

Modified Equation

- In order to determine the dominant error term of a finite difference equation, Taylor series expansions are substituted back into the finite difference equation and, after some algebraic manipulation, the so-called modified equation is obtained.
- To illustrate the procedure, the following FTCS-Explicit scheme is considered as a numerical solution of the parabolic equation.

$$u_j^{n+1} = u_j^n + d(u_{j+1}^n - 2u_j^n + u_{j-1}^n) \quad \text{where} \quad d = \frac{\nu \Delta t}{(\Delta y)^2}$$

The following Taylor series expansions

$$u_j^{n+1} = u_j^n + \Delta t \left(\frac{\partial u}{\partial t} \right) + \frac{(\Delta t)^2}{2} \left(\frac{\partial^2 u}{\partial t^2} \right) + \frac{(\Delta t)^3}{3!} \left(\frac{\partial^3 u}{\partial t^3} \right) + \frac{(\Delta t)^4}{4!} \left(\frac{\partial^4 u}{\partial t^4} \right) + O(\Delta t)^5$$

$$u_{j\pm 1}^n = u_j^n \pm \Delta y \left(\frac{\partial u}{\partial y} \right) + \frac{(\Delta y)^2}{2} \left(\frac{\partial^2 u}{\partial y^2} \right) \pm \frac{(\Delta y)^3}{3!} \left(\frac{\partial^3 u}{\partial y^3} \right) + \frac{(\Delta y)^4}{4!} \left(\frac{\partial^4 u}{\partial y^4} \right) \pm O(\Delta y)^5$$

are substituted back into the FTCS scheme to obtain the modified equation.

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Dividing by Δt the following equation is obtained

$$\begin{aligned} & \frac{\partial u}{\partial t} + \frac{(\Delta t)}{2} \left(\frac{\partial^2 u}{\partial t^2} \right) + \frac{(\Delta t)^2}{3!} \left(\frac{\partial^3 u}{\partial t^3} \right) + \frac{(\Delta t)^3}{4!} \left(\frac{\partial^4 u}{\partial t^4} \right) + O(\Delta t)^4 \\ & = \nu \left[\left(\frac{\partial^2 u}{\partial y^2} \right) + \frac{(\Delta y)^2}{12} \left(\frac{\partial^4 u}{\partial y^4} \right) + O(\Delta y)^4 \right] \end{aligned}$$

This equation can be written as

$$\frac{\partial u}{\partial t} - \nu \left(\frac{\partial^2 u}{\partial y^2} \right) = \underbrace{-\frac{(\Delta t)}{2} \left(\frac{\partial^2 u}{\partial t^2} \right) + \frac{\nu(\Delta y)^2}{12} \left(\frac{\partial^4 u}{\partial y^4} \right) + O[(\Delta t)^2, (\Delta y)^4]}_{\text{Truncation error}}$$

To check the consistency of the scheme

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