COSC 290 Discrete Structures

Lecture 33: Counting, IV

Prof. Michael Hay

Monday, Nov. 27, 2017

Colgate University

Plan for today

1. Four types of counting problems
2. Counting when order matters (2 ways)
3. Counting when order is irrelevant (2 ways)

Four types of counting problems

Examples

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- One runner for each of $k = 5$ track races from among a team of $n = 12$ available runners.

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- *[[MH: add one more? runner types]]*

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- A team of $k = 4$ runners to compete in a single cross-country race from among $n = 10$ available runners.
- One runner for each of $k = 5$ track races from among a team of $n = 12$ available runners.
- *[[MH: add one more? runner types]]*
- A selection of $k = 12$ donuts from $n = 3$ donut types (jelly, chocolate, glazed).

Four types of common counting problem

Given a set S with n elements, let us consider counting the number of ways to choose k elements from S. To formalize this counting problem, we must answer two questions:

- Does the order in which elements are selected matter?
- Is repetition allowed?

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The answers to these questions leads to four distinct counting problems:

	order matters	order irrelevant
repetition forbidden		
repetition allowed		

Example shown on board: let $S = \{A, B, C\}$ and $k = 2$. Write out solutions to all four versions of the problem. *[[MH: practice writing this out]]*

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Goal for today: fill in this table.

Counting when order matters (2 ways)

Order matters, repetition allowed

How many ways to choose a sequence of k (not necessarily distinct) elements from a set of n elements?

Example: one runner for each of $k = 5$ track races from among a team of $n = 12$ available runners. (Same runner can compete in multiple races.)

How many ways?

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$$\underbrace{n}_{\text{choices for first element}} \cdot \underbrace{n}_{\text{choices for second element}} \cdot \cdots \cdot \underbrace{n}_{\text{choices for } k^{th} \text{ element}} = n^k$$

Four counting problems

The number of ways to choose k items from a set S of n items when...

	order matters	order irrelevant
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How many ways to choose a sequence of k distinct elements from a set of n elements?

Example: a starting basketball lineup of $k = 5$ players at five positions (C, PF, SF, PG, SG) from among $n = 12$ players.

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How many ways? (Use the generalized product rule.)

$$\underbrace{(n)}_{\text{choices for first element}} \cdot \underbrace{(n-1)}_{\text{choices for second element}} \cdot \cdots \cdot \underbrace{(n-k+1)}_{\text{choices for } k^{th} \text{ element}} = \frac{n!}{(n-k)!}$$

Alernative derivation: using division rule

Let B be the set we are trying to count.

Let A be the set of all permutations of S. (Recall that a permutation of set S is an $|S|$-length sequence of elements of S with no repetitions.)

Let $f : A \to B$ map a permutation into k-element sequence by simply keeping first k elements of the permutation.

Example

$S = \{a, b, c, d, e\}$ and $k = 2$.

A	$\to$	B
$\langle a, b, c, d, e\rangle$	$\to$	$\langle a, b\rangle$
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How many permutations map to *same* k sequence?

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$$|B| = \frac{|A|}{(n-k)!} = \frac{n!}{(n-k)!}$$

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This counting problem comes up so often it has a special name/notation:

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

The binomial coefficient, denoted $\binom{n}{k}$, is the number of combinations of k elements chosen from n candidate elements.

Example: Counting bitstrings with k ones

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A length n bitstring has n bit positions $b_1 b_2 \dots b_n$.

Must choose a *set* of k positions where the ones will be placed. (The order in which the bit positions are chosen is irrelevant.)

Thus, the number of length n bitstrings that contain exactly k ones is $\binom{n}{k}$.

Example: subsets of a certain size

Let $S \coloneqq \{ a, b, c, d, e \}$. Let $n \coloneqq |S|$. How many subsets of size $k = 2$ can be constructed from S?

Example: subsets of a certain size

Let $S := \{ a, b, c, d, e \}$. Let $n := |S|$. How many subsets of size $k = 2$ can be constructed from S?

There are $\binom{n}{k} = \binom{5}{2} = 10$:

$\{ a, b \}, \{ a, c \}, \{ a, d \}, \{ a, e \},$
$\{ b, c \}, \{ b, d \}, \{ b, e \},$
$\{ c, d \}, \{ c, e \},$
$\{ d, e \}.$

Derivation of $\binom{n}{k}$ using division rule

Let C be the set we are trying to count.

Let A be the set of all permutations of S.

Let $g : A \to C$ map a permutation into k-element sequence by simply taking first k elements of the permutation and putting them in a set.

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g is a $k!(n - k)!$-to-1 function, so...

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The number of ways to choose k items from a set S of n items when...

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repetition allowed	n^k	

Poll: Counting number of ways to select lineups

Suppose your hockey team has only one goalie and 12 other players. You want to organize your time into a starting line (5 players), a backup line (5 more players), and benchwarmers (remaining 2 players).

Let's assume position does not matter.

How many different ways can you select the starting line, backup line, and benchwarmers?

A) 792
B) 16632
C) 95040
D) 3991680
E) I'm stumped

Order irrelevant, repetition allowed

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Example: how many ways to choose a dozen donuts from three donut types (jelly, chocolate, glazed)?

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$$\underbrace{00\ldots0}_{\text{jelly}}\ 1\ \underbrace{00\ldots0}_{\text{chocolate}}\ 1\ \underbrace{00\ldots0}_{\text{glazed}}$$

A bit-string with k zeroes and $n-1$ ones. (Total length of bit string is $n+k-1$.)

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$$\binom{n+k-1}{k}$$

Derivation, a little more formally

Use mapping rule. Represent a choice of k elements from set of n candidates as sequence $\langle x_1, x_2, \ldots, x_n \rangle$ where x_i is the number of times we chose candidate element i.

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Since we choose a total of k elements, we require:

$$\sum_{i=1}^{n} x_i = k$$

Bijective mapping to bit-strings:

$$f(\langle x_1, x_2, \ldots, x_n \rangle) = \underbrace{00\ldots0}_{x_1 \text{ times}} \; 1 \; \underbrace{00\ldots0}_{x_2 \text{ times}} \; 1 \; \ldots \; 1 \; \underbrace{00\ldots0}_{x_n \text{ times}}$$

(Bit string is always length $n + k - 1$ because there are $k - 1$ ones and the total number of zeros must add up to k.)

Four counting problems

The number of ways to choose k items from a set S of n items when...

	order matters	order irrelevant
repetition forbidden	$\frac{n!}{(n-k)!}$	$\binom{n}{k}$
repetition allowed	n^k	$\binom{n+k-1}{k}$

Poll

[[MH: 9.157-9.160]]

Exercises

[[MH: poker hands?]]