

연쇄법칙

(The Chain Rule)

The Chain Rule

▶ Start

▶ Start

Theorem

▶ Start

Theorem

[

▶ Start

Theorem

[*g is differentiable at x*

▶ Start

Theorem

[g is differentiable at x
 f is differentiable at $g(x)$

▶ Start

Theorem

$$\left[\begin{array}{l} g \text{ is differentiable at } x \\ f \text{ is differentiable at } g(x) \\ F = f \circ g \end{array} \right.$$

▶ Start

Theorem

[*g is differentiable at x*
 f is differentiable at $g(x)$
 $F = f \circ g$, $F(x) = f(g(x))$

▶ Start

Theorem

$$\left[\begin{array}{l} g \text{ is differentiable at } x \\ f \text{ is differentiable at } g(x) \\ F = f \circ g \text{ , } F(x) = f(g(x)) \\ y = f(u) \end{array} \right.$$

▶ Start

Theorem

$$\left[\begin{array}{l} g \text{ is differentiable at } x \\ f \text{ is differentiable at } g(x) \\ F = f \circ g, \quad F(x) = f(g(x)) \\ y = f(u) \\ u = g(x) \end{array} \right.$$

▶ Start

Theorem

$$\left[\begin{array}{l} g \text{ is differentiable at } x \\ f \text{ is differentiable at } g(x) \\ F = f \circ g, \quad F(x) = f(g(x)) \\ y = f(u) \\ u = g(x) \end{array} \right]$$

▶ Start

Theorem

$$\left[\begin{array}{l} g \text{ is differentiable at } x \\ f \text{ is differentiable at } g(x) \\ F = f \circ g, \quad F(x) = f(g(x)) \\ y = f(u) \\ u = g(x) \end{array} \right] \Rightarrow$$

▶ Start

Theorem

$$\left[\begin{array}{l} g \text{ is differentiable at } x \\ f \text{ is differentiable at } g(x) \\ F = f \circ g, \quad F(x) = f(g(x)) \\ y = f(u) \\ u = g(x) \end{array} \right] \Rightarrow \left[\right]$$

▶ Start

Theorem

$$\left[\begin{array}{l} g \text{ is differentiable at } x \\ f \text{ is differentiable at } g(x) \\ F = f \circ g, \quad F(x) = f(g(x)) \\ y = f(u) \\ u = g(x) \end{array} \right] \Rightarrow \left[\begin{array}{l} F \text{ is differentiable at } x \end{array} \right]$$

▶ Start

Theorem

$$\left[\begin{array}{l} g \text{ is differentiable at } x \\ f \text{ is differentiable at } g(x) \\ F = f \circ g, \quad F(x) = f(g(x)) \\ y = f(u) \\ u = g(x) \end{array} \right] \Rightarrow \left[\begin{array}{l} F \text{ is differentiable at } x \\ F'(x) = f'(g(x))g'(x) \end{array} \right]$$

▶ Start

Theorem

$$\left[\begin{array}{l} g \text{ is differentiable at } x \\ f \text{ is differentiable at } g(x) \\ F = f \circ g, \quad F(x) = f(g(x)) \\ y = f(u) \\ u = g(x) \end{array} \right] \Rightarrow \left[\begin{array}{l} F \text{ is differentiable at } x \\ F'(x) = f'(g(x))g'(x) \\ \frac{dy}{dx} = \frac{dy}{du} \frac{du}{dx} \end{array} \right]$$

▶ Start

Theorem

$$\left[\begin{array}{l} g \text{ is differentiable at } x \\ f \text{ is differentiable at } g(x) \\ F = f \circ g, \quad F(x) = f(g(x)) \\ y = f(u) \\ u = g(x) \end{array} \right] \Rightarrow \left[\begin{array}{l} F \text{ is differentiable at } x \\ F'(x) = f'(g(x))g'(x) \\ \frac{dy}{dx} = \frac{dy}{du} \frac{du}{dx} \end{array} \right]$$

▶ Start

Theorem

$$\left[\begin{array}{l} g \text{ is differentiable at } x \\ f \text{ is differentiable at } g(x) \\ F = f \circ g, \quad F(x) = f(g(x)) \\ y = f(u) \\ u = g(x) \end{array} \right] \Rightarrow \left[\begin{array}{l} F \text{ is differentiable at } x \\ F'(x) = f'(g(x))g'(x) \\ \frac{dy}{dx} = \frac{dy}{du} \frac{du}{dx} \end{array} \right]$$

▶ Start

Proof.

$$\varepsilon_1(h) =$$

▶ Start

Proof.

$$\varepsilon_1(h) = \left\{ \right.$$

▶ Start

Proof.

$$\varepsilon_1(h) = \begin{cases} \frac{g(x+h) - g(x)}{h} - g'(x) & , \quad h \neq 0 \end{cases}$$

▶ Start

Proof.

$$\varepsilon_1(h) = \begin{cases} \frac{g(x+h) - g(x)}{h} - g'(x) & , \quad h \neq 0 \\ 0 & , \quad h = 0 \end{cases}$$

▶ Start

Proof.

$$\varepsilon_1(h) = \begin{cases} \frac{g(x+h) - g(x)}{h} - g'(x) & , \quad h \neq 0 \\ 0 & , \quad h = 0 \end{cases}$$

▶ Start

Proof.

$$\varepsilon_1(h) = \begin{cases} \frac{g(x+h) - g(x)}{h} - g'(x) & , \quad h \neq 0 \\ 0 & , \quad h = 0 \end{cases} \quad \varepsilon_1 \text{ is continuous at } h = 0$$

▶ Start

Proof.

$$\varepsilon_1(h) = \begin{cases} \frac{g(x+h) - g(x)}{h} - g'(x) & , \quad h \neq 0 \\ 0 & , \quad h = 0 \end{cases} \quad \varepsilon_1 \text{ is continuous at } h = 0 \text{ (}\because g \text{ is differentiable at } x\text{)}$$

▶ Start

Proof.

$$\varepsilon_1(h) = \begin{cases} \frac{g(x+h) - g(x)}{h} - g'(x) & , \quad h \neq 0 \\ 0 & , \quad h = 0 \end{cases} \quad \varepsilon_1 \text{ is continuous at } h = 0 \text{ (}\because g \text{ is differentiable at } x\text{)}$$

$$h \cdot \varepsilon_1(h)$$

▶ Start

Proof.

$$\varepsilon_1(h) = \begin{cases} \frac{g(x+h) - g(x)}{h} - g'(x) & , \quad h \neq 0 \\ 0 & , \quad h = 0 \end{cases} \quad \varepsilon_1 \text{ is continuous at } h = 0 \text{ (}\because g \text{ is differentiable at } x\text{)}$$

$$h \cdot \varepsilon_1(h) = \{g(x+h) - g(x)\} - g'(x) \cdot h$$

▶ Start

Proof.

$$\varepsilon_1(h) = \begin{cases} \frac{g(x+h) - g(x)}{h} - g'(x) & , \quad h \neq 0 \\ 0 & , \quad h = 0 \end{cases} \quad \varepsilon_1 \text{ is continuous at } h = 0 \text{ (}\because g \text{ is differentiable at } x)$$

$$h \cdot \varepsilon_1(h) = \{g(x+h) - g(x)\} - g'(x) \cdot h \quad , \quad g(x+h) - g(x) = g'(x) \cdot h + h \cdot \varepsilon_1(h)$$

▶ Start

Proof.

$$\varepsilon_1(h) = \begin{cases} \frac{g(x+h) - g(x)}{h} - g'(x) & , \quad h \neq 0 \\ 0 & , \quad h = 0 \end{cases} \quad \varepsilon_1 \text{ is continuous at } h = 0 \quad (\because g \text{ is differentiable at } x)$$

$$h \cdot \varepsilon_1(h) = \{g(x+h) - g(x)\} - g'(x) \cdot h \quad , \quad g(x+h) - g(x) = g'(x) \cdot h + h \cdot \varepsilon_1(h)$$

$$\varepsilon_2(k) =$$

▶ Start

Proof.

$$\varepsilon_1(h) = \begin{cases} \frac{g(x+h) - g(x)}{h} - g'(x) & , \quad h \neq 0 \\ 0 & , \quad h = 0 \end{cases} \quad \varepsilon_1 \text{ is continuous at } h = 0 \text{ (}\because g \text{ is differentiable at } x)$$

$$h \cdot \varepsilon_1(h) = \{g(x+h) - g(x)\} - g'(x) \cdot h \quad , \quad g(x+h) - g(x) = g'(x) \cdot h + h \cdot \varepsilon_1(h)$$

$$\varepsilon_2(k) = \left\{ \right.$$

▶ Start

Proof.

$$\varepsilon_1(h) = \begin{cases} \frac{g(x+h) - g(x)}{h} - g'(x) & , \quad h \neq 0 \\ 0 & , \quad h = 0 \end{cases} \quad \varepsilon_1 \text{ is continuous at } h = 0 \text{ (}\because g \text{ is differentiable at } x)$$

$$h \cdot \varepsilon_1(h) = \{g(x+h) - g(x)\} - g'(x) \cdot h \quad , \quad g(x+h) - g(x) = g'(x) \cdot h + h \cdot \varepsilon_1(h)$$

$$\varepsilon_2(k) = \begin{cases} \frac{f(u+k) - f(u)}{k} - f'(u) & , \quad k \neq 0 \end{cases}$$

▶ Start

Proof.

$$\varepsilon_1(h) = \begin{cases} \frac{g(x+h) - g(x)}{h} - g'(x) & , \quad h \neq 0 \\ 0 & , \quad h = 0 \end{cases} \quad \varepsilon_1 \text{ is continuous at } h = 0 \text{ (}\because g \text{ is differentiable at } x)$$

$$h \cdot \varepsilon_1(h) = \{g(x+h) - g(x)\} - g'(x) \cdot h, \quad g(x+h) - g(x) = g'(x) \cdot h + h \cdot \varepsilon_1(h)$$

$$\varepsilon_2(k) = \begin{cases} \frac{f(u+k) - f(u)}{k} - f'(u) & , \quad k \neq 0 \\ 0 & , \quad k = 0 \end{cases}$$

▶ Start

Proof.

$$\varepsilon_1(h) = \begin{cases} \frac{g(x+h) - g(x)}{h} - g'(x) & , \quad h \neq 0 \\ 0 & , \quad h = 0 \end{cases} \quad \varepsilon_1 \text{ is continuous at } h = 0 \text{ (}\because g \text{ is differentiable at } x)$$

$$h \cdot \varepsilon_1(h) = \{g(x+h) - g(x)\} - g'(x) \cdot h, \quad g(x+h) - g(x) = g'(x) \cdot h + h \cdot \varepsilon_1(h)$$

$$\varepsilon_2(k) = \begin{cases} \frac{f(u+k) - f(u)}{k} - f'(u) & , \quad k \neq 0 \\ 0 & , \quad k = 0 \end{cases}$$

▶ Start

Proof.

$$\varepsilon_1(h) = \begin{cases} \frac{g(x+h) - g(x)}{h} - g'(x) & , \quad h \neq 0 \\ 0 & , \quad h = 0 \end{cases} \quad \varepsilon_1 \text{ is continuous at } h = 0 \text{ (}\because g \text{ is differentiable at } x\text{)}$$

$$h \cdot \varepsilon_1(h) = \{g(x+h) - g(x)\} - g'(x) \cdot h, \quad g(x+h) - g(x) = g'(x) \cdot h + h \cdot \varepsilon_1(h)$$

$$\varepsilon_2(k) = \begin{cases} \frac{f(u+k) - f(u)}{k} - f'(u) & , \quad k \neq 0 \\ 0 & , \quad k = 0 \end{cases} \quad \varepsilon_2 \text{ is continuous at } k = 0$$

▶ Start

Proof.

$$\varepsilon_1(h) = \begin{cases} \frac{g(x+h) - g(x)}{h} - g'(x) & , \quad h \neq 0 \\ 0 & , \quad h = 0 \end{cases} \quad \varepsilon_1 \text{ is continuous at } h = 0 \quad (\because g \text{ is differentiable at } x)$$

$$h \cdot \varepsilon_1(h) = \{g(x+h) - g(x)\} - g'(x) \cdot h \quad , \quad g(x+h) - g(x) = g'(x) \cdot h + h \cdot \varepsilon_1(h)$$

$$\varepsilon_2(k) = \begin{cases} \frac{f(u+k) - f(u)}{k} - f'(u) & , \quad k \neq 0 \\ 0 & , \quad k = 0 \end{cases} \quad \varepsilon_2 \text{ is continuous at } k = 0 \quad (\because f \text{ is differentiable at } u)$$

▶ Start

Proof.

$$\varepsilon_1(h) = \begin{cases} \frac{g(x+h) - g(x)}{h} - g'(x) & , \quad h \neq 0 \\ 0 & , \quad h = 0 \end{cases} \quad \varepsilon_1 \text{ is continuous at } h = 0 \quad (\because g \text{ is differentiable at } x)$$

$$h \cdot \varepsilon_1(h) = \{g(x+h) - g(x)\} - g'(x) \cdot h \quad , \quad g(x+h) - g(x) = g'(x) \cdot h + h \cdot \varepsilon_1(h)$$

$$\varepsilon_2(k) = \begin{cases} \frac{f(u+k) - f(u)}{k} - f'(u) & , \quad k \neq 0 \\ 0 & , \quad k = 0 \end{cases} \quad \varepsilon_2 \text{ is continuous at } k = 0 \quad (\because f \text{ is differentiable at } u)$$

$$k \cdot \varepsilon_2(k)$$

▶ Start

Proof.

$$\varepsilon_1(h) = \begin{cases} \frac{g(x+h) - g(x)}{h} - g'(x) & , \quad h \neq 0 \\ 0 & , \quad h = 0 \end{cases} \quad \varepsilon_1 \text{ is continuous at } h = 0 \quad (\because g \text{ is differentiable at } x)$$

$$h \cdot \varepsilon_1(h) = \{g(x+h) - g(x)\} - g'(x) \cdot h \quad , \quad g(x+h) - g(x) = g'(x) \cdot h + h \cdot \varepsilon_1(h)$$

$$\varepsilon_2(k) = \begin{cases} \frac{f(u+k) - f(u)}{k} - f'(u) & , \quad k \neq 0 \\ 0 & , \quad k = 0 \end{cases} \quad \varepsilon_2 \text{ is continuous at } k = 0 \quad (\because f \text{ is differentiable at } u)$$

$$k \cdot \varepsilon_2(k) = \{f(u+k) - f(u)\} - f'(u) \cdot k$$

▶ Start

Proof.

$$\varepsilon_1(h) = \begin{cases} \frac{g(x+h) - g(x)}{h} - g'(x) & , \quad h \neq 0 \\ 0 & , \quad h = 0 \end{cases} \quad \varepsilon_1 \text{ is continuous at } h = 0 \quad (\because g \text{ is differentiable at } x)$$

$$h \cdot \varepsilon_1(h) = \{g(x+h) - g(x)\} - g'(x) \cdot h \quad , \quad g(x+h) - g(x) = g'(x) \cdot h + h \cdot \varepsilon_1(h)$$

$$\varepsilon_2(k) = \begin{cases} \frac{f(u+k) - f(u)}{k} - f'(u) & , \quad k \neq 0 \\ 0 & , \quad k = 0 \end{cases} \quad \varepsilon_2 \text{ is continuous at } k = 0 \quad (\because f \text{ is differentiable at } u)$$

$$k \cdot \varepsilon_2(k) = \{f(u+k) - f(u)\} - f'(u) \cdot k \quad , \quad f(u+k) - f(u) = f'(u) \cdot k + k \cdot \varepsilon_2(k)$$

▶ Start

Proof.

$$\varepsilon_1(h) = \begin{cases} \frac{g(x+h) - g(x)}{h} - g'(x) & , \quad h \neq 0 \\ 0 & , \quad h = 0 \end{cases} \quad \varepsilon_1 \text{ is continuous at } h = 0 \quad (\because g \text{ is differentiable at } x)$$

$$h \cdot \varepsilon_1(h) = \{g(x+h) - g(x)\} - g'(x) \cdot h \quad , \quad g(x+h) - g(x) = g'(x) \cdot h + h \cdot \varepsilon_1(h)$$

$$\varepsilon_2(k) = \begin{cases} \frac{f(u+k) - f(u)}{k} - f'(u) & , \quad k \neq 0 \\ 0 & , \quad k = 0 \end{cases} \quad \varepsilon_2 \text{ is continuous at } k = 0 \quad (\because f \text{ is differentiable at } u)$$

$$k \cdot \varepsilon_2(k) = \{f(u+k) - f(u)\} - f'(u) \cdot k \quad , \quad f(u+k) - f(u) = f'(u) \cdot k + k \cdot \varepsilon_2(k)$$

$$f(u+k) - f(u)$$

▶ Start

Proof.

$$\varepsilon_1(h) = \begin{cases} \frac{g(x+h) - g(x)}{h} - g'(x) & , \quad h \neq 0 \\ 0 & , \quad h = 0 \end{cases} \quad \varepsilon_1 \text{ is continuous at } h = 0 \quad (\because g \text{ is differentiable at } x)$$

$$h \cdot \varepsilon_1(h) = \{g(x+h) - g(x)\} - g'(x) \cdot h \quad , \quad g(x+h) - g(x) = g'(x) \cdot h + h \cdot \varepsilon_1(h)$$

$$\varepsilon_2(k) = \begin{cases} \frac{f(u+k) - f(u)}{k} - f'(u) & , \quad k \neq 0 \\ 0 & , \quad k = 0 \end{cases} \quad \varepsilon_2 \text{ is continuous at } k = 0 \quad (\because f \text{ is differentiable at } u)$$

$$k \cdot \varepsilon_2(k) = \{f(u+k) - f(u)\} - f'(u) \cdot k \quad , \quad f(u+k) - f(u) = f'(u) \cdot k + k \cdot \varepsilon_2(k)$$

$$f(u+k) - f(u) = f'(u) \cdot k + k \cdot \varepsilon_2(k)$$

▶ Start

Proof.

$$\varepsilon_1(h) = \begin{cases} \frac{g(x+h) - g(x)}{h} - g'(x) & , \quad h \neq 0 \\ 0 & , \quad h = 0 \end{cases} \quad \varepsilon_1 \text{ is continuous at } h = 0 \quad (\because g \text{ is differentiable at } x)$$

$$h \cdot \varepsilon_1(h) = \{g(x+h) - g(x)\} - g'(x) \cdot h \quad , \quad g(x+h) - g(x) = g'(x) \cdot h + h \cdot \varepsilon_1(h)$$

$$\varepsilon_2(k) = \begin{cases} \frac{f(u+k) - f(u)}{k} - f'(u) & , \quad k \neq 0 \\ 0 & , \quad k = 0 \end{cases} \quad \varepsilon_2 \text{ is continuous at } k = 0 \quad (\because f \text{ is differentiable at } u)$$

$$k \cdot \varepsilon_2(k) = \{f(u+k) - f(u)\} - f'(u) \cdot k \quad , \quad f(u+k) - f(u) = f'(u) \cdot k + k \cdot \varepsilon_2(k)$$

$$f(u+k) - f(u) = f'(u) \cdot k + k \cdot \varepsilon_2(k)$$

(Let $k = g(x+h) - g(x)$, $g(x+h)$)

The Chain Rule

▶ Start

Proof.

$$\varepsilon_1(h) = \begin{cases} \frac{g(x+h) - g(x)}{h} - g'(x) & , \quad h \neq 0 \\ 0 & , \quad h = 0 \end{cases} \quad \varepsilon_1 \text{ is continuous at } h = 0 \quad (\because g \text{ is differentiable at } x)$$

$$h \cdot \varepsilon_1(h) = \{g(x+h) - g(x)\} - g'(x) \cdot h \quad , \quad g(x+h) - g(x) = g'(x) \cdot h + h \cdot \varepsilon_1(h)$$

$$\varepsilon_2(k) = \begin{cases} \frac{f(u+k) - f(u)}{k} - f'(u) & , \quad k \neq 0 \\ 0 & , \quad k = 0 \end{cases} \quad \varepsilon_2 \text{ is continuous at } k = 0 \quad (\because f \text{ is differentiable at } u)$$

$$k \cdot \varepsilon_2(k) = \{f(u+k) - f(u)\} - f'(u) \cdot k \quad , \quad f(u+k) - f(u) = f'(u) \cdot k + k \cdot \varepsilon_2(k)$$

$$f(u+k) - f(u) = f'(u) \cdot k + k \cdot \varepsilon_2(k)$$

(Let $k = g(x+h) - g(x)$, $g(x+h) = g(x) + k$)

The Chain Rule

▶ Start

Proof.

$$\varepsilon_1(h) = \begin{cases} \frac{g(x+h) - g(x)}{h} - g'(x) & , \quad h \neq 0 \\ 0 & , \quad h = 0 \end{cases} \quad \varepsilon_1 \text{ is continuous at } h = 0 \quad (\because g \text{ is differentiable at } x)$$

$$h \cdot \varepsilon_1(h) = \{g(x+h) - g(x)\} - g'(x) \cdot h \quad , \quad g(x+h) - g(x) = g'(x) \cdot h + h \cdot \varepsilon_1(h)$$

$$\varepsilon_2(k) = \begin{cases} \frac{f(u+k) - f(u)}{k} - f'(u) & , \quad k \neq 0 \\ 0 & , \quad k = 0 \end{cases} \quad \varepsilon_2 \text{ is continuous at } k = 0 \quad (\because f \text{ is differentiable at } u)$$

$$k \cdot \varepsilon_2(k) = \{f(u+k) - f(u)\} - f'(u) \cdot k \quad , \quad f(u+k) - f(u) = f'(u) \cdot k + k \cdot \varepsilon_2(k)$$

$$f(u+k) - f(u) = f'(u) \cdot k + k \cdot \varepsilon_2(k)$$

(Let $k = g(x+h) - g(x)$, $g(x+h) = g(x) + k = u + k$)

The Chain Rule

▶ Start

Proof.

$$\varepsilon_1(h) = \begin{cases} \frac{g(x+h) - g(x)}{h} - g'(x) & , \quad h \neq 0 \\ 0 & , \quad h = 0 \end{cases} \quad \varepsilon_1 \text{ is continuous at } h = 0 \quad (\because g \text{ is differentiable at } x)$$

$$h \cdot \varepsilon_1(h) = \{g(x+h) - g(x)\} - g'(x) \cdot h \quad , \quad g(x+h) - g(x) = g'(x) \cdot h + h \cdot \varepsilon_1(h)$$

$$\varepsilon_2(k) = \begin{cases} \frac{f(u+k) - f(u)}{k} - f'(u) & , \quad k \neq 0 \\ 0 & , \quad k = 0 \end{cases} \quad \varepsilon_2 \text{ is continuous at } k = 0 \quad (\because f \text{ is differentiable at } u)$$

$$k \cdot \varepsilon_2(k) = \{f(u+k) - f(u)\} - f'(u) \cdot k \quad , \quad f(u+k) - f(u) = f'(u) \cdot k + k \cdot \varepsilon_2(k)$$

$$\begin{aligned} f(u+k) - f(u) &= f'(u) \cdot k + k \cdot \varepsilon_2(k) \\ f(g(x+h)) - f(g(x)) &\quad (\text{Let } k = g(x+h) - g(x) \quad , \quad g(x+h) = g(x) + k = u + k) \end{aligned}$$

The Chain Rule

▶ Start

Proof.

$$\varepsilon_1(h) = \begin{cases} \frac{g(x+h) - g(x)}{h} - g'(x) & , \quad h \neq 0 \\ 0 & , \quad h = 0 \end{cases} \quad \varepsilon_1 \text{ is continuous at } h = 0 \quad (\because g \text{ is differentiable at } x)$$

$$h \cdot \varepsilon_1(h) = \{g(x+h) - g(x)\} - g'(x) \cdot h \quad , \quad g(x+h) - g(x) = g'(x) \cdot h + h \cdot \varepsilon_1(h)$$

$$\varepsilon_2(k) = \begin{cases} \frac{f(u+k) - f(u)}{k} - f'(u) & , \quad k \neq 0 \\ 0 & , \quad k = 0 \end{cases} \quad \varepsilon_2 \text{ is continuous at } k = 0 \quad (\because f \text{ is differentiable at } u)$$

$$k \cdot \varepsilon_2(k) = \{f(u+k) - f(u)\} - f'(u) \cdot k \quad , \quad f(u+k) - f(u) = f'(u) \cdot k + k \cdot \varepsilon_2(k)$$

$$\begin{aligned} f(u+k) - f(u) &= f'(u) \cdot k + k \cdot \varepsilon_2(k) \\ f(g(x+h)) - f(g(x)) &= \{f'(u) + \varepsilon_2(g(x+h) - g(x))\} \{g(x+h) - g(x)\} \end{aligned}$$

(Let $k = g(x+h) - g(x)$, $g(x+h) = g(x) + k = u + k$)

The Chain Rule

▶ Start

Proof.

$$\varepsilon_1(h) = \begin{cases} \frac{g(x+h) - g(x)}{h} - g'(x) & , \quad h \neq 0 \\ 0 & , \quad h = 0 \end{cases} \quad \varepsilon_1 \text{ is continuous at } h = 0 \quad (\because g \text{ is differentiable at } x)$$

$$h \cdot \varepsilon_1(h) = \{g(x+h) - g(x)\} - g'(x) \cdot h \quad , \quad g(x+h) - g(x) = g'(x) \cdot h + h \cdot \varepsilon_1(h)$$

$$\varepsilon_2(k) = \begin{cases} \frac{f(u+k) - f(u)}{k} - f'(u) & , \quad k \neq 0 \\ 0 & , \quad k = 0 \end{cases} \quad \varepsilon_2 \text{ is continuous at } k = 0 \quad (\because f \text{ is differentiable at } u)$$

$$k \cdot \varepsilon_2(k) = \{f(u+k) - f(u)\} - f'(u) \cdot k \quad , \quad f(u+k) - f(u) = f'(u) \cdot k + k \cdot \varepsilon_2(k)$$

$$\begin{aligned} f(u+k) - f(u) &= f'(u) \cdot k + k \cdot \varepsilon_2(k) \\ &\quad (\text{Let } k = g(x+h) - g(x) \text{ , } g(x+h) = g(x) + k = u + k) \\ f(g(x+h)) - f(g(x)) &= \{f'(u) + \varepsilon_2(g(x+h) - g(x))\} \{g(x+h) - g(x)\} \\ &= \{f'(u) + \varepsilon_2(g(x+h) - g(x))\} \{g'(x) + \varepsilon_1(h)\} \cdot h \end{aligned}$$

The Chain Rule

▶ Start

Proof.

$$\varepsilon_1(h) = \begin{cases} \frac{g(x+h) - g(x)}{h} - g'(x) & , \quad h \neq 0 \\ 0 & , \quad h = 0 \end{cases} \quad \varepsilon_1 \text{ is continuous at } h = 0 \quad (\because g \text{ is differentiable at } x)$$

$$h \cdot \varepsilon_1(h) = \{g(x+h) - g(x)\} - g'(x) \cdot h \quad , \quad g(x+h) - g(x) = g'(x) \cdot h + h \cdot \varepsilon_1(h)$$

$$\varepsilon_2(k) = \begin{cases} \frac{f(u+k) - f(u)}{k} - f'(u) & , \quad k \neq 0 \\ 0 & , \quad k = 0 \end{cases} \quad \varepsilon_2 \text{ is continuous at } k = 0 \quad (\because f \text{ is differentiable at } u)$$

$$k \cdot \varepsilon_2(k) = \{f(u+k) - f(u)\} - f'(u) \cdot k \quad , \quad f(u+k) - f(u) = f'(u) \cdot k + k \cdot \varepsilon_2(k)$$

$$\begin{aligned} f(u+k) - f(u) &= f'(u) \cdot k + k \cdot \varepsilon_2(k) \\ &\quad (\text{Let } k = g(x+h) - g(x) \text{ , } g(x+h) = g(x) + k = u + k) \\ f(g(x+h)) - f(g(x)) &= \{f'(u) + \varepsilon_2(g(x+h) - g(x))\} \{g(x+h) - g(x)\} \\ &= \{f'(u) + \varepsilon_2(g(x+h) - g(x))\} \{g'(x) + \varepsilon_1(h)\} \cdot h \end{aligned}$$

$$F'(x)$$

Proof.

$$\varepsilon_1(h) = \begin{cases} \frac{g(x+h) - g(x)}{h} - g'(x) & , \quad h \neq 0 \\ 0 & , \quad h = 0 \end{cases} \quad \varepsilon_1 \text{ is continuous at } h = 0 \quad (\because g \text{ is differentiable at } x)$$

$$h \cdot \varepsilon_1(h) = \{g(x+h) - g(x)\} - g'(x) \cdot h \quad , \quad g(x+h) - g(x) = g'(x) \cdot h + h \cdot \varepsilon_1(h)$$

$$\varepsilon_2(k) = \begin{cases} \frac{f(u+k) - f(u)}{k} - f'(u) & , \quad k \neq 0 \\ 0 & , \quad k = 0 \end{cases} \quad \varepsilon_2 \text{ is continuous at } k = 0 \quad (\because f \text{ is differentiable at } u)$$

$$k \cdot \varepsilon_2(k) = \{f(u+k) - f(u)\} - f'(u) \cdot k \quad , \quad f(u+k) - f(u) = f'(u) \cdot k + k \cdot \varepsilon_2(k)$$

$$\begin{aligned} f(u+k) - f(u) &= f'(u) \cdot k + k \cdot \varepsilon_2(k) \\ &\quad (\text{Let } k = g(x+h) - g(x) \text{ , } g(x+h) = g(x) + k = u + k) \\ f(g(x+h)) - f(g(x)) &= \{f'(u) + \varepsilon_2(g(x+h) - g(x))\} \{g(x+h) - g(x)\} \\ &= \{f'(u) + \varepsilon_2(g(x+h) - g(x))\} \{g'(x) + \varepsilon_1(h)\} \cdot h \end{aligned}$$

$$F'(x) = \lim_{h \rightarrow 0} \frac{f(g(x+h)) - f(g(x))}{h}$$

The Chain Rule

▶ Start

Proof.

$$\varepsilon_1(h) = \begin{cases} \frac{g(x+h) - g(x)}{h} - g'(x) & , \quad h \neq 0 \\ 0 & , \quad h = 0 \end{cases} \quad \varepsilon_1 \text{ is continuous at } h = 0 \quad (\because g \text{ is differentiable at } x)$$

$$h \cdot \varepsilon_1(h) = \{g(x+h) - g(x)\} - g'(x) \cdot h \quad , \quad g(x+h) - g(x) = g'(x) \cdot h + h \cdot \varepsilon_1(h)$$

$$\varepsilon_2(k) = \begin{cases} \frac{f(u+k) - f(u)}{k} - f'(u) & , \quad k \neq 0 \\ 0 & , \quad k = 0 \end{cases} \quad \varepsilon_2 \text{ is continuous at } k = 0 \quad (\because f \text{ is differentiable at } u)$$

$$k \cdot \varepsilon_2(k) = \{f(u+k) - f(u)\} - f'(u) \cdot k \quad , \quad f(u+k) - f(u) = f'(u) \cdot k + k \cdot \varepsilon_2(k)$$

$$\begin{aligned} f(u+k) - f(u) &= f'(u) \cdot k + k \cdot \varepsilon_2(k) \\ &\quad (\text{Let } k = g(x+h) - g(x) \text{ , } g(x+h) = g(x) + k = u + k) \\ f(g(x+h)) - f(g(x)) &= \{f'(u) + \varepsilon_2(g(x+h) - g(x))\} \{g(x+h) - g(x)\} \\ &= \{f'(u) + \varepsilon_2(g(x+h) - g(x))\} \{g'(x) + \varepsilon_1(h)\} \cdot h \end{aligned}$$

$$\begin{aligned} F'(x) &= \lim_{h \rightarrow 0} \frac{f(g(x+h)) - f(g(x))}{h} \\ &= \lim_{h \rightarrow 0} \{f'(u) + \varepsilon_2(g(x+h) - g(x))\} \{g'(x) + \varepsilon_1(h)\} \end{aligned}$$

The Chain Rule

▶ Start

Proof.

$$\varepsilon_1(h) = \begin{cases} \frac{g(x+h) - g(x)}{h} - g'(x) & , \quad h \neq 0 \\ 0 & , \quad h = 0 \end{cases} \quad \varepsilon_1 \text{ is continuous at } h = 0 \quad (\because g \text{ is differentiable at } x)$$

$$h \cdot \varepsilon_1(h) = \{g(x+h) - g(x)\} - g'(x) \cdot h \quad , \quad g(x+h) - g(x) = g'(x) \cdot h + h \cdot \varepsilon_1(h)$$

$$\varepsilon_2(k) = \begin{cases} \frac{f(u+k) - f(u)}{k} - f'(u) & , \quad k \neq 0 \\ 0 & , \quad k = 0 \end{cases} \quad \varepsilon_2 \text{ is continuous at } k = 0 \quad (\because f \text{ is differentiable at } u)$$

$$k \cdot \varepsilon_2(k) = \{f(u+k) - f(u)\} - f'(u) \cdot k \quad , \quad f(u+k) - f(u) = f'(u) \cdot k + k \cdot \varepsilon_2(k)$$

$$\begin{aligned} f(u+k) - f(u) &= f'(u) \cdot k + k \cdot \varepsilon_2(k) \\ &\quad (\text{Let } k = g(x+h) - g(x) \text{ , } g(x+h) = g(x) + k = u + k) \\ f(g(x+h)) - f(g(x)) &= \{f'(u) + \varepsilon_2(g(x+h) - g(x))\} \{g(x+h) - g(x)\} \\ &= \{f'(u) + \varepsilon_2(g(x+h) - g(x))\} \{g'(x) + \varepsilon_1(h)\} \cdot h \end{aligned}$$

$$\begin{aligned} F'(x) &= \lim_{h \rightarrow 0} \frac{f(g(x+h)) - f(g(x))}{h} \\ &= \lim_{h \rightarrow 0} \{f'(u) + \varepsilon_2(g(x+h) - g(x))\} \{g'(x) + \varepsilon_1(h)\} \\ &= f'(u)g'(x) \end{aligned}$$



The Chain Rule

▶ Start

Proof.

$$\varepsilon_1(h) = \begin{cases} \frac{g(x+h) - g(x)}{h} - g'(x) & , \quad h \neq 0 \\ 0 & , \quad h = 0 \end{cases} \quad \varepsilon_1 \text{ is continuous at } h = 0 \quad (\because g \text{ is differentiable at } x)$$

$$h \cdot \varepsilon_1(h) = \{g(x+h) - g(x)\} - g'(x) \cdot h \quad , \quad g(x+h) - g(x) = g'(x) \cdot h + h \cdot \varepsilon_1(h)$$

$$\varepsilon_2(k) = \begin{cases} \frac{f(u+k) - f(u)}{k} - f'(u) & , \quad k \neq 0 \\ 0 & , \quad k = 0 \end{cases} \quad \varepsilon_2 \text{ is continuous at } k = 0 \quad (\because f \text{ is differentiable at } u)$$

$$k \cdot \varepsilon_2(k) = \{f(u+k) - f(u)\} - f'(u) \cdot k \quad , \quad f(u+k) - f(u) = f'(u) \cdot k + k \cdot \varepsilon_2(k)$$

$$\begin{aligned} f(u+k) - f(u) &= f'(u) \cdot k + k \cdot \varepsilon_2(k) \\ &\quad (\text{Let } k = g(x+h) - g(x) \text{ , } g(x+h) = g(x) + k = u + k) \\ f(g(x+h)) - f(g(x)) &= \{f'(u) + \varepsilon_2(g(x+h) - g(x))\} \{g(x+h) - g(x)\} \\ &= \{f'(u) + \varepsilon_2(g(x+h) - g(x))\} \{g'(x) + \varepsilon_1(h)\} \cdot h \end{aligned}$$

$$\begin{aligned} F'(x) &= \lim_{h \rightarrow 0} \frac{f(g(x+h)) - f(g(x))}{h} \\ &= \lim_{h \rightarrow 0} \{f'(u) + \varepsilon_2(g(x+h) - g(x))\} \{g'(x) + \varepsilon_1(h)\} \\ &= f'(u)g'(x) = f'(g(x))g'(x) \end{aligned}$$



The Chain Rule

▶ Start

Proof.

$$\varepsilon_1(h) = \begin{cases} \frac{g(x+h) - g(x)}{h} - g'(x) & , \quad h \neq 0 \\ 0 & , \quad h = 0 \end{cases} \quad \varepsilon_1 \text{ is continuous at } h = 0 \quad (\because g \text{ is differentiable at } x)$$

$$h \cdot \varepsilon_1(h) = \{g(x+h) - g(x)\} - g'(x) \cdot h \quad , \quad g(x+h) - g(x) = g'(x) \cdot h + h \cdot \varepsilon_1(h)$$

$$\varepsilon_2(k) = \begin{cases} \frac{f(u+k) - f(u)}{k} - f'(u) & , \quad k \neq 0 \\ 0 & , \quad k = 0 \end{cases} \quad \varepsilon_2 \text{ is continuous at } k = 0 \quad (\because f \text{ is differentiable at } u)$$

$$k \cdot \varepsilon_2(k) = \{f(u+k) - f(u)\} - f'(u) \cdot k \quad , \quad f(u+k) - f(u) = f'(u) \cdot k + k \cdot \varepsilon_2(k)$$

$$\begin{aligned} f(u+k) - f(u) &= f'(u) \cdot k + k \cdot \varepsilon_2(k) \\ &\quad (\text{Let } k = g(x+h) - g(x) \text{ , } g(x+h) = g(x) + k = u + k) \\ f(g(x+h)) - f(g(x)) &= \{f'(u) + \varepsilon_2(g(x+h) - g(x))\} \{g(x+h) - g(x)\} \\ &= \{f'(u) + \varepsilon_2(g(x+h) - g(x))\} \{g'(x) + \varepsilon_1(h)\} \cdot h \end{aligned}$$

$$\begin{aligned} F'(x) &= \lim_{h \rightarrow 0} \frac{f(g(x+h)) - f(g(x))}{h} \\ &= \lim_{h \rightarrow 0} \{f'(u) + \varepsilon_2(g(x+h) - g(x))\} \{g'(x) + \varepsilon_1(h)\} \\ &= f'(u)g'(x) = f'(g(x))g'(x) \end{aligned}$$



▶ Home

END