

(The Joy of) Bayes Theorem



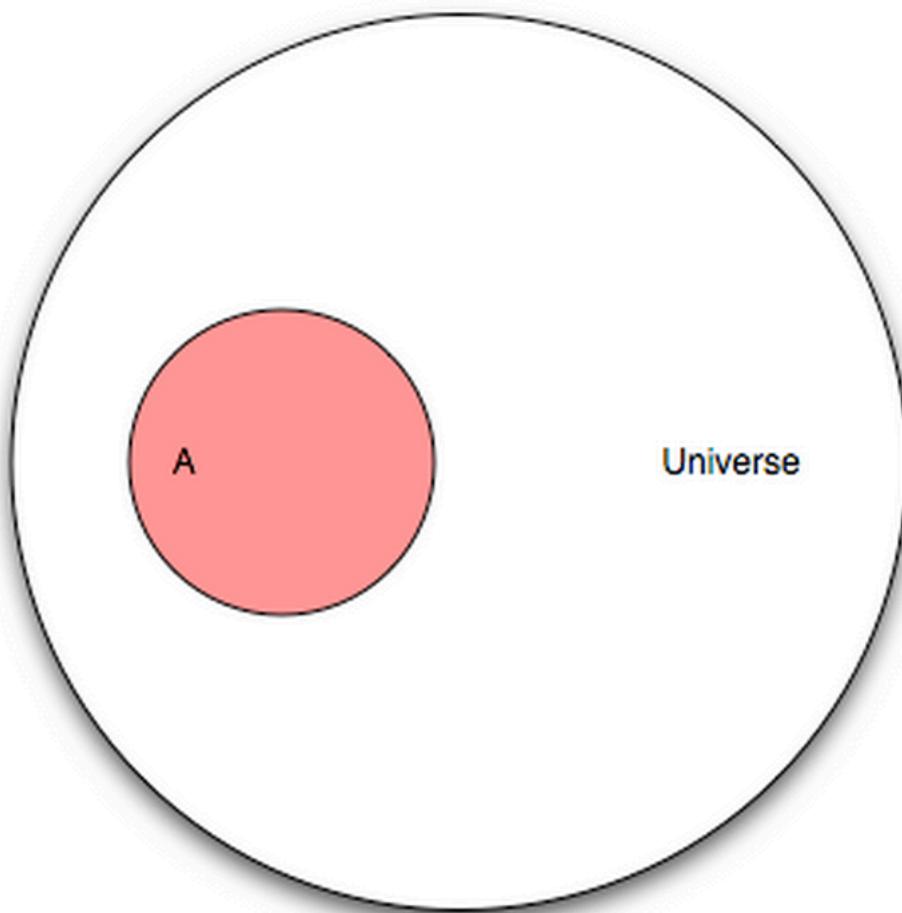
DATA SCIENCE BOOTCAMP

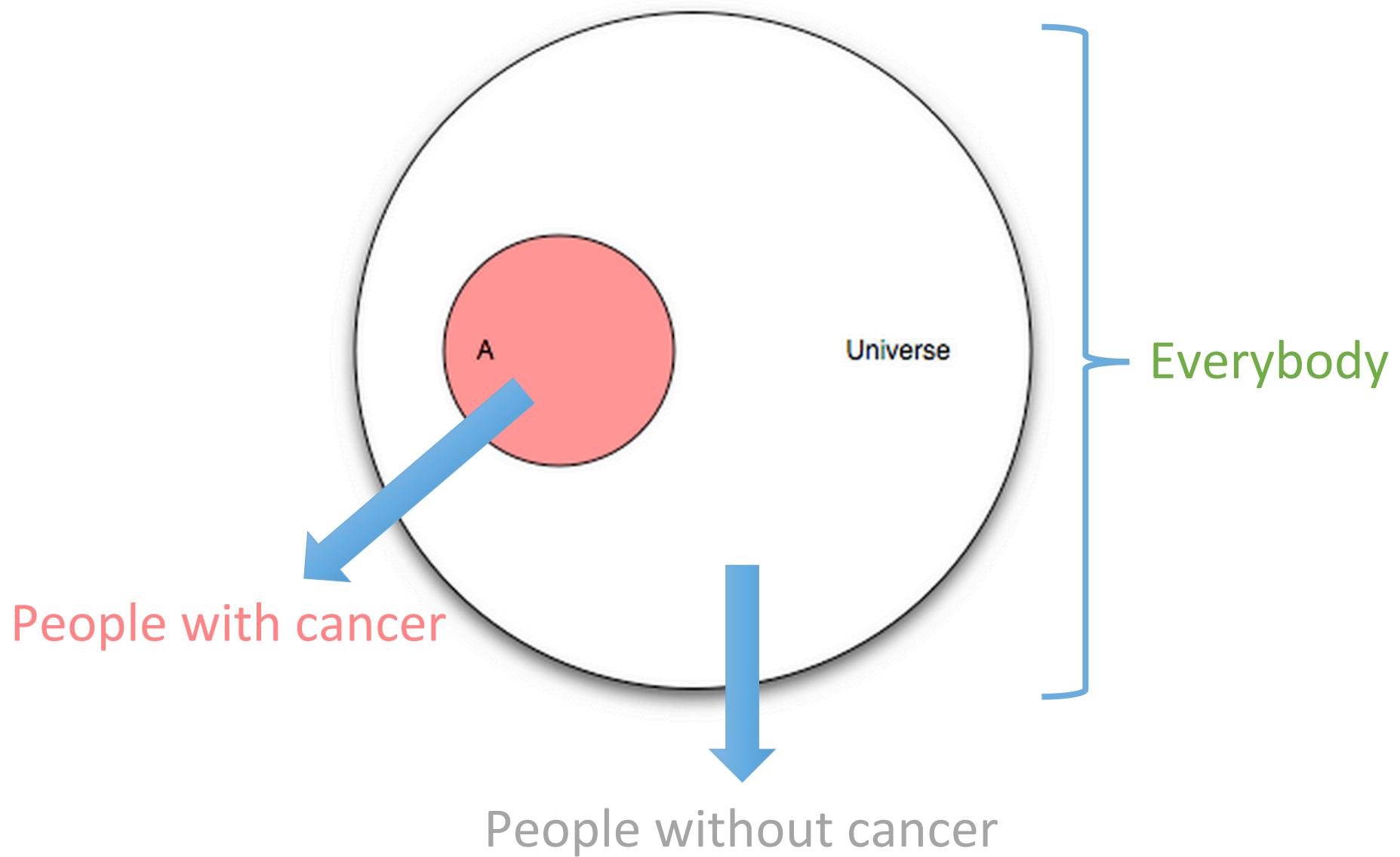
Thug Life. Gangsta.



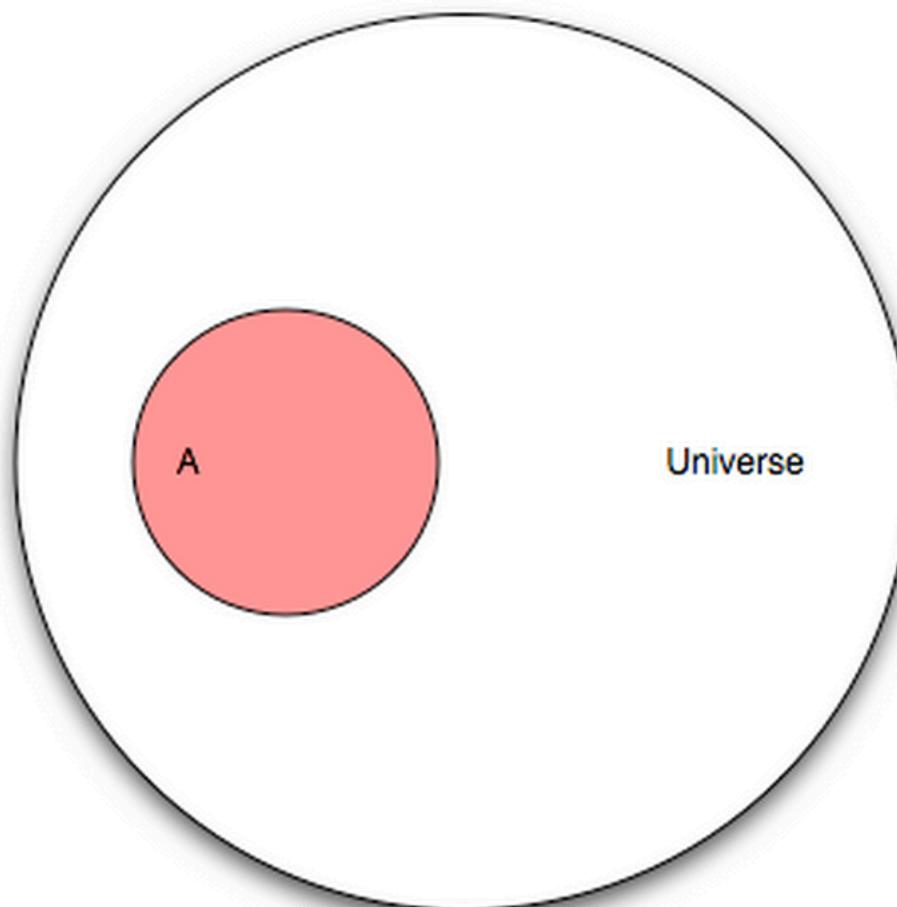
Bayes

If a person **tested positive** for cancer,
what is the probability of him/her actually having cancer?

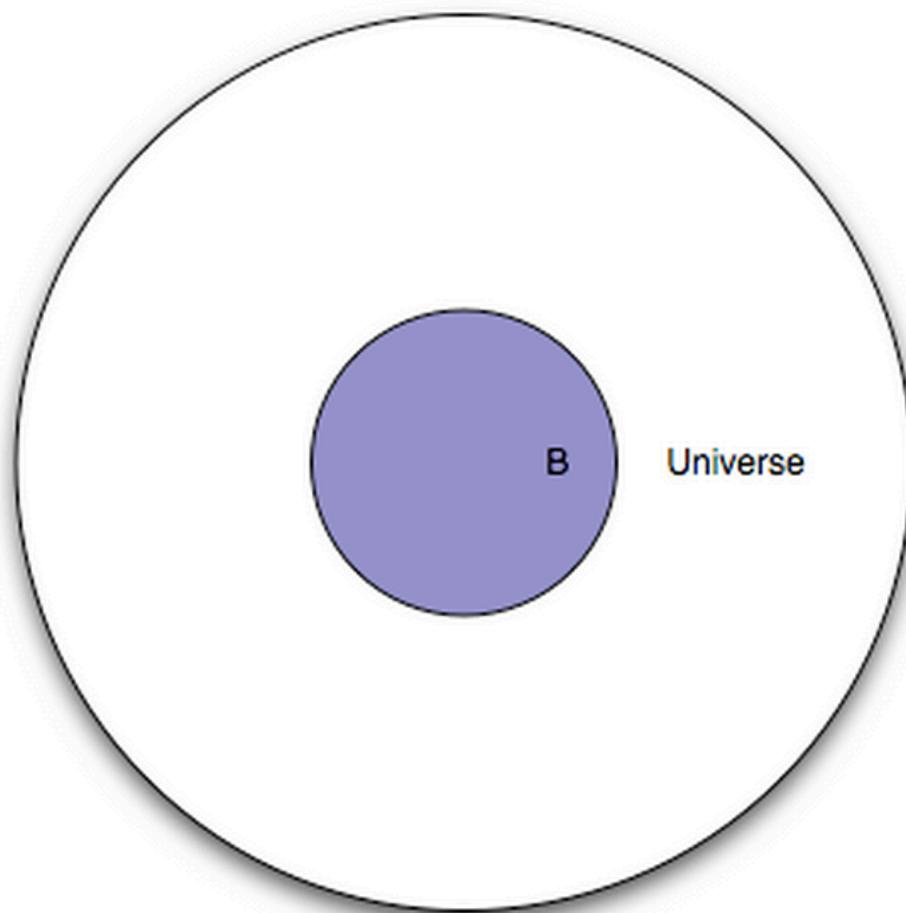




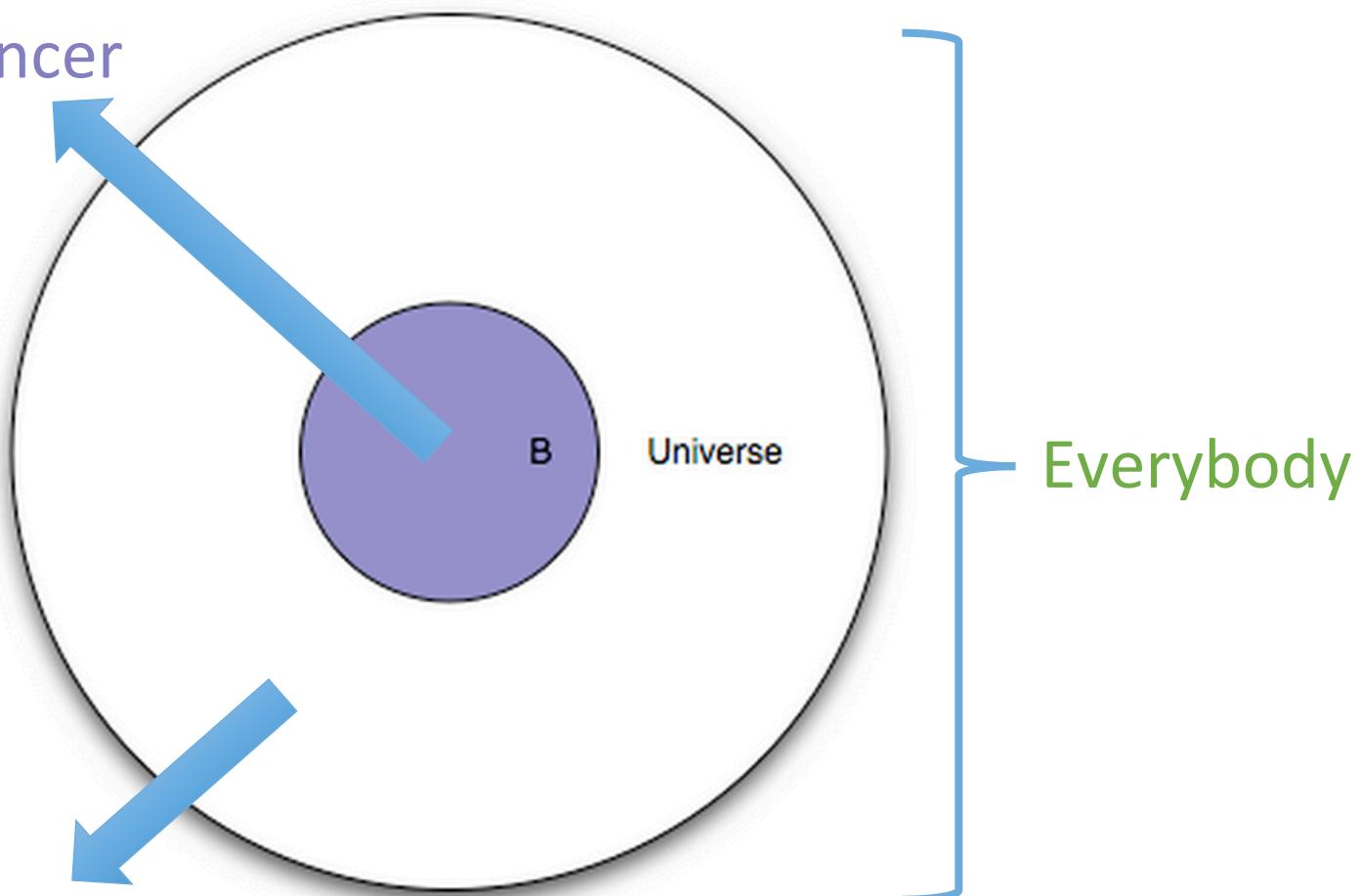
If I picked a random person from the universe, what is the probability of him/her having cancer?



$$P(A) = \frac{|A|}{|U|}$$

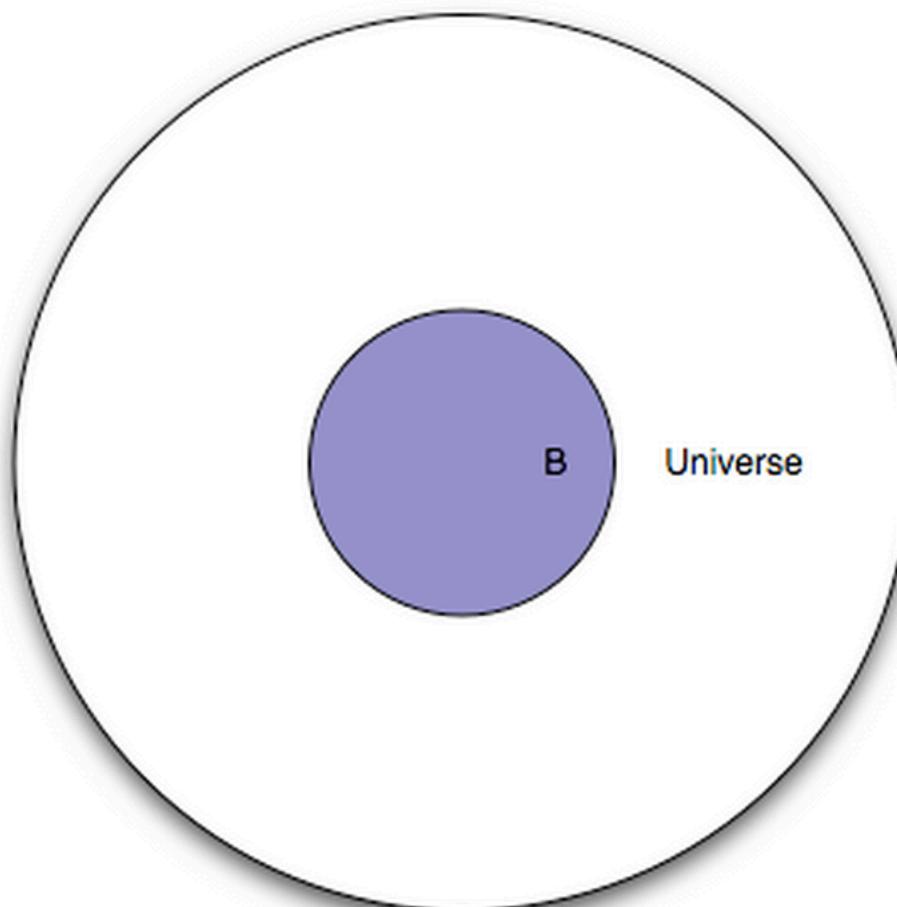


People that test
positive for cancer

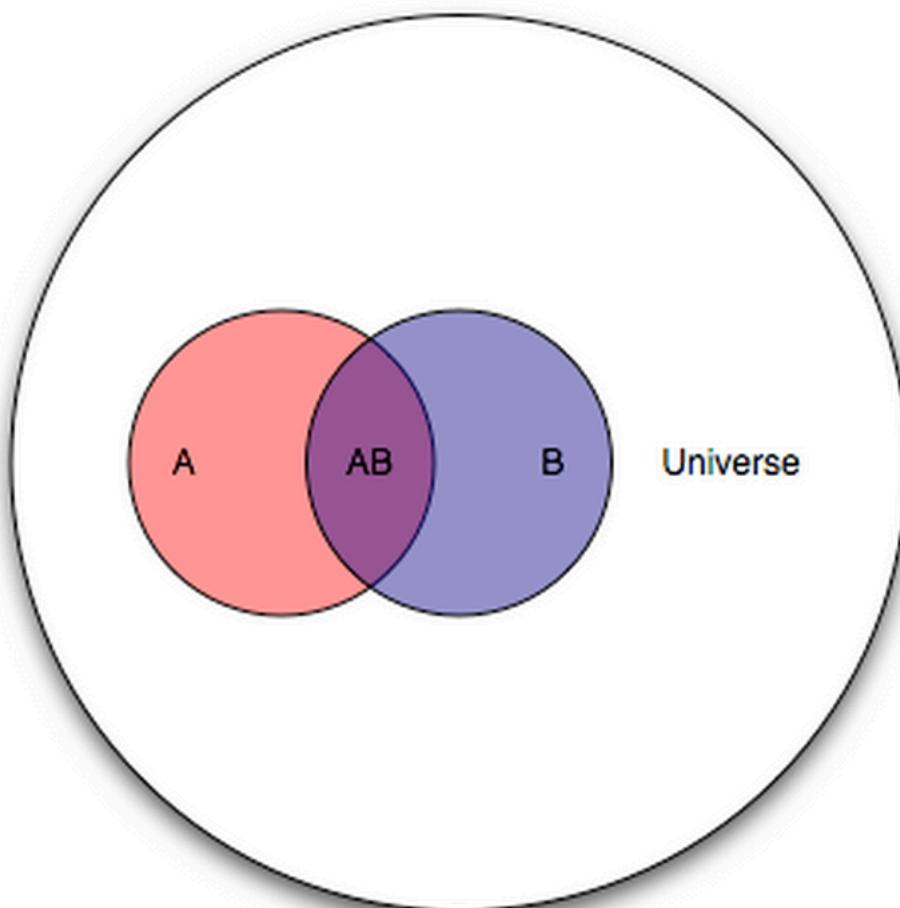


People that test
negative for cancer

If I picked a random person from the universe,
what is the probability of him/her testing positive for cancer?

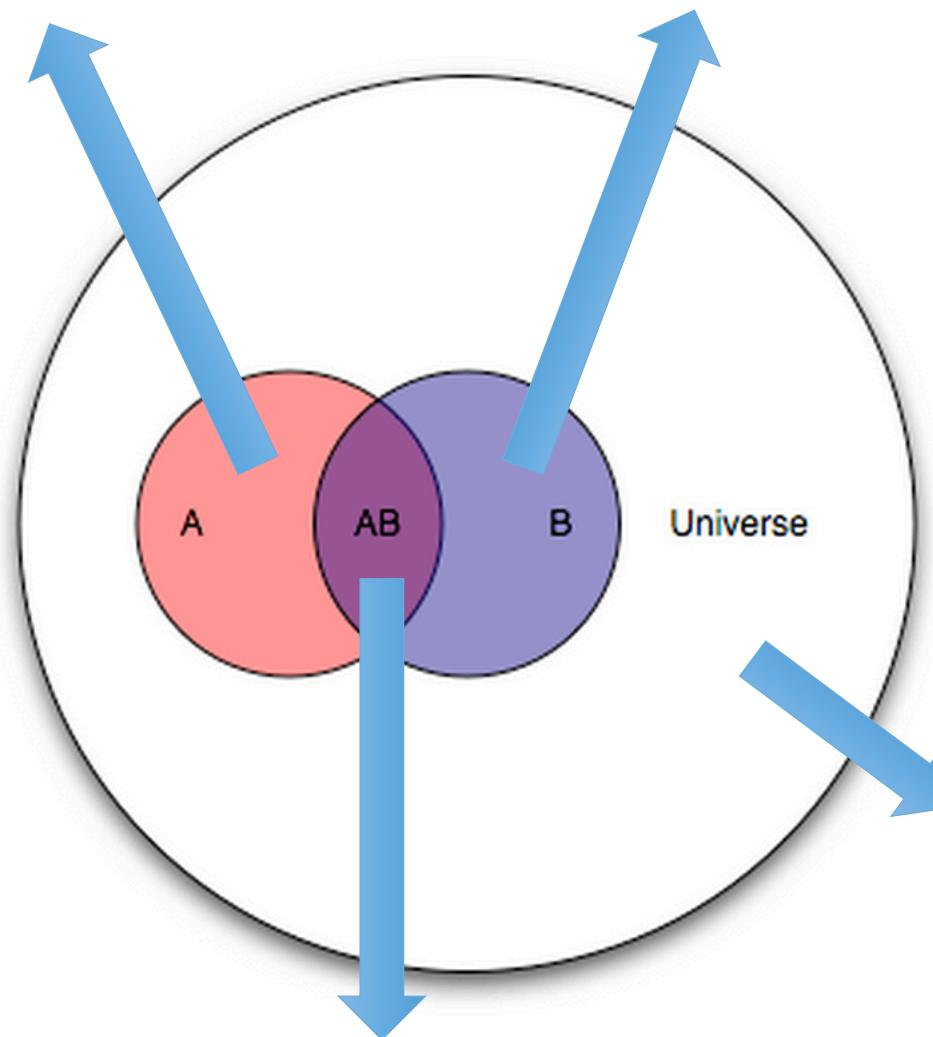


$$P(B) = \frac{|B|}{|U|}$$



People with cancer
that test negative

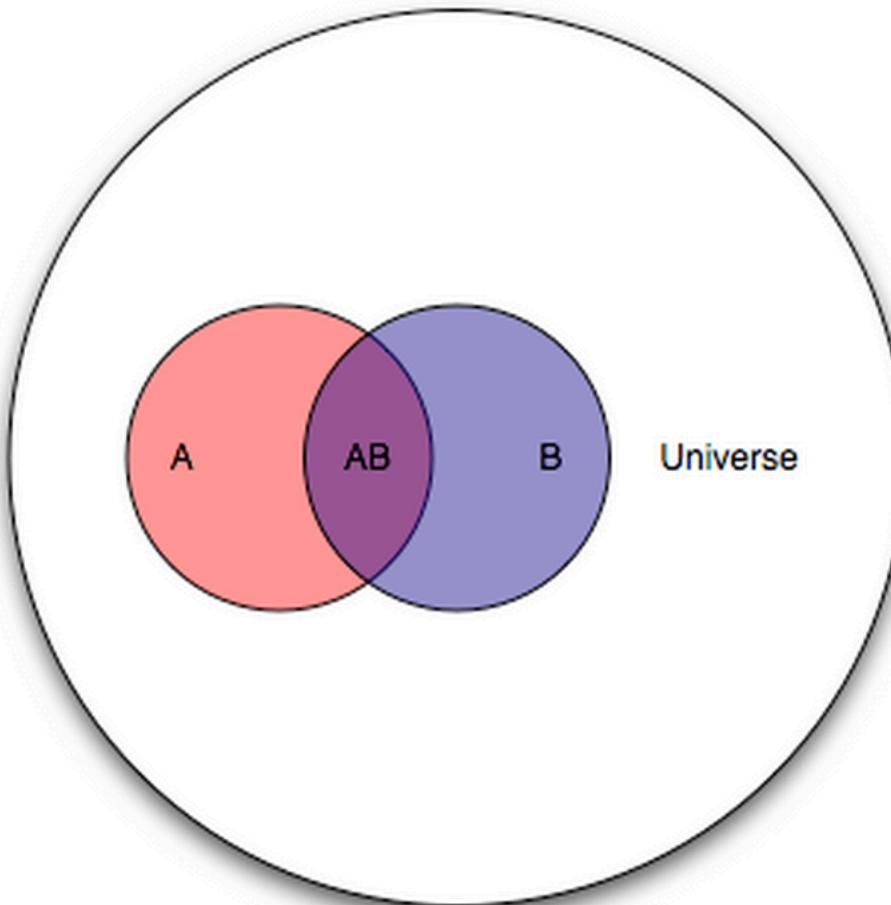
People without cancer
that test positive



People with cancer
that test positive

People without
cancer that
test negative

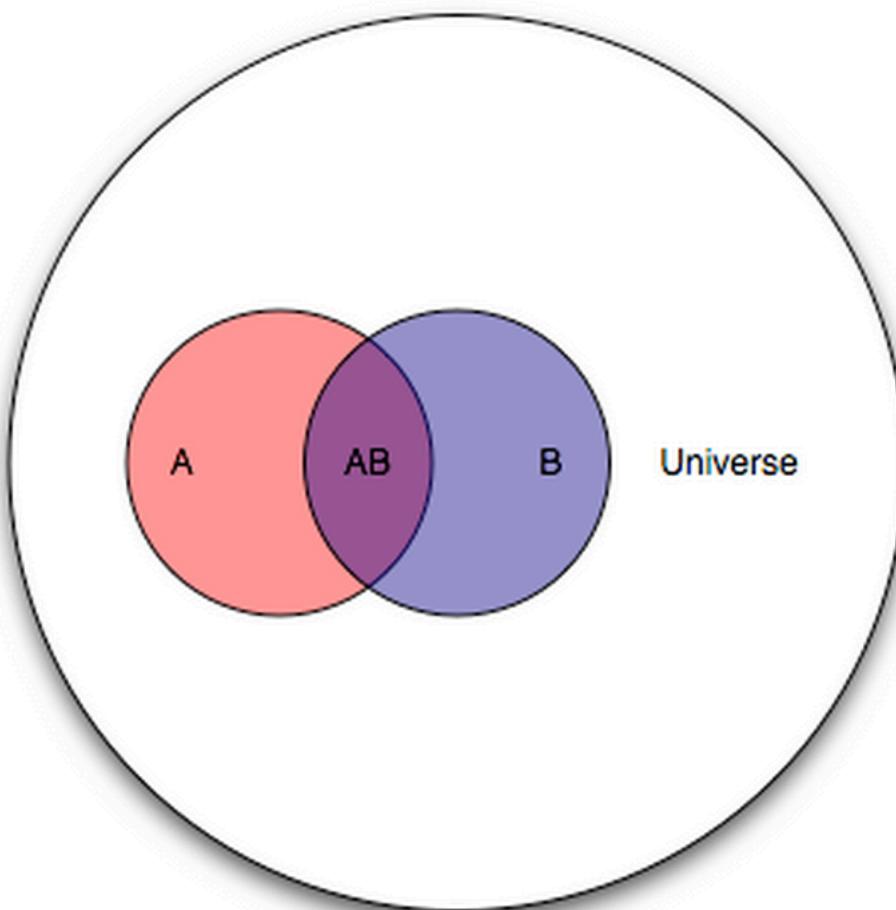
If I picked a random person from the universe,
what is the prob. of them
having cancer **AND** testing positive for cancer?



$$P(A, B) = \frac{|AB|}{|U|}$$

Joint
probability

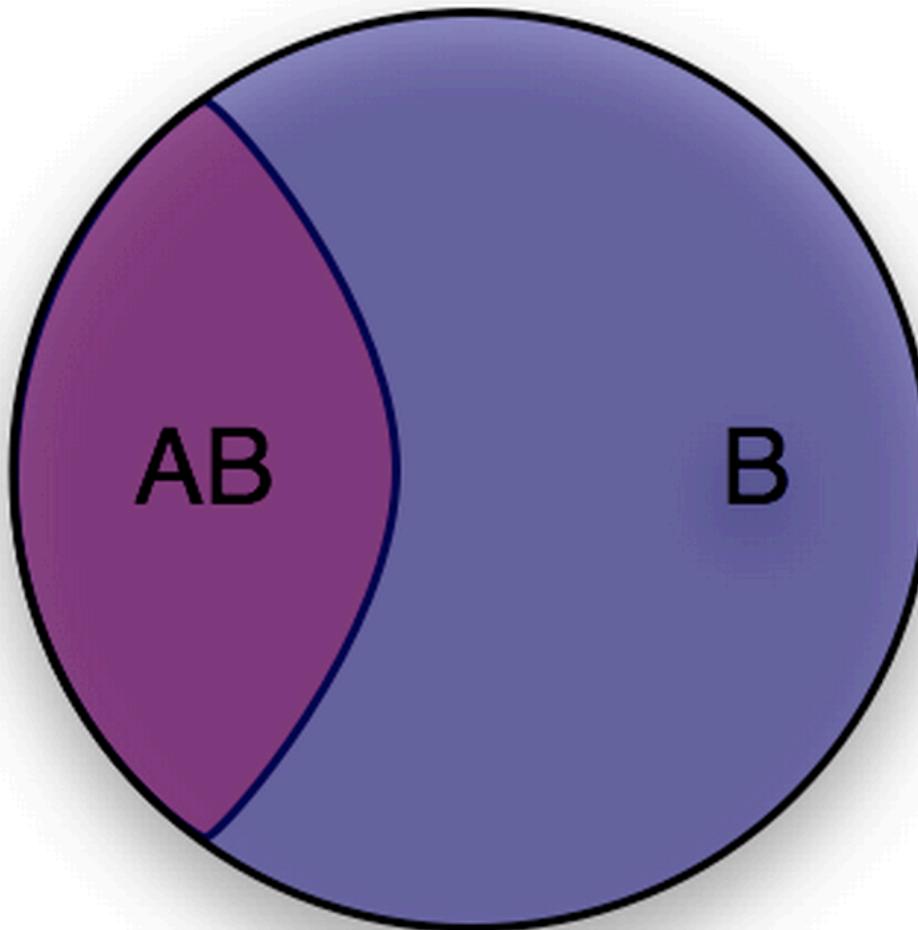
If I picked a random person **that tested positive**,
what is the prob. of him/her actually having cancer?



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

Conditional
probability

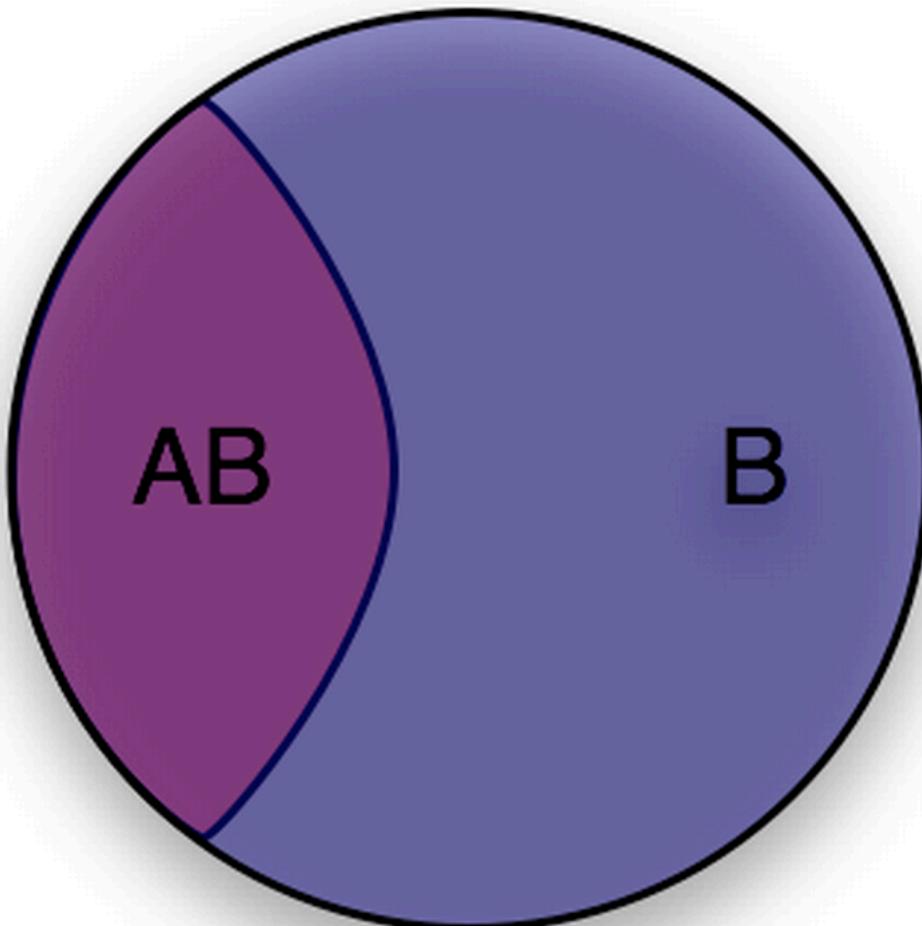
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$$P(A | B) = \frac{|AB|}{|B|}$$

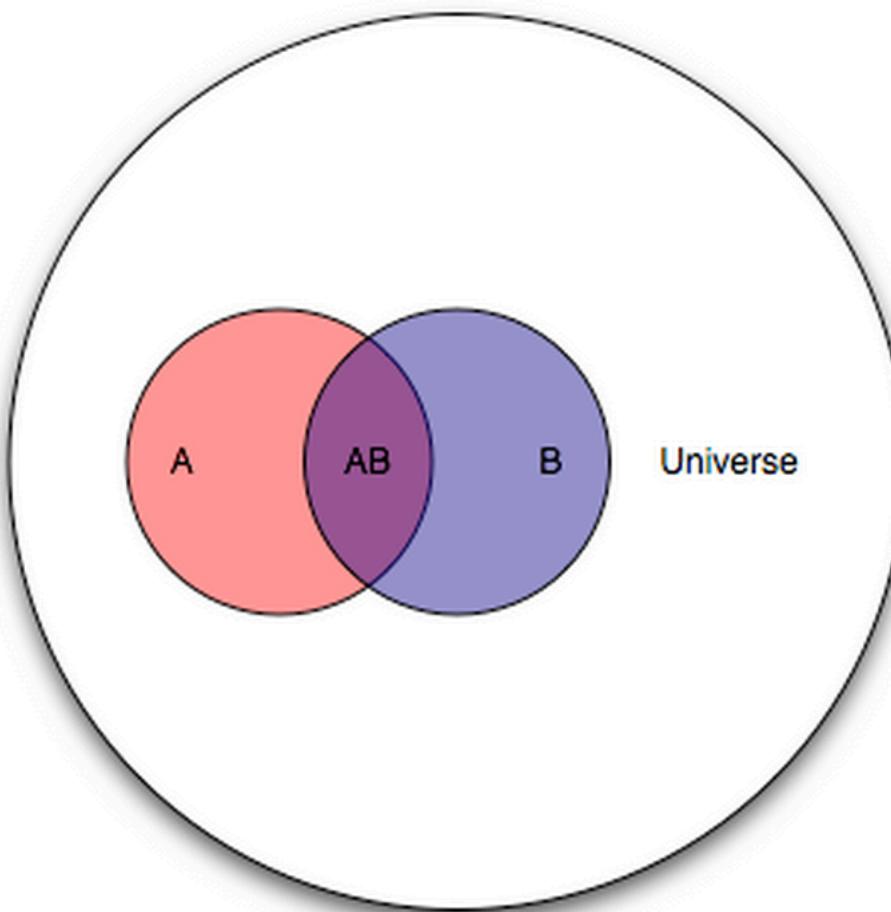
Conditional
probability

If I picked a random person **that tested positive**,
what is the prob. of him/her actually having cancer?



$$P(A|B) = \frac{|AB|}{|B|} = \frac{|AB|/|U|}{|B|/|U|} = \frac{P(A,B)}{P(B)}$$

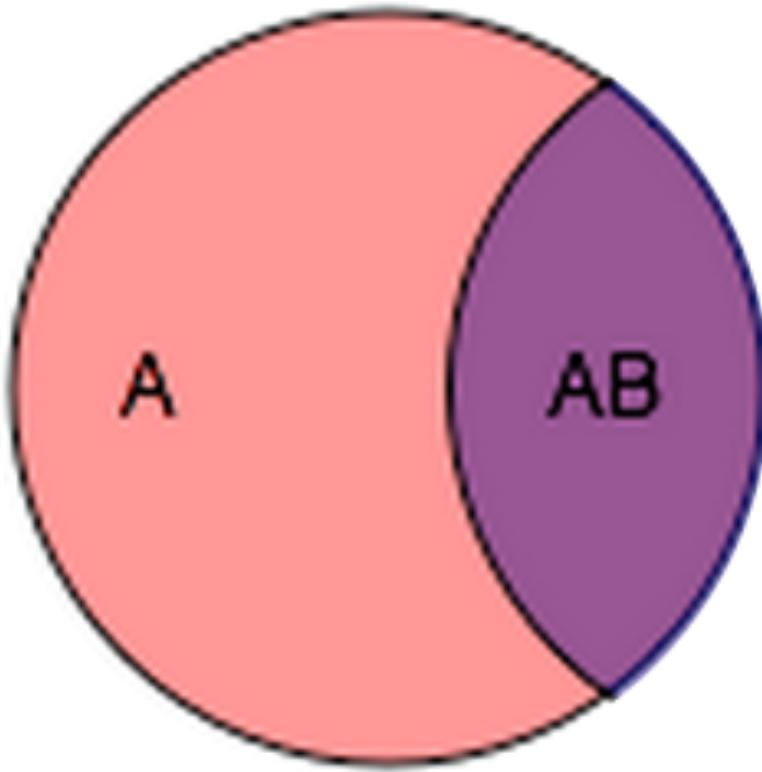
If I picked a random person **that has cancer**,
what is the prob. of him/her testing positive?



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

Conditional
probability

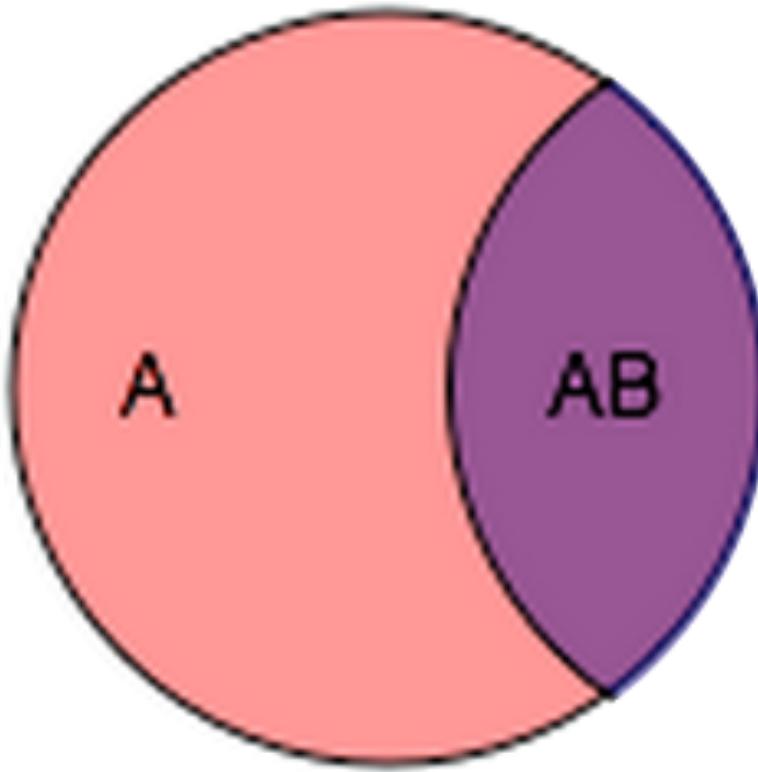
If I picked a random person **that has cancer**,
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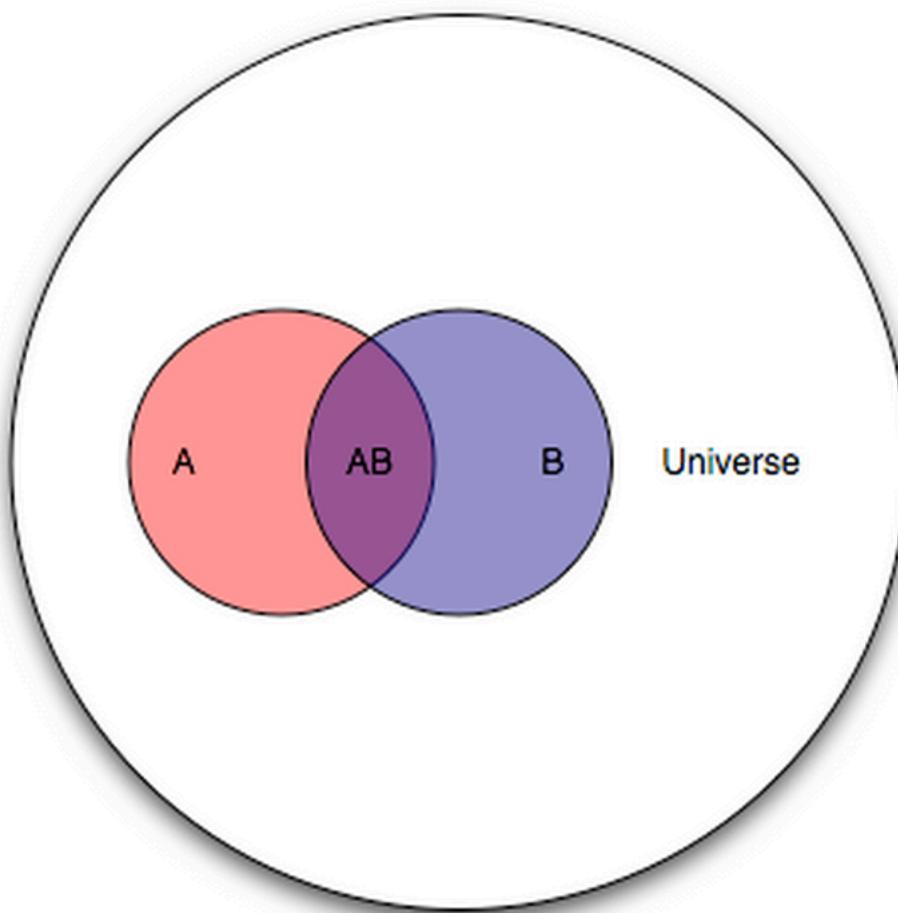
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Conditional
probability

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$$P(B|A) = \frac{|AB|}{|A|} = \frac{|AB|/|U|}{|A|/|U|} = \frac{P(A,B)}{P(A)}$$

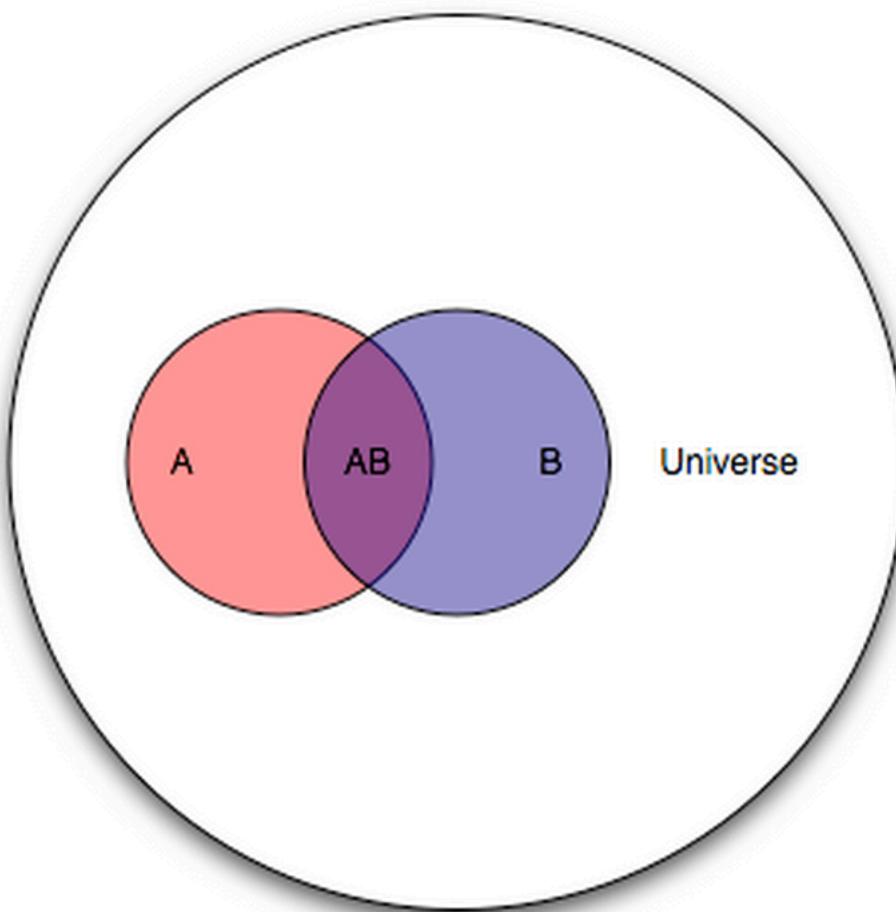


$P(\text{test positive} \mid \text{has cancer})$

$$P(B \mid A) = \frac{P(A, B)}{P(A)}$$

$P(\text{has cancer} \mid \text{test positive})$

$$P(A \mid B) = \frac{P(A, B)}{P(B)}$$

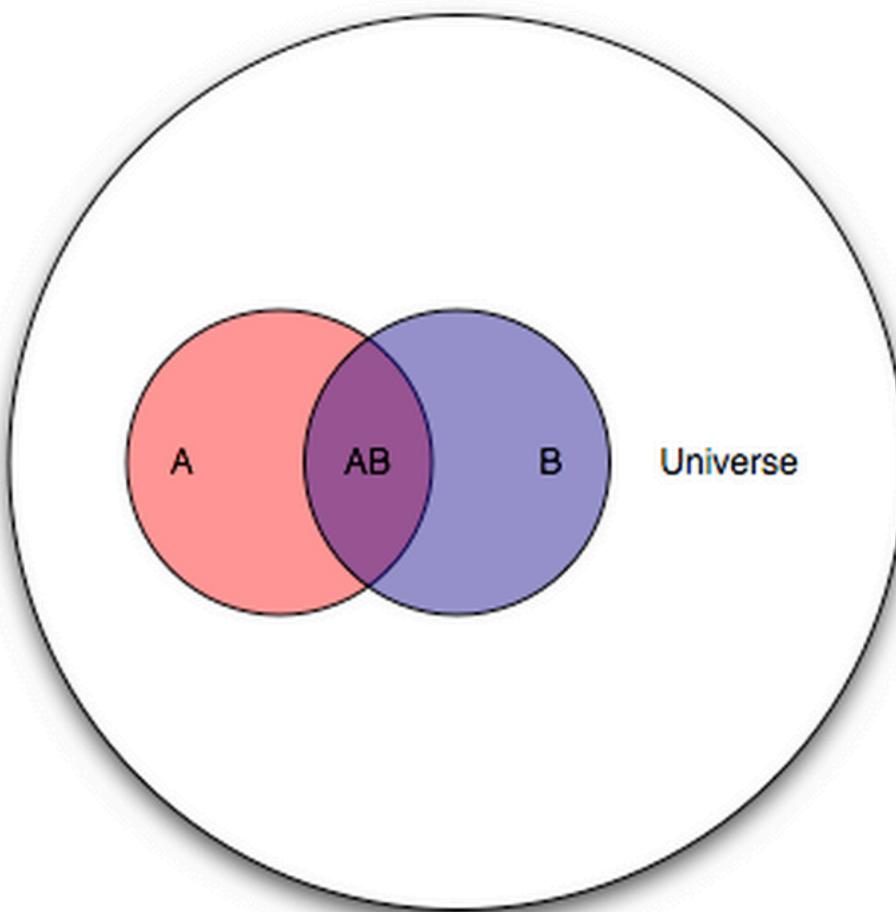


$P(\text{test positive} \mid \text{has cancer})$

$P(\text{has cancer} \mid \text{test positive})$

$$P(B \mid A)P(A) = P(A, B)$$

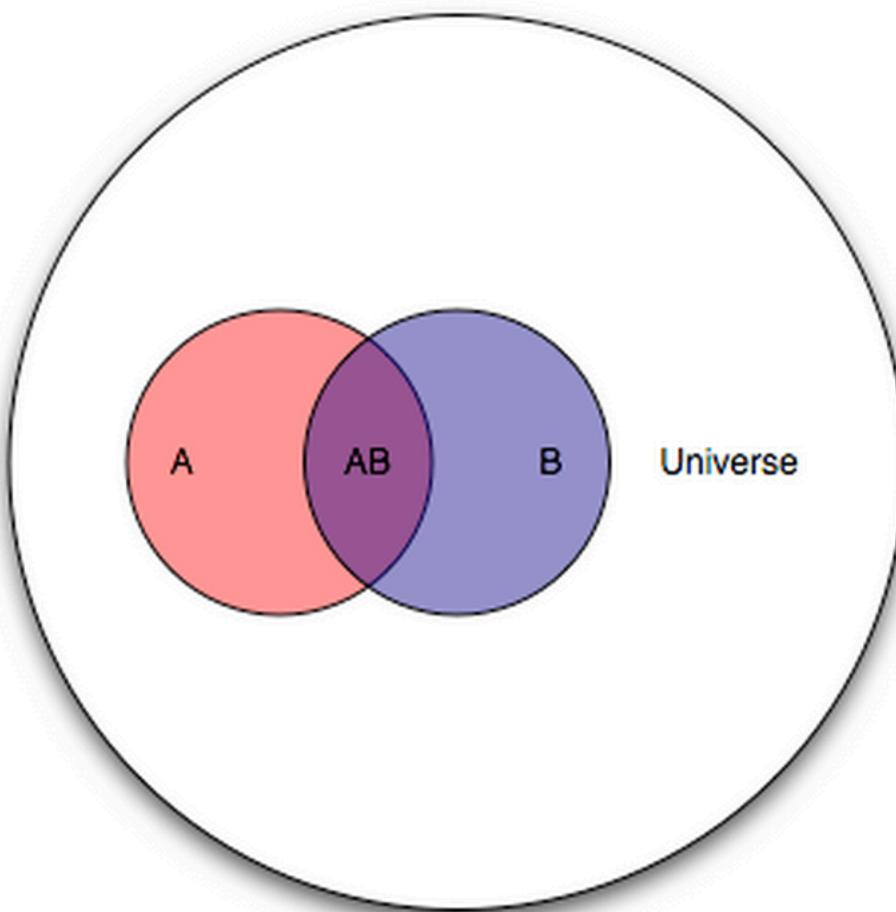
$$P(A, B) = P(A \mid B)P(B)$$



$P(\text{test positive} \mid \text{has cancer})$

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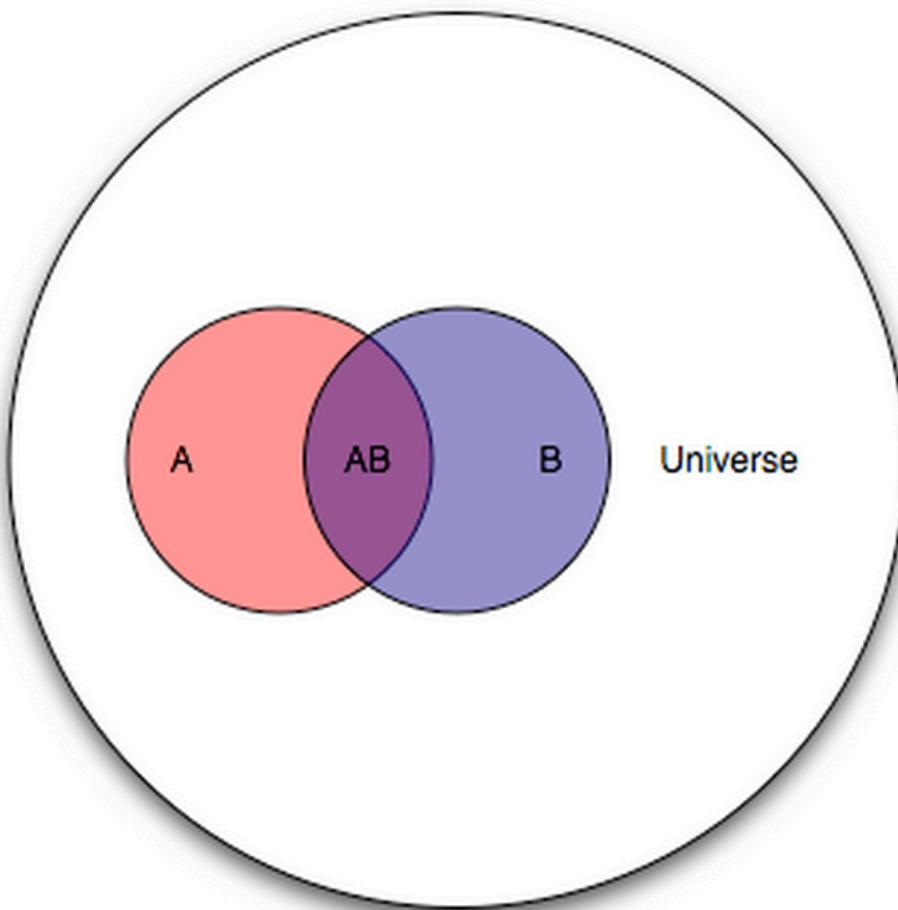
$$P(B \mid A)P(A) = P(A, B) = P(A \mid B)P(B)$$



$P(\text{test positive} \mid \text{has cancer})$

$P(\text{has cancer} \mid \text{test positive})$

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

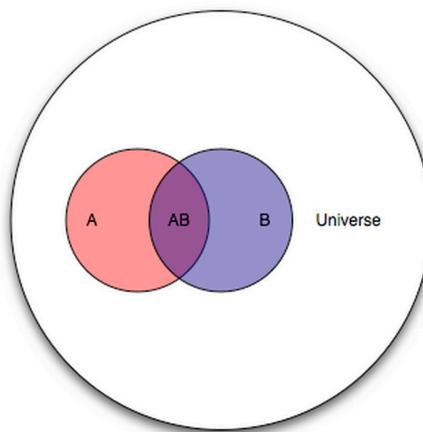


$$P(\text{test positive} \mid \text{has cancer}) \quad P(\text{has cancer} \mid \text{test positive})$$

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

P(has cancer)

P(test positive)



$$P(\text{has cancer} \mid \text{test positive}) = \frac{P(\text{test positive} \mid \text{has cancer}) P(\text{has cancer})}{P(\text{test positive})}$$

$$P(A \mid B) = \frac{P(B \mid A)P(A)}{P(B)}$$

1% of women at age forty who participate in routine screening have breast cancer. 80% of women with breast cancer will get positive mammograms. 9.6% of women without breast cancer will also get positive mammograms. A woman in this age group had a positive mammography in a routine screening. What is the probability that she actually has breast cancer?

$$P(\text{has cancer} \mid \text{test positive}) = \frac{P(\text{test positive} \mid \text{has cancer}) P(\text{has cancer})}{P(\text{test positive})}$$

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$$P(\text{has cancer}) = 0.01$$

$$P(\text{has cancer} \mid \text{test positive}) = \frac{P(\text{test positive} \mid \text{has cancer}) P(\text{has cancer})}{P(\text{test positive})}$$

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$$P(\text{has cancer}) = 0.01$$

$$P(\text{test positive} \mid \text{has cancer}) = 0.80$$

$$P(\text{has cancer} \mid \text{test positive}) = \frac{P(\text{test positive} \mid \text{has cancer}) P(\text{has cancer})}{P(\text{test positive})}$$

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$$P(\text{has cancer}) = 0.01$$

$$P(\text{test positive} \mid \text{has cancer}) = 0.80$$

$$\begin{aligned} P(\text{test positive}) &= P(\text{test positive, has cancer}) \\ &\quad + P(\text{test positive, not cancer}) \end{aligned}$$

$$P(\text{has cancer} \mid \text{test positive}) = \frac{P(\text{test positive} \mid \text{has cancer}) P(\text{has cancer})}{P(\text{test positive})}$$

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$$P(\text{test positive} \mid \text{has cancer}) = 0.80$$

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$$\begin{aligned} P(\text{test positive}) &= P(\text{test positive} \mid \text{has cancer}) P(\text{has cancer}) \\ &\quad + P(\text{test positive} \mid \text{not cancer}) P(\text{not cancer}) \\ &= 0.80 P(\text{has cancer}) + 0.096 P(\text{not cancer}) \end{aligned}$$

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$$P(\text{test positive}) = 0.103$$

$$P(\text{has cancer} \mid \text{test positive}) = \frac{P(\text{test positive} \mid \text{has cancer}) P(\text{has cancer})}{P(\text{test positive})}$$

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$$P(\text{has cancer} \mid \text{test positive}) = ?$$

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$$P(\text{test positive}) = 0.103$$

$$P(\text{has cancer} \mid \text{test positive}) = \frac{0.80 * 0.01}{0.103} = 0.078$$

$$P(\text{has cancer} \mid \text{test positive}) = \frac{P(\text{test positive} \mid \text{has cancer}) P(\text{has cancer})}{P(\text{test positive})}$$

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ONLY 7.8%

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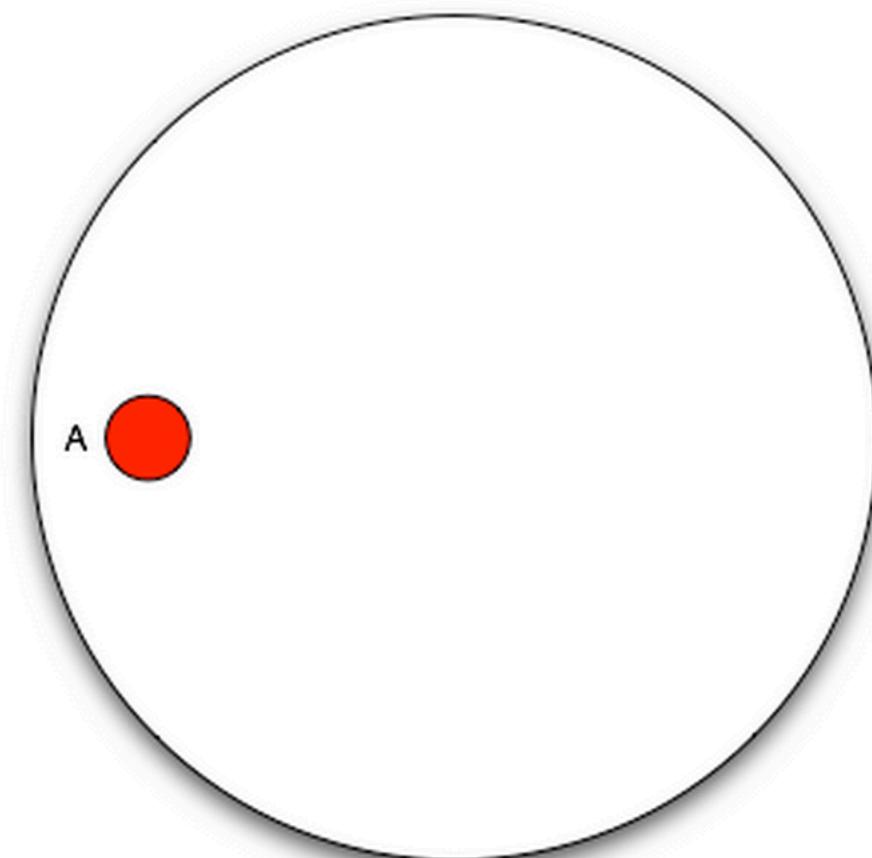
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ONLY 7.8%

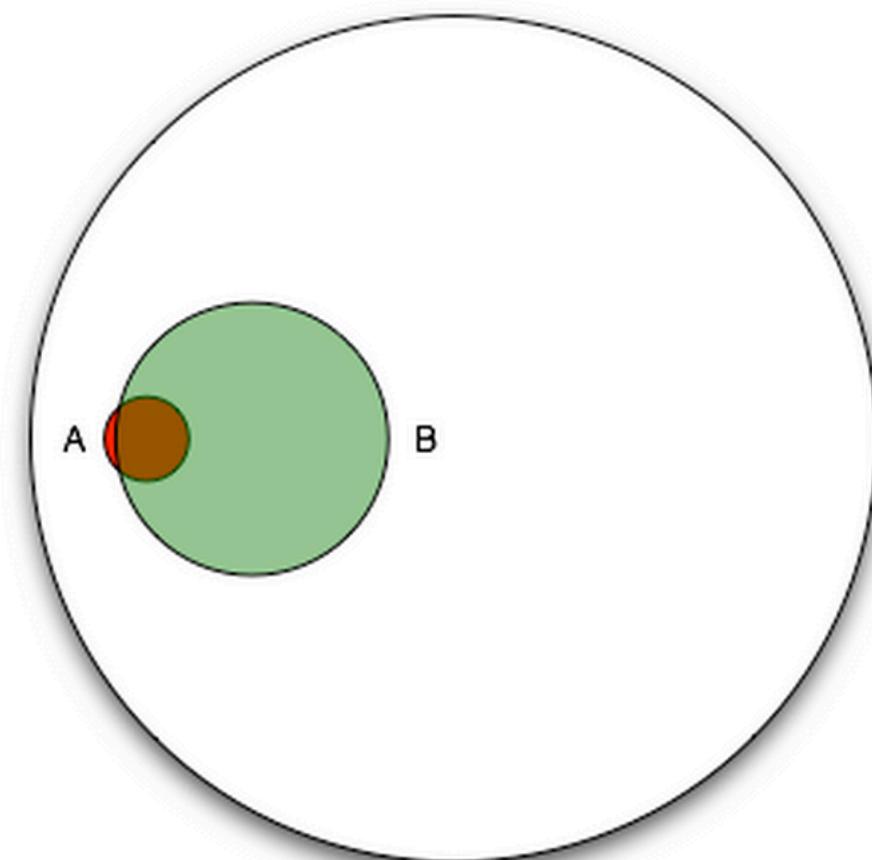
Most doctors guessed ~80%

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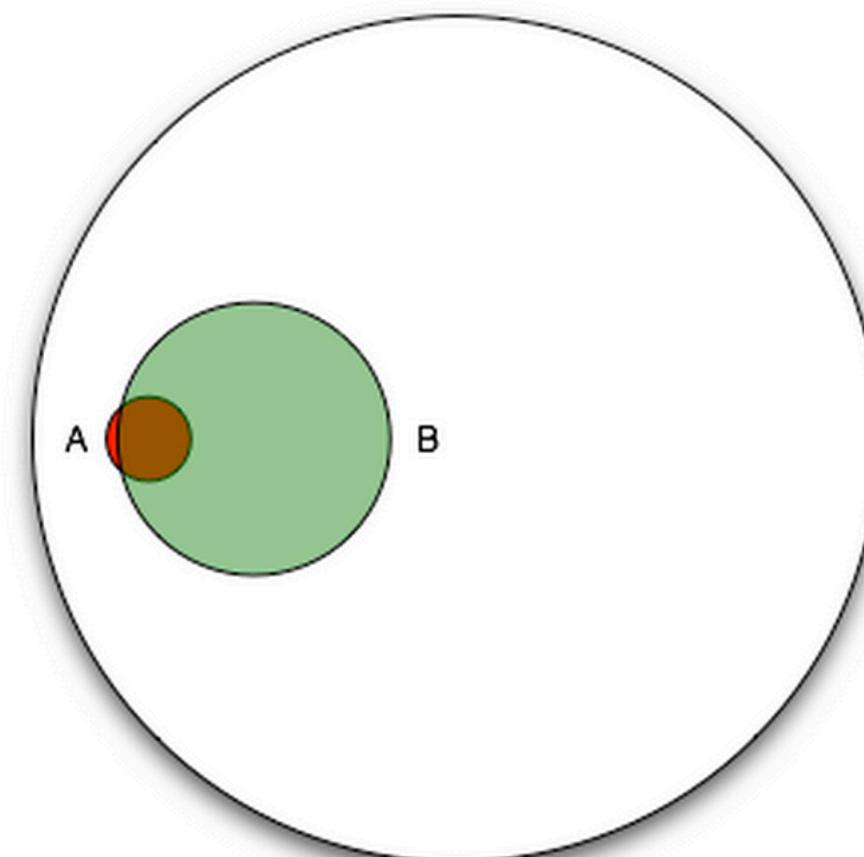
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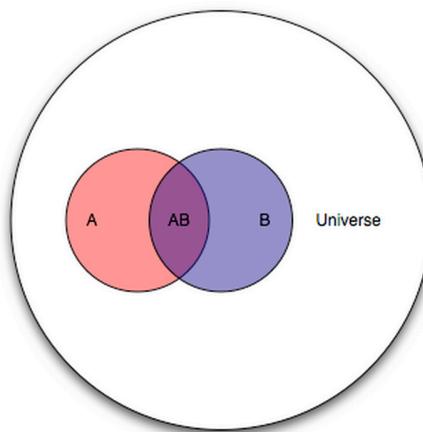


$$|A|/|U| = 1\%$$

$$|AB|/|A| = 80\%$$

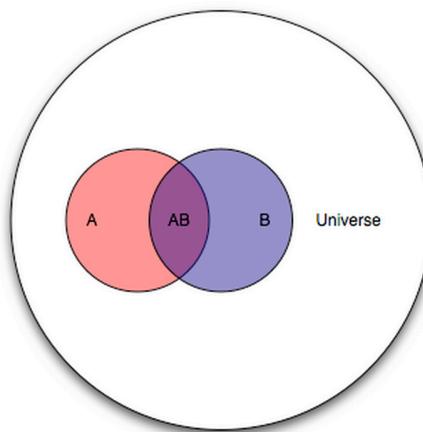
$$(|B| - |AB|)/(|U| - |A|) = 9.6\%$$

$$|AB|/|B| = 7.8\%$$



$$P(\text{has cancer} \mid \text{test positive}) = \frac{P(\text{test positive} \mid \text{has cancer}) P(\text{has cancer})}{P(\text{test positive})}$$

$$P(A \mid B) = \frac{P(B \mid A)P(A)}{P(B)}$$



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Another Perspective:
(Updating Knowledge)

$$P(A \mid B) = \frac{\text{posterior}}{\text{evidence}} = \frac{\text{likelihood}}{\text{prior}} = \frac{P(B \mid A)P(A)}{P(B)}$$

Movie Example:

What is the probability of a movie with Meryl Streep in it getting an Oscar nomination?



Movie Example:

What is the probability of a movie with Meryl Streep in it getting an Oscar nomination?
(in a given year, for Meryl Streep)



P(oscar nomination | Meryl Streep in the movie) = ?



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

P(oscar nomination | Meryl Streep in the movie) = ?

P(oscar nomination) = # nominated / # released



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



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NOMINEES

— The 87th Academy Award Nominations for the 2015 Oscars

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BEST PICTURE

American Sniper

Clint Eastwood, Robert Lorenz,
Andrew Lazar, Bradley Cooper and
Peter Morgan

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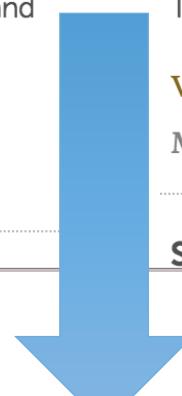
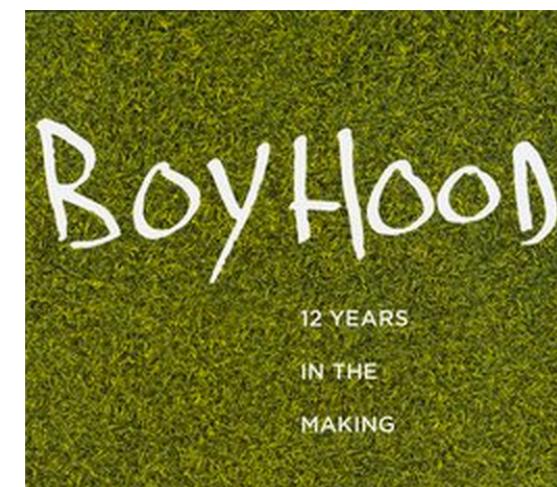
The Imitation Game

Nora Grossman, Ido Ostrowsky and
Teddy Schwarzman

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Selma



ACTRESS — in a Leading Role

Marion Cotillard

Two Days, One Night

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Felicity Jones

The Theory of Everything

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Rosamund Pike

Gone Girl

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[More Information](#)

Reese Witherspoon

Wild

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Winner

Julianne Moore

Still Alice

[View Trailer / ▶](#)



- Julianne Moore

ACTRESS

—*in a Supporting Role*

Patricia Arquette

Boyhood

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Laura Dern

Wild

[View Trailer / ▶](#)

[More Information](#)

Keira Knightley

The Imitation Game

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Emma Stone

Birdman or (The Unexpected Virtue of Ignorance)

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Meryl Streep

Into the Woods

[View Trailer / ▶](#)

[More Information](#)



Make Your Pick

- Meryl Streep

P(oscar nomination | Meryl Streep in the movie) = ?

P(oscar nomination) $\approx 10 / \# \text{ released}$



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



how many american movies released per year



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Number of Feature Film Produced by Country, latest ...

[chartsbin.com/view/pu4](#) ▾

This chart shows **number of feature film produced** in **each country**. Feature **film produced** include productions and co-productions. **Number of feature ...** Follow us...
Number of Feature Film Produced by Country, latest available year. Hello, you ...

Cinema of the United States - Wikipedia, the free encyclopedia

[en.wikipedia.org/wiki/Cinema_of_the_United_States](#) ▾ Wikipedia ▾

Jump to **Rise of Hollywood** - Before World War I, **movies** were **made** in several **U.S.** cities, but ... new, **many** Jewish immigrants found employment in the **U.S. film** industry.
... a **year**, seen by an audience of 90 million **Americans** per week.

[PDF] Theatrical Market Statistics - Motion Picture Association of...

[www.mpaa.org/.../2012-Theatrica...](#) ▾ Motion Picture Association of America ▾

Global box office for all films **released** in **each** country around the world reached ... saw increases in the **number of** frequent moviegoers in nearly **every** ethnicity and age ... International box office in **U.S.** dollars is up 32% over five **years** ago.

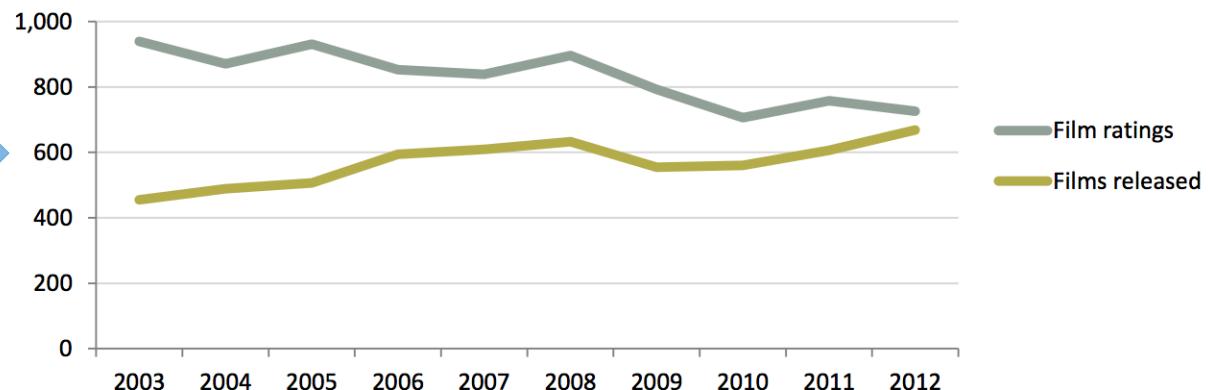


Films rated, released and produced

In 2012, the number of films rated by the Classification and Ratings Administration (CARA) was down 4% compared to 2011. The number of films released in theaters in U.S./Canada was up 10% compared to 2011, and up 5% from the previous historic high in 2008.

Films Rated by CARA and Films Released in Domestic Theaters

Sources: CARA (Film ratings), Rentrak Corporation (Films released)



Films rated, including non-theatrical films, decreased to 726 films in 2012, with a 4% drop in both member and non-member films rated. MPAA member films rated have been in decline since 2004, mirroring the decline in MPAA member films released in domestic theaters over the same period (see below).

Film Ratings¹⁶

Source: CARA (Film ratings), MPAA (Subtotals)

	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	12 vs. 11	12 vs. 03
Film ratings	939	867	928	853	840	897	793	706	758	726	-4%	-23%
-MPAA members ¹⁷	339	325	322	296	233	201	177	174	169	162	-4%	-52%

P(oscar nomination | Meryl Streep in the movie) = ?

P(oscar nomination) = 10 / 600



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

P(oscar nomination | Meryl Streep in the movie) = ?

P(oscar nomination) $\approx 10 / 600 = 1.67\%$



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

$P(\text{ oscar nomination} \mid \text{Meryl Streep in the movie}) = ?$

$P(\text{ oscar nomination}) \approx 10 / 600 = 1.67\%$

$P(\text{Meryl Streep in the movie}) = \# \text{ MS movies} / \# \text{ all}$



$$P(A \mid B) = \frac{P(B \mid A)P(A)}{P(B)}$$

P(oscar nomination | Meryl Streep in the movie) = ?

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Meryl Streep

Actress | Soundtrack | Producer



Considered by many critics to be the greatest living actress, Meryl Streep has been nominated for the Academy Award an astonishing 19 times, and has won it three times. Meryl was born Mary Louise Streep in 1949 in Summit, New Jersey, to Mary Wolf (Wilkinson), a commercial artist, and Harry William Streep, Jr., a pharmaceutical executive. Her ...

[See full bio »](#)

Born: [Mary Louise Streep](#)
June 22, 1949 in [Summit, New Jersey, USA](#)

[More at IMDbPro »](#)

Contact Info: [View agent, publicist and legal](#)
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Actress (74 credits)



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Florence Foster Jenkins (*pre-production*)

Florence Foster Jenkins

2015

Suffragette (*post-production*)

Emmeline Pankhurst

2015

Ricki and the Flash (*post-production*)

Ricki

2015

Into the Woods

Witch

2014

The Giver

Chief Elder

2014

The Homesman

Altha Carter

2014

August: Osage County

Violet Weston

2013

Hope Springs

Kay

2012

Web Therapy (TV Series)

Camilla Bowne

- Blindsides and Backslides (2012) ... Camilla Bowne
- Getting It Straight (2012) ... Camilla Bowne

2012

The Iron Lady

Margaret Thatcher

2011

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Kramer vs. Kramer

1979

Joanna Kramer

The Seduction of Joe Tynan

1979

Karen Traynor

Great Performances (TV Series)

1977-1979

Leilah / Edith Varney

- Uncommon Women... and Others (1979) ... Leilah
- Secret Service (1977) ... Edith Varney

Manhattan

1979

Jill

The Deer Hunter

1978

Linda

Holocaust (TV Mini-Series)

1978

Inga Helms Weiss

- Part 4 (1978) ... Inga Helms Weiss
- Part 2 (1978) ... Inga Helms Weiss
- Part I: The Gathering Darkness (1978) ... Inga Helms Weiss

Julia

1977

Anne Marie

The Deadliest Season (TV Movie)

1977

Sharon Miller

Everybody Rides the Carousel

1975

Stage 6 (voice)

Soundtrack (13 credits)

Show ▾

Producer (1 credit)

Show ▾

Thanks (5 credits)

Show ▾

Self (223 credits)

Show ▾

MS movies

74 movies

In 40 years

1.85

Meryl

Movies

per year

on average



P(oscar nomination | Meryl Streep in the movie) = ?

P(oscar nomination) $\approx 10 / 600 = 1.67\%$

P(Meryl Streep in the movie) $\approx 1.85 / 600 = 0.3\%$



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$P(\text{oscar nomination}) \approx 10 / 600 = 1.67\%$

$P(\text{Meryl Streep in the movie}) \approx 1.85 / 600 = 0.3\%$

$P(\text{Meryl Streep in the movie} \mid \text{oscar nomination}) =$
nominated MS movies / all nominated movies



$$P(A \mid B) = \frac{P(B \mid A)P(A)}{P(B)}$$

P(oscar nomination | Meryl Streep in the movie) = ?

P(oscar nomination) $\approx 10 / 600 = 1.67\%$

P(Meryl Streep in the movie) $\approx 1.85 / 600 = 0.3\%$

P(Meryl Streep in the movie | oscar nomination) =
nominated MS movies / 10



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

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Meryl Streep

From Wikipedia, the free encyclopedia

Meryl Streep (born **Mary Louise Streep**; June 22, 1949) is an American actress and producer. A three-time [Academy Award](#) winner, she is widely regarded as one of the greatest film actors of all time.^{[1][2][3]} Streep made her professional stage debut in *The Playboy of Seville* in 1971, and went on to receive a 1976 [Tony Award](#) nomination for [Best Featured Actor in a Play](#) for *A Memory of Two Mondays/27 Wagons Full of Cotton*. She made her screen debut in the 1977 television film *The Deadliest Season*, and made her film debut later that same year in *Julia*. In 1978, she won an [Emmy Award](#) for her role in the miniseries *Holocaust*, and received the first of her 19 Academy Award nominations for *The Deer Hunter*. She has more Academy Award nominations than any actor or actress in history, winning [Best Supporting Actress](#) for *Kramer vs. Kramer* (1979) and [Best Actress](#) for *Sophie's Choice* (1982) and *The Iron Lady* (2011).

Streep is one of only six actors who have won three or more competitive Academy Awards for acting. Her other nominated roles include *The French Lieutenant's Woman* (1981), *Silkwood* (1983), *Out of Africa* (1985), *A Cry in the Dark* (1988), *Hearts From the Edge* (1990), *The Bridges of Madison County* (1995), *Adaptation* (2002), *The Devil Wears Prada* (2006), *Doubt* (2008), *Julie & Julia* (2009), *August: Osage County* (2013), and *Into the Woods* (2014). She returned to the stage for the first time in over 20 years when *The Public Theater*'s 2002 revival of *The Seagull*, won a second Emmy Award in 2014 for the HBO miniseries *Angels in America* (2003), and starred in the Public Theater's 2014 production of

Meryl Streep
Ordre des Arts et des Lettres



Streep at the 2014 SAG Awards.

Born	Mary Louise Streep June 22, 1949 (age 65) Summit, New Jersey, U.S.
Occupation	Actress, producer
Years active	1971–present
Spouse(s)	Don Gummer (1978–present)

19 nominations 40 years → 0.475 nominations per year!

P(oscar nomination | Meryl Streep in the movie) = ?

P(oscar nomination) $\approx 10 / 600 = 1.67\%$

P(Meryl Streep in the movie) $\approx 1.85 / 600 = 0.3\%$

P(Meryl Streep in the movie | oscar nomination) =
nominated MS movies / 10



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

$P(\text{oscar nomination} \mid \text{Meryl Streep in the movie}) = ?$

$P(\text{oscar nomination}) \approx 10 / 600 = 1.67\%$

$P(\text{Meryl Streep in the movie}) \approx 1.85 / 600 = 0.3\%$

$P(\text{Meryl Streep in the movie} \mid \text{oscar nomination}) =$
 $0.475 / 10$



$$P(A \mid B) = \frac{P(B \mid A)P(A)}{P(B)}$$

$P(\text{oscar nomination} \mid \text{Meryl Streep in the movie}) = ?$

$P(\text{oscar nomination}) \approx 10 / 600 = 1.67\%$

$P(\text{Meryl Streep in the movie}) \approx 1.85 / 600 = 0.3\%$

$P(\text{Meryl Streep in the movie} \mid \text{oscar nomination}) = 4.8\%$

$0.475 / 10$



$$P(A \mid B) = \frac{P(B \mid A)P(A)}{P(B)}$$

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$P(\text{Meryl Streep in the movie} \mid \text{oscar nomination}) = 4.8\%$

$0.475 / 10$

$P(\text{nom} \mid \text{MS}) = P(\text{MS} \mid \text{nom})P(\text{nom}) / P(\text{MS})$



$$P(A \mid B) = \frac{P(B \mid A)P(A)}{P(B)}$$

$P(\text{oscar nomination} \mid \text{Meryl Streep in the movie}) = ?$

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$$0.475 / 10$$

$$\begin{aligned} P(\text{nom} \mid \text{MS}) &= P(\text{MS} \mid \text{nom})P(\text{nom}) / P(\text{MS}) \\ &= 4.8\% * 1.67\% / 0.3\% \end{aligned}$$



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$$0.475 / 10$$

$$\begin{aligned} P(\text{nom} \mid \text{MS}) &= P(\text{MS} \mid \text{nom})P(\text{nom}) / P(\text{MS}) \\ &= 4.8\% * 1.67\% / 0.3\% \\ &= 25.7\% \end{aligned}$$



$$P(A \mid B) = \frac{P(B \mid A)P(A)}{P(B)}$$

$P(\text{oscar nomination} \mid \text{Meryl Streep in the movie}) = ?$



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$$P(A \mid B) = \frac{P(B \mid A)P(A)}{P(B)}$$

$P(\text{oscar nomination} \mid \text{Meryl Streep in the movie}) = ?$

$= \# \text{ MS movie nominations} / \# \text{ MS movies}$



$$\begin{aligned} P(\text{nom} \mid \text{MS}) &= P(\text{MS} \mid \text{nom})P(\text{nom}) / P(\text{MS}) \\ &= 4.8\% * 1.67\% / 0.3\% \\ &= 25.7\% \end{aligned}$$

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$P(\text{oscar nomination} \mid \text{Meryl Streep in the movie}) = ?$

= # MS movie nominations / # MS movies

= (0.475 nom per year) / (1.85 MS movies per year)



$$P(\text{nom} \mid \text{MS}) = P(\text{MS} \mid \text{nom})P(\text{nom}) / P(\text{MS})$$

$$= 4.8\% * 1.67\% / 0.3\%$$

$$= 25.7\%$$

$$P(A \mid B) = \frac{P(B \mid A)P(A)}{P(B)}$$

$P(\text{oscar nomination} \mid \text{Meryl Streep in the movie}) = ?$

= # MS movie nominations / # MS movies

= (0.475 nom per year) / (1.85 MS movies per year)

= 0.475 / 1.85 = 25.7%

$P(\text{nom} \mid \text{MS}) = P(\text{MS} \mid \text{nom})P(\text{nom}) / P(\text{MS})$

= 4.8% * 1.67% / 0.3%

= 25.7%



$$P(A \mid B) = \frac{P(B \mid A)P(A)}{P(B)}$$

$P(\text{oscar nomination} \mid \text{Meryl Streep in the movie}) = ?$

= # MS movie nominations / # MS movies

= 19 MS nominations / 74 MS movies

= 25.7%

$P(\text{nom} \mid \text{MS}) = P(\text{MS} \mid \text{nom})P(\text{nom}) / P(\text{MS})$

= 4.8% * 1.67% / 0.3%

= 25.7%



$$P(A \mid B) = \frac{P(B \mid A)P(A)}{P(B)}$$

Nominated
non-Meryl movies

Meryl movies
that are not nominated

Nominated
movies
10 per year



Universe

Meryl movies
1.85 per year

Nominated Meryl movies
0.475 per year

Non-Meryl movies
that don't get
nominated

