Nov. 11 Math 1190 sec. 52 Fall 2016

Section 5.1: Area (under the graph of a nonnegative function)

Recovering Distance from Velocity The speedometer readings for a motorcycle are recorded at 12 second intervals. Use the information in the table to estimate the total distance traveled. Get estimates using
(a) left end points (beginning time of intervals), and
(b) right end points (ending time for each interval).

t in sec	0	12	24	36	48	60
v in ft/sec	20	28	25	22	24	27

t in sec	0	12	24	36	48	60
v in ft/sec	20	28	25	22	24	27

area = height x width

distance = rate x time

- left end

- right end

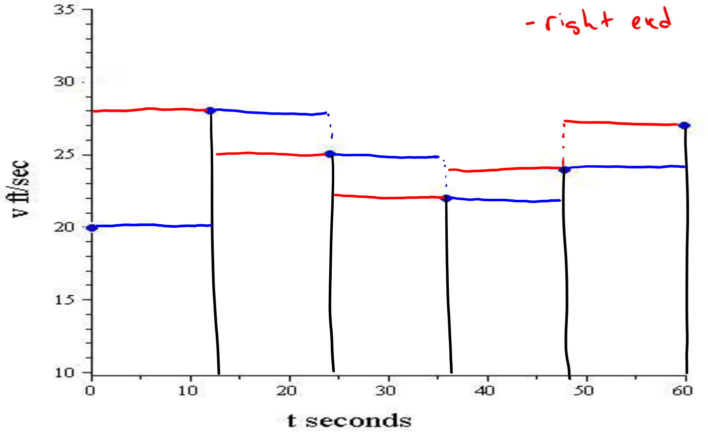


Figure: Graphical representation of motorcycle's velocity.

t in sec	0	12	24	36	48	60
v in ft/sec	20	28	25	22	24	27

Left end approximation

$$D \approx 20\,\frac{ft}{s}\cdot 12s + 28\,\frac{ft}{s}\cdot 12s + 25\,\frac{ft}{s}\cdot 12s$$

$$+ 22\,\frac{ft}{s}\cdot 12s + 24\,\frac{ft}{s}\cdot 12s$$

$$= 1428 \text{ ft}$$

t in sec	0	12	24	36	48	60
v in ft/sec	20	28	25	22	24	27

Right end point approximation

$$D \approx 28\,\frac{ft}{s}\cdot 12s + 25\,\frac{ft}{s}\cdot 12s + 22\,\frac{ft}{s}\cdot 12s$$

$$+ 24\,\frac{ft}{s}\cdot 12\,s + 27\,\frac{ft}{s}\cdot 12s$$

$$= 1512\ \text{ft}$$

Our Motorcycle's True Velocity is Probably "Smooth"

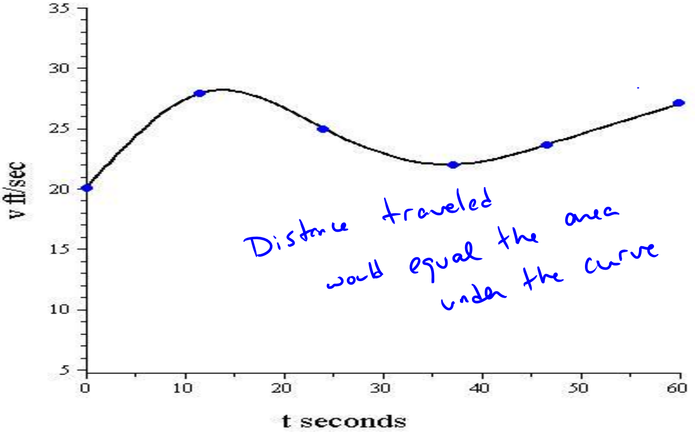


Figure: The true graph of the velocity probably looks more like this. But we only know for certain what it is at the recorded times.

Section 5.2: The Definite Integral

We saw that a sum of the form

$$f(c_1)\Delta x + f(c_2)\Delta x + \cdots + f(c_n)\Delta x$$

approximated the area of a region if f was continuous and positive.
And that under these conditions, the limit

$$\lim_{n\to\infty}\sum_{i=1}^{n} f(c_i)\Delta x = \lim_{n\to\infty}[f(c_1)\Delta x + f(c_2)\Delta x + \cdots + f(c_n)\Delta x]$$

was the value of this area.

Can we generalize this dropping the requirement that f is positive?
that f is continuous?

Definition (Definite Integral)

Let f be defined on an interval $[a, b]$. Let

$$x_0 = a < x_1 < x_2 < \cdots < x_n = b$$

be any partition of $[a, b]$, and $\{c_1, c_2, \ldots, c_n\}$ be any set of sample points. Then the **definite integral of** f **from** a **to** b is denoted and defined by

$$\int_a^b f(x)\,dx = \lim_{n\to\infty} \sum_{i=1}^{n} f(c_i)\Delta x_i$$

provided this limit exists. Here, the limit is taken over all possible partitions of $[a, b]$.

Terms and Notation

- **Riemann Sum:** any sum of the form $f(c_1)\Delta x + f(c_2)\Delta x + \cdots + f(c_n)\Delta x$
- **Integral Symbol/Sign:** $\int$ (a stretched "S" for "sum")
- **Integrable:** If the limit does exists, f is said to be integrable on $[a, b]$
- **Limits of Integration:** a is called the lower limit of integration, and b is the upper limit of integration
- **Integrand:** the expression "$f(x)$" is called the integrand

- **Differential:** dx is called a differential, it indicates what the variable is and can be thought of as the limit of Δx (just as it is in the derivative notation "$\frac{dy}{dx}$").

- **Dummy Variable/Variable of Integration:** the variable that appears in both the integrand and in the differential. For example, if the differential is dx, the dummy variable is x; it the differential is du, the dummy variable is u

$$\int_a^b f(x)\,dx$$

Important Remarks

(1) If the integral does exist, it is a **number**. That is, it does not depend on the dummy variable of integration. The following are equivalent.

$$\int_a^b f(x)\,dx = \int_a^b f(t)\,dt = \int_a^b f(q)\,dq$$

(2) The definite integral is a limit of Riemann Sums!

(3) If f is positive and continuous on $[a, b]$, then

$$\int_a^b f(x)\,dx = \text{ the area under the curve.}$$

Questions

Consider the integral $\int_{-3}^{\pi} f(r)\,dr$

(1) The dummy variable of integration is

(a) x
(b) r
(c) can't be determined without more information
(d) dr

Questions

(2) If it is known that $\int_{-3}^{\pi} f(r)\,dr = 7$, then

$$\int_{-3}^{\pi} f(x)\,dx = \int_{-3}^{\pi} f(r)\,dr = \int_{-3}^{\pi} f(\text{☺})\,d\text{☺}$$

(a) $7x$

(b) -7

(c) can't be determined without more information

(d) 7

What if f is continuous, but not always positive?

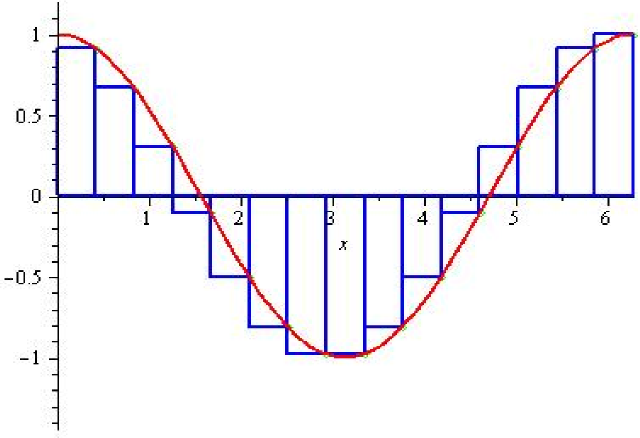


Figure: A function that changes signs on $[a, b]$. (Here, $f(x) = \cos x$, $a = 0$ and $b = 2\pi$; the partition has 15 subintervals.)

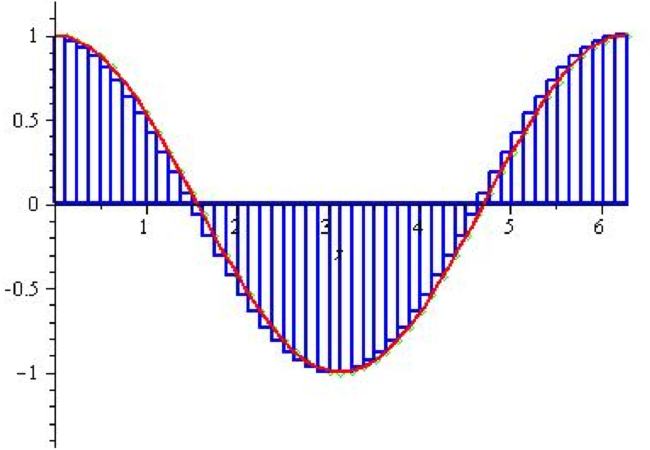


Figure: The same function but with 50 subintervals.

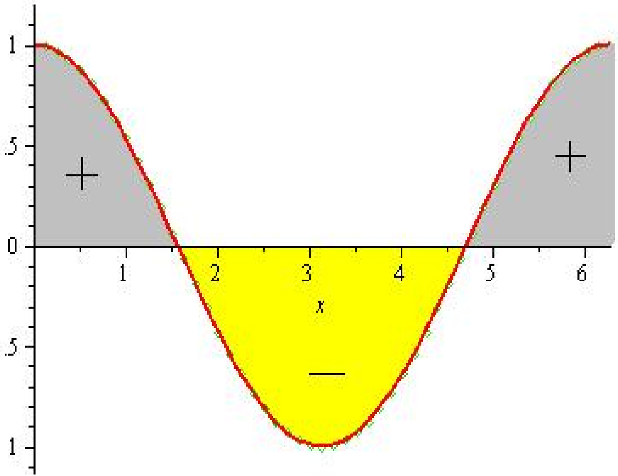


Figure: $\int_a^b f(x)\,dx =$ area of gray region $-$ area of yellow region

Example

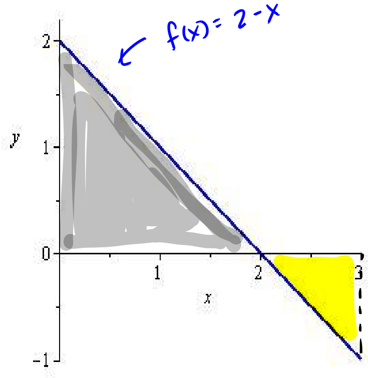
Use area to evaluate the integral $\int_0^3 (2-x)\,dx$.

Integrand $f(x) = 2 - x$

dummy variable is x

lower limit is 0

upper limit is 3



$$\int_0^3 (2-x)\,dx = \text{gray area} - \text{yellow area}$$

gray area $= \frac{1}{2}$ base $\cdot$ height $= \frac{1}{2} \cdot 2 \cdot 2 = 2$

yellow area $= \frac{1}{2}$ base $\cdot$ height $= \frac{1}{2} \cdot 1 \cdot 1 = \frac{1}{2}$

$$\int_0^3 (2-x)\,dx = 2 - \frac{1}{2} = \frac{3}{2}$$

Important Theorems:

Theorem: If f is continuous on $[a, b]$ or has only finitely many jump discontinuities on $[a, b]$, then f is integrable on $[a, b]$

Theorem: If f is continuous on $[a, b]$, then

$$\int_a^b f(x)\,dx = \lim_{n\to\infty} \sum_{i=1}^{n} f(c_i)\Delta x,$$

where

$$\Delta x = \frac{b-a}{n}, \quad \text{and} \quad c_i = a + i\Delta x.$$

A couple of definitions:

Definition: If $f(a)$ is defined, then

$$\int_a^a f(x)\,dx = 0.$$

In particular, the integral of a continuous function over a single point is zero.

Definition: If $\int_a^b f(x)\,dx$ exists, then

$$\int_b^a f(x)\,dx = -\int_a^b f(x)\,dx$$

Reversing the limits of integration negates the value of the integral.

Example

Evaluate $\int_{2}^{2} \cos^2 x \, dx$ $= 0$

$\int_{a}^{a} f(x)\,dx = 0$

and $\cos^2(2)$ exists

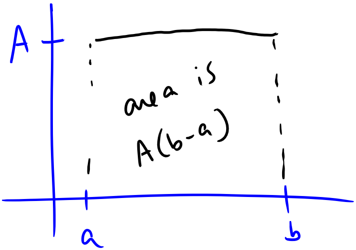
Suppose $\int_{1}^{5} f(x)\,dx = 4\pi$, evaluate $\int_{5}^{1} f(x)\,dx$ $= -\int_{1}^{5} f(x)\,dx$

$\Rightarrow \int_{5}^{1} f(x)\,dx = -4\pi$

A simple integral

If $f(x) = A$ where A is any constant, then

$$\int_a^b f(x)\,dx = \int_a^b A\,dx = A(b-a).$$



Question

$$\int_3^7 \pi \, dx = \pi(7-3) = 4\pi$$

(a) 4π

(b) 7π

(c) 3π

(d) can't be determined without more information