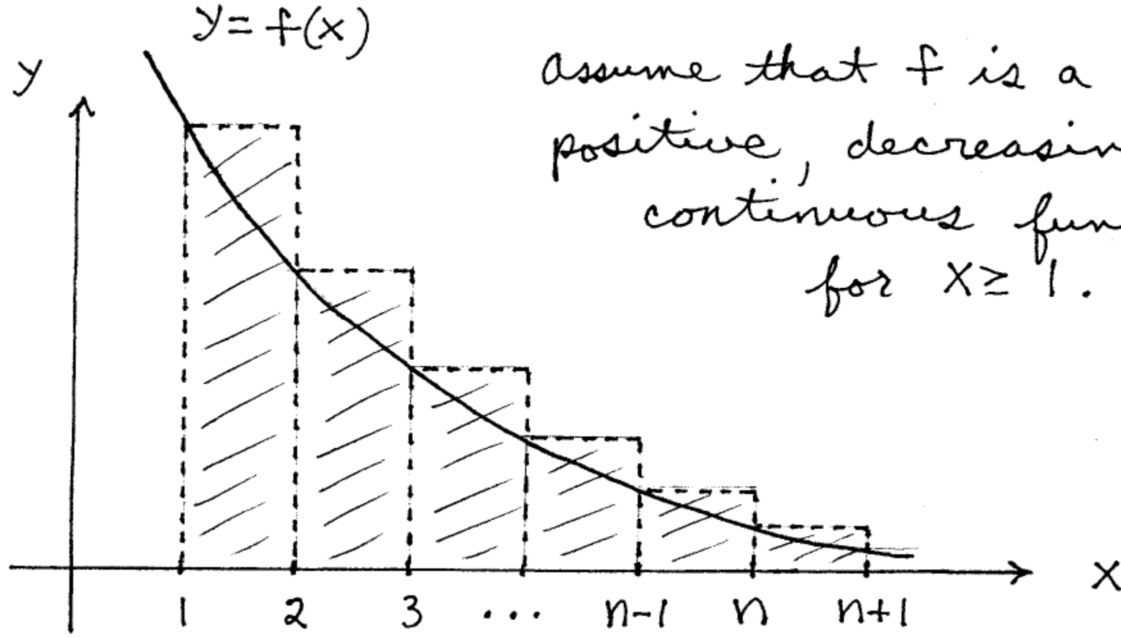
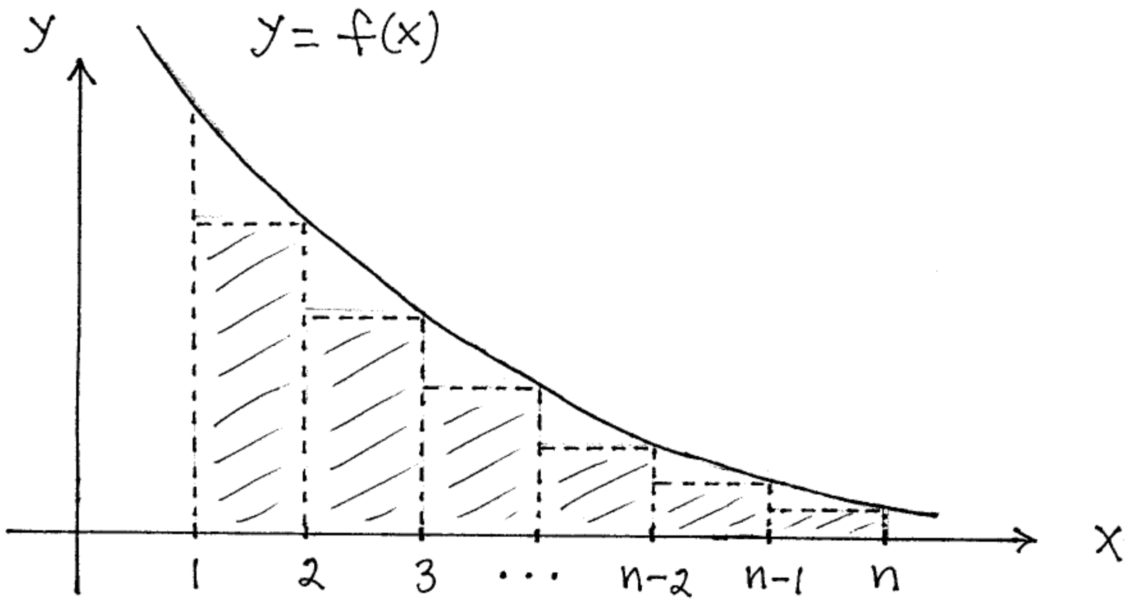
Math 21C
Kouba — Integral Test, P-Series Test, Infinite Series and Improper Integrals



assume that f is a positive, decreasing, continuous function for $x \geq 1$.

$$\int_1^{n+1} f(x)\,dx < f(1) + f(2) + f(3) + \cdots + f(n) \; ;$$



$$f(2) + f(3) + \cdots + f(n) < \int_1^n f(x)\,dx \Rightarrow$$

$$f(1) + f(2) + f(3) + \cdots + f(n) < f(1) + \int_1^n f(x)\,dx \; ;$$

It follows that

$$(*) \quad \boxed{\int_1^{n+1} f(x)\,dx < f(1)+f(2)+\cdots+f(n) < f(1)+\int_1^n f(x)\,dx}.$$

<u>Case 1</u>: Assume that $\int_1^\infty f(x)\,dx = L$ (finite). Then

$$f(1)+f(2)+\cdots+f(n) < f(1)+\int_1^n f(x)\,dx \Rightarrow$$

$$\lim_{n\to\infty}\left(f(1)+f(2)+\cdots+f(n)\right) < \lim_{n\to\infty}\left(f(1)+\int_1^n f(x)\,dx\right) \Rightarrow$$

$$\sum_{n=1}^\infty f(n) < f(1)+\int_1^\infty f(x)\,dx = f(1)+L < \infty, \text{ i.e.,}$$

$$\sum_{n=1}^\infty f(n) \text{ converges}.$$

<u>Case 2</u>: Assume that $\int_1^\infty f(x)\,dx = \infty$. Then

$$\int_1^{n+1} f(x)\,dx < f(1)+f(2)+\cdots+f(n) \Rightarrow$$

$$\lim_{n\to\infty}\int_1^{n+1} f(x)\,dx \le \lim_{n\to\infty}\left(f(1)+f(2)+\cdots+f(n)\right) \Rightarrow$$

$$\int_1^\infty f(x)\,dx \le \sum_{n=1}^\infty f(n) \Rightarrow \sum_{n=1}^\infty f(n) = \infty, \text{ i.e.,}$$

$$\sum_{n=1}^\infty f(n) \text{ diverges}.$$

This verifies the following series test.

<u>Integral Test</u>: Assume that function f is positive, decreasing, and continuous for $x \ge 1$.

a.) If $\int_1^\infty f(x)\,dx$ converges, then $\sum_{n=1}^\infty f(n)$ converges.

b.) If $\int_1^\infty f(x)\,dx$ diverges, then $\sum_{n=1}^\infty f(n)$ diverges.

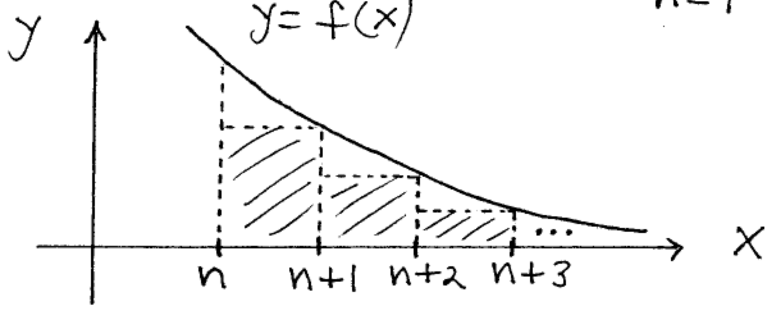
note that

$$\sum_{n=1}^{\infty} f(n) = \underbrace{f(1)+f(2)+\cdots+f(n)}_{S_n}+\underbrace{f(n+1)+f(n+2)+\cdots}_{R_n} ;$$

let $S_n = f(1)+f(2)+\cdots+f(n)$ be the nth <u>partial</u> <u>sum</u>, and let the infinite tail

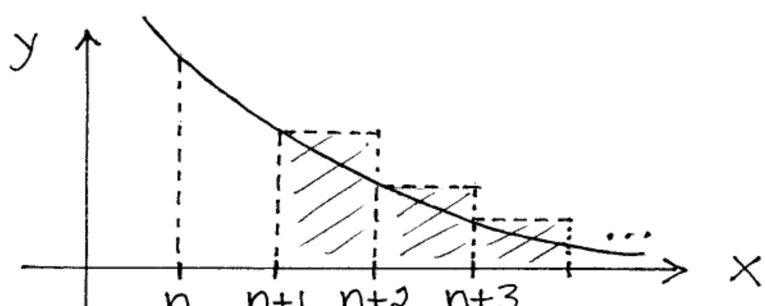
$$R_n = f(n+1)+f(n+2)+\cdots$$

be the <u>error</u> or <u>remainder</u> term for the infinite series $\sum_{n=1}^{\infty} f(n)$. Then



$$f(n+1)+f(n+2)+f(n+3)+\cdots < \int_n^{\infty} f(x)\,dx ,$$

and



$$\int_{n+1}^{\infty} f(x)\,dx < f(n+1)+f(n+2)+\cdots ,$$ so that

$$(*)(*) \quad \boxed{\int_{n+1}^{\infty} f(x)\,dx < f(n+1)+f(n+2)+\cdots < \int_n^{\infty} f(x)\,dx}$$

Def: (P-series Test) The series

$$\sum_{n=1}^{\infty} \frac{1}{n^p} = \frac{1}{1^p} + \frac{1}{2^p} + \frac{1}{3^p} + \cdots$$

is called a p-series. This series

1.) converges if $p > 1$.

2.) diverges if $p \leq 1$.

This follows easily from the Integral Test since $\int_1^{\infty} \frac{1}{x^p}\,dx$ converges if $p > 1$ and diverges if $p \leq 1$.