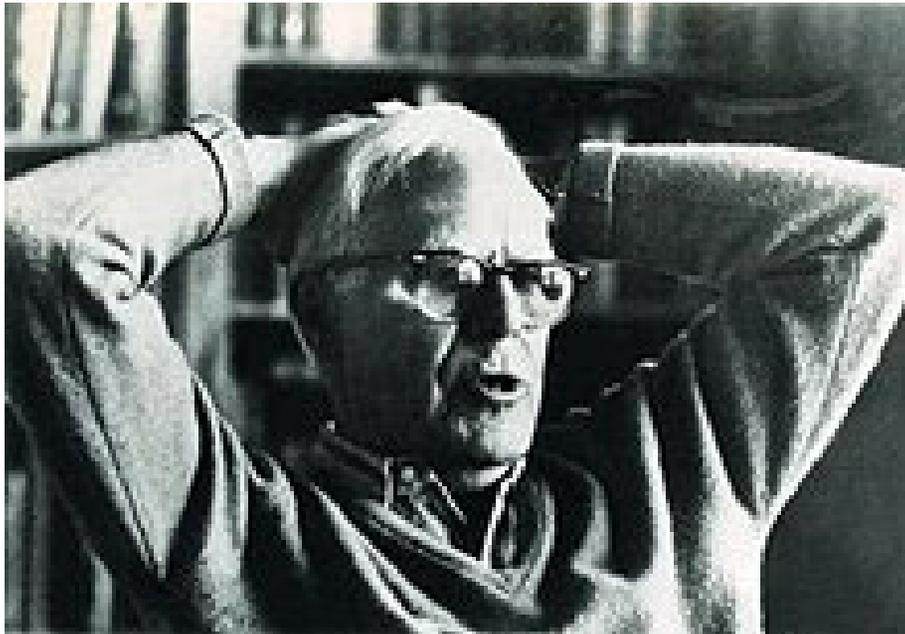


# Secretary problem

- An **employer** has a known number –  $n$  – of **applicants** for a secretary position, who are **interviewed one at a time**
- Employer can easily **evaluate and rank** applicants relative to each other but has no idea of the overall distribution of their quality
- Employer has only one chance to choose the secretary: gives **yes/no answer in the end of each interview** and cannot go back to rejected applicants
- How can employer **maximize the probability to choose the best secretary** among all applicants?



**Martin Gardner (1914 – 2010)**  
Described the “secretary problem”  
in *Scientific American* 1960.

was an American popular  
mathematics and popular  
science writer. Best known  
for “recreational mathematics”:  
He was behind the  
“Mathematical Games” section  
in *Scientific American*.



**Eugene Dynkin (1924 – 2014)**  
solved this problem in 1963.  
He referred to it as a “picky bride  
problem”

was a Soviet and later American  
mathematician, member of the  
US National Academy of Science.  
He has made contributions to the  
fields of probability and algebra.  
The Dynkin diagram, the Dynkin  
system, and Dynkin's lemma are  
all named after him.

# Who solved the secretary problem?

- Gardner outlined the solution in Sci Am 1960 but gave no formal proof
- Solution by Lindey was published in 1961:  
Lindey, D. V. (1961). Dynamic programming and decision theory. Appl. Statist. 10 39-51
- Dynkin's paper was published in 1963:  
Dynkin, E. B. (1963). The optimum choice of the instant for stopping a Markov process. Soviet Math. Dokl. 4 627-629
- When the celebrated German astronomer, Johannes Kepler (1571-1630), lost his first wife to cholera in 1611, he set about finding a new wife
- He spent 2 years on the process, had 11 candidates and married the 5<sup>th</sup> candidate ( $11/e \sim 4$  so he married the first after)

# What should the employer do?

- Employer **does not know the distribution of the quality of applicants** and **must learn it on the fly**
- Algorithm: look at the **first  $r-1$  applicants**, remember the best among them
- Hire the **first among next  $n-r+1$  applicants** who **is better than the best among the first  $r$  applicants**
- **How to choose the best  $r$ ?** Exploration vs exploitation
- When  **$r$  is too small – not enough information**: the best among  $r$  is not very good. You are likely to hire a bad secretary
- When  **$r$  is too large (e.g.  $r=n-1$ ) – you procrastinated for too long!** You have almost all the information, but you will have to hire the last applicant who is (likely) not particularly good

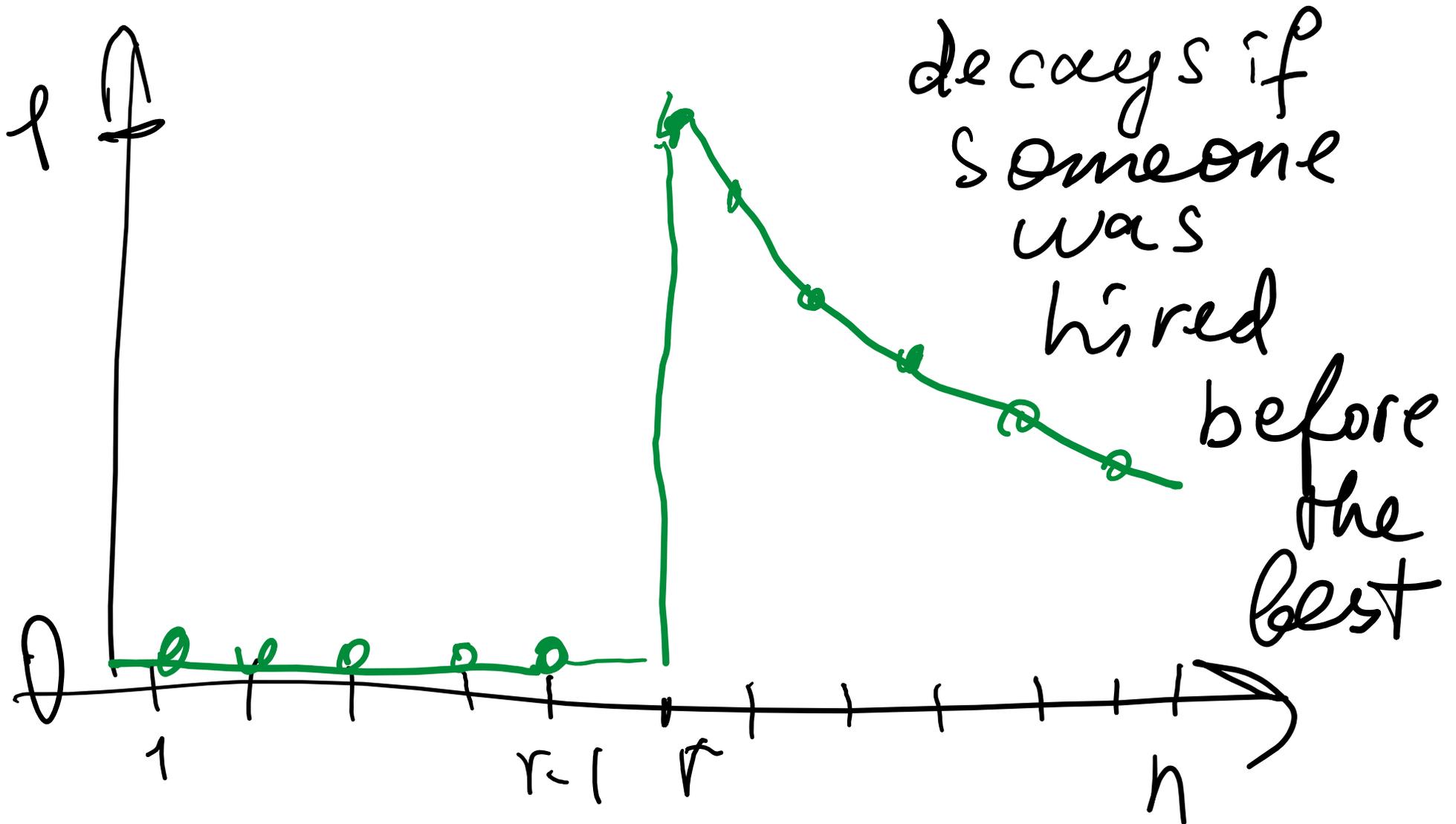
$$\begin{aligned} P(r) &= \sum_{i=1}^n P(\text{applicant } i \text{ is selected} \cap \text{applicant } i \text{ is the best}) \\ &= \sum_{i=1}^n P(\text{applicant } i \text{ is selected} | \text{applicant } i \text{ is the best}) \times P(\text{applicant } i \text{ is the best}) \end{aligned}$$

How to calculate?



The diagram consists of two hand-drawn arrows. The first arrow starts from the text 'How to calculate?' and points upwards and to the left towards the first term of the summation in the equation above. The second arrow starts from the fraction '1/n' and points upwards and to the right towards the conditional probability term 'P(applicant i is selected | applicant i is the best)' in the second line of the equation.

# Probability of hiring the best candidate if he/she has # $i$ in the queue

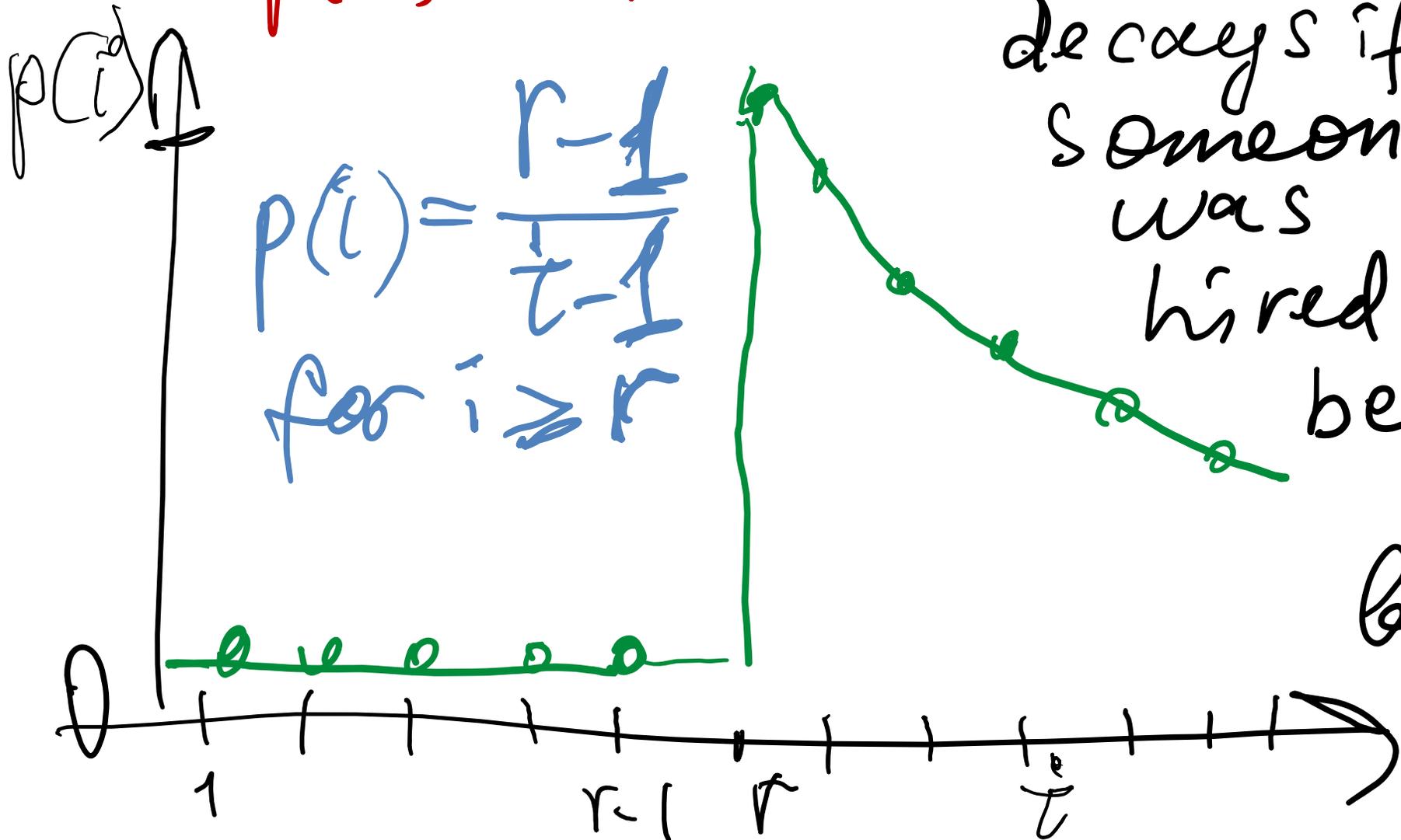


# Probability of hiring the best candidate if they are # $i$ in the queue

$$p(i) = 0 \text{ for } i < r$$

$$p(i) = \frac{r-1}{i-1} \text{ for } i \geq r$$

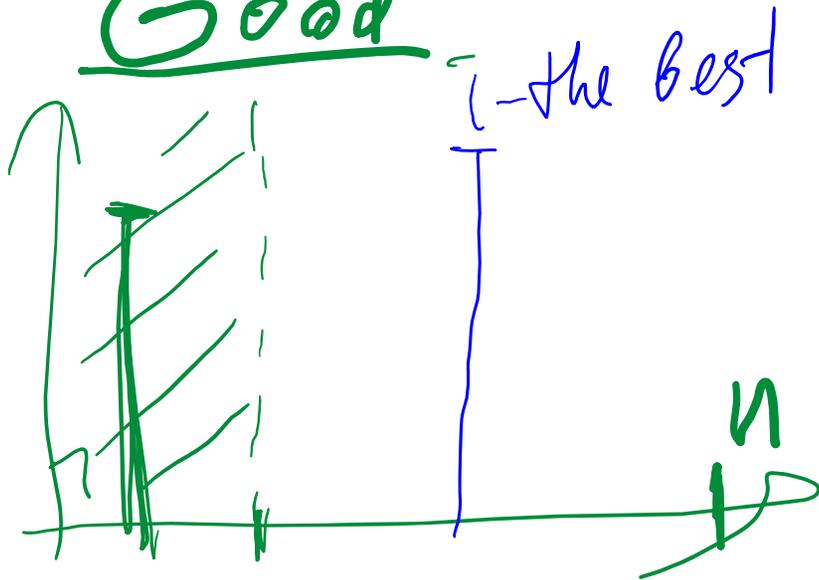
decays if  
someone  
was  
hired  
before  
the  
best



Look at  $i-1$  candidates before the best

$$\text{Prob} = \frac{r-1}{i-1}$$

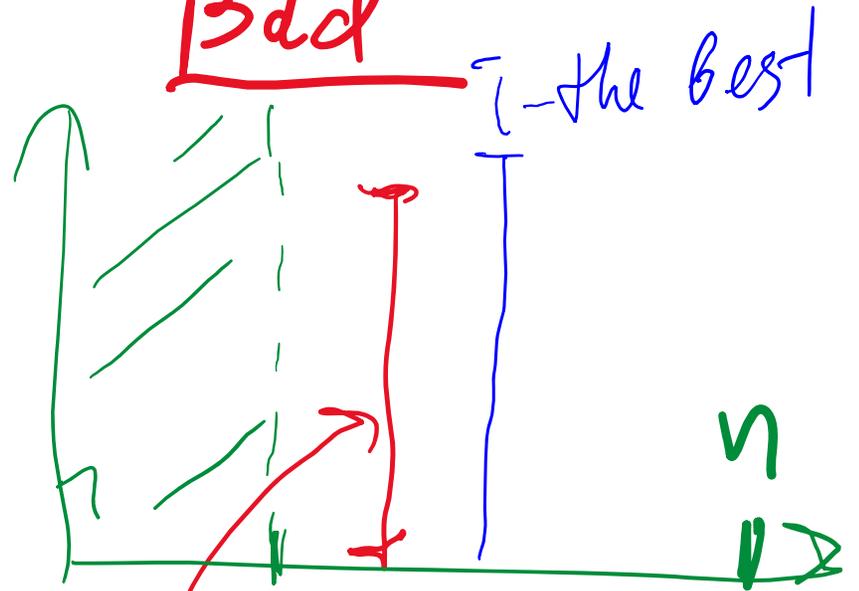
Good



the best among  $i-1$

$$\text{Prob} = \frac{i-r}{i-1}$$

Bad



the best among  $i-1$

$$\begin{aligned}
P(r) &= \sum_{i=1}^n P(\text{applicant } i \text{ is selected} \cap \text{applicant } i \text{ is the best}) \\
&= \sum_{i=1}^n P(\text{applicant } i \text{ is selected} | \text{applicant } i \text{ is the best}) \times P(\text{applicant } i \text{ is the best}) \\
&= \left[ \sum_{i=1}^{r-1} 0 + \sum_{i=r}^n P\left( \begin{array}{l} \text{the best of the first } i-1 \text{ applicants} \\ \text{is in the first } r-1 \text{ applicants} \end{array} \middle| \text{applicant } i \text{ is the best} \right) \right] \times \frac{1}{n} \\
&= \sum_{i=r}^n \frac{r-1}{i-1} \times \frac{1}{n} = \frac{r-1}{n} \sum_{i=r}^n \frac{1}{i-1}.
\end{aligned}$$



$$P(r) = \frac{r-1}{n} \sum_{i=r}^n \frac{1}{i-1}.$$

Letting  $n$  tend to infinity, writing  $x$  as the limit of  $r/n$ , using  $t$  for  $i/n$  and  $dt$  for  $1/n$ ,

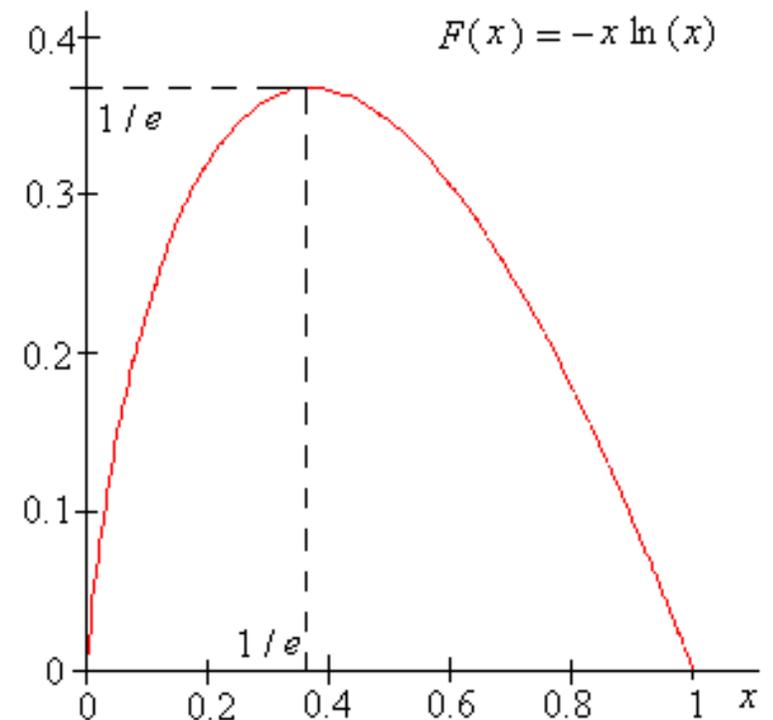
$$P(x) = x \int_x^1 \frac{1}{t} dt = -x \ln(x).$$

$$dP(x)/dx = -\ln(x) - 1$$

$$-\ln(x^*) - 1 = 0$$

$$x^* = 1/e = 0.3679$$

Probability of picking the best applicant is also  $1/e = 0.3679$



Credit: XKCD  
comics

WHY ARE THERE SLAVES IN THE BIBLE

WHY DO TWINS HAVE DIFFERENT FINGERPRINTS  
WHY ARE AMERICANS AFRAID OF DRAGONS

WHY IS HTTPS CROSSED OUT IN RED  
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WHY IS HTTPS IMPORTANT

# QUESTIONS

FOUND IN GOOGLE AUTOCOMplete



WHY ARE THERE WEEKS  
WHY DO I FEEL DIZZY

WHY AREN'T ECONOMISTS RICH

WHY ARE THERE SO MANY CROWS IN ROCHESTER, MN  
WHY IS THERE PHLEGM

WHY DO AMERICANS CALL IT SOCCER

WHY IS PSYCHIC WEAK TO BUG

WHY ARE MY EARS RINGING

WHY DO CHILDREN GET CANCER

WHY ARE THERE SO MANY AVENGERS

WHY IS POSEIDON ANGRY WITH ODYSSEUS

WHY ARE THE AVENGERS FIGHTING THE X MEN

WHY IS THERE ICE IN SPACE

## WHY ARE THERE ANTS IN MY LAPTOP

WHY IS EARTH TILTED

WHY ARE THERE GHOSTS

WHY IS THERE AN OWL IN MY BACKYARD

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WHY ARE THERE TINY SPIDERS IN MY HOUSE

WHY ARE THERE GHOSTS

WHY ARE THERE GODS

WHY DO SPIDERS COME INSIDE

WHY ARE THERE GHOSTS

WHY ARE THERE TWO SPOCKS

WHY ARE THERE HUGE SPIDERS IN MY HOUSE

WHY ARE THERE GHOSTS

WHY IS LIFE SO BORING

WHY ARE THERE LOTS OF SPIDERS IN MY HOUSE

WHY ARE THERE GHOSTS

WHY ARE CIGARETTES LEGAL

WHY ARE THERE SPIDERS IN MY ROOM

WHY ARE THERE GHOSTS

WHY ARE THERE DUCKS IN MY POOL

WHY ARE THERE SO MANY SPIDERS IN MY ROOM

WHY ARE THERE GHOSTS

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WHY IS THERE SO MUCH RAIN IN OHIO

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WHY IS OHIO WEATHER SO WEIRD  
WHY ARE THERE MALE AND FEMALE BIKES  
WHY ARE THERE BRIDESMAIDS

WHY AREN'T THERE DINOSAUR GHOSTS

WHY DO DYING PEOPLE REACH UP  
WHY AREN'T THERE VARICOSE ARTERIES  
WHY ARE OLD KUNGONS DIFFERENT

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WHY AREN'T MY QUAIL LAYING EGGS

WHY AREN'T MY QUAIL EGGS HATCHING

WHY ARE CIGARETTES LEGAL

WHY ARE THERE DUCKS IN MY POOL

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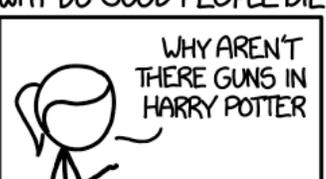
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WHY ARE ULTRASOUND MACHINES EXPENSIVE  
WHY IS STEALING WRONG



WHY ARE DOGS AFRAID OF FIREWORKS  
WHY IS THERE NO KING IN ENGLAND

# Simpson's paradox

## Edward Hugh Simpson

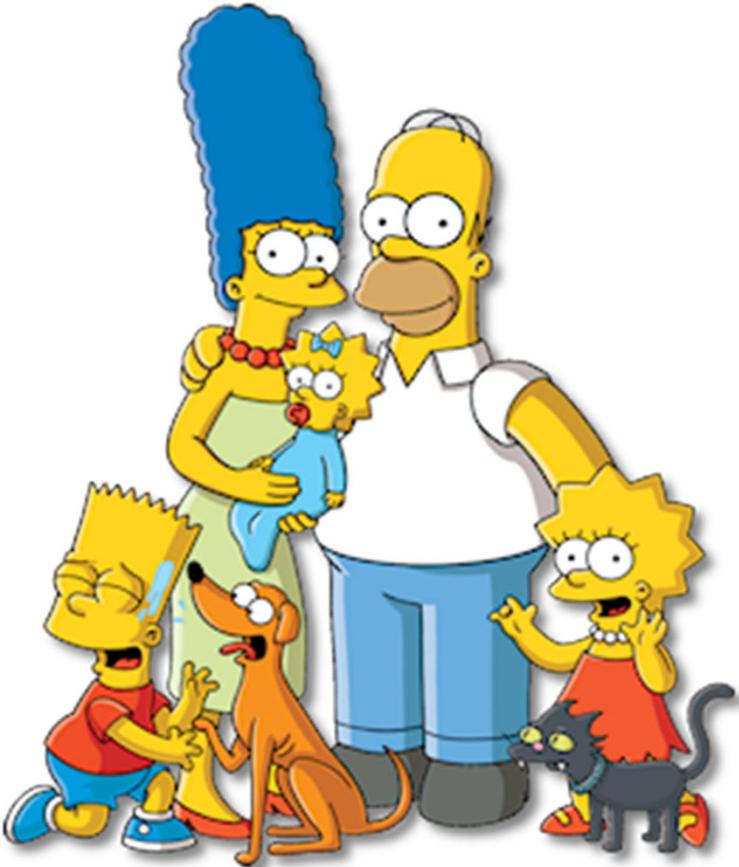
(10 December 1922 – 5 February 2019)

was a British codebreaker, statistician and civil servant.

"The Interpretation of Interaction in Contingency Tables", Journal of the Royal Statistical Society, 1951



Is it possible for one doctor to have a higher success rate than another doctor in every type of treatment he performs but to have a lower overall success rate across all treatment types?



Dr. Hibbert



Dr. Nick



# Simpson's Paradox

	Hibbert heart bandaid	Nick heart bandaid
Success	70	2
Failure	20	8

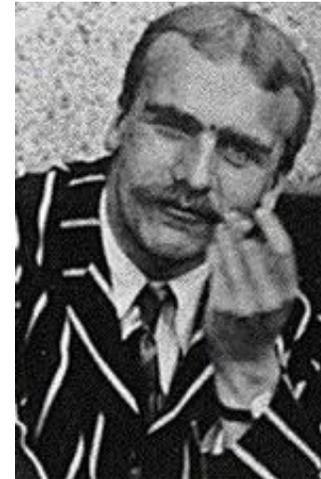
10	81
0	9

Dr. Hibbert: success rate = 80%

Dr. Nick: success rate = 83%

# Simpson's paradox might explain altruism

- Darwinian evolution has a problem with altruism
- “Selfish genes” do not care about others
- J. B. S. Haldane, (1892-1964)  
British geneticist, evolutionary biologist
- When asked if he would give his life to save a drowning brother answered: “No, but I would to save two brothers or eight cousins”
- Altruism in some insect colonies like ants is because they are all genetically similar.



# Altruism in bacteria

- Bacteria live in communities in close proximity to each other
- Individual bugs **spend significant resources** to produce **extracellular molecules**, excrete them outside of the cell to **share with others. That slows their growth**
  - Examples: extracellular enzymes, biofilm components, antimicrobial and anti-immune agents
- **Cheaters have faster growth rate**
  - **They can take over** by not producing any shared molecules
- **Evolutionary paradox: how bacteria can be altruistic?**

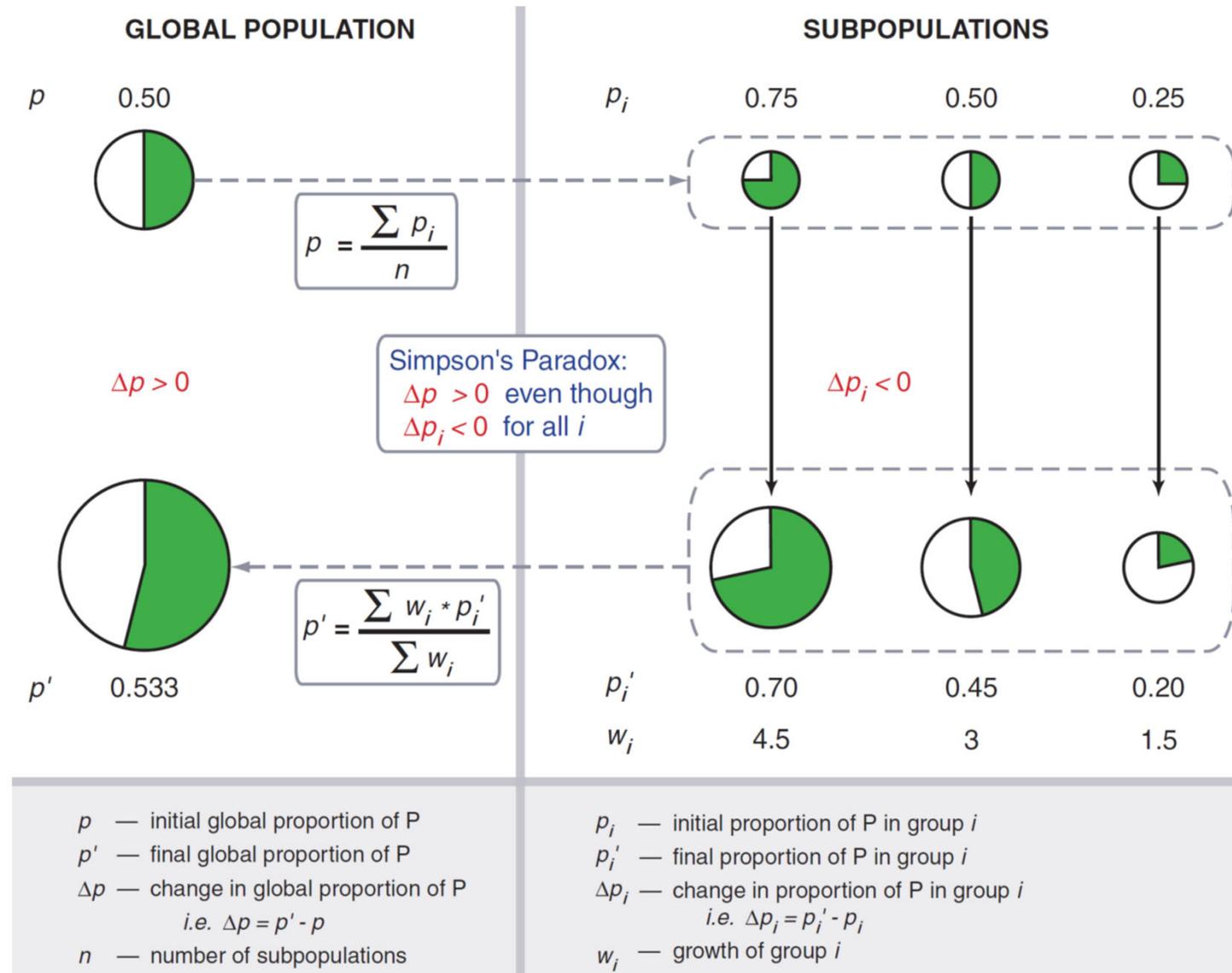


## **Simpson's Paradox in a Synthetic Microbial System**

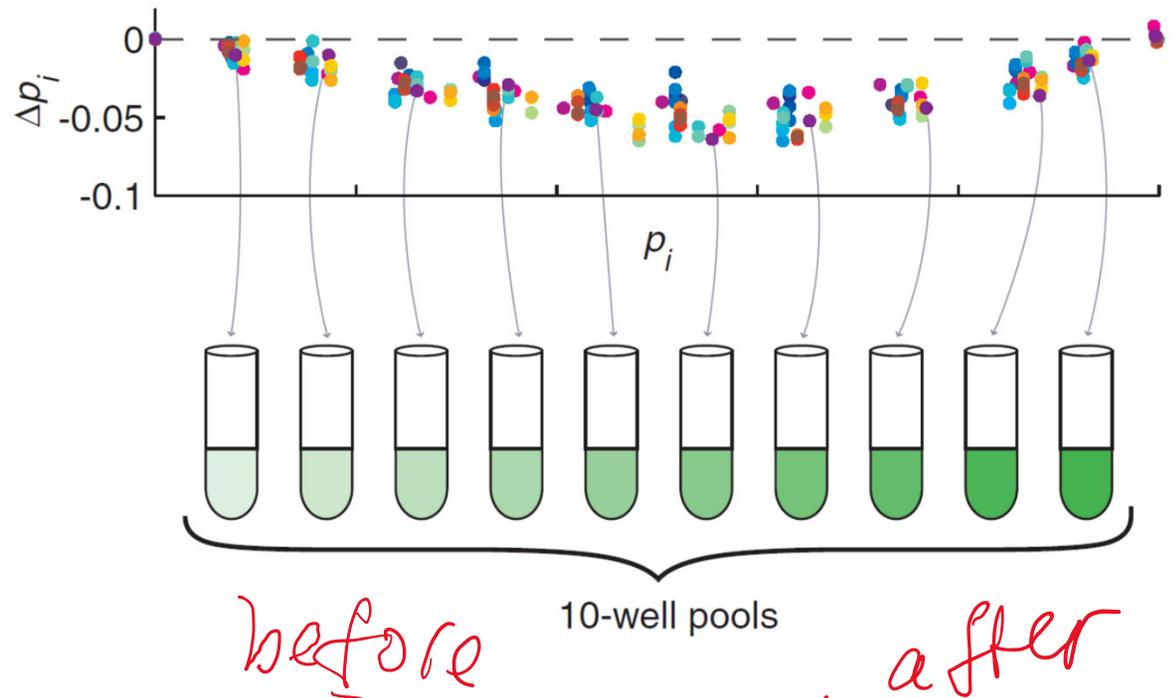
John S. Chuang,\* Olivier Rivoire, Stanislas Leibler

The maintenance of “public” or “common good” producers is a major question in the evolution of cooperation. Because nonproducers benefit from the shared resource without bearing its cost of production, they may proliferate faster than producers. We established a synthetic microbial system consisting of two *Escherichia coli* strains of common-good producers and nonproducers. Depending on the population structure, which was varied by forming groups with different initial compositions, an apparently paradoxical situation could be attained in which nonproducers grew faster within each group, yet producers increased overall. We show that a simple way to generate the variance required for this effect is through stochastic fluctuations via population bottlenecks. The synthetic approach described here thus provides a way to study generic mechanisms of natural selection.

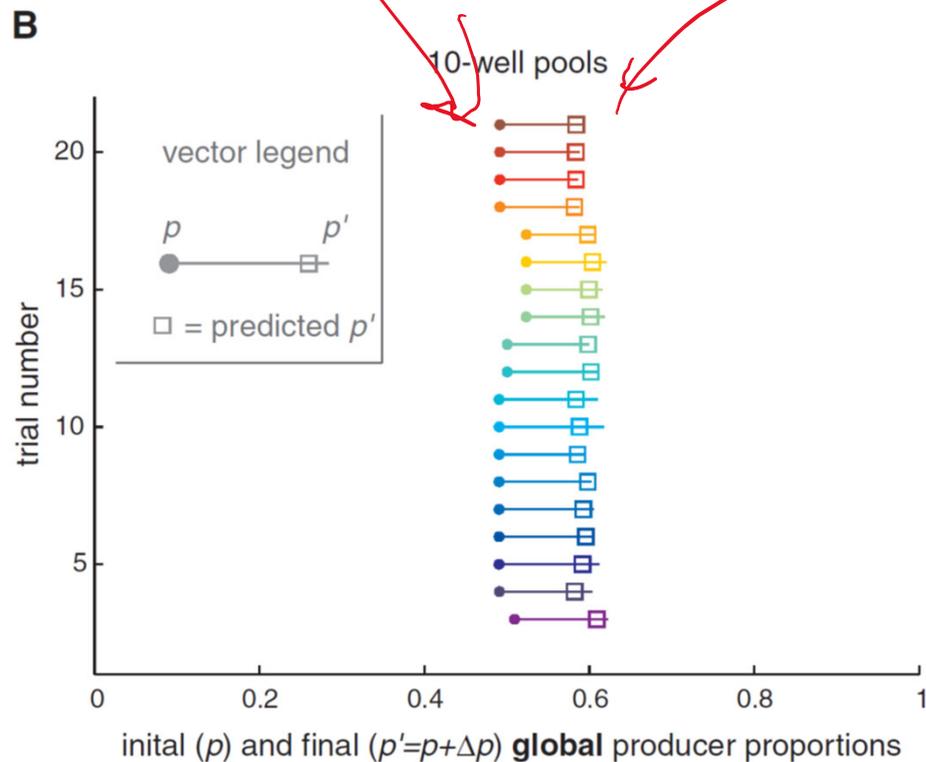
- The common good was a membrane-permeable Rhl autoinducer molecule rewired to activate antibiotic (chloramphenicol; Cm) resistance gene expression.



Fraction of altruists in  
 each of individual  
 test tubes dropped



Yet the overall fraction of  
 altruists in  
 all test tubes combined  
increased



Credit: XKCD  
comics

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WHY ARE THE AVENGERS FIGHTING THE X MEN  
WHY IS WOLVERINE NOT IN THE AVENGERS

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WHY DO SPIDER BITES ITCH

WHY IS DYING SO SCARY

WHY IS THERE NO GPS IN LAPTOPS

WHY DO KNEES CLICK  
WHY AREN'T THERE E GRADES  
WHY IS ISOLATION BAD  
WHY DO BOYS LIKE ME  
WHY DON'T BOYS LIKE ME  
WHY IS THERE ALWAYS A JAVA UPDATE  
WHY ARE THERE RED DOTS ON MY THIGHS

WHY IS LYING GOOD



WHY IS THERE AN OWL IN MY BACKYARD

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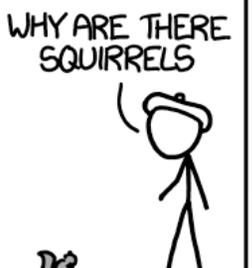
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WHY DO TREES DIE  
WHY IS THERE NO SOUND ON CNN  
WHY AREN'T POKEMON REAL  
WHY AREN'T BULLETS SHARP  
WHY DO DREAMS SEEM SO REAL

WHY IS THERE HELL IF GOD FORGIVES

WHY ARE THERE TINY SPIDERS IN MY HOUSE

WHY DO SPIDERS COME INSIDE

WHY ARE THERE HUGE SPIDERS IN MY HOUSE

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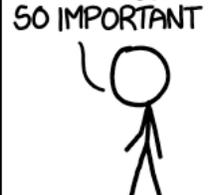
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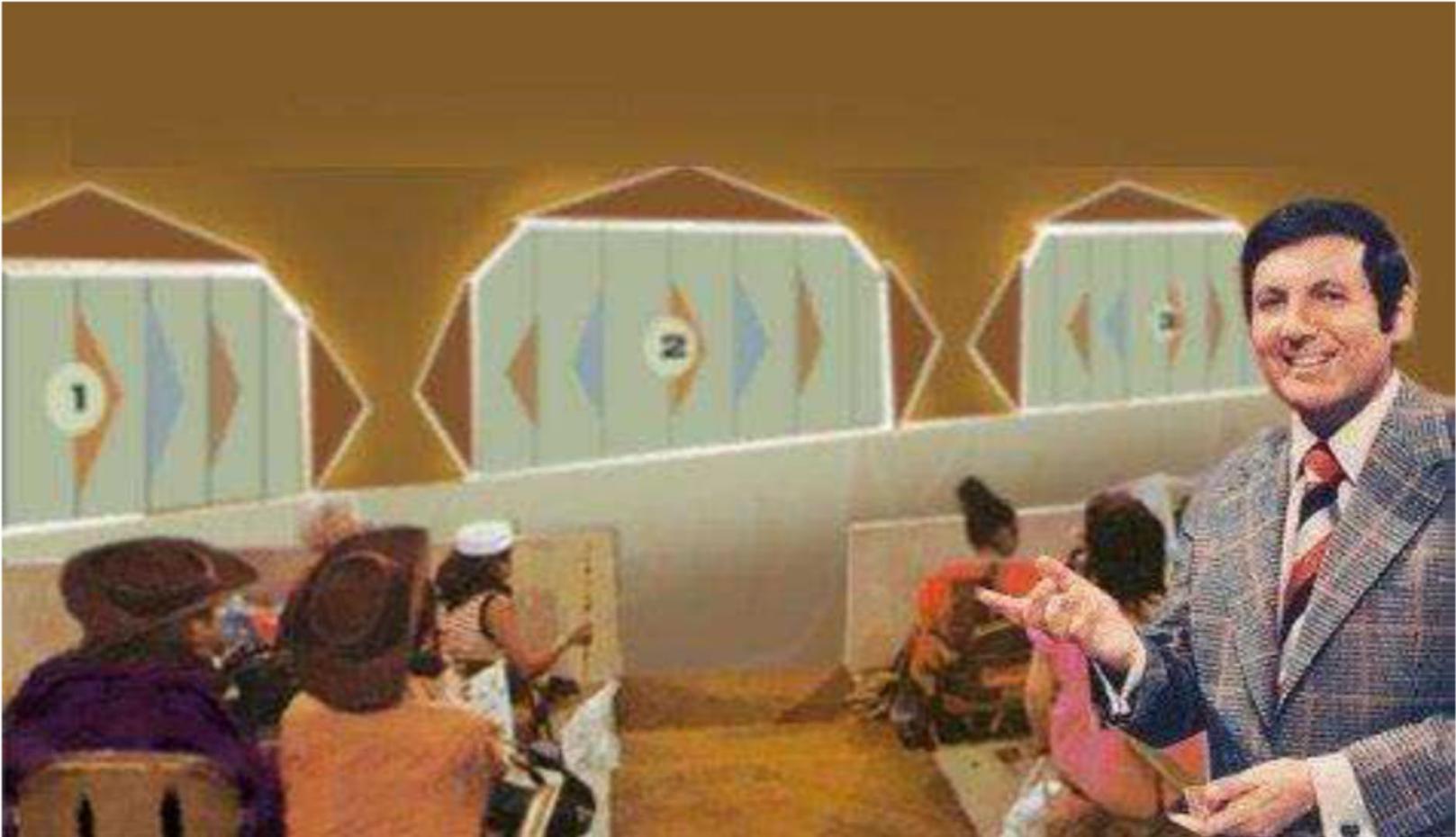
WHY IS SEX SO IMPORTANT



WHY ARE THERE FEMALE MR NIMES

WHY ARE DOGS AFRAID OF FIREWORKS  
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# Monty Hall problem



**Monty Hall** OC, OM (born Monte Halparin)

August 25, 1921 – September 30, 2017

was a Canadian-American game show host, producer, and philanthropist

**Game show “Let’s Make a Deal” aired 1963-now**

# Monty Hall problem

- In *Make a Deal* there are three closed doors. Behind a **random one of these doors** is a car; behind the other two are goats. **The contestant does not know where the car is, but Monty Hall does.**
- After the contestant picks a door Monty **always opens one of the remaining doors**, one he knows does not hide the car. If the contestant has already chosen the door with the car behind, **Monty is equally likely to open either of the two remaining doors.**
- After Monty has shown a goat behind the door that he opens, the **contestant is always given the option to switch doors.**
- What is the probability of winning the car under the switching and non-switching strategies?

Monty Hall problem.  
What strategy  
gives you a better chance  
to win the car?

- A. Better to switch doors
- B. Better not to switch doors
- C. Switching does not matter
- D. The answer depends on the phase of the moon
- E. I don't know

Get your i-clickers

Monty Hall problem.  
What strategy  
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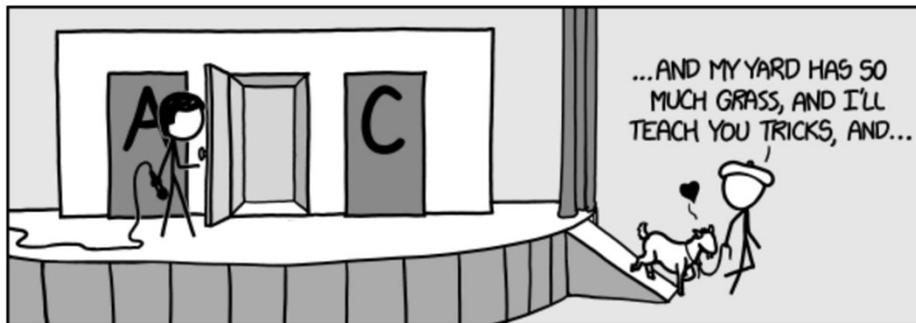
D. The answer depends on the phase of the moon

E. I don't know

Get your i-clickers

# Don't feel bad if you guessed wrong

- When first presented with the Monty Hall problem an overwhelming majority of people conclude that switching does not matter
- Out of 228 subjects in one study, only 13% chose to switch
- Paul Erdős, one of the most prolific mathematicians in history, remained unconvinced until he was shown a computer simulation confirming the predicted result



comic credits: [xkcd](#)

- BUT: pigeons exposed to the problem rapidly learn always to switch, unlike humans

# Solution #1 (intuitive)

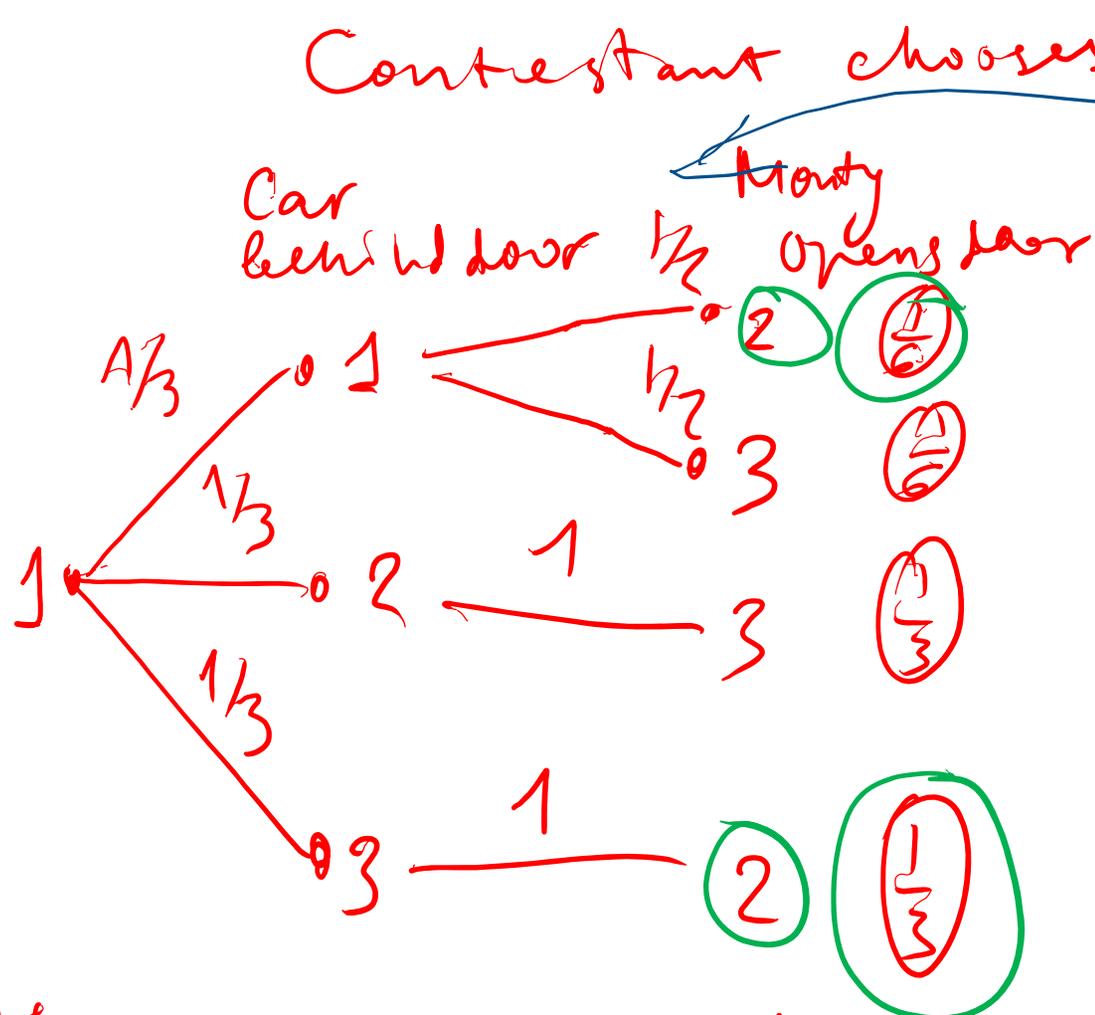
- With **Prob=1/3** you guess the car door right:  
**you loose the car if you switch**
- With **Prob=2/3** you got it wrong and picked a goat door. Then Monty opens another goat door. What is left is the car door.  
**You win the car if you switch!**

## Solution #2.

Tree & conditional probabilities

# Solution #2.

## Tree & conditional probabilities



conditional probability

$$P(\text{Monty opens door 2} \mid \text{car behind door 1}) = \frac{1}{2}$$

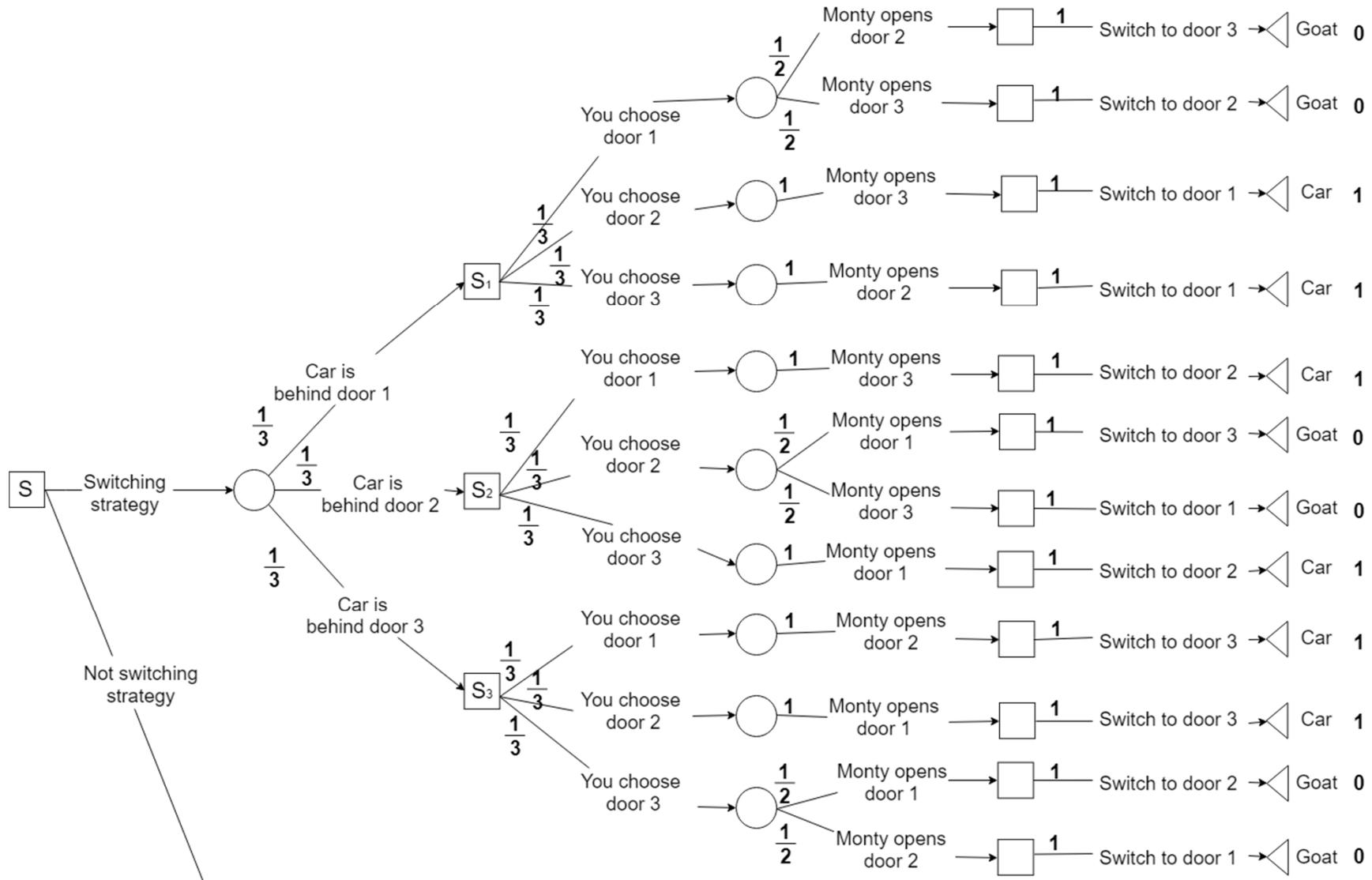
If Monty opened door 2

$$P(\text{win by switching}) = \frac{1}{3} + \frac{1}{3} = \frac{2}{3}$$

$$P(\text{win by staying}) = \frac{1/6}{1/3 + 1/6} = \frac{1}{3}$$

# A more detailed tree diagram

- <https://dacalderon.shinyapps.io/montyhall/>





# Let's check! Matlab template

- `Stats=??;`
- `%set Stats large...`
- `switch_count=0; noswitch_count=0; %set 0 at the beginning`
- `for n = 1:Stats`
- `a = randperm(3); %Monty places two goats and the car at random`
- `%a(1) -goat, a(2) -goat, a(3) - car`
- `i= floor(3.*rand)+1; %you select the door!`
- `% SWITCH STRATEGY`
- `if(i == a(1)) switch_count=switch_count+??; %a(2)-opened, switch to a(3), car!`
- `elseif (i == a(2)) switch_count = switch_count + ??;%a(1) opened, switch to a(3), car!`
- `else switch_count = switch_count + ??; %a(1)/a(2) opened, switch to a(2)/a(1), no car :-(`
- `end`
- `% NO SWITCH STRATEGY`
- `if(i == a(1)) noswitch_count = noswitch_count + ??; %a(2)-opened, no car :-(`
- `elseif (i==a(2)) noswitch_count = noswitch_count + ?? %a(1)-opened, no car :-(`
- `else noswitch_count = noswitch_count + ??; %a(1) or a(2)-opened, car!`
- `endend;`
- `disp('probability to win a car if switched doors=');`
- `disp(num2str(switch_count./??)); %# of cars with switching`
- `disp('probability to win a car if did not switch doors=');`
- `disp(num2str(noswitch_count./??)); %# of cars w/o switching`

# Matlab program

- `B=10000; %set B large...`
- `cars=0; carn=0; %set 0 at the beginning`
- `for i = 1:B`
- `a = randperm(3); %Monty places two goats and the car at random`
- `%a(1) -goat, a(2) -goat, a(3) - car`
- `i= floor(3.*rand)+1; %you select the door!`
- `% SWITCH STRATEGY`
- `if(i == a(1)) cars=cars+1; %a(2)-opened, switch to a(3), car!`
- `elseif (i == a(2)) cars = cars + 1 ;%a(1) opened, switch to a(3), car!`
- `else cars = cars + 0; %a(1)/a(2) opened, switch to a(2)/a(1), no car!`
- `end`
- `% SWITCH STRATEGY`
- `if(i == a(1)) carn = carn + 0; %a(2)-opened, no car`
- `elseif (i==a(2)) carn = carn + 0; %a(1)-opened, no car`
- `else carn = carn + 1; %a(1) or a(2)-opened, car!`
- `end`
- `end;`
- `disp('probability to win a car if switched doors=');`
- `disp(num2str(cars./B)); %# of cars with switching`
- `disp('probability to win a car if did not switch doors=');`
- `disp(num2str(carn./B)); %# of cars w/o switching`

Credit: XKCD  
comics

# WHY ARE THERE SLAVES IN THE BIBLE

WHY DO TWINS HAVE DIFFERENT FINGERPRINTS  
WHY ARE AMERICANS AFRAID OF DRAGONS

WHY IS HTTPS CROSSED OUT IN RED  
WHY IS THERE A LINE THROUGH HTTPS  
WHY IS THERE A RED LINE THROUGH HTTPS ON FACEBOOK  
WHY IS HTTPS IMPORTANT

# QUESTIONS FOUND IN GOOGLE AUTOCOMPLETE



WHY ARE THERE WEEKS  
WHY DO I FEEL DIZZY

WHY AREN'T ECONOMISTS RICH  
WHY DO AMERICANS CALL IT SOCCER  
WHY ARE MY EARS RINGING  
WHY ARE THERE SO MANY AVENGERS  
WHY ARE THE AVENGERS FIGHTING THE X MEN  
WHY IS WOLVERINE NOT IN THE AVENGERS

WHY ARE THERE SWARMS OF GNATS  
WHY IS THERE PHLEGM  
WHY ARE THERE SO MANY CROWS IN ROCHESTER, MN  
WHY IS PSYCHIC WEAK TO BUG  
WHY DO CHILDREN GET CANCER  
WHY IS POSEIDON ANGRY WITH ODYSSEUS  
WHY IS THERE ICE IN SPACE

# WHY ARE THERE ANTS IN MY LAPTOP

WHY IS EARTH TILTED  
WHY IS SPACE BLACK  
WHY IS OUTER SPACE SO COLD  
WHY ARE THERE PYRAMIDS ON THE MOON  
WHY IS NASA SHUTTING DOWN



WHY IS THERE AN OWL IN MY BACKYARD  
WHY IS THERE AN OWL OUTSIDE MY WINDOW  
WHY IS THERE AN OWL ON THE DOLLAR BILL  
WHY DO OWLS ATTACK PEOPLE  
WHY ARE AK 47s SO EXPENSIVE  
WHY ARE THERE HELICOPTERS CIRCLING MY HOUSE  
WHY ARE THERE GODS  
WHY ARE THERE TWO SPOCKS

WHY ARE DOGS AFRAID OF FIREWORKS  
WHY IS THERE NO KING IN ENGLAND

WHY ARE CIGARETTES LEGAL  
WHY ARE THERE DUCKS IN MY POOL  
WHY IS JESUS WHITE  
WHY IS THERE LIQUID IN MY EAR  
WHY DO Q TIPS FEEL GOOD  
WHY DO GOOD PEOPLE DIE

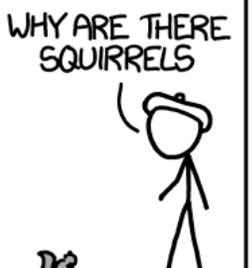


WHY IS LIFE SO BORING

WHY ARE ULTRASOUNDS IMPORTANT  
WHY ARE ULTRASOUND MACHINES EXPENSIVE  
WHY IS STEALING WRONG  
WHY AREN'T THERE ANY FOREIGN MILITARY BASES IN AMERICA

WHY DO WHALES JUMP  
WHY ARE WITCHES GREEN  
WHY ARE THERE MIRRORS ABOVE BEDS  
WHY DO I SAY UH  
WHY IS SEA SALT BETTER  
WHY ARE THERE TREES IN THE MIDDLE OF FIELDS  
WHY IS THERE NOT A POKEMON MMO  
WHY IS THERE LAUGHING IN TV SHOWS  
WHY ARE THERE DOORS ON THE FREEWAY  
WHY ARE THERE SO MANY SVCHOST.EXE RUNNING  
WHY AREN'T THERE ANY COUNTRIES IN ANTARCTICA  
WHY ARE THERE SCARY SOUNDS IN MINECRAFT  
WHY IS THERE KICKING IN MY STOMACH  
WHY ARE THERE TWO SLASHES AFTER HTTP  
WHY ARE THERE CELEBRITIES  
WHY DO SNAKES EXIST  
WHY DO OYSTERS HAVE PEARLS  
WHY ARE DUCKS CALLED DUCKS  
WHY DO THEY CALL IT THE CLAP  
WHY ARE KYLE AND CARTMAN FRIENDS  
WHY IS THERE AN ARROW ON AANG'S HEAD  
WHY ARE TEXT MESSAGES BLUE  
WHY ARE THERE MUSTACHES ON CLOTHES  
WHY ARE THERE MUSTACHES ON CARS  
WHY ARE THERE MUSTACHES EVERYWHERE  
WHY ARE THERE SO MANY BIRDS IN OHIO  
WHY IS THERE SO MUCH RAIN IN OHIO  
WHY IS OHIO WEATHER SO WEIRD

WHY ARE THERE MALE AND FEMALE BIKES  
WHY ARE THERE TINY SPIDERS IN MY HOUSE  
WHY DO SPIDERS COME INSIDE  
WHY ARE THERE HUGE SPIDERS IN MY HOUSE  
WHY ARE THERE LOTS OF SPIDERS IN MY HOUSE  
WHY ARE THERE SPIDERS IN MY ROOM  
WHY ARE THERE SO MANY SPIDERS IN MY ROOM  
WHY DO SPIDER BITES ITCH  
WHY IS DYING SO SCARY



WHY ARE THERE BRIDESMAIDS  
WHY DO DYING PEOPLE REACH UP  
WHY AREN'T THERE VARICOSE ARTERIES  
WHY ARE OLD KUNGONS DIFFERENT  
WHY IS THERE HELL IF GOD FORGIVES  
WHY IS THERE NO GPS IN LAPTOPS  
WHY DO KNEES CLICK  
WHY AREN'T THERE E GRADES  
WHY IS ISOLATION BAD  
WHY DO BOYS LIKE ME  
WHY DON'T BOYS LIKE ME  
WHY IS THERE ALWAYS A JAVA UPDATE  
WHY ARE THERE RED DOTS ON MY THIGHS  
WHY IS LYING GOOD



WHY IS PROGRAMMING SO HARD  
WHY IS THERE A 0 OHM RESISTOR  
WHY DO AMERICANS HATE SOCCER  
WHY DO RHYMES SOUND GOOD  
WHY DO TREES DIE  
WHY IS THERE NO SOUND ON CNN  
WHY AREN'T POKEMON REAL  
WHY AREN'T BULLETS SHARP  
WHY DO DREAMS SEEM SO REAL

WHY IS GPS FREE

# Let's check the theory by playing the game online

Go to <https://dacalderon.shinyapps.io/montyhall/>

- Right side will play “switch the door” strategy
- Left side of the auditorium will play “do not switch the door” strategy
- Each person should play at least 30 rounds (more is better)
- Multiple players at the same table add up your numbers of games played and separately the number of wins
- In the end I will **add up the numbers from all tables**

	Switch strategy			No switch strategy	
Table	Played	Won	Table	Played	Won
A	30	20	D	96	33
B	25	11	E	80	25
C	80	62	F	80	16
	135	93		256	74
P(win)	0.688889			0.289063	