# Day-56, Jan 25, 2025 (Magh 12, 2081 B.S.)

## # Conditional Probability:

Q. What is the probability of landing on heads twice? Given that the first one is heads.

H     T

50%     50%

| 1st | | 2nd |
|---|---|---|
| H | → | H |
| | → | T |
| T | → | H |
| | → | T |

H H

H T

T H

T T

$P(HH) = 1/4$

$\Rightarrow 0.25$

$$P(HH) = \frac{HH}{\begin{array}{c} HH \\ HT \\ TH \\ TT \end{array}}$$

Ans : if the first coin is head, to get two heads you need one more, which has probability of 1/2 of happening!

Notation:

What is the probability of landing on heads twice? Given that the first one is heads.

$$P(HH \mid 1st \text{ is } H)$$

| | 2nd (H) | 2nd (T) |
|---|---|---|
| 1st H | HH | HT |
| 1st H | ~~TH~~ | ~~TT~~ |

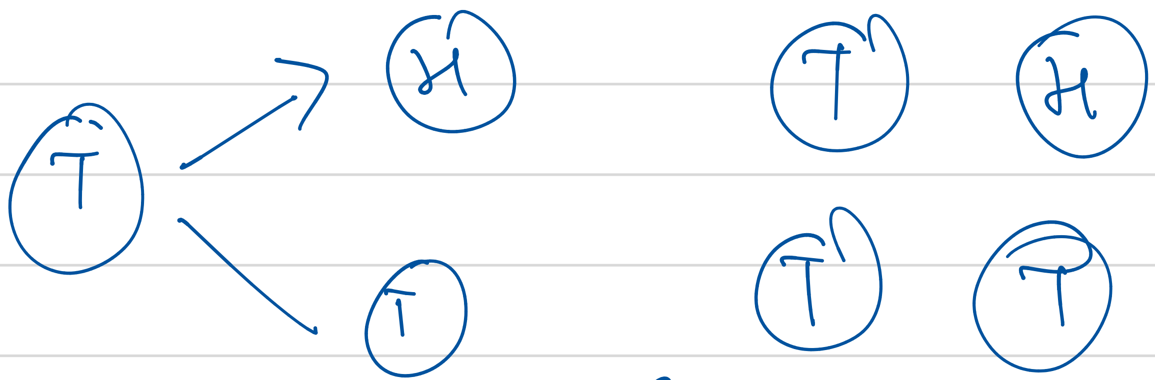
→ Probability of landing on heads twice. Given that the first one is heads.

$$P(HH \mid 1st \text{ is } H) = \frac{HH}{HH \quad HT} = 1/2$$

Q. When flipping a coin twice, what is the probability of getting two heads if the first coin lands in tails?

$\Rightarrow 0$

$$\therefore P(HH \mid 1st \text{ is } T) = \frac{0}{\begin{matrix} T & H \\ T & T \end{matrix}} \Rightarrow 0$$



No HH so the sample is '0'. Our condition changes the 'p'.

## Product Rule (for Independent Events)

$$P(A \cap B) = P(A) \cdot P(B) \text{ when } A \text{ and } B \text{ is independent.}$$

# Example on Conditional Probability on Dice Example:

Q. What is the probability that the first is 6 AND the sum = 10 ?

Here given,

Sum = 10

(6, 4), (4, 6)

$$P(\text{1st is } 6 \cap \text{Sum} = 10) = P(\text{1st is } 6) \cdot P(\text{Sum} = 10 \mid \text{1st } 6)$$

$$= \frac{1}{6} \cdot \frac{1}{6}$$

$$= \frac{1}{36}$$

$$P(\text{1st is } 6 \cap \text{Sum} = 10) = P(\text{1st is } 6) \cdot P(\text{Sum} = 10 \mid \text{1st } 6)$$

$$P(A \cap B) = P(A) \cdot P(B \mid A)$$

Where $P(B/A) = P(B)$

When Independent

Q. What is the probability that the sum is 10? Given that the first one is 6.
Dice.

$$P(\text{Sum} = 10 \cap \text{1st is } 6) = P(B) \cdot P(A/B)$$
Given sum is 10

$$\Rightarrow \frac{3}{36} \cdot 1/6$$

$$\Rightarrow 18/36 \neq 1/2$$

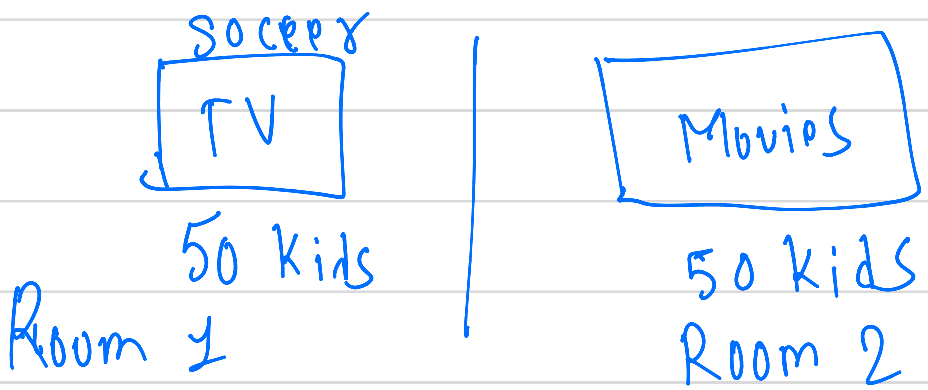
Q. What is the probability that the sum is 10? Given that the first one is 1.
Here given

$$p(S = 10 \cap \text{1st is One}) = P(S) \cdot P(\text{One}/S)$$
Given sum = 10

$$\Rightarrow \frac{3}{36} \cdot 0 \Rightarrow 0$$

**Quiz:**

50 play soccer and 50 don't play




Q. How many kids in Room 1 like soccer?

$\Rightarrow$ 50 (Assume)

**Quiz:**

40 play soccer,

60 don't play soccer. Now 80 % like to wear running shoes

How many kids wear running shoes?

$\Rightarrow$ 80 % of 40

$\Rightarrow \frac{80}{100} \times 40 \Rightarrow$ 32 wear running shoes

$P(S) = 0.4$ and $P(\text{not } S) = 0.6$ , $P(R|S) = 0.8$

$$P(\text{Soccer and Running shoes}) = P(S) \cdot P(R)$$

$$P(S \cap R) = P(S) \cdot P(R/S)$$

$$\Rightarrow 0.4 \cdot 0.8$$

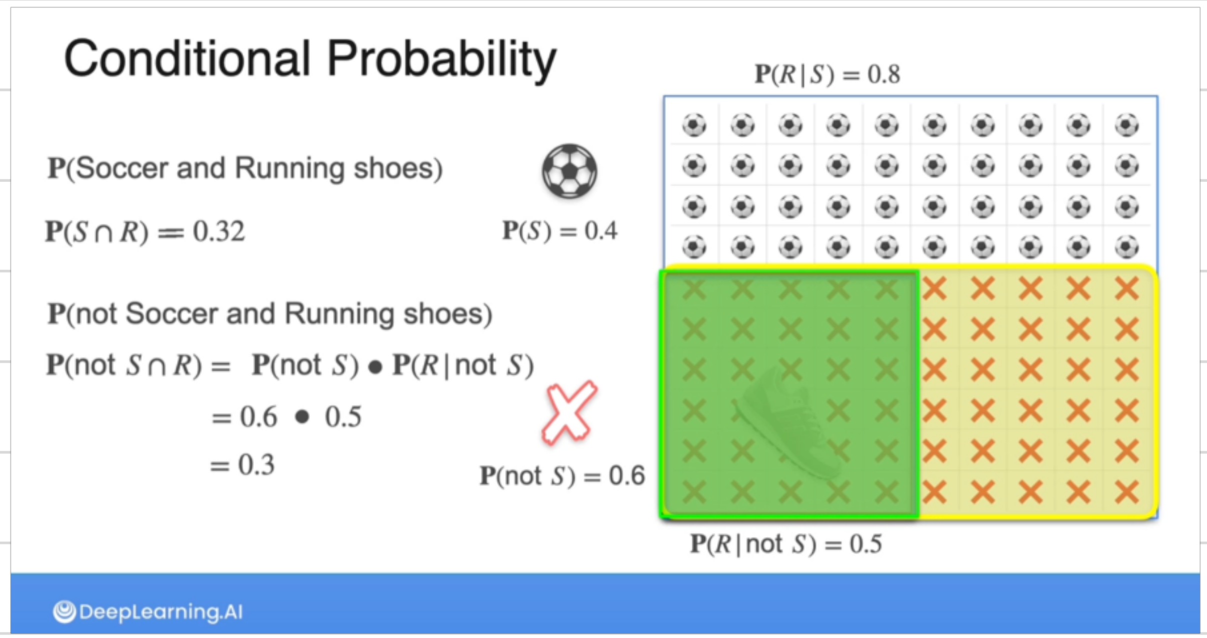
$$\boxed{P(S \cap R) = 0.32.}$$

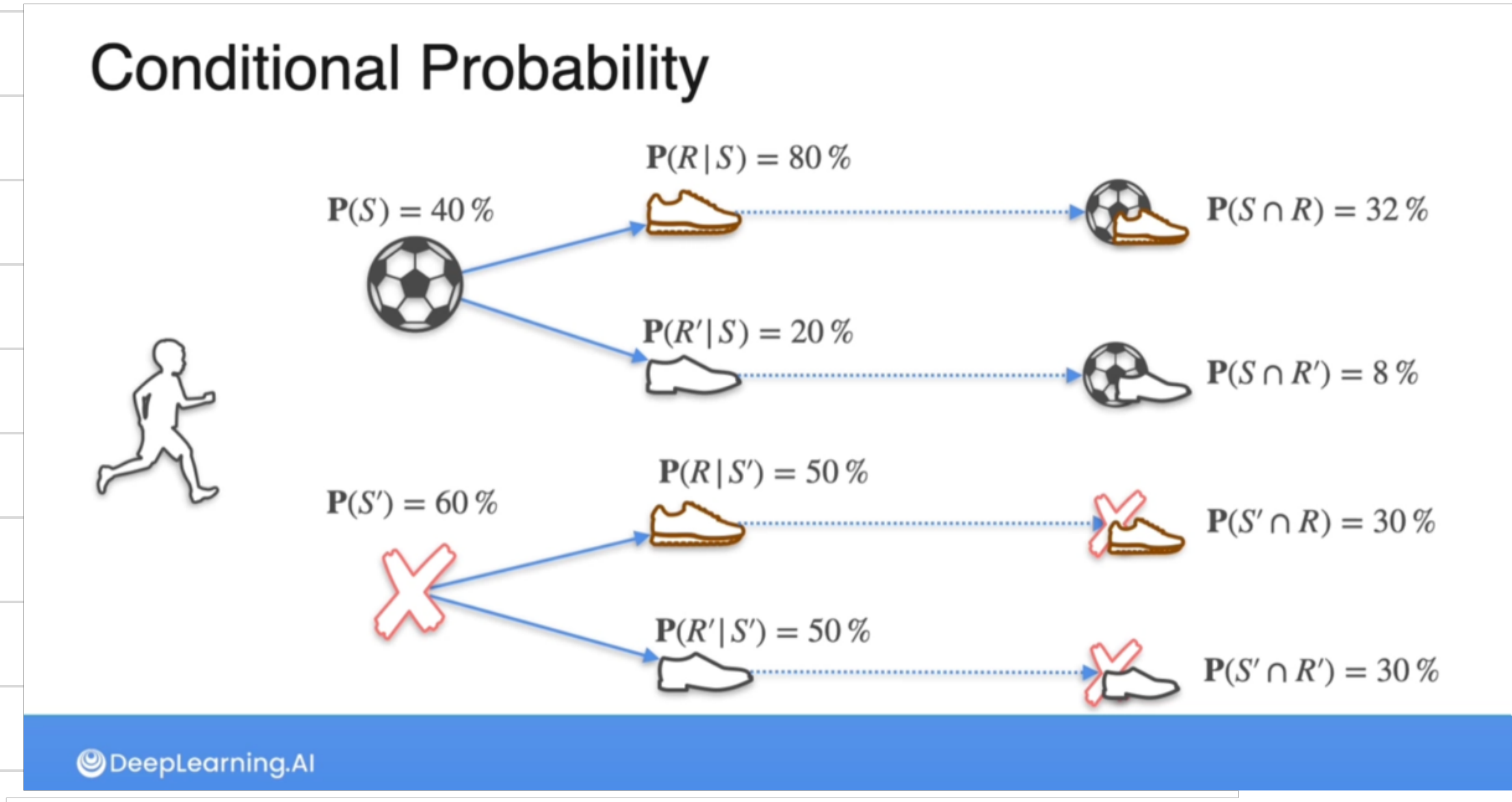
$$P(\text{not Soccer and Running shoes})$$

$$P(\text{not } S \cap R) = P(\text{not } S) \bullet P(R \mid \text{not } S)$$

$$\Rightarrow 0.6 \times 0.5$$

$$= 0.3$$




Conditional Probability
$P(S) = 40\,\%$
$P(R \mid S) = 80\,\%$
$P(S \cap R) = 32\,\%$
$P(R' \mid S) = 20\,\%$
$P(S \cap R') = 8\,\%$
$P(S') = 60\,\%$
$P(R \mid S') = 50\,\%$
$P(S' \cap R) = 30\,\%$
$P(R' \mid S') = 50\,\%$
$P(S' \cap R') = 30\,\%$
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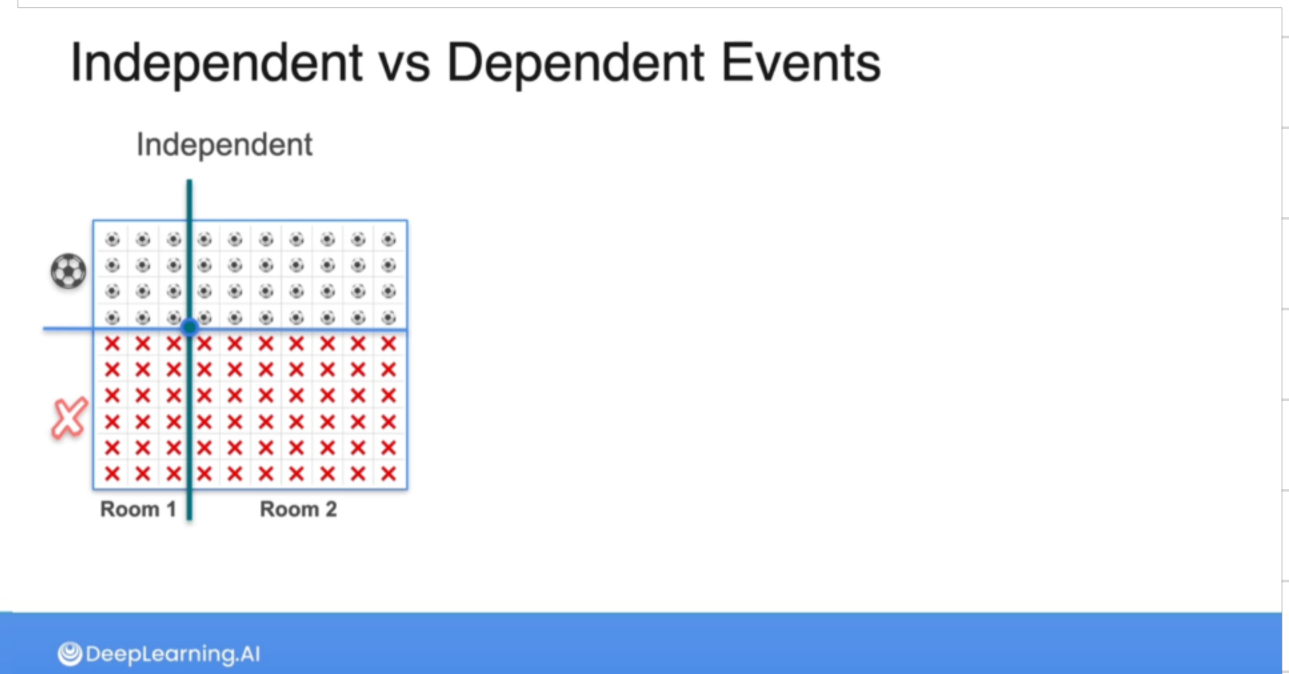
Independent vs Dependent Events
Independent
Room 1
Room 2
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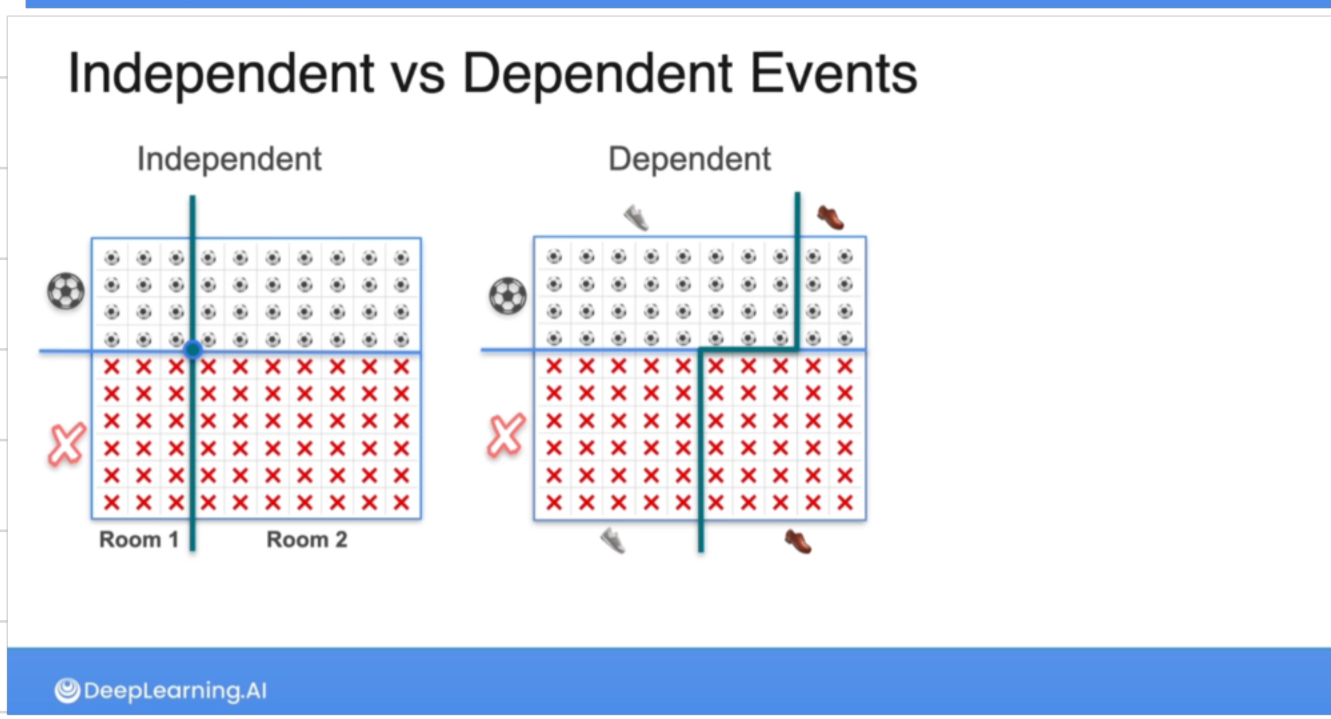
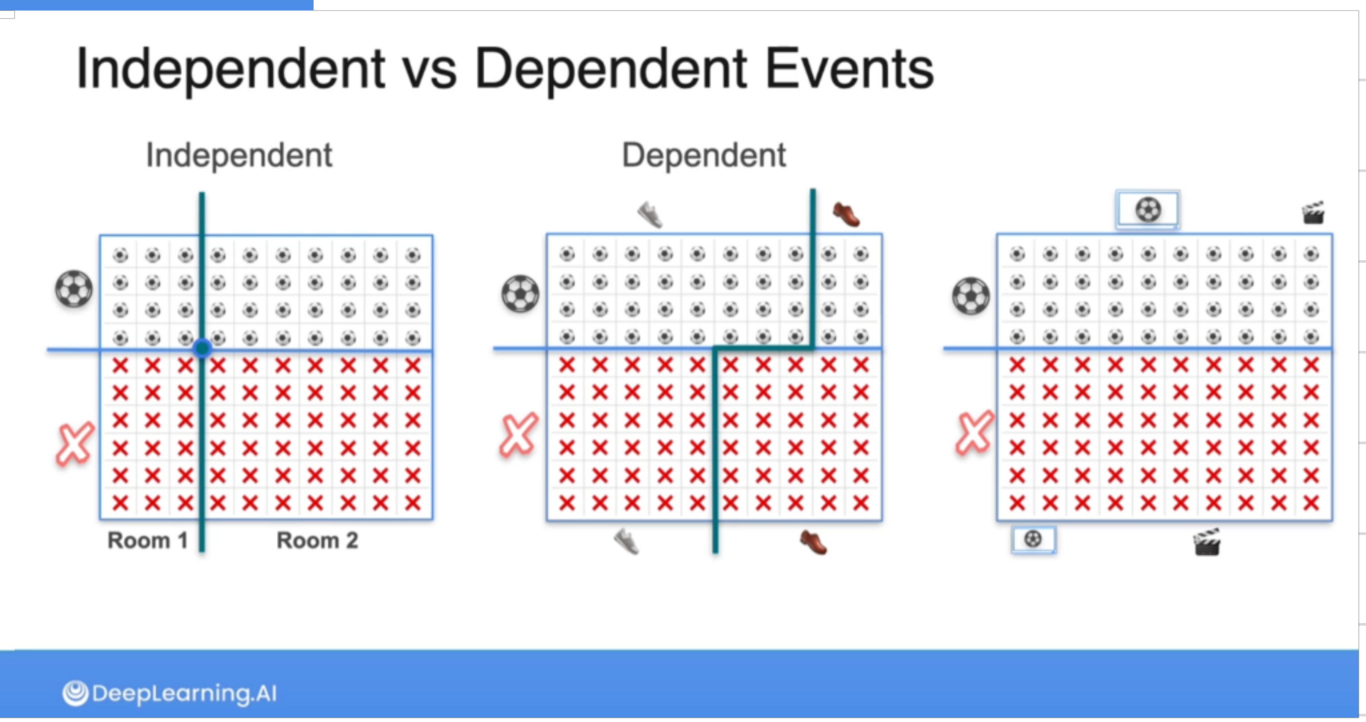

Independent vs Dependent Events
Independent
Dependent
Room 1
Room 2
DeepLearning.AI


Independent vs Dependent Events
Independent
Dependent
Room 1
Room 2
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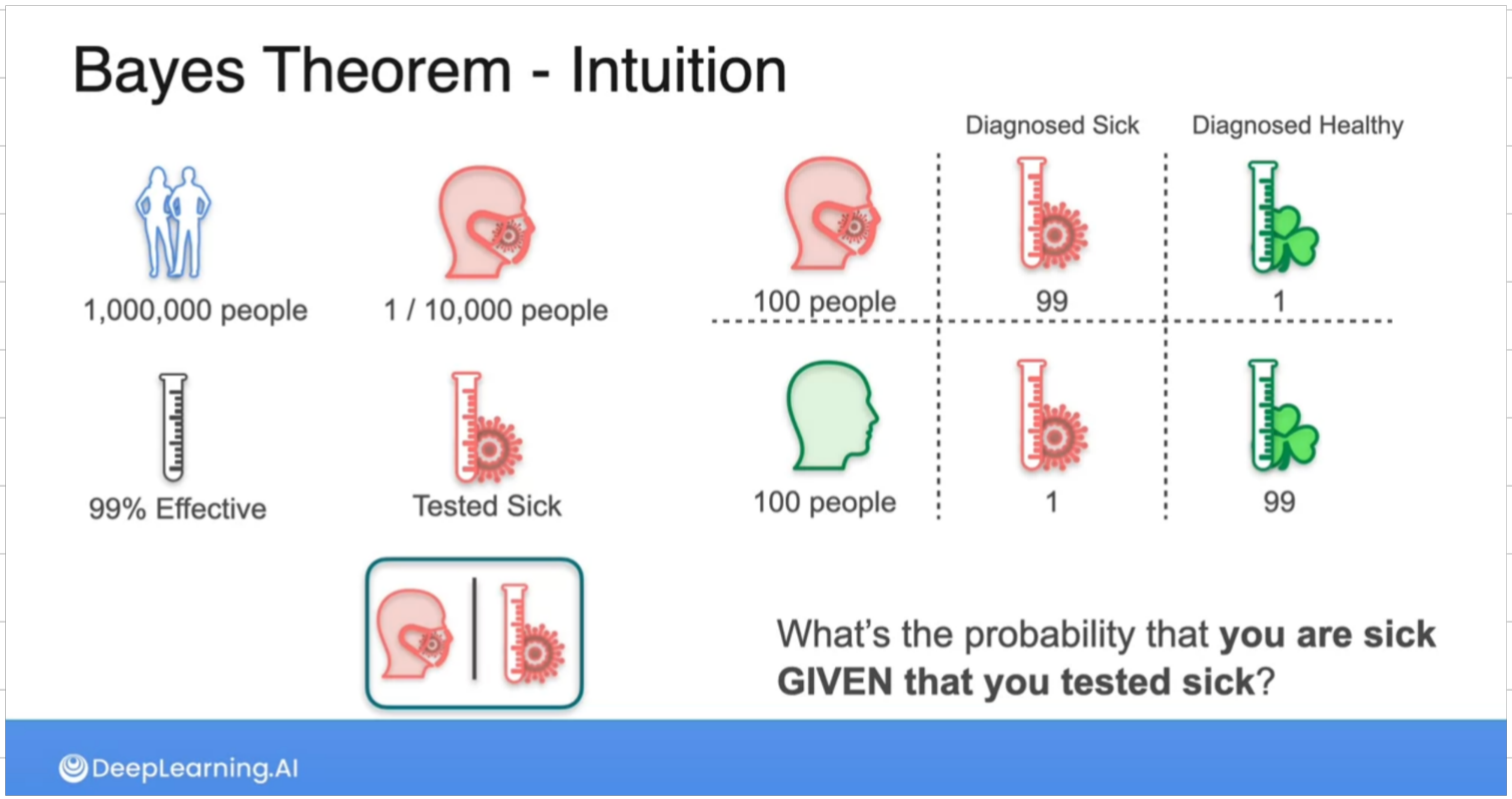
# Baye's Theorem - Intuition

Q. What's the probability that you are sick Given that you tested Sick ?




99% Means

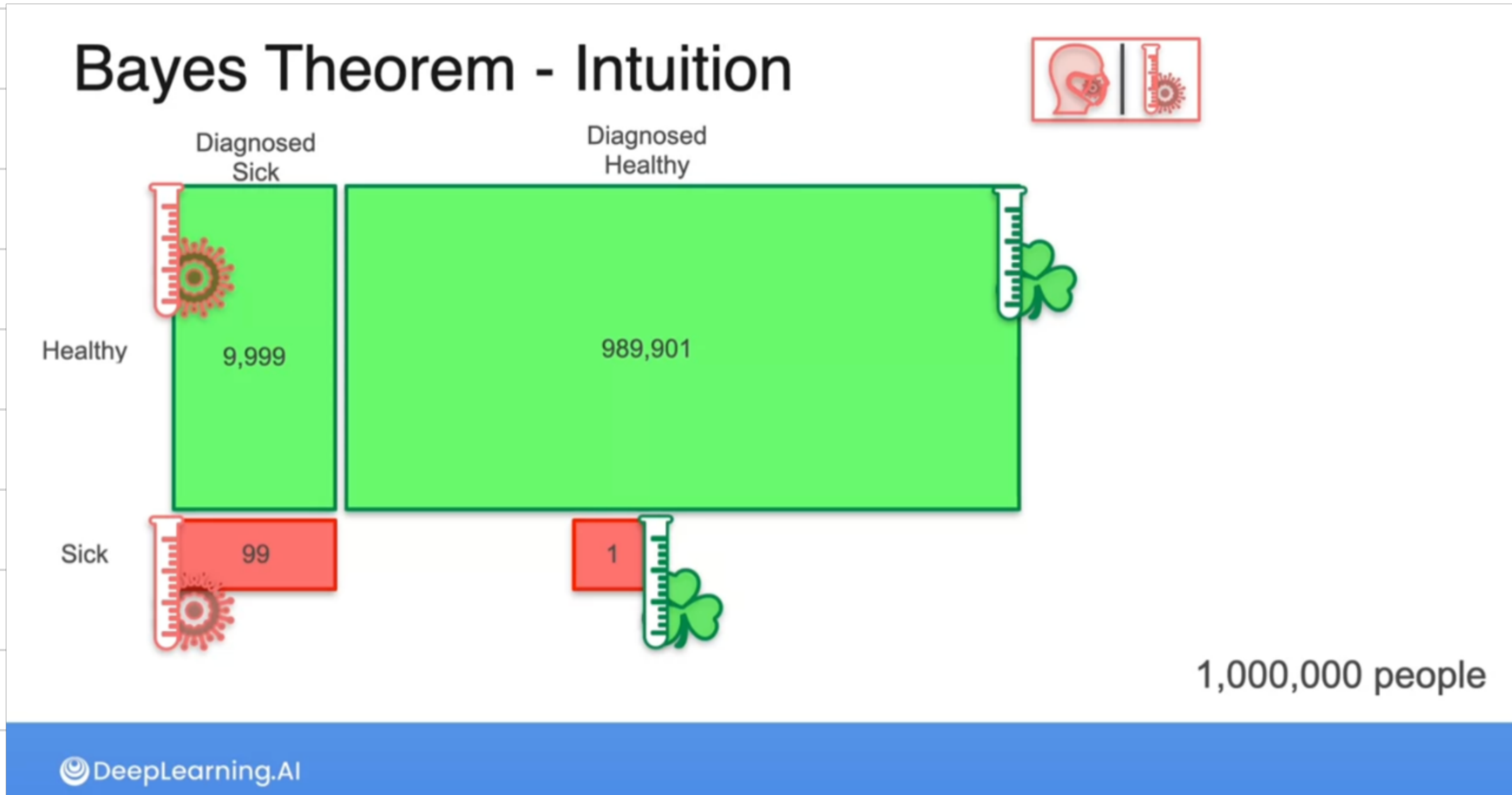
| | Diagnosed Sick | Heal |
|---|---|---|
| Healthy | 9,999 | 989,901 |
| Sick | 99 | 1 |

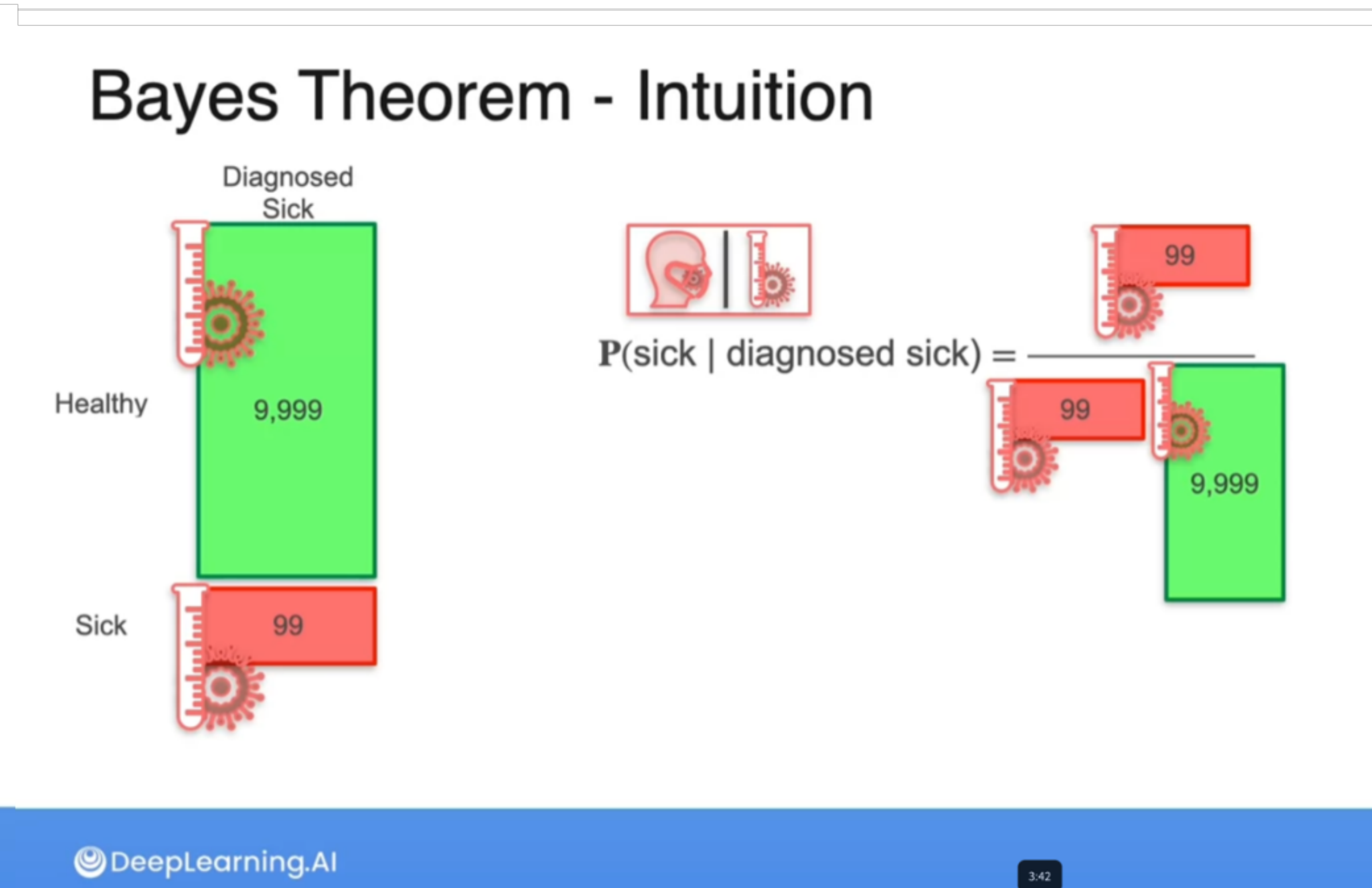
1,000,000 people

$$P(\text{Sick} \mid \text{diagnosed Sick}) = \frac{99}{99 + 9{,}999}$$

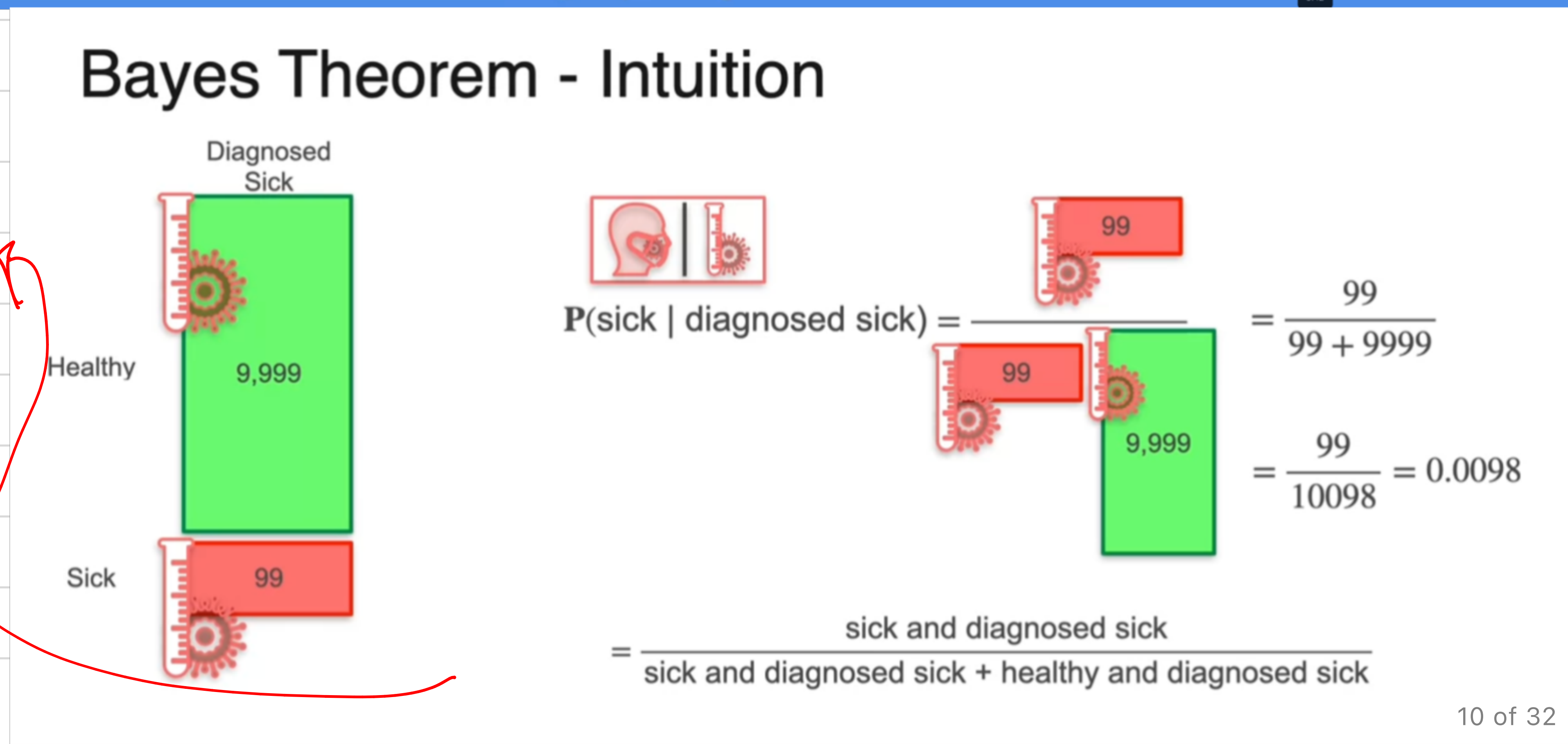
$$\Rightarrow \frac{99}{99 + 9999} \approx 0.0098$$

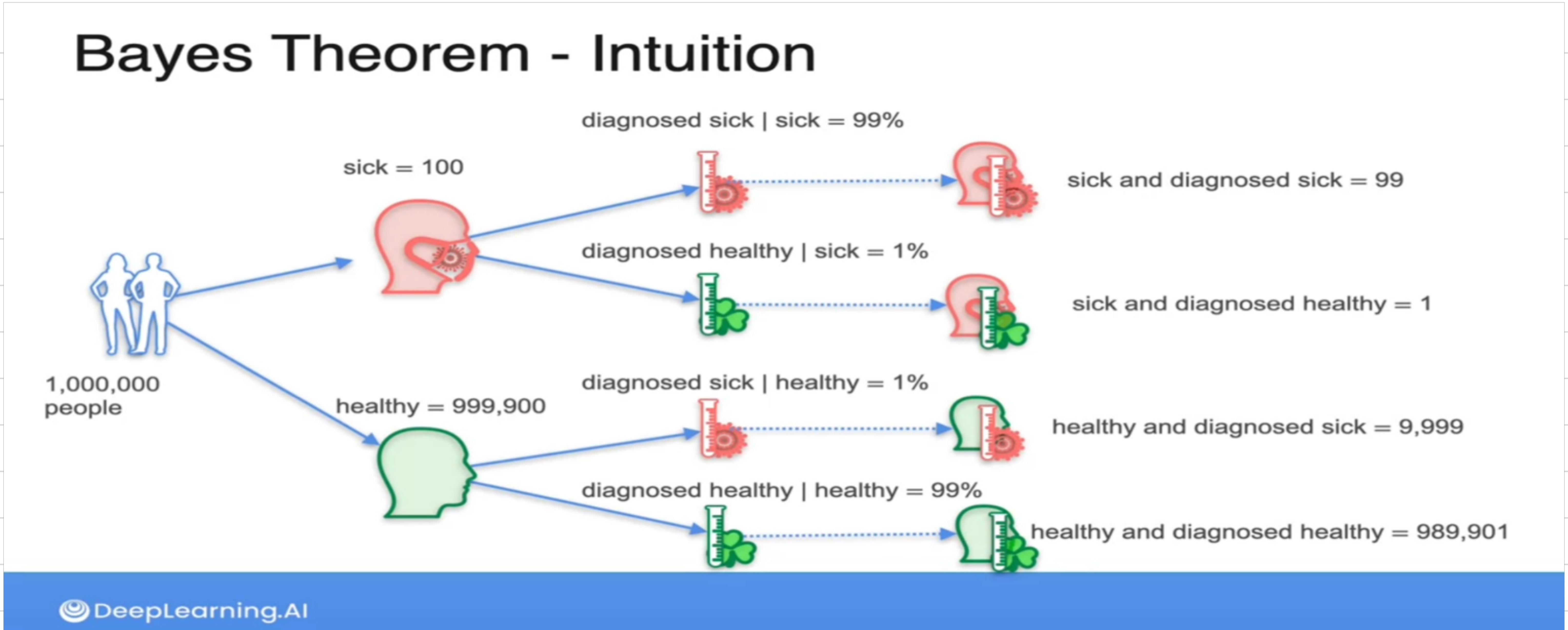
Actually Sick < 1%.




$$\Rightarrow \frac{\text{Sick and diagnosed sick}}{\text{everyone diagnosed sick}}$$




Bayes Theorem - Intuition
diagnosed sick | sick = 99%
sick = 100
sick and diagnosed sick = 99
diagnosed healthy | sick = 1%
sick and diagnosed healthy = 1
1,000,000 people
diagnosed sick | healthy = 1%
healthy = 999,900
healthy and diagnosed sick = 9,999
diagnosed healthy | healthy = 99%
healthy and diagnosed healthy = 989,901
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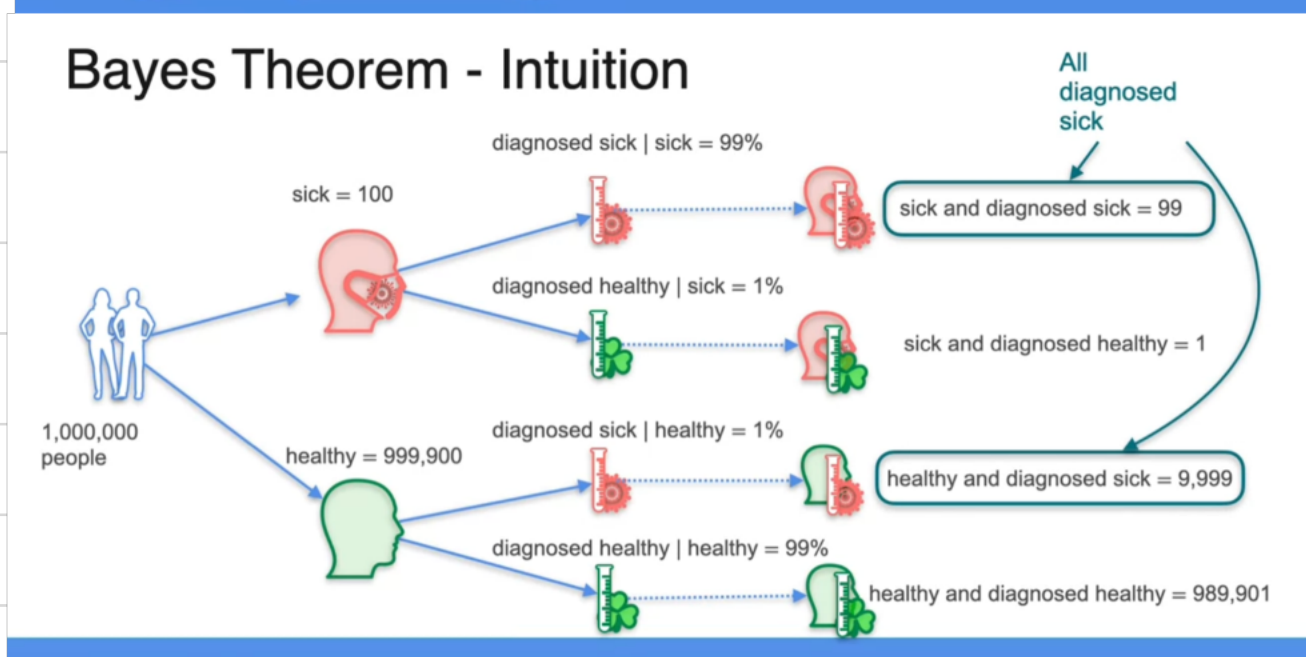
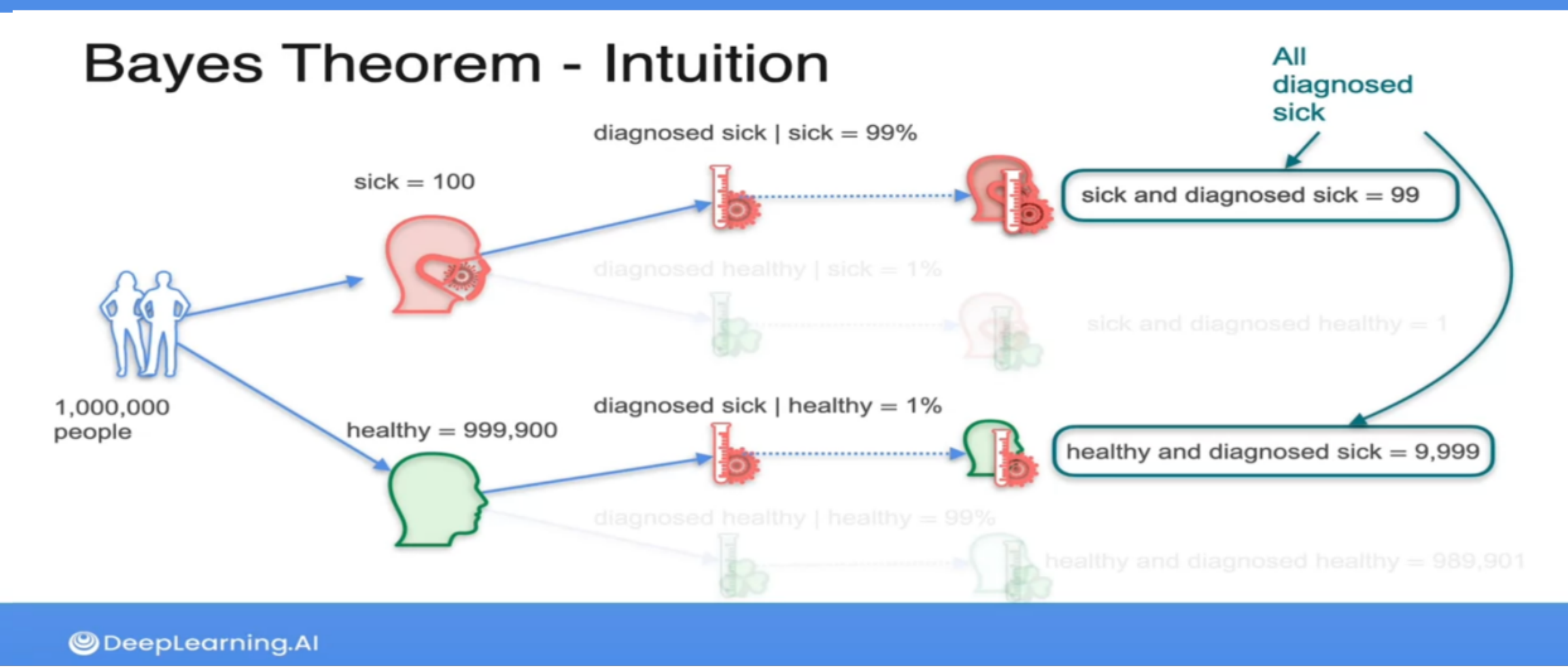

Bayes Theorem - Intuition
All diagnosed sick
diagnosed sick | sick = 99%
sick = 100
sick and diagnosed sick = 99
diagnosed healthy | sick = 1%
sick and diagnosed healthy = 1
1,000,000 people
diagnosed sick | healthy = 1%
healthy = 999,900
healthy and diagnosed sick = 9,999
diagnosed healthy | healthy = 99%
healthy and diagnosed healthy = 989,901


Bayes Theorem - Intuition
All diagnosed sick
diagnosed sick | sick = 99%
sick = 100
sick and diagnosed sick = 99
1,000,000 people
diagnosed sick | healthy = 1%
healthy = 999,900
healthy and diagnosed sick = 9,999
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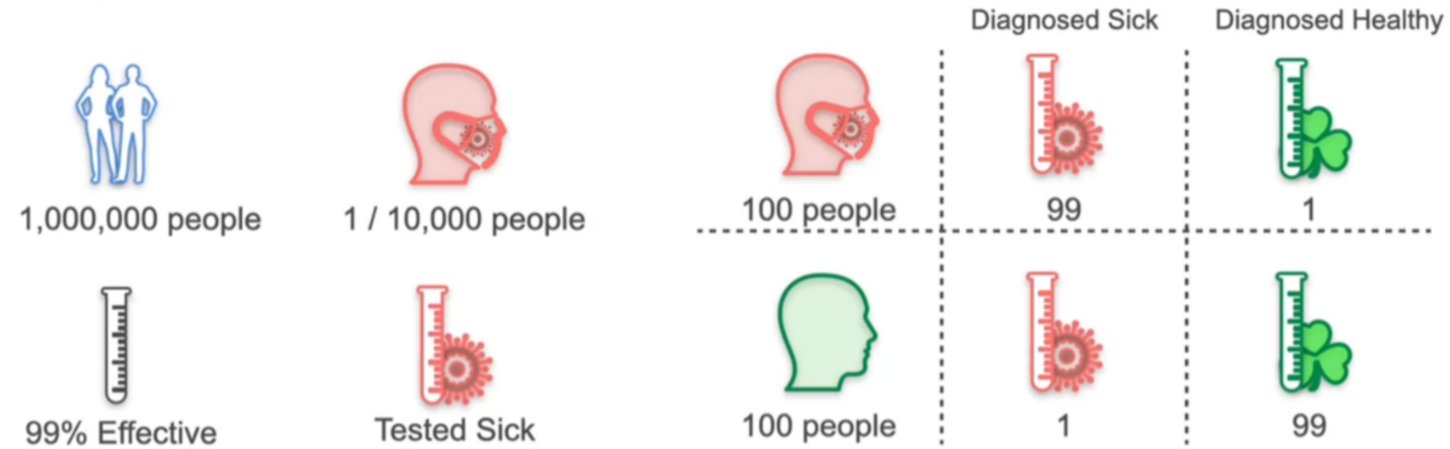
## Bayes Theorem - Intuition

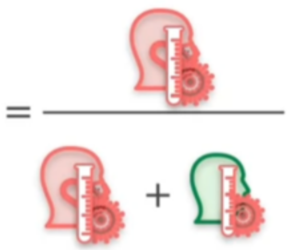



What's the probability that **you are sick GIVEN that you tested sick?**



## Bayes Theorem - Intuition

P(sick | diagnosed sick) =



$$\mathrm{P}(\text{sick} \mid \text{diagnosed sick}) = \frac{\text{sick and diagnosed sick} = 99}{\text{healthy and diagnosed sick} = 9{,}999 + \text{sick and diagnosed sick} = 99}$$

$$\mathrm{P}(\text{sick} \mid \text{diagnosed sick}) = \frac{99}{10098} = 0.0098$$

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$$P(A/B) = \frac{P(A \cap B)}{P(B)}$$

$$P(A/B) = \frac{P(\text{Sick and diagnosed Sick})}{P(\text{diagnosed Sick})}$$

$P(S) = 0.01\%$ $\quad P(nS) = 99.99\%$

## Bayes Theorem - Formula

$A$: sick

$B$: diagnosed sick

P(sick | diagnosed sick) = ?

$\mathrm{P}(A \mid B) = ?$

P(sick) = 0.01%

P(not sick) = 99.99%

P(diagnosed sick | sick) = 99%

P(diagnosed sick | not sick) = 1%

**From Conditional Probability**

$$\mathrm{P}(A \mid B) = \frac{\mathrm{P}(A \cap B)}{\mathrm{P}(B)}$$

$$\mathrm{P}(A \mid B) = \frac{\mathrm{P}(\text{sick and diagnosed sick})}{\mathrm{P}(\text{diagnosed sick})}$$

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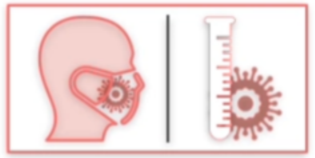
# Bayes Theorem - Formula



$A$: sick

$B$: diagnosed sick

$\mathbf{P}$(sick | diagnosed sick) = ?

$\mathbf{P}(A \mid B) = ?$

$\mathbf{P}$(sick) = 0.01%

$\mathbf{P}$(not sick) = 99.99%

$\mathbf{P}$(diagnosed sick | sick) = 99%

$\mathbf{P}$(diagnosed sick | not sick) = 1%

**From Conditional Probability**

$$\mathbf{P}(A \mid B) = \frac{\mathbf{P}(A \cap B)}{\mathbf{P}(B)}$$

$$\mathbf{P}(A \mid B) = \frac{\mathbf{P}(\text{sick and diagnosed sick})}{\mathbf{P}(\text{diagnosed sick})}$$

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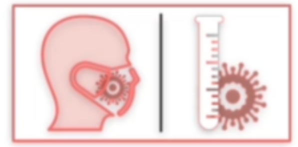
# Bayes Theorem - Formula



$A$: sick

$B$: diagnosed sick

$\mathbf{P}$(sick | diagnosed sick) = ?

$\mathbf{P}$(sick) = 0.01%

$\mathbf{P}$(not sick) = 99.99%

$\mathbf{P}$(diagnosed sick | sick) = 99%

$\mathbf{P}$(diagnosed sick | not sick) = 1%

$$\mathbf{P}(A \mid B) = \frac{\mathbf{P}(A \cap B)}{\mathbf{P}(B)}$$

$$\mathbf{P}(A \mid B) = \frac{\mathbf{P}(\text{sick and diagnosed}}{\mathbf{P}(\text{diagnosed sick})}$$

$\mathbf{P}$(sick and diagnosed sick) = ?

$\mathbf{P}$(diagnosed sick) = ?

**BAYES THEOREM FORMULA CAN HELP**

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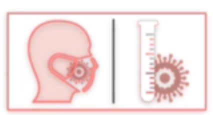
Q. Correct Expression for $P(\text{diagnosed sick}) = P(\text{sick} \cap \text{diagnosed sick}) + P(\text{not sick} \cap \text{diagnosed sick})$

# Bayes Theorem - Formula



$A$: sick

$B$: diagnosed sick

$\mathbf{P}$(sick | diagnosed sick) = ?

$\mathbf{P}$(sick) = 0.01%

$\mathbf{P}$(not sick) = 99.99%

$\mathbf{P}$(diagnosed sick | sick) = 99%

$\mathbf{P}$(diagnosed sick | not sick) = 1%

$$\mathbf{P}(A \mid B) = \frac{\mathbf{P}(A \cap B)}{\mathbf{P}(B)}$$

$$\mathbf{P}(A \mid B) = \frac{\mathbf{P}(\text{sick}) \bullet \mathbf{P}(\text{diagnosed sick} \mid \text{sick})}{\mathbf{P}(\text{diagnosed sick}) = ?}$$

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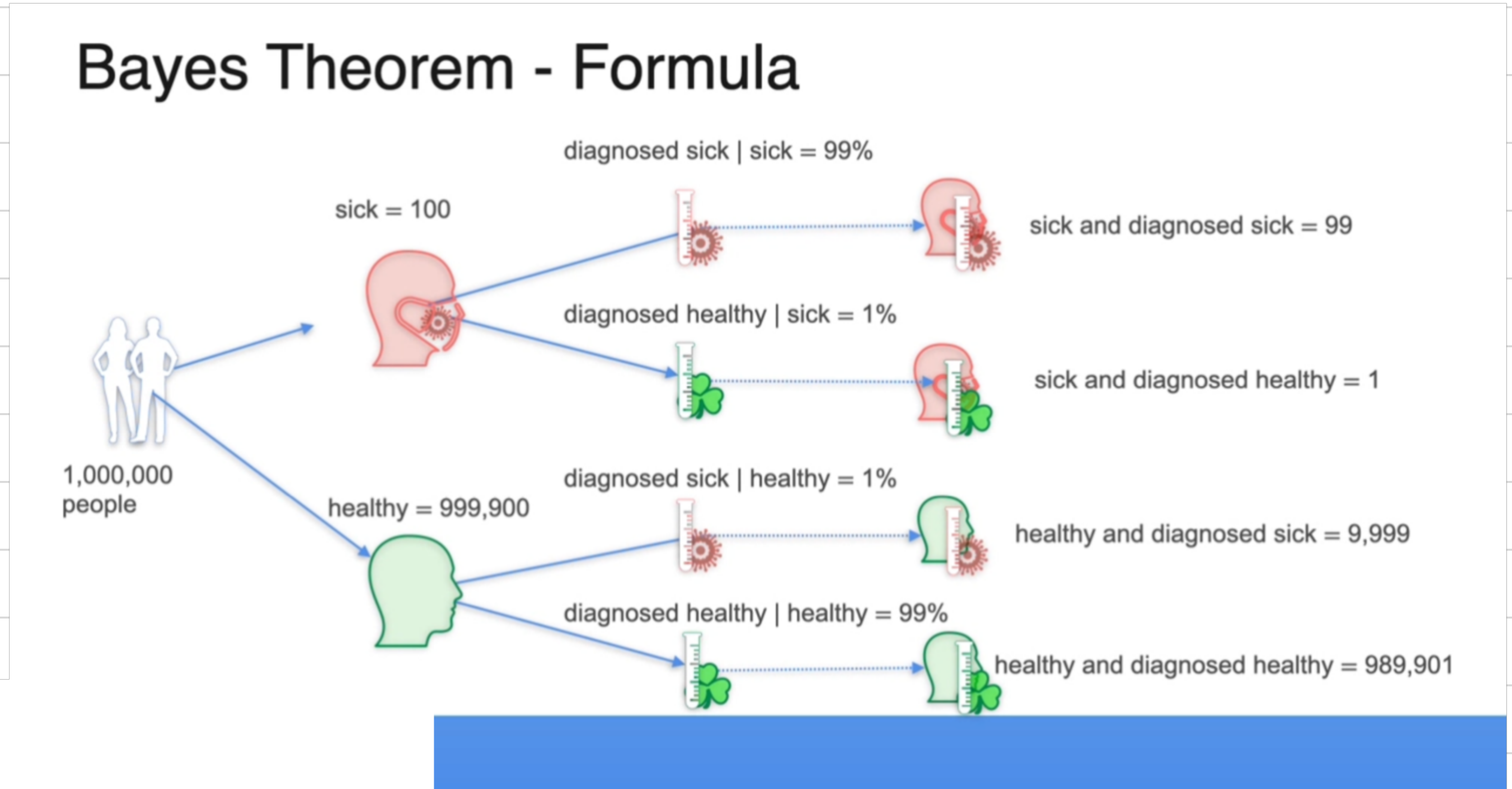
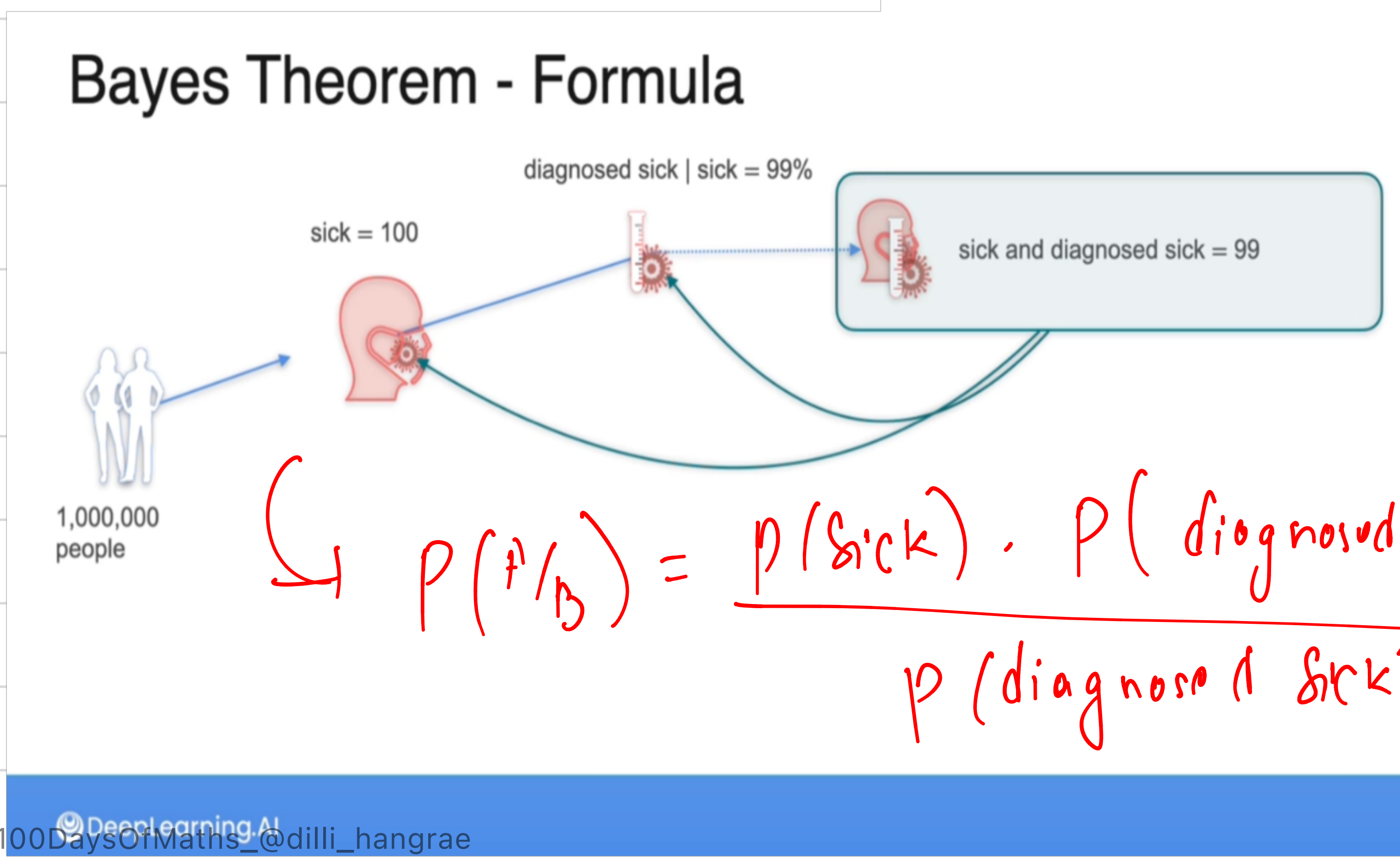
Tree of Possibilities:




$$\hookrightarrow P(A/B) = \frac{p(\text{sick}) \cdot P(\text{diagnosed sick} \mid \text{sick})}{p(\text{diagnosed sick})} \; ?$$

$P(\text{diagnosed Sick}) = ?$

$P(A) = 0.01\,\%$

$P(A') = 99.99\,\%$

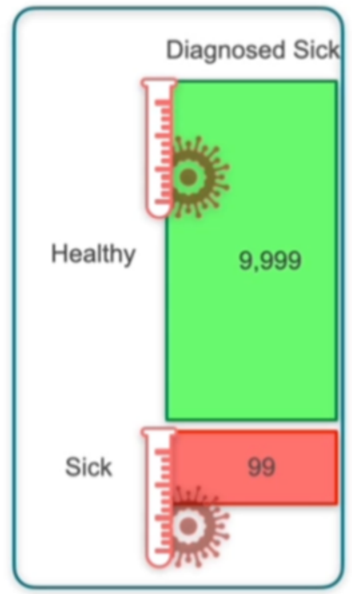
$P(B/A) = 99\,\%$

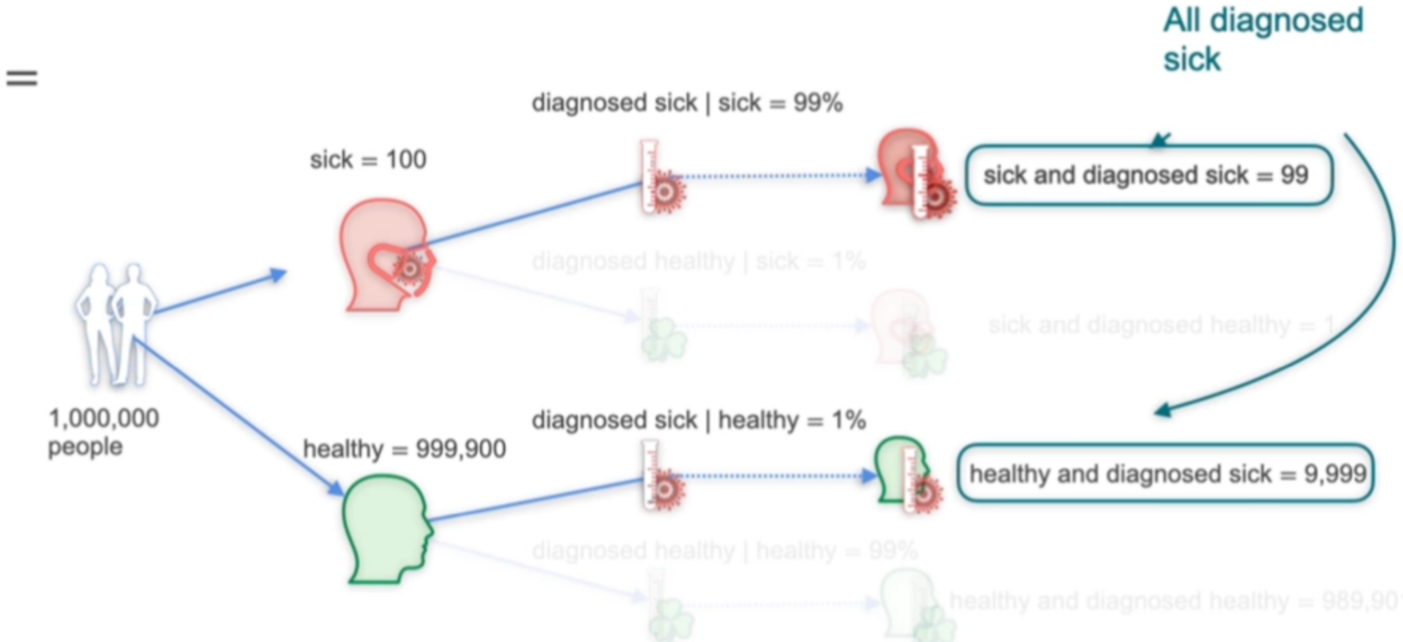
$P(B/A') = 1\,\%$

$$P(A/B) \Rightarrow \frac{P(A)\cdot P(B/A)}{P(A)\cdot P(B/A) + P(A')\cdot P(B/A')}$$

# Bayes Theorem - Formula

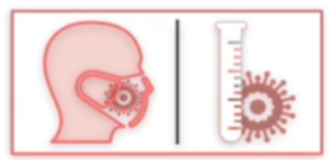
**P**(diagnosed sick) =




**P**(sick ∩ diagnosed sick) + **P**(not sick ∩ diagnosed sick)

# Bayes Theorem - Formula



*A*: sick

*B*: diagnosed sick

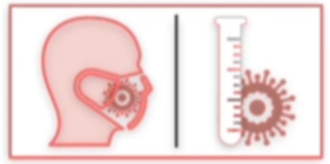
$$\mathbf{P}(A \mid B) = \frac{\mathbf{P}(A \cap B)}{\mathbf{P}(B)}$$

$$\mathbf{P}(A \mid B) = \frac{\mathbf{P}(\text{sick}) \bullet \mathbf{P}(\text{diagnosed sick} \mid \text{sick})}{\mathbf{P}(\text{sick} \cap \text{diagnosed sick}) + \mathbf{P}(\text{not sick} \cap \text{diagnosed sick})}$$

$$\mathbf{P}(\text{sick} \cap \text{diagnosed sick}) = \mathbf{P}(A \cap B) = \mathbf{P}(\text{sick}) \bullet \mathbf{P}(\text{diagnosed sick} \mid \text{sick})$$

$$\mathbf{P}(\text{not sick} \cap \text{diagnosed sick}) = \mathbf{P}(A' \cap B) = \mathbf{P}(\text{not sick}) \bullet \mathbf{P}(\text{diagnosed sick} \mid \text{not sick})$$

# Bayes Theorem - Formula



$A$: sick

$B$: diagnosed sick

$$\mathbf{P}(A \mid B) = \frac{\mathbf{P}(A \cap B)}{\mathbf{P}(B)}$$

$$\mathbf{P}(A \mid B) = \frac{\mathbf{P}(\text{sick}) \bullet \mathbf{P}(\text{diagnosed sick} \mid \text{sick})}{\mathbf{P}(\text{sick}) \bullet \mathbf{P}(\text{diagnosed sick} \mid \text{sick}) + \mathbf{P}(\text{not sick}) \bullet \mathbf{P}(\text{diagnosed sick} \mid \text{not sick})}$$

$\mathbf{P}(\text{sick}) = 0.01\%$

$\mathbf{P}(\text{not sick}) = 99.99\%$

$\mathbf{P}(\text{diagnosed sick} \mid \text{sick}) = 99\%$

$\mathbf{P}(\text{diagnosed sick} \mid \text{not sick}) = 1\%$

**BAYES THEOREM FORMULA**

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$$\Rightarrow \frac{0.01 \cdot 99\%}{0.01 \times 99 + 99.99 \times 1}$$

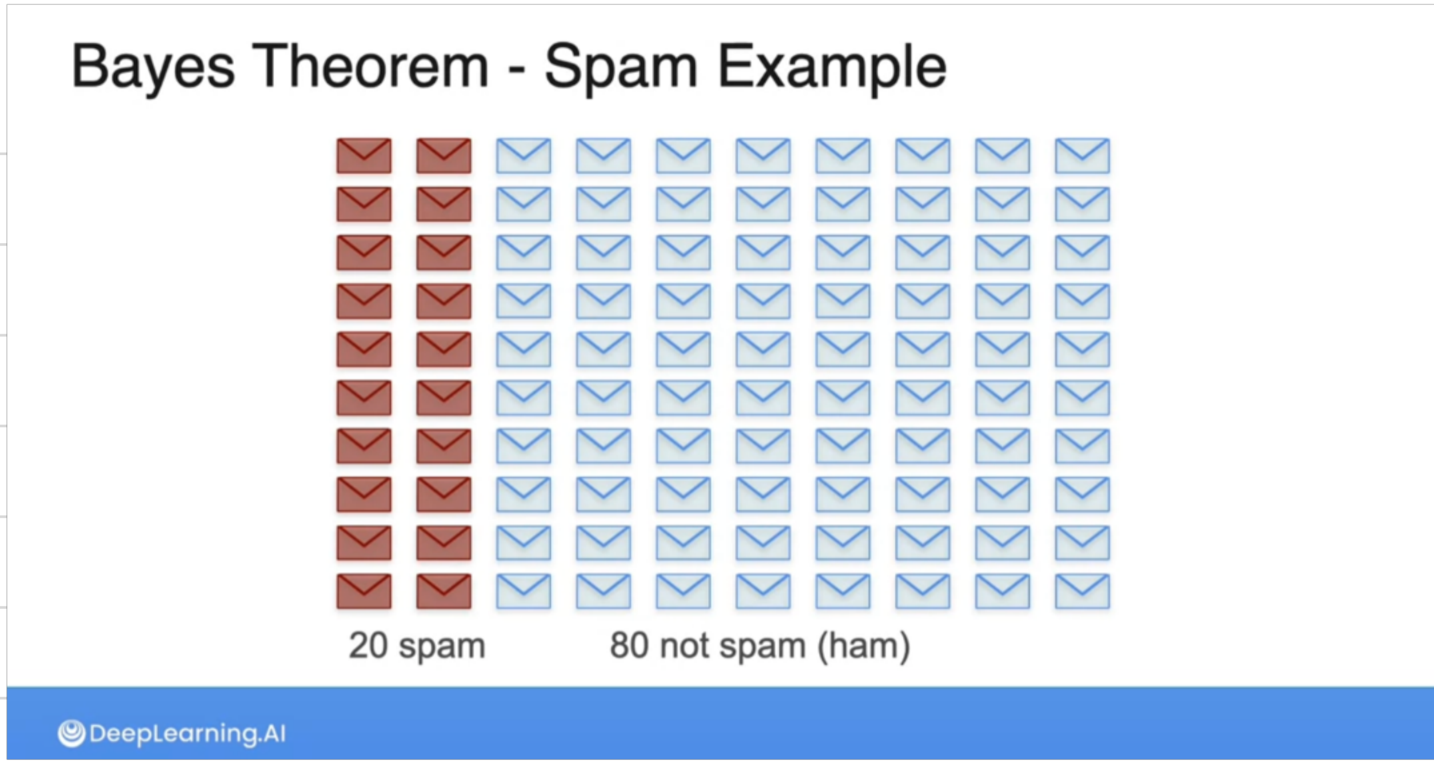
$$\Rightarrow \frac{P(A) \cdot P(B/A)}{P(A) \cdot P(B/A) + P(A') \cdot P(B/A')}$$

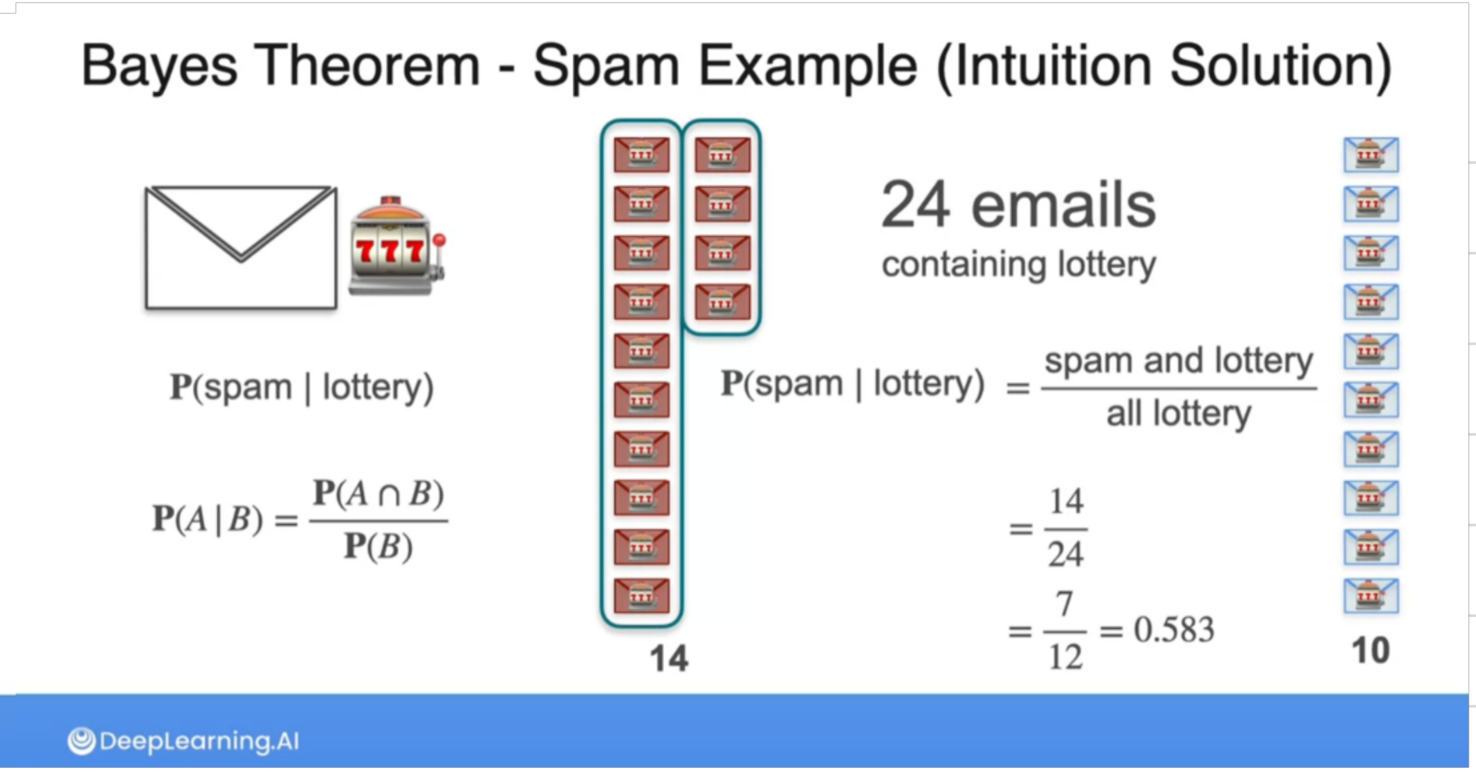
$$\Rightarrow 0.0098$$

$$\boxed{P(A/B) = 0.0098}$$

So, the Baye's Theoram is

$$\left[ P(A/B) = \frac{P(A) \cdot P(B/A)}{P(A) \cdot P(B/A) + P(A') \cdot P(B/A')} \right]$$




## Bayes Theorem - Spam Example (formula Solution):

P(Spam | lottery)

$$P(A/B) = \frac{P(A) \cdot P(B/A)}{P(A) \cdot P(B/A) + P(A') \cdot P(B/A')}$$

A ⇒ Email is Spam  B · Email contains lottery

$$P(\text{Spam} \mid \text{lottery}) = \frac{P(\text{Spam}) \cdot P(\text{lottery} \mid \text{Spam})}{P(\text{spam}) \cdot P(\text{lottery} \mid \text{Spam}) + P(\text{not Spam}) \cdot P(\text{lottery} \mid \text{not Spam})}$$

## Bayes Theorem - Spam Example (Formula Solution)

$P(\text{spam}) = 0.2$ $\quad P(\text{lottery} \mid \text{spam}) = 0.7$

$P(\text{not spam}) = 0.8$ $\quad P(\text{lottery} \mid \text{not spam}) = 0.125$

$$P(\text{spam} \mid \text{lottery}) = \frac{P(\text{spam}) \cdot P(\text{lottery} \mid \text{spam})}{P(\text{spam}) \cdot P(\text{lottery} \mid \text{spam}) + P(\text{not spam}) \cdot P(\text{lottery} \mid \text{not spam})}$$

$$P(\text{spam} \mid \text{lottery}) = \frac{0.2 \times 0.7}{(0.2 \times 0.7) + (0.8 \times 0.125)}$$

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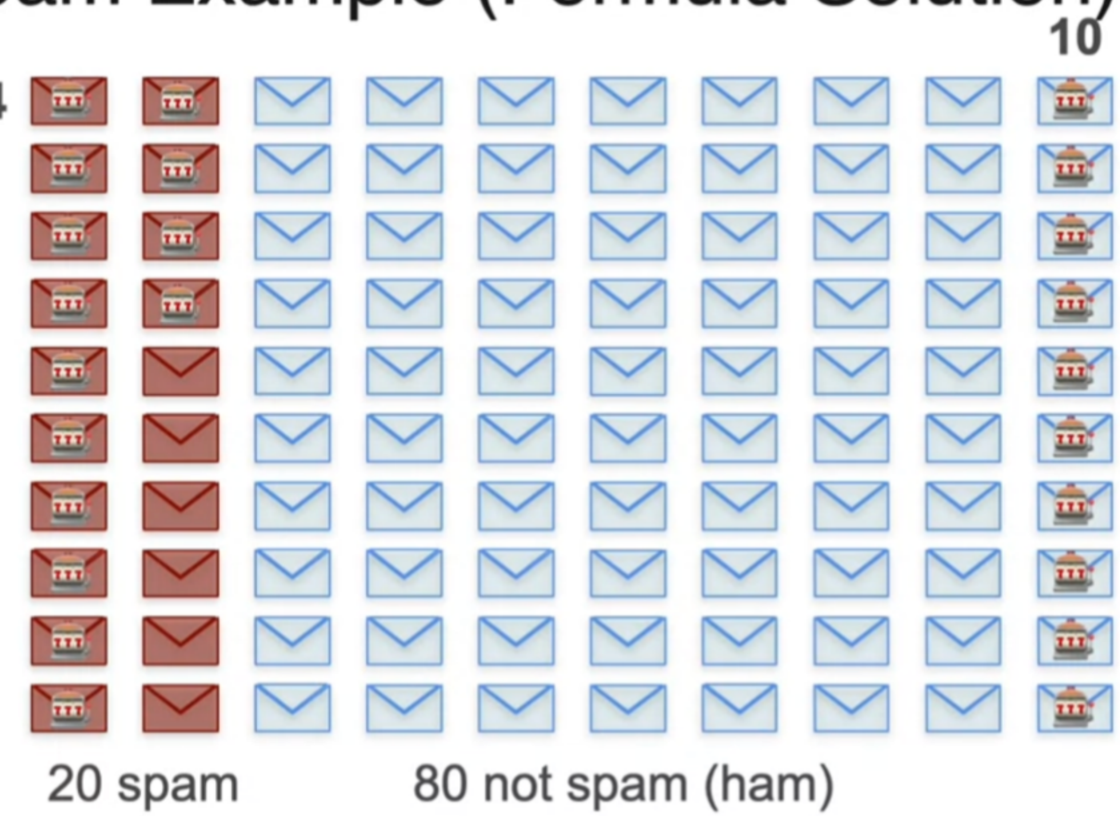
## Bayes Theorem - Spam Example (Formula Solution)

$$P(\text{spam}) = \frac{20}{100} = 0.2$$

$$P(\text{not spam}) = \frac{80}{100} = 0.8$$

$$P(\text{lottery} \mid \text{spam}) = \frac{14}{20} = 0.7$$

$$P(\text{lottery} \mid \text{not spam}) = \frac{10}{80} = 0.125$$

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$$\Rightarrow \frac{0.14}{(0.14) + (0.1)}$$

$$P(S|L) \Rightarrow 0.5833$$

email → Spam, Ham

### Bayes Theorem

**Prior**

$P(A)$

$$P(S) = \frac{P(S)}{P(S) + P(nS)}$$

**Event**

$E$

E contains lottery

**Posterior**

Spam and lottery

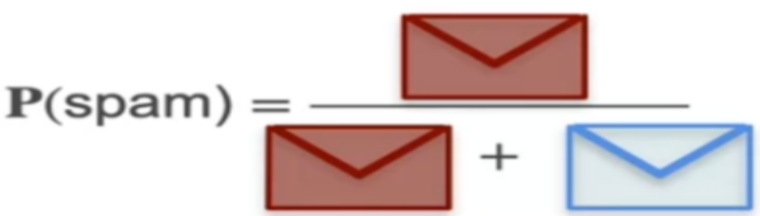
Ham and lottery

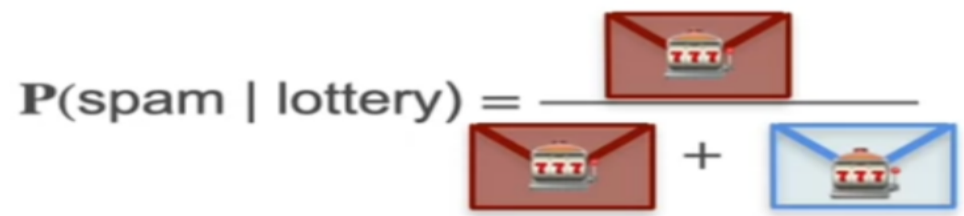
$$P(S|L) \Rightarrow \frac{P(SL)}{P(SL) + P(HSL)}$$

# Prior and Posterior

**PRIOR** | **EVENT** | **POSTERIOR**


Email contains lottery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## Prior and Posterior

**PRIOR**

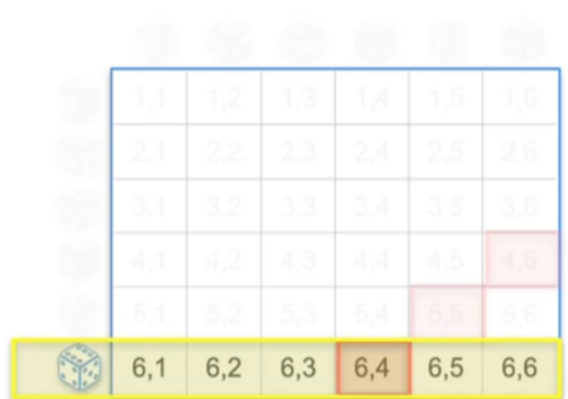
| | | | | | |
|---|---|---|---|---|---|
| 1,1 | 1,2 | 1,3 | 1,4 | 1,5 | 1,6 |
| 2,1 | 2,2 | 2,3 | 2,4 | 2,5 | 2,6 |
| 3,1 | 3,2 | 3,3 | 3,4 | 3,5 | 3,6 |
| 4,1 | 4,2 | 4,3 | 4,4 | 4,5 | 4,6 |
| 5,1 | 5,2 | 5,3 | 5,4 | 5,5 | 5,6 |
| 6,1 | 6,2 | 6,3 | 6,4 | 6,5 | 6,6 |

$$\mathbf{P}(\text{sum} = 10) = \frac{3}{36}$$

**EVENT**


1st dice is 6

**POSTERIOR**




$$\mathbf{P}(\text{sum} = 10 \mid \text{1st is 6}) = \frac{1}{6}$$

## Prior and Posterior

**PRIOR**


$$\mathbf{P}(HH) = \frac{1}{4}$$

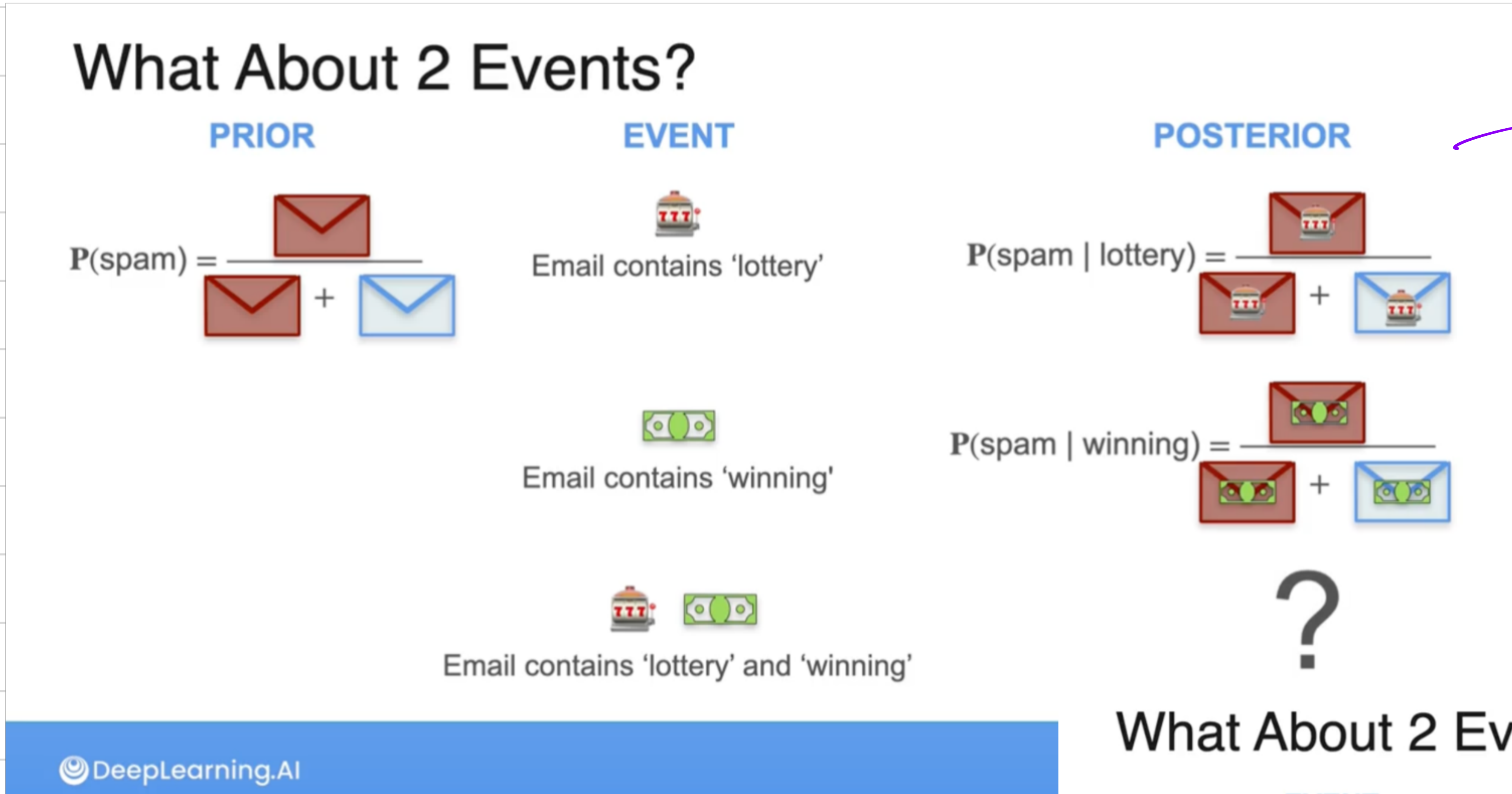
**EVENT**

1st coin is $H$

**POSTERIOR**

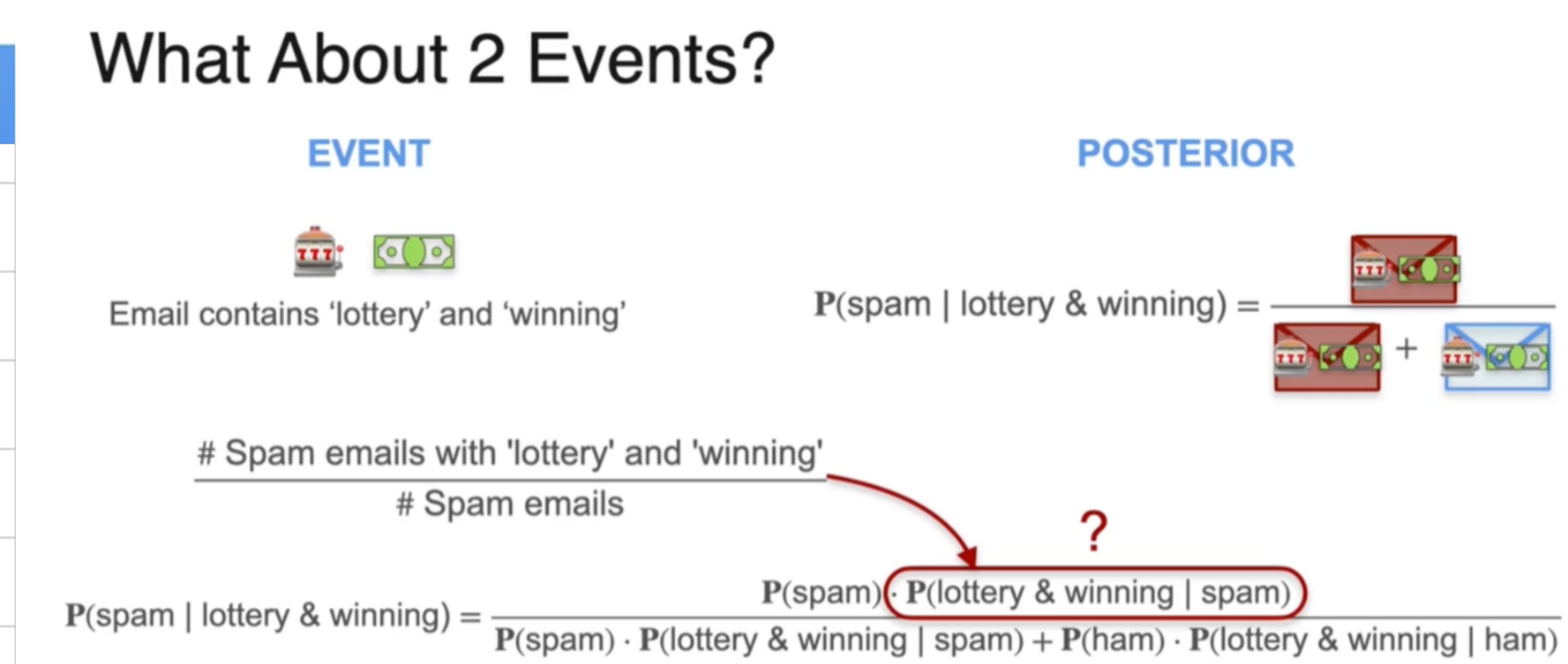

$$\mathbf{P}(HH \mid \text{1st is } H) = \frac{1}{2}$$

# Bayes theorem - The Naive Bayes Model:




This is okay since No overlapping or the complexity arises'

This one is not simple and the problem arises.



for that we have the NAIVE ASSUMPTION

# Is There a Quicker Way To Estimate the Probability?

**Naive assumption**

The appearances of 'lottery' and 'winning' are independent

$$P(A \cap B) = P(A) \cdot P(B)$$

$$P(\text{spam} \mid \text{lottery \& winning}) = \frac{P(\text{spam}) \cdot P(\text{lottery \& winning} \mid \text{spam})}{P(\text{spam}) \cdot P(\text{lottery \& winning} \mid \text{spam}) + P(\text{ham}) \cdot P(\text{lottery \& winning} \mid \text{ham})}$$

problem and the solution is

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# Is There a Quicker Way To Estimate the Probability?

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$$P(\text{Spam}) = \frac{20}{100}$$

$$P(\text{ham}) = \frac{80}{100}$$

# Is There a Quicker Way To Estimate the Probability?

## Naive assumption

The appearances of the words $w_1, w_2, \ldots, w_n$ are independent

$$\mathbf{P}(\text{spam} \mid w_1, \ldots, w_n) = \frac{\mathbf{P}(\text{spam}) \cdot \mathbf{P}(w_1 \mid \text{spam}) \cdots \mathbf{P}(w_n \mid \text{spam})}{\mathbf{P}(\text{spam}) \cdot \mathbf{P}(w_1 \mid \text{spam}) \cdots \mathbf{P}(w_n \mid \text{spam}) + \mathbf{P}(\text{ham}) \cdot \mathbf{P}(w_1 \mid \text{ham}) \cdots \mathbf{P}(w_n \mid \text{ham})}$$

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$$P(L \mid S) = \frac{14}{20}$$

$$P(L \mid H) = \frac{10}{80}$$

$$P(W \mid S) = \frac{15}{20} = 0.75$$

$$P(W \mid H) = \frac{8}{20}$$

So,

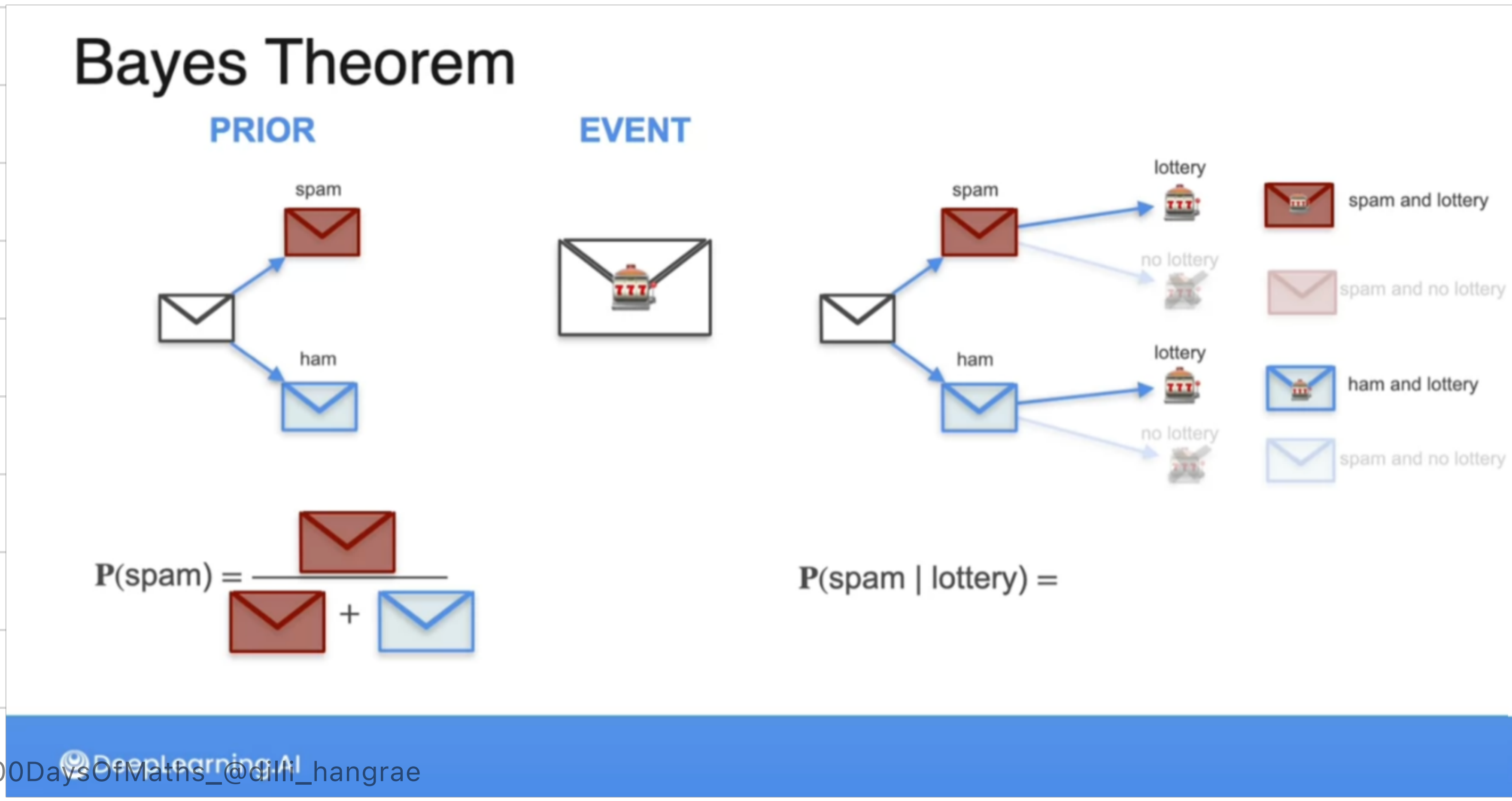
$$P(\text{spam} \mid \text{lottery}) \Rightarrow \frac{P(\text{spam}) \cdot P(\text{lottery} \mid \text{spam}) \cdot P(\text{winning} \mid \text{spam})}{P(\text{spam}) \cdot P(\text{lottery} \mid \text{spam}) \cdot P(\text{winning} \mid \text{spam}) + P(\text{ham}) \cdot P(\text{lottery} \mid \text{ham}) \cdot P(\text{winning} \mid \text{ham})}$$

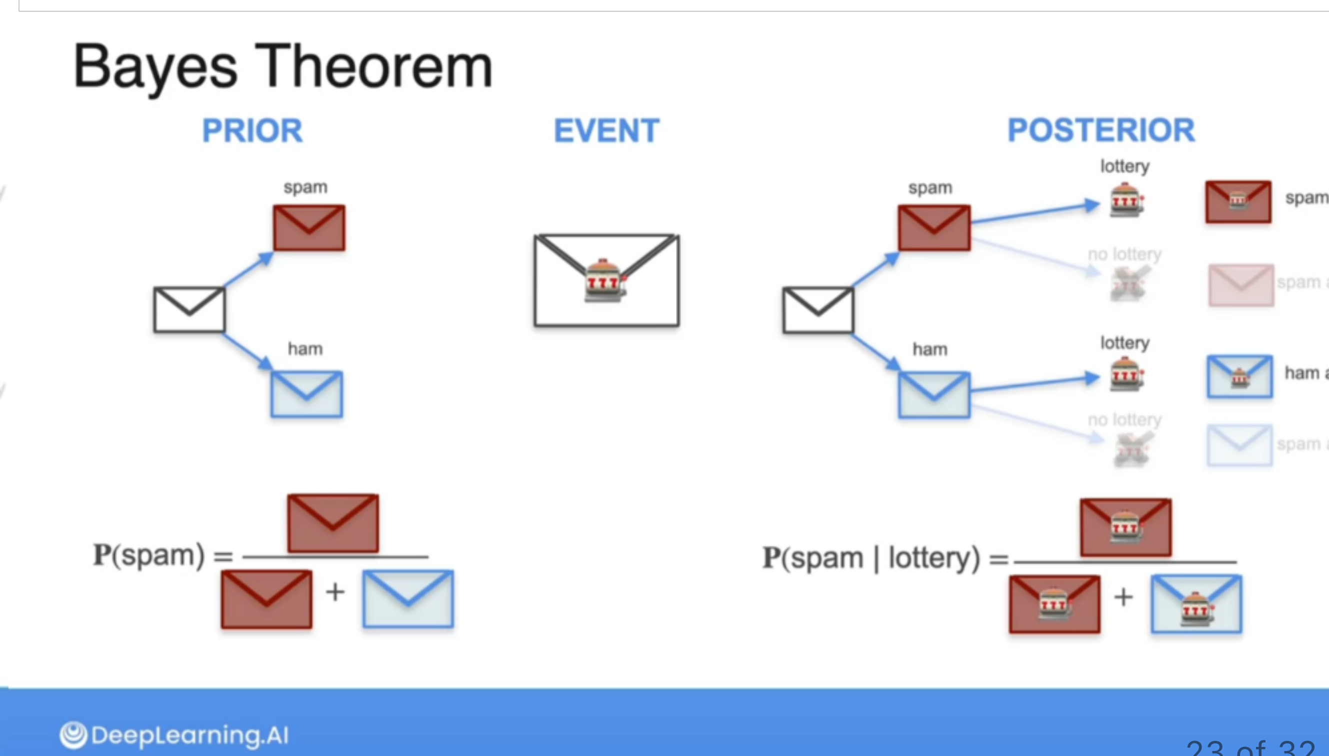
$\rightarrow 0.913$

# Probability in Machine Learning:

→ Recognize Cat in an Image based on the Probability that there's Cat in the Image or Not.

→ Image generation and probability of text generation that a bunch of words are sensitive text or it talks about it something.



# Example Problem

Classification

Patient 3

Patient 2

| Patient 1 | |
|---|---|
| Age | 29 |
| Gender | Female |
| Height | 169 cm |
| Weight | 62 kg |
| Smoker | No |
| ... | ... |
| Heart rate | 63 |
| Blood pressure | 120 90 |

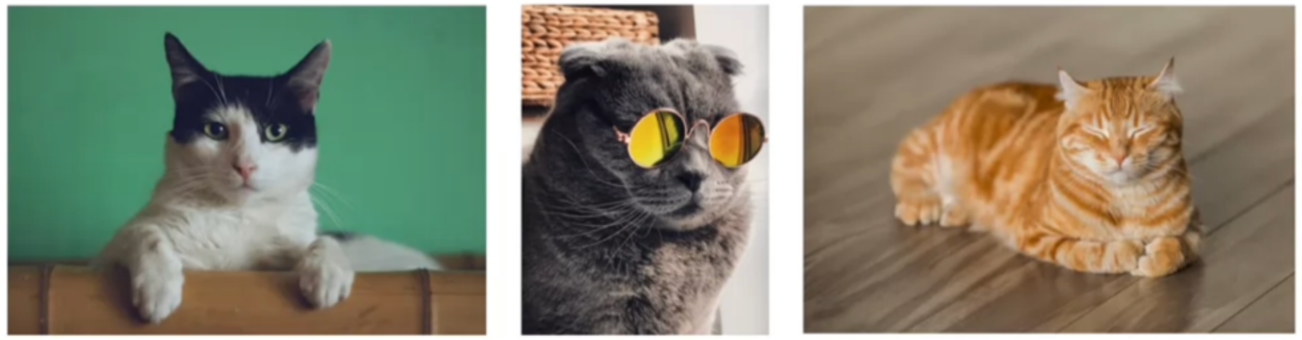
- Is this patient healthy?
- Calculate $\mathbf{P}(\text{healthy} \mid \text{symptoms and history})$



# Example Problem

Image recognition

- What is the probability that there is a cat in the image
- $\mathbf{P}(\text{cat} \mid \text{image}) = \mathbf{P}(\text{cat} \mid \text{pixel}_1, \text{pixel}_2, \ldots, \text{pixel}_n)$



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However RNN and transformer Architecture is widely used Instead of using only Pure Probability Method!

100DaysOfMaths_@dilli_hangrae

# Example Problem

Sentiment analysis

the first cold shower
even the monkey seems to want
a little coat of straw

Matsuo Bashō

- Is this a happy sentence?
- Calculate P(happy I words in the sentence)

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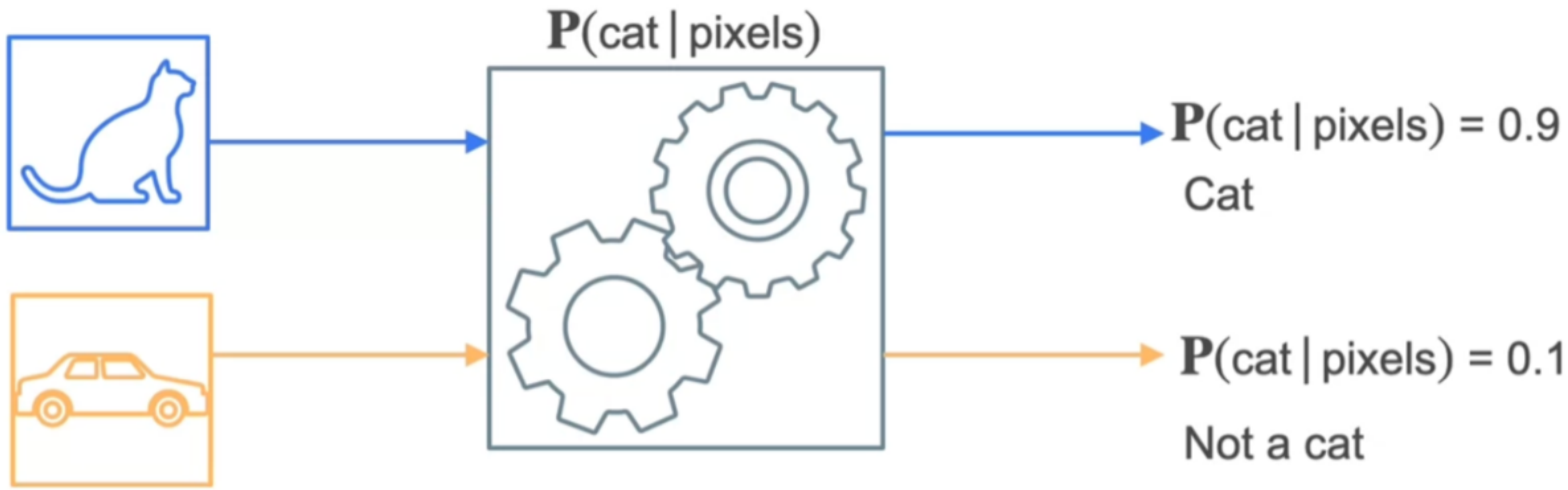
# Example Solution

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→ Application of Probability in Machine Learning.

# Example Problem: Generative Models

Face generation

- Generate a group of pixels such that the resulting image looks like a human face.
- Goal: generate images such that $\mathbf{P}$(face | pixels) is high.


Image generated by a StyleGAN

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# Random Variables:

Flip a Coin

$P(H) = 0.5$ $\quad$ $P(T) = 0.5$

$X =$ number of heads

Flip a Coin

1 heads $\quad$ 0 heads

$X = 1$ $\quad$ $X = 0$

$P(X = 1) = 0.5$ $\quad$ $P(X = 0) = 0.5$

$\rightarrow$ $X$ is a random Variable.

## From Events to Random Variables.

$X$ = Number of heads in 10 Coin tosses $\quad$ $P(H) = 0.5$

$X = 10$ $\quad$ H H H H H H H H H H $\quad$ $0.5^{10}$

$X = 9$ $\quad$ H T H H H H H H H H $\quad$ $0.5^{9}\ 0.5^{1}$

$X = 9$ $\quad$ H H H H T H H H H H $\quad$ $0.5^{9}\ 0.5^{1}$

$P(X = 0)$ ?

$P(X = 1)$ ?

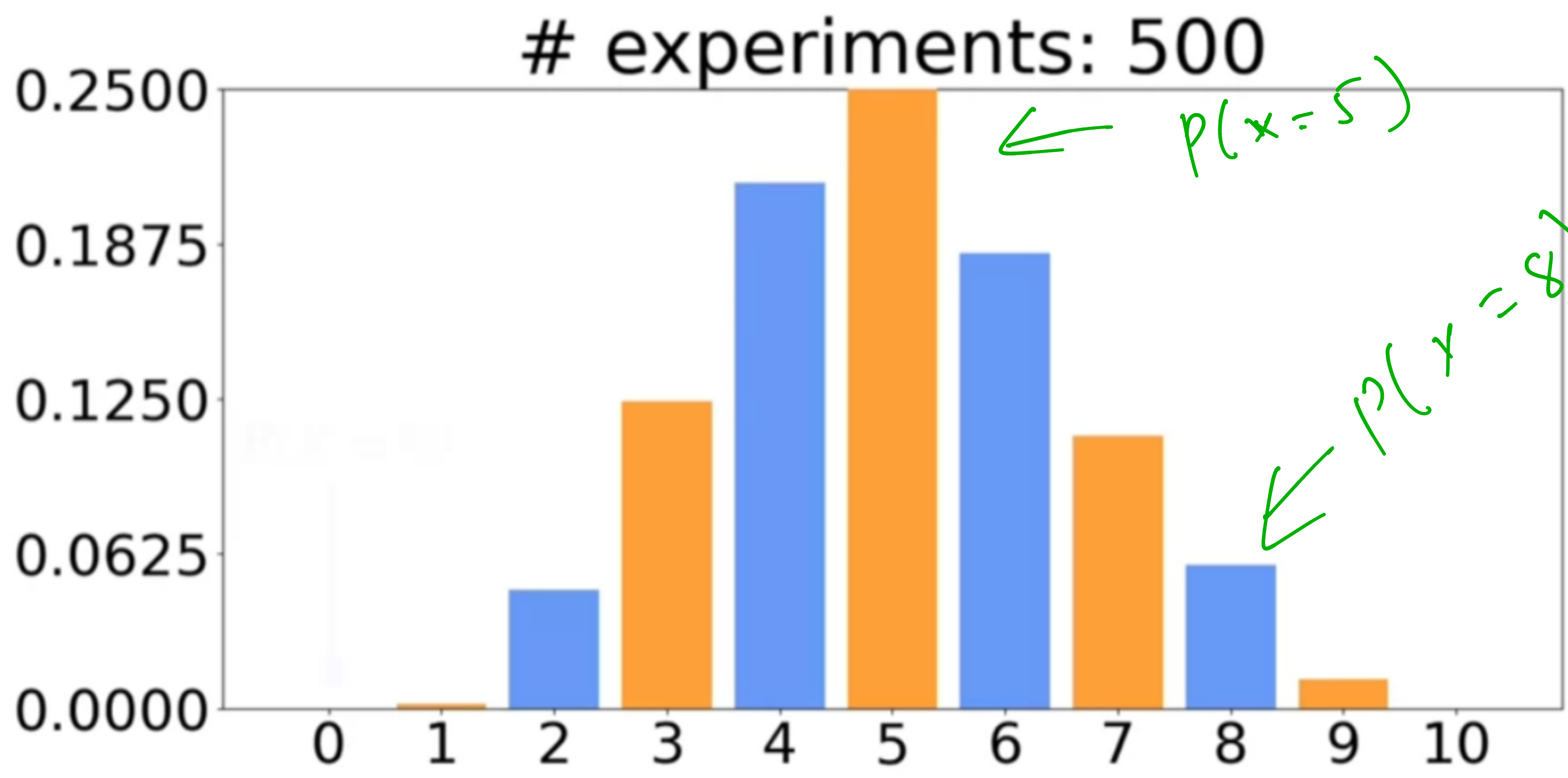
$\vdots$

$P(X = 10)$ ?

# Flipping a Fair Coin 500 Times

Here $x$ is the Head

8 Head 2 Tail




$p(x=5)$

$p(x=8)$

$\mathbf{P}(H) = 0.5$

Repeat 500 times

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- Random Variables allow you to model the whole experiment at once.

$X$ = number of Heads

$X$ = number of sick patients

$X$ = Number of 1's

$P(X=1) = 0.5$

$P(X=-7) = 0.2$

## Other Random Variables:

1. Wait time until the next bus arrives.
2. Height of an Gymnast's jump
3. No. of defective products in a shipment
4. mm of rain in November.

# Discrete and Continuous Random Variables

**Discrete random variables**


~~Finite number of values~~
(Could be infinite too)

Can take only a **countable** number of values

**Continuous random variables**

Infinite number of values

Takes values on an interval

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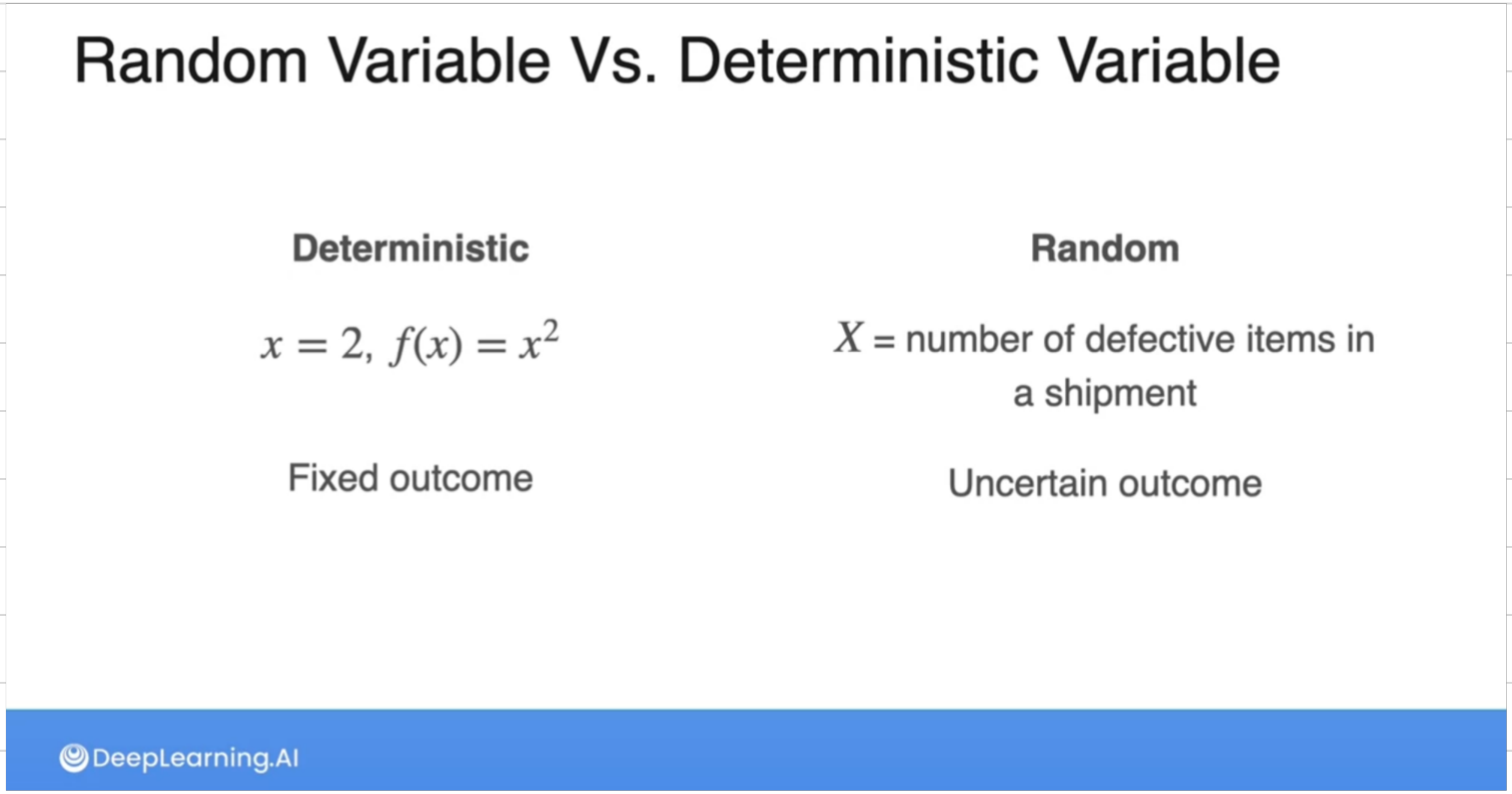


① Random Variable is not fixed and may associate with all the uncertainties.

# Probability Distribution:

All the possible scenarios that can happen and put them on this horizontal axis and for each one of them, look at the probability that they can have, this form of Probability Distribution is is the probability Distribution (Gaussian, Uniform, Exponential).

## Flip Three Coins

$X_1$: number of heads in **3** coin tosses


All three tails $(X = 0)$

One heads $(X = 1)$

Two heads $(X = 2)$

All three heads $(X = 3)$

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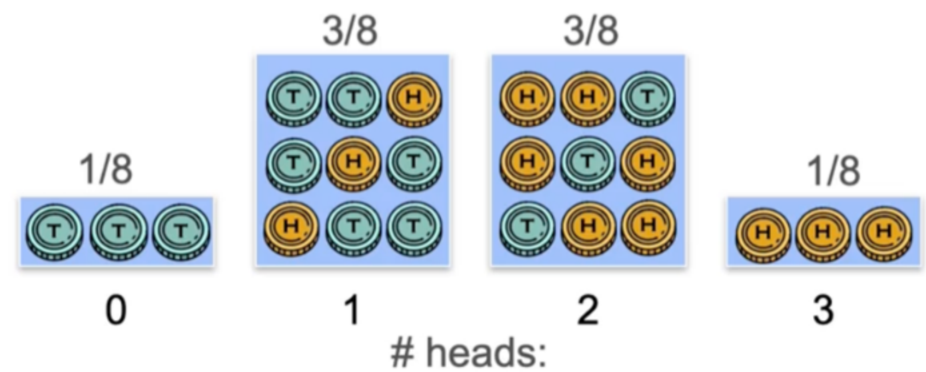
## Flip Three Coins

$X_1$: number of heads in **3** coin tosses

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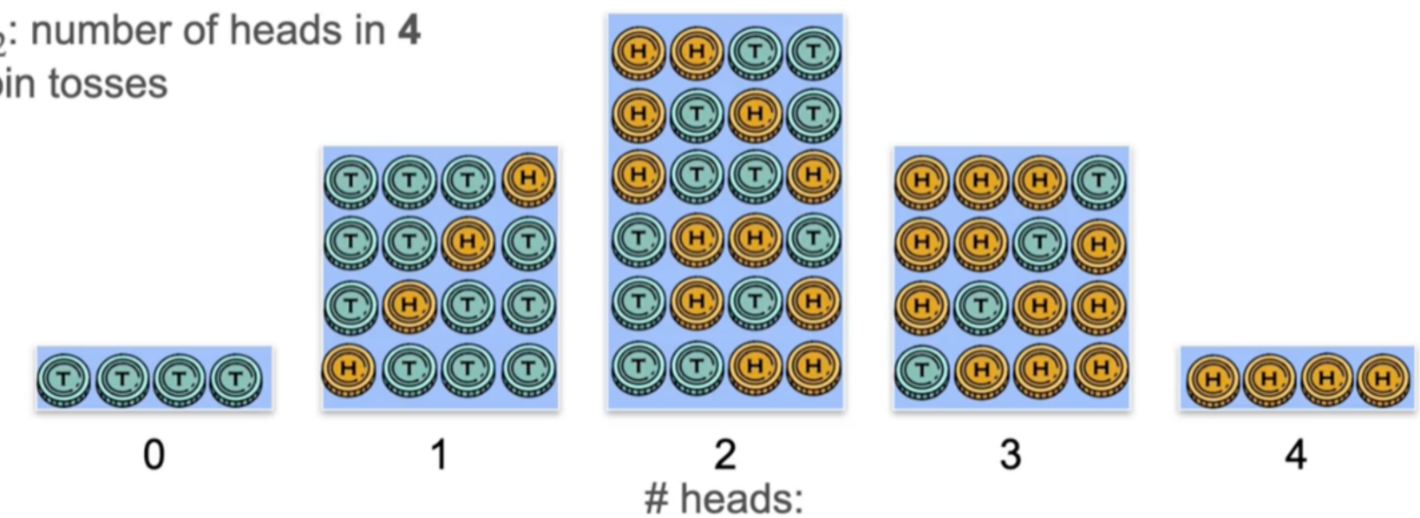
## Flip Four Coins

$X_2$: number of heads in **4** coin tosses

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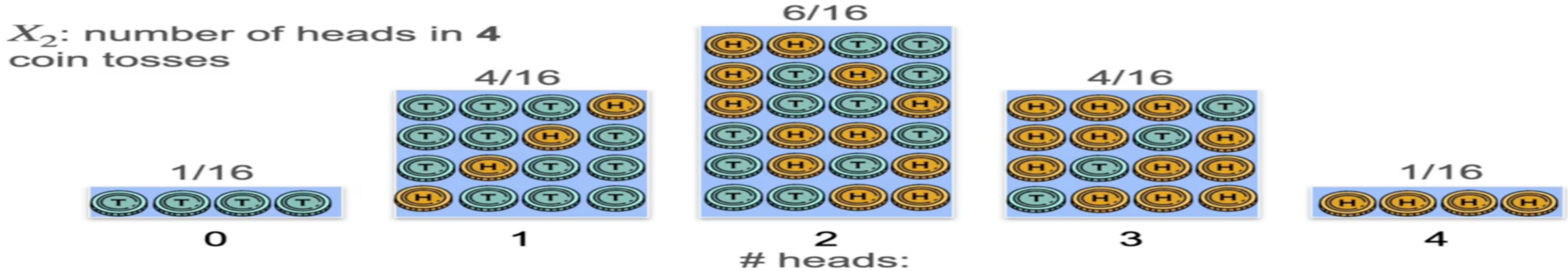
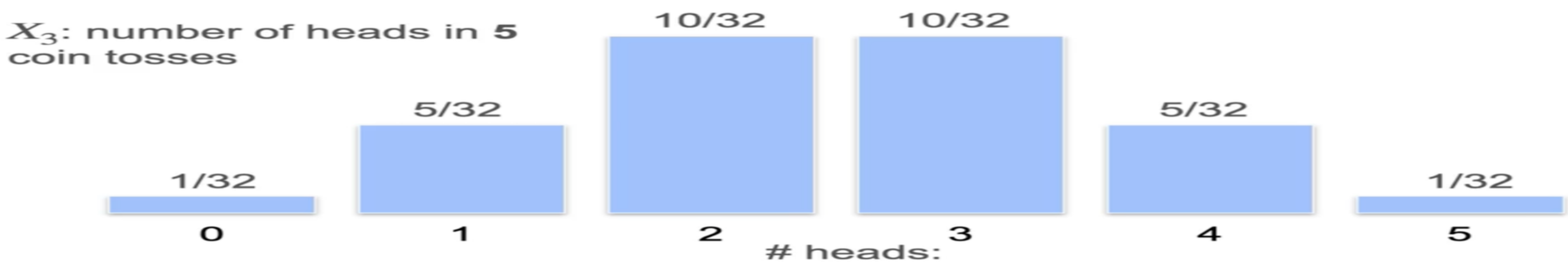
# Flip Four Coins



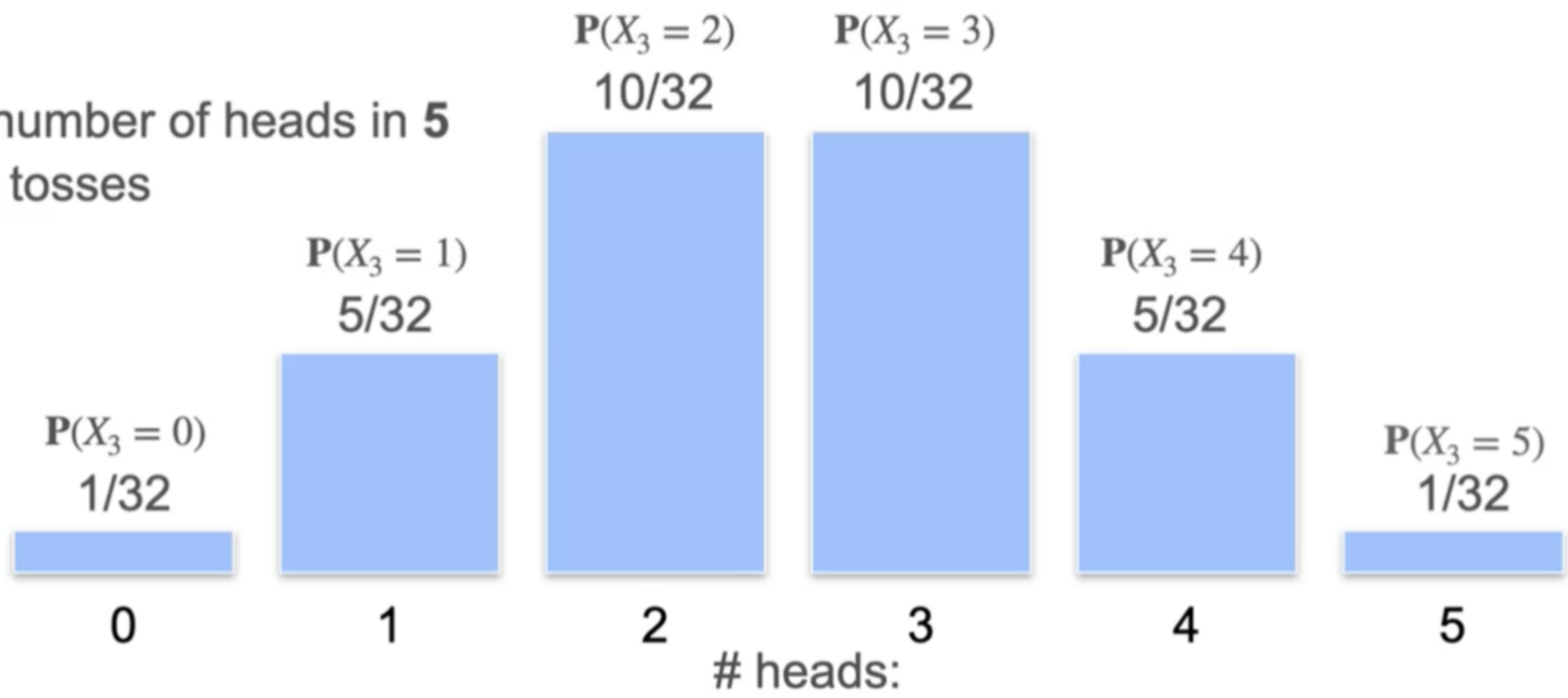



# Flip Five Coins



# Flip Five Coins

$X_3$: number of heads in **5** coin tosses

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## Can You See a Pattern?

$X_1, X_2, X_3, X_4$ are very similar

They all represent **number of heads in $n$ experiments**

The way the probability distributes along the possible outcomes seems to have a similar pattern

Could there be a **single model** to represent all this variables?

↓

Binomial distribution

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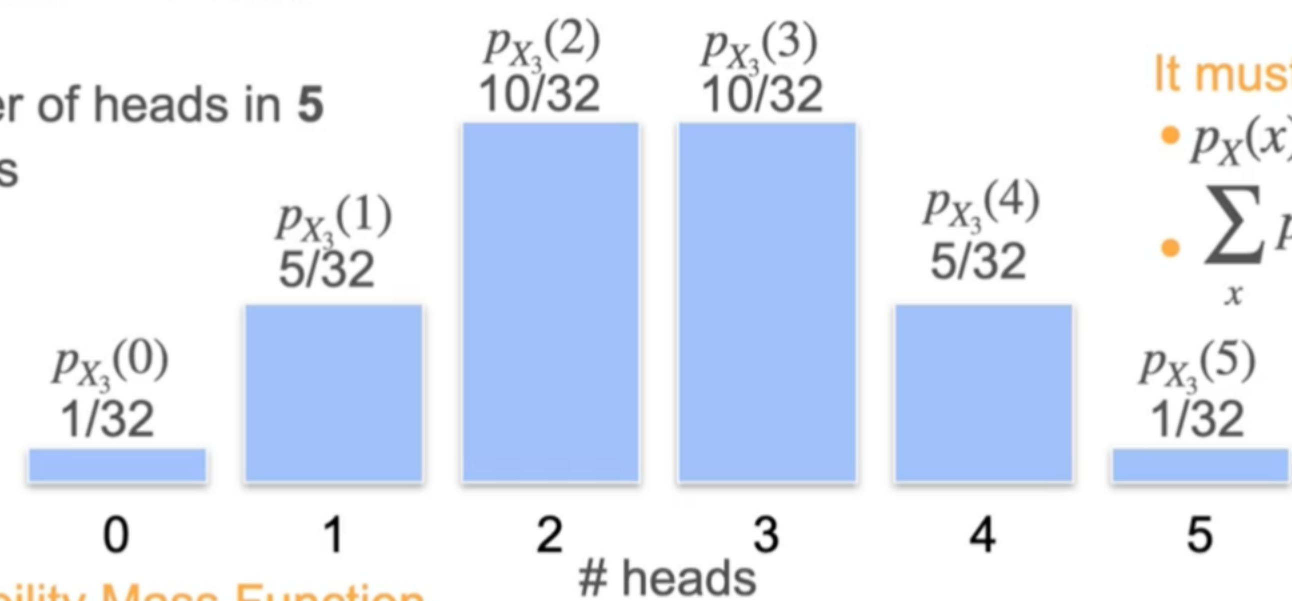
# Flip Five Coins

$X_3$: number of heads in **5** coin tosses




It must satisfy:

- $p_X(x) \geq 0$
- $\sum_x p_X(x) = 1$

Probability Mass Function (PMF)

$p_X(x) = \mathbf{P}(X_4 = x), \quad x = 0,1,2,3,4,5$

$$p_{X_3}(0) + p_{X_3}(1) + p_{X_3}(2) + p_{X_3}(3) + p_{X_3}(4) + p_{X_3}(5) = \frac{1}{32} + \frac{5}{32} + \frac{10}{32} + \frac{10}{32} + \frac{5}{32} + \frac{1}{32} = 1$$