18.600: Lecture 4

Axioms of probability and inclusion-exclusion

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Outline

Axioms of probability

Consequences of axioms

Inclusion exclusion

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Consequences of axioms

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- Countable additivity: $P(\cup_{i=1}^{\infty} E_i) = \sum_{i=1}^{\infty} P(E_i)$ if $E_i \cap E_j = \emptyset$ for each pair i and j.

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- Axioms breakdowns are money-making opportunities.

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Intersection notation

- We will sometimes write AB to denote the event $A \cap B$.

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- Can we show from the axioms that if S contains finitely many elements $x_1, \ldots, x_k$, then the values $\big(P(\{x_1\}), P(\{x_2\}), \ldots, P(\{x_k\})\big)$ determine the value of $P(A)$ for any $A \subset S$?

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- What k-tuples of values are consistent with the axioms?

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- 85 percent chose the second option.
- Could be correct using neurological/emotional definition. Or a "which story would you believe" interpretation (if witnesses offering more details are considered more credible).
- But axioms of probability imply that second option cannot be more likely than first.

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- There are some situations in which computing $P(E_1 \cup E_2 \cup \ldots \cup E_n)$ is a priori difficult, but it is relatively easy to compute probabilities of *intersections* of any collection of E_i. That is, we can easily compute quantities like $P(E_1 E_3 E_7)$ or $P(E_2 E_3 E_6 E_7 E_8)$.

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- In these situations, the inclusion-exclusion rule helps us compute unions. It gives us a way to express $P(E_1 \cup E_2 \cup \ldots \cup E_n)$ in terms of these intersection probabilities.

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\begin{aligned}
P(\cup_{i=1}^n E_i) = \sum_{i=1}^n P(E_i) - \sum_{i_1 < i_2} P(E_{i_1} E_{i_2}) + \ldots \\
+ (-1)^{(r+1)} \sum_{i_1 < i_2 < \ldots < i_r} P(E_{i_1} E_{i_2} \ldots E_{i_r}) \\
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- The notation $\sum_{i_1 < i_2 < \ldots < i_r}$ means a sum over all of the $\binom{n}{r}$ subsets of size r of the set $\{1, 2, \ldots, n\}$.

Inclusion-exclusion proof idea

- Consider a region of the Venn diagram contained in exactly $m > 0$ subsets. For example, if $m = 3$ and $n = 8$ we could consider the region $E_1 E_2 E_3^c E_4^c E_5 E_6^c E_7^c E_8^c$.

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- This region is contained in three single intersections (E_1, E_2, and E_5). It's contained in 3 double-intersections ($E_1 E_2$, $E_1 E_5$, and $E_2 E_5$). It's contained in only 1 triple-intersection ($E_1 E_2 E_5$).

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- How many is that?
- Answer: 1. (Follows from binomial expansion of $(1-1)^m$.)
- Thus each region in $E_1 \cup \ldots \cup E_n$ is counted exactly once in the inclusion exclusion sum, which implies the identity.