

**UCLA STAT 110 A**  
**Applied Probability & Statistics for Engineers**

• **Instructor:** Ivo Dinov,  
 Asst. Prof. In Statistics and Neurology

• **Teaching Assistant:** Christopher Barr

University of California, Los Angeles, Fall 2004  
<http://www.stat.ucla.edu/~dinov/>

Stat 110A, UCLA, Ivo Dinov Slide 1

Chapter 2

**Probability**

Slide 2 Stat 110A, UCLA, Ivo Dinov

2.1

**Sample Spaces and Events**


Slide 3 Stat 110A, UCLA, Ivo Dinov

Sample Space

The **sample space** of an experiment, denoted  $S$ , is the set of all possible outcomes of that experiment.

Slide 4 Stat 110A, UCLA, Ivo Dinov

Sample Space

Ex. Roll a die 

Outcomes: landing with a 1, 2, 3, 4, 5, or 6 face up.

Sample Space:  $S = \{1, 2, 3, 4, 5, 6\}$

Slide 5 Stat 110A, UCLA, Ivo Dinov

Events

An **event** is any collection (subset) of outcomes contained in the sample space  $S$ . An event is **simple** if it consists of exactly one outcome and **compound** if it consists of more than one outcome.

Slide 6 Stat 110A, UCLA, Ivo Dinov

## Relations from Set Theory

1. The **union** of two events  $A$  and  $B$  is the event consisting of all outcomes that are either in  $A$  or in  $B$ .

Notation:  $A \cup B$

Read:  $A$  or  $B$

Slide 7 Stat 110A, UCLA, Jon Dineen

## Relations from Set Theory

2. The **intersection** of two events  $A$  and  $B$  is the event consisting of all outcomes that are in both  $A$  and  $B$ .

Notation:  $A \cap B$

Read:  $A$  and  $B$

Slide 8 Stat 110A, UCLA, Jon Dineen

## Relations from Set Theory

3. The **complement** of an event  $A$  is the set of all outcomes in  $S$  that are not contained in  $A$ .

Notation:  $A'$

Slide 9 Stat 110A, UCLA, Jon Dineen

## Events

**Ex.** Rolling a die.  $S = \{1, 2, 3, 4, 5, 6\}$

Let  $A = \{1, 2, 3\}$  and  $B = \{1, 3, 5\}$

$A \cup B = \{1, 2, 3, 5\}$

$A \cap B = \{1, 3\}$

$A' = \{4, 5, 6\}$

Slide 10 Stat 110A, UCLA, Jon Dineen

## Mutually Exclusive

When  $A$  and  $B$  have no outcomes in common, they are **mutually exclusive** or **disjoint** events

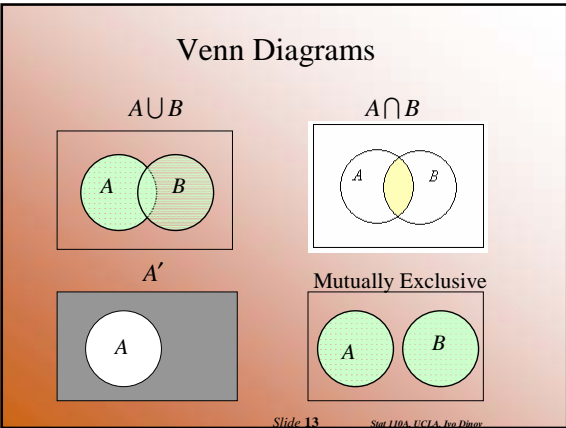
Slide 11 Stat 110A, UCLA, Jon Dineen

## Mutually Exclusive

**Ex.** When rolling a die, if event  $A = \{2, 4, 6\}$  (evens) and event  $B = \{1, 3, 5\}$  (odds), then  $A$  and  $B$  are mutually exclusive.

**Ex.** When drawing a single card from a standard deck of cards, if event  $A = \{\text{heart, diamond}\}$  (red) and event  $B = \{\text{spade, club}\}$  (black), then  $A$  and  $B$  are mutually exclusive.

Slide 12 Stat 110A, UCLA, Jon Dineen



## 2.2

# Axioms, Interpretations, and Properties of Probability

Slide 14 Stat 110A, UCLA, Jon Dineen

### Axioms of Probability

Axiom 1  $P(A) \geq 0$  for any event  $A$   
 Axiom 2  $P(S) = 1$   
 If all  $A_i$ 's are mutually exclusive, then  
 Axiom 3  $P(A_1 \cup A_2 \cup \dots \cup A_k) = \sum_{i=1}^k P(A_i)$   
(finite set)  

$$P(A_1 \cup A_2 \cup \dots) = \sum_{i=1}^{\infty} P(A_i)$$
(infinite set)

Slide 15 Stat 110A, UCLA, Jon Dineen

### Properties of Probability

For any event  $A$ ,  $P(A) = 1 - P(A')$ .

If  $A$  and  $B$  are mutually exclusive, then  $P(A \cap B) = 0$ .

For any two events  $A$  and  $B$ ,  
 $P(A \cup B) = P(A) + P(B) - P(A \cap B)$ .

Slide 16 Stat 110A, UCLA, Jon Dineen

**Ex.** A card is drawn from a well-shuffled deck of 52 playing cards. What is the probability that it is a queen or a heart?

$Q$  = Queen and  $H$  = Heart

$$P(Q) = \frac{4}{52}, P(H) = \frac{13}{52}, P(Q \cap H) = \frac{1}{52}$$

$$P(Q \cup H) = P(Q) + P(H) - P(Q \cap H)$$

$$= \frac{4}{52} + \frac{13}{52} - \frac{1}{52} = \frac{16}{52} = \frac{4}{13}$$

Slide 17 Stat 110A, UCLA, Jon Dineen

## 2.3

# Counting Techniques

Slide 18 Stat 110A, UCLA, Jon Dineen

## Product Rule

If the first element or object of an ordered pair can be used in  $n_1$  ways, and for each of these  $n_1$  ways the second can be selected  $n_2$  ways, then the number of pairs is  $n_1 n_2$ .

\*\* Note that this generalizes to  $k$  elements ( $k$  – tuples)

Slide 19 Stat 110A, UCLA, Jon Dineen

## Permutations

Any ordered sequence of  $k$  objects taken from a set of  $n$  distinct objects is called a **permutation** of size  $k$  of the objects.

Notation:  $P_{k,n}$

$$P_{k,n} = n(n-1) \cdot \dots \cdot (n-k+1)$$

Slide 20 Stat 110A, UCLA, Jon Dineen

## Factorial

For any positive integer  $m$ ,  $m!$  is read “ $m$  factorial” and is defined by  $m! = m(m-1) \cdot \dots \cdot (2)(1)$ . Also,  $0! = 1$ .

Note, now we can write:

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

Slide 21 Stat 110A, UCLA, Jon Dineen

Ex. A boy has 4 beads – red, white, blue, and yellow. How different ways can three of the beads be strung together in a row?



This is a permutation since the beads will be in a row (order).

$$P_{3,4} = \frac{4!}{(4-3)!} = 4! = 24$$

number selected

total

24 different ways

Slide 22 Stat 110A, UCLA, Jon Dineen

## Combinations

Given a set of  $n$  distinct objects, any unordered subset of size  $k$  of the objects is called a **combination**.

Notation:  $\binom{n}{k}$  or  $C_{k,n}$

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

Slide 23 Stat 110A, UCLA, Jon Dineen

Ex. A boy has 4 beads – red, white, blue, and yellow. How different ways can three of the beads be chosen to trade away?



This is a combination since they are chosen without regard to order.

$$\binom{4}{3} = \frac{4!}{3!(4-3)!} = \frac{4!}{3!} = 4$$

total

number selected

4 different ways

Slide 24 Stat 110A, UCLA, Jon Dineen

Ex. Three balls are selected at random without replacement from the jar below. Find the probability that one ball is red and two are black.



$$= \frac{\binom{2}{1} \binom{3}{2}}{\binom{8}{3}} = \frac{2 \cdot 3}{56} = \frac{3}{28}$$

Slide 25 Stat 110A, UCLA, Jon Dineen

## 2.4

# Conditional Probability

Slide 26 Stat 110A, UCLA, Jon Dineen

## Conditional Probability

For any two events  $A$  and  $B$  with  $P(B) > 0$ , the **conditional probability** of  $A$  given that  $B$  has occurred is defined by

$$P(A|B) = \frac{P(A \cap B)}{P(B)}$$

Which can be written:

$$P(A \cap B) = P(B) \cdot P(A|B)$$

Slide 27 Stat 110A, UCLA, Jon Dineen

## The Law of Total Probability

If the events  $A_1, A_2, \dots, A_k$  be mutually exclusive and exhaustive events. Then for any other event  $B$ ,

$$P(B) = \sum_{i=1}^k P(B \cap A_i) = \sum_{i=1}^k P(B|A_i)P(A_i)$$

Slide 28 Stat 110A, UCLA, Jon Dineen

## Bayes' Theorem

Let  $A_1, A_2, \dots, A_n$  be a collection of  $k$  mutually exclusive and exhaustive events with  $P(A_i) > 0$  for  $i = 1, 2, \dots, k$ . Then for any other event  $B$  for which  $P(B) > 0$  given by

$$P(A_j|B) = \frac{P(A_j)P(B|A_j)}{\sum_{i=1}^k P(A_i)P(B|A_i)}$$

$$j = 1, 2, \dots, k$$

Slide 29 Stat 110A, UCLA, Jon Dineen

Ex. A store stocks light bulbs from three suppliers. Suppliers  $A, B$ , and  $C$  supply 10%, 20%, and 70% of the bulbs respectively. It has been determined that company  $A$ 's bulbs are 1% defective while company  $B$ 's are 3% defective and company  $C$ 's are 4% defective. If a bulb is selected at random and found to be defective, what is the probability that it came from supplier  $B$ ?

Let  $D$  = defective

$$P(B|D) = \frac{P(B)P(D|B)}{P(A)P(D|A) + P(B)P(D|B) + P(C)P(D|C)}$$

$$= \frac{0.2(0.03)}{0.1(0.01) + 0.2(0.03) + 0.7(0.04)} \approx 0.1714$$

So about 0.17

Slide 30 Stat 110A, UCLA, Jon Dineen

### Bayesian Rule

- If  $\{A_1, A_2, \dots, A_n\}$  are a non-trivial partition of the sample space (mutually exclusive and  $\cup A_i = S, P(A_i) > 0$ ) then for any non-trivial event and  $B (P(B) > 0)$

$$P(A_i | B) = P(A_i \cap B) / P(B) = [P(B | A_i) \times P(A_i)] / P(B) = \frac{P(B | A_i) \times P(A_i)}{\sum_{k=1}^n P(B | A_k) P(A_k)}$$

Slide 31 Stat 110A, UCLA, Jon Dineen

### Bayesian Rule

$P(A_i) = \frac{P(A_i | B) \times P(A_i)}{\sum_{k=1}^n P(B | A_k) P(A_k)}$   $D =$  the test person has the disease.  $T =$  the test result is positive.

Ex: (Laboratory blood test) **Assume:**  $P(\text{positive Test} | \text{Disease}) = 0.95$  **Find:**  $P(\text{Disease} | \text{positive Test}) = ?$

$P(\text{positive Test} | \text{no Disease}) = 0.01$   $P(D | T) = ?$

$P(\text{Disease}) = 0.005$

$$P(D | T) = \frac{P(D \cap T)}{P(T)} = \frac{P(T | D) \times P(D)}{P(T | D) \times P(D) + P(T | D^c) \times P(D^c)}$$

$$= \frac{0.95 \times 0.005}{0.95 \times 0.005 + 0.01 \times 0.995} = \frac{0.00475}{0.02465} = 0.193$$

Slide 32 Stat 110A, UCLA, Jon Dineen

### Classes vs. Evidence Conditioning

- Classes:** healthy(NC), cancer
- Evidence:** positive mammogram (pos), negative mammogram (neg)
- If a woman has a positive mammogram result, what is the probability that she has breast cancer?

$$P(\text{class} | \text{evidence}) = \frac{P(\text{evidence} | \text{class}) \times P(\text{class})}{\sum_{\text{classes}} P(\text{evidence} | \text{class}) \times P(\text{class})}$$

$P(\text{cancer}) = 0.01$   
 $P(\text{pos} | \text{cancer}) = 0.8$   
 $P(\text{pos} | \text{healthy}) = 0.1$

$P(\text{cancer} | \text{pos}) = ?$   $\frac{P(C|P) = P(P|C) \times P(C)}{P(C|P) = P(P|C) \times P(C) + P(P|H) \times P(H)}$   
 $\frac{P(C|P) = 0.8 \times 0.01}{0.8 \times 0.01 + 0.1 \times 0.99} = ?$

Slide 33 Stat 110A, UCLA, Jon Dineen

# 2.5

## Independence

Slide 34 Stat 110A, UCLA, Jon Dineen

## Independent Events

Two event  $A$  and  $B$  are **independent events** if  $P(A \cap B) = P(A)P(B)$ .

Otherwise  $A$  and  $B$  are dependent.

Slide 35 Stat 110A, UCLA, Jon Dineen

## Independent Events

Events  $A$  and  $B$  are independent events if and only if

$$P(A \cap B) = P(A)P(B)$$

\*\* Note: this generalizes to more than two independent events.

Slide 36 Stat 110A, UCLA, Jon Dineen

## Theory of Counting = Combinatorial Analysis

**Generalized Principle of Counting:** If  $M$  (independent) experiments are performed and the first one has  $N_m$  possible outcomes,  $1 \leq m \leq M$ , then the TOTAL number of outcomes of the combined experiment is

$$N_1 \times N_2 \times \dots \times N_M$$

E.g., How many binary functions [ $f(i)=0$  or  $f(i)=1$ ], defined on a grid  $1, 2, 3, \dots, n$ , are there? How many numbers can be stored in 8 bits = 1 byte?

$$2 \times 2 \times \dots \times 2 = 2^n$$

Slide 37 Stat 110A, UCLA, Jon Dineen

## Permutation & Combination

**Permutation:** Number of **ordered** arrangements of  $r$  objects chosen from  $n$  *distinctive* objects

$$P_n^r = n(n-1)(n-2)\dots(n-r+1)$$

$$P_n^n = P_n^{n-r} \cdot P_r^r$$

e.g.  $P_6^3 = 6 \cdot 5 \cdot 4 = 120$ .

Slide 38 Stat 110A, UCLA, Jon Dineen

## Permutation & Combination

**Combination:** Number of **non-ordered** arrangements of  $r$  objects chosen from  $n$  *distinctive* objects:

$$C_n^r = P_n^r / r! = \frac{n!}{(n-r)!r!}$$

Or use notation of  $\binom{n}{r} = C_n^r$

e.g.  $3! = 6$ ,  $5! = 120$ ,  $0! = 1$

$$\binom{7}{3} = \frac{7!}{4!3!} = 35$$

Slide 39 Stat 110A, UCLA, Jon Dineen

## Permutation & Combination

**Combinatorial Identity:**

$$\binom{n}{r} = \binom{n-1}{r-1} + \binom{n-1}{r}$$

Analytic proof: (expand both hand sides)

Combinatorial argument: Given  $n$  object focus on one of them (obj. 1). There are  $\binom{n-1}{r-1}$  groups of size  $r$  that contain obj. 1 (since each group contains  $r-1$  other elements out of  $n-1$ ). Also, there are  $\binom{n-1}{r}$  groups of size  $r$ , that do not contain obj. 1. But the total of all  $r$ -size groups of  $n$ -objects is  $\binom{n}{r}$ !

Slide 40 Stat 110A, UCLA, Jon Dineen

## Permutation & Combination

**Combinatorial Identity:**

$$\binom{n}{r} = \binom{n}{n-r}$$

Analytic proof: (expand both hand sides)

Combinatorial argument: Given  $n$  objects the number of combinations of choosing any  $r$  of them is equivalent to choosing the remaining  $n-r$  of them (order-of-objs-not-important!)

Slide 41 Stat 110A, UCLA, Jon Dineen

## Examples

1. Suppose car plates are 7-digit, like **AB1234**. If all the letters can be used in the first 2 places, and all numbers can be used in the last 4, how many different plates can be made? How many plates are there with no repeating digits?

**Solution:** a)  $26 \cdot 26 \cdot 10 \cdot 10 \cdot 10 \cdot 10$

b)  $P_{26}^2 \cdot P_{10}^3 = 26 \cdot 25 \cdot 10 \cdot 9 \cdot 8 \cdot 7$

Slide 42 Stat 110A, UCLA, Jon Dineen

### Examples

2. How many different letter arrangement can be made from the 11 letters of MISSISSIPPI?

**Solution:** There are: 1 M, 4 I, 4 S, 2 P letters.

**Method 1:** consider different permutations:

$$11!/(1!4!4!2!)=34650$$

**Method 2:** consider combinations:

$$\binom{11}{1} \binom{10}{4} \binom{6}{4} \binom{2}{2} = \dots = \binom{11}{2} \binom{9}{4} \binom{5}{4} \binom{1}{1}$$

Slide 43 Stat 110A, UCLA, Jon Dineen

### Examples

3. There are N telephones, and any 2 phones are connected by 1 line. Then how many lines are needed all together?

**Solution:**  $C^2_N = N(N-1)/2$

If, N=5, complete graph with 5 nodes has  $C^2_5=10$  edges.

Slide 44 Stat 110A, UCLA, Jon Dineen

### Examples

4. N distinct balls with M of them white. Randomly choose n of the N balls. What is the probability that the sample contains exactly m white balls (suppose every ball is equally likely to be selected)?

**Solution:** a) For the event to occur, m out of M white balls are chosen, and n-m out of N-M non-white balls are chosen. And we get

$$\binom{M}{m} \binom{N-M}{n-m}$$

b) Then the probability is

Later These Probabilities

Will be associated with the name

HyperGeometric(N, n, m) distrib.

$$\frac{\binom{M}{m} \binom{N-M}{n-m}}{\binom{N}{n}}$$

Slide 45 Stat 110A, UCLA, Jon Dineen

### Examples

5. N boys (♂) and M girls (♀),  $M \leq N+1$ , stand in 1 line. How many arrangements are there so that no 2 girls stand next to each other?

There are N! ways of ordering the boys among themselves

There are M! ways of ordering the girls among themselves. NOTE - if girls are indistinguishable then there's no need for this factor!

**Solution:**  $N! \cdot \binom{N+1}{M} \cdot M!$



There are N+1 slots for the girls to fill between the boys  
And there are M girls to position in these slots, hence the coefficient in the middle.

How about they are arranged in a circle?

Answer:  $N! \binom{N}{M} M!$

E.g., N=3, M=2



Slide 46 Stat 110A, UCLA, Jon Dineen

### Examples

5a. How would this change if there are N functional (♂) and M defective chips (♀),  $M \leq N+1$ , in an assembly line?

**Solution:**  $\binom{N+1}{M}$



There are N+1 slots for the girls to fill between the boys  
And there are M girls to position in these slots, hence the coefficient in the middle.

Slide 47 Stat 110A, UCLA, Jon Dineen

### Binomial theorem & multinomial theorem

**Binomial theorem**  $(a + b)^n = \sum_{k=0}^n \binom{n}{k} a^k b^{n-k}$

Deriving from this, we can get such useful formula (a=b=1)

$$\binom{n}{0} + \binom{n}{1} + \dots + \binom{n}{n} = 2^n = (1 + 1)^n$$

Also from  $(1+x)^{m+n} = (1+x)^m (1+x)^n$  we obtain:

$$\binom{m+n}{k} = \sum_{i=0}^k \binom{m}{i} \binom{n}{k-i}$$

On the left is the coeff of  $1^k x^{(m+n-k)}$ . On the right is the same coeff in the product of  $(\dots + \text{coeff} * x^{(m-i)} + \dots) * (\dots + \text{coeff} * x^{(n-k+i)} + \dots)$ .

Slide 48 Stat 110A, UCLA, Jon Dineen



### Multinomial theorem

$$(a + b)^n = \sum_{k=0}^n \binom{n}{k} a^k b^{n-k}$$

**Generalization:** Divide  $n$  distinctive objects into  $k$  groups, with the size of every group  $n_1, \dots, n_k$  and  $n_1 + n_2 + \dots + n_k = n$

$$(x_1 + x_2 + \dots + x_k)^n = \sum \binom{n}{n_1, n_2, \dots, n_k} x_1^{n_1} x_2^{n_2} \dots x_k^{n_k}$$

where  $\binom{n}{n_1, n_2, \dots, n_k} = \binom{n}{n_1} \binom{n-n_1}{n_2} \dots \binom{n-n_1-\dots-n_{k-1}}{n_k} = \frac{n!}{n_1! n_2! \dots n_k!}$

**Multinomial Probabilities**  $p(n_1, \dots, n_k) = \frac{n!}{n_1! \dots n_k!} p_1^{n_1} \dots p_k^{n_k}$

Slide 49 Stat 110A, UCLA, Jon Dineen

### Multinomial theorem – will discuss in Ch. 03

•  $N$  independent trials with results falling in one of  $k$  possible categories labeled  $1, \dots, k$ . Let  $p_i$  = the probability of a trial resulting in the  $i^{\text{th}}$  category, where  $p_1 + \dots + p_k = 1$

•  $N_i$  = number of trials resulting in the  $i^{\text{th}}$  category, where  $N_1 + \dots + N_k = N$

• Ex: Suppose we have 9 people arriving at a meeting.

$P(\text{by Air}) = 0.4, P(\text{by Bus}) = 0.2$

$P(\text{by Automobile}) = 0.3, P(\text{by Train}) = 0.1$

$P(3 \text{ by Air, } 3 \text{ by Bus, } 1 \text{ by Auto, } 2 \text{ by Train}) = ?$

$P(2 \text{ by air}) = ?$

Slide 50 Stat 110A, UCLA, Jon Dineen

### Examples

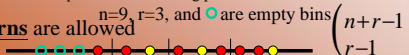
7. There are  $n$  balls randomly positioned in  $r$  distinguishable urns. Assume  $n \geq r$ . What is the number of possible combinations?



1) If the balls are distinguishable (labeled):  $r^n$  possible outcomes, where empty urns are permitted. Since each of the  $n$  balls can be placed in any of the  $r$  urns.

2) If the balls are indistinguishable: **no empty urns** are  $\binom{n-1}{r-1}$  allowed – select  $r-1$  of all possible  $n-1$  dividing points between the  $n$ -balls.

3) If **empty urns** are allowed  $\binom{n+r-1}{r-1}$  are empty bins



Slide 51 Stat 110A, UCLA, Jon Dineen

### Application – Number of integer solutions to linear equ's

1) There are  $\binom{n-1}{r-1}$  distinct positive integer-valued vectors  $(x_1, x_2, \dots, x_r)$  satisfying

$$x_1 + x_2 + \dots + x_r = n, \text{ \& } x_i > 0, 1 \leq i \leq r$$

2) There are  $\binom{n+r-1}{r-1}$  distinct positive integer-valued vectors  $(y_1, y_2, \dots, y_r)$  satisfying

$$y_1 + y_2 + \dots + y_r = n, \text{ \& } y_i \geq 0, 1 \leq i \leq r$$

Since there are  $n+r-1$  possible positions for the dividing splitters (or by letting  $y_i = x_i - 1$ , RHS =  $n+r$ ).

Slide 52 Stat 110A, UCLA, Jon Dineen

### Example

1) An investor has \$20k to invest in 4 potential stocks. Each investment is in increments of \$1k, to minimize transaction fees. In how many different ways can the money be invested?

2)  $x_1 + x_2 + x_3 + x_4 = 20, x_k \geq 0 \rightarrow \binom{23}{3} = 1,771$

3) If not all the money needs to be invested, let  $x_5$  be the left over money, then

$$x_1 + x_2 + x_3 + x_4 + x_5 = 20 \quad \binom{24}{4} = 10,626$$

Slide 53 Stat 110A, UCLA, Jon Dineen

### Examples

8. Randomly give  $n$  pairs of **distinctive shoes** to  $n$  people, with 2 shoes to everyone. How many arrangements can be made? How many arrangements are there, so that everyone gets an original pair? What is the the probability of the latter event,  $E$ ?

Solution: a) according to  $\binom{2n}{n_1, n_2, \dots, n_r} =$   
Note:  **$r = n = \# \text{ of pairs!}$**   $\binom{2n}{n_1} \binom{2n-n_1}{n_2} \dots \binom{2n-n_1-n_2-\dots-n_{r-1}}{n_r} =$   
total arrangements is

$$N = (2n)! / (2!)^n = (2n)! / 2^n$$

b) Regard every shoe pair  $\frac{(2n)!}{n_1! n_2! \dots n_r!} = \frac{(2n)!}{(2!)^n}$  as one object, and give them to people, there are  $M = n!$  arrangements.

c)  $P(E) = M/N = n! / [(2n)! / 2^n] = 1 / (2n-1)!!$  (Do  $n=6$ , case by hand!)

\*note:  $n!! = n(n-2)(n-4) \dots$

Slide 54 Stat 110A, UCLA, Jon Dineen

### Sterling Formula for asymptotic behavior of n!

Sterling formula:

$$n! \sim \sqrt{\frac{2\pi}{n}} \times \left(\frac{n}{e}\right)^n$$

$$\frac{\sqrt{\frac{2\pi}{n}} \times \left(\frac{n}{e}\right)^n}{\sqrt{\frac{2\pi}{n}} \times \left(\frac{n}{e}\right)^n} \xrightarrow{n \rightarrow \infty} 1$$

Slide 55 Stat 110A, UCLA, Jon Dineen

### Probability and Venn diagrams

Venn's diagram

Union:  $A \cup B$   
 Intersection:  $A \cap B$   
 $A^c$  denotes the part in  $\Omega$  but not in  $A$ .

Properties:

$A \cap B = B \cap A$	$A \cup B = B \cup A$
$(A \cap B) \cap C = A \cap (B \cap C)$	$(A \cup B) \cup C = A \cup (B \cup C)$
$(A \cap B) \cup C = (A \cup C) \cap (B \cup C)$	$(A \cup B) \cap C = (A \cap C) \cup (B \cap C)$

De Morgan's Law:  $A^c \cap B^c = (A \cup B)^c$ ,  $A^c \cup B^c = (A \cap B)^c$   
 Generalized:  $(\cap E_i)^c = \cup E_i^c$ ,  $(\cup E_i)^c = \cap E_i^c$ ,  $i = 1, 2, \dots, n$

Slide 56 Stat 110A, UCLA, Jon Dineen

### Probability and Venn diagrams

Proposition

$$P(A_1 \cup A_2 \cup \dots \cup A_n) =$$

$$\sum_{i=1}^n P(A_i) - \sum_{1 \leq i_1 < i_2 \leq n} P(A_{i_1} \cap A_{i_2}) + \dots$$

$$+ (-1)^{r+1} \sum_{1 \leq i_1 < i_2 < \dots < i_r \leq n} P(A_{i_1} \cap A_{i_2} \cap \dots \cap A_{i_r}) + \dots$$

$$+ (-1)^{n+1} P(A_{i_1} \cap A_{i_2} \cap \dots \cap A_{i_n})$$

Slide 57 Stat 110A, UCLA, Jon Dineen

### Let's Make a Deal Paradox – aka, Monty Hall 3-door problem

- This paradox is related to a popular television show in the 1970's. In the show, a contestant was given a choice of **three doors/cards** of which one contained a prize (**diamond**). The other two doors contained gag gifts like a chicken or a donkey (clubs).

Slide 58 Stat 110A, UCLA, Jon Dineen

### Let's Make a Deal Paradox.

- After the contestant chose an initial door, the host of the show then revealed an empty door among the two unchosen doors, and asks the contestant if he or she would like to switch to the other unchosen door. The question is should the contestant switch. Do the odds of winning increase by switching to the remaining door?

- Pick One card
- Show one Club Card
- Change 1<sup>st</sup> pick?

Slide 59 Stat 110A, UCLA, Jon Dineen

### Let's Make a Deal Paradox.

- The *intuition* of most people tells them that each of the doors, the chosen door and the unchosen door, are equally likely to contain the prize so that there is a **50-50 chance** of winning with either selection? This, however, is **not the case**.
- The **probability of winning by using the switching technique is 2/3**, while the odds of winning by not switching is 1/3. The easiest way to explain this is as follows:

Slide 60 Stat 110A, UCLA, Jon Dineen