

High-School Maths

Establish a workflow, get to know
our tools, review basic concepts

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#MathForDevs

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Motivating Examples

Math in real life

Mathematics in Nature

- Honeycomb cells

- Bees produce wax by consuming some of the honey they've made
- Wax production takes time and energy (honey)
- The hexagonal cells leave no unused space, and consume the least amount of wax and energy



- Snowflakes

- All snowflakes are unique but they are perfectly symmetrical
 - Each arm (unless damaged) is identical
- This makes them strong enough to stay together



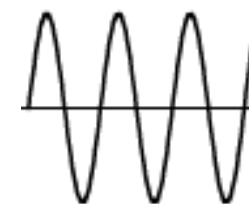
Mathematics in Nature (2)

- Romanesco broccoli
 - Each little floret looks exactly like the whole plant
 - This is called a fractal
 - Seen from above, the florets form a spiral
 - This is a Fibonacci spiral
- Fibonacci spirals everywhere
 - Flowers, pinecones
 - Animal shells
 - Hurricanes
 - Galaxies

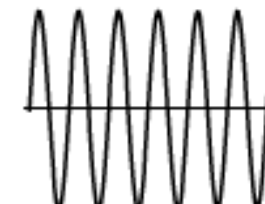


Mathematics in Music

- Sound is a combination of waves travelling through the air
 - Each sound wave has a frequency (pitch)
 - Every note is associated with a certain frequency
 - E.g., A4 produces 440 oscillations every second (440 *Hz*)
 - Some combinations of tones sound pleasant, others sound harsh
 - Our ears like simple frequency ratios, e.g. 2: 3 is better than 160: 231
 - All "good sounding" combinations of tones have simple ratios
 - Example: "A major" chord
 - A4: 440 *Hz*, C#5: 554,37 *Hz*, E5: 659,25 *Hz*
 - $A4: C\#5: E5 \approx 4: 5: 6$
 - $A4: E5 \approx 2: 3$



Lower
Pitch



Higher
Pitch



Methods

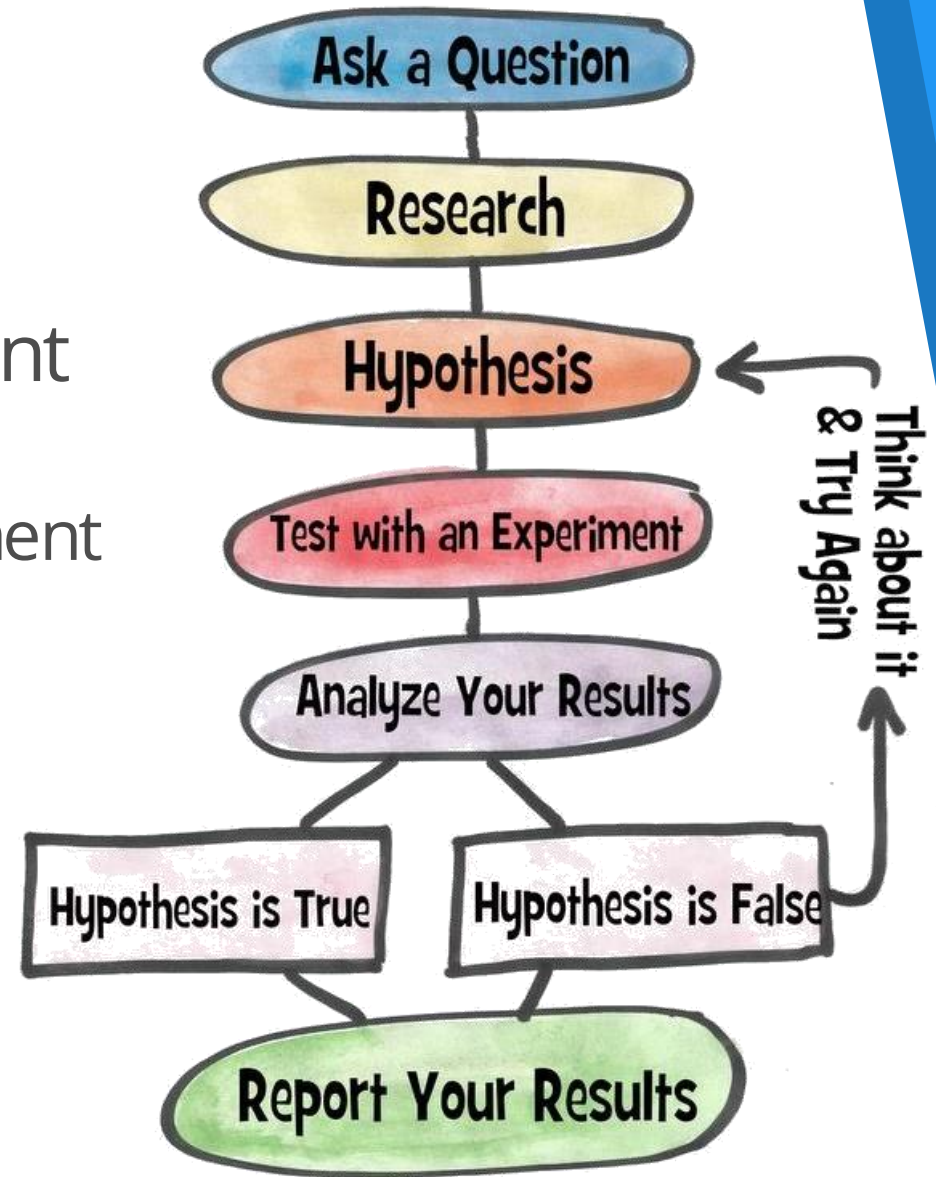
How not to get lost

Divide and conquer

- Useful for any kind of problem
 - Especially in algorithms and debugging
 - ... also, when invading countries
- Assumption: **Complicated things are a combination of many, very simple things**
 - Algorithms: Merge sort, Discrete Fourier transform
 - Software architecture:
 - "I want to build an ecommerce system"
 - ⇒ I want shop owners to add new products
 - ⇒ I want to store products in the DB ⇒ ...
 - ⇒ `def save_product(name, price)`
 - Debugging
 - The bug is somewhere in my code ⇒ ...
 - ⇒ the bug is "`>=`" instead of "`>`" on line 45 in `user.py`

The Scientific Method Steps

- Ask a question
- Do some research
- Form a hypothesis
- Test the hypothesis with an experiment
 - Experiment works \Rightarrow Analyze the data
 - Experiment doesn't work \Rightarrow Fix experiment
- Results align with hypothesis \Rightarrow OK
- Results don't align with hypothesis \Rightarrow new question, new hypothesis
- Communicate the results



Why use the Scientific Method?

- Useful when we're exploring something new
 - A new algorithm
 - A new codebase we've just been hired to work on
- Based on common logic
- Experiments
- **Example:** performance testing
 - **Research:** My logs show that this Web page on my server takes too much time to load
 - **Hypothesis:** This piece of code is too slow. I need to improve it
 - **Control:** Measure the runtime (in seconds)
 - **Experiment:** Try to fix the problem and repeat the runtime test
 - Did the fix bring a considerable performance gain?
 - **Communication:** Show the results and implement the fix



Setting Up Our Environment

Getting ready to conquer math,
science and programming

Anaconda

- You can install the Python interpreter and all libraries manually
 - Hard, boring and repetitive work
 - Error-prone
- Easy solution: platforms like **Anaconda**
 - Everything you need to get started with Python for science: Python interpreter, packages (720+), package manager, IDE
- Download from [the Anaconda website](#)
- Current version (March 2022): Anaconda 2021.11
 - Choose your platform (Windows, Linux, or MacOS)
 - Follow the installer



Setting Up an IDE (Optional)

- You can use the built-in IDE called **Spyder**
 - You can even use Notepad if that's your thing
- If you want to use another IDE, you have to configure it to work with Python
 - Syntax highlighting, autocomplete, etc.
- Visual Studio Code
 - My preferred editor / IDE
 - [Python in VS Code – tutorial](#)
 - [Python extension](#)
- Visual Studio
 - [Python Tools](#)

Python Online

- There are places where you can execute your code online
 - If you don't have access to Anaconda
 - Or you want to test something very quickly
- <https://www.python.org/shell/>
 - Provides a Python shell (CLI)
- <https://www.pythonanywhere.com/try-ipython/>
 - Provides an implementation of IPython (Interactive Python)
 - REPL (**R**ead – **E**xecute – **P**rint **L**oop)
 - No major difference to the Python shell
- To share your code, you can use
 - <http://ideone.com>
 - <https://gist.github.com/>
 - <http://pastebin.com/>

Jupyter Notebook

- A very nice and clean way to document your research
- Included in Anaconda
- Can create documents that contain live code, equations, visualizations and explanatory text
 - HTML / CSS / JavaScript
 - Markdown
 - $\text{L}^{\text{A}}\text{T}_{\text{E}}\text{X}$
 - Python
- Start – use the Anaconda shortcut
 - ... or type into the Command Prompt

```
jupyter notebook
```

How to Use Jupyter

- Create a new notebook
 - New > Python 3
- Every piece of text or code is in a cell
 - Text cells just contain text or Markdown



- Code cells contain code (obviously)
 - Code can be executed
 - Jupyter "remembers" the code
- Execute cell: **Ctrl + Enter**
 - Or use the menus

The diagram shows a Jupyter code cell. The input code is `In [2]: print("Hello world")`. Below the input, the output of the execution is displayed as `Hello world`.

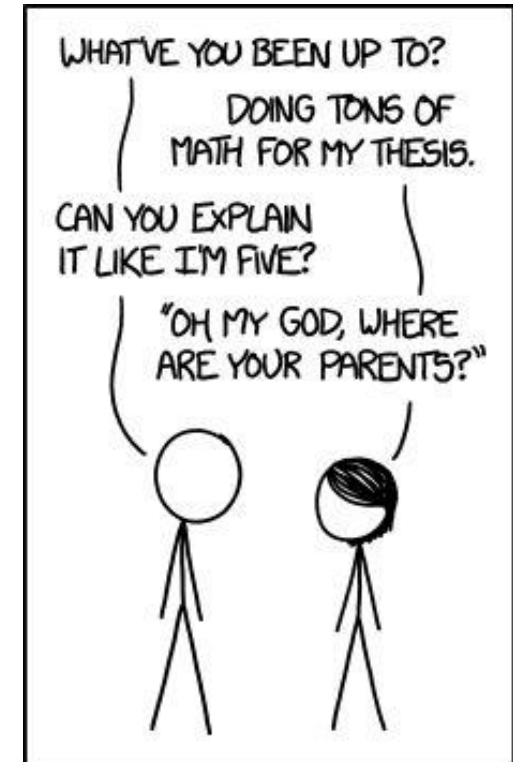


Math Notation

How to write more quickly
and concisely

Math Notation

- The basic symbols we use are numbers and letters
 - Usually English or Greek letters
- Special symbols: $=, \geq, \in, \rightarrow, \nabla, \infty, \int$
- Indices: $\sum_{n=0}^{10}, \lim_{x \rightarrow 0}$



Other Useful Notations

■ Scientific notation

- Used for very large or very small numbers
- Numbers are expressed as decimals with **exactly one** digit before the decimal point
- All other digits are expressed as a power of 10
- $15\ 000 = 1,5 \cdot 10^4$
- $0,000015 = 1,5 \cdot 10^{-5}$

■ Summation notation ("sigma" notation)

- Used as a shorthand for writing long sums of numbers / symbols
 - Very similar to a for-loop
 - Greek capital "sigma" denotes the sum, the two numbers below and above it denote the start and end points

$$\sum_{i=1}^5 i = 1 + 2 + 3 + 4 + 5$$

$$\sum_{k=1}^n x_k = x_1 + x_2 + \cdots + x_n$$

Equality Sign

- Important as it has different meanings
 - Like programming: "=", "==" and "==="

■ Identity

- The two statements around "=" are always equal: $x(x + 3) = x^2 + 3x$
 - We can also use the "identity" symbol: $(a + b)^2 \equiv a^2 + 2ab + b^2$
- ... for all "valid" symbols: $\frac{4x^2}{x} = 4x, x \neq 0$

■ Equation

- The two statements are true only for specific values of the symbols
$$2x + 5 = 4, x = -0.5 \qquad x^2 - 1 = 0, x = \pm 1 \qquad \frac{dx}{dt} = 5x - 3$$

- **Definition** (we can also use $:=$ or $\stackrel{\text{def}}{=}$, or even \equiv)

$$\sum i := \sum_{i=1}^n i := 1 + 2 + 3 + \cdots + n$$



Linear Equations

Simple, yet very useful

Linear Equations – Review

- Equations of a **variable** x
- x is "on its own"
 - Not inside a function (e.g. $\sin(x)$, $\frac{1}{x}$, e^x)
 - No powers (e.g. x^3)
- General form: $ax + b = 0$
 - a and b : fixed numbers (**parameters**)
- Examples
 - $2x + 3 = 0$
 - $2(2x + 3) - 3x - 3(-4 + 3x) = 12$
- Solutions of the parametric equation
 - $a = 0, b = 0 \Rightarrow 0.x = 0, \forall x$ (every x is a solution)
 - $a = 0, b \neq 0 \Rightarrow 0.x = -b$ (no solution)
 - $a \neq 0, \Rightarrow x = -b/a$ (one solution, regardless of b)

Exercise: Linear Equations

- Write a Python function which solves a linear equation given the definition from the previous slide
 - The function should accept the **a** and **b** as arguments
 - The function should return
 - The solution, if there is only one
 - **nan** if there is no solution
 - Empty list `[]` if all x satisfy the equation

```
import math
def solve_linear_equation(a, b):
    if a == 0:
        if b == 0:
            return []
        else:
            return math.nan
    else:
        return -b / a
```

```
solve_linear_equation(0, 0) # []
solve_linear_equation(0, 5) # nan
solve_linear_equation(5, 0) # 0.0
solve_linear_equation(5, 5) # -1.0
solve_linear_equation(2.5, -5.3) # 2.12
```

Linear Systems of Equations – Review

- Many simultaneous equations
 - To solve the system, we need to find values of the variable(s) which satisfy **all equations** at once
 - Even if all individual equations have solutions, the system may have no solution
- Solution
 - Method 1: Solve one equation and substitute
 - Method 2: Use sum of equations
 - Later, we'll learn a faster way of solving these systems

- Example

$$\begin{array}{l|l} 4x + 3y & = 7 \\ 3x + 5y & = 8 \\ x - 2y & = -1 \end{array}$$

Solving a Linear System

$$\begin{cases} 4x + 3y = 7 \\ 3x + 5y = 8 \\ x - 2y = -1 \end{cases}$$

$$(3) : x = -1 + 2y$$

$$(3) \rightarrow (2) : 3(-1 + 2y) + 5y = 8$$

$$-3 + 6y + 5y = 8$$

$$11y = 11$$

$$\boxed{y = 1}$$

$$(2) \rightarrow (3) : x = -1 + 2 \cdot 1$$

$$\boxed{x = 1}$$

$$(1) : 4 \cdot 1 + 3 \cdot 1 = 7$$

$\Rightarrow (x, y) = (1, 1)$ is the only solution of the system

- Note: The numbers of equations and variables matter
 - E.g., this system is "overdetermined"
 - We'll learn more about this later

Summary

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- Methods
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 - Scientific method
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- Linear equations and systems of equations

The image features a white background with two blue decorative bars. The top bar is a solid blue strip. The bottom bar consists of two layers: a darker blue line just above a solid blue strip. The word "Questions?" is centered in a blue, sans-serif font.

Questions?