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DeepLearning.AI

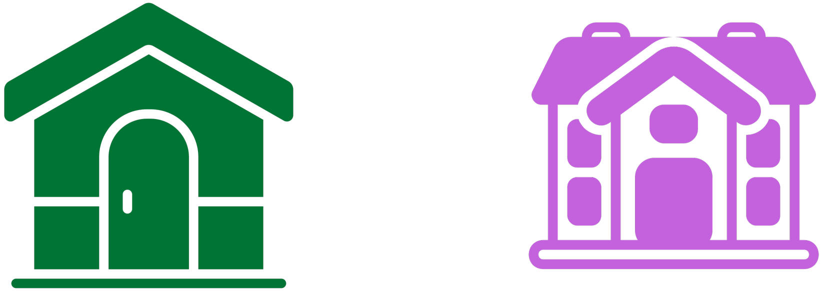
Derivatives and Optimization

Machine learning motivation

Machine Learning Motivation

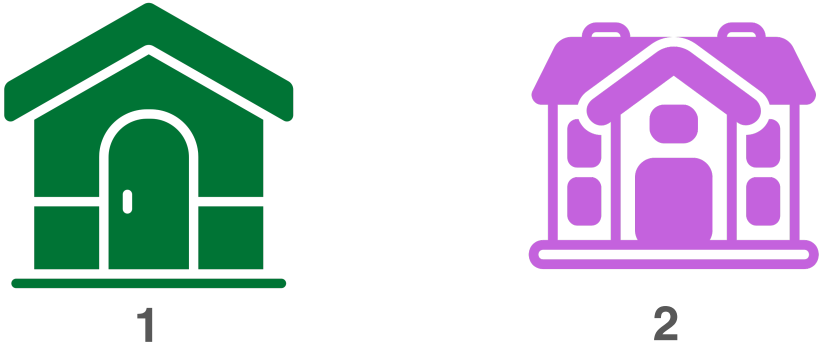
Machine Learning Motivation

Machine Learning Motivation



Number of Bedrooms

Machine Learning Motivation



Number of Bedrooms

Machine Learning Motivation

1

$150,000

2

$250,000

Number of Bedrooms

Machine Learning Motivation

Predict the price of a house using the number of bedrooms it has

1

$150,000

2

$250,000

Number of Bedrooms

Machine Learning Motivation

Predict the price of a house using the number of bedrooms it has

Machine Learning Motivation

Predict the price of a house using the number of bedrooms it has

Number of Bedrooms
1
2
3
5
6
7
8
9
10

Machine Learning Motivation

Predict the price of a house using the number of bedrooms it has

Number of Bedrooms	Price of House
1	$150,000
2	$250,000
3	$350,000
5	$600,000
6	$650,000
7	$750,000
8	$800,000
9	??
10	$1,050,000

Machine Learning Motivation

Predict the price of a house using the number of bedrooms it has

Number of Bedrooms	Price of House
1	$150,000
2	$250,000
3	$350,000
5	$600,000
6	$650,000
7	$750,000
8	$800,000
9	??
10	$1,050,000

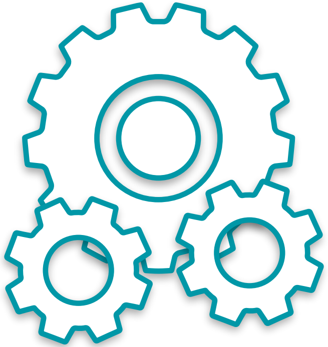
9 ???

Machine Learning Motivation

Predict the price of a house using the number of bedrooms it has

9 ???

Number of Bedrooms	Price of House
1	$150,000
2	$250,000
3	$350,000
5	$600,000
6	$650,000
7	$750,000
8	$800,000
9	??
10	$1,050,000



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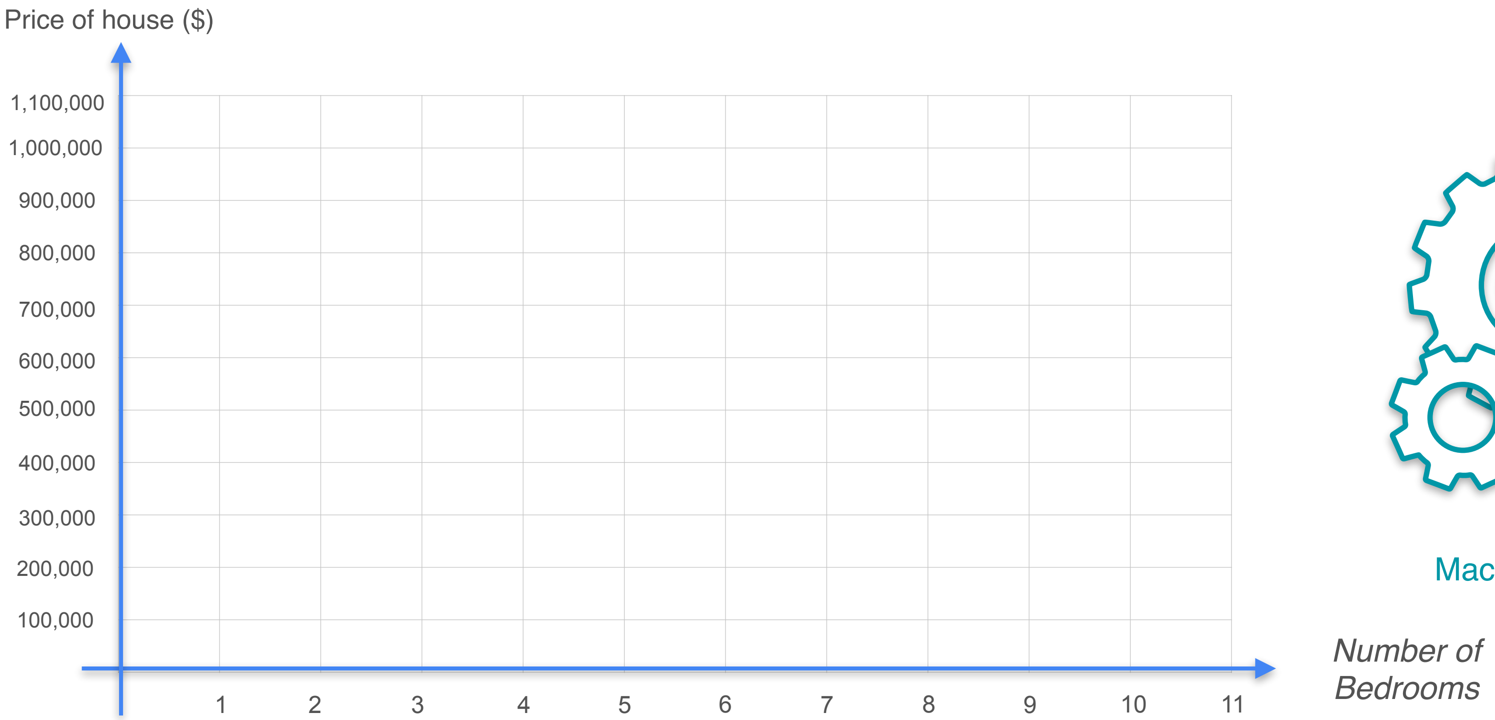
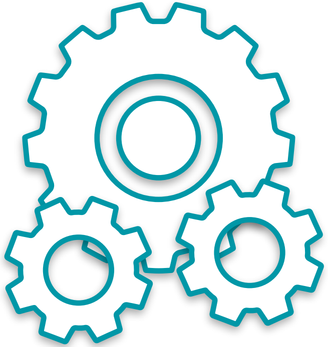
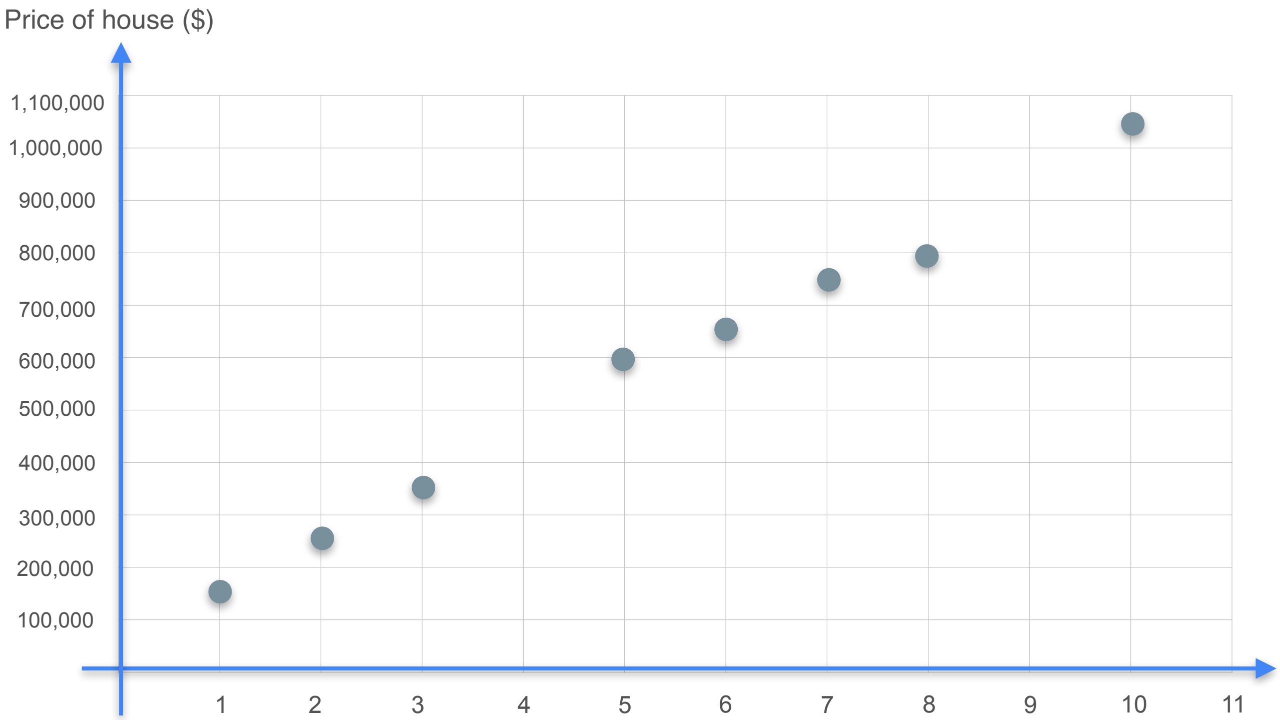


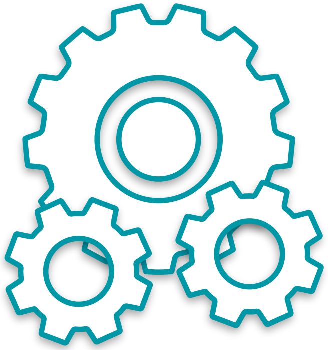


Machine Learning Model

Machine Learning Motivation

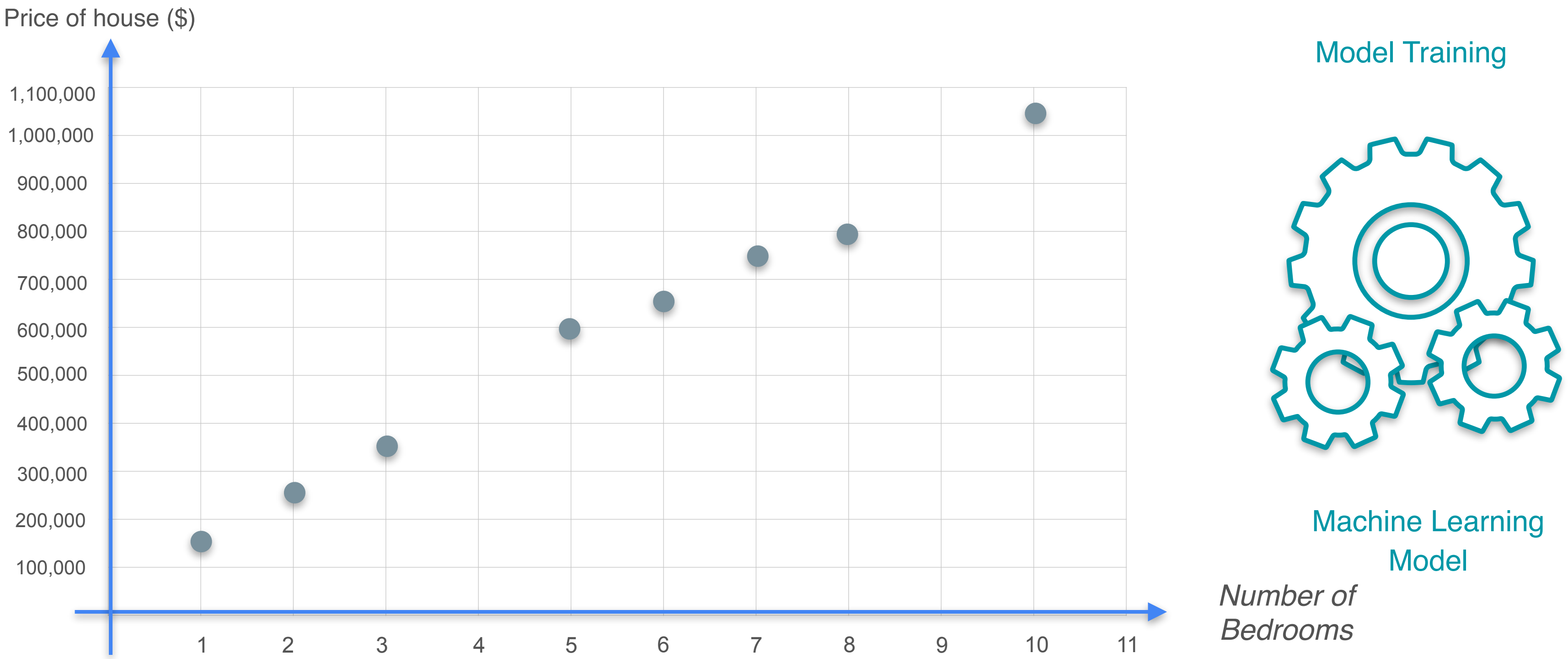


Number of Bedrooms



Machine Learning Model

Machine Learning Motivation



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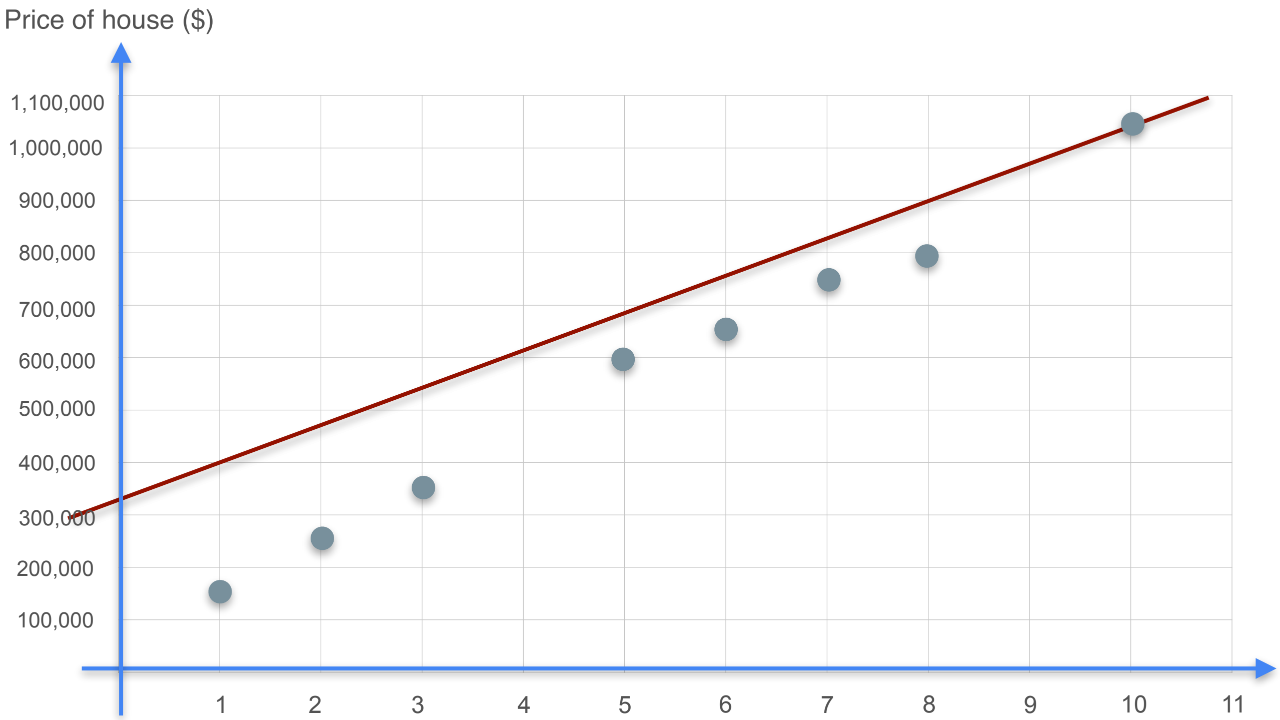
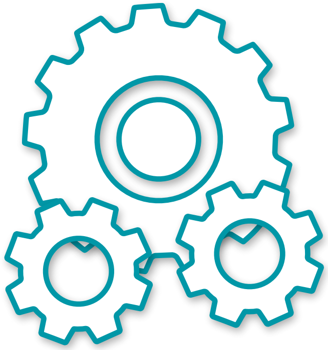


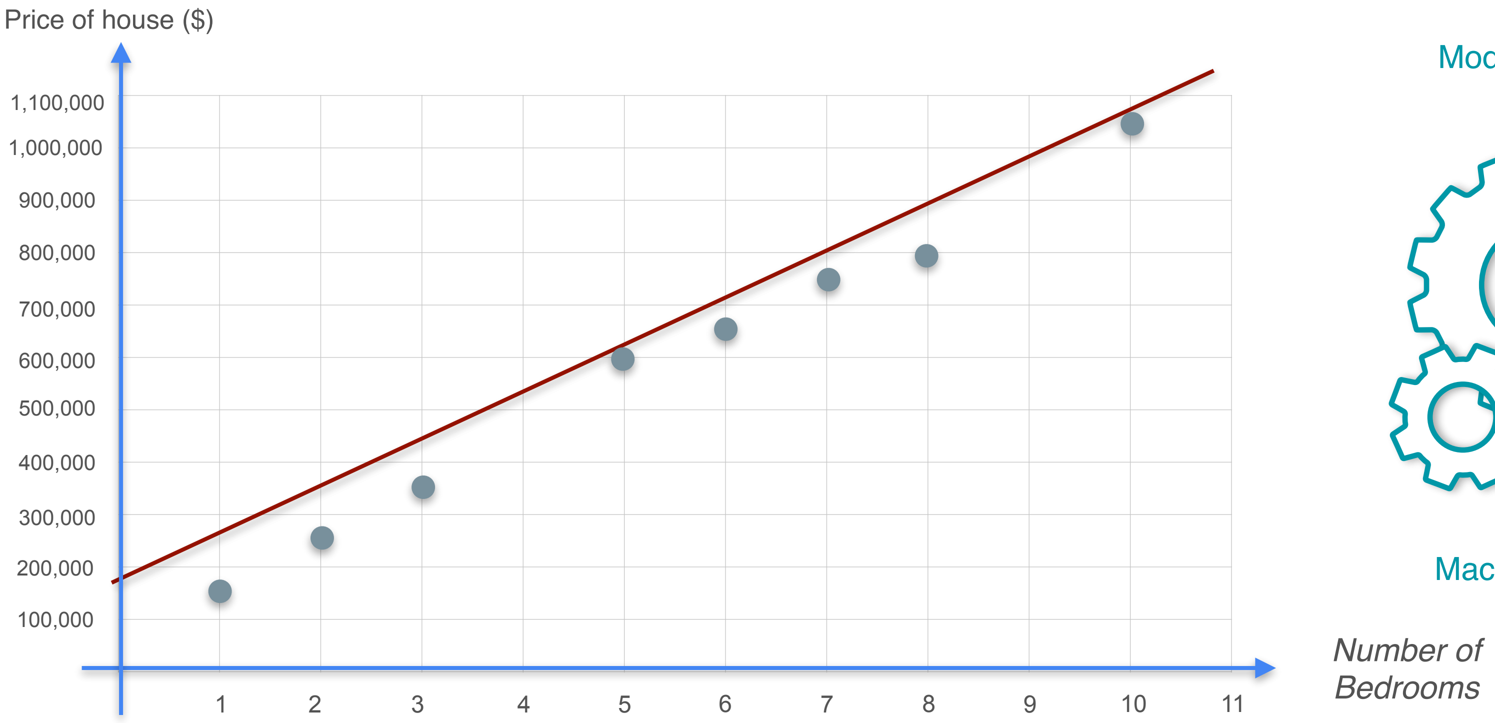
Model Training



Machine Learning Model

Number of Bedrooms

Machine Learning Motivation



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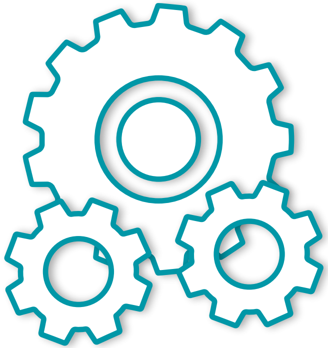
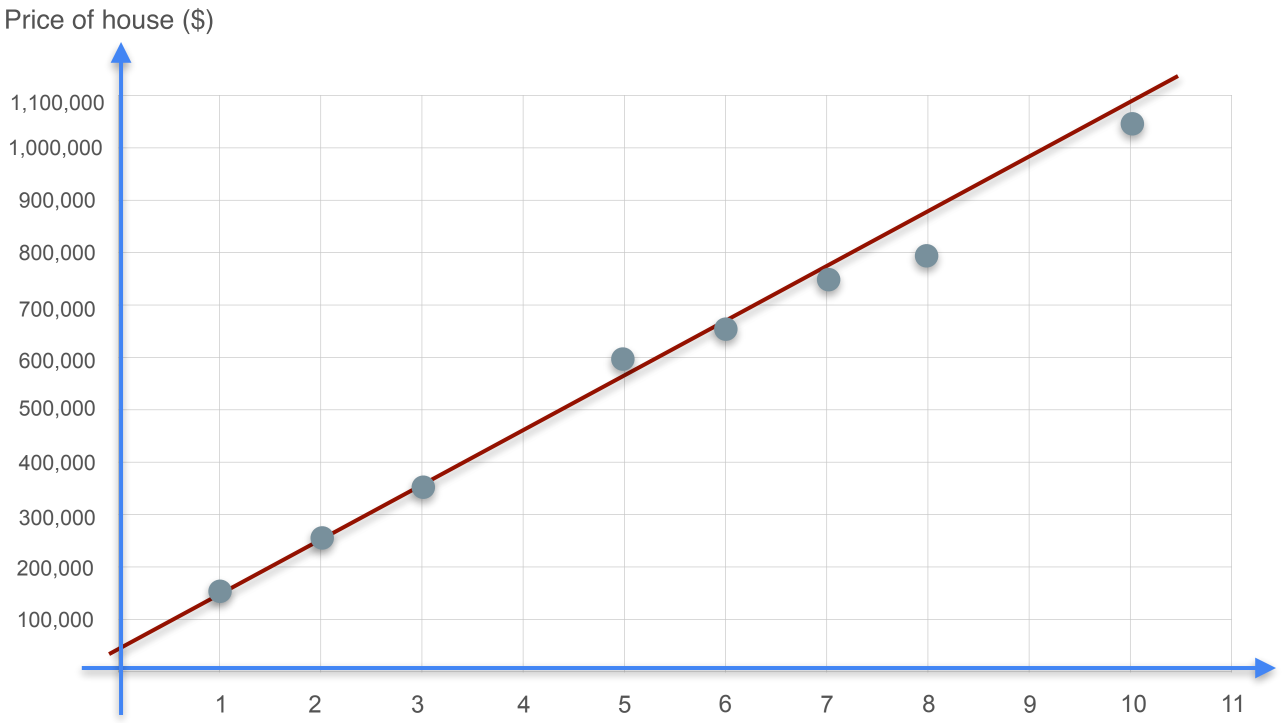
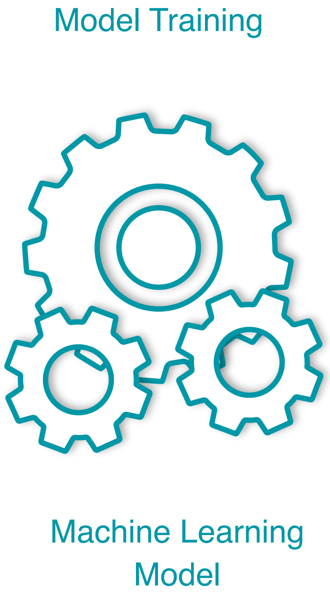


Machine Learning Model

Machine Learning Motivation





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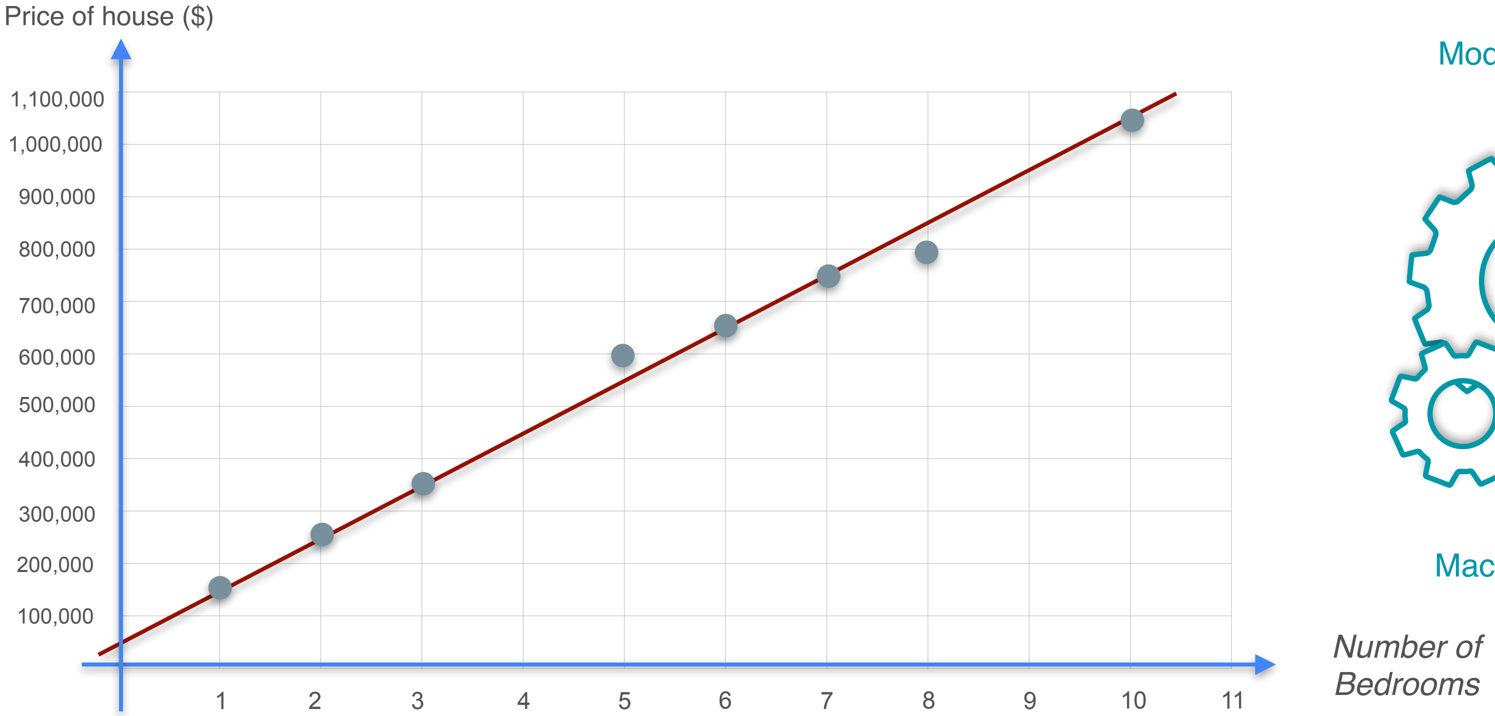

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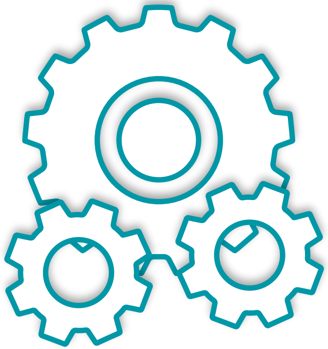

Machine Learning Model

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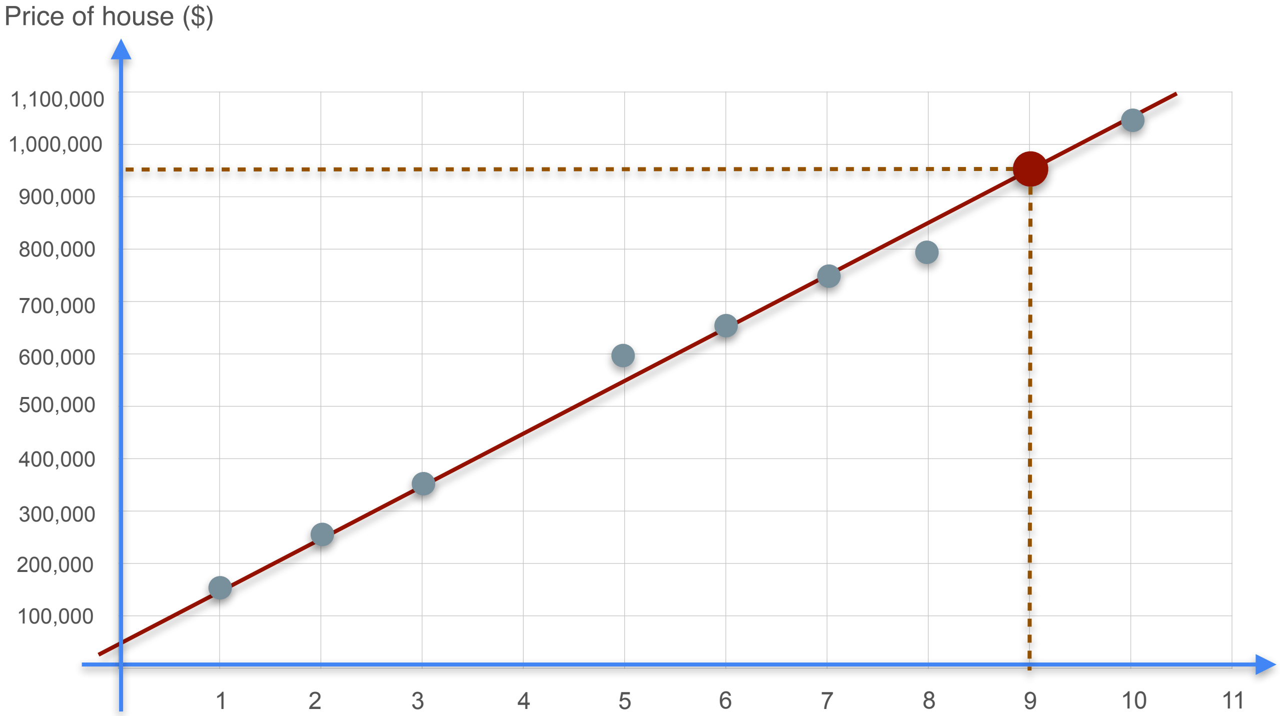

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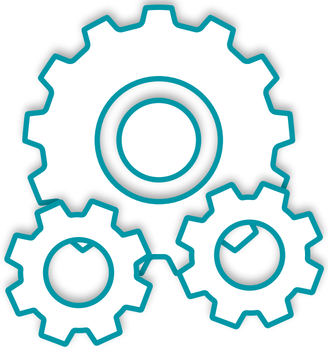
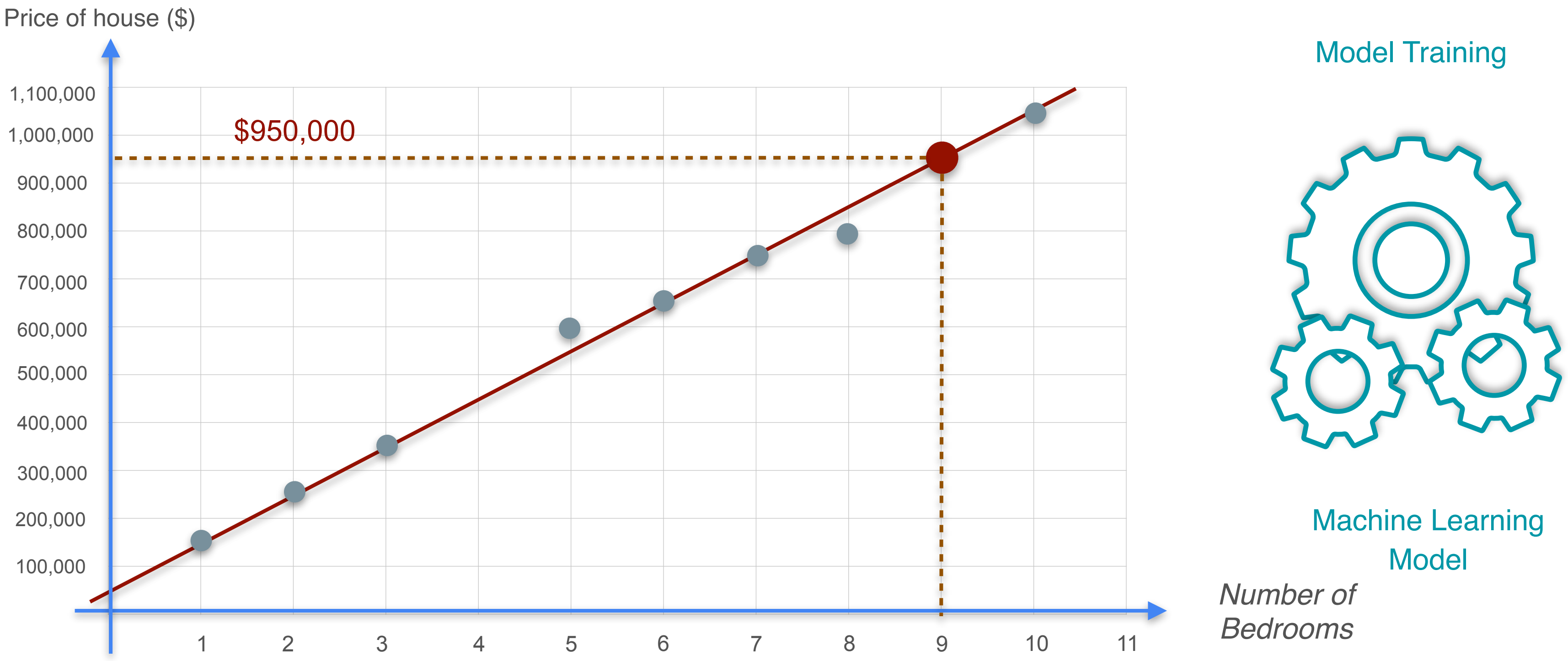


Machine Learning Model

Number of Bedrooms

Machine Learning Motivation



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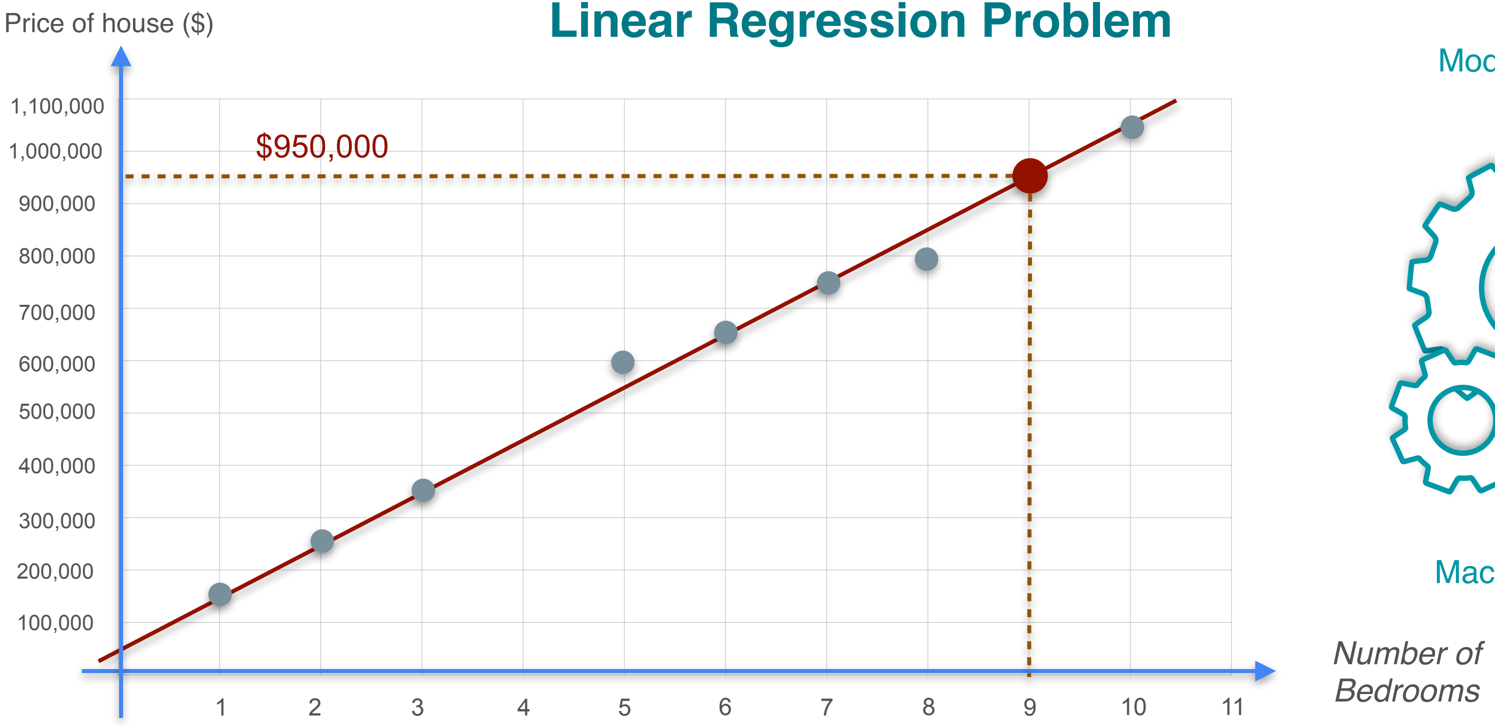
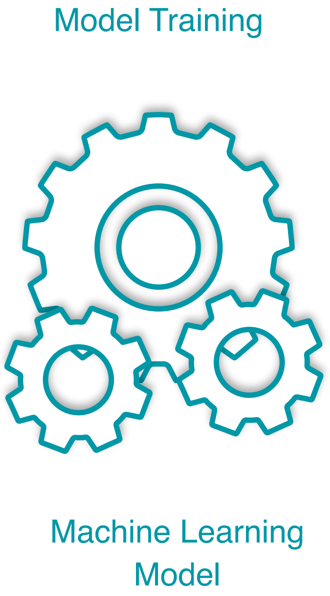
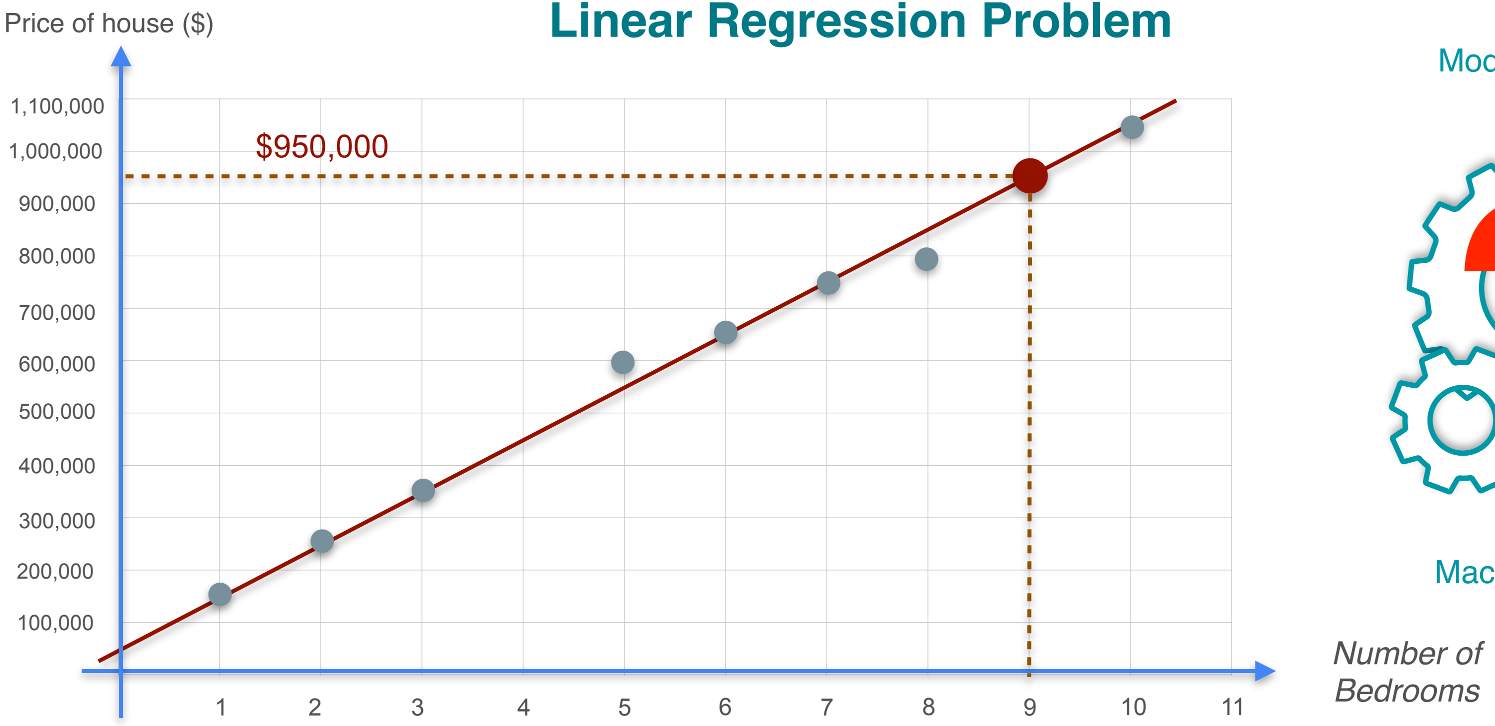


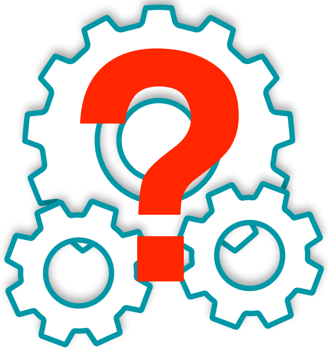


Machine Learning Motivation

Linear Regression Problem

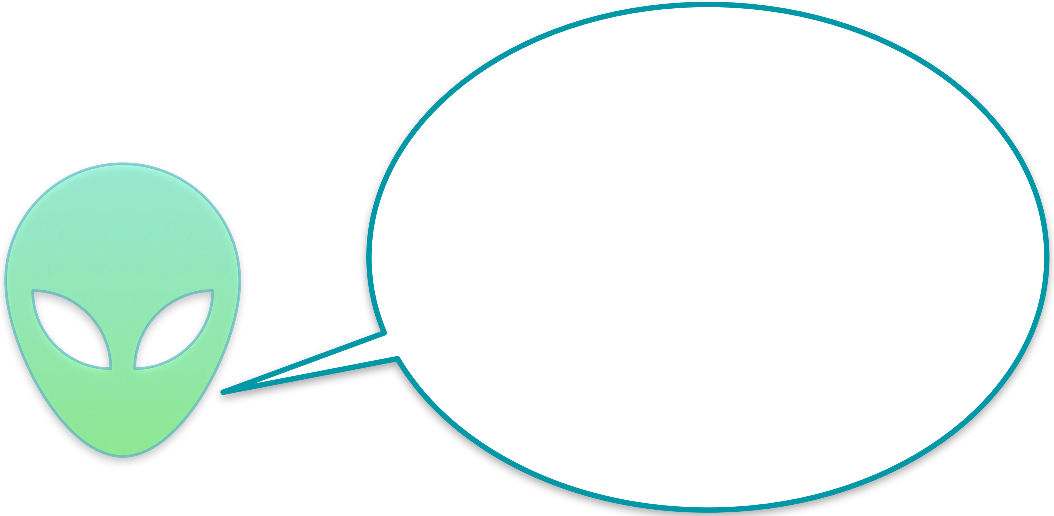


Model Training



Machine Learning Model

Machine Learning Motivation



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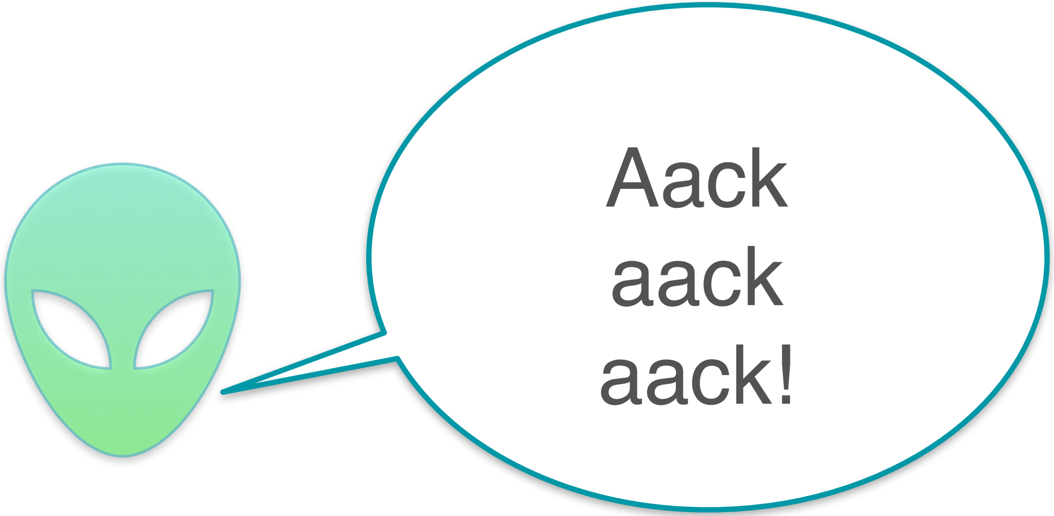

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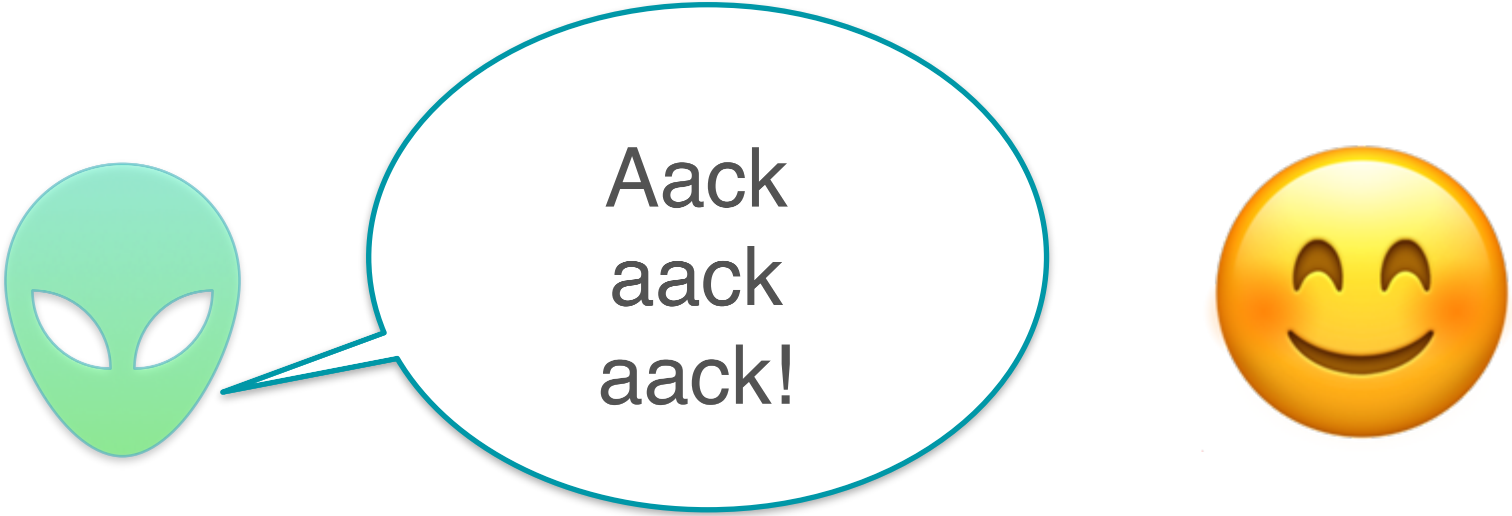

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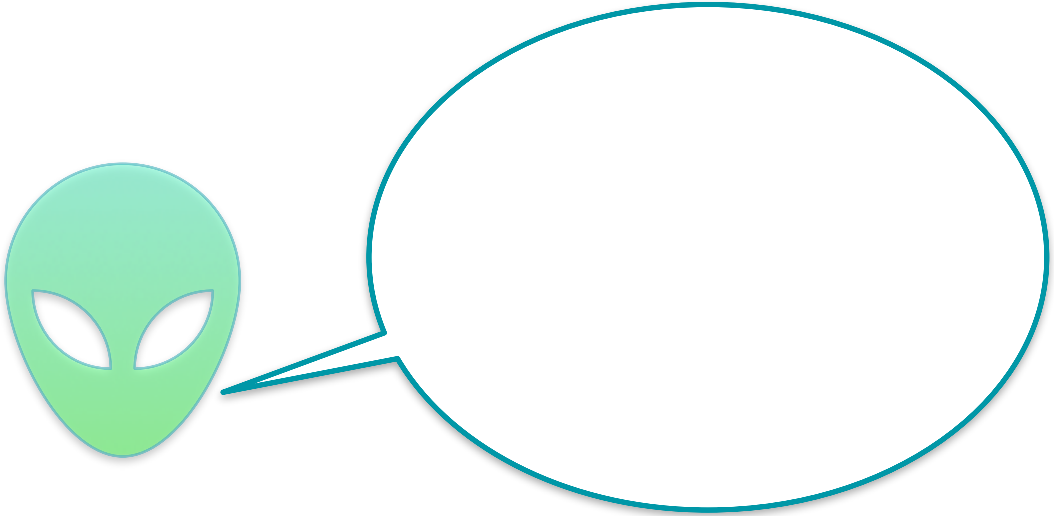

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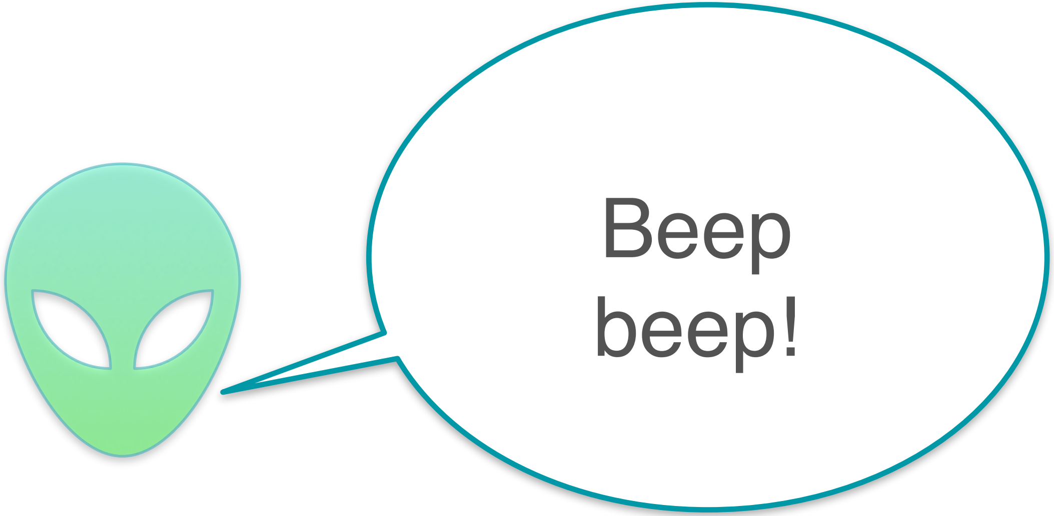

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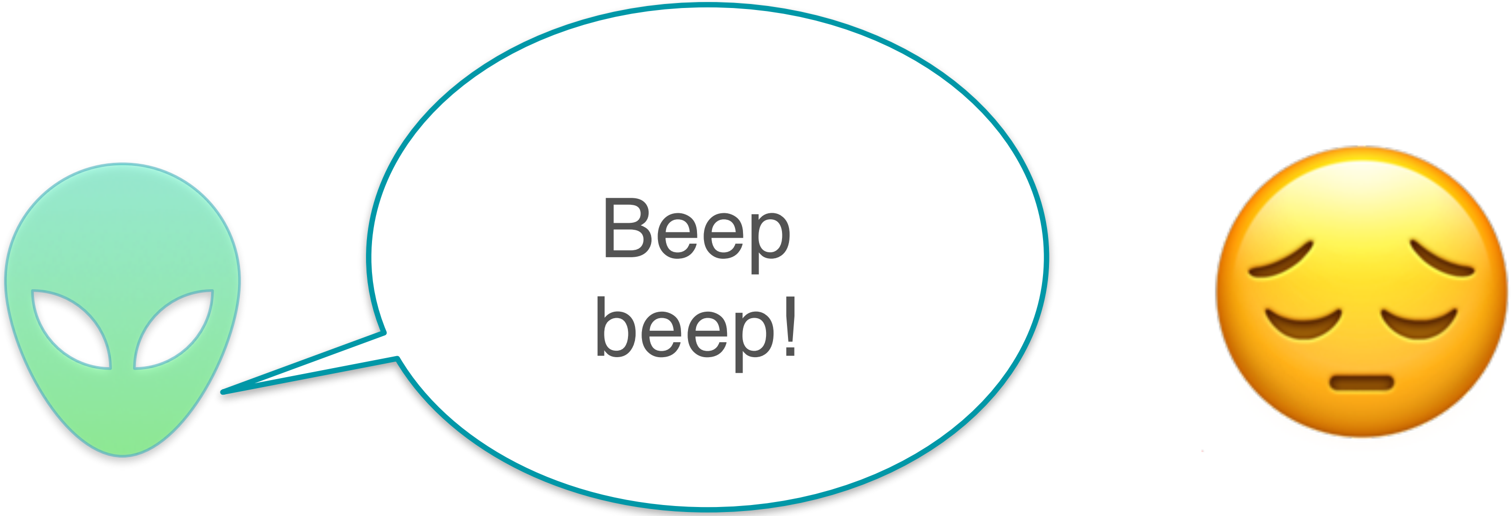

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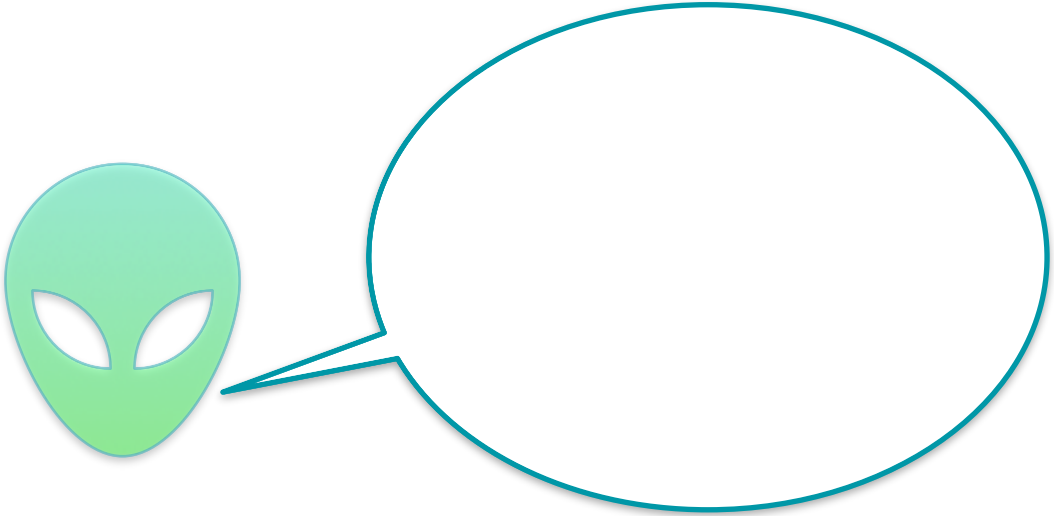

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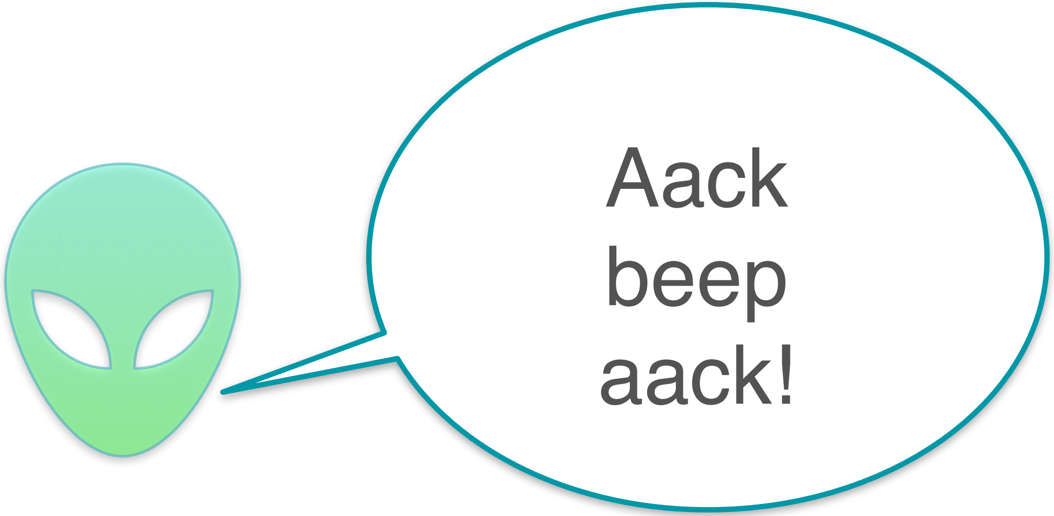

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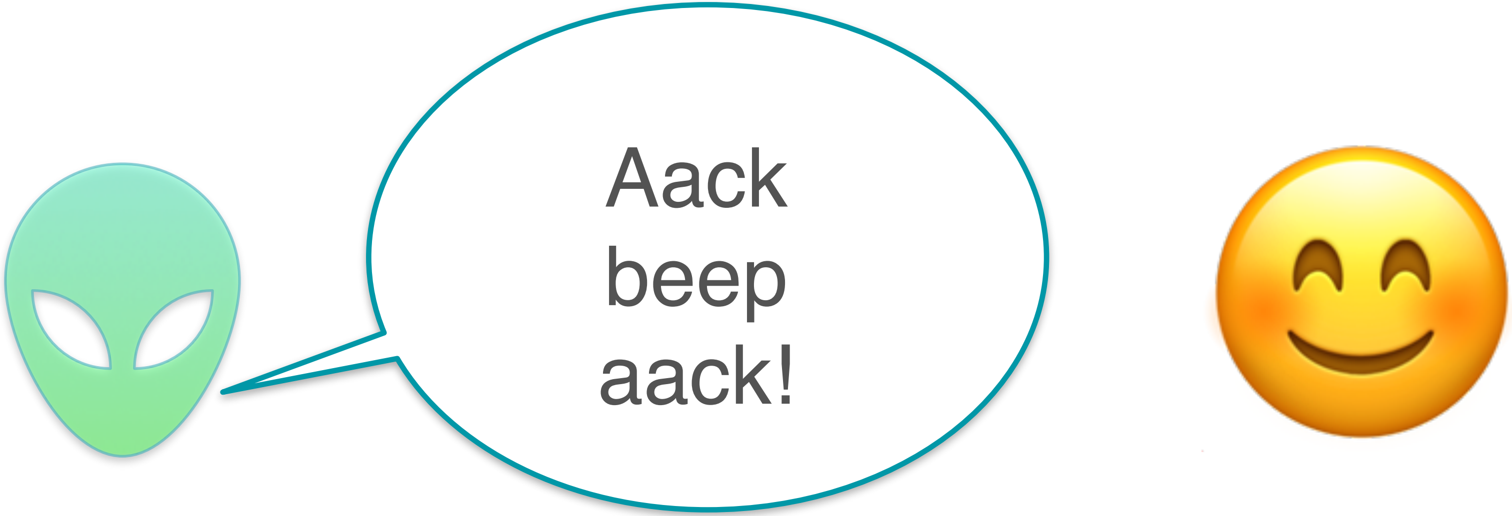

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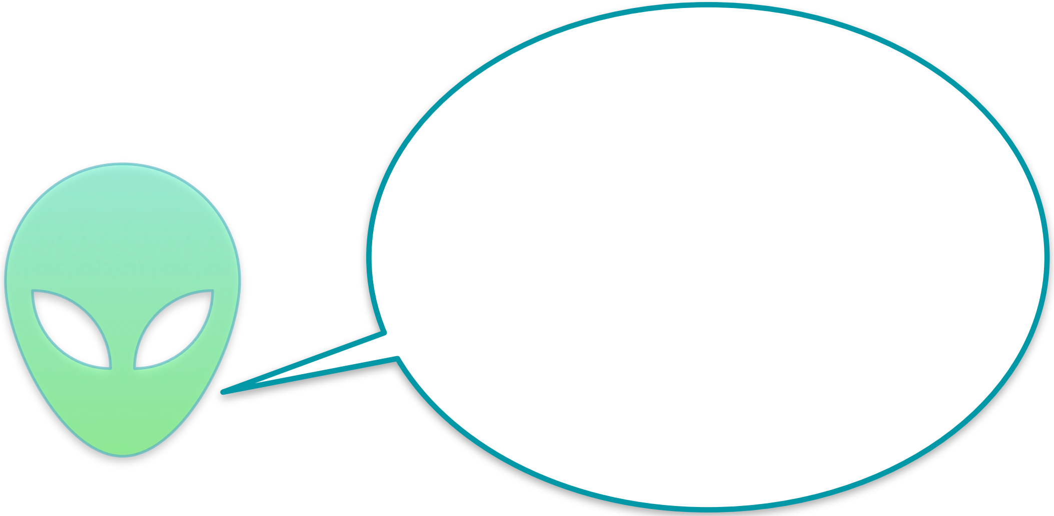

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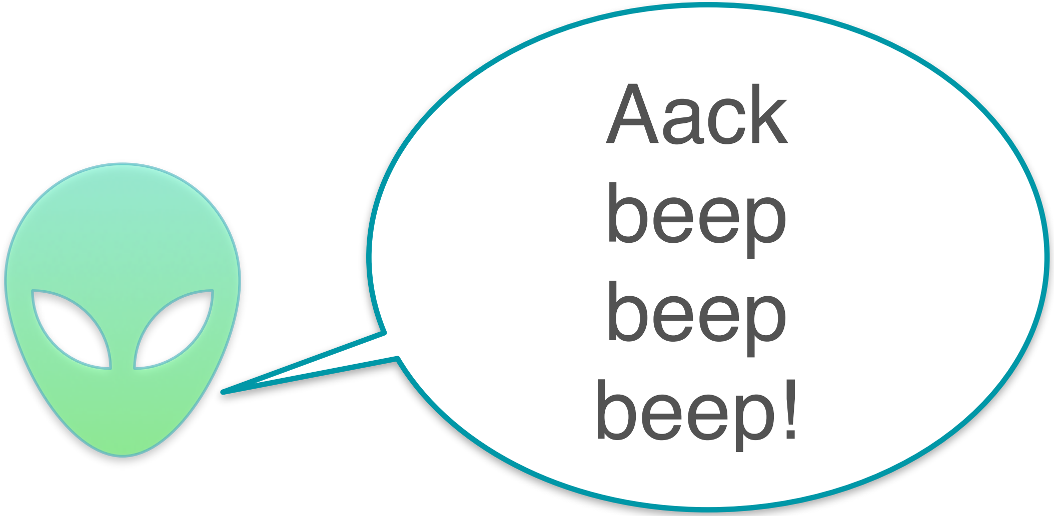

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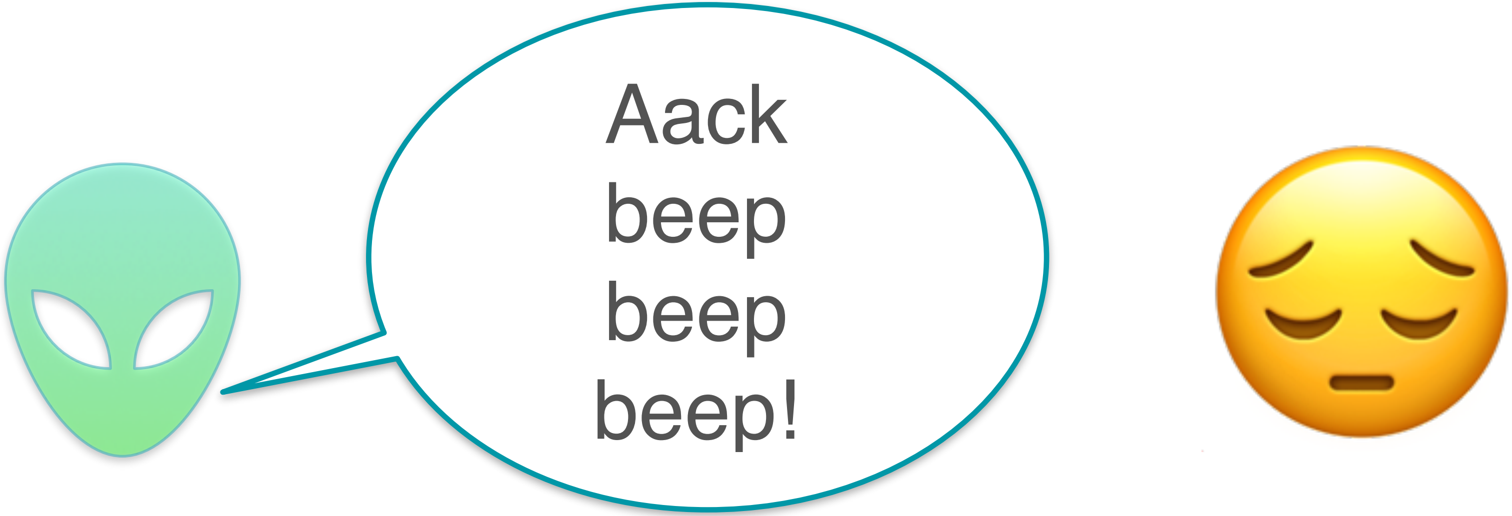


Machine Learning Motivation

Machine Learning Motivation

Sentence
Aack aack aack!
Beep beep!
Aack beep aack!
Aack beep beep beep!

Machine Learning Motivation

Sentence	*Aack*	*Beep*
Aack aack aack!	*3*	*0*
Beep beep!	*0*	*2*
Aack beep aack!	*2*	*1*
Aack beep beep beep!	*1*	*3*

Machine Learning Motivation

Sentence	Aack	Beep	Mood
Aack aack aack!	*3*	*0*	😊
Beep beep!	*0*	*2*	😔
Aack beep aack!	*2*	*1*	😊
Aack beep beep beep!	*1*	*3*	😔

Machine Learning Motivation

Sentence	Aack	Beep	Mood
Aack aack aack!	*3*	*0*	😊
Beep beep!	*0*	*2*	😔
Aack beep aack!	*2*	*1*	😊
Aack beep beep beep!	*1*	*3*	😔

A classification problem

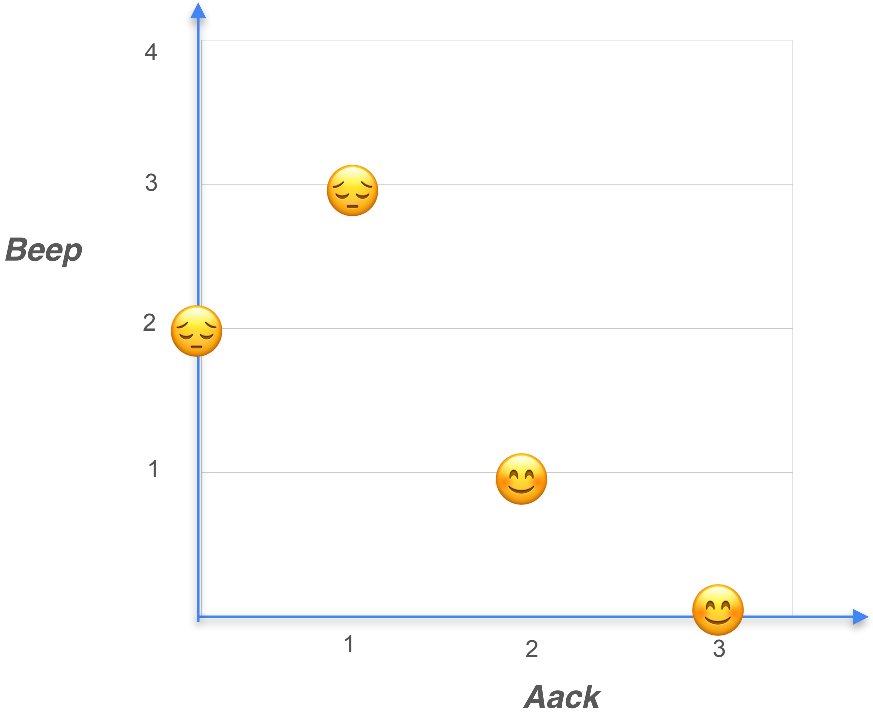
Machine Learning Motivation

Sentence	*Aack*	*Beep*	*Mood*
Aack aack aack!	*3*	*0*	😊
Beep beep!	*0*	*2*	😔
Aack beep aack!	*2*	*1*	😊
Aack beep beep beep!	*1*	*3*	😔

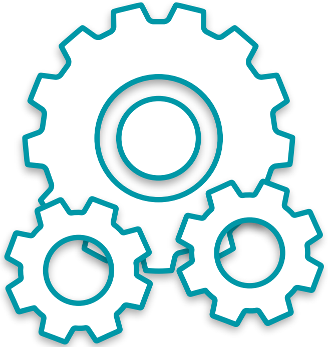
A classification problem

Sentiment analysis

Machine Learning Motivation

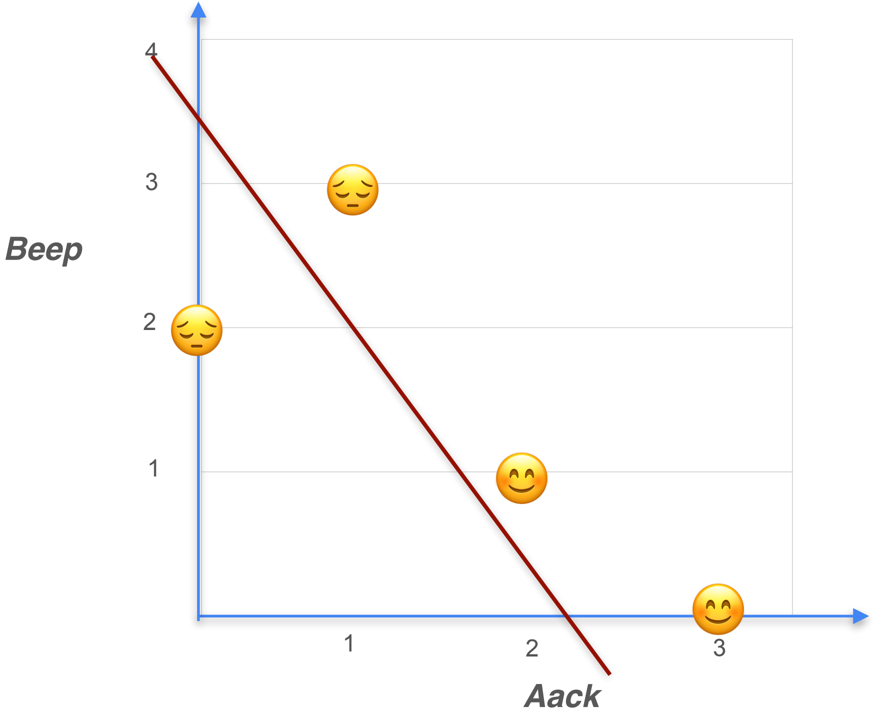


Model Training



Machine Learning Model

Machine Learning Motivation



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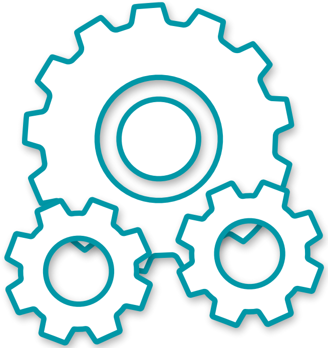
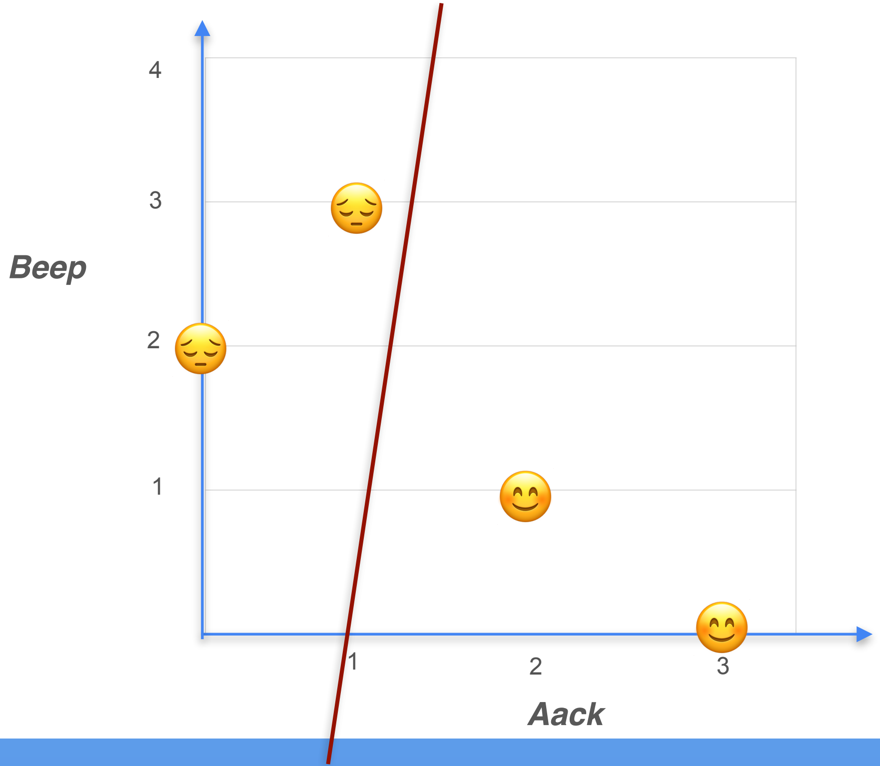
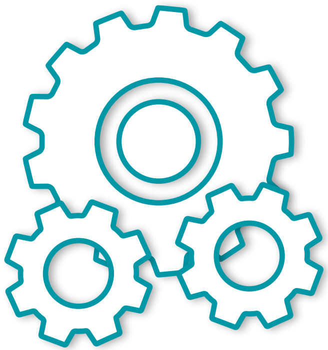


Machine Learning
Model

Machine Learning Motivation





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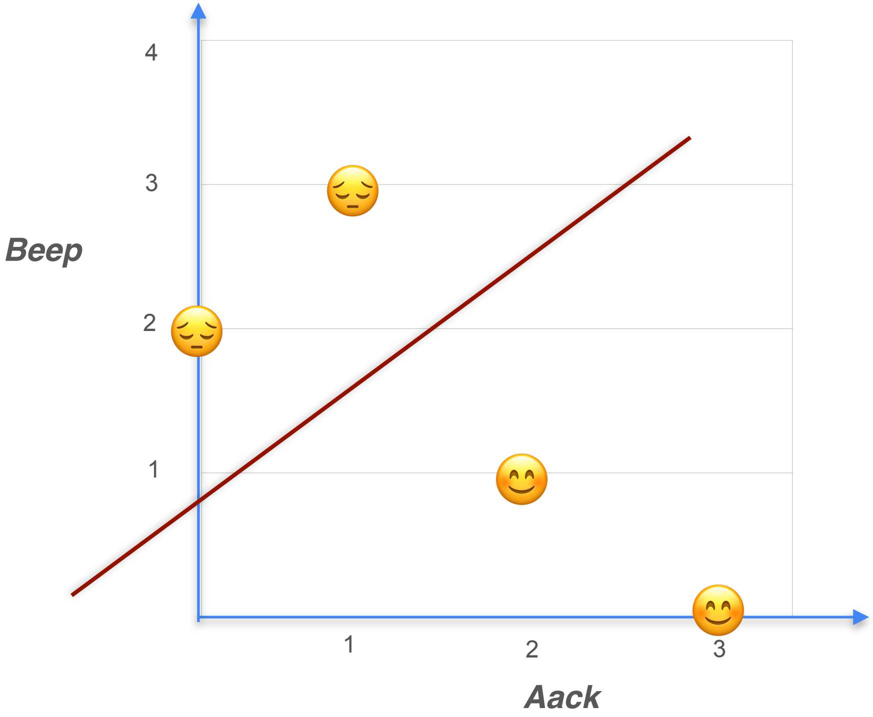

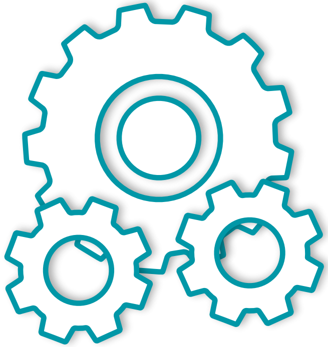

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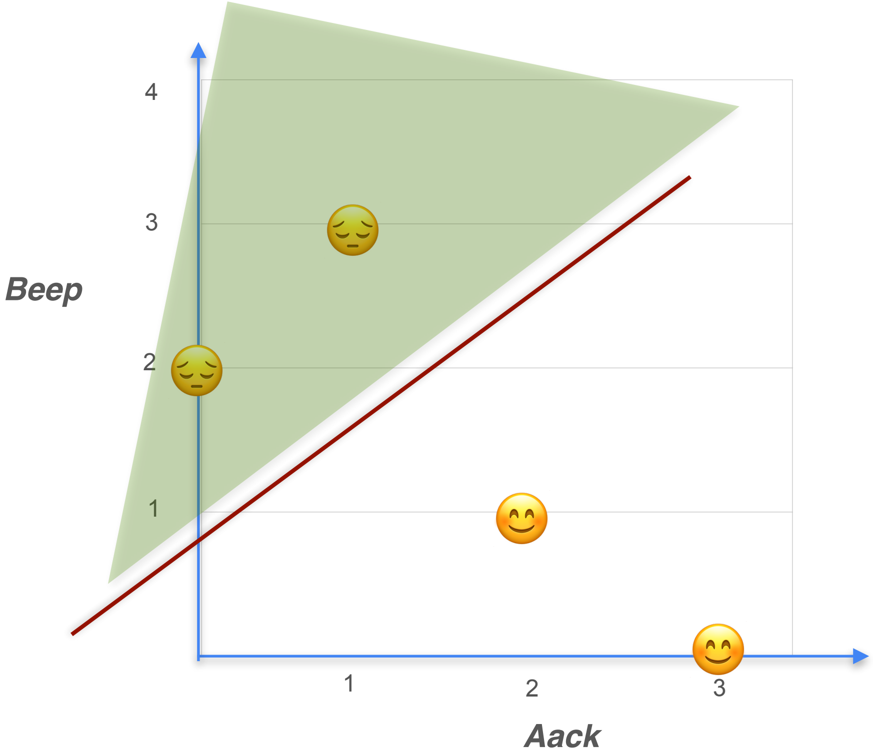

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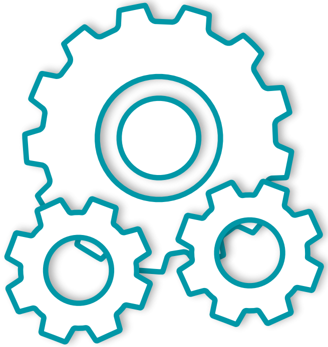
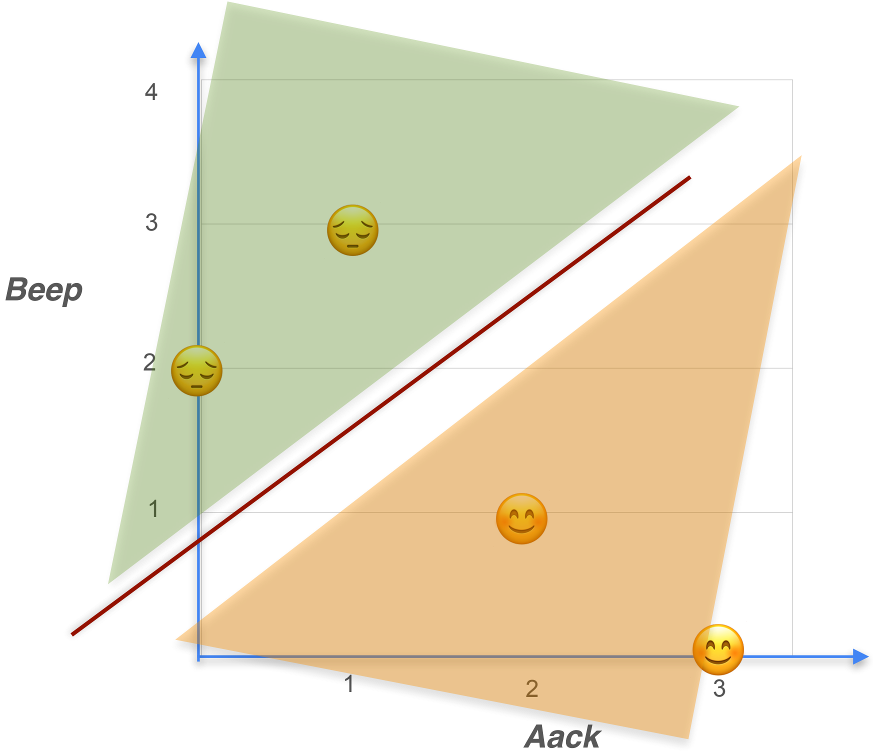
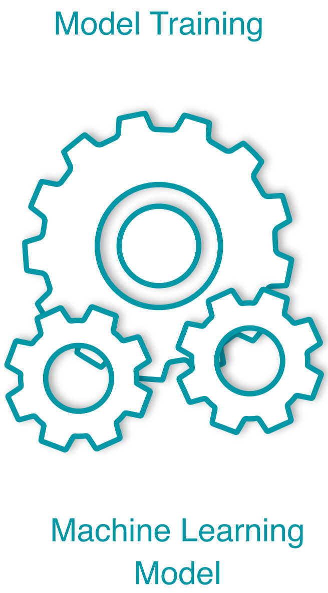


Machine Learning Model

Machine Learning Motivation





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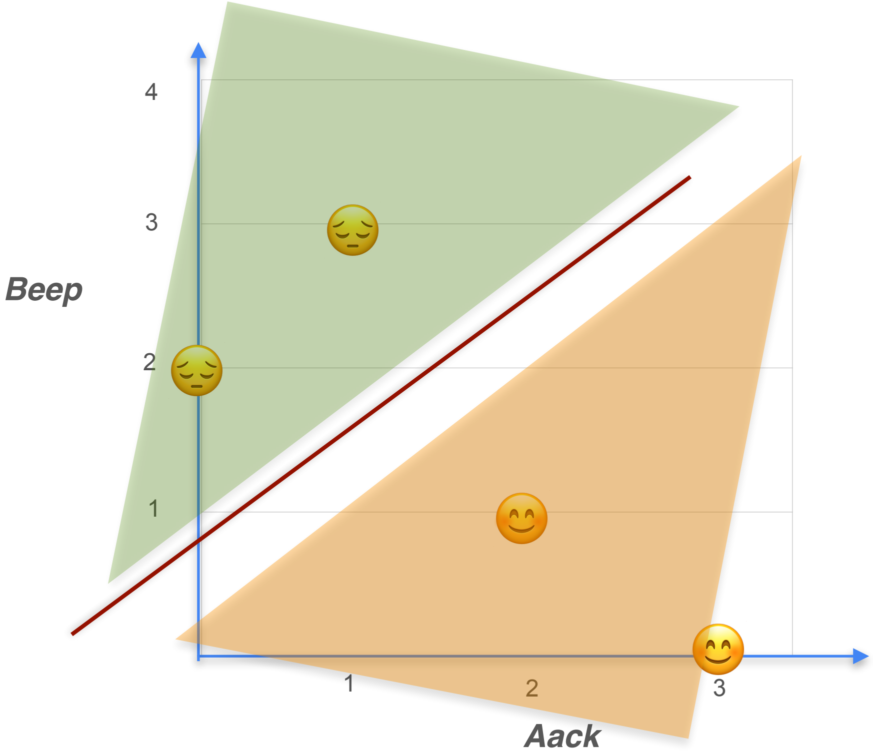

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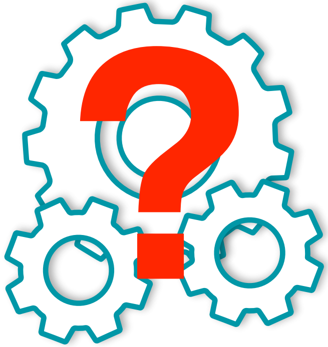
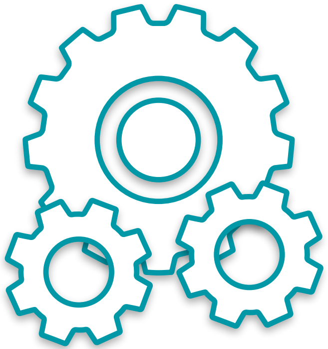


Machine Learning
Model

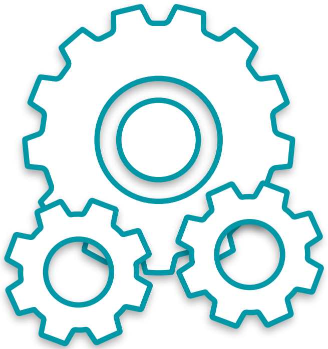
Machine Learning Motivation



Machine Learning
Model

Machine Learning Motivation

Maths concepts used in training a model



Machine Learning
Model

Machine Learning Motivation

Maths concepts used in training a model

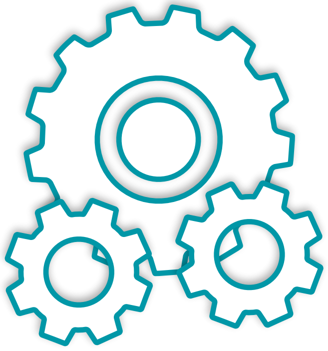
Gradients

Derivatives

Optimization

Loss and Cost functions

Gradient Descent



Machine Learning
Model

Machine Learning Motivation

Maths concepts used in training a model

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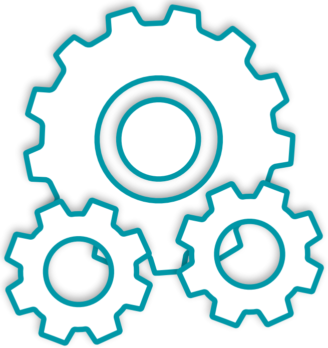


Machine Learning
Model

Linear Regression

Machine Learning Motivation

Maths concepts used in training a model

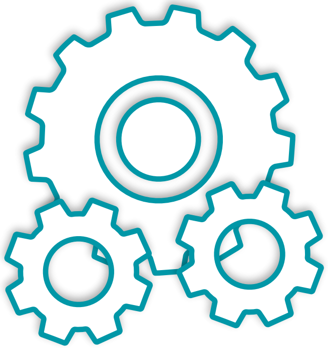
Gradients

Derivatives

Optimization

Loss and Cost functions

Gradient Descent



Machine Learning
Model

Linear Regression

Classification

Machine Learning Motivation

Maths concepts used in training a model

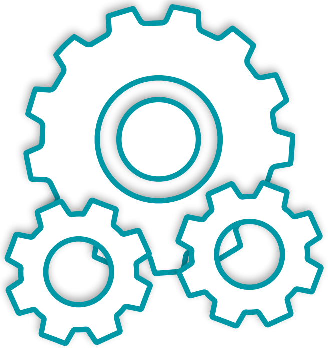
Gradients

Derivatives

Optimization

Loss and Cost functions

Gradient Descent



Machine Learning Model

Linear Regression

Classification

Neural Networks

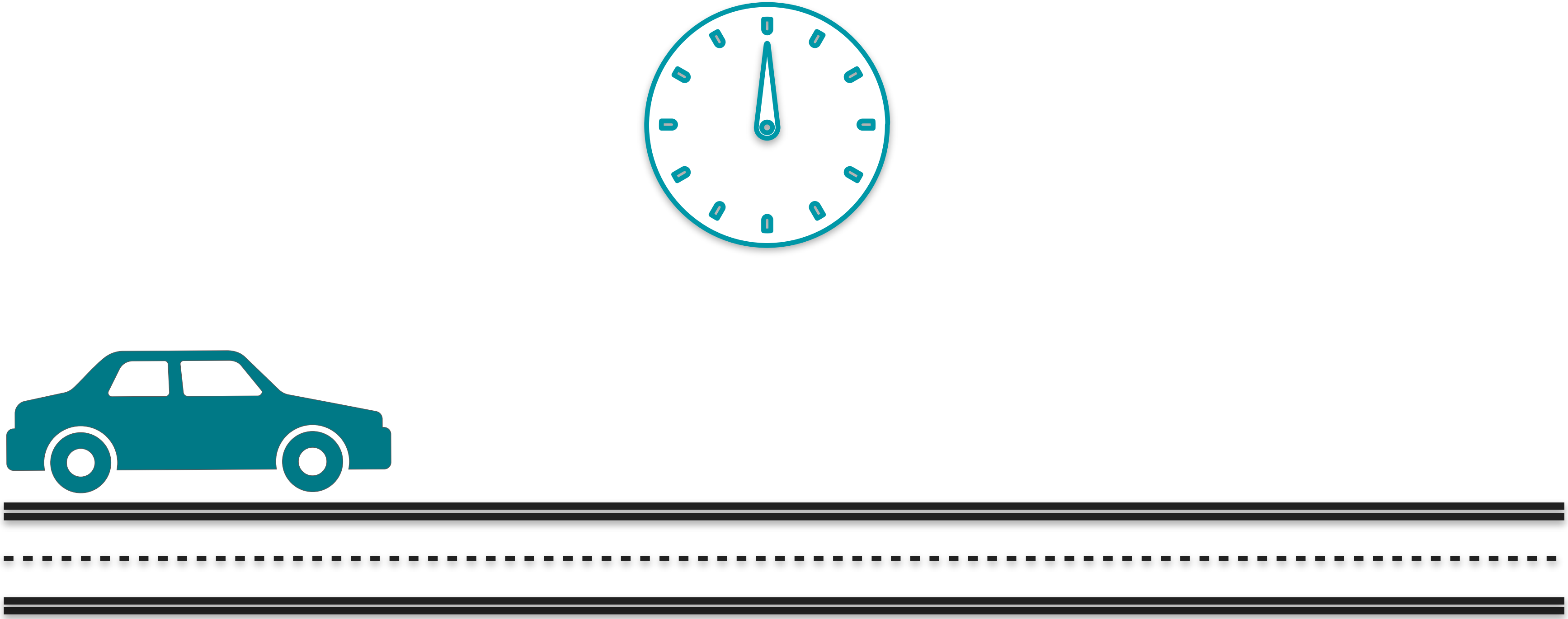
DeepLearning.AI

Derivatives and Optimization

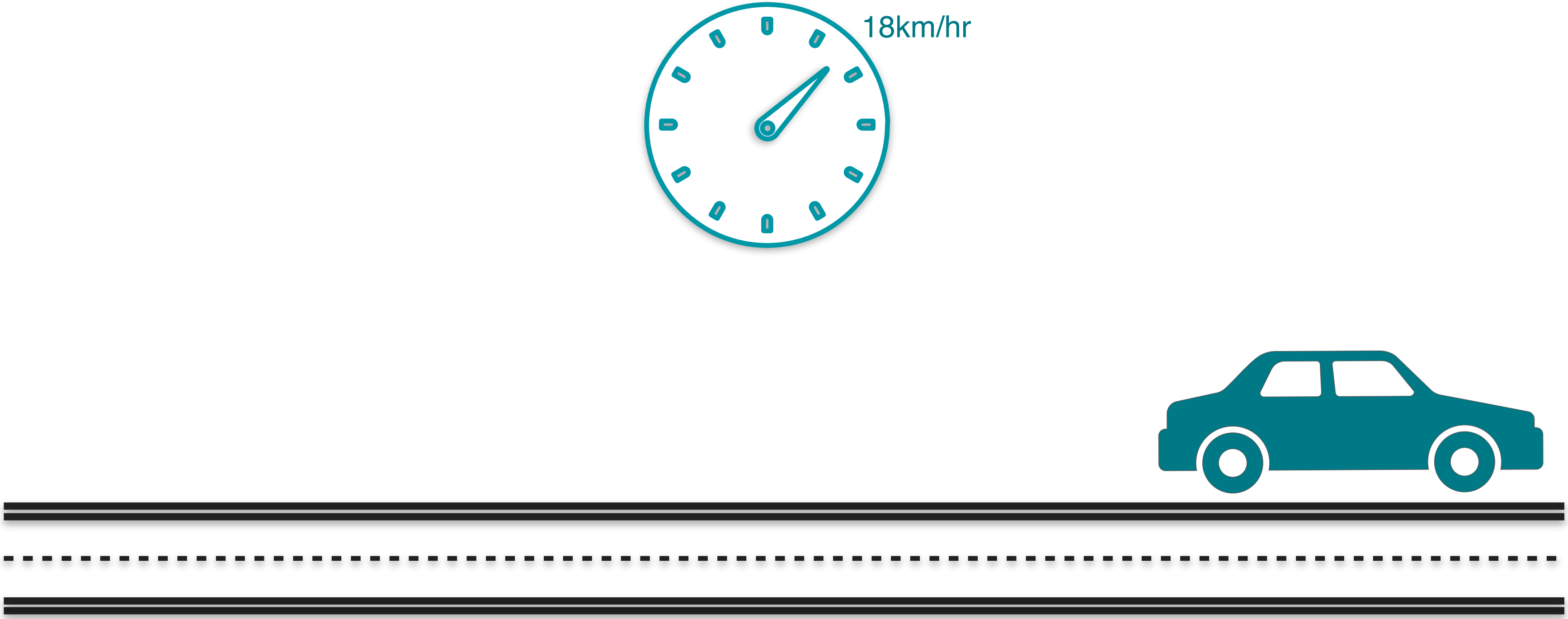
Introduction to derivatives

Introduction to Derivatives

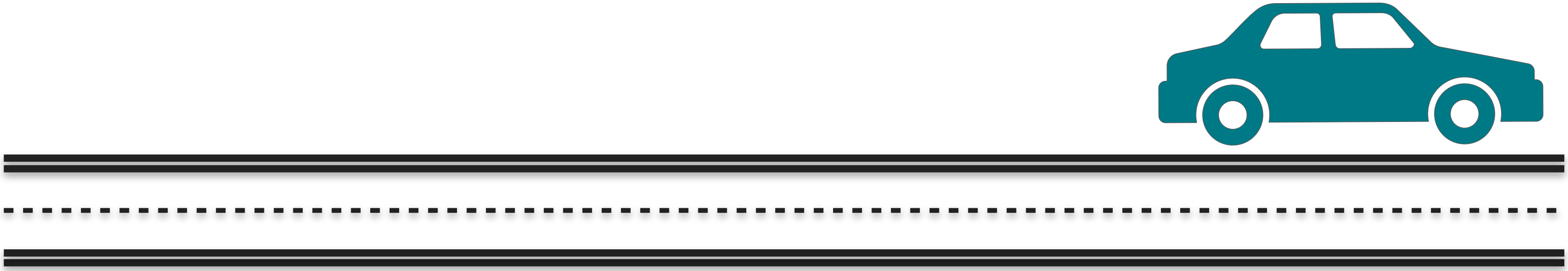
Introduction to Derivatives



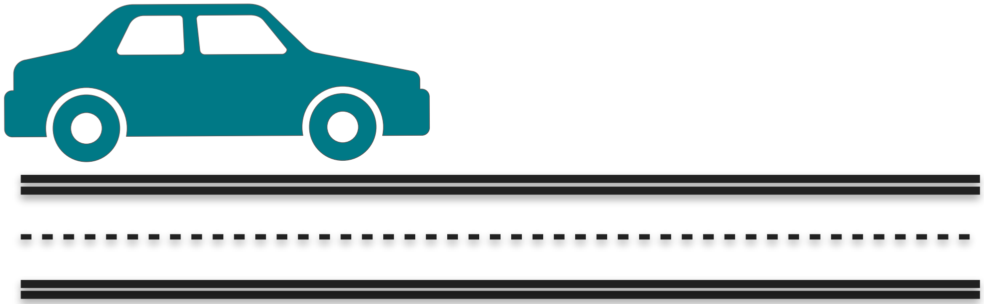
Introduction to Derivatives



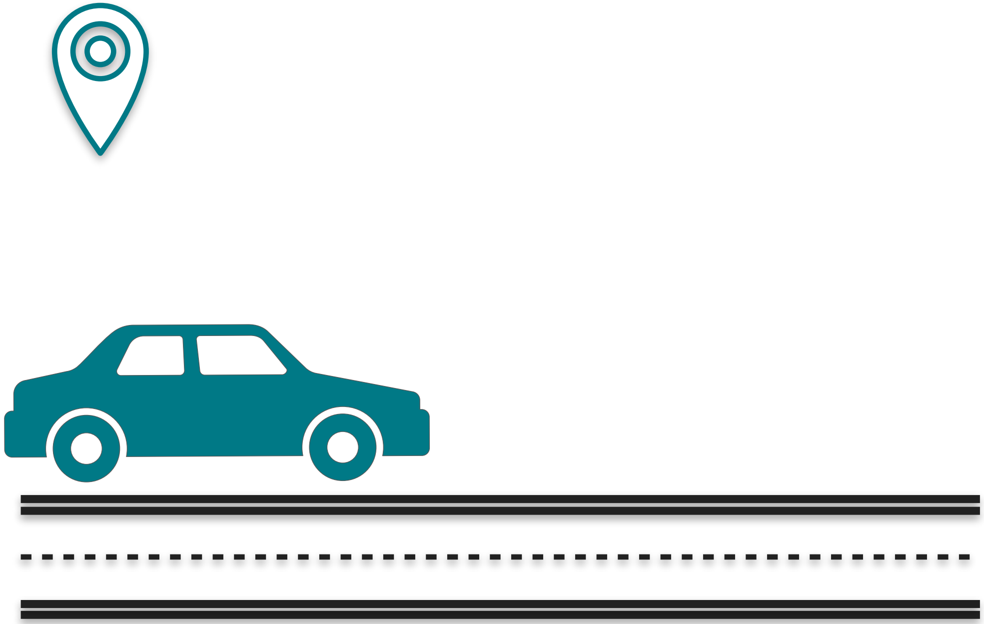
Introduction to Derivatives



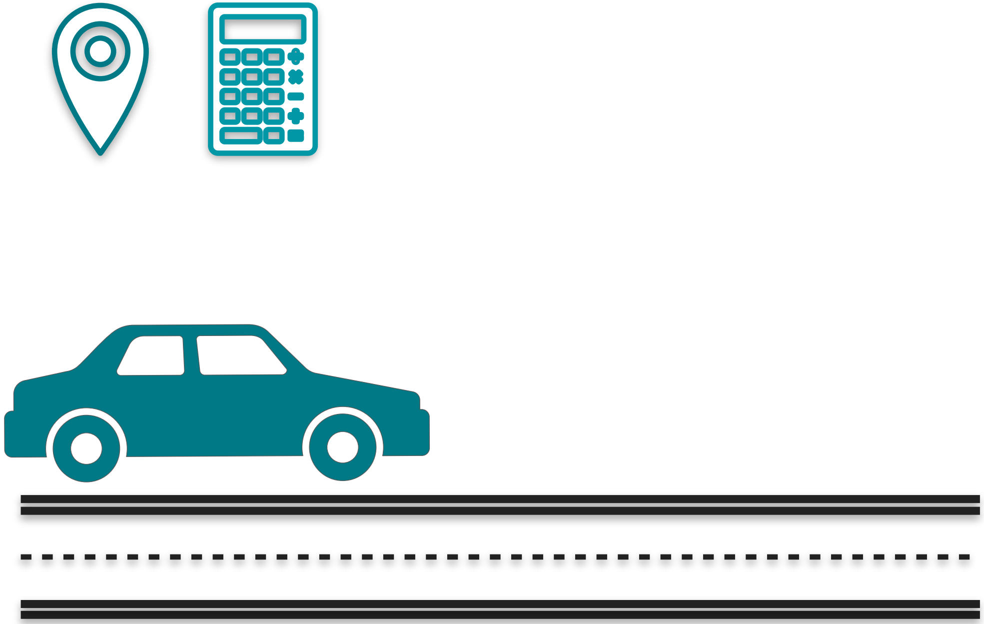
Introduction to Derivatives



Introduction to Derivatives

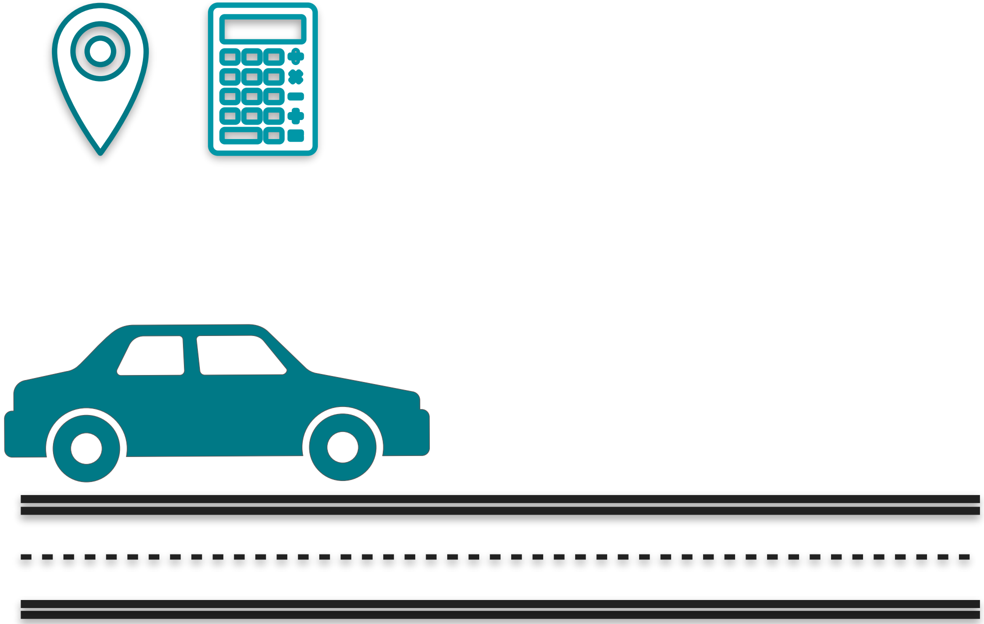


Introduction to Derivatives



Introduction to Derivatives

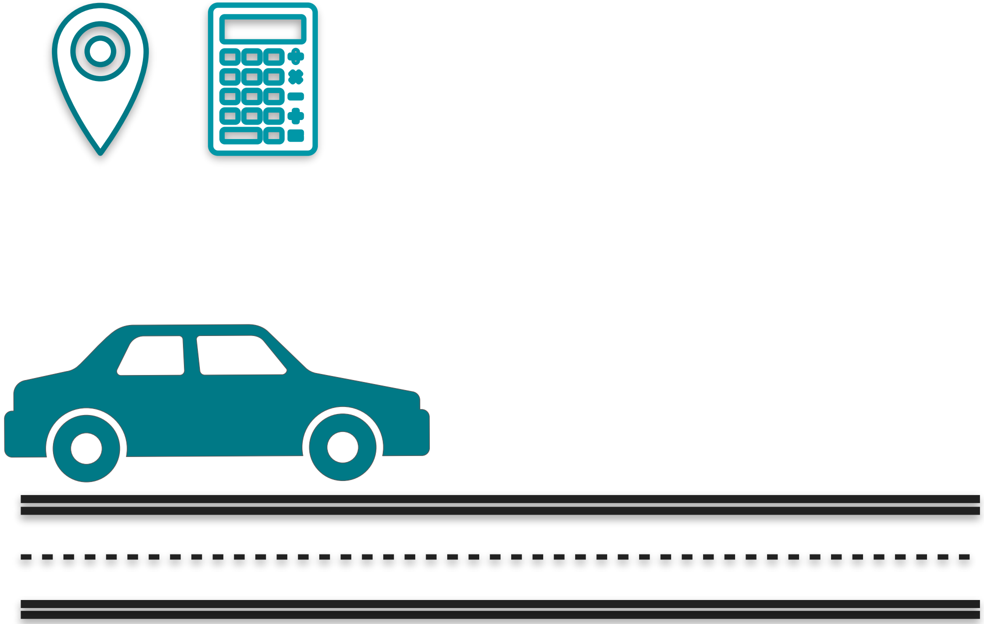
Every 5 seconds



Introduction to Derivatives

Every 5 seconds

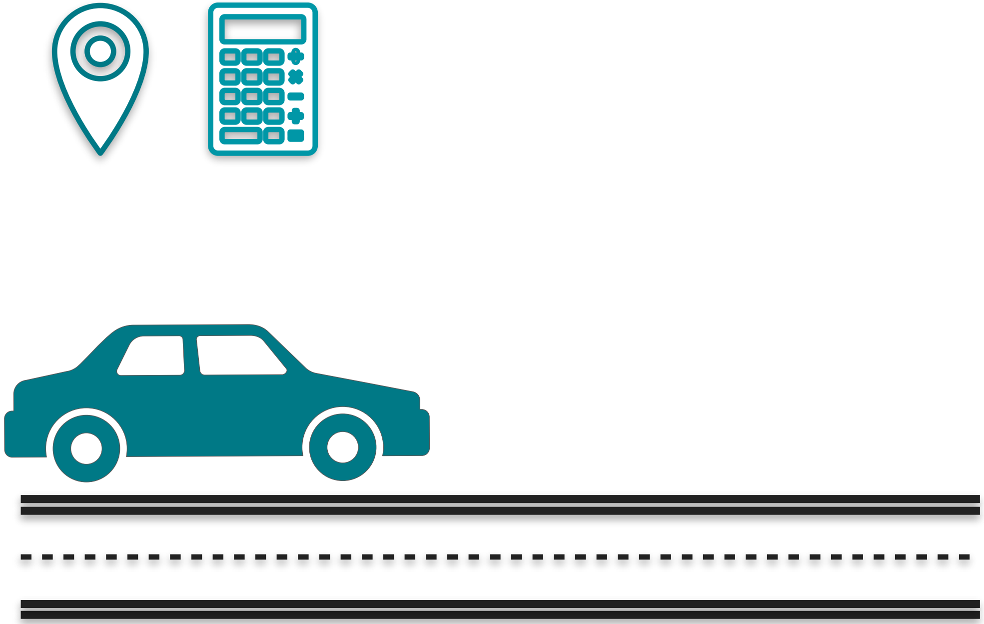
t (seconds)
0
5
10
15
20
25
30
35
40
45
50
55
60



Introduction to Derivatives

Every 5 seconds

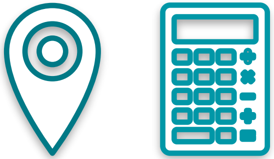
t (seconds)	x (meters)
0	0
5	36
10	122
15	202
20	265
25	351
30	441
35	551
40	591
45	716
50	816
55	900
60	1000



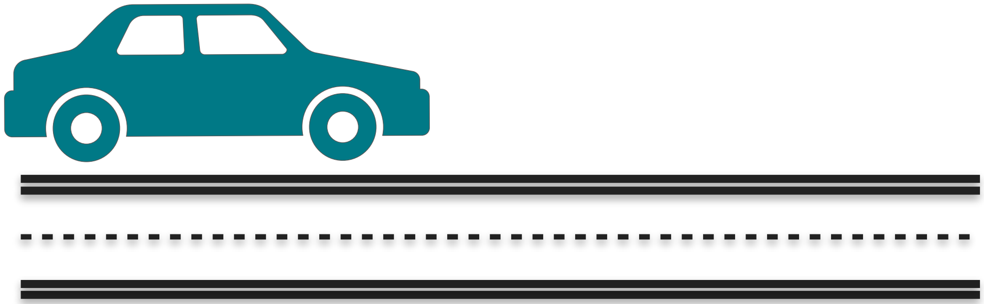
Introduction to Derivatives

Every 5 seconds

t (seconds)	x (meters)
0	0
5	36
10	122
15	202
20	265
25	351
30	441
35	551
40	591
45	716
50	816
55	900
60	1000



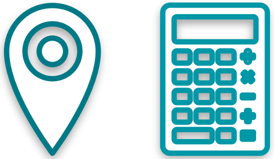
Is the car moving at a constant speed?



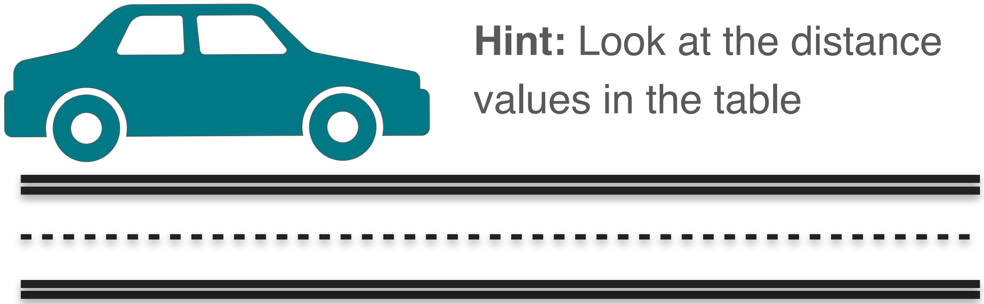
Introduction to Derivatives

Every 5 seconds

t (seconds)	x (meters)
0	0
5	36
10	122
15	202
20	265
25	351
30	441
35	551
40	591
45	716
50	816
55	900
60	1000



Is the car moving at a constant speed?



Hint: Look at the distance values in the table

Introduction to Derivatives

t (seconds)	x (meters)
0	0
5	36
10	122
15	202
20	265
25	351
30	441
35	551
40	591
45	716
50	816
55	900
60	1000

Introduction to Derivatives

t (seconds)	x (meters)
0	0
5	36
10	122
15	202
20	265
25	351
30	441
35	551
40	591
45	716
50	816
55	900
60	1000

Introduction to Derivatives

t (seconds)	x (meters)
0	0
5	36
10	122
15	202
20	265
25	351
30	441
35	551
40	591
45	716
50	816
55	900
60	1000

10 - 15 seconds: 202 - 122 = **80 meters**

Introduction to Derivatives

t (seconds)	x (meters)
0	0
5	36
10	122
15	202
20	265
25	351
30	441
35	551
40	591
45	716
50	816
55	900
60	1000

10 - 15 seconds: 202 - 122 = **80 meters**

Introduction to Derivatives

t (seconds)	x (meters)
0	0
5	36
10	122
15	202
20	265
25	351
30	441
35	551
40	591
45	716
50	816
55	900
60	1000

10 - 15 seconds: 202 - 122 = **80 meters**

15 - 20 seconds: 265 - 202 = **63 meters**

Introduction to Derivatives

t (seconds)	x (meters)
0	0
5	36
10	122
15	202
20	265
25	351
30	441
35	551
40	591
45	716
50	816
55	900
60	1000

10 - 15 seconds: 202 - 122 = **80 meters**

15 - 20 seconds: 265 - 202 = **63 meters**

Not traveling at constant speed

Introduction to Derivatives

t (seconds)	x (meters)
0	0
5	36
10	122
15	202
20	265
25	351
30	441
35	551
40	591
45	716
50	816
55	900
60	1000

Introduction to Derivatives

t (seconds)	x (meters)
0	0
5	36
10	122
15	202
20	265
25	351
30	441
35	551
40	591
45	716
50	816
55	900
60	1000

Can you use the information presented to determine your velocity at exactly ***t = 12.5 seconds***?

Introduction to Derivatives

t (seconds)	x (meters)
0	0
5	36
10	122
15	202
20	265
25	351
30	441
35	551
40	591
45	716
50	816
55	900
60	1000

Can you use the information presented to determine your velocity at exactly ***t = 12.5 seconds***?

Hint: velocity = distance traveled / time taken

Introduction to Derivatives

t (seconds)	x (meters)
0	0
5	36
10	122
15	202
20	275
25	351
30	441
35	551
40	591
45	716
50	816
55	900
60	1000

Can you use the information presented to determine your velocity at exactly ***t = 12.5 seconds***?

Introduction to Derivatives

t (seconds)	x (meters)
0	0
5	36
10	122
15	202
20	275
25	351
30	441
35	551
40	591
45	716
50	816
55	900
60	1000

Can you use the information presented to determine your velocity at exactly ***t = 12.5 seconds***?

Quiz : Slope of a Line 1

t (seconds)	x (meters)
0	0
5	36
10	122
15	202
20	275
25	351
30	441
35	551
40	591
45	716
50	816
55	900
60	1000

Quiz : Slope of a Line 1

t (seconds)	x (meters)
0	0
5	36
10	122
15	202
20	275
25	351
30	441
35	551
40	591
45	716
50	816
55	900
60	1000

What was the average velocity of the car on the interval from 10 to 15 seconds?

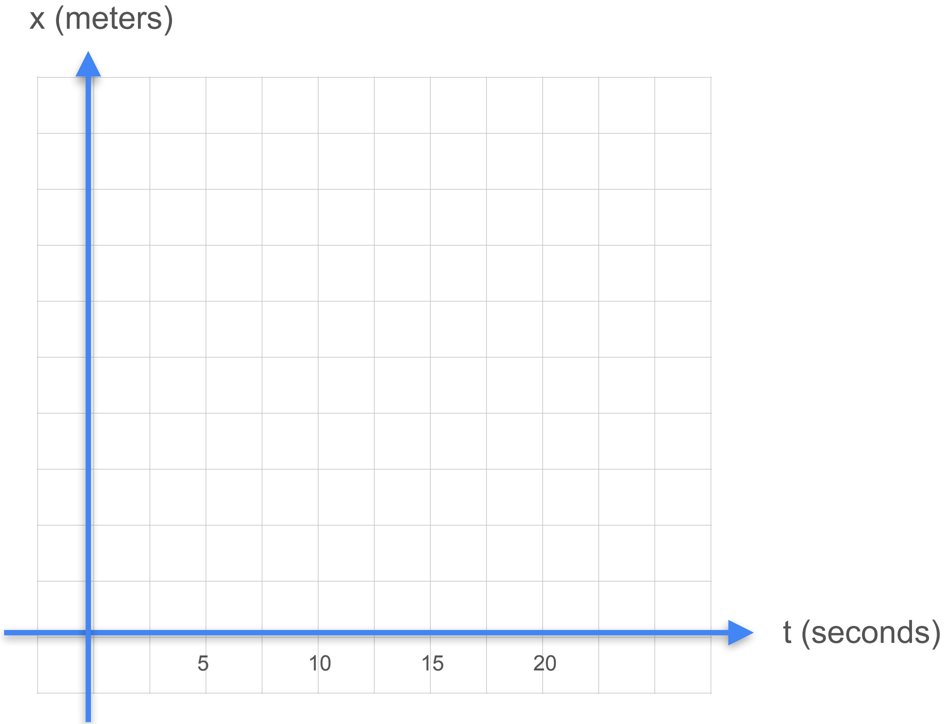
Quiz : Slope of a Line 1 - Solution

t (seconds)	x (meters)
0	0
5	36
10	122
15	202
20	275
25	351
30	441
35	551
40	591
45	716
50	816
55	900
60	1000

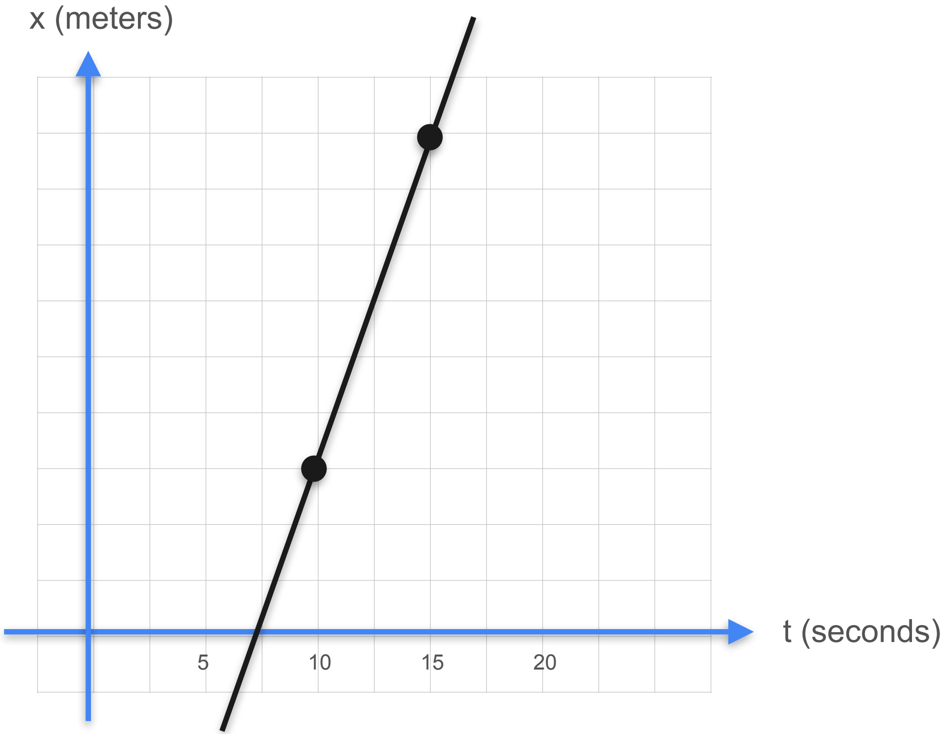
What was the average velocity of the car on the interval from 10 to 15 seconds?

Calculating the Slope

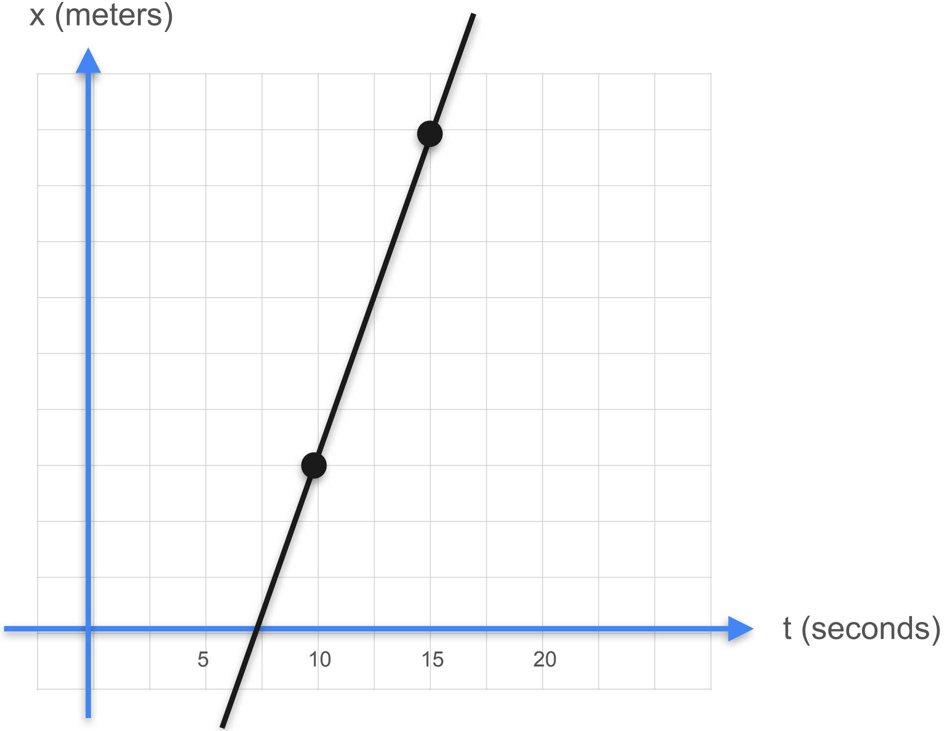
Calculating the Slope



Calculating the Slope

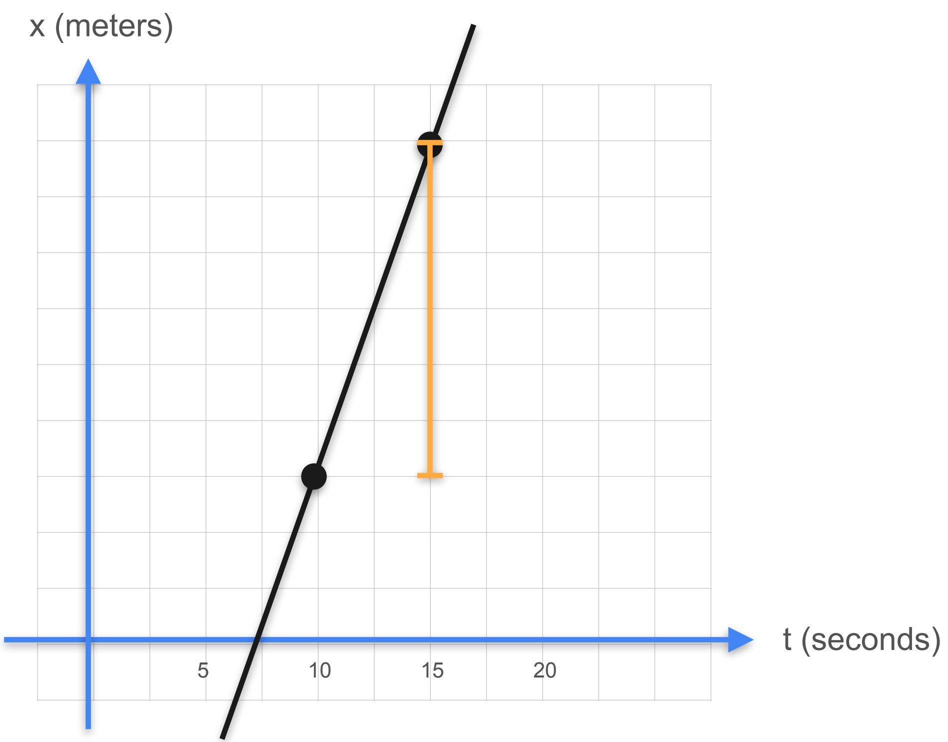


Calculating the Slope



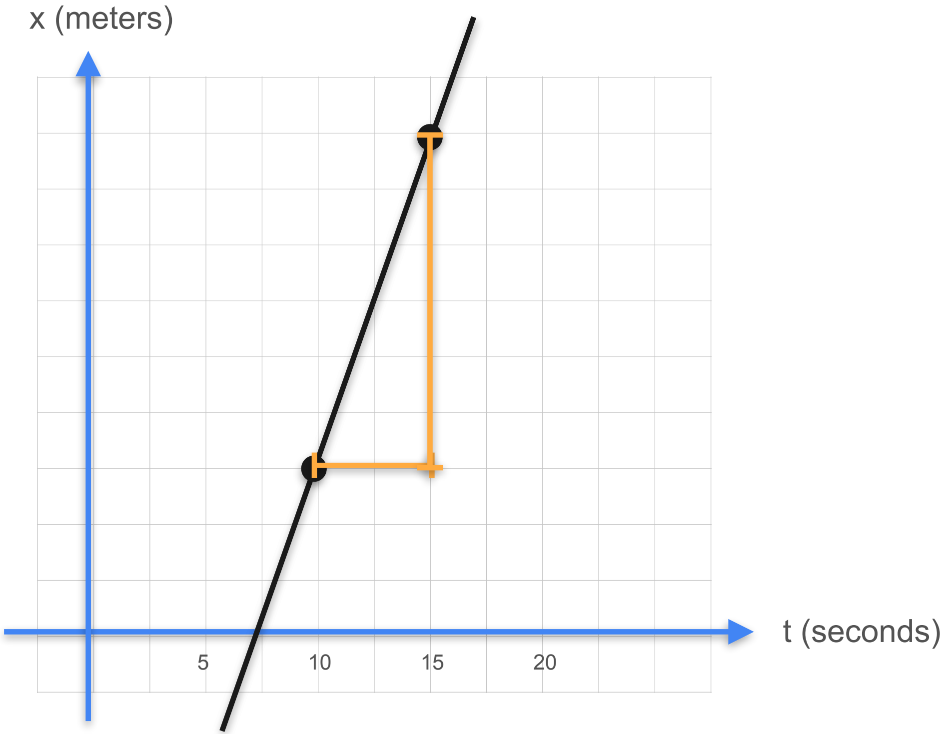
$$slope = \frac{rise}{run}$$

Calculating the Slope



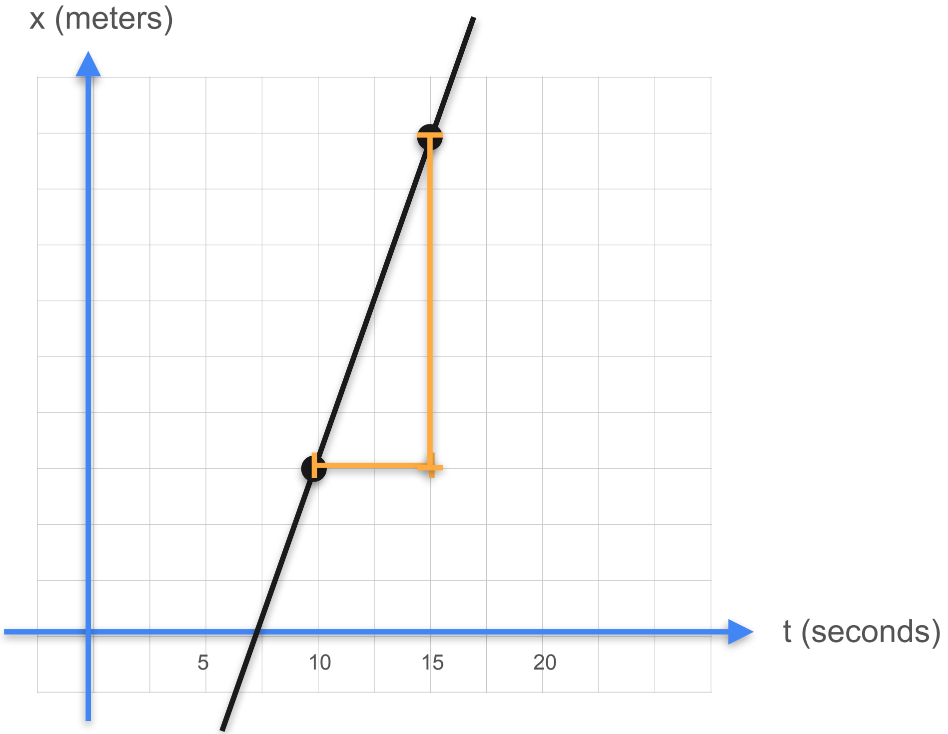
$$slope = \frac{rise}{run}$$

Calculating the Slope



$$slope = \frac{rise}{run}$$

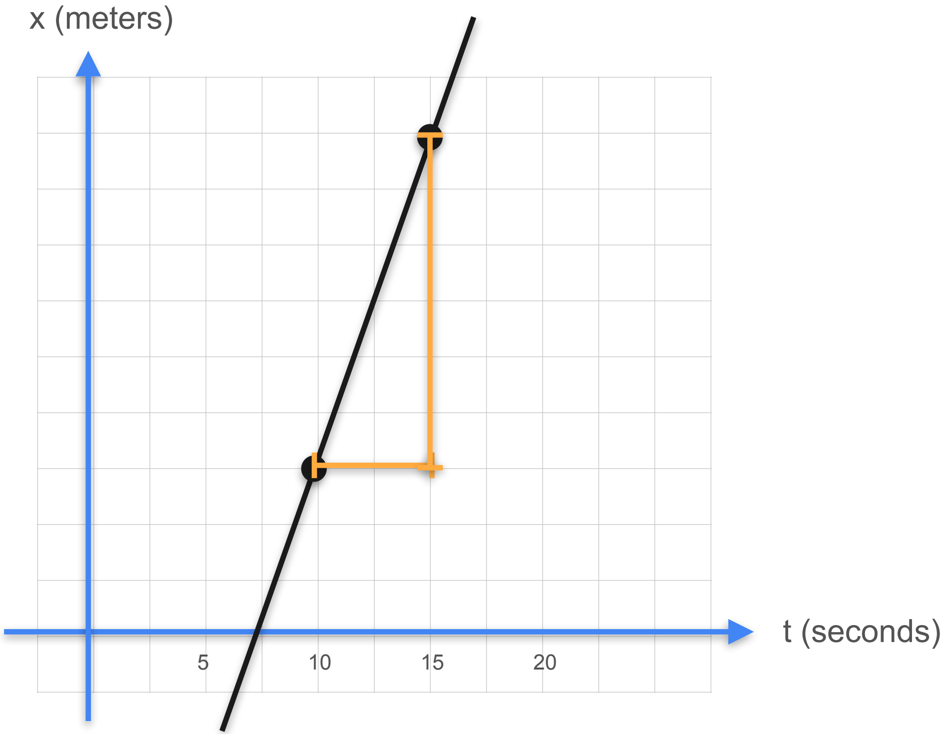
Calculating the Slope



$$slope = \frac{rise}{run}$$

$$slope = \frac{change\ in\ distance(\Delta x)}{change\ in\ time(\Delta t)}$$

Calculating the Slope

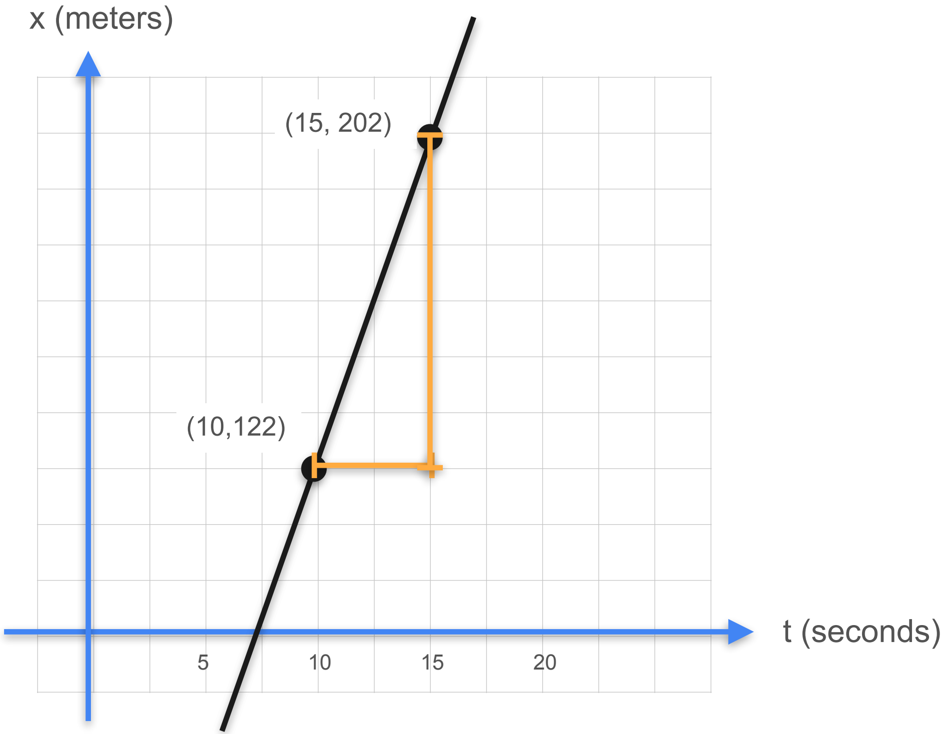


$$slope = \frac{rise}{run}$$

$$slope = \frac{change\ in\ distance(\Delta x)}{change\ in\ time(\Delta t)}$$

$$slope = \frac{x(15) - x(10)}{t(15) - t(10)}$$

Calculating the Slope

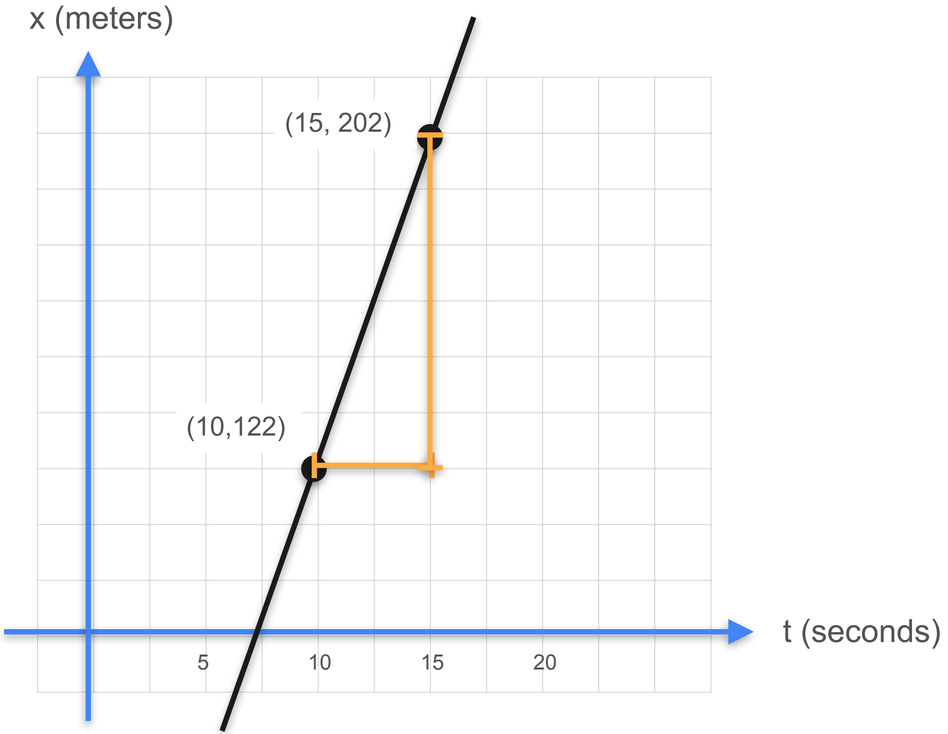


$$slope = \frac{rise}{run}$$

$$slope = \frac{change\ in\ distance(\Delta x)}{change\ in\ time(\Delta t)}$$

$$slope = \frac{x(15) - x(10)}{t(15) - t(10)}$$

Calculating the Slope



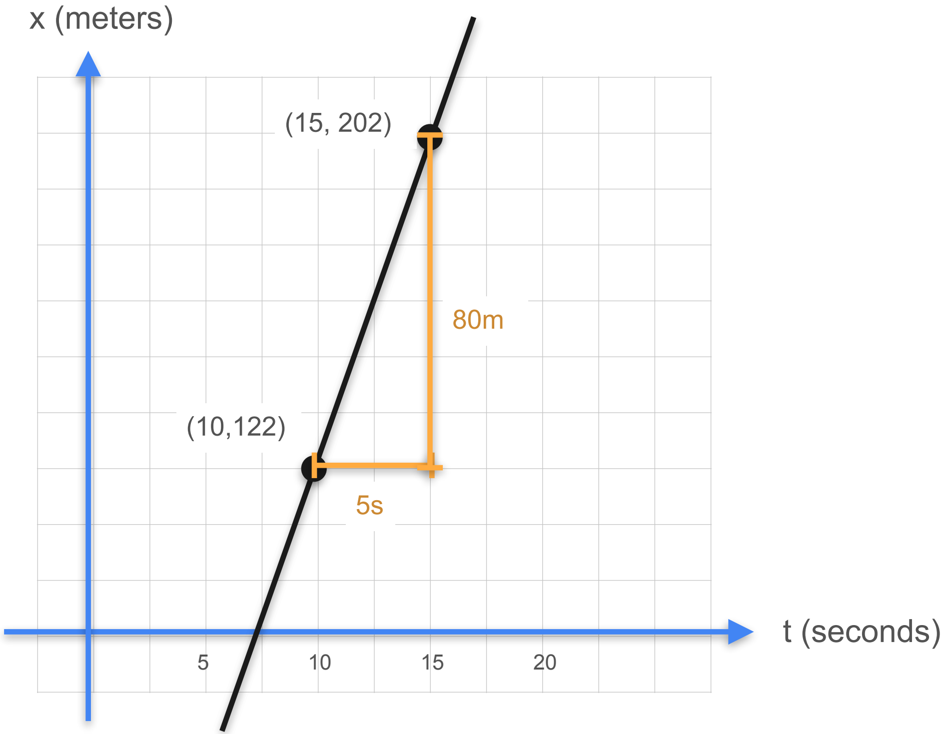
$$slope = \frac{rise}{run}$$

$$slope = \frac{change\ in\ distance(\Delta x)}{change\ in\ time(\Delta t)}$$

$$slope = \frac{x(15) - x(10)}{t(15) - t(10)}$$

$$slope = \frac{202m - 122m}{15s - 10s}$$

Calculating the Slope



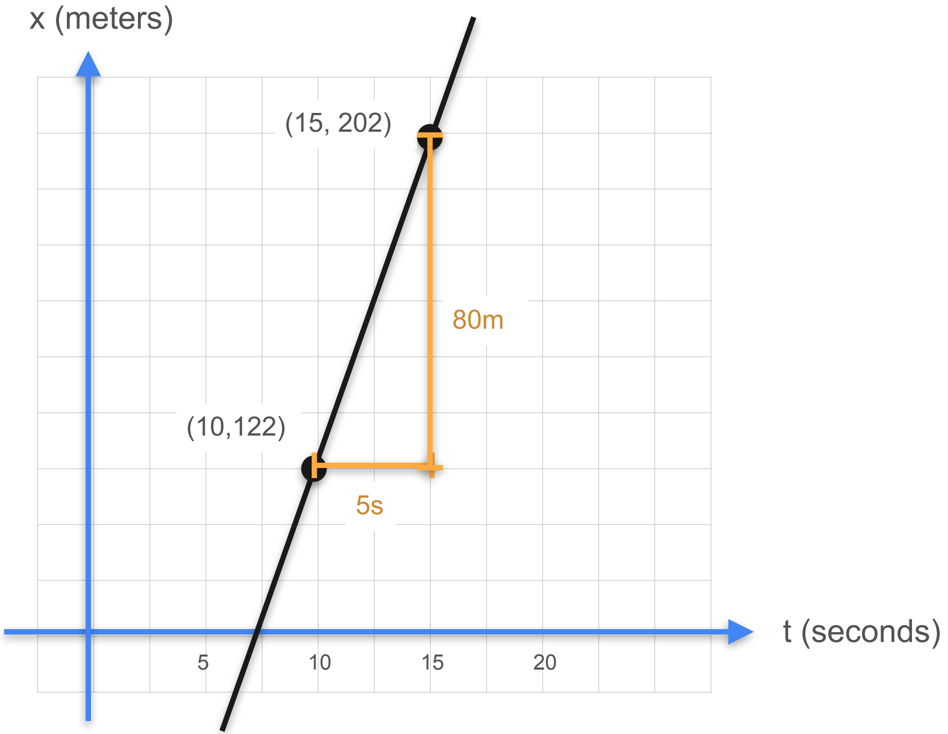
$$slope = \frac{rise}{run}$$

$$slope = \frac{change\ in\ distance(\Delta x)}{change\ in\ time(\Delta t)}$$

$$slope = \frac{x(15) - x(10)}{t(15) - t(10)}$$

$$slope = \frac{202m - 122m}{15s - 10s}$$

Calculating the Slope



$$slope = \frac{rise}{run}$$

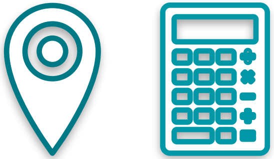
$$slope = \frac{change\ in\ distance(\Delta x)}{change\ in\ time(\Delta t)}$$

$$slope = \frac{x(15) - x(10)}{t(15) - t(10)}$$

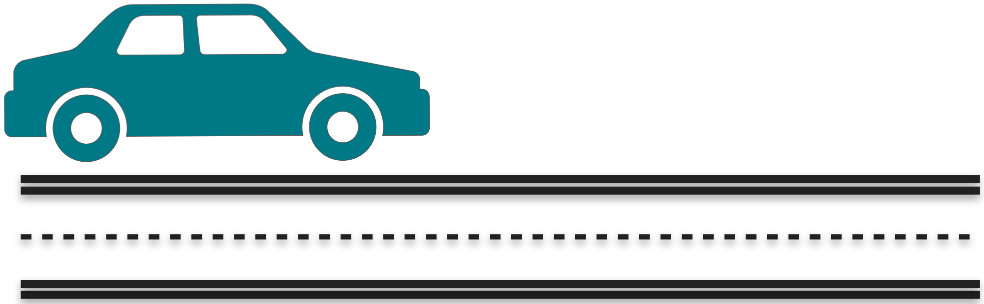
$$slope = \frac{202m - 122m}{15s - 10s}$$

$$slope = \frac{80m}{5s} = 16m/s$$

Introduction to Derivatives

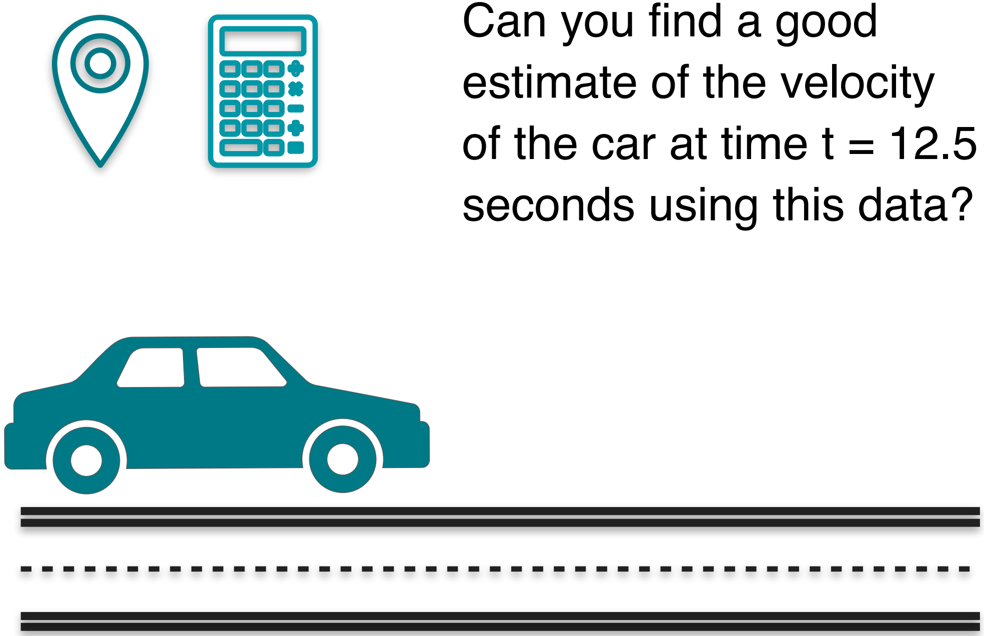


Can you find a good estimate of the velocity of the car at time t = 12.5 seconds using this data?



Introduction to Derivatives

Every second

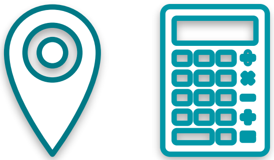


Can you find a good estimate of the velocity of the car at time t = 12.5 seconds using this data?

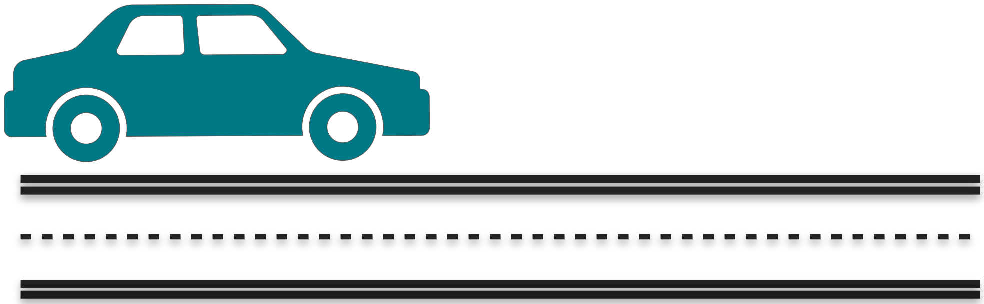
Introduction to Derivatives

Every second

t (s)
10
11
12
13
14
15
16
17
18
19
20



Can you find a good estimate of the velocity of the car at time t = 12.5 seconds using this data?

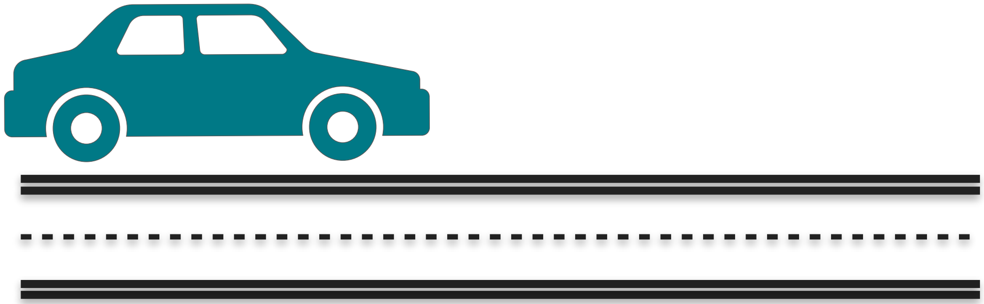


Introduction to Derivatives

Every second

t (s)	x(m)
10	122
11	138
12	155
13	170
14	186
15	202
16	218
17	234
18	250
19	265
20	265

Can you find a good estimate of the velocity of the car at time t = 12.5 seconds using this data?



Quiz : Slope of a Line 2

t (s)	x (m)
10	122
11	138
12	155
13	170
14	186
15	202
16	218
17	234
18	250
19	265
20	265

Can you find a good estimate of the velocity of the car at time t = 12.5 seconds using this data?

Quiz : Slope of a Line 2

t (s)	x (m)
10	122
11	138
12	155
13	170
14	186
15	202
16	218
17	234
18	250
19	265
20	265

Can you find a good estimate of the velocity of the car at time t = 12.5 seconds using this data?

$$slope = \frac{\Delta x}{\Delta t}$$

Quiz : Slope of a Line 2

t (s)	x (m)
10	122
11	138
12	155
13	170
14	186
15	202
16	218
17	234
18	250
19	265
20	265

Can you find a good estimate of the velocity of the car at time t = 12.5 seconds using this data?

$$slope = \frac{\Delta x}{\Delta t}$$

$$slope = \frac{x(13) - x(12)}{13s - 12s}$$

Quiz : Slope of a Line 2

t (s)	x (m)
10	122
11	138
12	155
13	170
14	186
15	202
16	218
17	234
18	250
19	265
20	265

Can you find a good estimate of the velocity of the car at time t = 12.5 seconds using this data?

$$slope = \frac{\Delta x}{\Delta t}$$

$$slope = \frac{x(13) - x(12)}{13s - 12s}$$

$$slope = \frac{170m - 155m}{1s}$$

Quiz : Slope of a Line 2

t (s)	x (m)
10	122
11	138
12	155
13	170
14	186
15	202
16	218
17	234
18	250
19	265
20	265

Can you find a good estimate of the velocity of the car at time t = 12.5 seconds using this data?

$$slope = \frac{\Delta x}{\Delta t}$$

$$slope = \frac{x(13) - x(12)}{13s - 12s}$$

$$slope = \frac{170m - 155m}{1s}$$

$$slope = 15m/s$$

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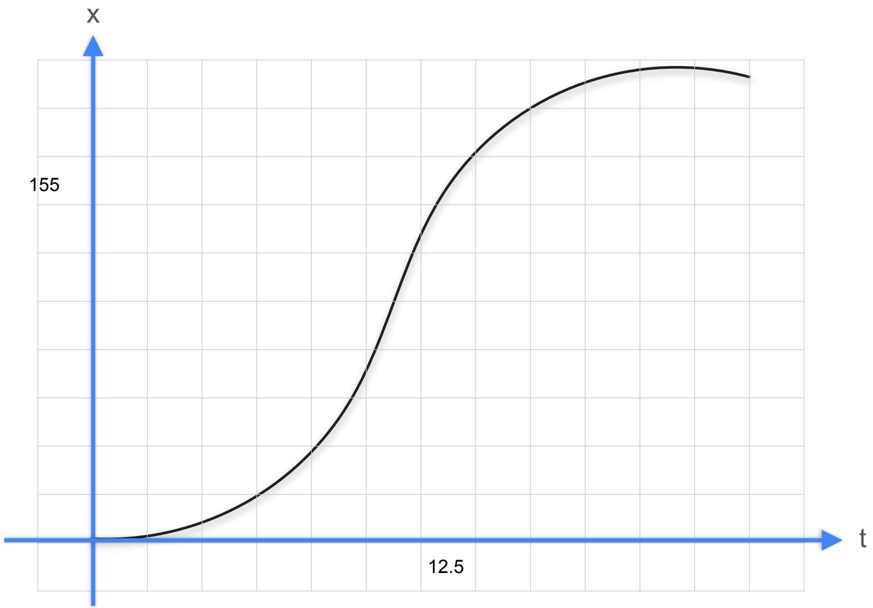
Derivatives and Optimization

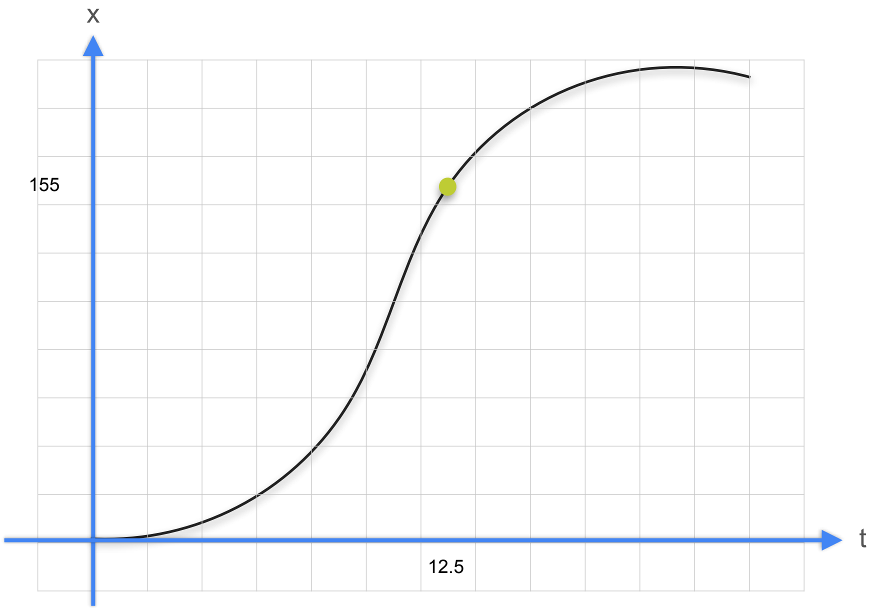
Derivatives and tangents

The derivative

The derivative

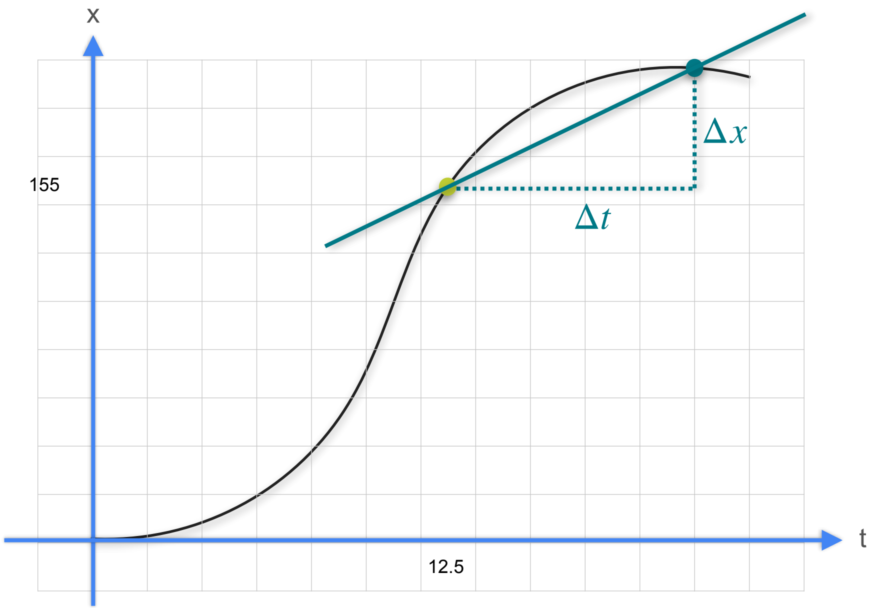


The derivative



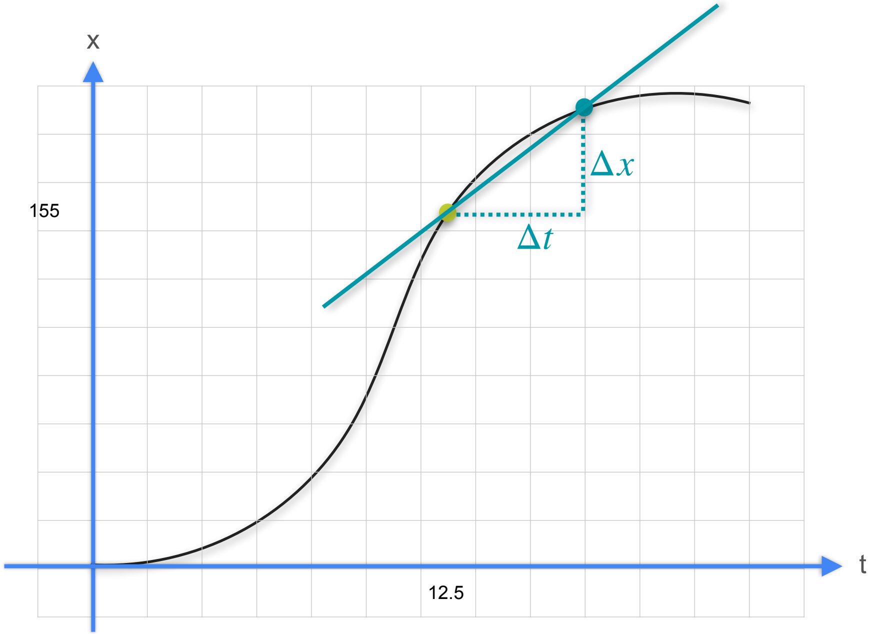
The derivative

$$\frac{\Delta x}{\Delta t}$$



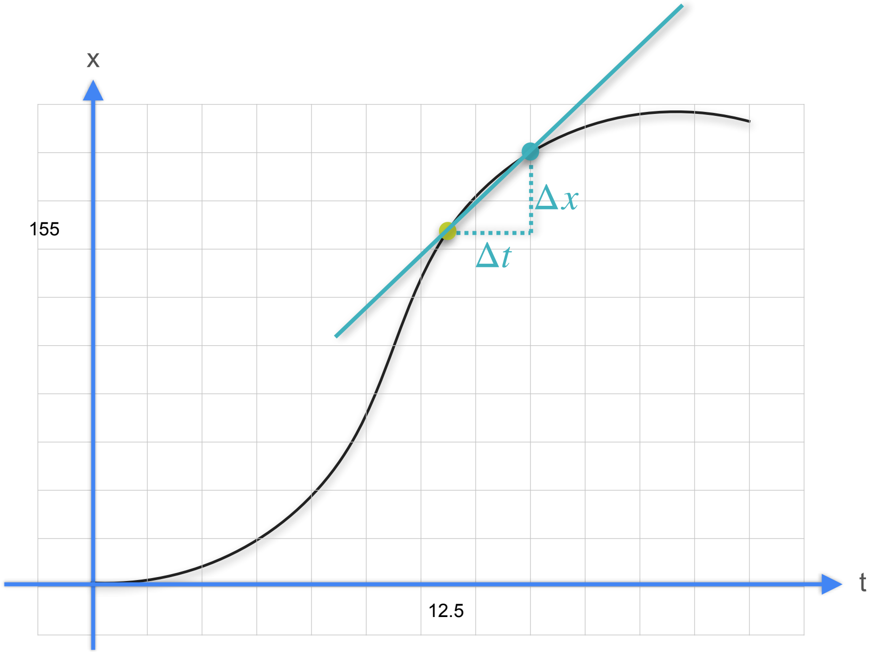
The derivative

$$\frac{\Delta x}{\Delta t} \qquad \frac{\Delta x}{\Delta t}$$



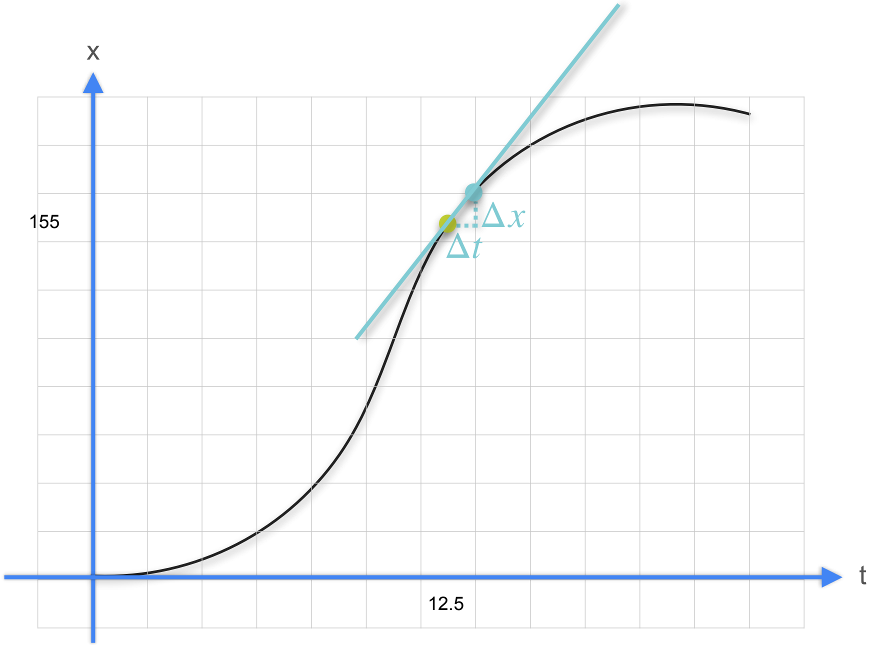
The derivative

$$\frac{\Delta x}{\Delta t} \quad \frac{\Delta x}{\Delta t} \quad \frac{\Delta x}{\Delta t}$$



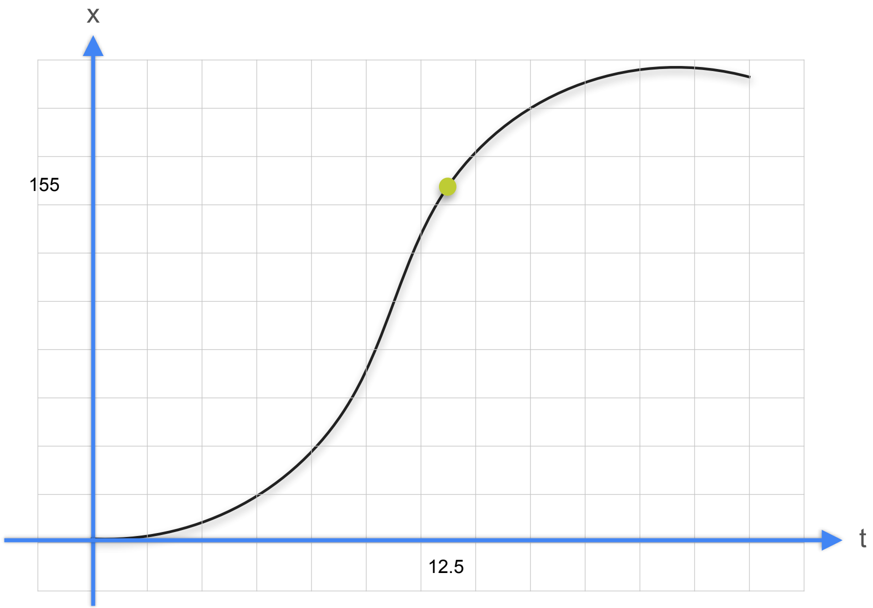
The derivative

$$\frac{\Delta x}{\Delta t} \quad \frac{\Delta x}{\Delta t} \quad \frac{\Delta x}{\Delta t} \quad \frac{\Delta x}{\Delta t}$$



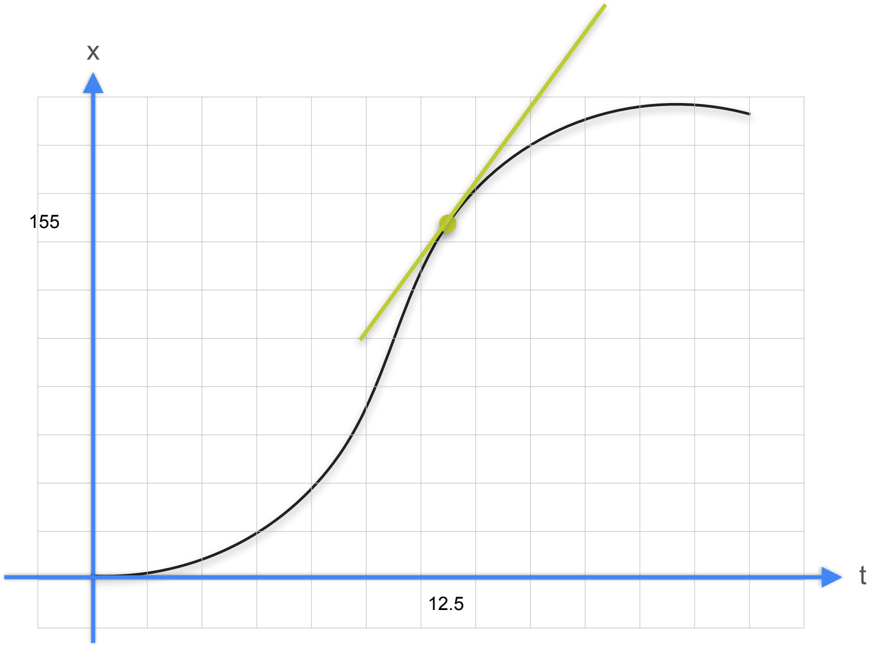
The derivative

$$\frac{\Delta x}{\Delta t} \quad \frac{\Delta x}{\Delta t} \quad \frac{\Delta x}{\Delta t} \quad \frac{\Delta x}{\Delta t} \longrightarrow \frac{dx}{dt}$$



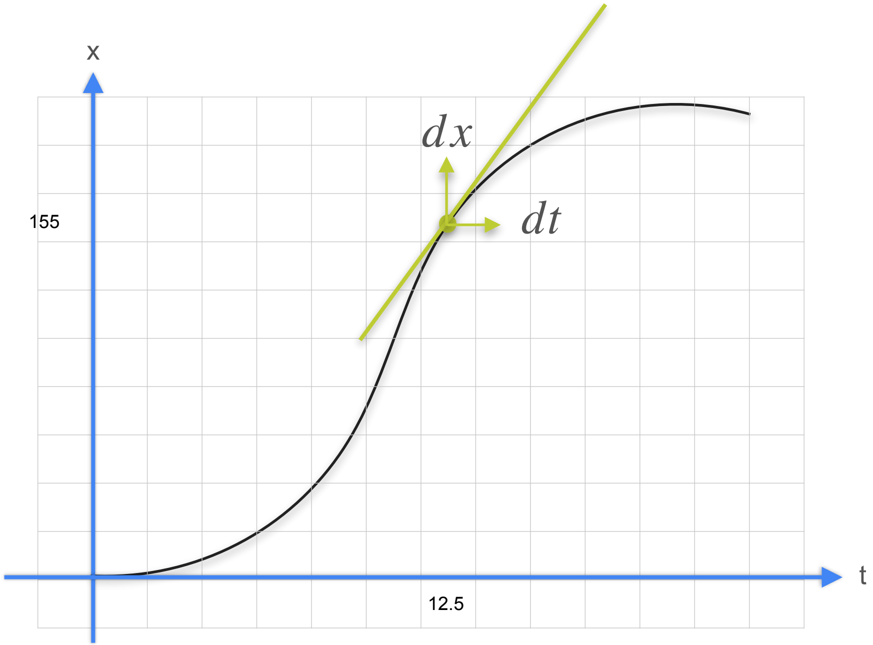
The derivative

$$\frac{\Delta x}{\Delta t} \quad \frac{\Delta x}{\Delta t} \quad \frac{\Delta x}{\Delta t} \quad \frac{\Delta x}{\Delta t} \longrightarrow \frac{dx}{dt}$$



The derivative

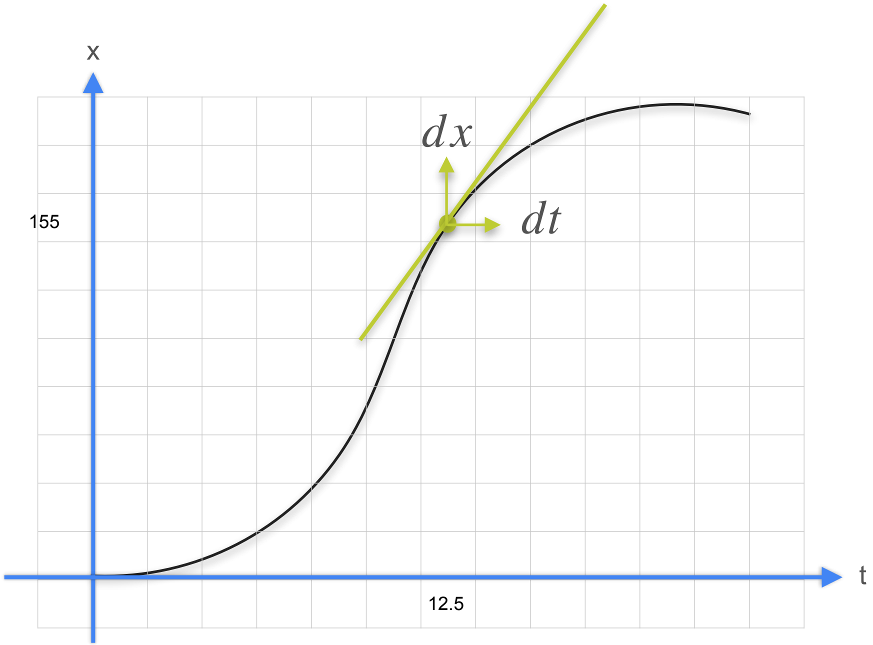
$$\frac{\Delta x}{\Delta t} \quad \frac{\Delta x}{\Delta t} \quad \frac{\Delta x}{\Delta t} \quad \frac{\Delta x}{\Delta t} \longrightarrow \frac{dx}{dt}$$



The derivative

$$\frac{\Delta x}{\Delta t} \quad \frac{\Delta x}{\Delta t} \quad \frac{\Delta x}{\Delta t} \quad \frac{\Delta x}{\Delta t} \longrightarrow \frac{dx}{dt}$$

Derivative



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Derivatives and Optimization

Slopes, maxima, and minima

Zero Slope

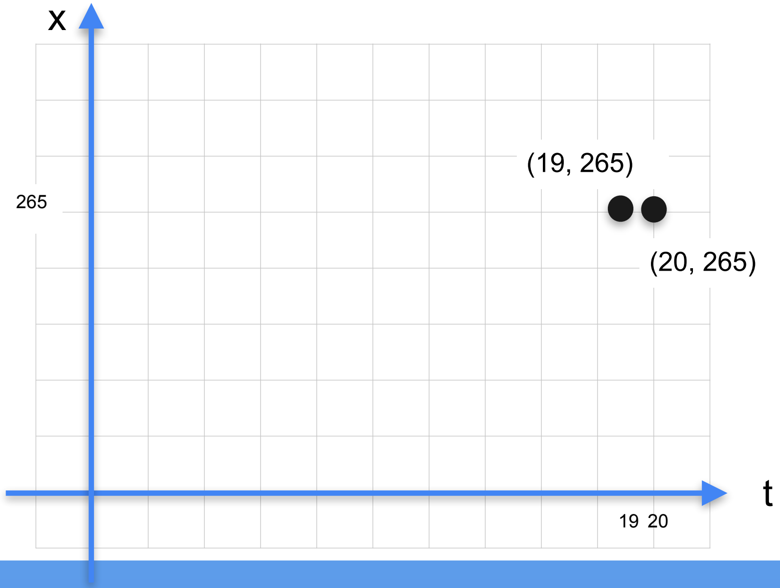
t (s)	x (m)
19	265
20	265

Zero Slope

t (s)	x (m)
19	265
20	265

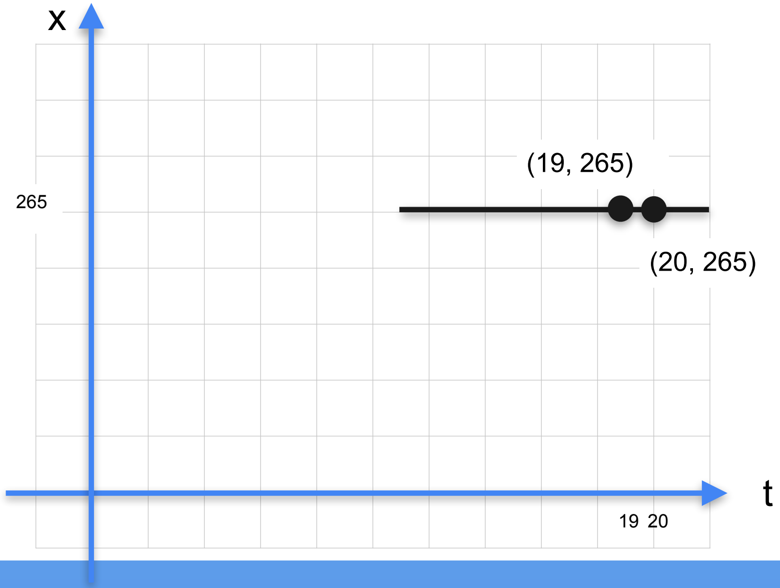
Zero Slope

t (s)	x (m)
19	265
20	265



Zero Slope

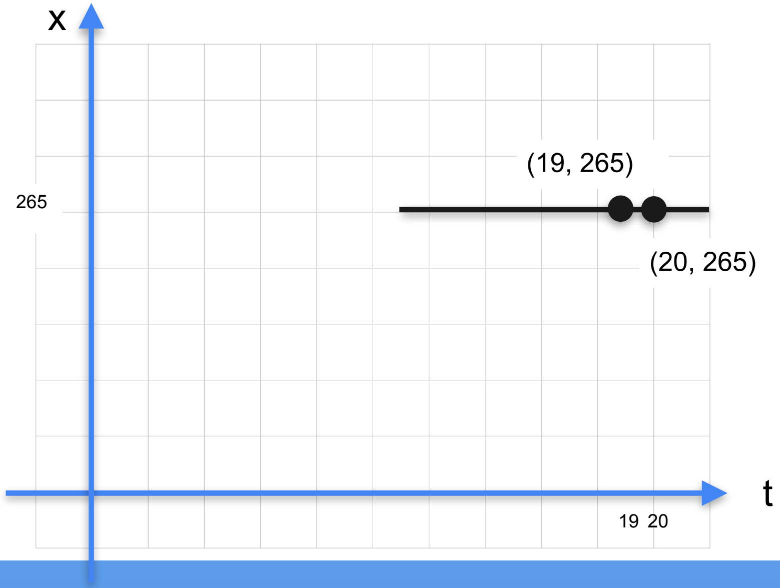
t (s)	x (m)
19	265
20	265



Zero Slope

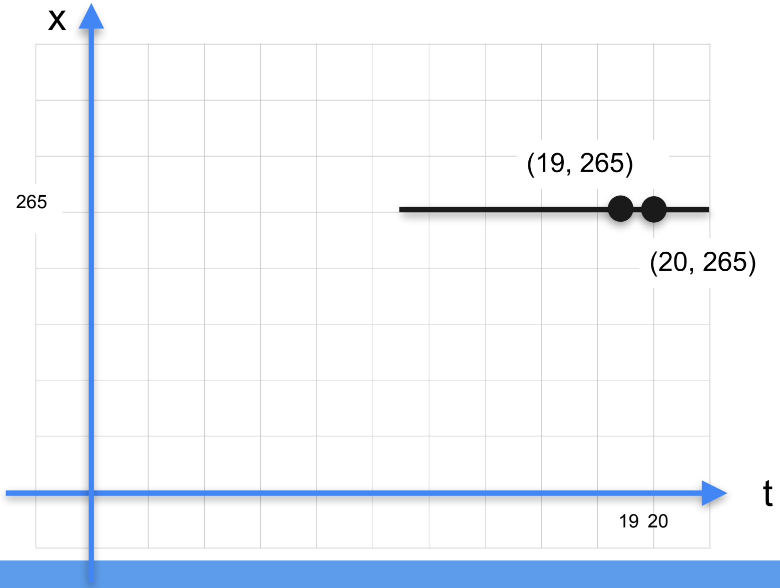
t (s)	x (m)
19	265
20	265

$$slope = \frac{\Delta x}{\Delta t}$$



Zero Slope

t (s)	x (m)
19	265
20	265

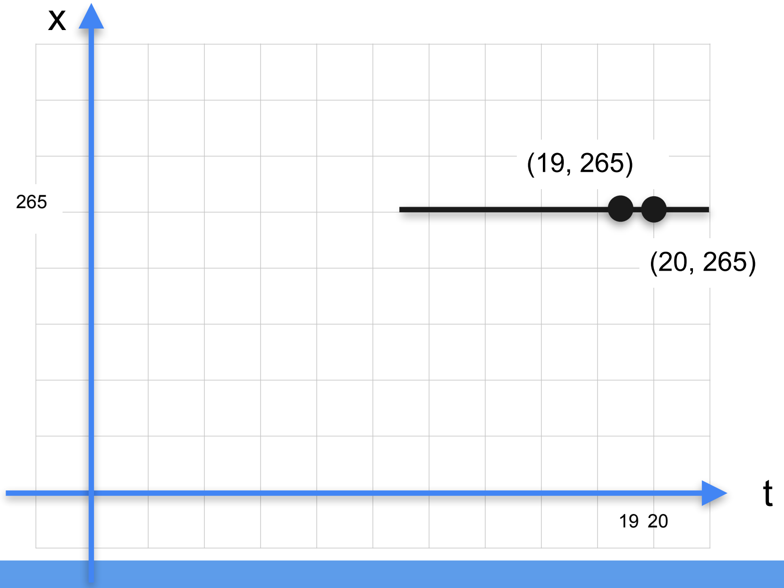


$$slope = \frac{\Delta x}{\Delta t}$$

$$slope = \frac{x(20) - x(19)}{20 - 19}$$

Zero Slope

t (s)	x (m)
19	265
20	265



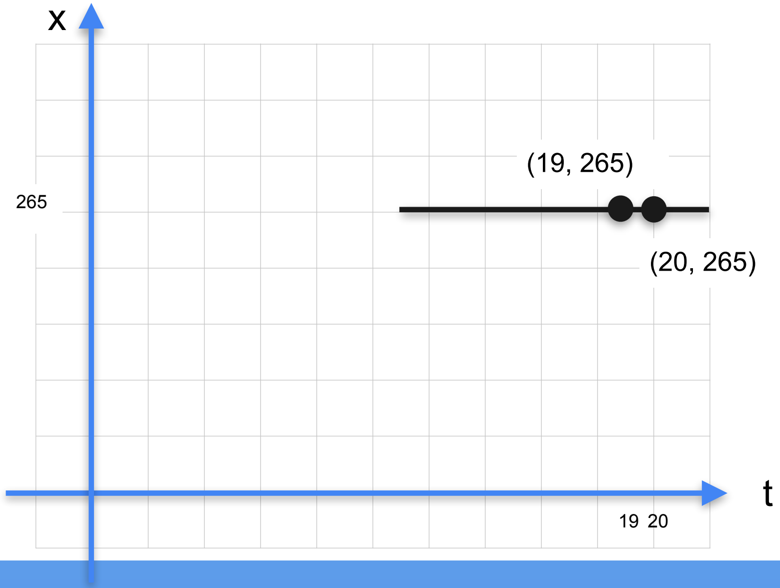
$$slope = \frac{\Delta x}{\Delta t}$$

$$slope = \frac{x(20) - x(19)}{20 - 19}$$

$$slope = \frac{265m - 265m}{1s}$$

Zero Slope

t (s)	x (m)
19	265
20	265



$$slope = \frac{\Delta x}{\Delta t}$$

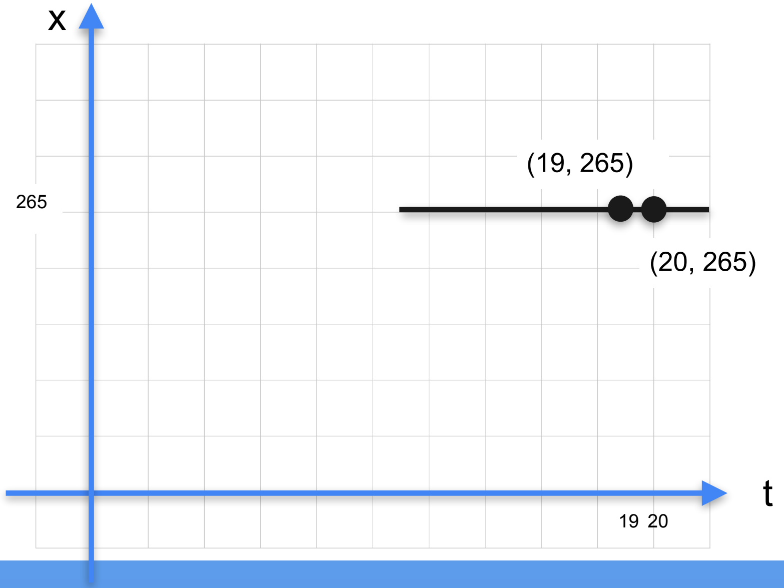
$$slope = \frac{x(20) - x(19)}{20 - 19}$$

$$slope = \frac{265m - 265m}{1s}$$

$$slope = \frac{0}{1}$$

Zero Slope

t (s)	x (m)
19	265
20	265



$$slope = \frac{\Delta x}{\Delta t}$$

$$slope = \frac{x(20) - x(19)}{20 - 19}$$

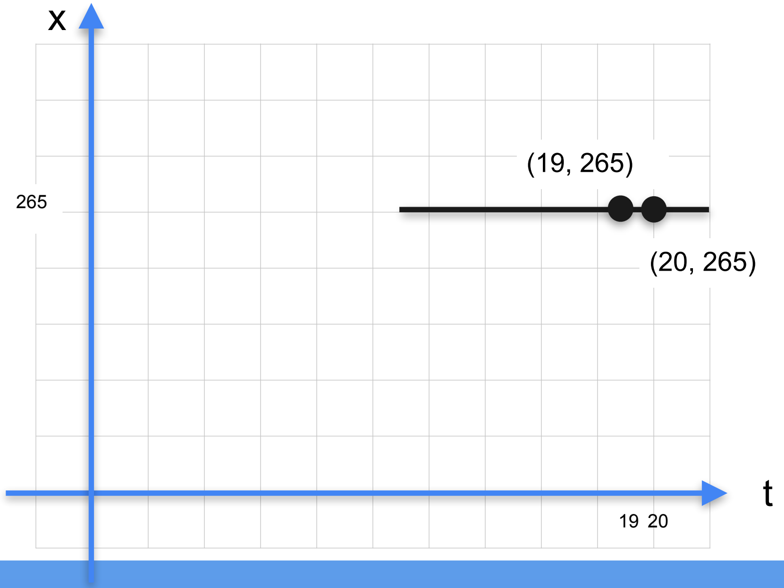
$$slope = \frac{265m - 265m}{1s}$$

$$slope = \frac{0}{1}$$

No rise in distance

Zero Slope

t (s)	x (m)
19	265
20	265



$$slope = \frac{\Delta x}{\Delta t}$$

$$slope = \frac{x(20) - x(19)}{20 - 19}$$

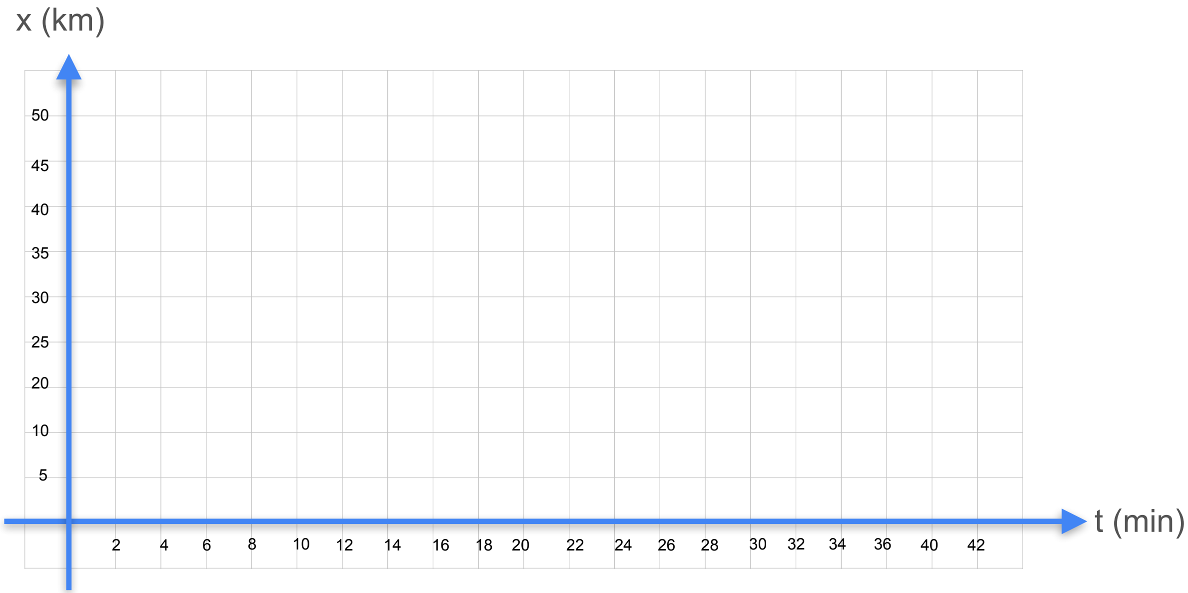
$$slope = \frac{265m - 265m}{1s}$$

$$slope = \frac{0}{1}$$

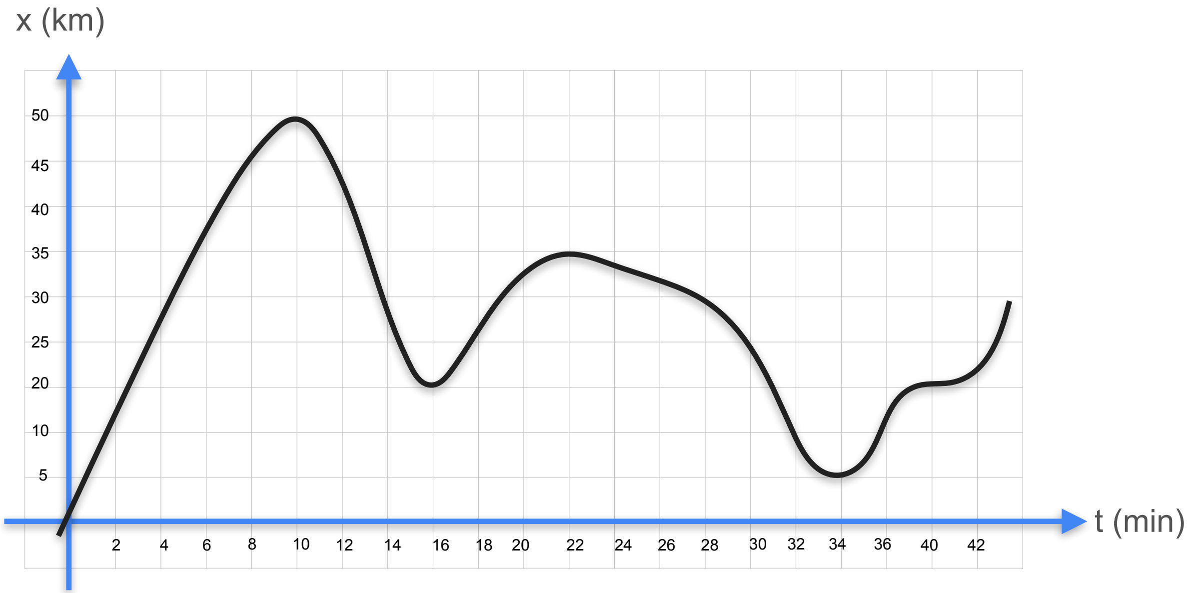
No rise in distance

$$slope = 0 \ m/s$$

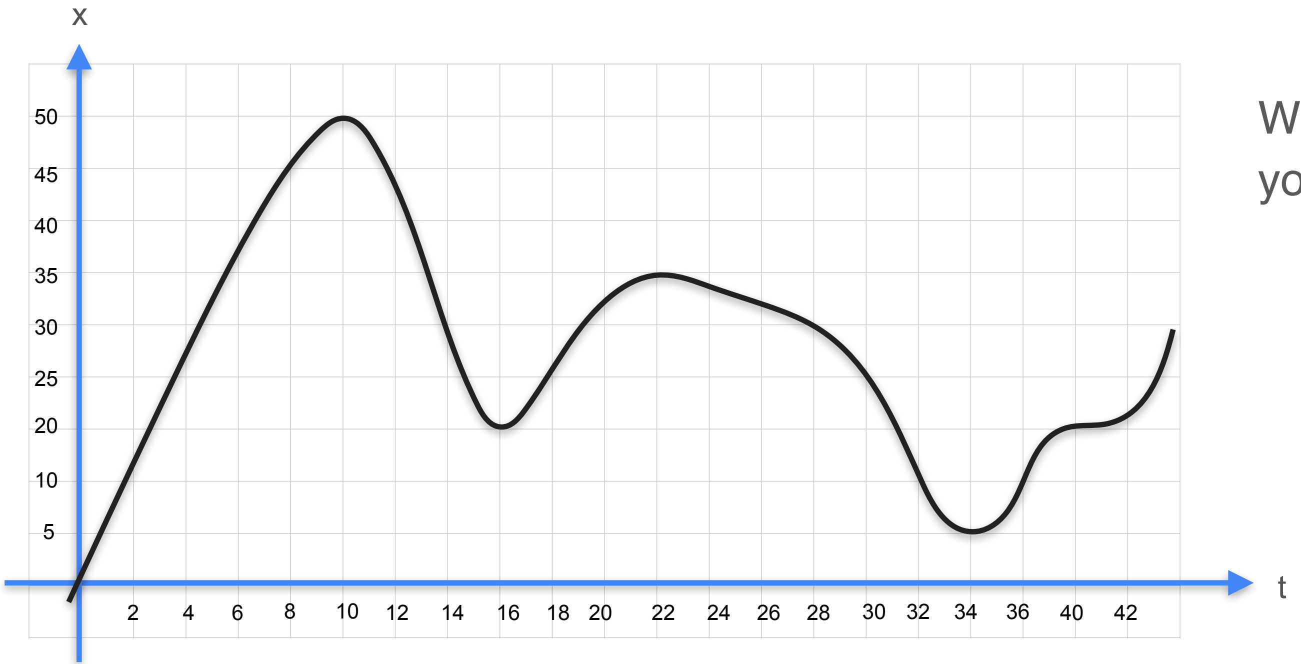
Minima and Maxima



Minima and Maxima

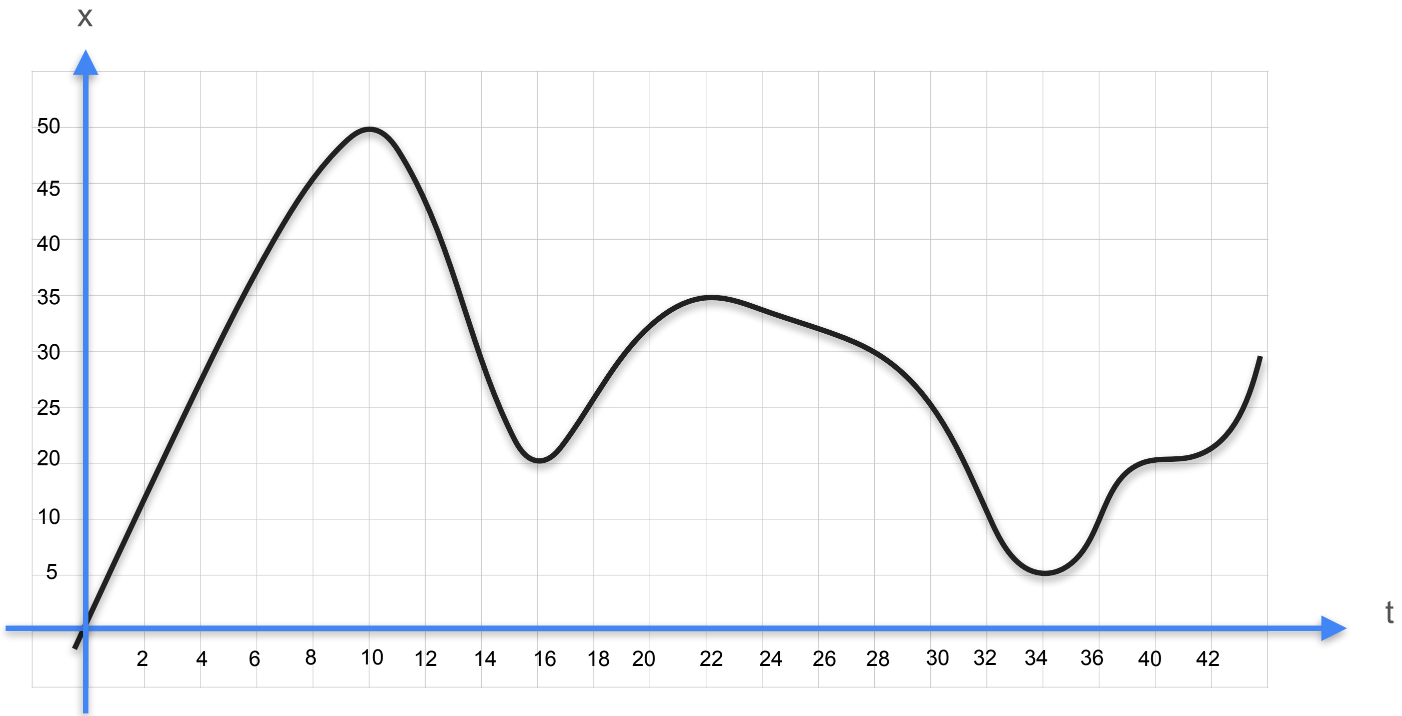


Quiz : Minima and Maxima 1

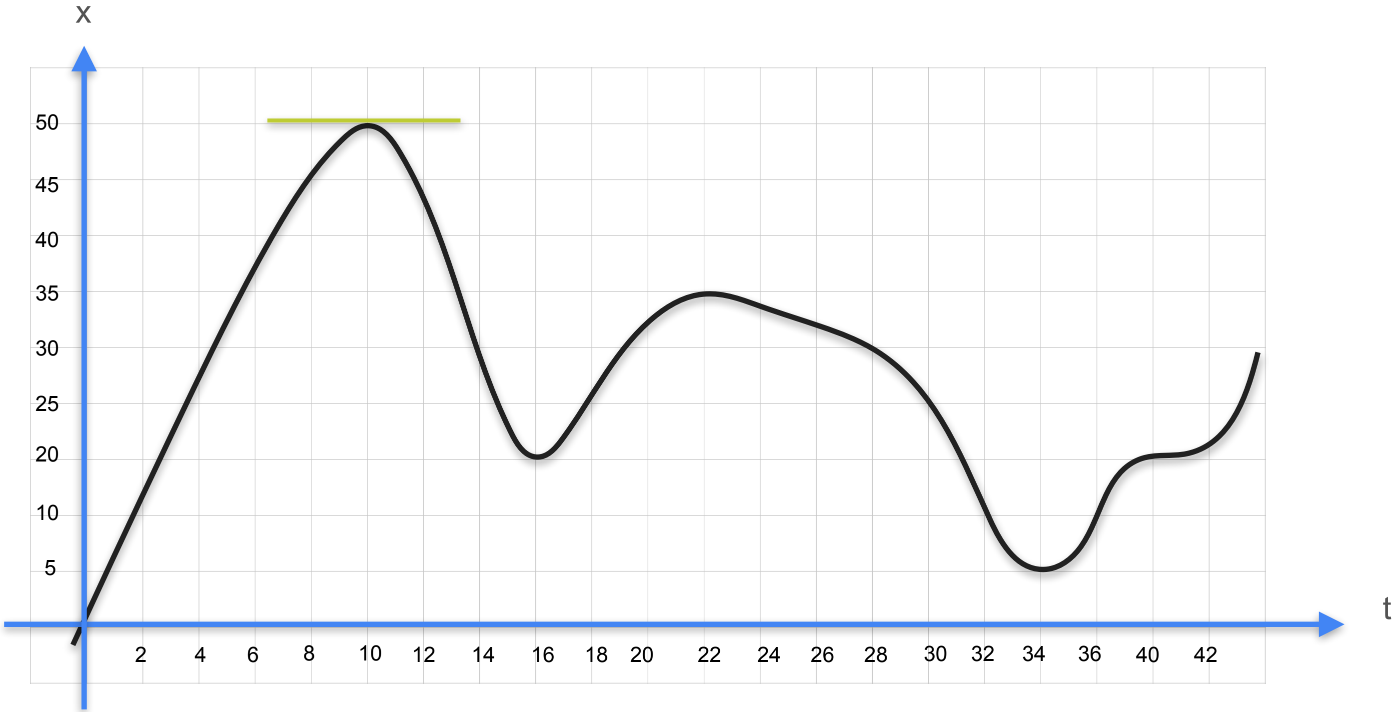


Where was the velocity of your car zero?

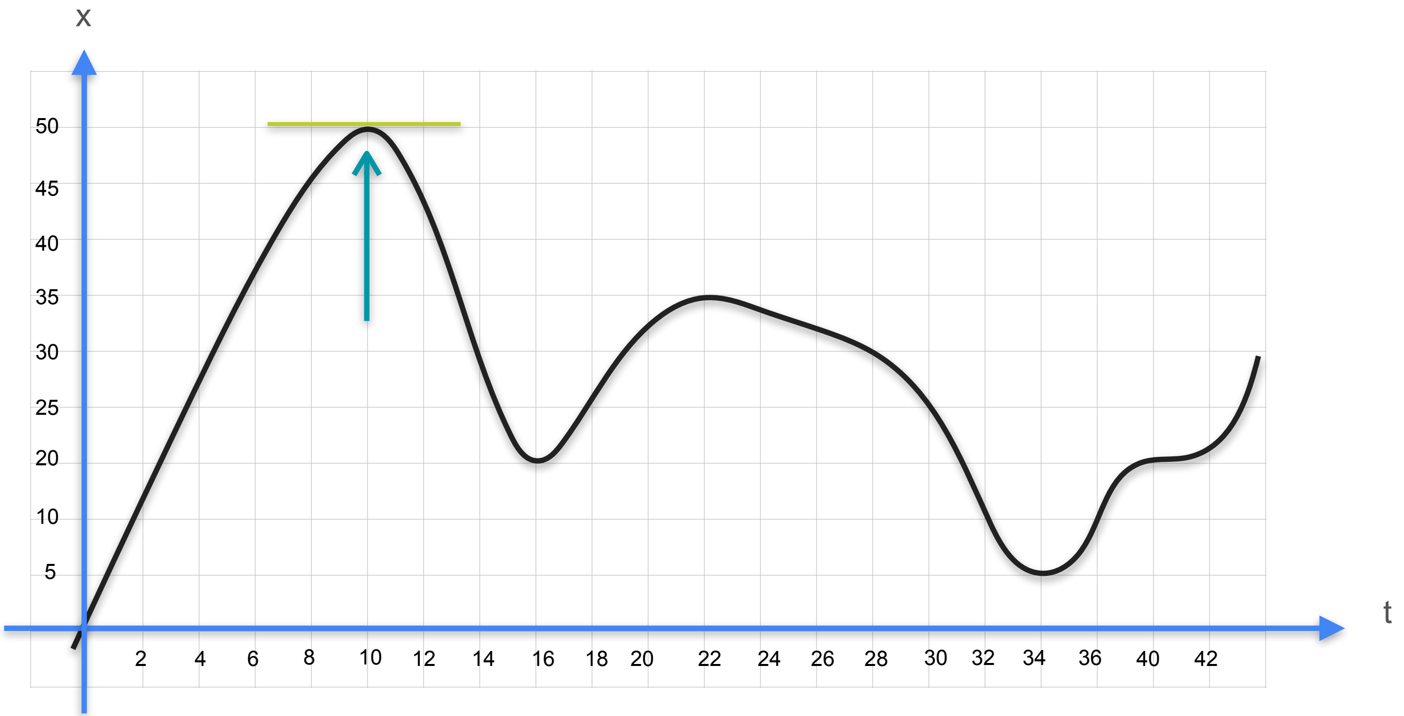
Quiz : Minima and Maxima 1 - Solution



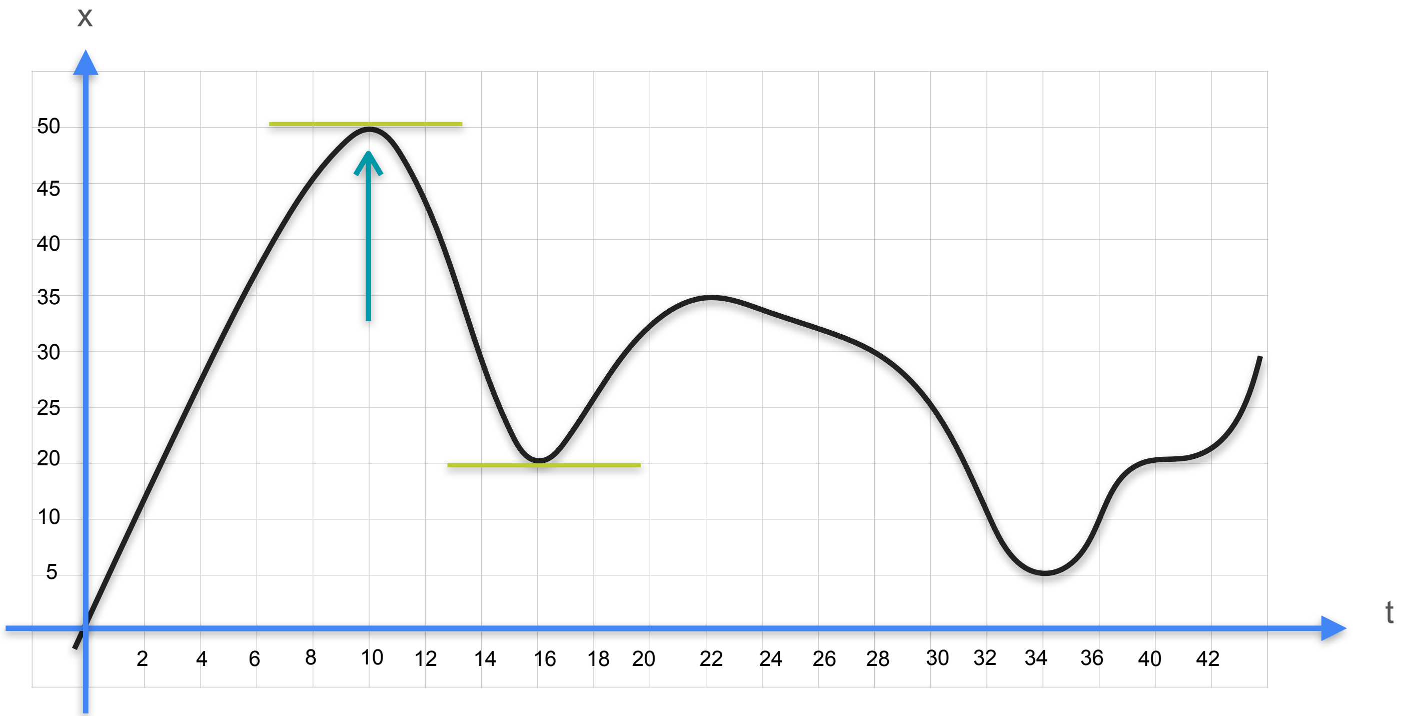
Quiz : Minima and Maxima 1 - Solution



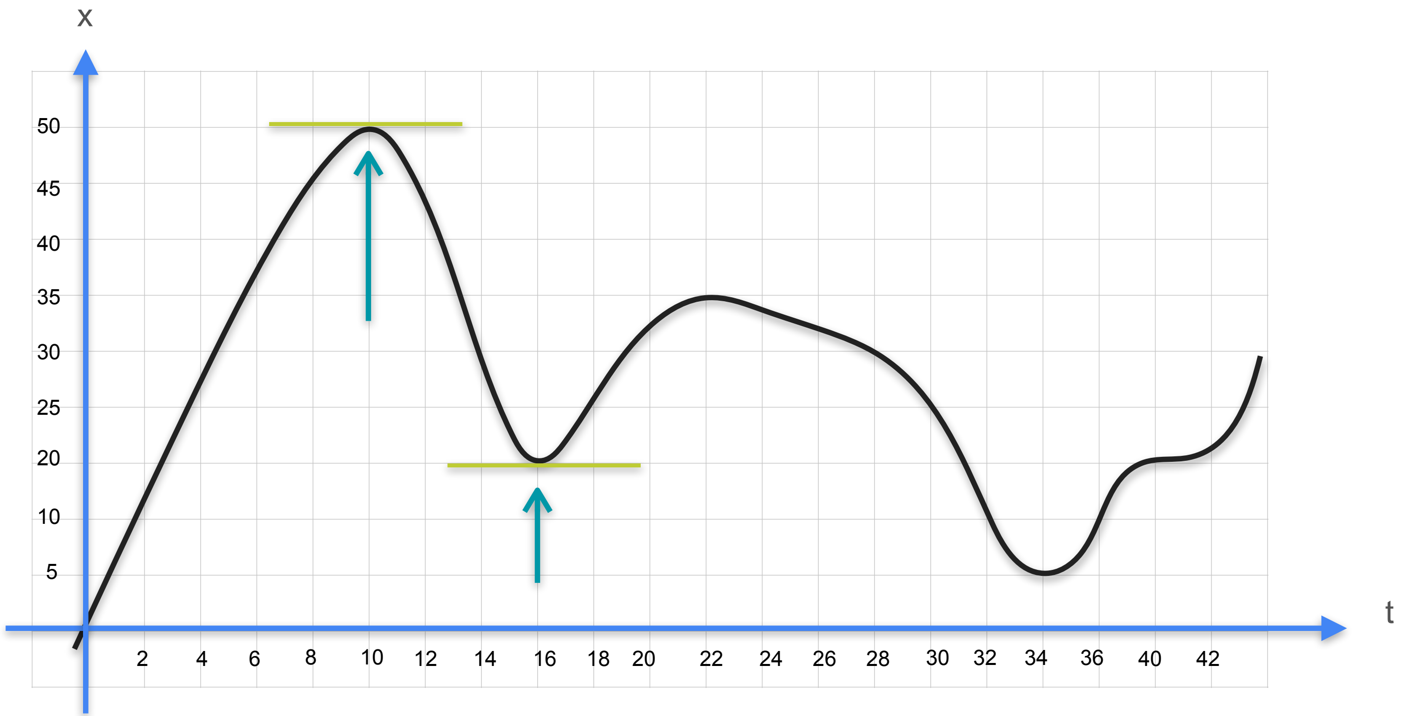
Quiz : Minima and Maxima 1 - Solution



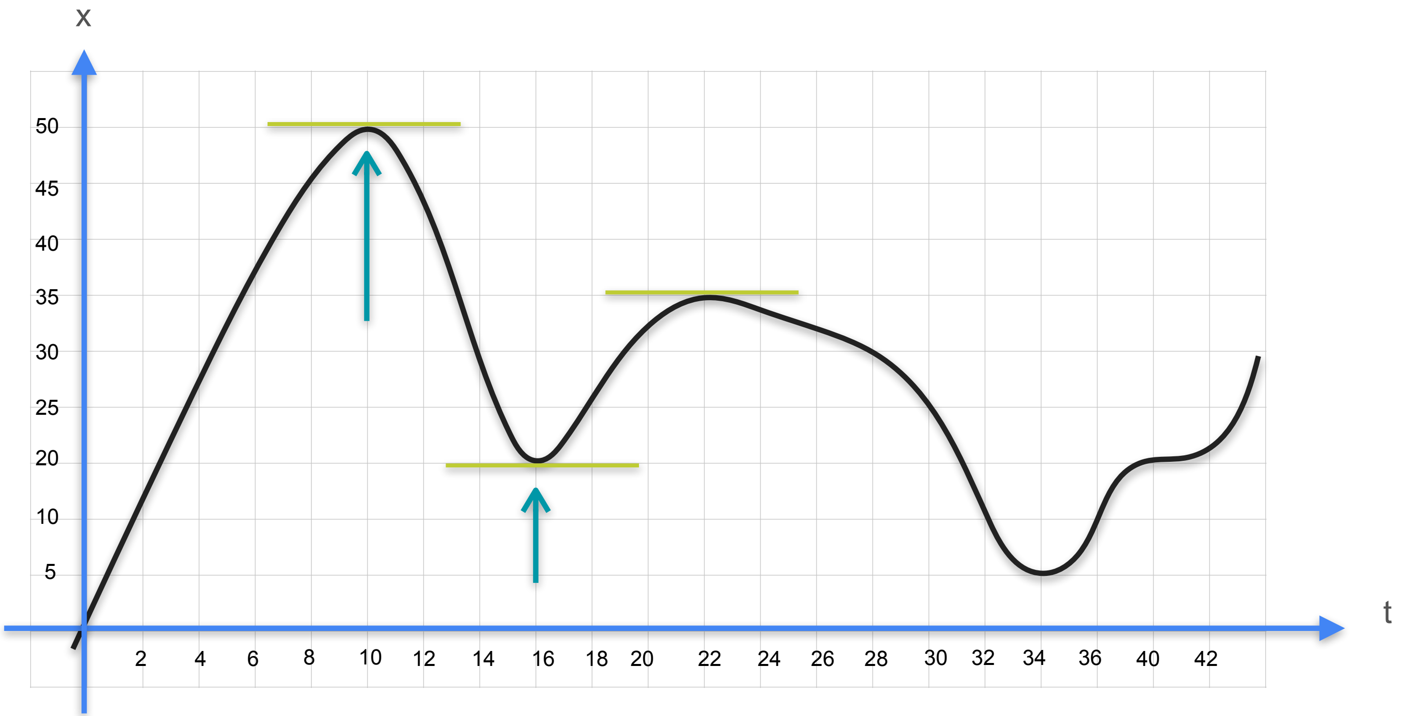
Quiz : Minima and Maxima 1 - Solution



Quiz : Minima and Maxima 1 - Solution



Quiz : Minima and Maxima 1 - Solution



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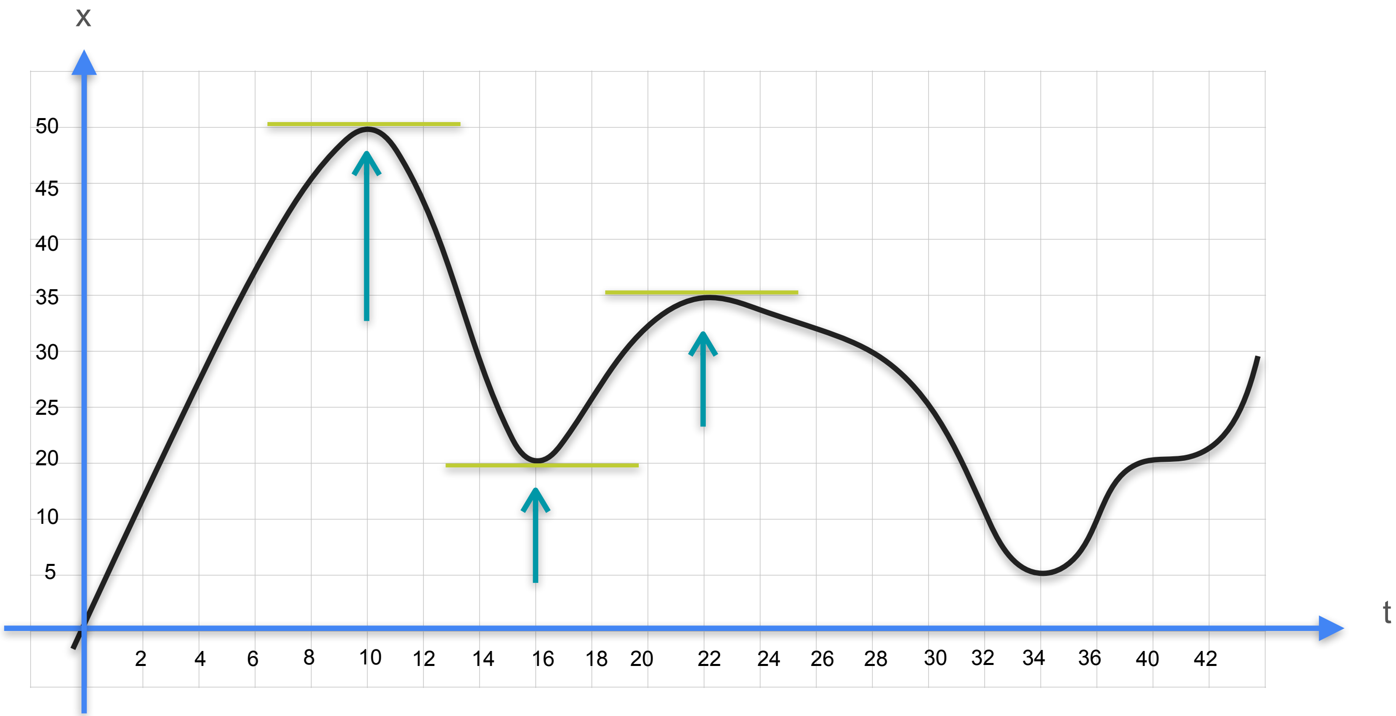
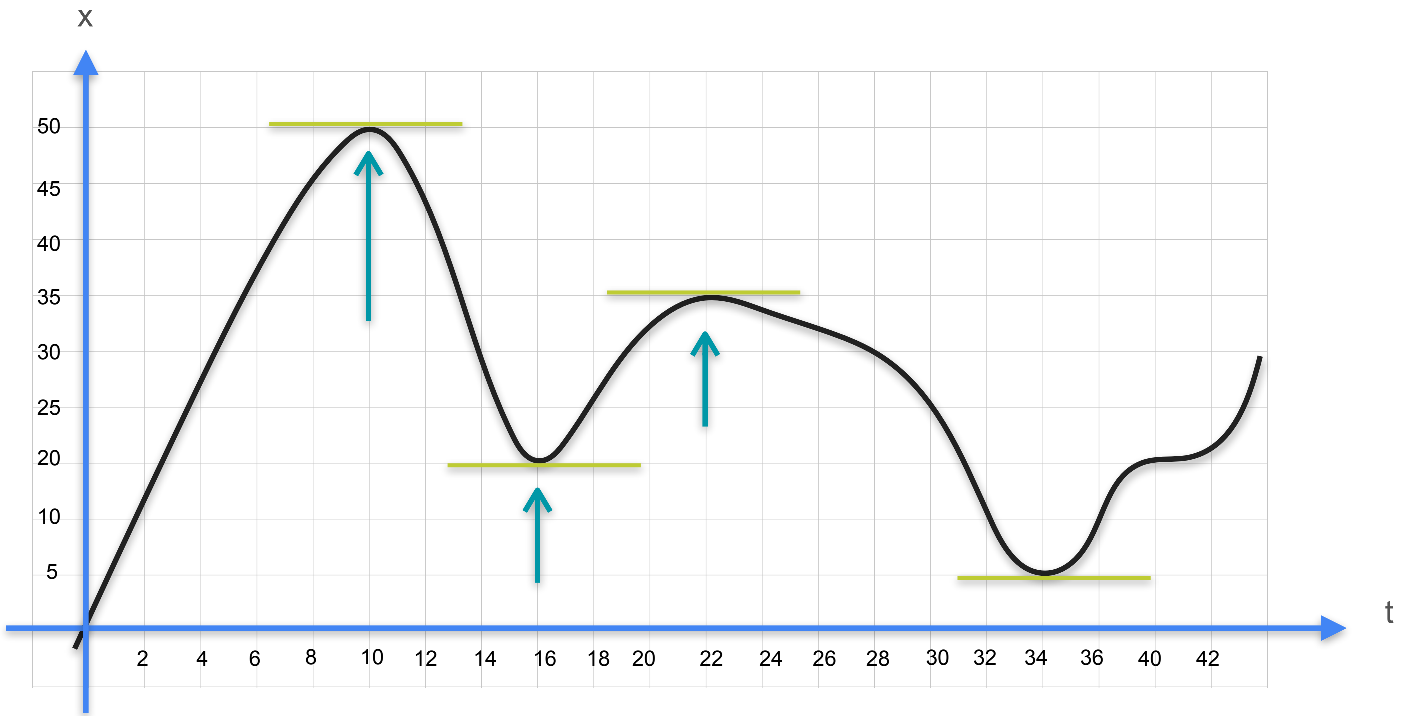
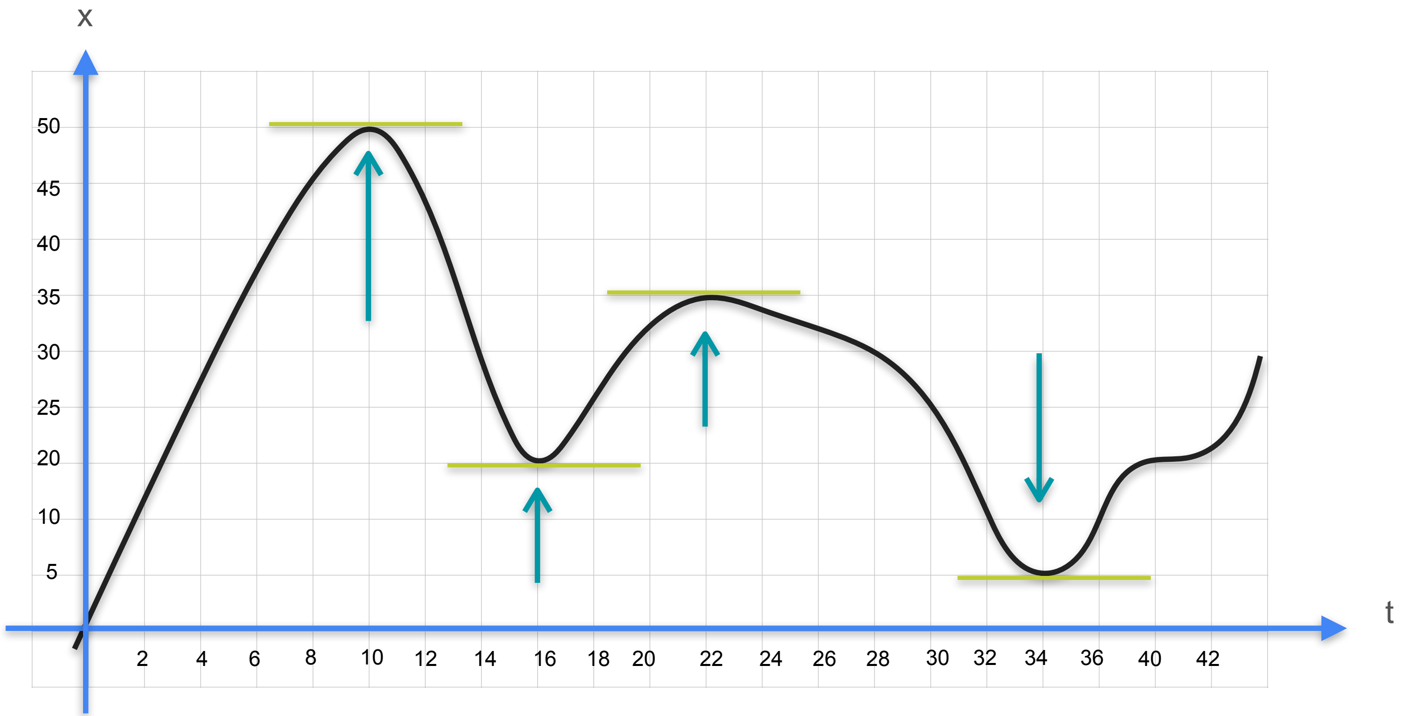
Quiz : Minima and Maxima 1 - Solution



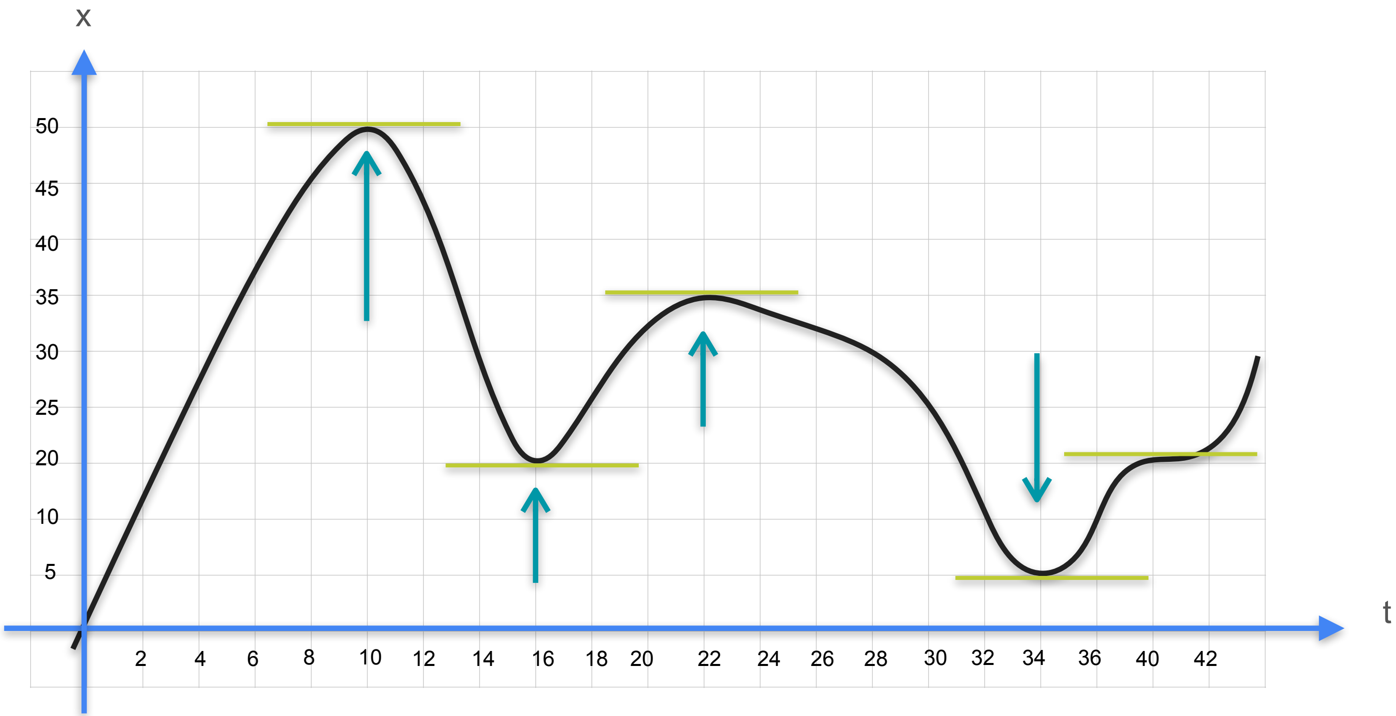
Quiz : Minima and Maxima 1 - Solution



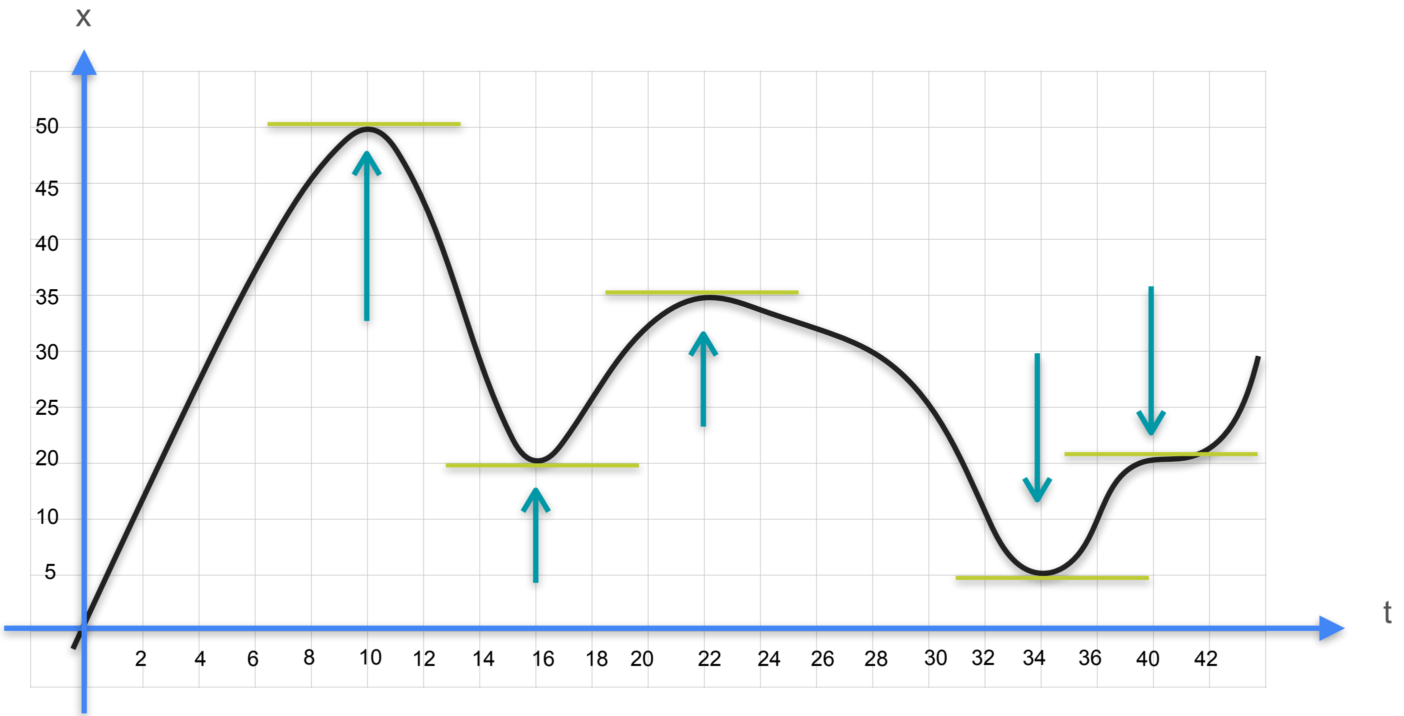
Quiz : Minima and Maxima 1 - Solution



Quiz : Minima and Maxima 1 - Solution



Quiz : Minima and Maxima 1 - Solution



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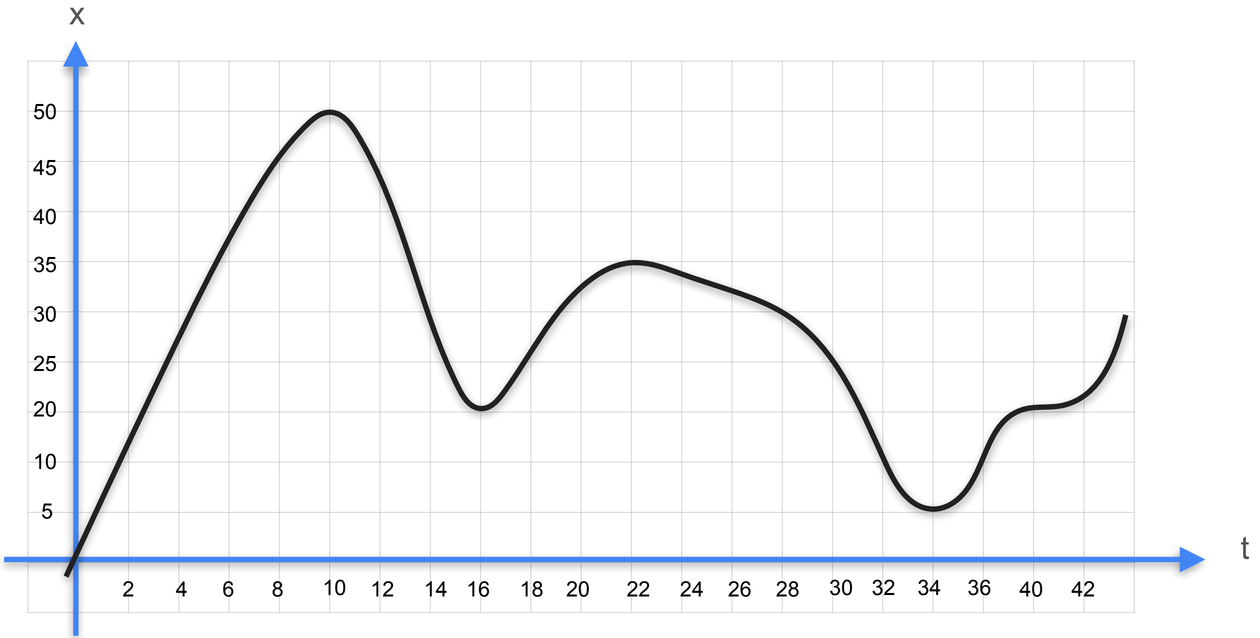
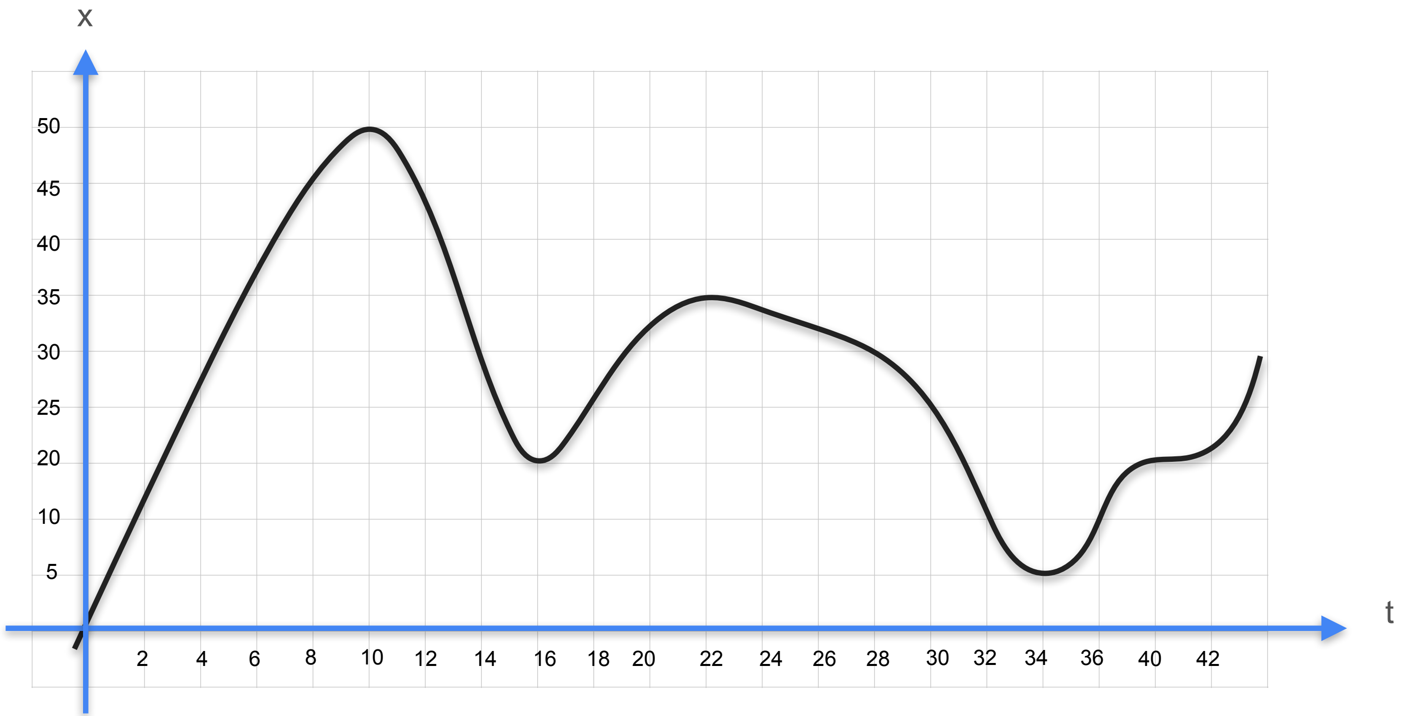
Quiz : Concept of Derivatives 3

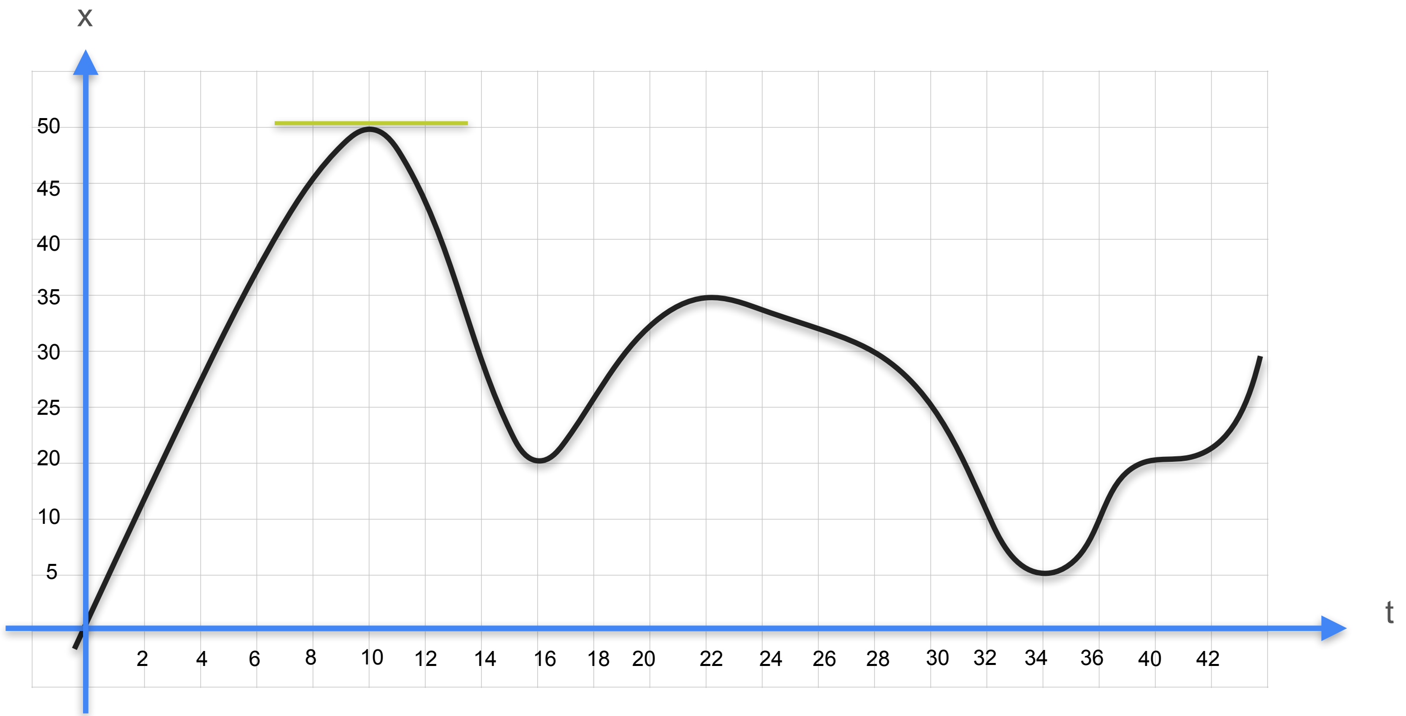


At what time was the car farthest from its starting point?

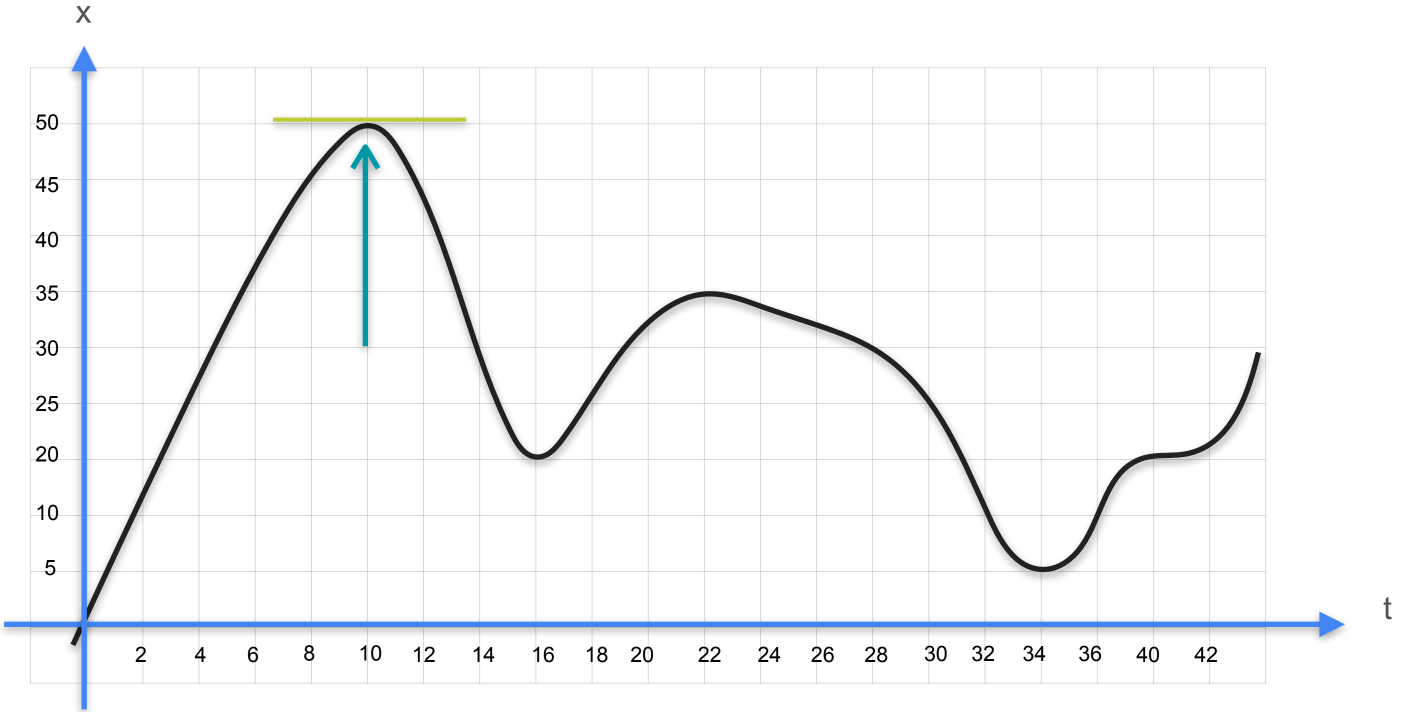
Quiz : Maxima & Minima - Solution



Quiz : Maxima & Minima - Solution



Quiz : Maxima & Minima - Solution



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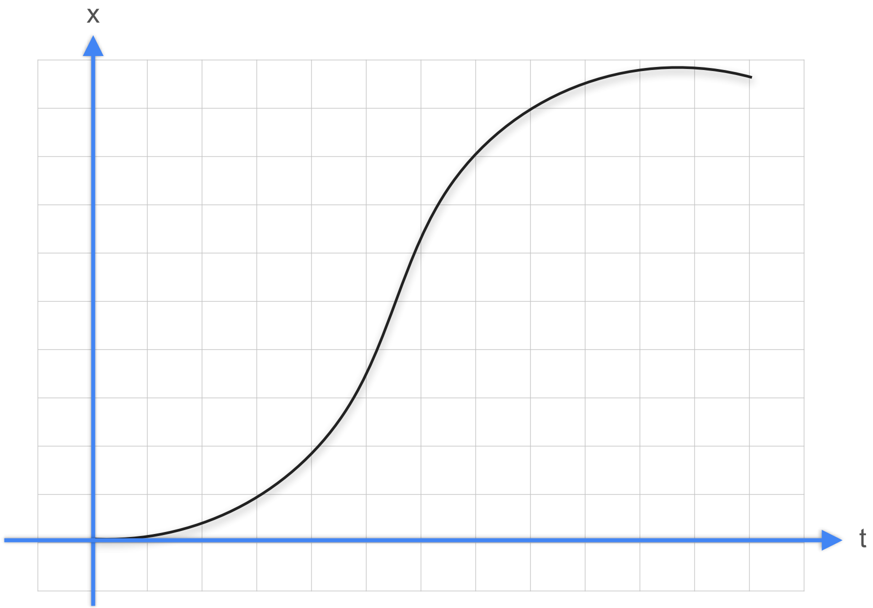
Derivatives and Optimization

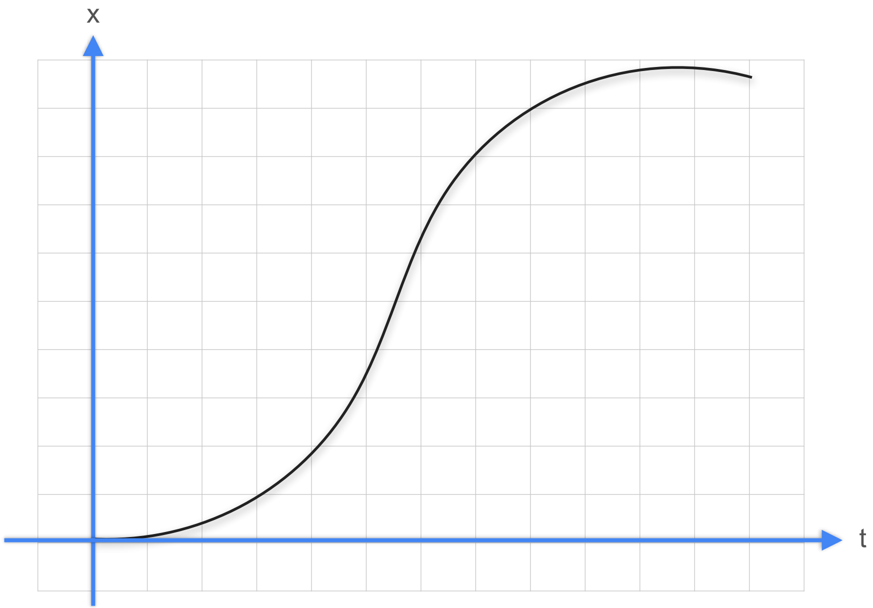
Derivative notation

Derivatives



Derivatives

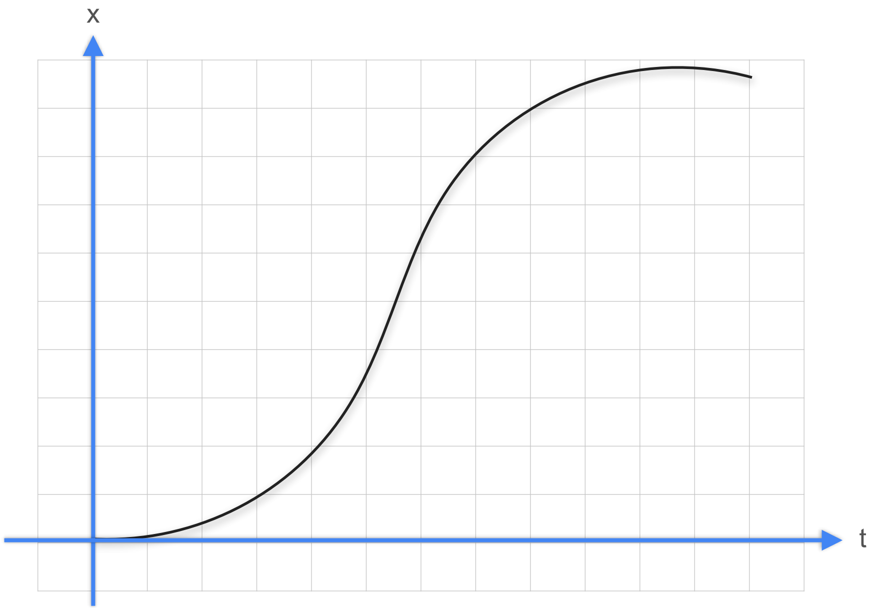
$$\text{slope} = \frac{\text{change in distance}}{\text{change in time}}$$



Derivatives

$$\text{slope} = \frac{\text{change in distance}}{\text{change in time}}$$

$$\text{slope} = \frac{\Delta x}{\Delta t}$$

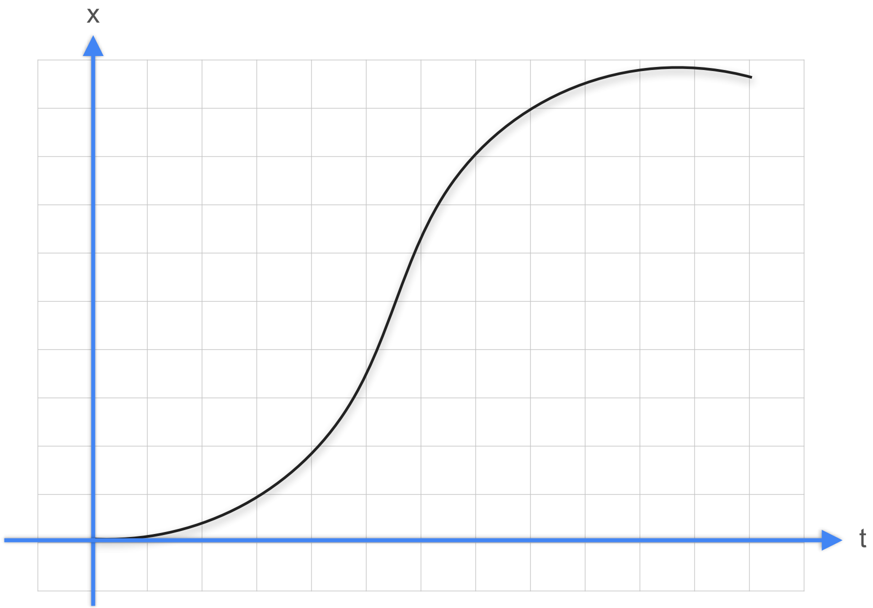


Derivatives

$$\text{slope} = \frac{\text{change in distance}}{\text{change in time}}$$

$$\text{slope} = \frac{\Delta x}{\Delta t}$$

$$\text{slope at a point} = \frac{dx}{dt}$$



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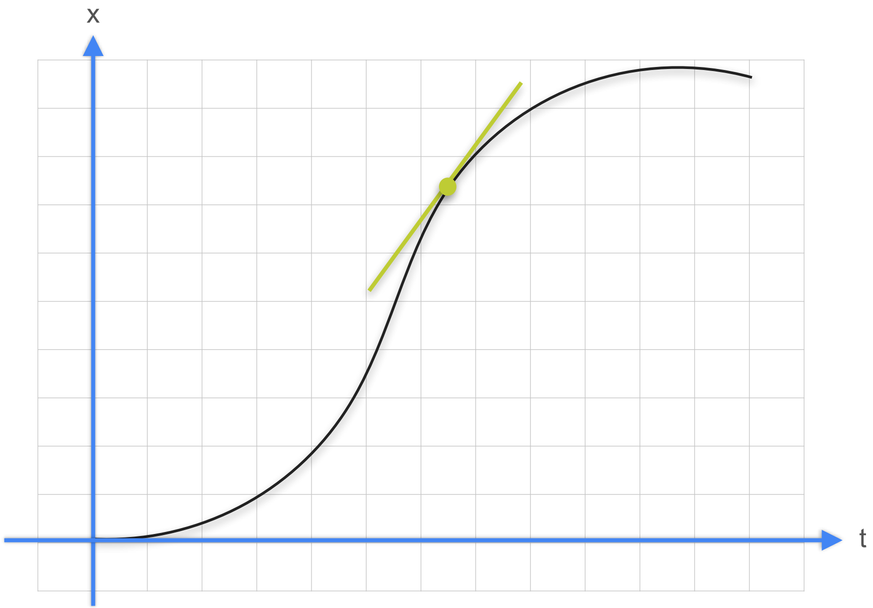

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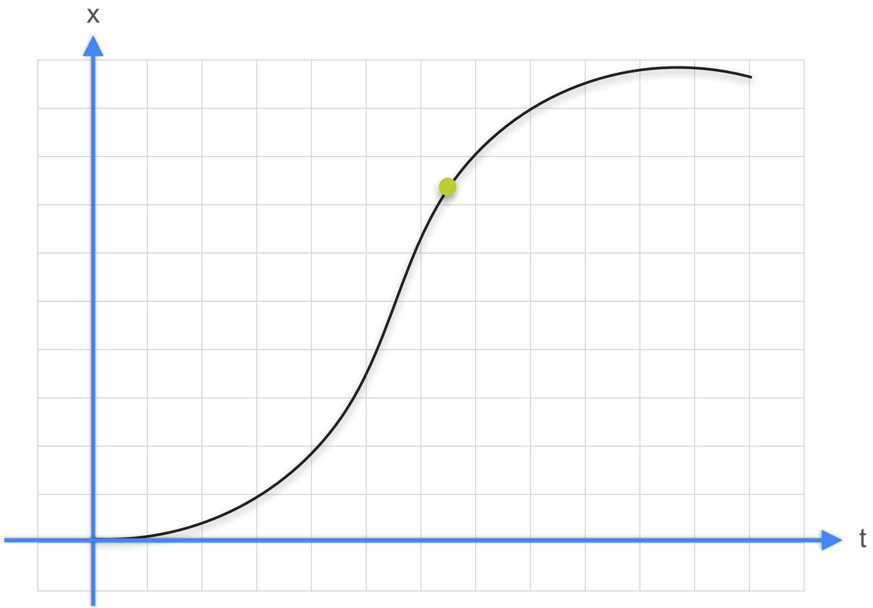

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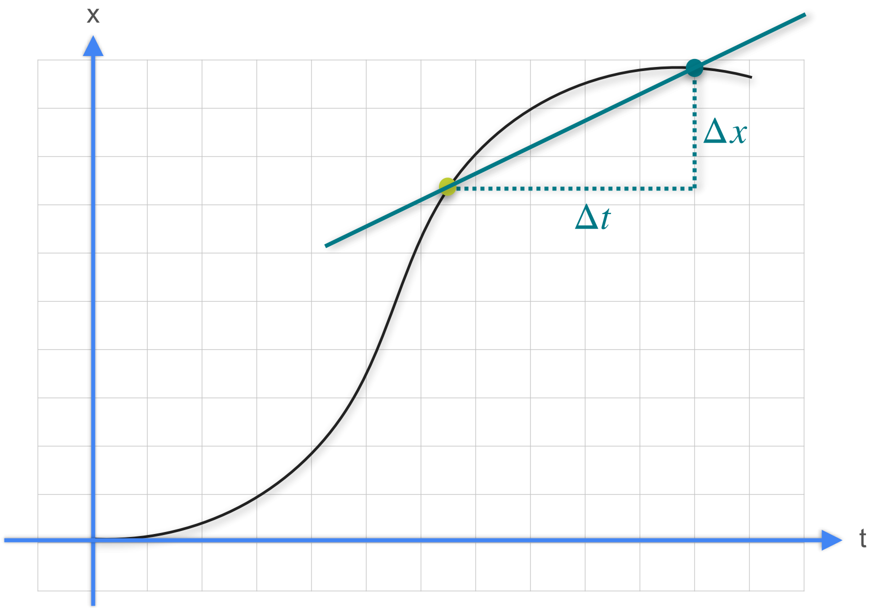

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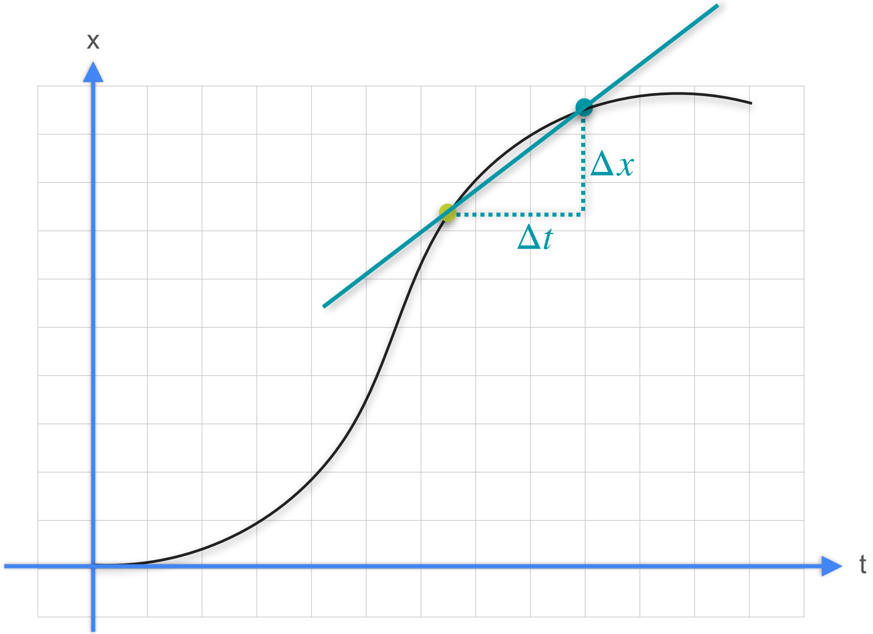

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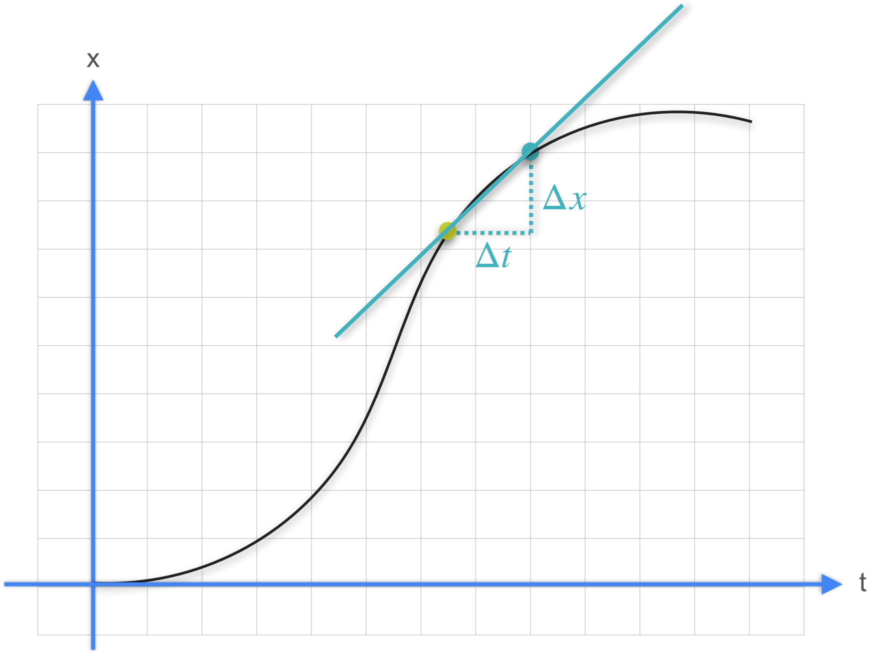

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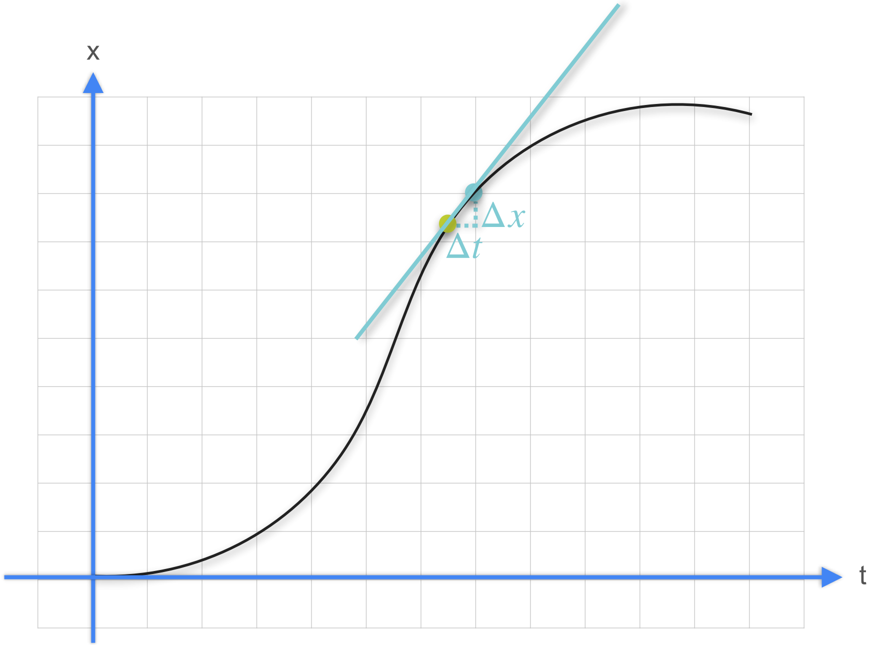

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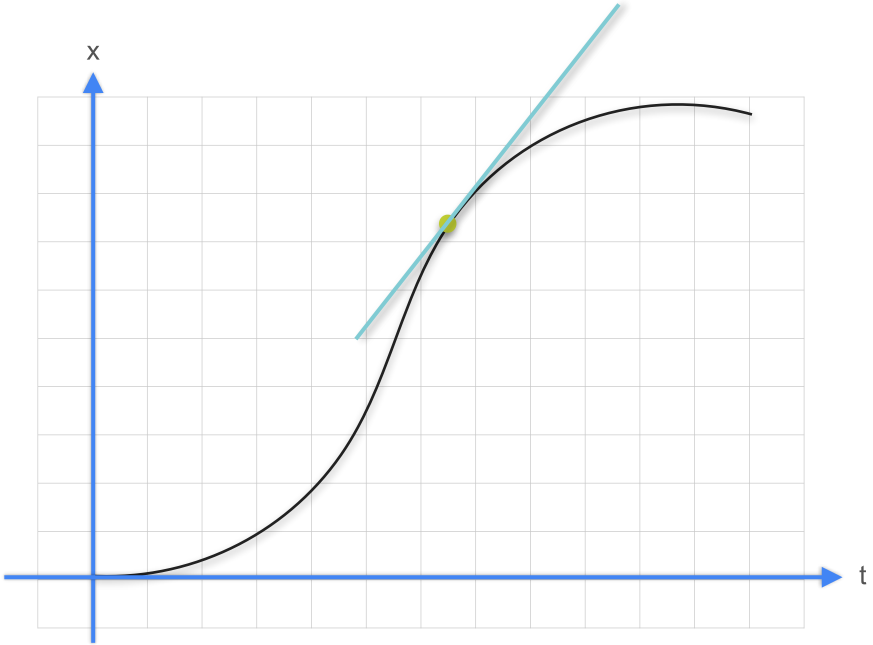

Derivatives

$$\text{slope} = \frac{\text{change in distance}}{\text{change in time}}$$

$$\text{slope} = \frac{\Delta x}{\Delta t}$$

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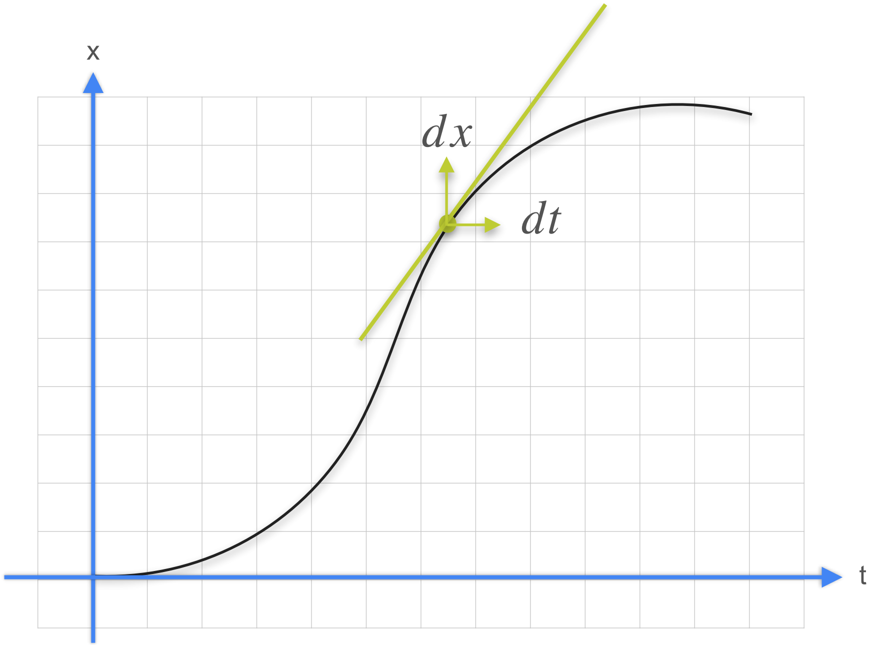
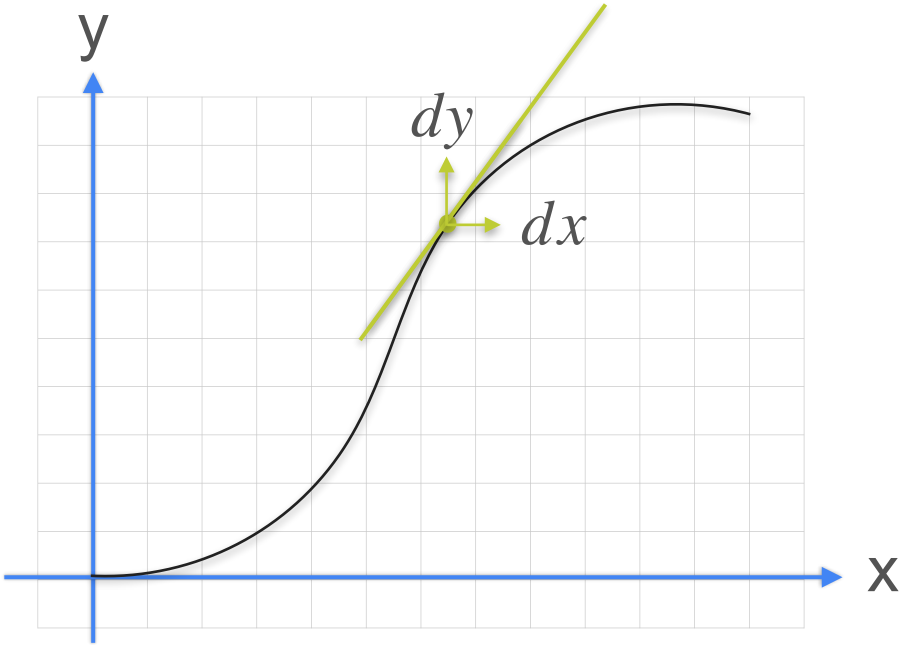


Derivatives

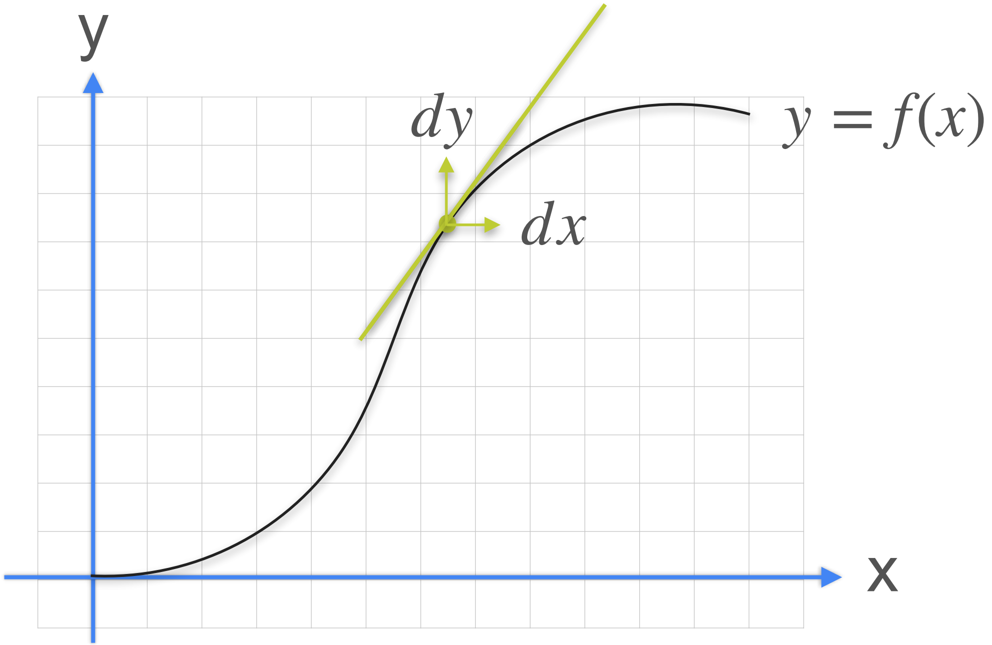
$$\text{slope} = \frac{\text{vertical change}}{\text{horizontal change}}$$

$$\text{slope} = \frac{\Delta y}{\Delta x}$$

$$\text{slope at a point} = \frac{dy}{dx}$$

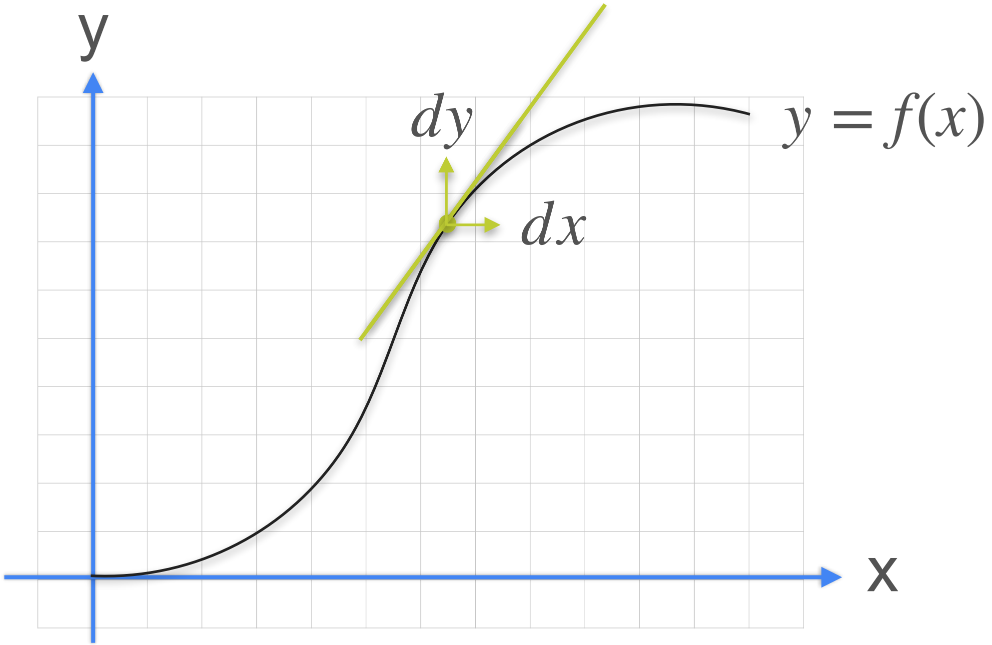


Derivatives



Derivatives

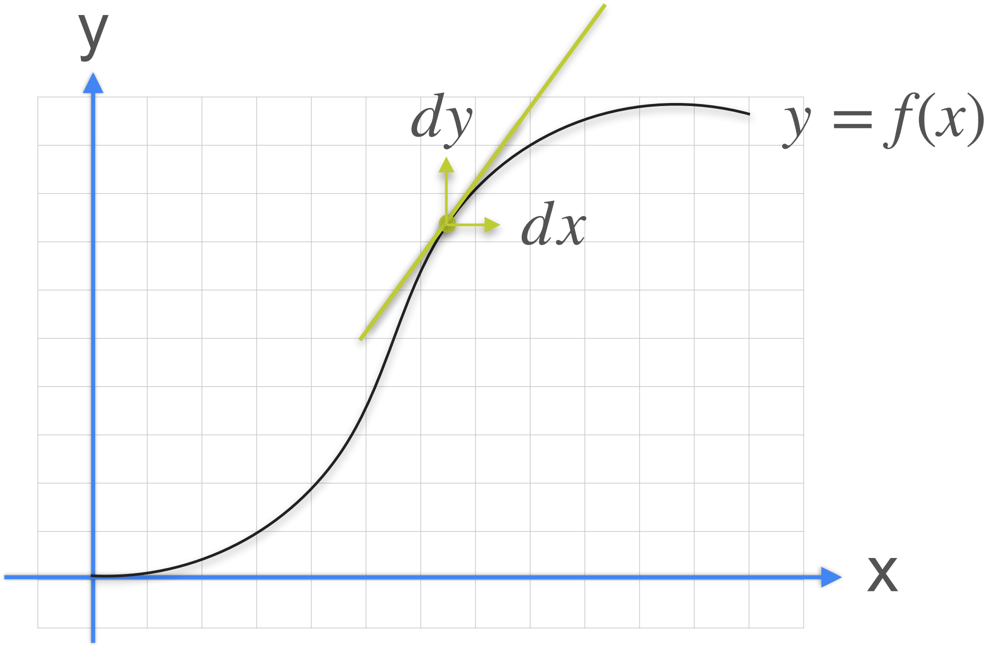
$$y = f(x)$$



Derivatives

$$y = f(x)$$

Derivative of f is expressed as:



Derivatives

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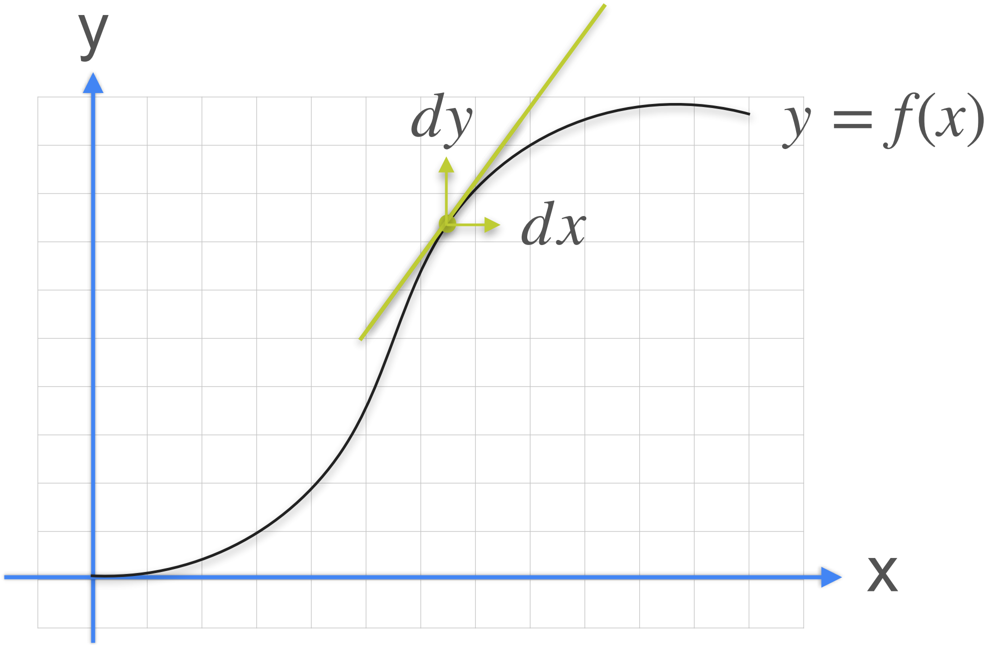
Derivative of f is expressed as:

$$\frac{d}{dx} f(x)$$

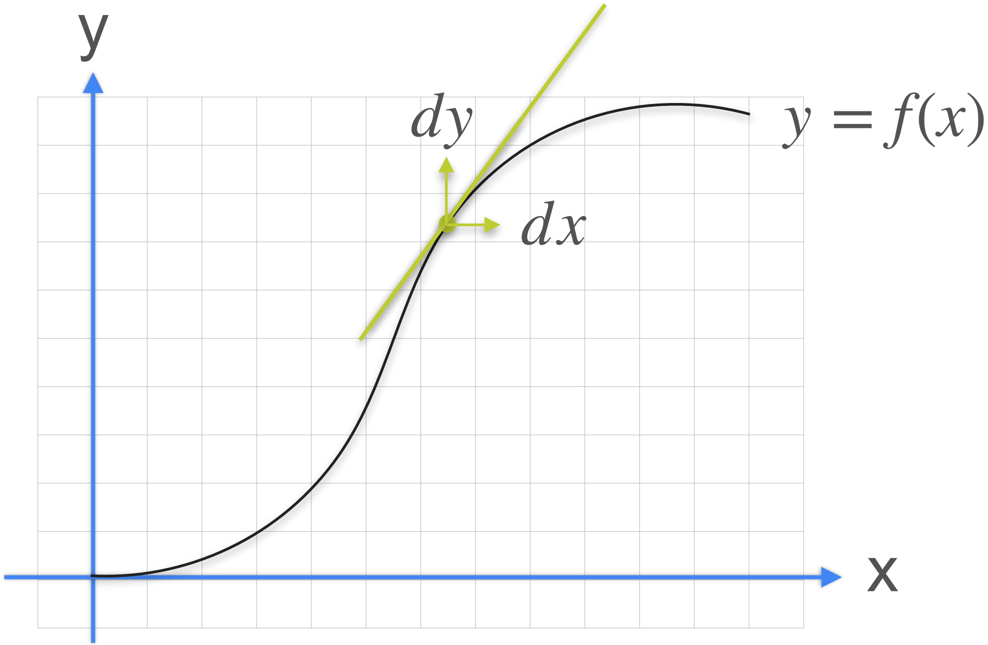


Derivatives

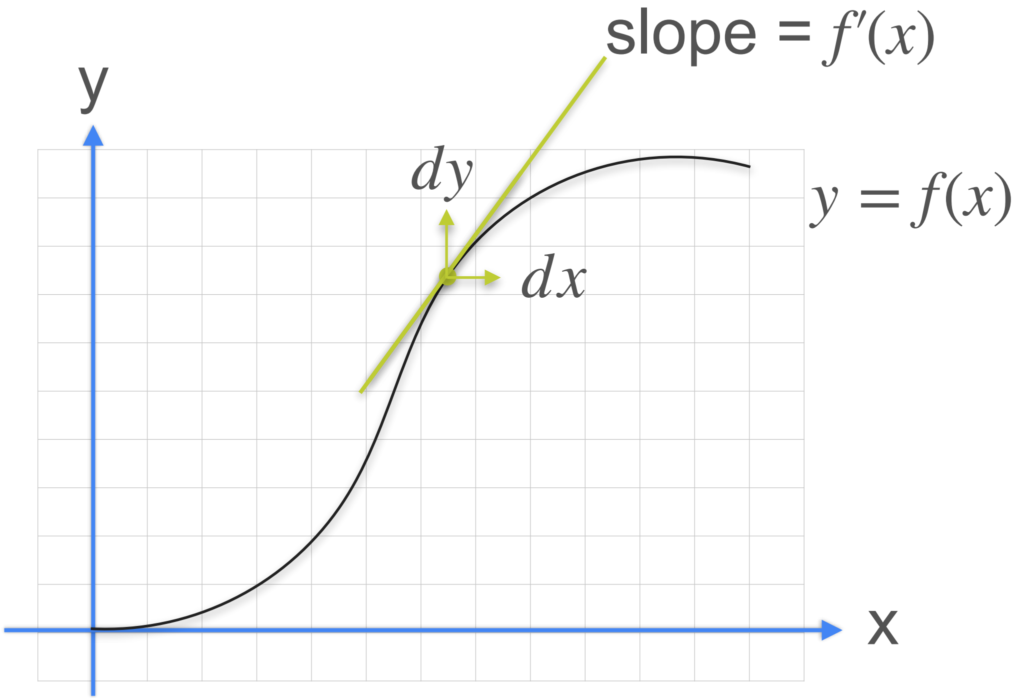
$$y = f(x)$$

Derivative of f is expressed as:

$$\frac{d}{dx} f(x) = \frac{dy}{dx}$$

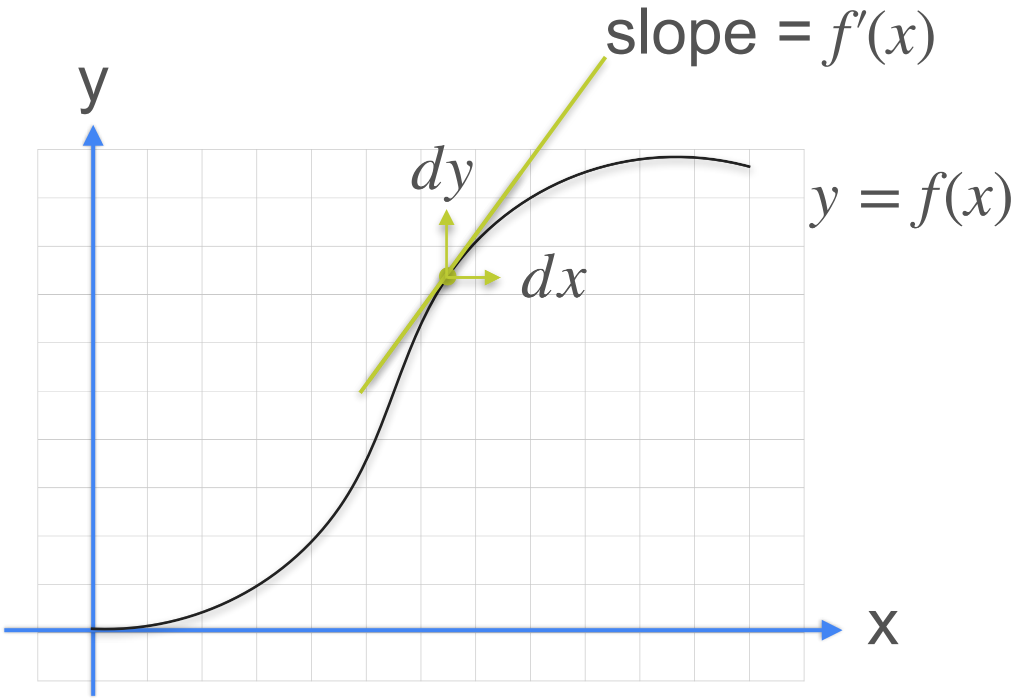


Derivatives: Lagrange's and Leibniz's Notation



Derivatives: Lagrange's and Leibniz's Notation

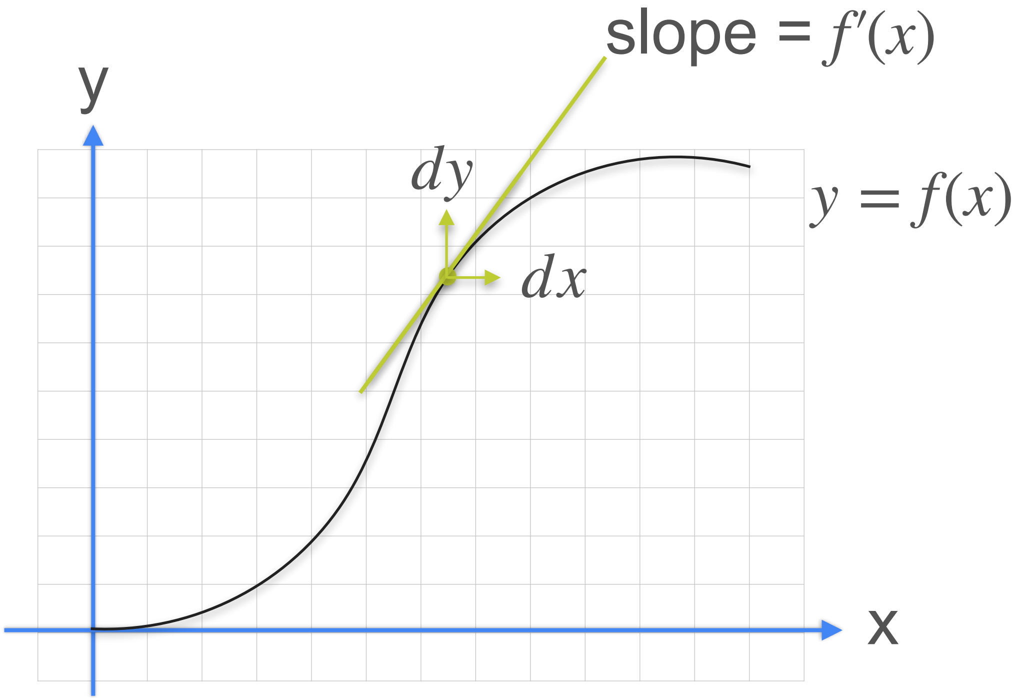
$$y = f(x)$$



Derivatives: Lagrange's and Leibniz's Notation

$y = f(x)$

Derivative of f is expressed as:

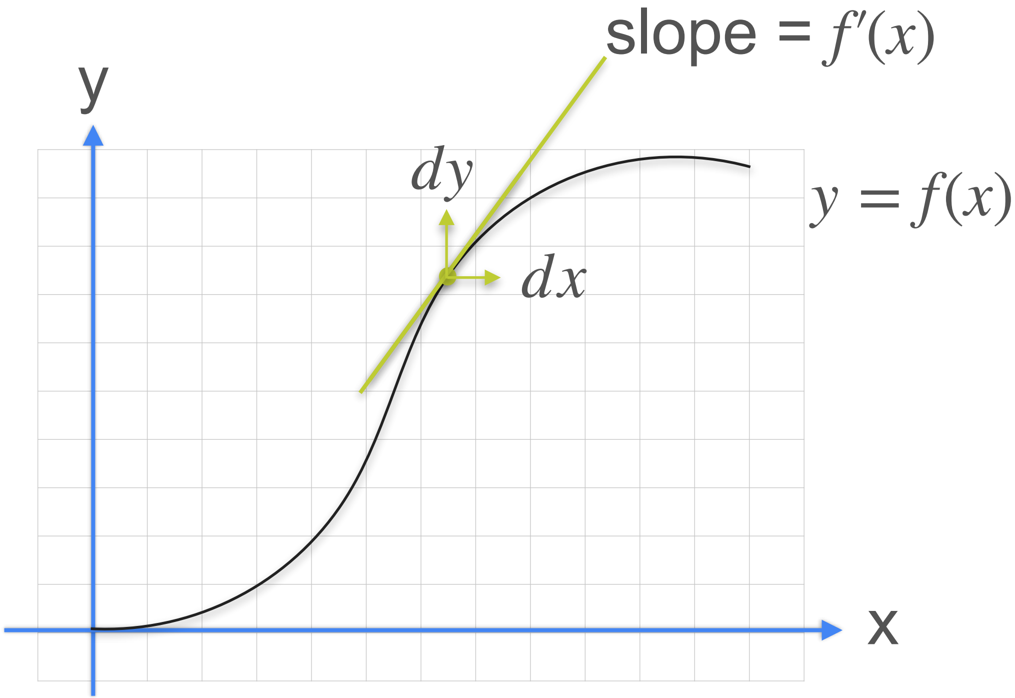


Derivatives: Lagrange's and Leibniz's Notation

$$y = f(x)$$

Derivative of f is expressed as:

$f'(x)$

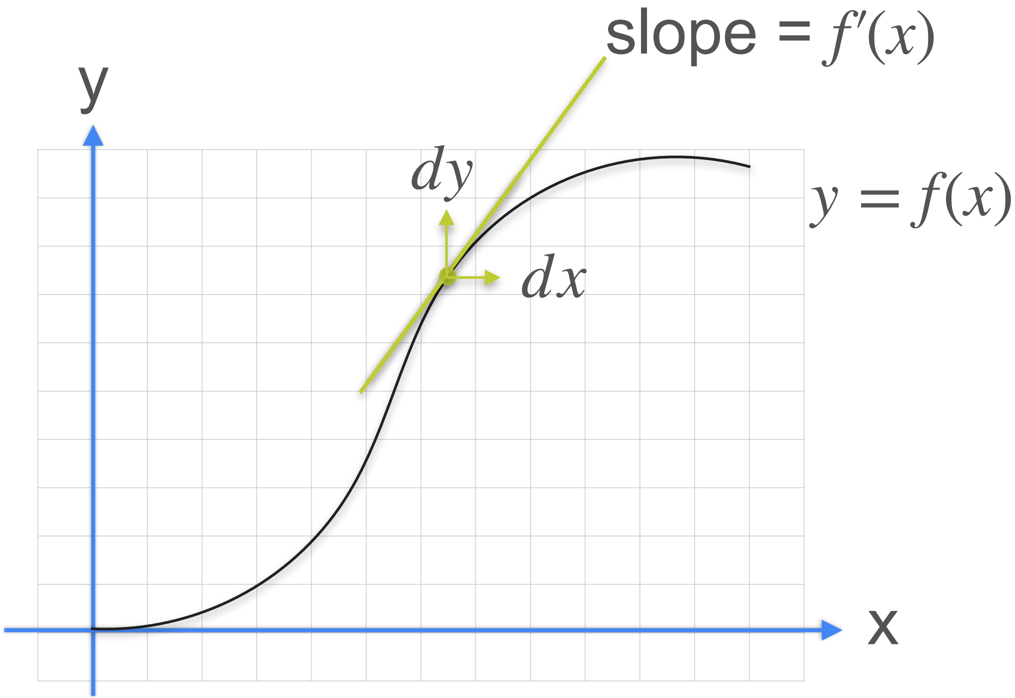


Derivatives: Lagrange's and Leibniz's Notation

$$y = f(x)$$

Derivative of f is expressed as:

$f'(x)$ **Lagrange's notation**



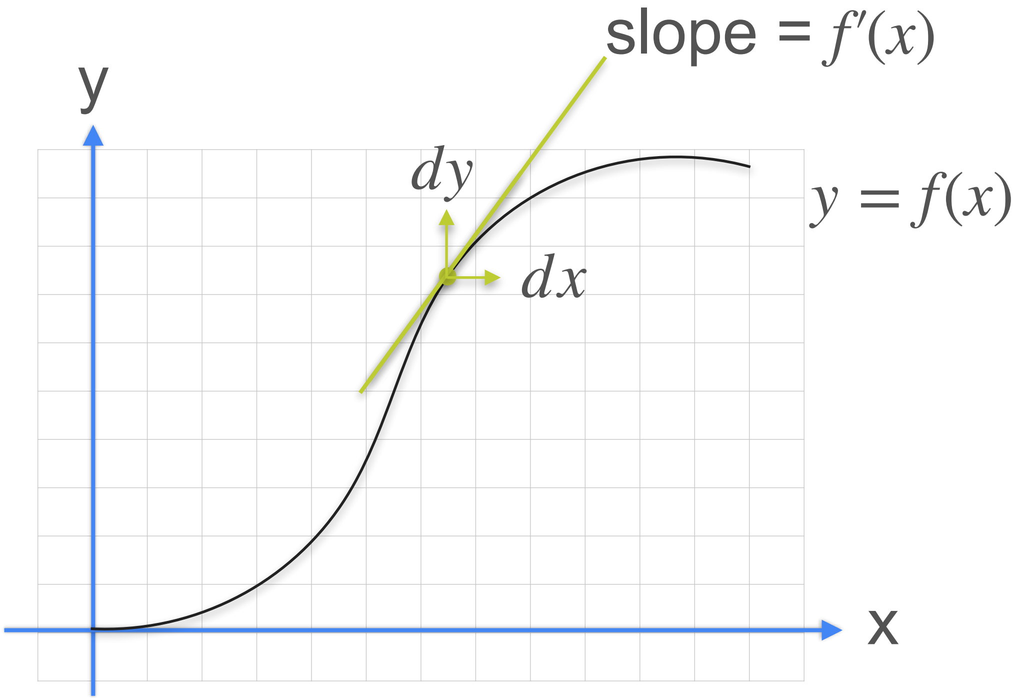
Derivatives: Lagrange's and Leibniz's Notation

$$y = f(x)$$

Derivative of f is expressed as:

$f'(x)$ **Lagrange's notation**

$$\frac{dy}{dx}$$



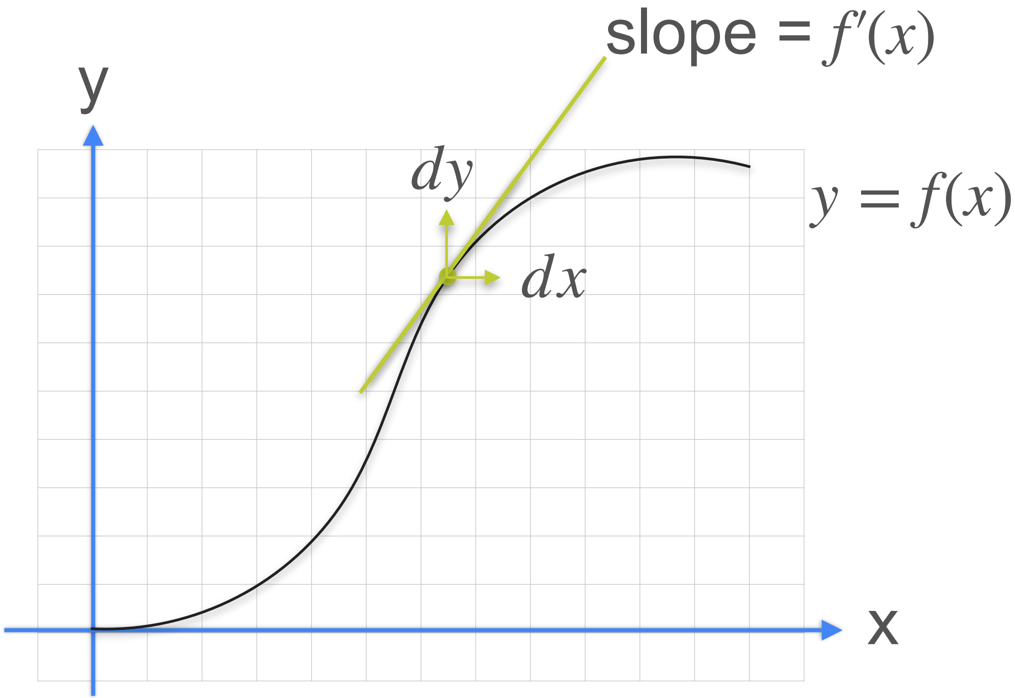
Derivatives: Lagrange’s and Leibniz’s Notation

$$y = f(x)$$

Derivative of f is expressed as:

$f'(x)$ **Lagrange's notation**

$$\frac{dy}{dx} = \frac{d}{dx}f(x)$$



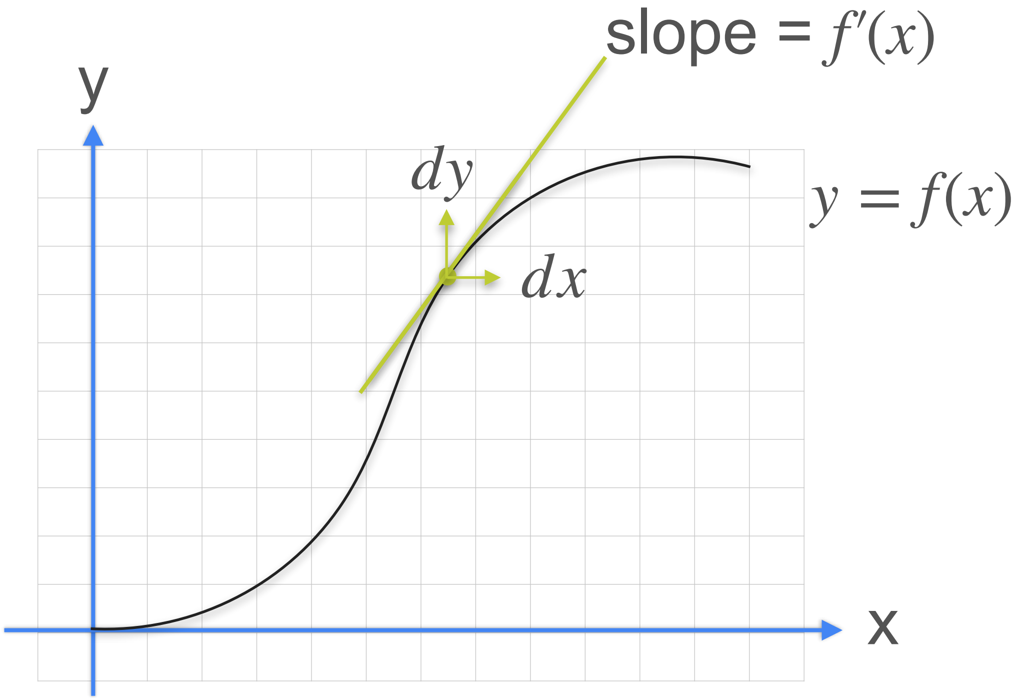
Derivatives: Lagrange's and Leibniz's Notation

$$y = f(x)$$

Derivative of f is expressed as:

$f'(x)$ **Lagrange's notation**

$$\frac{dy}{dx} = \frac{d}{dx} f(x)$$ **Leibniz's notation**



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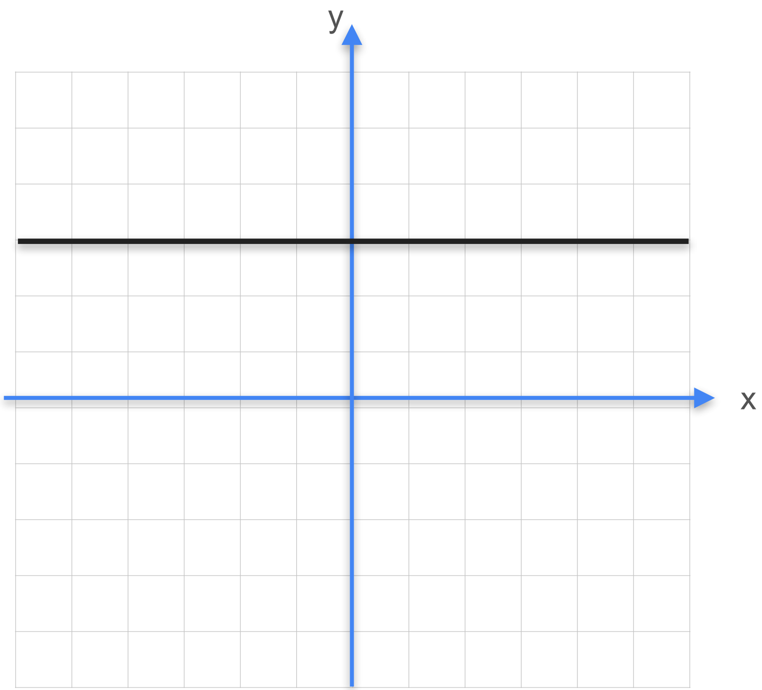
Derivatives and Optimization

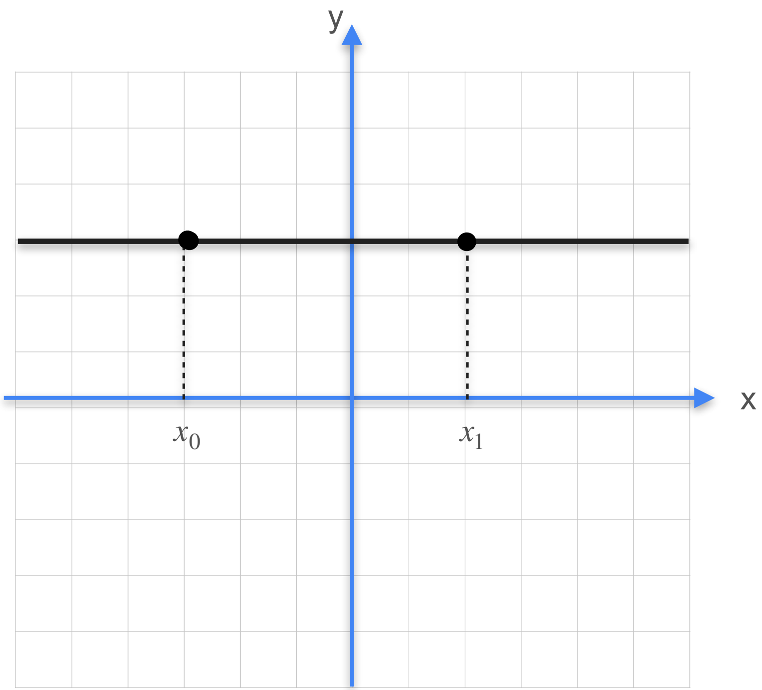
Some common derivatives: Lines

Derivative of a Constant

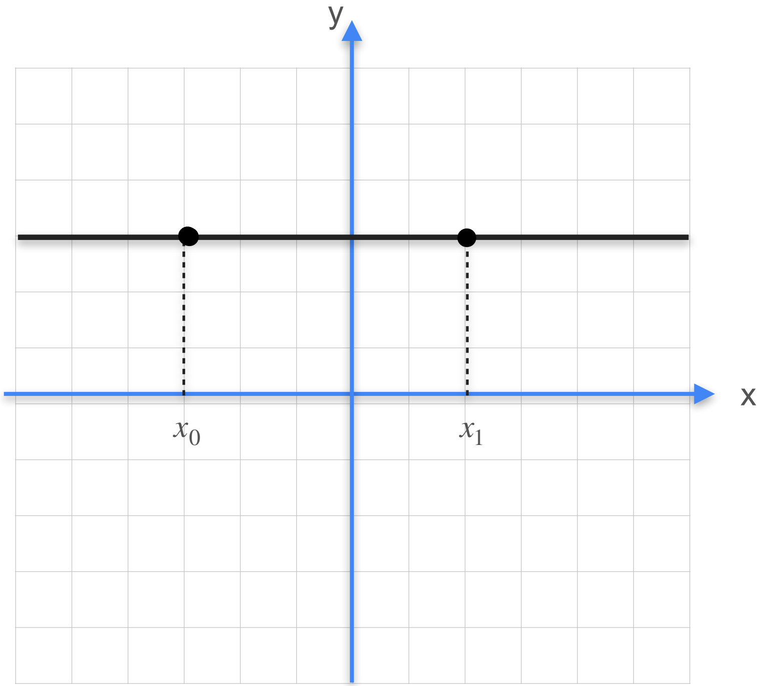
Derivative of a Constant



Derivative of a Constant

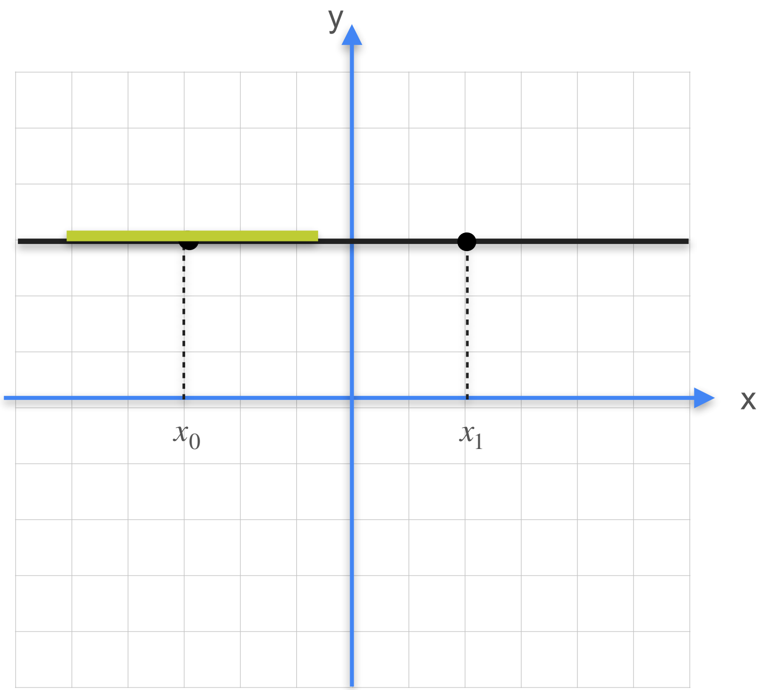


Derivative of a Constant



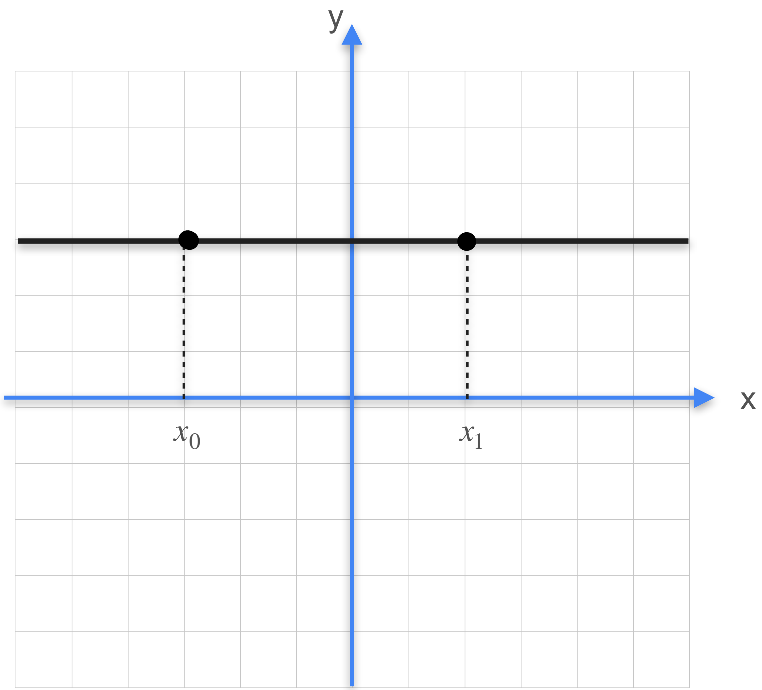
$$y = f(x) = c$$

Derivative of a Constant



$$y = f(x) = c$$

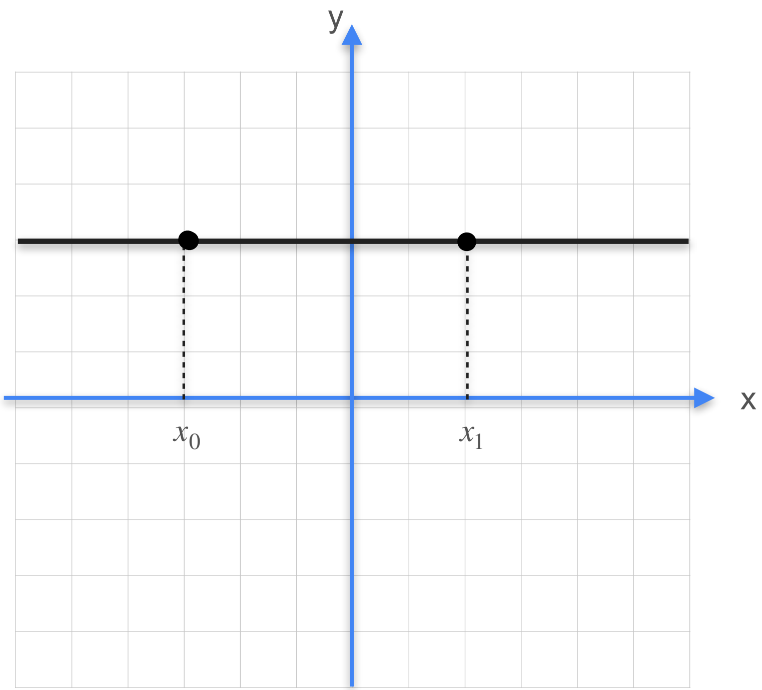
Derivative of a Constant



$$y = f(x) = c$$

Slope?

Derivative of a Constant

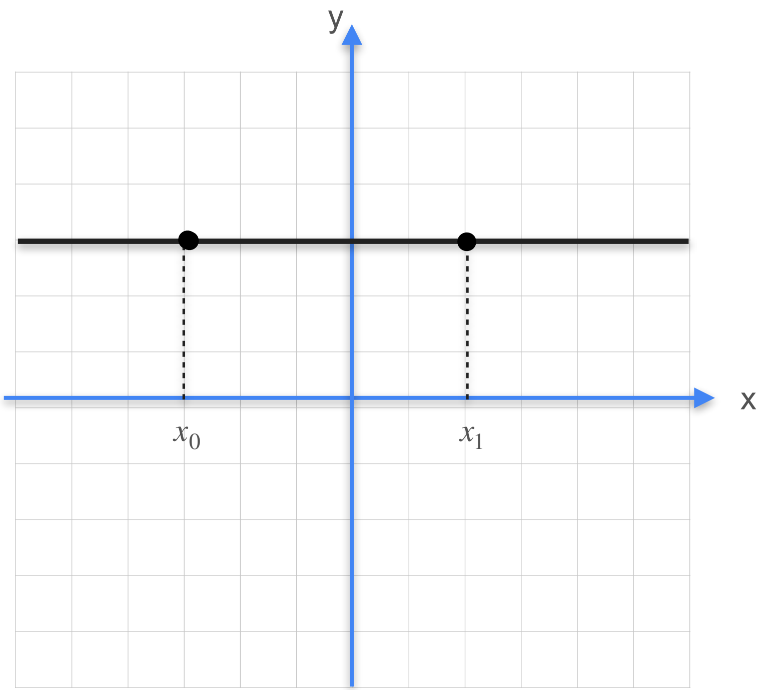


$$y = f(x) = c$$

Slope?

$$\frac{\Delta y}{\Delta x}$$

Derivative of a Constant

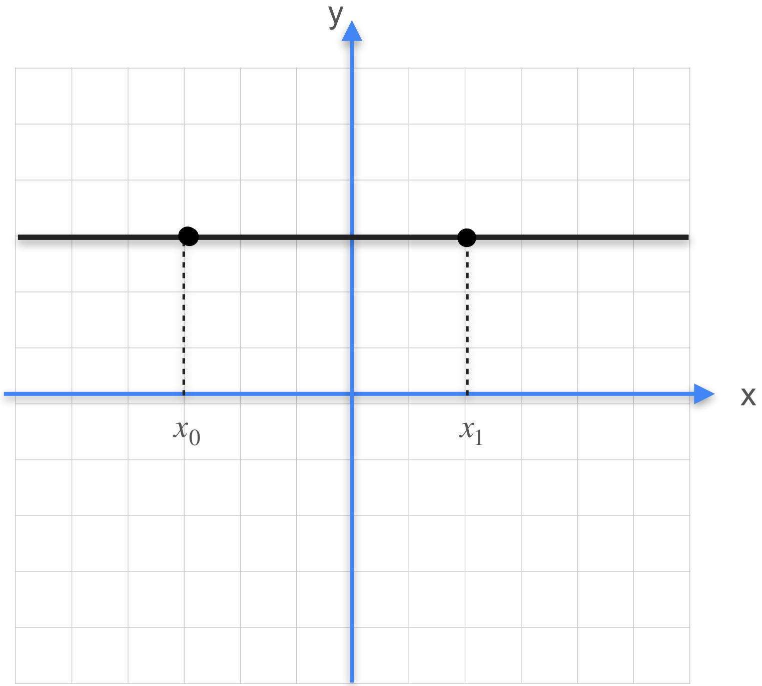


$$y = f(x) = c$$

Slope?

$$\frac{\Delta y}{\Delta x} = \frac{c - c}{x_1 - x_0} = 0$$

Derivative of a Constant



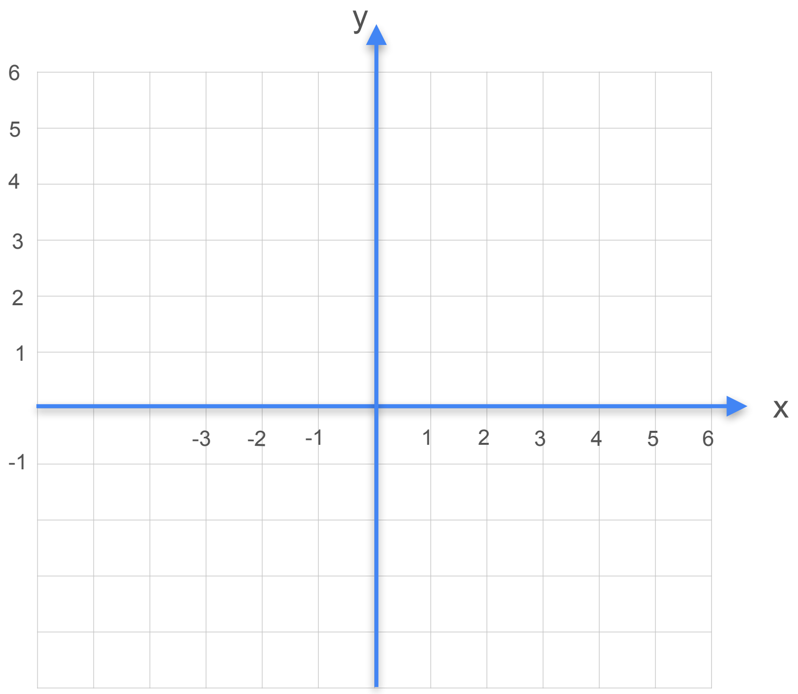
$$y = f(x) = c$$

Slope?

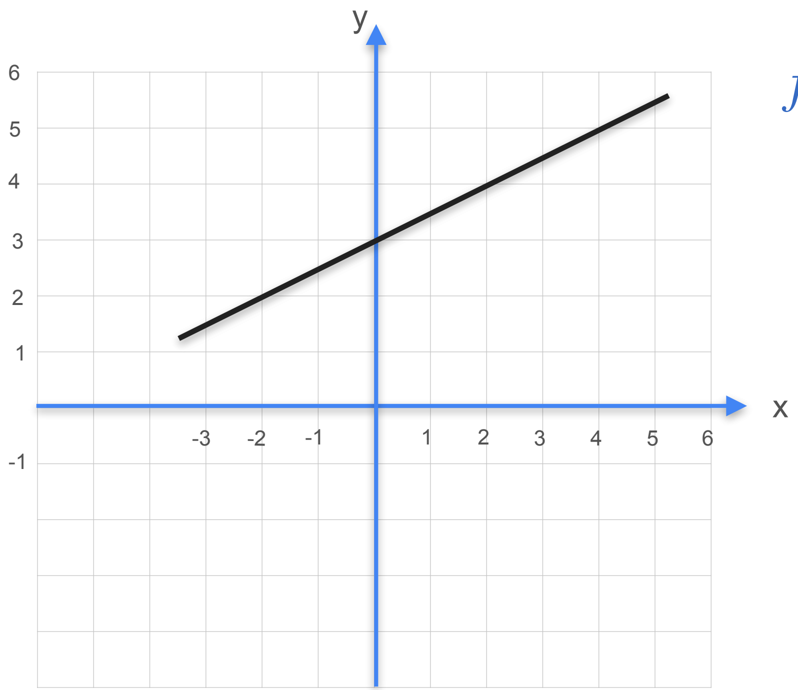
$$\frac{\Delta y}{\Delta x} = \frac{c - c}{x_1 - x_0} = 0 \rightarrow \boxed{f'(x) = 0}$$

Derivative of a Line

Derivative of a Line

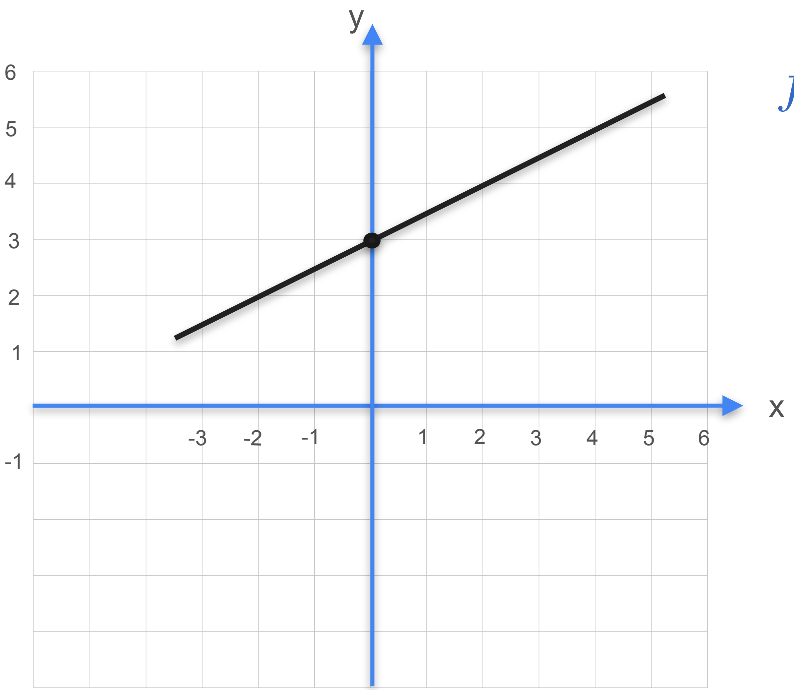


Derivative of a Line



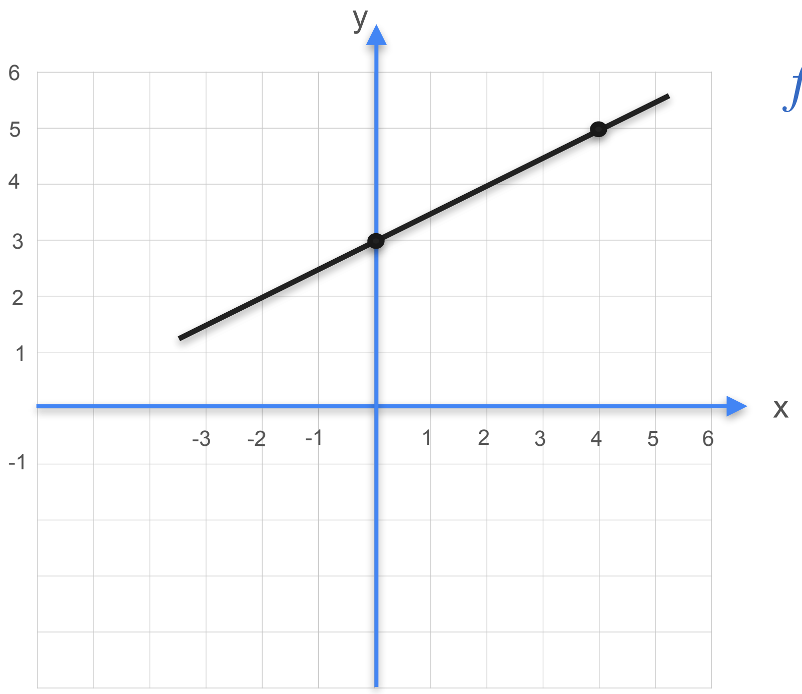
$$f(x) = ax + b$$

Derivative of a Line



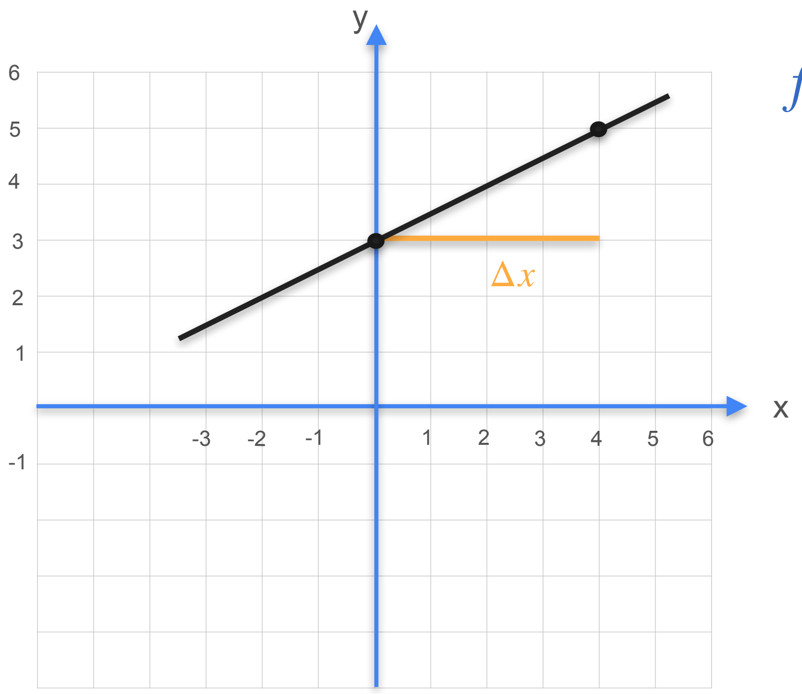
$$f(x) = ax + b$$

Derivative of a Line



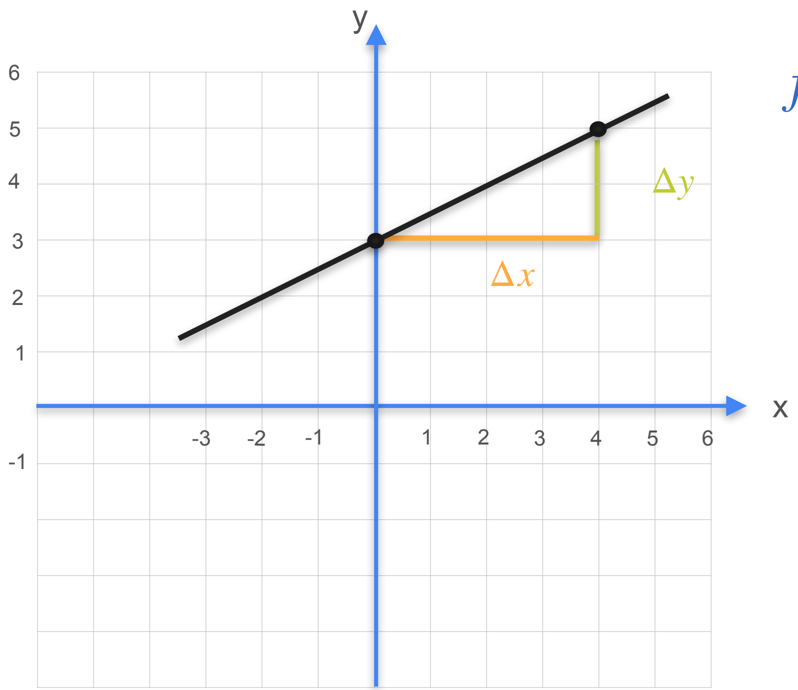
$$f(x) = ax + b$$

Derivative of a Line



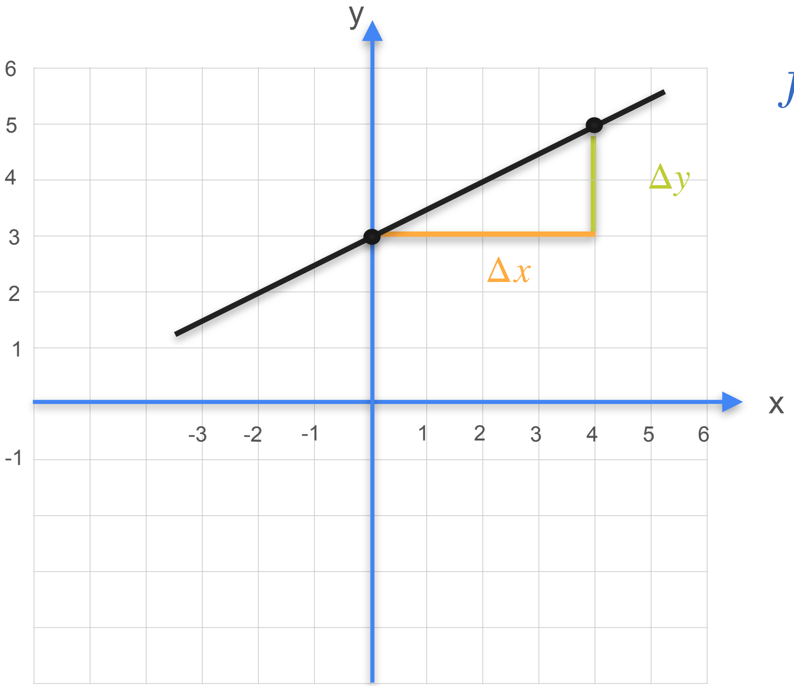
$$f(x) = ax + b$$

Derivative of a Line



$$f(x) = ax + b$$

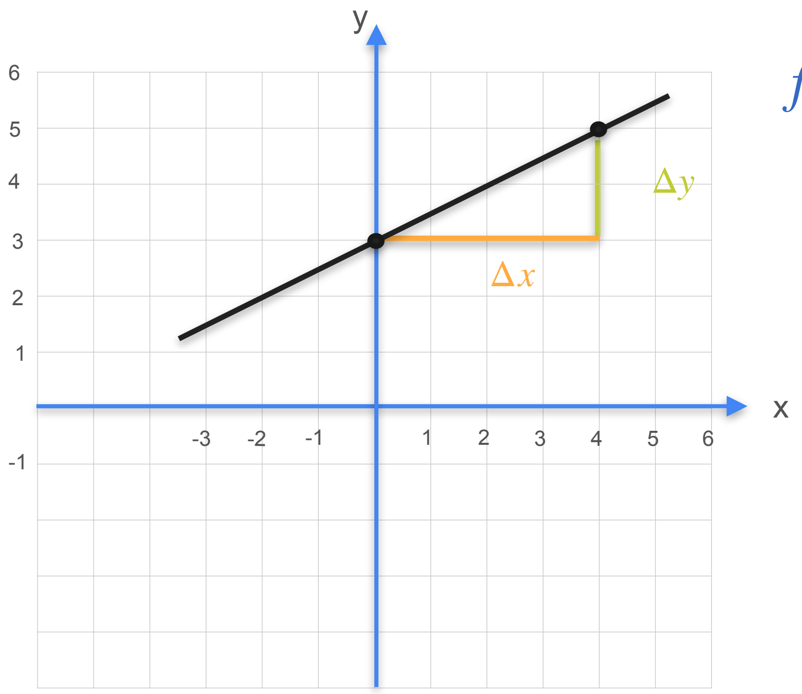
Derivative of a Line



$$f(x) = ax + b$$

$$\frac{\Delta y}{\Delta x}$$

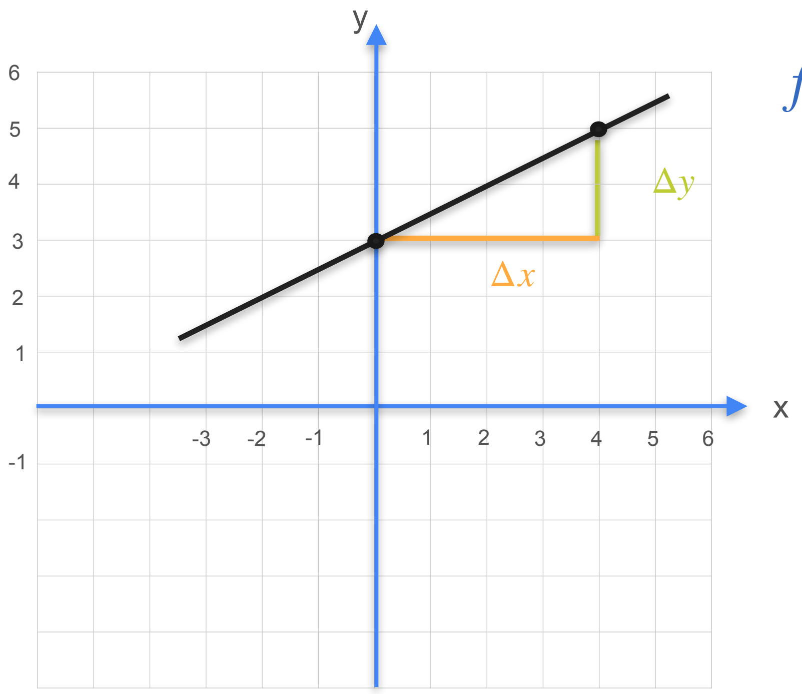
Derivative of a Line



$$f(x) = ax + b$$

$$\frac{\Delta y}{\Delta x} = \frac{\text{rise}}{\text{run}}$$

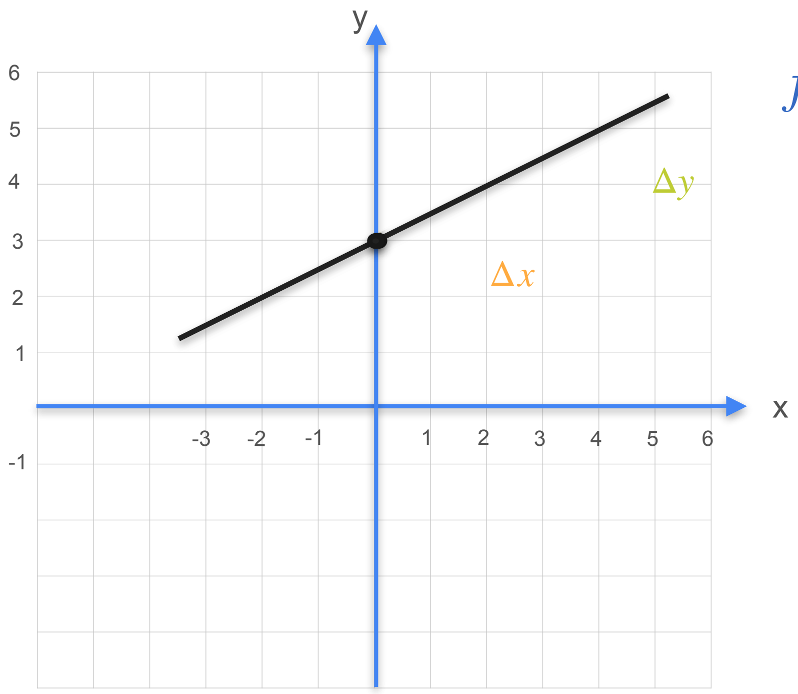
Derivative of a Line



$$f(x) = ax + b$$

$$\frac{\Delta y}{\Delta x} = \frac{\text{rise}}{\text{run}} = a$$

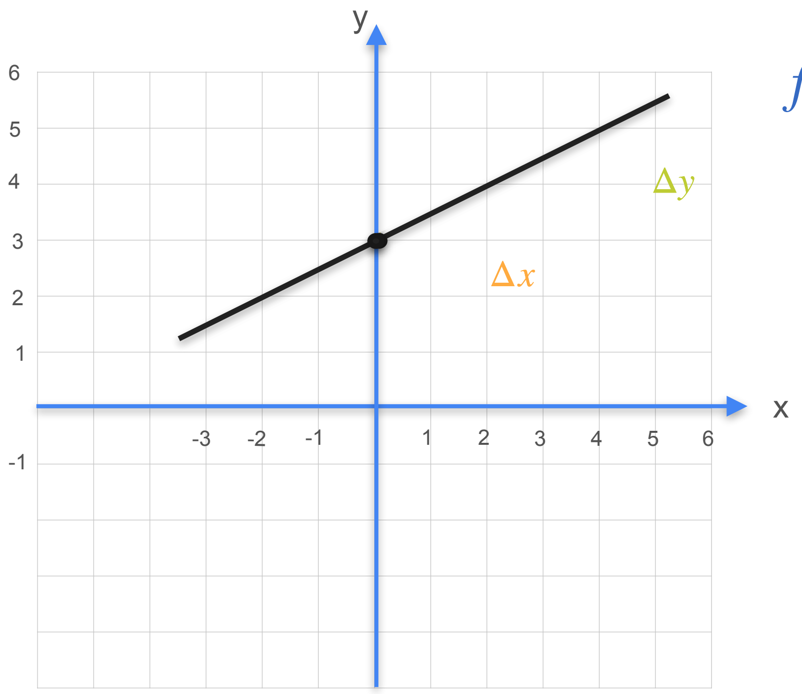
Derivative of a Line



$$f(x) = ax + b$$

$$\frac{\Delta y}{\Delta x} = \frac{\text{rise}}{\text{run}} = a$$

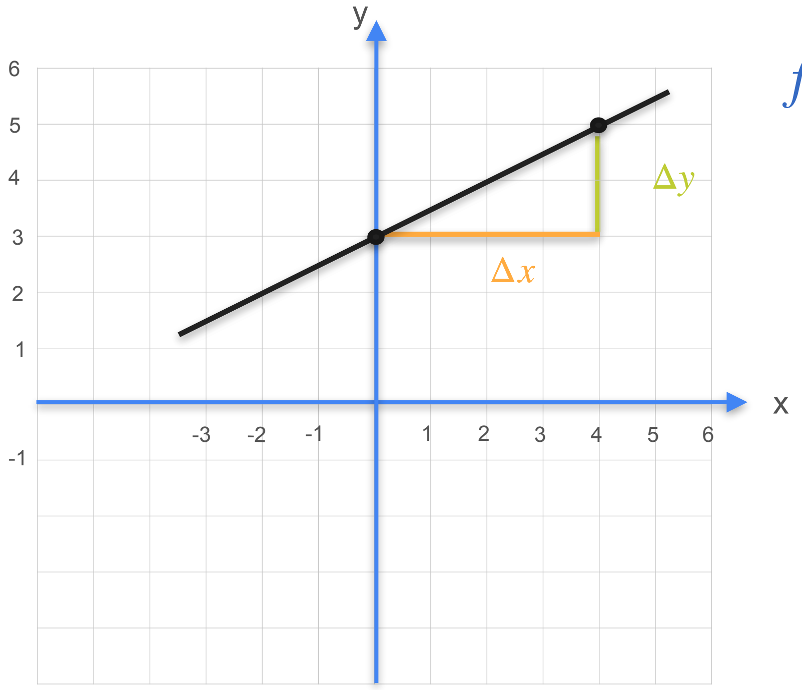
Derivative of a Line



$$f(x) = ax + b \Rightarrow f'(x) = a$$

$$\frac{\Delta y}{\Delta x} = \frac{\text{rise}}{\text{run}} = a$$

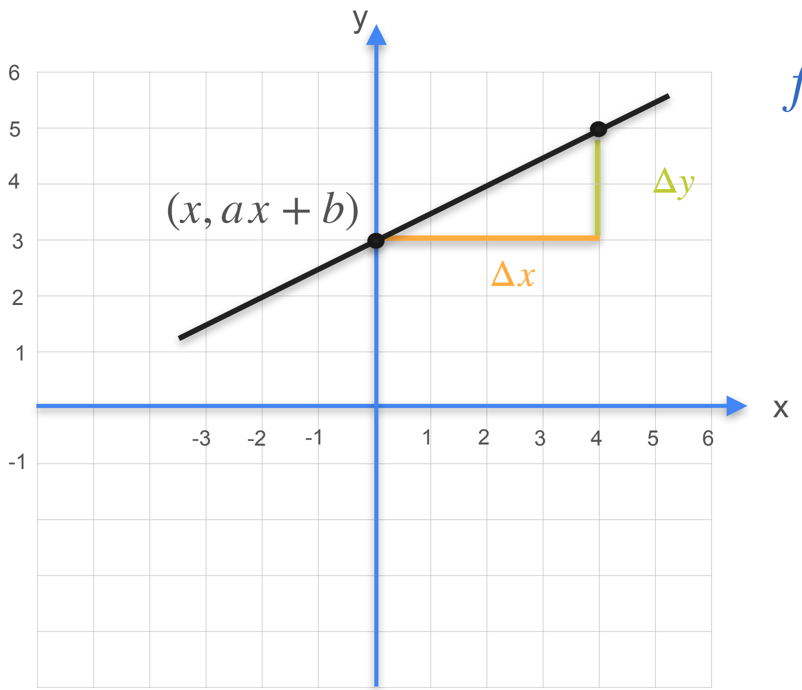
Derivative of a Line



$$f(x) = ax + b \Rightarrow f'(x) = a$$

$$\frac{\Delta y}{\Delta x} = \frac{\text{rise}}{\text{run}} = a$$

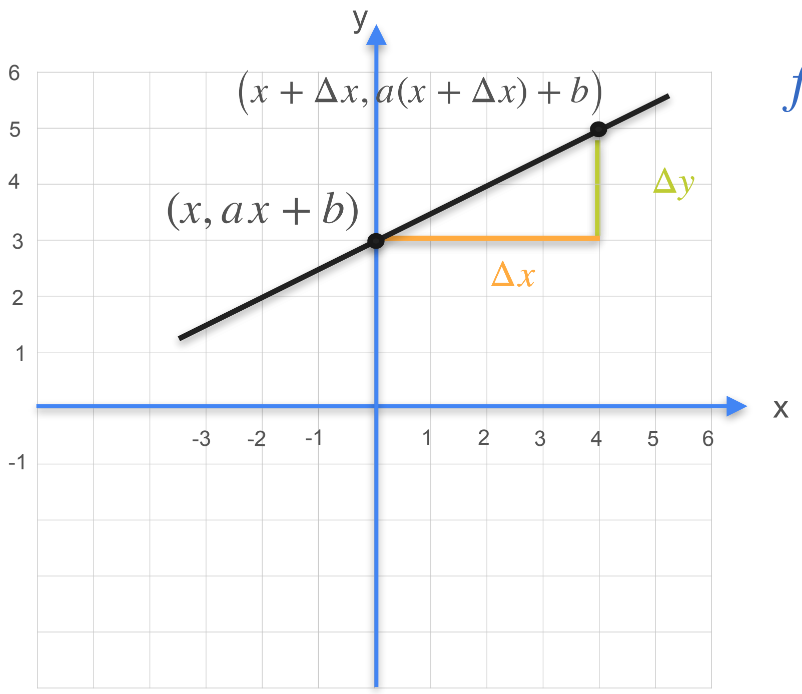
Derivative of a Line



$$f(x) = ax + b \Rightarrow f'(x) = a$$

$$\frac{\Delta y}{\Delta x} = \frac{\text{rise}}{\text{run}} = a$$

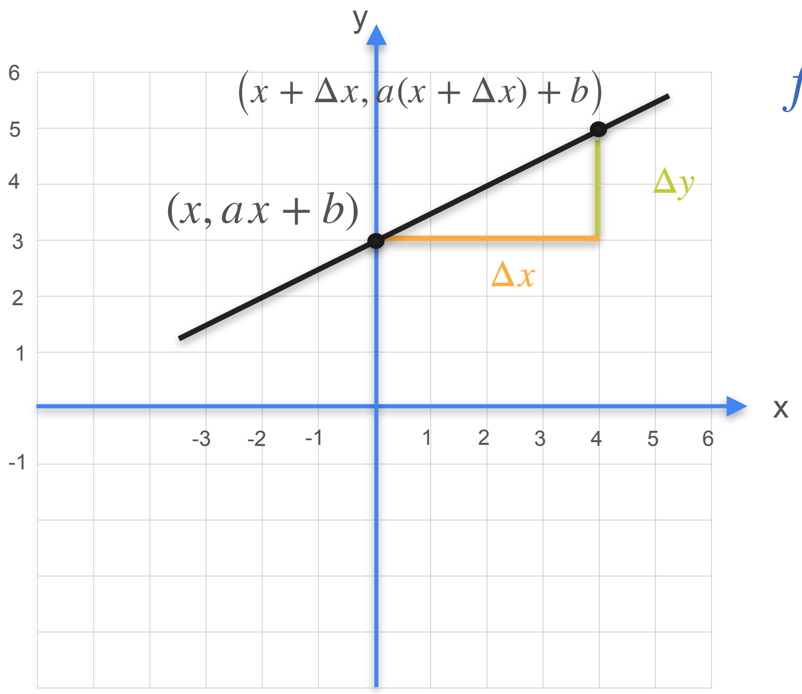
Derivative of a Line



$f(x) = ax + b \quad \Rightarrow \quad f'(x) = a$

$$\frac{\Delta y}{\Delta x} = \frac{\text{rise}}{\text{run}} = a$$

Derivative of a Line

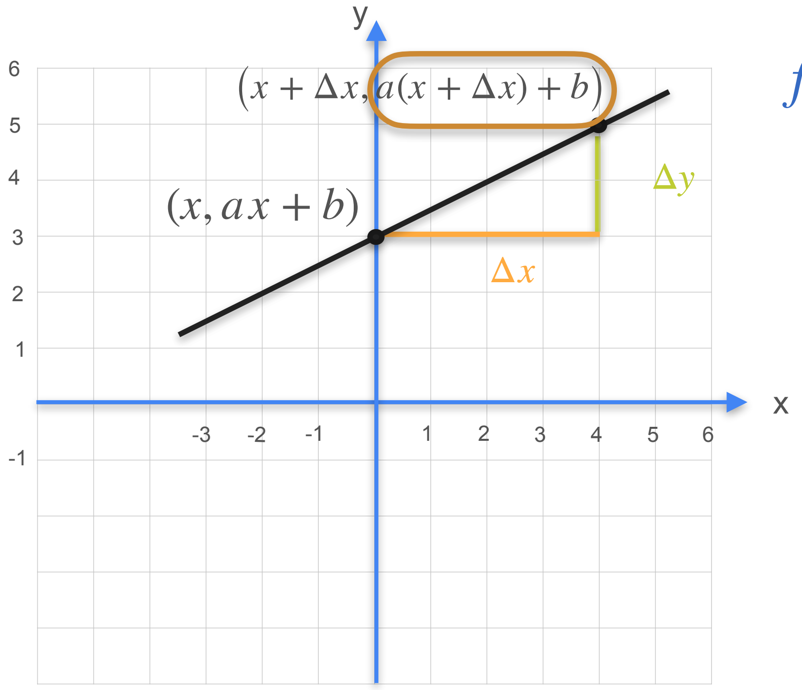


$$f(x) = ax + b \Rightarrow f'(x) = a$$

$$\frac{\Delta y}{\Delta x} = \frac{\text{rise}}{\text{run}} = a$$

$$\frac{\Delta y}{\Delta x}$$

Derivative of a Line



$f(x) = ax + b \Rightarrow f'(x) = a$

$$\frac{\Delta y}{\Delta x} = \frac{\text{rise}}{\text{run}} = a$$

$$\frac{\Delta y}{\Delta x}$$

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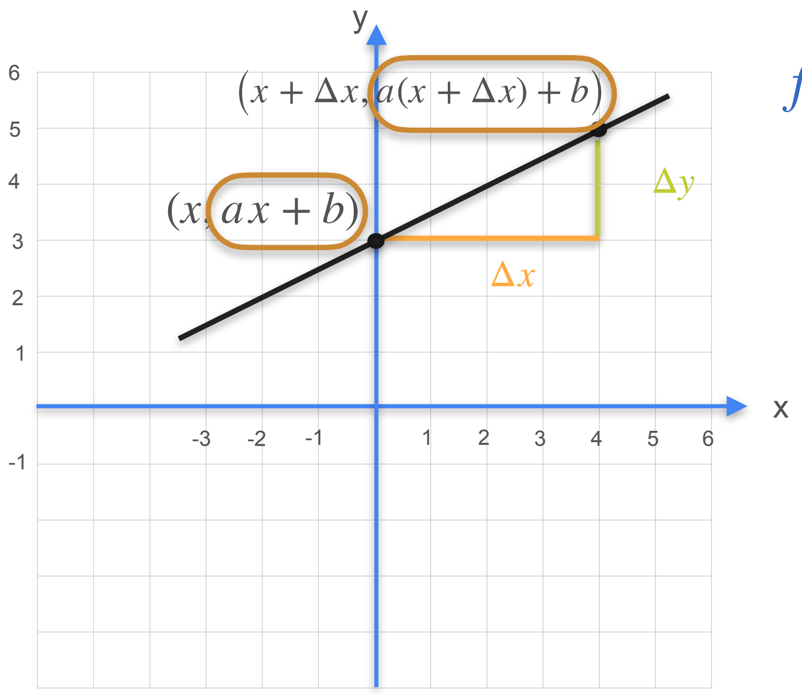
Derivative of a Line

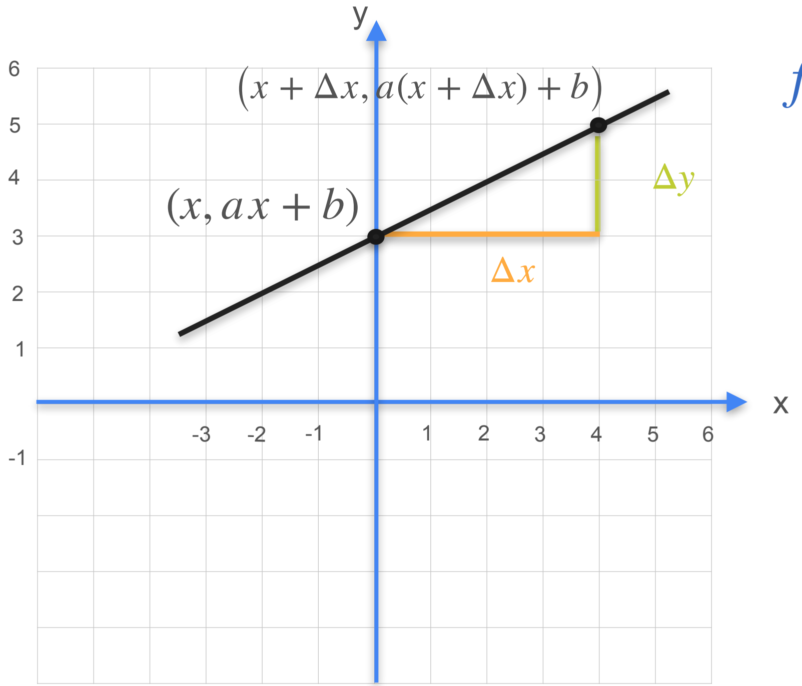


$$f(x) = ax + b \Rightarrow f'(x) = a$$

$$\frac{\Delta y}{\Delta x} = \frac{\text{rise}}{\text{run}} = a$$

$$\frac{\Delta y}{\Delta x}$$

Derivative of a Line

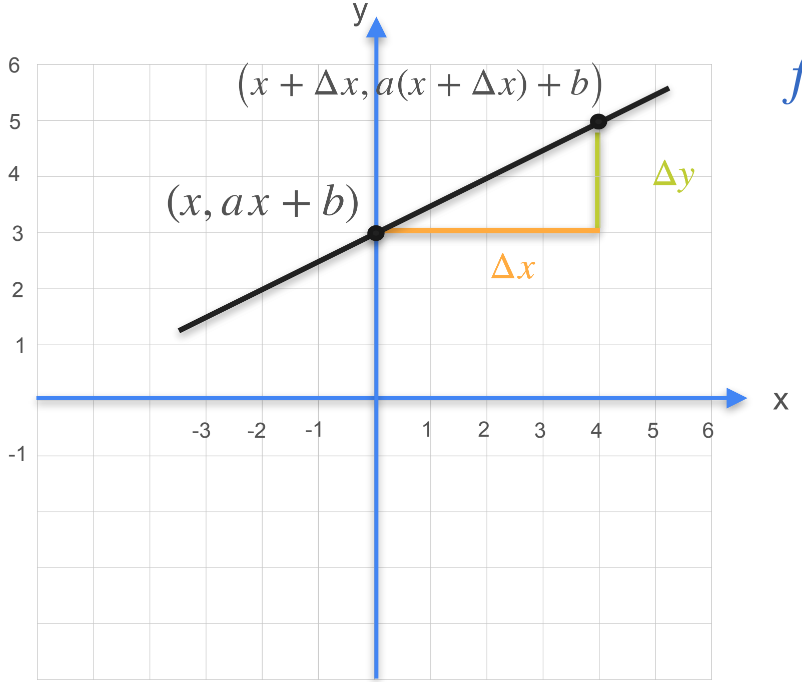


$$f(x) = ax + b \quad \Rightarrow \quad f'(x) = a$$

$$\frac{\Delta y}{\Delta x} = \frac{\text{rise}}{\text{run}} = a$$

$$\frac{\Delta y}{\Delta x} = \frac{a(x+\Delta x) + b - (ax+b)}{\Delta x}$$

Derivative of a Line

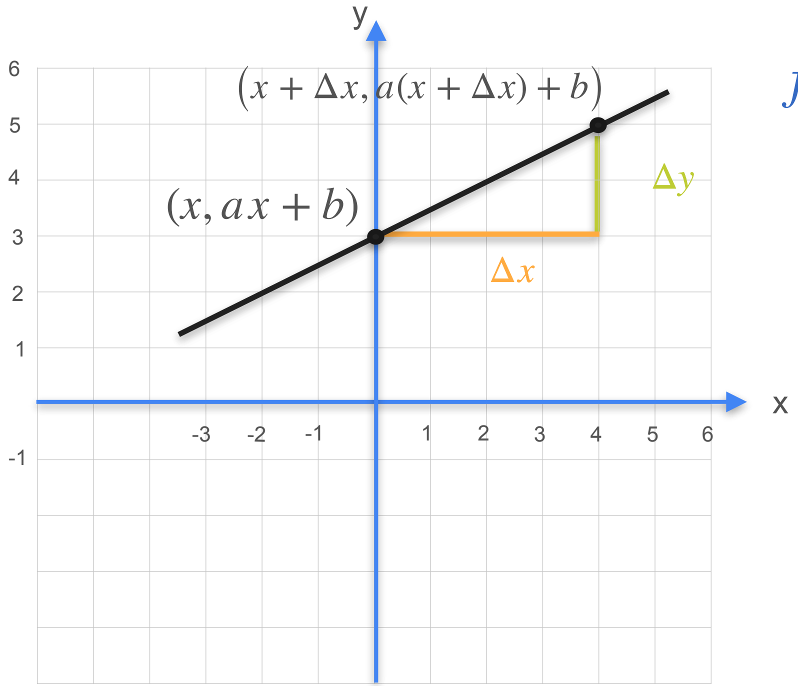


$$f(x) = ax + b \Rightarrow f'(x) = a$$

$$\frac{\Delta y}{\Delta x} = \frac{\text{rise}}{\text{run}} = a$$

$$\frac{\Delta y}{\Delta x} = \frac{a(\cancel{x} + \Delta x) + b - (a\cancel{x} + b)}{\Delta x}$$

Derivative of a Line

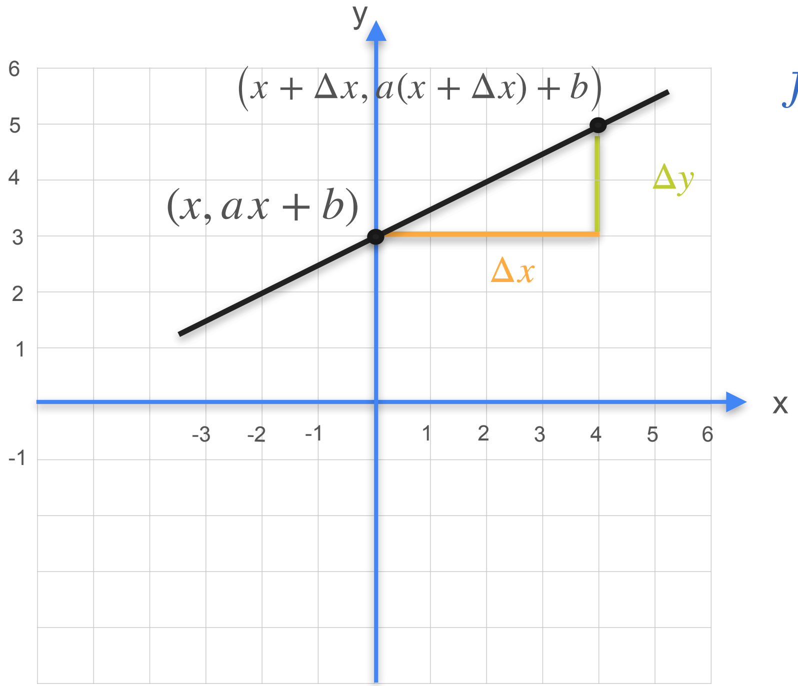


$$f(x) = ax + b \quad \Rightarrow \quad f'(x) = a$$

$$\frac{\Delta y}{\Delta x} = \frac{\text{rise}}{\text{run}} = a$$

$$\frac{\Delta y}{\Delta x} = \frac{a(\cancel{x} + \Delta x) + \cancel{b} - (\cancel{a}x + \cancel{b})}{\Delta x}$$

Derivative of a Line



$$f(x) = ax + b \quad \Rightarrow \quad f'(x) = a$$

$$\frac{\Delta y}{\Delta x} = \frac{\text{rise}}{\text{run}} = a$$

$$\frac{\Delta y}{\Delta x} = \frac{a(\cancel{x} + \Delta x) + \cancel{b} - (\cancel{a}x + \cancel{b})}{\Delta x}$$

$$= a\frac{\Delta x}{\Delta x}$$

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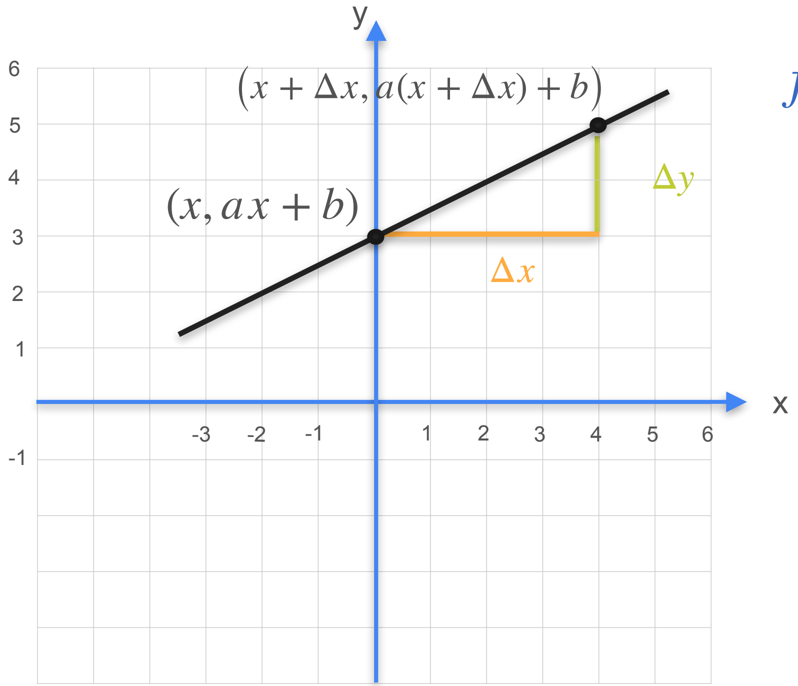
Derivative of a Line



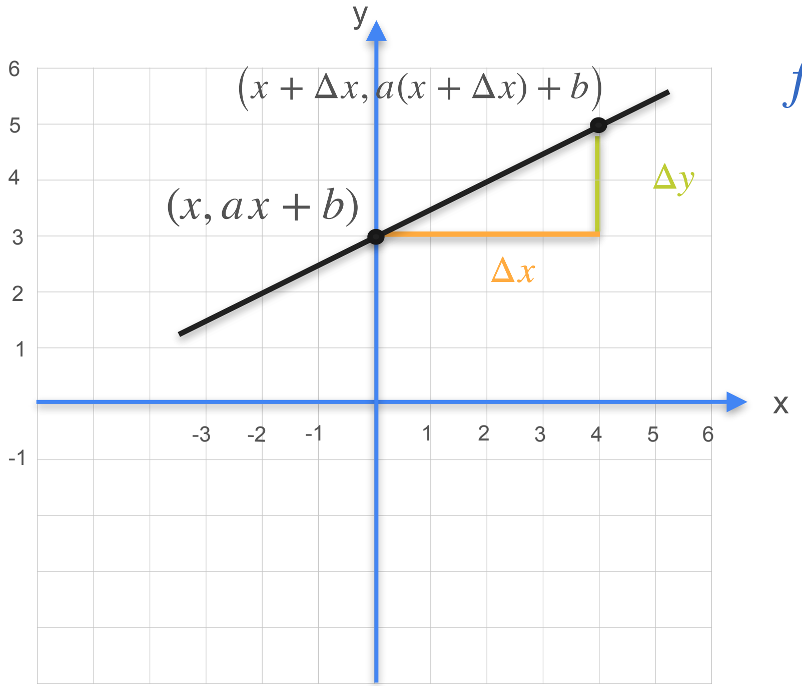
$$f(x) = ax + b \quad \Rightarrow \quad f'(x) = a$$

$$\frac{\Delta y}{\Delta x} = \frac{\text{rise}}{\text{run}} = a$$

$$\frac{\Delta y}{\Delta x} = \frac{a(\cancel{x} + \Delta x) + \cancel{b} - (\cancel{a}x + \cancel{b})}{\Delta x}$$

$$= a\frac{\cancel{\Delta x}}{\cancel{\Delta x}}$$

Derivative of a Line



$$f(x) = ax + b \Rightarrow f'(x) = a$$

$$\frac{\Delta y}{\Delta x} = \frac{\text{rise}}{\text{run}} = a$$

$$\frac{\Delta y}{\Delta x} = \frac{a(\cancel{x} + \Delta x) + \cancel{b} - (\cancel{ax} + \cancel{b})}{\Delta x}$$

$$= a\frac{\cancel{\Delta x}}{\cancel{\Delta x}} = a$$

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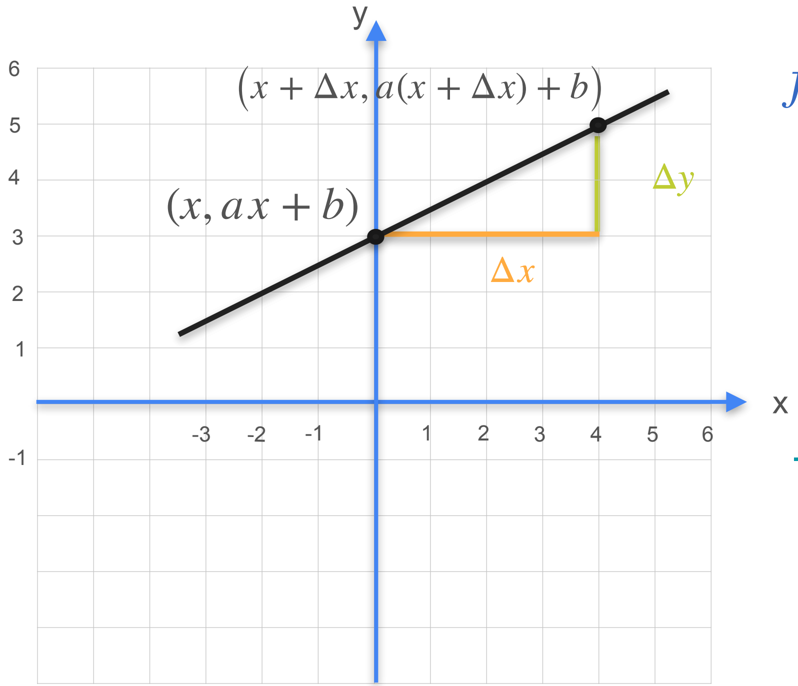
Derivative of a Line



$$f(x) = ax + b \quad \Rightarrow \quad f'(x) = a$$

$$\frac{\Delta y}{\Delta x} = \frac{\text{rise}}{\text{run}} = a$$

$$\frac{df}{dx} \; \boxed{\frac{\Delta y}{\Delta x}} = \frac{a(\cancel{x} + \Delta x) + \cancel{b} - (\cancel{a}x + \cancel{b})}{\Delta x}$$

$$= a\frac{\cancel{\Delta x}}{\cancel{\Delta x}} \quad = \boxed{a}$$

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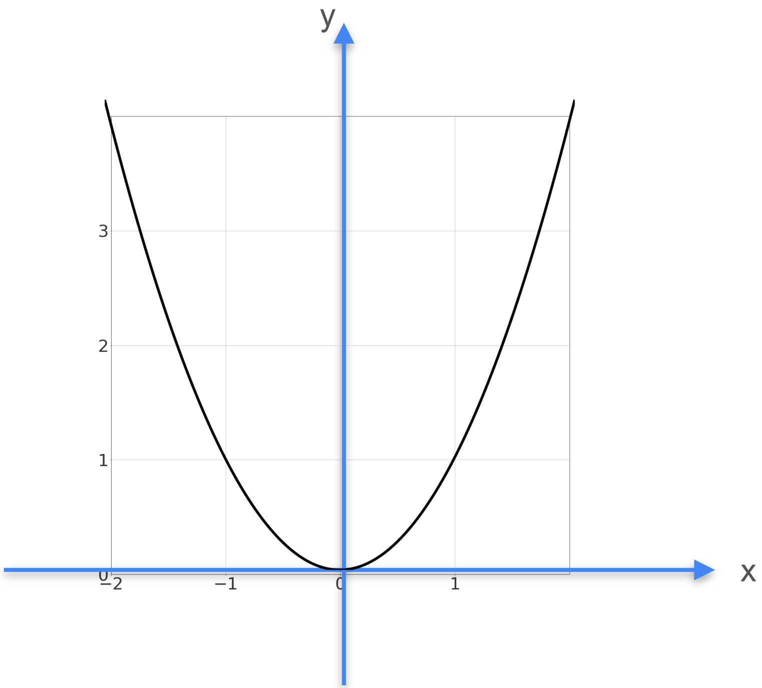
Derivatives and Optimization

Some common derivatives: Quadratics

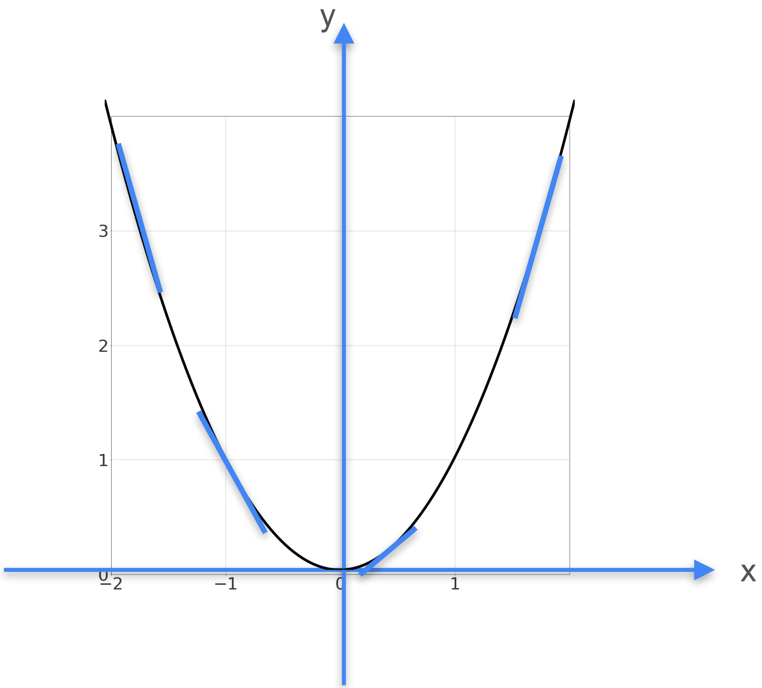
Derivative of Quadratic Functions

Derivative of Quadratic Functions



Quadratics: $y = f(x) = x^2$

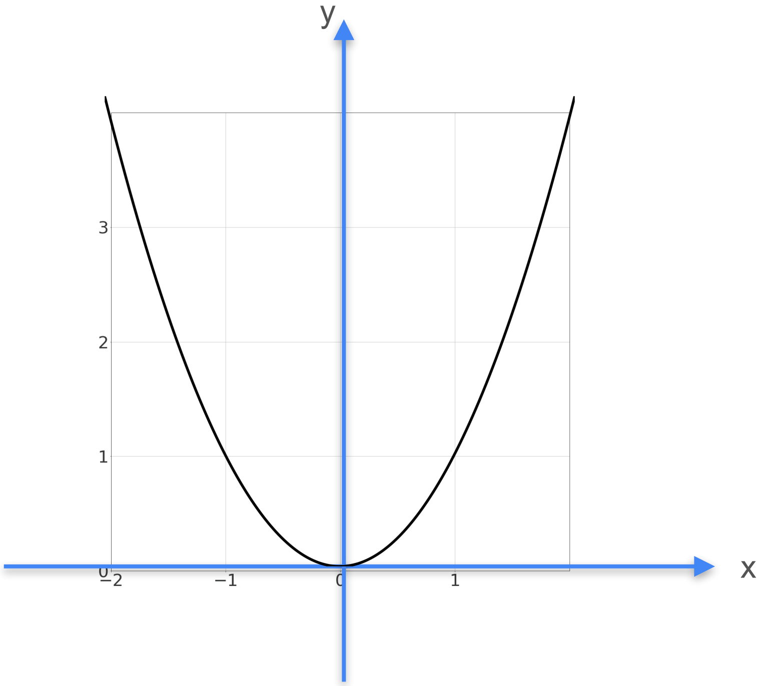
Derivative of Quadratic Functions



Quadratics: $y = f(x) = x^2$

Slope: $\dfrac{\Delta f}{\Delta x}$

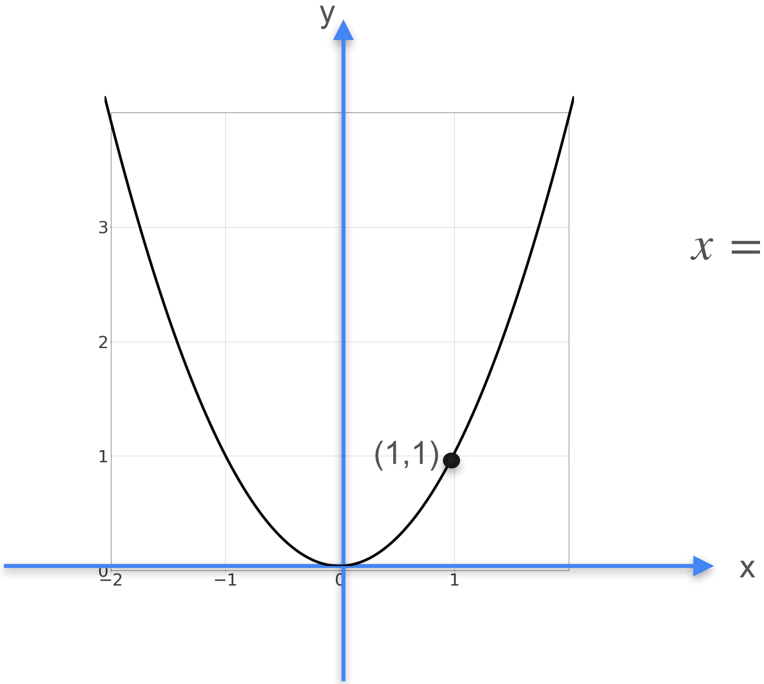
Derivative of Quadratic Functions



Quadratics: $y = f(x) = x^2$

Slope: $\dfrac{\Delta f}{\Delta x} = \dfrac{(x + \Delta x)^2 - (x)^2}{\Delta x}$

Derivative of Quadratic Functions

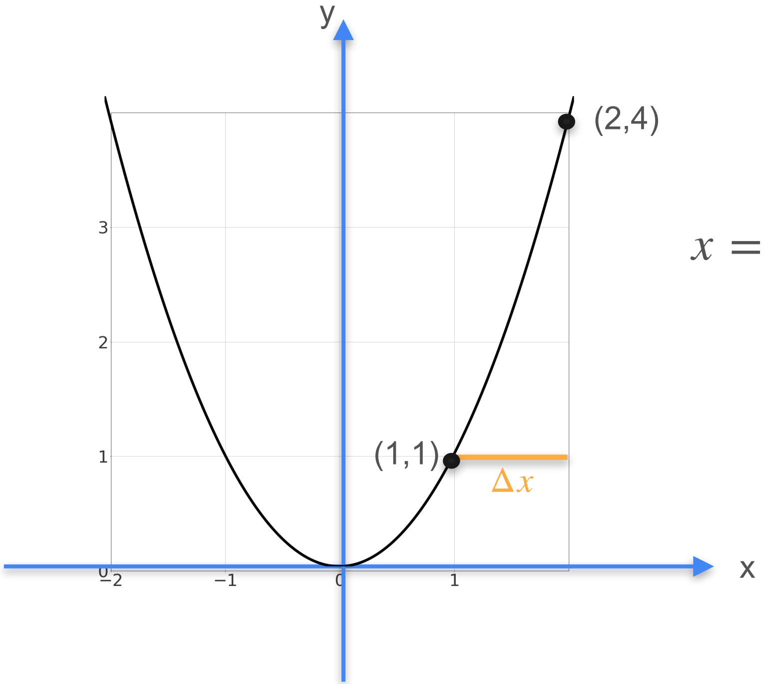


$x = 1$

Quadratics: $y = f(x) = x^2$

Slope: $\frac{\Delta f}{\Delta x} = \frac{(x + \Delta x)^2 - (x)^2}{\Delta x}$

Derivative of Quadratic Functions



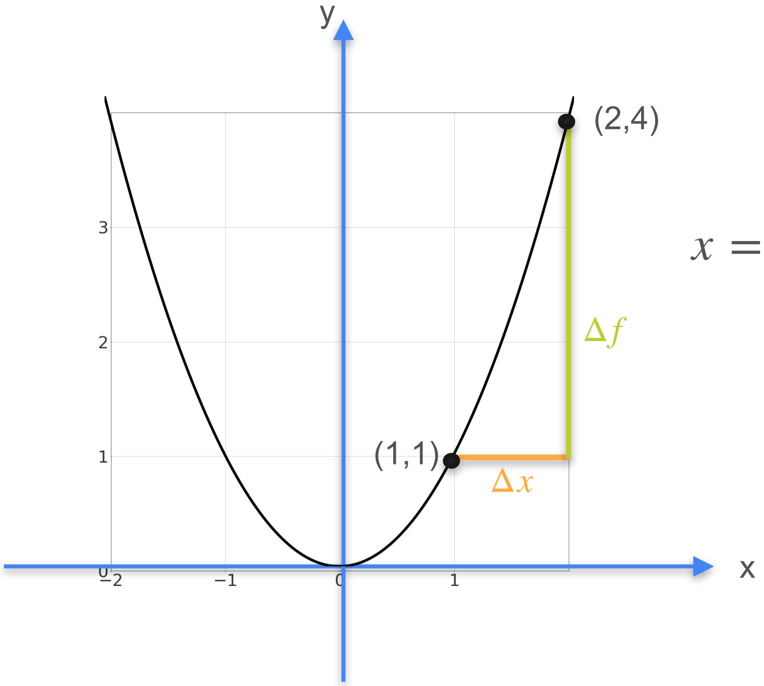
Quadratics: $y = f(x) = x^2$

Slope: $\dfrac{\Delta f}{\Delta x} = \dfrac{(x + \Delta x)^2 - (x)^2}{\Delta x}$

$x = 1$

Δx	1.0

Derivative of Quadratic Functions



Quadratics: $y = f(x) = x^2$

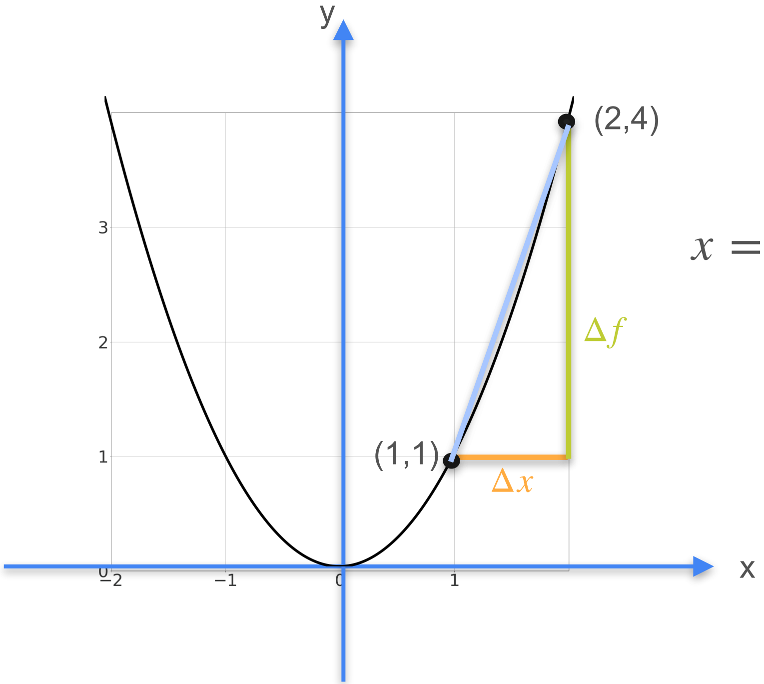
Slope: $\dfrac{\Delta f}{\Delta x} = \dfrac{(x + \Delta x)^2 - (x)^2}{\Delta x}$

$x = 1$

Δx	1.0
Δf	3

$(1 + 1)^2 - 1^2 = 4 - 1$

Derivative of Quadratic Functions



Quadratics: $y = f(x) = x^2$

Slope: $\dfrac{\Delta f}{\Delta x} = \dfrac{(x + \Delta x)^2 - (x)^2}{\Delta x}$

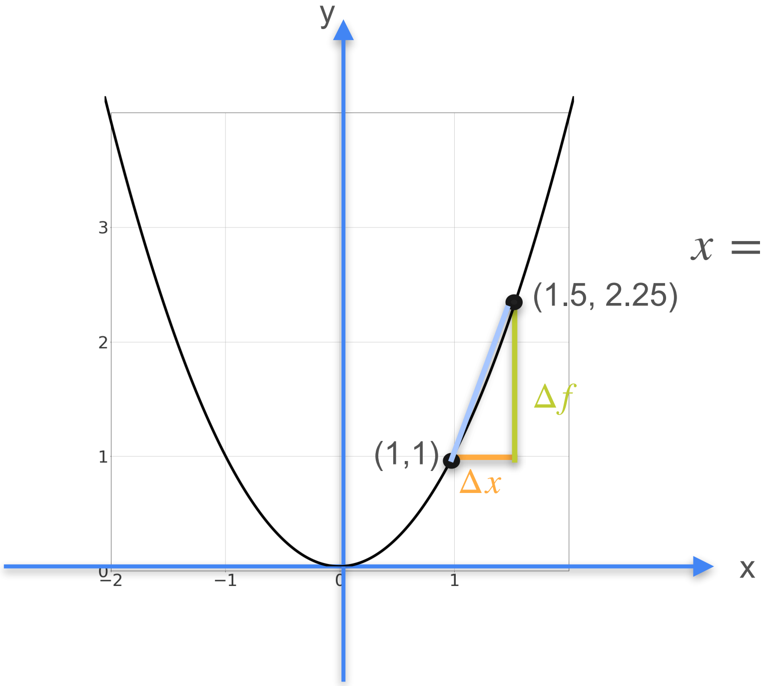
$x = 1$

Δx	1.0
Δf	3
Slope	3

$(1 + 1)^2 - 1^2 = 4 - 1$

$\dfrac{3}{1}$

Derivative of Quadratic Functions



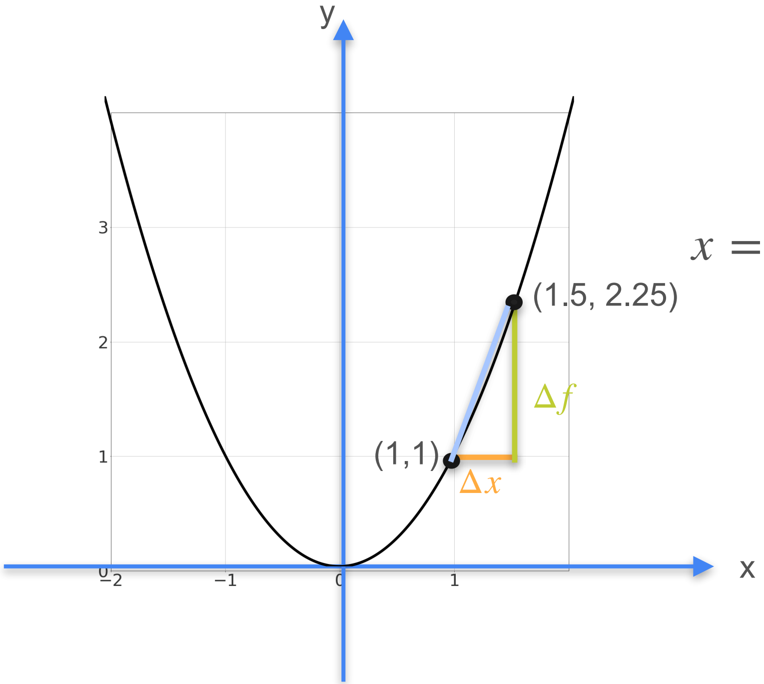
Quadratics: $y = f(x) = x^2$

Slope: $\dfrac{\Delta f}{\Delta x} = \dfrac{(x + \Delta x)^2 - (x)^2}{\Delta x}$

$x = 1$

Δx	1.0	1/2
Δf	3	
Slope	3	

Derivative of Quadratic Functions



Quadratics: $y = f(x) = x^2$

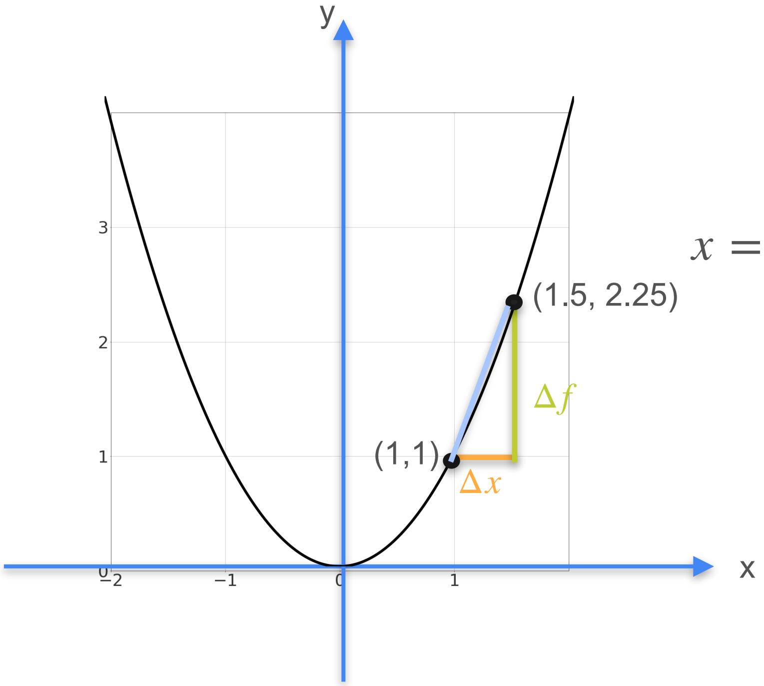
Slope: $\dfrac{\Delta f}{\Delta x} = \dfrac{(x + \Delta x)^2 - (x)^2}{\Delta x}$

$x = 1$

Δx	1.0	1/2
Δf	3	1.25
Slope	3	

$(1 + 0.5)^2 - 1^2 \ = 2.25 - 1$

Derivative of Quadratic Functions



Quadratics: $y = f(x) = x^2$

Slope: $\dfrac{\Delta f}{\Delta x} = \dfrac{(x + \Delta x)^2 - (x)^2}{\Delta x}$

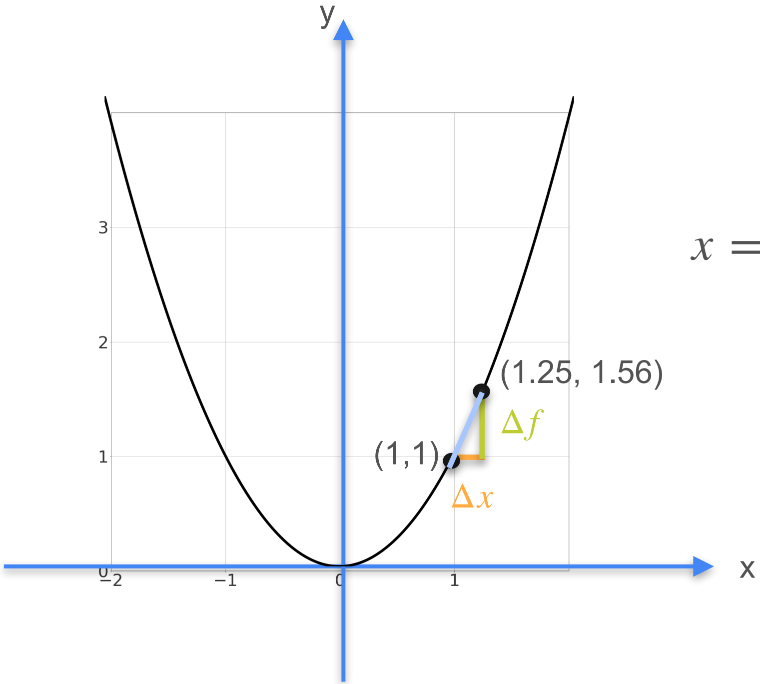
$x = 1$

Δx	1.0	1/2
Δf	3	1.25
Slope	3	2.5

$(1 + 0.5)^2 - 1^2 \;\; = 2.25 - 1$

$\dfrac{1.25}{0.5}$

Derivative of Quadratic Functions



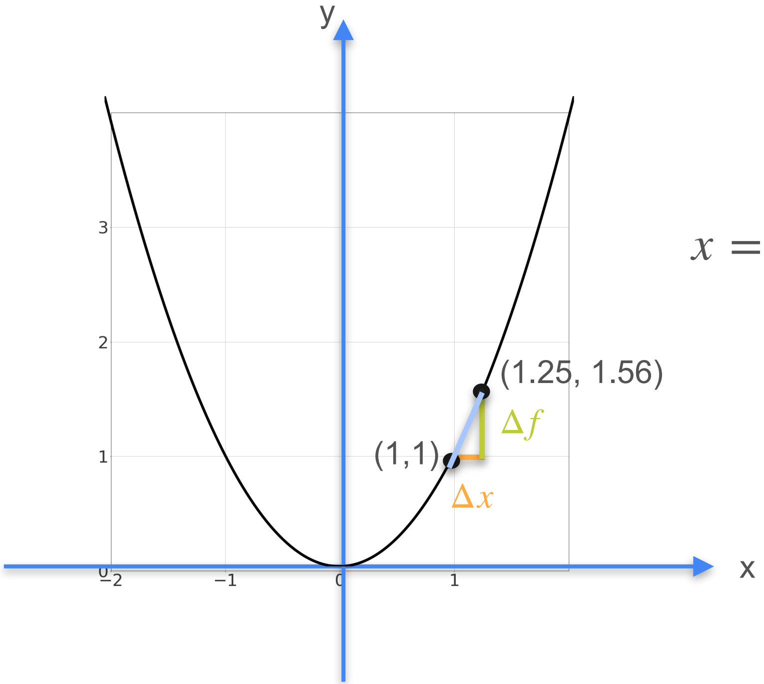
Quadratics: $y = f(x) = x^2$

Slope: $\dfrac{\Delta f}{\Delta x} = \dfrac{(x + \Delta x)^2 - (x)^2}{\Delta x}$

$x = 1$

Δx	1.0	1/2	1/4
Δf	3	1.25	
Slope	3	2.5	

Derivative of Quadratic Functions



Quadratics: $y = f(x) = x^2$

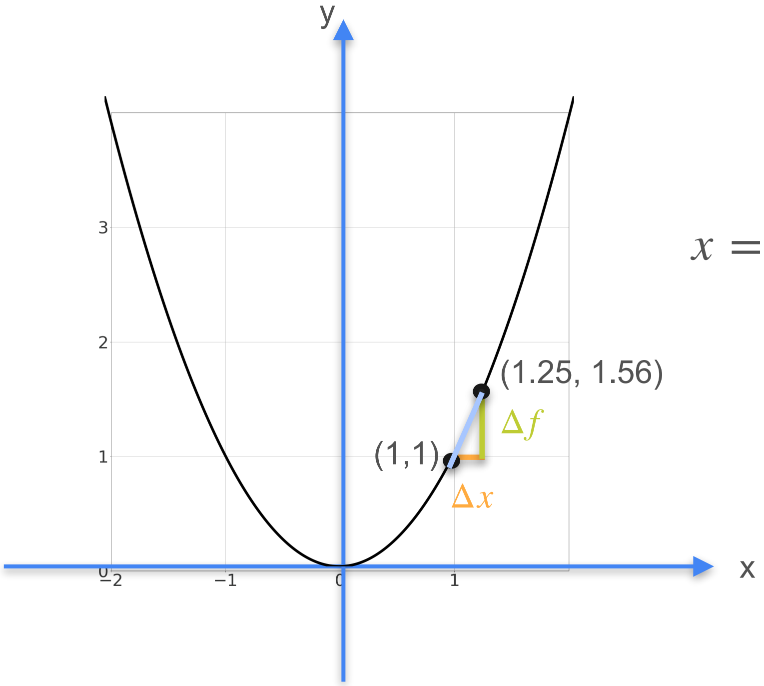
Slope: $\frac{\Delta f}{\Delta x} = \frac{(x + \Delta x)^2 - (x)^2}{\Delta x}$

$x = 1$

Δx	1.0	1/2	1/4
Δf	3	1.25	0.562
Slope	3	2.5	

$$(1 + 0.25)^2 - 1^2 = 1.56 - 1$$

Derivative of Quadratic Functions



Quadratics: $y = f(x) = x^2$

Slope: $\dfrac{\Delta f}{\Delta x} = \dfrac{(x + \Delta x)^2 - (x)^2}{\Delta x}$

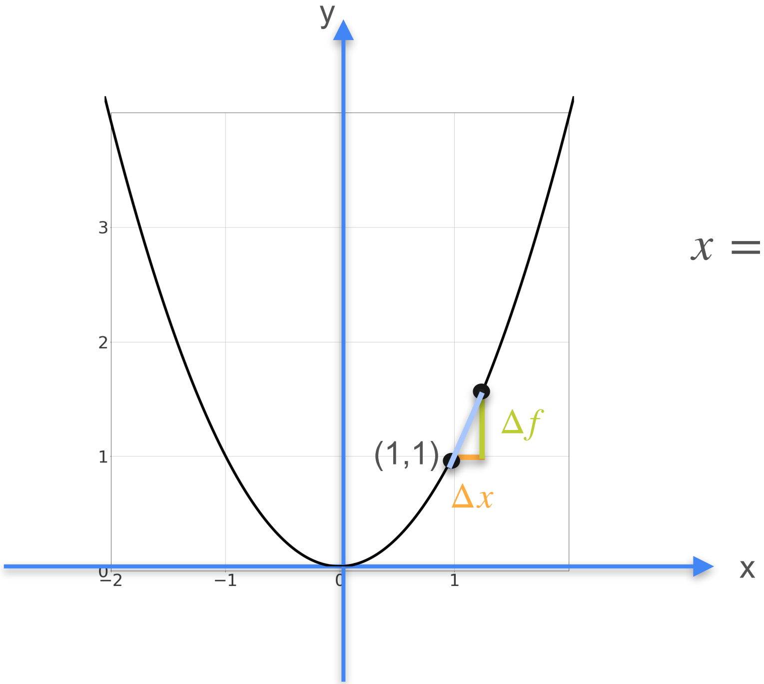
$x = 1$

Δx	1.0	1/2	1/4
Δf	3	1.25	0.562
Slope	3	2.5	2.25

$(1 + 0.25)^2 - 1^2 = 1.56 - 1$

$\dfrac{0.56}{0.25}$

Derivative of Quadratic Functions



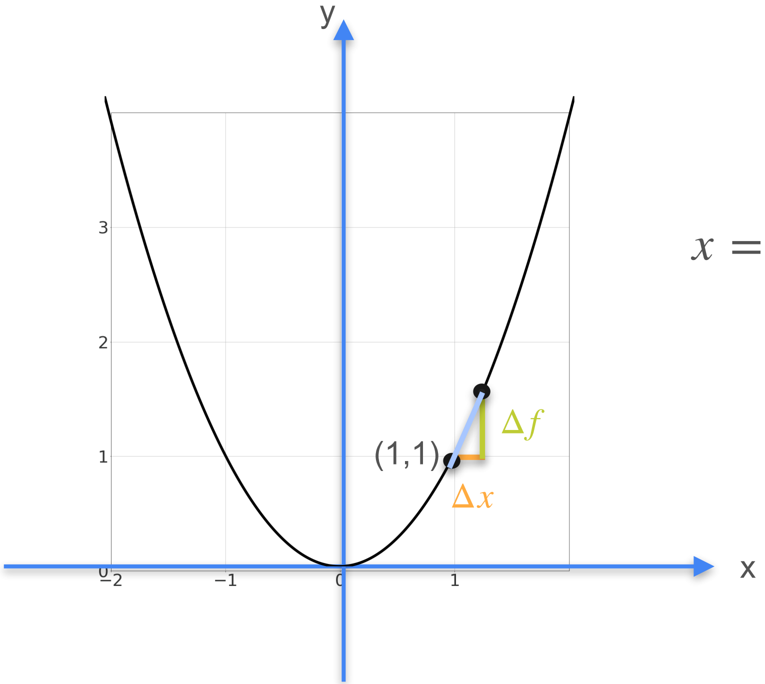
Quadratics: $y = f(x) = x^2$

Slope: $\dfrac{\Delta f}{\Delta x} = \dfrac{(x + \Delta x)^2 - (x)^2}{\Delta x}$

$x = 1$

Δx	1.0	1/2	1/4
Δf	3	1.25	0.562
Slope	3	2.5	2.25

Derivative of Quadratic Functions



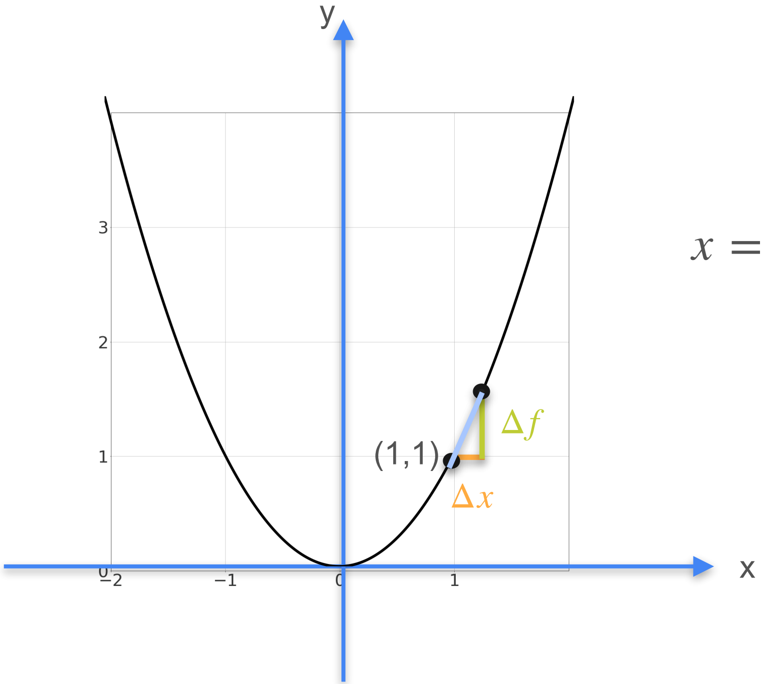
Quadratics: $y = f(x) = x^2$

Slope: $\dfrac{\Delta f}{\Delta x} = \dfrac{(x + \Delta x)^2 - (x)^2}{\Delta x}$

$x = 1$

Δx	1.0	1/2	1/4	1/8	1/16
Δf	3	1.25	0.562	0.265	
Slope	3	2.5	2.25	2.125	

Derivative of Quadratic Functions



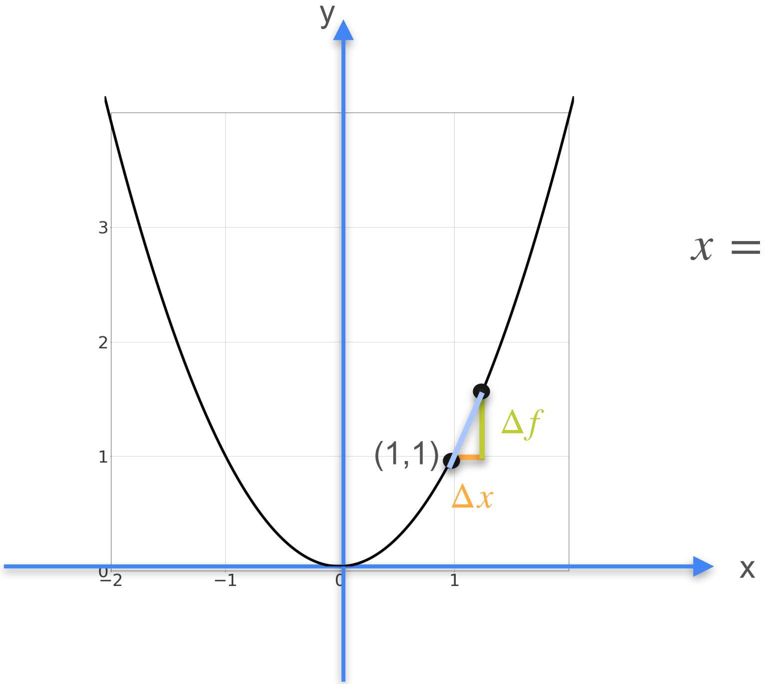
Quadratics: $y = f(x) = x^2$

Slope: $\dfrac{\Delta f}{\Delta x} = \dfrac{(x + \Delta x)^2 - (x)^2}{\Delta x}$

$x = 1$

Δx	1.0	1/2	1/4	1/8	1/16
Δf	3	1.25	0.562	0.265	0.128
Slope	3	2.5	2.25	2.125	

Derivative of Quadratic Functions



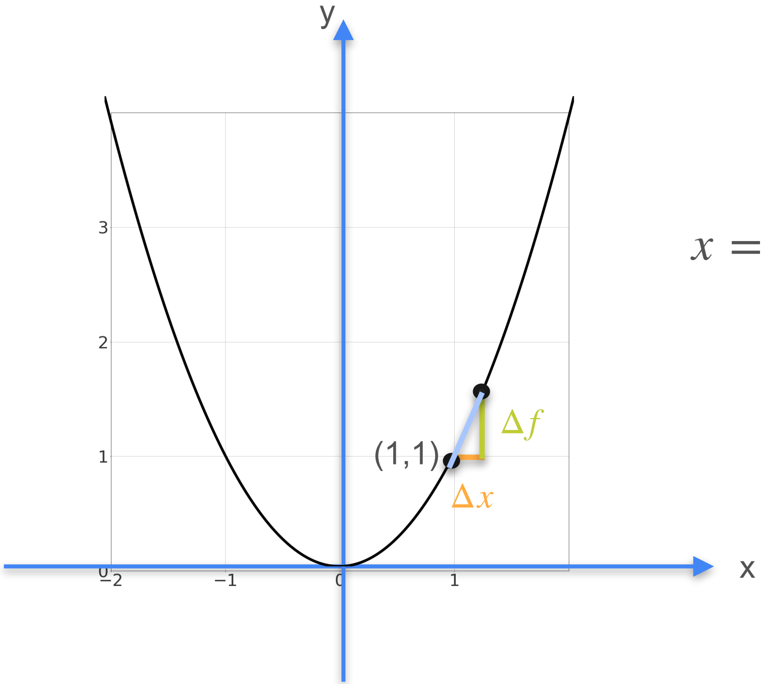
Quadratics: $y = f(x) = x^2$

Slope: $\dfrac{\Delta f}{\Delta x} = \dfrac{(x + \Delta x)^2 - (x)^2}{\Delta x}$

$x = 1$

Δx	1.0	1/2	1/4	1/8	1/16
Δf	3	1.25	0.562	0.265	0.128
Slope	3	2.5	2.25	2.125	2.065

Derivative of Quadratic Functions



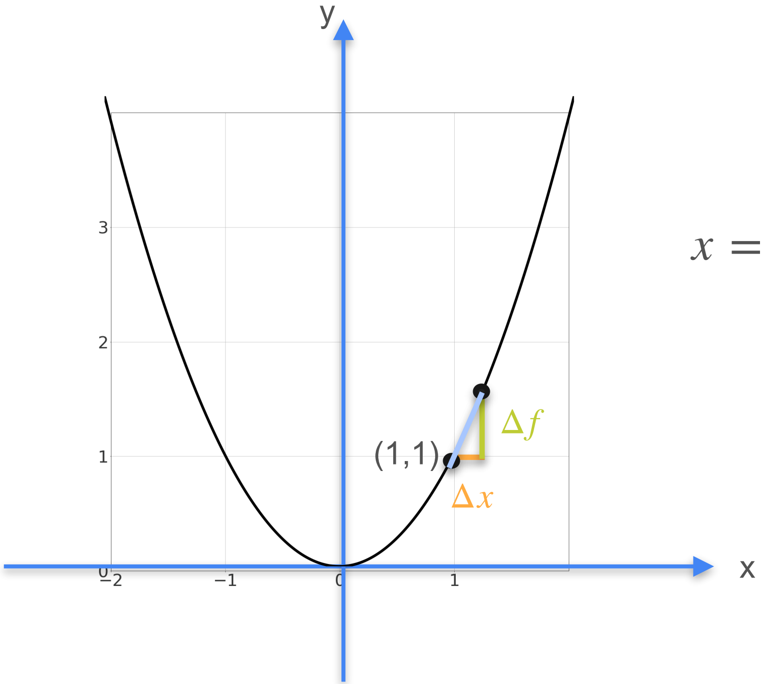
Quadratics: $y = f(x) = x^2$

Slope: $\dfrac{\Delta f}{\Delta x} = \dfrac{(x + \Delta x)^2 - (x)^2}{\Delta x}$

$x = 1$

Δx	1.0	1/2	1/4	1/8	1/16	1/1000
Δf	3	1.25	0.562	0.265	0.128	
Slope	3	2.5	2.25	2.125	2.065	

Derivative of Quadratic Functions



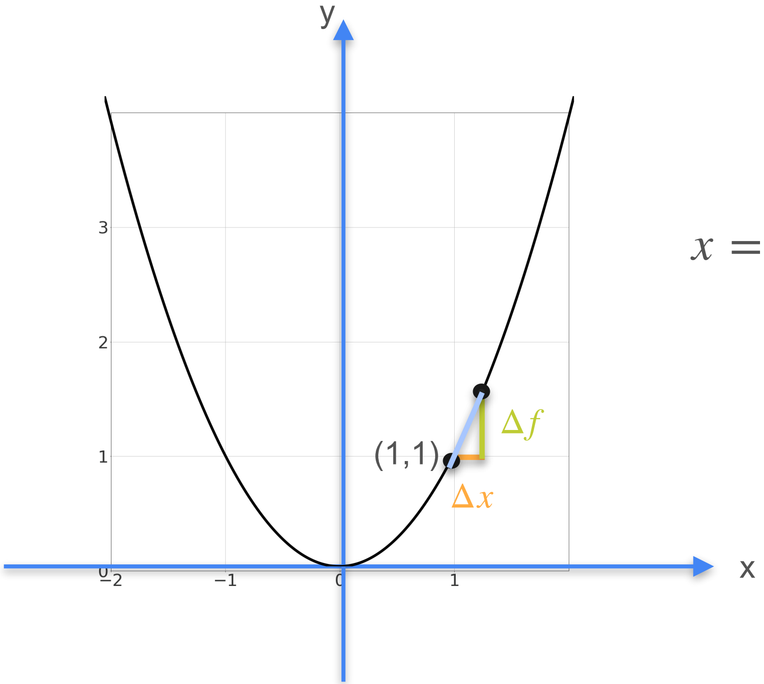
Quadratics: $y = f(x) = x^2$

Slope: $\dfrac{\Delta f}{\Delta x} = \dfrac{(x + \Delta x)^2 - (x)^2}{\Delta x}$

$x = 1$

Δx	1.0	1/2	1/4	1/8	1/16	1/1000
Δf	3	1.25	0.562	0.265	0.128	0.002
Slope	3	2.5	2.25	2.125	2.065	

Derivative of Quadratic Functions



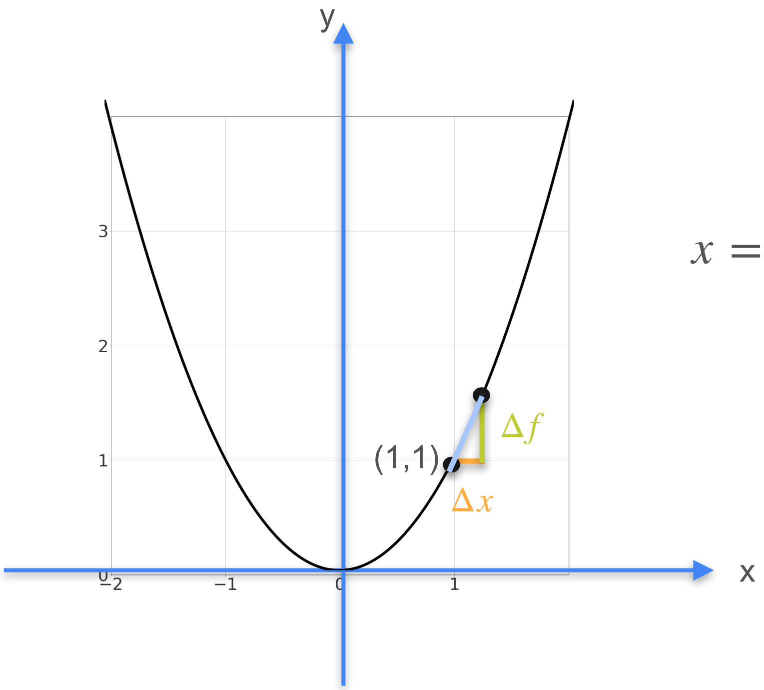
Quadratics: $y = f(x) = x^2$

Slope: $\frac{\Delta f}{\Delta x} = \frac{(x + \Delta x)^2 - (x)^2}{\Delta x}$

$x = 1$

Δx	1.0	1/2	1/4	1/8	1/16	1/1000
Δf	3	1.25	0.562	0.265	0.128	0.002
Slope	3	2.5	2.25	2.125	2.065	2.001

Derivative of Quadratic Functions



Quadratics: $y = f(x) = x^2$

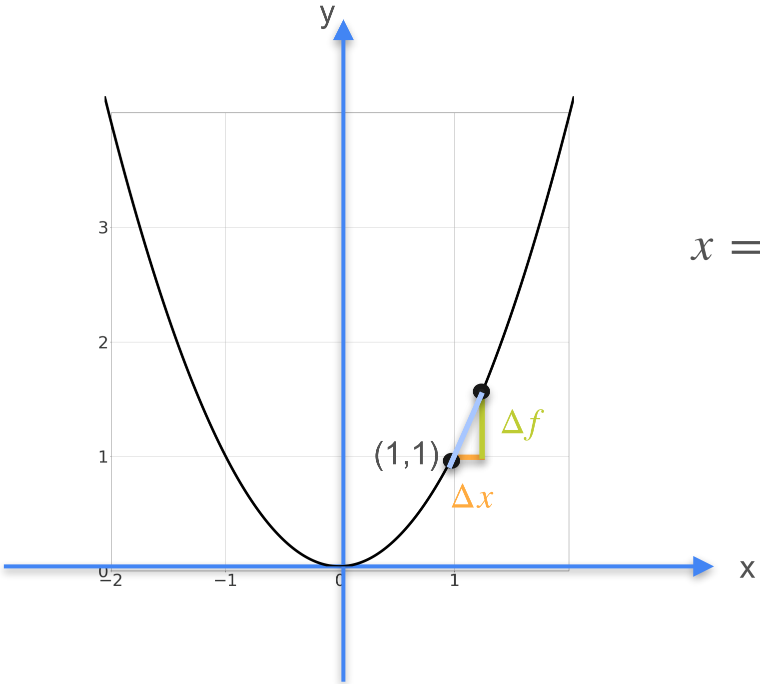
Slope: $\dfrac{\Delta f}{\Delta x} = \dfrac{(x+\Delta x)^2 - (x)^2}{\Delta x}$

$x = 1$

Δx	1.0	1/2	1/4	1/8	1/16	1/1000
Δf	3	1.25	0.562	0.265	0.128	0.002
Slope	3	2.5	2.25	2.125	2.065	2.001

$$f'(1) = \frac{d}{dx}f(1) = 2$$

Derivative of Quadratic Functions



Quadratics: $y = f(x) = x^2$

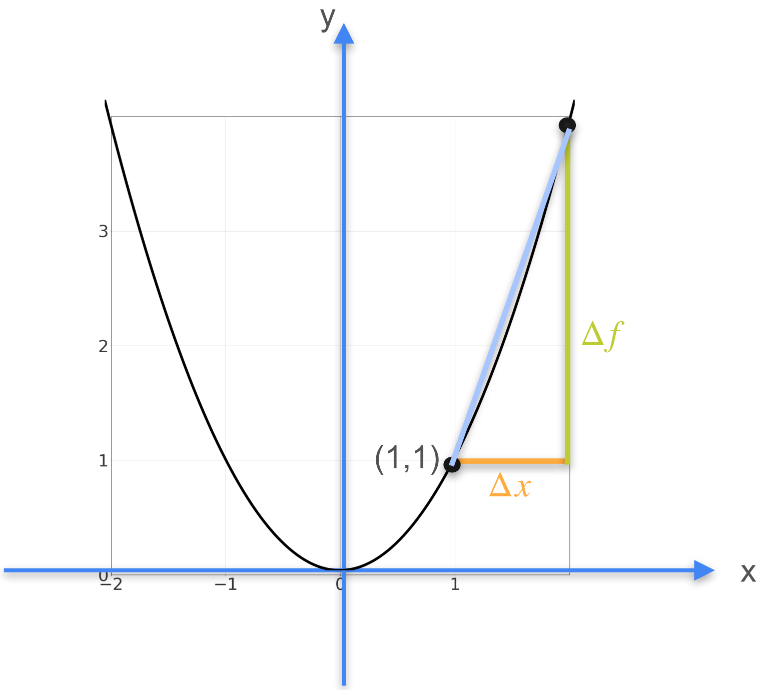
Slope: $\dfrac{\Delta f}{\Delta x} = \dfrac{(x + \Delta x)^2 - (x)^2}{\Delta x}$

$x = 1$

Δx	1.0	1/2	1/4	1/8	1/16	1/1000
Δf	3	1.25	0.562	0.265	0.128	0.002
Slope	3	2.5	2.25	2.125	2.065	2.001

$$f'(1) = \frac{d}{dx}f(1) = 2 = 2 \times 1$$

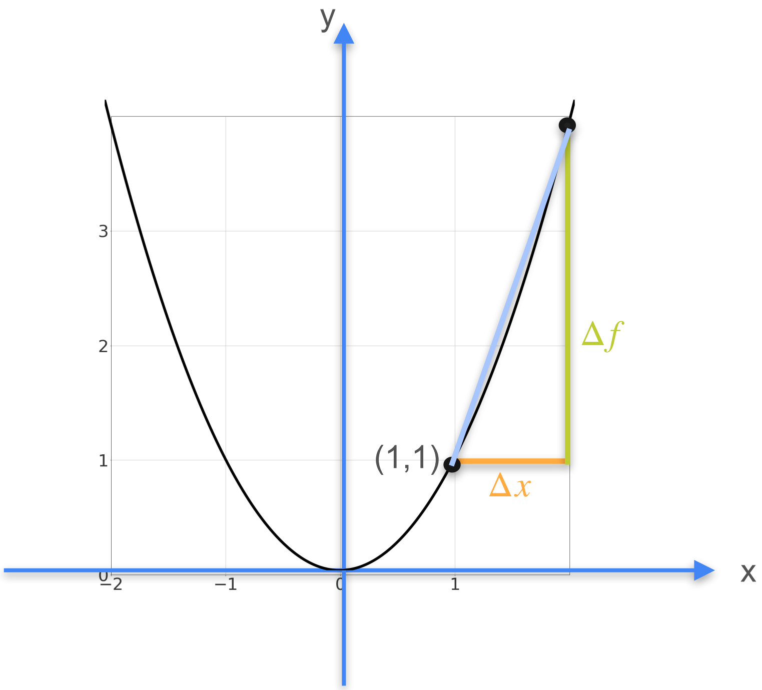
Derivative of Quadratic Functions



Quadratics: $y = f(x) = x^2$

Slope: $\dfrac{\Delta f}{\Delta x} = \dfrac{f(x + \Delta x) - f(x)}{\Delta x}$

Derivative of Quadratic Functions

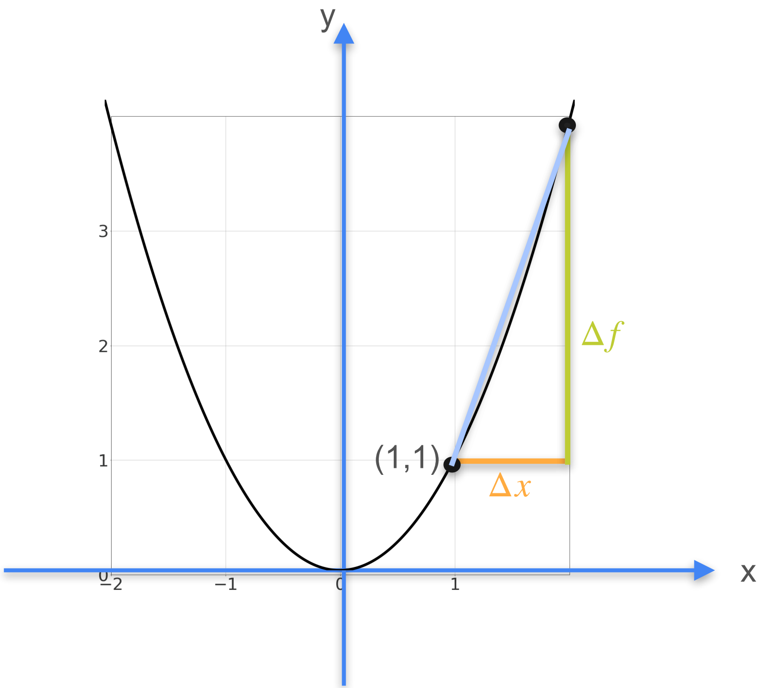


Quadratics: $y = f(x) = x^2$

Slope: $\dfrac{\Delta f}{\Delta x} = \dfrac{f(x + \Delta x) - f(x)}{\Delta x}$

$$\frac{\Delta f}{\Delta x}$$

Derivative of Quadratic Functions

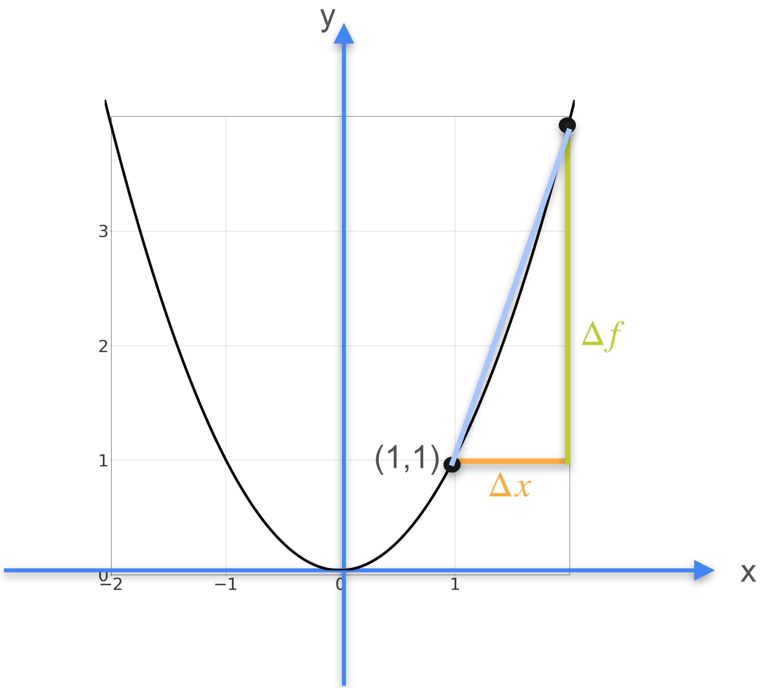


Quadratics: $y = f(x) = x^2$

Slope: $$\frac{\Delta f}{\Delta x} = \frac{f(x + \Delta x) - f(x)}{\Delta x}$$

$$\frac{\Delta f}{\Delta x} = \frac{(x + \Delta x)^2 \ - x^2}{\Delta x}$$

Derivative of Quadratic Functions



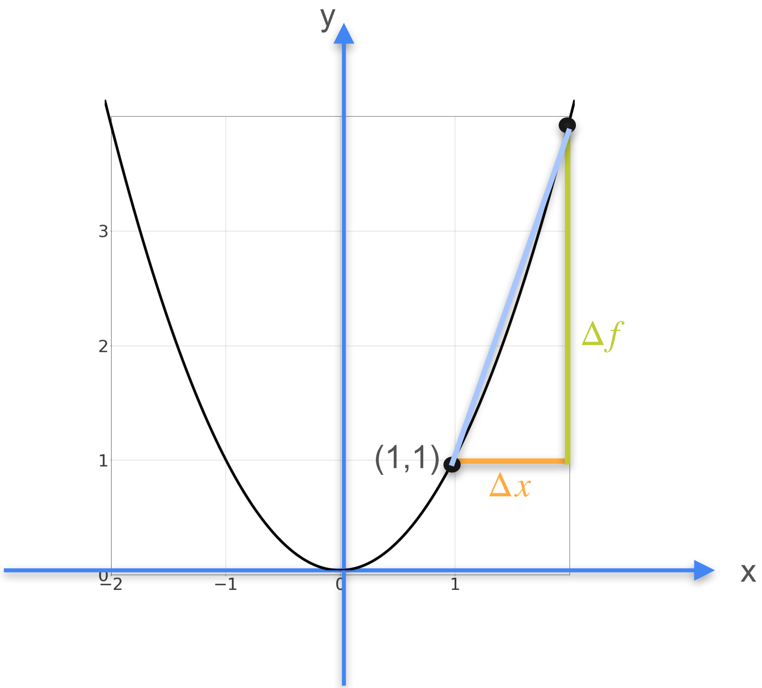
Quadratics: $y = f(x) = x^2$

Slope: $$\frac{\Delta f}{\Delta x} = \frac{f(x+\Delta x) - f(x)}{\Delta x}$$

$$\frac{\Delta f}{\Delta x} = \frac{(x+\Delta x)^2 - x^2}{\Delta x}$$

$$= \frac{x^2 + 2x\Delta x + (\Delta x)^2 - x^2}{\Delta x}$$

Derivative of Quadratic Functions



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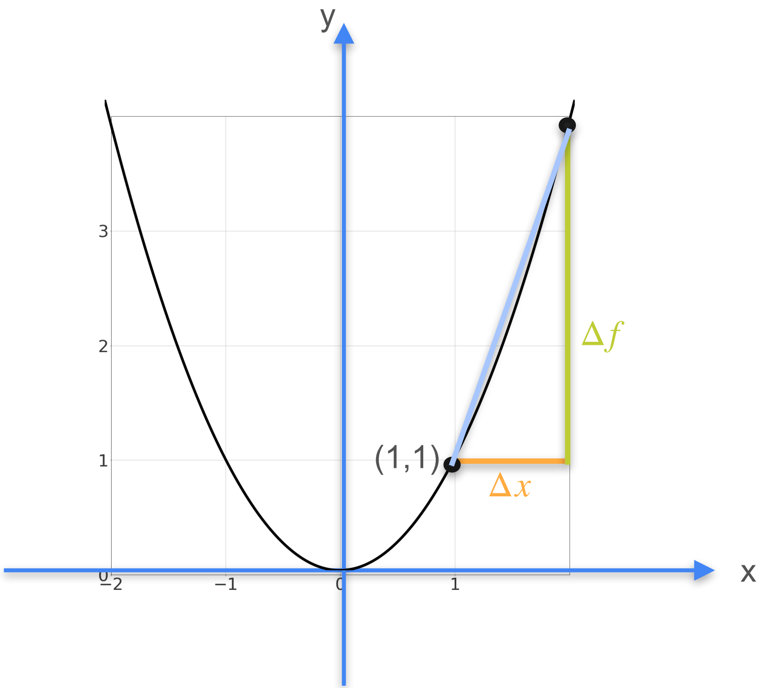
$$\frac{\Delta f}{\Delta x} = \frac{(x+\Delta x)^2 \ - x^2}{\Delta x}$$

$$= \frac{\cancel{x^2} + 2x\Delta x + (\Delta x)^2 - \cancel{x^2}}{\Delta x}$$

Derivative of Quadratic Functions



Quadratics: $y = f(x) = x^2$

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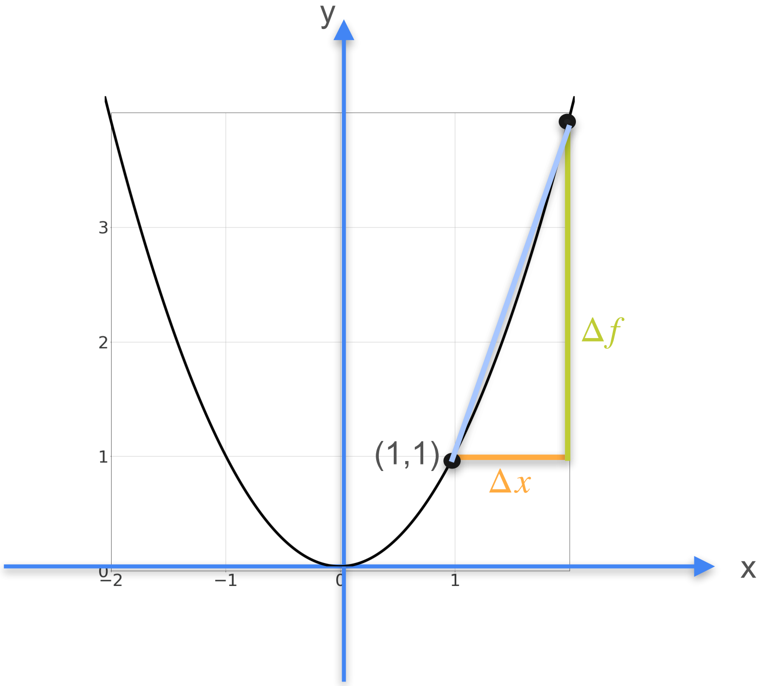
$$\frac{\Delta f}{\Delta x} = \frac{(x+\Delta x)^2 - x^2}{\Delta x}$$

$$= \frac{\cancel{x^2} + 2x\cancel{\Delta x} + (\Delta x)^{\cancel{2}} - \cancel{x^2}}{\cancel{\Delta} x}$$

Derivative of Quadratic Functions



Quadratics: $y = f(x) = x^2$

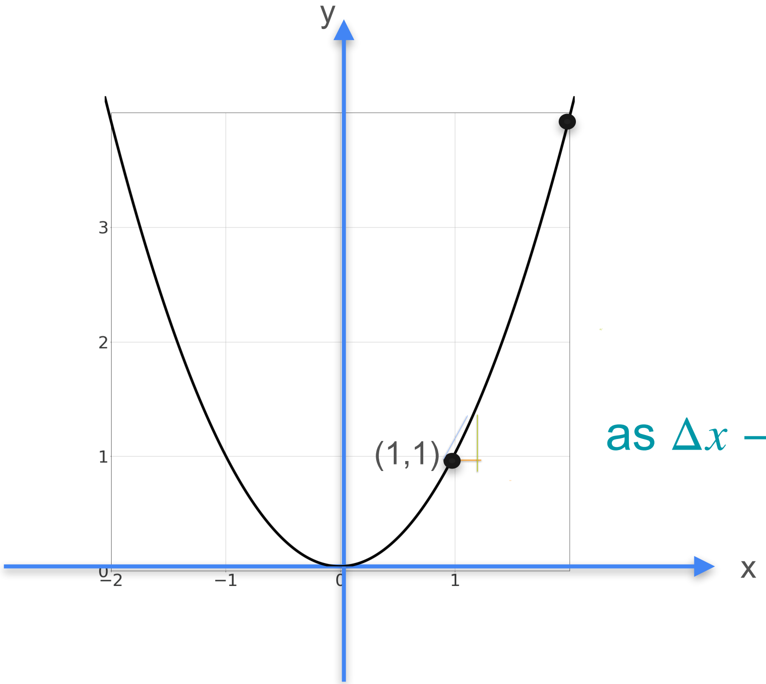
Slope: $$\frac{\Delta f}{\Delta x} = \frac{f(x+\Delta x) - f(x)}{\Delta x}$$

$$\frac{\Delta f}{\Delta x} = \frac{(x+\Delta x)^2 \ - x^2}{\Delta x}$$

$$= \frac{\cancel{x^2} + 2x\cancel{\Delta x} + (\Delta x)^{\cancel{2}} - \cancel{x^2}}{\cancel{\Delta} x}$$

$$= 2x + \Delta x$$

Derivative of Quadratic Functions



as $\Delta x \longrightarrow 0$

Quadratics: $y = f(x) = x^2$

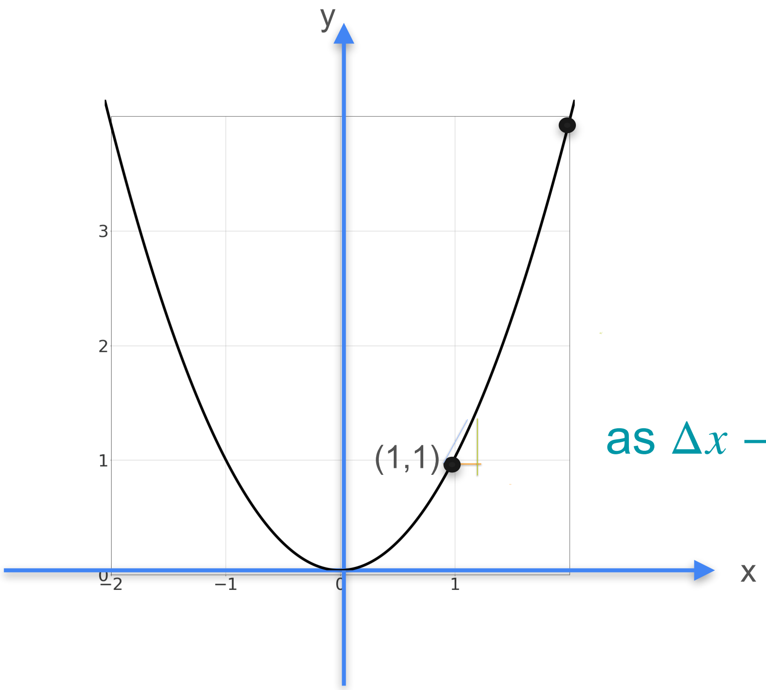
Slope: $$\frac{\Delta f}{\Delta x} = \frac{f(x+\Delta x) - f(x)}{\Delta x}$$

$$\frac{\Delta f}{\Delta x} = \frac{(x+\Delta x)^2 - x^2}{\Delta x}$$

$$= \frac{\cancel{x^2} + 2x\cancel{\Delta x} + (\Delta x)^{\cancel{2}} - \cancel{x^2}}{\cancel{\Delta} x}$$

$$= 2x + \Delta x$$

Derivative of Quadratic Functions



as $\Delta x \longrightarrow 0$

Quadratics: $y = f(x) = x^2$

Slope: $\frac{\Delta f}{\Delta x} = \frac{f(x+\Delta x) - f(x)}{\Delta x}$

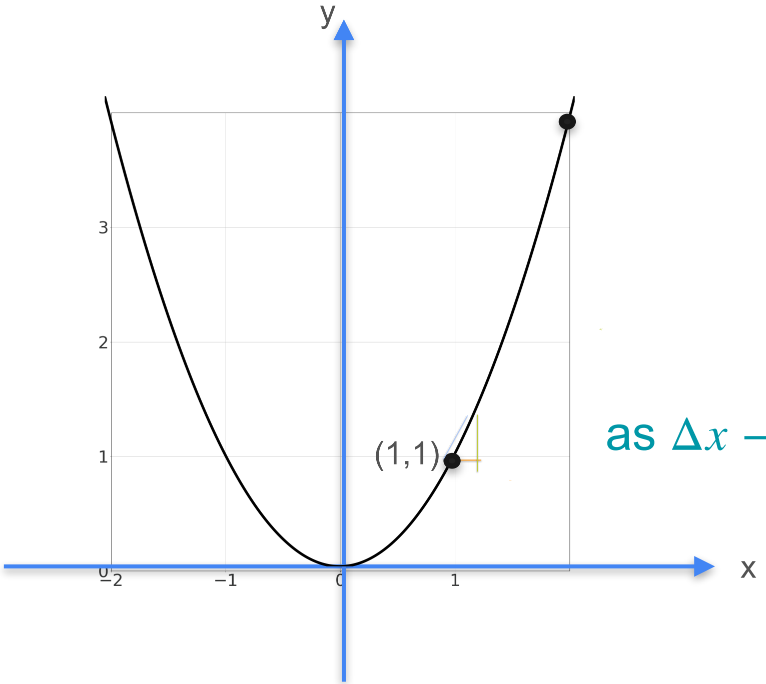
$$\frac{\Delta f}{\Delta x} = \frac{(x+\Delta x)^2 - x^2}{\Delta x}$$

$$= \frac{\cancel{x^2} + 2x\cancel{\Delta x} + (\Delta x)^{\cancel{2}} - \cancel{x^2}}{\cancel{\Delta x}}$$

$$= 2x + \boxed{\Delta x}$$

0

Derivative of Quadratic Functions



as $\Delta x \longrightarrow 0$

Quadratics: $y = f(x) = x^2$

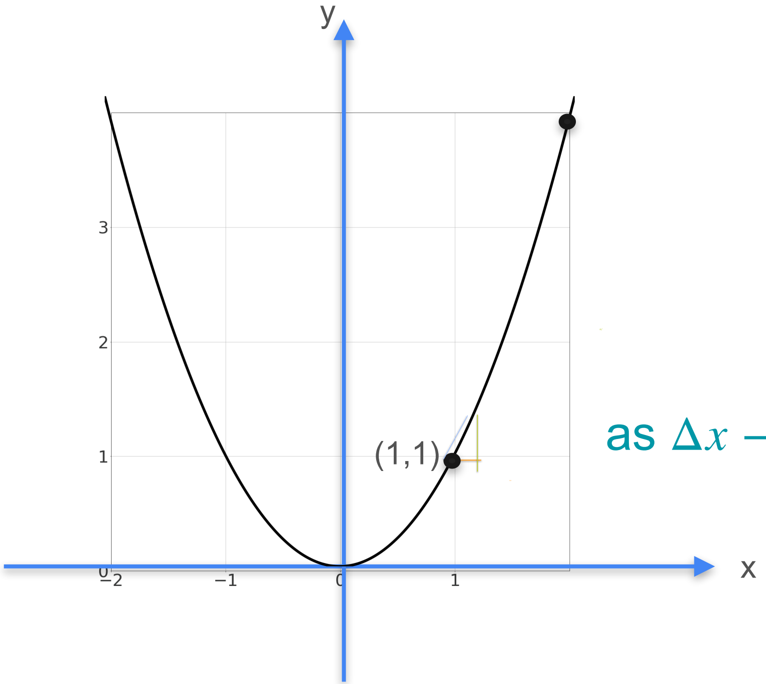
Slope: $\dfrac{\Delta f}{\Delta x} = \dfrac{f(x + \Delta x) - f(x)}{\Delta x}$

$$\boxed{\frac{\Delta f}{\Delta x}} = \frac{(x + \Delta x)^2 \; - x^2}{\Delta x}$$

$$= \frac{\cancel{x^2} + 2x\cancel{\Delta x} + (\Delta x)^{\cancel{2}} - \cancel{x^2}}{\cancel{\Delta x}}$$

$$= 2x + \boxed{\Delta x} \; 0$$

Derivative of Quadratic Functions



Quadratics: $y = f(x) = x^2$

Slope: $\dfrac{\Delta f}{\Delta x} = \dfrac{f(x+\Delta x) - f(x)}{\Delta x}$

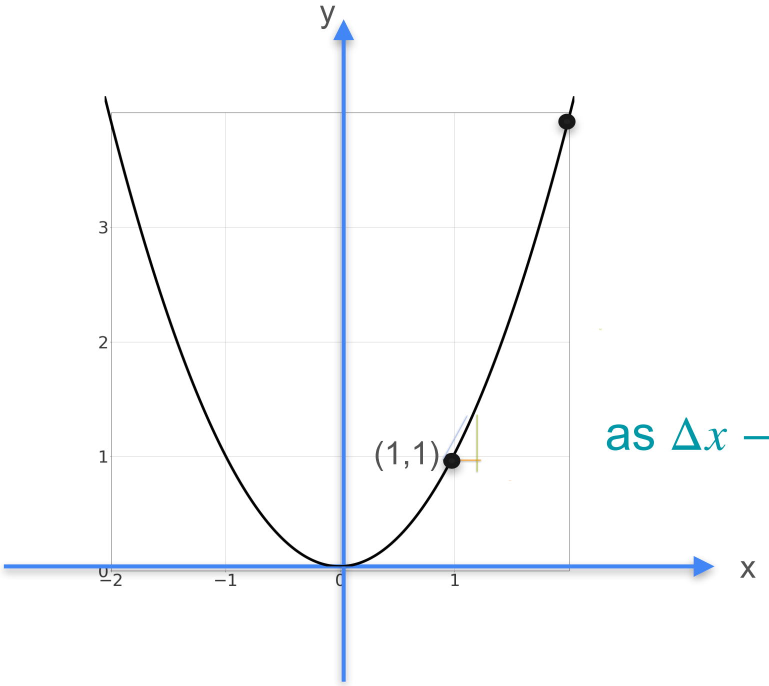
$\dfrac{df}{dx}$ $\boxed{\dfrac{\Delta f}{\Delta x}} = \dfrac{(x+\Delta x)^2 - x^2}{\Delta x}$

$= \dfrac{\cancel{x^2} + 2x\cancel{\Delta x} + (\Delta x)^{\cancel{2}} - \cancel{x^2}}{\cancel{\Delta x}}$

as $\Delta x \longrightarrow 0$

$= 2x + \boxed{\Delta x}$ 0

Derivative of Quadratic Functions



as $\Delta x \longrightarrow 0$

Quadratics: $y = f(x) = x^2$

Slope: $\dfrac{\Delta f}{\Delta x} = \dfrac{f(x+\Delta x) - f(x)}{\Delta x}$

$$\frac{df}{dx} \quad \boxed{\frac{\Delta f}{\Delta x}} = \frac{(x+\Delta x)^2 - x^2}{\Delta x}$$

$$= \frac{\cancel{x^2} + 2x\cancel{\Delta x} + (\Delta x)^{\cancel{2}} - \cancel{x^2}}{\cancel{\Delta}x}$$

$$= 2x + \boxed{\Delta x} \quad 0$$

$$f(x) = x^2 \Rightarrow f'(x) = 2x$$

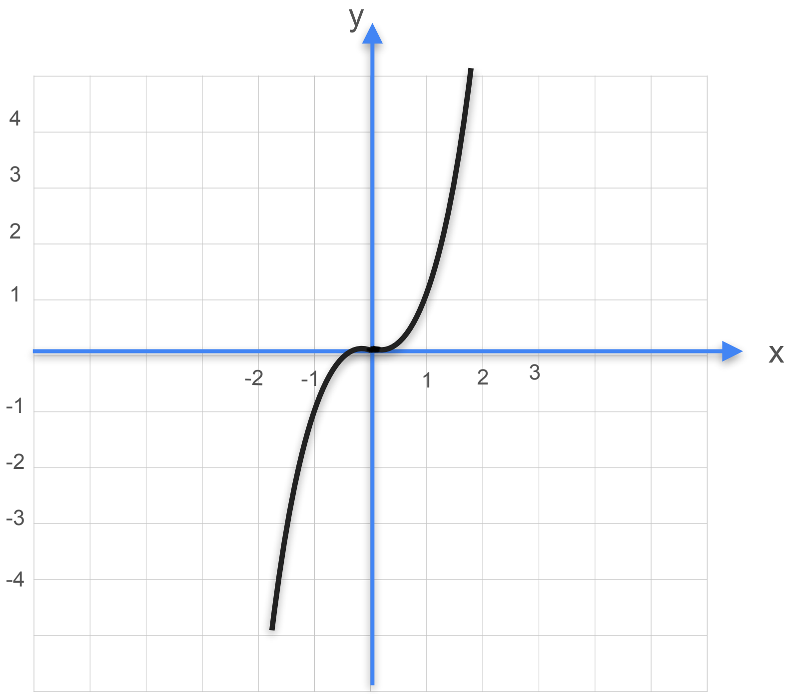
DeepLearning.AI

Derivatives and Optimization

Some common derivatives: Higher degree polynomials

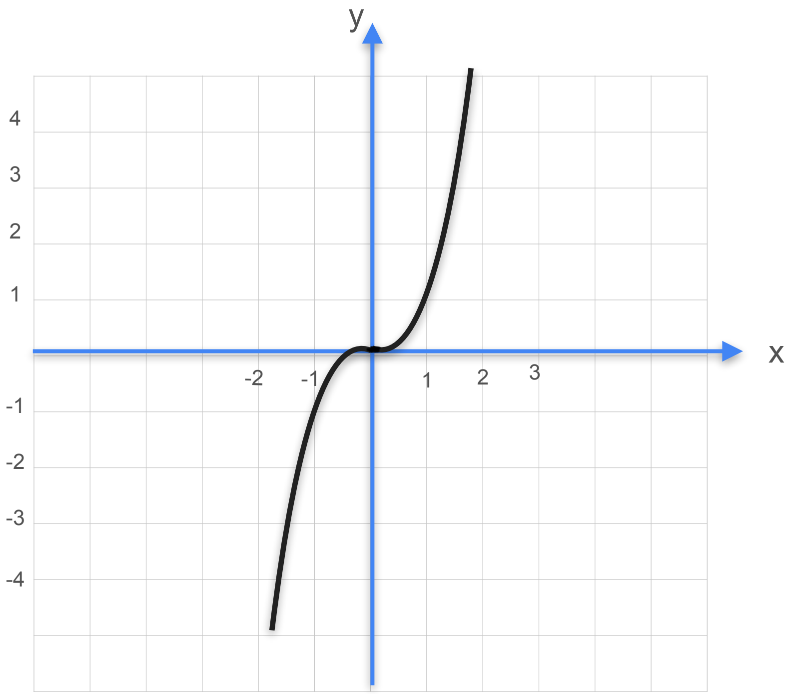
Derivative of Cubic Functions

Derivative of Cubic Functions



Cubic: $y = f(x) = x^3$

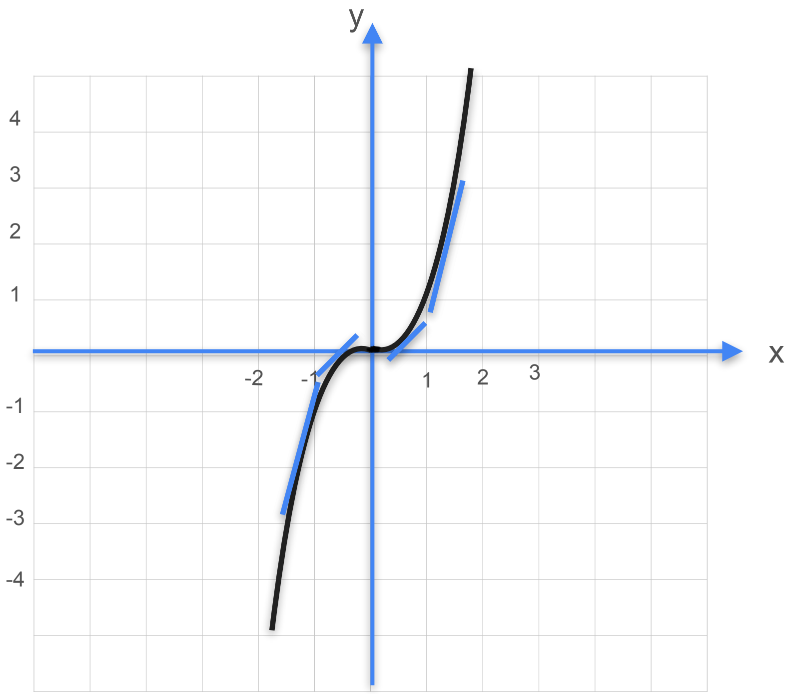
Derivative of Cubic Functions



Cubic: $y = f(x) = x^3$

Slope: $\dfrac{\Delta f}{\Delta x}$

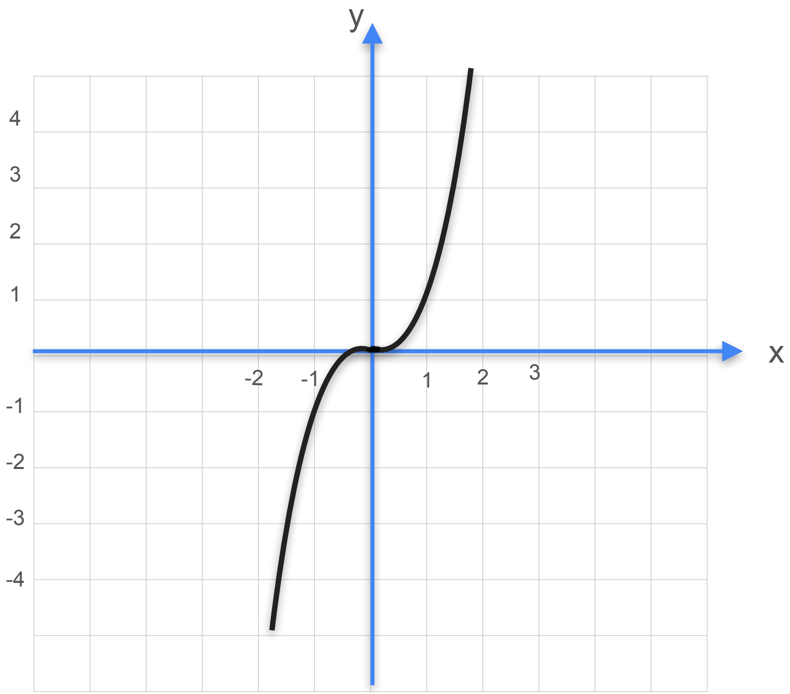
Derivative of Cubic Functions



Cubic: $y = f(x) = x^3$

Slope: $\dfrac{\Delta f}{\Delta x}$

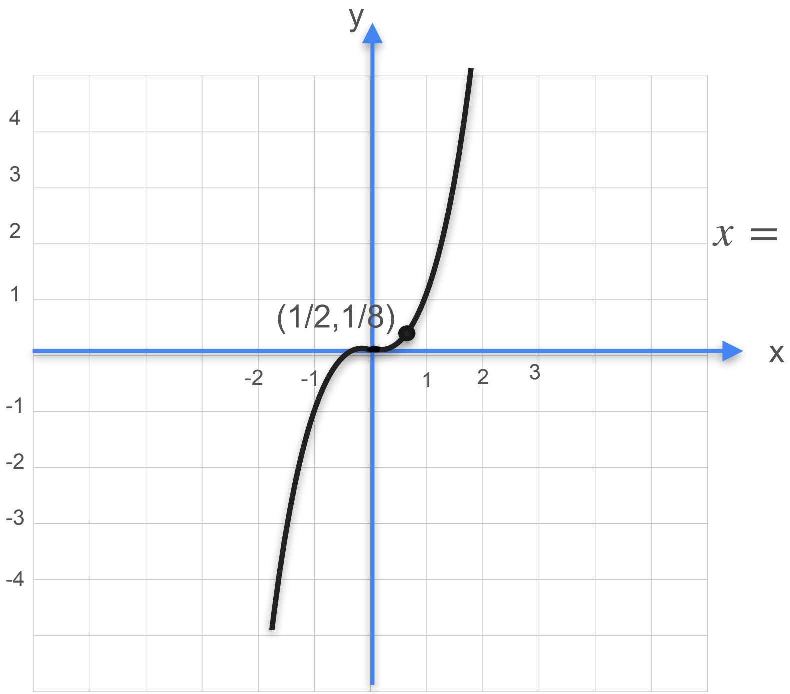
Derivative of Cubic Functions



Cubic: $y = f(x) = x^3$

Slope: $\dfrac{\Delta f}{\Delta x} = \dfrac{(x + \Delta x)^3 - (x)^3}{\Delta x}$

Derivative of Cubic Functions

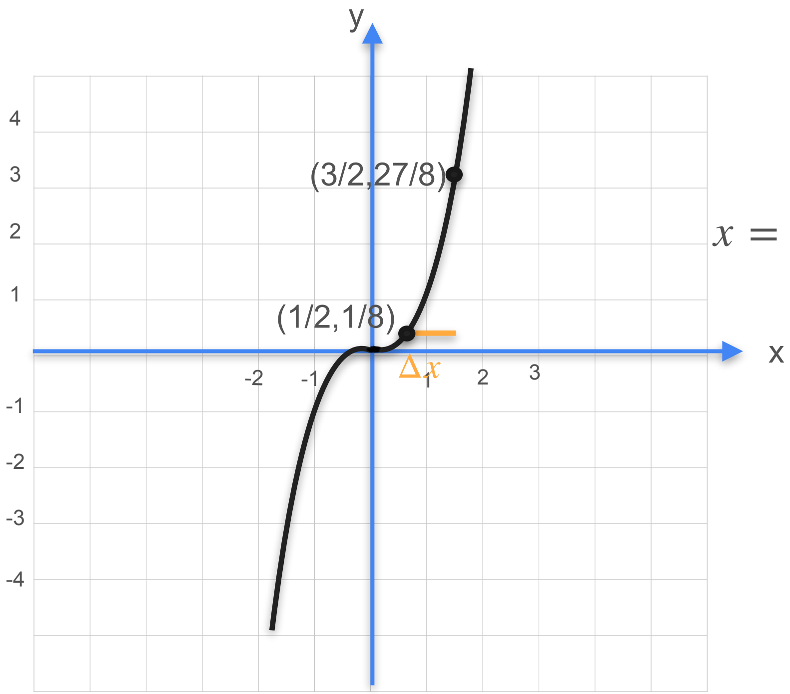


$x = 0.5$

Cubic: $y = f(x) = x^3$

Slope: $\frac{\Delta f}{\Delta x} = \frac{(x + \Delta x)^3 - (x)^3}{\Delta x}$

Derivative of Cubic Functions



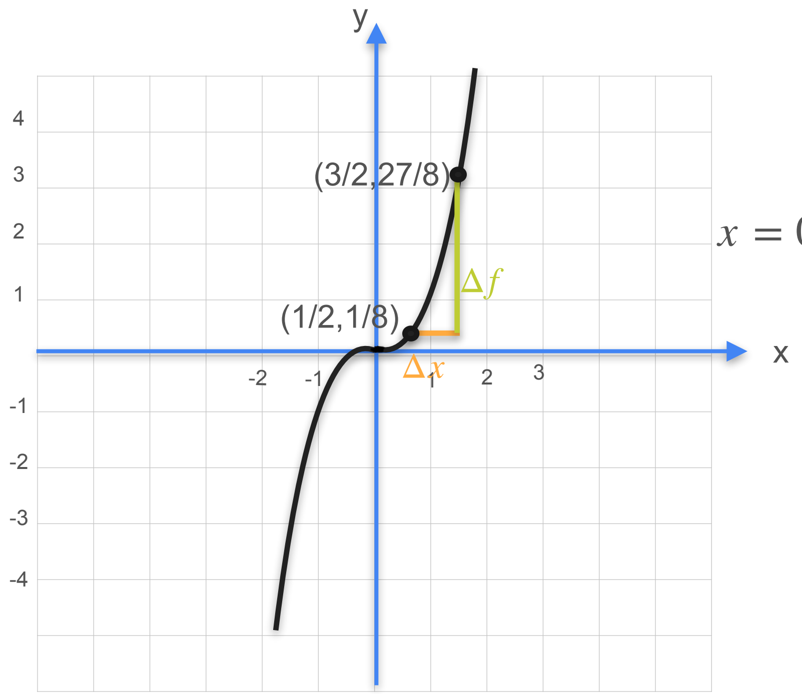
Cubic: $y = f(x) = x^3$

Slope: $\dfrac{\Delta f}{\Delta x} = \dfrac{(x + \Delta x)^3 - (x)^3}{\Delta x}$

$x = 0.5$

Δx	1.0

Derivative of Cubic Functions



Cubic: $y = f(x) = x^3$

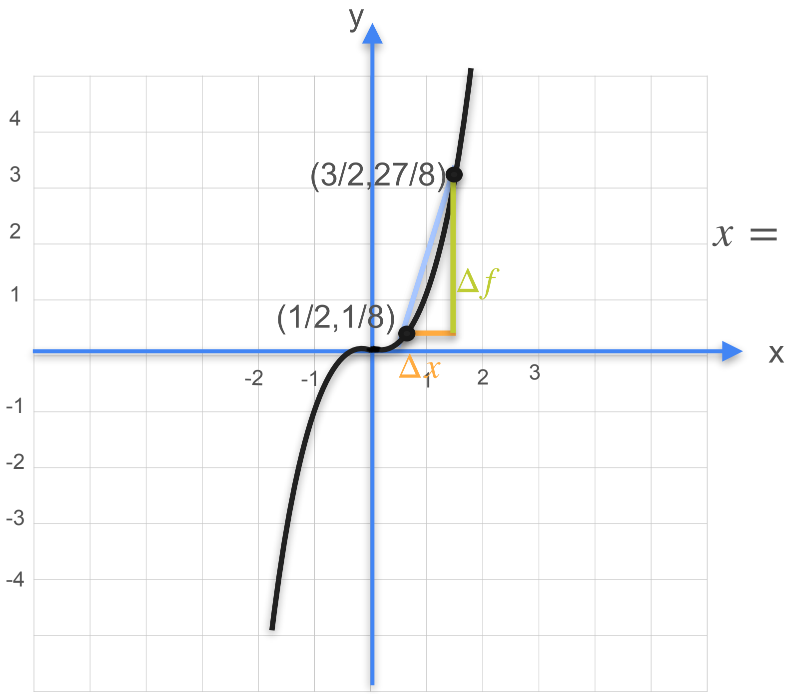
Slope: $\dfrac{\Delta f}{\Delta x} = \dfrac{(x + \Delta x)^3 - (x)^3}{\Delta x}$

$x = 0.5$

Δx	1.0
Δf	3.25

$$\left(\frac{1}{2} + 1\right)^3 - \left(\frac{1}{2}\right)^3 = \frac{27}{8} - \frac{1}{8}$$

Derivative of Cubic Functions



Cubic: $y = f(x) = x^3$

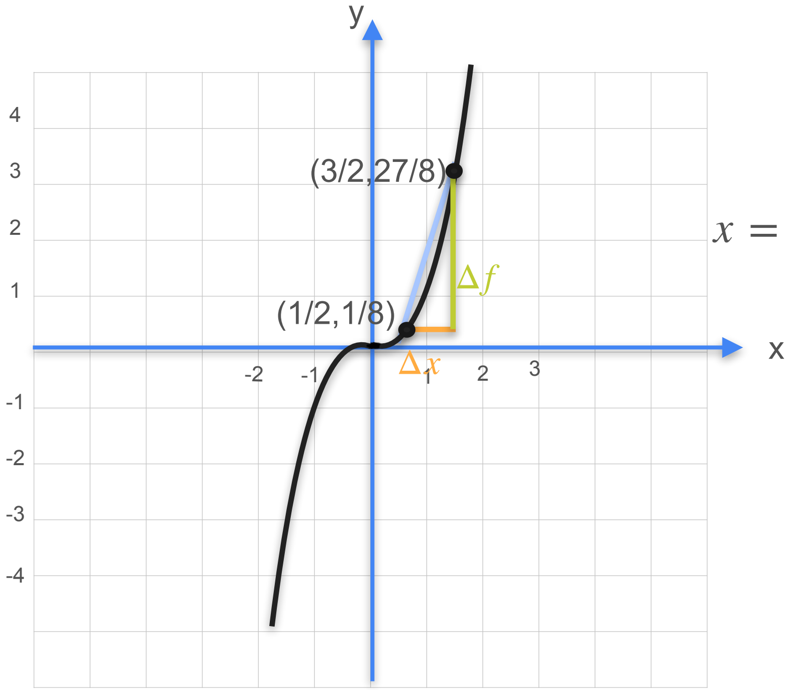
Slope: $\dfrac{\Delta f}{\Delta x} = \dfrac{(x + \Delta x)^3 - (x)^3}{\Delta x}$

$x = 0.5$

Δx	1.0
Δf	3.25
Slope	

$$\left(\frac{1}{2} + 1\right)^3 - \left(\frac{1}{2}\right)^3 = \frac{27}{8} - \frac{1}{8}$$

Derivative of Cubic Functions



Cubic: $y = f(x) = x^3$

Slope: $\dfrac{\Delta f}{\Delta x} = \dfrac{(x + \Delta x)^3 - (x)^3}{\Delta x}$

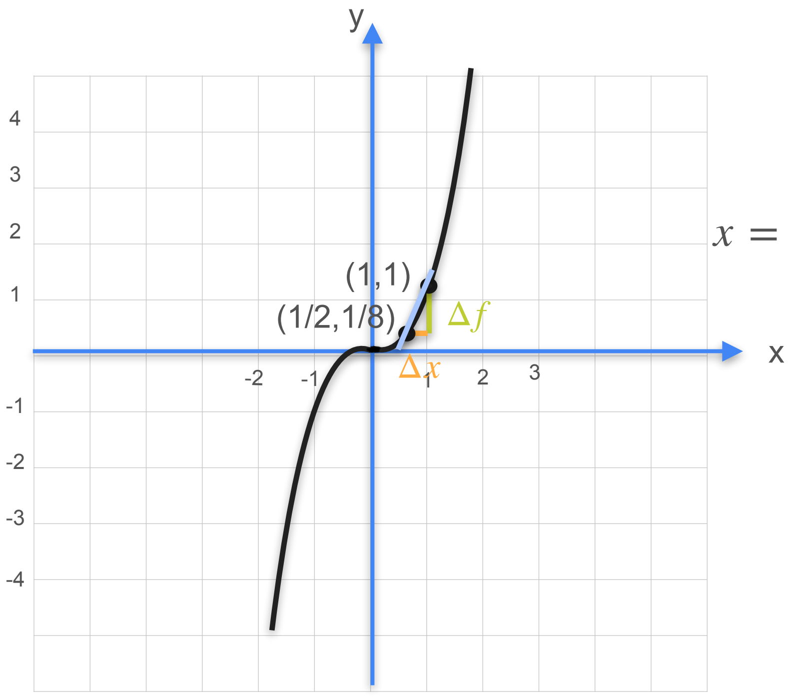
$x = 0.5$

Δx	1.0
Δf	3.25
Slope	3.25

$$\left(\frac{1}{2} + 1\right)^3 - \left(\frac{1}{2}\right)^3 = \frac{27}{8} - \frac{1}{8}$$

$$\frac{3.25}{1}$$

Derivative of Cubic Functions



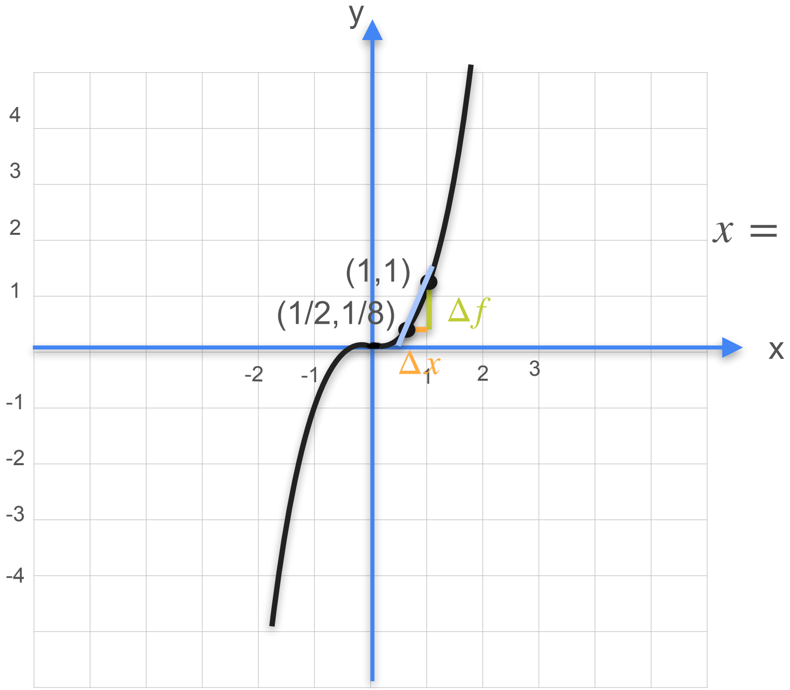
Cubic: $y = f(x) = x^3$

Slope: $\dfrac{\Delta f}{\Delta x} = \dfrac{(x + \Delta x)^3 - (x)^3}{\Delta x}$

$x = 0.5$

Δx	1.0
Δf	3.25
Slope	3.25

Derivative of Cubic Functions



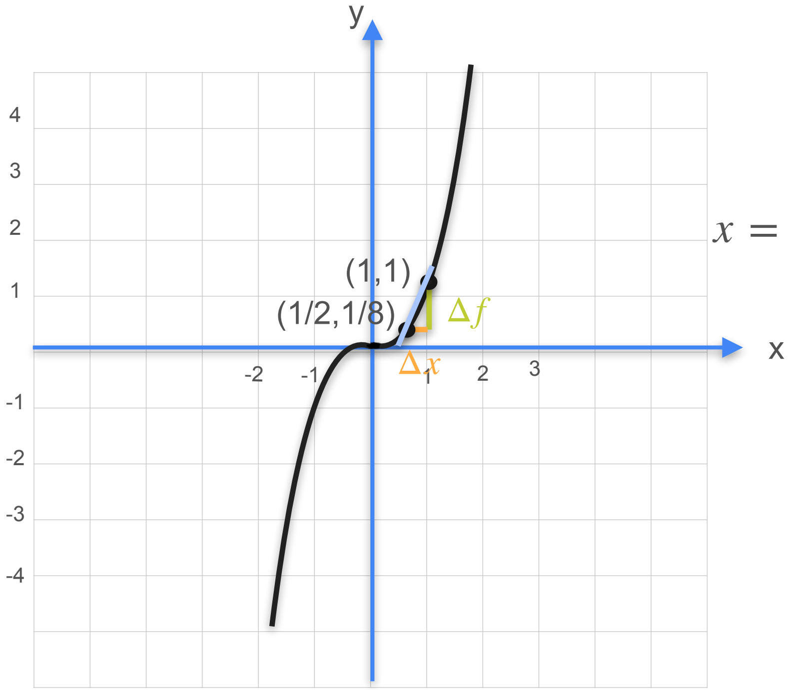
Cubic: $y = f(x) = x^3$

Slope: $\dfrac{\Delta f}{\Delta x} = \dfrac{(x + \Delta x)^3 - (x)^3}{\Delta x}$

$x = 0.5$

Δx	1.0	1/2
Δf	3.25	
Slope	3.25	

Derivative of Cubic Functions



Cubic: $y = f(x) = x^3$

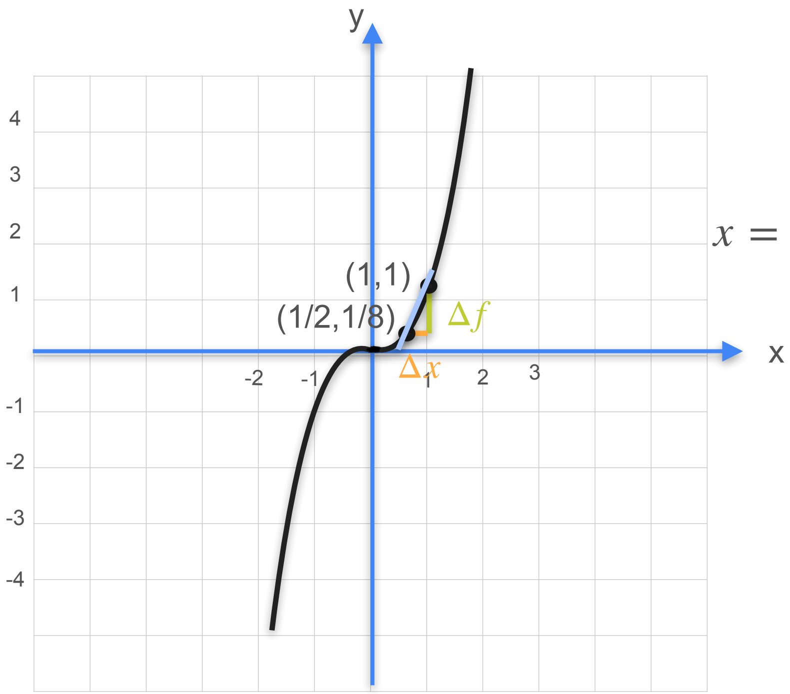
Slope: $\frac{\Delta f}{\Delta x} = \frac{(x + \Delta x)^3 - (x)^3}{\Delta x}$

$x = 0.5$

Δx	1.0	1/2
Δf	3.25	0.86
Slope	3.25	

$$\left(\frac{1}{2} + \frac{1}{2}\right)^3 - \left(\frac{1}{2}\right)^3 = 1 - \frac{1}{8}$$

Derivative of Cubic Functions



Cubic: $y = f(x) = x^3$

Slope: $\dfrac{\Delta f}{\Delta x} = \dfrac{(x + \Delta x)^3 - (x)^3}{\Delta x}$

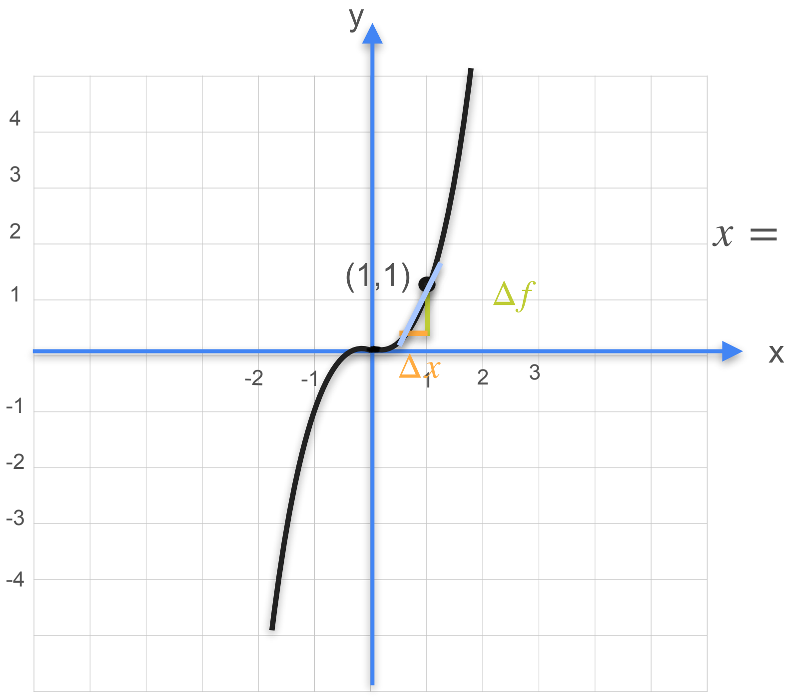
$x = 0.5$

Δx	1.0	1/2
Δf	3.25	0.86
Slope	3.25	1.75

$$\left(\frac{1}{2} + \frac{1}{2}\right)^3 - \left(\frac{1}{2}\right)^3 = 1 - \frac{1}{8}$$

$$\frac{0.86}{0.5}$$

Derivative of Cubic Functions



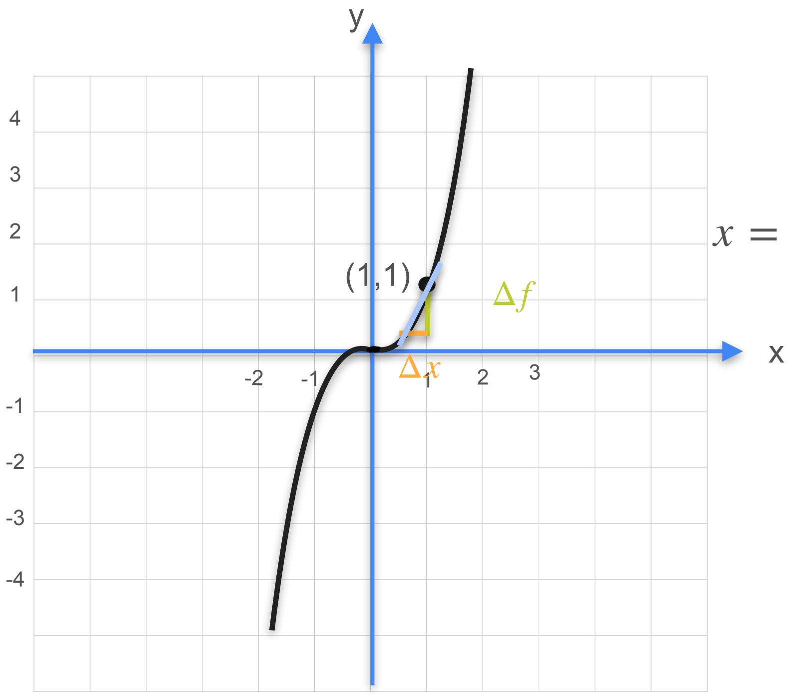
Cubic: $y = f(x) = x^3$

Slope: $\dfrac{\Delta f}{\Delta x} = \dfrac{(x + \Delta x)^3 - (x)^3}{\Delta x}$

$x = 0.5$

Δx	1.0	1/2
Δf	3.25	0.86
Slope	3.25	1.75

Derivative of Cubic Functions



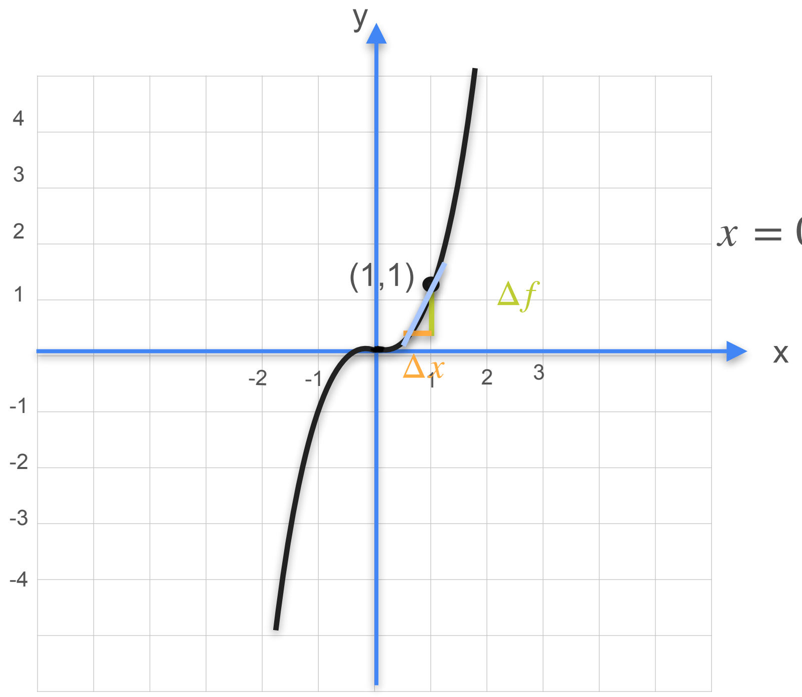
Cubic: $y = f(x) = x^3$

Slope: $\dfrac{\Delta f}{\Delta x} = \dfrac{(x + \Delta x)^3 - (x)^3}{\Delta x}$

$x = 0.5$

Δx	1.0	1/2	1/4
Δf	3.25	0.86	
Slope	3.25	1.75	

Derivative of Cubic Functions



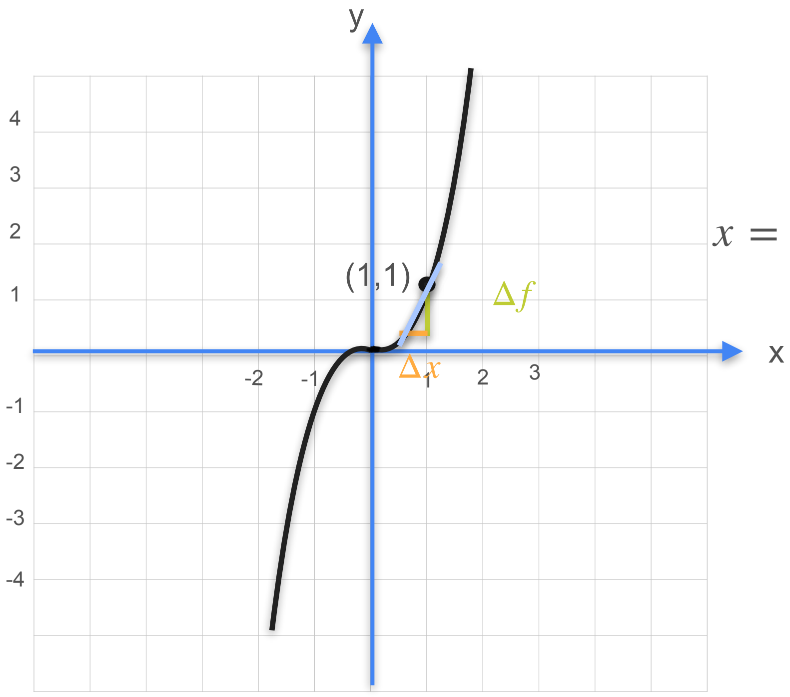
Cubic: $y = f(x) = x^3$

Slope: $\dfrac{\Delta f}{\Delta x} = \dfrac{(x + \Delta x)^3 - (x)^3}{\Delta x}$

$x = 0.5$

Δx	1.0	1/2	1/4
Δf	3.25	0.86	0.30
Slope	3.25	1.75	

Derivative of Cubic Functions



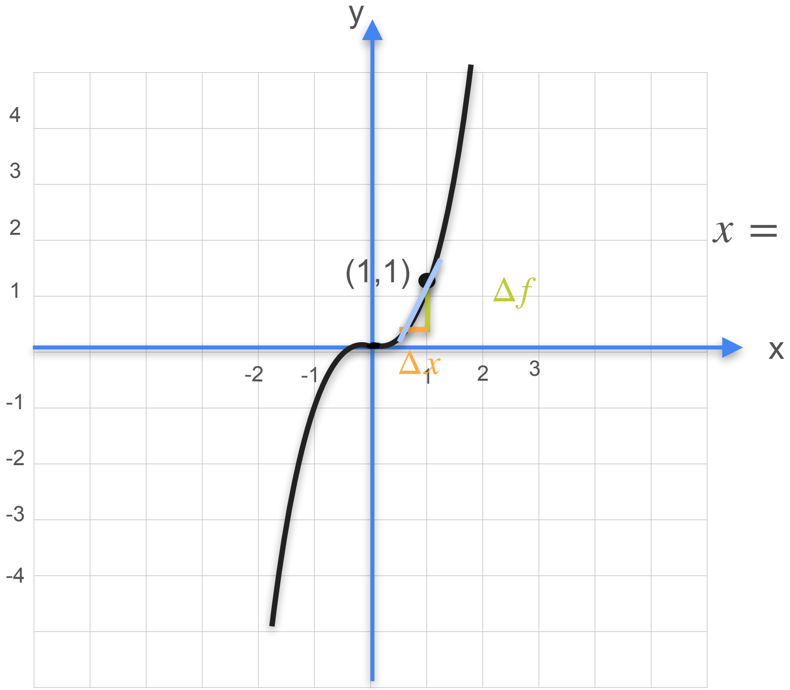
Cubic: $y = f(x) = x^3$

Slope: $\dfrac{\Delta f}{\Delta x} = \dfrac{(x + \Delta x)^3 - (x)^3}{\Delta x}$

$x = 0.5$

Δx	1.0	1/2	1/4
Δf	3.25	0.86	0.30
Slope	3.25	1.75	1.188

Derivative of Cubic Functions



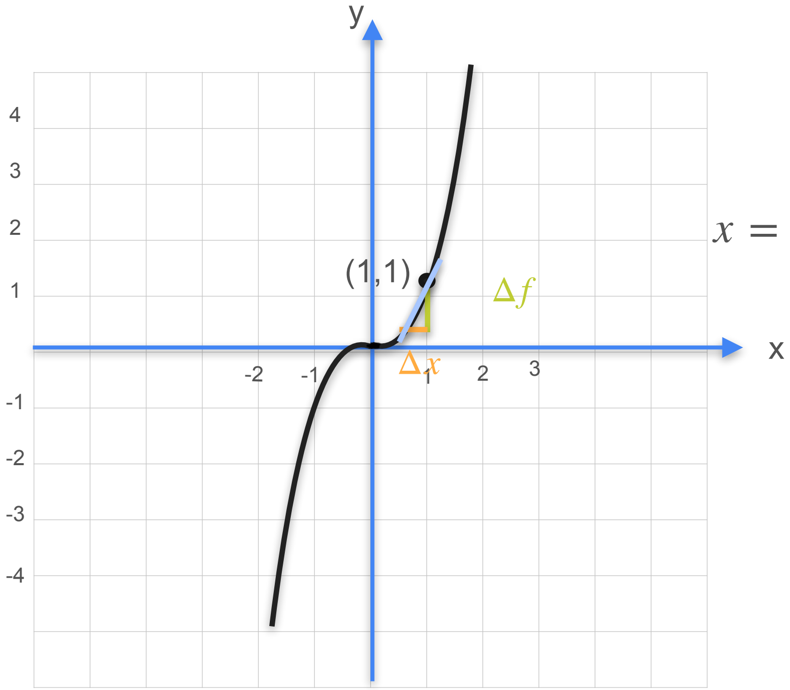
Cubic: $y = f(x) = x^3$

Slope: $\dfrac{\Delta f}{\Delta x} = \dfrac{(x + \Delta x)^3 - (x)^3}{\Delta x}$

$x = 0.5$

Δx	1.0	1/2	1/4	1/8
Δf	3.25	0.86	0.30	
Slope	3.25	1.75	1.188	

Derivative of Cubic Functions



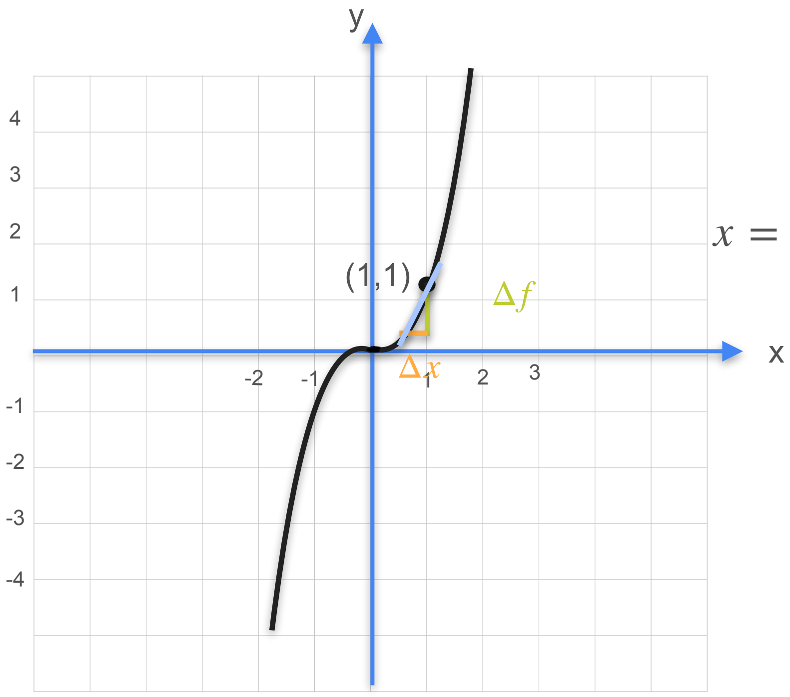
Cubic: $y = f(x) = x^3$

Slope: $\dfrac{\Delta f}{\Delta x} = \dfrac{(x + \Delta x)^3 - (x)^3}{\Delta x}$

$x = 0.5$

Δx	1.0	1/2	1/4	1/8
Δf	3.25	0.86	0.30	0.12
Slope	3.25	1.75	1.188	

Derivative of Cubic Functions



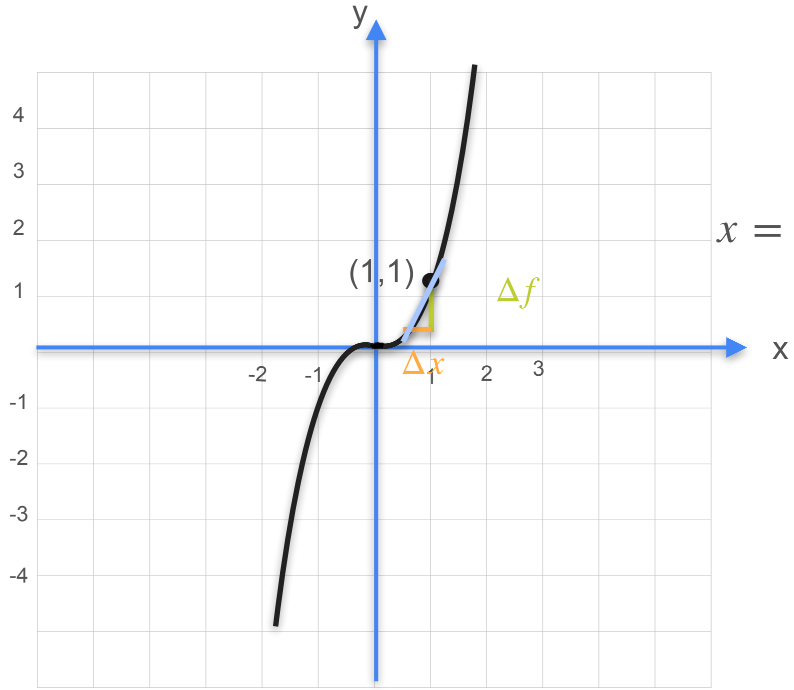
Cubic: $y = f(x) = x^3$

Slope: $\frac{\Delta f}{\Delta x} = \frac{(x + \Delta x)^3 - (x)^3}{\Delta x}$

$x = 0.5$

Δx	1.0	1/2	1/4	1/8
Δf	3.25	0.86	0.30	0.12
Slope	3.25	1.75	1.188	0.95

Derivative of Cubic Functions



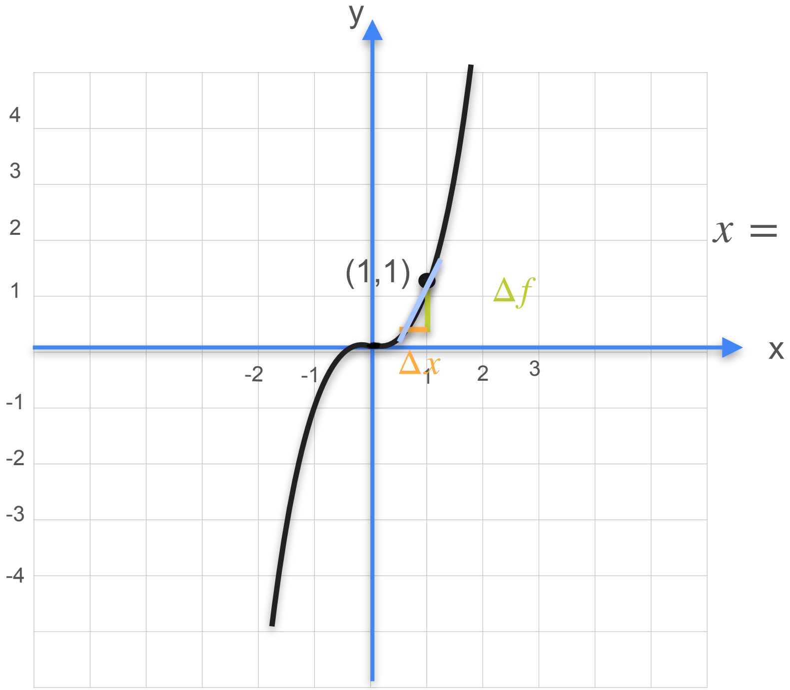
Cubic: $y = f(x) = x^3$

Slope: $\dfrac{\Delta f}{\Delta x} = \dfrac{(x+\Delta x)^3 - (x)^3}{\Delta x}$

$x = 0.5$

Δx	1.0	1/2	1/4	1/8	1/16
Δf	3.25	0.86	0.30	0.12	
Slope	3.25	1.75	1.188	0.95	

Derivative of Cubic Functions



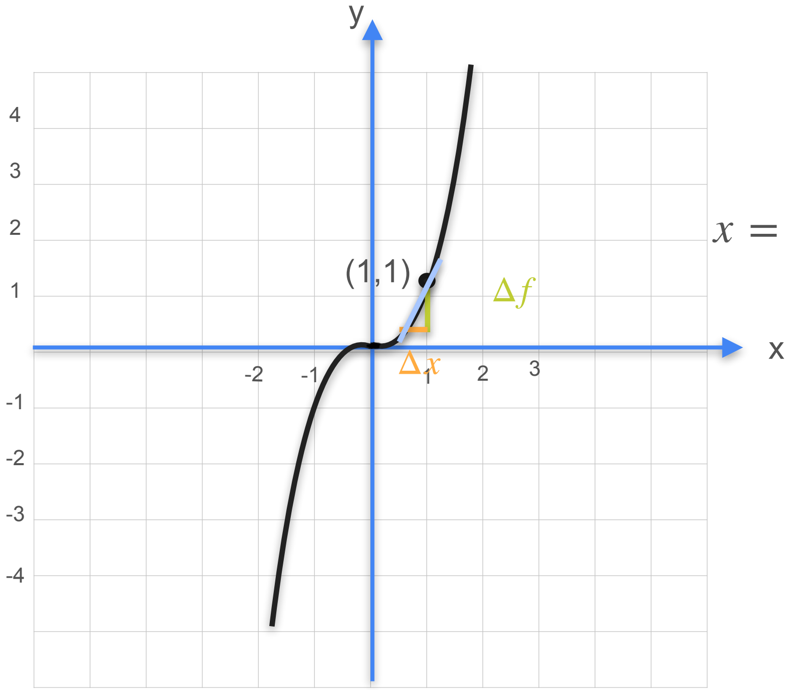
Cubic: $y = f(x) = x^3$

Slope: $\dfrac{\Delta f}{\Delta x} = \dfrac{(x + \Delta x)^3 - (x)^3}{\Delta x}$

$x = 0.5$

Δx	1.0	1/2	1/4	1/8	1/16
Δf	3.25	0.86	0.30	0.12	0.05
Slope	3.25	1.75	1.188	0.95	

Derivative of Cubic Functions



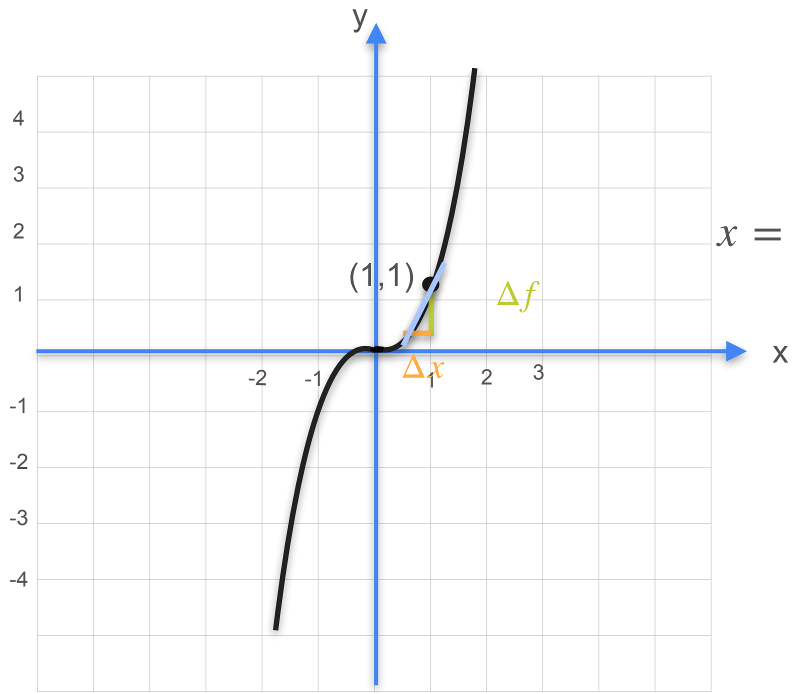
Cubic: $y = f(x) = x^3$

Slope: $\dfrac{\Delta f}{\Delta x} = \dfrac{(x + \Delta x)^3 - (x)^3}{\Delta x}$

$x = 0.5$

Δx	1.0	1/2	1/4	1/8	1/16
Δf	3.25	0.86	0.30	0.12	0.05
Slope	3.25	1.75	1.188	0.95	0.85

Derivative of Cubic Functions



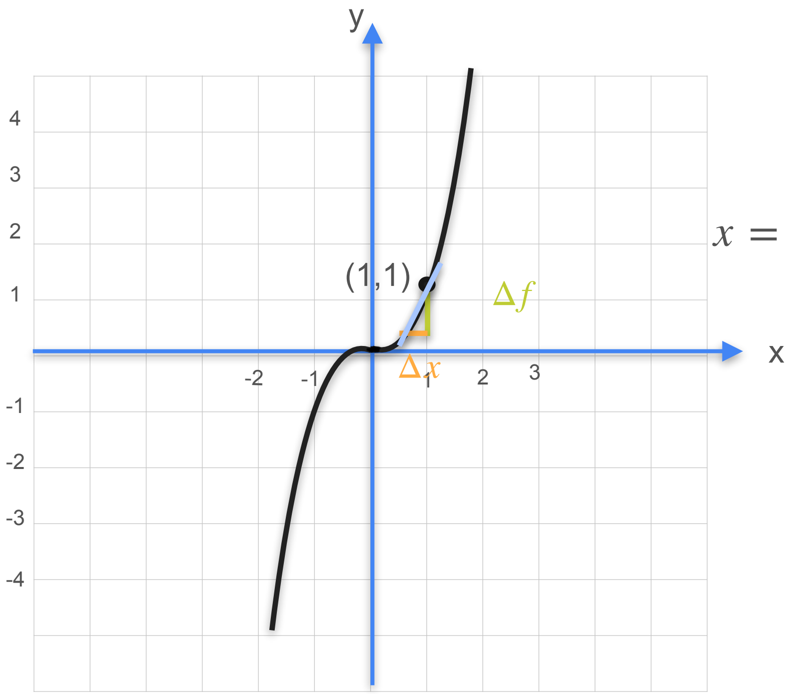
Cubic: $y = f(x) = x^3$

Slope: $\dfrac{\Delta f}{\Delta x} = \dfrac{(x + \Delta x)^3 - (x)^3}{\Delta x}$

$x = 0.5$

Δx	1.0	1/2	1/4	1/8	1/16	1/1000
Δf	3.25	0.86	0.30	0.12	0.05	
Slope	3.25	1.75	1.188	0.95	0.85	

Derivative of Cubic Functions



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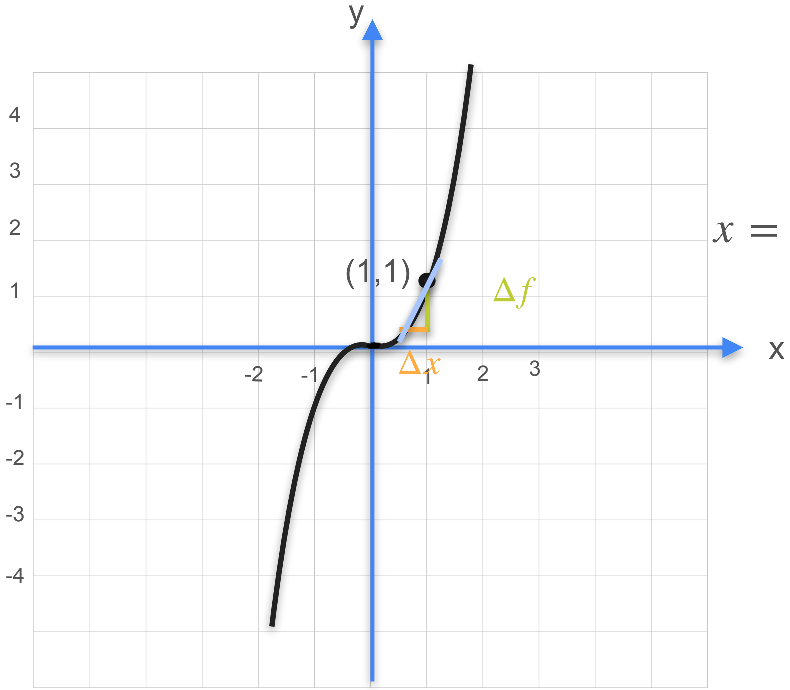
Derivative of Cubic Functions



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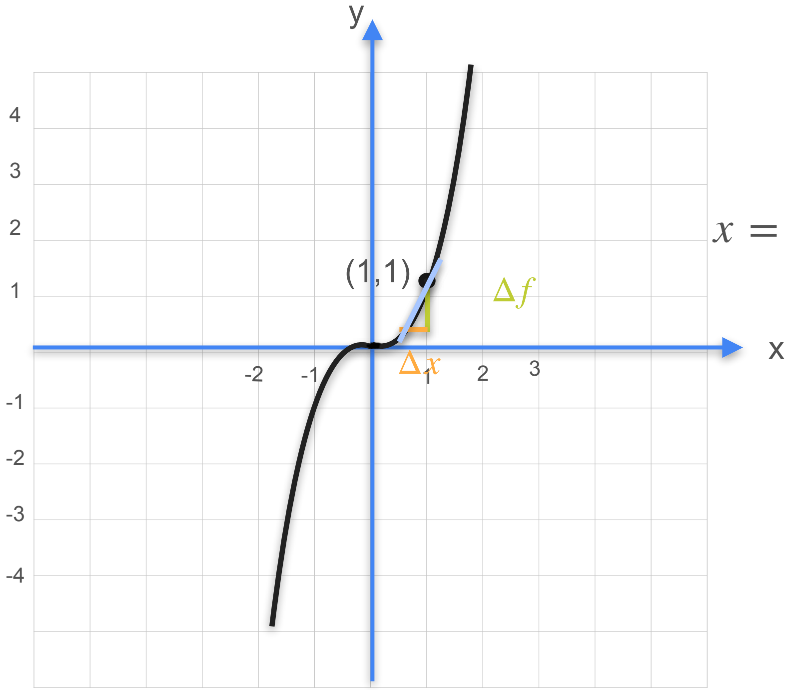
Derivative of Cubic Functions



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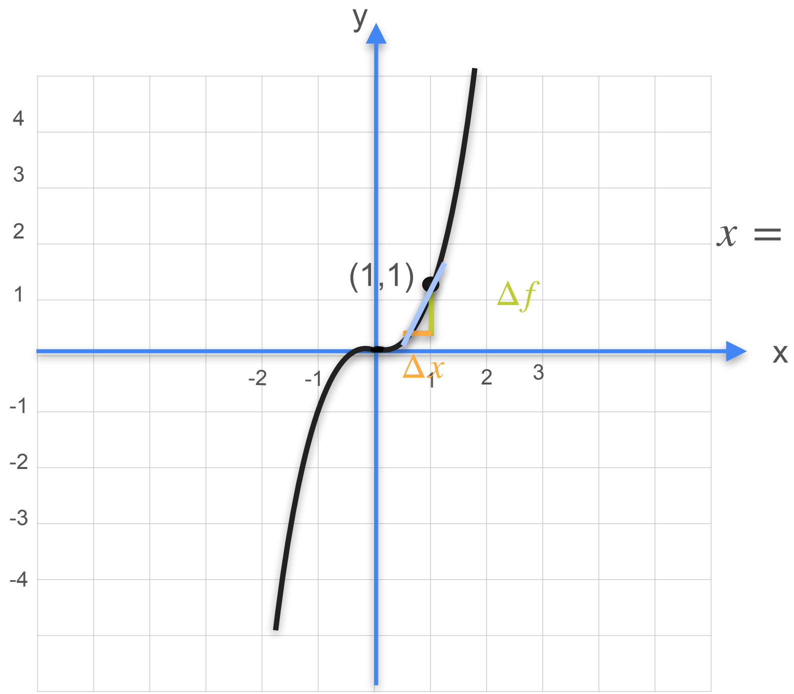
$$f'(0.5) = \frac{d}{dx} f(0.5) = 0.75 = 3 \times 0.5^2$$

Derivative of Cubic Functions



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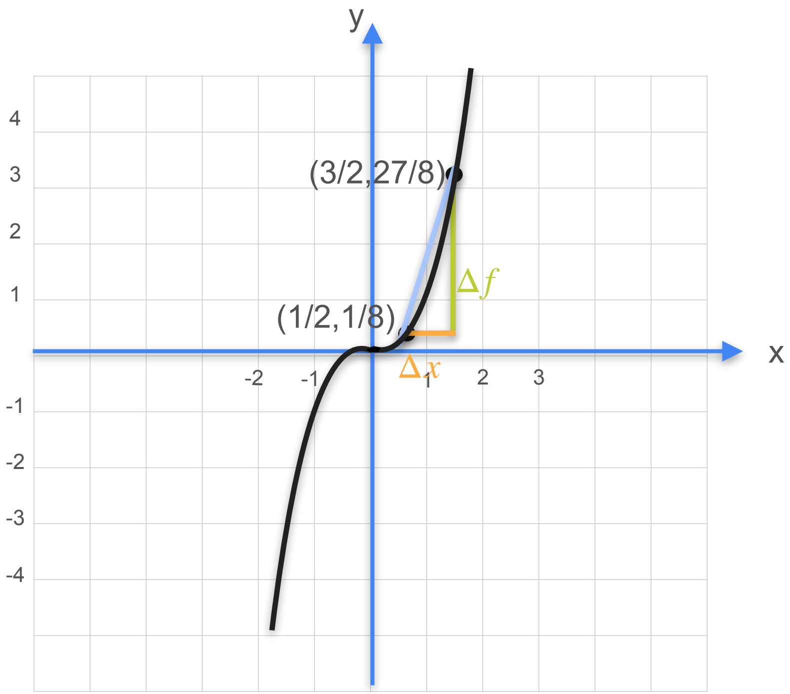
Derivative of Cubic Functions



Cubic: $y = f(x) = x^3$

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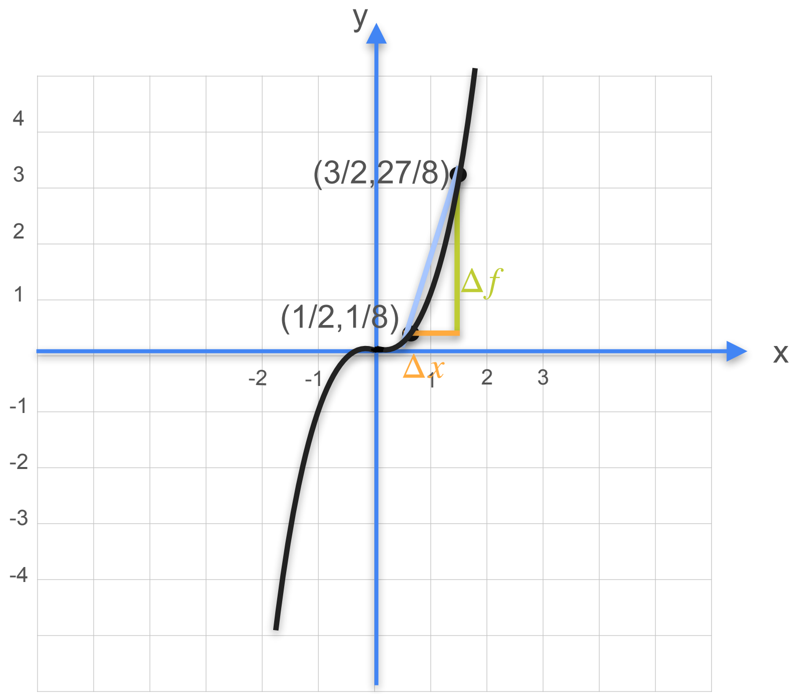
Derivative of Cubic Functions



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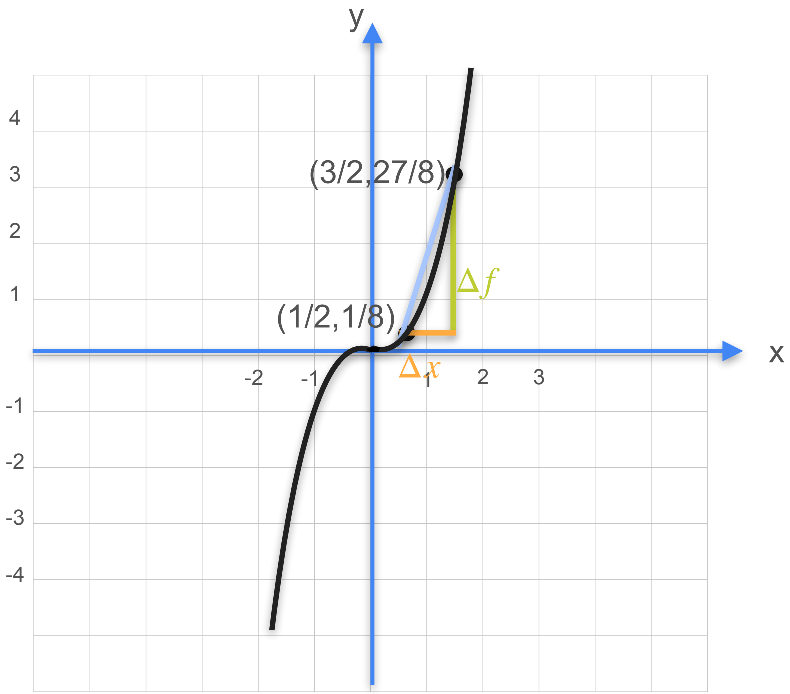
$$\frac{\Delta f}{\Delta x}$$

Derivative of Cubic Functions



Cubic: $y = f(x) = x^3$

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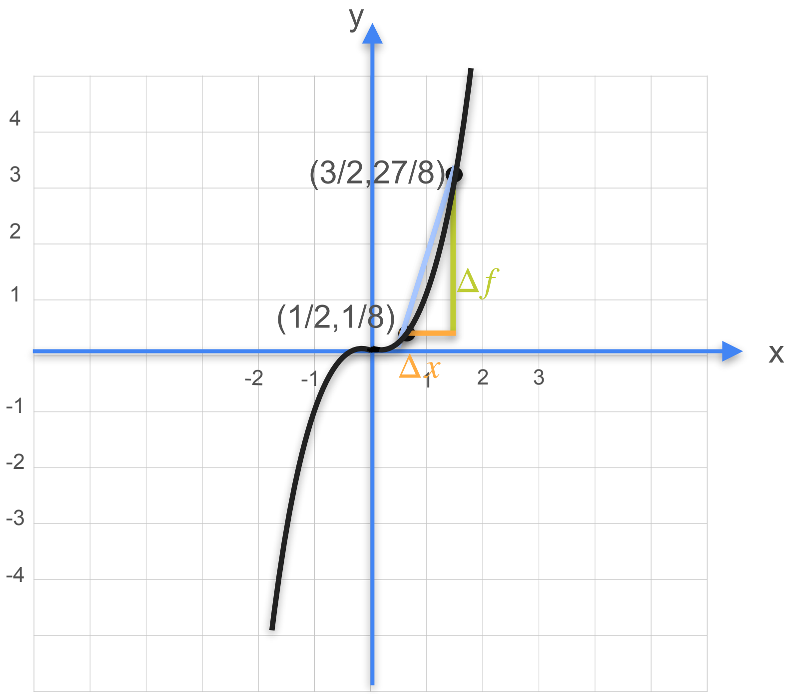
$\dfrac{\Delta f}{\Delta x}$ $\quad (x+\Delta x)^3 - x^3$

Derivative of Cubic Functions



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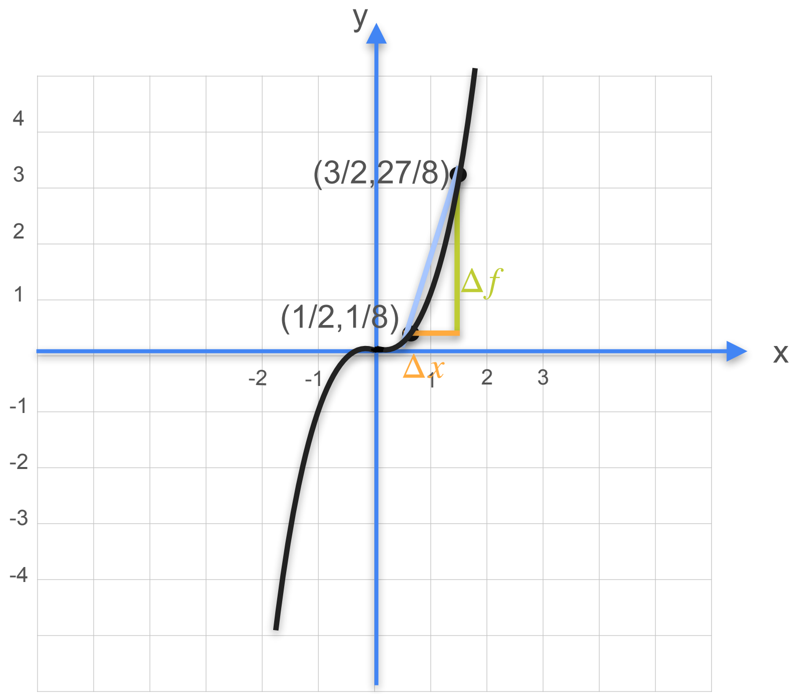
Derivative of Cubic Functions



Cubic: $y = f(x) = x^3$

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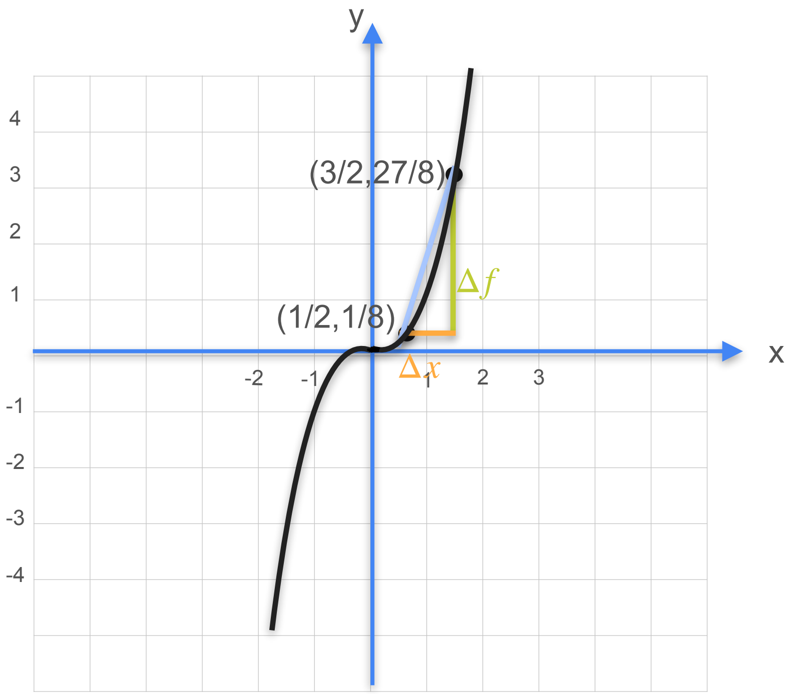
$$\frac{\Delta f}{\Delta x} = \frac{(x+\Delta x)^3 - x^3}{\Delta x}$$

$$= \frac{x^3 + 3x(\Delta x)^2 + 3x^2\Delta x + (\Delta x)^3 - x^3}{\Delta x}$$

Derivative of Cubic Functions



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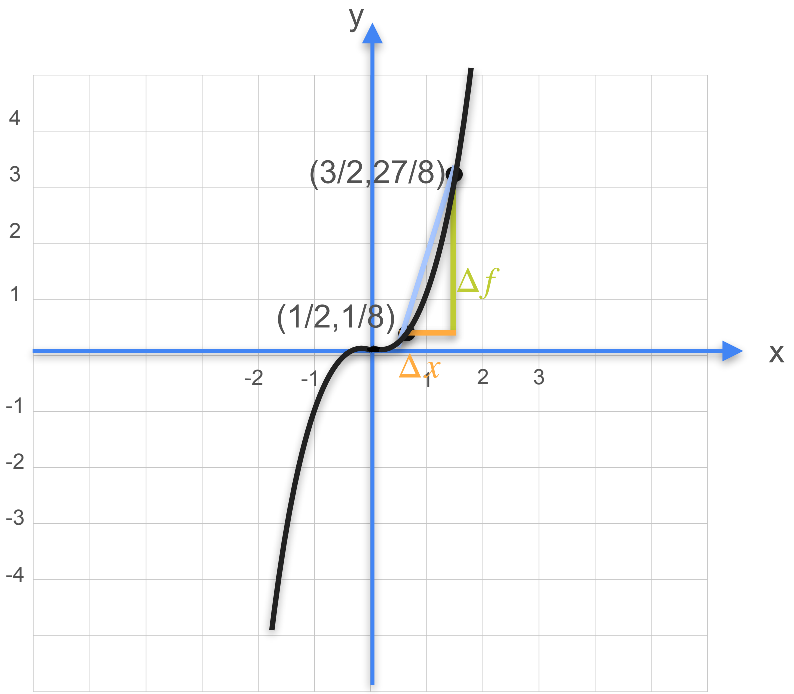
Derivative of Cubic Functions



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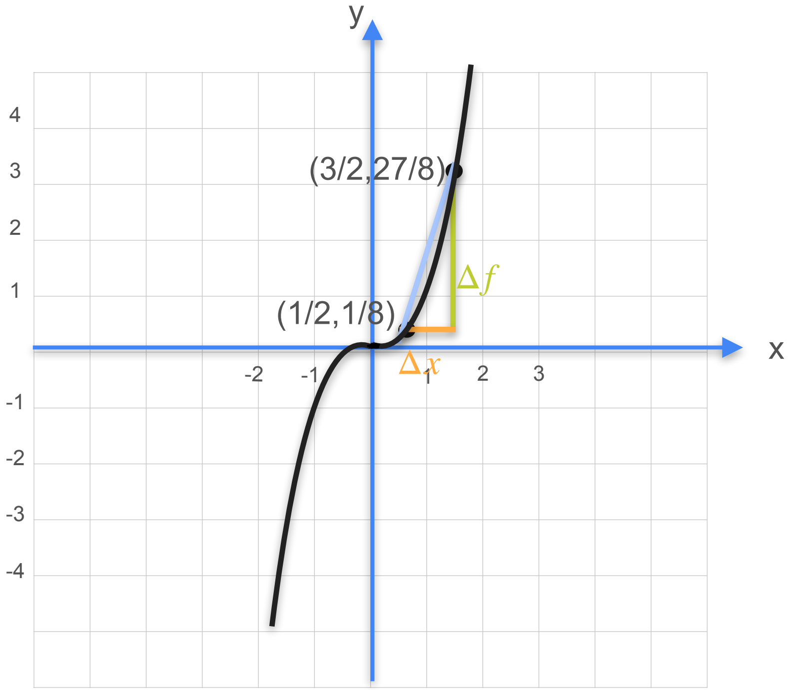
Derivative of Cubic Functions



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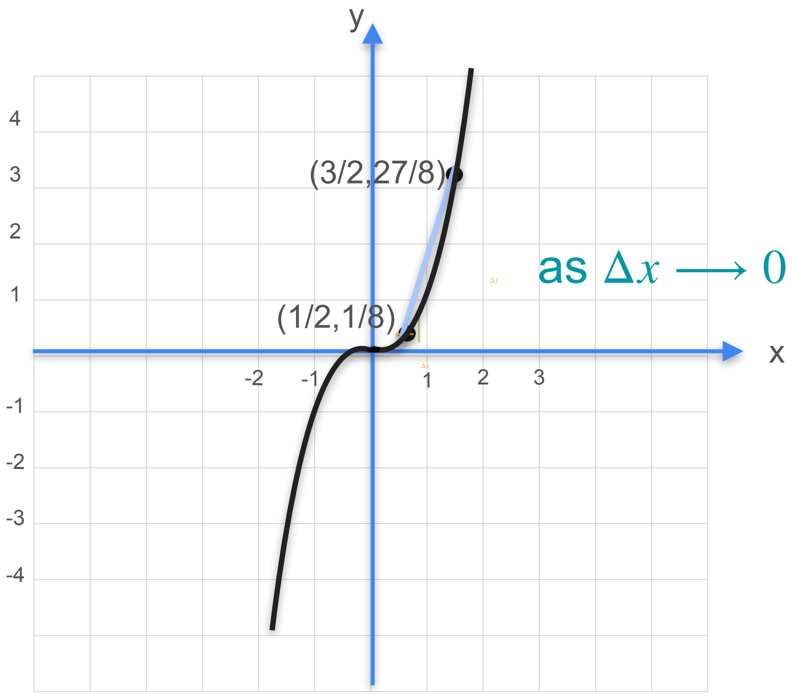
$$= 3x\Delta x + 3x^2 + \Delta x^2$$

Derivative of Cubic Functions



as $\Delta x \longrightarrow 0$

Cubic: $y = f(x) = x^3$

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$$\boxed{\frac{\Delta f}{\Delta x}} = \frac{(x+\Delta x)^3 - x^3}{\Delta x}$$

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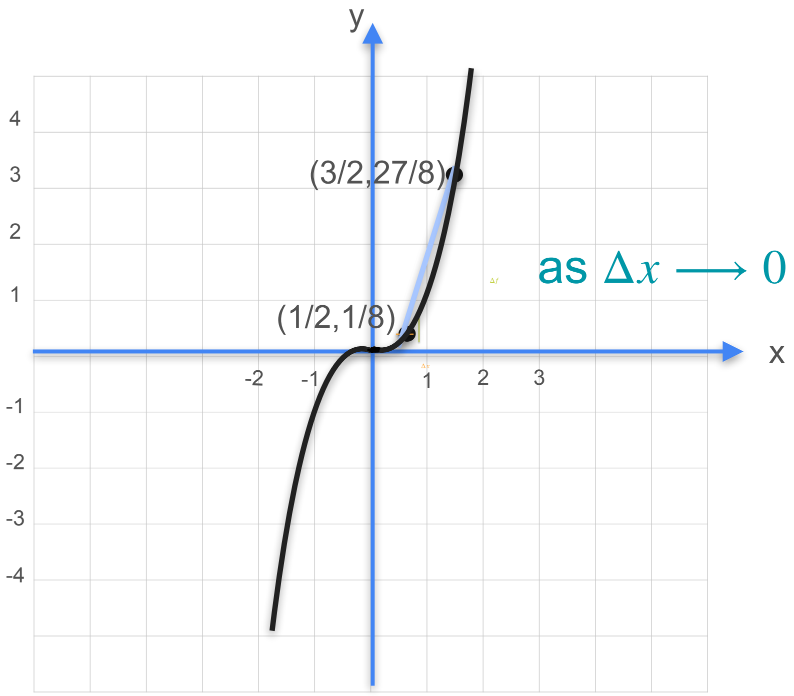
Derivative of Cubic Functions



Cubic: $y = f(x) = x^3$

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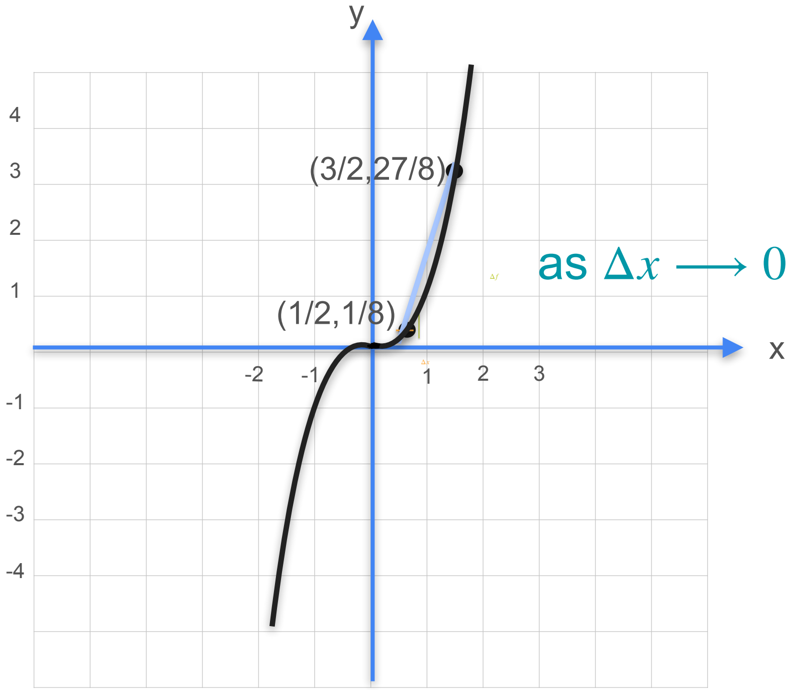
Derivative of Cubic Functions



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$$= 3x\boxed{\Delta x}^{0} + 3x^2 + \boxed{\Delta x^2}^{0}$$

$$f(x) = x^3 \Rightarrow f'(x) = 3x^2$$

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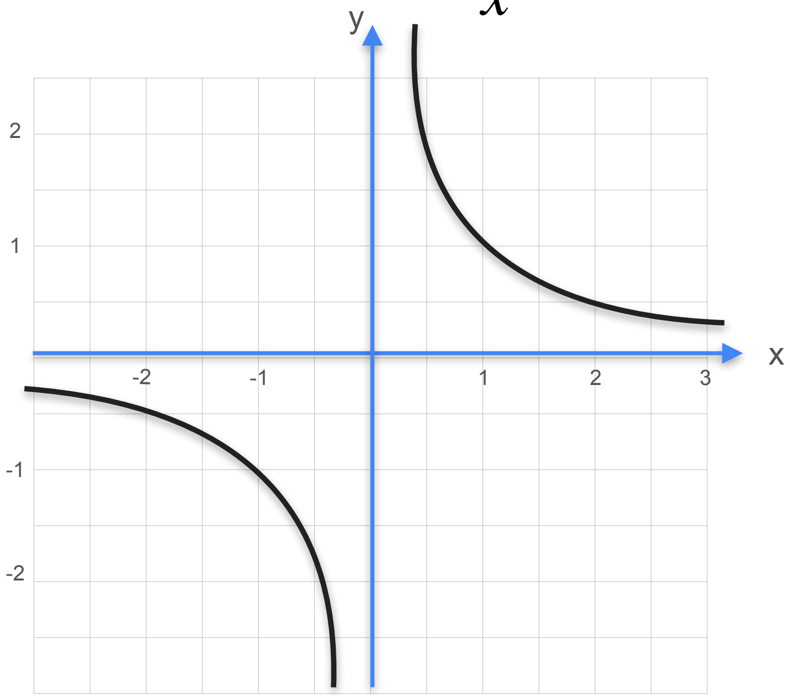
Derivatives and Optimization

Some common derivatives: Other power functions

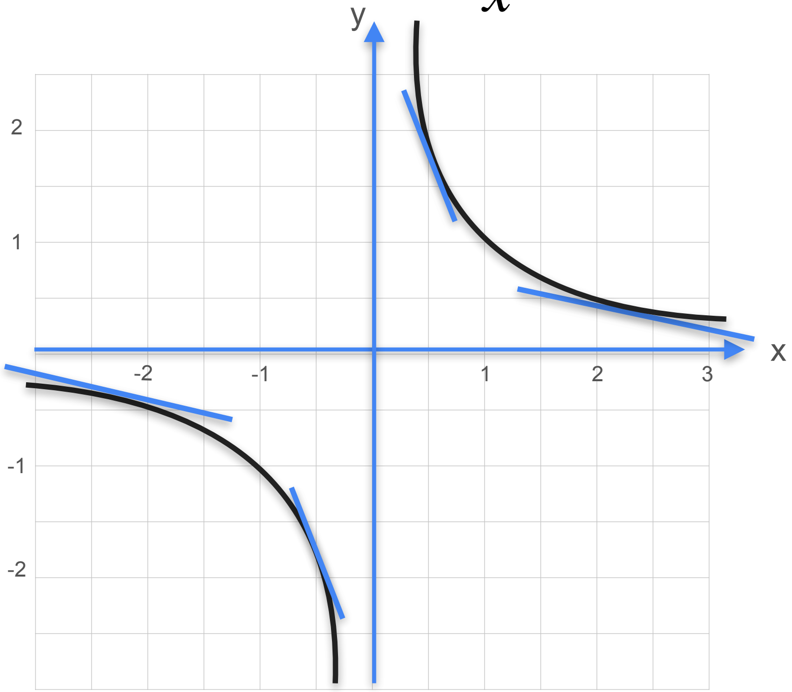
Derivative of $\frac{1}{x}$

Derivative of $\frac{1}{x}$



$$y = f(x) = x^{-1} = \frac{1}{x}$$

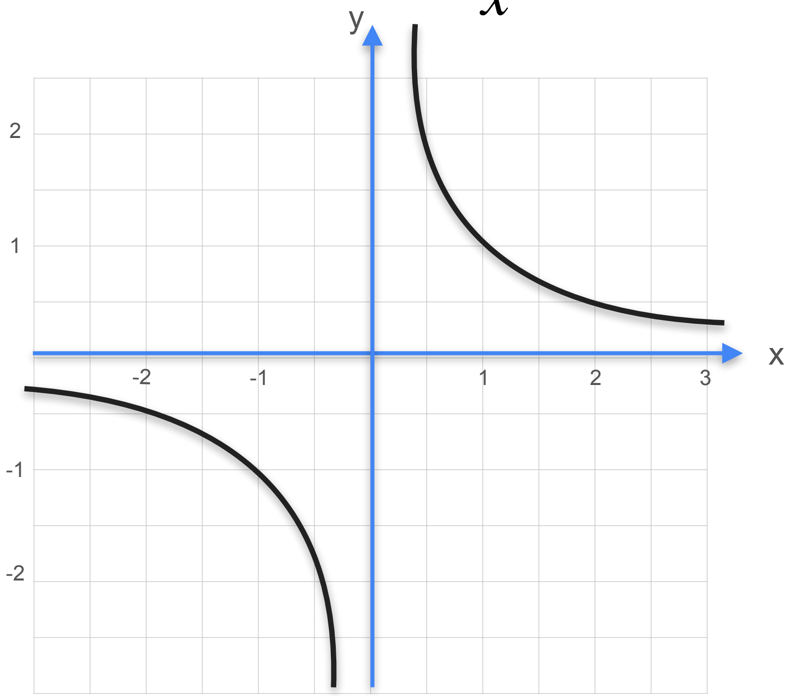
Derivative of $\frac{1}{x}$



$$y = f(x) = x^{-1} = \frac{1}{x}$$

Slope: $\frac{\Delta f}{\Delta x}$

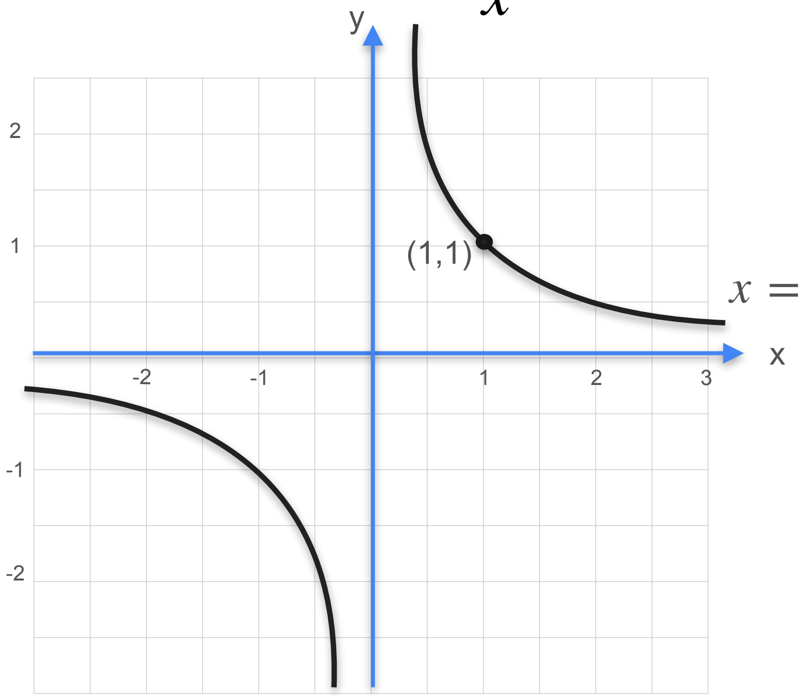
Derivative of $\frac{1}{x}$



$$y = f(x) = x^{-1} = \frac{1}{x}$$

Slope: $$\frac{\Delta f}{\Delta x} = \frac{(x+\Delta x)^{-1} - (x)^{-1}}{\Delta x}$$

Derivative of $\frac{1}{x}$

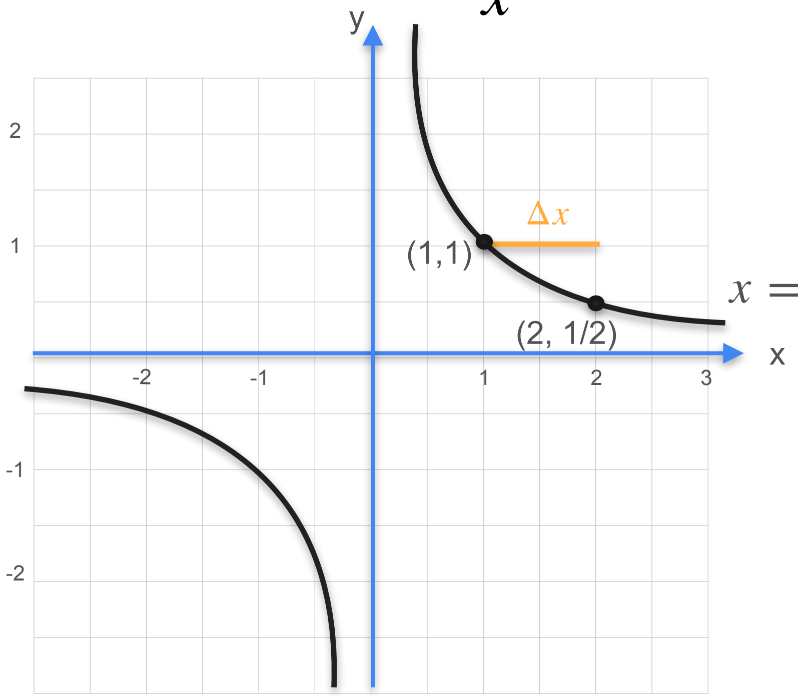


$x = 1$

$$y = f(x) = x^{-1} = \frac{1}{x}$$

Slope: $$\frac{\Delta f}{\Delta x} = \frac{(x + \Delta x)^{-1} - (x)^{-1}}{\Delta x}$$

Derivative of $\frac{1}{x}$



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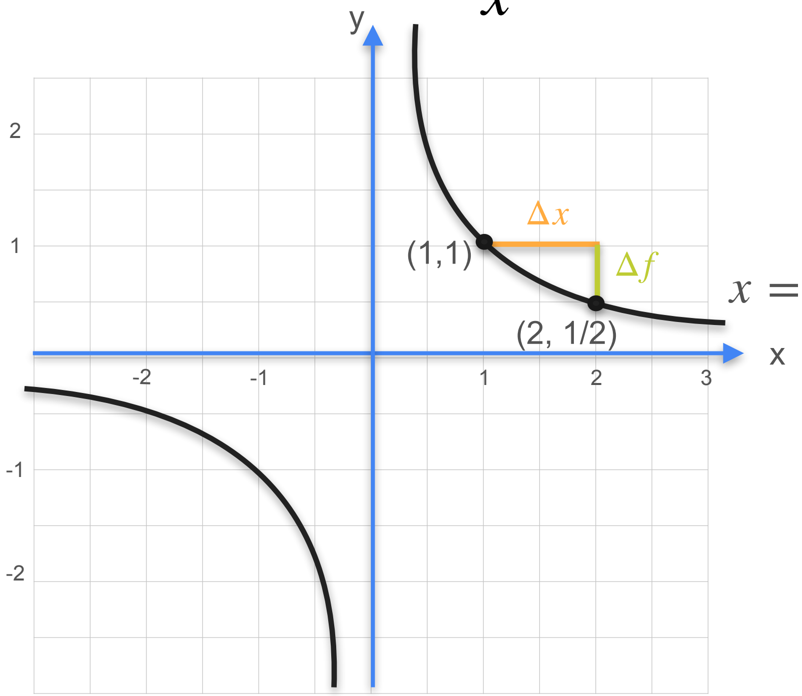
Slope: $\dfrac{\Delta f}{\Delta x} = \dfrac{(x + \Delta x)^{-1} - (x)^{-1}}{\Delta x}$

$x = 1$

Δx	1.0

Derivative of $\frac{1}{x}$



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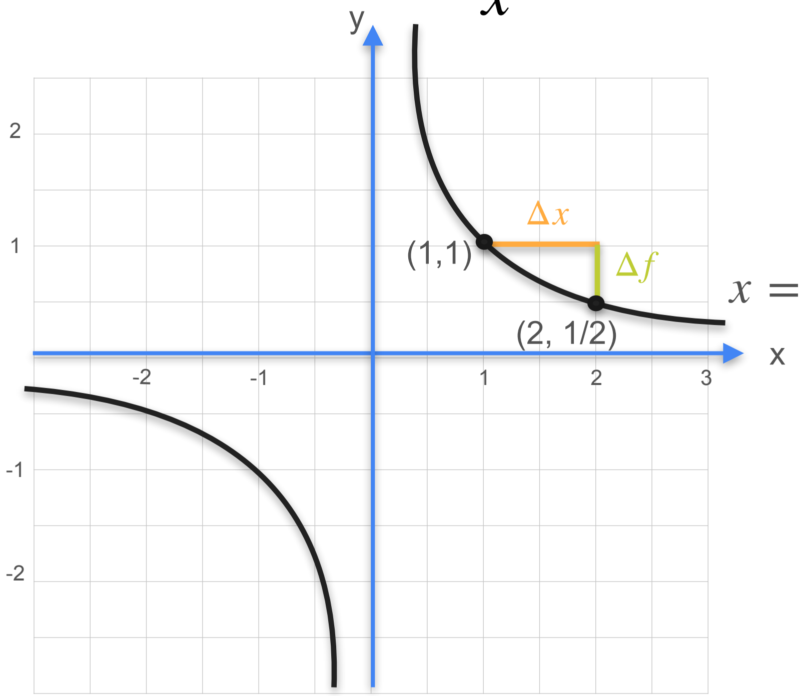
Slope: $\dfrac{\Delta f}{\Delta x} = \dfrac{(x + \Delta x)^{-1} - (x)^{-1}}{\Delta x}$

$x = 1$

Δx	1.0
Δf	

Derivative of $\frac{1}{x}$



$$y = f(x) = x^{-1} = \frac{1}{x}$$

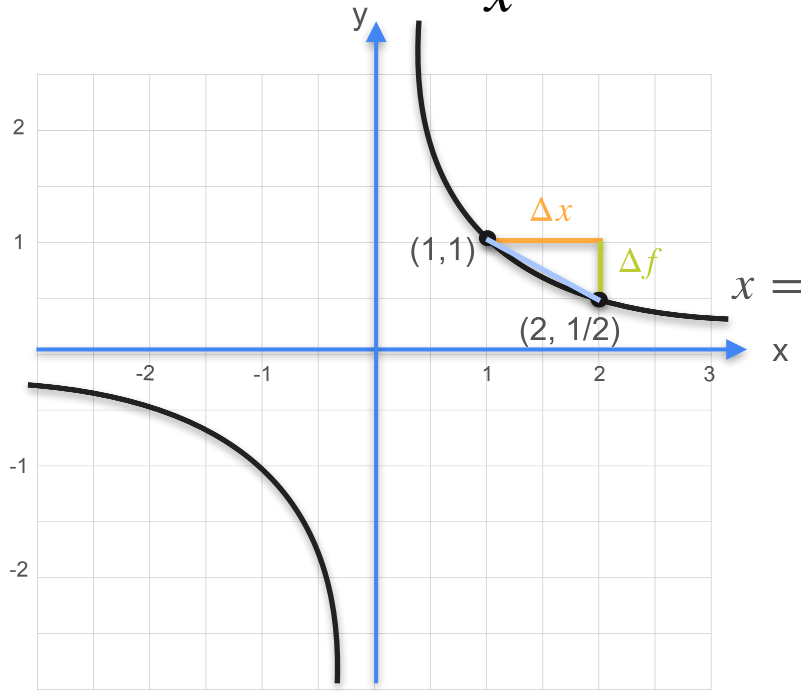
Slope: $\dfrac{\Delta f}{\Delta x} = \dfrac{(x + \Delta x)^{-1} - (x)^{-1}}{\Delta x}$

$x = 1$

Δx	1.0
Δf	-0.5

$$(1+1)^{-1} - 1^{-1} = \frac{1}{2} - 1$$

Derivative of $\frac{1}{x}$



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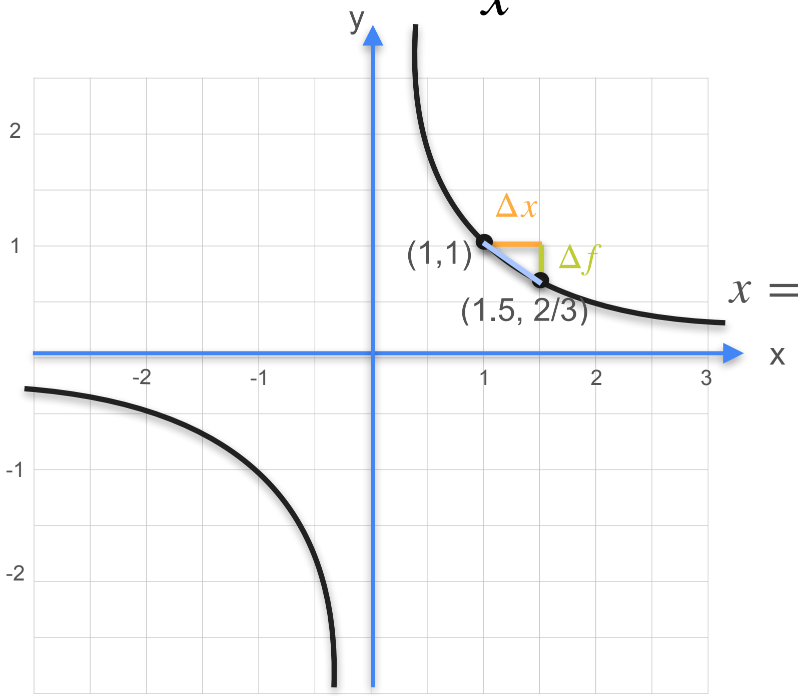
$x = 1$

Δx	1.0
Δf	-0.5
Slope	-0.5

$$(1+1)^{-1} - 1^{-1} = \frac{1}{2} - 1$$

$$\frac{-0.5}{1}$$

Derivative of $\frac{1}{x}$



Inverse: $y = f(x) = x^{-1} = \frac{1}{x}$

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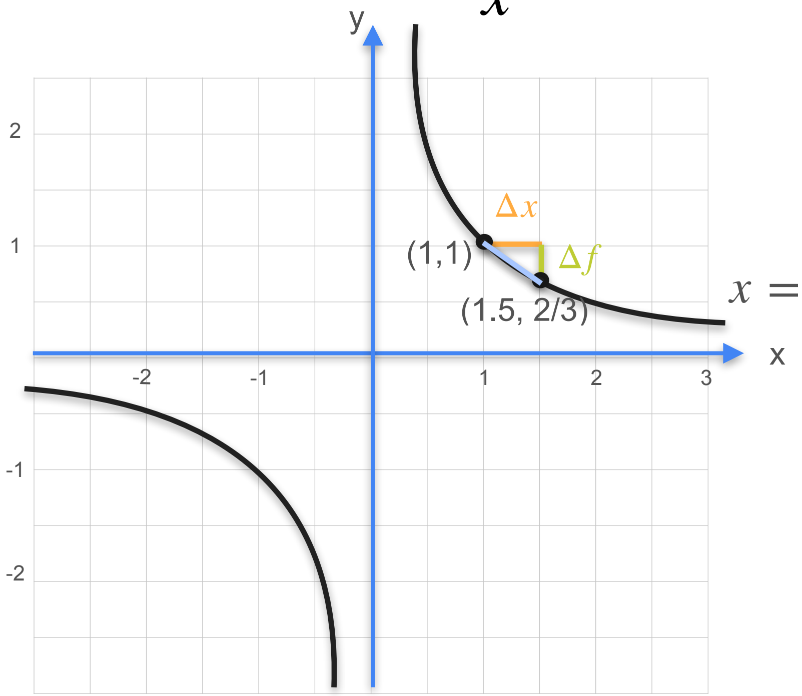
Derivative of $\frac{1}{x}$



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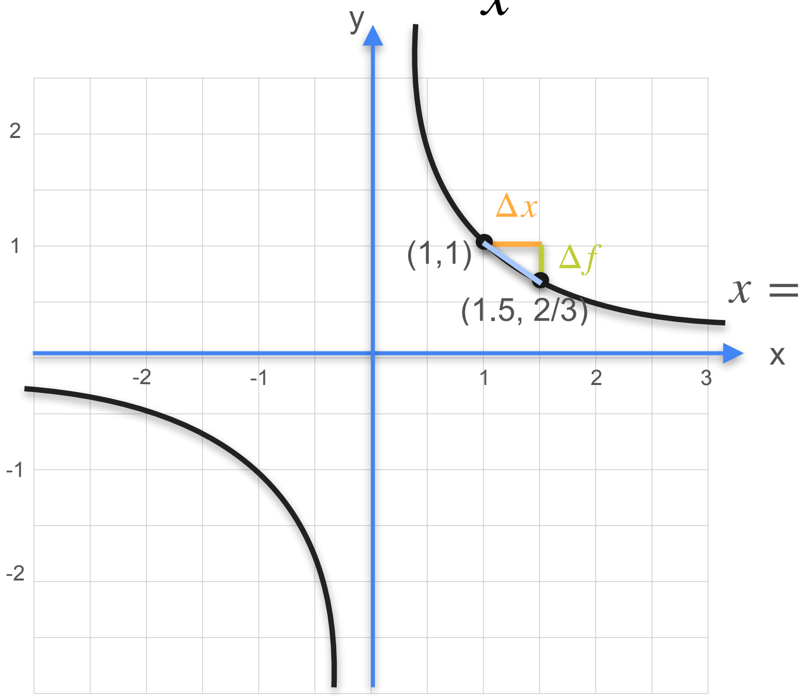
$x = 1$

Δx	1.0	1/2
Δf	-0.5	
Slope	-0.5	

Derivative of $\frac{1}{x}$



Inverse: $y = f(x) = x^{-1} = \frac{1}{x}$

Slope: $\frac{\Delta f}{\Delta x} = \frac{(x + \Delta x)^{-1} - (x)^{-1}}{\Delta x}$

$x = 1$

Δx	1.0	1/2
Δf	-0.5	-0.33
Slope	-0.5	

$$(1 + 0.5)^{-1} - 1^{-1} = \frac{2}{3} - 1$$

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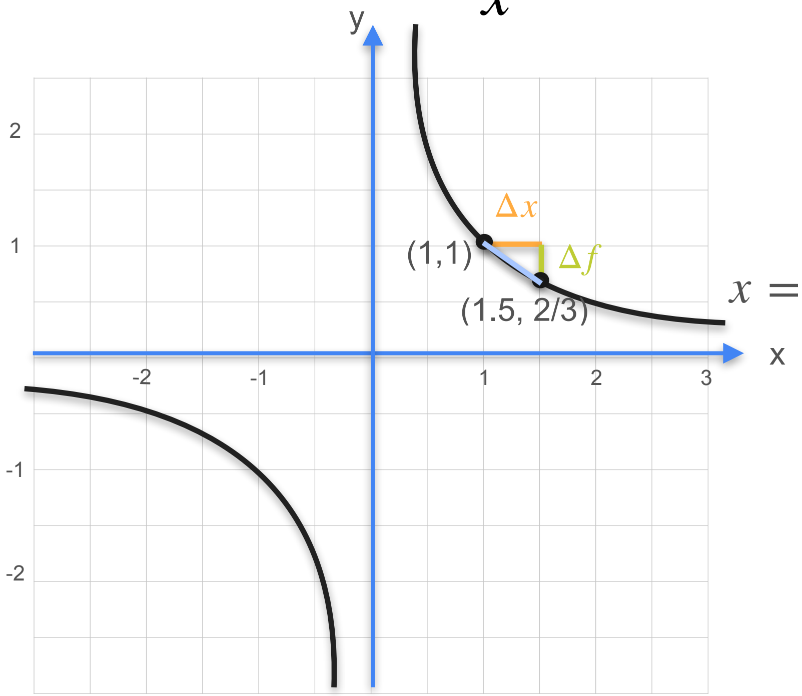
Derivative of $\frac{1}{x}$



Inverse: $y = f(x) = x^{-1} = \frac{1}{x}$

Slope: $\frac{\Delta f}{\Delta x} = \frac{(x + \Delta x)^{-1} - (x)^{-1}}{\Delta x}$

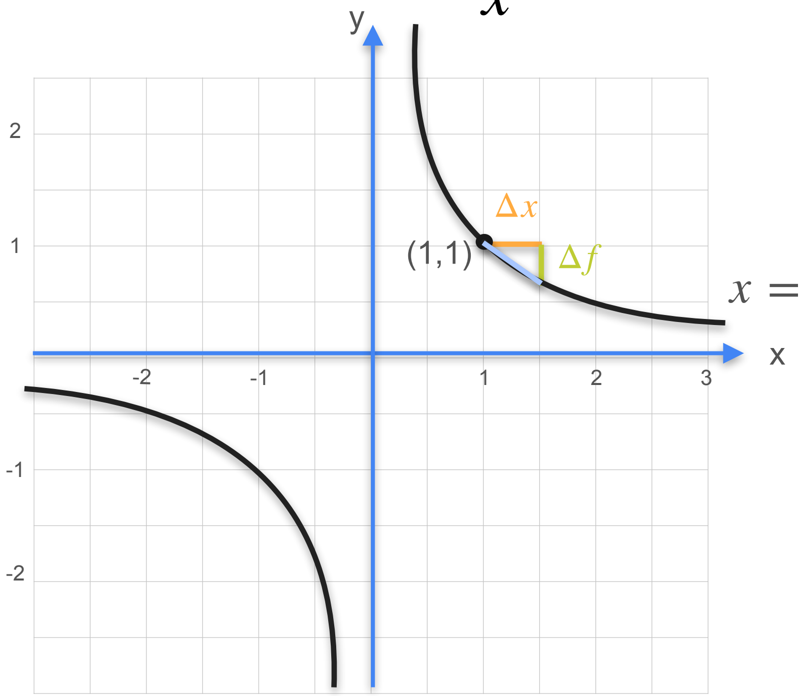
$x = 1$

Δx	1.0	1/2
Δf	-0.5	-0.33
Slope	-0.5	-0.67

$$(1 + 0.5)^{-1} - 1^{-1} = \frac{2}{3} - 1$$

$$\frac{0.33}{0.5}$$

Derivative of $\frac{1}{x}$



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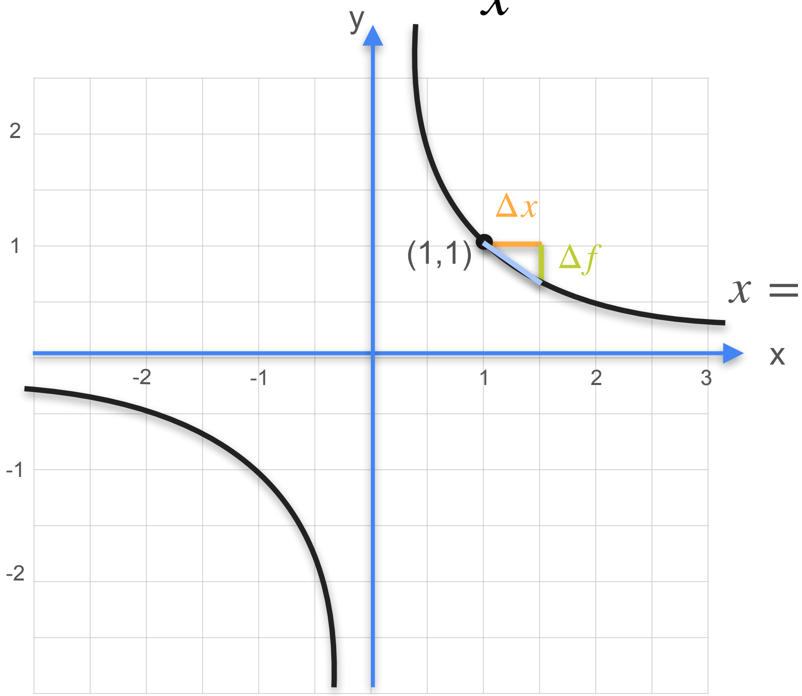
Derivative of $\frac{1}{x}$



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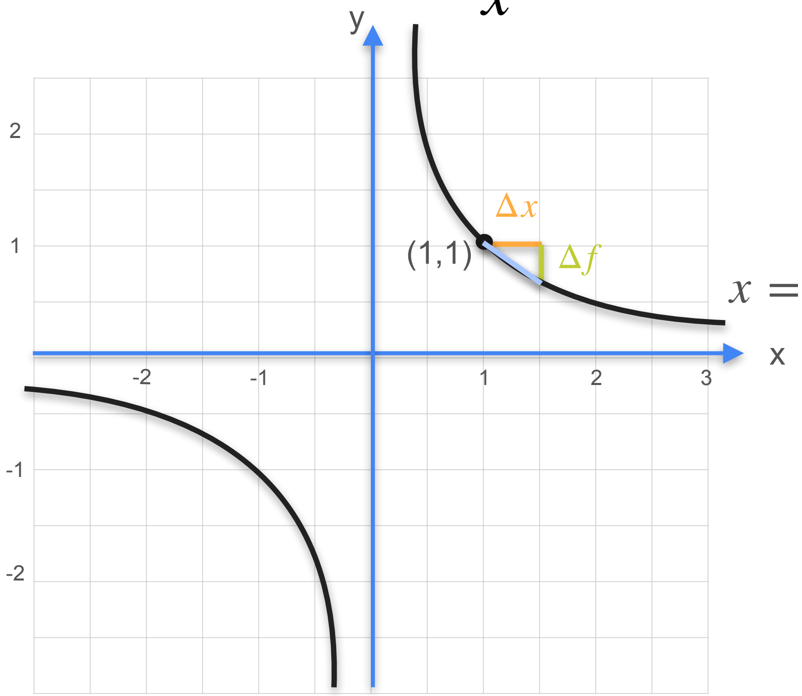
$x = 1$

Δx	1.0	1/2	1/4	1/8	1/16	1/1000
Δf	-0.5	-0.33	-0.2	-0.11	-0.06	-0.001
Slope	-0.5	-0.67	-0.8	-0.89	-0.94	-0.999

Derivative of $\frac{1}{x}$



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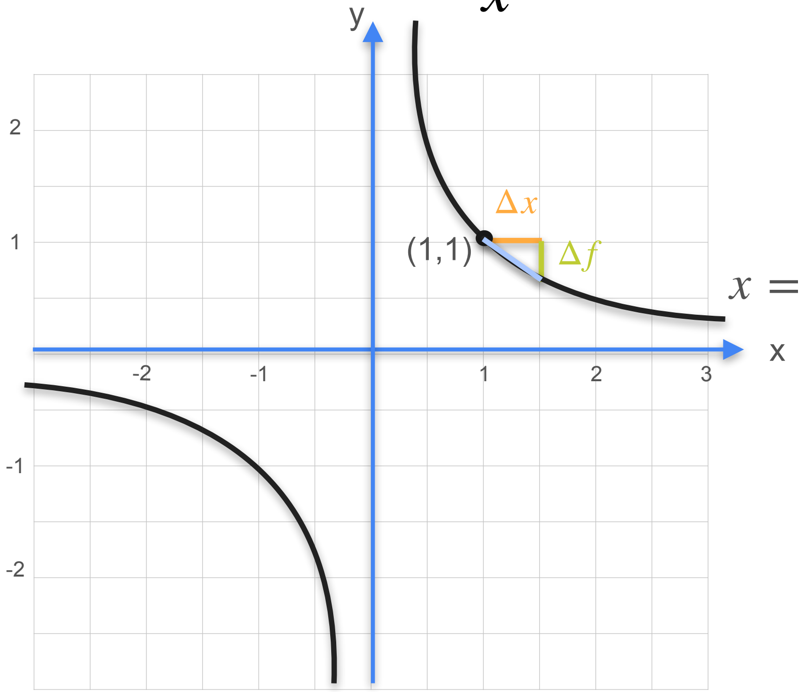
$$f'(1) = \frac{d}{dx}f(1) = -1$$

Derivative of $\frac{1}{x}$



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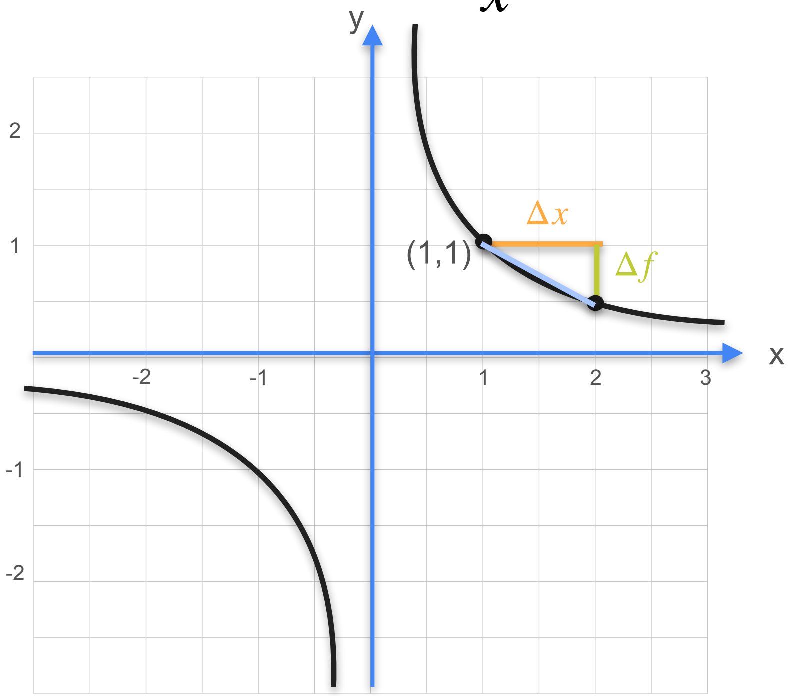
$$f'(1) = \frac{d}{dx} f(1) = -1 = -1 \times 1^2$$

Derivative of $\frac{1}{x}$



Inverse: $y = f(x) = x^{-1} = \frac{1}{x}$

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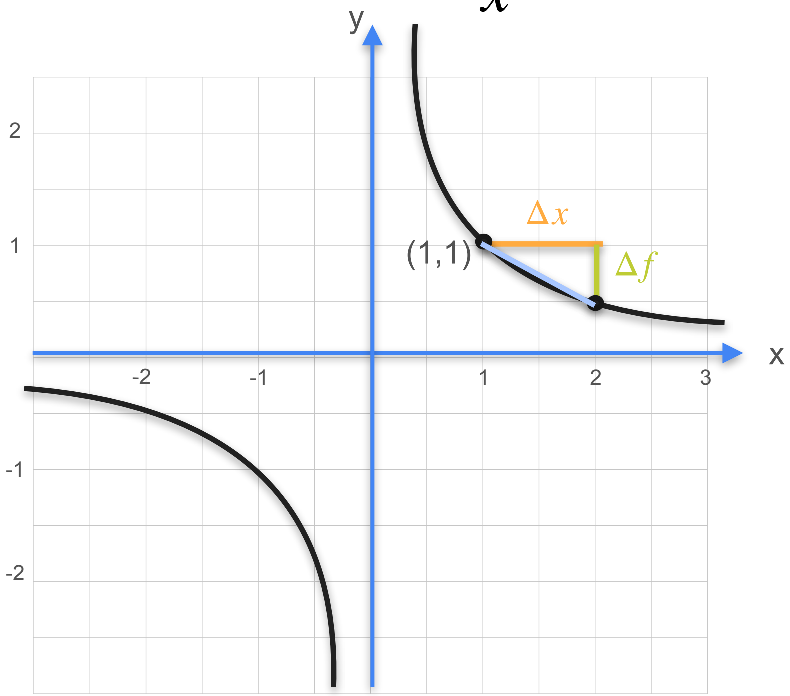
Derivative of $\frac{1}{x}$



Inverse: $y = f(x) = x^{-1} = \frac{1}{x}$

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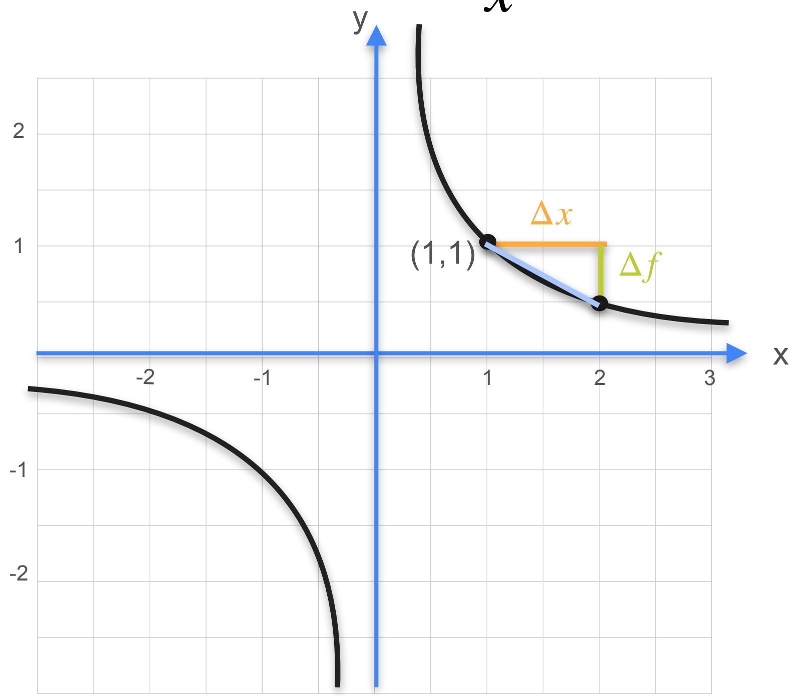
$$\frac{\Delta f}{\Delta x}$$

Derivative of $\frac{1}{x}$



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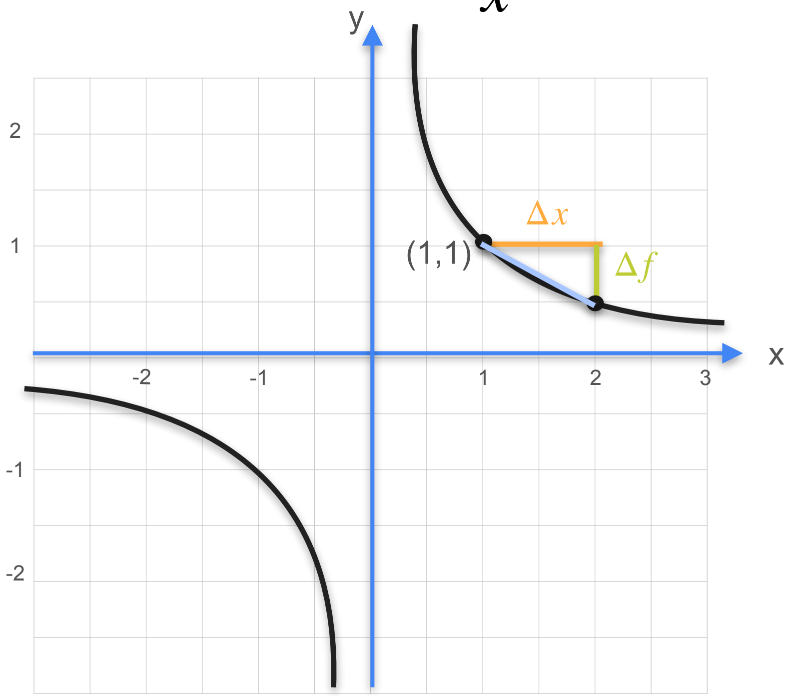
$$\frac{\Delta f}{\Delta x} = \frac{(x + \Delta x)^{-1} - x^{-1}}{\Delta x}$$

Derivative of $\frac{1}{x}$



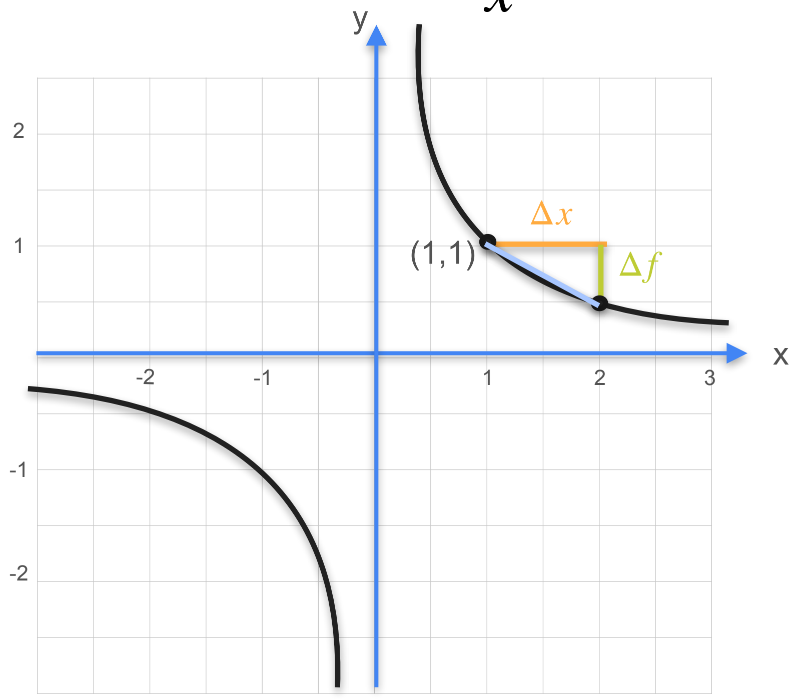
Inverse: $y = f(x) = x^{-1} = \frac{1}{x}$

Slope: $\frac{\Delta f}{\Delta x} = \frac{f(x + \Delta x) - f(x)}{\Delta x}$

$$\frac{\Delta f}{\Delta x} = \frac{(x + \Delta x)^{-1} - x^{-1}}{\Delta x}$$

$$= \frac{\frac{1}{x + \Delta x} - \frac{1}{x}}{\Delta x}$$

Derivative of $\frac{1}{x}$



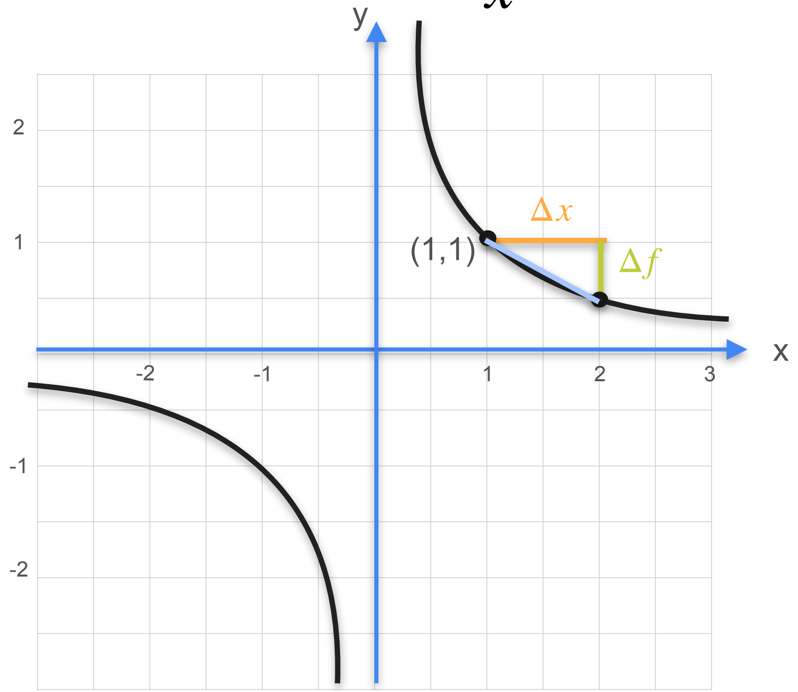
Inverse: $y = f(x) = x^{-1} = \frac{1}{x}$

Slope: $\frac{\Delta f}{\Delta x} = \frac{f(x+\Delta x) - f(x)}{\Delta x}$

$$\frac{\Delta f}{\Delta x} = \frac{(x+\Delta x)^{-1} - x^{-1}}{\Delta x}$$

$$= \frac{\frac{1}{x+\Delta x} - \frac{1}{x}}{\Delta x} = \frac{\frac{x-(x+\Delta x)}{(x+\Delta x)x}}{\Delta x}$$

Derivative of $\frac{1}{x}$



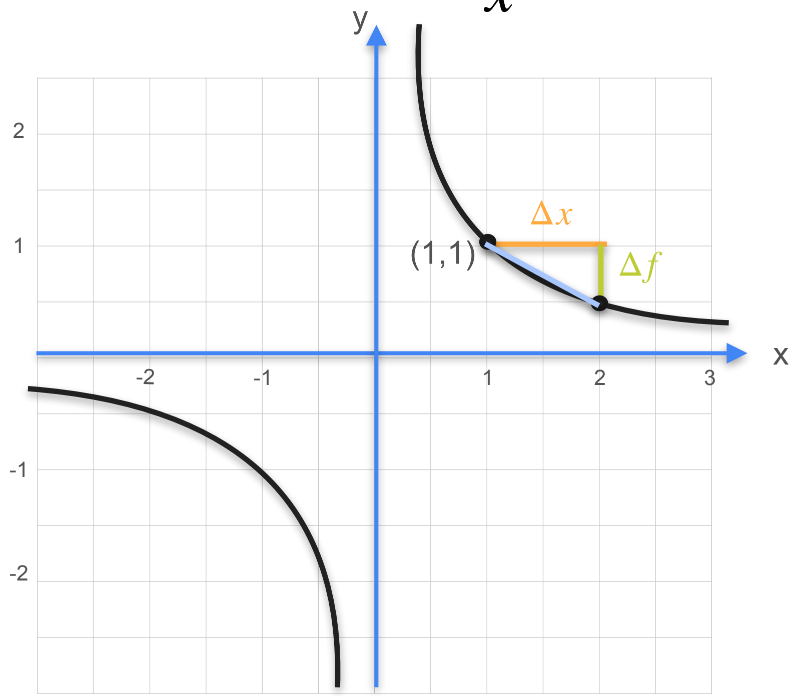
Inverse: $y = f(x) = x^{-1} = \dfrac{1}{x}$

Slope: $\dfrac{\Delta f}{\Delta x} = \dfrac{f(x+\Delta x) - f(x)}{\Delta x}$

$$\frac{\Delta f}{\Delta x} = \frac{(x+\Delta x)^{-1} - x^{-1}}{\Delta x}$$

$$= \frac{\frac{1}{x+\Delta x} - \frac{1}{x}}{\Delta x} = \frac{\frac{\cancel{x} - (\cancel{x} + \Delta x)}{(x+\Delta x)x}}{\Delta x}$$

Derivative of $\frac{1}{x}$



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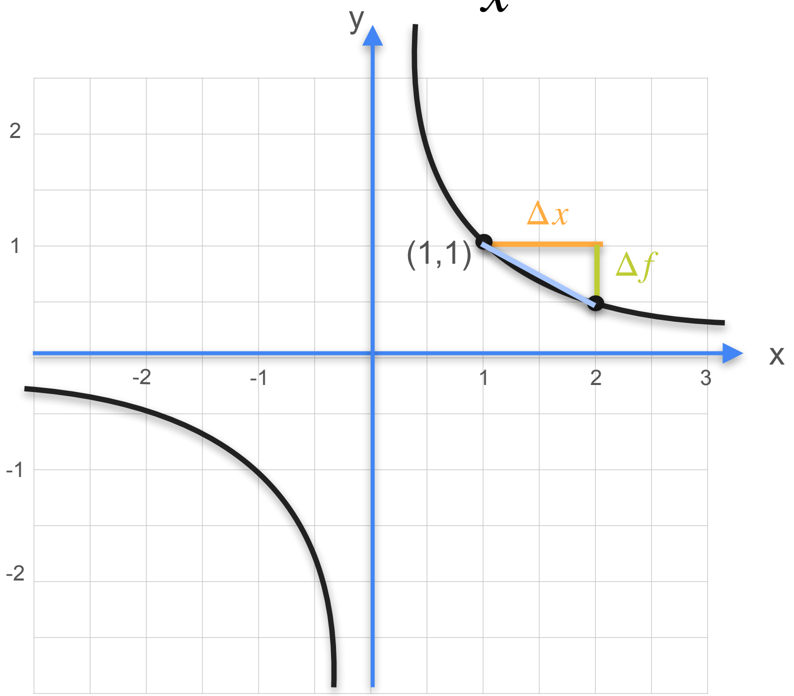
$$= \frac{\frac{1}{x+\Delta x} - \frac{1}{x}}{\Delta x} = \frac{\frac{\cancel{x} - (\cancel{x} + \cancel{\Delta x})}{(x+\Delta x)x}}{\cancel{\Delta x}}$$

Derivative of $\frac{1}{x}$



Inverse: $y = f(x) = x^{-1} = \frac{1}{x}$

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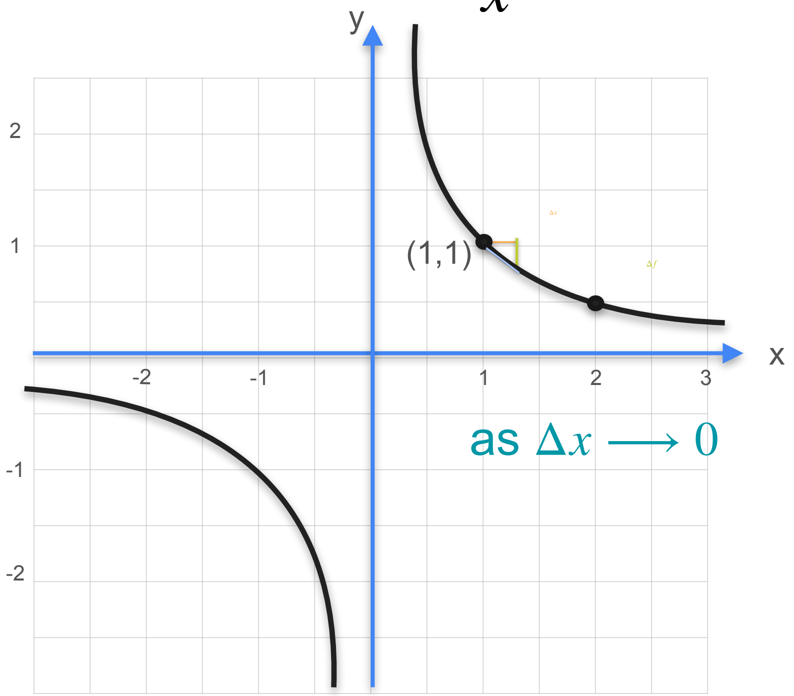
$$= -\frac{1}{x^2 + x\Delta x}$$

Derivative of $\frac{1}{x}$



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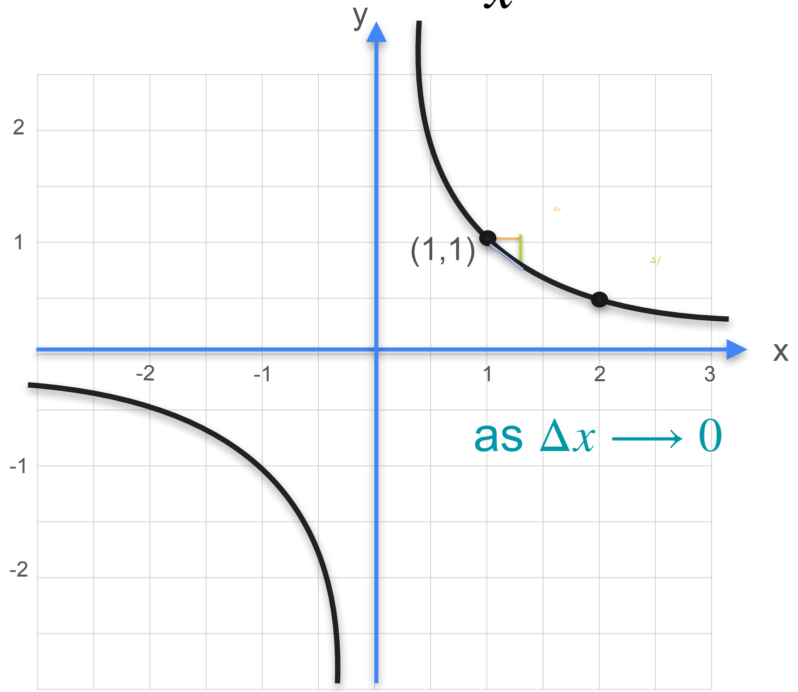
Derivative of $\frac{1}{x}$



Inverse: $y = f(x) = x^{-1} = \frac{1}{x}$

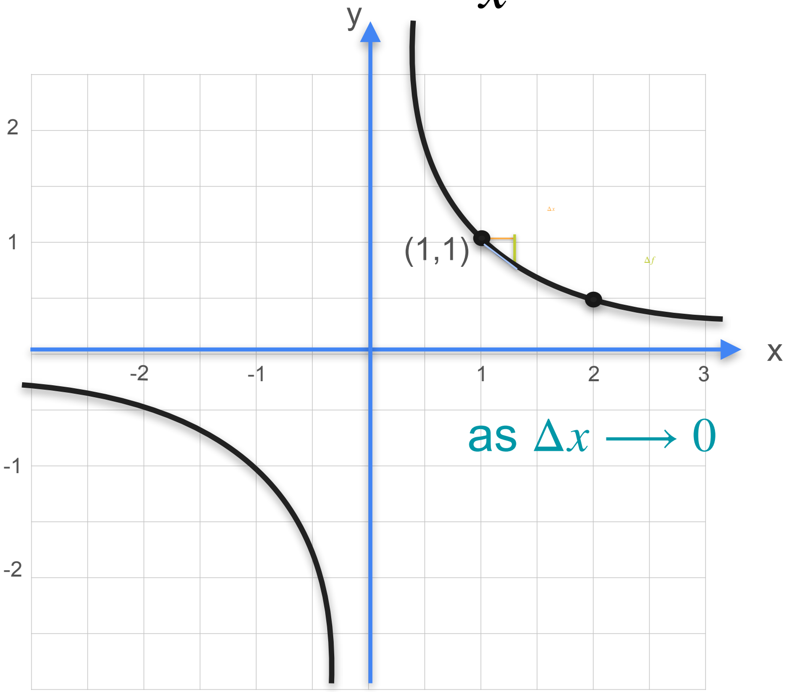
Slope: $\frac{\Delta f}{\Delta x} = \frac{f(x + \Delta x) - f(x)}{\Delta x}$

$$\frac{df}{dx} \quad \boxed{\frac{\Delta f}{\Delta x}} = \frac{(x + \Delta x)^{-1} - x^{-1}}{\Delta x}$$

$$= \frac{\frac{1}{x + \Delta x} - \frac{1}{x}}{\Delta x} = \frac{\frac{\cancel{x} - (\cancel{x} + \cancel{\Delta} x)}{(x + \Delta x)x}}{\cancel{\Delta} x}$$

$$= -\frac{1}{x^2 + x\boxed{\Delta x}} \quad 0$$

Derivative of $\frac{1}{x}$



as $\Delta x \longrightarrow 0$

Inverse: $y = f(x) = x^{-1} = \frac{1}{x}$

Slope: $\frac{\Delta f}{\Delta x} = \frac{f(x+\Delta x) - f(x)}{\Delta x}$

$$\frac{df}{dx} \quad \boxed{\frac{\Delta f}{\Delta x}} = \frac{(x+\Delta x)^{-1} - x^{-1}}{\Delta x}$$

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$$= -\frac{1}{x^2 + x\boxed{\Delta x}} \quad 0$$

$$f(x) = x^{-1} \Rightarrow f'(x) = -x^{-2}$$

Derivative of Power Functions

Derivative of Power Functions

$f(x) = x^2$

$f(x) = x^3$

$f(x) = x^{-1}$

Derivative of Power Functions

$$f(x) = x^2 \qquad f(x) = x^3 \qquad f(x) = x^{-1}$$

$$f'(x) = 2x^1 \qquad f'(x) = 3x^2 \qquad f'(x) = (-1)x^{-2}$$

Derivative of Power Functions

Can you spot the pattern?

$$f(x) = x^2 \qquad f(x) = x^3 \qquad f(x) = x^{-1}$$

$$f'(x) = 2x^1 \qquad f'(x) = 3x^2 \qquad f'(x) = (-1)x^{-2}$$

Derivative of Power Functions

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$$f(x) = x^{\boxed{2}} \qquad f(x) = x^{\boxed{3}} \qquad f(x) = x^{\boxed{-1}}$$

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Derivative of Power Functions

Can you spot the pattern?

$f(x) = x^{\boxed{2}}$

$f'(x) = 2x^{1}$

-1

$f(x) = x^{\boxed{3}}$

$f'(x) = 3x^{2}$

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$f'(x) = (-1)x^{-2}$

Derivative of Power Functions

Can you spot the pattern?

$f(x) = x^{\boxed{2}}$

-1

$f'(x) = 2x^1$

$f(x) = x^{\boxed{3}}$

$f'(x) = 3x^2$

$f(x) = x^{\boxed{-1}}$

$f'(x) = (-1)x^{-2}$

Derivative of Power Functions

Can you spot the pattern?

$$f(x) = x^{\boxed{2}} \qquad f(x) = x^{\boxed{3}} \qquad f(x) = x^{\boxed{-1}}$$

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Derivative of Power Functions

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-1 -1 -1

$$f'(x) = 2x^1 \qquad f'(x) = 3x^2 \qquad f'(x) = (-1)x^{-2}$$

$$f(x) = x^n \quad \Rightarrow \quad f'(x) = \frac{d}{dx}f(x) = nx^{n-1}$$

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Derivatives and Optimization

The inverse function and its derivative

Inverse Function

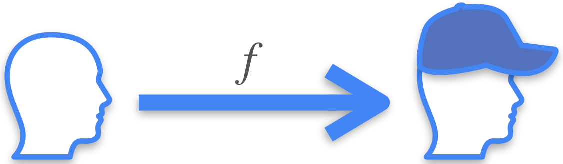
What's an inverse?

Inverse Function

What's an inverse?

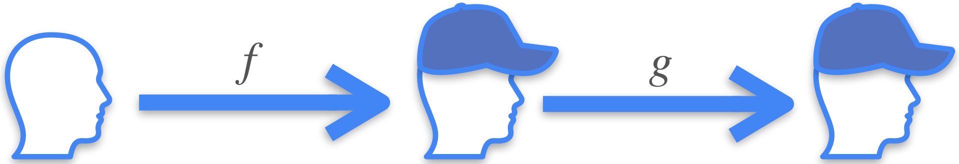
Inverse Function

What's an inverse?



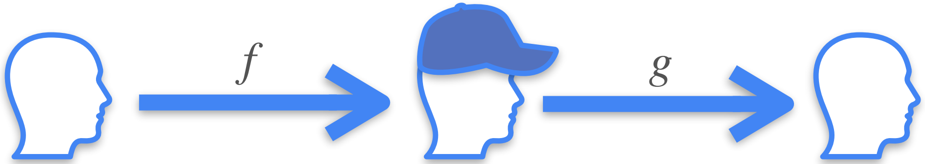
Inverse Function

What's an inverse?



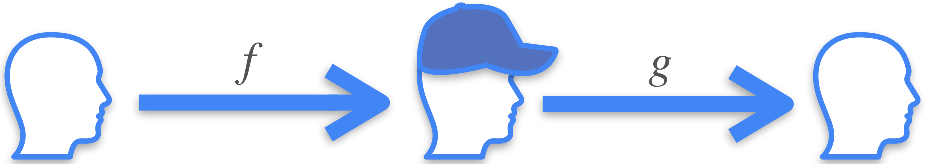
Inverse Function

What's an inverse?



Inverse Function

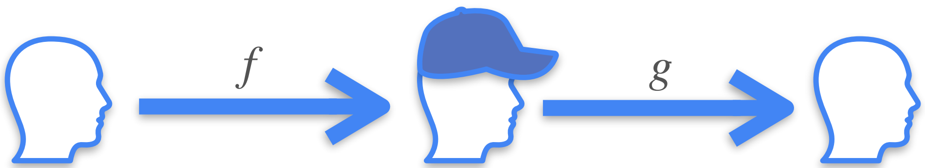
What's an inverse?



x

Inverse Function

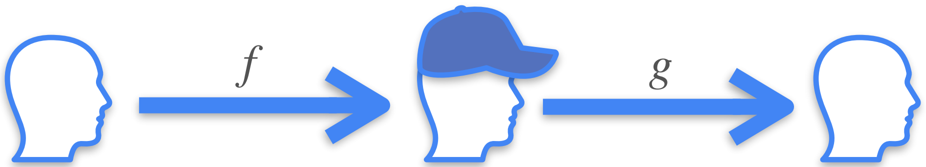
What's an inverse?



$$x \xrightarrow{f} x^2$$

Inverse Function

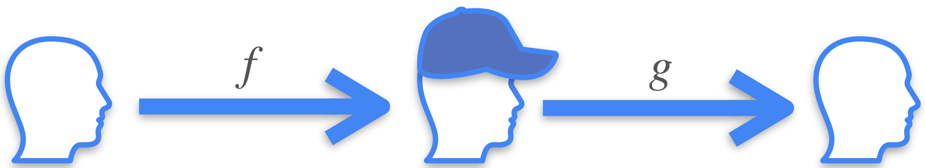
What's an inverse?



$$x \xrightarrow{f} x^2 \xrightarrow{g} x$$

Inverse Function

What's an inverse?

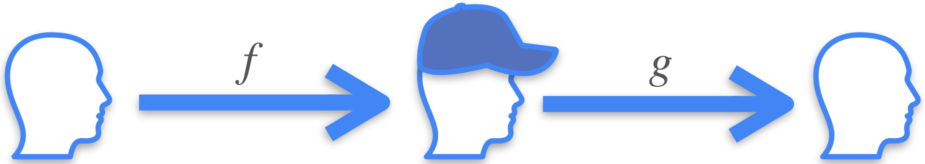


$$x \xrightarrow{f} x^2 \xrightarrow{g} x$$

$g(x)$ and $f(x)$ are inverses

Inverse Function

What's an inverse?



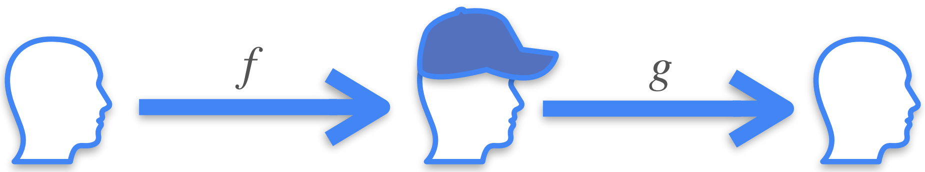
$$x \xrightarrow{f} x^2 \xrightarrow{g} x$$

$g(x)$ and $f(x)$ are inverses

$$g(x) = f^{-1}(x)$$

Inverse Function

What's an inverse?



$$x \xrightarrow{f} x^2 \xrightarrow{g} x$$

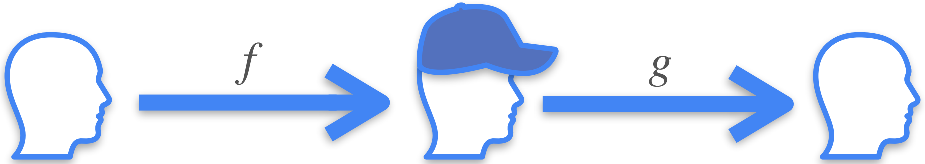
$g(x)$ and $f(x)$ are inverses

$$g(x) = f^{-1}(x)$$

$$g(f(x)) = x$$

Inverse Function

What's an inverse?



$$x \xrightarrow{f} x^2 \xrightarrow{g} x$$

$f(x)$

x^2

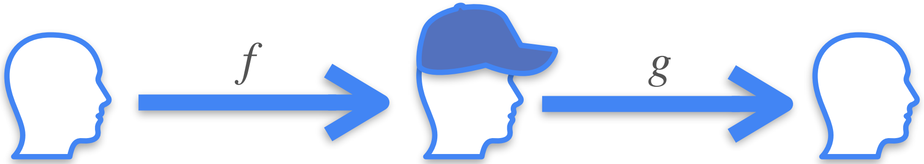
$g(x)$ and $f(x)$ are inverses

$$g(x) = f^{-1}(x)$$

$$g(f(x)) = x$$

Inverse Function

What's an inverse?



$$x \xrightarrow{f} x^2 \xrightarrow{g} x$$

$f(x)$

x^2

$g(x)$

$\sqrt{x}$

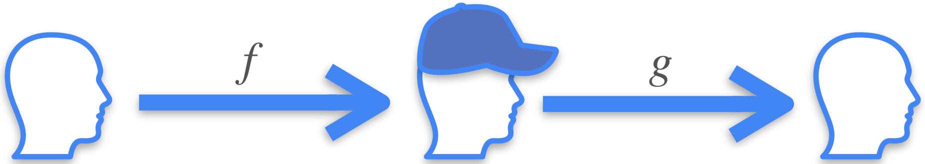
$g(x)$ and $f(x)$ are inverses

$$g(x) = f^{-1}(x)$$

$$g(f(x)) = x$$

Inverse Function

What's an inverse?



$$x \xrightarrow{f} x^2 \xrightarrow{g} x$$

$f(x)$

x^2

$g(x)$

$\sqrt{x}$

$g(x)$ and $f(x)$ are inverses

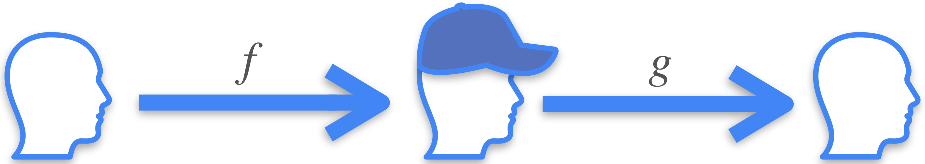
$$g(x) = f^{-1}(x)$$

$$g(f(x)) = x$$

$$\sqrt{x^2}$$

Inverse Function

What's an inverse?



$$x \xrightarrow{f} x^2 \xrightarrow{g} x$$

$f(x)$ $\qquad$ $g(x)$

x^2 $\qquad$ $\sqrt{x}$

$g(x)$ and $f(x)$ are inverses

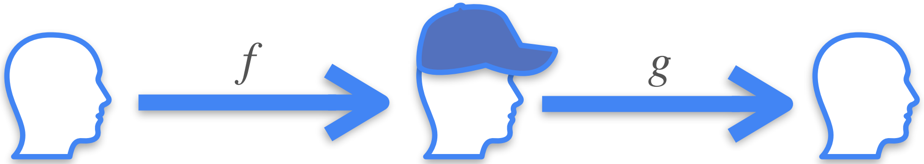
$$g(x) = f^{-1}(x)$$

$$g(f(x)) = x$$

$$\sqrt{x^2} = x$$

Inverse Function

What's an inverse?



$$x \xrightarrow[\substack{f(x) \\ x^2}]{f} x^2 \xrightarrow[\substack{g(x) \\ \sqrt{x}}]{g} x$$

$g(x)$ and $f(x)$ are inverses

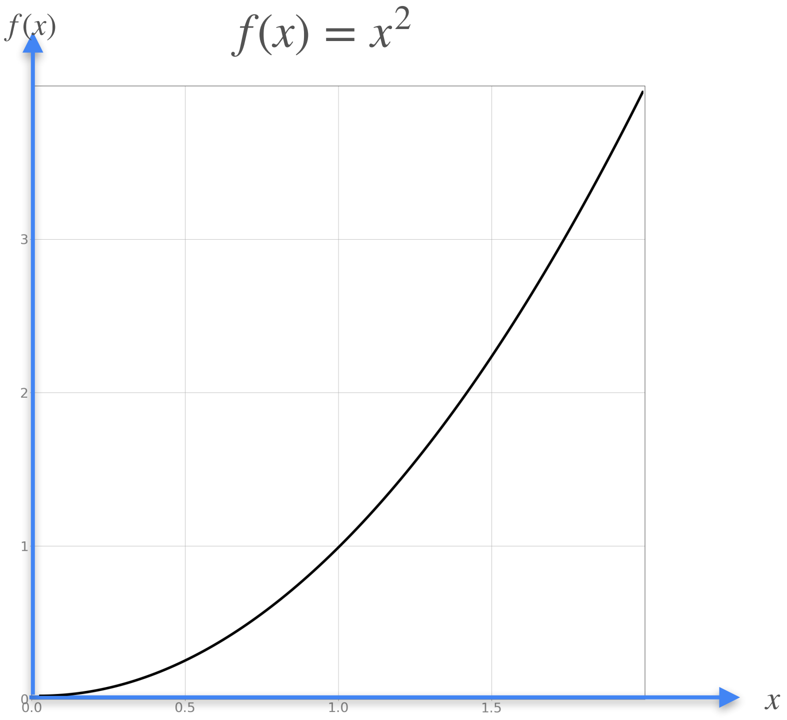
$$g(x) = f^{-1}(x)$$

$$g(f(x)) = x$$

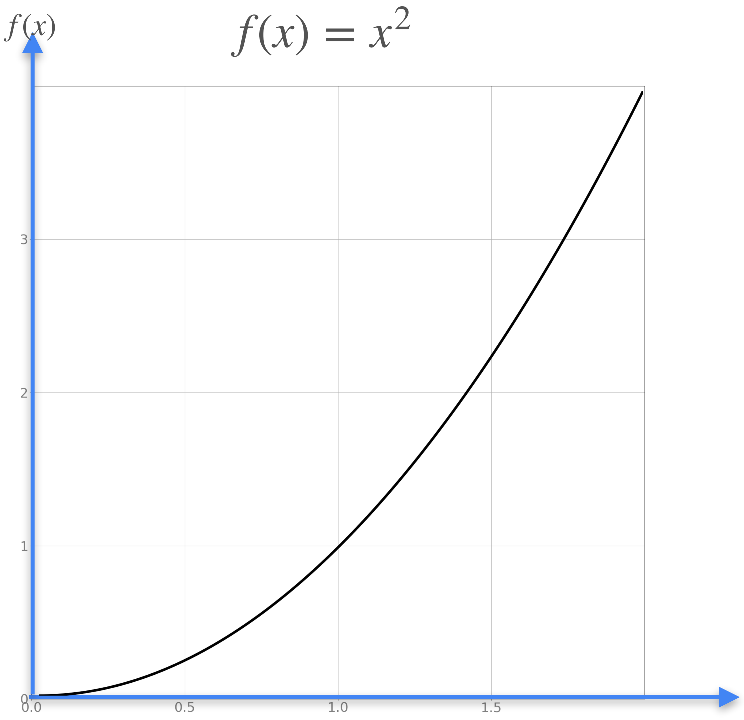
$\sqrt{x^2} = x$ for $x > 0$

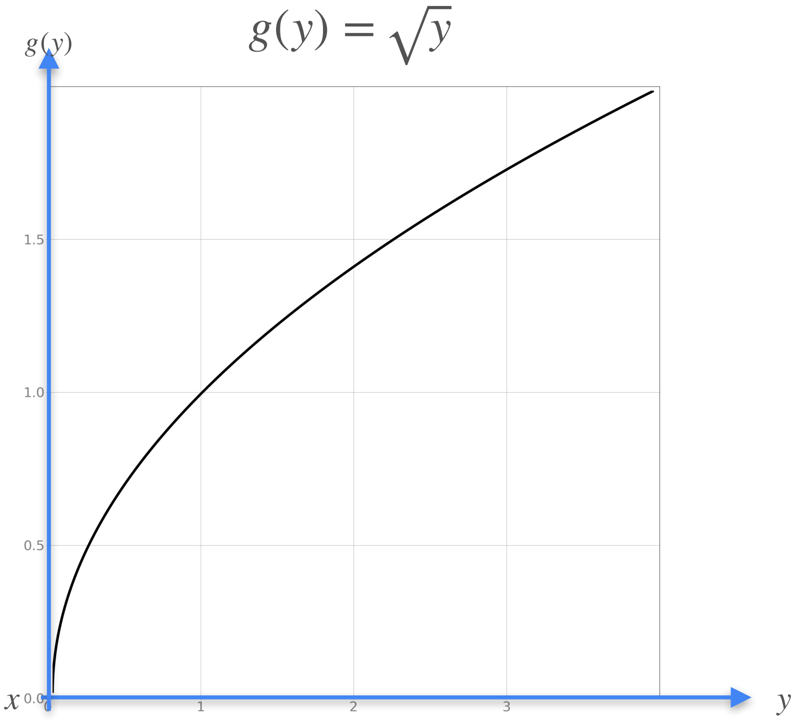
Derivative of the Inverse

Derivative of the Inverse



Derivative of the Inverse





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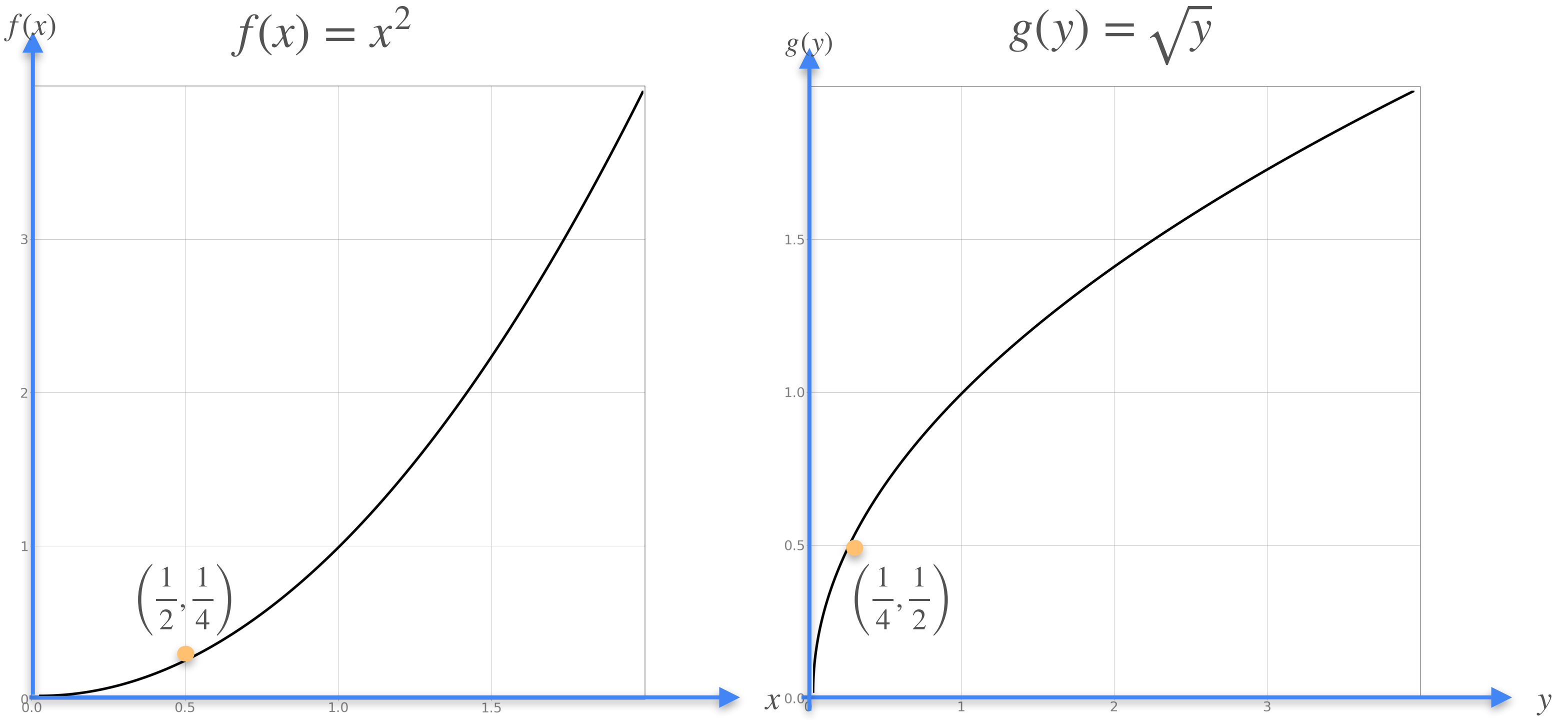

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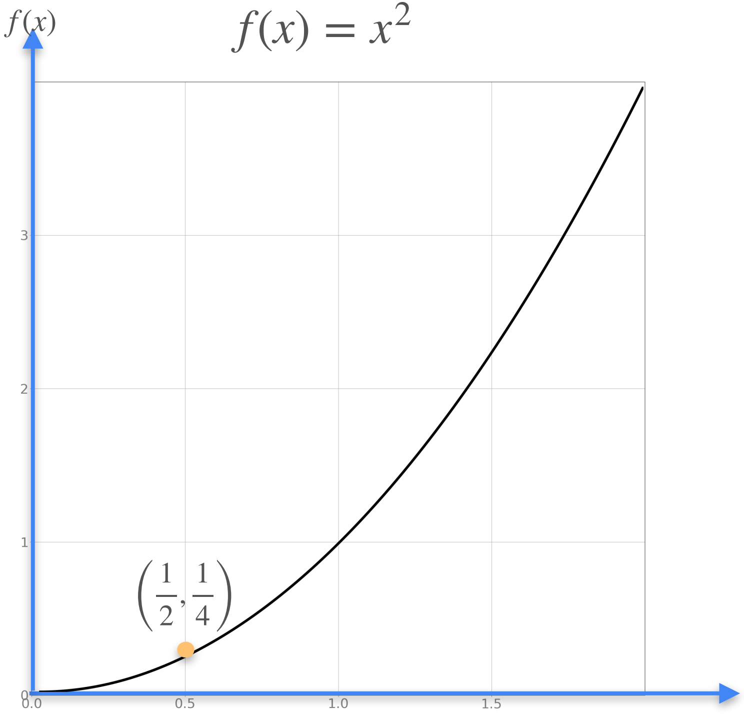
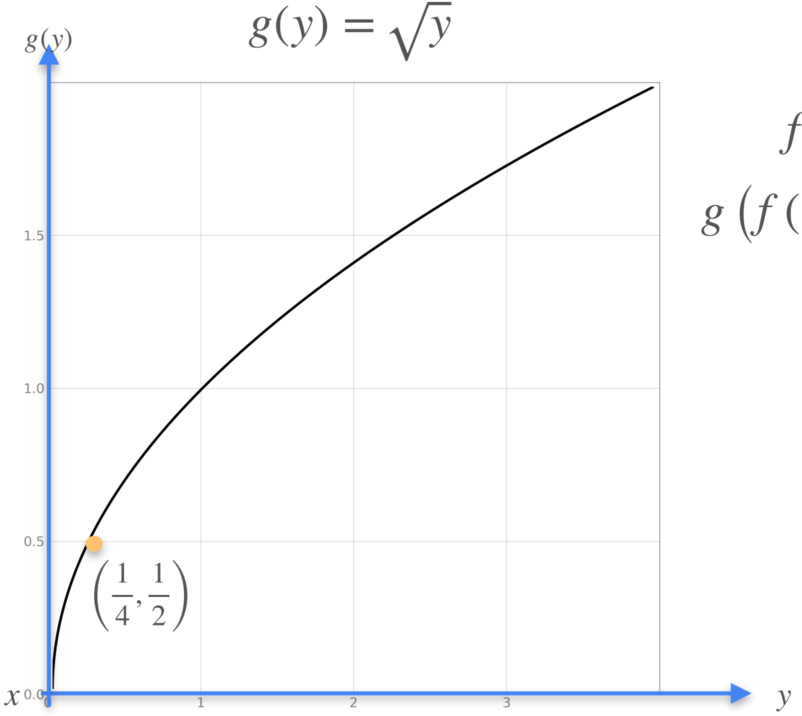
Derivative of the Inverse

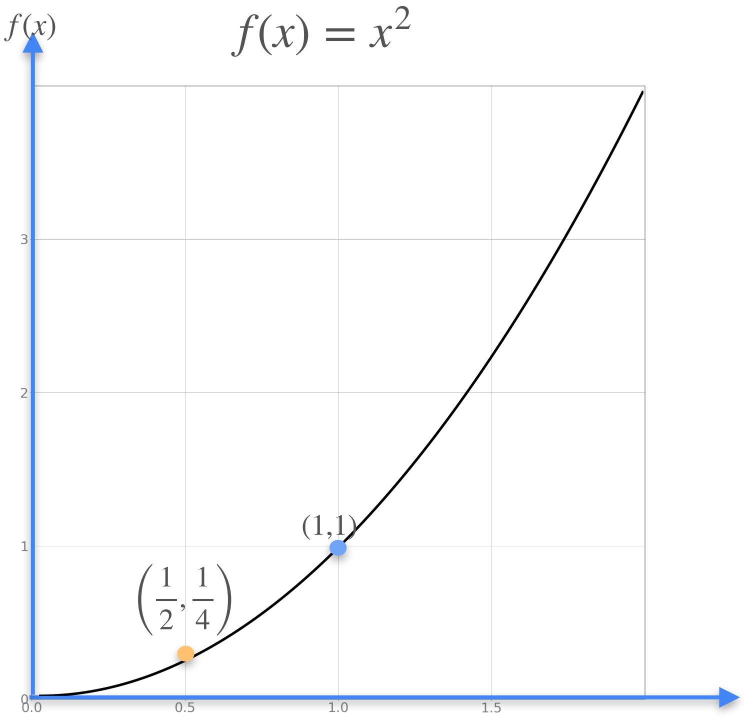


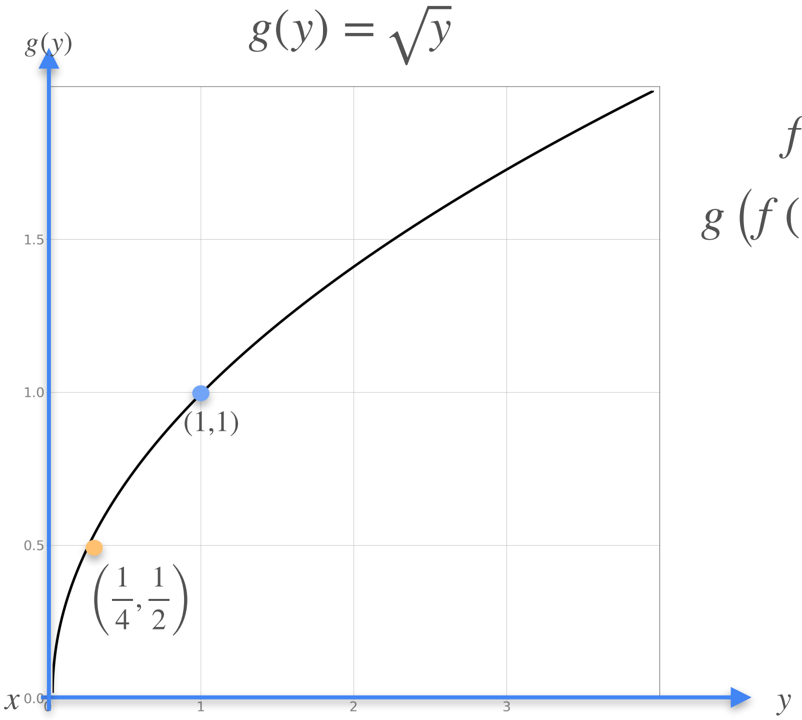


$$f(1/2) = 1/4$$

$$g\left(f(1/2)\right) = g(1/4) = 1/2$$

Derivative of the Inverse



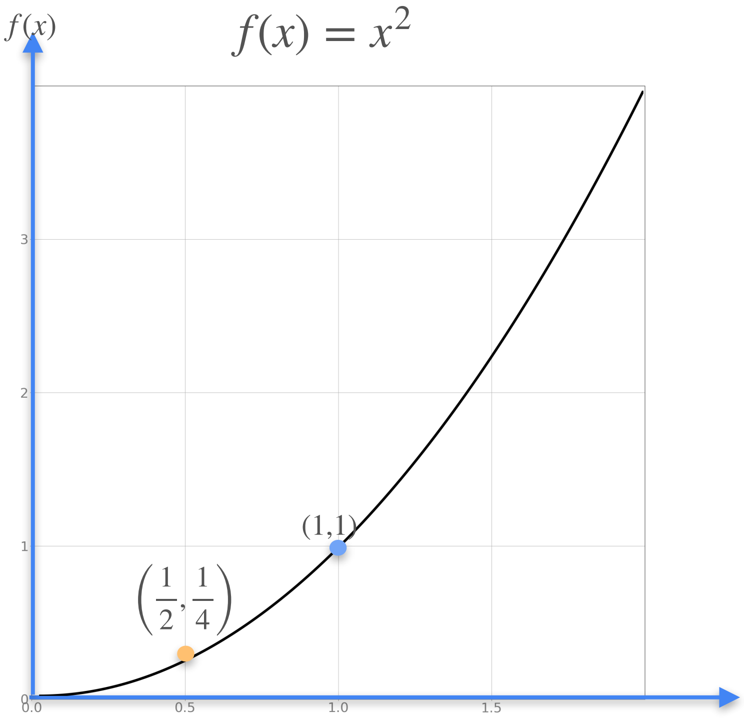


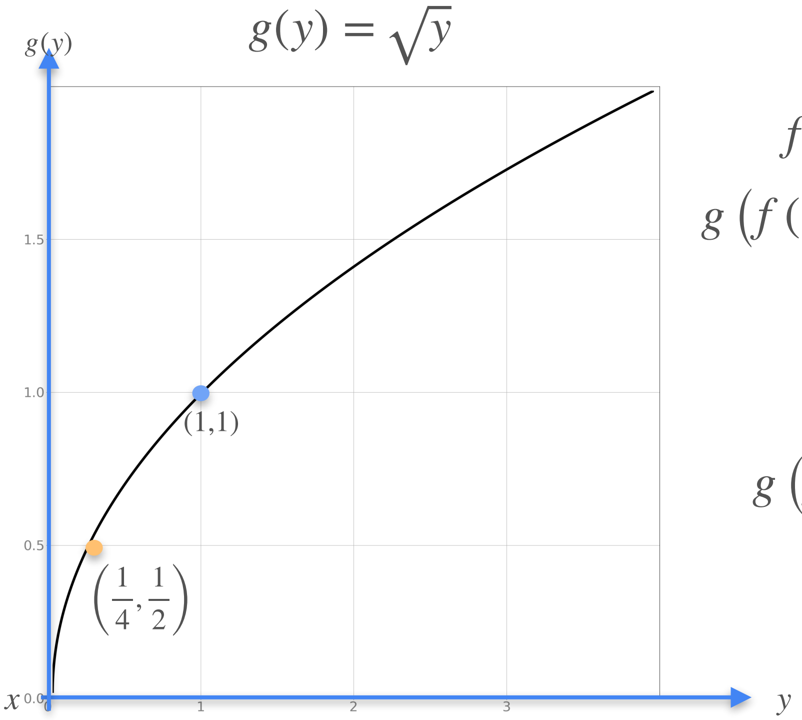
$$f(1/2) = 1/4$$

$$g\left(f(1/2)\right) = g(1/4)$$

$$= 1/2$$

Derivative of the Inverse





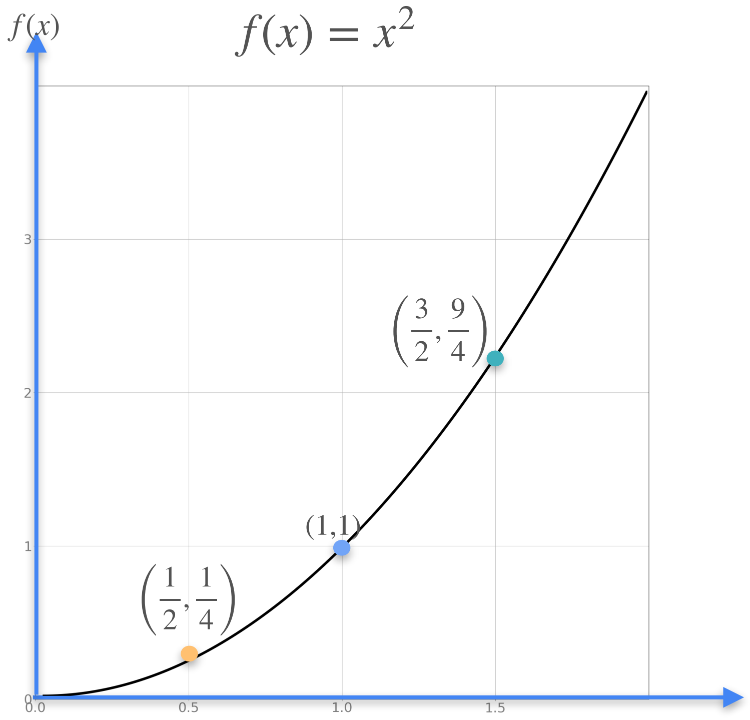
$$f(1/2) = 1/4$$

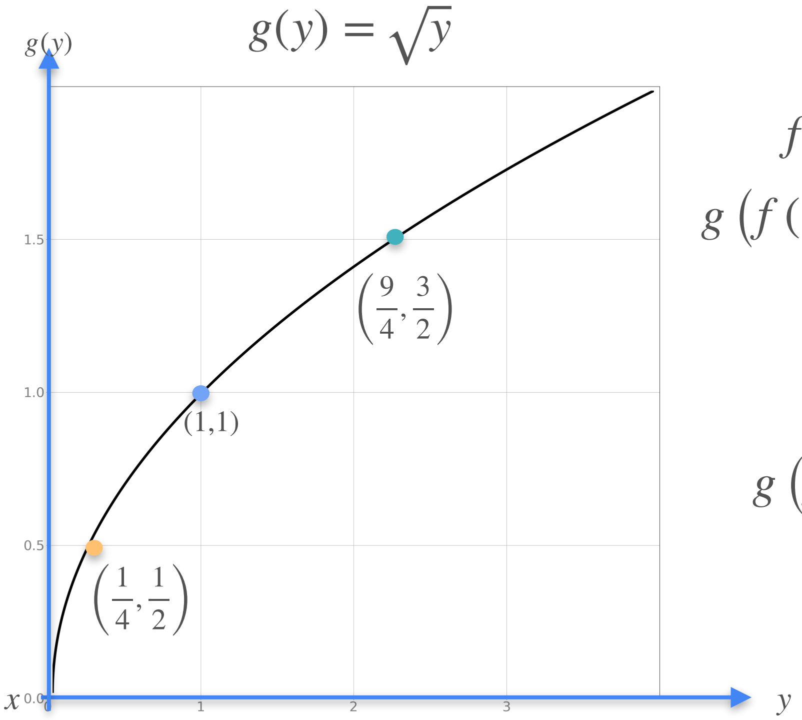
$$g\left(f(1/2)\right) = g(1/4)$$
$$= 1/2$$

$$f(1) = 1$$

$$g\left(f(1)\right) = g(1)$$
$$= 1$$

Derivative of the Inverse





$$f(1/2) = 1/4$$

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$$f(1) = 1$$

$$g\left(f(1)\right) = g(1) = 1$$

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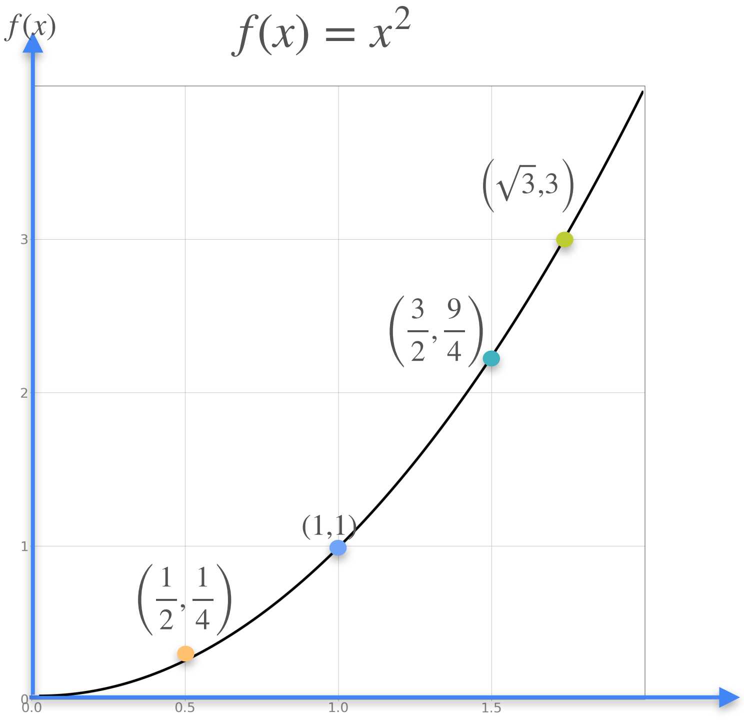
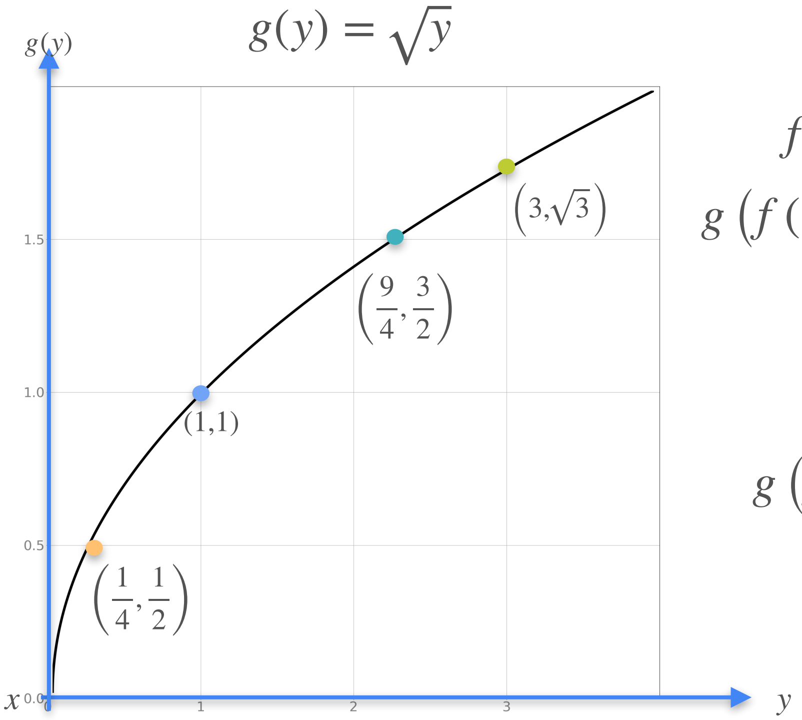
Derivative of the Inverse





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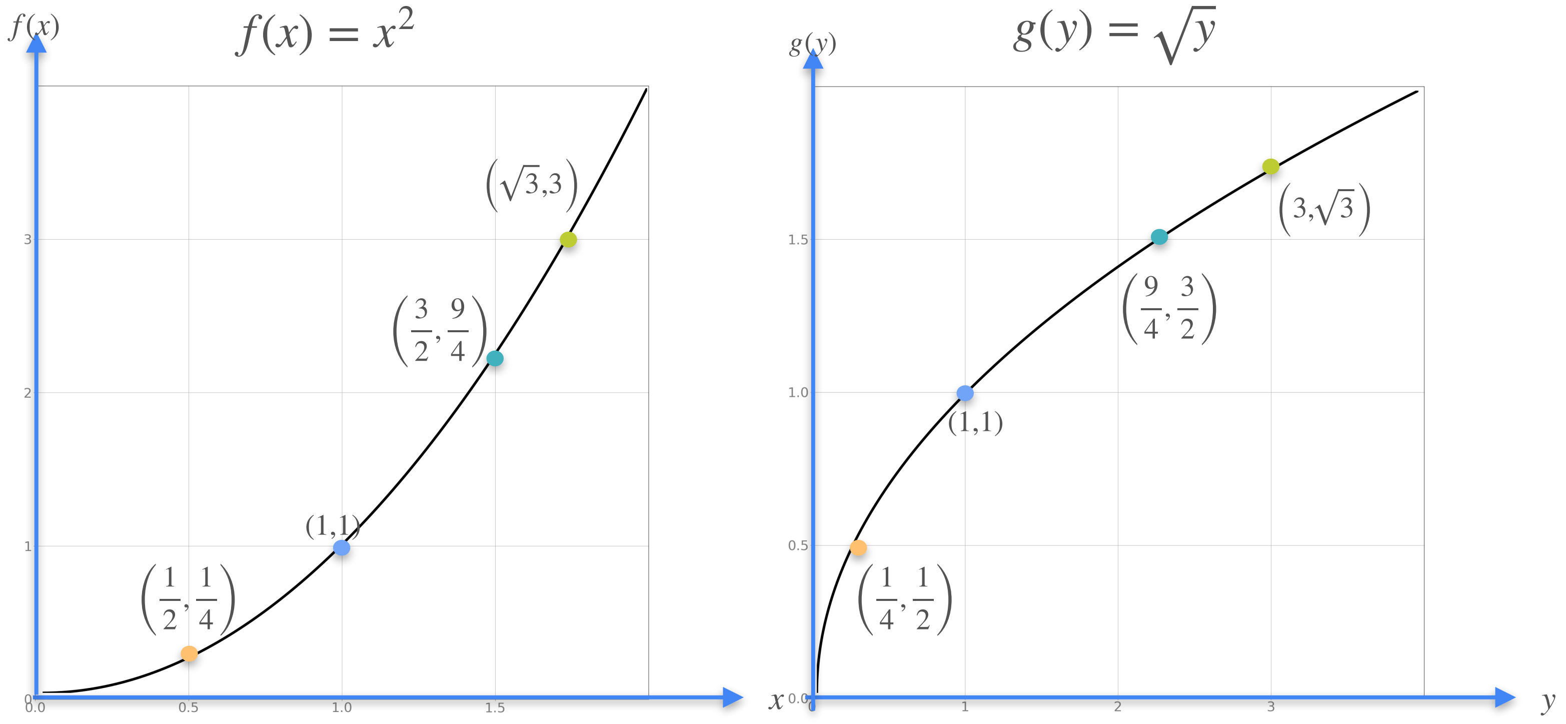
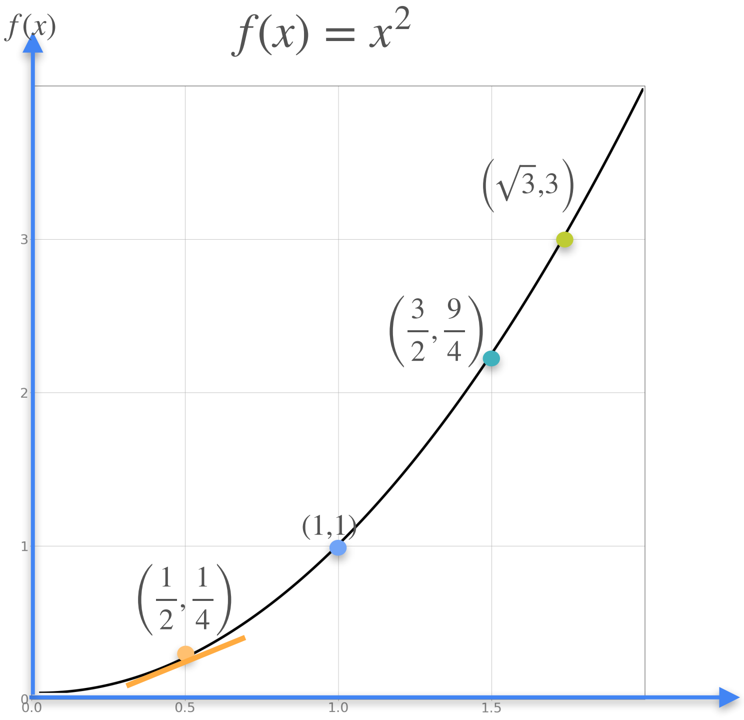
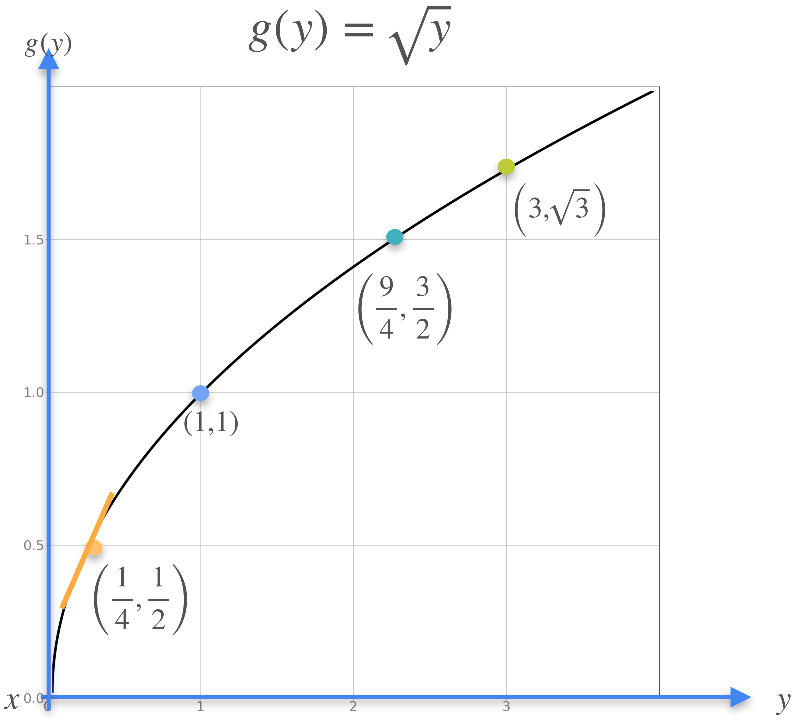
Derivative of the Inverse



Derivative of the Inverse





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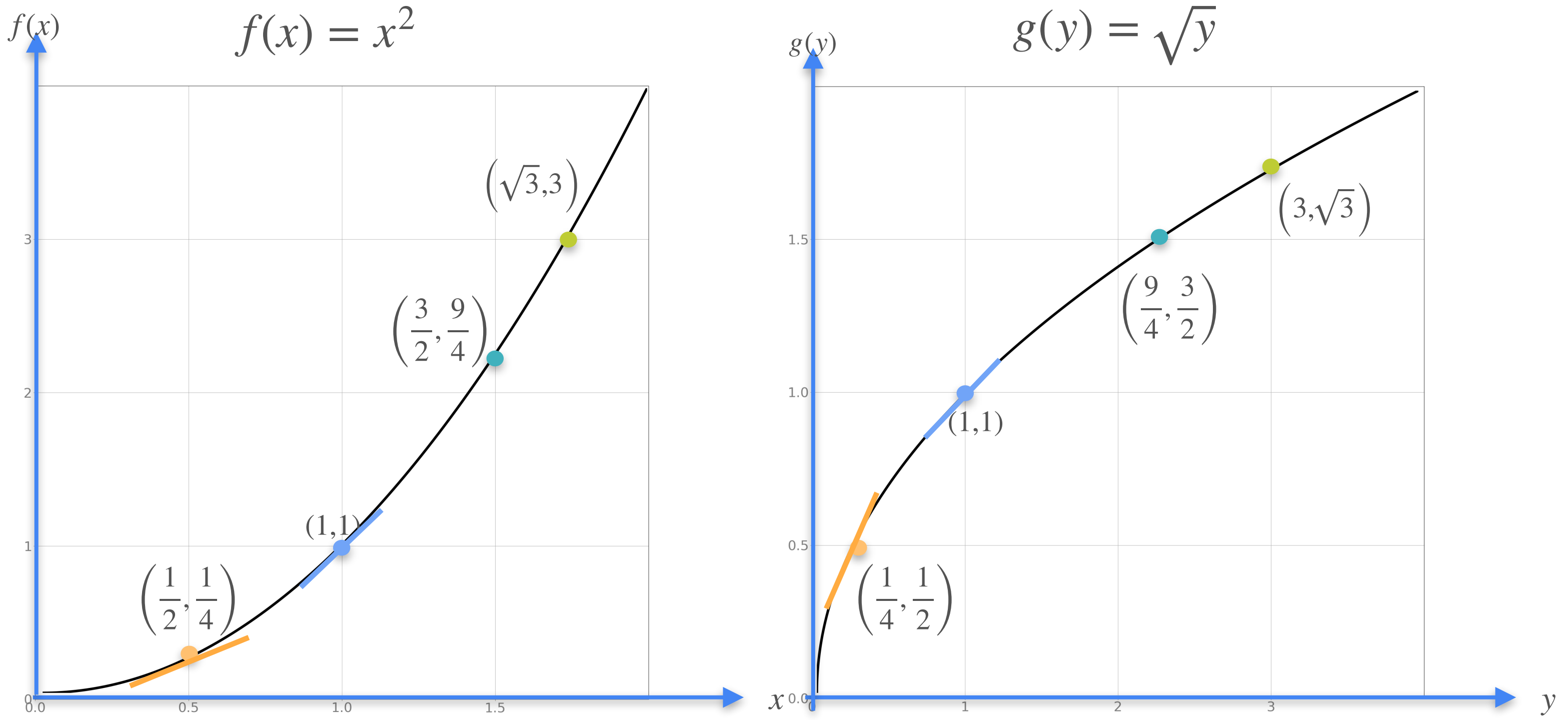
Derivative of the Inverse



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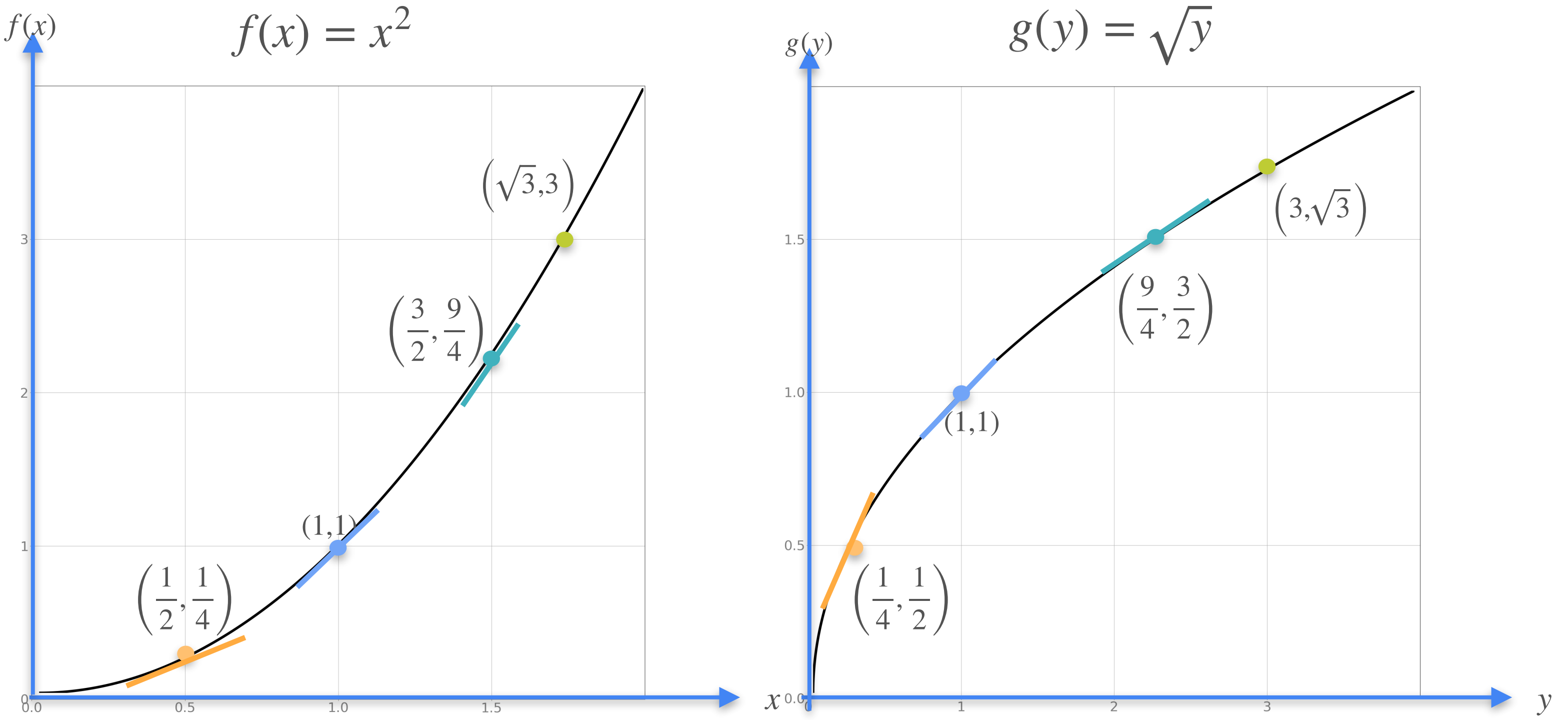
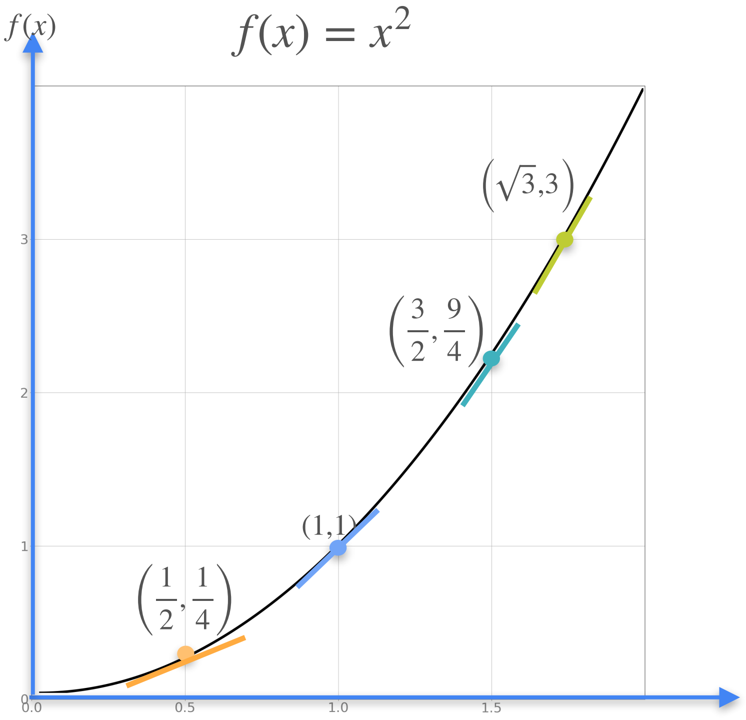
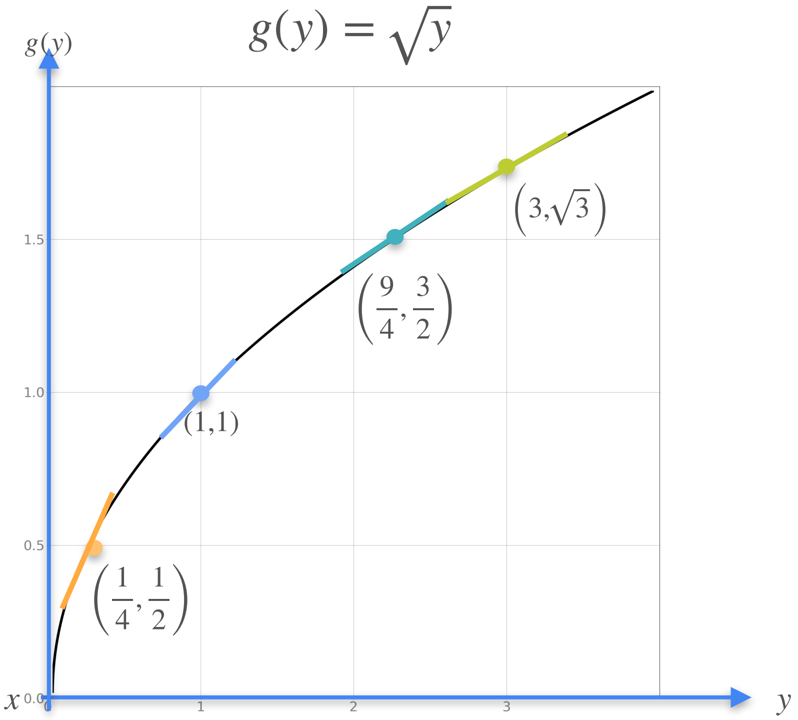
Derivative of the Inverse

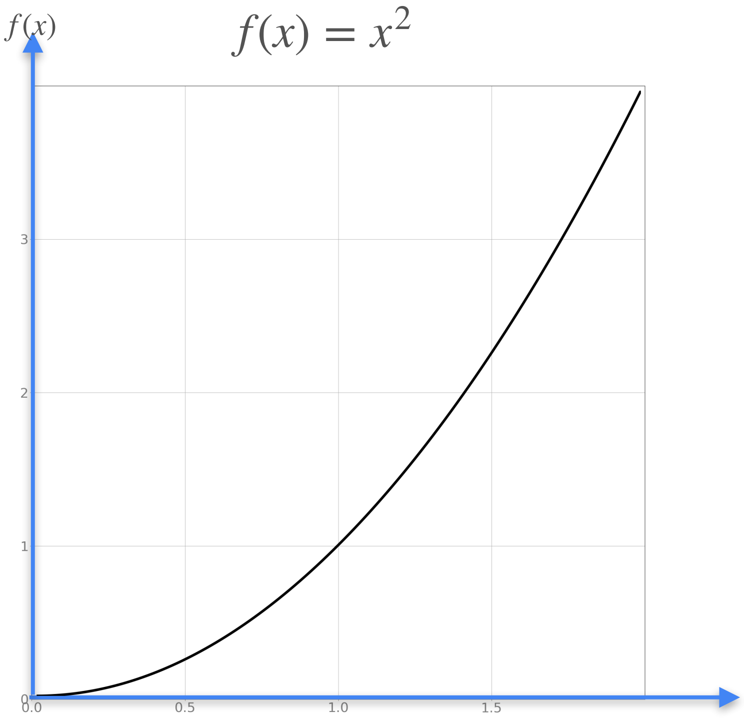


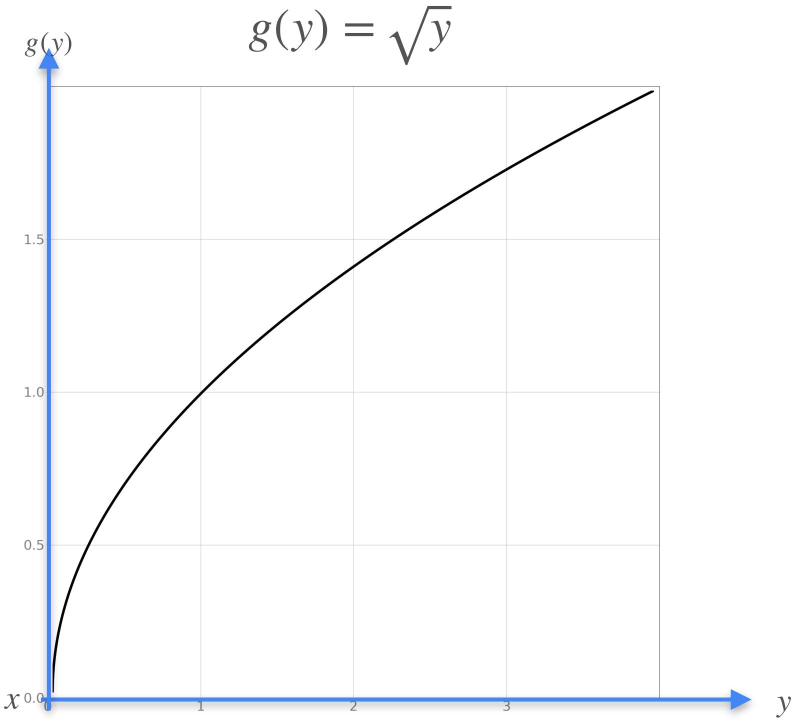
Derivative of the Inverse



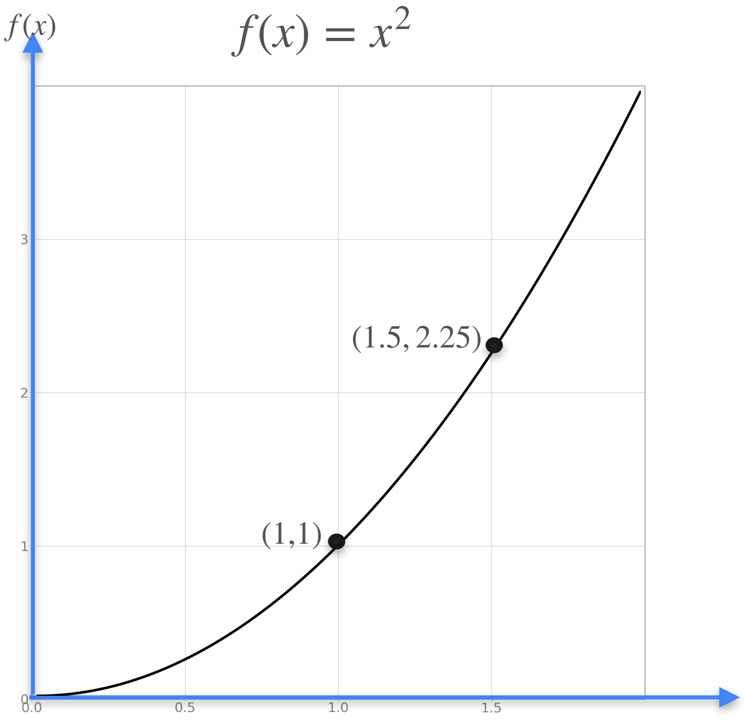


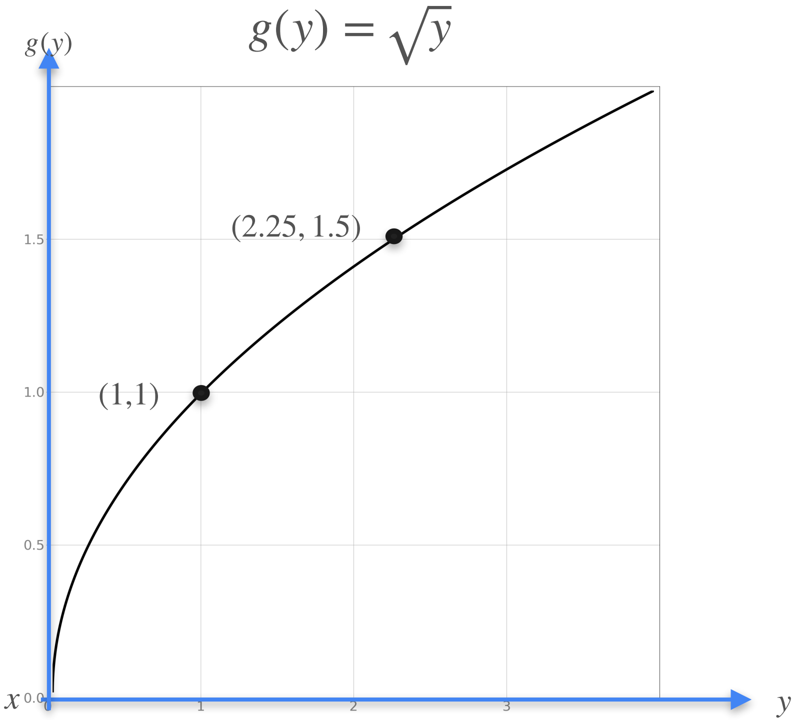
Derivative of the Inverse





Derivative of the Inverse





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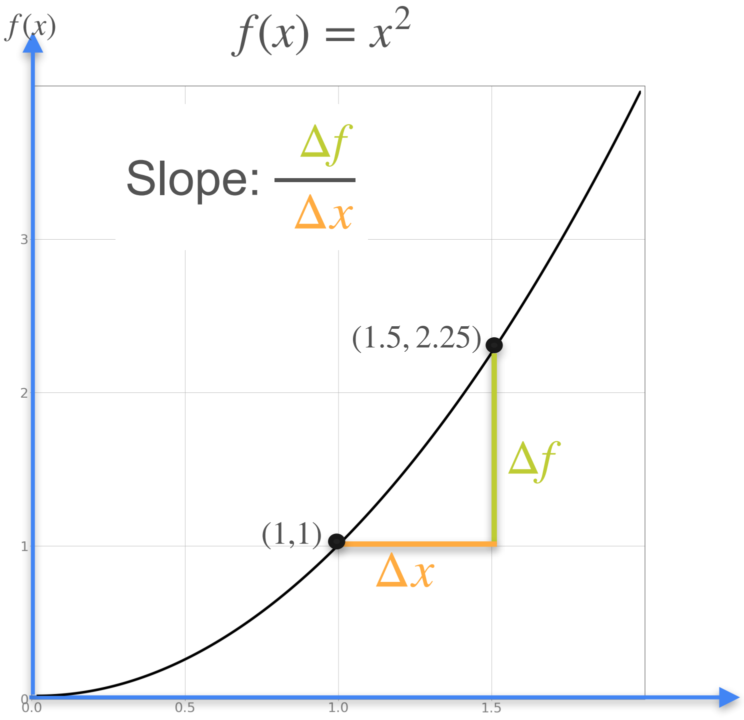
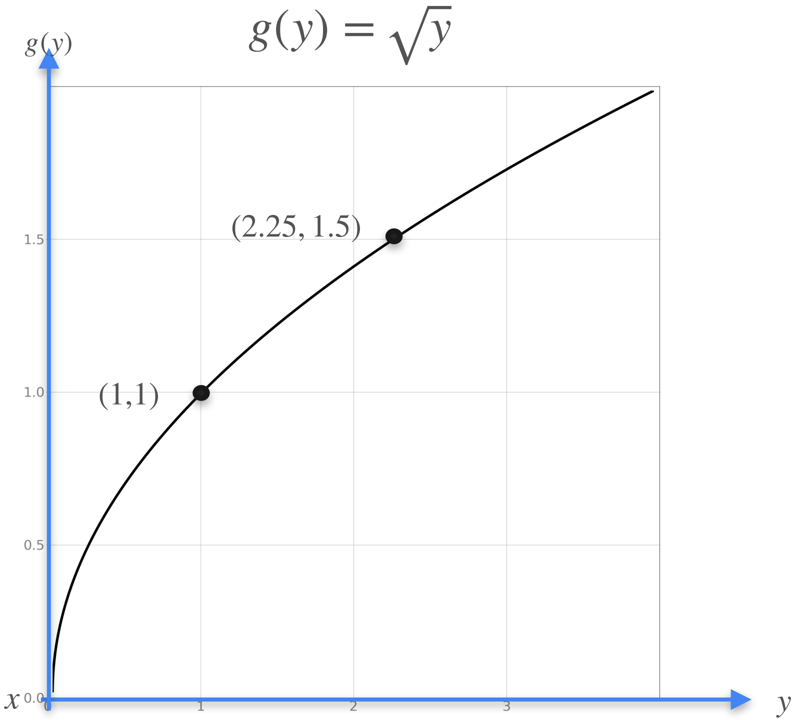
Derivative of the Inverse





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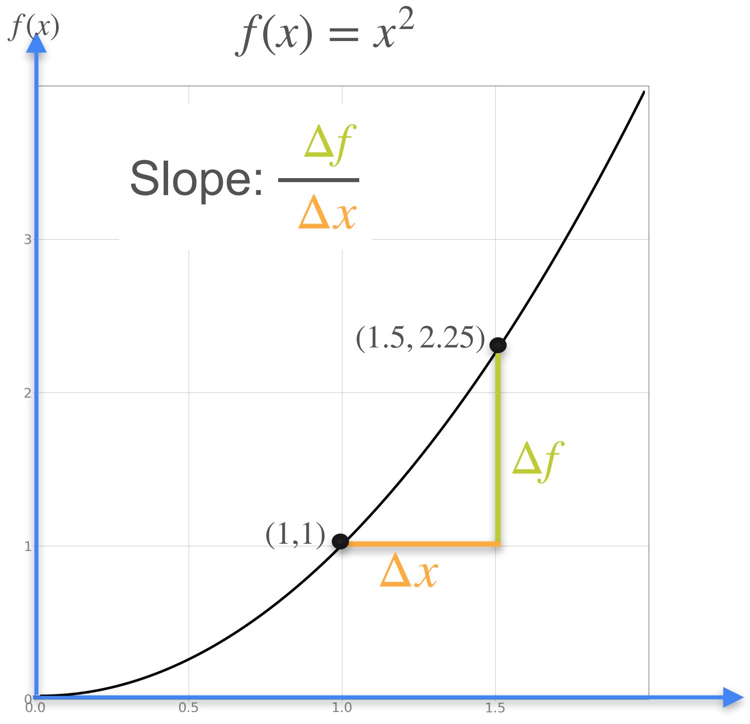

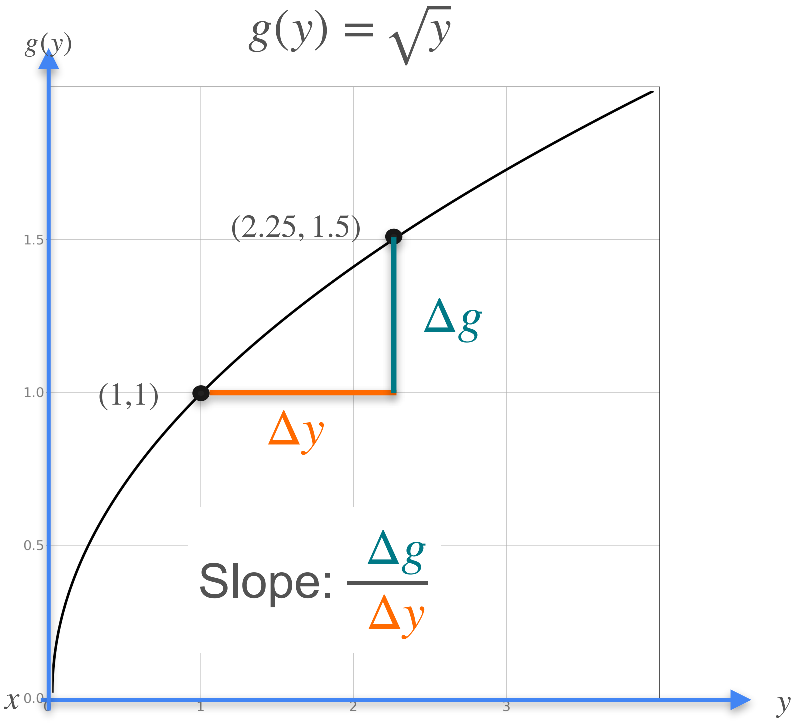

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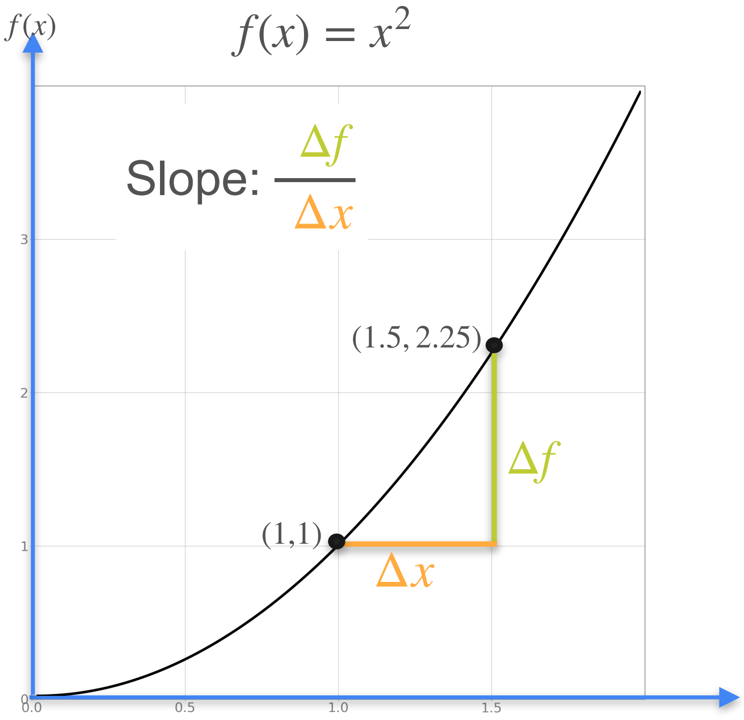

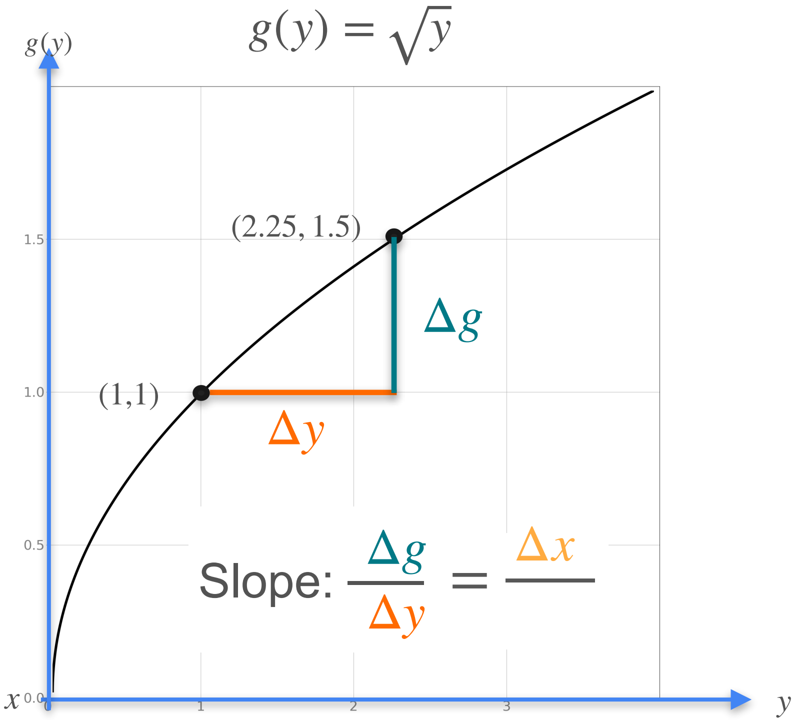

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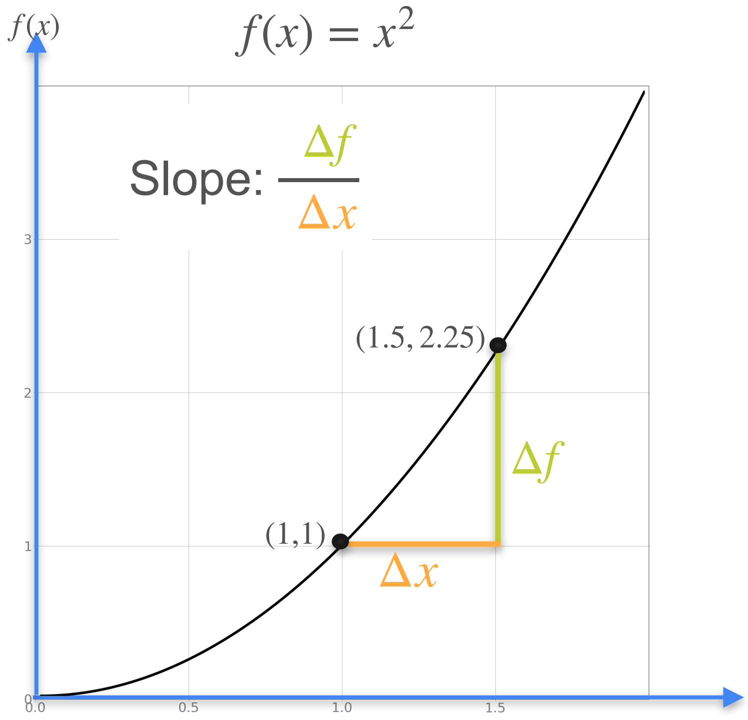

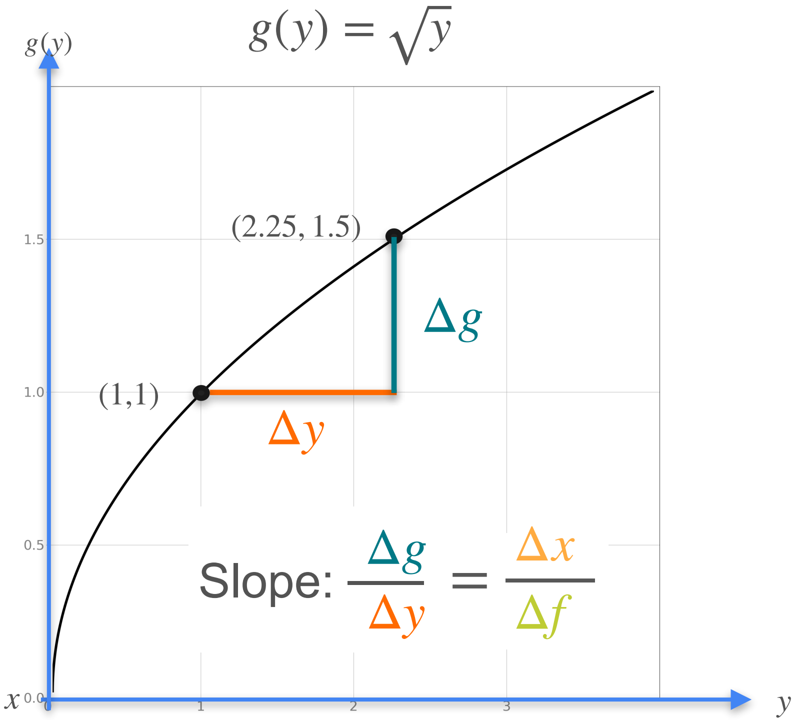

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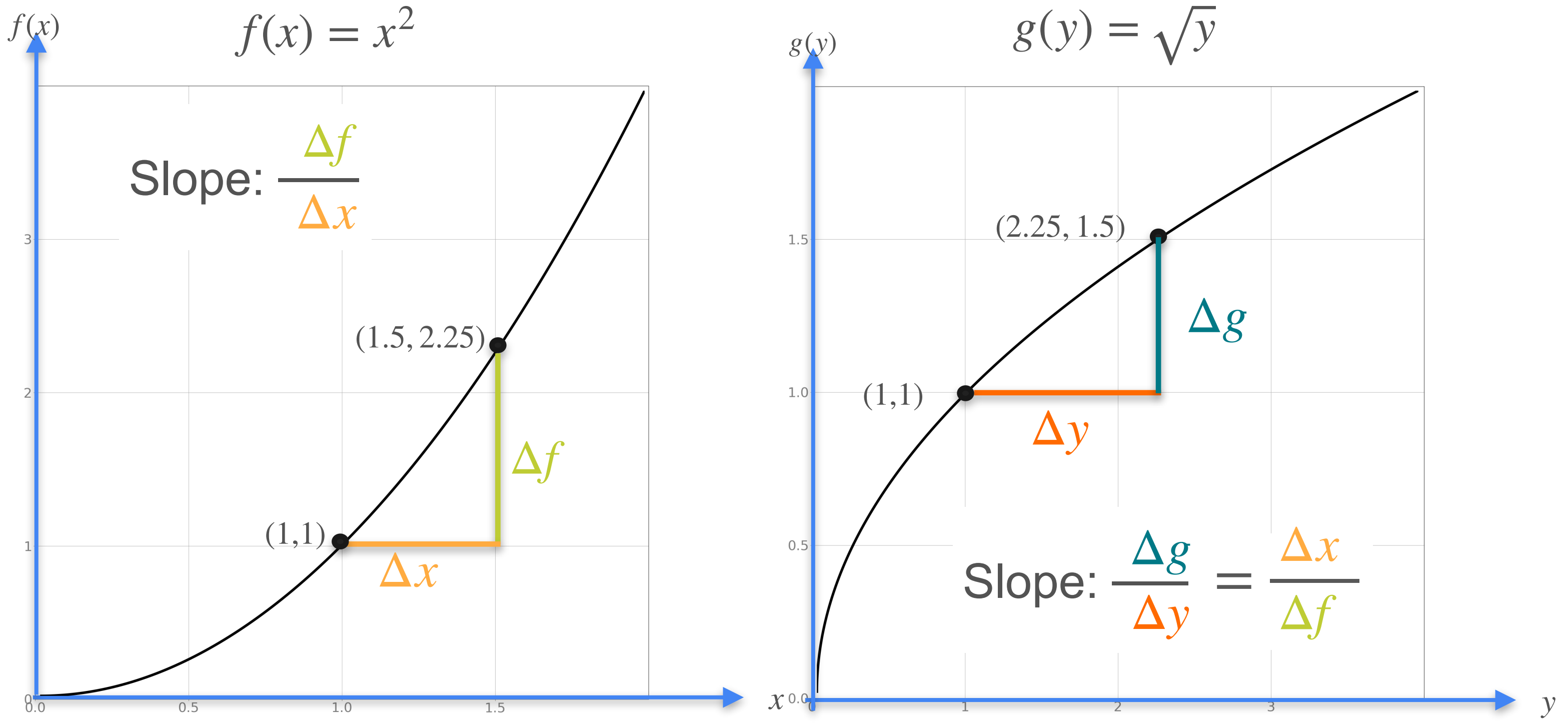

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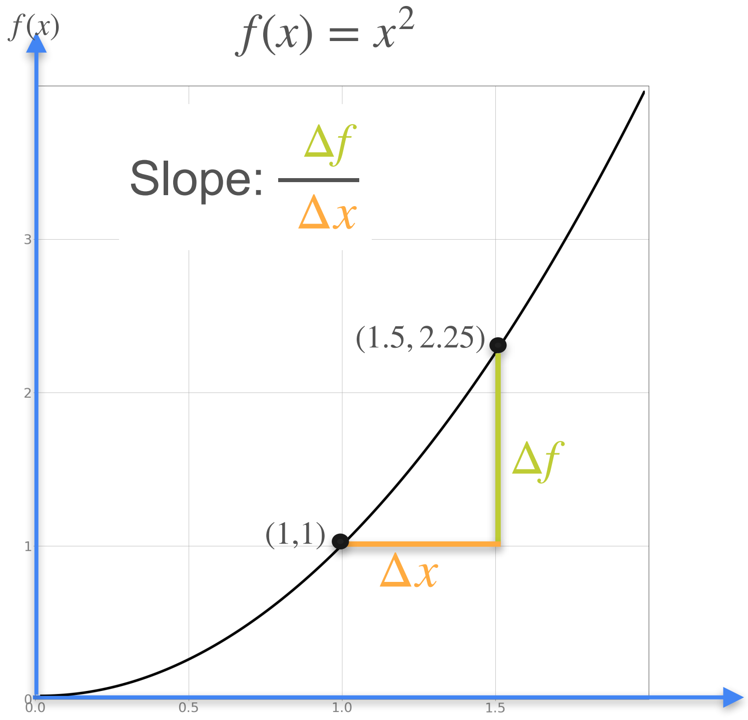
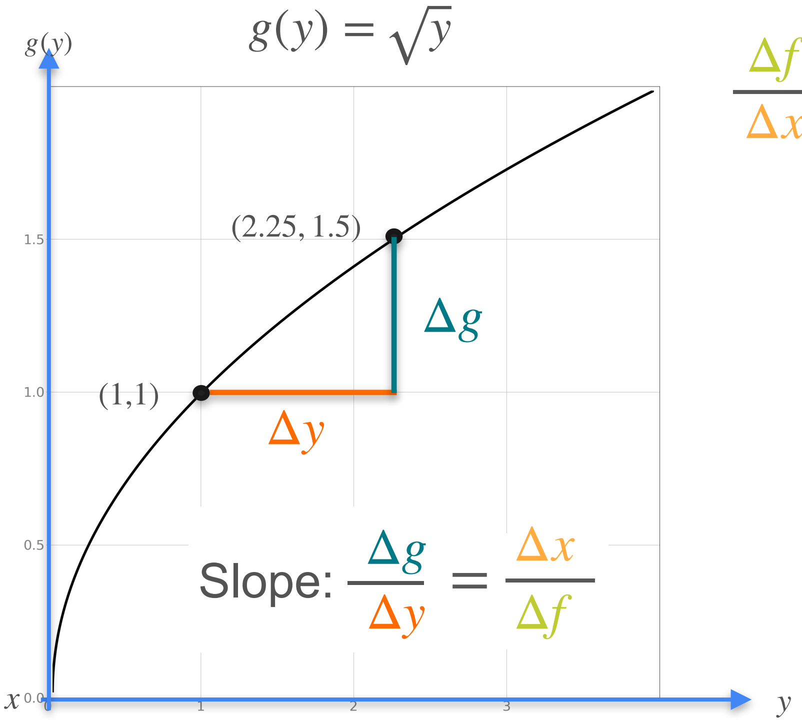
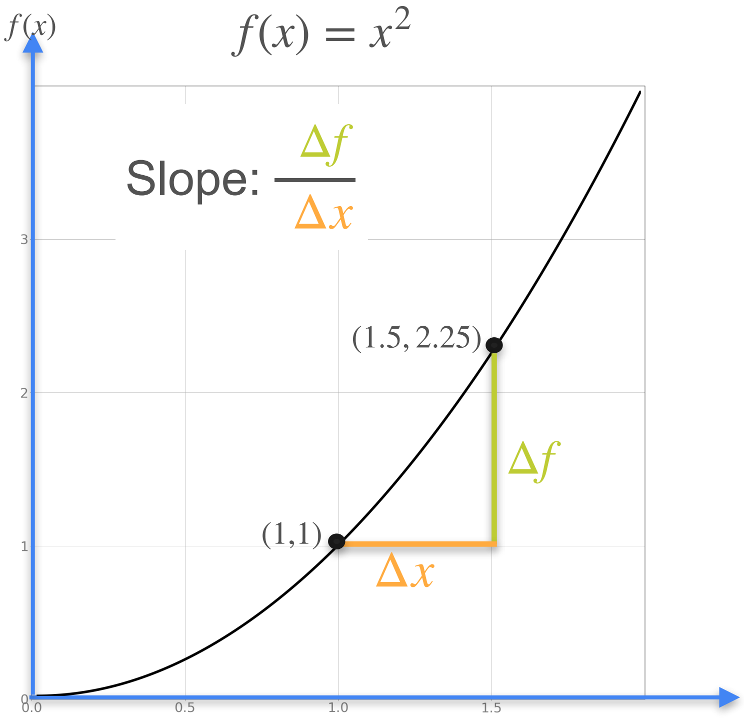
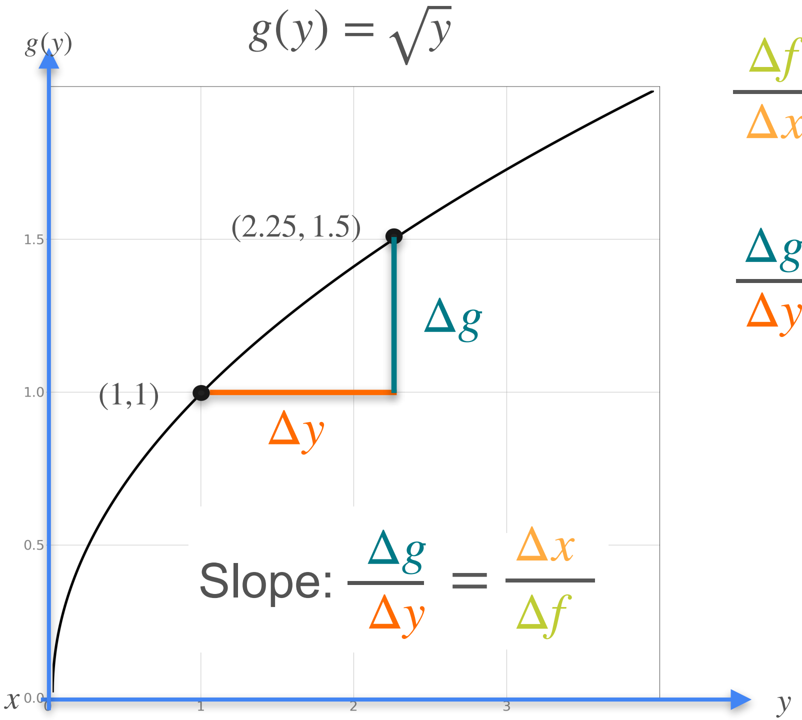




$$\frac{\Delta f}{\Delta x} = f'(x)$$

Derivative of the Inverse

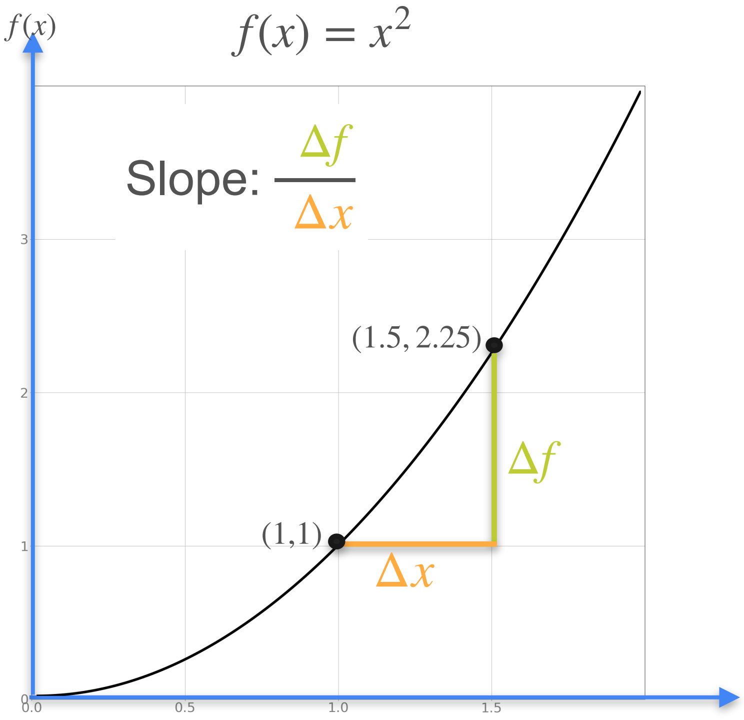


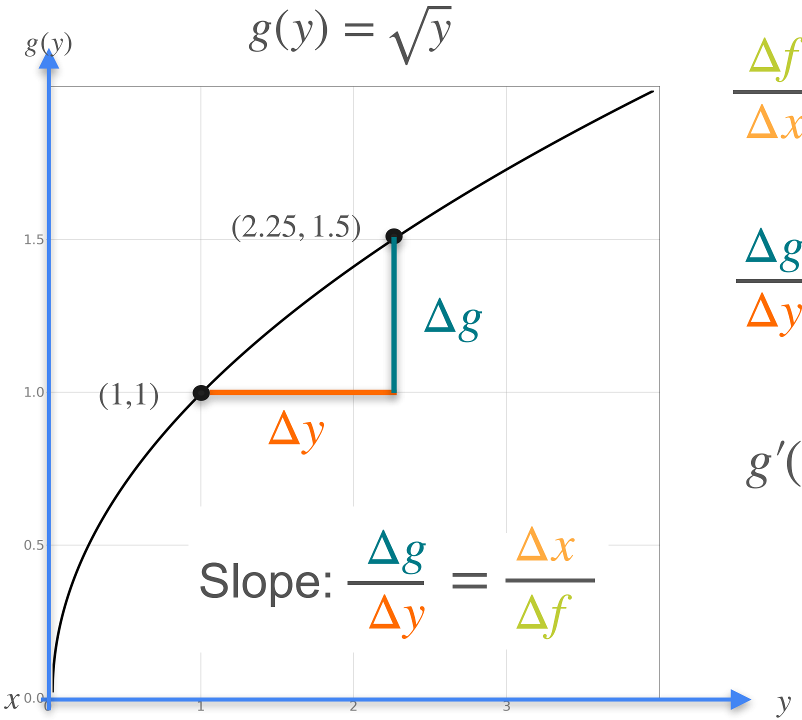


$$\frac{\Delta f}{\Delta x} = f'(x)$$

$$\frac{\Delta g}{\Delta y} = g'(y)$$

Derivative of the Inverse





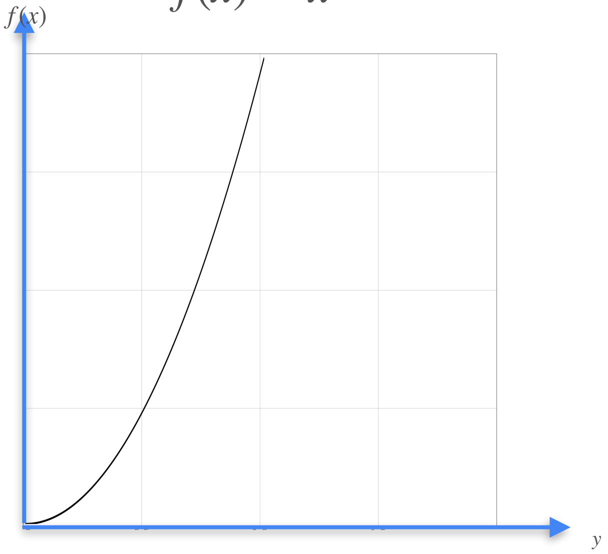
$$\frac{\Delta f}{\Delta x} = f'(x)$$

$$\frac{\Delta g}{\Delta y} = g'(y)$$

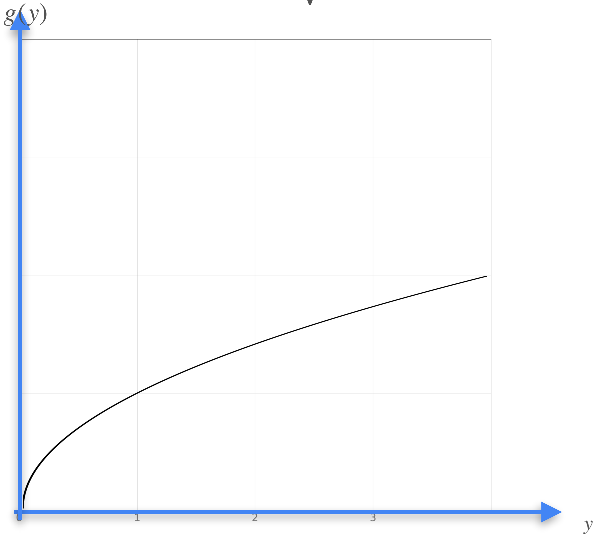
$$g'(y) = \frac{1}{f'(x)}$$

Derivative of the Inverse

$$f(x) = x^2$$



$$g(y) = \sqrt{y}$$



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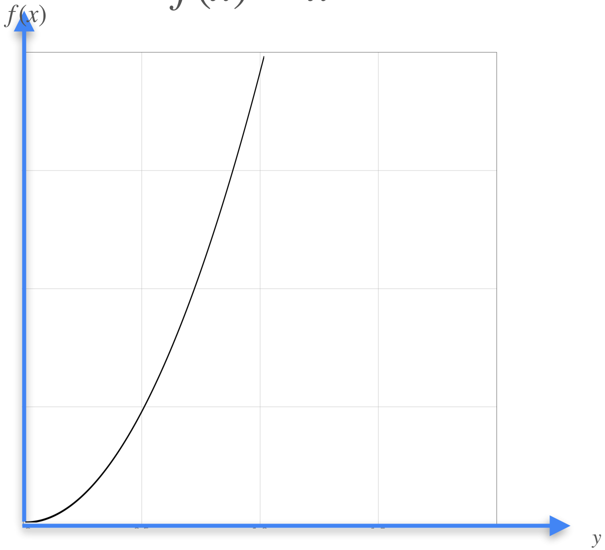

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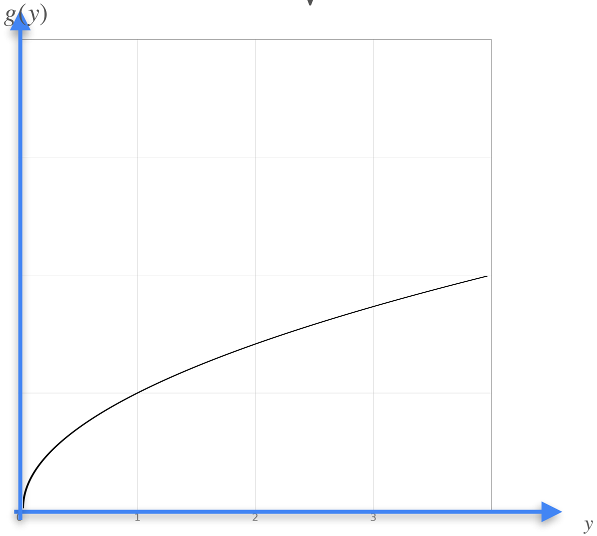


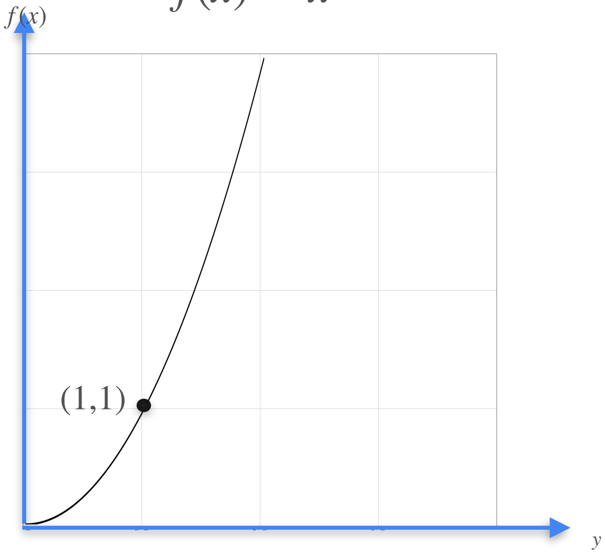
$$g'(y) = \frac{1}{f'(x)}$$

at the point $(1,1)$

$f(1) = 1$ $\qquad$ $g(1) = 1$

Derivative of the Inverse

$$f(x) = x^2$$



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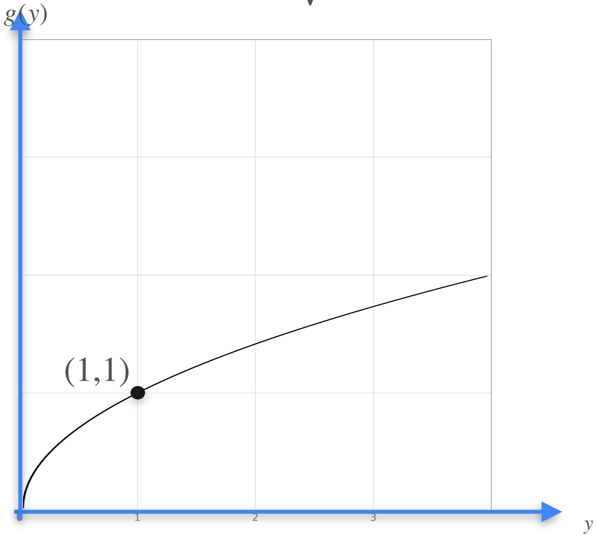

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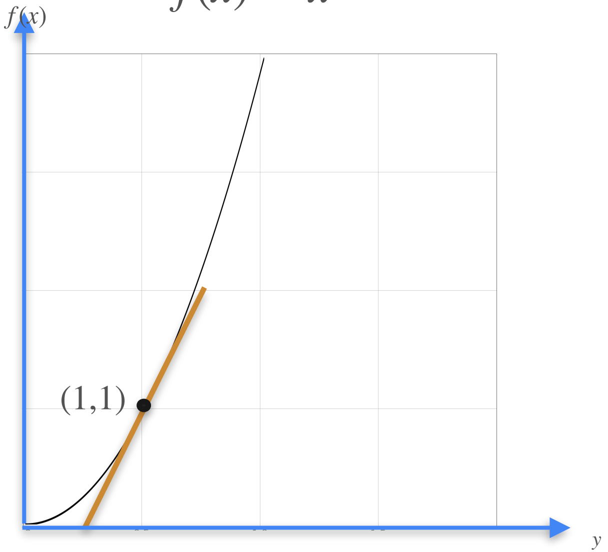

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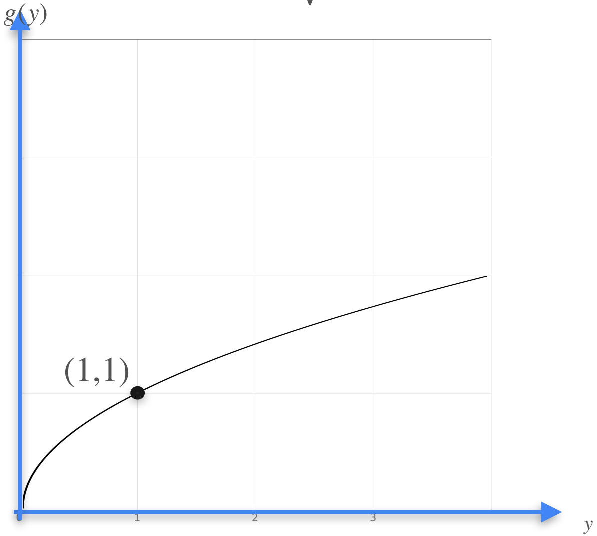

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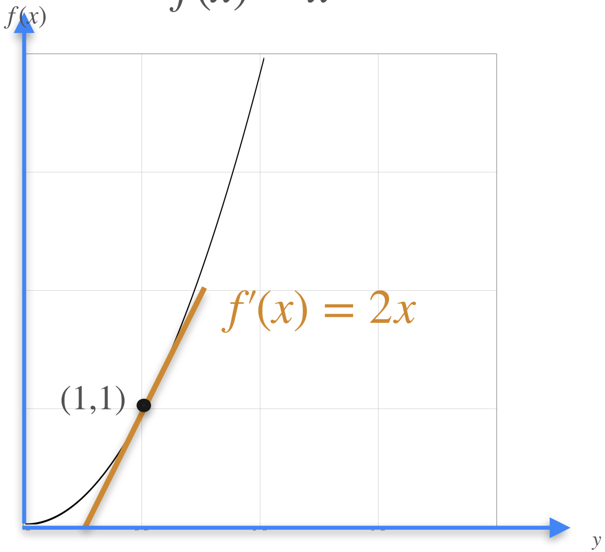

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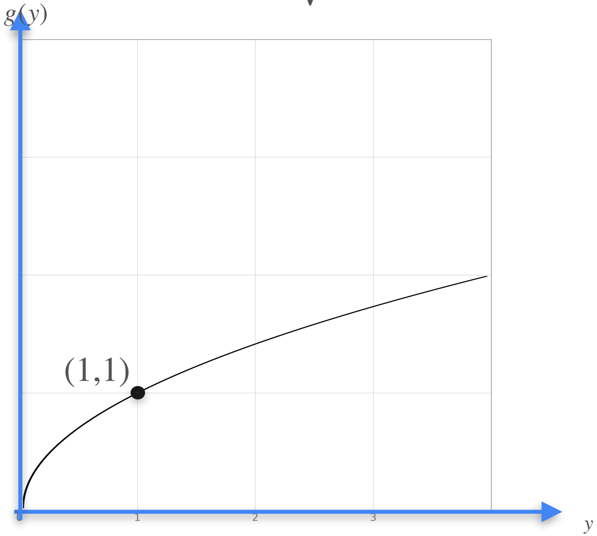

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Derivative of the Inverse

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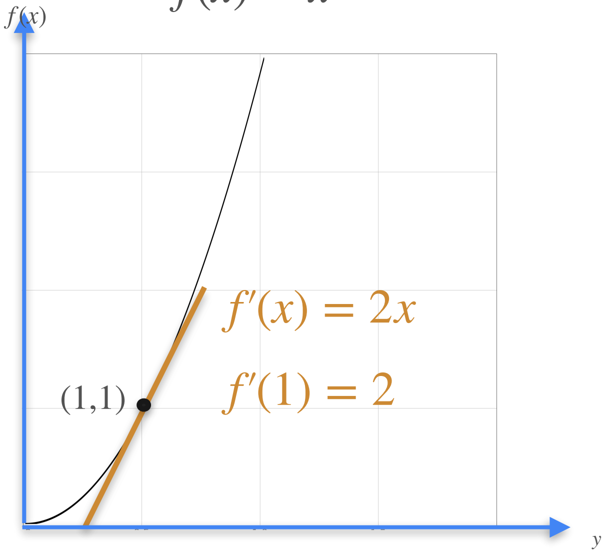
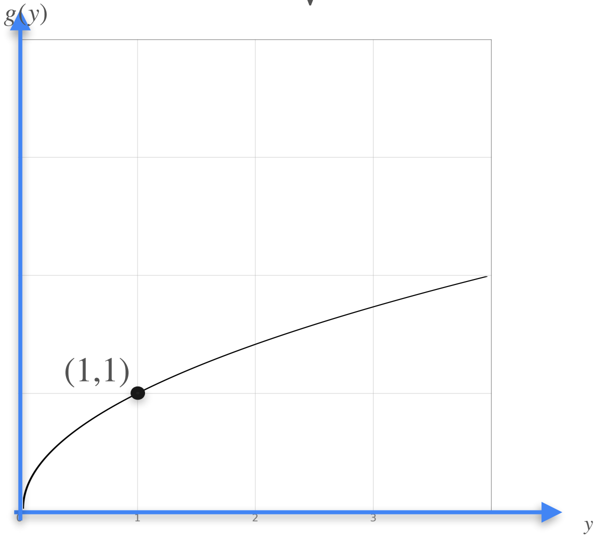


$g(y) = \sqrt{y}$



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Derivative of the Inverse

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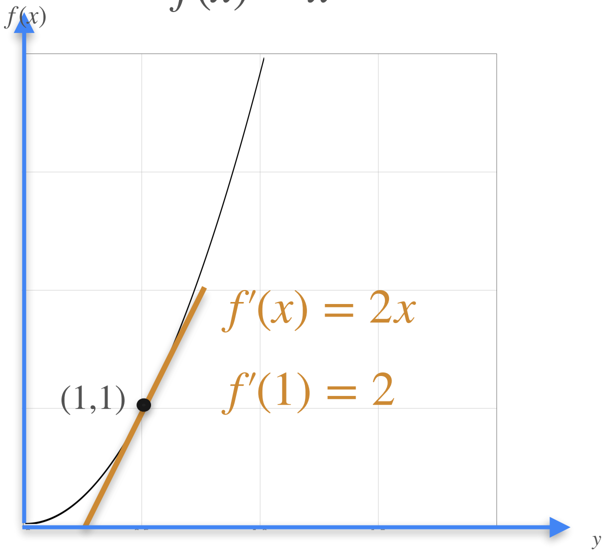

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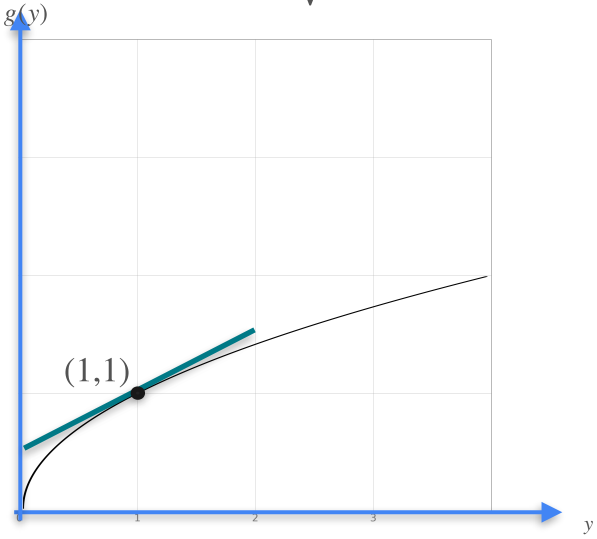

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Derivative of the Inverse

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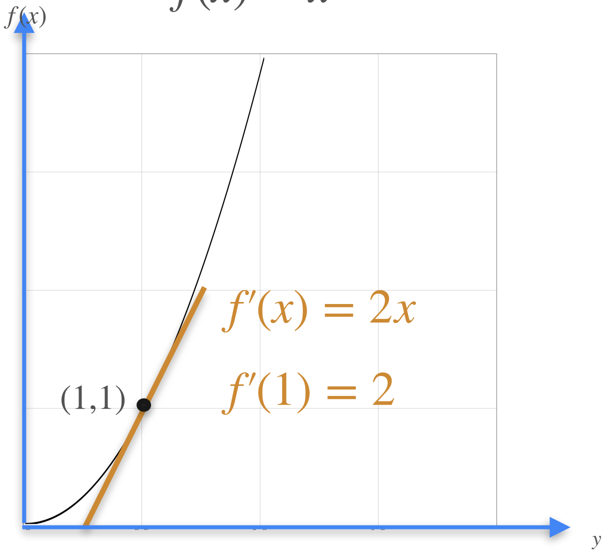

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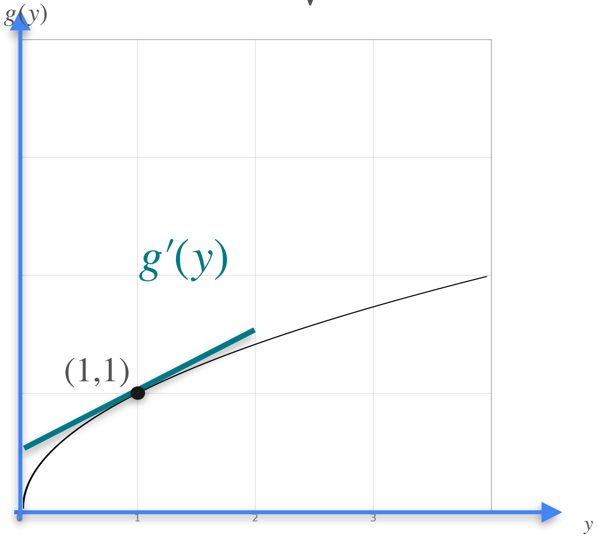

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Derivative of the Inverse

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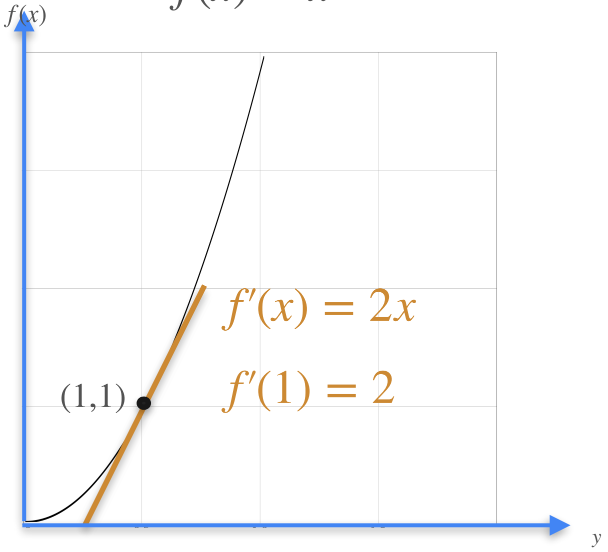

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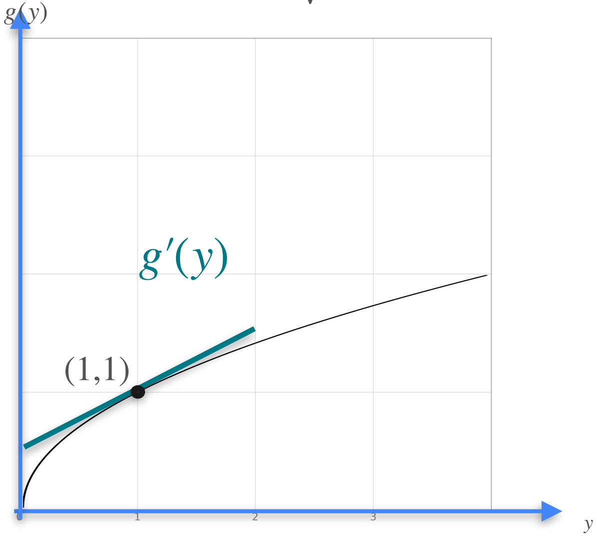

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Derivative of the Inverse

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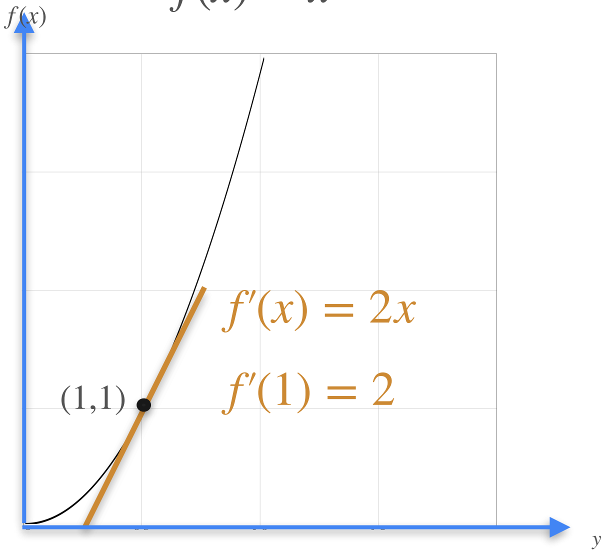
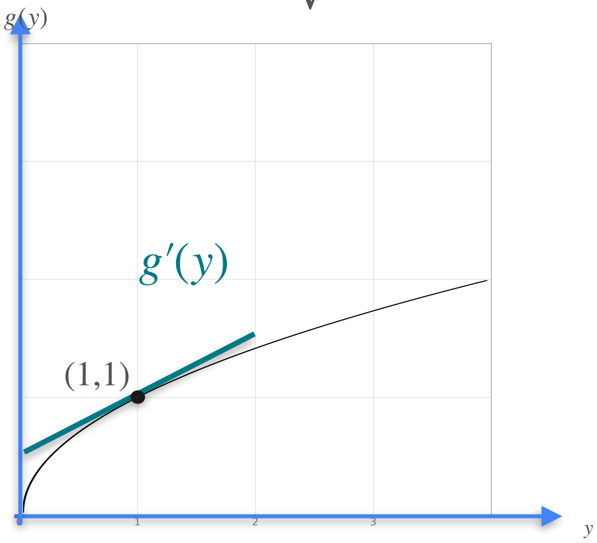


$$g(y) = \sqrt{y}$$



$$g'(y) = \frac{1}{f'(x)}$$

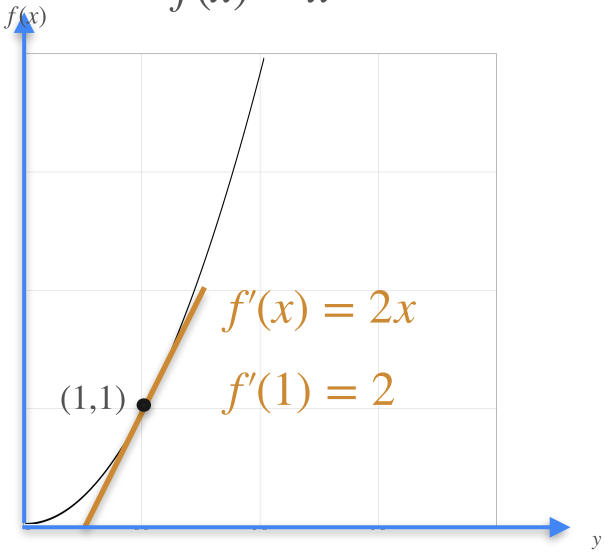
at the point $(1,1)$

$f(1) = 1$ $\qquad$ $g(1) = 1$

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

Derivative of the Inverse

$$f(x) = x^2$$



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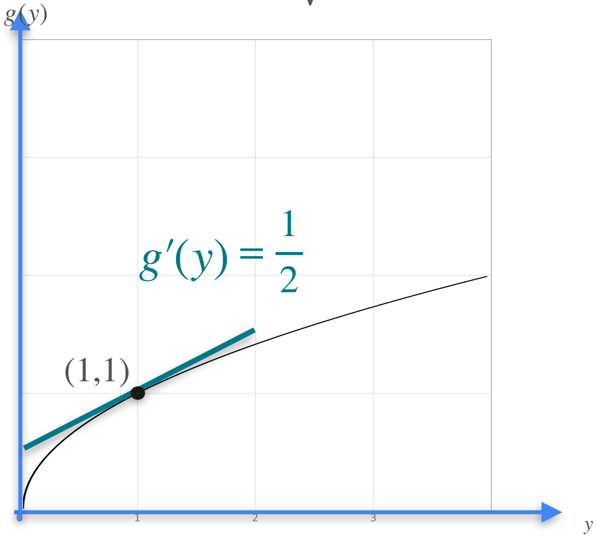

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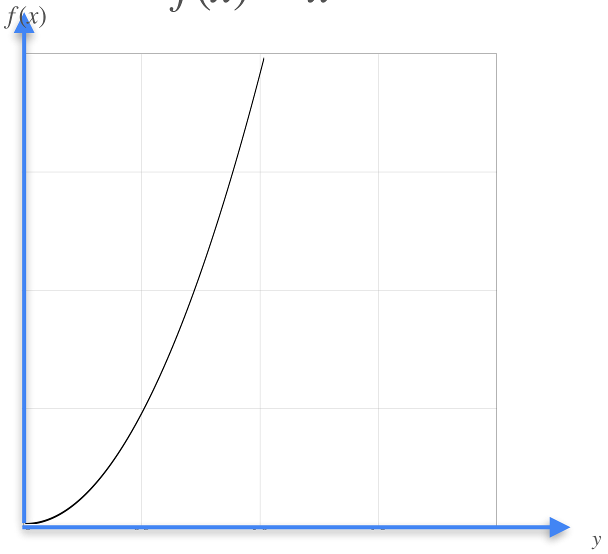

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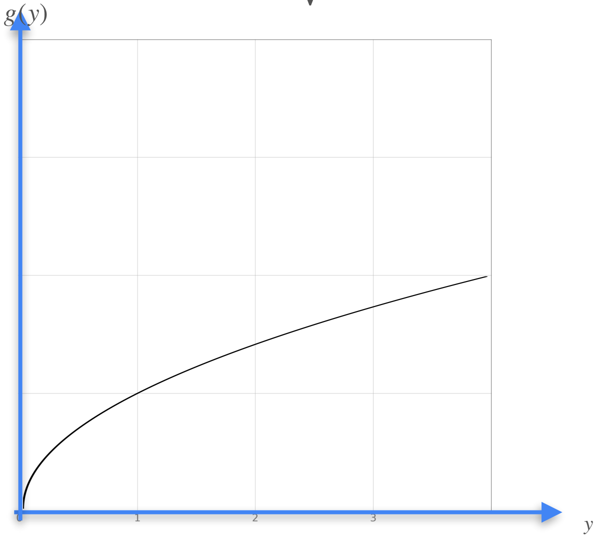

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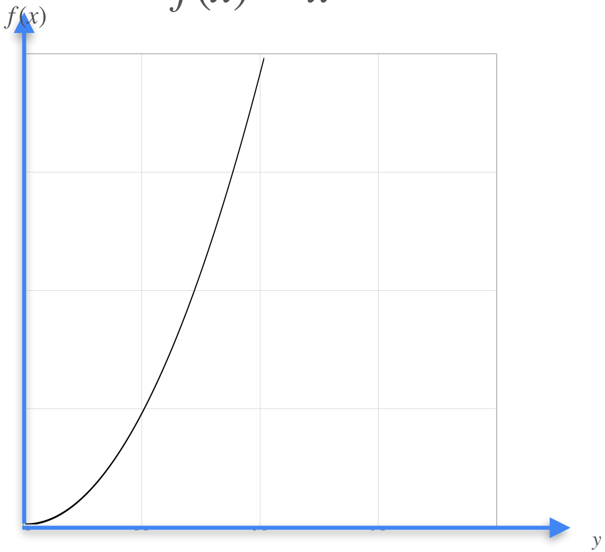

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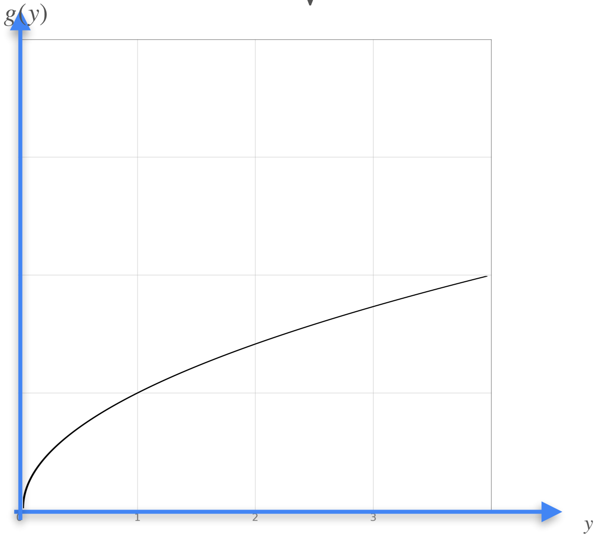


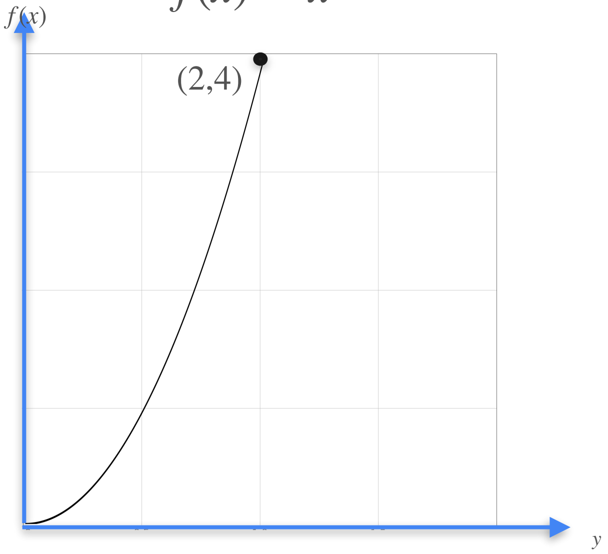
$$g'(y) = \frac{1}{f'(x)}$$

at the point $(2,4)$

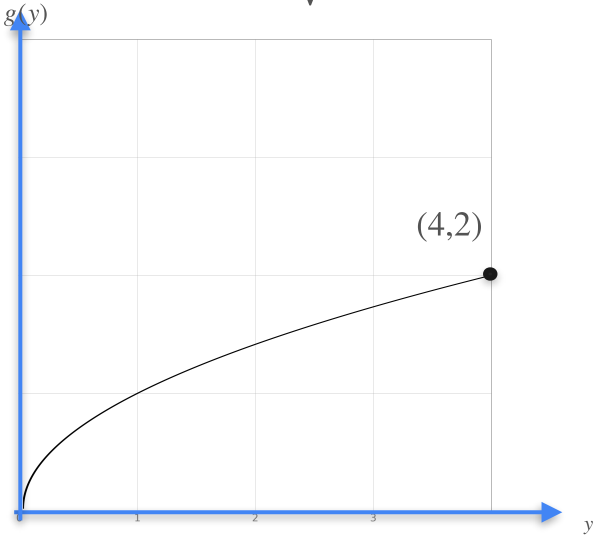
$f(2) = 4$ $\qquad$ $g(4) = 2$

Derivative of the Inverse

$$f(x) = x^2$$



$$g(y) = \sqrt{y}$$



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at the point $(2,4)$

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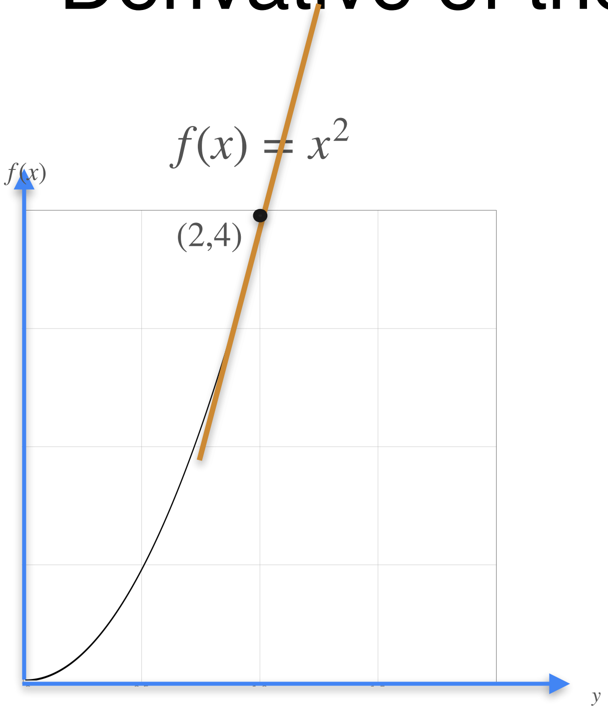
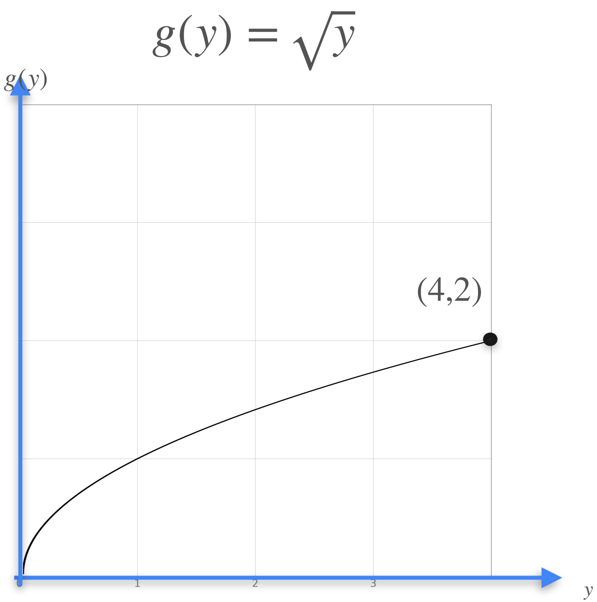
Derivative of the Inverse





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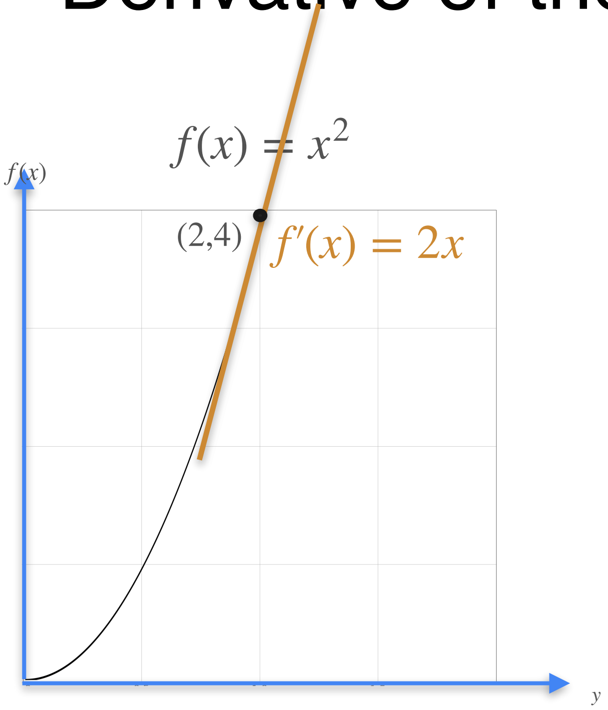

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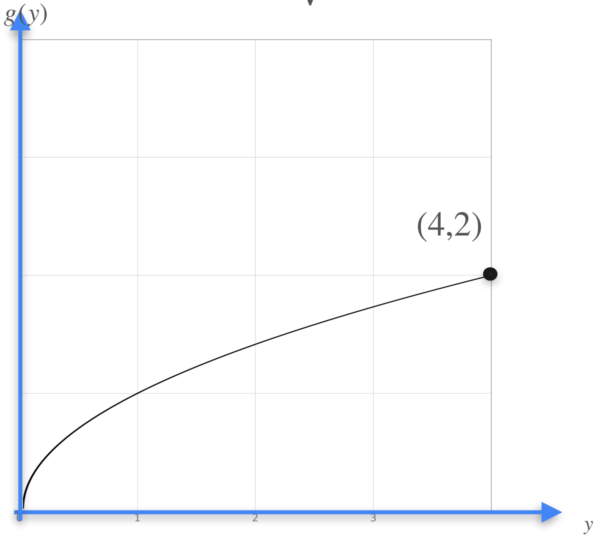

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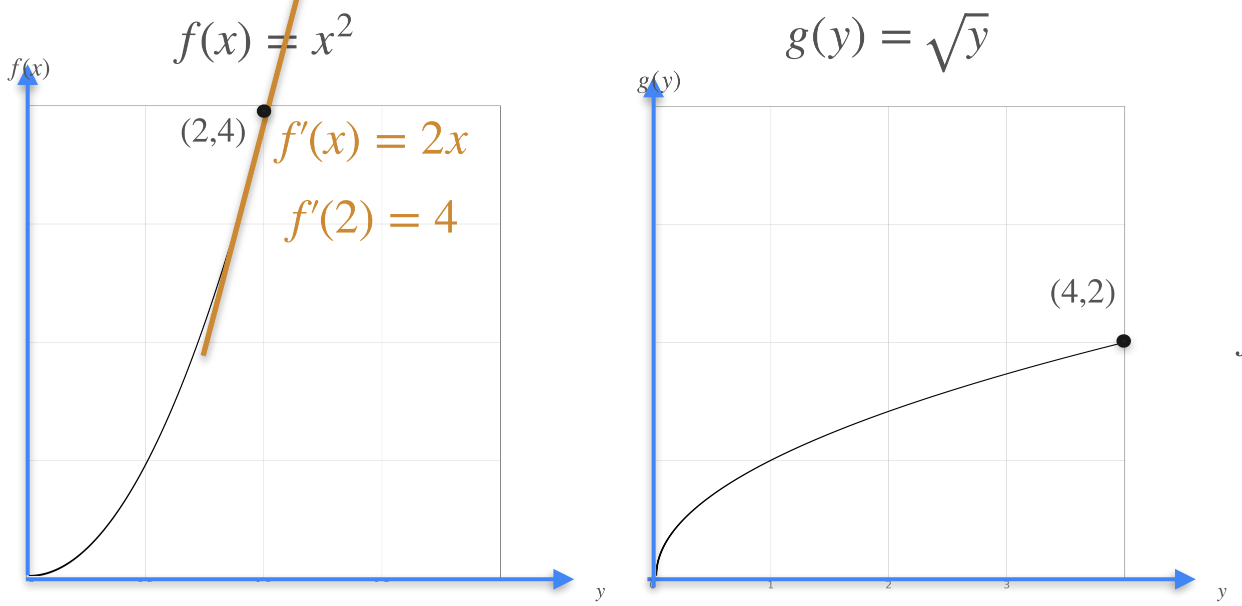

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at the point (2,4)

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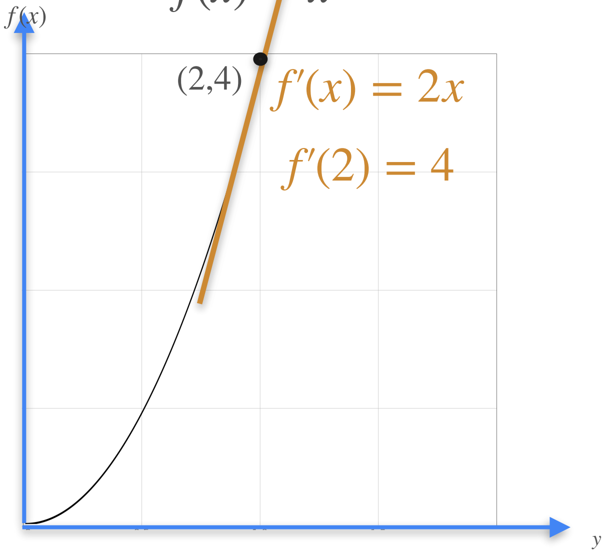
Derivative of the Inverse

$f(x) = x^2$



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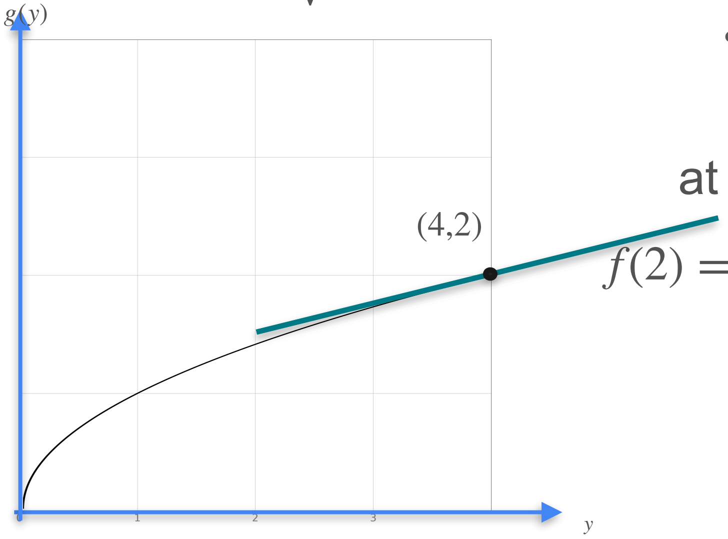

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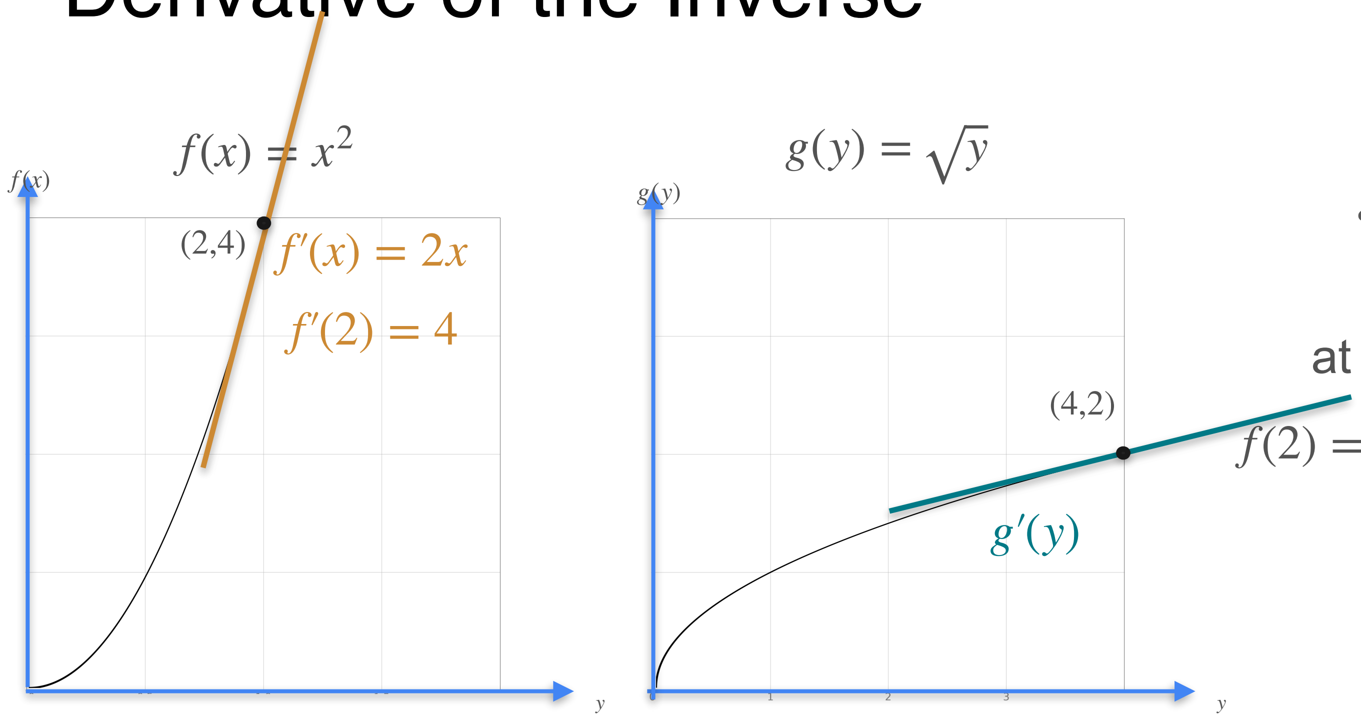

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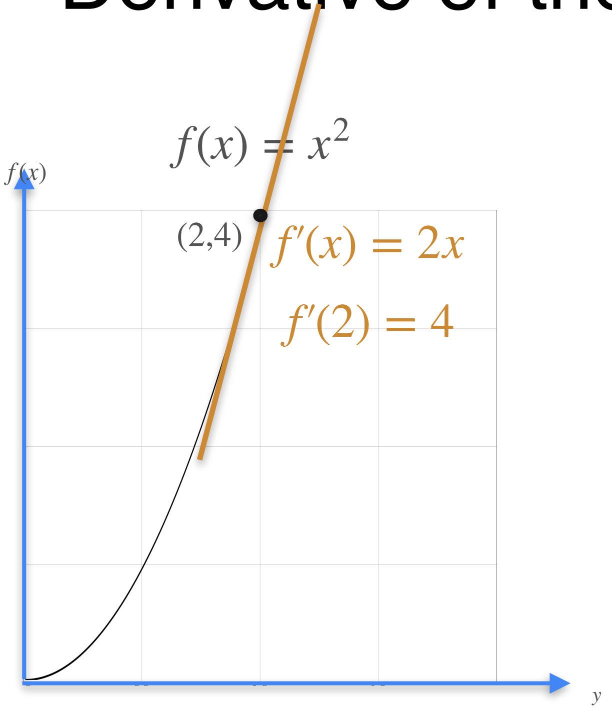
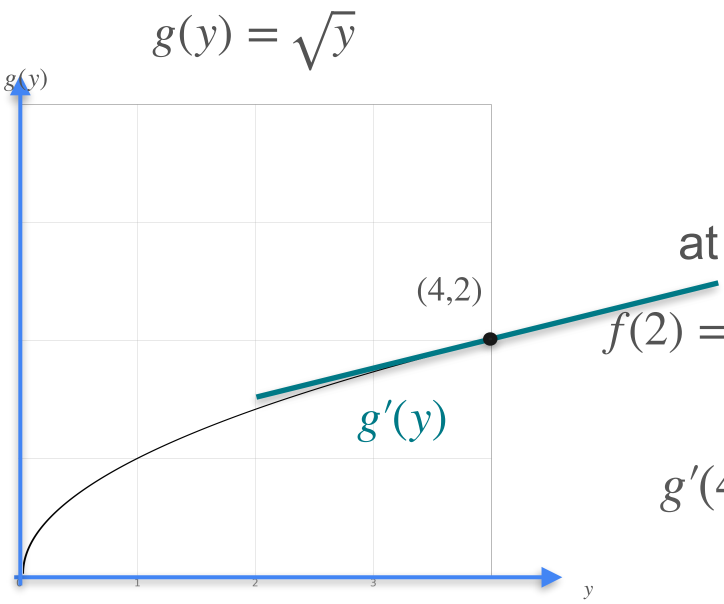
Derivative of the Inverse





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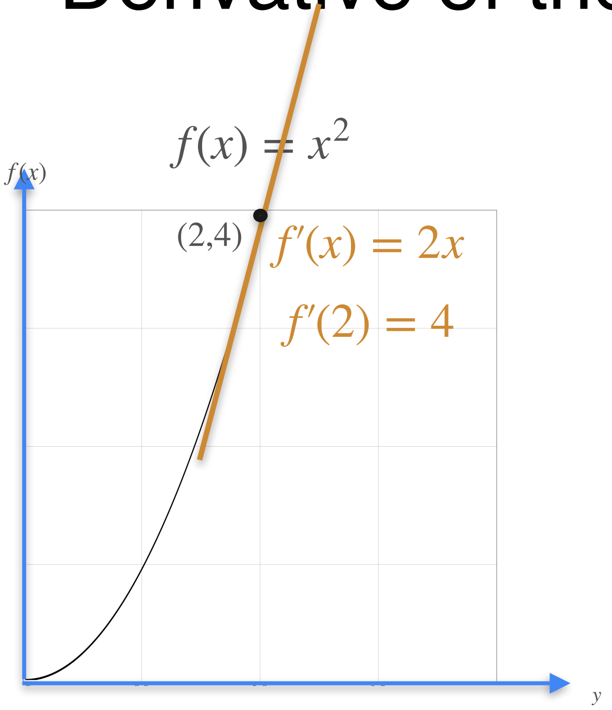
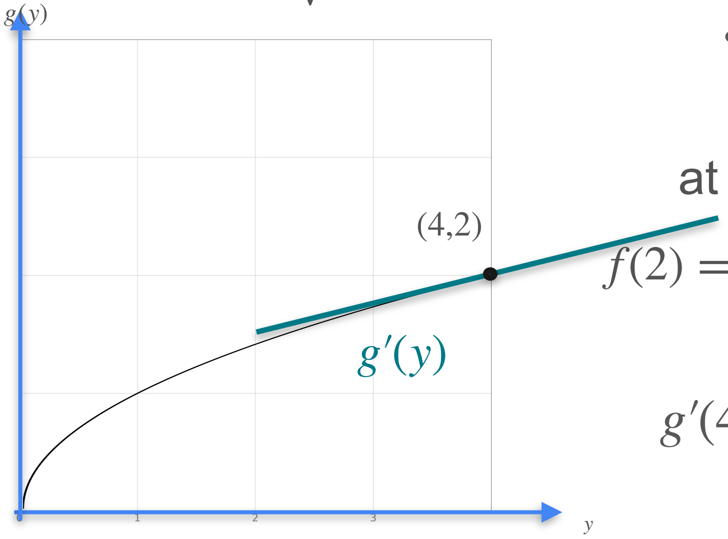


$$g(y) = \sqrt{y}$$



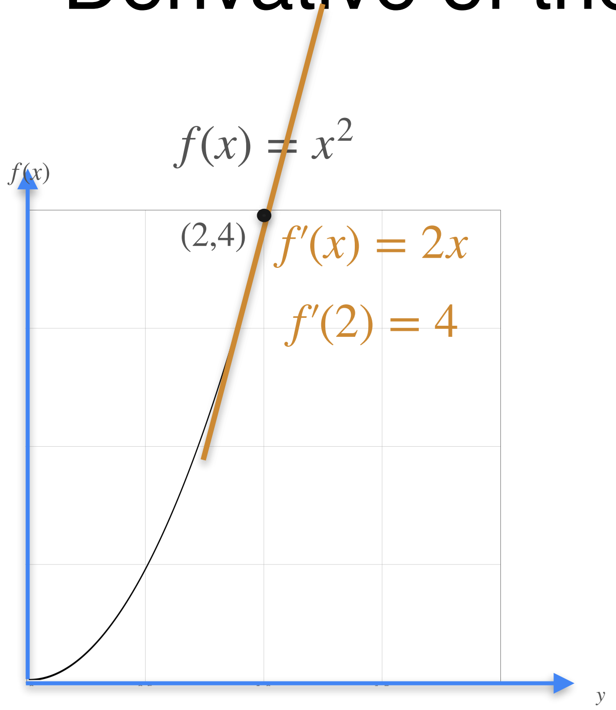
$$g'(y) = \frac{1}{f'(x)}$$

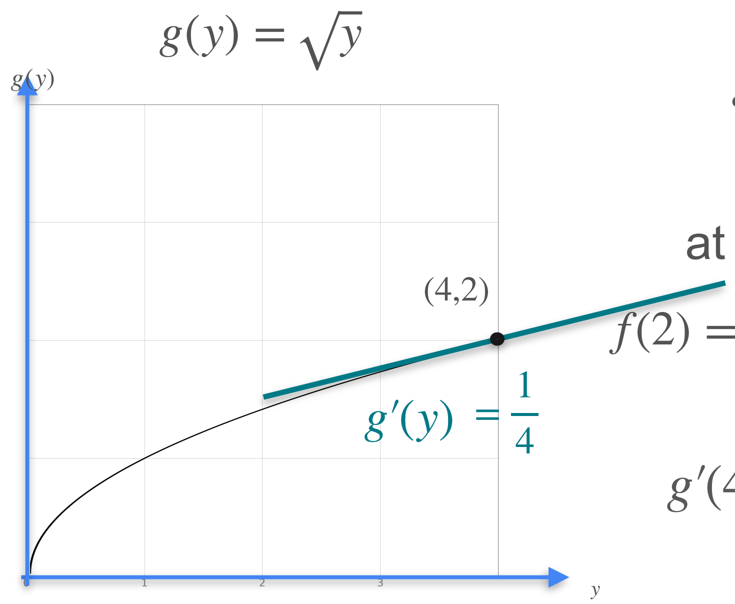
at the point $(2,4)$

$f(2) = 4$ $\qquad$ $g(4) = 2$

$$g'(4) = \frac{1}{f'(2)} = \frac{1}{4}$$

Derivative of the Inverse





$$g'(y) = \frac{1}{f'(x)}$$

at the point (2,4)

$f(2) = 4$ $\quad$ $g(4) = 2$

$$g'(4) = \frac{1}{f'(2)}$$

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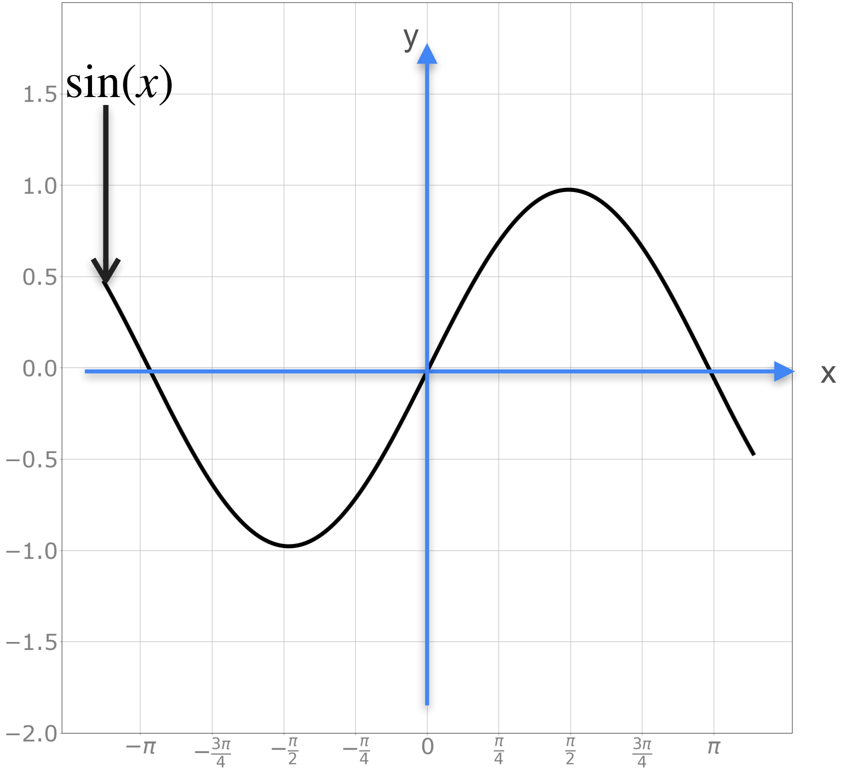
Derivatives and Optimization

Derivative of trigonometric functions

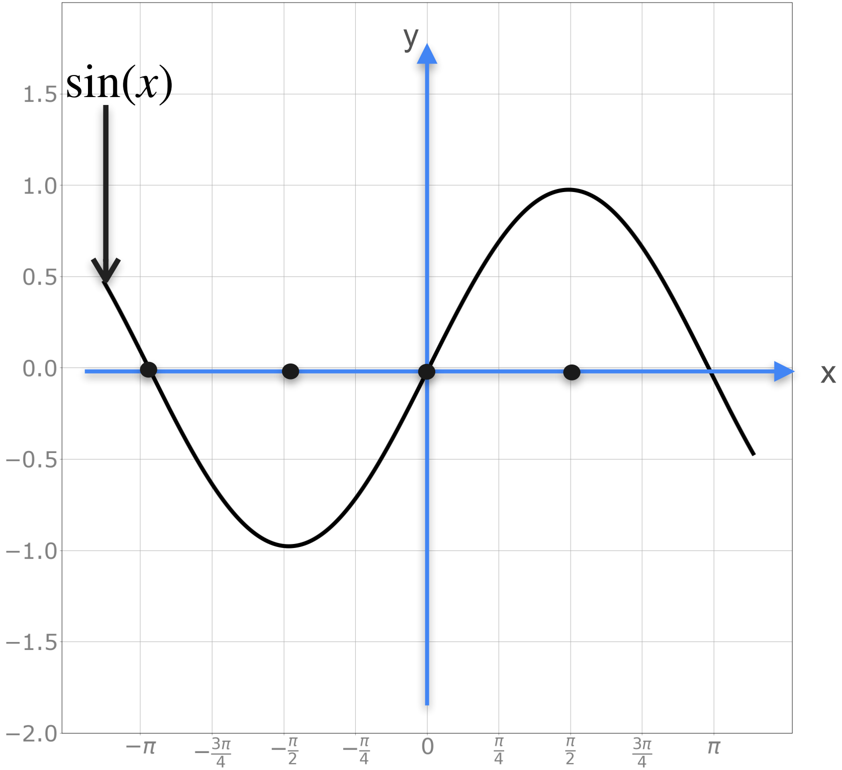
Derivative of Trigonometric Functions

Derivative of Trigonometric Functions



Sine $y = f(x) = \sin(x)$

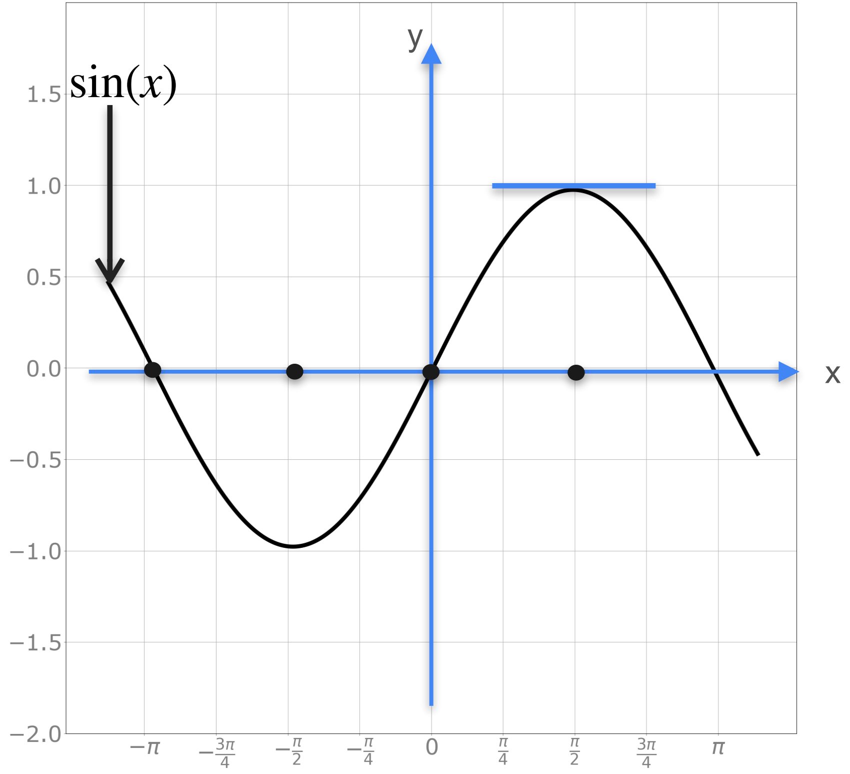
Derivative of Trigonometric Functions



Sine $y = f(x) = \sin(x)$

x	$\pi/2$	$-\pi/2$	0	$-\pi$

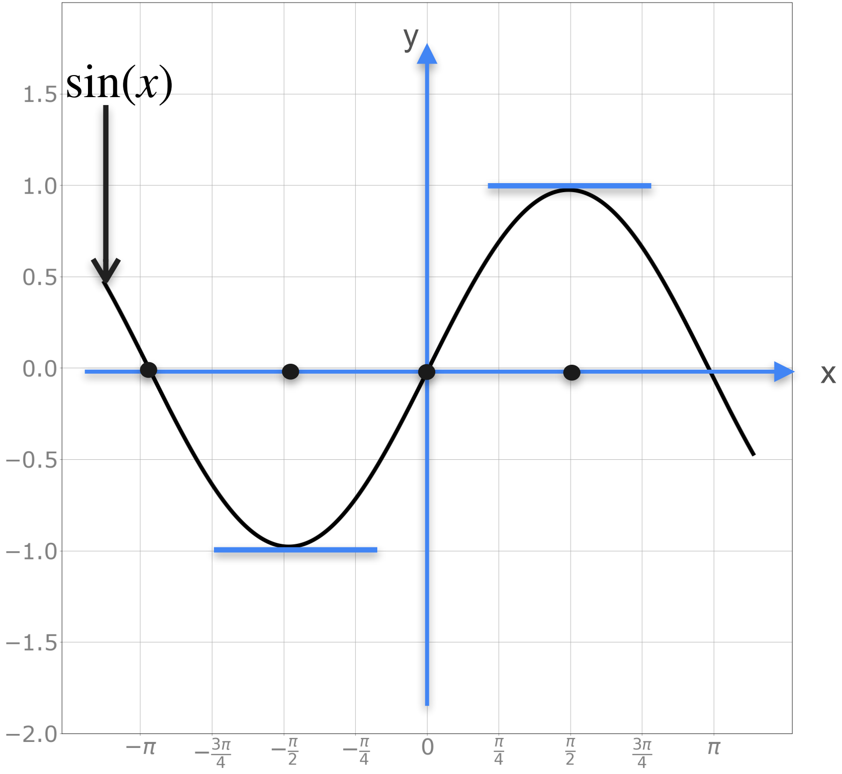
Derivative of Trigonometric Functions



Sine $y = f(x) = \sin(x)$

x	$\pi/2$	$-\pi/2$	0	$-\pi$
Slope	0			

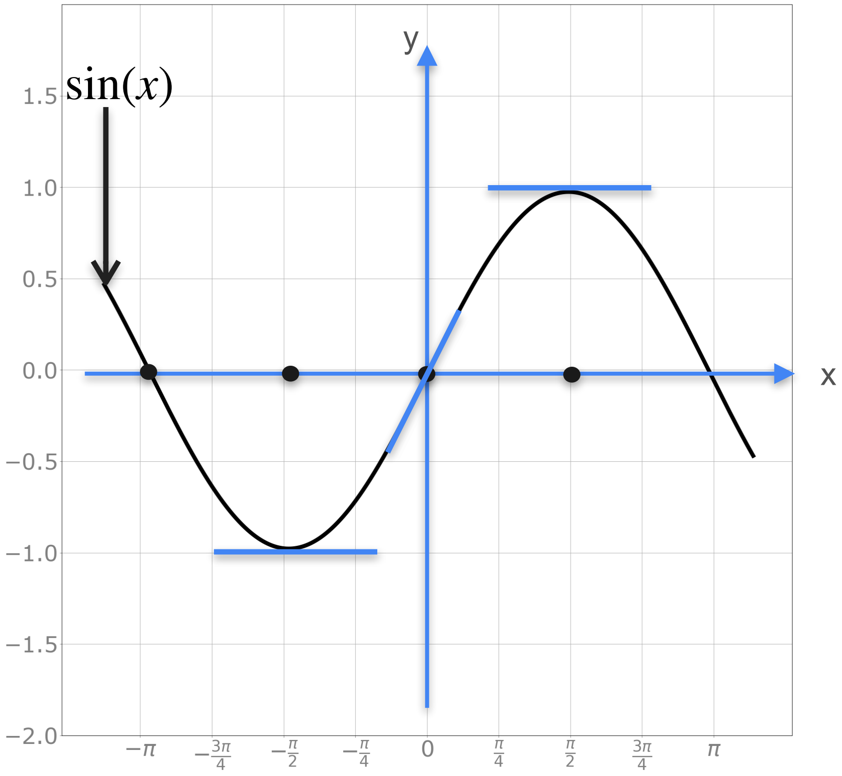
Derivative of Trigonometric Functions



Sine $y = f(x) = \sin(x)$

x	$\pi/2$	$-\pi/2$	0	$-\pi$
Slope	0	0		

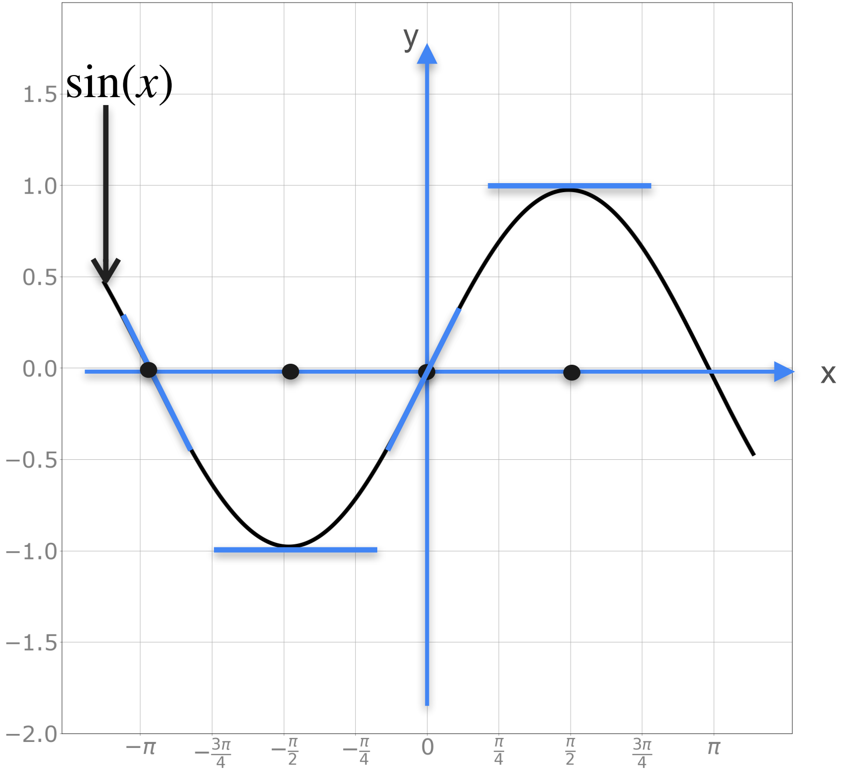
Derivative of Trigonometric Functions



Sine $y = f(x) = \sin(x)$

x	$\pi/2$	$-\pi/2$	0	$-\pi$
Slope	0	0	1	

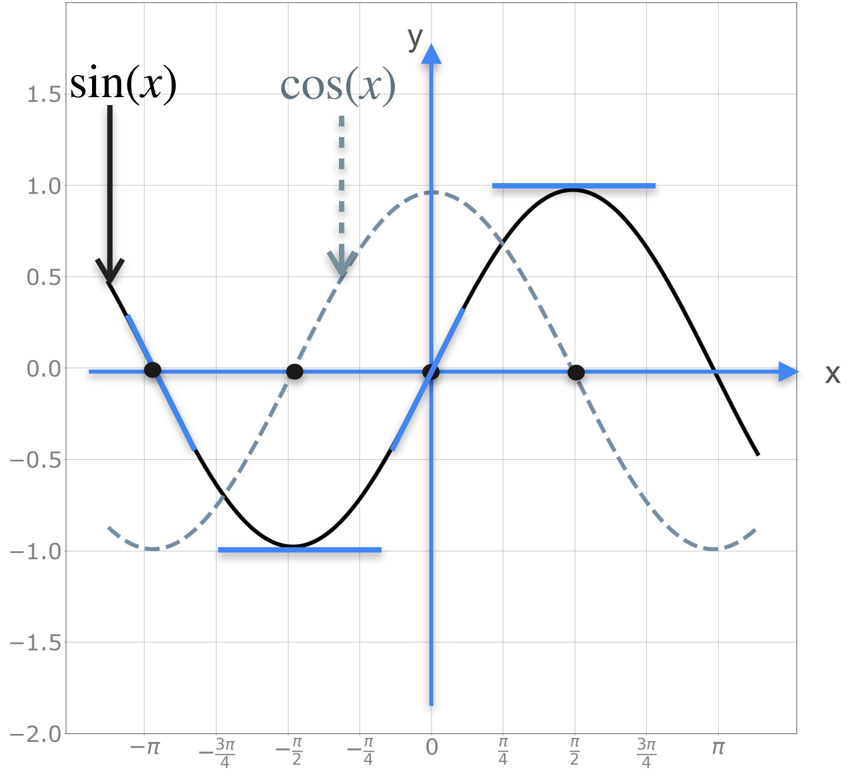
Derivative of Trigonometric Functions



Sine $y = f(x) = \sin(x)$

x	$\pi/2$	$-\pi/2$	0	$-\pi$
Slope	0	0	1	-1

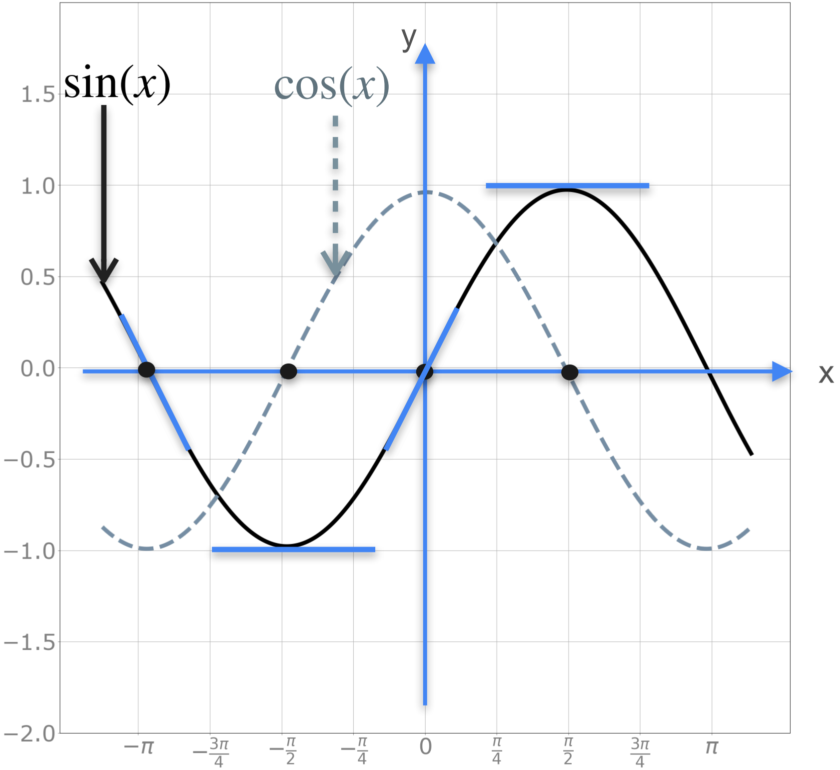
Derivative of Trigonometric Functions



Sine $y = f(x) = \sin(x)$

x	$\pi/2$	$-\pi/2$	0	$-\pi$
Slope	0	0	1	-1

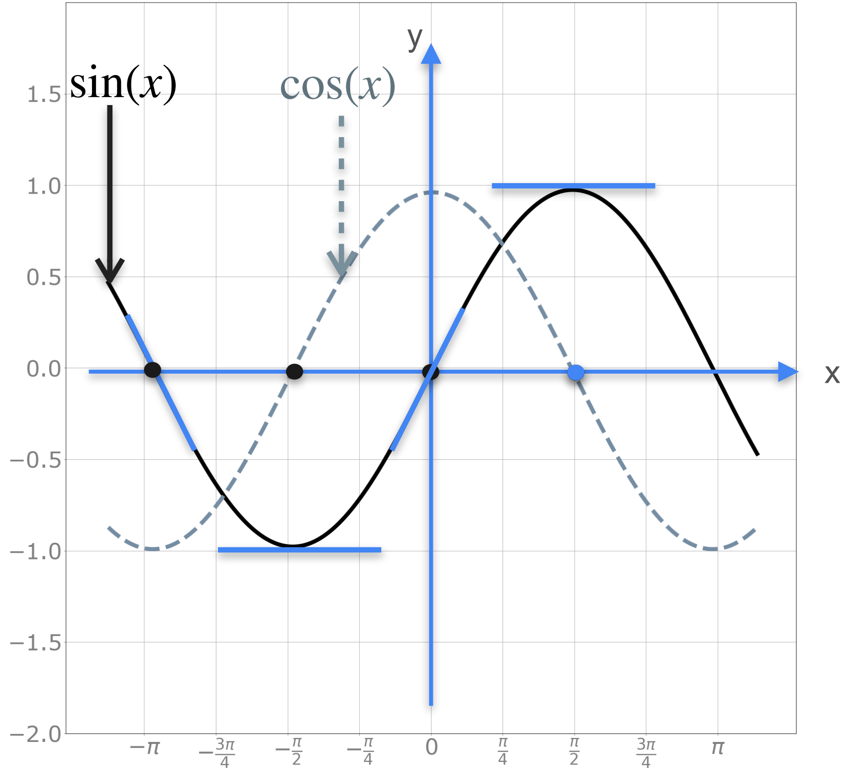
Derivative of Trigonometric Functions



Sine $y = f(x) = \sin(x)$

x	$\pi/2$	$-\pi/2$	0	$-\pi$
Slope	0	0	1	-1
$\cos(x)$				

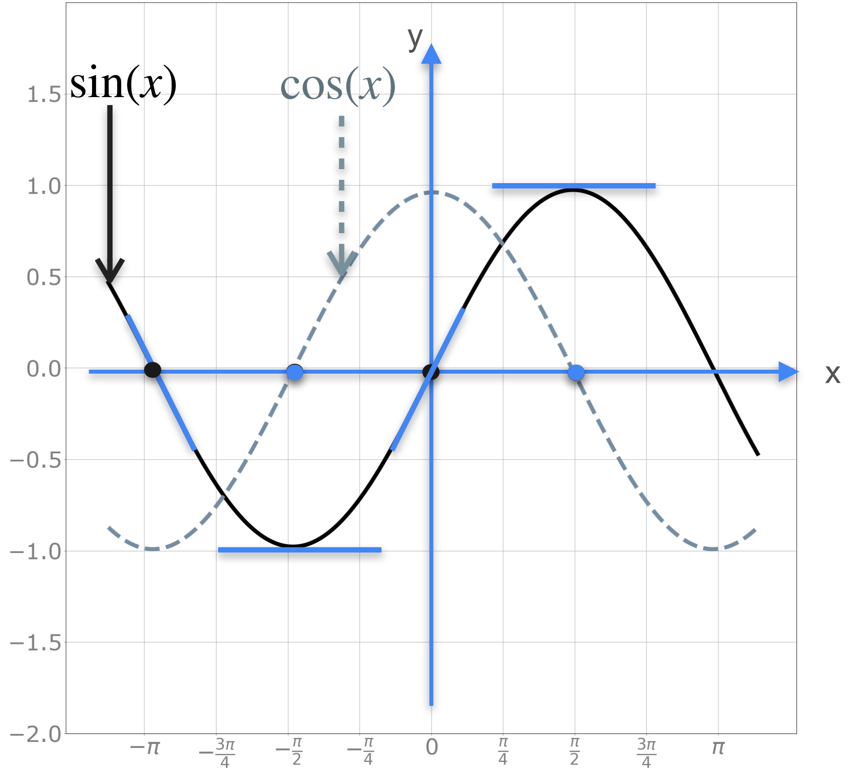
Derivative of Trigonometric Functions



Sine $y = f(x) = \sin(x)$

x	$\pi/2$	$-\pi/2$	0	$-\pi$
Slope	0	0	1	-1
$\cos(x)$	0			

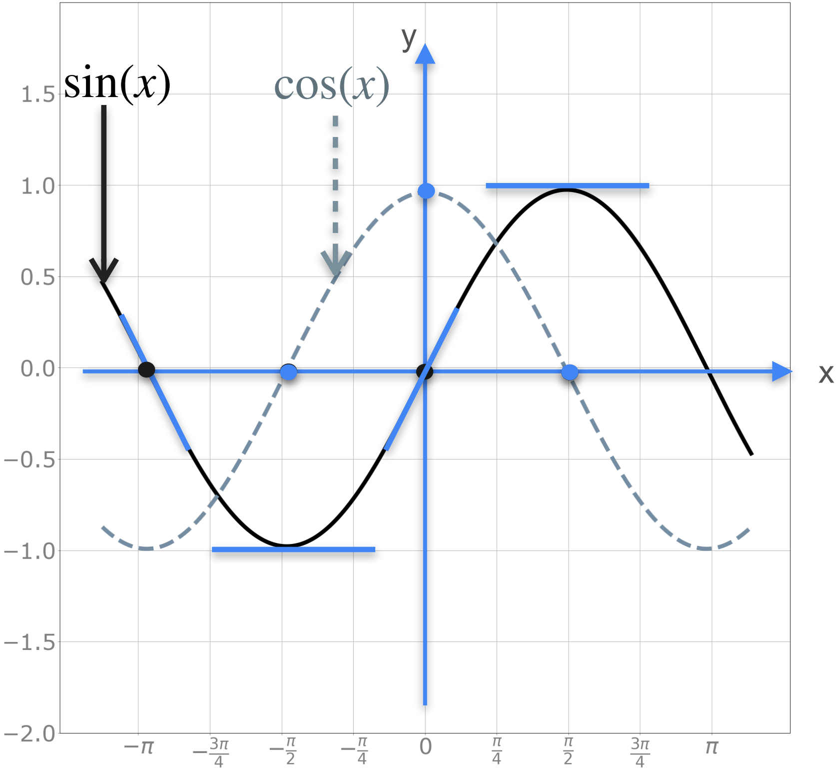
Derivative of Trigonometric Functions



Sine $y = f(x) = \sin(x)$

x	$\pi/2$	$-\pi/2$	0	$-\pi$
Slope	0	0	1	-1
$\cos(x)$	0	0		

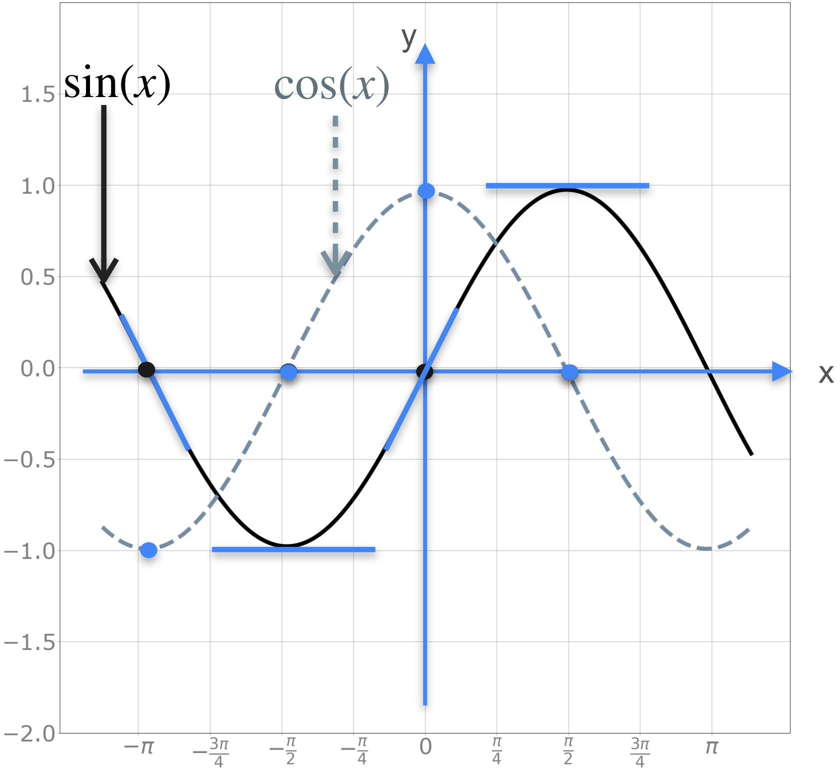
Derivative of Trigonometric Functions



Sine $y = f(x) = \sin(x)$

x	$\pi/2$	$-\pi/2$	0	$-\pi$
Slope	0	0	1	-1
$\cos(x)$	0	0	1	

Derivative of Trigonometric Functions



Sine $y = f(x) = \sin(x)$

x	$\pi/2$	$-\pi/2$	0	$-\pi$
Slope	0	0	1	-1
$\cos(x)$	0	0	1	-1

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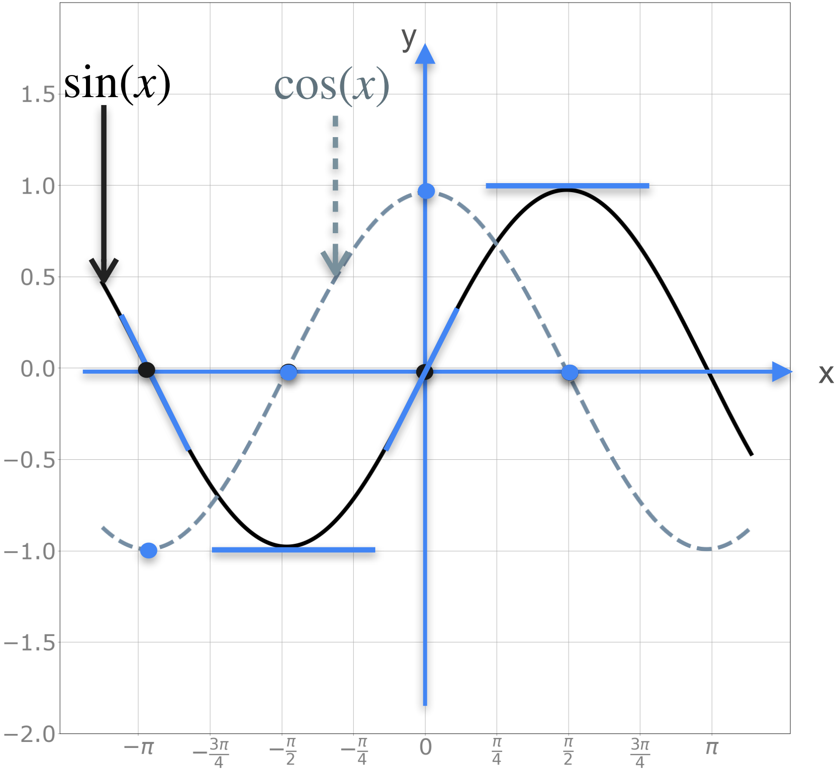
Derivative of Trigonometric Functions

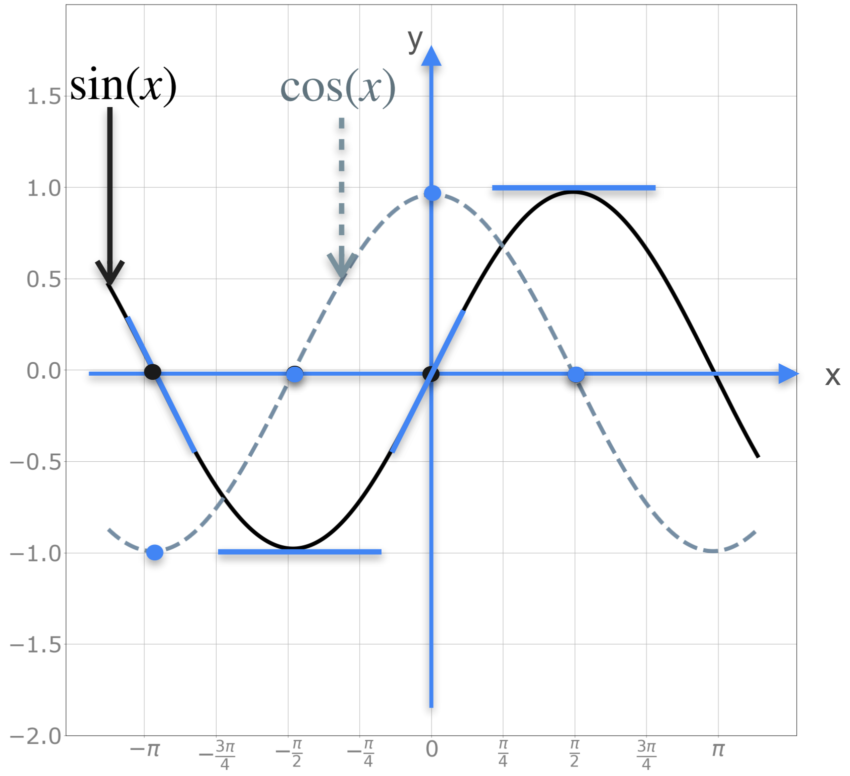


Sine $y = f(x) = \sin(x)$

x	$\pi/2$	$-\pi/2$	0	$-\pi$
Slope	0	0	1	-1
$\cos(x)$	0	0	1	-1

$f(x) = \sin(x) \Rightarrow f'(x) = \cos(x)$

Derivative of Trigonometric Functions



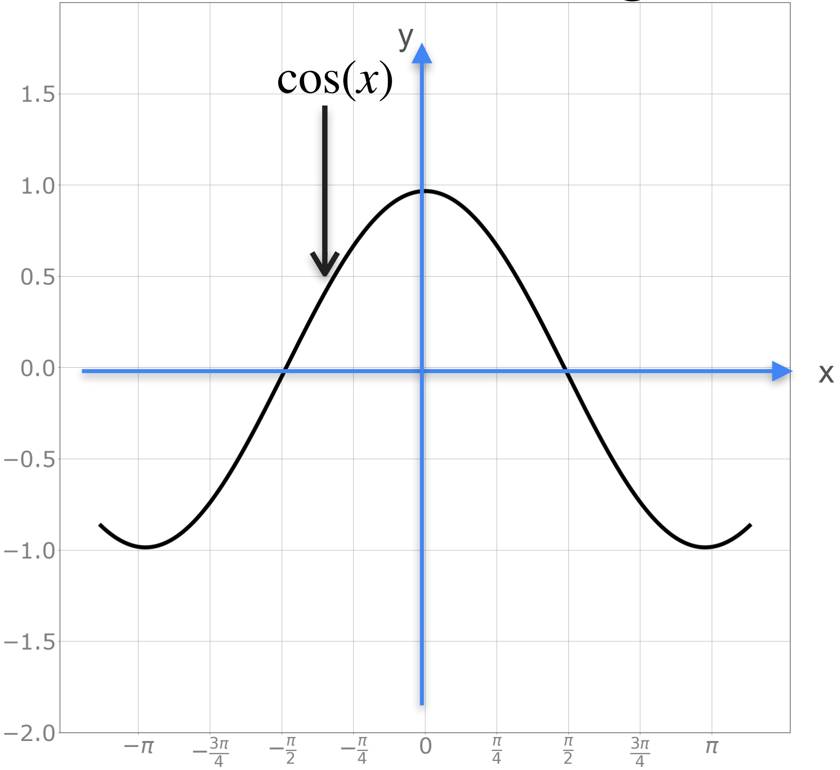
Sine $y = f(x) = \sin(x)$

x	$\pi/2$	$-\pi/2$	0	$-\pi$
Slope	0	0	1	-1
$\cos(x)$	0	0	1	-1

$$f(x) = \sin(x) \overset{??}{\Longrightarrow} f'(x) = \cos(x)$$

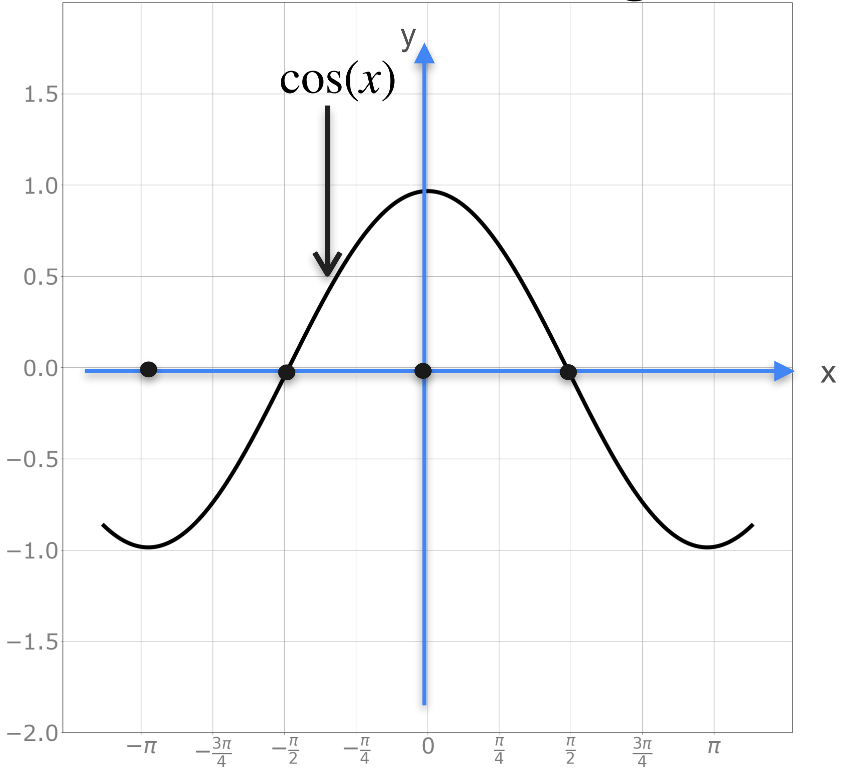
Derivative of Trigonometric Functions

Derivative of Trigonometric Functions



Cosine $y = f(x) = \cos(x)$

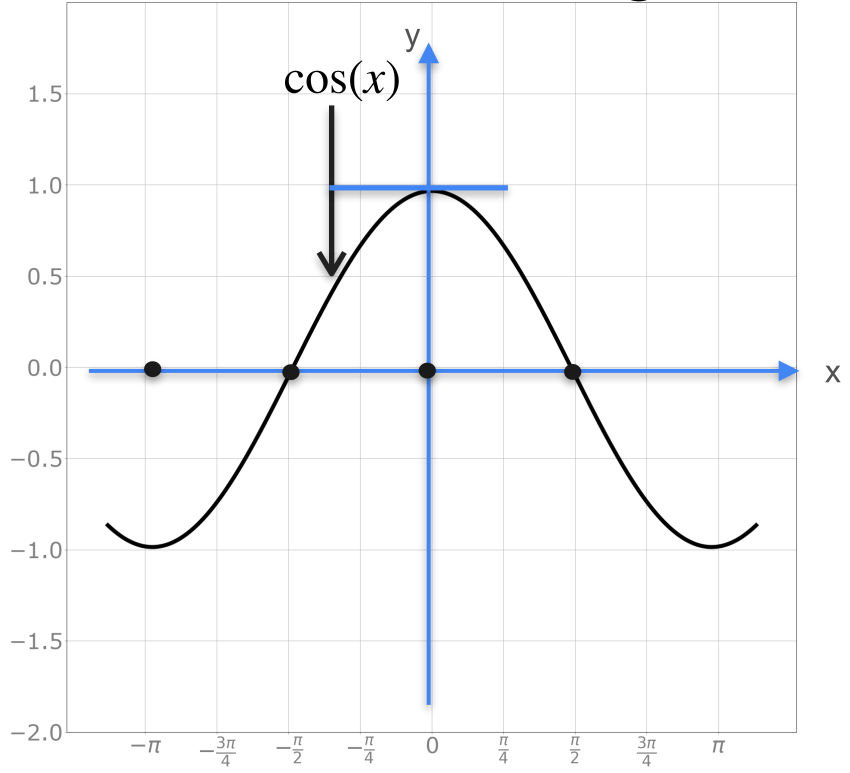
Derivative of Trigonometric Functions



Cosine $y = f(x) = \cos(x)$

x	0	$-\pi$	$\pi/2$	$-\pi/2$

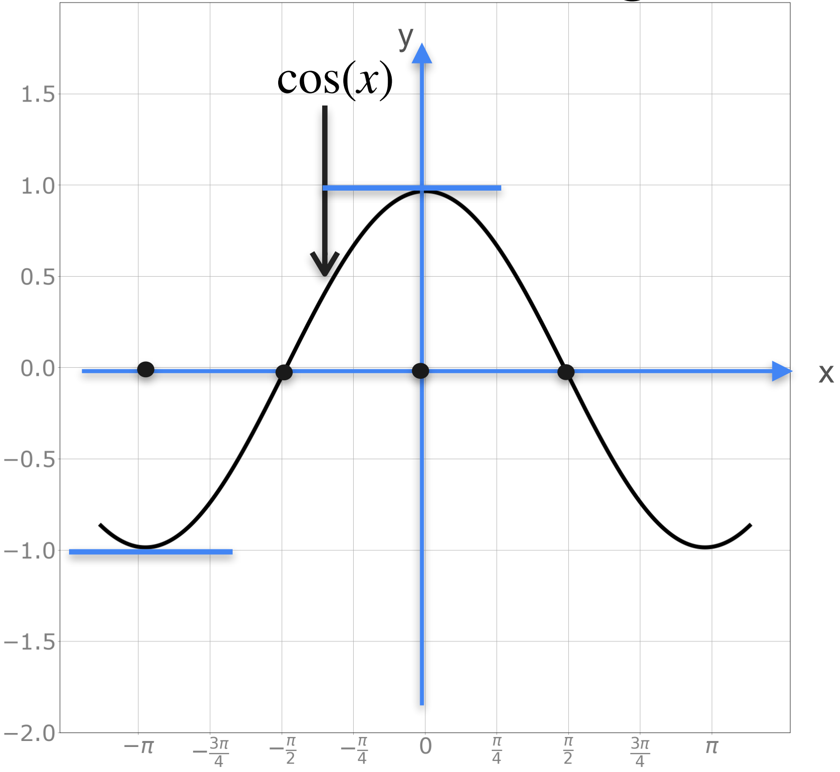
Derivative of Trigonometric Functions



Cosine $y = f(x) = \cos(x)$

x	0	$-\pi$	$\pi/2$	$-\pi/2$
Slope	0			

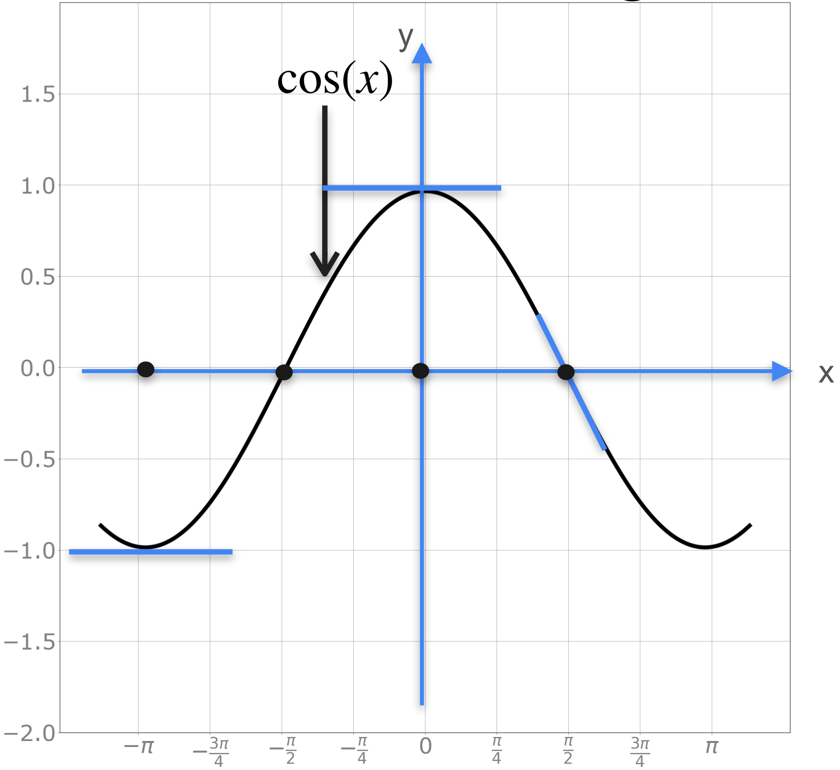
Derivative of Trigonometric Functions



Cosine $y = f(x) = \cos(x)$

x	0	$-\pi$	$\pi/2$	$-\pi/2$
Slope	0	0		

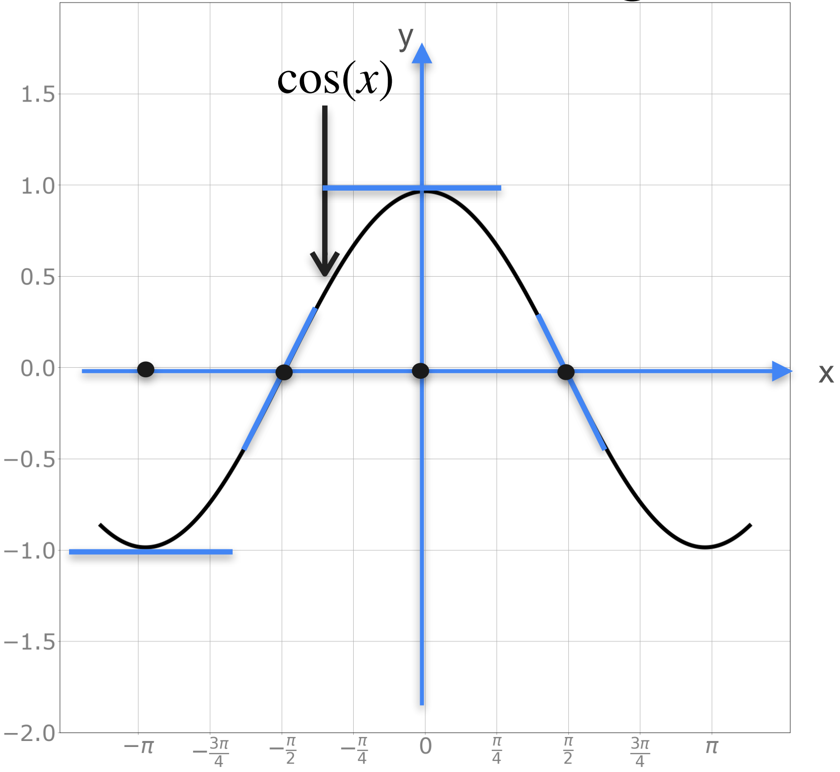
Derivative of Trigonometric Functions



Cosine $y = f(x) = \cos(x)$

x	0	$-\pi$	$\pi/2$	$-\pi/2$
Slope	0	0	-1	

Derivative of Trigonometric Functions



Cosine $y = f(x) = \cos(x)$

x	0	$-\pi$	$\pi/2$	$-\pi/2$
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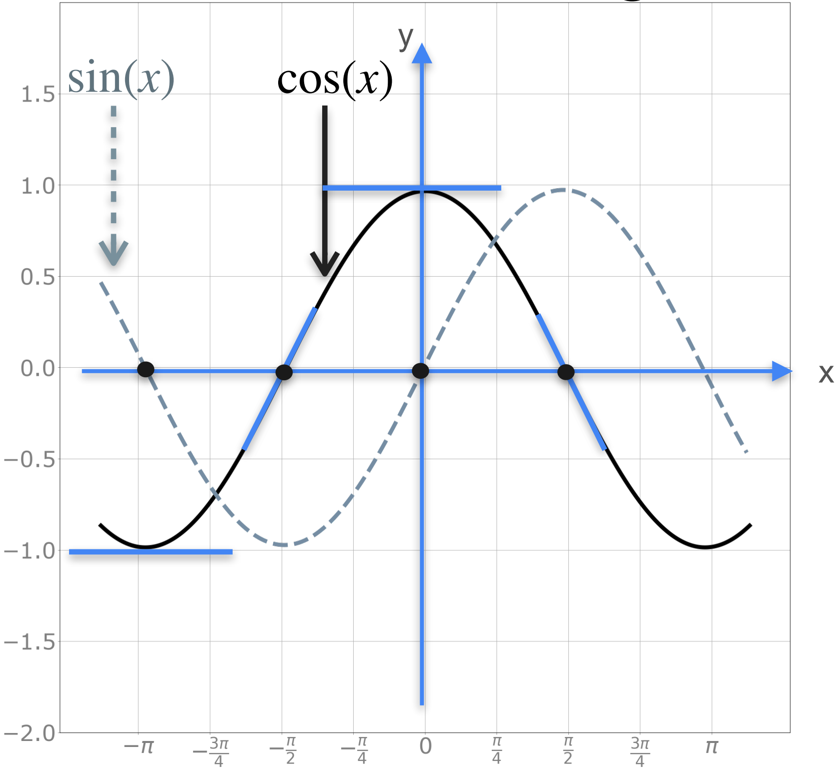
Derivative of Trigonometric Functions



Cosine $y = f(x) = \cos(x)$

x	0	$-\pi$	$\pi/2$	$-\pi/2$
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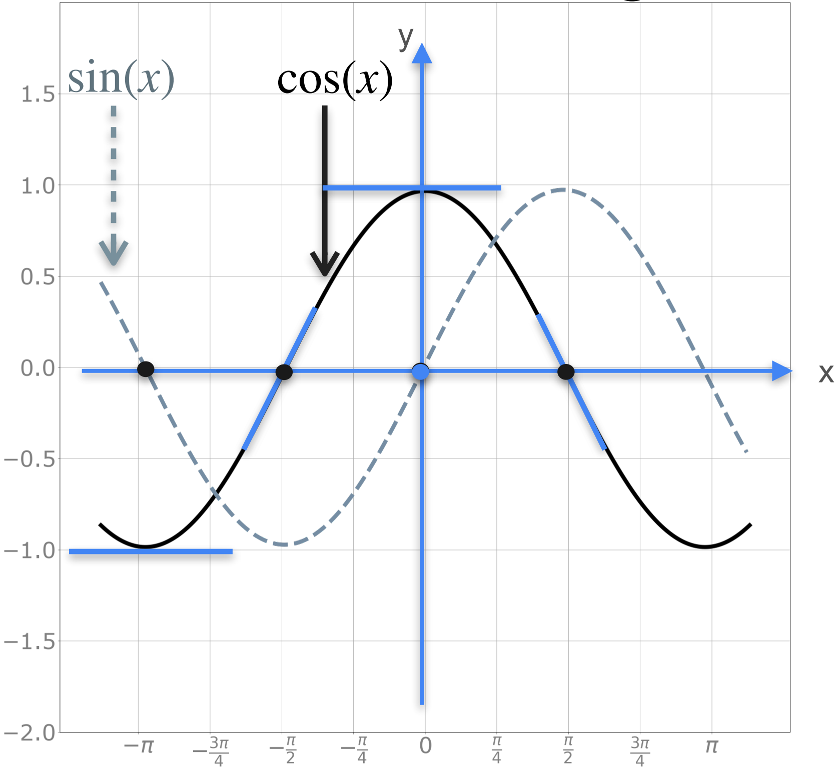
$\sin(x)$				

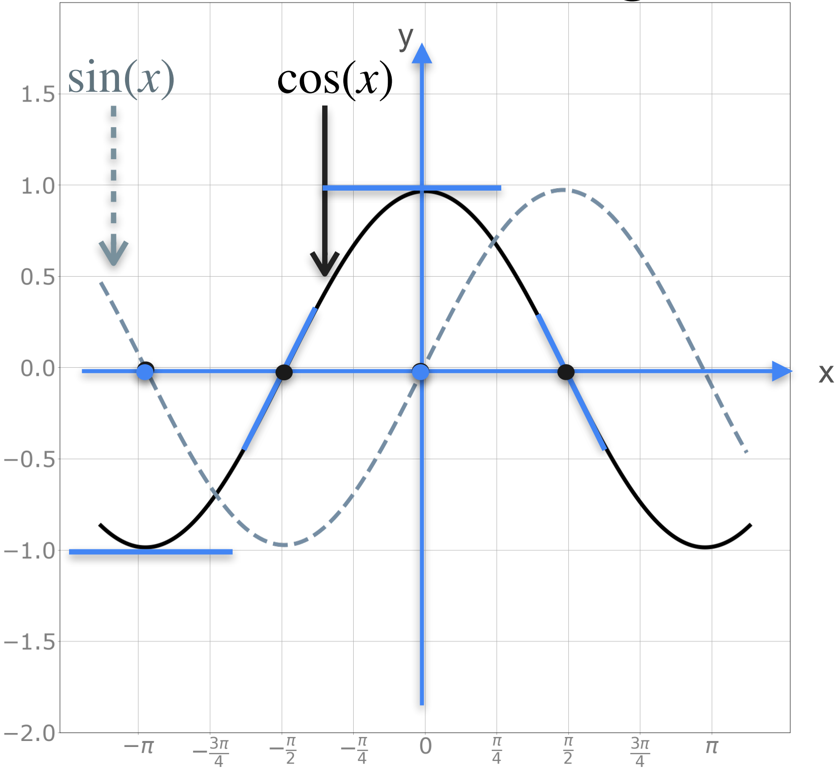
Derivative of Trigonometric Functions



Cosine $y = f(x) = \cos(x)$

x	0	$-\pi$	$\pi/2$	$-\pi/2$
Slope	0	0	-1	1
$\sin(x)$	0			

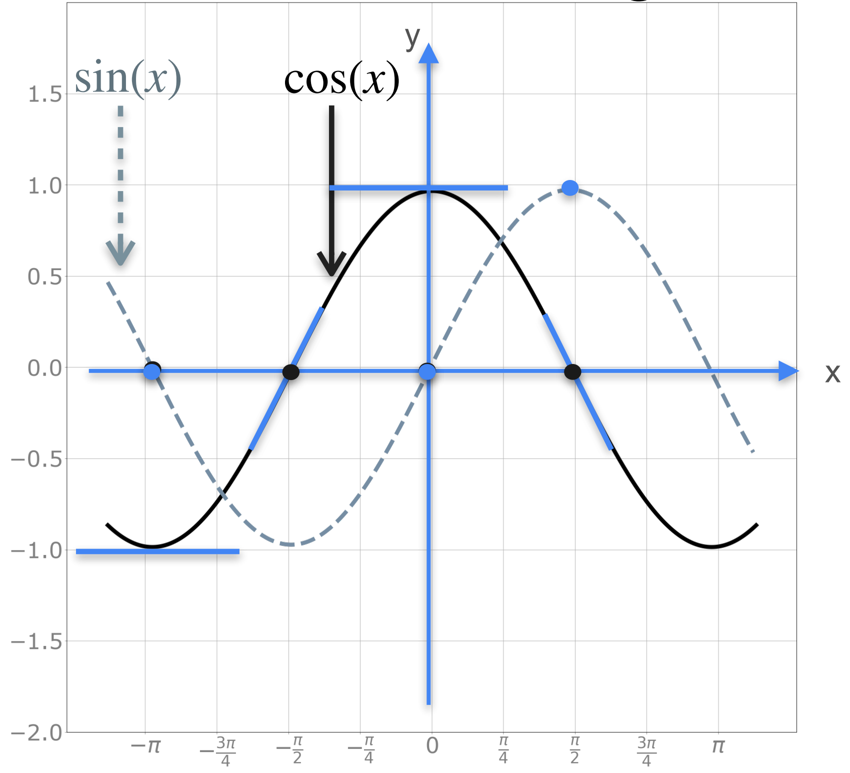
Derivative of Trigonometric Functions



Cosine $y = f(x) = \cos(x)$

x	0	$-\pi$	$\pi/2$	$-\pi/2$
Slope	0	0	-1	1
$\sin(x)$	0	0		

Derivative of Trigonometric Functions



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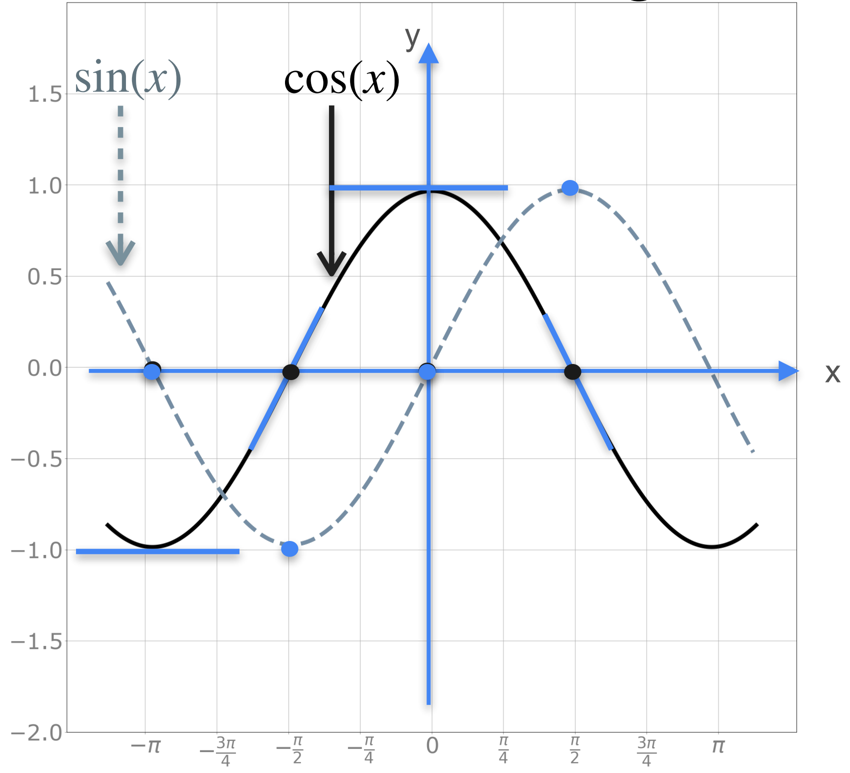
$\sin(x)$	0	0	1	

Derivative of Trigonometric Functions



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x	0	$-\pi$	$\pi/2$	$-\pi/2$
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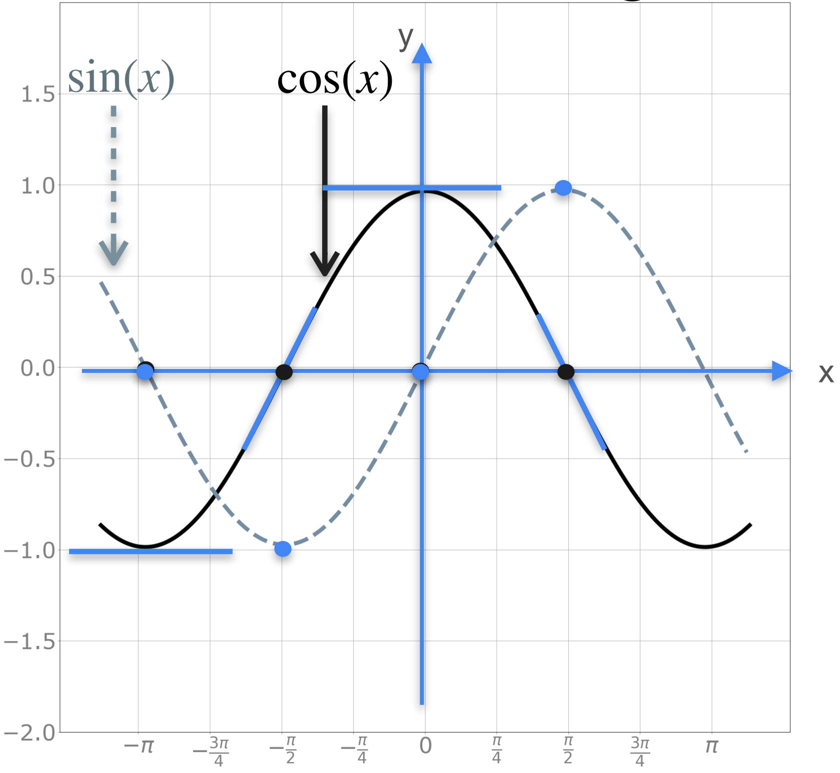
Derivative of Trigonometric Functions

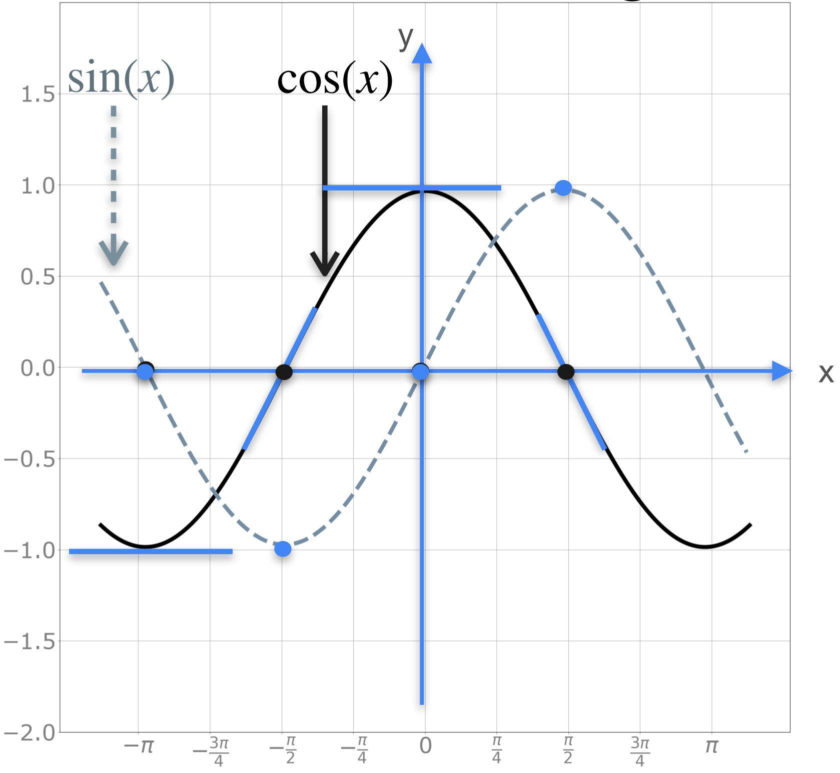


Cosine $y = f(x) = \cos(x)$

x	0	$-\pi$	$\pi/2$	$-\pi/2$
Slope	0	0	-1	1
$\sin(x)$	0	0	1	-1

$$f(x) = \cos(x) \Rightarrow f'(x) = -\sin(x)$$

Derivative of Trigonometric Functions



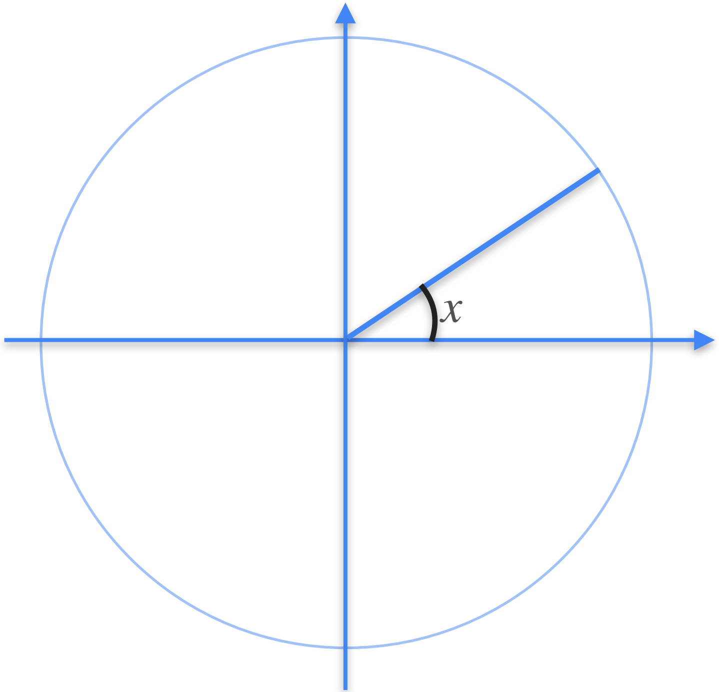
Cosine $y = f(x) = \cos(x)$

x	0	$-\pi$	$\pi/2$	$-\pi/2$
Slope	0	0	-1	1
$\sin(x)$	0	0	1	-1

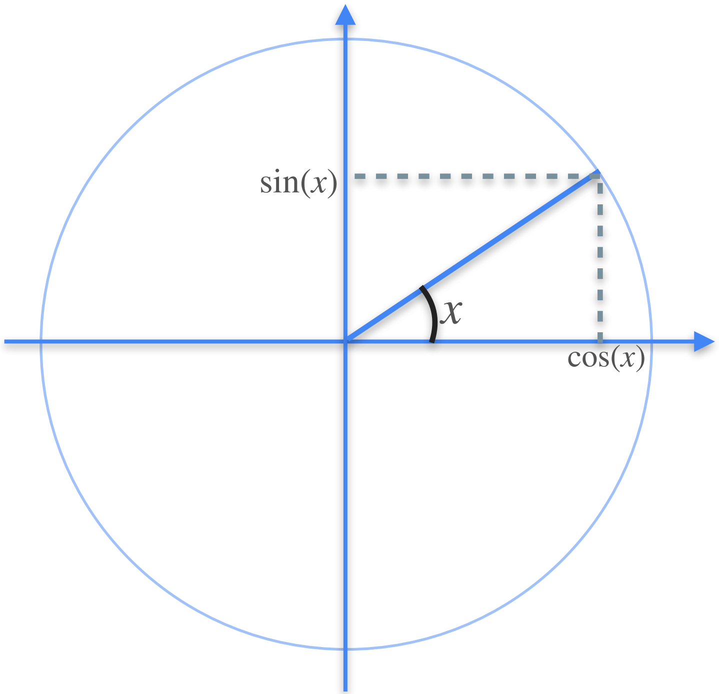
$$f(x) = \cos(x) \xrightarrow{??} f'(x) = -\sin(x)$$

Derivative of Trigonometric Functions

Derivative of Trigonometric Functions



Derivative of Trigonometric Functions



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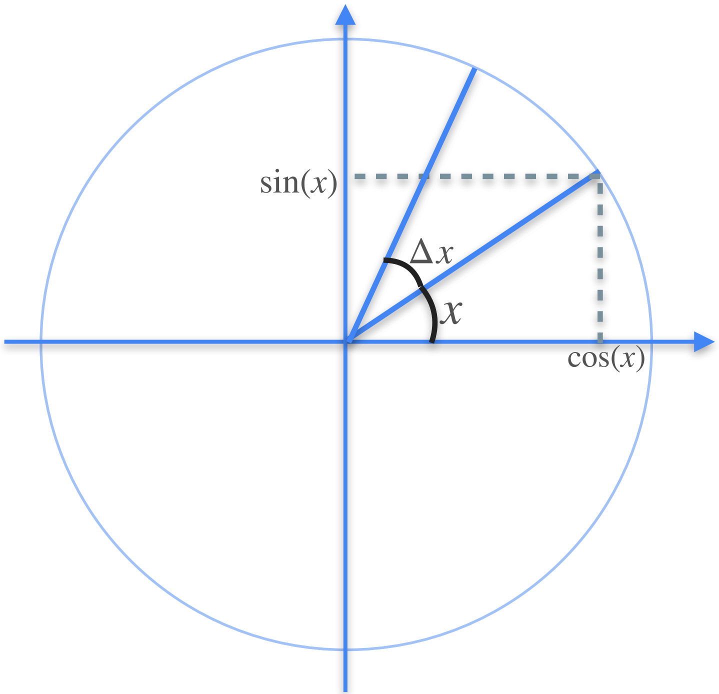

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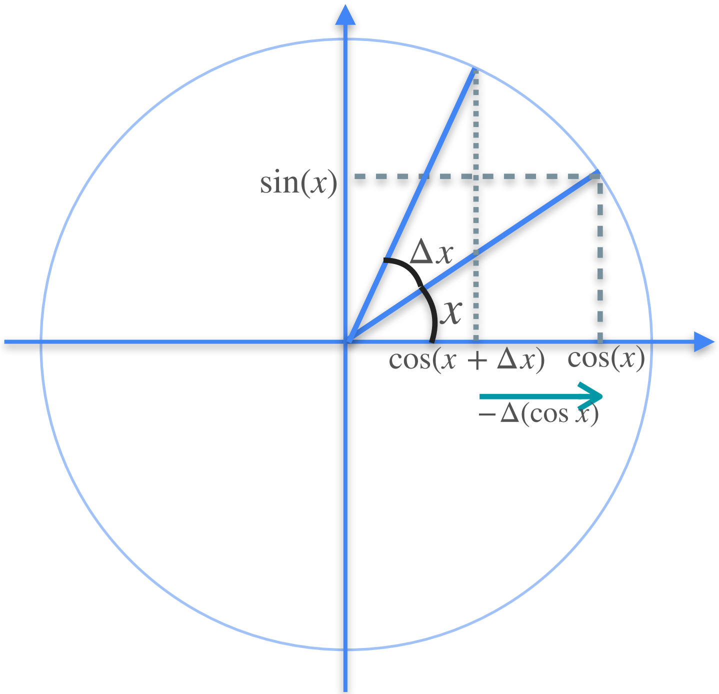

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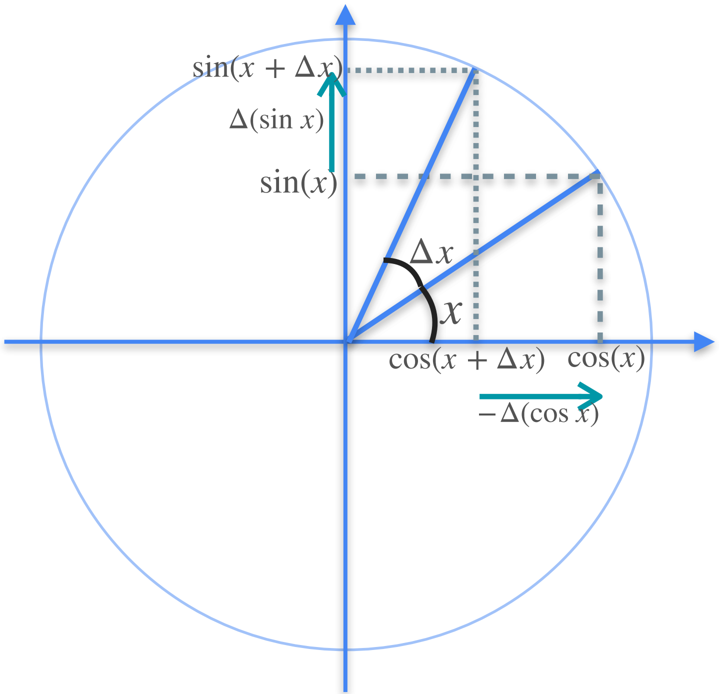
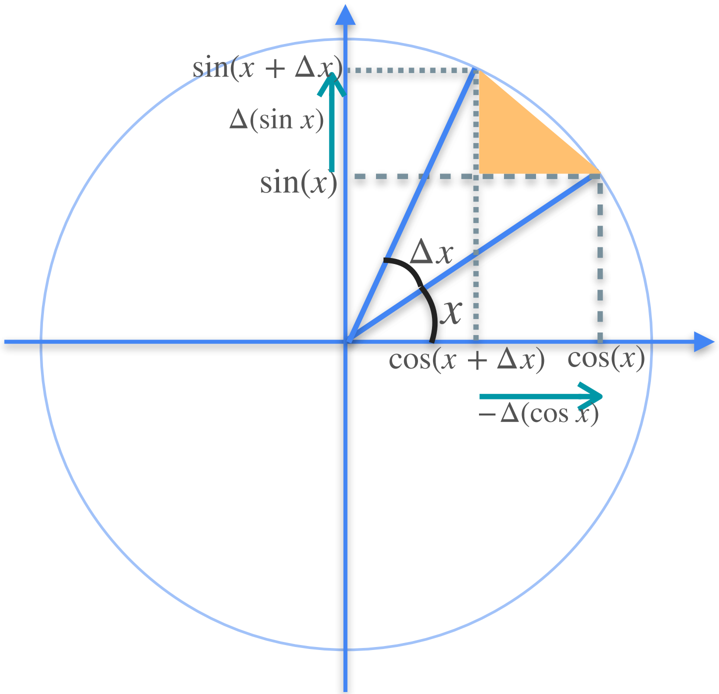


Derivative of Trigonometric Functions



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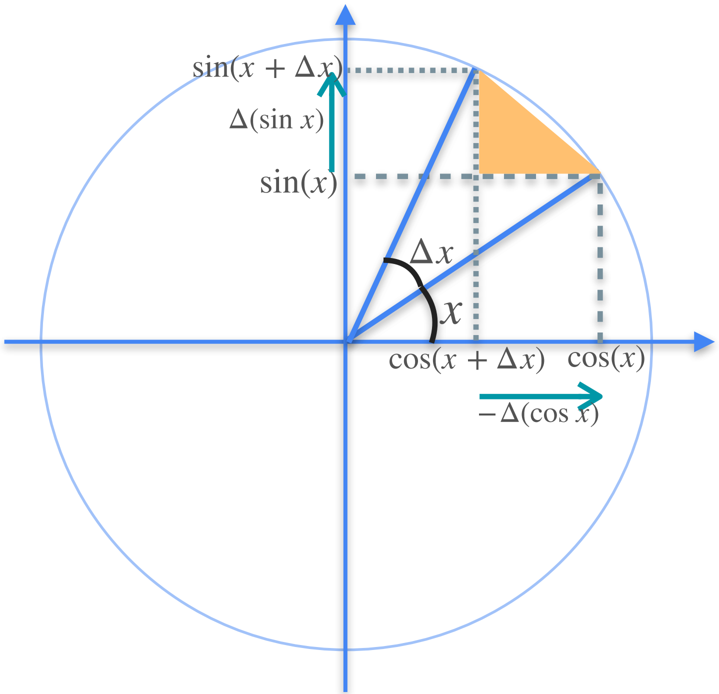
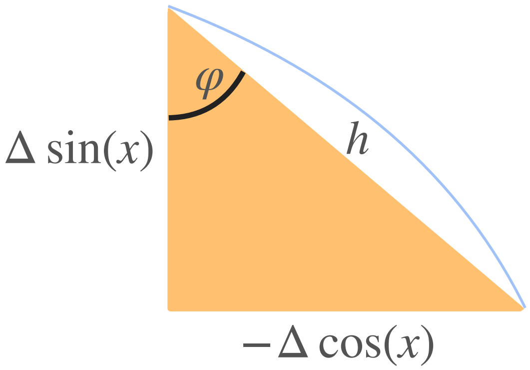
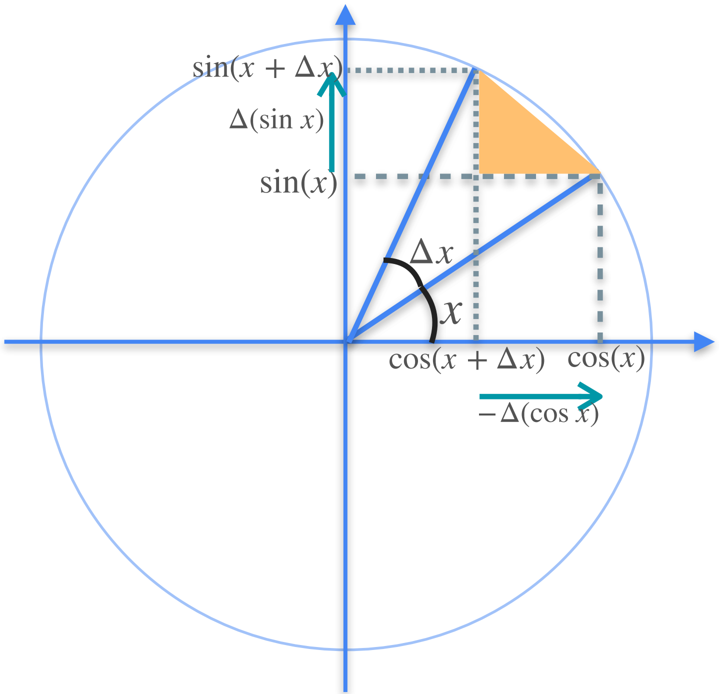
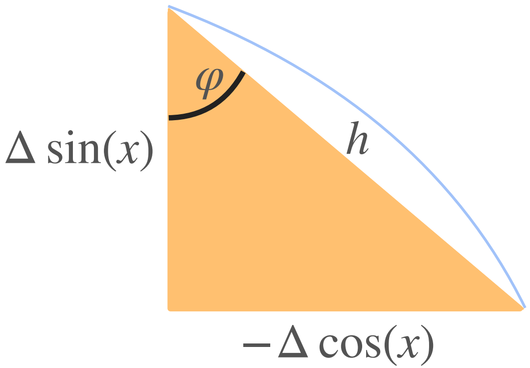




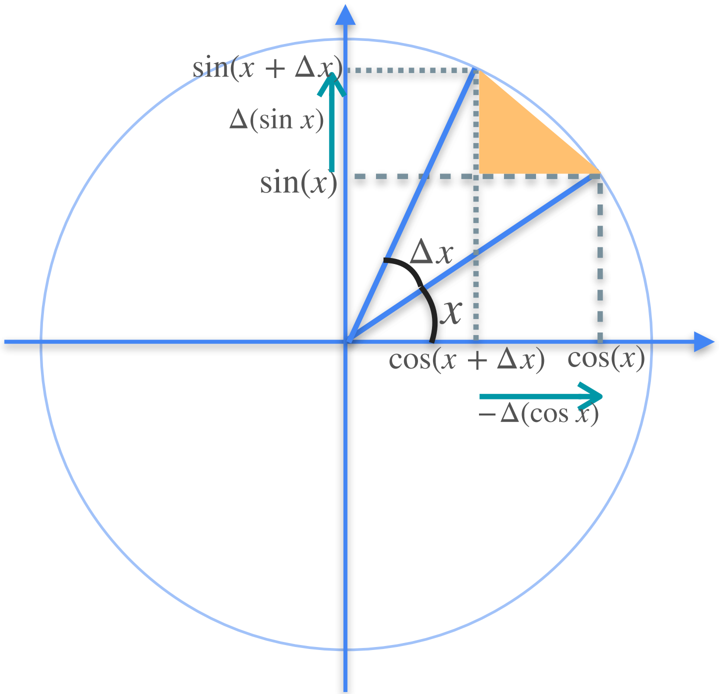
Derivative of Trigonometric Functions

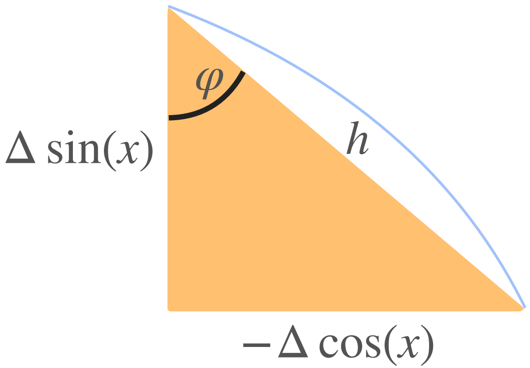




$$\cos(\varphi) = \frac{adj}{hyp}$$

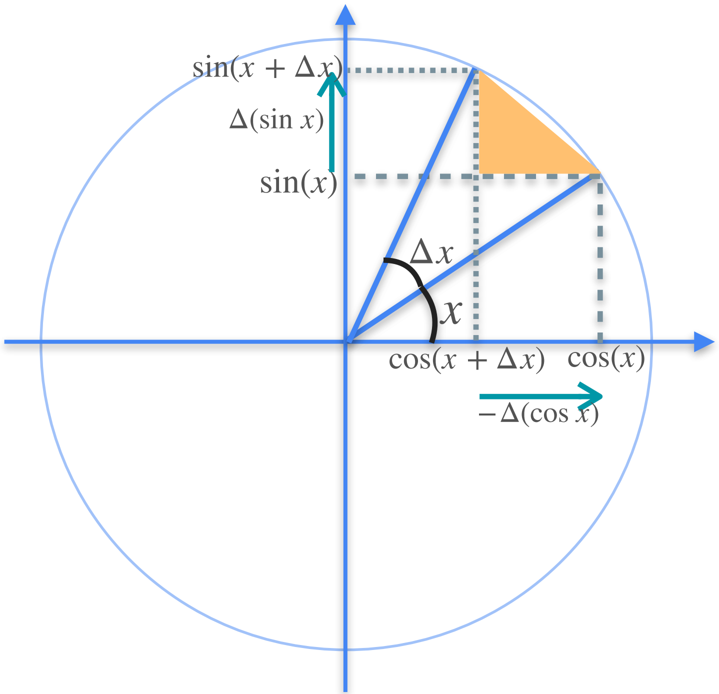
Derivative of Trigonometric Functions

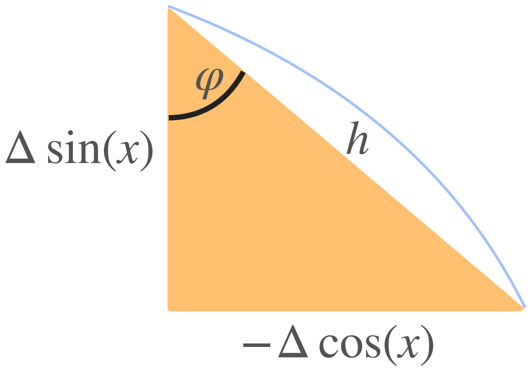




$$\cos(\varphi) = \frac{adj}{hyp} = \frac{\Delta(\sin x)}{h}$$

Derivative of Trigonometric Functions

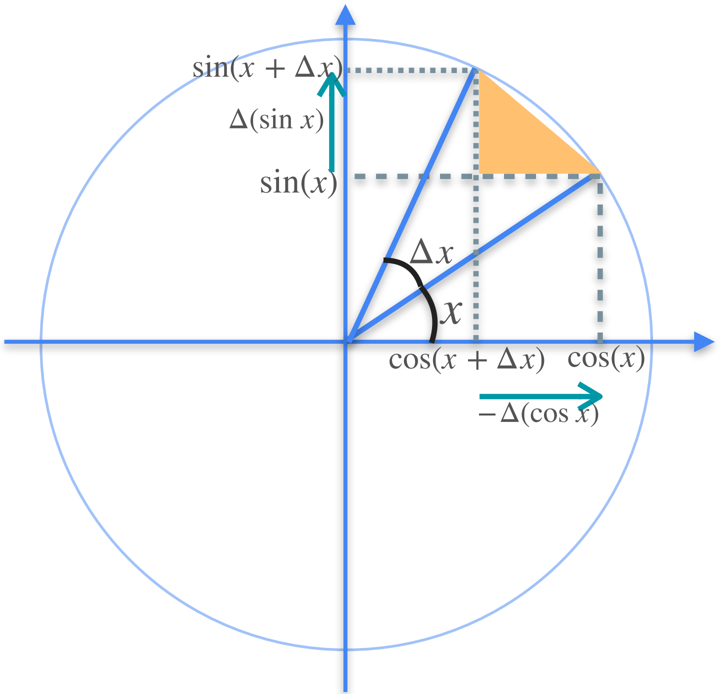


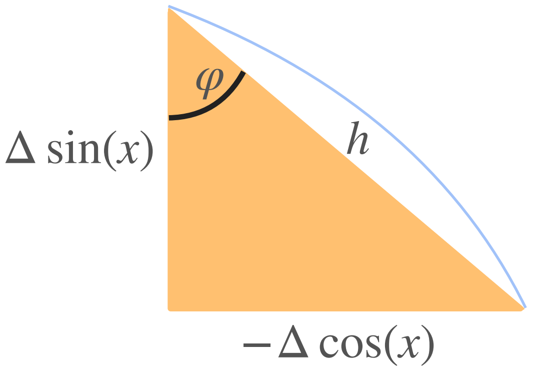


$$\Delta(\sin x) = h \cos(\varphi)$$

$$\cos(\varphi) = \frac{adj}{hyp} = \frac{\Delta(\sin x)}{h}$$

Derivative of Trigonometric Functions



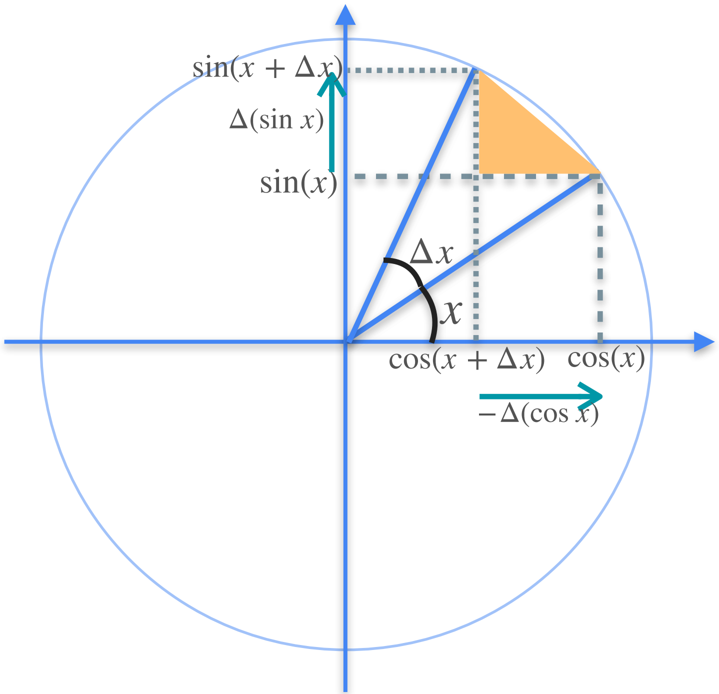


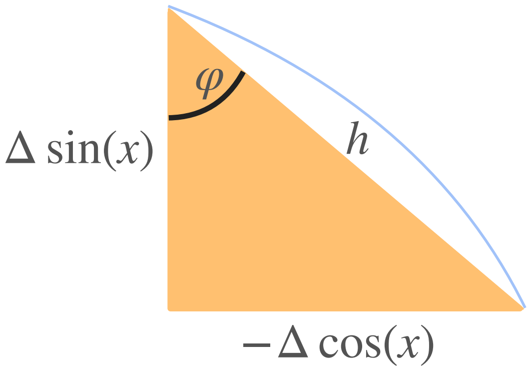
$$\Delta(\sin x) = h \cos(\varphi)$$

$$\cos(\varphi) = \frac{adj}{hyp} = \frac{\Delta(\sin x)}{h}$$

$$\sin(\varphi) = \frac{opp}{hyp}$$

Derivative of Trigonometric Functions



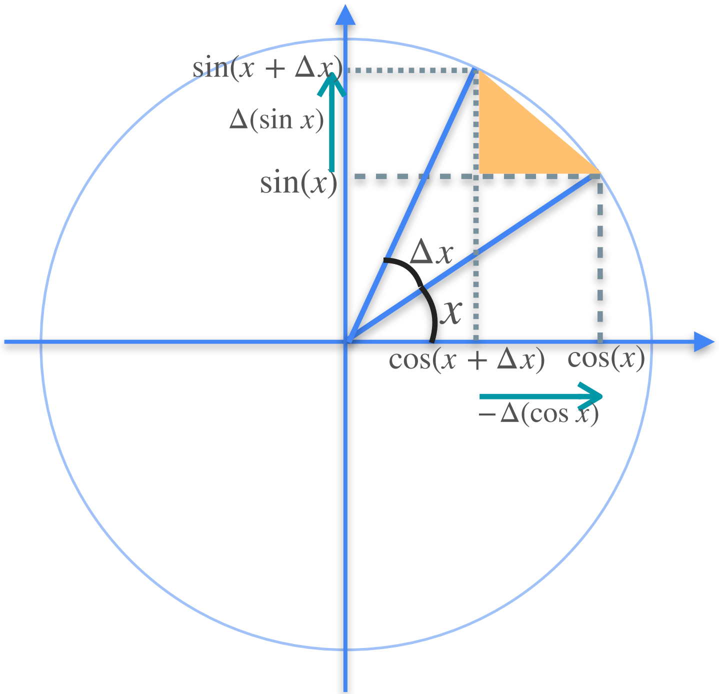


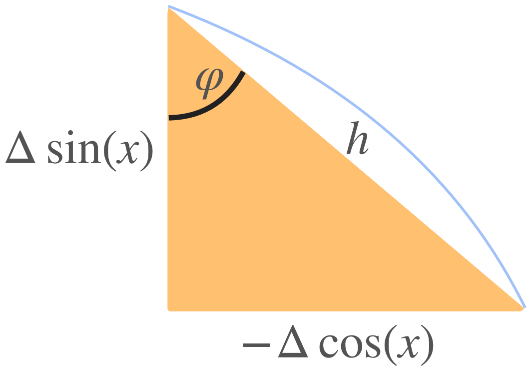
$$\Delta(\sin x) = h\cos(\varphi)$$

$$\cos(\varphi) = \frac{adj}{hyp} = \frac{\Delta(\sin x)}{h}$$

$$\sin(\varphi) = \frac{opp}{hyp} = \frac{-\Delta(\cos x)}{h}$$

Derivative of Trigonometric Functions





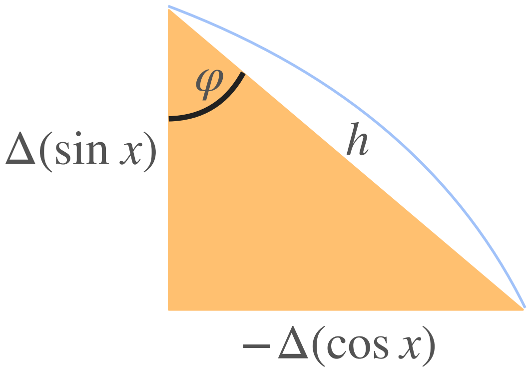
$$\Delta(\sin x) = h\cos(\varphi)$$

$$-\Delta(\cos x) = h\sin(\varphi)$$

$$\cos(\varphi) = \frac{adj}{hyp} = \frac{\Delta(\sin x)}{h}$$

$$\sin(\varphi) = \frac{opp}{hyp} = \frac{-\Delta(\cos x)}{h}$$

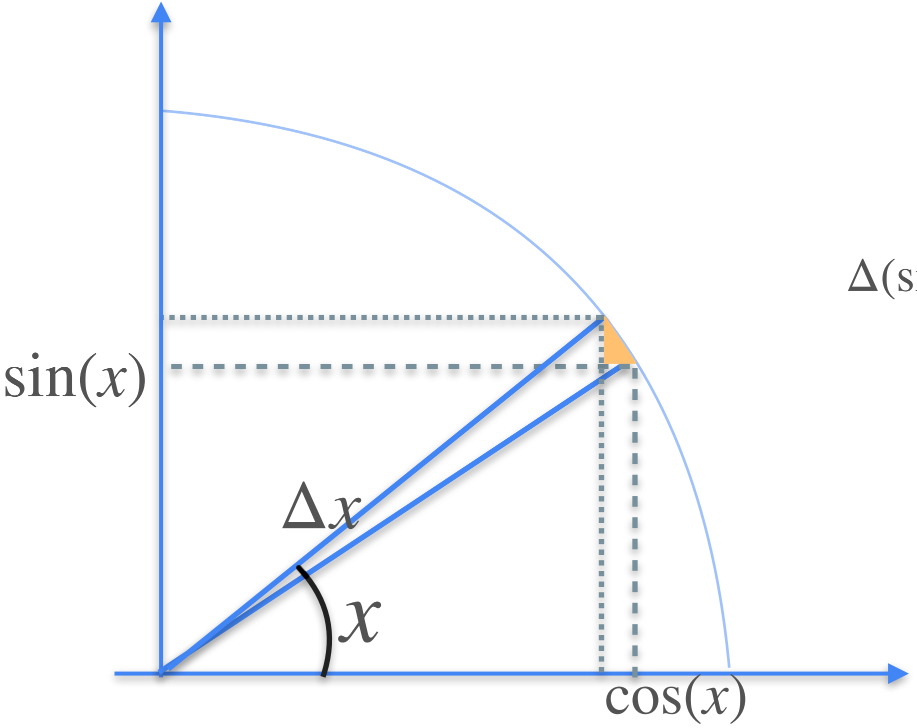
Derivative of Trigonometric Functions

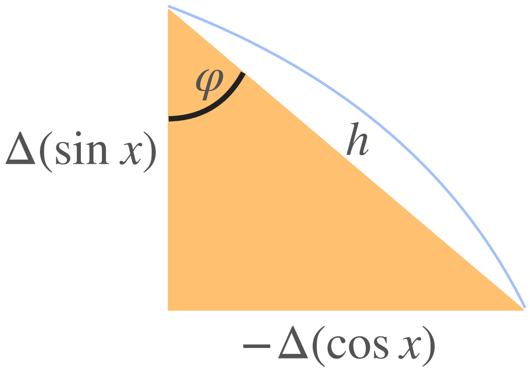


$$\Delta(\sin x) = h\cos(\varphi)$$

$$-\Delta(\cos x) = h\sin(\varphi)$$

Derivative of Trigonometric Functions

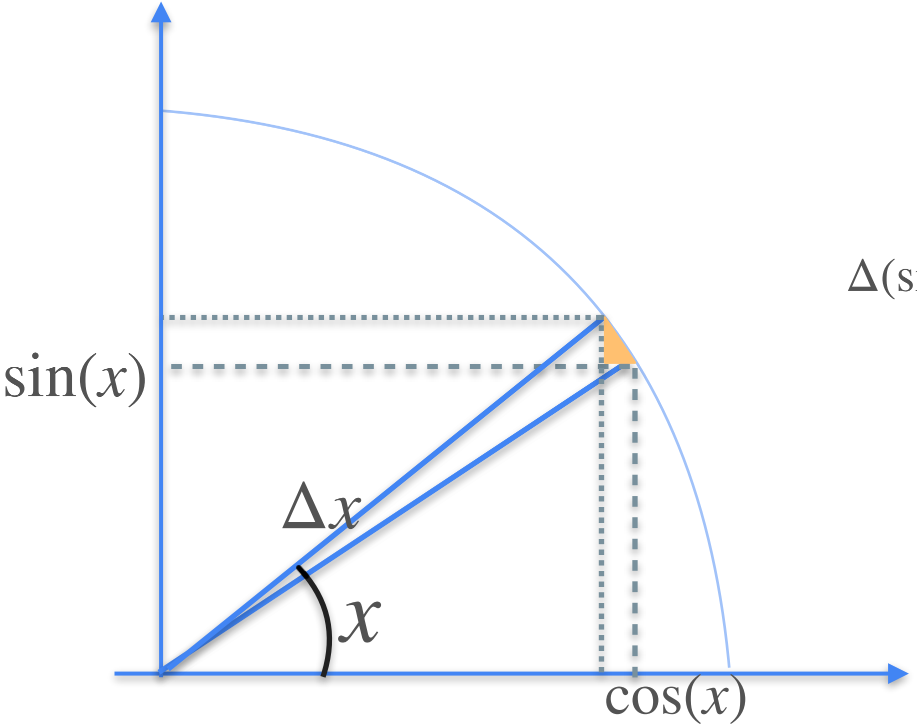


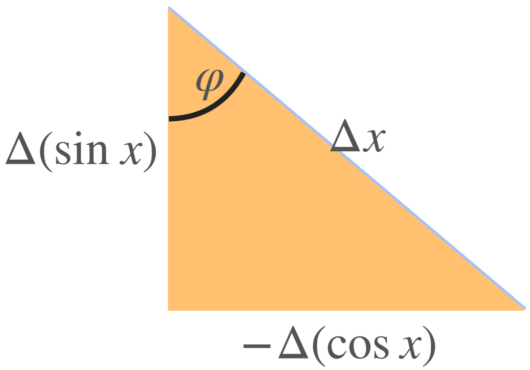


$$\Delta(\sin x) = h\cos(\varphi)$$

$$-\Delta(\cos x) = h\sin(\varphi)$$

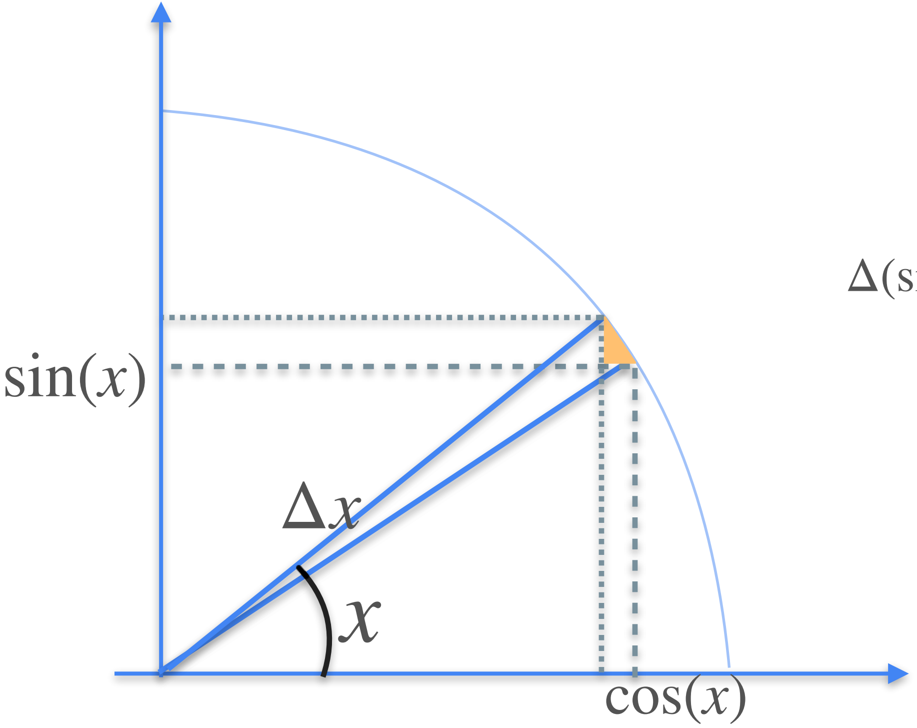
Derivative of Trigonometric Functions

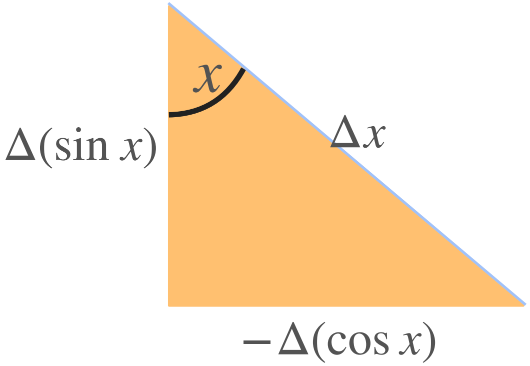




$$\Delta(\sin x) = h\cos(\varphi)$$
$$-\Delta(\cos x) = h\sin(\varphi)$$

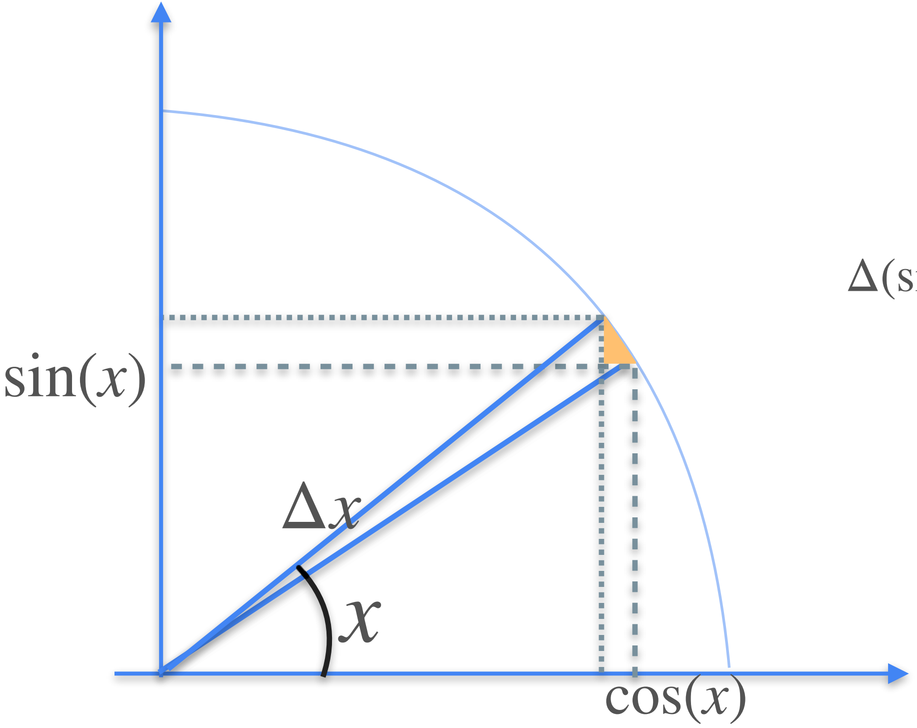
Derivative of Trigonometric Functions

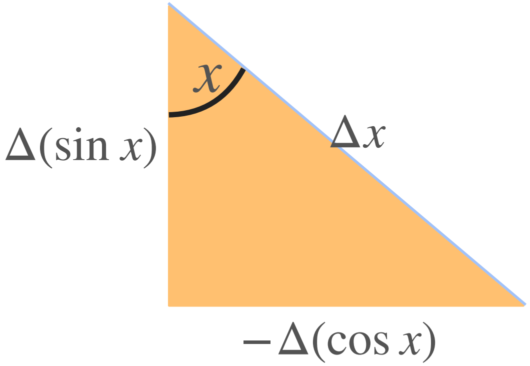




$$\Delta(\sin x) = h\cos(\varphi)$$
$$-\Delta(\cos x) = h\sin(\varphi)$$

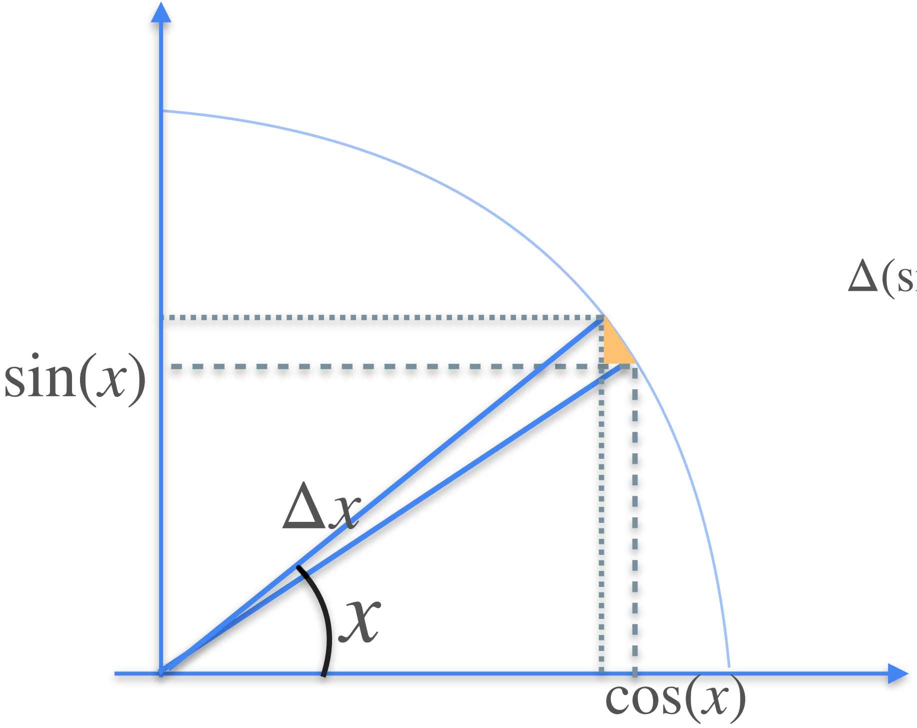
Derivative of Trigonometric Functions

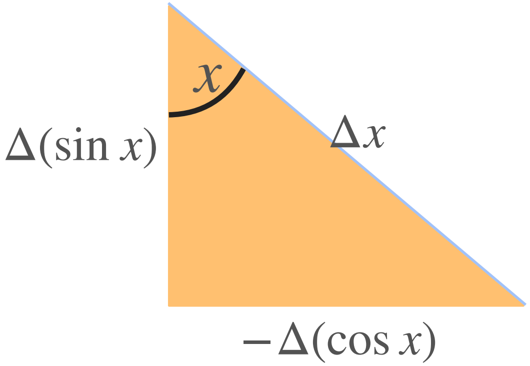




$$\Delta(\sin x) = \Delta x \cos(x)$$
$$-\Delta(\cos x) = h \sin(\varphi)$$

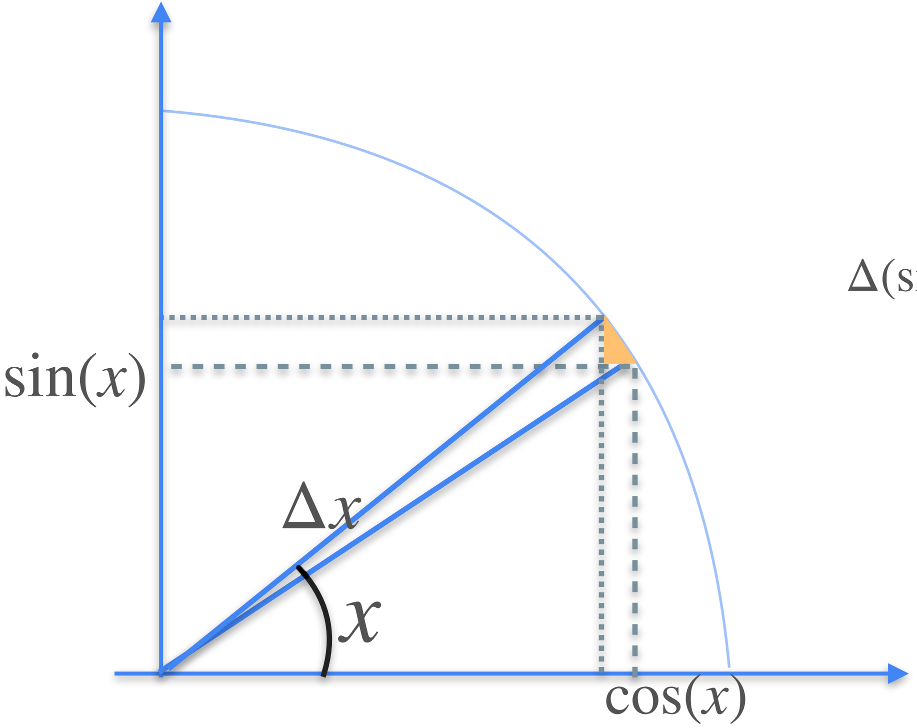
Derivative of Trigonometric Functions

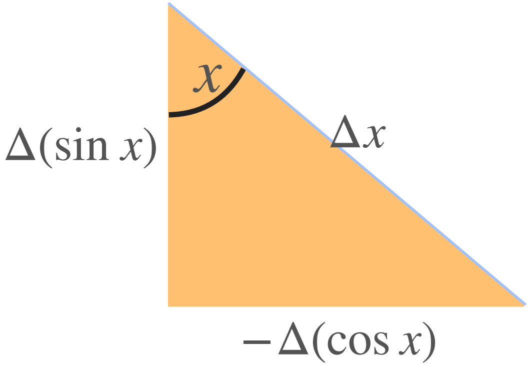




$$\Delta(\sin x) = \Delta x \cos(x)$$
$$-\Delta(\cos x) = \Delta x \sin(x)$$

Derivative of Trigonometric Functions



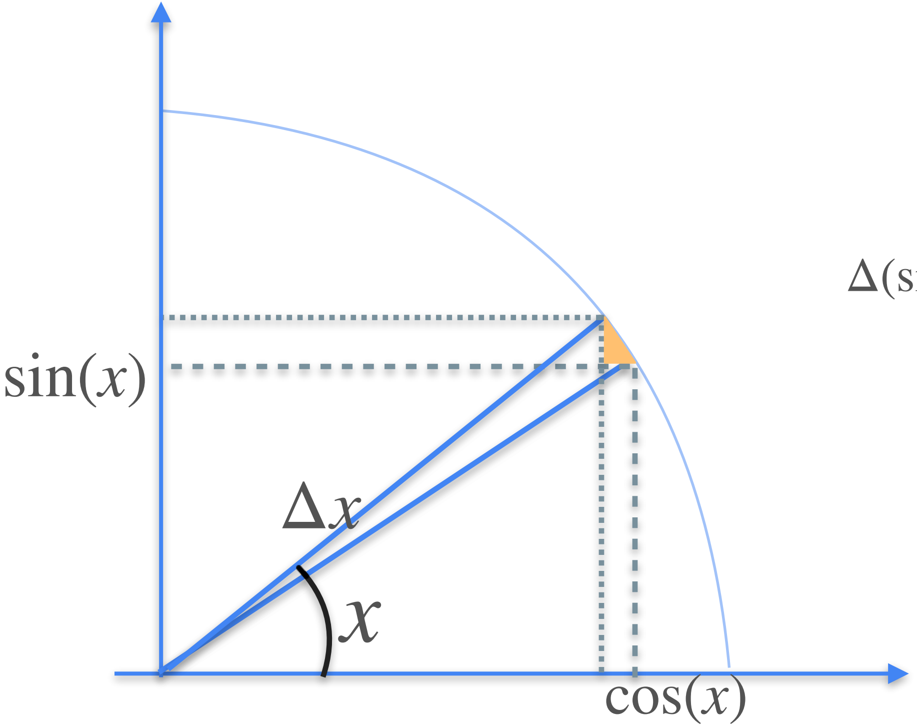


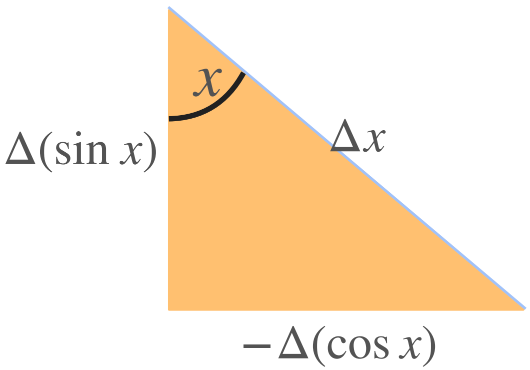
$$\Delta(\sin x) = \Delta x \cos(x)$$

$$-\Delta(\cos x) = \Delta x \sin(x)$$

$$f(x) = \sin(x) \Rightarrow f'(x) = \cos(x)$$

Derivative of Trigonometric Functions





$$\Delta(\sin x) = \Delta x \cos(x)$$

$$-\Delta(\cos x) = \Delta x \sin(x)$$

$f(x) = \sin(x) \Rightarrow f'(x) = \cos(x)$

$g(x) = \cos(x) \Rightarrow g'(x) = -\sin(x)$

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Derivatives and Optimization

Meaning of the exponential (e)

$e = 2.71828182\ldots$

e = 2.71828182…

n
$\left(1+\frac{1}{n}\right)^n$

$e = 2.71828182\ldots$

n	1
$\left(1+\frac{1}{n}\right)^n$	2

$$\left(1+\frac{1}{1}\right)^1$$

$e = 2.71828182\ldots$

n	1	10
$\left(1+\frac{1}{n}\right)^n$	2	2.594

$$\left(1+\frac{1}{10}\right)^{10}$$

e = 2.71828182…

n	1	10	100
$\left(1+\frac{1}{n}\right)^n$	2	2.594	2.705

$$\left(1+\frac{1}{100}\right)^{100}$$

e = 2.71828182…

n	1	10	100	1000
$\left(1+\frac{1}{n}\right)^{n}$	2	2.594	2.705	2.717

$$\left(1+\frac{1}{1000}\right)^{1000}$$

e = 2.71828182…

n	1	10	100	1000	∞
$\left(1+\frac{1}{n}\right)^n$	2	2.594	2.705	2.717	2.718

$e = 2.71828182\ldots$

n	1	10	100	1000	∞
$\left(1+\frac{1}{n}\right)^n$	2	2.594	2.705	2.717	e

$$f(x) = e^x$$

$$f'(x) = e^x$$

e = 2.71828182…

Interest rates

n	1	10	100	1000	∞
$\left(1+\frac{1}{n}\right)^n$	2	2.594	2.705	2.717	e

$$f(x) = e^x$$

$$f'(x) = e^x$$

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Choosing a Bank

Choosing a Bank

Bank 1

Interests
100% every year

Choosing a Bank

Bank 1

Interests
100% every year

(all your money once a year)

Choosing a Bank

Bank 1

Bank 2

Interests
100% every year

(all your money once a year)

Choosing a Bank

Bank 1

Interests
100% every year

(all your money once a year)

Bank 2

Interests
50% every 6 months

Choosing a Bank

Bank 1

Interests
100% every year

(all your money once a year)

Bank 2

Interests
50% every 6 months

(half of your money twice a year)

Choosing a Bank

Bank 1

Bank 2

Bank 3

Interests
100% every year

(all your money once a year)

Interests
50% every 6 months

(half of your money twice a year)

Choosing a Bank

Bank 1

Interests
100% every year

(all your money once a year)

Bank 2

Interests
50% every 6 months

(half of your money twice a year)

Bank 3

Interests
33.3% every 4 months

Choosing a Bank

Bank 1	Bank 2	Bank 3
Interests	**Interests**	**Interests**
100% every year	50% every 6 months	33.3% every 4 months
(all your money once a year)	(half of your money twice a year)	(A third of your money three times a year)

Which bank is better?

Bank 1

Interests
100% every year

(all your money once a year)

Bank 2

Interests
50% every 6 months

(half of your money twice a year)

Bank 3

Interests
33.3% every 4 months

(A third of your money three times a year)

Which bank is better?

Bank 1

Interests
100% every year

(all your money once a year)

Bank 2

Interests
50% every 6 months

(half of your money twice a year)

Bank 3

Interests
33.3% every 4 months

(A third of your money three times a year)

Which bank is better?

Bank 1	Bank 2	Bank 3
Interests	**Interests**	**Interests**
100% every year	50% every 6 months	33.3% every 4 months
(all your money once a year)	(half of your money twice a year)	(A third of your money three times a year)

You have $1

Bank 1

Interests
100% every year

(all your money once a year)

Bank 2

Interests
50% every 6 months

(half of your money twice a year)

Bank 3

Interests
33.3% every 4 months

(A third of your money three times a year)

You have $1

Bank 1

Interests
100% every year

(all your money once a year)

Now	US$1
In 1 year	US$2

Bank 2

Interests
50% every 6 months

(half of your money twice a year)

Bank 3

Interests
33.3% every 4 months

(A third of your money three times a year)

You have $1

Bank 1

Interests
100% every year

(all your money once a year)

Bank 2

Interests
50% every 6 months

(half of your money twice a year)

Bank 3

Interests
33.3% every 4 months

(A third of your money three times a year)

Now	US$1
In 1 year	US$2

+100%

You have $1

Bank 1

Interests
100% every year

(all your money once a year)

Now	US$1
In 1 year	US$2

+100%

Bank 2

Interests
50% every 6 months

(half of your money twice a year)

Now	US$1
In 1 year	?

Bank 3

Interests
33.3% every 4 months

(A third of your money three times a year)

You have $1

Bank 1

Interests
100% every year

(all your money once a year)

Now	US$1
In 1 year	US$2

+100%

Bank 2

Interests
50% every 6 months

(half of your money twice a year)

Now	US$1
In 1 year	?

Bank 3

Interests
33.3% every 4 months

(A third of your money three times a year)

Now	US$1
In 1 year	?

You have $1

Bank 1

Interests
100% every year

(all your money once a year)

Now	US$1
In 1 year	US$2

+100%

Bank 2

Interests
50% every 6 months

(half of your money twice a year)

Now	US$1
In 1 year	?

?

Bank 3

Interests
33.3% every 4 months

(A third of your money three times a year)

Now	US$1
In 1 year	?

You have $1

Bank 1

Interests
100% every year

(all your money once a year)

Now	US$1
In 1 year	US$2

+100%

Bank 2

Interests
50% every 6 months

(half of your money twice a year)

Now	US$1
In 1 year	?

Bank 3

Interests
33.3% every 4 months

(A third of your money three times a year)

Now	US$1
In 1 year	?

How Much Do I Have After 1 Year?

Bank 1

Interests
100% every year

Bank 2

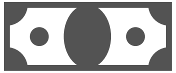
Interests
50% every 6 months

How Much Do I Have After 1 Year?

Bank 1

Interests
100% every year

Now



Bank 2

Interests
50% every 6 months

How Much Do I Have After 1 Year?

Bank 1

Interests
100% every year

Now

1

Bank 2

Interests
50% every 6 months

How Much Do I Have After 1 Year?

Bank 1

Interests
100% every year

Bank 2

Interests
50% every 6 months

Now

1

In 1 year

How Much Do I Have After 1 Year?

Bank 1

Interests
100% every year

Bank 2

Interests
50% every 6 months

Now

1

In 1 year

How Much Do I Have After 1 Year?

Bank 1

Interests
100% every year

Bank 2

Interests
50% every 6 months

	Now	**In 1 year**
Bank 1	1	2

How Much Do I Have After 1 Year?

Bank 1

Interests
100% every year

Now

1

In 1 year

2

$$(1+1)^1$$

Bank 2

Interests
50% every 6 months

How Much Do I Have After 1 Year?

Bank 1

Interests
100% every year

Now

1

In 1 year

2

$$(1+1)^1$$

Bank 2

Interests
50% every 6 months

Now

How Much Do I Have After 1 Year?

Bank 1

Interests
100% every year

Now

1

In 1 year

2

$$(1+1)^1$$

Bank 2

Interests
50% every 6 months

Now

1

How Much Do I Have After 1 Year?

Bank 1

Interests
100% every year

Now

1

In 1 year

2

$$(1+1)^1$$

Bank 2

Interests
50% every 6 months

Now

1

In 6 months

How Much Do I Have After 1 Year?

Bank 1

Interests
100% every year

Now

1

In 1 year

2

$$(1+1)^1$$

Bank 2

Interests
50% every 6 months

Now

1

In 6 months

How Much Do I Have After 1 Year?

Bank 1

Interests
100% every year

Now

1

In 1 year

2

$$(1+1)^1$$

Bank 2

Interests
50% every 6 months

Now

1

In 6 months

1.5

How Much Do I Have After 1 Year?

Bank 1

Interests
100% every year

Now

1

In 1 year

2

$$(1+1)^1$$

Bank 2

Interests
50% every 6 months

Now

1

In 6 months

1.5

$$1+\frac{1}{2}$$

How Much Do I Have After 1 Year?

Bank 1

Interests
100% every year

Now

1

In 1 year

2

$$(1+1)^1$$

Bank 2

Interests
50% every 6 months

Now

1

In 6 months

1.5

$$1+\frac{1}{2}$$

In 1 year

How Much Do I Have After 1 Year?

Bank 1

Interests
100% every year

	Now		In 1 year
Bank 1	**1**		**2** $(1+1)^1$
Bank 2	**1**	**1.5** $1+\frac{1}{2}$	

Bank 2

Interests
50% every 6 months

Now — **In 6 months** — **In 1 year**

How Much Do I Have After 1 Year?

Bank 1

Interests
100% every year

Now

1

In 1 year

2

$$(1+1)^1$$

Bank 2

Interests
50% every 6 months

Now

1

In 6 months

1.5

$$1+\frac{1}{2}$$

In 1 year

How Much Do I Have After 1 Year?

Bank 1

Interests
100% every year

Now

1

In 1 year

2

$$(1+1)^1$$

Bank 2

Interests
50% every 6 months

Now

1

In 6 months

1.5

$$1+\frac{1}{2}$$

In 1 year

How Much Do I Have After 1 Year?

Bank 1

Interests
100% every year

	Now		In 1 year
Bank 1	**1**		**2** $(1+1)^1$

Bank 2

Interests
50% every 6 months

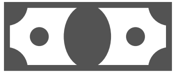
	Now	In 6 months	In 1 year
Bank 2	**1**	**1.5** $1+\frac{1}{2}$	**2.25**

How Much Do I Have After 1 Year?

Bank 1

Interests
100% every year

Now



1

In 1 year

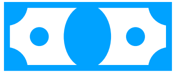
2

$$(1+1)^1$$

Bank 2

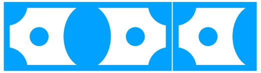
Interests
50% every 6 months

Now



1

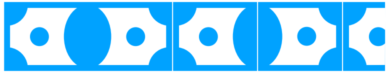
In 6 months



1.5

$$1+\frac{1}{2}$$

In 1 year



2.25

$$\left(1+\frac{1}{2}\right)^2$$

How Much Do I Have After 1 Year?

Bank 1

Interests
100% every year

	Now		**In 1 year**
Bank 1	**1**		**2** $(1+1)^1$
Bank 2	**1**	**1.5** $1+\frac{1}{2}$	**2.25** $\left(1+\frac{1}{2}\right)^2$

Bank 2

Interests
50% every 6 months

Now **In 6 months** **In 1 year**

Compound interest

Bank 1

Interests
100% every year

Now

1

In 1 year

2

$$(1+1)^1$$

Bank 2

Interests
50% every 6 months

Now

1

In 6 months

1.5

$$1+\frac{1}{2}$$

In 1 year

2.25

$$\left(1+\frac{1}{2}\right)^2$$

How Much Do I Have After 1 Year?

Bank 3

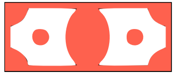
Interests
33.3% every 4 months

Now	**In 4 months**	**In 8 months**	**In 1 year**

How Much Do I Have After 1 Year?

Bank 3

Interests
33.3% every 4 months

	Now	**In 4 months**	**In 8 months**	**In 1 year**
				
	1			

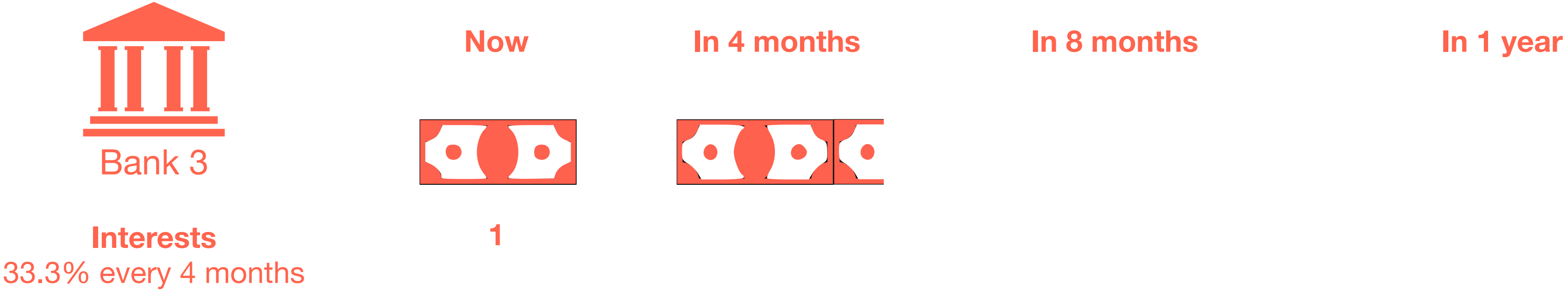
How Much Do I Have After 1 Year?

Bank 3

Interests
33.3% every 4 months

Now	In 4 months	In 8 months	In 1 year
1			

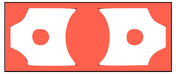
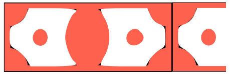
How Much Do I Have After 1 Year?



How Much Do I Have After 1 Year?

Bank 3

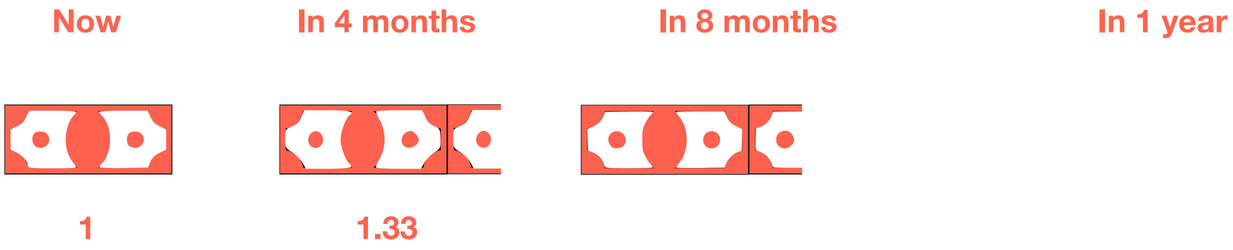
Interests
33.3% every 4 months

Now	**In 4 months**	**In 8 months**	**In 1 year**
			
1	**1.33**		

How Much Do I Have After 1 Year?

Bank 3

Interests
33.3% every 4 months

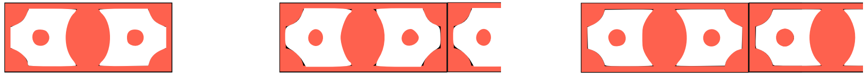


How Much Do I Have After 1 Year?

Bank 3

Interests
33.3% every 4 months

Now	In 4 months	In 8 months	In 1 year
1	1.33		



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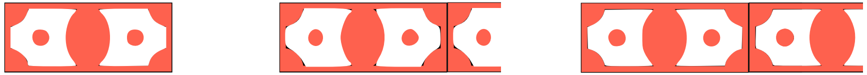
How Much Do I Have After 1 Year?

Bank 3

Interests
33.3% every 4 months

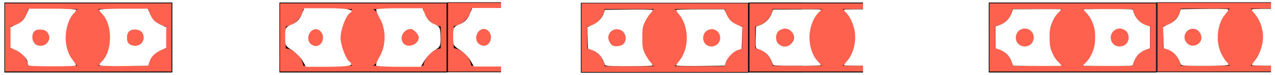
Now	In 4 months	In 8 months	In 1 year
1	1.33	1.77	



How Much Do I Have After 1 Year?

Bank 3

	Now	In 4 months	In 8 months	In 1 year



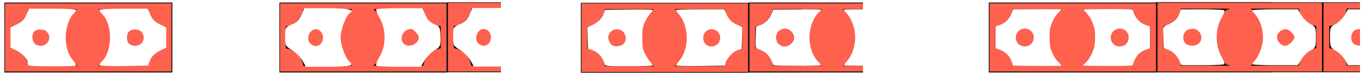
Interests 33.3% every 4 months	**1**	**1.33**	**1.77**	

How Much Do I Have After 1 Year?

Bank 3

Interests
33.3% every 4 months

Now	In 4 months	In 8 months	In 1 year
1	1.33	1.77	

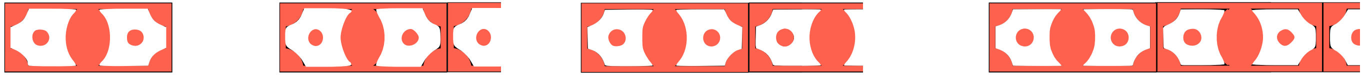


How Much Do I Have After 1 Year?

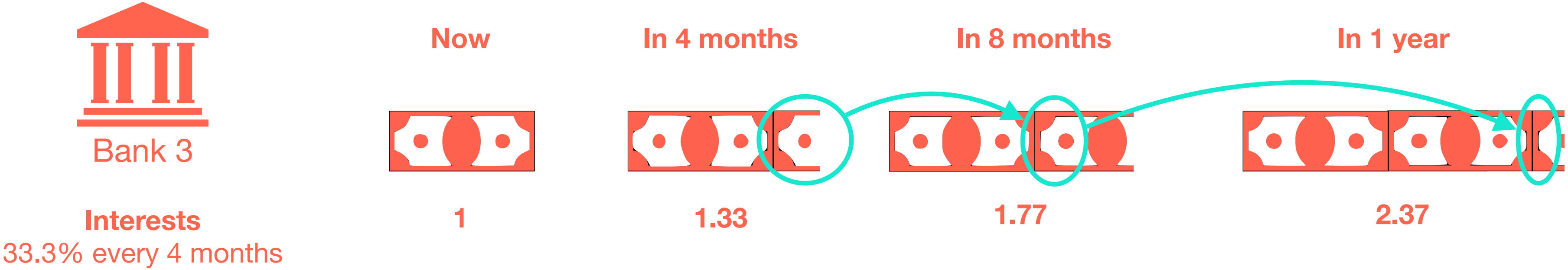
Bank 3

Interests
33.3% every 4 months

Now	In 4 months	In 8 months	In 1 year
1	1.33	1.77	2.37

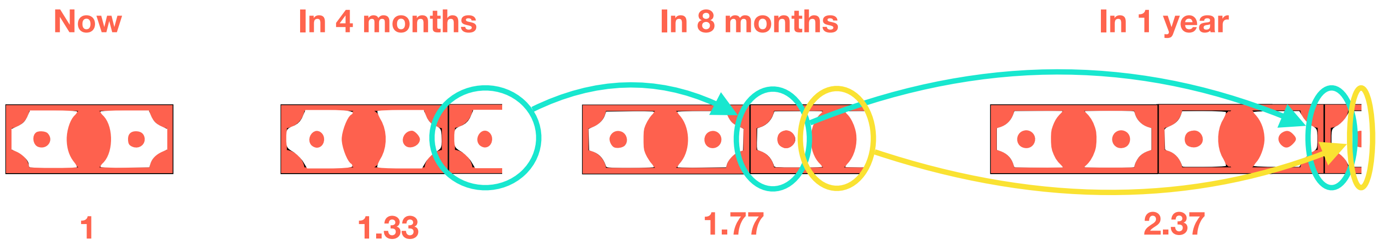


How Much Do I Have After 1 Year?



How Much Do I Have After 1 Year?

Interests
33.3% every 4 months

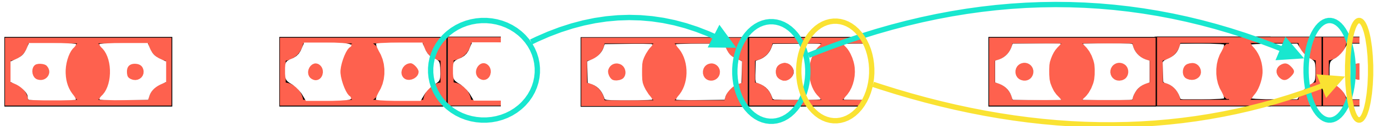


How Much Do I Have After 1 Year?

Bank 3

Interests
33.3% every 4 months

Now	In 4 months	In 8 months	In 1 year



1	1.33	1.77	2.37

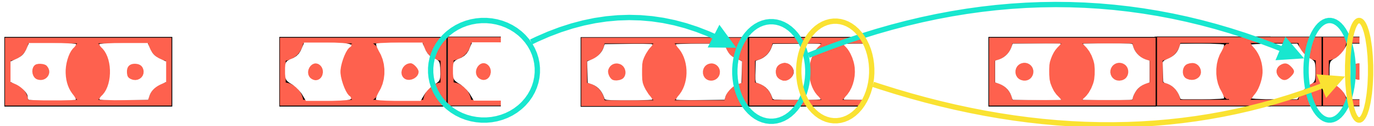
1

Original money

How Much Do I Have After 1 Year?

Bank 3

Interests
33.3% every 4 months

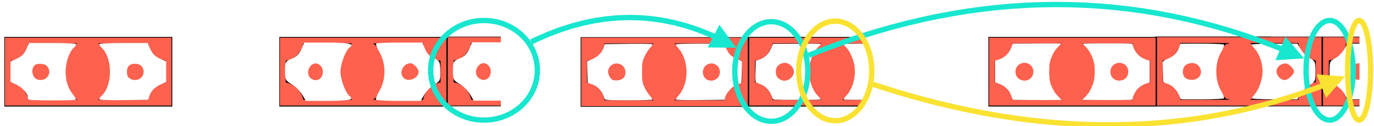
Now	In 4 months	In 8 months	In 1 year
			
1	**1.33**	**1.77**	**2.37**
1	$1+\frac{1}{3}$		
Original money	Add 1/3 of the money		

How Much Do I Have After 1 Year?

Bank 3

Interests
33.3% every 4 months

Now	**In 4 months**	**In 8 months**	**In 1 year**



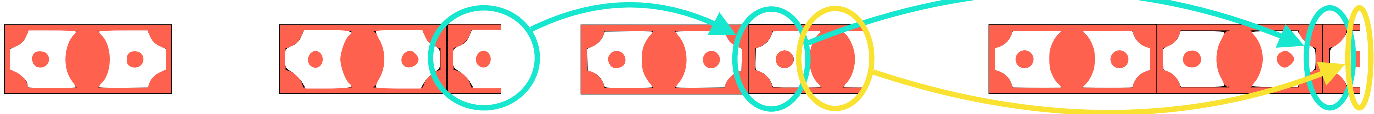
1	**1.33**	**1.77**	**2.37**
1	$1+\frac{1}{3}$	$\left(1+\frac{1}{3}\right)^2$	
Original money	Add 1/3 of the money	Add 1/3 of the money	

How Much Do I Have After 1 Year?

Bank 3

Interests
33.3% every 4 months

Now	In 4 months	In 8 months	In 1 year



1	**1.33**	**1.77**	**2.37**
1	$1+\frac{1}{3}$	$\left(1+\frac{1}{3}\right)^2$	$\left(1+\frac{1}{3}\right)^3$
Original money	Add 1/3 of the money	Add 1/3 of the money	Add 1/3 of the money

Which Bank Is Better?

Bank 1

Interests
100% every year

(all your money once a year)

Bank 2

Interests
50% every 6 months

(half of your money twice a year)

Bank 3

Interests
33.3% every 4 months

(A third of your money three times a year)

Which Bank Is Better?

Bank 1

Interests
100% every year

(all your money once a year)

Now	$1
In 1 year	$2

Bank 2

Interests
50% every 6 months

(half of your money twice a year)

Bank 3

Interests
33.3% every 4 months

(A third of your money three times a year)

Which Bank Is Better?

Bank 1

Interests
100% every year

(all your money once a year)

Now	$1
In 1 year	$2

Bank 2

Interests
50% every 6 months

(half of your money twice a year)

Now	$1
In 1 year	$2.25

Bank 3

Interests
33.3% every 4 months

(A third of your money three times a year)

Which Bank Is Better?

Bank 1

Interests
100% every year

(all your money once a year)

Now	$1
In 1 year	$2

Bank 2

Interests
50% every 6 months

(half of your money twice a year)

Now	$1
In 1 year	$2.25

Bank 3

Interests
33.3% every 4 months

(A third of your money three times a year)

Now	$1
In 1 year	$2.37

Which Bank Is Better?

Bank 1

Interests
100% every year

(all your money once a year)

Now	$1
In 1 year	$2

+100%

Bank 2

Interests
50% every 6 months

(half of your money twice a year)

Now	$1
In 1 year	$2.25

Bank 3

Interests
33.3% every 4 months

(A third of your money three times a year)

Now	$1
In 1 year	$2.37

Which Bank Is Better?

Bank 1

Interests
100% every year

(all your money once a year)

Now	$1
In 1 year	$2
In 2	$4
In 3	$8
In 4	$16

+100%
+100%
+100%
+100%

Bank 2

Interests
50% every 6 months

(half of your money twice a year)

Now	$1
In 1 year	$2.25

Bank 3

Interests
33.3% every 4 months

(A third of your money three times a year)

Now	$1
In 1 year	$2.37

Which Bank Is Better?

Bank 1

Interests
100% every year

(all your money once a year)

Now	$1
In 1 year	$2
In 2	$4
In 3	$8
In 4	$16

+100%
+100%
+100%
+100%

Bank 2

Interests
50% every 6 months

(half of your money twice a year)

Now	$1
In 1 year	$2.25

+125%

Bank 3

Interests
33.3% every 4 months

(A third of your money three times a year)

Now	$1
In 1 year	$2.37

Which Bank Is Better?

Bank 1

Interests
100% every year

(all your money once a year)

Now	$1
In 1 year	$2
In 2	$4
In 3	$8
In 4	$16

+100%
+100%
+100%
+100%

Bank 2

Interests
50% every 6 months

(half of your money twice a year)

Now	$1
In 1 year	$2.25
In 2	$5.06
In 3	$11.39
In 4	$25.63

+125%
+125%
+125%
+125%

Bank 3

Interests
33.3% every 4 months

(A third of your money three times a year)

Now	$1
In 1 year	$2.37

Which Bank Is Better?

Bank 1

Interests
100% every year

(all your money once a year)

Now	$1
In 1 year	$2
In 2	$4
In 3	$8
In 4	$16

+100%
+100%
+100%
+100%

Bank 2

Interests
50% every 6 months

(half of your money twice a year)

Now	$1
In 1 year	$2.25
In 2	$5.06
In 3	$11.39
In 4	$25.63

+125%
+125%
+125%
+125%

Bank 3

Interests
33.3% every 4 months

(A third of your money three times a year)

Now	$1
In 1 year	$2.37

+137%

Which Bank Is Better?

Bank 1

Interests
100% every year

(all your money once a year)

Now	$1
In 1 year	$2
In 2	$4
In 3	$8
In 4	$16

+100%
+100%
+100%
+100%

Bank 2

Interests
50% every 6 months

(half of your money twice a year)

Now	$1
In 1 year	$2.25
In 2	$5.06
In 3	$11.39
In 4	$25.63

+125%
+125%
+125%
+125%

Bank 3

Interests
33.3% every 4 months

(A third of your money three times a year)

Now	$1
In 1 year	$2.37
In 2	$5.62
In 3	$13.32
In 4	$31.57

+137%
+137%
+137%
+137%

Which Bank Is Better?

Bank 1

Interests
100% every year

(all your money once a year)

Now	$1

Bank 2

Interests
50% every 6 months

(half of your money twice a year)

Now	$1

Bank 3

Interests
33.3% every 4 months

(A third of your money three times a year)

Now	$1

Which Bank Is Better?

Bank 1

Interests
100% every year

(all your money once a year)

Now	$1

$$(1+1)^1 = 2$$

Bank 2

Interests
50% every 6 months

(half of your money twice a year)

Now	$1

Bank 3

Interests
33.3% every 4 months

(A third of your money three times a year)

Now	$1

Which Bank Is Better?

Bank 1

Interests
100% every year

(all your money once a year)

Now	\$1

$$(1+1)^1 = 2$$

Bank 2

Interests
50% every 6 months

(half of your money twice a year)

Now	\$1

$$\left(1+\frac{1}{2}\right)^2 = 2.25$$

Bank 3

Interests
33.3% every 4 months

(A third of your money three times a year)

Now	\$1

Which Bank Is Better?

Bank 1

Interests
100% every year

(all your money once a year)

Now	$1

$$(1+1)^1 = 2$$

Bank 2

Interests
50% every 6 months

(half of your money twice a year)

Now	$1

$$\left(1+\frac{1}{2}\right)^2 = 2.25$$

Bank 3

Interests
33.3% every 4 months

(A third of your money three times a year)

Now	$1

$$\left(1+\frac{1}{3}\right)^3 = 2.37$$

How Much Do I Have After 1 Year?

Bank 12

Interests
1/12 every month

Now	In 1 month	In 2 months	...	In 12 months

How Much Do I Have After 1 Year?

Bank 12

Interests
1/12 every month

Now	In 1 month	In 2 months	...	In 12 months
1				
Original money				

How Much Do I Have After 1 Year?

Bank 12

Interests
1/12 every month

Now	**In 1 month**	**In 2 months**	**…**	**In 12 months**
1	$1 + \frac{1}{12}$			
Original money	Add 1/12 of the money			

How Much Do I Have After 1 Year?

Bank 12

Interests
1/12 every month

Now	**In 1 month**	**In 2 months**	**...**	**In 12 months**
1	$1 + \frac{1}{12}$	$\left(1 + \frac{1}{12}\right)^2$		
Original money	Add 1/12 of the money	Add 1/12 of the money		

How Much Do I Have After 1 Year?

Bank 12

Interests
1/12 every month

Now	**In 1 month**	**In 2 months**	**...**	**In 12 months**
1	$1+\frac{1}{12}$	$\left(1+\frac{1}{12}\right)^2$	$\cdots$	
Original money	Add 1/12 of the money	Add 1/12 of the money		

How Much Do I Have After 1 Year?

Bank 12

Interests
1/12 every month

Now	**In 1 month**	**In 2 months**	**...**	**In 12 months**
1	$1+\frac{1}{12}$	$\left(1+\frac{1}{12}\right)^2$	$\cdots$	$\left(1+\frac{1}{12}\right)^{12}$
Original money	Add 1/12 of the money	Add 1/12 of the money		Add 1/12 of the money

At the end of the year:

How Much Do I Have After 1 Year?

Bank 12

Interests
1/12 every month

Now	**In 1 month**	**In 2 months**	**...**	**In 12 months**
1	$1+\frac{1}{12}$	$\left(1+\frac{1}{12}\right)^2$	$\cdots$	$\left(1+\frac{1}{12}\right)^{12}$
Original money	Add 1/12 of the money	Add 1/12 of the money		Add 1/12 of the money

At the end of the year: 2.61

In General

Bank n

Interests
1/n every interval

In General

Bank n

1	2	3	.	.	.	.	.	.	k	.	.	.	.	.	.	n-2	n-1	n

Interests
1/n every interval

In General

Bank n

1 year

1	2	3	.	.	.	.	.	.	k	.	.	.	.	.	.	n-2	n-1	n

Interests

1/n every interval

In General

Bank n

1 year

1	2	3	.	.	.	.	.	.	k	.	.	.	.	.	.	n-2	n-1	n

Interests
1/n every interval

Now

1

In General

Bank n

1 year

1	2	3	.	.	.	.	.	.	k	.	.	.	.	.	.	n-2	n-1	n

Interests
1/n every interval

Now	**In 1 interval**
1	$1 + \frac{1}{n}$

In General

Bank n

1 year

1	2	3	.	.	.	.	.	.	k	.	.	.	.	.	.	n-2	n-1	n

Interests
1/n every interval

Now	**In 1 interval**	**In 2 intervals**
1	$1 + \frac{1}{n}$	$\left(1 + \frac{1}{n}\right)^2$

In General

Bank n

1 year

1	2	3	.	.	.	.	.	.	k	.	.	.	.	.	.	n-2	n-1	n

Interests
1/n every interval

Now	**In 1 interval**	**In 2 intervals**
1	$1+\frac{1}{n}$	$\left(1+\frac{1}{n}\right)^2$

$$\left(1+\frac{1}{n}\right)+\frac{1}{n}\left(1+\frac{1}{n}\right)$$

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In General

Bank n

1 year

1	2	3	.	.	.	.	.	.	k	.	.	.	.	.	.	n-2	n-1	n

Interests
1/n every interval

Now	**In 1 interval**	**In 2 intervals**
1	$1+\frac{1}{n}$	$\left(1+\frac{1}{n}\right)^2$

$$\left(1+\frac{1}{n}\right)+\frac{1}{n}\left(1+\frac{1}{n}\right)$$

Money

In General

Bank n

1 year

1	2	3	.	.	.	.	.	.	k	.	.	.	.	.	.	n-2	n-1	n

Interests
1/n every interval

Now	**In 1 interval**	**In 2 intervals**
1	$1 + \frac{1}{n}$	$\left(1 + \frac{1}{n}\right)^2$

$$\underbrace{\left(1 + \frac{1}{n}\right)}_{\text{Money}} + \underbrace{\frac{1}{n}\left(1 + \frac{1}{n}\right)}_{\text{Interest}}$$

In General

Bank n

1 year

1	2	3	.	.	.	.	.	.	k	.	.	.	.	.	.	n-2	n-1	n

Interests

1/n every interval

Now	**In 1 interval**	**In 2 intervals**
1	$1+\frac{1}{n}$	$\left(1+\frac{1}{n}\right)^2$

$$\underbrace{\left(1+\frac{1}{n}\right)}_{\text{Money}} + \underbrace{\frac{1}{n}\left(1+\frac{1}{n}\right)}_{\text{Interest}}$$

In General

Bank n

1 year

1	2	3	.	.	.	.	.	.	k	.	.	.	.	.	.	n-2	n-1	n

Interests
1/n every interval

Now	**In 1 interval**	**In 2 intervals**	**In 3 intervals**
1	$1+\frac{1}{n}$	$\left(1+\frac{1}{n}\right)^2$	$\left(1+\frac{1}{n}\right)^3$

$$\underbrace{\left(1+\frac{1}{n}\right)}_{\text{Money}} + \underbrace{\frac{1}{n}\left(1+\frac{1}{n}\right)}_{\text{Interest}}$$

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In General

Bank n

Interests
1/n every interval

1 year

1	2	3	.	.	.	.	.	.	k	.	.	.	.	.	.	n-2	n-1	n

Now	**In 1 interval**	**In 2 intervals**	**In 3 intervals**	...
1	$1+\frac{1}{n}$	$\left(1+\frac{1}{n}\right)^2$	$\left(1+\frac{1}{n}\right)^3$	

$$\underbrace{\left(1+\frac{1}{n}\right)}_{\text{Money}} + \underbrace{\frac{1}{n}\left(1+\frac{1}{n}\right)}_{\text{Interest}}$$

In General

Bank n

1 year

1	2	3	.	.	.	.	.	.	k	.	.	.	.	.	.	n-2	n-1	n

Interests
1/n every interval

Now	**In 1 interval**	**In 2 intervals**	**In 3 intervals**	...	**In k intervals**
1	$1+\frac{1}{n}$	$\left(1+\frac{1}{n}\right)^2$	$\left(1+\frac{1}{n}\right)^3$		$\left(1+\frac{1}{n}\right)^k$

$$\underbrace{\left(1+\frac{1}{n}\right)}_{\text{Money}} + \underbrace{\frac{1}{n}\left(1+\frac{1}{n}\right)}_{\text{Interest}}$$

In General

Bank n

1 year

1	2	3	.	.	.	.	.	.	k	.	.	.	.	.	.	n-2	n-1	n

Interests
1/n every interval

Now	**In 1 interval**	**In 2 intervals**	**In 3 intervals**	...	**In k intervals**	...
1	$1+\frac{1}{n}$	$\left(1+\frac{1}{n}\right)^2$	$\left(1+\frac{1}{n}\right)^3$		$\left(1+\frac{1}{n}\right)^k$	

$$\underbrace{\left(1+\frac{1}{n}\right)}_{\text{Money}} + \underbrace{\frac{1}{n}\left(1+\frac{1}{n}\right)}_{\text{Interest}}$$

In General

Bank n

1 year

1	2	3	.	.	.	.	.	.	k	.	.	.	.	.	.	n-2	n-1	n

Interests
1/n every interval

Now	In 1 interval	In 2 intervals	In 3 intervals	...	In k intervals	...	In 1 year (n intervals)
1	$1+\frac{1}{n}$	$\left(1+\frac{1}{n}\right)^2$	$\left(1+\frac{1}{n}\right)^3$		$\left(1+\frac{1}{n}\right)^k$		$\left(1+\frac{1}{n}\right)^n$

$$\underbrace{\left(1+\frac{1}{n}\right)}_{\text{Money}}+\underbrace{\frac{1}{n}\left(1+\frac{1}{n}\right)}_{\text{Interest}}$$

In General

Bank n

Interests
1/n every interval

In General

Bank n

Interests
1/n every interval

In 1 year

$$\left(1 + \frac{1}{n}\right)^n$$

In General

Bank n

Interests
1/n every interval

In 1 year

$$\left(1 + \frac{1}{n}\right)^n$$

1/n of your money

In General

Bank n

Interests
1/n every interval

In 1 year

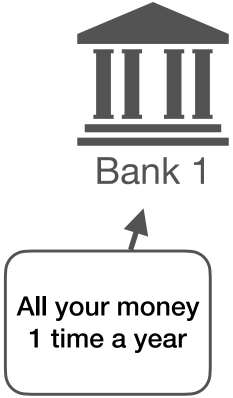
$$\left(1 + \frac{1}{n}\right)^{n}$$

n times

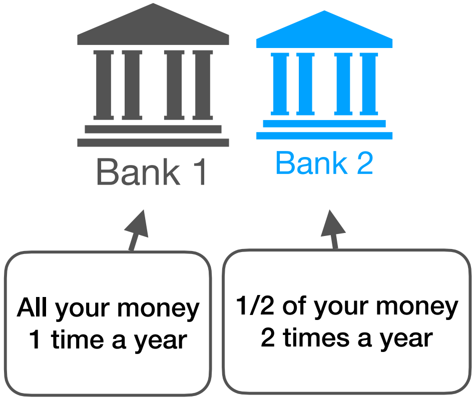
1/n of your money

A Lot of Banks

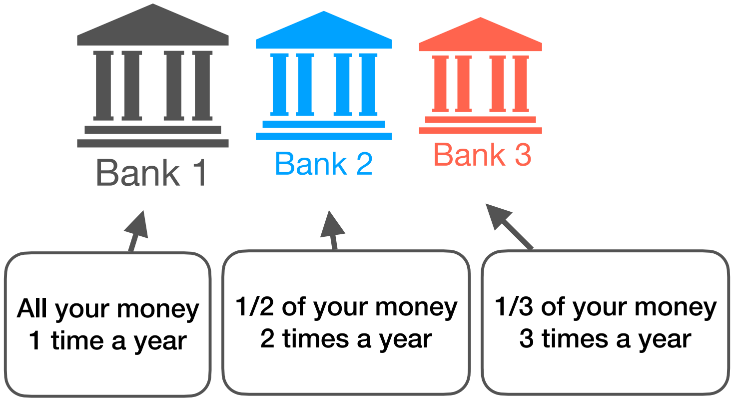
A Lot of Banks



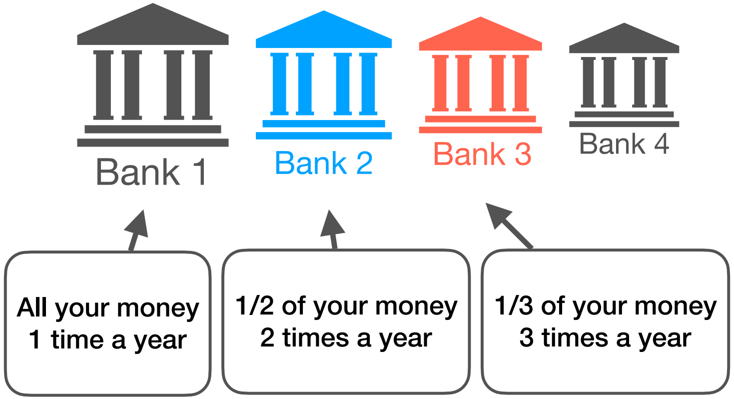
A Lot of Banks



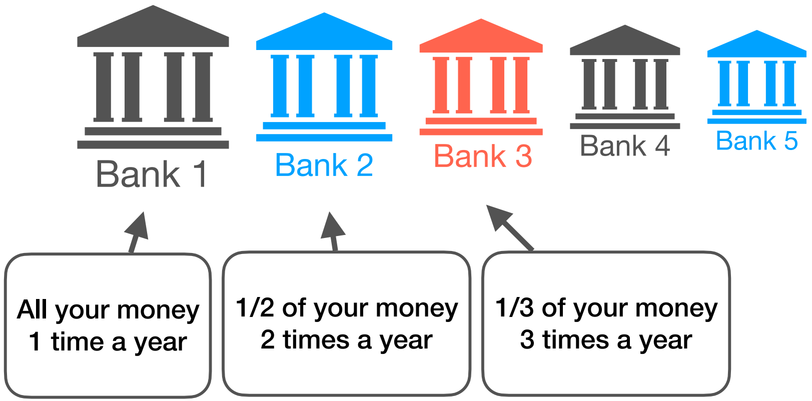
A Lot of Banks



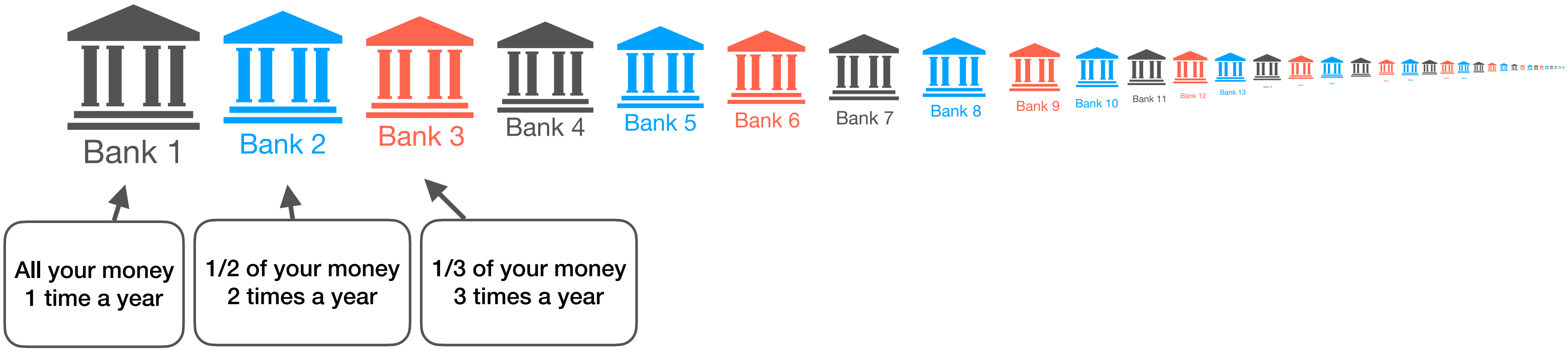
A Lot of Banks



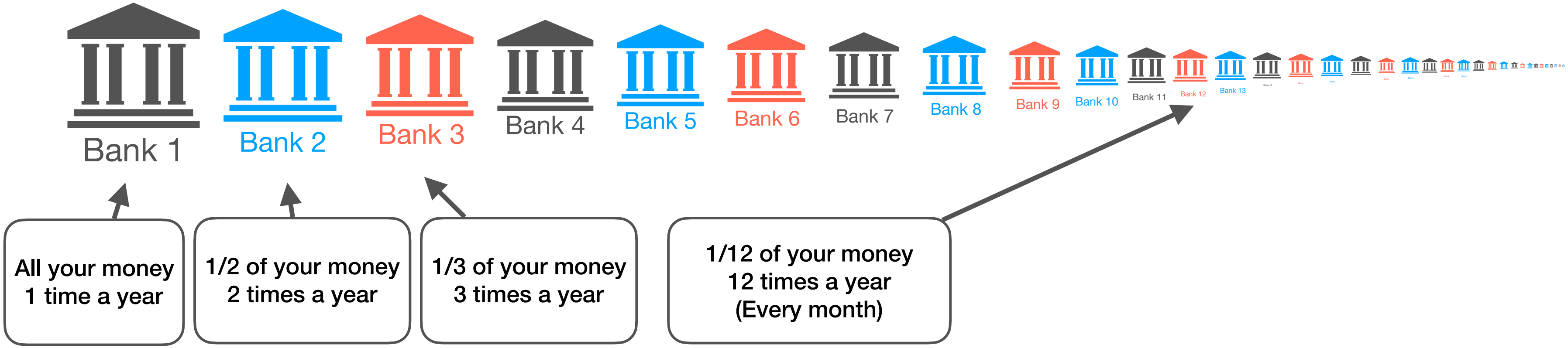
A Lot of Banks



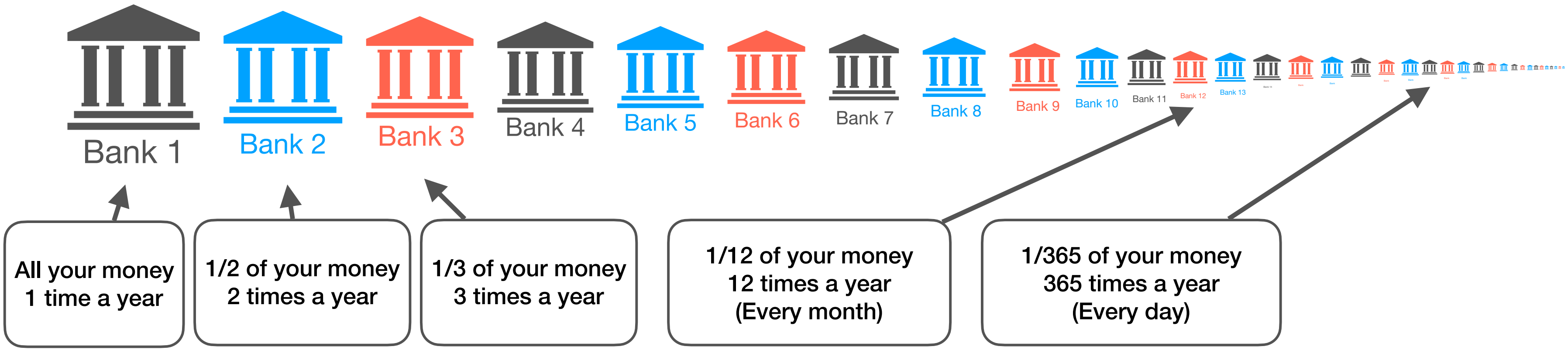
A Lot of Banks



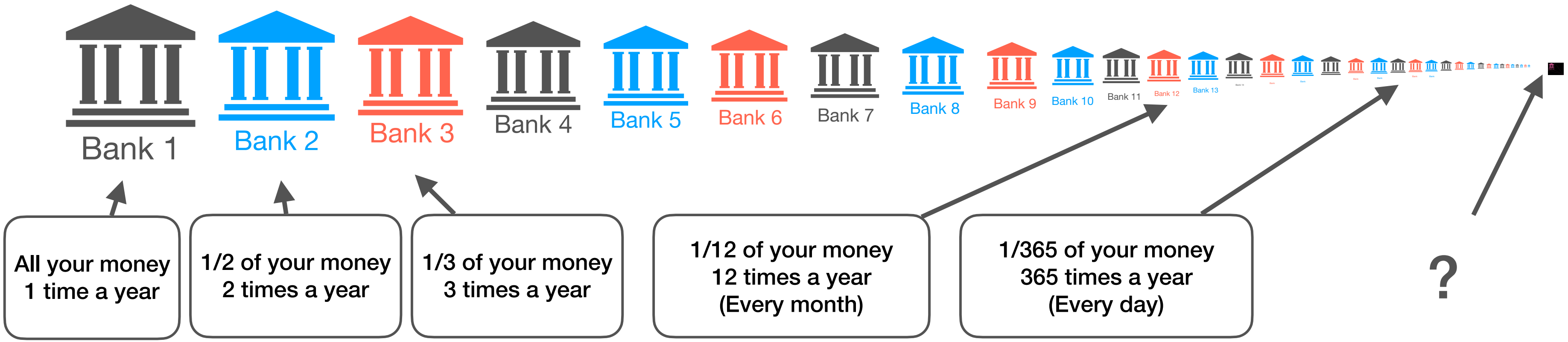
A Lot of Banks



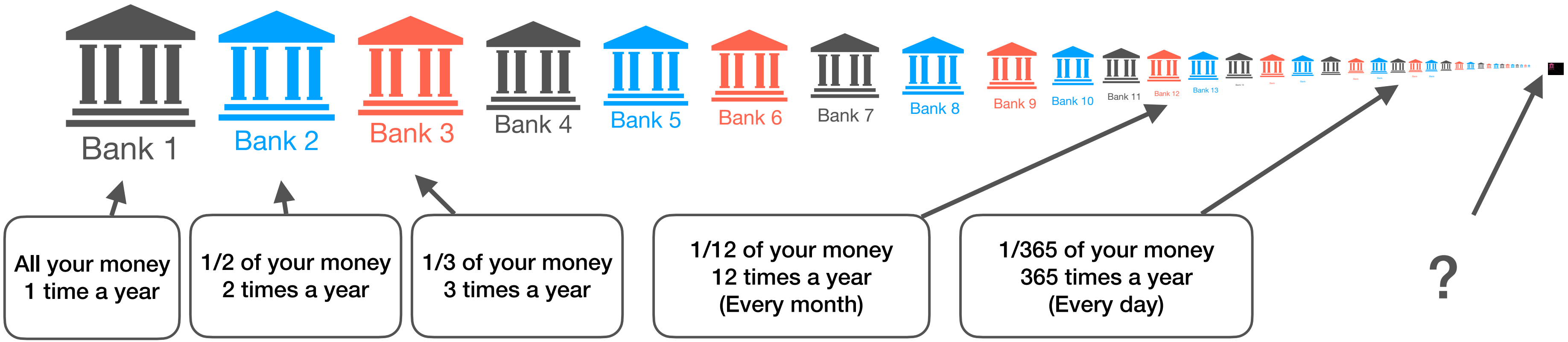
A Lot of Banks



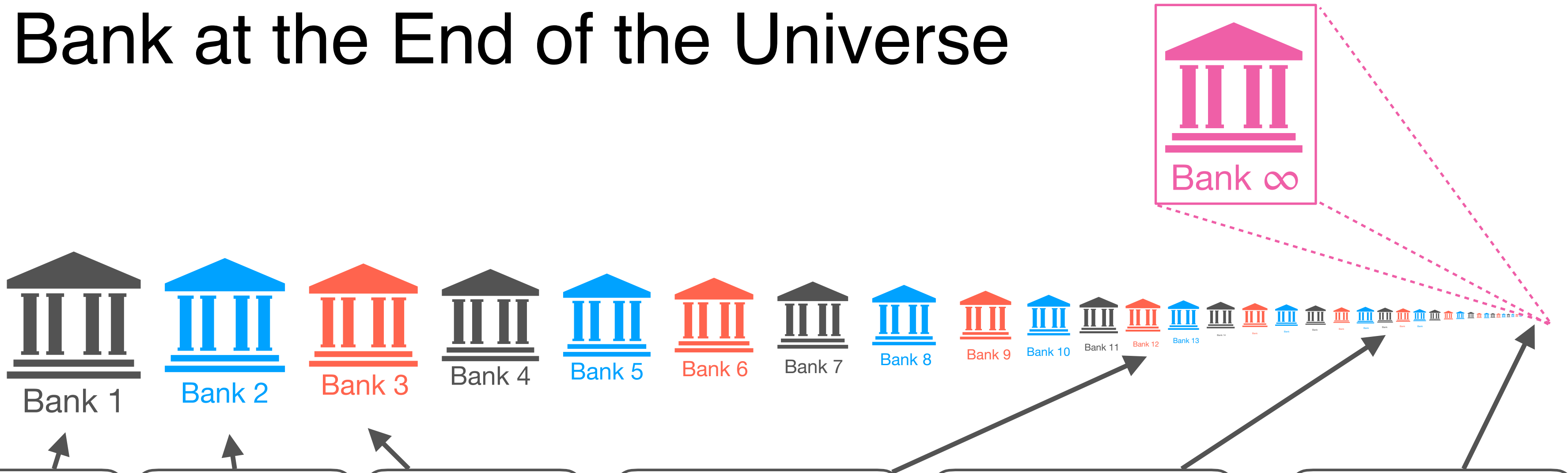
A Lot of Banks



Bank at the end of the universe



Bank at the End of the Universe



All your money
1 time a year

1/2 of your money
2 times a year

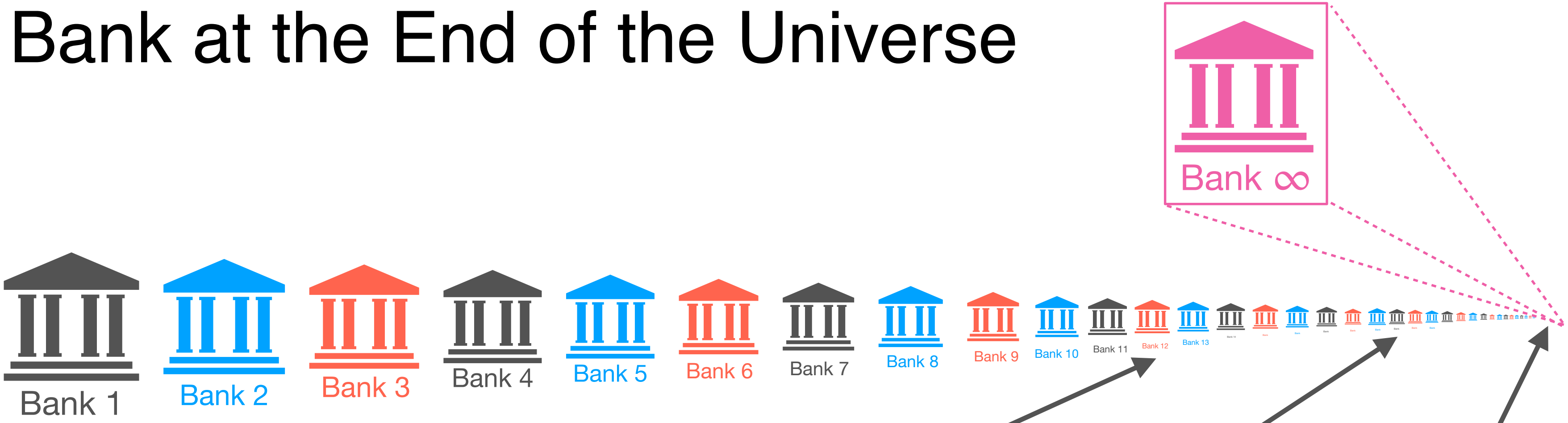
1/3 of your money
3 times a year

1/12 of your money
12 times a year
(Every month)

1/365 of your money
365 times a year
(Every day)

1/∞ of your money
∞ times a year

Bank at the End of the Universe



All your money
1 time a year

1/2 of your money
2 times a year

1/3 of your money
3 times a year

1/12 of your money
12 times a year
(Every month)

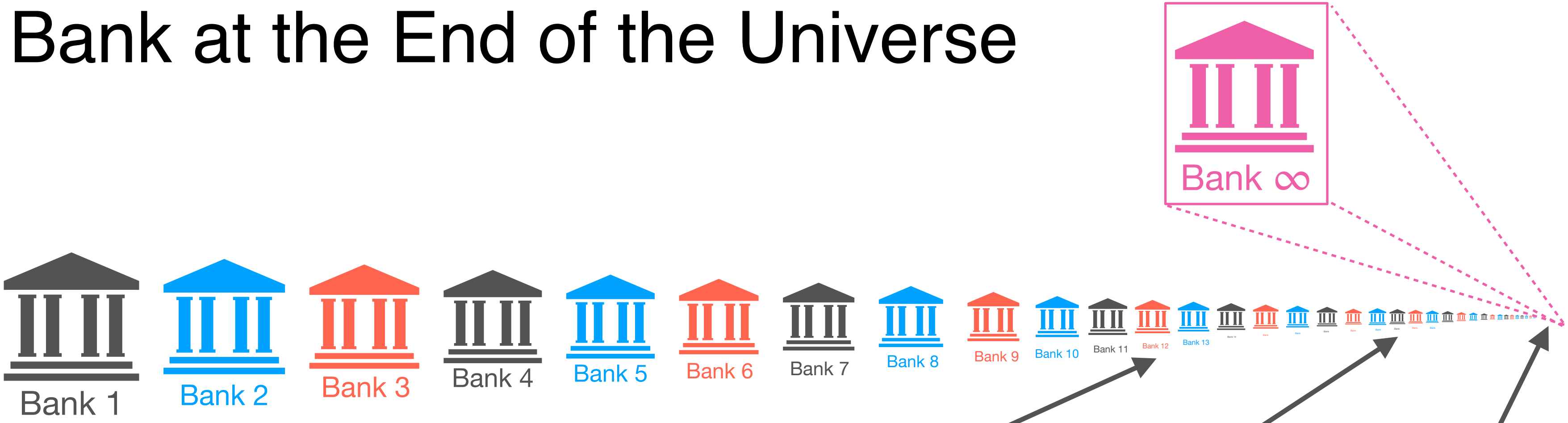
1/365 of your money
365 times a year
(Every day)

1/∞ of your money
∞ times a year

$$(1+1)^1$$

$$2$$

Bank at the End of the Universe



All your money
1 time a year

1/2 of your money
2 times a year

1/3 of your money
3 times a year

1/12 of your money
12 times a year
(Every month)

1/365 of your money
365 times a year
(Every day)

1/∞ of your money
∞ times a year

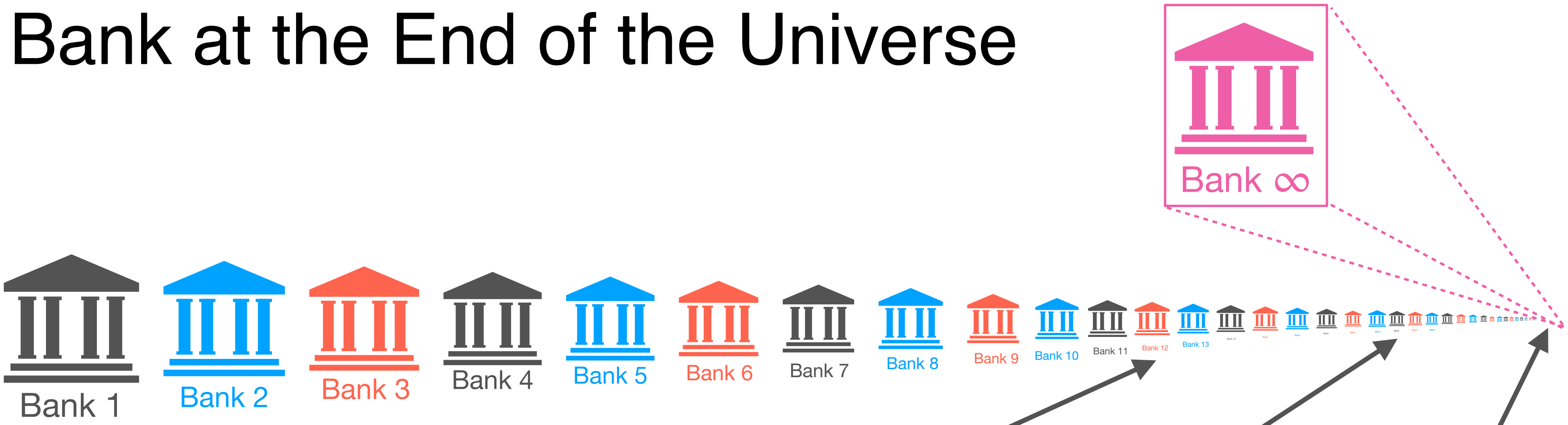
$$(1+1)^1$$

$$2$$

$$\left(1+\frac{1}{2}\right)^2$$

$$2.25$$

Bank at the End of the Universe



All your money
1 time a year

1/2 of your money
2 times a year

1/3 of your money
3 times a year

1/12 of your money
12 times a year
(Every month)

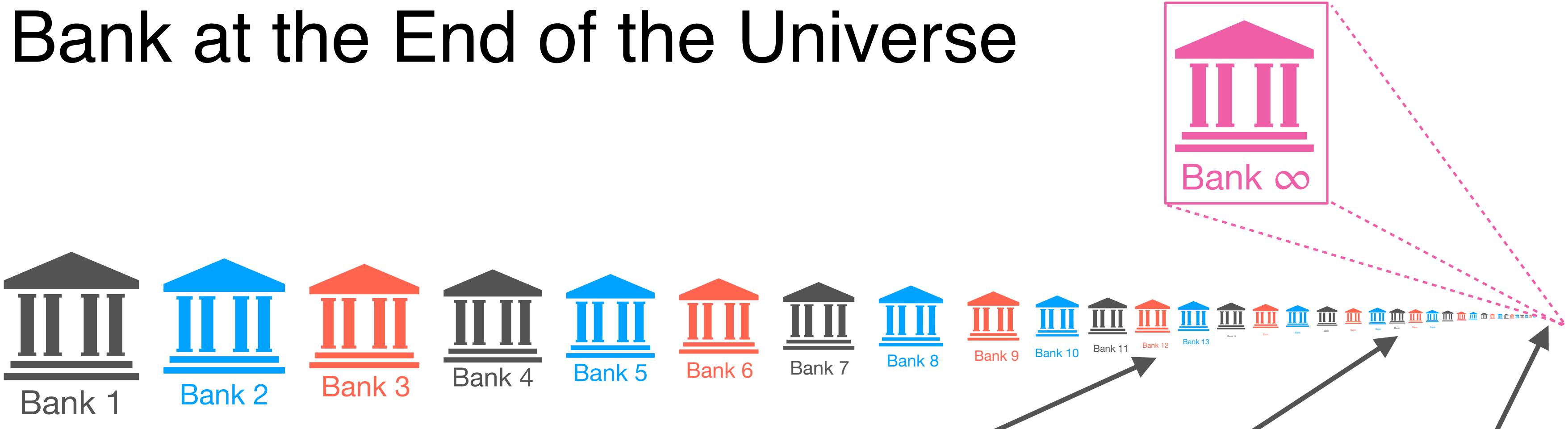
1/365 of your money
365 times a year
(Every day)

1/∞ of your money
∞ times a year

$(1+1)^1$ $\quad$ $\left(1+\frac{1}{2}\right)^2$ $\quad$ $\left(1+\frac{1}{3}\right)^3$

2 $\quad$ 2.25 $\quad$ 2.37

Bank at the End of the Universe



All your money
1 time a year

1/2 of your money
2 times a year

1/3 of your money
3 times a year

1/12 of your money
12 times a year
(Every month)

1/365 of your money
365 times a year
(Every day)

1/∞ of your money
∞ times a year

$$(1+1)^1$$

2

$$\left(1+\frac{1}{2}\right)^2$$

2.25

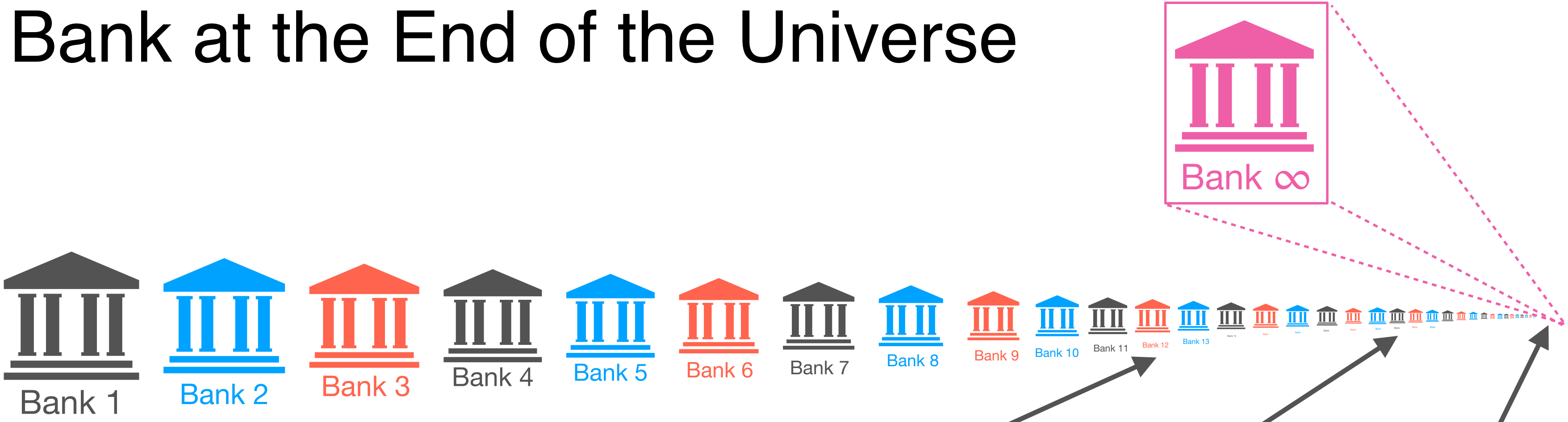
$$\left(1+\frac{1}{3}\right)^3$$

2.37

$$\left(1+\frac{1}{12}\right)^{12}$$

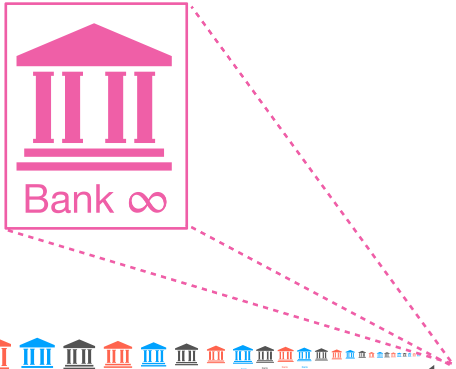
2.613

Bank at the End of the Universe



All your money 1 time a year	1/2 of your money 2 times a year	1/3 of your money 3 times a year	1/12 of your money 12 times a year (Every month)	1/365 of your money 365 times a year (Every day)	1/∞ of your money ∞ times a year
$(1+1)^1$	$\left(1+\frac{1}{2}\right)^2$	$\left(1+\frac{1}{3}\right)^3$	$\left(1+\frac{1}{12}\right)^{12}$	$\left(1+\frac{1}{365}\right)^{365}$	
2	2.25	2.37	2.613	2.7145	

Bank at the End of the Universe



All your money
1 time a year

$$(1+1)^1$$

2

1/2 of your money
2 times a year

$$\left(1+\frac{1}{2}\right)^2$$

2.25

1/3 of your money
3 times a year

$$\left(1+\frac{1}{3}\right)^3$$

2.37

1/12 of your money
12 times a year
(Every month)

$$\left(1+\frac{1}{12}\right)^{12}$$

2.613

1/365 of your money
365 times a year
(Every day)

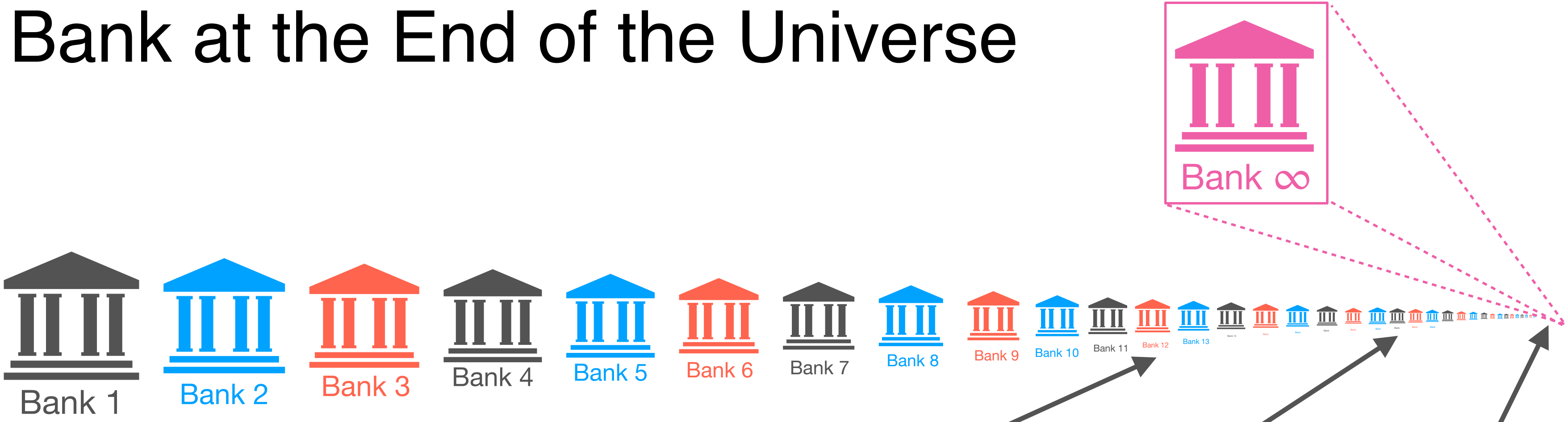
$$\left(1+\frac{1}{365}\right)^{365}$$

2.7145

1/∞ of your money
∞ times a year

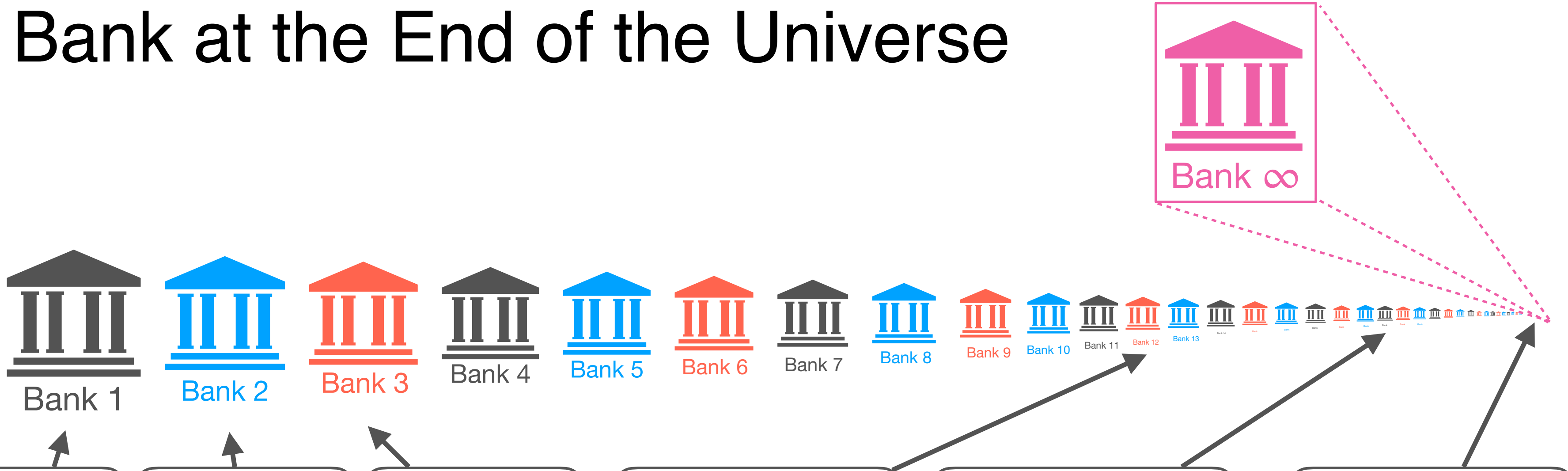
$$\left(1+\frac{1}{\infty}\right)^{\infty}$$

Bank at the End of the Universe



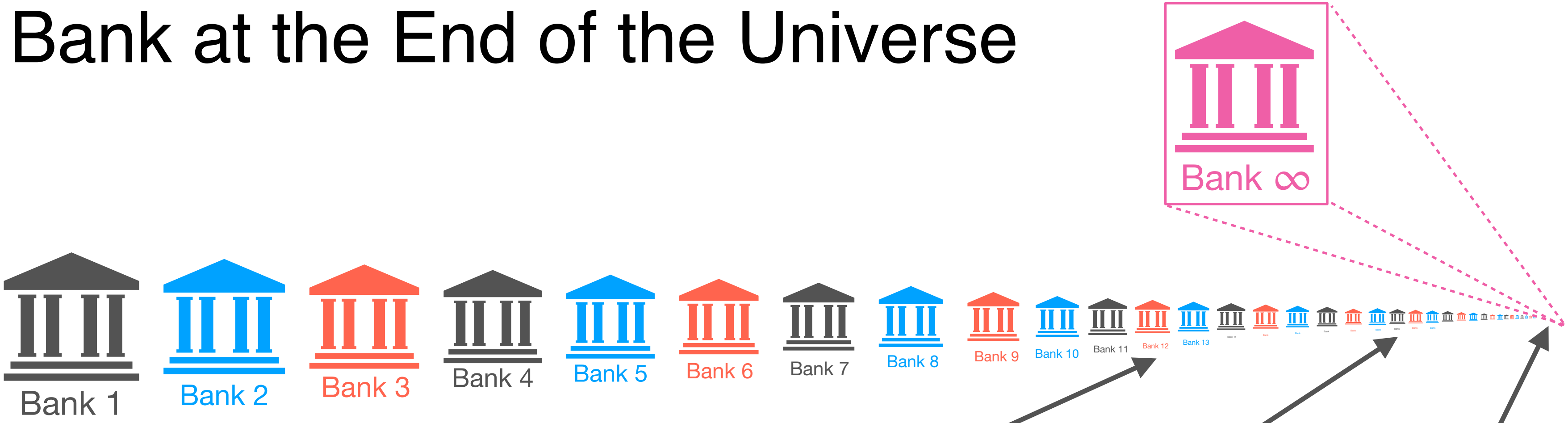
All your money 1 time a year	1/2 of your money 2 times a year	1/3 of your money 3 times a year	1/12 of your money 12 times a year (Every month)	1/365 of your money 365 times a year (Every day)	1/∞ of your money ∞ times a year
$(1+1)^1$	$\left(1+\frac{1}{2}\right)^2$	$\left(1+\frac{1}{3}\right)^3$	$\left(1+\frac{1}{12}\right)^{12}$	$\left(1+\frac{1}{365}\right)^{365}$	
2	2.25	2.37	2.613	2.7145	

Bank at the End of the Universe



All your money 1 time a year	1/2 of your money 2 times a year	1/3 of your money 3 times a year	1/12 of your money 12 times a year (Every month)	1/365 of your money 365 times a year (Every day)	1/∞ of your money ∞ times a year
$(1+1)^1$	$\left(1+\frac{1}{2}\right)^2$	$\left(1+\frac{1}{3}\right)^3$	$\left(1+\frac{1}{12}\right)^{12}$	$\left(1+\frac{1}{365}\right)^{365}$	
2	2.25	2.37	2.613	2.7145	2.71828182...

Bank at the End of the Universe



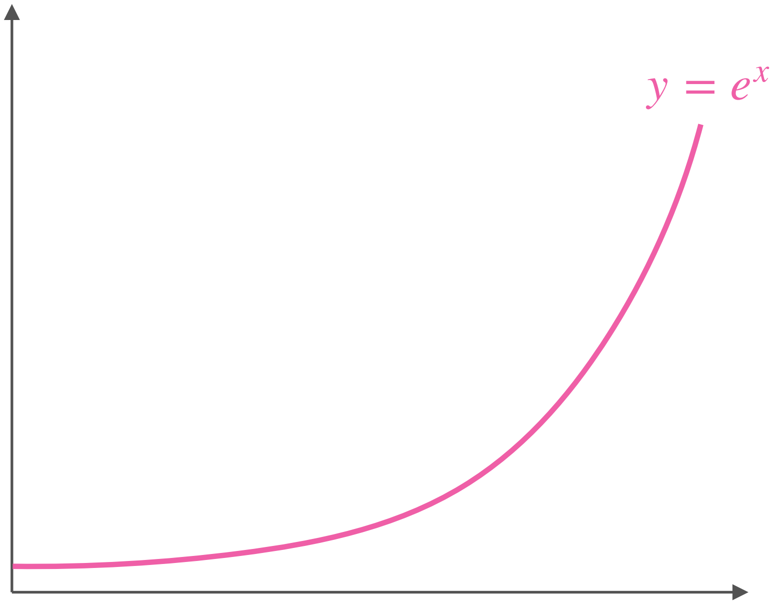
All your money 1 time a year	1/2 of your money 2 times a year	1/3 of your money 3 times a year	1/12 of your money 12 times a year (Every month)	1/365 of your money 365 times a year (Every day)	1/∞ of your money ∞ times a year
$(1+1)^1$	$\left(1+\frac{1}{2}\right)^2$	$\left(1+\frac{1}{3}\right)^3$	$\left(1+\frac{1}{12}\right)^{12}$	$\left(1+\frac{1}{365}\right)^{365}$	
2	2.25	2.37	2.613	2.7145	$e = 2.71828182...$

DeepLearning.AI

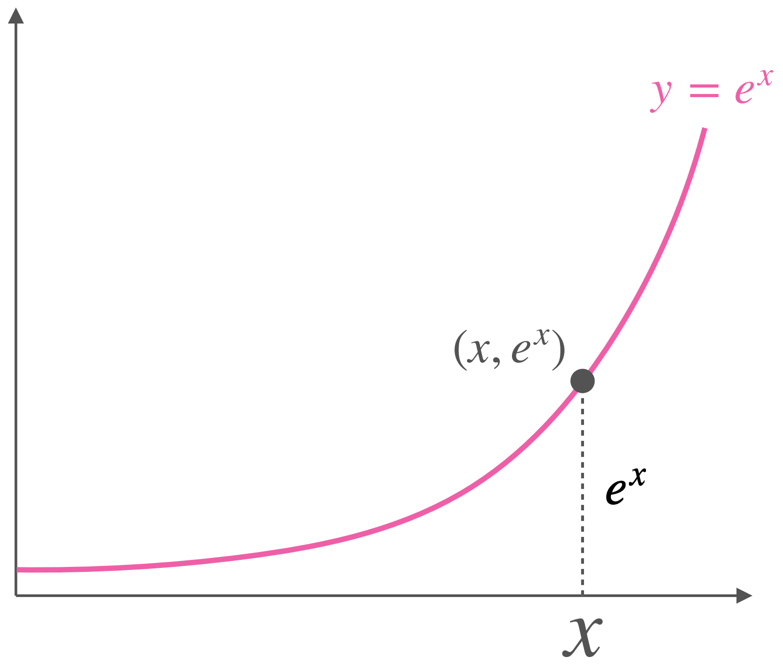
Derivatives and Optimization

The derivative of e^x

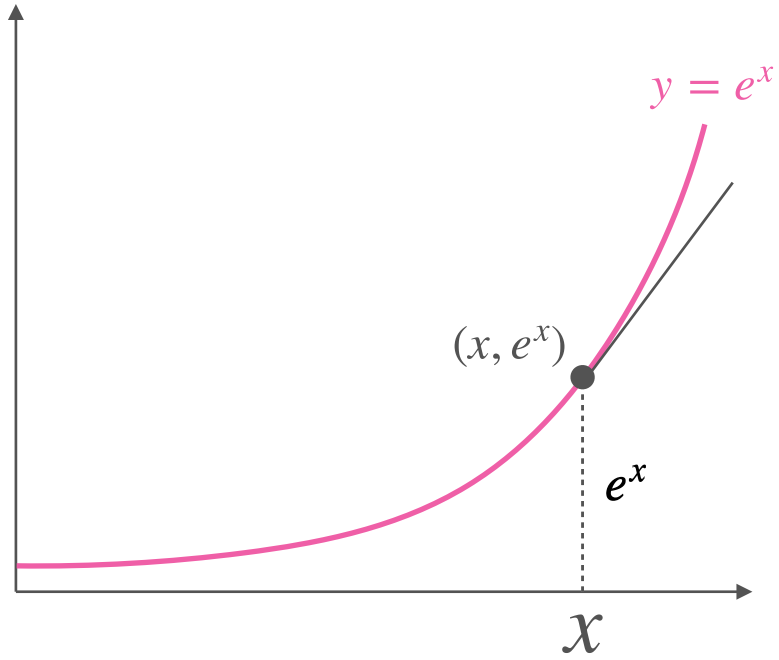
The Derivative of e^x Is Also e^x



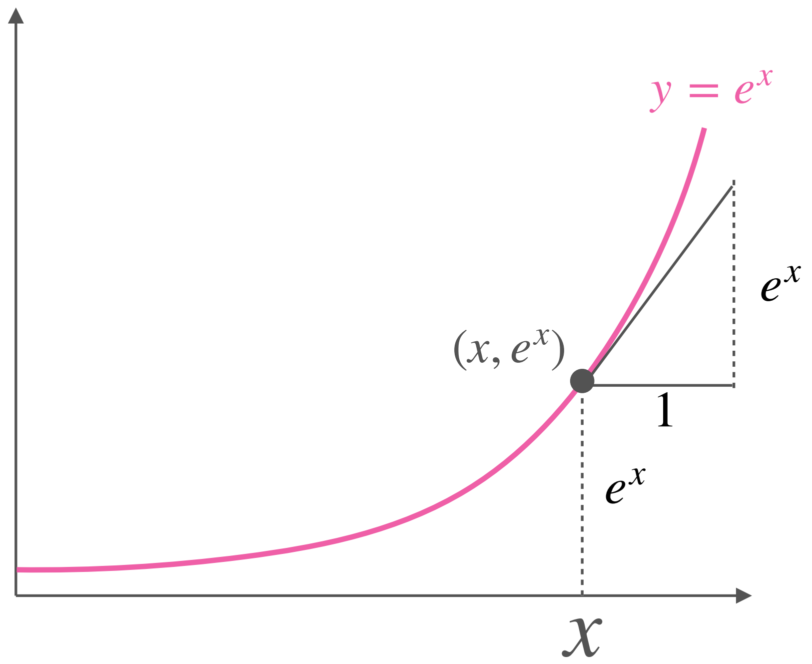
The Derivative of e^x Is Also e^x



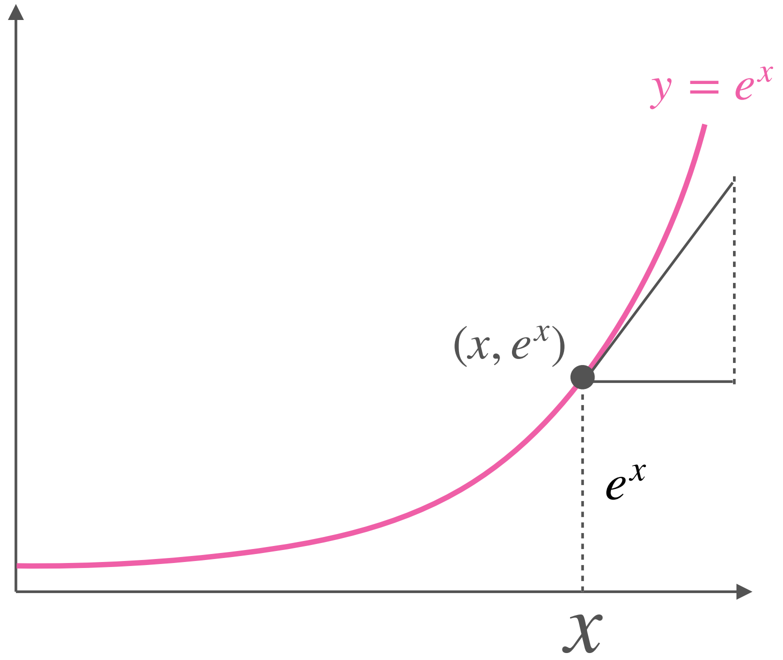
The Derivative of e^x Is Also e^x



The Derivative of e^x Is Also e^x

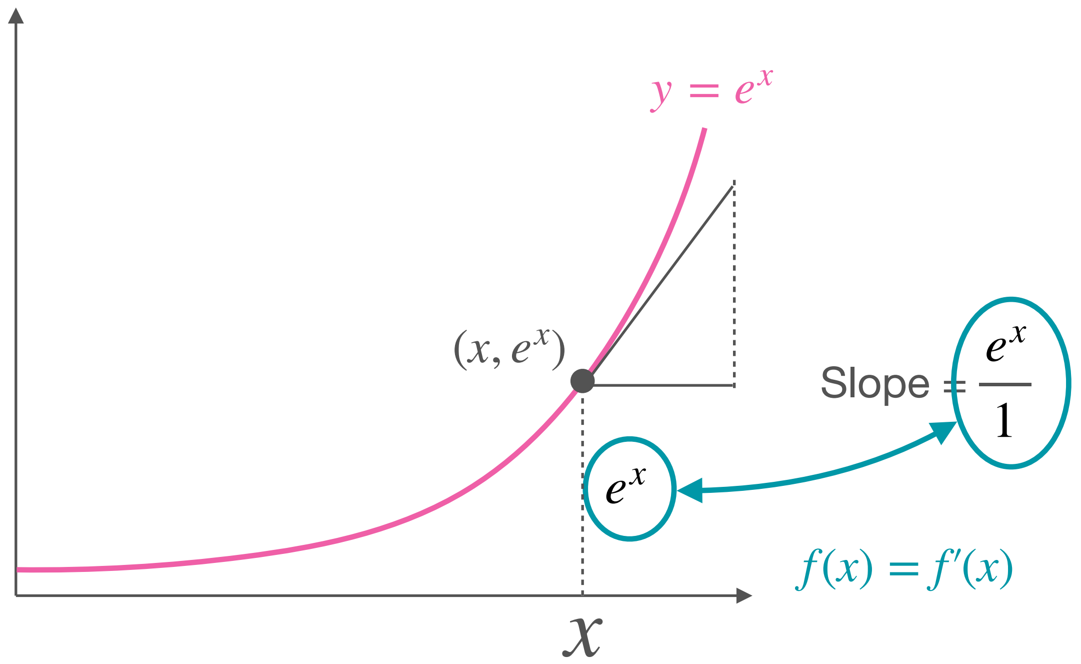


The Derivative of e^x Is Also e^x



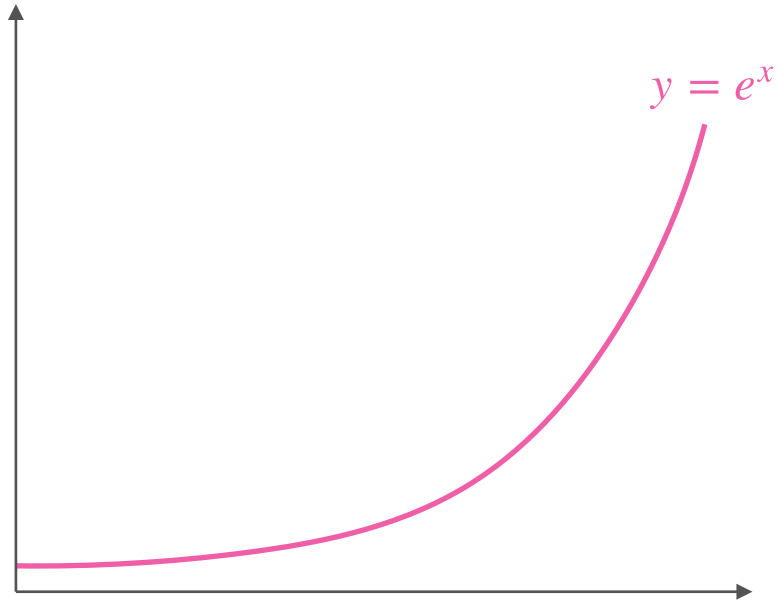
Slope $= \dfrac{e^x}{1}$

The Derivative of e^x Is Also e^x



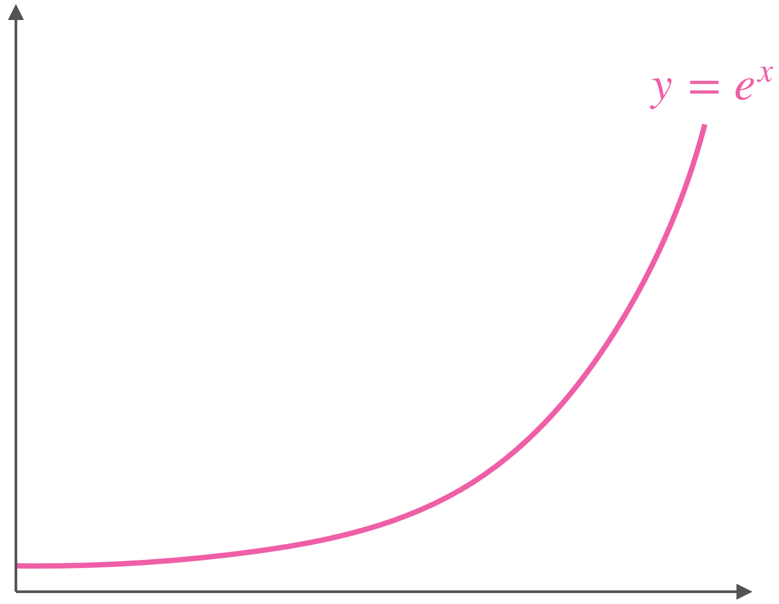
Derivative of e^x

Derivative of e^x



Exponential: $y = f(x) = e^x$

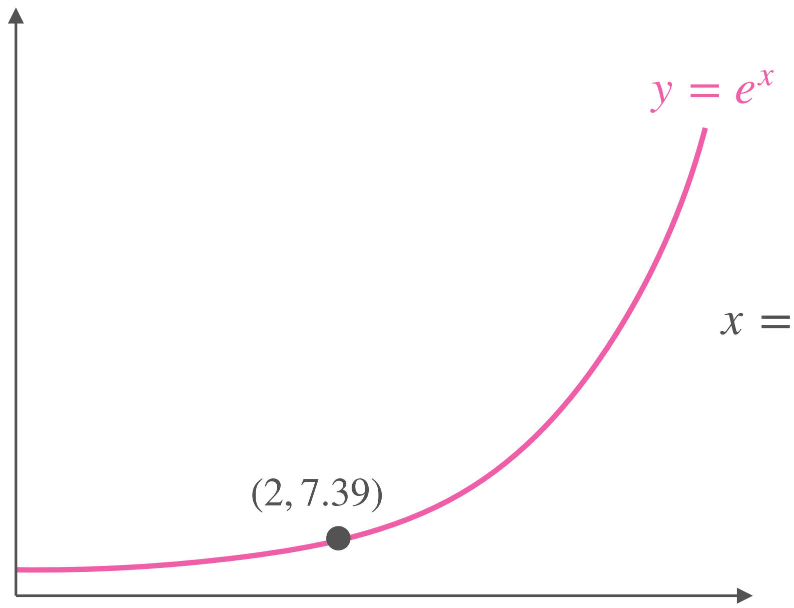
Derivative of e^x



Exponential: $y = f(x) = e^x$

Slope: $\dfrac{\Delta f}{\Delta x} = \dfrac{e^{x+\Delta x} - e^x}{\Delta x}$

Derivative of e^x

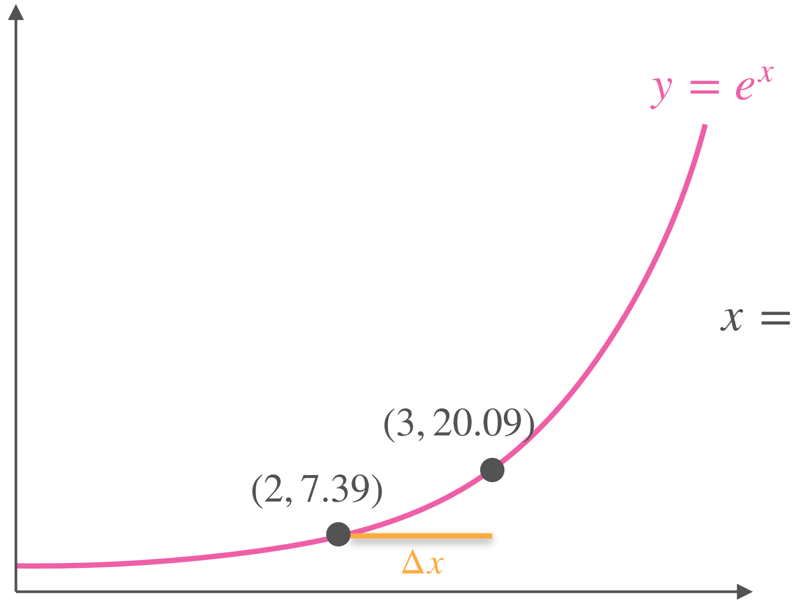


$x = 2$

Exponential: $y = f(x) = e^x$

Slope: $\dfrac{\Delta f}{\Delta x} = \dfrac{e^{x+\Delta x} - e^x}{\Delta x}$

Derivative of e^x



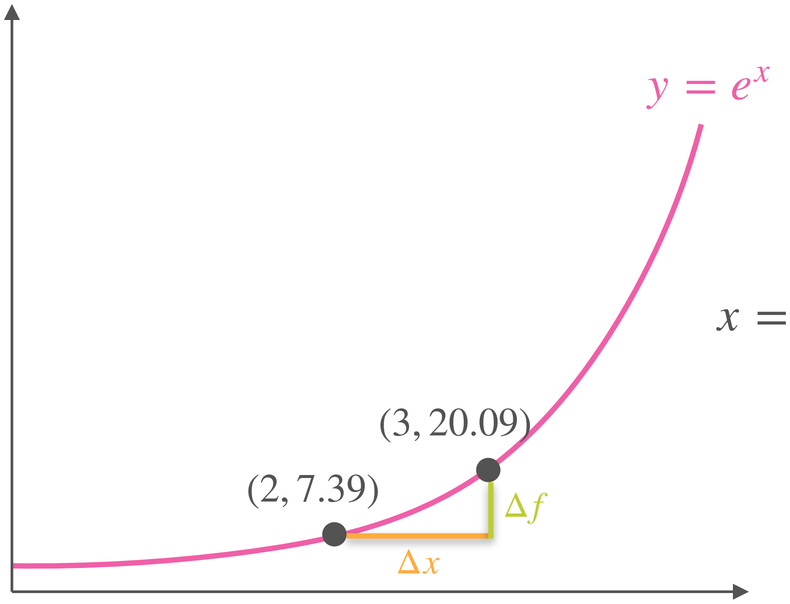
Exponential: $y = f(x) = e^x$

Slope: $\frac{\Delta f}{\Delta x} = \frac{e^{x+\Delta x} - e^x}{\Delta x}$

$x = 2$

Δx	1.0

Derivative of e^x



Exponential: $y = f(x) = e^x$

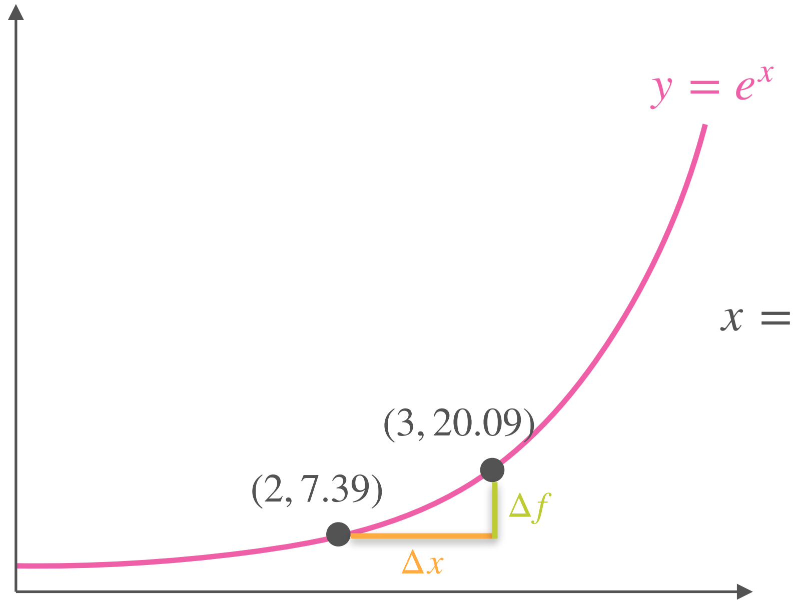
Slope: $\dfrac{\Delta f}{\Delta x} = \dfrac{e^{x+\Delta x} - e^x}{\Delta x}$

$x = 2$

Δx	1.0
Δf	12.70

$e^{2+1} - e^2 = 20.09 - 7.39$

Derivative of e^x



Exponential: $y = f(x) = e^x$

Slope: $\dfrac{\Delta f}{\Delta x} = \dfrac{e^{x+\Delta x} - e^x}{\Delta x}$

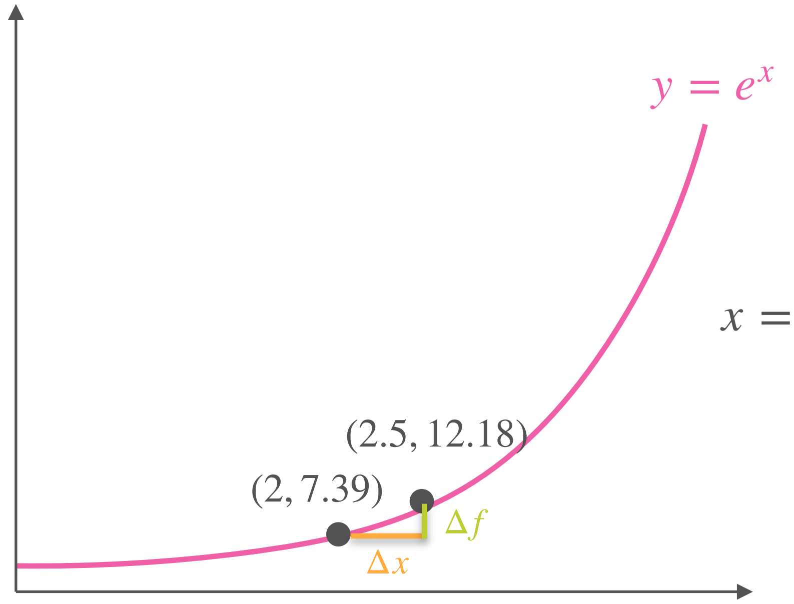
$x = 2$

Δx	1.0
Δf	12.70
Slope	12.70

$e^{2+1} - e^2 = 20.09 - 7.39$

$\dfrac{12.70}{1}$

Derivative of e^x



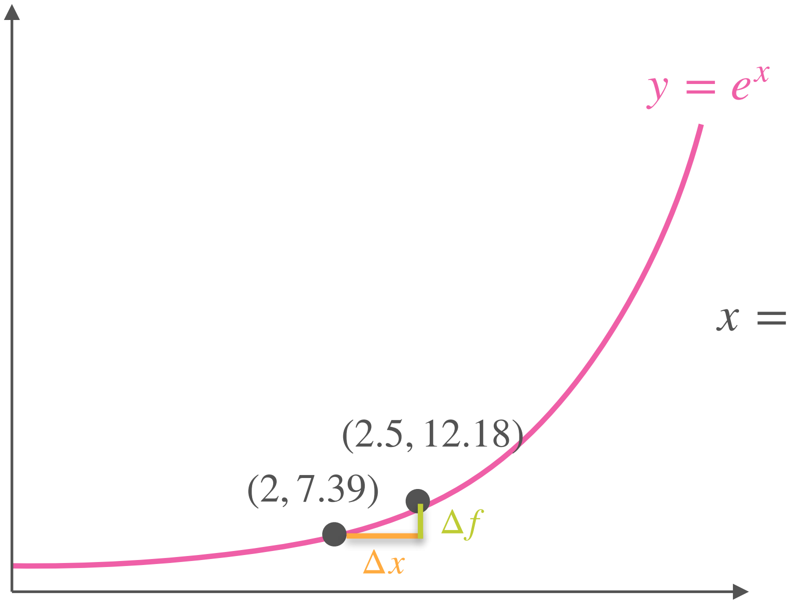
Exponential: $y = f(x) = e^x$

Slope: $\dfrac{\Delta f}{\Delta x} = \dfrac{e^{x+\Delta x} - e^x}{\Delta x}$

$x = 2$

Δx	1.0	1/2
Δf	12.70	
Slope	12.70	

Derivative of e^x



Exponential: $y = f(x) = e^x$

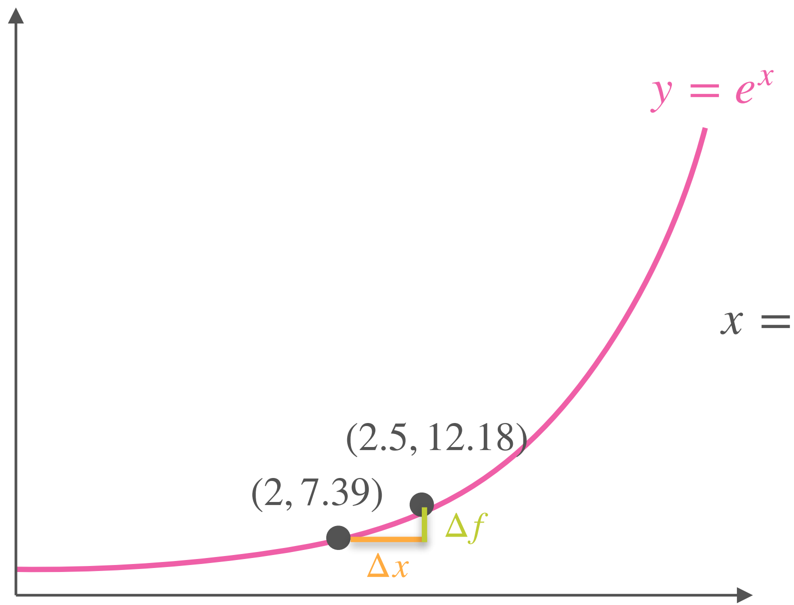
Slope: $\dfrac{\Delta f}{\Delta x} = \dfrac{e^{x+\Delta x} - e^x}{\Delta x}$

$x = 2$

Δx	1.0	1/2
Δf	12.70	4.79
Slope	12.70	

$e^{2+0.5} - e^2 = 12.18 - 7.39$

Derivative of e^x



Exponential: $y = f(x) = e^x$

Slope: $\dfrac{\Delta f}{\Delta x} = \dfrac{e^{x+\Delta x} - e^x}{\Delta x}$

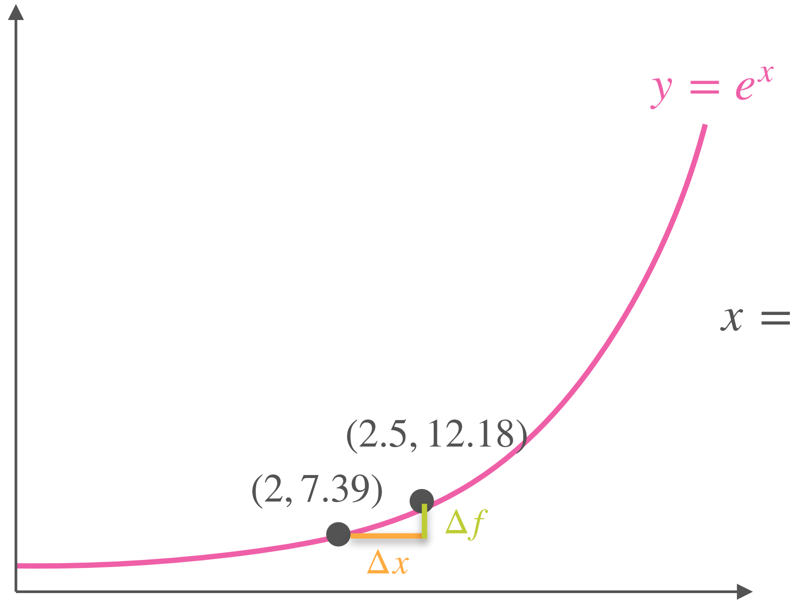
$x = 2$

Δx	1.0	1/2
Δf	12.70	4.79
Slope	12.70	9.59

$e^{2+0.5} - e^2 = 12.18 - 7.39$

$\dfrac{4.79}{0.5}$

Derivative of e^x



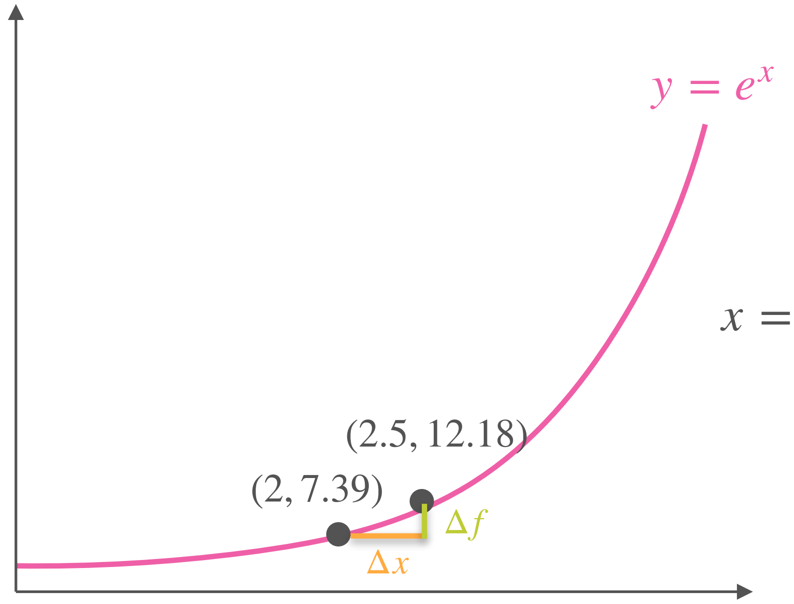
Exponential: $y = f(x) = e^x$

Slope: $\frac{\Delta f}{\Delta x} = \frac{e^{x+\Delta x} - e^x}{\Delta x}$

$x = 2$

Δx	1.0	1/2	1/4
Δf	12.70	4.79	
Slope	12.70	9.59	

Derivative of e^x



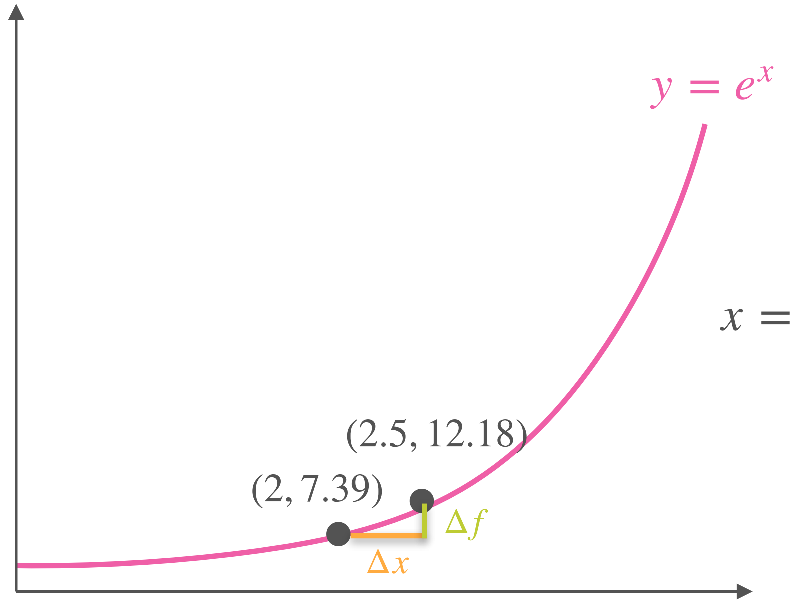
Exponential: $y = f(x) = e^x$

Slope: $\frac{\Delta f}{\Delta x} = \frac{e^{x+\Delta x} - e^x}{\Delta x}$

$x = 2$

Δx	1.0	1/2	1/4
Δf	12.70	4.79	2.10
Slope	12.70	9.59	

Derivative of e^x



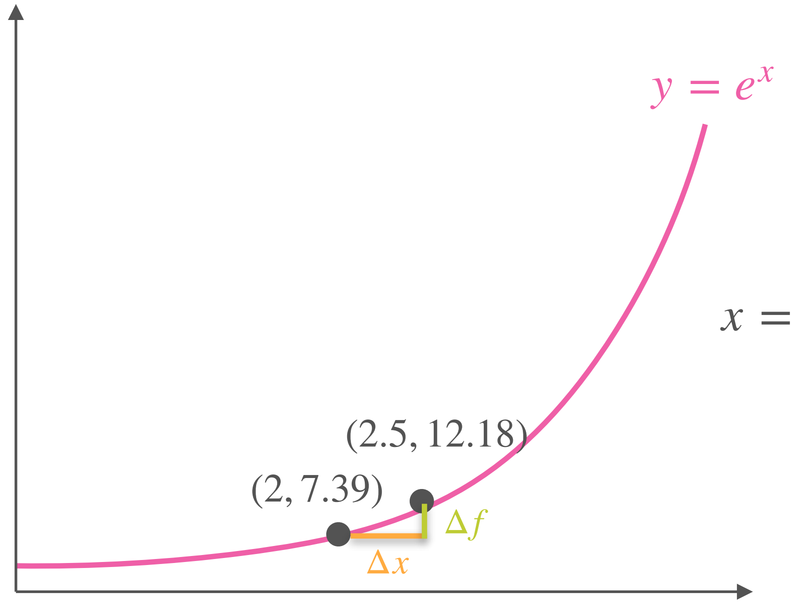
Exponential: $y = f(x) = e^x$

Slope: $\dfrac{\Delta f}{\Delta x} = \dfrac{e^{x+\Delta x} - e^x}{\Delta x}$

$x = 2$

Δx	1.0	1/2	1/4
Δf	12.70	4.79	2.10
Slope	12.70	9.59	8.39

Derivative of e^x



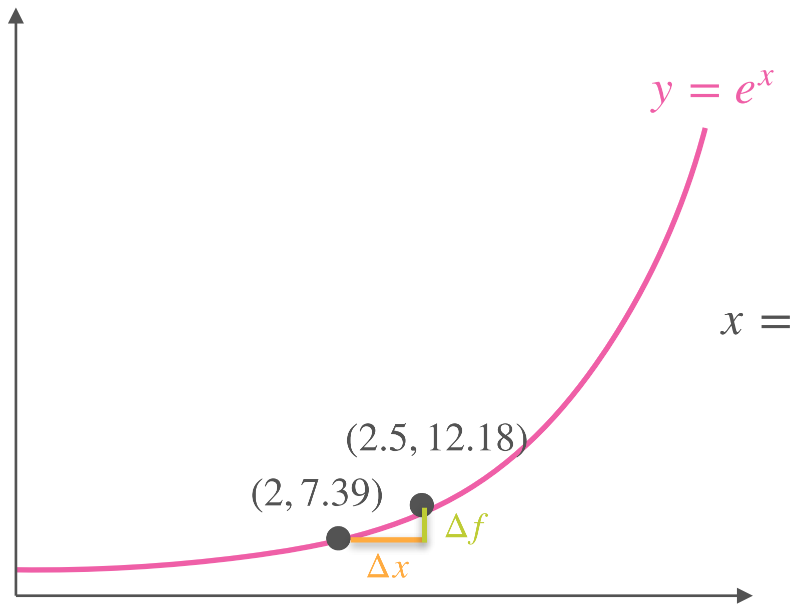
Exponential: $y = f(x) = e^x$

Slope: $\dfrac{\Delta f}{\Delta x} = \dfrac{e^{x+\Delta x} - e^x}{\Delta x}$

$x = 2$

Δx	1.0	1/2	1/4	1/8
Δf	12.70	4.79	2.10	
Slope	12.70	9.59	8.39	

Derivative of e^x



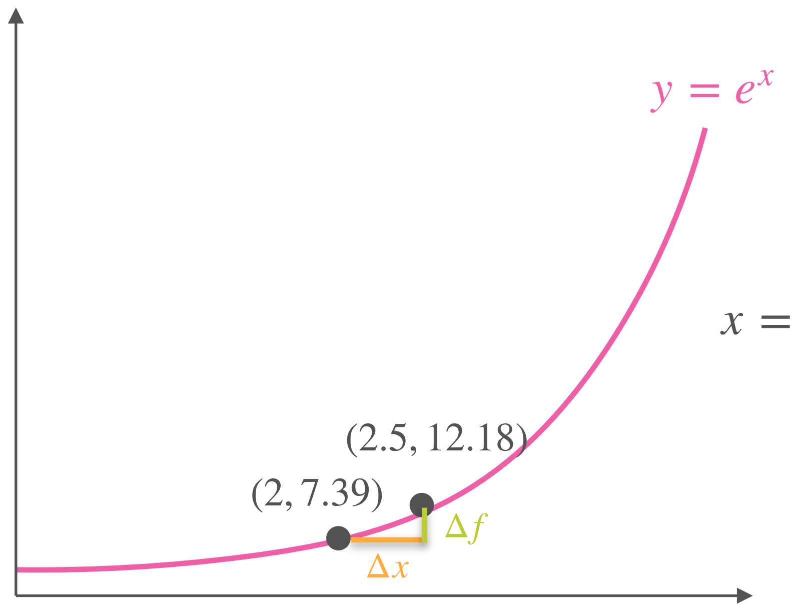
Exponential: $y = f(x) = e^x$

Slope: $\frac{\Delta f}{\Delta x} = \frac{e^{x+\Delta x} - e^x}{\Delta x}$

$x = 2$

Δx	1.0	1/2	1/4	1/8
Δf	12.70	4.79	2.10	0.98
Slope	12.70	9.59	8.39	

Derivative of e^x



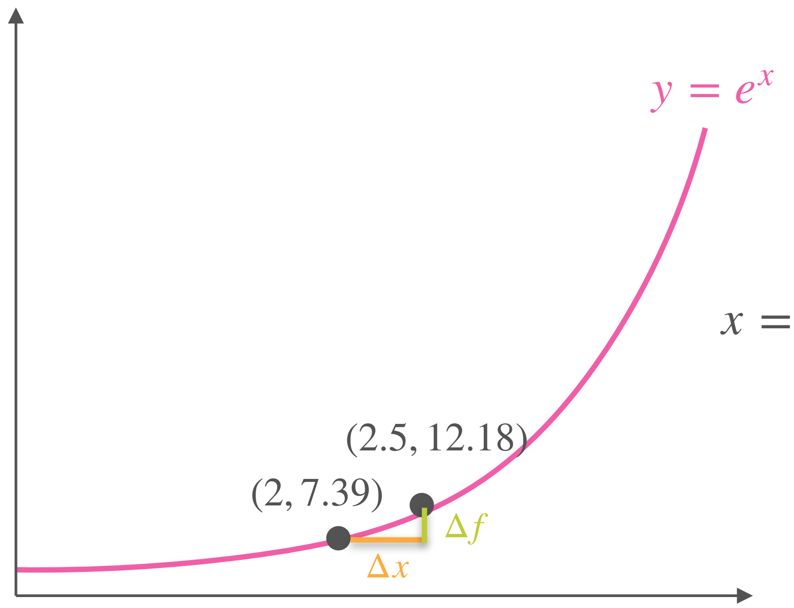
Exponential: $y = f(x) = e^x$

Slope: $\frac{\Delta f}{\Delta x} = \frac{e^{x+\Delta x} - e^x}{\Delta x}$

$x = 2$

Δx	1.0	1/2	1/4	1/8
Δf	12.70	4.79	2.10	0.98
Slope	12.70	9.59	8.39	7.87

Derivative of e^x



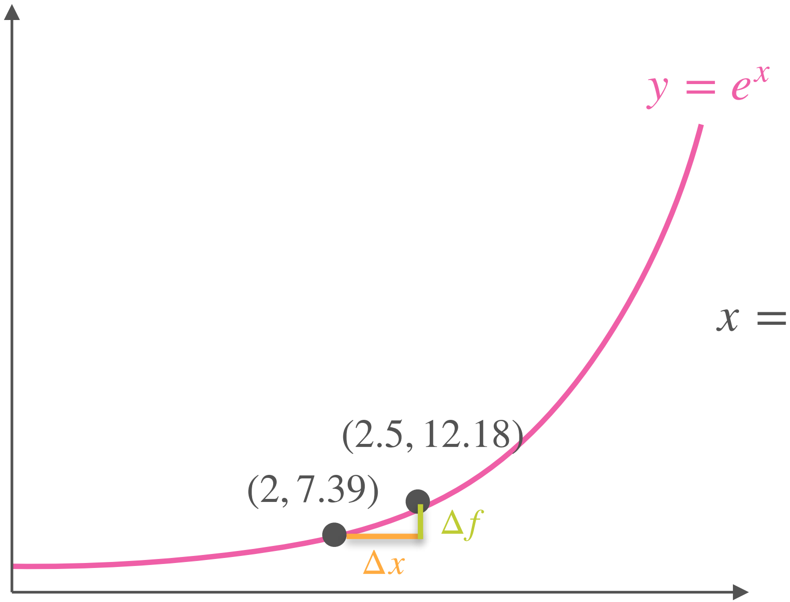
Exponential: $y = f(x) = e^x$

Slope: $\frac{\Delta f}{\Delta x} = \frac{e^{x+\Delta x} - e^x}{\Delta x}$

$x = 2$

Δx	1.0	1/2	1/4	1/8	1/16
Δf	12.70	4.79	2.10	0.98	
Slope	12.70	9.59	8.39	7.87	

Derivative of e^x



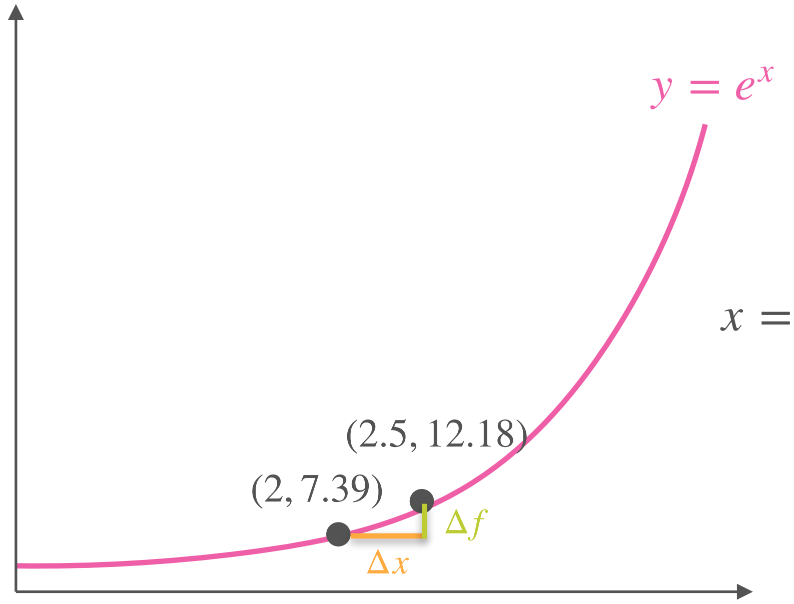
Exponential: $y = f(x) = e^x$

Slope: $\frac{\Delta f}{\Delta x} = \frac{e^{x+\Delta x} - e^x}{\Delta x}$

$x = 2$

Δx	1.0	1/2	1/4	1/8	1/16
Δf	12.70	4.79	2.10	0.98	0.48
Slope	12.70	9.59	8.39	7.87	

Derivative of e^x



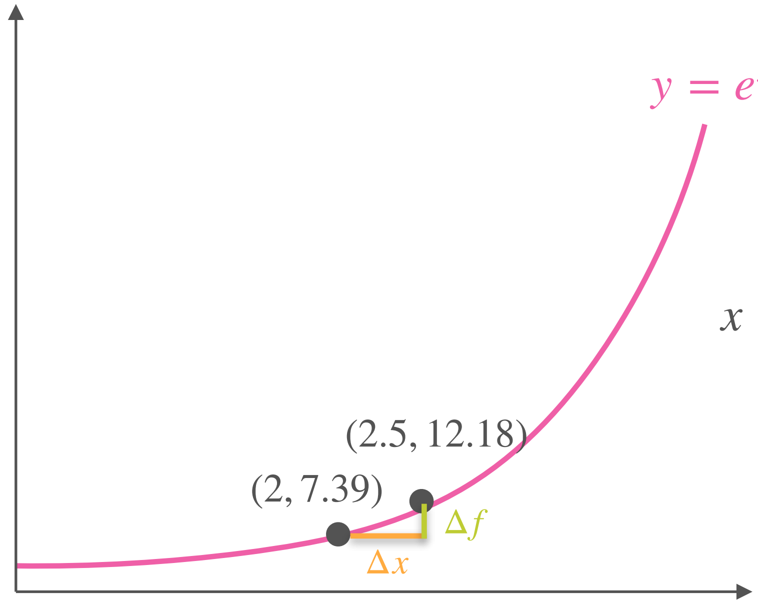
Exponential: $y = f(x) = e^x$

Slope: $\dfrac{\Delta f}{\Delta x} = \dfrac{e^{x+\Delta x} - e^x}{\Delta x}$

$x = 2$

Δx	1.0	1/2	1/4	1/8	1/16
Δf	12.70	4.79	2.10	0.98	0.48
Slope	12.70	9.59	8.39	7.87	7.62

Derivative of e^x



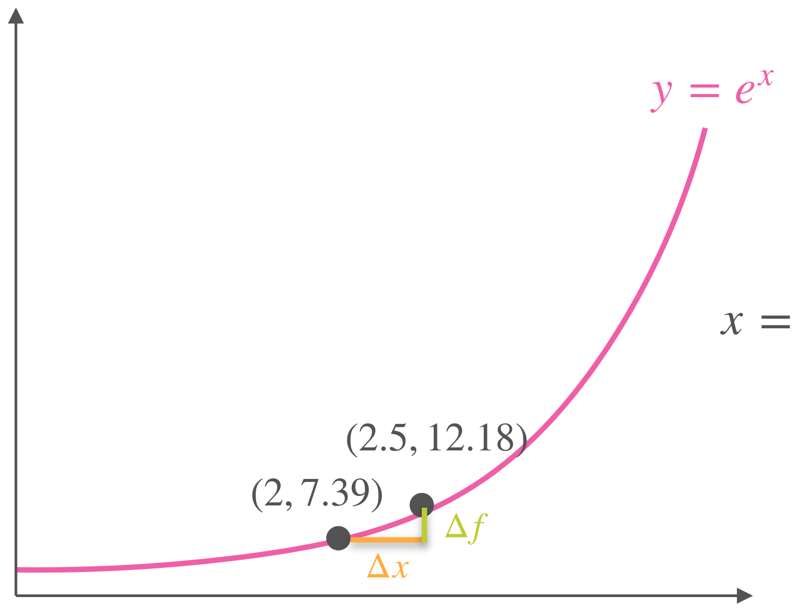
Exponential: $y = f(x) = e^x$

Slope: $\dfrac{\Delta f}{\Delta x} = \dfrac{e^{x+\Delta x} - e^x}{\Delta x}$

$x = 2$

Δx	1.0	1/2	1/4	1/8	1/16	1/1000
Δf	12.70	4.79	2.10	0.98	0.48	
Slope	12.70	9.59	8.39	7.87	7.62	

Derivative of e^x



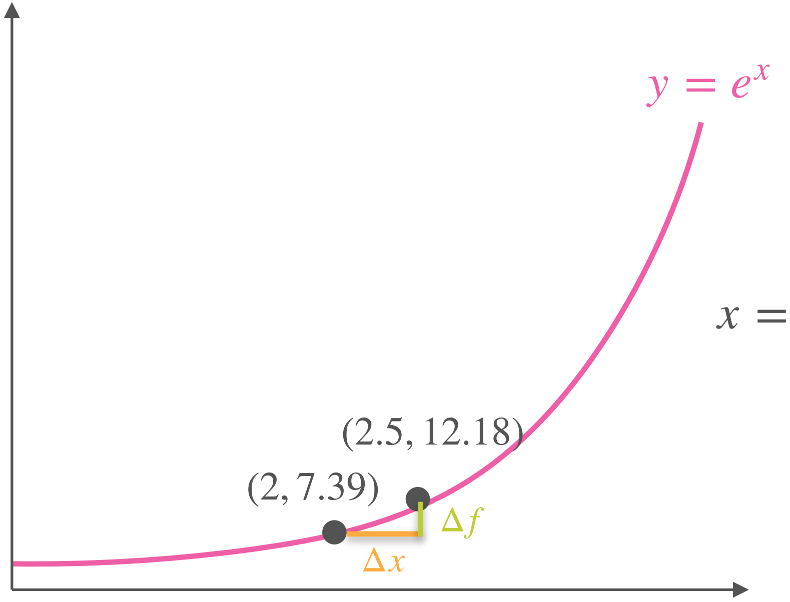
Exponential: $y = f(x) = e^x$

Slope: $\dfrac{\Delta f}{\Delta x} = \dfrac{e^{x+\Delta x} - e^x}{\Delta x}$

$x = 2$

Δx	1.0	1/2	1/4	1/8	1/16	1/1000
Δf	12.70	4.79	2.10	0.98	0.48	0.007
Slope	12.70	9.59	8.39	7.87	7.62	

Derivative of e^x



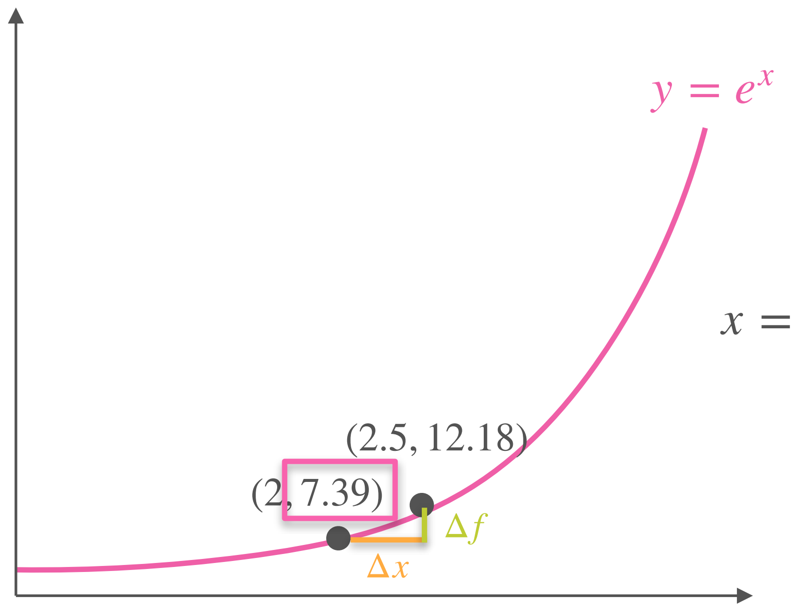
Exponential: $y = f(x) = e^x$

Slope: $\dfrac{\Delta f}{\Delta x} = \dfrac{e^{x+\Delta x} - e^x}{\Delta x}$

$x = 2$

Δx	1.0	1/2	1/4	1/8	1/16	1/1000
Δf	12.70	4.79	2.10	0.98	0.48	0.007
Slope	12.70	9.59	8.39	7.87	7.62	7.39

Derivative of e^x



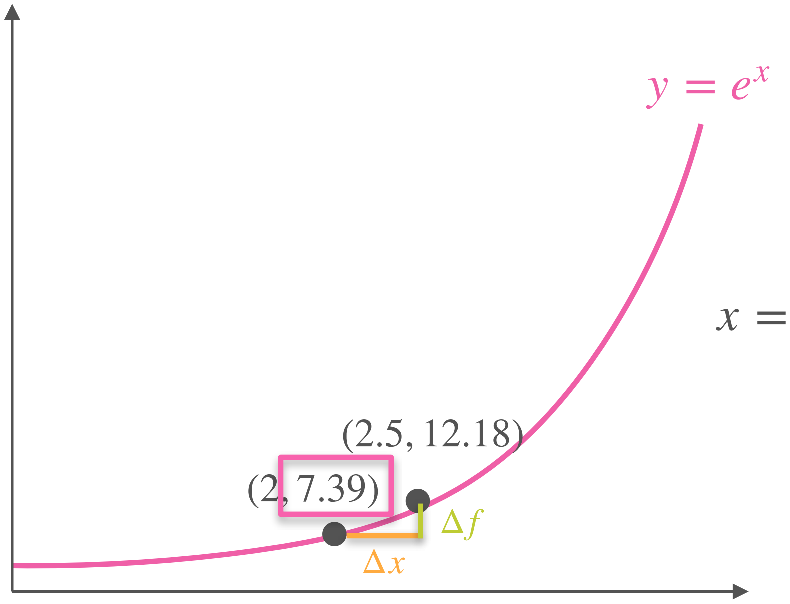
Exponential: $y = f(x) = e^x$

Slope: $\dfrac{\Delta f}{\Delta x} = \dfrac{e^{x+\Delta x} - e^x}{\Delta x}$

$x = 2$

Δx	1.0	1/2	1/4	1/8	1/16	1/1000
Δf	12.70	4.79	2.10	0.98	0.48	0.007
Slope	12.70	9.59	8.39	7.87	7.62	$\boxed{7.39}$

Derivative of e^x



Exponential: $y = f(x) = e^x$

Slope: $\dfrac{\Delta f}{\Delta x} = \dfrac{e^{x+\Delta x} - e^x}{\Delta x}$

$x = 2$

Δx	1.0	1/2	1/4	1/8	1/16	1/1000
Δf	12.70	4.79	2.10	0.98	0.48	0.007
Slope	12.70	9.59	8.39	7.87	7.62	$\boxed{7.39}$

$\boxed{e^2}$

(Reading Item) Derivative of a^x

$$a^x = e^{x \log(a)}$$

$$\frac{d}{dx} a^x = \log(a) e^{x \log(a)} = \log(a) a^x$$

DeepLearning.AI

Derivatives and Optimization

The derivative of $\log(x)$

Logarithm

Logarithm

$$e^{?} = 3$$

Logarithm

$$\log(3)$$

$$e^{?} = 3$$

Logarithm

$$\log(3)$$

$$e^{?} = 3 \qquad e^{?} = x$$

Logarithm

$$\log(3)$$

$$e^{?} = 3$$

$$\log(x)$$

$$e^{?} = x$$

Logarithm

$$\log(3)$$

$$e^{?} = 3$$

$$\log(x)$$

$$e^{?} = x$$

$$f(x) = e^x$$

Logarithm

$$\log(3) \qquad \log(x)$$

$$e^{?} = 3 \qquad e^{?} = x$$

$$f(x) = e^x \qquad f^{-1}(y) = \log(y)$$

Logarithm

$$\log(3)$$

$$e^{?} = 3$$

$$\log(x)$$

$$e^{?} = x$$

$$f(x) = e^x \qquad f^{-1}(y) = \log(y)$$

$$e^{\log(x)} = x$$

Logarithm

$$\log(3) \qquad \log(x)$$

$$e^{?} = 3 \qquad e^{?} = x$$

$$f(x) = e^x \qquad f^{-1}(y) = \log(y)$$

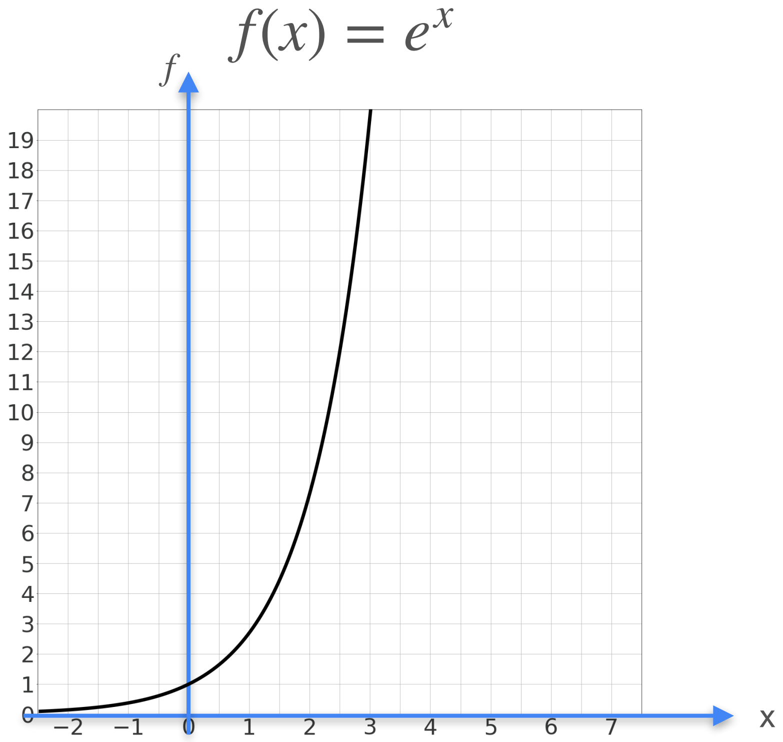
$$e^{\log(x)} = x \qquad \log(e^y) = y$$

Logarithm

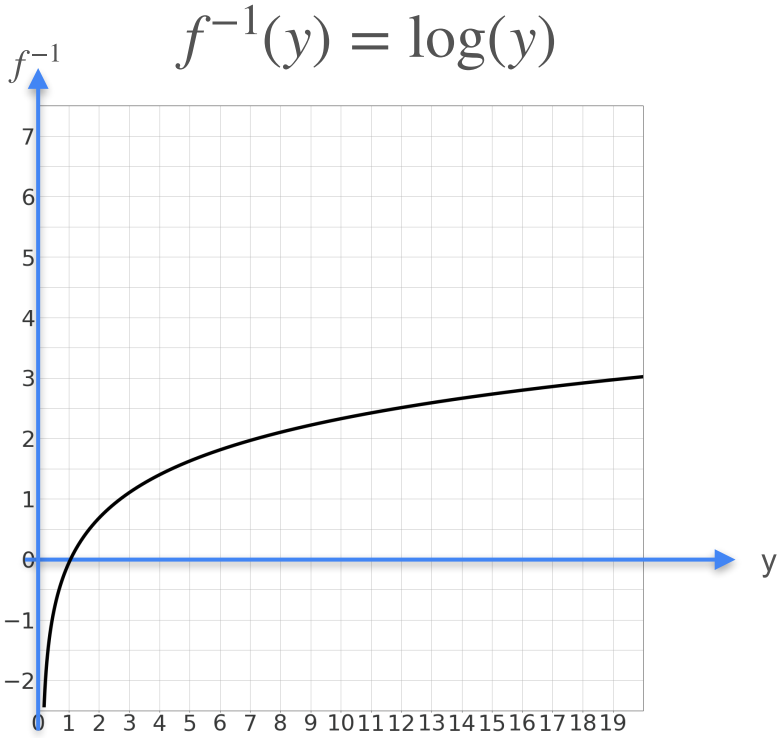
$$f(x) = e^x$$

$$f^{-1}(y) = \log(y)$$

Logarithm

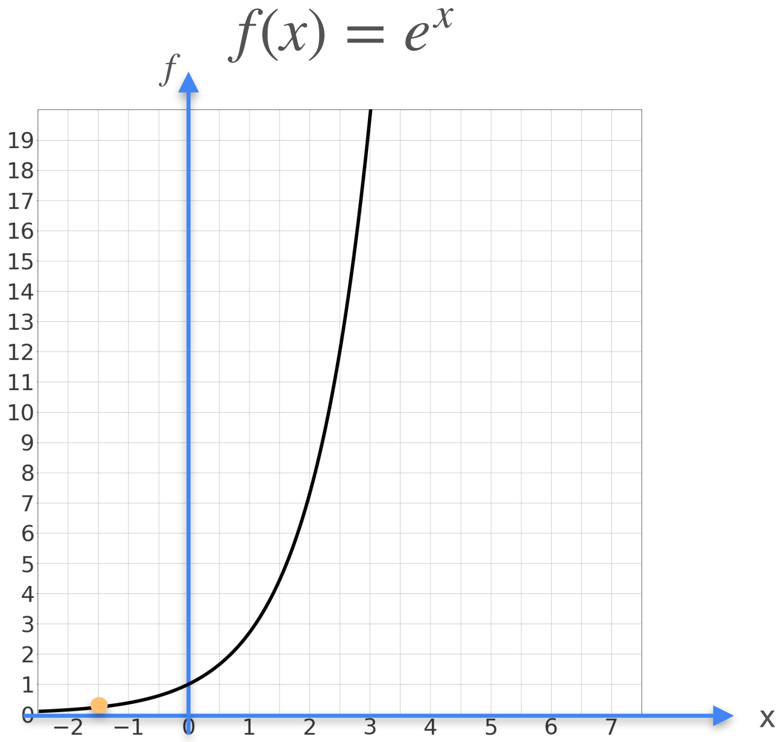


$f(x) = e^x$
f
19 18 17 16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0
−2 −1 0 1 2 3 4 5 6 7
x

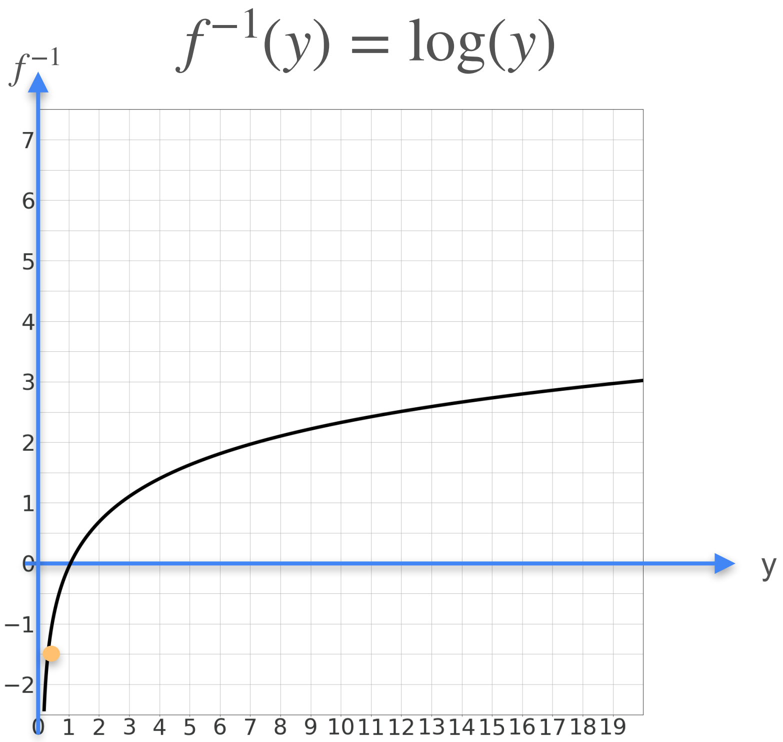


$f^{-1}(y) = \log(y)$
f^{-1}
7 6 5 4 3 2 1 0 −1 −2
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19
y

Logarithm

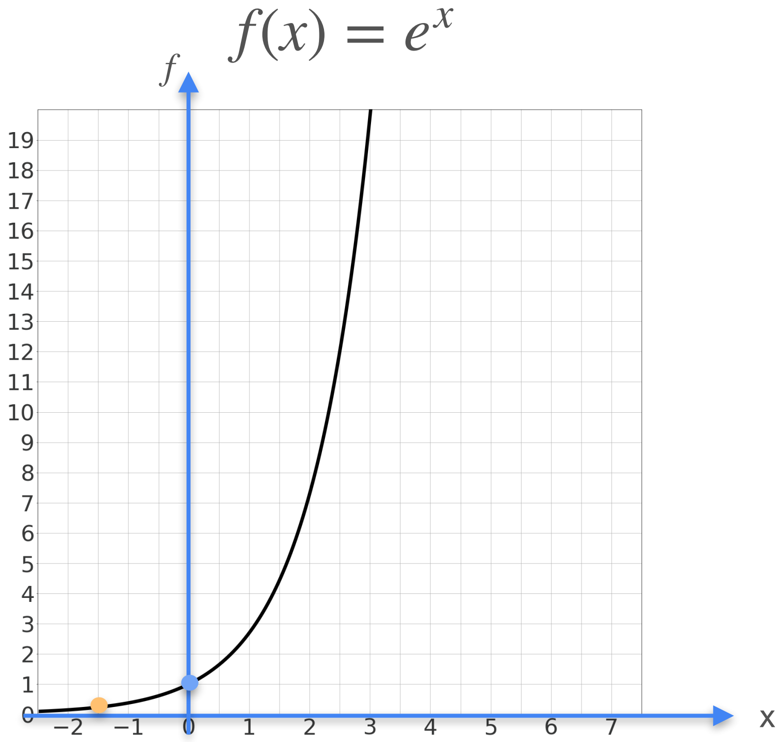


$f(x) = e^x$
f
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
−2
−1
0
1
2
3
4
5
6
7
x

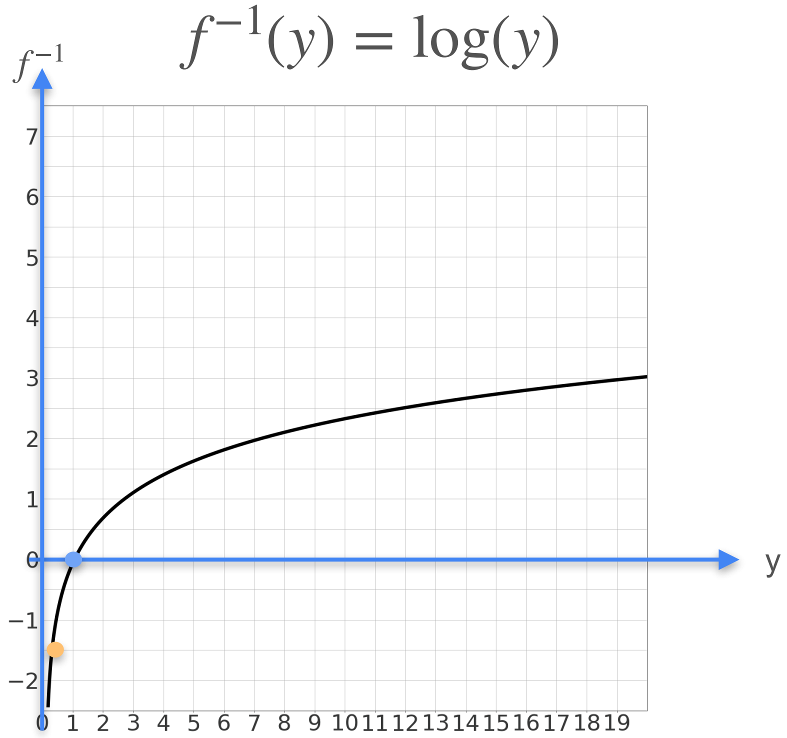


$f^{-1}(y) = \log(y)$
f^{-1}
7
6
5
4
3
2
1
0
−1
−2
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19
y

Logarithm

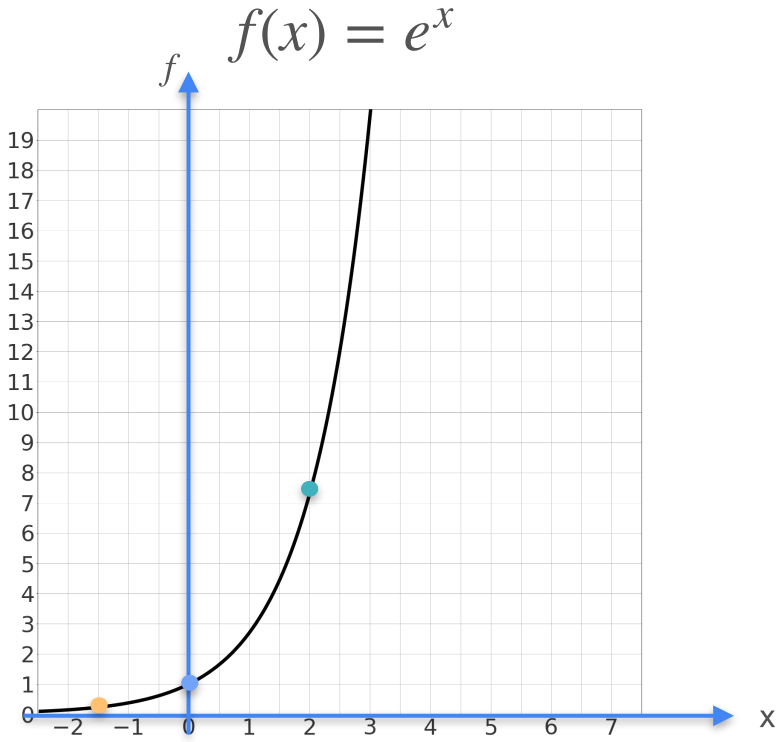


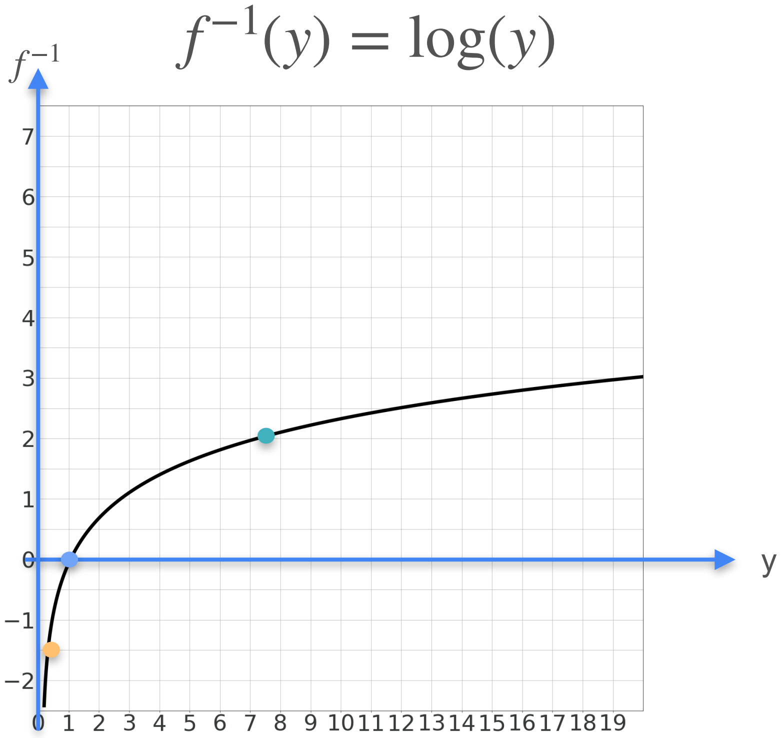
$f(x) = e^x$
f
x
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
−2
−1
0
1
2
3
4
5
6
7



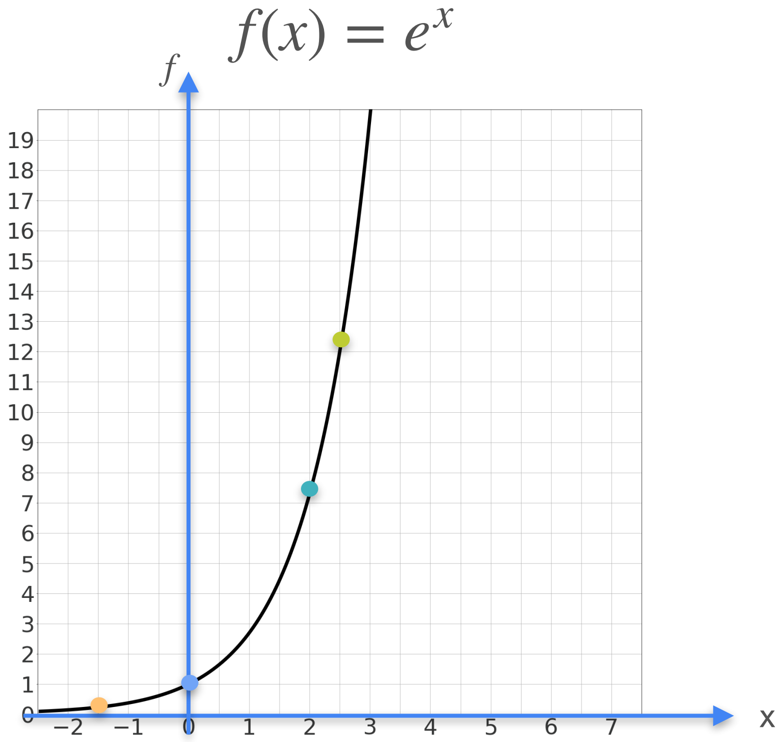
$f^{-1}(y) = \log(y)$
f^{-1}
y
7
6
5
4
3
2
1
0
−1
−2
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19

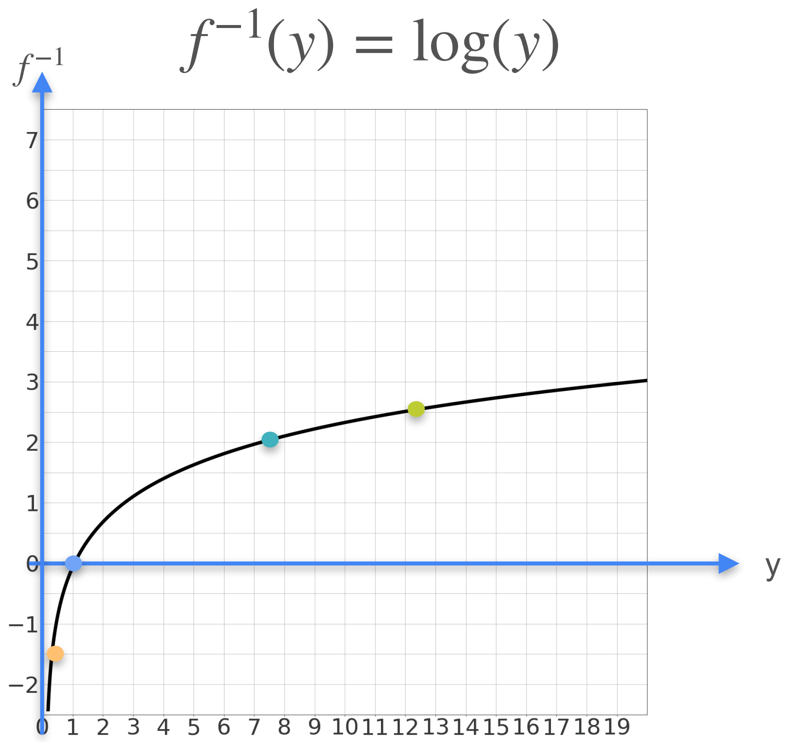
Logarithm





Logarithm


$f(x) = e^x$
f
x
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
−2
−1
0
1
2
3
4
5
6
7


$f^{-1}(y) = \log(y)$
f^{-1}
y
7
6
5
4
3
2
1
0
−1
−2
0
1
2
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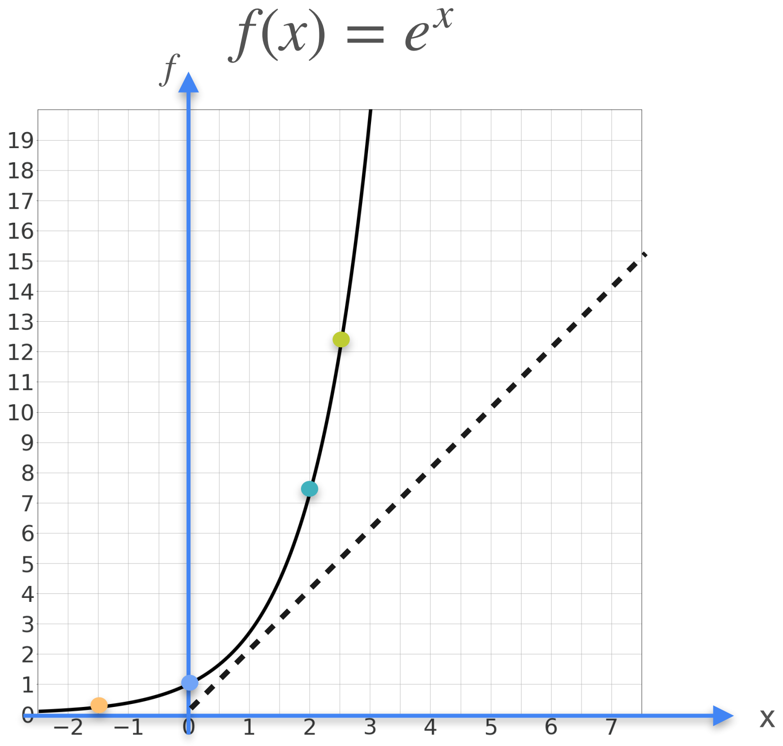
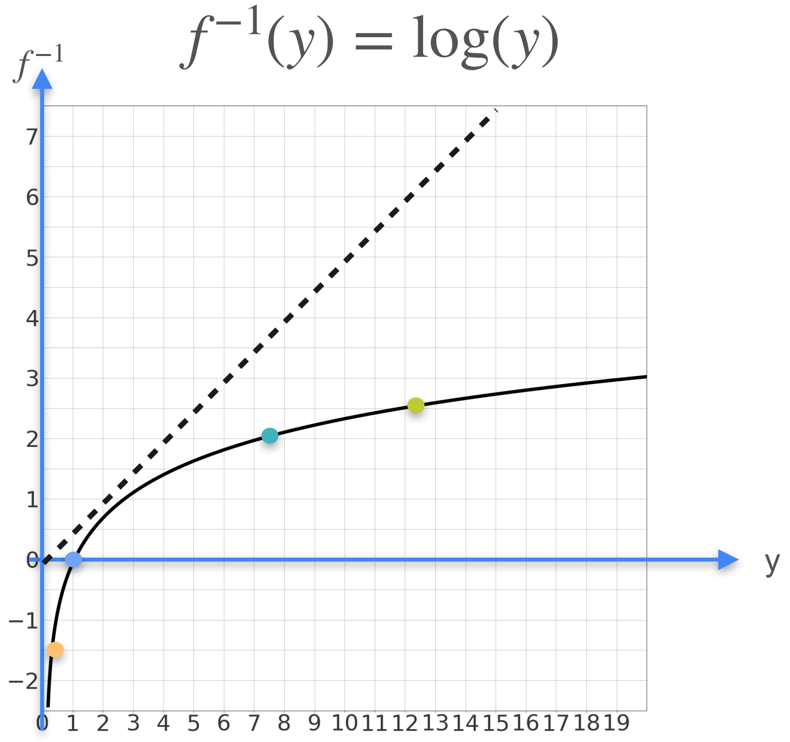
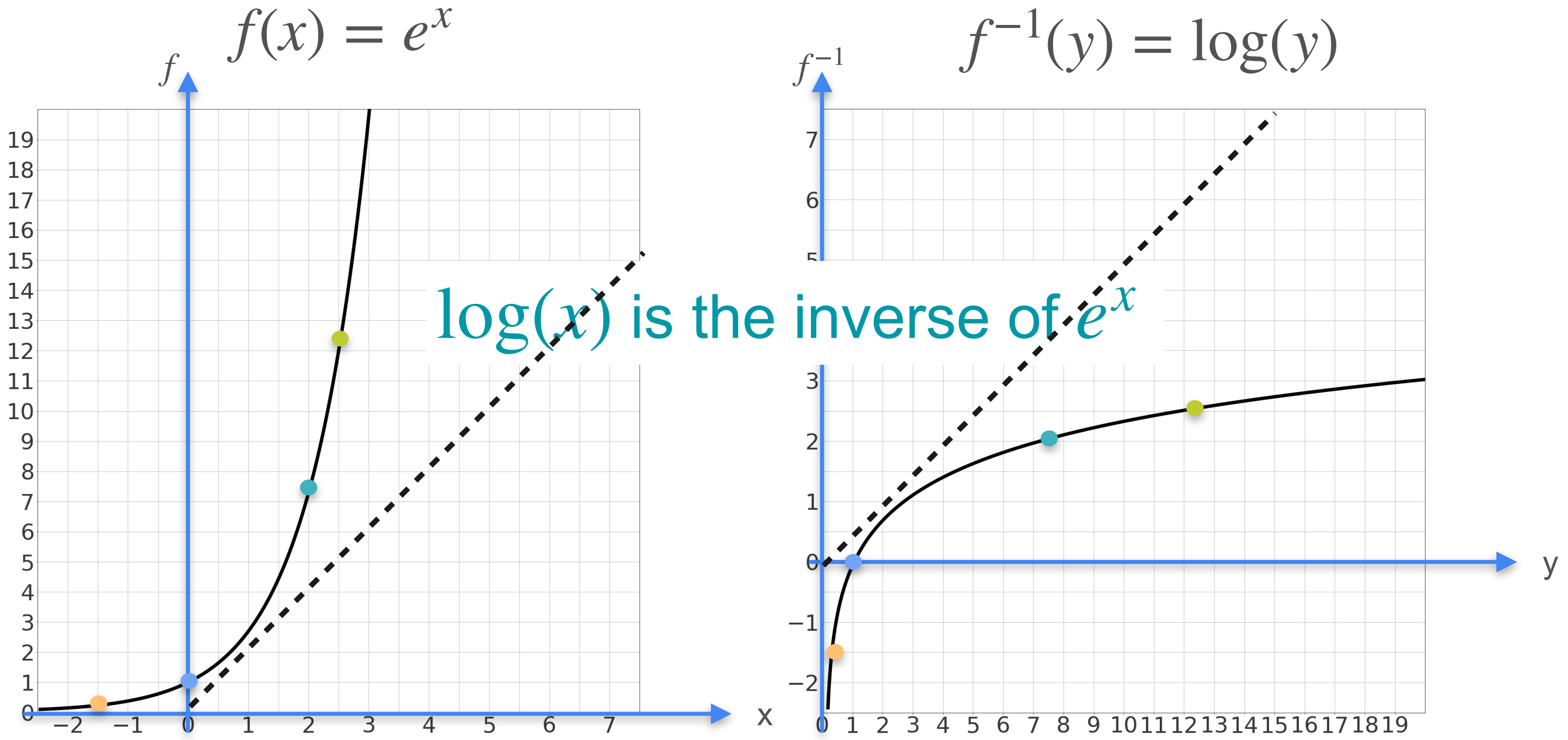
18
19

Logarithm





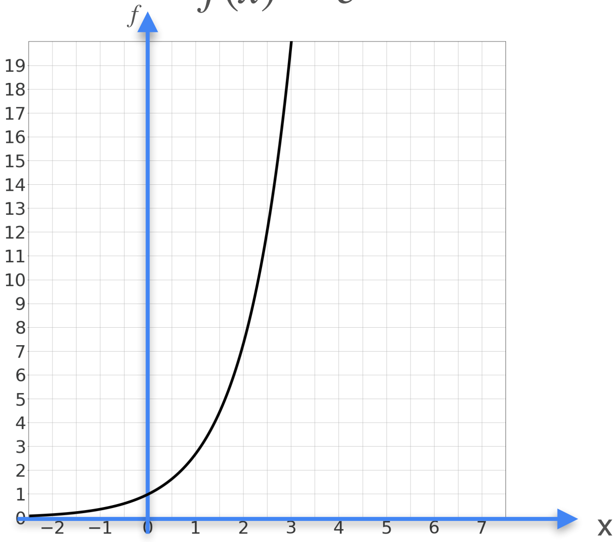
Logarithm



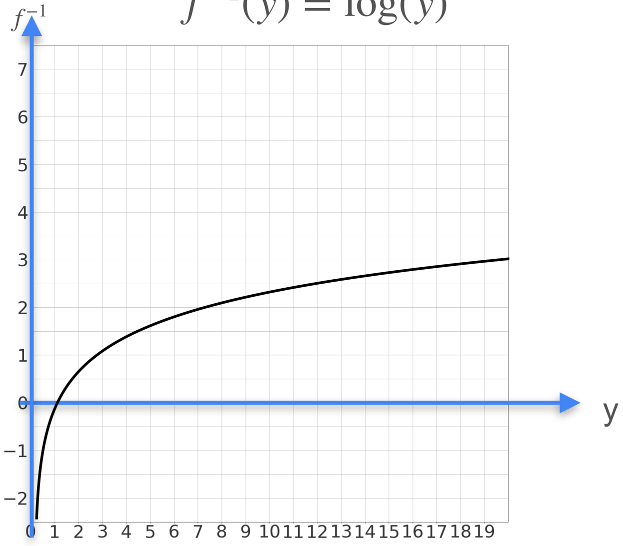
$\log(x)$ is the inverse of e^x

Logarithm

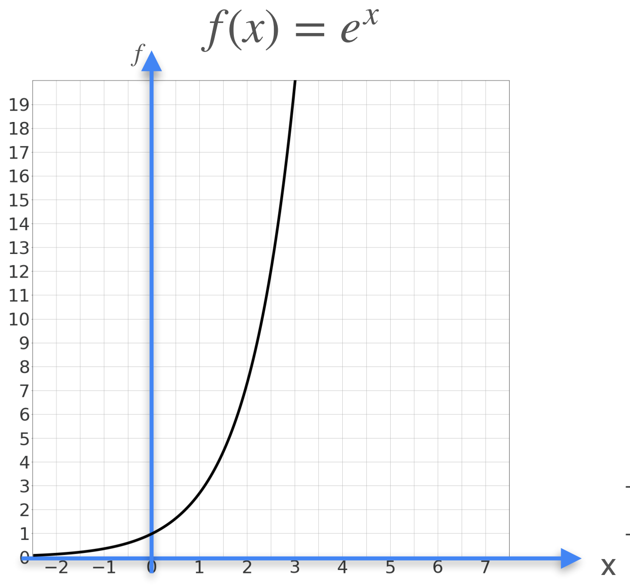
$f(x) = e^x$

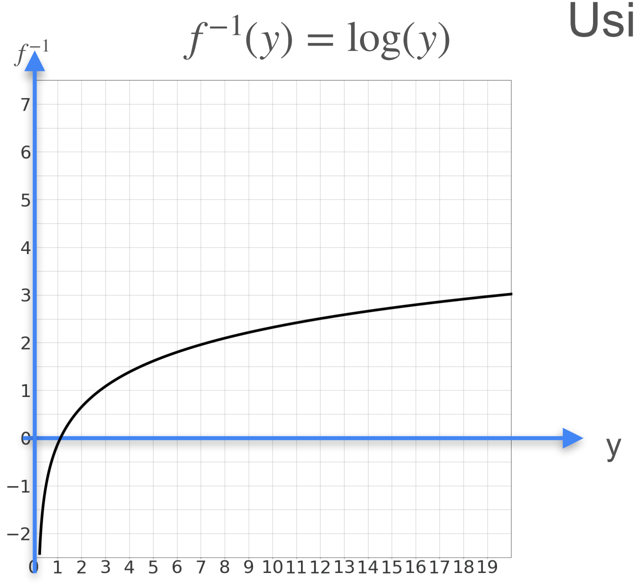


$f^{-1}(y) = \log(y)$



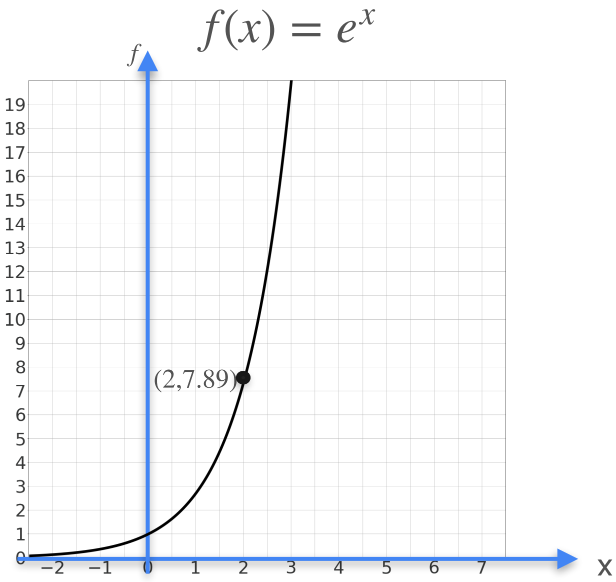
Logarithm

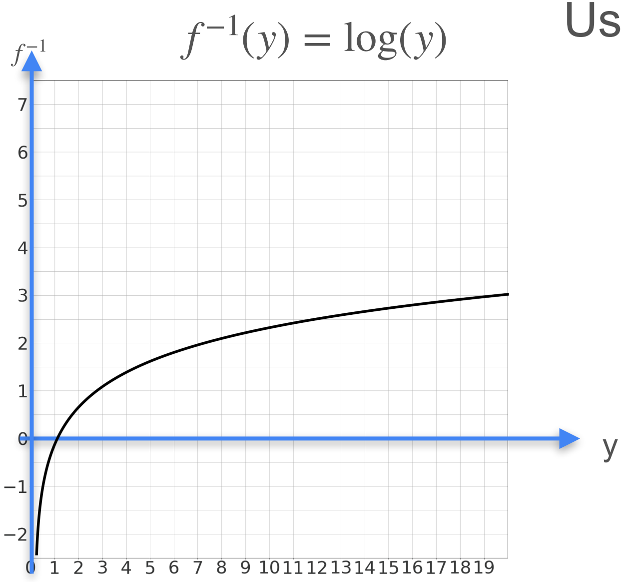




Using the result for inverses

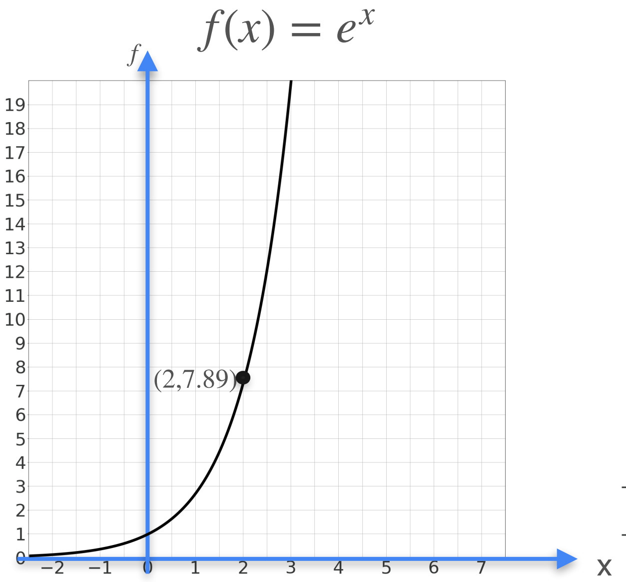
Logarithm

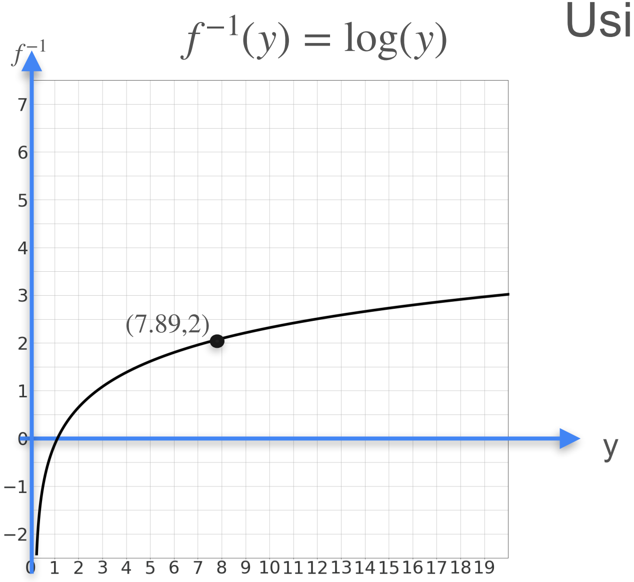




Using the result for inverses

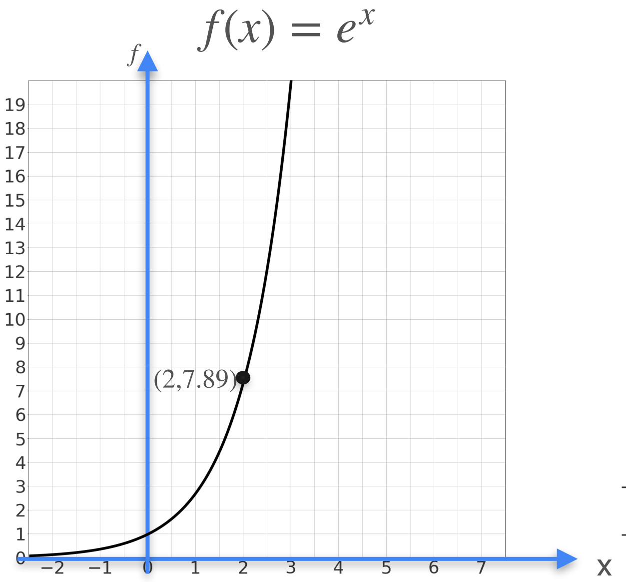
Logarithm

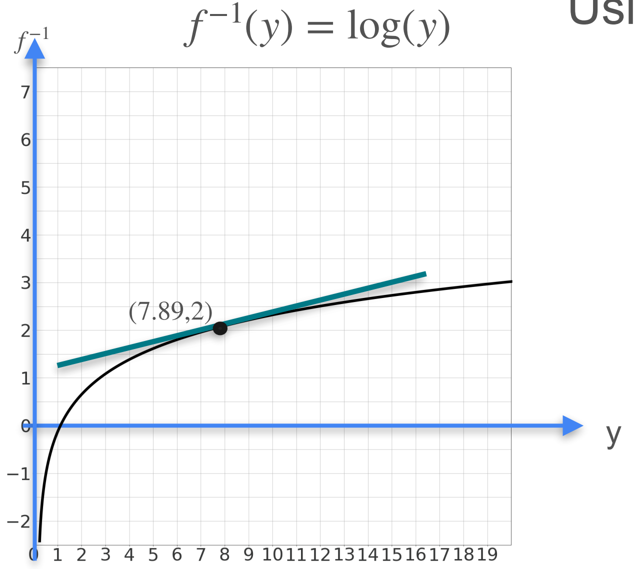




Using the result for inverses

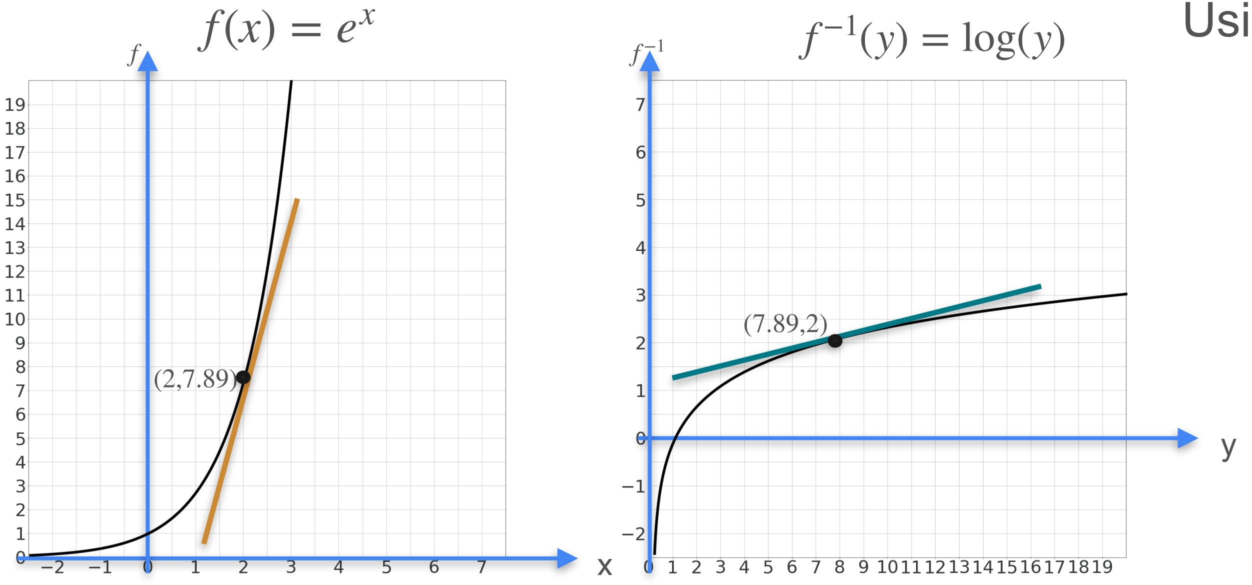
Logarithm





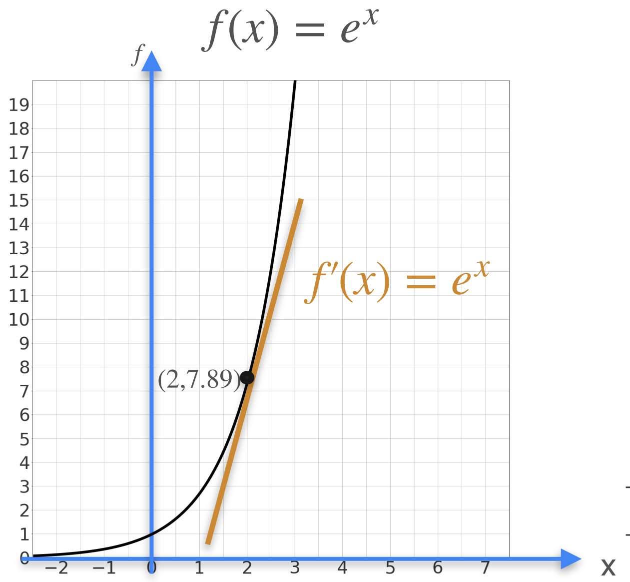
Using the result for inverses

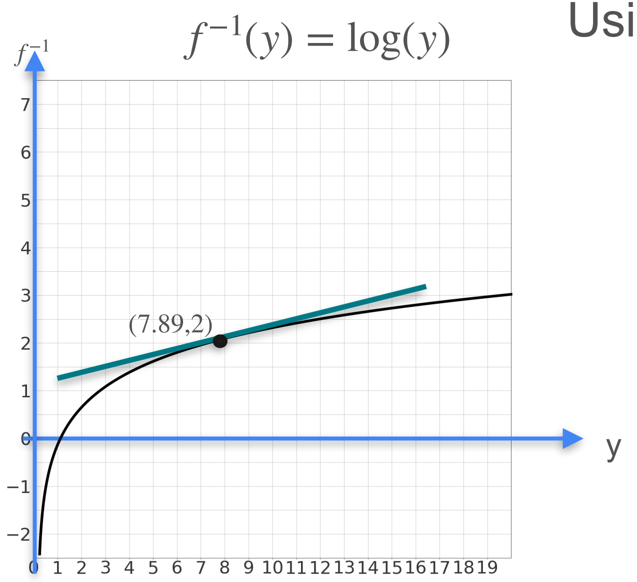
Logarithm



Using the result for inverses

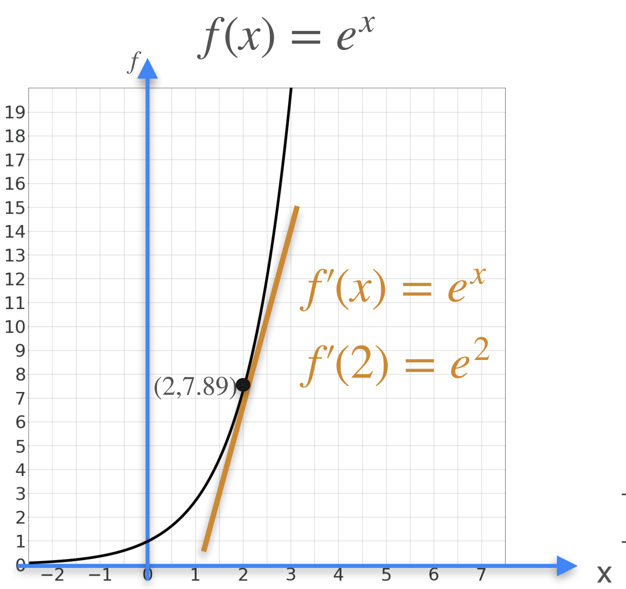
Logarithm

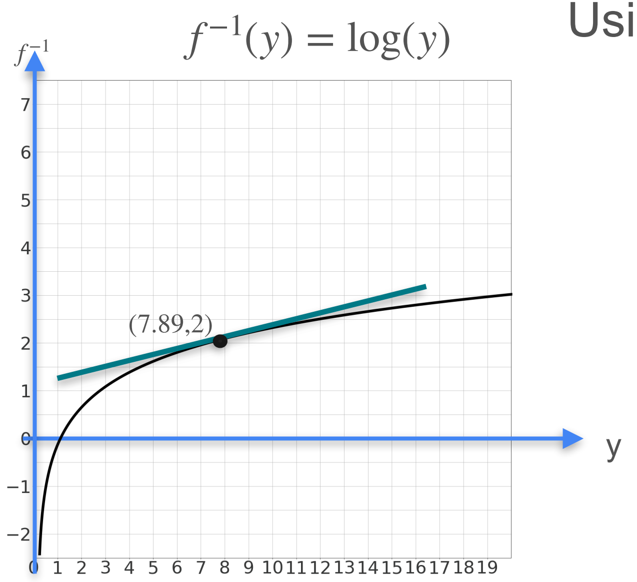




Using the result for inverses

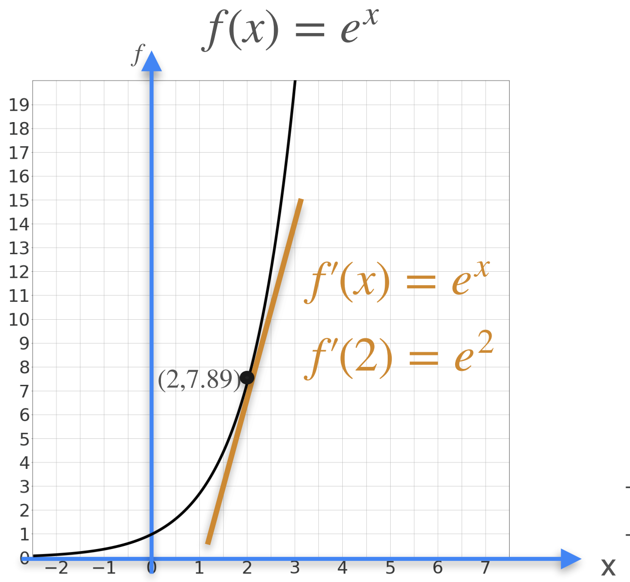
Logarithm

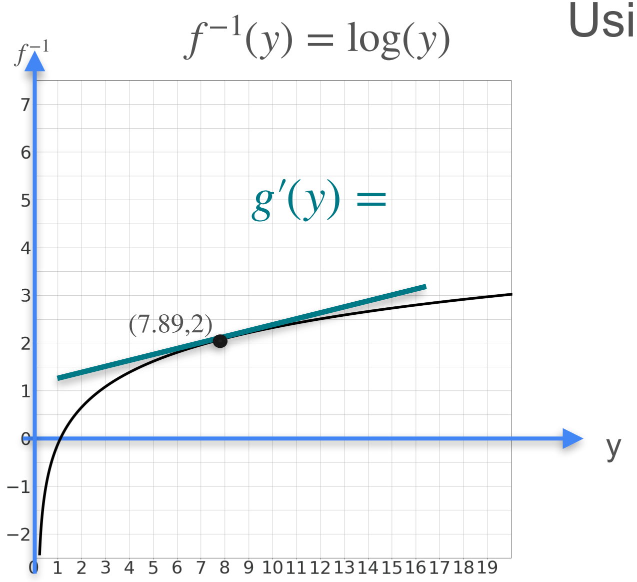




Using the result for inverses

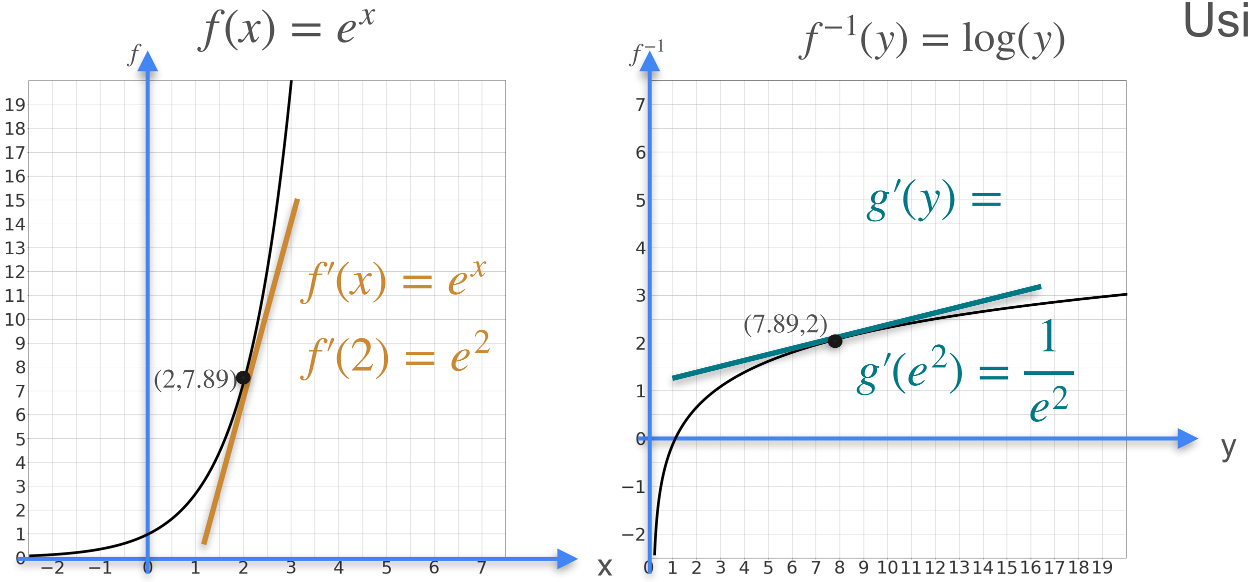
Logarithm





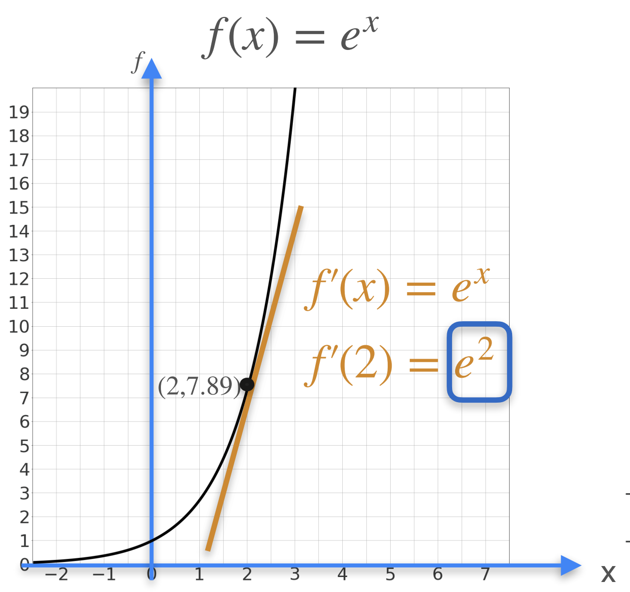
Using the result for inverses

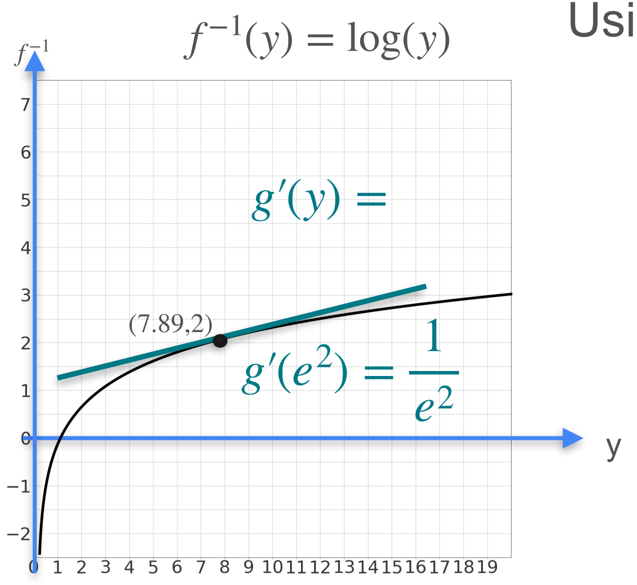
Logarithm



Using the result for inverses

Logarithm

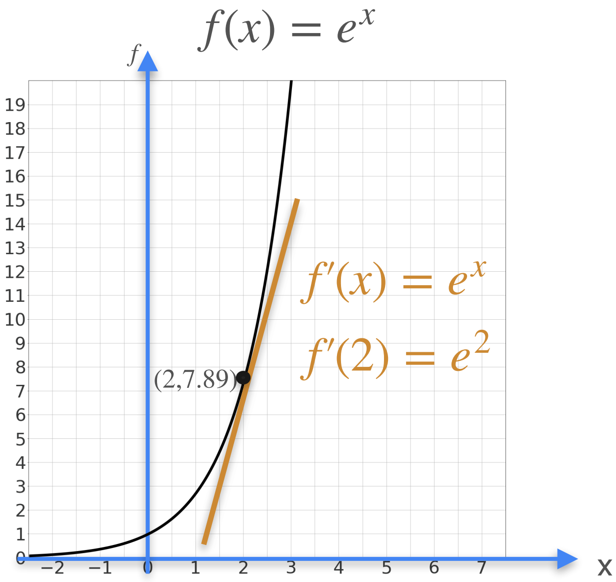


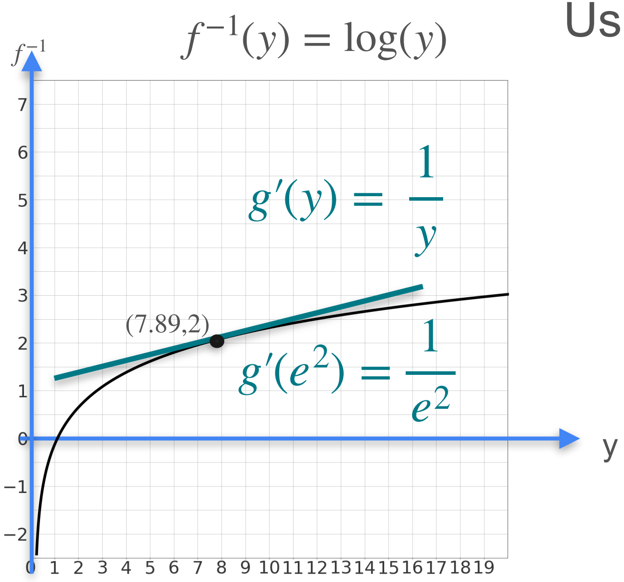


Using the result for inverses

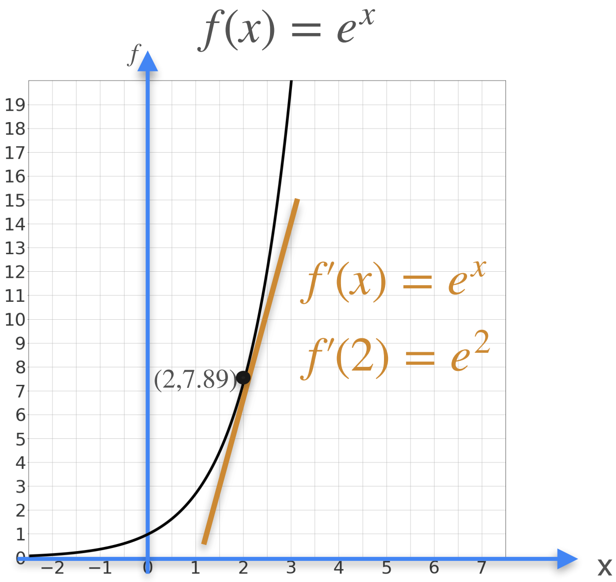
Logarithm

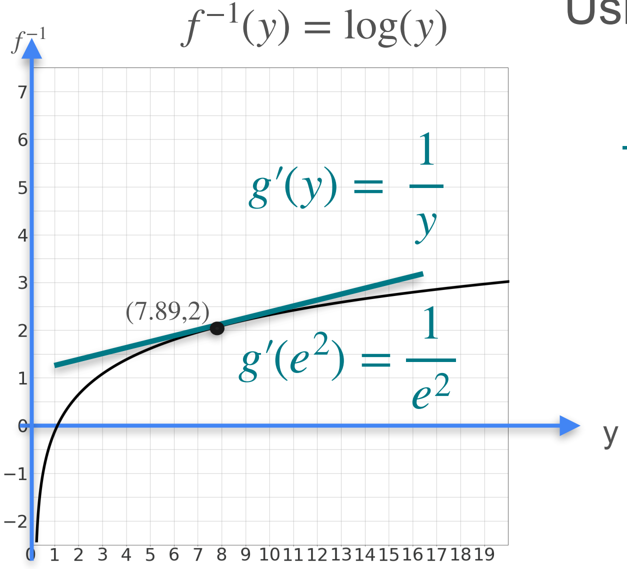
Using the result for inverses





Logarithm

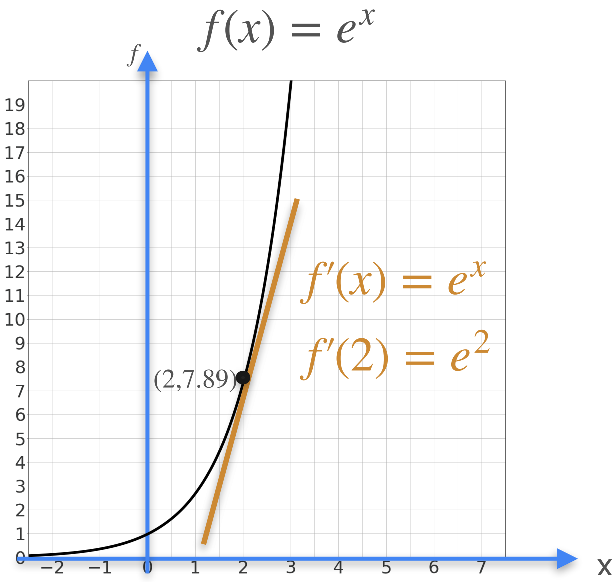


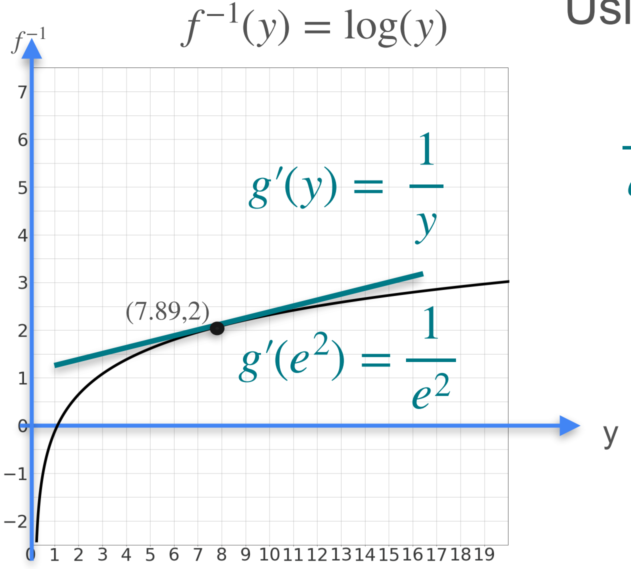


Using the result for inverses

$$\frac{d}{dy} f^{-1}(y) = \frac{1}{f'(x)}$$

Logarithm

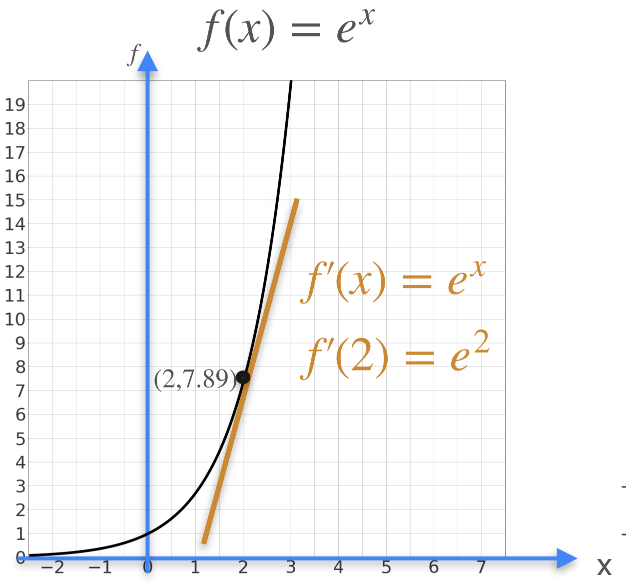


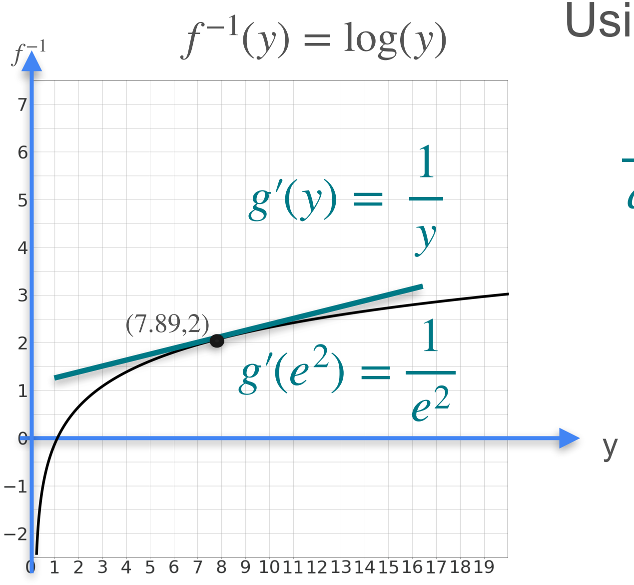


Using the result for inverses

$$\frac{d}{dy} f^{-1}(y) = \frac{1}{f'\left(f^{-1}(y)\right)}$$

Logarithm



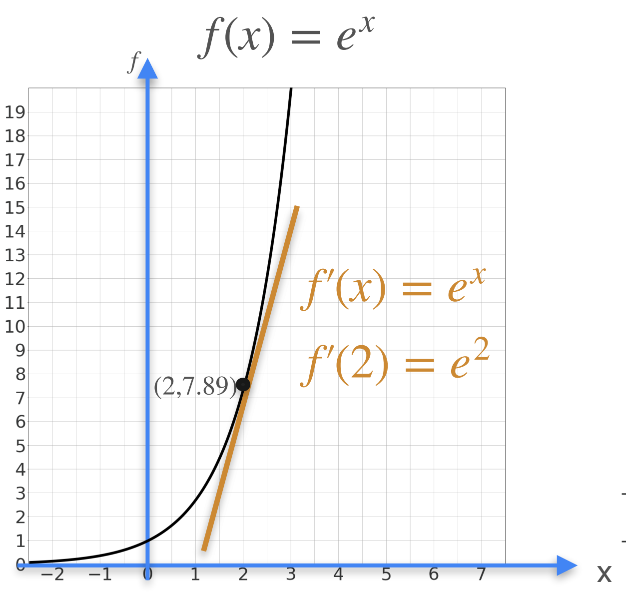


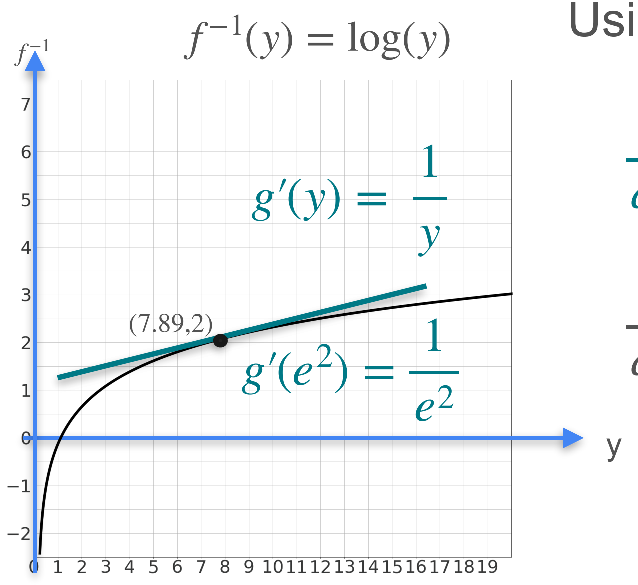
Using the result for inverses

$$\frac{d}{dy} f^{-1}(y) = \frac{1}{f'\left(f^{-1}(y)\right)}$$

$$\log(y)$$

Logarithm



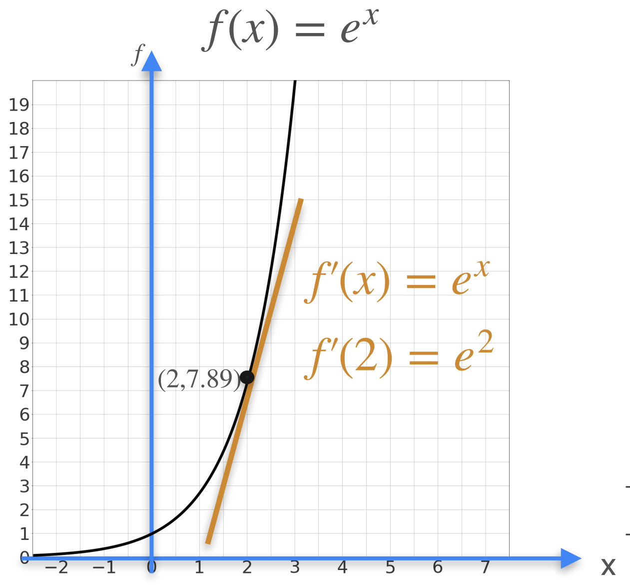


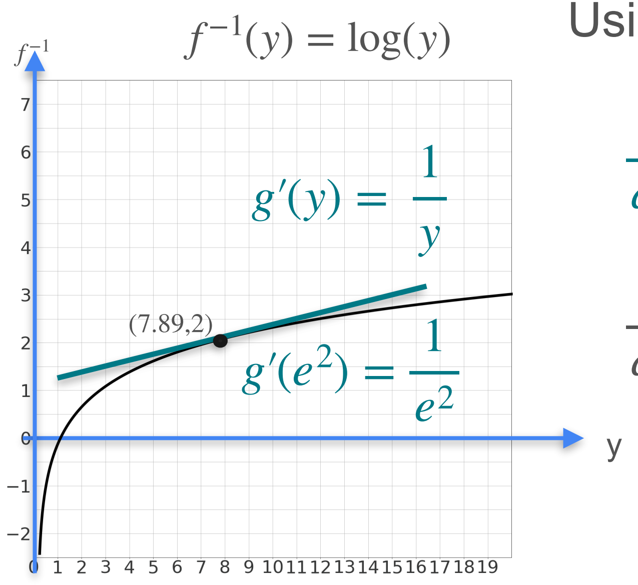
Using the result for inverses

$$\frac{d}{dy} f^{-1}(y) = \frac{1}{f'\left(f^{-1}(y)\right)}$$

$$\frac{d}{dy} \log(y)$$

Logarithm



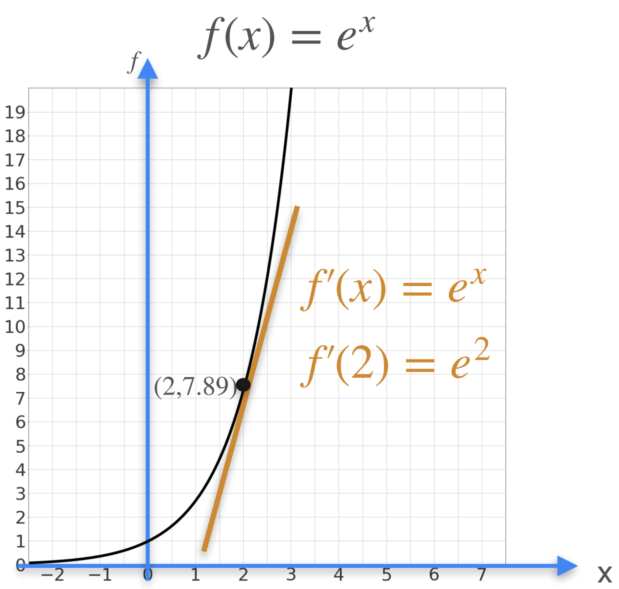


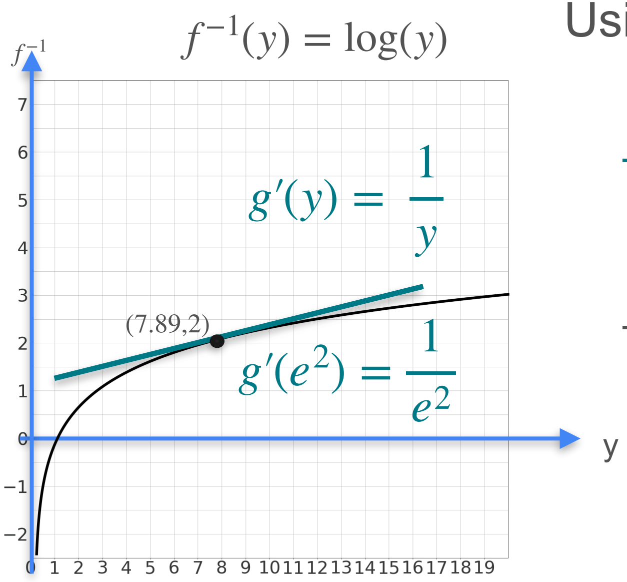
Using the result for inverses

$$\frac{d}{dy} f^{-1}(y) = \frac{1}{f'\left(f^{-1}(y)\right)}$$

$$\frac{d}{dy} \log(y) = \frac{1}{}$$

Logarithm



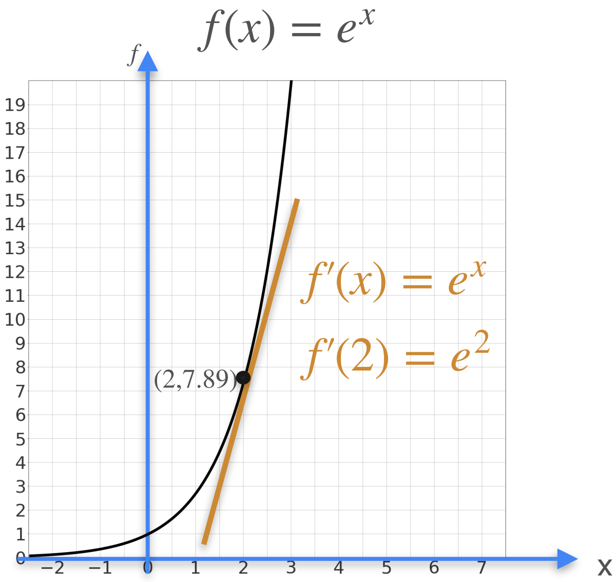


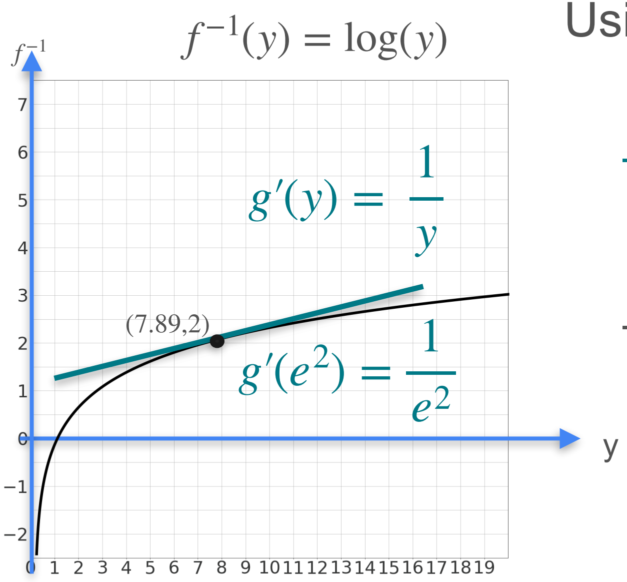
Using the result for inverses

$$\frac{d}{dy} f^{-1}(y) = \frac{1}{f'\left(f^{-1}(y)\right)}$$

$$\frac{d}{dy} \log(y) = \frac{1}{e^{\log(y)}}$$

Logarithm





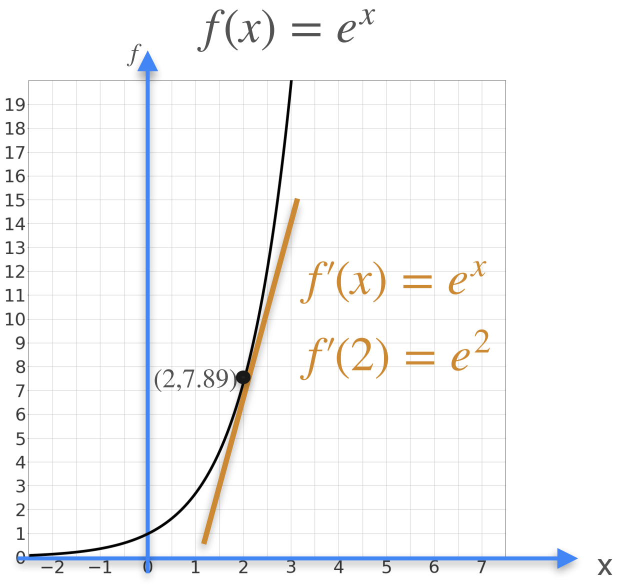
Using the result for inverses

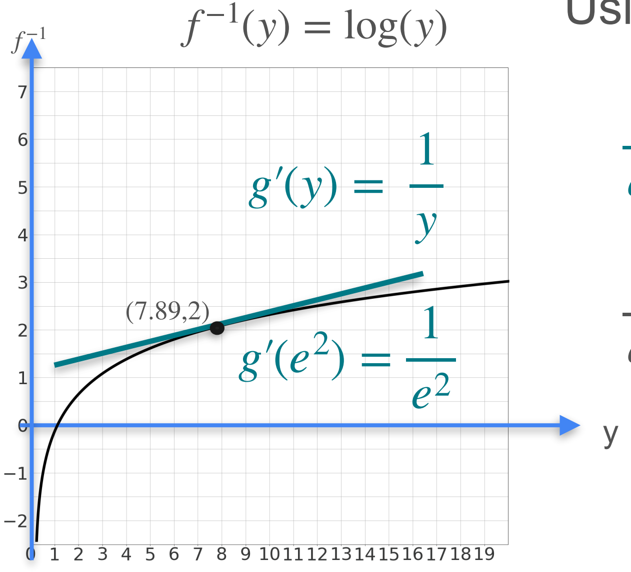
$$\frac{d}{dy} f^{-1}(y) = \frac{1}{f'\left(f^{-1}(y)\right)}$$

$$\frac{d}{dy} \log(y) = \frac{1}{e^{\log(y)}}$$

$$= \frac{1}{y}$$

Logarithm





Using the result for inverses

$$\frac{d}{dy} f^{-1}(y) = \frac{1}{f'\left(f^{-1}(y)\right)}$$

$$\frac{d}{dy} \log(y) = \frac{1}{e^{\log(y)}}$$

$$= \frac{1}{y}$$

$$\frac{d}{dy} \log(y) = \frac{1}{y}$$

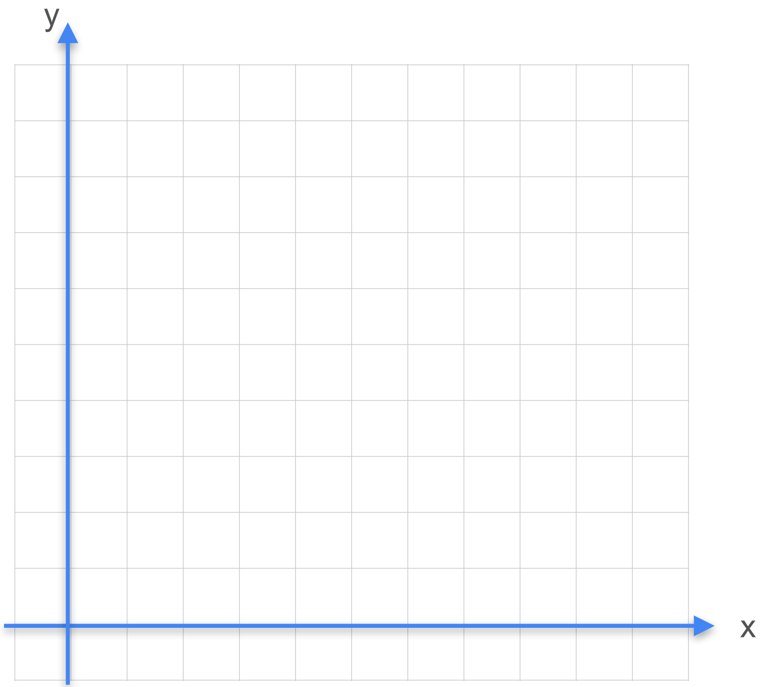
DeepLearning.AI

Derivatives and Optimization

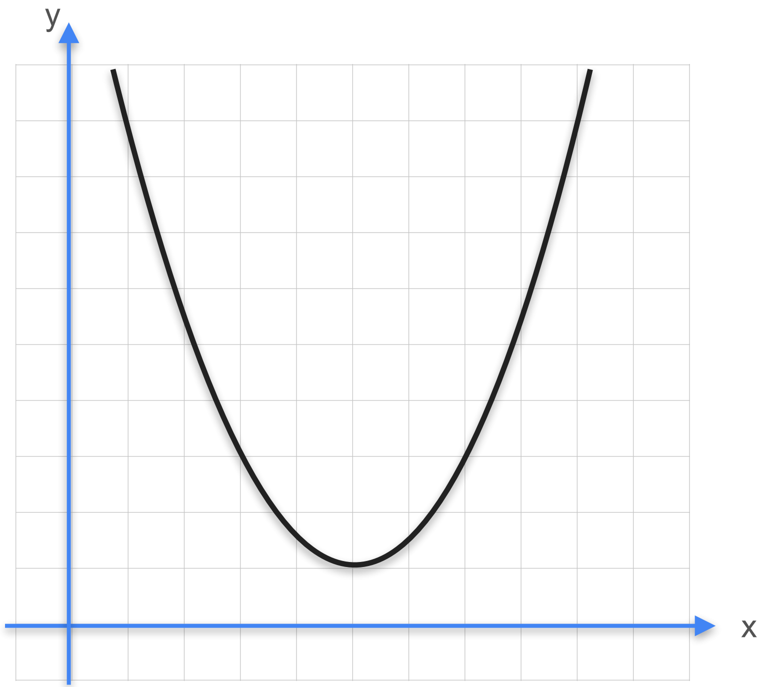
Existence of the derivative

Differentiable Function

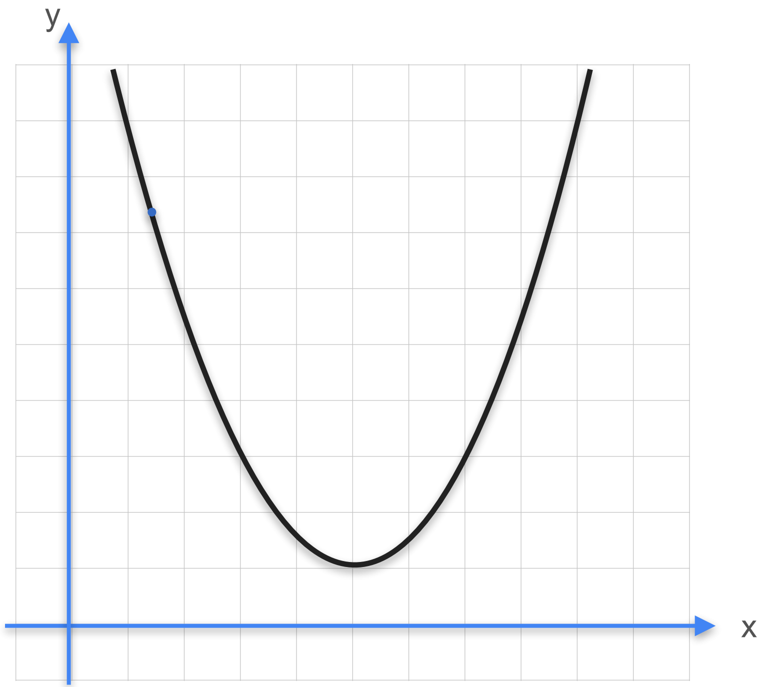
Differentiable Function



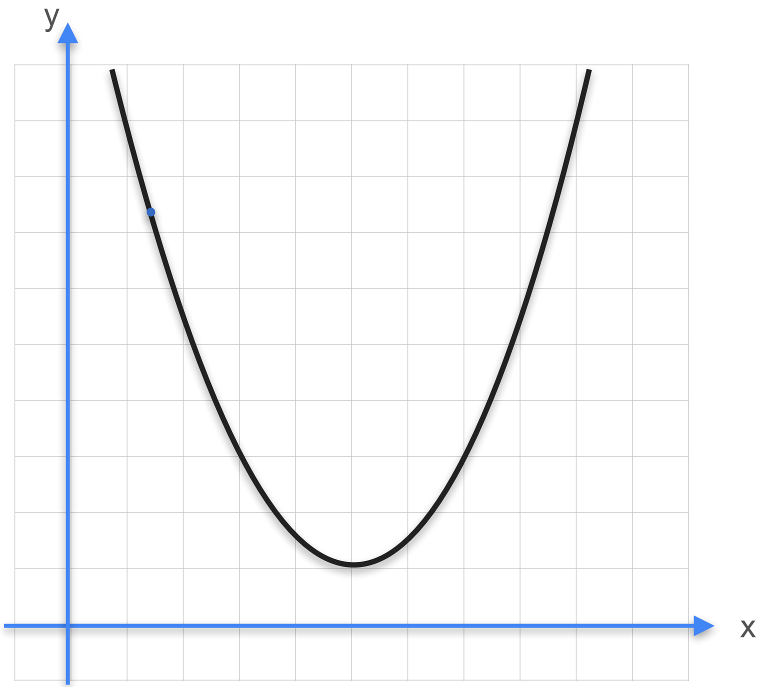
Differentiable Function



Differentiable Function



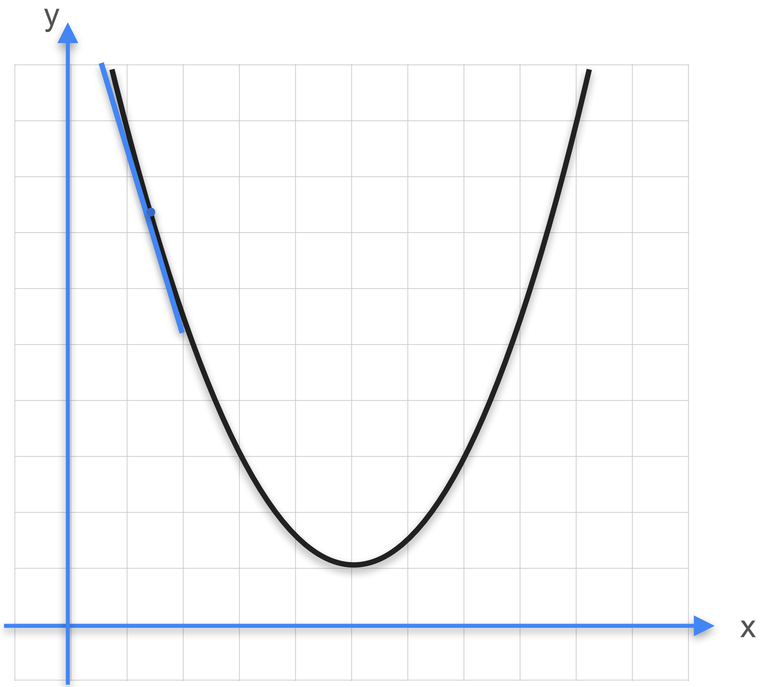
Differentiable Function



For a function to be differentiable at a point:

The derivative has to exist for that point

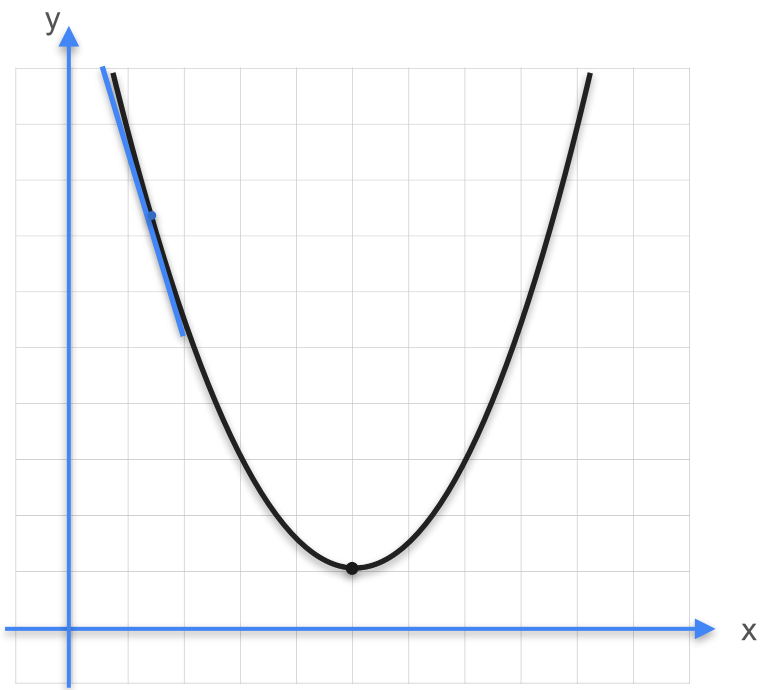
Differentiable Function



For a function to be differentiable at a point:

The derivative has to exist for that point

Differentiable Function



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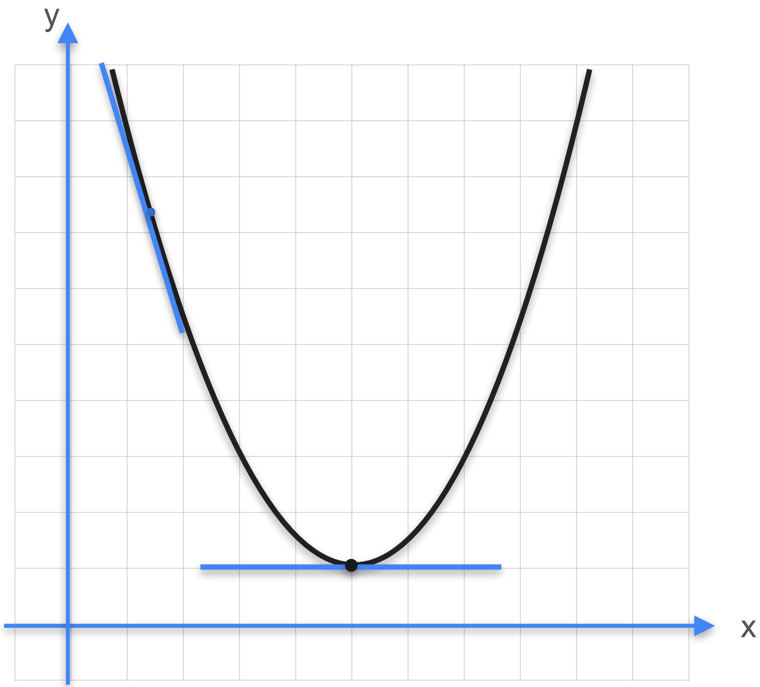
Differentiable Function



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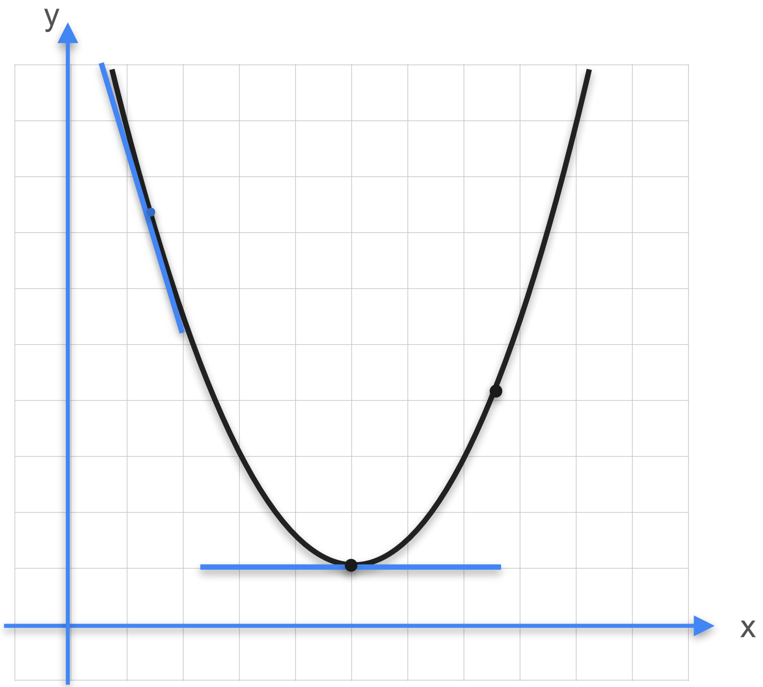
Differentiable Function



For a function to be differentiable at a point:

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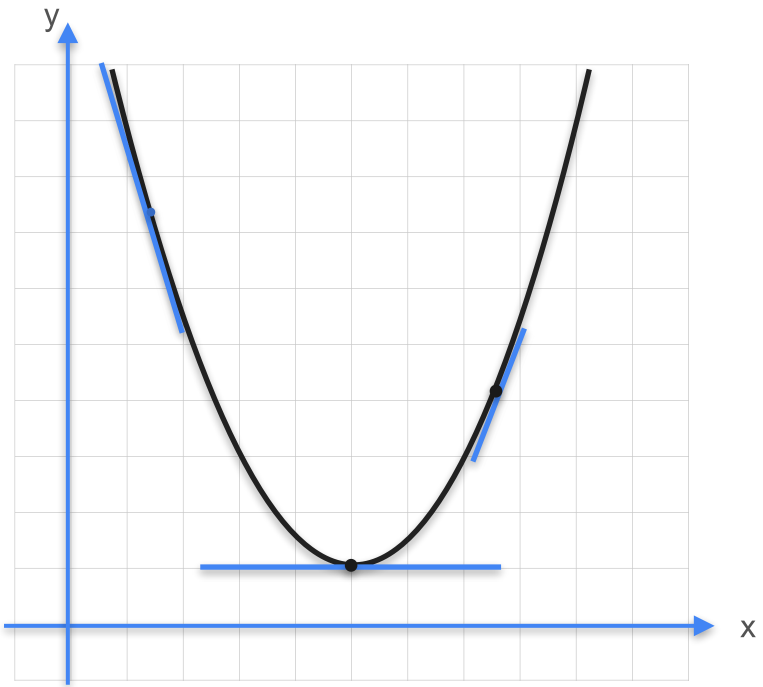
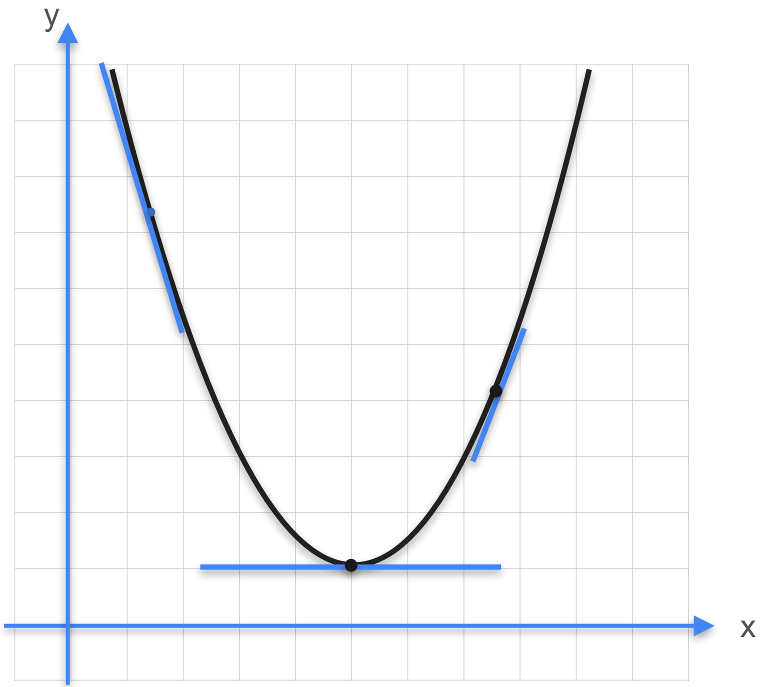
Differentiable Function



For a function to be differentiable at a point:

The derivative has to exist for that point

Differentiable Function



For a function to be differentiable at a point:

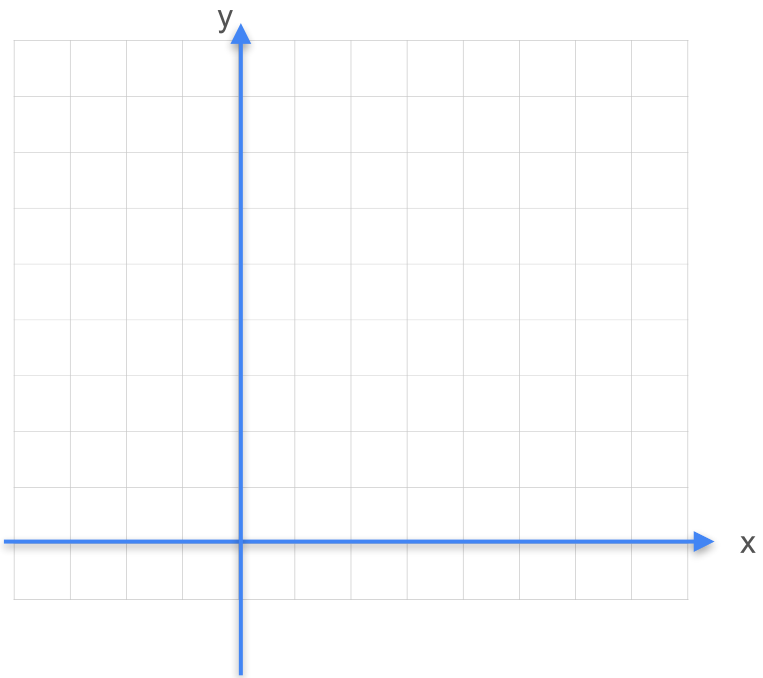
The derivative has to exist for that point

For a function to be differentiable at an interval:

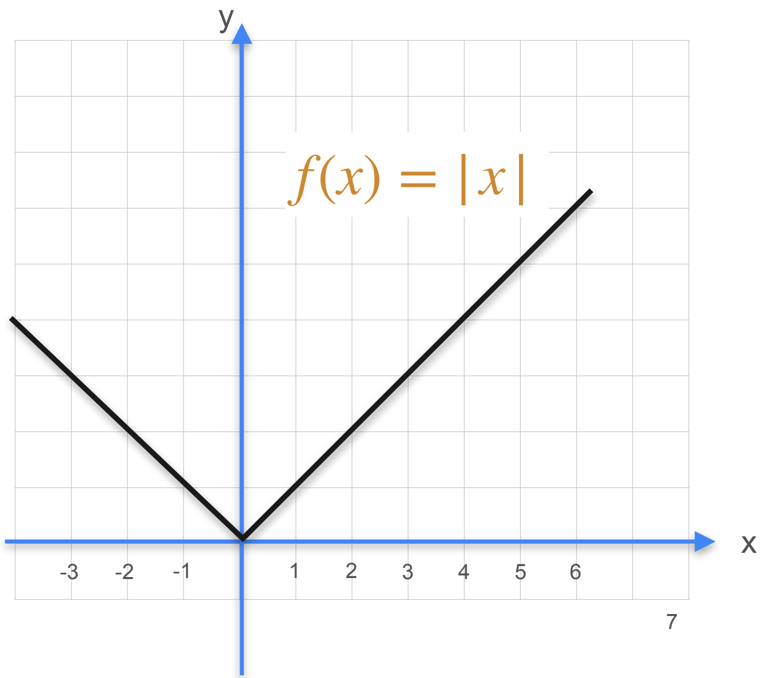
The derivative has to exist for *every* point in the interval

Non Differentiable Functions

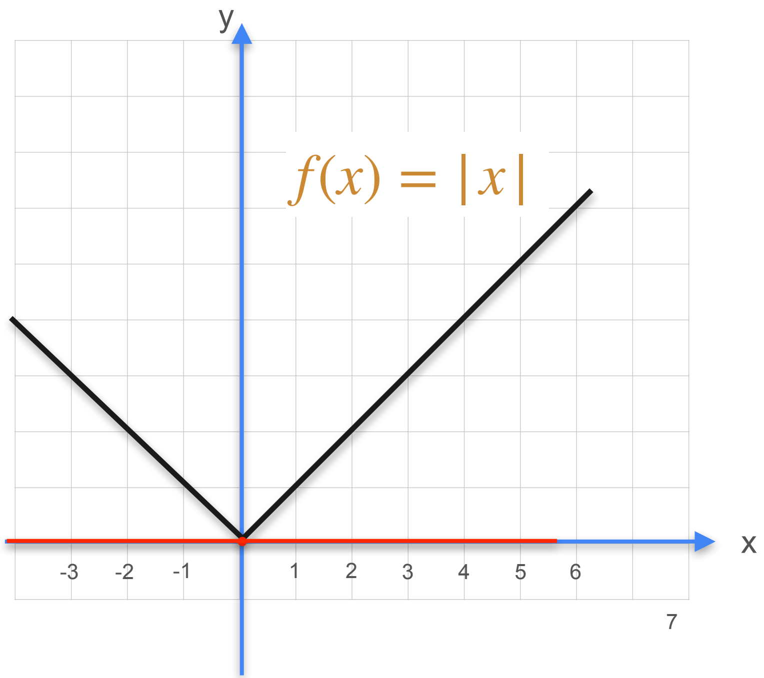
Non Differentiable Functions



Non Differentiable Functions



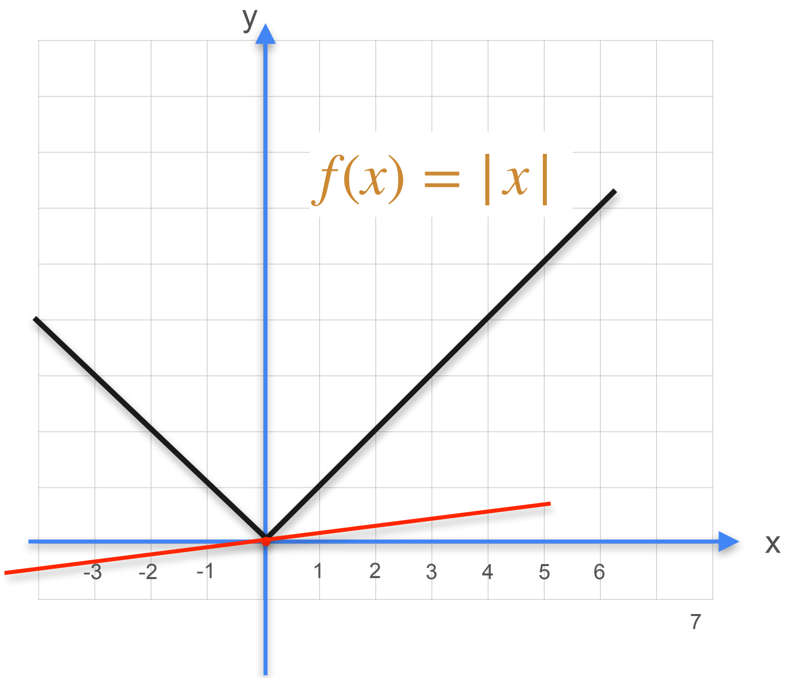
Non Differentiable Functions



The absolute value function.

$$f(x) = \begin{cases} x, & \textit{if } x \geq 0 \\ -x, & \textit{if } x < 0 \end{cases}$$

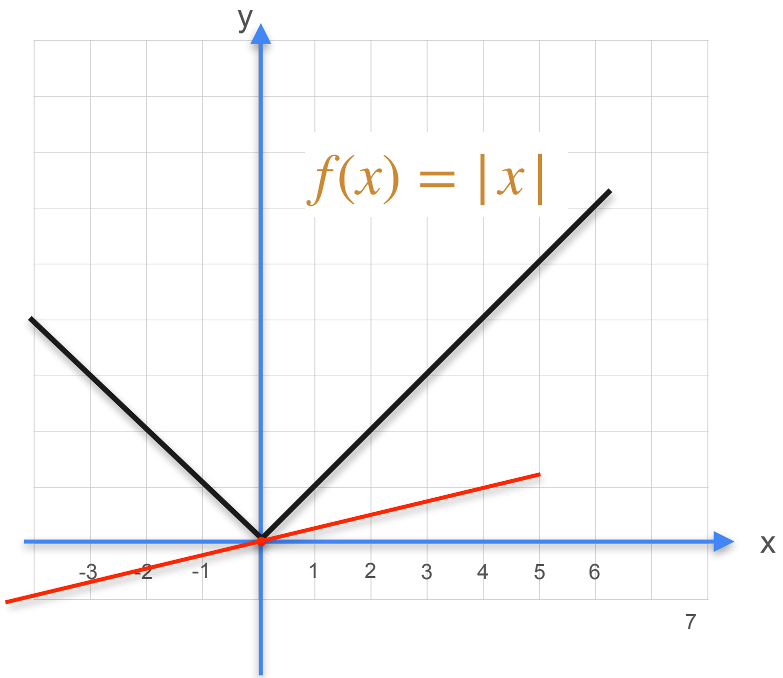
Non Differentiable Functions



The absolute value function.

$$f(x) = \begin{cases} x, & \textit{if } x \geq 0 \\ -x, & \textit{if } x < 0 \end{cases}$$

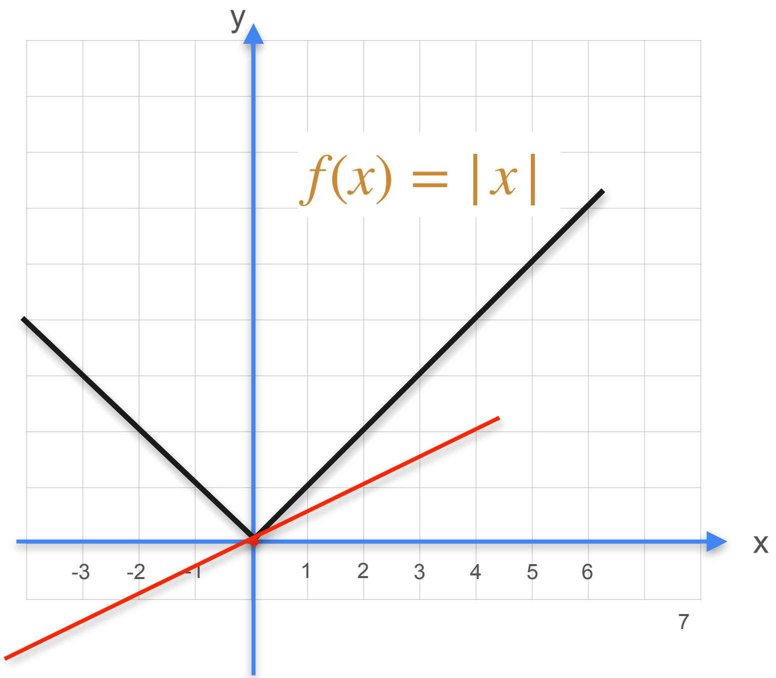
Non Differentiable Functions



The absolute value function.

$$f(x) = \begin{cases} x, & \textit{if } x \geq 0 \\ -x, & \textit{if } x < 0 \end{cases}$$

Non Differentiable Functions



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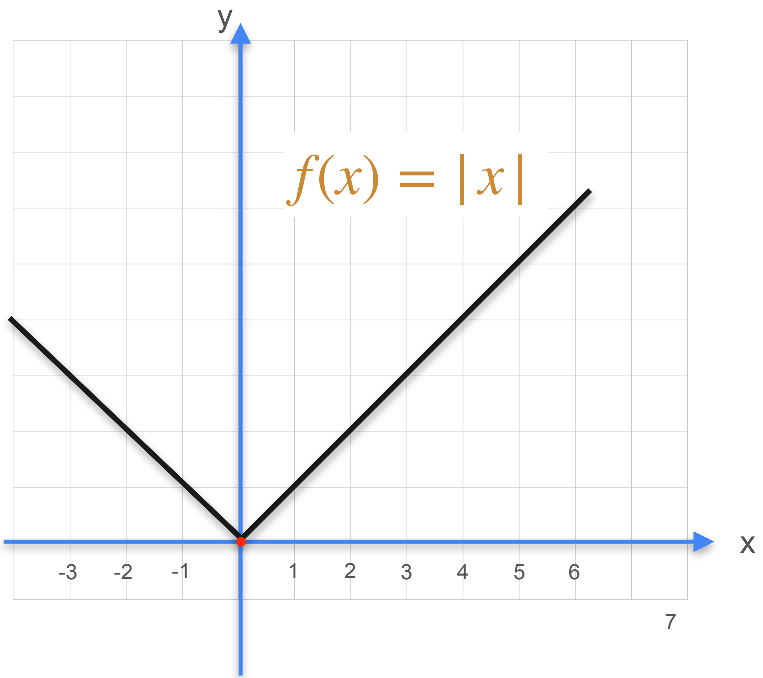

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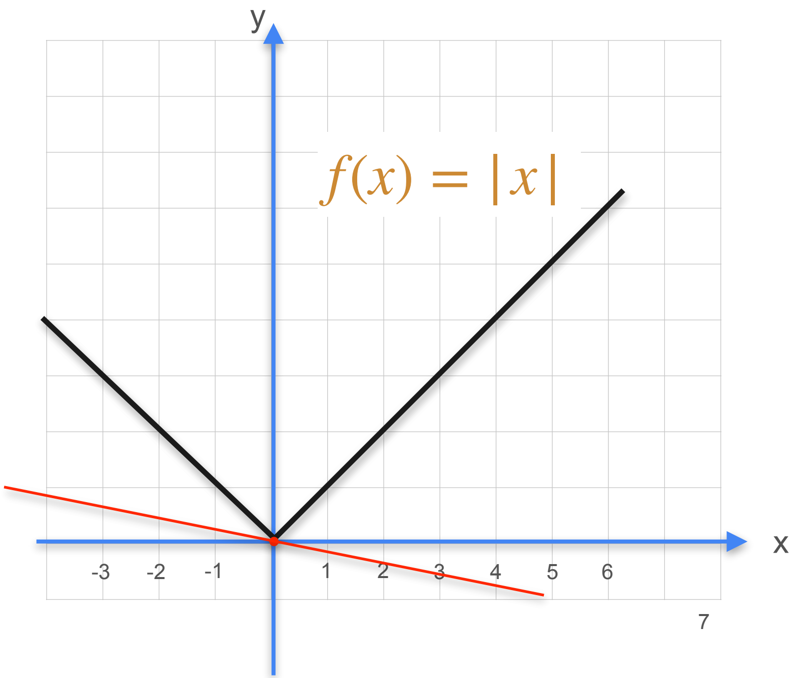
Non Differentiable Functions



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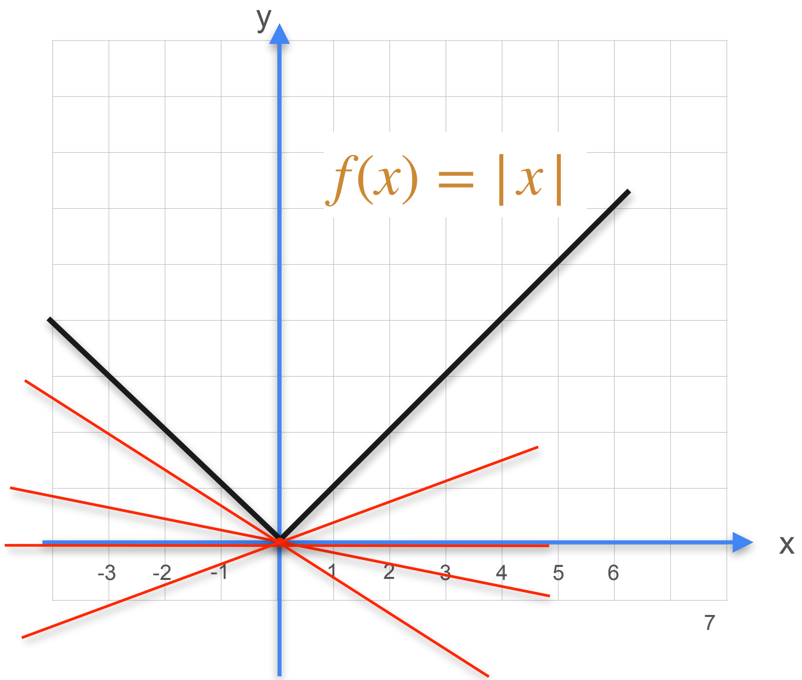
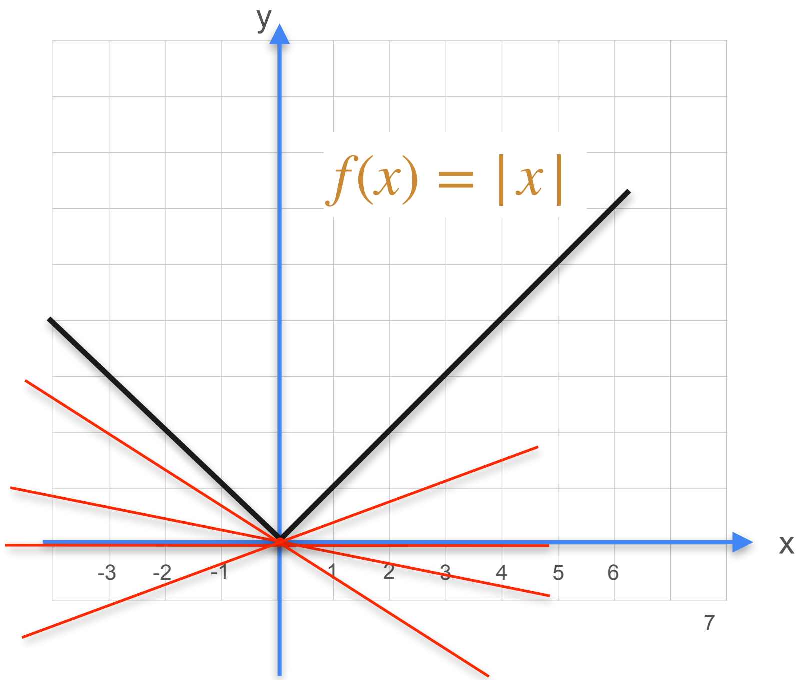


The absolute value function.

At x = 0, the derivative does not exist

Non Differentiable Functions



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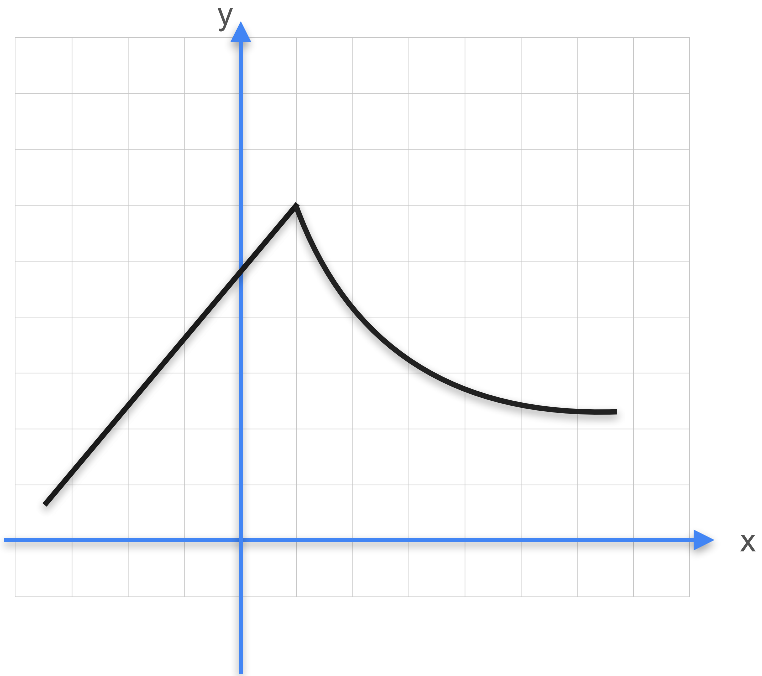
At x = 0, the derivative does not exist

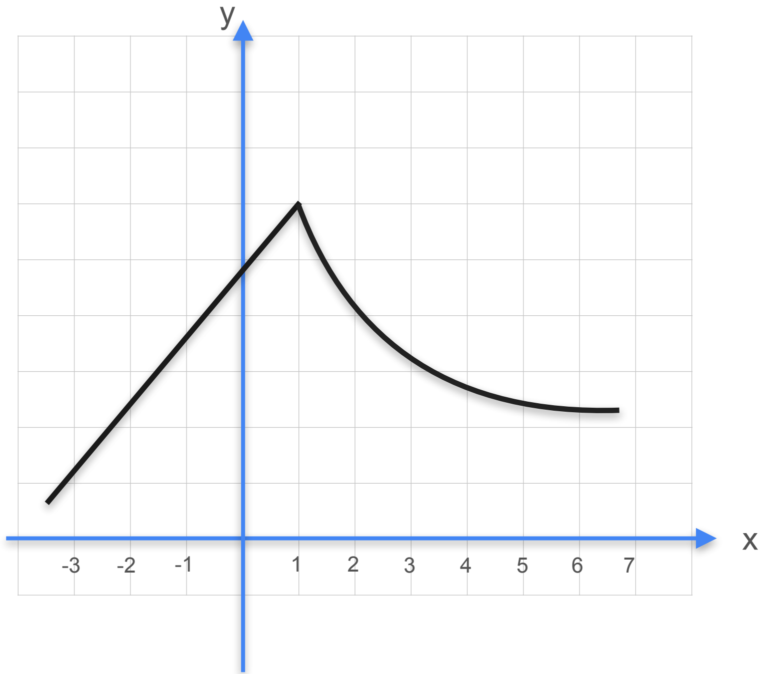
Generally, when a function has a corner or a cusp, the function is not differentiable at that point.

Non Differentiable Functions - Quiz 1

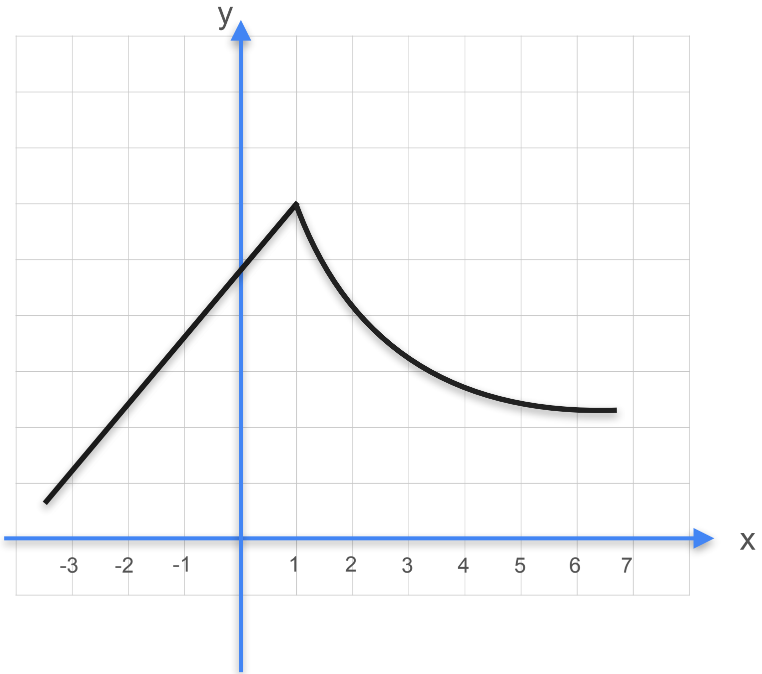
Non Differentiable Functions - Quiz 1



Non Differentiable Functions - Quiz 1

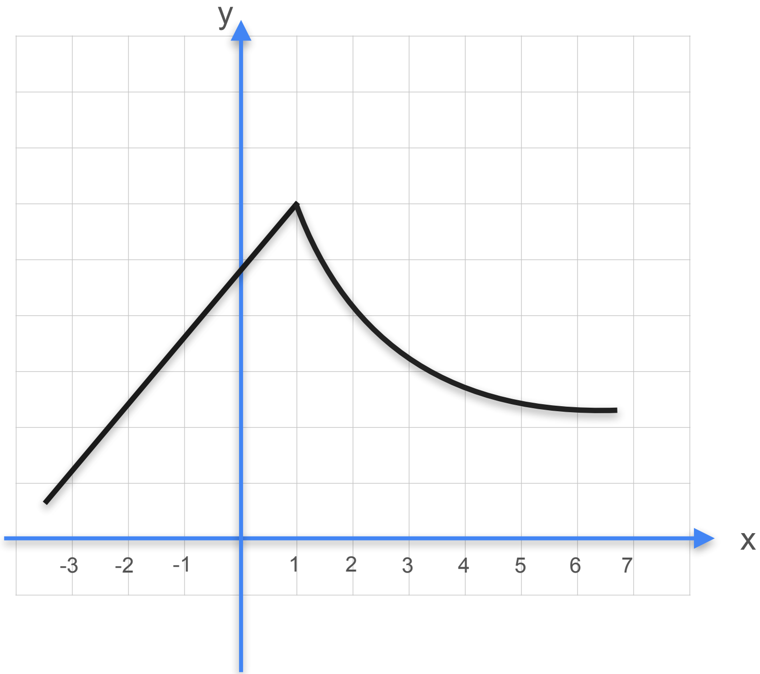


Non Differentiable Functions - Quiz 1



At which point in this function does the derivative not exist?

Non Differentiable Functions - Quiz 1



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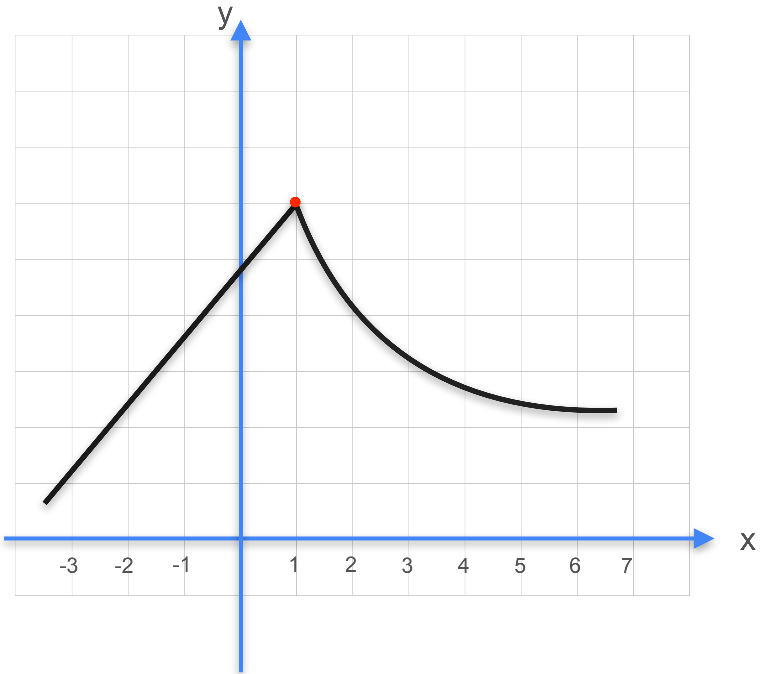
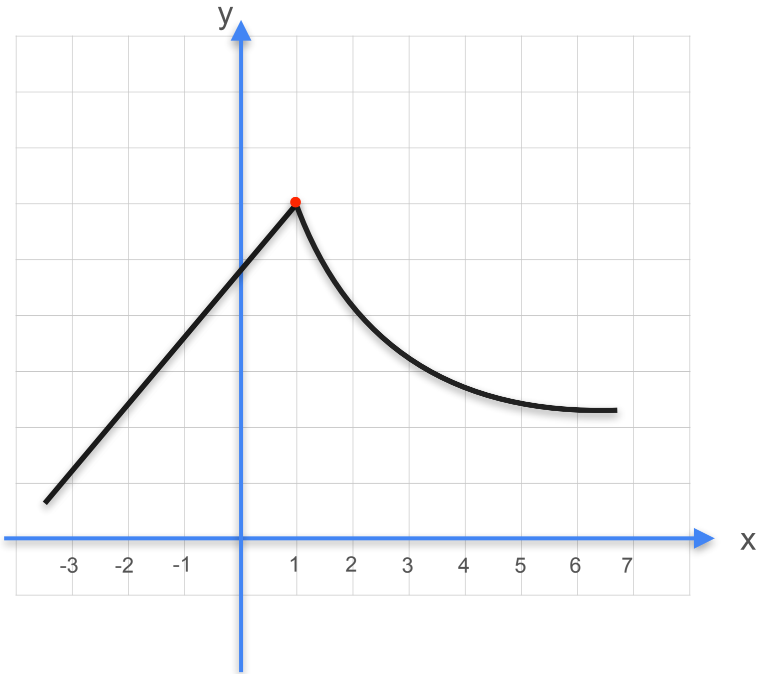


At which point in this function does the derivative not exist?

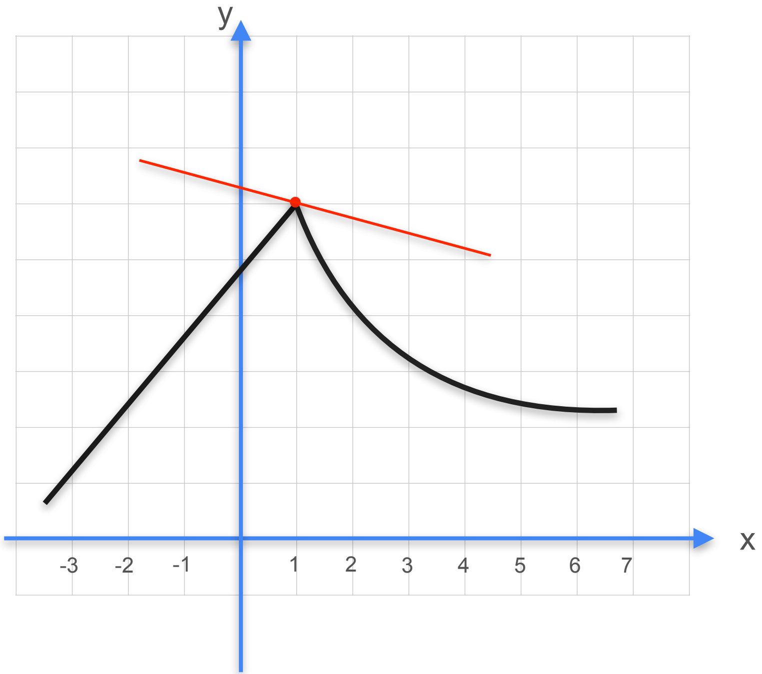
Non Differentiable Functions - Quiz 1



At which point in this function does the derivative not exist?

The entire function is non-differentiable because a derivative does not exist for all points in the domain.

Non Differentiable Functions - Quiz 1



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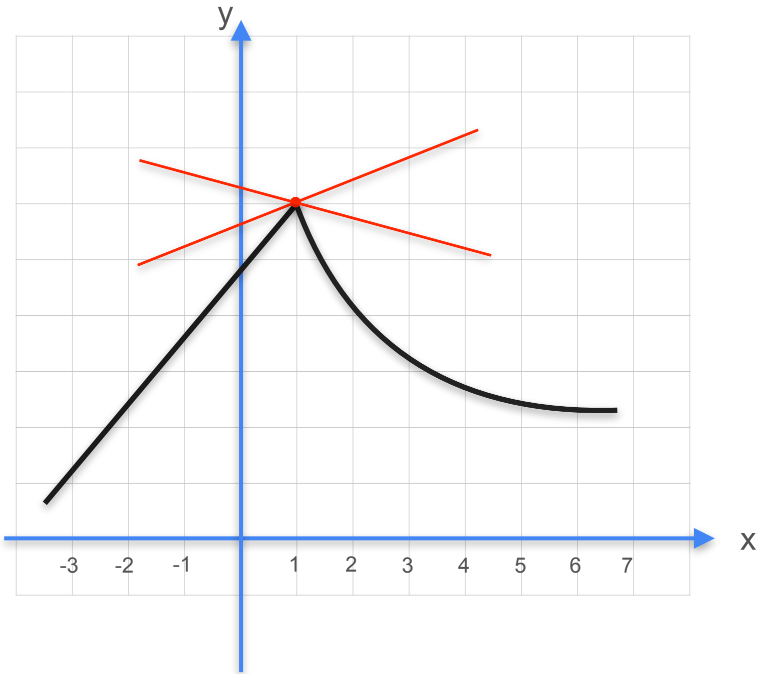

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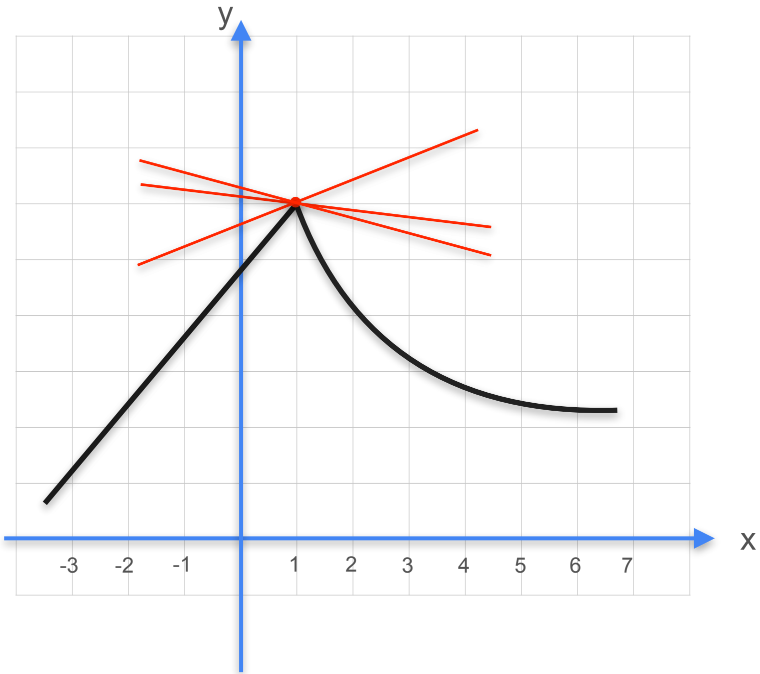

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Non Differentiable Functions - Quiz 2

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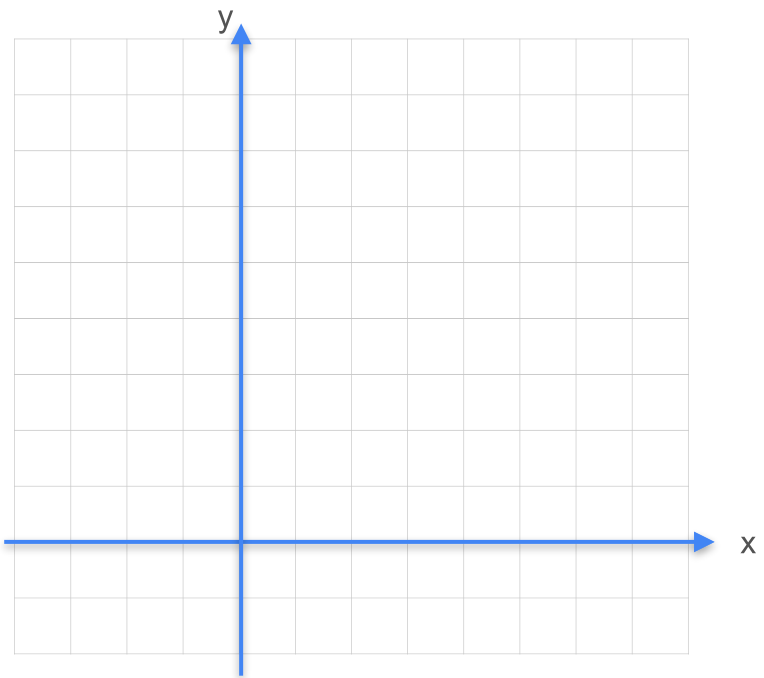

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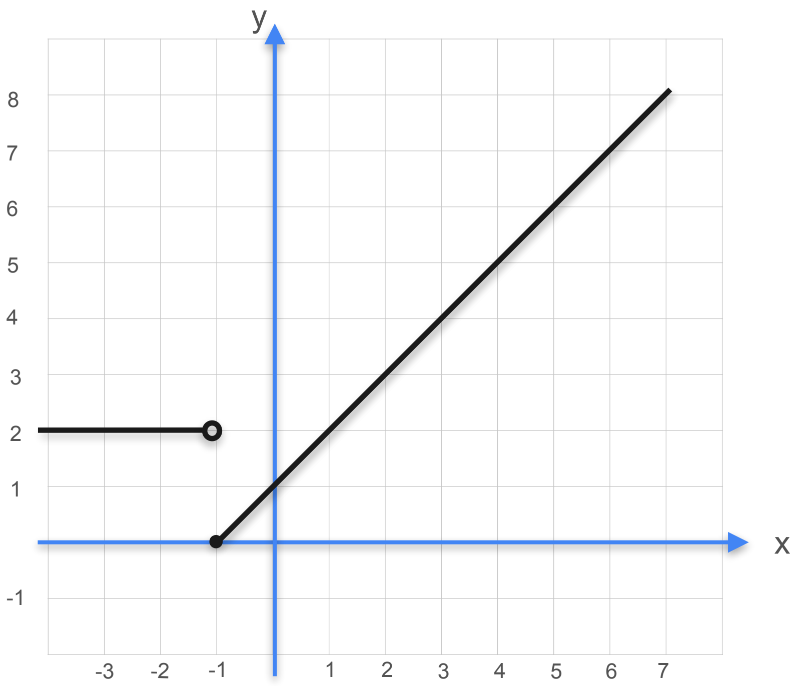

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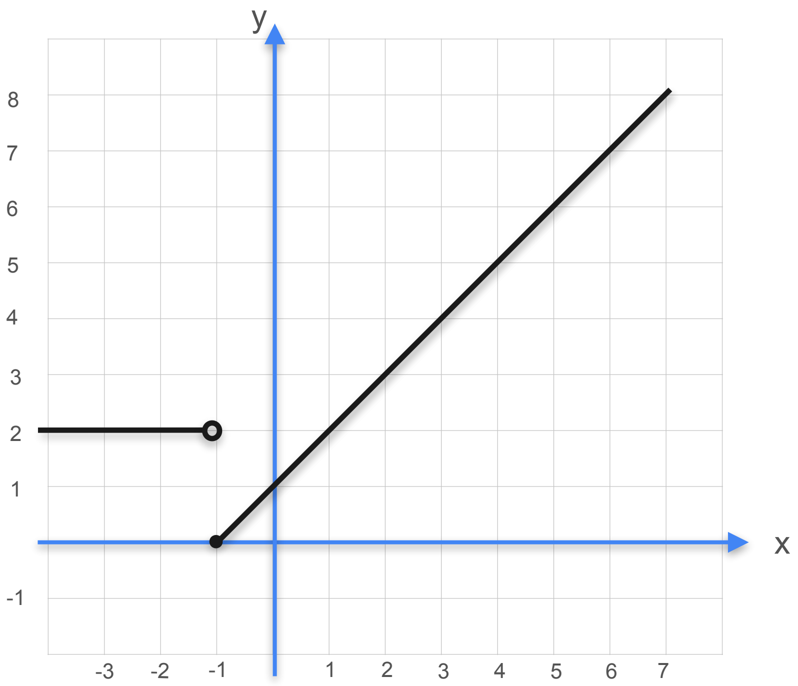

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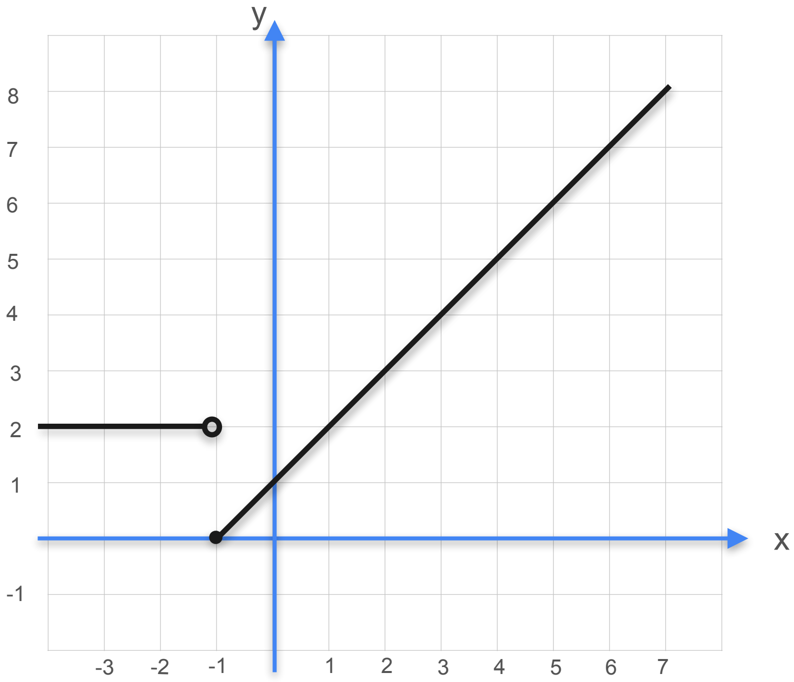
Non Differentiable Functions



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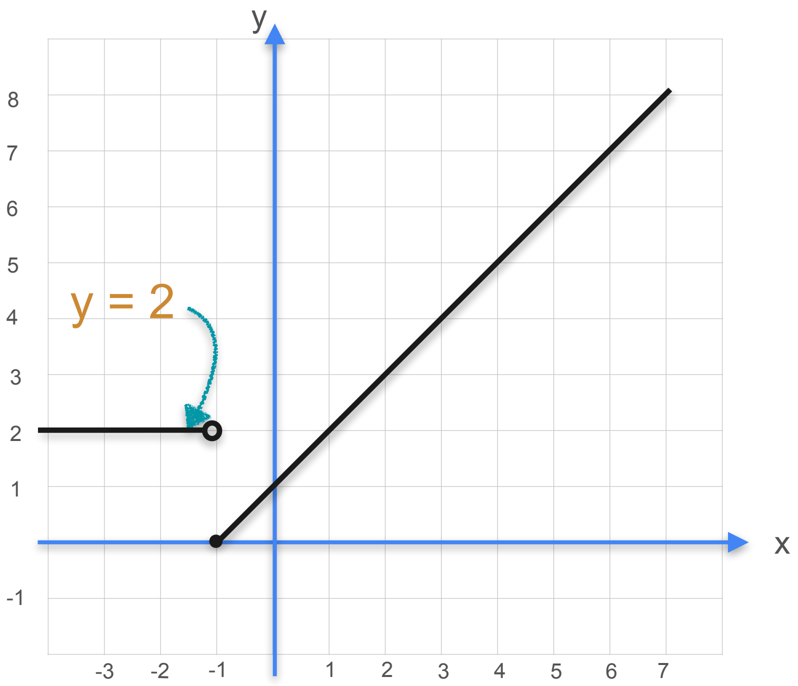

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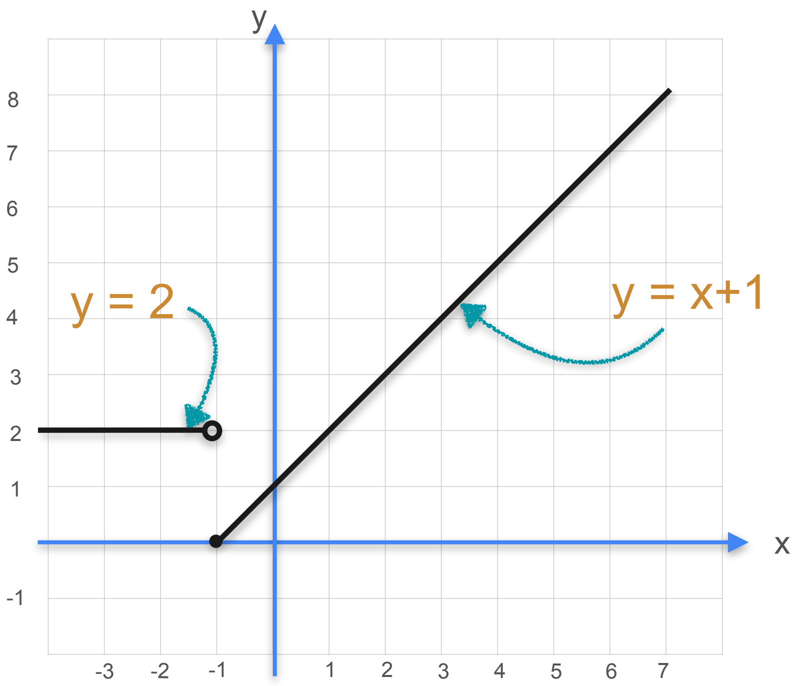

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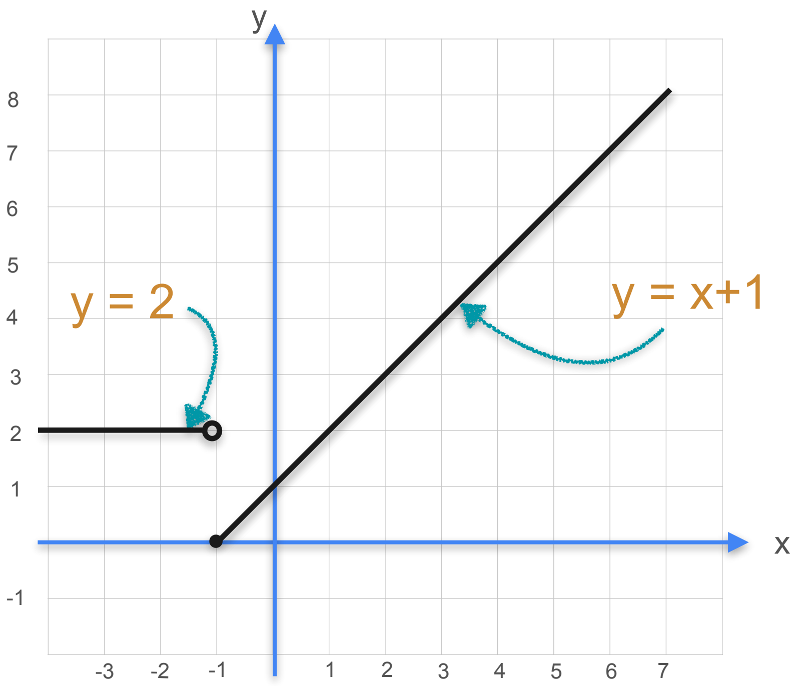
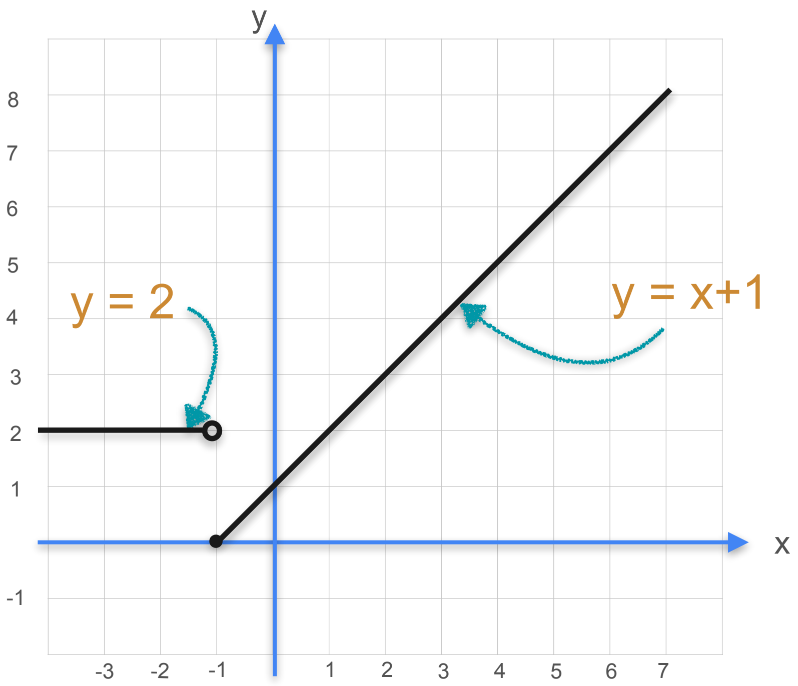


This is a piece-wise function.

$$f(x) = \begin{cases} 2, & \textit{if } x < -1 \\ x + 1, & \textit{if } x \geq -1 \end{cases}$$

Non Differentiable Functions



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Jump Discontinuity

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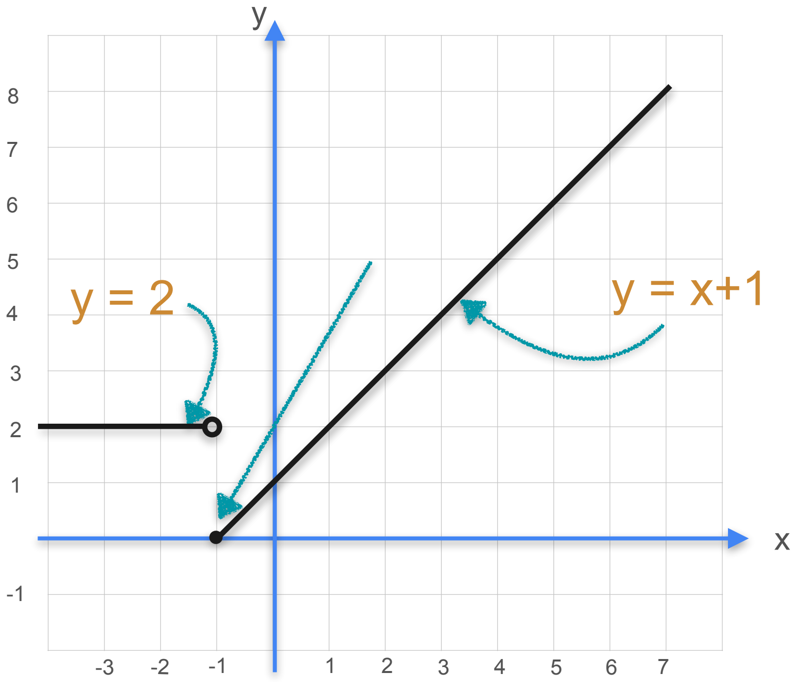

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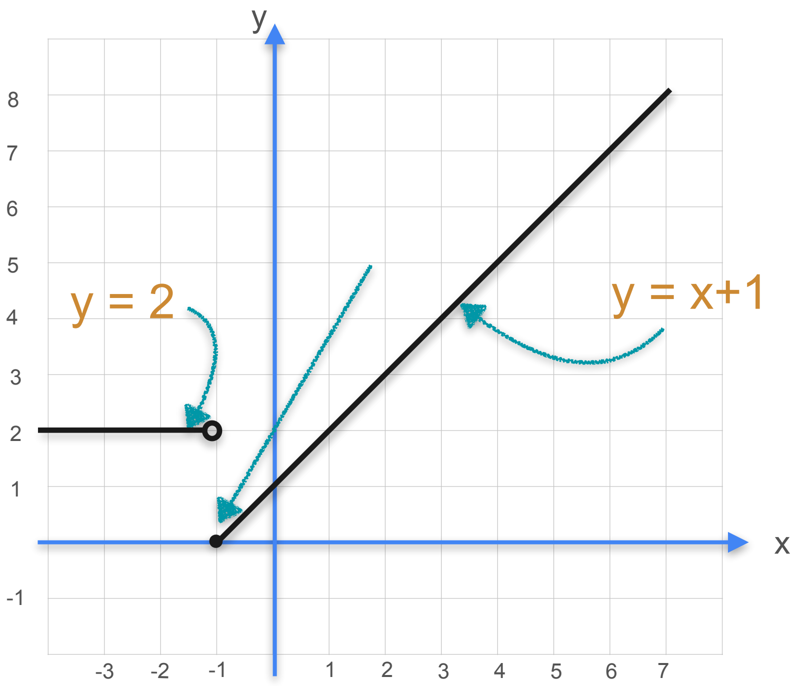

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The graph of the function does not appear to be continuous

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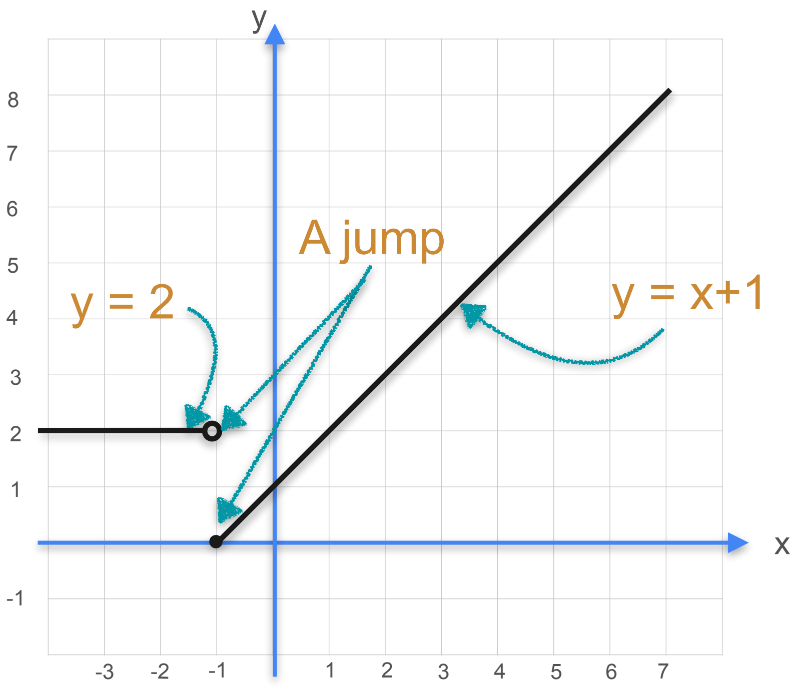

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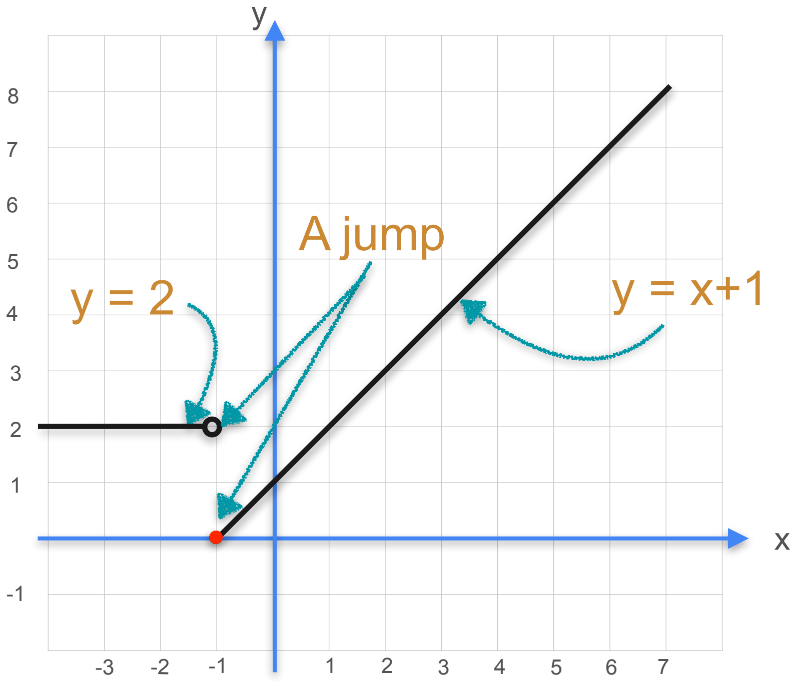

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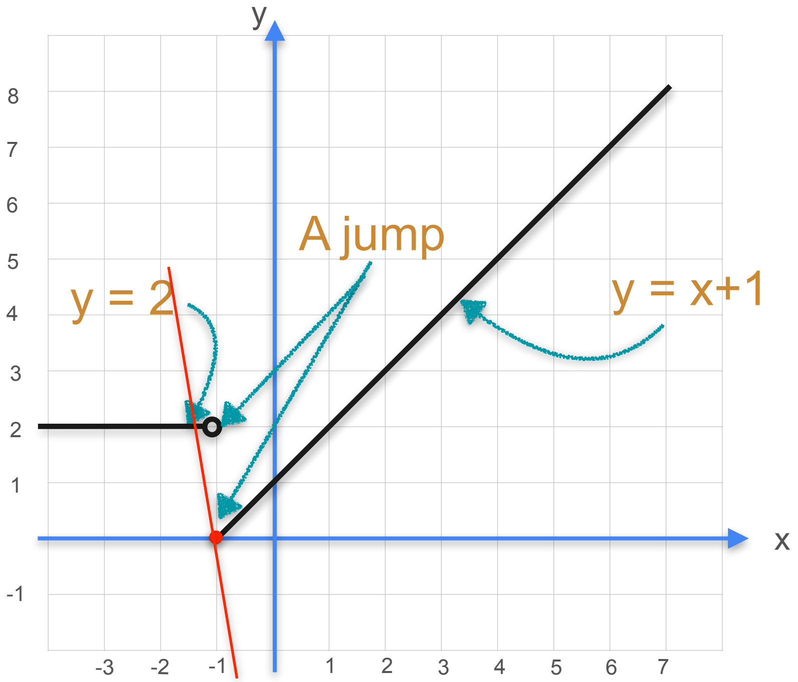

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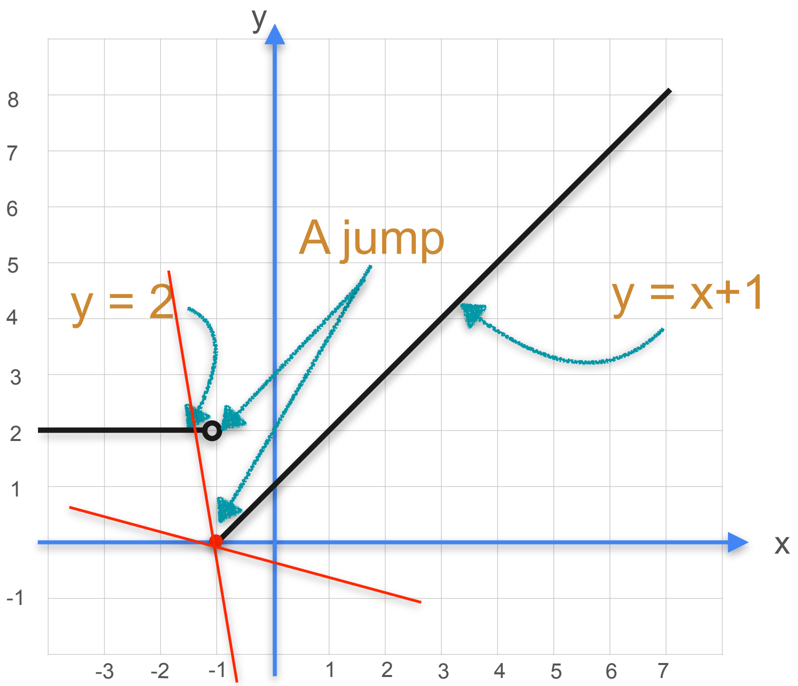

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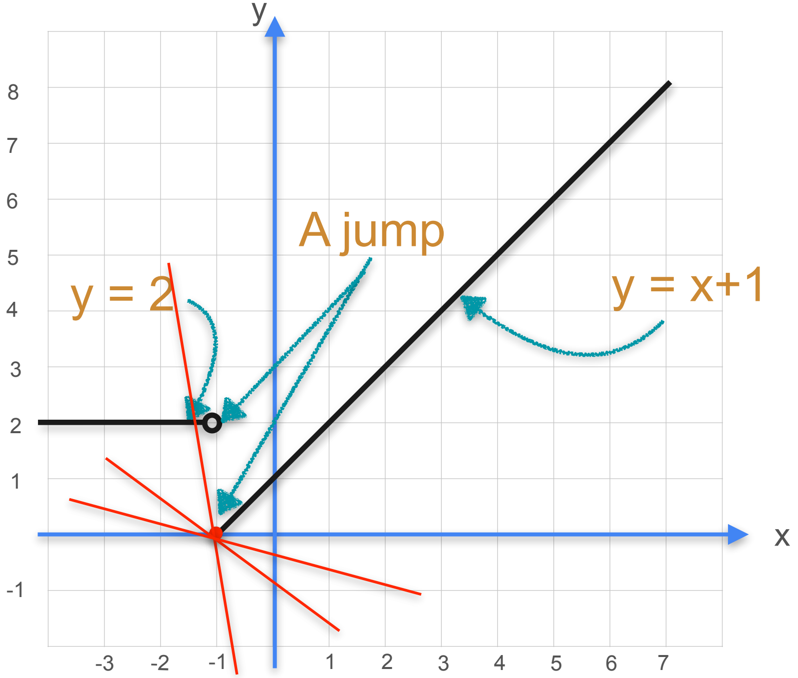

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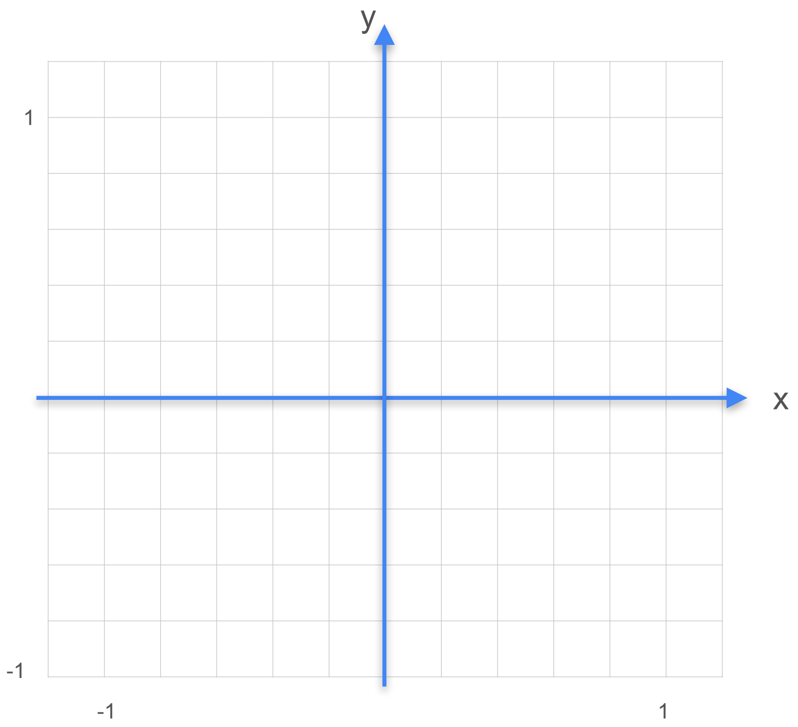

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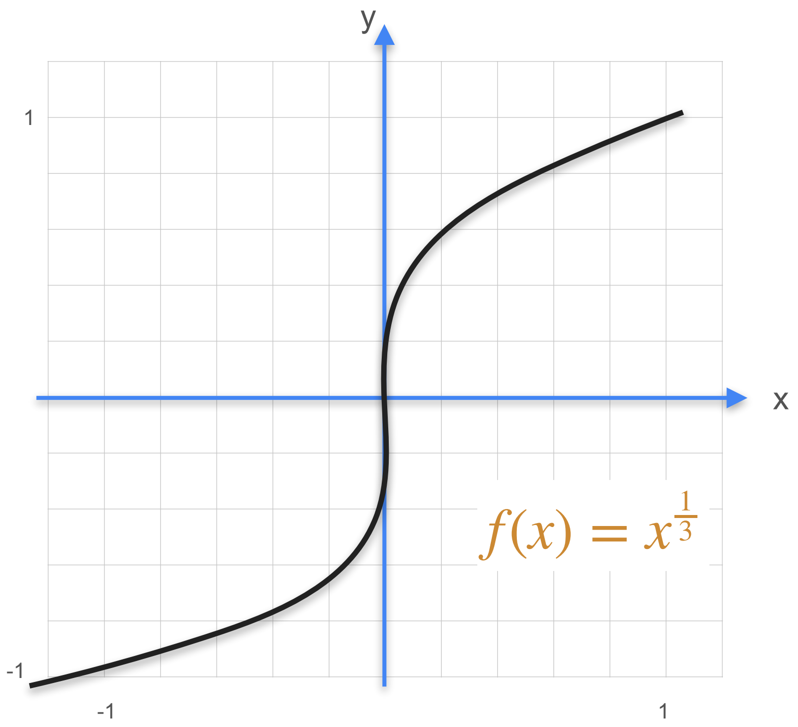

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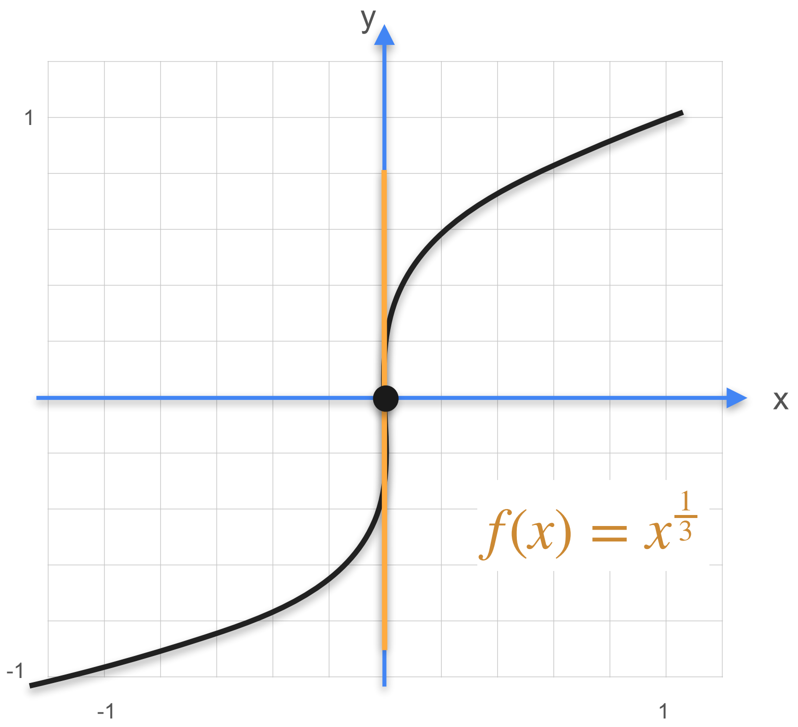

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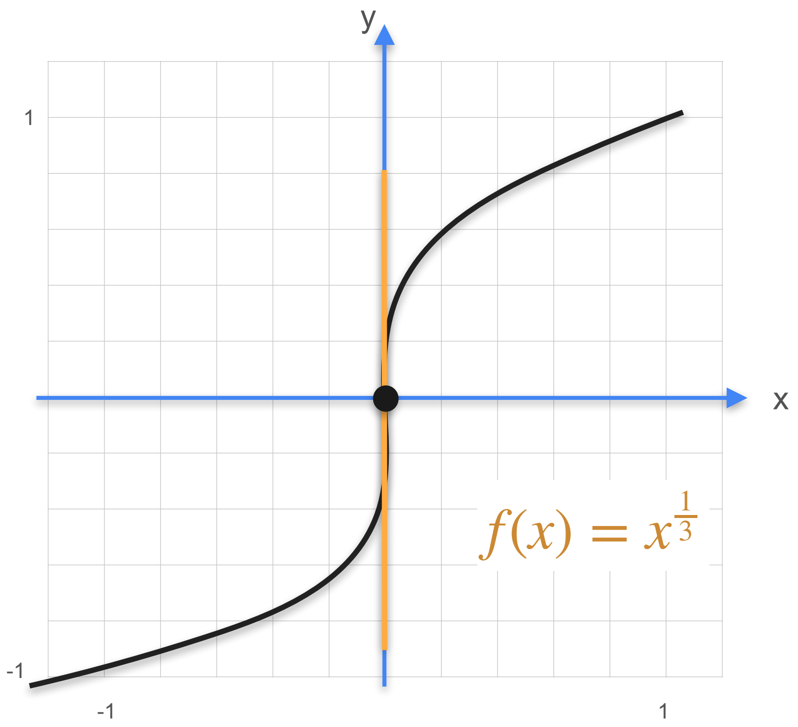
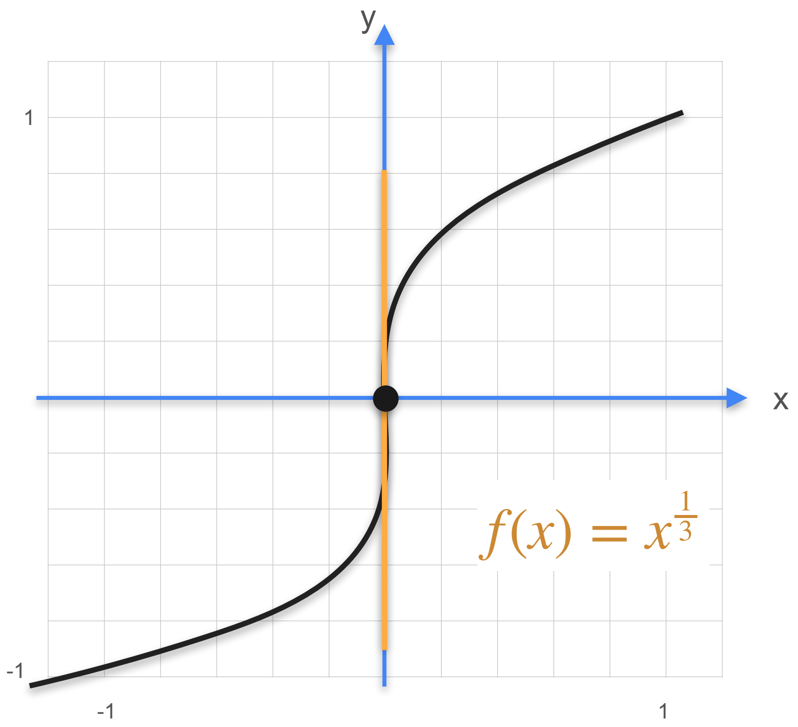


Vertical tangents

Non Differentiable Functions



Vertical tangents

At $x = 0$, this graph has a tangent line that runs straight up parallel to the y-axis

Recap: Non-Differentiable Functions

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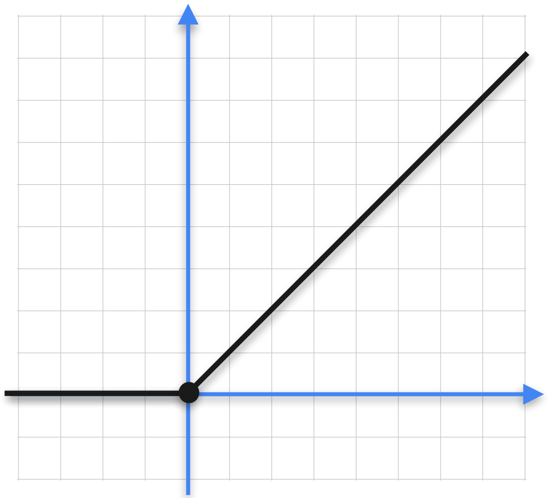

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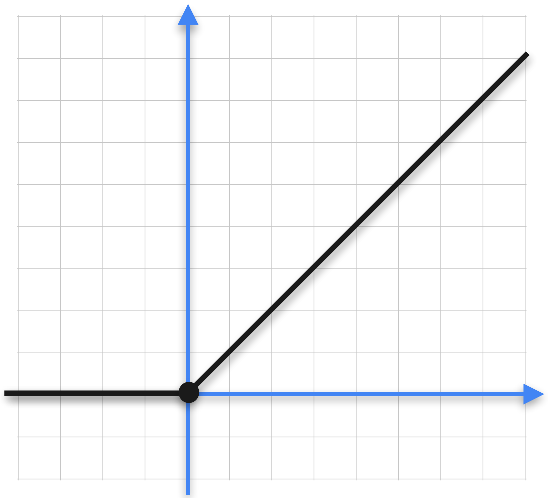

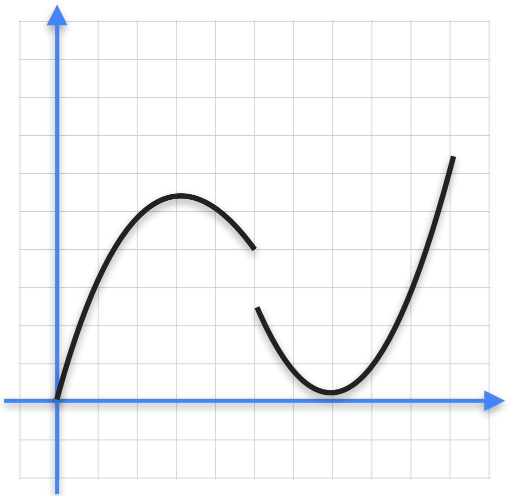

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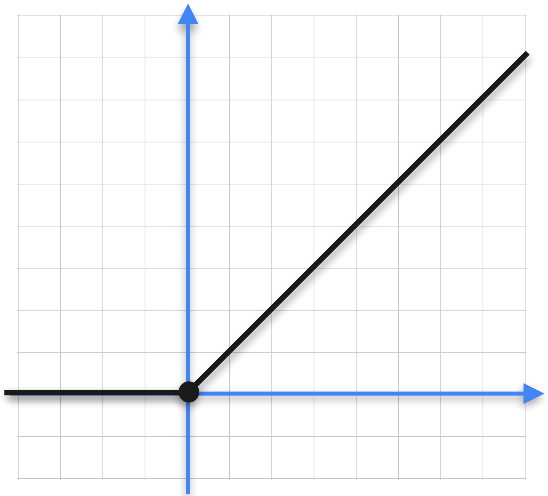

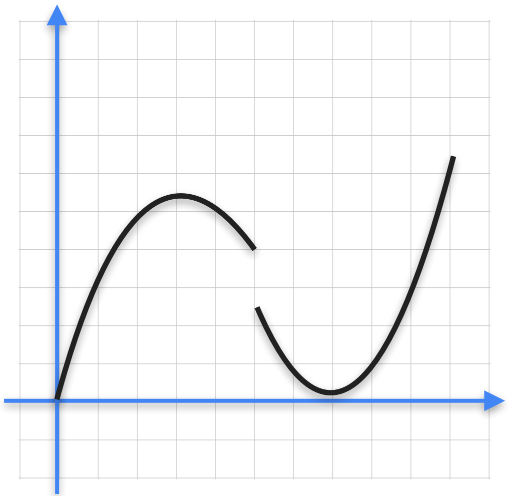

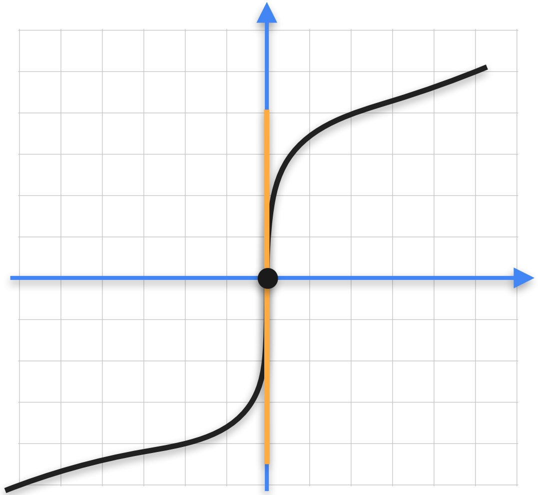

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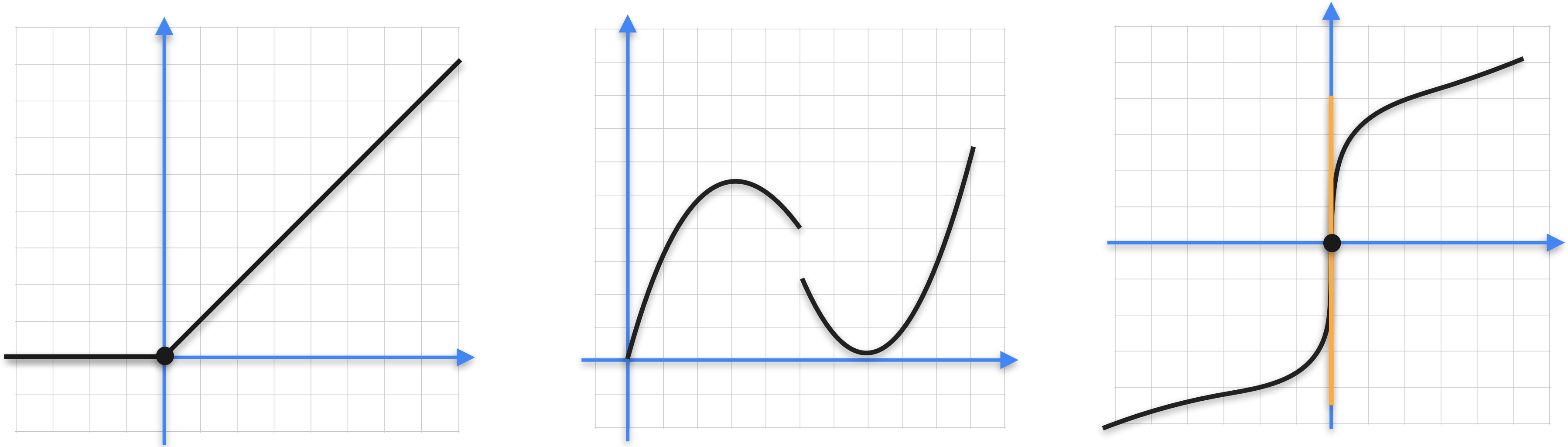
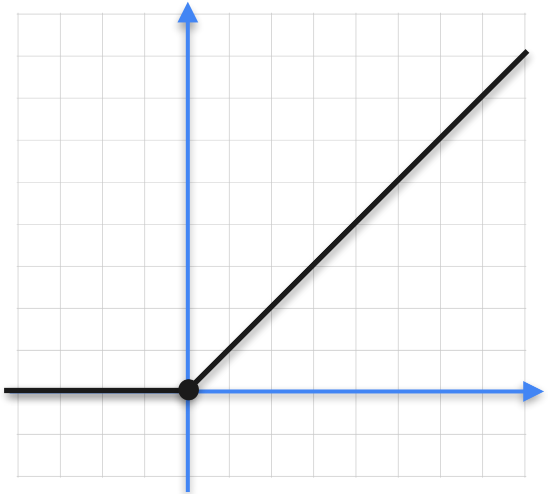


Corners/Cusps

Recap: Non-Differentiable Functions



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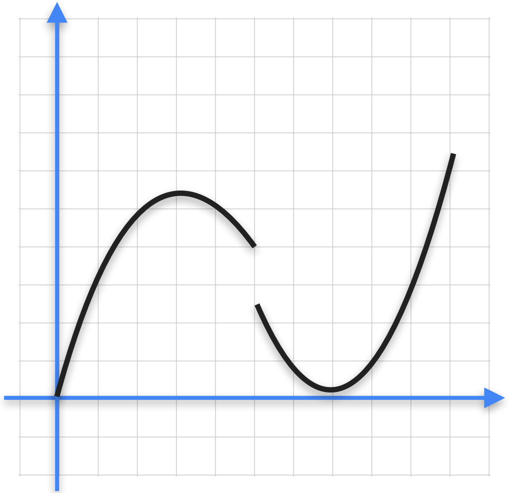
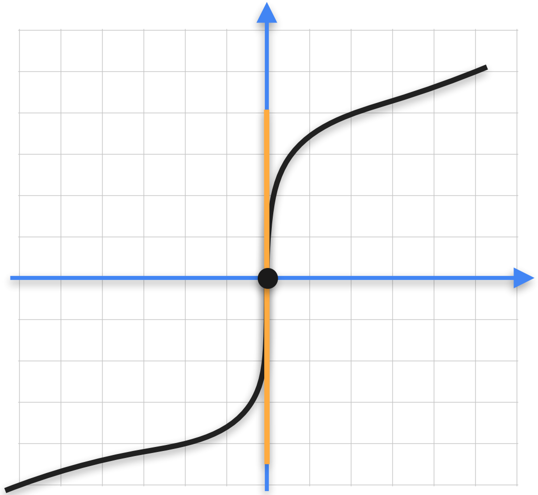


Jump Discontinuity



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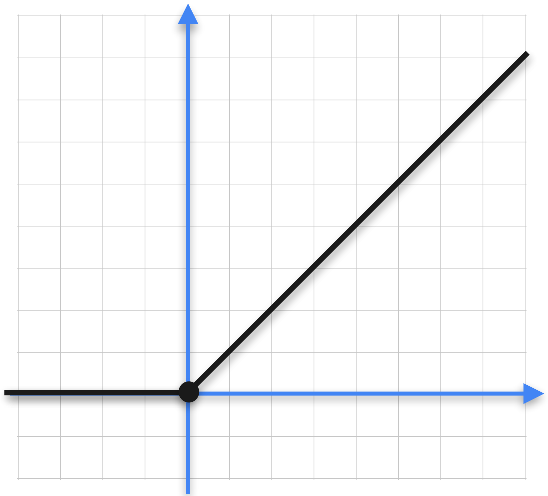

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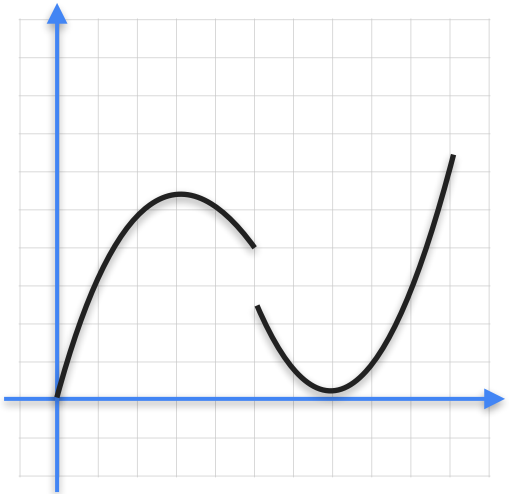

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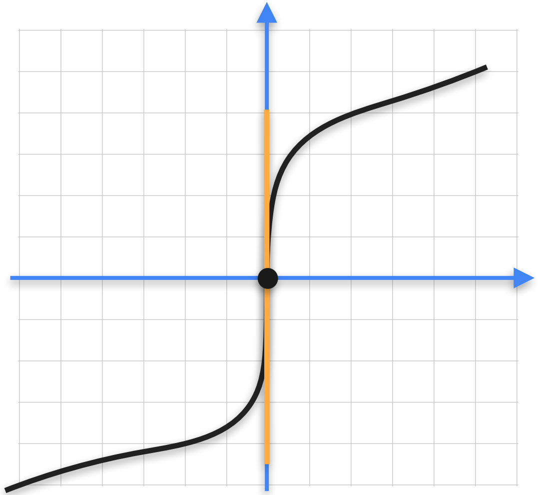


Vertical tangents

DeepLearning.AI

Derivatives and Optimization

Properties of the derivative: Multiplication by scalars

The Sum Rule

$$f = 4g$$

The Sum Rule

$$f' = 4g$$

The Sum Rule

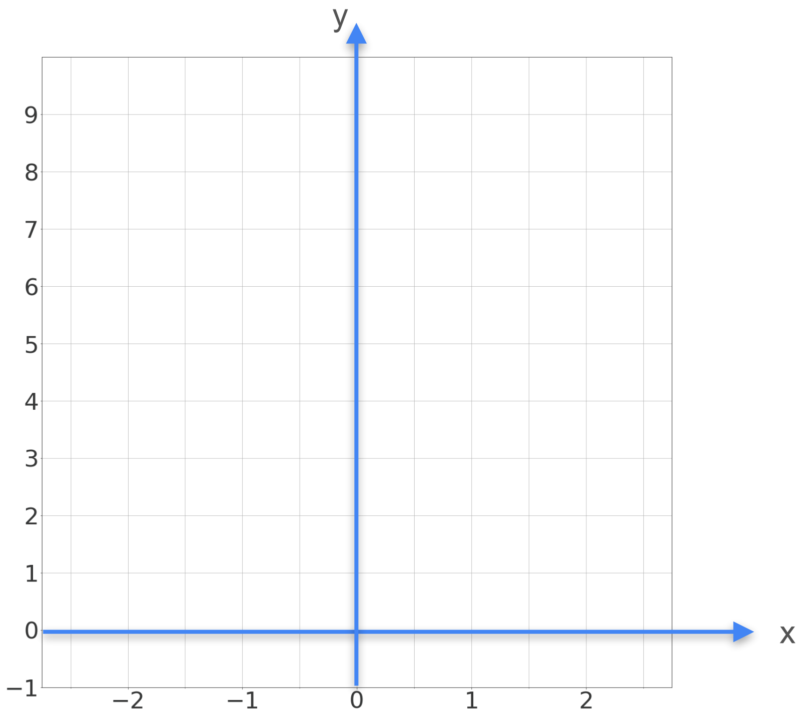
$$f' = 4g'$$

The Sum Rule

$$f' = c g'$$

Multiplication by a Scalar

Multiplication by a Scalar



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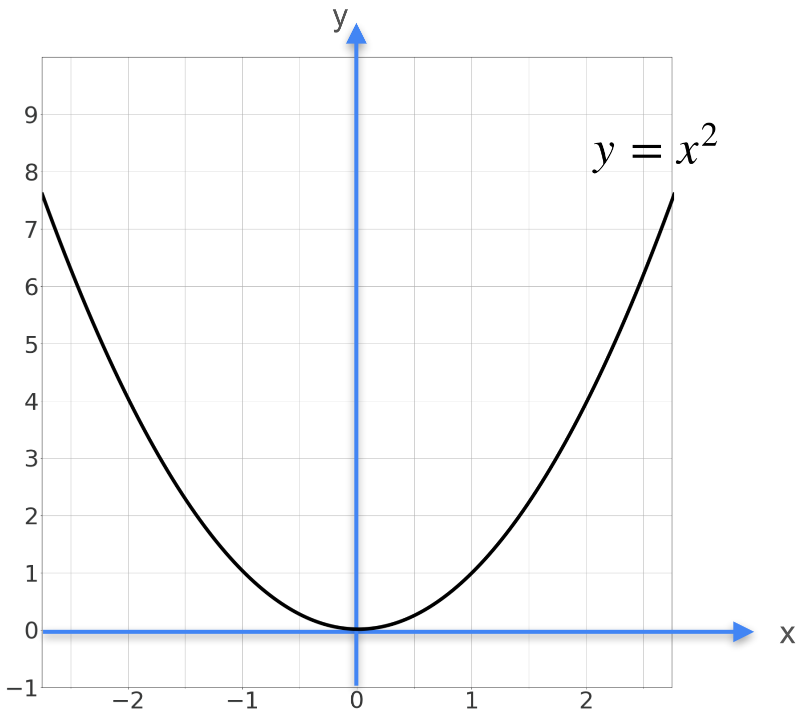

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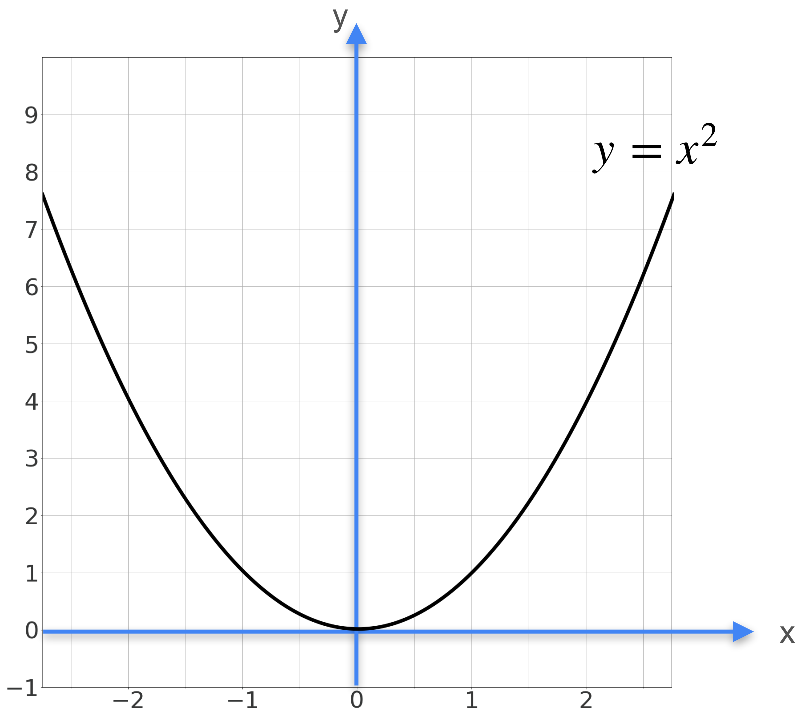

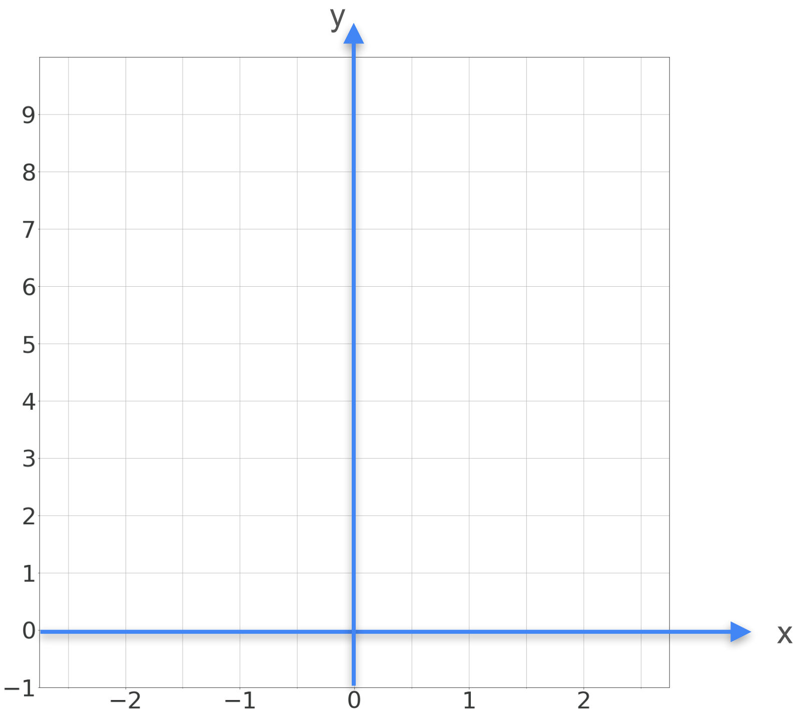

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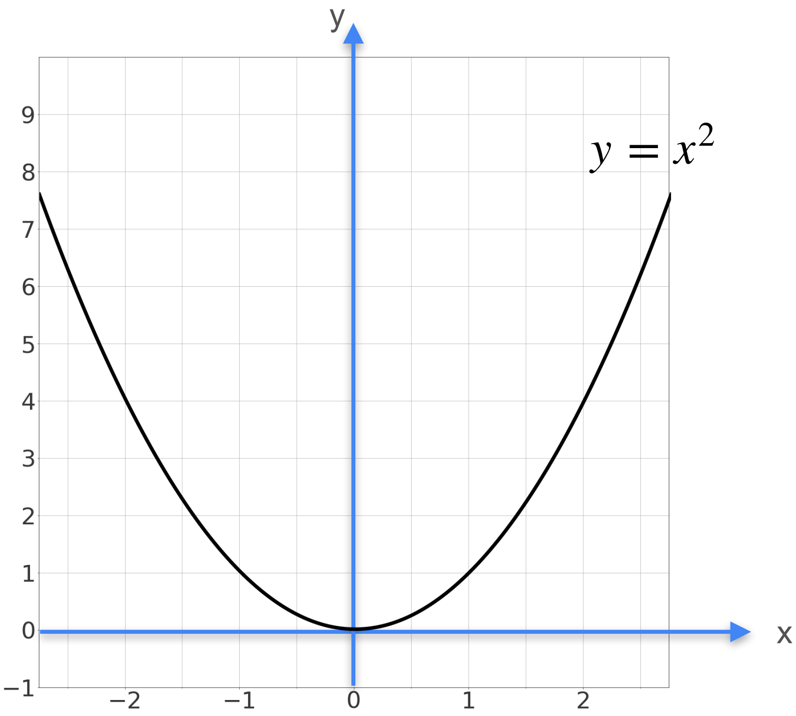

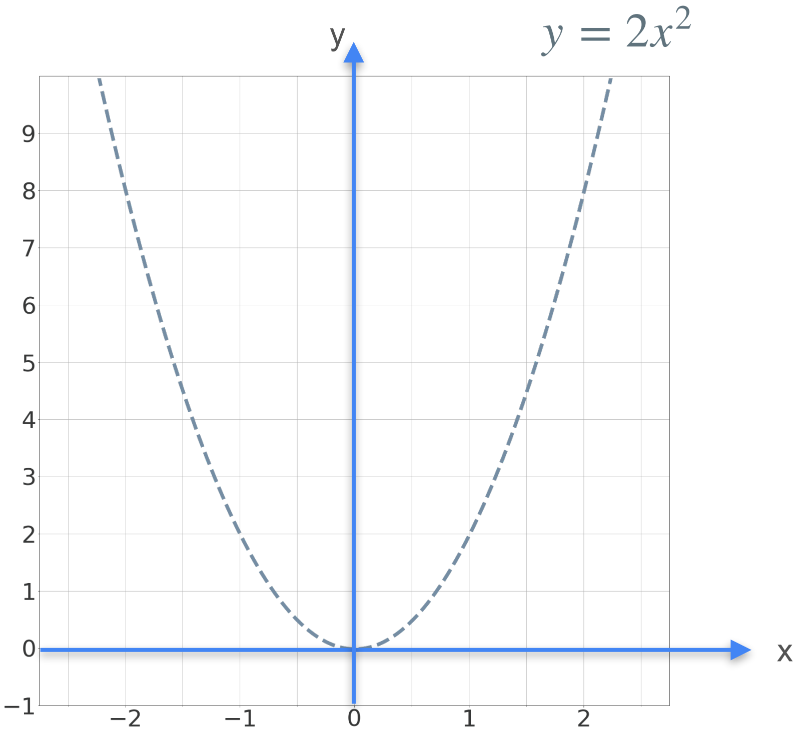

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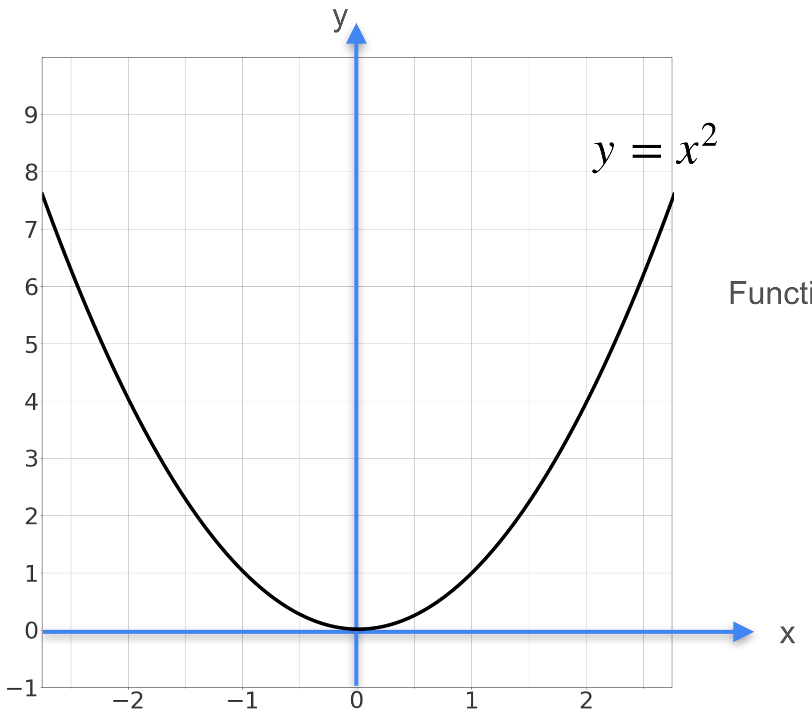
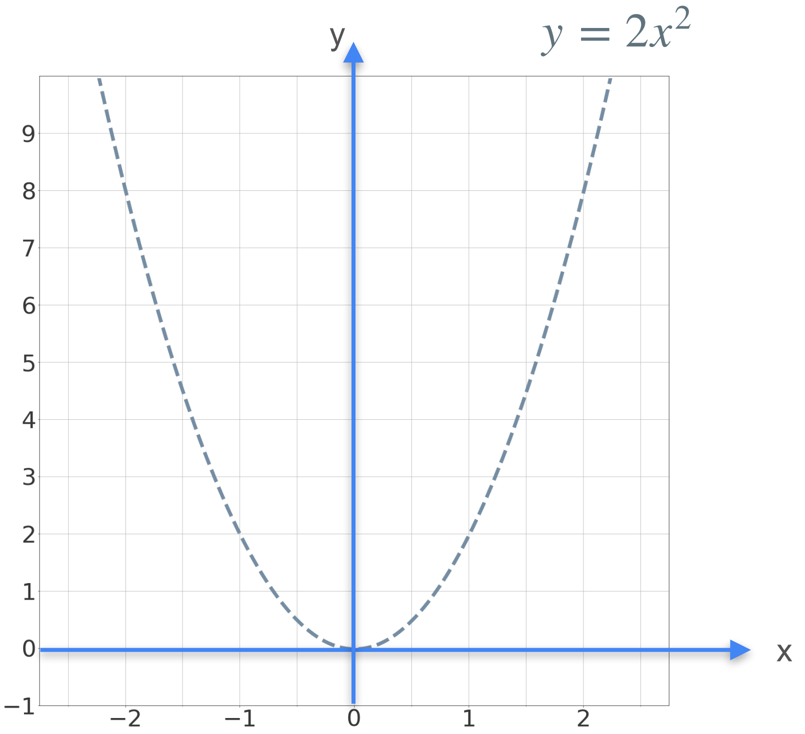


Function multiplies by 2



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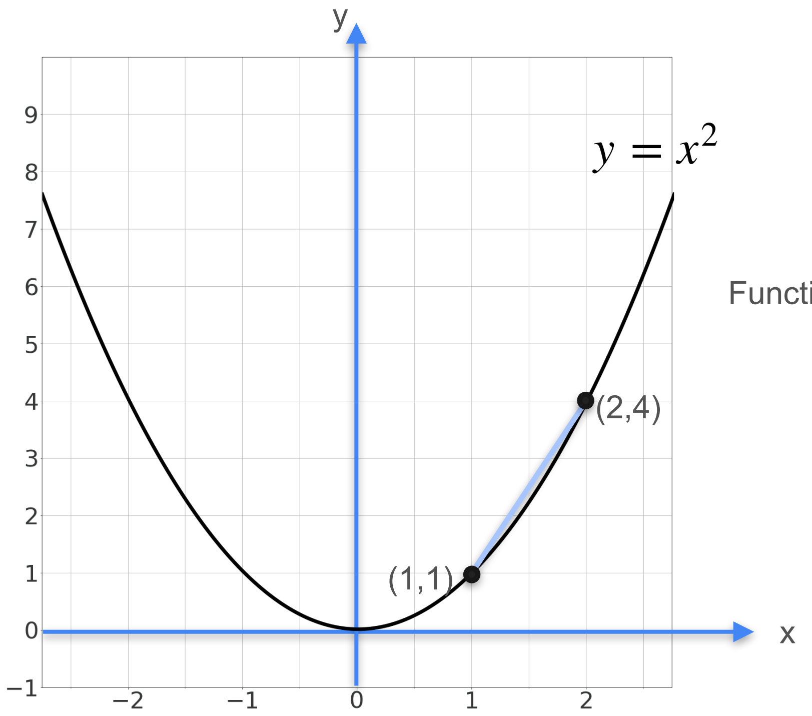

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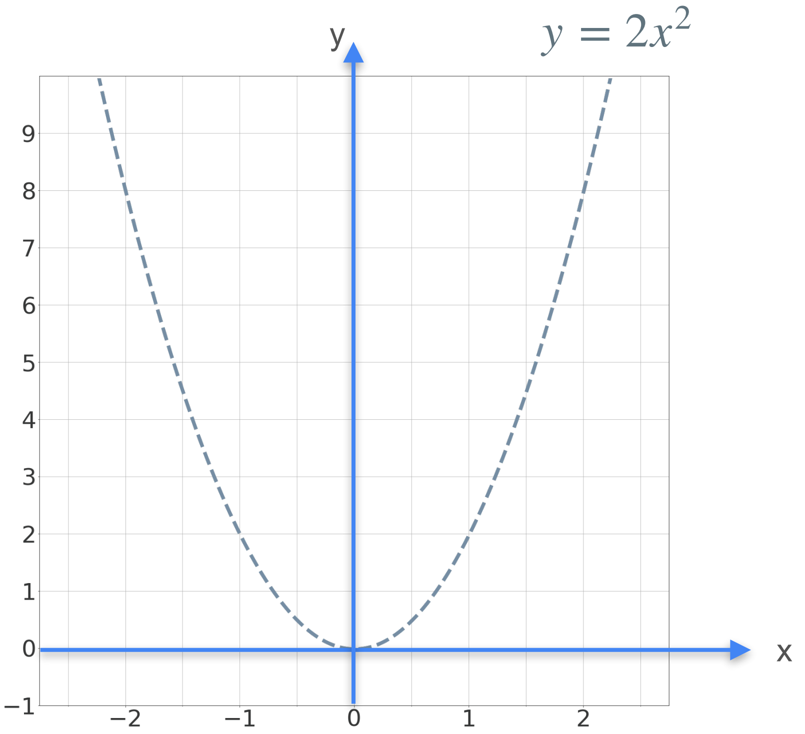

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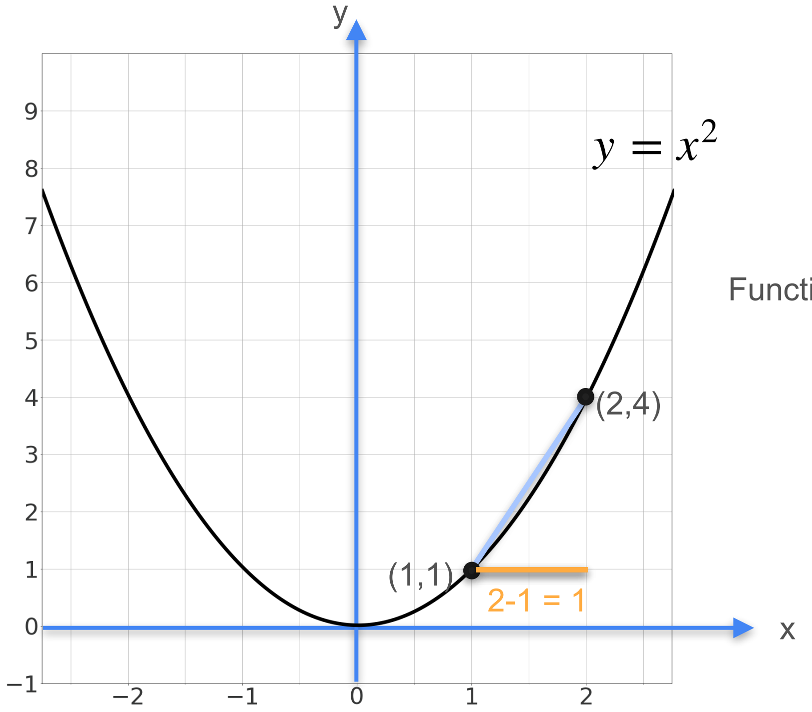

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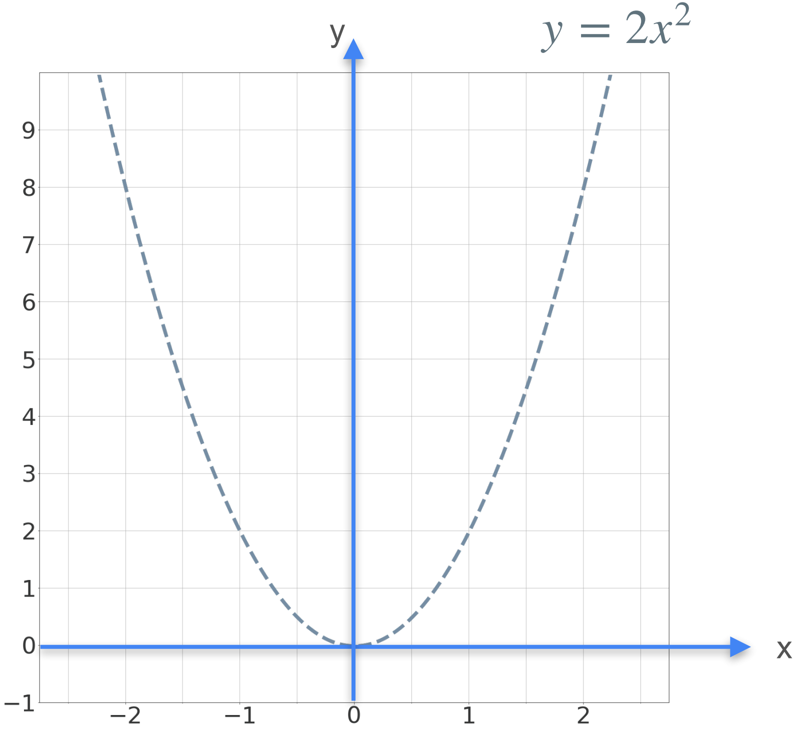

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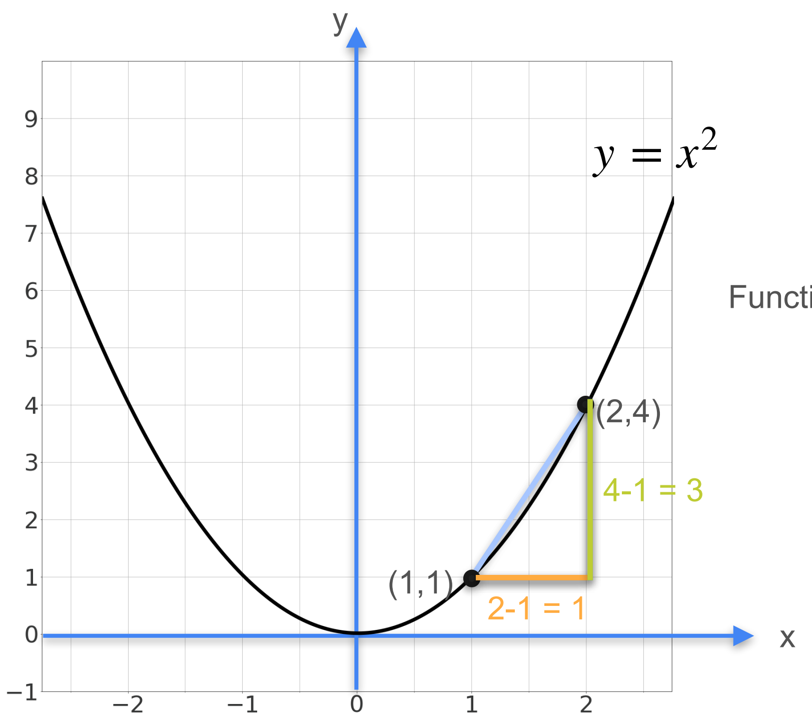

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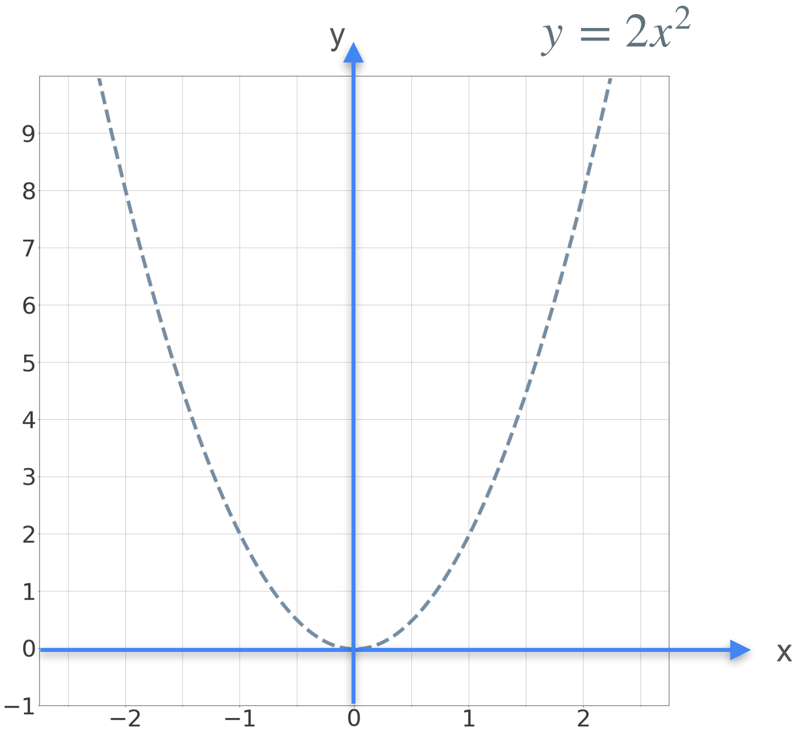
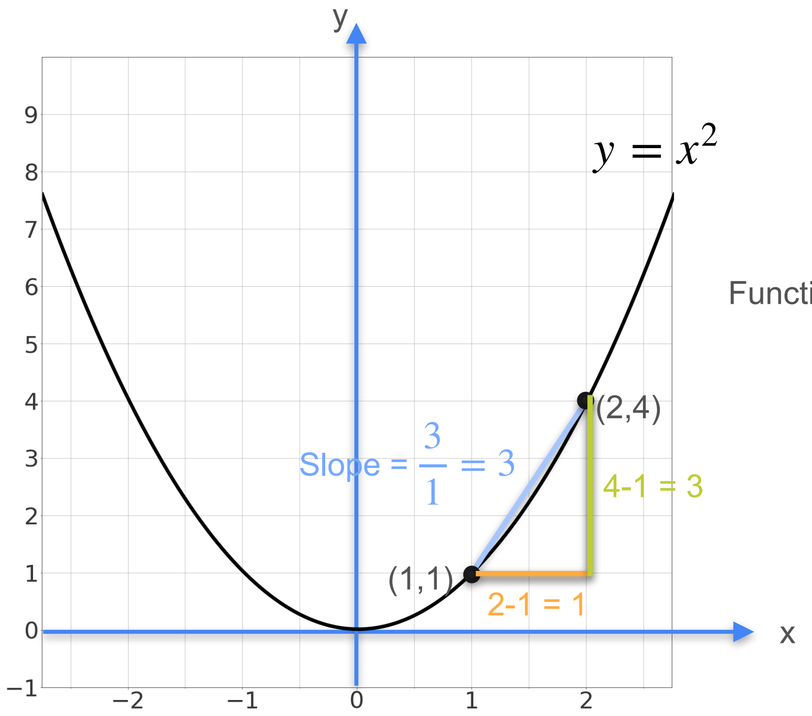
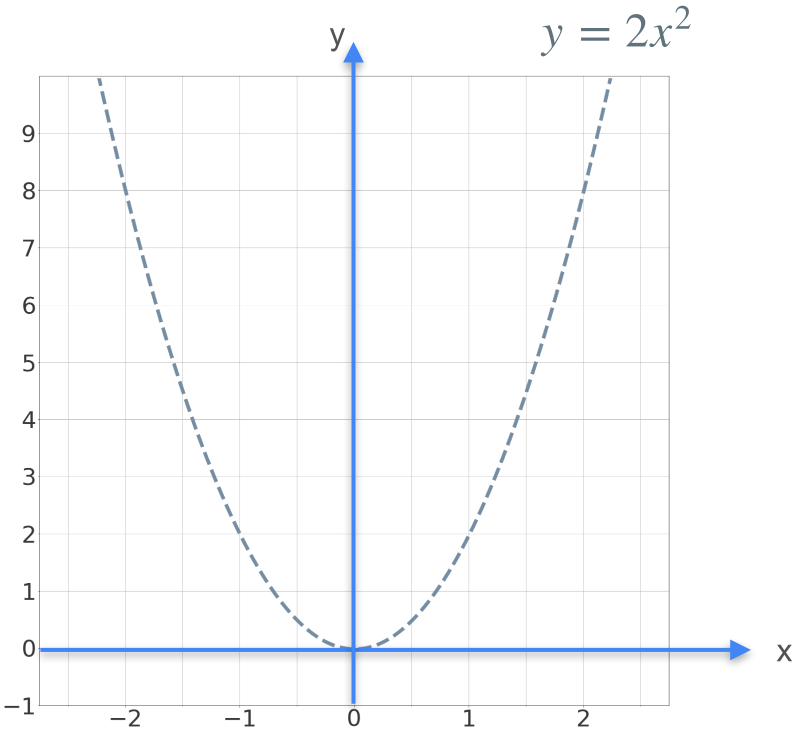


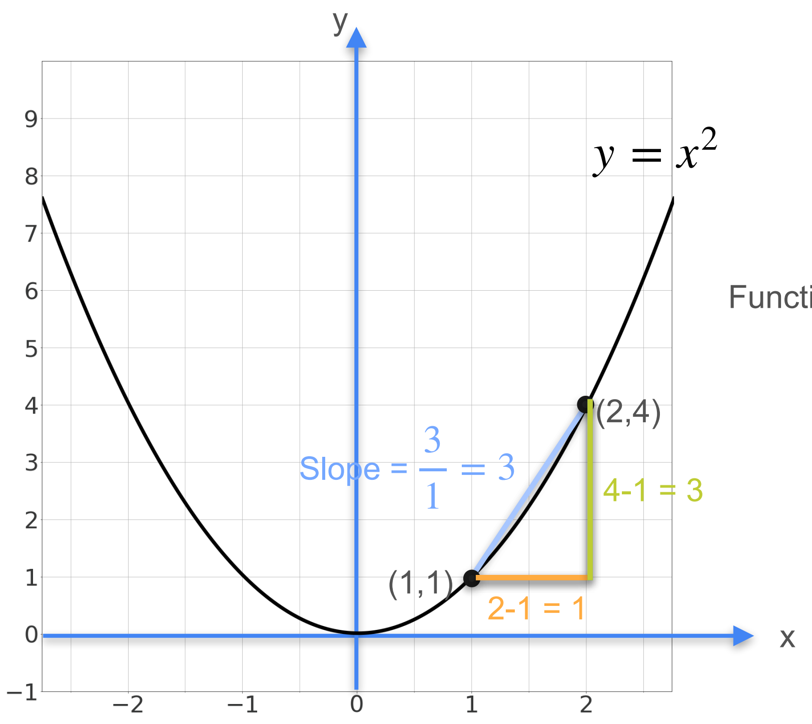
Multiplication by a Scalar



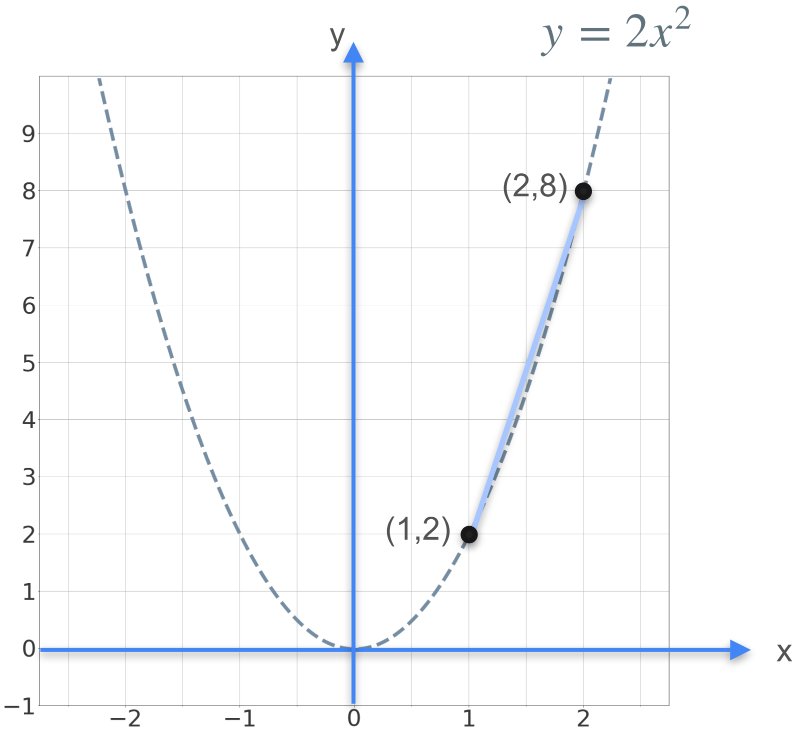
Function multiplies by 2



Multiplication by a Scalar



Function multiplies by 2



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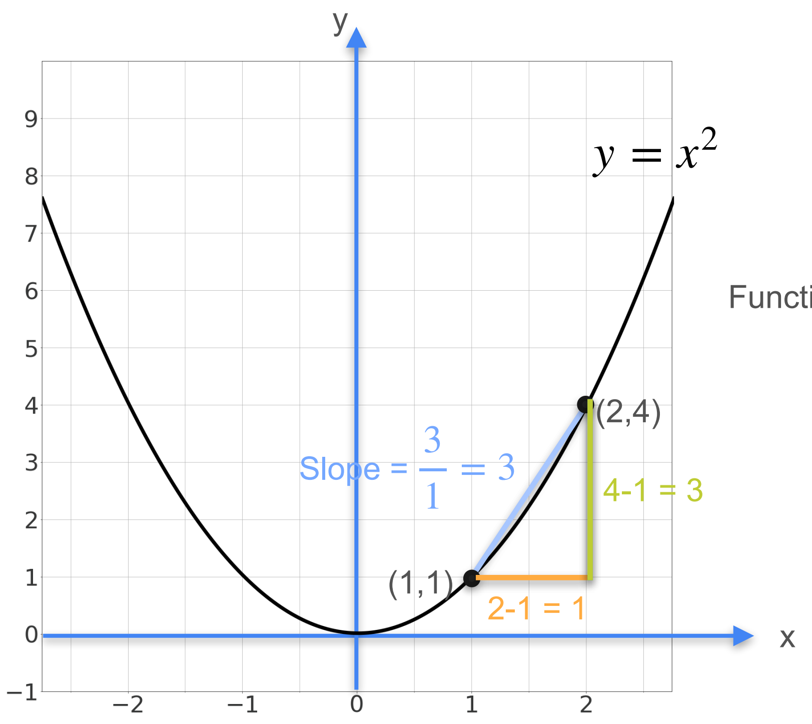
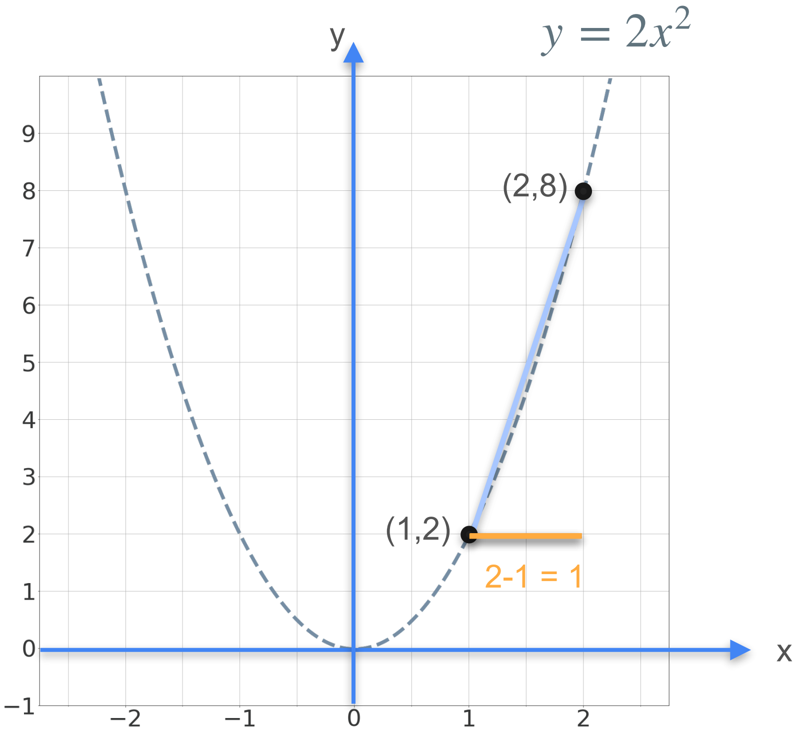
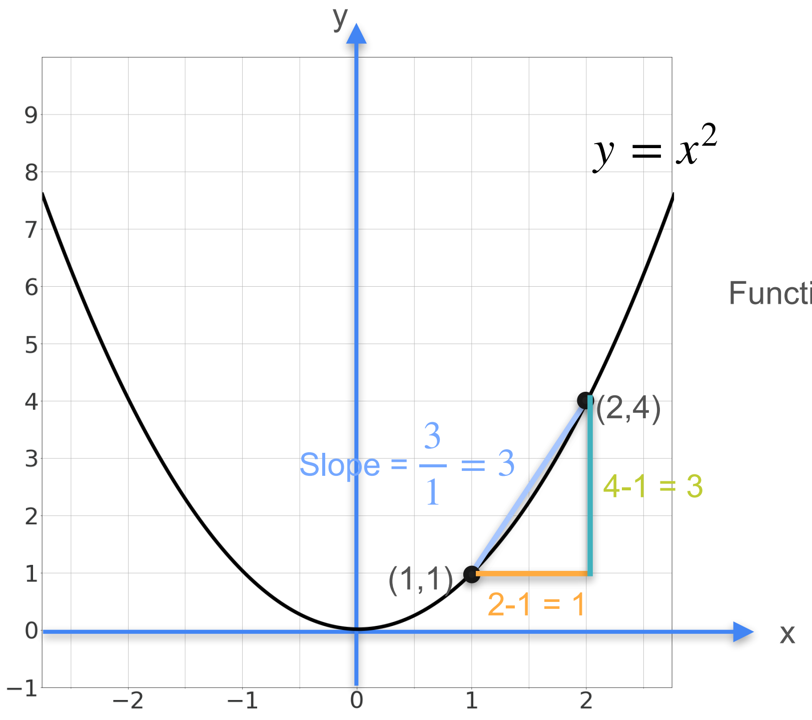


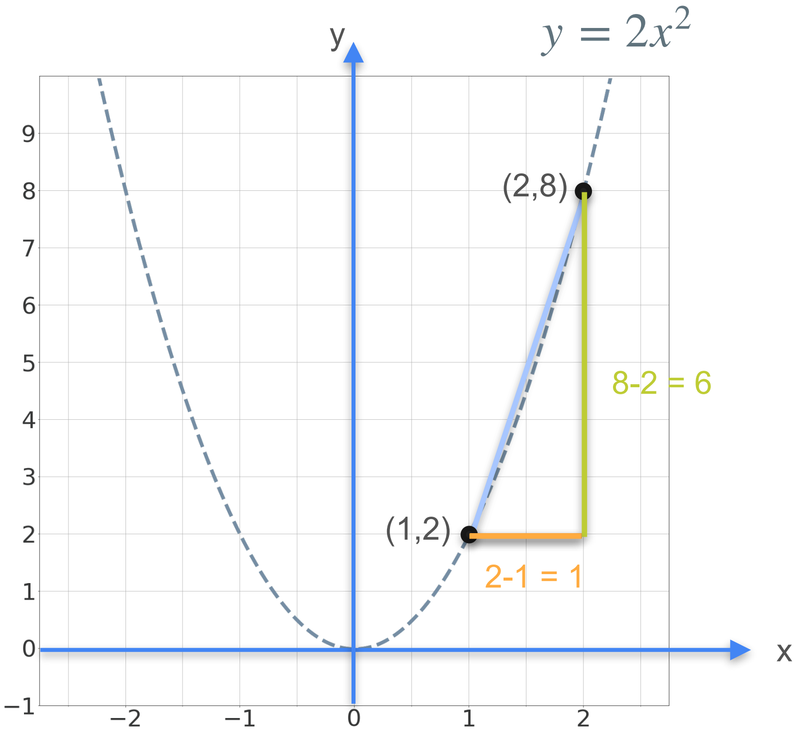
Function multiplies by 2



Multiplication by a Scalar



Function multiplies by 2



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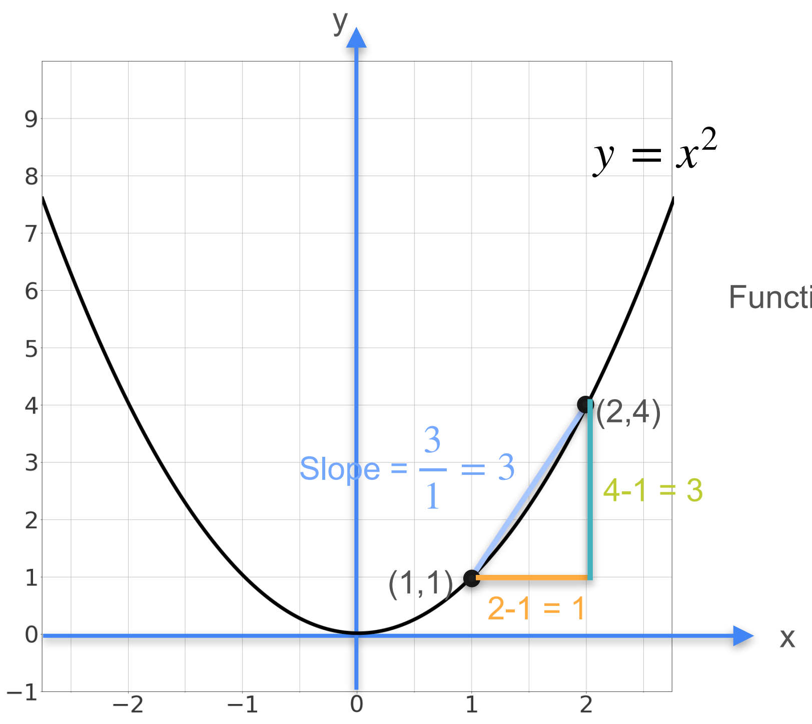

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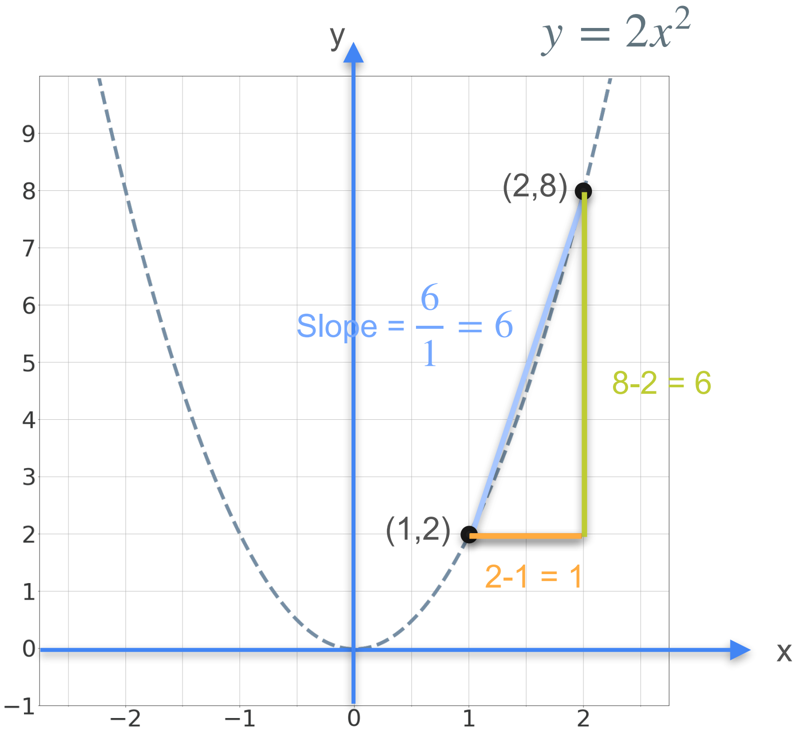
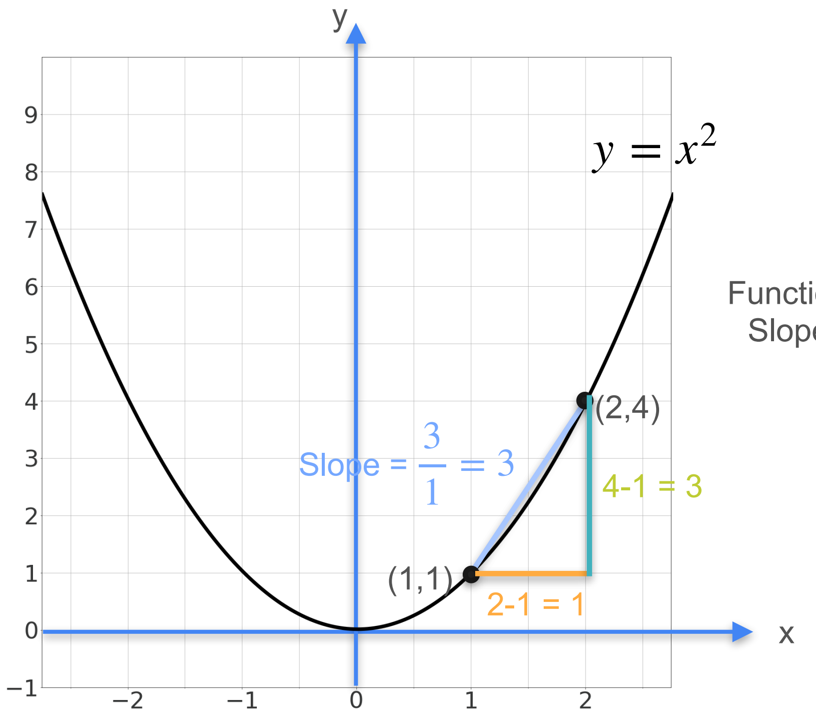
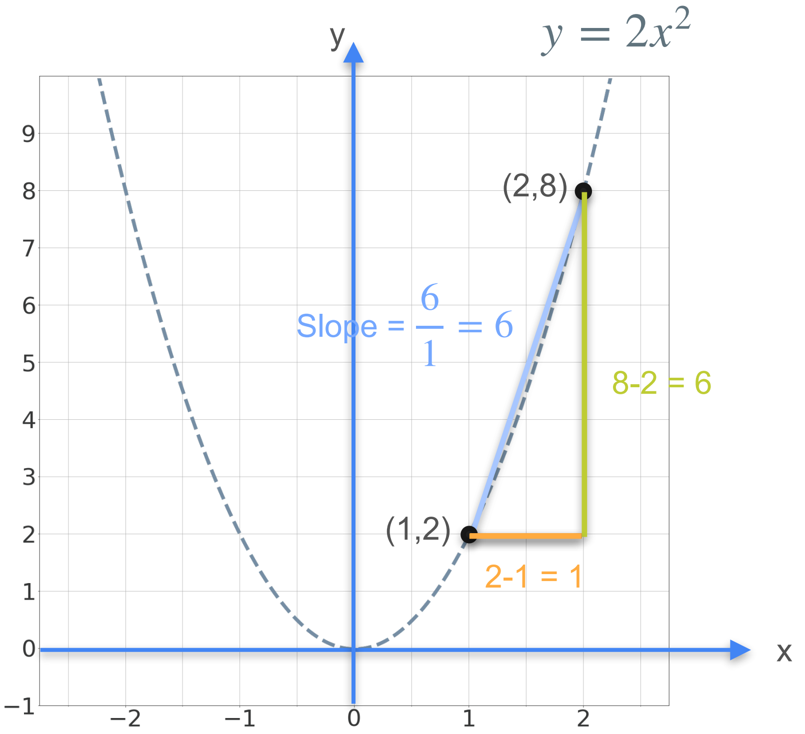


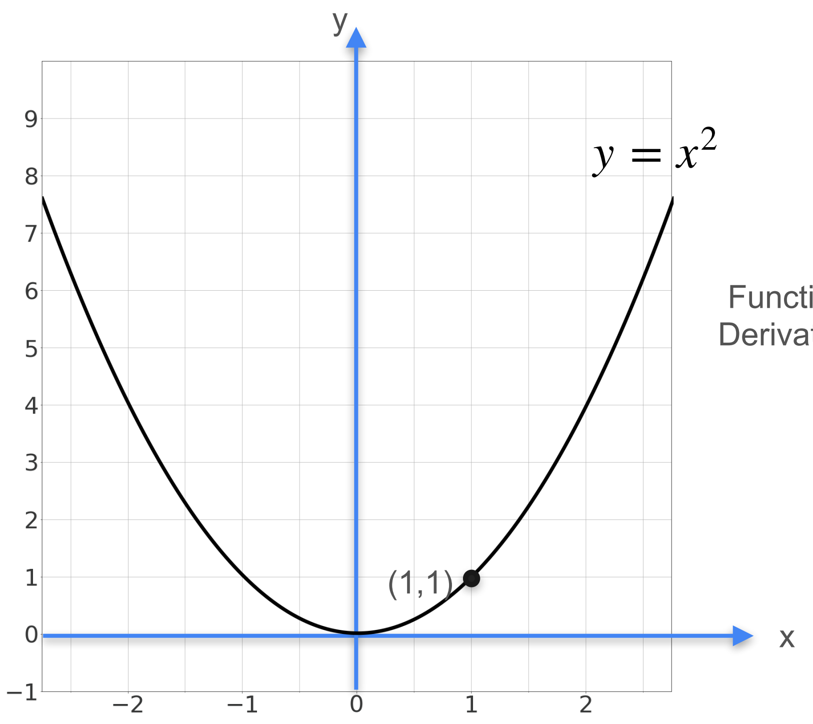
Multiplication by a Scalar



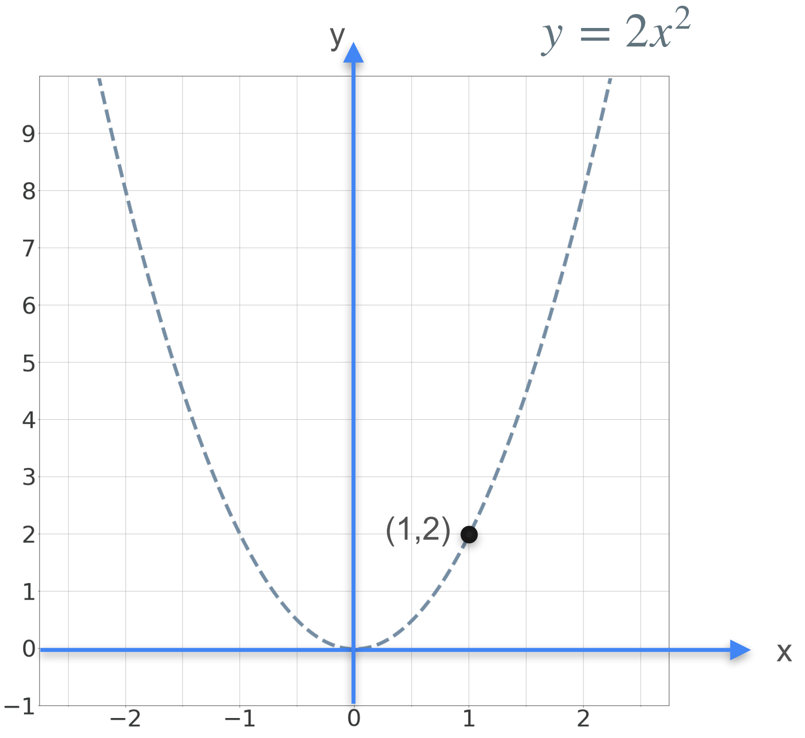
Function multiplies by 2
Slope multiplies by 2



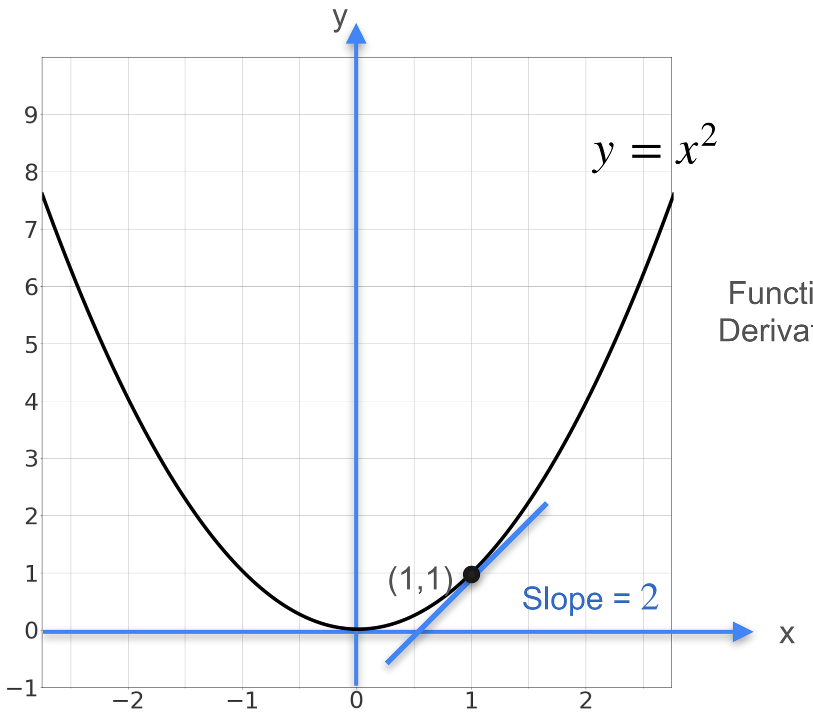
Multiplication by a Scalar



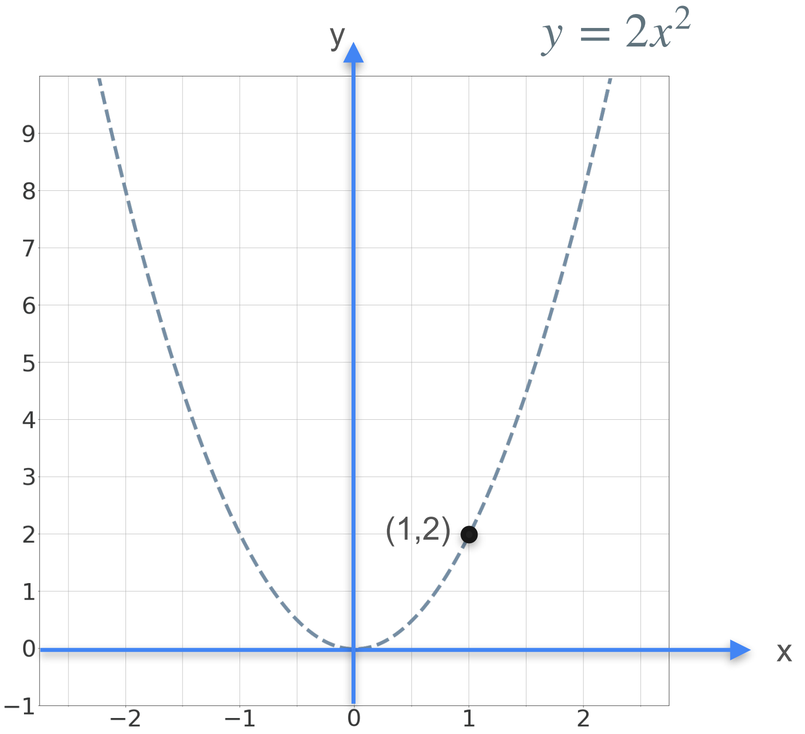
Function multiplies by 2
Derivative multiplies by 2



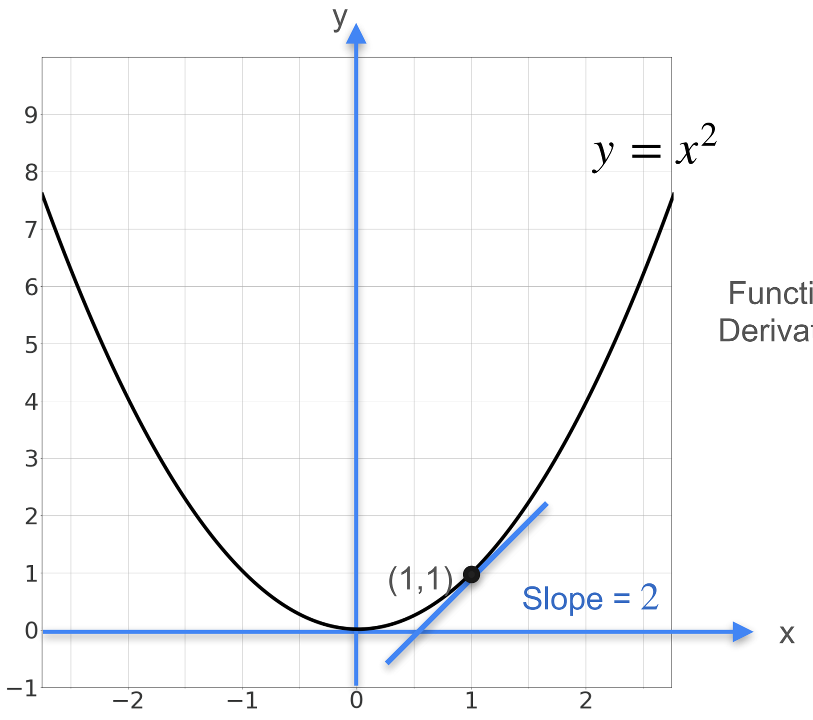
Multiplication by a Scalar



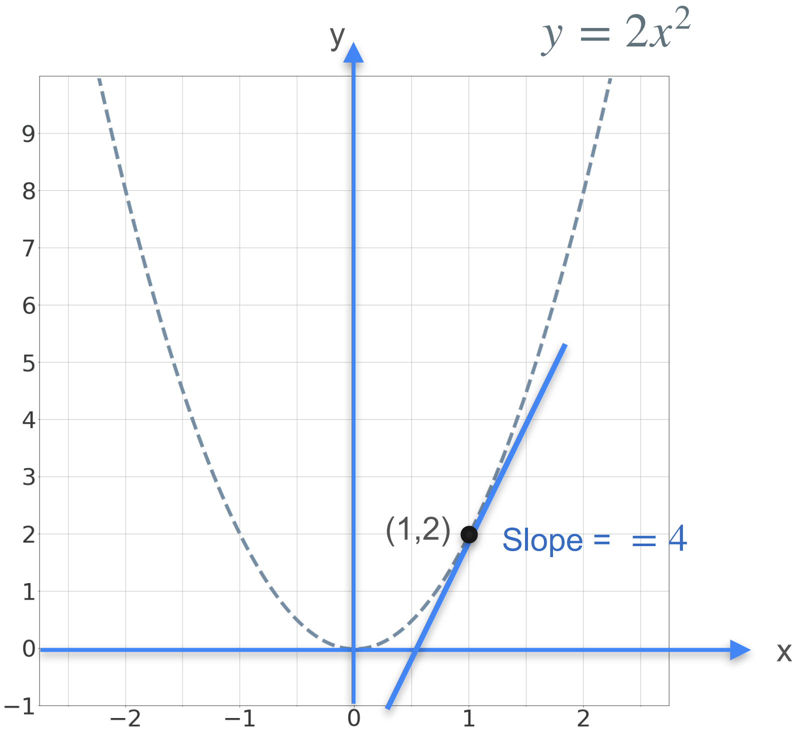
Function multiplies by 2
Derivative multiplies by 2



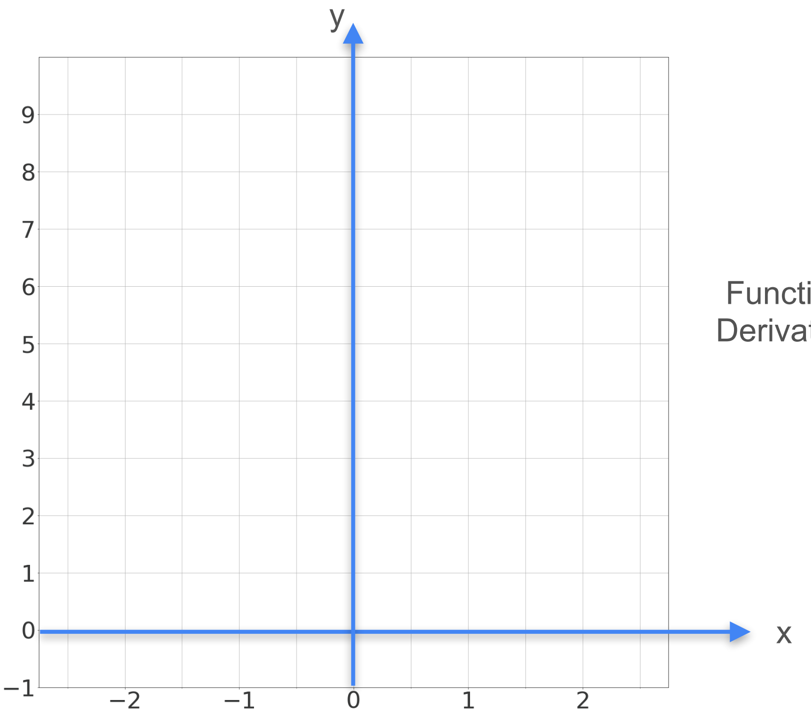
Multiplication by a Scalar



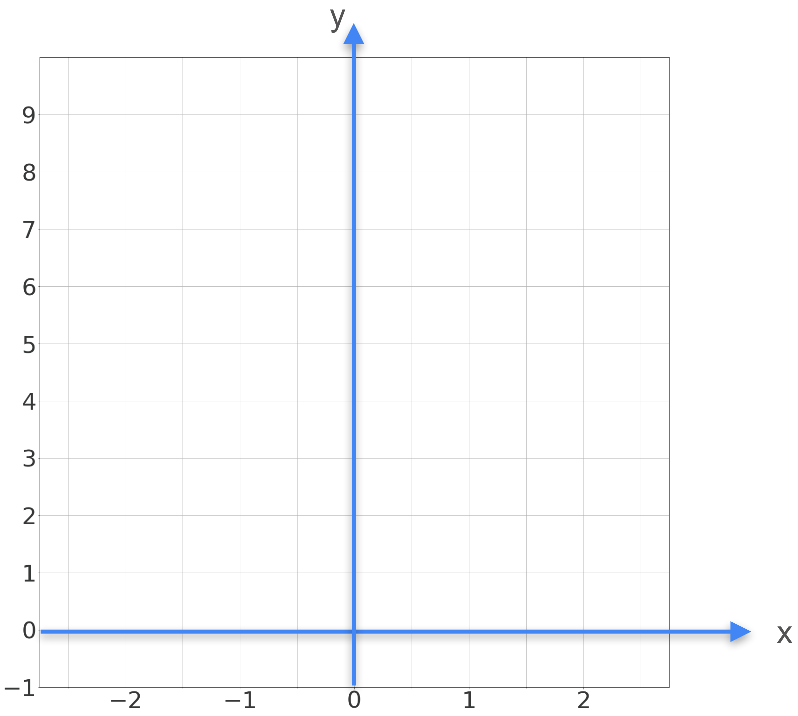
Function multiplies by 2
Derivative multiplies by 2



Multiplication by a Scalar



Function multiplies by c
Derivative multiplies by c



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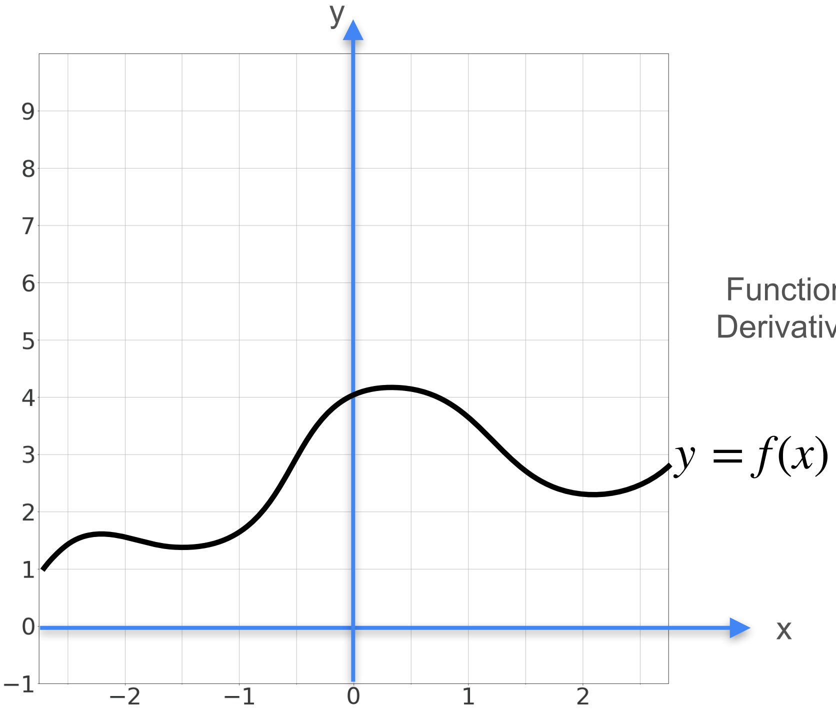
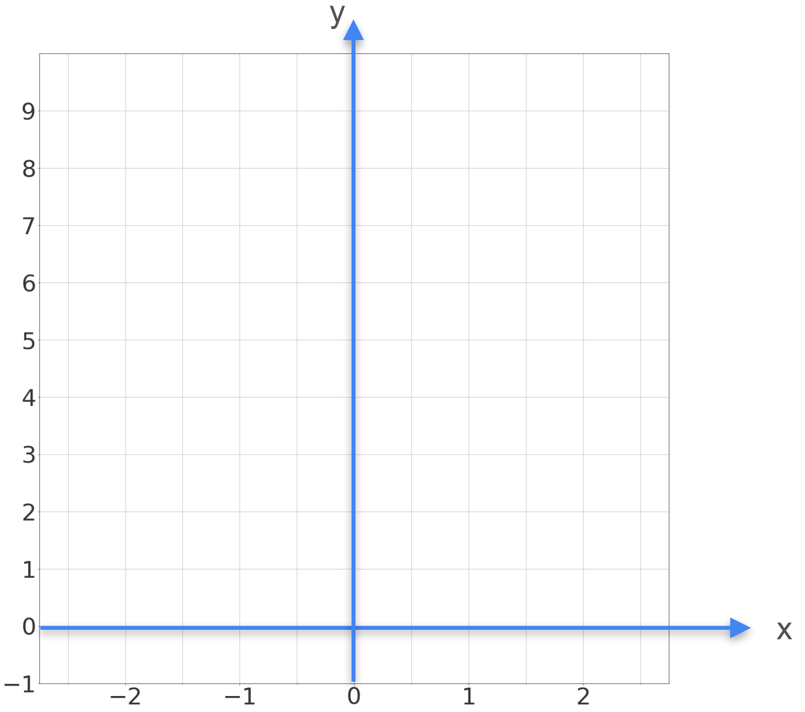
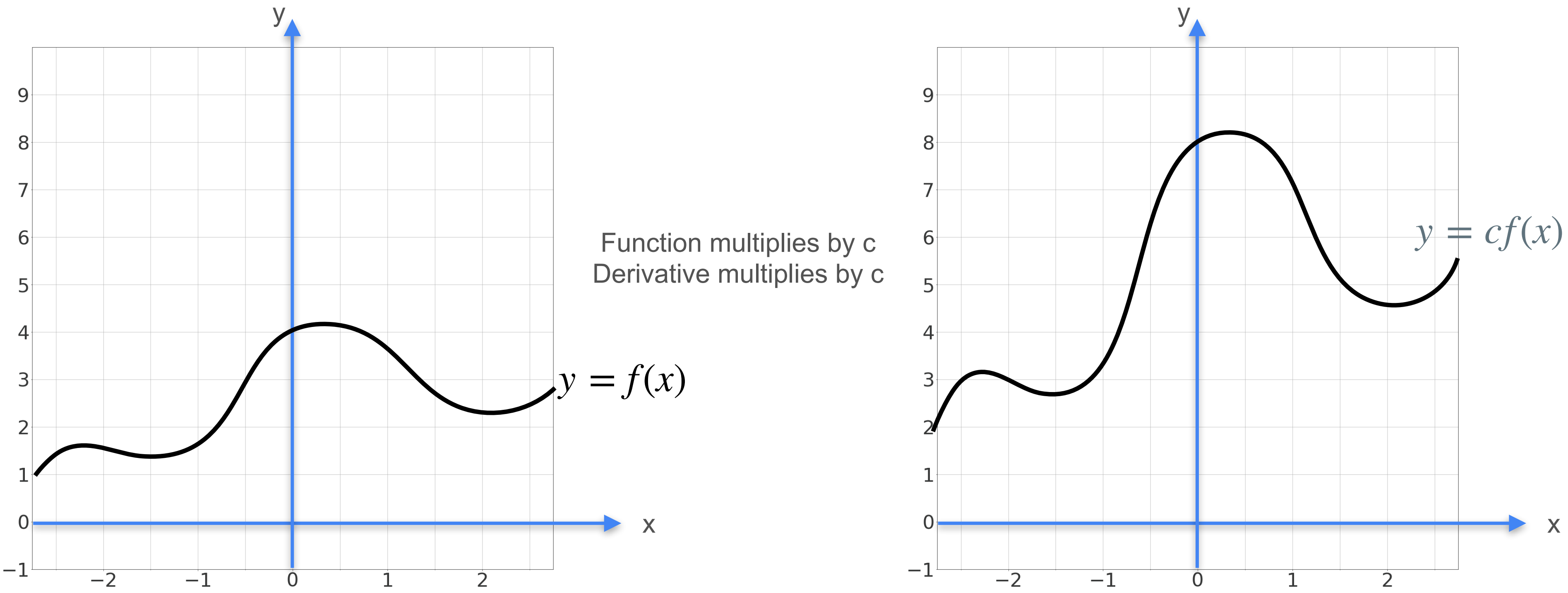
Multiplication by a Scalar



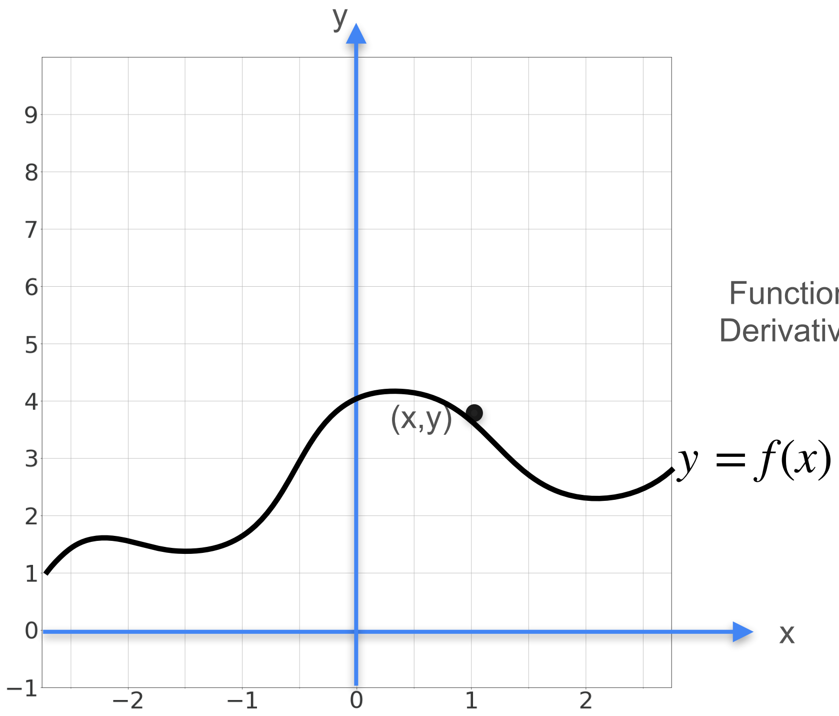
Function multiplies by c
Derivative multiplies by c



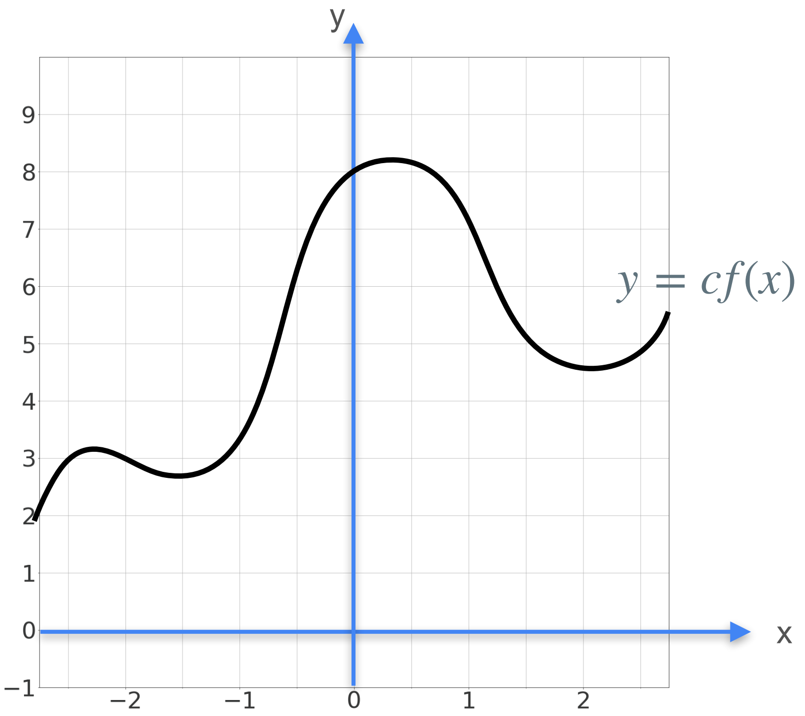
Multiplication by a Scalar



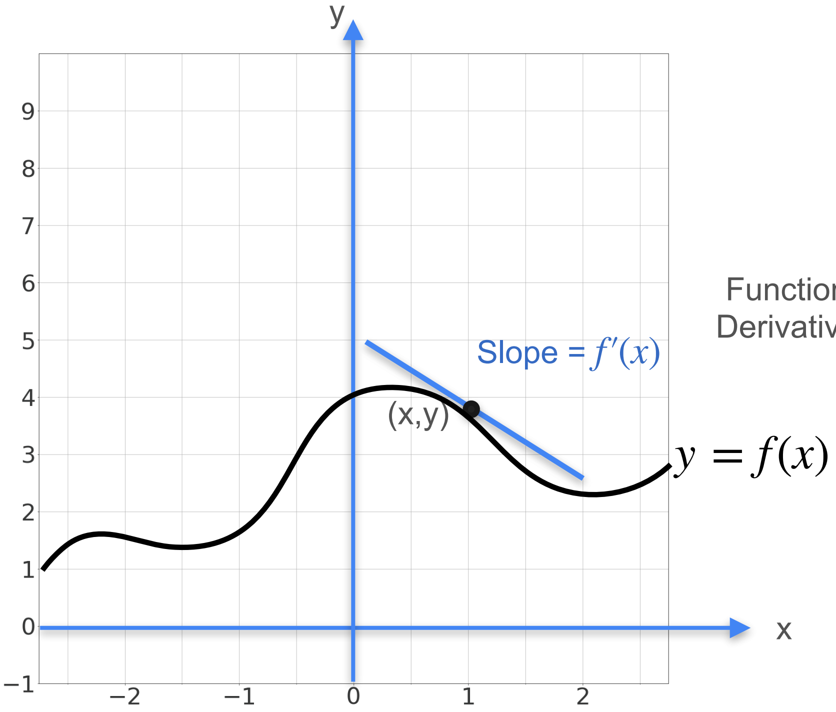
Multiplication by a Scalar



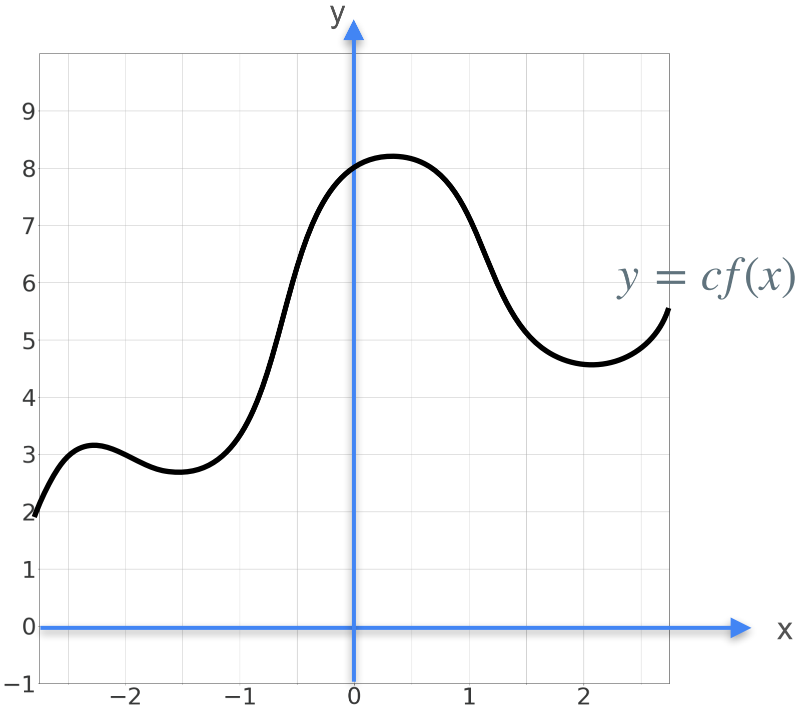
Function multiplies by c
Derivative multiplies by c



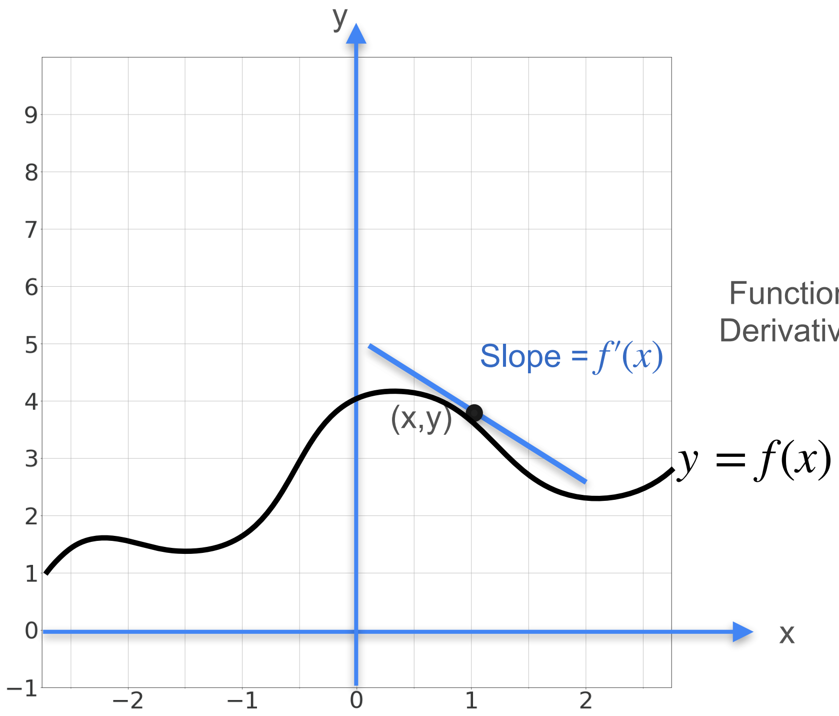
Multiplication by a Scalar



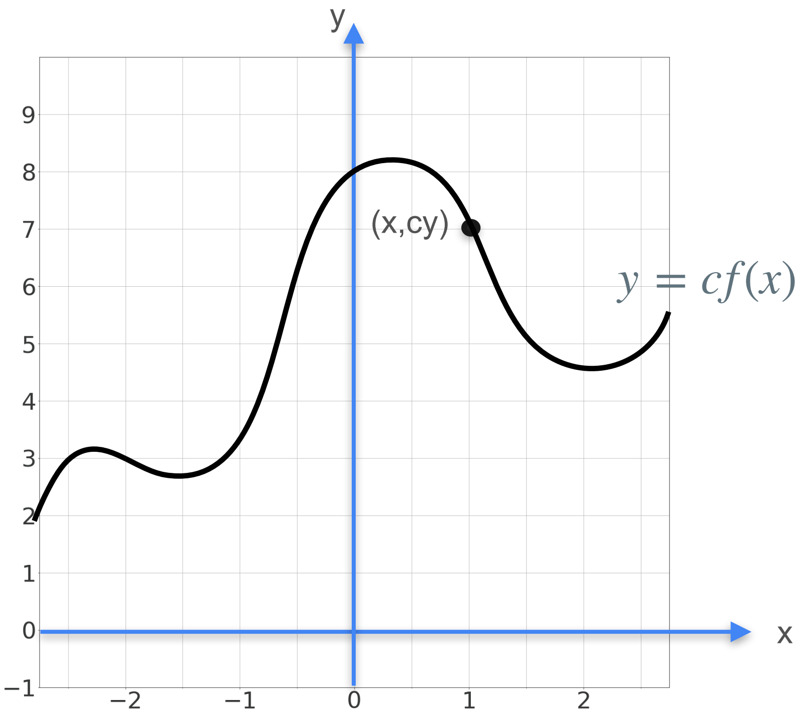
Function multiplies by c
Derivative multiplies by c



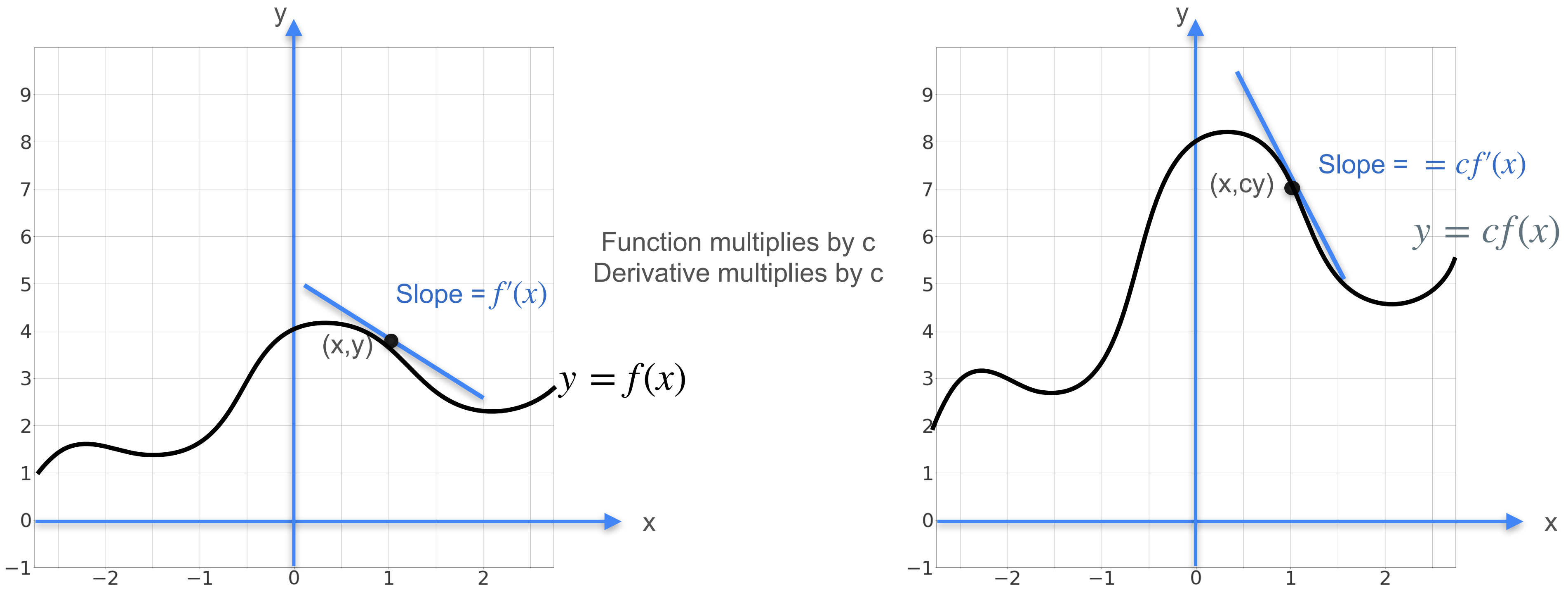
Multiplication by a Scalar



Function multiplies by c
Derivative multiplies by c



Multiplication by a Scalar



Function multiplies by c
Derivative multiplies by c

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Derivatives and Optimization

Properties of the derivative: The sum rule

The Sum Rule

$$f = g + h$$

The Sum Rule

$$f' = g + h$$

The Sum Rule

$$f' = g' + h$$

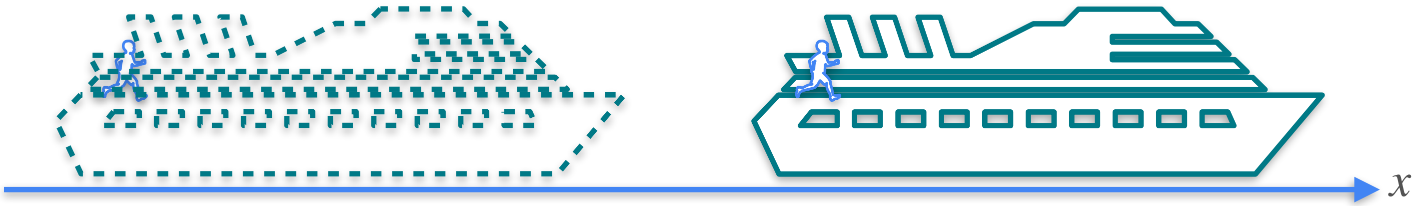
The Sum Rule

$$f' = g' + h'$$

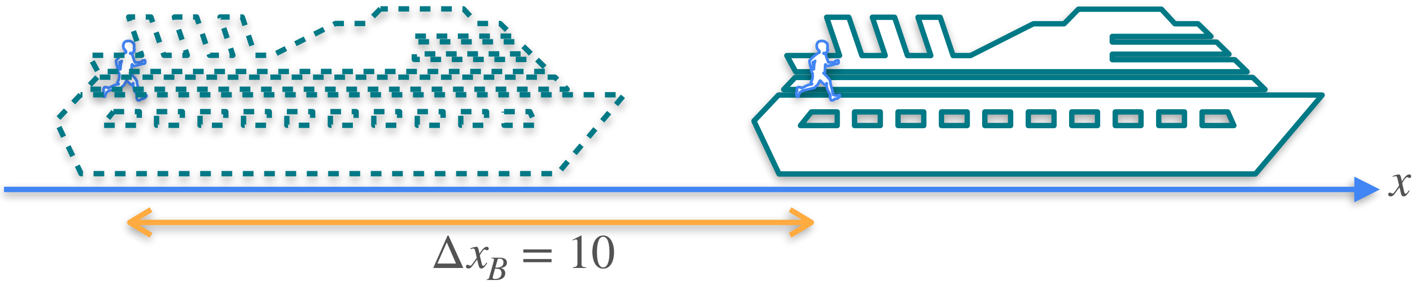
Sum Rule

Sum Rule

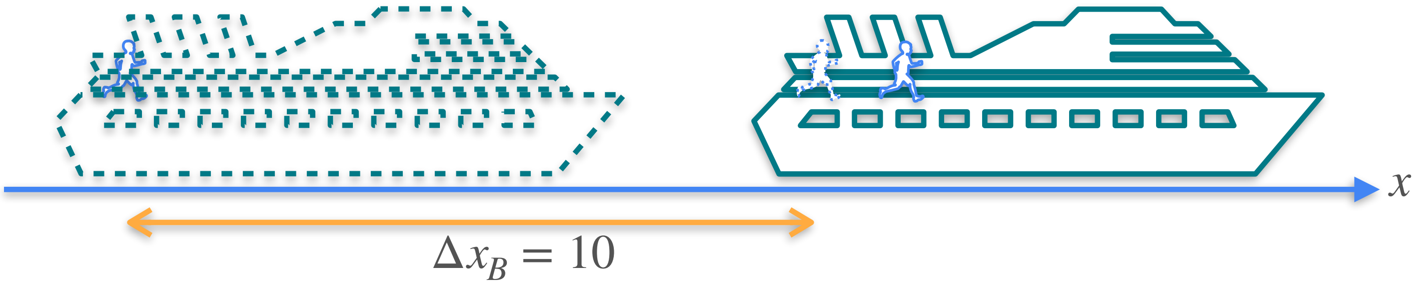
Sum Rule



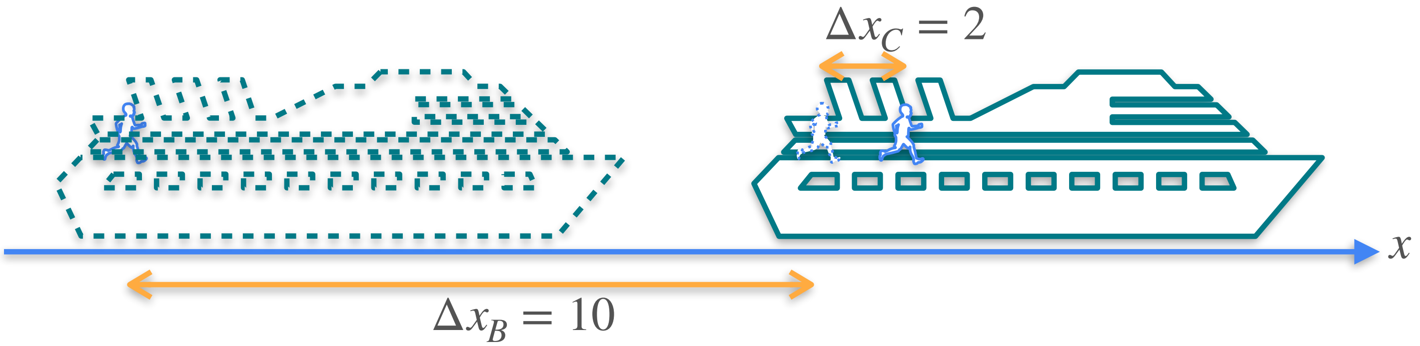
Sum Rule



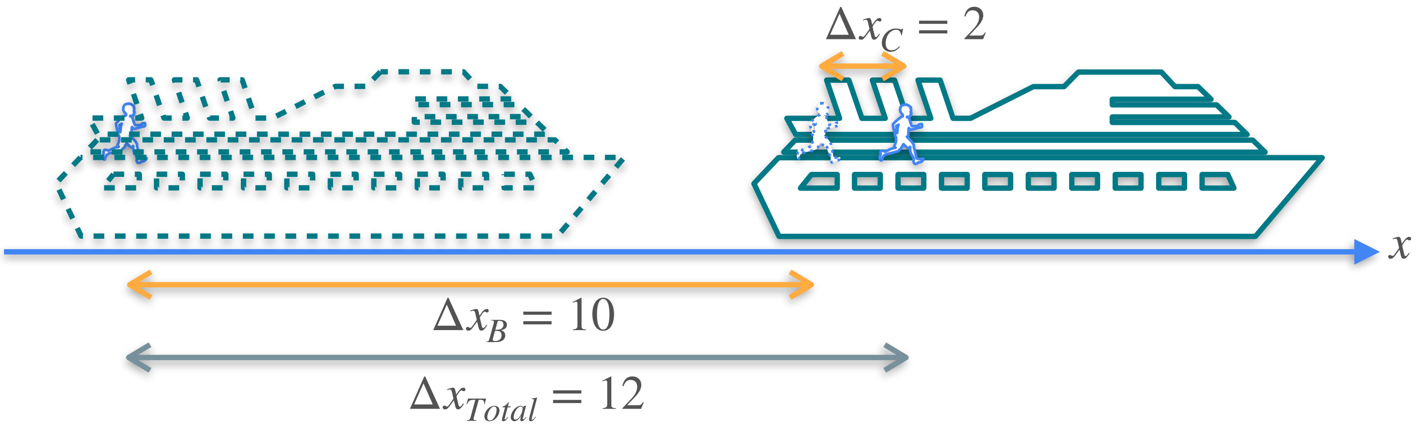
Sum Rule



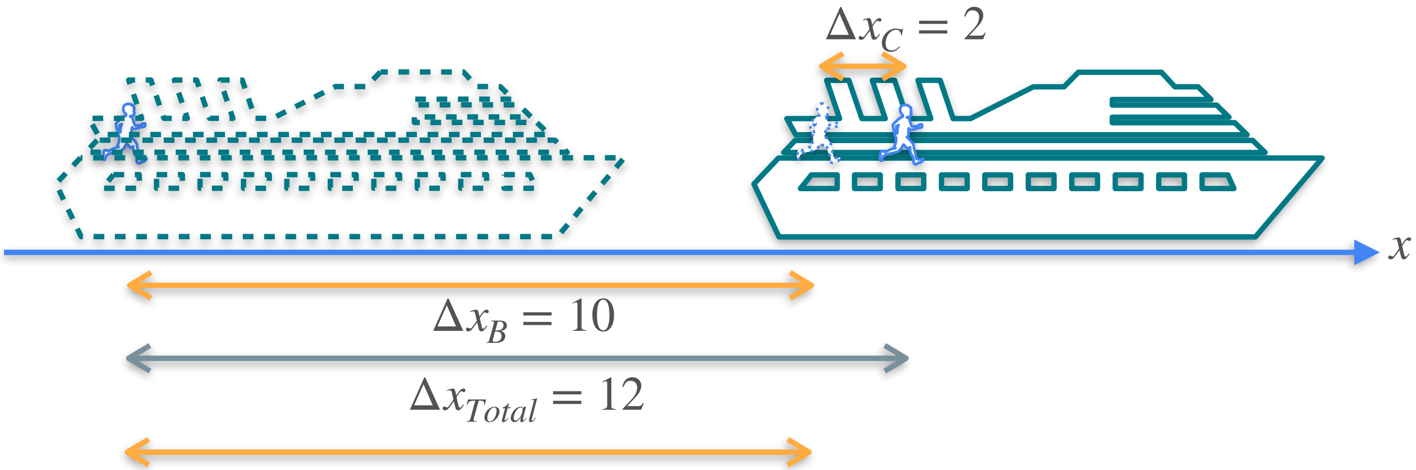
Sum Rule



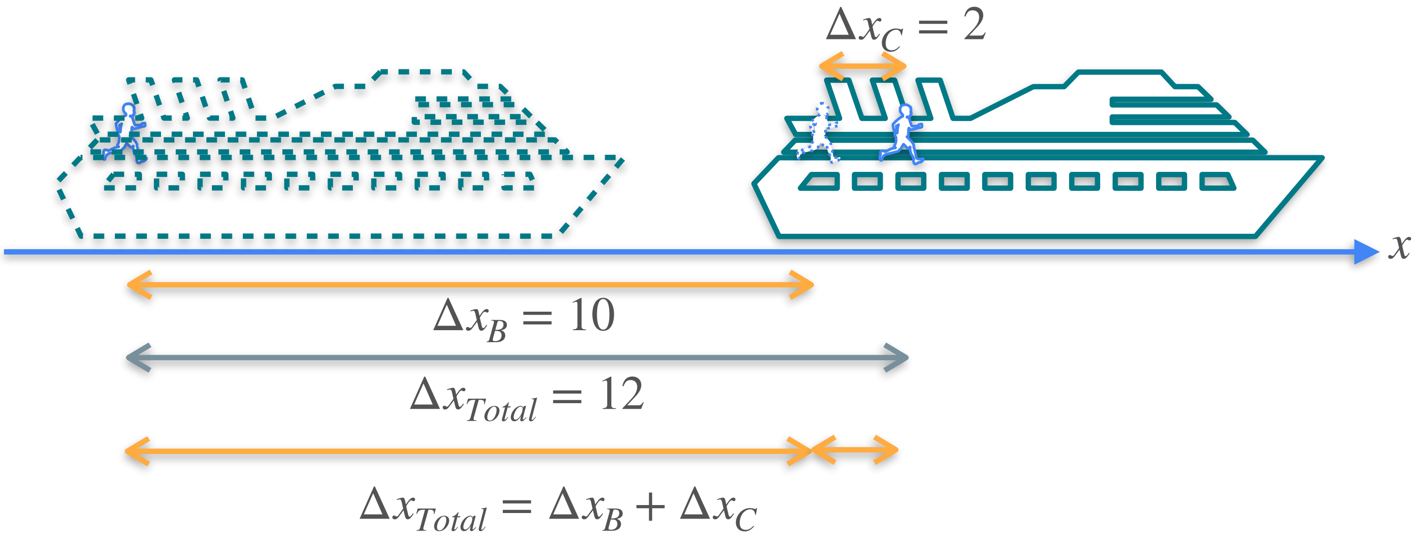
Sum Rule



Sum Rule

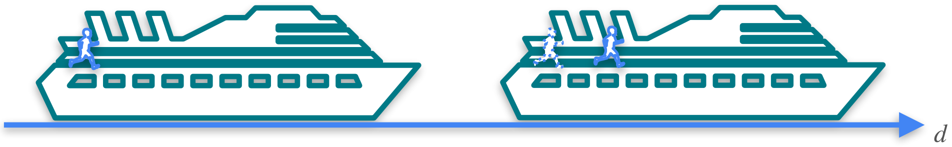


Sum Rule



$\Delta x_C = 2$
x
$\Delta x_B = 10$
$\Delta x_{Total} = 12$
$\Delta x_{Total} = \Delta x_B + \Delta x_C$

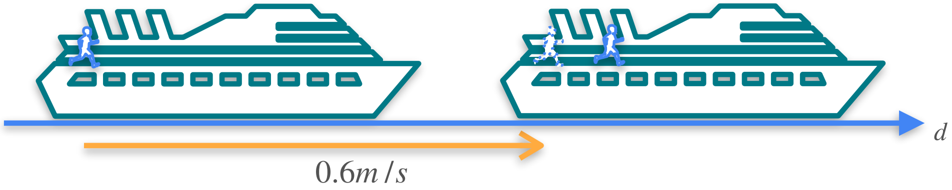
Quiz:



- Speed of the boat: 0.6 m/s
- Speed of the child inside the boat: 0.05 m/s
- Both travel in the same direction.

What is the speed of the child with respect to the earth?

Quiz:



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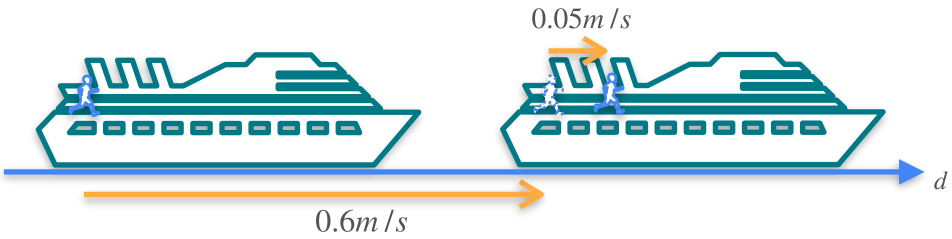

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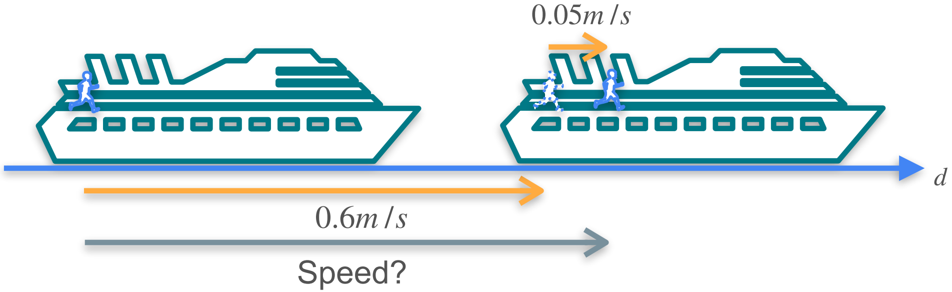

- Speed of the boat: 0.6 m/s
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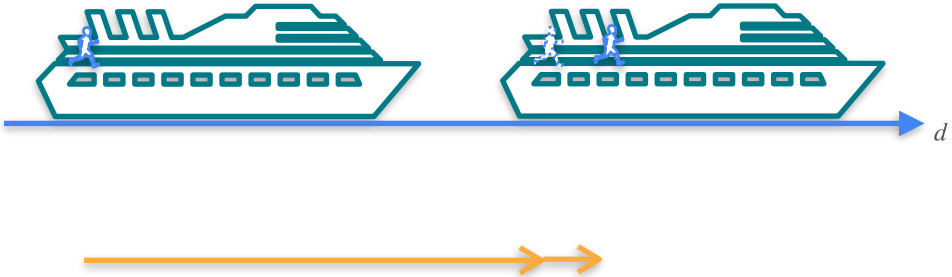
Solution:



Speed $= 0.6 m/s + 0.05 m/s = 0.65 m/s$

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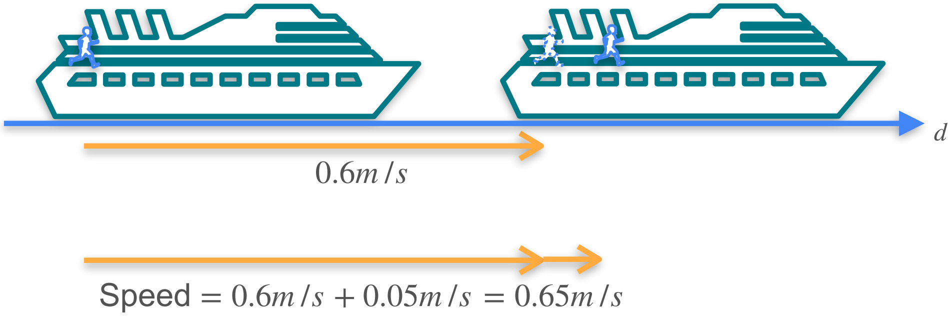

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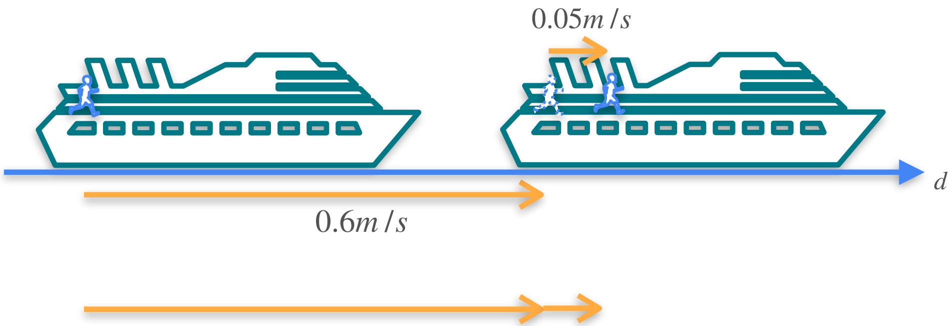

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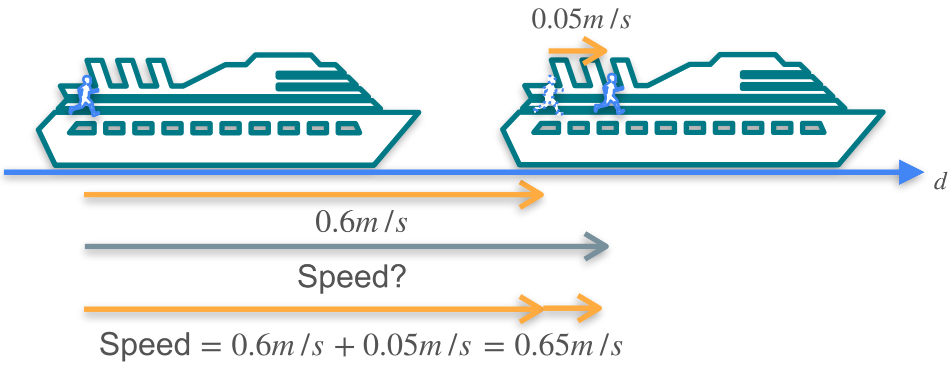

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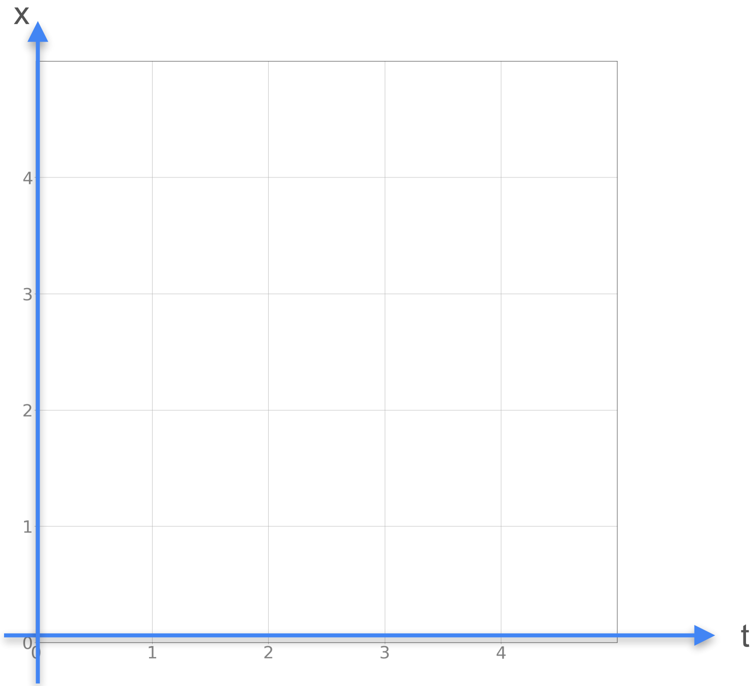
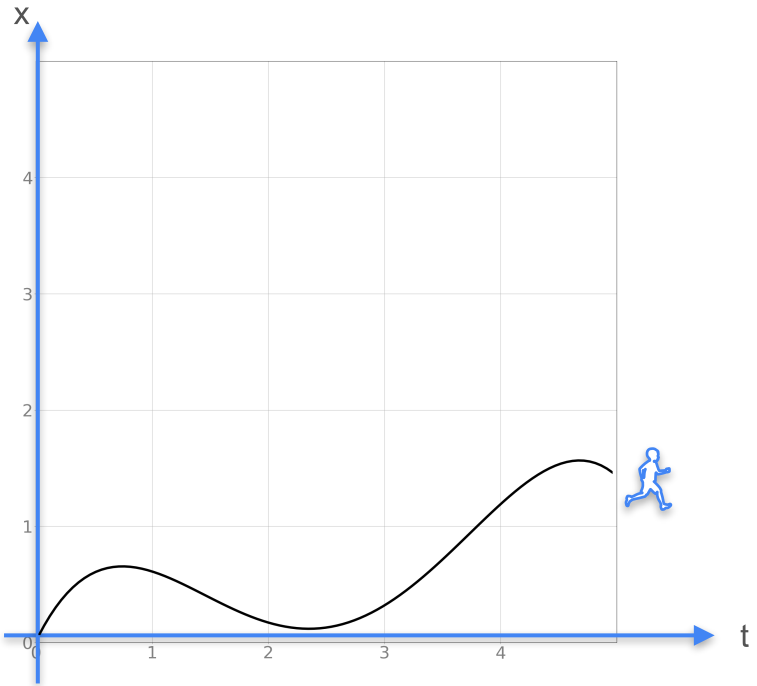
Sum Rule

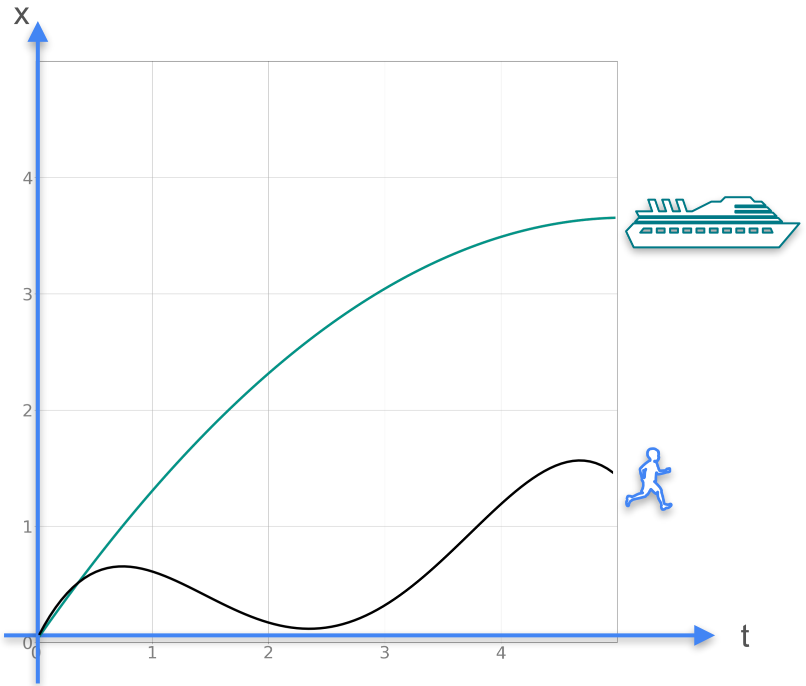
Sum Rule



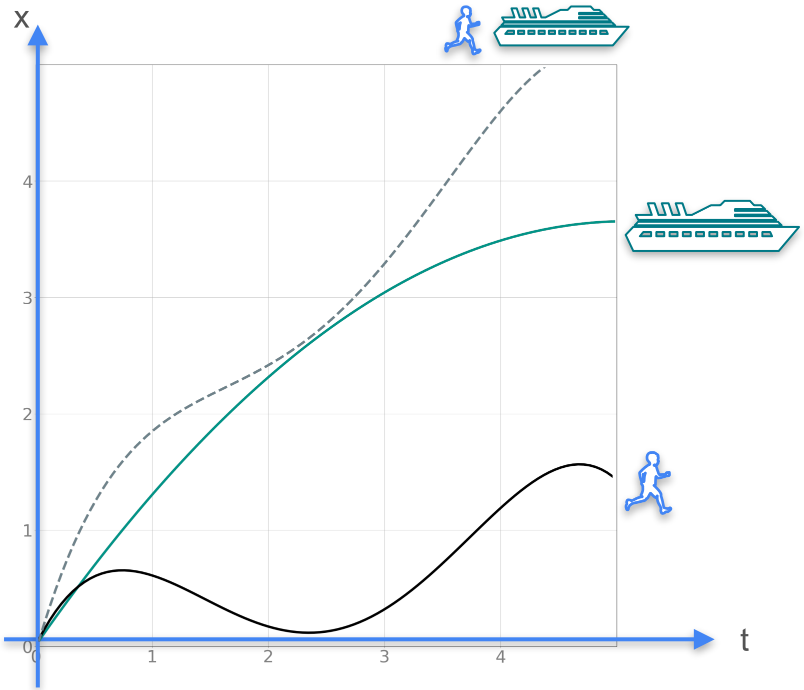
Sum Rule



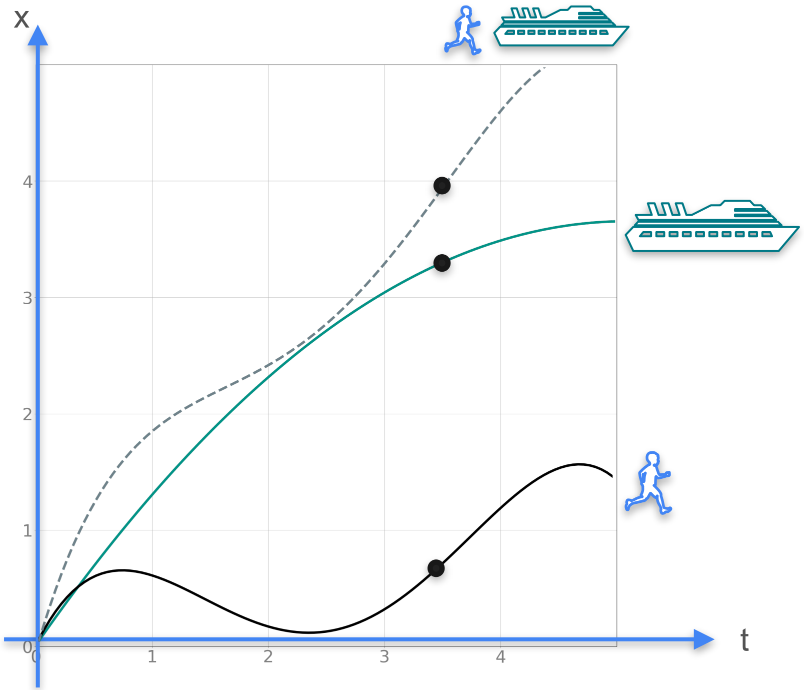
Sum Rule



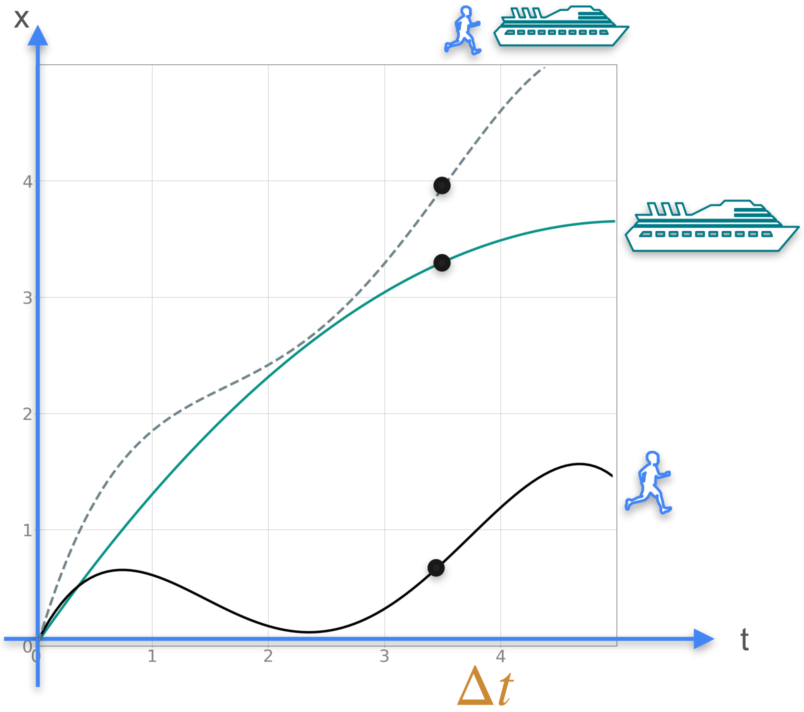
Sum Rule



Sum Rule



Sum Rule



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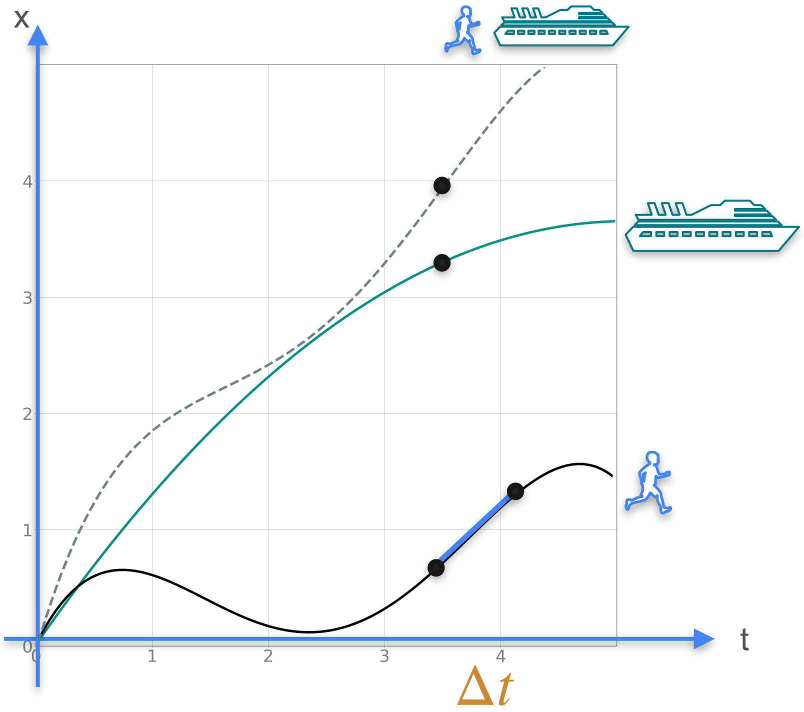
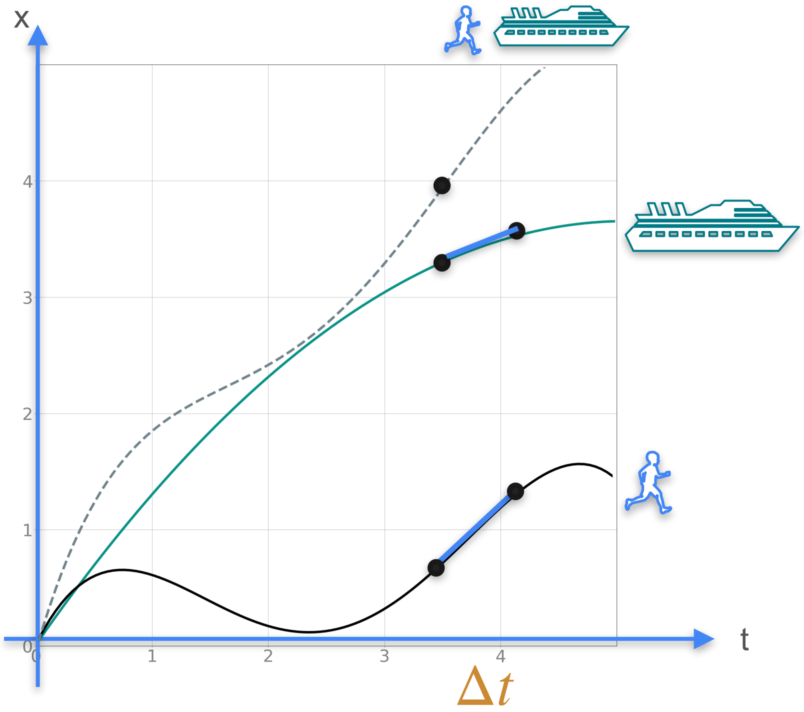
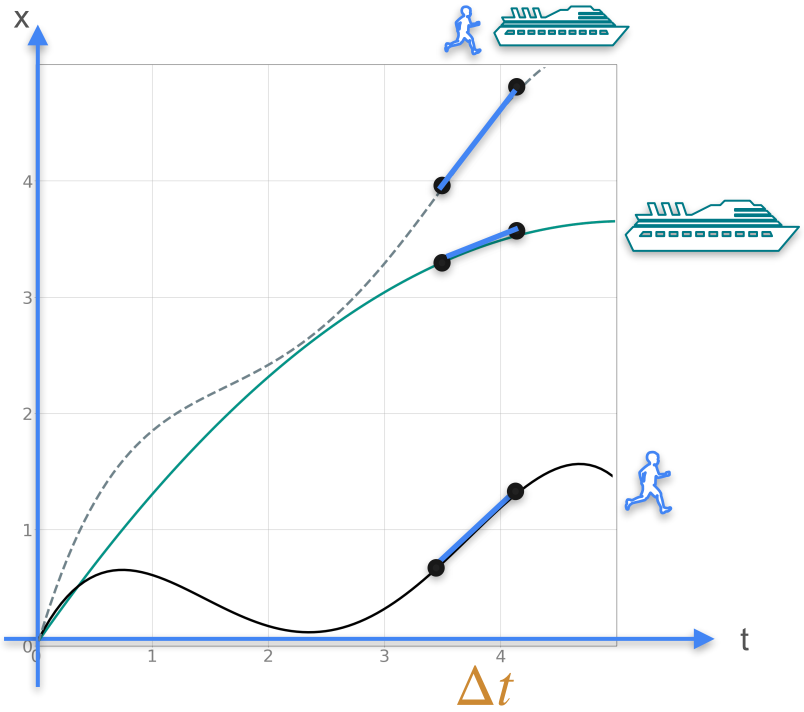


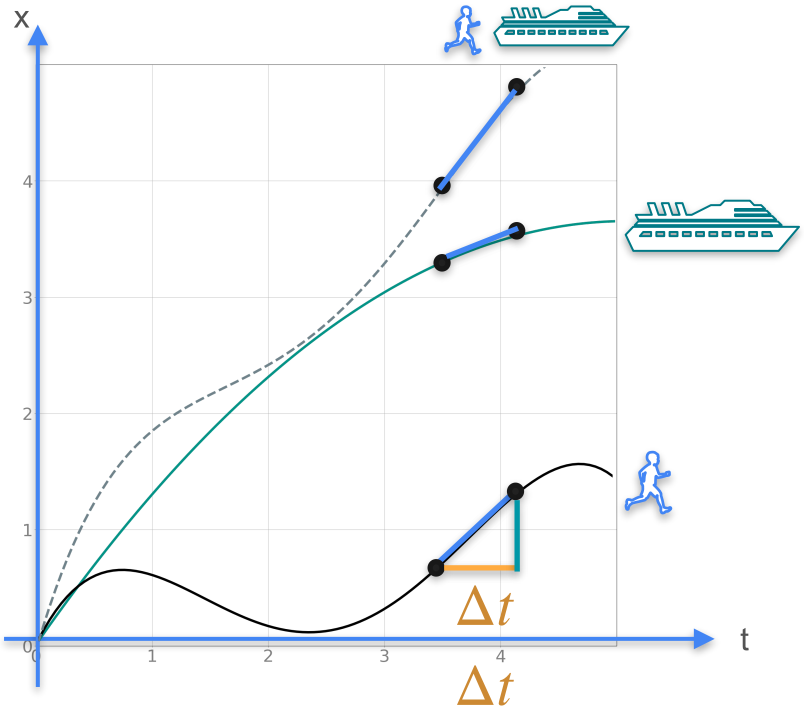
Sum Rule



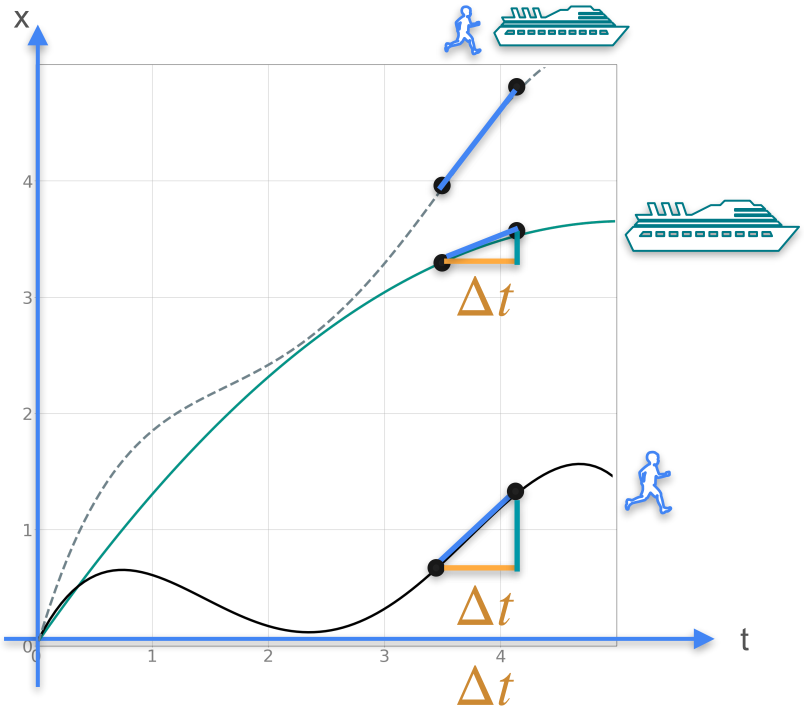
Sum Rule



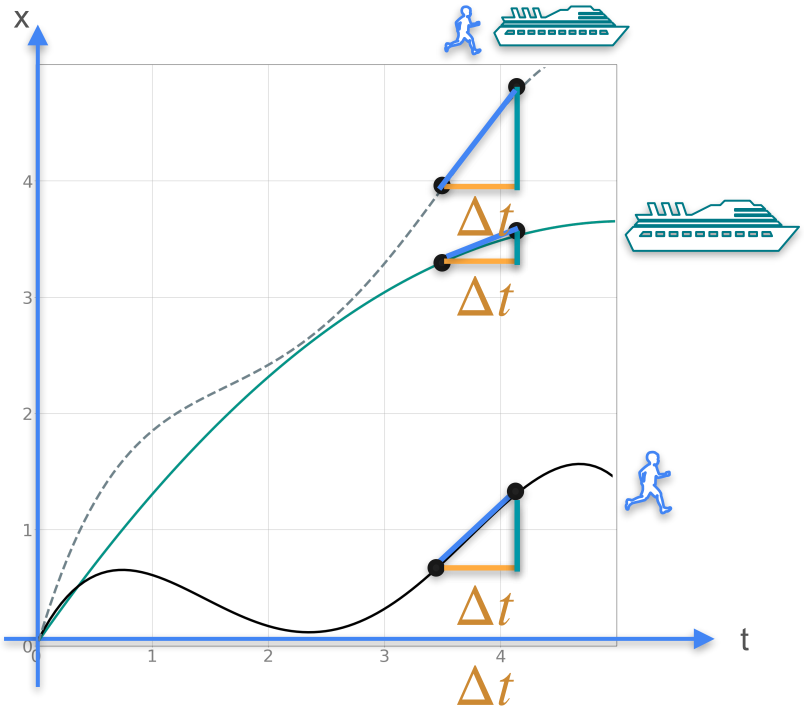
Sum Rule



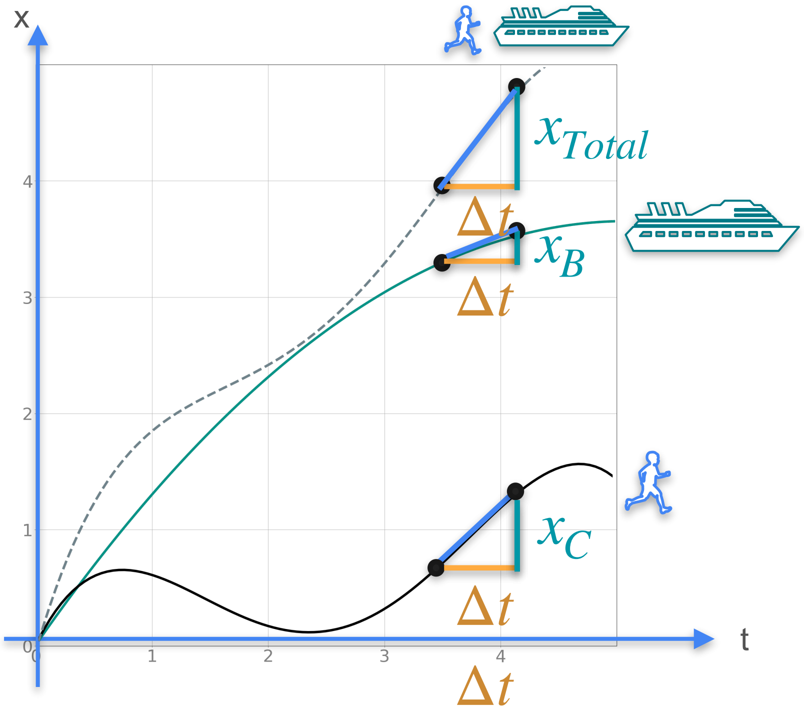
Sum Rule



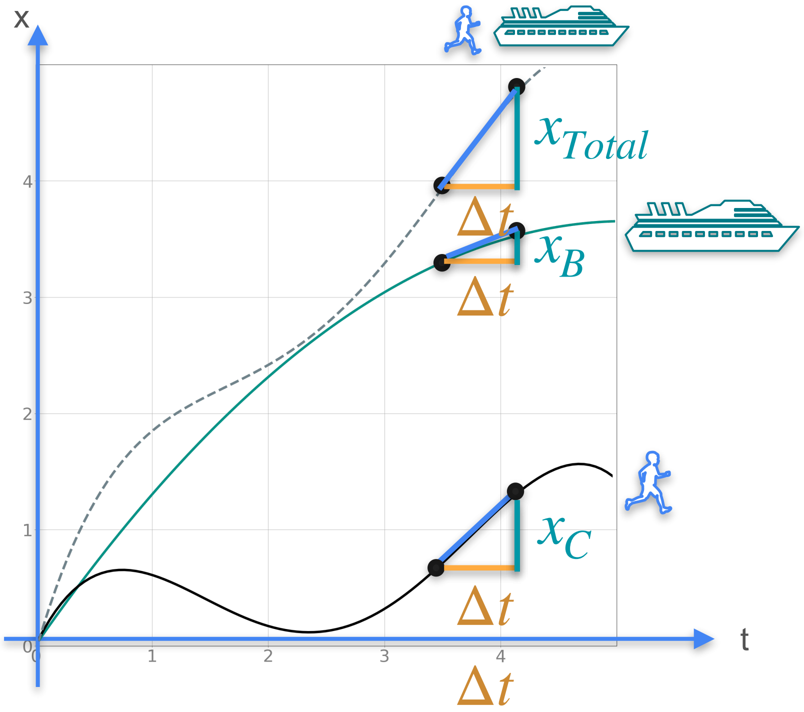
Sum Rule



Sum Rule

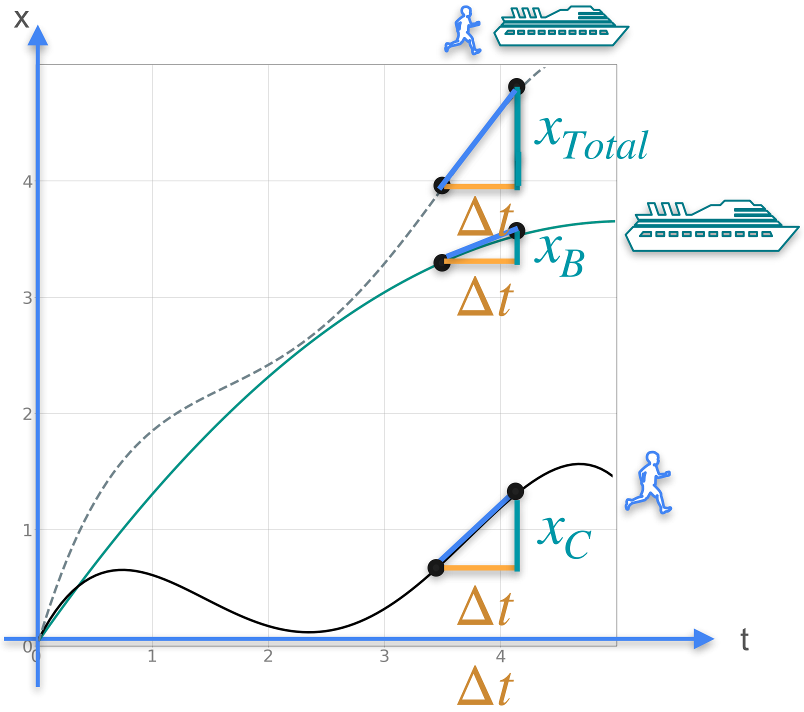


Sum Rule



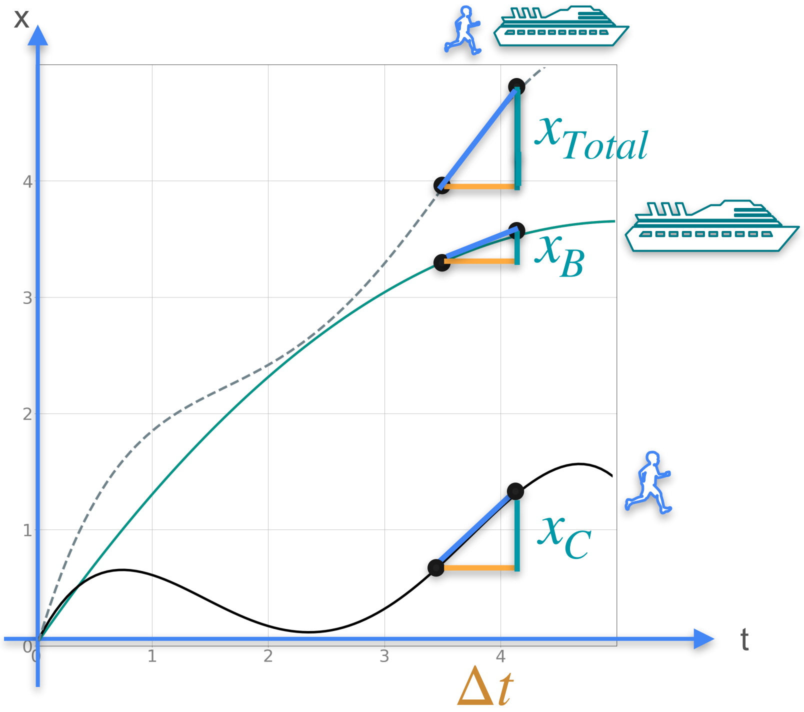
$$x_{Total} = x_B + x_C$$

Sum Rule



$$x_{Total} = x_B + x_C$$

Sum Rule

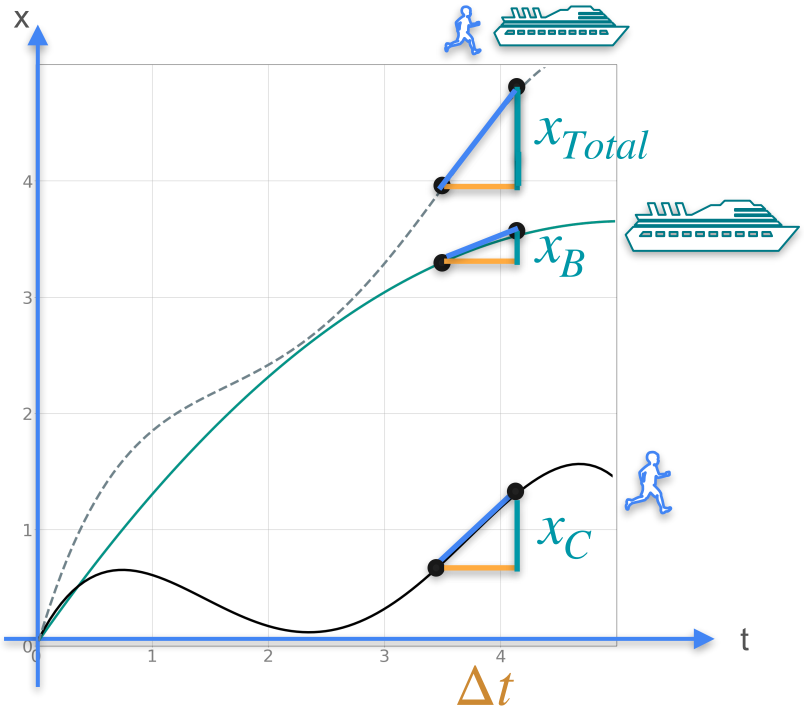


$$x_{Total} = x_B + x_C$$

$$\Downarrow$$

$$\frac{x_{Total}}{\Delta t} = \frac{x_B}{\Delta t} + \frac{x_C}{\Delta t}$$

Sum Rule



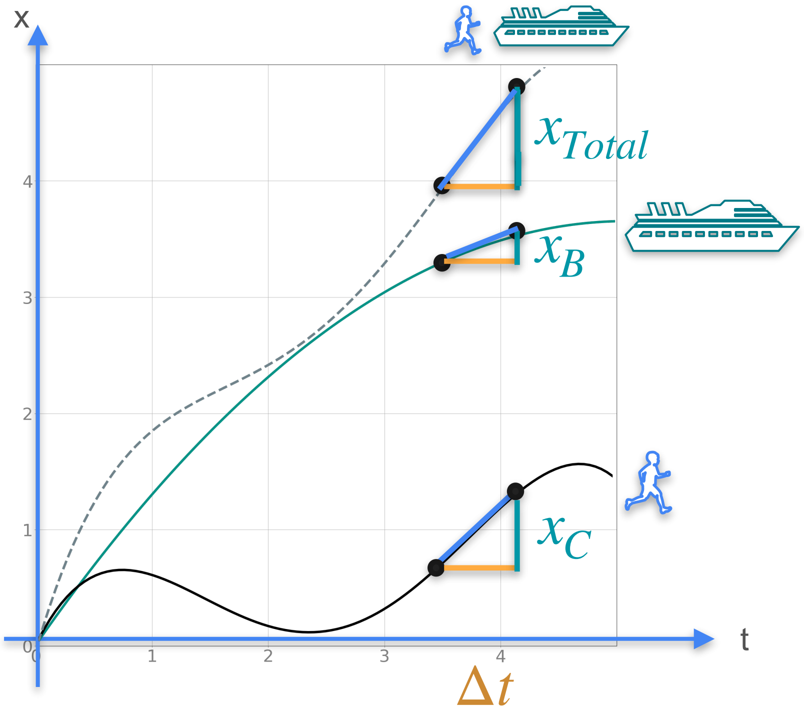
$$x_{Total} = x_B + x_C$$

$$\Downarrow$$

$$\frac{x_{Total}}{\Delta t} = \frac{x_B}{\Delta t} + \frac{x_C}{\Delta t}$$

$$\Downarrow$$

Sum Rule



$$x_{Total} = x_B + x_C$$

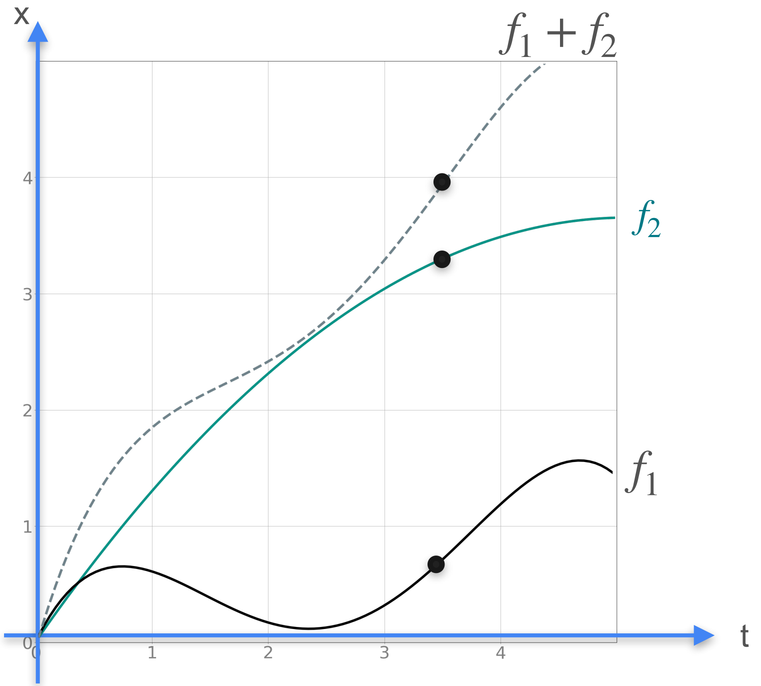
$$\Downarrow$$

$$\frac{x_{Total}}{\Delta t} = \frac{x_B}{\Delta t} + \frac{x_C}{\Delta t}$$

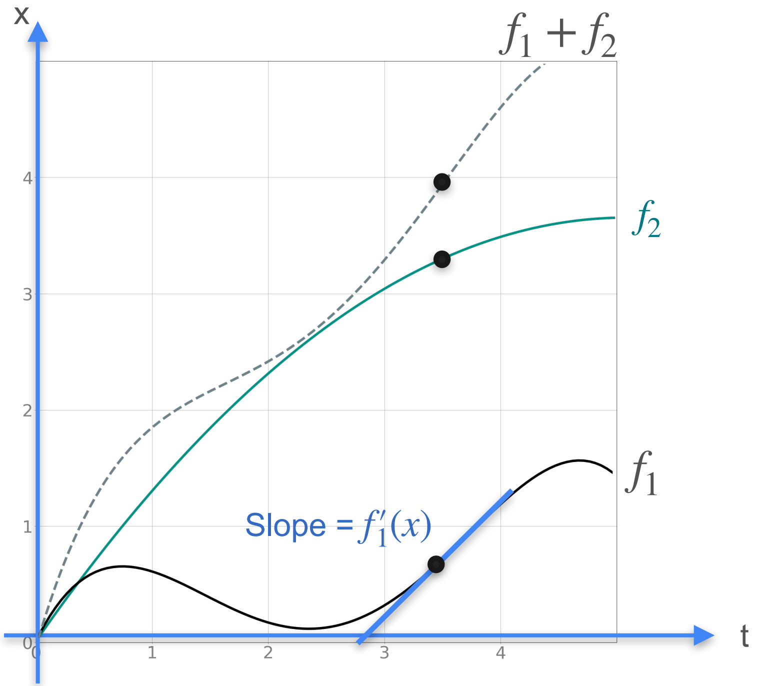
$$\Downarrow$$

$$v_{Total} = v_B + v_C$$

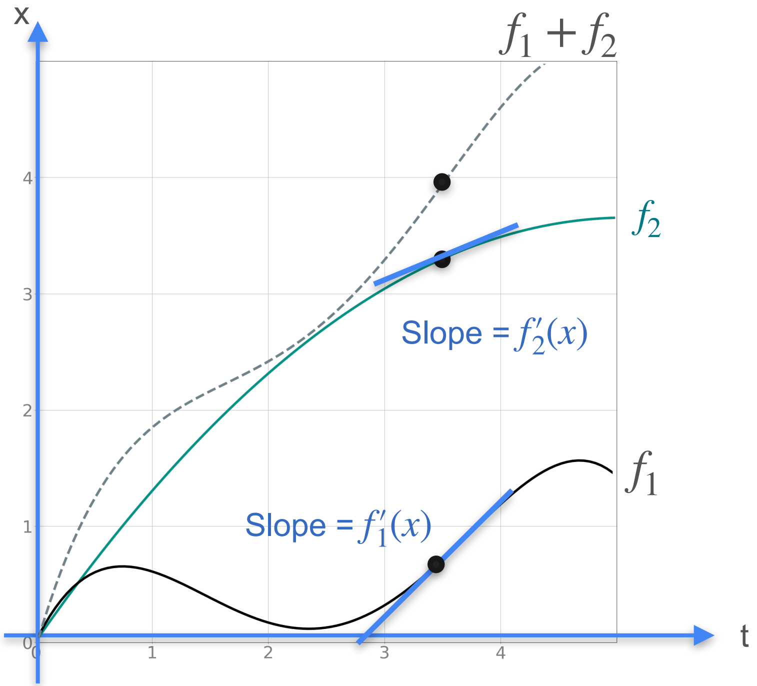
Sum Rule



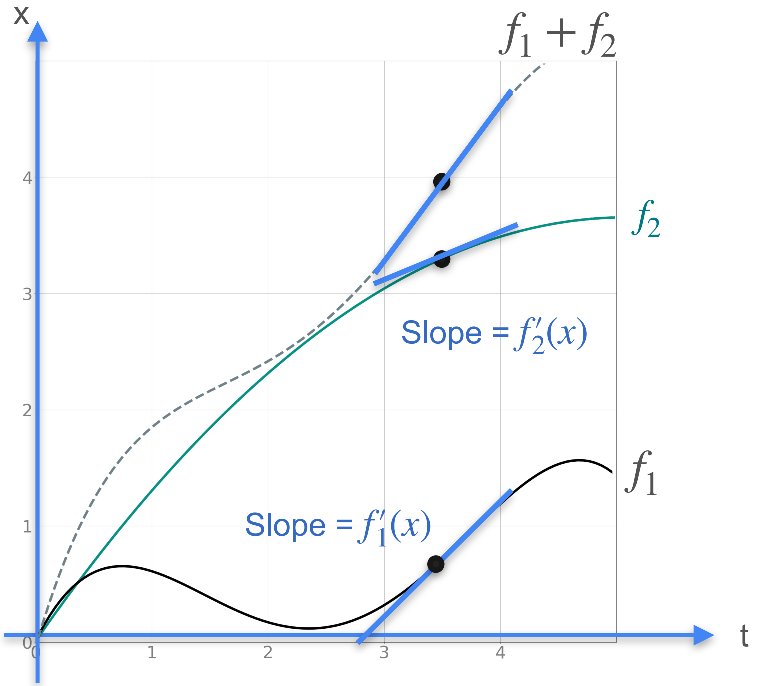
Sum Rule



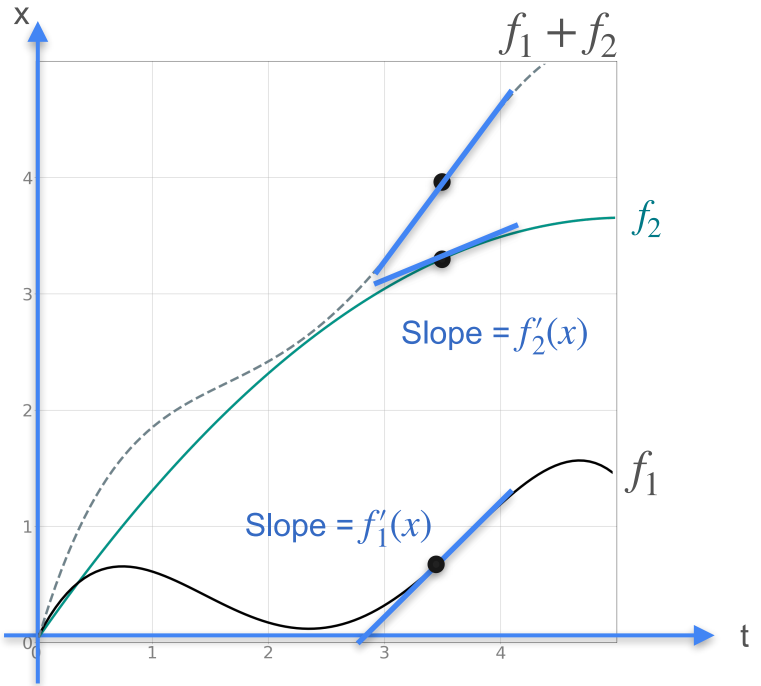
Sum Rule



Sum Rule

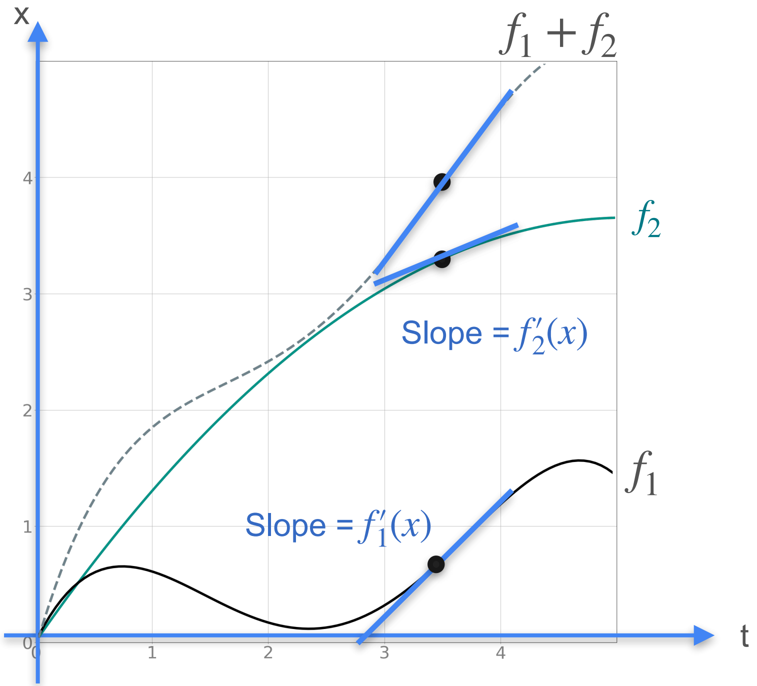


Sum Rule



$$f = f_1 + f_2$$

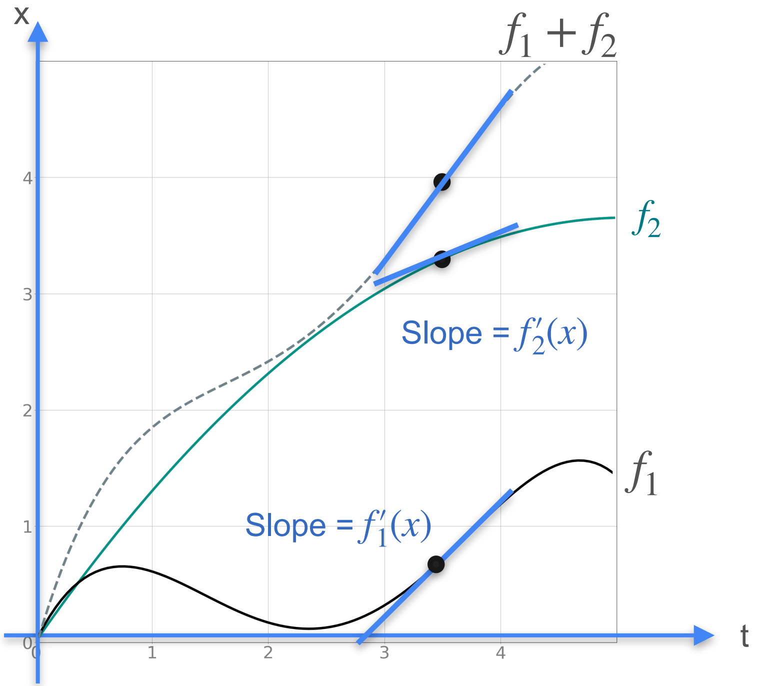
Sum Rule



$$f = f_1 + f_2$$

$$\Downarrow$$

Sum Rule

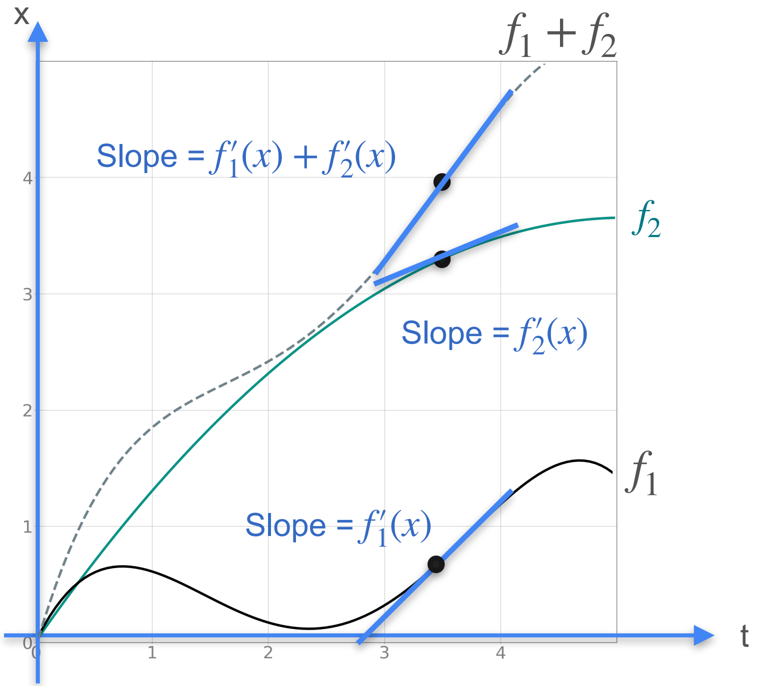


$$f = f_1 + f_2$$

$$\Downarrow$$

$$f' = f_1' + f_2'$$

Sum Rule



$$f = f_1 + f_2$$

$$\Downarrow$$

$$f' = f_1' + f_2'$$

DeepLearning.AI

Derivatives and Optimization

Properties of the derivative: The product rule

The Product Rule

$$f = gh$$

The Product Rule

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The Product Rule

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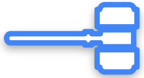
The Product Rule

$$f = gh$$

The Product Rule

$$f = gh$$



$$f'$$

The Product Rule

$$f = gh$$

$$f' = g'h$$

The Product Rule

$$f = gh$$

$$f' = g'h + gh'$$

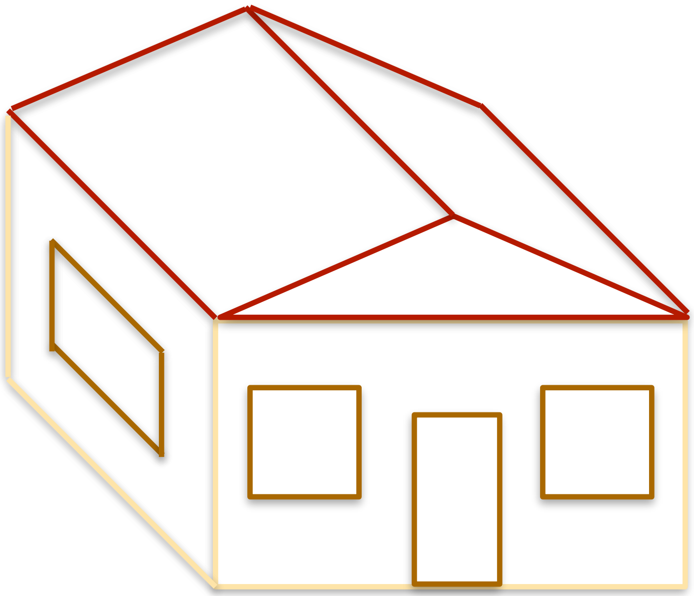
The Product Rule

$$f = gh$$

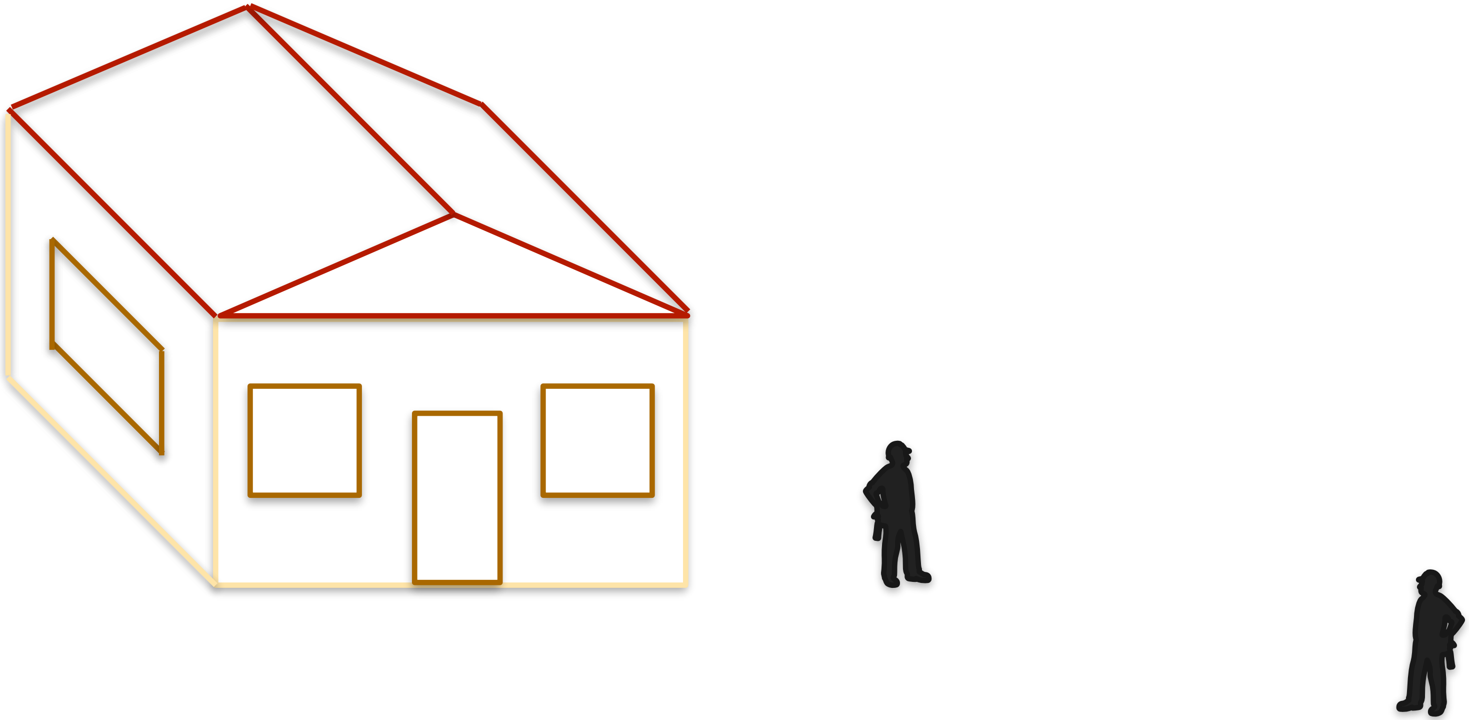
$$f' = g'h + gh'$$

Product Rule

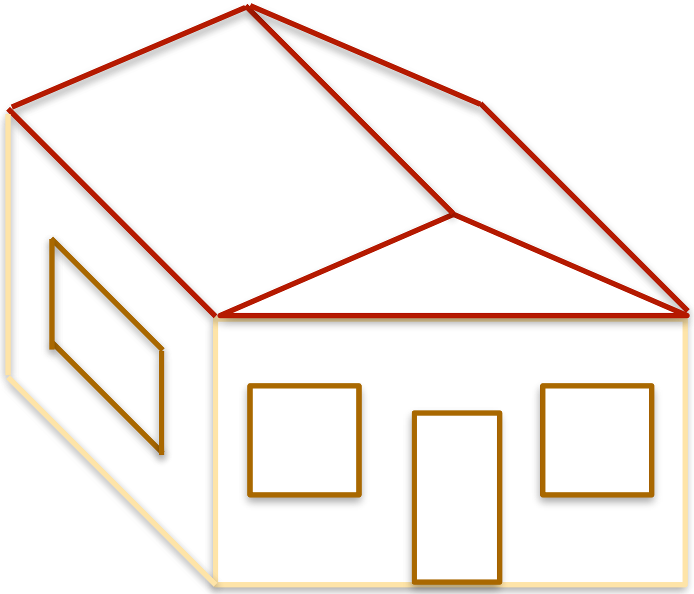
Product Rule

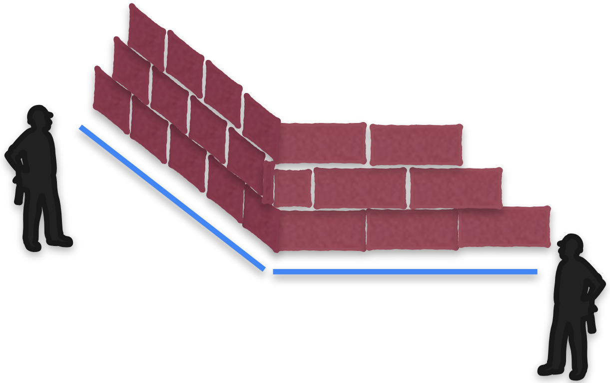


Product Rule

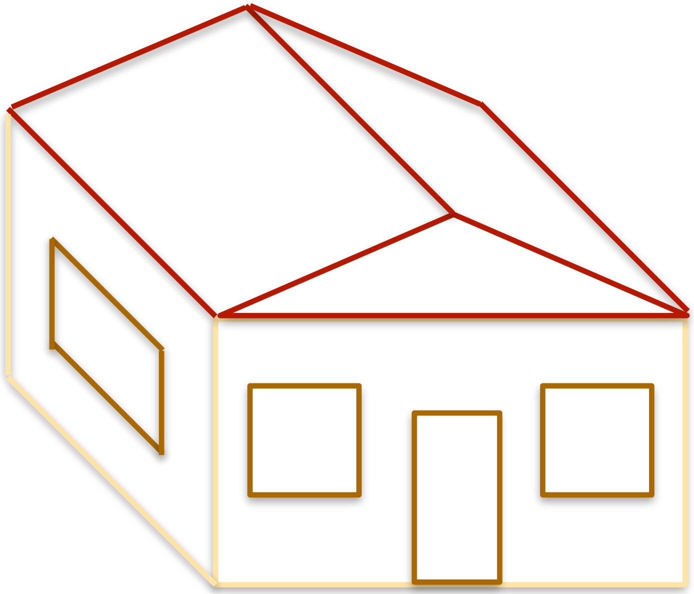


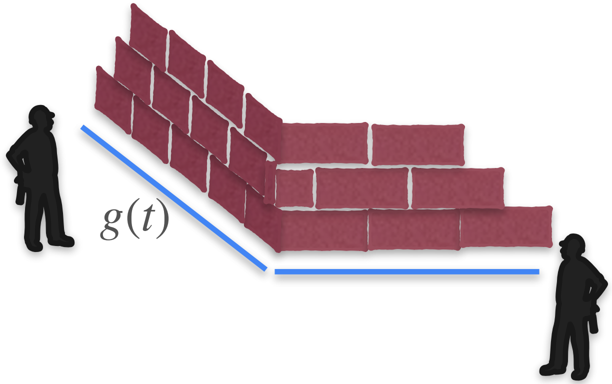
Product Rule



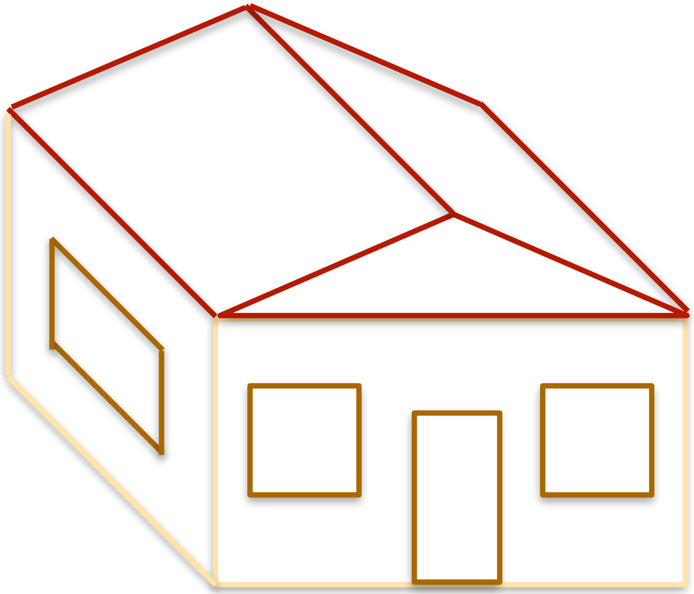


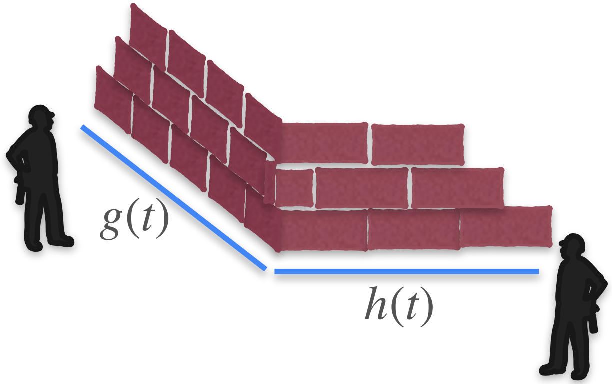
Product Rule



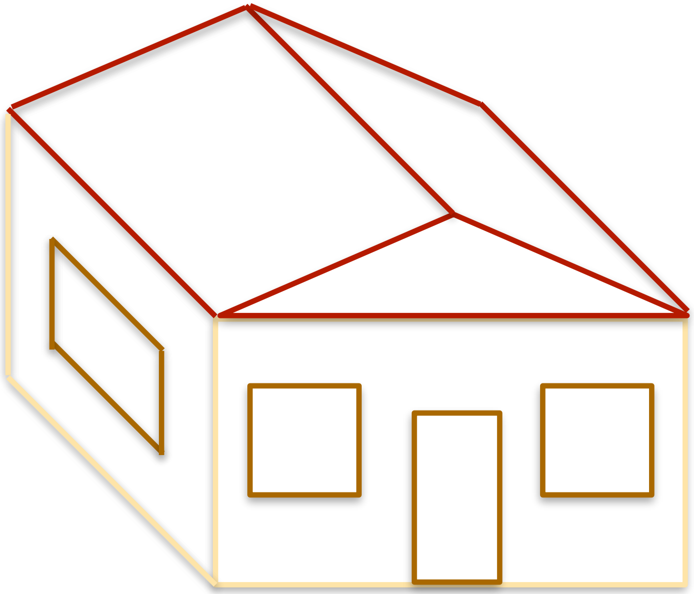


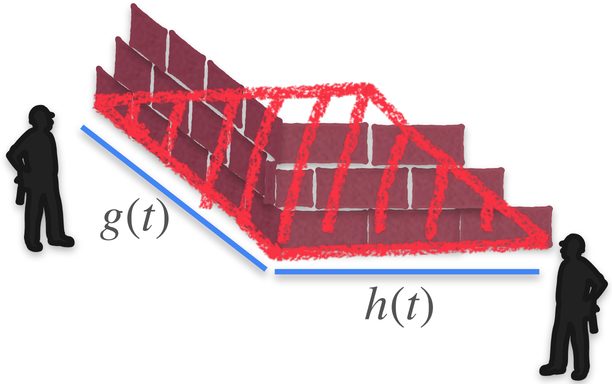
Product Rule



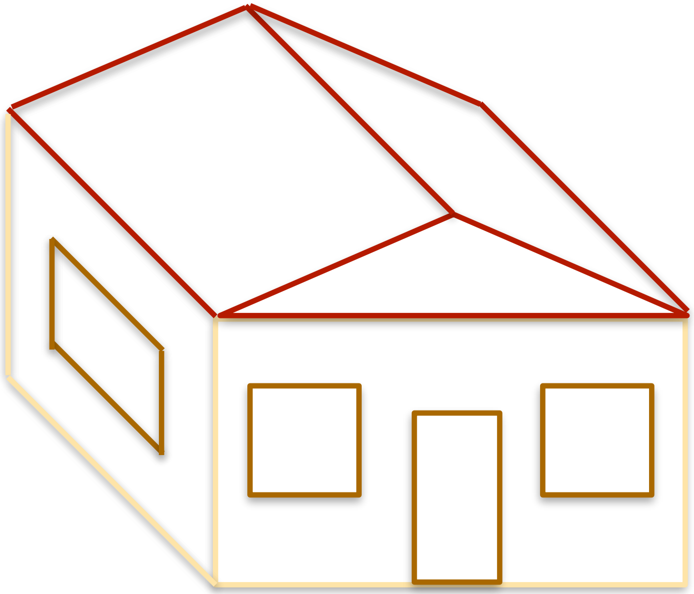


Product Rule

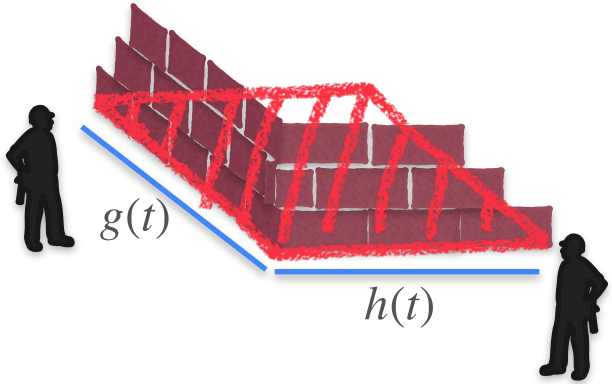




Product Rule



$$f(t) = g(t)h(t)$$



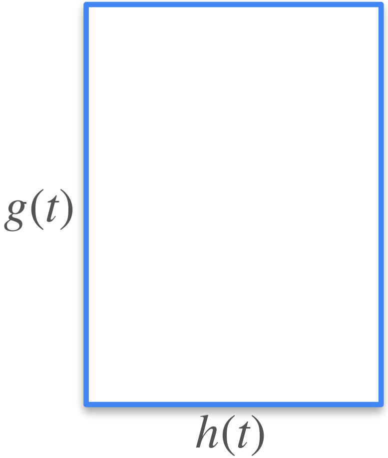
Product Rule

Product Rule

$$y = f(t) = g(t)h(t)$$

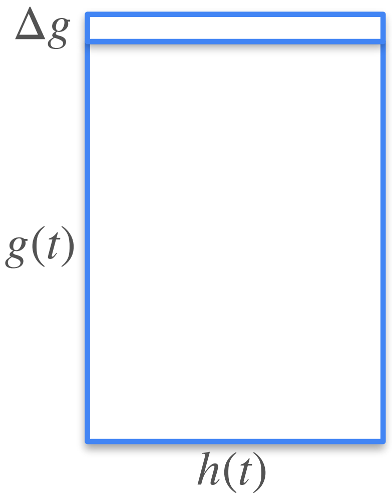
Product Rule

$$y = f(t) = g(t)h(t)$$



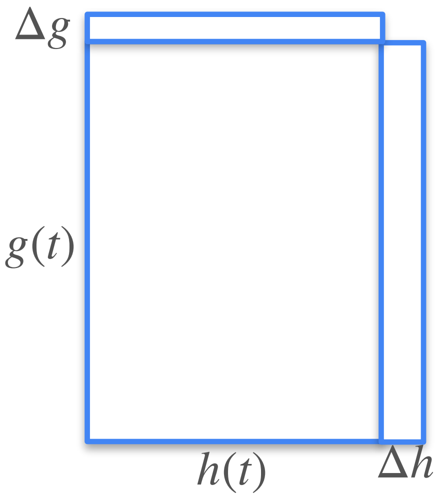
Product Rule

$$y = f(t) = g(t)h(t)$$



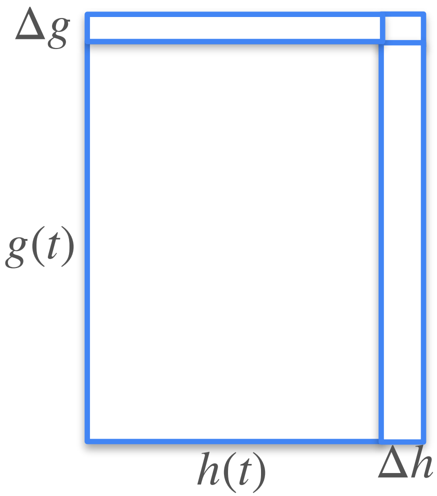
Product Rule

$$y = f(t) = g(t)h(t)$$



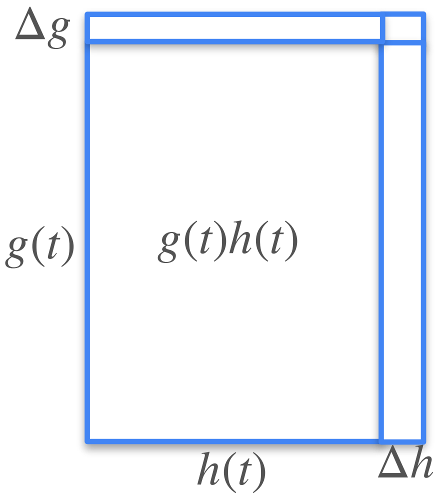
Product Rule

$$y = f(t) = g(t)h(t)$$



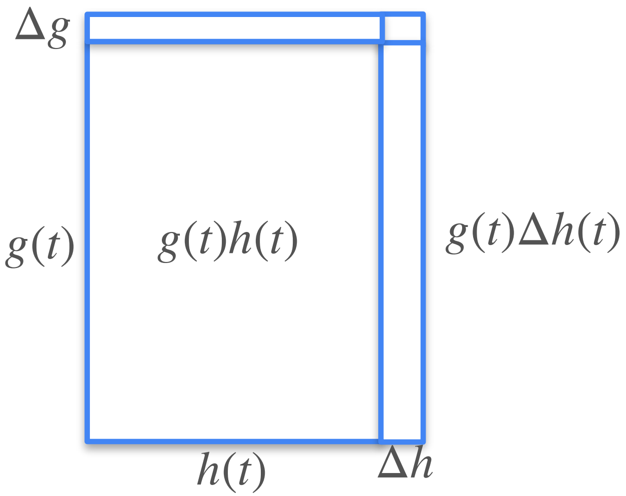
Product Rule

$$y = f(t) = g(t)h(t)$$

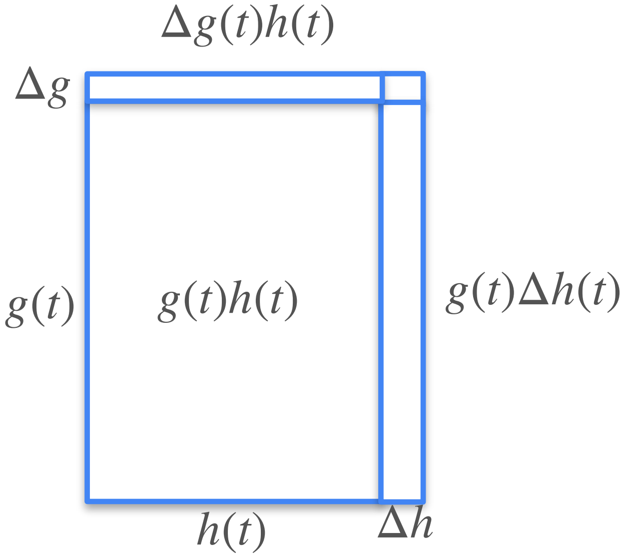


Product Rule

$$y = f(t) = g(t)h(t)$$



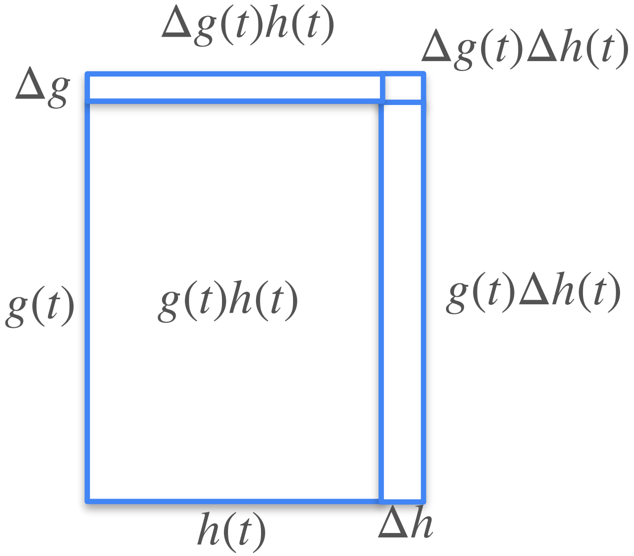
Product Rule



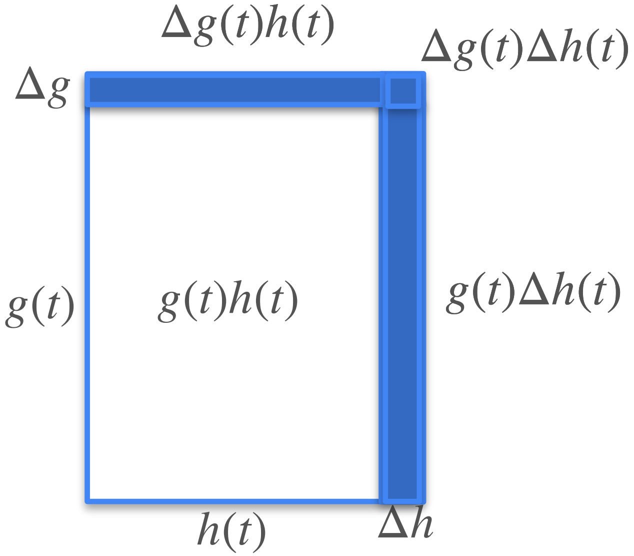
$$y = f(t) = g(t)h(t)$$

Product Rule

$$y = f(t) = g(t)h(t)$$



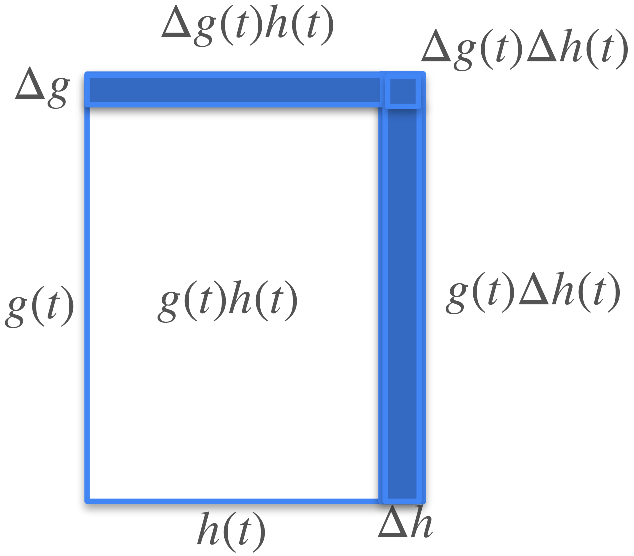
Product Rule



$$y = f(t) = g(t)h(t)$$

$$\frac{\Delta f(t)}{\Delta t}$$

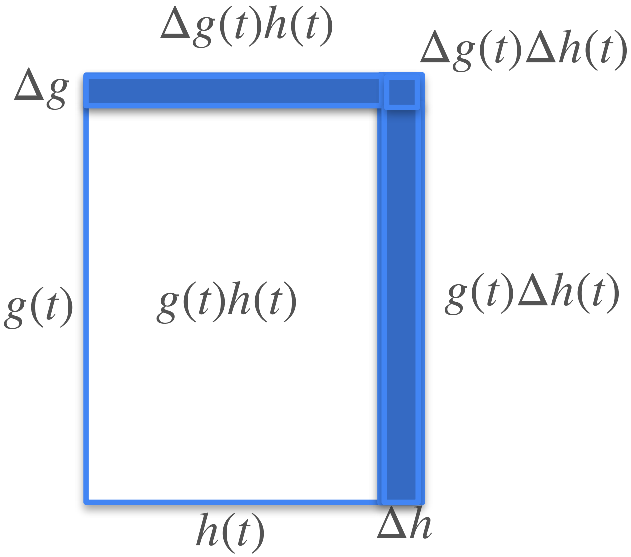
Product Rule



$$y = f(t) = g(t)h(t)$$

$$\frac{\Delta f(t)}{\Delta t} = \frac{\Delta g(t)h(t) + g(t)\Delta h(t) + \Delta g(t)\Delta h(t)}{\Delta t}$$

Product Rule

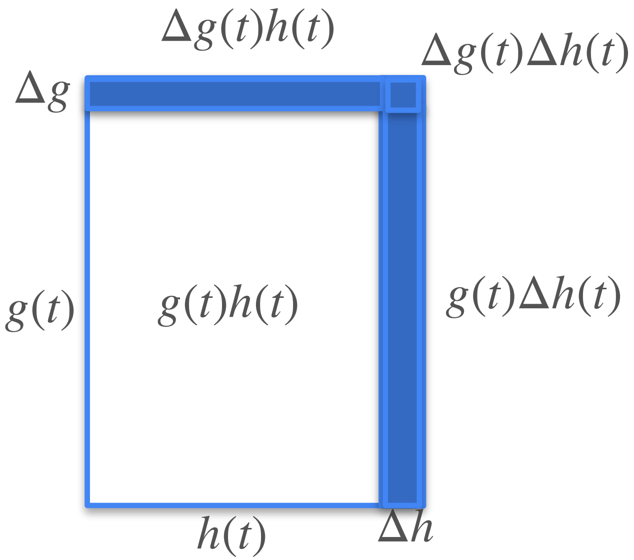


$$y = f(t) = g(t)h(t)$$

$$\frac{\Delta f(t)}{\Delta t} = \frac{\Delta g(t)h(t) + g(t)\Delta h(t) + \Delta g(t)\Delta h(t)}{\Delta t}$$

$$= \frac{\Delta g(t)}{\Delta t}h(t) + g(t)\frac{\Delta h(t)}{\Delta t} + \frac{\Delta g(t)\Delta h(t)}{\Delta t}$$

Product Rule



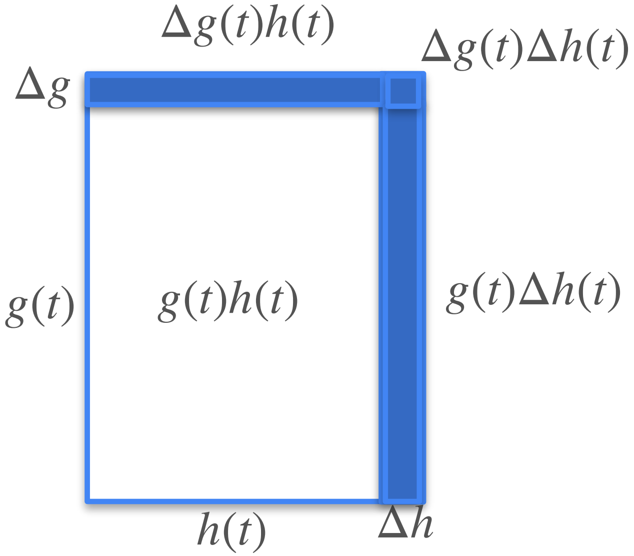
$$y = f(t) = g(t)h(t)$$

$$\frac{\Delta f(t)}{\Delta t} = \frac{\Delta g(t)h(t) + g(t)\Delta h(t) + \Delta g(t)\Delta h(t)}{\Delta t}$$

$$= \frac{\Delta g(t)}{\Delta t}h(t) + g(t)\frac{\Delta h(t)}{\Delta t} + \frac{\Delta g(t)\Delta h(t)}{\Delta t}$$

as $\Delta t \longrightarrow 0$

Product Rule



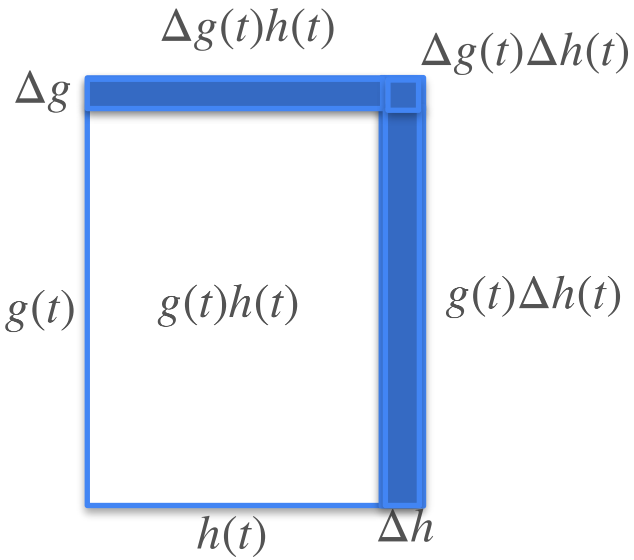
$$y = f(t) = g(t)h(t)$$

$$\overset{f'(t)}{\frac{\Delta f(t)}{\Delta t}} = \frac{\Delta g(t)h(t) + g(t)\Delta h(t) + \Delta g(t)\Delta h(t)}{\Delta t}$$

$$= \frac{\Delta g(t)}{\Delta t}h(t) + g(t)\frac{\Delta h(t)}{\Delta t} + \frac{\Delta g(t)\Delta h(t)}{\Delta t}$$

as $\Delta t \longrightarrow 0$

Product Rule



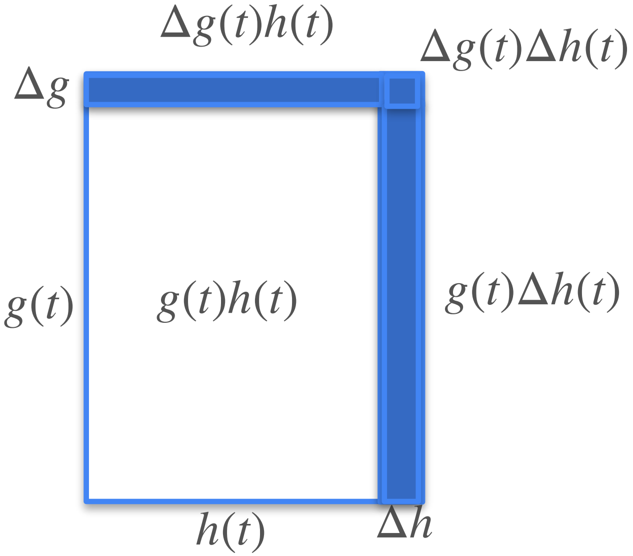
$$y = f(t) = g(t)h(t)$$

$$\overbrace{\frac{\Delta f(t)}{\Delta t}}^{f'(t)} = \frac{\Delta g(t)h(t) + g(t)\Delta h(t) + \Delta g(t)\Delta h(t)}{\Delta t}$$

$$= \overbrace{\frac{\Delta g(t)}{\Delta t}h(t)}^{g'(t)h(t)} + g(t)\frac{\Delta h(t)}{\Delta t} + \frac{\Delta g(t)\Delta h(t)}{\Delta t}$$

as $\Delta t \longrightarrow 0$

Product Rule



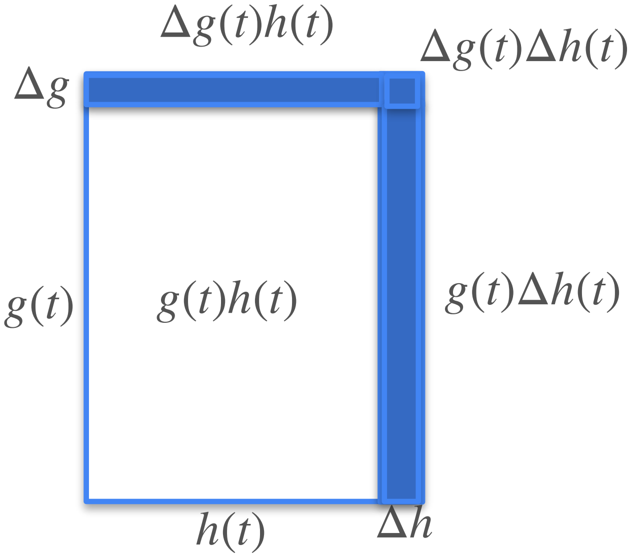
$$y = f(t) = g(t)h(t)$$

$$\overset{f'(t)}{\frac{\Delta f(t)}{\Delta t}} = \frac{\Delta g(t)h(t) + g(t)\Delta h(t) + \Delta g(t)\Delta h(t)}{\Delta t}$$

$$= \overset{g'(t)h(t)}{\frac{\Delta g(t)}{\Delta t}h(t)} + \overset{g(t)h'(t)}{g(t)\frac{\Delta h(t)}{\Delta t}} + \frac{\Delta g(t)\Delta h(t)}{\Delta t}$$

as $\Delta t \longrightarrow 0$

Product Rule



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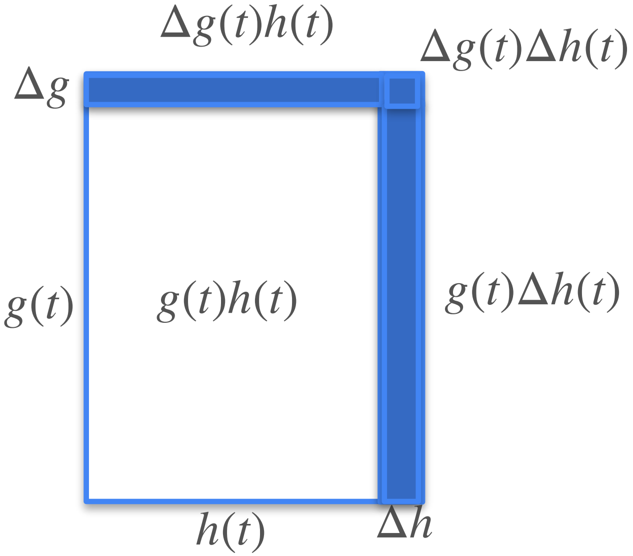
as $\Delta t \longrightarrow 0$

Product Rule



$$y = f(t) = g(t)h(t)$$

$$\overset{f'(t)}{\frac{\Delta f(t)}{\Delta t}} = \frac{\Delta g(t)h(t) + g(t)\Delta h(t) + \Delta g(t)\Delta h(t)}{\Delta t}$$

$$= \overset{g'(t)h(t)}{\frac{\Delta g(t)}{\Delta t}h(t)} + \overset{g(t)h'(t)}{g(t)\frac{\Delta h(t)}{\Delta t}} + \overset{0}{\frac{\Delta g(t)\Delta h(t)}{\Delta t}}$$

as $\Delta t \longrightarrow 0$

$$f'(t) = g'(t)h(t) + g(t)h'(t)$$

DeepLearning.AI

Derivatives and Optimization

Properties of the derivative: The chain rule

The Chain Rule

The Chain Rule

$$h(t)$$

The Chain Rule

$$g(h(t))$$

The Chain Rule

$$\frac{d}{dt}\, g(h(t))$$

The Chain Rule

$$\frac{d}{dt} g(h(t))$$

$$\frac{dh}{dt}$$

The Chain Rule

$$\frac{d}{dt} g(h(t))$$

$$\frac{dg}{dh} \frac{dh}{dt}$$

The Chain Rule

$$\frac{d}{dt} g(h(t))$$

$$= \frac{dg}{dh} \cdot \frac{dh}{dt}$$

The Chain Rule

$$g(h(t))$$

$$\frac{dg}{dh} \quad \frac{dh}{dt}$$

The Chain Rule

$$f(\,g(\,h(t)\,)\,)$$

$$\frac{dg}{dh} \quad \frac{dh}{dt}$$

The Chain Rule

$$\frac{d}{dt} f(g(h(t)))$$

$$\frac{dg}{dh} \frac{dh}{dt}$$

The Chain Rule

$$\frac{d}{dt} f(g(h(t)))$$

$$\frac{df}{dg} \frac{dg}{dh} \frac{dh}{dt}$$

The Chain Rule

$$\frac{d}{dt} f(g(h(t))) = \frac{df}{dg} \cdot \frac{dg}{dh} \cdot \frac{dh}{dt}$$

The Chain Rule

$$\frac{d}{dt} g(h(t)) = \frac{dg}{dh} \cdot \frac{dh}{dt}$$

The Chain Rule

$$\frac{d}{dt} g(h(t)) = \frac{dg}{dh} \cdot \frac{dh}{dt}$$

$$=$$

The Chain Rule

$$\frac{d}{dt} g(h(t)) = \frac{dg}{dh} \cdot \frac{dh}{dt}$$

$$= \qquad h'(t)$$

The Chain Rule

$$\frac{d}{dt} g(h(t)) = \frac{dg}{dh} \cdot \frac{dh}{dt}$$

$$= g'(h(t)) \cdot h'(t)$$

The Chain Rule

$$\frac{d}{dt} f(g(h(t))) = \frac{df}{dg} \cdot \frac{dg}{dh} \cdot \frac{dh}{dt}$$

The Chain Rule

$$\frac{d}{dt} f(g(h(t))) = \frac{df}{dg} \cdot \frac{dg}{dh} \cdot \frac{dh}{dt}$$

$$=$$

The Chain Rule

$$\frac{d}{dt} f(g(h(t))) = \frac{df}{dg} \cdot \frac{dg}{dh} \cdot \frac{dh}{dt}$$

$$= \qquad\qquad\qquad\qquad h'(t)$$

The Chain Rule

$$\frac{d}{dt} f(g(h(t))) = \frac{df}{dg} \cdot \frac{dg}{dh} \cdot \frac{dh}{dt}$$

$$= \qquad g'(h(t)) \cdot h'(t)$$

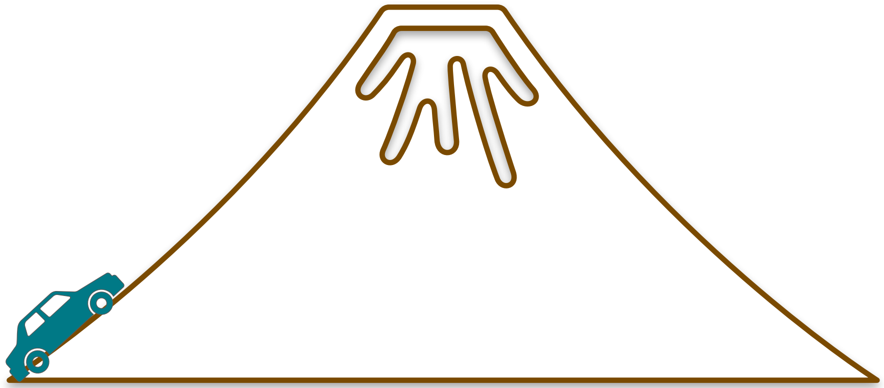
The Chain Rule

$$\frac{d}{dt} f(g(h(t))) = \frac{df}{dg} \cdot \frac{dg}{dh} \cdot \frac{dh}{dt}$$

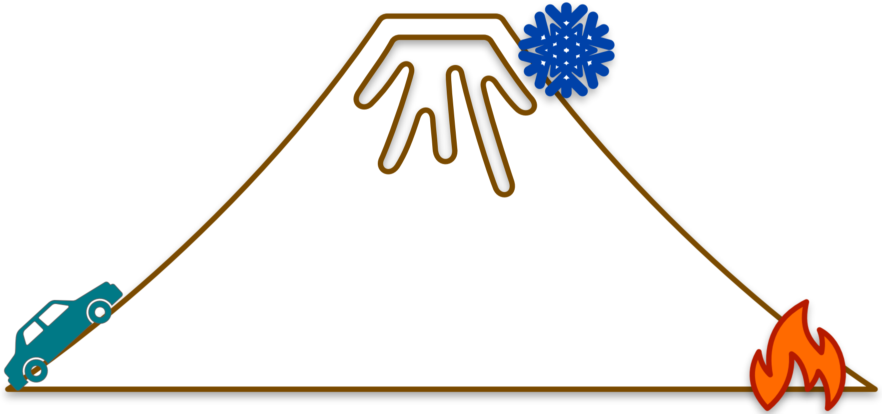
$$= f'(g(h(t))) \cdot g'(h(t)) \cdot h'(t)$$

Idea of Chain Rule

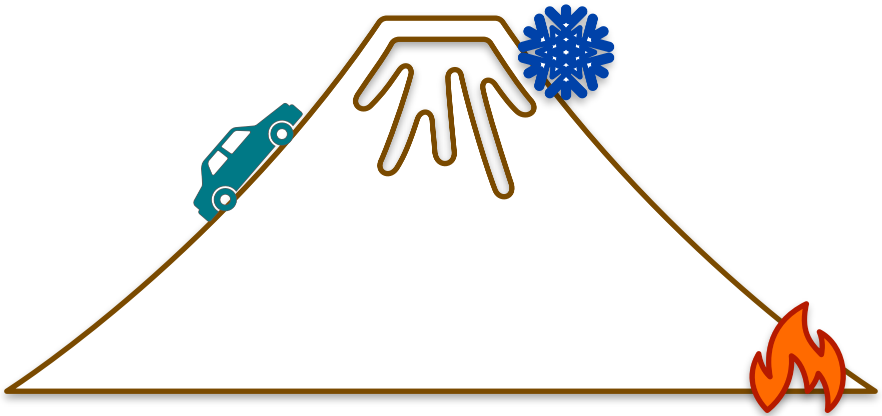
Idea of Chain Rule



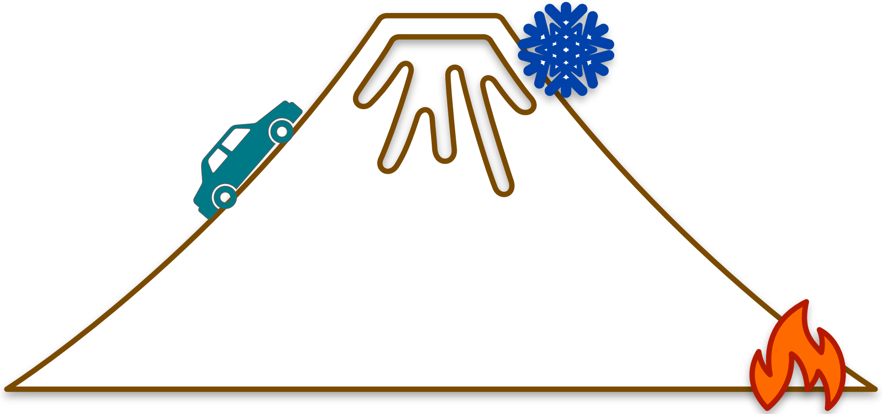
Idea of Chain Rule



Idea of Chain Rule

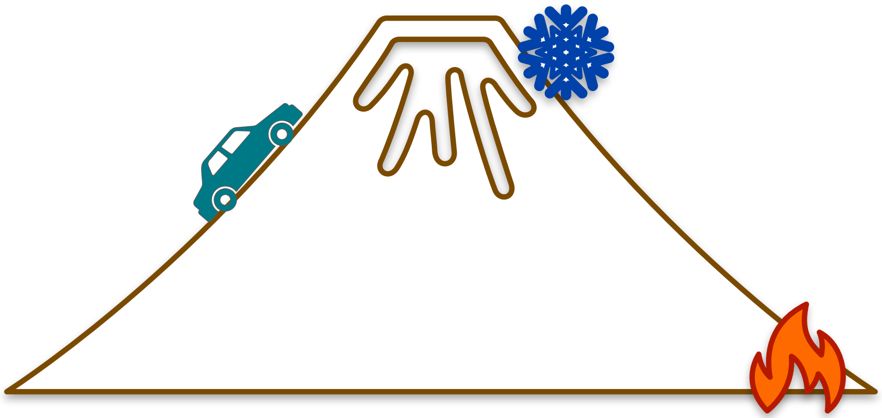


Idea of Chain Rule



Temperature changes w.r.t. height $\frac{dT}{dh}$

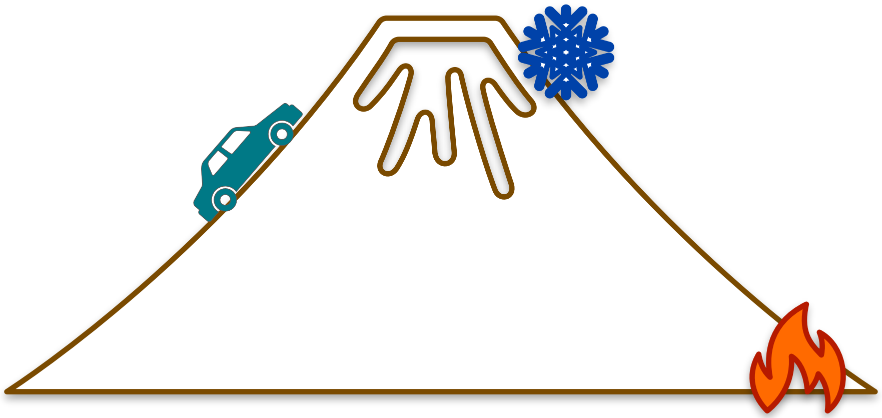
Idea of Chain Rule



Temperature changes w.r.t. height $\frac{dT}{dh}$

height changes w.r.t. time $\frac{dh}{dt}$

Idea of Chain Rule



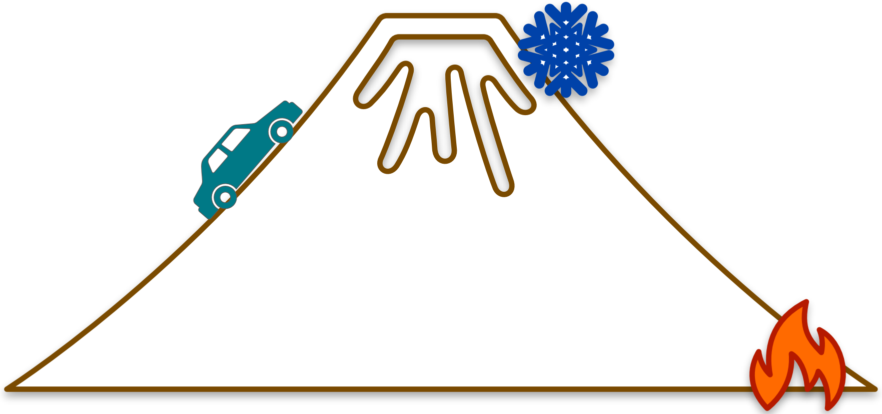
Temperature changes w.r.t. height $\frac{dT}{dh}$

height changes w.r.t. time $\frac{dh}{dt}$

$\Downarrow$

Temperature changes w.r.t. time $\frac{dT}{dt}$

Idea of Chain Rule



Temperature changes w.r.t. height $\frac{dT}{dh}$

height changes w.r.t. time $\frac{dh}{dt}$

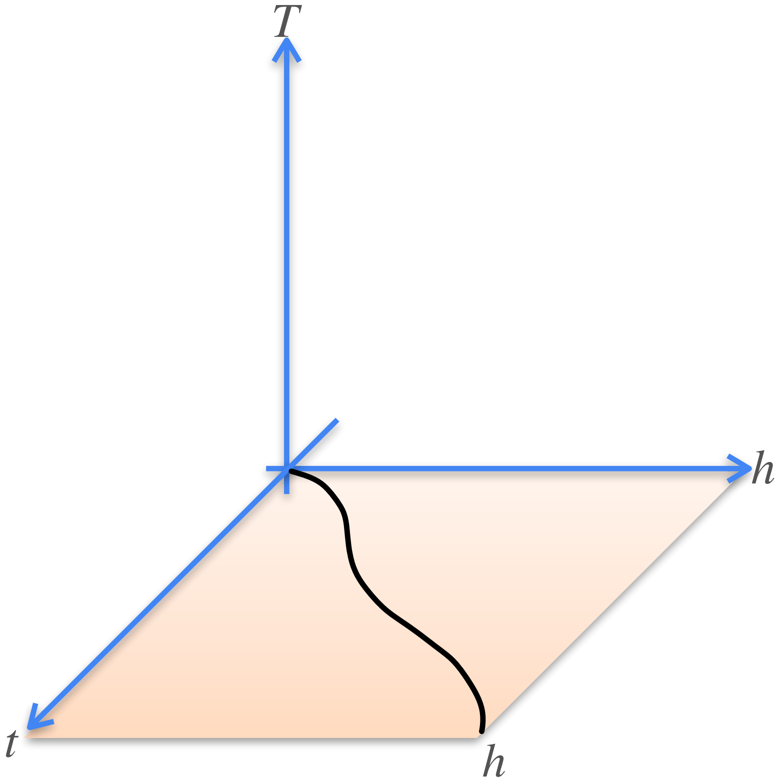
$\Downarrow$

Temperature changes w.r.t. time $\frac{dT}{dt}$

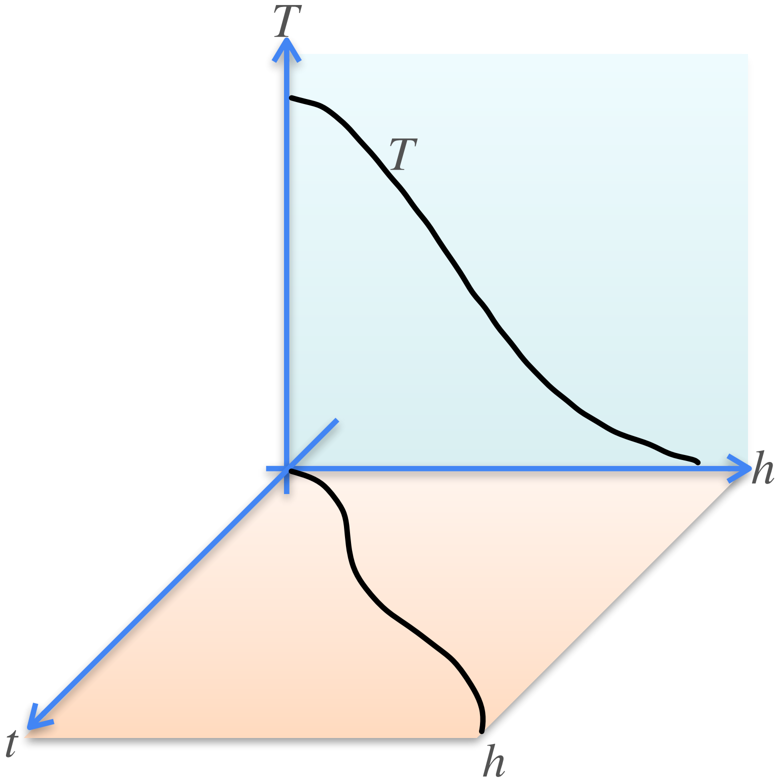
$$\frac{dT}{dt} = \frac{dT}{dh} \frac{dh}{dt}$$

Chain Rule

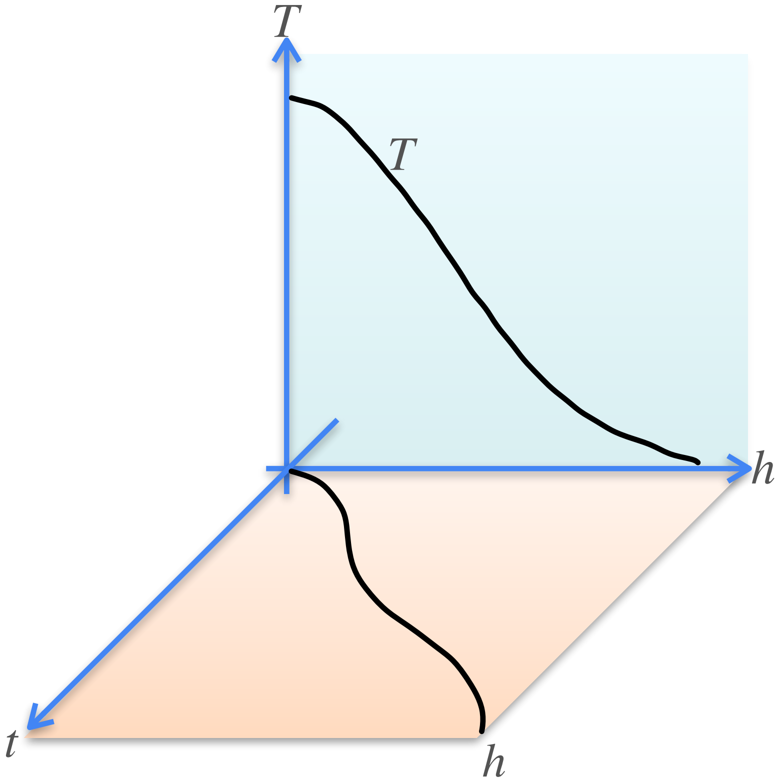
Chain Rule



Chain Rule

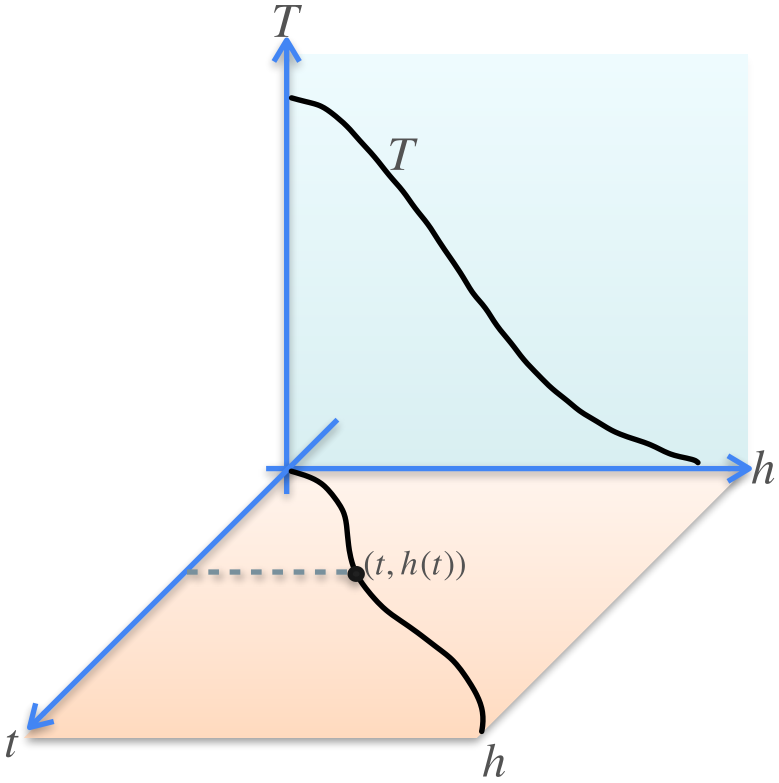


Chain Rule



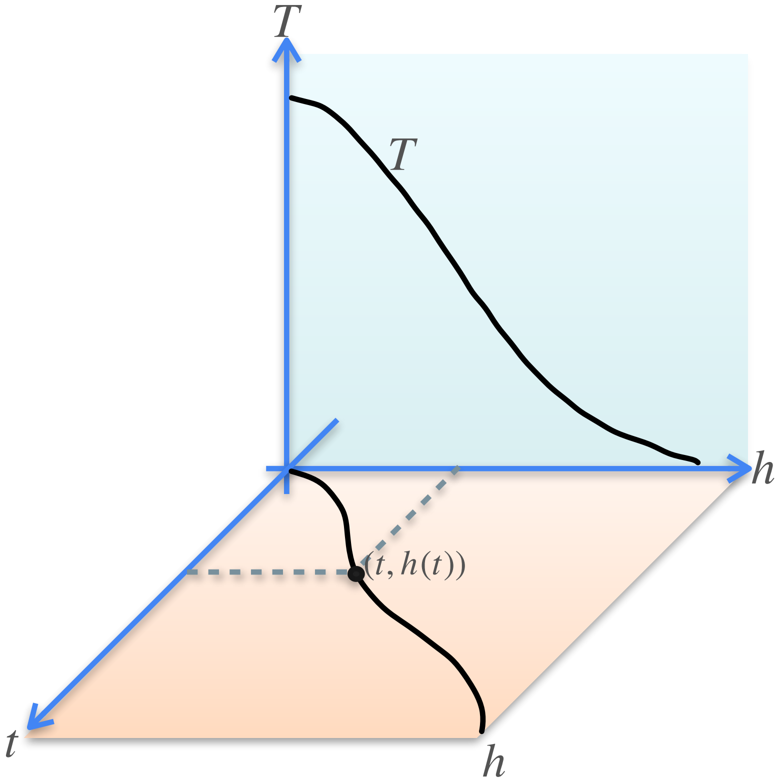
$\Delta t \rightarrow \Delta h \rightarrow \Delta T$

Chain Rule



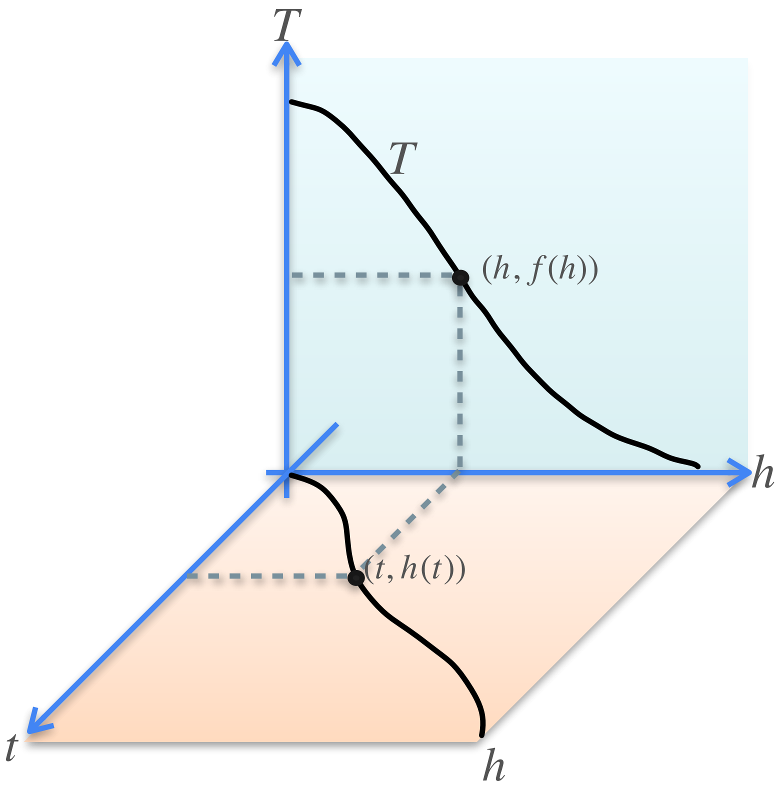
$$\Delta t \rightarrow \Delta h \rightarrow \Delta T$$

Chain Rule



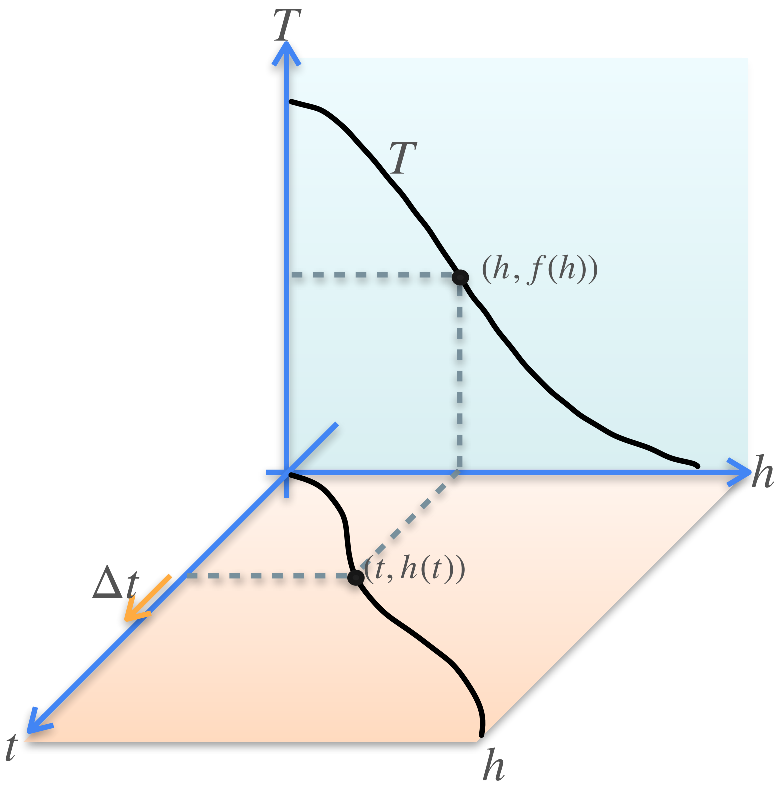
$\Delta t \rightarrow \Delta h \rightarrow \Delta T$

Chain Rule



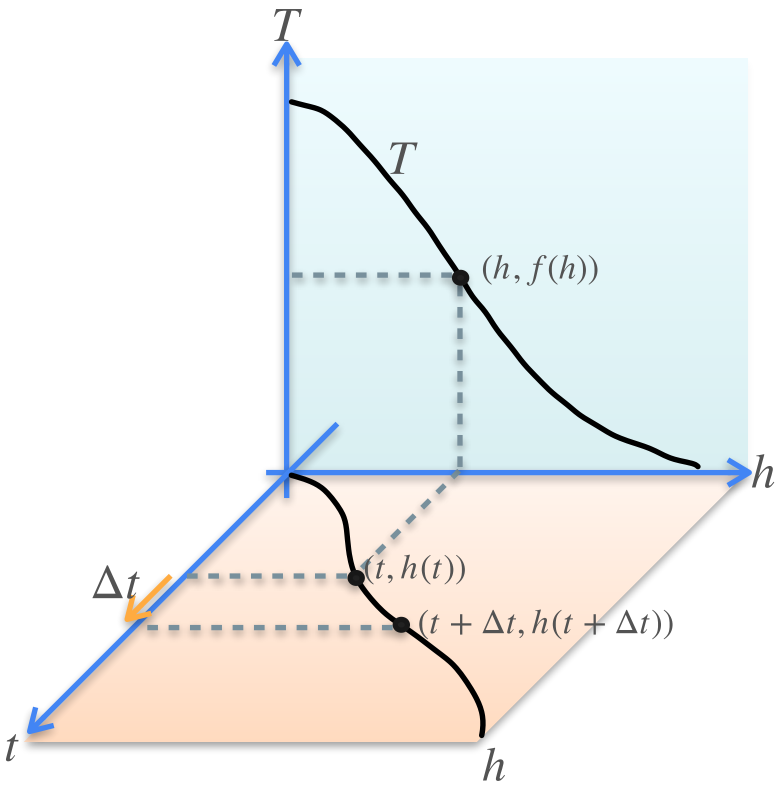
$$\Delta t \rightarrow \Delta h \rightarrow \Delta T$$

Chain Rule



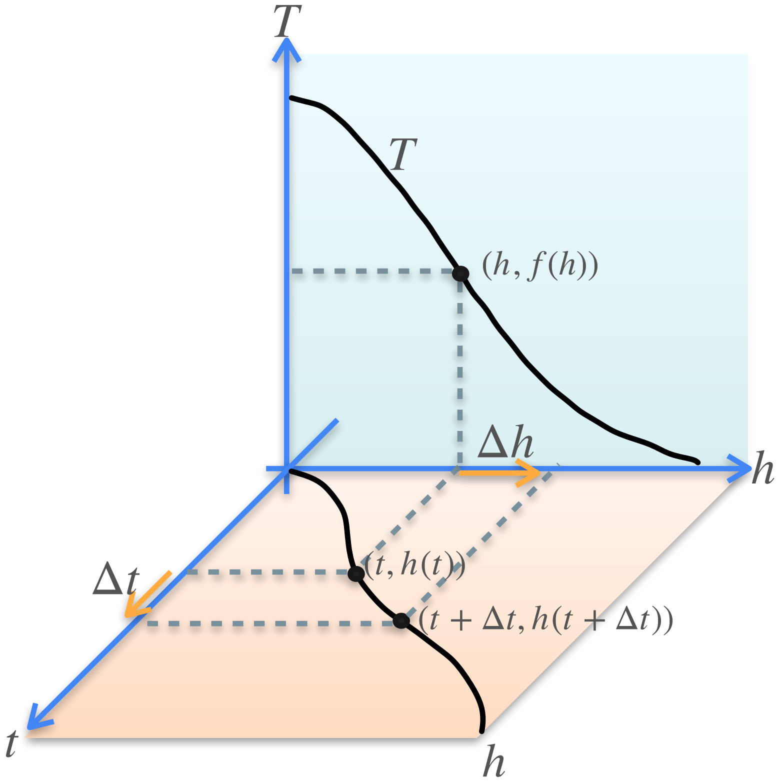
$$\Delta t \rightarrow \Delta h \rightarrow \Delta T$$

Chain Rule



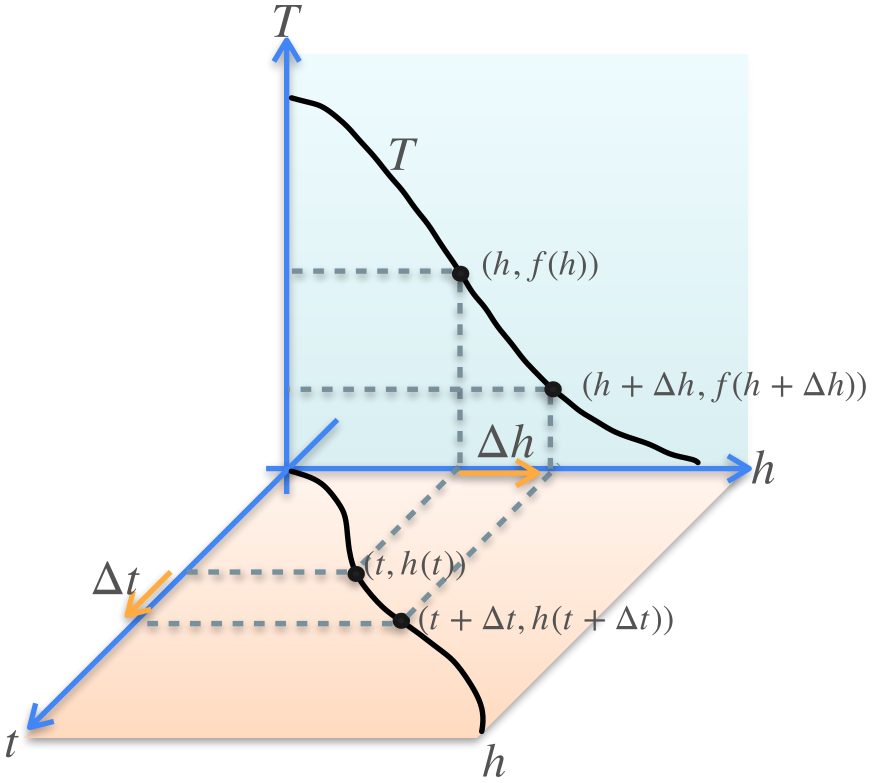
$\Delta t \rightarrow \Delta h \rightarrow \Delta T$

Chain Rule



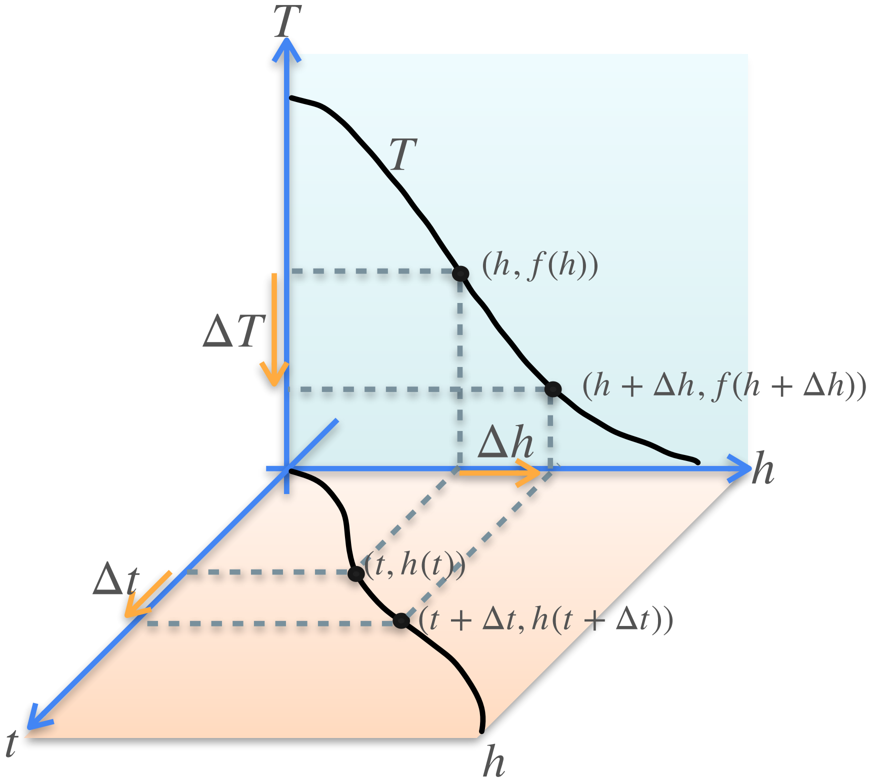
$\Delta t \rightarrow \Delta h \rightarrow \Delta T$

Chain Rule



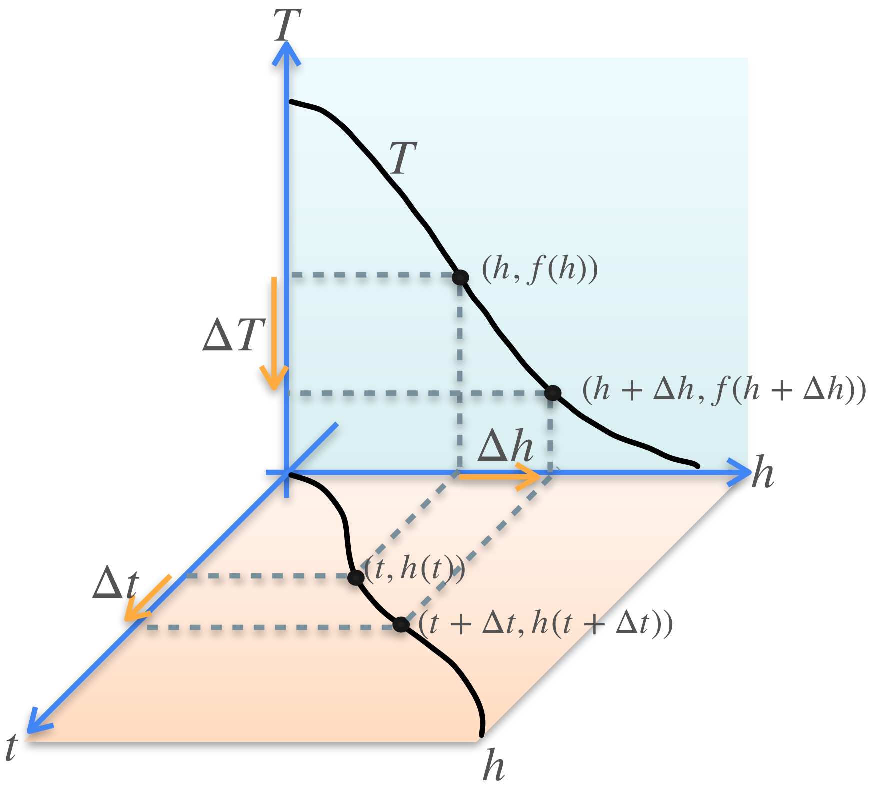
$\Delta t \rightarrow \Delta h \rightarrow \Delta T$

Chain Rule



$\Delta t \rightarrow \Delta h \rightarrow \Delta T$

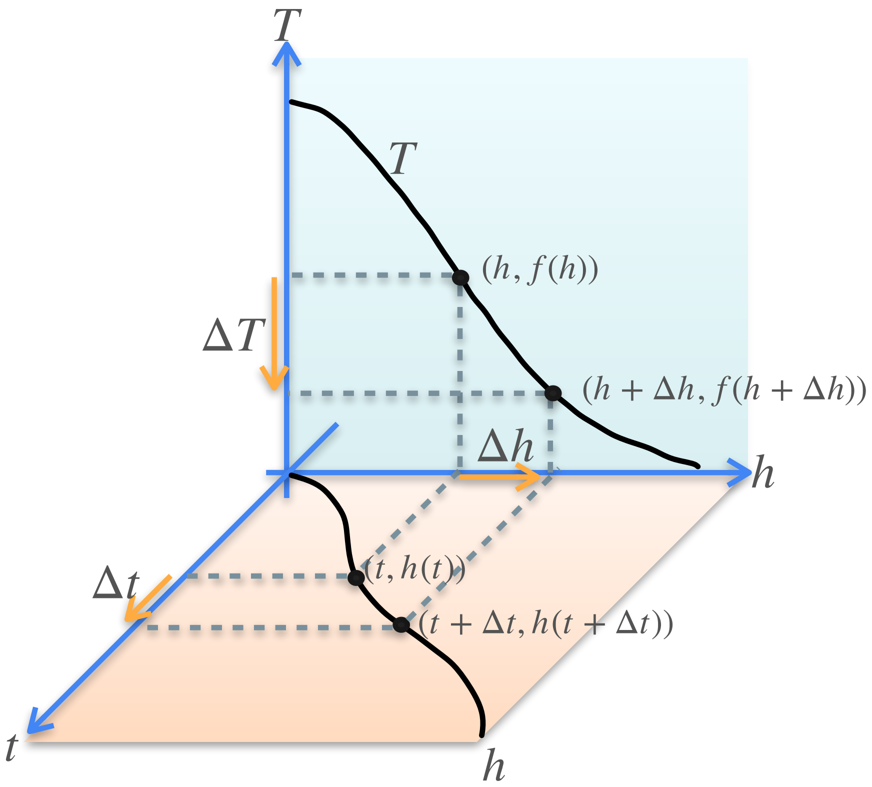
Chain Rule



$$\Delta t \rightarrow \Delta h \rightarrow \Delta T$$

$$\frac{\Delta T}{\Delta t} =$$

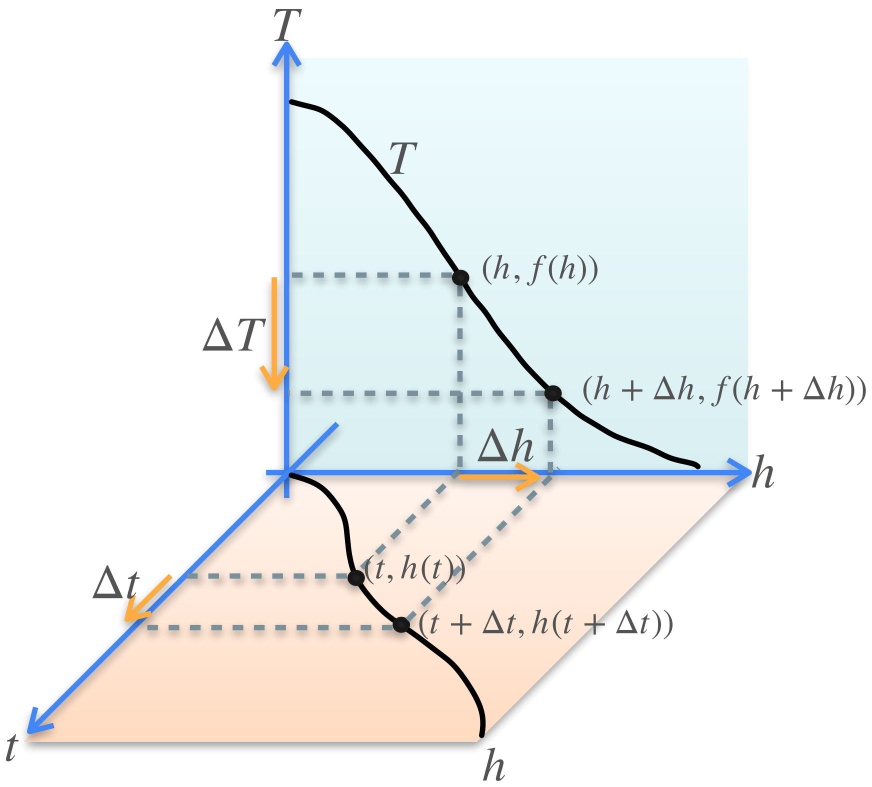
Chain Rule



$$\Delta t \rightarrow \Delta h \rightarrow \Delta T$$

$$\frac{\Delta T}{\Delta t} = \qquad \frac{\Delta h}{\Delta t}$$

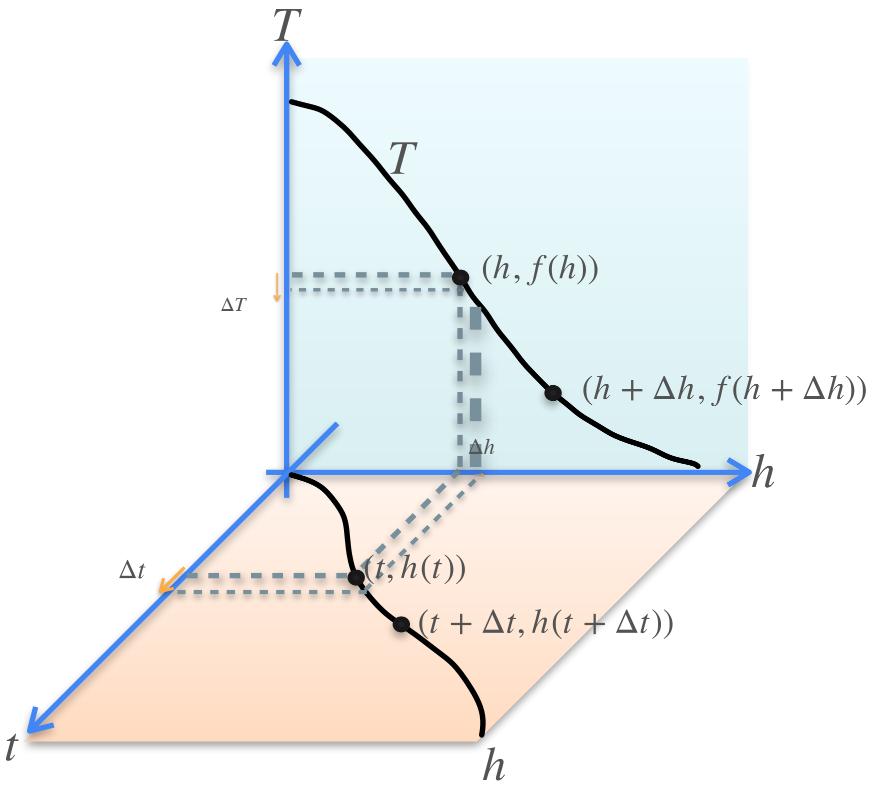
Chain Rule



$$\Delta t \rightarrow \Delta h \rightarrow \Delta T$$

$$\frac{\Delta T}{\Delta t} = \frac{\Delta T}{\Delta h}\frac{\Delta h}{\Delta t}$$

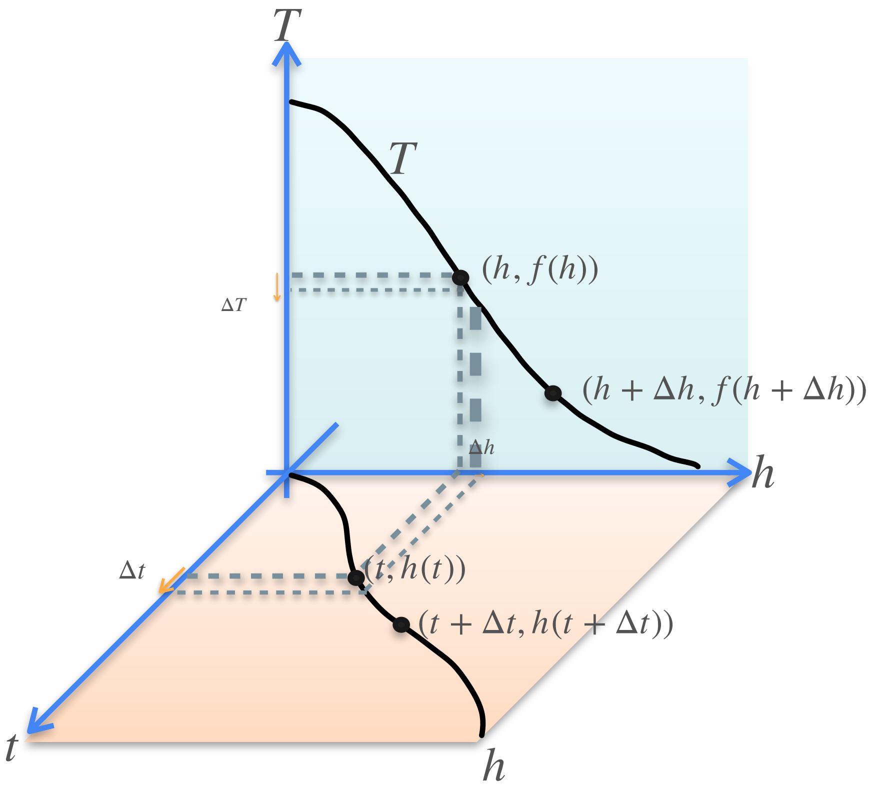
Chain Rule



$$\Delta t \rightarrow \Delta h \rightarrow \Delta T$$

$$\frac{\Delta T}{\Delta t} = \frac{\Delta T}{\Delta h} \frac{\Delta h}{\Delta t}$$

Chain Rule

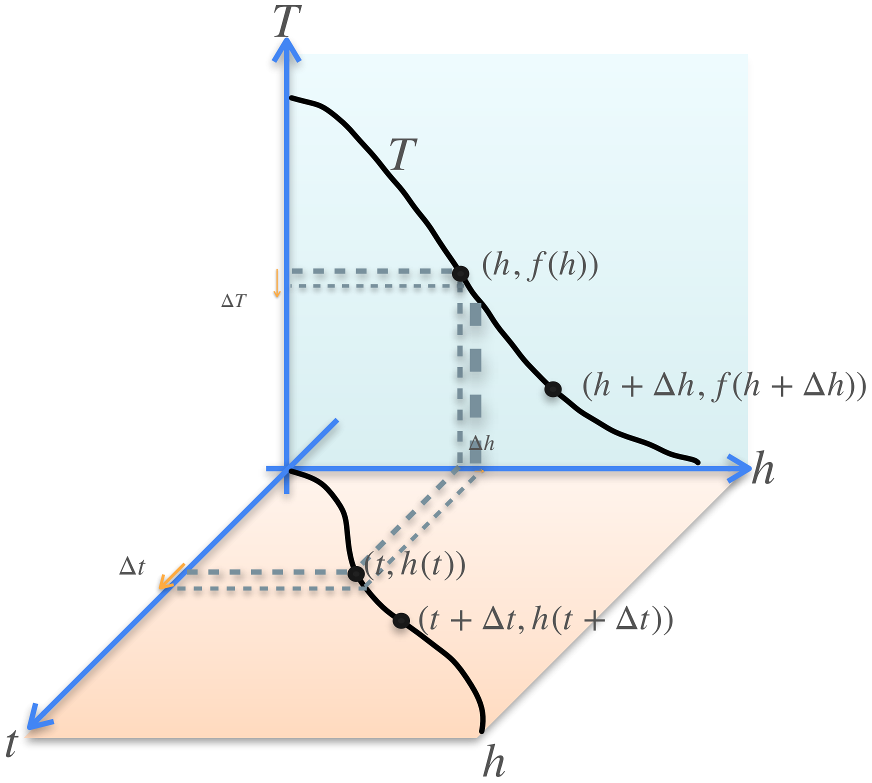


$$\Delta t \rightarrow \Delta h \rightarrow \Delta T$$

$$\frac{\Delta T}{\Delta t} = \frac{\Delta T}{\Delta h} \frac{\Delta h}{\Delta t}$$

$$\frac{dT}{dt}$$

Chain Rule

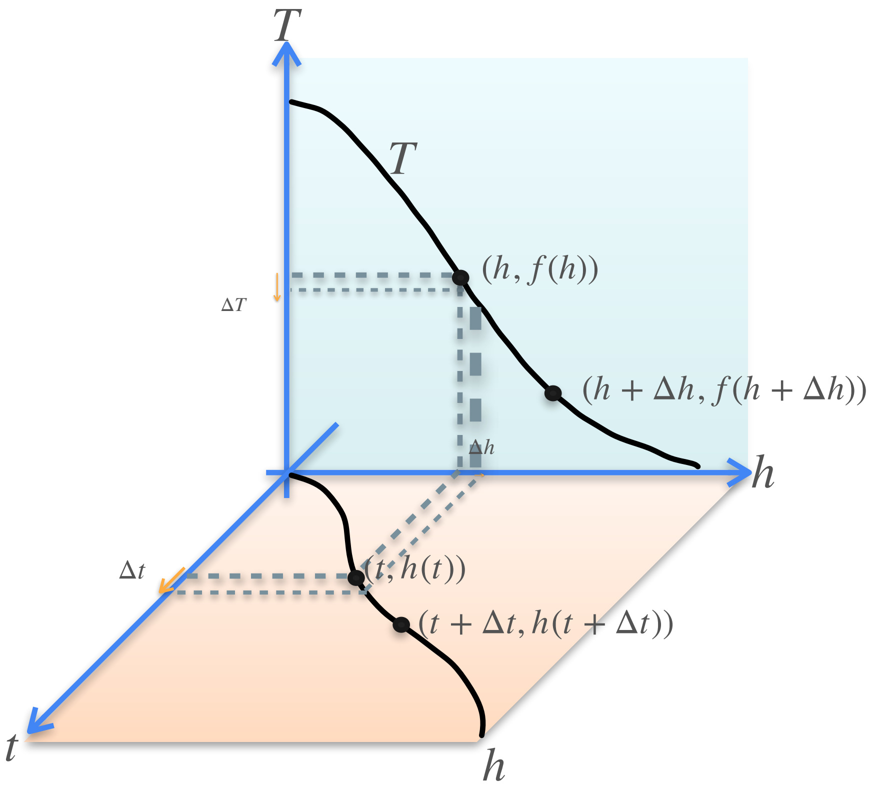


$$\Delta t \rightarrow \Delta h \rightarrow \Delta T$$

$$\frac{\Delta T}{\Delta t} = \frac{\Delta T}{\Delta h} \frac{\Delta h}{\Delta t}$$

$$\frac{dT}{dt} = \frac{dT}{dh}$$

Chain Rule



$$\Delta t \rightarrow \Delta h \rightarrow \Delta T$$

$$\frac{\Delta T}{\Delta t} = \frac{\Delta T}{\Delta h} \frac{\Delta h}{\Delta t}$$

$$\frac{dT}{dt} = \frac{dT}{dh} \frac{dh}{dt}$$

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Derivatives and Optimization

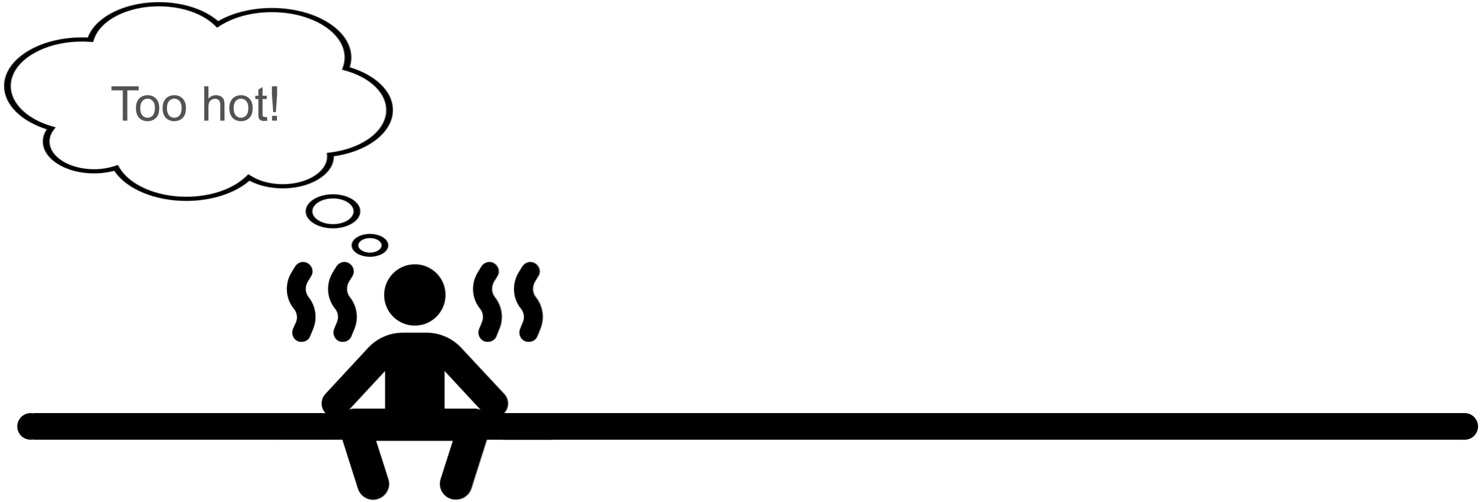
Introduction to optimization

Motivation for Optimization

Motivation for Optimization

Motivation for Optimization

Motivation for Optimization



Motivation for Optimization

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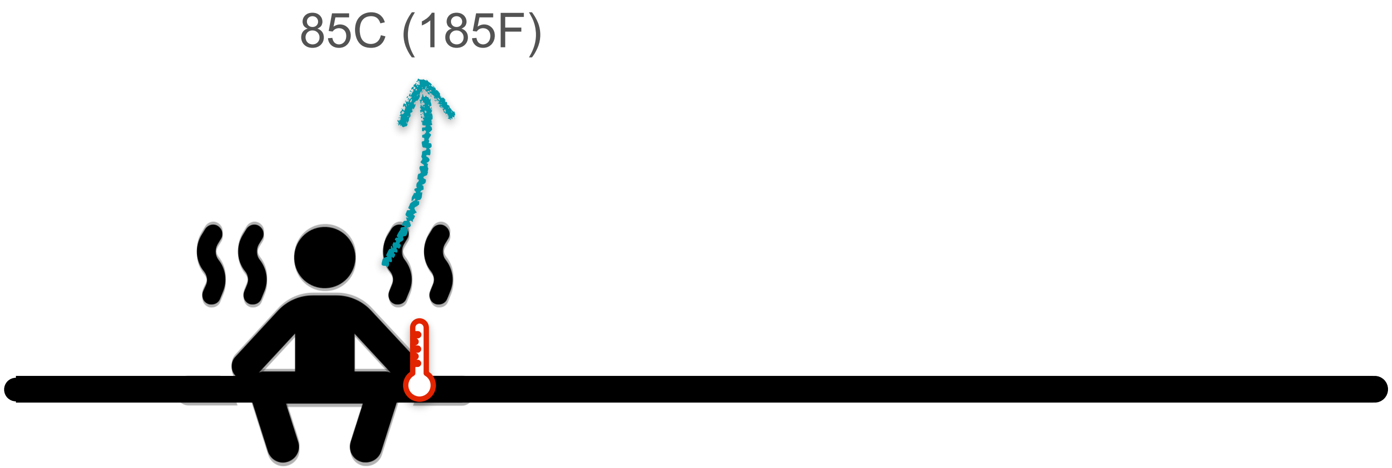

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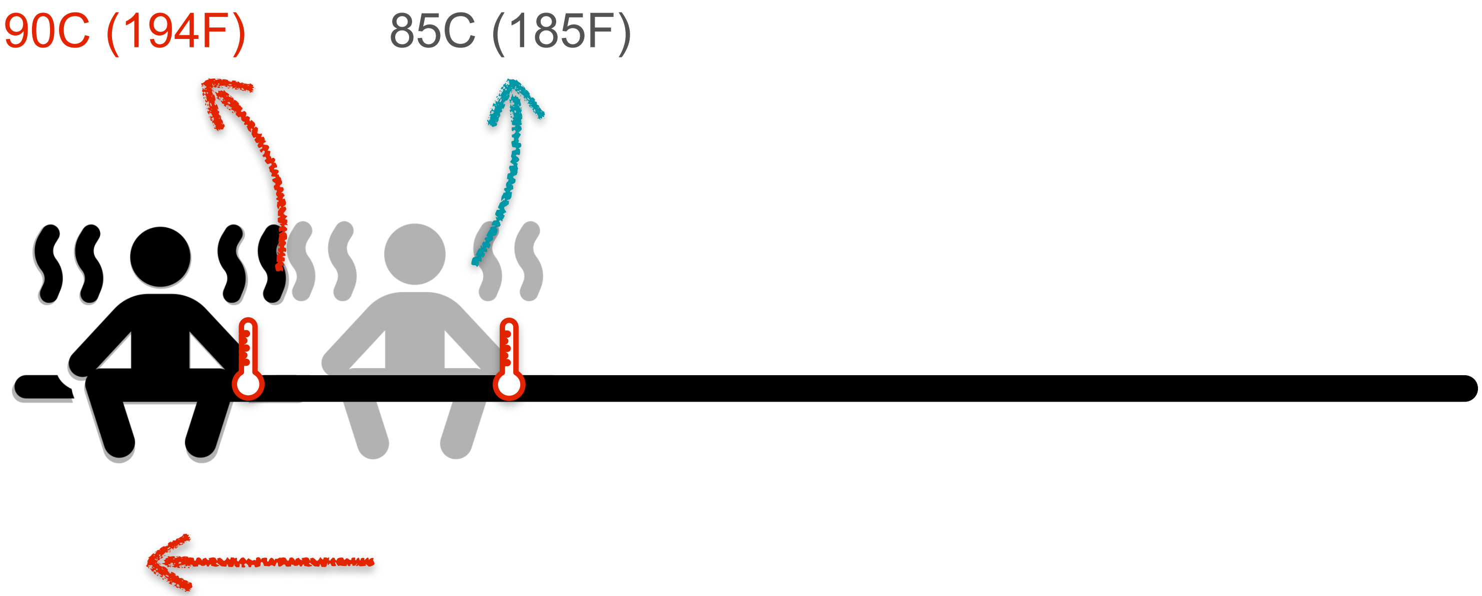

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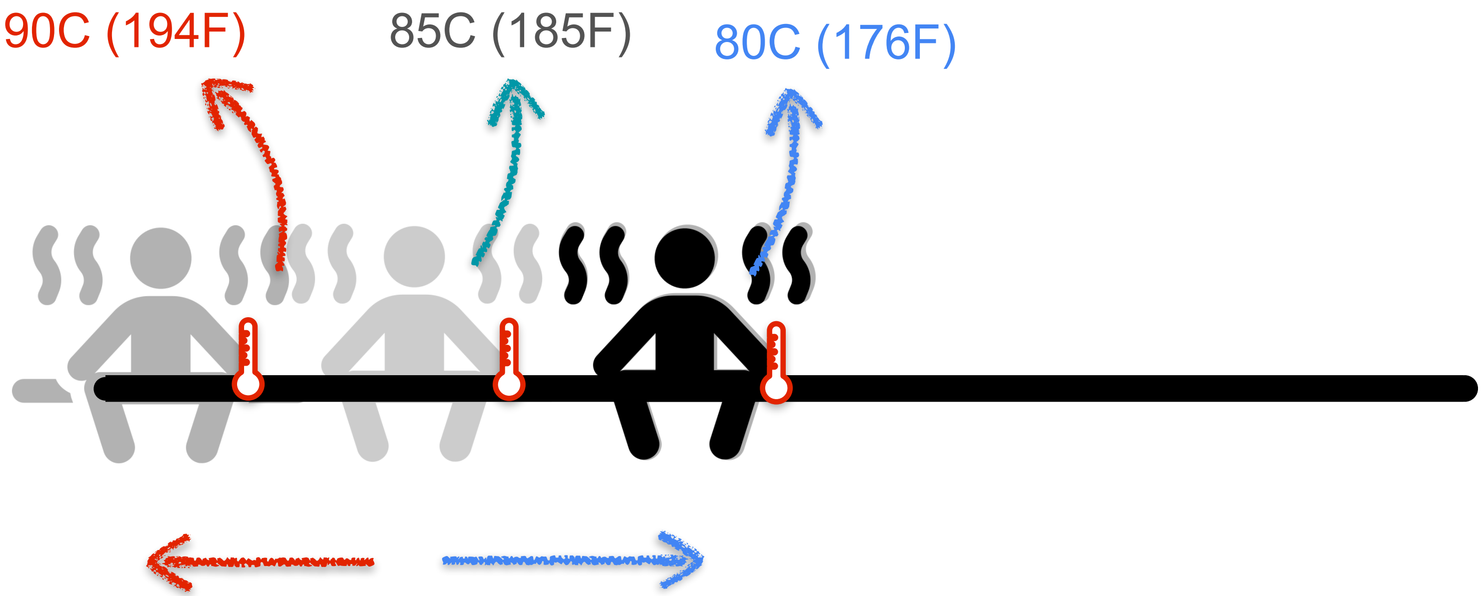

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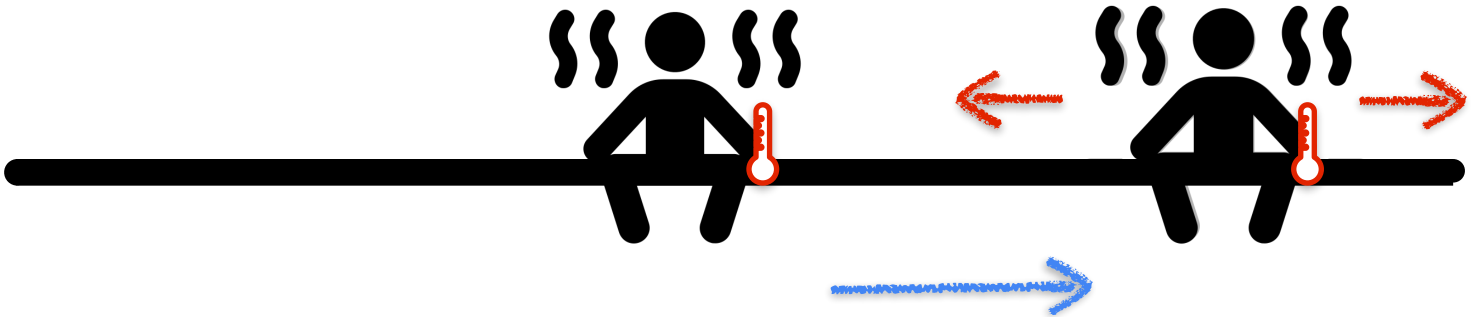

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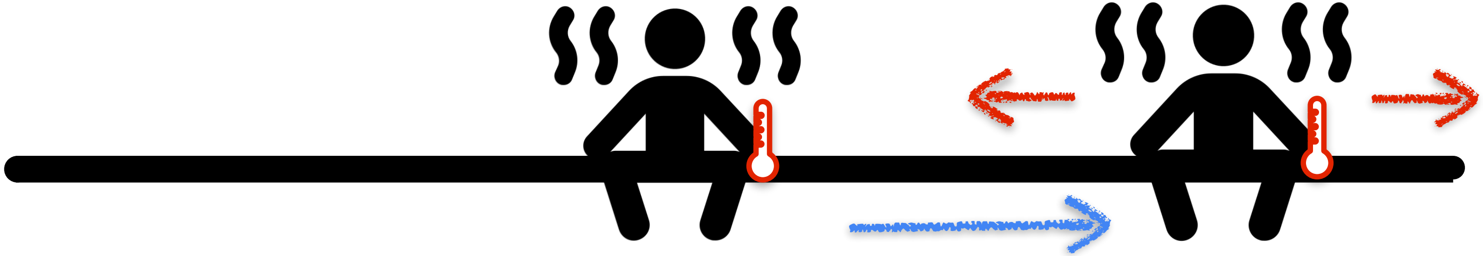

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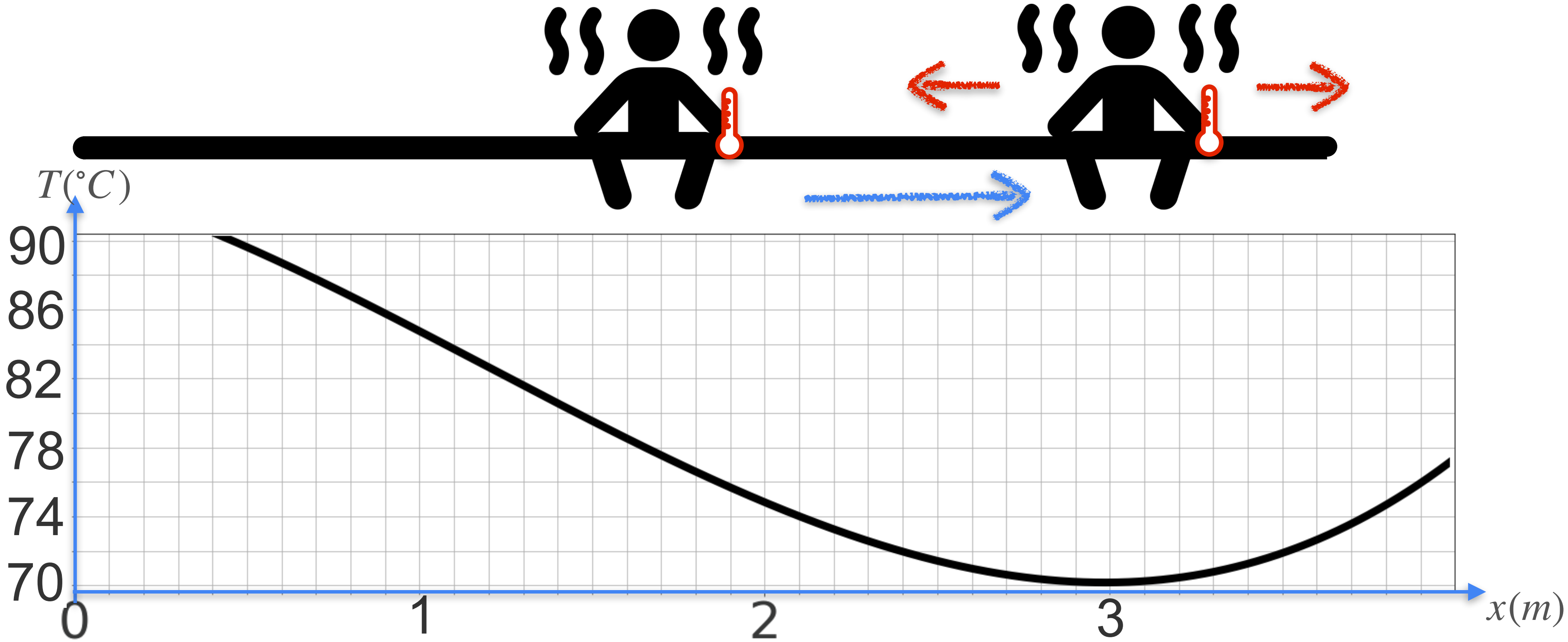

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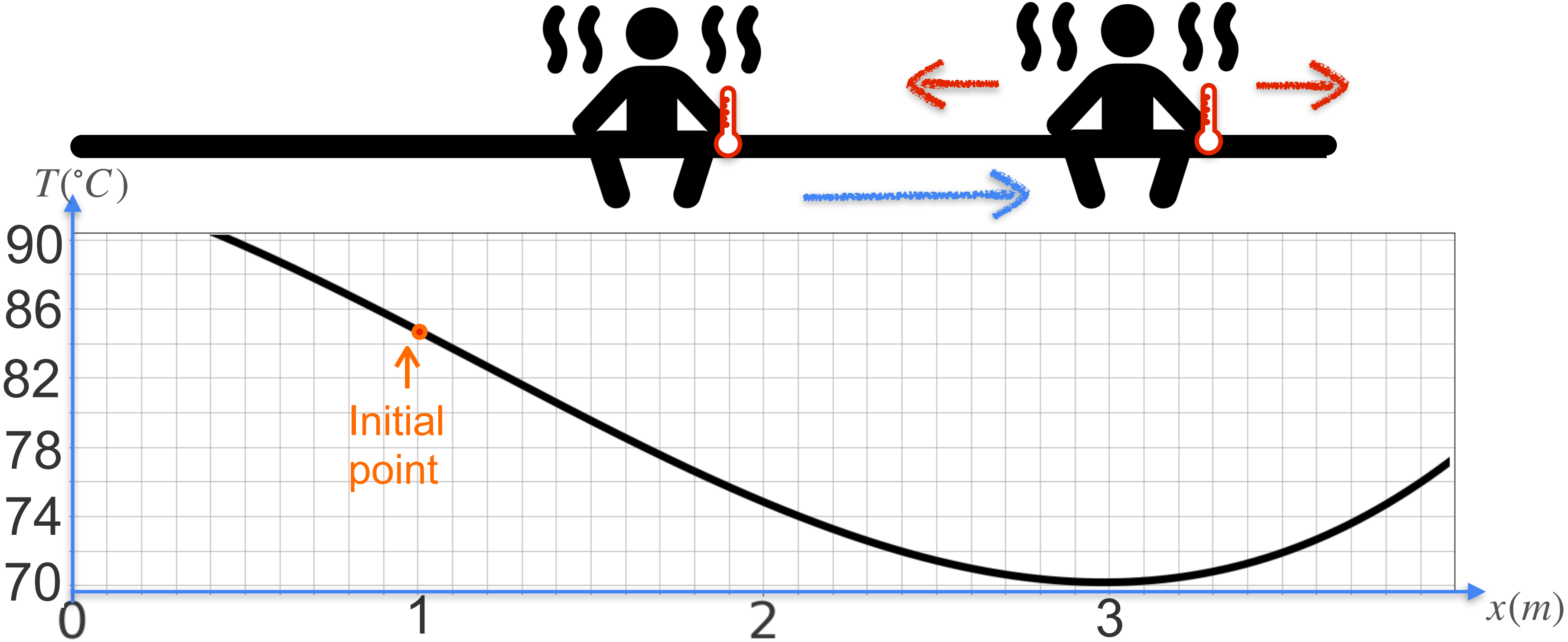

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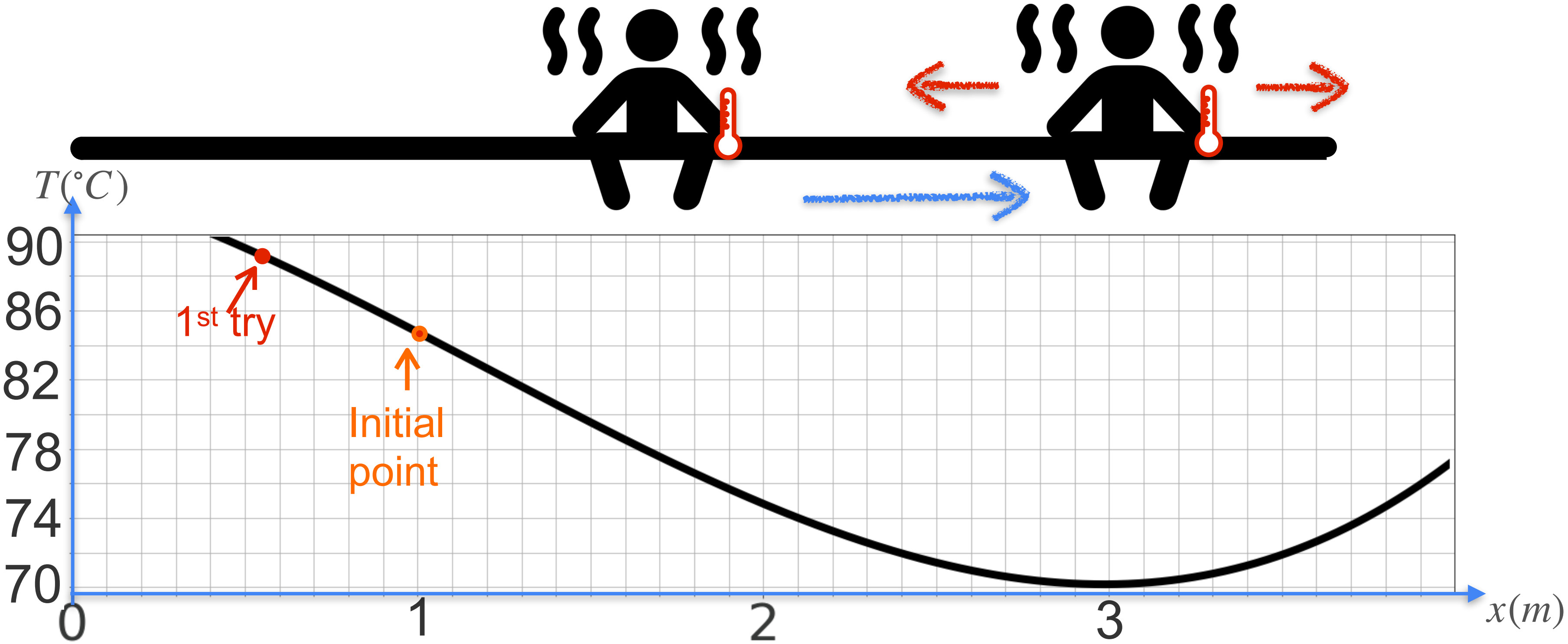

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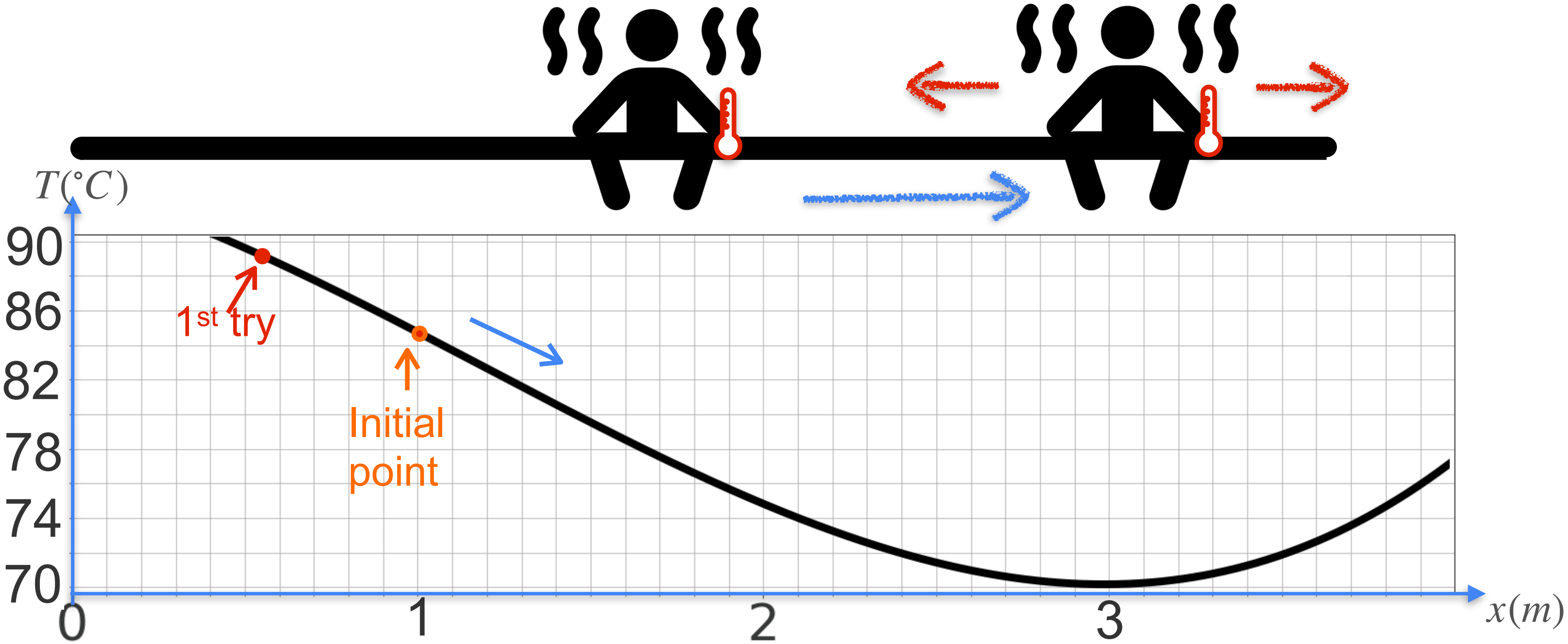

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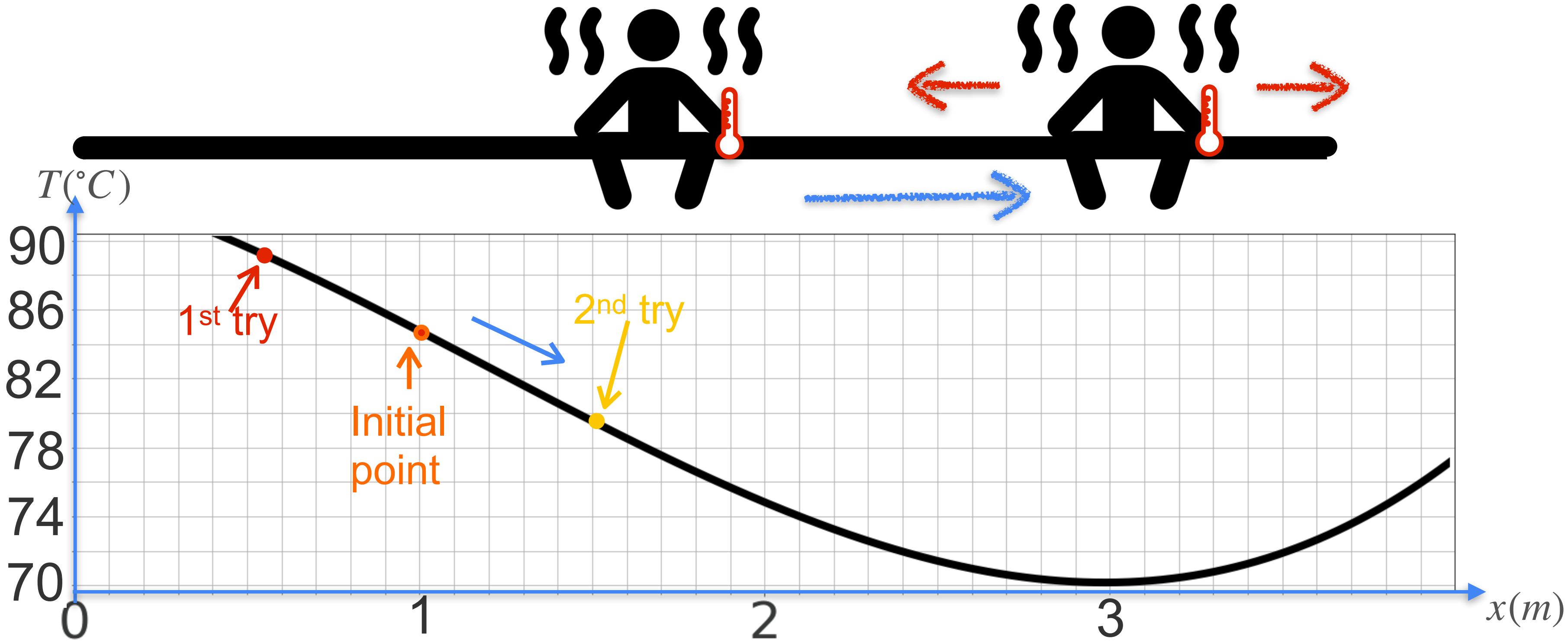

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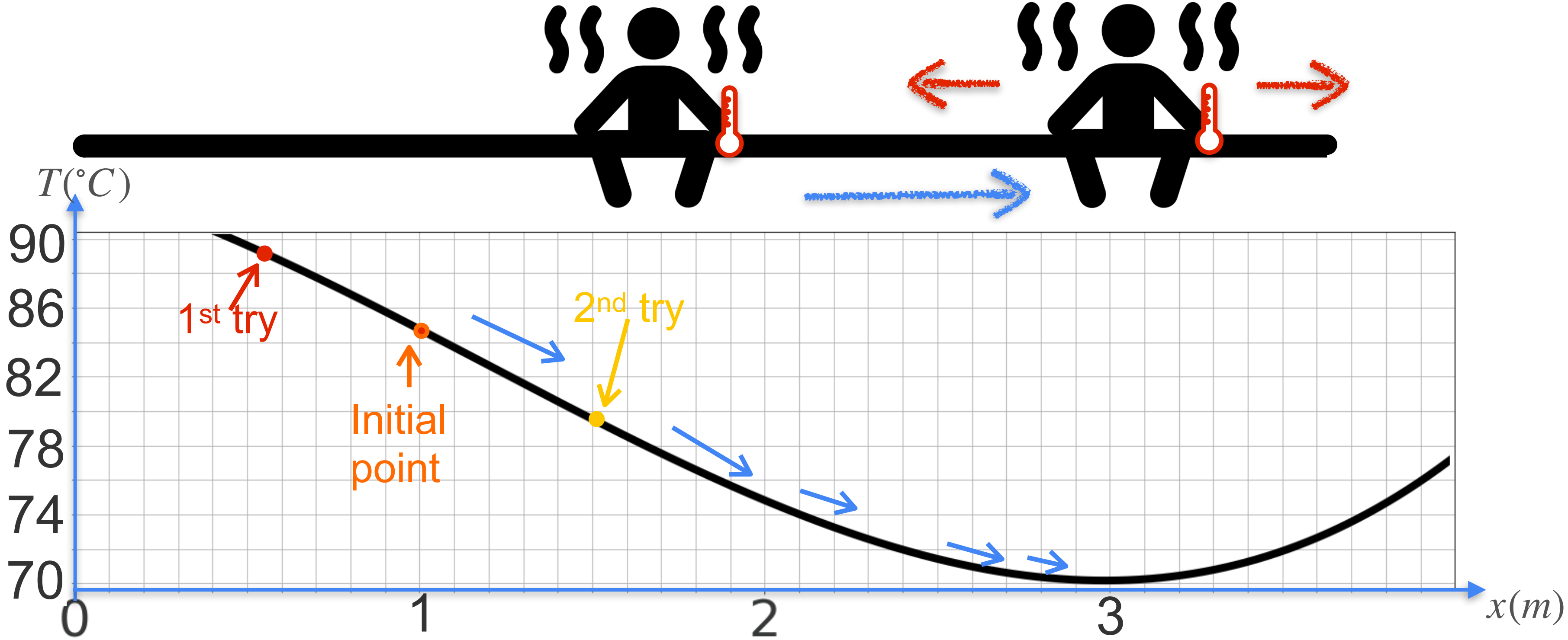

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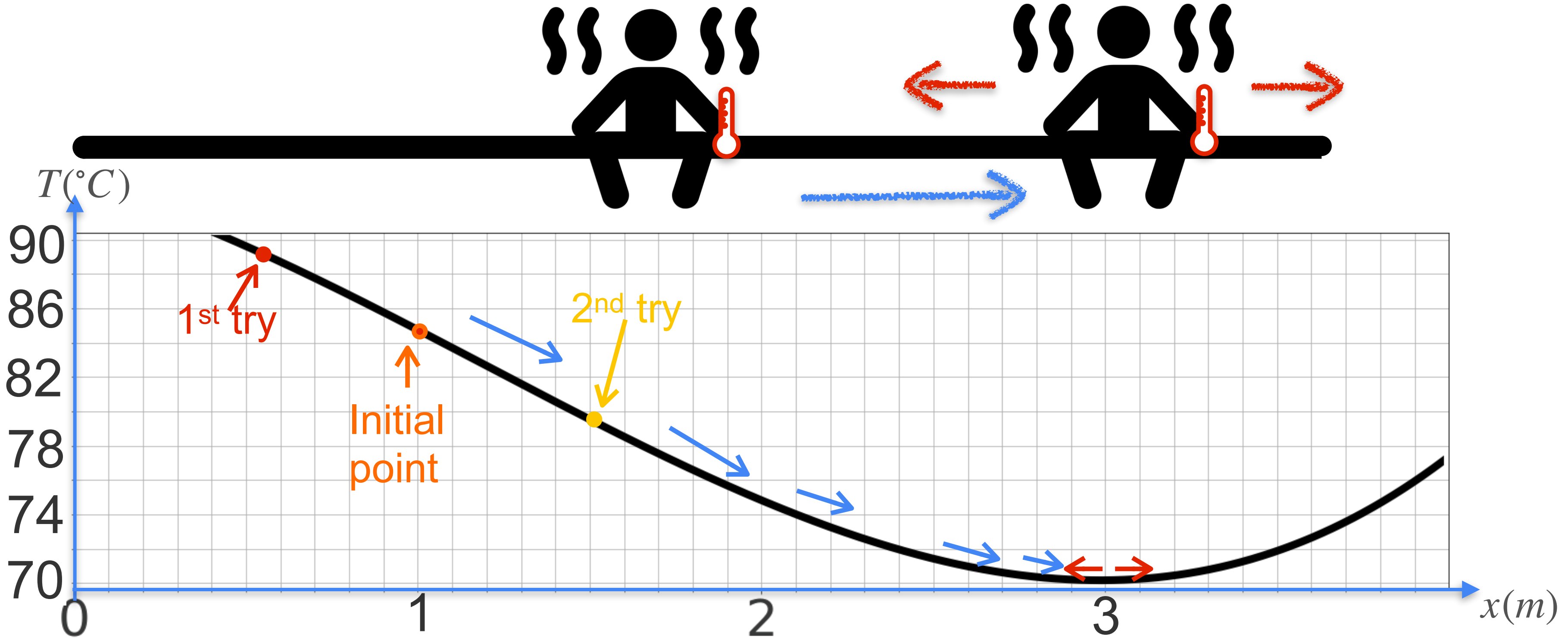

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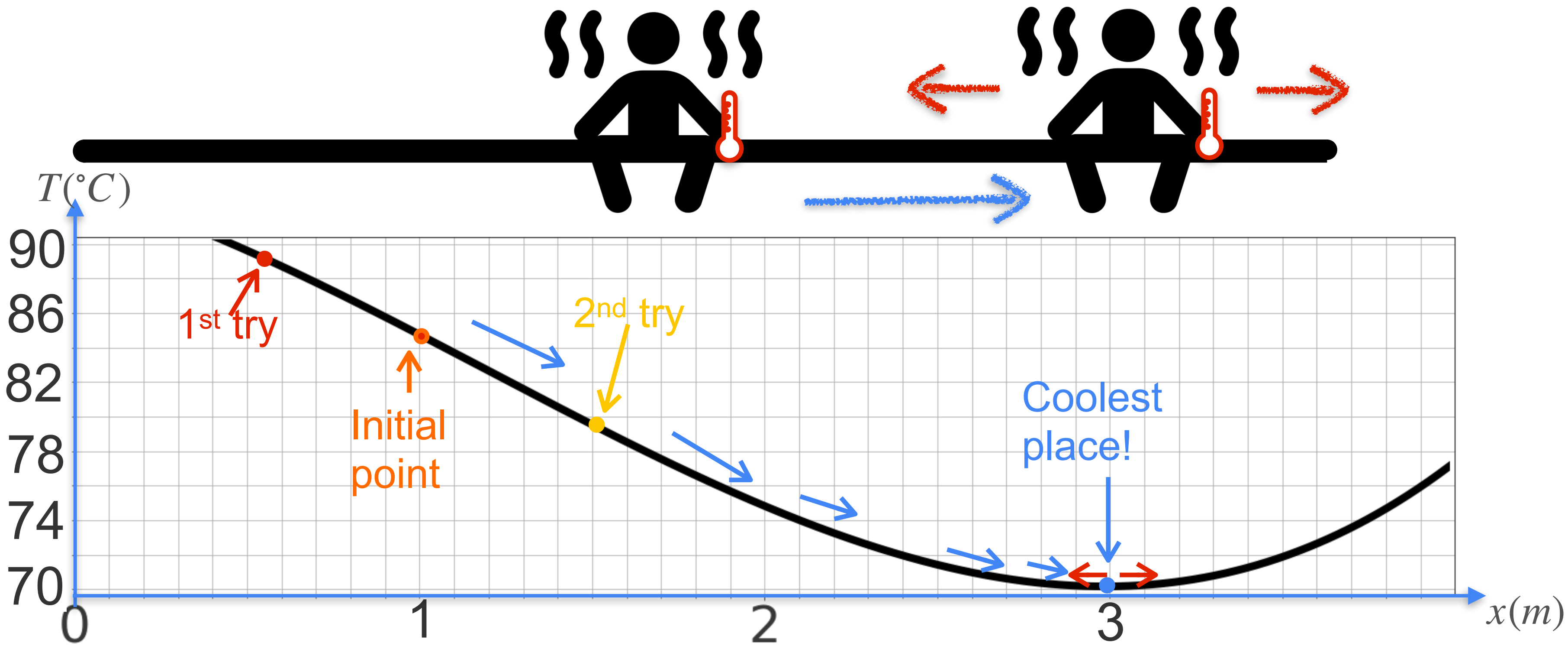

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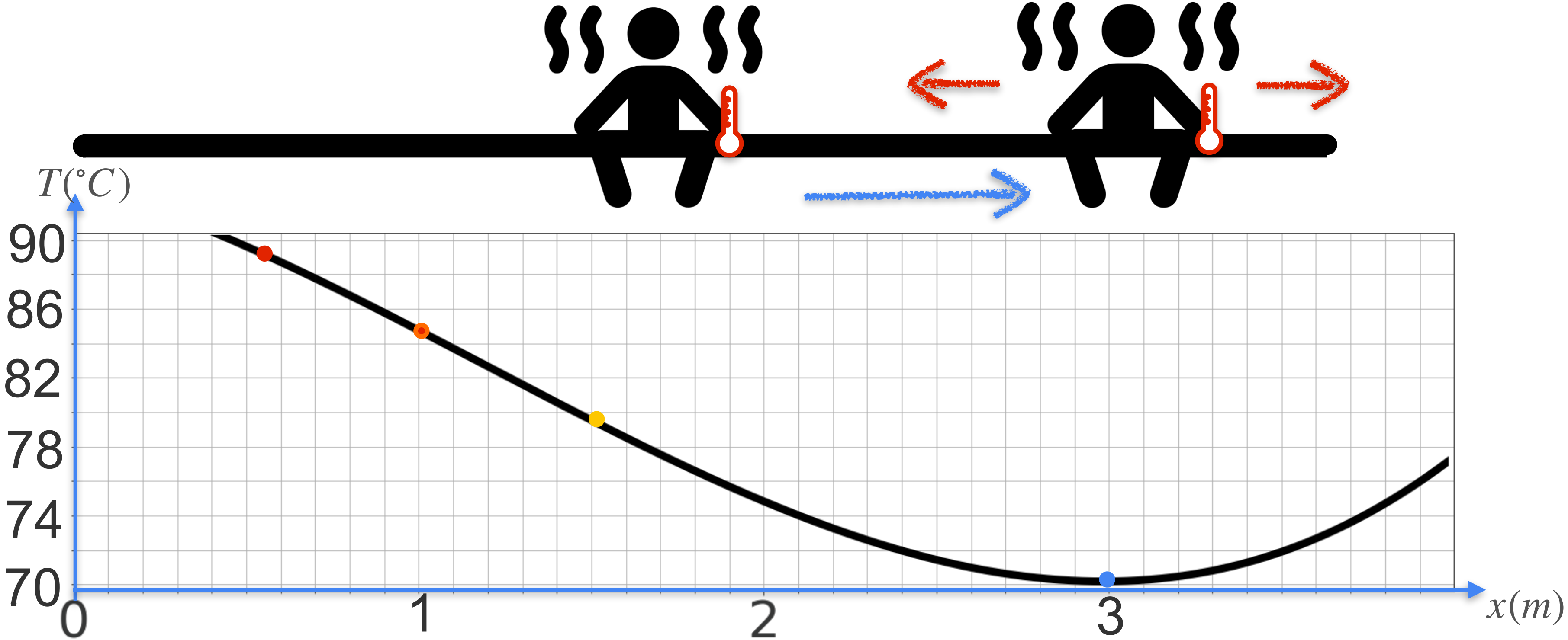

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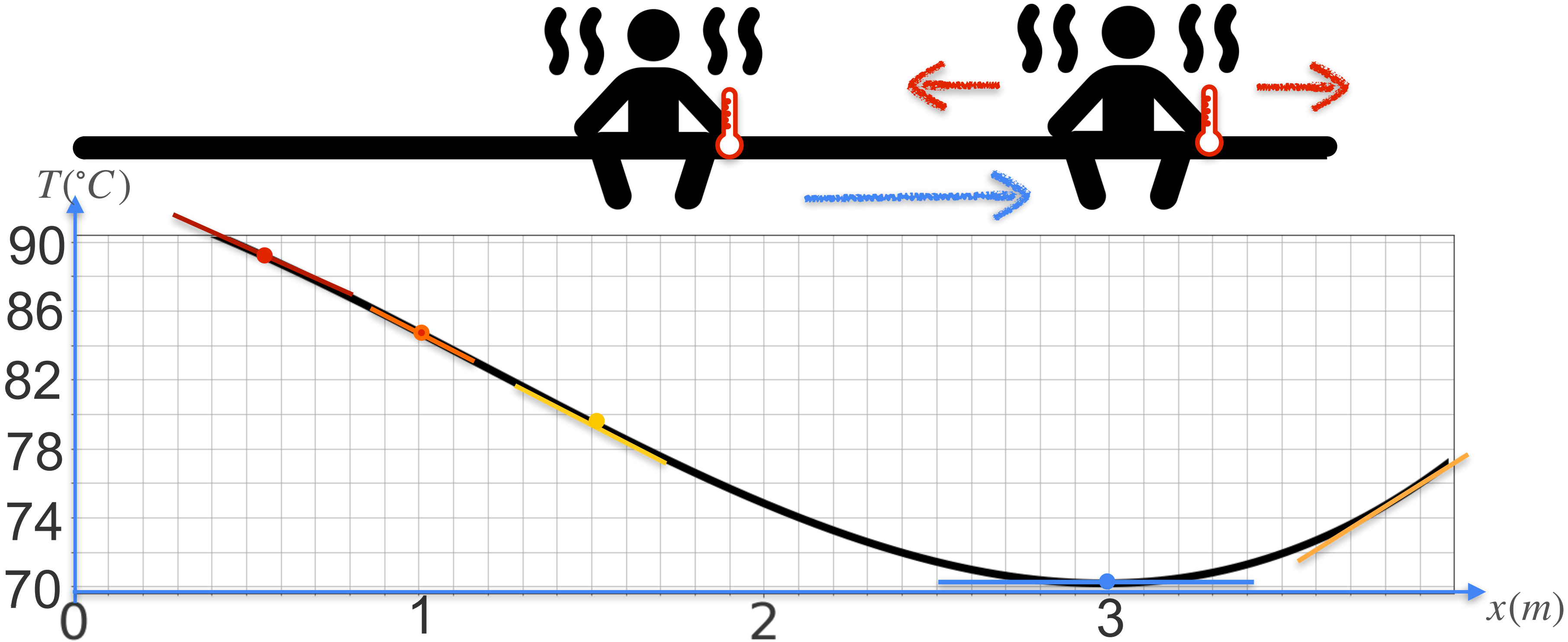

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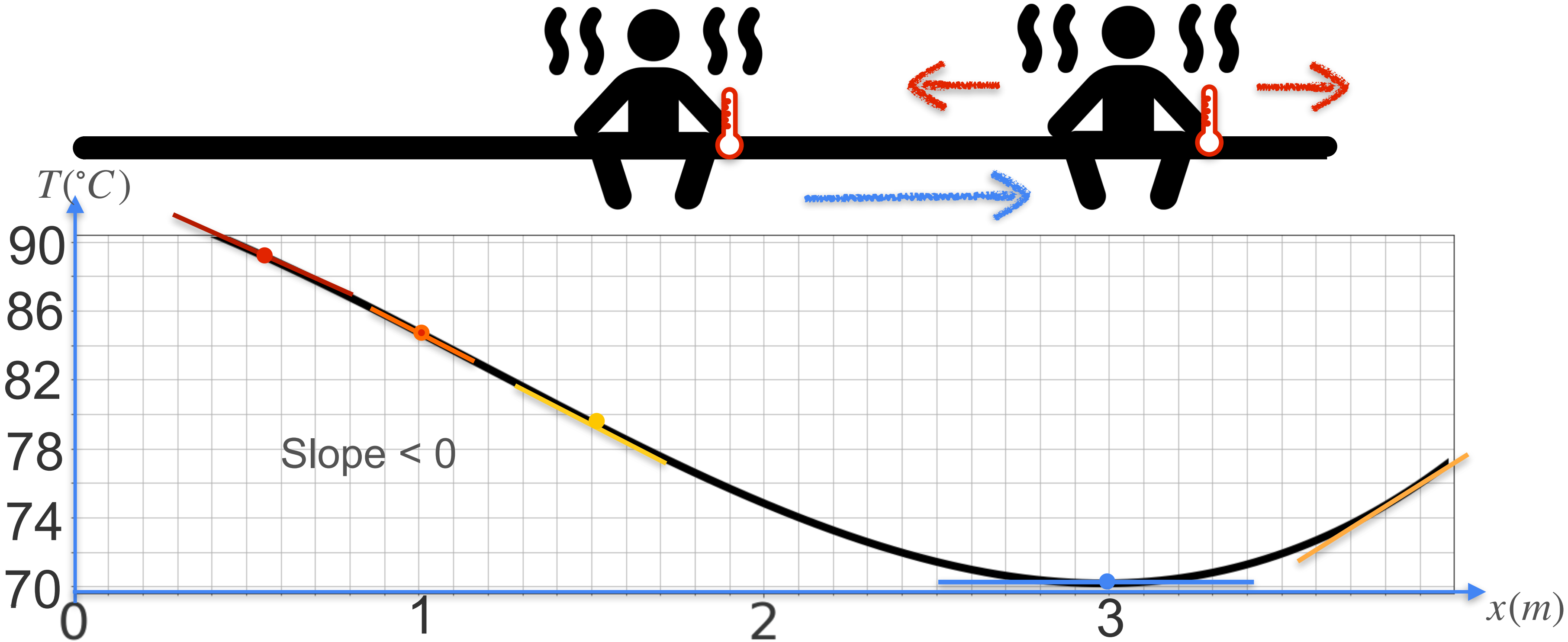

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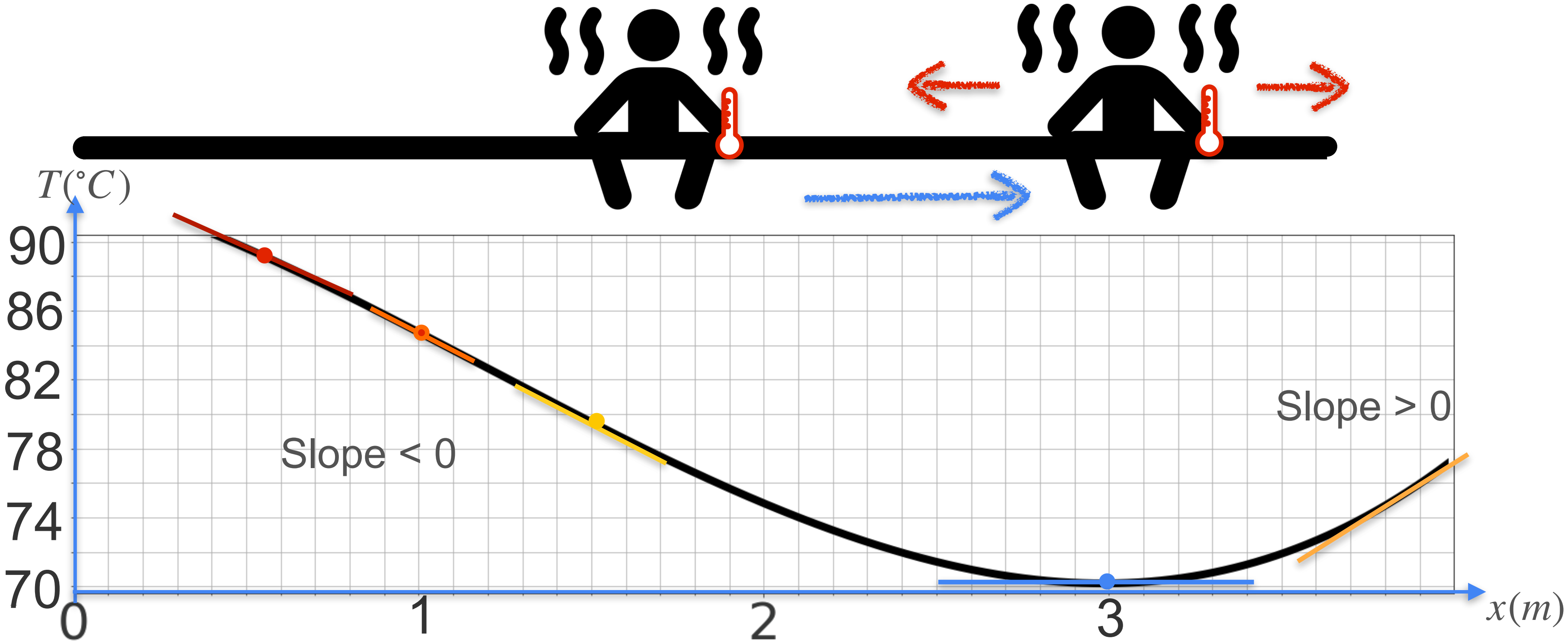

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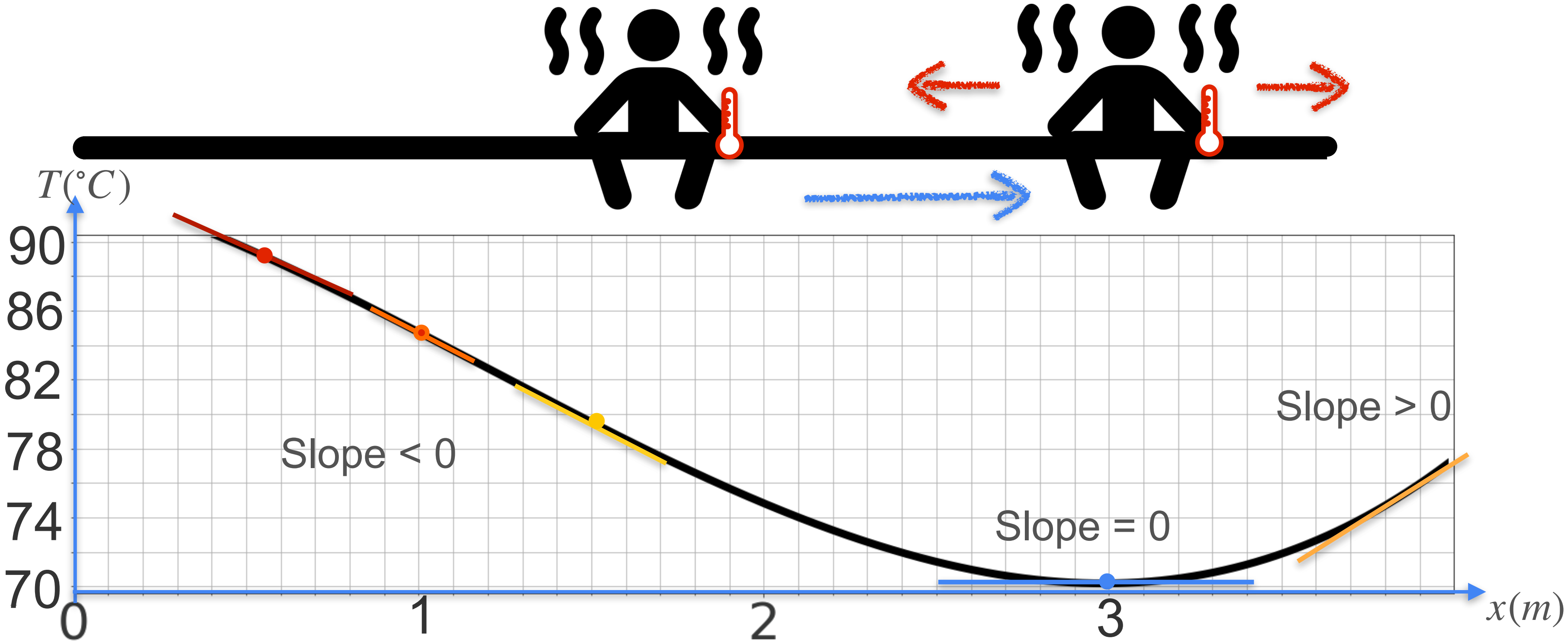
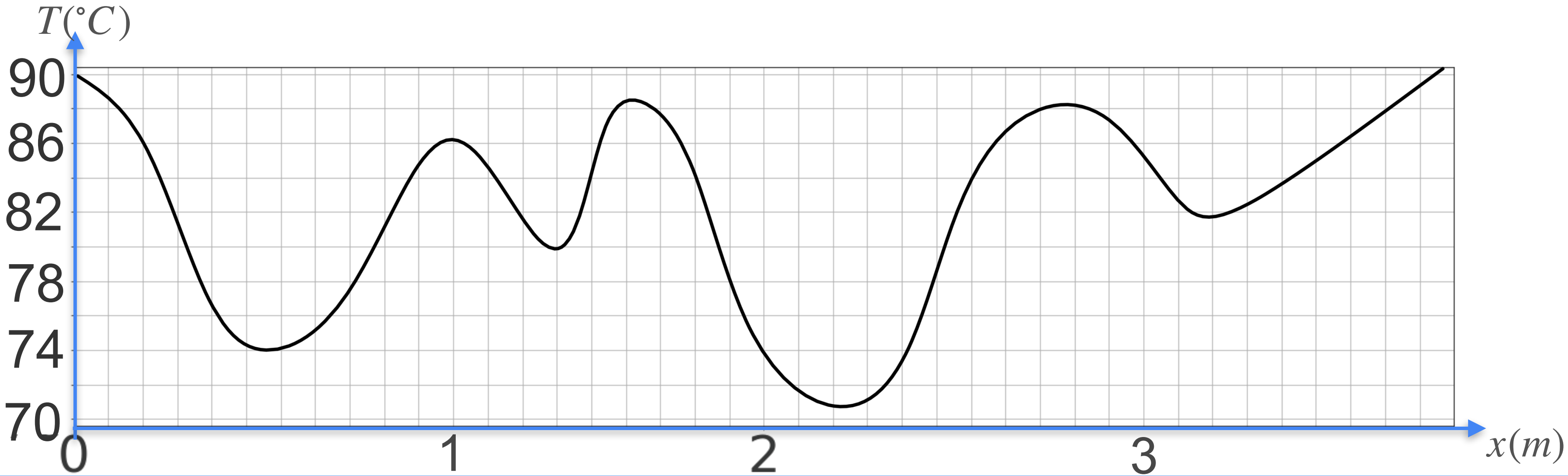
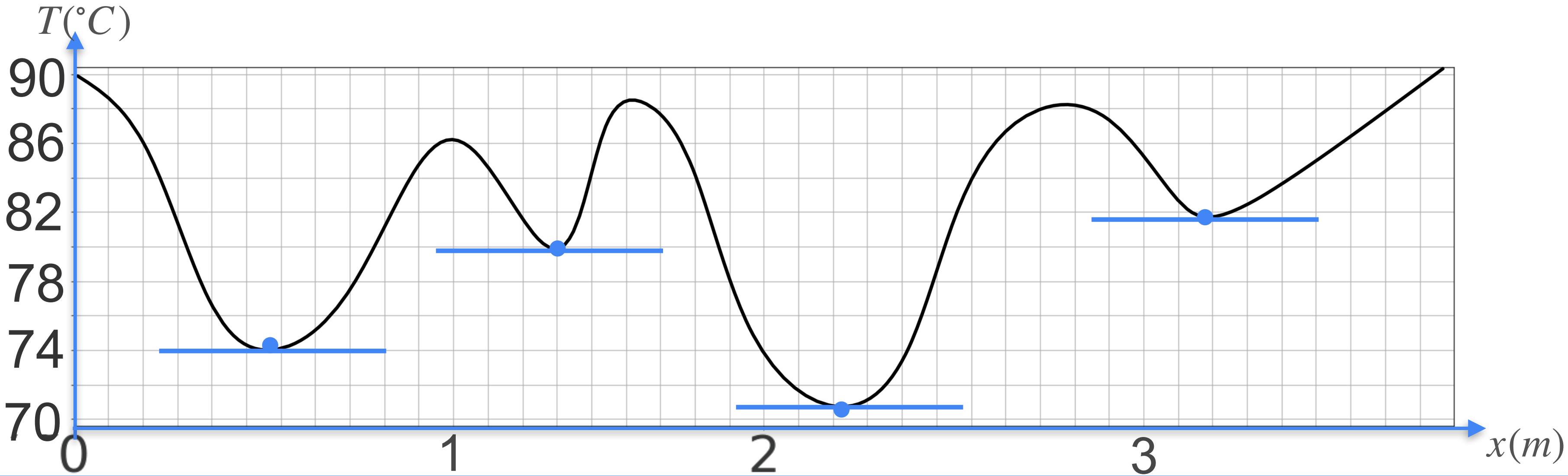


Multiple Minima

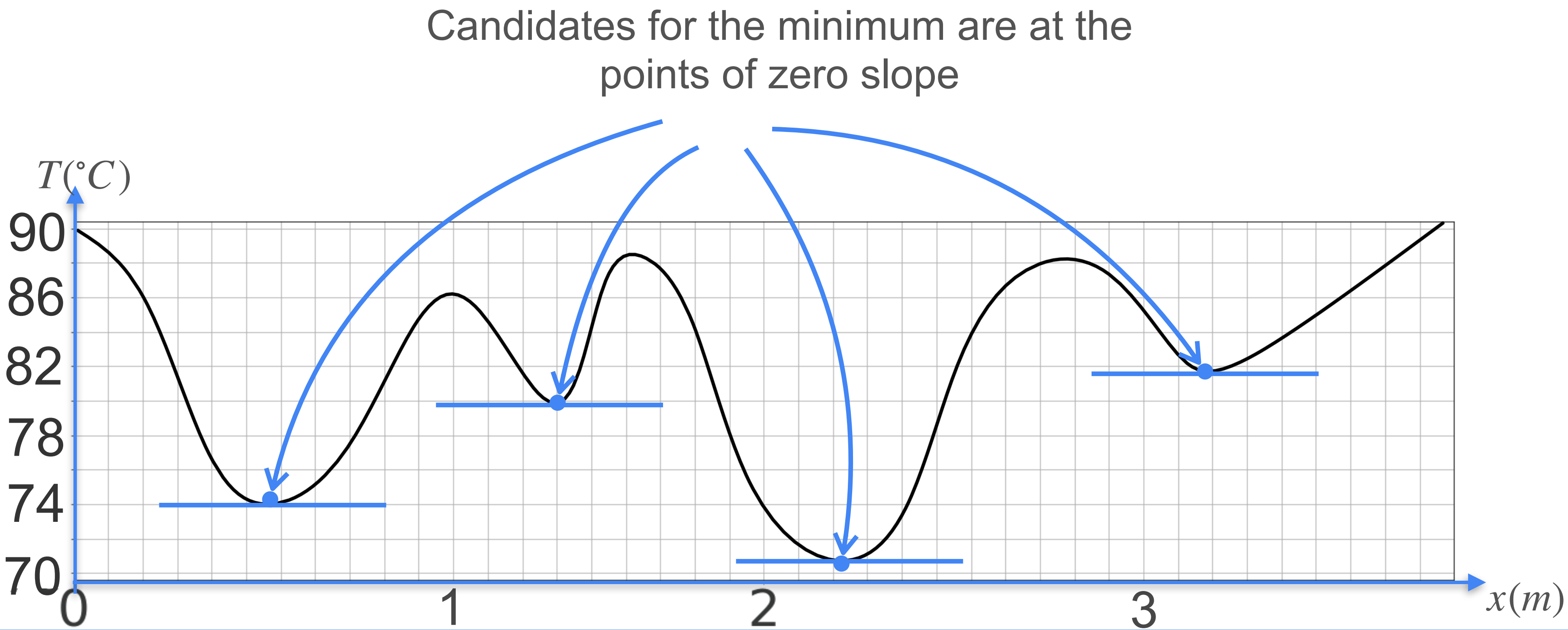
Multiple Minima



Multiple Minima

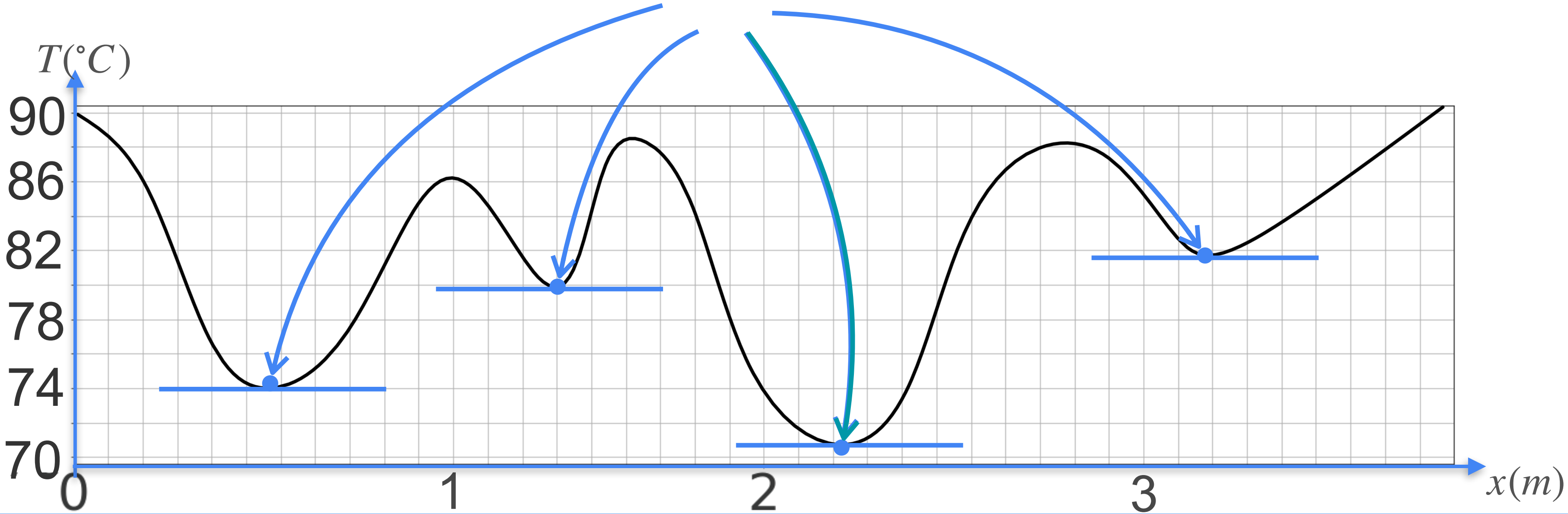


Multiple Minima



Multiple Minima

Candidates for the minimum are at the points of zero slope



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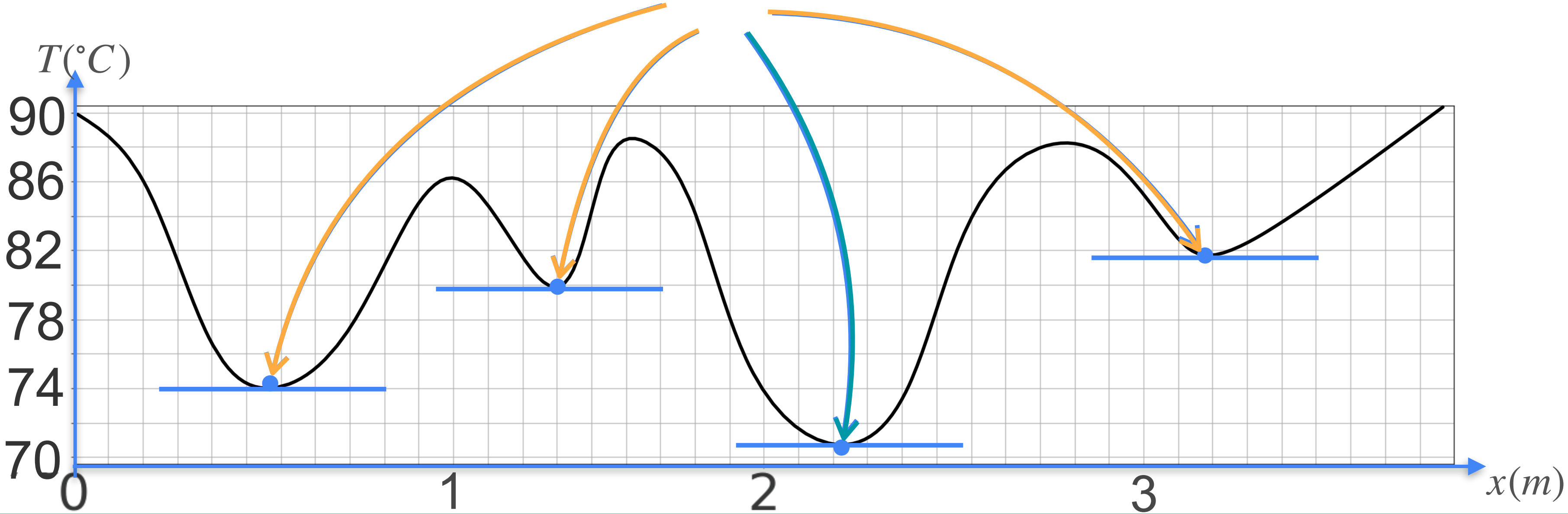

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Derivatives and Optimization

Optimization of squared loss: The one powerline problem

Cost Function Motivation

Cost Function Motivation

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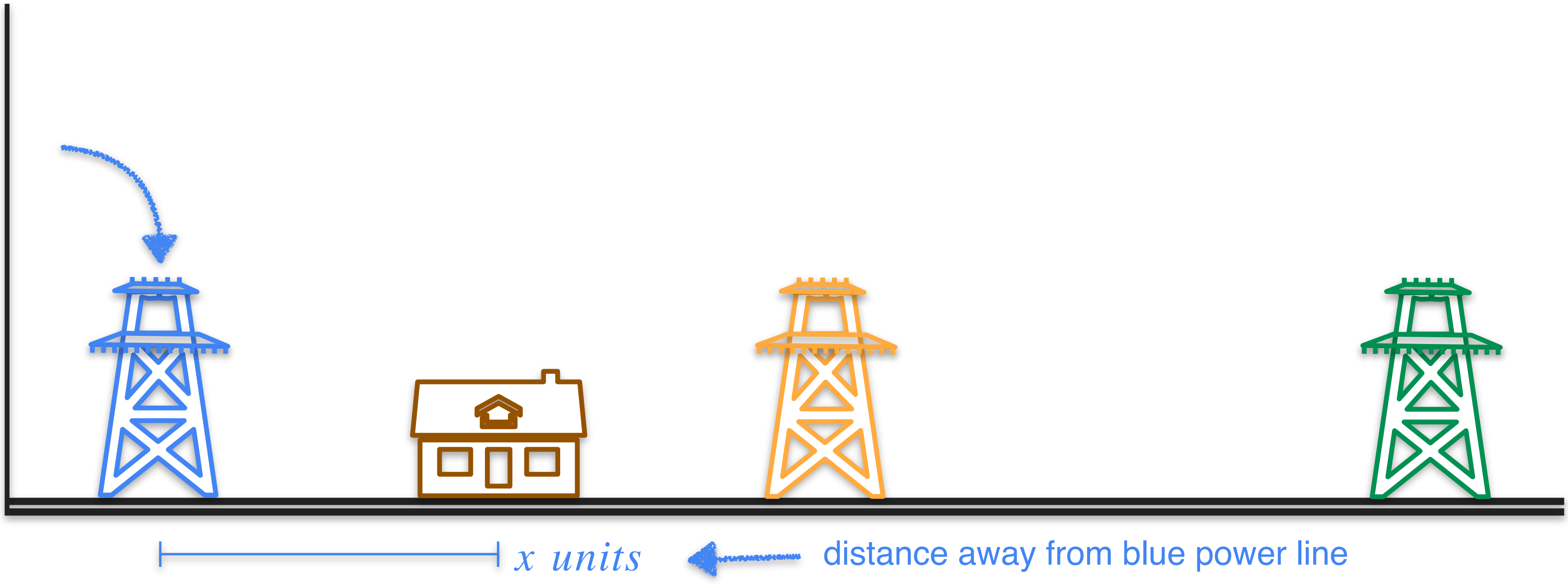

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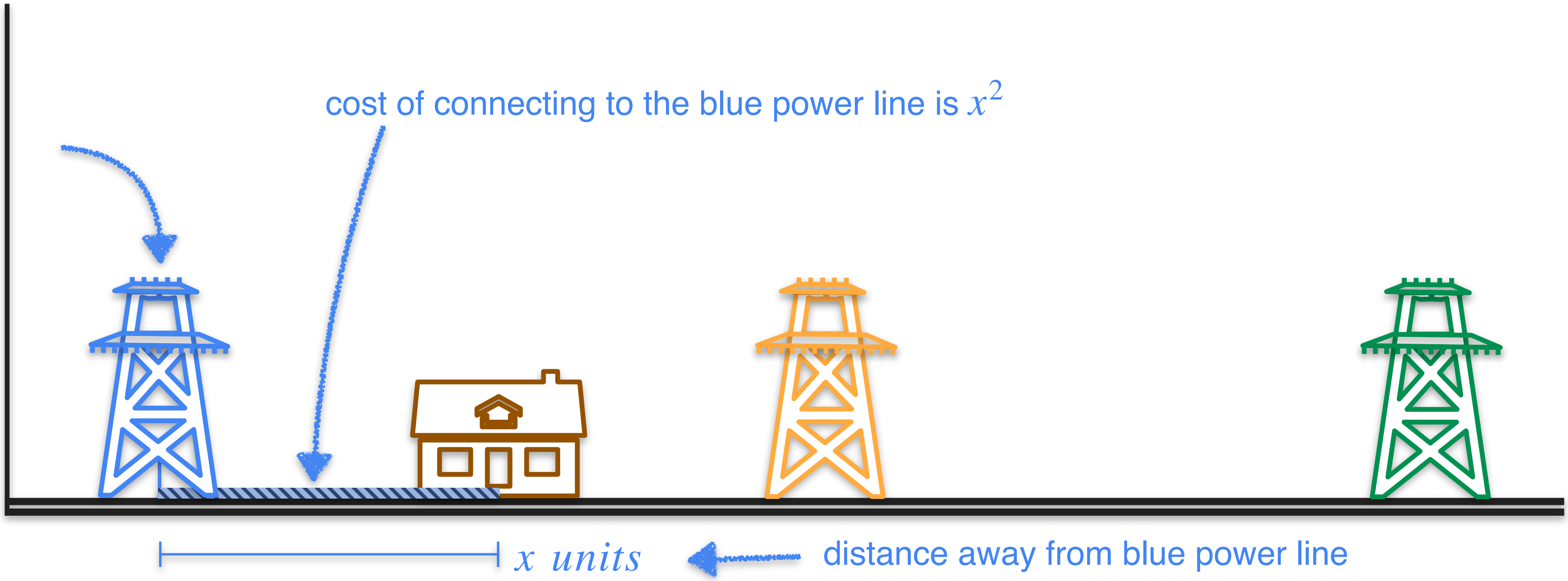

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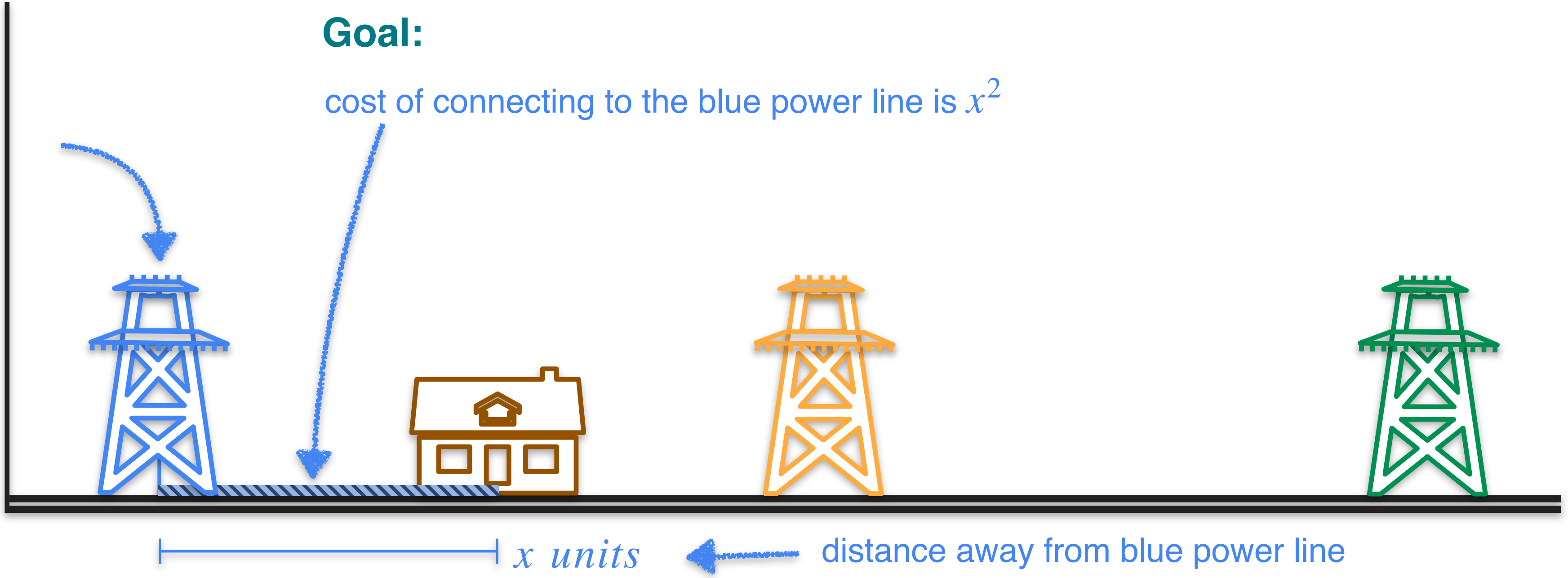

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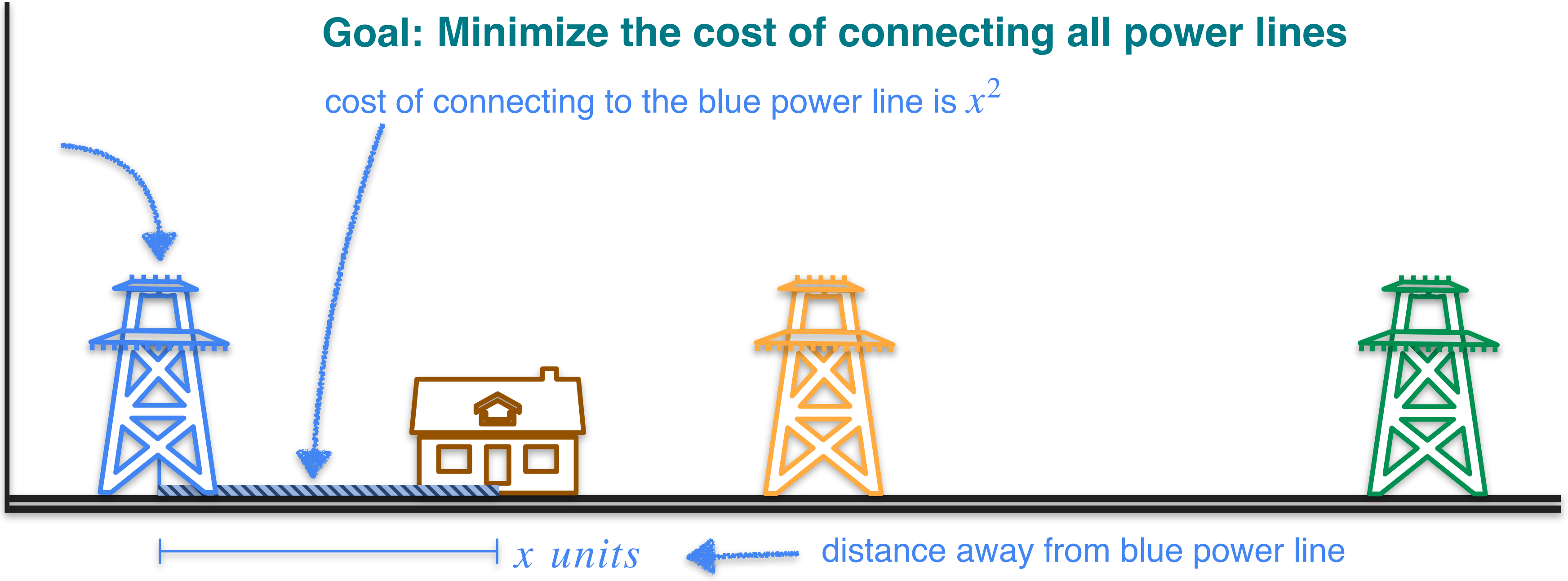

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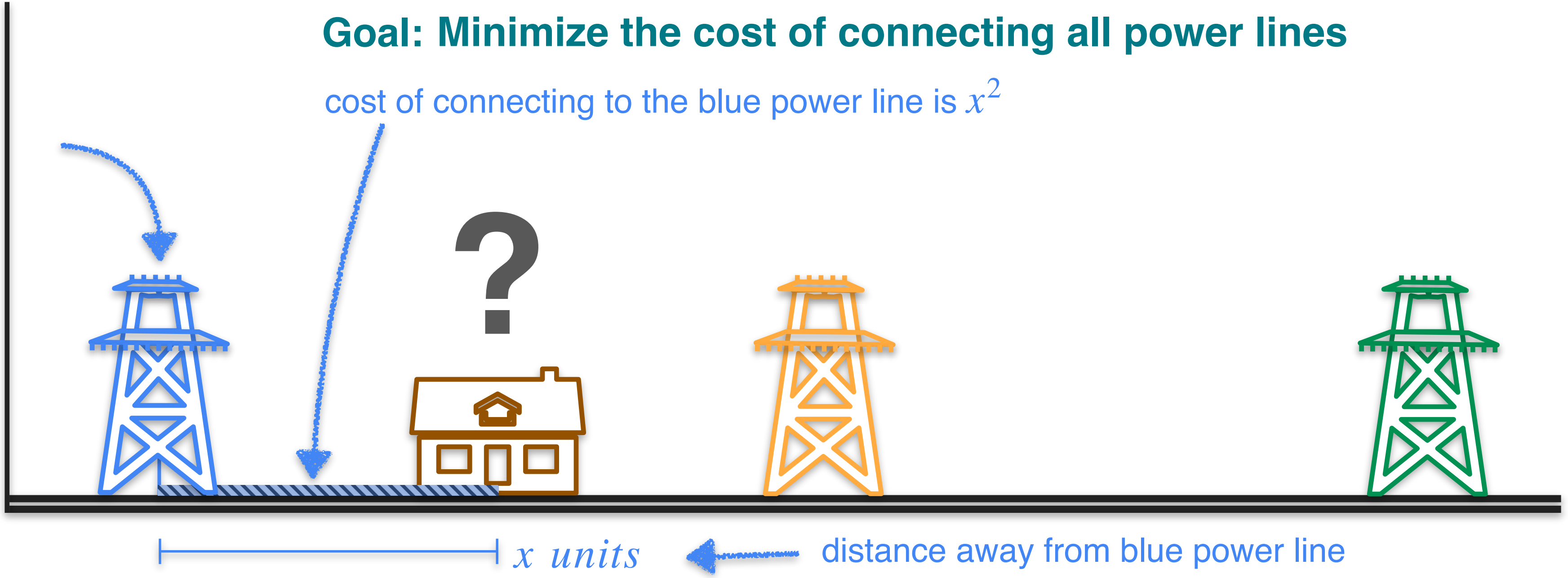

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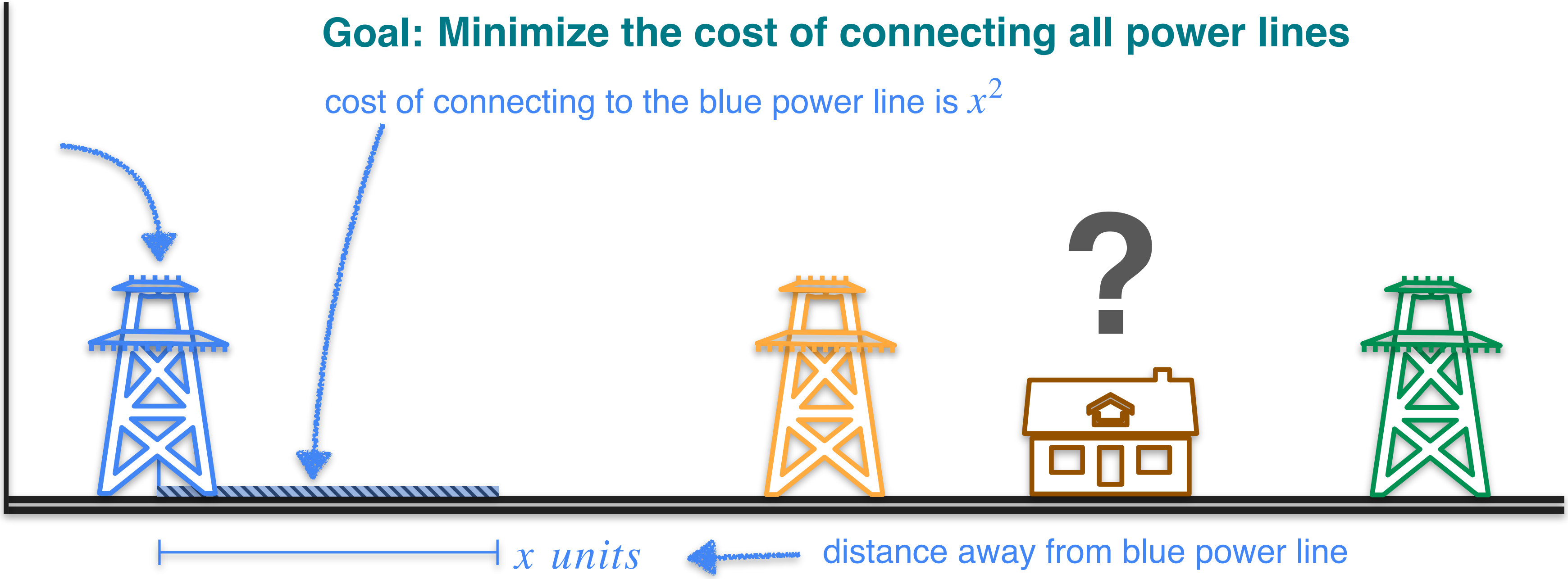

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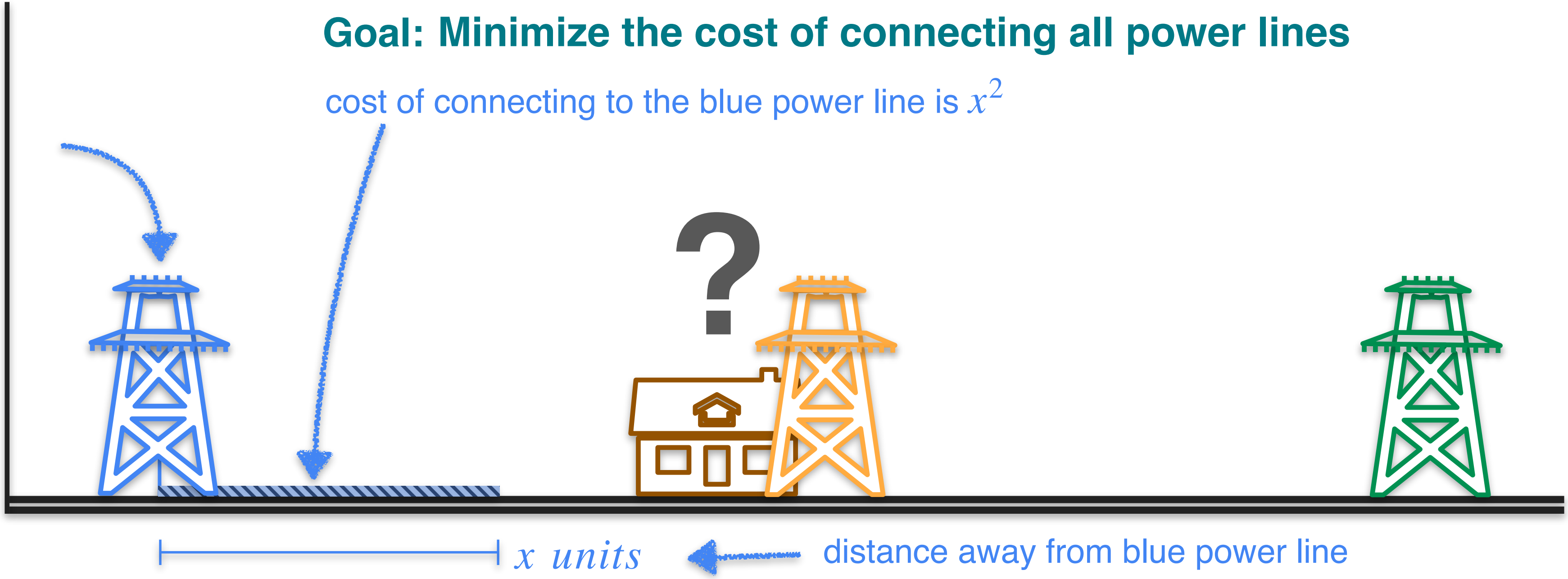
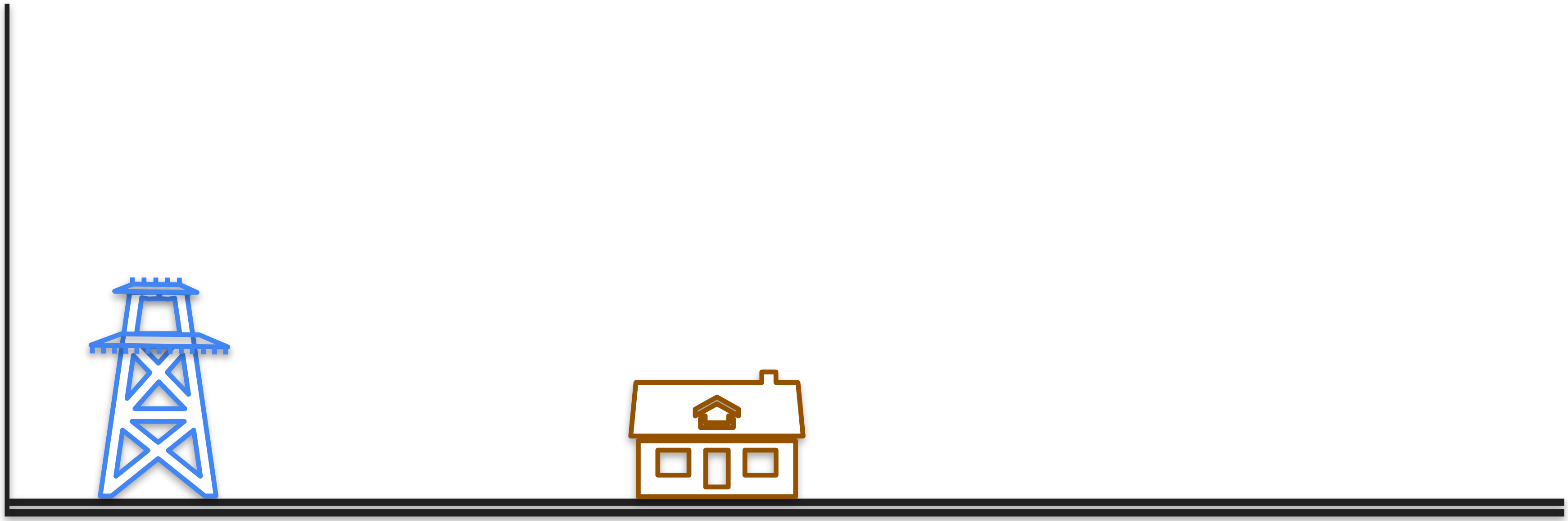


One Power Line Problem



One Power Line Problem

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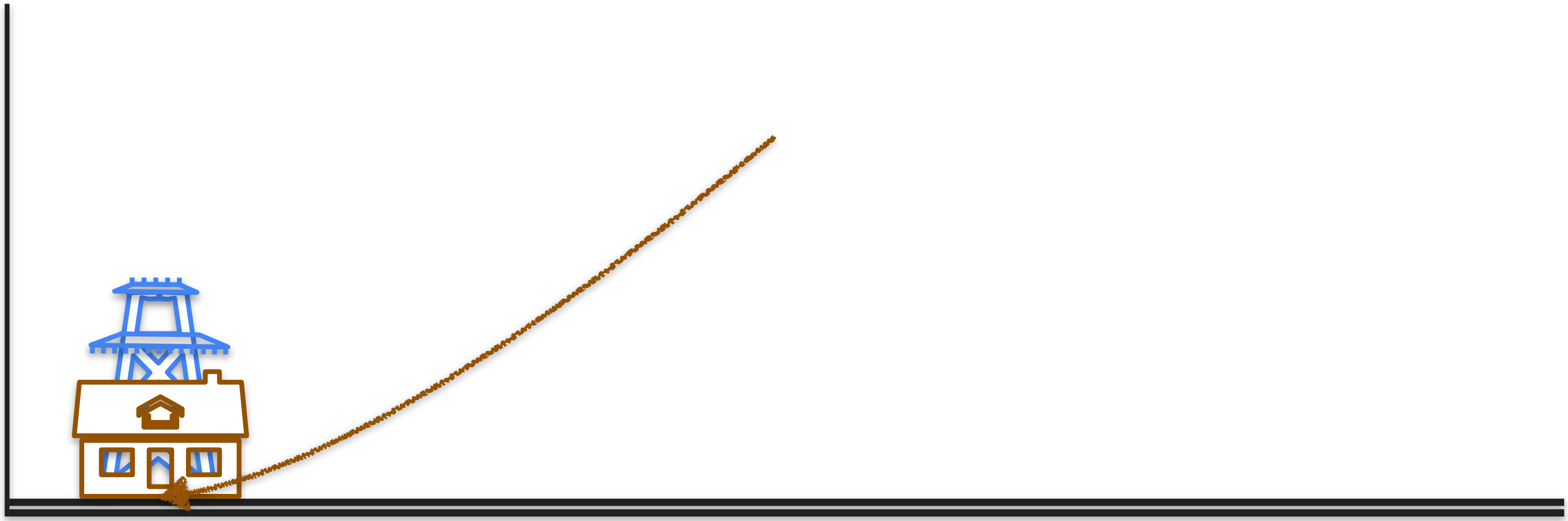

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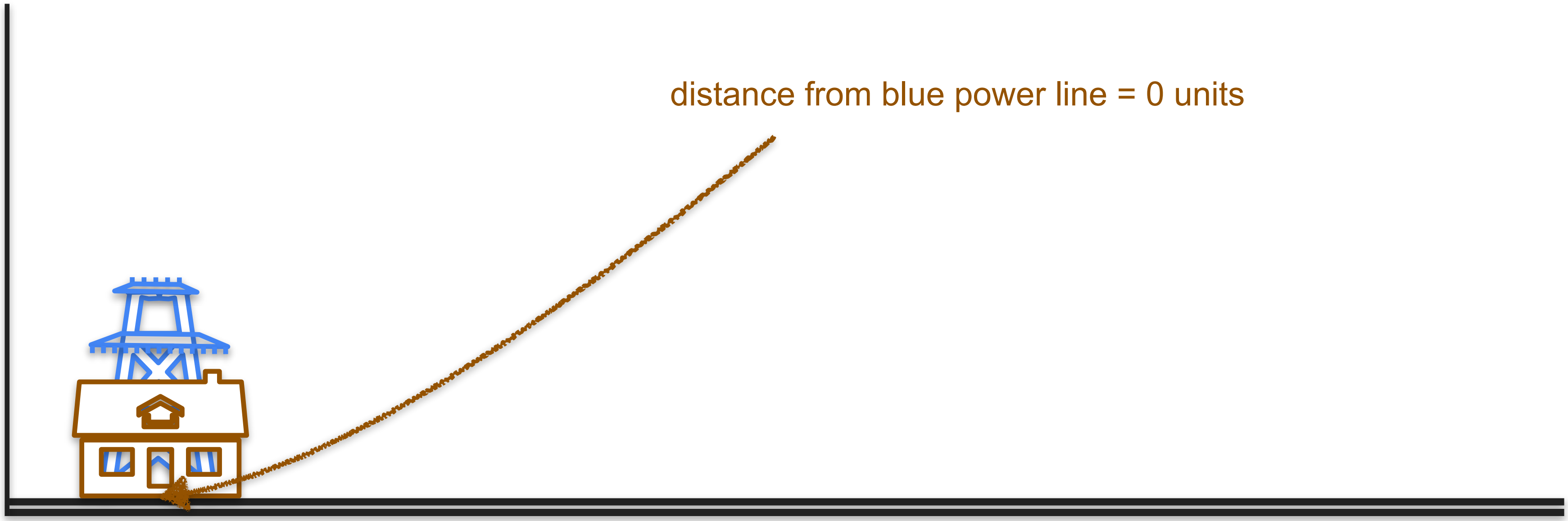

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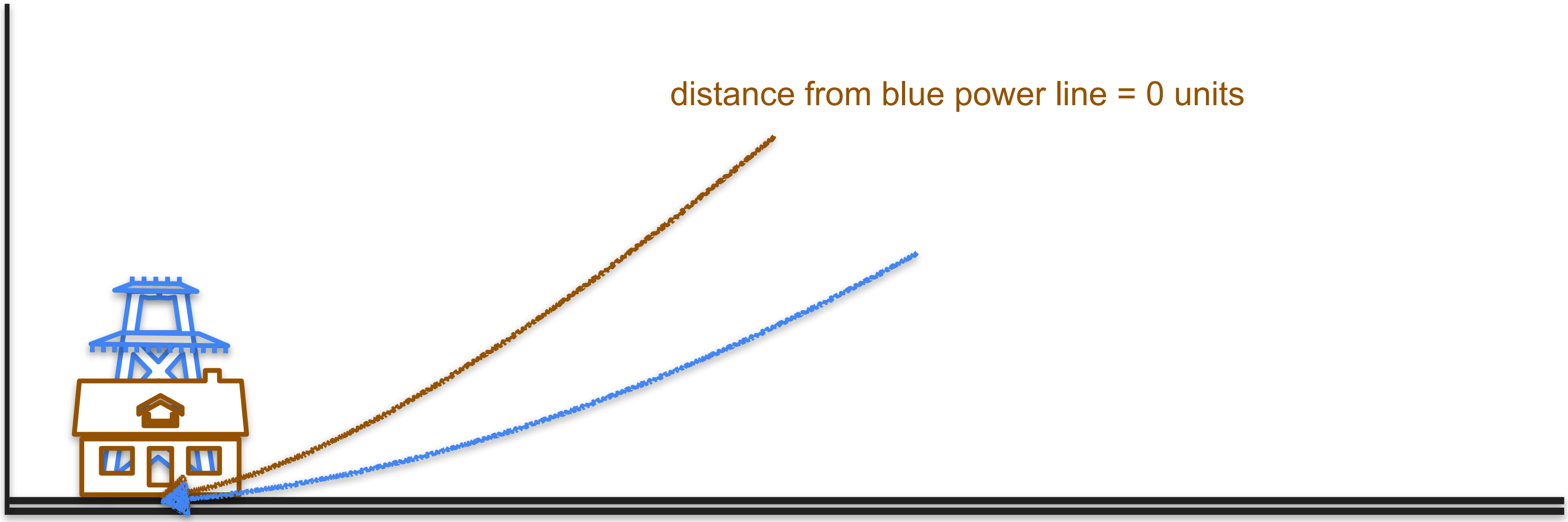

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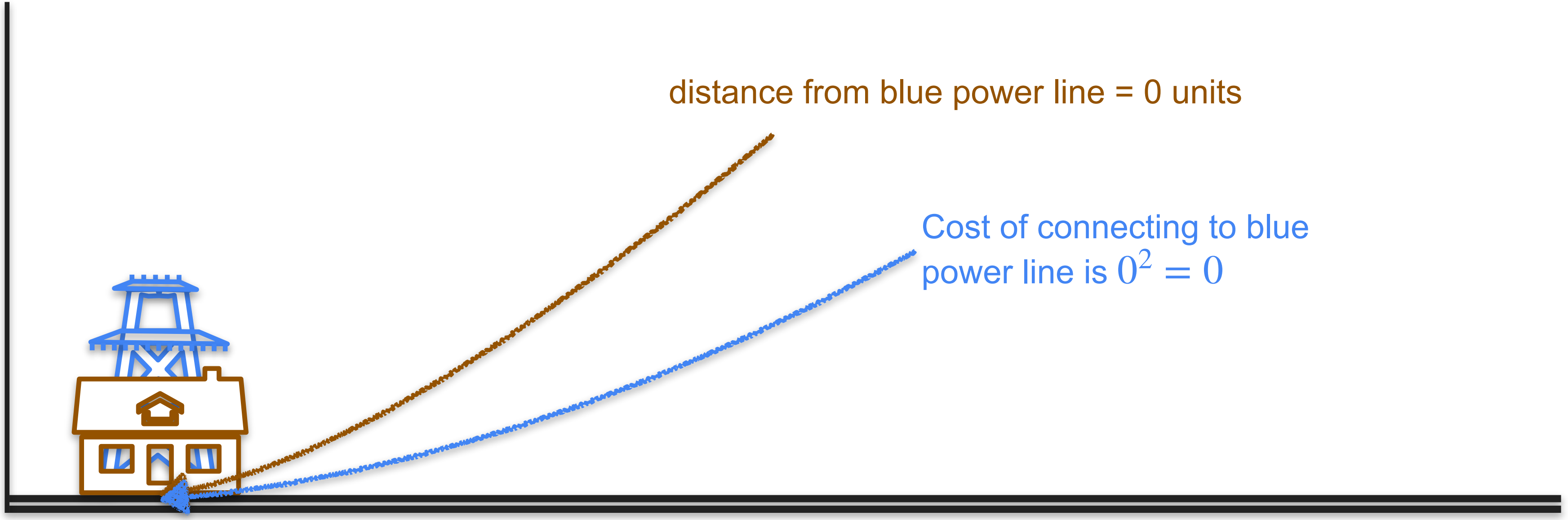

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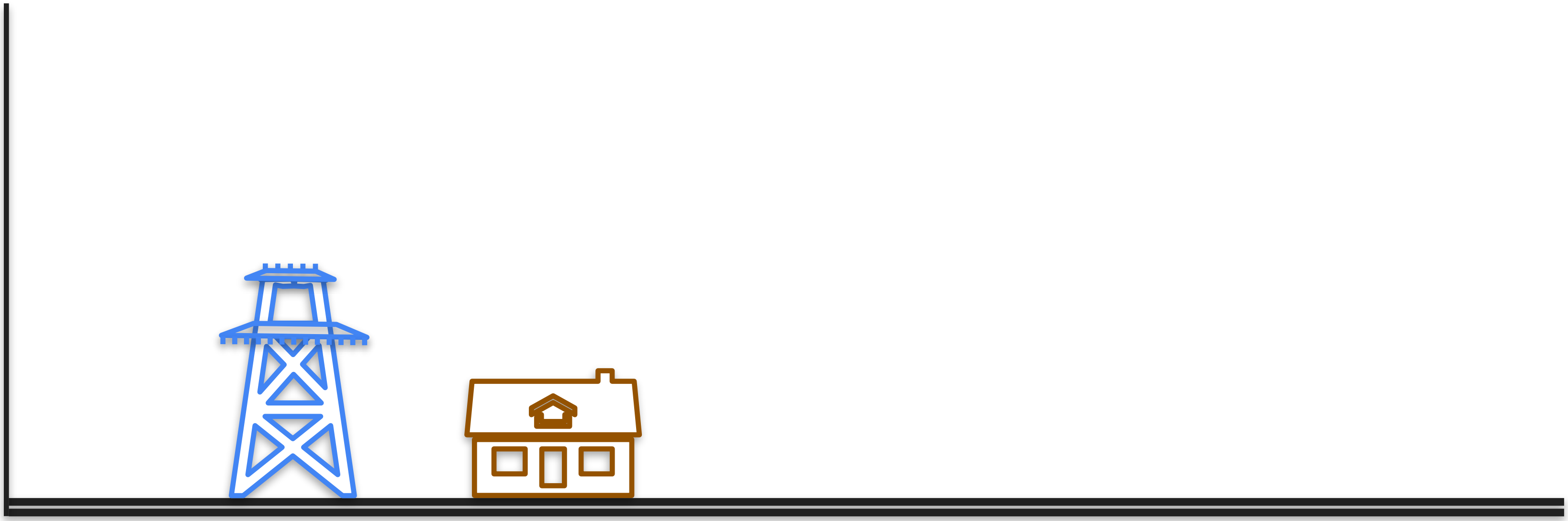
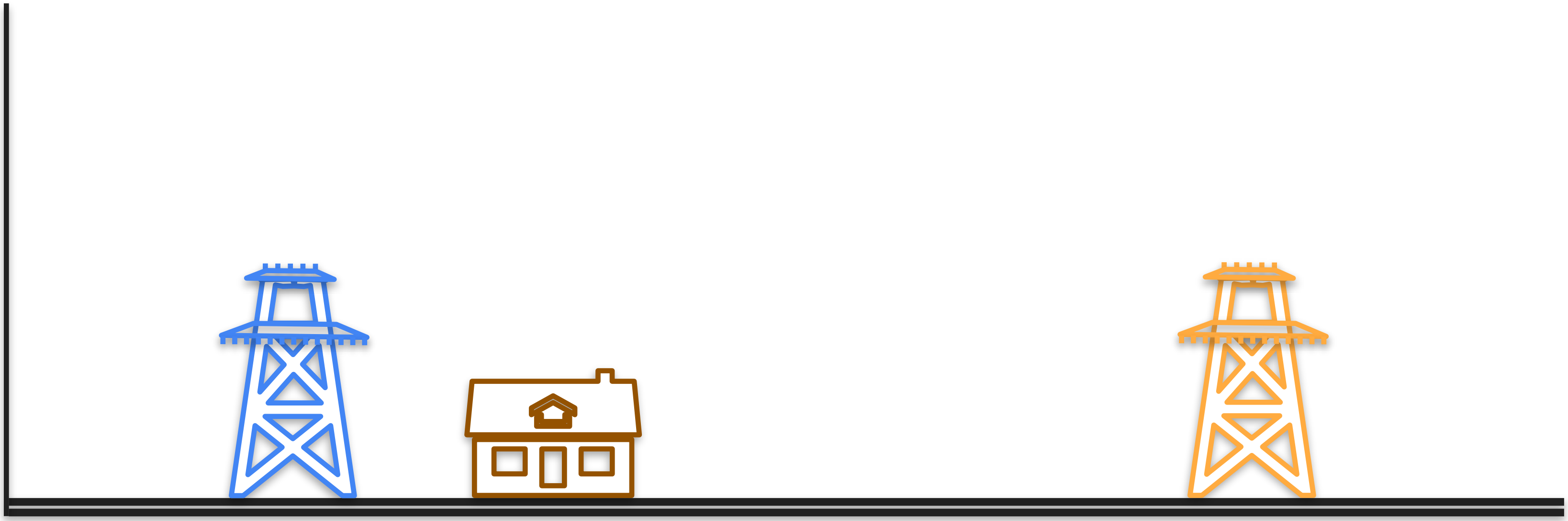
Derivatives and Optimization

Optimization of squared loss: The two powerline problem

Two Power Line Problem



Two Power Line Problem



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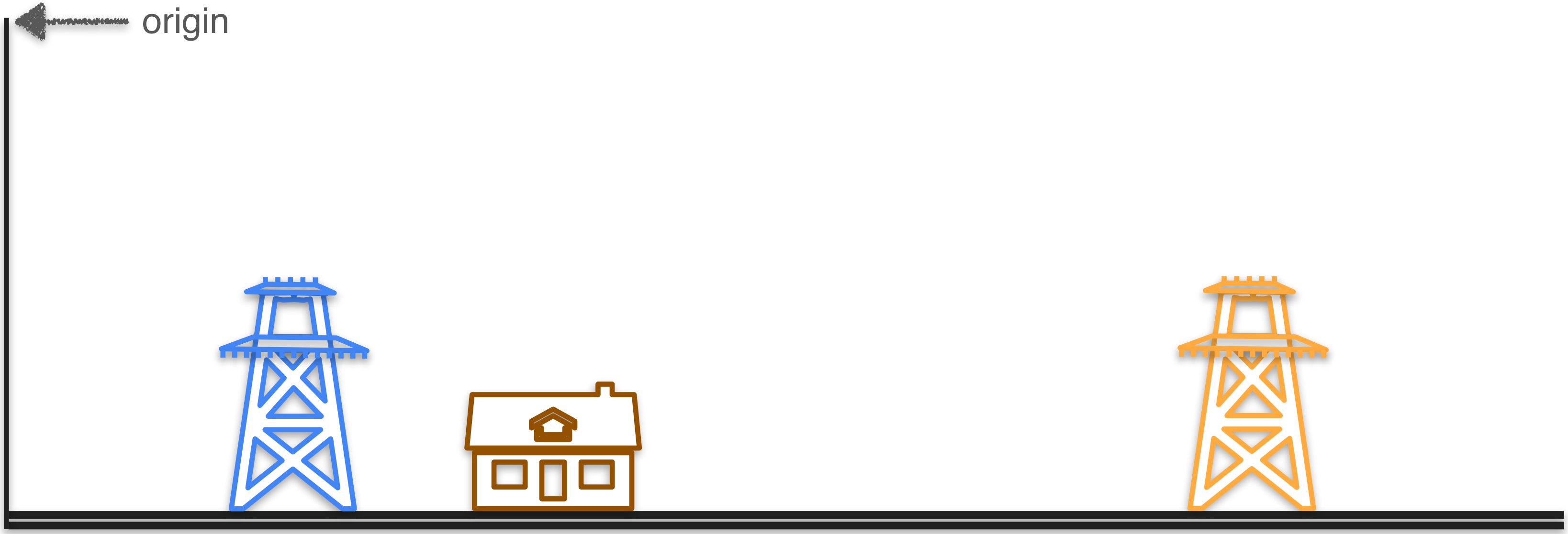

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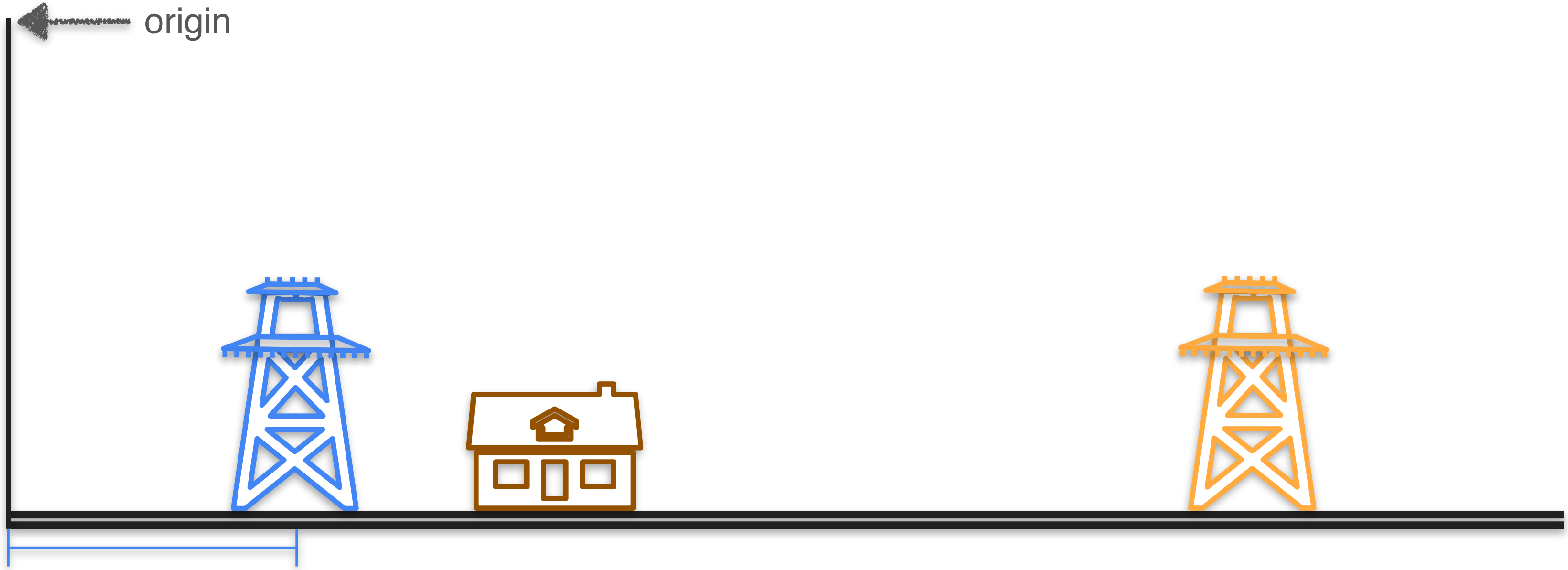

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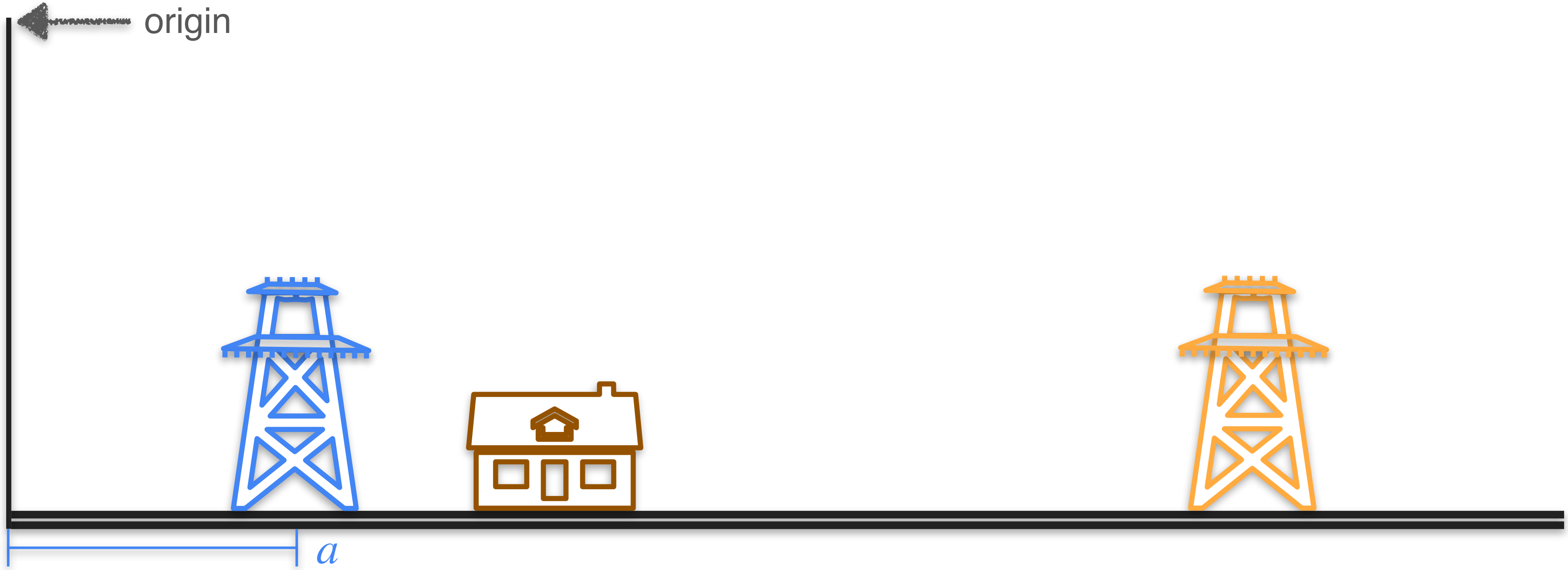

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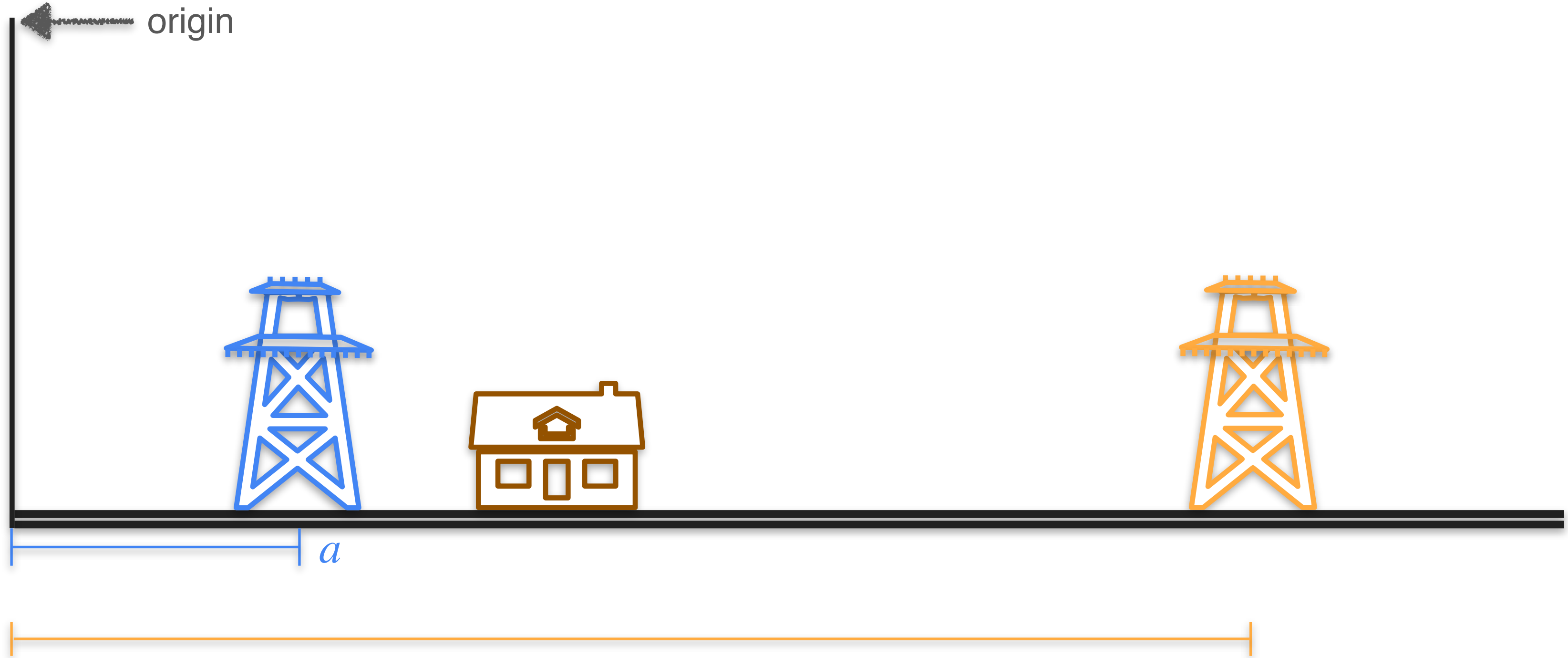

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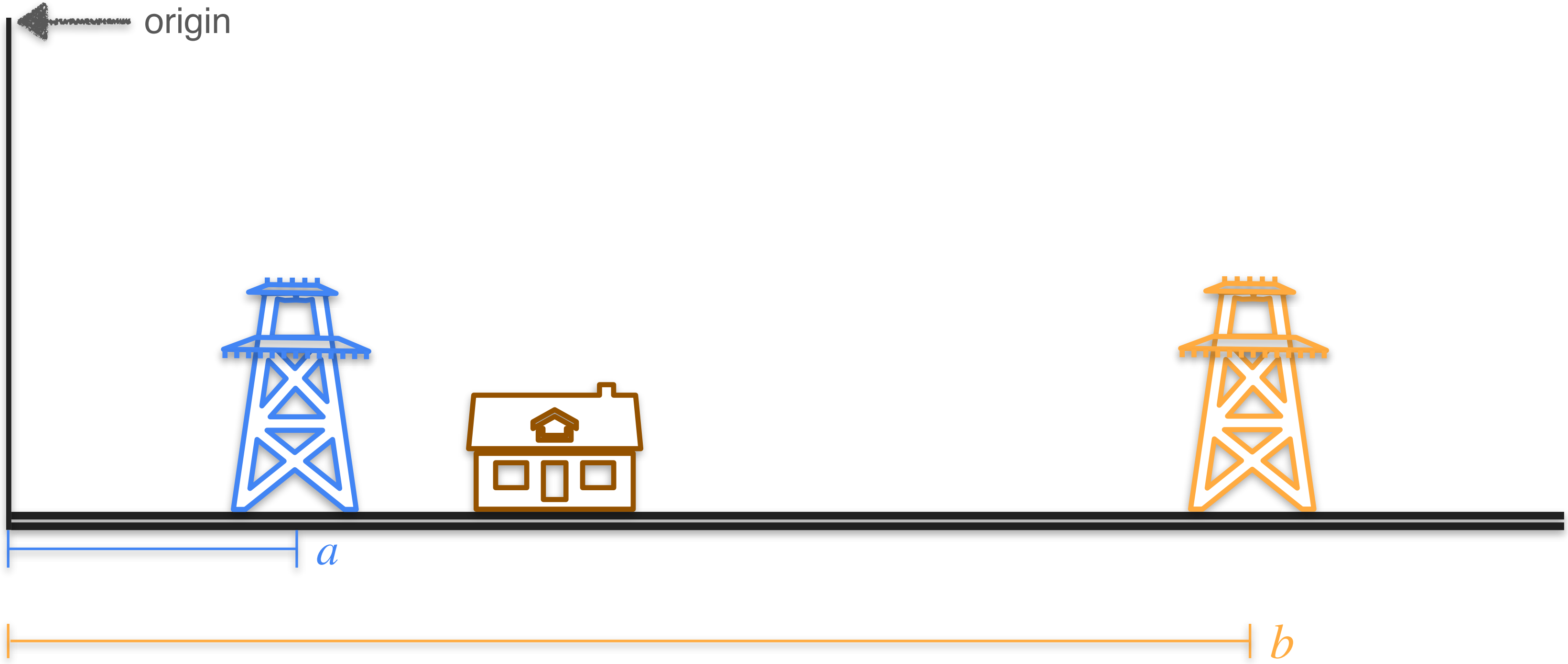

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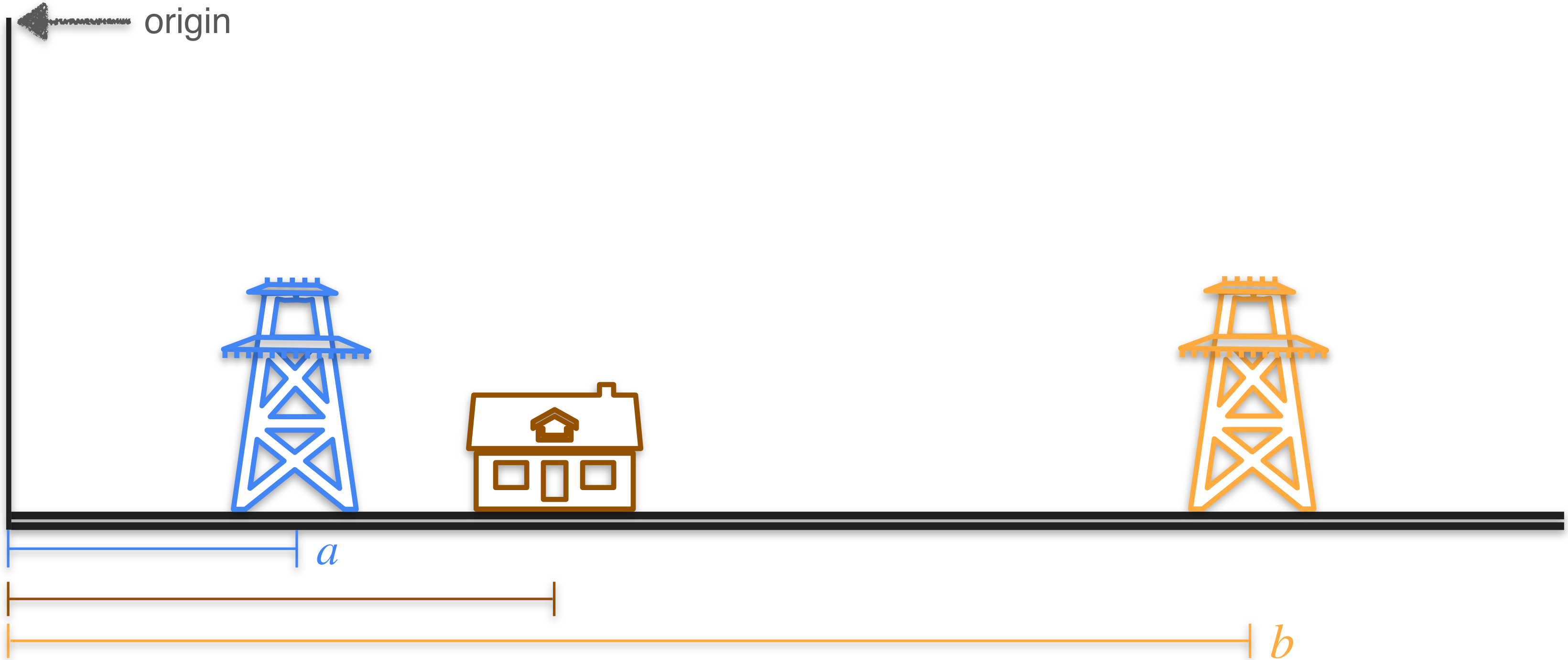

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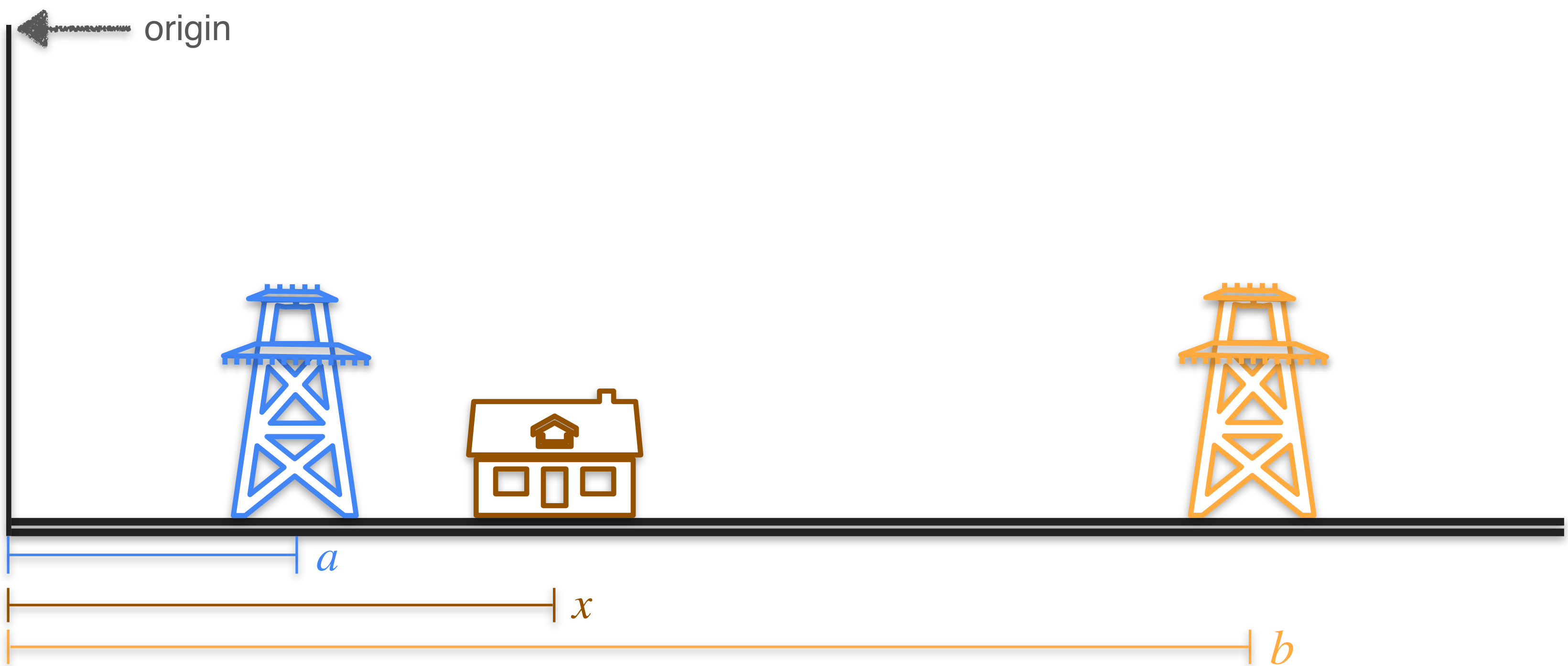

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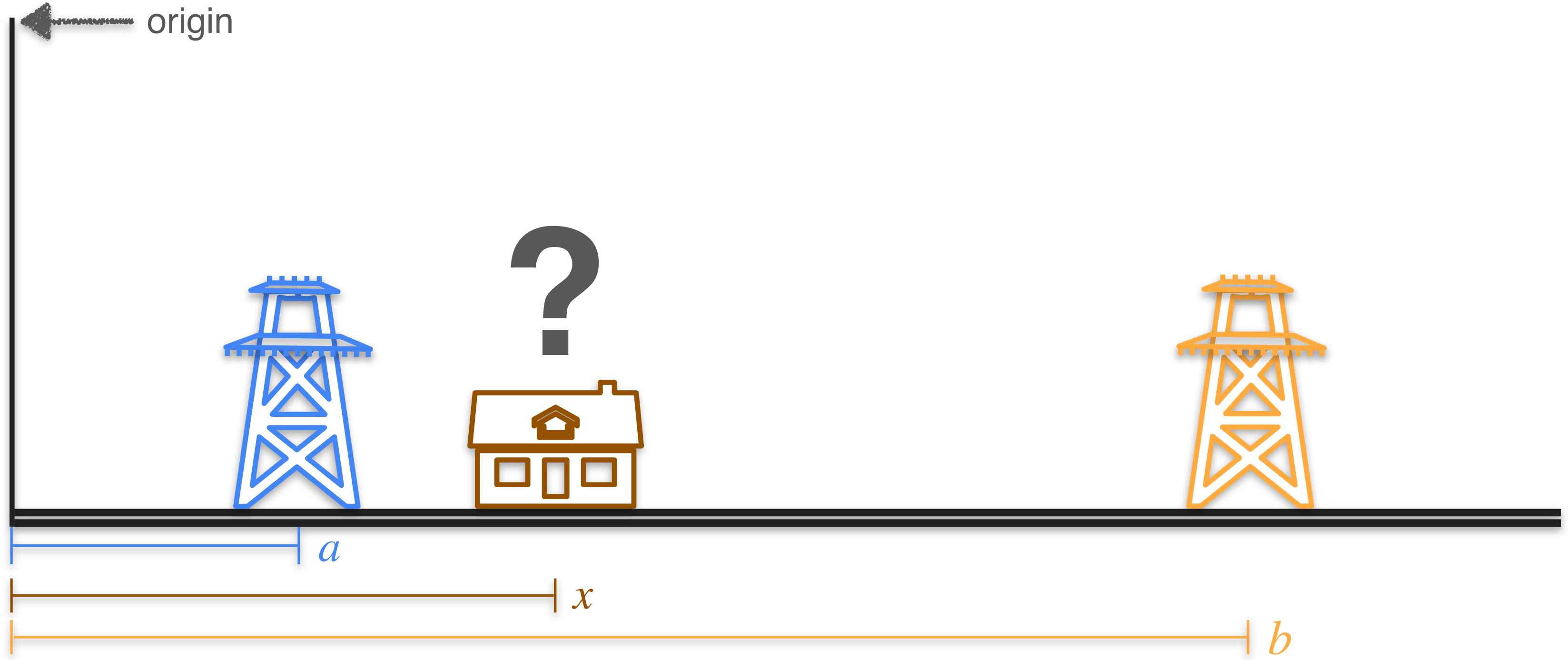

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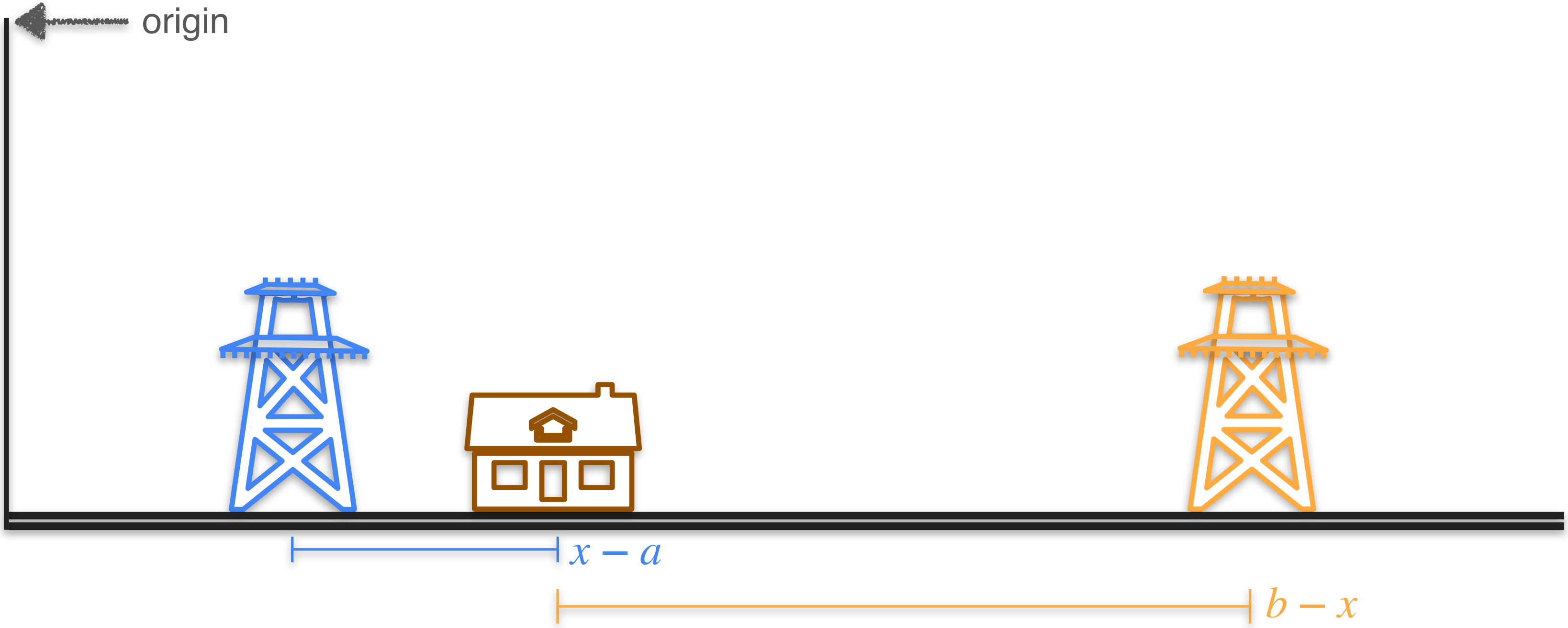

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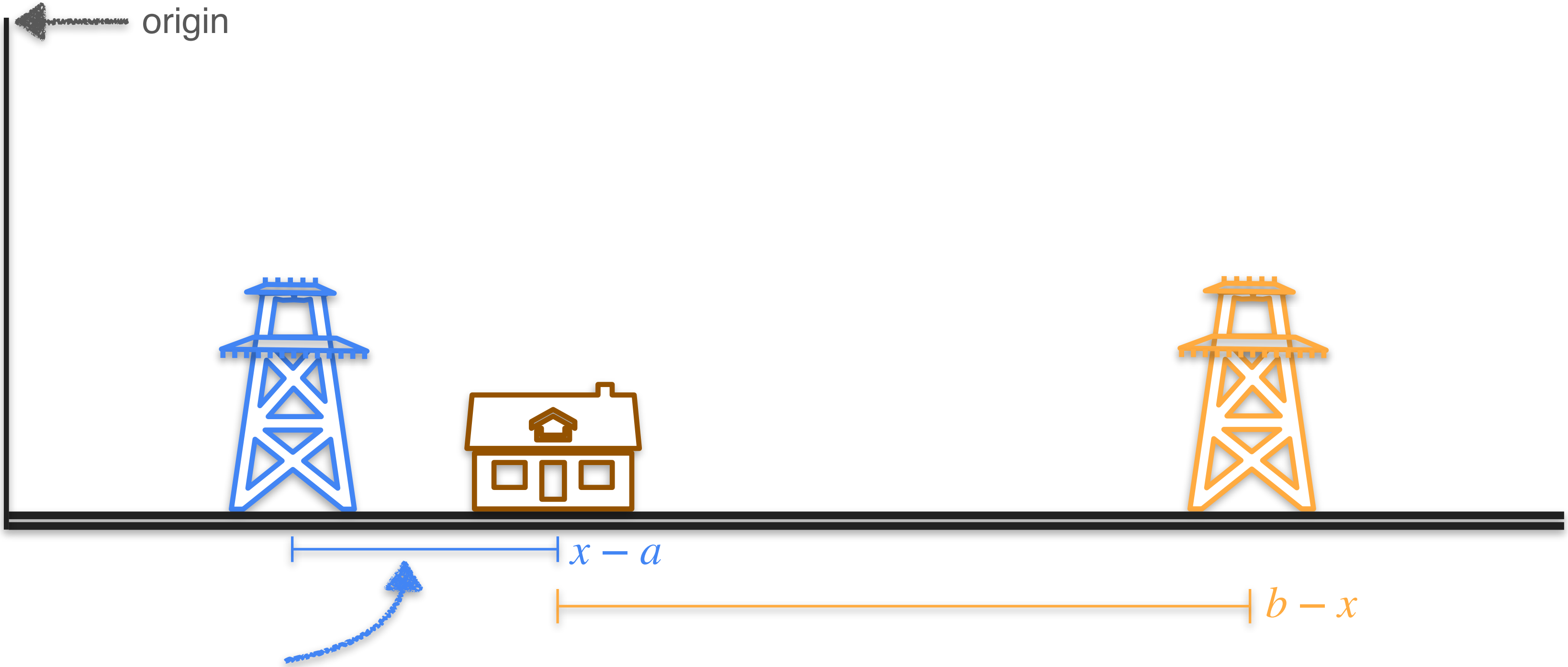

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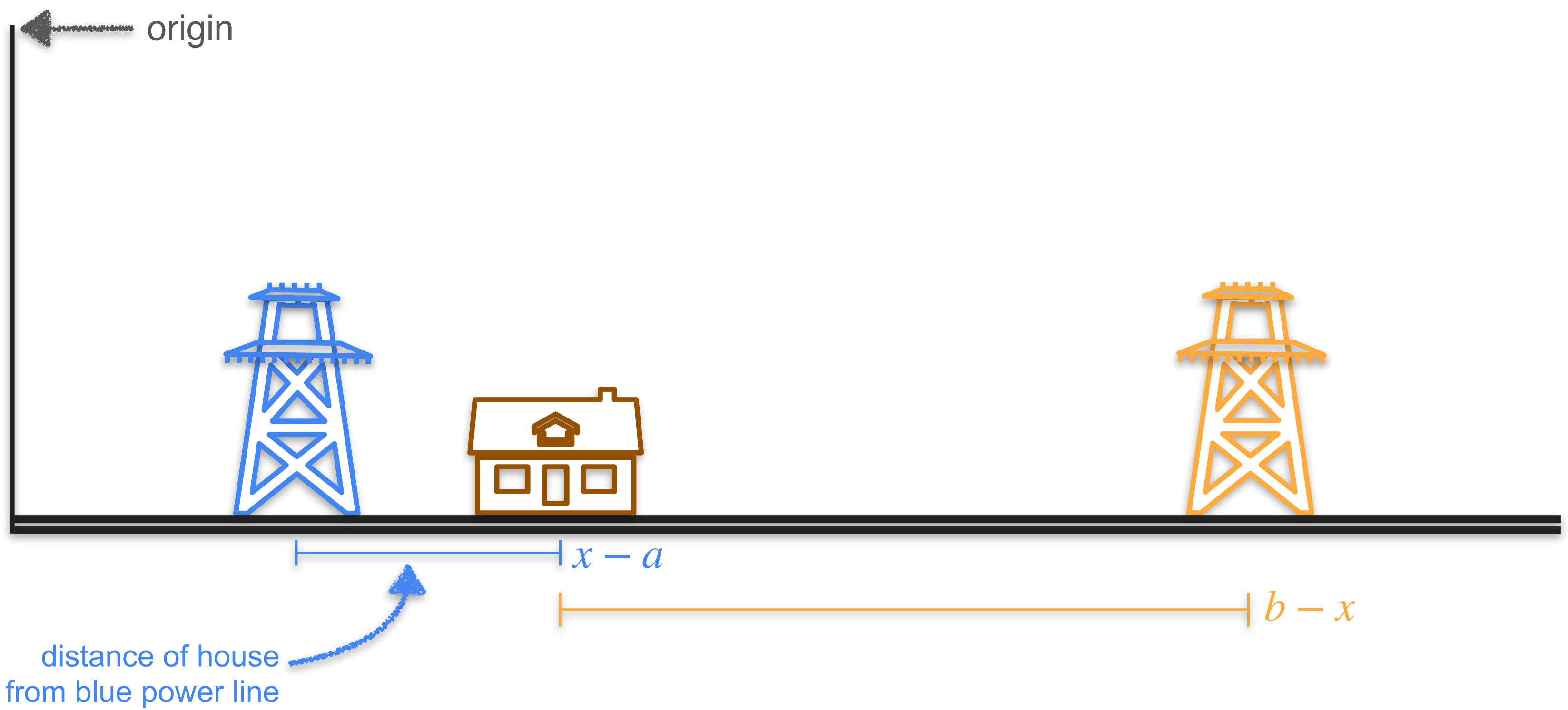

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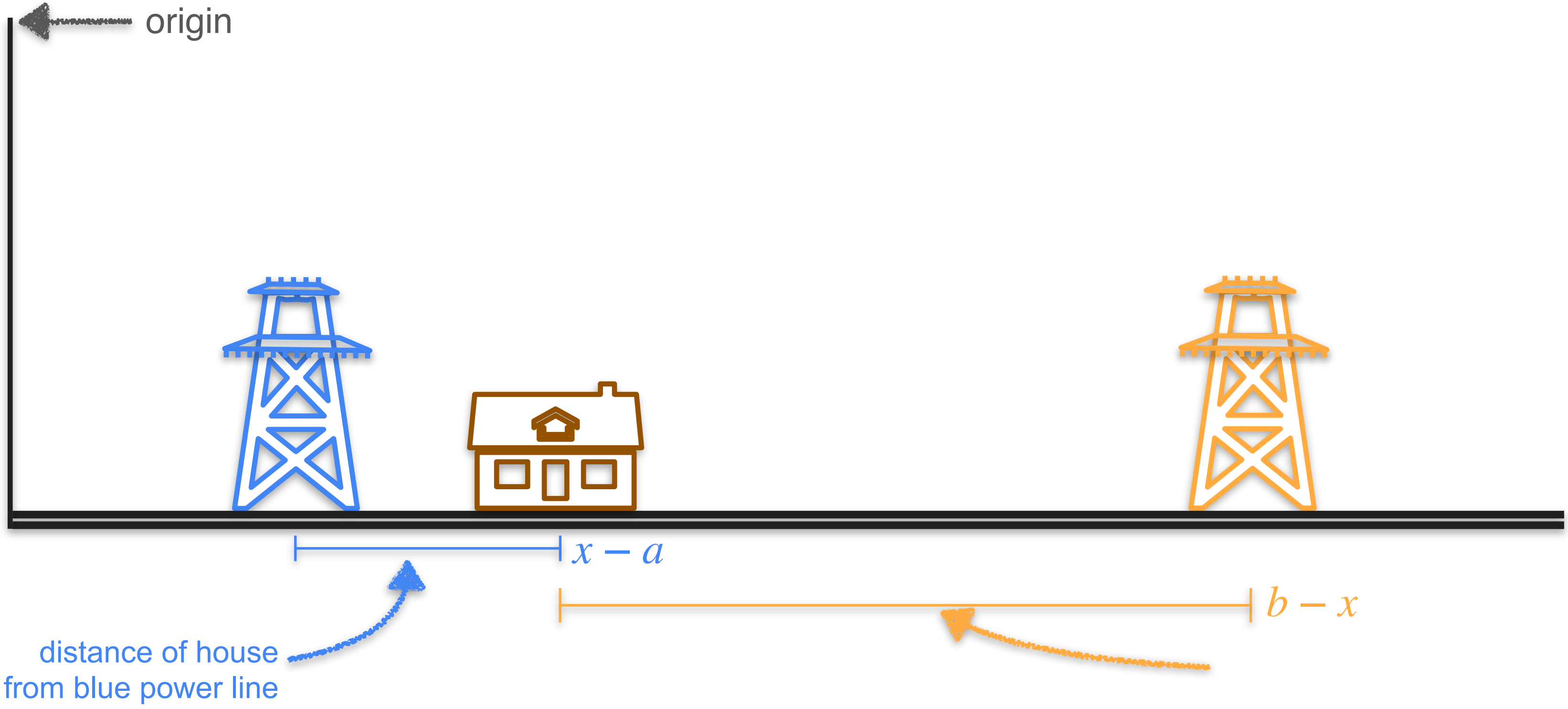
Two Power Line Problem



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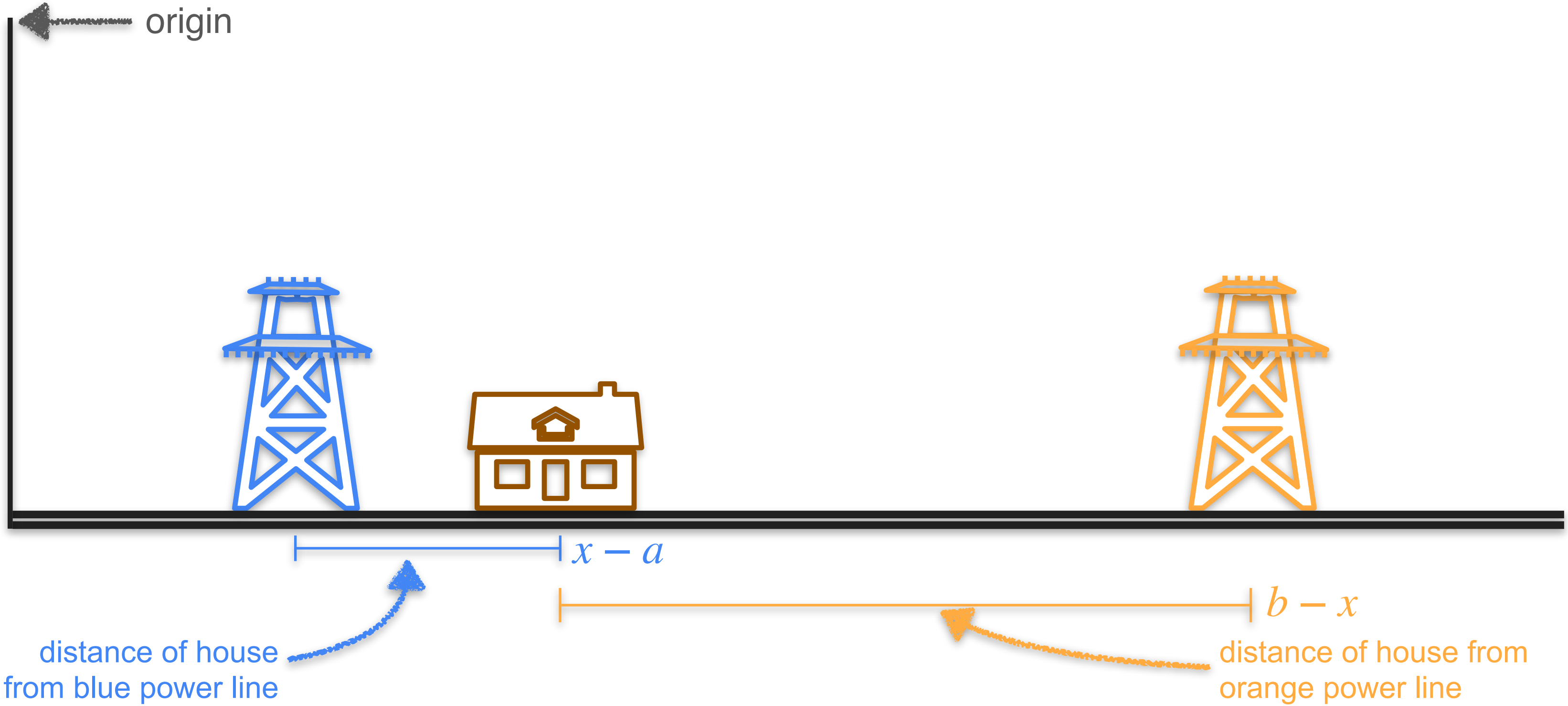

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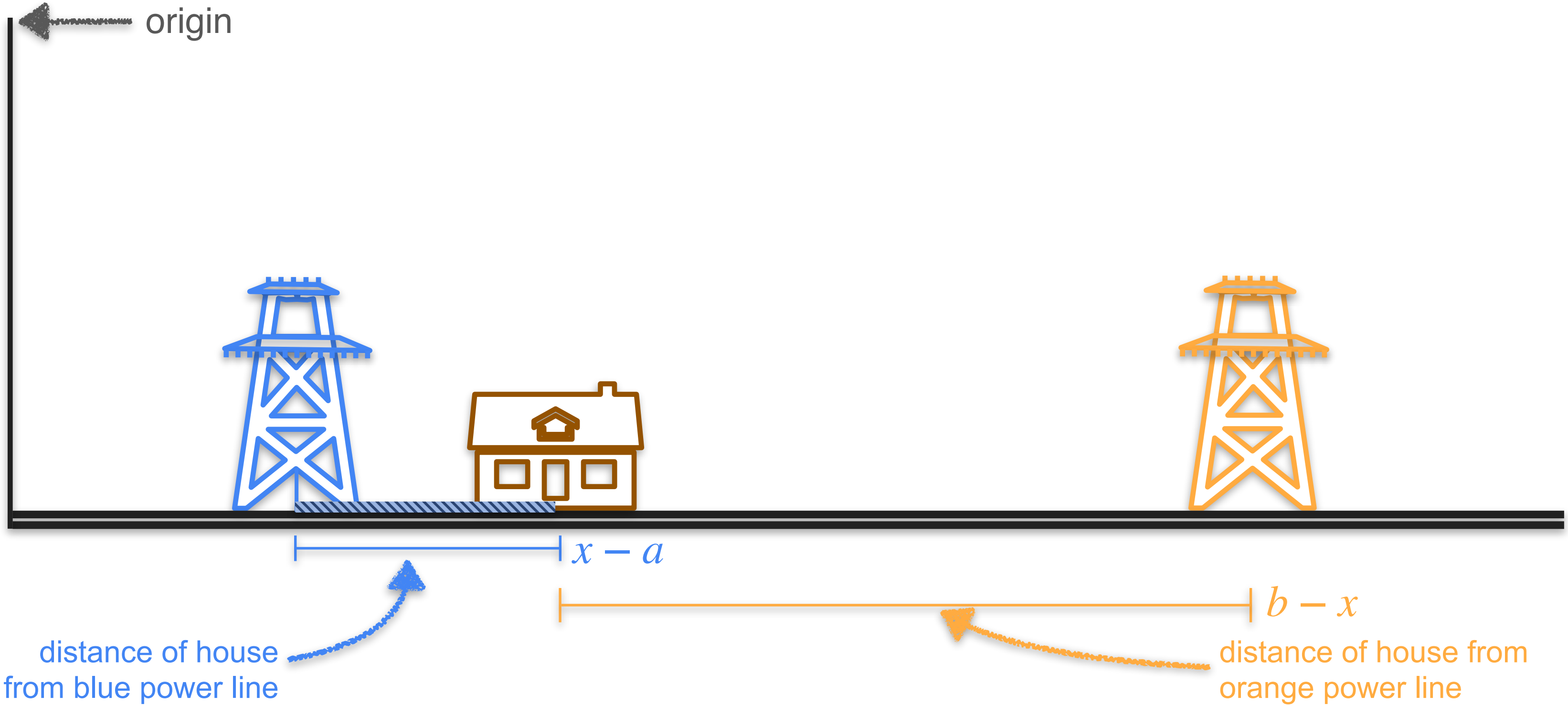

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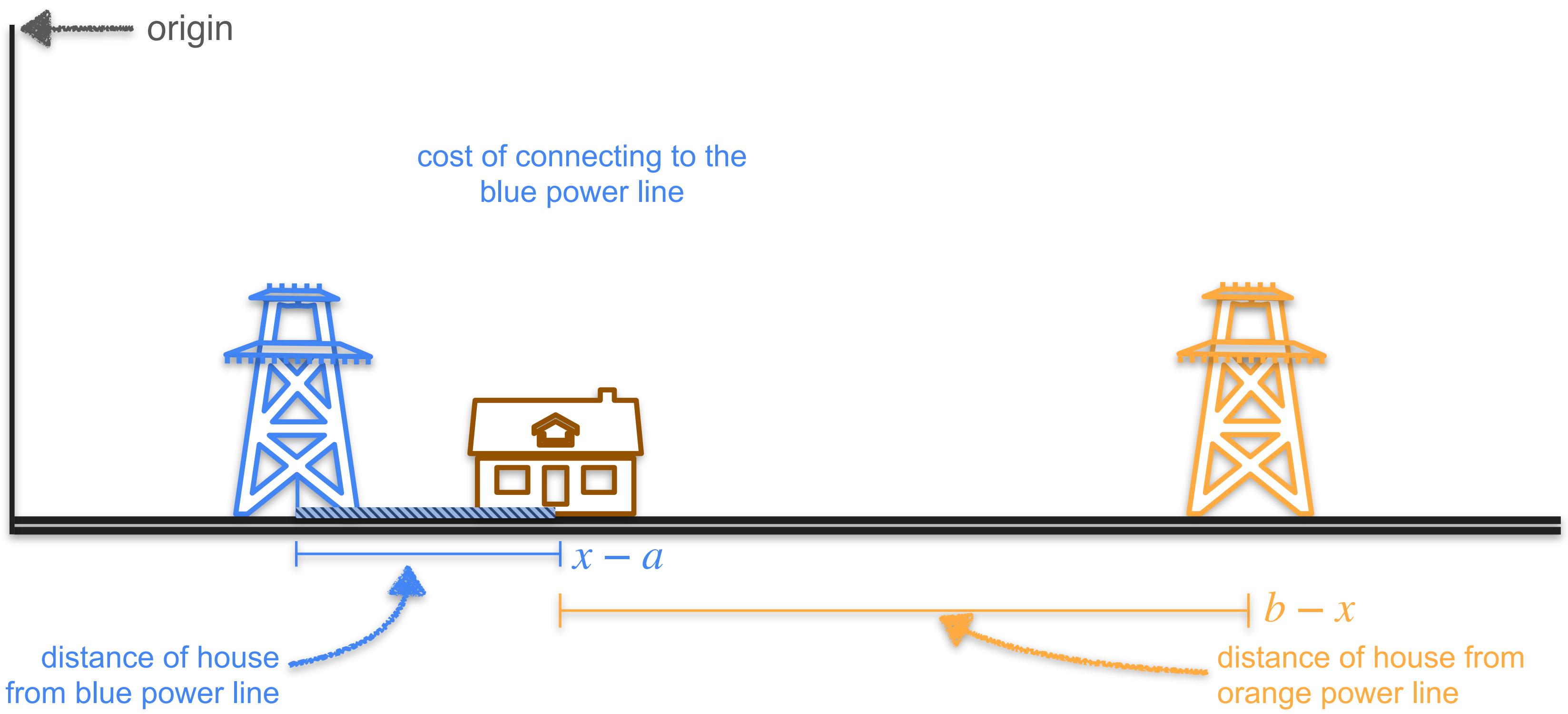

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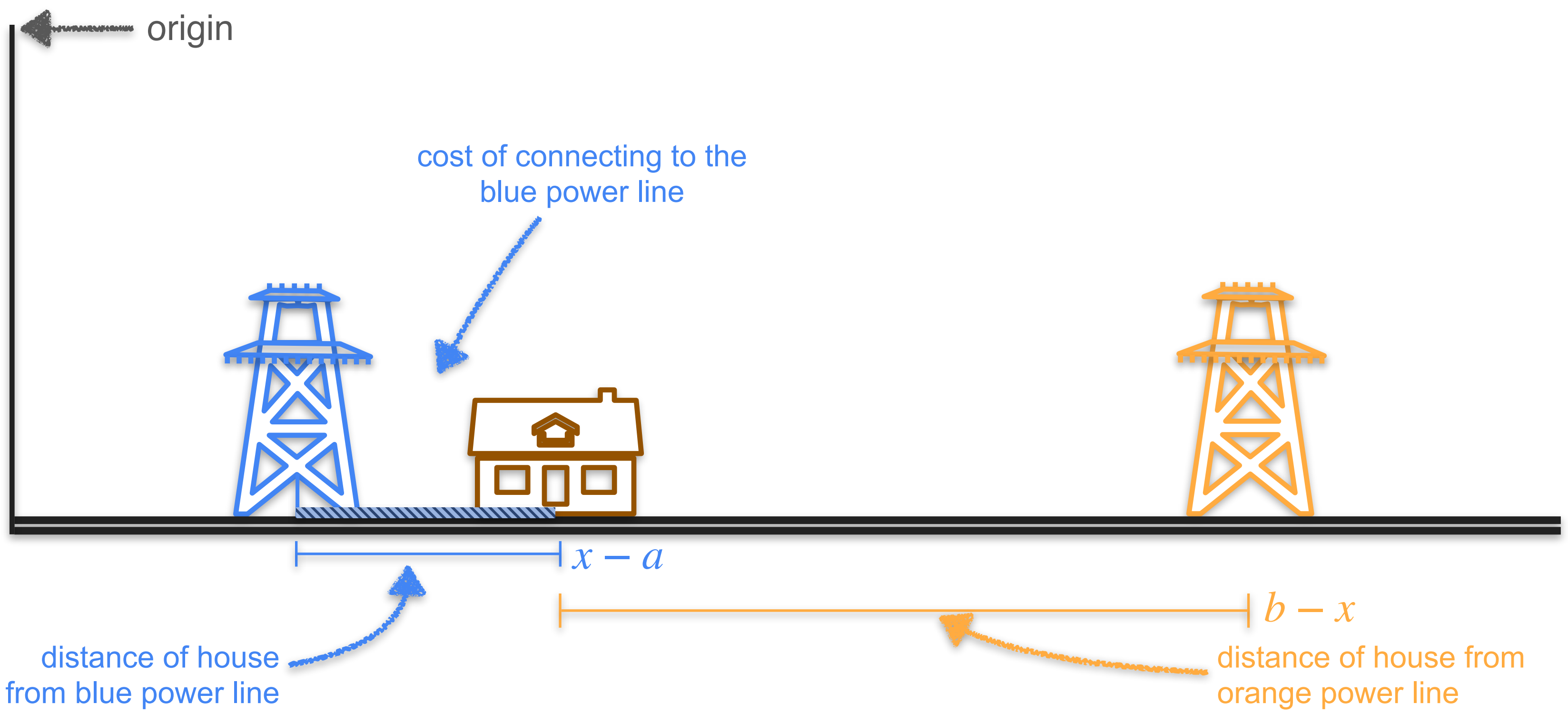

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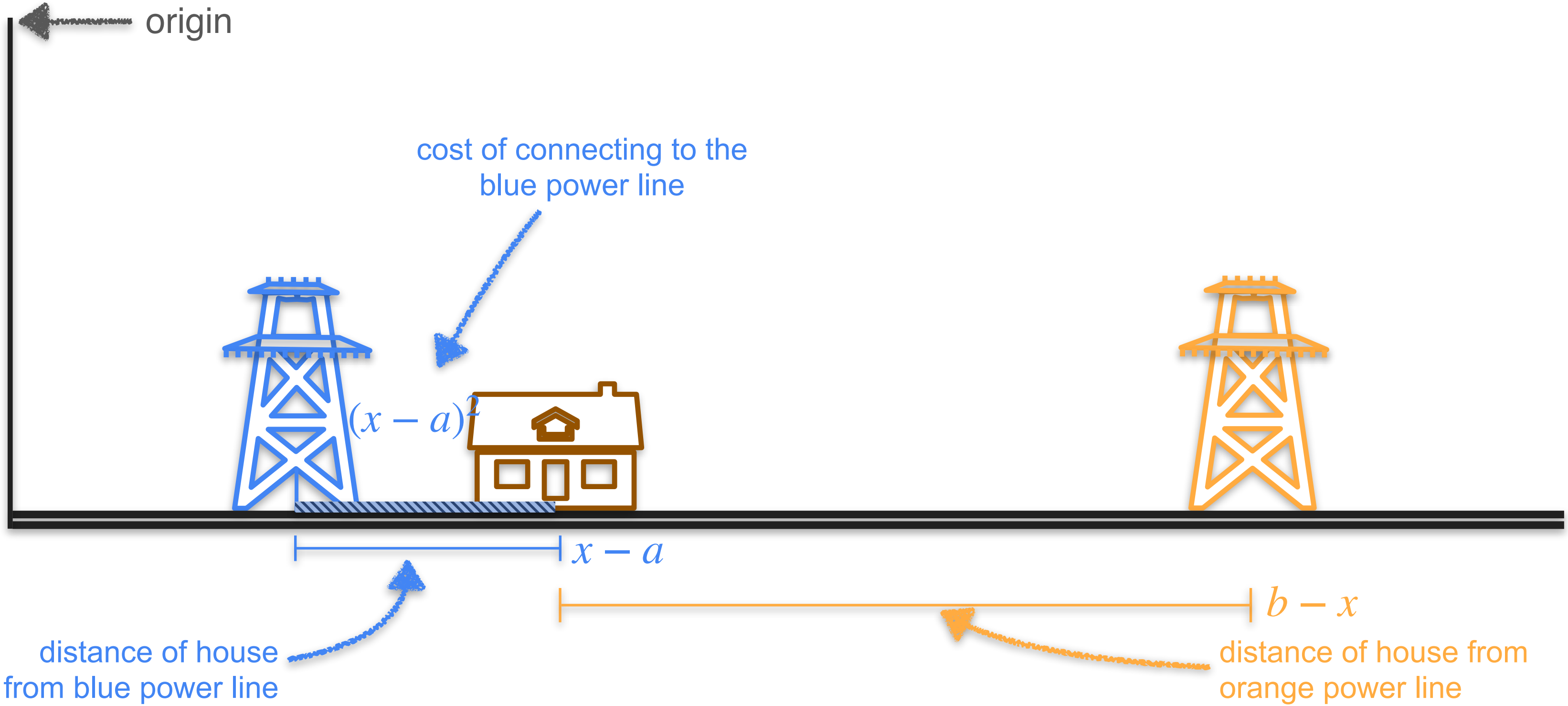
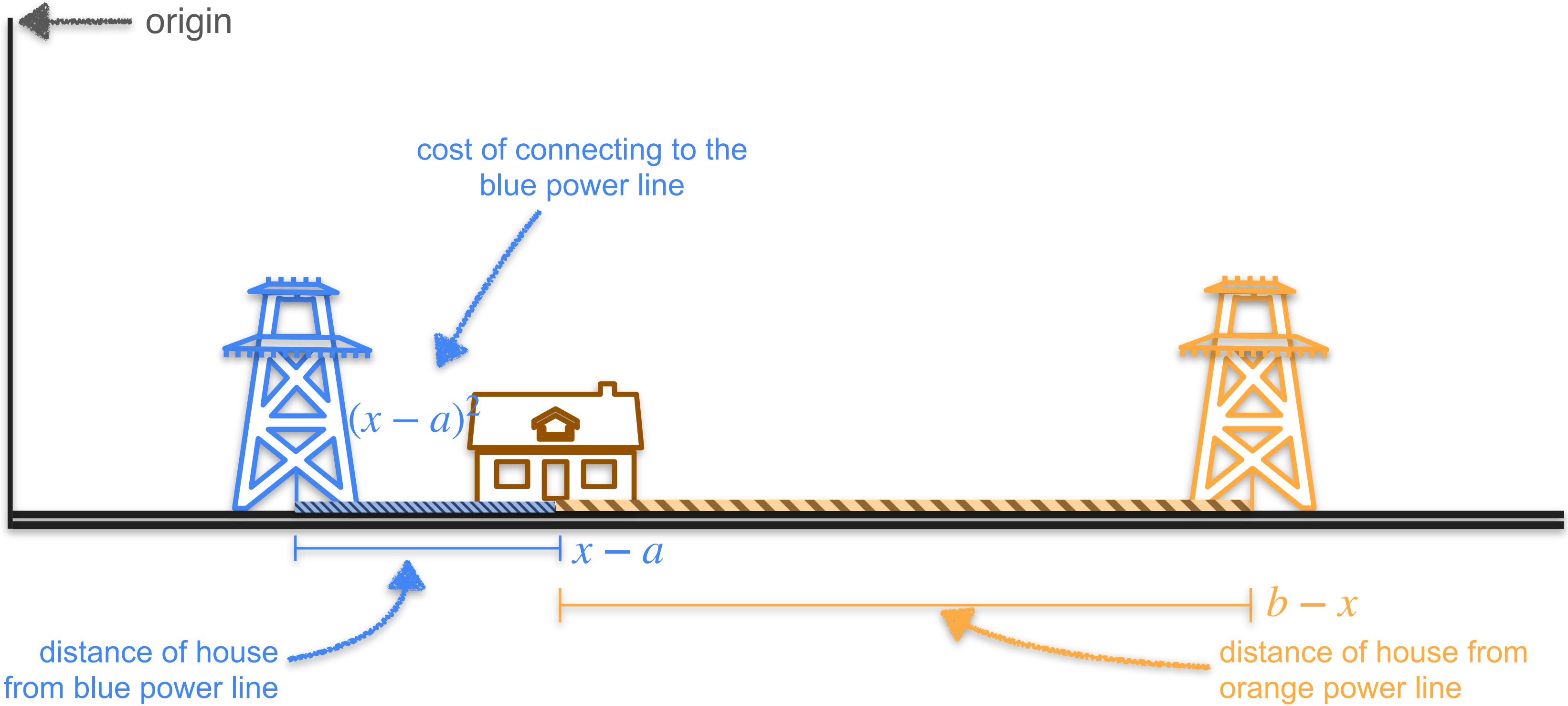


Two Power Line Problem



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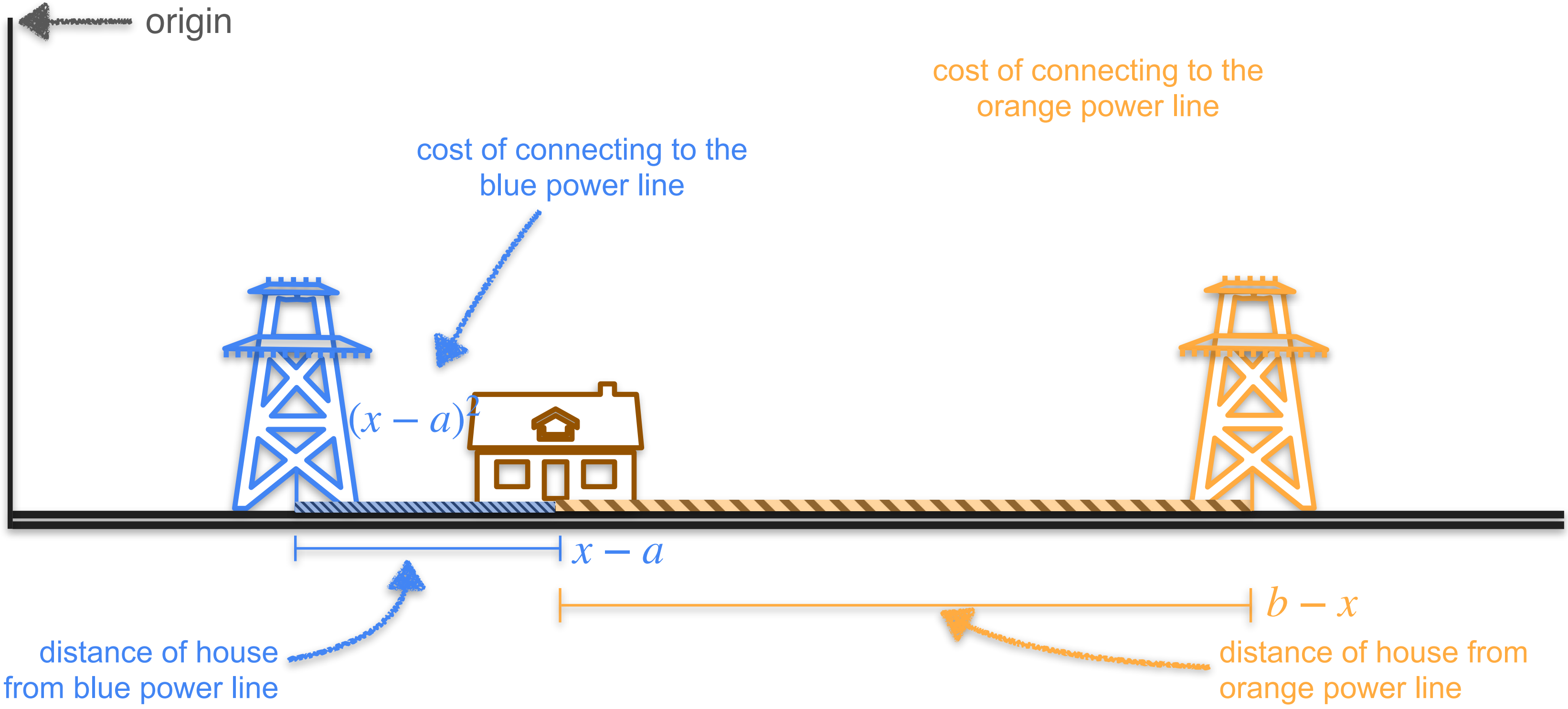

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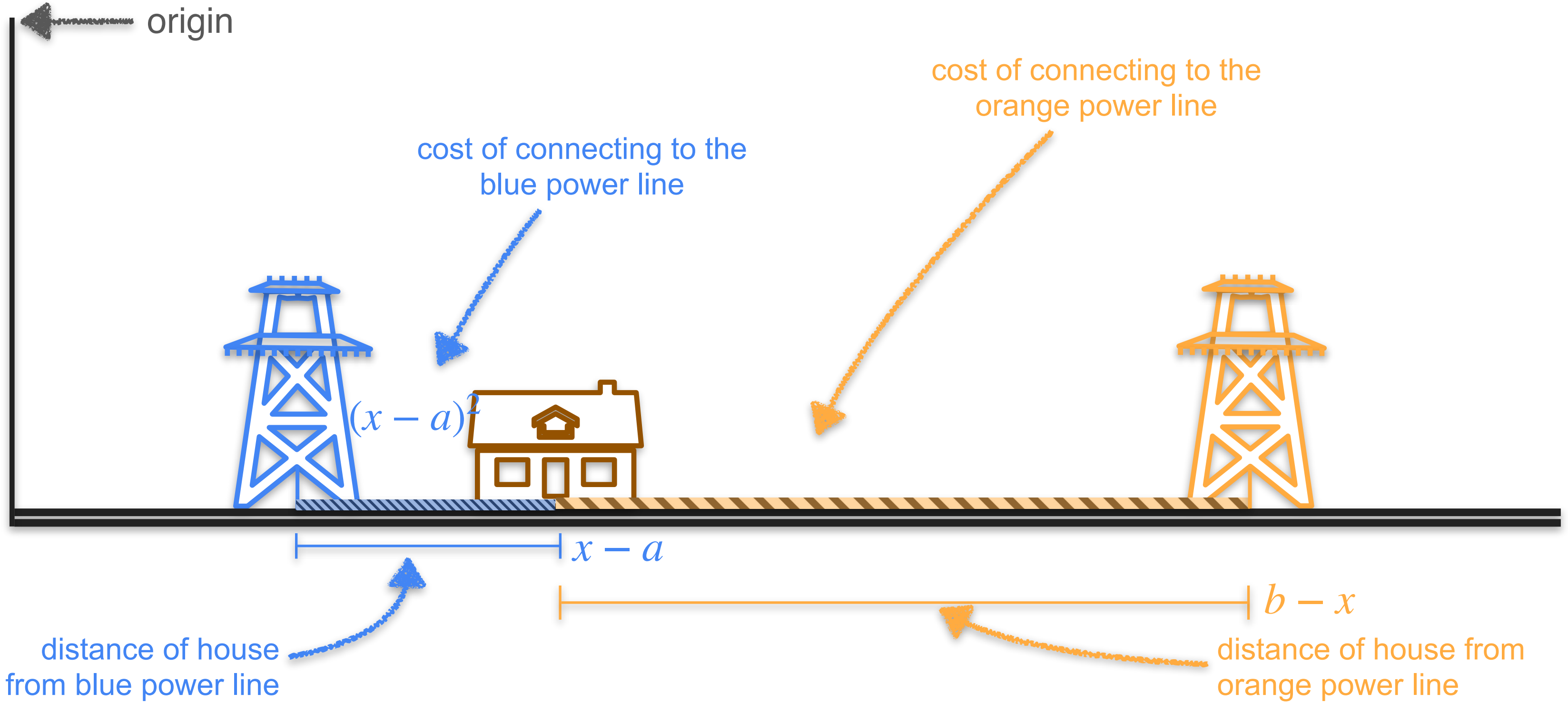
Two Power Line Problem



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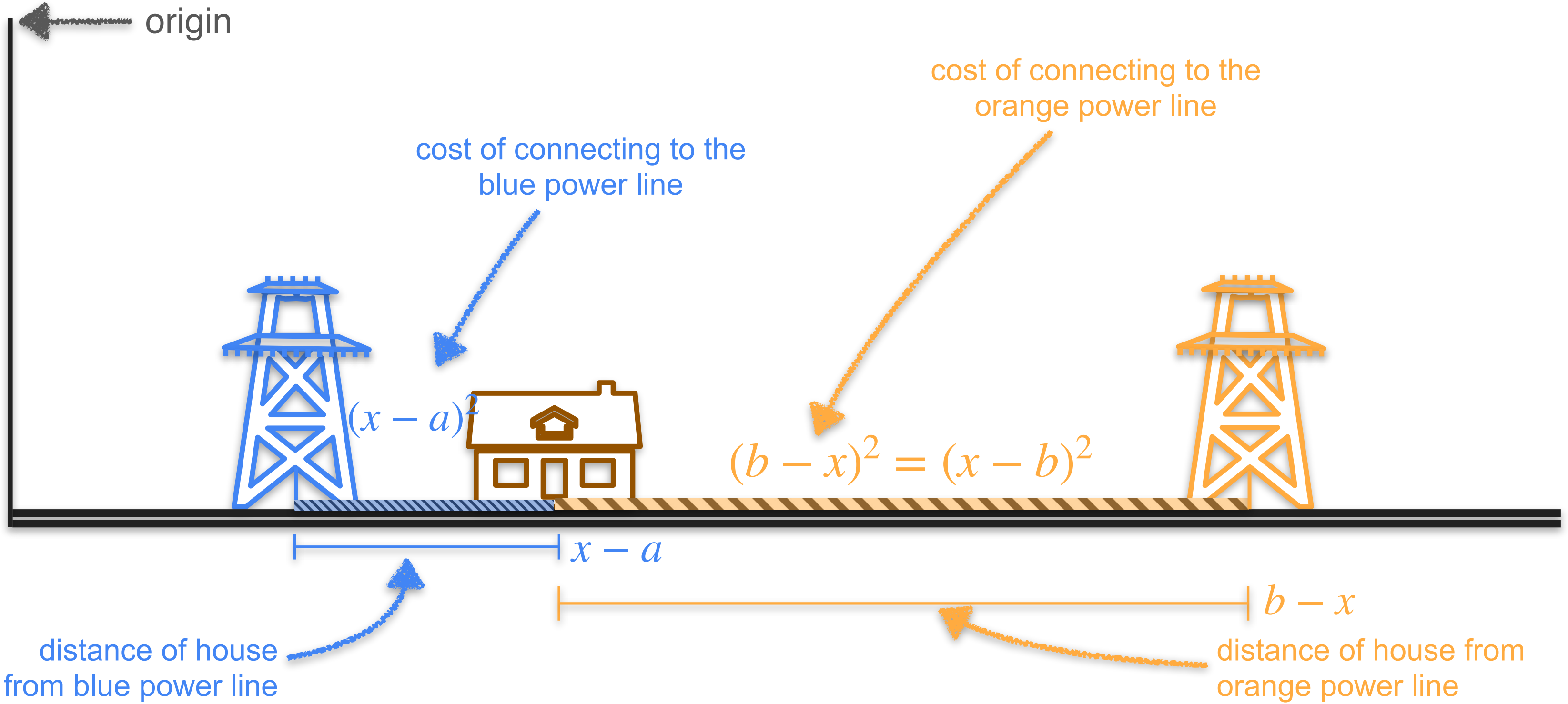

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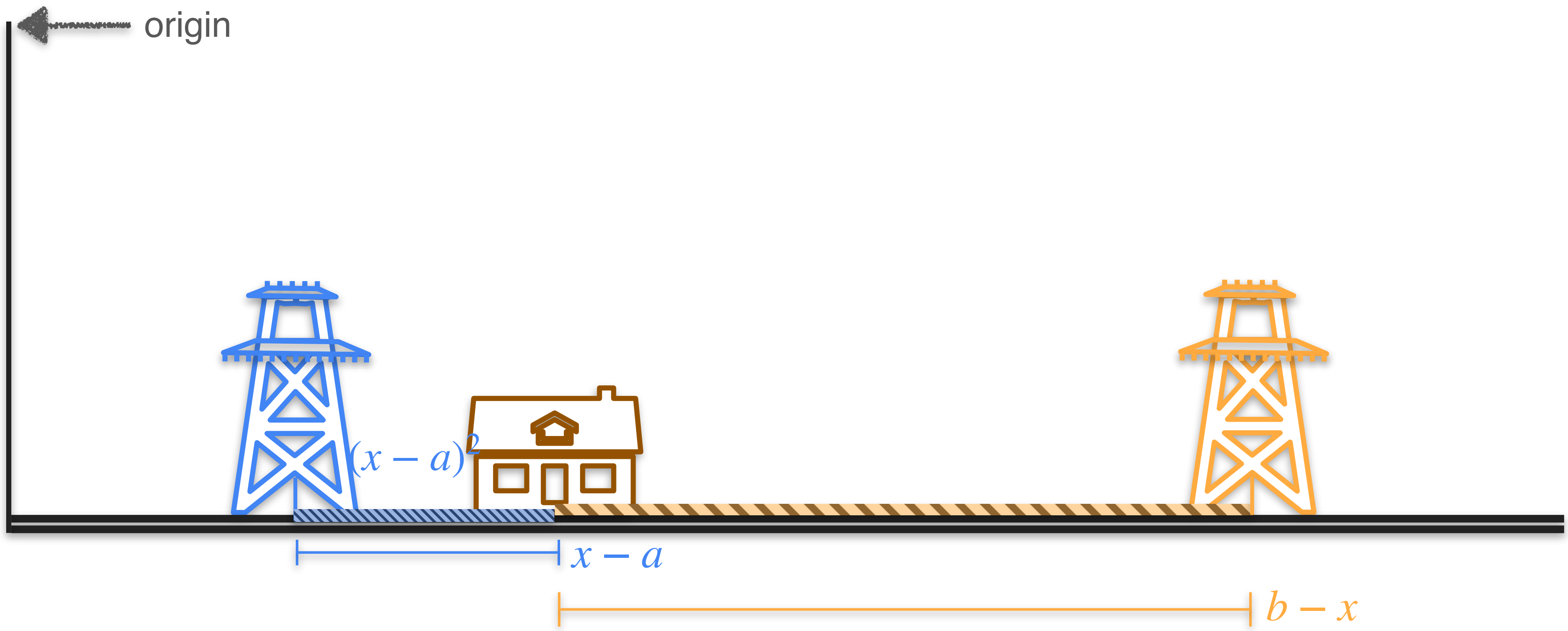

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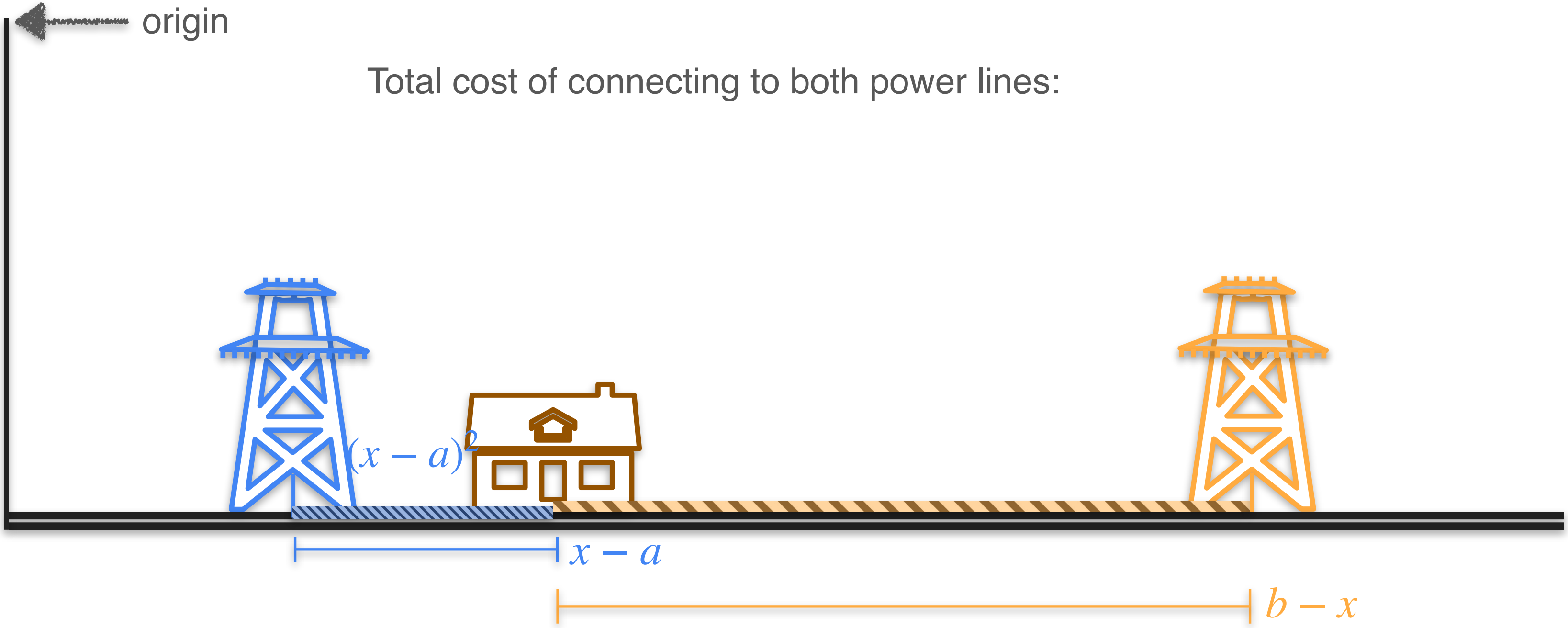
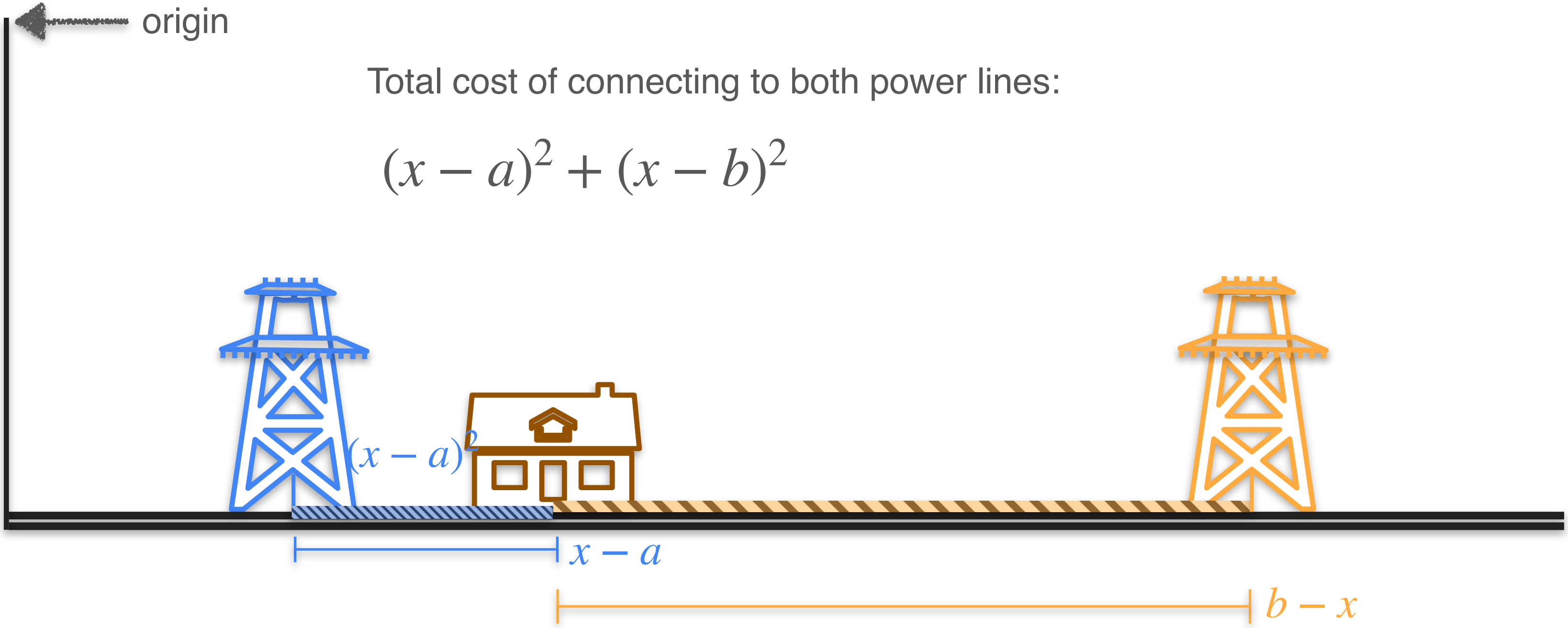


Two Power Line Problem

Total cost of connecting to both power lines:

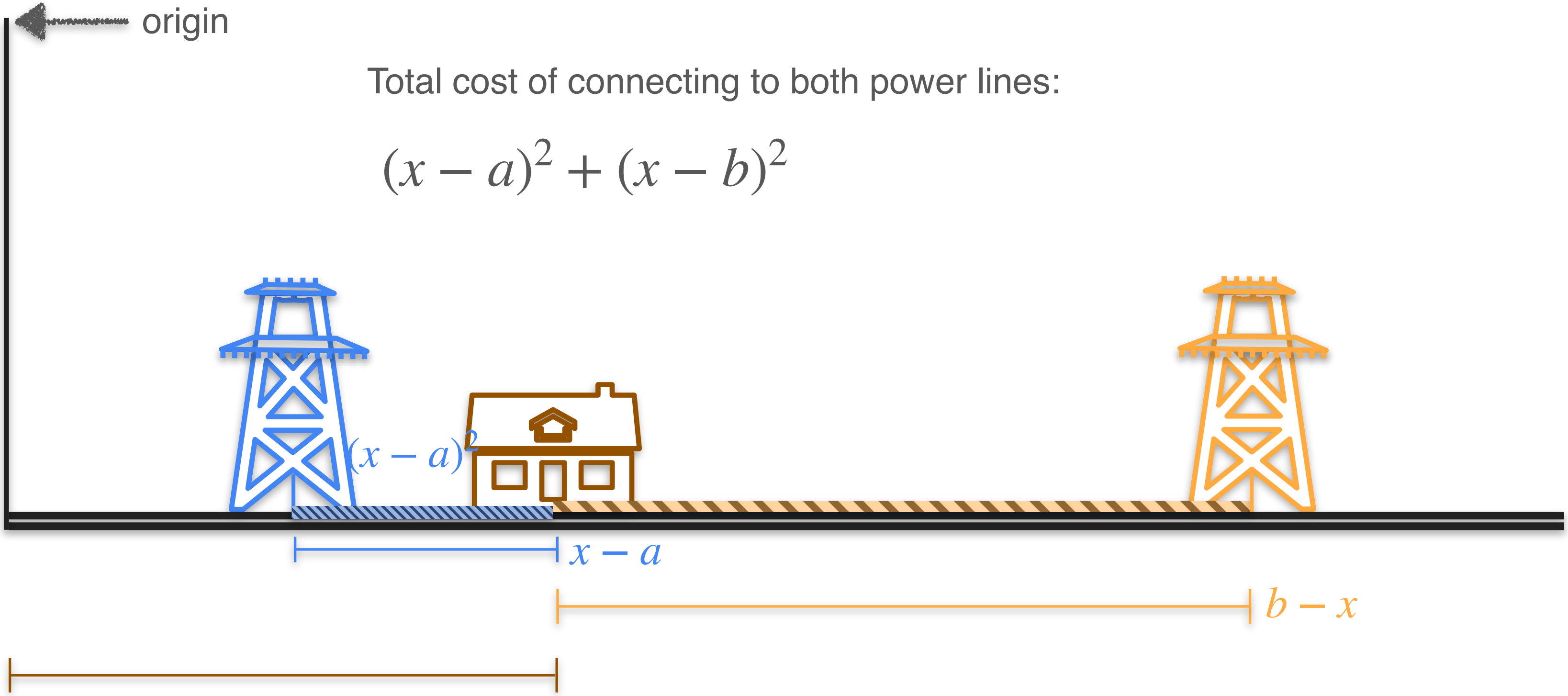
$$(x-a)^2 + (x-b)^2$$



Two Power Line Problem

Total cost of connecting to both power lines:

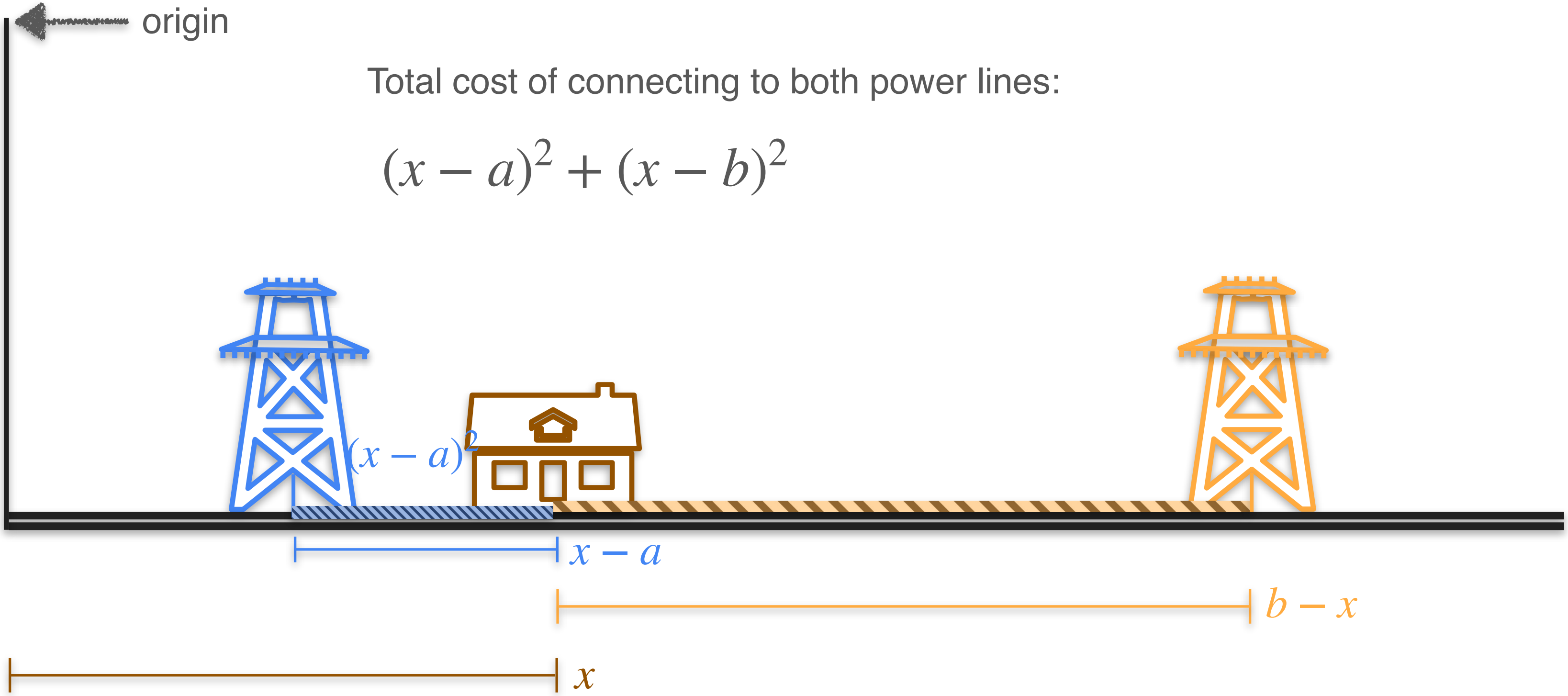
$$(x-a)^2 + (x-b)^2$$



Two Power Line Problem

Total cost of connecting to both power lines:

$$(x-a)^2 + (x-b)^2$$

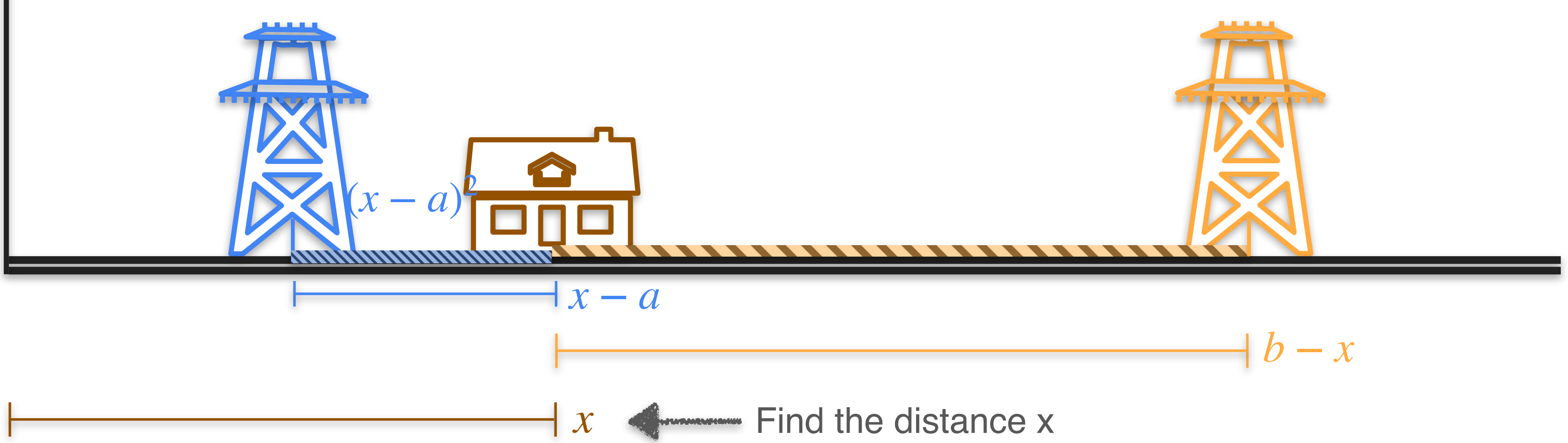


Two Power Line Problem

origin

Total cost of connecting to both power lines:

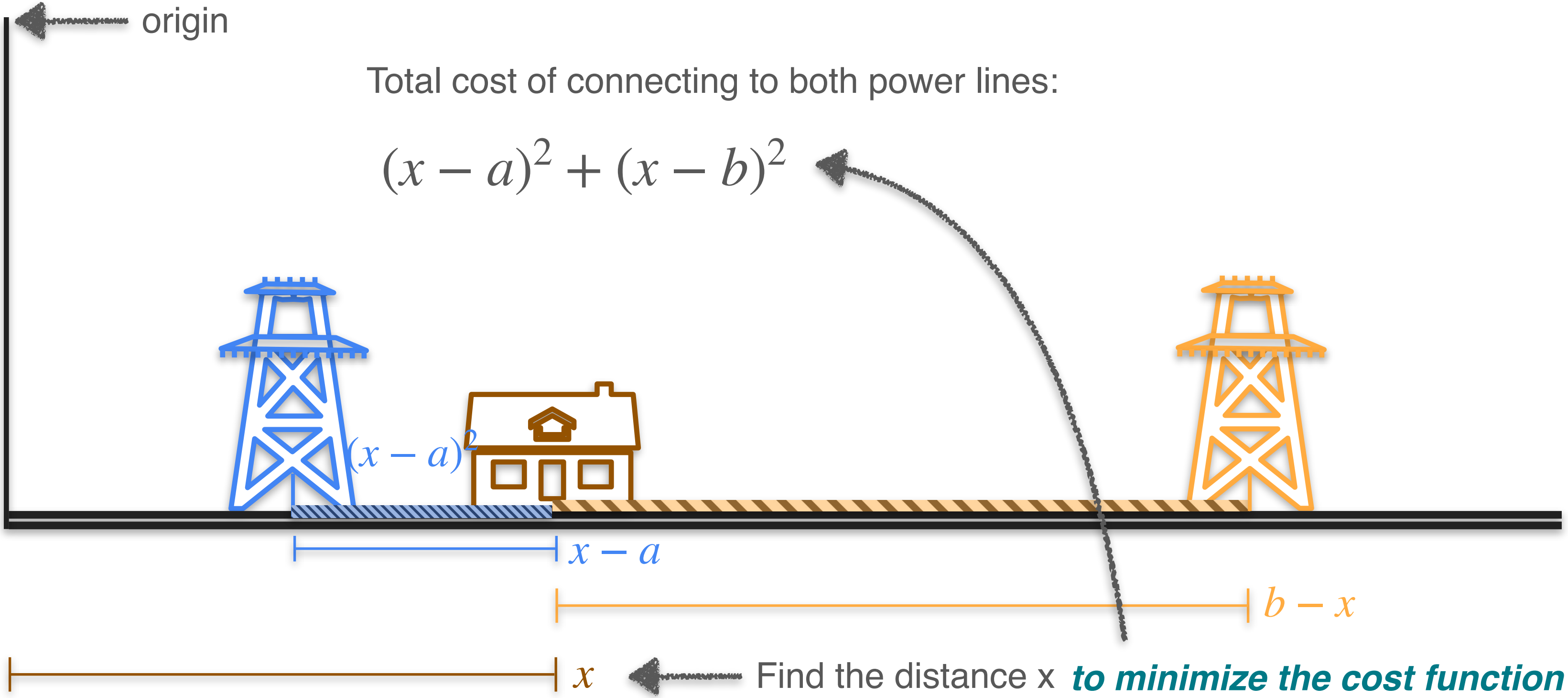
$$(x-a)^2 + (x-b)^2$$



Two Power Line Problem

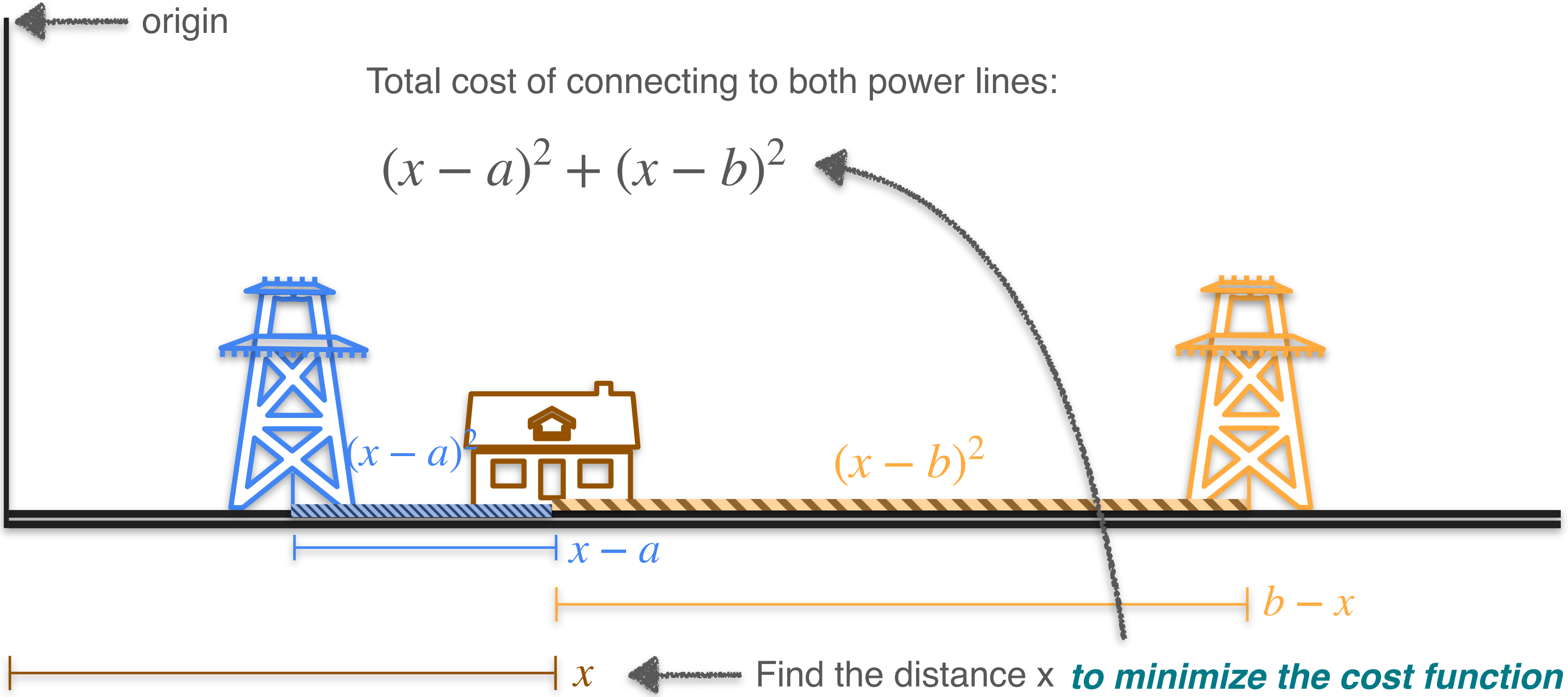
Total cost of connecting to both power lines:

$$(x-a)^2 + (x-b)^2$$



Find the distance x ***to minimize the cost function***

Two Power Line Problem



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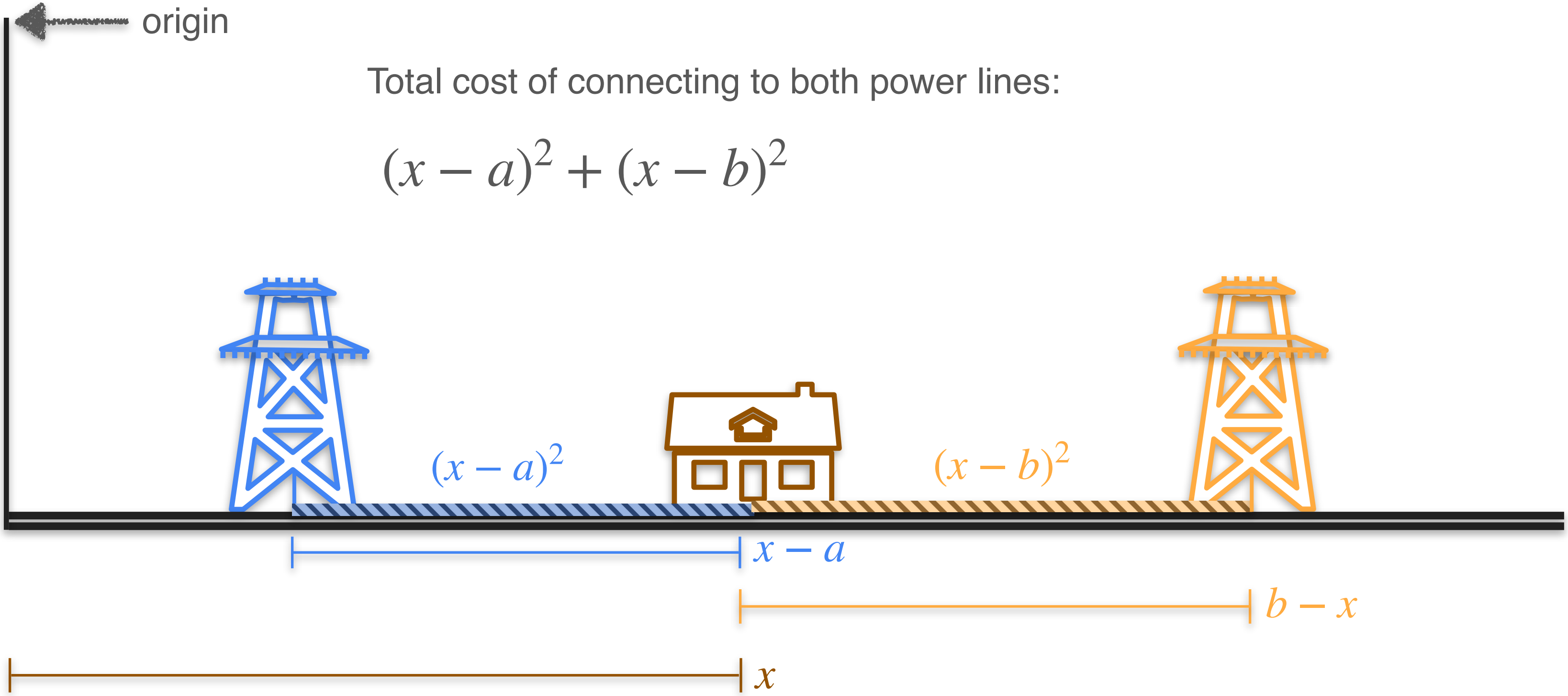
Two Power Line Problem

Total cost of connecting to both power lines:

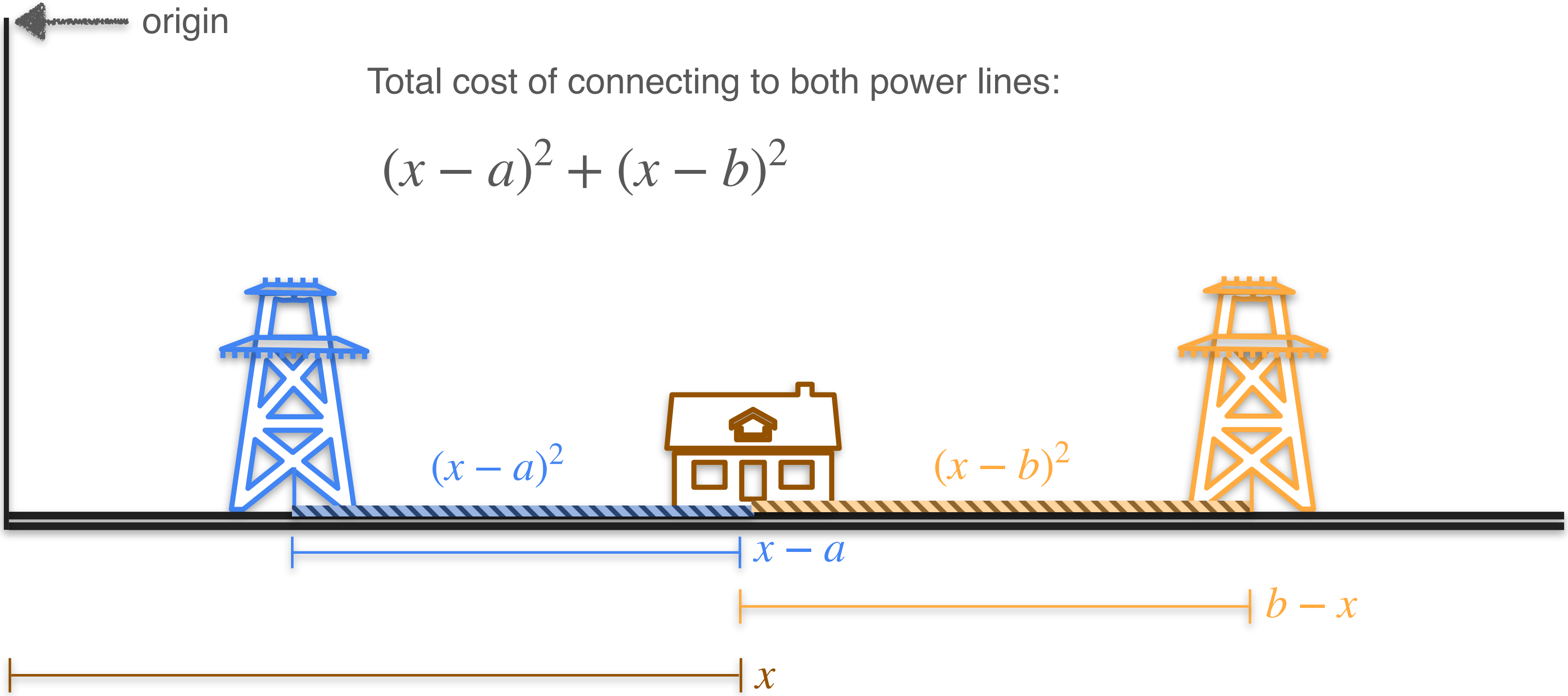
$$(x-a)^2 + (x-b)^2$$



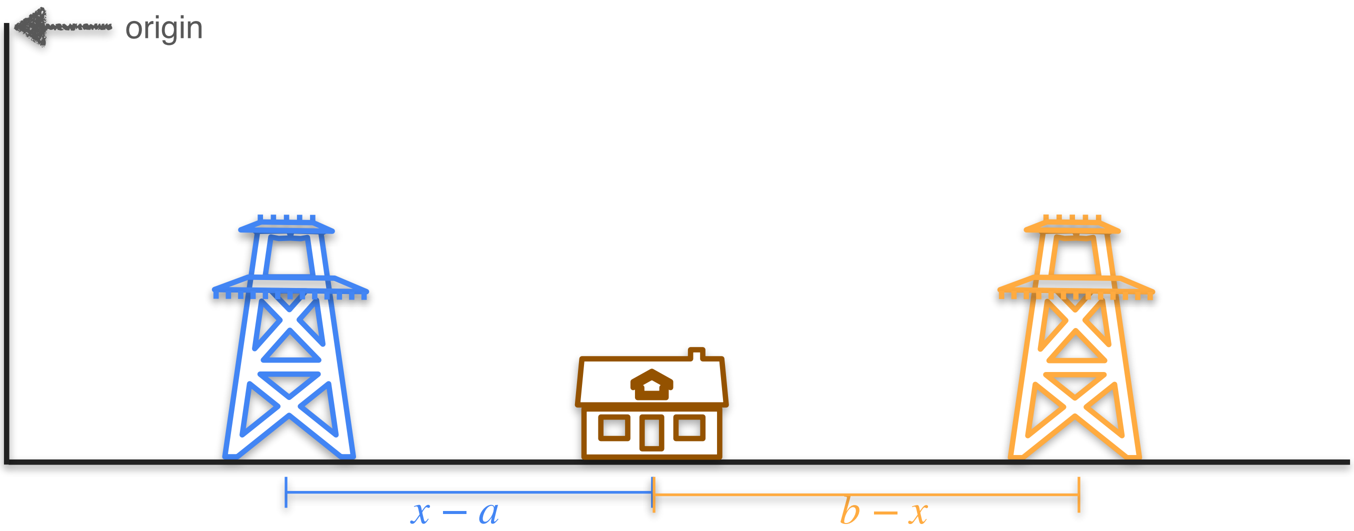
Two Power Line Problem

Total cost of connecting to both power lines:

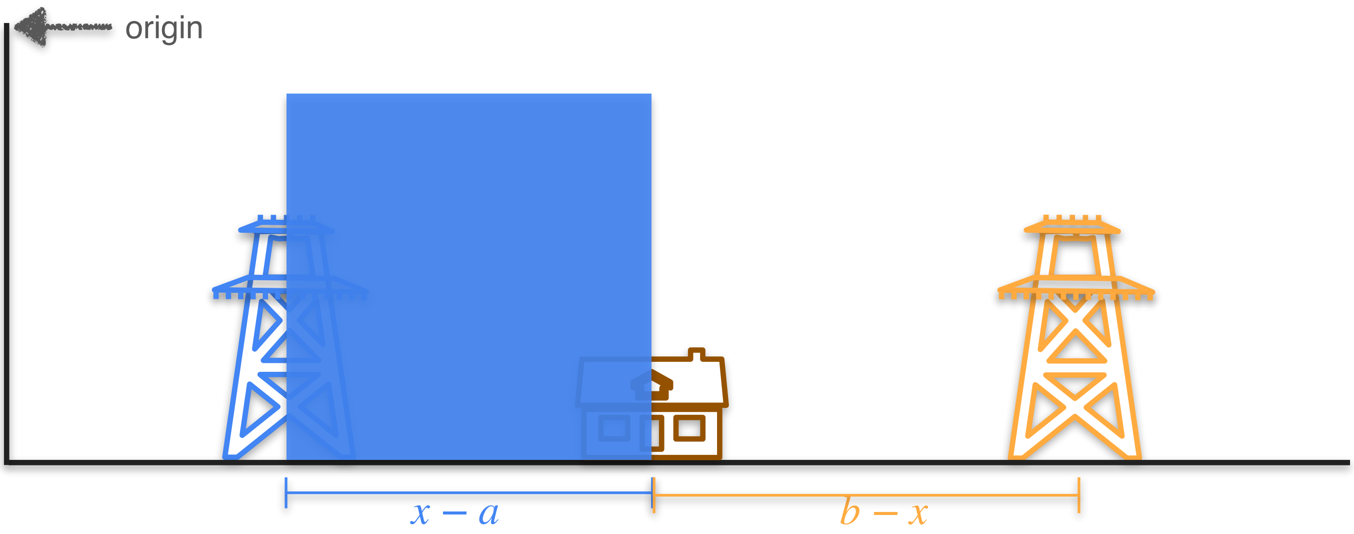
$$(x-a)^2 + (x-b)^2$$



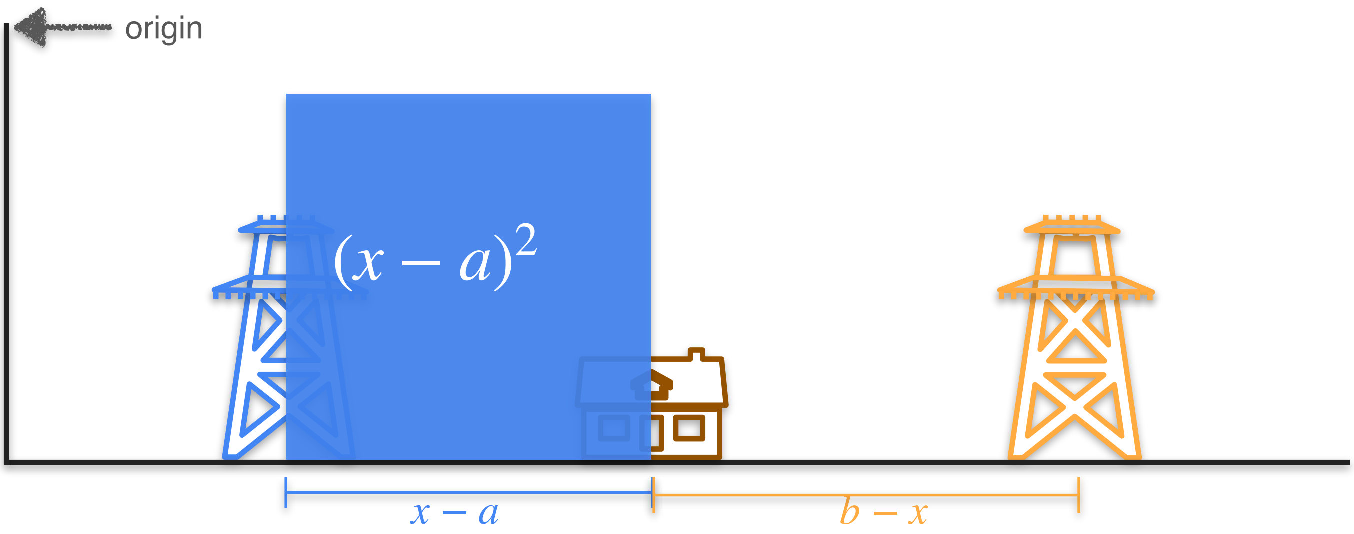
Two Power Line Problem - Square Analogy



Two Power Line Problem - Square Analogy



Two Power Line Problem - Square Analogy



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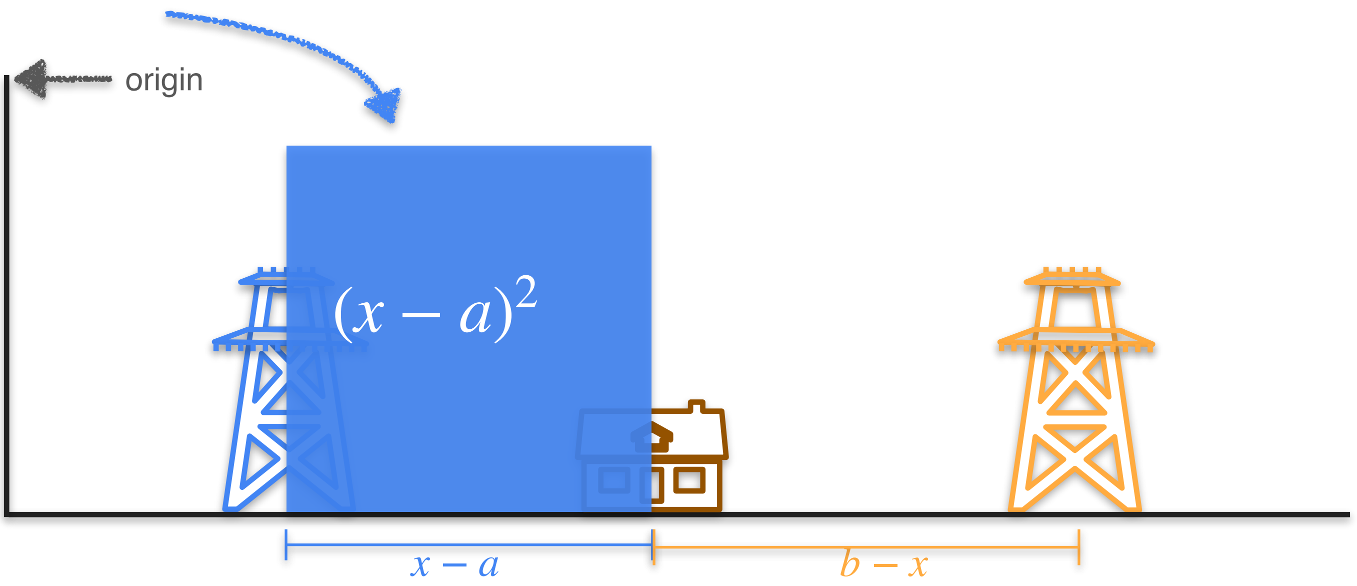

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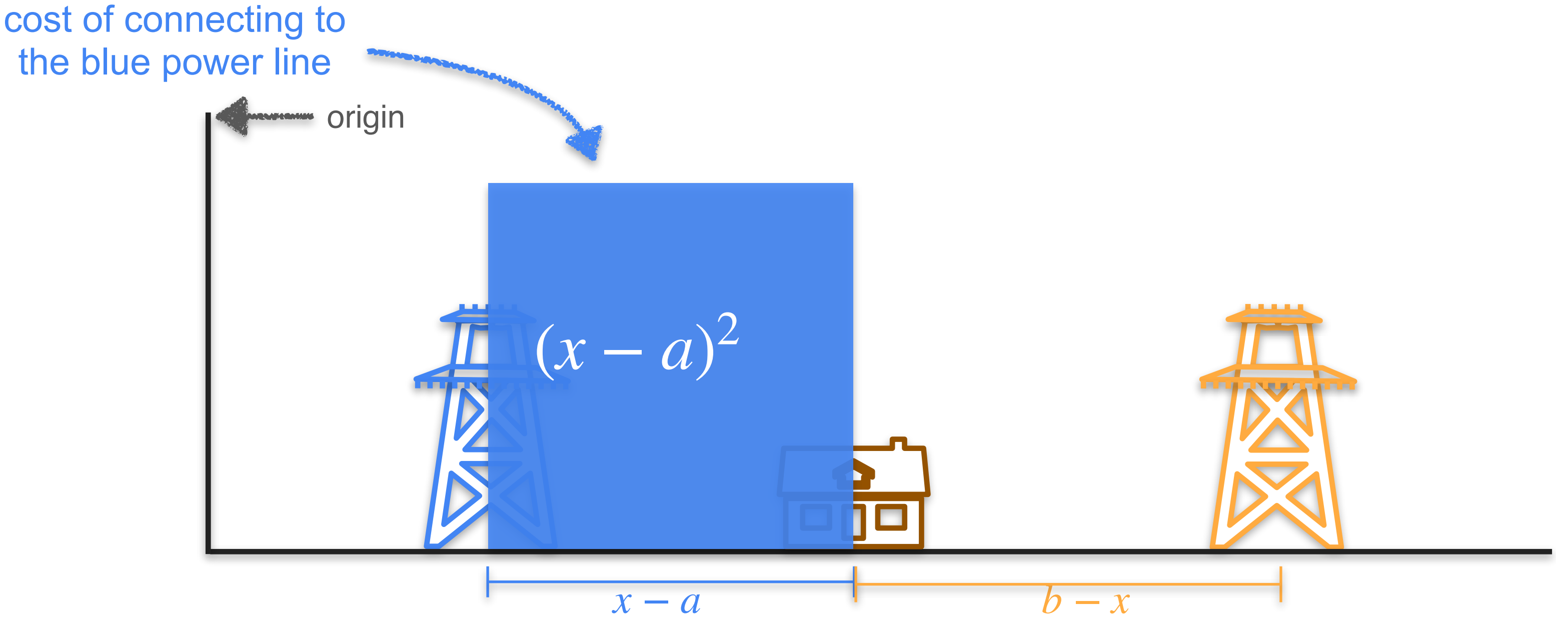
Two Power Line Problem - Square Analogy



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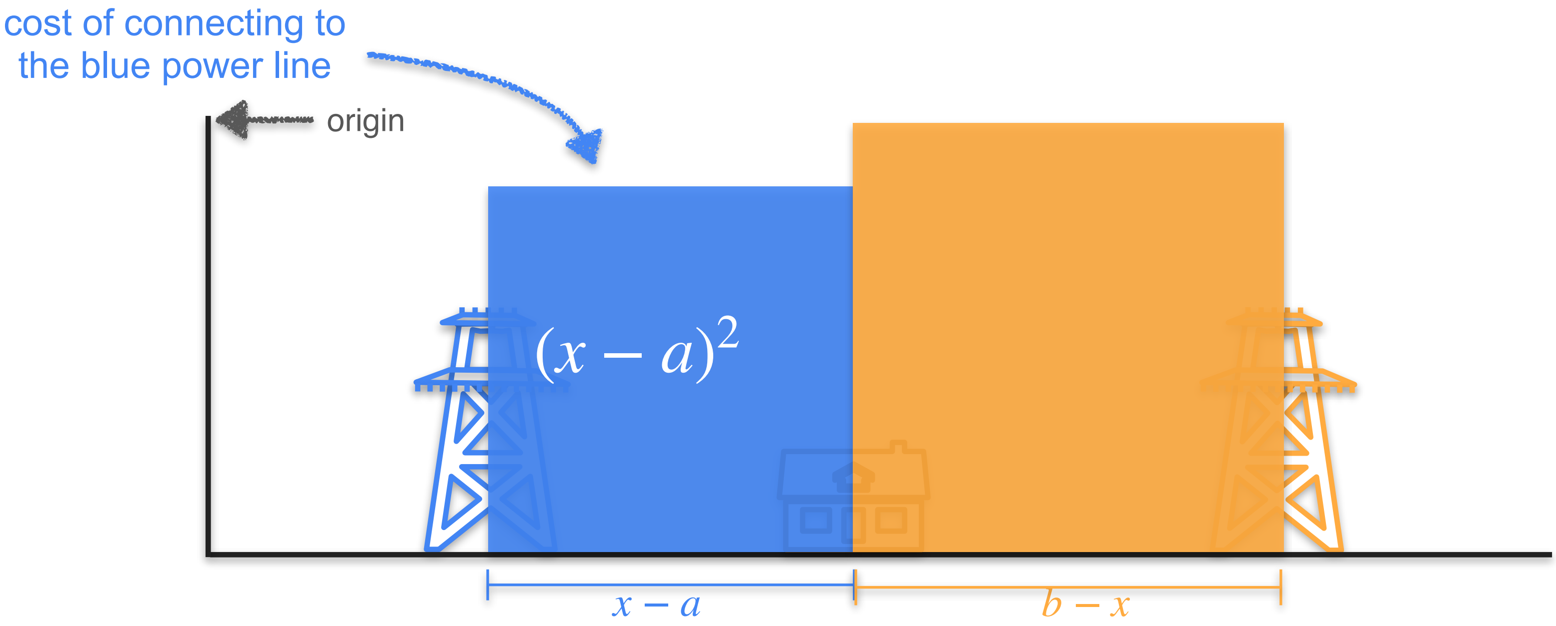

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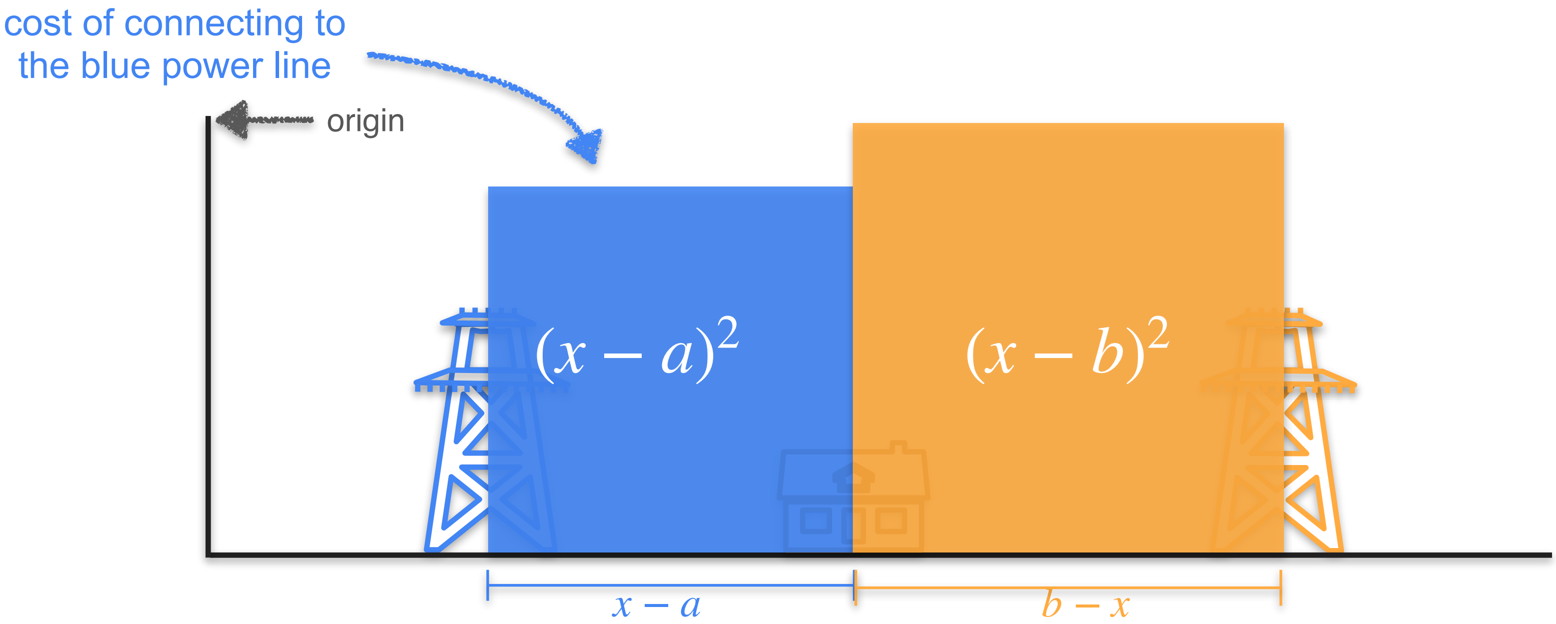

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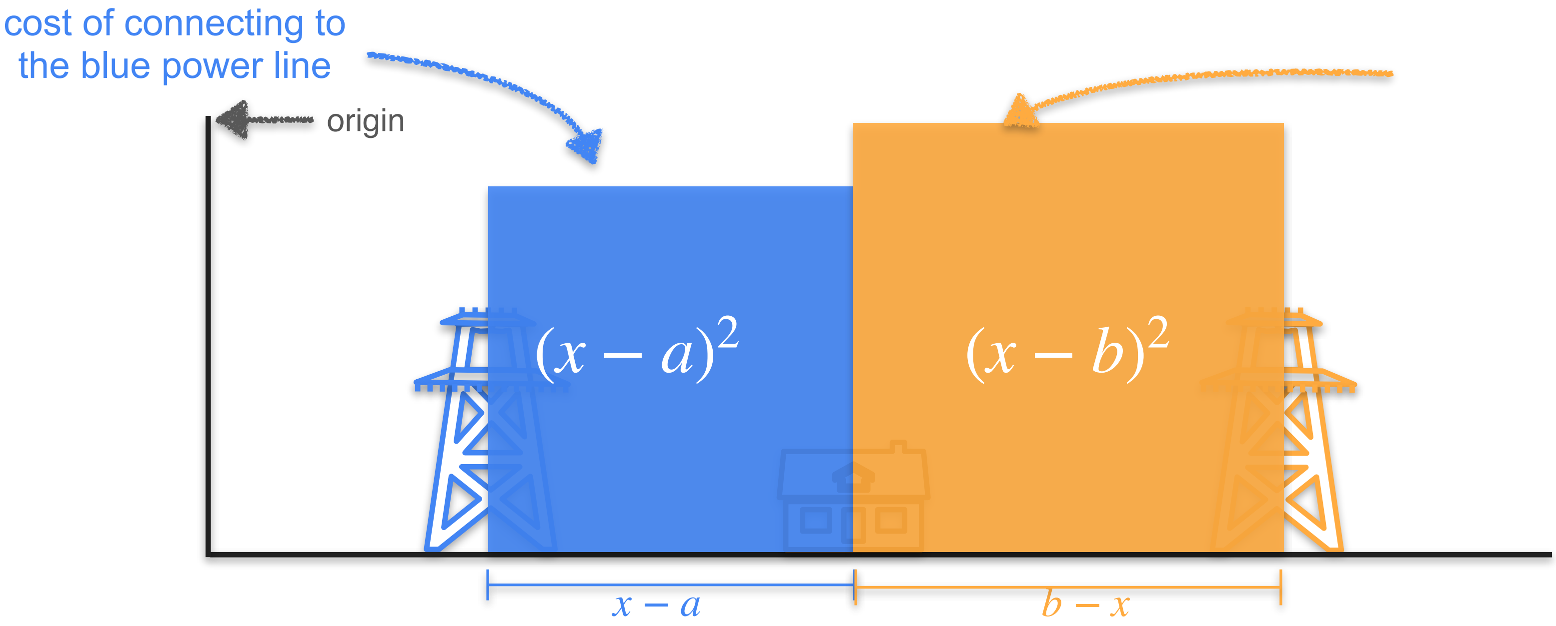

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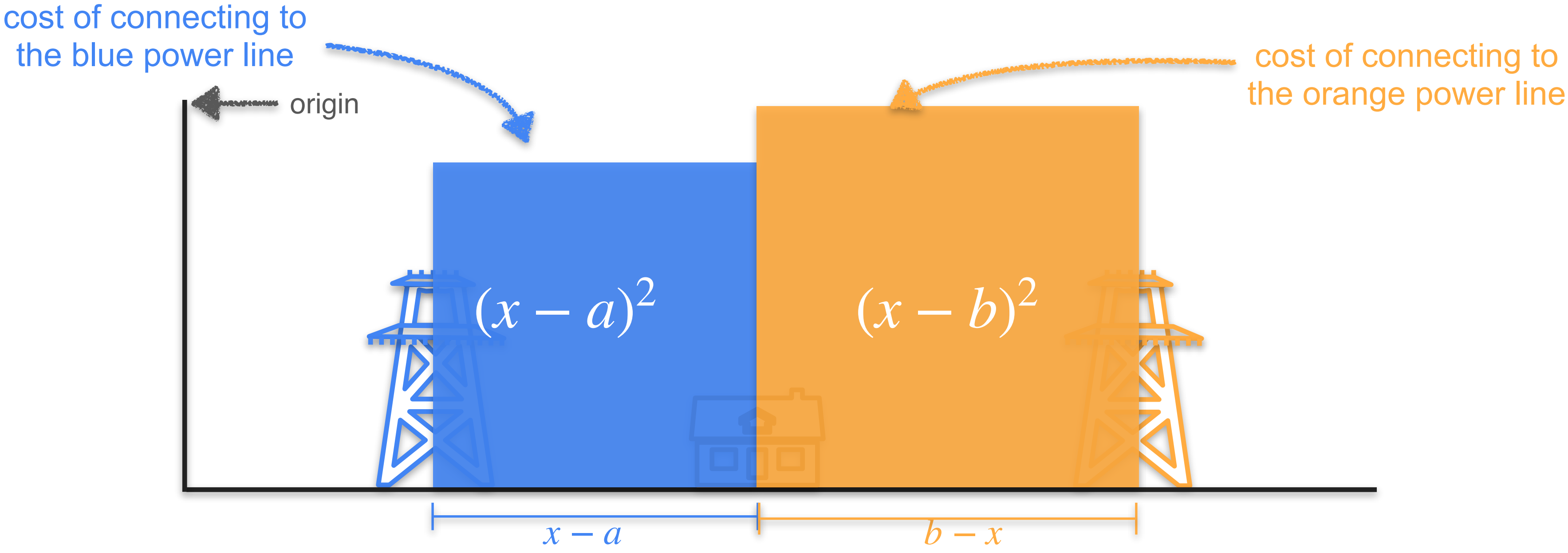

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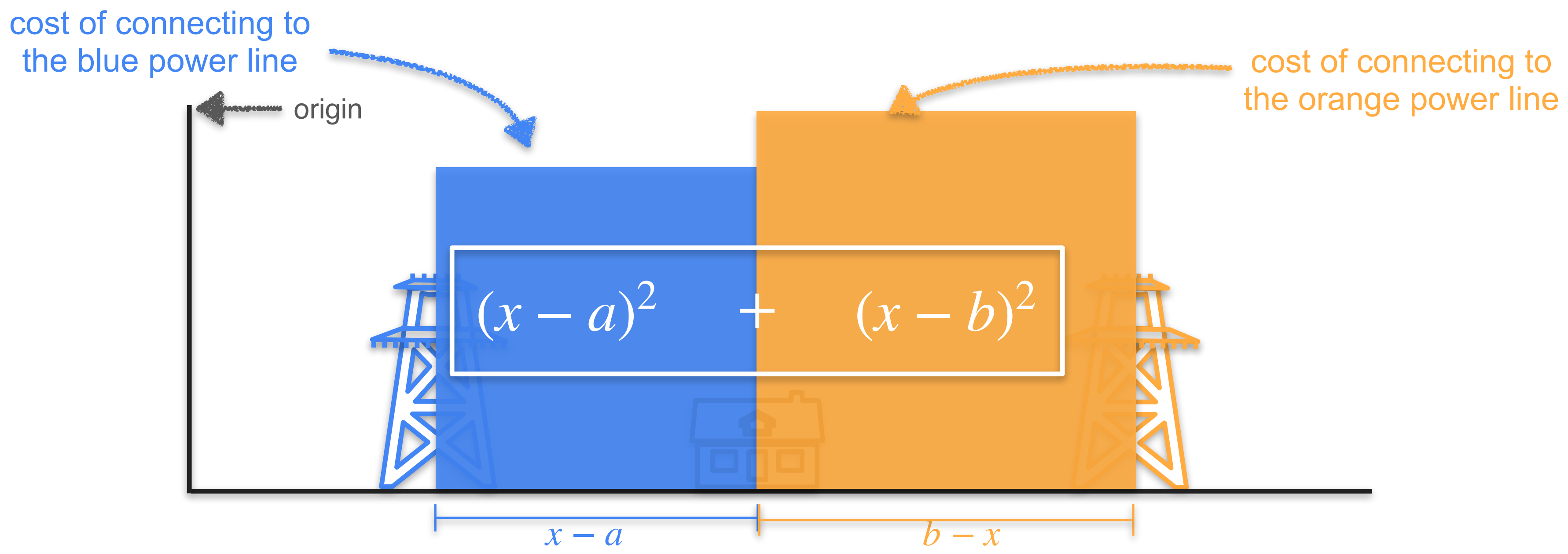
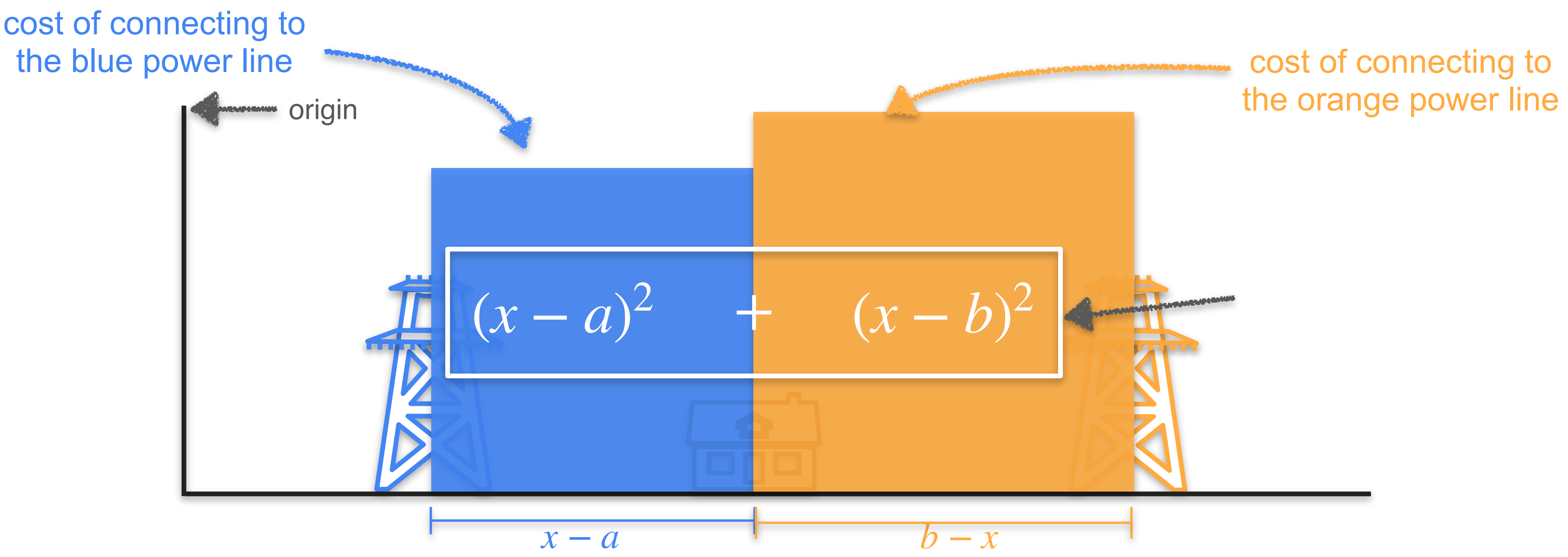


Two Power Line Problem - Square Analogy



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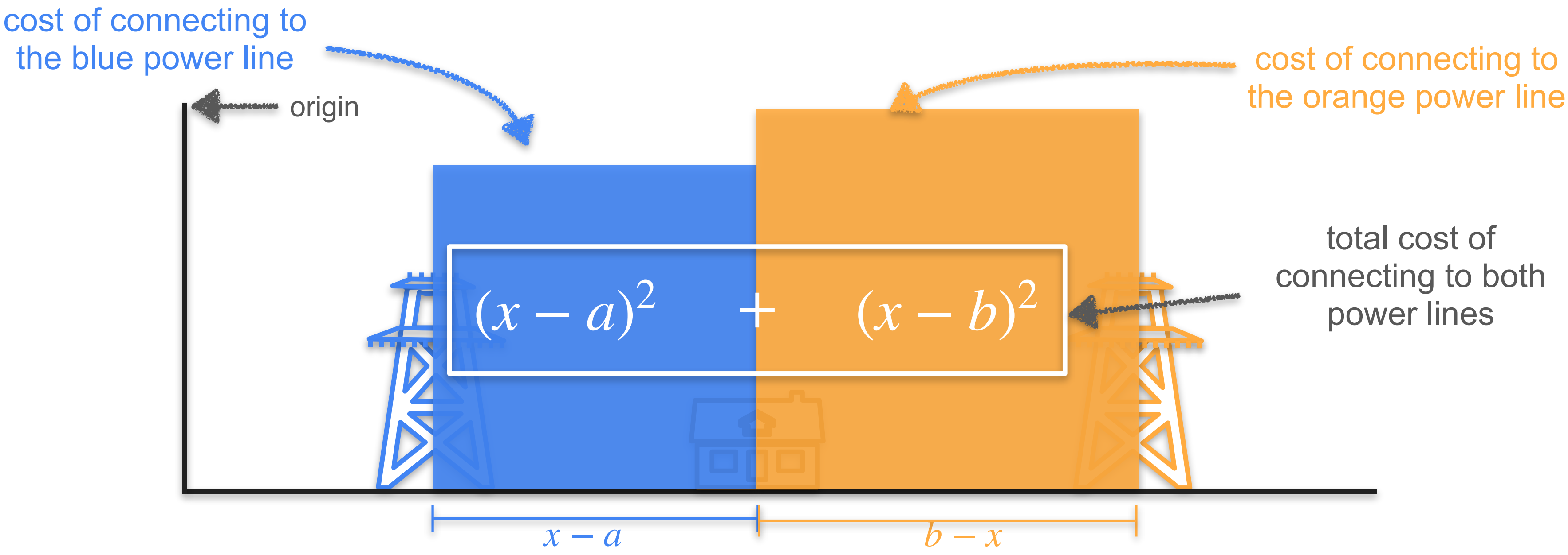
Two Power Line Problem - Square Analogy



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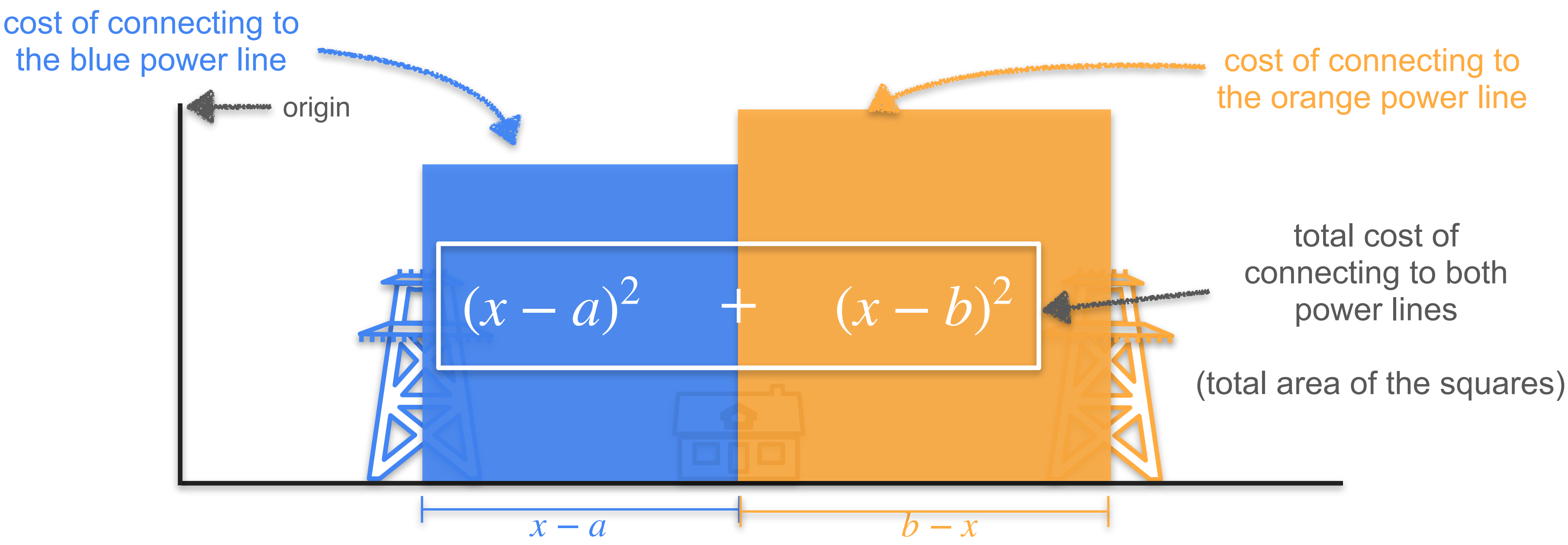

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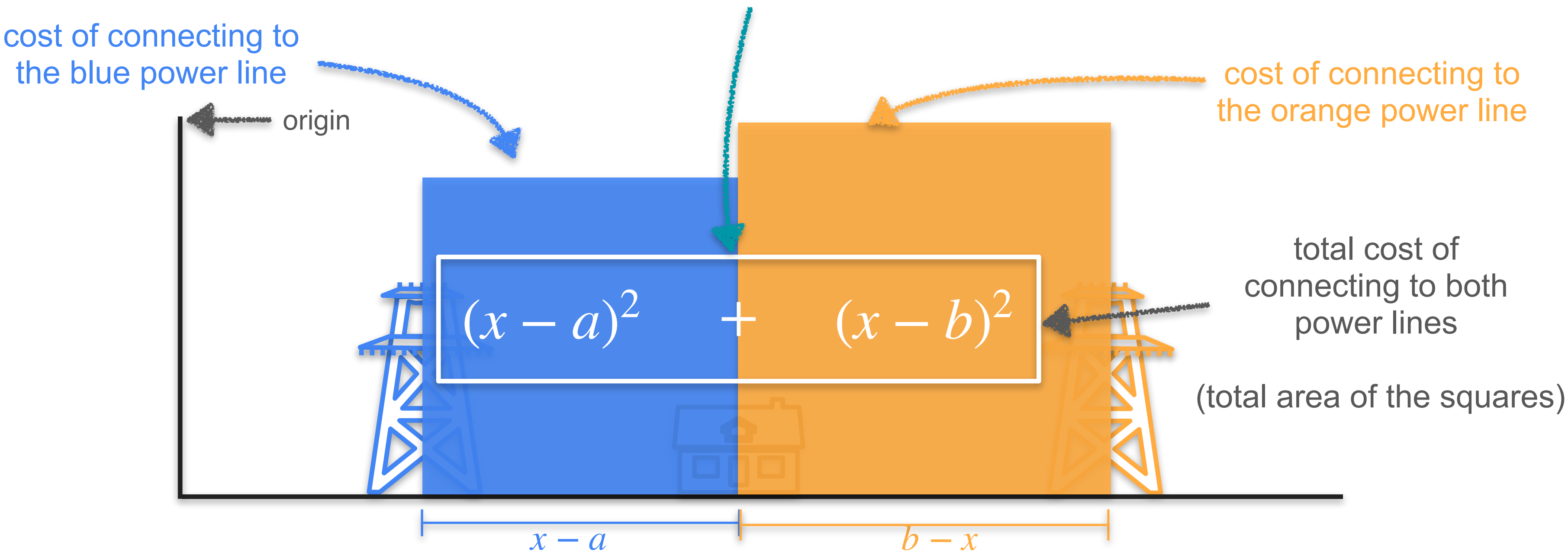
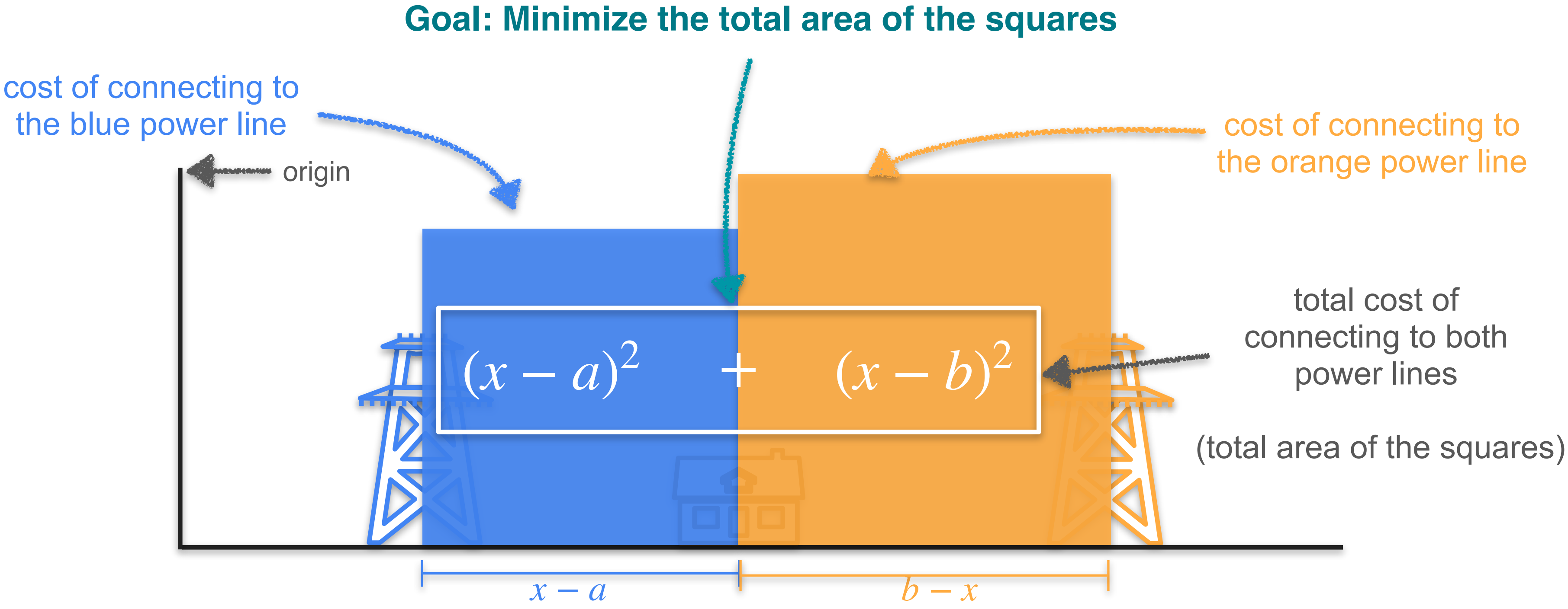
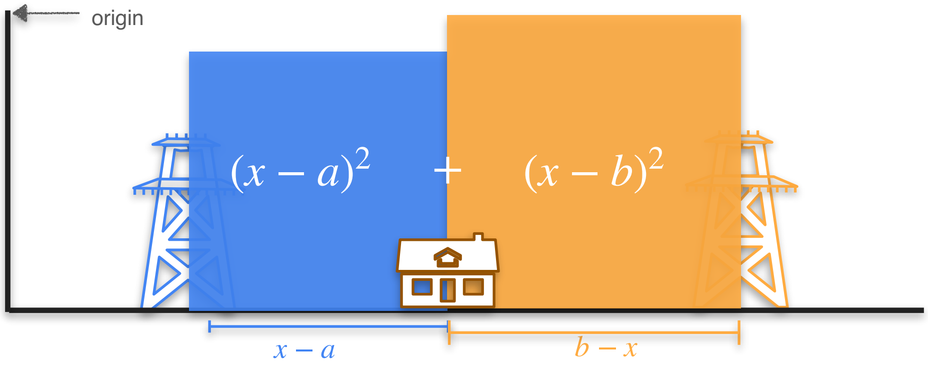
Two Power Line Problem - Square Analogy



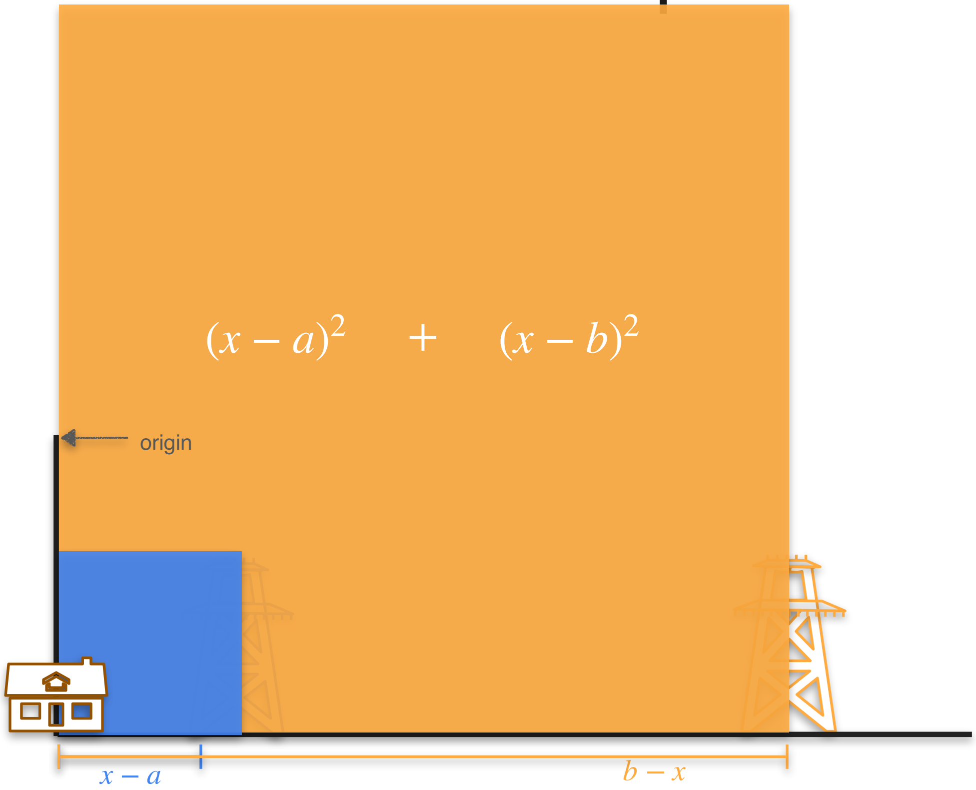
Two Power Line Problem - Square Analogy



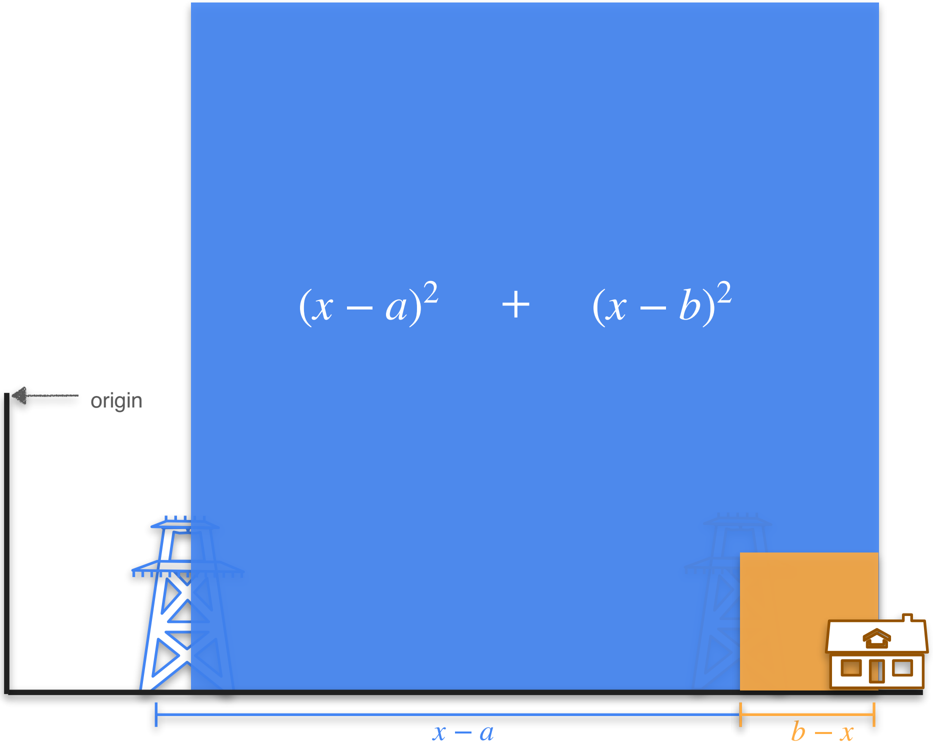
Minimize the Total Area of Squares



Minimize the Total Area of Squares



Minimize the Total Area of Squares



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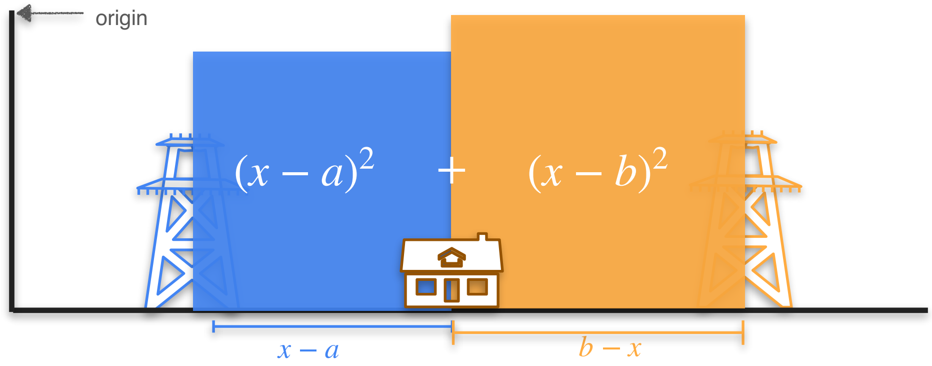


Two Power Line Problem

Two Power Line Problem

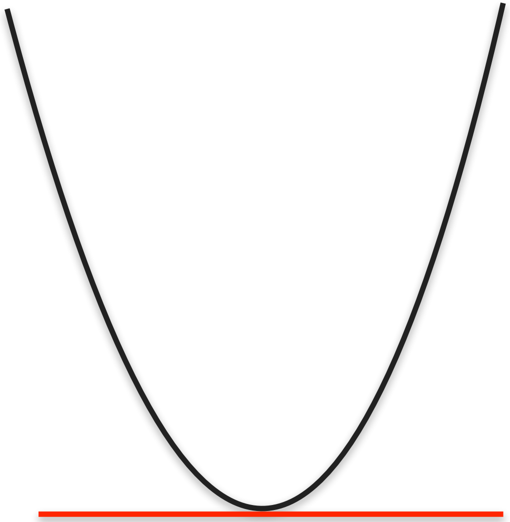
$$(x-a)^2 + (x-b)^2$$

Two Power Line Problem

$$(x-a)^2 + (x-b)^2$$

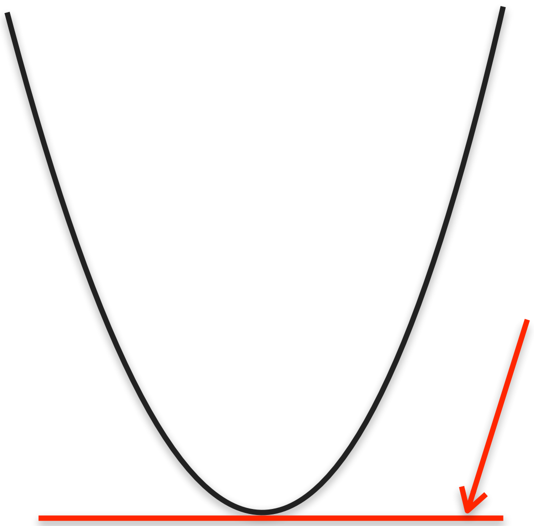
Two Power Line Problem

$$(x-a)^2+(x-b)^2$$



Two Power Line Problem

$$(x-a)^2 + (x-b)^2$$



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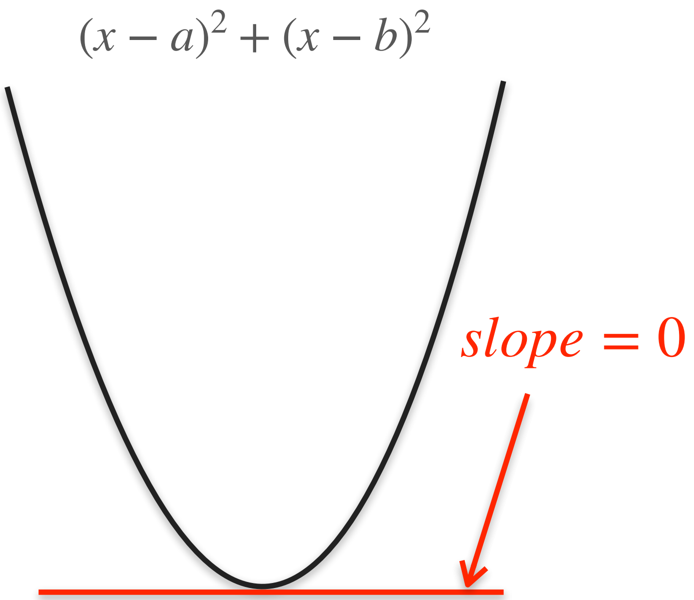

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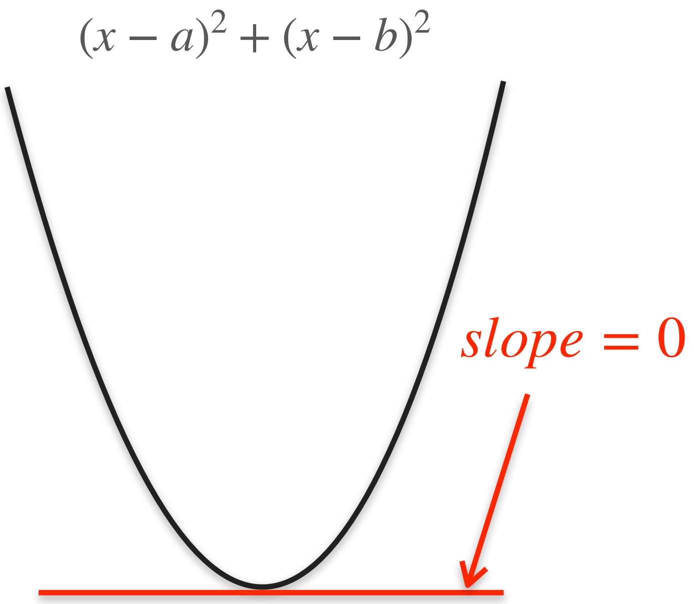
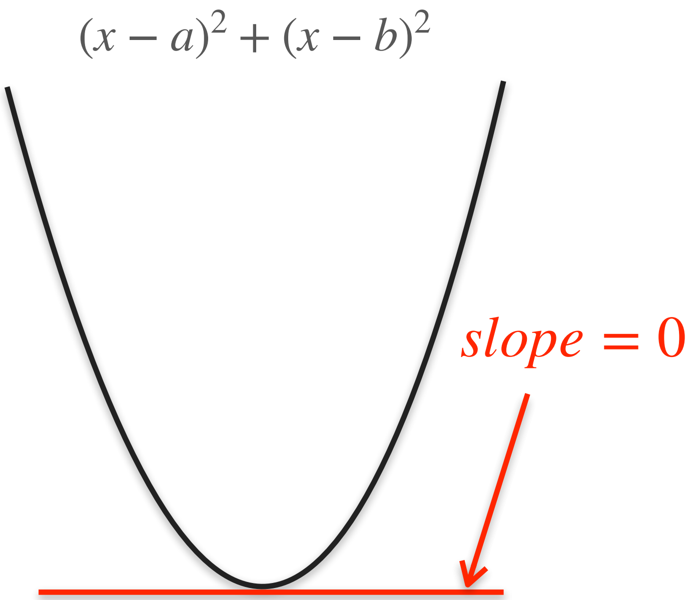


$$\frac{d}{dx}\left[(x-a)^2 + (x-b)^2\right] = 0$$

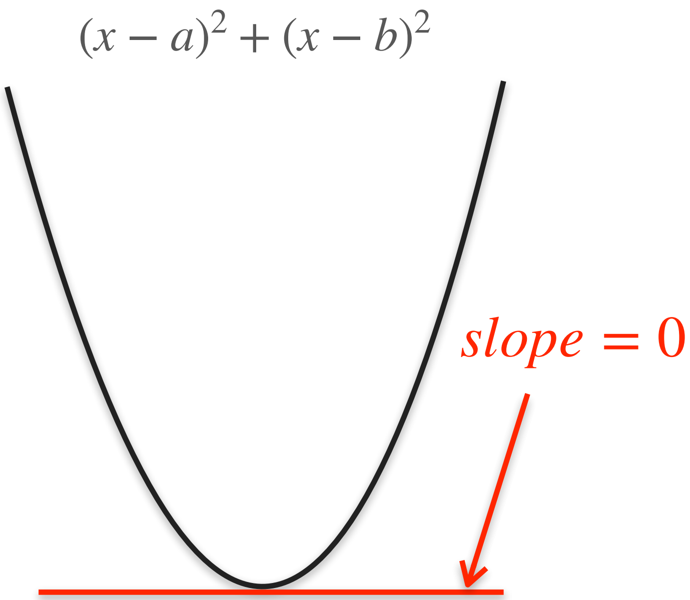
Two Power Line Problem



$$\frac{d}{dx}\left[(x-a)^2 + (x-b)^2\right] = 0$$

$$2(x-a) + 2(x-b) = 0$$

Two Power Line Problem

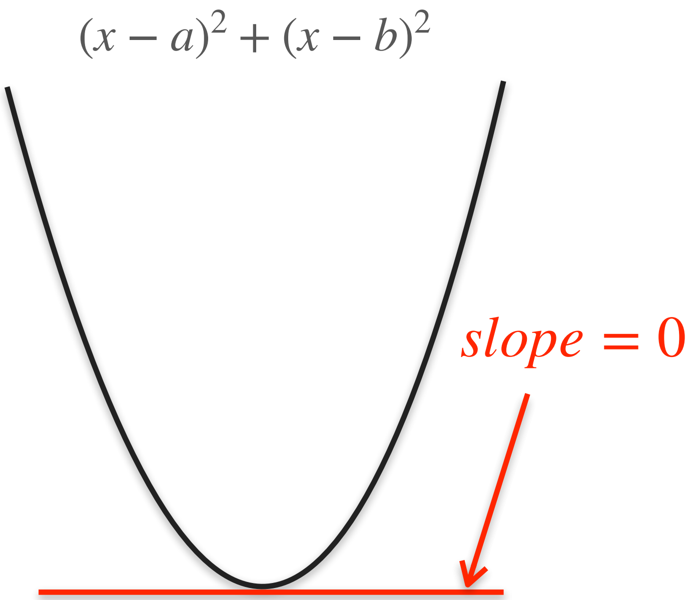


$$\frac{d}{dx}\left[(x-a)^2 + (x-b)^2\right] = 0$$

$$2(x-a) + 2(x-b) = 0$$

$$(x-a) + (x-b) = 0$$

Two Power Line Problem



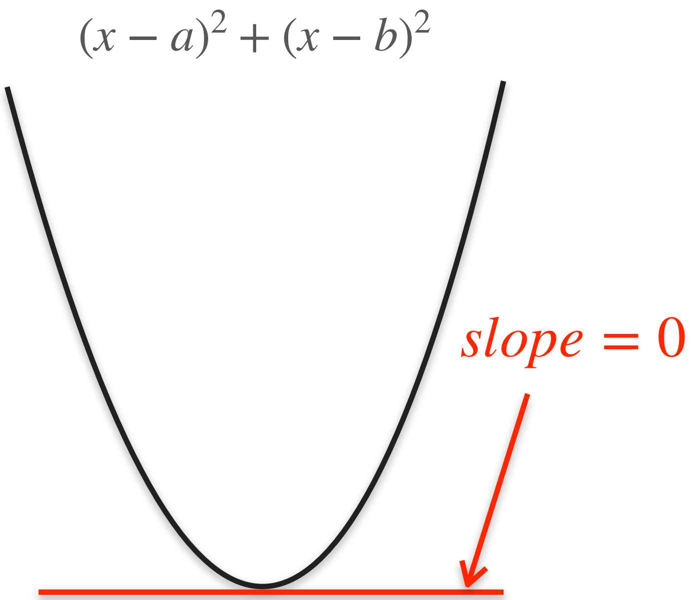
$$\frac{d}{dx}\left[(x-a)^2 + (x-b)^2\right] = 0$$

$$2(x-a) + 2(x-b) = 0$$

$$(x-a) + (x-b) = 0$$

$$2x - a - b = 0$$

Two Power Line Problem



$$\frac{d}{dx}\left[(x-a)^2+(x-b)^2\right]=0$$

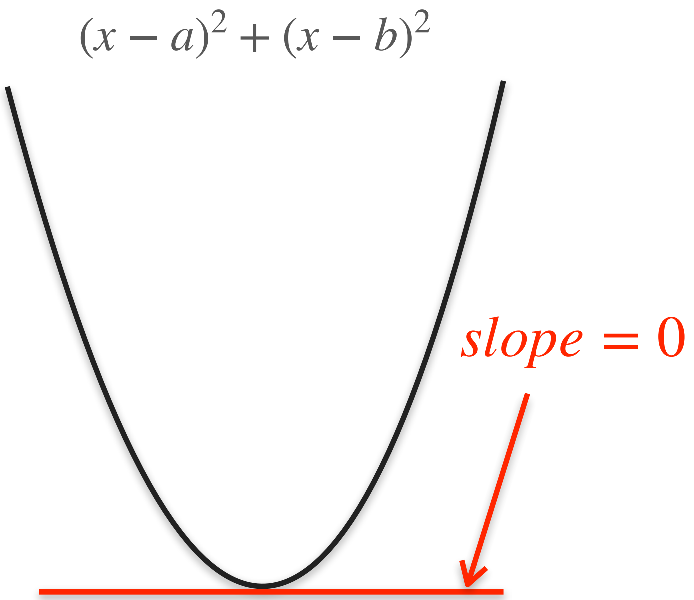
$$2(x-a)+2(x-b)=0$$

$$(x-a)+(x-b)=0$$

$$2x-a-b=0$$

$$2x=a+b$$

Two Power Line Problem



$$\frac{d}{dx}\left[(x-a)^2+(x-b)^2\right]=0$$

$$2(x-a)+2(x-b)=0$$

$$(x-a)+(x-b)=0$$

$$2x-a-b=0$$

$$2x=a+b$$

$$x=\frac{a+b}{2}$$

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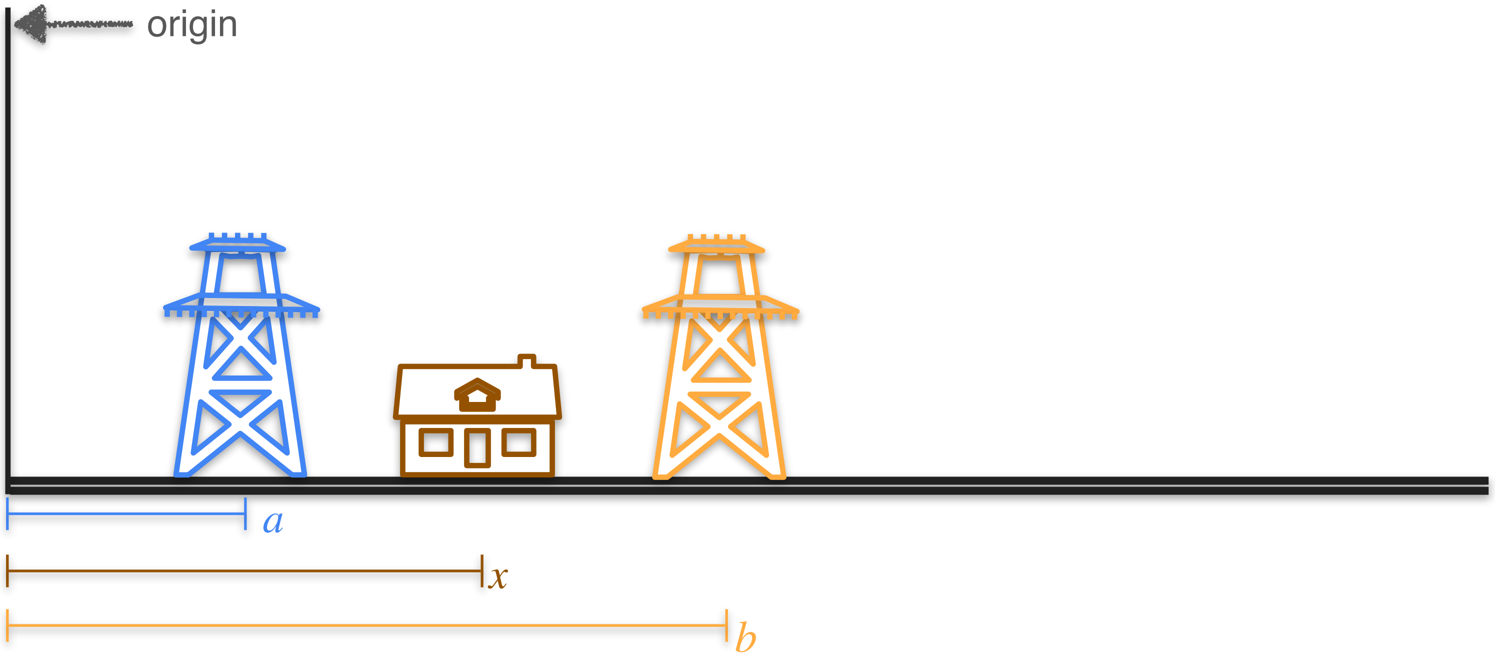
Derivatives and Optimization

Optimization of squared loss: The three powerline problem

Three Power Line Problem



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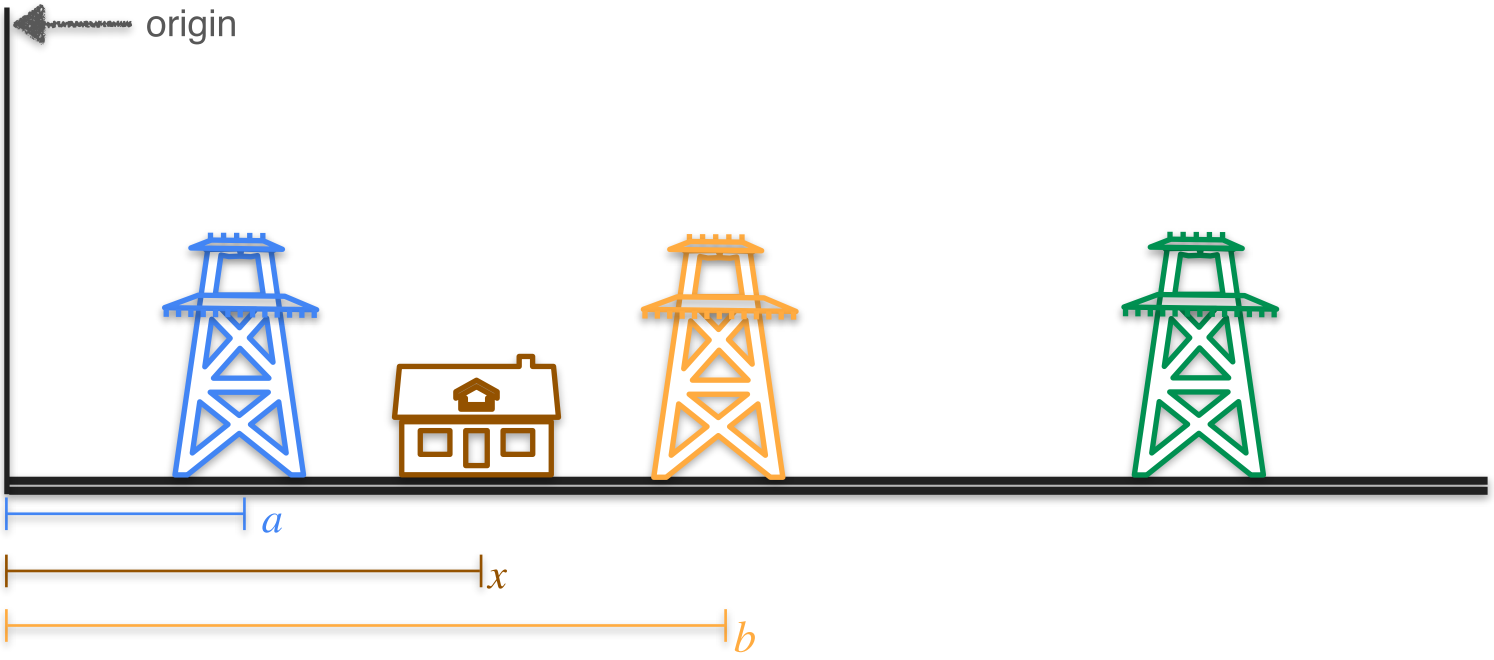

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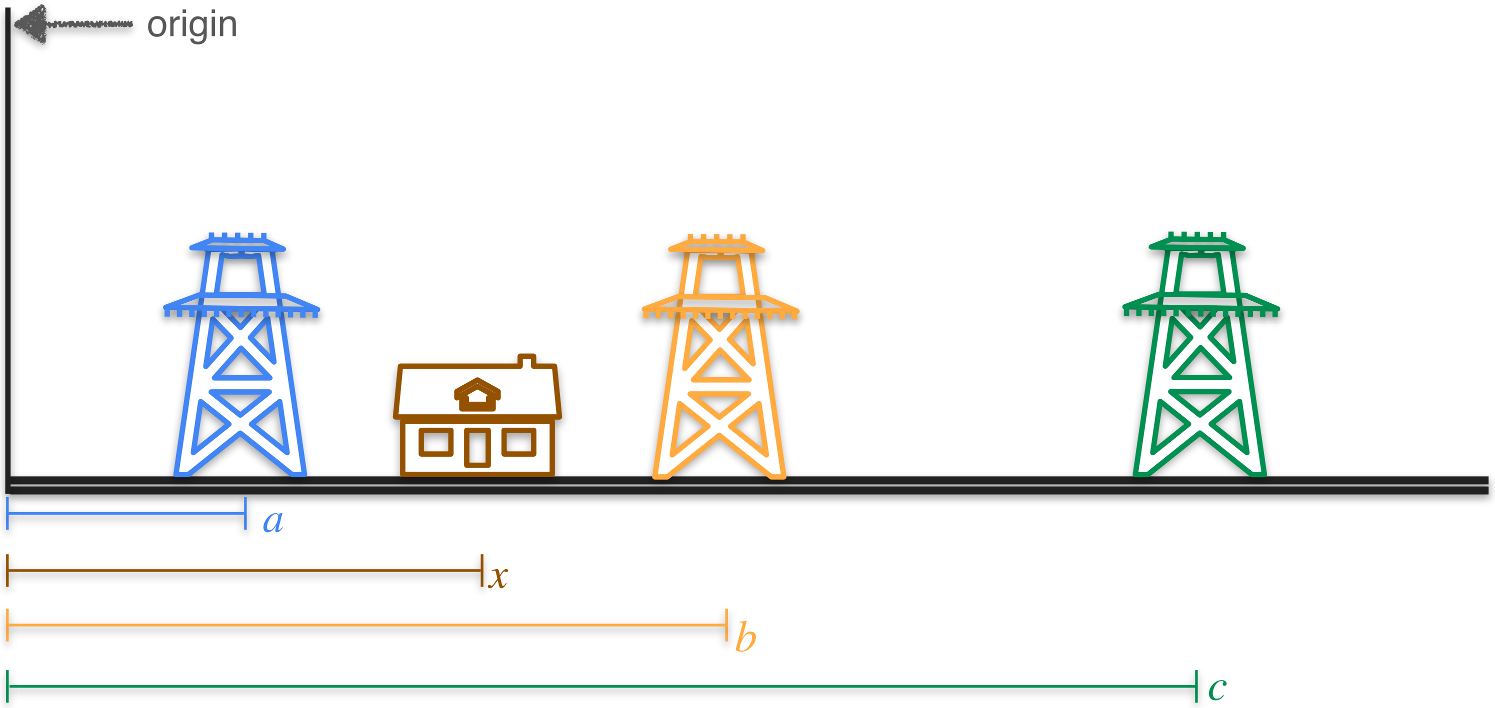

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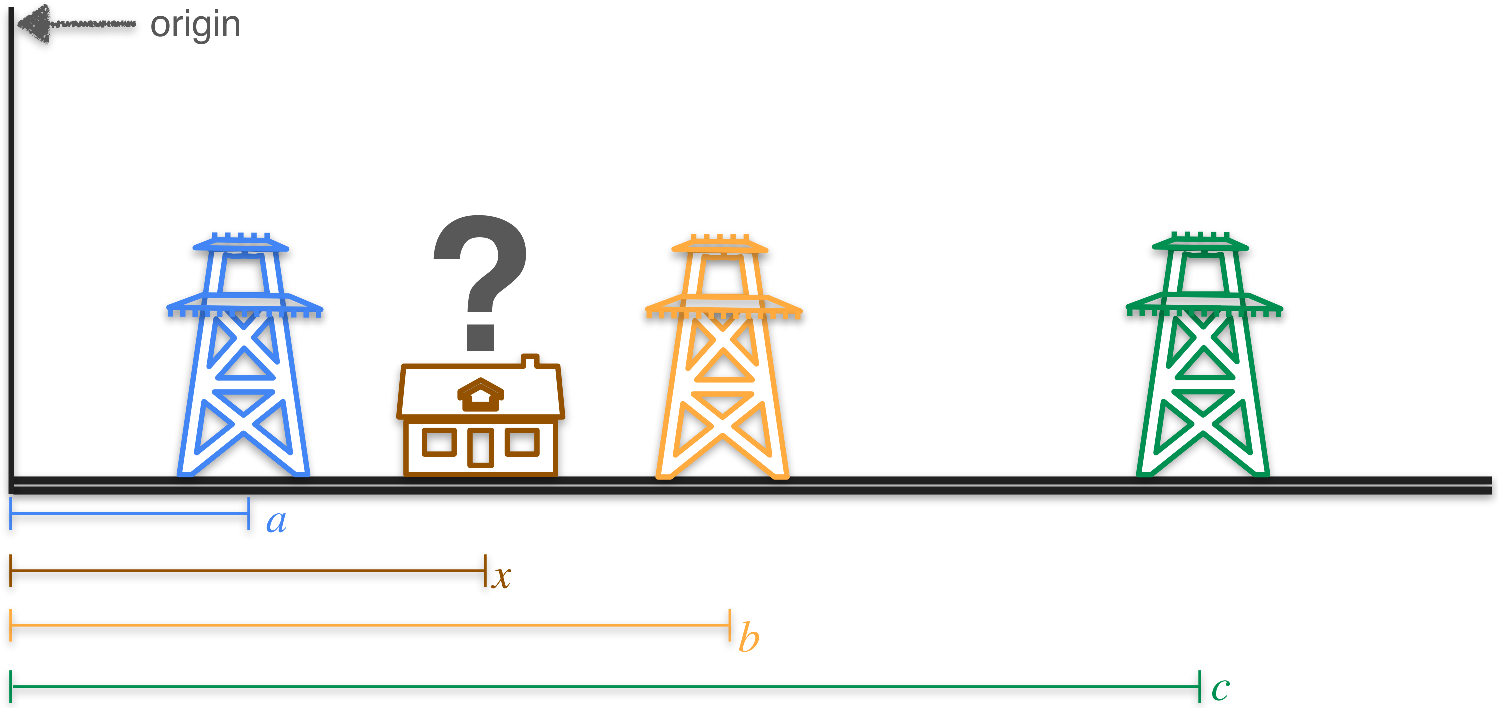

Three Power Line Problem

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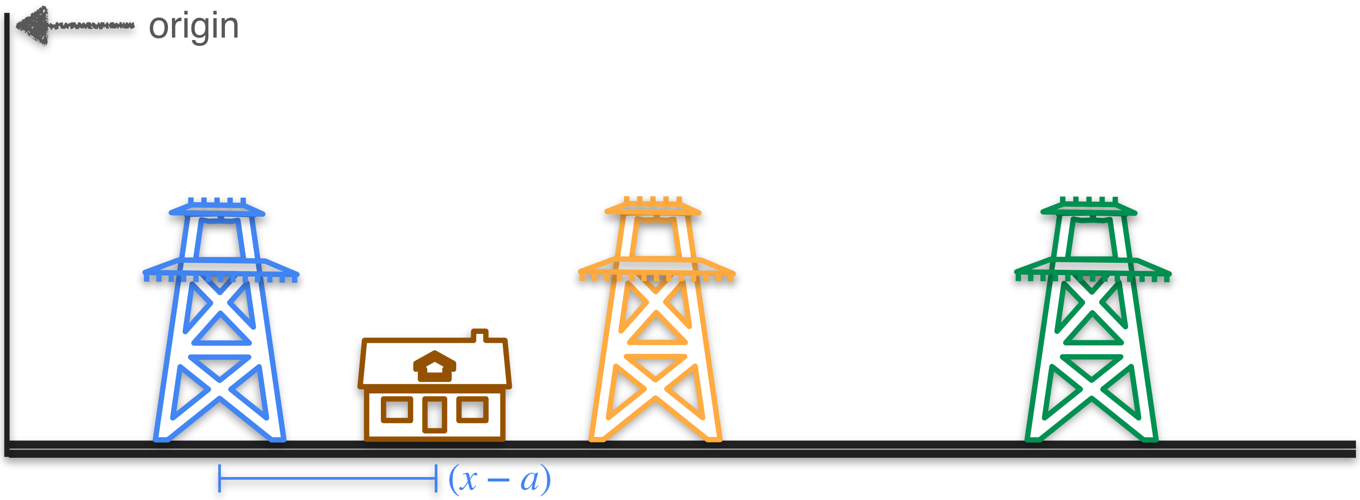
Three Power Line Problem



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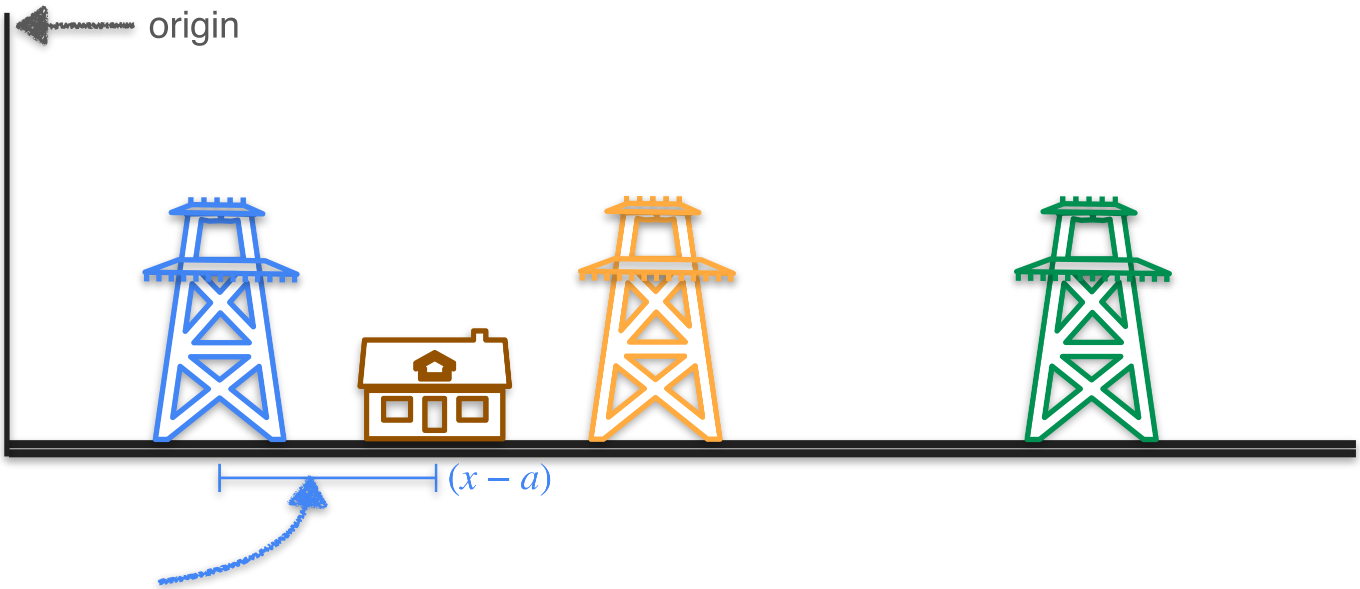

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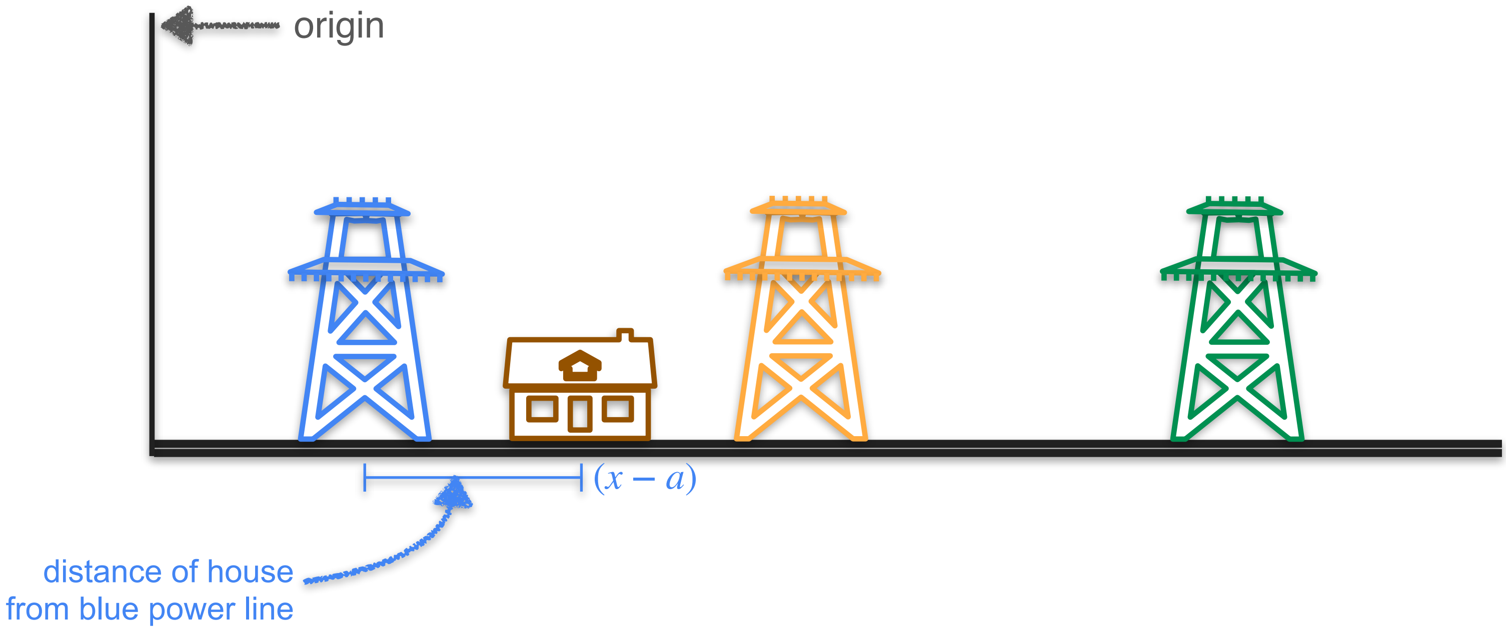

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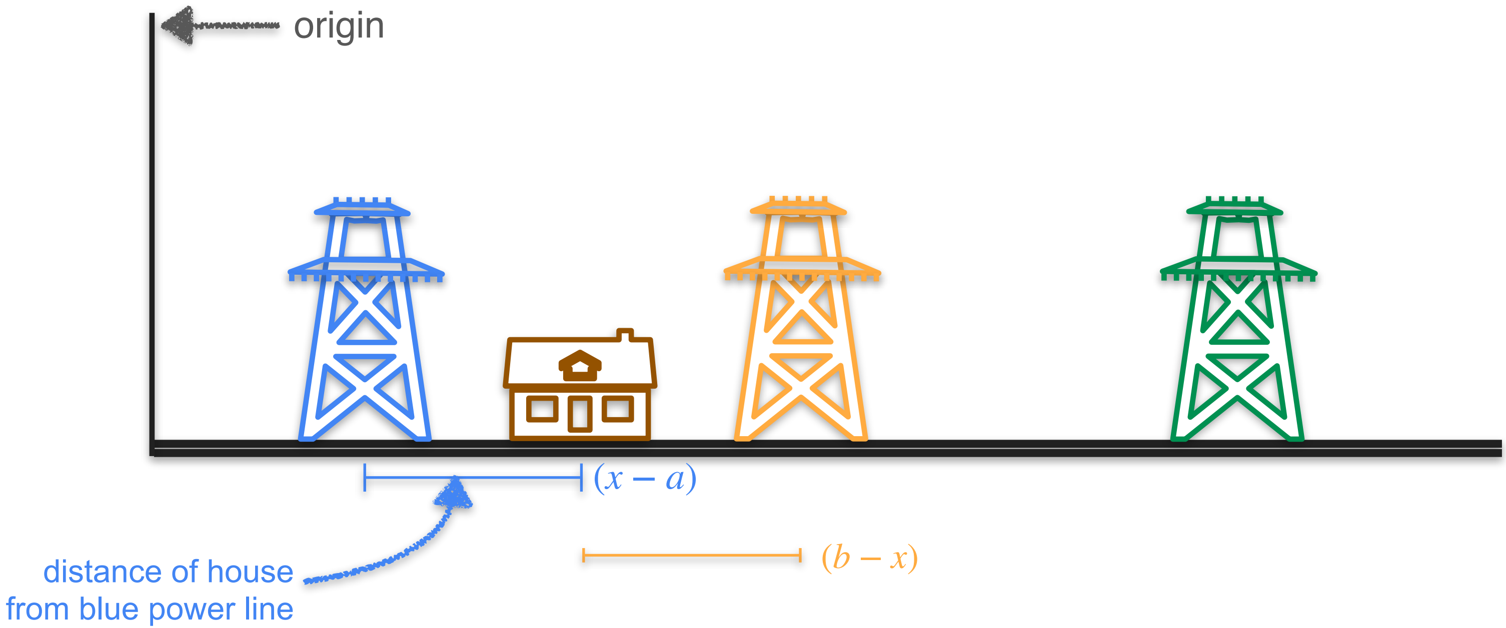

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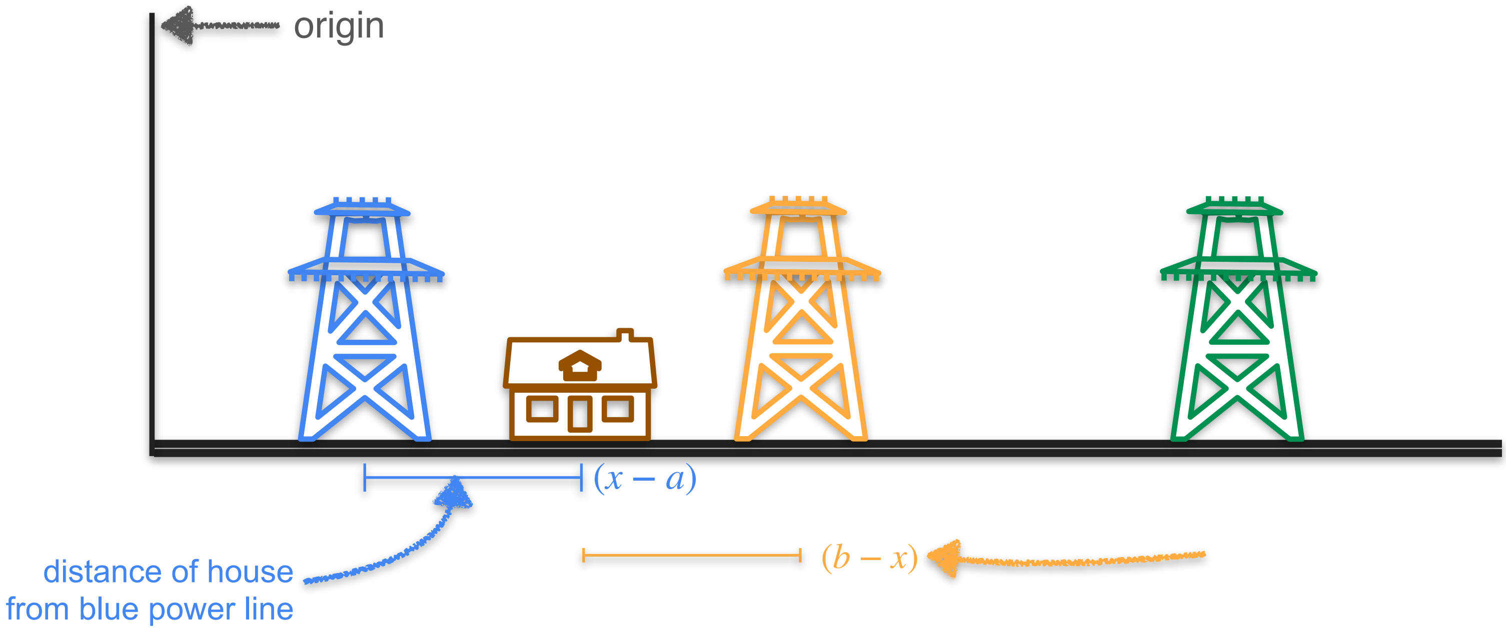

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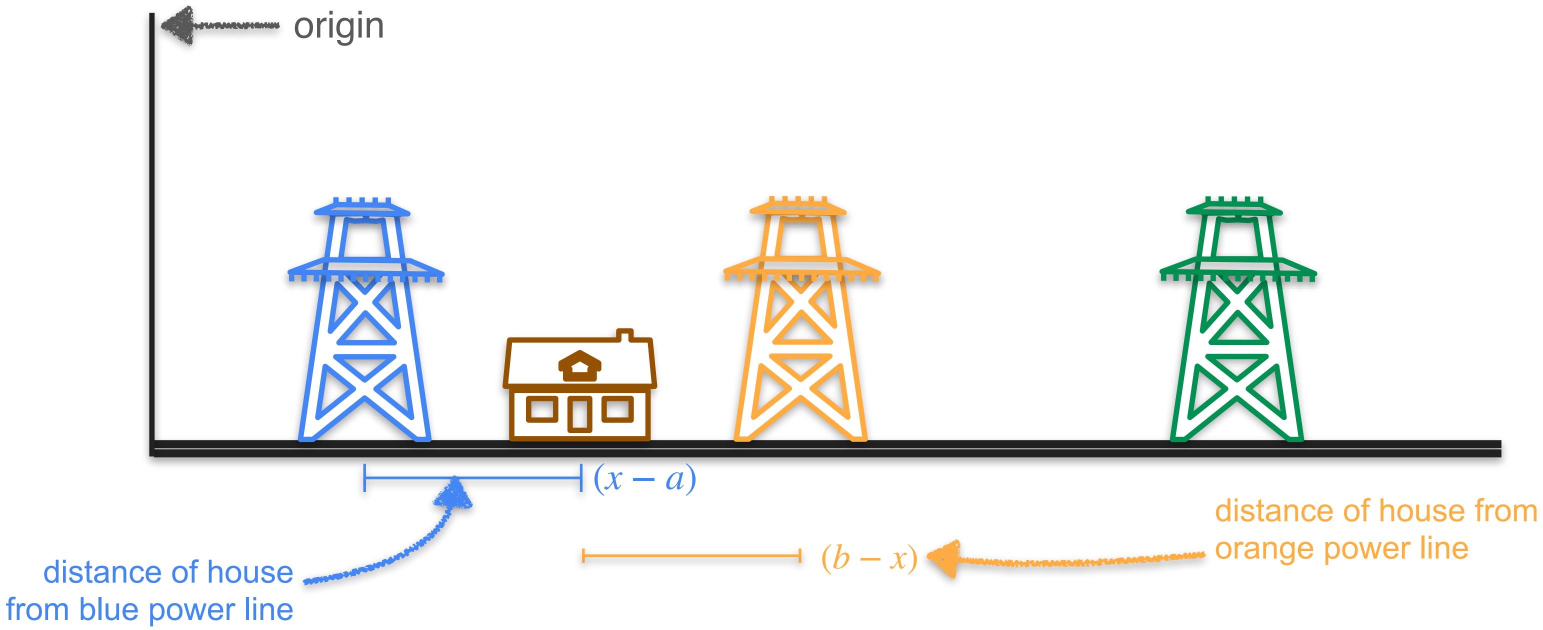

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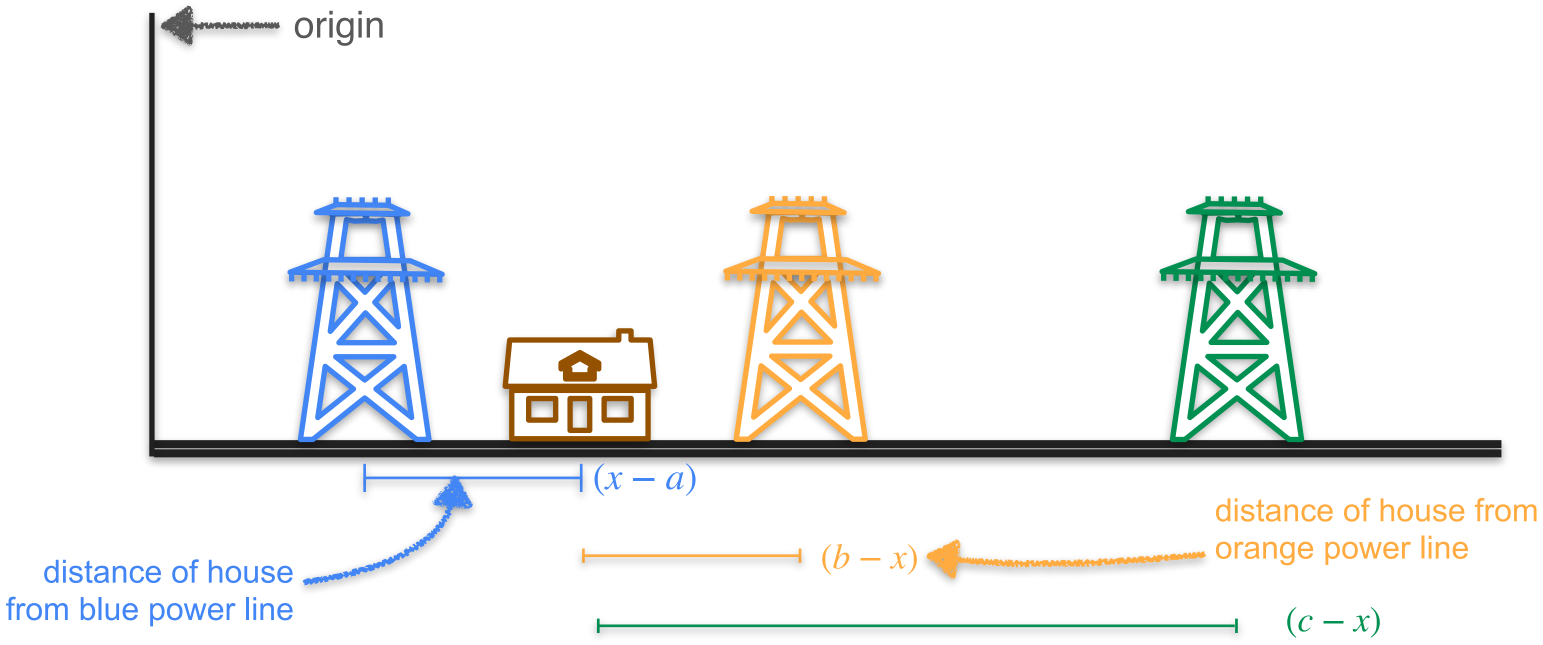
Three Power Line Problem



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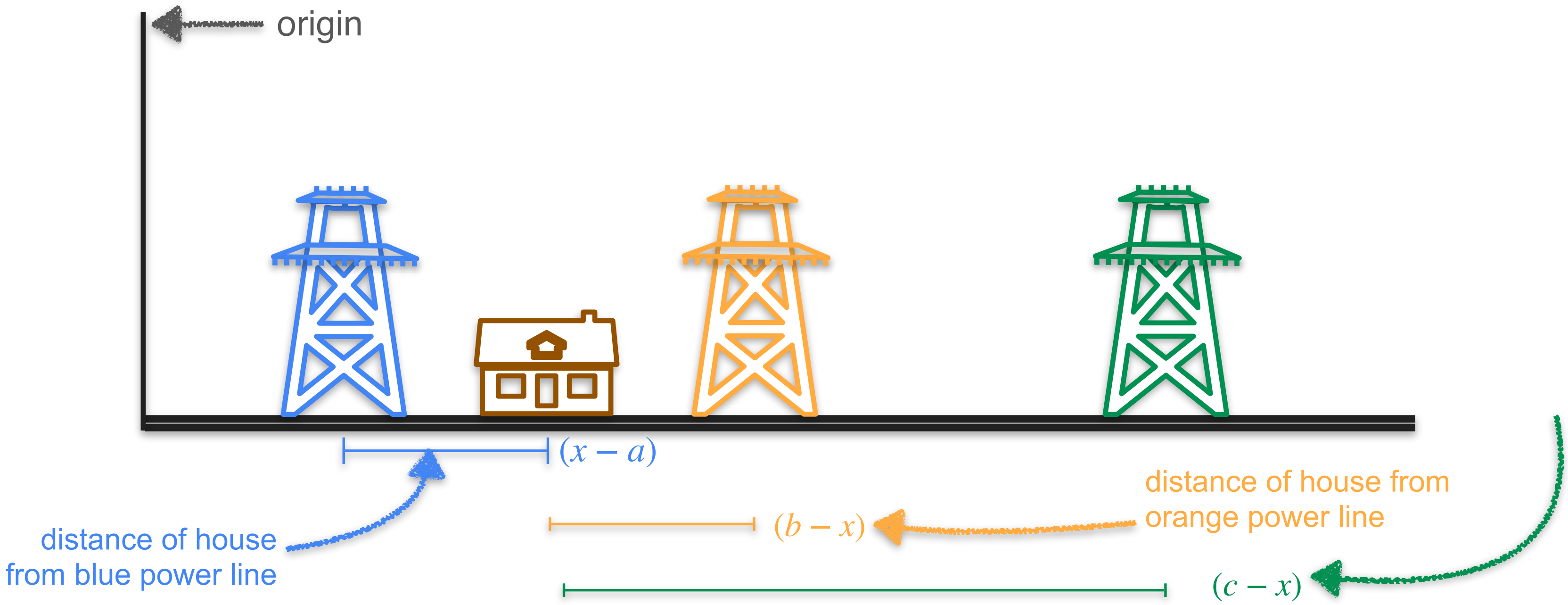

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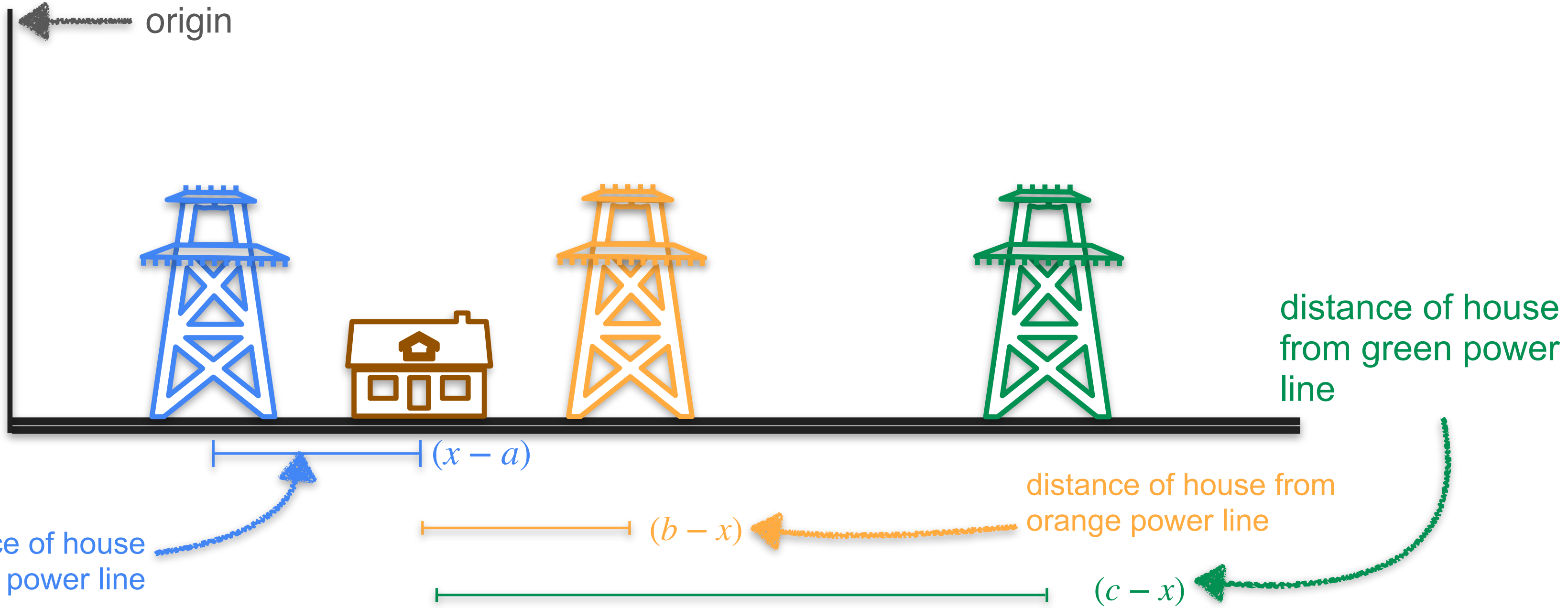

Three Power Line Problem

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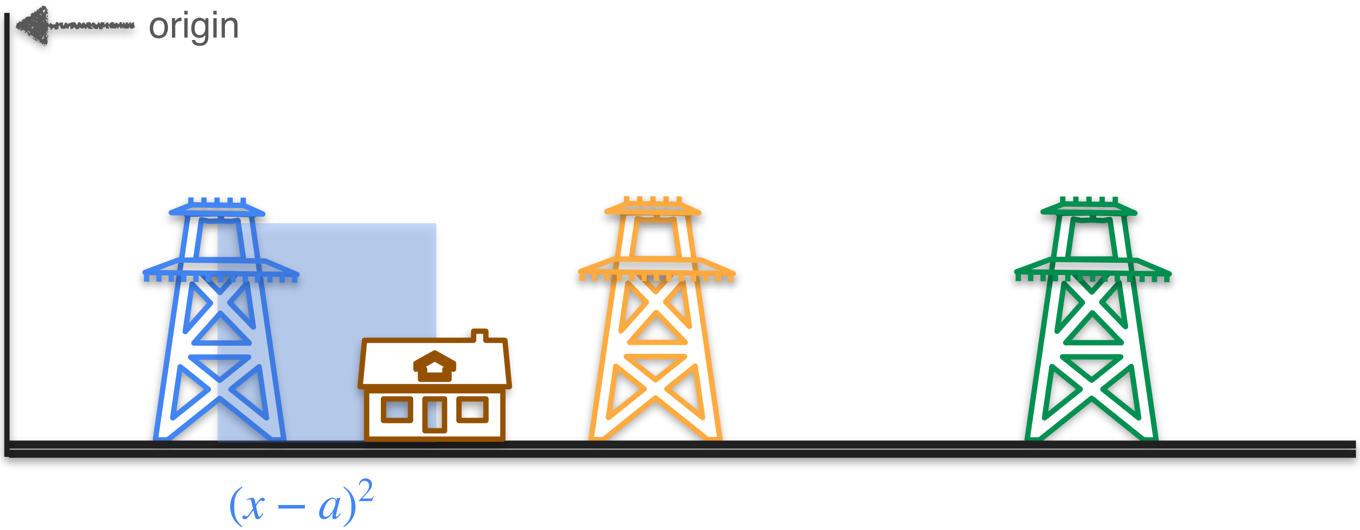

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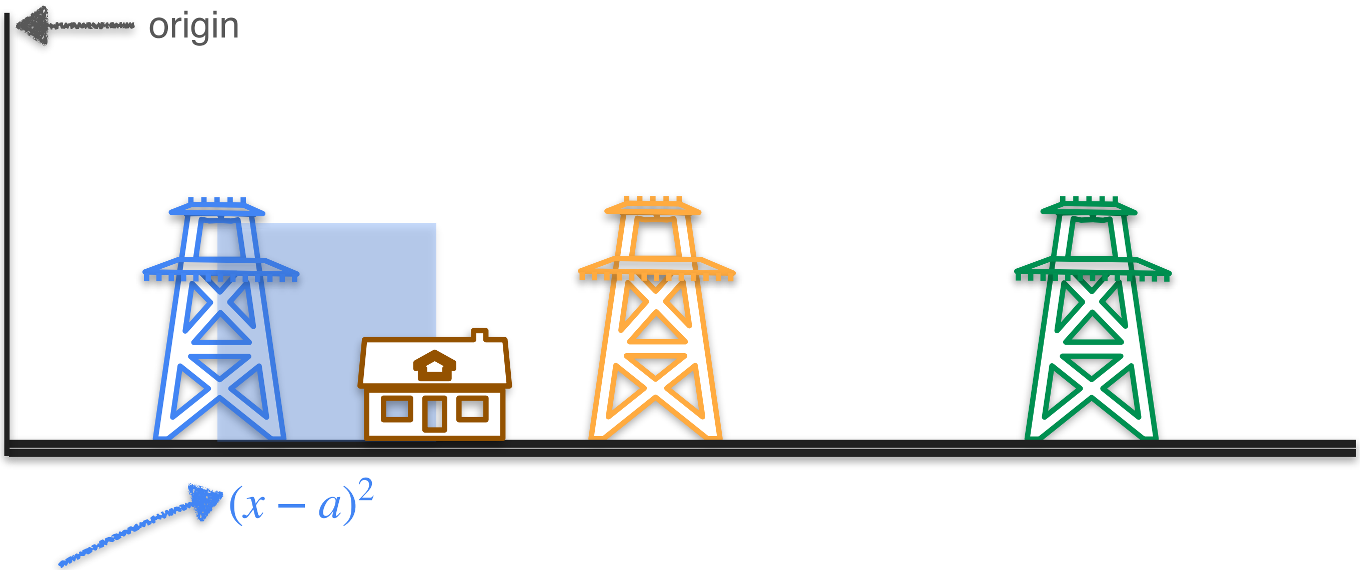

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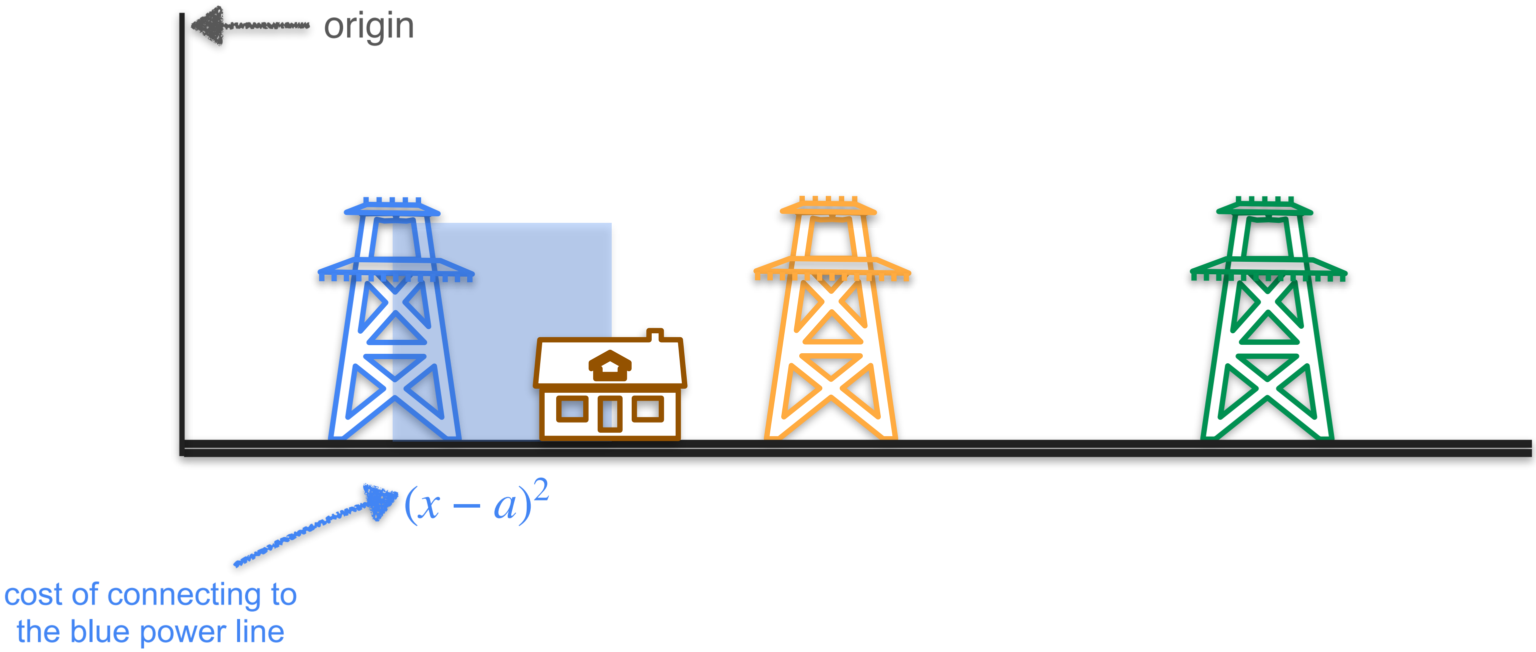

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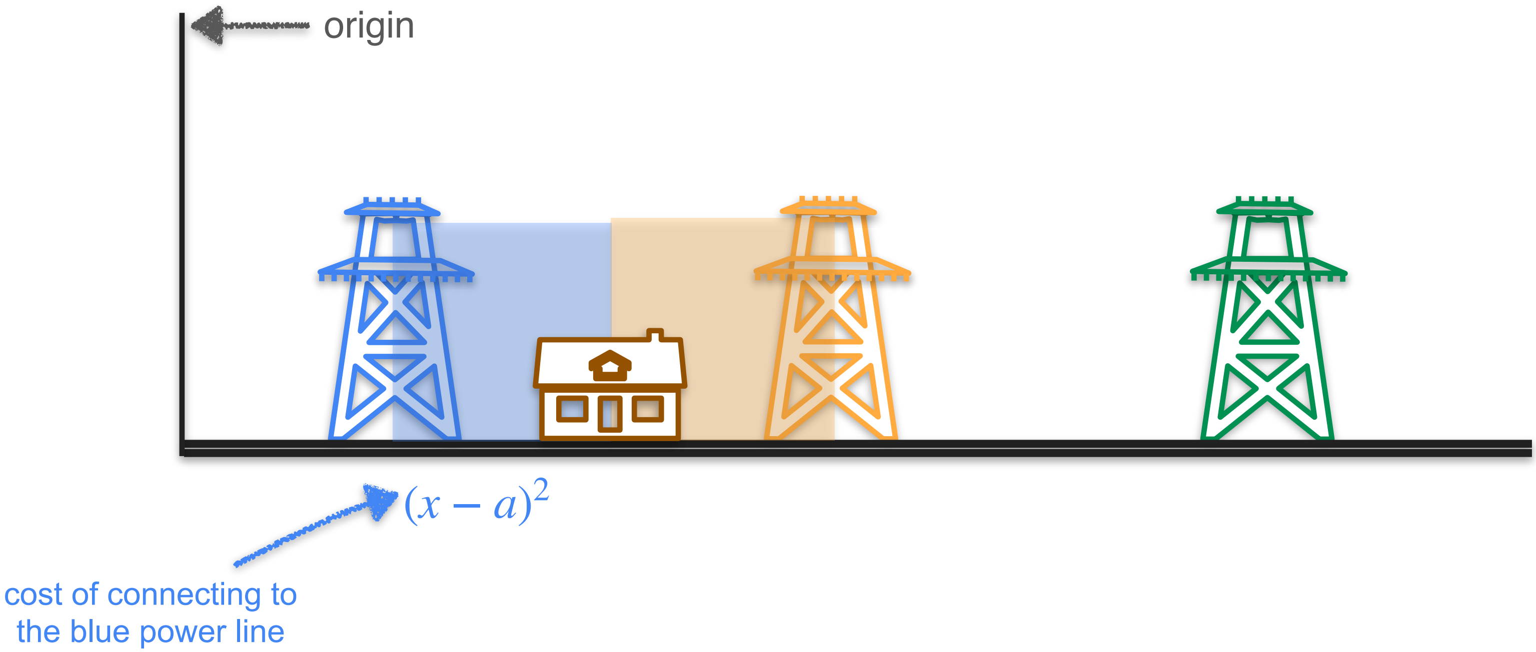

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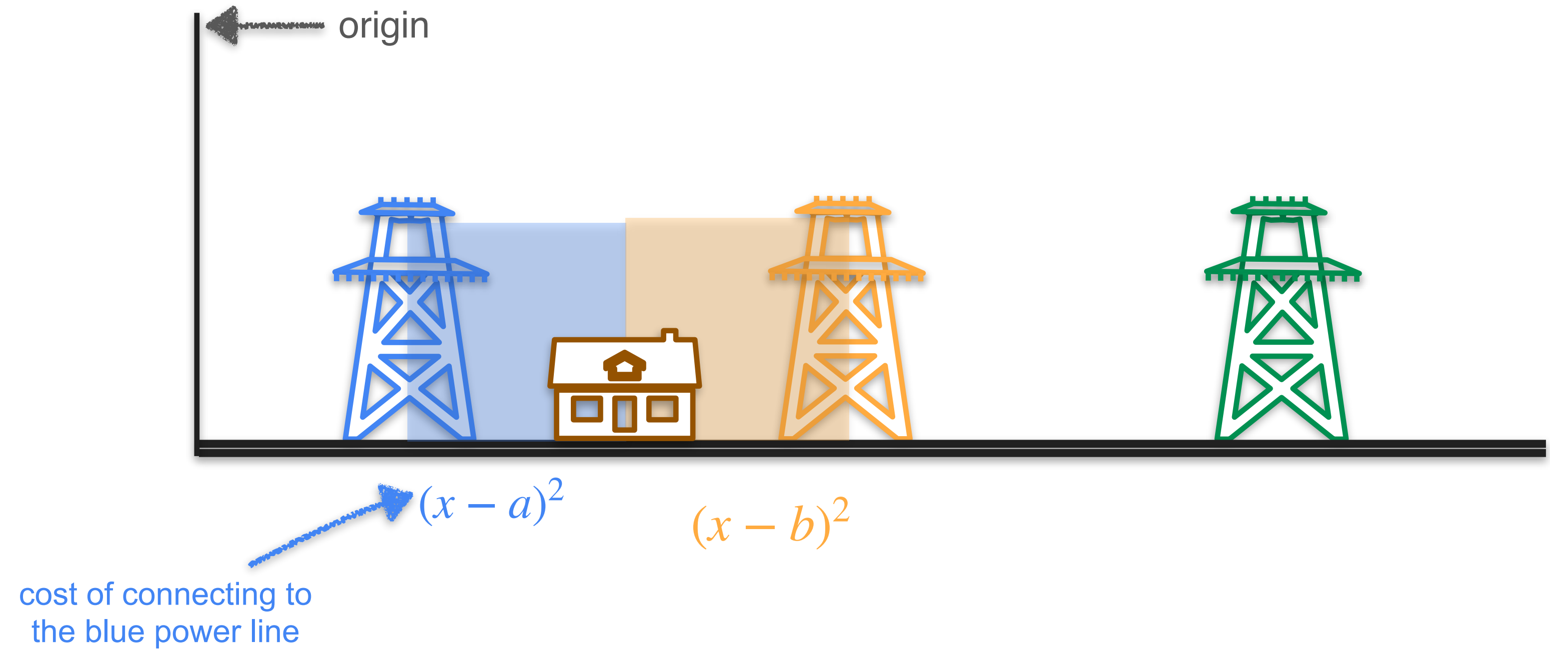

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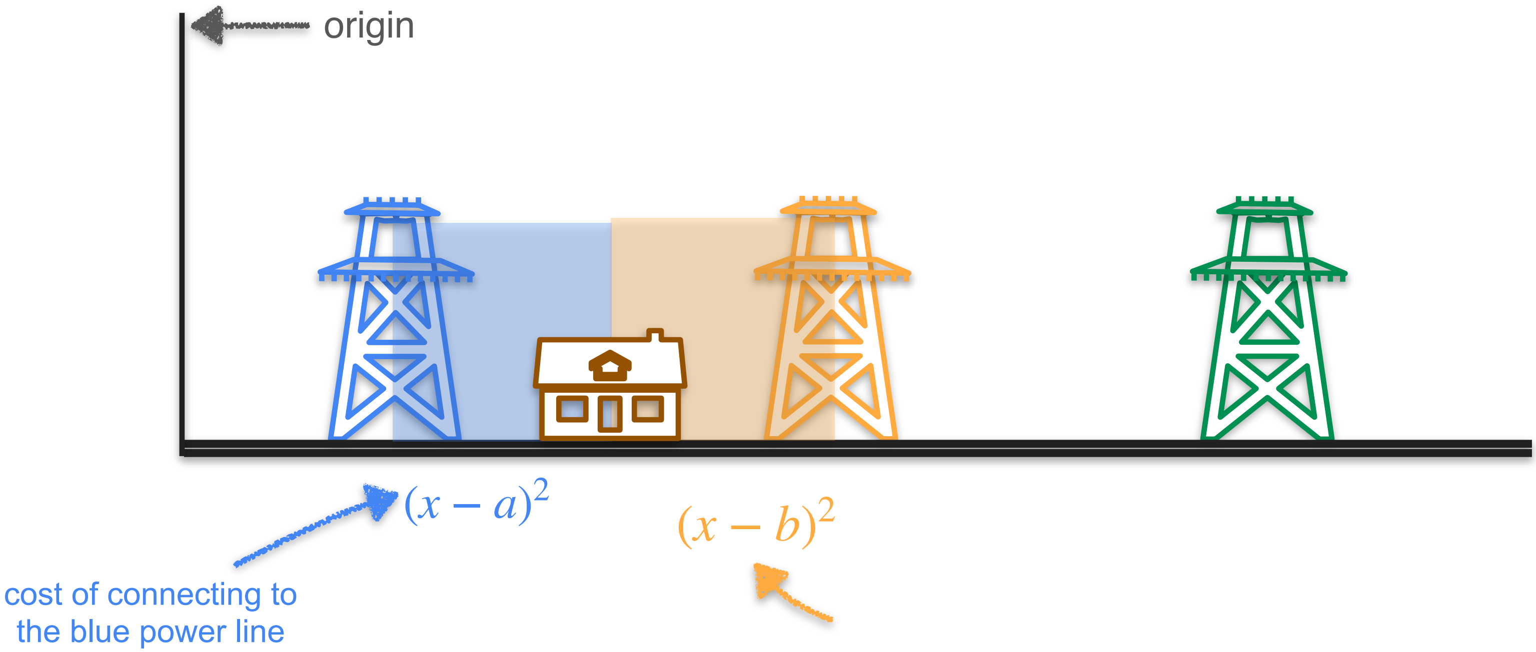

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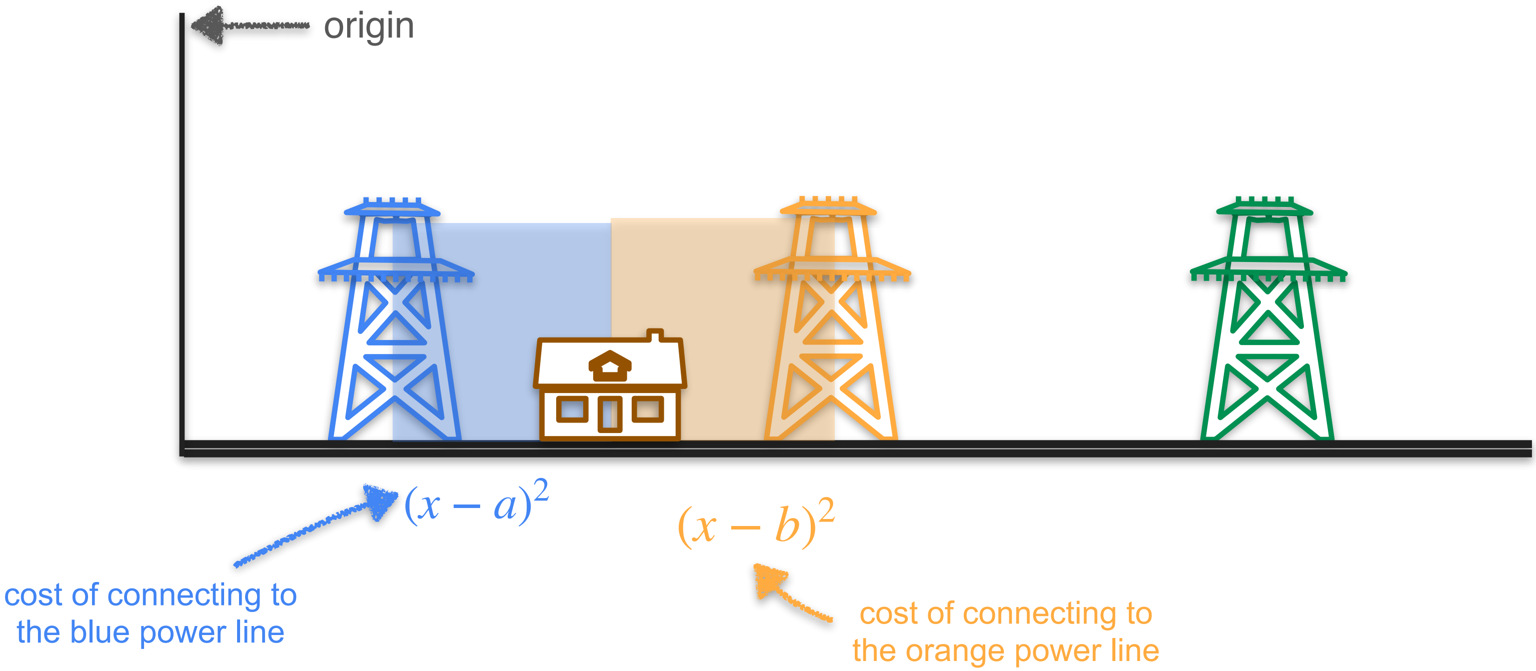

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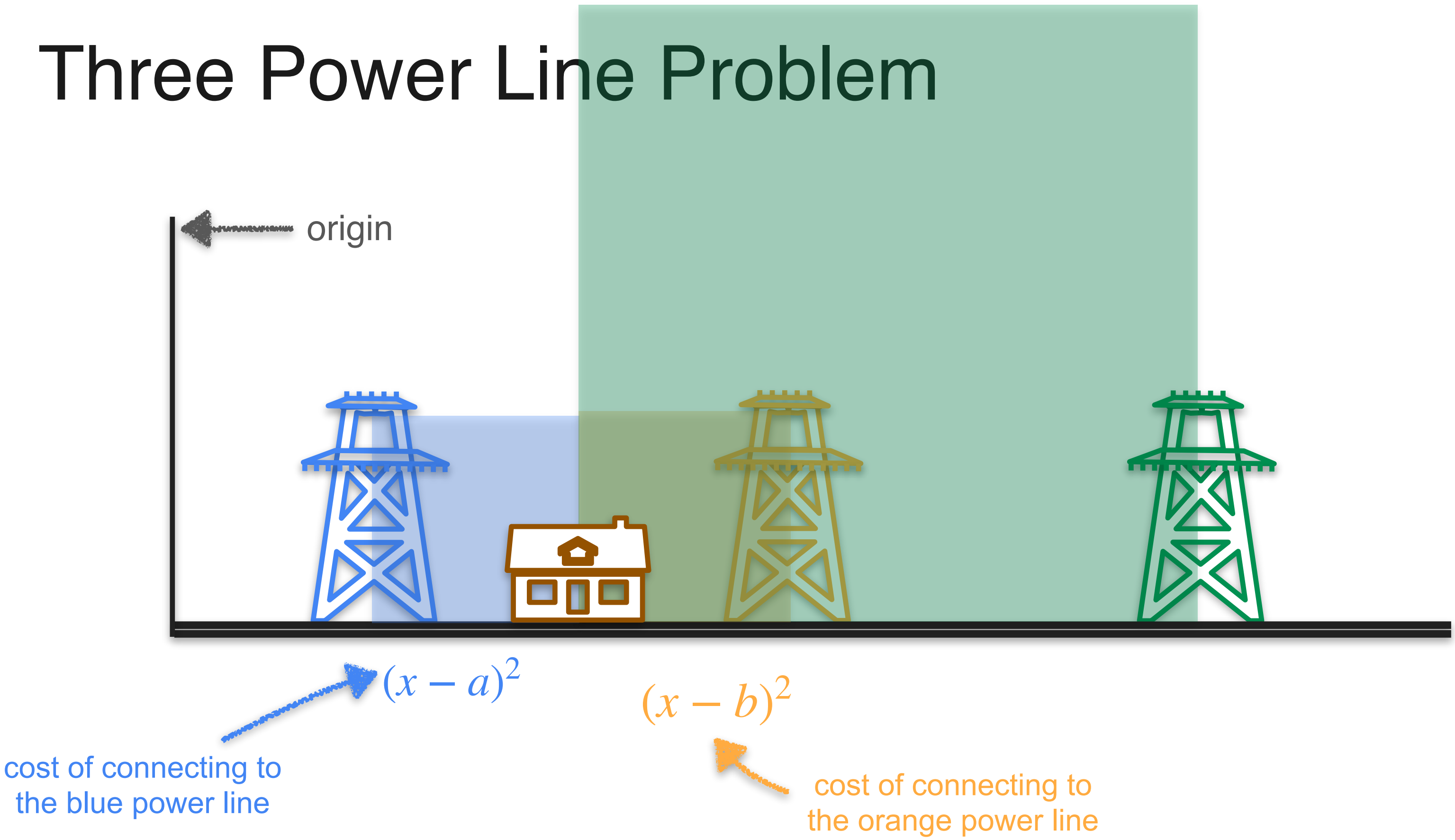
Three Power Line Problem



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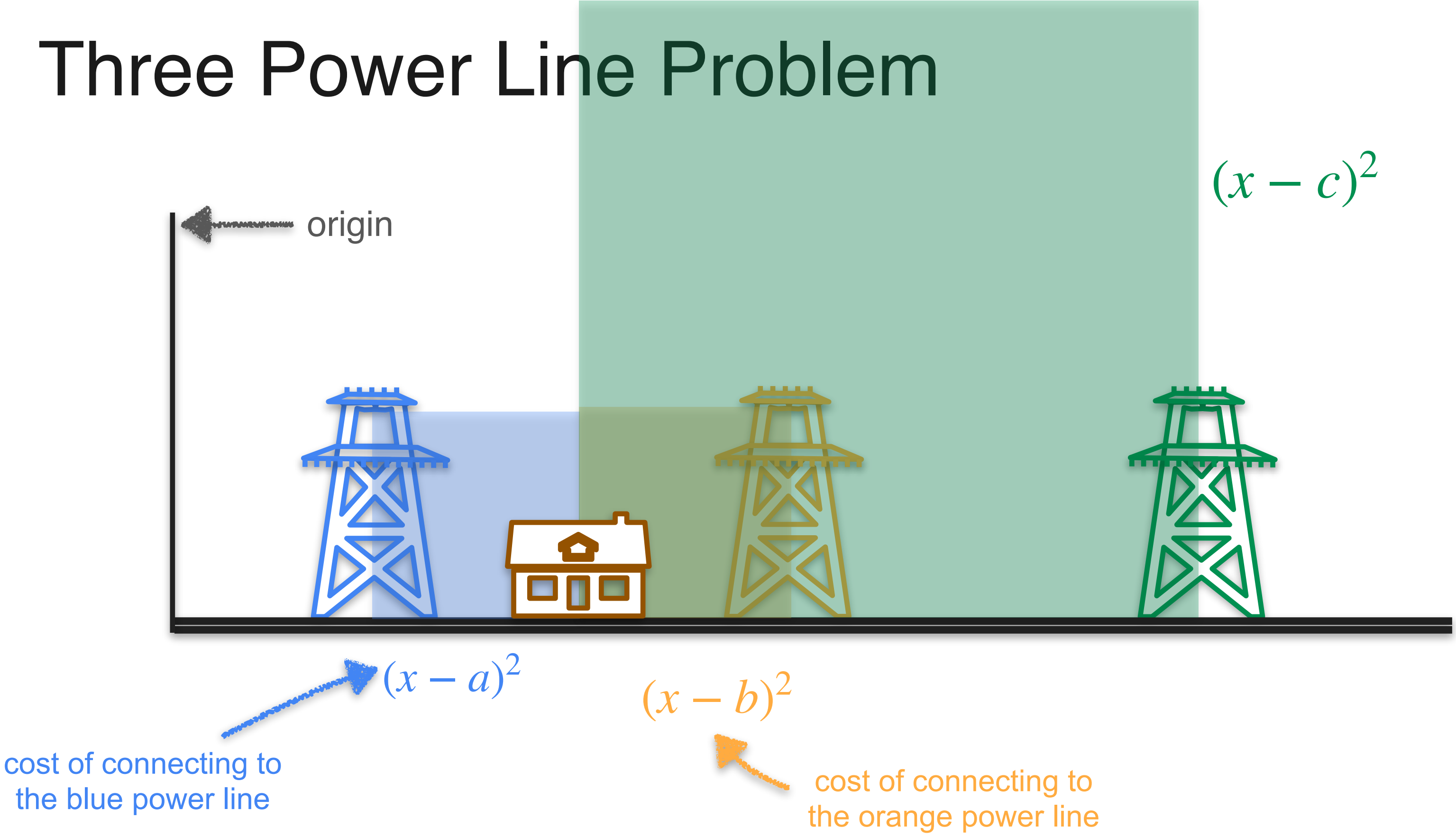

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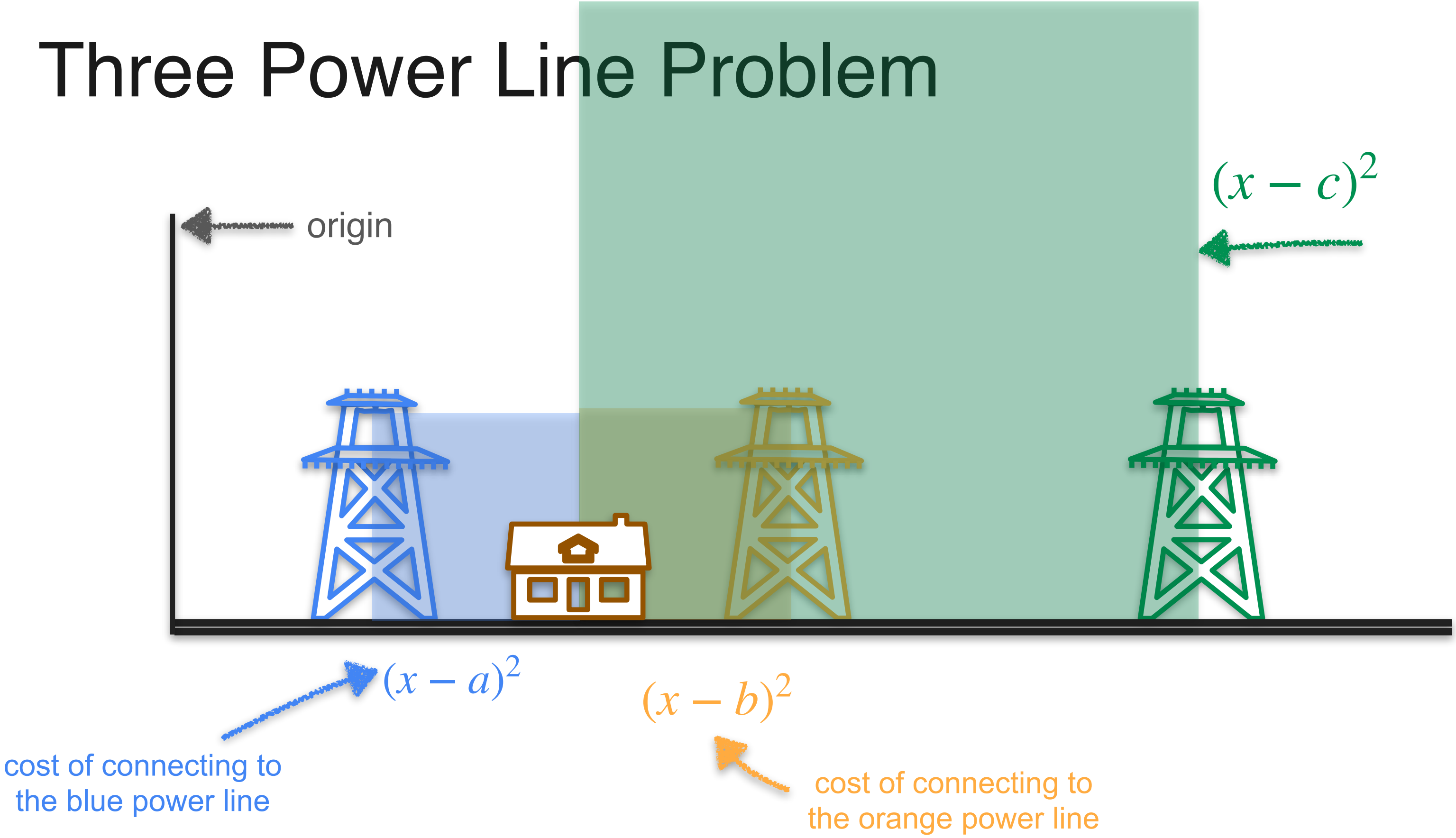
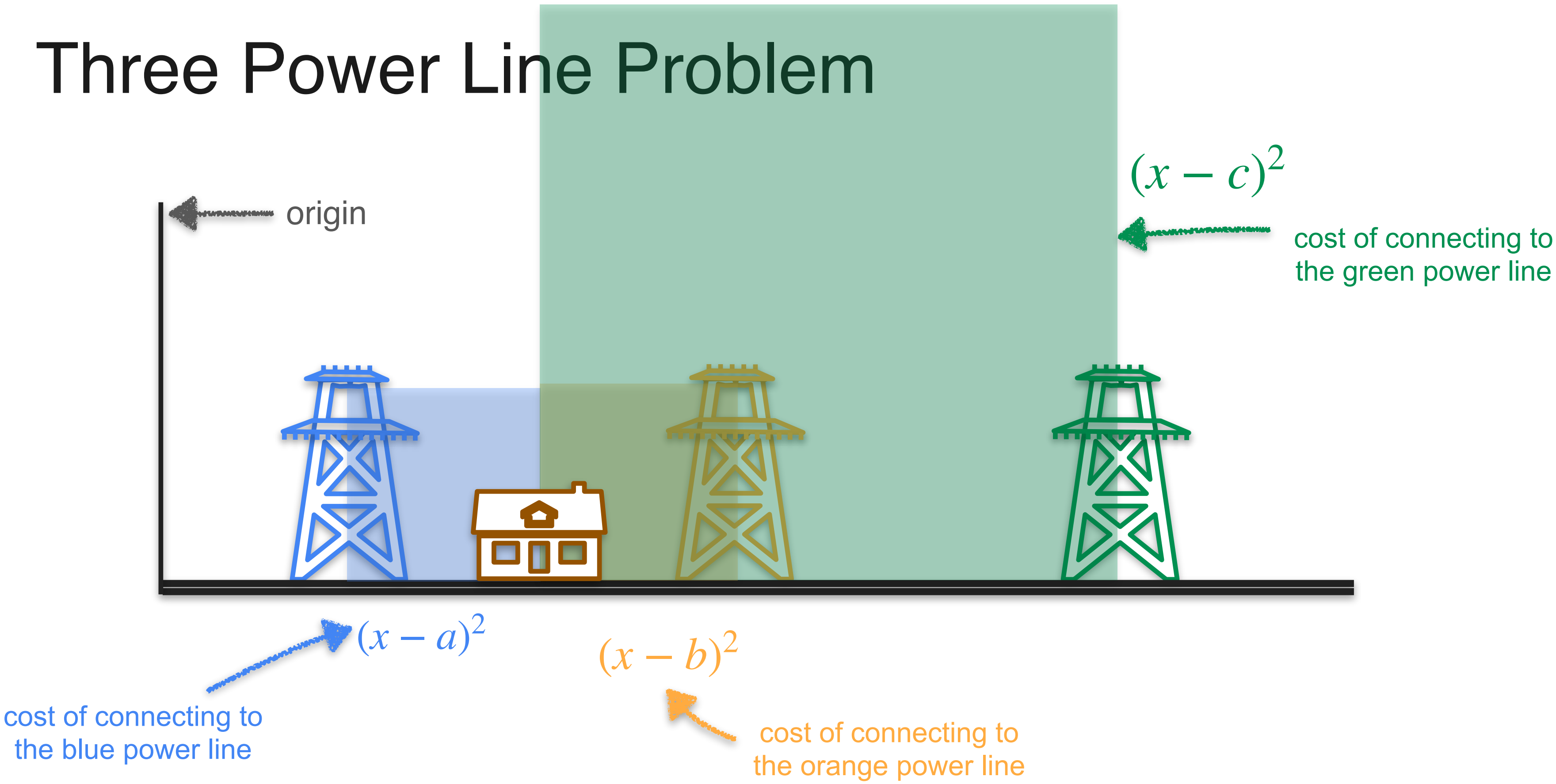
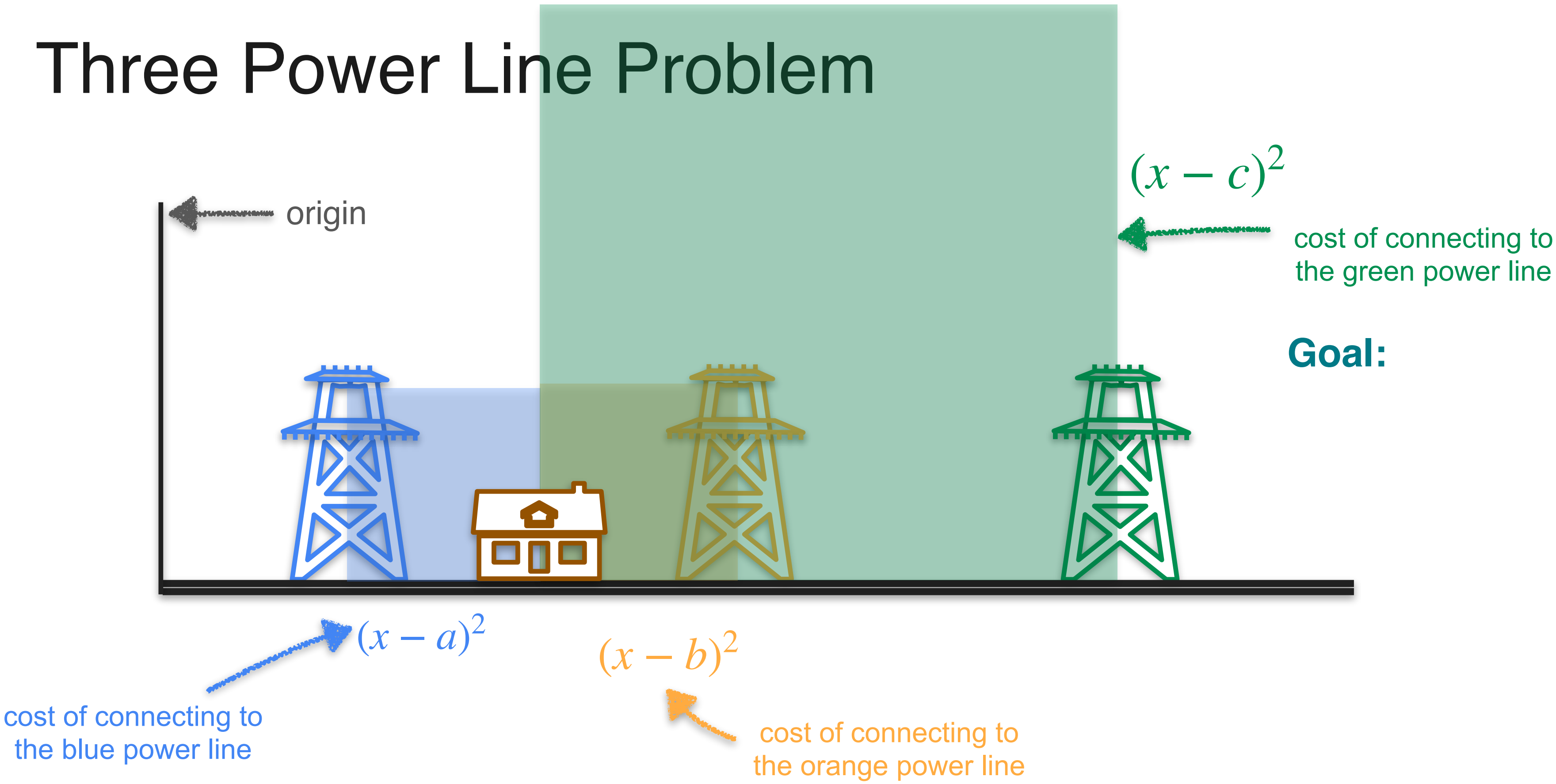


Three Power Line Problem

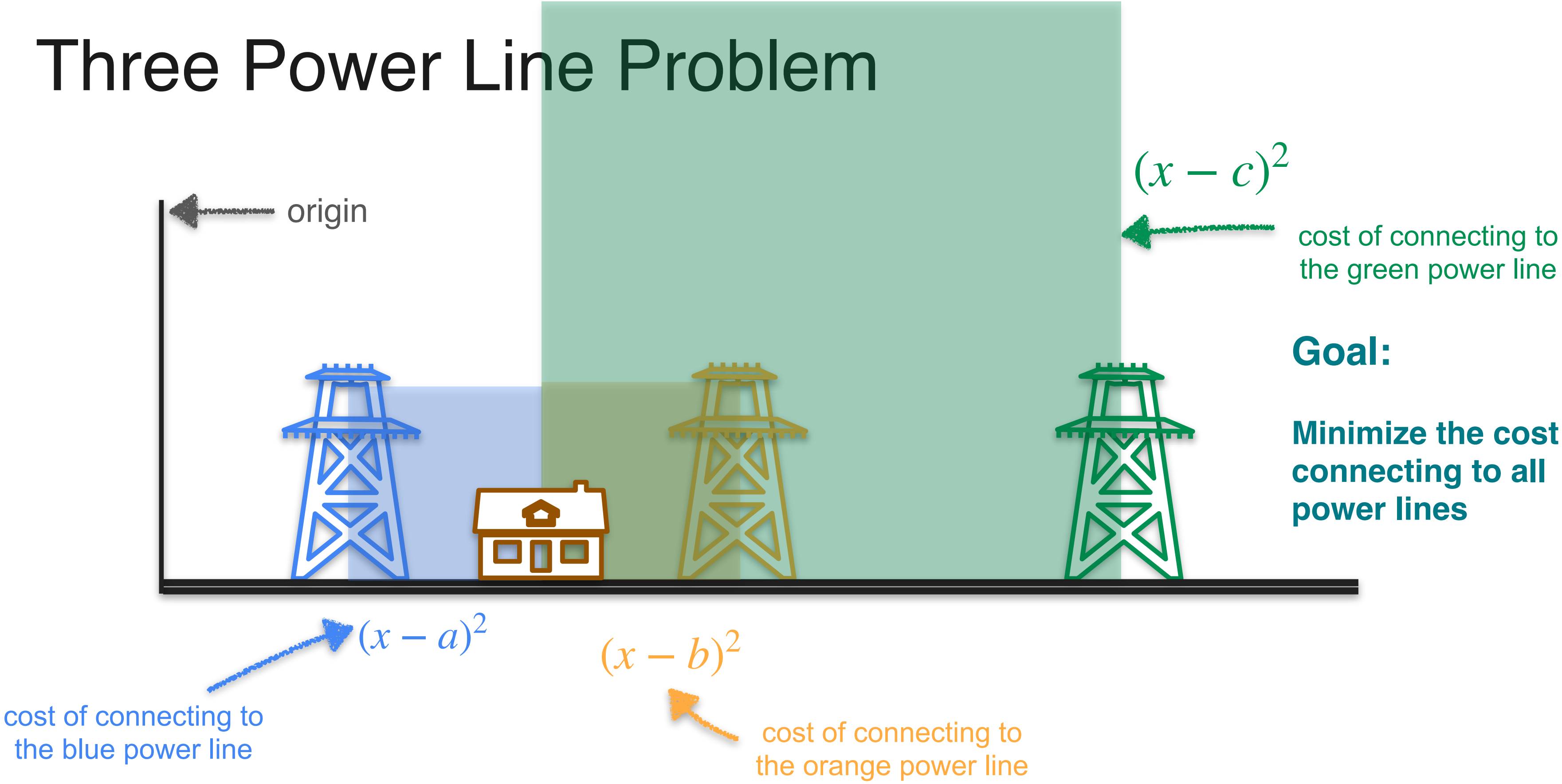


Three Power Line Problem



Goal:

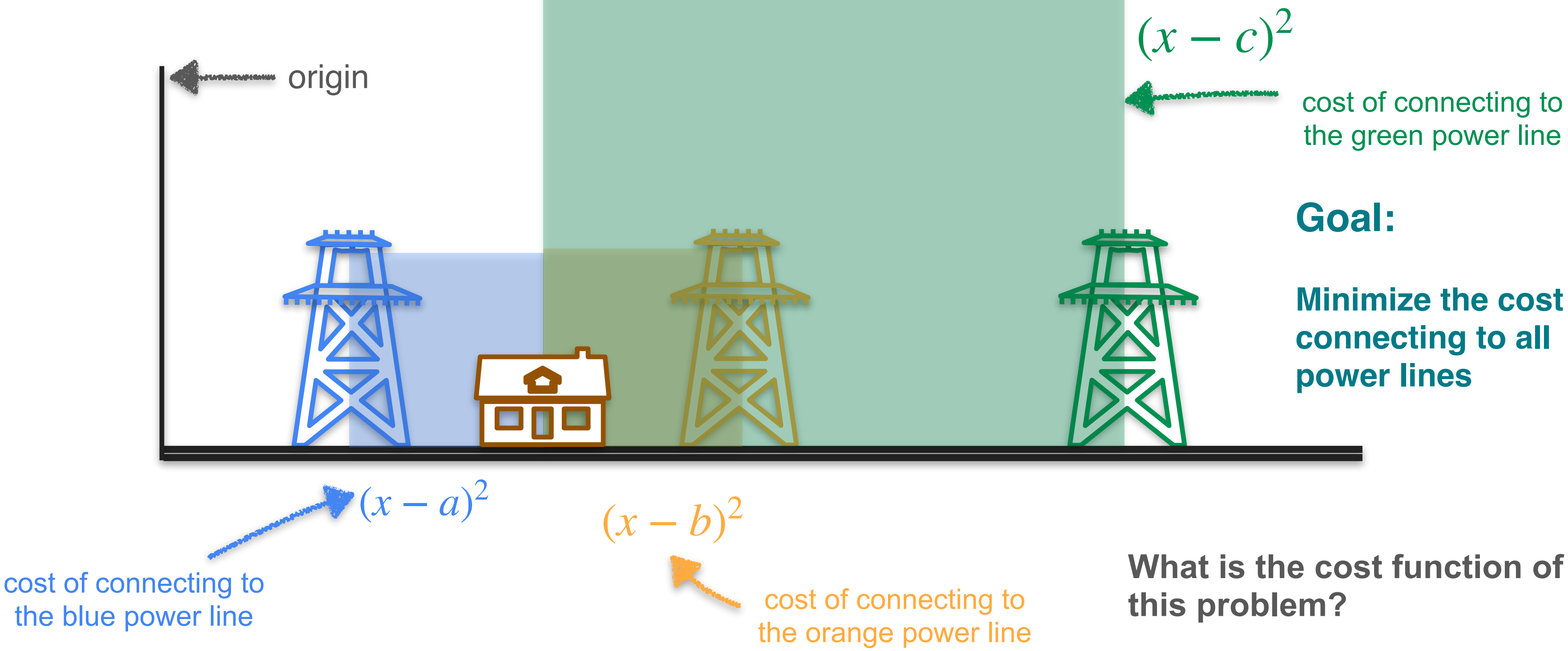
Three Power Line Problem



Goal:

Minimize the cost of connecting to all power lines

Three Power Line Problem

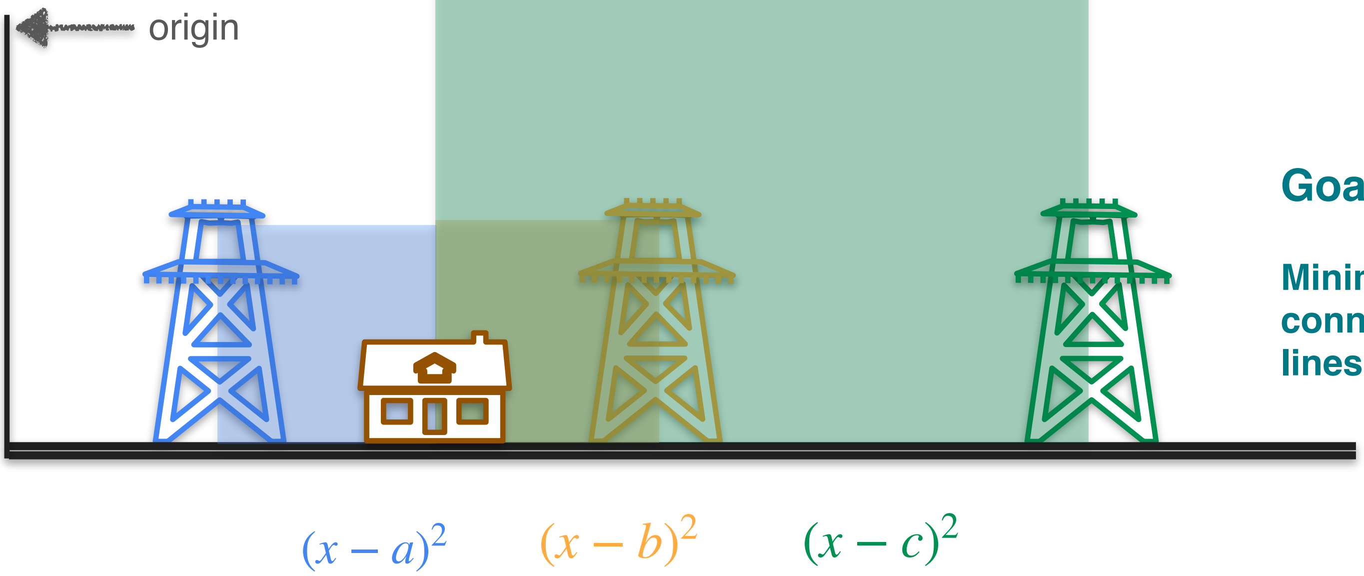


Goal:

Minimize the cost of connecting to all power lines

What is the cost function of this problem?

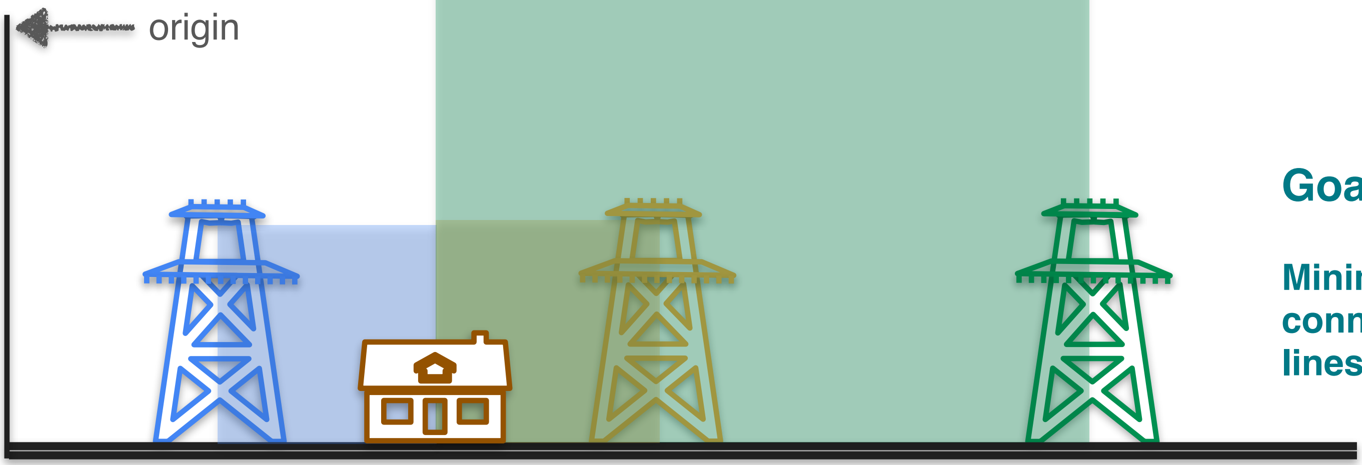
Three Power Line Problem



Goal:

Minimize the cost of connecting all power lines

Three Power Line Problem

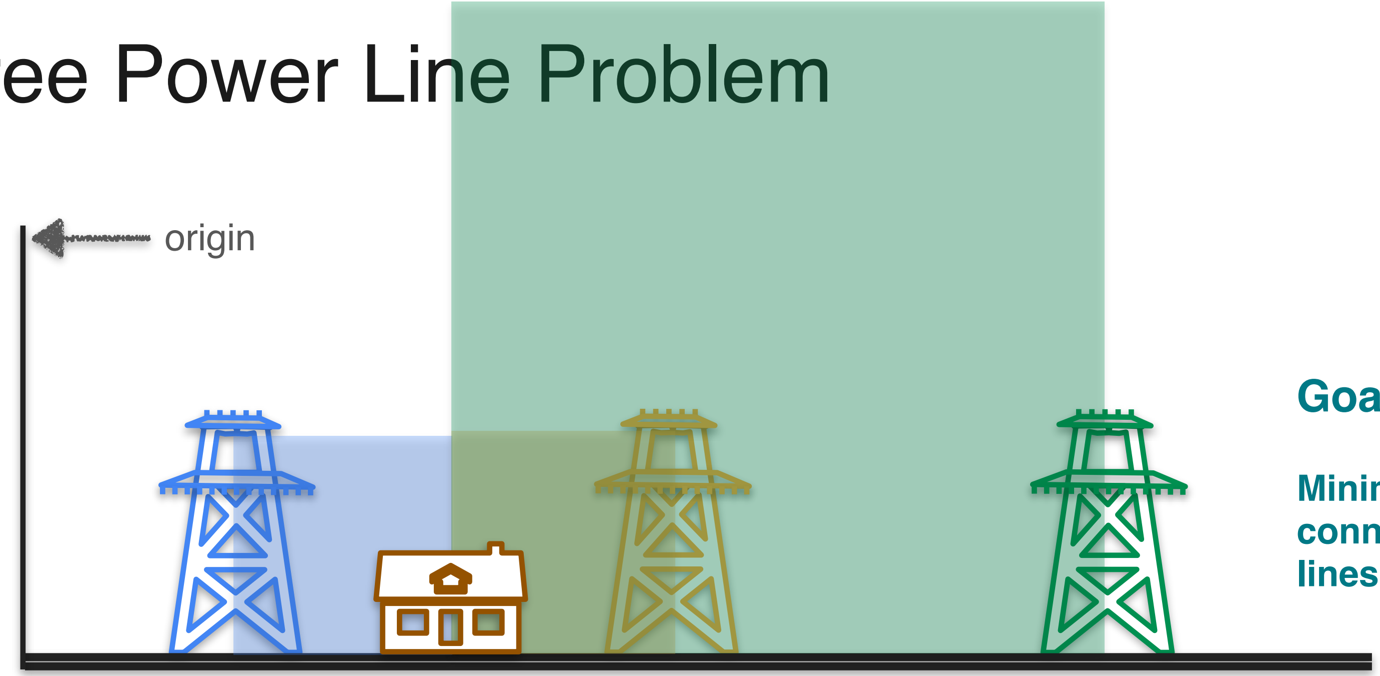


Goal:

Minimize the cost of connecting all power lines

$$(x-a)^2 + (x-b)^2 + (x-c)^2$$

Three Power Line Problem

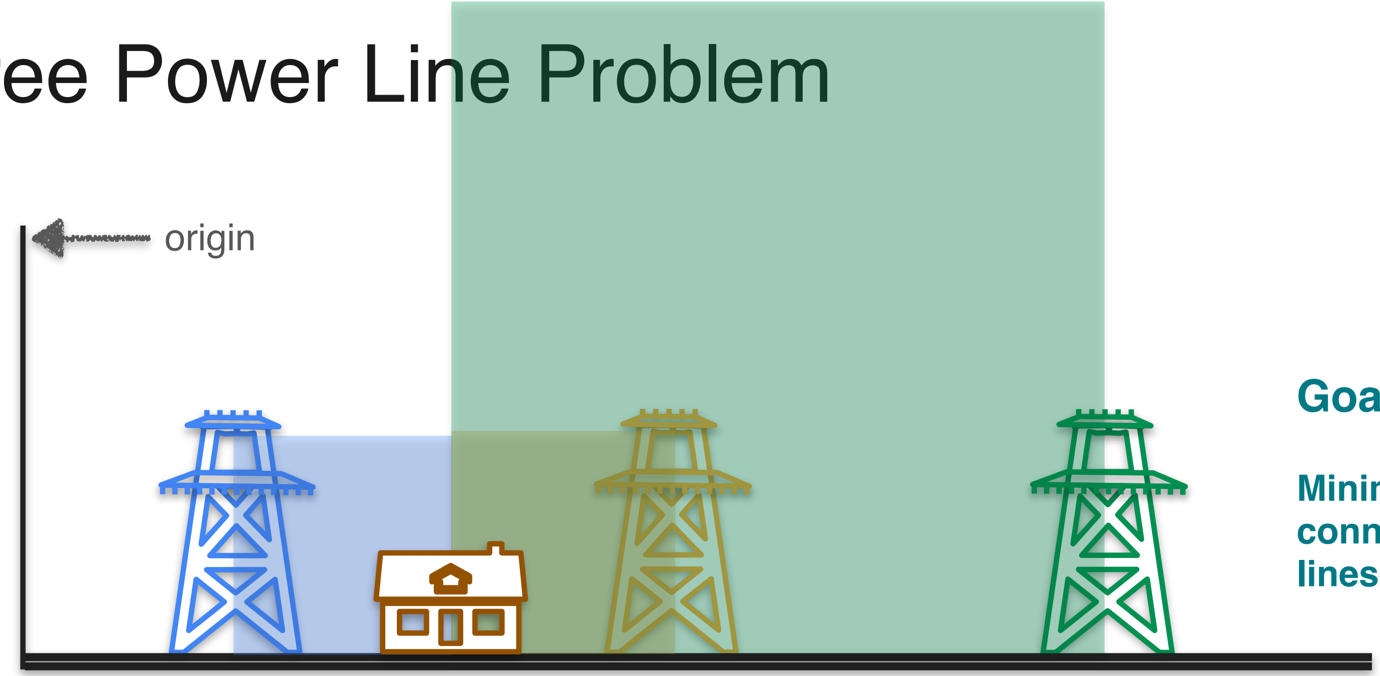


Goal:

Minimize the cost of connecting all power lines

Cost function = $(x-a)^2 + (x-b)^2 + (x-c)^2$

Three Power Line Problem



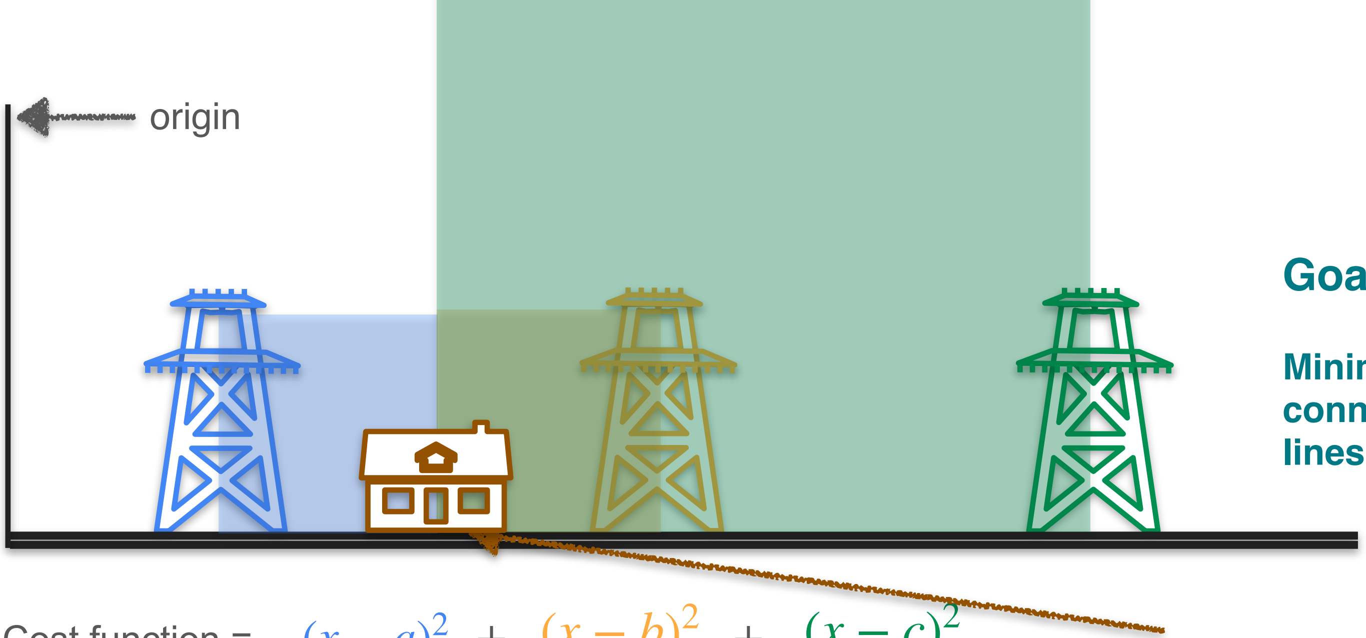
Goal:

Minimize the cost of connecting all power lines

Cost function = $(x-a)^2 + (x-b)^2 + (x-c)^2$

Total area of squares

Three Power Line Problem



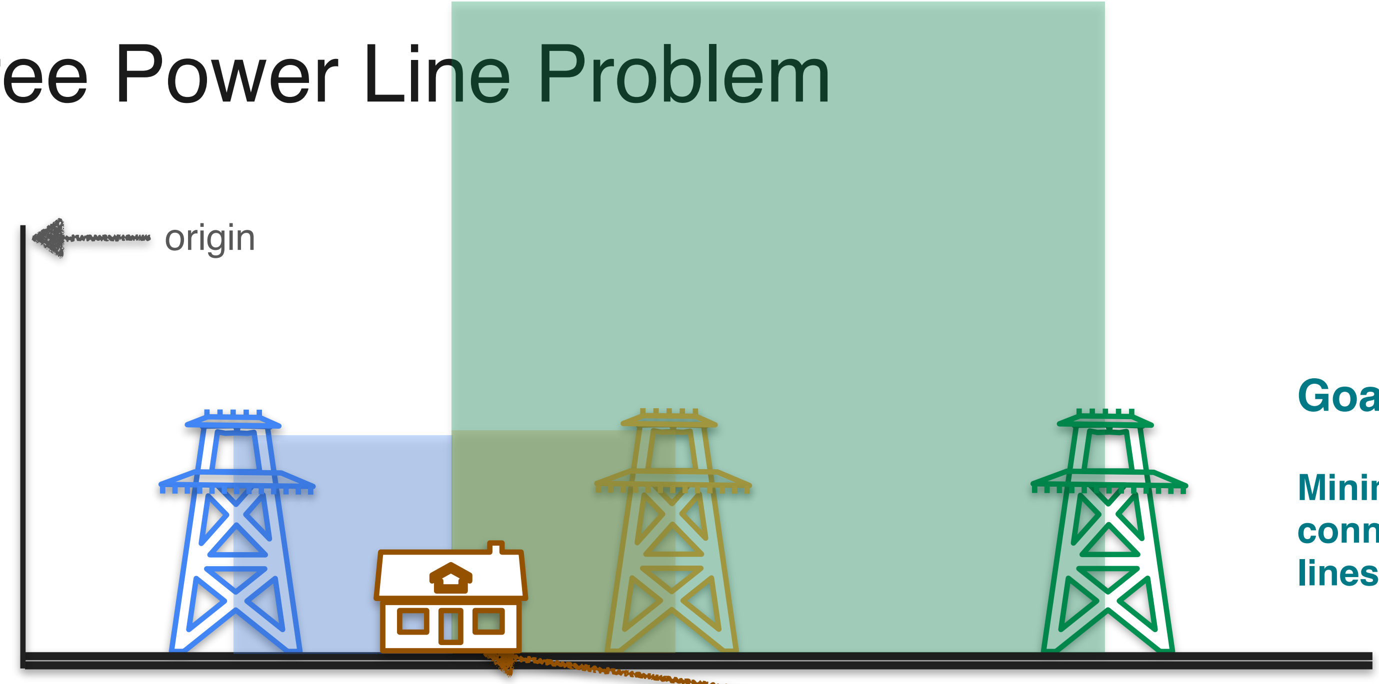
Goal:

Minimize the cost of connecting all power lines

Cost function = $(x-a)^2 + (x-b)^2 + (x-c)^2$

Total area of squares

Three Power Line Problem



Goal:

Minimize the cost of connecting all power lines

Cost function = $(x-a)^2 + (x-b)^2 + (x-c)^2$

Total area of squares

Where should you put the house to minimize the cost?

Three Power Line Problem

Goal:

Minimize the cost of connecting all power lines

Cost function = $(x-a)^2 + (x-b)^2 + (x-c)^2$ **Minimize this cost function**

Solution:

Three Power Line Problem

Goal:

Minimize the cost of connecting all power lines

Cost function = $(x-a)^2 + (x-b)^2 + (x-c)^2$

Minimize this cost function

Solution: $x = \dfrac{a+b+c}{3}$

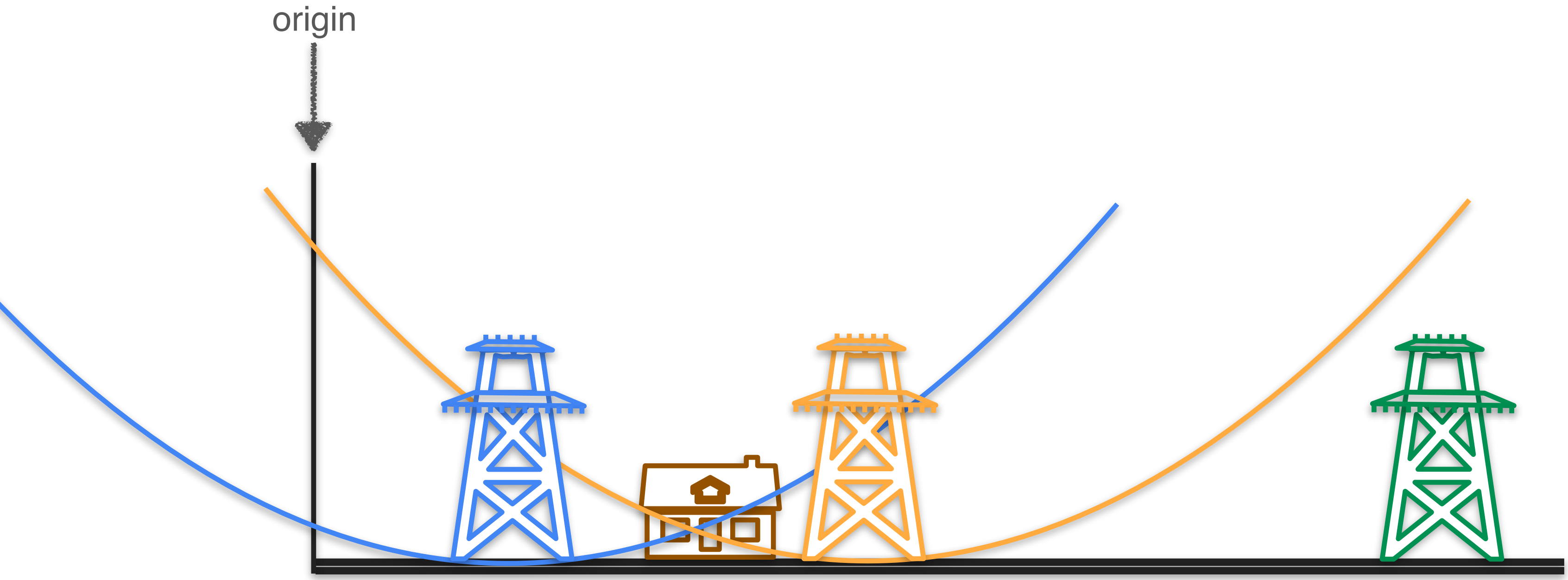
Three Power Line Problem

$$(x-a)^2 \quad + \quad (x-b)^2 \quad + \quad (x-c)^2$$

Three Power Line Problem

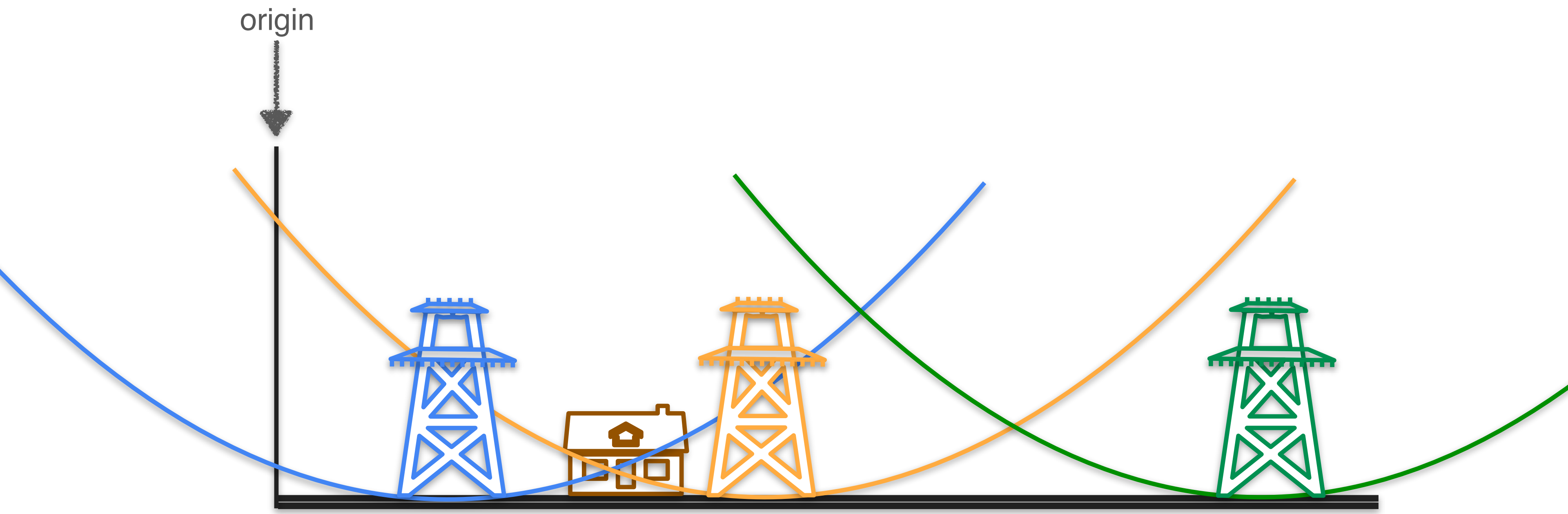
$$(x-a)^2 \quad + \quad (x-b)^2 \quad + \quad (x-c)^2$$

Three Power Line Problem



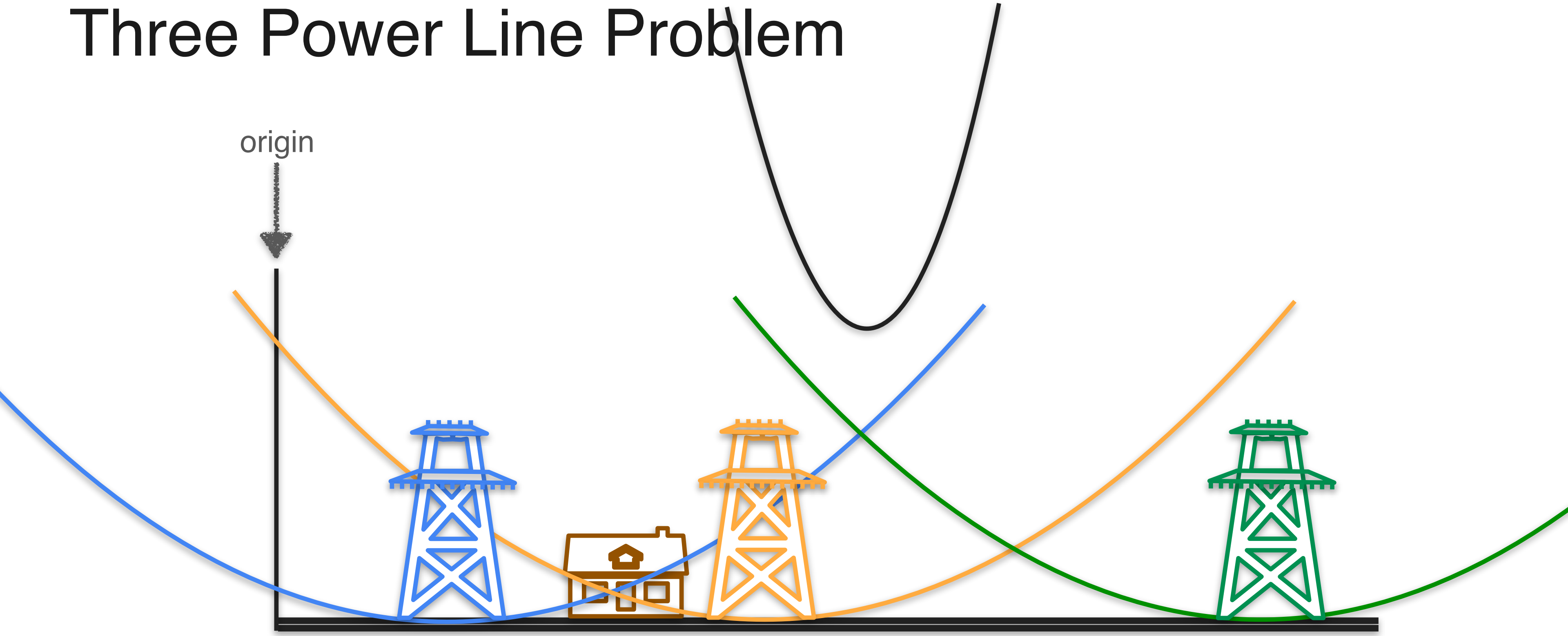
$$(x-a)^2 \quad + \quad (x-b)^2 \quad + \quad (x-c)^2$$

Three Power Line Problem



$$(x-a)^2 + (x-b)^2 + (x-c)^2$$

Three Power Line Problem



$$(x-a)^2 \quad + \quad (x-b)^2 \quad + \quad (x-c)^2$$

Three Power Line Problem

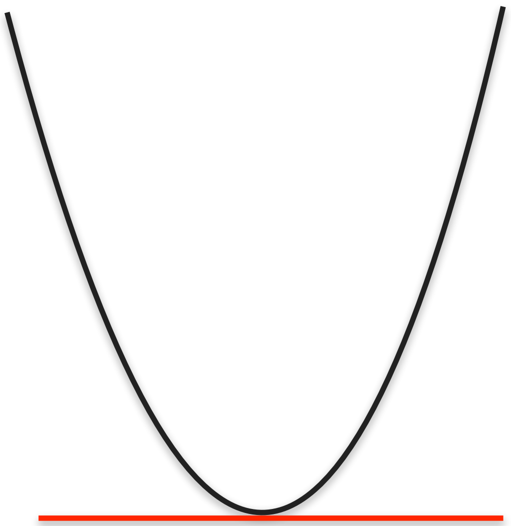
$$(x-a)^2 + (x-b)^2 + (x-c)^2$$

Three Power Line Problem

$$(x-a)^2 + (x-b)^2 + (x-c)^2$$

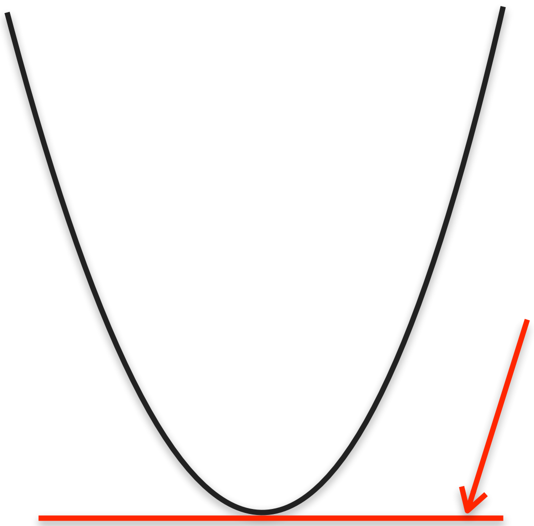
Three Power Line Problem

$$(x-a)^2 + (x-b)^2 + (x-c)^2$$

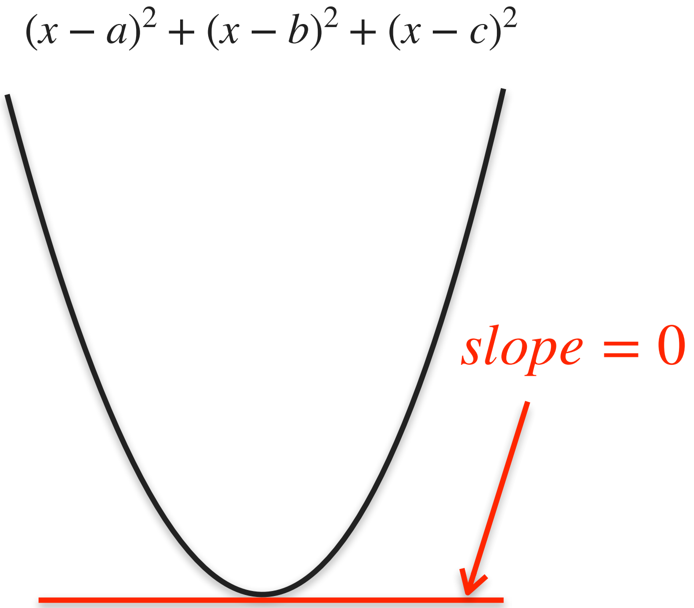


Three Power Line Problem

$$(x-a)^2+(x-b)^2+(x-c)^2$$

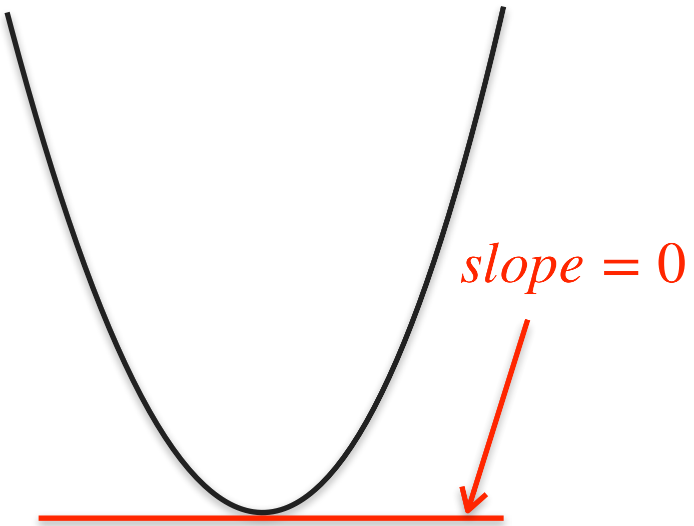


Three Power Line Problem



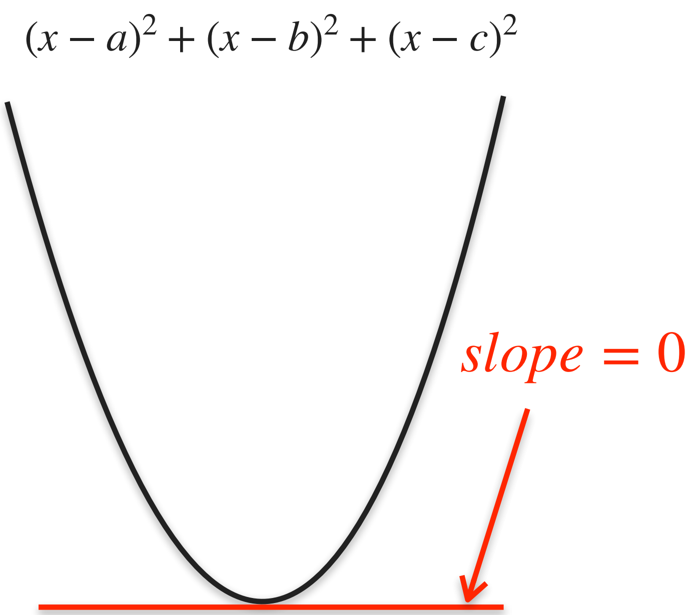
Three Power Line Problem

$$(x-a)^2 + (x-b)^2 + (x-c)^2$$



$$\frac{d}{dx}\left[(x-a)^2 + (x-b)^2 + (x-c)^2\right] = 0$$

Three Power Line Problem

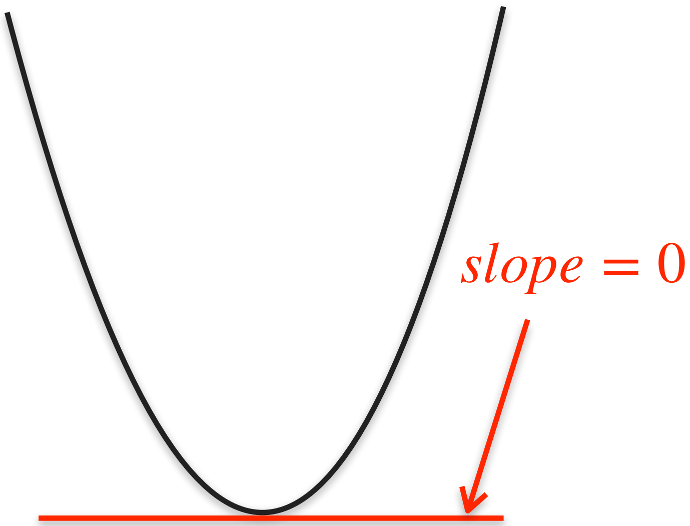


$$\frac{d}{dx}\left[(x-a)^2+(x-b)^2+(x-c)^2\right]=0$$

$$2(x-a)+2(x-b)+2(x-c)=0$$

Three Power Line Problem

$$(x-a)^2 + (x-b)^2 + (x-c)^2$$



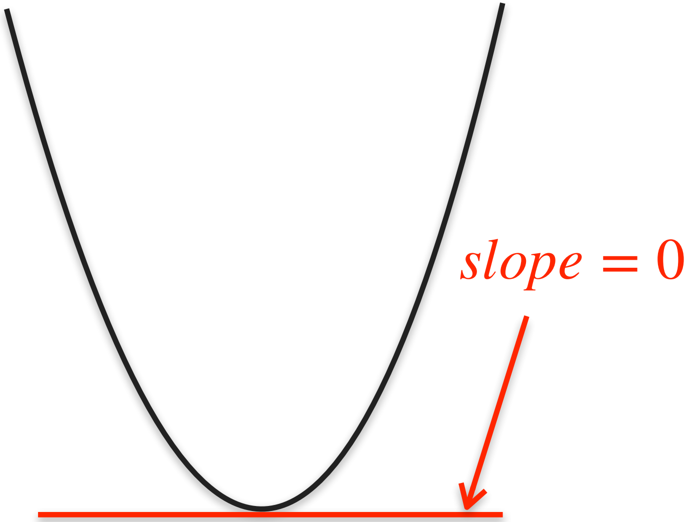
$$\frac{d}{dx}\left[(x-a)^2 + (x-b)^2 + (x-c)^2\right] = 0$$

$$2(x-a) + 2(x-b) + 2(x-c) = 0$$

$$(x-a) + (x-b) + (x-c) = 0$$

Three Power Line Problem

$$(x-a)^2 + (x-b)^2 + (x-c)^2$$



$$\frac{d}{dx}\left[(x-a)^2 + (x-b)^2 + (x-c)^2\right] = 0$$

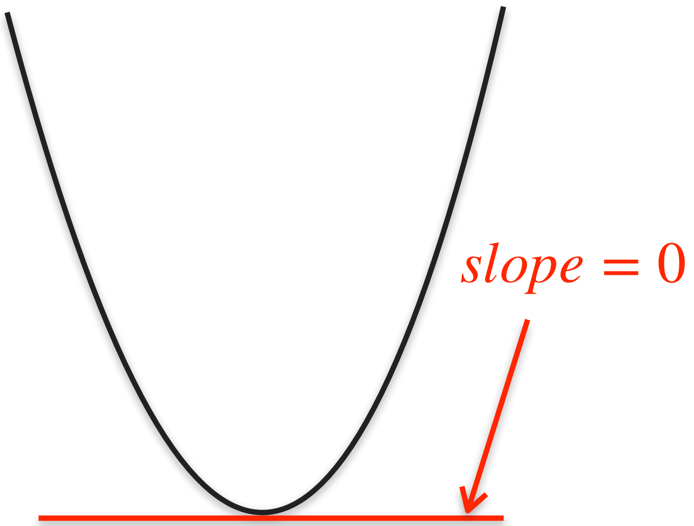
$$2(x-a) + 2(x-b) + 2(x-c) = 0$$

$$(x-a) + (x-b) + (x-c) = 0$$

$$3x - a - b - c = 0$$

Three Power Line Problem

$$(x-a)^2 + (x-b)^2 + (x-c)^2$$



$$\frac{d}{dx}\left[(x-a)^2 + (x-b)^2 + (x-c)^2\right] = 0$$

$$2(x-a) + 2(x-b) + 2(x-c) = 0$$

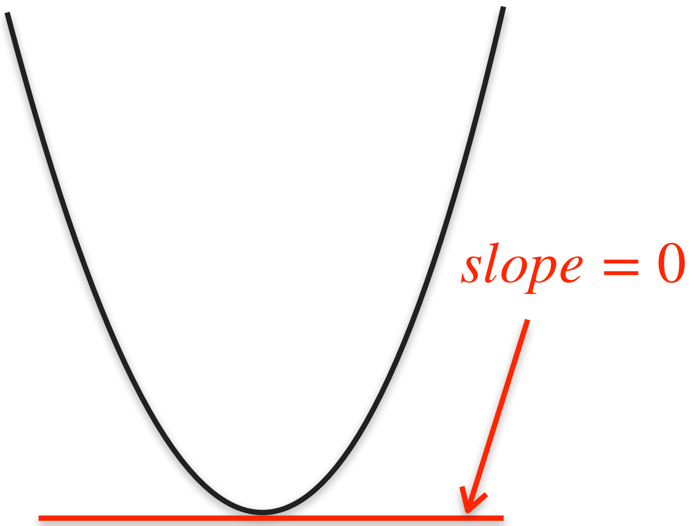
$$(x-a) + (x-b) + (x-c) = 0$$

$$3x - a - b - c = 0$$

$$3x = a + b + c$$

Three Power Line Problem

$$(x-a)^2 + (x-b)^2 + (x-c)^2$$



$$\frac{d}{dx}\left[(x-a)^2 + (x-b)^2 + (x-c)^2\right] = 0$$

$$2(x-a) + 2(x-b) + 2(x-c) = 0$$

$$(x-a) + (x-b) + (x-c) = 0$$

$$3x - a - b - c = 0$$

$$3x = a + b + c$$

$$x = \frac{a+b+c}{3}$$

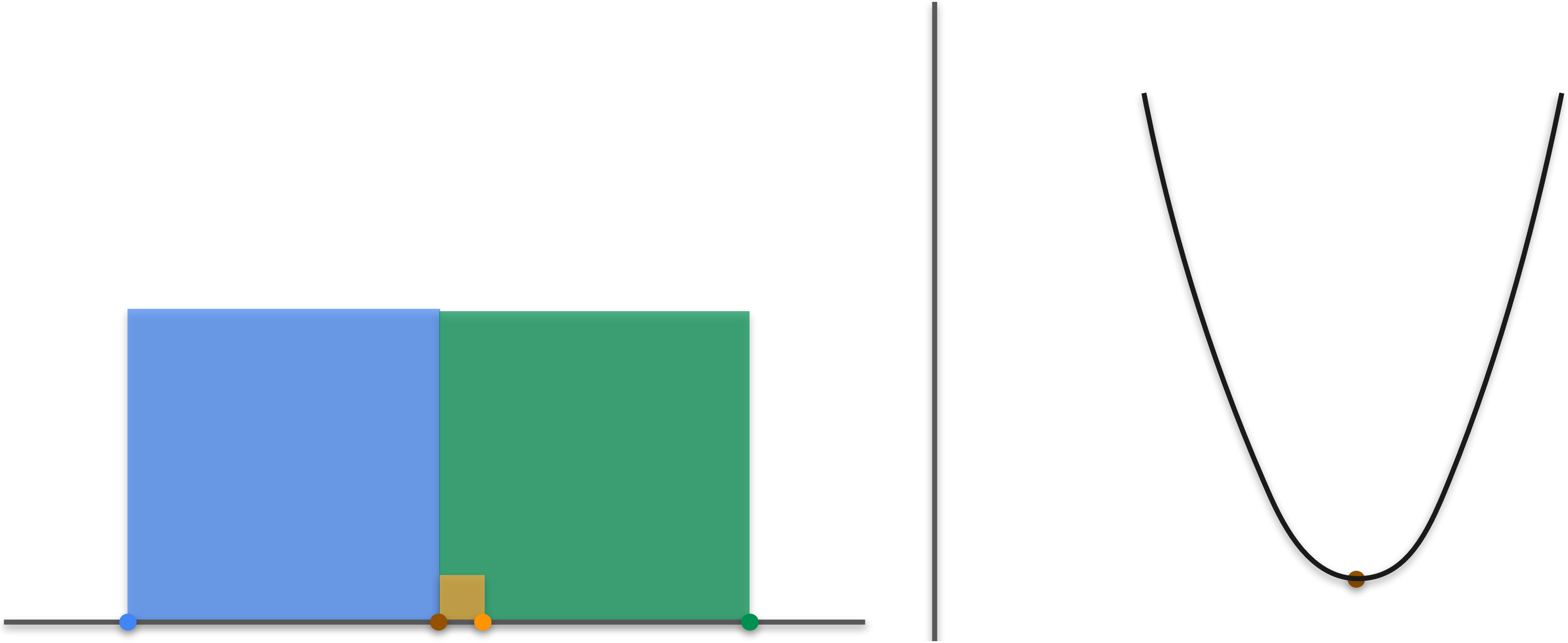
Three Power Line Problem: Square Analogy

Problem: Minimize total area of the squares

Three Power Line Problem: Square Analogy

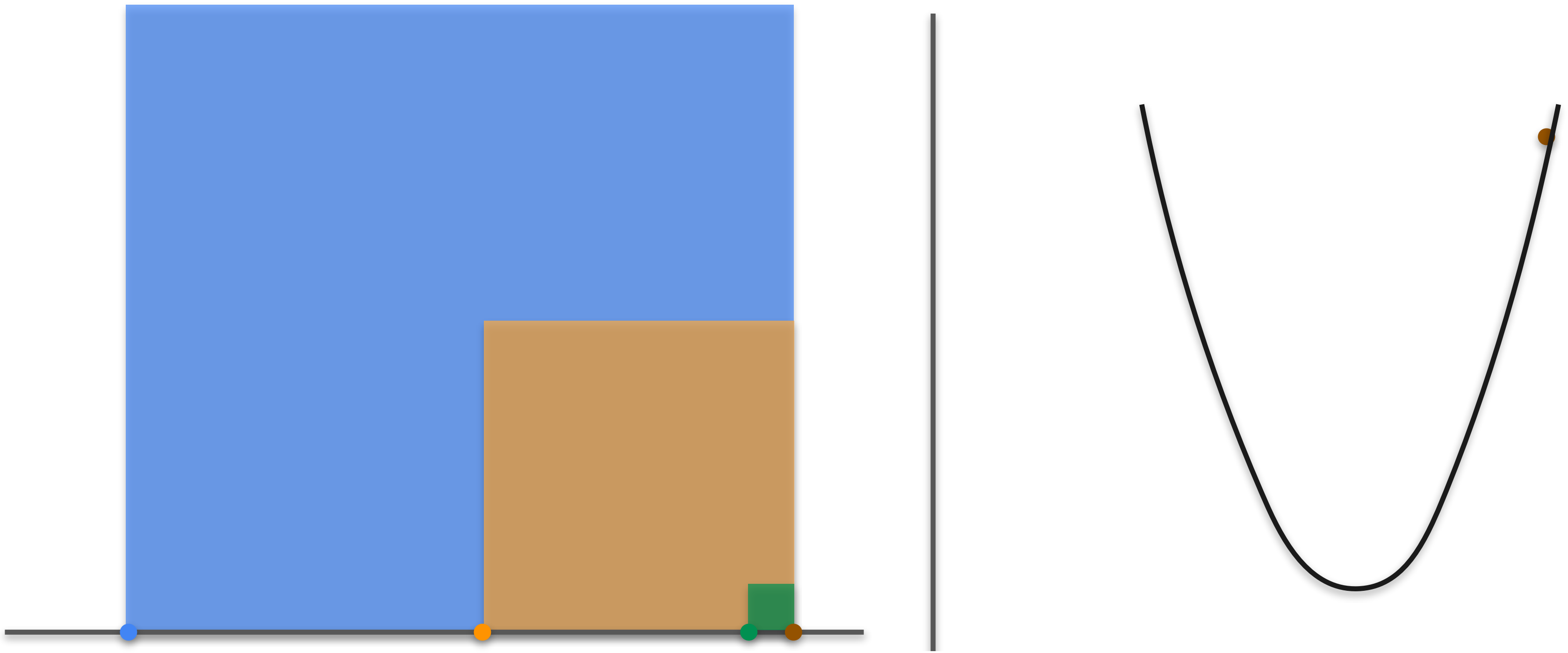
Problem: Minimize total area of the squares

Three Power Line Problem: Square Analogy



Problem: Minimize total area of the squares

Three Power Line Problem: Square Analogy



Problem: Minimize total area of the squares

The Square Loss

Minimize $(x - a_1)^2 + (x - a_2)^2 + \cdots + (x - a_n)^2$

The Square Loss

Minimize $(x-a_1)^2+(x-a_2)^2+\cdots+(x-a_n)^2$

Solution: $x=\dfrac{a_1+a_2+\cdots+a_n}{n}$

DeepLearning.AI

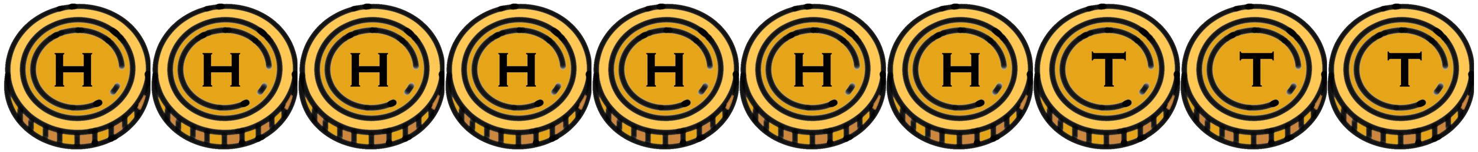
Derivatives and Optimization

Optimization of log-loss
Part 1

Coin Toss

Coin Toss

Coin Toss



Coin Toss

Coin 1

70% 30%

Coin Toss

Coin 1

70% 30%

Coin 2

50% 50%

Coin Toss

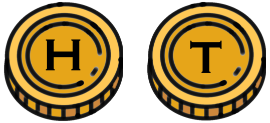
Coin 1

70% 30%

Coin 2

50% 50%

Coin 3



30% 70%

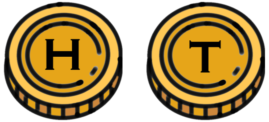
Quiz

- Which of the three coins would you choose to maximize your chances of winning?

Coin 1

70% 30%

Coin 2



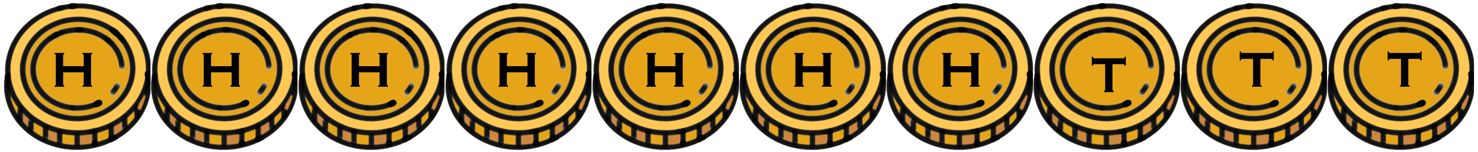
50% 50%

Coin 3

30% 70%

Coins Toss

Coins Toss



Coin 1 $0.7 \times 0.7 \times 0.7 \times 0.7 \times 0.7 \times 0.7 \times 0.7 \times 0.3 \times 0.3 \times 0.3 = 0.7^7 0.3^3$

$= 0.00222$

Coins Toss

Coin 1 $\quad 0.7 \times 0.7 \times 0.7 \times 0.7 \times 0.7 \times 0.7 \times 0.7 \times 0.3 \times 0.3 \times 0.3 = 0.7^7 0.3^3$

$$= 0.00222$$

Coin 2 $\quad 0.5 \times 0.5 \times 0.5 \times 0.5 \times 0.5 \times 0.5 \times 0.5 \times 0.5 \times 0.5 \times 0.5 = 0.5^7 0.5^3$

$$= 0.00097$$

Coins Toss

Coin 1 $0.7 \times 0.7 \times 0.7 \times 0.7 \times 0.7 \times 0.7 \times 0.7 \times 0.3 \times 0.3 \times 0.3 = 0.7^7 0.3^3$

$= 0.00222$

Coin 2 $0.5 \times 0.5 \times 0.5 \times 0.5 \times 0.5 \times 0.5 \times 0.5 \times 0.5 \times 0.5 \times 0.5 = 0.5^7 0.5^3$

$= 0.00097$

Coin 3 $0.3 \times 0.3 \times 0.3 \times 0.3 \times 0.3 \times 0.3 \times 0.3 \times 0.7 \times 0.7 \times 0.7 = 0.3^7 0.7^3$

$= 0.00008$

Coins Toss

Coin 1 $0.7 \times 0.7 \times 0.7 \times 0.7 \times 0.7 \times 0.7 \times 0.7 \times 0.3 \times 0.3 \times 0.3 = 0.7^7 0.3^3$

$= 0.00222$

Coin 2 $0.5 \times 0.5 \times 0.5 \times 0.5 \times 0.5 \times 0.5 \times 0.5 \times 0.5 \times 0.5 \times 0.5 = 0.5^7 0.5^3$

$= 0.00097$

Coin 3 $0.3 \times 0.3 \times 0.3 \times 0.3 \times 0.3 \times 0.3 \times 0.3 \times 0.7 \times 0.7 \times 0.7 = 0.3^7 0.7^3$

$= 0.00008$

Coin Toss

Coin Toss

p

Coin Toss

p $(1-p)$

Coin Toss

p $\quad$ $(1-p)$

Chances of winning: $p^7(1-p)^3 = g(p)$

Coin Toss

p $\quad$ $(1-p)$

Chances of winning: $p^7(1-p)^3 = g(p)$

Goal: maximize $g(p)$

Coin Toss

Coin Toss

$$\frac{dg}{dp} = \frac{d}{dp}(p^7(1-p)^3)$$

Coin Toss

Product rule

$$\frac{dg}{dp} = \frac{d}{dp}(p^7(1-p)^3) = \frac{d(p^7)}{dp}(1-p)^3 + p^7\frac{d\left((1-p)^3\right)}{dp}$$

Coin Toss

Product rule

$$\frac{dg}{dp} = \frac{d}{dp}(p^7(1-p)^3) = \frac{d(p^7)}{dp}(1-p)^3 + p^7 \boxed{\frac{d\left((1-p)^3\right)}{dp}}$$

$$= 7p^6(1-p)^3 + p^7 \boxed{3(1-p)^2(-1)}$$

Chain rule

Coin Toss

Product rule

$$\frac{dg}{dp} = \frac{d}{dp}(p^7(1-p)^3) = \frac{d(p^7)}{dp}(1-p)^3 + p^7 \boxed{\frac{d\left((1-p)^3\right)}{dp}}$$

Chain rule

$$= 7p^6(1-p)^3 + p^7 \boxed{3(1-p)^2(-1)}$$

$$= p^6(1-p)^2\left[7(1-p) - 3p\right]$$

Coin Toss

Product rule

$$\frac{dg}{dp} = \frac{d}{dp}(p^7(1-p)^3) = \frac{d(p^7)}{dp}(1-p)^3 + p^7 \boxed{\frac{d\left((1-p)^3\right)}{dp}}$$

Chain rule

$$= 7p^6(1-p)^3 + p^7 \boxed{3(1-p)^2(-1)}$$

$$= p^6(1-p)^2\left[7(1-p) - 3p\right]$$

$$= p^6(1-p)^2(7-10p)$$

Coin Toss

Product rule

$$\frac{dg}{dp} = \frac{d}{dp}(p^7(1-p)^3) = \frac{d(p^7)}{dp}(1-p)^3 + p^7 \boxed{\frac{d\left((1-p)^3\right)}{dp}}$$

Chain rule

$$= 7p^6(1-p)^3 + p^7 \boxed{3(1-p)^2(-1)}$$

$$= p^6(1-p)^2\left[7(1-p) - 3p\right]$$

$$= p^6(1-p)^2(7-10p) = 0$$

Coin Toss

Product rule

$$\frac{dg}{dp} = \frac{d}{dp}(p^7(1-p)^3) = \frac{d(p^7)}{dp}(1-p)^3 + p^7 \boxed{\frac{d\left((1-p)^3\right)}{dp}}$$

Chain rule

$$= 7p^6(1-p)^3 + p^7 \boxed{3(1-p)^2(-1)}$$

$$= p^6(1-p)^2\left[7(1-p) - 3p\right]$$

$$= \boxed{p^6}(1-p)^2(7-10p) = 0$$

$$p = 0$$

Coin Toss

$$\frac{dg}{dp} = \frac{d}{dp}(p^7(1-p)^3) \overset{\text{Product rule}}{=} \frac{d(p^7)}{dp}(1-p)^3 + p^7 \boxed{\frac{d\left((1-p)^3\right)}{dp}}$$

Chain rule

$$= 7p^6(1-p)^3 + p^7 \boxed{3(1-p)^2(-1)}$$

$$= p^6(1-p)^2\left[7(1-p) - 3p\right]$$

$$= \boxed{p^6}\boxed{(1-p)^2}(7-10p) = 0$$

$$p = 0$$

$$p = 1$$

Coin Toss

$$\frac{dg}{dp} = \frac{d}{dp}\left(p^7(1-p)^3\right) \overset{\text{Product rule}}{=} \frac{d(p^7)}{dp}(1-p)^3 + p^7\boxed{\frac{d\left((1-p)^3\right)}{dp}}$$

$$= 7p^6(1-p)^3 + p^7\boxed{3(1-p)^2(-1)}$$

Chain rule

$$= p^6(1-p)^2\left[7(1-p) - 3p\right]$$

$$= \boxed{p^6}\boxed{(1-p)^2}\boxed{(7-10p)} = 0$$

$p = 0$

$p = 1$

$p = 0.7$

Coin Toss

Product rule

$$\frac{dg}{dp} = \frac{d}{dp}\left(p^7(1-p)^3\right) = \frac{d(p^7)}{dp}(1-p)^3 + p^7 \boxed{\frac{d\left((1-p)^3\right)}{dp}}$$

Chain rule

$$= 7p^6(1-p)^3 + p^7 \boxed{3(1-p)^2(-1)}$$

$$= p^6(1-p)^2\left[7(1-p) - 3p\right]$$

$$= \boxed{p^6}\boxed{(1-p)^2}\boxed{(7-10p)} = 0$$

$\cancel{p = 0}$

$p = 1$

$p = 0.7$

Coin Toss

Product rule

$$\frac{dg}{dp} = \frac{d}{dp}\left(p^7(1-p)^3\right) = \frac{d(p^7)}{dp}(1-p)^3 + p^7\boxed{\frac{d\left((1-p)^3\right)}{dp}}$$

Chain rule

$$= 7p^6(1-p)^3 + p^7\boxed{3(1-p)^2(-1)}$$

$$= p^6(1-p)^2\left[7(1-p) - 3p\right]$$

$$= \boxed{p^6}\boxed{(1-p)^2}\boxed{(7-10p)} = 0$$

$$\cancel{p = 0} \qquad \cancel{p = 1} \qquad p = 0.7$$

Coin Toss

Product rule

$$\frac{dg}{dp} = \frac{d}{dp}(p^7(1-p)^3) = \frac{d(p^7)}{dp}(1-p)^3 + p^7 \boxed{\frac{d\left((1-p)^3\right)}{dp}}$$

Chain rule

$$= 7p^6(1-p)^3 + p^7 \boxed{3(1-p)^2(-1)}$$

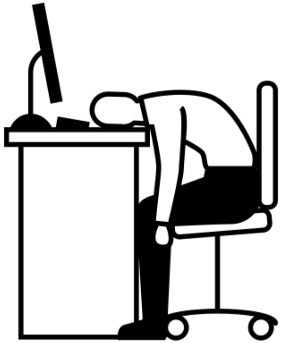
$$= p^6(1-p)^2\left[7(1-p) - 3p\right]$$

$$= \boxed{p^6}\boxed{(1-p)^2}\boxed{(7-10p)} = 0$$

$\cancel{p = 0}$

$\cancel{p = 1}$

$p = 0.7$



Coin Toss

Coin Toss

$$\log(g(p))$$

Coin Toss

$$\log(g(p)) \quad = \log(p^7(1-p)^3)$$

Coin Toss

$$\log(g(p)) = \log(p^7(1-p)^3) = \log\left(p^7\right) + \log\left((1-p)^3\right)$$

Coin Toss

$$\log(g(p)) = \log(p^7(1-p)^3) = \log\left(p^7\right) + \log\left((1-p)^3\right)$$

$$= 7\log(p) + 3\log(1-p)$$

Coin Toss

$$\log(g(p)) = \log(p^7(1-p)^3) = \log\left(p^7\right) + \log\left((1-p)^3\right)$$

$$= 7\log(p) + 3\log(1-p) = G(p)$$

Coin Toss

$$\log(g(p)) = \log(p^7(1-p)^3) = \log\left(p^7\right) + \log\left((1-p)^3\right)$$

$$= 7\log(p) + 3\log(1-p) = G(p)$$

$$\frac{dG(p)}{dp} = \frac{d}{dp}(7\log(p) + 3\log(1-p))$$

Coin Toss

$$\log(g(p)) = \log(p^7(1-p)^3) = \log\left(p^7\right) + \log\left((1-p)^3\right)$$

$$= 7\log(p) + 3\log(1-p) = G(p)$$

$$\frac{dG(p)}{dp} = \frac{d}{dp}(7\log(p) + 3\log(1-p)) = 7\frac{1}{p} + 3\frac{1}{1-p}(-1)$$

Coin Toss

$$\log(g(p)) = \log(p^7(1-p)^3) = \log\left(p^7\right) + \log\left((1-p)^3\right)$$

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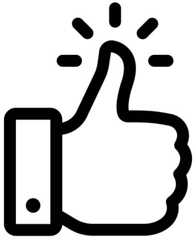

Coin Toss

$$\log(g(p)) \;= \log(p^7(1-p)^3) \;= \log\left(p^7\right) + \log\left((1-p)^3\right)$$

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$-G(p)$ is the logloss

$$\frac{dG(p)}{dp} = \frac{d}{dp}(7\log(p) + 3\log(1-p)) = 7\frac{1}{p} + 3\frac{1}{1-p}(-1)$$

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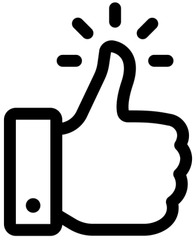


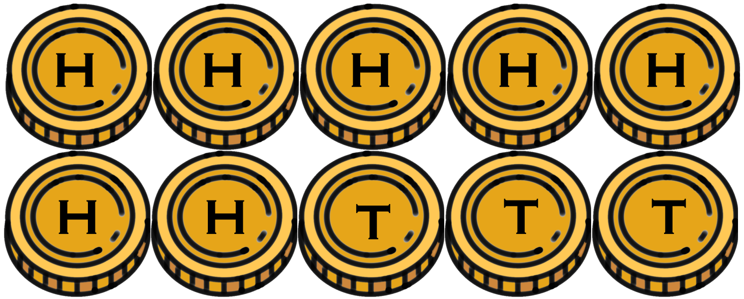
DeepLearning.AI

Derivatives and Optimization

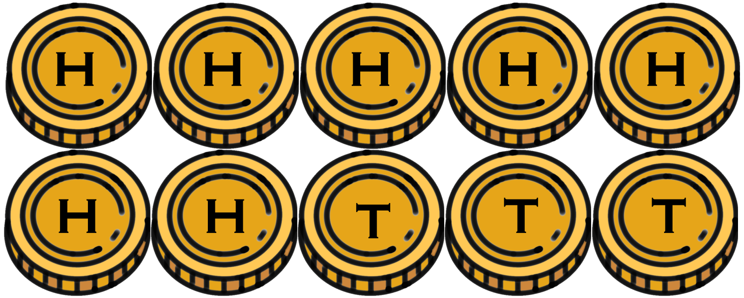
Optimization of log-loss
Part 2

Relationship With ML

Relationship With ML

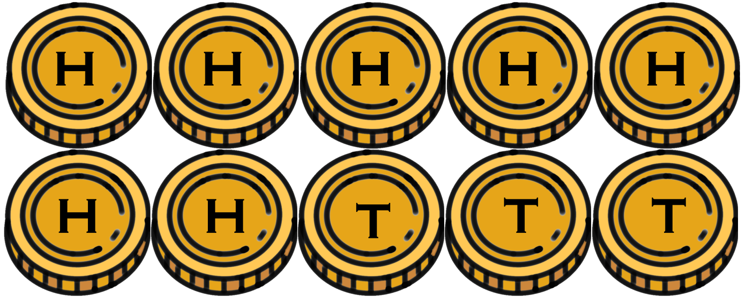


Relationship With ML



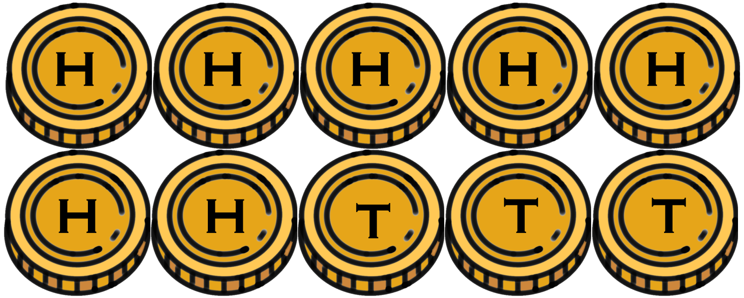
Data

Relationship With ML



Data

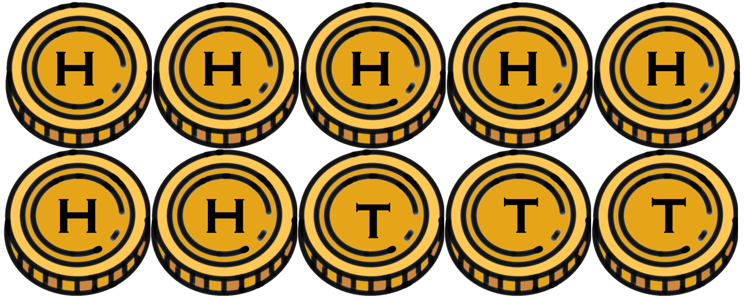
Relationship With ML



Data

p

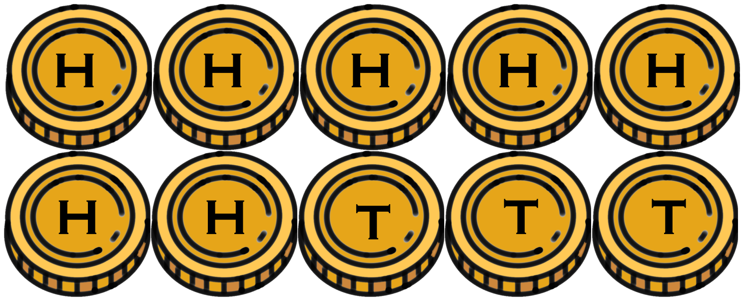
Relationship With ML



Data

p

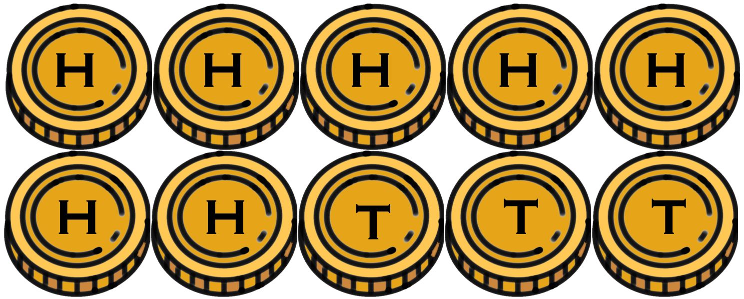
Relationship With ML



Data

p $(1 - p)$

Relationship With ML



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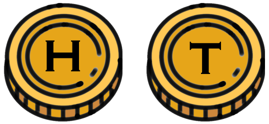
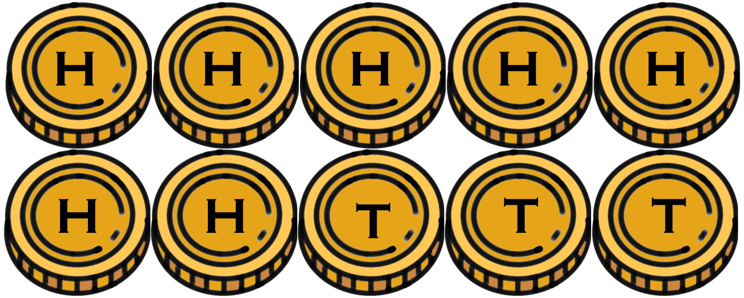


p $(1 - p)$

Model

Relationship With ML



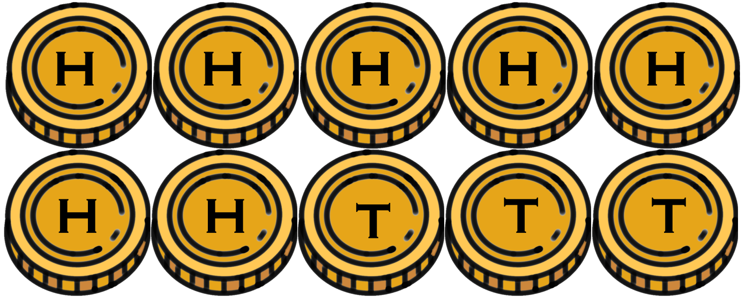
p $(1-p)$

Data

Model

Minimized log-loss

Relationship With ML



p $(1-p)$

Data

Model

Minimized log-loss

$p = 0.7$

Why the Logarithm?

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1. Derivative of products is hard, derivative of sums is easy

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$$f(p) = p^6(1-p)^2(3-p)^9(p-4)^{13}(10-p)^{500}$$

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$$f(p) = p^6(1-p)^2(3-p)^9(p-4)^{13}(10-p)^{500}$$

$$\frac{df}{dp}$$

$$\left[6p^5\right](1-p)^2(3-p)^9(p-4)^{13}(10-p)^{500}+$$
$$p^6\left[2(1-p)\right](3-p)^9(p-4)^{13}(10-p)^{500}(-1)+$$
$$p^6(1-p)^2\left[9(3-p)^8\right](p-4)^{13}(10-p)^{500}(-1)+$$
$$p^6(1-p)^2(3-p)^9\left[13(p-4)^{12}\right](10-p)^{500}+$$
$$p^6(1-p)^2(3-p)^9(p-4)^{13}\left[500(10-p)^{499}\right](-1)$$

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$$p^6(1-p)^2(3-p)^9(p-4)^{13}\left[500(10-p)^{499}\right](-1)$$

$$\frac{d}{dp}\log(f)$$

$$\frac{6}{p}+\frac{2}{1-p}(-1)+\frac{9}{3-p}(-1)+$$
$$\frac{13}{p-4}+\frac{500}{10-p}(-1)$$

Why the Logarithm?

1. Derivative of products is hard, derivative if sums is easy

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$$\frac{df}{dp} \Rightarrow \frac{d}{dp}\log(f)$$

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1. Derivative of products is hard, derivative if sums is easy

$$f(p) = p^6(1-p)^2(3-p)^9(p-4)^{13}(10-p)^{500}$$

$$\frac{df}{dp} \quad \Rightarrow \quad \frac{d}{dp}\log(f)$$

2. Product of lots of tiny things is tiny!

DeepLearning.AI

Derivatives and Optimization

Conclusion