

Before next class:

- **Watch videos 3.4, 3.5, 3.8**

Tangent line to a line?

What is the equation of the line tangent to the graph of $y = x$ at the point with x -coordinate 7?

(A) $y = x + 7$

(B) $y = x$

(C) $y = 7$

(D) $x = 7$

(E) There is no tangent line at that point.

(F) There is more than one tangent line at that point.

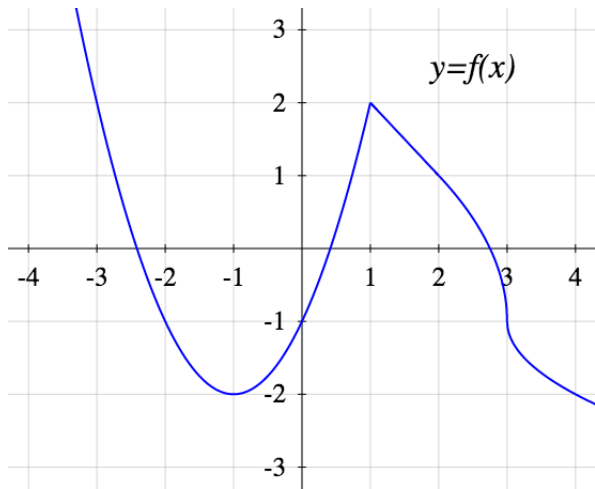
Prove these statements are false with counterexamples

Let C be a curve. Let P be a point in C .

- (A) The line tangent to C at P intersects C at only one point: P .
- (B) If a line intersects C only at P , then that line must be the tangent line to C at P .
- (C) The tangent line to C at P intersects C at P and “does not cross” C at P .
(This means that, near P , it stays on one side of C .)
- (D) If a line intersects C at P and “does not cross” C at P , then it is the tangent line to C at P .

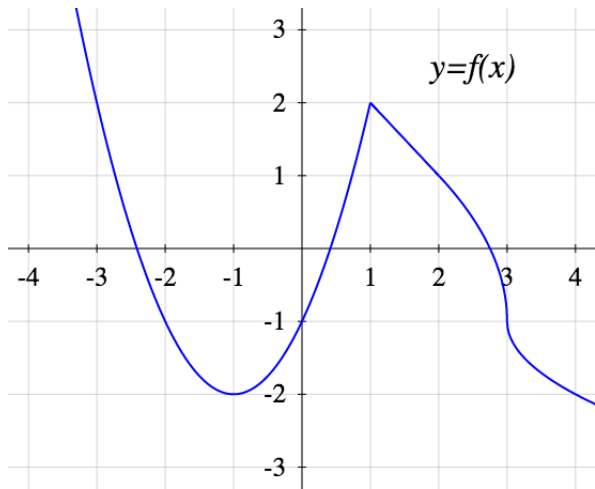
Tangent line from a graph

This is the graph of the function f . Write the (approximate) equation of the line tangent to it at the point with x -coordinate -2 .



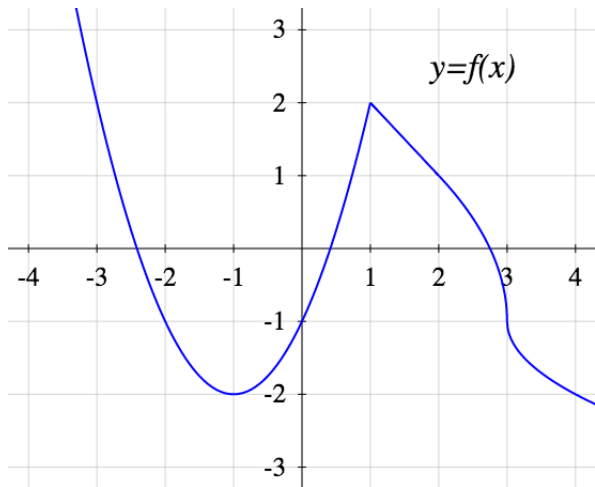
Tangent line from a graph

This is the graph of the function f . Write the (approximate) equation of the line tangent to it at the point with x -coordinate -1 .



Derivative from a graph

This is the graph of the function f .
Sketch the graph of its derivative f' .



Derivatives from the definition

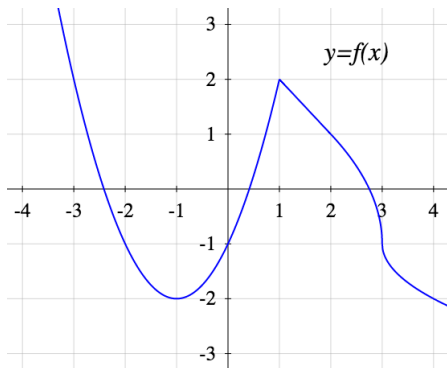
Let

$$g(x) = \frac{2}{\sqrt{x}}$$

Calculate $g'(4)$ directly from the definition of derivative as a limit.

Warmup:

Sketch $y = f'(x)$.



Before next class:

- Watch videos 3.6, 3.7, 3.9

Differentiable functions

Let $a \in \mathbb{R}$.

Let f be a function with domain \mathbb{R} .

Assume f is differentiable everywhere.

What can we conclude?

(A) $f(a)$ is defined.

(B) $\lim_{x \rightarrow a} f(x)$ exists.

(C) f is continuous at a .

(D) $f'(a)$ exists.

(E) $\lim_{x \rightarrow a} f'(x)$ exists.

(F) f' is continuous at a .

Computations: Basic differentiation rules

Compute the derivative of the following functions:

$$(A) \ f(x) = x^{100} - 3x^9 - 2 \quad (D) \ f(x) = \sqrt{x}(1 + 2x)$$

$$(B) \ f(x) = \sqrt[3]{x} + 6 \quad (E) \ f(x) = \frac{x^6 + 1}{x^3}$$

$$(C) \ f(x) = \frac{4}{x^4} \quad (F) \ f(x) = \frac{x^2 - 2}{x^2 + 2}$$

Higher order derivatives

Let $g(x) = \frac{1}{x^3}$.

- Calculate the first few derivatives.
- Make a conjecture for a formula for the n -th derivative $g^{(n)}(x)$.
- Prove it by induction.

Before next class:

- **Watch videos 3.10, 3.11**

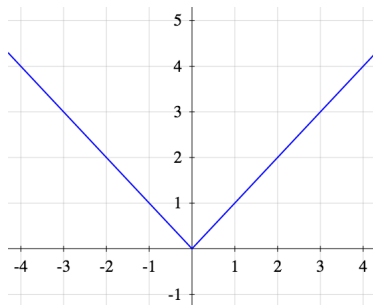
Let f be a continuous function with domain \mathbb{R} .

- (A) We know $f(4) = 3$ and $f(4.2) = 2.2$.
Based only on this, give your best estimate for $f(4.1)$.
- (B) We know $f(4) = 3$ and $f'(4) = 0.6$.
Based only on this, give your best estimate for $f(4.1)$.
- (C) We know $f(4) = 3$ and $f(4.1) = 4$.
Based only on this, give your best estimate for $f'(4)$.

Absolute value and tangent lines

At $(0,0)$ the graph of $y = |x|$...

- (A) ... has one tangent line: $y = 0$
- (B) ... has one tangent line: $x = 0$
- (C) ... has two tangent lines $y = x$ and $y = -x$
- (D) ... has no tangent line



Absolute value and derivatives

Let $h(x) = x|x|$. What is $h'(0)$?

- (A) It is 0.
- (B) It doesn't exist because $|x|$ is not differentiable at 0.
- (C) It doesn't exist because the right- and left-limits, when computing the derivative, are different.
- (D) It doesn't exist because it has a corner.
- (E) It doesn't exist for a different reason.

Write a proof for the quotient rule for derivatives

Theorem

- Let $a \in \mathbb{R}$.
- Let f and g be functions defined at and near a . Assume $g(x) \neq 0$ for x close to a .
- We define the function h by $h(x) = \frac{f(x)}{g(x)}$.

IF f and g are differentiable at a ,
THEN h is differentiable at a , and

$$h'(a) = \frac{f'(a)g(a) - f(a)g'(a)}{g(a)^2}.$$

Write a proof directly from the definition of derivative.
Hint: Imitate the proof of the product rule in Video 3.6.

Check your proof

- (A) Did you use the *definition* of derivative?
- (B) Are there words or only equations?
- (C) Does every step follow logically?
- (D) Did you only assume things you could assume?

- (E) Did you assume at some point that a function was differentiable? If so, did you justify it?
- (F) Did you assume at some point that a function was continuous? If so, did you justify it?

If you answered “no” to (F), you probably missed something important.

Critique this proof

$$\begin{aligned}h'(a) &= \lim_{x \rightarrow a} \frac{h(x) - h(a)}{x - a} = \lim_{x \rightarrow a} \frac{\frac{f(x)}{g(x)} - \frac{f(a)}{g(a)}}{x - a} \\&= \lim_{x \rightarrow a} \frac{f(x)g(a) - f(a)g(x)}{g(x)g(a)(x - a)} \\&= \lim_{x \rightarrow a} \frac{f(x)g(a) - f(a)g(a) + f(a)g(a) - f(a)g(x)}{g(x)g(a)(x - a)} \\&= \lim_{x \rightarrow a} \left\{ \left[\frac{f(x) - f(a)}{x - a} g(a) - f(a) \frac{g(x) - g(a)}{x - a} \right] \frac{1}{g(x)g(a)} \right\} \\&= [f'(a)g(a) - f(a)g'(a)] \frac{1}{g(a)g(a)}\end{aligned}$$

True or False - Differentiability vs Continuity

Let f be a function with domain \mathbb{R} . Let $c \in \mathbb{R}$.

Which of these implications are true?

- (A) IF f is continuous at c , THEN f is differentiable at c
- (B) IF f is differentiable at c , THEN f is continuous at c
- (C) IF f is differentiable at c , THEN f' is continuous at c
- (D) IF f' is continuous at c , THEN f is continuous at c
- (E) IF f is differentiable at c , THEN f is continuous at and near c .
- (F) IF f is continuous at and near c , THEN f is differentiable at c .

True or False - Differentiability and Operations

Let f be a function with domain \mathbb{R} . Let $c \in \mathbb{R}$.

Let $g(x) = f(x)^2$. Which of these implications are true?

- (A) IF f is differentiable at c , THEN $f + f'$ is continuous at c
- (B) IF f is differentiable at c , THEN $3f$ is differentiable at c .
- (C) IF f is differentiable at c , THEN g is differentiable at c .
- (D) IF g is differentiable at c , THEN f is differentiable at c .
- (E) IF f is differentiable at c , THEN $1/f$ is differentiable at c .

Warmup: Get out and review your proof of the Quotient Rule.

Before next class:

- Watch videos 3.12, 3.13

Check your proof

- (A) Did you use the *definition* of derivative?
- (B) Are there words or only equations?
- (C) Does every step follow logically?
- (D) Did you only assume things you could assume?

- (E) Did you assume at some point that a function was differentiable? If so, did you justify it?
- (F) Did you assume at some point that a function was continuous? If so, did you justify it?

If you answered “no” to (F), you probably missed something important.

Quick composition

Let f and g be differentiable functions and let $h = f \circ g$. What is $h'(2)$?

- (A) $f'(2) \circ g'(2)$
- (B) $f'(2)g'(2)$
- (C) $f'(g(2))g'(2)$
- (D) $f'(g(2)) \circ g'(2)$
- (E) $f'(g(x))g'(2)$
- (F) $f' \circ g'(2)$
- (G) $f'(g'(2))$

Quick composition 2

Let f and g be differentiable functions. Which statements have a mathematical meaning?

(A) $f'(2) \circ g'(2)$

(B) $f'(2)g'(2)$

(C) $f'(g(2))g'(2)$

(D) $f'(g(2)) \circ g'(2)$

(E) $f'(g(x))g'(2)$

(F) $f' \circ g'(2)$

(G) $f'(g'(2))$

True or False - Differentiability and Composition

Let f and g be functions with domain \mathbb{R} . Let $c \in \mathbb{R}$. Assume f and g are differentiable at c . What can we conclude?

(A) $f \circ g$ is differentiable at c .

(B) $f \circ f$ is differentiable at c .

(C) $f \circ \sin$ is differentiable at c .

(D) $\sin \circ f$ is differentiable at c .

Computations: Chain rule

Compute the derivative of

(A) $f(x) = (2x^2 + x + 1)^8$

(B) $f(x) = \frac{1}{\left(x + \sqrt{x^2 + x}\right)^{137}}$

Without using a calculator, estimate $\sqrt[20]{1.01}$ as well as you can.

Hint: You know the value of $f(x) = \sqrt[20]{x}$ and its derivative at one point very close to 1.01. Use the tangent line at that point as an approximation.

Estimations – 3

(A) We know

$$f(0) = 2, \quad f'(0) = 3, \quad g(0) = 7, \quad g'(0) = 5.$$

Compute $\lim_{x \rightarrow 0} \frac{f(x)}{g(x)}.$

(B) We know

$$f(0) = 0, \quad f'(0) = 3, \quad g(0) = 0, \quad g'(0) = 5.$$

- When x is close to 0, give estimates for $f(x)$ and $g(x)$ using the tangent lines at 0.

- Use those estimates to compute $\lim_{x \rightarrow 0} \frac{f(x)}{g(x)}.$

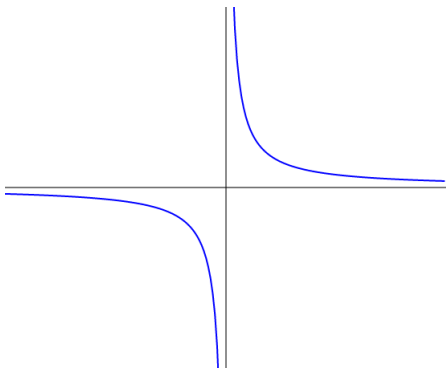
MAT137 Lecture 21 — Trig Derivatives and Implicit Differentiation

Before next class:

- **Watch videos 4.1, 4.2**

From the derivative to the function

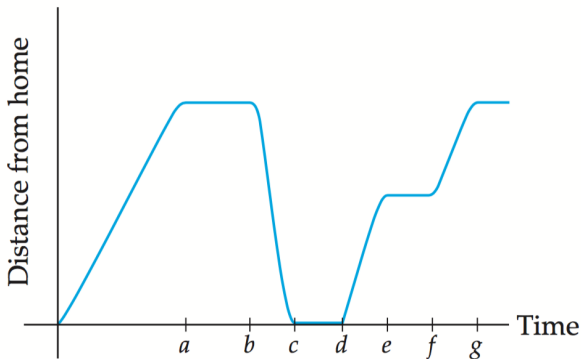
- (A) Sketch the graph of a continuous function with domain \mathbb{R} , whose derivative has the graph below.
- (B) Sketch the graph of a non-continuous function whose derivative has the graph below.



Bella

The graph below describes Bella's distance from home one morning as she drives between her home and school.

Describe a possible scenario for her travels that morning. Then sketch the corresponding graph of his velocity.



Jacob walked at 5 km/h for 20 minutes and then sprinted at 15 km/h for 8 minutes.

- (A) How fast would Edward have to walk or run to go the same distance as Jacob did in the same time while moving at a constant speed?
- (B) Sketch a graph of Jacob's and Edward's positions over time on the same set of axes.

A long chain

The function below has 137 square roots:

$$f(x) = \sqrt{x + \sqrt{x + \sqrt{x + \sqrt{x + \dots + \sqrt{x + \sqrt{x + 1}}}}}}$$

Find the equation of the line tangent to the graph of f at the point with x -coordinate 0.

Computations: Trig derivatives

Compute the derivatives of the following functions:

(A) $f(x) = \tan(3x^2 + 1)$

(B) $f(x) = (\cos x)(\sin 2x)(\tan 3x)$

(C) $f(x) = \cos(\sin(\tan x))$

(D) $f(x) = \cos\left(3x + \sqrt{1 + \sin^2 x^2}\right)$

Vertical things

- Construct a function f that has a **vertical asymptote** at $x = 2$.
- Construct a function g that has a **vertical tangent line** at $x = 2$.

Absolute value and derivatives - 2

True or False?

For all $n \in \mathbb{Z}$ and all x , $\frac{d}{dx}|x|^n = nx|x|^{n-2}$.

Richard Nixon, during the 1972 US Presidential campaign, (paraphrased):

Inflation is increasing, but the rate of increase of inflation is decreasing.

Let

- C = cost of life
- t = time

What did Nixon say in terms of derivatives?

Chain rule from a graph

If f and g are the functions whose graphs are shown.

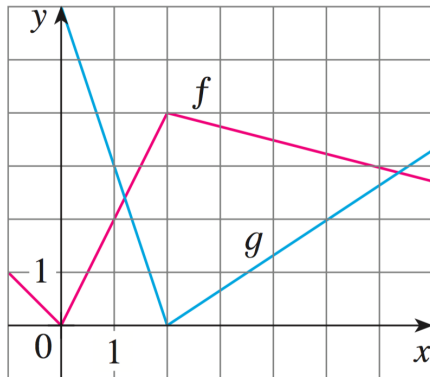
Let $u(x) = f(g(x))$ and $v(x) = g(f(x))$.

Find each derivative, if it exists.

If it does not exist, explain why.

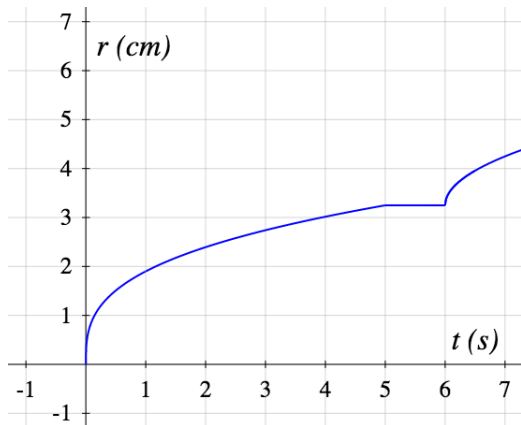
(A) $u'(1)$

(B) $v'(1)$



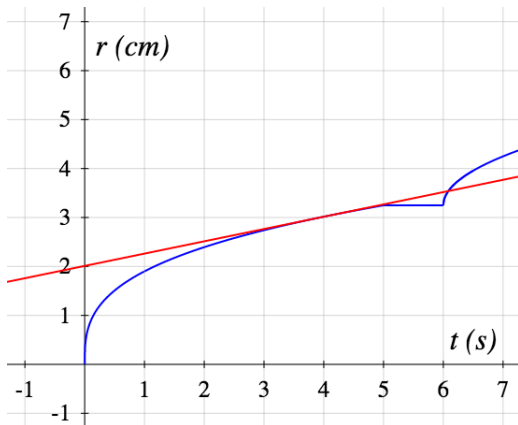
Balloon

I am inflating a spherical balloon. Below is the graph of the radius r (in cm) as a function of time t (in s). At what rate is the volume of the balloon increasing at time $4s$?



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An alternative proof of the quotient rule

Assume we have already proven the product rule, the power rule, and the chain rule.

Obtain a formula for the derivative of $h(x) = \frac{f(x)}{g(x)}$.

Hint: $\frac{f(x)}{g(x)} = f(x) \cdot g(x)^{-1}$

Derivatives of $(f \circ g)$

Assume f and g are functions that have all their derivatives. Find formulas for

(A) $(f \circ g)'(x)$

(B) $(f \circ g)''(x)$

(C) $(f \circ g)'''(x)$

in terms of the values of f , g and their derivatives.

Hint: The first one is simply the chain rule.

Derivatives of $(f \circ g)$

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Challenge: Find a formula for $(f \circ g)^{(n)}(x)$
(This is beyond the scope of this course).

Derivative of \cos

Let $g(x) = \cos x$.

Obtain and prove a formula for its derivative directly from the definition of derivative as a limit.

Hint: Imitate the derivation in Video 3.12.

If you need a trig identity that you do not know, google it or ask another student.

Derivatives of the other trig functions

Use the basic differentiation rules, as well as

$$\frac{d}{dx} \sin x = \cos x, \quad \frac{d}{dx} \cos x = -\sin x,$$

to quickly obtain and prove formulas for the derivatives of tan, cot, sec, and csc.

Product of trig functions

Let $f(x) = \sin x \cos x$. What is its derivative $f'(x)$?

- (A) $1 - 2 \sin^2(x)$
- (B) $2 \cos^2(x) - 1$
- (C) $\cos 2x$
- (D) all of the above
- (E) none of the above

A pesky function

$$\text{Let } h(x) = \begin{cases} x^2 \sin \frac{1}{x} & \text{if } x \neq 0 \\ 0 & \text{if } x = 0 \end{cases}.$$

- (A) Calculate $h'(x)$ for any $x \neq 0$.
- (B) Using the definition of derivative, calculate $h'(0)$.
- (C) Calculate $\lim_{x \rightarrow 0} h'(x)$

Hint: Questions 2 and 3 have different answers.

A pesky function

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Hint: Questions 2 and 3 have different answers.

- (D) Is h continuous at 0?
- (E) Is h differentiable at 0?
- (F) Is h' continuous at 0?

Implicit differentiation

The equation

$$\sin(x + y) + xy^2 = 0$$

defines a function $y = h(x)$ near $(0, 0)$. [▶ graph](#)

Using implicit differentiation, compute

- (A) $h(0)$ (B) $h'(0)$ (C) $h''(0)$ (D) $h'''(0)$