

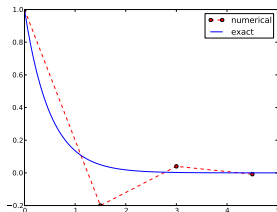
# On Schemes for Exponential Decay

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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 `red_shadow`.

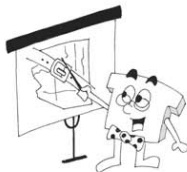
# Mathematical problem

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

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

Here,

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



# Numerical solution method

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

Numerical scheme:

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

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# Forward Euler explained

<http://youtube.com/PtJrPEIHNJw>

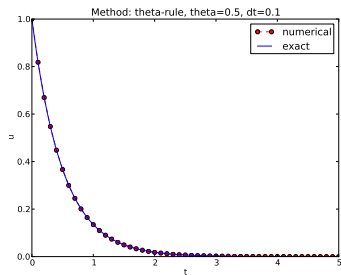
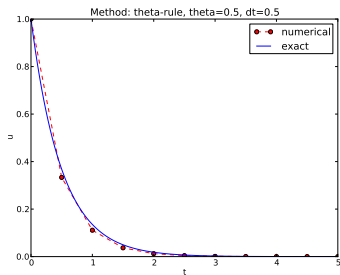
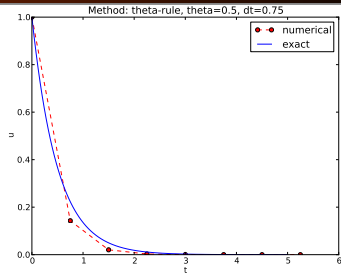
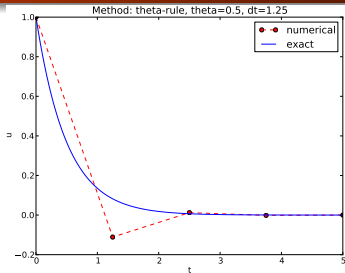
# Implementation

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 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:

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

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