

CALCULUS 2

INTEGRAL & DIFFERENTIAL CALCULUS FOR ADVANCED STUDENTS

INTEGRATION

DEFINITIONS

Integration. The definite integral expresses the idea of adding the values of a function over a continuous interval.

Riemann sum. A regular Riemann sum of a function f defined on $[a, b]$ is approximated by a partition, which is a finite division of $[a, b]$ into subintervals, typically expressed by endpoints $x_0, x_1, x_2, \dots, x_n$ and a sampling of points, one point from each subinterval, say c_i from $[x_{i-1}, x_i]$. The associated Riemann sum is $\sum_{i=1}^n f(c_i)(x_i - x_{i-1})$.

A **regular partition** has subintervals all the same length, $x_i - x_{i-1} = \Delta x$, $x_i = a + i\Delta x$. A partition's **norm** is the maximum subinterval length. A **left sum** takes the left endpoint $c_i = x_{i-1}$ of each subinterval, a **right sum** the right endpoint, an **upper sum** (or **circumscribed sum**) takes a point c_i in each subinterval where the maximum value of f is achieved, a **lower sum** the minimum value. E.g., the upper R -sum of $\sin x$ over $[\pi/2, 3\pi/2]$ with a regular partition of n intervals is the left sum (since the curve is decreasing on the interval): $\sum_{i=1}^n \sin(x_{i-1}) \Delta x = \Delta x \sum_{i=1}^n \sin(x_{i-1})$.



Definite integral. The definite integral of f from a to b may be denoted as $\int_a^b f(x) dx$ or $\int_a^b f(x) dx$. The limit is said to exist if some number A can be called the integral value for the following: every $\epsilon > 0$ there is a δ such that all Riemann sums on partitions of $[a, b]$ with norm less than δ differ from A by less than ϵ . It then is said to exist and A the function is said to be integrable and the value is denoted $\int_a^b f(x) dx$ or $\int_a^b f(x) dx$. The function must be bounded on the integrable. The function f is called the **integrand** and the points a and b are called the **lower limit** and **upper limit** of integration, respectively. The most integral value is the function of $\int_a^b f(x) dx$ from f and $[a, b]$ as well as to the resulting value of $\int_a^b f(x) dx$.

Indefinite integral. An antiderivative of a function f is a function F whose derivative is f (not required for all x in some classes) on an interval. Any two antiderivatives of a function on an interval differ by a constant in consequence of the Mean Value Theorem. E.g., both $\frac{1}{2}x^2 + 1$ and $\frac{1}{2}x^2 - 1$ are antiderivatives of x , differing by $\frac{1}{2}$. The indefinite integral of a function f denoted $\int f(x) dx$, is an expression for the family of antiderivatives on a general (often unspecified) interval. E.g., for $f(x) = x - 2$, or for $x > 0$, $\int (x - 2) dx = \frac{1}{2}x^2 - 2x + C$.

The constant C , which may have any real value, is the constant of integration. Computer programs, and other tools, may omit the constant, it being understood by the user/interpreter that the given antiderivative is just one representative of a class.

INTERPRETATIONS

Area under a curve. If f is nonnegative and continuous on $[a, b]$, then $\int_a^b f(x) dx$ gives the area between the curve and the graph. The area function $A(x) = \int_a^x f(t) dt$ gives the area accumulated up to x . If f is negative, the integral is the negative of the area.

Average value. The average value of f over an interval $[a, b]$ may be defined by average value $= \frac{1}{b-a} \int_a^b f(x) dx$. A rough estimate of an integral may be made by estimating the average value, the bounding the graph and multiplying it by the length of the interval. This idea is known as the **disk method** for integrals, as the theory explains.

Continued 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. E.g., if velocity is a velocity (the rate of change of position), then $\int_a^b v(t) dt$ is the approximate displacement (change in the distance) from $t = a$ until the displacement, the distance traveled given the approximate change in position over the entire time interval. In the limit of small time increments, one gets the exact total displacement: $\int_a^b v(t) dt = s(b) - s(a)$.

Integral curve. Imagine that a function f describes a slope field for each x . Plotting line segments with slope $f(x)$ at points (x, y) for various y and doing this for various x will give a **slope field**. An antiderivative of f is a function whose graph is tangent to the slope field at each point. The graph of the antiderivative is called an **integral curve** of the slope field.

Antiderivative to higher order problems. The solution to the differential equation $y'' = f(x)$ with initial value $y(a) = y_0$ is $y(x)$ such that $\int_a^x \int_a^t f(x) dx dt$.

THEORY

Integration & Integration. A continuous function on a closed interval is integrable. Integrability on $[a, b]$ implies integrability on closed subintervals of $[a, b]$. Assuming f is integrable on $[a, b]$ and $[c, d]$ then all a in $[a, b]$, then $\int_a^b f(x) dx = \int_a^c f(x) dx + \int_c^b f(x) dx$. Use this to check integral evaluations with rough estimates of antiderivatives.

Basic Integral Bounds



If f is nonnegative, then $\int_a^b f(x) dx$ is nonnegative. If f is integrable on $[a, b]$, then so is $|f|$ and $|\int_a^b f(x) dx| \leq \int_a^b |f(x)| dx$.

Fundamental theorem of calculus. One part of the theorem is used to evaluate integrals. If f is continuous on $[a, b]$ and F is an antiderivative of f on that interval, then $\int_a^b f(x) dx = F(b) - F(a)$. The other part of the theorem states that if f is continuous on $[a, b]$, then $\int_a^b f(x) dx = F(b) - F(a)$.

A function F is said to be an antiderivative of f on $[a, b]$ if $F'(x) = f(x)$ for all x in $[a, b]$. The area function $A(x) = \int_a^x f(t) dt$ is an antiderivative of f on $[a, b]$.

Fundamental Theorem



Antiderivatives of integrals. Functions are often defined as integrals. E.g., the "area integral function" is $A(x) = \int_a^x f(t) dt$. To differentiate such, use the second part of the Fundamental theorem: **Antiderivatives.** A function such as $\int_a^x f(t) dt$ is a composite involving $A(x) = \int_a^x f(t) dt$. To differentiate, use the chain rule and the fundamental theorem: $\frac{d}{dx} \int_a^x f(t) dt = f(x)$. **Chain rule theorem for integrals.** If f and g are continuous on $[a, b]$, then there is a c in $[a, b]$ such that $\int_a^b f(x) g(x) dx = f(c) \int_a^b g(x) dx$. In the case $g(x) = 1$, the average value of f is stated as $\frac{1}{b-a} \int_a^b f(x) dx = f(c)$.

NET for Integrals



Change of variable theorem. An integral and limits of integration can be changed to make an integral easier to approach or evaluate. In effect, the "area" is roughly redistributed without changing the integral value. If f is a function with continuous derivatives and f is continuous, then $\int_a^b f(x) dx = \int_{g(a)}^{g(b)} f(g(t)) g'(t) dt$, where a and b are points with $g(a) = a$ and $g(b) = b$. In practice, substitutions are applied, sometimes after trials, and that means to know some values $u = g(t)$, $du = g'(t) dt$. For instance, $\int_a^b \sqrt{1-t^2} dt = \int_a^b \sqrt{1-u^2} du$ would do, which becomes $\int_a^b \sqrt{1-u^2} du$ with $u = \sin t$ or $u = \cos t$ or $u = \tan t$. The formula is often used iteratively, starting with $\int_a^b f(x) dx = \int_{g(a)}^{g(b)} f(g(t)) g'(t) dt$ on page 2.

Variable Substitution. A rigorous definition is that $\int_a^b f(x) dx = \int_{g(a)}^{g(b)} f(g(t)) g'(t) dt$. The change of variable formula with $u = g(t)$ yields $\int_a^b f(x) dx = \int_{g(a)}^{g(b)} f(u) \frac{du}{g'(t)}$, showing that $\frac{du}{g'(t)} = \frac{1}{g'(t)} du$. The other elementary properties of the integral may now be derived for each desired form, this definition. In this approach, no inverse function is defined and is defined to be the second derivative of g .



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