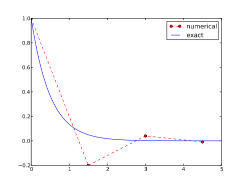
On Schemes for Exponential Decay

Hans Petter Langtangen[1,2]

Center for Biomedical Computing, Simula Research Laboratory[1]

Department of Informatics, University of Oslo[2]

Oct 19, 2014



Goal

The primary goal of this demo talk is to demonstrate how to write talks with DocOnce and get them rendered in numerous HTML formats.

Layout

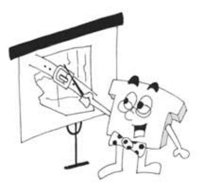
This version utilizes beamer slides with the theme `dark_gradient`.

Problem setting and methods

We aim to solve the (almost) simplest possible differential equation problem

$$u'(t) = -au(t) \qquad (1)$$

$$u(0) = I \qquad (2)$$



Here,

- $t \in (0, T]$
- a, I, and T are prescribed parameters
- $u(t)$ is the unknown function
- The ODE (??) has the initial condition (??)

The ODE problem is solved by a finite difference scheme

- Mesh in time: $0 = t_0 < t_1 \cdots < t_N = T$
- Assume constant $\Delta t = t_n - t_{n-1}$
- u^n: numerical approx to the exact solution at t_n

The θ rule,

$$u^{n+1} = \frac{1-(1-\theta)a\Delta t}{1+\theta a\Delta t}u^n, \quad n = 0, 1, \ldots, N-1$$

contains the Forward Euler ($\theta = 0$), the Backward Euler ($\theta = 1$), and the Crank-Nicolson ($\theta = 0.5$) schemes.

The ODE problem is solved by a finite difference scheme

- Mesh in time: $0 = t_0 < t_1 \cdots < t_N = T$
- Assume constant $\Delta t = t_n - t_{n-1}$
- u^n: numerical approx to the exact solution at t_n

The θ rule,

$$u^{n+1} = \frac{1-(1-\theta)a\Delta t}{1+\theta a\Delta t}u^n, \quad n = 0, 1, \ldots, N-1$$

contains the Forward Euler ($\theta = 0$), the Backward Euler ($\theta = 1$), and the Crank-Nicolson ($\theta = 0.5$) schemes.

The ODE problem is solved by a finite difference scheme

- Mesh in time: $0 = t_0 < t_1 \cdots < t_N = T$
- Assume constant $\Delta t = t_n - t_{n-1}$
- u^n: numerical approx to the exact solution at t_n

The θ rule,

$$u^{n+1} = \frac{1 - (1-\theta)a\Delta t}{1 + \theta a\Delta t} u^n, \quad n = 0, 1, \ldots, N-1$$

contains the Forward Euler ($\theta = 0$), the Backward Euler ($\theta = 1$), and the Crank-Nicolson ($\theta = 0.5$) schemes.

The Forward Euler scheme explained

http://youtube.com/PtJrPEIHNJw

Implementation

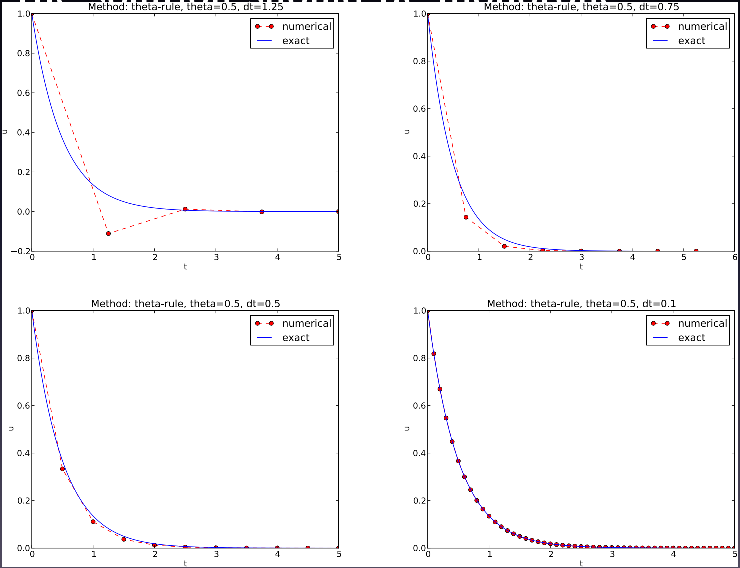
Implementation in a Python function:

```
def solver(I, a, T, dt, theta):
    """Solve u'=-a*u, u(0)=I, for t in (0,T]; step: dt."""
    dt = float(dt)              # avoid integer division
    N = int(round(T/dt))        # no of time intervals
    T = N*dt                    # adjust T to fit time step dt
    u = zeros(N+1)              # array of u[n] values
    t = linspace(0, T, N+1)     # time mesh

    u[0] = I                    # assign initial condition
    for n in range(0, N):       # n=0,1,...,N-1
        u[n+1] = (1 - (1-theta)*a*dt)/(1 + theta*dt*a)*u[n]
    return u, t
```

Results

The Crank-Nicolson method shows oscillatory behavior for not sufficiently small time steps, while the solution should be monotone



The artifacts can be explained by some theory

Exact solution of the scheme:

$$u^n = A^n, \quad A = \frac{1-(1-\theta)a\Delta t}{1+\theta a\Delta t}\,.$$

Key results:

- Stability: $|A| < 1$
- No oscillations: $A > 0$
- Always for Backward Euler ($\theta = 1$)
- $\Delta t < 1/a$ for Forward Euler ($\theta = 0$)
- $\Delta t < 2/a$ for Crank-Nicolson ($\theta = 1/2$)

Concluding remarks:

The artifacts can be explained by some theory

Exact solution of the scheme:

$$u^n = A^n, \quad A = \frac{1 - (1-\theta)a\Delta t}{1 + \theta a \Delta t}\,.$$

Key results:

- Stability: $|A| < 1$
- No oscillations: $A > 0$
- Always for Backward Euler ($\theta = 1$)
- $\Delta t < 1/a$ for Forward Euler ($\theta = 0$)
- $\Delta t < 2/a$ for Crank-Nicolson ($\theta = 1/2$)

Concluding remarks:

The artifacts can be explained by some theory

Exact solution of the scheme:

$$u^n = A^n, \quad A = \frac{1-(1-\theta)a\Delta t}{1+\theta a\Delta t}\,.$$

Key results:

- Stability: $|A| < 1$
- No oscillations: $A > 0$
- Always for Backward Euler ($\theta = 1$)
- $\Delta t < 1/a$ for Forward Euler ($\theta = 0$)
- $\Delta t < 2/a$ for Crank-Nicolson ($\theta = 1/2$)

Concluding remarks:

The artifacts can be explained by some theory

Exact solution of the scheme:

$$u^n = A^n, \quad A = \frac{1 - (1-\theta)a\Delta t}{1 + \theta a \Delta t} \,.$$

Key results:

- Stability: $|A| < 1$
- No oscillations: $A > 0$
- Always for Backward Euler ($\theta = 1$)
- $\Delta t < 1/a$ for Forward Euler ($\theta = 0$)
- $\Delta t < 2/a$ for Crank-Nicolson ($\theta = 1/2$)

Concluding remarks: