

# Understanding the Derivative

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## 1 Introduction

Differentiation is a concept of Mathematics studied in Calculus. There is an ongoing discussion as to who was the first to define differentiation: Leibniz or Newton [1].

Differentiation allows for the calculation of the slope of the tangent of a curve at any given point as shown in Figure 1.

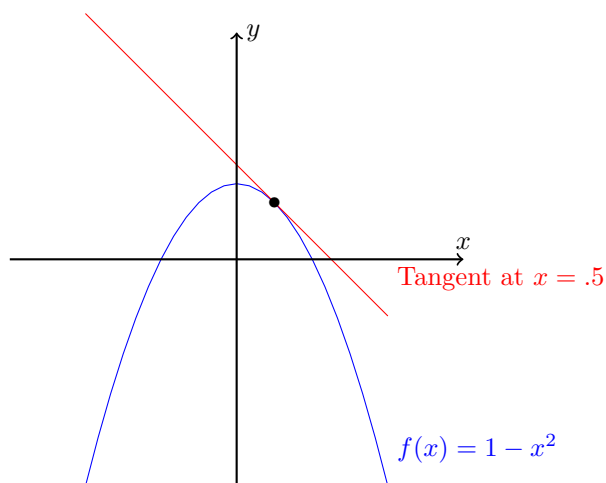


Figure 1: The plot of  $f(x) = 1 - x^2$  with a tangent at  $x = .5$ .

Differentiation is now a technique taught to mathematics students throughout the world. In this document I will discuss some aspects of differentiation.

## 2 Exploring the derivative using Sage

The definition of the limit of  $f(x)$  at  $x = a$  denoted as  $f'(a)$  is:

$$f'(a) = \lim_{h \rightarrow 0} \frac{f(a+h) - f(a)}{h} \quad (1)$$

The following code can be used in sage to give the above limit:

```
def illustrate(f, a):  
    """  
    Function to take a function and illustrate the limiting definition of a derivative at a given point  
    """  
    lst = []
```

```

for h in xrange(.01, 3, .01):
    lst.append([h, (f(a+h)-f(a))/h])
return list_plot(lst, axes_labels=['$x$', '$\\frac{f(.02f+h)-f(.02f)}{h}$' % (a,a)])

```

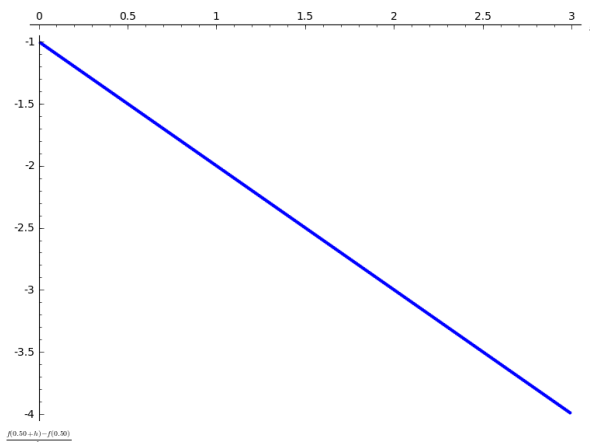


Figure 2: The derivative of  $f(x) = 1 - x^2$  at  $x = .5$  converging to  $-1$  as  $h \rightarrow 0$ .

If we want to plot the tangent at a point  $\alpha$  to a function we can use the following:

$$\begin{array}{ll}
 y = ax + b & \text{(definition of a straight line)} \\
 f'(a)x + b & \text{(definition of the derivative)} \\
 f'(a)x + f(a) - f'(a)a & \text{(we know that the line intersects } f \text{ at } (a, f(a))
 \end{array}$$

We can combine this with the approach of the previous piece of code to see how the tangential line converges as the limiting definition of the derivative converges:

```

def convergetangentialline(f, a, x1, x2, nbrofplots=50, epsilon=.1):
    """
    Function to make a tangential line converge
    """
    clr = rainbow(nbrofplots)
    k = 0
    h = epsilon
    p = plot(f, x, x1, x2)
    while k < nbrofplots:
        tangent(x) = fdash(f, a, h) * x + f(a) - fdash(f, a, h) * a
        p += plot(tangent(x), x, x1, x2, color=clr[k])
        h += epsilon
        k += 1
    return p

```

The plot shown in Figure 3 shows how the lines shown converge to the actual tangent to  $1 - x^2$  as  $x = 2$  (the red line is the 'closest' curve).

Note here that the last plot is given using the **real** definition of the derivative and not the approximation.

### 3 Conclusions

In this report I have explored the limiting definition of the limit showing how as  $h \rightarrow 0$  we can visualise the derivative of a function. The code involved <https://sage.maths.cf.ac.uk/home/pub/18/> uses the

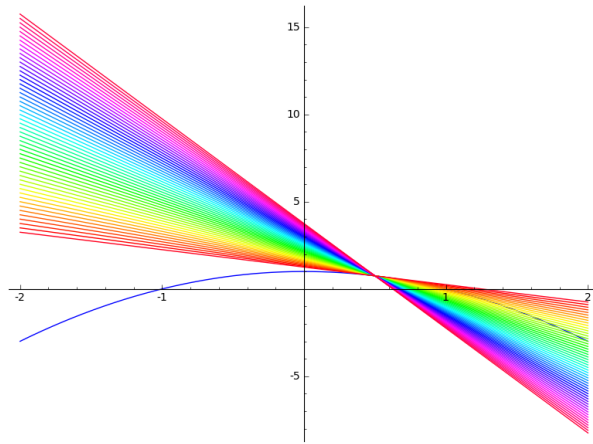


Figure 3: Lines converging to the tangent curve as  $h \rightarrow 0$ .

differentiation capabilities of Sage but also the plotting abilities.

There are various other aspects that could be explored such as symbolic differentiation rules. For example:

$$\frac{dx^n}{dx} = (n+1)x^n \text{ if } x \neq -1$$

Furthermore it is interesting to note that there exists some functions that **are not** differentiable at a point such as the function  $f(x) = \sin(1/x)$  which is not differentiable at  $x = 0$ . A plot of this function is shown in Figure 4.

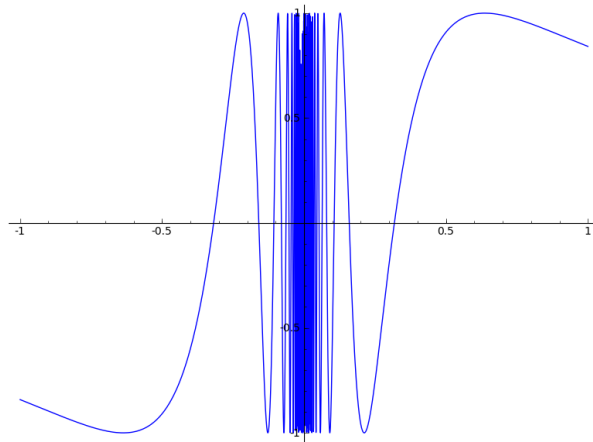


Figure 4: None differentiable function at  $x = 0$ .

## References

- [1] Jason Socrates Bardi. The calculus wars: Newton. *Leibniz, and the Greatest Mathematical Clash of All Time* (Thunder Mouth, New York, 2006), 2006.