

# Local Polynomial Approximation

In numerical analysis, we approximate functions locally using polynomials.

The strategy is:

- ▶ Assume a local polynomial model
- ▶ Determine coefficients by enforcing agreement at a point
- ▶ Use the result to construct numerical methods

This approach underlies finite differences and finite elements.

## Assumed Local Approximation

We assume that near a point  $x_0$ , the function  $f(x)$  can be approximated by

$$f(x) \approx d + a(x - x_0) + b(x - x_0)^2 + c(x - x_0)^3.$$

The coefficients  $a$ ,  $b$ ,  $c$ , and  $d$  are unknown and will be determined by matching derivatives at  $x_0$ .

## Matching the Function Value

Evaluate the approximation at  $x = x_0$ :

$$f(x_0) = d.$$

$$\boxed{d = f(x_0)}$$

The constant term ensures the approximation is exact at the expansion point.

## Matching the First Derivative

Differentiate the approximation:

$$\frac{d}{dx} = a + 2b(x - x_0) + 3c(x - x_0)^2.$$

Evaluating at  $x = x_0$ :

$$f'(x_0) = a.$$

$$a = f'(x_0)$$

## Matching the Second Derivative

Differentiate again:

$$\frac{d^2}{dx^2} = 2b + 6c(x - x_0).$$

Evaluating at  $x = x_0$ :

$$f''(x_0) = 2b.$$

$$b = \frac{1}{2}f''(x_0)$$

## Matching the Third Derivative

Differentiate a third time:

$$\frac{d^3}{dx^3} = 6c.$$

Evaluating at  $x = x_0$ :

$$f^{(3)}(x_0) = 6c.$$

$$c = \frac{1}{6}f^{(3)}(x_0)$$

## Recovered Taylor Expansion

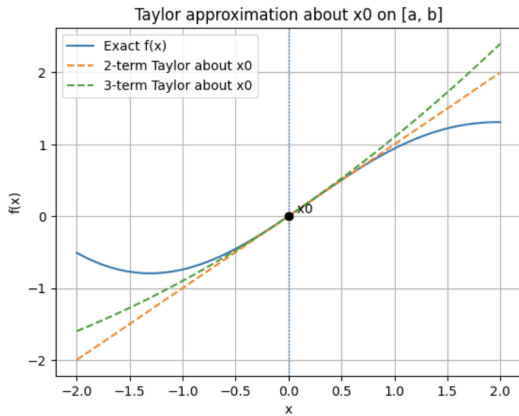
Substituting the coefficients into the approximation:

$$f(x) \approx f(x_0) + f'(x_0)(x - x_0) + \frac{f''(x_0)}{2}(x - x_0)^2 + \frac{f^{(3)}(x_0)}{6}(x - x_0)^3.$$

This is the Taylor expansion of  $f(x)$  about  $x_0$ , truncated after the cubic term.

# Taylor Expansion About the Center of the Interval

$$f(x) = \sin x + \frac{1}{10}x^2$$

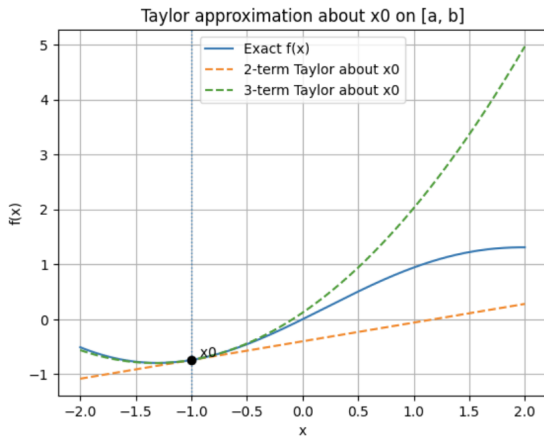


Key Observation



# Taylor Expansion About an Off-Center Point

$$f(x) = \sin x + \frac{1}{10}x^2$$



Key Observation

## Key Takeaways

- ▶ Taylor series are constructed by matching derivatives at a point
- ▶ Each additional term enforces agreement of one higher derivative
- ▶ The constant term ensures exact agreement at the expansion point
- ▶ This construction will be reused to derive finite difference formulas