Register for the midterm
and take the exam at CBTF

No Wednesday class next week!

Midterm Info

- Closed book exam at CBTF; no books, notes, laptops, phones…
- Calculators (not on smartphones) are provided by CBTF
- The following two printouts and lecture slides will be provided

STANDARD NORMAL DISTRIBUTION: Table Values Represent AREA to the LEFT of the Z score.

Z	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
0.0	.50000	.50399	.50798	.51197	.51595	.51994	.52392	.52790	.53188	.53586
0.1	.53983	.54380	.54776	.55172	.55567	.55962	.56356	.56749	.57142	.57535
0.2	.57926	.58317	.58706	.59095	.59483	.59871	.60257	.60642	.61026	.61409
0.3	.61791	.62172	.62552	.62930	.63307	.63683	.64058	.64431	.64803	.65173
0.4	.65542	.65910	.66276	.66640	.67003	.67364	.67724	.68082	.68439	.68793
0.5	.69146	.69497	.69847	.70194	.70540	.70884	.71226	.71566	.71904	.72240
0.6	.72575	.72907	.73237	.73565	.73891	.74215	.74537	.74857	.75175	.75490
0.7	.75804	.76115	.76424	.76730	.77035	.77337	.77637	.77935	.78230	.78524
0.8	.78814	.79103	.79389	.79673	.79955	.80234	.80511	.80785	.81057	.81327
0.9	.81594	.81859	.82121	.82381	.82639	.82894	.83147	.83398	.83646	.83891
1.0	.84134	.84375	.84614	.84849	.85083	.85314	.85543	.85769	.85993	.86214
1.1	.86433	.86650	.86864	.87076	.87286	.87493	.87698	.87900	.88100	.88298
1.2	.88493	.88686	.88877	.89065	.89251	.89435	.89617	.89796	.89973	.90147
1.3	.90320	.90490	.90658	.90824	.90988	.91149	.91309	.91466	.91621	.91774
1.4	.91924	.92073	.92220	.92364	.92507	.92647	.92785	.92922	.93056	.93189
1.5	.93319	.93448	.93574	.93699	.93822	.93943	.94062	.94179	.94295	.94408
1.6	.94520	.94630	.94738	.94845	.94950	.95053	.95154	.95254	.95352	.95449
1.7	.95543	.95637	.95728	.95818	.95907	.95994	.96080	.96164	.96246	.96327
1.8	.96407	.96485	.96562	.96638	.96712	.96784	.96856	.96926	.96995	.97062
1.9	.97128	.97193	.97257	.97320	.97381	.97441	.97500	.97558	.97615	.97670
2.0	.97725	.97778	.97831	.97882	.97932	.97982	.98030	.98077	.98124	.98169
2.1	.98214	.98257	.98300	.98341	.98382	.98422	.98461	.98500	.98537	.98574
2.2	.98610	.98645	.98679	.98713	.98745	.98778	.98809	.98840	.98870	.98899
2.3	.98928	.98956	.98983	.99010	.99036	.99061	.99086	.99111	.99134	.99158
2.4	.99180	.99202	.99224	.99245	.99266	.99286	.99305	.99324	.99343	.99361
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2.6	.99534	.99547	.99560	.99573	.99585	.99598	.99609	.99621	.99632	.99643
2.7	.99653	.99664	.99674	.99683	.99693	.99702	.99711	.99720	.99728	.99736
2.8	.99744	.99752	.99760	.99767	.99774	.99781	.99788	.99795	.99801	.99807
2.9	.99813	.99819	.99825	.99831	.99836	.99841	.99846	.99851	.99856	.99861
3.0	.99865	.99869	.99874	.99878	.99882	.99886	.99889	.99893	.99896	.99900
3.1	.99903	.99906	.99910	.99913	.99916	.99918	.99921	.99924	.99926	.99929
3.2	.99931	.99934	.99936	.99938	.99940	.99942	.99944	.99946	.99948	.99950
3.3	.99952	.99953	.99955	.99957	.99958	.99960	.99961	.99962	.99964	.99965
3.4	.99966	.99968	.99969	.99970	.99971	.99972	.99973	.99974	.99975	.99976
3.5	.99977	.99978	.99978	.99979	.99980	.99981	.99981	.99982	.99983	.99983
3.6	.99984	.99985	.99985	.99986	.99986	.99987	.99987	.99988	.99988	.99989
3.7	.99989	.99990	.99990	.99990	.99991	.99991	.99992	.99992	.99992	.99992
3.8	.99993	.99993	.99993	.99994	.99994	.99994	.99994	.99995	.99995	.99995
3.9	.99995	.99995	.99996	.99996	.99996	.99996	.99996	.99996	.99997	.99997

Name	Probability Distribution	Mean	Variance	Section in Book
Discrete				
Uniform	$\frac{1}{n}, a \le b$	$\frac{(b+a)}{2}$	$\frac{(b-a+1)^2-1}{12}$	3-5
Binomial	$\binom{n}{x}p^x(1-p)^{n-x}$, $x = 0, 1, \ldots, n, 0 \le p \le 1$	np	$np(1-p)$	3-6
Geometric	$(1-p)^{x-1}p$, $x = 1, 2, \ldots, 0 \le p \le 1$	$1/p$	$(1-p)/p^2$	3-7.1
Negative binomial	$\binom{x-1}{r-1}(1-p)^{x-r}p^r$ $x = r, r+1, r+2, \ldots, 0 \le p \le 1$	r/p	$r(1-p)/p^2$	3-7.2
Hypergeometric	$\frac{\binom{K}{x}\binom{N-K}{n-x}}{\binom{N}{n}}$ $x = \max(0, n-N+K), 1, \ldots$ $\min(K, n), K \le N, n \le N$	np, where $p = \frac{K}{N}$	$np(1-p)\left(\frac{N-n}{N-1}\right)$	3-8
Poisson	$\frac{e^{-\lambda}\lambda^x}{x!}, x = 0, 1, 2, \ldots, 0 < \lambda$	λ	λ	3-9
Continuous				
Uniform	$\frac{1}{b-a}, a \le x \le b$	$\frac{(b+a)}{2}$	$\frac{(b-a)^2}{12}$	4-5
Normal	$\frac{1}{\sigma\sqrt{2\pi}}e^{-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2}$ $-\infty < x < \infty, -\infty < \mu < \infty, 0 < \sigma$	μ	σ^2	4-6
Exponential	$\lambda e^{-\lambda x}, 0 \le x, 0 < \lambda$	$1/\lambda$	$1/\lambda^2$	4-8
Erlang	$\frac{\lambda^r x^{r-1}e^{-\lambda x}}{(r-1)!}, 0 < x, r = 1, 2, \ldots$	r/λ	r/λ^2	4-9.1
Gamma	$\frac{\lambda^r x^{r-1}e^{-\lambda x}}{\Gamma(r)}, 0 < x, 0 < r, 0 < \lambda$	r/λ	r/λ^2	4-9.2

What is included in the midterm?

- Continuous Random Variables
  - Uniform
  - Constant rate process
  - Exponential, Gamma
  - Gaussian, Log-normal
- Joint/Marginal/Conditional probabilities, correlations and covariations
- Review questions connecting to the material covered in Midterm 1
- No Matlab exercises (since no computers)

New rules

- You have 4 (not 3) tries for each question
  - First attempt 100% of the points
  - Second attempt 100% of the points
  - Third attempt ~75% of the points
  - Fourth attempt ~50% of the points
- If you get an error after the first attempt
  - Think hard where could you were wrong before resubmitting
- Many questions with a), b), c) require a) and b) to be solved correctly in order for c) to be solved
  - Look at what went wrong in a) and b) first. Your c) idea may be fine

Continuous Probability Distributions

2. (8 points) The length of stay at a specific emergency department in Phoenix, Arizona, in 2009 had a mean of 4.6 hours with a standard deviation of 2.9. Assume that the length of stay is normally distributed.

(A) (4 points) What is the probability of a length of stay greater than 10 hours?

(B) (4 points) How long does one have to stay in this emergency room to know that approximately 25% of all visits last even longer?

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3.6	.99984	.99985	.99985	.99986	.99986	.99987	.99987	.99988	.99988	.99989
3.7	.99989	.99990	.99990	.99990	.99991	.99991	.99992	.99992	.99992	.99992
3.8	.99993	.99993	.99993	.99994	.99994	.99994	.99994	.99995	.99995	.99995
3.9	.99995	.99995	.99996	.99996	.99996	.99996	.99996	.99996	.99997	.99997

2. (8 points) The length of stay at a specific emergency department in Phoenix, Arizona, in 2009 had a mean of 4.6 hours with a standard deviation of 2.9. Assume that the length of stay is normally distributed.

(A) (4 points) What is the probability of a length of stay greater than 10 hours?

Answer: (10-4.6)/2.9=1.86 Using table one finds Prob=1-0.9687=0.0313

(B) (4 points) How long does one have to stay in this emergency room to know that approximately 25% of all visits last even longer?

Answer: Using table one finds P(Z<0.67)=0.75 meaning it is 4.6+2.9*0.67=6.543

1. **(8 points)** The expression level of a *TP53* tumor suppressor gene in a randomly selected cell is normally distributed with mean $\mu = 20$, and standard deviation $\sigma = 8$.

   (A)(4 points) What is the probability that the expression level in a given cell will be between 24 and 16?

   (B)(4 points) How many cells does one have to sample (on average) until there will be exactly 2 cells with such "close to average" *TP53* expression?

1. **(8 points)** The expression level of a *TP53* tumor suppressor gene in a randomly selected cell is normally distributed with mean $\mu = 20$, and standard deviation $\sigma = 8$.

(A)(4 points) What is the probability that the expression level in a given cell will be between 24 and 16?

Answer: Using table one finds Prob(Z<0.5)=0.6914. Thus the answer is 0.6914-(1-0.6914)=0.3829

(B) (4 points) On average, how many cells does one have to sample until there will be exactly 2 cells with such "close to average" *TP53* expression?

Answer: Using the negative binomial distribution one gets 2./0.3829=5.22

1. (6 points) There are about 1000 ribosomes in E. coli cell. Each ribosome generates proteins at a rate of 12 amino acids/sec. An average protein has 300 amino acids.
http://bionumbers.hms.harvard.edu/bionumber.aspx?&id=107785&ver=3&trm=ribosome%20translation%20rate

(a) Calculate the rate λ at which all ribosomes in the cell combined crank up the proteins

(b) If one observes the cell during 0.1 seconds what is the probability that at least one new protein will be produced?

(c) That exactly 4 proteins will be produced?

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(a) Calculate the rate λ at which all ribosomes in the cell combined crank up the proteins

Answer: $12 \times \frac{1000}{300} = 40$ proteins/sec

(b) If one observes the cell during 0.1 seconds what is the probability that at least one new protein will be produced?

Answer: On average, there are 4 proteins that are produced during the time window of 0.1 sec.
$P(X \geq 1) = 1 - P(X = 0) = 1 - e^{-4} = 0.9817$

(c) That exactly 4 proteins will be produced?

Answer: $P(X = 4) = \frac{4^4 e^{-4}}{4!} = 0.1954$

Joint Probability Distributions

1. **(20 points)** The joint probability mass function of discrete random variables X and Y taking values x = 1, 2, 3 and y = 1, 2, 3, respectively, is given by $f_{XY}(x, y) = c^*(x + y)$. Determine the following:
   a) **(2 points)** Find c
   b) **(2 points)** Find probability of the event, where X = 1 and Y < 3
   c) **(2 points)** Find marginal probability $P_Y(Y = 2)$
   d) **(2 points)** Find marginal probability distribution of the random variable X
   e) **(2 points)** Find E(X), E(Y), V(X), and V(Y)
   f) **(2 points)** Find conditional probability distribution of Y given that X = 1
   g) **(2 points)** Conditional probability distribution of X given that Y = 2
   h) **(2 points)** Are X and Y independent?
   i) **(2 points)** What is the covariance for X and Y?
   j) **(2 points)** What is the correlation for X and Y?

1. **(20 points)** The joint probability mass function of discrete random variables X and Y taking values x = 1, 2, 3 and y = 1, 2, 3, respectively, is given by $f_{XY}(x, y) = c*(x + y)$. Determine the following:

a) **(2 points)** Find c

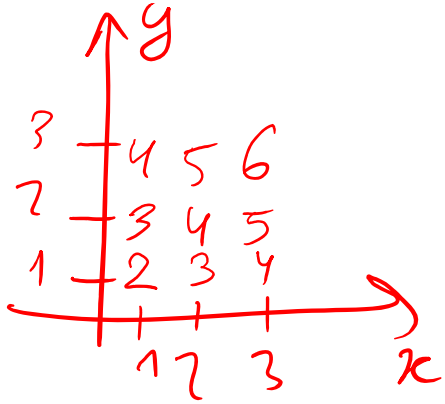
b) **(2 points)** Find probability of the event, where X = 1 and Y < 3

c) **(2 points)** Find marginal probability $P_Y(Y = 2)$

f) **(2 points)** Find conditional probability distribution of Y given that X = 1

(a) $1 = c \cdot (2 + 3 + 4 + 3 + 4 + 5 + 4 + 5 + 6)$

$c = 1/36$



$\times c$

(b) $P(X=1, Y<3) = \frac{2+3}{36} = \frac{5}{36}$

(c) $P_Y(Y=2) = \frac{3+4+5}{36} = \frac{12}{36} = \frac{1}{3}$

(f) $P(Y=2 \mid X=1) = \frac{P(Y=2, X=1)}{P_X(X=1)} = \frac{3/36}{(2+3+4)/36} = \frac{1}{3}$

1. **(20 points)** The joint probability mass function of discrete random variables X and Y taking values x = 1, 2, 3 and y = 1, 2, 3, respectively, is given by a formula $f_{XY}(x, y) = c*(x + y)$. Determine the following:

a) **(2 points)** Find c

Answer: $\sum_R f(x,y) = c*(2+3+4+3+4+5+4+5+6) = 1$, c*36 = 1. Thus, c = 1/36

b) **(2 points)** Find probability of the event where X = 1 and Y < 3

Answer: $P(X=1, Y<3) = f_{XY}(1,1) + f_{XY}(1,2) = \frac{1}{36}(2+3) = 5/36$

c) **(2 points)** Find marginal probability $P_Y(Y = 2)$

Answers: $P(Y=2) = f_{XY}(1,2) + f_{XY}(2,2) + f_{XY}(3,2) = \frac{1}{36}(3+4+5) = 1/3$

f) **(2 points)** Find conditional probability distribution of Y given that X = 1

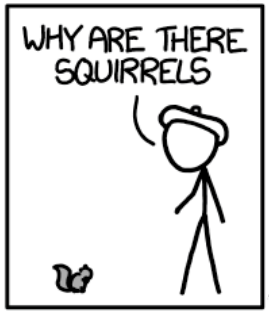
Answers: $f_{Y|X}(y) = \dfrac{f_{XY}(1,y)}{f_X(1)}$

y	$f_{Y\|X}(y)$
1	(2/36)/(1/4)=2/9
2	(3/36)/(1/4)=1/3
3	(4/36)/(1/4)=4/9

Credit: XKCD comics

QUESTIONS
FOUND IN GOOGLE AUTOCOMPLETE

WHY DO WHALES JUMP
WHY ARE WITCHES GREEN
WHY ARE THERE MIRRORS ABOVE BEDS
WHY DO I SAY UH
WHY IS SEA SALT BETTER
WHY ARE THERE TREES IN THE MIDDLE OF FIELDS
WHY IS THERE NOT A POKEMON MMO
WHY IS THERE LAUGHING IN TV SHOWS
WHY ARE THERE DOORS ON THE FREEWAY
WHY ARE THERE SO MANY SVCHOST.EXE RUNNING
WHY AREN'T THERE ANY COUNTRIES IN ANTARCTICA
WHY ARE THERE SCARY SOUNDS IN MINECRAFT
WHY IS THERE KICKING IN MY STOMACH
WHY ARE THERE TWO SLASHES AFTER HTTP
WHY ARE THERE CELEBRITIES
WHY DO SNAKES EXIST
WHY DO OYSTERS HAVE PEARLS
WHY ARE DUCKS CALLED DUCKS
WHY DO THEY CALL IT THE CLAP
WHY ARE KYLE AND CARTMAN FRIENDS
WHY IS THERE AN ARROW ON AANG'S HEAD
WHY ARE TEXT MESSAGES BLUE
WHY ARE THERE MUSTACHES ON CLOTHES
WHY ARE THERE MUSTACHES ON CARS
WHY ARE THERE MUSTACHES EVERYWHERE
WHY ARE THERE SO MANY BIRDS IN OHIO
WHY IS THERE SO MUCH RAIN IN OHIO
WHY IS OHIO WEATHER SO WEIRD
WHY ARE THERE MALE AND FEMALE BIKES
WHY ARE THERE BRIDESMAIDS
WHY DO DYING PEOPLE REACH UP
WHY AREN'T THERE VARICOSE ARTERIES
WHY ARE OLD KLINGONS DIFFERENT



WHY IS PROGRAMMING SO HARD
WHY IS THERE A 0 OHM RESISTOR
WHY DO AMERICANS HATE SOCCER
WHY DO RHYMES SOUND GOOD
WHY DO TREES DIE
WHY IS THERE NO SOUND ON CNN
WHY AREN'T POKEMON REAL
WHY AREN'T BULLETS SHARP
WHY DO DREAMS SEEM SO REAL

WHY ARE THERE TINY SPIDERS IN MY HOUSE
WHY DO SPIDERS COME INSIDE
WHY ARE THERE HUGE SPIDERS IN MY HOUSE
WHY ARE THERE LOTS OF SPIDERS IN MY HOUSE
WHY ARE THERE SPIDERS IN MY ROOM
WHY ARE THERE SO MANY SPIDERS IN MY ROOM
WHY DO SPIDER BITES ITCH
WHY IS DYING SO SCARY
WHY IS THERE NO GPS IN LAPTOPS
WHY DO KNEES CLICK
WHY AREN'T THERE E GRADES
WHY IS ISOLATION BAD
WHY DO BOYS LIKE ME
WHY DON'T BOYS LIKE ME
WHY IS THERE ALWAYS A JAVA UPDATE
WHY ARE THERE RED DOTS ON MY THIGHS
WHY IS LYING GOOD



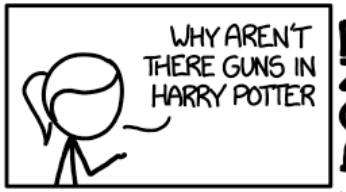
WHY ARE THERE SLAVES IN THE BIBLE
WHY DO TWINS HAVE DIFFERENT FINGERPRINTS
WHY ARE AMERICANS AFRAID OF DRAGONS
WHY IS HTTPS CROSSED OUT IN RED
WHY IS THERE A LINE THROUGH HTTPS
WHY IS THERE A RED LINE THROUGH HTTPS ON FACEBOOK
WHY IS HTTPS IMPORTANT



WHY ARE THERE SWARMS OF GNATS
WHY IS THERE PHLEGM
WHY ARE THERE SO MANY CROWS IN ROCHESTER, MN
WHY AREN'T ECONOMISTS RICH
WHY DO AMERICANS CALL IT SOCCER
WHY ARE MY EARS RINGING
WHY ARE THERE SO MANY AVENGERS
WHY ARE THE AVENGERS FIGHTING THE X MEN
WHY IS WOLVERINE NOT IN THE AVENGERS
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HW1 Problem 5

You enter a room with three arcade games. One game is rigged so that you always lose. The other two let you win with probability 0.2.

(a) If you play a game at random, what is the probability that you win?

(b) You play a game at random and lose. What is the probability that it was a fair game?

HW1 Problem 5

You enter a room with three arcade games. One game is rigged so that you always lose. The other two let you win with probability 0.2.

(a) If you play a game at random, what is the probability that you win?

Answer: $P(W) = 0.2 \cdot (2/3) + 0 \cdot (1/3) = 0.1333$

$P(W') = 0.8667$

(b) You play a game at random and lose. What is the probability that it is a fair game?

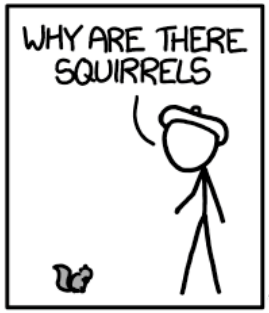
Answer: $P(F|W') = P(W'|F)P(F)/ P(W') =$

$0.8 \cdot (2/3)/0.8667 = 0.6154$

Credit: XKCD comics

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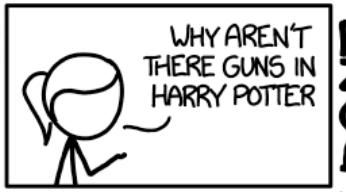
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HW3 Problem 6

Times between bus arrivals are exponential with mean 20 minutes. Steve and Andrew are late unless they board a bus by 8:50 am. Steve arrives at 8:00; Andrew arrives at a time uniform between 8:00 and 8:30. Each takes the first bus.

(a) What is the probability that Steve is late?

(b) What is the probability that Andrew is late?

(c) What is the probability that they take different buses?

HW3 Problem 6

Times between bus arrivals are exponential with mean 20 minutes. Steve and Andrew are late unless they board a bus by 8:50 am. Steve arrives at 8:00; Andrew arrives at a time uniform between 8:00 and 8:30. Each takes the first bus.

(a) What is the probability that Steve is late?

Answer: $P(T > 50) = e^{(-50/20)} = 0.08208$

(b) What is the probability that Andrew is late?

Answer: $(1/30)\int_0^{30} e^{(-(50-x)/20)}\, dx = 0.1905$

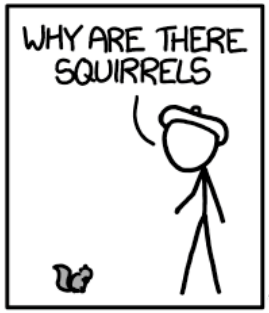
(c) What is the probability that they take different buses?

Answer: $1 - (1/30)\int_0^{30} e^{(-x/20)}\, dx = 0.4821$

Credit: XKCD comics

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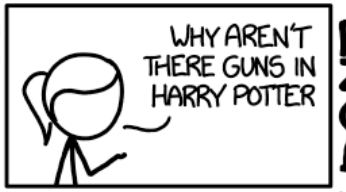
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I can show you how to solve any HW1-HW3 problem.

Which one do you choose?