find the greatest possible domain of the following functions if (i) the output is restricted to complex numbers and (ii) the output is restricted to be real numbers:

1. $f(x) := x$;
2. $f(x) := ax + b$;
3. $f(x) := \frac{a}{x}$;
4. $f(x) := x^2$;
5. $f(x) := a(x - h)^2 + k$;
6. $f(x) := \sqrt{x}$;
7. $f(x) := \sqrt[3]{x}$;
8. $f(x) := \frac{1}{\sqrt{x}}$;

A **codomain** is where the output can go to. It is more likely a limitation of the output of the function so that we know where our target is. Similarly, we shall usually talk about the *greatest possible codomain of the function* if we need to find the natural restrictions, and the *domain of the function* if we are going to define our target output.

Essential Practice 1.1.3.2. Find the greatest possible codomain of the following functions if the input is unrestricted:

1. $f(x) := x;$
2. $f(x) := ax + b;$
3. $f(x) := \frac{a}{x};$
4. $f(x) := x^2;$
5. $f(x) := a(x - h)^2 + k;$
6. $f(x) := \sqrt{x};$
7. $f(x) := \sqrt[3]{x};$
8. $f(x) := \frac{1}{\sqrt{x}};$

With domain and codomain, we can now define a function in a more explicit manner. Writing a function with where the inputs are in and where the outputs to go, we have a nice notation - an arrow \rightarrow to emphasis the direction from domain to codomain. In general, we will write

$$f : D \rightarrow R$$

to specify the function f is a function goes from domain D to codomain R . The formal way to define a function is like below:

$$f : \mathbb{R} \rightarrow \mathbb{R}, x \mapsto f(x)$$

which reads ‘a function f sending a real number x to a real number $f(x)$ ’.

Example. For a function sending a natural number n to a natural number 2^n , we may write its definition as

$$f : \mathbb{N} \rightarrow \mathbb{N}, n \mapsto 2^n$$

Example. For a function sending an integer n to a rational number 2^n , we may write its definition as

$$f : \mathbb{Z} \rightarrow \mathbb{Q}, n \mapsto 2^n$$

We shall see both example shows the same function process $f(n) := 2^n$ but different domain and codomain. Therefore, we acknowledge that although both functions are having the same process, they are indeed representing different things, which yields they are in fact different functions.

1.2 Graph of a function

1.2.1 Blobs-and-arrows diagram for discrete functions

1.2.2 The pairing table and xy-coordination

1.3 Fundamental properties of a graph

1.3.1 points lying on the graph

1.3.2 x-intercept

1.3.3 y-intercept

1.3.4 general intersection

1.4 Solving equations using graphs of functions

1.5 Transformation of functions

1.5.1 Translation

1.5.2 Dilation

1.6 Challenging questions

2 Linear functions

2.1 Fundamental concepts of points

2.1.1 Distance between two points

2.1.2 Mid-point and Division points

2.2 Different forms of a linear function

2.2.1 Slope of a line

2.2.2 Two-point form

2.2.3 Point-slope form

2.2.4 Slope-intercept form

2.2.5 General form

2.2.6 Special: Intercept-form

2.3 Parallel lines and Perpendicular lines

2.3.1 Point of intersection

2.3.2 Parallel lines

2.3.3 Perpendicular lines

2.3.4 Number of intersections

2.4 Angle of elevation and depression

2.5 Additional content: Point-line distance

By definition, the distance between two points on a \mathbb{R}^2 plane is

Definition 2.1 (Distance between two points). *Let $A(x_1, y_1)$ and $B(x_2, y_2)$ be two points on \mathbb{R}^2 -plane. The distance between A and B is computed by the formula*

$$\text{dist}(A, B) := \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2}$$

Now let $L : ax + by + c = 0$ be a straight line and $P(x_0, y_0)$ be a point on \mathbb{R}^2 -plane. Note that with the following axiom

Axiom. *The distance between a point P and a line L is defined by the shortest distance between P and a point on L*

$$\text{dist}(P, L) := \inf\{\text{dist}(P, Q) : Q \in L\}$$

we can choose the perpendicular displacement of P from L to define the distance. Using the line Γ perpendicular to L passing through P , we can find such Q by following computation:

$$\begin{cases} L : ax + by + c = 0 \\ \Gamma : bx - ay + (ay_0 - bx_0) = 0 \end{cases} \implies Q\left(\frac{b^2x_0 - aby_0 - ac}{a^2 + b^2}, \frac{a^2y_0 - abx_0 - bc}{a^2 + b^2}\right)$$

Therefore, the distance between P and Q is

$$\begin{aligned} \text{dist}(P, Q) &= \frac{1}{a^2 + b^2} \sqrt{[(a^2 + b^2)x_0 - (b^2x_0 - aby_0 - ac)]^2 + [(a^2 + b^2)y_0 - (a^2y_0 - abx_0 - bc)]^2} \\ &= \frac{1}{a^2 + b^2} \sqrt{(a^2x_0 + aby_0 + ac)^2 + (b^2y_0 + abx_0 + bc)^2} \\ &= \frac{\sqrt{a^2 + b^2} \sqrt{(ax_0 + by_0 + c)^2}}{a^2 + b^2} \\ &= \frac{\sqrt{(ax_0 + by_0 + c)^2}}{\sqrt{a^2 + b^2}} \\ &= \left| \frac{ax_0 + by_0 + c}{\sqrt{a^2 + b^2}} \right| \end{aligned}$$

2.6 Linear inequalities

2.6.1 One variable inequality

2.6.2 Two variable inequality

2.6.3 Linear programming

2.7 Challenging questions

3 Quadratic functions

3.1 Solving Quadratic Equations

3.1.1 The square-root method

3.1.2 General form and Completing the square method

3.1.3 The quadratic formula

3.2 Solvability of Quadratic Equations

3.2.1 Discriminant: the factor affecting solvability

3.2.2 Application of solvability

3.3 Relation between coefficients and roots

3.3.1 What does it mean by a root?

3.3.2 The Vieta formula

3.3.3 Forming quadratic equations with given roots

3.4 Vertex form of a quadratic function

3.4.1 Obtaining vertex form using Transformation

3.4.2 Relation between vertex form and general form

3.4.3 Opening direction

3.4.4 The axis of symmetry

3.4.5 The extremum of quadratic functions

3.5 Quadratic inequalities

3.5.1 Boolean algebra

3.5.2 Solving quadratic inequalities

3.6 Challenging questions

4 Polynomial functions

4.1 Arithmetic rules for polynomials

4.1.1 Addition, Subtraction and Multiplication

4.1.2 Division

4.2 Divisibility of polynomials

4.2.1 Division algorithm

4.2.2 Remainder Theorem

4.2.3 Factor Theorem and General Vieta formula

4.3 G.C.D. and L.C.M.

4.3.1 Greatest common divisor

4.3.2 Least common multiple

4.4 Positional notation

4.4.1 Binary, Octal, Decimal and Hexadecimal

4.4.2 Conversion between different bases

4.5 Challenging questions

5 Exponential and Logarithmic functions

5.1 Exponential functions

5.1.1 Law of Exponential algebra

5.1.2 Seeing surds as fractional exponents

5.1.3 Solving equations using exponentiation method

5.2 Logarithmic functions

5.2.1 What is Logarithm?

5.2.2 Law of Logarithmic algebra

5.2.3 Solving equations using Logarithmic method

5.3 Challenging questions

6 Sequence as a function of natural numbers

6.1 What is a sequence?

6.2 Arithmetic sequence

6.2.1 General form

6.2.2 Summation of arithmetic sequence

6.3 Geometric sequence

6.3.1 General form

6.3.2 Summation on Geometric sequence

6.3.3 Infinite sum of Geometric sequence

6.4 Additional content: Arithmetic-Geometric sequence

6.5 Challenging questions