3.6 Chain Rule: Derivative of Composite Functions

Goal:
Find derivatives of composite functions.

Examples:

$y = (2x^3 + 1)^{10}$ $g(x)=\sqrt{9 - 4x}$ $y = [\sin(2x^3+1)]^5$

Study 3.6 # 215 - 237, 241, 243, 253, 255 or 257, 259

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Extra problems

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3.6 Chain Rule: Derivative of Composite Functions

$$y = (2x^3 + 1)^2$$

$y = (2x^3 + 1)^{10}$

F: dy/dx

$$y = (2x^3+1)(2x^3+1)$$

$$\frac{dy}{dx} = (2x^3+1)(6x^2) + (2x^3+1)(6x^2)$$

$$= 2(6x^2)(2x^3+1) = 12x^2(2x^3+1)$$

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3.6 Chain Rule: Derivative of Composite Functions

$y = (2x^3 + 1)^2$ F: dy/dx $y = (2x^3 + 1)^{10}$

$y = (2x^3 + 1)(2x^3 + 1)$

$dy/dx = (2x^3 + 1)(6x^2) + (2x^3 + 1)(6x^2)$ Use Product Rule

$dy/dx = 2(2x^3 + 1)(6x^2)$

$dy/dx = 12x^2(2x^3 + 1)$

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3.6 Chain Rule: Derivative of Composite Functions

$y = (2x^3 + 1)^{10}$

$y = (2x^3 + 1)^2$ F: dy/dx

Can we use the Power Rule to get the correct answer?

$\frac{dy}{dx} \neq 2(2x^3+1)^1$? $dy/dx = 12x^2(2x^3 + 1)$

$6x^2$ from previous

NO! Not alone.

NEED FACTOR: $6x^2 = \frac{d\,[2x^3+1]}{dx}$

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3.6 Chain Rule: Derivative of Composite Functions

$y = (2x^3 + 1)^{10}$

What makes this a composite function?

$y = (2x^3 + 1)^2$

let $u = 2x^3 + 1$, then $y = u^2$

u is a function of x and
y is a function of u

....

OR: let $f(x) = 2x^3 + 1$, and $g(x) = x^2$ From Chapter 1

then $y = g(f(x))$

$g(f(x)) = (2x^3+1)^2$

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3.6 Chain Rule: Derivative of Composite Functions

$y = (2x^3 + 1)^{10}$

$y = (2x^3 + 1)^2$ F: dy/dx

Find dy/dx again, from the beginning to the end.

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3.6 Chain Rule: Derivative of Composite Functions

$y = (2x^3 + 1)^{10}$ F: dy/dx

For composite functions where y = f(u) and u = f(x),

$$\boxed{\begin{array}{c}\text{Chain Rule}\\[6pt] \dfrac{dy}{dx} = \dfrac{dy}{du} \cdot \dfrac{du}{dx}\end{array}}$$

3.6 Chain Rule: Derivative of Composite Functions

$y = (2x^3 + 1)^{10}$ F: dy/dx

$y = u^{10}$ | $u = 2x^3 + 1$

$\dfrac{dy}{du} = 10u^9$ | $\dfrac{du}{dx} = 6x^2$

$$\frac{dy}{dx} = \frac{dy}{du} \cdot \frac{du}{dx}$$
$$= 10u^9\, 6x^2$$
$$= 10(2x^3+1)^9\, 6x^2$$

$$\frac{dy}{dx} = 10(2x^3+1)^9(6x^2)$$
$$= 60x^2(2x^3+1)^9$$

3.6 Chain Rule: Derivative of Composite Functions

$y = (2x^3 + 1)^{10}$ F: dy/dx

Directly

$dy/dx=10(2x^3+1)^9(6x^2)$

$dy/dx= 60x^2(2x^3+1)^9$

Using u substitution for inner function

$y = u^{10}$ $u = 2x^3+1$

$\frac{dy}{du} = 10u^9$ $\frac{du}{dx} = 6x^2$

$$\frac{dy}{dx} = \frac{dy}{du} \cdot \frac{du}{dx}$$

$$= 10u^9(6x^2)$$

$$= 10(2x^3+1)^9(6x^2)$$

$$= 60x^2(2x^3+1)^9$$

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3.6 Chain Rule: Derivative of Composite Functions

Chain Rule

If:

1) $y = f(u)$ is a differentiable function of u, and
2) $u=g(x)$ is a differentiable function of x,

then

$y = f(g(x))$ is a differentiable function of x, and

$$\boxed{\frac{dy}{dx} = \frac{dy}{du} \bullet \frac{du}{dx}}$$

or

$$\boxed{\frac{d}{dx}[f(g(x))] = f'(g(x))g'(x)}$$

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3.6 Chain Rule: Derivative of Composite Functions

228. $y = \left(3x^2 + 3x - 1\right)^4$ F: dy/dx

$$\frac{dy}{dx} = 4(3x^2+3x-1)^3(6x+3)$$

$$= 12(2x+1)(3x^2+3x-1)^3$$

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3.6 Chain Rule: Derivative of Composite Functions

228. $y = \left(3x^2 + 3x - 1\right)^4$

F: dy/dx

Directly

$dy/dx=4(3x^2+3x-1)^3(6x+3)$

$dy/dx=4(6x+3)(3x^2+3x-1)^3$

Using u substitution for inner function

$y = u^4 \qquad u = 3x^2+3x-1$

$\frac{dy}{du} = 4u^3 \qquad \frac{du}{dx} = 6x+3$

$$\frac{dy}{dx} = \frac{dy}{du} \cdot \frac{du}{dx}$$

$$= 4u^3(6x+3)$$

$$= 4(3x^2+3x-1)^3(6x+3)$$

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3.6 Chain Rule: Derivative of Composite Functions

222. $y = \sin^5(x)$ F: dy/dx

Rewrite: $y = [\sin x]^5$

3.6 Chain Rule: Derivative of Composite Functions

222. $y = \sin^5(x)$ F: dy/dx

Rewrite: $y = [\sin x]^5$

Directly

$dy/dx = 5(\sin x)^4 (\cos x)$

Using u substitution for inner function

$y = u^5 \qquad u = \sin x$

$\frac{dy}{du} = 5u^4 \qquad \frac{du}{dx} = \cos x$

$$\frac{dy}{dx} = \frac{dy}{du} \cdot \frac{du}{dx}$$

$$= 5u^4 (\cos x)$$

$$= 5(\sin x)^4 (\cos x)$$

3.6 Chain Rule: Derivative of Composite Functions

$y = \sin x^5$ F: dy/dx

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3.6 Chain Rule: Derivative of Composite Functions

$y = \sin x^5$ F: dy/dx

$$\frac{dy}{dx} = (\cos x^5)(5x^4)$$

$$= 5x^4 \cos x^5$$

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3.6 Chain Rule: Derivative of Composite Functions

$$y = (\sin x^2)^3$$ F: dy/dx

3.6 Chain Rule: Derivative of Composite Functions

$y = (\sin x^2)^3$ F: dy/dx

$y = (\sin x^2)^3$

$y = (\quad)^3$ Outer function is cube of something: $(\square)^3$

$y = (\sin \quad)^3$ Inner function is sine of something: $\sin \square$

$y = (\sin x^2)^3$ Innermost function is square of something: $(\square)^2$

3.6 Chain Rule: Derivative of Composite Functions

$y = (\sin x^2)^3$ F: dy/dx

Chain Rule

$$\frac{dy}{dx} = \frac{dy}{du} \cdot \frac{du}{dx}$$

$y = f(u) = u^3$

$u = g(v) = \sin v$

$v = h(x) = x^2$

then $y = f(g(h(x)))$

expanded chain rule:

$$\frac{dy}{dx} = \frac{dy}{du} \cdot \frac{du}{dv} \cdot \frac{dv}{dx}$$

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3.6 Chain Rule: Derivative of Composite Functions

$y = (\sin x^2)^3$ F: dy/dx

Chain Rule

$$\frac{dy}{dx} = \frac{dy}{du} \cdot \frac{du}{dx}$$

$y = f(u) = u^3$

$u = g(v) = \sin v$

$v = h(x) = x^2$

then $y = f(g(h(x)))$

$$\frac{dy}{dx} = 3(\sin x^2)^2 \cdot (\cos x^2)(2x)$$

$$= 6x(\cos x^2)(\sin x^2)^2$$

expanded chain rule:

$$\frac{dy}{dx} = \frac{dy}{du} \cdot \frac{du}{dv} \cdot \frac{dv}{dx}$$

NOTE: $\sin^2 x \neq \sin x^2$

$\sin^2 x = (\sin x)^2$

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3.6 Chain Rule: Derivative of Composite Functions

$y = \sin \underline{x^2}$

$\frac{dy}{dx} = +(\cos x^2)(2x)$

$= +2x \cos x^2$

$\sin^2 x \neq \sin x^2$

$(\sin x)^2 \neq \sin x^2$

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3.6 Chain Rule: Derivative of Composite Functions

co-functions

$\frac{d(\sin x)}{dx} = \cos x$

$\frac{d(\cos x)}{dx} = -\sin x$

$\frac{d(\tan x)}{dx} = \sec^2 x$

$\frac{d(\cot x)}{dx} = -\csc^2 x$

$\frac{d(\sec x)}{dx} = \sec x \tan x$

$\frac{d(\csc x)}{dx} = -\csc x \cot x$

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3.6 Chain Rule: Derivative of Composite Functions

co-functions

$$\frac{d(\sin u)}{dx} = \cos u \frac{du}{dx} \qquad \frac{d(\cos u)}{dx} = -\sin u \frac{du}{dx}$$

$$\frac{d(\tan u)}{dx} = \sec^2 u \frac{du}{dx} \qquad \frac{d(\cot u)}{dx} = -\csc^2 u \frac{du}{dx}$$

$$\frac{d(\sec x)}{dx} = \sec u \tan u \frac{du}{dx} \qquad \frac{d(\csc u)}{dx} = -\csc u \cot u \frac{du}{dx}$$

$$\sin^2(3x^2-4x+1) + \cos^2(3x^2-4x+1) = 1$$

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$$y = \cos\sqrt{t} \qquad F: \frac{dy}{dt}$$

$$\frac{dy}{dt} = -(\sin\sqrt{t})\left(\frac{1}{2}t^{-1/2}\right) = \frac{-\sin\sqrt{t}}{2\sqrt{t}}$$

$$\sqrt{t} = t^{1/2}$$

$$\frac{d(t^{1/2})}{dt} = \frac{1}{2}t^{-1/2}$$

3.6 Chain Rule: Derivative of Composite Functions

226. $y = \cot^2 x$

232. $y = \dfrac{1}{\sin^2(x)}$

234. $y = x^2 \cos^4 x$

224. $y = \tan(\sec x)$

242. **[T]** Find the equation of the tangent line to $y = \left(3x + \frac{1}{x}\right)^2$ at the point $(1, 16)$. Use a calculator to graph the function and the tangent line together.

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3.6 Chain Rule: Derivative of Composite Functions

226. $y = \cot^2 x$

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3.6 Chain Rule: Derivative of Composite Functions

226. $y = \cot^2 x$

$$\frac{dy}{dx} = 2\cot x\,(-\csc^2 x)$$

$$= -2\cot x \csc^3 x$$

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3.6 Chain Rule: Derivative of Composite Functions

232. $y = \dfrac{1}{\sin^2(x)}$

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3.6 Chain Rule: Derivative of Composite Functions

232. $y = \dfrac{1}{\sin^2(x)} = \csc^2 x$

$y = (\sin x)^{-2}$

$\dfrac{dy}{dx} = -2(\sin x)^{-3}\cos x$

$= -\dfrac{2\cos x}{\sin^3 x}$

$\dfrac{dy}{dx} = 2\csc x(-\csc x \cot x)$

$= \boxed{-2\csc^2 x \cot x}$

$= -2\dfrac{1}{\sin^2 x}\cdot\dfrac{\cos x}{\sin x}$

$= -\dfrac{2\cos x}{\sin^3 x}$

3.6 Chain Rule: Derivative of Composite Functions

234. $y = x^2 \cos^4 x$

3.6 Chain Rule: Derivative of Composite Functions

$$234. \quad y = (x^2)(\cos^4 x)$$

$$\frac{dy}{dx} = x^2 \frac{d(\cos^4 x)}{dx} + \cos^4 x \frac{d(x^2)}{dx}$$

$$= x^2 4\cos^3 x(-\sin x) + 2x\cos^4 x$$

$$= -4x^2 \sin x \cos^3 x + 2x\cos^4 x$$

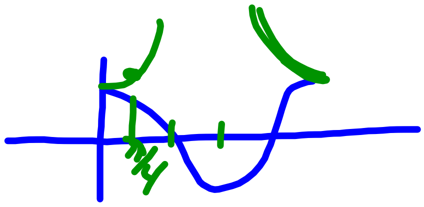
3.6 Chain Rule: Derivative of Composite Functions

$$224. \quad y = \tan(\sec x)$$

3.6 Chain Rule: Derivative of Composite Functions

224. $y = \tan(\sec x)$

$$\frac{dy}{dx} = \sec^2(\sec x)\sec x \tan x$$



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3.6 Chain Rule: Derivative of Composite Functions

242. **[T]** Find the equation of the tangent line to $y = \left(3x + \frac{1}{x}\right)^2$ at the point (1, 16). Use a calculator to graph the function and the tangent line together.

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3.6 Chain Rule: Derivative of Composite Functions

242. **[T]** Find the equation of the tangent line to $y = \left(3x + \frac{1}{x}\right)^2$ at the point (1, 16). Use a calculator to graph the function and the tangent line together.

F: eq. tan. line. at (1, 16)

$y = \left(3x + \frac{1}{x}\right)^2$

$y = (3x + x^{-1})^2$

$\frac{dy}{dx} = 2(3x + x^{-1})^1 (3 - x^{-2})$

$\frac{dy}{dx} = 2\left(3x + \frac{1}{x}\right)\left(3 - \frac{1}{x^2}\right)$

$\left.\frac{dy}{dx}\right|_{(1,16)} = 2(3+1)(3-1)$

$m_T = 2(4)(2) = 16$

$y - y_1 = m_T(x - x_1)$

$y - 16 = m_T(x - 1)$

$y - 16 = 16(x - 1)$

$y - 16 = 16x - 16$

$y = 16x$

3.6 Chain Rule: Derivative of Composite Functions

Follow-up

236. $y = \sqrt{6 + \sec \pi x^2}$

Try $y = \sqrt{6 + \sin x}$

$y = \sqrt{10 + \sec x}$

3.6 Chain Rule: Derivative of Composite Functions

This is the beginning of extra problems that were not done in class.

$G: y = \sqrt[3]{6x^2+1}$ $F: \frac{dy}{dx}$

$= (6x^2+1)^{1/3}$ $u = 6x^2+1$

$\frac{dy}{dx} = \frac{1}{3}(6x^2+1)^{-2/3}(12x)$

$= \frac{4x}{(6x^2+1)^{2/3}}$ $\frac{4x}{\sqrt[3]{(6x^2+1)^2}}$

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derivative practice

3.6 Chain Rule: Derivative of Composite Functions

$g(x) = \sqrt{9-4x}$ $F: g'(x)$

$y = (9-4x)^{1/2}$ $u = 9-4x$

$\frac{du}{dx} = -4$

$y = u^{1/2}$

$\frac{dy}{du} = \frac{1}{2}u^{-1/2} = \frac{1}{2\sqrt{u}}$

$\frac{dy}{dx} = \frac{dy}{du} \cdot \frac{du}{dx}$

$= \frac{1}{2\sqrt{9-4x}} \cdot (-4) = \frac{-2}{\sqrt{9-4x}}$

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3.6 Chain Rule: Derivative of Composite Functions

$$h(t)=\left(\frac{t^2}{t^3+2}\right)^2 \qquad F: h'(t)$$

$$u=\frac{t^2}{t^3+2}$$

$$h=u^2$$

$$\frac{dh}{dt}=2u\cdot\frac{du}{dt}$$

$$=2\cdot\frac{t^2}{(t^3+2)}\cdot\frac{t(4-t^3)}{(t^3+2)^2}$$

$$=\frac{2t^3(4-t^3)}{(t^3+2)^3}$$

$$\frac{du}{dt}=\frac{(t^3+2)(2t)-t^2(3t^2)}{(t^3+2)^2}$$

$$=\frac{2t^4+4t-3t^4}{(t^3+2)^2}$$

$$=\frac{4t-t^4}{(t^3+2)^2}$$

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3.6 Chain Rule: Derivative of Composite Functions

$$h(t)=\left(\frac{t^2}{t^3+2}\right)^2 \qquad F: h'(t)$$

one option: $\left(\frac{a}{b}\right)^2=\frac{a^2}{b^2}$

$$=\frac{t^4}{(t^3+2)^2}=\frac{t^4}{t^6+4t^3+4}$$

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then use Quotient Rule

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3.6 Chain Rule: Derivative of Composite Functions

G: $f(x) = \frac{1}{(x^2-3x)^2}$

F: $\boxed{f'(x)}$ at $(4, \frac{1}{16})$

or $f'(4)$

$= (x^2-3x)^{-2}$

$u = x^2-3x$

$\frac{du}{dx} = 2x-3$

$f'(x) = -2(x^2-3x)^{-3}(2x-3)$

$= \frac{-2(2x-3)}{(x^2-3x)^3}$

$f'(4) = \frac{-2(5)}{(16-12)^3} = \frac{-10}{64} = \frac{-5}{32}$

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2.4 Chain Rule: Derivative of Composite Functions

$y = \sqrt{\frac{2x}{x+1}} = \left(\frac{2x}{x+1}\right)^{1/2}$

$u = \frac{2x}{x+1}$

$\frac{du}{dx} = \frac{(x+1)2-2x(1)}{(x+1)^2}$

$= \frac{2x+2-2x}{(x+1)^2}$

$= \frac{2}{(x+1)^2}$

$y = u^{1/2}$

$\frac{dy}{du} = \frac{1}{2}u^{-1/2}$

$\frac{dy}{dx} = \frac{dy}{du} \cdot \frac{du}{dx}$

$= \frac{1}{2\sqrt{u}} \cdot \frac{2}{(x+1)^2}$

$= \frac{1}{\sqrt{\frac{2x}{x+1}}} \cdot \frac{1}{(x+1)^2} = \sqrt{\frac{x+1}{2x}} \cdot \frac{1}{(x+1)^2} = \frac{(x+1)^{\frac{1}{2}}}{\sqrt{2x}(x+1)^2}$

$= \frac{1}{\sqrt{2x}(x+1)^{3/2}}$

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2.4 Chain Rule: Derivative of Composite Functions

$$g(t)=\sqrt{\sqrt{t+1}+1}=\left((t+1)^{1/2}+1\right)^{1/2}$$

$$g'(t)=\frac{1}{2}\left[(t+1)^{1/2}+1\right]^{-1/2}\frac{d\left[(t+1)^{1/2}+1\right]}{dt}$$

$$=\frac{1}{2}\left[(t+1)^{1/2}+1\right]^{-1/2}\cdot\left[\frac{1}{2}(t+1)^{-1/2}\frac{d(t+1)}{dt}\right]$$

$$\frac{d(t+1)}{dt}=1$$

$$=\frac{1}{2}\left[(t+1)^{1/2}+1\right]^{-1/2}\cdot\left[\frac{1}{2}(t+1)^{-1/2}(1)\right]$$

$$=\frac{1}{2\sqrt{\sqrt{t+1}+1}}\cdot\frac{1}{2\sqrt{t+1}}$$

$$=\frac{1}{4\sqrt{t+1}\sqrt{\sqrt{t+1}+1}}$$

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2.4 Chain Rule: Derivative of Composite Functions

$$y=(9x+2)^{2/3}$$

F: $\frac{dy}{dx}$

$u=9x+2$

$\frac{du}{dx}=9$

$$\frac{dy}{dx}=\frac{2}{3}(9x+2)^{-1/3}(9)$$

$$=\frac{6}{(9x+2)^{1/3}}$$

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G: $y = 2\tan^3 x$

F: eq. of tang at $\left(\frac{\pi}{4}, 2\right)$

$y - y_1 = m_T(x - x_1)$

$y - 2 = m_T\left(x - \frac{\pi}{4}\right)$

$u = \tan x$

$\frac{du}{dx} = \sec^2 x$

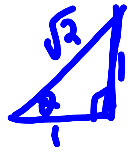
$\frac{dy}{dx} = 2\cdot 3(\tan x)^2 \sec^2 x$

$= 6\tan^2 x \sec^2 x$

$\left.\frac{dy}{dx}\right|_{\left(\frac{\pi}{4},2\right)} = 6\left(\tan\frac{\pi}{4}\right)^2\left(\sec\frac{\pi}{4}\right)^2$

$= 6\cdot 1\cdot\left(\frac{1}{\cos\frac{\pi}{4}}\right)^2 = 6\cdot 1\cdot(\sqrt{2})^2$

$= 12$



$y - 2 = 12\left(x - \frac{\pi}{4}\right)$

$y = 12x - 3\pi + 2$

2.4 Chain Rule: Derivative of Composite Functions

$y = (9x+2)^{2/3}$

F: $\frac{dy}{dx}$

$y = u^{2/3}$

$\frac{dy}{du} = \frac{2}{3}u^{-1/3}$

$u = 9x + 2$

$\frac{du}{dx} = 9$

$\frac{dy}{dx} = \frac{dy}{du}\cdot\frac{du}{dx}$

$= \frac{2}{3}u^{-1/3}\cdot 9 = \frac{6}{u^{1/3}} = \frac{6}{(9x+2)^{1/3}}$

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2.4 Chain Rule: Derivative of Composite Functions

$y = \sqrt{5-3x}$ F: dy/dx

$y = \sqrt{5-3x} = (5-3x)^{1/2}$

$u = 5-3x$

$\frac{du}{dx} = -3$

$y = u^{1/2}$

$\frac{dy}{du} = \frac{1}{2}u^{-1/2}$

$\frac{dy}{dx} = \frac{dy}{du} \cdot \frac{du}{dx} = \frac{1}{2}u^{-1/2}(-3) = \frac{-3}{2u^{1/2}}$

$= \frac{-3}{2\sqrt{5-3x}}$

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2.4 Chain Rule: Derivative of Composite Functions

$y = \sin \pi x$ F: dy/dx

$u = \pi x$

$\frac{du}{dx} = \pi$

$\frac{dy}{dx} = (\cos \pi x)\,\pi$

$= \pi \cos \pi x$

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2.4 Chain Rule: Derivative of Composite Functions

$y = \sin \underline{\frac{3\pi}{2}x}$

F: dy/dx

$u = \frac{3\pi}{2}x$

$\frac{du}{dx} = \frac{3\pi}{2}$

$\frac{dy}{dx} = \frac{3\pi}{2}\cos\frac{3\pi}{2}x$

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