工程數學 -- 微分方程

Differential Equations (DE)

授課者：丁建均

教學網頁： http://djj.ee.ntu.edu.tw/DE.htm
(請上課前來這個網站將講義印好)

歡迎大家來修課！

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上課時間：星期三 第 3, 4 節 (AM 10:20~12:10)

星期五 第 2 節 (AM 9:10~10:00)

上課地點： 電二 143

課本： "Differential Equations-with Boundary-Value Problem",

7th edition, Dennis G. Zill and Michael R. Cullen

評分方式：四次作業一次小考 10%, 期中考 45%, 期末考

注意事項：

(1)請上課前，來這個網頁，將上課資料印好。

http://djj.ee.ntu.edu.tw/DE.htm

(2) 請各位同學踴躍出席 。

(3) 作業不可以抄襲。作業若寫錯但有用心寫仍可以有 40%~90% 的分數，但抄襲或借人抄襲不給分。

(4) 我週一至週四下午都在辦公室，有什麼問題 ，歡迎同學們來找我

上課日期

	Date (Wednesday, Friday)	Remark
1.	9/12, 9/14	
2.	9/19, 9/21	
3.	9/26, 9/28	
4.	10/3, 10/5	
5.	10/12	10/10 國慶
6.	10/17, 10/19	
7.	10/24, 10/26	
8.	10/31, 11/2	
9.	11/7: Midterm; (Chaps.1-5), 11/9	範圍：(Chaps.1-5)
10.	11/14, 11/16	
11.	11/21, 11/23	
12.	11/28, 11/30	
13.	12/5, 12/7	
14.	12/12, 12/14	
15.	12/19, 12/21	
16.	12/26, 12/28	
17.	1/2, 1/4	
18.	1/9 Finals	範圍：(Chaps. 6, 7, 11, 12, 14)

課程大綱

- Introduction (Chap. 1)
- First Order DE
  - 解法 (Chap. 2)
  - 應用 (Chap. 3)
- Higher Order DE
  - 解法 (Chap. 4)
  - 應用 (Chap. 5)
  - 多項式解法 (Chap. 6)
- Partial DE (Chap. 12)
- Transforms
  - Laplace Transform (Chap. 7)
  - Fourier Series (Chap. 11)
  - Fourier Transform (Chap. 14)

Chapter 1 Introduction to Differential Equations

1.1 Definitions and Terminology (術語)

(1)Differential Equation (DE): any equation containing derivation (page 2, definition 1.1)

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

x: independent variable 自變數

$y(x)$: dependent variable 應變數

$$\int_0^x \sin(2\pi t)\, f(t)\, dt + \frac{d^3 f(x)}{dx^3} = g(x)$$

- Note: In the text book, $f(x)$ is often simplified as f

- notations of differentiation

$$\frac{df}{dx}, \quad \frac{d^2 f}{dx^2}, \quad \frac{d^3 f}{dx^3}, \quad \frac{d^4 f}{dx^4}, \ \ldots\ldots\ldots\ \text{Leibniz notation}$$

$$f', \quad f'', \quad f''', \quad f^{(4)}, \ \ldots\ldots\ldots\ \text{prime notation}$$

$$\dot{f}, \quad \ddot{f}, \quad \dddot{f}, \quad \ddddot{f}, \ \ldots\ldots\ldots\ \text{dot notation}$$

$$f_x, \quad f_{xx}, \quad f_{xxx}, \quad f_{xxxx}, \ \ldots\ldots\ldots\ \text{subscript notation}$$

(2) Ordinary Differential Equation (ODE):

differentiation with respect to one independent variable

$$\frac{d^3u}{dx^3}+\frac{d^2u}{dx^2}+\frac{du}{dx}+\cos(6x)u=0 \qquad \frac{dx}{dt}+\frac{dy}{dt}+\frac{dz}{dt}=2xy+z$$

(3) Partial Differential Equation (PDE):

differentiation with respect to two or more independent variables

$$\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}=0 \qquad \frac{\partial x}{\partial t}=\frac{\partial y}{\partial \tau}$$

(4) Order of a Differentiation Equation: the order of the highest derivative in the equation

$$\frac{d^7 u}{dx^7} + 2\frac{d^6 u}{dx^6} + 3\frac{du}{dx} + u = 0$$

7th order

$$\frac{d^2 y}{dx^2} + 5\frac{dy}{dx} - 4y = e^x$$

2nd order

(5) Linear Differentiation Equation:

$$a_n(x)\frac{d^n y}{dx^n} + a_{n-1}(x)\frac{d^{n-1} y}{dx^{n-1}} + \cdots + a_1(x)\frac{dy}{dx} + a_0(x)\,y = g(x)$$

All the coefficient terms are independent of *y*.

Property of linear differentiation equations:

If $a_n(x)\frac{d^n y_1}{dx^n} + a_{n-1}(x)\frac{d^{n-1} y_1}{dx^{n-1}} + \cdots + a_1(x)\frac{dy_1}{dx} + a_0(x)\,y_1 = g_1(x)$

$$a_n(x)\frac{d^n y_2}{dx^n} + a_{n-1}(x)\frac{d^{n-1} y_2}{dx^{n-1}} + \cdots + a_1(x)\frac{dy_2}{dx} + a_0(x)\,y_2 = g_2(x)$$

and $y_3 = by_1 + cy_2$, then

$$a_n(x)\frac{d^n y_3}{dx^n} + a_{n-1}(x)\frac{d^{n-1} y_3}{dx^{n-1}} + \cdots + a_1(x)\frac{dy_3}{dx} + a_0(x)\,y_3 = bg_1(x) + cg_2(x)$$

(6) Non-Linear Differentiation Equation

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

$$\frac{d^2y}{dx^2}+\frac{dy}{dx}+y^2=e^x$$

$$\frac{d^2y}{dx^2}+\frac{dy}{dx}+e^y=e^x$$

(7) Explicit Solution (page 6)

The solution is expressed as $y = \phi(x)$

(8) Implicit Solution (page 7)

Example: $\dfrac{dy^2}{dx} = -x$,

Solution: $\dfrac{1}{2}x^2 + y^2 = c$ (implicit solution)

$y = \sqrt{c - x^2/2}$

or $y = -\sqrt{c - x^2/2}$ (explicit solution)

1.2 Initial Value Problem (IVP)

A differentiation equation always has more than one solution.

for $\dfrac{dy}{dx}=1$,

$y=x$, $y=x+1$, $y=x+2$ … are all the solutions of the above differentiation equation.

General form of the solution: $y=x+c$, where c is any constant.

The initial value (未必在 $x=0$) is helpful for obtain the unique solution.

$\dfrac{dy}{dx}=1$ and $y(0)=2$ $\longrightarrow$ $y=x+2$

$\dfrac{dy}{dx}=1$ and $y(2)=3.5$ $\longrightarrow$ $y=x+1.5$

The k^{th} order differential equation usually requires k initial conditions (or k boundary conditions) to obtain the unique solution.

$$\frac{d^2 y}{dx^2} = 1$$

solution: $y = x^2/2 + bx + c$,

b and c can be any constant

$y(1) = 2$ and $y(2) = 3$ (boundary conditions，在不同點)

$y(0) = 1$ and $y'(0) = 5$ (initial conditions)

$y(0) = 1$ and $y'(3) = 2$ (boundary conditions，在不同點)

For the k^{th} order differential equation, the initial conditions can be 0^{th} ~ $(k-1)^{th}$ derivatives at some points.

1.3 Differential Equations as Mathematical Model

Physical meaning of differentiation:

the variation at certain time or certain place

Example 1:

$$\frac{dA(t)}{dt} = kA(t)$$

A: population

人口增加量和人口呈正比

Example 2:

$$\frac{dT}{dt} = k(T - T_m)$$

T: 熱開水溫度，

T_m: 環境溫度

t: 時間

大一微積分所學的：

$\int f(t)\,dt$ 的解

例如： $\int \frac{1}{t}\,dt = \ln|t| + c$

$$\frac{dA(t)}{dt} = \frac{1}{t} \longrightarrow A(t) = \ln|t| + c$$

問題：

$$\int \frac{1}{t^2+4}\,dt = ?$$

(1) 若等號兩邊都出現 dependent variable (如 pages 15, 16 的例子)

(2) 若 order of DE 大於 1

$$\frac{d^2A(t)}{dt^2} + 2\frac{dA(t)}{dt} = 1$$

Review

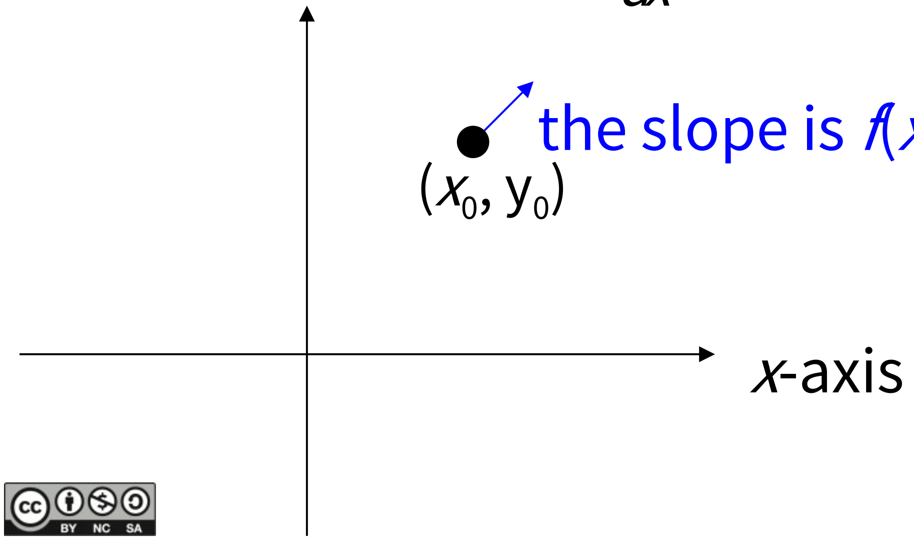
- dependent variable and independent variable
- DE
- PDE and ODE
- Order of DE
- linear DE and nonlinear DE
- explicit solution and implicit solution
- initial value
- IVP

Chapter 2 First Order Differential Equation

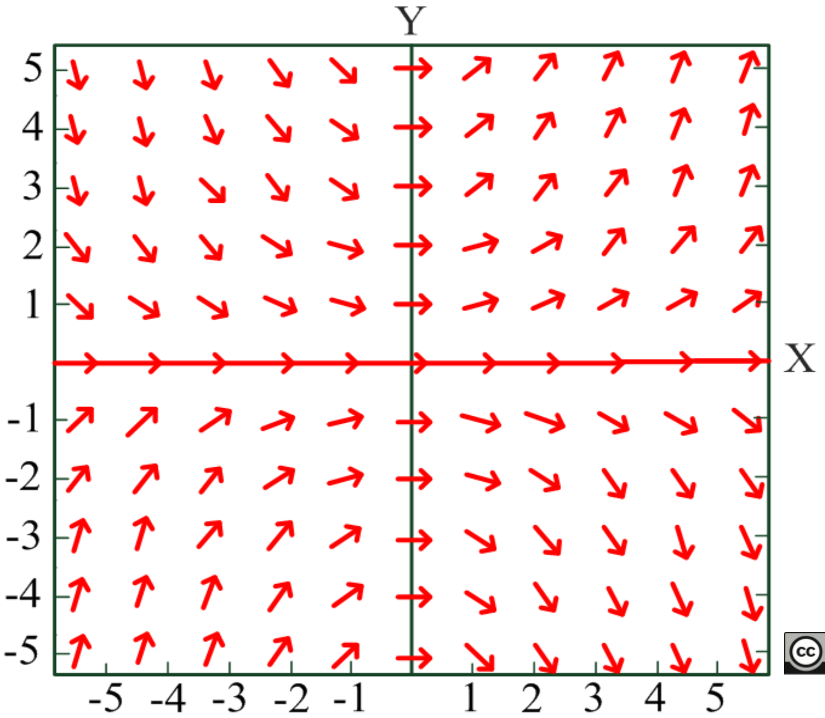
2-1 Solution Curves without a Solution

Instead of using analytic methods, the DE can be solved by graphs (圖解)

slopes and the field directions: $\frac{dy}{dx} = f(x, y)$

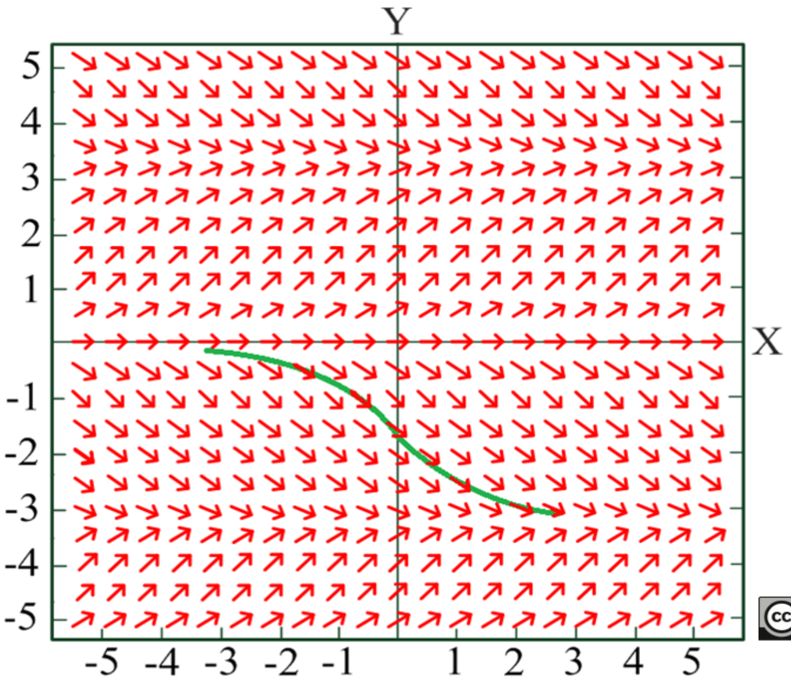


Example 1 $dy/dx = 0.2xy$



资料來源： Fig. 2-1-3(a) of "Differential Equations-with Boundary-Value Problem", 7th ed., Dennis G. Zill and Michael R. Cullen.

Example 2 $dy/dx = \sin(y)$, $y(0) = -3/2$



資料來源： Fig. 2-1-4 of “Differential Equations-with Boundary-Value Problem”, 7th ed., Dennis G. Zill and Michael R. Cullen.

With initial conditions, one curve can be obtained

Advantage:

It can solve some 1st order DEs that cannot be solved by mathematics.

Disadvantage:

It can only be used for the case of the 1st order DE.

It requires a lot of time

Section 2-6 A Numerical Method

- Another way to solve the DE without analytic methods
- independent variable $\xrightarrow{\text{sampling(取樣)}}$ $x_0,\ x_1, x_2, \ldots\ldots\ldots\ldots$
- Find the solution of $\dfrac{dy(x)}{dx} = f(x, y)$

Since $\dfrac{dy(x)}{dx} = f(x, y) \xrightarrow[\text{approximation}]{} \dfrac{y(x_{n+1}) - y(x_n)}{x_{n+1} - x_n} = f(x_n, y(x_n))$

$$y(x_{n+1}) = \underbrace{y(x_n)}_{\text{前一點的值}} + f(x_n, y(x_n))\underbrace{(x_{n+1} - x_n)}_{\text{取樣間格}}$$

- Example:

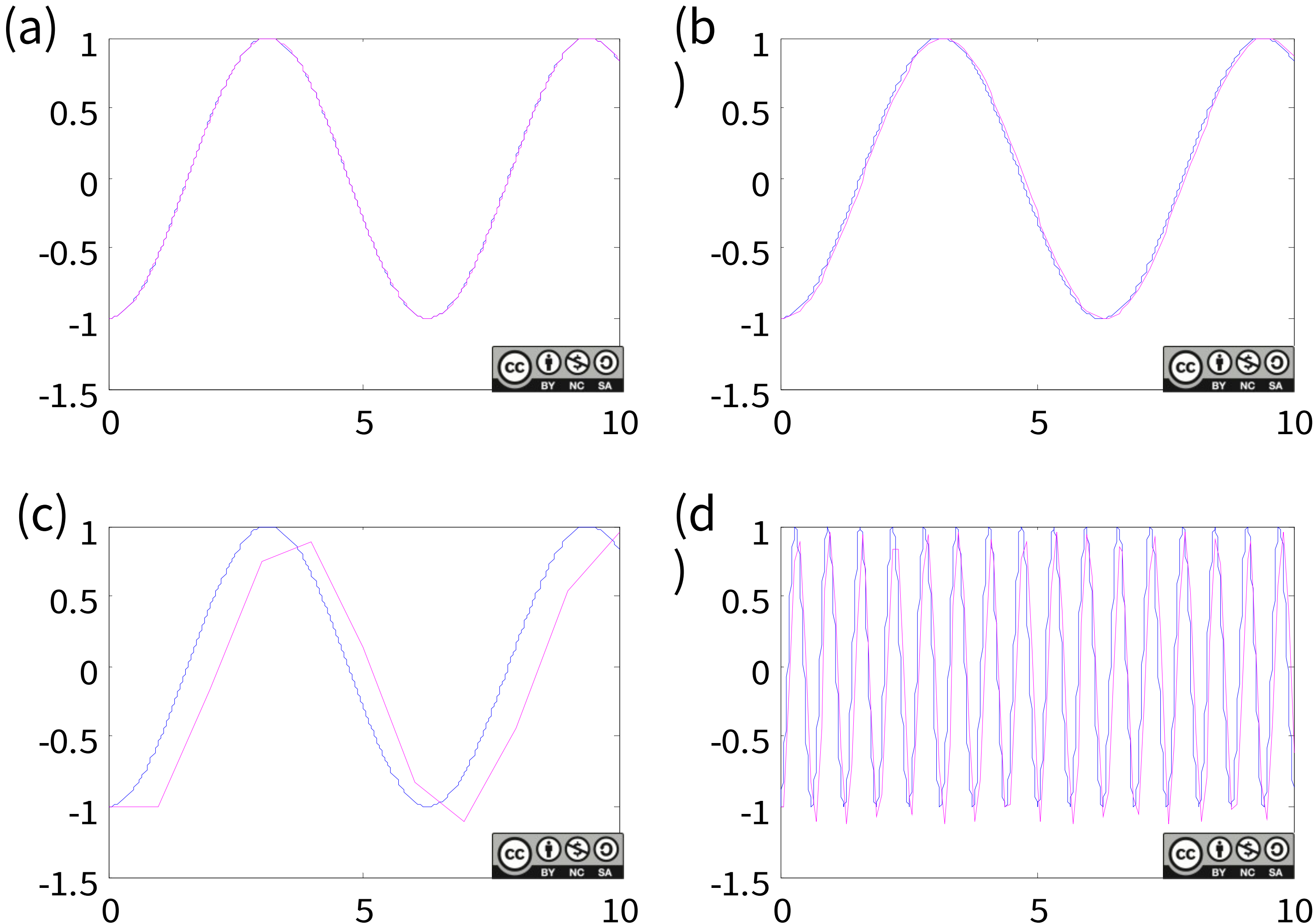
- $dy(x)/dx = 0.2xy$ $\longrightarrow$ $y(x_{n+1}) = y(x_n) + 0.2x_n y(x_n)*(x_{n+1} - x_n)$.

- $dy/dx = \sin(x)$ $\longrightarrow$ $y(x_{n+1}) = y(x_n) + \sin(x_n)*(x_{n+1} - x_n)$. .

後面為 $dy/dx = \sin(x)$, $y(0) = -1$,
(a) $x_{n+1} - x_n = 0.01$, (b) $x_{n+1} - x_n = 0.1$,
(c) $x_{n+1} - x_n = 1$, (d) $x_{n+1} - x_n = 0.1$, $dy/dx = 10\sin(10x)$ 的例子

Constraint for obtaining accurate results:

(1) small sampling interval (2) small variation of $f(x, y)$


(a)
(b)
(c)
(d)
1
0.5
0
-0.5
-1
-1.5
0
5
10
cc BY NC SA

Advantages

-- It can solve some 1st order DEs that cannot be solved by mathematics.

-- can be used for solving a complicated DE (not constrained for the 1st
order case)

-- suitable for computer simulation

Disadvantages

-- numerical error （數值方法的課程對此有詳細探討）

Exercises for Practicing

(not homework, but are encouraged to practice)

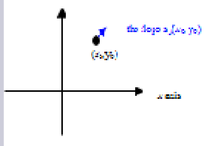
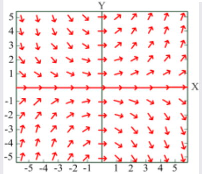
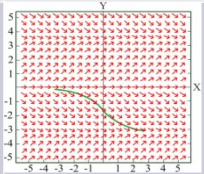
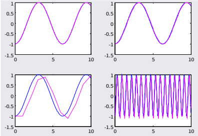
1-1: 1, 13, 19, 23, 33

1-2: 3, 13, 21, 33

1-3: 2, 7, 28

2-1: 1, 13, 20, 25, 33

2-6: 1, 3

頁碼	作品	版權圖示	來源 / 作者
19			台灣大學 電信工程研究所 丁建均教授 以創用CC「姓名標示－非商業性－相同方式分享」臺灣3.0版授權釋出。
20			台灣大學 電信工程研究所 丁建均教授 以創用CC「姓名標示－非商業性－相同方式分享」臺灣3.0版授權釋出。
21			台灣大學 電信工程研究所 丁建均教授 以創用CC「姓名標示－非商業性－相同方式分享」臺灣3.0版授權釋出。
25			台灣大學 電信工程研究所 丁建均教授 以創用CC「姓名標示－非商業性－相同方式分享」臺灣 3.0 版授權釋出。