Name ____________________________ Class Time _____

Math 2250, Numerical Methods
Maple Project Sample Solution
Spring 2010

References: Code in `maple` appears in `2250mapleL4-sample-S2010.txt` at URL `http://www.math.utah.edu/~gustafso/`. This document: `2250mapleL4-sample-S2010.pdf`. Other related and required documents are available at the web site:

- Numerical Solution of First Order DE (typeset, 19 pages, 220k pdf). A resource similar to the textbook, with maple examples and deeper detail. It is for a second reading, in case Edwards-Penney left too many questions unanswered.
- Numerical DE coding hints, `2250numerical-hints.txt`, TEXT Document (1 page, 2k). A modified portion of this document is appended here, for completeness.
- The web copy `2250mapleL4-sample-S2010.txt` of the text in this document is suited for mouse copy and paste of maple code segments.

Problem ER-2. (E & P Exercise 2.6-36, Symbolic Solution)

The exact symbolic solution of the Logistic problem $y' = 0.02225y - 0.0003y^2$, $y(0) = 25$ is

$$y(x) = \frac{2225}{30 + 59e^{-89x/4000}}.$$

Using textbook techniques, Chapter 2, derive the answer. Then check the answer in maple.

Solution.
Derivation Details. The differential equation is a Verhulst-Logistic equation, studied in Section 2.1, appearing as equation (6):

$$\frac{dy}{dx} = ky(M - y), \quad kM = 0.02225, \quad k = 0.0003.$$

The unique solution $y(x)$ with $y(0) = y_0$ is given by equation (7):

$$y(x) = \frac{My_0}{y_0 + (M - y_0)e^{-kMx}}.$$

The fraction will be multiplied top and bottom by the factor k/y_0, to obtain

$$\begin{aligned} y(t) &= \frac{k/y_0}{k/y_0}\,\frac{My_0}{y_0 + (M - y_0)e^{-kMx}} \\ &= \frac{kM}{k + (kM/y_0 - k)e^{-kMx}} \\ &= \frac{0.02225}{0.0003 + (0.02225/25 - 0.0003)e^{-0.02225x}} \\ &= \frac{100000}{100000}\,\frac{0.02225}{0.0003 + (0.02225/25 - 0.0003)e^{-0.02225x}} \\ &= \frac{2225}{30 + 59e^{-89x/4000}}. \end{aligned}$$

Answer Check in Maple.

```
# Check the exact symbolic solution
 de:=diff(y(t),t)=0.02225 *y(t) - 0.0003*y(t)^2;
 ic:= y(0)=25;
 dsolve({de,ic},y(t));
```

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Name ___________________________ Class Time _____

Maple Project Sample Solution: Numerical Methods
Math 2250 S2010

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Problem L4.1. (E & P Exercise 2.6-36)

Consider the initial value problem $y' = 0.02225y - 0.0003y^2$, $y(0) = 25$ with symbolic solution $y(t) = \dfrac{2225}{30 + 59e^{-89t/4000}}$. Apply Euler's method to finds the numerical solution $y(x)$ on $x = 0$ to $x = 250$. Write computer code to produce two dot tables. The first has $n + 1 = 101$ rows, $h = 250/n = 2.5$. The second has $n + 1 = 201$ rows, $h = 250/n = 1.25$. The computation should find the missing digits in the table below.

x	0.0	50	100	150	200	250
y-approx, $h = 2.5$	25.00000000	45.0101????	61.2965????	69.4877????	72.6063????	73.6622????
y-approx, $h = 1.25$	25.00000000	45.0280????	61.2316????	69.4052????	72.5539????	73.6367????
actual $y(x)$	25.00000000	45.04465339	61.16674082	69.32324992	72.50146404	73.61087799
Error(approx,actual)	0.0000%	0.03??%	0.10??%	0.11??%	0.07??%	0.03??%

Part I. Reproduce, by transcribing computer data, the table above, and fill in missing digits. For the percentage error with $h = 250/200 = 1.25$, use the equation

$$Error(approx, actual) = 100\frac{|approx - actual|}{|actual|}.$$

Solution.

y-approx, $h = 2.5$, 25.00000000, 45.01012660, 61.29651142, 69.48777402, 72.60632272, 73.66229582.

y-approx, $h = 1.25$, 25.00000000, 45.02802159, 61.23165186, 69.40522495, 72.55394452, 73.63678526.

Symbolic $y(x)$, 25.00000000 45.04465339 61.16674082 69.32324992 72.50146404 73.61087799.

Error(approx,actual), $h = 1.25$, percentages 0.0, 0.03692291704, 0.1061214626, 0.1182504140, 0.07238540724, 0.03519489335.

Part II. Hand-check the first dot table for one step. The answer should be the same as line 2 of the first dot table (which has 101 lines). Assume the given symbolic solution is correct. Don't repeat details already done in ER-2. Test the answers against the symbolic solution, as suggested in the table above.

Hand Check for Euler.

```
One step.
h=2.5
x0 = 0
y0 = 25
f(x,y) = 0.02225 y - 0.0003 y^2
y1 = y0 + h f(x0,y0)
   = 25 + 2.5 (0.02225 (25) - 0.0003 (25)^2)
   = 25.921875
Dots[1] = [0, 25], Dots[2] = [2.500000000, 25.92187500]. Answer checks.
```

Symbolic Solution Check.

The Euler answer and the symbolic answer **agree to one digit**.

Part III. Include an appendix of the computer code used.

```
# Now for the Euler code to make the dot table, error percentages and plot.
  # Euler. Group 1, initialize.
   f:=(x,y)->0.02225 *y - 0.0003*y^2;
   x0:=0:y0:=25:Dots:=[x0,y0]:n:=100:h:=250/n:
  # Group 2, repeat n times. Euler's method
```

```
  for i from 1 to n do
   Y:=y0+h*f(x0,y0);
   x0:=x0+h:y0:=Y:Dots:=Dots,[evalf(x0),evalf(y0)];
  od:
  # Group 3, display relevant dots and plot.
   Exact:=x->2225/(30+59*exp(-89 *x/4000));
   P:=unapply(evalf(100*abs(exact-approx)/abs(exact)),(exact,approx)):
   m:=n/5:X:=[seq(1+m*j,j=0..n/m)]: # List of relevant indices
   print("Dots"),seq(Dots[k],k=X);
   print("Exact"),seq(Exact(Dots[k][1]),k=X);
   print("Error"),seq(P(Exact(Dots[k][1]),Dots[k][2]),k=X);
   #plot([Dots]);
### The output from this program:
                                "Dots"
  [0, 25], [50., 45.01012660], [100., 61.29651142], [150., 69.48777402],
  [200., 72.60632272], [250., 73.66229582]
                               "Exact"
  25, 45.04465339, 61.16674082, 69.32324992, 72.50146404, 73.61087799
                               "Error"
  0., 0.07665014025, 0.2121587619, 0.2373288907, 0.1446297415, 0.06985085819
```

Problem L4.2. (E & P Exercise 2.6-36)

Consider the initial value problem $y' = 0.02225y - 0.0003y^2$, $y(0) = 25$ with symbolic solution $y(t) = \dfrac{2225}{30 + 59e^{-89t/4000}}$. Apply Heun's method to finds the numerical solution $y(x)$ on $x = 0$ to $x = 250$. Write computer code to produce two dot tables. The first has $n + 1 = 101$ rows, $h = 250/n = 2.5$. The second has $n + 1 = 201$ rows, $h = 250/n = 1.25$. The computation should find the missing digits in the table below.

x	0.0	50	100	150	200	250
y-approx, $h = 2.5$	25.00000000	45.0419????	61.1624????	69.3195????	72.4992????	73.6098????.
y-approx, $h = 1.25$	25.00000000	45.0439????	61.1656????	69.3223????	72.5009????	73.6106????.
actual $y(x)$	25.00000000	45.04465339	61.16674082	69.32324992	72.50146404	73.61087799
Error(approx,actual)	0.0000%	0.001??%	0.001??%	0.001??%	0.000??%	0.000??%

Part I. Reproduce, by transcribing computer data, the table above, and fill in missing digits. For the percentage error with $h = 250/200 = 1.25$, use the equation

$$Error(approx, actual) = 100\frac{|approx - actual|}{|actual|}.$$

Solution.

y-approx, $h = 2.5$, 25, 45.04191584, 61.16246299, 69.31954666, 72.49927181, 73.60981811.

y-approx, $h = 1.25$, 25, 45.04396719, 61.16567946, 69.32233642, 72.50092484, 73.61061773.

Symbolic $y(x)$, 25, 45.04465339, 61.16674082, 69.32324992, 72.50146404, 73.61087799.

Error(approx,actual), $h = 1.25$, percentages 0.0, 0.001523377245, 0.001735191357, 0.001317739721, 0.0007437091197, 0.0003535618744.

Part II. Hand-check the first dot table for one step. The answer should be the same as line 2 of the first dot table (which has 101 lines). Assume the given symbolic solution is correct. Don't repeat details already done in ER-2. Test the answers against the symbolic solution, as suggested in the table above.

Hand Check for Heun.

```
One step.
h=2.5
x0 = 0
y0 = 25
f(x,y) = 0.02225 y - 0.0003 y^2
y1 = y0 + h f(x0,y0)
   = 25 + 2.5 (0.02225 (25) - 0.0003 (25)^2)
   = 25.921875
```

```
y2 = y0 + h(f(x0,y0)+f(x0+h,y1))/2
   = 25 + 2.5 (0.02225 (25) - 0.0003 (25)^2)/2 +
     2.5 (0.02225 (25.921875) - 0.0003 (25.921875)^2)/2
   = 25.92991080
Dots[1] = [0, 25], Dots[2] = [2.500000000, 25.92991080]. Answer checks.
```

Symbolic Solution Check.

The Heun answer and the symbolic answer **agree to two digits**.

Part III. Include an appendix of the computer code used.

```
# Now for the Heun code to make the dot table, error percentages and plot.
  # Heun. Group 1, initialize.
   f:=(x,y)->0.02225 *y - 0.0003*y^2;
   x0:=0:y0:=25:Dots:=[x0,y0]:n:=100:h:=250/n:
  # Group 2, repeat n times. Heun's method
  for i from 1 to n do
   Y1:=y0+h*f(x0,y0);
   Y:=y0+h*(f(x0,y0)+f(x0+h,Y1))/2;
   x0:=x0+h:y0:=Y:Dots:=Dots,[evalf(x0),evalf(y0)];
  od:
  # Group 3, display relevant dots and plot.
   Exact:=x->2225/(30+59*exp(-89 *x/4000));
   P:=unapply(evalf(100*abs(exact-approx)/abs(exact)),(exact,approx)):
   m:=n/5:X:=[seq(1+m*j,j=0..n/m)]: # List of relevant indices
   print("Dots"),seq(Dots[k],k=X);
   print("Exact"),seq(Exact(Dots[k][1]),k=X);
   print("Error"),seq(P(Exact(Dots[k][1]),Dots[k][2]),k=X);
   #plot([Dots]);
### The output from this program:
                                "Dots"
  [0, 25], [50., 45.04191584], [100., 61.16246299],
        [150., 69.31954666], [200., 72.49927181], [250., 73.60981811]
                                "Exact"
 25, 45.04465339, 61.16674082, 69.32324992, 72.50146404, 73.61087799
                                "Error"
 0., 0.006077413842, 0.006993719042, 0.005342017295, 0.003023704458,
       0.001439841541
```

Problem L4.3. (E & P Exercise 2.6-36)

Consider the initial value problem $y' = 0.02225y - 0.0003y^2$, $y(0) = 25$ with symbolic solution $y(t) = \dfrac{2225}{30 + 59e^{-89t/4000}}$. Apply the RK4 method to finds the numerical solution $y(x)$ on $x = 0$ to $x = 250$. Write computer code to produce two dot tables. The first has $n + 1 = 101$ rows, $h = 250/n = 2.5$. The second has $n + 1 = 201$ rows, $h = 250/n = 1.25$. The computation should find the missing digits in the table below.

x	0.0	50	100	150	200	250
y-approx, $h = 2.5$	25.00000000	45.04465???	61.16674???	69.32324???	72.50146???	73.61087???.
y-approx, $h = 1.25$	25.00000000	45.04465???	61.16674???	69.32324???	72.50146???	73.61087???.
actual $y(x)$	25.00000000	45.04465339	61.16674082	69.32324992	72.50146404	73.61087799
Error(approx,actual)	0.000000%	0.00000??%	0.00000??%	0.00000??%	0.00000??%	0.00000??%

Part I. Reproduce, by transcribing computer data, the table above, and fill in missing digits. For the percentage error with $h = 250/200 = 1.25$, use the equation

$$Error(approx, actual) = 100\frac{|approx - actual|}{|actual|}.$$

Solution.

y-approx, $h = 2.5$, 25.0, 45.04465322, 61.16674048, 69.32324952, 72.50146380, 73.61087789.

y-approx, $h = 1.25$, 25.0, 45.04465348, 61.16674086, 69.32324992, 72.50146405, 73.61087799.

Symbolic $y(x)$, 25, 45.04465339, 61.16674082, 69.32324992, 72.50146404, 73.61087799.

Error(approx,actual), $h = 1.25$, percentages 0.0, 0.3774032814e-6, 0.5558576368e-6, 0.5770069933e-6, 0.3310277981e-6, 0.1358494868e-6.

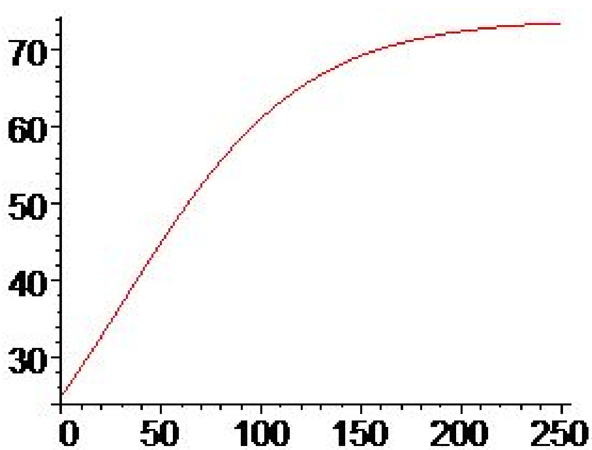
Part II. Assume the given symbolic solution is correct. Don't repeat details already done in ER-2. Test the answers against the symbolic solution, as suggested in the table above.

Symbolic Solution Check.

The RK4 answer and the symbolic answer **agree to six digits**.

Part III. Include an appendix of the computer code used.

```
# Now for the RK4 code to make the dot table, error percentages and plot.
  # RK4. Group 1, initialize.
   f:=(x,y)->0.02225 *y - 0.0003*y^2;
   x0:=0:y0:=25:Dots:=[x0,y0]:n:=100:h:=250/n:
  # Group 2, repeat n times. RK4 method.
 for i from 1 to n do
  k1:=h*f(x0,y0):
  k2:=h*f(x0+h/2,y0+k1/2):
  k3:=h*f(x0+h/2,y0+k2/2):
  k4:=h*f(x0+h,y0+k3):
  Y:=y0+(k1+2*k2+2*k3+k4)/6:
  x0:=x0+h:y0:=Y:Dots:=Dots,[evalf(x0),evalf(y0)];
 od:
  # Group 3, display relevant dots and plot.
   Exact:=x->2225/(30+59*exp(-89 *x/4000));
   P:=unapply(evalf(100*abs(exact-approx)/abs(exact)),(exact,approx)):
   m:=n/5:X:=[seq(1+m*j,j=0..n/m)]: # List of relevant indices
   print("Dots"),seq(Dots[k],k=X);
   print("Exact"),seq(Exact(Dots[k][1]),k=X);
   print("Error"),seq(P(Exact(Dots[k][1]),Dots[k][2]),k=X);
   plot([Dots]);
### The output from this program:
                                "Dots"
  [0, 25], [50., 45.04465322], [100., 61.16674048],
        [150., 69.32324952], [200., 72.50146380], [250., 73.61087789]
                               "Exact"
 25, 45.04465339, 61.16674082, 69.32324992, 72.50146404, 73.61087799
                               "Error"
0.0, .3774032814e-6, .5558576368e-6, .5770069933e-6, .3310277981e-6, .1358494868e-6
```



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End of Sample Maple Lab: Numerical Methods.

```
# Warning: These snips of code made for y'=1-x-y, y(0)=3.
#          Code computes approx values for y(0.1) to y(1).
# 'Dots' is the list of dots for connect-the-dots graphics.
# =========================================
# Euler. Group 1, initialize.
 f:=(x,y)->1-x-y:
 x0:=0:y0:=3:h:=0.1:Dots:=[x0,y0]:n:=200:
# Group 2, repeat n times. Euler's method
for i from 1 to n do
 Y:=y0+h*f(x0,y0);
 x0:=x0+h:y0:=Y:Dots:=Dots,[x0,y0];
od:
# Group 3, display relevant dots and plot.
 Exact:=x->2-x+exp(-x);
 P:=unapply(evalf(100*abs(exact-approx)/abs(exact)),(exact,approx)):
 m:=40:X:=[seq(1+m*j,j=0..n/m)]: # List of relevant indices
 print("Dots"),seq(Dots[k],k=X);
 print("Exact"),seq(Exact(Dots[k][1]),k=X);
 print("Error"),seq(P(Exact(Dots[k][1]),Dots[k][2]),k=X);
 plot([Dots]);
# =========================================
# Heun. Group 1, initialize.
 f:=(x,y)->1-x-y:
 x0:=0:y0:=3:h:=0.1:Dots:=[x0,y0]:n:=200:
# Group 2, repeat n times. Heun method.
for i from 1 to n do
 Y1:=y0+h*f(x0,y0);
 Y:=y0+h*(f(x0,y0)+f(x0+h,Y1))/2:
 x0:=x0+h:y0:=Y:Dots:=Dots,[x0,y0];
od:
# Group 3, display relevant dots and plot.
 Dots[1],Dots[2],seq(Dots[1+40*j],j=1..n/40);
 plot([Dots]);

# =========================================
# RK4. Group 1, initialize.
 f:=(x,y)->1-x-y:
 x0:=0:y0:=3:h:=0.1:Dots:=[x0,y0]:n:=100:
# Group 2, repeat n times. RK4 method.
for i from 1 to n do
 k1:=h*f(x0,y0):
 k2:=h*f(x0+h/2,y0+k1/2):
 k3:=h*f(x0+h/2,y0+k2/2):
 k4:=h*f(x0+h,y0+k3):
 Y:=y0+(k1+2*k2+2*k3+k4)/6:
 x0:=x0+h:y0:=Y:Dots:=Dots,[x0,y0];
od:
# Group 3, display some dots and plot.
 Dots[1],Dots[2],Dots[101];
 plot([Dots]);
```