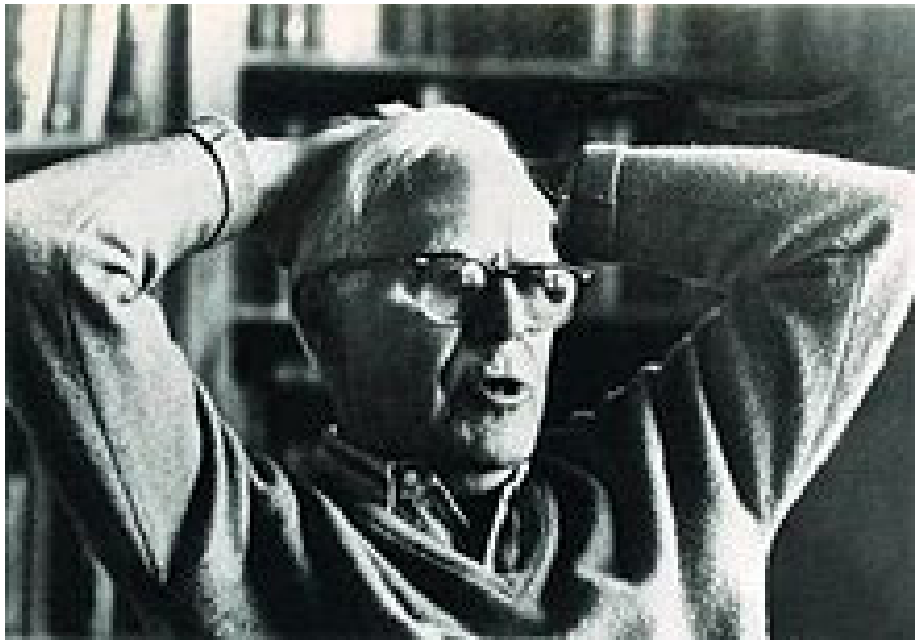
Secretary problem

- 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^{th} candidate (11/e~4 so he married the first after)

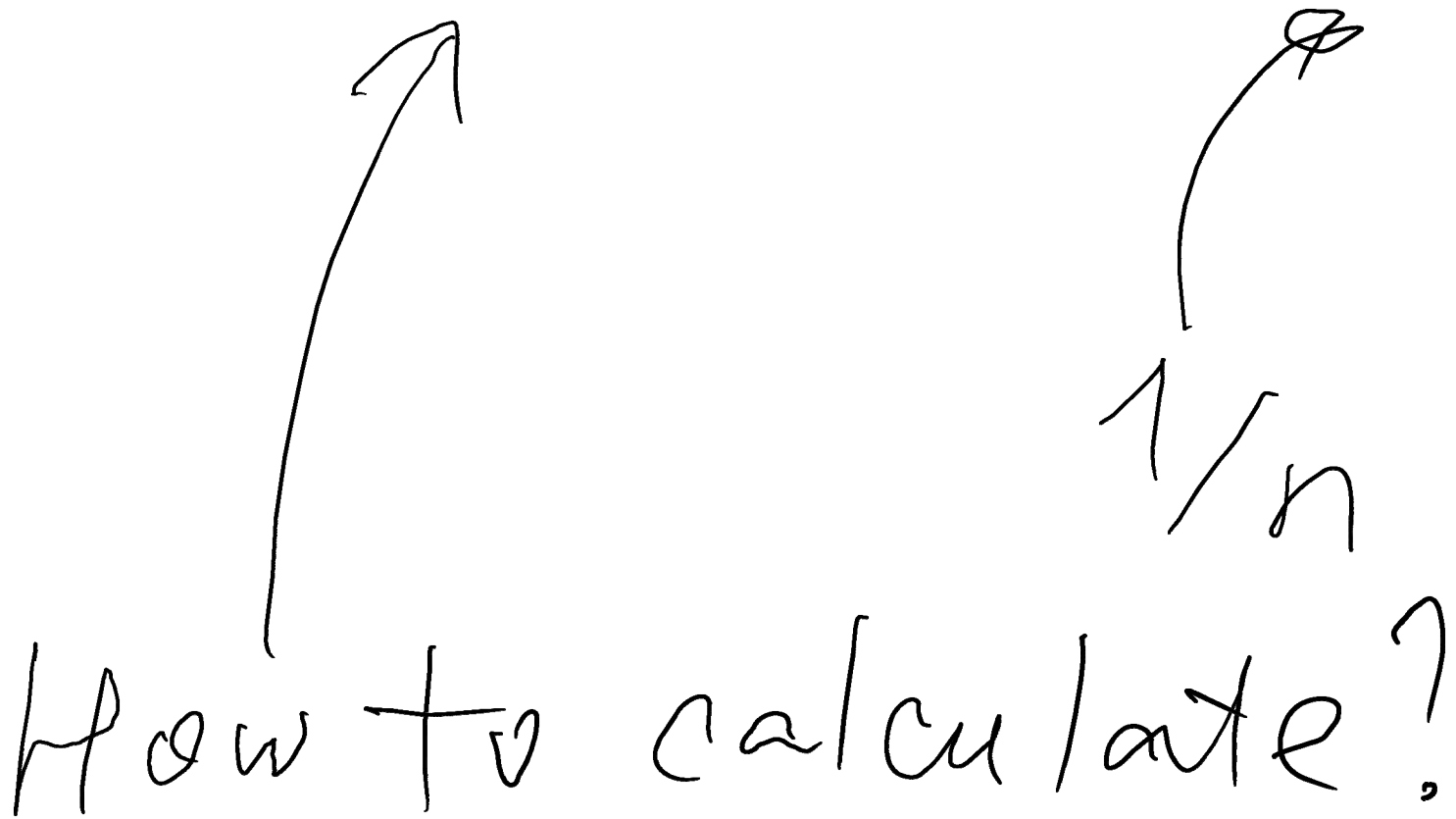
Thomas S Ferguson, Statistical Science 1989, Who Solved the Secretary Problem?

What should the employer do?

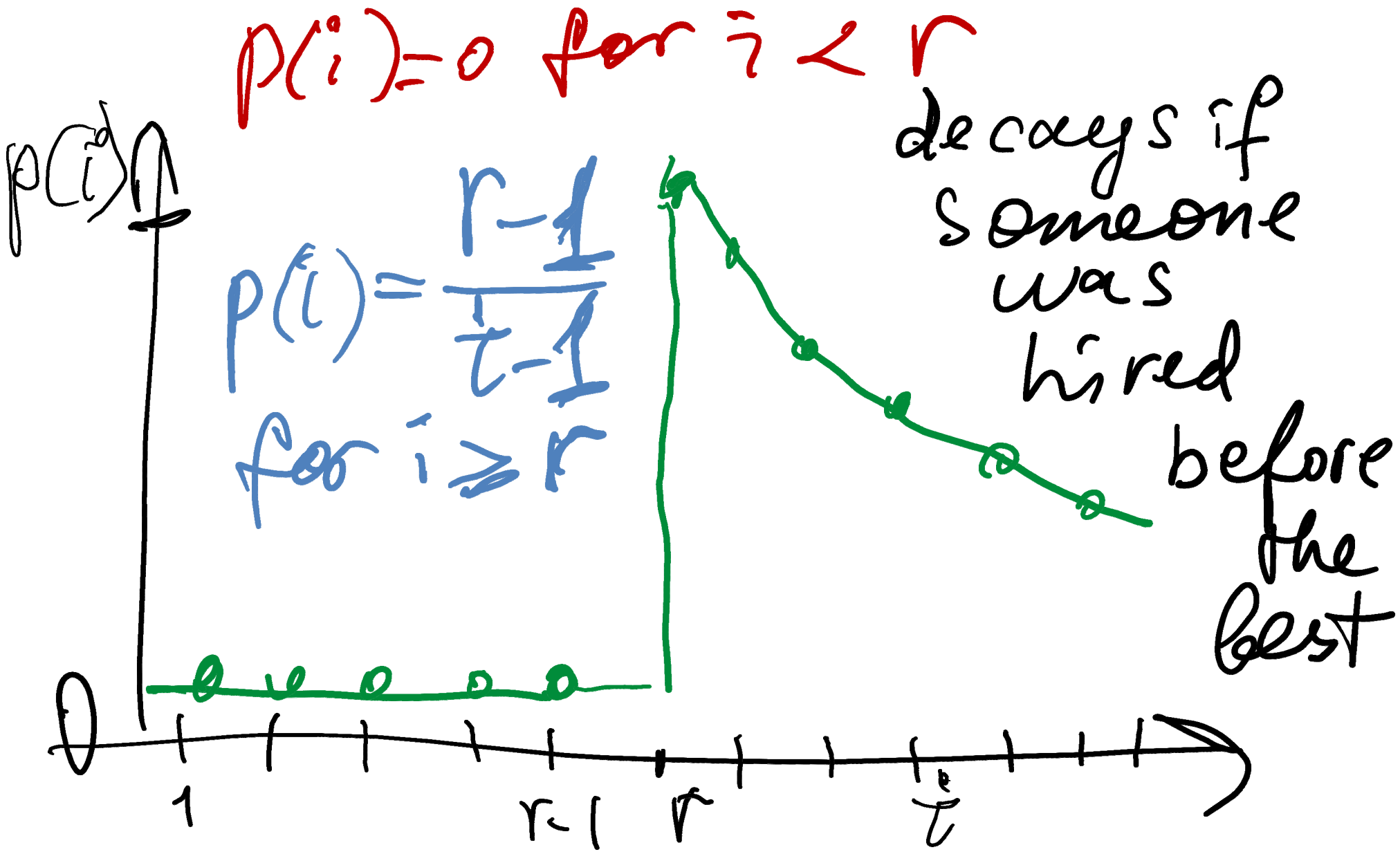
- Employer does not know the distribution of the quality of applicants and must learn it on the fly
- Algorithm: look at the first ***r-1*** applicants, remember the best among them
- Hire the first among next ***n-r+1*** applicants who is better than the best among the first ***r*** applicants
- How 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

$$P(r) = \sum_{i=1}^{n} P\left(\text{applicant } i \text{ is selected} \cap \text{applicant } i \text{ is the best}\right)$$

$$= \sum_{i=1}^{n} P\left(\text{applicant } i \text{ is selected} \middle| \text{applicant } i \text{ is the best}\right) \times P\left(\text{applicant } i \text{ is the best}\right)$$



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

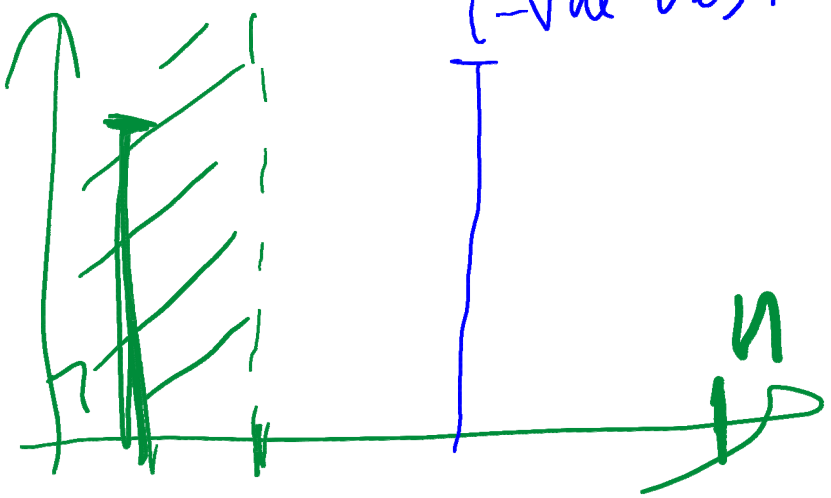


Look at $i-1$ candidates before the best

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

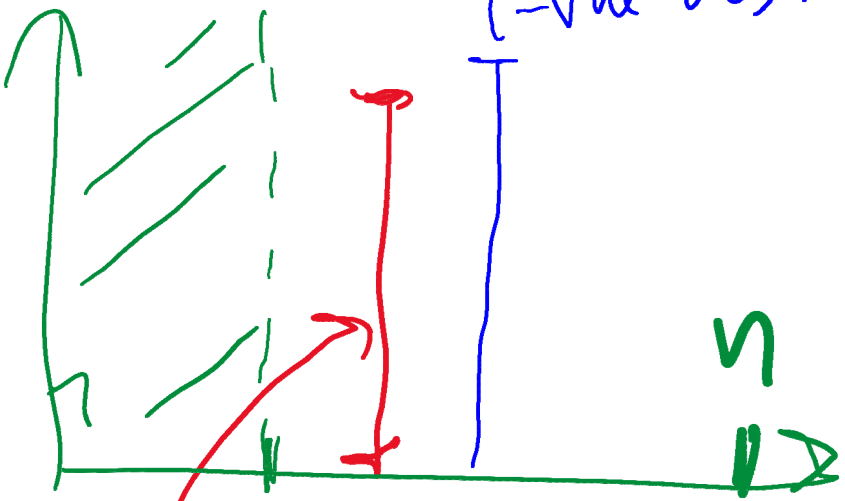
$$\text{Prob} = \frac{i-r}{i-1}$$

Good



the best among $i-1$

Bad



the best among $i-1$

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

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

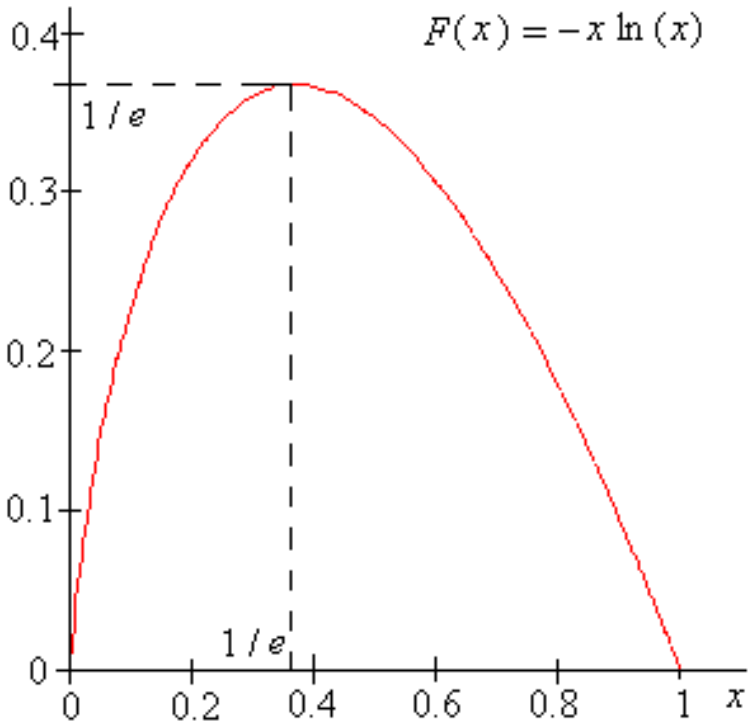
Letting *n* tend to infinity, writing x as the limit of *r*/*n*, using *t* for *i*/*n* and *dt* for 1/*n*,

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

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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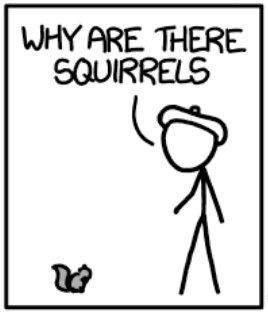

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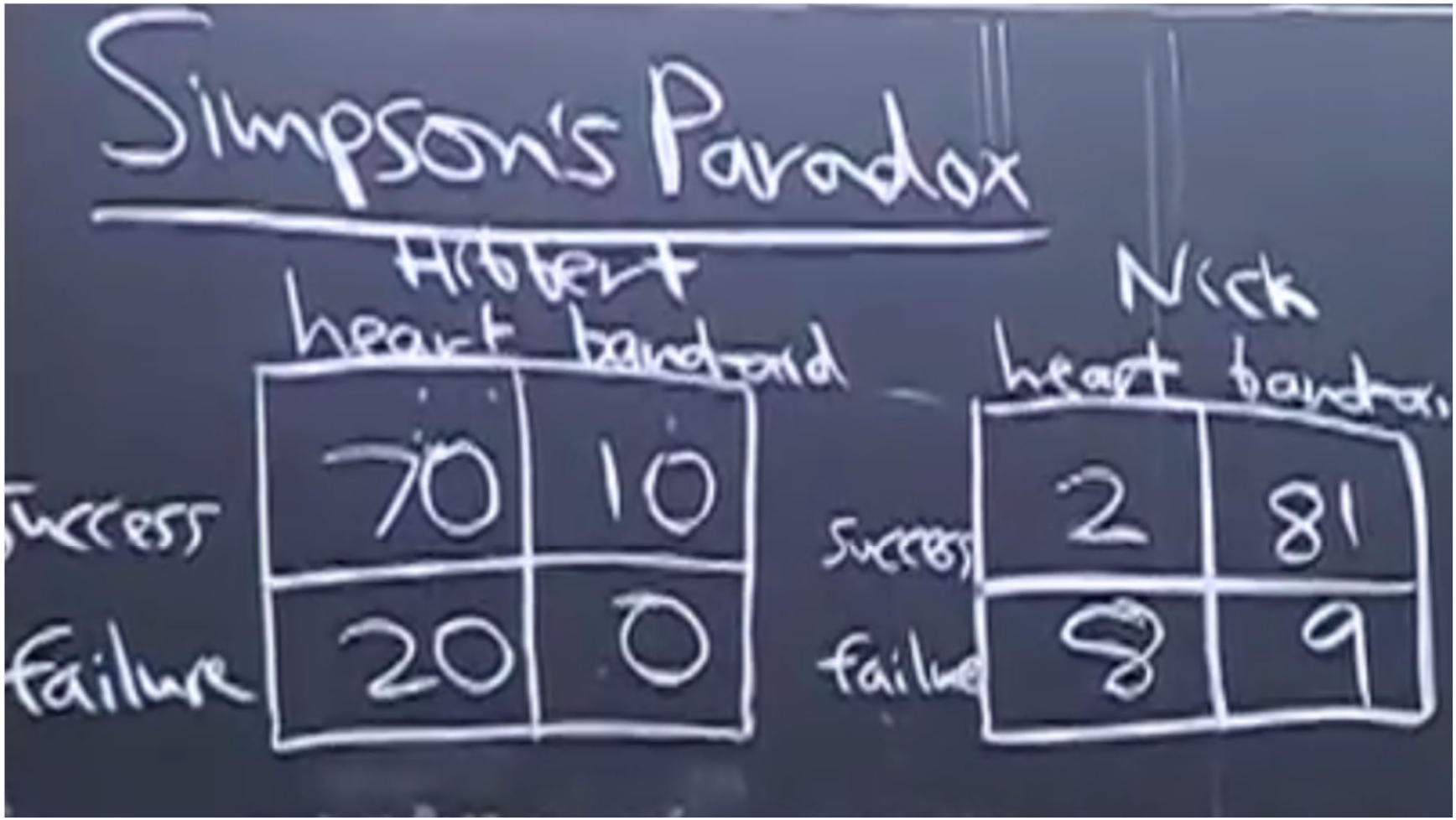
Simpson's paradox

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

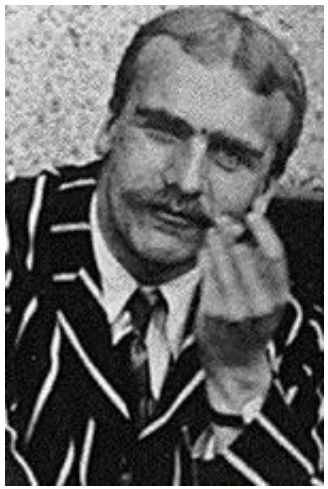


Dr. Hibbert: success rate =80%

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?**

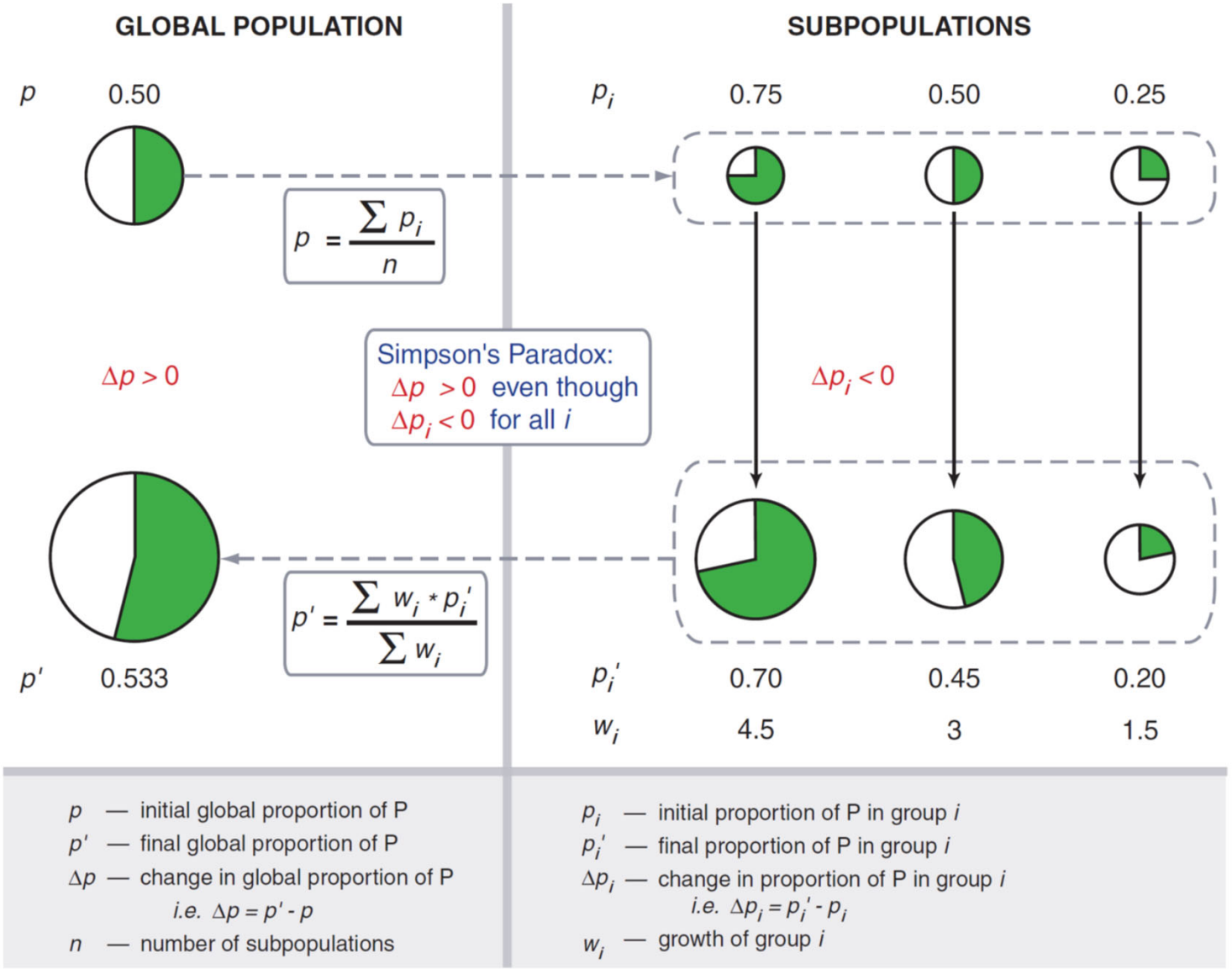
Chuang, Rivoire, and Leibler's answer

Simpson's Paradox in a Synthetic Microbial System

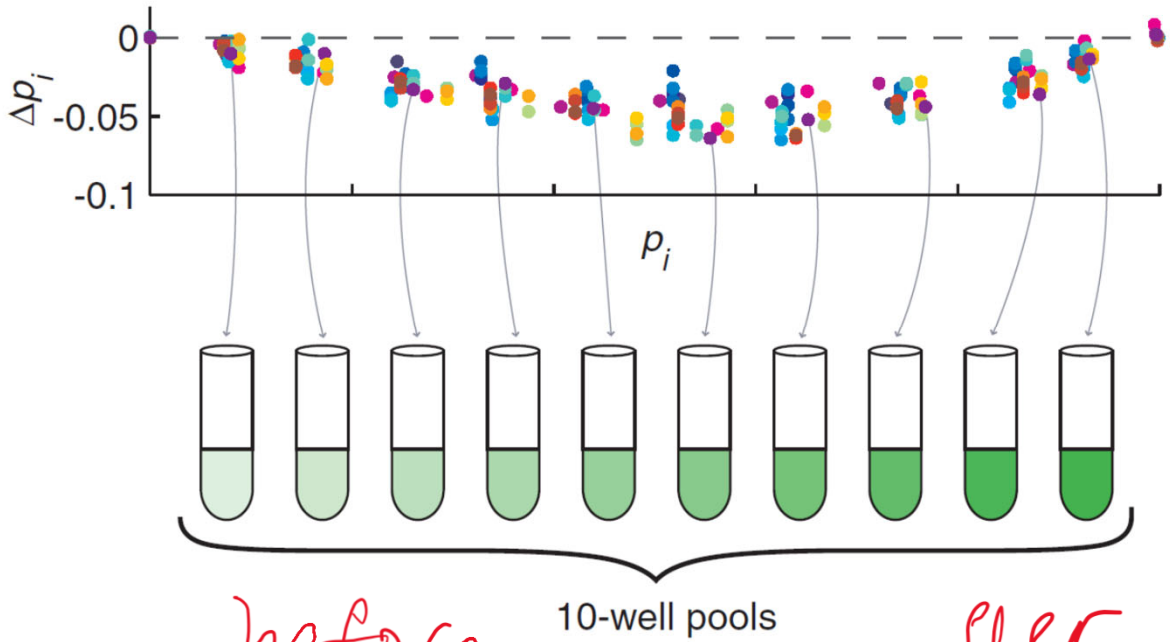
John S. Chuang,* Olivier Rivoire, Stanislas Leibler

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.

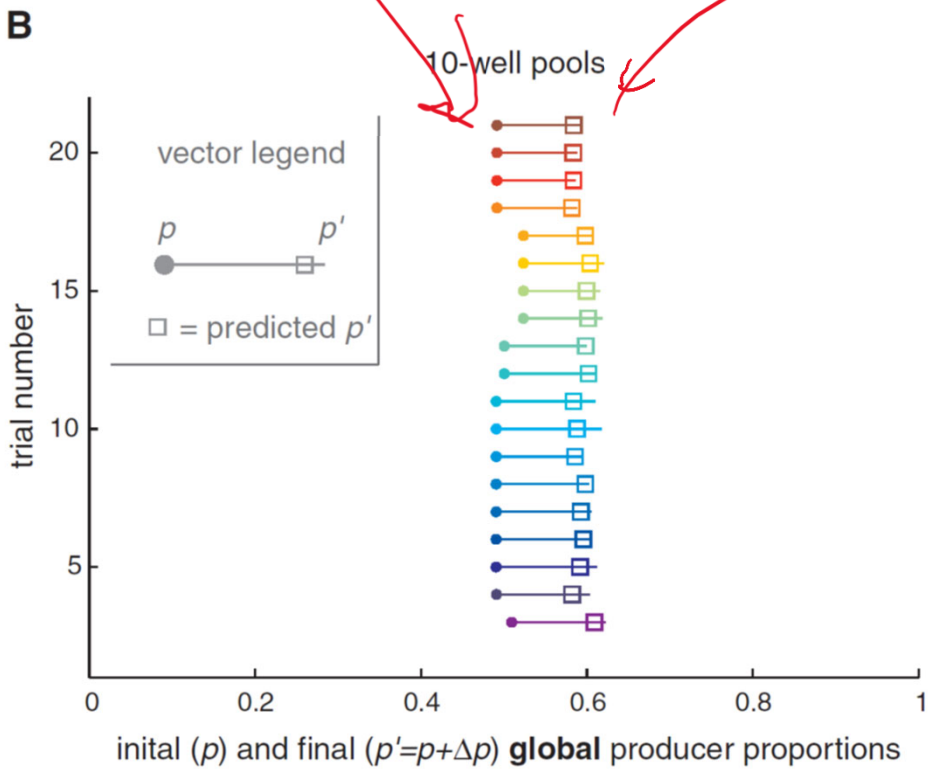
- The common good was a membrane-permeable Rhl autoinducer molecule rewired to activate antibiotic (chloramphenicol; Cm) resistance gene expression.



Fraction of altruists in
each of individual
test tubes dropped



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



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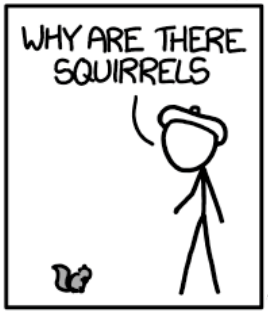

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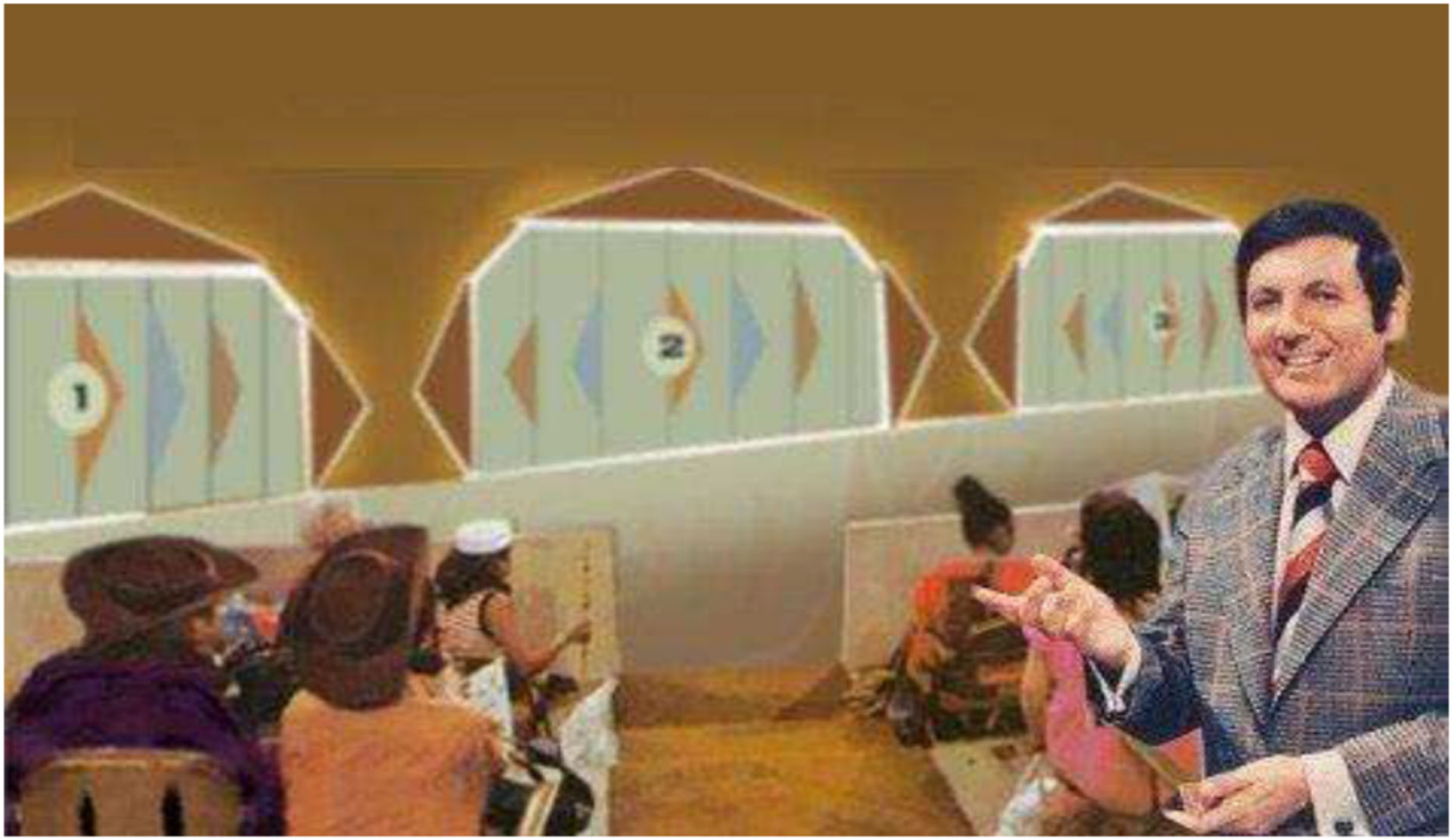
Monty Hall problem



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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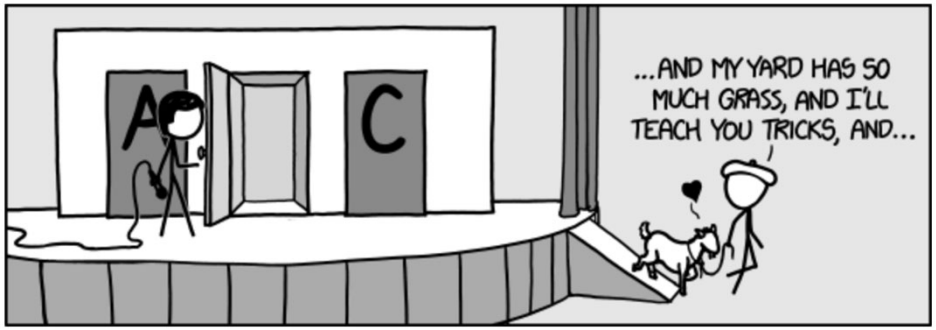
Don’t feel bad if you guessed wrong

- When first presented with the Monty Hall problem an overwhelming majority of people 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

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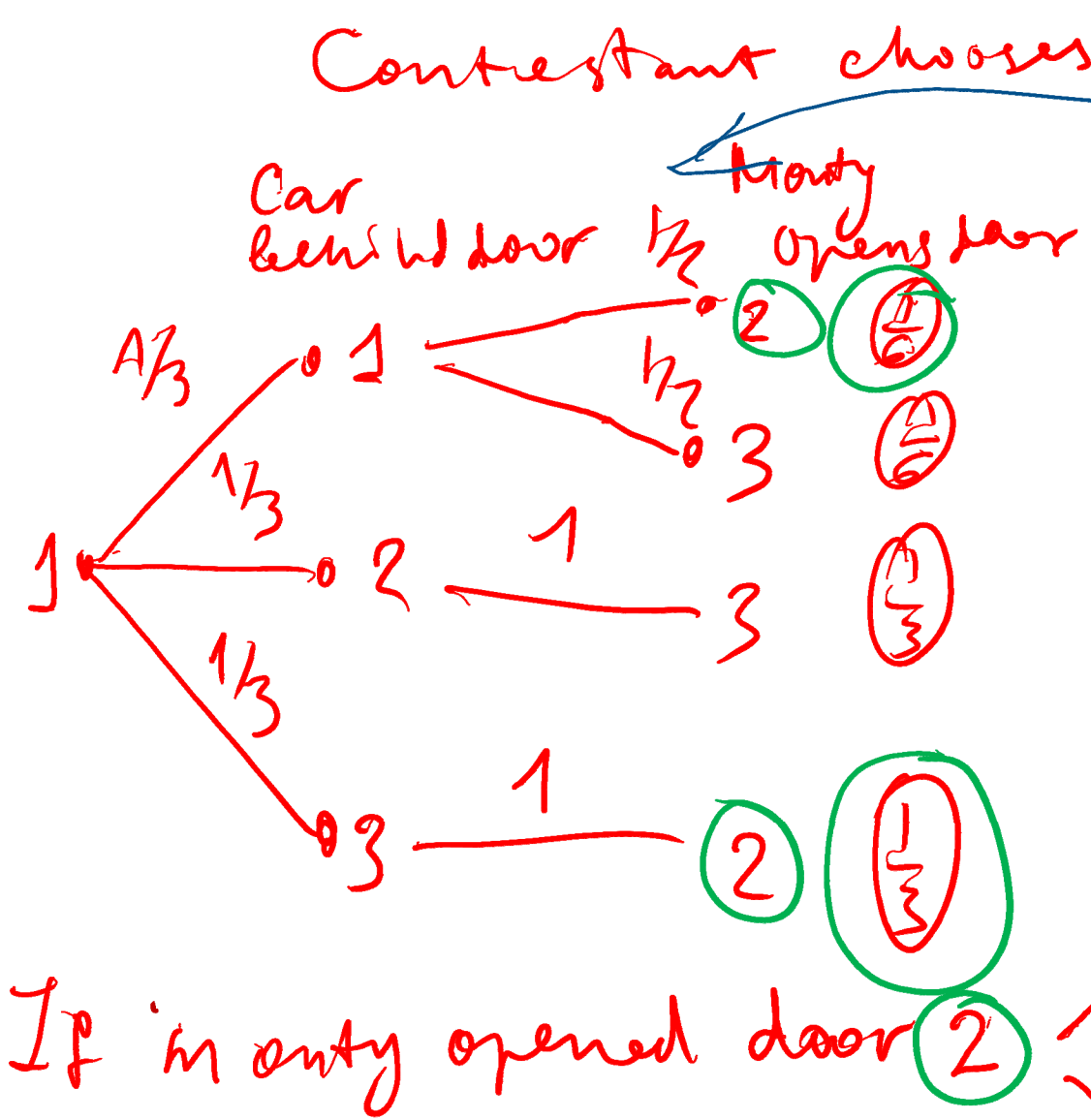
Tree & conditional probabilities



conditional probability

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

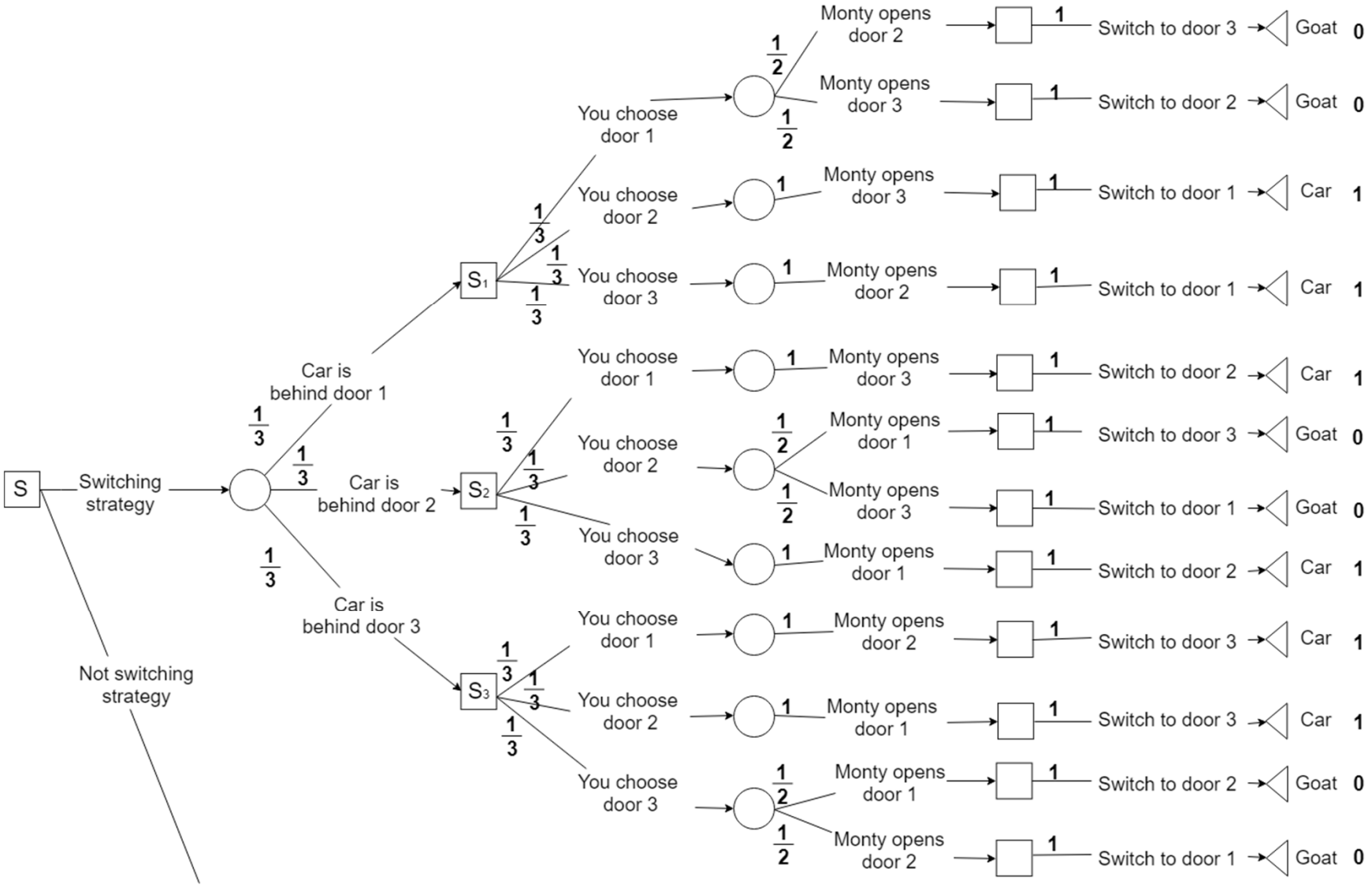
If Monty opened door 2

$\text{Prob}(\text{win by switching}) = \frac{\frac{1}{3}}{\frac{1}{3}+\frac{1}{6}} = \frac{2}{3}$

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

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

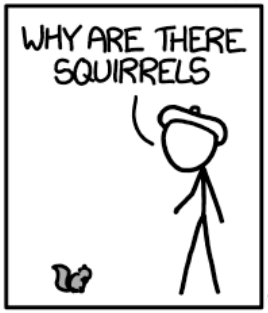
```
B=10000;  %set B large...
cars=0; carn=0; %set 0 at the beginning
for i = 1:B
a = randperm(3); %Monty places two goats and the car at random
%a(1) -goat, a(2) -goat, a(3) - car
i= floor(3.*rand)+1; %you select the door!
% SWITCH STRATEGY
if(i == a(1)) cars=cars+1; %a(2)-opened, switch to a(3), car!
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

QUESTIONS
FOUND IN GOOGLE AUTOCOMPLETE

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 ARE THERE SQUIRRELS



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 DO IGUANAS DIE
WHY AREN'T THERE DINOSAUR GHOSTS
WHY IS THERE HELL IF GOD FORGIVES
WHY IS GPS FREE

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 IS LYING GOOD

WHY IS SEX SO IMPORTANT

WHY ARE THERE SLAVES IN THE BIBLE
WHY DO TWINS HAVE DIFFERENT FINGERPRINTS
WHY ARE AMERICANS AFRAID OF DRAGONS
WHY IS YKK ON ALL ZIPPERS
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

WHY AREN'T MY ARMS GROWING

WHY ARE THERE WEEKS
WHY DO I FEEL DIZZY

WHY ARE THERE SWARMS OF GNATS
WHY IS THERE PHLEGM
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 IS THERE LAVA

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 DOGS AFRAID OF FIREWORKS

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 ARE THERE FEMALE MR MIMES

WHY ARE THERE GHOSTS

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 THERE NO KING IN ENGLAND
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 AREN'T THERE GUNS IN HARRY POTTER

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