2526-MA140 Engineering Calculus

Week 06, Lecture 1
Maxima and Minima

Dr Niall Madden

University of Galway

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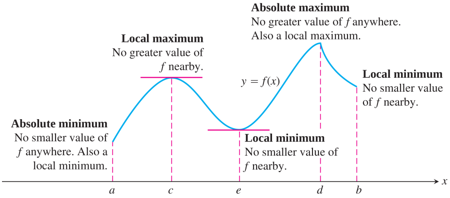


Today, we'll max out on...

See also: Section 4.3 (Maxima and Minima) of **Calculus** by Strang & Herman: `https://math.libretexts.org/Bookshelves/Calculus/Calculus_(OpenStax)`

Info: Survey, Assignments, etc

- The module survey for MA140 has started. Please take a few minutes to complete it. See https://universityofgalway.instructure.com/courses/46734/discussion_topics/189325
  - It only takes a few minutes
  - We take in the input seriously, and will update you on the main findings and the actions we will take.
  - Try to mix positive comments with suggestions for improvements.
- **Assignment 3** I added an extra 23 hours (for reasons...). Now due tomorrow (21st) at 17:00
- **Assignment 4** is open and is due next Tuesday (28th) at 17:00.
- **Assignment 5** will be posted soon.
- Grades for the class test have been posted. There were some updates/corrections. Grades are now final (I hope!). Answers have been posted to https://universityofgalway.instructure.com/courses/46734/files?preview=2948747

Higher-order Derivatives

At the end of the last class, we started learning about higher-order derivatives.

- if $f(x)$ is a function, then $f'(x)$ is a function whose value at x is the derivative of f at that point.
- So, since $f'(x)$ is a function, and we can differentiate functions, we can differentiate f' itself.
- The **derivative of the derivative** of f is called that **second derivative** of f.
- It is denoted as $\quad f''(x) \quad \text{or} \quad \dfrac{d^2y}{dx^2} \quad \text{or} \quad f^{(2)}(x).$
- We can continue this process to get third derivatives, fourth derivatives, etc, etc. However, the most important are the 1st and 2nd: f' and f'' provide valuable information about the function and its graph, particularly concerning local or global maxima, local/global minima and points of inflection.

Higher-order Derivatives

Example

Find the **second** derivative of the functions

(i) $f_1(x) = 3x^2 + 2x + 1$

(ii) $f_2(x) = e^x$

(iii) $f_3(x) = \ln(x)$

(iv) $f_4(x) = \sin(x)$

This section of MA140 is concerned with using techniques of differentiation to finding where a function is

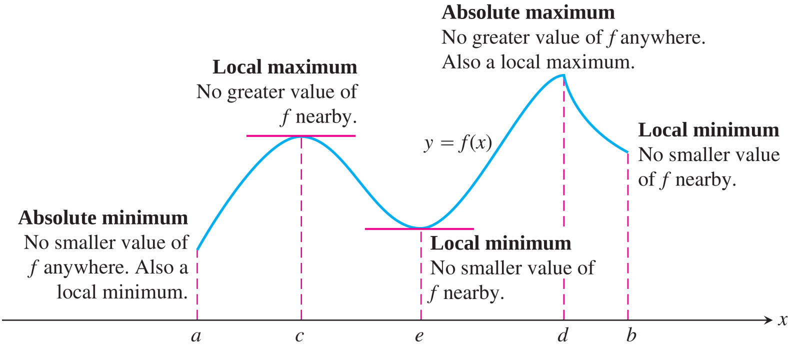
- Increasing
- Decreasing
- Has its maximum value
- Has its minimum value

Along the way we'll learn about **critical values** and the **first derivative test**.

Mathematical English

- The plural of **maximum** is **maxima**;
- The plural of **minimum** is **minima**;
- An **extremum** a maximum or a minimum.
- The plural of **extremum** is **extrema**.

Given an interval $[a, b] = \{x \in \mathbb{R} \mid a \leqslant x \leqslant b\}$, consider the function $f : [a, b] \to \mathbb{R}$ whose graph is given below. It illustrates local and absolute (="global") maxima and minima. Collectively, these are called **extrema**.



Definition: critical points

Let c in an point in the domain of a function f. We say that $x = c$ is a **critical point** of $f(x)$ if either

$$f'(c) = 0 \qquad \text{or} \qquad f'(c) \text{ does not exist.}$$

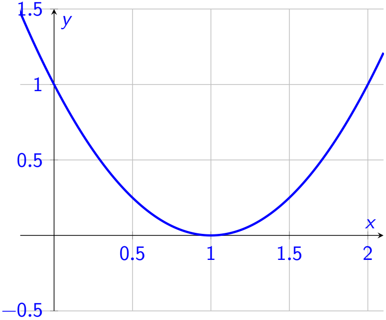
Important: If f has am extremum at $x = c$, then c must be a critical point of f (This is called "Fermat's Theorem").

So, to find a maximum or minimum of f, it is enough to check at the critical points.

Warning: All extrema are at critical points, but not all critical points correspond to a extrema.

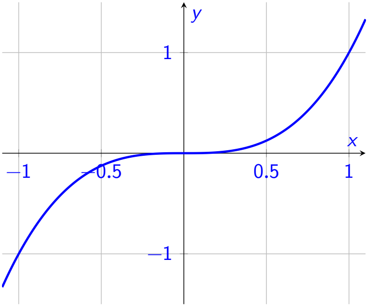
Example

$f(x) = x^2 - 2x + 1$ has one critical point. Find it. Does it correspond to an extremum?



Example

Find all critical points of $f(x) = x^3$. Do they correspond to extrema?



Definition (Increasing/Decreasing)

Let f be a function whose domain includes the interval $[a, b]$. Let let x_1 and x_2 be any two points in $[a, b]$ with $x_1 < x_2$.

- If $\boxed{f(x_1) < f(x_2)}$, then f is said to be *increasing* on $[a, b]$.
- If $\boxed{f(x_1) > f(x_2)}$, then f is said to be *decreasing* on $[a, b]$.

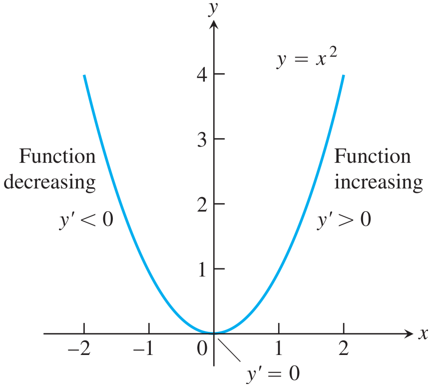
Example

The function $f(x) = x^2$ is decreasing on $(-\infty, 0]$, and increasing on $[0, \infty)$.

Theorem

Suppose that f is differentiable on an interval $[a, b]$.

- If $f'(x) > 0$ at each point $x \in [a, b]$, then f is increasing.
- If $f'(x) < 0$ at each point $x \in [a, b]$, then f is decreasing.



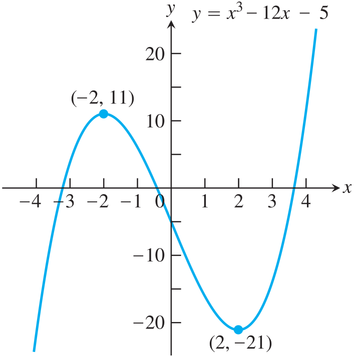
Example

Find the critical points of $f(x) = x^3 - 12x - 5$ and identify the intervals on which f is increasing and decreasing

Idea: find $f'(x)$ and then solve for $f'(x) = 0$.

The critical points $c = -2$ and $c = 2$ of $f(x) = x^3 - 12x - 5$ subdivide the domain of f into intervals $(-\infty, -2), (-2, 2)$ and $(2, \infty)$ on which f' is either positive or negative. We determine the sign of f' by evaluating f at a convenient point in each subinterval.

	$-\infty$ to -2	-2	-2 to 2	2	2 to ∞
$3(x+2)$	$-$	$\bullet$	$+$		$+$
$x-2$	$-$		$-$	$\bullet$	$+$
$f'(x)$	$+$	$\bullet$	$-$	$\bullet$	$+$



Important:

- If $f(x)$ has a local minimum of $f(x)$ at $x = c$, then it switches from **decreasing** to **increasing**. That means, $f'(x)$ changes sign at $x = 2$. Therefore, $f'(c) = 0$.
- If $f(x)$ has a local maximum at $x = c$, we have that $f'(c) = 0$.

First Derivative Test for local maxima and minima

Suppose that c is a critical point of a differentiable function f.

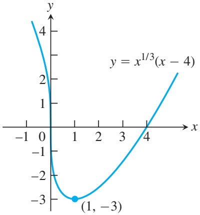
- If f' changes from negative to positive through c, then f has a local minimum at c.
- If f' changes from positive to negative through c, then f has a local maximum at c.
- If f' does not change sign through c (that is, f' is positive on both sides of c or negative on both sides), then f does not have a local maximum or minimum at c.

Example

Find the critical points of $f(x) = x^{\frac{1}{3}}(x-4)$. Identify the local maxima and minima (if any).

First find $f'(x)$, and then where it is either zero or undefined:

	$(-\infty, 0)$	$(0, 1)$	$(1, \infty)$
$4(x-1)$	$-$	$-$	$+$
$3x^{2/3}$	$+$	$+$	$+$
$f'(x)$	$-$	$-$	$+$



Review

If a function g is differentiable on an interval $[a, b]$, then

- $g'(x) > 0$ for all $x \in [a, b] \Leftrightarrow g$ increasing on $[a, b]$.
- $g'(x) < 0$ for all $x \in [a, b] \Leftrightarrow g$ decreasing on $[a, b]I$.

Similarly, if g' is also differentiable on $[a, b]$, then

- $(g')'(x) = g''(x) > 0$ for all $x \in [a, b] \Leftrightarrow g'$ increasing on I.
- $(g')'(x) = g''(x) < 0$ for all $x \in [a, b] \Leftrightarrow g'$ decreasing on I.

Exercises

Exercise 6.1.1

Let $f(x) = x^2 e^x$. Find $f'(x)$, $f''(x)$ and $f'''(x)$.

Exercise 6.1.2 : 23/24 Exam, Q3(a)

Let $f(x) = \ln(x^2 + 1)$.

(i) Find all critical point(s) of f and determine whether f has a local minimum, local maximum or neither.

(ii) Determine the interval on which f is increasing.

(iii) Determine the interval on which f is decreasing.

(iv) Find all point(s) of inflection of f, justifying your answer.