

CSE 312

Foundations of Computing II

Anna R. Karlin

**Welcome back to in-person classes and to
CSE 312 in particular!!**

<https://courses.cs.washington.edu/312>

Questions and Discussions

- **Office hours throughout the week (starting Friday)**
- **Ed Discussion**

You should have received an invitation (synchronized with the class roster)

- Material (resources tab)
- Announcement (discussion tab)
- Discussion (discussion tab)

Use Ed discussion forum as much as possible. You can make private posts that only the staff can view! Email instructors for personal issues.

Lectures and Sections

- **Lectures MWF**
 - 1:30-2:20pm
 - Recorded on Panopto
- **Ask questions in the edstem thread**
 - Questions will either be answered by a TA, or will be passed on to Anna.
 - Some questions may be deferred to the end of the lecture.
 - Feel free to answer your fellow classmate's questions on edstem

Lectures and Sections

- **Sections Thu (start tomorrow!)**
 - Not recorded, for privacy of student discussion

To make tomorrow's section useful, I will try to get through a lot today.

Grading etc.

- **Concept checks after each lecture 15%**
 - Released by 3pm after lecture. Must be done by 30 mins before the next lecture.
 - Simple questions to reinforce concepts taught in each class.
 - Keep you engaged throughout the week, so that homework becomes less of a hurdle
- **8 Homeworks (Gradescope) 60%**
 - Most will be in teams of 2. Submit a single solution only. Some will have coding component.
- **3 quizzes: 15%**
- **Final (problem set): 10%**

Grading etc.

Check out the syllabus for policies on late submission and everything else.

Bring questions about syllabus and administrivia to class Friday.

Homework

- HW1 is already out and is due 11:59pm next Wednesday.
- In general, every HW is due one week after it's released.
- There is some possibility that later HWs might be released on different days of the week.

Foundations of Computing II

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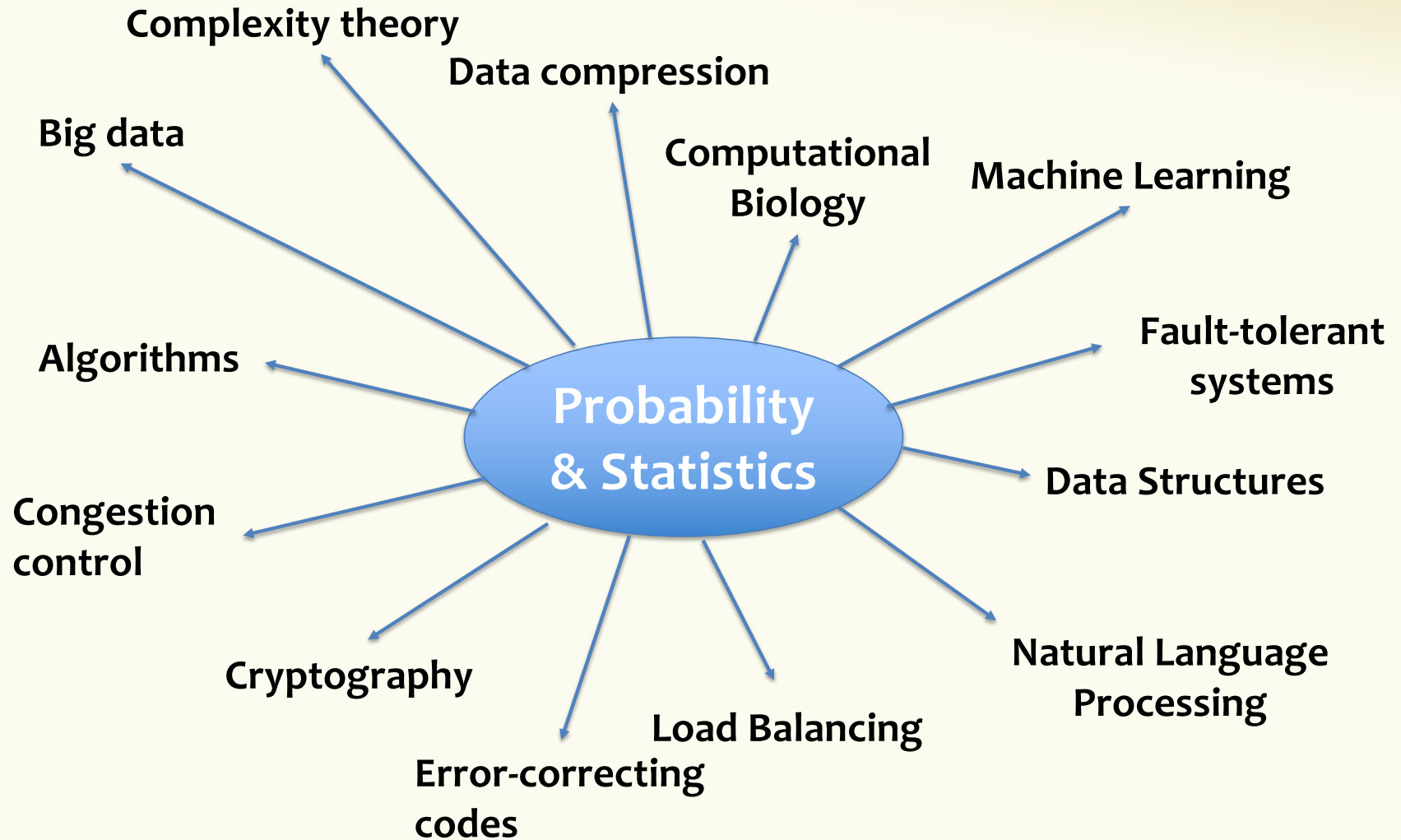
Introduction to Probability & Statistics for computer scientists



What is probability??

Why probability?!

+ much more!



Content

- **Counting (basis of discrete probability)**
 - Counting, Permutation, Combination, inclusion-exclusion, Pigeonhole Principle
- **What is probability**
 - Probability space, events, basic properties of probabilities, conditional probability, independence, expectation, variance
- **Properties of probability**
 - Various inequalities, Zoo of discrete random variables, Concentration, Tail bounds
- **Continuous Probability & Statistics**
 - Probability Density Functions, Cumulative Density Functions, Uniform, Exponential, Normal distributions, Central Limit Theorem, Estimation
- **Applications**
 - A sample of randomized algorithms, differential privacy, learning ...

CSE 312

Foundations of Computing II

Lecture 1: Counting



Anna R. Karlin

Slide Credit: Based in part on Stefano Tessaro's slides for 312 19au incorporating ideas from Alex Tsun, Rachel Lin, Hunter Schafer & myself 😊

Today: Counting



We are interested in counting the number of objects with a certain given property.

“How many ways are there to assign 7 TAs to 5 sections, such that each section is assigned to two TAs, and no TA is assigned to more than two sections?”

“How many integer solutions $(x, y, z) \in \mathbb{Z}^3$ does the equation $x^3 + y^3 = z^3$ have?”

Generally: Question boils down to computing cardinality $|S|$ of some given set S .

(Discrete) Probability and Counting are Twin Brothers

“What is the probability that a random student from CSE312 has black hair?”

$$= \frac{\# \text{ students with black hair}}{\# \text{ students}}$$



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Sum Rule

If you can choose from

- **Either** one of n options,
 - **OR** one of m options with **NO overlap** with the previous n ,
- then the number of possible outcomes is

$$n + m$$

Counting “lunches”

If your starter can be **either** one soup (6 choices) **or** one salad (8 choices), how many possible starters?



Product Rule: If each outcome is constructed by a sequential process where there are

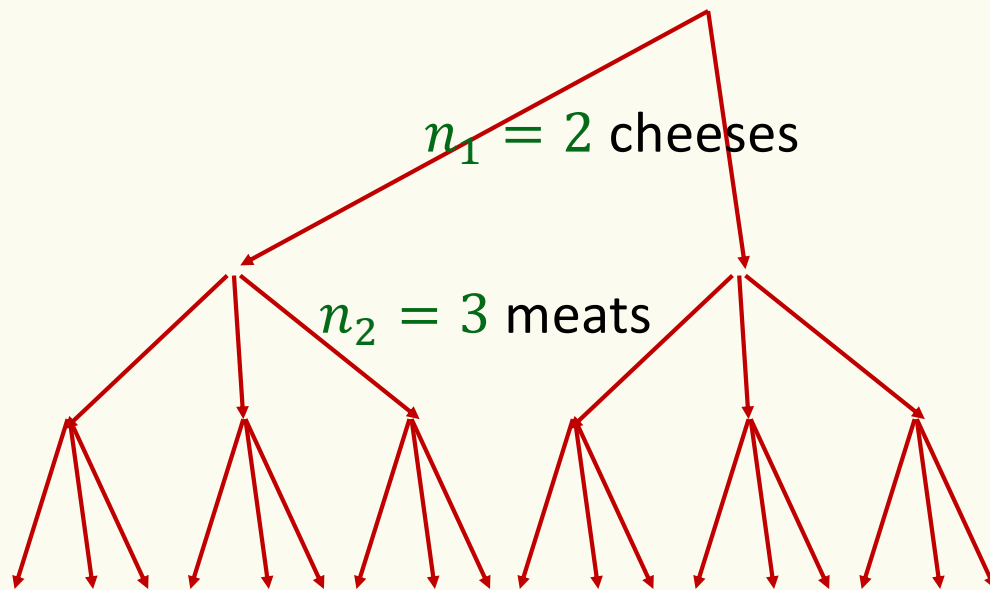
- n_1 choices for the first step,
- n_2 choices for the second step (given the first choice), ..., and
- n_k choices for the k^{th} step (given the previous choices),

then the total number of outcomes is $n_1 \times n_2 \times \cdots \times n_k$

Product Rule: In a sequential process, if there are

- n_1 choices for the first step,
- n_2 choices for the second step (given the first choice), ..., and
- n_k choices for the k^{th} step (given the previous choices),

then the total number of outcomes is $n_1 \times n_2 \times \cdots \times n_k$



Example: "How many subways?"

$$\square \times \square \times \square = \square$$



Example – Strings

How many strings of length 5 over the alphabet $\{A, B, C, \dots, Z\}$ are there?

- E.g., AZURE, BINGO, TANGO, STEVE, SARAH, ...

$$\square \times \square \times \square \times \square \times \square = \square$$

Example – Strings

How many binary strings of length n over the alphabet $\{0,1\}$?

- E.g., $0 \cdots 0$, $1 \cdots 1$, $0 \cdots 01$, ...

$$\square \times \square \times \square \times \square \times \square = \square$$

Example – Power set

Definition. The **power set** of S is

$$2^S \stackrel{\text{def}}{=} \{X: X \subseteq S\}$$

Example.

$$S = \{\star, \spadesuit\} \quad 2^{\{\star, \spadesuit\}} = \{\emptyset, \{\star\}, \{\spadesuit\}, \{\star, \spadesuit\}\}$$

$$S = \emptyset \quad 2^\emptyset = \{\emptyset\}$$

...

How many different subsets of S are there if $S = n$?

Example – Power set – number of subsets of S

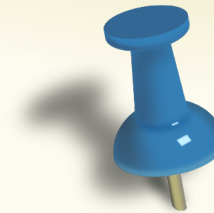
$$S = \{e_1, e_2, e_3, \dots, e_n\}$$

What is the number of subsets of S , i.e., $|2^S|$?

$$\square \times \square \times \square \dots \times \square = \square$$

Example – ATMs and Pin codes

- How many 4 –digit pin codes are there?
- Each digit one of $\{0, 1, 2, \dots, 9\}$



$$\square \times \square \times \square \times \square = \square$$

possible
first digits

possible
second digits

possible
third digits

possible
fourth digits

possible
pins



Example – ATMs and Pin codes – Stronger Pins

- How many **10-digit** pin codes are there with no repeating digit?
- Each digit one of $\{0, 1, 2, \dots, 9\}$; must use each digit **exactly once**

$$\begin{array}{ccccccccccc} \square & \times & \square & \times & \square & \times & \dots & \times & \square & \times & \square & = & \square \\ \# \text{ possible} & & \# \text{ possible} & & \# \text{ possible} & & & & & & & & \# \text{ possible} \\ \text{first} & & \text{second} & & \text{third} & & & & & & & & \text{pins} \\ \text{digits} & & \text{digits} & & \text{digits} & & & & & & & & \end{array}$$

Permutations

“How many ways to order n distinct objects?”

$$\text{Answer} = n \times (n - 1) \times (n - 2) \times \cdots \times 2 \times 1$$

Definition. The **factorial function** is

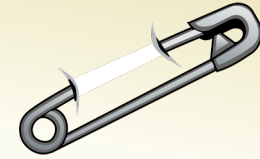
$$n! = n \times (n - 1) \times \cdots \times 2 \times 1$$

Read as “ n factorial”

Note: $0! = 1$

Huge: Grows
exponentially in n

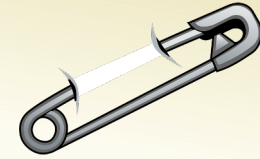
Example – ATMs and Pin codes – Tricky Pins



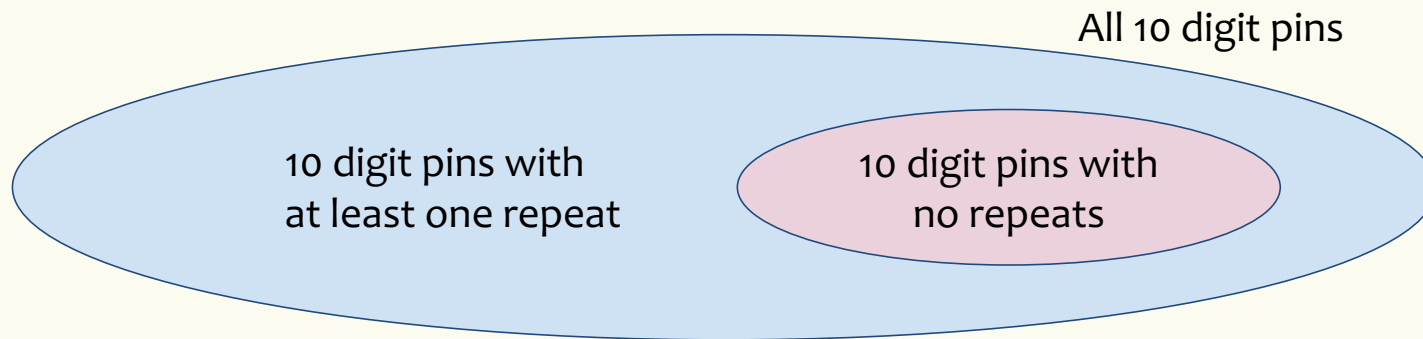
- How many 10–digit pin codes with **at least one digit repeated once**?
- Examples: 1111111111, 1234567889, 1353483595

$$\begin{array}{ccccccc} \boxed{} & \times & \boxed{} & \times & \boxed{} & \times \dots \times & \boxed{} & \times & \boxed{} & = & \boxed{} \\ \# \text{ possible} & & \# \text{ possible} & & \# \text{ possible} & & \dots & & & & \# \text{ possible} \\ \text{first} & & \text{second} & & \text{third} & & & & & & \text{pins} \\ \text{digits} & & \text{digits} & & \text{digits} & & & & & & \end{array}$$

Example – ATMs and Pin codes – Tricky Pins



- How many 10–digit pin codes with at least one digit repeated once?



Complementary Counting

Let U be a set and S a subset of interest

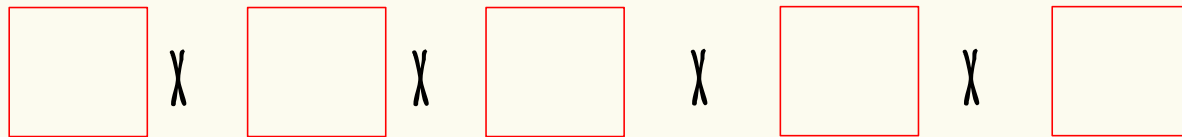
Let $U \setminus S$ denote the set difference (the part of U that is not in S)

Then $|U \setminus S| = |U| - |S|$

Distinct Letters

“How many sequences of 5 distinct alphabet letters from $\{A, B, \dots, Z\}$?”

E.g., AZURE, BINGO, TANGO. But not: STEVE, SARAH



Distinct Letters

“How many sequences of 5 distinct alphabet letters from {A, B, ..., Z}?”

E.g., AZURE, BINGO, TANGO. But not: STEVE, SARAH

Answer: $26 \times 25 \times 24 \times 23 \times 22 = 7893600$

In general

Aka: k -permutations

Fact. # of ways to arrange k out of n distinct objects in a sequence.

$$P(n, k) = n \times (n - 1) \times \cdots \times (n - k + 1) = \frac{n!}{(n - k)!}$$

We say “ n pick k ”

Number of Subsets

“How many size-5 subsets of $\{A, B, \dots, Z\}$?”

E.g., $\{A, Z, U, R, E\}$, $\{B, I, N, G, O\}$, $\{T, A, N, G, O\}$. But not:
 $\{S, T, E, V\}$, $\{S, A, R, H\}$, ...

Number of Subsets

“How many size-5 subsets of $\{A, B, \dots, Z\}$?”

E.g., $\{A, Z, U, R, E\}$, $\{B, I, N, G, O\}$, $\{T, A, N, G, O\}$. But not:
 $\{S, T, E, V\}$, $\{S, A, R, H\}$, ...

Difference from k -permutations: NO ORDER

Different sequences: TANGO, OGNAT, ATNGO, NATGO, ONATG ...

Same set: $\{T, A, N, G, O\}$, $\{O, G, N, A, T\}$, $\{A, T, N, G, O\}$, $\{N, A, T, G, O\}$, $\{O, N, A, T, G\}$

How to count number of 5 element subsets of $\{A, B, \dots, Z\}$?

Consider the following process:

1. Choose an **unordered** subset $S \subseteq \{A, B, \dots, Z\}$ of size $|S| = 5$
e.g. $S = \{A, G, N, O, T\}$
2. Choose a permutation of letters in S
e.g., *TANGO, AGNOT, NAGOT, GOTAN, GOATN, NGOAT, ...*

Outcome: An **ordered** sequence of 5 distinct letters from $\{A, B, \dots, Z\}$

$$\square \times \square = \square$$

Number of Subsets – Idea for how to count

Consider the following process:

1. Choose an **unordered** subset $S \subseteq \{A, B, \dots, Z\}$ of size $|S| = 5$. e.g. $S = \{A, G, N, O, T\}$
1. Choose a permutation of letters in S
e.g., *TANGO, AGNOT, NAGOT, GOTAN, GOATN, NGOAT, ...*

Outcome: An **ordered** sequence of 5 distinct letters from $\{A, B, \dots, Z\}$

???

×

5!

=

$\frac{26!}{21!}$

$$??? = \frac{26!}{21!5!} = 65780$$

Number of Subsets -- don't care about order

Fact. The number of subsets of size k of a set of size n is

$$C(n, k) = \binom{n}{k} = \frac{n!}{k!(n-k)!}$$

we say “ n choose k ”

[also called **combinations**
or **binomial coefficients**]

Quick Summary

- **Sum Rule**

If you can choose from

- **Either** one of n options,
- **OR** one of m options with **NO overlap** with the previous n ,

then the number of possible outcomes of the experiment is $n + m$

- **Product Rule**

In a sequential process, if there are

- n_1 choices for the first step,
- n_2 choices for the second step (given the first choice), ..., and
- n_k choices for the k^{th} step (given the previous choices),

then the total number of outcomes is $n_1 \times n_2 \times \cdots \times n_k$

- **Complementary Counting**

Quick Summary

- **K-sequences**: How many length k sequences over alphabet of size n ?
repetition allowed.
 - Product rule $\rightarrow n^k$
- **K-permutations**: How many length k sequences over alphabet of size n , without repetition?
 - Permutation $\rightarrow \frac{n!}{(n-k)!}$
- **K-combinations**: How many size k subsets of a set of size n (without repetition and without order)?
 - Combination $\rightarrow \binom{n}{k} = \frac{n!}{k!(n-k)!}$

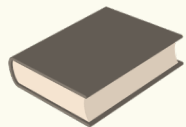
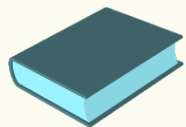
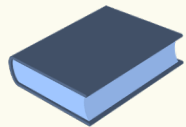
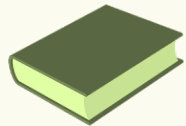
***The first concept check (CC) will be out
by 3pm and is due 1:00pm Friday***

The concept checks are meant to help you immediately reinforce what is learned in each lecture. (Today's CC also reviews summation notation.)

Students from previous quarters found them really useful!

Product rule – Another example

5 books



“How many ways are there to distribute 5 books among Alice, Bob, and Charlie?”

Every book to one person, everyone gets ≥ 0 books.



Alice

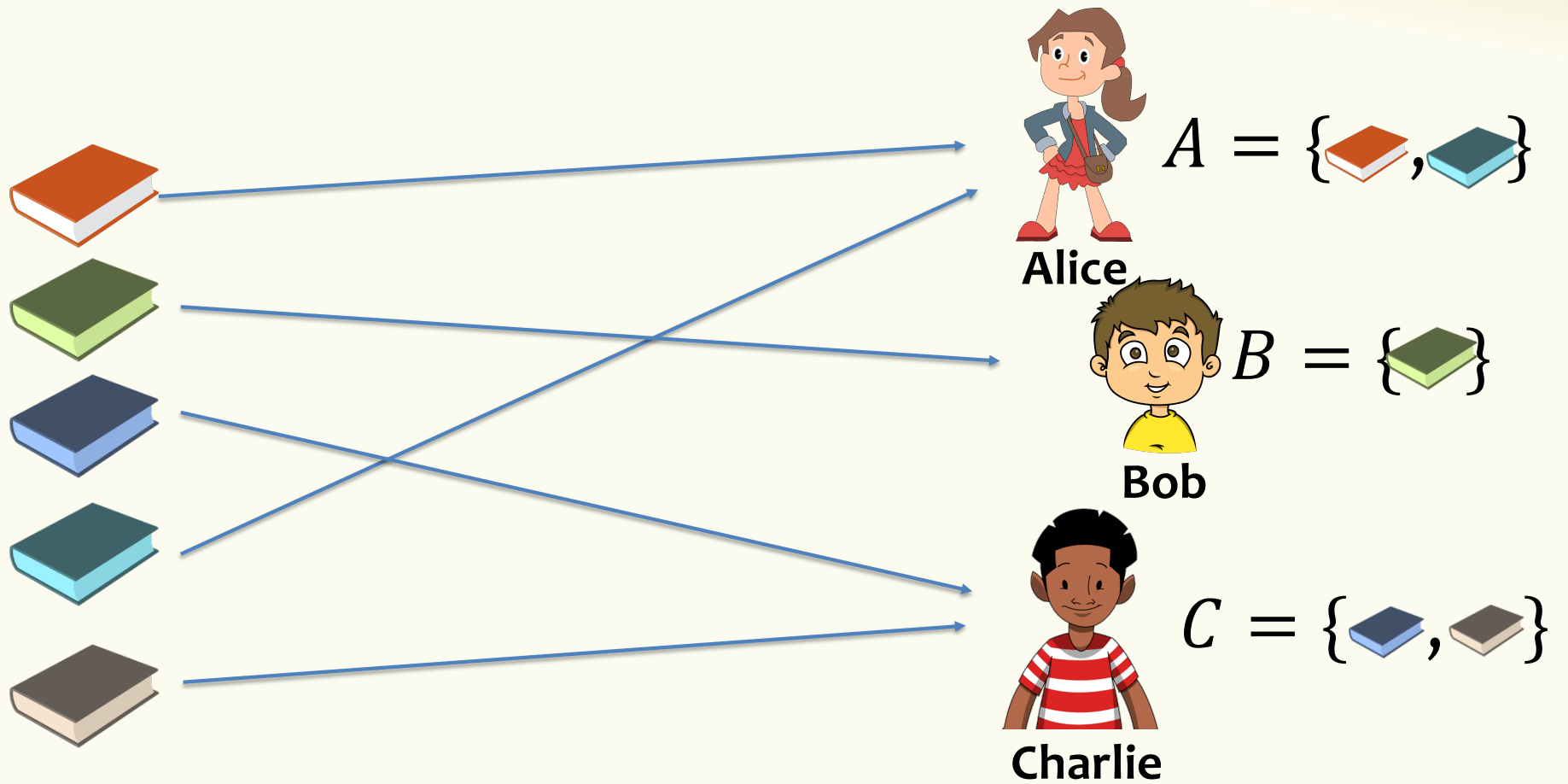


Bob



Charlie

Example Book Assignment



Book assignment

$2^5 = 32$ options

\times



$A = \{\text{orange book}, \text{blue book}\}$

$2^5 = 32$ options

\times



$B = \{\text{green book}\}$

$2^5 = 32$ options



$C = \{\text{blue book}, \text{grey book}\}$

= 32^3 assignment

Book assignment – Modeling

Correct?

Poll:

- A. right
- B. Overcount
- C. Undercount
- D. No idea

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$2^5 = 32$ options

λ



$A = \{\text{orange book}, \text{blue book}\}$

$2^5 = 32$ options



$B = \{\text{green book}\}$

$2^5 = 32$ options

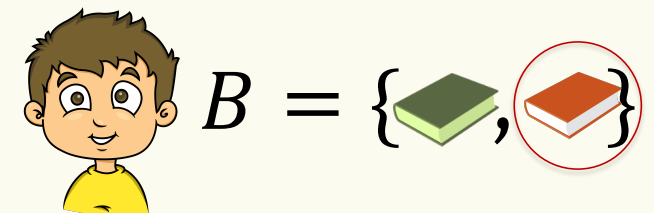
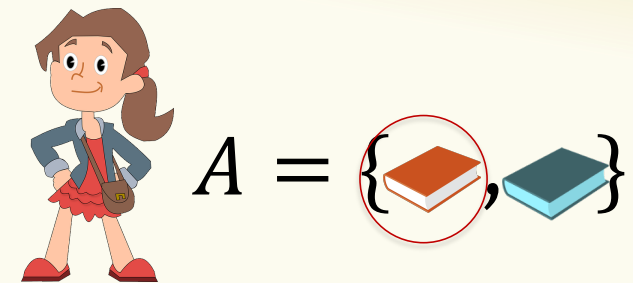


$C = \{\text{blue book}, \text{grey book}\}$

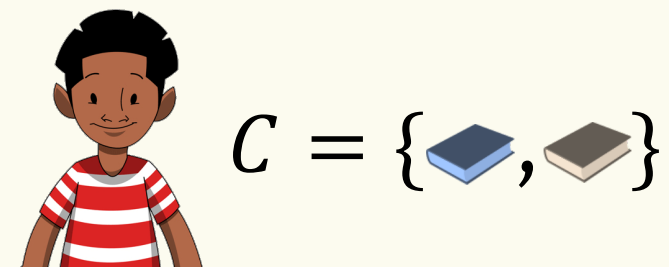
= 32^3 assignment

Problem – Overcounting

Problem: We are counting some invalid assignments!!!
→ overcounting!



What went wrong in the sequential process?
After assigning set A to Alice, set B is no longer a valid option for Bob



Book assignment – Second try

$2^5 = 32$ options

χ



$A = \{\text{orange book}, \text{blue book}\}$

χ



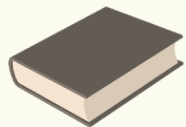
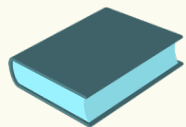
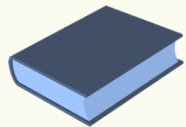
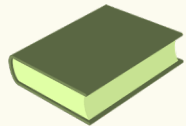
$B = \{\text{green book}\}$



$C = \{\text{blue book}, \text{grey book}\}$

Product rule – A better way

5 books



“How many ways are there to distribute 5 books among Alice, Bob, and Charlie?”

Every book to one person, everyone gets ≥ 0 books.



Alice



Bob



Charlie

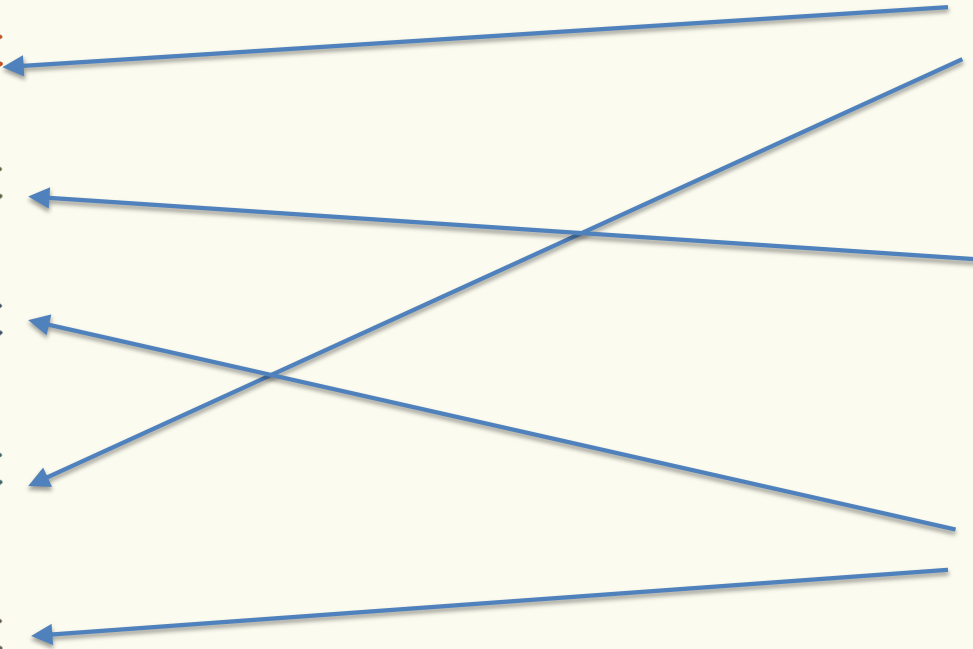
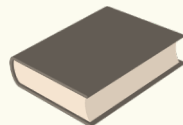
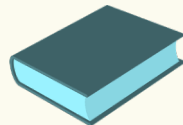
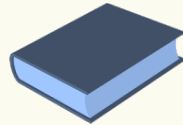
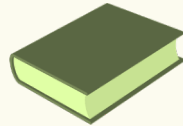
Book assignments – Choices tell you who gets each book

X

X

X

X

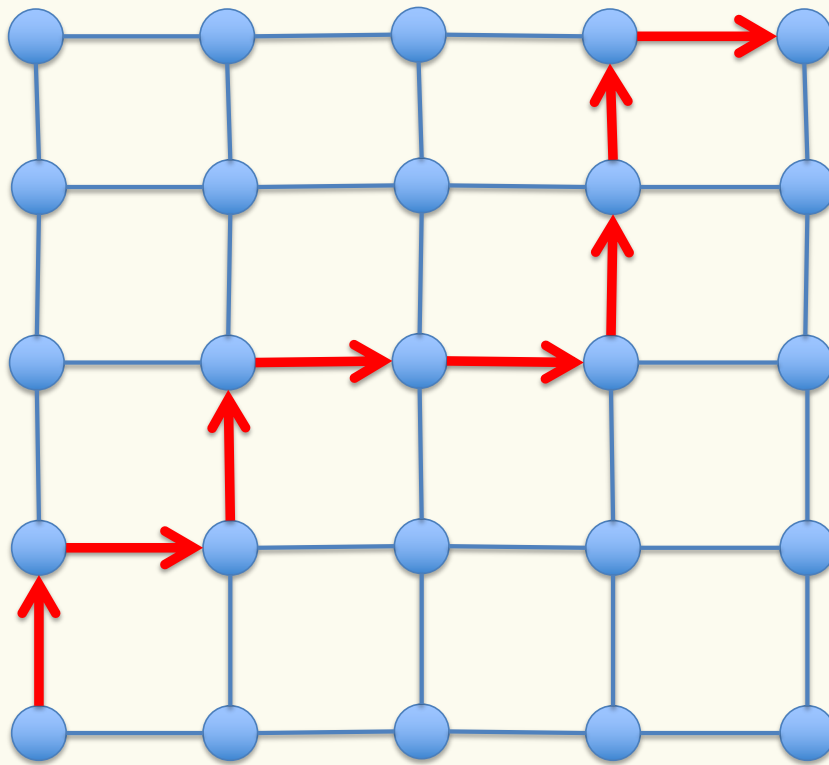


Lesson: Representation of what we are counting is very important!

Think about the various possible ways you could make a sequence of choices that leads to an outcome in the set of outcomes you are trying to count.



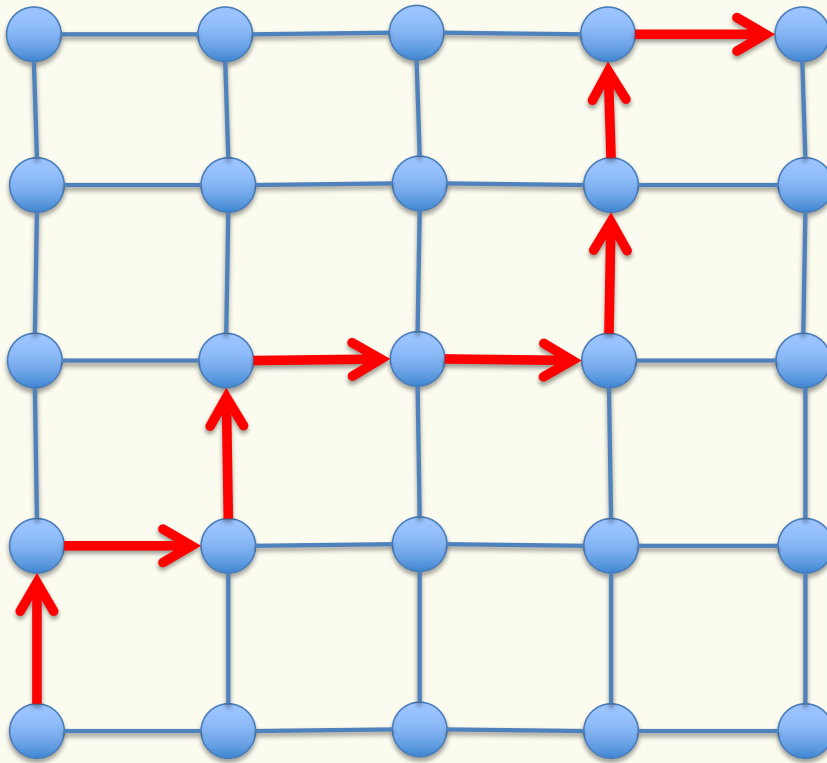
Example – Counting Paths



“How many shortest paths from Gates to Starbucks?”

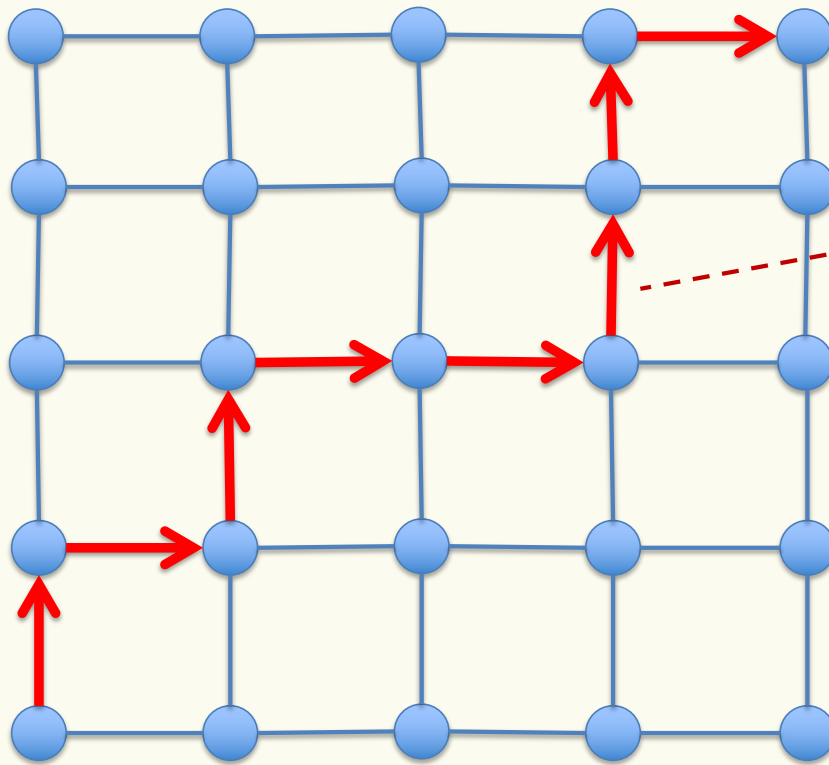


Example – Counting Paths



How do we represent a path?

Example – Counting Paths



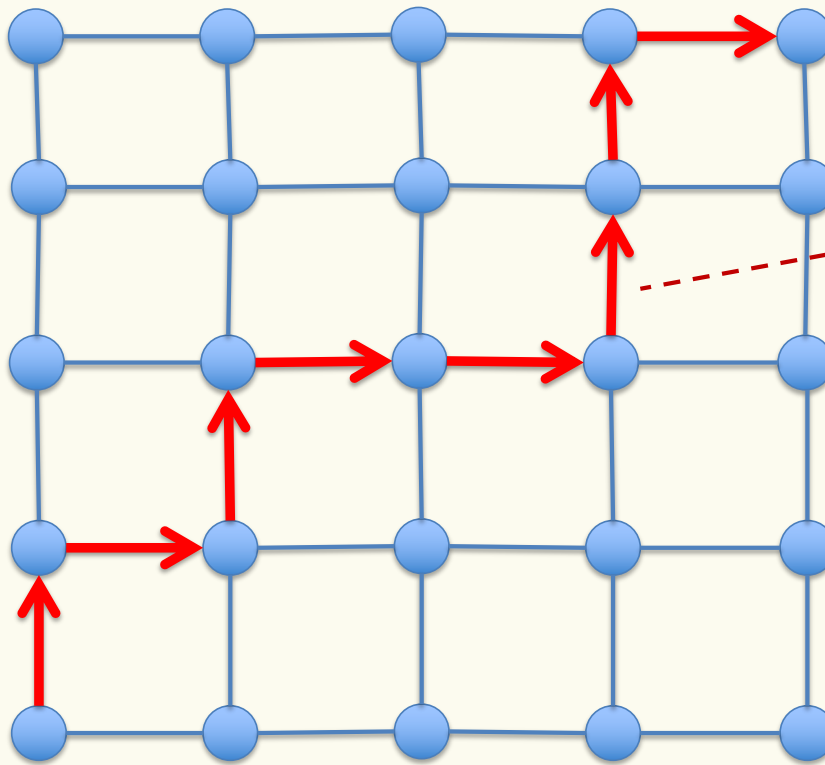
Path $\in \{\uparrow, \rightarrow\}^8$

$(\uparrow, \rightarrow, \uparrow, \rightarrow, \rightarrow, \uparrow, \uparrow, \rightarrow)$

$\# \uparrow\text{'s} = \# \rightarrow\text{'s}$



Example – Counting Paths



Path $\in \{\uparrow, \rightarrow\}^8$

$(\uparrow, \rightarrow, \uparrow, \rightarrow, \rightarrow, \uparrow, \uparrow, \rightarrow)$

\uparrow 's = # \rightarrow 's

Poll:

A. 2^8

B. $\frac{8!}{4!}$

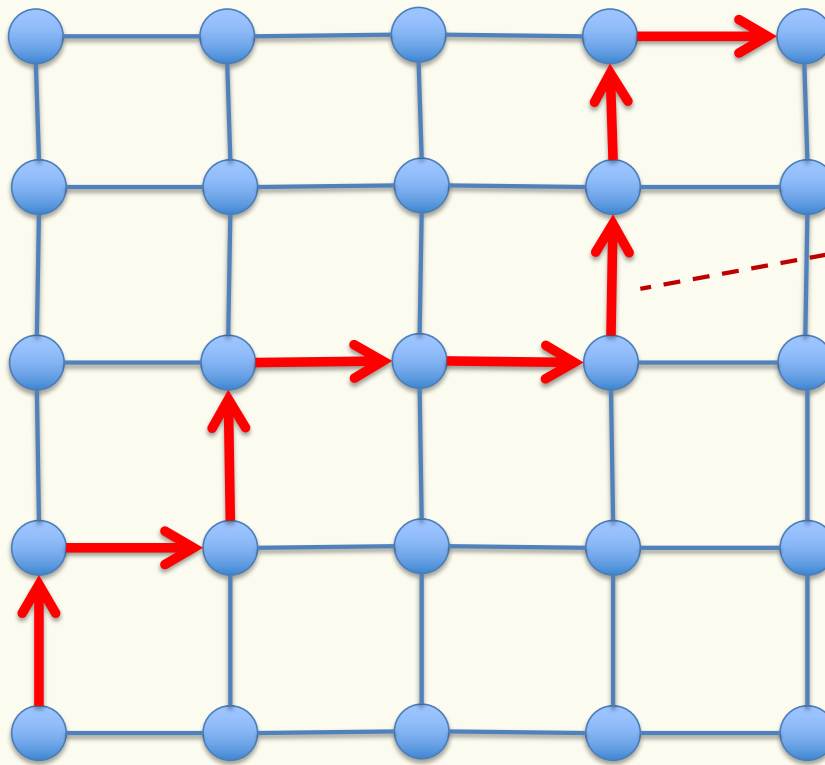
C. $\binom{8}{4} = \frac{8!}{4!4!}$

D. No idea



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Example – Counting Paths



Path $\in \{\uparrow, \rightarrow\}^8$

$(\uparrow, \rightarrow, \uparrow, \rightarrow, \rightarrow, \uparrow, \uparrow, \rightarrow)$

$\# \uparrow\text{'s} = \# \rightarrow\text{'s}$



