Goal: Differentiate functions of the form $F(x, y) = 0$. Use this to find the derivative of conic sections and inverse trigonometric functions.

Recall ① If y is a function of x

- $\frac{d}{dx}(y^2) = 2y\frac{dy}{dx}$

  $[y(x)]^2$

- $\ln(y) = \ln(y(x))$

  $\frac{d}{dx}(\ln y) = \frac{1}{y} \cdot \frac{dy}{dx}$

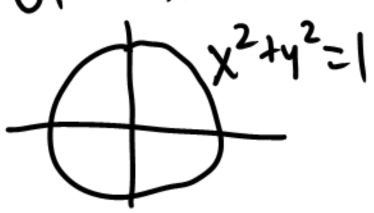
- $\sin(y) = \cos(y) \cdot \frac{dy}{dx}$

② Taking the derivative does not change equality

$$y - 2x - 1 = 0$$
$$\frac{d}{dx}(y - 2x - 1) = \frac{d}{dx}(0)$$
$$y' - 2 = 0$$
$$y' = 2$$

$$y = 2x + 1$$
$$y' = 2$$

Q: How can we find the slope of the tangent line of the unit circle?



A: Recognize that y is a function of x

$$\frac{d}{dx}(x^2 + y^2) = \frac{d}{dx}(1)$$
$$2x + 2y\frac{dy}{dx} = 0$$
$$2y\frac{dy}{dx} = -2x$$
$$\longrightarrow \frac{dy}{dx} = -\frac{2x}{2y} = -\frac{x}{y}$$

Q: Can we write $\frac{dy}{dx}$ solely as a function of x?

A: Sometimes!

$$x^2+y^2=1$$
$$y^2=1-x^2$$
$$y=\pm\sqrt{1-x^2}$$

$$\frac{dy}{dx}=\begin{cases} -\frac{x}{\sqrt{1-x^2}} & \text{if } y>0 \\ -\frac{x}{(-\sqrt{1-x^2})} & \text{if } y<0 \end{cases}$$

$x^2+y^2=1$ is an example of an <u>implicit function</u> of x. Finding $\frac{dy}{dx}$ is called <u>implicit differentiation</u>

Ex/

Explicit Functions	Implicit Functions
$y=f(x)$	$F(x,y)=0$
$y=2x-1$	$x^2+y^2-1=0$
$y=\sin(x)$	$\sin(xy)=0$
$y=\ln(x^2)\cdot\cos(x)$	$e^{xy}+x^2=0$

$\frac{dy}{dx}=y'$

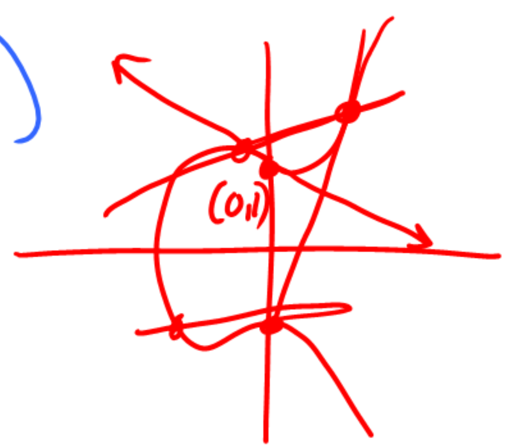
Ex/ Find $\frac{dy}{dx}$ for the elliptic curve

$$y^2=x^3-x-1$$

$y=F(x)$

at $(x,y)=(0,1)$

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



$$\left.\frac{dy}{dx}\right]_{(0,1)} = \frac{3(0)^2-1}{2(1)} = -\frac{1}{2}$$

$$[x \cdot y_{(x)}]'$$

Ex2/ Find $\frac{dy}{dx}$ given $\sin(xy) = x$

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

$$\cos(xy) \cdot [xy]' = 1$$

$$\cos(xy)\left[y + x\frac{dy}{dx}\right] = 1$$

$$y\cos(xy) + x\cos(xy)\frac{dy}{dx} = 1$$

$$x\cos(xy)\frac{dy}{dx} = 1 - y\cos(xy)$$

$$\frac{dy}{dx} = \frac{1 - y\cos(xy)}{x\cos(xy)}$$

Ex3/ Find $\frac{dy}{dx}$ given $xe^y = 9y$

$$\frac{d}{dx}(xe^y) = \frac{d}{dx}(9y)$$

$$e^y + xe^y\frac{dy}{dx} = 9\frac{dy}{dx}$$

$$xe^y\frac{dy}{dx} - 9\frac{dy}{dx} = -e^y$$

$$(xe^y - 9)\frac{dy}{dx} = -e^y$$

$$\frac{dy}{dx} = -\frac{e^y}{xe^y-9} = \frac{e^y}{9-xe^y}$$

Ex/ ~~Find~~ Find $\frac{dy}{dx}$ given $\ln\left(\frac{x}{y}\right) = 6x$

$$\frac{d}{dx}\left(\ln(x) - \ln(y)\right) = \frac{d}{dx}(6x)$$

$$(-y)\left(\frac{1}{x} - \frac{1}{y}\cdot\frac{dy}{dx}\right) = (6)(-y)$$

$$-\frac{y}{x} + \frac{dy}{dx} = -6y$$

$$\frac{dy}{dx} = \frac{y}{x} - 6y$$

Ex5/ Find $\frac{dy}{dx}$ for the algebraic curve

$$\frac{d}{dx}\left(y^3 + yx^2\right) = \frac{d}{dx}\left(x^3 + xy^2\right)$$

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

$$3y^2\frac{dy}{dx} + x^2\frac{dy}{dx} + 2xy = 3x^2 + y^2 + 2xy\frac{dy}{dx}$$

$$3y^2\frac{dy}{dx} + x^2\frac{dy}{dx} - 2xy\frac{dy}{dx} = 3x^2 + y^2 - 2xy$$

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

$$\frac{dy}{dx} = \frac{3x^2 + y^2 - 2xy}{3y^2 + x^2 - 2xy}$$

Derivatives Of Inverse Trig Functions

Ex6/ Find $\frac{dy}{dx}$ if $y = \sin^{-1}(x)$

$$\sin(y) = \sin(\sin^{-1}(x))$$

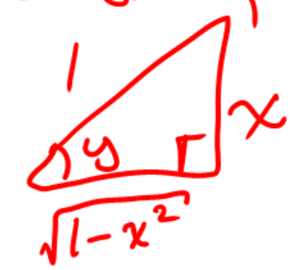
$$\frac{d}{dx}(\sin(y)) = \frac{d}{dx}(x)$$

$$\cos(y) \cdot \frac{dy}{dx} = 1$$

$$\frac{dy}{dx} = \frac{1}{\cos(y)}$$

$$\frac{dy}{dx} = \frac{1}{\sqrt{1-x^2}}$$

$\sin(y) = \frac{x}{1}$



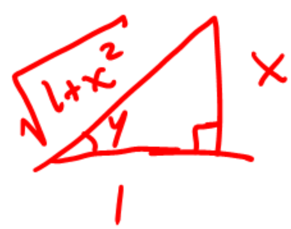
Ex7/ Repeat for $y = \tan^{-1}(x)$

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

$$\sec^2(y) \cdot \frac{dy}{dx} = 1$$

$$\frac{dy}{dx} = \frac{1}{\sec^2(y)} = \frac{1}{1+x^2}$$

$\tan(y) = \frac{x}{1}$



Other Examples

Ex/ $\frac{d}{dx}\left(\frac{1}{x} + \frac{1}{y}\right) = \frac{d}{dx}(1)$

Recall $\frac{d}{dx}\left(\frac{1}{x}\right) = -x^{-2} = -\frac{1}{x^2}$

$$\left(-\frac{1}{x^2} - \frac{1}{y^2} \cdot \frac{dy}{dx} = 0\right)(-y^2)$$

$$\frac{y^2}{x^2} + \frac{dy}{dx} = 0$$

$$\frac{dy}{dx} = -\frac{y^2}{x^2}$$

Ex/ $\sqrt{x} + \sqrt{y} = 4$

Recall $\frac{d}{dx}(\sqrt{x}) = \frac{1}{2\sqrt{x}}$

$$\frac{d}{dx}(\sqrt{x} + \sqrt{y}) = \frac{d}{dx}(4)$$

$$\frac{1}{2\sqrt{x}} + \frac{1}{2\sqrt{y}} \cdot \frac{dy}{dx} = 0$$

$$\frac{1}{2\sqrt{y}} \frac{dy}{dx} = -\frac{1}{2\sqrt{x}}$$

$$\frac{dy}{dx} = -\frac{2\sqrt{y}}{2\sqrt{x}} = -\sqrt{\frac{y}{x}}$$