UCLA STAT 13

Introduction to Statistical Methods for the Life and Health Sciences

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University of California, Los Angeles, Fall 2007
http://www.stat.ucla.edu/~dinov/courses_students.html

Probability

- Probability is important to statistics because:
  - study results can be influenced by variation
  - it provides theoretical groundwork for statistical inference
- 0 ≤ P(A) ≤ 1
  - In English please: the probability of event A **must** be between zero and one.
  - Note: P(A) = Pr(A)

Random Sampling

- A simple random sample of n items is a sample in which:
  - every member of the population has an equal chance of being selected.
  - the members of the sample are chosen independently.

Random Sampling

Example: Consider our class as the population under study. If we select a sample of size 5, each possible sample of size 5 must have the same chance of being selected.

- When a sample is chosen randomly it is the process of selection that is random.
- How could we randomly select five members from this class randomly?

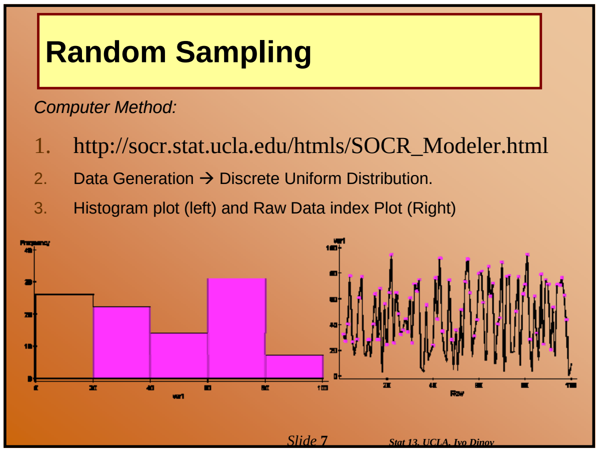
Random Sampling

- Random Number Table (e.g., Table 1 in text)
- Random Number generator on a computer (e.g., www.socr.ucla.edu SOCR Modeler → Random Number Generation
- Which one is the best?
- Example (cont'): Let's randomly select five students from this class using the table and the computer.

Random Sampling

Table Method (p. 670 in book):

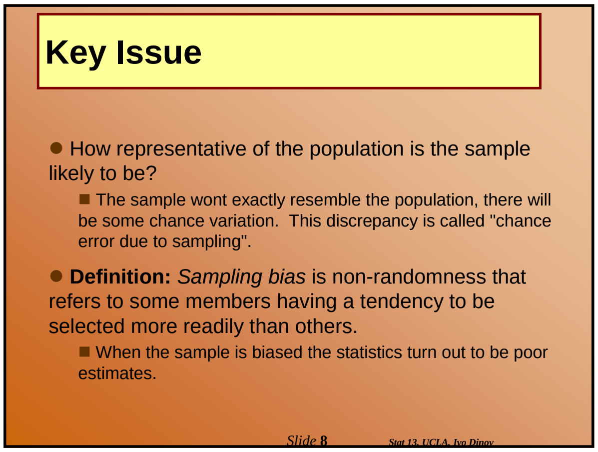
1. Randomly assign id's to each member in the population (1 - n)
2. Choose a place to start in table (close eyes)
3. Start with the first number (must have the same number of digits as n), this is the first member of the sample.
4. Work left, right, up or down, just stay consistent.
5. Choose the next number (must have the same number of digits as n), this is the second member of the sample.
6. Repeat step 5 until all members are selected. If a number is repeated or not possible move to the next following your algorithm.



Random Sampling

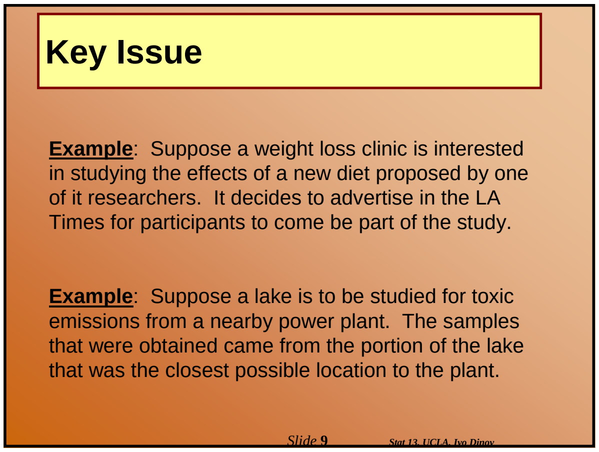
Computer Method:

1. http://socr.stat.ucla.edu/htmls/SOCR_Modeler.html
2. Data Generation → Discrete Uniform Distribution.
3. Histogram plot (left) and Raw Data index Plot (Right)



Key Issue

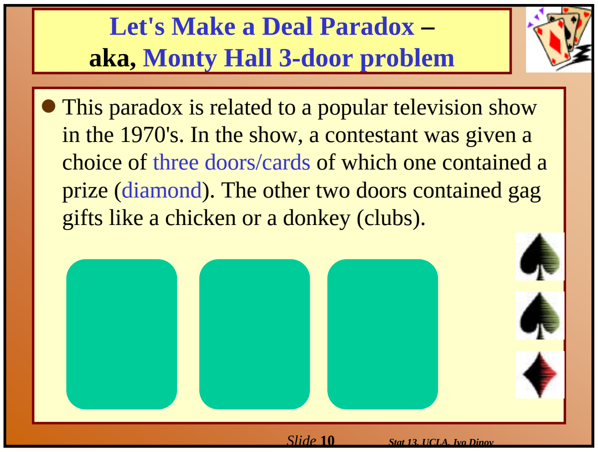
- How representative of the population is the sample likely to be?
  - The sample wont exactly resemble the population, there will be some chance variation. This discrepancy is called "chance error due to sampling".
- **Definition:** *Sampling bias* is non-randomness that refers to some members having a tendency to be selected more readily than others.
  - When the sample is biased the statistics turn out to be poor estimates.



Key Issue

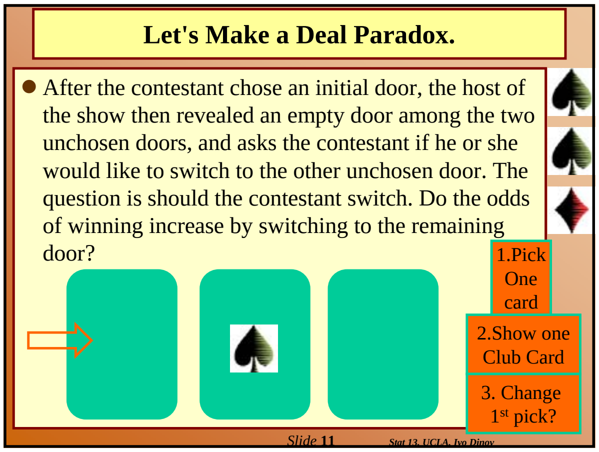
Example: Suppose a weight loss clinic is interested in studying the effects of a new diet proposed by one of it researchers. It decides to advertise in the LA Times for participants to come be part of the study.

Example: Suppose a lake is to be studied for toxic emissions from a nearby power plant. The samples that were obtained came from the portion of the lake that was the closest possible location to the plant.



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).



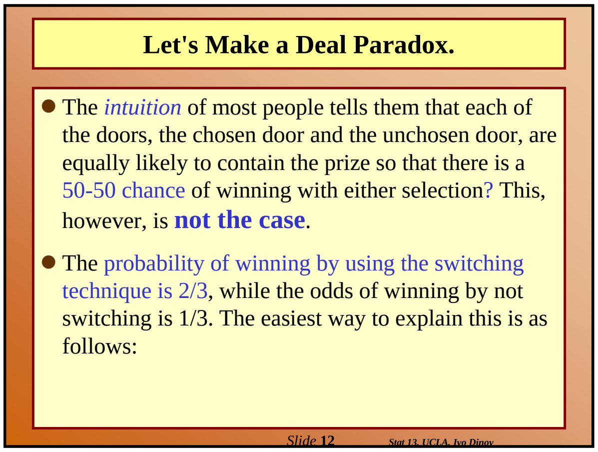
Let's Make a Deal Paradox.

- 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?

1.Pick One card

2.Show one Club Card

3. Change 1st pick?



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:

Let's Make a Deal Paradox.

- The probability of picking the wrong door in the initial stage of the game is 2/3.
- If the contestant picks the wrong door initially, the host must reveal the remaining empty door in the second stage of the game. Thus, if the contestant switches after picking the wrong door initially, the contestant will win the prize.
- The probability of winning by switching then reduces to the probability of picking the wrong door in the initial stage which is clearly 2/3.
- **Demos:**
- file:///C:/Ivo.dir/UCLA_Classes/Applets.dir/SOCR/Prototype1.1/classes/TestExperiment.html
- C:\Ivo.dir\UCLA_Classes\Applets.dir\StatGames.exe

Long run behavior of coin tossing

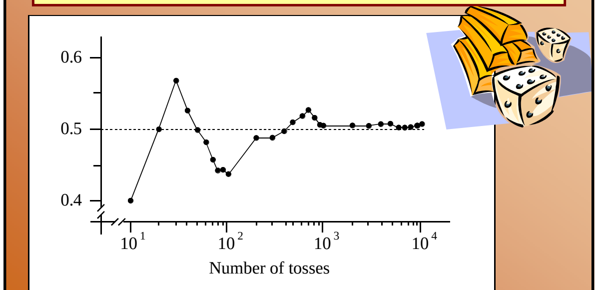


Figure 4.1.1 Proportion of heads versus number of tosses for John Kerrich's coin tossing experiment.

From *Chance Encounters* by C.J. Wild and G.A.F. Seber, © John Wiley & Sons, 2000.

Definitions …

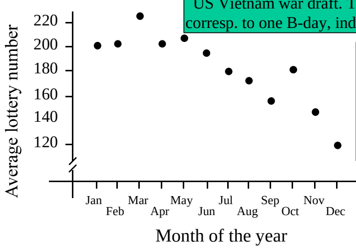
- The law of averages about the behavior of coin tosses – the relative proportion (relative frequency) of heads-to-tails in a coin toss experiment becomes more and more stable as the number of tosses increases. The law of averages applies to relative frequencies not absolute counts of #H and #T.
- Two widely held misconceptions about what the law of averages about coin tosses:
  - Differences between the actual numbers of heads & tails becomes more and more variable with increase of the number of tosses – a seq. of 10 heads doesn't increase the chance of a tail on the next trial.
  - Coin toss results are fair, but behavior is still unpredictable.

Coin Toss Models

- Is the coin tossing model adequate for describing the sex order of children in families?
  - This is a rough model which is not exact. In most countries rates of B/G is different; form 48% … 52%, usually. Birth rates of boys in some places are higher than girls, however, female population seems to be about 51%.
  - Independence, if a second child is born the chance it has the same gender (as the first child) is slightly bigger.

Data from a "random" draw

366 cylinders (for each day in the year) for the US Vietnam war draft. The N-th drawn number, corresp. to one B-day, indicating order of drafting.



So, people born later in the year tend to have lower lottery numbers and a bigger chance of actually being drafted.

Figure 4.3.1 Average lottery numbers by month. Replotted from data in Fienberg [1971].

From *Chance Encounters* by C.J. Wild and G.A.F. Seber, © John Wiley & Sons, 2000.

Types of Probability

- Probability models have two essential components (*sample space*, the space of all possible outcomes from an experiment; and a list of *probabilities* for each event in the sample space). Where do the outcomes and the probabilities come from?
- Probabilities from models – say mathematical/physical description of the sample space and the chance of each event. Construct a fair die tossing game.
- Probabilities from data – data observations determine our probability distribution. Say we toss a coin 100 times and the observed Head/Tail counts are used as probabilities.
- Subjective Probabilities – combining data and psychological factors to design a reasonable probability table (e.g., gambling, stock market).

Sample Spaces and Probabilities

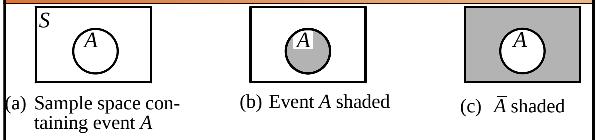
- When the relative frequency of an event in the past is used to estimate the probability that it will occur in the future, what assumption is being made?
  - The underlying process is stable over time;
  - Our relative frequencies must be taken from large numbers for us to have confidence in them as probabilities.
- All statisticians agree about how probabilities are to be combined and manipulated (in math terms), however, not all agree what probabilities should be associated with for a particular real-world event.
- When a weather forecaster says that there is a 70% chance of rain tomorrow, what do you think this statement means? (Based on our past knowledge, according to the barometric pressure, temperature, etc. of the conditions we expect tomorrow, 70% of the time it did rain under such conditions.)

Sample spaces and events

- A ***sample space***, *S*, for a random experiment is the set of all possible outcomes of the experiment.
- An ***event*** is a *collection* of outcomes.
- An event ***occurs*** if any outcome making up that event occurs.

The complement of an event

- The complement of an event *A*, denoted $\bar{A}$, occurs *if and only if A* does not occur.

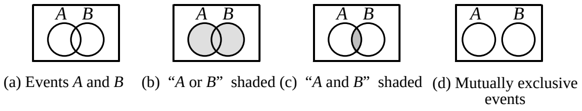


(a) Sample space containing event *A* (b) Event *A* shaded (c) $\bar{A}$ shaded

Figure 4.4.1 An event *A* in the sample space *S*.

Combining events – *all statisticians agree on*

- "***A* or *B***" contains all outcomes in *A* **or** *B* (or both).
- "***A* and *B***" contains all outcomes which are **in both** *A* and *B*.



(a) Events *A* and *B* (b) "*A* or *B*" shaded (c) "*A* and *B*" shaded (d) Mutually exclusive events

Figure 4.4.2 Two events.

From *Chance Encounters* by C.J. Wild and G.A.F. Seber, © John Wiley & Sons, 2000.

Mutually exclusive events cannot occur at the same time.

Probability distributions

- Probabilities always lie between 0 and 1 and they sum up to 1 (across all simple events) .
- ***pr(A)*** can be obtained by adding up the probabilities of all the outcomes in *A*.

$$pr(A) = \sum_{\substack{E \ \text{outcome} \\ \text{in} \ \text{event} \ A}} pr(E)$$

Job losses in the US

TABLE 4.4.1 Job Losses in the US (in thousands) for 1987 to 1991

	Reason for Job Loss			
	Workplace moved/closed	Slack work	Position abolished	Total
Male	1,703	1,196	548	3,447
Female	1,210	564	363	2,137
Total	2,913	1,760	911	5,584

Job losses cont.

	Workplace moved/closed	Slack work	Position abolished	Total
Male	1,703	1,196	548	3,447
Female	1,210	564	363	2,137
Total	2,913	1,760	911	5,584

TABLE 4.4.2 Proportions of Job Losses from Table 4.4.1

	Reason for Job Loss			
	Workplace moved/closed	Slack work	Position abolished	Row totals
Male	.305	.214	.098	.617
Female	.217	.101	.065	.383
Column totals	.552	.315	.163	1.000

Review

- What is a sample space? What are the two essential criteria that must be satisfied by a possible sample space? (completeness – every outcome is represented; and uniqueness – no outcome is represented more than once.
- What is an event? (collection of outcomes)
- If A is an event, what do we mean by its complement, $\bar{A}$? When does $\bar{A}$ occur?
- If *A* and *B* are events, when does ***A* or *B*** occur? When does ***A* and *B*** occur?

Properties of probability distributions

- A sequence of number $\{p_1, p_2, p_3, \ldots, p_n\}$ is a probability distribution for a sample space S = $\{s_1, s_2, s_3, \ldots, s_n\}$, if pr($s_k$) = p_k, for each 1<=k<=n. The two essential properties of a probability distribution $p_1, p_2, \ldots, p_n$?

$$p_k \ge 0; \quad \sum_k p_k = 1$$

- How do we get the probability of an event from the probabilities of outcomes that make up that event?
- If all outcomes are distinct & equally likely, how do we calculate *pr(A)* ? If $A = \{a_1, a_2, a_3, \ldots, a_9\}$ and ***$pr(a_1)=pr(a_2)=\ldots=pr(a_9)=p$;*** then

pr(A) = 9 x pr(a_1) = 9p.

Example of probability distributions

- Tossing a coin twice. *Sample space* S={HH, HT, TH, TT}, for a fair coin each outcome is equally likely, so the probabilities of the 4 possible outcomes should be identical, *p*. Since, p(HH)=p(HT)=p(TH)=p(TT)=p and

$$p_k \ge 0; \quad \sum_k p_k = 1$$

- p = ¼ = 0.25.

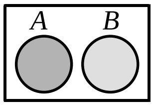
Proportion vs. Probability

- How do the concepts of a proportion and a probability differ? A proportion is a partial description of a real population. The probabilities give us the chance of something happening in a random experiment. Sometimes, proportions are identical to probabilities (e.g., in a real population under the experiment *choose-a-unit-at-random).*
- See the ***two-way table of counts*** (*contingency table*) on Table 4.4.1, slide 19. E.g., *choose-a-person-at-random* from the ones laid off, and compute the chance that the person would be a male, laid off due to position-closing. We can apply the same rules for manipulating probabilities to proportions, in the case where these two are identical.

Rules for manipulating Probability Distributions

For mutually exclusive events,

pr(*A* or *B*) = pr(*A*) + pr(*B*)



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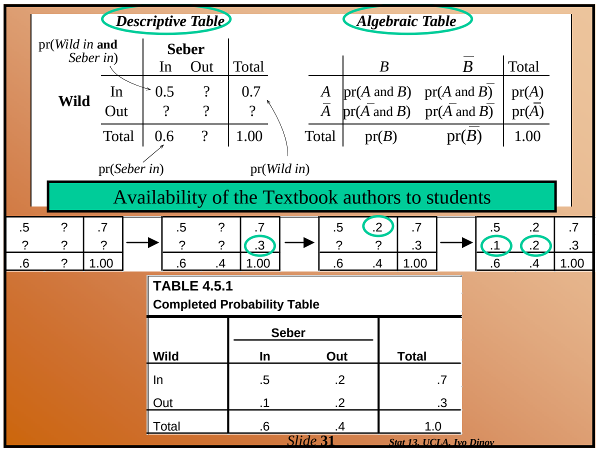


Descriptive Table

pr(*Wild in* **and** *Seber in*)

		Seber In	Out	Total
Wild	In	0.5	?	0.7
	Out	?	?	?
	Total	0.6	?	1.00

pr(*Seber in*)

pr(*Wild in*)

Algebraic Table

	B	$\bar{B}$	Total
A	pr(A and B)	pr(A and $\bar{B}$)	pr(A)
$\bar{A}$	pr($\bar{A}$ and B)	pr($\bar{A}$ and $\bar{B}$)	pr($\bar{A}$)
Total	pr(B)	pr($\bar{B}$)	1.00

Availability of the Textbook authors to students

.5	?	.7
?	?	?
.6	?	1.00

→

.5	?	.7
?	?	.3
.6	.4	1.00

→

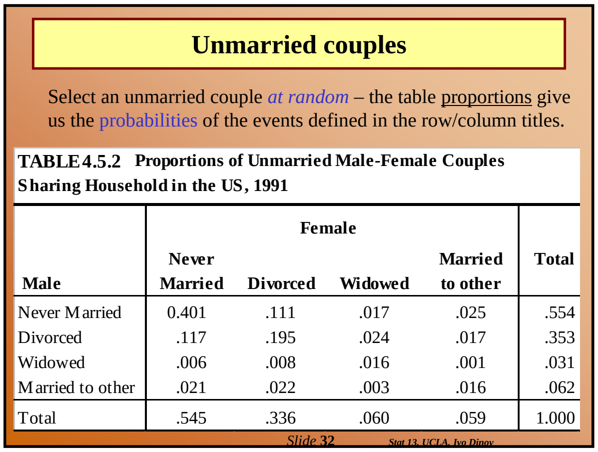
.5	.2	.7
?	?	.3
.6	.4	1.00

→

.5	.2	.7
.1	.2	.3
.6	.4	1.00

TABLE 4.5.1
Completed Probability Table

Wild	**Seber** **In**	**Out**	**Total**
In	.5	.2	.7
Out	.1	.2	.3
Total	.6	.4	1.0

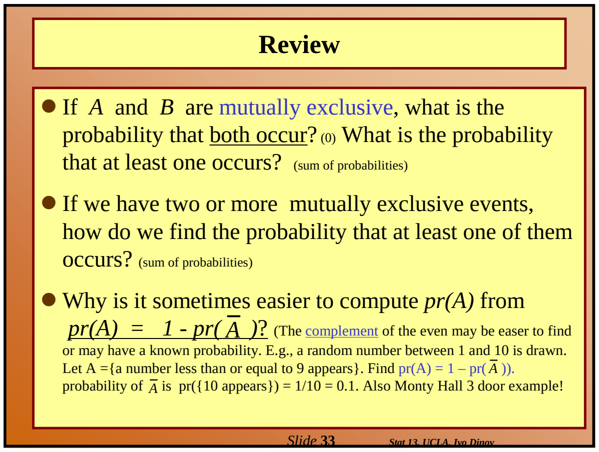


Unmarried couples

Select an unmarried couple *at random* – the table proportions give us the probabilities of the events defined in the row/column titles.

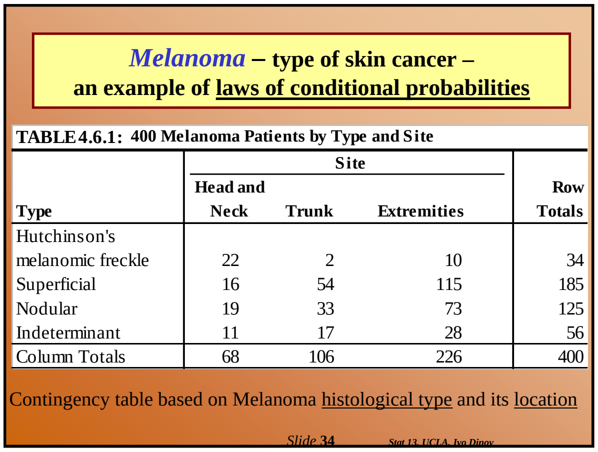
TABLE 4.5.2 Proportions of Unmarried Male-Female Couples Sharing Household in the US, 1991

Male	**Female** Never Married	Divorced	Widowed	Married to other	**Total**
Never Married	0.401	.111	.017	.025	.554
Divorced	.117	.195	.024	.017	.353
Widowed	.006	.008	.016	.001	.031
Married to other	.021	.022	.003	.016	.062
Total	.545	.336	.060	.059	1.000



Review

- If A and B are mutually exclusive, what is the probability that both occur? (0) What is the probability that at least one occurs? (sum of probabilities)
- If we have two or more mutually exclusive events, how do we find the probability that at least one of them occurs? (sum of probabilities)
- Why is it sometimes easier to compute *pr(A)* from *pr(A) = 1 - pr($\bar{A}$)*? (The complement of the even may be easer to find or may have a known probability. E.g., a random number between 1 and 10 is drawn. Let A ={a number less than or equal to 9 appears}. Find pr(A) = 1 – pr($\bar{A}$)). probability of $\bar{A}$ is pr({10 appears}) = 1/10 = 0.1. Also Monty Hall 3 door example!

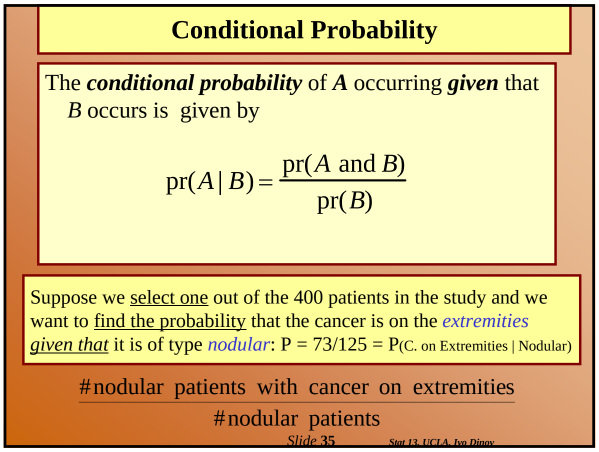


Melanoma – type of skin cancer – an example of laws of conditional probabilities

TABLE 4.6.1: 400 Melanoma Patients by Type and Site

Type	**Site** **Head and Neck**	**Trunk**	**Extremities**	**Row Totals**
Hutchinson's melanomic freckle	22	2	10	34
Superficial	16	54	115	185
Nodular	19	33	73	125
Indeterminant	11	17	28	56
Column Totals	68	106	226	400

Contingency table based on Melanoma histological type and its location



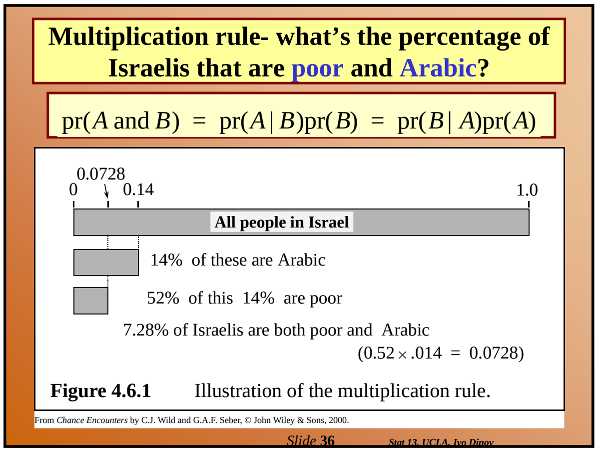
Conditional Probability

The ***conditional probability*** of ***A*** occurring ***given*** that B occurs is given by

$$\text{pr}(A \mid B) = \frac{\text{pr}(A \text{ and } B)}{\text{pr}(B)}$$

Suppose we select one out of the 400 patients in the study and we want to find the probability that the cancer is on the *extremities* given that it is of type *nodular*: P = 73/125 = P(C. on Extremities | Nodular)

$$\frac{\#\text{nodular patients with cancer on extremities}}{\#\text{nodular patients}}$$



Multiplication rule- what's the percentage of Israelis that are poor and Arabic?

$$\text{pr}(A \text{ and } B) = \text{pr}(A \mid B)\text{pr}(B) = \text{pr}(B \mid A)\text{pr}(A)$$

Figure 4.6.1 Illustration of the multiplication rule.

From *Chance Encounters* by C.J. Wild and G.A.F. Seber, © John Wiley & Sons, 2000.

A tree diagram for computing conditional probabilities

Suppose we draw 2 balls at random one at a time *without replacement* from an urn containing **4 black** and **3 white** balls, otherwise identical. What is the probability that the *second ball is black*? Sample Spc?

Mutually exclusive

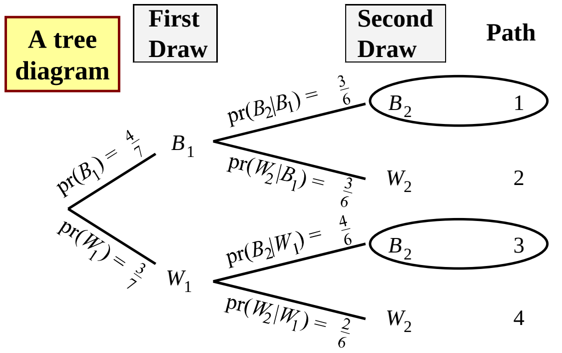
P({*2-nd ball is black*}) =

P({*2-nd is black*} &{*1-st is black*}) +

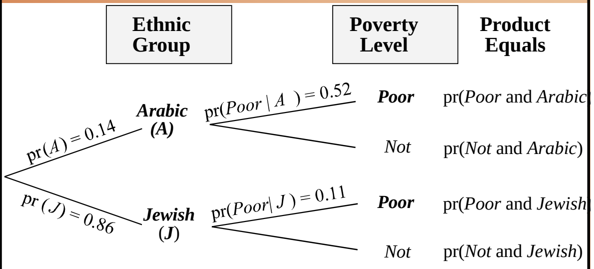
P({2-nd is black} &{*1-st is white*}) =

4/7 x 3/6 + 4/6 x 3/7 = 4/7.

A tree diagram



Tree diagram for poverty in Israel



2-way table for poverty in Israel

pr(*Poor* and *Arabic*) =
pr(*Poor*|*Arabic*) × pr(*Arabic*)
[= 52% of 14%]

pr(*Poor* and *Jewish*) =
pr(*Poor*|*Jewish*) × pr(*Jewish*)
[= 11% of 86%]

		Ethnicity		
		Arabic	Jewish	Total
Poverty	Poor	.52 × .14	.11 × .86	?
	Not poor	?	?	?
	Total	.14	.86	1.00

pr(*Arabic*) = .14

pr(*Jewish*) = .86

Figure 4.6.4 Proportions by Ethnicity and Poverty.

P(A & B) = P(A | B) x P(B),

P(A | B) = P(A & B) / P(B)

P(A & B) = P(B & A) = P(B | A) x P(A).

P(A | B) = [P(B | A) x P(A)] / P(B).

2-way table for poverty in Israel cont.

pr(*Poor* and *Arabic*) =
pr(*Poor*|*Arabic*) × pr(*Arabic*)
[= 52% of 14%]

pr(*Poor* and *Jewish*) =
pr(*Poor*|*Jewish*) × pr(*Jewish*)
[= 11% of 86%]

		Ethnicity		
		Arabic	Jewish	Total
Poverty	Poor	.52 × .14	.11 × .86	?
	Not poor	?	?	?
	Total	.14	.86	1.00

pr(*Arabic*) = .14

pr(*Jewish*) = .86

TABLE 4.6.3 Proportions by Ethnicity and Poverty

		Ethnicity		
		Arabic	**Jewish**	**Total**
Poverty	Poor	.0728	.0946	.1674
	Not Poor	.0672	.7654	.8326
	Total	.14	.86	1.00

Conditional probabilities and 2-way tables

- Many problems involving conditional probabilities can be solved by constructing two-way tables
- This includes *reversing the order of conditioning*

P(A & B) = P(A | B) x P(B) = P(B | A) x P(A)

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?

$$P(class \mid evidence) = \frac{P(evidence \mid class) \times P(class)}{P(evidence)}$$

$$P(cancer) = 0.01$$

$$P(pos \mid cancer) = 0.8$$

$$P(positive) = 0.107$$

$$P(cancer \mid pos) = ?$$

Proportional usage of *oral contraceptives* and their rates of failure

We need to complete the two-way contingency table of proportions

pr(*Failed* and *Oral*) =
pr(*Failed* | *Oral*) × pr(*Oral*)
[= 5% of 32%]

pr(*Failed* and *IUD*) =
pr(*Failed* | *IUD*) × pr(*IUD*)
[= 6% of 3%]

		Method					
		Steril.	Oral	Barrier	IUD	Sperm.	Total
Outcome	Failed	0 × .38	.05 × .32	.14 × .24	.06 × .03	.26 × .03	?
	Didn't	?	?	?	?	?	?
	Total	.38	.32	.24	.03	.03	1.00

pr(*Steril.*) = .38 pr(*Barrier*) = .24 pr(*IUD*) = .03

Oral contraceptives cont.

pr(*Failed* and *Oral*) =
pr(*Failed* | *Oral*) × pr(*Oral*)
[= 5% of 32%]

pr(*Failed* and *IUD*) =
pr(*Failed* | *IUD*) × pr(*IUD*)
[= 6% of 3%]

		Method					
		Steril.	Oral	Barrier	IUD	Sperm.	Total
Outcome	Failed	0 × .38	.05 × .32	.14 × .24	.06 × .03	.26 × .03	?
	Didn't	?	?	?	?	?	?
	Total	.38	.32	.24	.03	.03	1.00

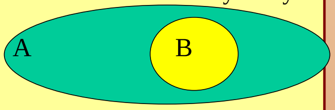
pr(*Steril.*) = .38 pr(*Barrier*) = .24 pr(*IUD*) = .03

TABLE 4.6.4 Table Constructed from the Data in Example 4.6.8

		Method					
		Steril.	**Oral**	**Barrier**	**IUD**	**Sperm.**	**Total**
Outcome	Failed	0	.0160	.0336	.0018	.0078	.0592
	Didn't	.3800	.3040	.2064	.0282	.0222	.9408
	Total	.3800	.3200	.2400	.0300	.0300	1.0000

Remarks …

- In *pr(A | B)*, how should the symbol " | " is read *given that*.
- How do we interpret the fact that: *The event A always occurs when B occurs*? What can you say about pr(*A* | *B*)?



- When drawing a probability tree for a particular problem, how do you know *what events* to use for the first fan of branches and which events to use for the subsequent branching? (at each branching stage condition on all the info available up to here. E.g., at first branching use all simple events, no prior is available. At 3-rd branching condition of the previous 2 events, etc.).

TABLE 4.6.5 Number of Individuals Having a Given Mean Absorbance Ratio (MAR) in the ELISA for HIV Antibodies

MAR	Healthy Donor		HIV patients	
<2	202	} 275	0	} 2 False-Negatives (FNE)
2 - 2.99	73	Test cut-off	2	
3 - 3.99	15	False-positives	7	Power of a test is:
4 - 4.99	3		7	1-P(FNE)=
5 - 5.99	2		15	1-P(Neg|HIV)
6 -11.99	2		36	~ 0.976
12+	0		21	
Total	297		88	

Adapted from Weiss et al.[1985]

HIV cont.

pr(*HIV* and *Positive*) =
pr(*Positive*|*HIV*) × pr(*HIV*)
[= 98% of 1%]

pr(*Not HIV* and *Negative*) =
pr(*Negative*|*Not HIV*) × pr(*Not HIV*)
[= 93% of 99%]

		Test result		
		Positive	Negative	Total
Disease status	HIV	.98 × .01	?	.01
	Not HIV	?	.93 × .99	.99
	Total	?	?	1.00

pr(*HIV*) = .01
pr(*Not HIV*) = .99

Figure 4.6.6 Putting HIV information into the table.

From *Chance Encounters* by C.J. Wild and G.A.F. Seber, © John Wiley & Sons, 2000.

HIV – reconstructing the contingency table

pr(*HIV* and *Positive*) = pr(*Positive*|*HIV*) × pr(*HIV*)
[= 98% of 1%]

pr(*Not HIV* and *Negative*) = pr(*Negative*|*Not HIV*) × pr(*Not HIV*)
[= 93% of 99%]

		Test result		
		Positive	Negative	Total
Disease status	HIV	.98 × .01	?	.01 ← pr(*HIV*) = .01
	Not HIV	?	.93 × .99	.99 ← pr(*Not HIV*) = .99
	Total	?	?	1.00

TABLE 4.6.6 Proportions by Disease Status and Test Result

		Test Result		
		Positive	**Negative**	**Total**
Disease	HIV	.0098	.0002	.01
Status	Not HIV	.0693	.9207	.99
	Total	.0791	.9209	1.00

Proportions of HIV infections by country

TABLE 4.6.7 Proportions Infected with HIV

Country	**No. AIDS Cases**	**Population (millions)**	**pr(HIV)**	Having | Test **pr(HIV | Positive)**
United States	218,301	252.7	0.00864	0.109
Canada	6,116	26.7	0.00229	0.031
Australia	3,238	16.8	0.00193	0.026
New Zealand	323	3.4	0.00095	0.013
United Kingdom	5,451	57.3	0.00095	0.013
Ireland	142	3.6	0.00039	0.005

Statistical independence

- Events *A* and *B* are *statistically independent* if knowing whether *B* has occurred gives no new information about the chances of *A* occurring,

  i.e. if **pr(*A* | *B*) = pr(*A*)**

- Similarly, P(*B* | *A*) = P(*B*), since

  $P(B|A)=P(B \,\&\, A)/P(A) = P(\cancel{A|}B)P(B)/\cancel{P(A)} = P(B)$

- If *A* and *B* are *statistically independent*, then

$$\text{pr}(\,A \text{ and } B) = \text{pr}(A) \times \text{pr}(B)$$

People vs. Collins

TABLE 4.7.2 Frequencies Assumed by the Prosecution

Yellow car	$\frac{1}{10}$	Girl with blond hair	$\frac{1}{3}$
Man with mustache	$\frac{1}{4}$	Black man with beard	$\frac{1}{10}$
Girl with ponytail	$\frac{1}{10}$	Interracial couple in car	$\frac{1}{1000}$

- The first occasion where a conviction was made in an American court of law, largely on statistical evidence, 1964. A woman was mugged and the offender was described as a wearing dark cloths, with blond hair in a pony tail who got into a yellow car driven by a black male accomplice with mustache and beard. The suspect brought to trial were picked out in a line-up and fit all of the descriptions. Using the *product rule for probabilities* an expert witness computed the chance that a random couple meets these characteristics, as 1:12,000,000.

Formula summary cont.

- pr(*S*) = 1
- $\text{pr}(\bar{A}) = 1 - \text{pr}(A)$
- If *A* and *B* are mutually exclusive events, then pr(*A* or *B*) = pr(*A*) + pr(*B*)

  (here "or" is used in the inclusive sense)

- If $A_1, A_2, \ldots, A_k$ are mutually exclusive events, then

  $\text{pr}(A_1 \text{ or } A_2 \text{ or } \ldots \text{ or } A_k) = \text{pr}(A_1)+\text{pr}(A_2)+\ldots+\text{pr}(A_k)$

Formula summary cont.

Conditional probability

- Definition:

$$\text{pr}(A\,|\,B) = \frac{\text{pr}(A \text{ and } B)}{\text{pr}(B)}$$

- Multiplication formula:

$$\text{pr}(A \text{ and } B) = \text{pr}(B|A)\text{pr}(A) = \text{pr}(A|B)\text{pr}(B)$$

Formula summary cont.

Multiplication Rule under independence:

- If A and B are independent events, then

$$\text{pr}(A \text{ and } B) = \text{pr}(A)\ \text{pr}(B)$$

- If $A_1, A_2, \ldots, A_n$ are mutually independent,

$\text{pr}(A_1 \text{ and } A_2 \text{ and} \ldots \text{and } A_n) = \text{pr}(A_1)\ \text{pr}(A_2) \ldots \text{pr}(A_n)$

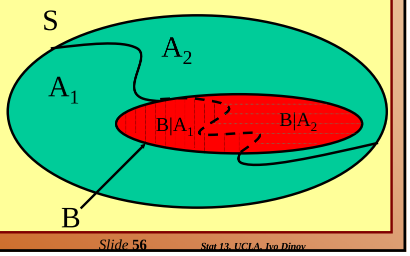
Law of Total Probability

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

$$P(B) = P(B|A_1)P(A_1) + P(B|A_2)P(A_2) + \ldots + P(B|A_n)P(A_n)$$

Ex:

$P(B) = P(B|A_1)P(A_1) +$
$P(B|A_2)P(A_2)$



Bayesian Rule

- If $\{A_1, A_2, \ldots, A_n\}$ 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 ($P(B) > 0$)

$$P(A_i \mid B) = P(A_i \cap B) / P(B) = [P(B \mid A_i) \times P(A_i)] / P(B) =$$

$$= \frac{P(B \mid A_i) \times P(A_i)}{\sum_{k=1}^{n} P(B \mid A_k) P(A_k)}$$

Bayesian Rule

$$P(A_i) = \frac{P(A_i \mid B) \times P(A_i)}{\sum_{k=1}^{n} P(B \mid A_k) P(A_k)}$$

D **= the test person has the disease.**

T **= the test result is positive.**

Ex: (Laboratory blood test) **Assume:**

P(positive Test| Disease) = 0.95

P(positive Test| no Disease)=0.01

P(Disease) = 0.005

Find:

P(Disease|positive Test)=?

P(D | T) = ?

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

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

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?

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

$$P(cancer) = 0.01$$

$$P(pos \mid cancer) = 0.8$$

$$P(pos \mid healthy) = 0.1$$

$$P(cancer \mid pos) = ?$$

P(C|P)=P(P|C)xP(C)/[P(P|C)xP(C)+ P(P|H)xP(H)]
P(C|P)=0.8x0.01 / [0.8x0.01 + 0.1x0.99] = ?

Bayesian Rule (different data/example!)

True Disease State

Test Results	No Disease	Disease	Total
Negative	OK (0.98505)	False Negative II (0.00025)	0.9853
Positive	False Positive I (0.00995)	OK (0.00475)	0.0147
Total	0.995	0.005	1.0

$$P(T \cap D^C) = P(T \mid D^C) \times P(D^C) = 0.01 \times 0.995 = 0.00995$$

Power of Test = $1 - P(T^C \mid D)$ = 0.00025/0.005 = 0.95

Sensitivity: **TP/(TP+FN) =** 0.00475/(0.00475+ 0.00025)= 0.95

Specificity: **TN/(TN+FP) =** 0.98505/(0.98505+ 0.00995) = 0.99

Examples – Birthday Paradox

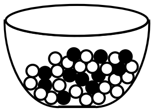
- The Birthday Paradox: In a random group of N people, what is the change that at least two people have the same birthday?
- E.x., if N=23, P>0.5. Main confusion arises from the fact that in real life we rarely meet people having the same birthday as us, and we meet more than 23 people.
- The reason for such high probability is that any of the 23 people can compare their birthday with any other one, not just you comparing your birthday to anybody else's.
- There are N-Choose-2 = 20*19/2 ways to select a pair or people. Assume there are 365 days in a year, P(one-particular-pair-same-B-day)=1/365, and
- P(one-particular-pair-failure)=1-1/365 ~ 0.99726.
- For N=20, 20-Choose-2 = 190. E={No 2 people have the same birthday is the event all 190 pairs fail (have different birthdays)}, then P(E) = P(failure)^{190} = 0.99726^{190} = 0.59.
- Hence, P(at-least-one-success)=1-0.59=0.41, quite high.
- Note: for N=42 ➔ P>0.9 …

The two-color urn model

N balls in an urn, of which there are

M black balls

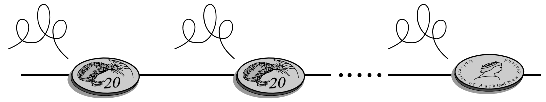
$N - M$ white balls



Sample n balls and count X = # black balls in sample

We will compute the probability distribution of the R.V. *X*

The biased-coin tossing model



toss 1 pr(H) = p

toss 2 pr(H) = p

toss n pr(H) = p

Perform n tosses and count X = # heads

We also want to compute the probability distribution of this R.V. *X*!
Are the two-color urn and the biased-coin models <u>related</u>? How do we present the models in <u>mathematical terms</u>?

The answer is: Binomial distribution

- The distribution of the <u>number of heads in *n* tosses of a biased coin</u> is called the ***Binomial distribution***.

Binomial(N, p) – the probability distribution of the number of Heads in an N-toss coin experiment, where the probability for Head occurring in each trial is p.

E.g., Binomial(6, 0.7)

	x	0	1	2	3	4	5	6
Individual	**pr($X = x$)**	0.001	0.010	0.060	0.185	0.324	0.303	0.118
Cumulative	**pr($X \leq x$)**	0.001	0.011	0.070	0.256	0.580	0.882	1.000

For example P(X=0) = P(all 6 tosses are Tails) =

$$(1-0.7)^6 = 0.3^6 = 0.001$$

Binary random process

The ***biased-coin tossing model*** is a physical model for situations which can be characterized as a series of trials where:

- each trial has only two outcomes: *success* or *failure*;
- p = P(*success*) is the same for every trial; and
- trials are independent.

- The distribution of X = number of successes (heads) in N such trials is

Binomial(N, p)

Sampling from a finite population – Binomial Approximation

If we take a sample of size *n*

- from a much larger population (of size *N*)
- in which a proportion *p* have a characteristic of interest, then the distribution of ***X*, the number in the sample with that characteristic**,
- is *approximately* Binomial(*n*, *p*).
  - ☐ (Operating Rule: Approximation is adequate if *n* / *N*< 0.1.)
- Example, polling the US population to see what proportion is/has-been married.

Binomial Probabilities – the moment we all have been waiting for!

- Suppose X ~ Binomial(n, p), then the probability

$$P(X = x) = \binom{n}{x} p^{x} (1-p)^{(n-x)}, \quad 0 \le x \le n$$

- Where the binomial coefficients are defined by

$$\binom{n}{x} = \frac{n!}{(n-x)!\ x!}, \qquad n! = 1 \times 2 \times 3 \times \ldots \times (n-1) \times n$$

***n*-factorial**

Expected values

- The game of chance: cost to play:$1.50; Prices {$1, $2, $3}, probabilities of winning each price are {0.6, 0.3, 0.1}, respectively.
- Should we play the game? What are our chances of winning/loosing?

Prize ($)	x	1	2	3	
Probability	pr(x)	0.6	0.3	0.1	
What we would "expect" from 100 games					*add across row*
Number of games won		0.6×100	0.3×100	0.1×100	
$ won		$1 \times 0.6 \times 100$	$2 \times 0.3 \times 100$	$3 \times 0.1 \times 100$	Sum

Total prize money = Sum;   ***Average prize money*** = Sum/100

$$= 1 \times 0.6 + 2 \times 0.3 + 3 \times 0.1$$
$$= 1.5$$

***Theoretically* Fair Game: price to play EQ the expected return!**

Definition of the expected value, in general.

- The expected value:

$$\mathrm{E(X)} = \sum_{\text{all } x} x\ \mathrm{P}(x) \left(= \int_{\text{all } X} x\ \mathrm{P}(x) dx \right)$$

- = Sum of (value times probability of value)

Example

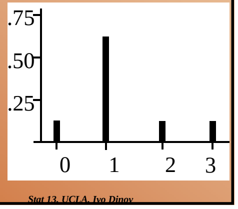
In the at least one of each or at most 3 children example, where X ={number of Girls} we have:

X	0	1	2	3
pr(*x*)	$\frac{1}{8}$	$\frac{5}{8}$	$\frac{1}{8}$	$\frac{1}{8}$

$$\mathrm{E}(X) = \sum_{x} x\,\mathrm{P}(x)$$

$$= 0 \times \frac{1}{8} + 1 \times \frac{5}{8} + 2 \times \frac{1}{8} + 3 \times \frac{1}{8}$$

$$= 1.25$$



The expected value and population mean

μ_x = **E**(*X*) is called the ***mean*** of the distribution of *X*.

μ_X = **E**(*X*) is usually called the ***population mean.***

μ_x is the point where the bar graph of P(*X* = *x*) balances.

Population standard deviation

The *population standard deviation* is

$$\mathrm{sd}(X) = \sqrt{\mathrm{E}[(X - \mu)^2]}$$

Note that if X is a RV, then (X-μ) is also a RV, and so is (X-μ)^2. Hence, the *expectation*, E[(X-μ)^2], makes sense.

Population mean & standard deviation

Expected value:

$$E(X) = \sum_x xP(X = x)$$

Variance

$$Var(X) = \sum_x (x - E(x))^2 P(X = x)$$

Standard Deviation

$$SD(X) = \sqrt{Var(X)} = \sqrt{\sum_x (x - E(x))^2 P(X = x)}$$

For the Binomial distribution . . . Mean & SD

$$\mathrm{E}(X) = np,$$

$$\mathrm{sd}(X) = \sqrt{np(1-p)}$$

Example – 3.18

3.18. In a certain population of the European starling, there are 5,000 nests with young. The distribution of brood size (number of young in a nest) is given in the table. If a young starling is chosen at random and let Y' be the size of its brood. Find:

Index	Size of Broods	Frequency
1	90	90
2	230	460
3	610	1,830
4	1400	5,600
5	1760	8,800
6	750	4,500
7	130	910
8	26	208
9	3	27
10	1	10
Total	5,000	22,435

(a) *Pr{Y' = 3}* =

1,830 / 22,435 = 0.0816 (8.16%)

(b) *Pr{Y' >= 7}* =

(910 + 208 + 27 + 10) / 22,435 =

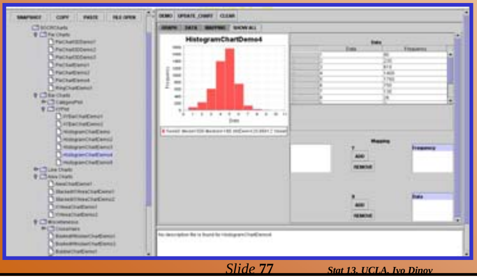
1,155 / 22,435 = 0.0515 (5.15%)

(c) Choosing a young at random gives a ***selection of broods*** which is not random, but is biased toward larger broods (because a larger brood has more chances to be selected). Therefore *Pr{Y' >= 7}* is larger than *Pr{Y >= 7}*.

Example – 3.18

Use HistogramChartDemo4: http://socr.ucla.edu/htmls/SOCR_Charts.html

3.18. In a certain population of the European starling, there are 5,000 nests with young. The distribution of brood size (number of young in a nest) is given in the table. If a young starling is chosen at random and let Y' be the size of its brood.



The Normal Distribution

- Recall: in chapter 2 we used histograms to represent frequency distributions.
  - We can think of a histogram as an approximation of the true population distribution.
- A smooth curve representing a frequency distribution is called a density curve.

Linear Scaling (affine transformations) *aX* + *b*

Why is that so?

E(*a**X*** + *b*) = ***a*** E(***X***) +*b*   SD(*a**X*** +*b*) = |***a***| SD(***X***)

$$E(aX+b) = \sum_{x=0}^{n}(a\,x+b)\ P(X=x) =$$

$$\sum_{x=0}^{n} a\ x\ P(X=x) + \sum_{x=0}^{n} b\ P(X=x) =$$

$$a\ \sum_{x=0}^{n} x\ P(X=x) + b\ \sum_{x=0}^{n} P(X=x) =$$

$$aE(X) + b\times 1 = aE(X) + b.$$

Linear Scaling (affine transformations) *aX* + *b*

And why do we care?

E(*a**X*** + *b*) = ***a*** E(***X***) +*b*   SD(*a**X*** +*b*) = |***a***| SD(***X***)

-E.g., say the rules for the game of chance we saw before change and the new pay-off is as follows: {$0, $1.50, $3}, with probabilities of {0.6, 0.3, 0.1}, as before. What is the newly expected return of the game? Remember the old expectation was equal to the entrance fee of $1.50, and the game was fair!

Y = 3(X-1)/2

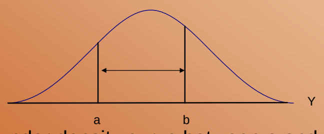
{$1, $2, $3} → {$0, $1.50, $3},

E(Y) = 3/2 E(X) –3/2 = 3 / 4 = $0.75

And the game became clearly biased. Note how easy it is to compute E(Y).

The Normal Distribution

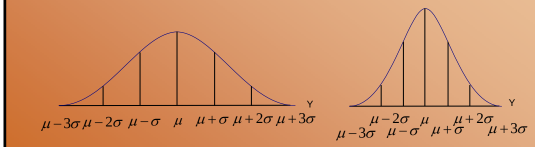
- The normal distribution is described by a unimodal, bell shaped, symmetric density curve



- Area under density curve between a and b is equal to the proportion of Y values between a and b.
- The area under the whole curve is equal 1.0

The Normal Distribution

- Each normal curve is characterized by it's μ and σ



- If random variable Y is normal with mean μ and standard deviation σ, we write

Y ~ N(μ , σ^2)

http://www.SOCR.ucla.edu/htmls/SOCR_Distributions.html

The Normal Distribution

- A normal density curve can be summarized with the following formula:

$$f(y) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{y-\mu}{\sigma}\right)^2}$$

- Every normal curve uses this formula, what makes them different is what gets plugged in for μ and σ
- Each normal curve is centered at μ and the width depends on σ
- (small = tall, large = short/wide).

Areas under the normal curve

- Because each normal curve is the result of a single formula the areas under the normal curve have been computed and tabulated for ease of use.
- The Standard Scale
  - Any normal curve can be converted into a normal curve with
  - μ = 0 and σ = 1. This is called the standard normal.

Areas under the normal curve

- The process of converting normal data to the standard scale is called standardizing.
- To convert Y into Z (a z-score) use the following formula:

$$Z = \frac{Y - \mu}{\sigma}$$

- What does a z-score measure?

Areas under the normal curve

- Table 3 (also in front of book) gives areas under the standard normal curve

Example: Find the area that corresponds to $z < 2.0$

- Always good to draw a picture!

Example: Find the area that corresponds to $z > 2.0$

Example: Find the area that corresponds to $1.0 < z < 2.0$

Example: Find the area that corresponds to $z < 2.56$

Tables are antiquated → Use tools like SOCR (socr.ucla.edu)

Relationship to the Empirical Rule

- Recall the Empirical Rule

$$\bar{y} \pm s \approx 68\%$$
$$\bar{y} \pm 2s \approx 95\%$$
$$\bar{y} \pm 3s \approx> 99\%$$

- How can we use the standard normal distribution to verify the properties of the empirical rule?

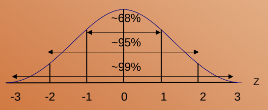
The area: $-1 < z < 1 = 0.8413 - 0.1587 = 0.6826$

The area: $-2.0 < z < 2.0 = 0.9772 - 0.0228 = 0.9544$

The area: $-3.0 < z < 3.0 = 0.9987 - 0.0013 = 0.9974$

Relationship to the Empirical Rule

- Visually:
- http://socr.stat.ucla.edu/htmls/SOCR_Distributions.html



Application to Data

Example: Suppose that the average systolic blood pressure (SBP) for a Los Angeles freeway commuter follows a normal distribution with mean 130 mmHg and standard deviation 20 mmHg.

Find the percentage of LA freeway commuters that have a SBP less than 100.

- First step: Rewrite with notation!
  - Y ~ N(130, 20)

Application to Data

- Second step: Identify what we are trying to solve!
  - Find the percentage for: $y < 100$
- Third step: Standardize

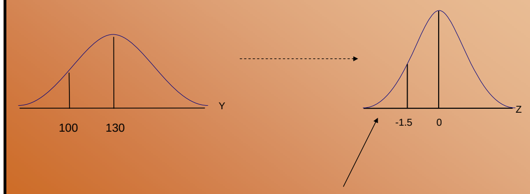
$$Z = \frac{Y - \mu}{\sigma} = \frac{100 - 130}{20} = -1.5$$

- Fourth Step: Use the standard normal table to solve
  - $y < 100 = z < -1.5 = 0.0668$

Therefore approximately 6.7% of LA freeway commuters have SBP less than 100 mmHg.

Application to Data

- Visually



z < -1.5 = 0.0668

Application to Data

- Try these:
  - What percentage of LA freeway commuters have SBP greater than 155 mmHg?
  - Between 120 and 175?
- Can also be interpreted in terms of probability.
  - What is the probability that a randomly selected freeway commuter will have a SBP less than 100?

P(Y < 100) = 0.0668

Normal *approximation* to Binomial

- Suppose Y~Binomial(n, p)
- Then $Y=Y_1+ Y_2+ Y_3+\ldots+ Y_n$, where
  - Y_k~Bernoulli(p) , $E(Y_k)=p$ & $Var(Y_k)=p(1-p)$ ➔
  - E(Y)=np & Var(Y)=np(1-p), SD(Y)= $(np(1-p))^{1/2}$
  - Standardize Y:
    - ❑ $Z=(Y-np) / (np(1-p))^{1/2}$
    - ❑ By CLT ➔ Z ~ N(0, 1). So, Y ~ *N* [np, $(np(1-p))^{1/2}$]
- Normal Approx to Binomial is reasonable when np >=10 & n(1-p)>10 (p & (1-p) are NOT too small relative to n).

Normal *approximation* to Binomial – Example

- Roulette wheel investigation:
- Compute P(Y>=58), where Y~Binomial(100, 0.47) –
  - The proportion of the Binomial(100, 0.47) population having more than 58 reds (successes) out of 100 roulette spins (trials).
  - Since np=47>=10 & n(1-p)=53>10 Normal approx is justified.

Roulette has 38 slots
18red 18black 2 neutral

- Z=(Y-np)/Sqrt(np(1-p)) = (58-100*0.47)/Sqrt(100*0.47*0.53)=2.2
- P(Y>=58) ⟵ ➔ P(Z>=2.2) = 0.0139
- True P(Y>=58) = 0.0177, using SOCR (demo!)
- Binomial approx useful when no access to SOCR available or when N is large!

Assessing Normality

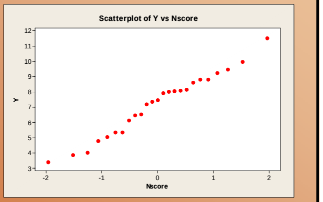
- How can we tell if our data is normally distributed?
- Several methods for checking normality
  - Mean = Median
  - Empirical Rule
    - ❑ Check the percent of data that within 1 sd, 2 sd and 3 sd (should be approximately 68%, 95% and 99.7%).
  - Histogram or dotplot
  - Normal Probability Plot
- Why do we care if the data is normally distributed?

Normal Probability Plots

- A normal probability plot is a graph that is used to assess normality in a data set.
- When we look at a normal plot we want to see a straight line.
  - This means that the distribution is approximately normal.
  - Sometimes easier to see if a line is straight, than if a histogram is bell shaped.

Normal Probability Plots

- This is how the plot works:
  - We take the data and plot it against normal scores
  - To compute normal scores we take expected values of ordered observations from a sample of size n that is normally distributed N(0,1).
  - When we then compare these "normal scores" to the actual y values on a graph, if the data were normal, we will see our straight line.



Normal Probability Plots

Example: height example from book p.134-135

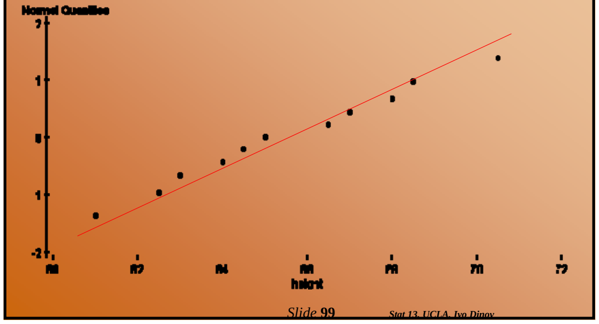
Suppose we have the height for 11 women.

height (in)	Nscore
61.0	-1.59322
62.5	-1.06056
63.0	-0.72791
64.0	-0.46149
64.5	-0.22469
65.0	0.00000
66.5	0.22469
67.0	0.46149
68.0	0.72791
68.5	1.06056
70.5	1.59322

Calculated using SOCR, slightly different than formula from text.

Normal Probability Plots

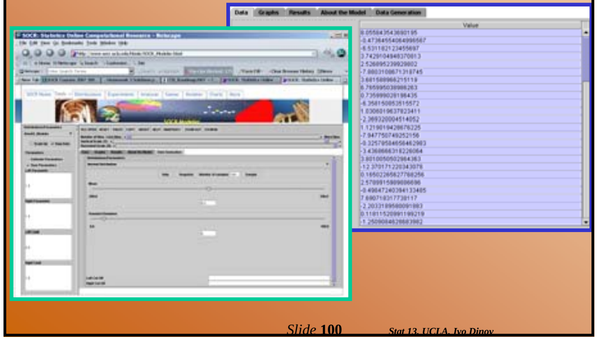
Example (cont'): Normal probability plot



Normal Probability Plots - Simulation

Example: Random Sampling from Normal (0,5): Raw Sample + QQPlot

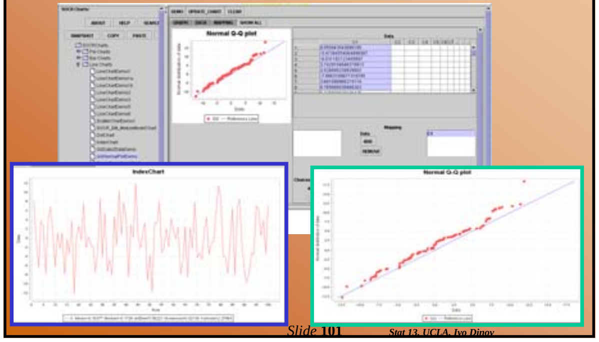
http://www.socr.ucla.edu/htmls/SOCR_Modeler.html, **Data Generation**



Normal Probability Plots - Simulation

Example: Random Sampling from Normal (0,5): 100 Raw Sample + Graphs

http://www.socr.ucla.edu/htmls/SOCR_Charts.html, **Index & QQ Plots**



Normal Probability Plots - Simulation

Example: Random Sampling from Normal (0,5): 100 Raw Sample + Graphs

http://www.socr.ucla.edu/htmls/SOCR_Charts.html, **Histogram Plot**