```
//  file: integ_test.cpp
//
//  This is a test program for basic integration methods.
//
//  Programmer:  Dick Furnstahl  furnstahl.1@osu.edu
//
//  Revision history:
//       04-Jan-2004  original version, for 780.20 Computational Physics
//       08-Jan-2005  changed functions to pass integrand
//       09-Jan-2011  updated functions
//
//  Notes:
//   * define with floats to emphasize round-off error
//   * compile with:  "g++ -Wall -c integ_test.cpp"
//   * adapted from: "Projects in Computational Physics" by Landau and Paez
//              copyrighted by John Wiley and Sons, New York
//              code copyrighted by RH Landau
//
//*****************************************************************

// include files
#include <iostream>
#include <iomanip>
#include <fstream>
#include <cmath>
using namespace std;

#include "integ_routines.h"           // prototypes for integration routines

float my_integrand (float x);

const double ME = 2.718281828459045235 4E0;      // Euler's number

//*****************************************************************

int
main ()
{
  // set up the integration specifiction
  const int max_intervals = 501;        // maximum number of intervals
  const float lower = 0.0;      // lower limit of integration
  const float upper = 1.0;      // upper limit of integration

  const double answer = 1. - 1. / ME;   // the "exact" answer for the test
  float result = 0.;  // approximate answer

  // open the output file stream
  ofstream integ_out ("integ.dat");         // save data in integ.dat
  integ_out << "# N  trapezoid    Simpsons    Gauss " << endl;
  integ_out << "#-------------------------------------" << endl;

  // Simpson's rule requires an odd number of intervals
  for (int i = 3; i <= max_intervals; i += 2)
  {
    integ_out << setw(4) << i;

    result = trapezoid_rule (i, lower, upper, &my_integrand);
    integ_out << " " << scientific << fabs (result - answer);

    result = simpsons_rule (i, lower, upper, &my_integrand);
    integ_out << " " << scientific << fabs (result - answer);

    result = gauss_quadrature (i, lower, upper, &my_integrand);
    integ_out << " " << scientific << fabs (result - answer);

    integ_out << endl;
  }

  cout << "data stored in integ.dat\n";
```



```
  integ_out.close ();

  return (0);
}

//*****************************************************************

// the function we want to integrate
float
my_integrand (float x)
{
  return (exp (-x));
}
```

```
//  file: integ_routines.cpp
//
//  These are routines for trapezoid, Simpson and Gauss rules
//
//  Programmer:  Dick Furnstahl  furnstahl.1@osu.edu
//
//  Revision history:
//      04-Jan-2004  original version, for 780.20 Computational Physics
//      08-Jan-2005  function to be integrated now passed, changed names
//      09-Jan-2011  new names and rearranged; fixed old bug
//
//  Notes:
//   * define with floats to emphasize round-off error
//   * compile with:  "g++ -Wall -c integ_routines.cpp" or makefile
//   * adapted from: "Projects in Computational Physics" by Landau and Paez
//              copyrighted by John Wiley and Sons, New York
//              code copyrighted by RH Landau
//   * equation for interval h = (b-a)/(N-1) with x_min=a and x_max=b
//
//*****************************************************************

// include files
#include <cmath>
#include "integ_routines.h"    // integration routine prototypes

//*****************************************************************

// Integration using trapezoid rule
float trapezoid_rule ( int num_pts, float x_min, float x_max,
                       float (*integrand) (float x) )
{
   float interval = ((x_max - x_min)/float(num_pts - 1));  // called h in notes
   float sum=  0.;  // initialize integration sum to zero

   for (int n=2; n<num_pts; n++)          // sum the midpoint contributions
   {
     float x = x_min + interval * float(n-1);
     sum += interval * integrand(x);
   }
   // add in the endpoint contributions
   sum +=  (interval/2.) * (integrand(x_min) + integrand(x_max));

   return (sum);
}

//*****************************************************************

// Integration using Simpson's rule
float simpsons_rule ( int num_pts, float x_min, float x_max,
                      float (*integrand) (float x) )
{
   float interval = ((x_max - x_min)/float(num_pts - 1));  // called h in notes
   float sum=  0.;  // initialize integration sum to zero

   for (int n=2; n<num_pts; n+=2)                // loop for odd points
   {
     float x = x_min + interval * float(n-1);
     sum += (4./3.)*interval * integrand(x);
   }
   for (int n=3; n<num_pts; n+=2)                // loop for even points
   {
     float x = x_min + interval * float(n-1);
     sum += (2./3.)*interval * integrand(x);
   }
   // add in the endpoint contributions
   sum +=  (interval/3.) * (integrand(x_min) + integrand(x_max));

   return (sum);
```



```
//*****************************************************************

// Integration using Gauss quadrature rule
float gauss_quadrature ( int num_pts, float x_min, float x_max,
                         float (*integrand) (float x) )
{
   float quadra = 0.;
   double weight[1000], x[1000];             // for points and weights

   gauss (num_pts, 0, x_min, x_max, x, weight);      // returns Legendre
                                                     //  points and weights
   for (int n=0; n< num_pts; n++)
   {
      quadra += integrand(x[n])*weight[n];      // calculating the integral
   }
   return (quadra);
}
```