

# Measuring Errors

Major: All Engineering Majors

Authors: Autar Kaw, Luke Snyder

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Transforming Numerical Methods Education for STEM  
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# Measuring Errors

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# Why measure errors?

- 1) To determine the accuracy of numerical results.
- 2) To develop stopping criteria for iterative algorithms.

# True Error

- Defined as the difference between the true value in a calculation and the approximate value found using a numerical method etc.

True Error = True Value – Approximate Value

# Example—True Error

The derivative,  $f'(x)$  of a function  $f(x)$  can be approximated by the equation,

$$f'(x) \approx \frac{f(x+h) - f(x)}{h}$$

If  $f(x) = 7e^{0.5x}$  and  $h = 0.3$

- a) Find the approximate value of  $f'(2)$
- b) True value of  $f'(2)$
- c) True error for part (a)

# Example (cont.)

Solution:

a) For  $x = 2$  and  $h = 0.3$

$$\begin{aligned} f'(2) &\approx \frac{f(2+0.3) - f(2)}{0.3} \\ &= \frac{f(2.3) - f(2)}{0.3} \\ &= \frac{7e^{0.5(2.3)} - 7e^{0.5(2)}}{0.3} \\ &= \frac{22.107 - 19.028}{0.3} = 10.263 \end{aligned}$$

# Example (cont.)

Solution:

b) The exact value of  $f'(2)$  can be found by using our knowledge of differential calculus.

$$\begin{aligned}f(x) &= 7e^{0.5x} \\f'(x) &= 7 \times 0.5 \times e^{0.5x} \\&= 3.5e^{0.5x}\end{aligned}$$

So the true value of  $f'(2)$  is

$$\begin{aligned}f'(2) &= 3.5e^{0.5(2)} \\&= 9.5140\end{aligned}$$

True error is calculated as

$$\begin{aligned}E_t &= \text{True Value} - \text{Approximate Value} \\&= 9.5140 - 10.263 = -0.722\end{aligned}$$

# Relative True Error

- Defined as the ratio between the true error, and the true value.

$$\text{Relative True Error ( } \epsilon_t \text{ )} = \frac{\text{True Error}}{\text{True Value}}$$



# Example—Relative True Error

Following from the previous example for true error, find the relative true error for  $f(x) = 7e^{0.5x}$  at  $f'(2)$  with  $h = 0.3$

From the previous example,

$$E_t = -0.722$$

Relative True Error is defined as

$$\begin{aligned}\epsilon_t &= \frac{\text{True Error}}{\text{True Value}} \\ &= \frac{-0.722}{9.5140} = -0.075888\end{aligned}$$

as a percentage,

$$\epsilon_t = -0.075888 \times 100\% = -7.5888\%$$

# Approximate Error

- What can be done if true values are not known or are very difficult to obtain?
- Approximate error is defined as the difference between the present approximation and the previous approximation.

Approximate Error ( $E_a$ ) = Present Approximation – Previous Approximation

# Example—Approximate Error

For  $f(x) = 7e^{0.5x}$  at  $x = 2$  find the following,

a)  $f'(2)$  using  $h = 0.3$

b)  $f'(2)$  using  $h = 0.15$

c) approximate error for the value of  $f'(2)$  for part b)

Solution:

a) For  $x = 2$  and  $h = 0.3$

$$f'(x) \approx \frac{f(x+h) - f(x)}{h}$$

$$f'(2) \approx \frac{f(2+0.3) - f(2)}{0.3}$$

# Example (cont.)

Solution: (cont.)

$$\begin{aligned} &= \frac{f(2.3) - f(2)}{0.3} \\ &= \frac{7e^{0.5(2.3)} - 7e^{0.5(2)}}{0.3} \\ &= \frac{22.107 - 19.028}{0.3} = 10.263 \end{aligned}$$

b) For  $x = 2$  and  $h = 0.15$

$$\begin{aligned} f'(2) &\approx \frac{f(2 + 0.15) - f(2)}{0.15} \\ &= \frac{f(2.15) - f(2)}{0.15} \end{aligned}$$

# Example (cont.)

Solution: (cont.)

$$\begin{aligned} &= \frac{7e^{0.5(2.15)} - 7e^{0.5(2)}}{0.15} \\ &= \frac{20.50 - 19.028}{0.15} = 9.8800 \end{aligned}$$

c) So the approximate error,  $E_a$  is

$$\begin{aligned} E_a &= \text{Present Approximation} - \text{Previous Approximation} \\ &= 9.8800 - 10.263 \\ &= -0.38300 \end{aligned}$$

# Relative Approximate Error

- Defined as the ratio between the approximate error and the present approximation.

$$\text{Relative Approximate Error } (\epsilon_a) = \frac{\text{Approximate Error}}{\text{Present Approximation}}$$

## Example—Relative Approximate Error

For  $f(x) = 7e^{0.5x}$  at  $x = 2$ , find the relative approximate error using values from  $h = 0.3$  and  $h = 0.15$

Solution:

From Example 3, the approximate value of  $f'(2) = 10.263$  using  $h = 0.3$  and  $f'(2) = 9.8800$  using  $h = 0.15$

$$\begin{aligned} E_a &= \text{Present Approximation} - \text{Previous Approximation} \\ &= 9.8800 - 10.263 \\ &= -0.38300 \end{aligned}$$

# Example (cont.)

Solution: (cont.)

$$\begin{aligned}\epsilon_a &= \frac{\text{Approximate Error}}{\text{Present Approximation}} \\ &= \frac{-0.38300}{9.8800} = -0.038765\end{aligned}$$

as a percentage,

$$\epsilon_a = -0.038765 \times 100\% = -3.8765\%$$

Absolute relative approximate errors may also need to be calculated,

$$|\epsilon_a| = |-0.038765| = 0.038765 \text{ or } 3.8765\%$$



# How is Absolute Relative Error used as a stopping criterion?

If  $|\epsilon_a| \leq \epsilon_s$  where  $\epsilon_s$  is a pre-specified tolerance, then no further iterations are necessary and the process is stopped.

If at least  $m$  significant digits are required to be correct in the final answer, then

$$|\epsilon_a| \leq 0.5 \times 10^{2-m}$$

# Table of Values

For  $f(x) = 7e^{0.5x}$  at  $x = 2$  with varying step size,  $h$

| $h$   | $f'(2)$ | $ \epsilon_a $ | $m$ |
|-------|---------|----------------|-----|
| 0.3   | 10.263  | N/A            | 0   |
| 0.15  | 9.8800  | 0.038765%      | 3   |
| 0.10  | 9.7558  | 0.012731%      | 3   |
| 0.01  | 9.5378  | 0.024953%      | 3   |
| 0.001 | 9.5164  | 0.002248%      | 4   |

# Additional Resources

For all resources on this topic such as digital audiovisual lectures, primers, textbook chapters, multiple-choice tests, worksheets in MATLAB, MATHEMATICA, MathCad and MAPLE, blogs, related physical problems, please visit

[http://numericalmethods.eng.usf.edu/topics/measuring\\_errors.html](http://numericalmethods.eng.usf.edu/topics/measuring_errors.html)

**THE END**

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