

# Numerical Integration: Simpson's Rule and Newton-Cotes Formulas

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## Overview

As we have learned in Calculus I, there are two ways to evaluate a definite integral: using the Fundamental Theorem of calculus or numerical approximations. While FTC is nice in theory, it cannot be applied in many cases, as antiderivatives are often difficult or even impossible to find. Using computers, numerical integration is the most general and practical way to evaluate definite integrals. In Calculus I, we explored Riemann Sum approximations. In this lab, we will use Maple to experience some new approximations that provide more accuracy with less computation.

## Maple Essentials

The *Approximate Integrals* tutor can be started from maple's Tools menu:

**Tools** → **Tutors** → **Calculus - Single Variable** → **Approximate Integrals ...**

**Note:** *The Approximate Integrals tutor is identical to the Riemann Sums tutor.*

## Related course material/Preparation

Recall that §8.7 of the textbook introduced the trapezoidal approximation as the average of the Riemann left endpoint approximation and the Riemann right endpoint approximation. Similarly, Simpson's rule is introduced there as a weighted average of the Riemann midpoint approximation and the trapezoidal approximation. Geometrically, the trapezoidal approximation and Simpson's rule use a line and a parabola (polynomials of degree 1 and 2), respectively, to approximate  $y = f(x)$  in each subinterval. In the trapezoidal approximation, the line is determined by the left and right endpoints of the curve in each subinterval. To determine a parabola, you need three points. Therefore, the left and right endpoints and the midpoint of the curve in each subinterval are used in Simpson's rule. In this point of view, the above two approximations are special cases (order 1 and order 2) of the general Newton-Cotes formula of order  $k$ , where a polynomial of degree  $k$  determined by  $k + 1$  points on  $y = f(x)$  is used to approximate the function  $y = f(x)$  in each subinterval. Using Maple, we can experience and compare all those approximations with plots, animations, formulas, and more.

## Notation

You should be careful about the value  $n$ , the number of subintervals. Recall that the notation used in Section 8.7 of the textbook for the Simpson's Rule approximation is  $S_{2n}$ . This means that if we want to find  $S_{10}$ , we would input  $n = 5$  since there are 5 subintervals and  $2n = 10$ . We will choose **Subintervals** in the **Approximate Integrals** tutor so that Maple 10 will use the same notation as what is used by the textbook.

## Activities

Use the **Approximate Integrals** tutor to approximate the following integrals by

a) the trapezoidal approximation, b) Simpson's rule, c) another method of your choice.

Start with a small number of subintervals, say  $n = 3$ , so you can see the geometry. Gradually increase  $n$  and describe what happens to your approximation. In each case, what is the smallest  $n$  needed such that the absolute error is less than 0.0001? How do different methods compare with each other?

$$1) \int_0^{\pi} \sin x \, dx \quad 2) \int_0^1 e^{-x^2} \, dx \quad 3) \int_1^2 \sqrt{x^3 - 1} \, dx \quad 4) \int_0^2 \sin(x^2) \, dx \quad 5) \int_1^3 \sqrt{\ln x} \, dx$$

**Note:** These integrals appear on pages 566-567 of the textbook.

*Example: Integral 1*

1. Launch the *Approximate Integrals* tutor from maple's Tools menu.
2. Choose **Subintervals** in the **Partition** type box
3. Plug in  $f(x) = \sin(x)$ ,  $a = 0$ ,  $b = \text{Pi}$ , and  $n = 3$ .
4. Choose your method, say Simpson's rule, and click **Display**. How close is the approximation (the blue graph) to the original curve (the red one)?
5. You should see that the **Approximate Integral** = 2.000863190 and the **Actual Integral** = 2. Therefore, the absolute error is 0.000863190.
6. Gradually increase  $n$  and click on **Display** each time. You should see that  $n = 6$  is the smallest number of subintervals needed to have the required accuracy (the absolute error=0.000052625). This is very nice as you need to have about  $n = 180$  subintervals in order to have the same accuracy using Riemann Sum approximations.
7. Choose a method and a small value, say  $n = 2$ , and click on **Animate**.
8. Repeat the above for other methods.
9. Choose a value, say  $n = 10$ , and click on **Compare** to see all approximations at once and compare. (Don't forget to choose **Subintervals** in the new window, too.)
10. Before exit from the tutor and start the next activity, copy the command from **Maple Command** box on the bottom (use Ctrl+C) so you do not have to type as much or to remember the long command.

*Working with maple command:*

- Start by including the `Student[Calculus1]` package.  
`>with(Student[Calculus1]):`
- Paste the command copied from the tutor and click on the plot generated to bring up the animation tool-bar.  
`>ApproximateInt(sin(x), 0..Pi, 'partition' = 2, 'method' = trapezoid, 'iterations' = 6, 'output' = 'animation', 'showarea' = false);`
- Delete the last option `'showarea' = false` and play the animation again.  
`>ApproximateInt(sin(x), 0..Pi, 'partition' = 2, 'method' = trapezoid, 'iterations' = 6, 'output' = 'animation');`
- To see the formula for your approximation, change `'output'` option from `'animation'` to `sum` and name it as, say `Approx`. You may delete the option `'iteration'=6` since it is only needed for animations.  
`>Approx:=ApproximateInt(sin(x), 0..Pi, 'partition' = 2, 'method' = trapezoid, 'iterations' = 6, 'output' = sum);`
- Find the absolute error associated with this approximation.  
`>Err:=evalf(abs(int(sin(x), x=0..Pi) - Approx));`
- To see the formula in general form for  $k$  subintervals, change `'partition'` option from `=2` to `=k`.  
`>Approx:=ApproximateInt(sin(x), 0..Pi, 'partition' = k, 'method' = trapezoid, 'iterations' = 6, 'output' = sum);`
- Find the limit of the above formula, which should be equal to the actual value of the integral.  
`>limit(Approx, k=infinity);`  
 Note: The limit of some infinite sums can be very hard to find (even for Maple).
- You may want to refer to the help menu and try other fun examples with the command.

*Assignment*

Finish lab activities and do exercises 2, 4, and 5 on page 566 of the textbook.