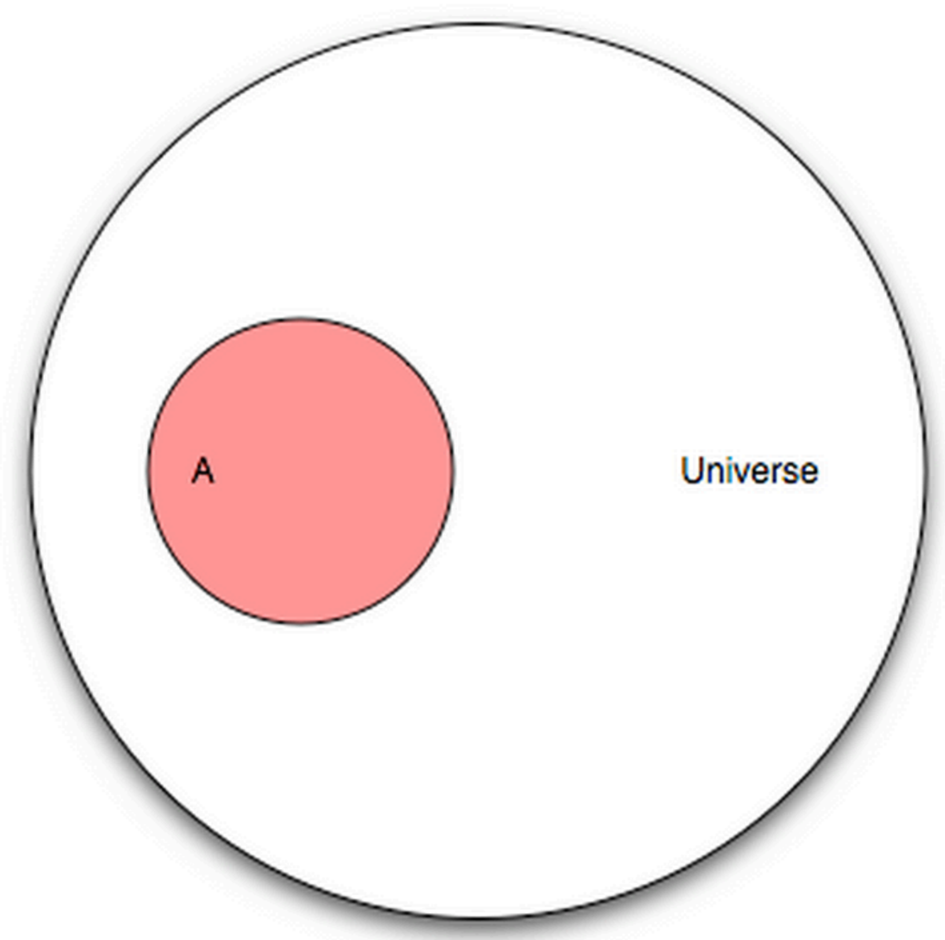
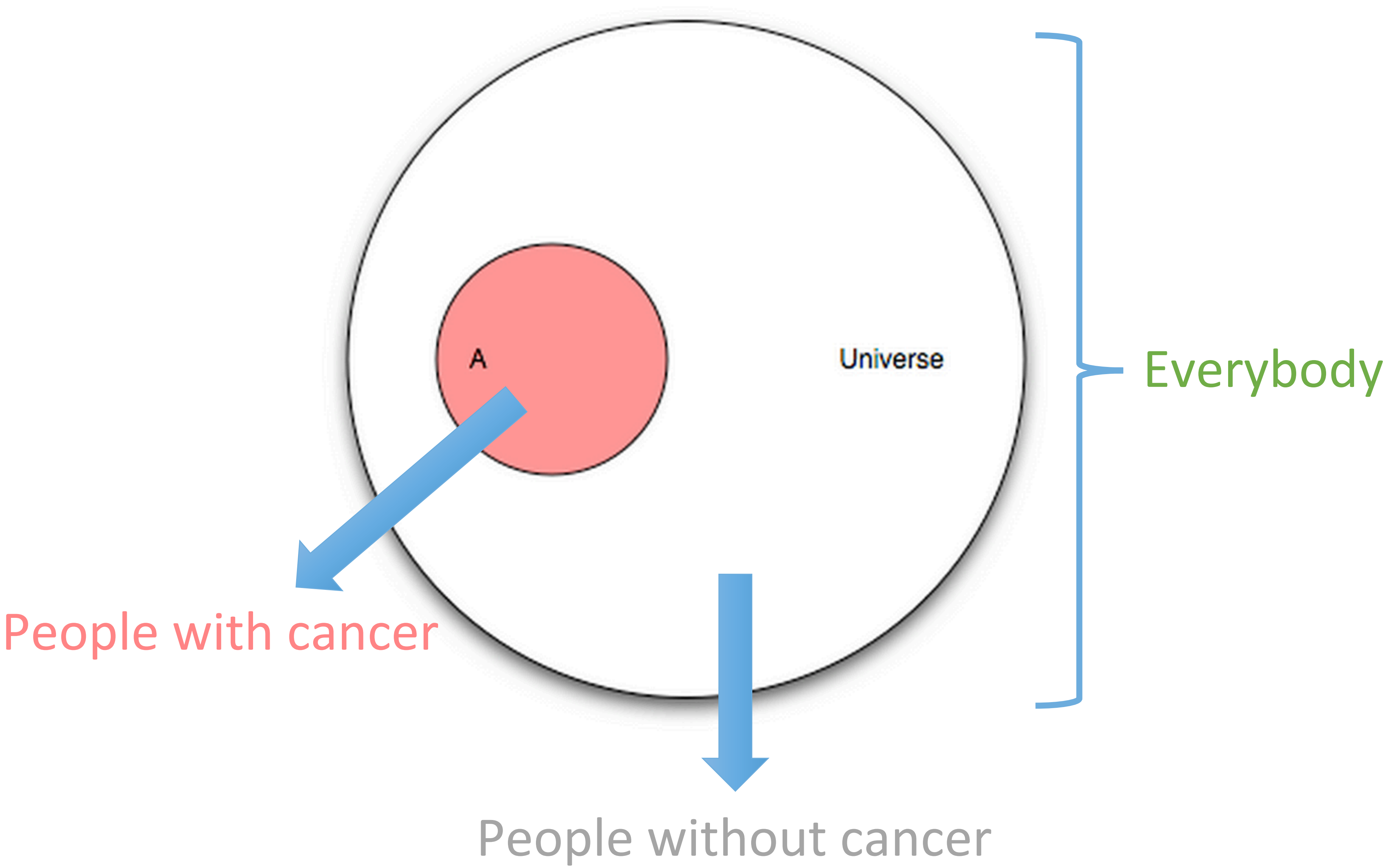
(The Joy of)
Bayes Theorem

DATA SCIENCE BOOTCAMP

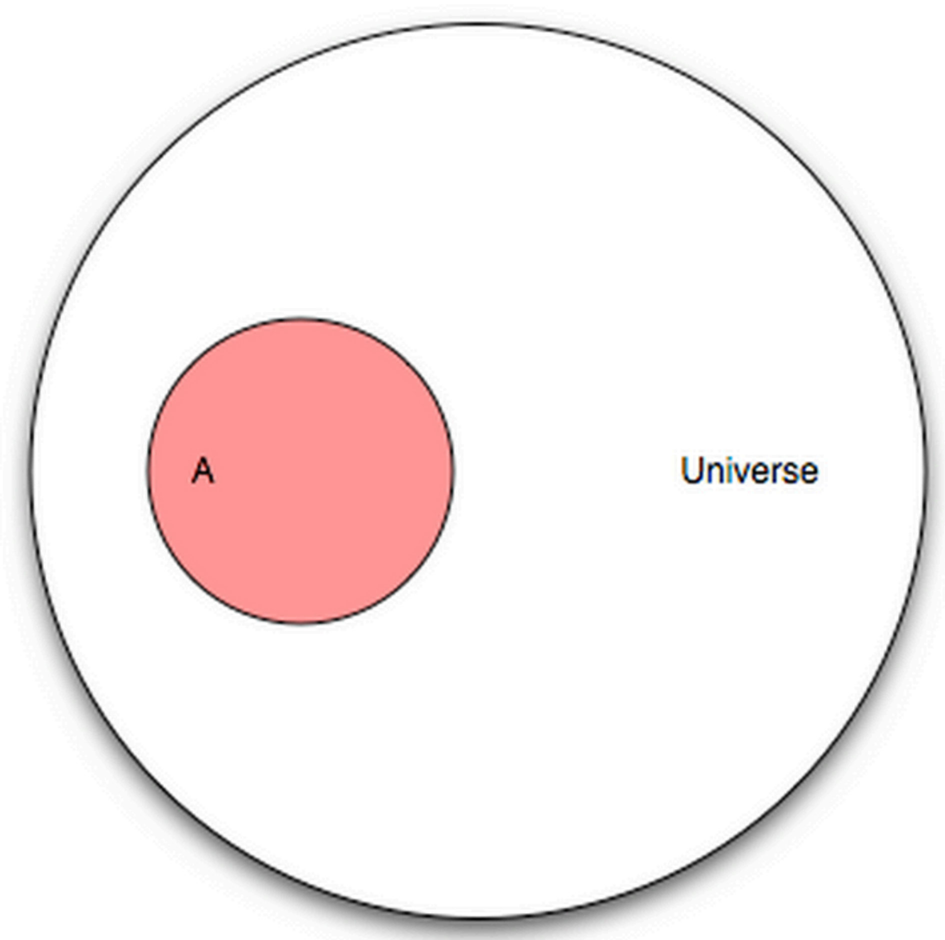
If a person **tested positive** for cancer,
what is the probability of him/her actually having cancer?



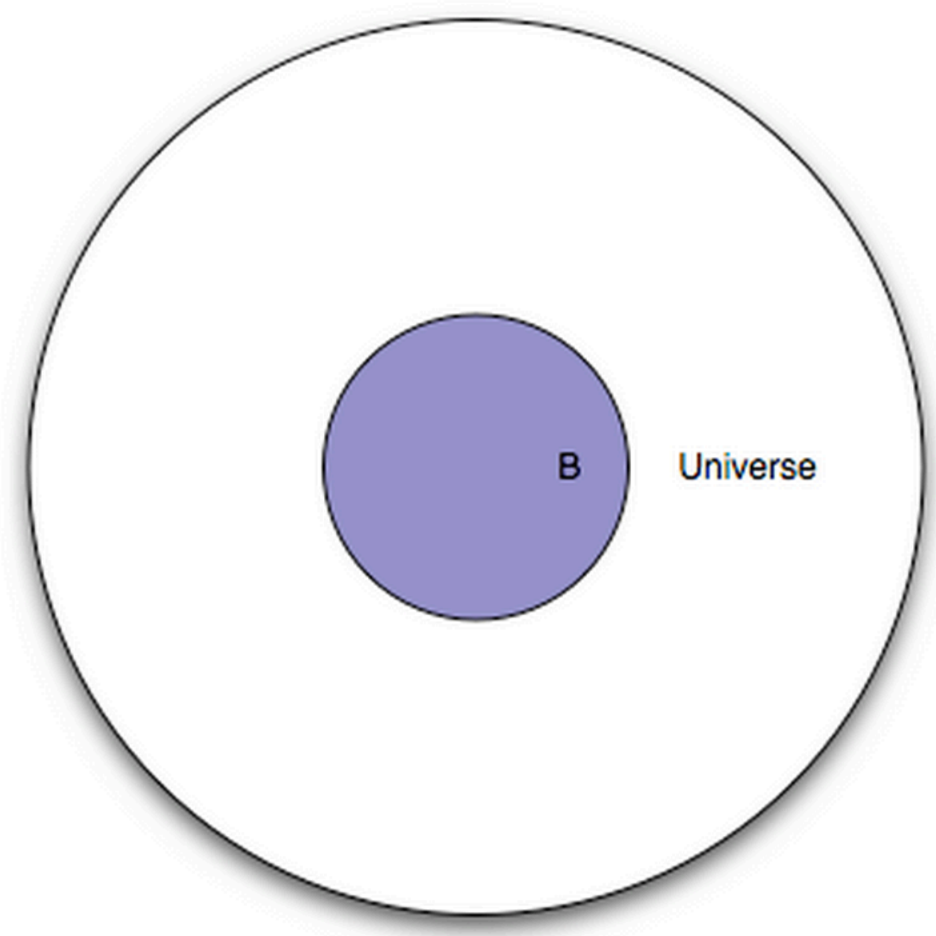
http://oscarbonilla.com/2009/05/visualizing-bayes-theorem/

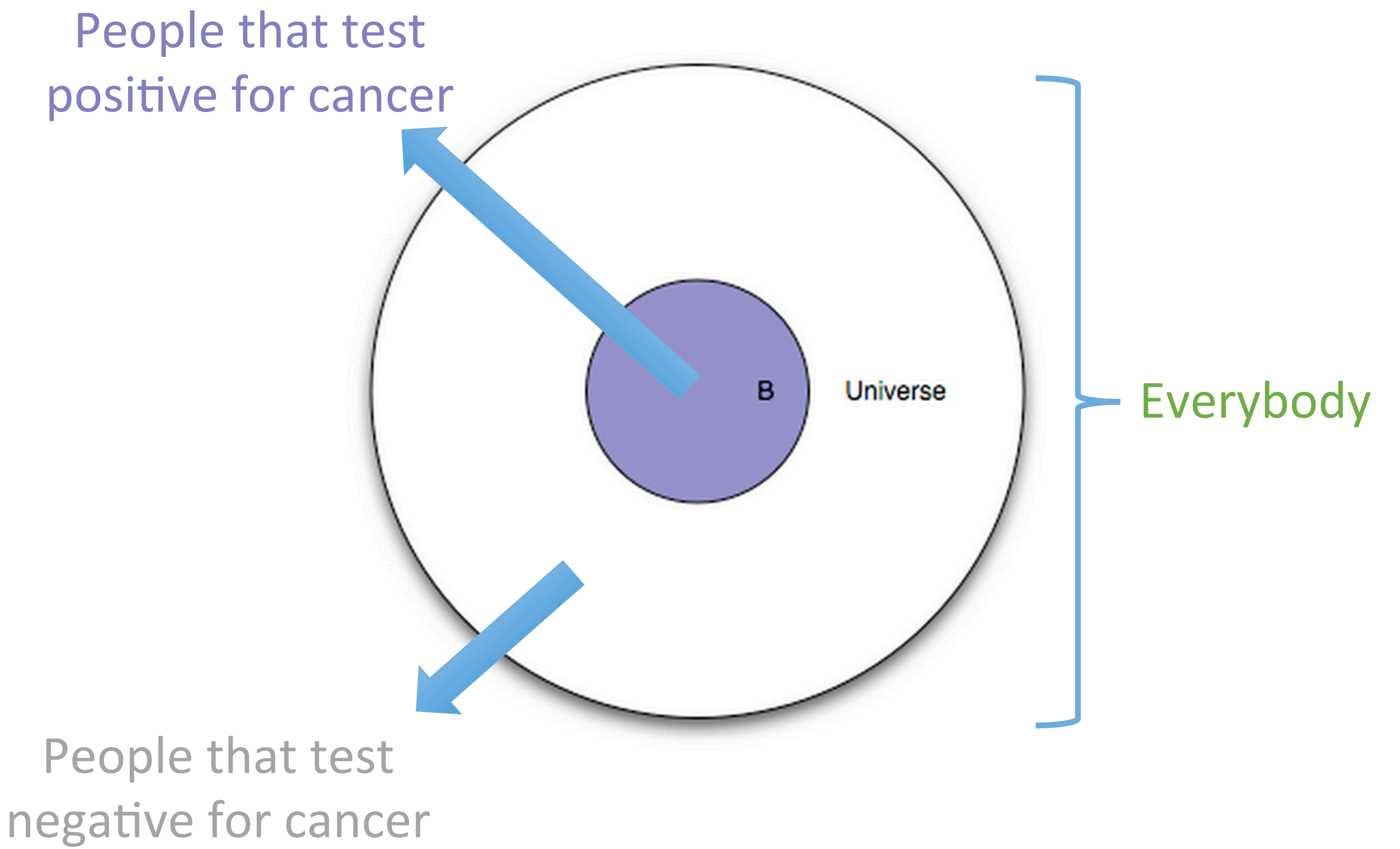

A
Universe
Everybody
People with cancer
People without cancer

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

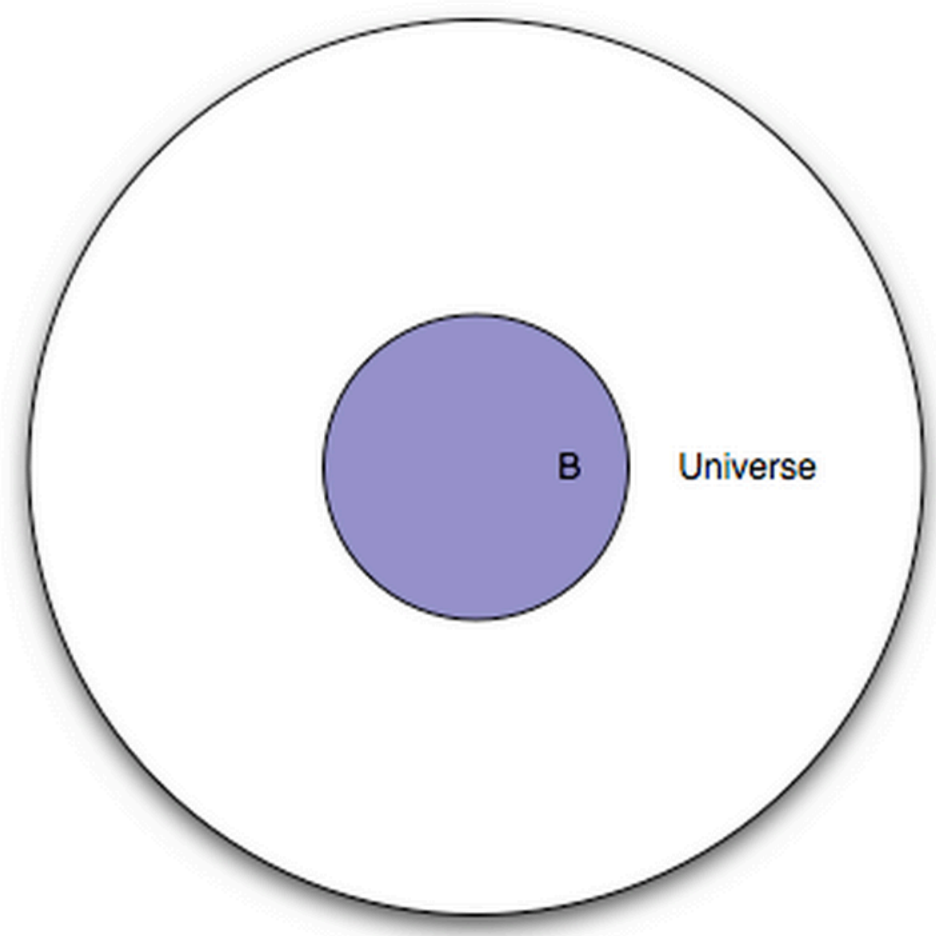


$$P(A) = \frac{|A|}{|U|}$$

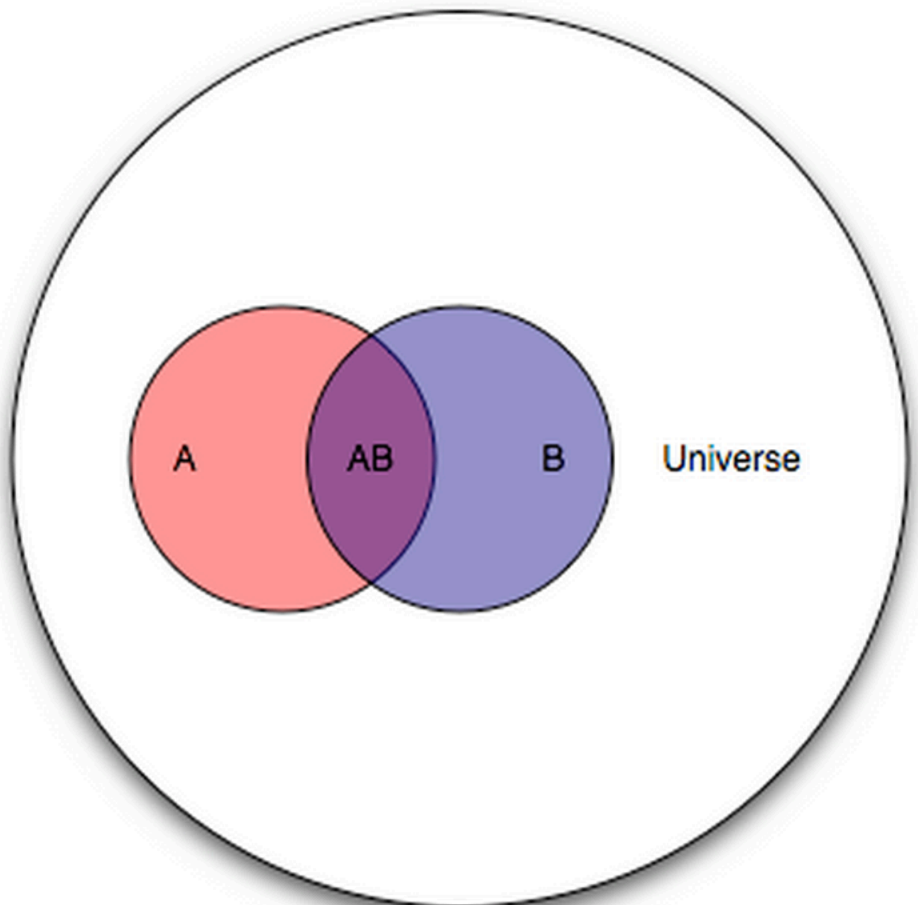

B
Universe

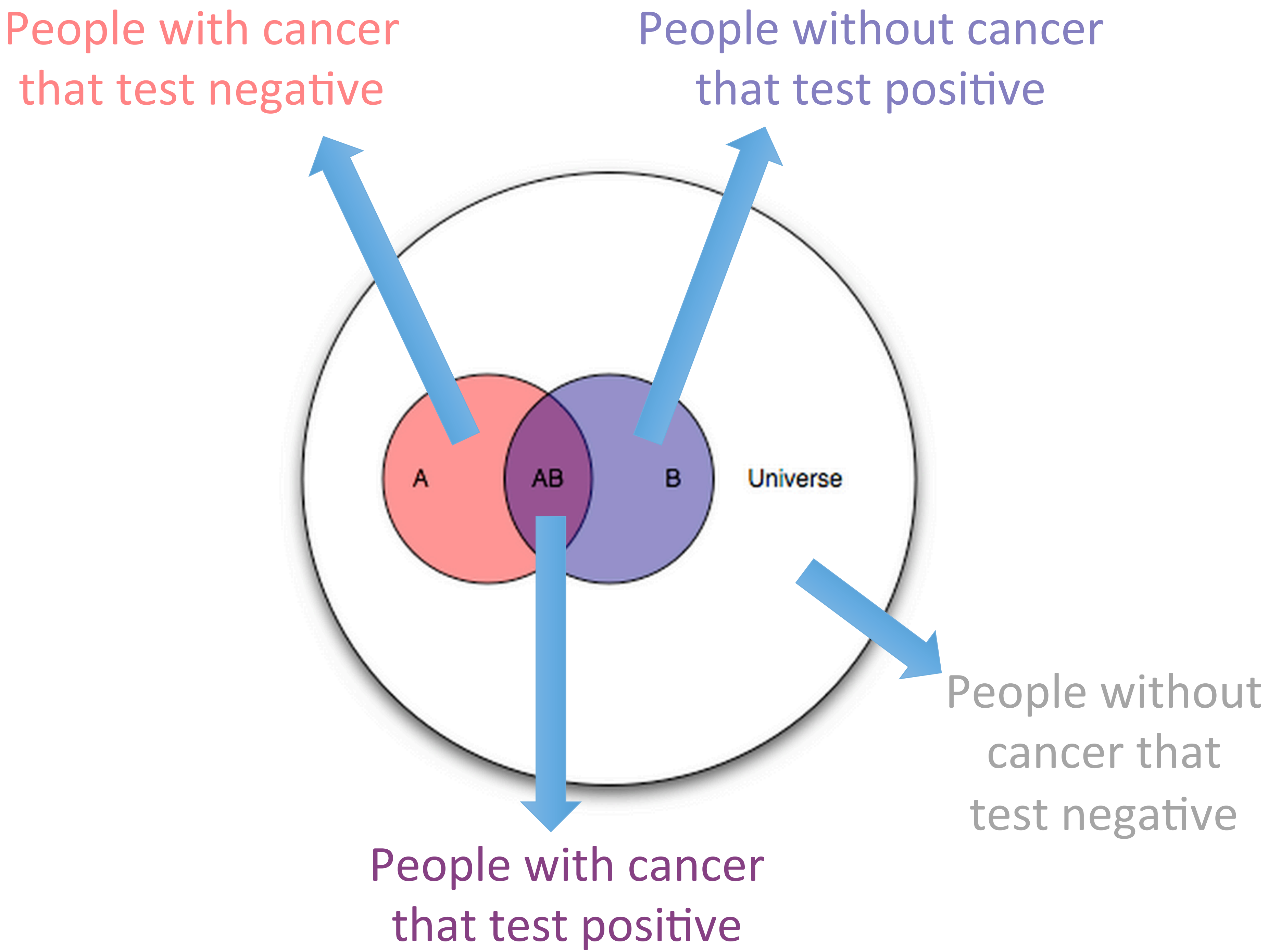

People that test positive for cancer
B
Universe
Everybody
People that test negative for cancer

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

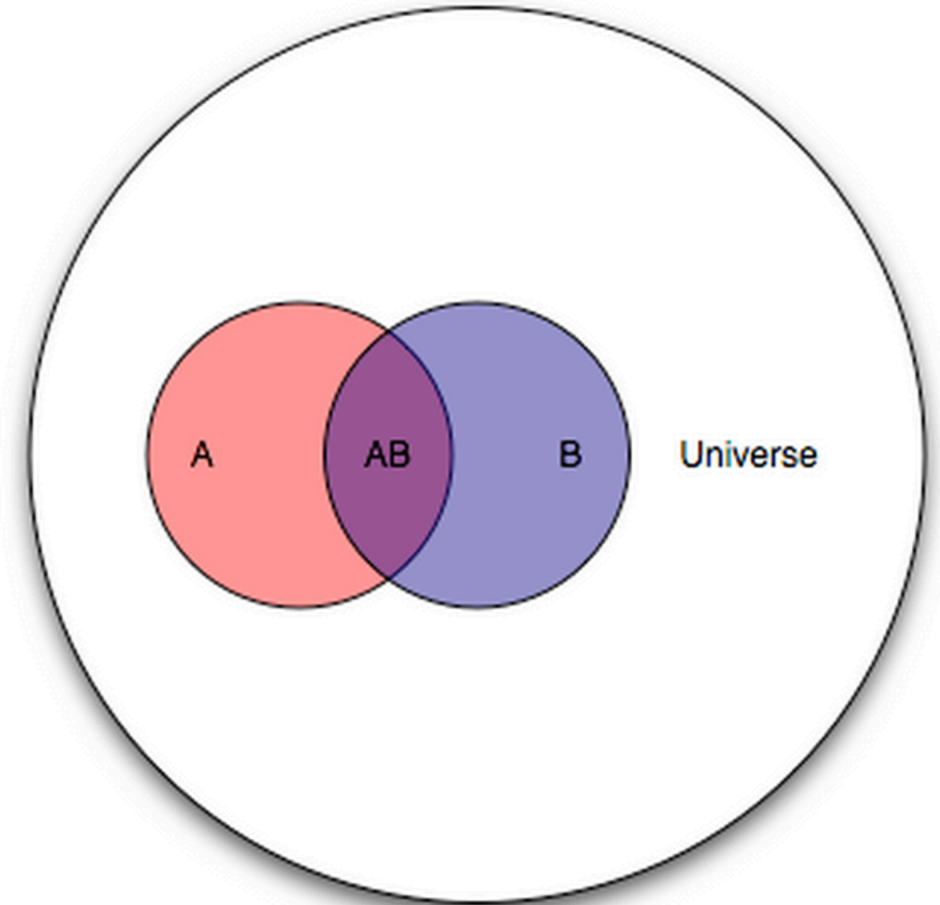


$$P(B) = \frac{|B|}{|U|}$$


A
AB
B
Universe


People with cancer that test negative
People without cancer that test positive
A
AB
B
Universe
People without cancer that test negative
People with cancer that test positive

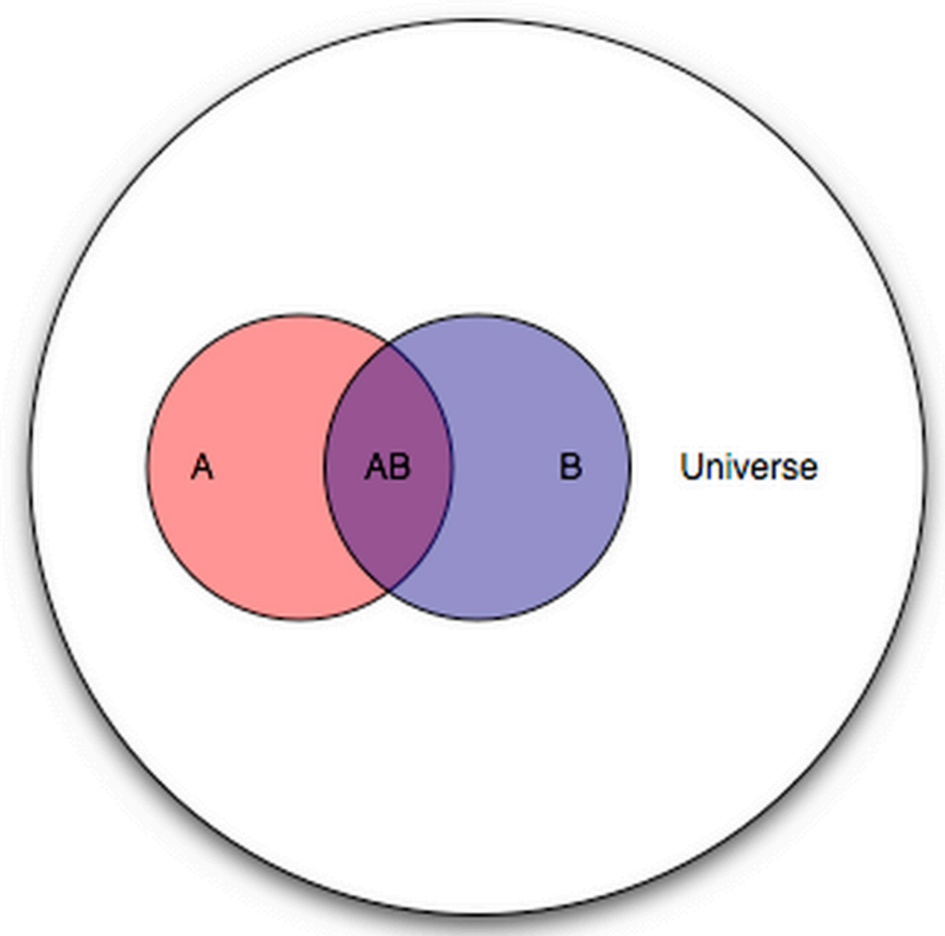
If I picked a random person from the universe, what is the prob. of them having cancer **AND** testing positive for cancer?



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

Joint probability

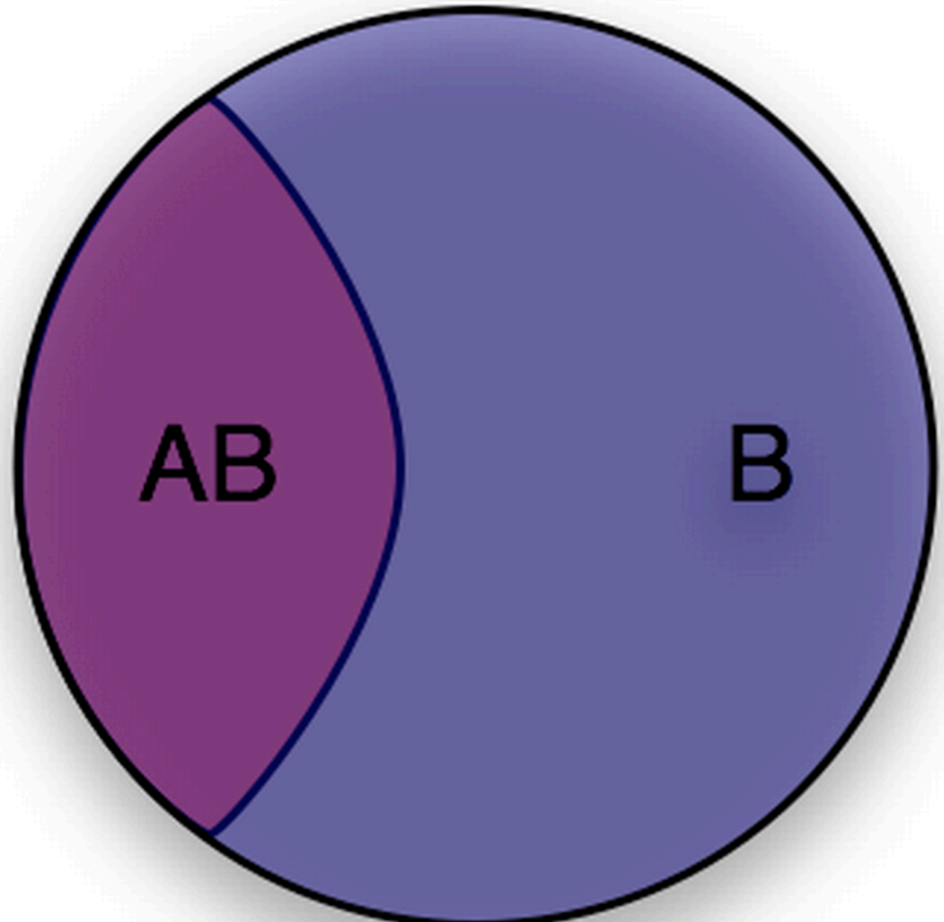
If I picked a random person **that tested positive**, what is the prob. of him/her actually having cancer?



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

Conditional probability

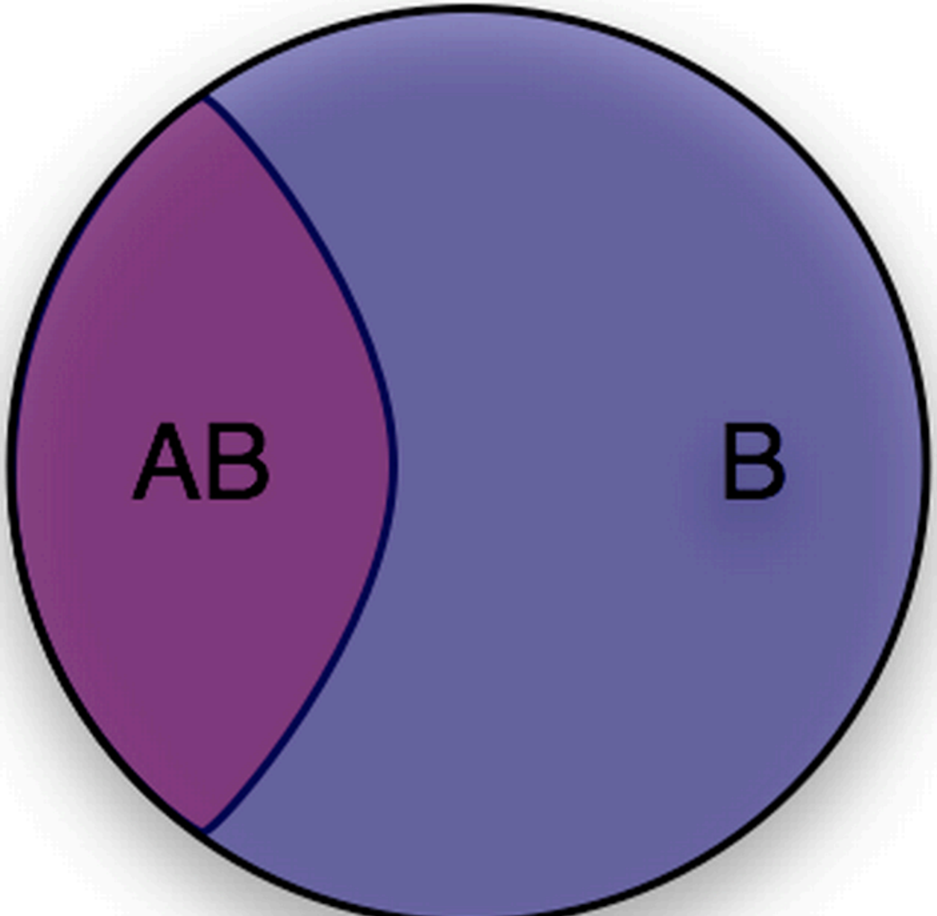
If I picked a random person **that tested positive**, what is the prob. of him/her actually having cancer?



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

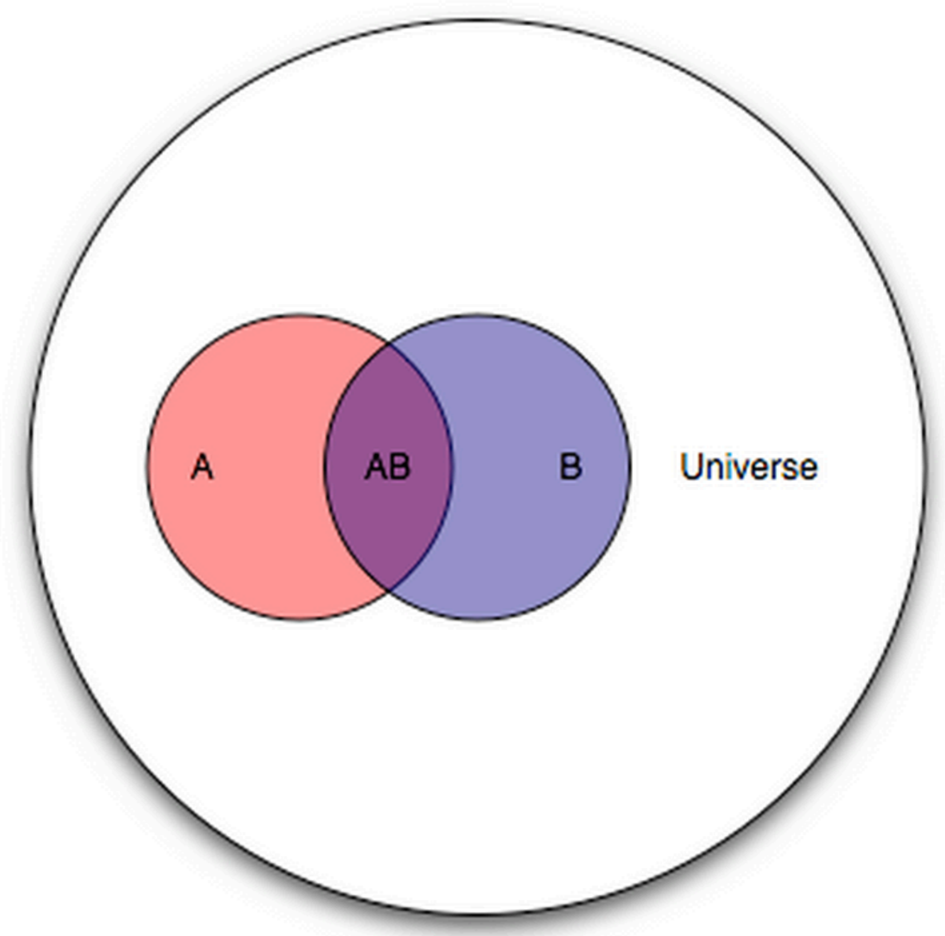
Conditional probability

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



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

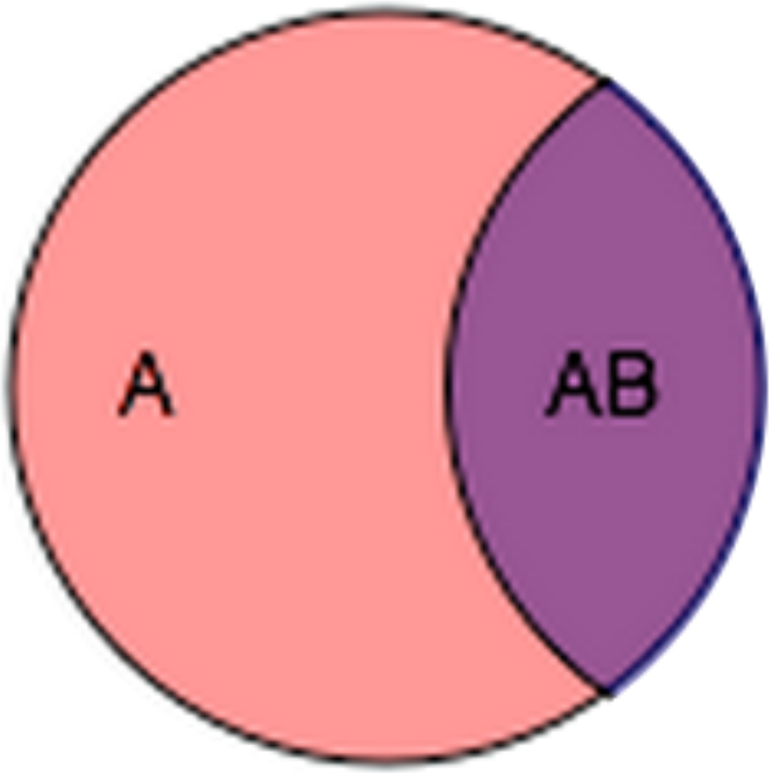
If I picked a random person **that has cancer**, what is the prob. of him/her testing positive?



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

Conditional probability

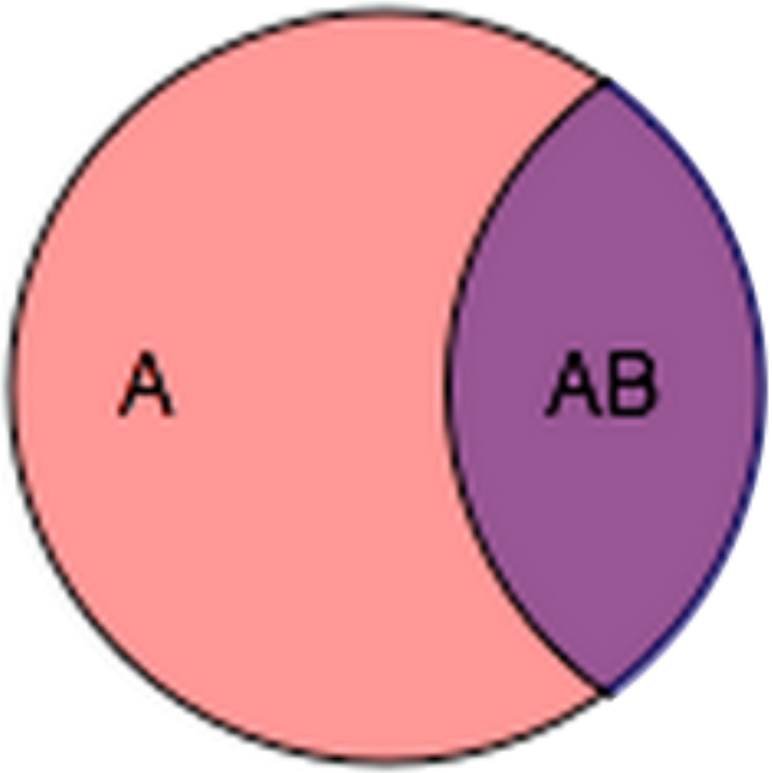
If I picked a random person **that has cancer**, what is the prob. of him/her testing positive?



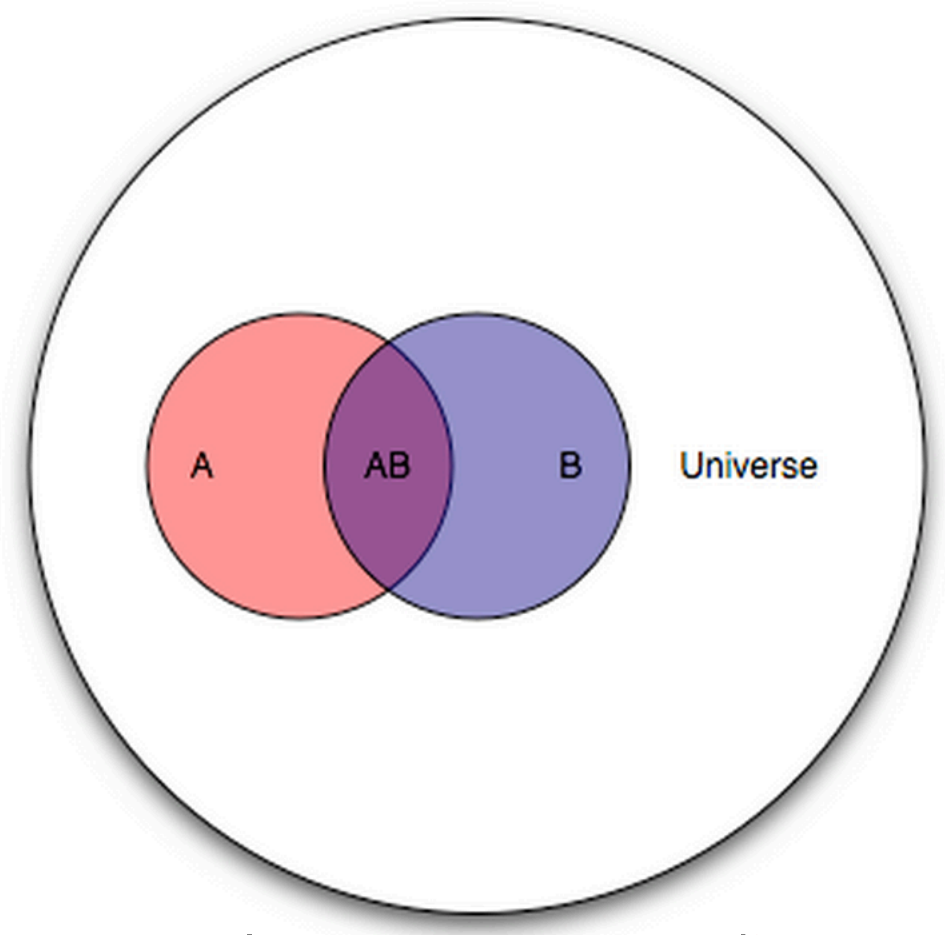
$$P(B \mid A) = \frac{|AB|}{|A|}$$

Conditional probability

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



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

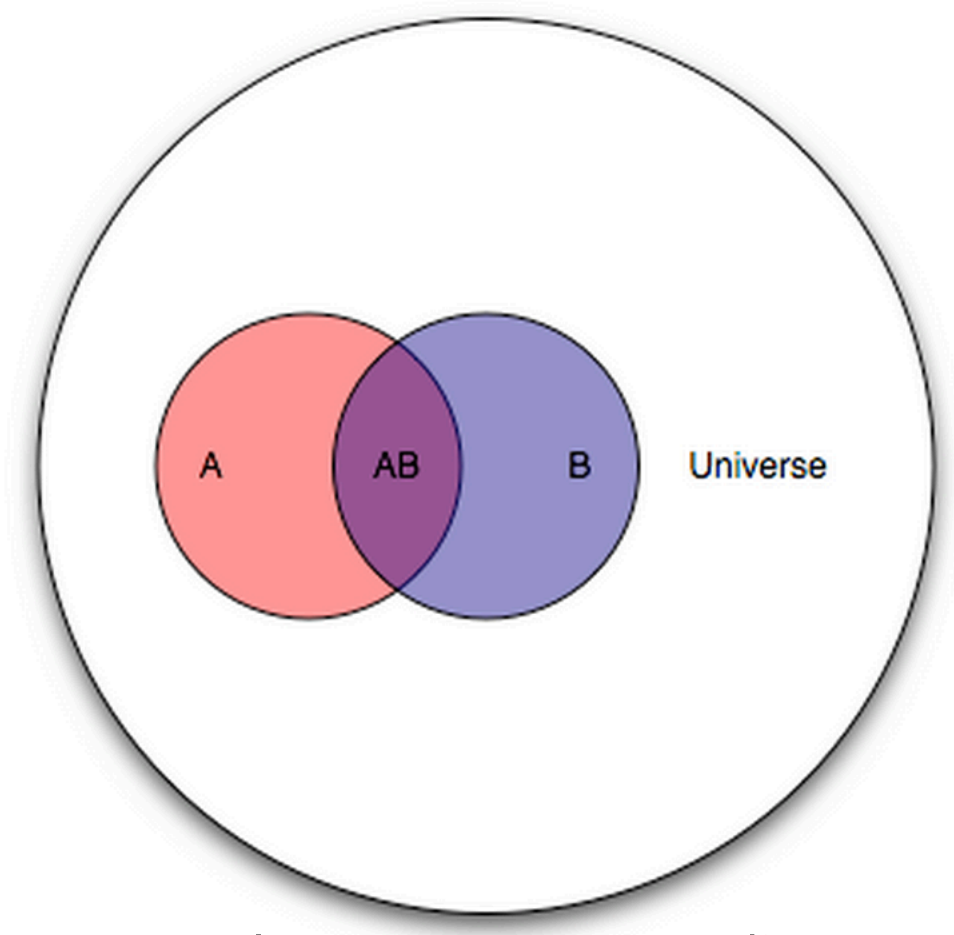


P(test positive | has cancer)

P(has cancer | test positive)

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

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

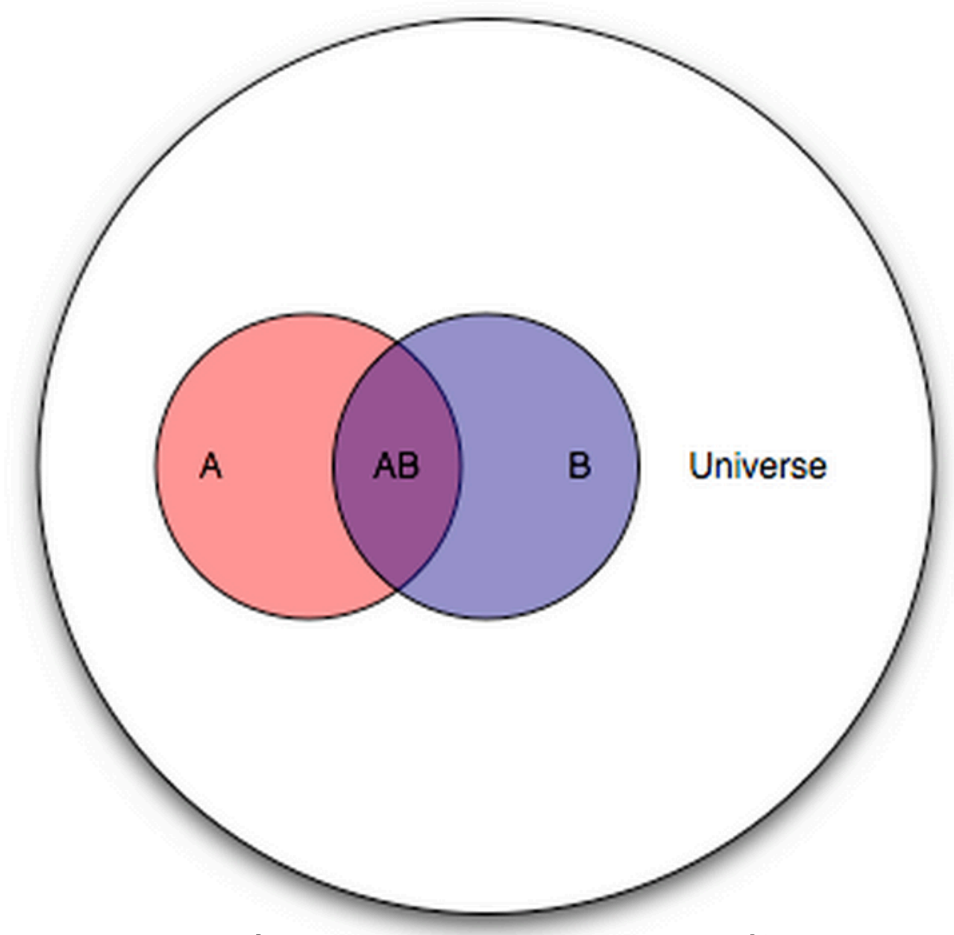


P(test positive | has cancer)

P(has cancer | test positive)

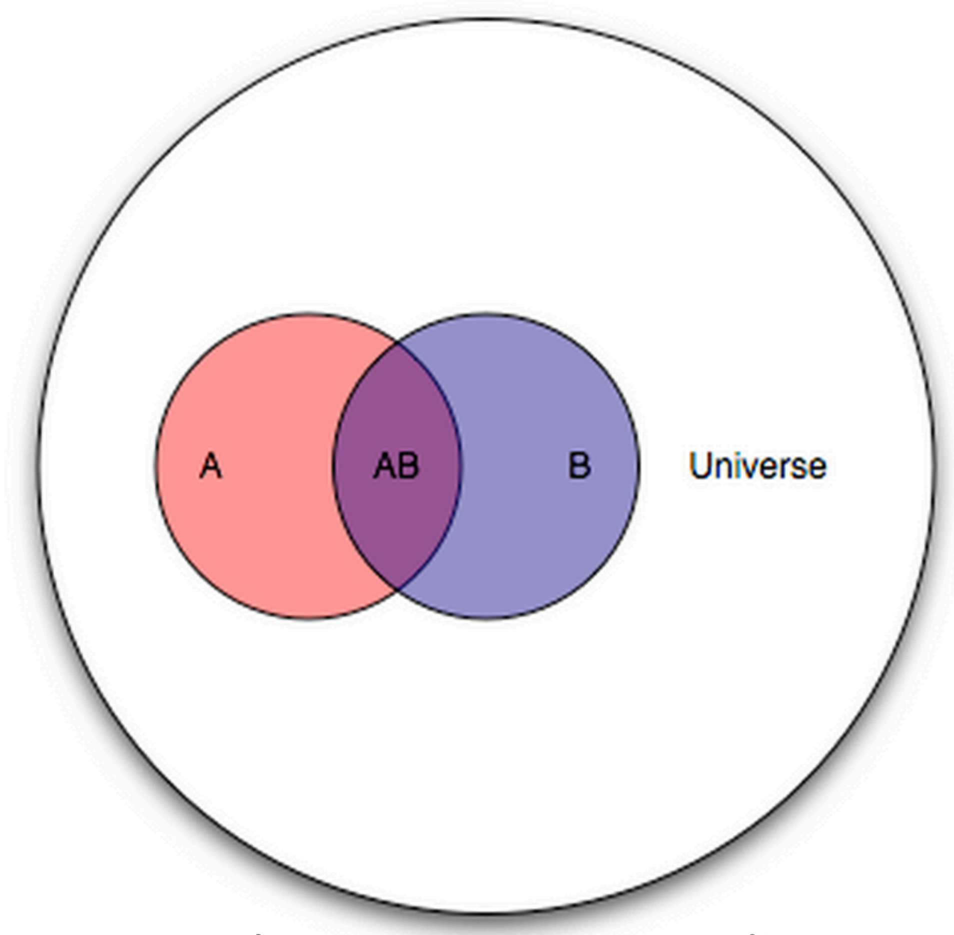
$$P(B \mid A)P(A) = P(A,B)$$

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



P(test positive | has cancer) P(has cancer | test positive)

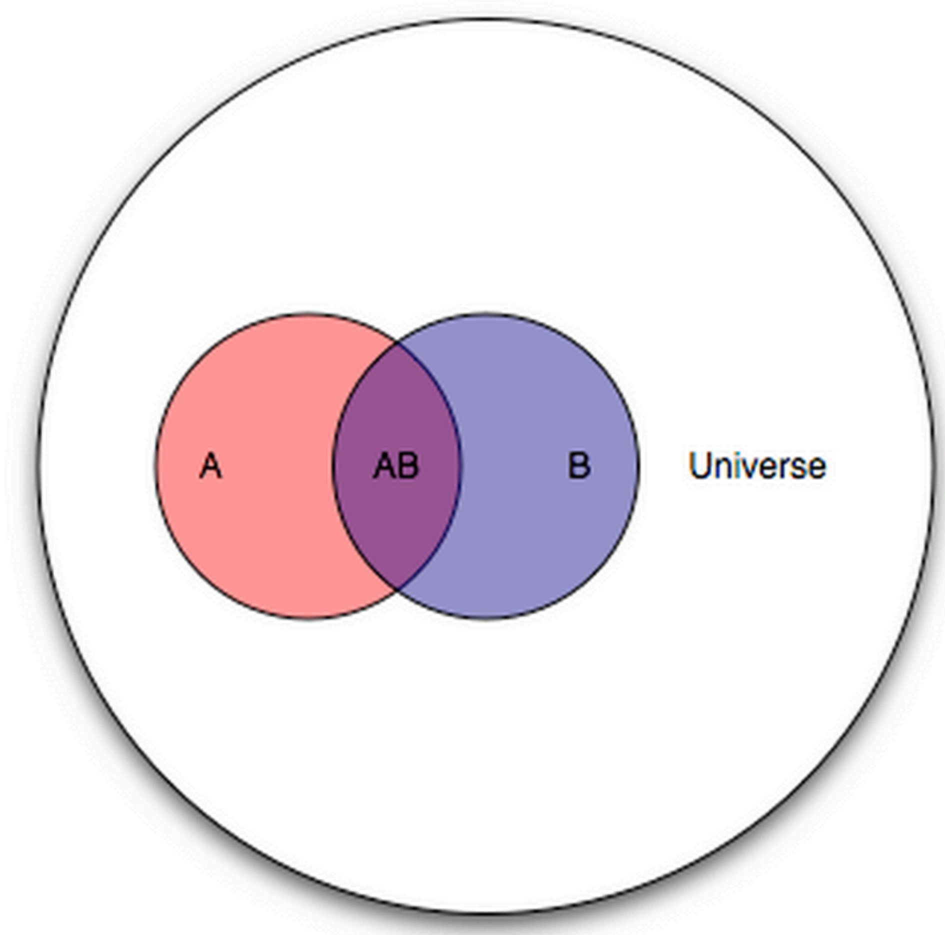
$$P(B \mid A)P(A) = P(A,B) = P(A \mid B)P(B)$$



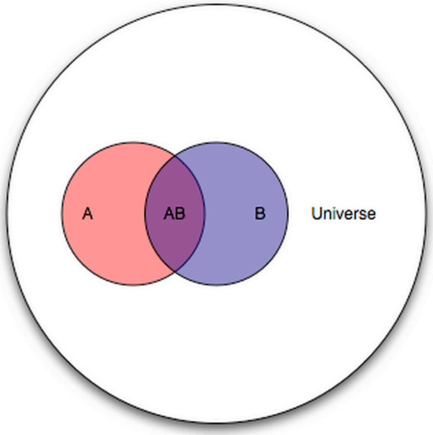
P(test positive | has cancer)

P(has cancer | test positive)

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



$$\overbrace{P(B \mid A)}^{P(\text{test positive} \mid \text{has cancer})}\underbrace{P(A)}_{P(\text{has cancer})} = \overbrace{P(A \mid B)}^{P(\text{has cancer} \mid \text{test positive})}\underbrace{P(B)}_{P(\text{test positive})}$$



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

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

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

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

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

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

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

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

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P(has cancer) = 0.01

P(test positive | has cancer) = 0.80

P(test positive) = P(test positive|has cancer) P(has cancer)
+ P(test positive|not cancer) P(not cancer)
= 0.80 P(has cancer) + 0.096 P(not 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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$$\begin{aligned} P(\text{test positive}) &= P(\text{test positive} \mid \text{has cancer})\, P(\text{has cancer}) \\ &\quad + P(\text{test positive} \mid \text{not cancer})\, P(\text{not cancer}) \\ &= 0.80\, P(\text{has cancer}) + 0.096\, P(\text{not cancer}) \\ &= 0.80 * \quad 0.01 \qquad + 0.096 * (1 - 0.01) \end{aligned}$$

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

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P(has cancer) = 0.01

P(test positive | has cancer) = 0.80

$$
\begin{aligned}
P(\text{test positive}) &= P(\text{test positive} \mid \text{has cancer})\, P(\text{has cancer}) \\
&\quad + P(\text{test positive} \mid \text{not cancer})\, P(\text{not cancer}) \\
&= 0.80\, P(\text{has cancer}) + 0.096\, P(\text{not cancer}) \\
&= 0.80 * 0.01 + 0.096 * (1 - 0.01)
\end{aligned}
$$

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

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

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

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

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

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

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

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

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

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

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P(has cancer) = 0.01

P(test positive | has cancer) = 0.80

P(test positive) = 0.103

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

ONLY 7.8%

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P(has cancer) = 0.01

P(test positive | has cancer) = 0.80

P(test positive) = 0.103

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

ONLY 7.8%

Most doctors guessed ~80%

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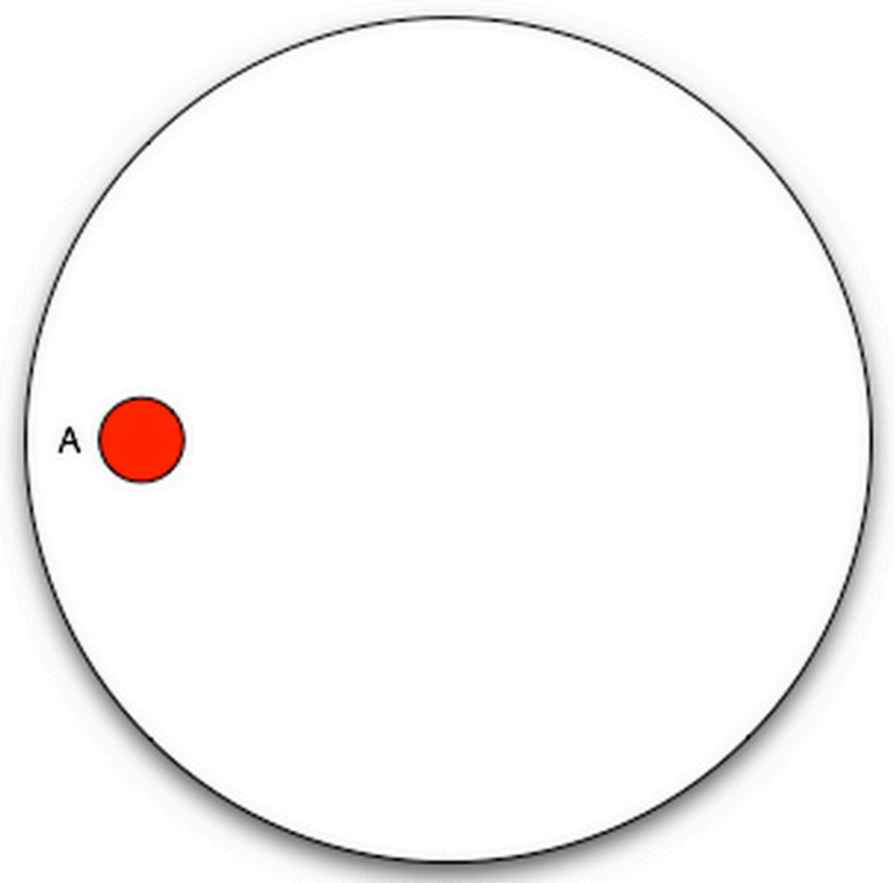

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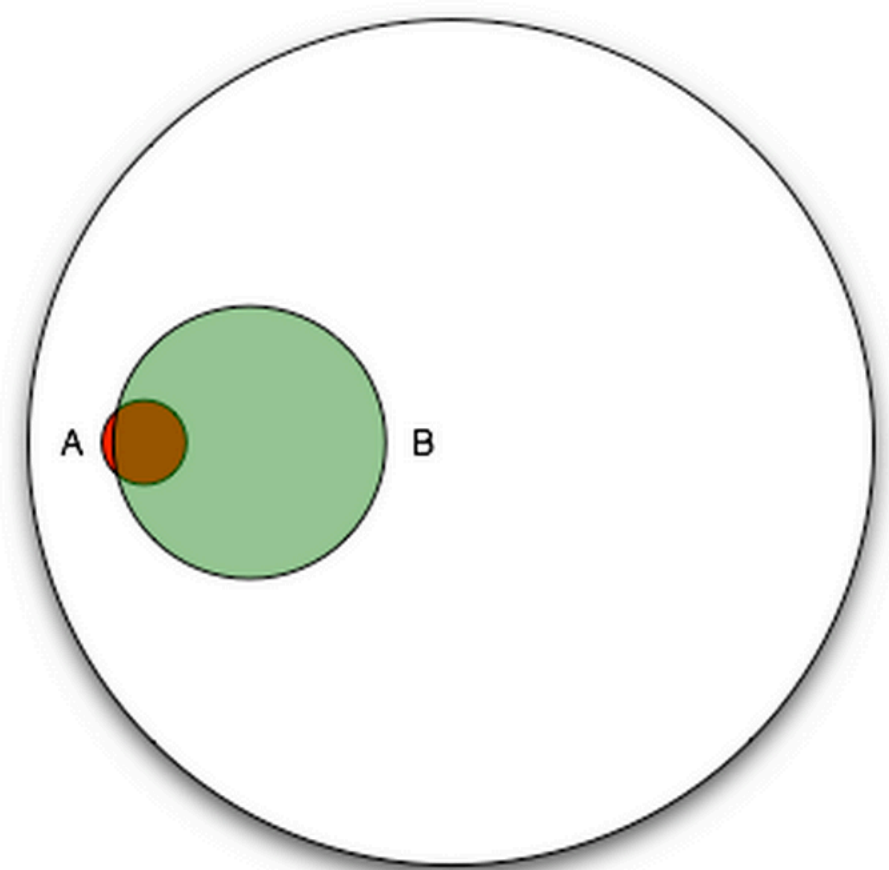

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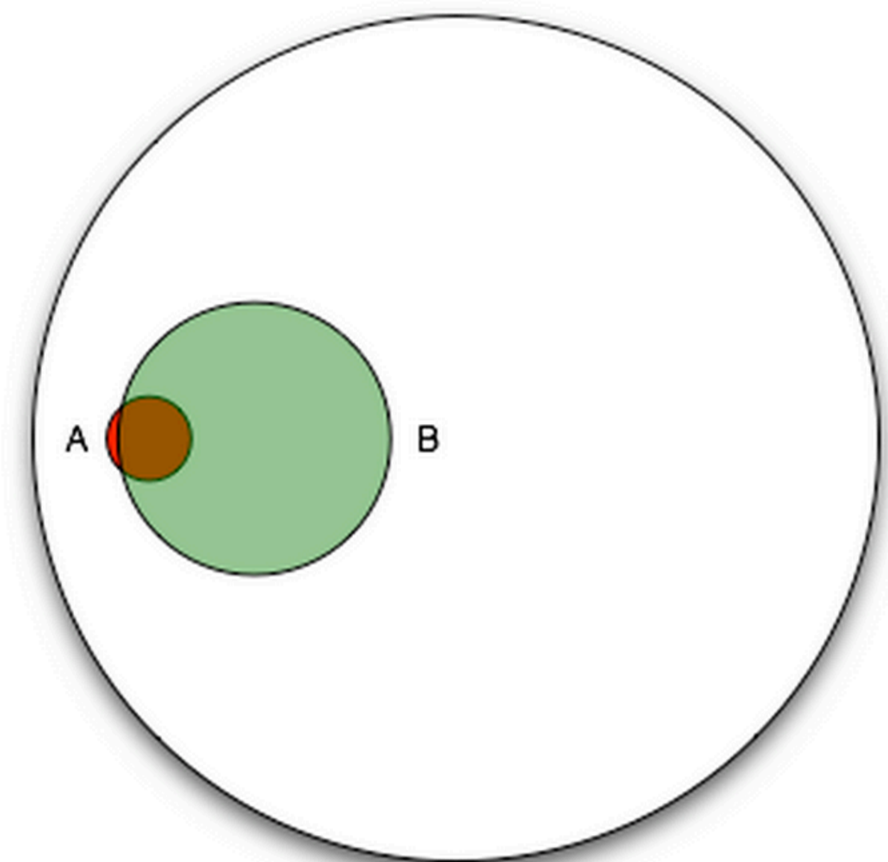
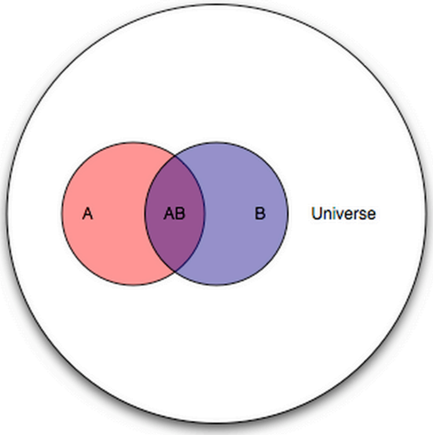


$|A|/|U| = 1\%$

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

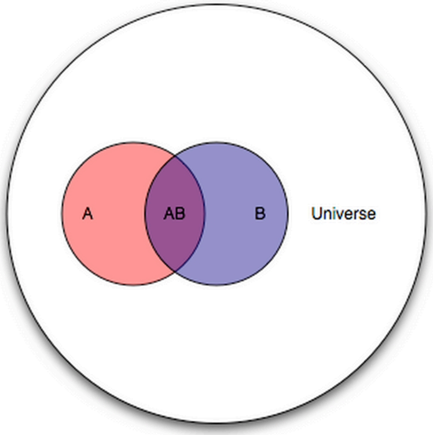
$(|B|-|AB|)/(|U|-|A|) = 9.6\%$

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



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

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



P(has cancer| test positive) $=$ $\dfrac{\text{P(test positive | has cancer) P(has cancer)}}{\text{P(test positive)}}$

Another Perspective:

(Updating Knowledge)

$$\underbrace{P(A\,|\,B)}_{\text{posterior}} = \frac{\overbrace{P(B\,|\,A)}^{\text{likelihood}}\overbrace{P(A)}^{\text{prior}}}{\underbrace{P(B)}_{\text{evidence}}}$$

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) = ?

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

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

P(oscar nomination) = # nominated / # released

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

oscar.go.com/nominees

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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

View Trailer / ▶

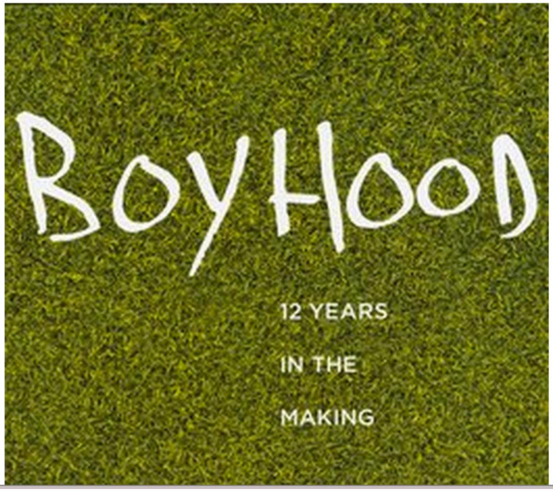
More Information

The Imitation Game
Nora Grossman, Ido Ostrowsky and Teddy Schwarzman

View Trailer / ▶

More Information

Selma



ACTRESS
in a Leading Role

Marion Cotillard
Two Days, One Night

View Trailer / ▶

More Information

Rosamund Pike
Gone Girl

View Trailer / ▶

More Information

Felicity Jones
The Theory of Everything

View Trailer / ▶

More Information

Reese Witherspoon
Wild

View Trailer / ▶

More Information

Winner
Julianne Moore
Still Alice

View Trailer / ▶

- Julianne Moore

ACTRESS
in a Supporting Role

Patricia Arquette
Boyhood

View Trailer / ▶

More Information

Laura Dern
Wild

View Trailer / ▶

More Information

Keira Knightley
The Imitation Game

View Trailer / ▶

More Information

Emma Stone
Birdman or (The Unexpected Virtue of Ignorance)

View Trailer / ▶

More Information

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) ≈ 10 / # released

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

https://www.google.com/webhp?sourceid=chrome-instant&ion=1&espv=2&es_th=1&ie=UTF-8#q=how%20many%20a...

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Google how many american movies released per year +Irmak

Web News Images Videos Maps More Search tools

About 143,000,000 results (0.52 seconds)

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.

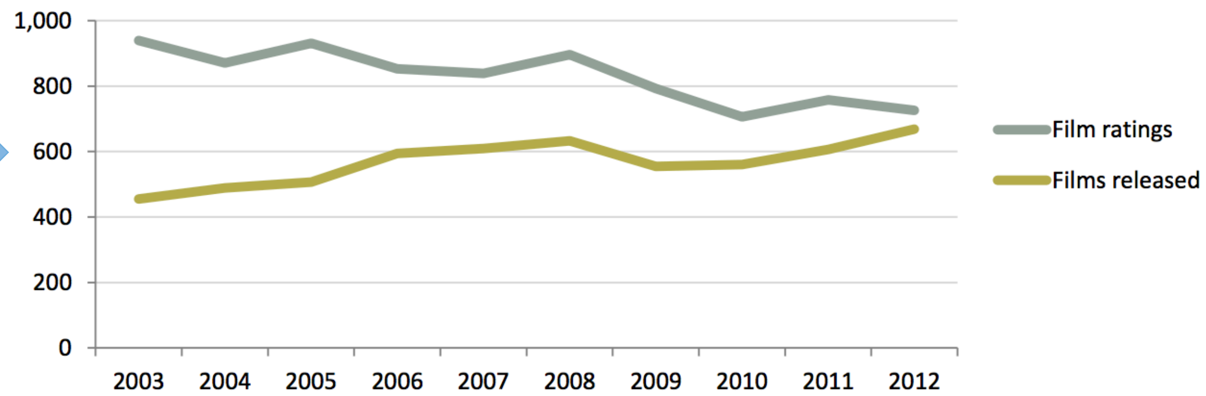
[PDF] Theatrical Market Statistics - Motion Picture Association of...
www.mpaa.org/.../2012-Theatrica... Motion Picture Association of America
Global box office for all **films released** in **each** country around the world reached ... saw increases in the **number of** frequent moviegoers in nearly **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 Ratings[16]

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

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

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

P(oscar nomination) ≈ 10 / 600 = 1.67%

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P(Meryl Streep in the movie) = # MS movies / # 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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P(Meryl Streep in the movie) = # MS movies / 600

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


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Meryl Streep
74
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
Represent Meryl Streep? Add or change photos
746 photos | 143 videos | 12608 news articles »
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Keith Simanton chats with Je
Aniston about the drama Cak
opens in the U.S. on January
IMDb What to Watch: Cake

Filmography

Show all | Show by... | Edit

Jump to: Actress | Soundtrack | Producer | Thanks | Self | Archive footage

Actress (74 credits)

Hide

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 Bowner - Blindsides and Backslides (2012) ... Camilla Bowner - Getting It Straight (2012) ... Camilla Bowner	2012
The Iron Lady Margaret Thatcher	2011

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Master Class

The Good House

The Senator's Wife

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Kramer vs. Kramer Joanna Kramer	1979
The Seduction of Joe Tynan Karen Traynor	1979
Great Performances (TV Series) Leilah / Edith Varney - Uncommon Women... and Others (1979) ... Leilah - Secret Service (1977) ... Edith Varney	1977-1979
Manhattan Jill	1979
The Deer Hunter Linda	1978
Holocaust (TV Mini-Series) Inga Helms Weiss - Part 4 (1978) ... Inga Helms Weiss - Part 2 (1978) ... Inga Helms Weiss - Part I: The Gathering Darkness (1978) ... Inga Helms Weiss	1978
Julia Anne Marie	1977
The Deadliest Season (TV Movie) Sharon Miller	1977
Everybody Rides the Carousel Stage 6 (voice)	1975

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) = ?

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P(Meryl Streep in the movie) ≈ 1.85 / 600 = 0.3%

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P(Meryl Streep in the movie) ≈ 1.85 / 600 = 0.3%

P(Meryl Streep in the movie | 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) = ?

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P(Meryl Streep in the movie) ≈ 1.85 / 600 = 0.3%

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

\# nominated MS movies / 10

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

en.wikipedia.org/wiki/Meryl_Streep

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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 nomina… any actor or actress in history, winning Best Supporting Actress for *Krame… …er* (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 m… …petitive Academy Awards for acting. Her other nominated roles include *The French L… …t's Woman* (1981), *Silkwood* (1983), *Out of Africa* (1985), *A Cry in the Dark* (19… …ards From the Edge* (1990), *The Bridges of Madison County* (1995), *Adaptation* (20… …Devil Wears Prada* (2006), *Doubt* (2008), *Julie & Julia* (2009), *August: Osage Coun…* and *Into the Woods* (2014). She returned to the stage for the first time in over 2… …n The Public Theater's 2002 revival of *The Seagull*, won a second Emmy Award i… …r the HBO miniseries *Angels in America* (2003), and starred in the Public Theater… …roduction 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) ≈ 10 / 600 = 1.67%

P(Meryl Streep in the movie) ≈ 1.85 / 600 = 0.3%

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

nominated MS movies / 10

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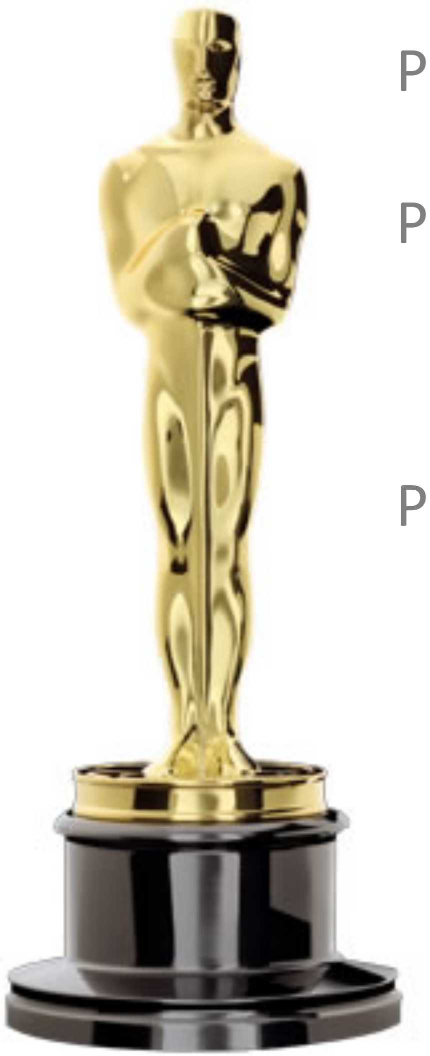
P(Meryl Streep in the movie) ≈ 1.85 / 600 = 0.3%

P(Meryl Streep in the movie | oscar nomination)=4.8%

0.475 / 10

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



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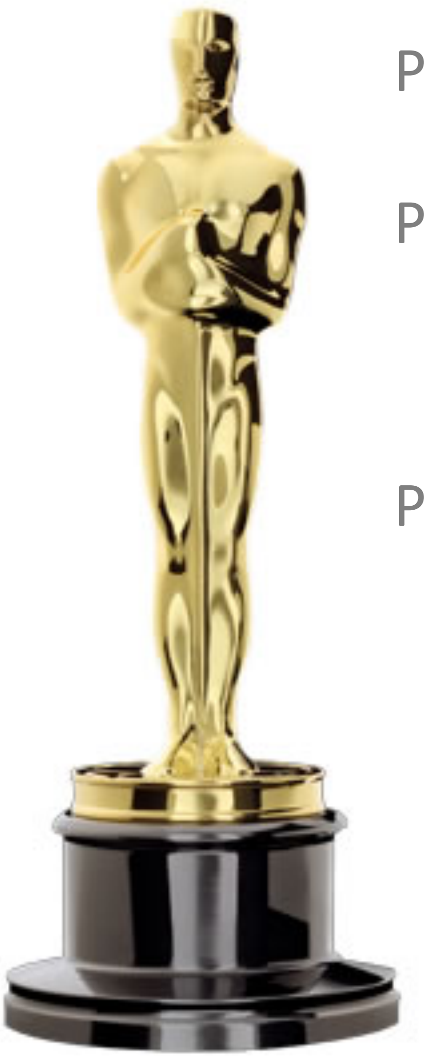
P(Meryl Streep in the movie | oscar nomination)=4.8%

0.475 / 10

P(nom | MS) = P(MS | nom)P(nom) / P(MS)

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



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

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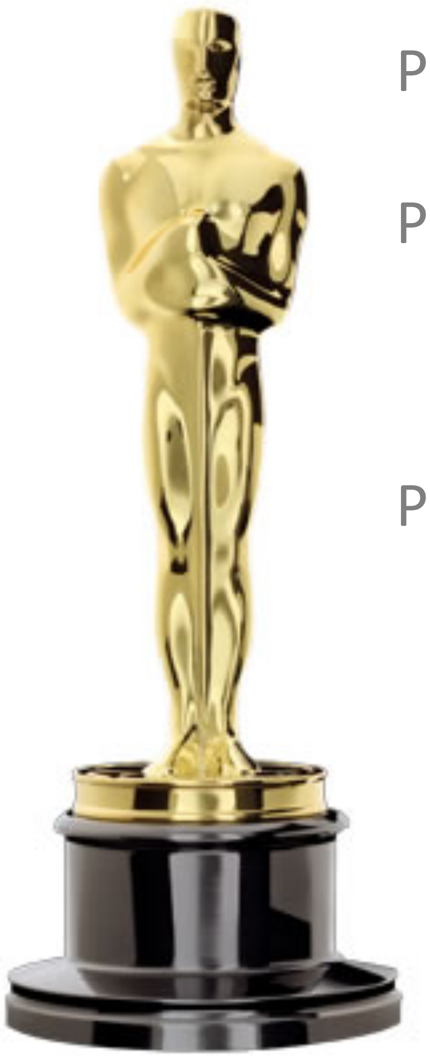
P(Meryl Streep in the movie|oscar nomination)=4.8%

0.475 / 10

P(nom|MS) = P(MS|nom)P(nom) / P(MS)

= 4.8% * 1.67% / 0.3%

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



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P(Meryl Streep in the movie|oscar nomination)=4.8%

0.475 / 10

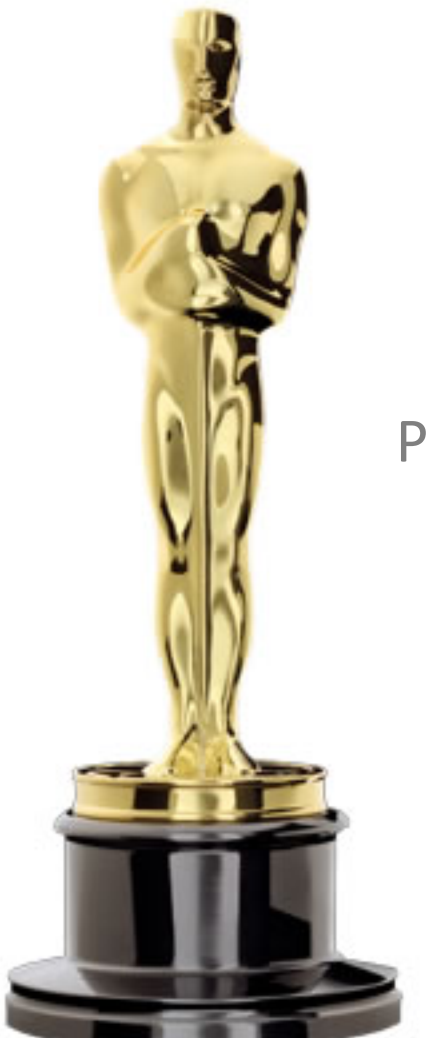
P(nom|MS) = P(MS|nom)P(nom) / P(MS)

= 4.8% * 1.67% / 0.3%

= 25.7%

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

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



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

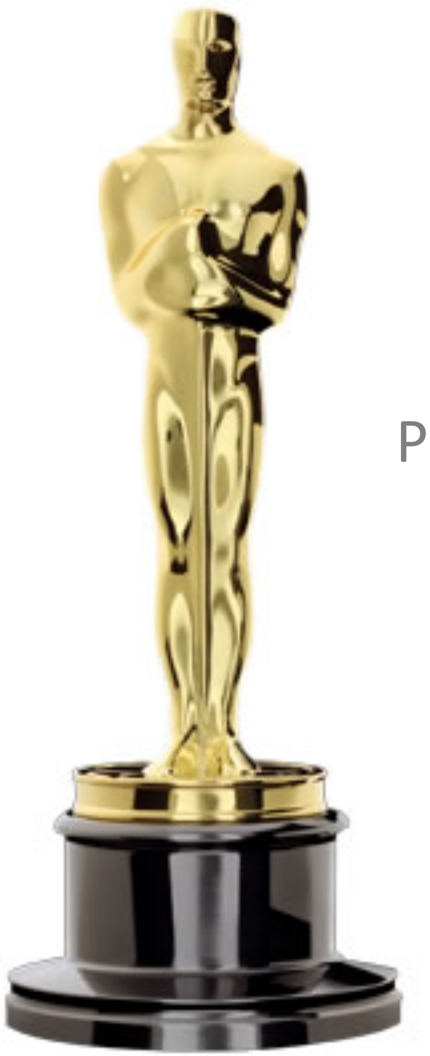
$$= 4.8\% * 1.67\% \,/\, 0.3\%$$

$$= 25.7\%$$

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

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

= # MS movie nominations / # MS movies



P(nom|MS) = P(MS|nom)P(nom) / P(MS)

= 4.8% * 1.67% / 0.3%

= 25.7%

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

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

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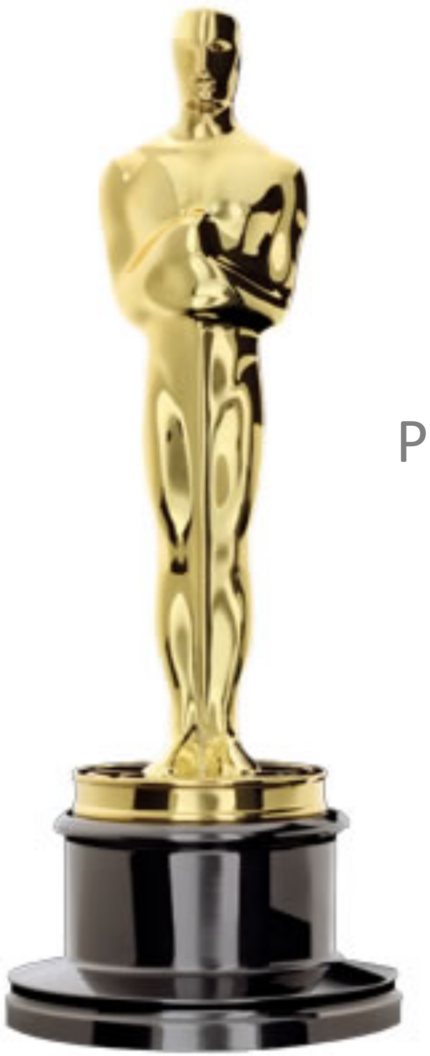
= (0.475 nom per year) / (1.85 MS movies per year)



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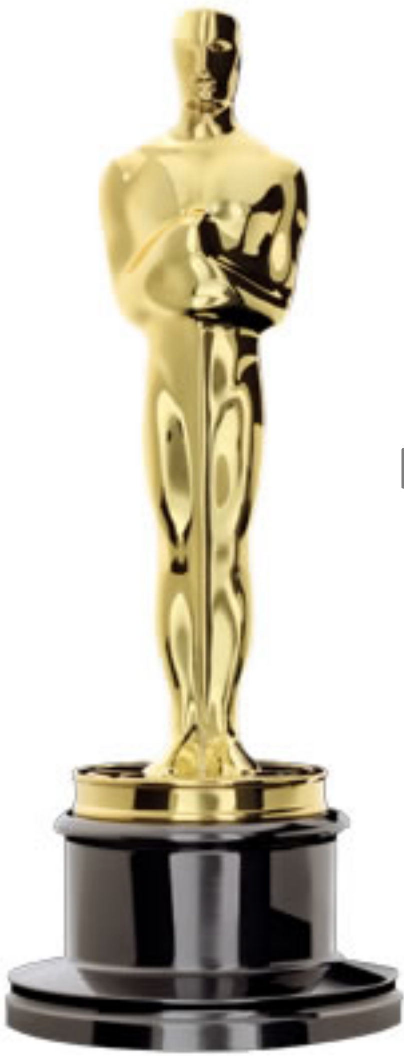


P(oscar nomination | Meryl Streep in the movie) = ?

= # MS movie nominations / # MS movies

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

= 0.475 / 1.85 = 25.7%

P(nom|MS) = P(MS|nom)P(nom) / P(MS)

= 4.8% * 1.67% / 0.3%

= 25.7%

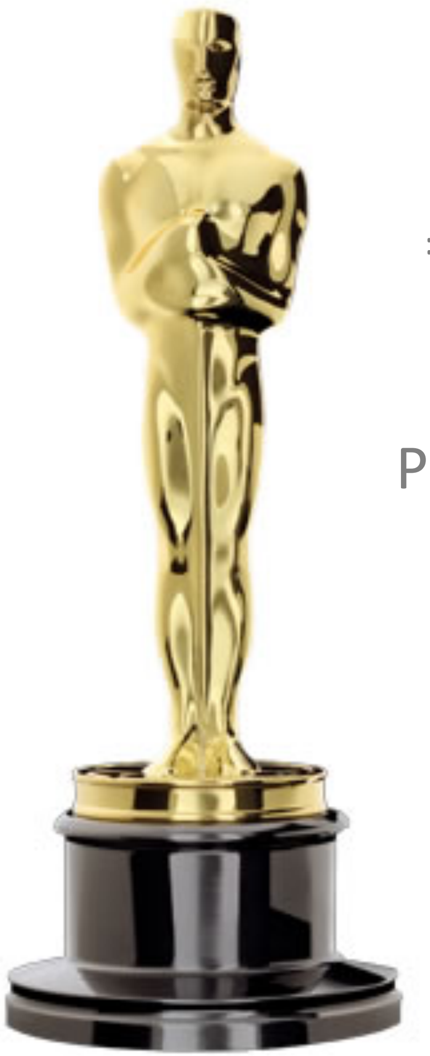
$$P(A \mid B) = \frac{P(B \mid A)P(A)}{P(B)}$$

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

= # MS movie nominations / # MS movies

= 19 MS nominations / 74 MS movies

= 25.7%



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= 4.8% * 1.67% / 0.3%

= 25.7%

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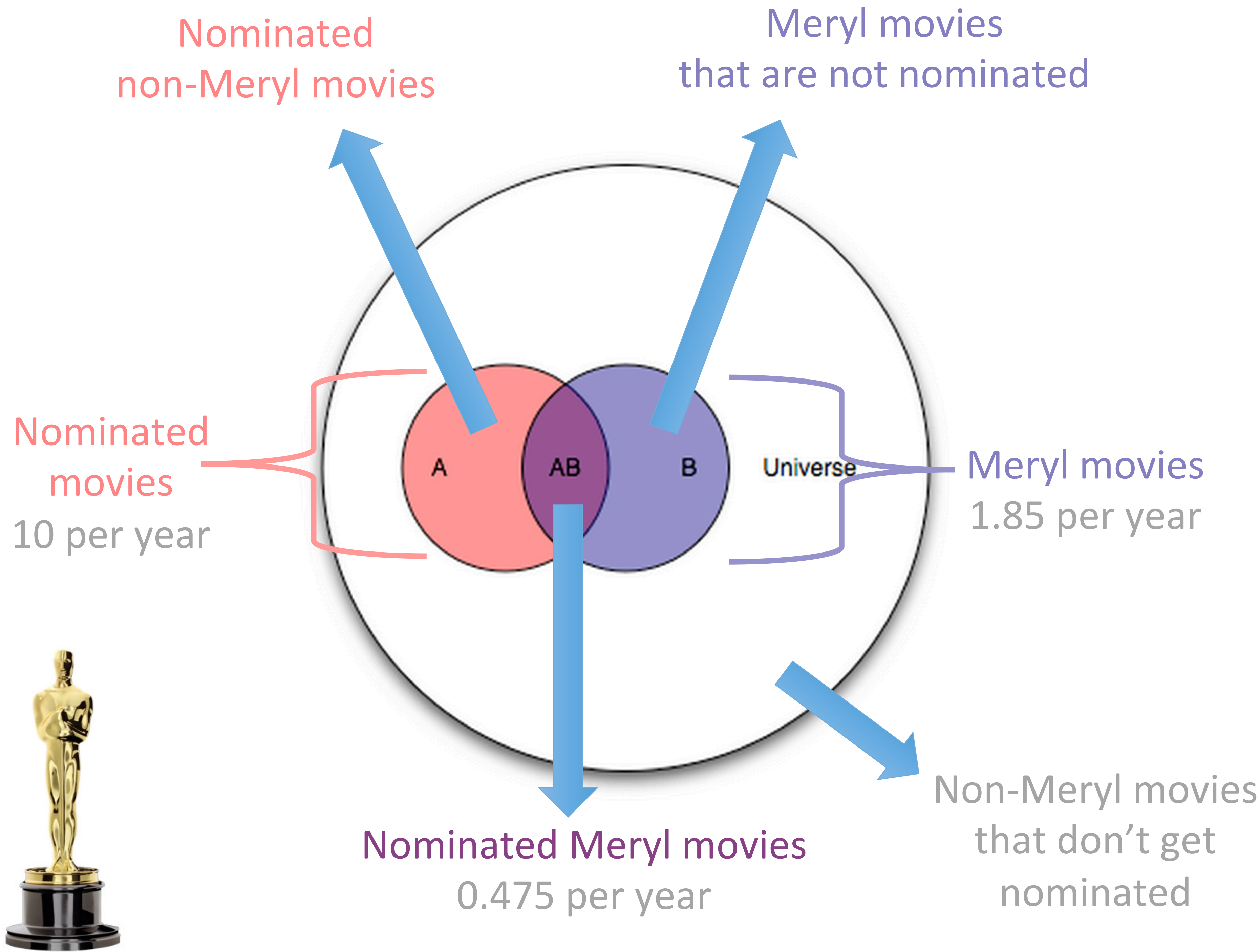
Nominated
non-Meryl movies
Meryl movies
that are not nominated
Nominated
movies
10 per year
A
AB
B
Universe
Meryl movies
1.85 per year
Nominated Meryl movies
0.475 per year
Non-Meryl movies
that don't get
nominated