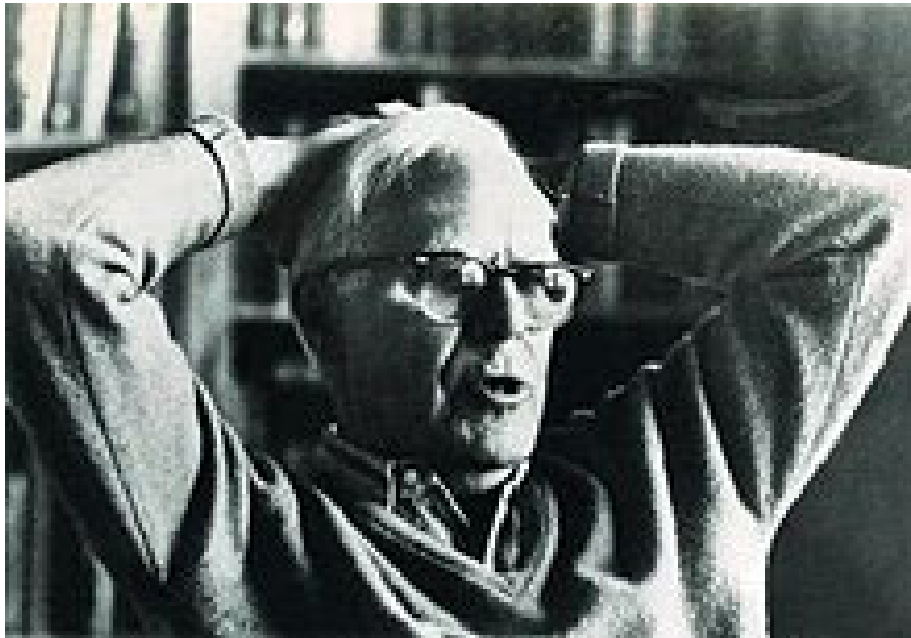


# Secretary problem

- An **employer** has a known number –  $n$  – of **applicants** for a secretary position, whom 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?

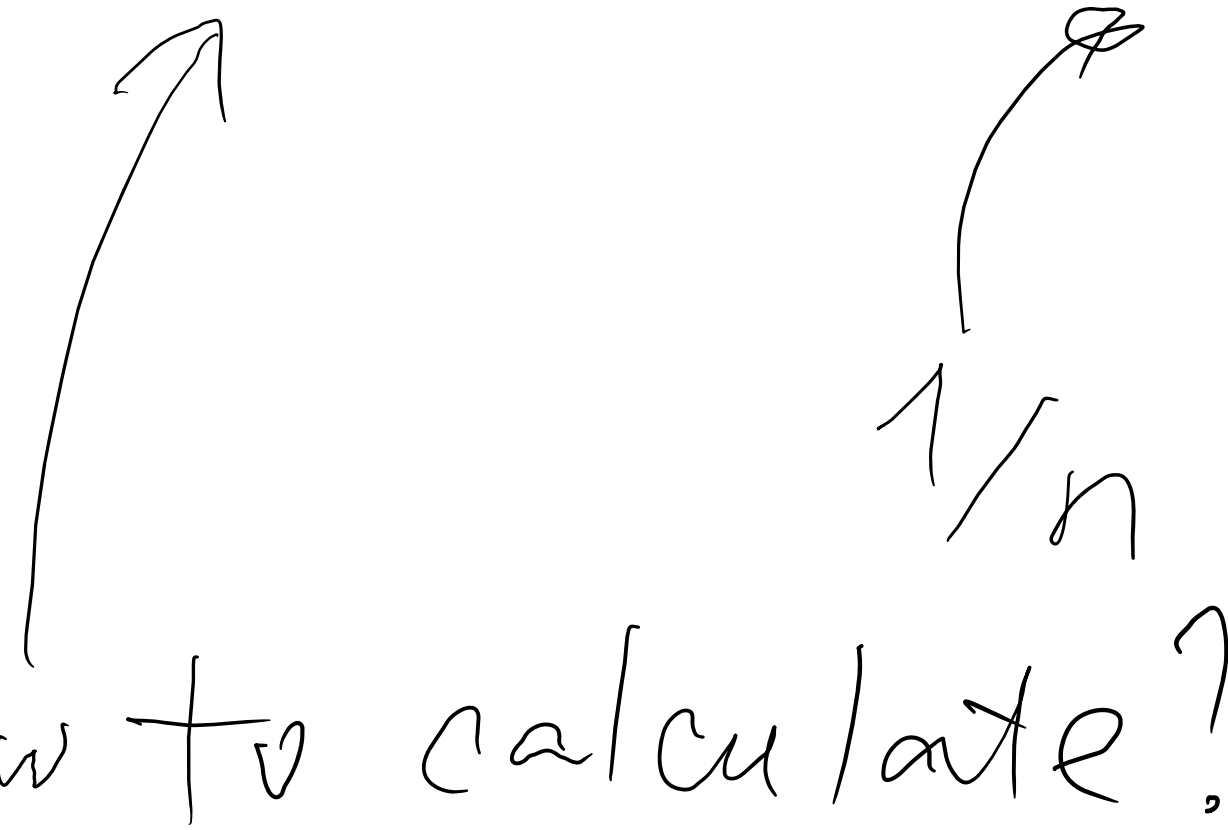
- Gardner outlined the solution in Sci Am 1960 but gave no formal proof
- Solution by Lindey was published in 1961:  
Lindey, D. V. (1961). Dynamic programming and decision theory. Appl. Statist. 10 39-51
- Dynkin's paper was published in 1963:  
Dynkin, E. B. (1963). The optimum choice of the instant 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 **has to 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  $r$ ?**
- 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?



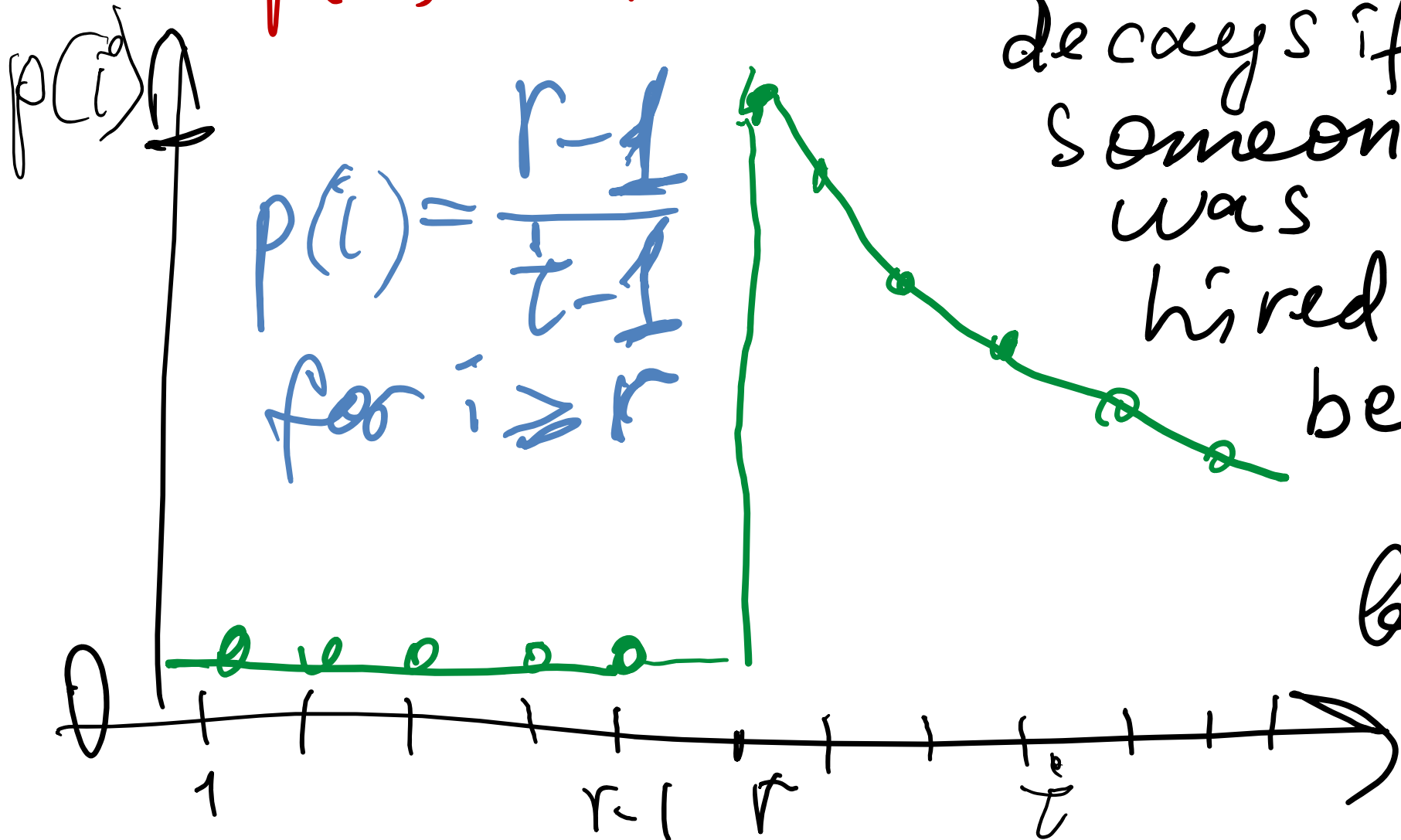
The image shows two hand-drawn arrows. The first arrow starts from the text 'How to calculate?' and points to the first term of the equation,  $P(\text{applicant } i \text{ is selected} \cap \text{applicant } i \text{ is the best})$ . The second arrow starts from the text 'How to calculate?' and points to the second term of the equation,  $P(\text{applicant } i \text{ is selected} | \text{applicant } i \text{ is the best}) \times P(\text{applicant } i \text{ is the best})$ . Below the second arrow, the fraction  $1/n$  is written, indicating the value of the conditional probability term.

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

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

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

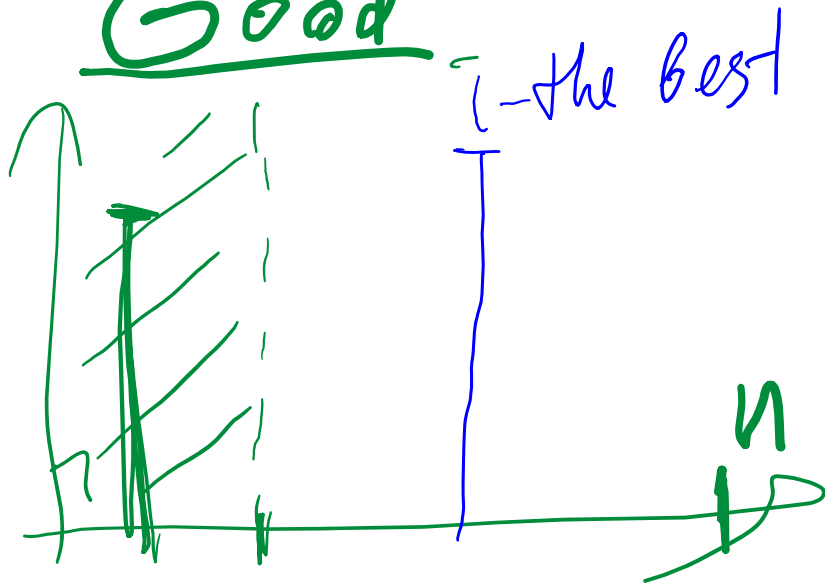
decays if  
someone  
was  
hired  
before  
the  
best



Look at  $i-1$  candidates before the best

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

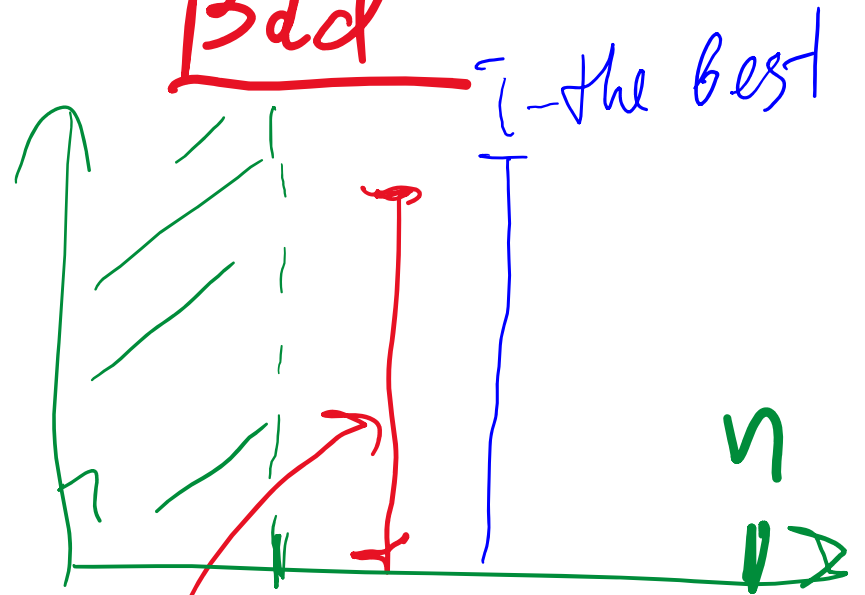
Good



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  $1/n$ ,

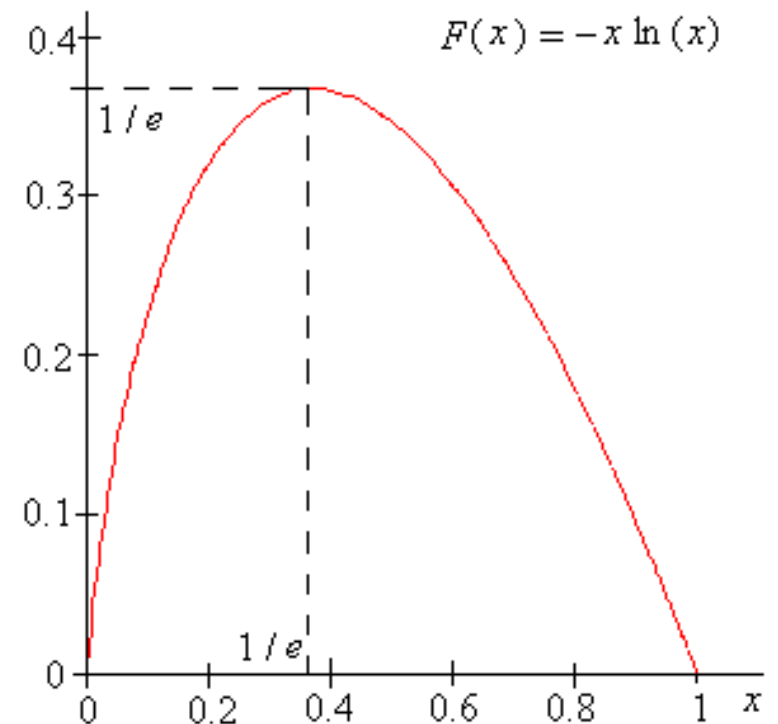
$$P(x) = x \int_x^1 \frac{1}{t} dt = -x \ln(x).$$

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

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

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

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



Credit: XKCD  
comics

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WHY ARE ULTRASOUND MACHINES EXPENSIVE  
WHY IS STEALING WRONG

# 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

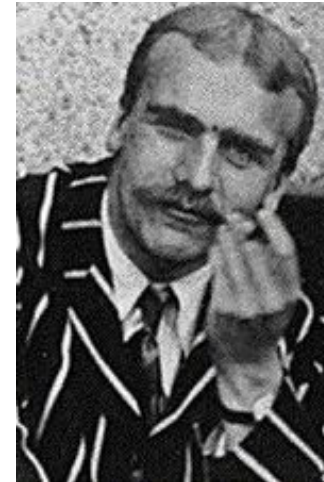
	Hibbert heart bandaid	Nick heart bandaid
Success	10	81
Failure	0	9

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?**



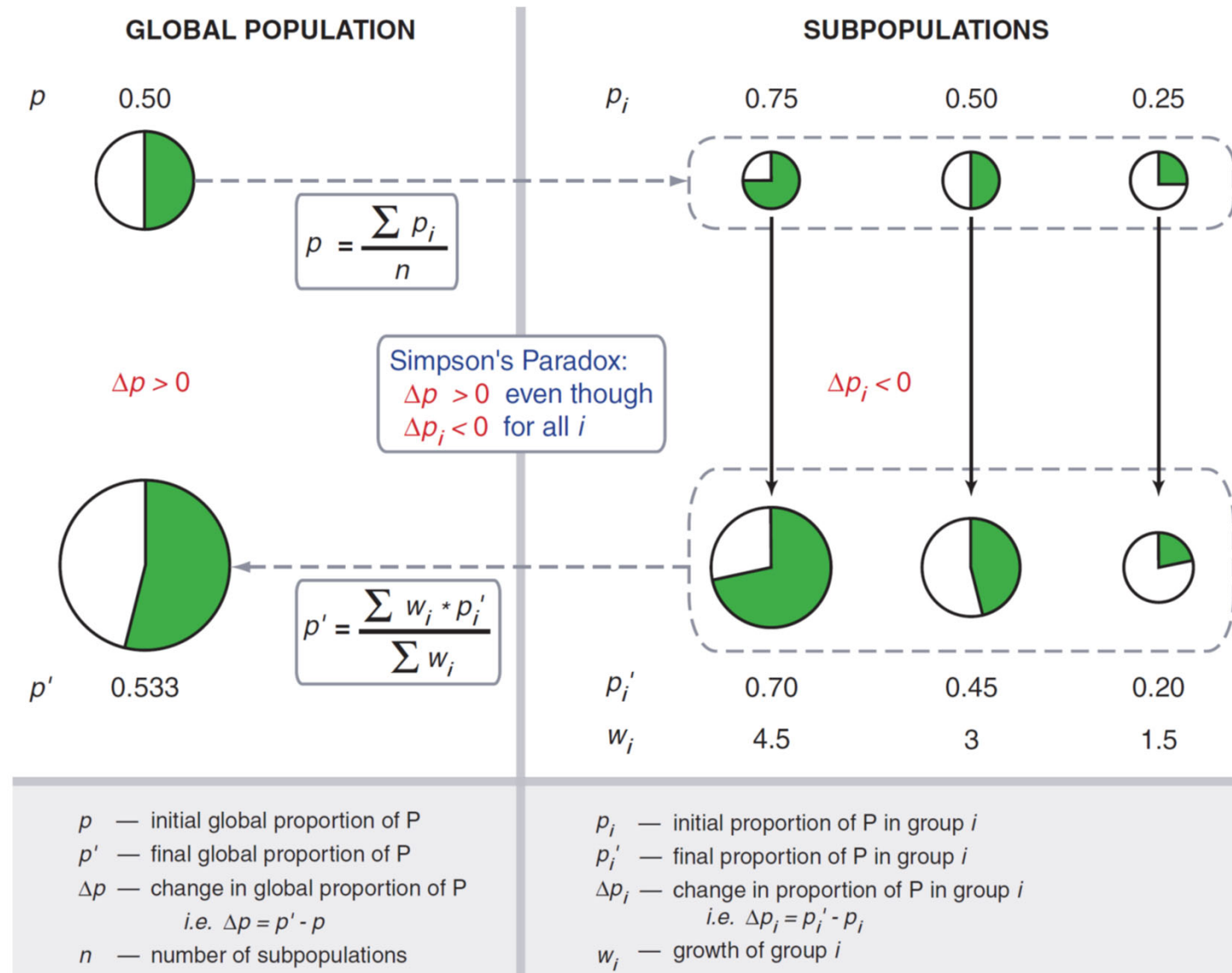


## Simpson's Paradox in a Synthetic Microbial System

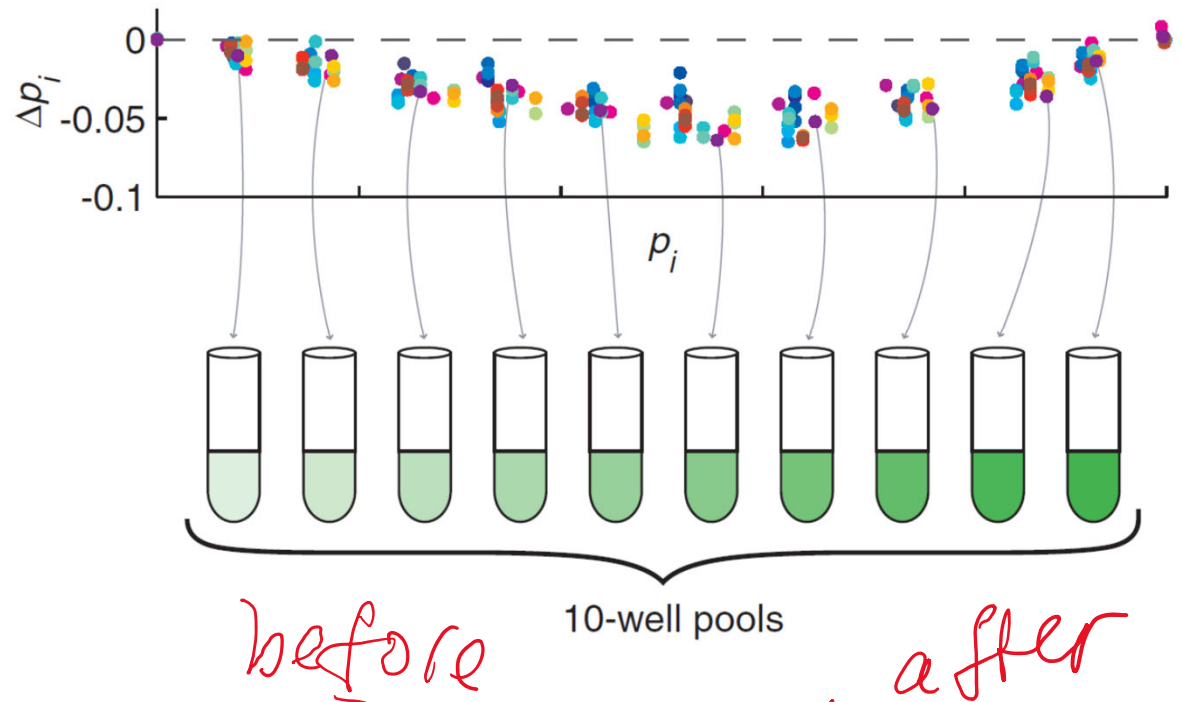
John S. Chuang,\* Olivier Rivoire, Stanislas Leibler

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.

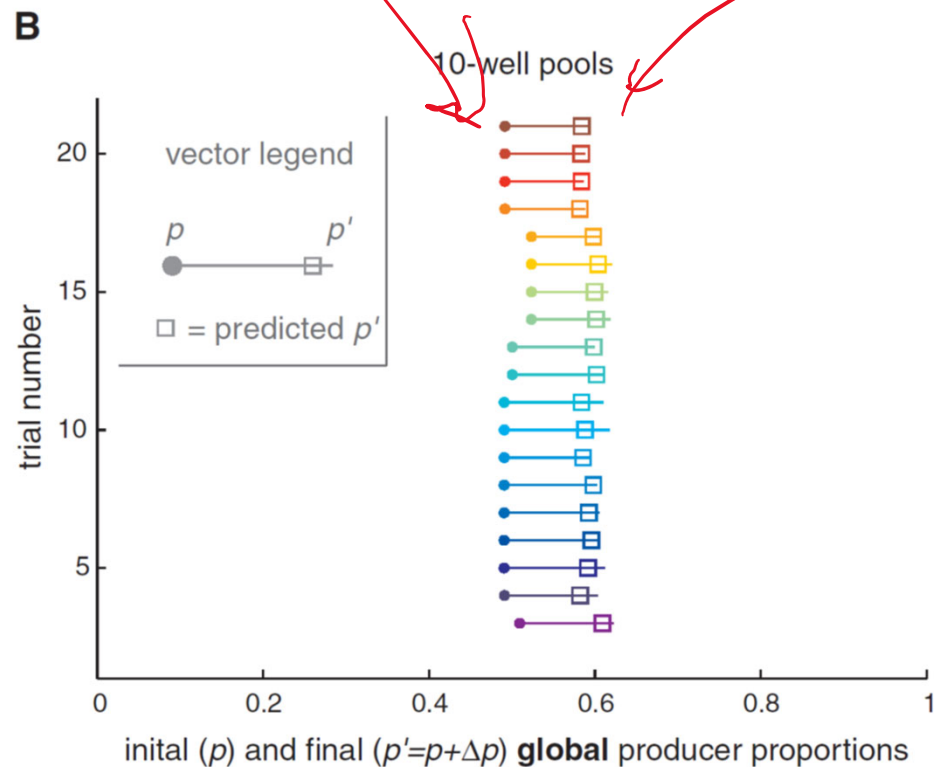
- The common good was a membrane-permeable Rhl autoinducer molecule rewired to activate antibiotic (chloramphenicol; Cm) resistance gene expression.



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 IS NASA SHUTTING DOWN

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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

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# Don't feel bad if you guessed wrong

- When first presented with the Monty Hall problem an overwhelming majority of people assume that each door has an equal probability and 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
- Pigeons repeatedly exposed to the problem show that they rapidly learn always to switch, unlike humans

# Solution #1 (intuitive)

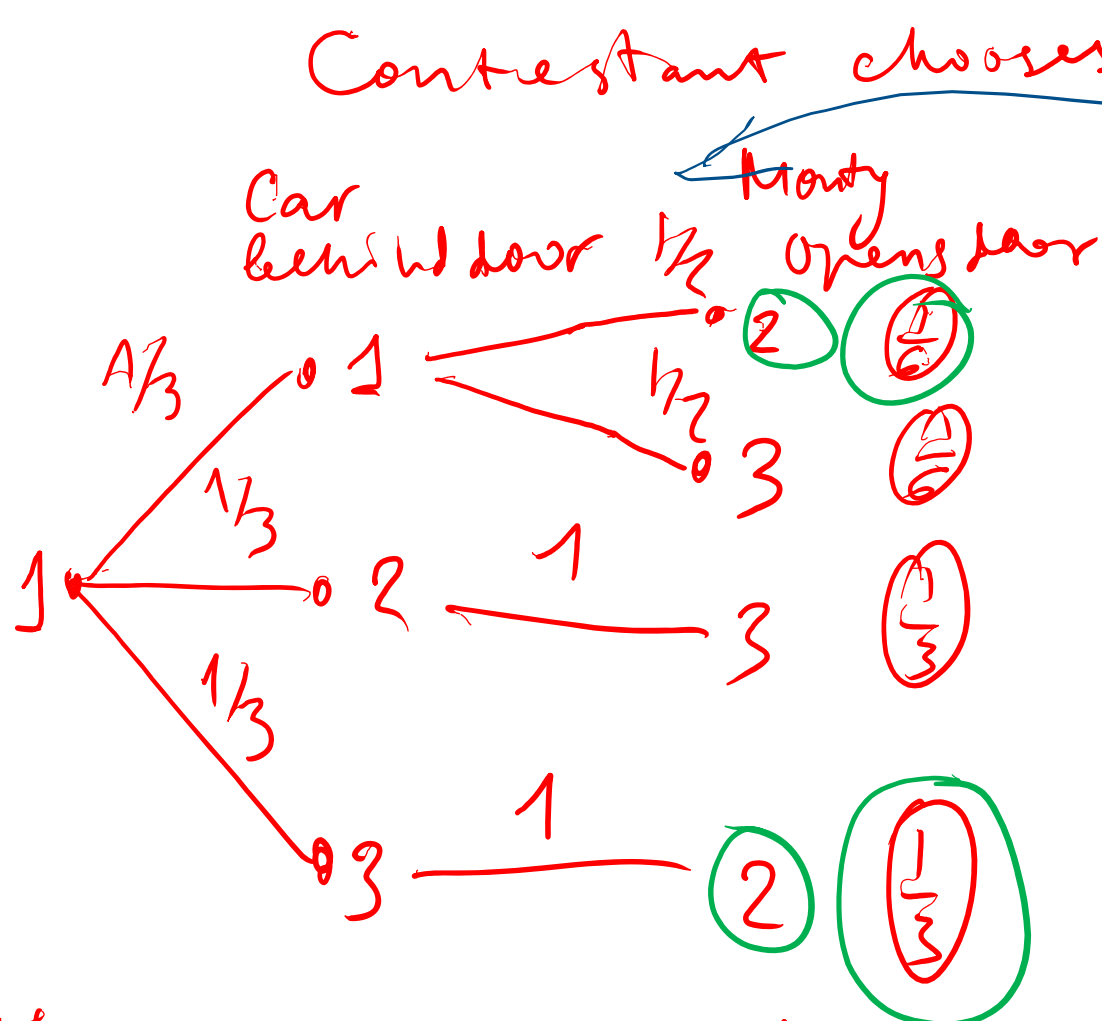
- With **Prob=1/3** you guess the car door right:  
**you loose the car if you switch**
- With **Prob=2/3** you got it wrong and picked a goat door. Then Monty opens another goat door. What is left is the car door.  
**You win the car if you switch!**

## 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

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

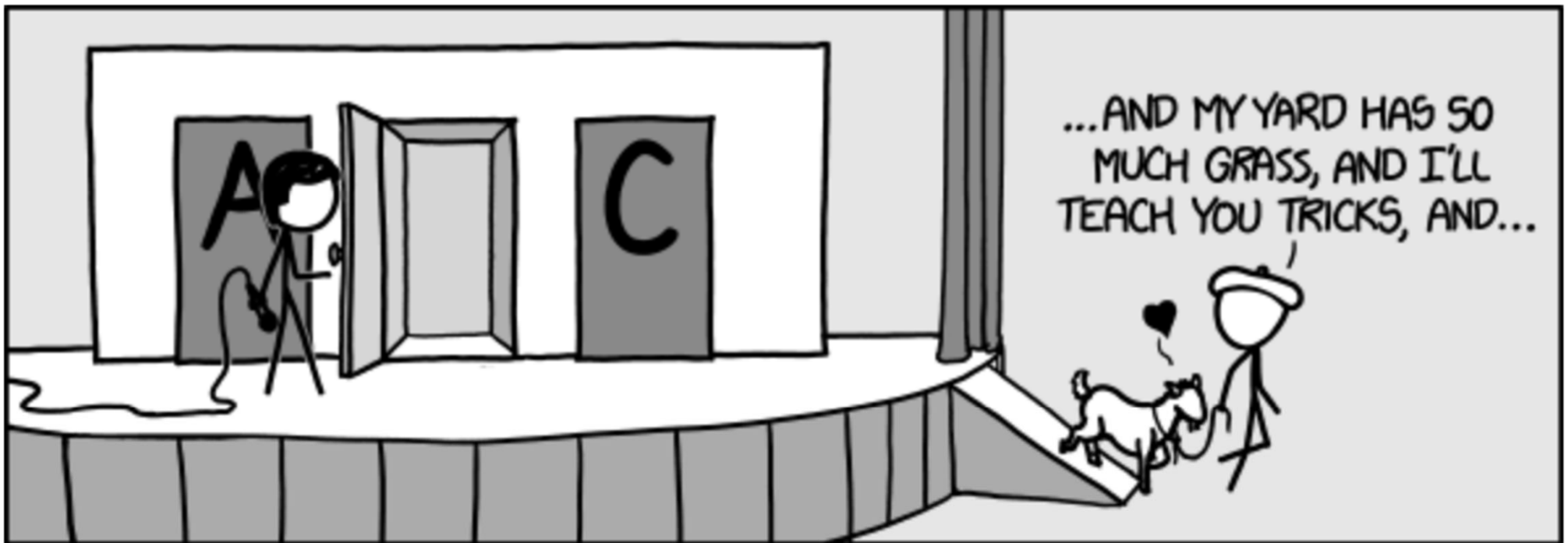
$$P(\text{win by staying}) = \frac{1/6}{1/3 + 1/6} = \frac{1}{3}$$

# A more detailed tree diagram

- Shinyapp website

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

Thanks to my former BIOE 505 student,  
Alejandra Zeballos Castro, for bringing it to my attention



comic credits: [xkcd](#)

# Let's check the theory by playing the game

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	

# Let's check with more random experiments

- `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 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 IS MT VESUVIUS THERE

WHY DO THEY SAY T MINUS

WHY ARE THERE OBELISKS

WHY ARE WRESTLERS ALWAYS WET

WHY ARE OCEANS BECOMING MORE ACIDIC

WHY IS ARWEN DYING

WHY AREN'T MY QUAIL LAYING EGGS  
WHY AREN'T MY QUAIL EGGS HATCHING

WHY AREN'T THERE ANY FOREIGN MILITARY BASES IN AMERICA

WHY IS LIFE SO BORING

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 ARE ULTRASOUNDS IMPORTANT  
WHY ARE ULTRASOUND MACHINES EXPENSIVE  
WHY IS STEALING WRONG

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

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



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 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 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 AREN'T THERE DINOSAUR GHOSTS

WHY ARE THERE FEMALE MR NIMES

WHY DO IGUANAS DIE

WHY IS THERE LAW

WHY ARE THERE GHOSTS

WHY IS THERE HELL IF GOD FORGIVES

WHY IS GPS FREE

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 TWO SLASHES AFTER HTTP

WHY ARE THERE SO MANY CROWS IN ROCHESTER, MN

WHY IS THERE ICE IN SPACE

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