

Integration

Riemann Sum

The primary application of integration is to determine the area between a function and the x -axis. A Riemann sum is an approximation of this area that is found using rectangles.

A Riemann sum of a function f defined on the interval $[a, b]$ is determined by a partition, which is a finite division of $[a, b]$ into subintervals. This interval is typically expressed by $a = x_0 < x_1 < x_2 < \dots < x_n = b$ and a sampling of points with one point from each subinterval, for example, c_i from $[x_{i-1}, x_i]$. The associated

$$\text{Riemann sum is } \sum_{i=1}^n f(c_i)(x_i - x_{i-1})$$

A regular partition has subintervals of the same length: $x_i - x_{i-1} = \frac{b-a}{n}$ and $c_i = x_{i-1} + \Delta x$. A partition's norm is its maximum subinterval length, Δx , both norm values the left endpoint $c_i = x_{i-1}$ of each subinterval, whereas a right norm takes the right endpoint.

EX: The sum of the areas of the rectangles that group rectangles in left Riemann sum of $f(x) = x^2$ on the interval $[0, 10]$ using partitions that are 2 units wide.



EX: The sum of the areas of the rectangles (right graph) represents a right Riemann sum of $f(x) = x^2$ on the interval $[0, 10]$ using partitions that are 2 units wide.

The upper sum of a continuous function f takes a point c_i in each subinterval where the maximum value of f is achieved. A lower sum takes the minimum value of f for each subinterval.

Definite Integral

As the partitions of a Riemann sum get smaller and smaller, the area approximation gets closer and closer to the actual area under the curve. The definite integral of f on the interval $[a, b]$ is defined as

$$\int_a^b f(x) dx = \lim_{n \rightarrow \infty} \sum_{i=1}^n f(c_i)(x_i - x_{i-1})$$

The expression to be integrated, $f(x) dx$, is called the integrand. The definite integral exists when f is continuous on $[a, b]$. Then the function is used as the integrand.

Antiderivative

An antiderivative of a function f is a function F whose derivative is f . $F'(x) = f(x)$ for all x in some domain. Usually, an interval, they are antiderivatives of a function on an interval differ by a constant.

EX: The functions $g(x) = x^2 + 3x + 2$ and $h(x) = x^2 + 3x + 7$ are both antiderivatives of $f(x) = 2x + 3$ because $g'(x) = 2x + 3$ and $h'(x) = 2x + 3$.

The indefinite integral of a function f is denoted $\int f(x) dx$ and represents the family of antiderivatives as a typical (often unspecified) interval.

EX: $\int \frac{1}{x^2} dx = -x^{-1} + C = -\frac{1}{x} + C$, where C is a constant called the constant of integration.

Mean Value Theorem

Let f be a continuous function on the interval $[a, b]$. Then there exists a number c in (a, b) such that $\int_a^b f(x) dx = (b-a)f(c)$.

In other words, $f(c)$ is the average value of f on $[a, b]$.



Fundamental Theorem of Calculus

There are two parts to the fundamental theorem of calculus.

1. First Part (Evaluating Integrals) If f is a continuous function on $[a, b]$, and $F(x)$ is an antiderivative of f on that interval, then $\int_a^b f(x) dx = F(b) - F(a)$.

EX: Evaluate $\int_0^2 (x^2 + 3x) dx$ given that $\int_0^2 (x^2 + 3x) dx = F(2) - F(0) = 14$.

$$\begin{aligned} \int_0^2 (x^2 + 3x) dx &= F(2) - F(0) \\ &= 7 + 6 - (0 + 0) \\ &= 13 + 0 \\ &= 13 \end{aligned}$$

The area of the shaded region between $f(x)$ and the x -axis on $[0, 2]$ is 13 square units.



2. Second Part (Determining Antiderivatives) If f is a continuous function on $[a, b]$, then the function $F(x) = \int_a^x f(t) dt$ is an antiderivative of f on $[a, b]$ and $F'(x) = f(x)$.

$$\text{EX: } \int_0^2 (x^2 + 3x) dx = \frac{1}{3}x^3 + \frac{3}{2}x^2 = \frac{8}{3} + 6 - 0 = \frac{26}{3}$$

Integration of Integrals

Area Under a Curve

If f is nonnegative and continuous on $[a, b]$, then $F(x) = \int_a^x f(t) dt$ gives the area between the graph of the function and the x -axis.

The area function $A(x) = \int_a^x f(t) dt$ gives the accumulated area on the interval from a up to x . If f is negative, the integral is the opposite of the area.

Average Value

The average value of f over an interval $[a, b]$ is defined by the expression

$$\text{average value} = \frac{1}{b-a} \int_a^b f(x) dx$$

EX: Find the average value of $f(x) = \sin(x)$ on the interval $[0, \pi]$.

$$\begin{aligned} \text{average value} &= \frac{1}{\pi - 0} \int_0^\pi \sin(x) dx \\ &= \frac{1}{\pi} [-\cos(x)]_0^\pi \\ &= \frac{1}{\pi} [-\cos(\pi) - (-\cos(0))] = \frac{2}{\pi} \end{aligned}$$

The average value of $f(x)$ on the interval $[a, b]$ is $\frac{1}{b-a} \int_a^b f(x) dx$.

A rough estimate of an integral may be made by estimating the average value of a function. Or, important and multiplying it by the length of the interval.

Accumulated Change

The integral of a rate of change of a quantity over a time interval gives the total change in the quantity over the time interval.

EX: Let $v(t)$ represent the velocity of an object as a function of time. Then $v(t) dt$ represents the velocity (the rate of change of position) of the object. Furthermore, $\int_a^b v(t) dt$ represents the approximate displacement (measuring in the time interval from $t = a$ to $t = b$).

Adding the displacements for all time increments gives the approximate change in position over the entire time interval. In the limit of small time increments, the total displacement (or accumulation) is found: $\int_a^b v(t) dt = s(b) - s(a)$.



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Calculus 2 Quickstudy Academic

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