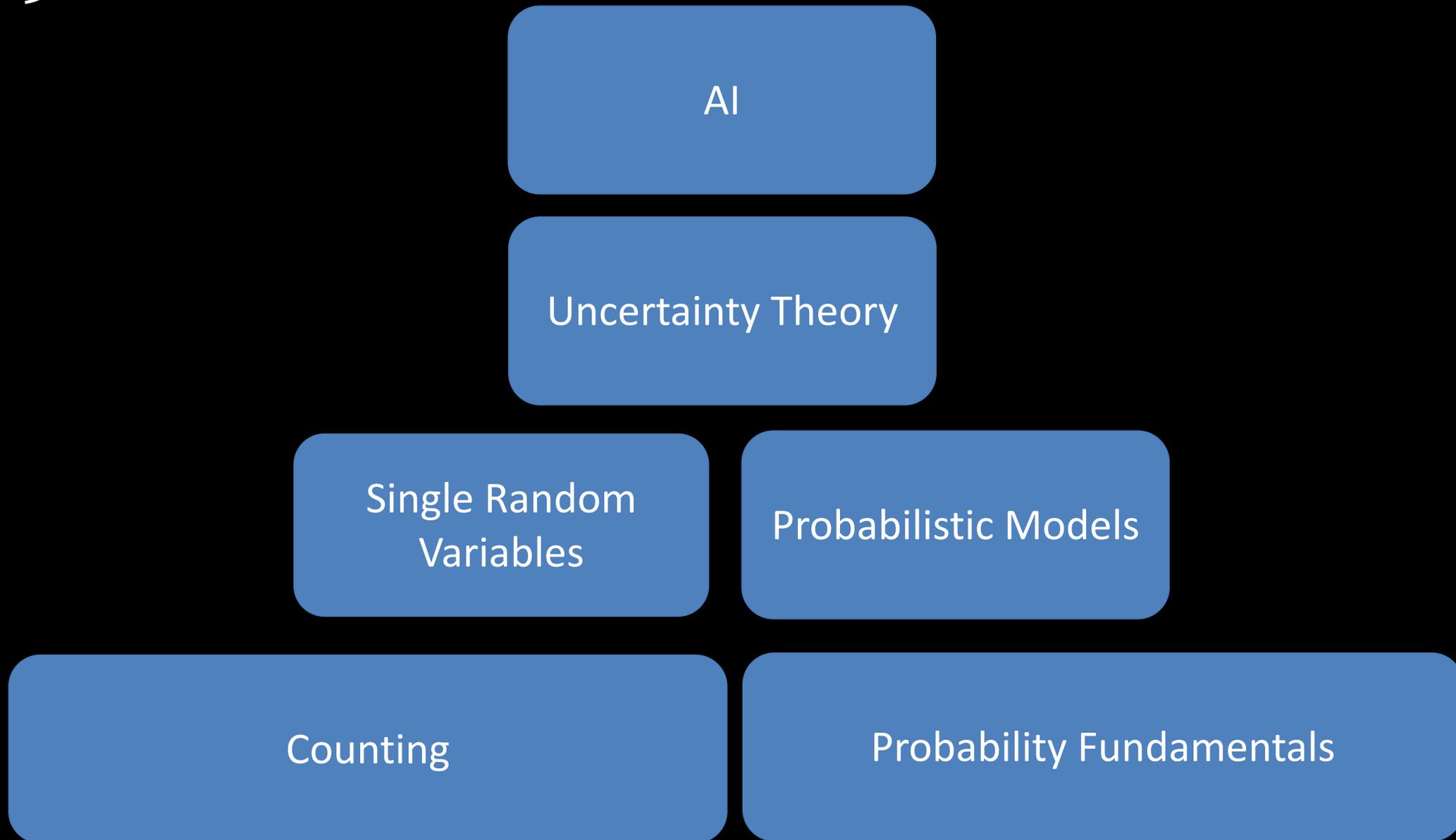


Future of Probability

Chris Piech



Learning Goal: Abundance of important problems



Open Problem: One Shot Learning

B Lake, R Salakhutdinov, J Tenenbaum. Science 2015.

Human-level concept learning through probabilistic program induction.



४	५	६	७	८
९	०	१	२	३

Current deep learning methods are not enough to move the needle as far as we want, **especially on socially relevant problems** that often do not have the benefit of massive public datasets. The best new ideas are coming from probability theory



Open Problem: One Shot Learning

B Lake, R Salakhutdinov, J Tenenbaum. Science 2015.

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Current deep learning methods are not enough to move the needle as far as we want, **especially on socially relevant problems** that often do not have the benefit of massive public datasets. The best new ideas are coming from probability theory



Today

Digital Future of Probability

Themes to look out for:

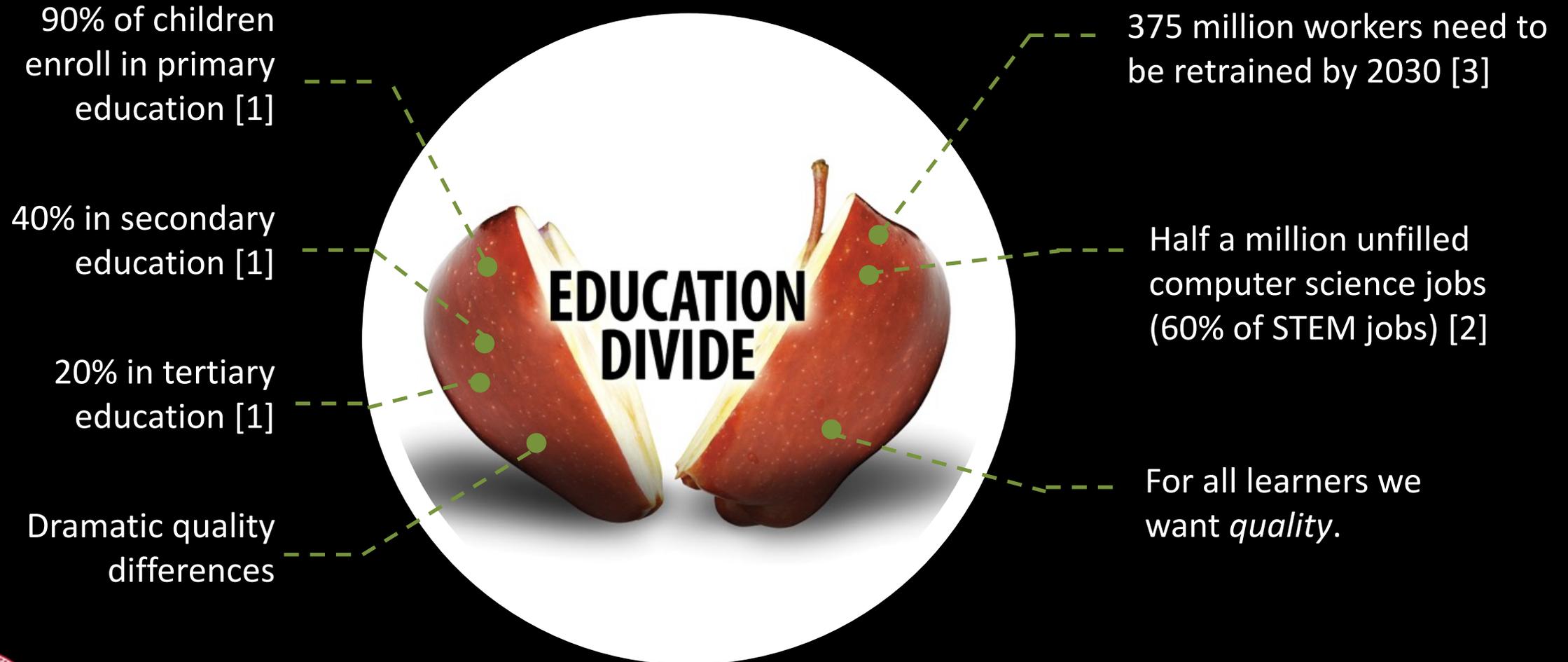
Probabilistic Modelling vs Deep Learning
Distributions vs Point Estimates

Let me tell you a story about one particular problem.

It will give you a sense of what it takes to do research in **applied probability**, and our desire to solve the problems, will lead us to deep **theoretical** challenges in modern AI.

Application -> Theory

Quality Education Gap



[1] *World development indicators 2015*. World Bank Publications, 2015.

[2] USA Bureau of Labor Statistics Employment Projections , 2016.

[3] Jobs lost, jobs gained. McKinsey Global Institute, 2017.



Smart Phone Access

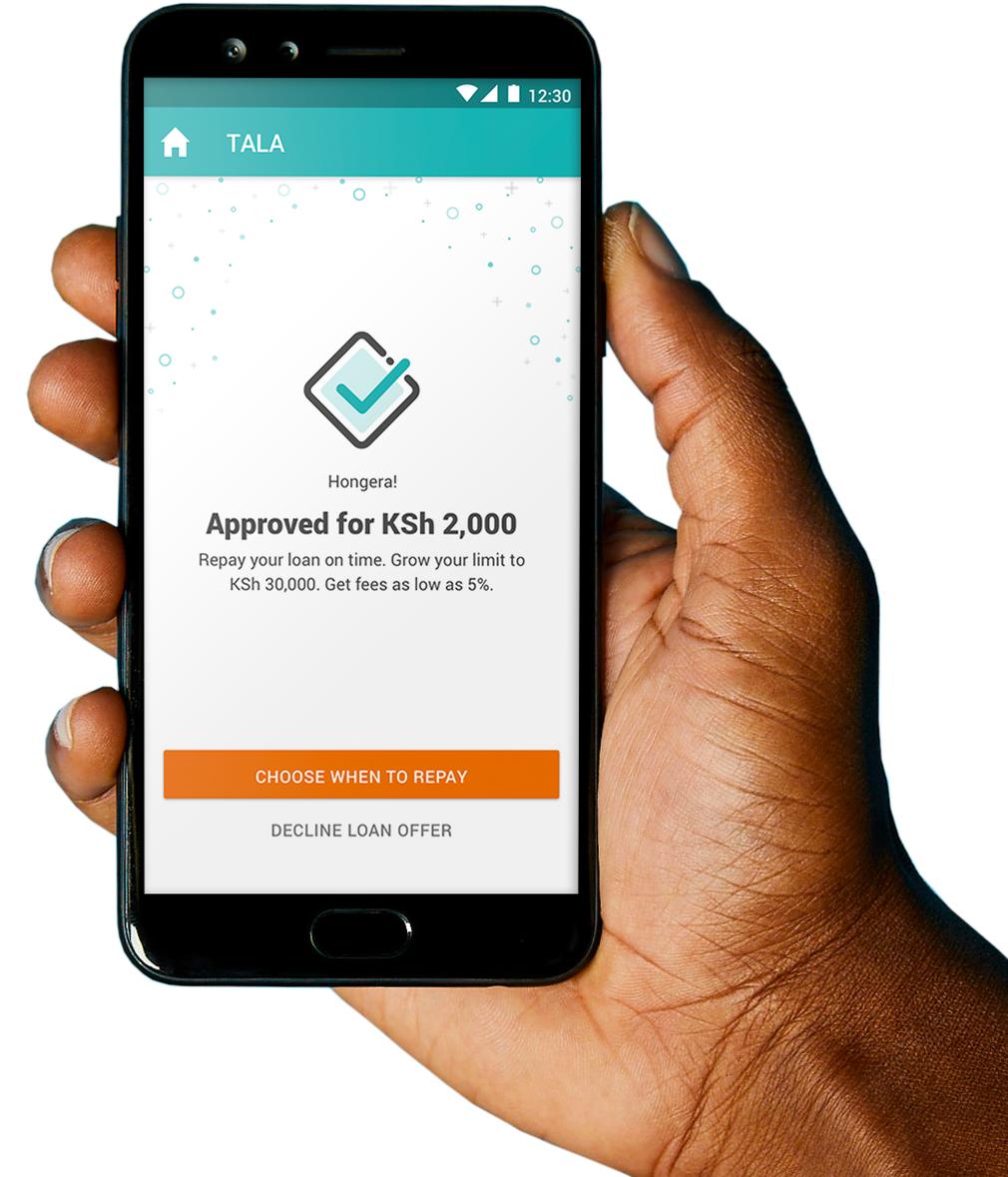
Advanced Economies



Emerging Economies

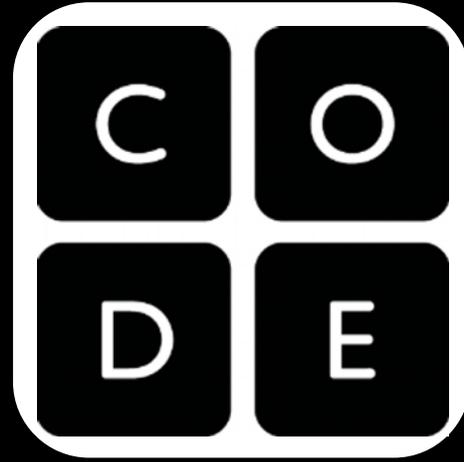


- Smartphone
- Mobile
- No phone

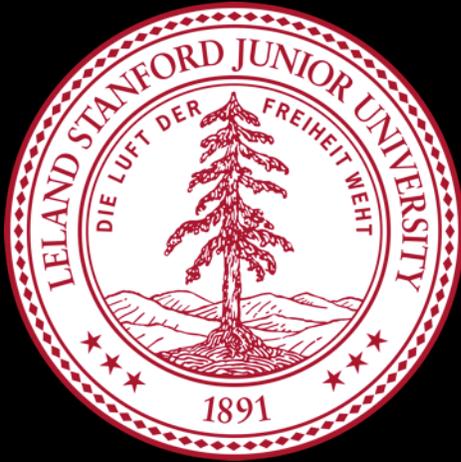


Unprecedented Data

coursera



edX

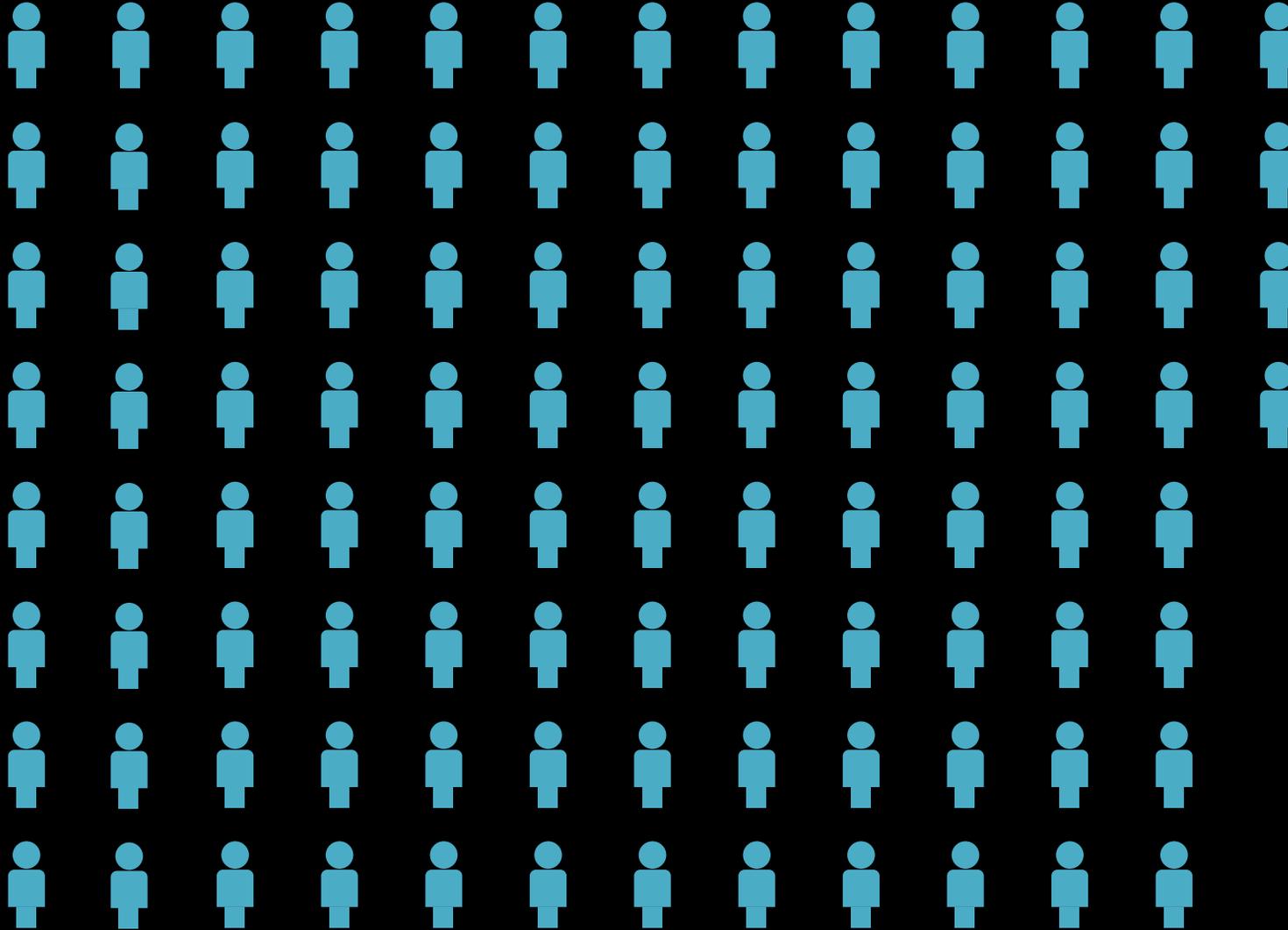


**U
UDACITY**

Over 50 million learners



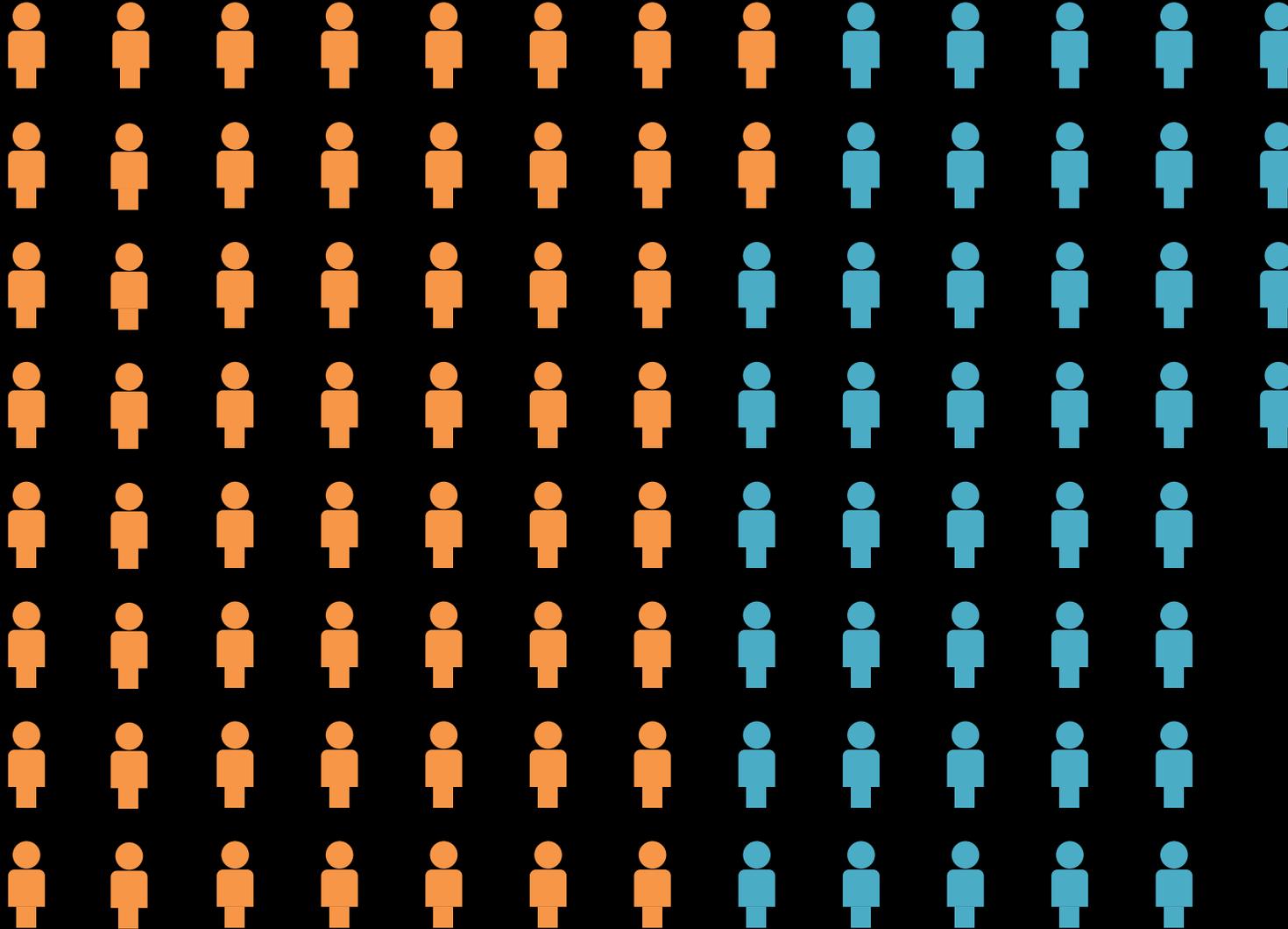
US K-12 Students



= 500,000 learners



Code.org Students



= 500,000 learners



Code.org by the numbers

1,234,127 teachers

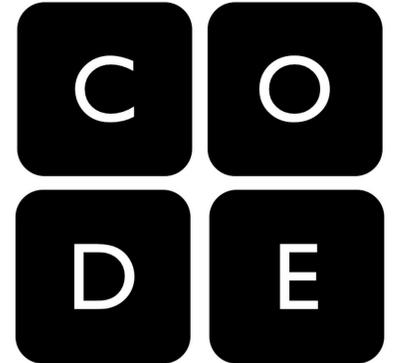
42M unique enrolled students

Used in **180+** countries

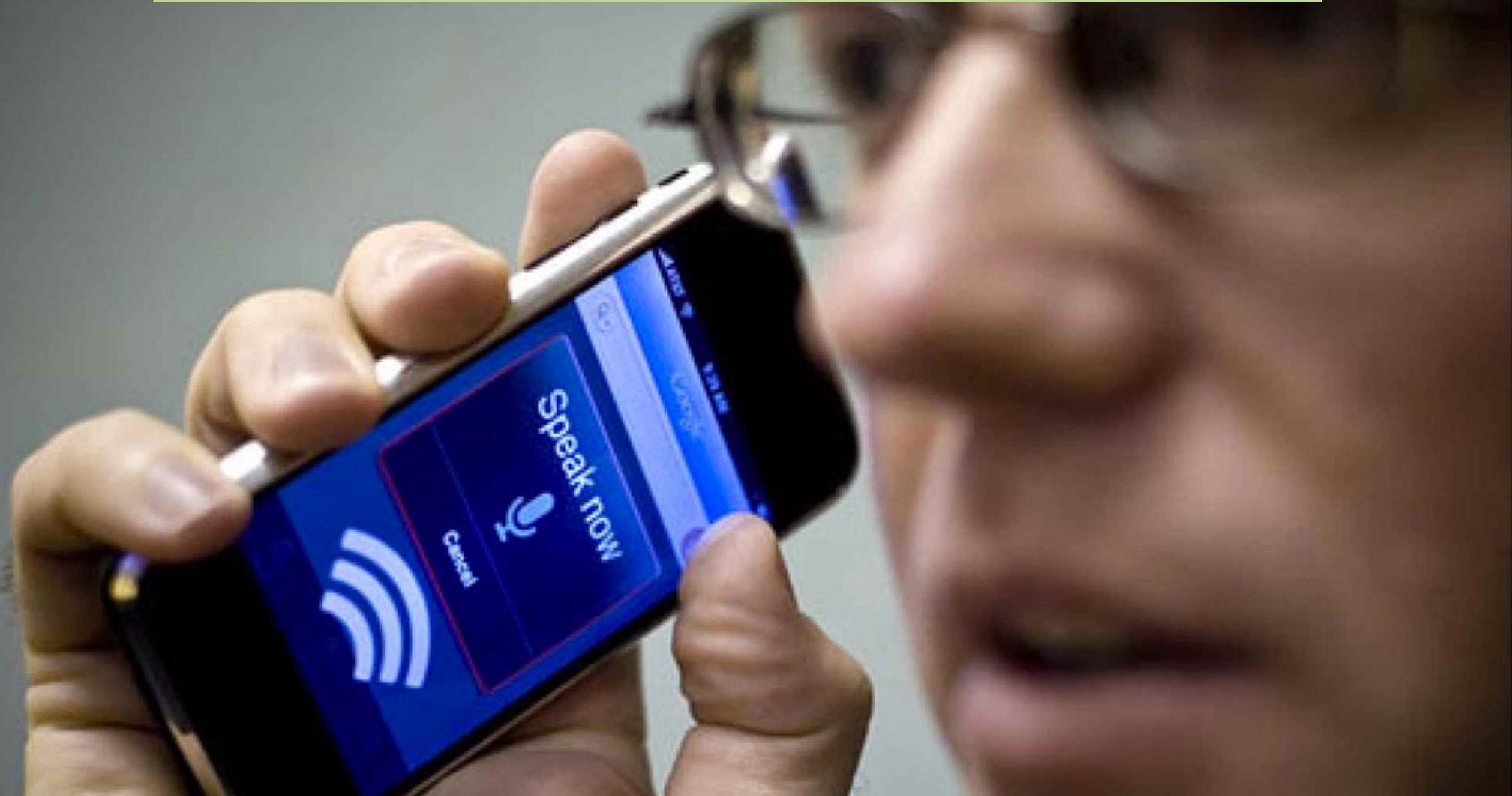
832M hour of code sessions

4 papers publish with our lab

50M K12 students in the US



Speech Recognition



Clear
Societal Need

Scale
education

Grand Challenge
in Education

Autonomously support
education by better
understanding students.

Online
assignments

Deep
Learning

New
Datasets of
Learning

AI
Renaissance



Feedback is Labor Intensive



Online classes have not solved the feedback problem [1].



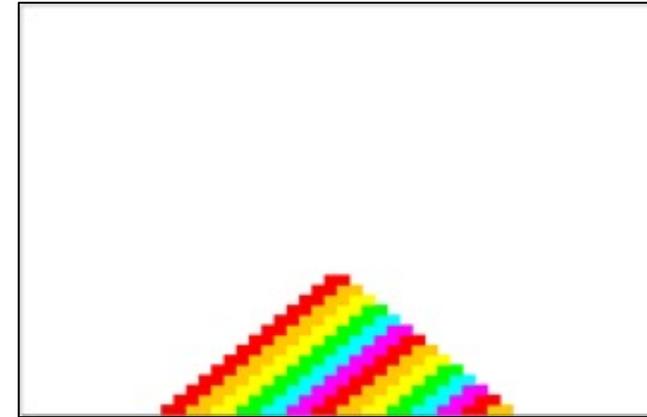
[1] *Deconstructing Disengagement. Analysing learner subpopulations in MOOCs.* Kizilcec, Piech, Schneider. Over 600 citations since 2013



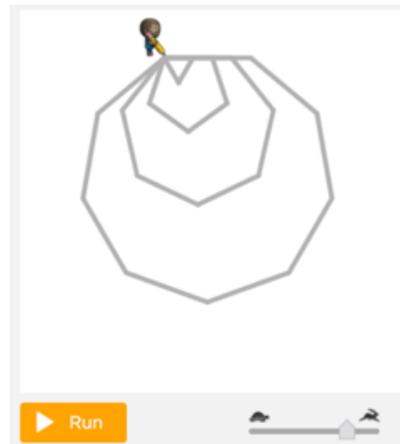
Many domains of student work

$$\begin{aligned} & 9 \times 6 \\ &= (10 - \boxed{}) \times 6 \\ &= 10 \times 6 - \boxed{} \times 6 \\ &= 60 - \boxed{} \\ &= \boxed{} \end{aligned}$$

```
when run
repeat until [acorn]
do
  if path ahead
  do
    turn left
  else
    move forward
```



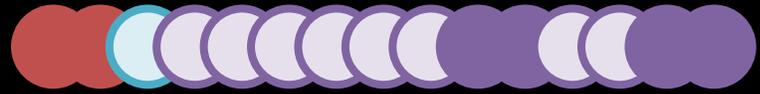
Why did the original pilgrims come to America?



Chapter 0: Always start simple

First deep learning for education

KHAN
Student



1

10

Exercise index

Exercise Type:

Answer:



Solving for x-intercept



Correct



Solving for y-intercept



Incorrect



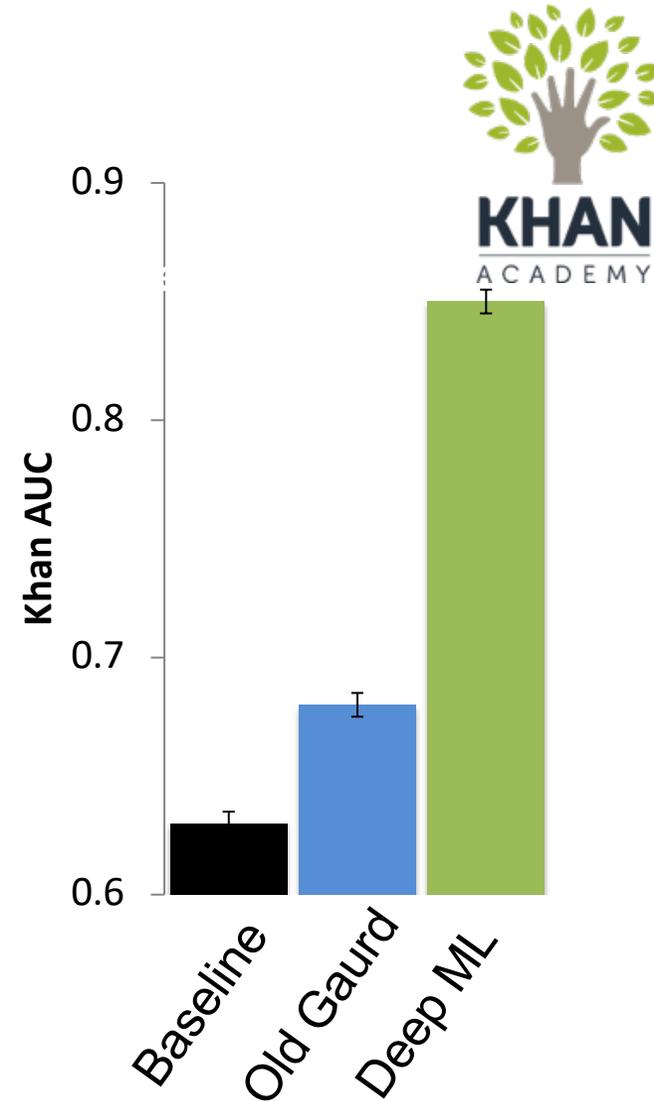
Graphing linear equations



Square roots



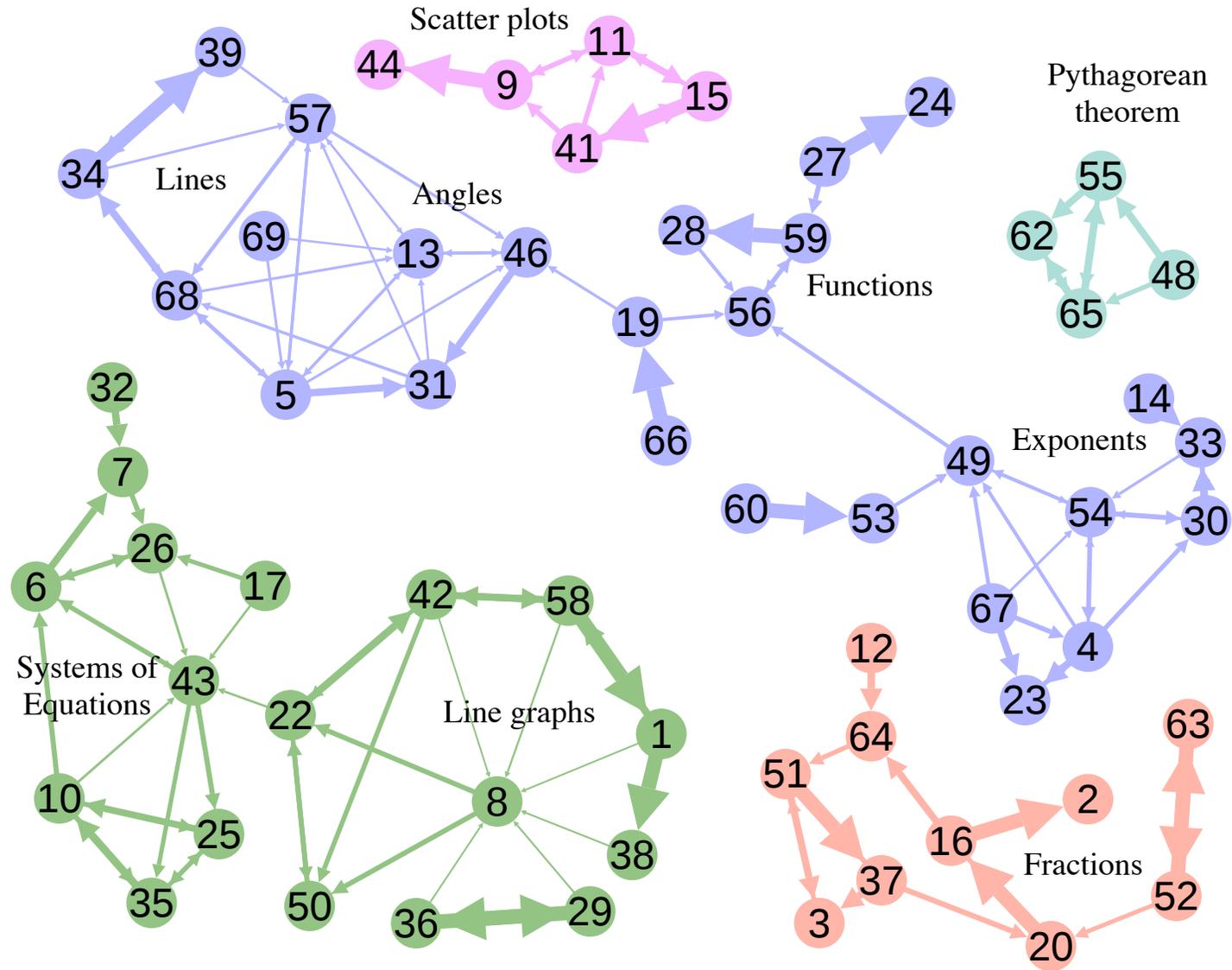
Slope of a line



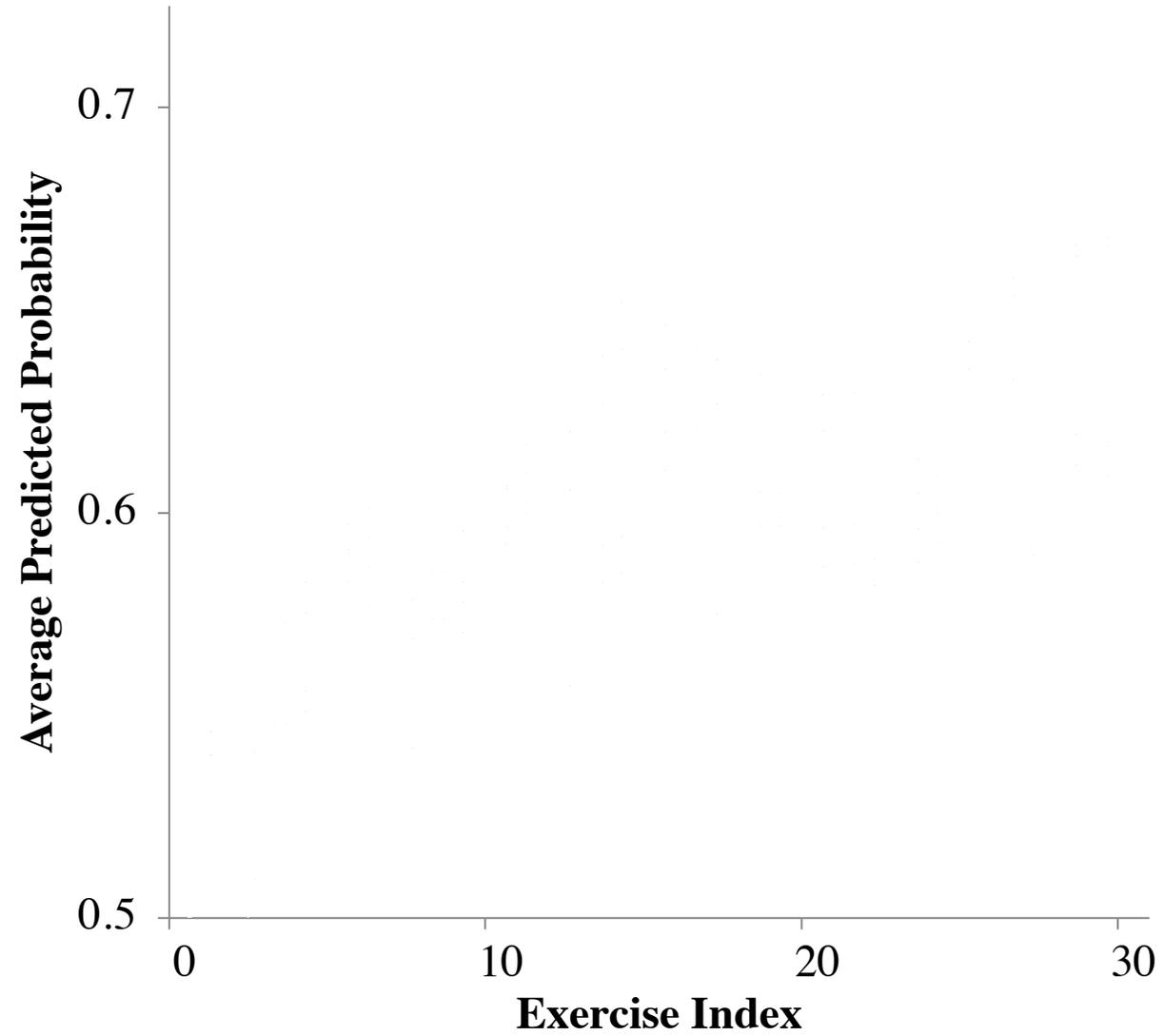
Old Problem



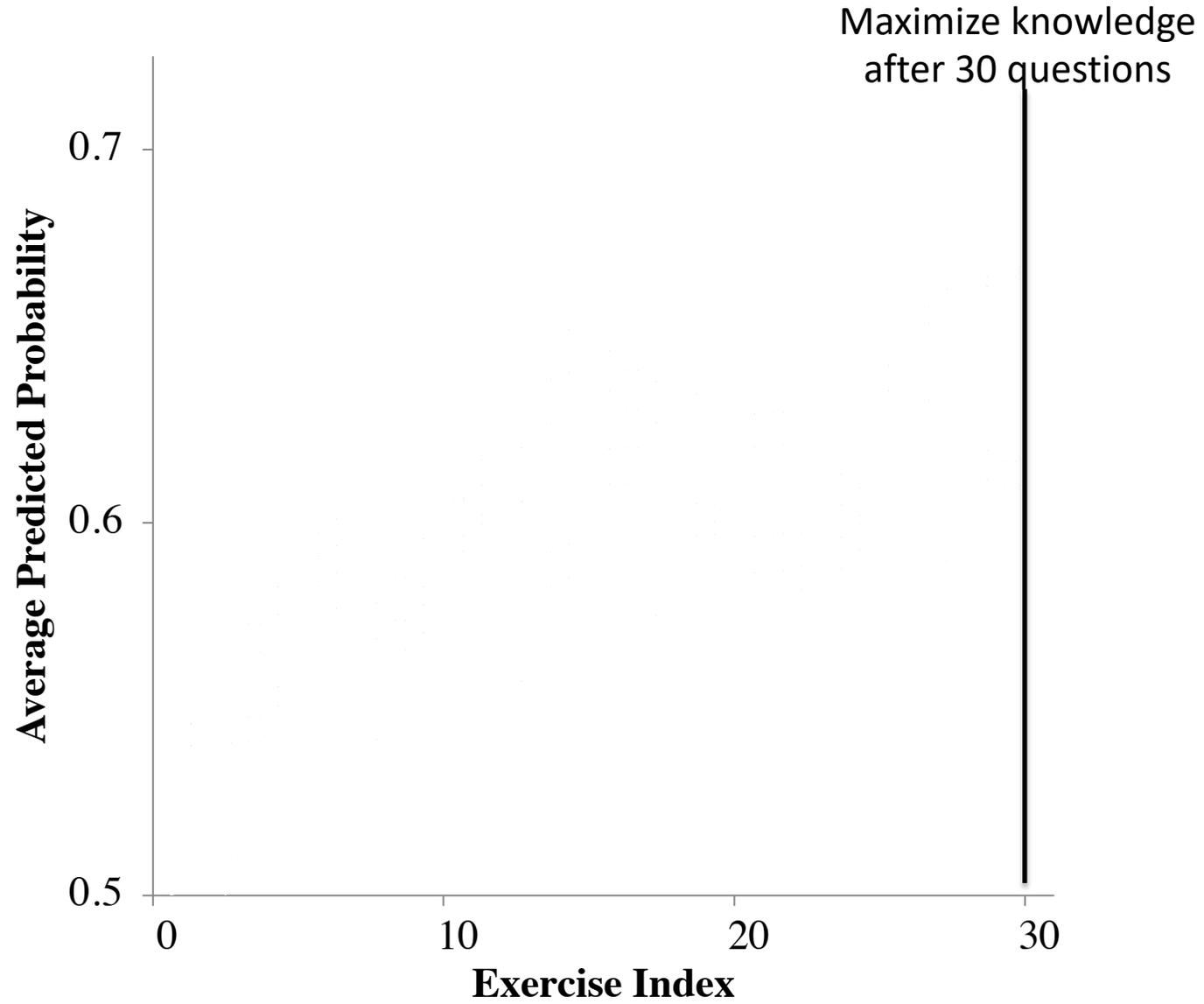
Learns Concept Relationships



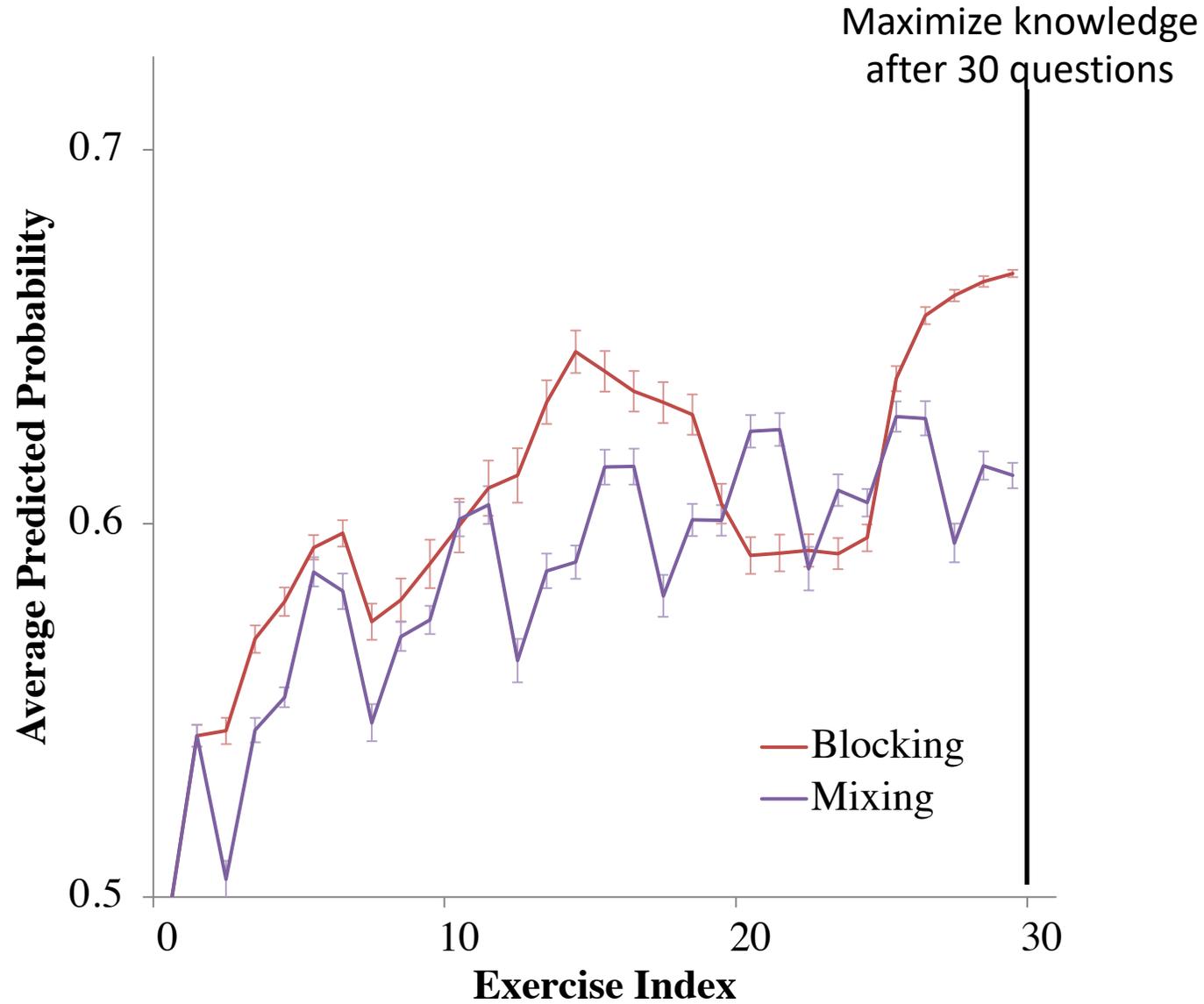
Optimal Teaching



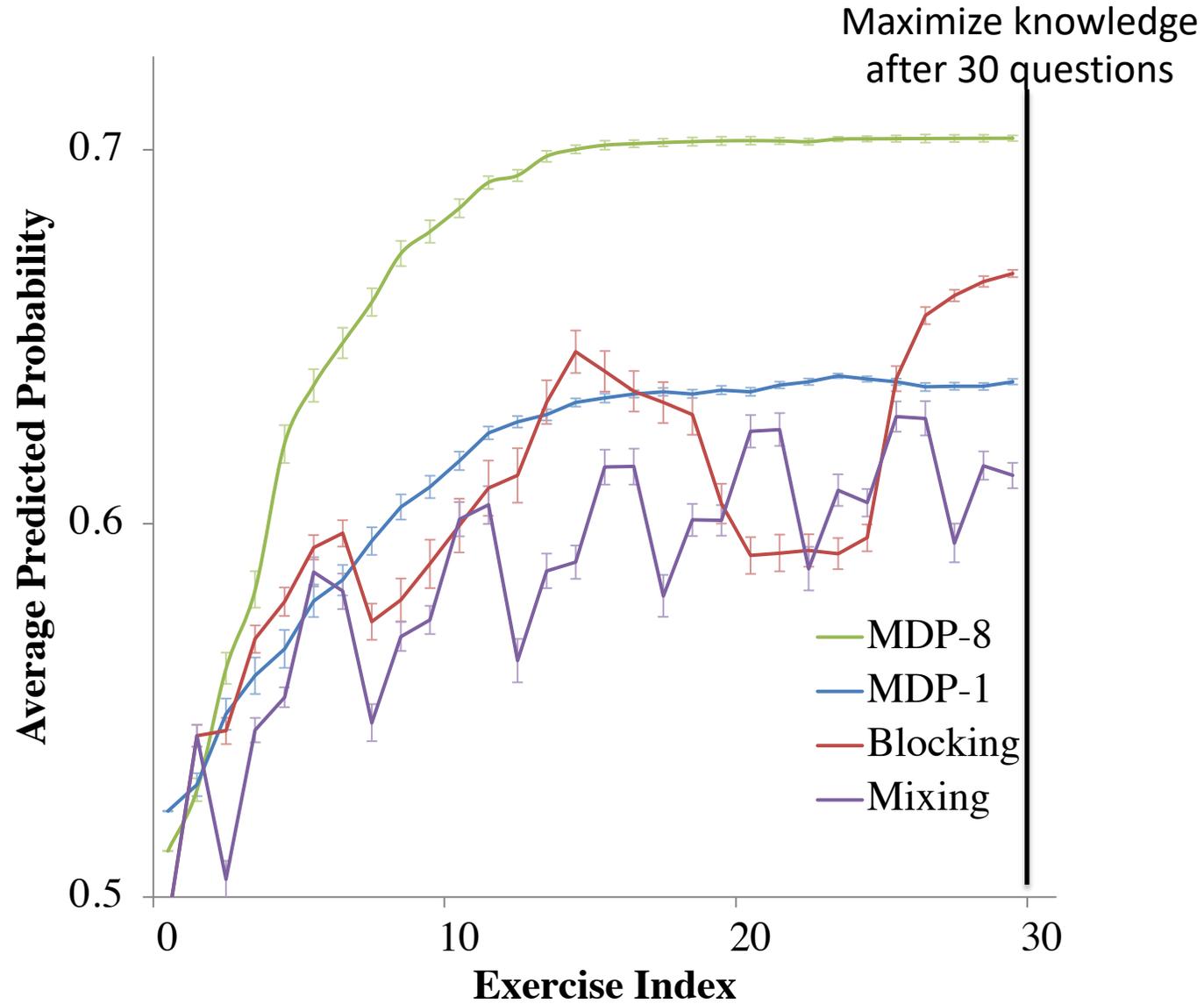
Optimal Teaching



Optimal Teaching



Optimal Teaching



We truly would rather move beyond
correct / incorrect



Some domains are very hard

Introduction to Python Upgrade to Pro

script.py

```
1 my_name = "Codecademy"  
2 print("Hello and welcome " + my_name + "!"  
3
```

File "script.py", line 3

SyntaxError: unexpected EOF while parsing

Hi! I'm Elsa of Arendelle. Help me create a single line.

Not quite. You have to use a block you aren't using yet.

Less

Blocks workspace: 3 / 2 blocks Start Over Show Code

- move forward by 100 pixels
- turn right by 90 degrees
- turn left by 90 degrees
- when run
 - turn left by 90 degrees
 - turn left by 90 degrees



Can you understand this code?

Top Secret x Chris

← → ↻ 🏠 ⓘ Not Secure

Question Solution

Instructions

- If there are many moves, focus on the first one
- Random code strategy is for when the student seems to be trying things randomly
- Lookout for students who don't get nesting or pre/post conditions. Often extra blocks in a body is an indication that they don't get that the post of the loop has to match the precondition

Question



Student 0

```
import code.org.*;

public class MySoln {
    public void run() {
        move(50);
        for(int i=0; i<4; i++){
            if(frontIsClear()) {
                turnLeft(90);
            }
            for(int j=0; j<i; i++){
                move(i * 20);
                turnRight(120);
                move(10);
            }
        }
    }
}
```

Label Console

✓ Num Done: 8273

Strategy

- Beeper Boundry (most people do this)
- Triangle Strategy
- Recursive Strategy

Looping

- Correct use of looping
- Doesn't use a while
- Doesn't have correct stop condition

Stanford TAs label 800 submissions

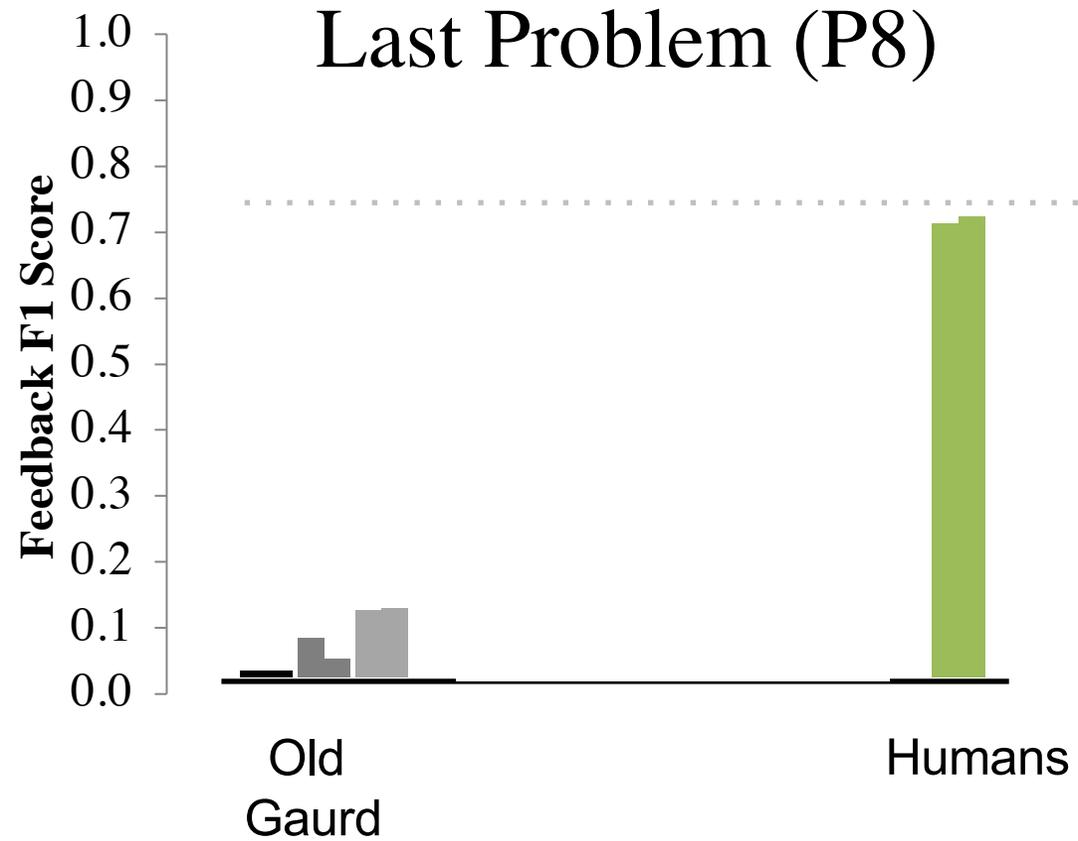
- Loop post condition doesn't match precondition
- Repetition of bodies

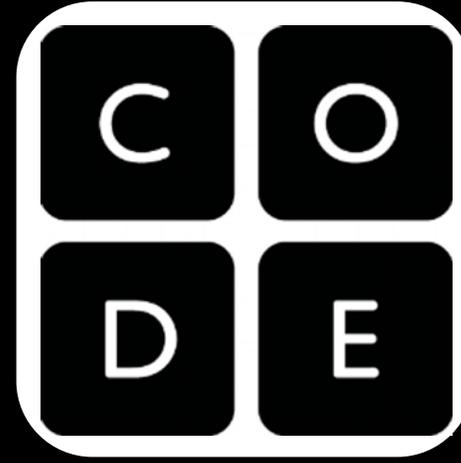
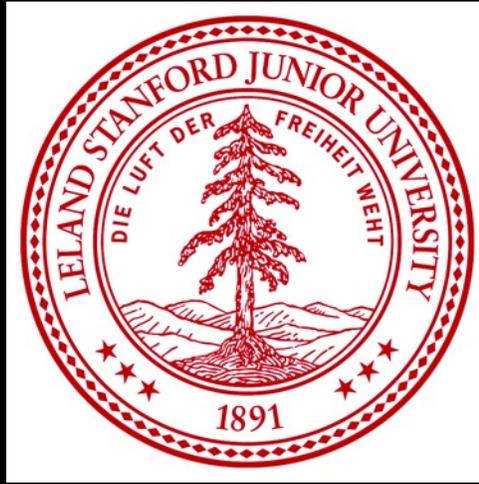
Cleanup

Record label

Traditional Deep Learning Doesn't Work

Label student code





Can we provide feedback
by dynamic analysis?



Starter code

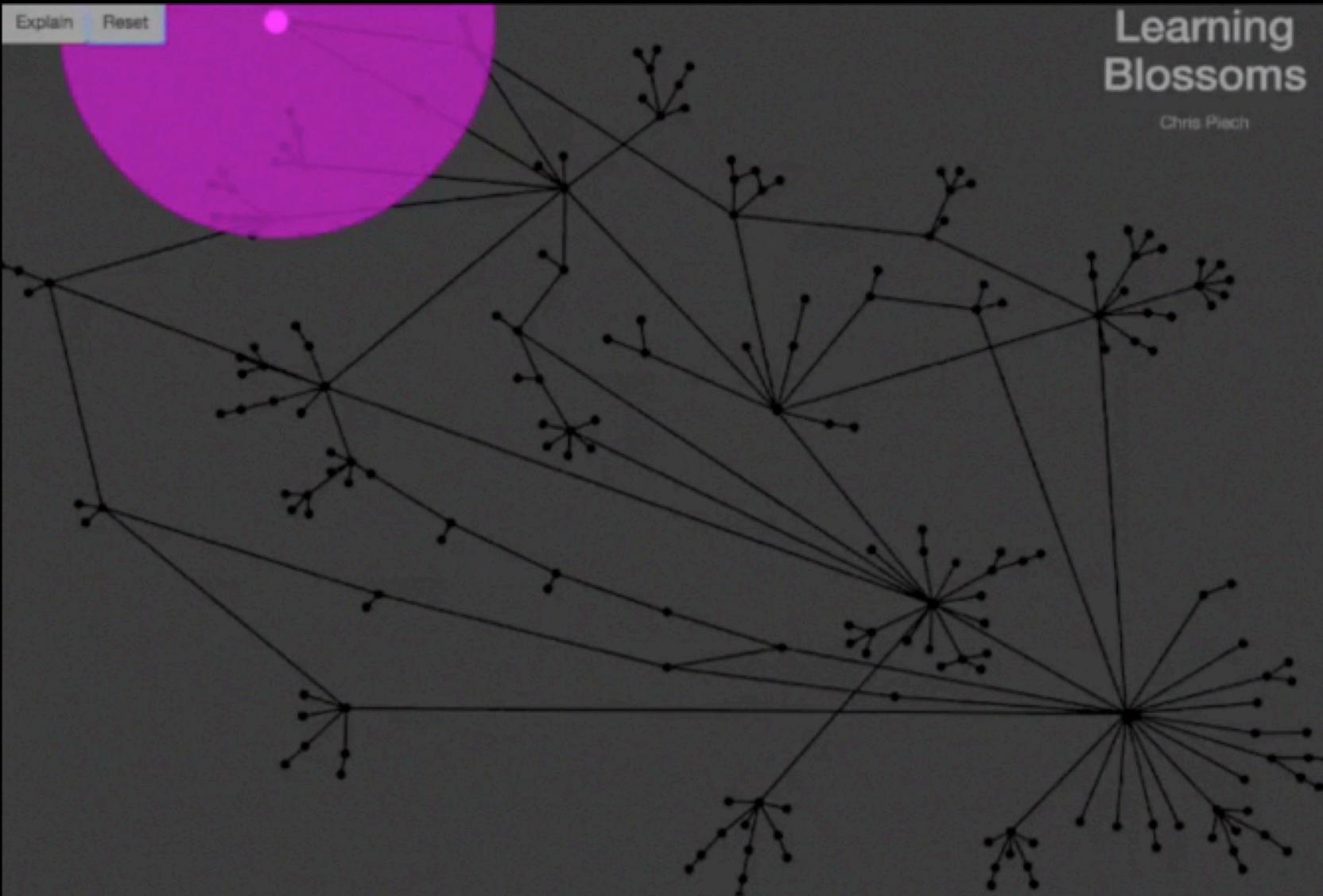
First attempt

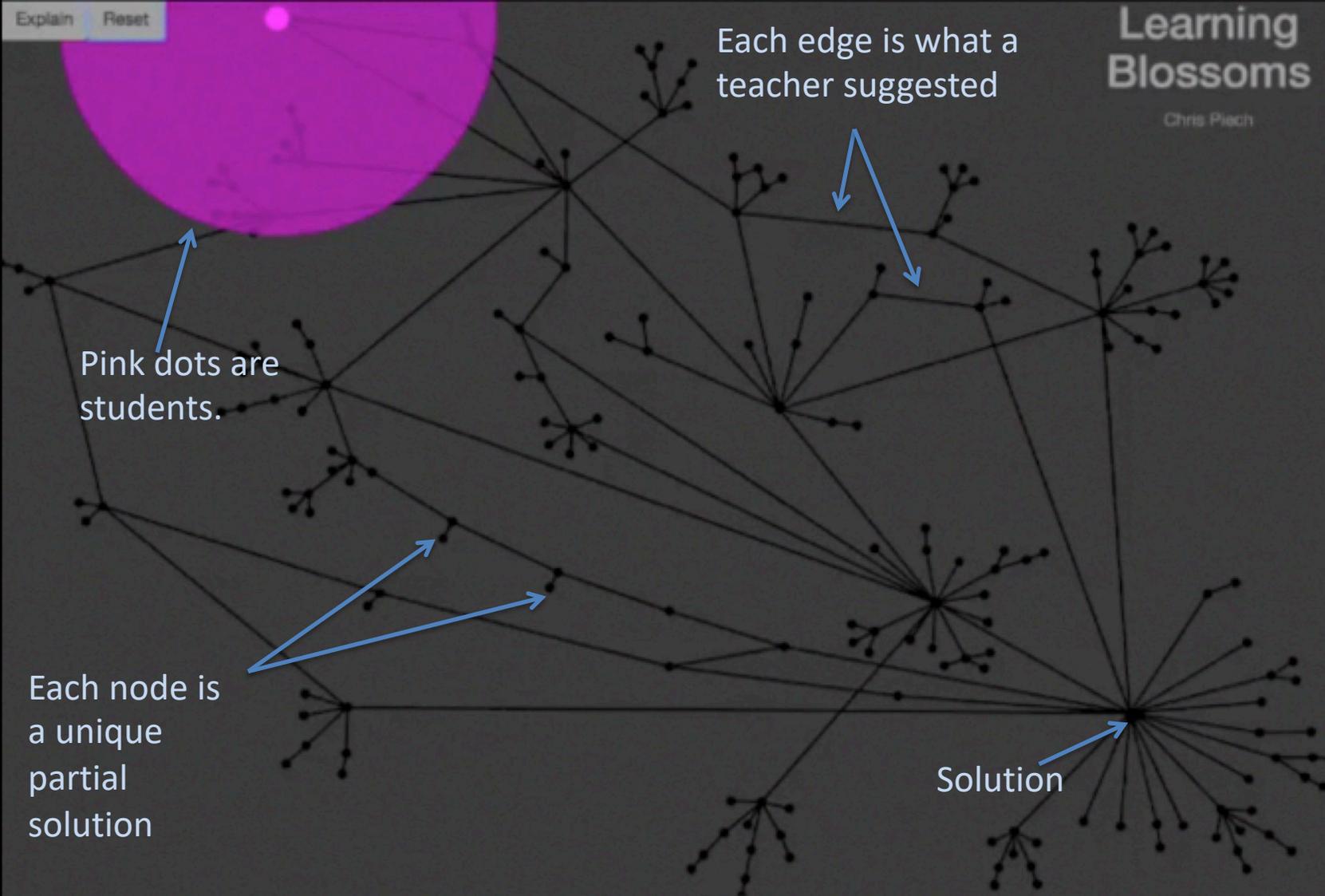
...

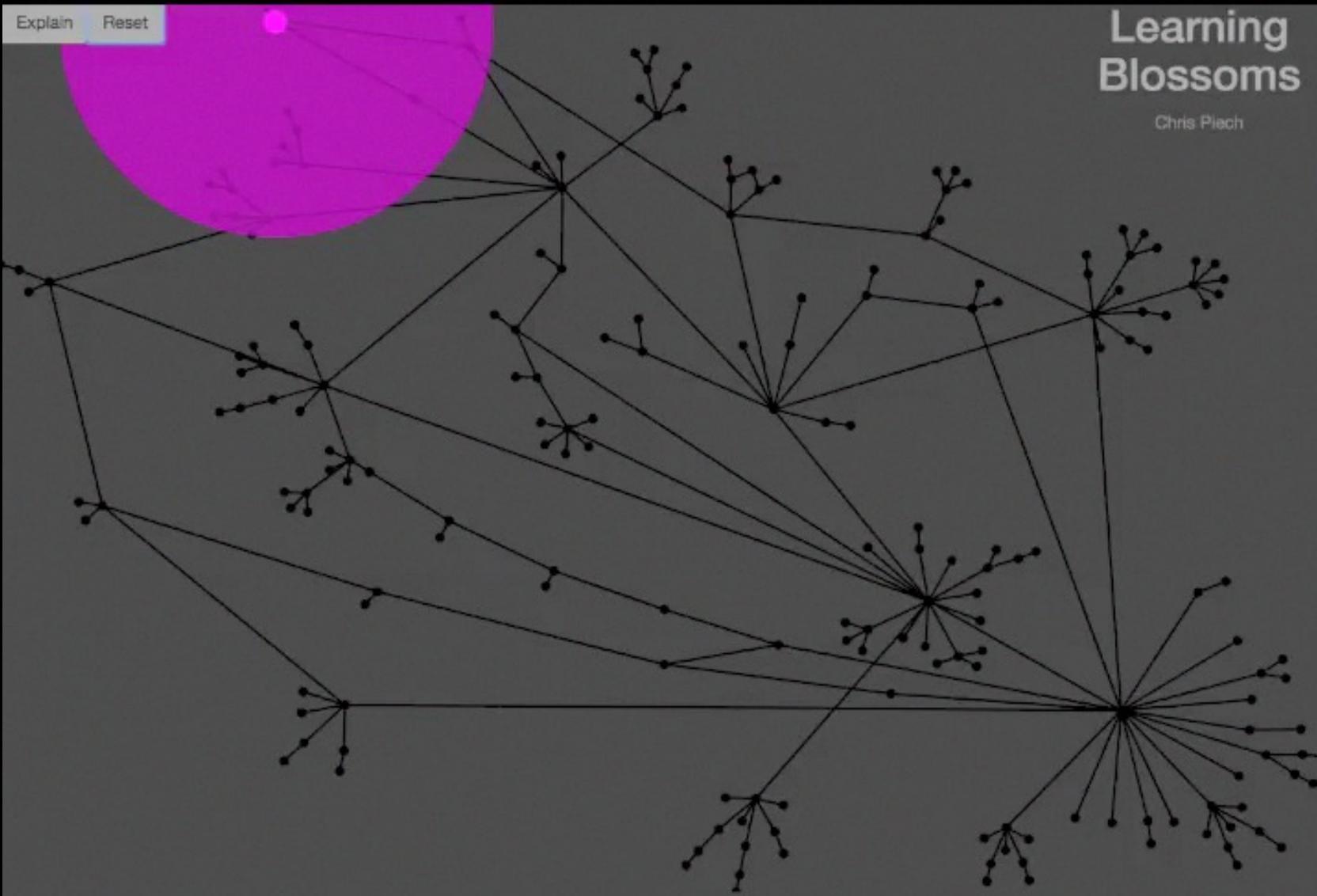
Final solution



Chapter 1: Better data source?

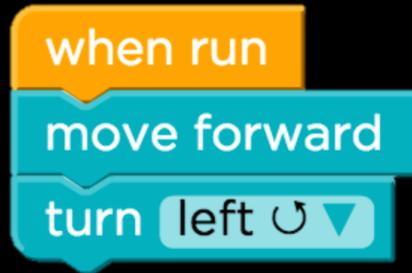






The Crowd is Un-wise

Temporal methods tried:
Shortest path
Min Time
Expected Success
Reinforcement learning
Most Common Next
Most Popular Path



18%



45%



12%



Desirable Path Algorithms

Poisson Common Path

$\gamma(s) =$ First step in the *most frequent* path to the solution from s , taken by *average* students. Assume poisson process.

Predicted next
partial solution



Desirable Path Algorithms

Poisson Common Path

$$\gamma(s) = \arg \min_{p \in Z(s)} \sum_{x \in p} \frac{1}{\lambda_x}$$

Diagram illustrating the Poisson Common Path algorithm. The equation is annotated with labels and arrows:

- $\gamma(s)$: Predicted next partial solution
- $p \in Z(s)$: Paths to solution
- $\sum_{x \in p}$: Partial solutions in the path
- $\frac{1}{\lambda_x}$: Submission count of partial solution

The term $\sum_{x \in p} \frac{1}{\lambda_x}$ is labeled as Path Cost.



Only worked well for 6 line programs...

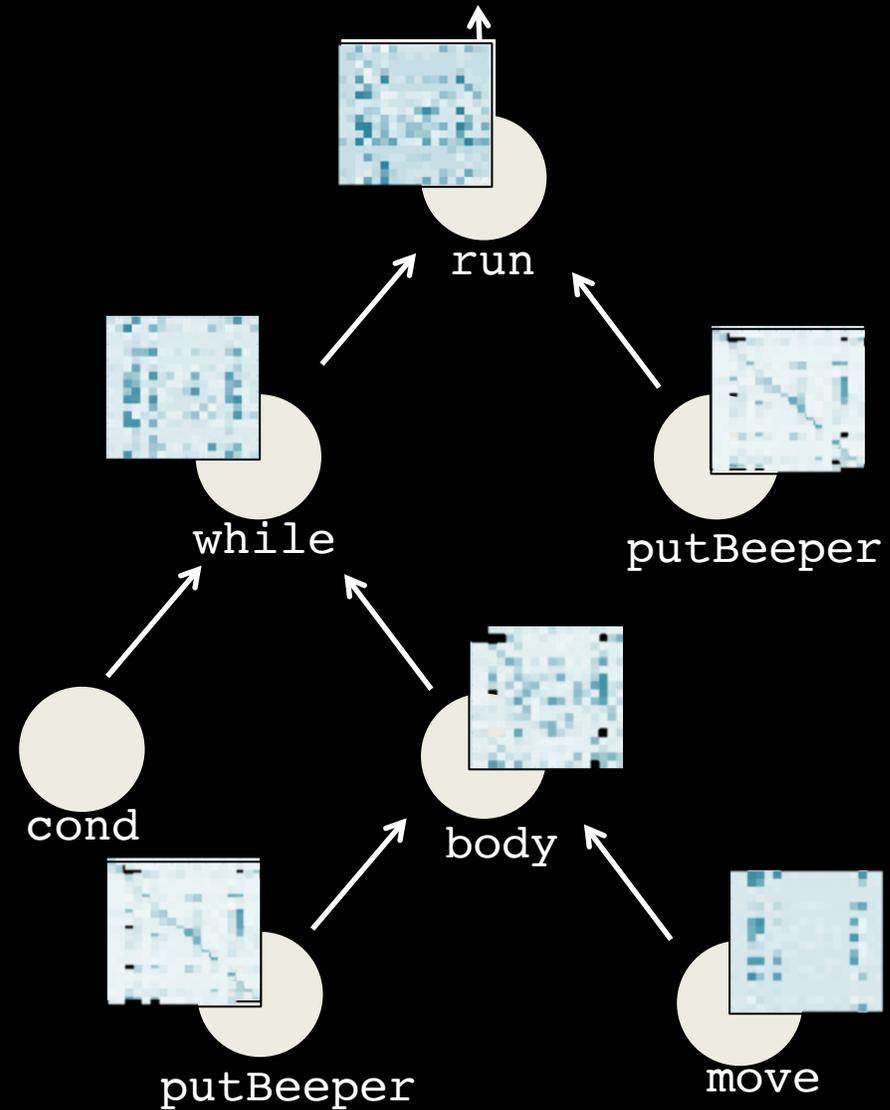
Chapter 2: Start to invent new algorithms...



Neural Network to Encode a Program

It looks like you have a fencepost error!

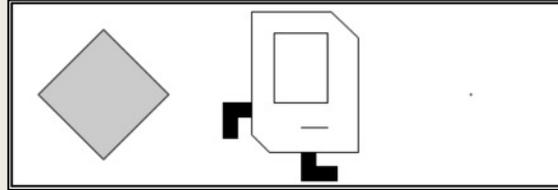
```
// User defined method
private void run() {
  while(isClear()){
    putBeeper();
    move();
  }
  putBeeper();
}
```



*Note: this was coded pre-tensor flow



Collect Triples



Precondition

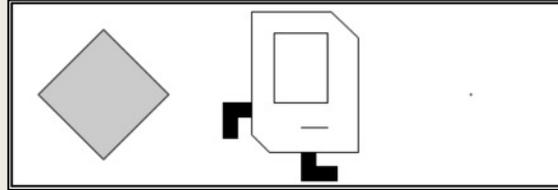
```
putBeeper ( ) ;  
move ( ) ;
```

Code

About 5 million triples per assignment



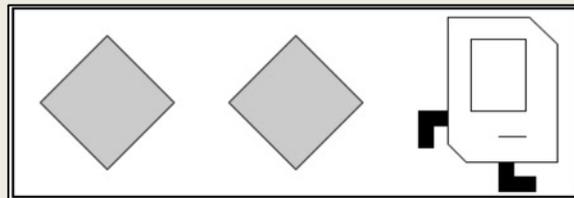
Collect Triples



Precondition

```
putBeeper ( );  
move ( );
```

Code



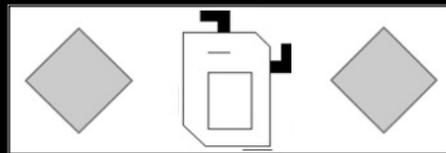
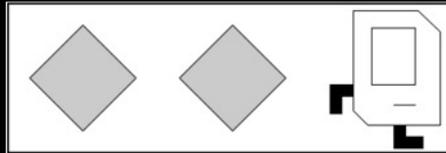
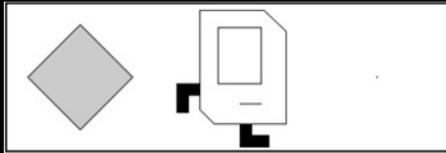
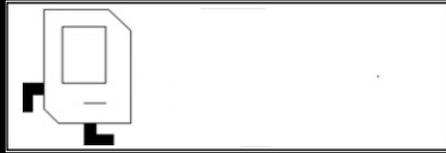
Postcondition

About 5 million triples per assignment



A Code Phrase is a Mapping

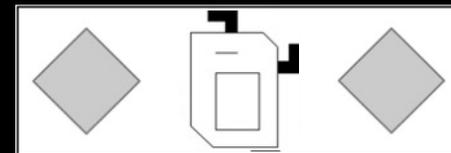
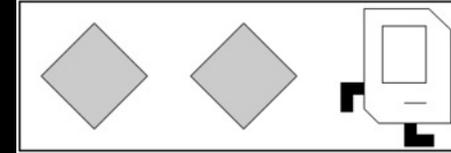
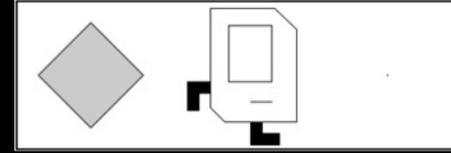
All possible preconditions



⋮



All possible postconditions



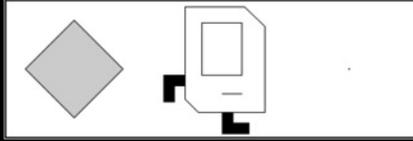
⋮



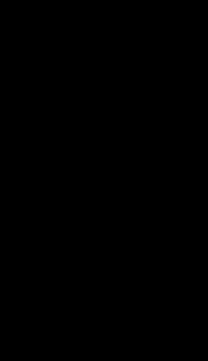
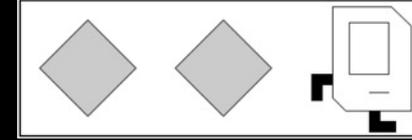
```
putBeeper();  
move();
```



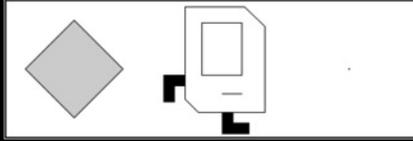
Neural Network for Programs



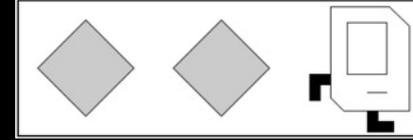
```
method step() {  
    putBeeper();  
    move();  
}
```



Neural Network for Programs



```
method step() {  
  putBeeper();  
  move();  
}
```



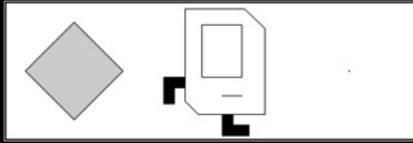
Raw Precondition

Program Matrix

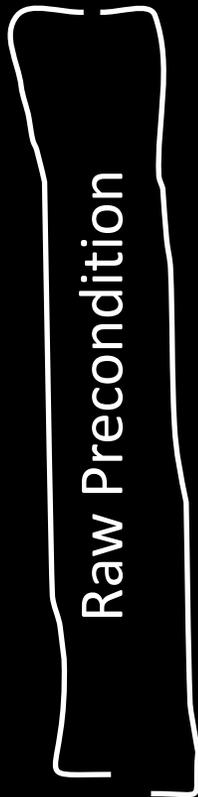
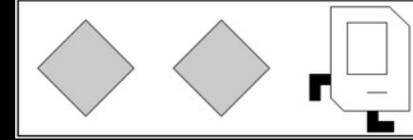
*coded pre-tensor flow



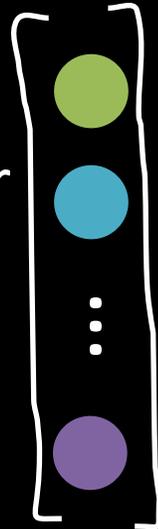
Neural Network for Programs



```
method step() {  
  putBeeper();  
  move();  
}
```

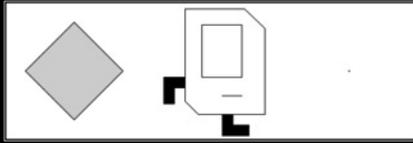


Encoder
→

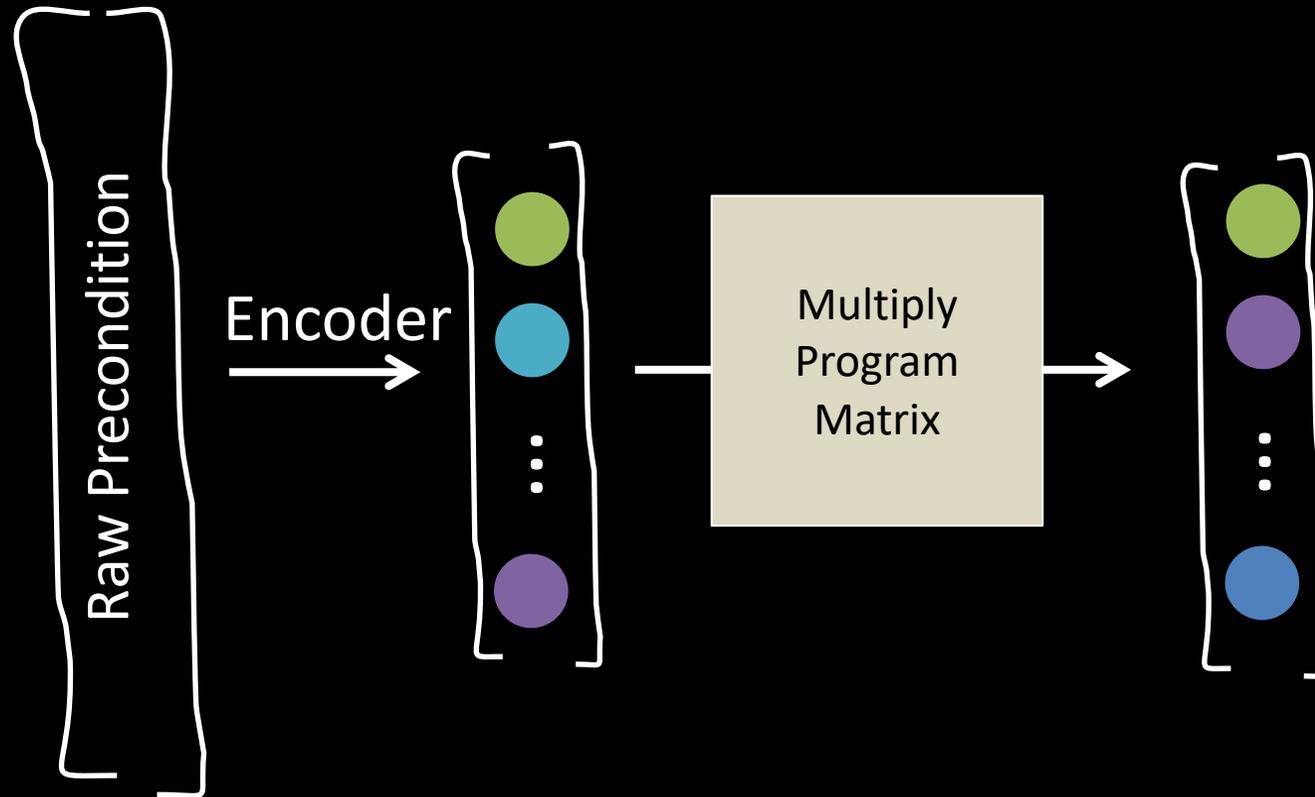
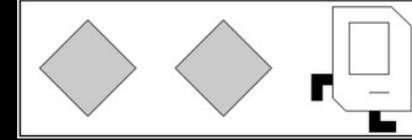


*coded pre-tensor flow

Neural Network for Programs



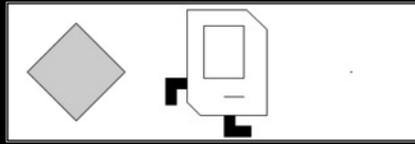
```
method step() {  
  putBeeper();  
  move();  
}
```



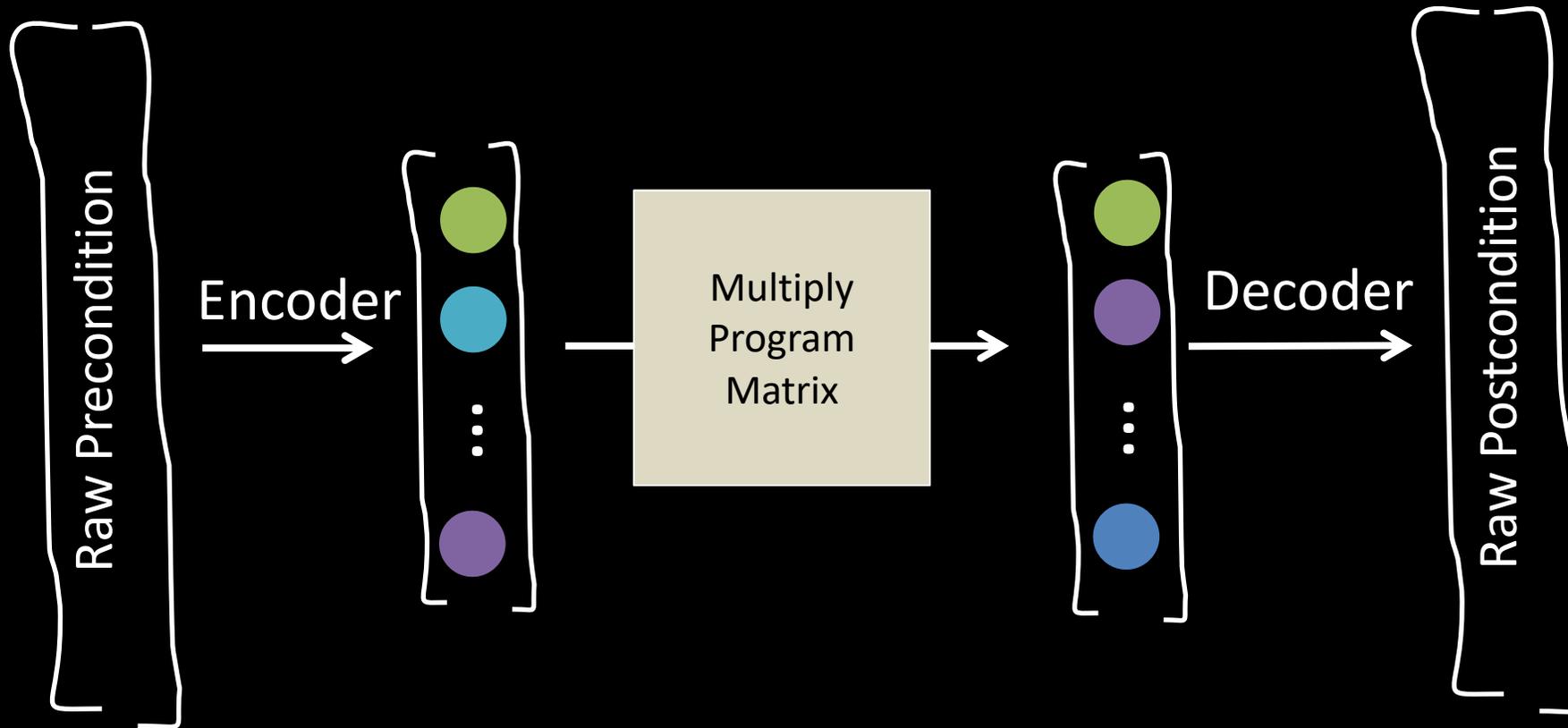
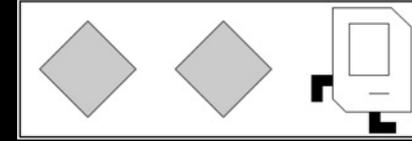
*coded pre-tensor flow



Neural Network for Programs



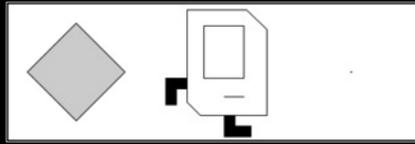
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}
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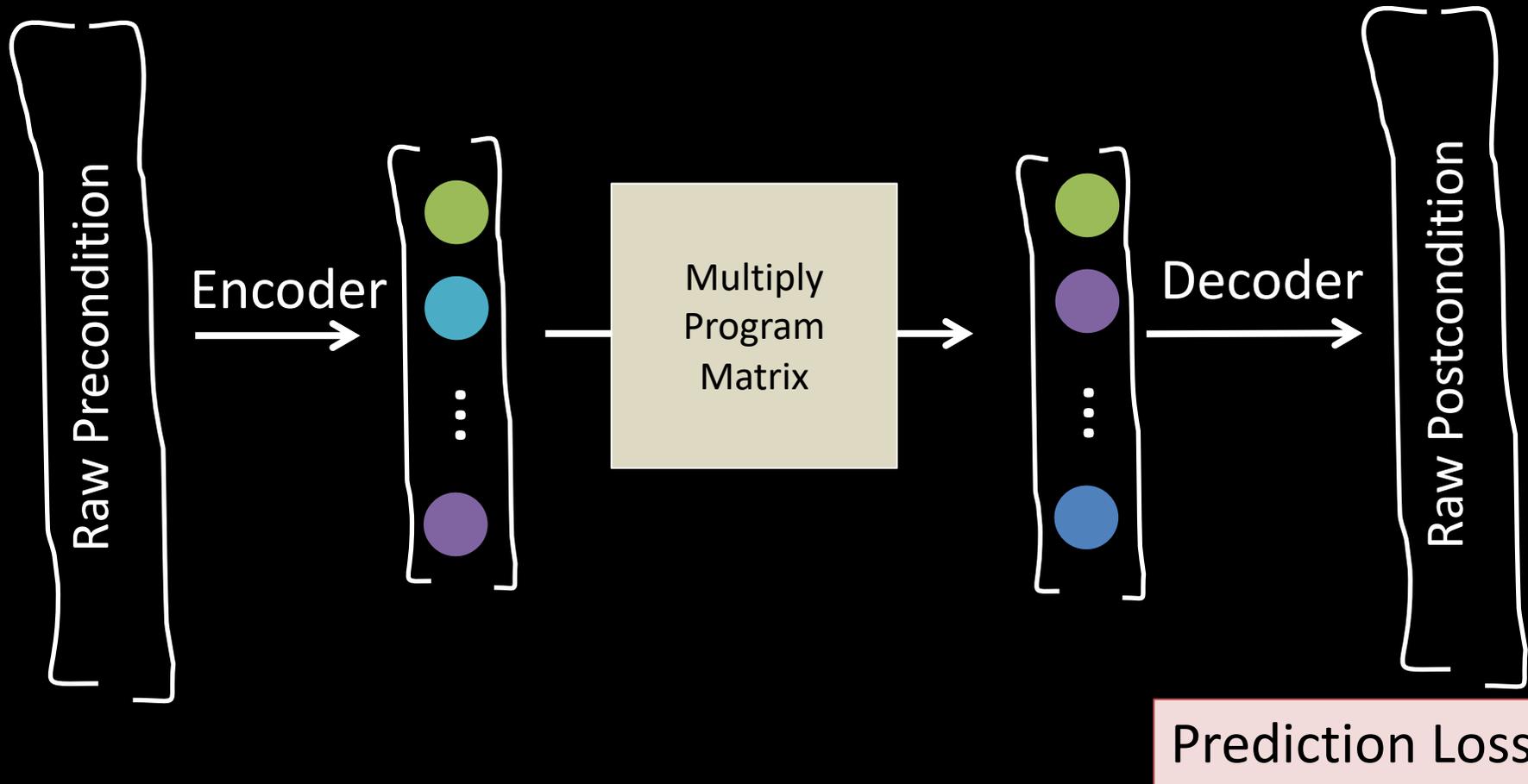
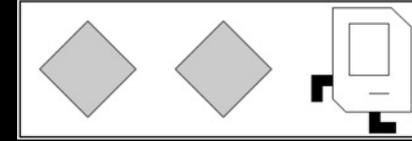
*coded pre-tensor flow



Neural Network for Programs



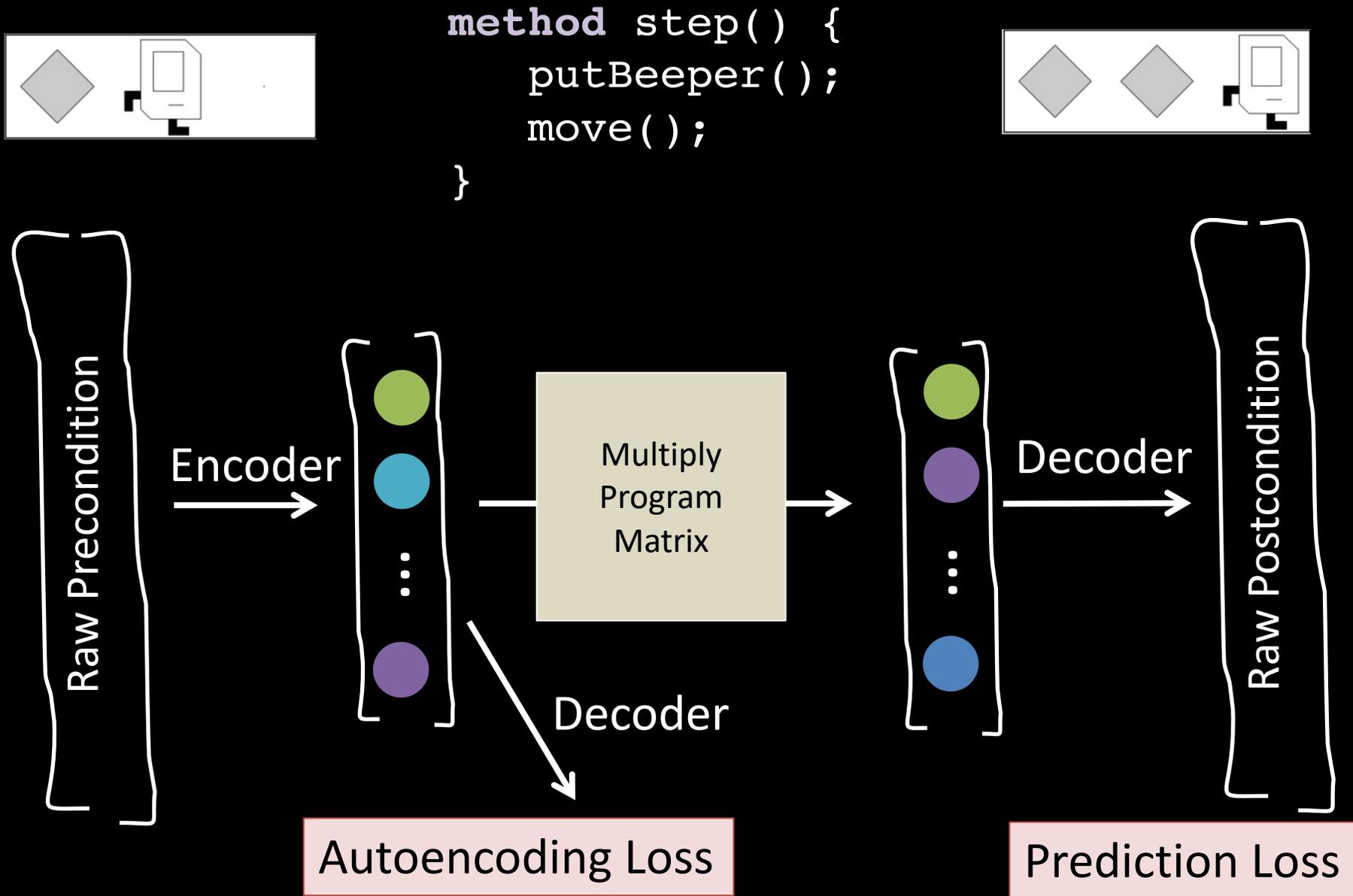
```
method step() {  
  putBeeper();  
  move();  
}
```



*coded pre-tensor flow



Neural Network for Programs



*coded pre-tensor flow

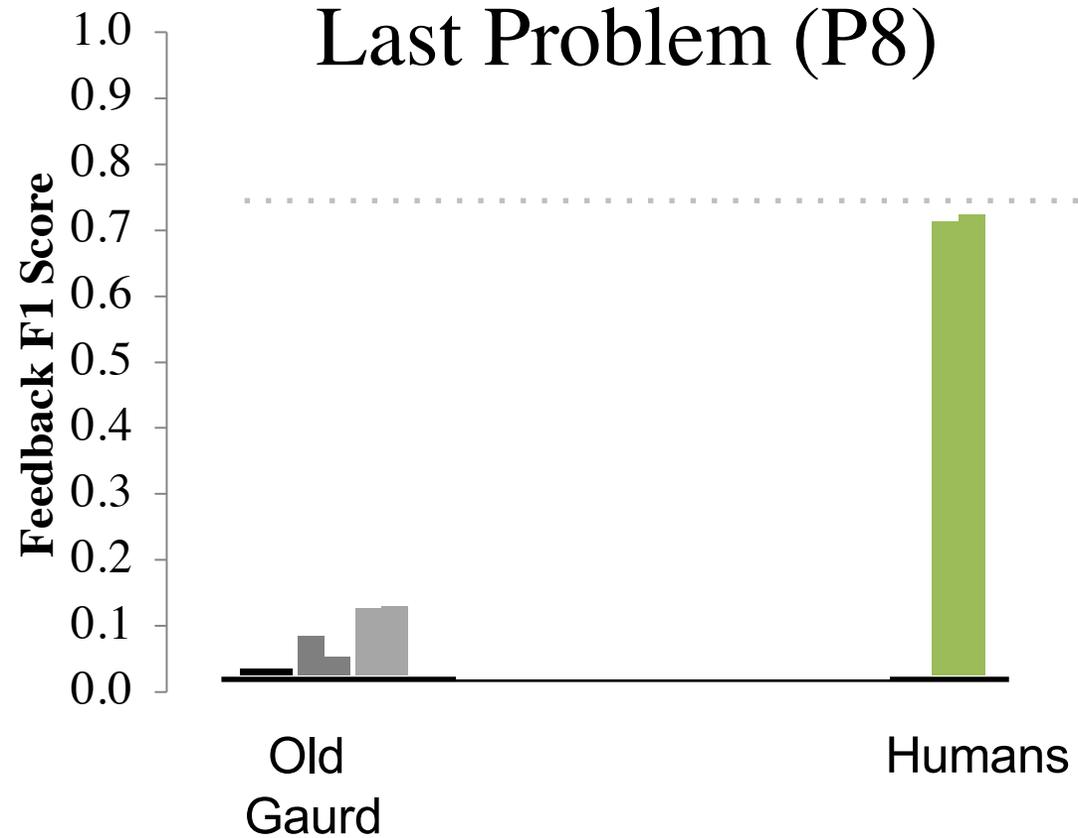


Does it work?



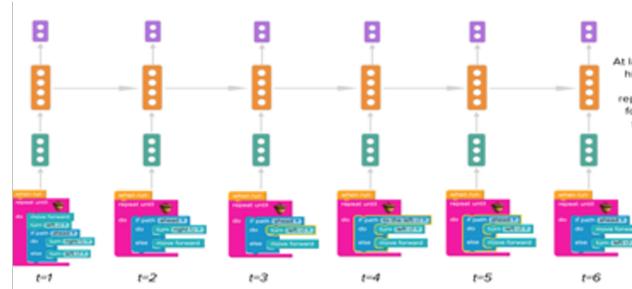
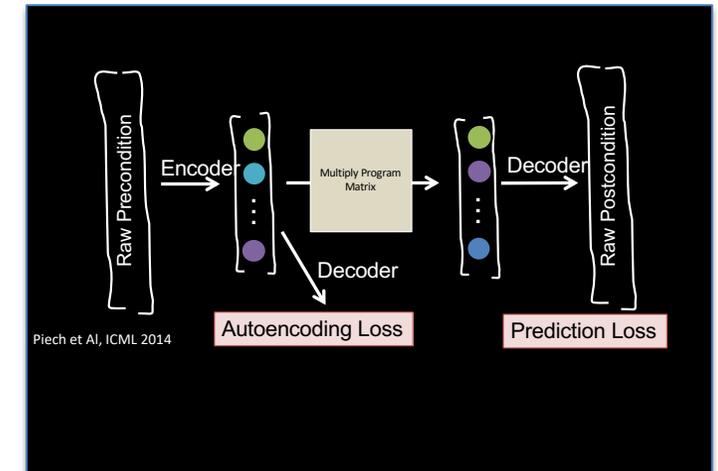
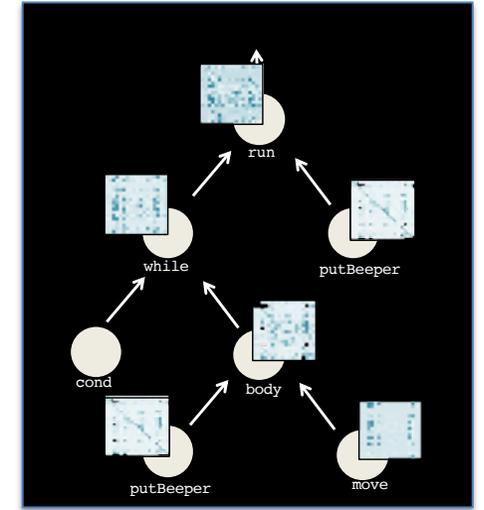
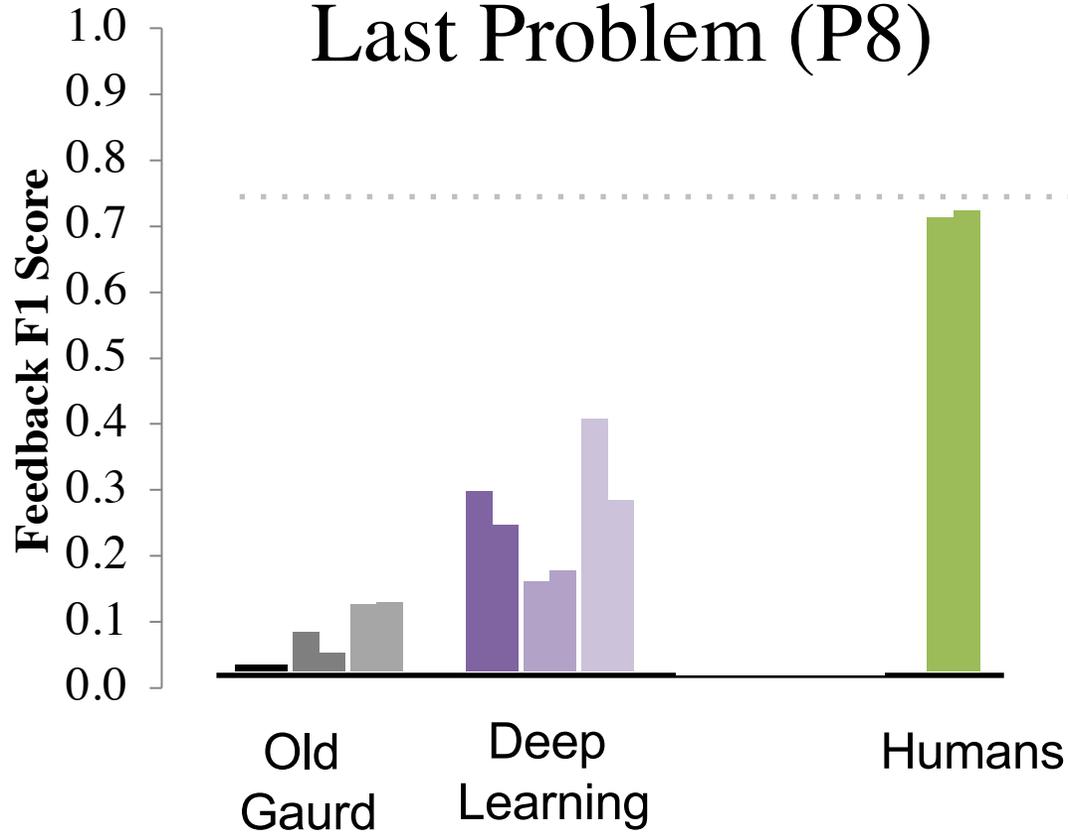
Traditional Deep Learning Doesn't Work

Label student code



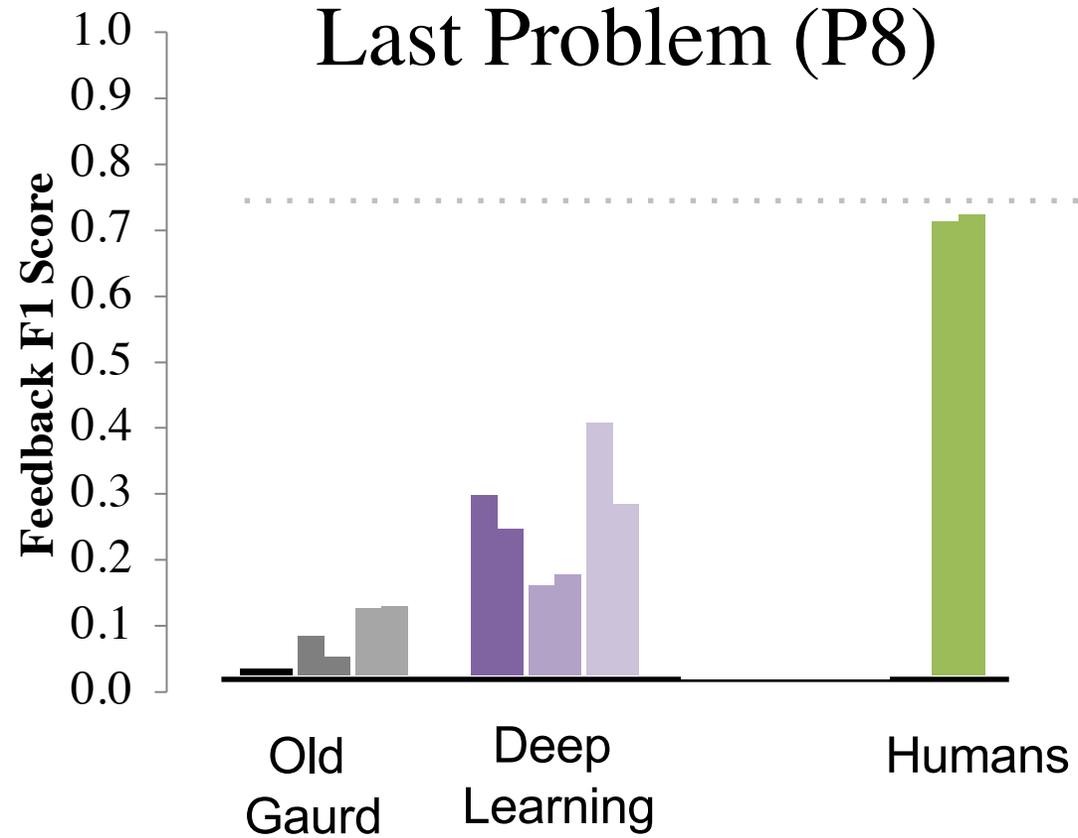
Inaccurate, Uninterpretable, and Data Hungry

Label student code



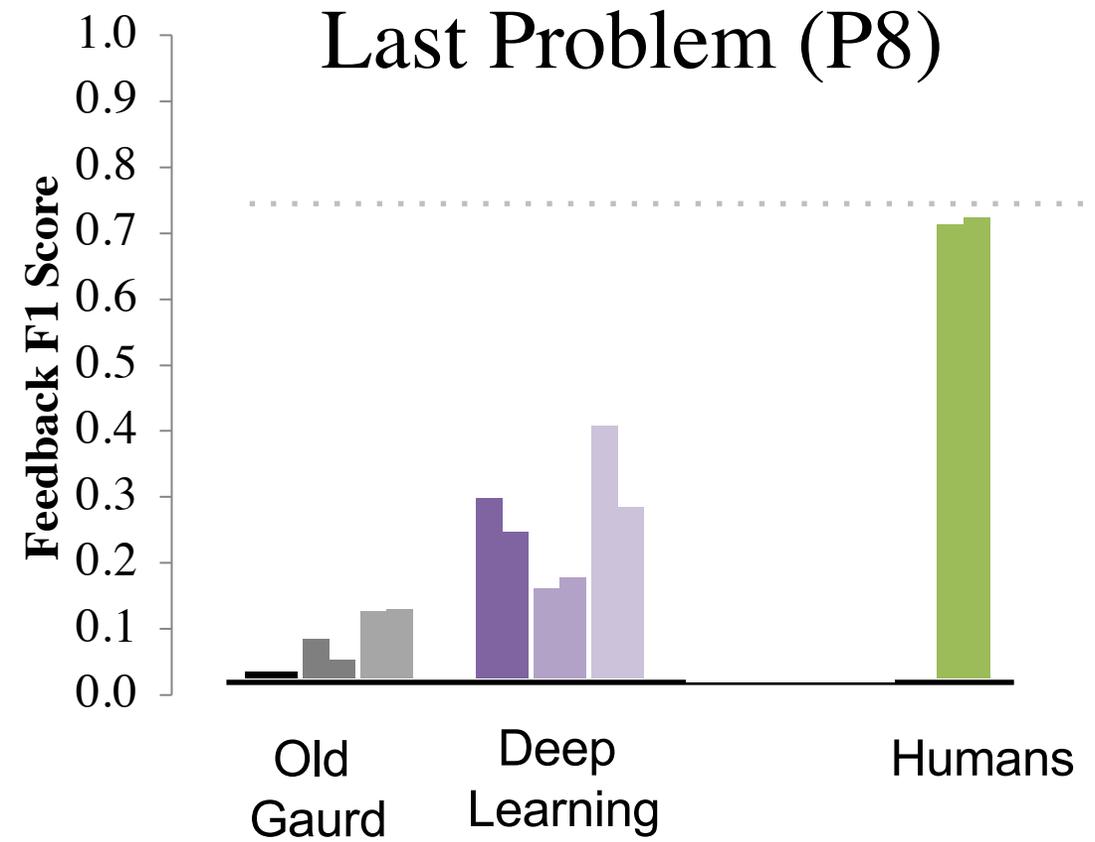
Inaccurate, Uninterpretable, and Data Hungry

Label student code



Inaccurate, Uninterpretable, and Data Hungry

Label student code



We need one shot learning

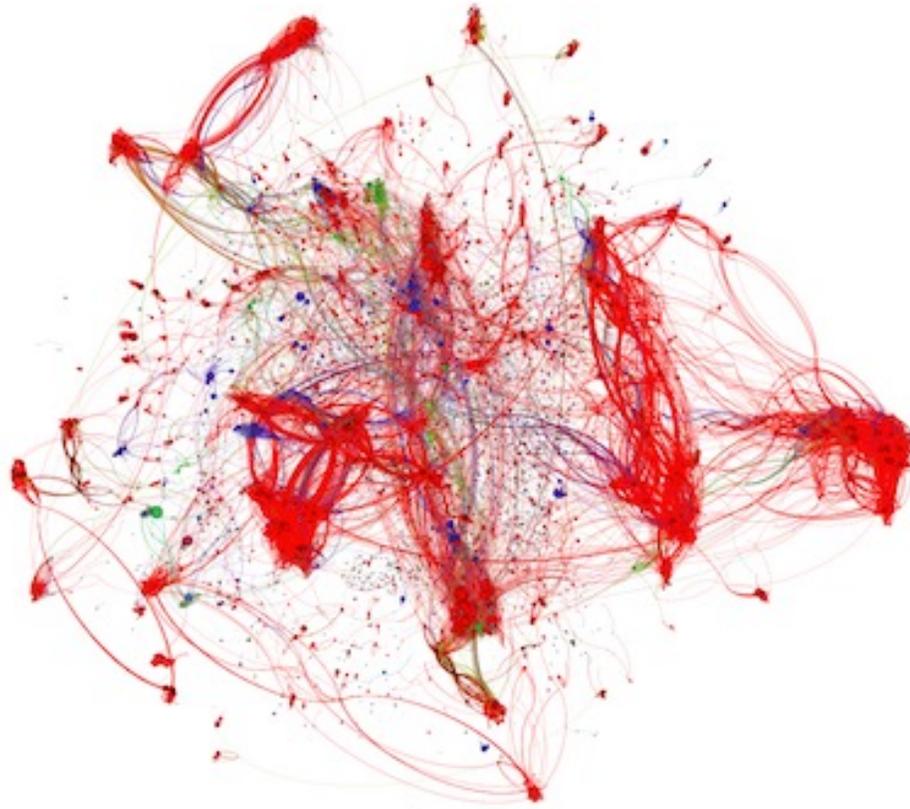
We need verifiability



Why is it so hard?

Hard Problem

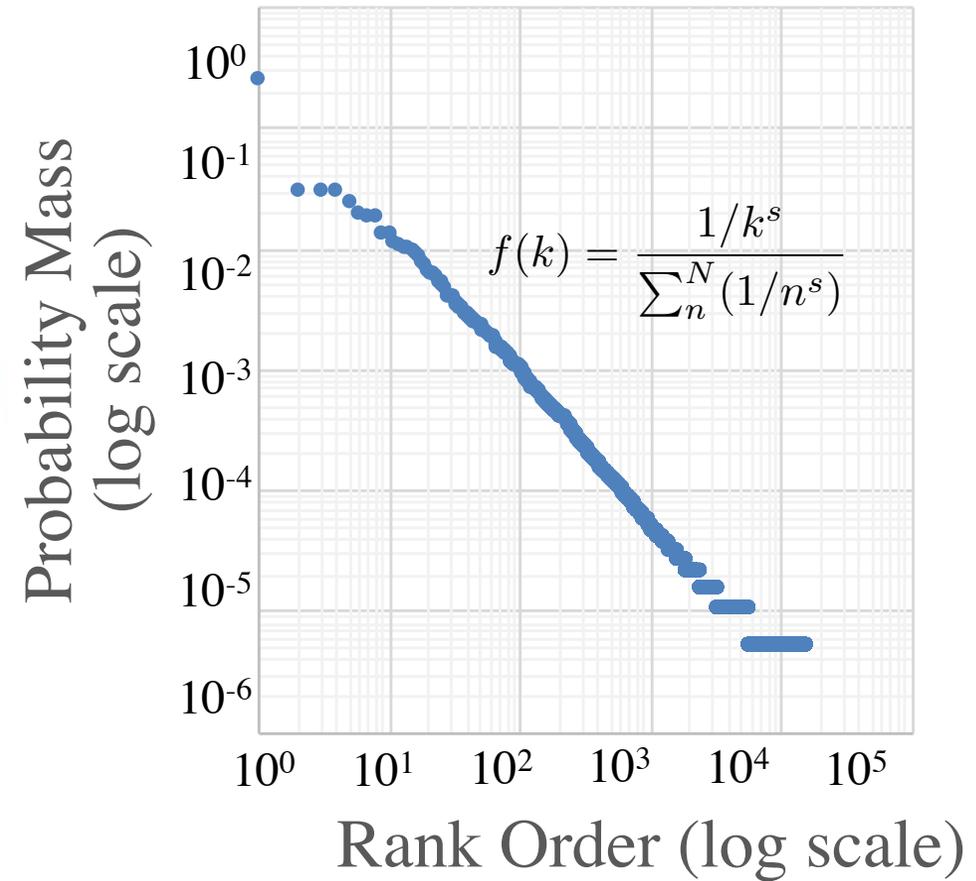
Brute force solution?



1 million unique solutions to
programming Linear Regression

WWW 2014

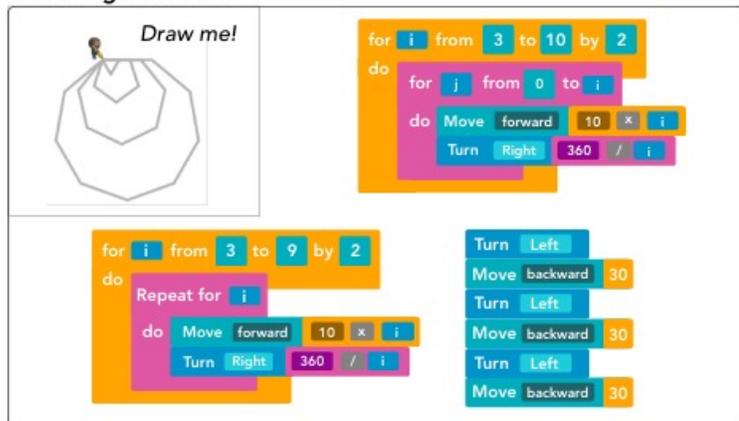
Code Zipf Plot



They are all Zipf!

(a) Datasets in Computational Education

Code.org Problem 8



Draw me!

```

for i from 3 to 10 by 2
do
  for j from 0 to i
  do
    Move forward 10 x i
    Turn Right 360 / i
  
```

```

for i from 3 to 9 by 2
do
  Repeat for i
  do
    Move forward 10 x i
    Turn Right 360 / i
  
```

```

Turn Left
Move backward 30
Turn Left
Move backward 30
Turn Left
Move backward 30

```

Powergrading P13

What is one reason the original colonists came to America?

- Religious freedom
- For religious freedom
- Freedom

- declared our independence from england
- religious freedom
- as a criminal punishment

- to create a new colony
- to find better economic prospects
- to break away from the church in great britain

CS1: Liftoff

Write a Java Program to print the numbers 10 down to 1 and then write liftoff. You must use a loop.

```

public void run() {
  for (int i=START; i>0; i -=1)
  {
    println(i);
  }
  println("Liftoff");
}

```

```

public void run() {
  int x = START;
  int y = 1;
  int z = 9;
  while (x>=1) {
    println(x);
    x=z;
    z=x-y;
  }
  println("Liftoff");
}

```

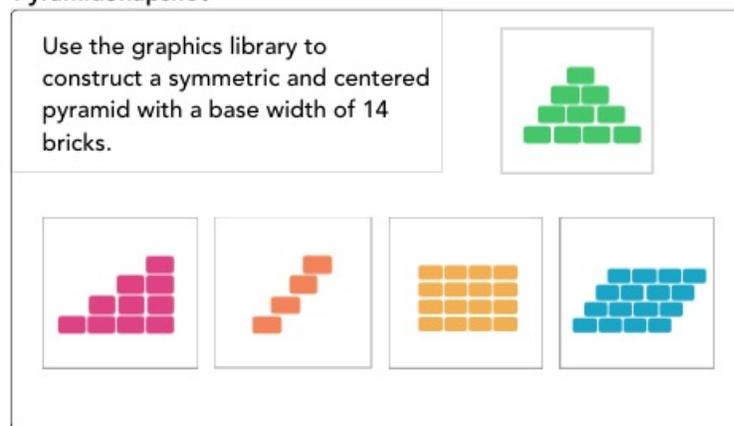
```

public void run() {
  for(int i = START; i>0; i--)
  {
    println(i);
    pause(1000);
  }
  println("Liftoff!");
}

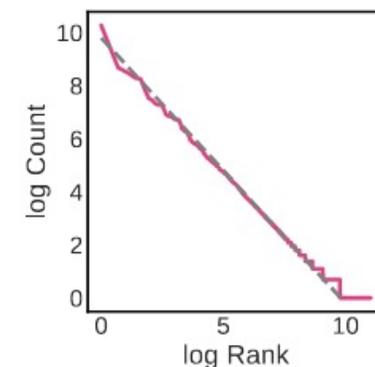
```

PyramidSnapshot

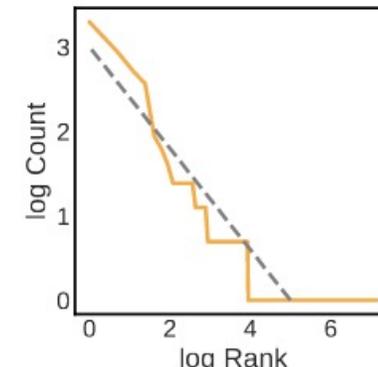
Use the graphics library to construct a symmetric and centered pyramid with a base width of 14 bricks.



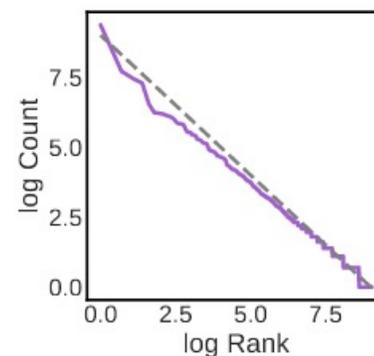
(b) Code.org P8



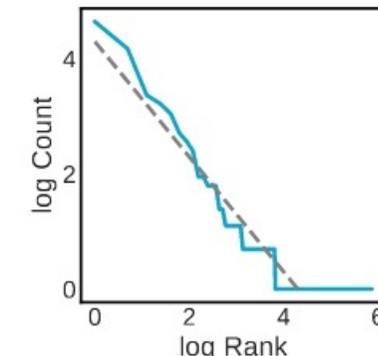
(c) CS1: Liftoff



(d) Pyramid



(e) Powergrading



[Suspense]

Chapter 3: Back to the drawing board

Humans Don't Need Much Data

Single training example:

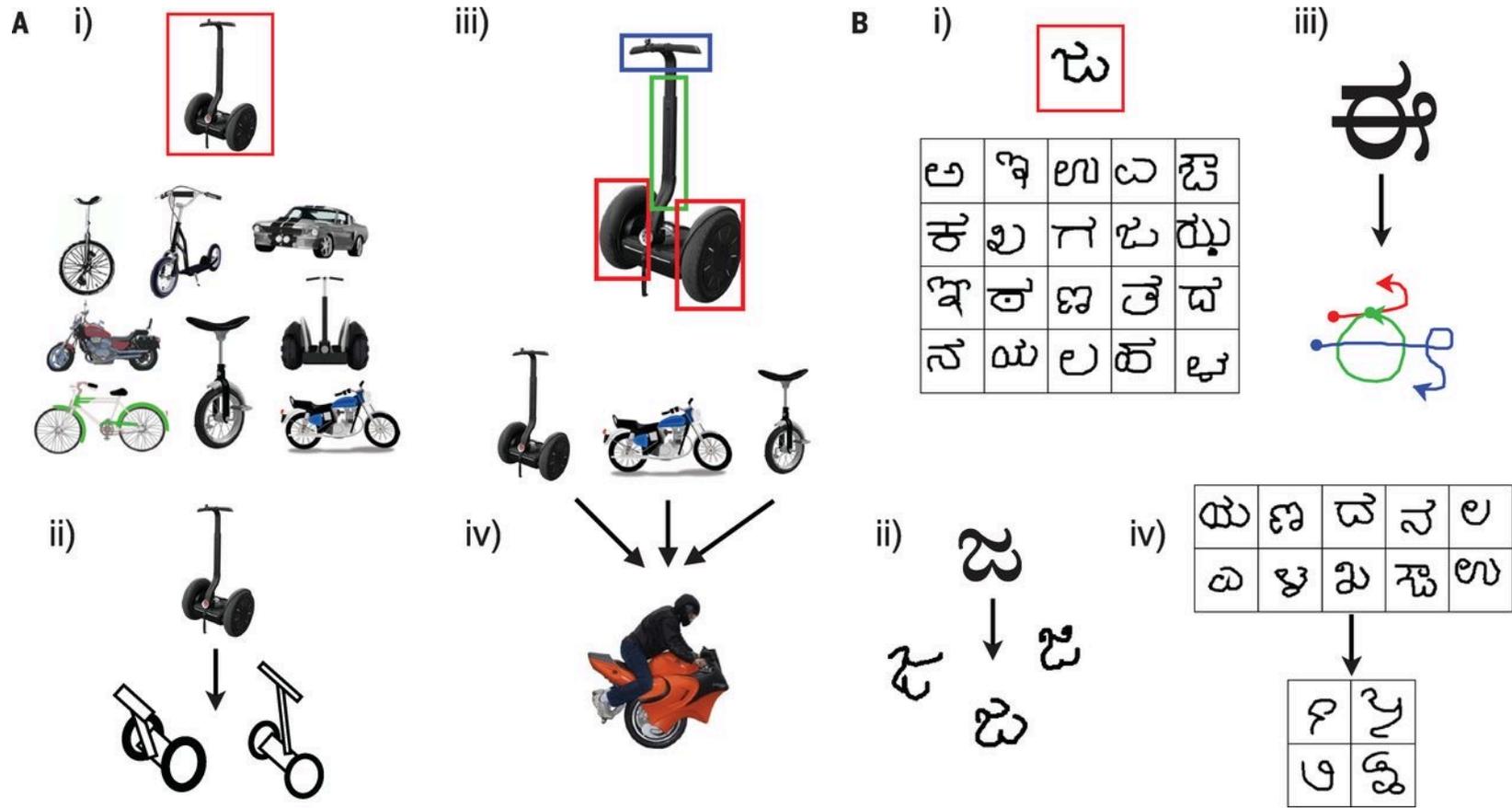
ॐ

Test set:

ॐ ॐ ॐ
ॐ ॐ ॐ
ॐ ॐ ॐ



Fig. 1 People can learn rich concepts from limited data.



Brenden M. Lake et al. Science 2015;350:1332-1338



Fig. 2 Simple visual concepts for comparing human and machine learning.



Brenden M. Lake et al. Science 2015;350:1332-1338



Bayesian Program Learning

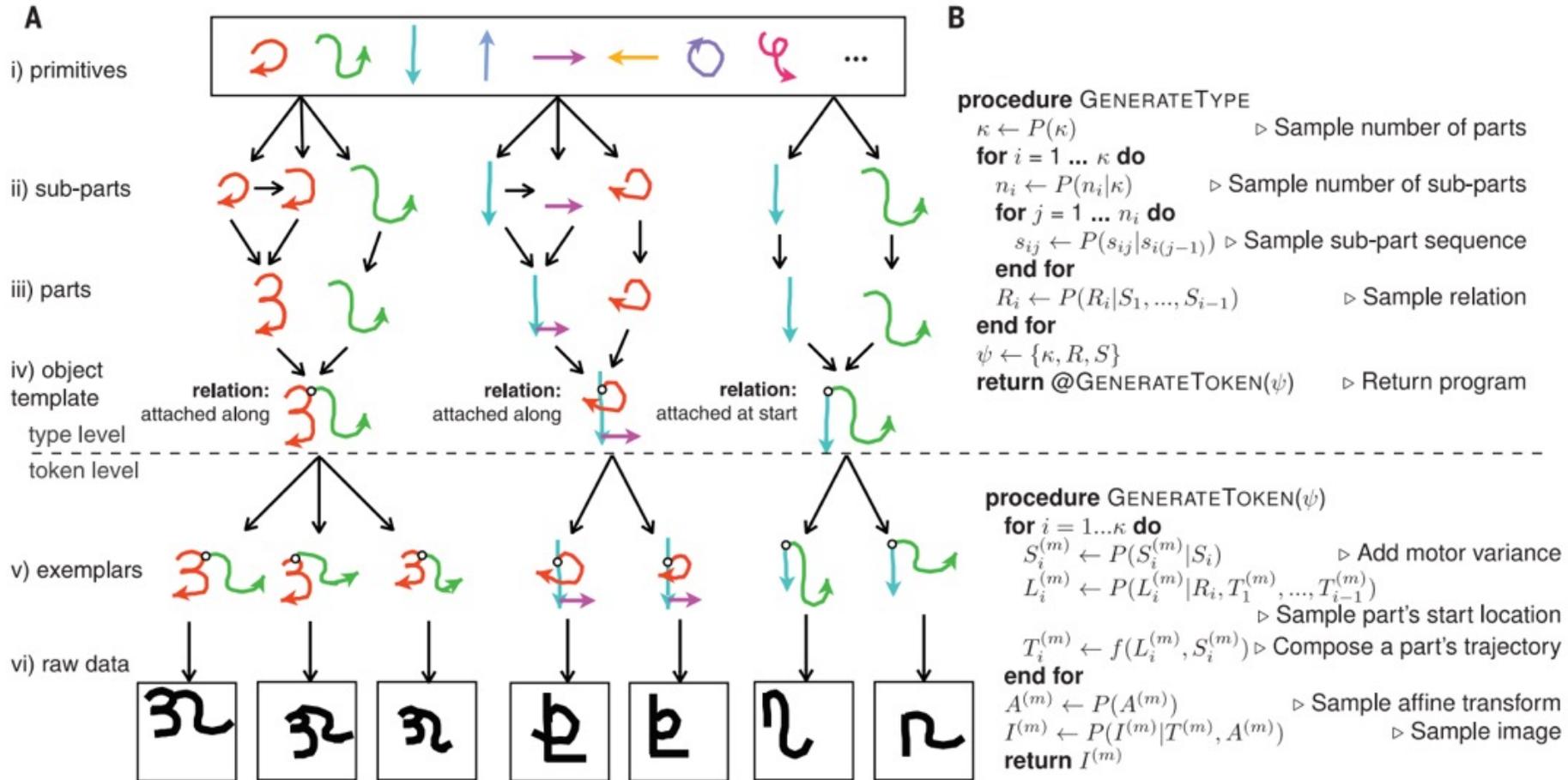
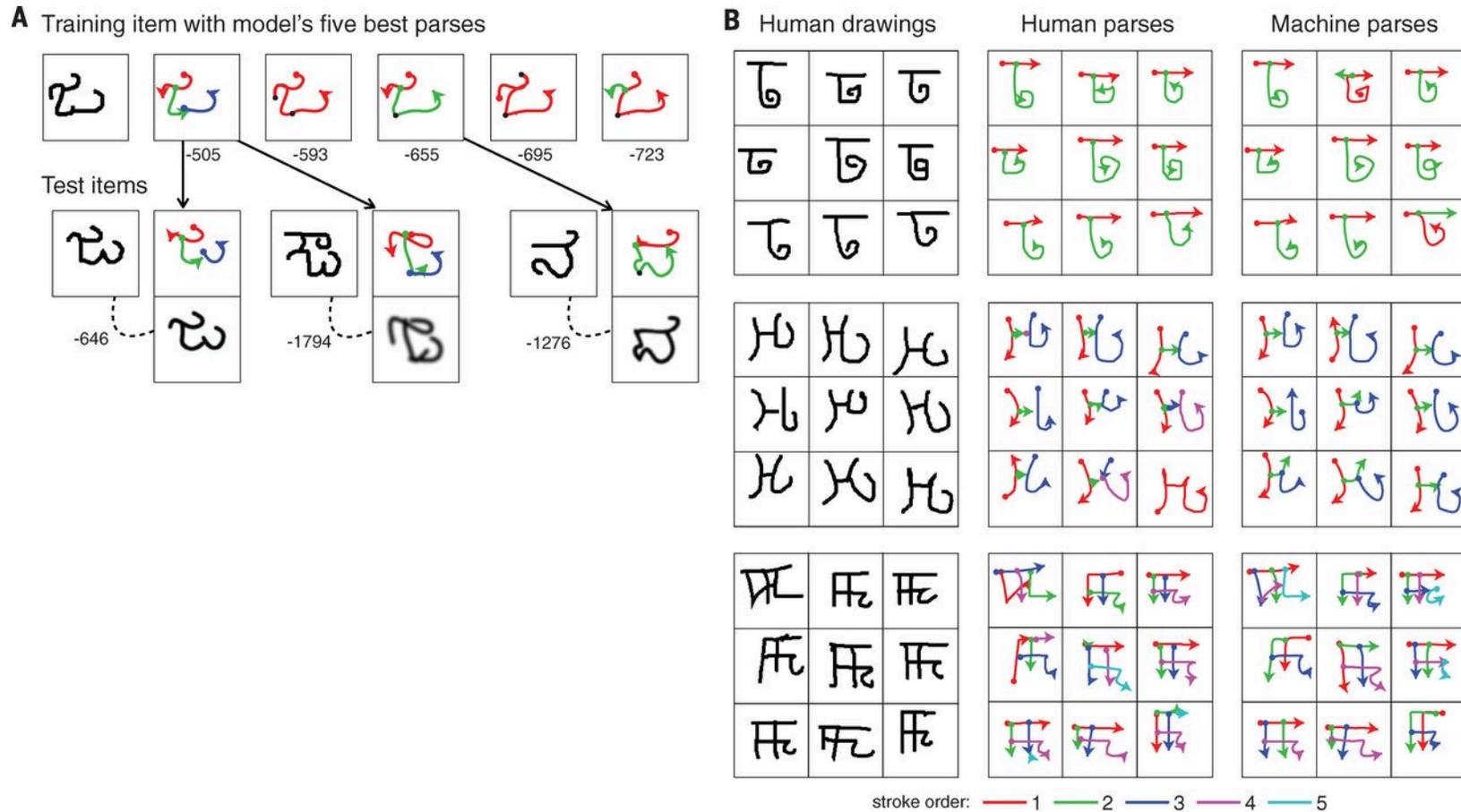


Fig. 4 Inferring motor programs from images.

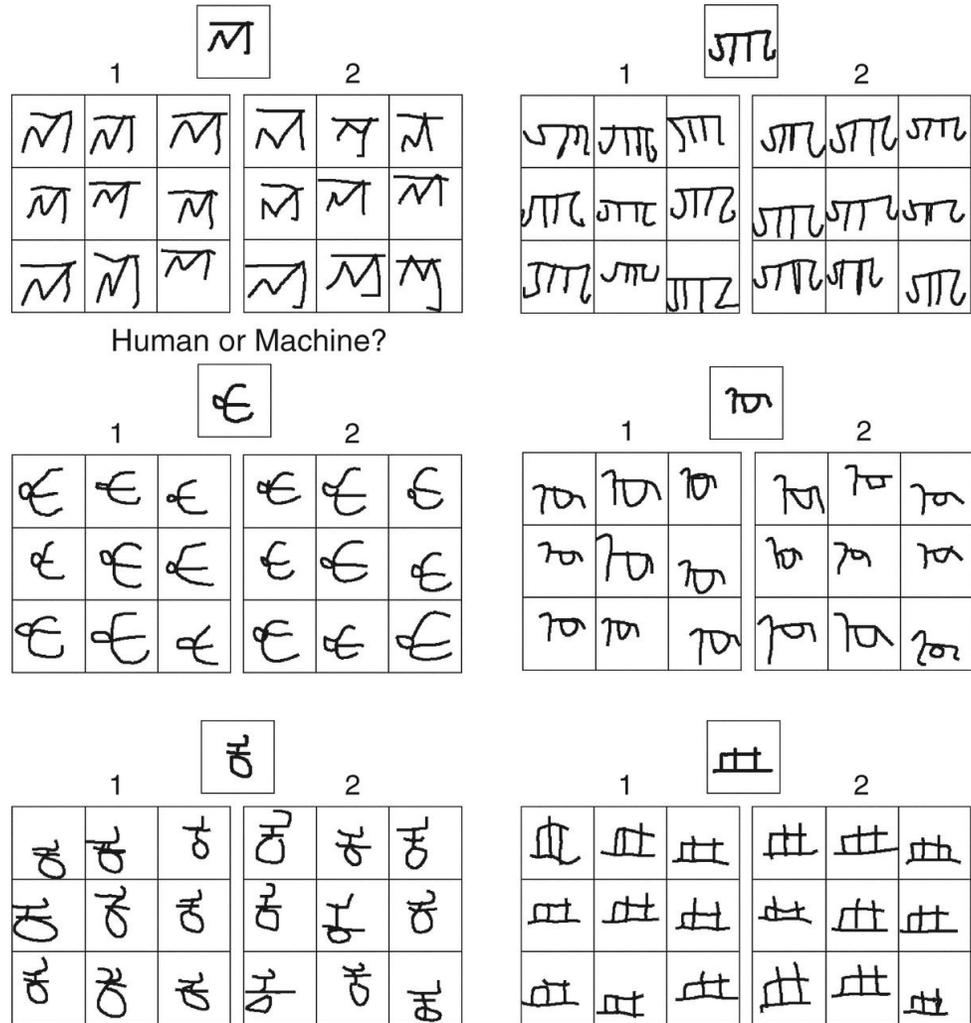


Brenden M. Lake et al. *Science* 2015;350:1332-1338

Copyright © 2015, American Association for the Advancement of Science



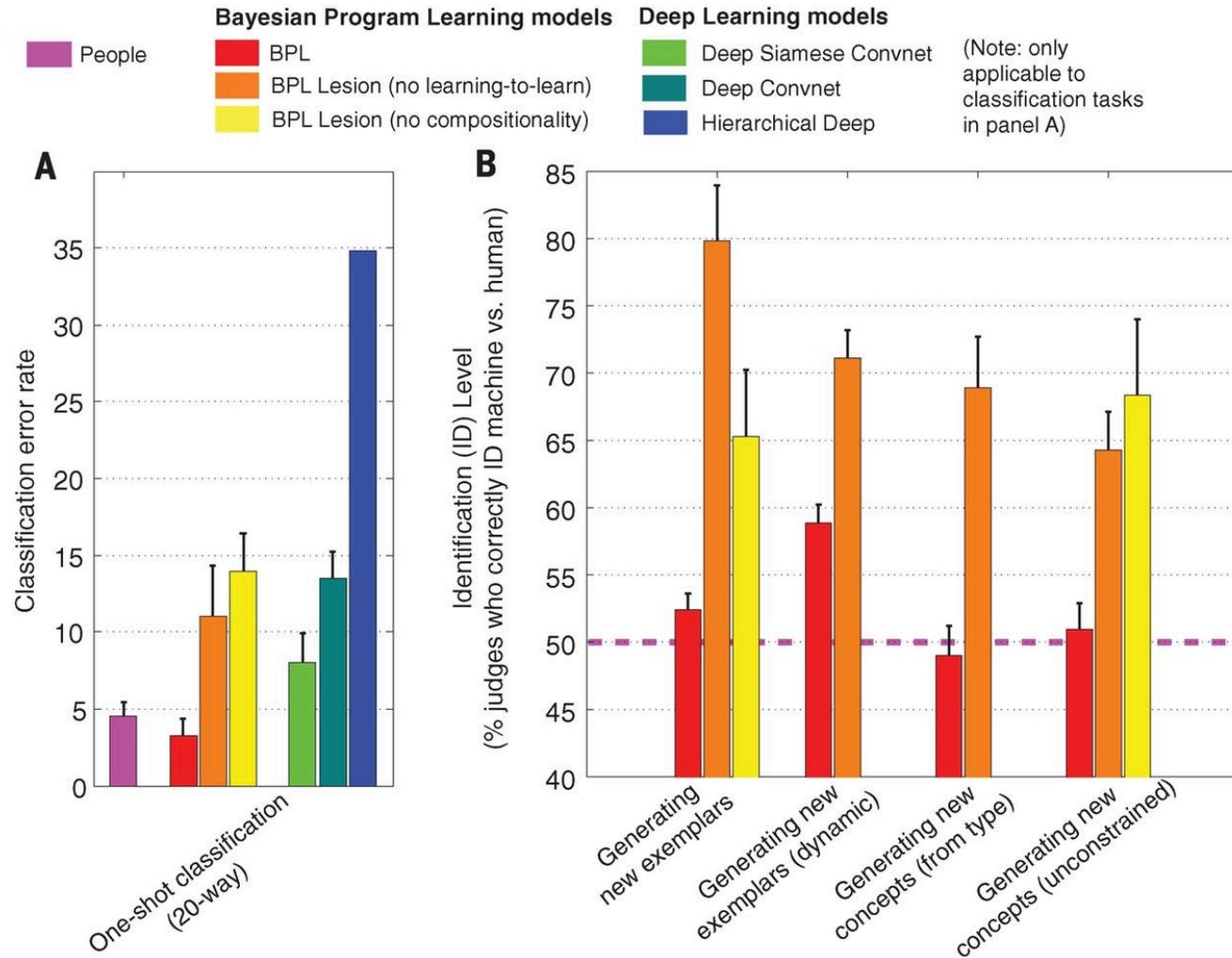
Fig. 5 Generating new exemplars.



Brenden M. Lake et al. Science 2015;350:1332-1338



Fig. 6 Human and machine performance was compared on (A) one-shot classification and (B) four generative tasks.

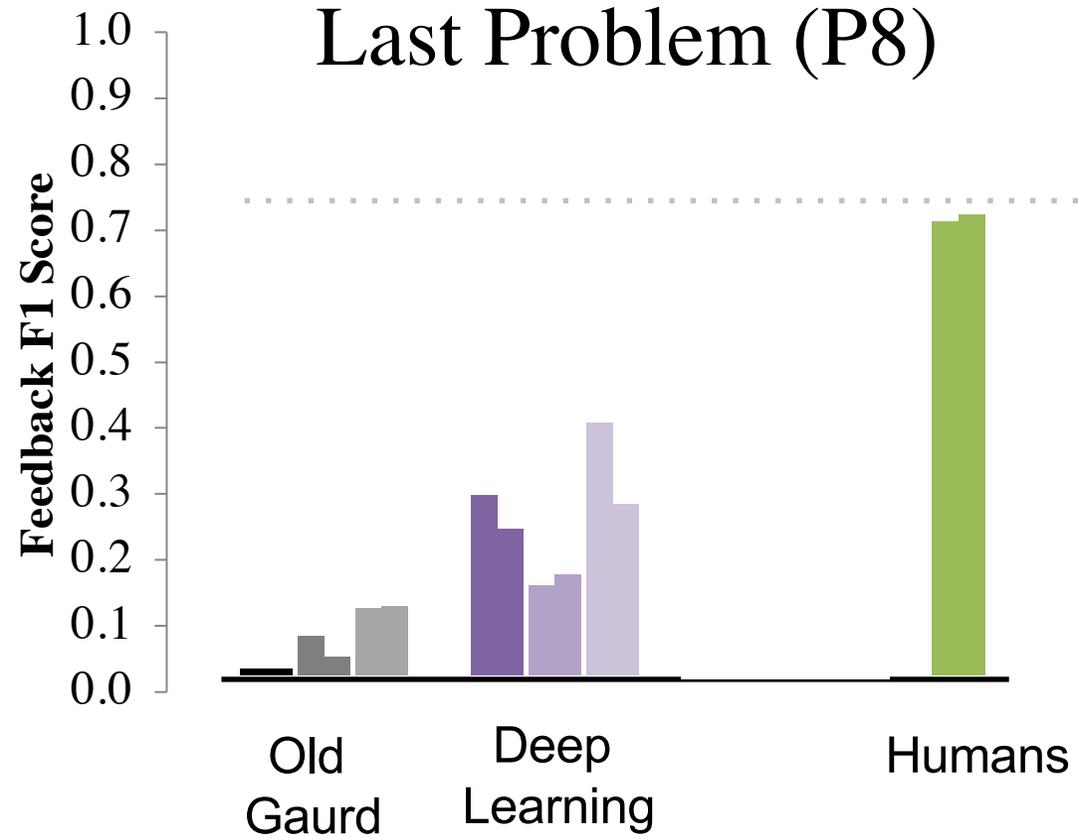


Brenden M. Lake et al. *Science* 2015;350:1332-1338



Generative Understanding

Label student code



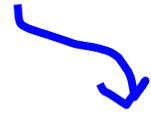
Grading is Hard



Grading:

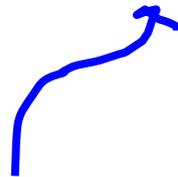
Infer ability and choices from code

Student ability



$$P(\Theta, C | \Pi)$$

Student choices

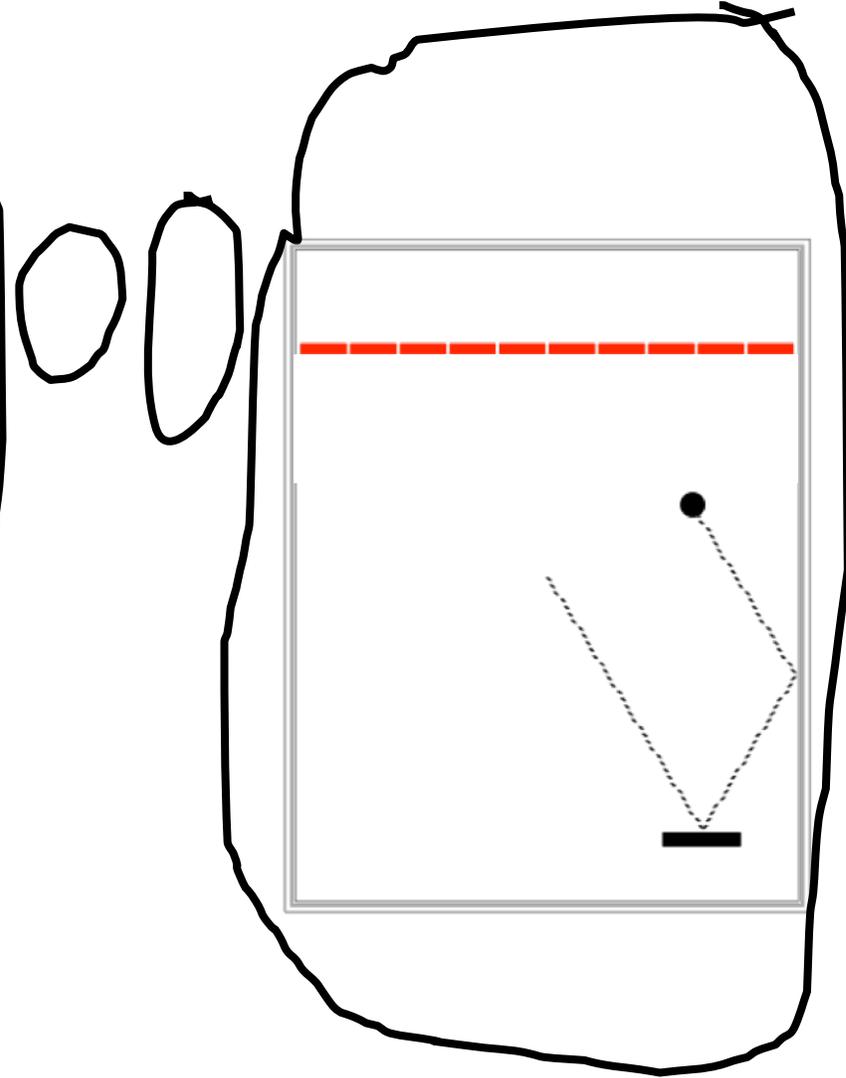


Student code

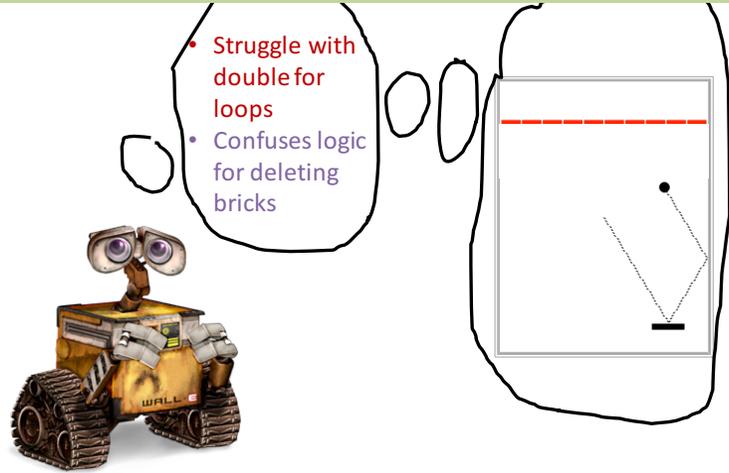


Generative Probabilistic Model?

- Struggle with double for loops
- Confuses logic for deleting bricks



Imagine Students



This is easy and exponential
human impact

A students
“ability”

$$\Theta \sim \text{pythonSample}$$

A students
“choices”

$$C \sim \text{pythonSample} | \Theta$$

The resulting
code

$$\Pi \sim \text{pythonSample} | C$$



This is hard and linear
human impact

$$P(\Theta, C | \Pi)$$

Infer ability and
choices from code



Bayesian Programming Language



ideaToText



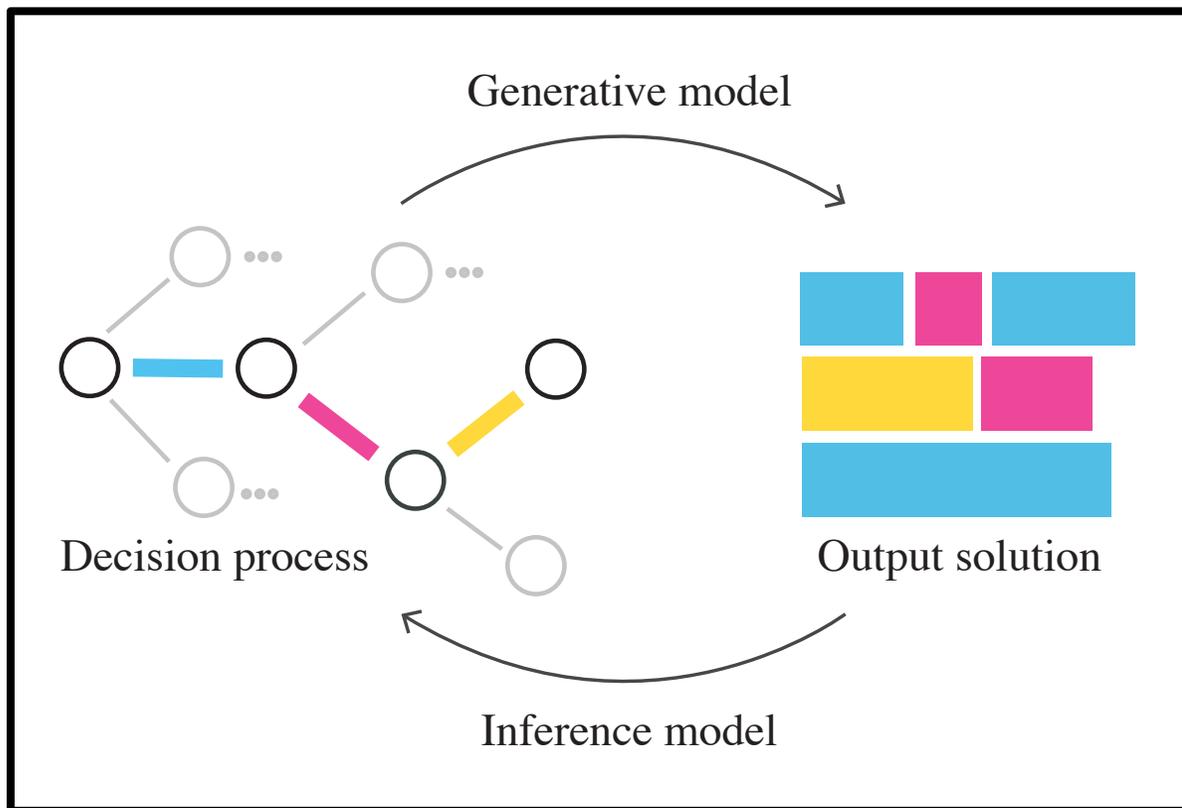
Teachers Articulate N misconceptions

```
7
8 # This python class is a RubricSampling Decision
9 # it generates programs that print the numbers 10 -> 1
10 class Countdown(Decision):
11
12     def registerChoices(self):
13         # these are the main strategies for printing out a
14         # countdown
15         self.addRubricChoices('loop-style', {
16             'for' :  $\theta_1$ ,
17             'while' :  $\theta_2$ ,
18             'none' :  $\theta_3$ ,
19             'empty' :  $\theta_4$ 
20         })
21
22     # we can make some grading choices based on which
23     # strategy they chose (did they actually use a loop?)
24     def processChoices(self):
25         style = self.getChoice('loop-style')
26         hasLoop = style != 'none' and style != 'empty'
27         self.addLabel('rubric-hasLoop', hasLoop)
28
29
30     # Based on their strategy render a different decision
31     def renderCode(self):
32         style = self.getChoice('loop-style')
33         if style == 'for': return '{ForSoln}'
34         if style == 'while': return '{WhileSoln}'
35         if style == 'none': return '{NoLoopSoln}'
36         if style == 'empty': return ''
37
```

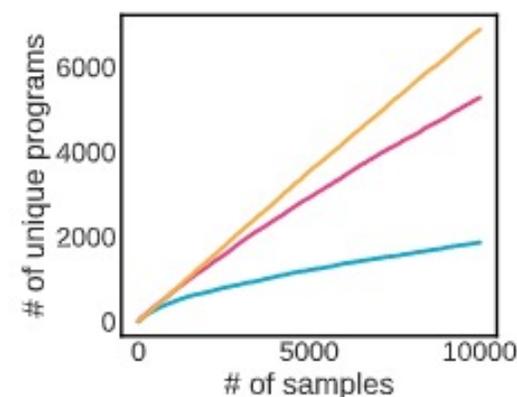
1. This is code for a single decision point
2. Give a name to the choice that the student is making (it is a random variable)
3. How do those choices translate into feedback?
4. What does the code look like? Often evokes other decision points



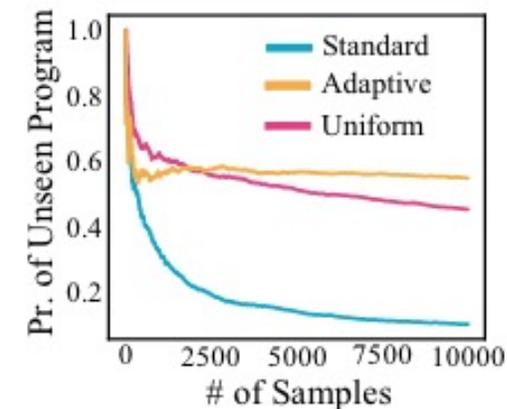
Generative Understanding



Idea: (1) sample a ton, then (2) build a neural network to learn to predict decisions



(a) Uniqueness



(b) Good-Turing

Decision process

Next choice

$$p_G(x_{a_1}, \dots, x_{a_T} | y) = \prod_{t=1}^T p_G(x_{a_t} | y, \mathbf{x}_{<a_t})$$

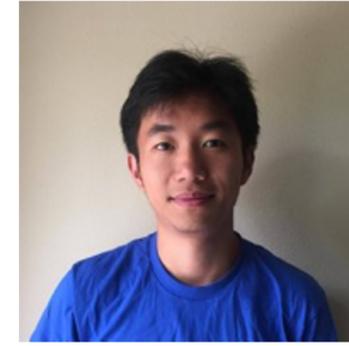
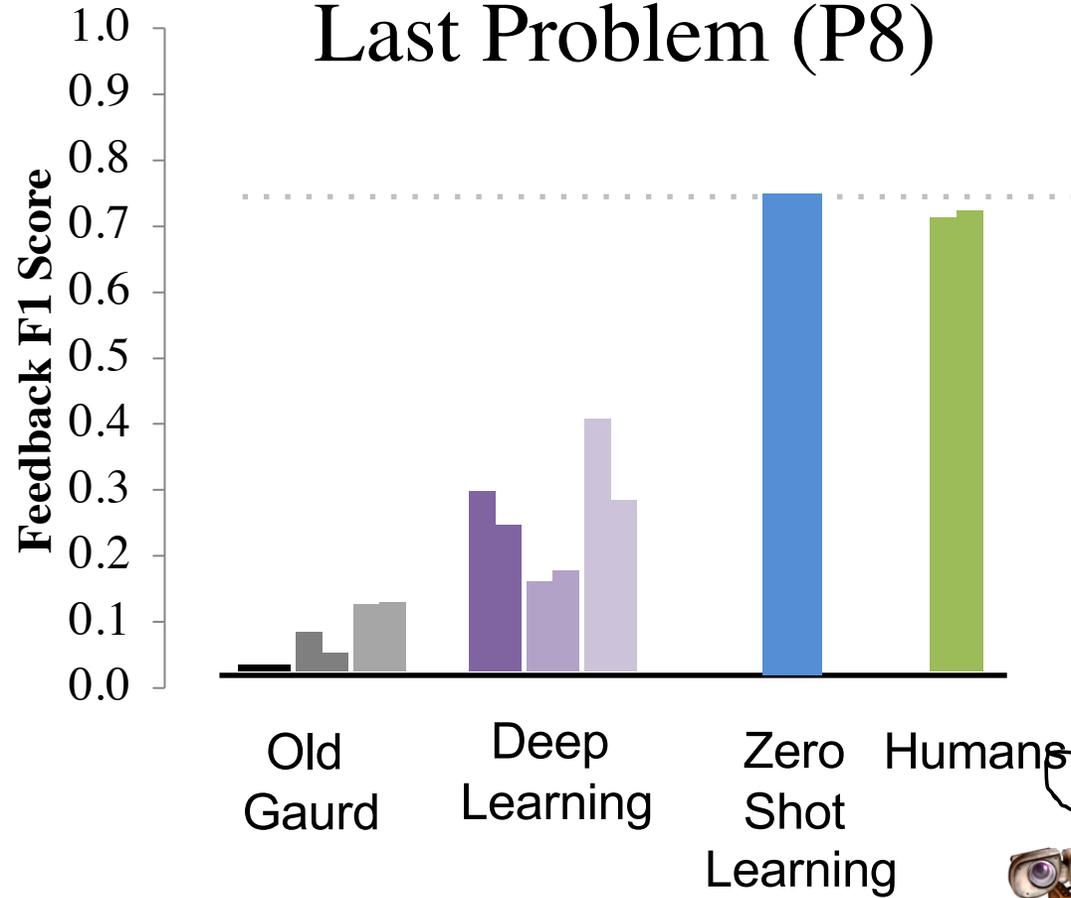
solution

Previous choices

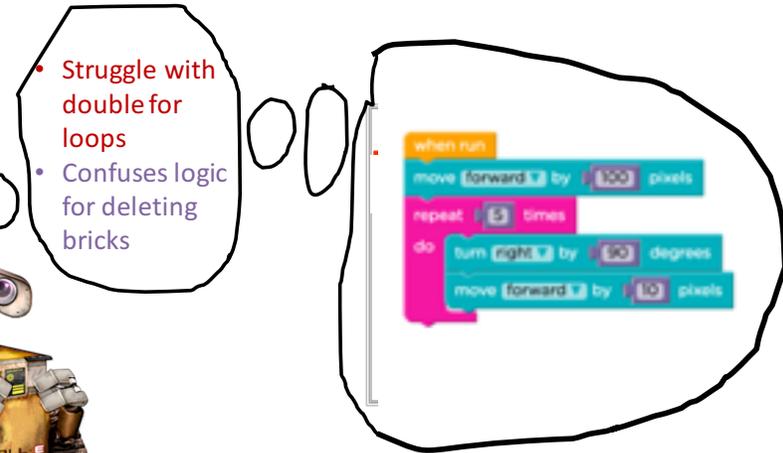


Generative Understanding

Label student code



*Outstanding Student
paper award, AAAI 2019*



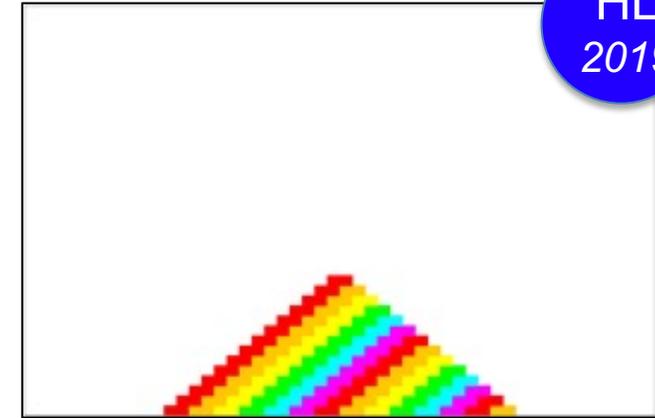
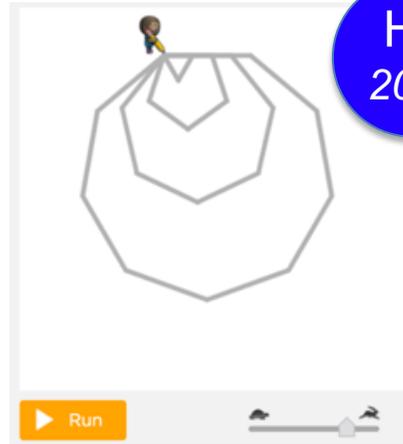
Not just for code

Results from early 2019

Many domains of student work

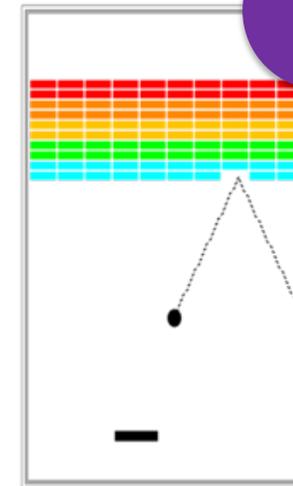
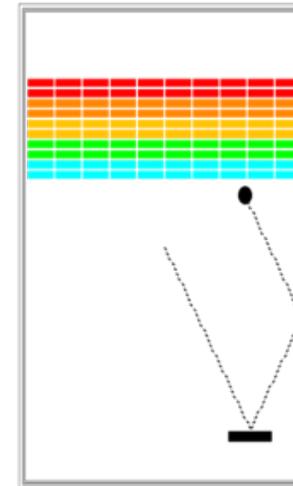
HL
2017

$$\begin{aligned} & 9 \times 6 \\ &= (10 - \boxed{}) \times 6 \\ &= 10 \times 6 - \boxed{} \times 6 \\ &= 60 - \boxed{} \\ &= \boxed{} \end{aligned}$$



NH
2019

Why did the original colonists come to America?



?



NH

Near Human

HL

Human Level

SH

Super Human Level



So what?

What does this mean for me?!?

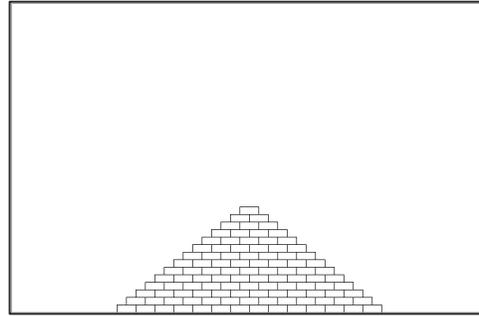
Understanding Process

2,600 students

130,000 partial solutions

μ snapshots per student = 50

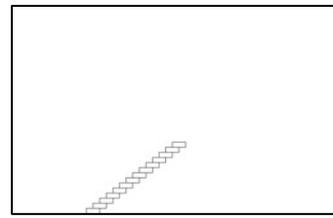
μ time per student = 2 hours



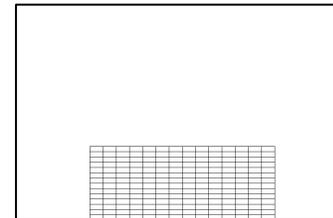
Step 1



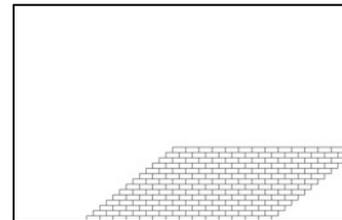
Step 2



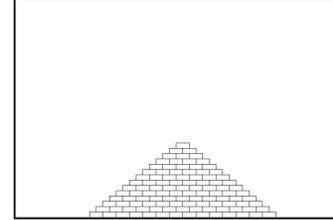
Step 3



Step 4



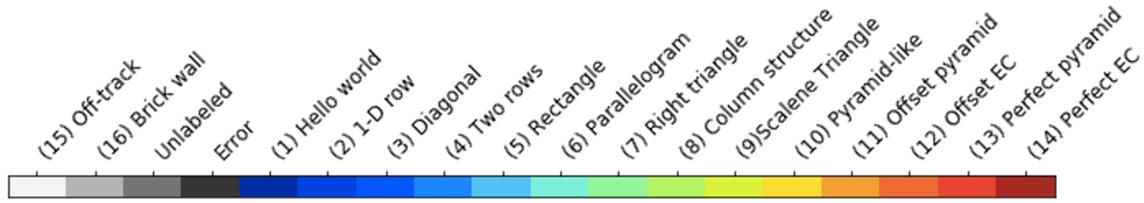
Step 5



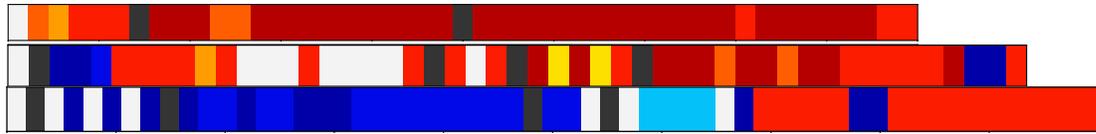
Step 6



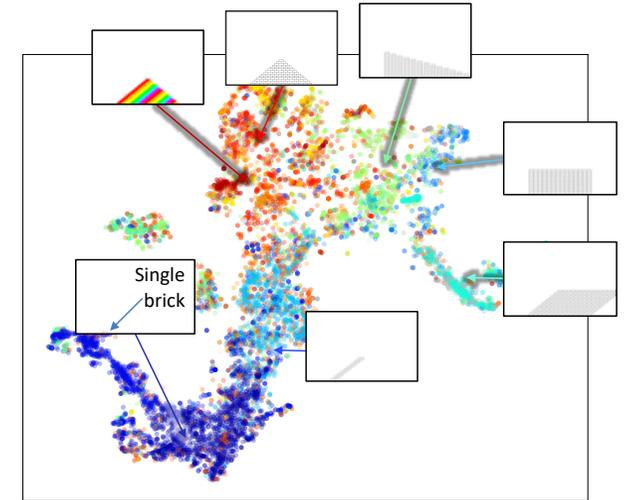
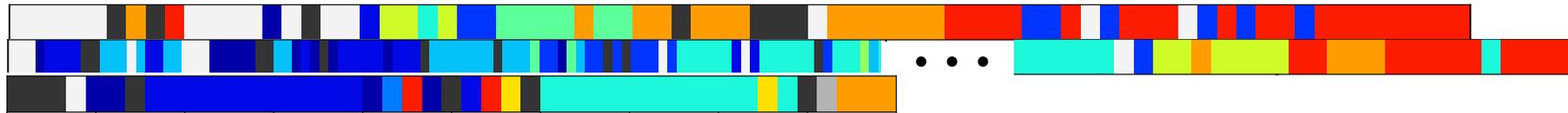
Understanding Process



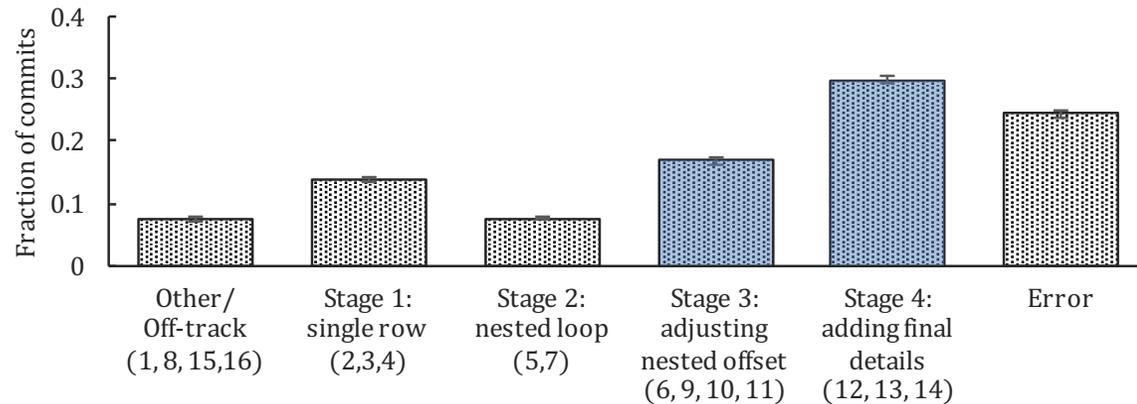
Students scoring in 99th percentile on midterm exam



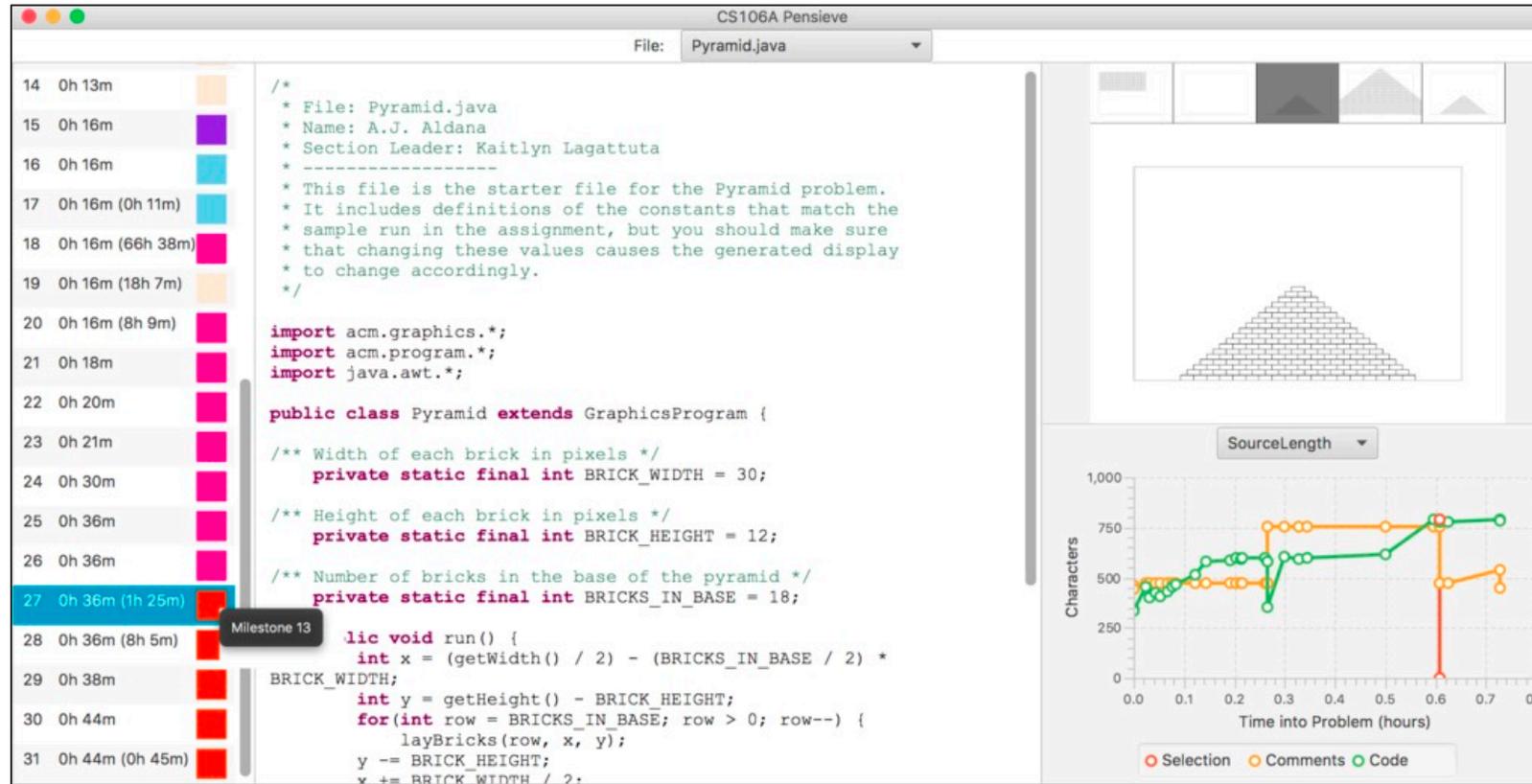
Students scoring in $\leq 3^{\text{rd}}$ percentile on midterm exam



t-SNE embedding of 130,000 partial solutions



Understanding Process



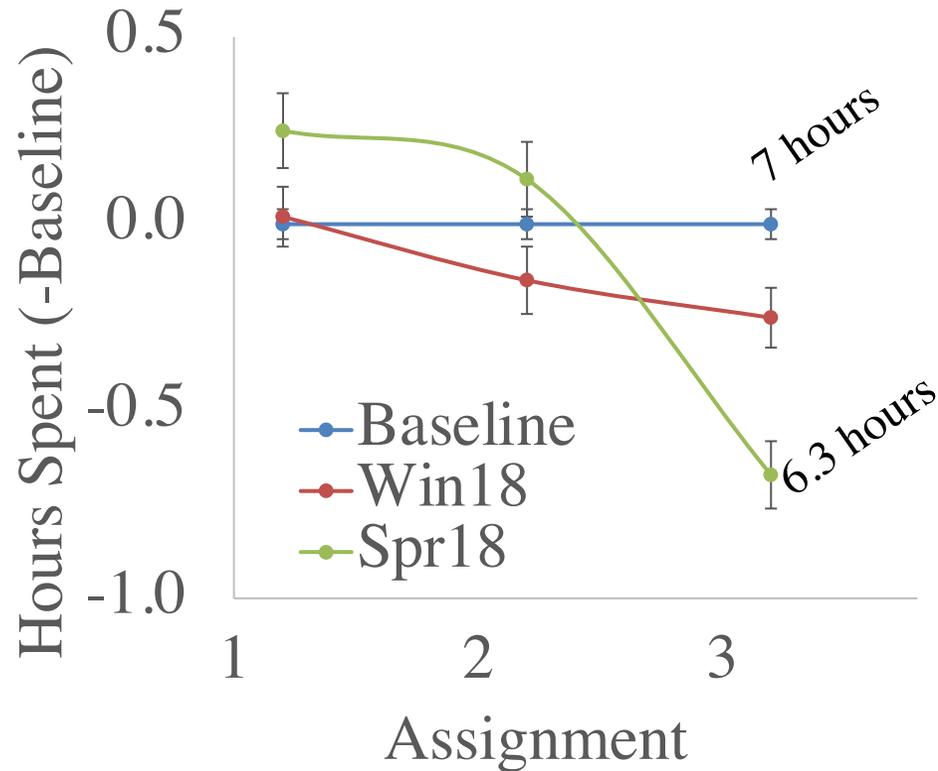
One quarter, all students were *shown* their progress:

- Early correction of bad habits.
- Chance to teach the art of programming.
- Academic dishonesty becomes much harder.



Understanding Process

Using assignment *timing* as pre-post

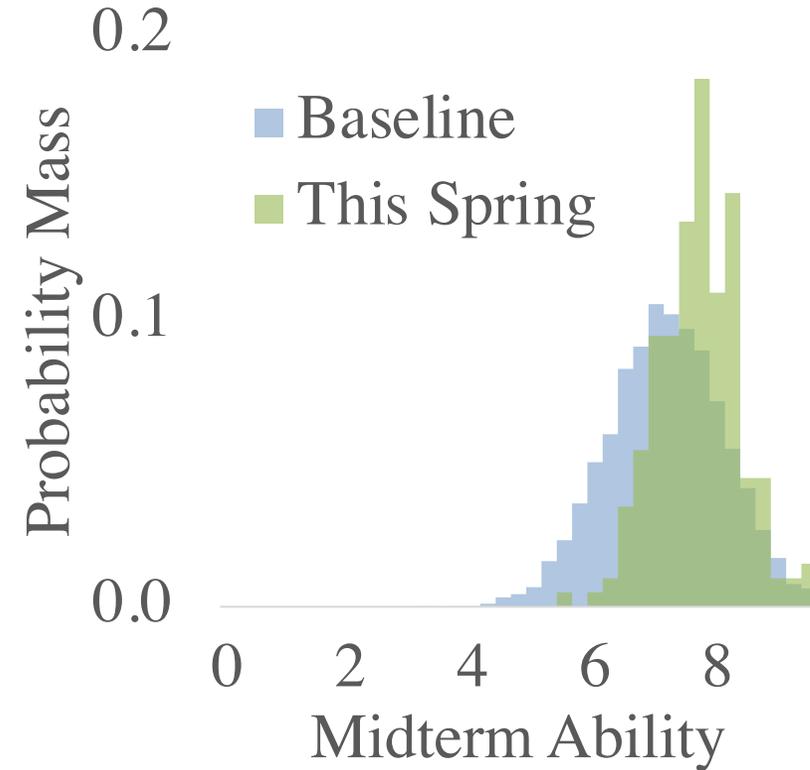


$$E[\hat{X}_3 | X_1] - E[X_3] = 42 \text{ mins}$$

Predicted time Actual time $p < 0.00001$

Assignments are taking less time

Item Response Theory based ability assessment



$$S_{i,j} = n \cdot \sigma(a_i - d_j)$$

Score points ability difficulty

Students perform better than expected



Feedback on *process* is an open problem

Our understanding of student work is not
perfect

Hit a ceiling with cs106a midterm

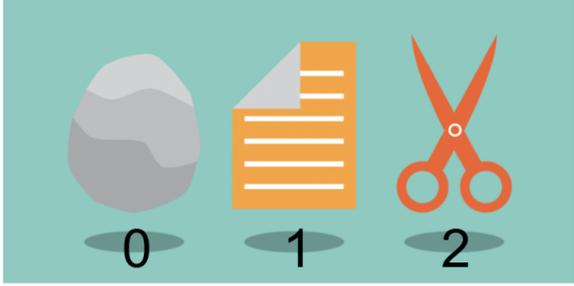
Midterm Grading Challenge

Browse Q3 | DynamoDB · AWS Console

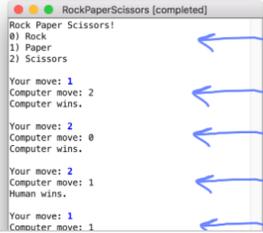
localhost:3000/#/view/cs106aMidWin19/3/abigail8/cpiech/8daa714e79a10cb

Question | Solution | Starter | Student | Answer

Rock Paper Scissors (30 points)



Write a `ConsoleProgram` that has a user play rock paper scissors against a computer until either the user or the computer has **three** "wins". To make the code simpler, use integers to represent the different plays (0 is rock, 1 is paper, 2 is scissors). Example run:



- A brief intro message
- Round 1 The user's paper lost to the computer's scissors
- Round 2 The user's scissors lost to the computer's rock
- Round 3 The user's scissors beat the computer's paper
- Round 4 Both played paper

```
1 public class RockPaperScissors extends ConsoleProgram {
2
3     /* constants */
4     private static final int ROCK = 0;
5     private static final int PAPER = 1;
6     private static final int SCISSORS = 2;
7     private static final int N_WINS = 3;
8
9     private RandomGenerator rg = new RandomGenerator();
10
11    public void run() {
12        introMessage();
13        for (int i = 0; i < N_WINS; i++) {
14            inputNumber();
15            roundWinner();
16        }
17        gameWinner;
18    }
19
20    private void introMessage() {
21        println("Rock Paper Scissors!");
22        println("0) Rock");
23        println("1) Paper");
24        println("2) Scissors");
25        println(" ");
26    }
27
28    private void inputNumber() {
29        int a = readInt("Your move: ");
30        int computerMove = rg.nextInt(3);
31        int b = readInt("Computer move: " + computerMove);
32
33        private int computer = 0;
34        private int human = 0;
35
36    private void roundWinner {
37        if (a == 1 && b == 0) {
38            println("Human wins.");

```

Browse Answers

Grade: 26/30 points ✓ grade submitted!

Rubric: Standard

- For loop instead of a while loop (should go up to 3 wins by computer or user not 3 games)

User Inputting Move (3 points)

- Perfect (0 points)
- Minor Error (1 points)
- Major Error (2 points)
- Totally Wrong (3 points)

Computer Generating Move (4 points)

- Perfect (0 points)
- Minor Error (1 points)
- Major Error (2 points)
- Major Errors/No Attempt (4 points)

Determining the winner of a round (6 points)

- Perfect (0 points)
- Minor Error (1 points)
- Major Error (2 points)

Exam / Question 3 / Student

< Previous | Submit Grade | Next >

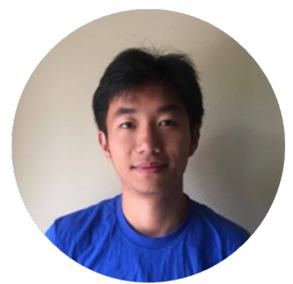
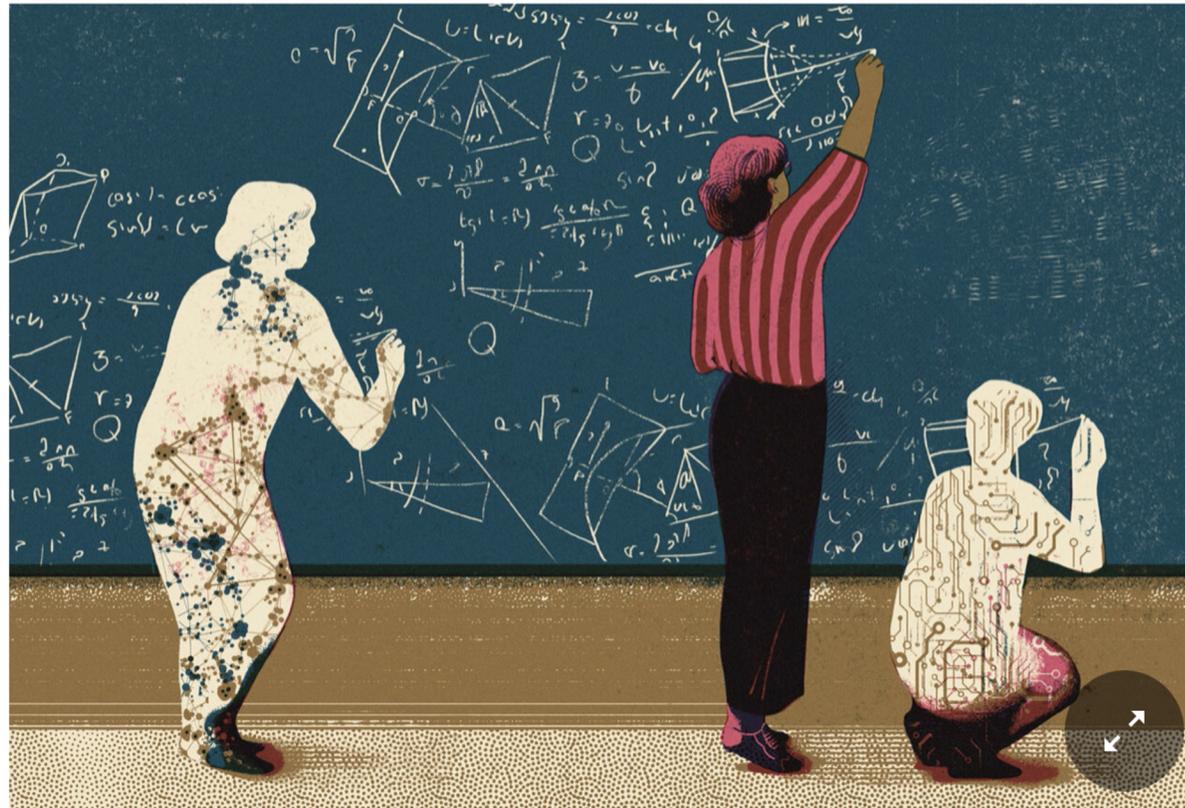
The
New York
Times

Can A.I. Grade Your Next Test?

Neural networks could give online education a boost by providing automated feedback to students.

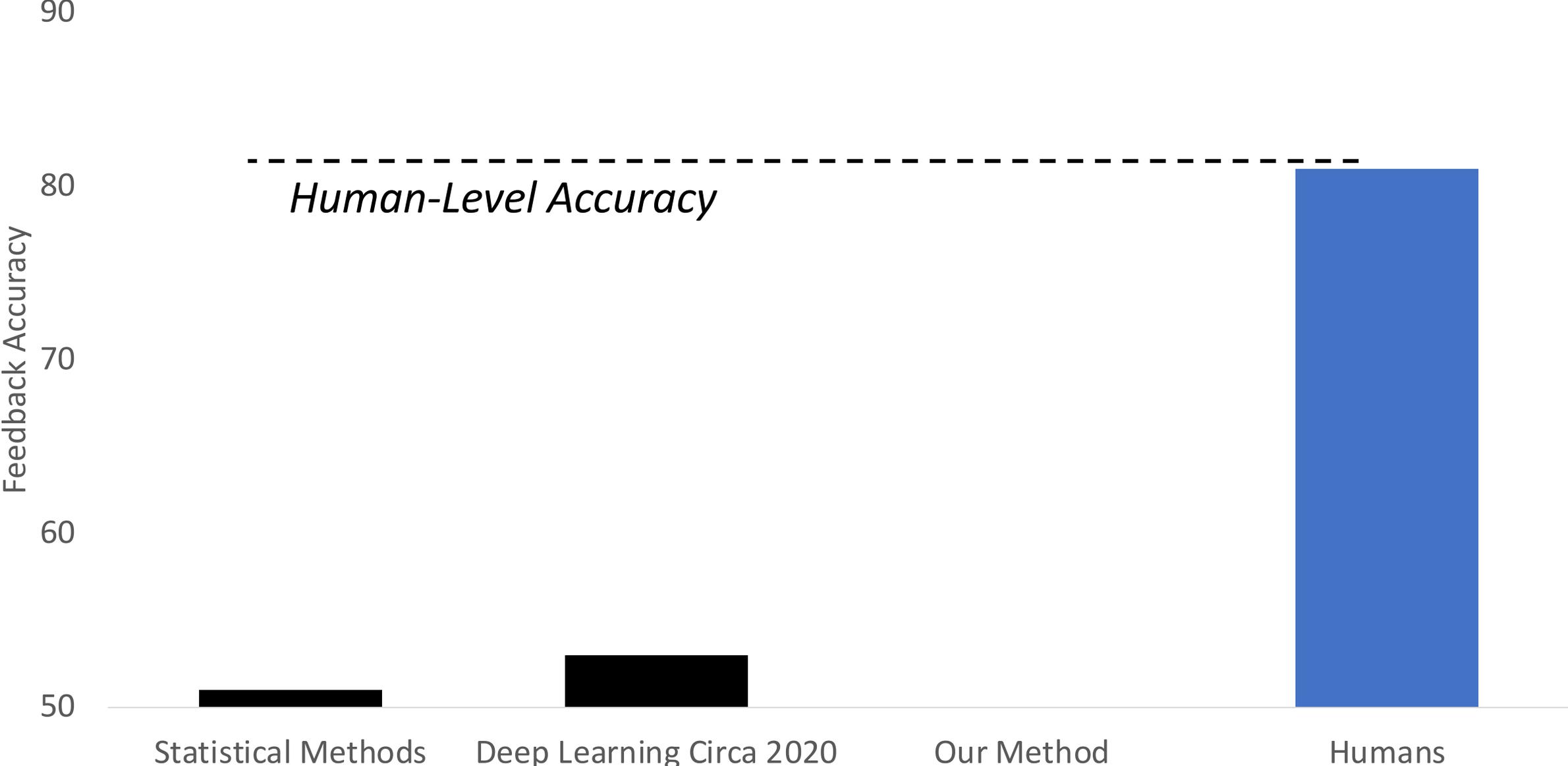


Stanford | News

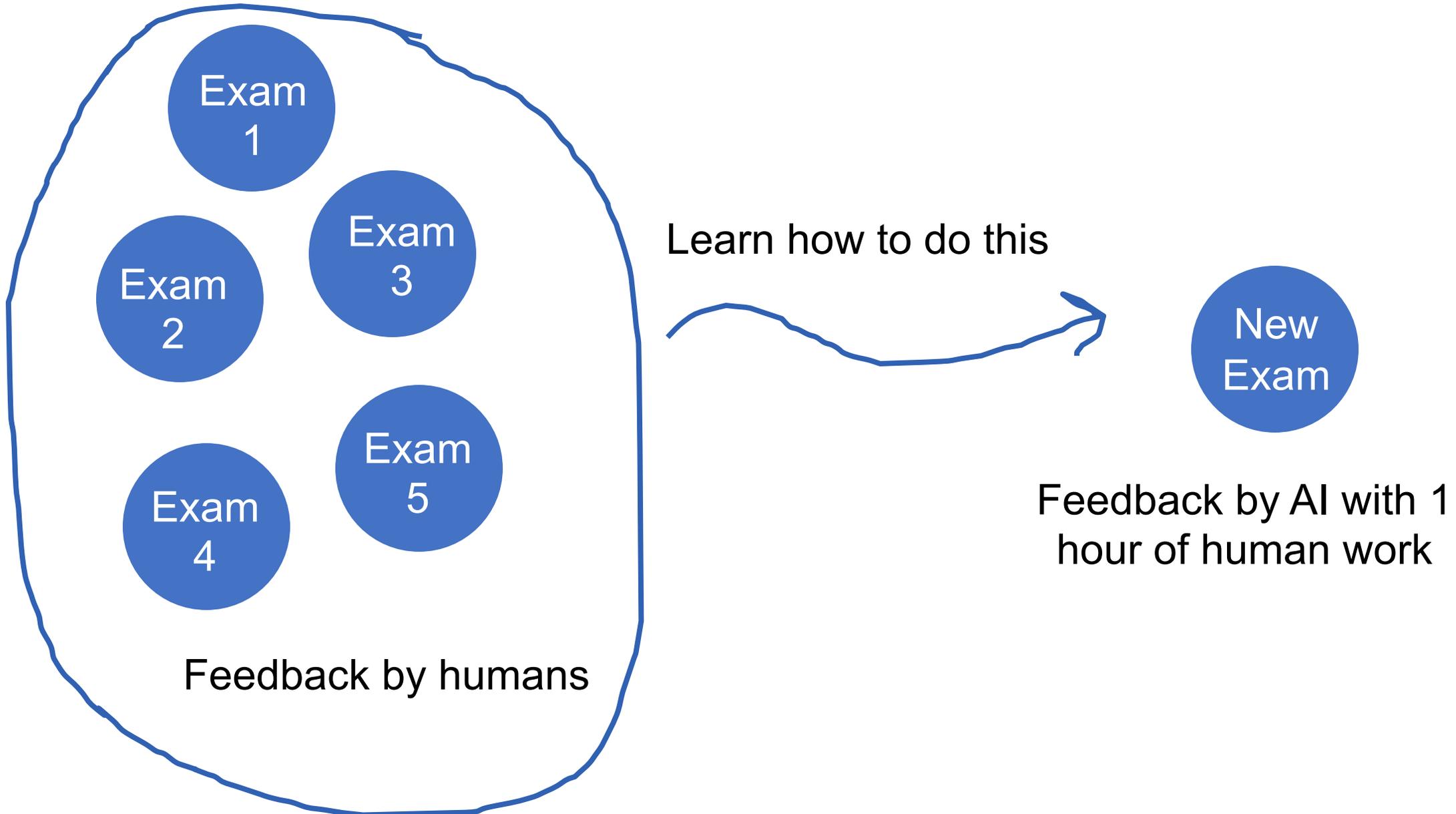


<https://www.nytimes.com/2021/07/20/technology/ai-education-neural-networks.html>

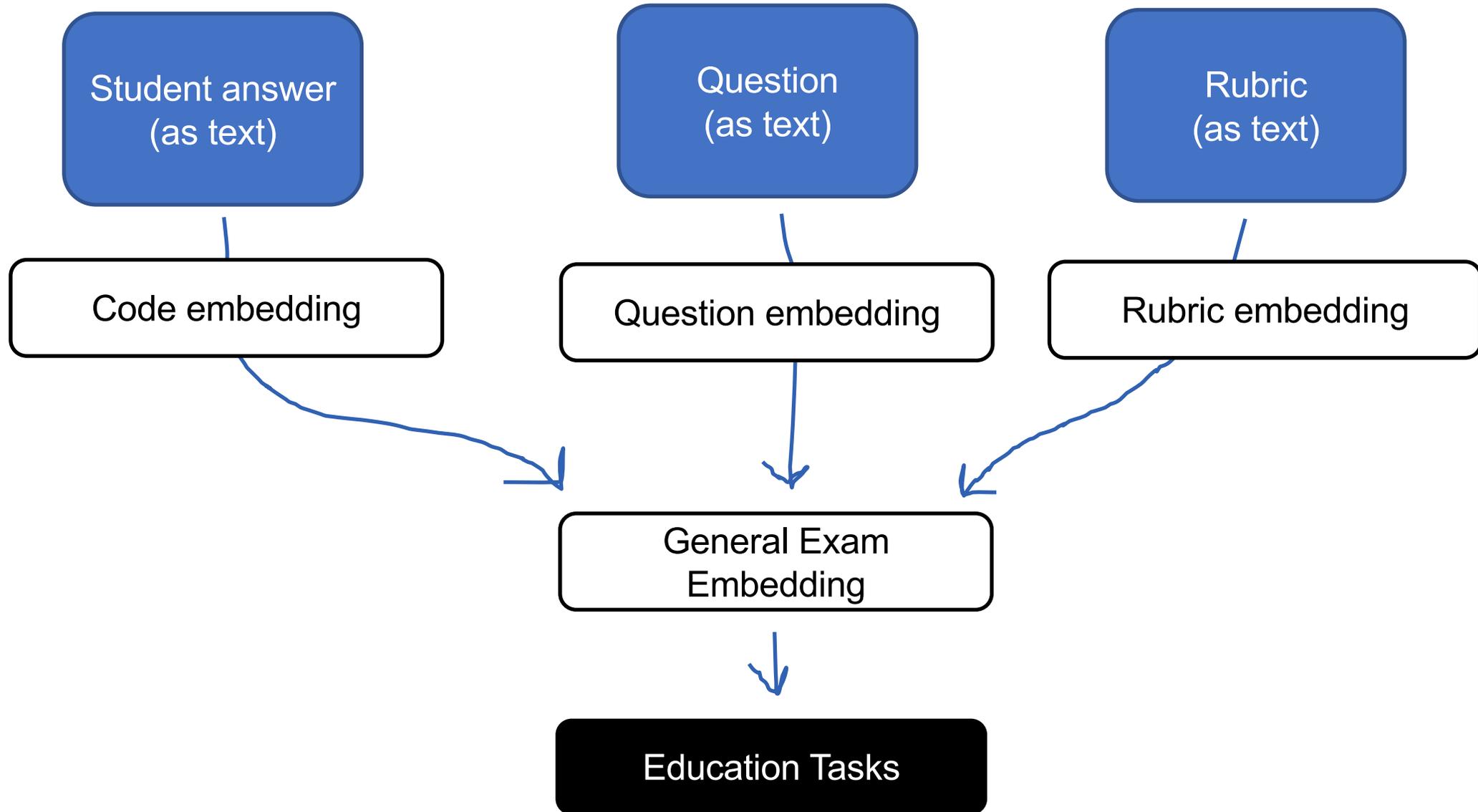
Rubric Level Accuracy on Few-Shot Grading a Novel Question



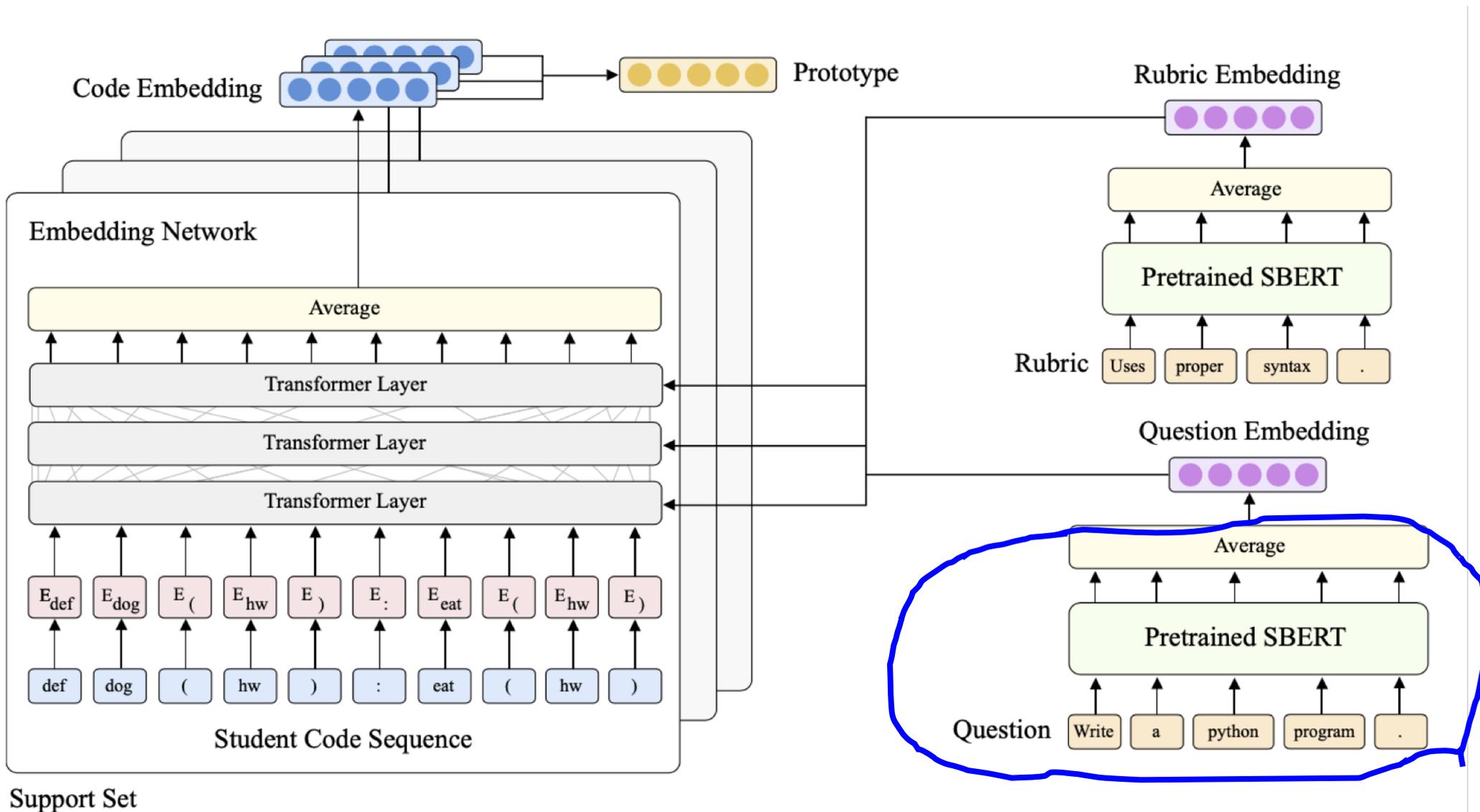
Give Feedback on Fresh Stanford Midterm



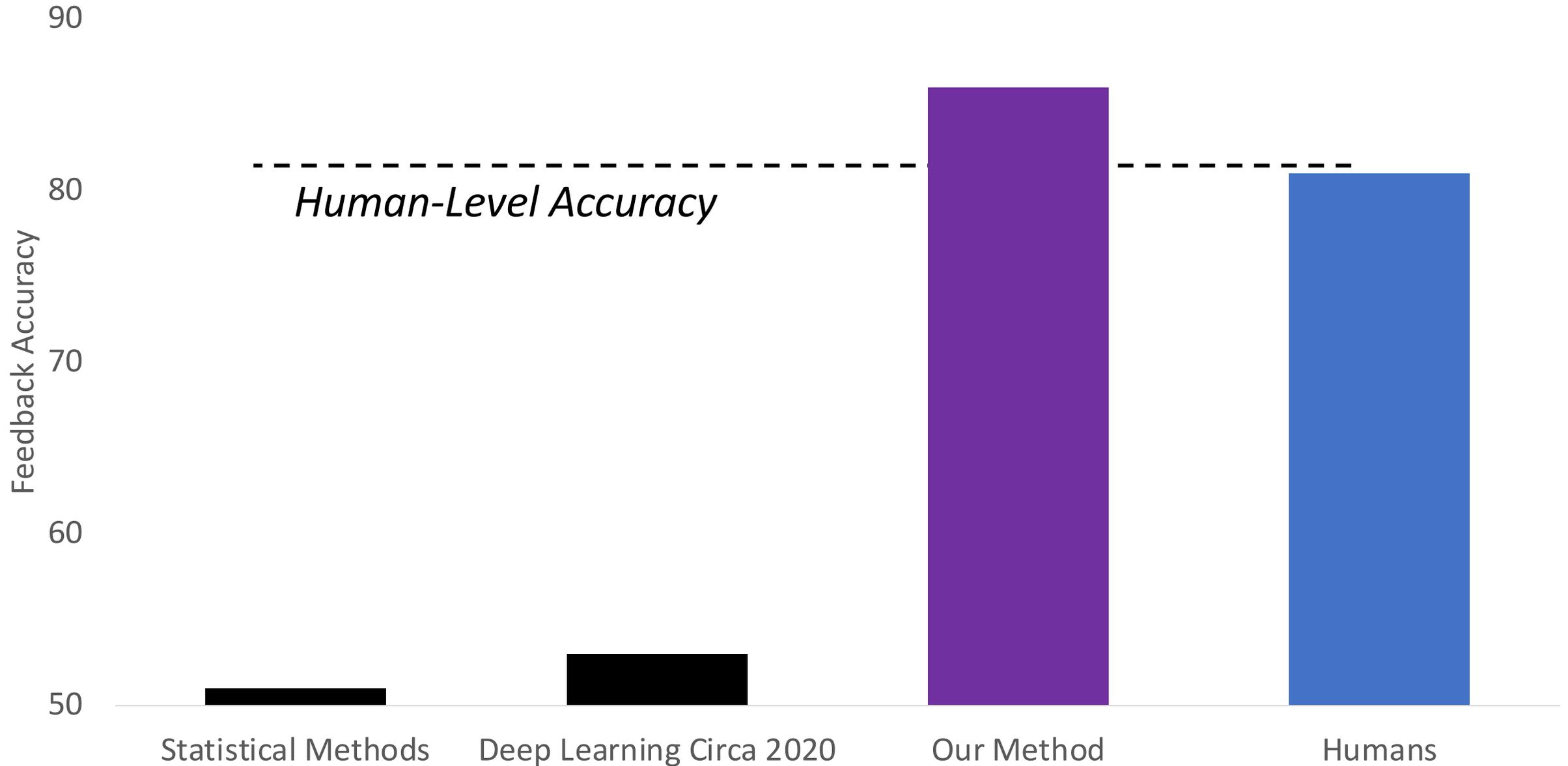
General Exam Grading Model



Invented the Proto-Transformer



Rubric Level Accuracy on Few-Shot Grading a Novel Question



Stanford Code in Place:



1100+ section leaders teach

12,000+ students

1/2 of CS106A

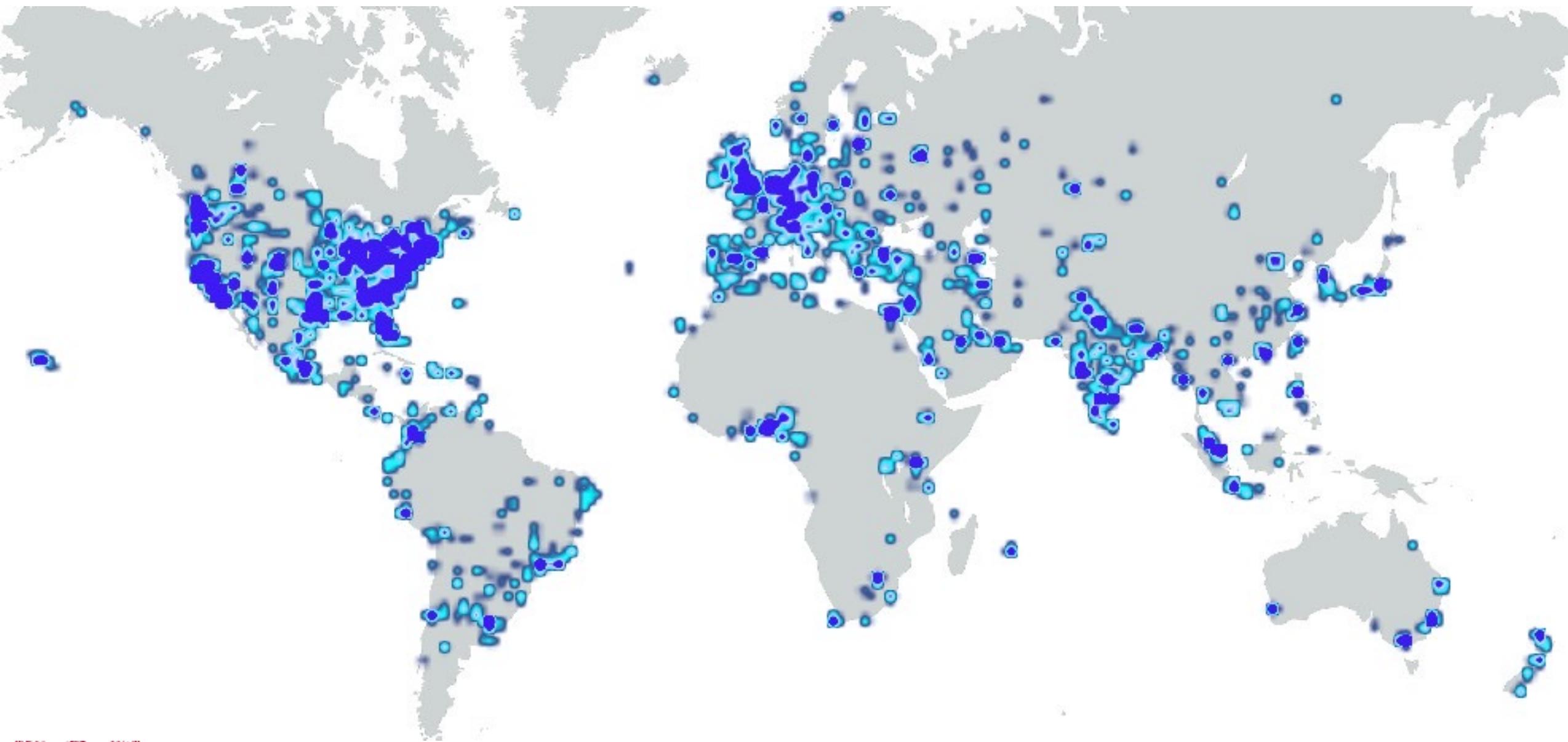
As Community Service

Featured in



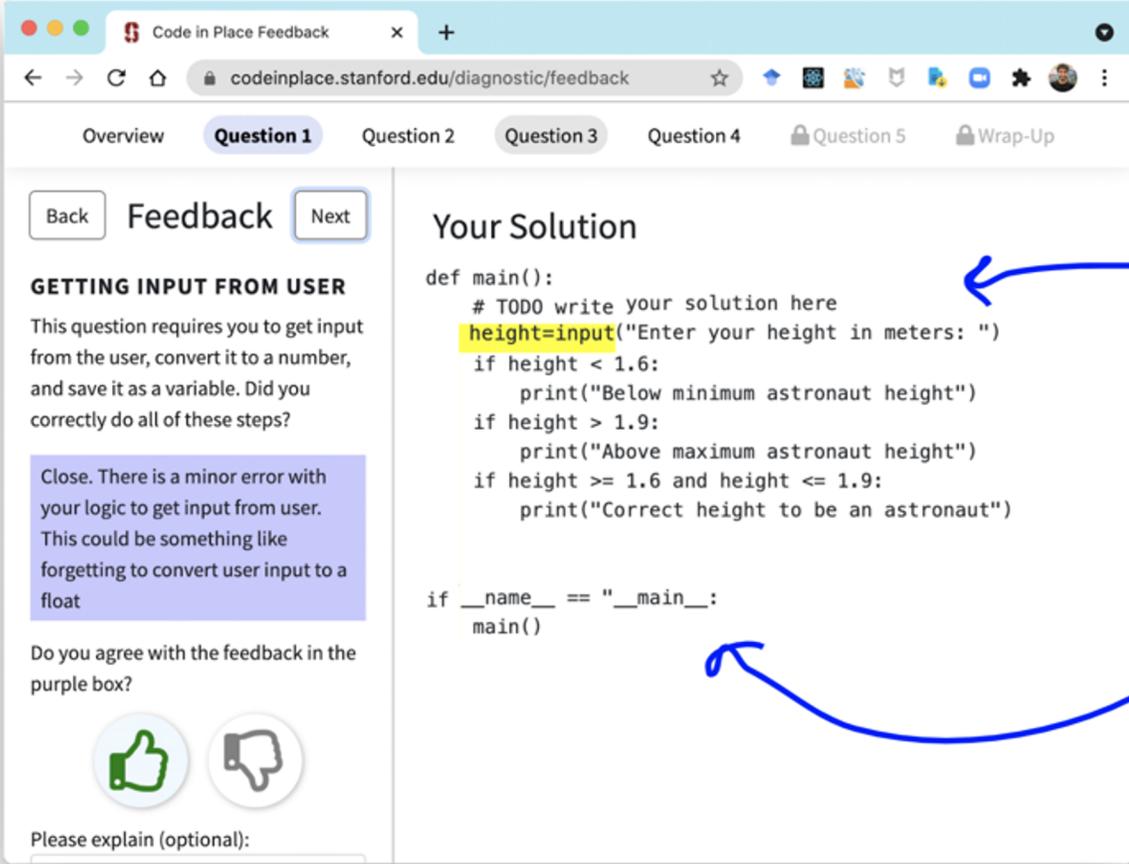
**SCIENTIFIC
AMERICAN**





Gave Feedback to 3,500 Real Students

Do you agree? AI feedback **97.9%**. Human feedback 96.7%



The screenshot shows a web browser window titled "Code in Place Feedback" with the URL "codeinplace.stanford.edu/diagnostic/feedback". The interface includes navigation tabs for "Overview", "Question 1", "Question 2", "Question 3", "Question 4", "Question 5", and "Wrap-Up". The "Question 1" tab is active, showing a "Feedback" section with "Back" and "Next" buttons. The feedback text reads: "GETTING INPUT FROM USER. This question requires you to get input from the user, convert it to a number, and save it as a variable. Did you correctly do all of these steps? Close. There is a minor error with your logic to get input from user. This could be something like forgetting to convert user input to a float. Do you agree with the feedback in the purple box?" Below the feedback are thumbs-up and thumbs-down icons, and a text input field labeled "Please explain (optional):".

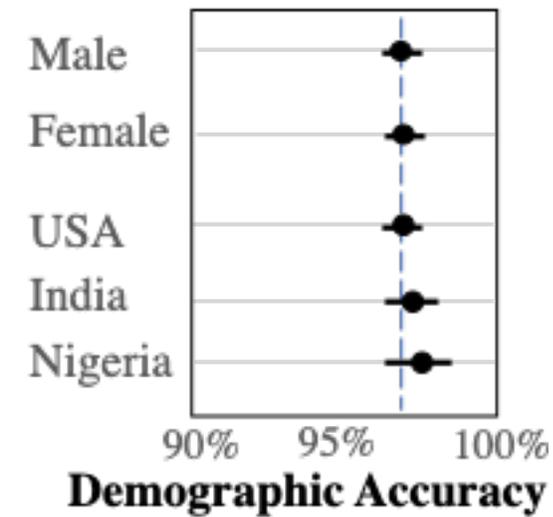
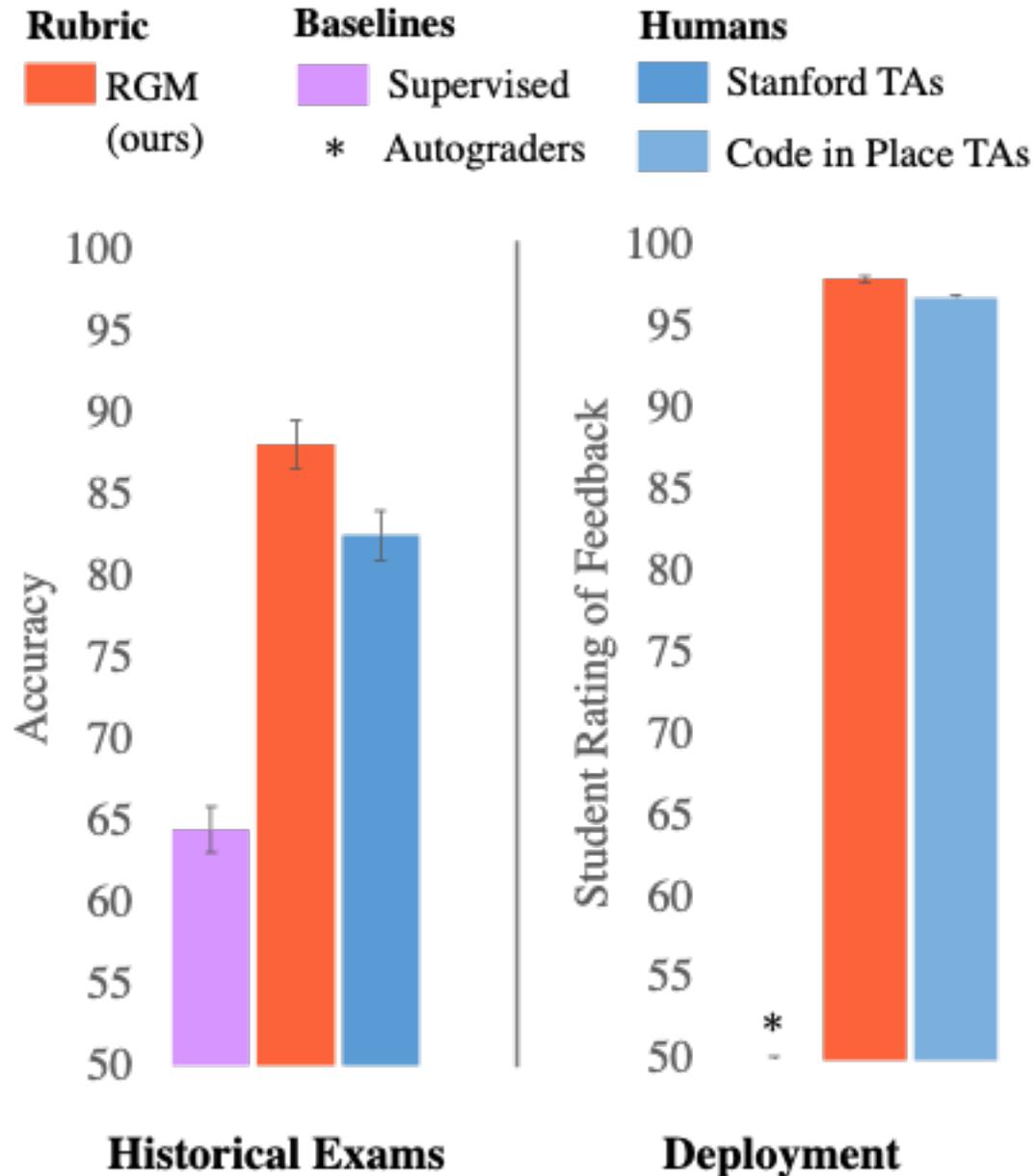
The "Your Solution" section displays Python code:

```
def main():  
    # TODO write your solution here  
    height=input("Enter your height in meters: ")  
    if height < 1.6:  
        print("Below minimum astronaut height")  
    if height > 1.9:  
        print("Above maximum astronaut height")  
    if height >= 1.6 and height <= 1.9:  
        print("Correct height to be an astronaut")  
  
if __name__ == "__main__":  
    main()
```

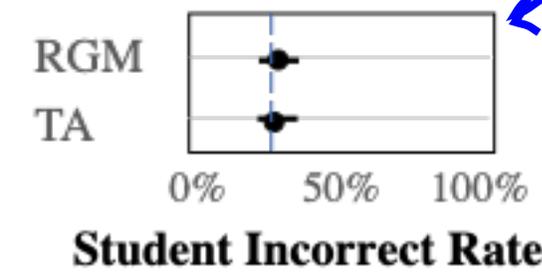
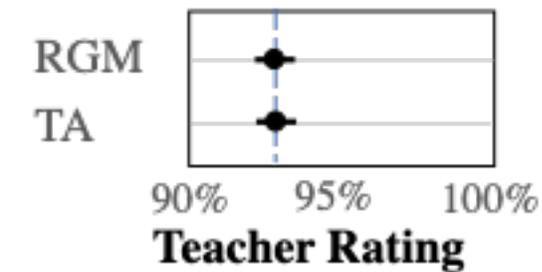
Annotations with blue arrows point to specific parts of the interface:

- "AI generated feedback" points to the feedback text in the purple box.
- "Students evaluate the feedback" points to the thumbs-up and thumbs-down icons.
- "Algorithm uses attention to highlight where in the code the error comes from" points to the highlighted line `height=input("Enter your height in meters: ")`.
- "Syntax error (missing ") here would prevent auto graders from being useful." points to the closing quote in the `main()` function call.

Impact and Fairness Analysis (work in progress)



calibration



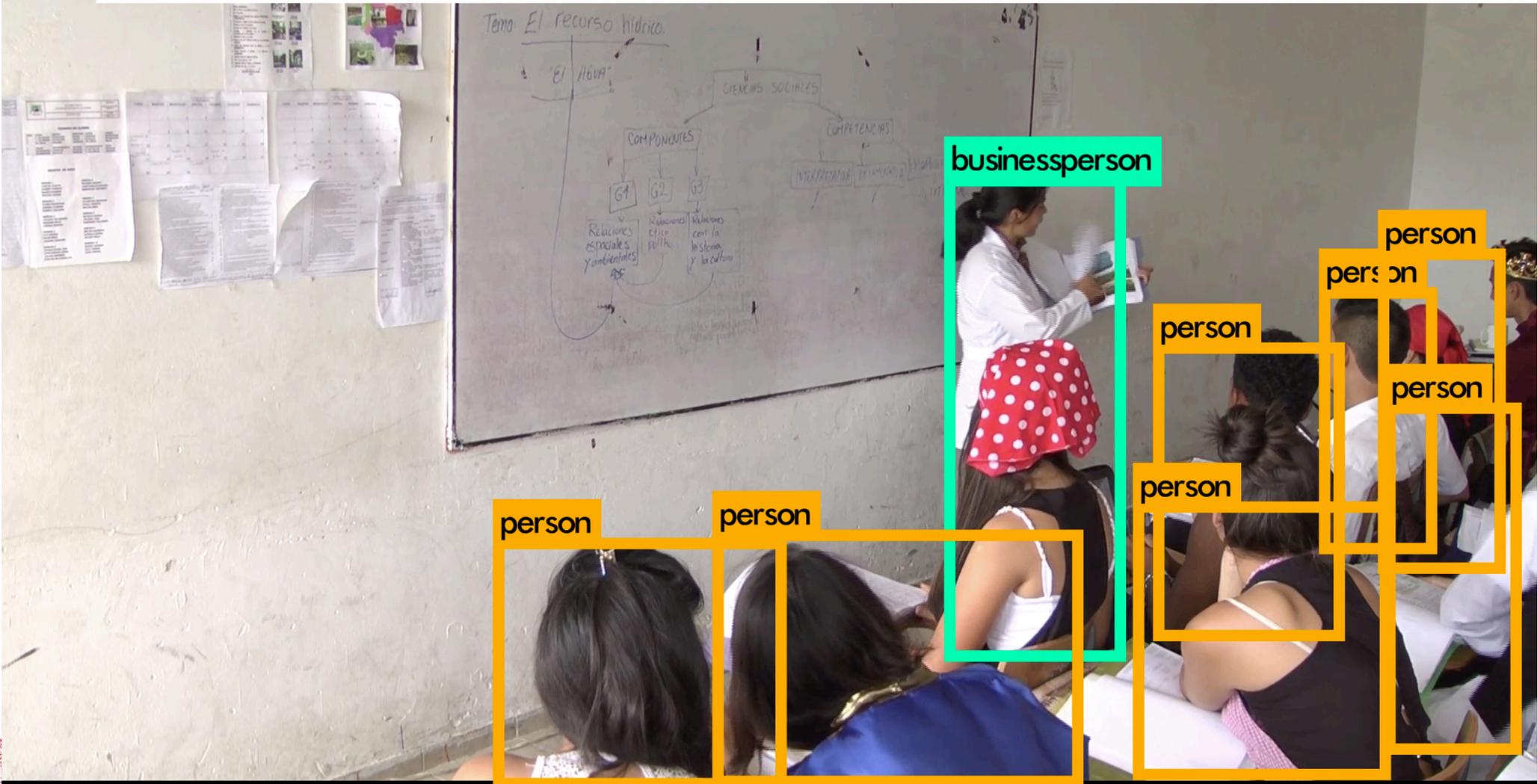
Towards parity??



That is just one example:
New problems

Feedback for Teachers

200,000 videos of teachers in Colombia, Chile and USA teaching



AI Teacher Training

1

Record Class



2

**Transcribe & Anonymize
Recording**



3

**Analyze
Transcripts**



4

**Generate
Insights**



Causal impact of AI teacher Training

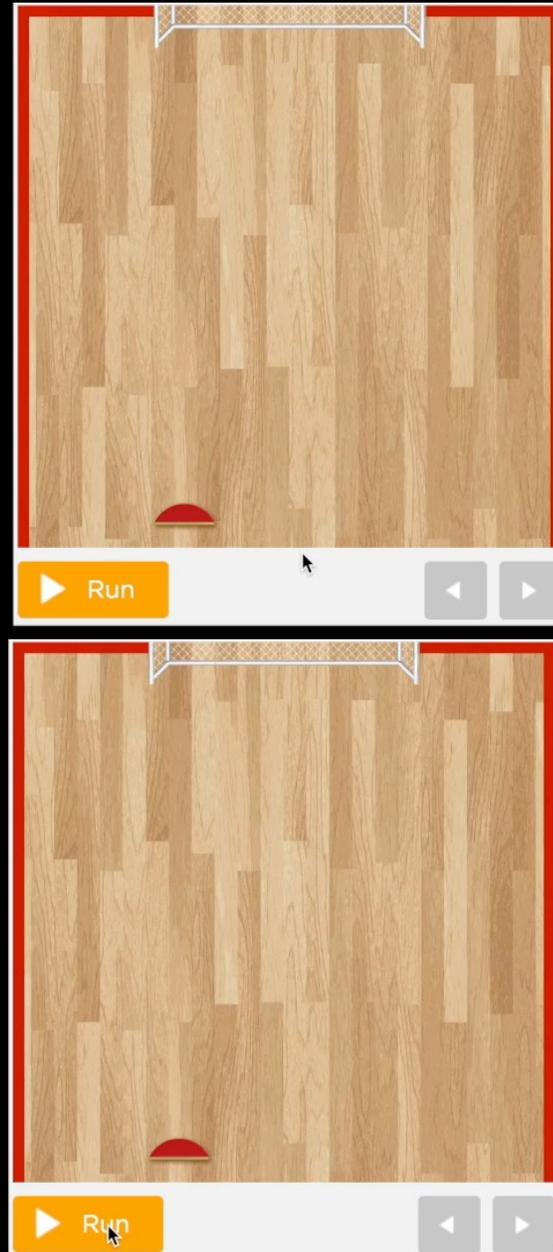
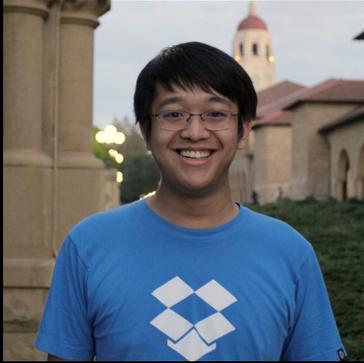
Within 4 lessons, as a result of training

1. Teachers asked 10% **more questions**
2. Teachers “**took up**” student ideas 10% more
3. Students were significantly more likely to:
recommend the class ($p < 0.05$),
find sections helpful ($p < 0.05$)



Play 2 Grade

Allen Nie



Problem:

Grade the ~1M unique student implementations of this problem on code.org

Input:

Teacher gives you one example of each mistake on their rubric and one example of invariances

Theory contribution:

First model to build deep RL for a classification task . *Instead of learning an environment you are learning to test an environment*

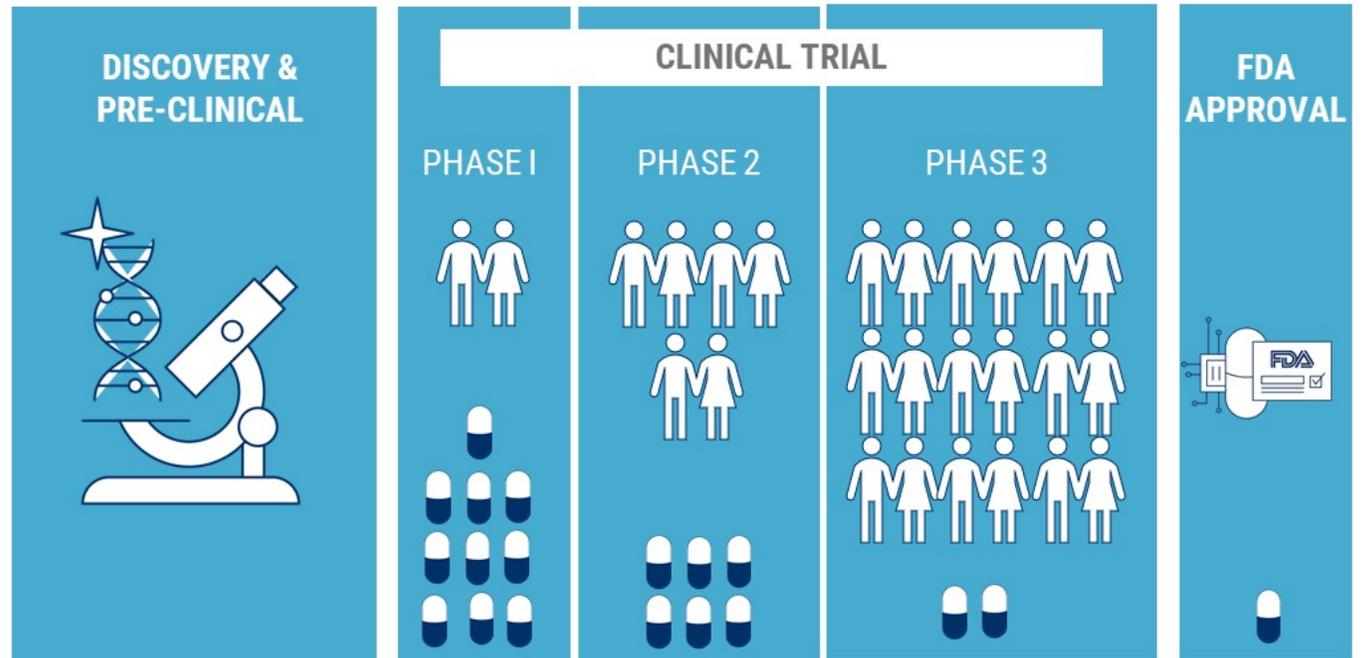
Impact:

Immediately change what sort of assignments are auto-gradable



More than education

 Bringing a drug to market is a drawn-out process



Source: cbinsights.com

 CBINSIGHTS

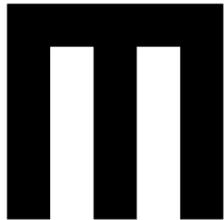


More than education

Vision Test

myeyes.ai/measure

Left Eye



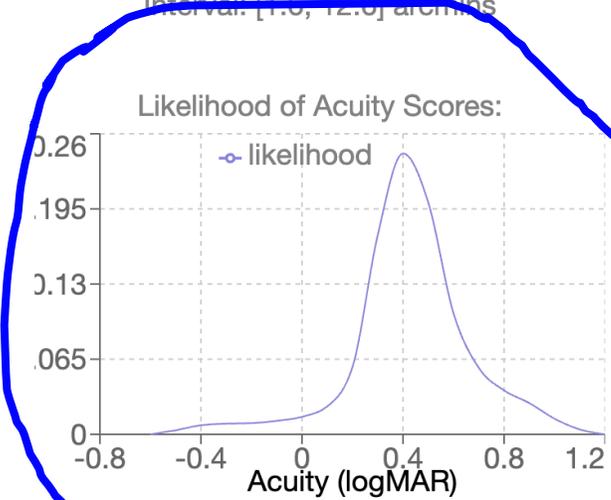
Featured in
THE LANCET

Progress: 10%

StAT Algorithm

N done: 2
Curr size: 3.3 arcmin
Curr size: 0.5 logMAR
MAP acuity: 2.5 arcmin
MAP acuity: 0.4 logMAR
Interval: [1.0, 12.0] arcmins

Likelihood of Acuity Scores:



Acuity (logMAR)	Likelihood
-0.8	0.00
-0.4	0.01
0.0	0.05
0.4	0.26
0.8	0.05
1.2	0.00



What else should be a **random variable**?

Grades??

Application -> Theory

Understand social science,
especially with small data

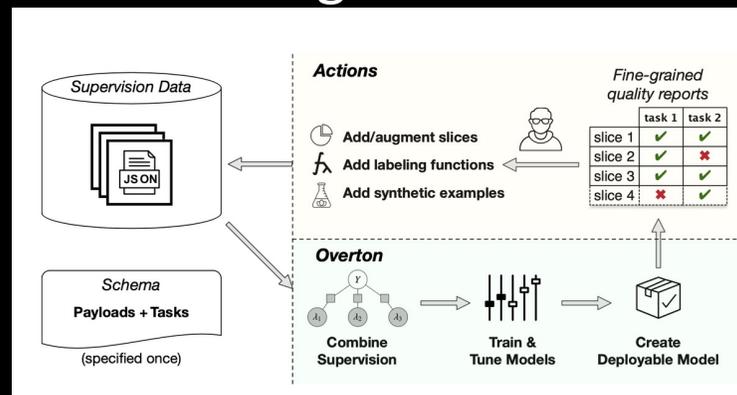
Explain why it made the
choices it did

What are things that AI
currently can't do?

Teach humans based on
what it has learned

Understand language

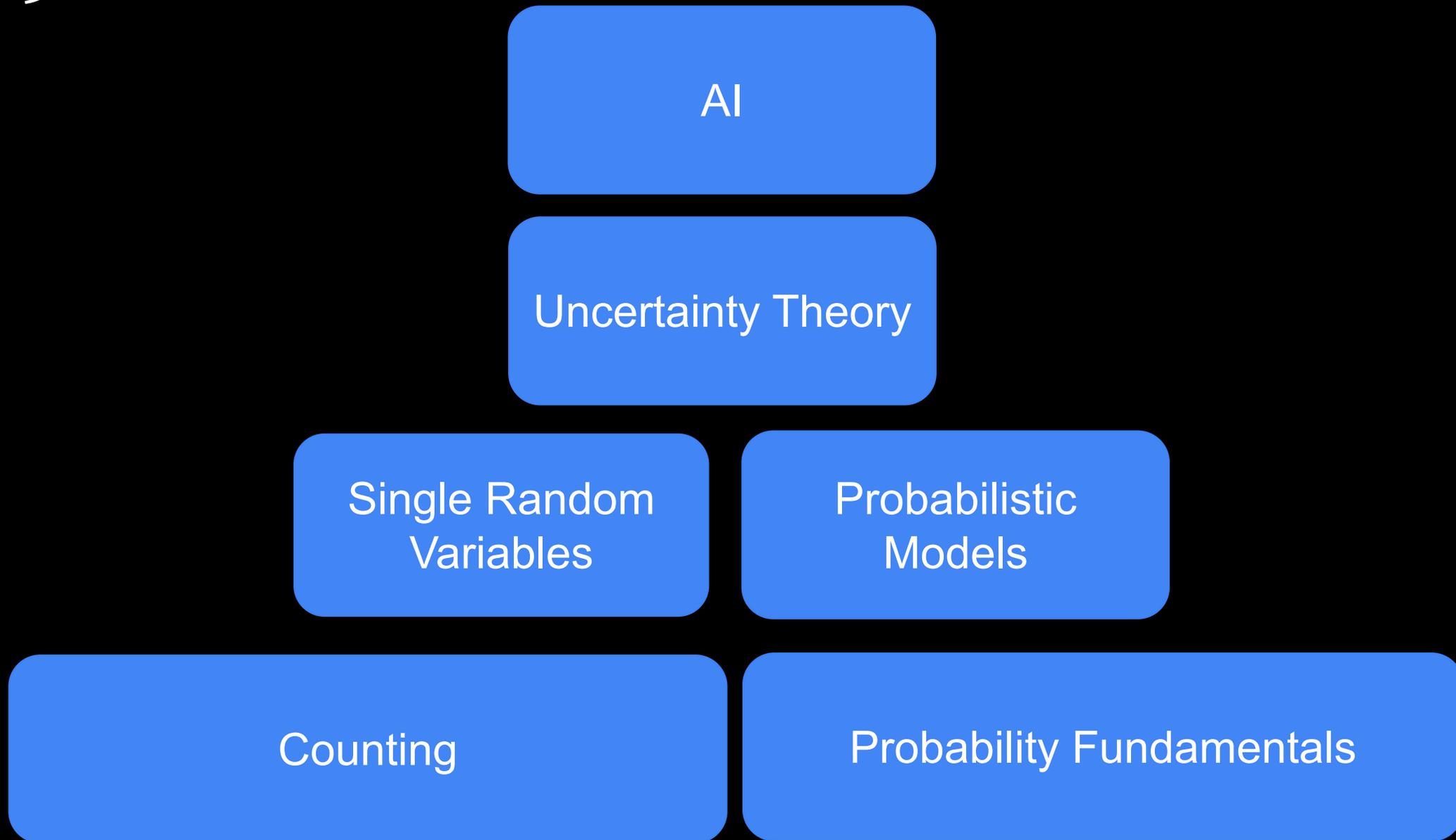
Design itself



Learning Goal: Abundance of important problems

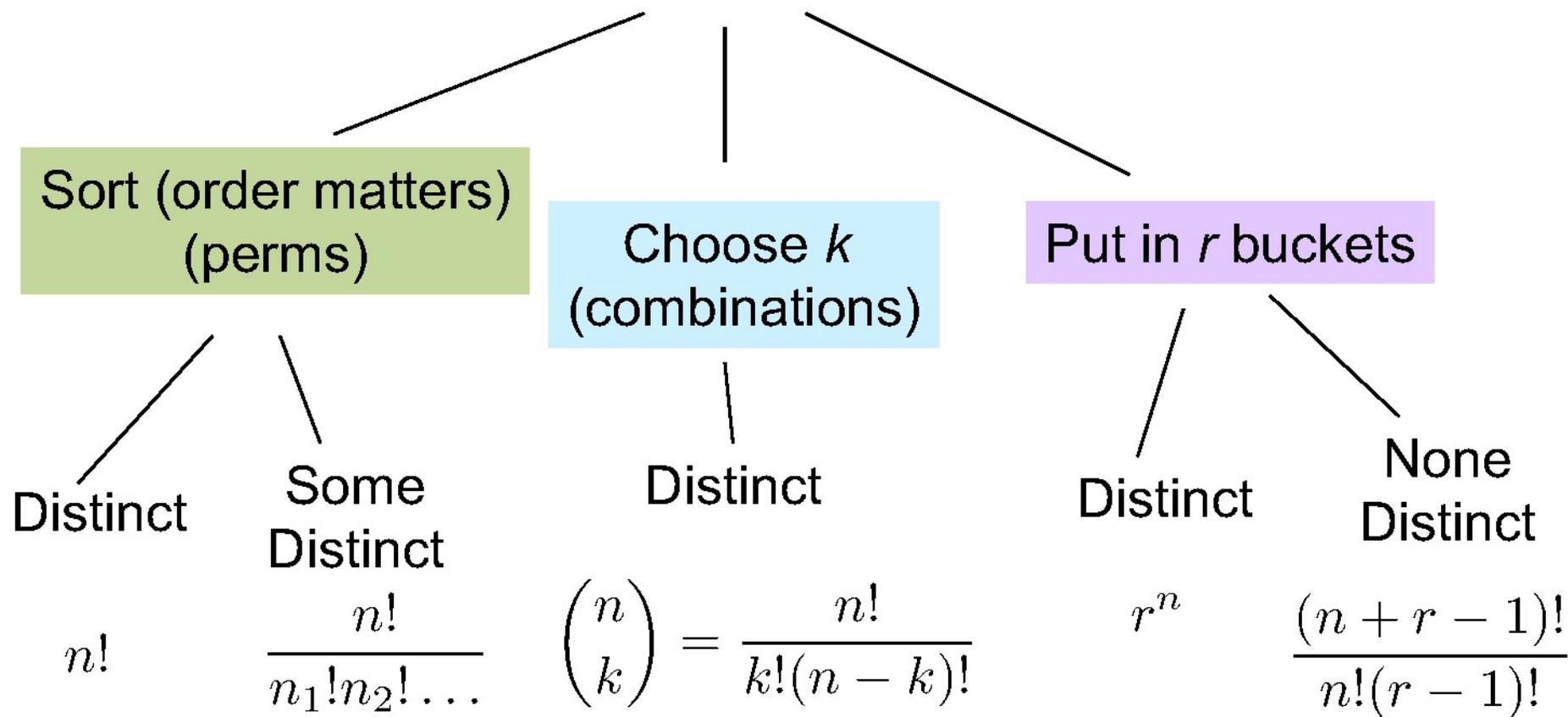


Last Class...



Counting Rules

Counting operations on n objects



Counting



Ayesha



Tim



Irina



Joey



Waddie



COURSE VALUES

Everyone is welcome.
Intellectual joy. Be kind. Be humane. Social connection.
Learn by doing. Thrill of building. Adapt to new contexts. Especially in a hard time 🦠.



WHEN YOU MEET YOUR BEST FRIEND

Somewhere you didn't expect to.



Trailing the dovetail shuffle to it's lair – Persi Diaconosis

What is a Probability?

$$P(E) = \lim_{n \rightarrow \infty} \frac{n(E)}{n}$$



Netflix and Learn

$$P(E|F) = \frac{P(EF)}{P(F)}$$

Definition of
Cond. Probability

- Let E be the event that a user watches the given movie.
- Let F be the event that the same user watches CODA (2021).



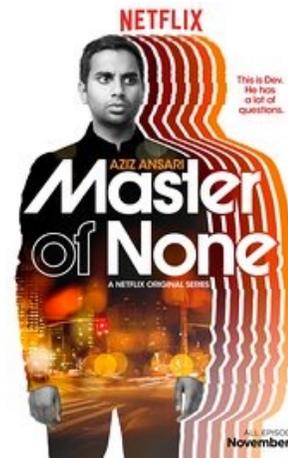
$$P(E) = 0.19$$

$$P(E|F) = 0.14$$



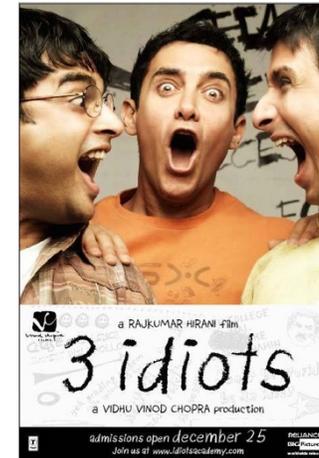
$$P(E) = 0.32$$

$$P(E|F) = 0.35$$



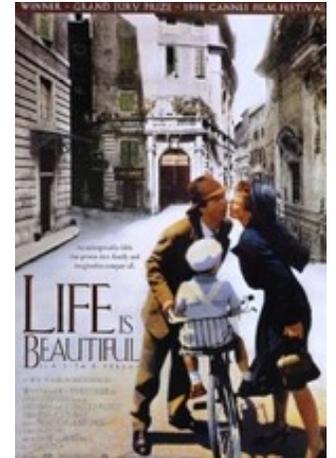
$$P(E) = 0.20$$

$$P(E|F) = 0.20$$



$$P(E) = 0.09$$

$$P(E|F) = 0.72$$



$$P(E) = 0.20$$

$$P(E|F) = 0.42$$

Monty Hall Problem

and Wayne Brady



Marilyn discovers the
Probability Bug

Zika Test



Positive Zika.

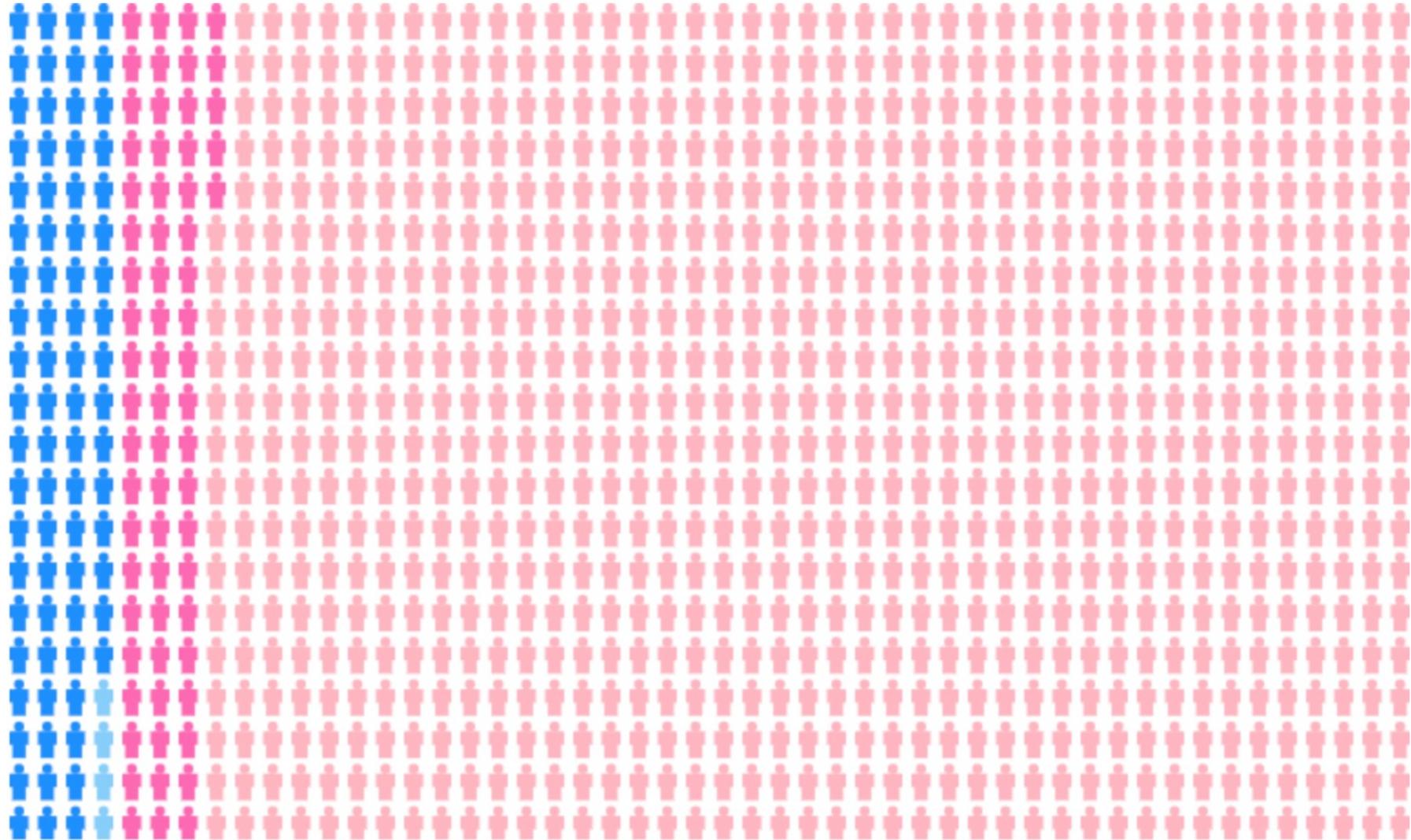
What is the probability of zika?

-
- *0.1% of people have zika*
 - *90% positive rate for people with zika*
 - *7% positive rate for people without zika*

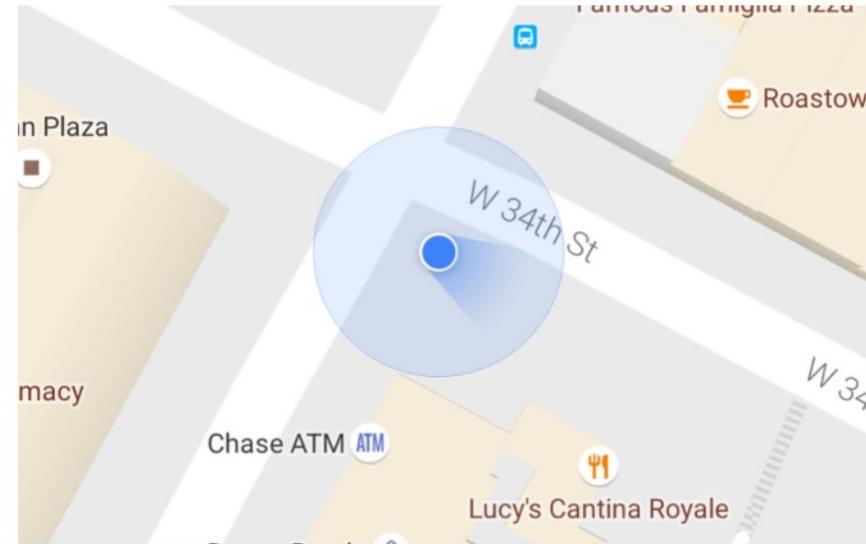
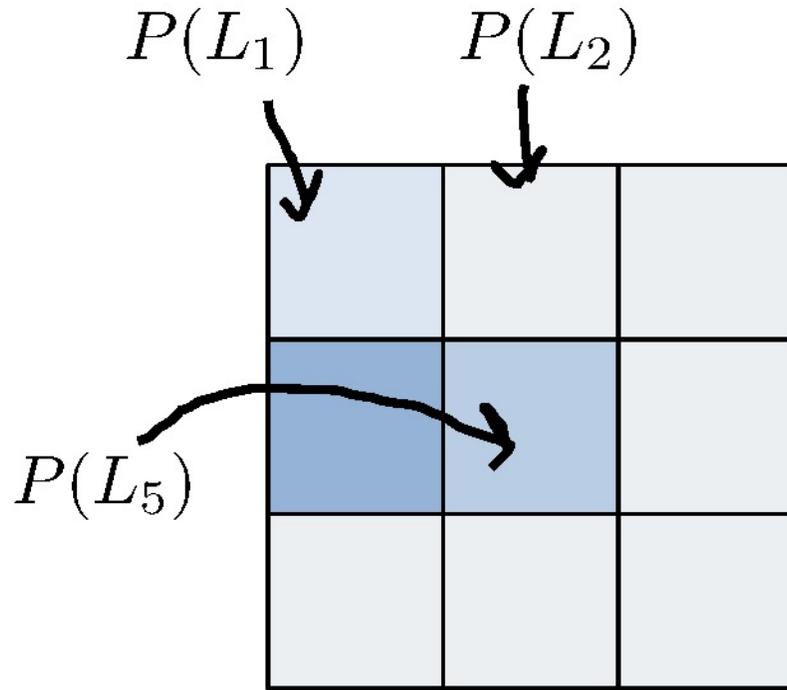
The right answer is 1%



Bayes Theorem Intuition



Update Belief



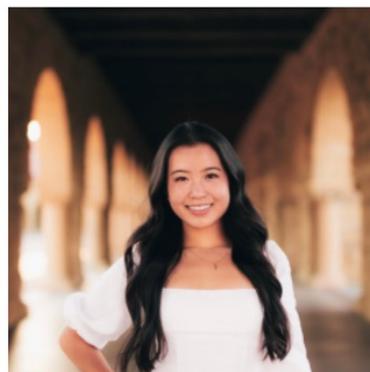
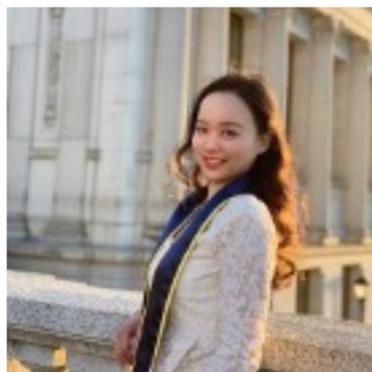
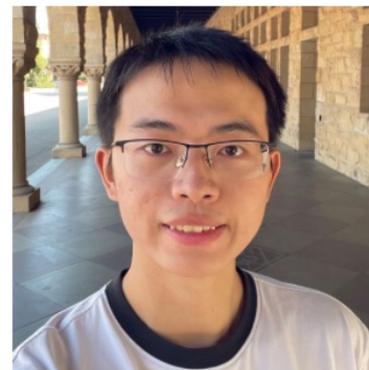
Before Observation



Recall our Ebola Bats



Sections and Office Hours with your TA



Third Year of Sections



I'm not a robot


reCAPTCHA
[Privacy - Terms](#)

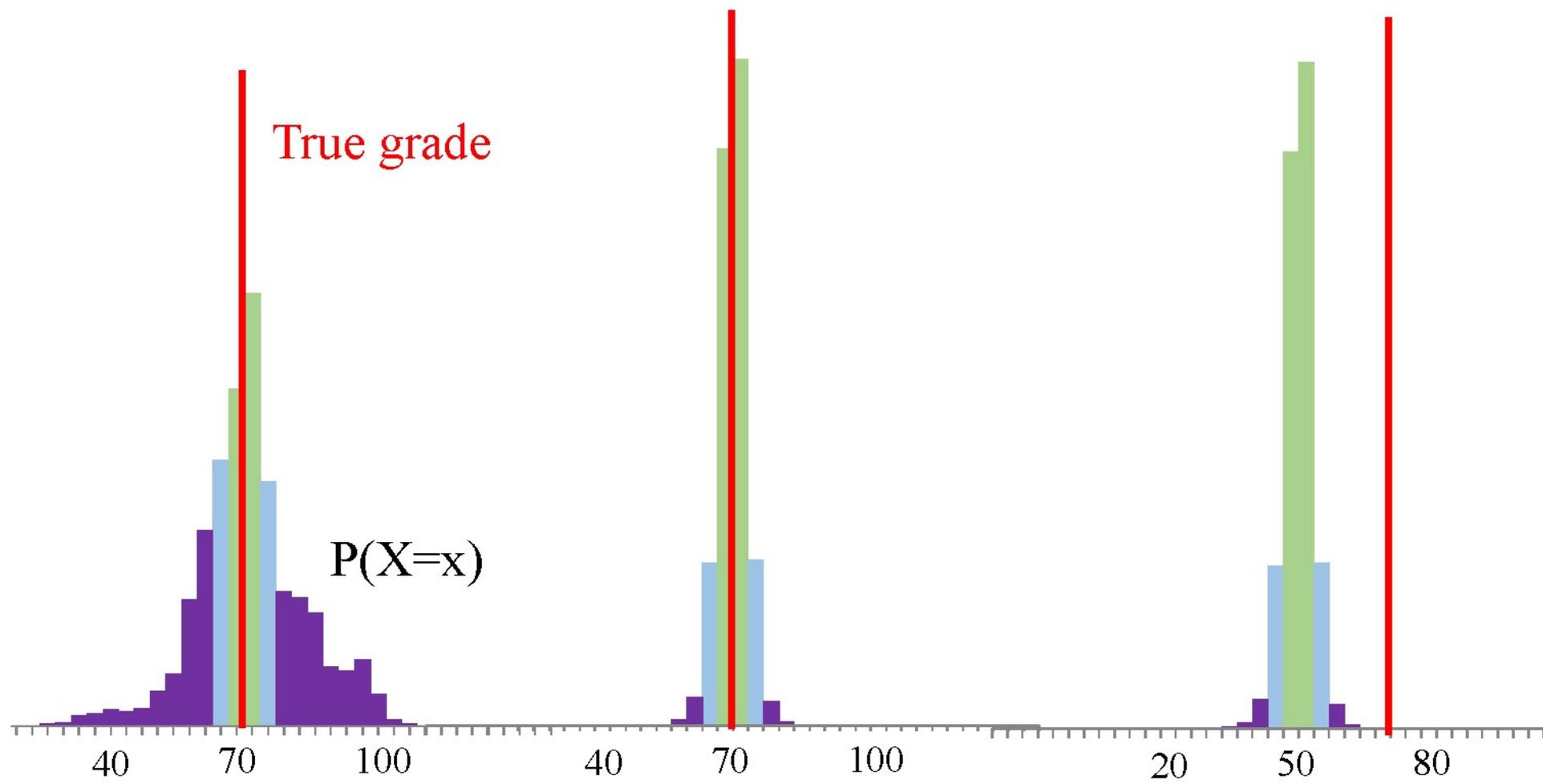


X		O
O	X	
		X



Random Variables

X is the score a peer grader gives to an assignment submission

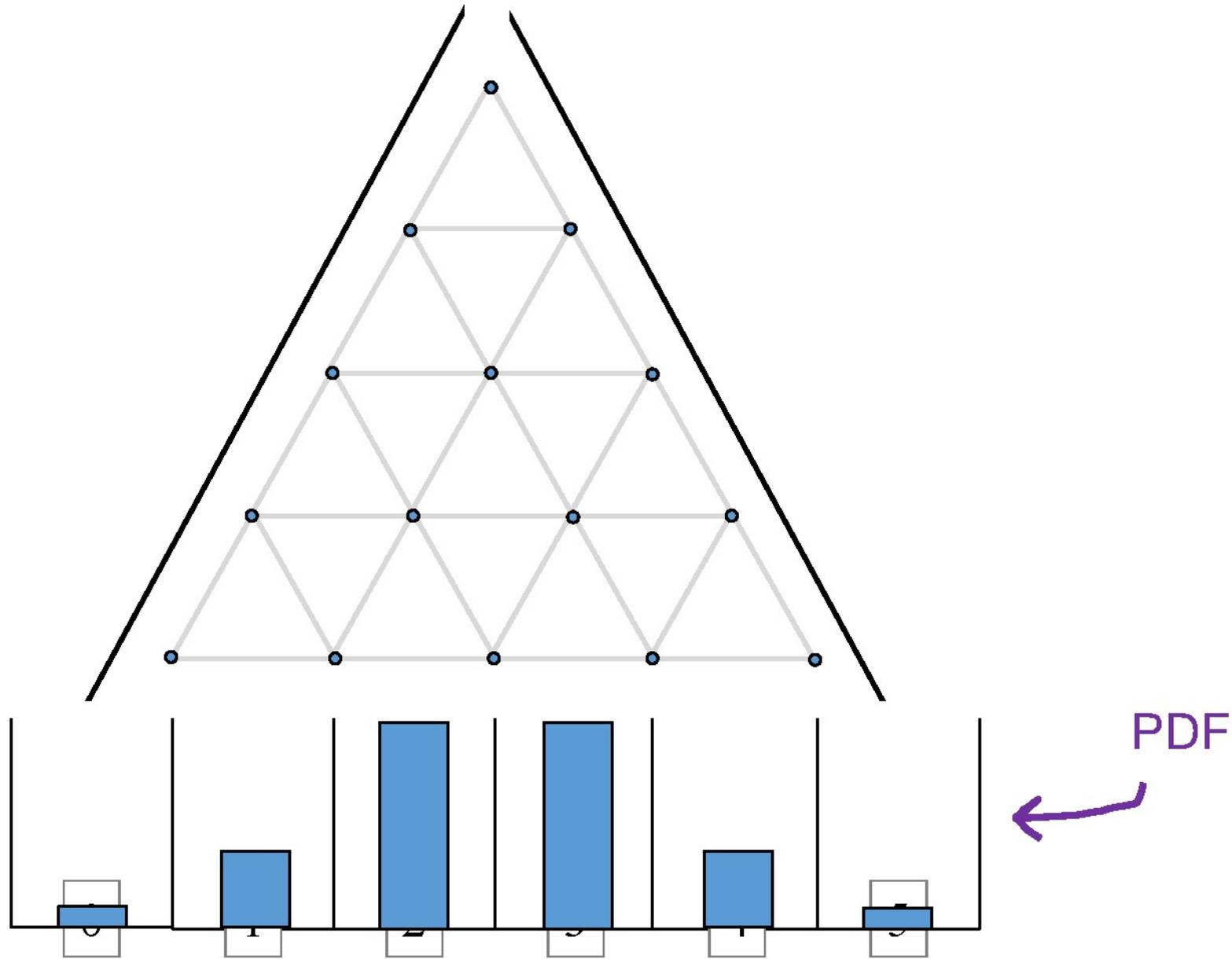


A

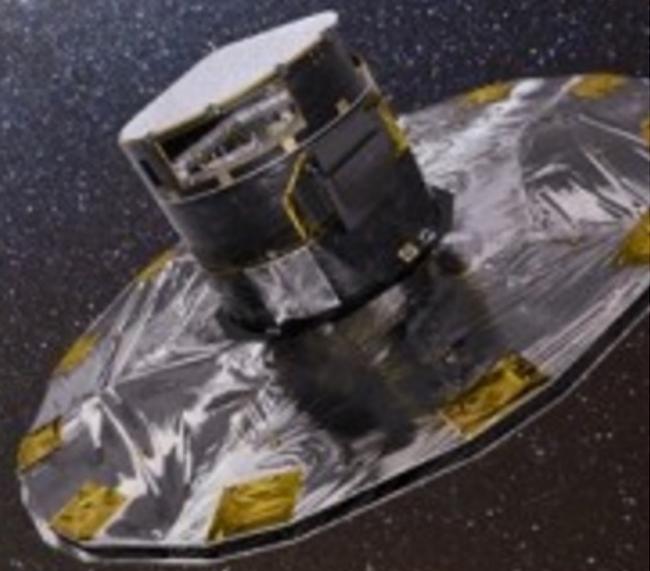
B

C

Binomial



1001

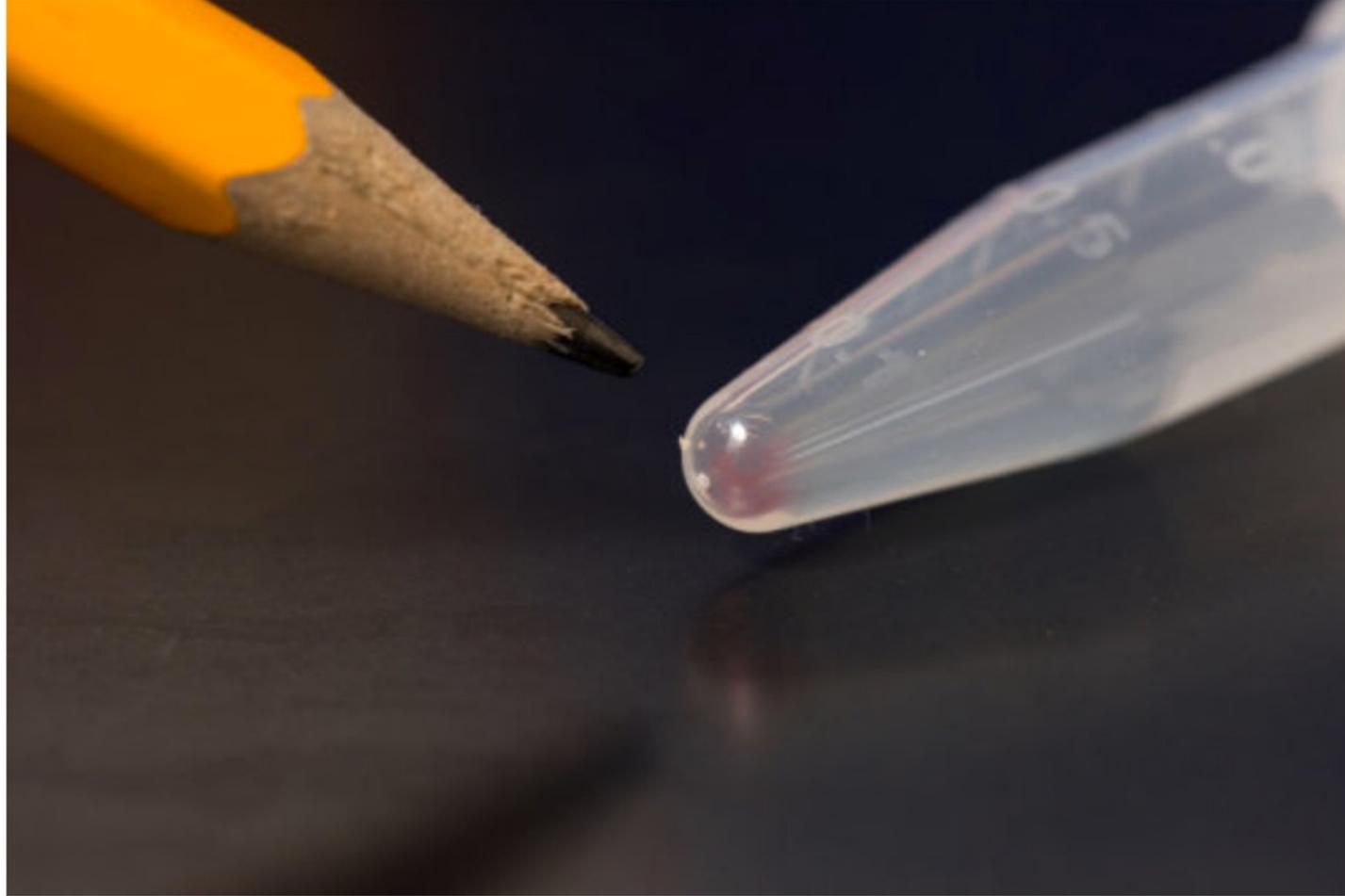


Geometric

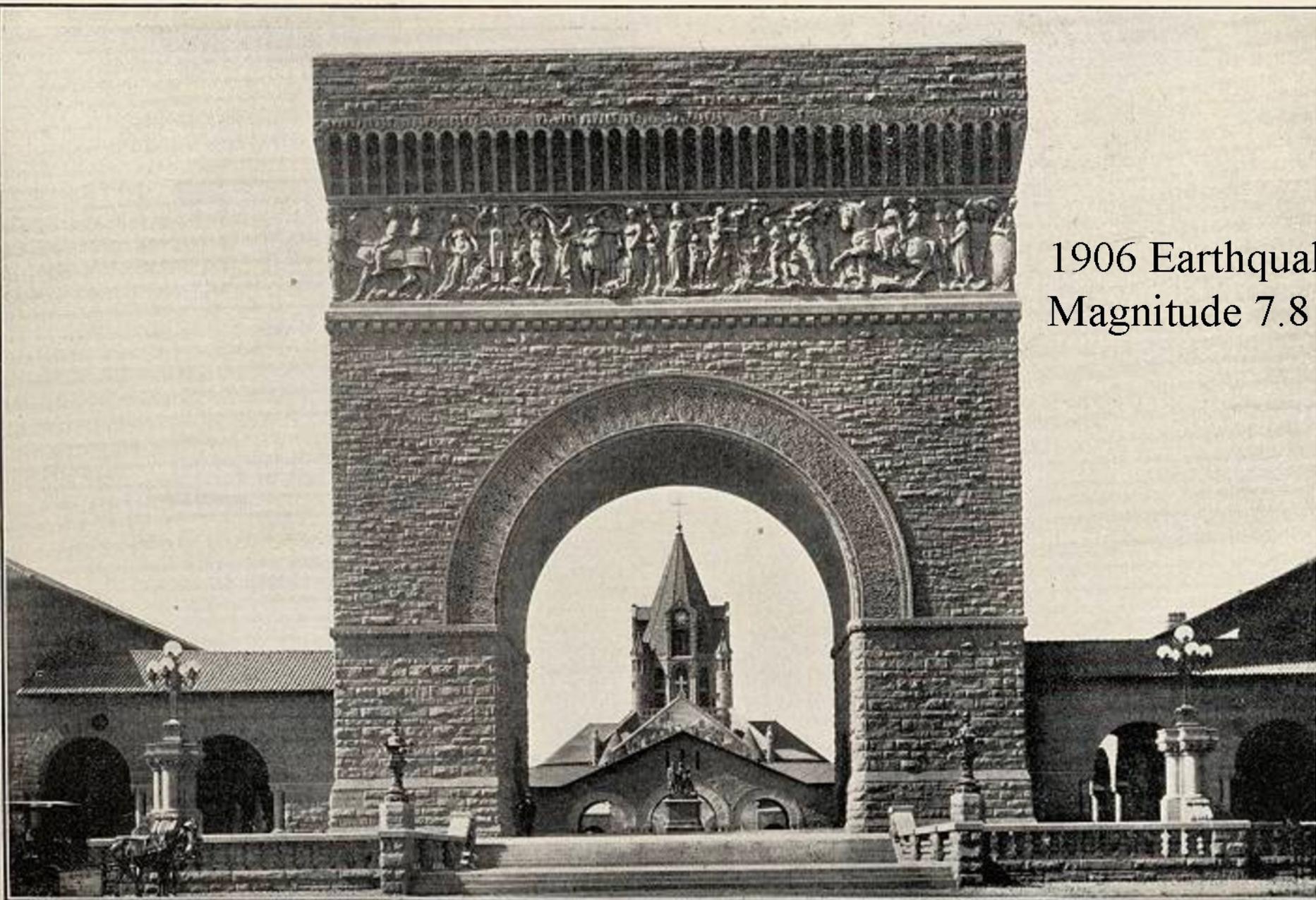
Sequence 1:

TTHTHTTTHTTTHTTTHTTTHTTHTHTT
HTTHTTTHHTHTHTTHTTHTTHTTHTT
HTHTHTHTHTTHTTHTTHTHTHTHTTHT
TTHTHTTHTHTHTHTHTHTHTHTHTHTT
TTHTHTHTHTHTHTTHTTHTTHTTHTHTT

Storing Data on DNA



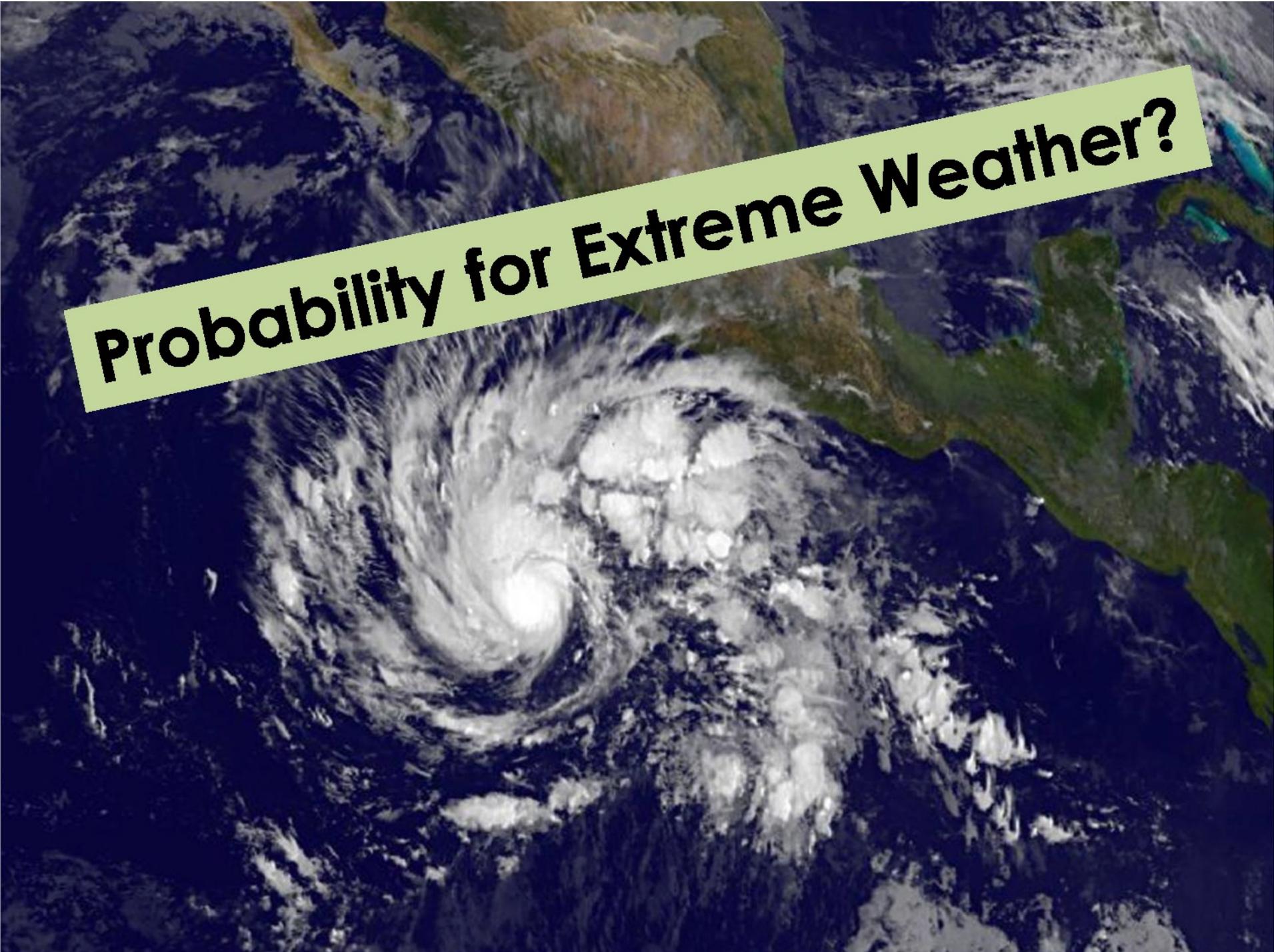
All the movies, images, emails and other digital data from more than 600 smartphones (10,000 gigabytes) can be stored in the faint pink smear of DNA at the end of this test tube.



1906 Earthquake
Magnitude 7.8

ILL. No. 65. MEMORIAL ARCH, WITH CHURCH IN BACKGROUND, STANFORD UNIVERSITY, SHOWING TYPES OF CARVED WORK WITH THE SANDSTONE.

Probability for Extreme Weather?

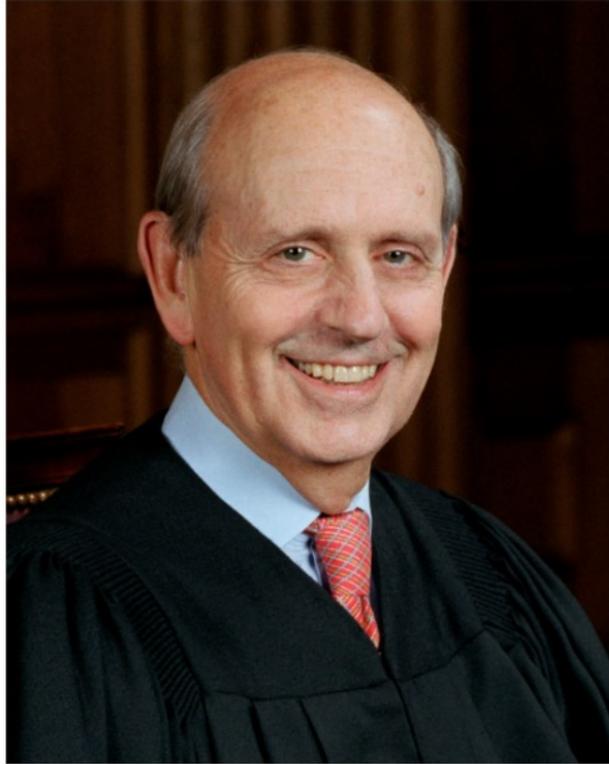


Bit Coin Mining

You “mine a bitcoin” if, for given data D , you find a number N such that $\text{Hash}(D, N)$ produces a string that starts with g zeroes.

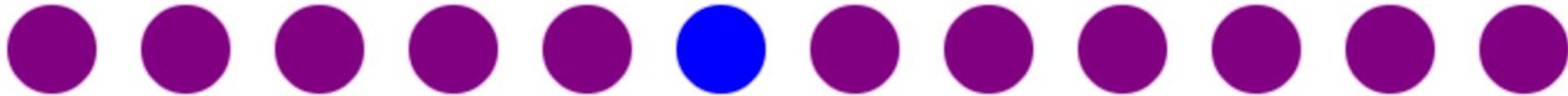


Representative Juries



Simulate

Simulation:

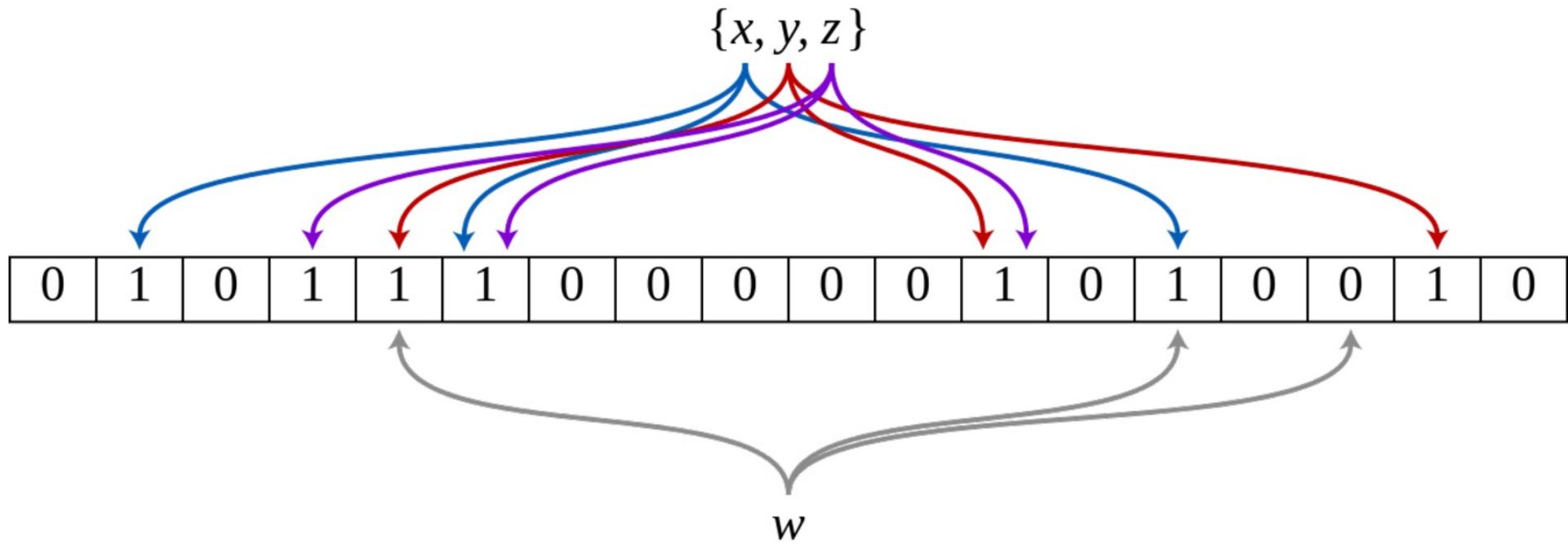


Dating at Stanford

Each person you date has a 0.2 probability of being someone you spend your life with. What is the average number of people one will date? What is the standard deviation?



Bloom Filter



random() ?

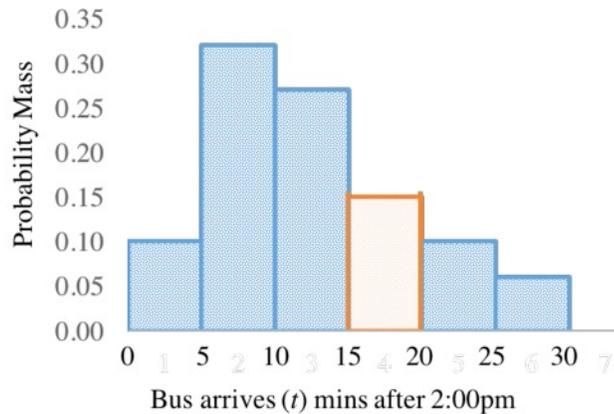
Riding the Marguerite



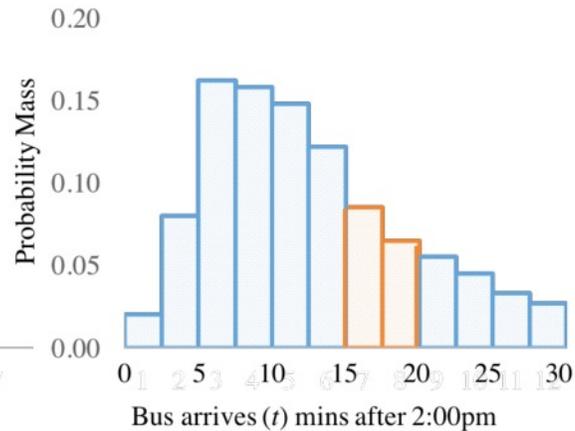
You are running to the bus stop.
You don't know exactly when
the bus arrives. You arrive at
2:20pm.

What is $P(\text{wait} < 5 \text{ min})$?

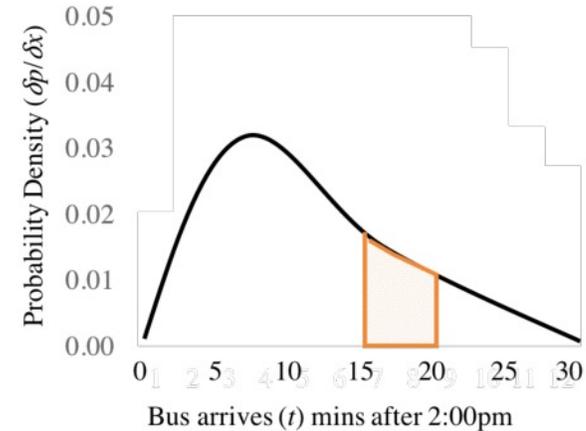
Discretize into 5 min chunks



Discretize into 2.5 min chunks



The limit at discretization size $\rightarrow 0$



Integrals

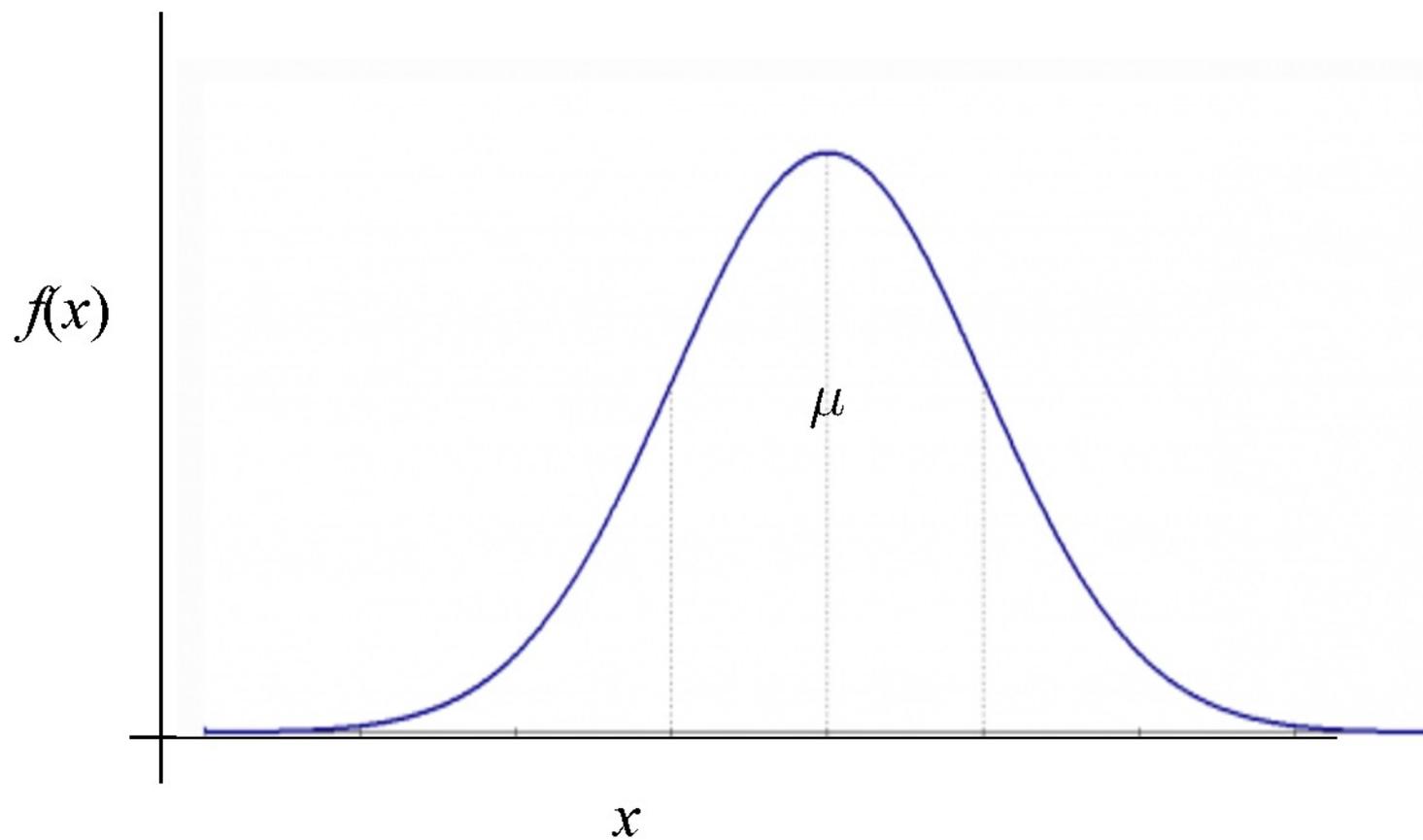


*loving, not scary

Probability Density Function

$$\mathcal{N}(\mu, \sigma^2)$$

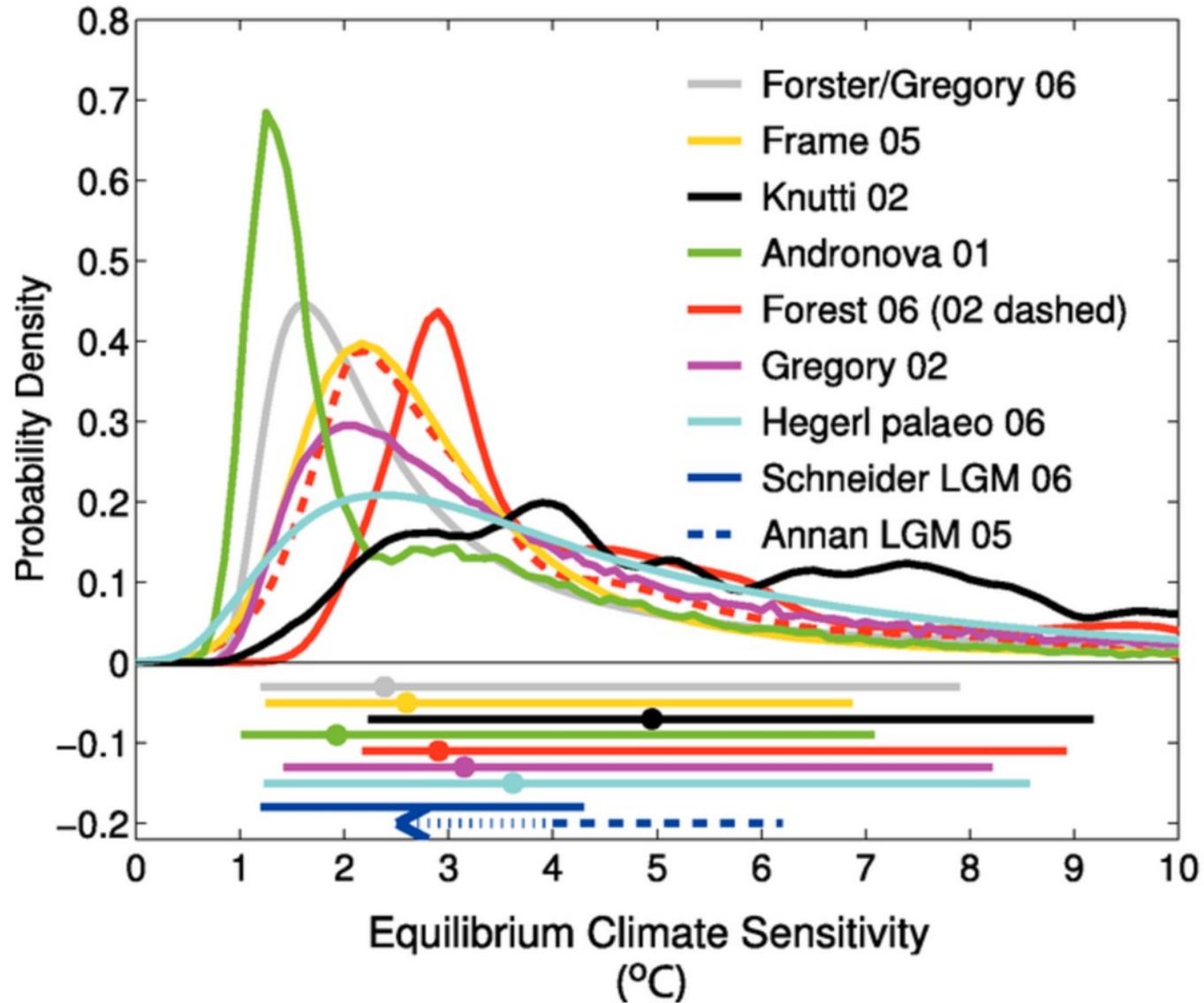
$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(x-\mu)^2}{2\sigma^2}}$$



What do you get if you
integrate over a
probability density function?

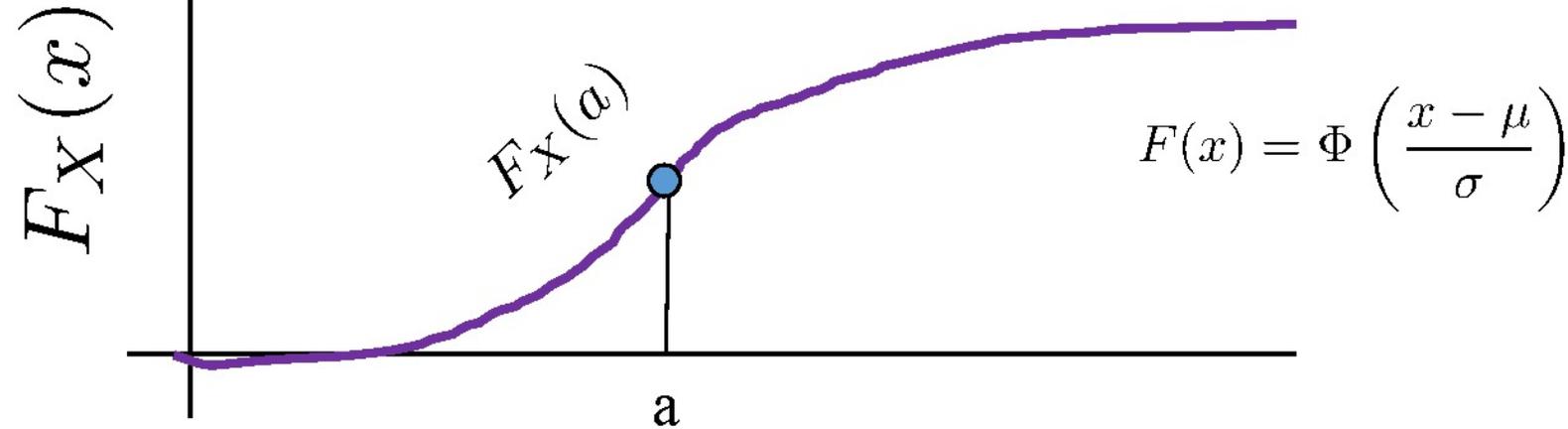
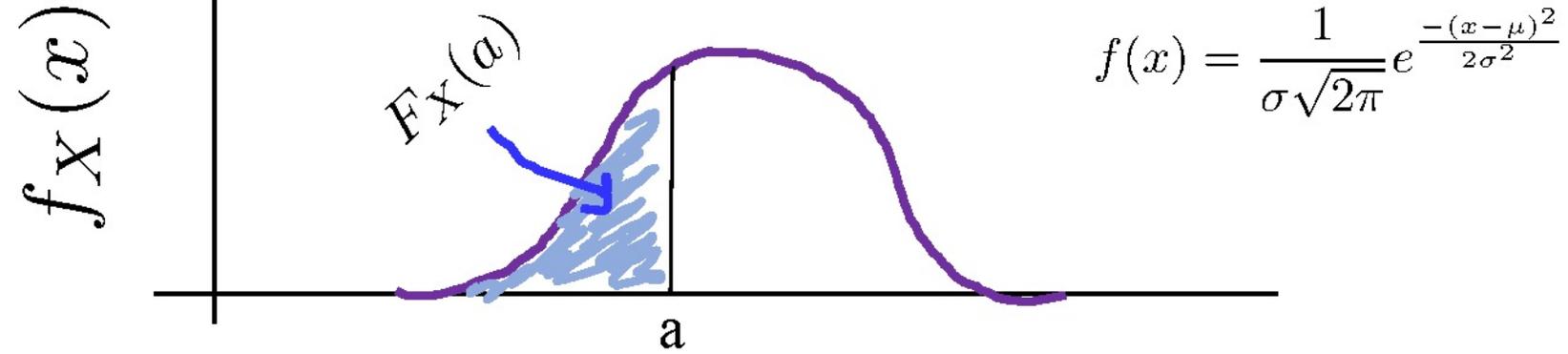
A probability!

Climate Sensitivity



PDF and CDF of a Normal

$$X \sim N(\mu, \sigma^2)$$



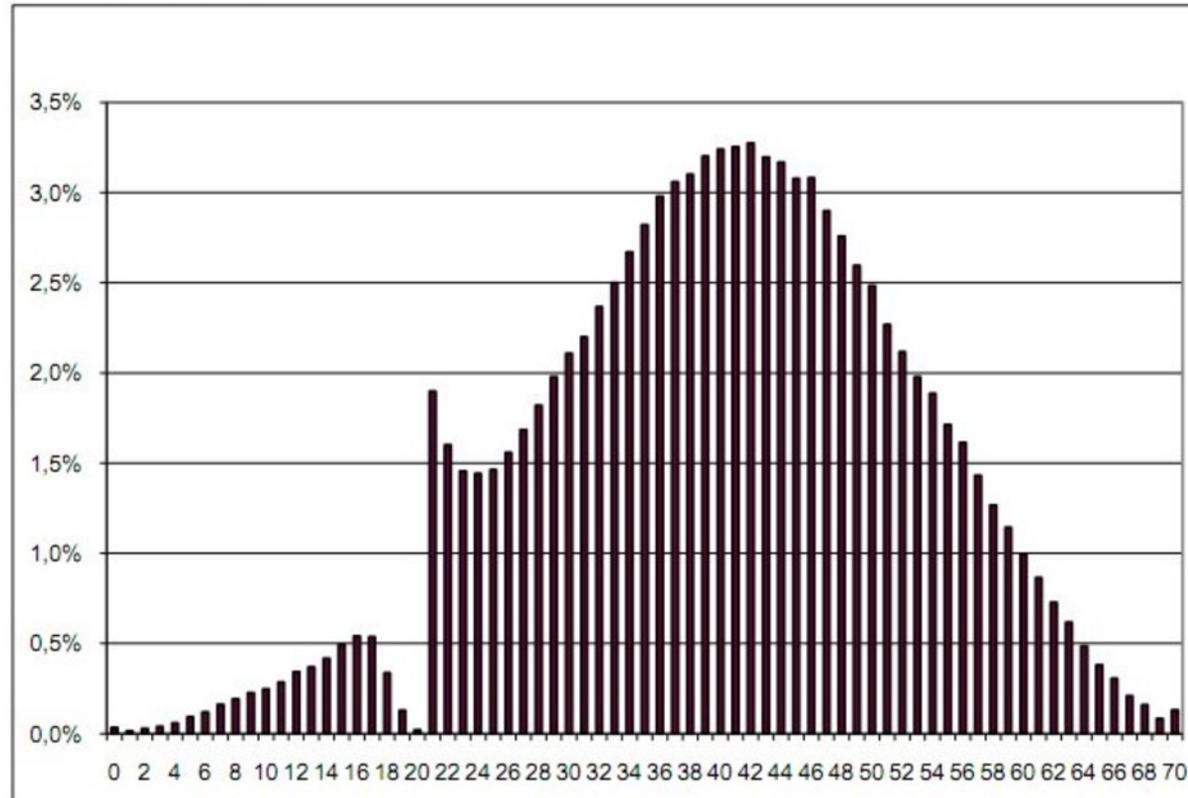
A CDF is the integral from $-\infty$ to x of the PDF

Altruism?

Scores for a standardized test that students in Poland are required to pass before moving on in school

See if you can guess the minimum score to pass the test.

2.1. Poziom podstawowy



Wykres 1. Rozkład wyników na poziomie podstawowym

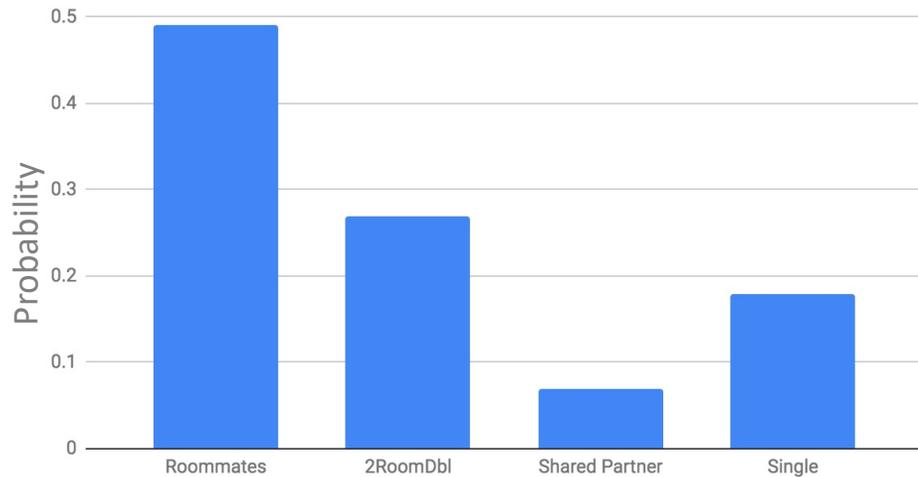
Probabilistic Models



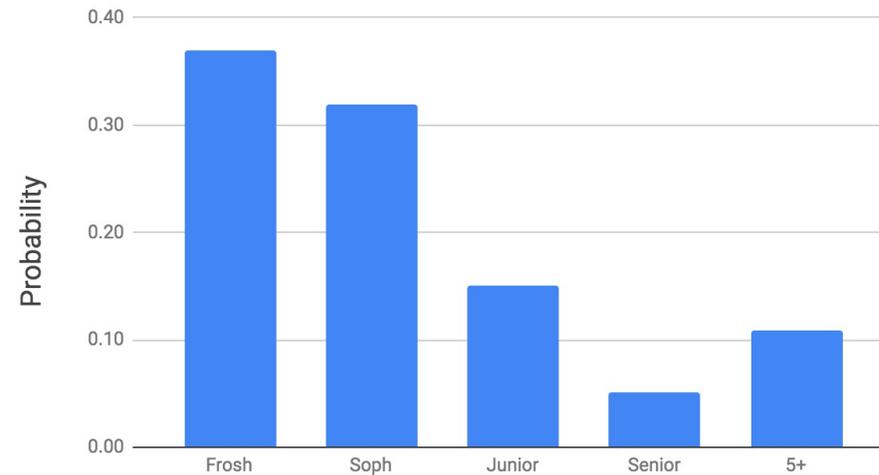
Joint Probability Table

	Roommates	2RoomDbl	Shared Partner	Single	
Frosh	0.30	0.07	0.00	0.00	0.37
Soph	0.12	0.18	0.00	0.03	0.32
Junior	0.04	0.01	0.00	0.10	0.15
Senior	0.01	0.02	0.02	0.01	0.05
5+	0.02	0.00	0.05	0.04	0.11
	0.49	0.27	0.07	0.18	1.00

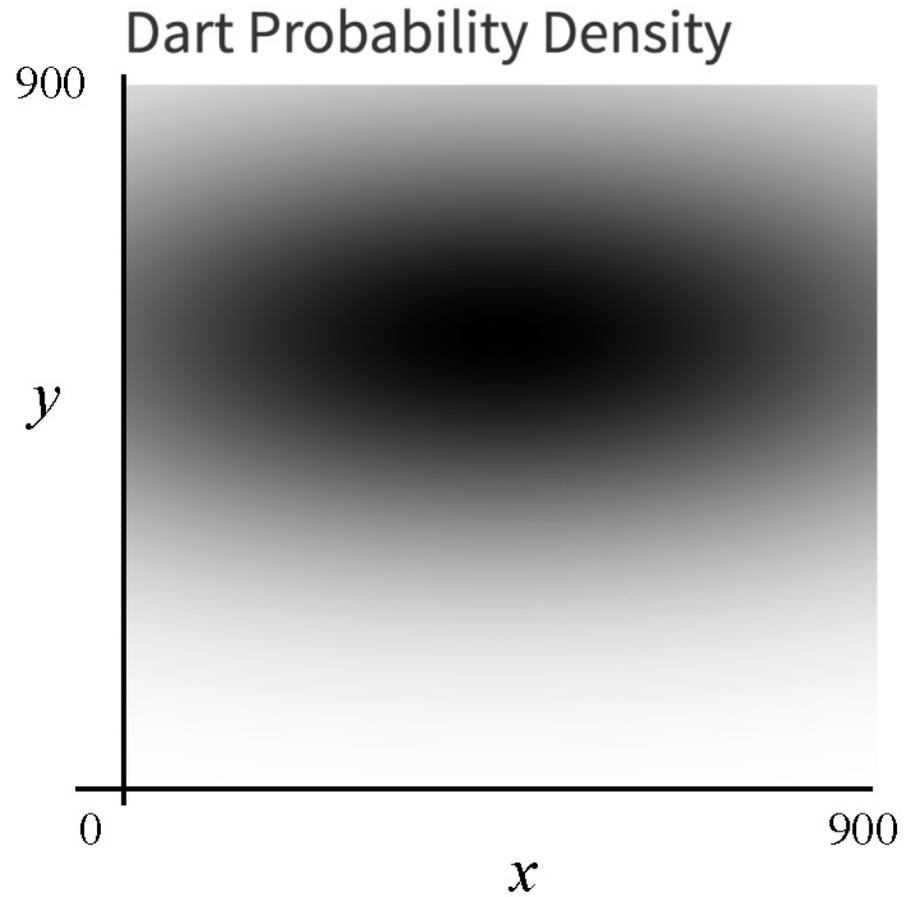
Marginal Room type



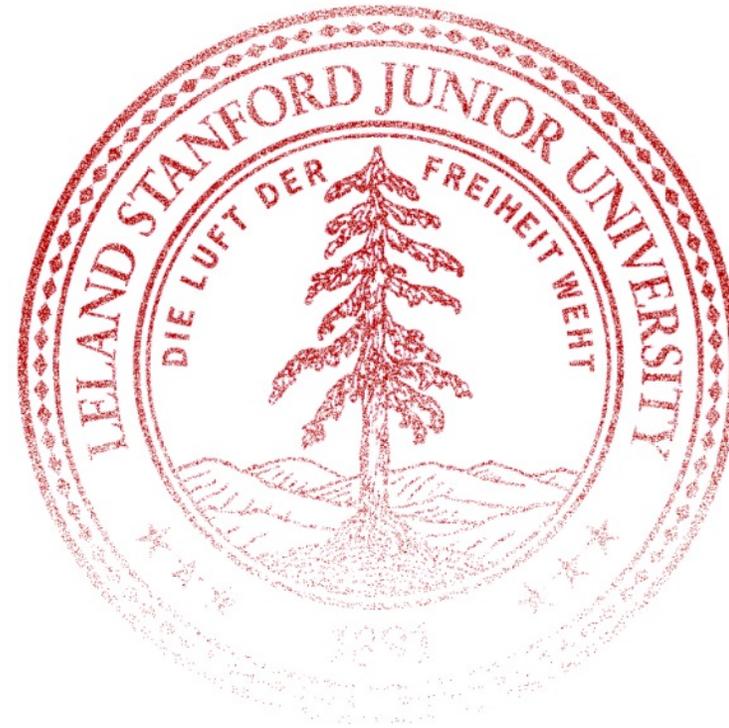
Marginal Year



Joint Dart Distribution



Dart Results



Multinomial

Example document:

“Pay for Viagra with a credit-card. Viagra is great.
So are credit-cards. Risk free Viagra. Click for free.”

$n = 18$

$$P \left(\begin{array}{l} \text{Viagra} = 2 \\ \text{Free} = 2 \\ \text{Risk} = 1 \\ \text{Credit-card: } 2 \\ \dots \\ \text{For} = 2 \end{array} \middle| \text{spam} \right) = \frac{n!}{2!2! \dots 2!} p_{\text{viagra}}^2 p_{\text{free}}^2 \dots p_{\text{for}}^2$$

It's a Multinomial!

Probability of seeing
this document | spam

The probability of a word in
spam email being viagra



General “Inference”



General “Inference”

WebMD Symptom Checker BETA

INFO SYMPTOMS QUESTIONS CONDITIONS DETAILS TREATMENT

Add more symptoms

Type your main symptom here

or Choose common symptoms

bloating cough diarrhea dizziness fatigue

fever headache muscle cramp nausea

throat irritation

AGE 30 GENDER Male

MY SYMPTOMS

cough × throat irritation ×

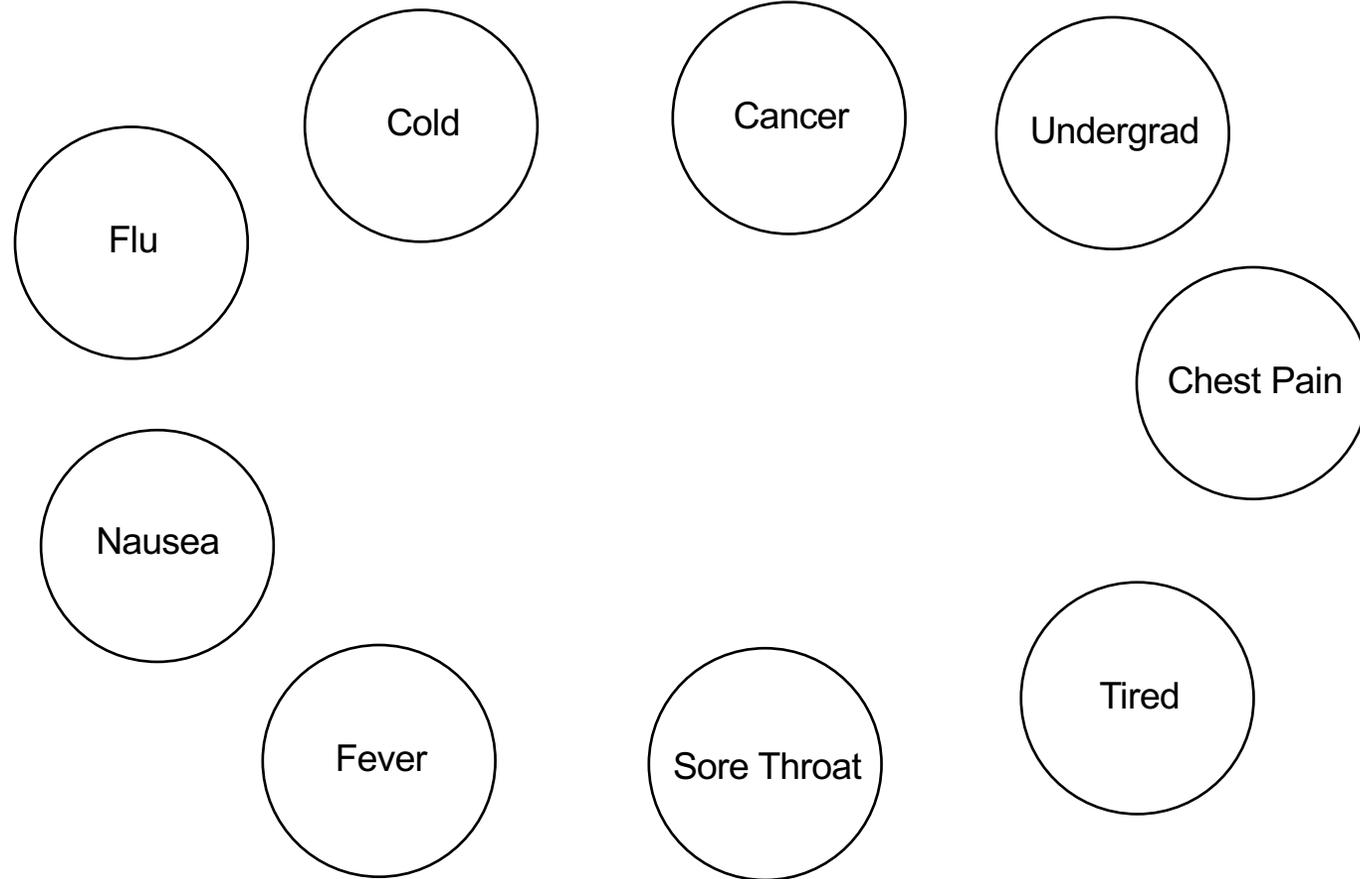
sneezing ×

Results Strength: MODERATE

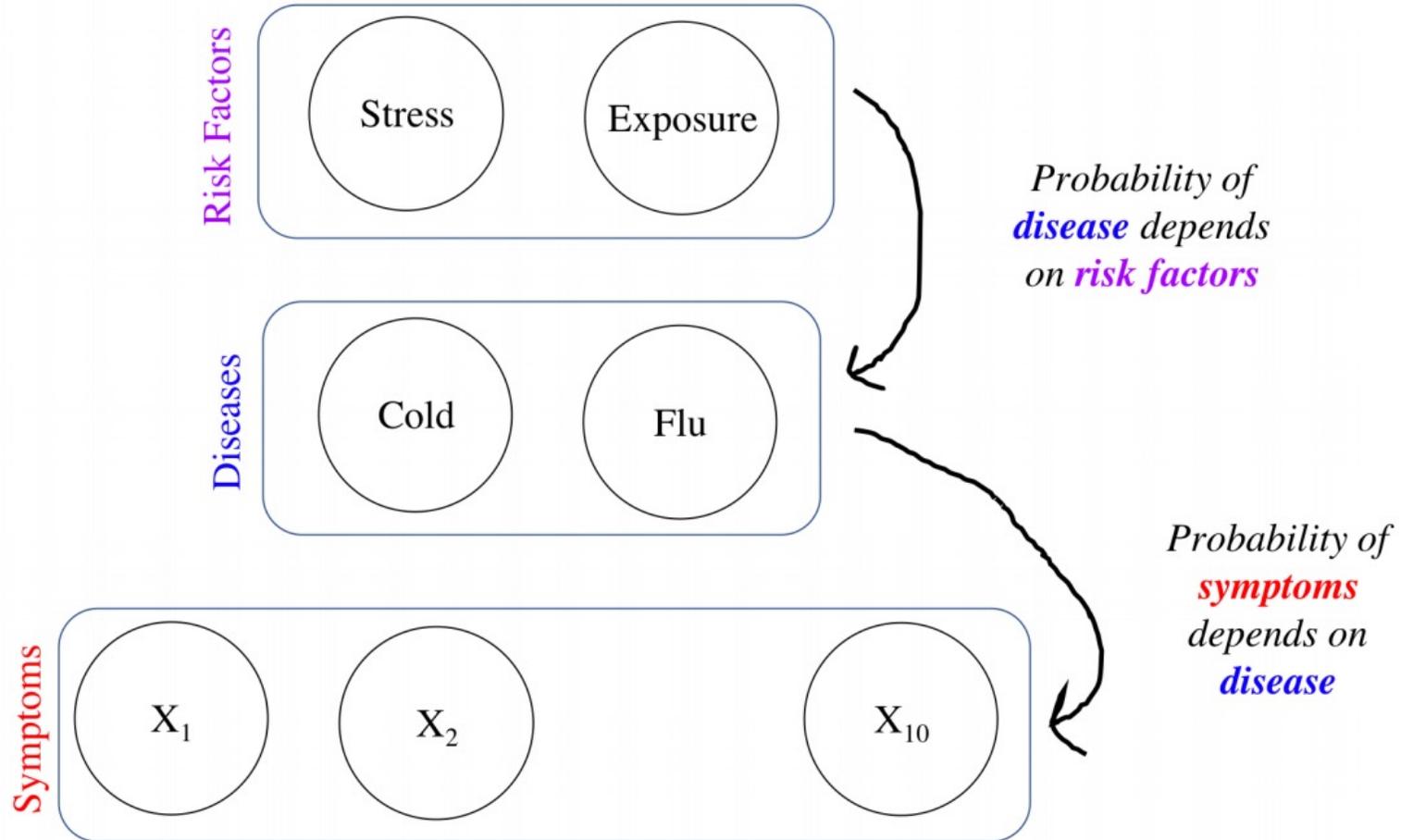
< Previous

Info Continue >

Lots of Random Vars?



Bayes Nets!

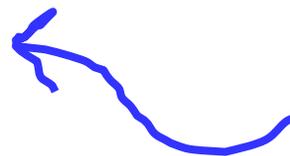


Alg #1: Rejection Sampling

```
3 N_SAMPLES = 100000
4
5 # Program: Joint Sa
6 # -----
7 # we can answer any
8 # with multivariate
9 # where conditioned
10 def main():
11     obs = getObserv
12     print 'Observat
13
14     samples = sampl
15     prob = probFluG
16     print 'Pr(Flu)
```

```
[0, 0, 0, 0]
[0, 1, 0, 1]
[1, 0, 1, 0]
[1, 1, 1, 1]
[0, 1, 0, 1]
[0, 1, 0, 0]
[0, 0, 0, 0]
[0, 1, 1, 1]
[0, 1, 0, 0]
[0, 1, 0, 1]
[0, 1, 0, 0]
[0, 1, 0, 1]
[0, 1, 0, 1]
[0, 0, 0, 0]
[1, 1, 1, 1]
[0, 0, 0, 0]
[0, 0, 0, 0]
[1, 1, 1, 1]
[0, 1, 0, 0]
```

Each one of these is
one posterior sample:



[Flu, Ugrad, Fever, Tired]

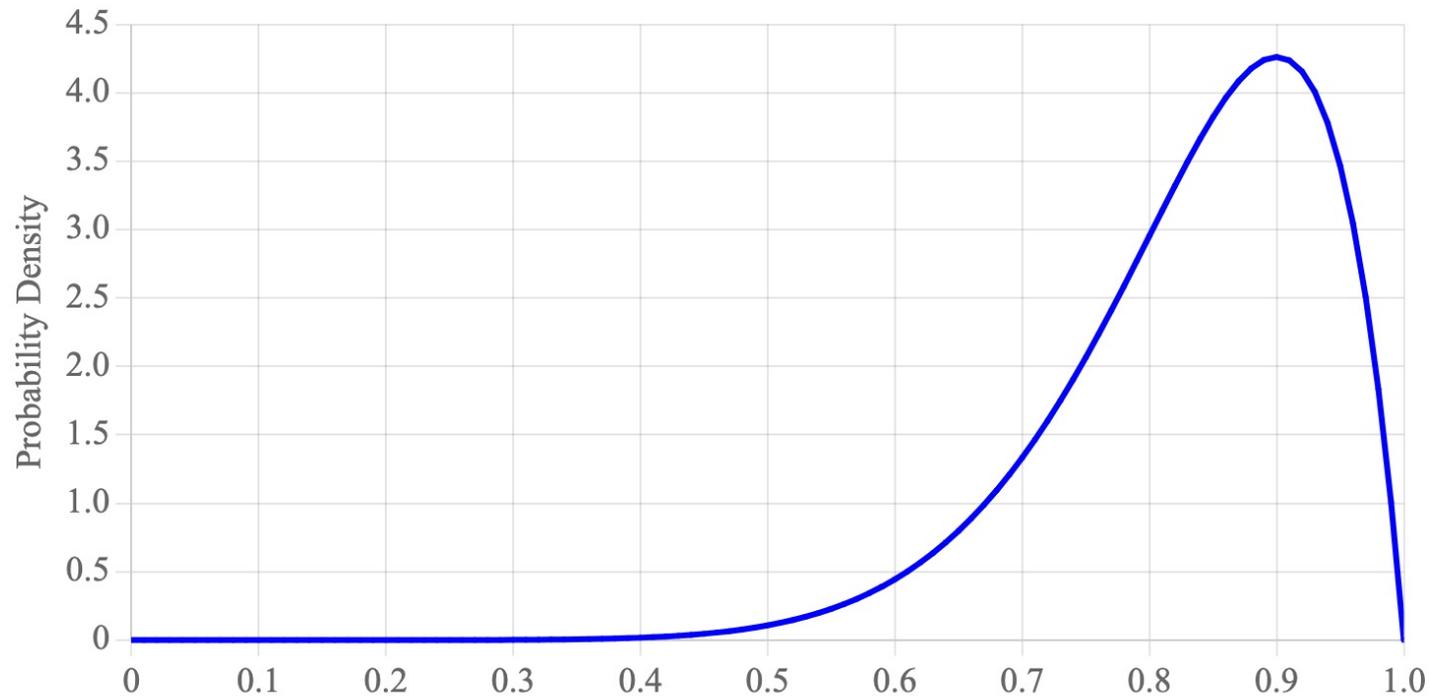
```
Observation = [None, None, None, 1]
Pr(Flu | Obs) = 0.140635888502
>
```

Uncertainty Theory



$$\begin{aligned}
 & f(X = x | H = 9, T = 1) \\
 &= \frac{P(H = 9, T = 1 | X = x) \cdot f(X = x)}{P(H = 9, T = 1)} && \text{Bayes Theorem} \\
 &= \frac{\binom{10}{9} x^9 (1 - x)^1 \cdot f(X = x)}{P(H = 9, T = 1)} && \text{Binomial PMF} \\
 &= \frac{\binom{10}{9} x^9 (1 - x)^1 \cdot 1}{P(H = 9, T = 1)} && \text{Uniform PDF} \\
 &= \frac{\binom{10}{9}}{P(H = 9, T = 1)} x^9 (1 - x)^1 && \text{Constants to front} \\
 &= K \cdot x^9 (1 - x)^1 && \text{Rename constant}
 \end{aligned}$$

Lets take a look at that function. For now we can let $K = \frac{1}{110}$. Regardless of K we will get the same shape, just scaled:



Lets Play!

Drug A

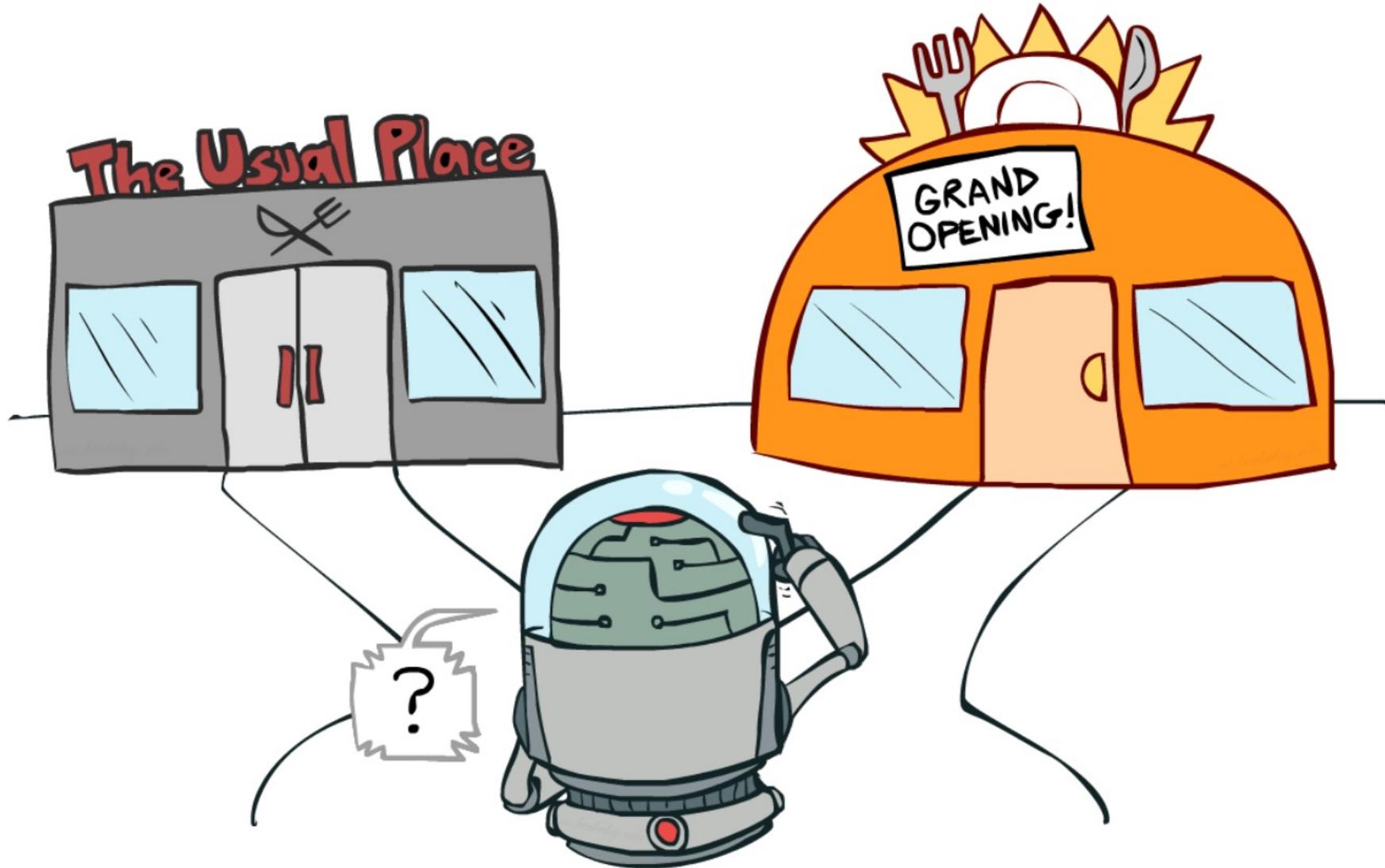


Drug B

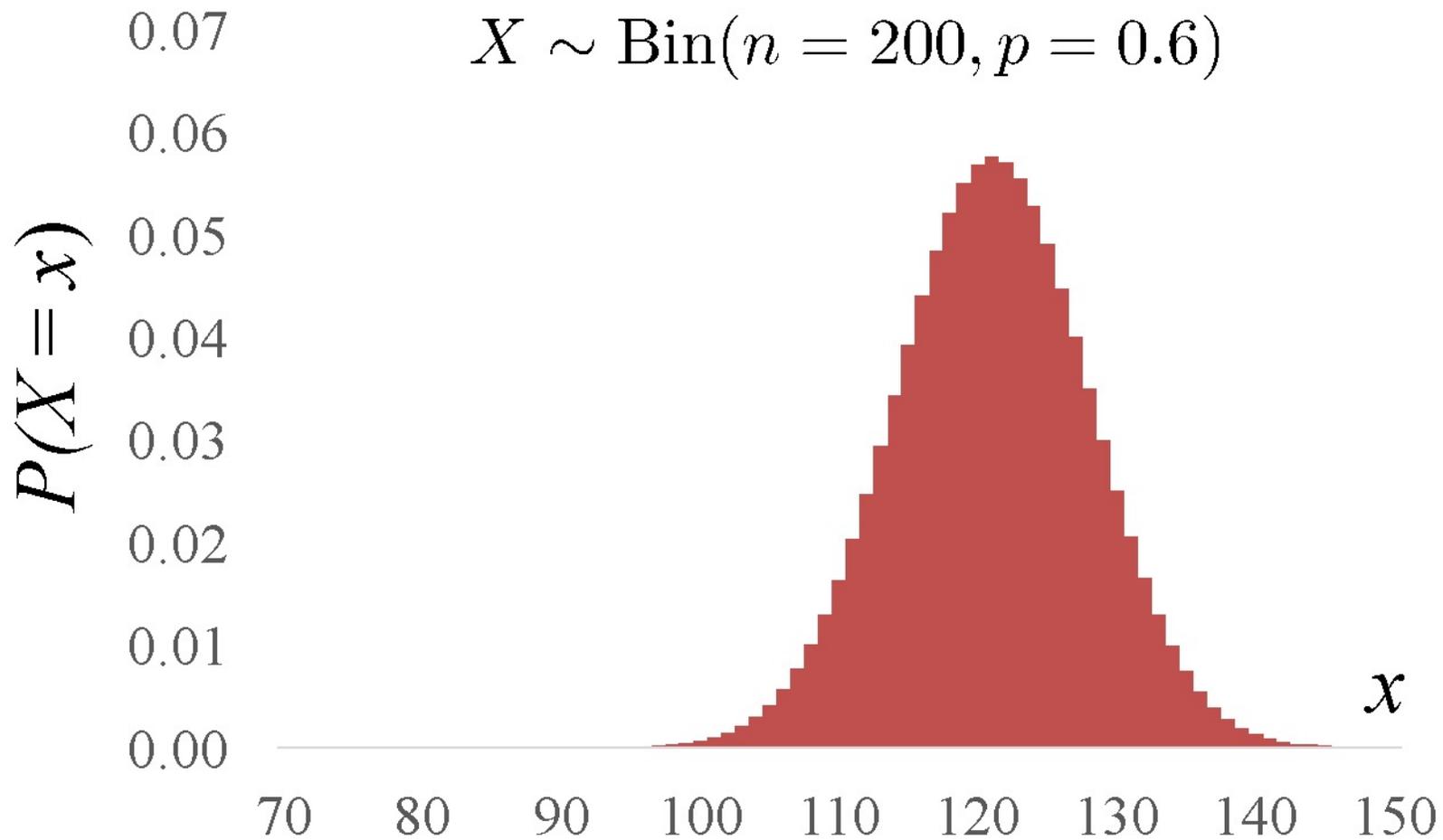


Which one do you give to a patient?

Thompson Sampling



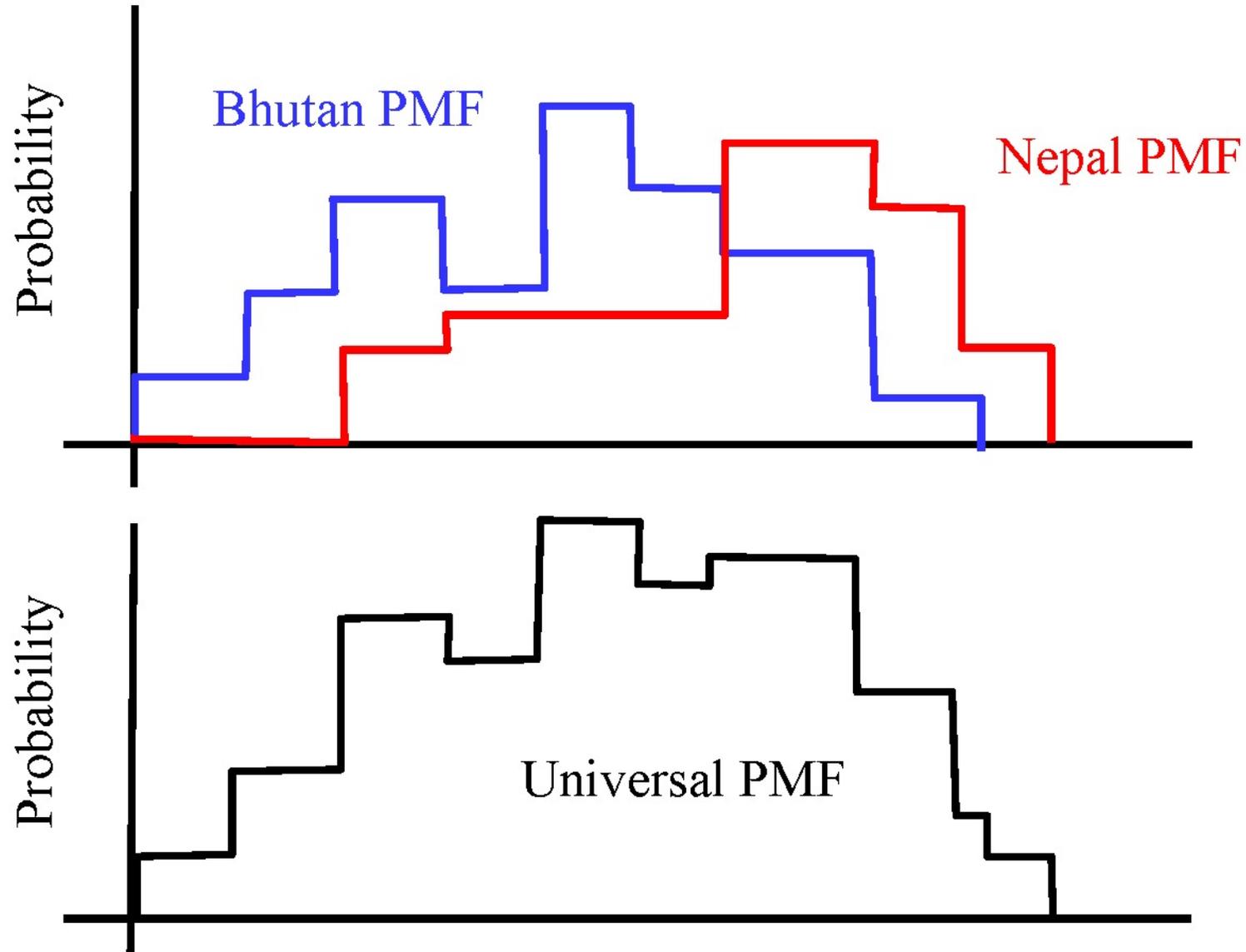
C.L.T. Explains This



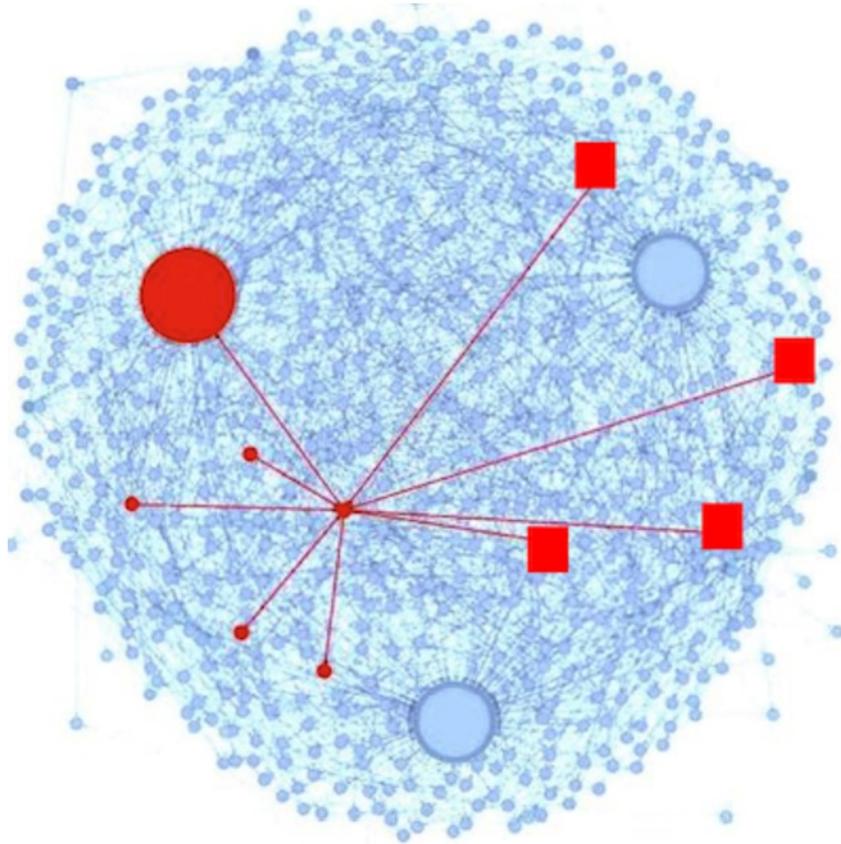
Bootstrap



Universal Sample



Peer Grading

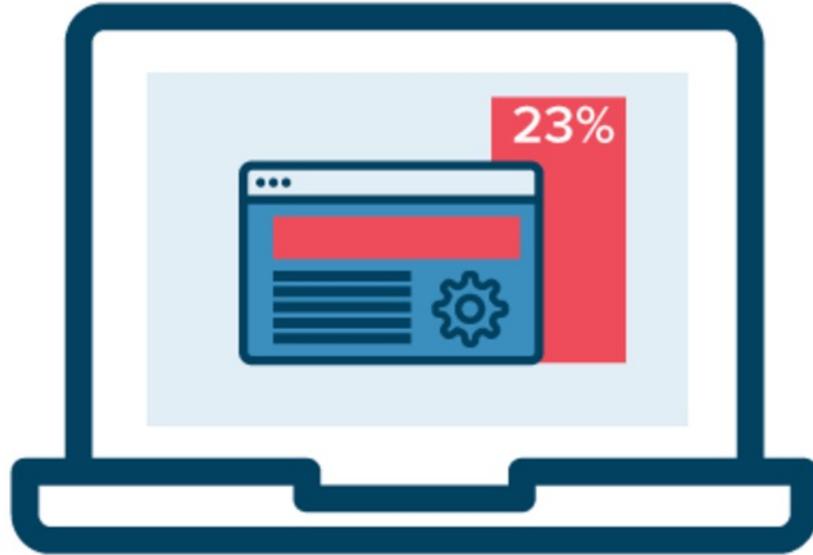


Peer Grading on Coursera
HCI.

31,067 peer grades for
3,607 students.

A/B Testing

A



CONTROL

B



VARIATION

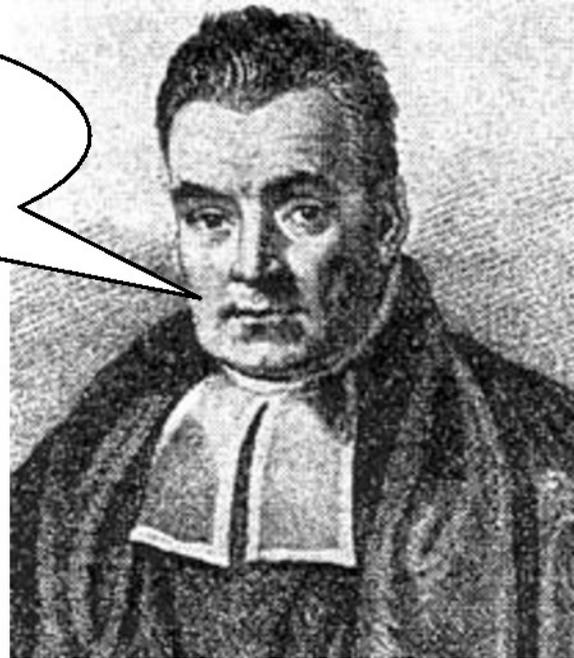


Machine Learning



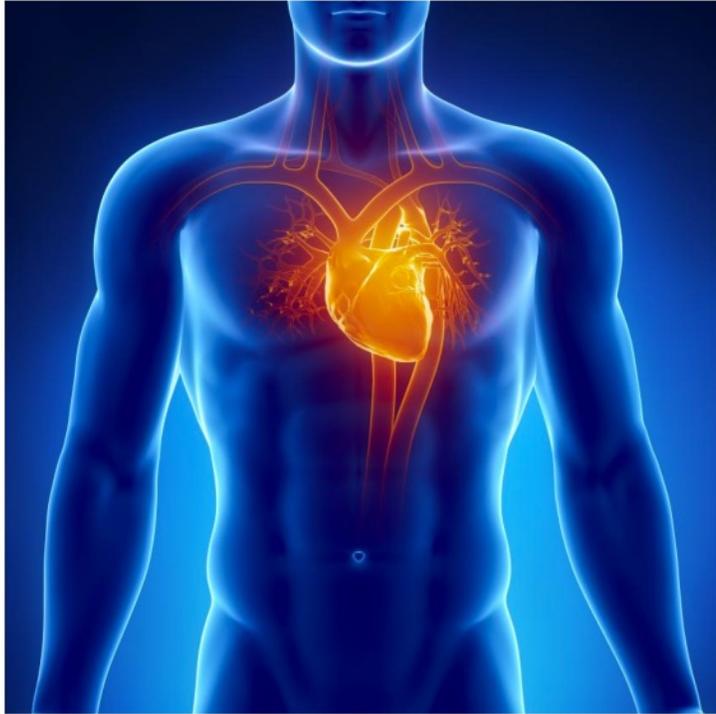
MAP: Most Probable Parameter

So good to see
you again!



Machine Learning

Heart



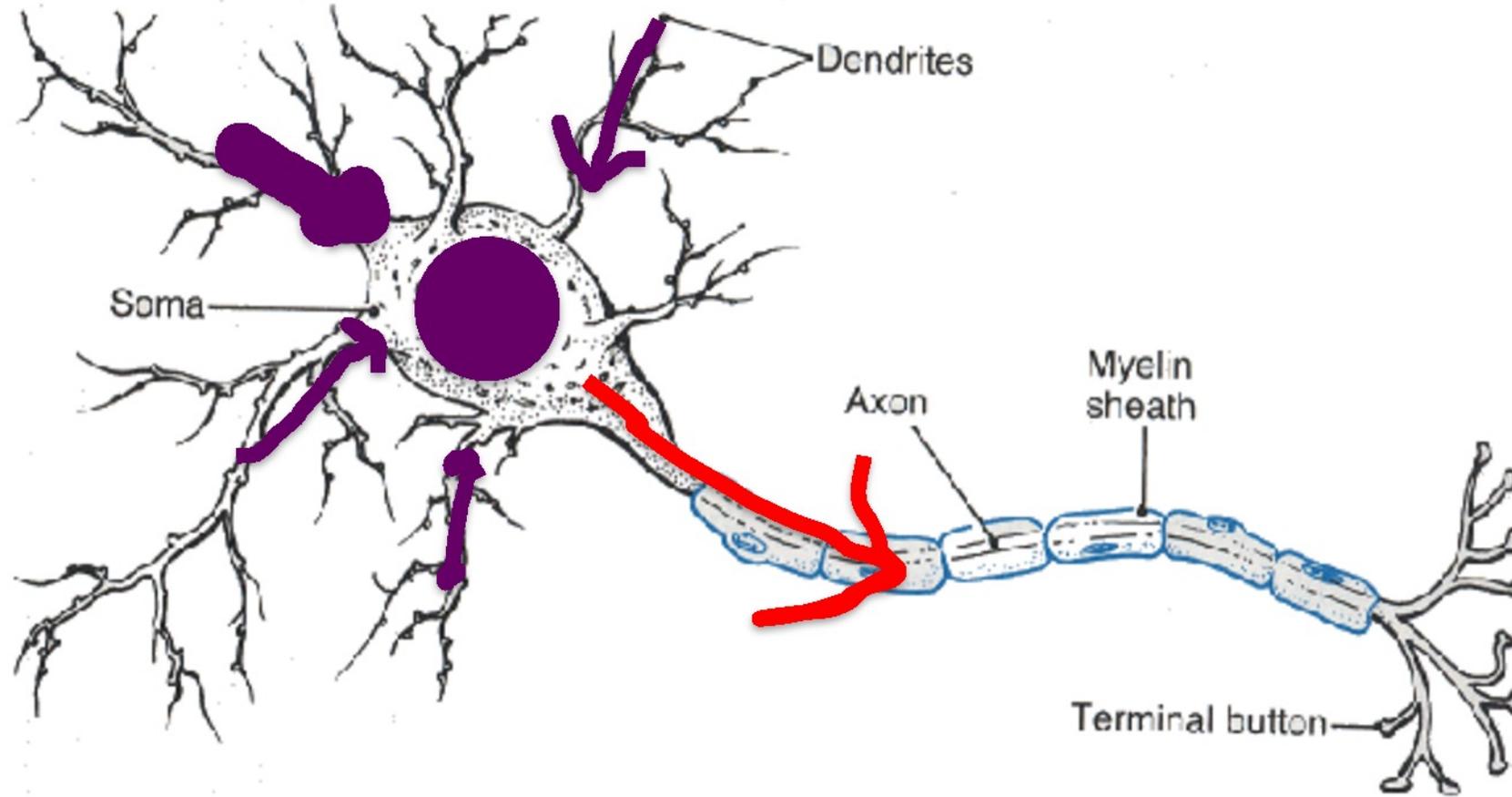
Ancestry



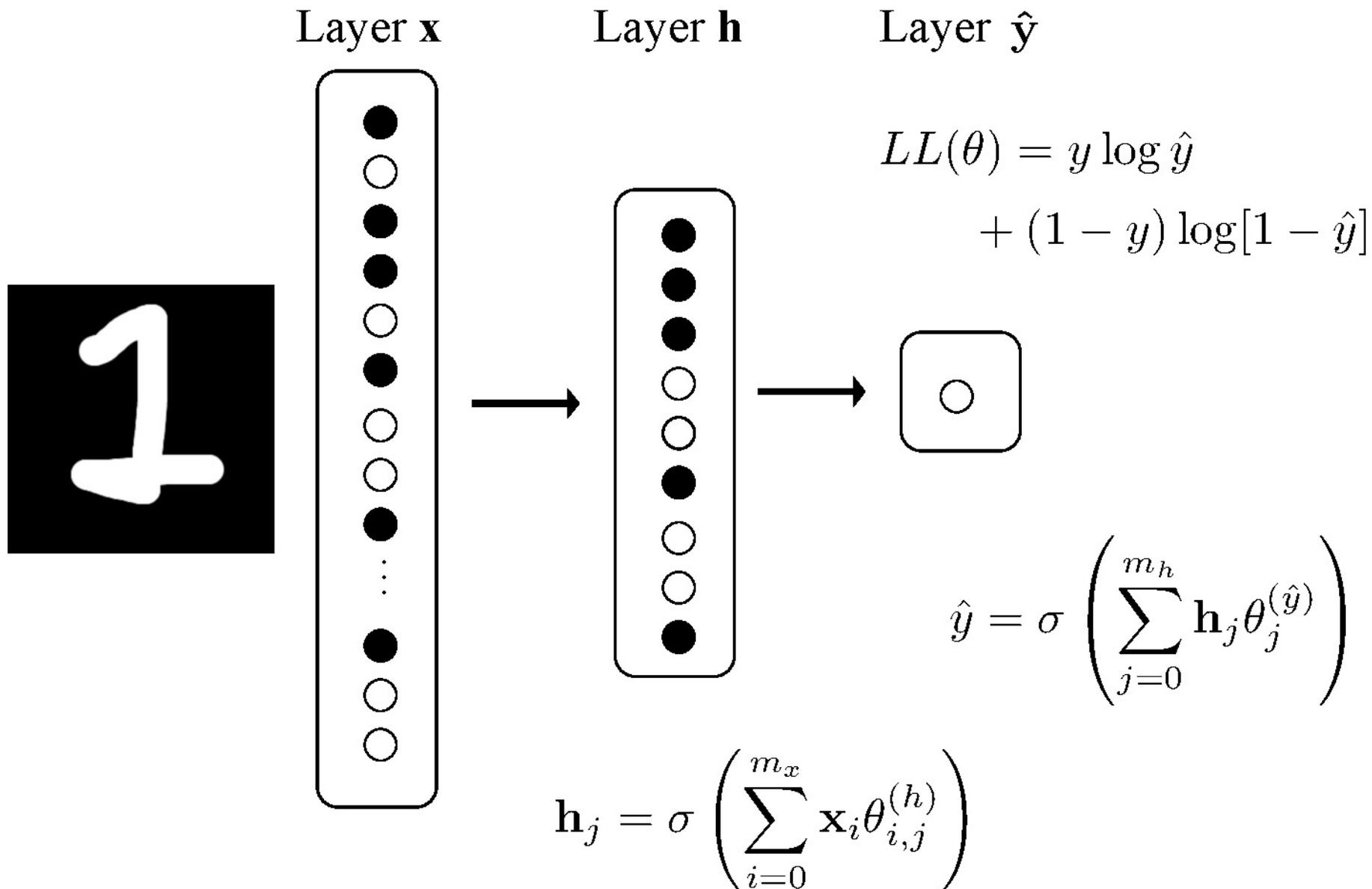
Netflix

NETFLIX

Logistic Regression

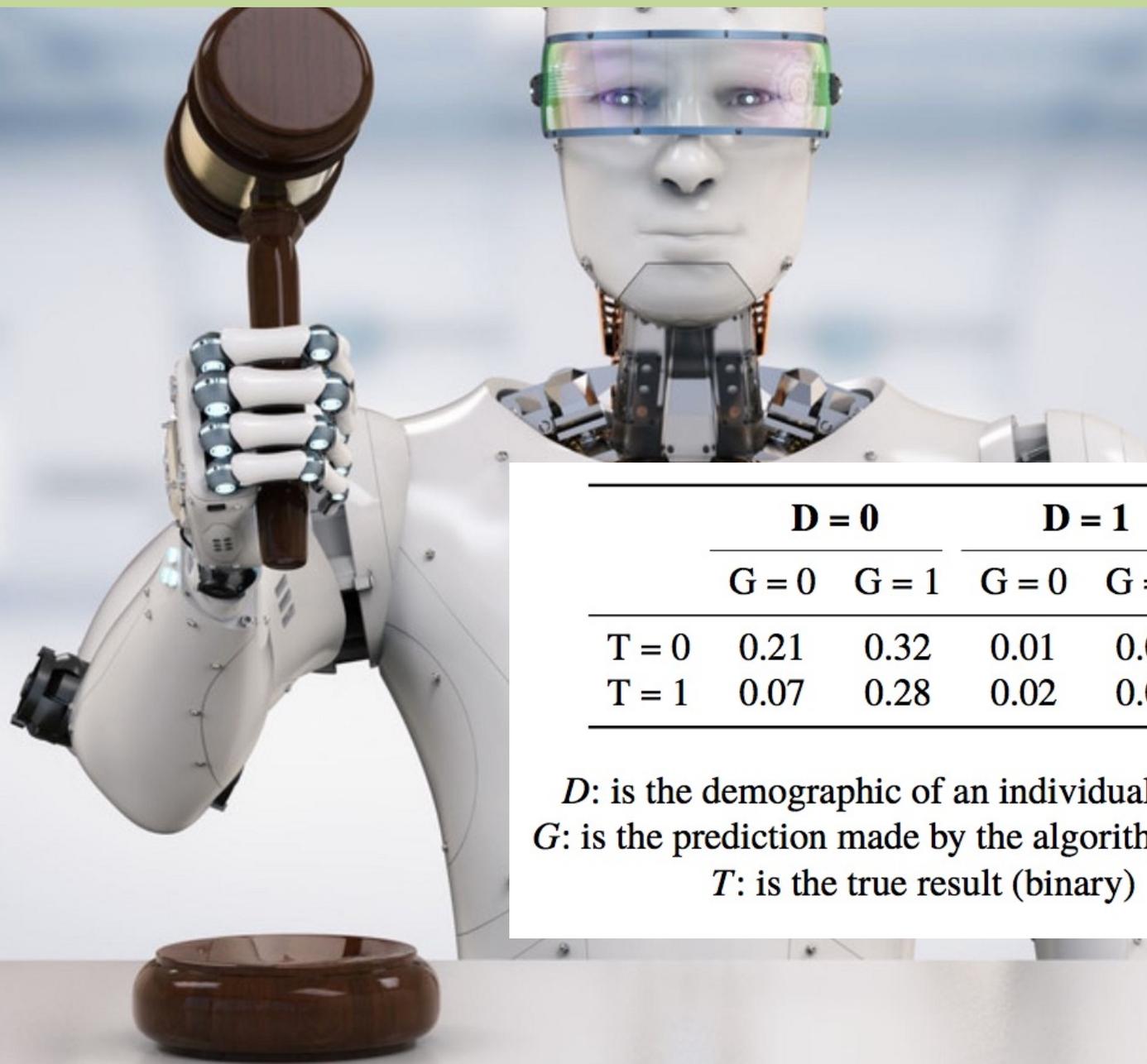


Deep Learning



NEW

Algorithmic Fairness



	D = 0		D = 1	
	G = 0	G = 1	G = 0	G = 1
T = 0	0.21	0.32	0.01	0.01
T = 1	0.07	0.28	0.02	0.08

D: is the demographic of an individual (binary)
G: is the prediction made by the algorithm (binary)
T: is the true result (binary)

By the numbers

~ 30 Major Keys



Naïve Bayes Assumption:

$$P(\mathbf{x}|y) = \prod_i P(x_i|y)$$

64 Course Reader Chapters

NEW



The screenshot shows a web browser window with the URL `chrispiech.github.io/probabilityForComputerScientists/en/examples/name2age/`. The page has a dark sidebar on the left with a navigation menu. The main content area is white and contains a list of assumptions, a demo section with a line graph, and a section titled 'Names that Give Away Your Age'.

Navigation Menu (Left Sidebar):

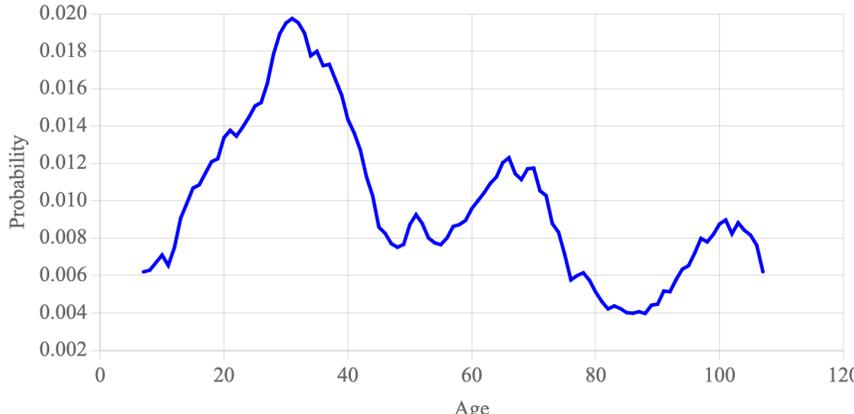
- 100 Binomial Problems
- Jury Selection
- Grading Eye Inflammation
- Gaussian CDF Calculator
- Grades are Not Normal
- Curse of Dimensionality
- Probability of Baby Delivery
- Part 3: Probabilistic Models**
- Joint Probability
- Multinomial
- Continuous Joint
- Inference
- Bayesian Networks
- Independence in Variables
- Correlation
- General Inference
- Worked Examples
- CS109 Logo
- Fairness in AI
- Federalist Paper Authorship
- Name to Age
- Bridge Distribution
- Tracking in 2D
- Part 4: Uncertainty Theory**
- Beta Distribution
- Adding Random Variables
- Central Limit Theorem
- Sampling
- Bootstrapping
- Algorithmic Analysis
- Worked Examples

Assumptions:

1. This data only is accurate for names of people in the US. The probability of age given names could be very different in other countries.
2. The US census is not perfect. It does not capture all people who are resident in the US, and there are demographics which are underrepresented. This will also skew our results.

Demo

Query Name: ✓



Age	Probability
10	0.006
20	0.012
30	0.019
40	0.014
50	0.008
60	0.010
65	0.012
70	0.010
80	0.004
90	0.005
100	0.008
110	0.006

Records with name: 589753

This demo is based on real data from US Social Security applications between 1914 and 2014. Thank you to <https://www.kaggle.com/kaggle-us-baby-names> for compiling the data. [Download Data](#)

Names that Give Away Your Age

Some names have certain years where they were exceptionally popular. These names provide quite a lot of information about birth year. Let's look at some of the names with the highest max probability.

1 Personal Challenge



25% Participation Rate!



1 New Walker



t h a n k y o u

A row of ten light-colored wooden blocks, each with a single lowercase letter, spelling out the words 'thank you'. The blocks are arranged on a dark wooden surface. The background is a soft-focus bokeh of warm, golden-yellow lights, creating a warm and appreciative atmosphere.