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Calculus Cheat Sheet

Limits

Definitions

Precise Definition : We say $\lim_{x\to a} f(x) = L$ if for every $\varepsilon > 0$ there is a $\delta > 0$ such that whenever $0 < |x-a| < \delta$ then $|f(x) - L| < \varepsilon$.

"Working" Definition : We say $\lim_{x\to a} f(x) = L$ if we can make $f(x)$ as close to L as we want by taking x sufficiently close to a (on either side of a) without letting $x = a$.

Right hand limit : $\lim_{x\to a^+} f(x) = L$. This has the same definition as the limit except it requires $x > a$.

Left hand limit : $\lim_{x\to a^-} f(x) = L$. This has the same definition as the limit except it requires $x < a$.

Limit at Infinity : We say $\lim_{x\to\infty} f(x) = L$ if we can make $f(x)$ as close to L as we want by taking x large enough and positive.

There is a similar definition for $\lim_{x\to-\infty} f(x) = L$ except we require x large and negative.

Infinite Limit : We say $\lim_{x\to a} f(x) = \infty$ if we can make $f(x)$ arbitrarily large (and positive) by taking x sufficiently close to a (on either side of a) without letting $x = a$.

There is a similar definition for $\lim_{x\to a} f(x) = -\infty$ except we make $f(x)$ arbitrarily large and negative.

Relationship between the limit and one-sided limits

$\lim_{x\to a} f(x) = L \Rightarrow \lim_{x\to a^+} f(x) = \lim_{x\to a^-} f(x) = L$ $\qquad$ $\lim_{x\to a^+} f(x) = \lim_{x\to a^-} f(x) = L \Rightarrow \lim_{x\to a} f(x) = L$

$\lim_{x\to a^+} f(x) \neq \lim_{x\to a^-} f(x) \Rightarrow \lim_{x\to a} f(x)$ Does Not Exist

Properties

Assume $\lim_{x\to a} f(x)$ and $\lim_{x\to a} g(x)$ both exist and c is any number then,

1. $\lim_{x\to a}[cf(x)] = c\lim_{x\to a} f(x)$
2. $\lim_{x\to a}[f(x) \pm g(x)] = \lim_{x\to a} f(x) \pm \lim_{x\to a} g(x)$
3. $\lim_{x\to a}[f(x)g(x)] = \lim_{x\to a} f(x) \lim_{x\to a} g(x)$
4. $\lim_{x\to a}\left[\frac{f(x)}{g(x)}\right] = \frac{\lim_{x\to a} f(x)}{\lim_{x\to a} g(x)}$ provided $\lim_{x\to a} g(x) \neq 0$
5. $\lim_{x\to a}[f(x)]^n = \left[\lim_{x\to a} f(x)\right]^n$
6. $\lim_{x\to a}\left[\sqrt[n]{f(x)}\right] = \sqrt[n]{\lim_{x\to a} f(x)}$

Basic Limit Evaluations at $\pm\infty$

Note : $\operatorname{sgn}(a) = 1$ if $a > 0$ and $\operatorname{sgn}(a) = -1$ if $a < 0$.

1. $\lim_{x\to\infty} \mathbf{e}^x = \infty$ & $\lim_{x\to-\infty} \mathbf{e}^x = 0$
2. $\lim_{x\to\infty} \ln(x) = \infty$ & $\lim_{x\to 0^+} \ln(x) = -\infty$
3. If $r > 0$ then $\lim_{x\to\infty} \frac{b}{x^r} = 0$
4. If $r > 0$ and x^r is real for negative x then $\lim_{x\to-\infty} \frac{b}{x^r} = 0$
5. n even : $\lim_{x\to\pm\infty} x^n = \infty$
6. n odd : $\lim_{x\to\infty} x^n = \infty$ & $\lim_{x\to-\infty} x^n = -\infty$
7. n even : $\lim_{x\to\pm\infty} a x^n + \cdots + b x + c = \operatorname{sgn}(a)\infty$
8. n odd : $\lim_{x\to\infty} a x^n + \cdots + b x + c = \operatorname{sgn}(a)\infty$
9. n odd : $\lim_{x\to-\infty} a x^n + \cdots + c x + d = -\operatorname{sgn}(a)\infty$

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Cheatography

Sequences and Series Cheat Sheet

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General Rules

Telescoping and Geometric series are the only types of series that you can estimate sums from. So, you must use these test's properties to estimate these sums

If the question is asking for absolute convergence or conditional convergence. You will need to use the Ratio Test, Root Test, or the definition of Absolute/Conditional Convergence

Must show **ALL** work to receive full credit for questions. Study the process to solve the problems, don't just guess through the review

Tests

Test for Divergence(TFD)	Inconclusive	You absolutely cannot determine if a series is convergent from this test.
	Diverges	If limit of series ≠0 or ∞
Integral Test	Converges	If integral of series <∞
	Diverges	If integral of series =∞
Ratio Test	Converges/ Converges Absolutely	If limit of 0<|(ak+1) /(ak)|<1
	Diverges	If limit >1
	Inconclusive	If limit =1
Root Test	Converges/ Converges Absolutely	If 0<limit of the kth root of |ak|<1
	Diverges	If limit of the kth root of |ak|>1
	Inconclusive	If limit of kth root of |ak|=1
Direct Comparison Test(CT)	Converges	If Σbk converges AND bk is the larger of the two functions

Tests (cont)

	Diverges	If Σbk diverges AND bk is smaller of two functions
Limit Comparison Test(LCT)	Converges	If bk converges AND limit of 0<(ak)/(bk)<∞
	Diverges	If bk AND limit of 0<(ak)/(bk)<∞
Alternating Series Test(AST)	Converges	If all 3 conditions for AST are met
	Diverges	If limit condition fails, Σak is immediately divergent by TFD

Properties of Special Series

Geometric Series	Converges	If Absolute Value of r<1. Converges at S=(first term)/(1-r)
	Diverges	If Absolute Value of r≥1
P-Series	Converges	If p>1
	Diverges	If p≤1
Telescoping	Converges	Value that the limit of the remaining terms approach
	Diverges	Almost never. On the test it will converge
Definition of Convergence	Absolute Convergence	If and only if Σ|ak| is convergent
	Conditional Convergence	If and only if Σak is convergent, but Σ|ak| is divergent

When to Use Tests

Properties	If you can identify the series as a geometric, p, or telescoping series, then use their respective properties. If the given series looks close to one of these series **see if you can use algebra to rearrange it into one of them**
Test for Divergence(TFD)	Should at least eyeball this test first to see if the limit of the series does not approach 0. If series does not approach 0, then **Σak divergent by TFD**
Comparison Tests(CT and LCT)	**ONLY POSITIVE TERMS!** If you can tell if the series has negative terms,((-1)^k or sin/cos), do not use this test. If series has is rational and has a root in the denominator, compare with a p-series. |ak| gives use absolute convergence
Alternating Series Test(AST)	Series with (-1)^k can be testes with AST
Integral Test	**ONLY POSITIVE TERMS!** If you can look at the function and easily take the integral, it is probably good to use this test
Ratio Test	If series contains: k!, or powers and exponentials, **almost guaranteed to use ratio test**

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Variation of Parameters

In the last section we looked at the method of undetermined coefficients for finding a particular solution to

$$p(t)y'' + q(t)y' + r(t)y = g(t) \qquad (1)$$

and we saw that while it reduced things down to just an algebra problem, the algebra could become quite messy. On top of that undetermined coefficients will only work for a fairly small class of functions.

The method of Variation of Parameters is a much more general method that can be used in many more cases. However, there are two disadvantages to the method. First, the complimentary solution is absolutely required to do the problem. This is in contrast to the method of undetermined coefficients where it was advisable to have the complimentary solution on hand, but was not required. Second, as we will see, in order to complete the method we will be doing a couple of integrals and there is no guarantee that we will be able to do the integrals. So, while it will always be possible to write down a formula to get the particular solution, we may not be able to actually find it if the integrals are too difficult or if we are unable to find the complimentary solution.

We're going to derive the formula for variation of parameters. We'll start off by acknowledging that the complimentary solution to (1) is

$$y_c(t) = c_1 y_1(t) + c_2 y_2(t)$$

Remember as well that this is the general solution to the homogeneous differential equation.

$$p(t)y'' + q(t)y' + r(t)y = 0 \qquad (2)$$

Also recall that in order to write down the complimentary solution we know that $y_1(t)$ and $y_2(t)$ are a fundamental set of solutions.

What we're going to do is see if we can find a pair of functions, $u_1(t)$ and $u_2(t)$ so that

$$Y_P(t) = u_1(t)y_1(t) + u_2(t)y_2(t)$$

will be a solution to (1). We have two unknowns here and so we'll need two equations eventually. One equation is easy. Our proposed solution must satisfy the differential equation, so we'll get the first equation by plugging our proposed solution into (1). The second equation can come from a variety of places. We are going to get our second equation simply by making an assumption that will make our work easier. We'll say more about this shortly.

So, let's start. If we're going to plug our proposed solution into the differential equation we're going to need some derivatives so let's get those. The first derivative is

$$Y_P'(t) = u_1' y_1 + u_1 y_1' + u_2' y_2 + u_2 y_2'$$

Here's the assumption. Simply to make the first derivative easier to deal with we are going to assume that whatever $u_1(t)$ and $u_2(t)$ are they will satisfy the following.

$$u_1' y_1 + u_2' y_2 = 0 \qquad (3)$$

Now, there is no reason ahead of time to believe that this can be done. However, we will see that this will work out. We simply make this assumption on the hope that it won't cause problems down the

Extrema

Absolute Extrema

1. $x = c$ is an absolute maximum of $f(x)$ if $f(c) \ge f(x)$ for all x in the domain.
2. $x = c$ is an absolute minimum of $f(x)$ if $f(c) \le f(x)$ for all x in the domain.

Fermat's Theorem

If $f(x)$ has a relative (or local) extrema at $x = c$, then $x = c$ is a critical point of $f(x)$.

Extreme Value Theorem

If $f(x)$ is continuous on the closed interval $[a,b]$ then there exist numbers c and d so that, **1.** $a \le c, d \le b$, **2.** $f(c)$ is the abs. max. in $[a,b]$, **3.** $f(d)$ is the abs. min. in $[a,b]$.

Finding Absolute Extrema

To find the absolute extrema of the continuous function $f(x)$ on the interval $[a,b]$ use the following process.

1. Find all critical points of $f(x)$ in $[a,b]$.
2. Evaluate $f(x)$ at all points found in Step 1.
3. Evaluate $f(a)$ and $f(b)$.
4. Identify the abs. max. (largest function value) and the abs. min.(smallest function value) from the evaluations in Steps 2 & 3.

Relative (local) Extrema

1. $x = c$ is a relative (or local) maximum of $f(x)$ if $f(c) \ge f(x)$ for all x near c.
2. $x = c$ is a relative (or local) minimum of $f(x)$ if $f(c) \le f(x)$ for all x near c.

1st Derivative Test

If $x = c$ is a critical point of $f(x)$ then $x = c$ is

1. a rel. max. of $f(x)$ if $f'(x) > 0$ to the left of $x = c$ and $f'(x) < 0$ to the right of $x = c$.
2. a rel. min. of $f(x)$ if $f'(x) < 0$ to the left of $x = c$ and $f'(x) > 0$ to the right of $x = c$.
3. not a relative extrema of $f(x)$ if $f'(x)$ is the same sign on both sides of $x = c$.

2nd Derivative Test

If $x = c$ is a critical point of $f(x)$ such that $f'(c) = 0$ then $x = c$

1. is a relative maximum of $f(x)$ if $f''(c) < 0$.
2. is a relative minimum of $f(x)$ if $f''(c) > 0$.
3. may be a relative maximum, relative minimum, or neither if $f''(c) = 0$.

Finding Relative Extrema and/or Classify Critical Points

1. Find all critical points of $f(x)$.
2. Use the 1st derivative test or the 2nd derivative test on each critical point.

Mean Value Theorem

If $f(x)$ is continuous on the closed interval $[a,b]$ and differentiable on the open interval (a,b) then there is a number $a < c < b$ such that $f'(c) = \frac{f(b) - f(a)}{b - a}$.

Newton's Method

If x_n is the n^{th} guess for the root/solution of $f(x) = 0$ then $(n+1)^{st}$ guess is $x_{n+1} = x_n - \frac{f(x_n)}{f'(x_n)}$ provided $f'(x_n)$ exists.

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 1 Calculus Cheat Sheet Limits Definitions Precise Definition : We say lim f (x) = L if Limit at Infinity : We say lim f (x) = L if we x a x . for every e > 0 there is a d > 0 such that can make f (x) as close to L as we want by whenever 0 < x - a < d then f (x) - L < e . taking x large enough and positive. Working Definition : We say lim f (x) = L There is a similar definition for lim f (x) = L. x a x - . if we can make f (x) as close to L as we want except we require x large and negative. by taking x sufficiently close to a (on either side of a) without letting x = a . Infinite Limit : We say lim f (x) = if we x a can make f (x) arbitrarily large (and positive). Right hand limit : lim+ f (x) = L . This has by taking x sufficiently close to a (on either side x a the same definition as the limit except it of a) without letting x = a . requires x > a . There is a similar definition for lim f (x) =.2 X a Left hand limit : lim- f (x) = L . This has the x a except we make f (x) arbitrarily large and same definition as the limit except it requires negative. x 0 and sgn (a) = -1 if a < 0.3 1. lim e x = & lim e x = 0 5. n even : lim x n = . x x - x . 2. lim ln (x) = & lim ln (x) = - 6. n odd : lim x n = & lim x n = - . x x 0 + x x - . 3. If r > 0 then lim b =0 7. n even : lim a x + L + b x + c = sgn (a) . n x . xr x . 8. n odd : lim a x n + L + b x + c = sgn (a) . 4. If r > 0 and x r is real for negative x x . b then lim r = 0 9. n odd : lim a x n + L + c x + d = - sgn (a) . x - . x - x Visit for a complete set of Calculus Notes . 2005 Paul Dawkins Calculus Cheat Sheet Evaluation Techniques Continuous Functions L'Hospital's Rule If f (x) is continuous at a then lim f (x) = f (a) f (x) 0 f (x) . x a If lim = or lim = then, x a g (x) 0 x a g (x) . Continuous Functions and Composition f (x) f (x). f (x) is continuous at b and lim g (x) = b then lim = lim a is a number, or - . x a g (x) x a g (x). x a x a (x a). lim f (g (x)) = f lim g (x) = f (b) Polynomials at Infinity p (x) and q (x) are polynomials.4 To compute Factor and Cancel p (x). lim x 2 + 4 x - 12. = lim (x - 2)(x + 6) lim x q (x). factor largest power of x in q (x) out x 2 x - 2x 2 x 2 x (x - 2). of both p (x) and q (x) then compute limit. x+6 8. = lim x 2 x = =4. Rationalize Numerator/Denominator 2. lim 3x 2 - 4. = lim 2 5. ( ). x 2 3 - 42. x 3 - 42. = lim 5 x = - 3. 3- x 3- x 3+ x x - 5 x - 2 x 2 x - x ( ). x -2. x - . x -2 2. lim 2 = lim 2 Piecewise Function x 9 x - 81 x 9 x - 81 3 + x x 2 + 5 if x < -2. = lim 9- x = lim -1 lim g (x) where g (x) = . ( ). (x - 81) 3 + x x 9 (x + 9) 3 + x ( ) 1 - 3x if x -2. x -2. x 9 2. Compute two one sided limits, -1 1 lim- g (x) = lim- x 2 + 5 = 9. = =- (18)(6) 108 x -2 x -2. lim g (x) = lim+ 1 - 3 x = 7. Combine Rational Expressions x -2+ x -2. 1 1 1 1 x - (x + h) One sided limits are different so lim g (x). lim - = lim x -2. h 0 h x + h x h 0 h x (x + h) doesn't exist.5 If the two one sided limits had been equal then lim g (x) would have existed 1 -h -1 1 x -2. = lim = lim = - h 0 h x (x + h) h 0 x (x + h) x2 and had the same value.. Some Continuous Functions Partial list of continuous functions and the values of x for which they are continuous. 1. Polynomials for all x. 7. cos (x) and sin (x) for all x. 2. Rational function, except for x's that give division by zero. 8. tan (x) and sec (x) provided 3. n x (n odd) for all x. 3p p p 3p x L , - , - , , ,L. 4. n x (n even) for all x 0 . 2 2 2 2. 9. cot (x) and csc (x) provided 5. e x for all x. 6. ln x for x > 0 . x L , -2p , -p , 0, p , 2p ,L. Intermediate Value Theorem Suppose that f (x) is continuous on [a, b] and let M be any number between f (a) and f (b) . Then there exists a number c such that a < c < b and f (c) = M . Visit for a complete set of Calculus Notes . 2005 Paul Dawkins Calculus Cheat Sheet Derivatives Definition and Notation f (x + h) - f (x).6 If y = f (x) then the derivative is defined to be f (x) = lim . h 0 h If y = f (x) then all of the following are If y = f (x) all of the following are equivalent equivalent notations for the derivative. notations for derivative evaluated at x = a . df dy d df dy f (x) = y = = (f (x)) = Df (x) f (a) = y x =a = = = Df (a). dx dx dx dx x =a dx x =a Interpretation of the Derivative If y = f (x) then, 2. f (a) is the instantaneous rate of 1. m = f (a) is the slope of the tangent change of f (x) at x = a . line to y = f (x) at x = a and the 3. If f (x) is the position of an object at equation of the tangent line at x = a is time x then f (a) is the velocity of given by y = f (a) + f (a)(x - a) . the object at x = a . Basic Properties and Formulas If f (x) and g (x) are differentiable functions (the derivative exists), c and n are any real numbers, d 1. (c f) = c f (x) 5.7 (c) = 0. dx 2. (f g) = f (x) g (x) 6. d n (x) = n x n-1 Power Rule dx 3. (f g) = f g + f g Product Rule d 7. ( ). f (g (x)) = f (g (x)) g (x). f f g - f g dx 4. = Quotient Rule This is the Chain Rule g g2. Common Derivatives d d d x dx (x) = 1. dx (csc x) = - csc x cot x dx (a) = a x ln (a). d d d x dx (sin x) = cos x dx (cot x) = - csc2 x dx (e) = ex d d 1 d 1. dx (cos x) = - sin x dx (sin -1 x) =. dx (ln (x)) = , x > 0. x 1 - x2. d d 1. dx (tan x) = sec2 x d (cos -1 x) = - 1. dx (ln x) = x , x 0. dx 1 - x2. d d 1. dx (sec x) = sec x tan x d (tan -1 x) =. 1. dx (log a (x)) =. x ln a , x>0. dx 1 + x2. Visit for a complete set of Calculus Notes . 2005 Paul Dawkins Calculus Cheat Sheet Chain Rule Variants The chain rule applied to some specific functions. 1. d dx ( ) n -1. f (x) = n f (x) f (x). n 5. d dx ( ). cos f (x) = - f (x) sin f (x).8 2. dx e (. d f (x).). = f (x) e f (x) 6. d dx ( ). tan f (x) = f (x) sec 2 f (x) . f (x). d 3. d (. ln f (x) =) 7. (sec [f (x)]) = f (x) sec [f (x)] tan [f (x)]. dx f (x) dx d f (x). 4. d ( ). sin f (x) = f (x) cos f (x) 8. (. tan -1 f (x) =). 1 + f (x) . 2. dx dx Higher Order Derivatives The Second Derivative is denoted as The nth Derivative is denoted as d2 f dn f f (x) = f (2) (x) = 2 and is defined as f (n) (x) = n and is defined as dx dx f (x) = (f (x)) , the derivative of the . ( ). f (n) (x) = f (n -1) (x) , the derivative of first derivative, f (x) . the (n-1)st derivative, f (n-1) (x) . Implicit Differentiation . Find y if e 2 x -9 y + x y = sin (y) + 11x . Remember y = y (x) here, so products/quotients of x and y 3 2. will use the product/quotient rule and derivatives of y will use the chain rule. The trick is to differentiate as normal and every time you differentiate a y you tack on a y (from the chain rule).9 After differentiating solve for y . e 2 x -9 y (2 - 9 y) + 3 x 2 y 2 + 2 x3 y y = cos (y) y + 11. 11 - 2e 2 x -9 y - 3x 2 y 2. 2e 2 x -9 y - 9 y e 2 x -9 y + 3x y + 2 x y y = cos (y) y + 11. 2 2 3. y = 3. 2 x y - 9e2 x -9 y - cos (y). (2 x y - 9e x 3 2 -9 y - cos (y)) y = 11 - 2e2 x -9 y - 3x 2 y 2. Increasing/Decreasing Concave Up/Concave Down Critical Points x = c is a critical point of f (x) provided either Concave Up/Concave Down 1. If f (x) > 0 for all x in an interval I then 1. f (c) = 0 or 2. f (c) doesn't exist. f (x) is concave up on the interval I. Increasing/Decreasing 2. If f (x) < 0 for all x in an interval I then 1. If f (x) > 0 for all x in an interval I then f (x) is concave down on the interval I. f (x) is increasing on the interval I. 2. If f (x) < 0 for all x in an interval I then Inflection Points x = c is a inflection point of f (x) if the f (x) is decreasing on the interval I.10 Concavity changes at x = c . 3. If f (x) = 0 for all x in an interval I then f (x) is constant on the interval I. Visit for a complete set of Calculus Notes . 2005 Paul Dawkins Calculus Cheat Sheet Extrema Absolute Extrema Relative (local) Extrema 1. x = c is an absolute maximum of f (x) 1. x = c is a relative (or local) maximum of if f (c) f (x) for all x in the domain. f (x) if f (c) f (x) for all x near c. 2. x = c is a relative (or local) minimum of 2. x = c is an absolute minimum of f (x). f (x) if f (c) f (x) for all x near c. if f (c) f (x) for all x in the domain. 1st Derivative Test Fermat's Theorem If x = c is a critical point of f (x) then x = c is If f (x) has a relative (or local) extrema at 1. a rel. max. of f (x) if f (x) > 0 to the left x = c , then x = c is a critical point of f (x) . of x = c and f (x) < 0 to the right of x = c . Extreme Value Theorem 2.

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