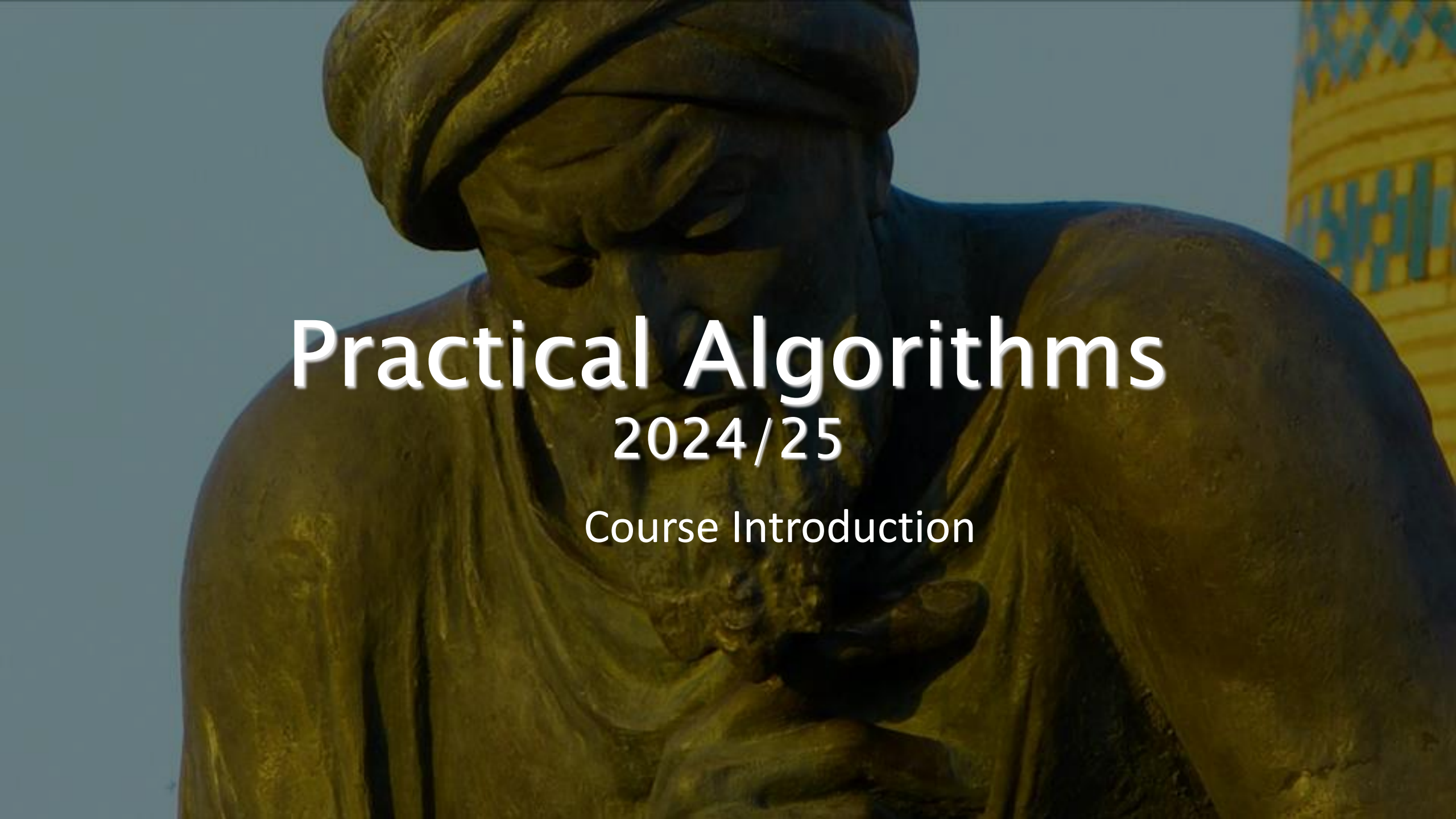


Practical Algorithms

2024/25

Course Introduction

Who are we?

Lecturers:

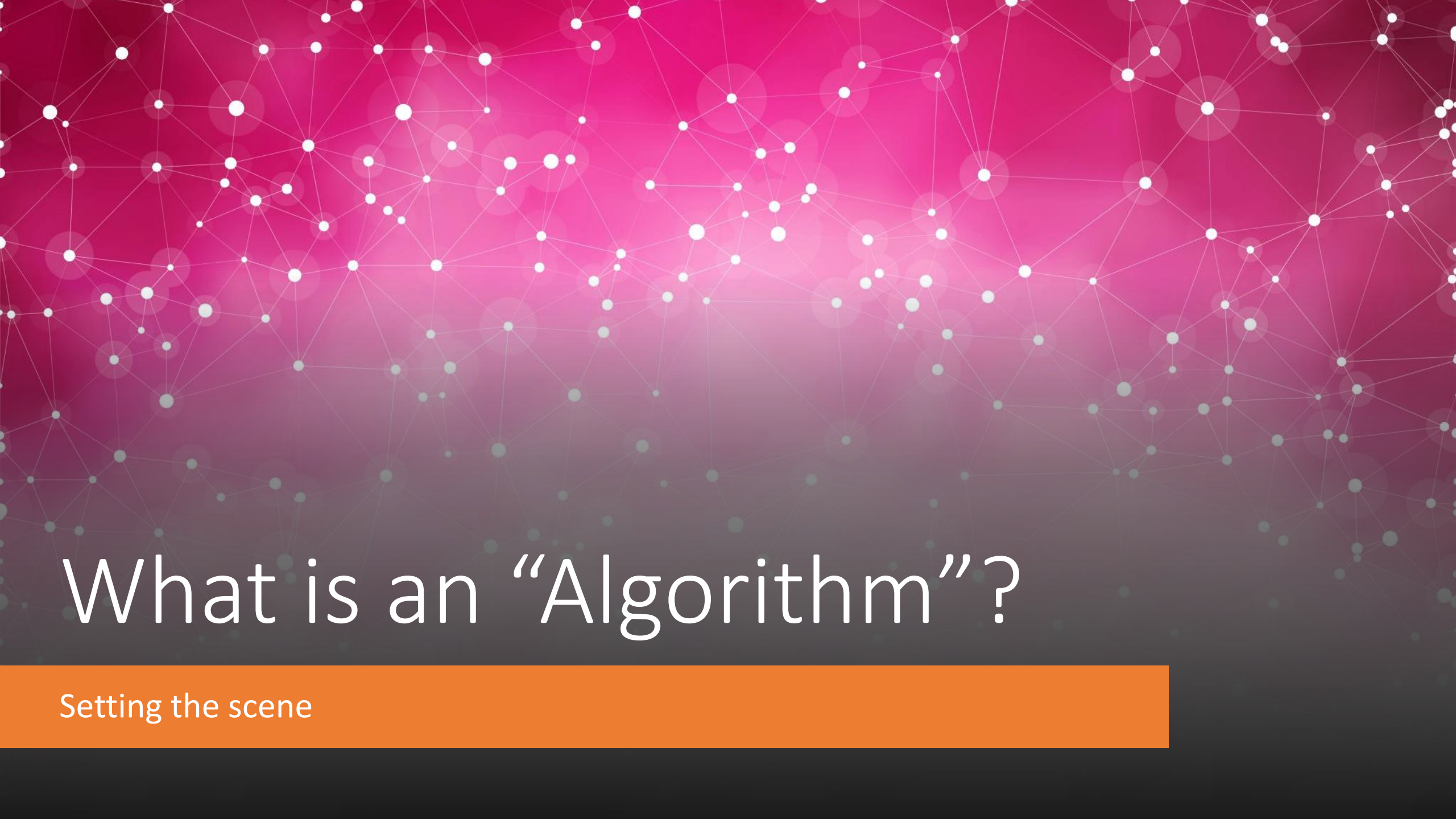
Dr S **Waqar** Nabi

Dr **Yiannis** Giannakopoulos

Tutors:

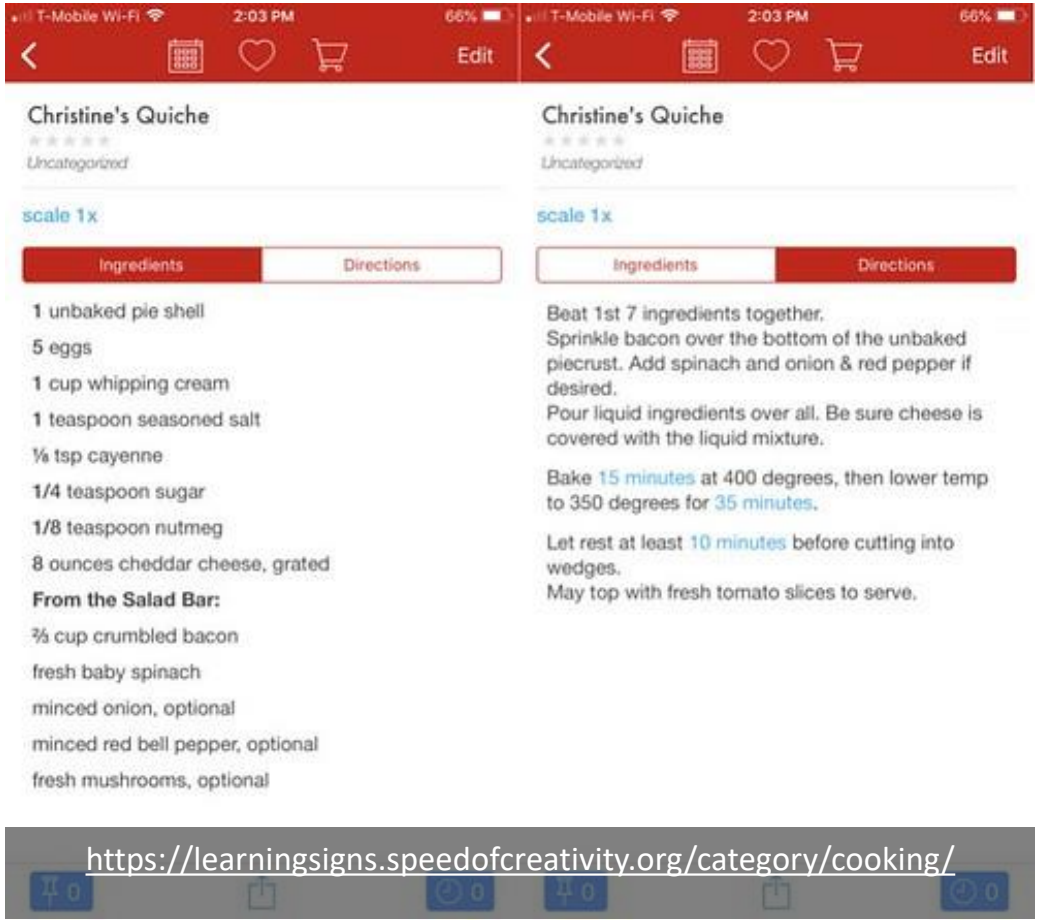
Laura Larios-Jones

Ethan Hunter


What is an “Algorithm”?
Setting the scene

First: Defining “Algorithm”

- Dictionary (common English) definition:
  - “A procedure for solving a (mathematical) problem in a finite number of steps that frequently involves repetitions of an operation;
  - broadly: a **step-by-step method** for accomplishing some task.”
- E.g.
  - recipe for a dish
  - multiplying numbers



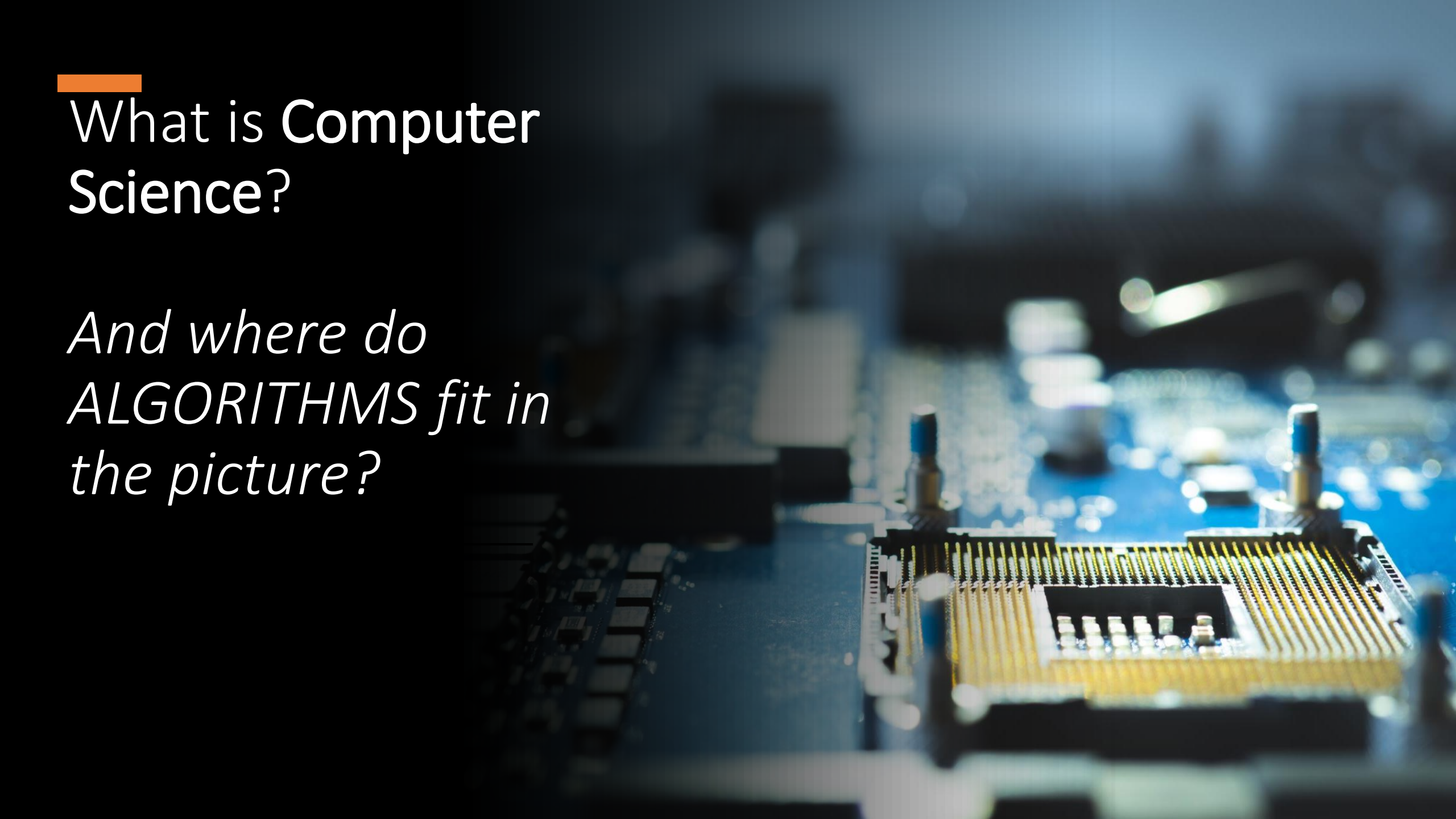
https://learningsigns.speedofcreativity.org/category/cooking/

Importance of Algorithms

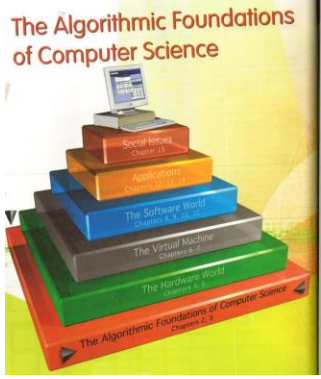
"If we can specify an algorithm to solve a problem, then we can automate its solution."

What is **Computer Science**?

And where do ALGORITHMS fit in the picture?



One Definition of Computer Science places Algorithms at the heart of it[1]



Computer Science is the study of *Algorithms,* including:

1. Their formal and mathematical properties
   - "Studying the behaviour of algorithms to determine whether they are **correct** and **efficient".**
2. Their hardware realizations
   - "Designing and building **computer systems** that are able to execute algorithms".
3. Their linguistic realizations
   - "Designing **programming languages** and translating algorithms into these languages so that they can be executed by the hardware".
4. Their applications
   - "Identifying important **problems**, and designing correct and efficient **software** packages to solve these problems".

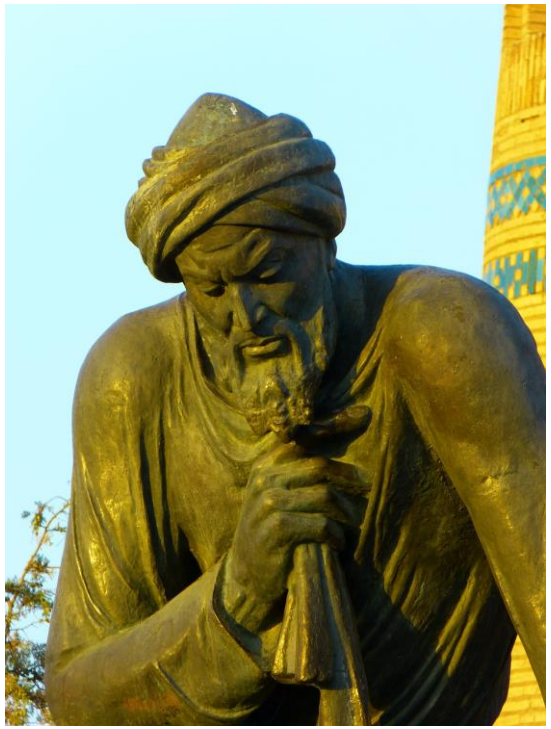
[added: Software Engineering may be viewed as having a higher emphasis on #4]

ALGORITHMS & COMPUTERS - SOME BACK STORY

"In 1812 he [Babbage] was sitting in his rooms in the Analytical Society looking at a table of logarithms, which he knew to be full of mistakes, when the idea occurred to him of computing all tabular functions by machinery. The French government had produced several tables by a new method. Three or four of their mathematicians decided how to compute the tables, half a dozen more broke down the operations into simple stages, and the work itself, which was restricted to addition and subtraction, was done by eighty computers who knew only these two arithmetical processes. Here, for the first time, mass production was applied to arithmetic, and Babbage was seized by the idea that the labours of the unskilled computers [people] could be taken over completely by machinery which would be **quicker** and **more reliable**."

[https://en.wikipedia.org/wiki/Charles_Babbage#cite_note-146]

Some Key Figures



Why algorithms are called algorithms

Ada Lovelace: Great Minds

Who Was Aristotle? (Famous Philosophers)

Also worth checking out:

- The Big Bang - Ada Lovelace & Charles Babbage - Strange But True
  https://www.youtube.com/watch?v=4kueyMImxhY
- Early Computing: Crash Course Computer Science #1
  https://www.youtube.com/watch?v=O5nskjZ_GoI
- Logic (Podcast, “In our Times”)
  https://www.bbc.co.uk/programmes/b00vcqcx

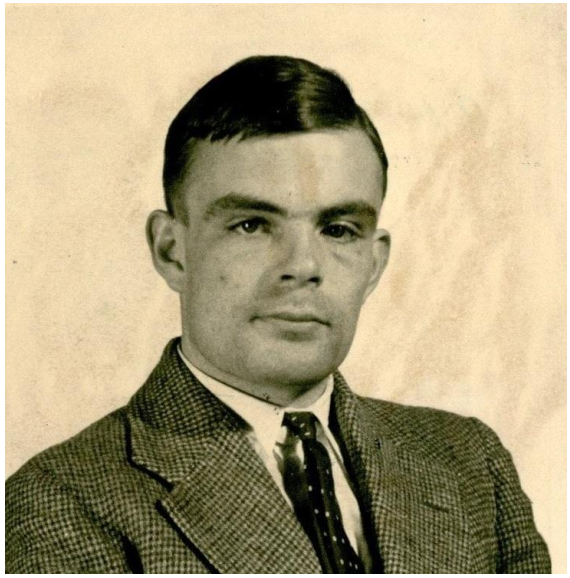
Diagram for the computation by the Engine of the Numbers of Bernoulli. See Note G. (page 722 *et seq.*)

Number of Operation.	Nature of Operation.	Variables acted upon.	Variables receiving results.	Indication of change in the value on any Variable.	Statement of Results.	Data. ${}^1V_1$ 0 0 0 1 [1]	Data. ${}^1V_2$ 0 0 0 2 [2]	Data. ${}^1V_3$ 0 0 0 4 [n]	Working Variables. ${}^0V_4$ 0 0 0 0 [ ]	${}^0V_5$ 0 0 0 0 [ ]	${}^0V_6$ 0 0 0 0 [ ]	${}^0V_7$ 0 0 0 0 [ ]	${}^0V_8$ 0 0 0 0 [ ]	${}^0V_9$ 0 0 0 0 [ ]	${}^0V_{10}$ 0 0 0 0 [ ]	${}^0V_{11}$ 0 0 0 0 [ ]	${}^0V_{12}$ 0 0 0 0 [ ]	${}^0V_{13}$ ..... 0 0 0 0 [ ]	Result Variables. ${}^1V_{21}$ B_1 in a decimal fraction. [B_1]	${}^1V_{22}$ B_3 in a decimal fraction. [B_3]	${}^1V_{23}$ B_5 in a decimal fraction. [B_5]	${}^0V_{24}$... 0 0 0 0 [B_7]
1	×	${}^1V_2 \times {}^1V_3$	${}^1V_4, {}^1V_5, {}^1V_6$	${}^1V_2 = {}^1V_2$, ${}^1V_3 = {}^1V_3$	$= 2n$	...	2	n	$2n$	$2n$	$2n$											
2	−	${}^1V_4 - {}^1V_1$	${}^2V_4$	${}^1V_4 = {}^2V_4$, ${}^1V_1 = {}^1V_1$	$= 2n-1$	1	...	...	$2n-1$													
3	+	${}^1V_5 + {}^1V_1$	${}^2V_5$	${}^1V_5 = {}^2V_5$, ${}^1V_1 = {}^1V_1$	$= 2n+1$	1	...	...	...	$2n+1$												
4	÷	${}^2V_5 \div {}^2V_4$	${}^1V_{11}$	${}^2V_5 = {}^0V_5$, ${}^2V_4 = {}^0V_4$	$= \frac{2n-1}{2n+1}$	...	...	...	0	0	...	...	...	...	...	$\frac{2n-1}{2n+1}$						
5	÷	${}^1V_{11} \div {}^1V_2$	${}^2V_{11}$	${}^1V_{11} = {}^2V_{11}$, ${}^1V_2 = {}^1V_2$	$= \frac{1}{2} \cdot \frac{2n-1}{2n+1}$	...	2	...	...	...	...	...	...	...	...	$\frac{1}{2} \cdot \frac{2n-1}{2n+1}$						
6	−	${}^0V_{13} - {}^2V_{11}$	${}^1V_{13}$	${}^2V_{11} = {}^0V_{11}$, ${}^0V_{13} = {}^1V_{13}$	$= -\frac{1}{2} \cdot \frac{2n-1}{2n+1} = A_0$	...	...	...	...	...	...	...	...	...	...	0	.....	$-\frac{1}{2} \cdot \frac{2n-1}{2n+1} = A_0$				
7	−	${}^1V_3 - {}^1V_1$	${}^1V_{10}$	${}^1V_3 = {}^1V_3$, ${}^1V_1 = {}^1V_1$	$= n-1\ (=3)$	1	...	n	...	...	...	...	...	...	$n-1$							
8	+	${}^1V_2 + {}^0V_7$	${}^1V_7$	${}^1V_2 = {}^1V_2$, ${}^0V_7 = {}^1V_7$	$= 2 + 0 = 2$	...	2	...	...	...	...	2										
9	÷	${}^1V_6 \div {}^1V_7$	${}^3V_{11}$	${}^1V_6 = {}^1V_6$, ${}^0V_{11} = {}^3V_{11}$	$= \frac{2n}{2} = A_1$	...	...	...	...	...	$2n$	2	...	...	...	$\frac{2n}{2} = A_1$						
10	×	${}^1V_{21} \times {}^3V_{11}$	${}^1V_{12}$	${}^1V_{21} = {}^1V_{21}$, ${}^3V_{11} = {}^3V_{11}$	$= B_1 \cdot \frac{2n}{2} = B_1 A_1$	...	...	...	...	...	...	...	...	...	...	$\frac{2n}{2} = A_1$	$B_1 \cdot \frac{2n}{2} = B_1 A_1$	.....	B_1			
11	+	${}^1V_{12} + {}^1V_{13}$	${}^2V_{13}$	${}^1V_{12} = {}^0V_{12}$, ${}^1V_{13} = {}^2V_{13}$	$= -\frac{1}{2} \cdot \frac{2n-1}{2n+1} + B_1 \cdot \frac{2n}{2}$ ...	...	...	...	...	...	...	...	...	...	...	.....	0	$\left\{-\frac{1}{2} \cdot \frac{2n-1}{2n+1} + B_1 \cdot \frac{2n}{2}\right\}$				
12	−	${}^1V_{10} - {}^1V_1$	${}^2V_{10}$	${}^1V_{10} = {}^2V_{10}$, ${}^1V_1 = {}^1V_1$	$= n-2\ (=2)$	1	...	...	...	...	...	...	...	...	$n-2$							
13	−	${}^1V_6 - {}^1V_1$	${}^2V_6$	${}^1V_6 = {}^2V_6$, ${}^1V_1 = {}^1V_1$	$= 2n-1$	1	...	...	...	...	$2n-1$											
14	+	${}^1V_1 + {}^1V_7$	${}^2V_7$	${}^1V_1 = {}^1V_1$, ${}^1V_7 = {}^2V_7$	$= 2 + 1 = 3$	1	...	...	...	...	...	3										
15	÷	${}^2V_6 \div {}^2V_7$	${}^1V_8$	${}^2V_6 = {}^2V_6$, ${}^2V_7 = {}^2V_7$	$= \frac{2n-1}{3}$	...	...	...	...	...	$2n-1$	3	$\frac{2n-1}{3}$									
16	×	${}^1V_8 \times {}^3V_{11}$	${}^4V_{11}$	${}^1V_8 = {}^0V_8$, ${}^3V_{11} = {}^4V_{11}$	$= \frac{2n}{2} \cdot \frac{2n-1}{3}$	...	...	...	...	...	...	...	0	...	...	$\frac{2n}{2} \cdot \frac{2n-1}{3}$						
17	−	${}^2V_6 - {}^1V_1$	${}^3V_6$	${}^2V_6 = {}^3V_6$, ${}^1V_1 = {}^1V_1$	$= 2n-2$	1	...	...	...	...	$2n-2$											
18	+	${}^1V_1 + {}^2V_7$	${}^3V_7$	${}^2V_7 = {}^3V_7$, ${}^1V_1 = {}^1V_1$	$= 3 + 1 = 4$	1	...	...	...	...	...	4										
19	÷	${}^3V_6 \div {}^3V_7$	${}^1V_9$	${}^3V_6 = {}^3V_6$, ${}^3V_7 = {}^3V_7$	$= \frac{2n-2}{4}$	...	...	...	...	...	$2n-2$	4	...	$\frac{2n-2}{4}$	...	$\left\{\frac{2n}{2} \cdot \frac{2n-1}{3} \cdot \frac{2n-2}{3} = A_3\right\}$							
20	×	${}^1V_9 \times {}^4V_{11}$	${}^5V_{11}$	${}^1V_9 = {}^0V_9$, ${}^4V_{11} = {}^5V_{11}$	$= \frac{2n}{2} \cdot \frac{2n-1}{3} \cdot \frac{2n-2}{4} = A_3$	...	...	...	...	...	...	...	...	0								
21	×	${}^1V_{22} \times {}^5V_{11}$	${}^0V_{12}$	${}^1V_{22} = {}^1V_{22}$, ${}^0V_{12} = {}^2V_{12}$	$= B_3 \cdot \frac{2n}{2} \cdot \frac{2n-1}{3} \cdot \frac{2n-2}{3} = B_3 A_3$	...	...	...	...	...	...	...	...	...	...	0	$B_3 A_3$	.....	.....	B_3		
22	+	${}^2V_{12} + {}^2V_{13}$	${}^3V_{13}$	${}^2V_{12} = {}^0V_{12}$, ${}^2V_{13} = {}^3V_{13}$	$= A_0 + B_1 A_1 + B_3 A_3$	...	...	...	...	...	...	...	...	...	...	.....	0	$\{A_3 + B_1 A_1 + B_3 A_3\}$				
23	−	${}^2V_{10} - {}^1V_1$	${}^3V_{10}$	${}^2V_{10} = {}^3V_{10}$, ${}^1V_1 = {}^1V_1$	$= n-3\ (=1)$	1	...	...	...	...	...	...	...	...	$n-3$							

Here follows a repetition of Operations thirteen to twenty-three.

24	+	${}^4V_{13} + {}^0V_{24}$	${}^1V_{24}$	${}^4V_{13} = {}^0V_{13}$, ${}^0V_{24} = {}^1V_{24}$	$= B_7$	...	...	...	...	...	...	...	...	...	...	.....	.....	.....	.....	.....	.....	B_7
25	+	${}^1V_1 + {}^1V_3$	${}^1V_3$	${}^1V_1 = {}^1V_1$, ${}^1V_3 = {}^1V_3$, ${}^5V_6 = {}^0V_6$, ${}^5V_7 = {}^0V_7$	$= n+1 = 4+1 = 5$ ..... by a Variable-card. by a Variable-card.	1	...	$n+1$	...	...	0	0										

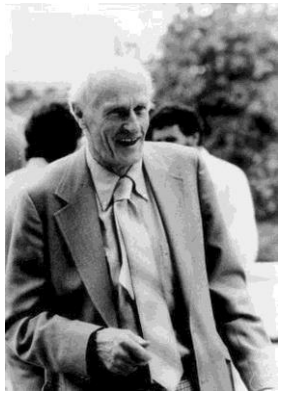
Other pivotal figures



Alan Turing (1912 – 1954)

David Hilbert

Kurt Gödel



Stephen Kleene

Alonzo Church

This course and Algorithms

- Understanding algorithms
- Writing and programming algorithms
- Analyzing algorithms
- Learning about “data structures” that together with algorithms can be used to solve real world problems
- Developing basic concepts of logic and mathematics needed to treat algorithms *formally*
- Developing skills in using a computer language to solve problems using algorithms and data structures

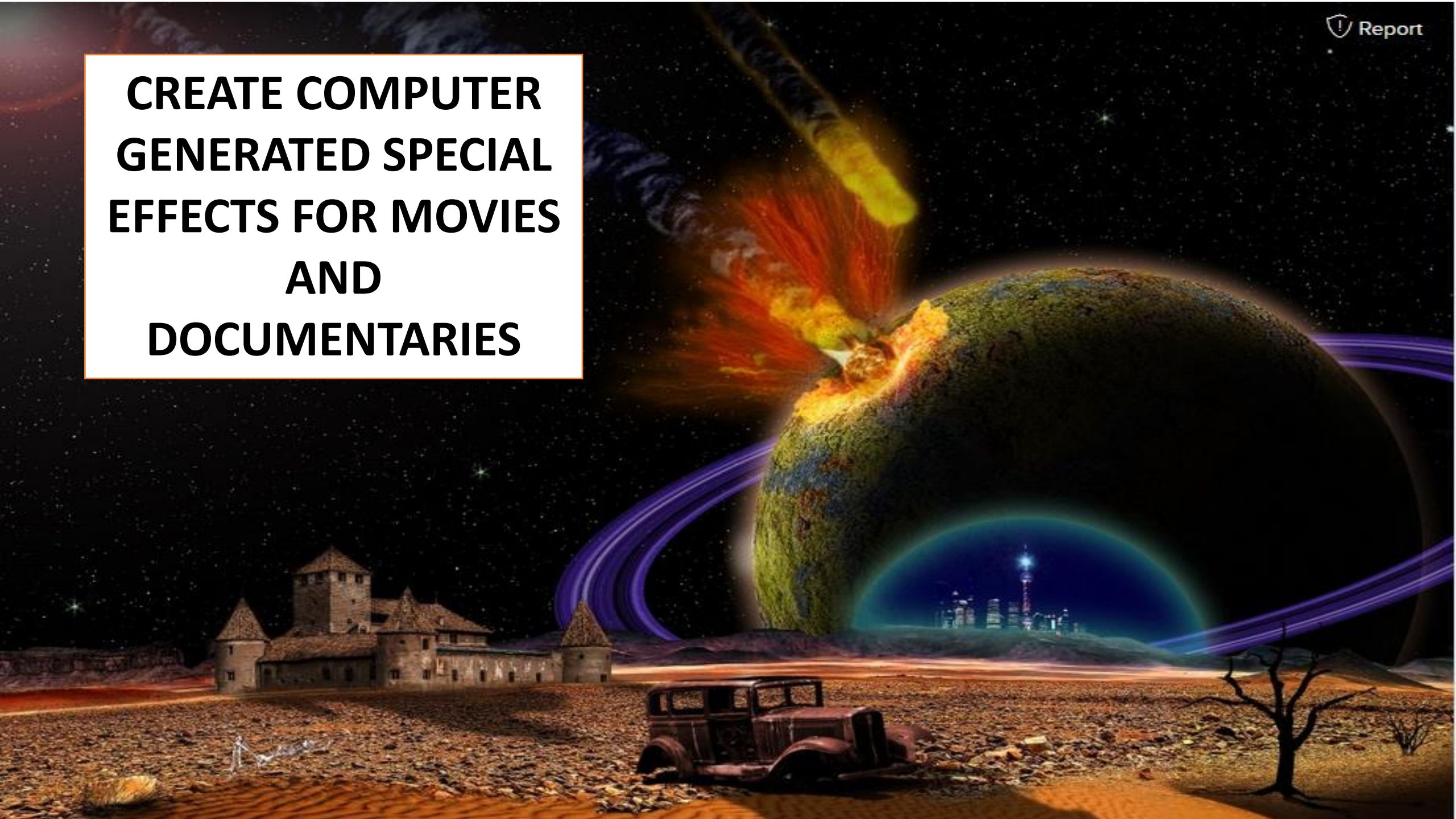
Applications of Algorithms

A wee sample only…

- **Optimization**
- **Operations Research**
- **Logistics**

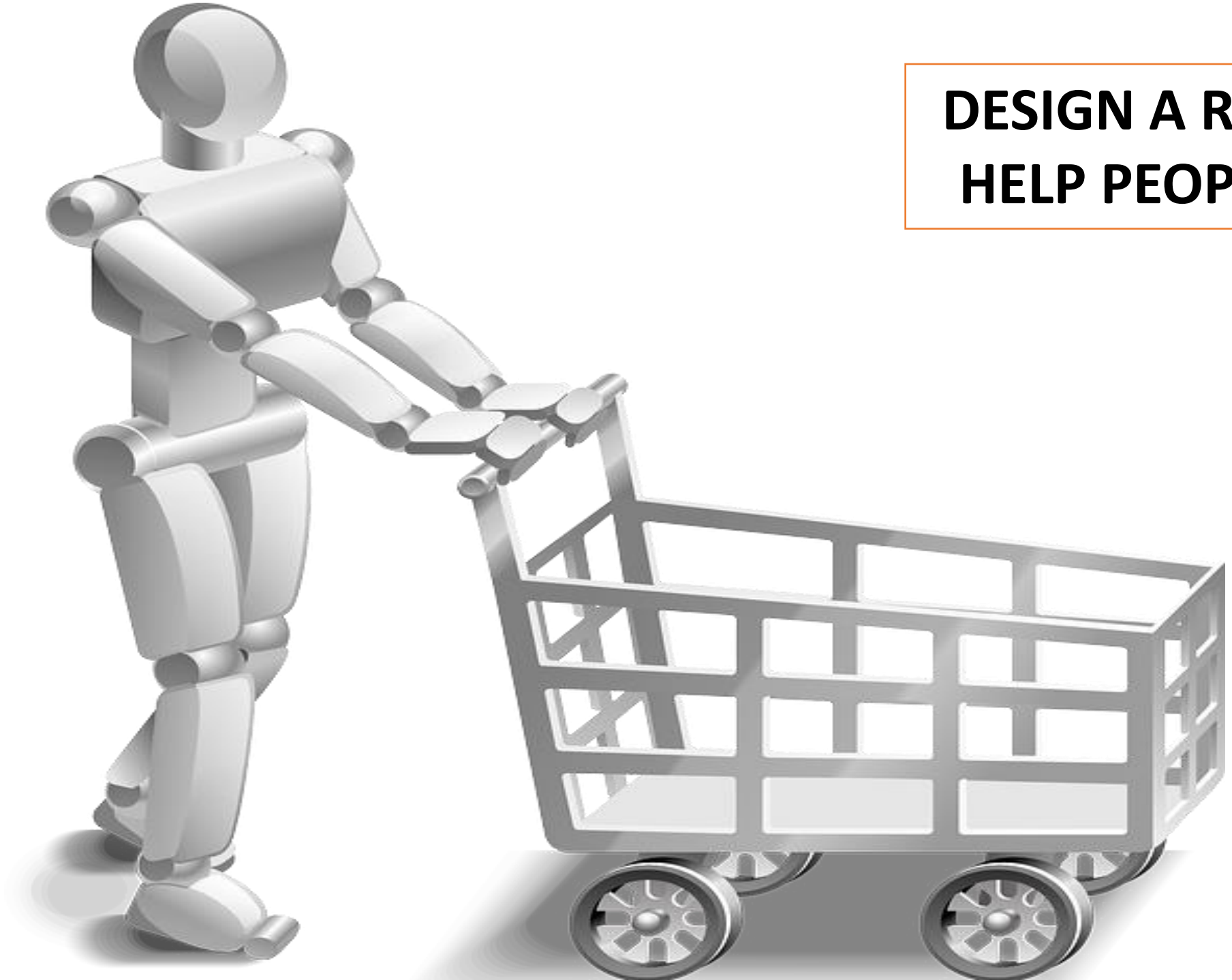
- Security
- Cryptography
- Cryptocurrencies and distributed ledgers

DESIGN COMPUTER GAMES


Report
CREATE COMPUTER GENERATED SPECIAL EFFECTS FOR MOVIES AND DOCUMENTARIES


GET THE MARS ROVER TO BEHAVE SENSIBLY WHEN ITS OUT THERE ALL ALONE ☹

DESIGN A ROBOT TO HELP PEOPLE SHOP




“SIMULATE” AND
STUDY THE
FORMATION OF
STARS AND GALAXIES

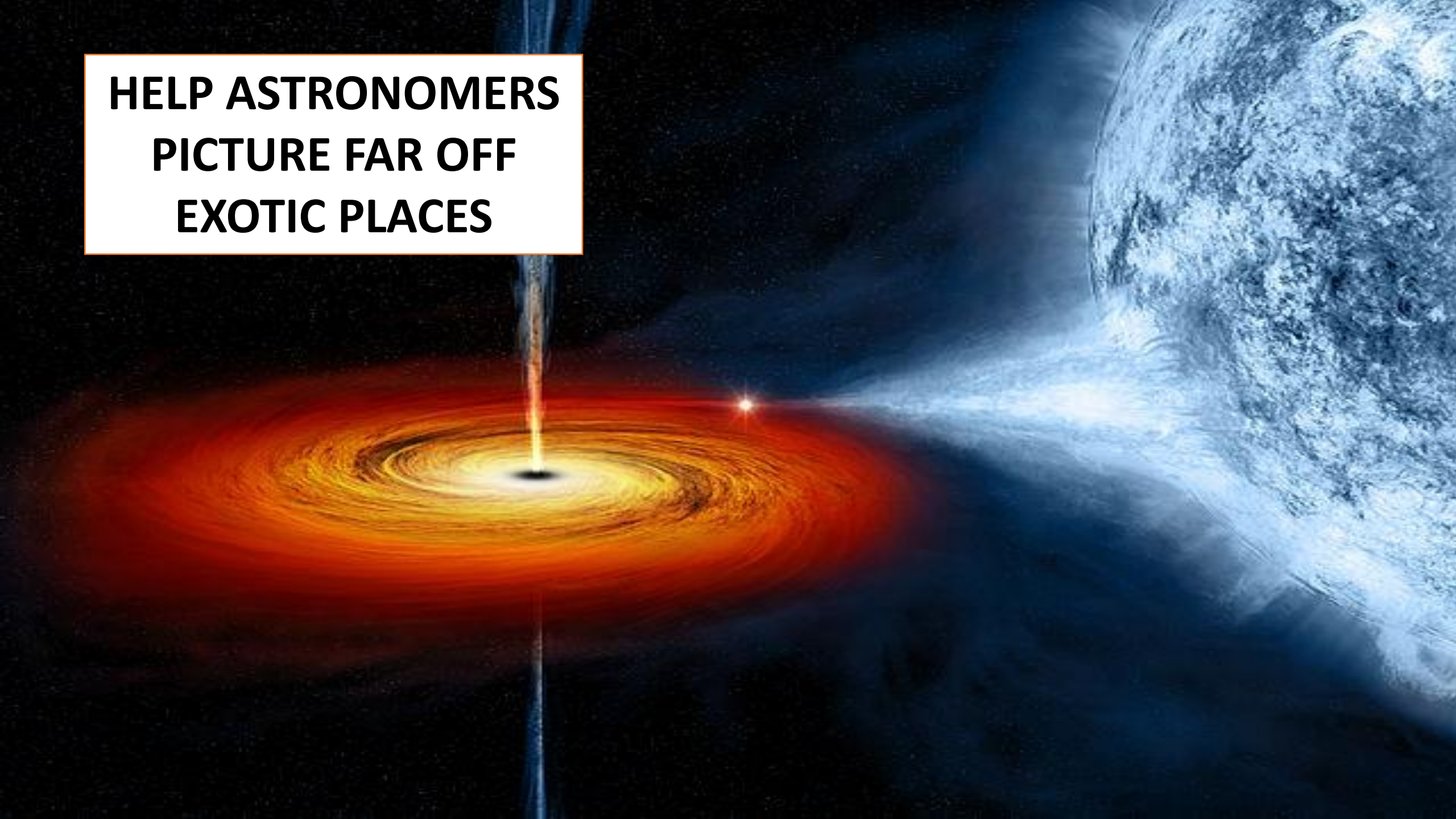
DESIGN FLIGHT SIMULATORS FOR TRAINING PILOTS


NEXT GENERATION
OF “PRECISION
MEDICINE”

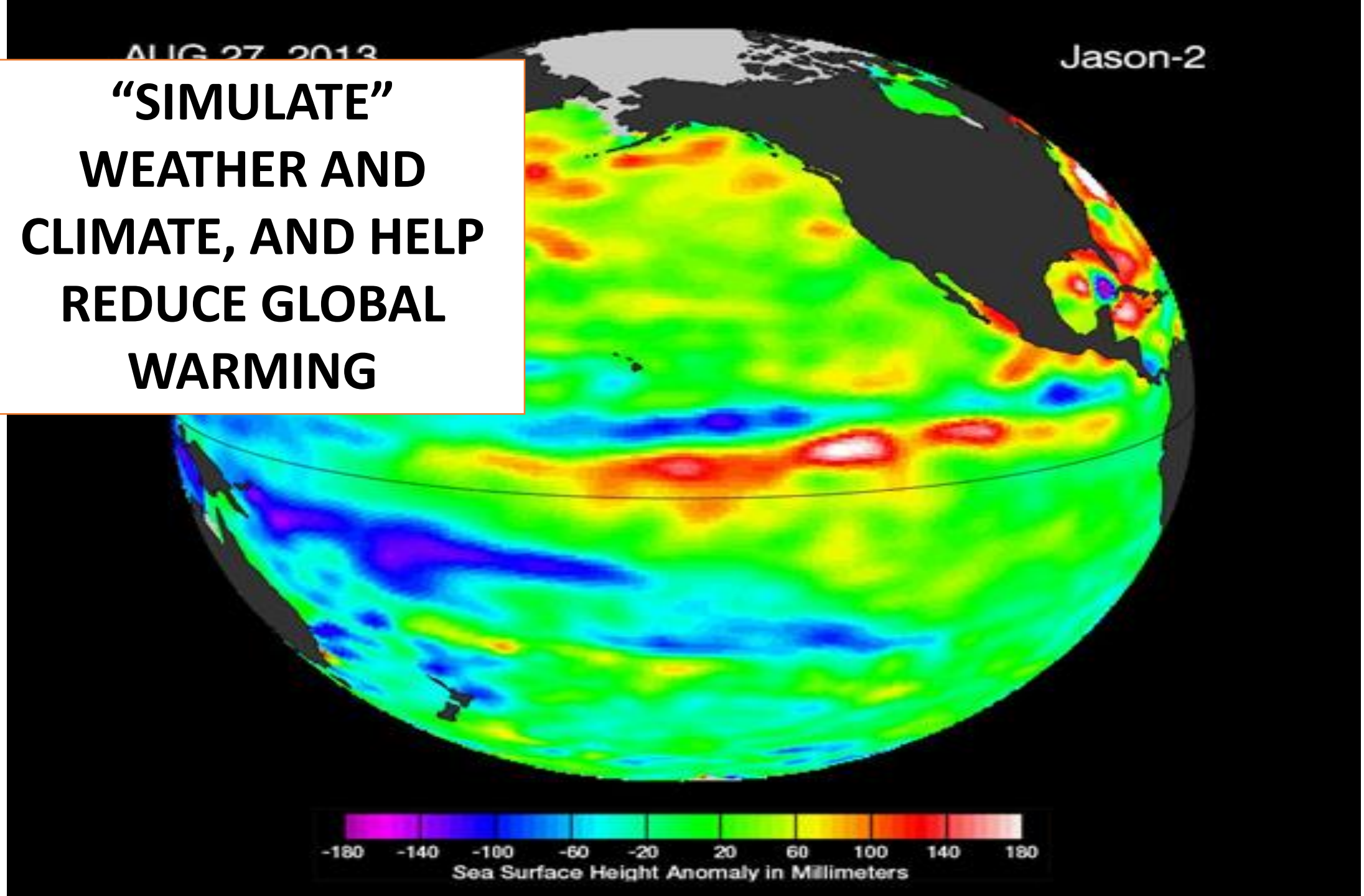

FIND PEOPLE
ORGANS FOR
TRANSPLANT

GET PEOPLE TO CELESTIAL BODIES…
…OTHER THAN EARTH!

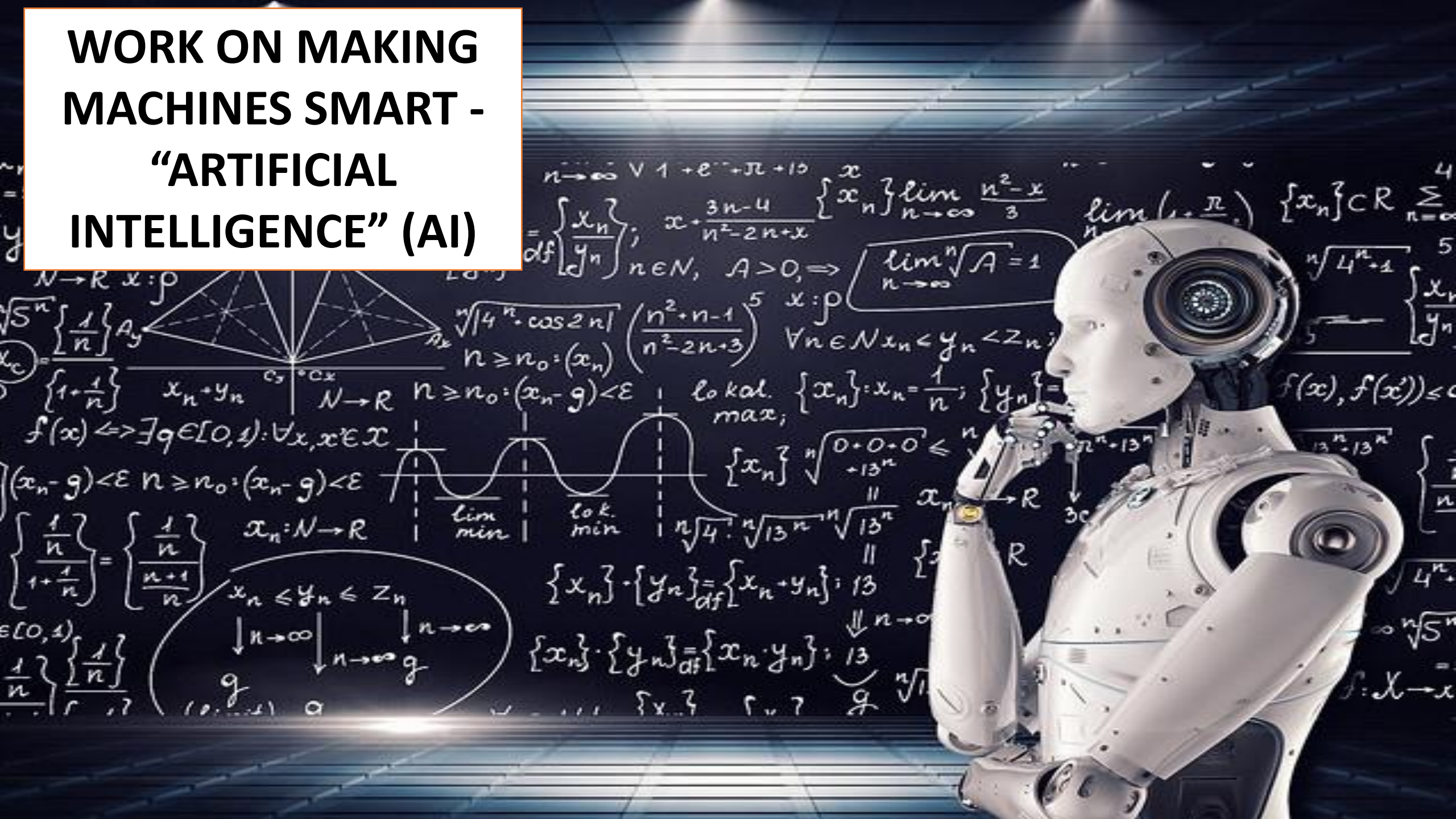
HELP ASTRONOMERS PICTURE FAR OFF EXOTIC PLACES



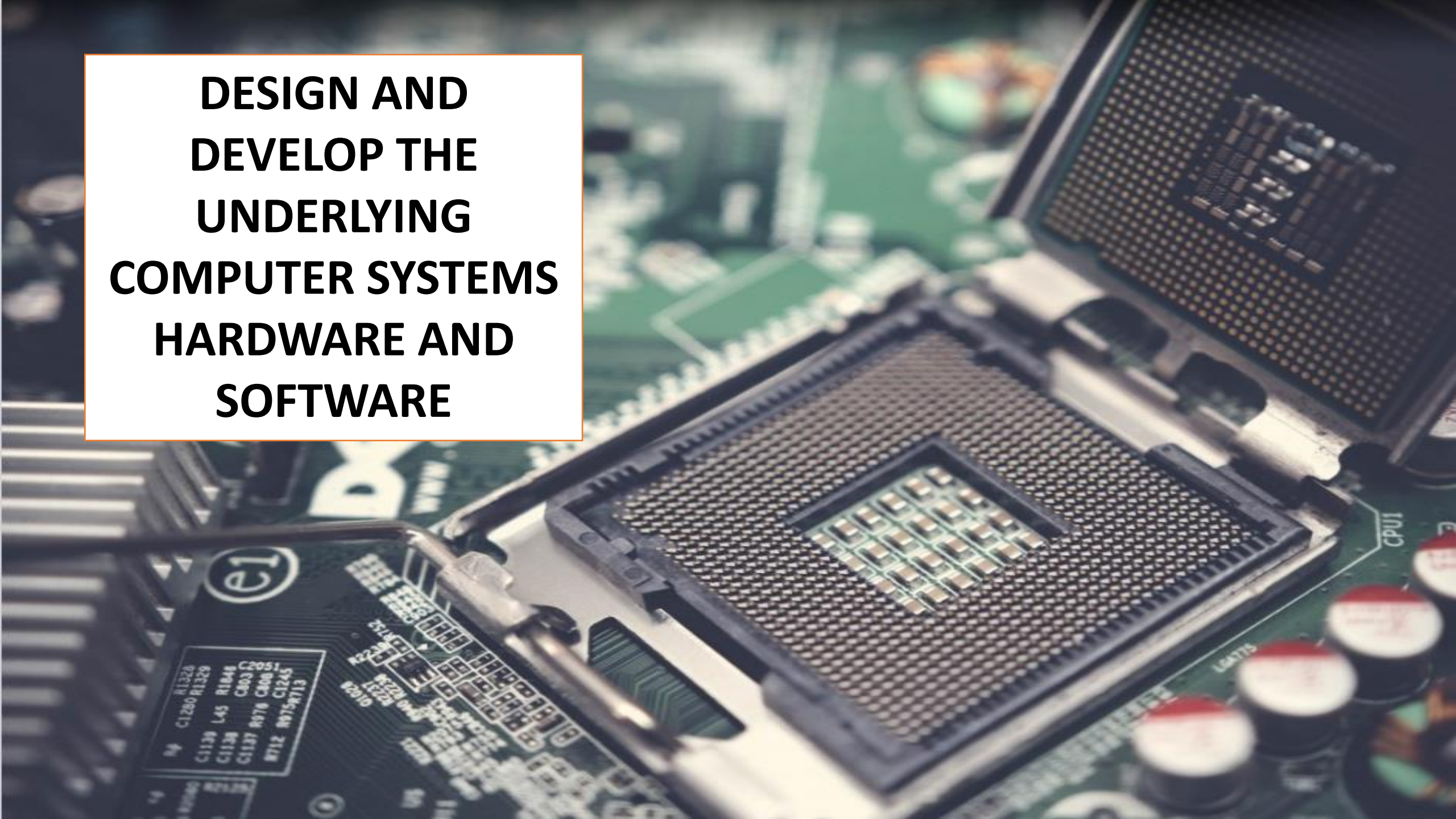
“SIMULATE” WEATHER AND CLIMATE, AND HELP REDUCE GLOBAL WARMING



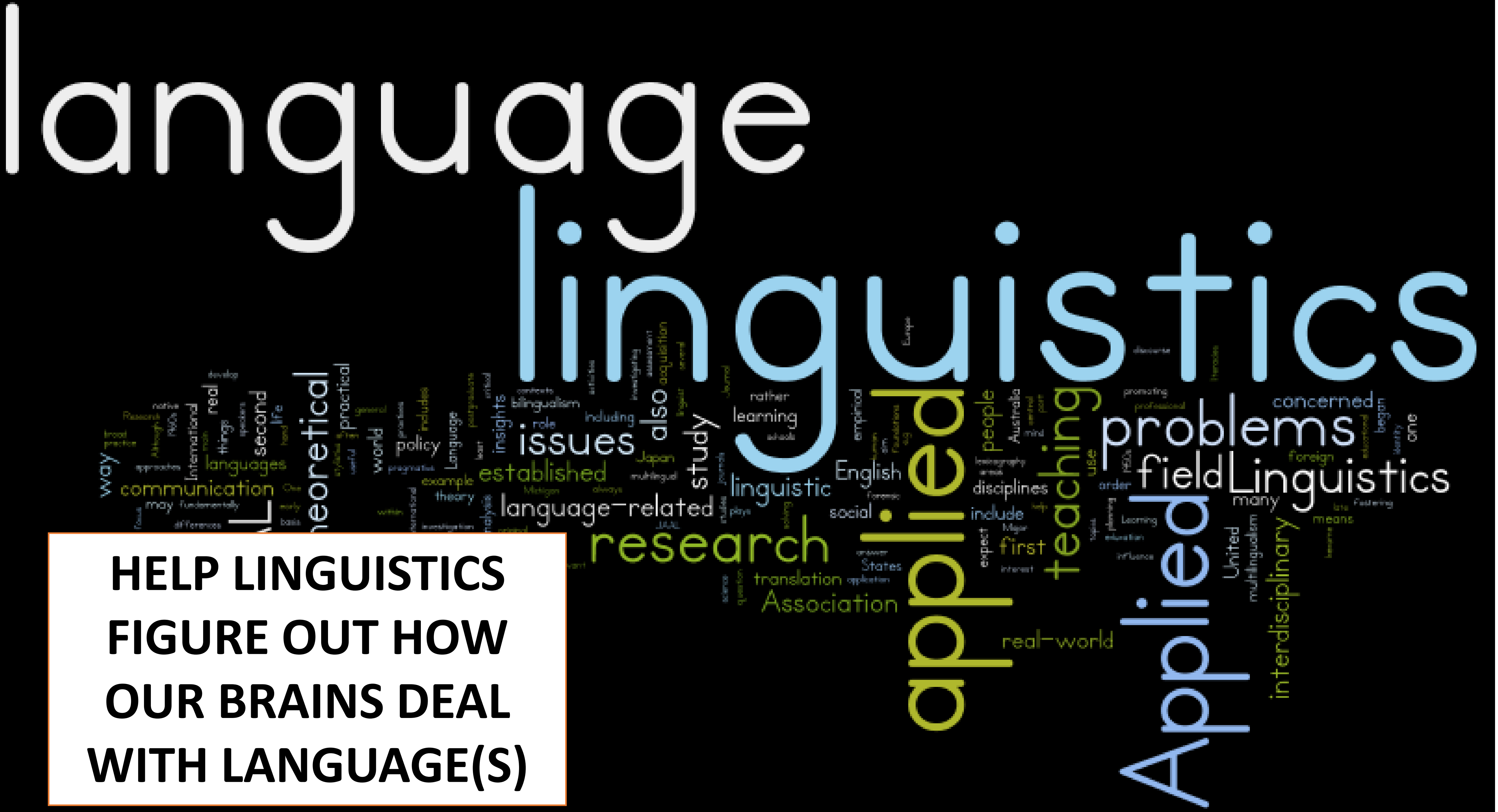
WORK ON MAKING MACHINES SMART - “ARTIFICIAL INTELLIGENCE” (AI)



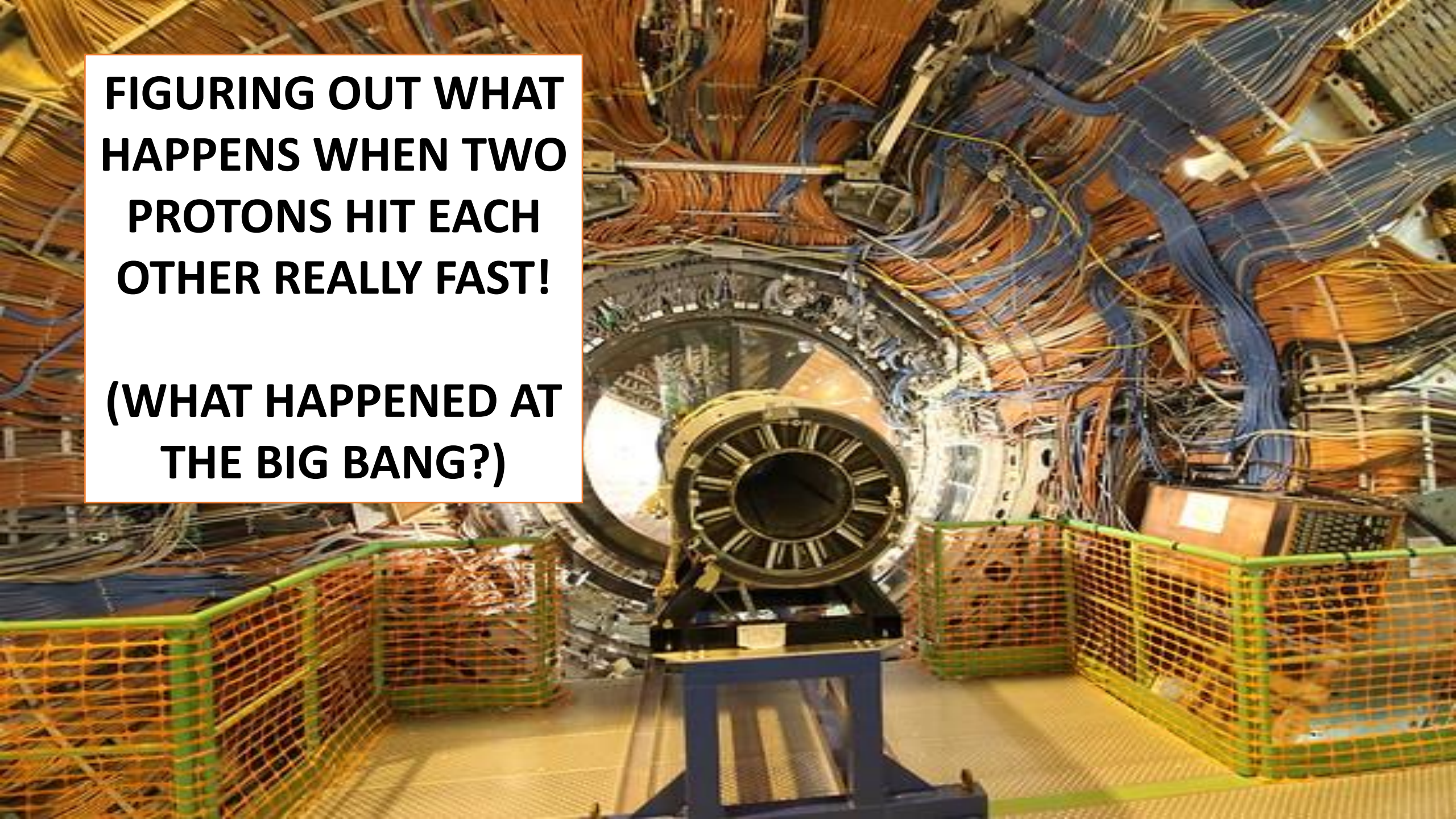
DESIGN NEW COOL WAYS FOR “HUMAN-COMPUTER INTERACTION”


DESIGN AND DEVELOP THE UNDERLYING COMPUTER SYSTEMS HARDWARE AND SOFTWARE

CONTRIBUTE TO DESIGNING NEXT GENERATION PROSTHETICS



HELP LINGUISTICS FIGURE OUT HOW OUR BRAINS DEAL WITH LANGUAGE(S)


FIGURING OUT WHAT HAPPENS WHEN TWO PROTONS HIT EACH OTHER REALLY FAST!
(WHAT HAPPENED AT THE BIG BANG?)

- Artificial Intelligence
- Machine Learning

Incentives & Fairness

Decision making under uncertainty