Announcements:
- Midterm exam keys on web.
- *No* grade disputes now. See syllabus for information.
- Grades are curved at end of quarter, not now.
- Material gets harder from here on! Practice problems with answers will be posted on website for Chapters 7 to 9 as we cover them.
- Friday discussion this week *is* for credit.
- Please complete survey by Friday. (You should have received email about it.)

Homework (due Monday, Feb 11)
Chapter 7: #12, 22, 30, 34

Chapter 7
Probability

Today: 7.1 to 7.3, start 7.4

Wed: 7.4, 7.5; Skip 7.6

Fri: 8.1 to 8.3

Next Mon: Section 7.7 and supplemental material on intuition and probability

Random Circumstance

A *random circumstance* is one in which the *outcome* is *unpredictable*.

Could be unpredictable because:
- It *isn't determined* yet

  or
- We have *incomplete knowledge*

Example of a random circumstance

- Sex of an unborn child is unpredictable, so it is a random circumstance.
- We can talk about the *probability* that a child will be a boy. What does that mean?

Depends on why it is unpredictable:
- Before conception:
  - It *isn't determined* yet
- After conception:
  - We have *incomplete knowledge*

Goals in this chapter

- Understand what is meant by "probability"
- Assign probabilities to possible outcomes of random circumstances.
- Learn how to use probability wisely

What does probability mean??

What does it mean to say:
- *The probability of rain tomorrow is .2.*
- *The probability that a coin toss will land heads up is ½.*
- *The probability that humans will survive to the year 3000 is .8.*

Is the word "probability" interpreted the same way in all of these?

Two basic interpretations of probability (Summary box, p. 226)

Interpretation 1: Relative frequency

- Used for *repeatable* circumstances
- The *probability* of an outcome is the *proportion* of time that outcome does or will happen *in the long run.*

Interpretation 2: Personal probability (subjective)

- Most useful for *one-time events*
- The *probability* of an outcome is *the degree to which* an individual *believes* it will happen.

Two methods for determining relative frequency probability

1. **Make an assumption** about the physical world *or*
2. **Observe** the *relative frequency* of an outcome over many repetitions. "Repetitions" can be:
   a. Over *time*, such as how often a flight is late
   b. Over *individuals*, by measuring a representative sample from a larger population and observing the *relative frequency* of an outcome or category of interest, such as the probability that a randomly selected person is left-handed.

How relative frequency probabilities are determined, Method 1:

Make an assumption about the physical world. Examples:

- Flip a coin, **probability** it lands heads = ½.

We *assume* the coin is balanced in such a way that it is equally likely to land on either side.

- Draw a card from a shuffled, regular deck of cards, **probability** of getting a heart = ¼

We *assume* all cards are equally likely to be drawn

How relative frequency probabilities are determined, Method 2a (over time):

Observe the *relative frequency* of an outcome over many repetitions (*long run relative frequency)*

Probability that a flight will be on time:

- According to United Airline's website, the probability that Flight 1444 from SNA to Chicago will be *on time* (within 15 minutes of stated arrival time) is 0.71. Probability > 30 minutes late is 0.23.
- Based on *observing* this particular flight over many, many days; it was on time on 71% of those days. The *relative frequency* on time = 0.71

How relative frequency probabilities are determined, Method 2b (over individuals):

Measure a representative sample and observe the *relative frequency* of possible outcomes or categories for the sample

Probability that an adult female in the US believes in life after death is about .789. [It's .72 for males]

- Based on a national survey that asked 517 women if they believe in life after death
- 408 said yes
- Relative frequency is 408/517 = .789

Note about methods 2a and 2b:

Usually these are just *estimates* of the true probability, based on *n* repetitions or *n* people in the sample. So, they have an associated *margin of error* with them.

Example:

Probability that an adult female in the US believes in life after death = .789, based on n = 517 women.

Margin of error is $\frac{1}{\sqrt{517}}$ = .044.

Personal Probability: Especially useful for one-time only events

- The *personal probability* of an outcome is *the degree to which* an individual *believes* it will happen.
- Could be different for two different people.

Personal Probability Examples

- What is the probability that *you* will get a B in this class? We can't base the answer on relative frequency!
- LA Times, 10/8/09, scientists have determined that the probability of the asteroid Apophis hitting the earth in 2036 is 1 in 250,000. In 2004, they thought the probability was .027 that it would hit earth in 2029. "Expert opinion" has been updated.

Notes about personal probability

- Sometimes the individual is an expert, and combines subjective information with data and models, such as in assessing the probability of a magnitude 7 or higher earthquake in our area in the next 10 years.
- Sometime there is overlap in these methods, such as determining probability of rain tomorrow – uses similar pasts.

Summary of interpretations

- Interpretation 1: Relative frequency
  - Method 1: Physical assumption
  - Method 2a: Observe long run over time
  - Method 2b: Observe proportion of a sample
- Interpretation 2: Personal probability

Clicker questions *not* for credit!

The probability that the winning "Daily 3" lottery number tomorrow evening will be 777 is 1/1000.

Which interpretation is best?

A. Rel. freq. based on physical assumption
B. Rel. freq. based on long run over time
C. Rel. freq. based on representative sample
D. Personal probability

Clicker questions *not* for credit!

The probability that the San Francisco 49ers will win the Super Bowl next year is .15.

Which interpretation is best?

A. Rel. freq. based on physical assumption
B. Rel. freq. based on long run over time
C. Rel. freq. based on representative sample
D. Personal probability

Clicker questions *not* for credit!

Based on the past, the probability that a live single birth in the U.S. will be a boy is .512.

Which interpretation is best?

A. Rel. freq. based on physical assumption
B. Rel. freq. based on long run over time
C. Rel. freq. based on representative sample
D. Personal probability

Section 7.3: Probability definitions and relationships

We will use 2 examples to illustrate:

1. Daily 3 lottery winning number.
   Outcome = 3 digit number, from 000 to 999
2. Choice of 3 parking lots on campus. You try Lot 1, if full then Lot 2, if full then Lot 3.
   Lot 1 works 30% of the time, you aren't late
   Lot 2 works 50% of the time, you are late
   Lot 3 always works, so you park there 20% of the time, and when you do, you are very late!

Definitions of *Sample space* and *Simple event*

The sample space S for a random circumstance is the collection of unique, non-overlapping outcomes.

A simple event is *one outcome* in the sample space.

Ex 1: S = {000, 001, 002, …, 999}
One simple event: 659
There are 1000 simple events.

Ex 2: S = {Lot 1, Lot 2, Lot 3}
One simple event: Lot 2
There are 3 simple events.

Definition And Notation For *Events*

- Event: *any subset* of the sample space.
- Compound event: More than one simple event.

Notation for events: A, B, C, etc.

Ex 1: A = *winning number begins with 00*
A = {000, 001, 002, 003,…, 009}
B = *all same digits* = {000, 111, …, 999}

Ex 2: A = *late for class* = {Lot 2, Lot 3}

Probability of Events: Notation and Rules (for all interpretations and methods)

Notation: P(A) = probability of the event A

Rules: Probabilities are always assigned to *simple events* such that these 2 rules must hold:

1. $0 \le P(A) \le 1$ for each simple event A
2. The *sum* of probabilities of *all* simple events in the sample space is 1.

The probability of *any* event is the sum of probabilities for the simple events that are part of it.

Special Case: Assigning Probabilities to *Equally Likely* Simple Events

Equally Likely Simple Events
If there are *k* simple events in the sample space and they are all equally likely, then the probability of the occurrence of each one is 1/*k*.

Example:
Roll a fair die with numbers 1 to 6, so *k* = 6.
S = {1, 2, 3, 4, 5, 6}, each with probability 1/6.

Example: California Daily 3 Lottery

Random Circumstance:
A three-digit winning lottery number is selected.

Sample Space:
{000, 001, 002, 003, . . . , 997, 998, 999}.
There are 1000 simple events.

Physical assumption: all three-digit numbers are equally likely.

Probabilities for Simple Event: Probability that any specific three-digit number is a winner is 1/1000.

California Daily 3 Lottery, continued

Examples of Complex Events:

- **Event A** = last digit is a 9 = {009, 019, . . . , 999}.
- ***P*(A) = 100/1000 = 1/10** (there are 100 simple events)
- **Event B** = three digits are all the same {000, 111, 222, 333, 444, 555, 666, 777, 888, 999}.
- ***P*(B) = 10/1000 = 1/100** (there are 10 simple events)

Example 2: Simple events are *not* equally likely

Simple Event	*Probability*
Park in Lot 1	.30
Park in Lot 2	.50
Park in Lot 3	.20

Note that these sum to 1

Event A = late for class = {Lot 2, Lot 3}
P(A) = .50 + .20 = .70

Probability in daily language:

People express probabilities as percents, proportions, probabilities. These are all equivalent:

- United flight 1444 from SNA to Chicago arrives on time 71 percent of the time.
- The proportion of time United flight 436 arrives on time is .71.
- The probability that United flight 436 will arrive on time is .71.

RELATIONSHIPS BETWEEN EVENTS

- Defined for events in the *same random circumstance only:*
  - Complement of an event
    - The event doesn't happen
  - Mutually exclusive events = disjoint events
    - Two events don't overlap
- Defined for events in the same *or* different random circumstances:
  - Independent events
  - Conditional events

Definition and Rule 1 (apply to events in the *same* random circumstance):

Definition: One event is the **complement** of another event if:

- They have no simple events in common, AND
- They cover all simple events

Notation: The complement of A is $\mathbf{A^C}$

RULE 1: $P(A^C) = 1 - P(A)$

Ex 2: *Random circumstance* = parking on one day
A = late for class, A^C = on time
P(A) = .70, so $P(A^C) = 1 - .70 = .30$

Complementary Events, Continued

Rule 1: $P(A) + P(A^C) = 1$

Example: *Daily 3 Lottery*

A = player buying single ticket wins
A^C = player does not win
***P*(A) = 1/1000** so ***P*(A^C) = 999/1000**

Example: *On-time flights*

A = flight you are taking will be on time
A^C = flight will be late
Suppose *P*(A) = .81, then ***P*(A^C) = 1 – .81 = .19.**

Mutually Exclusive Events

Two events are **mutually exclusive**, or equivalently **disjoint**, if they do not contain *any* of the same simple events (outcomes). (Applies in *same random circumstance*.)

Example: Daily 3 Lottery
A = all three digits are the same (000, 111, etc.)
B = the number starts with 13 (130, 131, etc.)

The events A and B are mutually exclusive (disjoint), but they are not complementary.
(No overlap, but *don't* cover all possibilities.)

Independent and Dependent Events

- Two events are **independent** of each other if knowing that one will occur (or has occurred) *does not change* the probability that the other occurs.
- Two events are **dependent** if knowing that one will occur (or has occurred) *changes* the probability that the other occurs.

The definitions can apply *either* …
to events *within the same random circumstance* or
to events *from two separate random circumstances.*

EXAMPLE OF INDEPENDENT EVENTS

- Events in the *same random circumstance:*
  Daily 3 lottery on the *same* draw
  A = *first* digit is 0
  B = *last* digit is 9 P(B) = 1/10
  Knowing first digit is 0, P(B) is *still* 1/10.
- Events in *different random circumstances*:
  Daily 3 lottery on *different* draws
  A = *today's* winning number is 191
  B = *tomorrow's* winning number is 875
  Knowing today's # was 191, P(B) is *still* 1/1000

Mutually exclusive or independent?

- If two events are mutually exclusive (disjoint), they *cannot* be independent:
  - If *disjoint*, then knowing A occurs means P(B) = 0
  - In *independent*, knowing A occurs gives no knowledge of P(B)

Example of mutually exclusive (disjoint):
A = *today's* winning number is 191,
B = *today's* winning number is 875

Example of independent:
A = *today's* winning number is 191
B = *tomorrow's* winning number is 875

Conditional Probabilities

The conditional probability of the event B, given that the event A has occurred or will occur, is the long-run relative frequency with which event B occurs when circumstances are such that A also occurs; written as ***P*(B|A).**

P(B) = *unconditional* probability event B occurs.

P(B|A) = "probability of B given A"
= *conditional* probability event B occurs *given that we know A has occurred or will occur*.

EXAMPLE OF CONDITIONAL PROBABILITY

TABLE 2.3 Nighttime Lighting in Infancy and Eyesight

Slept with:	No Myopia	Myopia	High Myopia	Total
Darkness	155 (90%)	15 (9%)	2 (1%)	172
Nightlight	153 (66%)	72 (31%)	7 (3%)	232
Full Light	34 (45%)	36 (48%)	5 (7%)	75
Total	342 (71%)	123 (26%)	14 (3%)	479

Random circumstance: Observe one randomly selected child

A = child slept in darkness as infant [Use "total" column.]

P(A) = 172/479 = .36

B = child did not develop myopia [Use "total" row]

P(B) = 342/479 = **.71**

P(B|A) = P(no myopia | slept in dark) [Use "darkness" row]

= 155/172 = **.90** ≠ **P(B)**

NOTES ABOUT CONDITIONAL PROBABILITY

1. P(B|A) generally does *not* equal P(B).
2. P(B|A) = P(B) *only* when A and B are independent events
3. In Chapter 4, we were actually testing if two types of events were *independent.*
4. *Conditional* probabilities are similar to *row* and *column* proportions (percents) in contingency tables. Myopia example on previous page: P(no myopia | dark) is the *row* proportion for no myopia.

Homework (due Monday, Feb 11)

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