

01204211 Discrete Mathematics
Lecture 10: Counting 2

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Listing all subsets¹

- ▶ From the previous lecture, we know that a set with n elements has 2^n subsets.
- ▶ Let's try to enumerate them.
- ▶ As an example, consider set $\{a, b, c\}$ and its subsets.
- ▶ There are many ways of listing all 8 subsets.
 - ▶ $\emptyset, \{a\}, \{a, b\}, \{a, b, c\}, \{a, c\}, \{b\}, \{b, c\}, \{c\}$
Note that we treat each subset as a word in a dictionary and use the dictionary order.
 - ▶ $\emptyset, \{a\}, \{b\}, \{c\}, \{a, b\}, \{a, c\}, \{b, c\}, \{a, b, c\}$
In this case, we order by their cardinalities, then use dictionary ordering for subsets with the same numbers of elements.

¹This section follows section 1.3 from [LPV].

A different representation (1)

- ▶ There is a different representation for subsets which is particularly useful when listing subsets.
- ▶ To represent a subset of $A = \{a, b, c\}$, we consider each element of A one-by-one in some fixed order. If that element is in the subset, we write down 1, if it is not we write down 0.
- ▶ For examples:
 - ▶ $\{a, c\}$ is represented as: 101
 - ▶ $\{a\}$ is represented as: 100
 - ▶ $\{b, c\}$ is represented as: 011
 - ▶ $\{\}$ is represented as: 000

A different representation (2)

- ▶ Note that we represent a subset as a string with 0's and 1's. You may recall that these strings can be considered as binary numbers.
- ▶ Thus, we can associate the numerical values of the representations with the subsets:
 - ▶ $\{a, c\}$ is rep. as: $101_2 = 5$, $\{a\}$ is rep. as: $100_2 = 4$
 - ▶ $\{b, c\}$ is rep. as: $011_2 = 3$, $\{\}$ is rep. as: $000_2 = 0$
- ▶ Also, this representation can be considered backwards, i.e., if we start with an integer 6, we can write down its binary representation: 110_2 and turns it into a subset $\{a, b\}$.

A correspondence

Let's see a full list of correspondence between $\{0, 1, 2, \dots, 7\}$ and subsets of $\{a, b, c\}$.

- ▶ $0 \leftrightarrow 000_2 \leftrightarrow \{\}$
- ▶ $1 \leftrightarrow 001_2 \leftrightarrow \{c\}$
- ▶ $2 \leftrightarrow 010_2 \leftrightarrow \{b\}$
- ▶ $3 \leftrightarrow 011_2 \leftrightarrow \{c, b\}$
- ▶ $4 \leftrightarrow 100_2 \leftrightarrow \{a\}$
- ▶ $5 \leftrightarrow 101_2 \leftrightarrow \{a, c\}$
- ▶ $6 \leftrightarrow 110_2 \leftrightarrow \{a, b\}$
- ▶ $7 \leftrightarrow 111_2 \leftrightarrow \{a, b, c\}$

Do you notice anything interesting?

A general case

Similarly, we can describe a representation for each subset of a set A with n elements. As we consider each element a of A , we put 1 if $a \in A$ and put 0 if $a \notin A$.

Each subset is represented uniquely as a string of 0 and 1 of length n . Also, each string corresponds to only one subset. Then, we can conclude that the number of subsets equal the number of bit strings of length n .

How many bit strings of length n are there?

There are 2^n bit strings; hence, the number of subsets is also 2^n . This is another proof of the following theorem:

Theorem: The number of subsets of a set with n elements is 2^n .

Two proofs

Why do we need two proofs of the same statement?

Really, it does not make a statement stronger, truer, “more” correct. But each proof usually reveals additional facts related to the statement.

- ▶ The first proof considers a procedure for constructing subsets.
- ▶ The second proof introduces a nice technique for counting. I.e., instead of counting subsets directly, we show that we have a “special” correspondence between subsets and binary numbers, and then just count the numbers.

A bijection

What is so special about this correspondence?

- ▶ For each number, there is exactly **one** subset that corresponds to it.
- ▶ For each subset, there is exactly **one** number that it corresponds to.

With these two properties, we can conclude that both sets have the same cardinality.

This type of correspondence is called a **one-to-one correspondence** or **bijection**.

Sequences of choices

Previously, when we want to count the number of bit strings of length n , we use this argument:

Suppose that to select an object, you have to make k decisions. The first decision has n_1 choices, the second decision has n_2 choices, and so on. More precisely, for $1 \leq i \leq k$, the i -th decision has n_i choices. Then the number of ways you can select an object is $n_1 \cdot n_2 \cdots n_{k-1} \cdot n_k$.

Example 1

A car license number consists of two English letters and one number from 1 to 9999. How many possible license numbers are there?

Example 2

10 students stand in a line. You want to give them ice cream. There are 4 flavours, but you don't want to give the same flavour to any consecutive students. In how many ways can you give out the ice cream to these students?

Permutations

Counting permutations: an example

We want to count the number of permutations. Let's try with a small example: permutations of set $\{a, b, c\}$.

Counting permutations

Number of permutations

We have proved this theorem.

Theorem: The number of permutations of a set with n elements is $n!$.