

ODE Cheat Sheet

First Order Equations

Separable

$$y'(x) = f(x)g(y)$$
$$\int \frac{dy}{g(y)} = \int f(x) dx + C$$

Linear First Order

$$y'(x) + p(x)y(x) = f(x)$$
$$\mu(x) = \exp \int p(x) dx \quad \text{Integrating factor.}$$
$$(\mu y)' = \mu f \quad \text{Exact Derivative.}$$
$$\text{Solution: } y(x) = \frac{1}{\mu(x)} \left(\int f(x)\mu(x) dx + C \right)$$

Exact

$$0 = M(x, y) dx + N(x, y) dy$$
$$\text{Solution: } u(x, y) = \text{const where} \quad \text{Condition: } M_y = N_x$$
$$dx = \frac{\partial u}{\partial x} dx + \frac{\partial u}{\partial y} dy$$
$$\frac{\partial u}{\partial x} = M(x, y), \quad \frac{\partial u}{\partial y} = N(x, y)$$

Non-Exact Form

$$\mu(x, y) (M(x, y) dx + N(x, y) dy) = du(x, y)$$
$$M_y = N_x$$
$$N \frac{\partial \mu}{\partial y} - M \frac{\partial \mu}{\partial x} = \mu \left(\frac{\partial M}{\partial x} - \frac{\partial N}{\partial y} \right)$$

Special cases

$$\text{If } \frac{\partial M}{\partial y} = h(x), \text{ then } \mu(x) = \exp \int h(x) dx$$
$$\text{If } \frac{\partial N}{\partial x} = -h(x), \text{ then } \mu(x) = \exp \int h(x) dx$$

Second Order Equations

Linear

$$a(x)y''(x) + b(x)y'(x) + c(x)y(x) = f(x)$$
$$y(x) = y_h(x) + y_p(x)$$
$$y_h(x) = c_1 y_1(x) + c_2 y_2(x)$$

Constant Coefficients

$$ay''(x) + by'(x) + cy(x) = f(x)$$
$$y(x) = e^{rx} \Rightarrow ar^2 + br + c = 0$$

Cases

$$\text{Distinct, real roots: } r = r_{1,2}, y_h(x) = c_1 e^{r_1 x} + c_2 e^{r_2 x}$$

$$\text{One real root: } y_h(x) = (c_1 + c_2 x)e^{rx}$$

$$\text{Complex roots: } r = \alpha \pm i\beta, y_h(x) = (c_1 \cos \beta x + c_2 \sin \beta x)e^{\alpha x}$$

Cauchy-Euler Equations

$$ax^2 y''(x) + bx y'(x) + cy(x) = f(x)$$
$$y(x) = x^r \Rightarrow ar(r-1) + br + c = 0$$

Cases

$$\text{Distinct, real roots: } r = r_{1,2}, y_h(x) = c_1 x^{r_1} + c_2 x^{r_2}$$

$$\text{One real root: } y_h(x) = (c_1 + c_2 \ln|x|)x^r$$

$$\text{Complex roots: } r = \alpha \pm i\beta,$$

$$y_h(x) = (c_1 \cos \beta \ln|x| + c_2 \sin \beta \ln|x|)x^\alpha$$

Nonhomogeneous Problems

Method of Undetermined Coefficients

$$\begin{array}{ll} f(x) & y_p(x) \\ a_n x^n + \dots + a_1 x + a_0 & \frac{b_n}{b_n} x^n + \dots + \frac{b_1}{b_n} x + \frac{b_0}{b_n} \\ a_0 e^{ax} & \frac{b_0}{b_n} e^{ax} \\ A \cos \omega x + B \sin \omega x & A \cos \omega x + B \sin \omega x \end{array}$$

Modified Method of Undetermined Coefficients If any term in the guess $y_p(x)$ is a solution of the homogeneous equation, then multiply the guess by x^k , where k is the smallest positive integer such that no term in $x^k y_p(x)$ is a solution of the homogeneous problem.

Reduction of Order

Homogeneous Case

Given $y_1(x)$ satisfies $L[y] = 0$, find second linearly independent solution as $v(x) = v(x)y_1(x)$, $z = v'$ satisfies a separable ODE.

Nonhomogeneous Case

Given $y_1(x)$ satisfies $L[y] = 0$, find solution of $L[y] = f$ as $v(x) = v(x)y_1(x)$, $z = v'$ satisfies a first order linear ODE.

Method of Variation of Parameters

$$y_p(x) = c_1(x)y_1(x) + c_2(x)y_2(x)$$
$$c_1'(x)y_1(x) + c_2'(x)y_2(x) = 0$$
$$c_1'(x)y_1'(x) + c_2'(x)y_2'(x) = \frac{f(x)}{a(x)}$$

Applications

Free Fall

$$x''(t) = -g$$
$$x'(t) = -gt + f(t)$$

Population Dynamics

$$P'(t) = kP(t)$$
$$P''(t) = kP'(t) - kP^2(t)$$

Newton's Law of Cooling

$$T'(t) = -k(T(t) - T_a)$$

Oscillations

$$mx''(t) + bx(t) = 0$$
$$mx''(t) + bx'(t) + bx(t) = 0$$
$$mx''(t) + bx'(t) + bx(t) = F(t)$$

Types of Damped Oscillation

Overdamped, $b^2 > 4mk$

Critically Damped, $b^2 = 4mk$

Underdamped, $b^2 < 4mk$

Numerical Methods

Euler's Method

$$y_0 = y(t_0)$$
$$y_n = y_{n-1} + \Delta x f(x_{n-1}, y_{n-1}), \quad n = 1, \dots, N$$

Series Solutions

Taylor Method

$$f(x) = \sum_{n=0}^{\infty} \frac{f^{(n)}(a)}{n!} (x-a)^n, \quad r_n = \frac{f^{(n)}(a)}{n!}$$

1. Differentiate DE repeatedly.
2. Apply initial conditions.
3. Find Taylor coefficients.
4. Insert coefficients into series form for $y(x)$.

Power Series Solution

1. Let $y(x) = \sum_{n=0}^{\infty} c_n (x-a)^n$.
2. Find $y'(x)$, $y''(x)$.
3. Insert expansions in DE.
4. Collect like terms using reindexing.
5. Find recurrence relation.
6. Solve for coefficients and insert in $y(x)$ series.

Ordinary and Singular Points

$$y'' + a(x)y' + b(x)y = 0, \quad a_0 \neq 0$$

Ordinary point: $a(x), b(x)$ real analytic in $|x - x_0| < R$

Regular singular point: $(x - x_0)a(x), (x - x_0)^2 b(x)$ have convergent Taylor series about $x = x_0$

Irregular singular point: Not ordinary or regular singular point.

Frobenius Method

1. Let $y(x) = \sum_{n=0}^{\infty} c_n (x - x_0)^{n+r}$.
2. Obtain indicial equation $r(r-1) + a_0 r + b_0$.
3. Find recurrence relation based on types of roots of indicial equation.
4. Solve for coefficients and insert in $y(x)$ series.

Laplace Transforms

Transform Pairs

x	$\frac{1}{s^2}$
x^n	$\frac{n!}{s^{n+1}}, \quad n \geq 0$
x^n	$\frac{n!}{s^{n+1}}, \quad n \geq 0$
$\sin at$	$\frac{a}{s^2 + a^2}$
$\cos at$	$\frac{s}{s^2 + a^2}$
$\sinh at$	$\frac{a}{s^2 - a^2}$
$\cosh at$	$\frac{s}{s^2 - a^2}$
$f(t - a)$	$\frac{e^{-as}}{s}, \quad a \geq 0$
$\delta(t - a)$	$e^{-as}, \quad a \geq 0, a > 0$

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Wesolvethem

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The Quotient of Murder Ada Madison,2013 Dr Sophie Knowles loves using puzzles to make math fun for students But when winter seizes Henley College she must thaw out a cold case to track down a killer her most difficult puzzle yet Winter Intersession is in full swing and campus is buzzing over the concert celebrating the bell tower s reopening The building has been shuttered for twenty five years and Sophie s shocked to learn why a student leapt from it to her death But she s even more troubled by the secrecy surrounding the case After Sophie performs some quick calculations she s left with a nagging question Was it really suicide When one of Sophie s favorite students a performer in the concert is brutally beaten and left in a coma Sophie s mind kicks into overdrive The horrific incidents seem too coincidental to be unrelated but can Sophie put together the pieces from a twenty five year old murder before any other students get hurt

Simulating, Analyzing, and Animating Dynamical Systems Bard Ermentrout,2002-01-01 Simulating Analyzing and Animating Dynamical Systems A Guide to XPPAUT for Researchers and Students provides sophisticated numerical methods for the fast and accurate solution of a variety of equations including ordinary differential equations delay equations integral equations functional equations and some partial differential equations as well as boundary value problems It introduces many modeling techniques and methods for analyzing the resulting equations Instructors students and researchers will all benefit from this book which demonstrates how to use software tools to simulate and study sets of equations that arise in a variety of applications Instructors will learn how to use computer software in their differential equations and modeling classes while students will learn how to create animations of their equations that can be displayed on the World Wide Web Researchers will be introduced to useful tricks that will allow them to take full advantage of XPPAUT s capabilities

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