

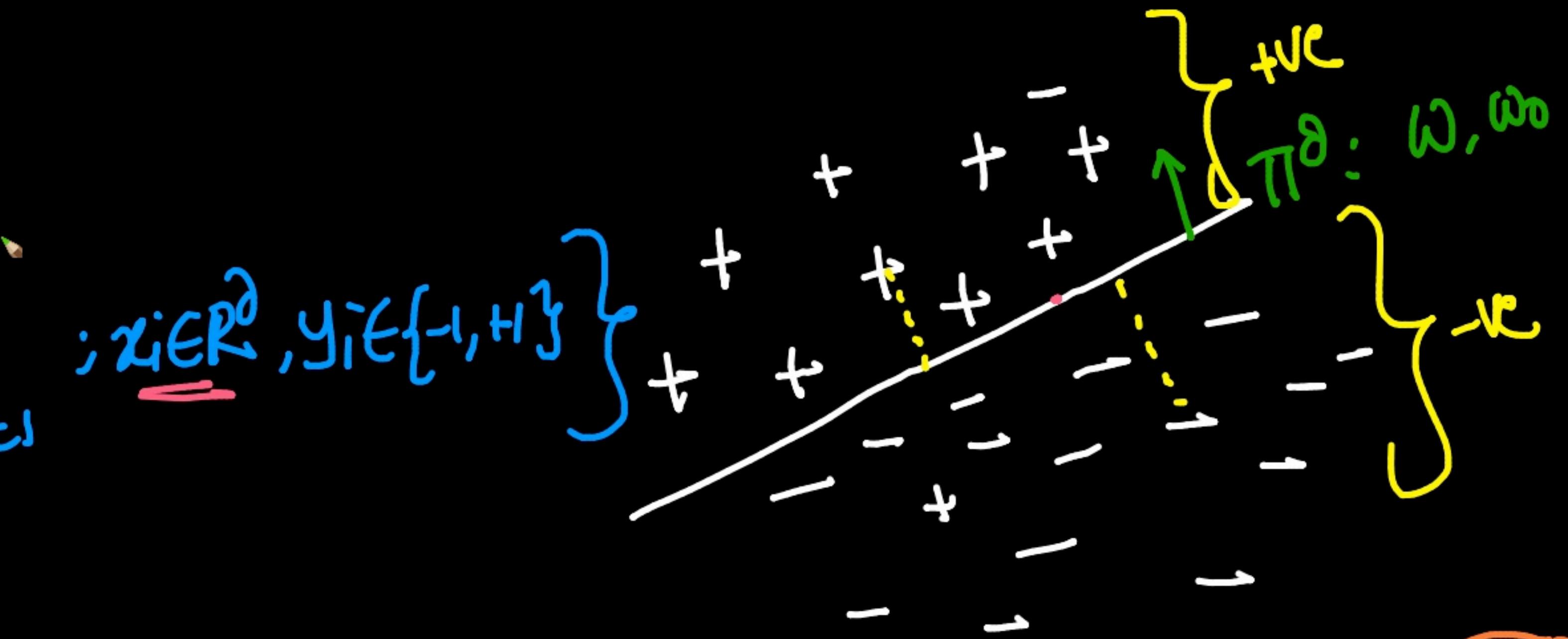
Optimization - 1

class starts @ 9:03 PM

[Case-study → OPS]

[Wed & Friday]

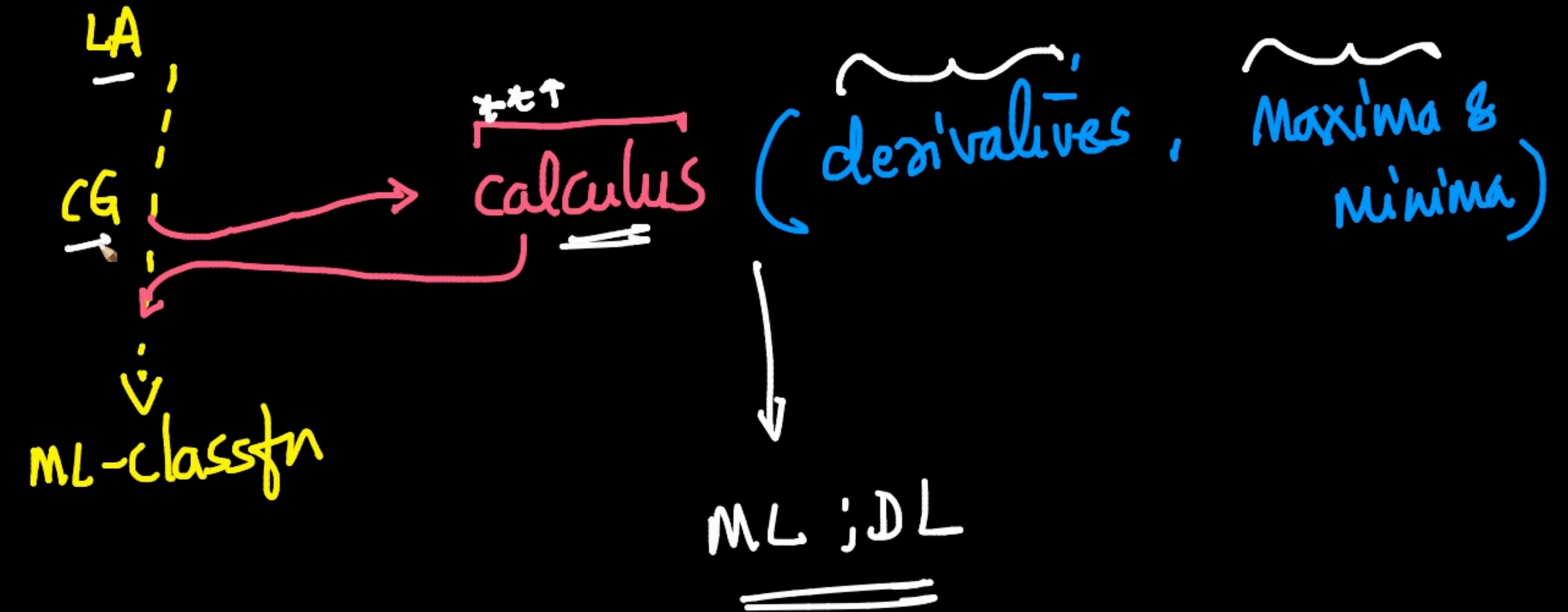
$$\mathcal{D} = \left\{ (\underline{x}_i, y_i) \right\}_{i=1}^n ; \underline{x}_i \in \mathbb{R}^d, y_i \in \{-1, +1\}$$



find \underline{w}, w_0
 $\underline{w} \in \mathbb{R}^d, w_0 \in \mathbb{R}$
 s.t.

$$\begin{aligned}
 & \text{Max } \sum_{i=1}^n \frac{\underline{w}^\top \underline{x}_i + w_0}{\|\underline{w}\|} \cdot y_i \\
 & z_i
 \end{aligned}$$

$\underline{w}, w_0 \rightarrow \underline{w} + 1$
 $\text{Max } f(\underline{w}, w_0)$



find $\omega \in \mathbb{R}^d$ & w_0 s.t

$$\max [z_1, z_2, z_3, \dots, z_n]$$

$$\max \sum_{i=1}^n z_i$$

(Q) $\max \prod_{i=1}^n z_i$

$$= \max (z_1 \cdot z_2 \cdot \dots \cdot z_n)$$

$$= \max \log(z_1 \cdot z_2 \cdot \dots \cdot z_n)$$

$$\log(z) \rightarrow -\infty$$

$$\log(a \cdot b) = \log a + \log b$$

where

$$z_i = \frac{\omega^T x_i + w_0}{\|\omega\|} \cdot y_i$$

a) product could be large (?) \rightarrow overflow

✓ b) any $\underline{\underline{z_i = 0}}$

c) Math gets little complicated
↓
product-rule

Concepts

Limits

continuity & differentiation

Differentiation (one-variable)

Maxima & minima

Partial differentiation

Gradient Descent ; SGD

ML & AI

plot log(x) - Google Search x plot(1/x) - Google Search x +

google.com/search?q=plot(1%2Fx)&rlz=1C5CHFA_enIN958IN958&oq=plot(1%2Fx)&aqs=chrome..69i57j0i30l7j0i8i30l2.3160j1j1&sourceid=chrome&ie=UTF-8

Google plot(1/x)

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About 1,60,00,00,000 results (0.37 seconds)

Graph for $1/x$

$f(x) = y$

$x \neq 0$

$x \in \mathbb{R}$

$f(x) = \frac{1}{x}$

Wolfram Alpha
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plot 1/x

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Use interactive calculators to plot and graph functions. Try 3D plots, equations, inequalities, polar and parametric plots. Specify ranges for variables.

Images for plot

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Graph for $1/x$

y

x

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

$\lim_{x \rightarrow 0^+} \left(\frac{1}{x}\right) = +\infty$

$\lim_{x \rightarrow 0^-} \left(\frac{1}{x}\right) = -\infty$

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plot 1/x

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Images for plot

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Google

plot(x^2)

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Graph for x^2

$f(x) = x^2$

$\lim_{x \rightarrow 0^+} x^2 = 0$

$\lim_{x \rightarrow 0^-} x^2 = 0$

Wolfram Alpha
<https://www.wolframalpha.com> › mathematics › plotting & graphics

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Use interactive calculators to **plot** and **graph** functions. Try 3D **plots**, equations, inequalities, polar and parametric **plots**. Specify ranges for variables.

Plot $x^3 - 6x^2 + 4x + 12$ · Plot $\sin x$, $\cos x$, $\tan x$ · Plot $x e$ · Plot $Ai(x)$

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plot x2

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Mathway

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Google plot(x^2)

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Graph for x^2

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Plot $x^3 - 6x^2 + 4x + 12$ · Plot $\sin x, \cos x, \tan x$ · Plot $x e$ · Plot $Ai(x)$

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plot x2
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Two-sided limits:

$\lim_{x \rightarrow 0} (x^2) = 0$

because

$$\lim_{x \rightarrow 0^-} x^2 = \lim_{x \rightarrow 0^+} x^2$$

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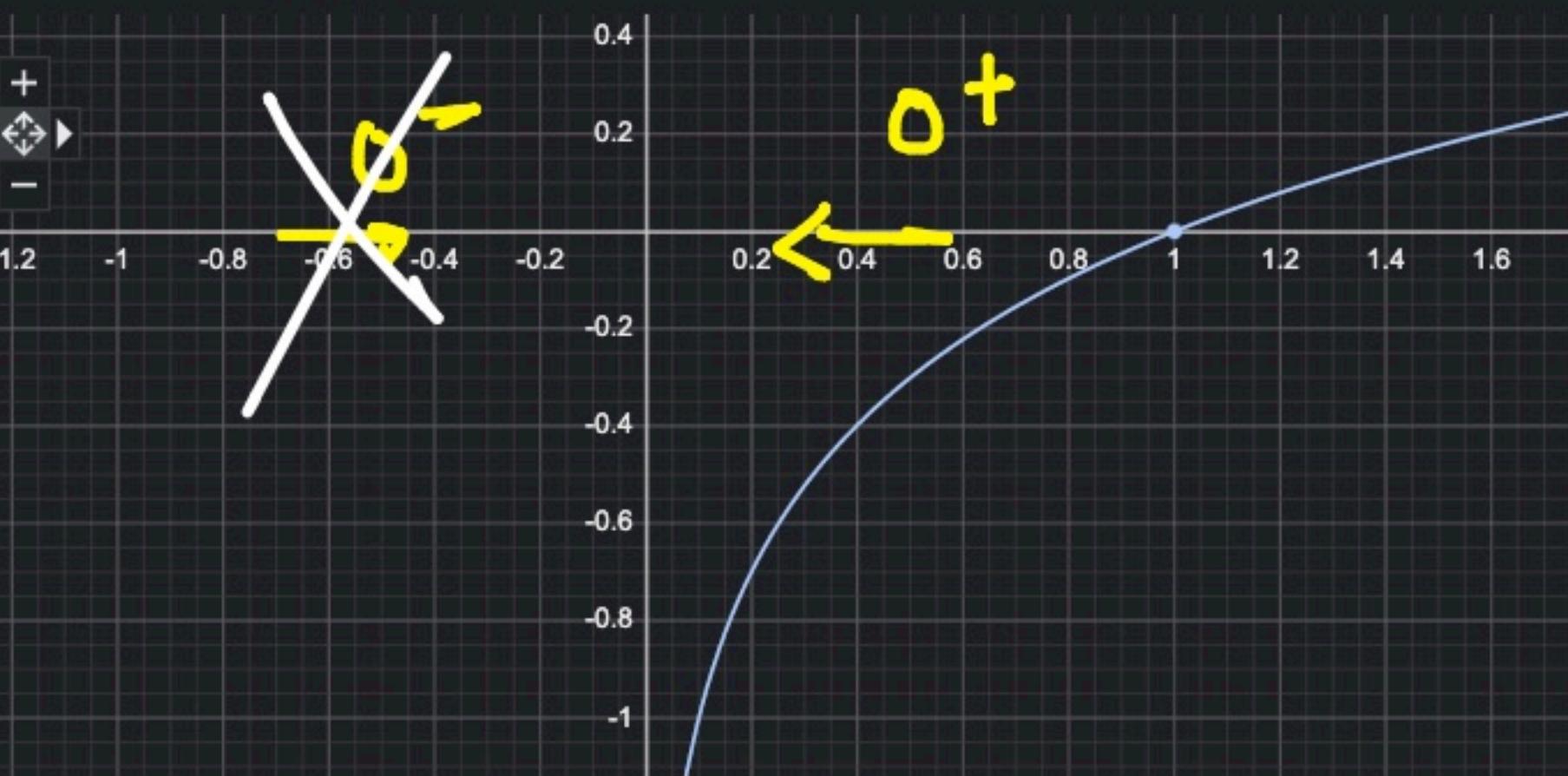
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plot(log(x)) x

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Graph for $\log(x)$



$\log(x)$

$\lim_{x \rightarrow 0^-} \log(x) = ?$

$\lim_{x \rightarrow 0^+} \log(x) = ?$

$\lim_{x \rightarrow \infty} \log(x) = ?$

Domain of $f(x)$

domain $\log(x) = \underline{\mathbb{R}}^+$

RapidTables.com
<https://www.rapiddtables.com/math/algebra/logarithm-graph.html>

logarithm graph | graph of $\log(x)$

Graph of $\log(x)$. $\log(x)$ function graph. Logarithm graph. $y = f(x) = \log_{10}(x)$. $\log(x)$ graph properties. $\log(x)$ is defined for positive values of x . $\log(x)$...

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plot $y=\log(x)$ and $y=(\log \log x)$

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Graph for $\log(x)$

RapidTables.com

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Graph of $\log(x)$. $\log(x)$ function graph. Logarithm graph. $y = f(x) = \log_{10}(x)$. $\log(x)$ graph properties. $\log(x)$ is defined for positive values of x. $\log(x)$...

Wolfram Alpha

plot y=log(x) and y=(log log x)

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Range of $f(x) = \log(x)$

domain $\log(x) = \mathbb{R}^+$

Range $\log(x) = \mathbb{R}$

plot log(x) - Google Search x plot(abs(x)) - Google Search x +

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plot(abs(x))

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Graph for $|x|$

Khan Academy
<https://www.khanacademy.org/math/algebra/absolute-value-graphs-and-functions/review-abs-value-graphs-and-functions-article>

Absolute value graph and function review (article)
A coordinate plane. The x- and y-axes both scale by one. The graph is of the function y equals the absolute value of x . The vertex is at the point zero, zero.

People also ask :
How do I graph the absolute value of x ?
How do you plot an abs

$\lim_{x \rightarrow \infty} e^x = \infty$

$\lim_{x \rightarrow -\infty} e^x = 0$

$\text{dom } e^x = \mathbb{R}$

$\text{range } e^x = \mathbb{R}^+ = (0, \infty)$

plot log(x) - Google Search

plot(abs(x)) - Google Search

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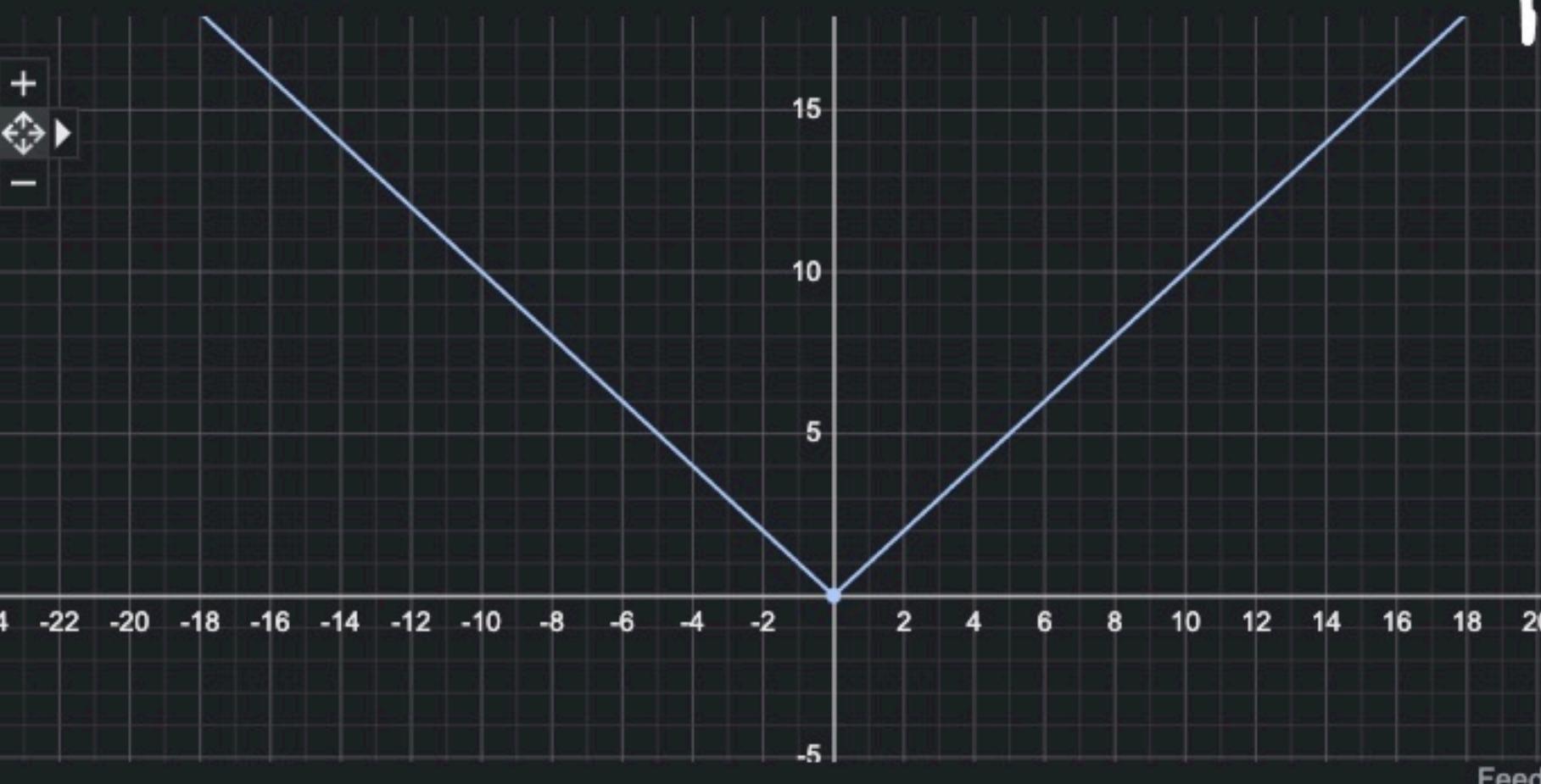
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Graph for $|x|$ 

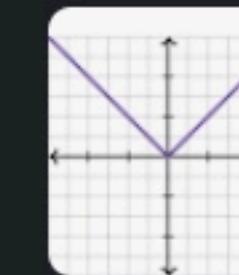
$$|x| = \begin{cases} x & \text{if } x \geq 0 \\ -x & \text{if } x < 0 \end{cases}$$



Khan Academy

<https://www.khanacademy.org/math/algebra/absolute-value-graphs-and-functions/review> [Absolute value graph and function review \(article\)](#)

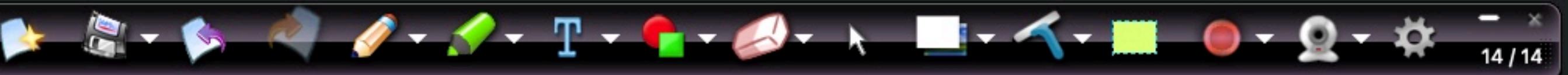
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People also ask

How do I graph the absolute value of x?

How do you plot an abs



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Google plot(1/x)

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Graph for $1/x$

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Use interactive calculators to plot and graph functions. Try 3D plots, equations, inequalities, polar and parametric plots. Specify ranges for variables.

$\lim_{x \rightarrow 0} \left(\frac{1}{x}\right) = \text{Not defined}$

$\lim_{x \rightarrow 0^+} \frac{1}{x} = +\infty$

$\lim_{x \rightarrow 0^-} \frac{1}{x} = -\infty$

plot log(x) - Google Search | plot(abs(x)) - Google Search | plot(1/x) - Google Search +
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Google plot(1/x)

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Graph for $1/x$

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plot 1/x

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$\lim_{x \rightarrow 2} \frac{1}{x} = \frac{1}{2}$

$\lim_{x \rightarrow 0} \frac{1}{x} = \text{not defined}$

Images for plot

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Graph for $|x|$

$|x| = f(x)$

$\lim_{x \rightarrow \infty} |x| = 0$

$\text{Dom } |x| = \mathbb{R}$

$\text{range } |x| = \mathbb{R}^+ \cup \{0\}$

$[0, \infty)$

Khan Academy
<https://www.khanacademy.org/math/algebra/absolute-value-graphs-and-functions/review>

Absolute value graph and function review (article)
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People also ask

How do I graph the absolute value of x ?
How do you plot an abs

17 / 17

Most used fns in ML & DL

✓ polynomials: x^2, x^3, x^2+x

✓ $\log(x)$ & $e^x = \exp(x)$

✓ $|x|$

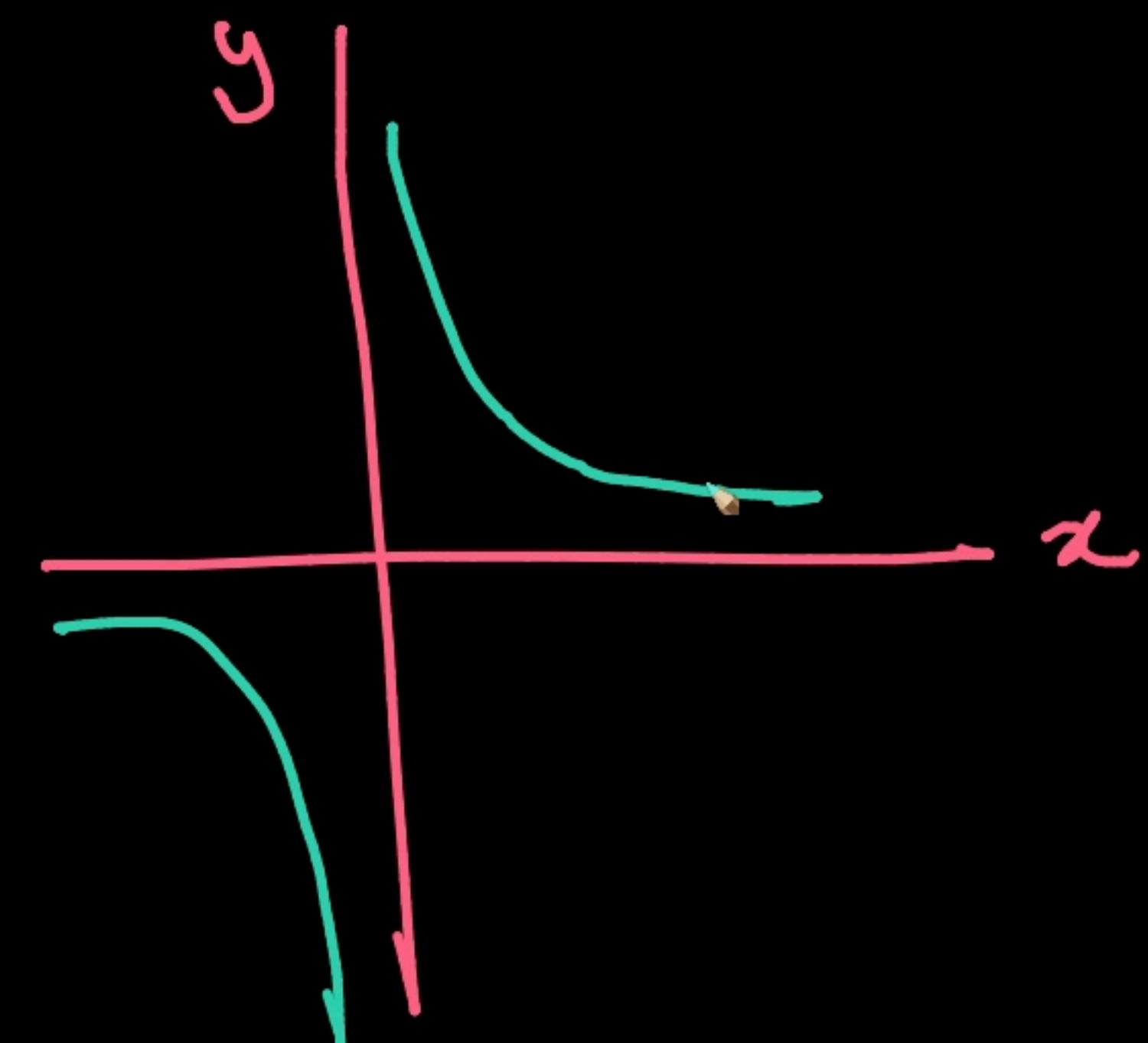
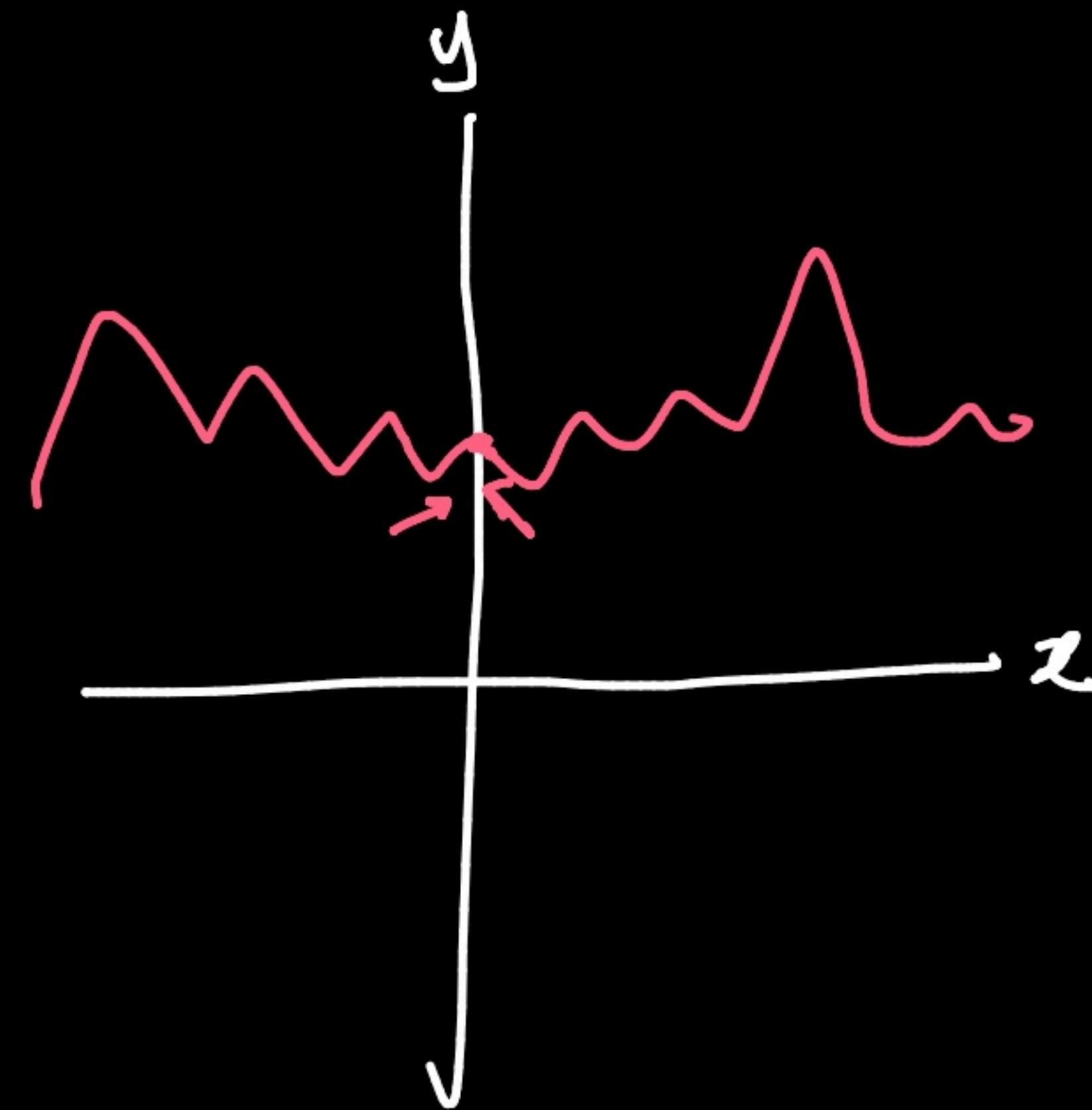
compositions

$$\log(x^2) + e^x$$

$$\log(x)$$

$$f(g(x))$$

$$\overline{x} \\ x^2$$



Max $f(x) \rightarrow$ Maxima & minima \rightarrow diff

continuity

limits

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google.com/search?q=plot%281%2Fabs%28x%29%29&rlz=1C5CHFA_enIN958IN958&ei=HS2sZPfyAf7e4-EPhJ6HoAU&ved=0ahUKEwi39YCbw4SAAxV-7zgGHQTPAVQQ4dUDCA8&uact=5&oq=plot%281%2Fabs%28... Update

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plot(1/abs(x))

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Graph for $1/|x|$

$\lim_{x \rightarrow 0} \frac{1}{|x|} = \infty$

Socratic
[https://socratic.org/questions/how-do-you-graph-y... :\)](https://socratic.org/questions/how-do-you-graph-y-abs(x-1))

How do you graph $y = \text{abs}(x-1)$?

The **-1** in the **absolute value bars** means the **graph** is going to shift one to the right and if it was **+1** the **graph** would shift to the left one.

2 answers · Use a calculator table Explanation: Honestly it's like 2·1010 times easier...

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<https://www.khanacademy.org/math/algebra/absolute-value-graphs-and-functions-review> ::

Absolute value graph and function review (article)

A coordinate plane. The x- and y-axes both scale by one. The **graph** is of the function y equals the **absolute value**

21 / 21

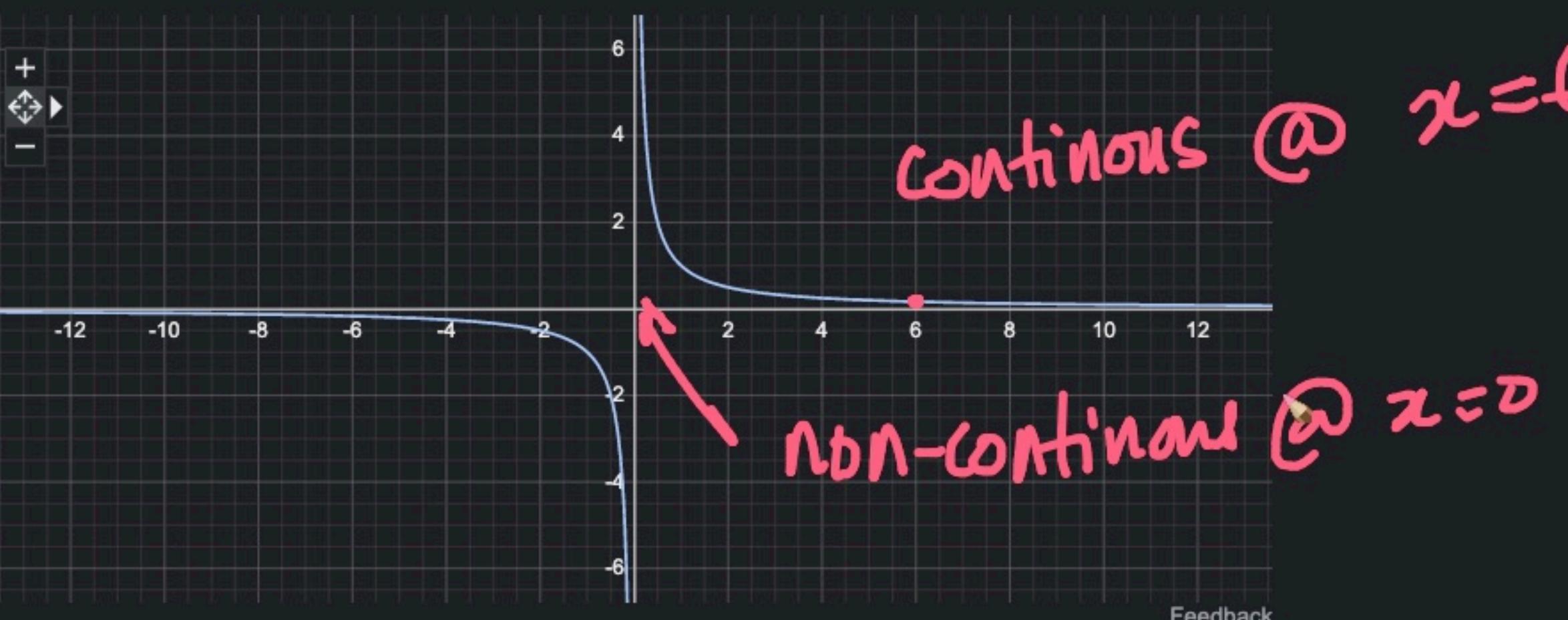
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Graph for $1/x$



Feedback



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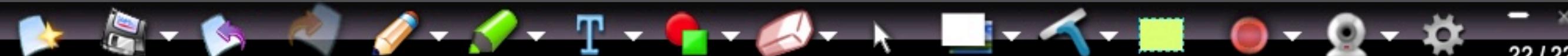
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<https://www.mathway.com>

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plot(1/(x)) - Google Search

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X



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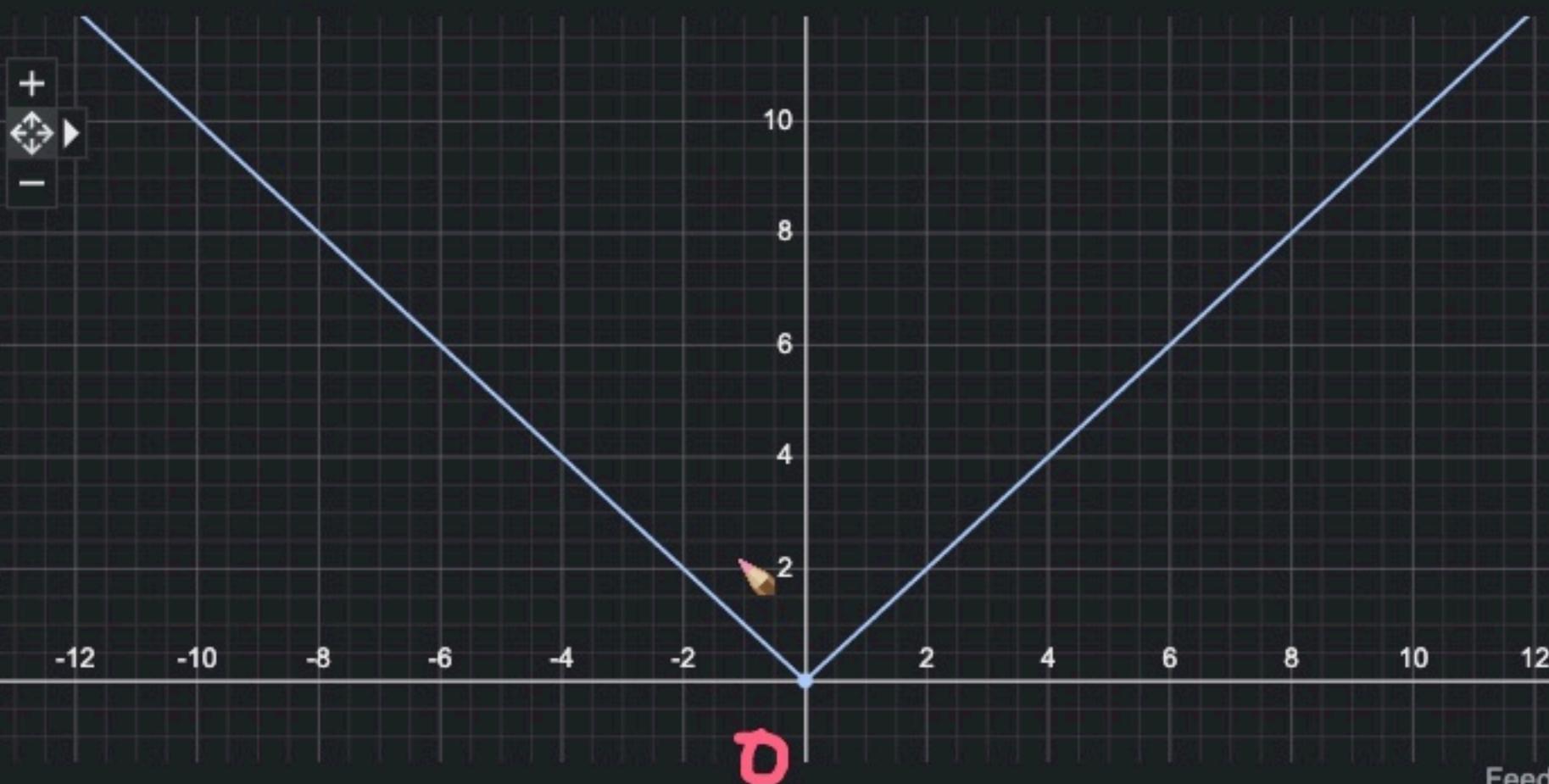
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Graph for $|x|$ 

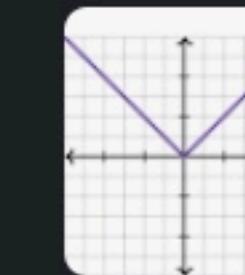
continuous everywhere in its
domain



Khan Academy

<https://www.khanacademy.org/math/algebra/absolute-value-graphs-and-functions/review>[Absolute value graph and function review \(article\)](#)

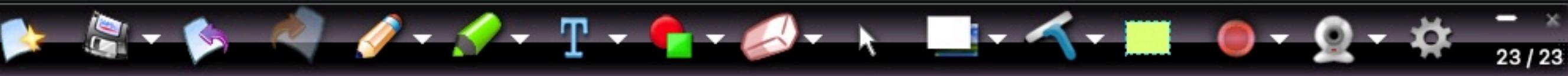
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People also ask

How do I graph the absolute value of x?

How do you plot an abs



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Graph for $\tan(x)$

Wolfram Alpha
[https://www.wolframalpha.com/input/?i=plot+tan\(x\)](https://www.wolframalpha.com/input/?i=plot+tan(x))

plot tan(x)
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People also ask :

How do you plot a tan function?

How to plot tan x in mat

24 / 24

Google

plot (abs(x))



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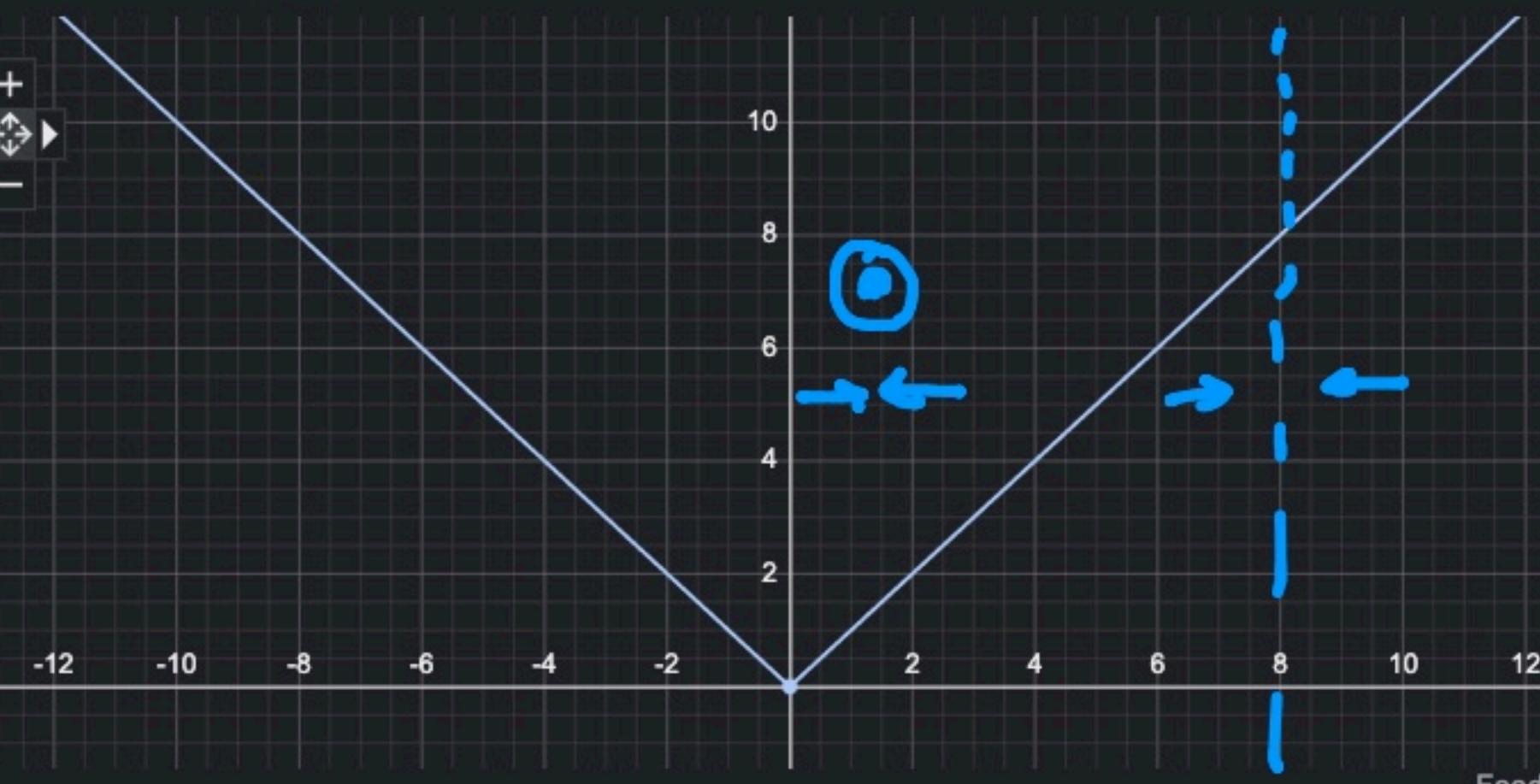
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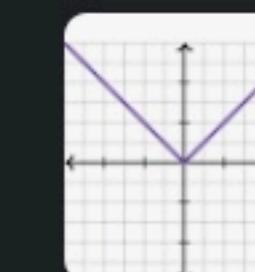
Graph for $|x|$ 

Khan Academy

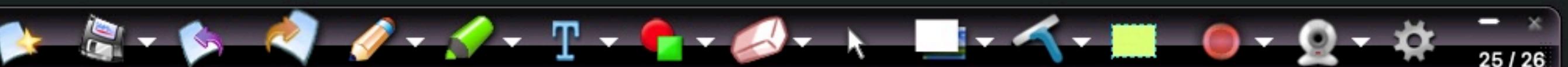
<https://www.khanacademy.org/math/algebra/absolute-value-graphs-and-functions/review>

Absolute value graph and function review (article)

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People also ask How do I graph the absolute value of x ?

How do you plot an abs

Math:

$f(x)$ is continuous @ a

if $f(a)$ is defined

$$\lim_{x \rightarrow a^+} f(x) = \lim_{x \rightarrow a^-} f(x) = f(a)$$

$x \rightarrow a^-$

$=f(a)$

Google

plot(x^2)



Images

Formula

Equation

Calculator

Answer

Example

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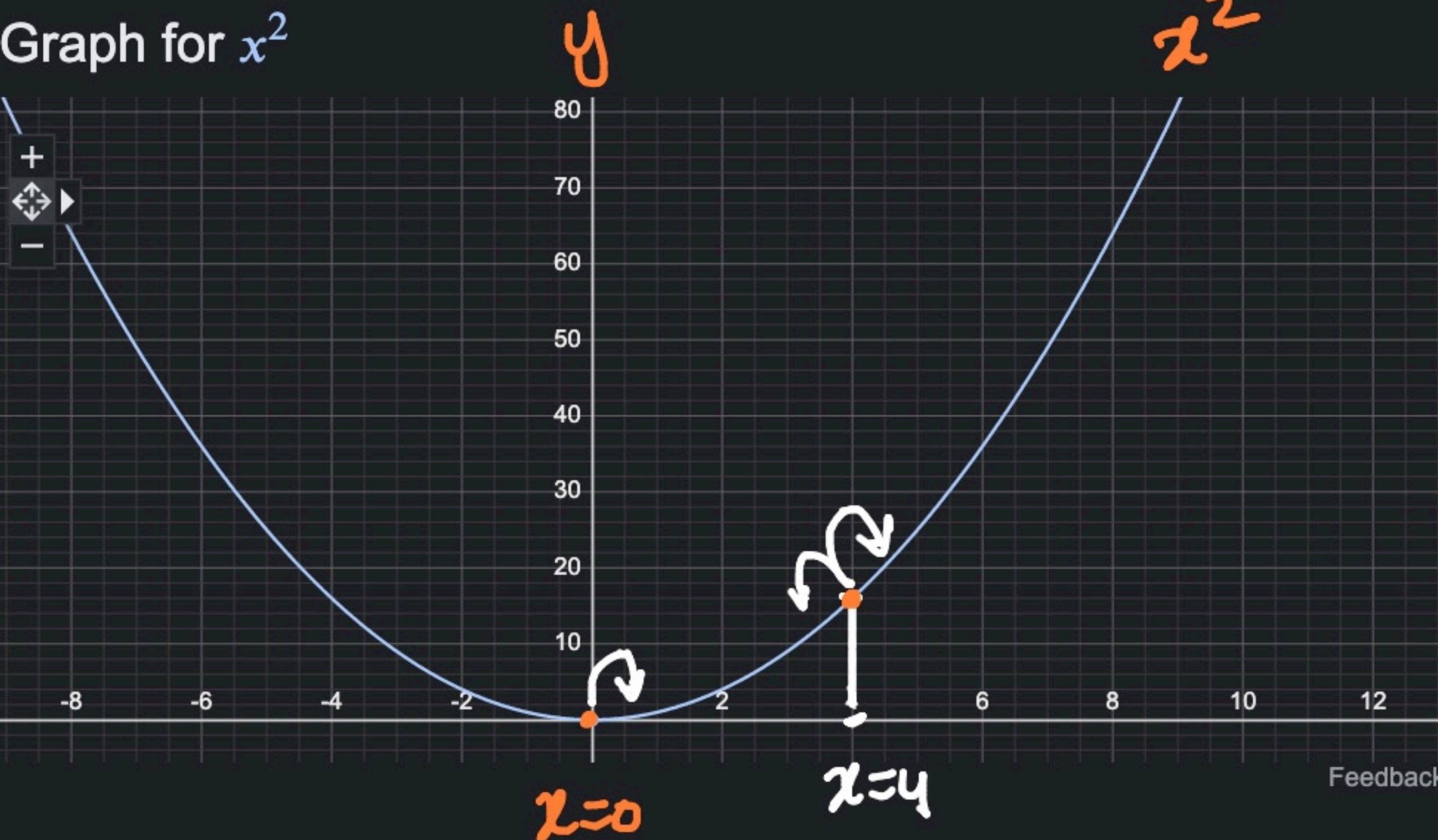
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Graph for x^2 

derivatives = rate of change

$$x = 4 \quad x = 4.1$$

$$x^2 = 16$$

$$x^2 = 16.81$$

0.81 for 0.1

$$x = 0.1$$

$$x^2 = 0.01$$

$$x = 0.1$$

$$x^2 = 0.01$$



Mathway

<https://www.mathway.com> › Algebra

Graph x=2

Google

plot(x^2)



Images

Formula

Equation

Calculator

Answer

Example

Shopping

Maps

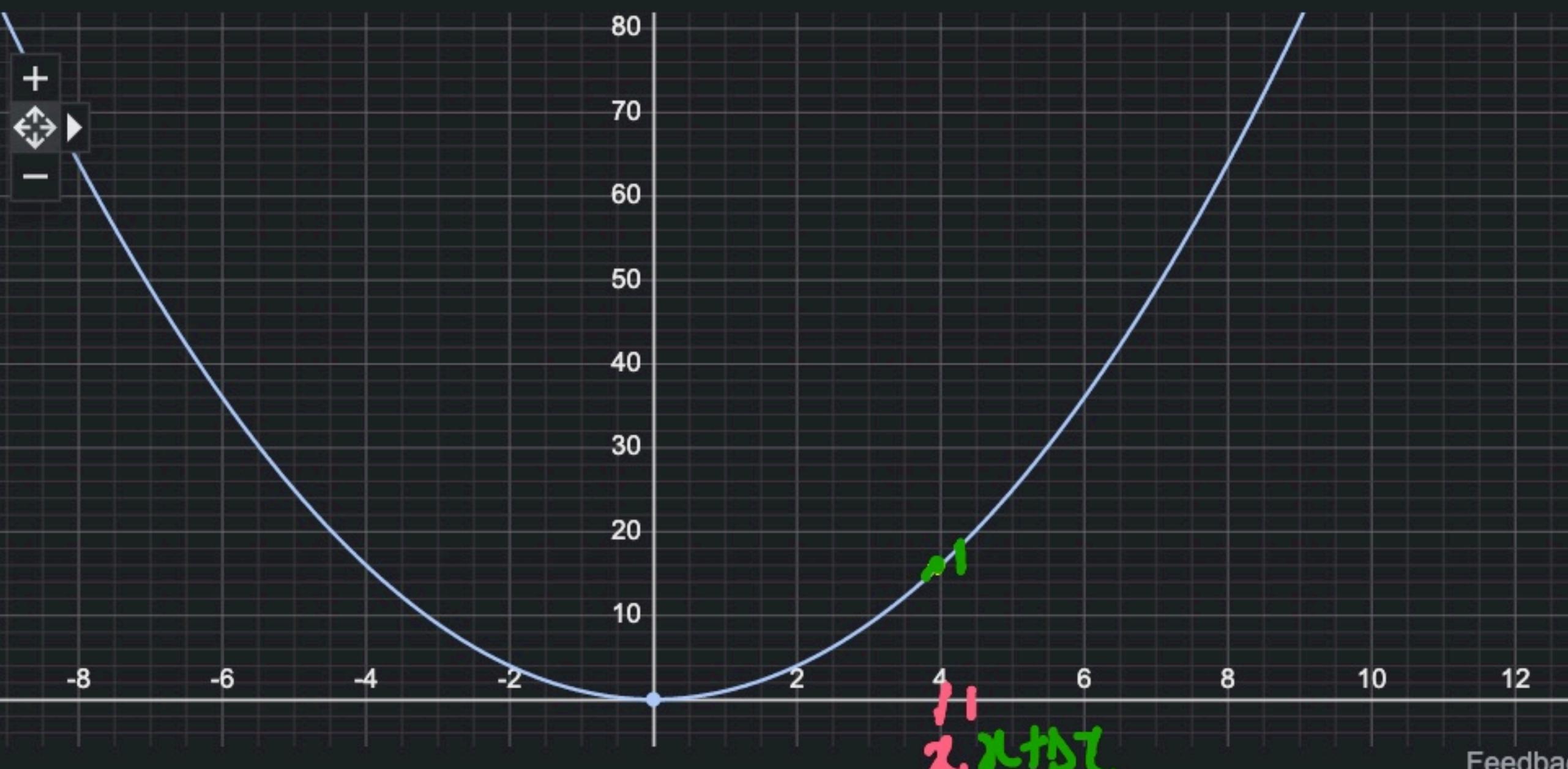
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Graph for x^2 

Mathway

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Graph x=2

derivative of $x^2 = f(x)$ @ $x=4$

$$\frac{-f(x) + f(x + \Delta x)}{\Delta x}$$

$$\lim_{\Delta x \rightarrow 0} \frac{-f(x) + f(x + \Delta x)}{\Delta x} = \frac{\Delta y}{\Delta x}$$

Google

plot(x^2)



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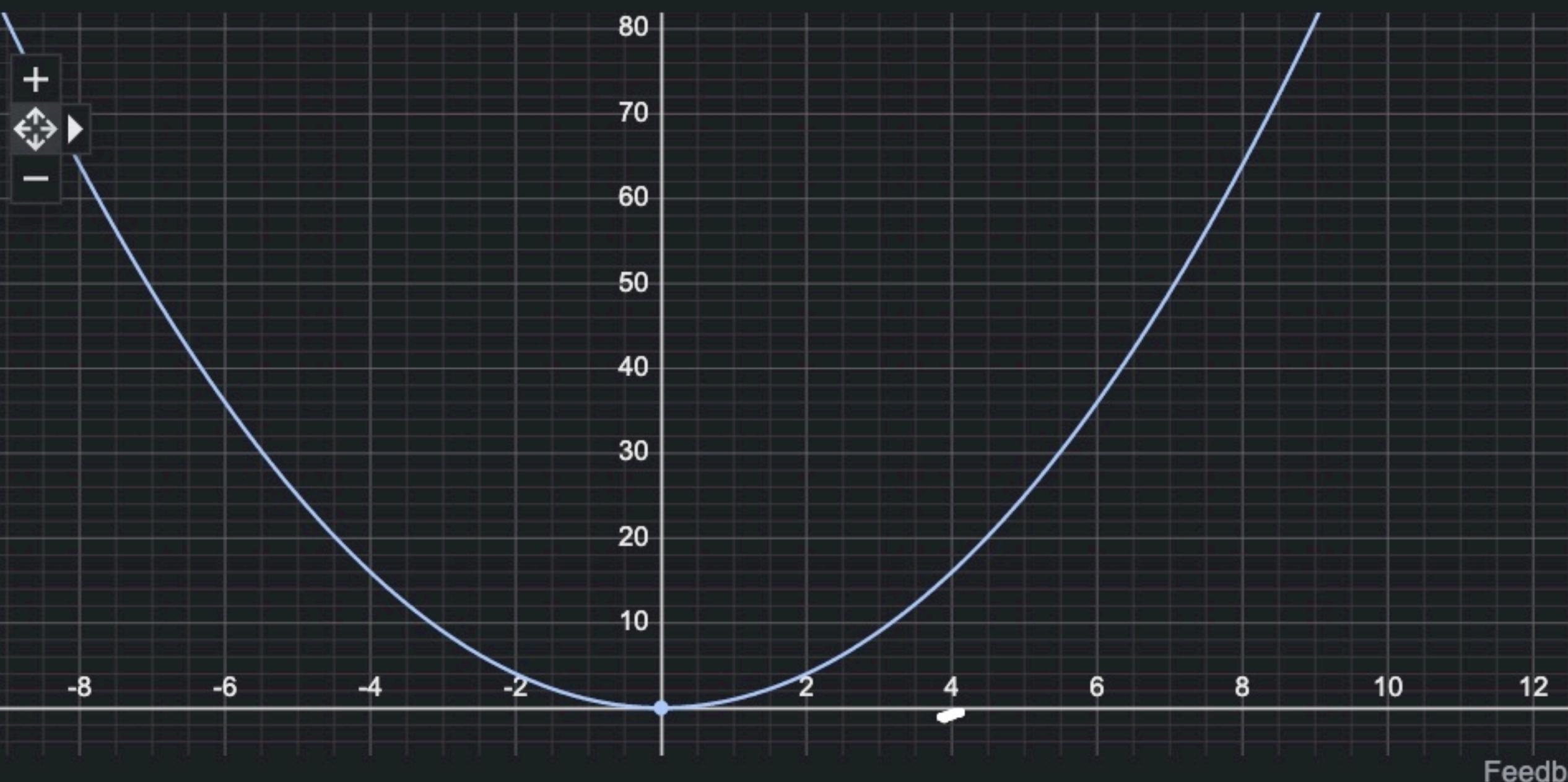
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Graph for x^2 

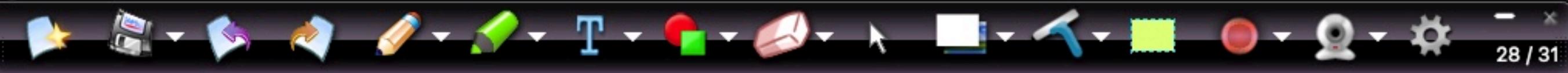
- $\Delta x = 0 \cdot 1 \rightarrow \checkmark$
- $\Delta x = 0 \cdot 0 \rightarrow \checkmark$
- $\Delta x = 0 \cdot 00 \rightarrow \checkmark$
- $\Delta x = 0 \cdot 0000 \rightarrow \checkmark$
- $\Delta x = 0 \cdot 10 \rightarrow \checkmark$
- ✓



Mathway

<https://www.mathway.com> › Algebra

Graph x=2



Google

plot(x^2)



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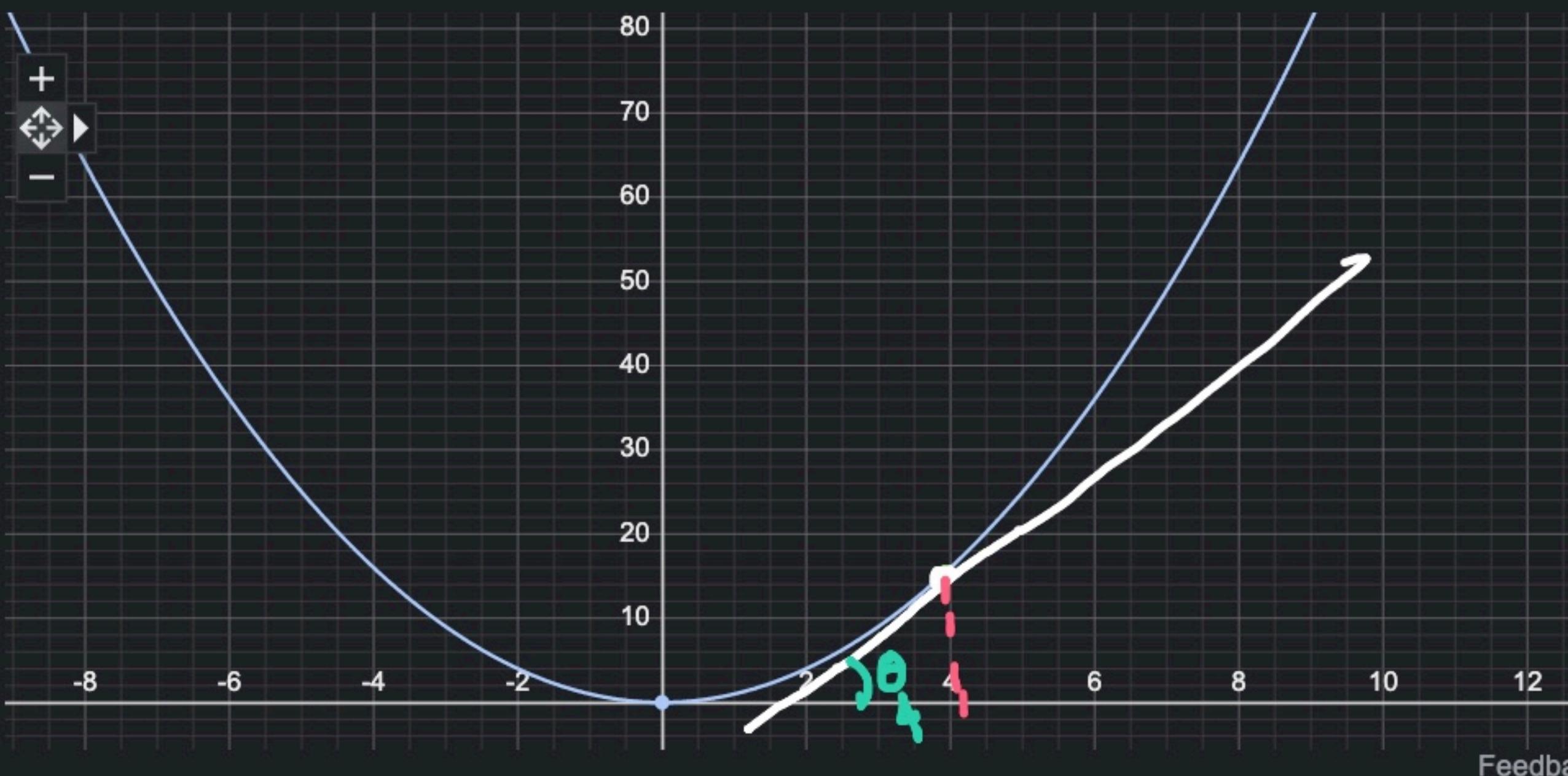
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Graph for x^2 

Geometrical:

$$\frac{df(x)}{dx} \Big|_{x=4}$$

$\equiv \tan(\theta)$

$\equiv \text{slope of tangent}$

$\equiv f'(x) @ x=4$



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Graph x=2

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plot(x^2)



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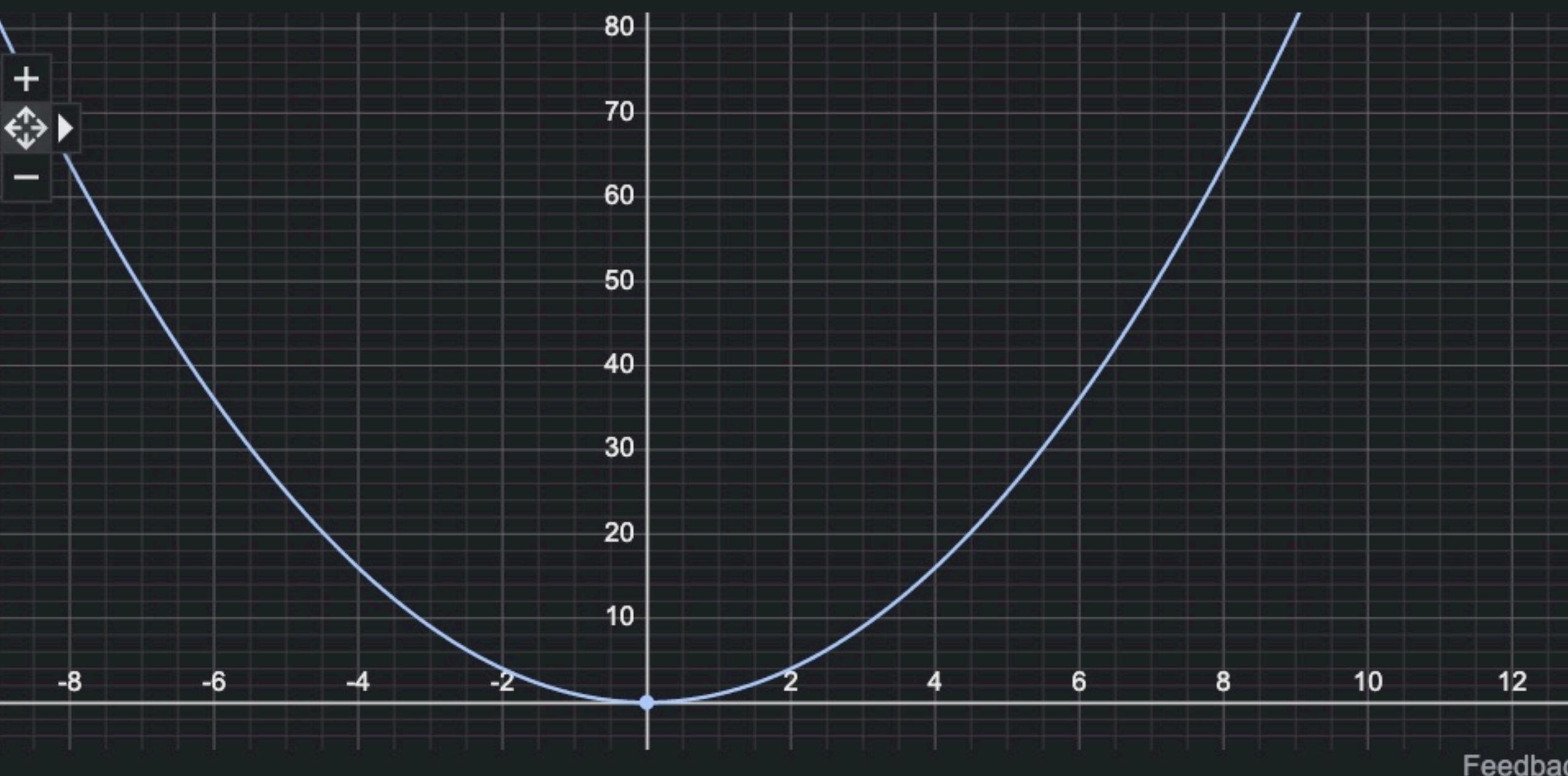
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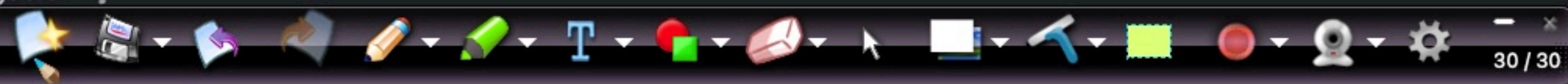
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Graph for x^2 

Feedback



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plot(x^2)



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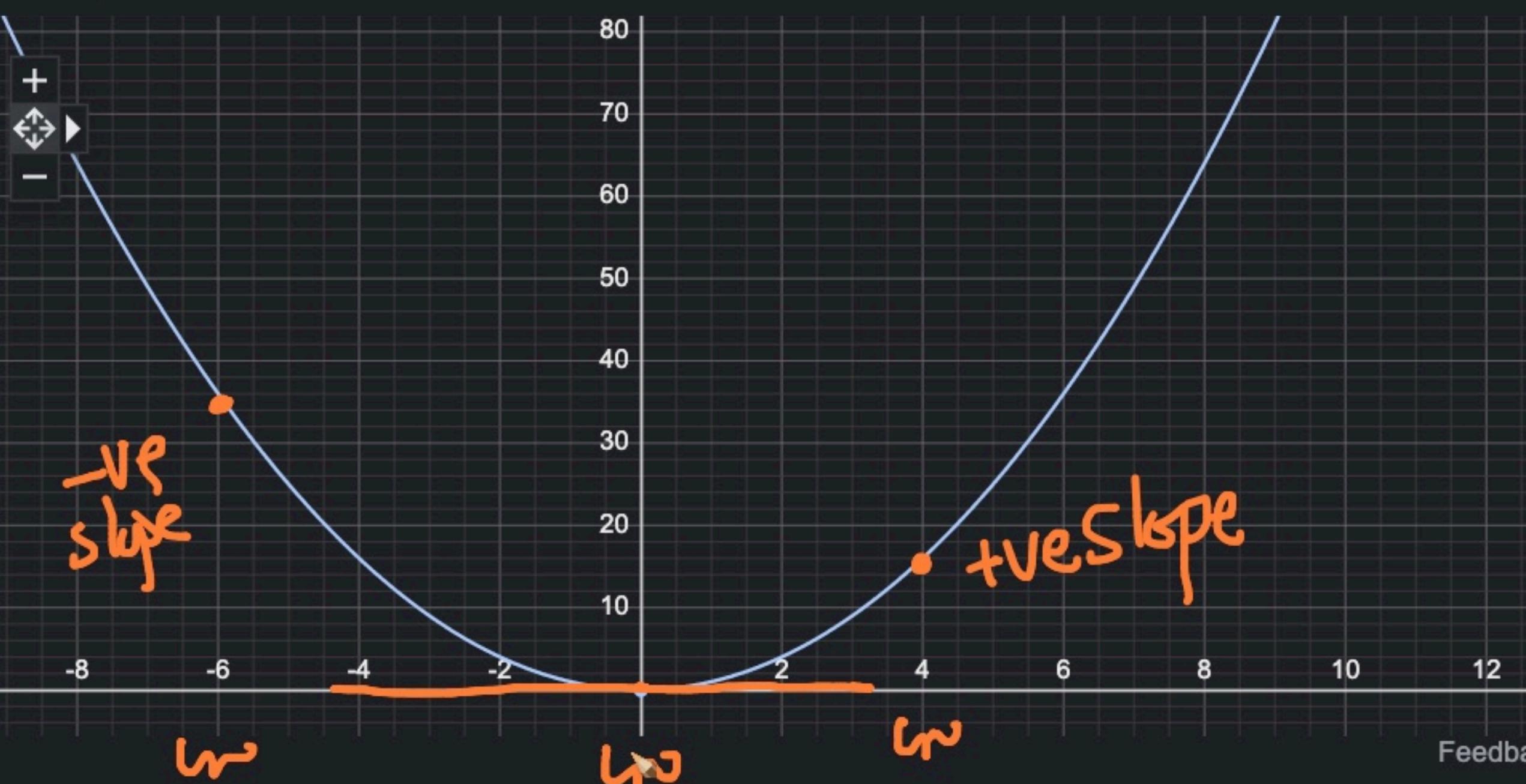
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Graph for x^2 

der of x^2 @ $x=0$

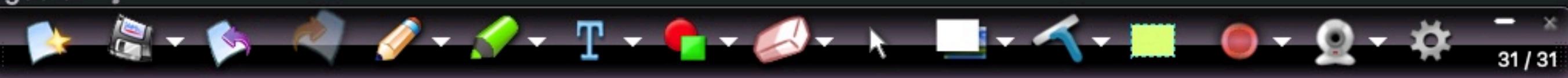
$$\underline{\underline{\tan \delta = 0}}$$



Mathway

<https://www.mathway.com> › Algebra

Graph x=2



Images

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Equation

Calculator

Answer

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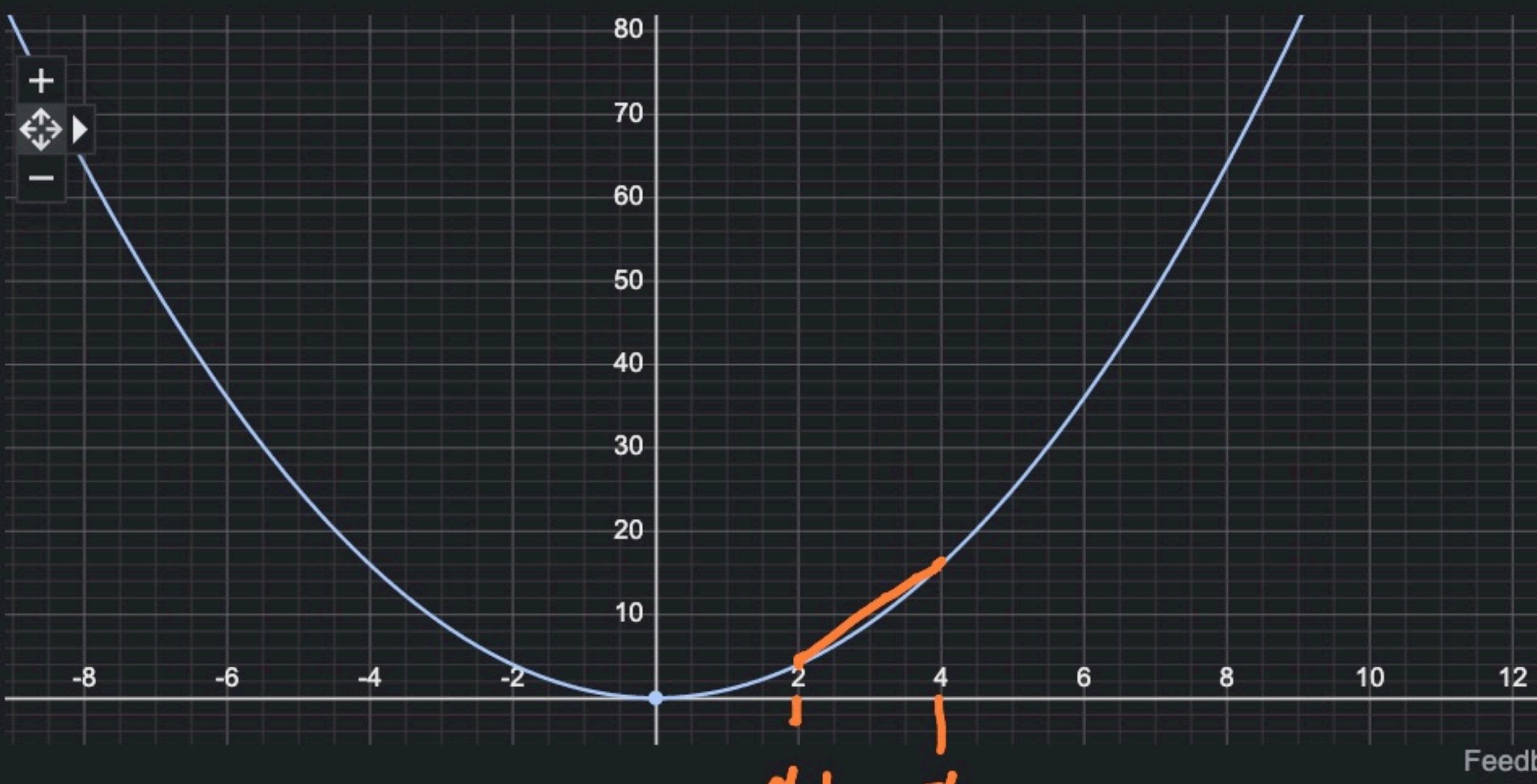
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Graph for x^2



Mathway

<https://www.mathway.com> › Algebra

Graph $x=2$

Graph the line using the slope, y-intercept, and two points. Slope: Undefined. y-intercept: No y-intercept.

Secant:

line from $f(x_1)$ to $f(x_2)$

Tangent
Secant as $x_2 \rightarrow x_1$

$x_2 - x_1 \rightarrow 0$

Images

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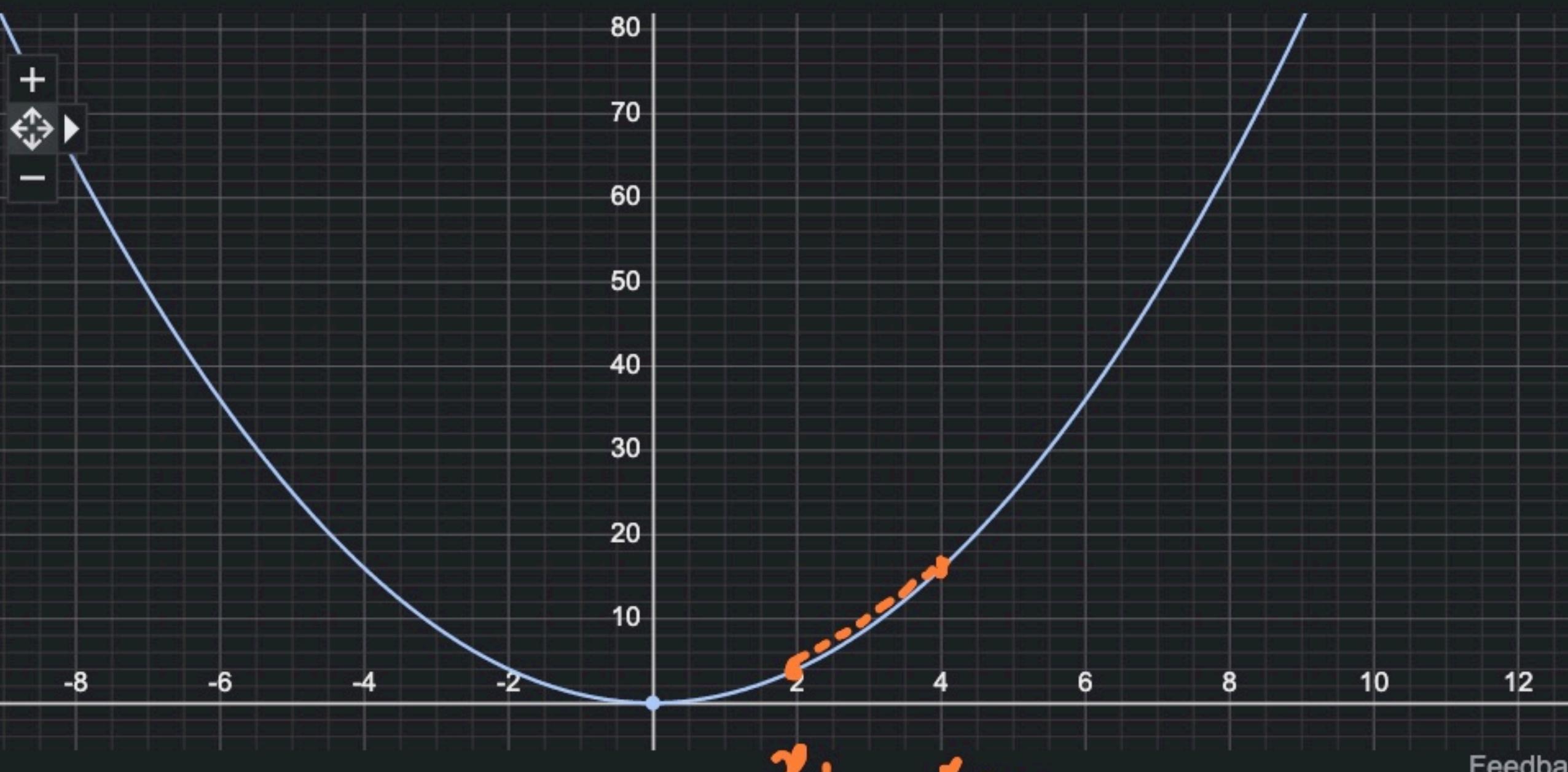
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Graph for x^2



$$\frac{\Delta y}{\Delta x} = \frac{f(x_2) - f(x_1)}{x_2 - x_1}$$



Mathway

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Graph $x=2$

Graph the line using the slope, y-intercept, and two points. Slope: Undefined. y-intercept: No y-intercept.

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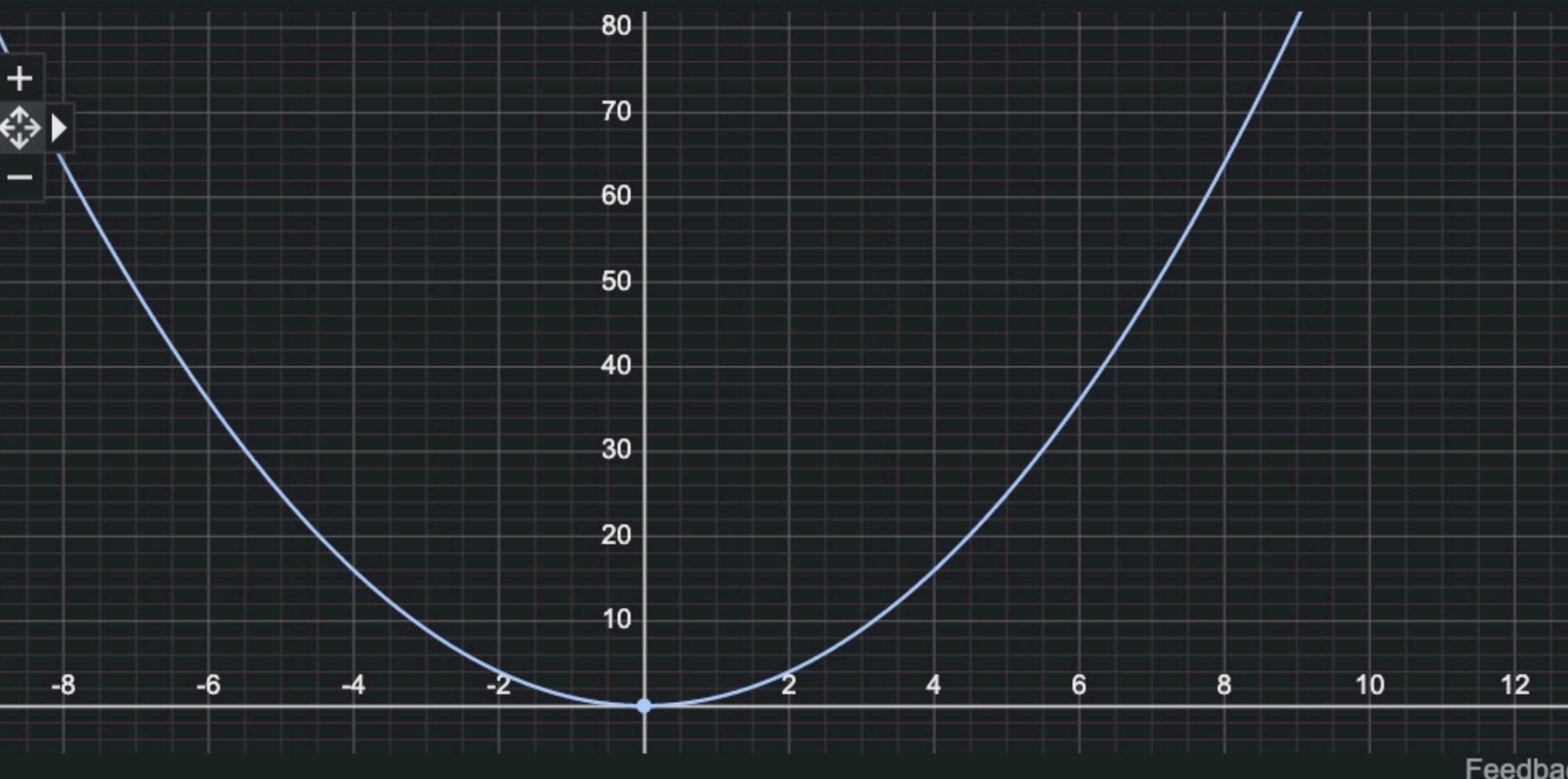
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Graph for x^2



d (x²)

Feedback



Mathway

<https://www.mathway.com> › Algebra

:

Graph $x=2$

Graph the line using the slope, y-intercept, and two points. Slope: Undefined. y-intercept: No y-intercept.



$$\frac{d(f(x))}{dx} = \lim_{\Delta x \rightarrow 0} \frac{(x + \Delta x)^2 - x^2}{\Delta x}$$

$$= \lim_{\Delta x \rightarrow 0} \frac{x^2 + 2\cancel{\Delta x} \cdot x + \cancel{\Delta x}^2 - x^2}{\cancel{\Delta x}}$$

$$= \lim_{\Delta x \rightarrow 0} 2 \cdot x + \textcircled{\Delta x} = 2x$$

Polynomials

$$\frac{d x^2}{dx} = 2x$$

$$\frac{d x^n}{dx} = n x^{n-1}$$

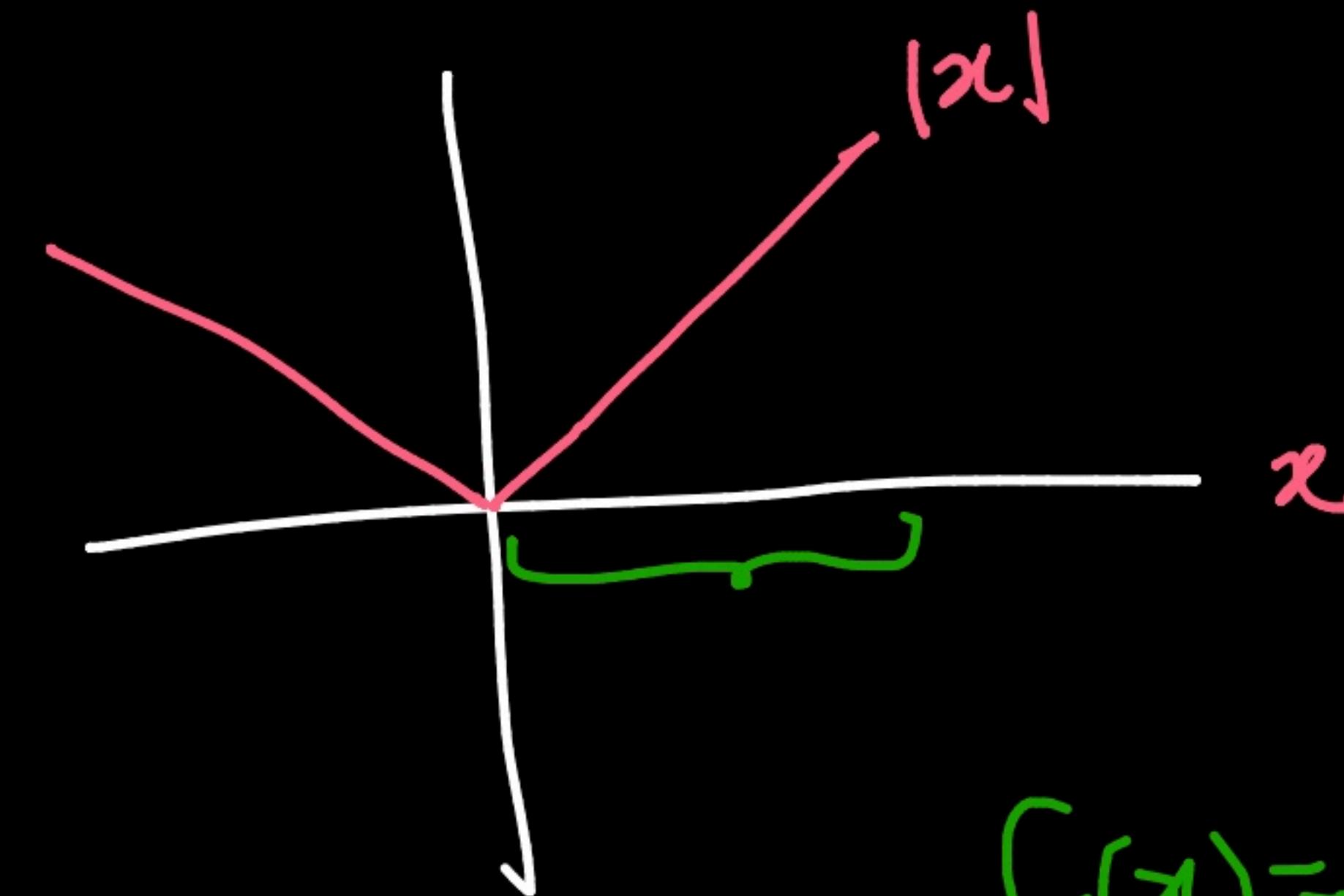
$n \neq 0$,
 $n = \text{real number}$

$$\frac{d x^{2.5}}{dx} = 2.5 x^{1.5}$$

$$\frac{d(\log(x))}{dx} = \frac{1}{x}$$

$$\frac{d(e^x)}{dx} = e^x$$

$$\frac{d|z|}{dx}$$



$$f(z) = |z|$$

Case 1: $z > 0$:

$$f(z) = z^{\frac{1}{2}}$$

$$\frac{df(z)}{dz} = \frac{1}{2}z^{-\frac{1}{2}}$$

Case 2: $x < 0$

$$f(x) = -x$$

$$\frac{df(x)}{dx} \approx -1$$

Case 3: $x = 0$

$$\lim_{\Delta x \rightarrow 0} \frac{|(x + \Delta x)| - |x|}{\Delta x}$$

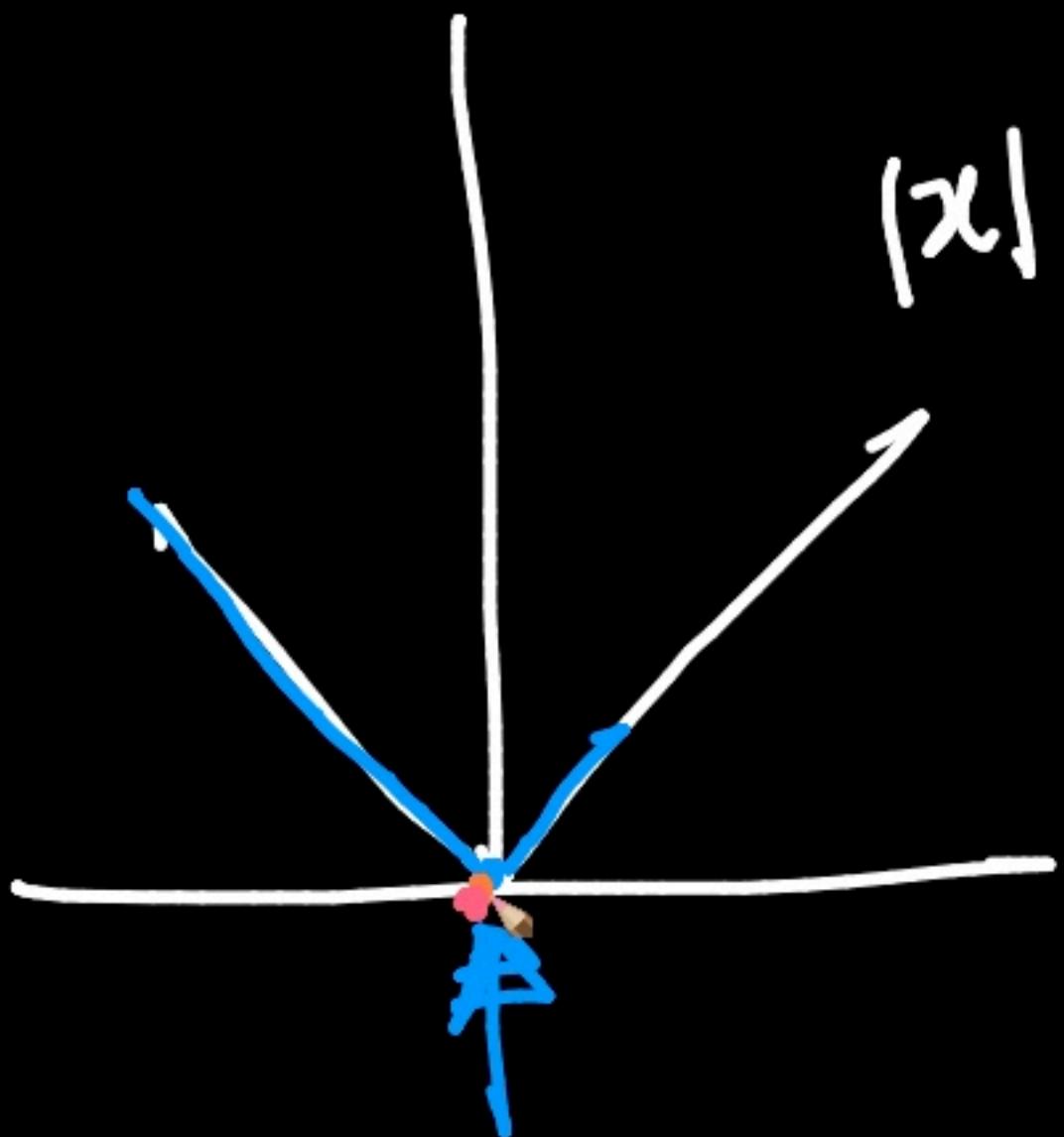
$$= \lim_{\Delta x \rightarrow 0} \frac{|\Delta x|}{\Delta x}$$

$$\Rightarrow \lim_{\substack{\Delta x \rightarrow 0^+ \\ \Delta x \rightarrow 0^-}} \frac{|\Delta x|}{\Delta x} = +1$$

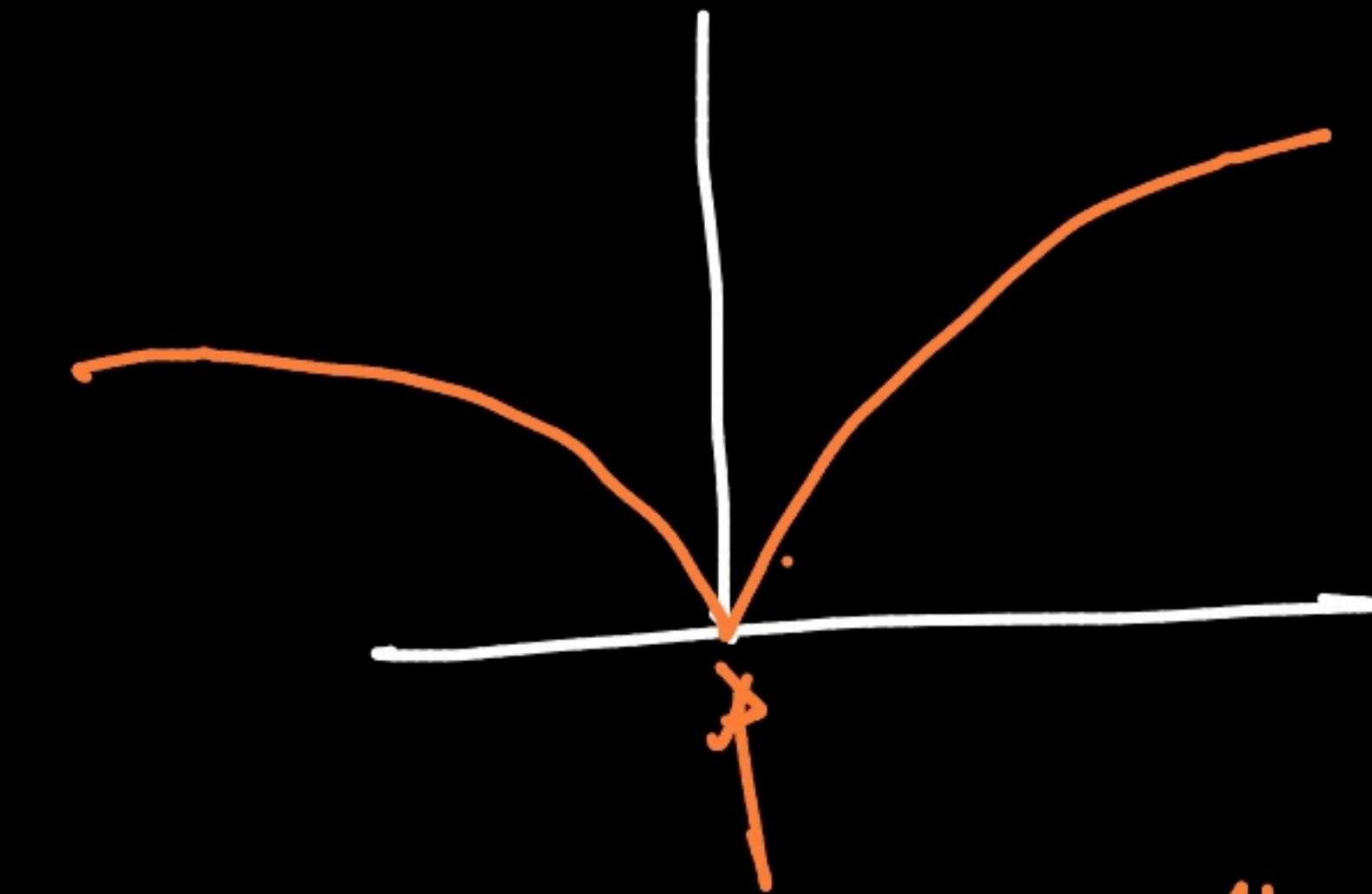
$$\lim_{\Delta x \rightarrow 0^-} \frac{|\Delta x|}{\Delta x} = -1$$

$$\frac{d|x|}{dx} = \begin{cases} +1 & \text{if } x > 0 \\ -1 & \text{if } x < 0 \\ \text{ND} @ x=0 \end{cases}$$

Differentiability (geom) / intuition



not differentiable
(NOT smooth)



not smooth

not continuous \rightarrow not differentiable

{ Differentiable @ x

↳ continuous @ x

$\rightarrow \lim_{\Delta x \rightarrow 0} \frac{f(x + \Delta x) - f(x)}{\Delta x}$ exists

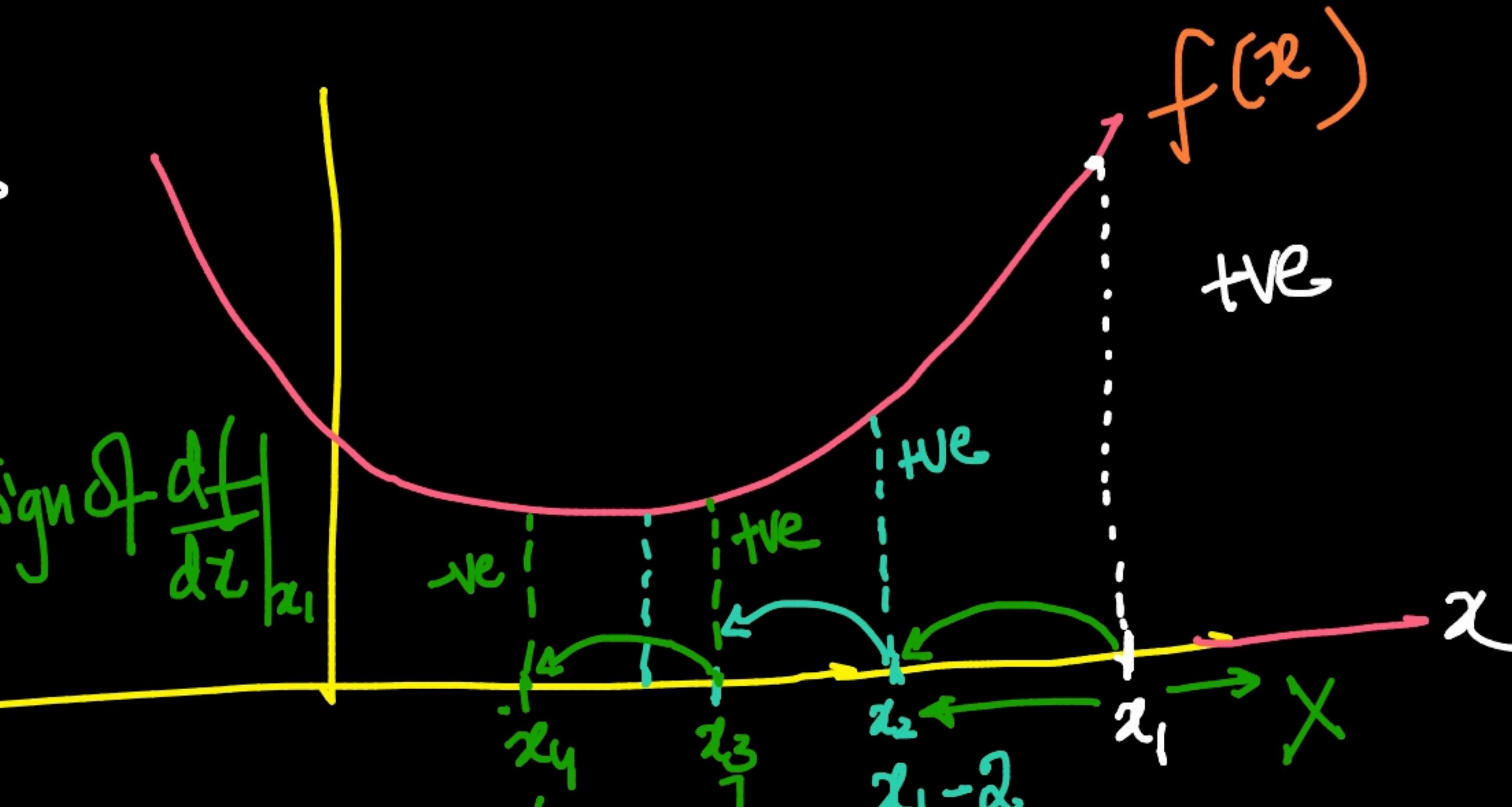
1. randomly pick x_1

2. $\frac{df}{dx} \Big|_{x_1}$: limits

3. decide which sign of $\frac{df}{dx} \Big|_{x_1}$ side to move

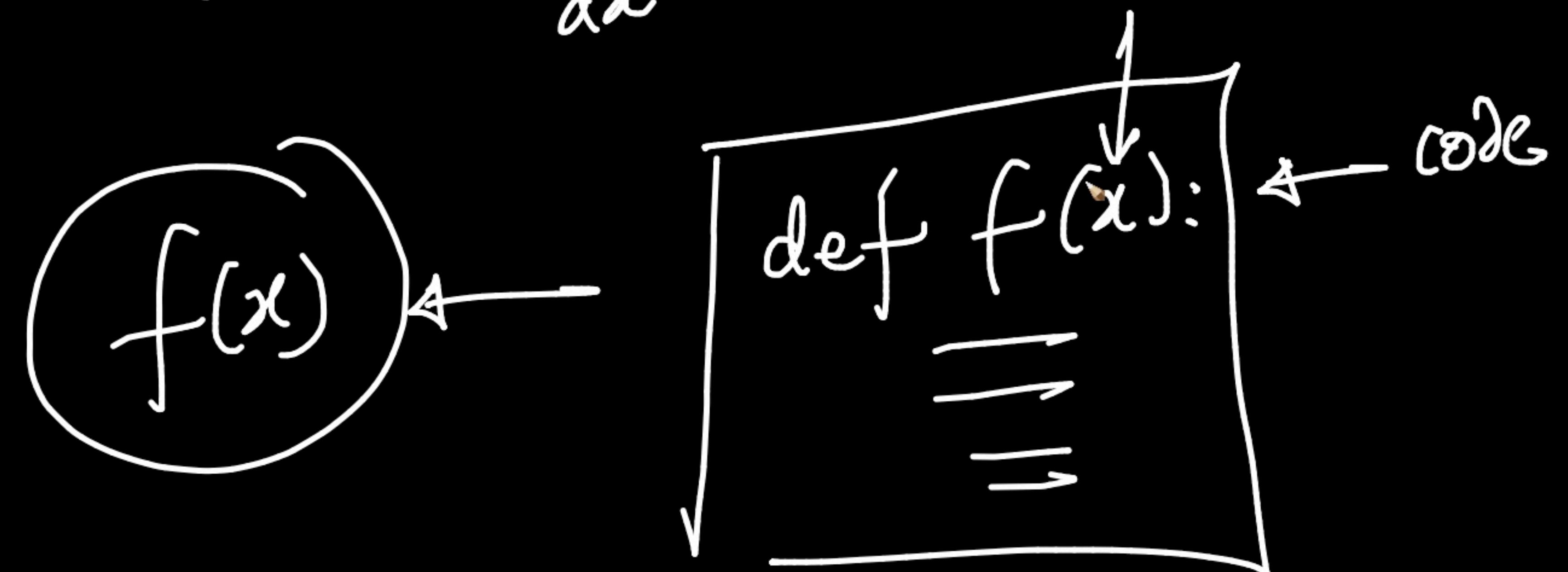
4. iteratively move towards the minimum

Using (3)



find \mathbf{x} s.t $f(\mathbf{x})$ is minimum

$$f'(x) = \frac{df(x)}{dx} = 0 \quad \checkmark$$



$$\lim_{\Delta x \rightarrow 0} \frac{f(x + \Delta x) - f(x)}{\Delta x}$$

$$\Delta x = 0.061$$

$$\Delta x = 0.0001$$

⋮

Rules of differentiation:

$$\frac{df(x)}{dx} = \frac{df}{dx} = f' = \frac{dy}{dx} = y'$$

if $y = f(x)$

$$\frac{d}{dx} (f(x) + g(x)) = \frac{df}{dx} + \frac{dg}{dx}$$

Product rule:

$$\frac{d(f(x) \cdot g(x))}{dx} = f(x) \frac{dg}{dx} + g(x) \frac{df}{dx}$$

chain rule

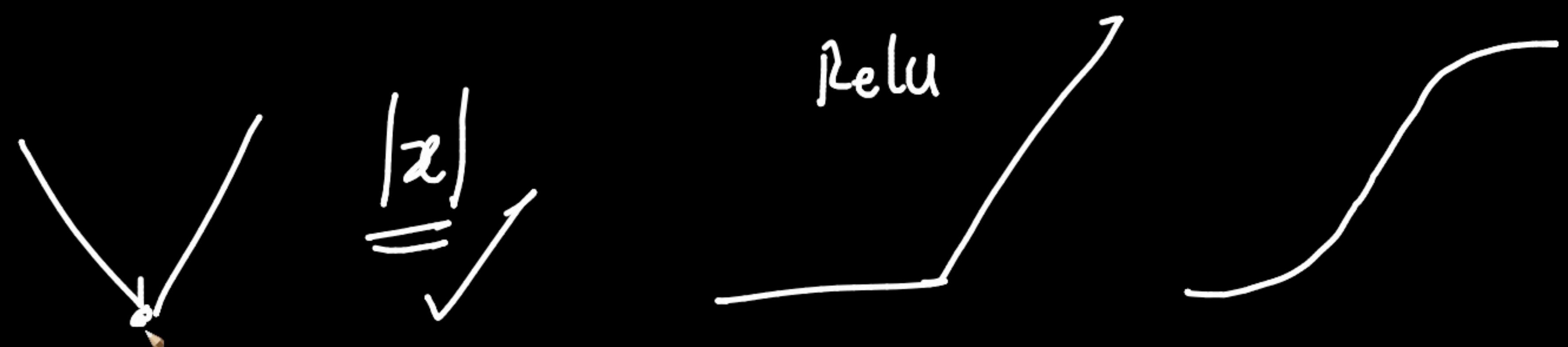
$$\left[\frac{d f(g(x))}{dx} \right] = f'(g(x)) \cdot g'(x)$$

Diagram: A yellow bracket encloses the term $f(g(x))$. Two yellow arrows point from the top of this bracket to the function $\log(x^2)$ above it.

$$\left[\frac{d \log(x^2)}{dx} \right] = 2x \cdot \frac{1}{x^2} = \frac{2}{x}$$

Diagram: A red bracket encloses the term $\log(x^2)$. A red arrow points from the top of this bracket to the function $\log(x^2)$ above it.

$$\frac{d}{dx} \left(e^{x^2} \right) = 2x \cdot e^{x^2}$$



$$\frac{d}{dx} \left(\frac{f(x)}{g(x)} \right) = \frac{f'(x)g(x) - g'(x)f(x)}{(g(x))^2}$$

to