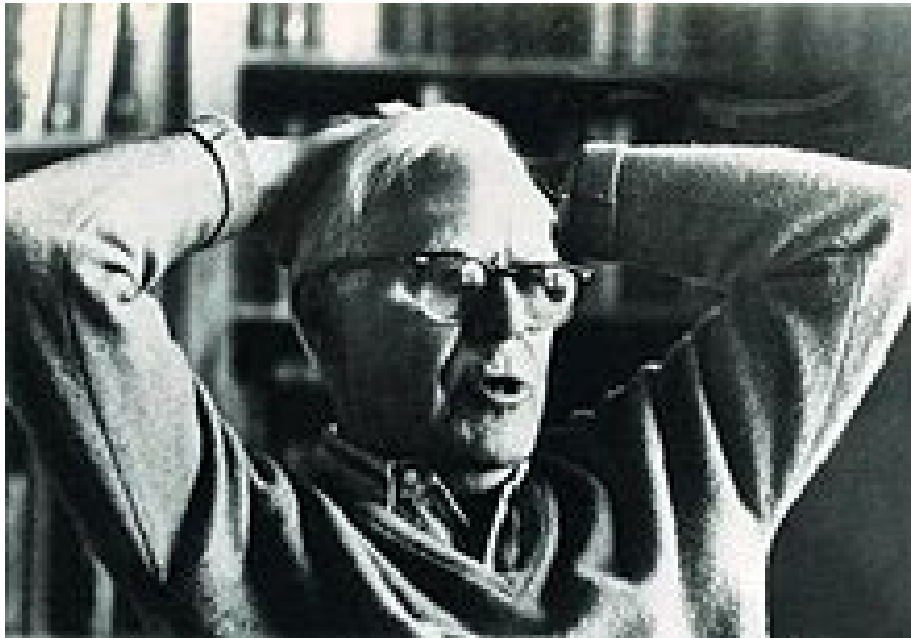


Secretary problem

- 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?

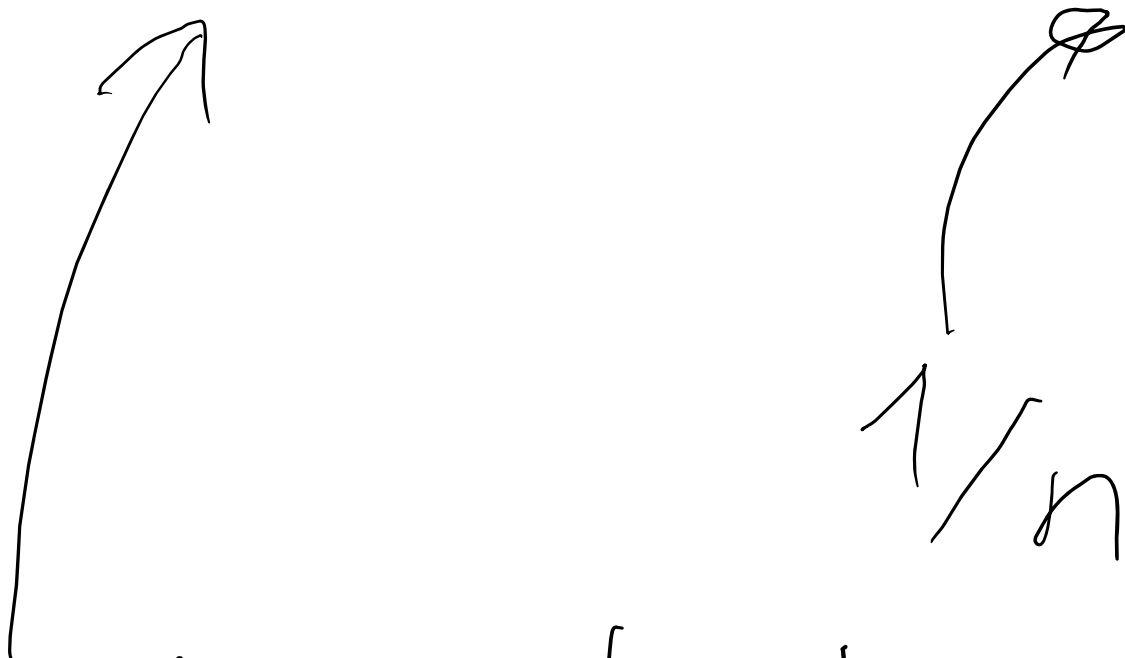
- Gardner outlined the solution in Sci Am 1960 but gave no formal proof
- Solution by Lindey was published in 1961:
Lindey, D. V. (1961). Dynamic programming and decision theory. Appl. Statist. 10 39-51
- Dynkin's paper was published in 1963:
Dynkin, E. B. (1963). The optimum choice of the instant for 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 5th 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?



$1/n$

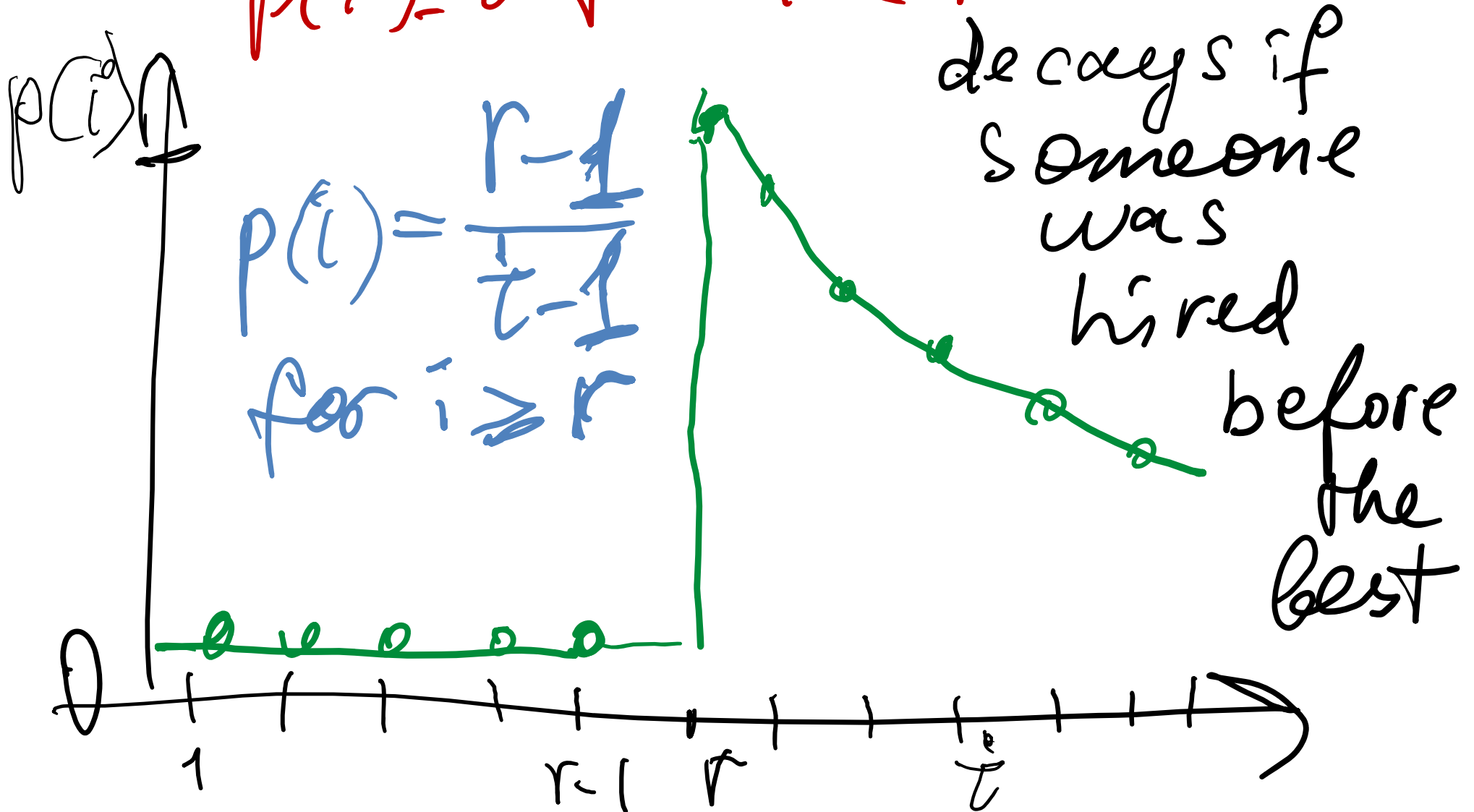
Probability of hiring the best candidate if he/she has # i in the queue



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

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

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

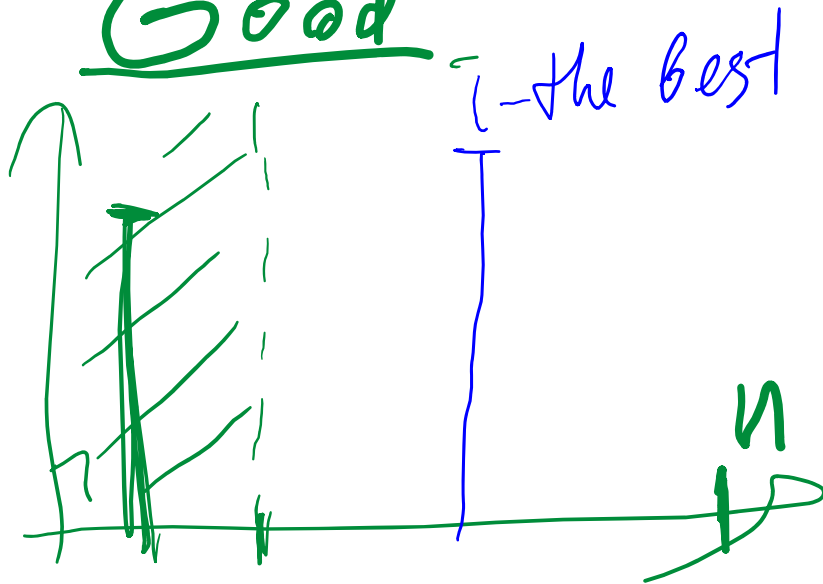


Look at $i-1$ candidates
before the best

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

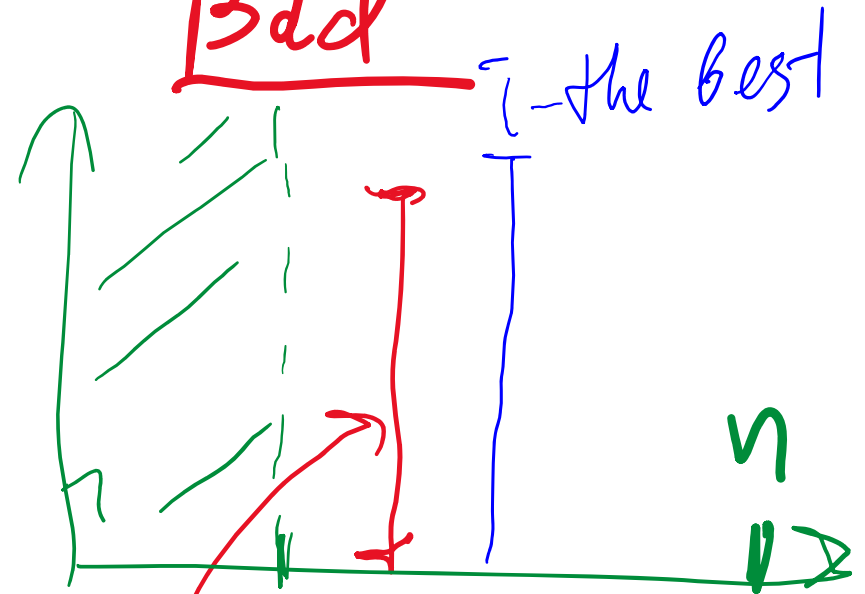
$$\text{Prob} = \frac{i-r}{i-1}$$

Good



the best among $i-1$

Bad



the best among $i-1$

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

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

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

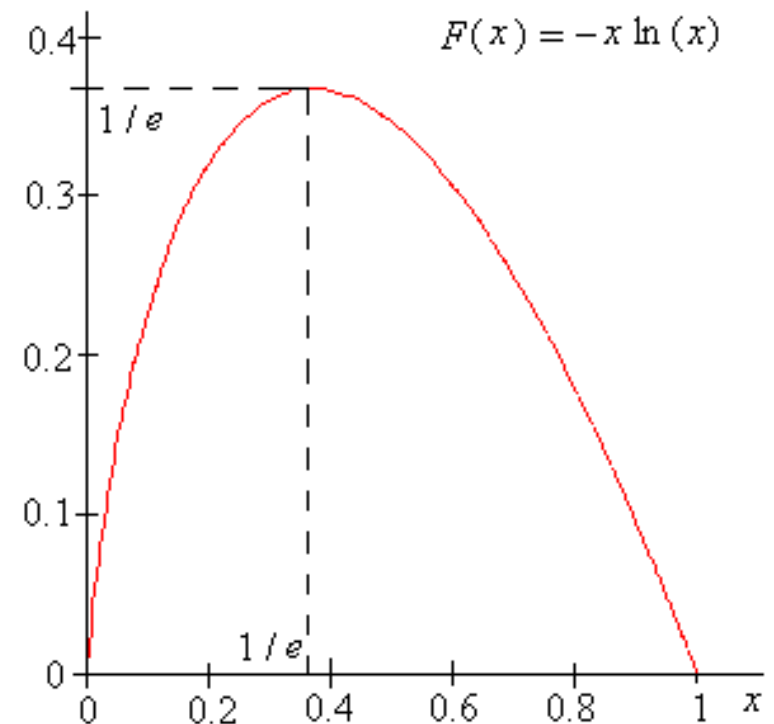
$$P(x) = x \int_x^1 \frac{1}{t} dt = -x \ln(x).$$

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

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

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

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



Credit: XKCD
comics

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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

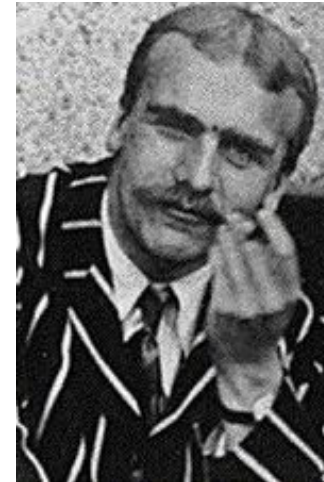
	Hibbert heart bandaid	Nick heart bandaid
Success	70	2
Failure	20	8
	10	81
	0	9

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?**

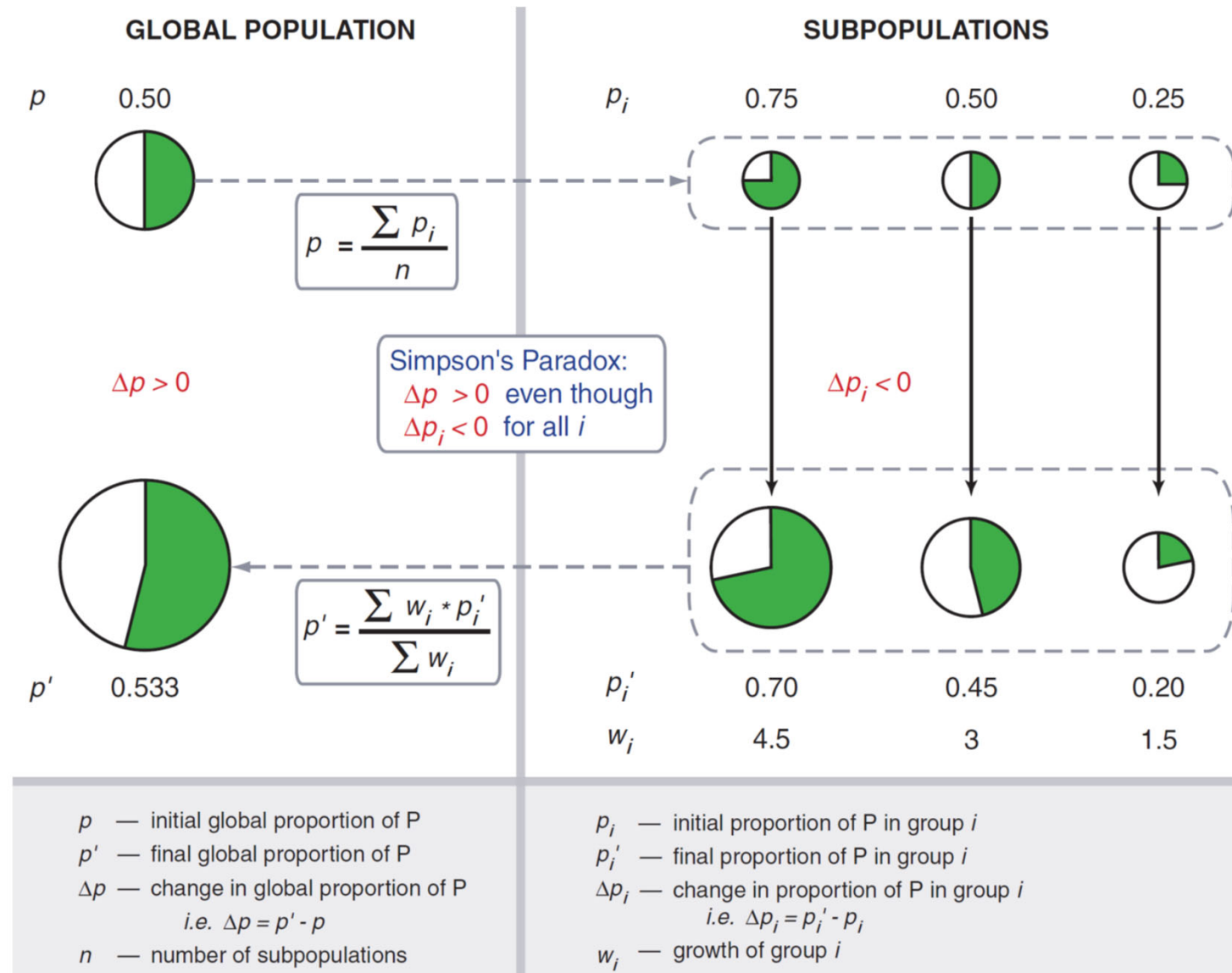


Simpson's Paradox in a Synthetic Microbial System

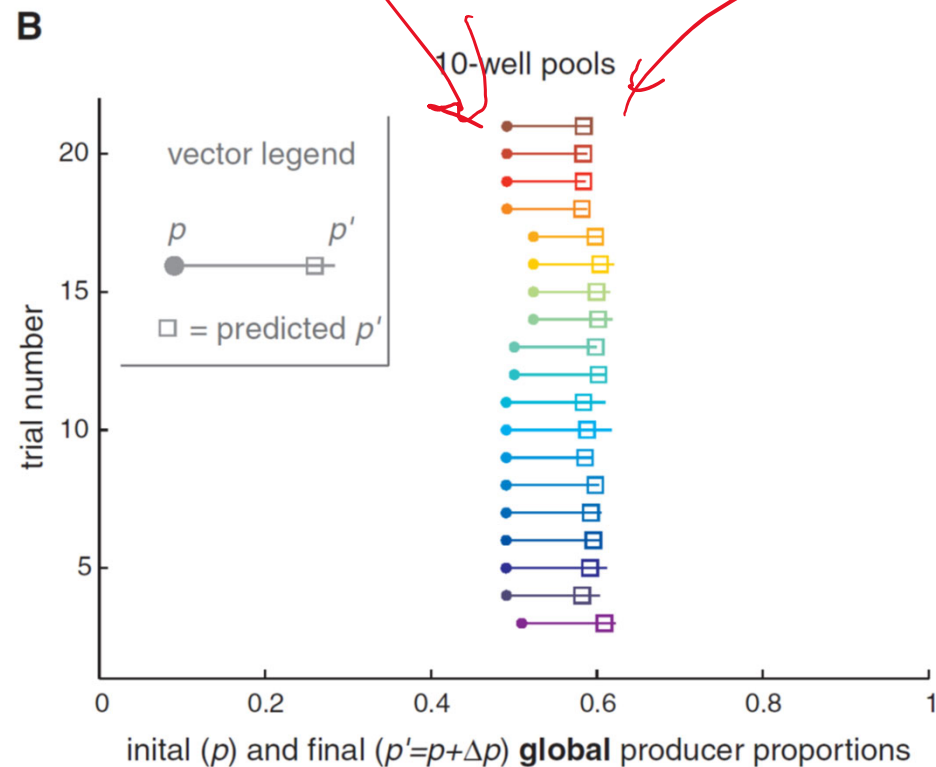
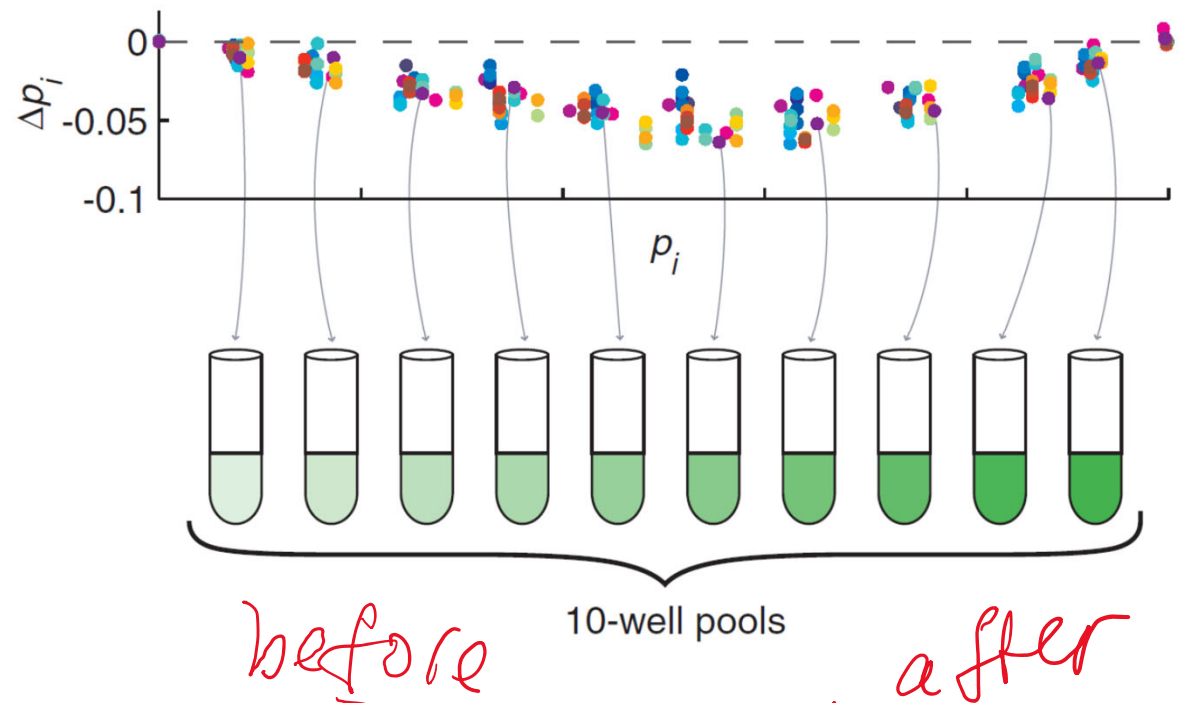
John S. Chuang,* Olivier Rivoire, Stanislas Leibler

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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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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A. Better to switch doors

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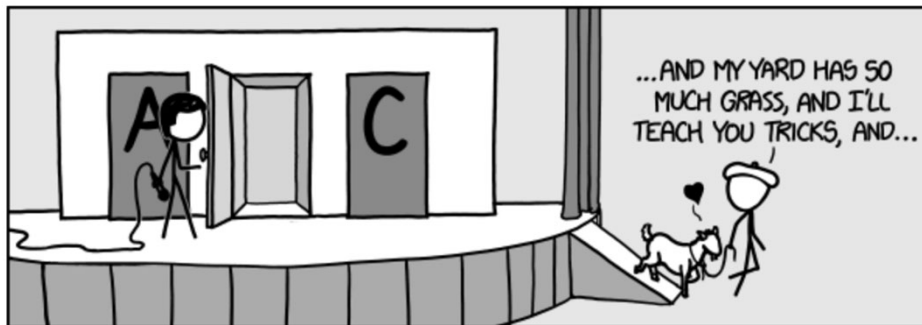
D. The answer depends on the phase of the moon

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)

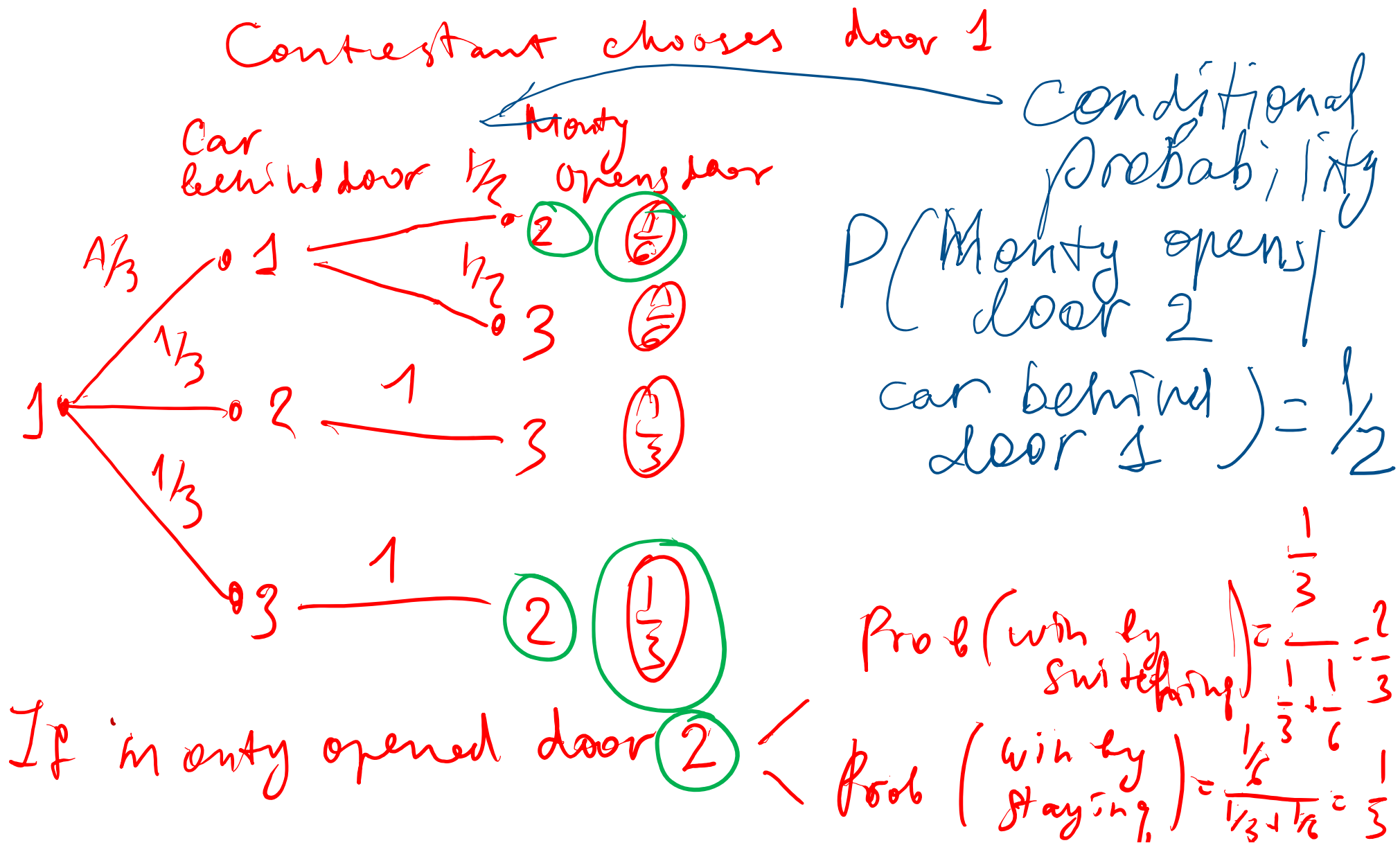
- With **Prob=1/3** you guess the car door right:
you loose the car if you switch
- With **Prob=2/3** you got it wrong and picked a goat door. Then Monty opens another goat door. What is left is the car door.
You win the car if you switch!

Solution #2.

Tree & conditional probabilities

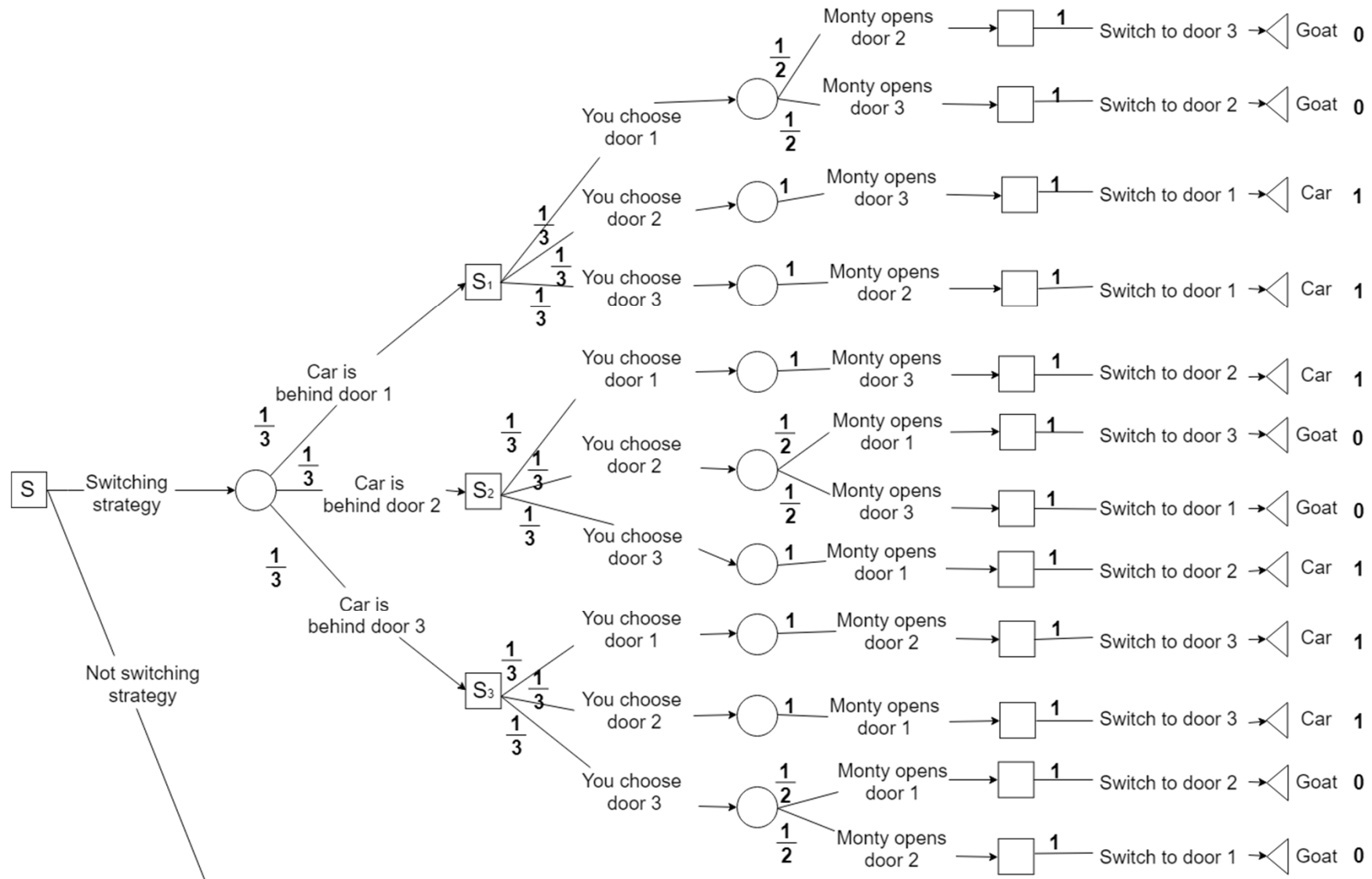
Solution #2.

Tree & conditional probabilities



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`

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	