

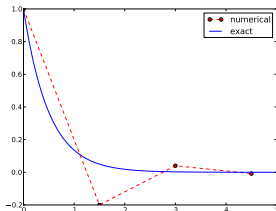
On Schemes for Exponential Decay

Hans Petter Langtangen^{1,2}

Center for Biomedical Computing, Simula Research Laboratory¹

Department of Informatics, University of Oslo²

Aug 30, 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 `cbc`.

Mathematical problem

$$u'(t) = -au(t), \quad (1)$$

$$u(0) = I, \quad (2)$$

- ▶ $t \in (0, T]$
- ▶ a , I , and T are prescribed parameters
- ▶ $u(t)$ is the unknown function



Numerical solution method

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

Numerical scheme:

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

Numerical solution method

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

Numerical scheme:

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

Numerical solution method

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

Numerical scheme:

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

Forward Euler explained

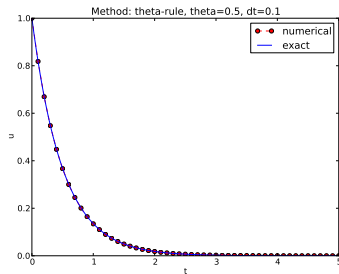
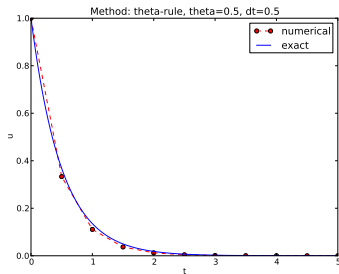
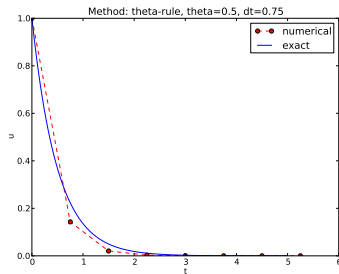
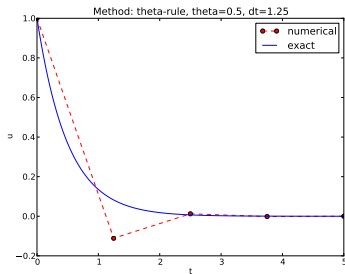
<http://youtube.com/PtJrPEIHNJw>

Implementation

The numerical method is implemented in a Python function:

```
def solver(I, a, T, dt, theta):  
    """Solve  $u' = -a*u$ ,  $u(0) = I$ , for  $t$  in  $(0, T]$  with steps of  $dt$ ."""  
    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):     #  $n=0, 1, \dots, N-1$   
        u[n+1] = (1 - (1-theta)*a*dt)/(1 + theta*dt*a)*u[n]  
    return u, t
```


The Crank-Nicolson method



The artifacts can be explained by some theory

Exact solution of the scheme:

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

- ▶ 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:

Only the Backward Euler scheme is guaranteed to always give qualitatively correct results.

The artifacts can be explained by some theory

Exact solution of the scheme:

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

- ▶ 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:

Only the Backward Euler scheme is guaranteed to always give qualitatively correct results.

The artifacts can be explained by some theory

Exact solution of the scheme:

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

- ▶ 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:

Only the Backward Euler scheme is guaranteed to always give qualitatively correct results.

The artifacts can be explained by some theory

Exact solution of the scheme:

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

- ▶ 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:

Only the Backward Euler scheme is guaranteed to always give qualitatively correct results.