4.5 Increasing, Decreasing, Concavity, and Tests for Extrema

Goals:

1. Understand how the sign of the derivative of a function relates to the behavior of the function, re: increasing or decreasing.
2. Use the First Derivative Test to determine relative extrema.
3. Understand how the sign of the 2nd derivative of a function relates to the behavior of the function, re: concave up or concave down.
4. Determine intervals where a function is concave up or concave down.
5. Find Inflection Points of a curve.
6. Use the Second Derivative Test to determine relative extrema.

Study 4.5 # 195, 197, 201, 203, 209-213, 221-229, 234, 237

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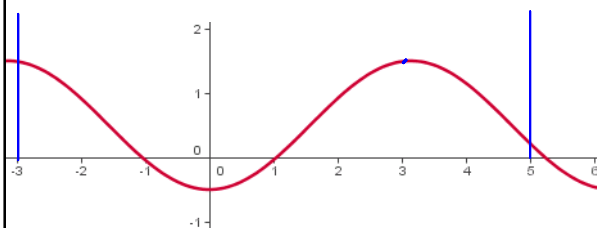
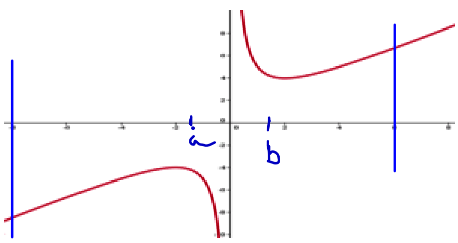
4.5 Increasing, Decreasing, Concavity, and Tests for Extrema

Find: Intervals where function is increasing or decreasing.



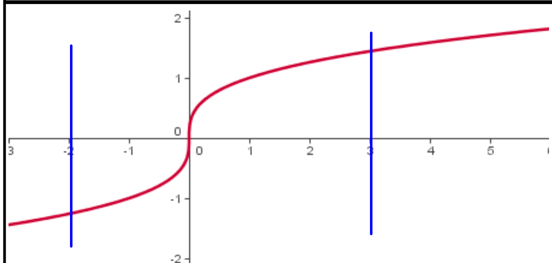
Consider [-3,5]

Increasing	Decreasing



Consider [-8,6]

Increasing	Decreasing



Consider [-2,3]

Increasing	Decreasing

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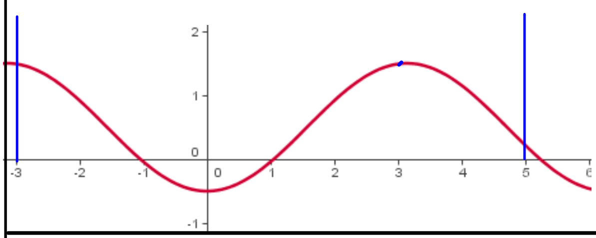
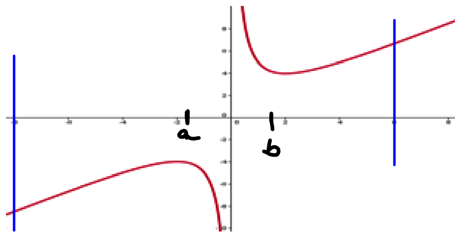
4.5 Increasing, Decreasing, Concavity, and Tests for Extrema

Find: Intervals where function is increasing or decreasing.



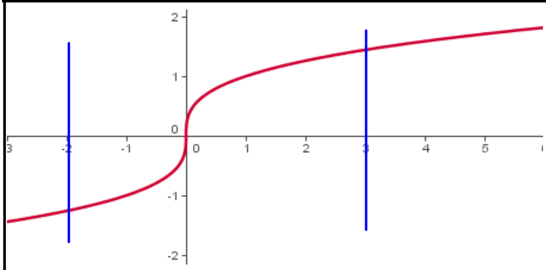
Consider [-3,5]

Increasing	Decreasing
(0,3)	(-3,0)
	(3,5)



Consider [-8,6]

Increasing	Decreasing
(-8,a)	(a,0)
(b,6)	(0,b)



Consider [-2,3]

Increasing	Decreasing
(-2,3)	

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4.5 Increasing, Decreasing, Concavity, and Tests for Extrema

Can we tell if a function is increasing or decreasing, if we do not see it's graph? How?
Is there a way to test for increasing or decreasing?

Hint: Consider the slope of the tangent line.

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4.5 Increasing, Decreasing, Concavity, and Tests for Extrema

Conclude:

Yes. We can tell if a function is increasing or decreasing, if we consider the slope of the tangent line. In particular we need to look at the sign of the slope. Is it positive or negative?

How can we examine the sign of slope of the tangent line?

4.5 Increasing, Decreasing, Concavity, and Tests for Extrema

Conclude:

Yes. We can tell if a function is increasing or decreasing, if we consider the slope of the tangent line. In particular we need to look at the sign of the slope. Is it positive or negative?

How can we examine the sign of slope of the tangent line?

1. Find the derivative.
2. Determine the intervals where the derivative is positive. and where it is negative.

4.5 Increasing, Decreasing, Concavity, and Tests for Extrema

Test for Increasing & Decreasing Functions

Let f be a function that is continuous on [a,b], and differentiable on (a,b), then:

1. If **f '(x) > 0** for all x on (a,b),

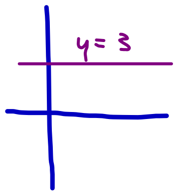
   then f is **increasing** on [a,b]

2. If **f '(x) < 0** for all x on (a,b),

   then f is **decreasing** on [a,b]

3. If **f '(x) = 0** for all x on (a,b),

   then f is **constant** on [a,b]



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4.5 Increasing, Decreasing, Concavity, and Tests for Extrema

Find the intervals where y is increasing and intervals where y is decreasing. $y = -(x-1)^2$

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4.5 Increasing, Decreasing, Concavity, and Tests for Extrema

Find the intervals where y is increasing and intervals where y is decreasing. $y = -(x - 1)^2$

CN:
1. y defined?
2. x when y' =0?
3. x when y' dne?

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

CNs: ① y def. ② $\frac{dy}{dx} = 0$: $x - 1 = 0$, $x = 1$ CN. ③ $\frac{dy}{dx}$ exists all x

		1	
		$(-\infty, 1)$	$(1, \infty)$
test	x	0	2
	$x-1$	$-$	$+$
$\frac{dy}{dx} =$	$-2(x-1)$	$+$	$-$
	y	incr	decr

Tabular representation of the number line, the sign of the derivative, and the incr or decr status of the function

y incr. on $(-\infty, 1)$
y decr.on $(1, \infty)$

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4.5 Increasing, Decreasing, Concavity, and Tests for Extrema

Find the intervals where y is increasing and intervals where y is decreasing. $y = x^4 - 2x^2$

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4.5 Increasing, Decreasing, Concavity, and Tests for Extrema

Find the intervals where y is increasing and intervals where y is decreasing. $y = x^4 - 2x^2$

$1 - 2 = -1$

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

CNs: $x = -1, 0, 1$

other CNs? No.
dy/dx exists for all x

	$(-\infty,-1)$	$(-1,0)$	$(0,1)$	$(1,\infty)$
	-1	0	1	
x	-2	$-\frac{1}{2}$	$\frac{1}{2}$	2
4x	$-$	$-$	$+$	$+$
x+1	$-$	$+$	$+$	$+$
x-1	$-$	$-$	$-$	$+$
$\frac{dy}{dx}$	$-$	$+$	$-$	$+$
y	decr	incr	decr	incr

$(-1,-1)$ rel. min

$(0,0)$ rel. max

$(1,-1)$ rel. min.

y decr. $(-\infty,-1)$, $(0,1)$
incr $(-1,0)$, $(1,\infty)$

4.5 Increasing, Decreasing, Concavity, and Tests for Extrema

Wow! We can use this approach to determine max and mins!

The First Derivative Test for Relative Extrema

Let **c be a Critical Number** of the function f that is continuous on the open interval I containing c. If f is differentiable on the interval, except possibly at c, then f(c) can be classified as:

1. **a relative min, if f ' (x) changes from negative to positive at c.** \ /

2. **a relative maximum, if f ' (x) changes from positive to negative at c** / \

3. **neither a max nor a min if f ' (x) is positive on both sides of c / / or negative on both sides of c \ **

4.5 Increasing, Decreasing, Concavity, and Tests for Extrema

Find **Relative Extrema** of a continuous function using **intervals** and the **First Derivative Test**

1. Find **critical numbers** [f defined and f '(c) = 0 or f '(c) undefined]
2. **Determine intervals** for evaluation of f ' and begin the interval table:
   a) Locate the **critical numbers along a number line** containing the domain of the function
   b) Determine the **intervals, using the critical numbers as endpoints**.
3. Continue the interval table by:
   a) Selecting a test value for each interval.
   b) Write f '(x) in factored form in the first column.
   c) For each interval, find the sign of f '(x) by determining the number of negative factors.
4. Determine whether f(x), the original function, is increasing (when f '(x) >0) or decreasing (when f '(x) <0) on each interval.
5. The critical value for which f(x) is increasing to the left and decreasing to the right is a relative max. / \
6. The critical value for which f(x) is decreasing to the left and increasing to the right is a relative min. \ /
7. Find the corresponding f or y value for each critical value determined to be a relative max or min, and write the ordered pair (c,f(c)).

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4.5 Increasing, Decreasing, Concavity, and Tests for Extrema

G: $f(x) = x^2 + 8x + 10$ F: a) CNs, b) interv inc, decr, c) rel.extrema

step-by-step: 1st Deriv Test

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4.5 Increasing, Decreasing, Concavity, and Tests for Extrema

G: $f(x) = x^2 + 8x + 10$ F: a) CNs, b) inter inc, decr, c) rel.extrema

$f(x) = x^2 + 8x + 10$

F: a) CNs, b) inter. ↑, ↓ c) rel. extr.

$f'(x) = 2x + 8 = 2(x+4)$

CN: $x = -4$

other CNs? No.
dy/dx exists for all x

	$(-\infty,-4)$	-4	$(-4,\infty)$
x	-5		0
$f'(x)=2(x+4)$	$-$		$+$
$f(x)$	decr.		incr.

$f(-4) = (-4)^2 + 8(-4) + 10$
$= 16 - 32 + 10$
-6

$(-4, -6)$ rel. min

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4.5 Increasing, Decreasing, Concavity, and Tests for Extrema

$f(x) = x^3 - 6x^2 + 15$

F: intervals where f is incr, decr
relative extrema

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4.5 Increasing, Decreasing, Concavity, and Tests for Extrema

F: intervals where f is incr, decr
relative extrema

$f(x) = x^3 - 6x^2 + 15$

$f(4) = 64 - 96 + 15 = 79 - 96$

$f'(x) = 3x^2 - 12x$

CNs $f'(x) = 0$ or ~~DNE~~

$3x(x-4) = 0$

$3x = 0 \quad | \quad x - 4 = 0$

$\boxed{x = 0 \quad | \quad x = 4 \text{ CN.}}$

	$(-\infty, 0)$	0	$(0, 4)$	4	$(4, \infty)$
x	-1		1		5
$3x$	$-$		$+$		$+$
$x-4$	$-$		$-$		$+$
$f'(x)$	$+$		$-$		$+$
$f(x)$	incr		decr		incr.

$(0, 15)$ rel. MAX

$(4, -17)$ rel MIN

4.5 Increasing, Decreasing, Concavity, and Tests for Extrema

Compare f(x), f '(x), f ''(x)

Consider: $y = x^3 - x$

Graph of function
1st Derivative: graph, slope of, relate to y?
2nd derivative: graph, relate to y?

4.5 Increasing, Decreasing, Concavity, and Tests for Extrema

Consider: $y = x^3 - x$

Graph of function
1st Derivative: graph, slope of, relate to y?
2nd derivative: graph, relate to y?

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

Compare f(x), f '(x), f "(x)

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4.5 Increasing, Decreasing, Concavity, and Tests for Extrema

Graph of function
1st Derivative: graph, slope of, relate to y?
2nd derivative: graph, relate to y?

Consider: $y = x^3 - x$

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

$$\frac{d^2y}{dx^2} = 6x$$

Compare f(x), f '(x), f "(x)

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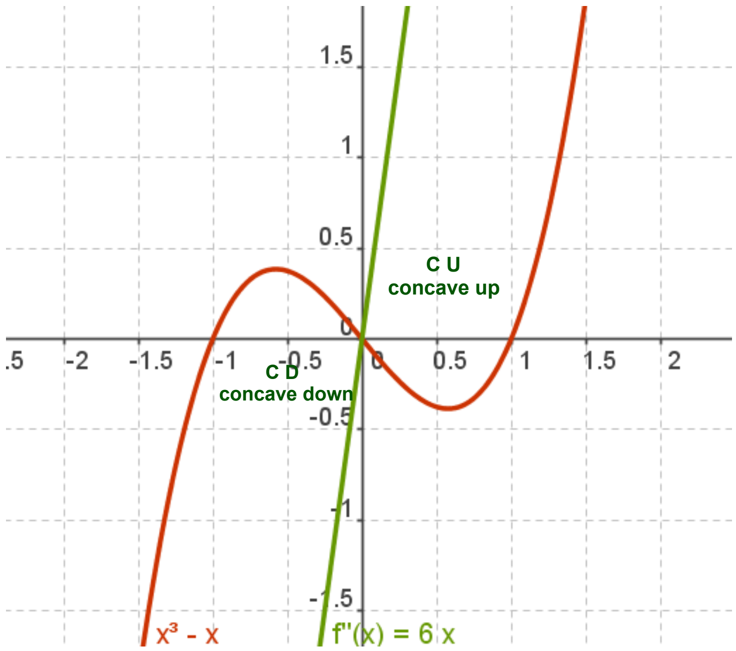
4.5 Increasing, Decreasing, Concavity, and Tests for Extrema

How does the 2nd derivative relate to original function?



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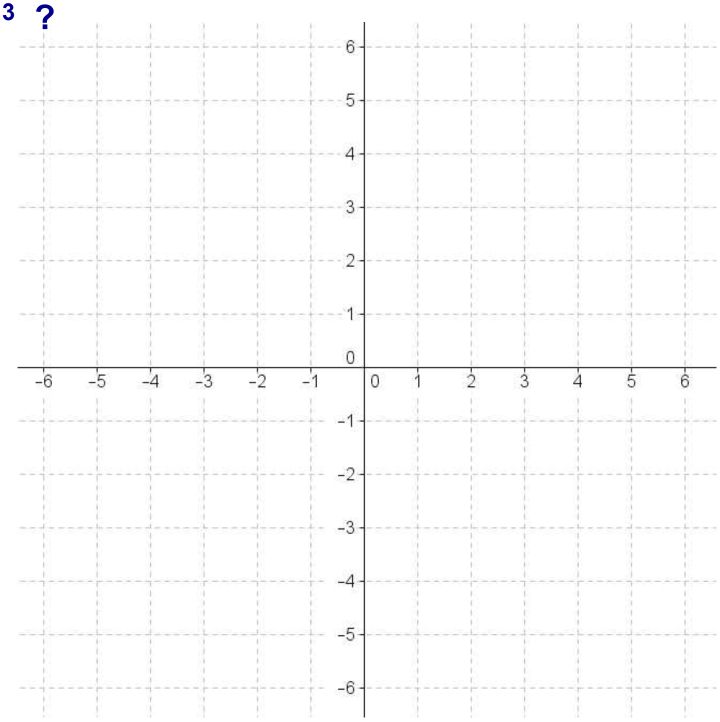
4.5 Increasing, Decreasing, Concavity, and Tests for Extrema

What about $y = x^3$?

$\dfrac{dy}{dx} =$

$\dfrac{d^2y}{dx^2} =$



C D concave down C U concave up

Change f(x) to x^3

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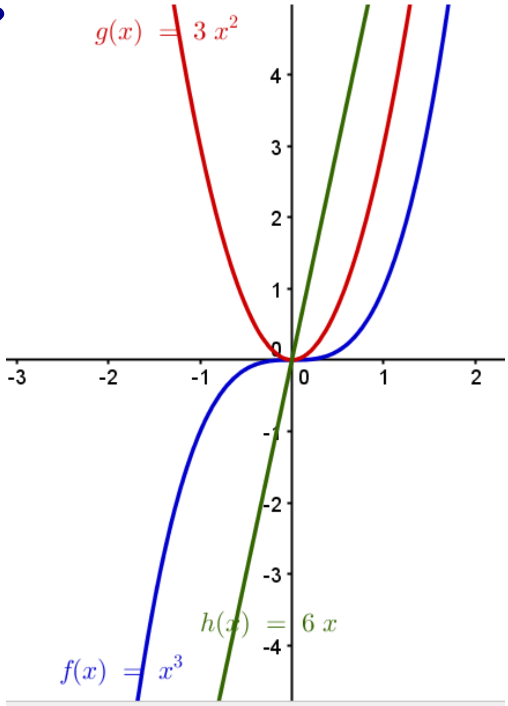
4.5 Increasing, Decreasing, Concavity, and Tests for Extrema

What about $y = x^3$?

$\frac{dy}{dx} =$

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



Compare f(x), f '(x), f "(x)

C D
concave down

C U
concave up

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4.5 Increasing, Decreasing, Concavity, and Tests for Extrema

How does the 2nd derivative relate to original function?

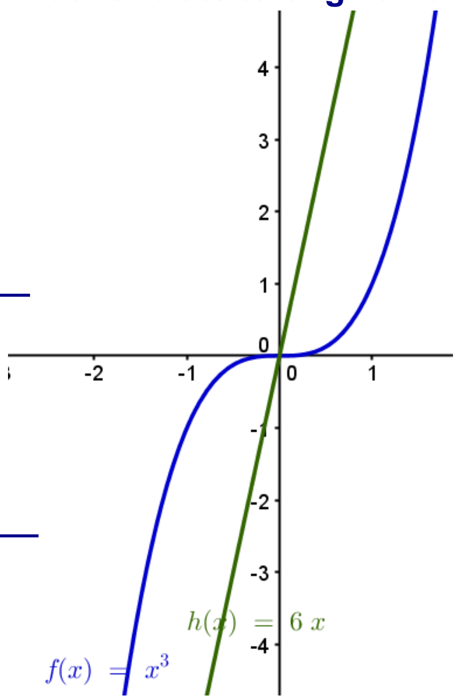
What about $y = x^3$?

When $\frac{d^2y}{dx^2} < 0$?

then y is ________________

When $\frac{d^2y}{dx^2} > 0$?

then y is ________________



C D
concave down

C U
concave up

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4.5 Increasing, Decreasing, Concavity, and Tests for Extrema

How does the 2nd derivative relate to original function?

What about $y = x^3$?

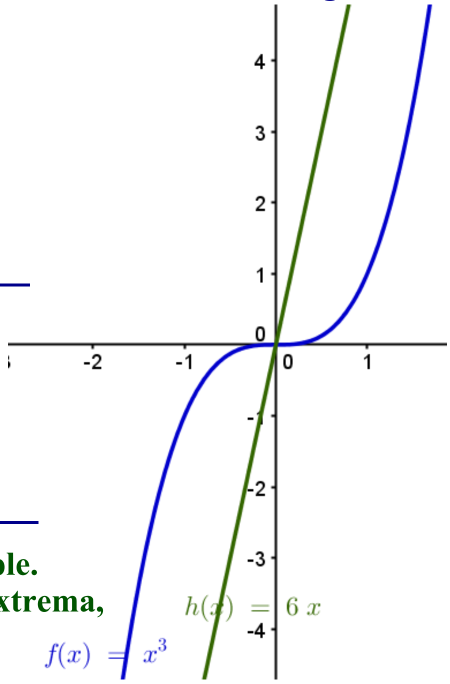
When $\frac{d^2y}{dx^2} < 0$?

then y is C D concave down

When $\frac{d^2y}{dx^2} > 0$?

then y is C U concave up

Similar to previous example.
Even though no relative extrema,
it is still c.u. when x>0
and c.d. when x<0.



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4.5 Increasing, Decreasing, Concavity, and Tests for Extrema

Definition of Concavity

Let f be differentiable on an open interval . The graph of *f* is:

concave upward on I if f ' is increasing on I

concave downward on I if f ' is decreasing on I

or when f '' (x) > 0

or when f '' (x) < 0

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4.5 Increasing, Decreasing, Concavity, and Tests for Extrema

Step by step: on-line

2nd Derivative Test for Relative Extrema

Let f be a function, with
f '(c) = 0 and (horizontal slope)
f "(x) continuous on open interval containing c

1. If f "(c) > 0, then f has a local Min at (c, f(c))
C.U

2. If f "(c) < 0, then f has a local Max at (c, f(c))
C.D

1. If f "(c) = 0, then the test fails

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4.5 Increasing, Decreasing, Concavity, and Tests for Extrema

Step by step: on-line

2nd Derivative Test for Relative Extrema: Step by Step

1. Find f '(x) and values of c where f '(c) =0 [not quite critical numbers - does not include f '(c) undefined]
2. Find f "(x). Is it continuous at c? Test only valid when continuous.
3. Find the sign of f "(c) for all c.
4. Determine the relative extrema using the Second Derivative Test:

   a) If f "(c) > 0, then f is concave up and f(c) is a **relative min**

   b) If f "(c) < 0, then f is concave down and f(c) is a **relative max**

   c) If f "(c) = 0, then the test fails. (consider an Inflection Point - a point where concavity changes)

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4.5 Increasing, Decreasing, Concavity, and Tests for Extrema

Step by step: on-line

$y = x^3 - x$ F: Rel. extr, 2nd derivative test

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4.5 Increasing, Decreasing, Concavity, and Tests for Extrema

G: $y = x^3 - x$ F: Rel. extr, 2nd deriv. test

$y = x^3 - x$

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

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

$= 6x$

CNs: $3x^2 = 1$

$x^2 = 1/3$

$x = \pm\sqrt{1/3}$

at $x = \frac{1}{\sqrt{3}}$, $\frac{d^2y}{dx^2} > 0 \therefore$ c.u.

$\left(\frac{1}{\sqrt{3}}, \_\right)$ rel. min.

$x = -\frac{1}{\sqrt{3}}$, $\frac{d^2y}{dx^2} < 0 \therefore$ c.d.

$\left(-\frac{1}{\sqrt{3}}, \_\right)$ rel. max

$y = x(x^2-1)$

$x = \frac{1}{\sqrt{3}}: \frac{1}{\sqrt{3}}\left(\frac{1}{3} - 1\right)$

$-\frac{2}{3\sqrt{3}}$

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4.5 Increasing, Decreasing, Concavity, and Tests for Extrema

Example: G: $h(x) = x^5 - 5x + 2$
F: open interval where c.u. and c.d.

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4.5 Increasing, Decreasing, Concavity, and Tests for Extrema

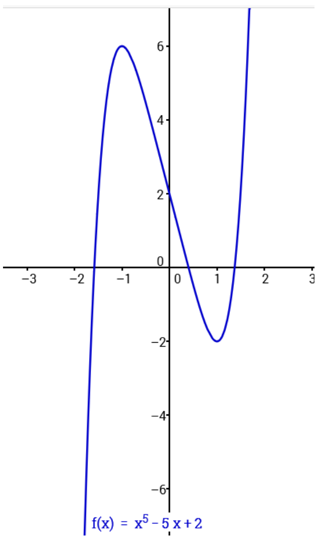
Example: G: $h(x) = x^5 - 5x + 2$ $-1 \; +5 \; +2$
F: open interval where c.u. and c.d. need h"(x)

$h'(x) = 5x^4 - 5 = 5(x^4 - 1) = 5(x^2+1)(x^2-1)$

$h''(x) = 20x^3$

$x > 0,\ h''(x) > 0$; c.u

$x < 0,\ h''(x) < 0$; c.d



NOT ASKED FOR

rel. extr: CN: $x = \pm 1$

$h''(-1) < 0 \therefore$ c.d $(-1, 6)$ rel MAX

$h''(1) > 0 \therefore$ c.u $(1, -2)$ rel MIN

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4.5 Increasing, Decreasing, Concavity, and Tests for Extrema

Definition of Point of Inflection

Let f be a function that is **continuous** on an open interval and let c be a point on the interval. If the graph of **f has a tangent line** at this point (c,f(c)), then this point is a **point of inflection** of the graph of f if the **concavity of f changes** from upward to downward (or downward to upward) at the point

Inflection Point at (c,f(c))
1. f continuous
2. f has a tangent line
3. concavity changes
   (f '' changes sign)

If *(c,f(c))* is a point of inflection of the graph of f, then
either $f''(c) = 0$ or $f''(c)$ does not exist at x = c.

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Class Notes: Prof. G. Battaly, Westchester Community College, NY

4.5 Increasing, Decreasing, Concavity, and Tests for Extrema

Inflection Point at (c,f(c))
1. f continuous
2. f has a tangent line
3. concavity changes
   (f '' changes sign)

Example: G: $f(x) = 2x^3 - 3x^2 - 12x + 5$
F: IP

Compare f(x), f '(x), f ''(x)

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4.5 Increasing, Decreasing, Concavity, and Tests for Extrema

Example: G: $f(x) = 2x^3 - 3x^2 - 12x + 5$
F: IP $\rightarrow$ ① cont. ② tang. line exists, or polyn. ③ Conc. change f''

$f'(x) = 6x^2 - 6x - 12$ $= 6(x^2 - x - 2)$ $= 6(x-2)(x+1)$

CN: x = -1, 2
but not required for IP

$f''(x) = 12x - 6$
$= 6(2x-1)$

poss IP when $f''(x) = 0$

$2x - 1 = 0$
$x = \frac{1}{2}$

x =1/2 is possible IP
need to show change in concavity
[change in sign of f "(x)]

	$(-2, \frac{1}{2})$	$(\frac{1}{2}, 2)$
x	0	1
$f'' = 6(2x-1)$	$-$	$+$
$f(x)$	c.d	c.u

$f(\frac{1}{2}) = 2(\frac{1}{2})^3 - 3(\frac{1}{2})^2 - 12(\frac{1}{2}) + 5$
$= \frac{2}{8} - \frac{3}{4} - 6 + 5$
$= \frac{2-6}{8} - 1 = \frac{-4}{8} - 1 = -3/2$

$\therefore (\frac{1}{2}, \frac{-3}{2})$ IP

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Calculus Home Page Problems for 3.4

4.5 Increasing, Decreasing, Concavity, and Tests for Extrema

Example: G: $f(x) = 2x^3 - 3x^2 - 12x + 5$
F: [redacted] Rel Extr. 2nd Deriv. Test

$\therefore (\frac{1}{2}, \frac{-3}{2})$ IP

$f'(x) = 6x^2 - 6x - 12 = 6(x^2 - x - 2)$
$= 6(x-2)(x+1)$

$f''(x) = 12x - 6$
$= 6(2x-1)$

CN: x = -1, 2
but not required for IP

$6(x-2)(x+1) = 0$
$(x-2)(x+1) = 0$
$x - 2 = 0 \quad | \quad x + 1 = 0$
$x = 2 \quad | \quad x = -1$

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4.5 Increasing, Decreasing, Concavity, and Tests for Extrema

Rel Extr. 2nd Deriv. Test

Example: G: $f(x) = 2x^3 - 3x^2 - 12x + 5$
F:

$f'(x) = 6x^2 - 6x - 12 = 6(x^2 - x - 2)$
$= 6(x-2)(x+1)$
$f''(x) = 12x - 6$
$= 6(2x-1)$

$\therefore \left(\frac{1}{2}, \frac{-3}{2}\right)$ IP

CN: x = -1, 2
but not required for IP

$6(x-2)(x+1) = 0$
$(x-2)(x+1) = 0$
$x-2=0 \mid x+1=0$
$x=2 \mid x=-1$

$f''(2) > 0 \therefore$ c.u. $(2, -15)$ rel. MIN

$f''(-1) < 0 \therefore$ c.d. $(-1, 12)$ rel MAX

$x=2$

$f(2) = 2(2^3) - 3(2^2) - 12(2) + 5$
$\cancel{16 - 12} - 24 + 5 = -15$
$-20 + 5$

$x=-1$

$f(-1) = 2(-1)^3 - 3(-1)^2 - 12(-1) + 5$
$= -2 - 3 + 12 + 5 = 12$

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4.5 Increasing, Decreasing, Concavity, and Tests for Extrema

Theorum: Points of Inflection

If $(c, f(c))$ is a point of inflection of the graph of f, then either:

$f''(c) = 0$ or f'' does not exist at $x = c$

how?

Consider: $y = x^{1/3}$ has IP and $y = x^{2/3}$ no IP

Change f(x) to x^(1/3)

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4.5 Increasing, Decreasing, Concavity, and Tests for Extrema

Theorum: Points of Inflection

If $(c,f(c))$ is a point of inflection of the graph of f, then either:

$f''(c) = 0$ or f'' does not exist at $x = c$

how?

$y = x^{1/3}$

$\frac{dy}{dx} = \frac{1}{3}x^{-2/3}$

$\frac{d^2y}{dx^2} = -\frac{2}{9}x^{-5/3} = \frac{-2}{9x^{5/3}}$

Consider:

$y = x^{1/3}$

(0,0) is IP $\begin{cases} x<0, \frac{d^2y}{dx^2} > 0 \text{ c.u.} \\ x>0, \frac{d^2y}{dx^2} < 0 \text{ c.d.} \end{cases}$

change in concavity from concave up to concave down

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4.5 Increasing, Decreasing, Concavity, and Tests for Extrema

Theorum: Points of Inflection

If $(c,f(c))$ is a point of inflection of the graph of f, then either:

$f''(c) = 0$ or f'' does not exist at $x = c$

how?

$y = x^{2/3}$

$\frac{dy}{dx} = \frac{2}{3}x^{-1/3}$

$\frac{d^2y}{dx^2} = -\frac{2}{9}x^{-4/3}$

$\frac{d^2y}{dx^2} = \frac{-2}{9x^{4/3}}$

Consider:

$y = x^{2/3}$

(0,0) not IP $\begin{cases} x<0, \frac{d^2y}{dx^2} < 0 \text{ c.d.} \\ x>0, \frac{d^2y}{dx^2} < 0 \text{ c.d.} \end{cases}$

no change in concavity

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4.5 Increasing, Decreasing, Concavity, and Tests for Extrema

226. $f(x) = x^4 - 6x^3$

For the following exercises, determine

a. intervals where f is increasing or decreasing,

b. local minima and maxima of f,

c. intervals where f is concave up and concave down, and

d. the inflection points of f.

Change f(x) to x^(1/3)

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Problems for 3.4

Homework

4.5 Increasing, Decreasing, Concavity, and Tests for Extrema

226. $f(x) = x^4 - 6x^3$

$f'(x) = 4x^3 - 18x^2 = 2x^2(2x-9)$

$f''(x) = 12x^2 - 36x$ CN: $x = 0, 9/2$

$= 12x(x-3)$ poss IP $x = 0, 3$

	0	3	$4\frac{1}{2}$	
test	-1	1	4	5
f '(x)=2x²(2x-9)	−	−	−	+
f (x)	decr	decr	decr	incr
f "(x)=12x(x-3)	+	−	+	+
f (x)	cu	cd	cu	cu

(0,__) IP

(3,__) IP

(9/2,____) rel.MIN

(0,0)IP

(3,-81)IP

(9/2,-136.7) rel.MIN

Change f(x) to x^(1/3)

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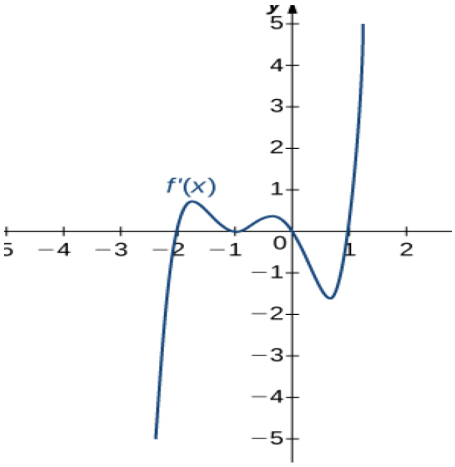
4.5 Increasing, Decreasing, Concavity, and Tests for Extrema

For the following exercises, analyze the graphs of f', then list all intervals where f is increasing or decreasing.



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4.5 Increasing, Decreasing, Concavity, and Tests for Extrema

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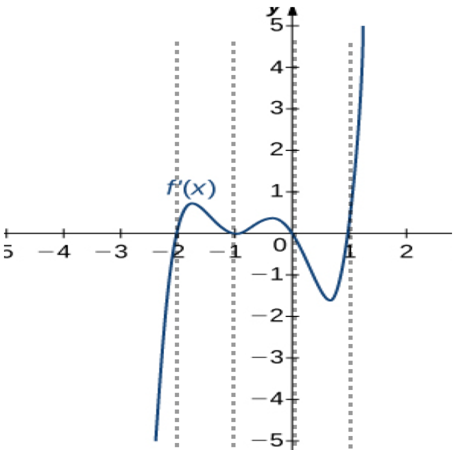

	(-inf,-2)	(-2,-1)	(-1,0)	(-0,1)	(1,inf)
f '(x)	-	+	+	-	+
f (x)	decr	incr	incr	decr	incr

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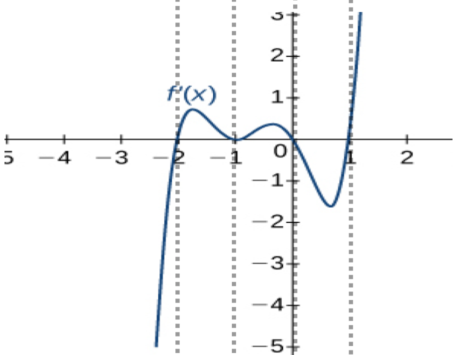
4.5 Increasing, Decreasing, Concavity, and Tests for Extrema

For the following exercises, analyze the graphs of f', then list all intervals where f is increasing or decreasing.

F: which represent relative extrema?



	(-inf,-2)	(-2,-1)	(-1,0)	(-0,1)	(1,inf)
f '(x)	-	+	+	-	+
f (x)	decr	incr	incr	decr	incr

(-2,__) Rel MIN

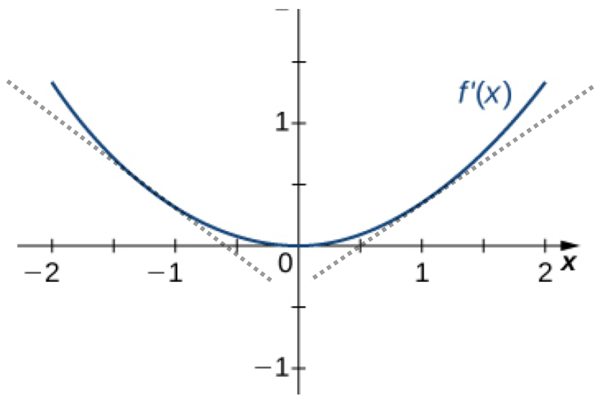
(0,__) Rel MAX

(1,__) Rel MIN

Do not know the y-values
Need the function itself to find the y-values

4.5 Increasing, Decreasing, Concavity, and Tests for Extrema

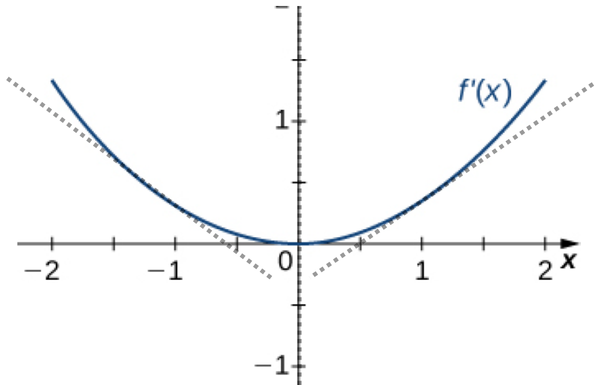
For the following exercises, analyze the graphs of f', then list all inflection points and intervals f that are concave up and concave down.



To determine the sign of f "(x), need to look at slope of f '(x)

4.5 Increasing, Decreasing, Concavity, and Tests for Extrema

For the following exercises, analyze the graphs of f', then list all inflection points and intervals f that are concave up and concave down.



(-inf, 0) (0, inf)

slope of f '(x) = f "(x) - +

f (x) c.d. c.u

(0,0) is I.P.
change in concavity fr.
concave down to concave up

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