



Modeling
Chris Piech
CS109, Stanford University

Midterm Tuesday July 23rd, 7pm

Where to Go

Building 300, room 300. Building 300 is part of main quad (the older buildings in the center of campus).



5 pages front and back of notes, closed book, closed calculator



Review

Last Week: Joint Distributions

Joint Distribution *noun*

The probability of a simultaneous assignment to ***all*** the random variables in a probabilistic model.

Eg:

$$P(X = x, Y = y)$$

$$f(X = x, Y = y)$$

$$P(X = x, Y = y, \dots, Z = z)$$

Monday, Wednesday: Inference

Inference *noun*

An updated belief about a random variable (or multiple) based on conditional knowledge regarding another random variable (or multiple) in a probabilistic model.

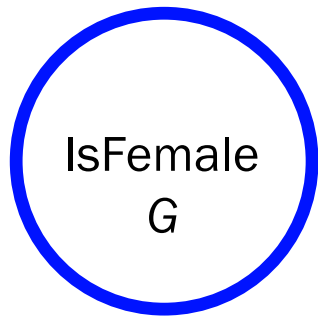
TLDR: conditional probability with random variables.

Inference with Continuous

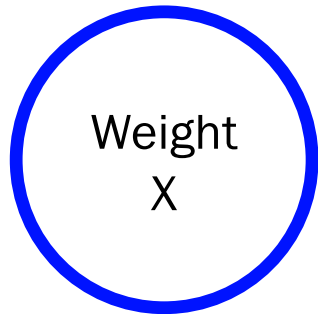
Q: At birth, girl elephant weights are distributed as a Gaussian with mean = 160kg, std = 7kg. At birth, boy elephant weights are distributed as a Gaussian with mean = 165kg, std = 3kg. All you know about a newborn elephant is that it is 163kg. What is the probability that it is a girl?



Model Shown Graphically



$G = 1$ is $\text{Bern}(p = 0.5)$



$X | G = 1$ is $N(\mu = 160, \sigma^2 = 7^2)$

$X | G = 0$ is $N(\mu = 165, \sigma^2 = 3^2)$

Q: What is $P(G = 1 | X = 163)$

Harder when inferred random variable
is not a Bernoulli

Learning Goals

1. Perspective on the artform of how to design probabilistic models
2. How to calculate Correlations
3. Use and verify Independence with Random Variables



Lets talk about how to make a model

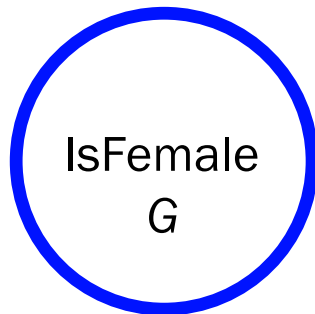
Model Version #1: Python That Outputs a **Joint** Sample



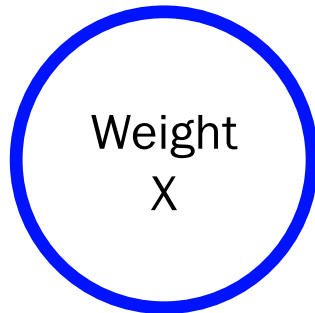
Sample Baby
Elephant

Sex: Female
Weight: 161kg

Model Version #2: Bayesian Network



$G = 1$ is $\text{Bern}(p = 0.5)$



$X | G = 1$ is $N(\mu = 160, \sigma^2 = 7^2)$

$X | G = 0$ is $N(\mu = 165, \sigma^2 = 3^2)$

Does this define the joint?

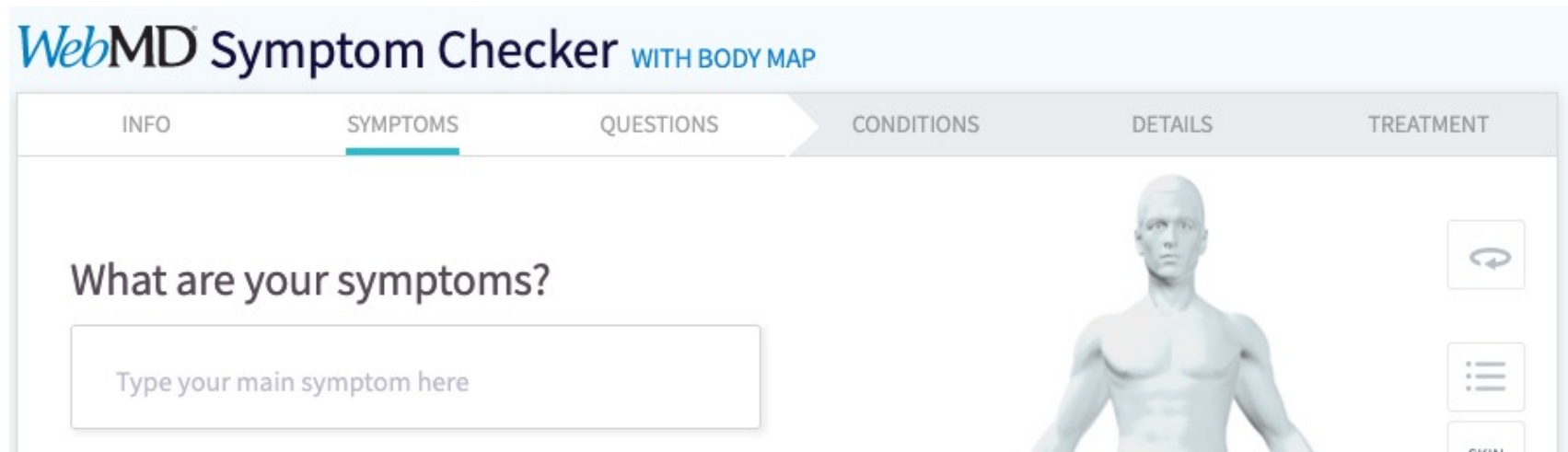
$$f(G = g, X = x)$$

$$= f(X = x | G = g)P(G = g)$$

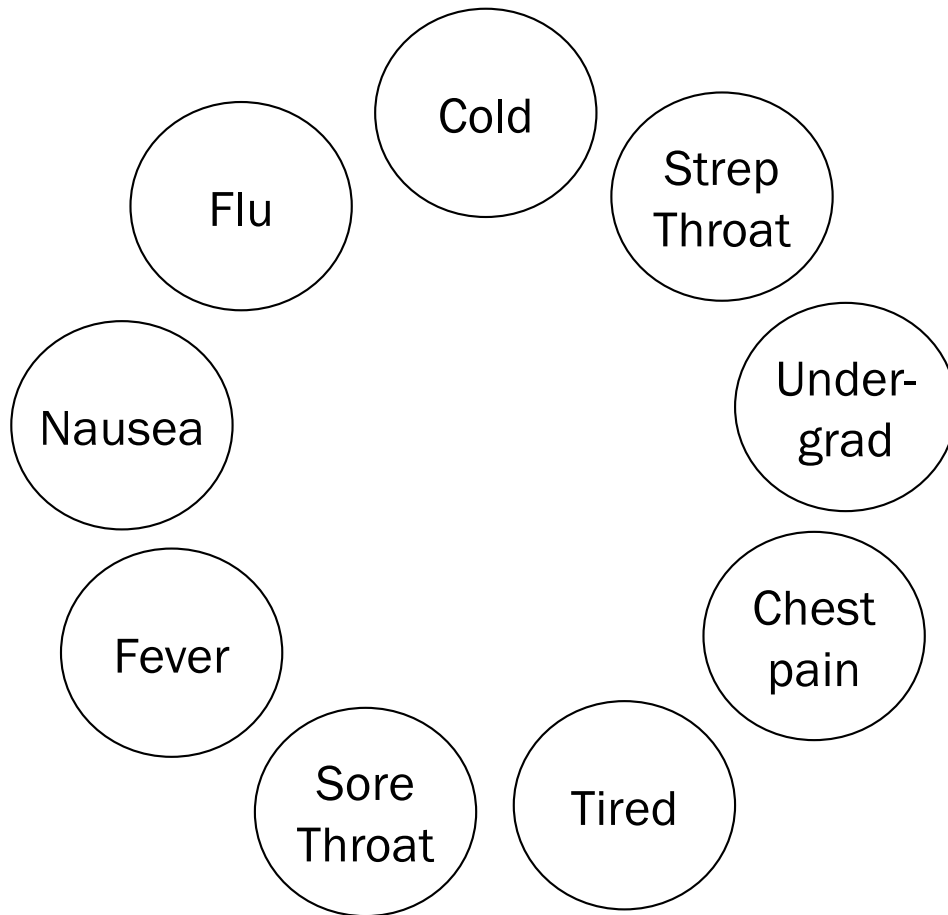
Why You Need a Model

*Web*MD[®]

Inference



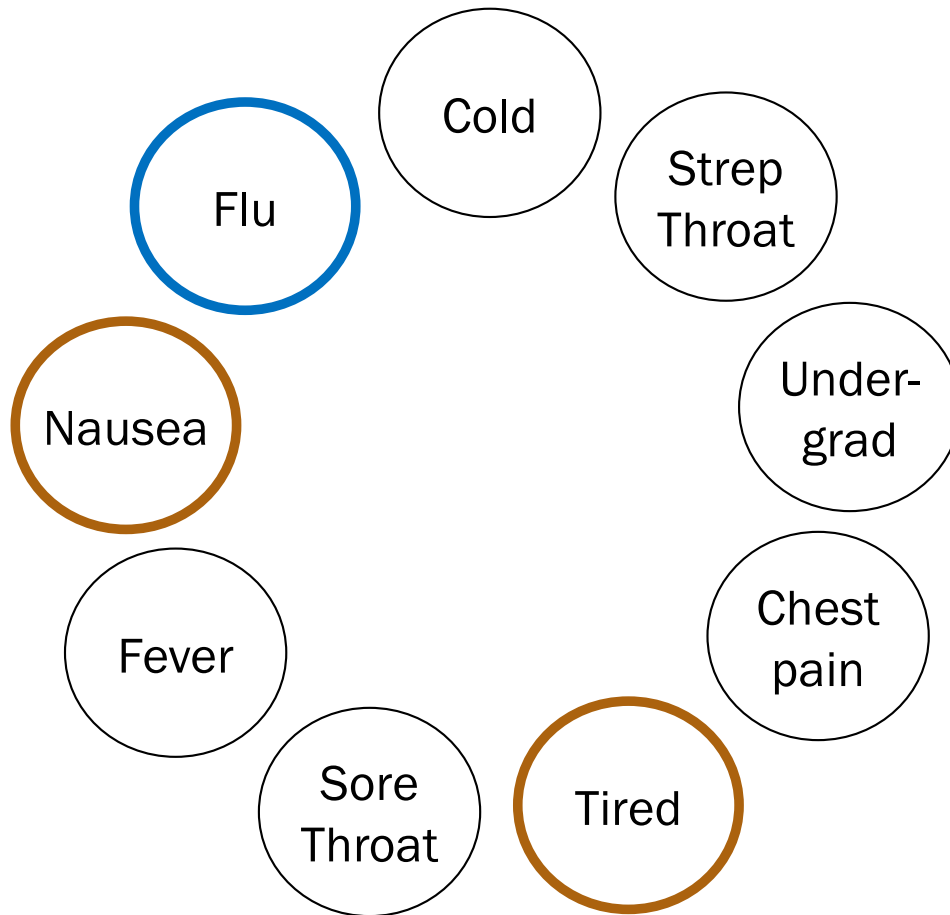
Inference



Inference question:

Given the values of some random variables, what are the conditional distributions of some other random variables?

Inference

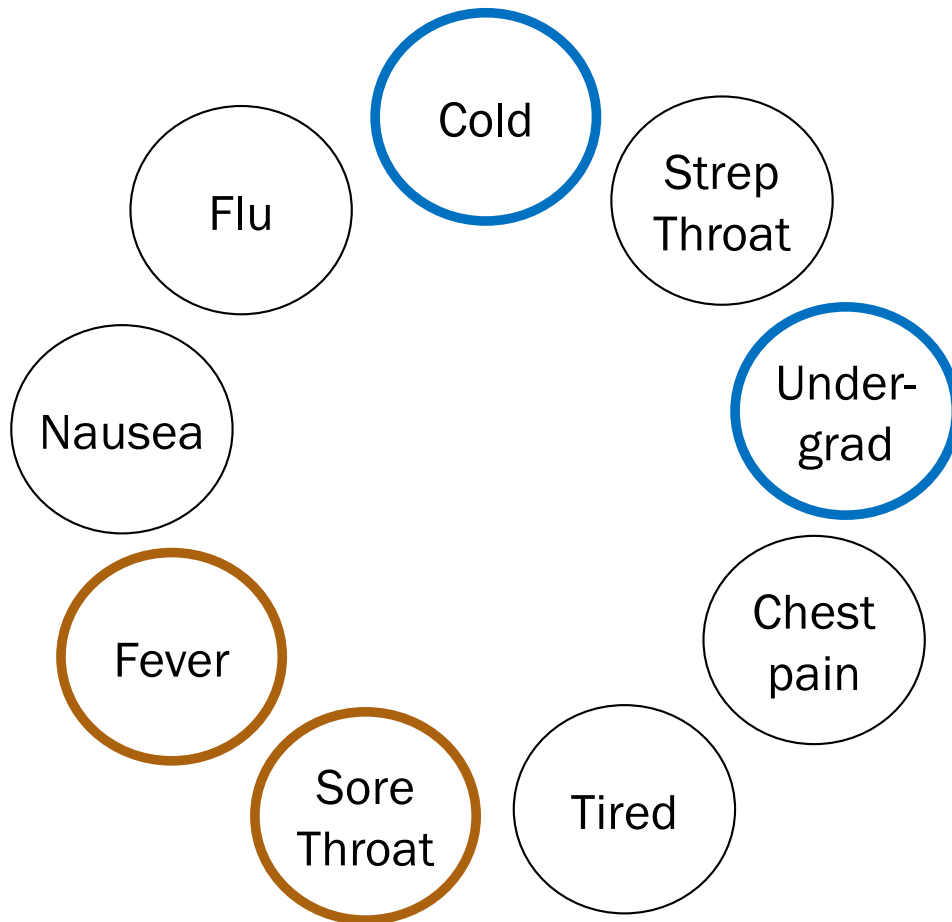


One inference question:

$$P(F = 1 | N = 1, T = 1)$$

$$= \frac{P(F = 1, N = 1, T = 1)}{P(N = 1, T = 1)}$$

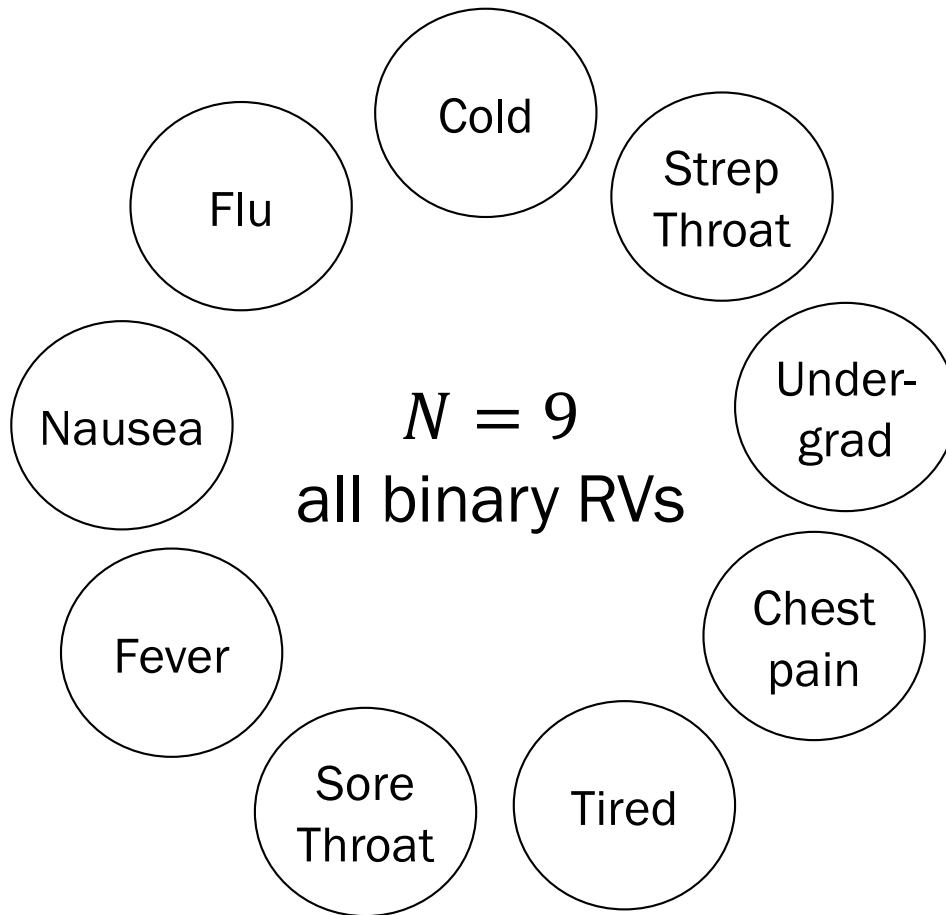
Inference



Another inference question:

$$P(C_o = 1, U = 1 | S = 0, F_e = 0) \\ = \frac{P(C_o = 1, U = 1, S = 0, F_e = 0)}{P(S = 0, F_e = 0)}$$

Inference



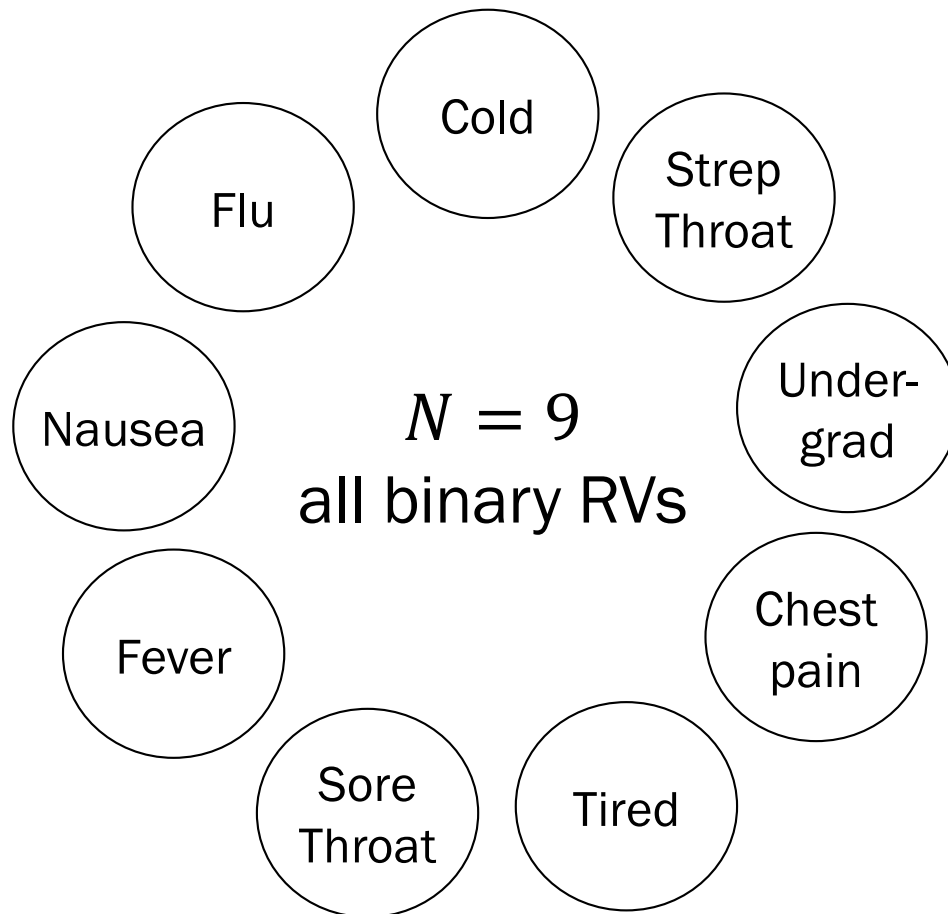
If we knew the **joint distribution**, we can answer all probabilistic inference questions.

What is the size of the joint probability table?

- A. 2^{N-1} entries
- B. N^2 entries
- C. 2^N entries
- D. None/other/don't know



Inference



If we knew the **joint distribution**, we can answer all probabilistic inference questions.

What is the size of the joint probability table?

- A. 2^{N-1} entries
- B. N^2 entries
- C. 2^N entries
- D. None/other/don't know

Naively specifying a joint distribution is, in general, intractable.



Bayesian Networks

A simpler WebMD

Flu

Under-grad

Fever

Tired

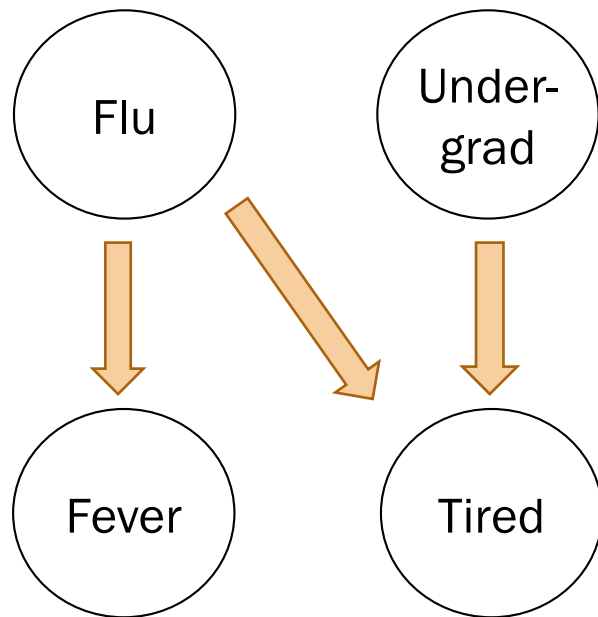
Great! Just specify $2^4 = 16$ joint probabilities...?

$$P(F_{lu} = a, F_{ev} = b, U = c, T = d)$$

What would a Stanford flu expert do?

Describe the joint distribution using causality!

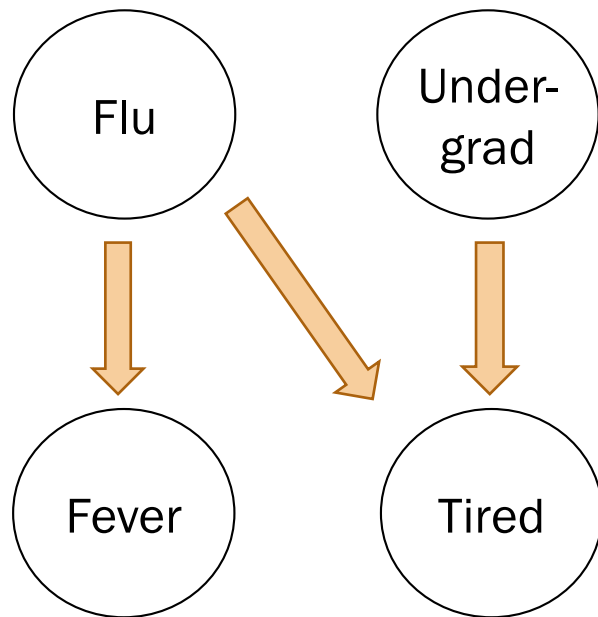
Constructing a Bayesian Network



What would a Stanford flu expert do?

- ✓ 1. Describe the joint distribution using causality.
2. Provide $P(\text{values}|\text{parents})$ for each random variable
3. Implicitly assumes independences.

Constructing a Bayesian Network



$$P(T = 1|F_{lu} = 0, U = 0)$$
$$P(T = 1|F_{lu} = 0, U = 1)$$
$$P(T = 1|F_{lu} = 1, U = 0)$$
$$P(T = 1|F_{lu} = 1, U = 1)$$

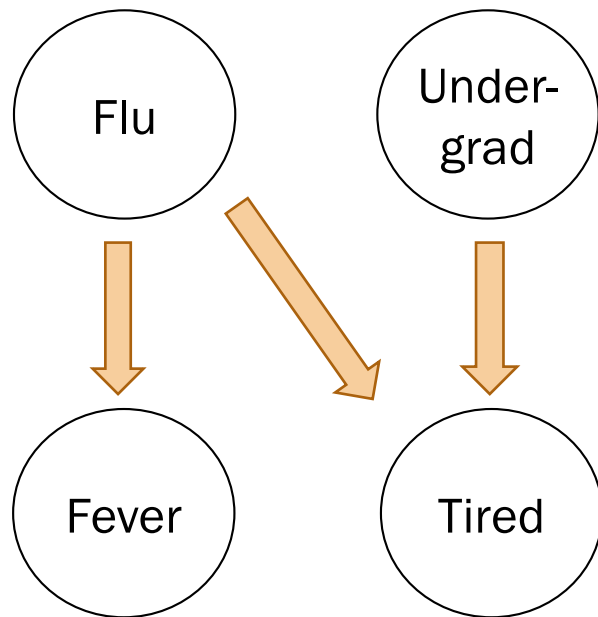
In a Bayesian Network,
Each random variable is caused by
its **parents**. Def $P(\text{node} \mid \text{parents})$

- Node: random variable
- Directed edge: causality

Examples:

- $P(F_{lu} = 1)$
- $P(U = 0)$
- $P(F_{ev} = 1|F_{lu} = 1), P(F_{ev} = 1|F_{lu} = 0)$
- $P(T = 1|F_{lu} = 0, U = 0) \dots$

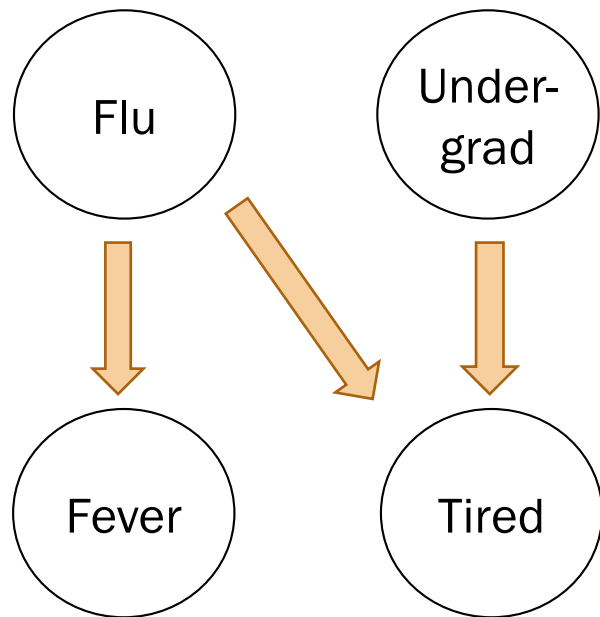
Constructing a Bayesian Network



What would a Stanford flu expert do?

- ✓ 1. Describe the joint distribution using causality.
- ✓ 2. Provide $P(\text{values}|\text{parents})$ for each random variable
- ✓ 3. Implicitly assumes independences.

Constructing a Bayesian Network

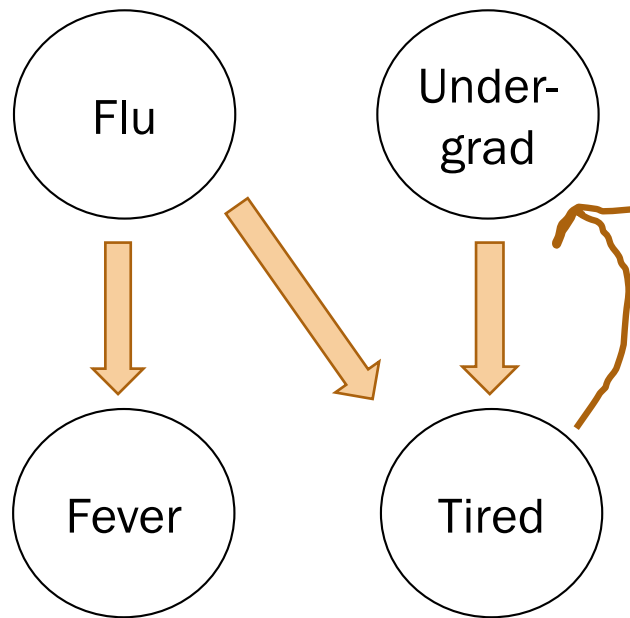


This model assumes that Flu and being an Undergraduate are independent.

Neat trick: it also assumes that fever and tired are conditionally independent given Flu.

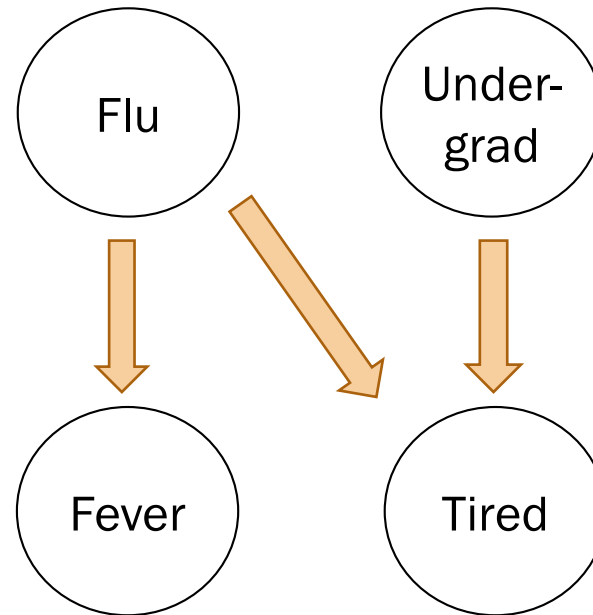
You need to tell a generative story. You do **not** need to be able to reason about all the implied independencies

Bug: Constructing a Bayesian Network



Must be acyclic!

Bayesian Network Assumption:



$$\begin{aligned} P(\text{Joint}) &= P(X_1 = x_1 \dots X_n = x_n) \\ &= \prod_i P(X_i = x_i | \text{parents of } X_i) \end{aligned}$$



Bayes Nets tell a generative story.

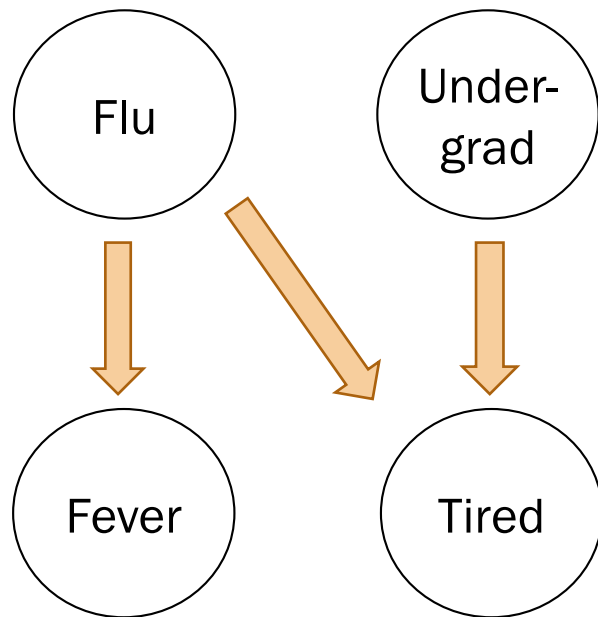
This leads to many independence assumptions

Makes it **tractable** to represent the joint

Inference via math

$$P(F_{lu} = 1) = 0.1$$

$$P(U = 1) = 0.8$$



1. $P(F_{lu} = 0, U = 1, F_{ev} = 0, T = 1)$?

Compute joint probabilities using chain rule.

$$P(F_{ev} = 1 | F_{lu} = 1) = 0.9$$

$$P(F_{ev} = 1 | F_{lu} = 0) = 0.05$$

$$P(T = 1 | F_{lu} = 0, U = 0) = 0.1$$

$$P(T = 1 | F_{lu} = 0, U = 1) = 0.8$$

$$P(T = 1 | F_{lu} = 1, U = 0) = 0.9$$

$$P(T = 1 | F_{lu} = 1, U = 1) = 1.0$$

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Independence of RVs

Independent discrete RVs

Recall the definition of independent events E and F :

$$P(EF) = P(E)P(F)$$

Two discrete random variables X and Y are **independent** if:

for all x, y :

$$P(X = x, Y = y) = P(X = x)P(Y = y)$$

Different notation,
same idea:

$$p(x, y) = p(x)p(y)$$

- Intuitively: knowing value of X tells us nothing about the distribution of Y (and vice versa)
- If two variables are not independent, they are called **dependent**.

Can I discover independence from
data?

ROCK

The Sound: Vigorous, defiant, energetic, inventive

The Roots: Rhythm & blues, country

The Pioneers: Bill Haley, Chuck Berry, Fats Domino, Little Richard, Buddy Holly, Elvis Presley

The Places: Cleveland, New Orleans, Detroit, New York City

The Ensemble: Electric guitar, bass, drums, keyboard, vocals

"We're a rock group. We're noisy, raucous, emotional and weird."

—Angus Young (b. 1939)
Lead guitarist of rock band AC/DC

HIP-HOP Rap

The Sound: Rhythmic, unvarnished, adaptable, streetwise

The Roots: Rhythm & blues, soul, funk, reggae

The Pioneers: Afrika Bambaataa, Kool Herc, DJ Hollywood, Grandmaster Flash, Kurtis Blow, Grandmaster Caz

The Places: New York City (South Bronx)

The Ensemble: Vinyl, turntable, vocals

"The beautiful thing about hip-hop is it's like an audio collage. You can take any genre of music and do it in a hip-hop way and it'll be a hip-hop song."

—Jah Khalib (b. 1972)
Hip-hop artist

LATIN American

The Sound: Syncopated, enthusiastic, diverse, vibrant

The Roots: Spain, Africa, Caribbean, South America

The Pioneers: Arsenio Rodriguez, Machito, Pérez Prado, Tito Puente, Celia Cruz, Johnny Pacheco

The Places: Cuba, Puerto Rico, Mexico, Miami, New York

The Ensemble: Congas, bongos, maracas, guiro, guitar, vocals

"This genre has dancing and rhythm. I came to with an emphasis on Latin salsa music that was familiar to people in Latin America and everybody identified with the songs."

—Renee Marcaro (b. 1946)
Salsa singer and pianist

Folk

The Sound: Grassroots, narrative, sincere, lyrical

The Roots: Ballads, immigrant folklore, spirituals, cowboy songs

The Pioneers: Lead Belly, Odetta, Woody Guthrie, Pete Seeger, Bob Dylan, Joan Baez

The Places: Appalachia, Deep South, Western frontier

The Ensemble: Guitar, banjo, fiddle, accordion, vocals

"I liked the rhythm [of folk music]. I liked the melodies, the sound by generations of singers. Above all, I liked the words... they seemed fresh, straightforward, honest."

—Peter Dinklage (b. 1926)
Folk musician

COUNTRY Western

The Sound: Genuine, uncomplicated, nostalgic, informal

The Roots: European ballads, folk and gospel songs

The Pioneers: Uncle Dave Macon, the Carter Family, Jimmie Rodgers, Roy Acuff, Gene Autry, Bill Monroe

The Places: Appalachia, Nashville, Chicago, Western U.S.

The Ensemble: Fiddle, banjo, guitar, harmonica, accordion, vocals

"Country music is three chords and the truth."

—Merle Haggard (1921–2009)
Country music singer

CLASSICAL

The Sound: Intricate, polished, structured, harmonious

The Roots: Sacred music, choral chants, madrigals, dance rhythms

The Pioneers: J.S. Bach, Handel, Haydn, Mozart, Beethoven, Brahms

The Places: Austria, Germany, France, Italy

The Ensemble: Strings, woodwinds, brass, percussion, vocals

"I carry my thoughts about with me a long time... before writing them down. I change many things, discard others, and try again and again until I am satisfied."

—Ludwig van Beethoven (1770–1827)
Composer

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| | A | B | C | D | E | F | G | H | I |
|----|-------|-------|------|---------|-----------------|---------|-----|------|----|
| 1 | Music | Dance | Folk | Country | Classical music | Musical | Pop | Rock | Me |
| 2 | | 5 | 2 | 1 | 2 | 2 | 1 | 5 | 5 |
| 3 | | 4 | 2 | 1 | 1 | 1 | 2 | 3 | 5 |
| 4 | | 5 | 2 | 2 | 3 | 4 | 5 | 3 | 5 |
| 5 | | 5 | 2 | 1 | 1 | 1 | 1 | 2 | 2 |
| 6 | | 5 | 4 | 3 | 2 | 4 | 3 | 5 | 3 |
| 7 | | 5 | 2 | 3 | 2 | 3 | 3 | 2 | 5 |
| 8 | | 5 | 5 | 3 | 1 | 2 | 2 | 5 | 3 |
| 9 | | 5 | 3 | 2 | 1 | 2 | 2 | 4 | 5 |
| 10 | | 5 | 3 | 1 | 1 | 2 | 4 | 3 | 5 |
| 11 | | 5 | 2 | 5 | 2 | 2 | 5 | 3 | 5 |
| 12 | | 5 | 3 | 2 | 1 | 2 | 3 | 4 | 3 |
| 13 | | 5 | 1 | 1 | 1 | 4 | 1 | 2 | 5 |
| 14 | | 5 | 1 | 2 | 1 | 4 | 3 | 3 | 5 |
| 15 | | 5 | 5 | 3 | 2 | 1 | 5 | 5 | 2 |
| 16 | | 5 | 2 | 1 | 1 | 2 | 3 | 4 | 5 |
| 17 | | 1 | 2 | 2 | 3 | 4 | 3 | 3 | 5 |
| 18 | | 5 | 3 | 1 | 1 | 1 | 2 | 4 | 4 |
| 19 | | 5 | 3 | 3 | 3 | 2 | 2 | 4 | 4 |
| 20 | | 5 | 5 | 4 | 3 | 4 | 5 | 5 | 4 |
| 21 | | 5 | 3 | 3 | 2 | 4 | 2 | 2 | 4 |
| 22 | | 5 | 3 | 2 | 3 | 4 | 3 | 2 | 5 |
| 23 | | 5 | 1 | 1 | 3 | 2 | 2 | 2 | 5 |
| 24 | | 5 | 3 | 2 | 3 | 3 | 3 | 4 | |
| 25 | | 5 | 4 | 2 | 2 | 2 | 4 | 4 | 5 |
| 26 | | 5 | 3 | 1 | 1 | 4 | 3 | 3 | 5 |
| 27 | | 5 | 4 | 2 | 1 | 2 | 3 | 5 | 1 |
| 28 | | 5 | 5 | 5 | 4 | 5 | 3 | 4 | 4 |
| 29 | | 4 | 3 | 4 | 1 | 3 | 2 | 2 | 4 |
| 30 | | 5 | 5 | 1 | 1 | 1 | 1 | 3 | 4 |
| 31 | | 5 | 3 | 4 | 2 | 3 | 3 | 3 | 4 |
| 32 | | 4 | 4 | 3 | 3 | 3 | 3 | 4 | 4 |
| 33 | | 4 | 4 | 1 | 3 | 2 | 3 | 5 | 3 |
| 34 | | 5 | 3 | 1 | 3 | 2 | 3 | 3 | 4 |
| 35 | | 5 | 2 | 2 | 3 | 4 | 5 | 4 | 3 |

music | +

Ready | 100%

Why is it harder to find independences here than for bat DNA expression?

| | A | B | C | D | E | F | G | H | Me |
|----|-------|-------|------|---------|-----------------|---------|-----|------|----|
| 1 | Music | Dance | Folk | Country | Classical music | Musical | Pop | Rock | Me |
| 2 | | 5 | 2 | 1 | 2 | 2 | 1 | 5 | 5 |
| 3 | | 4 | 2 | 1 | 1 | 1 | 2 | 3 | 5 |
| 4 | | 5 | 2 | 2 | 3 | 4 | 5 | 3 | 5 |
| 5 | | 5 | 2 | 1 | 1 | 1 | 1 | 2 | 2 |
| 6 | | 5 | 4 | 3 | 2 | 4 | 3 | 5 | 3 |
| 7 | | 5 | 2 | 3 | 2 | 3 | 3 | 2 | 5 |
| 8 | | 5 | 5 | 3 | 1 | 2 | 2 | 5 | 3 |
| 9 | | 5 | 3 | 2 | 1 | 2 | 2 | 4 | 5 |
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| 11 | | 5 | 2 | 5 | 2 | 2 | 5 | 3 | 5 |
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| 13 | | 5 | 1 | 1 | 1 | 4 | 1 | 2 | 5 |
| 14 | | 5 | 1 | 2 | 1 | 4 | 3 | 3 | 5 |
| 15 | | 5 | 5 | 3 | 2 | 1 | 5 | 5 | 2 |
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| 18 | | 5 | 3 | 1 | 1 | 1 | 2 | 4 | 4 |
| 19 | | 5 | 3 | 3 | 3 | 2 | 2 | 4 | 4 |
| 20 | | 5 | 5 | 4 | 3 | 4 | 5 | 5 | 4 |
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| 22 | | 5 | 3 | 2 | 3 | 4 | 3 | 2 | 5 |
| 23 | | 5 | 1 | 1 | 3 | 2 | 2 | 2 | 5 |
| 24 | | 5 | 3 | 2 | 3 | 3 | 3 | 4 | |
| 25 | | 5 | 4 | 2 | 2 | 2 | 4 | 4 | 5 |
| 26 | | 5 | 3 | 1 | 1 | 4 | 3 | 3 | 5 |
| 27 | | 5 | 4 | 2 | 1 | 2 | 3 | 5 | 1 |
| 28 | | 5 | 5 | 5 | 4 | 5 | 3 | 4 | 4 |
| 29 | | 4 | 3 | 4 | 1 | 3 | 2 | 2 | 4 |
| 30 | | 5 | 5 | 1 | 1 | 1 | 1 | 3 | 4 |
| 31 | | 5 | 3 | 4 | 2 | 3 | 3 | 3 | 4 |
| 32 | | 4 | 4 | 3 | 3 | 3 | 3 | 4 | 4 |
| 33 | | 4 | 4 | 1 | 3 | 2 | 3 | 5 | 3 |
| 34 | | 5 | 3 | 1 | 3 | 2 | 3 | 3 | 4 |
| 35 | | 5 | 2 | 2 | 3 | 4 | 5 | 4 | 3 |



Dance of the Covariance

Recall our Ebola Bats

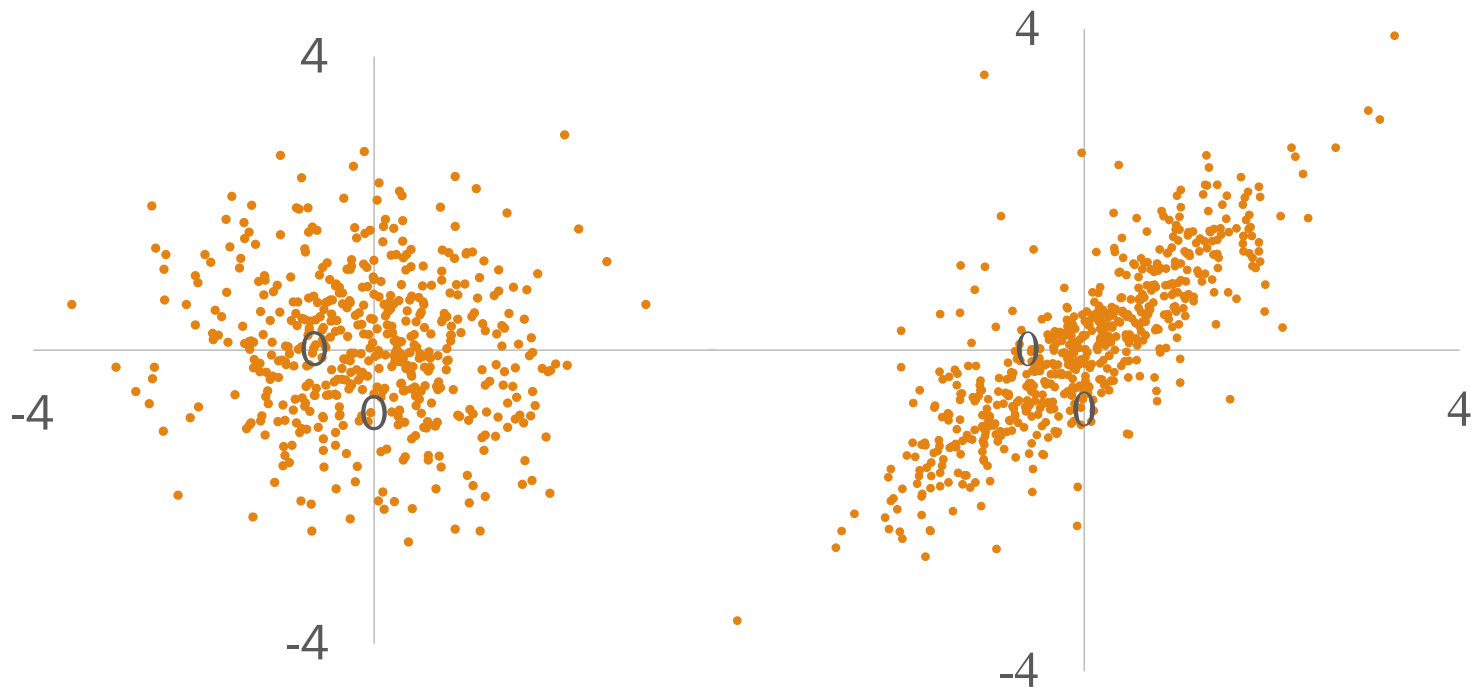


Expression Amount

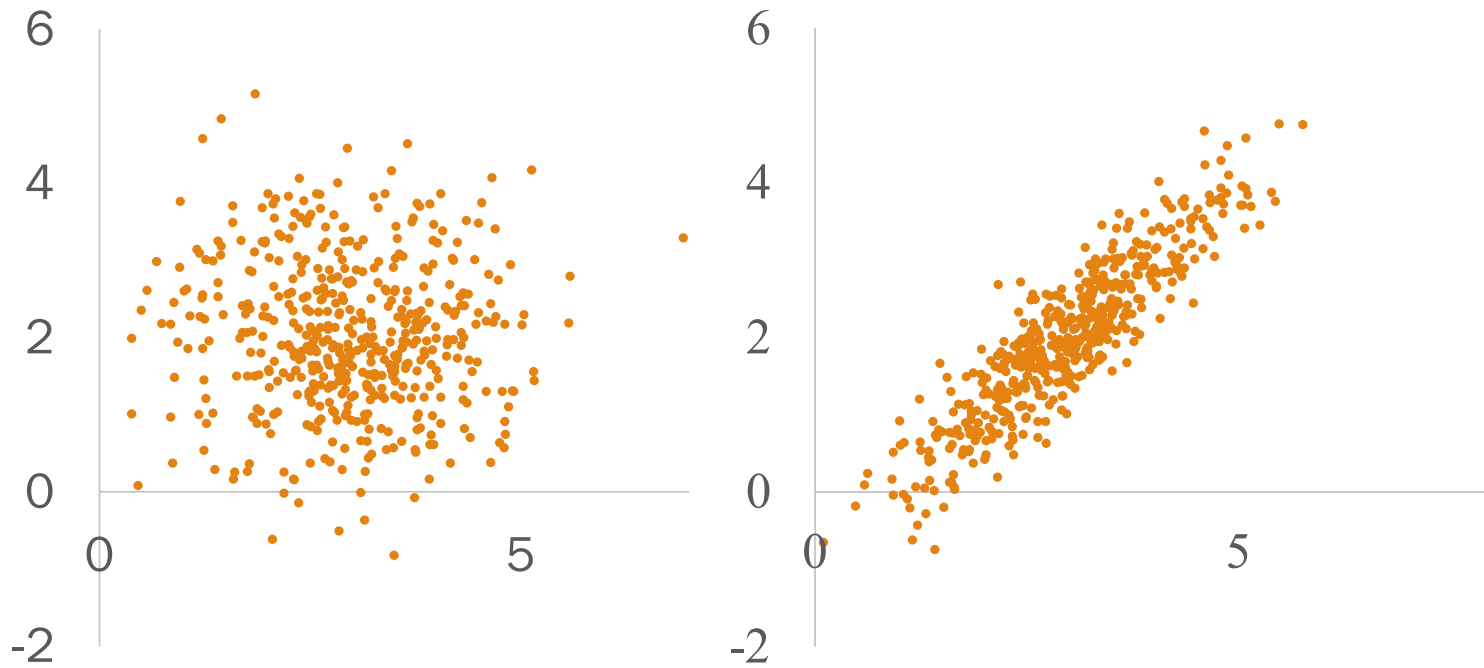
| Gene5 | Trait |
|-------|-------|
| 0.76 | 0.83 |
| 0.94 | 0.85 |
| 0.82 | 0.03 |
| 0.94 | 0.32 |
| 0.50 | 0.10 |
| 0.40 | 0.53 |
| 0.90 | 0.67 |
| 0.29 | 0.71 |
| 0.72 | 0.25 |
| 0.15 | 0.24 |
| 0.79 | 0.98 |
| 0.68 | 0.77 |
| 0.71 | 0.37 |
| 0.36 | 0.18 |
| 0.62 | 0.08 |
| 0.59 | 0.38 |
| 0.82 | 0.76 |

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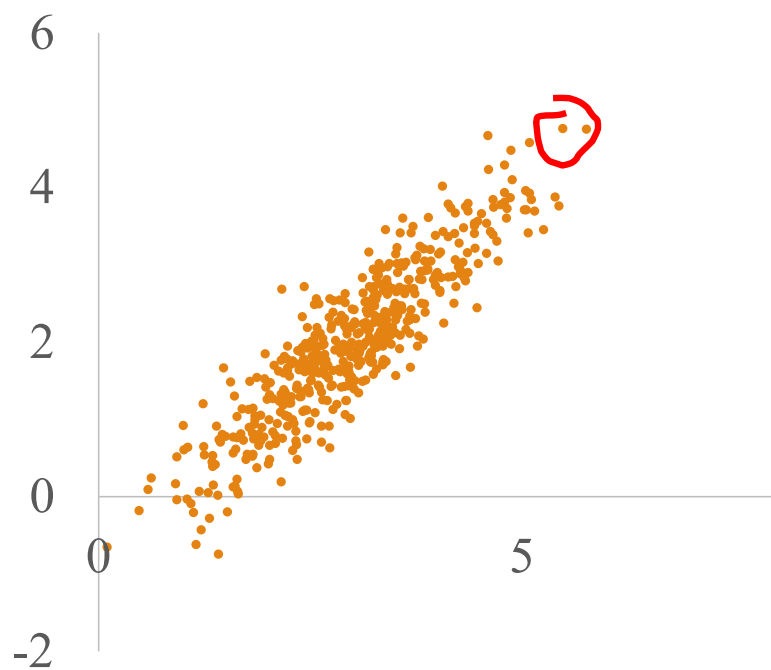
Spot The Difference



Spot The Difference



Vary Together

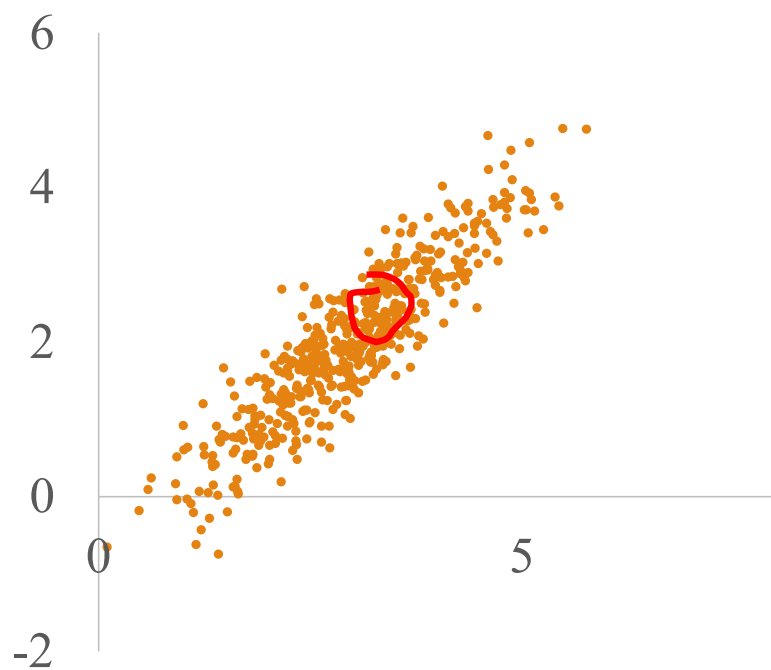


$$x - E[x] = 3$$

$$y - E[y] = 2.6$$

$$(x - E[x])(y - E[y]) = 7.8$$

Vary Together

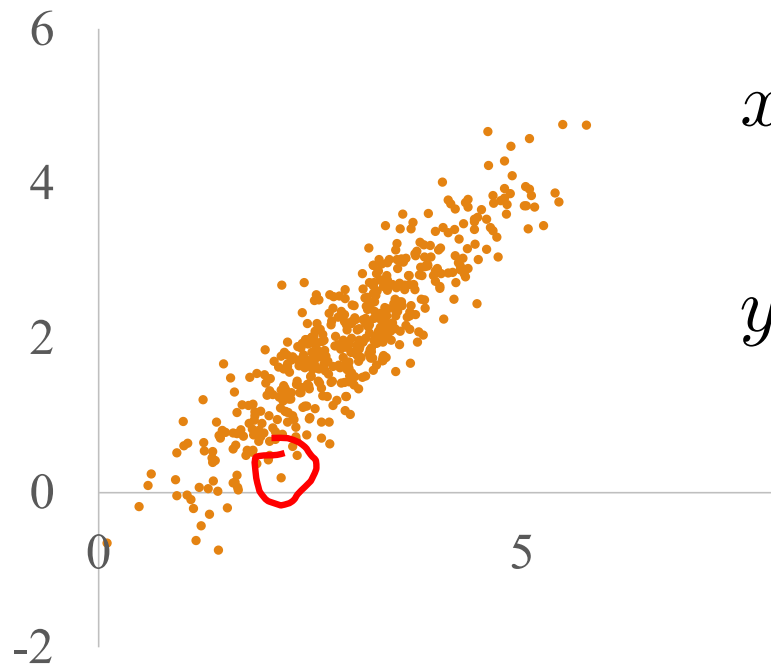


$$x - E[x] \approx 0$$

$$y - E[y] \approx 0$$

$$(x - E[x])(y - E[y]) = 0$$

Vary Together

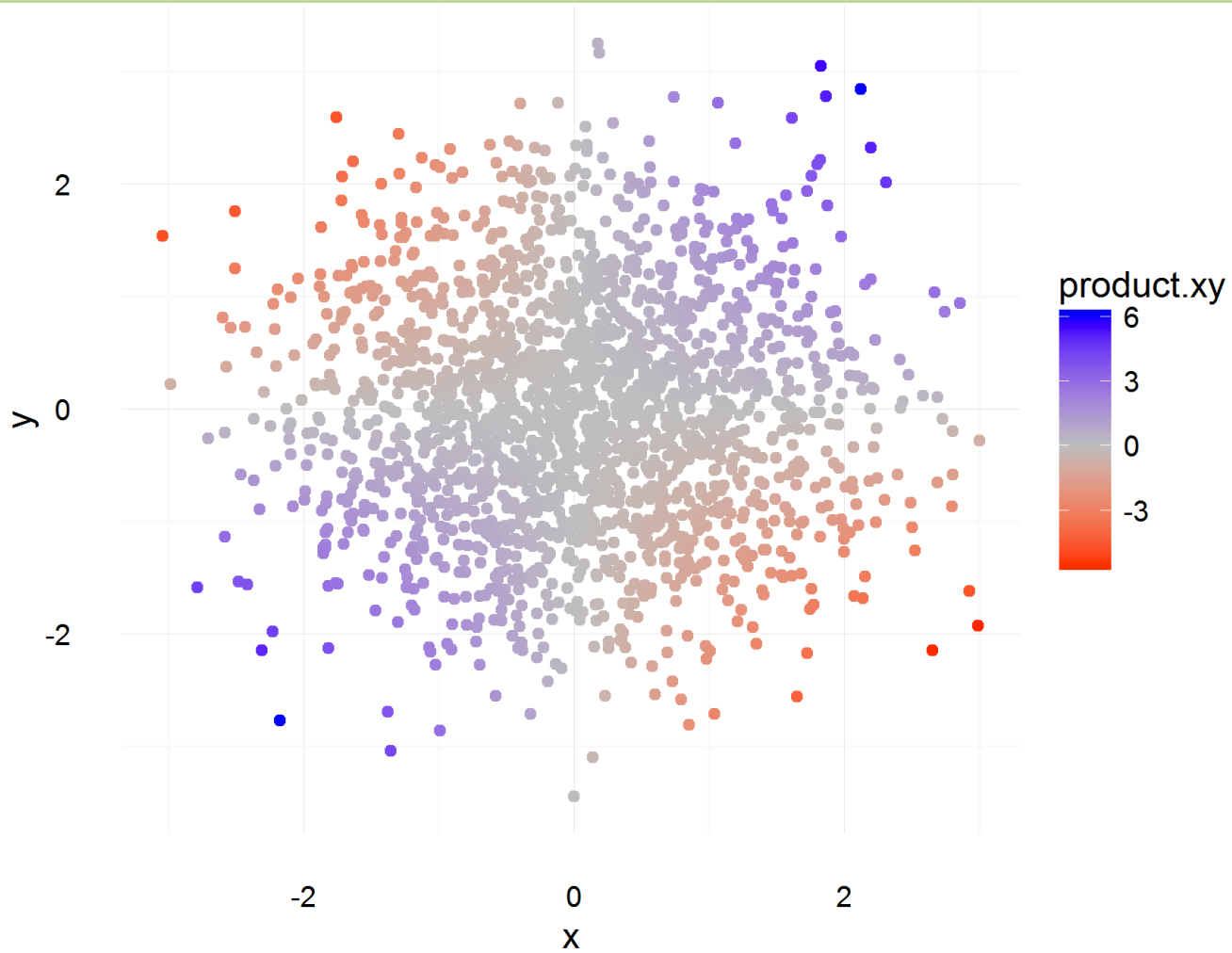


$$x - E[x] = -1.1$$

$$y - E[y] = -2.8$$

$$(x - E[x])(y - E[y]) \approx 3.1$$

Understanding Covariance



The Dance of the Covariance

Say X and Y are arbitrary random variables

Covariance of X and Y :

$$\text{Cov}(X, Y) = E[(X - E[X])(Y - E[Y])]$$

| x | y | $(x - E[X])(y - E[Y])p(x,y)$ |
|-------------|-------------|------------------------------|
| Above mean | Above mean | Positive |
| Bellow mean | Bellow mean | Positive |
| Bellow mean | Above mean | Negative |
| Above mean | Bellow mean | Negative |

The Dance of the Covariance

Say X and Y are arbitrary random variables

Covariance of X and Y :

$$\text{Cov}(X, Y) = E[(X - E[X])(Y - E[Y])]$$

Equivalently:

$$\begin{aligned}\text{Cov}(X, Y) &= E[XY - E[X]Y - XE[Y] + E[Y]E[X]] \\ &= E[XY] - E[X]E[Y] - E[X]E[Y] + E[X]E[Y] \\ &= E[XY] - E[X]E[Y]\end{aligned}$$

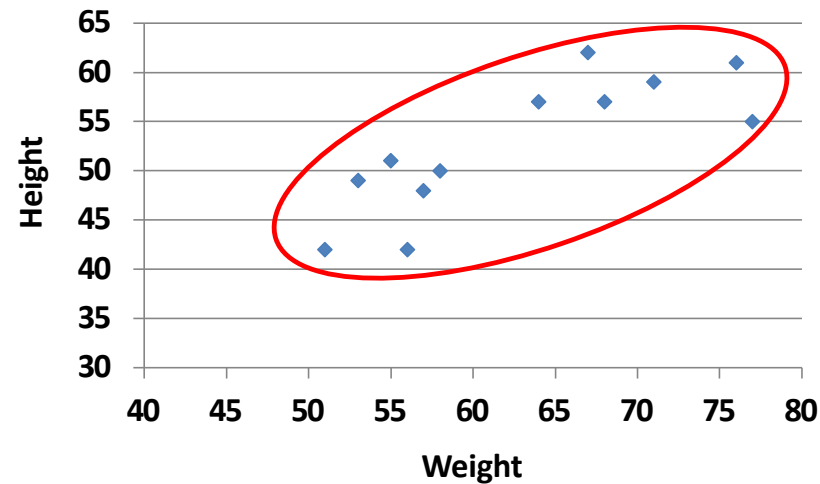
- X and Y independent, $E[XY] = E[X]E[Y] \rightarrow \text{Cov}(X, Y) = 0$
- But $\text{Cov}(X, Y) = 0$ does **not** imply X and Y independent!

Covariance and Data

Consider the following data:

| Weight | Height | Weight * Height |
|--------|--------|-----------------|
| 64 | 57 | 3648 |
| 71 | 59 | 4189 |
| 53 | 49 | 2597 |
| 67 | 62 | 4154 |
| 55 | 51 | 2805 |
| 58 | 50 | 2900 |
| 77 | 55 | 4235 |
| 57 | 48 | 2736 |
| 56 | 42 | 2352 |
| 51 | 42 | 2142 |
| 76 | 61 | 4636 |
| 68 | 57 | 3876 |

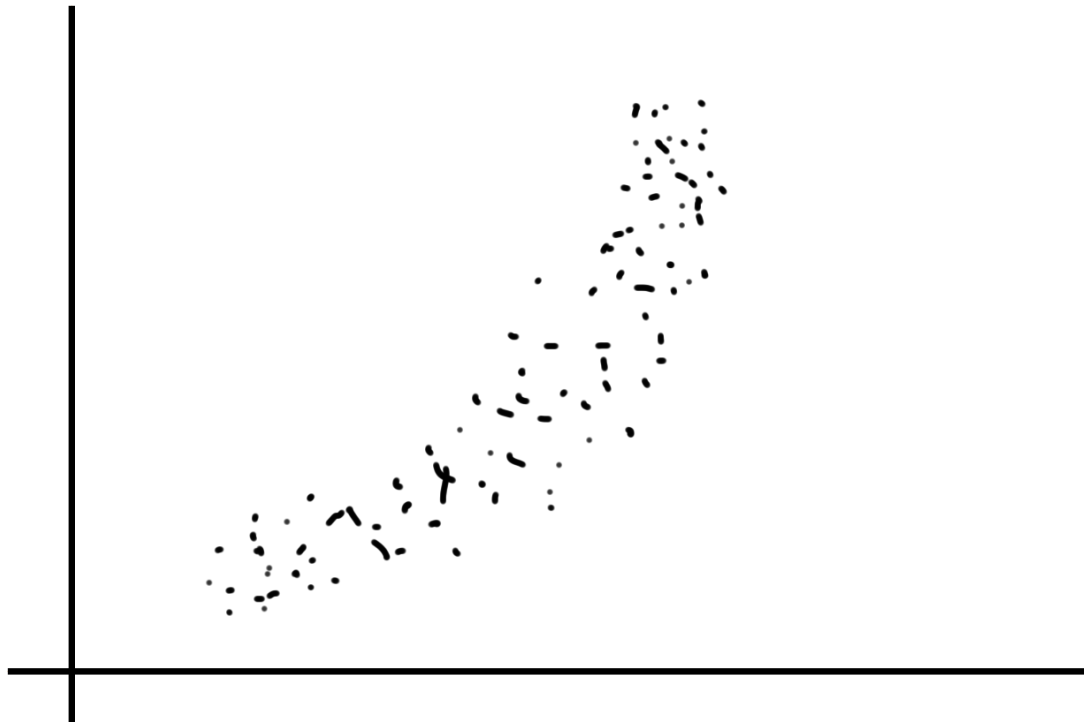
$$\begin{array}{l} E[W] \\ = 62.75 \end{array} \quad \begin{array}{l} E[H] \\ = 52.75 \end{array} \quad \begin{array}{l} E[W*H] \\ = 3355.83 \end{array}$$



$$\begin{aligned} \text{Cov}(W, H) &= E[W*H] - E[W]E[H] \\ &= 3355.83 - (62.75)(52.75) \\ &= 45.77 \end{aligned}$$

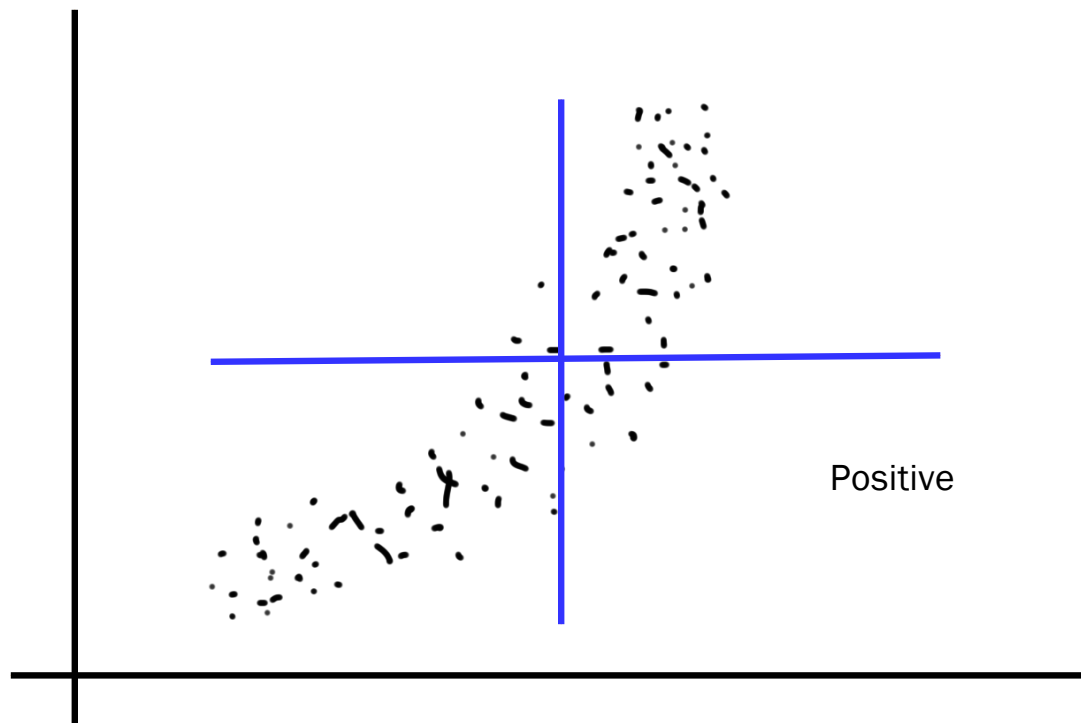
Covariance

Poll: (a) positive, (b) negative, (c) zero



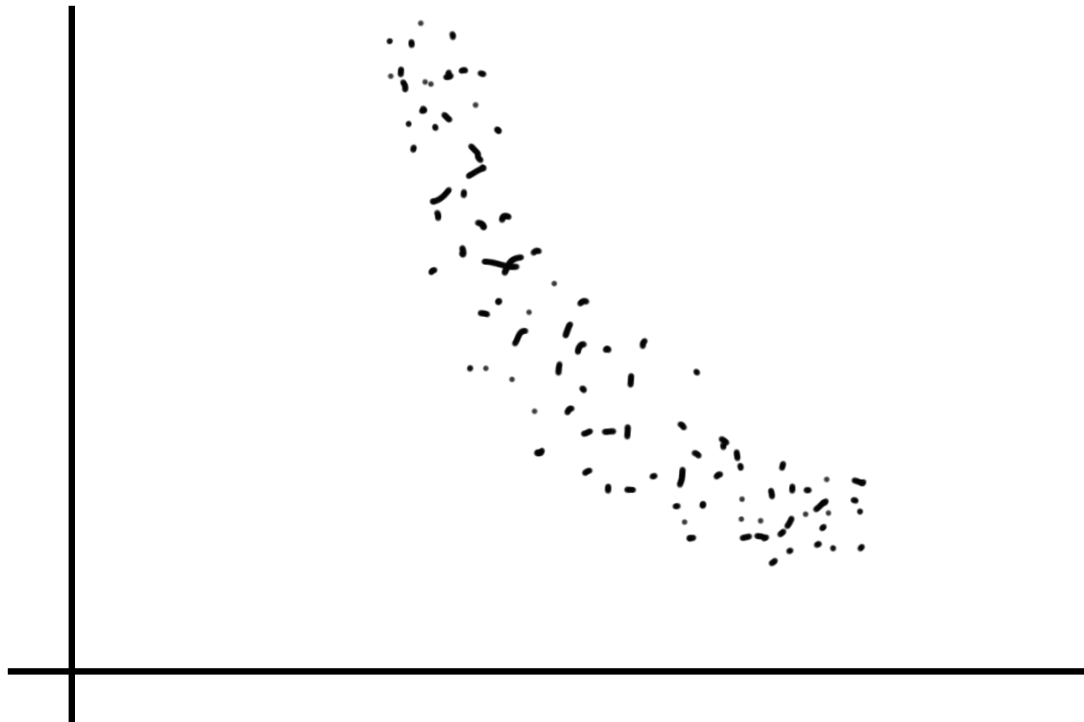
Covariance

Is the Covariance: (a) positive, (b) negative, (c) zero



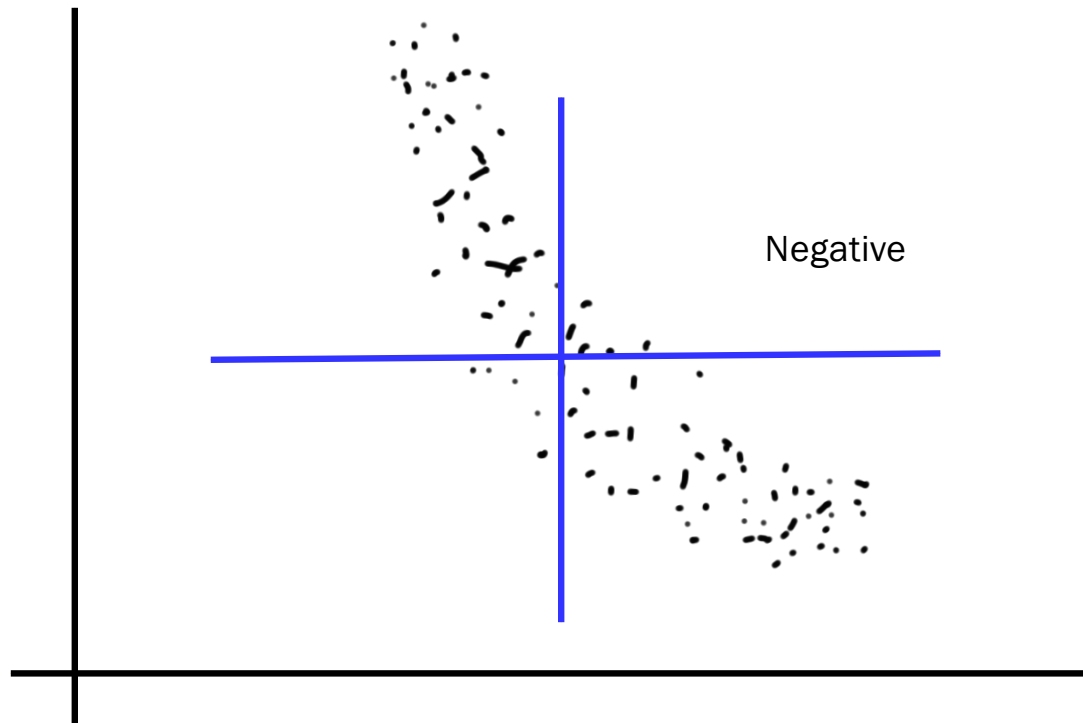
Covariance

Is the Covariance: (a) positive, (b) negative, (c) zero



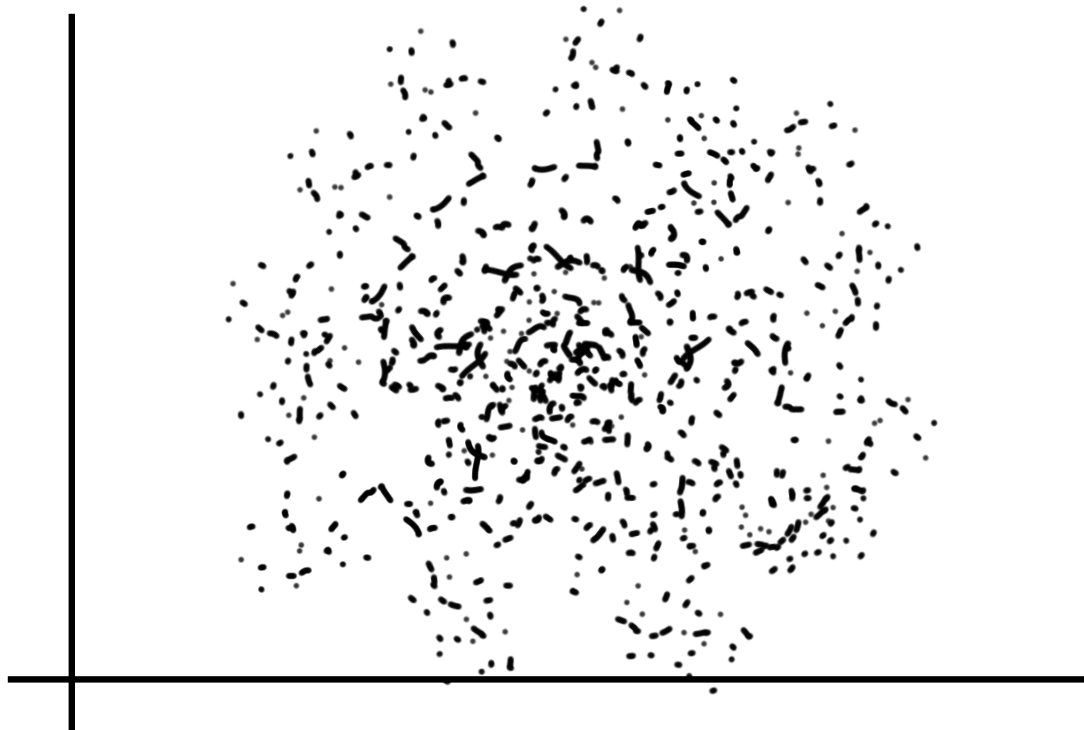
Covariance

Is the Covariance: (a) positive, (b) negative, (c) zero



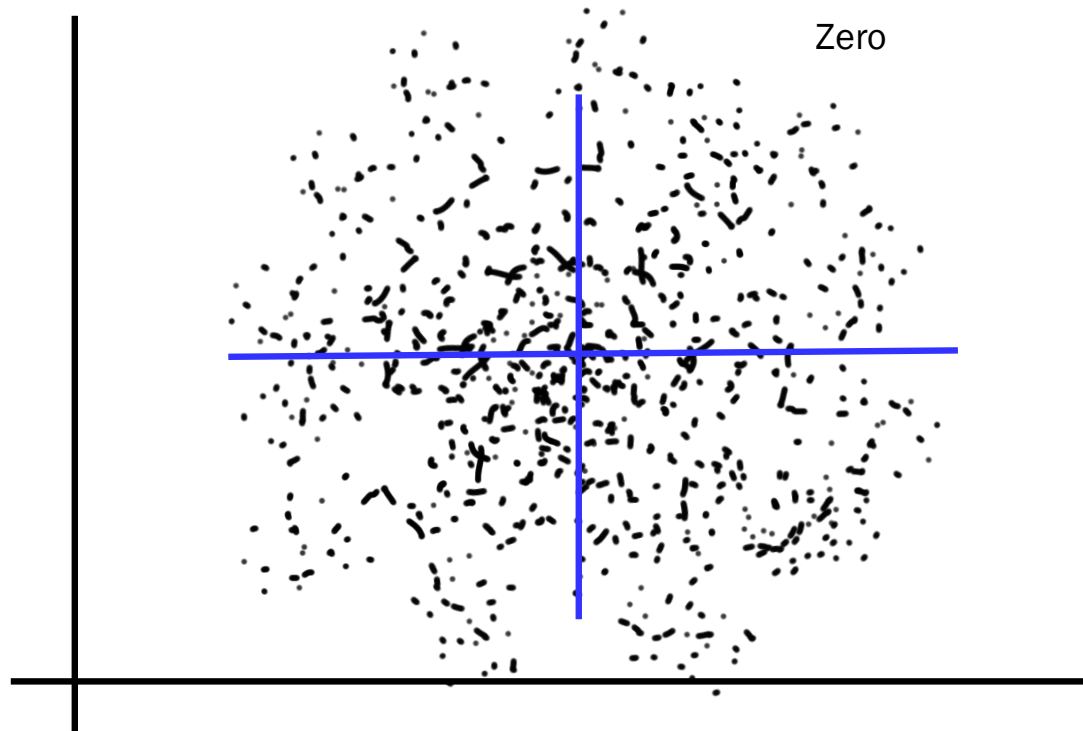
Covariance

Is the Covariance: (a) positive, (b) negative, (c) zero



Covariance

Is the Covariance: (a) positive, (b) negative, (c) zero



Independence and Covariance

X and Y are random variables with PMF:

| Y \ X | -1 | 0 | 1 | $p_Y(y)$ |
|----------|-----|-----|-----|----------|
| 0 | 1/3 | 0 | 1/3 | 2/3 |
| 1 | 0 | 1/3 | 0 | 1/3 |
| $p_X(x)$ | 1/3 | 1/3 | 1/3 | 1 |

$$Y = \begin{cases} 0 & \text{if } X \neq 0 \\ 1 & \text{otherwise} \end{cases}$$

- $E[X] = -1(1/3) + 0(1/3) + 1(1/3) = 0$
- $E[Y] = 0(2/3) + 1(1/3) = 1/3$
- Since $XY = 0$, $E[XY] = 0$
- $\text{Cov}(X, Y) = E[XY] - E[X]E[Y] = 0 - 0 = 0$

But, X and Y are clearly dependent!

Properties of Covariance

Say X and Y are arbitrary random variables

- $\text{Cov}(X, Y) = \text{Cov}(Y, X)$
- $\text{Cov}(X, X) = E[X^2] - E[X]E[X] = \text{Var}(X)$
- $\text{Cov}(aX + b, Y) = a\text{Cov}(X, Y)$

Correlation

Viva La Correlación

Say X and Y are arbitrary random variables

- Correlation of X and Y , denoted $\rho(X, Y)$:

$$\rho(X, Y) = \frac{\text{Cov}(X, Y)}{\sqrt{\text{Var}(X)\text{Var}(Y)}}$$

- Note: $-1 \leq \rho(X, Y) \leq 1$
- Correlation measures linearity between X and Y
- $\rho(X, Y) = 1 \quad \Rightarrow \quad Y = aX + b \quad \text{where } a = \sigma_y/\sigma_x$
- $\rho(X, Y) = -1 \quad \Rightarrow \quad Y = aX + b \quad \text{where } a = -\sigma_y/\sigma_x$
- $\rho(X, Y) = 0 \quad \Rightarrow \quad \text{absence of linear relationship}$
 - But, X and Y can still be related in some other way!
- If $\rho(X, Y) = 0$, we say X and Y are “uncorrelated”
 - Note: Independence implies uncorrelated, but not vice versa!

Viva La Correlación

Say X and Y are arbitrary random variables

- Correlation of X and Y , denoted $\rho(X, Y)$:

$$\rho(X, Y) = \frac{\text{Cov}(X, Y)}{\sqrt{\text{Var}(X)\text{Var}(Y)}}$$

Say $Y = cX$. Correlation should be 1.

ROCK

The Sound: Vigorous, defiant, energetic, inventive

The Roots: Rhythm & blues, country

The Pioneers: Bill Haley, Chuck Berry, Fats Domino, Little Richard, Buddy Holly, Elvis Presley

The Places: Cleveland, New Orleans, Detroit, New York City

The Ensemble: Electric guitar, bass, drums, keyboard, vocals

"We're a rock group. We're noisy, raucy, sentimental and weird."

—Angus Young (b. 1939)
Lead guitarist of rock band AC/DC

HIP-HOP Rap

The Sound: Rhythmic, unvarnished, adaptable, streetwise

The Roots: Rhythm & blues, soul, funk, reggae

The Pioneers: Afrika Bambaataa, Kool Herc, DJ Hollywood, Grandmaster Flash, Kurtis Blow, Grandmaster Caz

The Places: New York City (South Bronx)

The Ensemble: Vinyl, turntable, vocals

"The beautiful thing about hip-hop is it's like an audio collage. You can take any genre of music and do it in a hip-hop way and it'll be a hip-hop song."

—Laurie R King (b. 1952)
Hip-hop artist

LATIN American

The Sound: Syncopated, enthusiastic, diverse, vibrant

The Roots: Spain, Africa, Caribbean, South America

The Pioneers: Arsenio Rodriguez, Machito, Pérez Prado, Tito Puente, Celia Cruz, Johnny Pacheco

The Places: Cuba, Puerto Rico, Mexico, Miami, New York

The Ensemble: Congas, bongos, maracas, guiro, guitar, vocals

"This genre has dancing and rhythm. I came to with an emphasis on Latin salsa music that was familiar to people in Latin America and everybody identified with the songs."

—Ruben Blades (b. 1948)
Salsa singer and actor

Folk

The Sound: Grassroots, narrative, sincere, lyrical

The Roots: Ballads, immigrant folklore, spirituals, cowboy songs

The Pioneers: Lead Belly, Odetta, Woody Guthrie, Pete Seeger, Bob Dylan, Joan Baez

The Places: Appalachia, Deep South, Western frontier

The Ensemble: Guitar, banjo, fiddle, accordion, vocals

"I liked the rhythm [of folk music]. I liked the melodies, the sound by generations of singers. Above all, I liked the words... they seemed fresh, straightforward, honest."

—Peter Dinklage (b. 1926)
Folk musician

COUNTRY Western

The Sound: Genuine, uncomplicated, nostalgic, informal

The Roots: European ballads, folk and gospel songs

The Pioneers: Uncle Dave Macon, the Carter Family, Jimmie Rodgers, Roy Acuff, Gene Autry, Bill Monroe

The Places: Appalachia, Nashville, Chicago, Western U.S.

The Ensemble: Fiddle, banjo, guitar, harmonica, accordion, vocals

"Country music is three chords and the truth."

—Merle Haggard (1921–2006)
Country music singer

CLASSICAL

The Sound: Intricate, polished, structured, harmonious

The Roots: Sacred music, choral chants, madrigals, dance rhythms

The Pioneers: J.S. Bach, Handel, Haydn, Mozart, Beethoven, Brahms

The Places: Austria, Germany, France, Italy

The Ensemble: Strings, woodwinds, brass, percussion, vocals

"I carry my thoughts about with me a long time... before writing them down. I change many things, discard others, and try again and again until I am satisfied."

—Ludwig van Beethoven (1770–1827)
Composer

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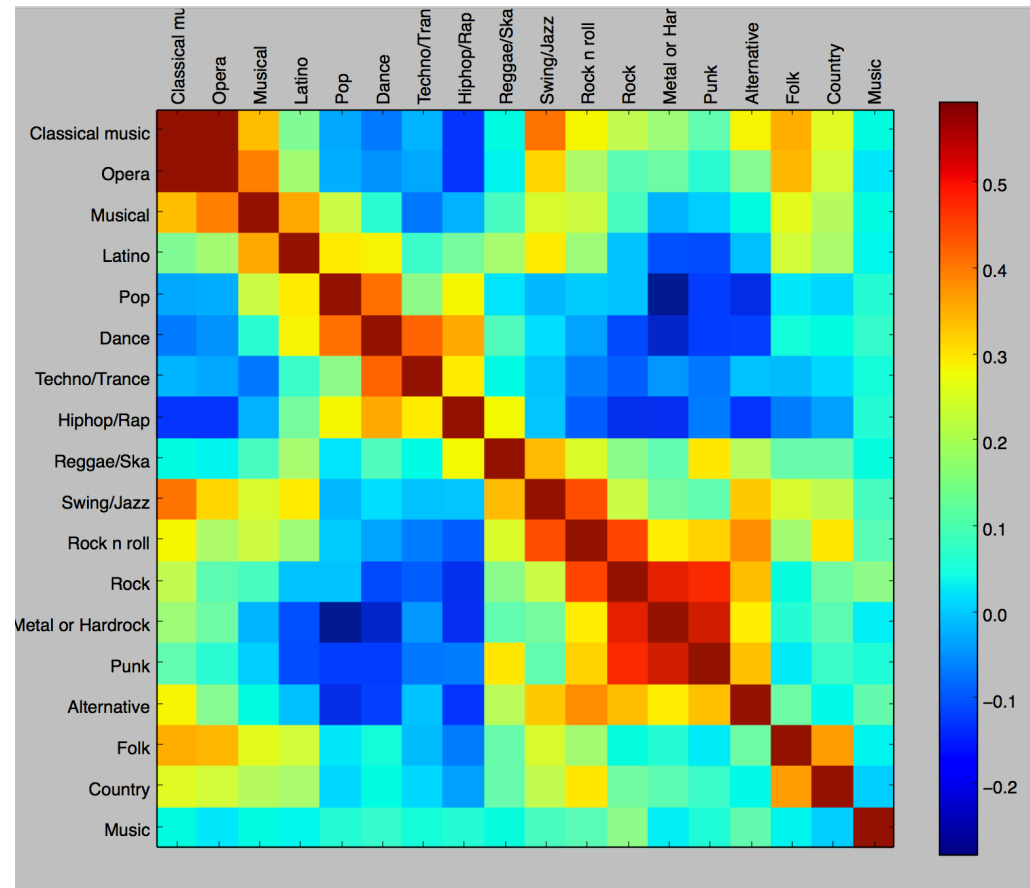
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| | A | B | C | D | E | F | G | H | I |
|----|-------|-------|------|---------|-----------------|---------|-----|------|----|
| 1 | Music | Dance | Folk | Country | Classical music | Musical | Pop | Rock | Me |
| 2 | | 5 | 2 | 1 | 2 | 2 | 1 | 5 | 5 |
| 3 | | 4 | 2 | 1 | 1 | 1 | 2 | 3 | 5 |
| 4 | | 5 | 2 | 2 | 3 | 4 | 5 | 3 | 5 |
| 5 | | 5 | 2 | 1 | 1 | 1 | 1 | 2 | 2 |
| 6 | | 5 | 4 | 3 | 2 | 4 | 3 | 5 | 3 |
| 7 | | 5 | 2 | 3 | 2 | 3 | 3 | 2 | 5 |
| 8 | | 5 | 5 | 3 | 1 | 2 | 2 | 5 | 3 |
| 9 | | 5 | 3 | 2 | 1 | 2 | 2 | 4 | 5 |
| 10 | | 5 | 3 | 1 | 1 | 2 | 4 | 3 | 5 |
| 11 | | 5 | 2 | 5 | 2 | 2 | 5 | 3 | 5 |
| 12 | | 5 | 3 | 2 | 1 | 2 | 3 | 4 | 3 |
| 13 | | 5 | 1 | 1 | 1 | 4 | 1 | 2 | 5 |
| 14 | | 5 | 1 | 2 | 1 | 4 | 3 | 3 | 5 |
| 15 | | 5 | 5 | 3 | 2 | 1 | 5 | 5 | 2 |
| 16 | | 5 | 2 | 1 | 1 | 2 | 3 | 4 | 5 |
| 17 | | 1 | 2 | 2 | 3 | 4 | 3 | 3 | 5 |
| 18 | | 5 | 3 | 1 | 1 | 1 | 2 | 4 | 4 |
| 19 | | 5 | 3 | 3 | 3 | 2 | 2 | 4 | 4 |
| 20 | | 5 | 5 | 4 | 3 | 4 | 5 | 5 | 4 |
| 21 | | 5 | 3 | 3 | 2 | 4 | 2 | 2 | 4 |
| 22 | | 5 | 3 | 2 | 3 | 4 | 3 | 2 | 5 |
| 23 | | 5 | 1 | 1 | 3 | 2 | 2 | 2 | 5 |
| 24 | | 5 | 3 | 2 | 3 | 3 | 3 | 4 | |
| 25 | | 5 | 4 | 2 | 2 | 2 | 4 | 4 | 5 |
| 26 | | 5 | 3 | 1 | 1 | 4 | 3 | 3 | 5 |
| 27 | | 5 | 4 | 2 | 1 | 2 | 3 | 5 | 1 |
| 28 | | 5 | 5 | 5 | 4 | 5 | 3 | 4 | 4 |
| 29 | | 4 | 3 | 4 | 1 | 3 | 2 | 2 | 4 |
| 30 | | 5 | 5 | 1 | 1 | 1 | 1 | 3 | 4 |
| 31 | | 5 | 3 | 4 | 2 | 3 | 3 | 3 | 4 |
| 32 | | 4 | 4 | 3 | 3 | 3 | 3 | 4 | 4 |
| 33 | | 4 | 4 | 1 | 3 | 2 | 3 | 5 | 3 |
| 34 | | 5 | 3 | 1 | 3 | 2 | 3 | 3 | 4 |
| 35 | | 5 | 2 | 2 | 3 | 4 | 5 | 4 | 3 |

music | +

Ready | 100%

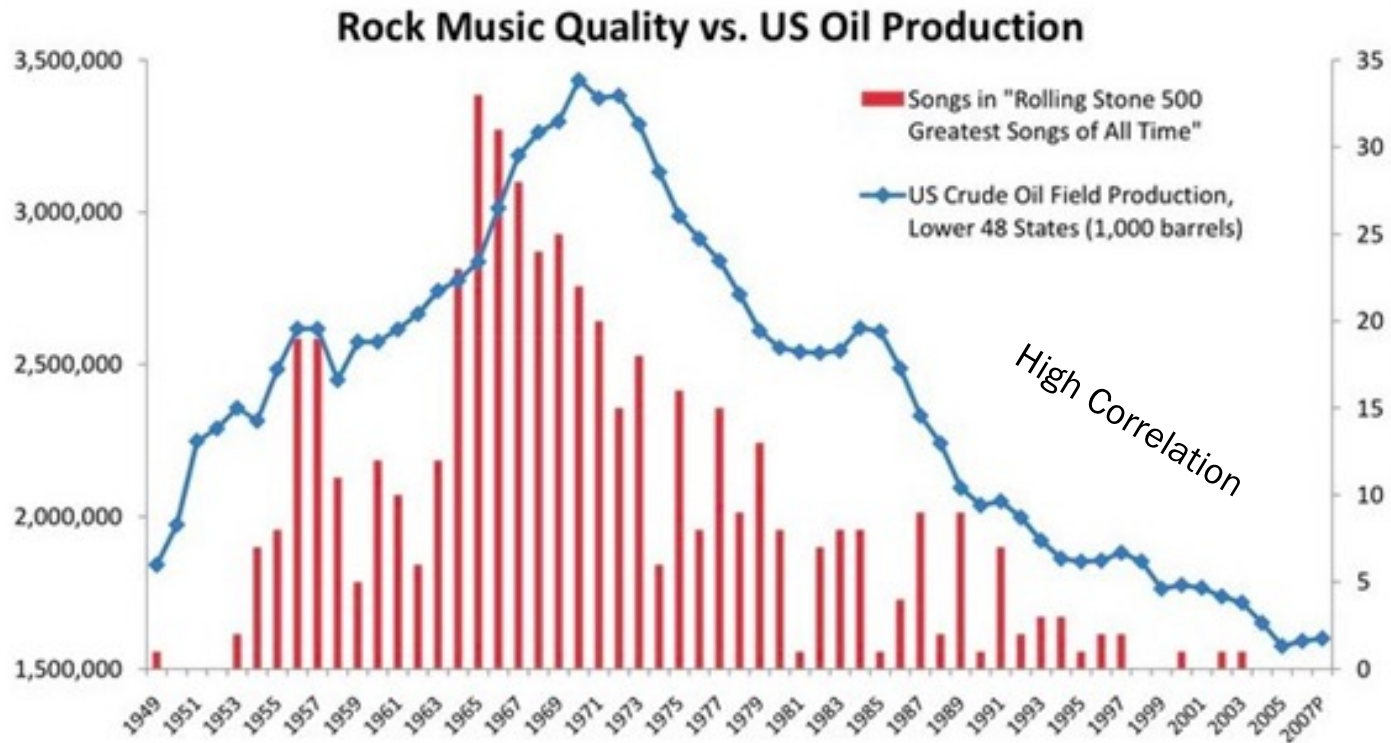
Correlation of Music Tastes



How do you know if your model is good?

Answer: it is accurate at inference
(especially tasks you care about)

Rock Music Vs Oil?

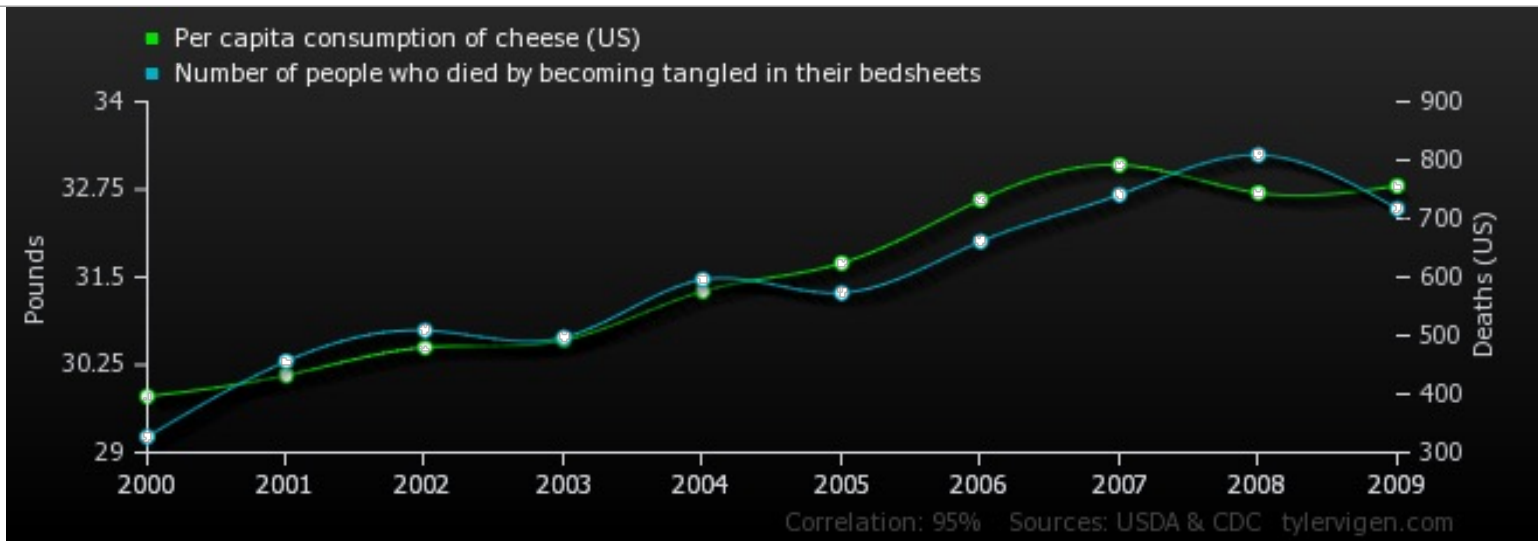


Hubbert Peak Theory

<http://www.aei.org/publication/blog/>

Stanford University

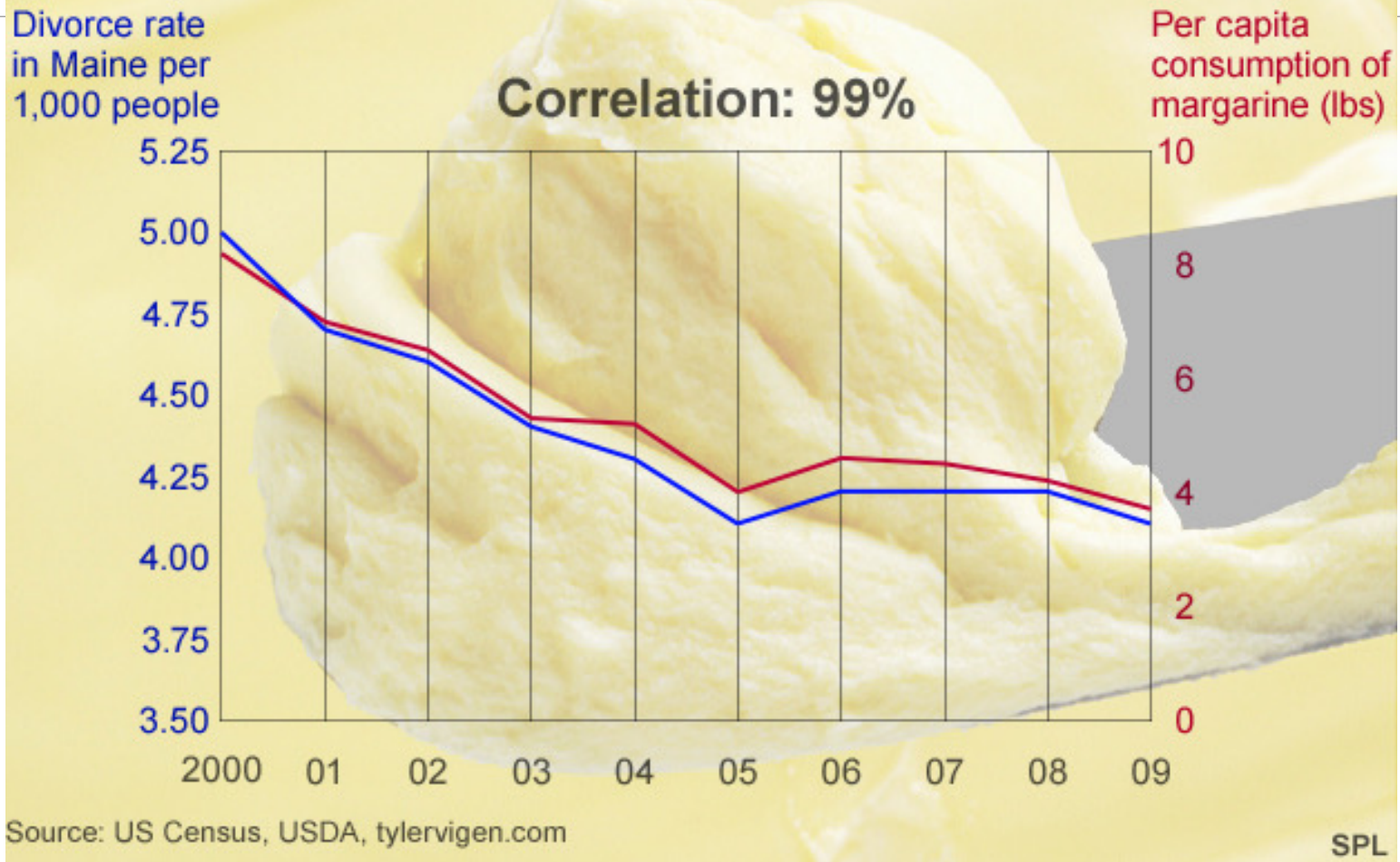
Tell your friends!



| | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 |
|--|------|------|------|------|------|------|------|------|------|------|
| <i>Per capita consumption of cheese (US)</i> Pounds (USDA) | 29.8 | 30.1 | 30.5 | 30.6 | 31.3 | 31.7 | 32.6 | 33.1 | 32.7 | 32.8 |
| <i>Number of people who died by becoming tangled in their bedsheets</i> Deaths (US) (CDC) | 327 | 456 | 509 | 497 | 596 | 573 | 661 | 741 | 809 | 717 |

Correlation: 0.947091

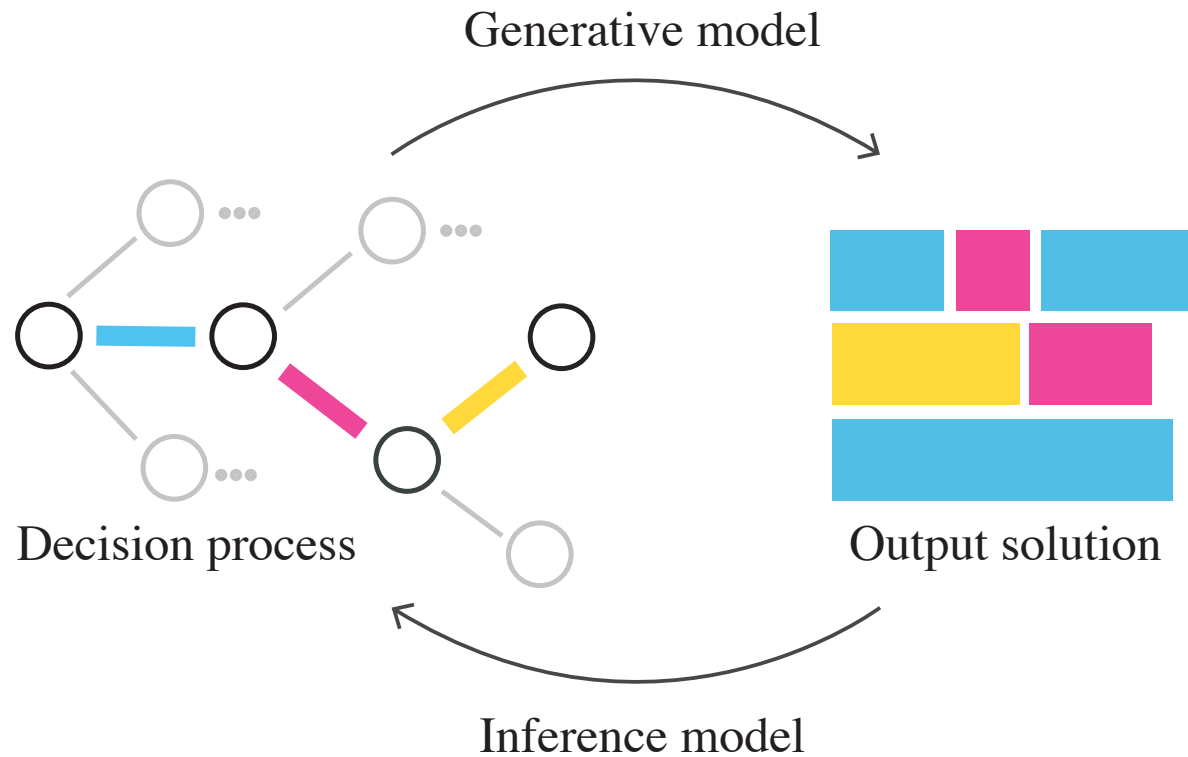
Divorce Vs Butter?



<http://www.bbc.com/news/magazine-27537142>

Stanford University

Wednesday: General Inference



Goodluck on the midterm!!