MATH 135 Calculus 1, Fall 2015

Worksheet for Sections 1.1 and 1.2

The first chapter focuses on reviewing the key material from precalculus that will be crucial to understanding calculus. The main points of the first two sections are described in this handout. Please read the handout carefully and complete all the exercises.

1.1 Real Numbers, Functions, and Graphs

A **function** is a rule that assigns to each input element in the **domain** a unique output element in the **range**. The set of inputs to a function is called the **domain**, while the set of outputs is called the **range**. If a function $f : A \mapsto B$ maps from the set A to the set B (but not necessarily all of B), then we often call B the **co-domain**.

We will use four different methods to describe a function: analytically (an explicit formula), graphically, numerically (table), and verbally (described in words). Typically, we will use x and t as the independent variables (inputs) and letters such as $y, N,$ s (for position), v (for velocity) or a (for acceleration) as the dependent variables (outputs). When graphing a function, we will always assume the independent variable is plotted on the horizontal axis while the dependent variable is plotted on the vertical axis. In order to represent a function, a graph must pass the **vertical line test**, that is, any vertical line through the graph can only pass through at most one point. Otherwise, one input in the domain would have more than one output in the range, violating the definition of a function.

We say that a function f is **increasing** on an interval I if

$$f(x_1) \ < \ f(x_2) \quad \text{whenever } x_1 < x_2 \text{ in } I.$$

Likewise, f is **decreasing** on an interval I if

$$f(x_1) \ > \ f(x_2) \quad \text{whenever } x_1 < x_2 \text{ in } I.$$

This is much easier to see visually. Increasing functions move upwards from left to right while decreasing functions move downwards from left to right.

A function that satisfies $f(-x) = f(x)$ for all x in its domain is called an **even** function. The graph of an even function is symmetric about the vertical axis. If a function satisfies $f(-x) = -f(x)$ for all x in its domain, then it is an **odd** function. The graph of an odd function is symmetric about the origin (after reflecting about both the horizontal and vertical axes, the same graph is obtained.)

Examples of even functions include $7,\ x^2,\ x^4,\ |x|,\ x^{-2},\ \cos x$.

Examples of odd functions include $x,\ x^3,\ x^5,\ 1/x,\ \sin x,\ \tan x$.

Exercise 0.1 *Below, sketch the graph of an even function, an odd function, and a function that is neither even nor odd. Can a function be* **both** *even and odd? Hint: What would it look like?*

The Absolute Value Function $f(x) = |x|$

One of the most important functions in calculus (and in much of mathematics) is the **absolute value** function. The graph of this function is a V with vertex at the origin. Although you may have learned that the absolute value is always positive, this hardly captures the meaning of this function. The absolute value is used to measure distance. For example, $|4| = 4$ and $|-4| = 4$ both indicate that the points 4 and -4 are each four units from 0 on the number line. In general, the expression $|a - b|$ gives the distance between the numbers a and b on the number line. Thus, $|2 - 5| = 3$ since 2 and 5 are 3 units apart on the number line. Similarly, $|3 + 4| = |3 - -4| = 7$ since 3 and -4 are 7 units apart.

The piecewise definition for $|x|$ is

$$|x| = \begin{cases} x & \text{if } x \geq 0 \\ -x & \text{if } x < 0. \end{cases}$$

It simply says that if x is positive, then $|x|$ is itself, x. But if x is negative, then $|x|$ is the opposite of itself, $-x$.

The key to understanding expressions with absolute values is to think in terms of distance. For example, $|x - 5| < 3$ means that the distance between the numbers x and 5 is less than 3. In other words, the solution to this inequality is the set of x-values that are less than 3 units away from 5. If you draw a number line, you can see that these are all the numbers between 2 and 8, that is $2 < x < 8$ or, using interval notation, the solution is $(2, 8)$.

One important observation about absolute values is that $|x| < r$ is equivalent to the inequality $-r < x < r$, or the interval $(-r, r)$. Again, this is easy to understand in terms of distance because $|x - 0| = |x|$, so $|x| < r$ just means the set of points that are less than r away from the origin.

Exercise 0.2 *Translate the following expression into words and then solve the inequality.*

(a) $|x + 3| \;<\; 4$ **(b)** $|x - 3/2| \;\geq\; 5.$

Exercise 0.3 (Challenge Problem) *Find all x-values that satisfy the following equation.*
<u>Hint:</u> Interpret the equation in terms of distance and draw a picture.

$$|x - 4| - |x + 1| \;=\; 5$$

Shifting and Scaling functions

One key idea in mathematics is to apply a transformation to a graph (or function) and convert it into a new, but related graph. The simplest way to do this is to shift the graph (translation) or scale it (stretch or compress).

Here are the basic rules for shifting a graph vertically or horizontally. The constant c is assumed to be a positive real number.

- $f(x) + c$ shifts the graph of $f(x)$ upward by c units.
- $f(x) - c$ shifts the graph of $f(x)$ downward by c units.
- $f(x + c)$ shifts the graph of $f(x)$ to the left by c units.
- $f(x - c)$ shifts the graph of $f(x)$ to the right by c units.

Notice the difference between the vertical and horizontal shifts. The vertical shifts occur by adding/subtracting c **outside** the parentheses. This effects the output of the function—a range change. Meanwhile, the horizontal shifts occur by adding/subtracting c **inside** the parentheses. This alters what goes into the function—a domain change. For a domain change, it is the x-axis that gets shifted. For example, for the function $f(x + 2)$, we are really shifting the x-axis two units to the right, which has the effect of shifting the graph of f two units to the left.

Here are the basic rules for scaling a graph vertically (range change) or horizontally (domain change). We assume that $c > 1$.

- $cf(x)$ stretches the graph of $f(x)$ vertically by a factor of c units.
- $\frac{1}{c} \cdot f(x)$ compresses the graph of $f(x)$ vertically by a factor of c units.
- $f(cx)$ compresses the graph of $f(x)$ horizontally by a factor of c units.
- $f(\frac{1}{c} \cdot x)$ stretches the graph of $f(x)$ horizontally by a factor of c units.

Reflections

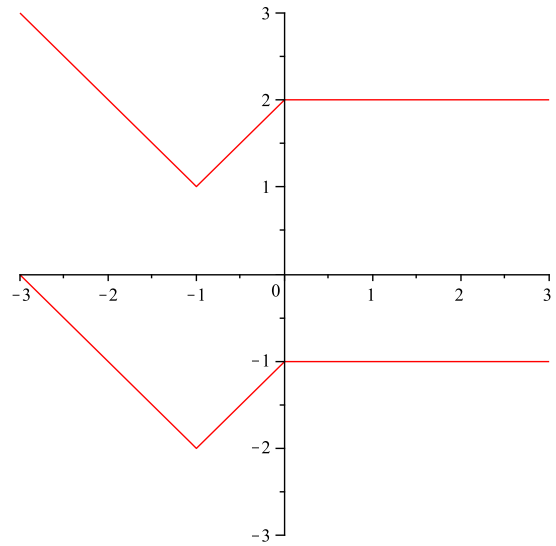
The transformation $-f(x)$ reflects the graph of $f(x)$ about the x-axis. Each point (x, y) on the graph of $y = f(x)$ is mapped to the point $(x, -y)$ on the graph of $y = -f(x)$.

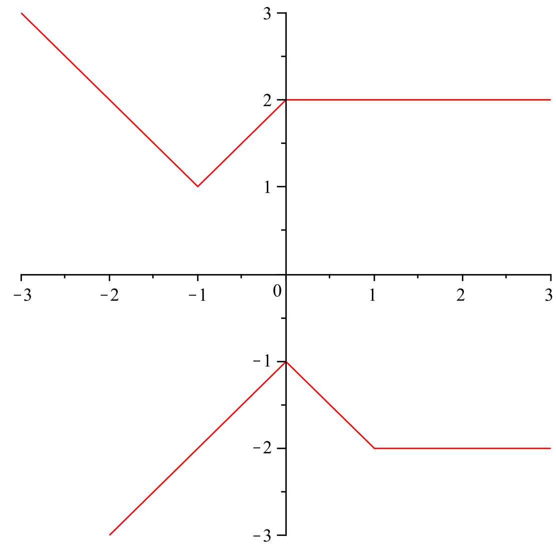
The transformation $f(-x)$ reflects the graph of $f(x)$ about the y-axis. Each point (x, y) on the graph of $y = f(x)$ is mapped to the point $(-x, y)$ on the graph of $y = f(-x)$.

Note that since $f(x) = f(-x)$ for an even function, the graph of an even function is symmetric with respect to the y-axis. Simply put, the equation $f(x) = f(-x)$ means that reflecting the graph of $f(x)$ about the y-axis has no effect on the graph.

Similarly, an odd function is defined by $f(-x) = -f(x)$, which is equivalent to $f(x) = -f(-x)$. This means that the graph of an odd function is symmetric with respect to the origin. In other words, reflecting the graph of $f(x)$ about the x-axis and then again about the y-axis has no effect on the graph.

Exercise 0.4 *For each of the graphs shown below, one or more transformations have been applied to the original function $f(x)$ (top graph) to obtain a new function $g(x)$ (bottom graph). In mathematical terms, state the formula for $g(x)$ in terms of $f(x)$. For example, a typical answer might be $g(x) = 4f(x + 7)$.*





(a) $g(x) =$ __________________ **(b)** $g(x) =$ __________________

1.2 Linear and Quadratic Functions

Linear Functions

A **linear function** is one of the form $f(x) = mx + b$, where m and b are arbitrary constants. It is "linear" in x (no exponents, fractions, trig, etc.). The graph of a linear function is a line. The constant m is the **slope** of the line and this number has the same value everywhere on the line. If (x_1, y_1) and (x_2, y_2) are any two points on the line, then the slope is given by

$$m = \frac{y_2 - y_1}{x_2 - x_1} = \frac{\Delta y}{\Delta x} \qquad (\Delta \text{ means change}).$$

This number will be the same no matter which two points on the line are chosen.

Two important equations for a line are:

1. Slope-intercept form: $y = mx + b$ (m is the slope and b is the y-intercept.)

2. Point-slope form: $y - y_0 = m(x - x_0)$ (m is the slope and (x_0, y_0) is any point on the line.)

If $m > 0$, then the line is increasing while if $m < 0$, the line is decreasing. When $m = 0$, the line has zero slope and is horizontal (a constant function). Two lines are **parallel** when they have the same slope, while two lines are **perpendicular** if the product of their slopes is -1.

Exercise 0.5 *Find the equation of the line with the given information.*

(a) *The line passing through the points* $(-2, 3)$ *and* $(4, 1)$.

(b) *The line parallel to* $2y + 5x = 0$, *passing through* $(2, 5)$.

(c) *The line perpendicular to* $2y + 5x = 0$, *passing through* $(2, 5)$.

Quadratic Functions

A **quadratic function** is a function of the form $f(x) = ax^2 + bx + c$, where a, b, and c are arbitrary constants and $a \neq 0$. The graph of a quadratic function is a **parabola**, an important curve that arises in many fields (e.g., physics, acoustics, astronomy). The parabola opens up when $a > 0$ and down for $a < 0$. The x-coordinate of the vertex of the parabola is located at $x = -b/(2a)$.

A quadratic function may have either two, one, or zero real roots, found by solving the equation $ax^2 + bx + c = 0$. The number of roots is determined by the **discriminant** $D = b^2 - 4ac$. If $D > 0$, then there are two distinct real roots. If $D = 0$, then there is one root, called a **repeated root**. If $D < 0$, then there are no real roots. The roots can be found either by factoring $ax^2 + bx + c = 0$ (in special cases) or by using the quadratic formula

$$\frac{-b \pm \sqrt{b^2 - 4ac}}{2a} = \frac{-b \pm \sqrt{D}}{2a}.$$

Note the appearance of D under the square root. If $D < 0$, then the roots are not real. In this case, the parabola does not cross the x-axis. If $D > 0$, then the two real roots are equidistant from the x-coordinate of the vertex of the parabola.

Exercise 0.6 *Find the roots of the quadratic function* $f(x) = -3x^2 + 9x + 12$ *and use them to draw a sketch of the graph of* $f(x)$.

Completing the Square

One important algebraic technique for understanding quadratic functions is **completing the square**. This means to write the function as a multiple of a perfect square plus a constant. Here is an example:

$$\begin{aligned} 2x^2 + 6x + 7 &= 2(x^2 + 3x + \underline{\hspace{2cm}}) + 7 \\ &= 2\left(x^2 + 3x + \frac{9}{4}\right) + \frac{5}{2} \\ &= 2\left(x + \frac{3}{2}\right)^2 + \frac{5}{2} \end{aligned}$$

The key to completing the square is to add and subtract the correct constant (9/4 in the above example) to make the factorization into a perfect square. This constant is found by taking the coefficient of the linear term, cutting it in half, and then squaring.

Exercise 0.7 *By completing the square, find the range of the quadratic function* $f(x) = 4x^2 - 24x + 31$.

Exercise 0.8 *Find the quadratic function that is even and passes through the points* $(-1, 1)$ *and* $(2, 13)$.