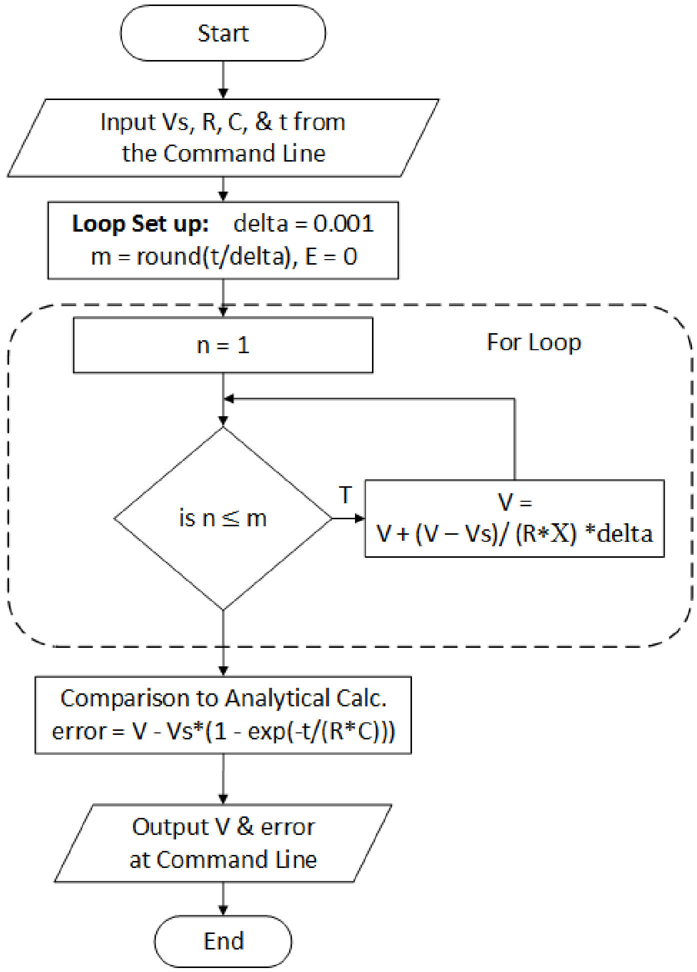
1. Flow Chart



2. Hand test calculations

$$V_d = V_s\left(1 - e^{-t/RC}\right)$$

V_s (Volts)	R (Ohms)	C (Farads)	t (sec.)	Vc (Volts)
9	300	0.003	1	6.04
9	300	0.003	3	8.68
9	1000	0.001	1	5.7
9	1000	0.001	3	8.6

Note: In the code that follows the check equation is built into the function. If students include this and output it in their validation, they do not need to include test calculations here.

3. Code

```
function [V, error] = ChargingV(Vs, R, C, t)
% This function will calculate the voltage of a capacitor in an RC charging
% circuit with a constant source voltage and the capacitor starting in a
% completely discharged state(i.e. Q(t=0) = 0).
%
% [V] = charging2(Vs, R, C, t, delta)
% Inputs:   Vs = constant supply voltage (Volts)
%            R = resistor resistance (Ohms)
%            C = capacitor capacitance (Farads)
%            t = time of desired voltage (seconds)
%
% Output:   V = voltage of capacitor at time t (Volts)
% S. Scott Moor               Updated: March 2016

% Internal  delta = size of the time steps in the approximation (seconds)

% Determine number of loops required and initialize accumulation variable
delta = 0.001;
m = round(t/delta);
V=0;
% Loop with recursion formula to estimate the charge on the capacitor
for n = 1:m
    V = V + (Vs - V)/(R*C)*delta;
end
% Calculate error in above by comparing to integral result
error = V - Vs*(1 - exp(-t/(R*C)));
```

4. Validation ➔ First two test cases required. At least one other case should be included.

```
>> [V, error] = ChargingV( 9, 300, 0.003, 1)
V =
  6.0373
error =
 1.8288e-07
>> [V, error] = ChargingV( 9, 300, 0.003, 3)
V =
  8.6789
error =
 5.9456e-08

>> [V, error] = ChargingV( 9, 100, 0.001, 0.1)
V =
  5.7057
error =
  0.0166

>> [V, error] = ChargingV( 9, 100, 0.001, 0.3)
V =
  8.5586
error =
  0.0067
```

All tests match the hand calculations results in step 4.

Results for Table 1

Table 1: Numerical estimates of voltage (pay attention to program units)
(for, Vs = 9 V; R = 1000 Ω; C = 0.001 F; t = 1)

Δ t (sec)	**Numerical estimate of V (Volts)**	**Error in Estimate of V (Volts)**
0.1	5.8619	0.1728
0.01	5.7057	0.0166
0.001	5.6907	0.0017
0.0001	5.6893	1.6555e-04

Problem ID 9.2 Cap. Time to Charge Programmer Solution – S. Scott Moor

Set Up/ Planning Type of Program: ☐ Script ☑ Function

1. Problem Statement (in your own words):

Προγραμ το χαλχυλατε τηε τιμε ρεθυιρεδ το χηαργε α χαπαχιτορ το α γιϖεν ϖολταγε ιν αν ΡΧ χηαργινγ χιρχυιτ ωιτη α στεαδψ ΔΧ σουρχε. (Ποιντσ φορ ρεασοναβλε αττεμπτ ατ γοαλ. Σηουλδ βε ιν στυδεντσ οων ωορδσ).

2. Inputs: (full name, variable to be used, units) –

Problem does not specify I/O details. Therefore there is a great deal of flexibility on exact setup of I/O. It should be logical and match program provided.

Variable Name	Description	Units or Values	Input Source*
ςδ	Δεσιρεδ Χηαργινγ ϖολταγε	ςολτσ	Χομμανδ λινε
ςσ	Σουρχε ςολταγε	ςολτσ	Χομμανδ Λινε
Ρ	Ρεσιστανχε	Οημσ	Χομμανδ Λινε
Χ	Χαπαχιτανχε	Φαραδσ	Χομμανδ Λινε

* Possible sources: command line, file, interactive input (input or menu functions)

3. Output: (full name, variable to be used, units)

Variable Name	Description	Units or Values	Output type*
τ	τιμε ρεθυιρεδ φορ χαπαχιτορ το ρεαχη ςδ	σεχονδσ	Χομμανδ Λινε

* Possible types: command line, file, display, figure window

4. Solution Steps (order of these two parts may be varied):

(1) Perform calculation on test case(s) (2) Identify the steps/equations using a flowchart

Test cases using exponential formula

$$V_d = V_s\left(1 - e^{-t/RC}\right)$$

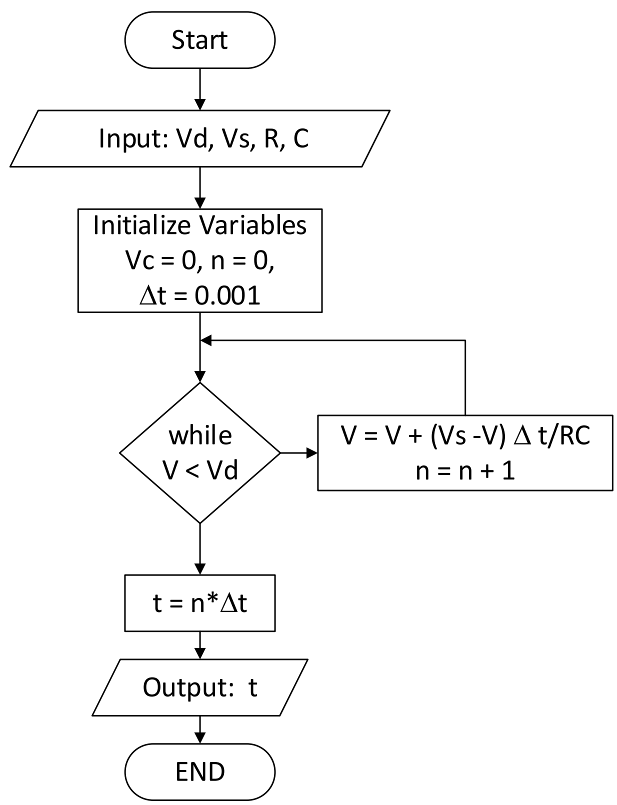
Solve for time $\frac{V_s - V_d}{V_s} = e^{-t/RC}$

$$ln\left(\frac{V_s - V_d}{V_s}\right) = -t/RC$$

$$t = -RC\ ln\left(\frac{V_s - V_d}{V_s}\right)$$

V_d (Volts)	V_s (Volts)	R (Ohms)	C (Farads)	t (sec.)
8	**9**	**200**	**0.0004**	**0.176**
4	9	100	0.001	0.059
8	9	1000	0.001	2.197
4	9	1000	0.001	0.588

Note students could also get test points with program developed in class. First point is required. Others are extra.



Program Code (with comments):

```
function [t] = ChargingNew(Vd, Vs, R, C)
% This function will calculate the the time for a capctor to reach a given
% voltage in an RC charging circuit with a constant source voltage and
% the capacitor starting in a
% completely discharged state(i.e. Q(t=0) = 0).
%
% [V] = ChargingNew(Vs, R, C, t, delta)
% Inputs:   Vd = desired voltage drop across the capacitor
%           Vs = constant supply voltage (Volts)
%           R = resistor resistance (Ohms)
%           C = capacitor capacitance (Farads)
%
% Output:  t = time to reach desired voltage (seconds)

% Intermediate  V = voltage of in a given loop(Volts)
%               delta = size of the time steps(seconds)

% initialize accumulation variables, total time and step size
V=0;
t=0;
delta = 0.001;

% Loop with recursion formula to estimate the charge on the capacitor
while V <= Vd
    V = V + (Vs - V)/(R*C)*delta;        % Accumulation of voltage
    % could also accumulate charge      Q = Q + (Vs/R - Q/(R*C))*delta
    % & then converts charge to voltage V = Q/C;
    t = t + delta;                      % Accumulate the elapsed time
end
```

Validation: (prove that the program works by showing the execution and comparing to known results from another source, e.g. hand calculations from step 4).

First test cases is required. Multiple test cases preferred.

```
>> ChargingNew(8,9,200,0.0004)
ans =
  0.1750

>> ChargingNew(4,9,100,0.001)
ans =
  0.0590
>> ChargingNew(8,9,1000,0.001)
ans =
  2.1970
>> ChargingNew(4,9,1000,0.001)
ans =
  0.5880
```

All tests match the hand calculations results in step 4.