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# Differential Equations

⇒ An equation which involves unknown function of one or several variables that relates the values of the function itself and its derivatives of various orders.

- ordinary differential equation (ode) : not involve partial derivatives
- partial differential equation (pde) : involves partial derivatives
- order of the differential equation is the order of the highest derivatives

Examples:

$$\frac{d^2y}{dx^2} + \frac{dy}{dx} = 3x \sin y \quad \rightarrow \text{second order ordinary differential equation}$$

$$\frac{\partial y}{\partial t} + x \frac{\partial y}{\partial x} = \frac{x+t}{x-t} \quad \rightarrow \text{first order partial differential equation}$$

Find the solution of the differential equation  $\frac{dy}{dx} = xe^y$  that satisfies the initial condition  $y(0) = 0$ .

$$\int e^{-y} dy = \int x dx$$

$$-e^{-y} + A = \frac{x^2}{2} + B$$

$$-e^{-y} = \frac{x^2}{2} + C$$

$$e^{-y} = -\frac{x^2}{2} + D$$

$$y = -\ln\left(-\frac{x^2}{2} + D\right)$$

$\frac{dy}{dx} = g(x)h(y)$

$$\int e^{ax} dx = \frac{1}{a} e^{ax} + C$$

$$0 = -\ln\left(-\frac{0^2}{2} + D\right)$$

$$0 = -\ln D$$

$$e^0 = e^{\ln D}$$

$$e^0 = e^{\ln D}$$

$$1 = D$$

$$y = -\ln\left(-\frac{x^2}{2} + 1\right)$$

$$y' = 2 + 2y + y^2, \quad y(0) = 0$$

$$y' = (y+1)^2 + 1$$

$$u = y+1$$

$$du = dy$$

$$u' = u^2 + 1$$

$$\frac{du}{dt} = u^2 + 1$$

$$du = (u^2 + 1) dt$$

$$\int \frac{du}{u^2 + 1} = \int dt$$

$$\arctan(u) = t + C$$

$$\arctan(y+1) = t + C$$

$$\arctan(1) = 0 + C$$

$$C = \pi/4$$

$$\arctan(y+1) = t + \pi/4$$

$$y = \tan(t + \pi/4) - 1$$

**Differential Equations**

**Example 1:** Find the particular solution for  $\frac{dy}{dx} = 2x - 3y$ ,  $y(0) = 0$ .

Step 1: Separate the variables  $y$  and  $x$ .

$$y' = 2x - 3y \Rightarrow y' + 3y = 2x$$

Step 2: Integrate both sides.

$$\int (y' + 3y) dx = \int 2x dx$$

$$y + \frac{3}{2}y^2 = x^2 + C$$

Step 3: Evaluate (and substitute) for the given point (in this case  $(0,0)$ ).

$$0 + \frac{3}{2}(0)^2 = 0^2 + C \Rightarrow C = 0$$

The particular solution is  $y^2 + 2y = x^2$ .

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**Example 2:** Find a general solution for  $x \frac{dy}{dx} + y = 2x^2y$ .

Step 1: Separate the variables  $y$  and  $x$ .

$$x \frac{dy}{dx} + y = 2x^2y \Rightarrow \frac{dy}{dx} + \frac{y}{x} = 2xy$$

Step 2: Integrate both sides.

$$\int \left(\frac{dy}{dx} + \frac{y}{x}\right) dx = \int 2xy dx$$

$$y + \ln|x| \cdot y = x^2y + C$$

Step 3: Evaluate (and substitute) for the given point (in this case  $(1,1)$ ).

$$1 + \ln|1| \cdot 1 = 1^2 \cdot 1 + C \Rightarrow C = 0$$

The general solution is  $y = \frac{1}{x^2}$ .

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**Example 3:** Find a general solution for  $x \frac{dy}{dx} + y = 0$ .

Step 1: Separate the variables  $y$  and  $x$ .

$$x \frac{dy}{dx} + y = 0 \Rightarrow \frac{dy}{dx} + \frac{y}{x} = 0$$

Step 2: Integrate both sides.

$$\int \left(\frac{dy}{dx} + \frac{y}{x}\right) dx = \int 0 dx$$

$$y + \ln|x| \cdot y = C$$

Step 3: Evaluate (and substitute) for the given point (in this case  $(1,1)$ ).

$$1 + \ln|1| \cdot 1 = C \Rightarrow C = 1$$

The general solution is  $y = \frac{1}{x}$ .



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