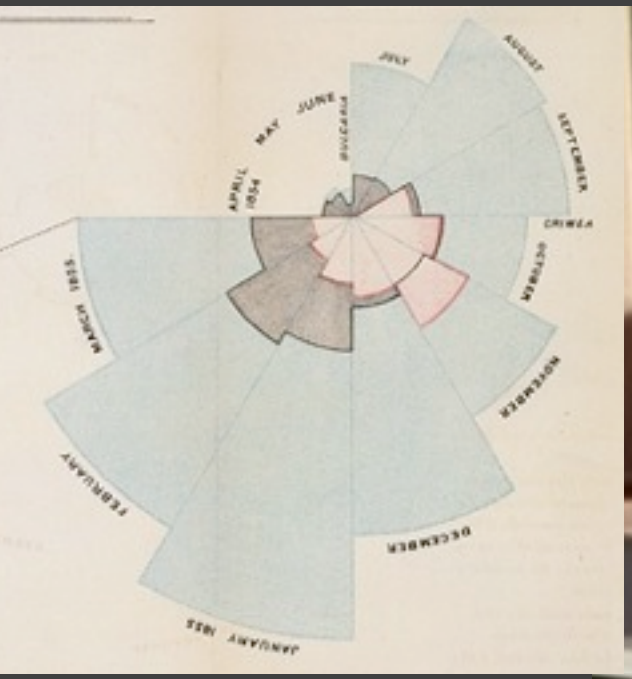
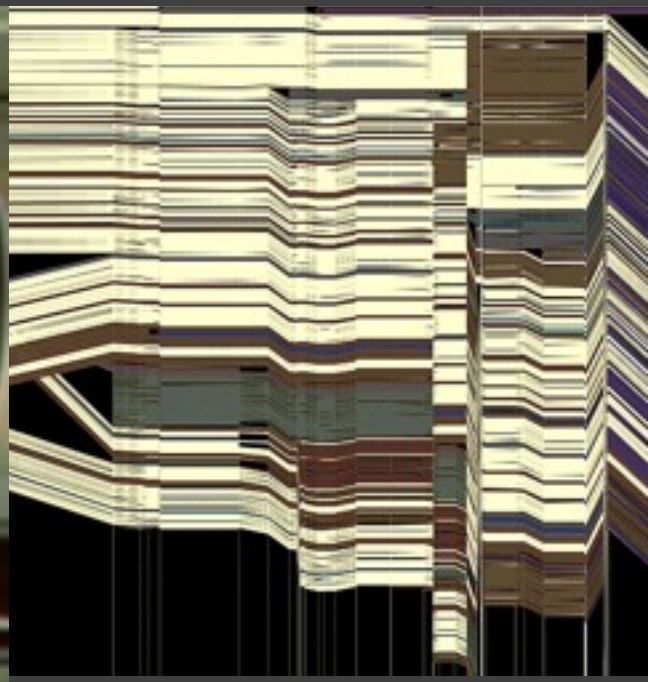
CSE512 :: 14 Jan 2014

Visualization Design

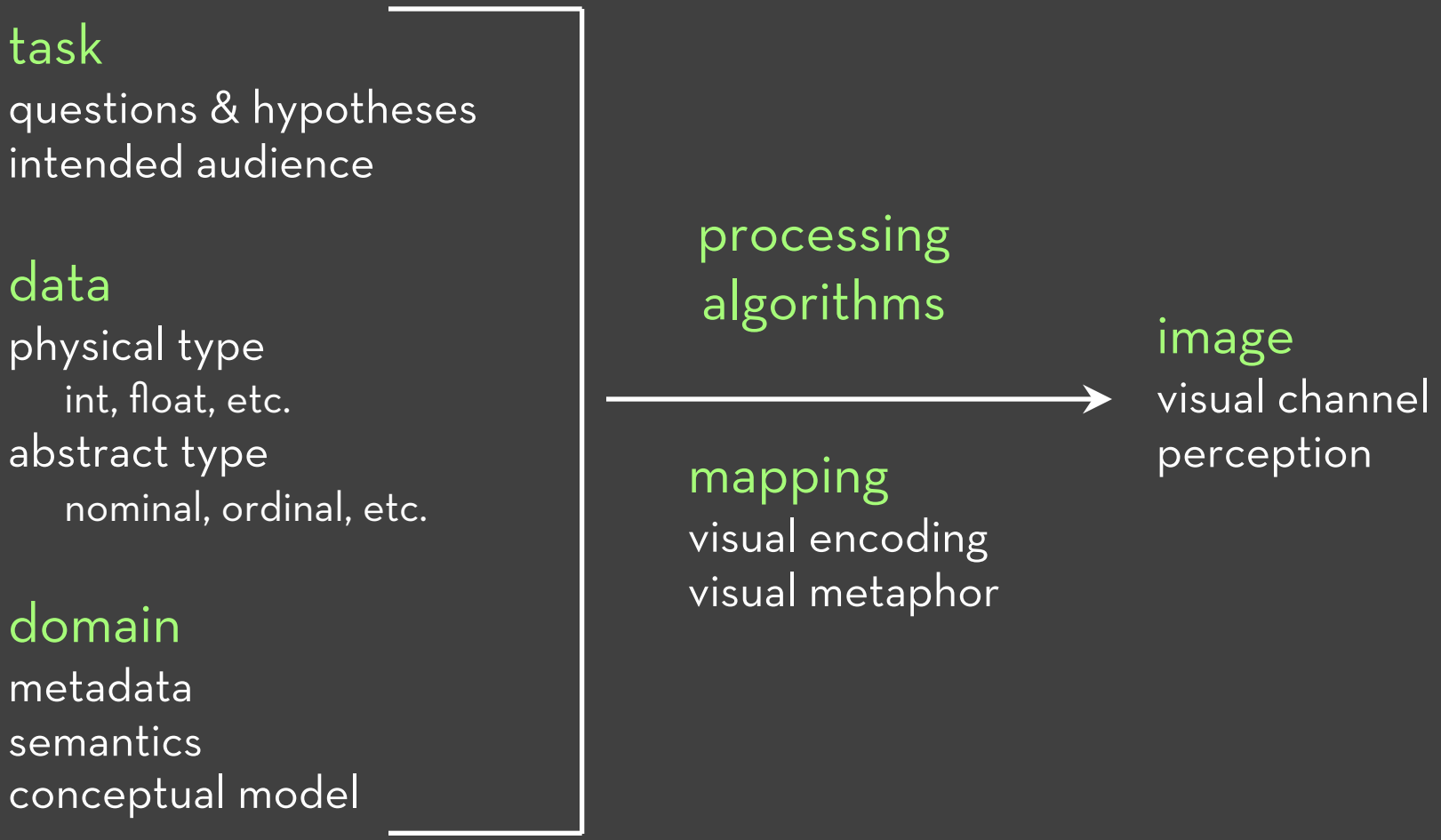




Jeffrey Heer University of Washington

Last Time:
Data and Image Models

The Big Picture



Nominal, Ordinal and Quantitative

N - Nominal (labels)

- Operations: =, ≠

O - Ordered (rank-ordered, sorted)

- Operations: =, ≠, <, >

Q - Interval (location of zero arbitrary)

- Operations: =, ≠, <, >, -
- Can measure distances or spans

Q - Ratio (zero fixed)

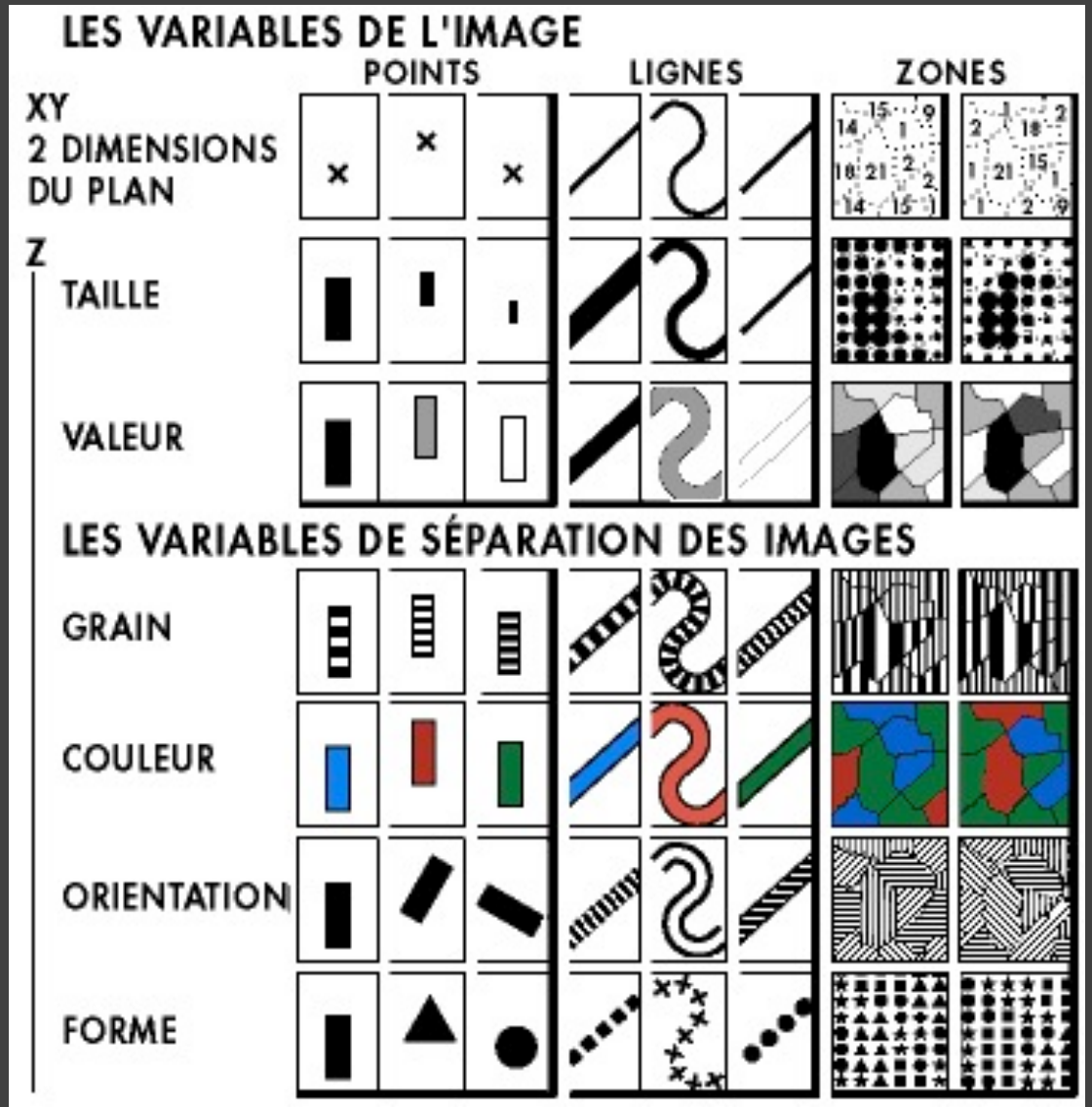
- Operations: =, ≠, <, >, -, %
- Can measure ratios or proportions

S. S. Stevens, On the theory of scales of measurements, 1946

Visual Encoding Variables

Position
Size
Value
Texture
Color
Orientation
Shape

Others?



Formalizing Design

(Mackinlay 1986)

Choosing Visual Encodings

Challenge:
Assume 8 visual encodings and *n* data attributes.
We would like to pick the "best" encoding among a combinatorial set of possibilities with size $(n+1)^8$

Principle of Consistency:
The properties of the image (visual variables) should match the properties of the data.

Principle of Importance Ordering:
Encode the most important information in the most effective way.

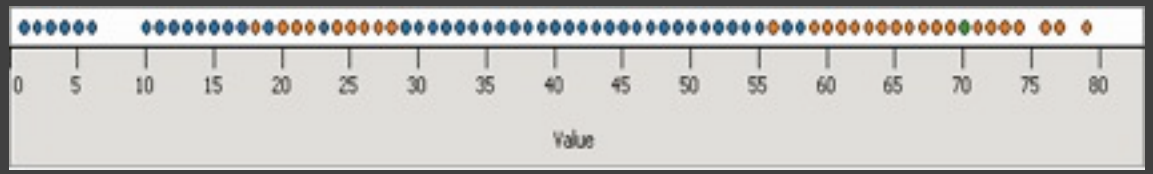
Design Criteria (Mackinlay)

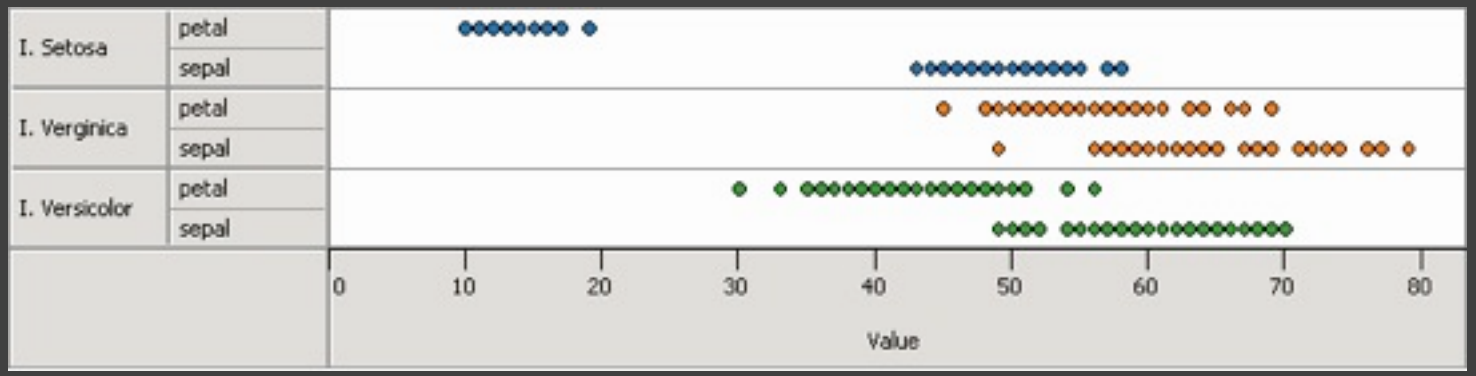
Expressiveness

A set of facts is expressible in a visual language if the sentences (i.e. the visualizations) in the language express all the facts in the set of data, and only the facts in the data.

Cannot express the facts

A one-to-many (1 → N) relation cannot be expressed in a single horizontal dot plot because multiple tuples are mapped to the same position





Expresses facts not in the data

A length is interpreted as a quantitative value;

∴ Length of bar says something untrue about N data

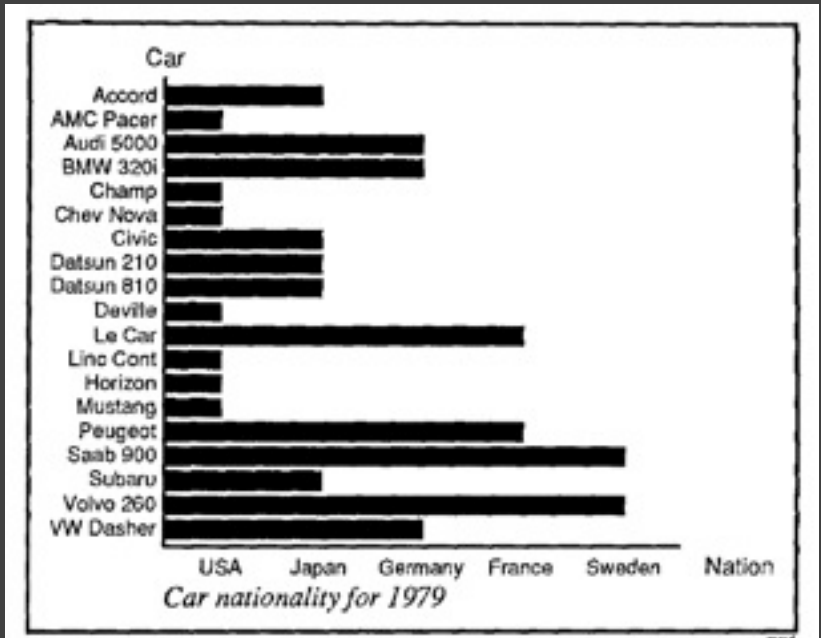


Fig. 11. Incorrect use of a bar chart for the *Nation* relation. The lengths of the bars suggest an ordering on the vertical axis, as if the USA cars were longer or better than the other cars, which is not true for the *Nation* relation.

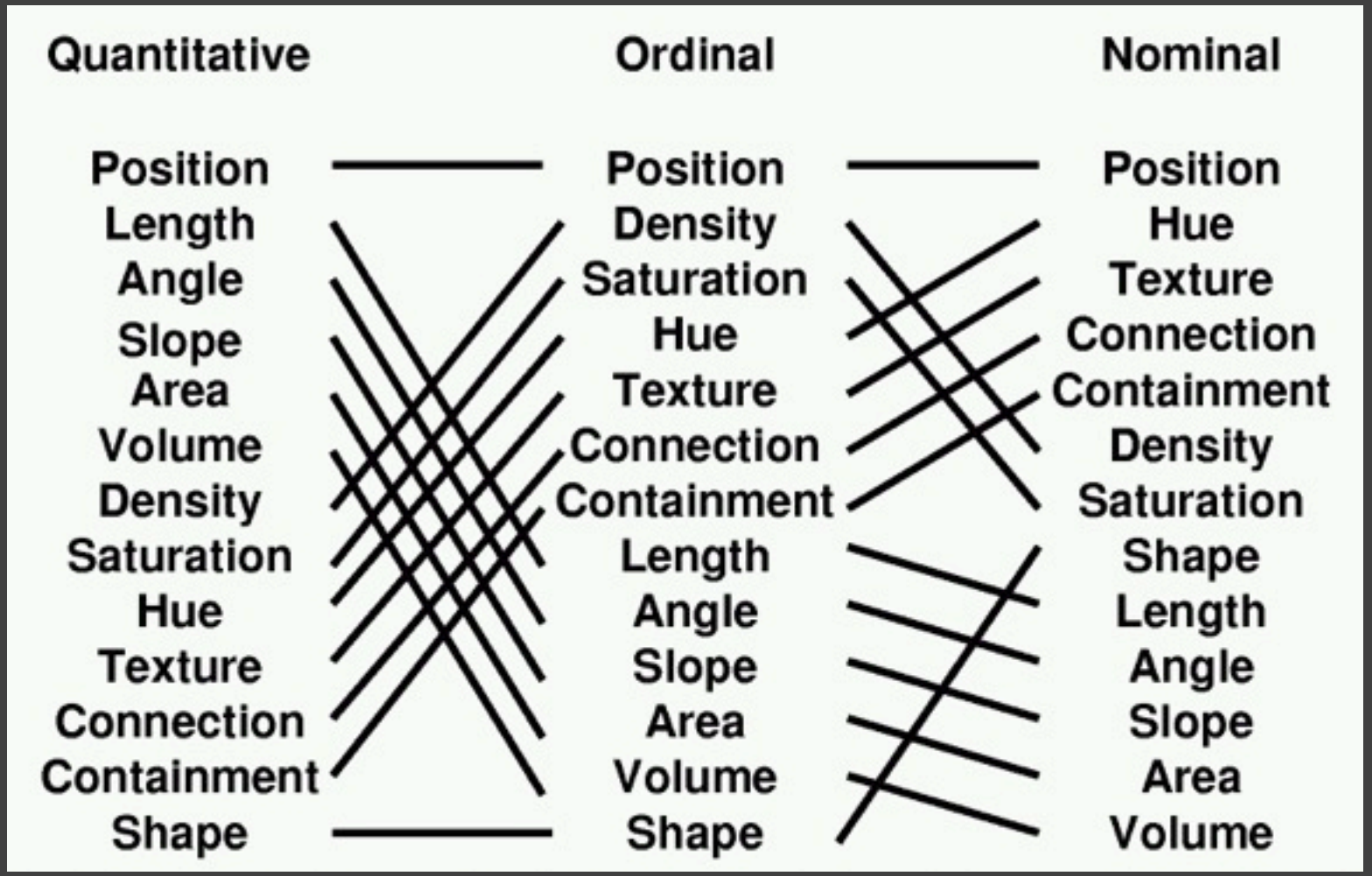
[Mackinlay, APT, 1986]

Design Criteria (Mackinlay)

Expressiveness
A set of facts is expressible in a visual language if the sentences (i.e. the visualizations) in the language express all the facts in the set of data, and only the facts in the data.

Effectiveness
A visualization is more effective than another visualization if the information conveyed by one visualization is more readily perceived than the information in the other visualization.

Mackinlay's Ranking



Conjectured *effectiveness* of the encoding

Mackinlay's Design Algorithm

User formally specifies data model and type

- Additional input: ordered list of data variables to show

APT searches over design space

- Tests expressiveness of each visual encoding
- Generates specification for encodings that pass test
- Tests perceptual effectiveness of resulting image

Outputs the "most effective" visualization

Limitations

Does not cover many visualization techniques

- Bertin and others discuss networks, maps, diagrams
- Does not consider 3D, animation, illustration, photography, ...

Does not model interaction

Does not consider semantic data types / conventions

Assignment 1 Review

Design Considerations

Title, labels, legend, captions, source!

Expressiveness and Effectiveness

Avoid unexpressive marks (lines? bars? gradients?)

Use perceptually effective encodings

Don't distract: faint gridlines, pastel highlights/fills

The "elimination diet" approach – start minimal

Support comparison and pattern perception

Between elements, to a reference line, or to totals

Design Considerations

Group / sort data by meaningful dimensions

Transform data (e.g., invert, log, normalize)

Are model choices (regression lines) appropriate?

Reduce cognitive overhead

Minimize visual search, minimize ambiguity

-> Avoid legend lookups if direct labeling works

-> Avoid color mappings with indiscernible colors

Be consistent! **Visual inferences** should consistently support **data inferences**

In-Class Review Rubric

Expressiveness

- Prioritizes important information / Avoids false inferences
- Consistent visual mappings (e.g., respect color mappings)
- Make encodings *meaningful* rather than arbitrary

Effectiveness

- Facilitates accurate decoding / Minimizes cognitive overhead
- Highlight elements of primary interest

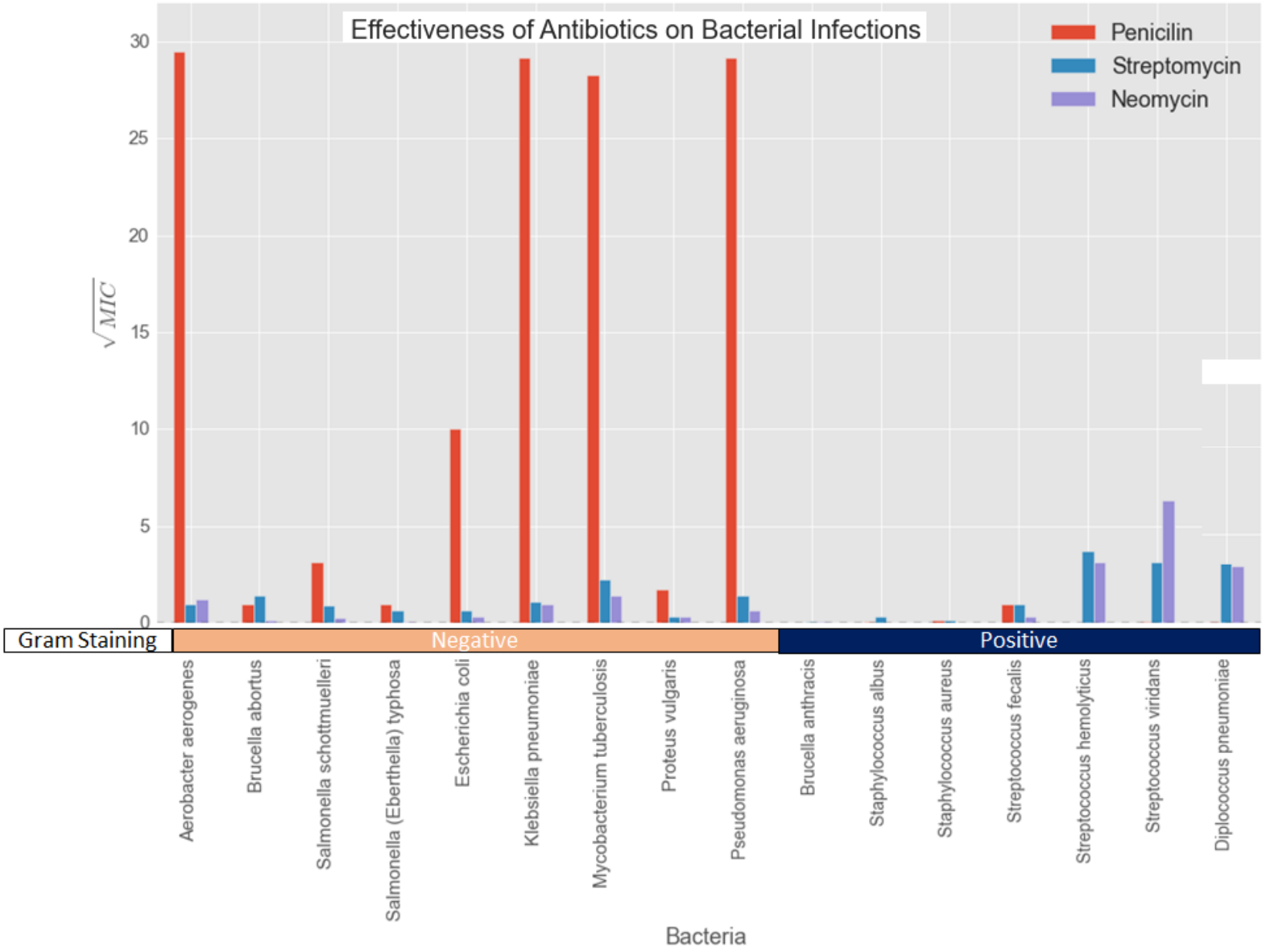
Grouping / Sorting

Data Transformation

Non-Data Elements

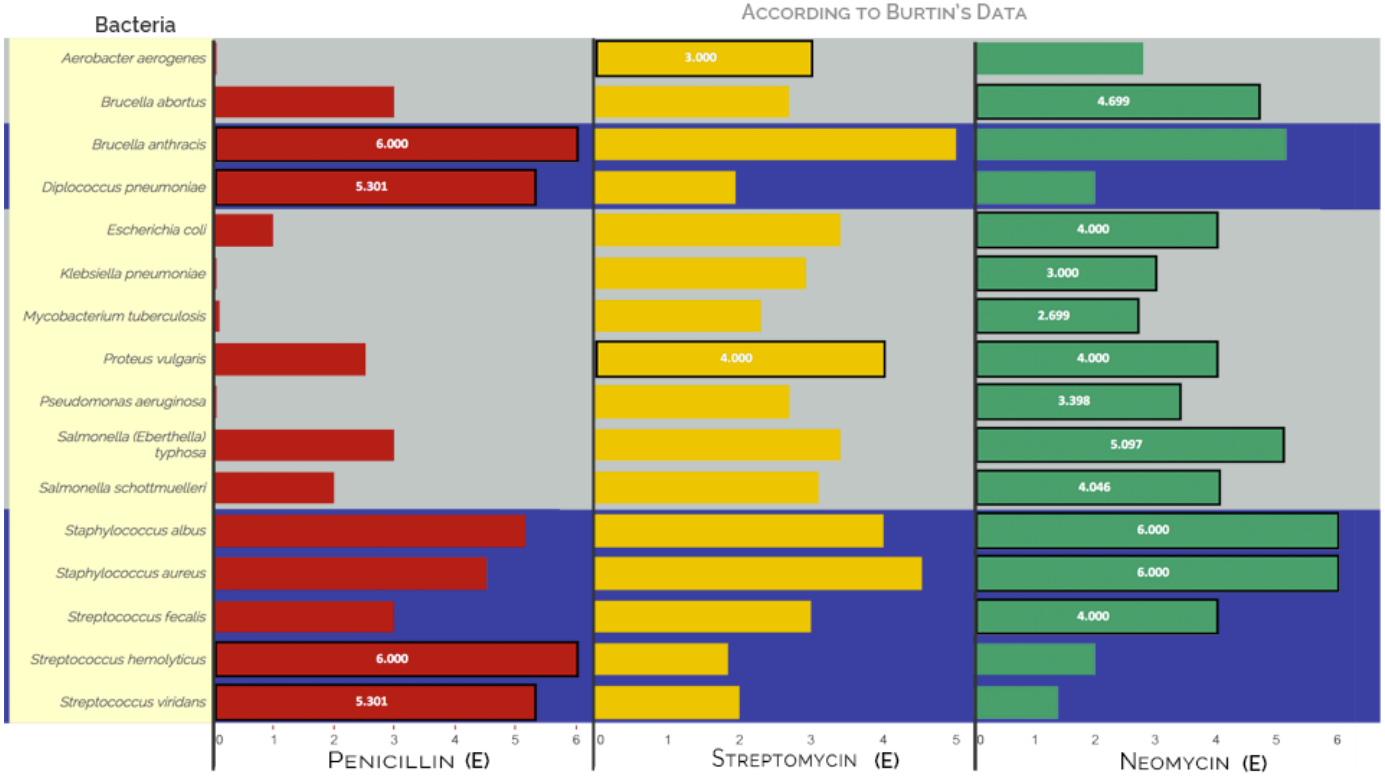
- Descriptive: Title, Label, Caption, Data Source, Annotations
- Reference: Gridlines, Legend

Bar Charts


Effectiveness of Antibiotics on Bacterial Infections
Penicilin
Streptomycin
Neomycin
$\sqrt{MIC}$
30
25
20
15
10
5
0
Gram Staining
Negative
Positive
Aerobacter aerogenes
Brucella abortus
Salmonella schottmuelleri
Salmonella (Eberthella) typhosa
Escherichia coli
Klebsiella pneumoniae
Mycobacterium tuberculosis
Proteus vulgaris
Pseudomonas aeruginosa
Brucella anthracis
Staphylococcus albus
Staphylococcus aureus
Streptococcus fecalis
Streptococcus hemolyticus
Streptococcus viridans
Diplococcus pneumoniae
Bacteria

Effectiveness of different antibiotics on various bacteria during World War II

According to Burtin's Data



Legend

- # Most Effective*
- −VE Gram Stain
- +VE Gram Stain

Effectiveness:

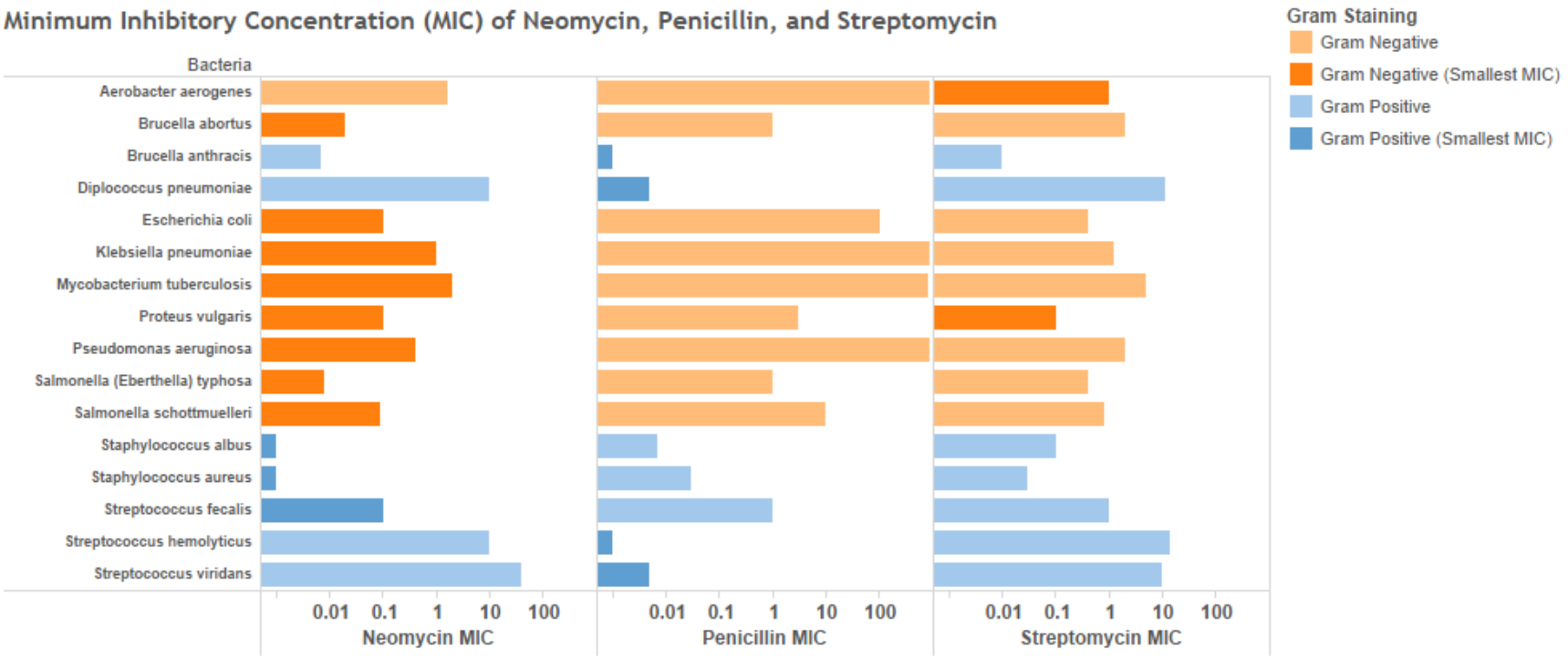
$E = \log_{10}(1000/MIC_x \text{ of Antibiotic})$

Key:

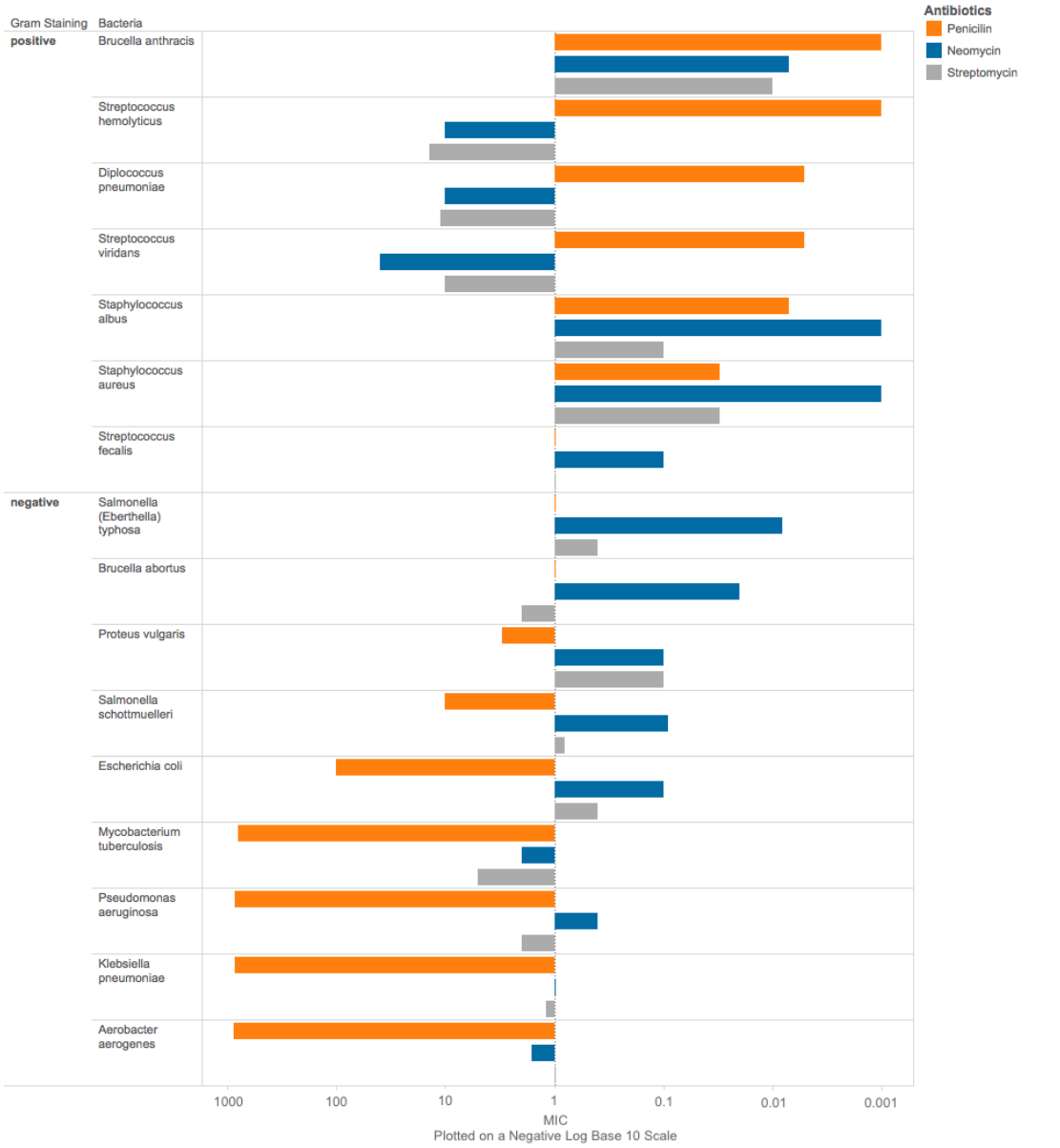
E: Effectiveness of Antibiotic

MIC: Min. Inhibitory Concentration

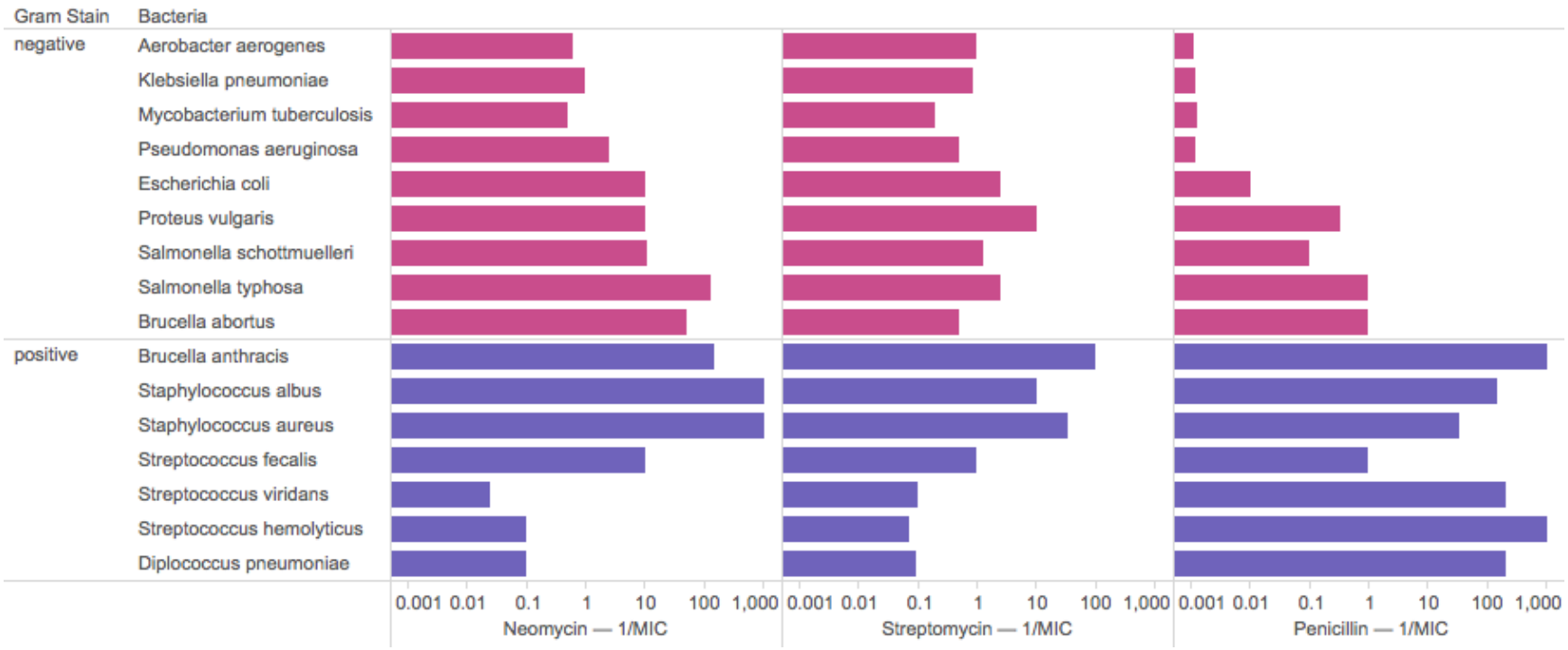
*Most effective of the three for identified bacteria

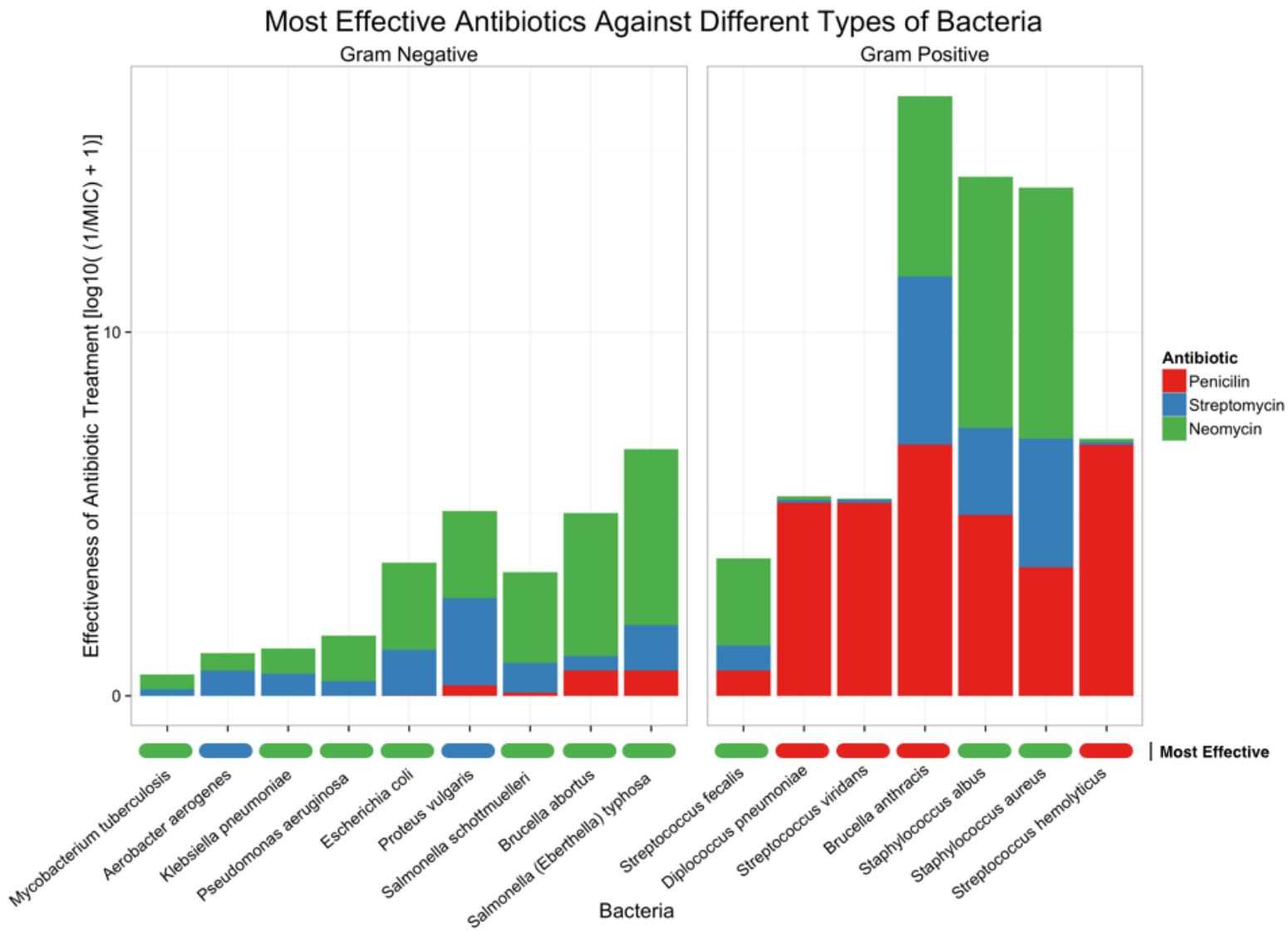

Minimum Inhibitory Concentration (MIC) of Neomycin, Penicillin, and Streptomycin
Bacteria
Aerobacter aerogenes
Brucella abortus
Brucella anthracis
Diplococcus pneumoniae
Escherichia coli
Klebsiella pneumoniae
Mycobacterium tuberculosis
Proteus vulgaris
Pseudomonas aeruginosa
Salmonella (Eberthella) typhosa
Salmonella schottmuelleri
Staphylococcus albus
Staphylococcus aureus
Streptococcus fecalis
Streptococcus hemolyticus
Streptococcus viridans
0.01 0.1 1 10 100
Neomycin MIC
0.01 0.1 1 10 100
Penicillin MIC
0.01 0.1 1 10 100
Streptomycin MIC
Gram Staining
Gram Negative
Gram Negative (Smallest MIC)
Gram Positive
Gram Positive (Smallest MIC)

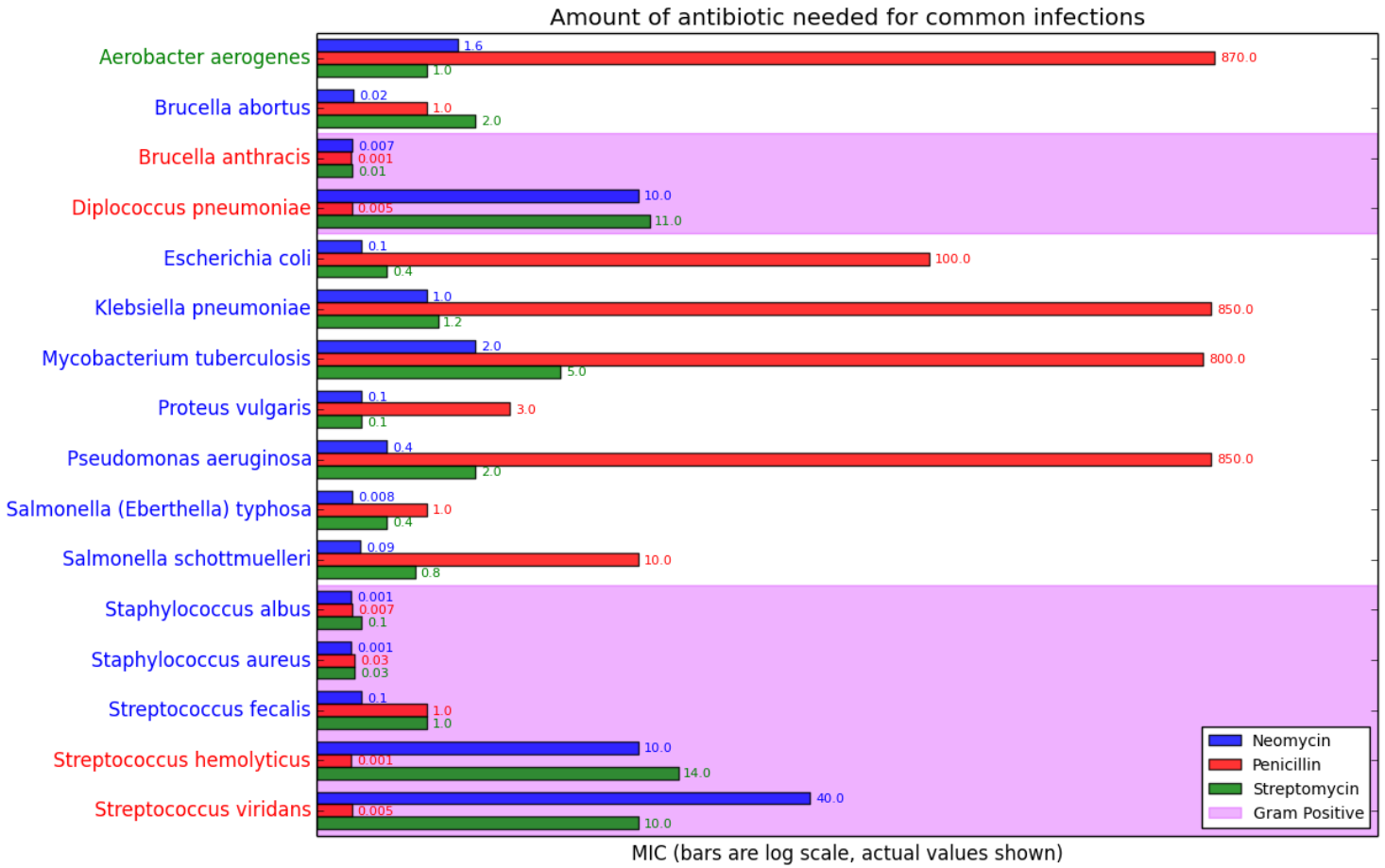
Effectiveness of Three Antibiotics Relative to a Minimum Inhibitory Concentration (MIC) of 1.0

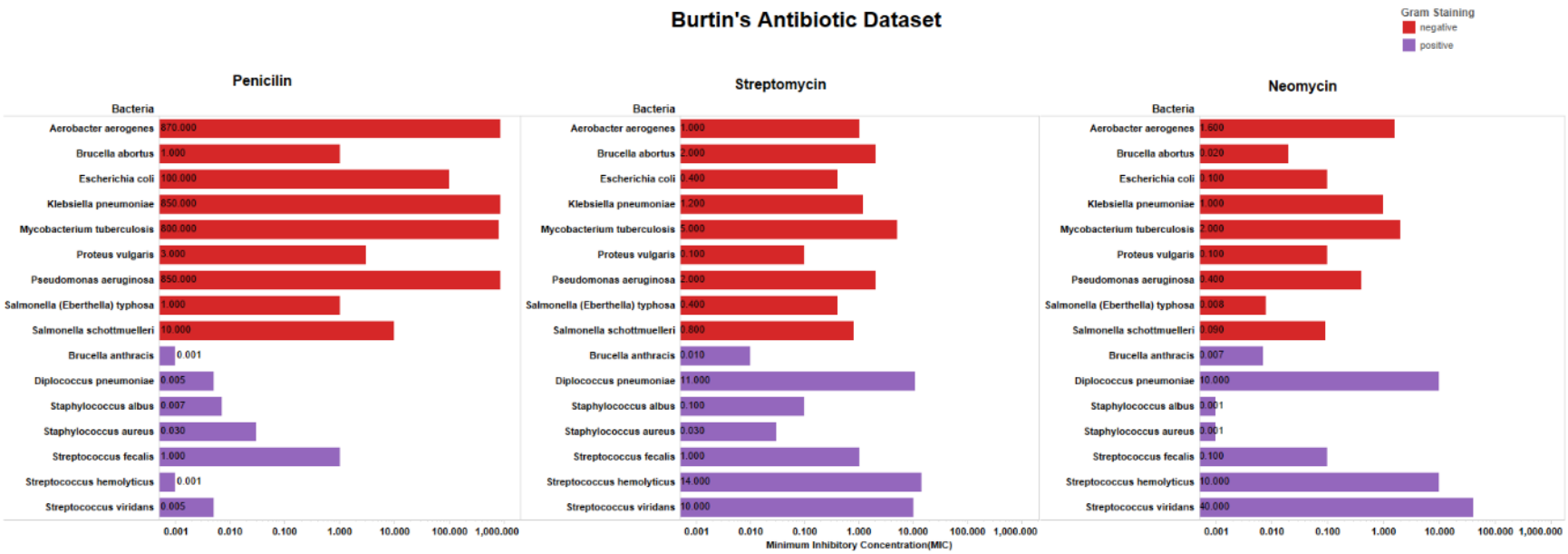


Effectiveness of antibiotics Neomycin, Streptomycin, and Penicillin

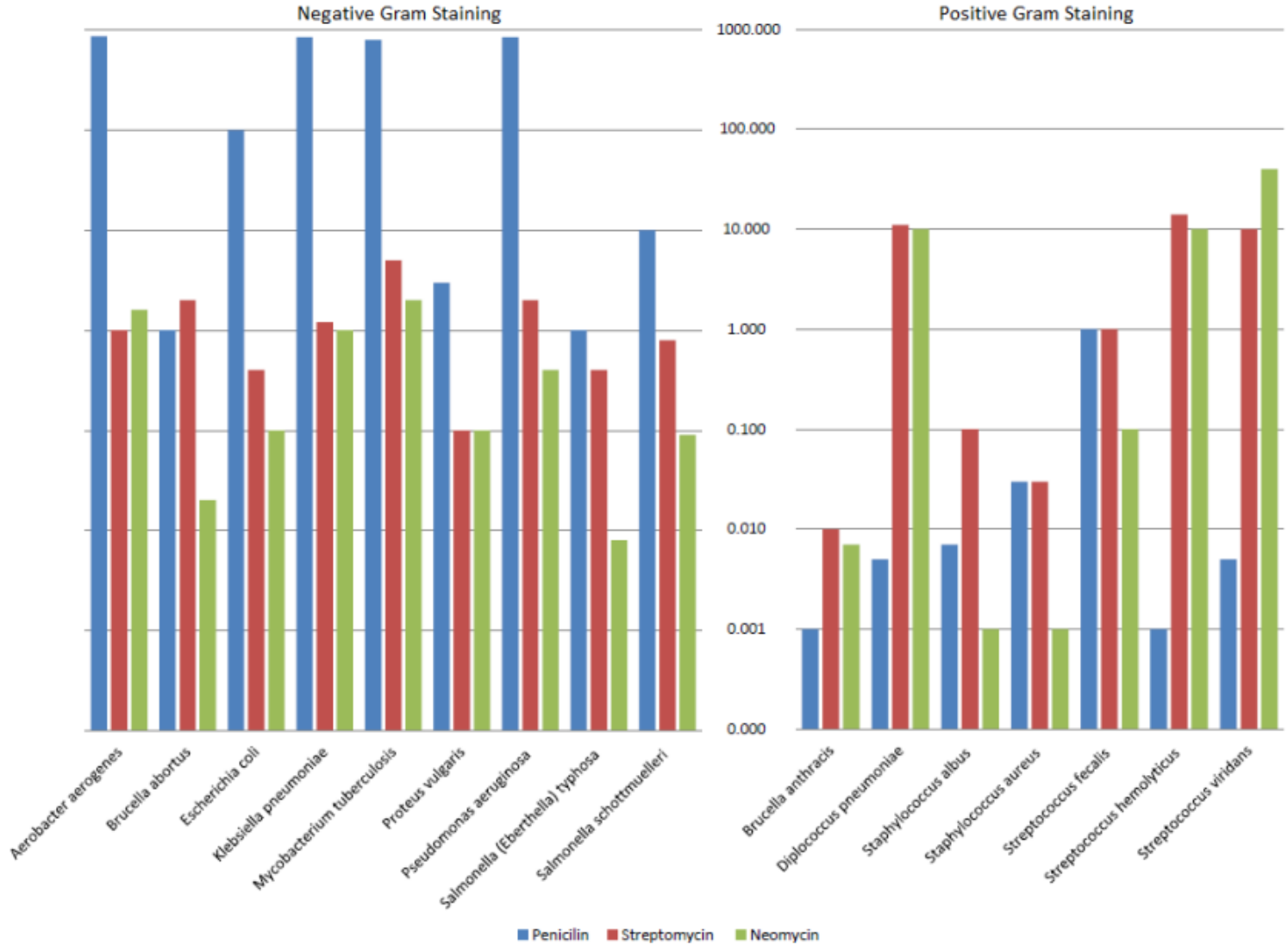


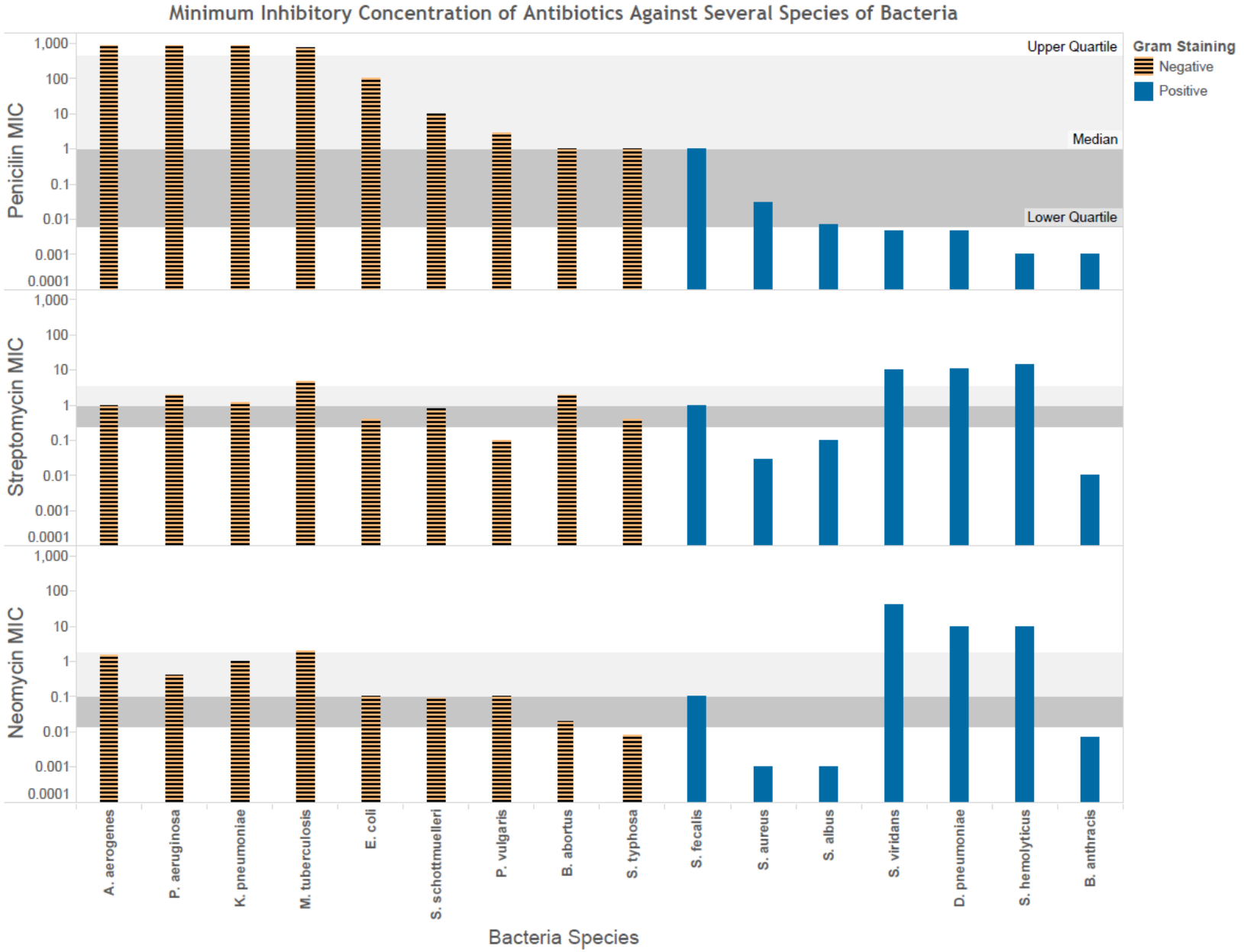

Most Effective Antibiotics Against Different Types of Bacteria
Gram Negative
Gram Positive
Effectiveness of Antibiotic Treatment [log10((1/MIC) + 1)]
10
0
Antibiotic
Penicillin
Streptomycin
Neomycin
Most Effective
Mycobacterium tuberculosis
Aerobacter aerogenes
Klebsiella pneumoniae
Pseudomonas aeruginosa
Escherichia coli
Proteus vulgaris
Salmonella schottmuelleri
Brucella abortus
Salmonella (Eberthella) typhosa
Streptococcus fecalis
Diplococcus pneumoniae
Streptococcus viridans
Brucella anthracis
Staphylococcus albus
Staphylococcus aureus
Streptococcus hemolyticus
Bacteria

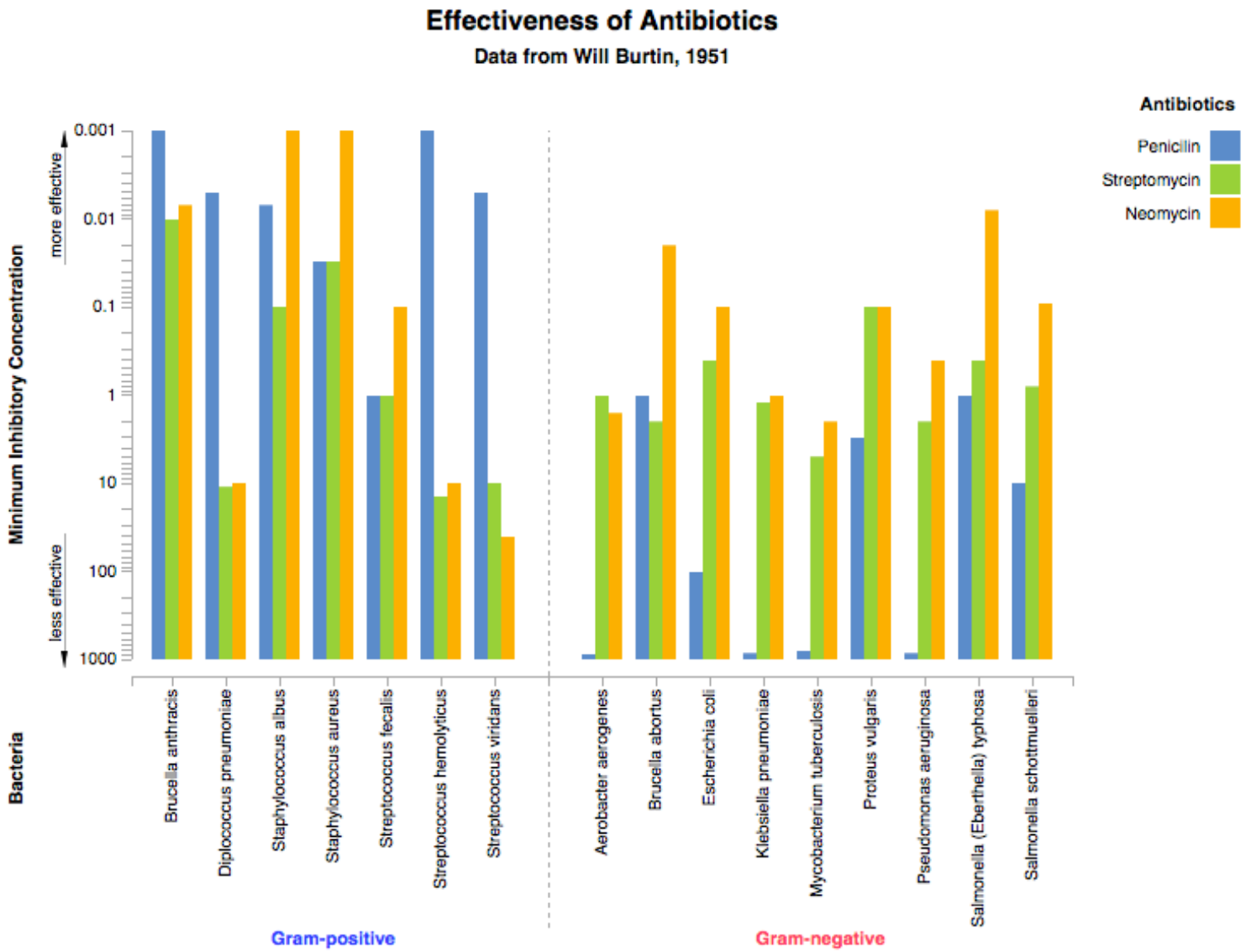

Amount of antibiotic needed for common infections
Aerobacter aerogenes
Brucella abortus
Brucella anthracis
Diplococcus pneumoniae
Escherichia coli
Klebsiella pneumoniae
Mycobacterium tuberculosis
Proteus vulgaris
Pseudomonas aeruginosa
Salmonella (Eberthella) typhosa
Salmonella schottmuelleri
Staphylococcus albus
Staphylococcus aureus
Streptococcus fecalis
Streptococcus hemolyticus
Streptococcus viridans
1.6
870.0
1.0
0.02
1.0
2.0
0.007
0.001
0.01
10.0
0.005
11.0
0.1
100.0
0.4
1.0
850.0
1.2
2.0
800.0
5.0
0.1
3.0
0.1
0.4
850.0
2.0
0.008
1.0
0.4
0.09
10.0
0.8
0.001
0.007
0.1
0.001
0.03
0.03
0.1
1.0
1.0
10.0
0.001
14.0
40.0
0.005
10.0
Neomycin
Penicillin
Streptomycin
Gram Positive
MIC (bars are log scale, actual values shown)


Burtin's Antibiotic Dataset
Gram Staining
negative
positive
Penicillin
Streptomycin
Neomycin
Bacteria
Aerobacter aerogenes
Brucella abortus
Escherichia coli
Klebsiella pneumoniae
Mycobacterium tuberculosis
Proteus vulgaris
Pseudomonas aeruginosa
Salmonella (Eberthella) typhosa
Salmonella schottmuelleri
Brucella anthracis
Diplococcus pneumoniae
Staphylococcus albus
Staphylococcus aureus
Streptococcus fecalis
Streptococcus hemolyticus
Streptococcus viridans
870.000
1.000
100.000
850.000
800.000
3.000
850.000
1.000
10.000
0.001
0.005
0.007
0.030
1.000
0.001
0.005
1.000
2.000
0.400
1.200
5.000
0.100
2.000
0.400
0.800
0.010
11.000
0.100
0.030
1.000
14.000
10.000
1.600
0.020
0.100
1.000
2.000
0.100
0.400
0.008
0.090
0.007
10.000
0.001
0.001
0.100
10.000
40.000
0.001
0.010
0.100
1.000
10.000
100.000
1,000.000
Minimum Inhibitory Concentration(MIC)

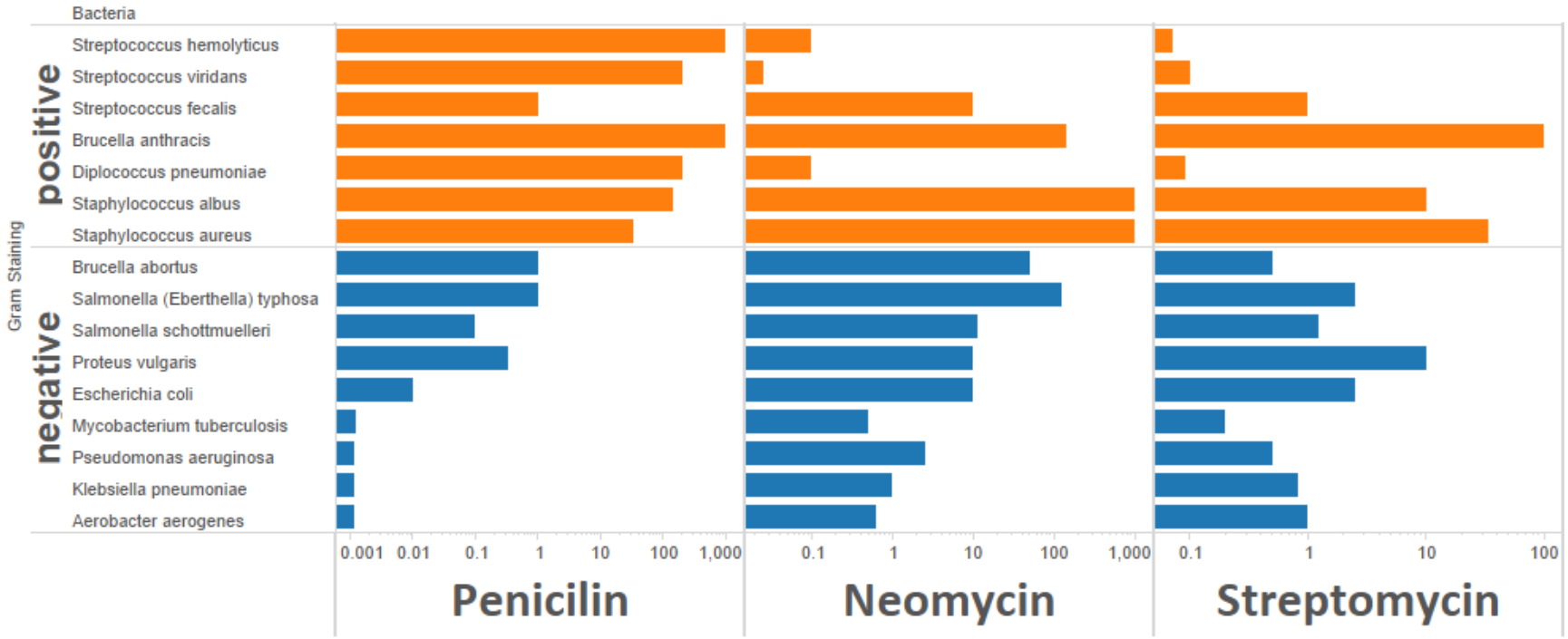
Minimum Inhibitory Concentration of Antibiotics on Negative and Positive Gram Staining Bacteria




Minimum Inhibitory Concentration of Antibiotics Against Several Species of Bacteria
Penicilin MIC
Streptomycin MIC
Neomycin MIC
1,000
100
10
1
0.1
0.01
0.001
0.0001
Upper Quartile
Median
Lower Quartile
Gram Staining
Negative
Positive
A. aerogenes
P. aeruginosa
K. pneumoniae
M. tuberculosis
E. coli
S. schottmuelleri
P. vulgaris
B. abortus
S. typhosa
S. fecalis
S. aureus
S. albus
S. viridans
D. pneumoniae
S. hemolyticus
B. anthracis
Bacteria Species

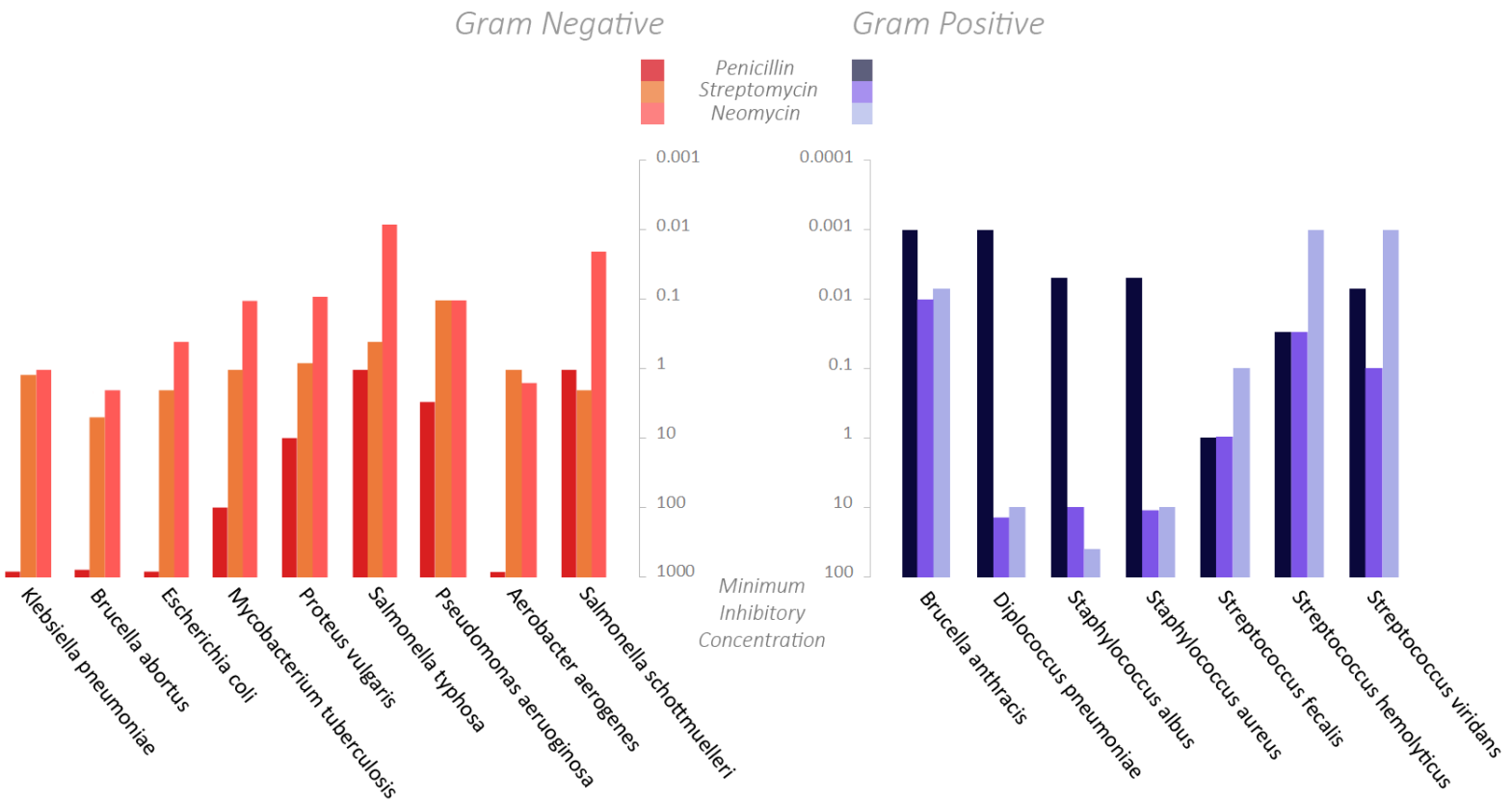

Effectiveness of Antibiotics
Data from Will Burtin, 1951
Antibiotics
Penicillin
Streptomycin
Neomycin
Minimum Inhibitory Concentration
more effective
less effective
0.001
0.01
0.1
1
10
100
1000
Bacteria
Brucella anthracis
Diplococcus pneumoniae
Staphylococcus albus
Staphylococcus aureus
Streptococcus fecalis
Streptococcus hemolyticus
Streptococcus viridans
Aerobacter aerogenes
Brucella abortus
Escherichia coli
Klebsiella pneumoniae
Mycobacterium tuberculosis
Proteus vulgaris
Pseudomonas aeruginosa
Salmonella (Eberthella) typhosa
Salmonella schottmuelleri
Gram-positive
Gram-negative

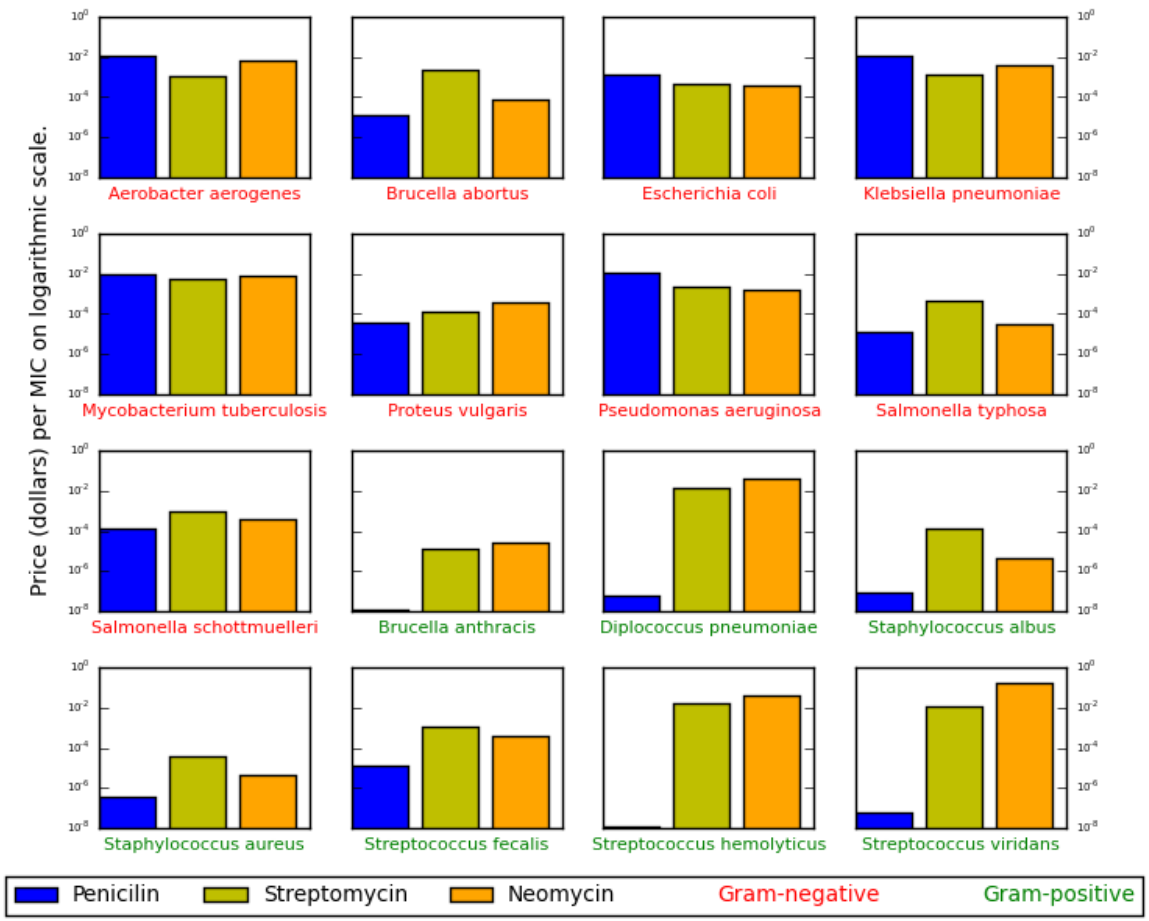
Effectiveness of three antibiotics against a variety of bacteria



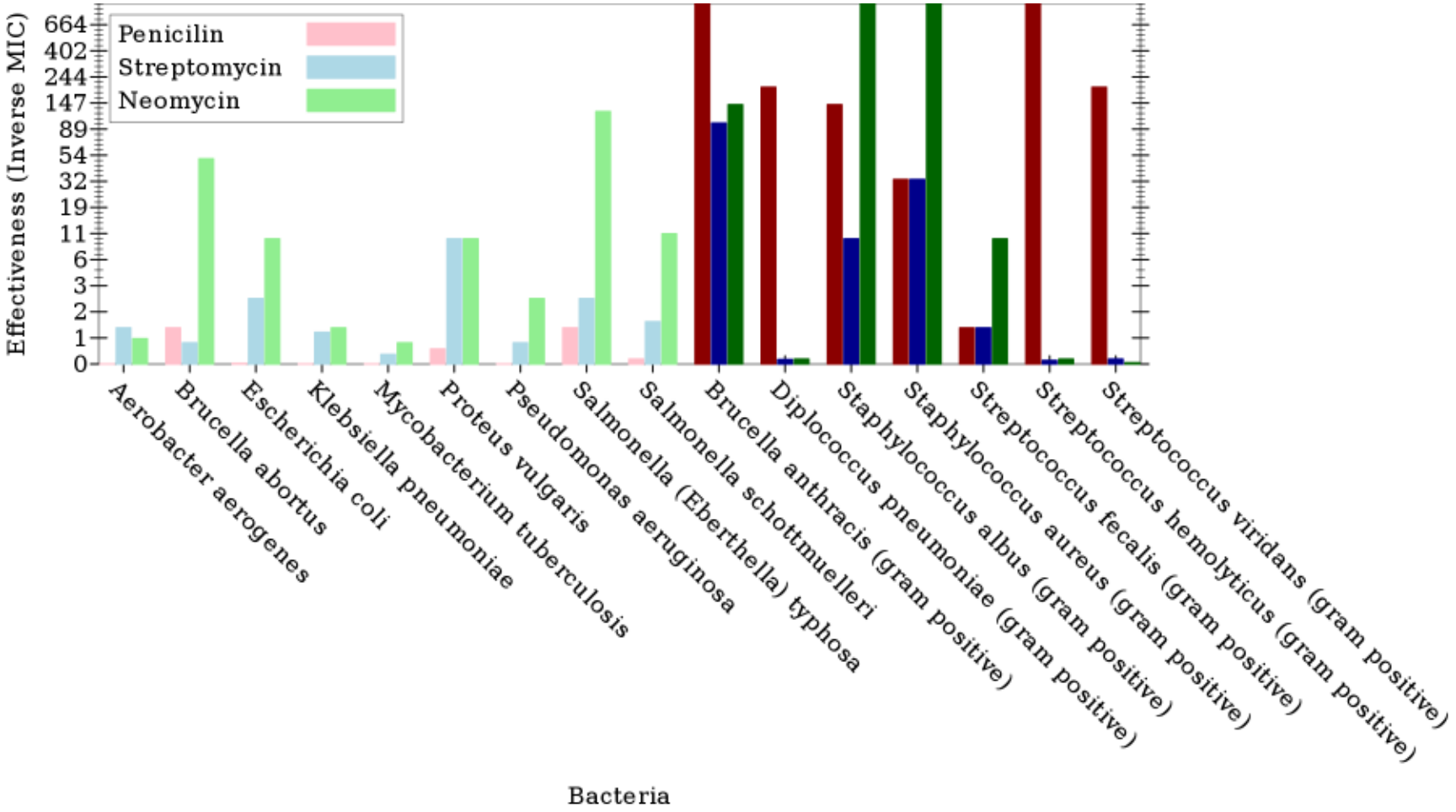
Inverse values of MIC of Penicilin, Neomycin and Streptomycin for each Bacteria broken down by Gram Staining. Color shows details about Gram Staining. Length shows the effectiveness of antibiotics.

Antibiotic Effectiveness

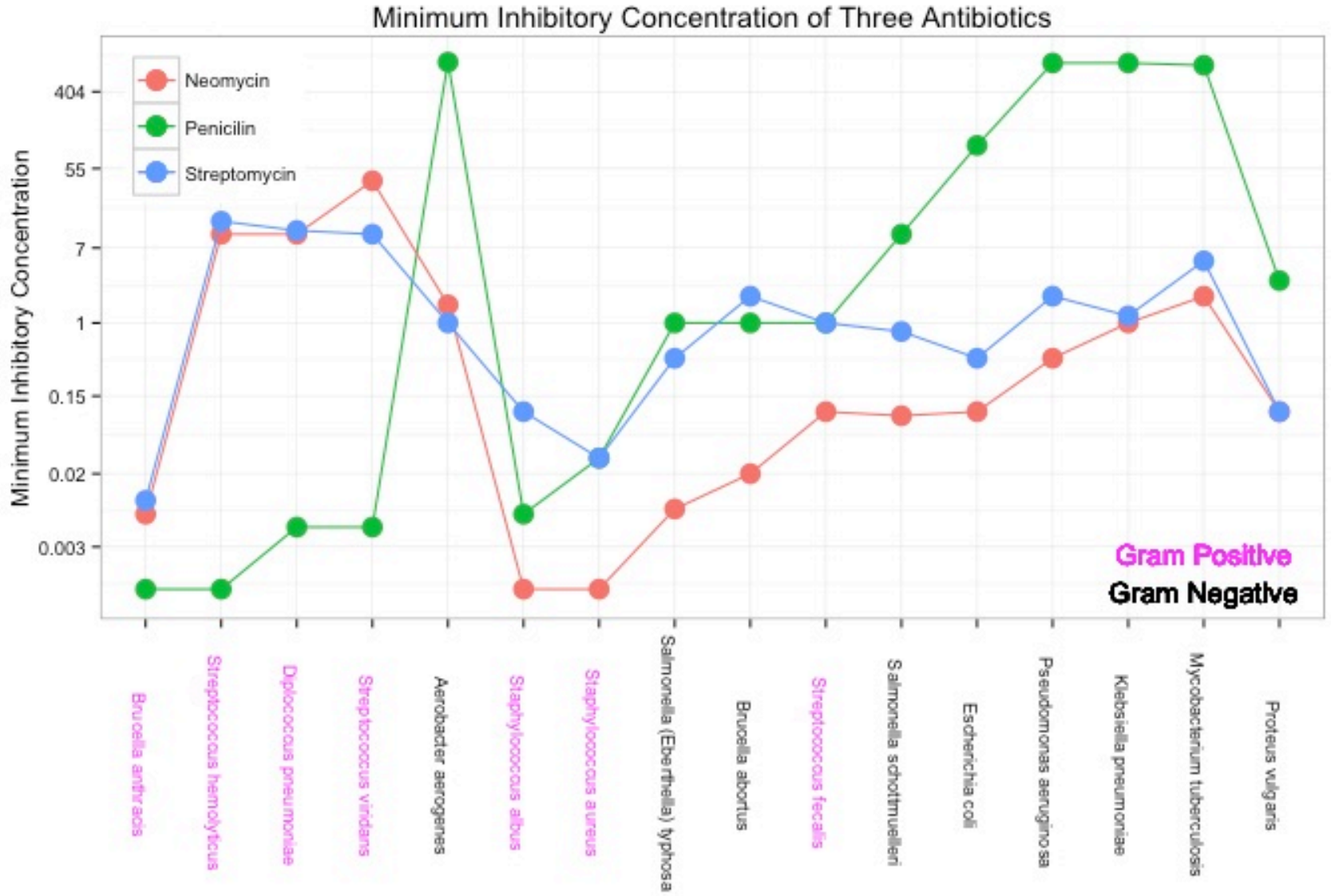




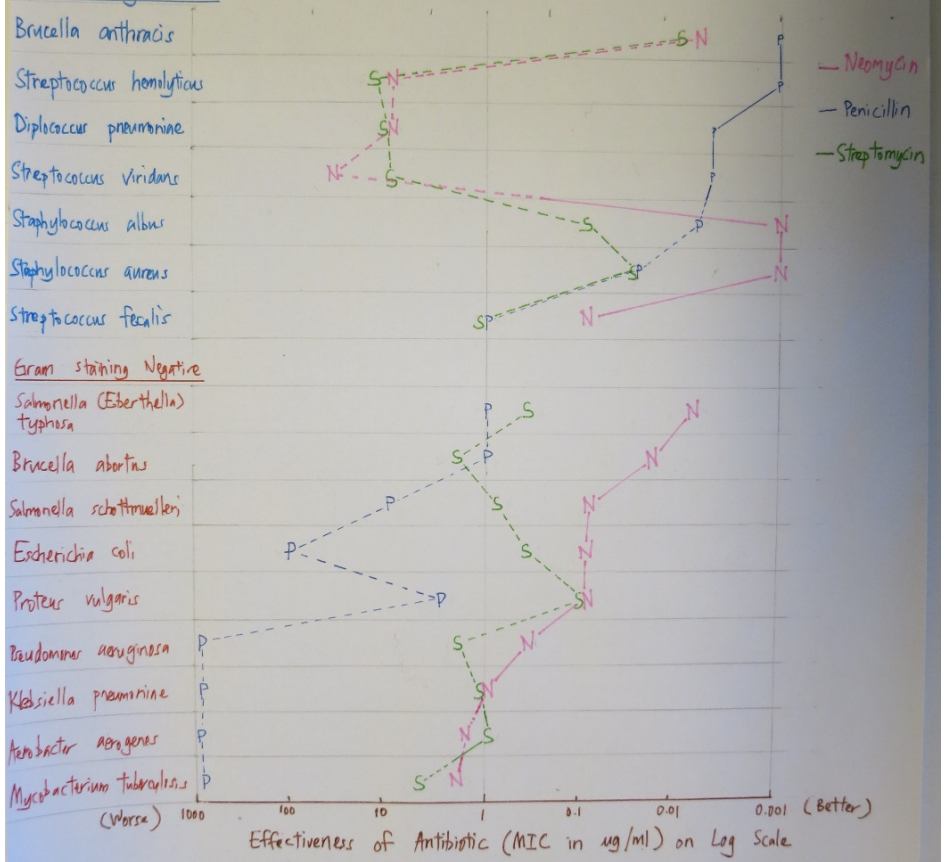
MIC (minimum inhibitory concentration) is the minimum concentration of the drug required to prevent the growth of the bacteria in vitro. The bacteria's names are colored by their test result (positive or negative) on a technique called Gram Staining. The price per mg of each drug in Seattle is as follows: Penicilin: $0.01, Streptymycin: $1.20, Neomycin: $4.04.


Penicilin
Streptomycin
Neomycin
Effectiveness (Inverse MIC)
664
402
244
147
89
54
32
19
11
6
3
2
1
0
Aerobacter aerogenes
Brucella abortus
Escherichia coli
Klebsiella pneumoniae
Mycobacterium tuberculosis
Proteus vulgaris
Pseudomonas aeruginosa
Salmonella (Eberthella) typhosa
Salmonella schottmuelleri
Brucella anthracis (gram positive)
Diplococcus pneumoniae (gram positive)
Staphylococcus albus (gram positive)
Staphylococcus aureus (gram positive)
Streptococcus fecalis (gram positive)
Streptococcus hemolyticus (gram positive)
Streptococcus viridans (gram positive)
Bacteria

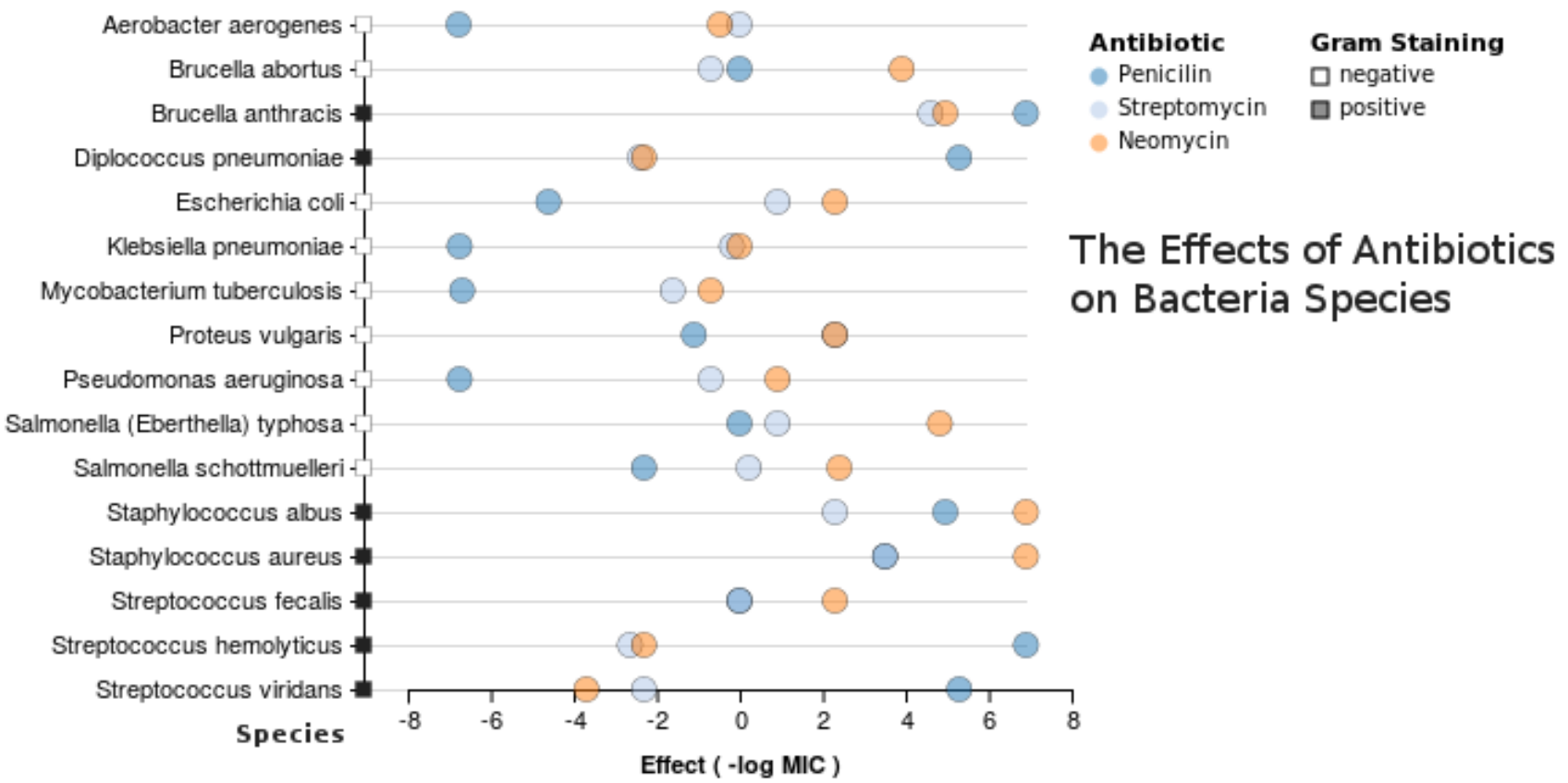
Line Charts

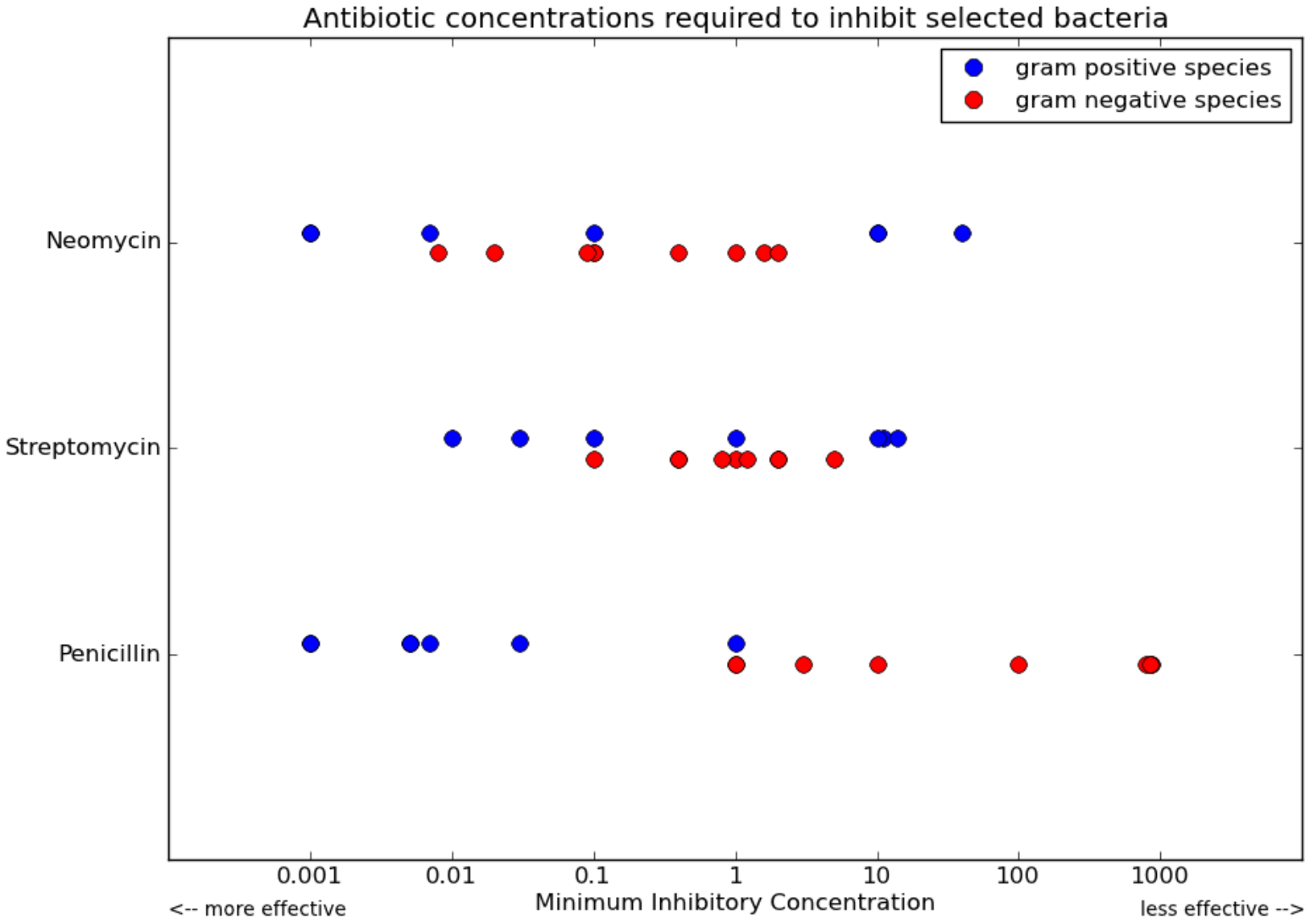

Minimum Inhibitory Concentration of Three Antibiotics
Minimum Inhibitory Concentration
404
55
7
1
0.15
0.02
0.003
Neomycin
Penicilin
Streptomycin
Gram Positive
Gram Negative
Brucella anthracis
Streptococcus haemolyticus
Diplococcus pneumoniae
Streptococcus viridans
Aerobacter aerogenes
Staphylococcus albus
Staphylococcus aureus
Salmonella (Eberthella) typhosa
Brucella abortus
Streptococcus fecalis
Salmonella schottmuelleri
Escherichia coli
Pseudomonas aeruginosa
Klebsiella pneumoniae
Mycobacterium tuberculosis
Proteus vulgaris

COMPARISON OF ANTIBIOTICS

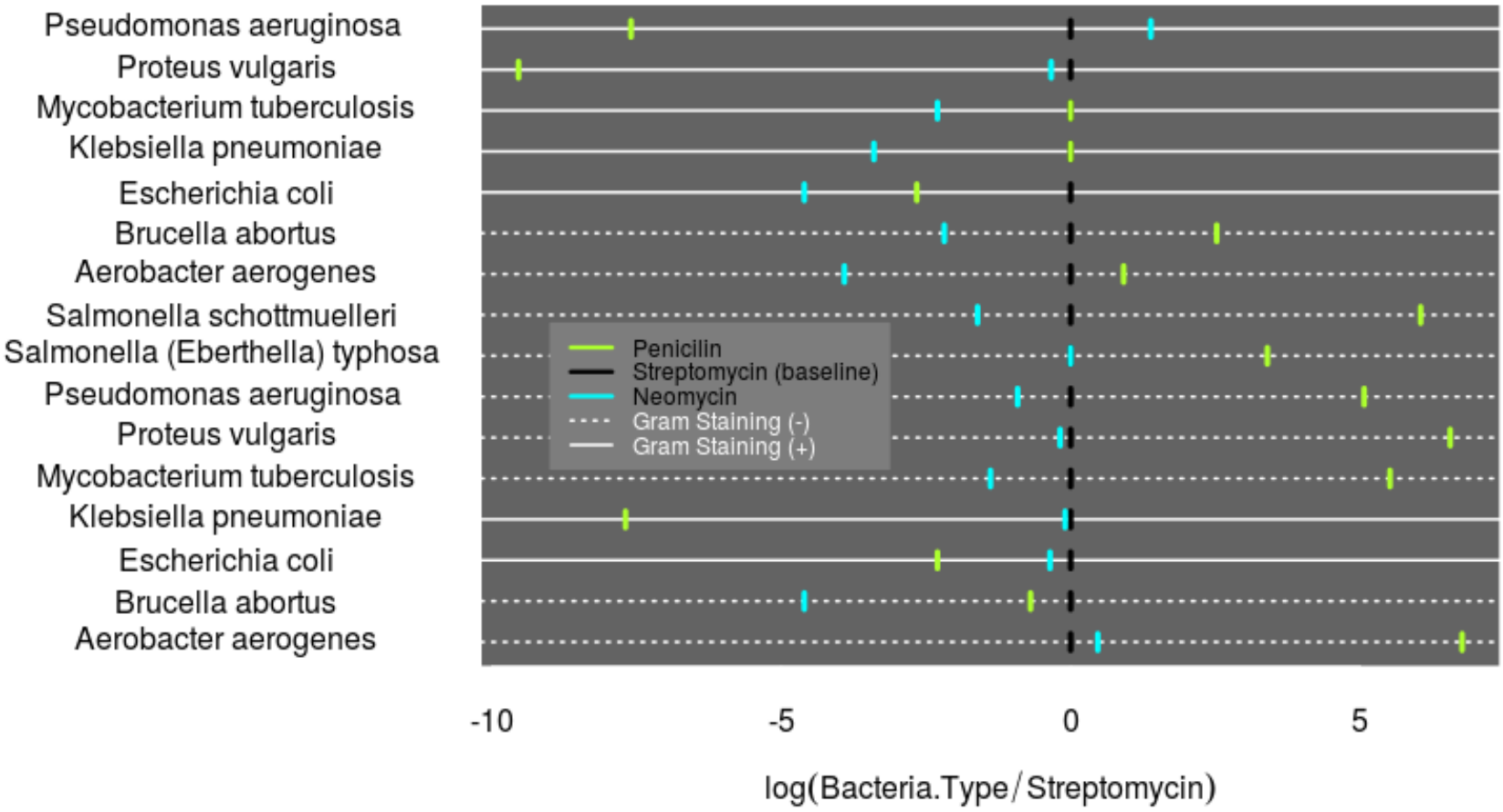


Dot Plots

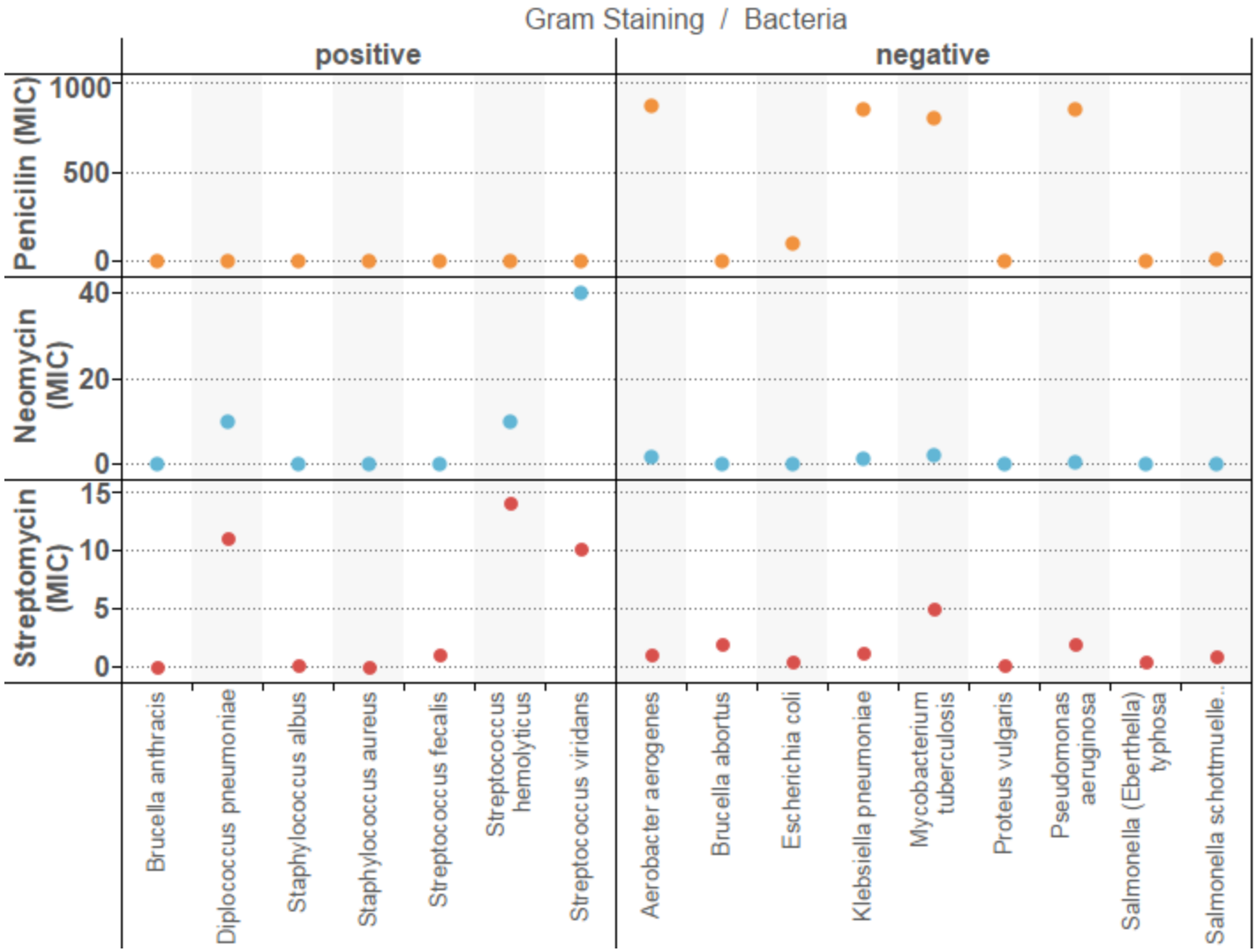

Aerobacter aerogenes
Brucella abortus
Brucella anthracis
Diplococcus pneumoniae
Escherichia coli
Klebsiella pneumoniae
Mycobacterium tuberculosis
Proteus vulgaris
Pseudomonas aeruginosa
Salmonella (Eberthella) typhosa
Salmonella schottmuelleri
Staphylococcus albus
Staphylococcus aureus
Streptococcus fecalis
Streptococcus hemolyticus
Streptococcus viridans
Species
-8
-6
-4
-2
0
2
4
6
8
Effect (-log MIC)
Antibiotic
Penicilin
Streptomycin
Neomycin
Gram Staining
negative
positive
The Effects of Antibiotics on Bacteria Species


Antibiotic concentrations required to inhibit selected bacteria
gram positive species
gram negative species
Neomycin
Streptomycin
Penicillin
0.001
0.01
0.1
1
10
100
1000
<-- more effective
Minimum Inhibitory Concentration
less effective -->

Performances of Antibiotics on Various Bacteria



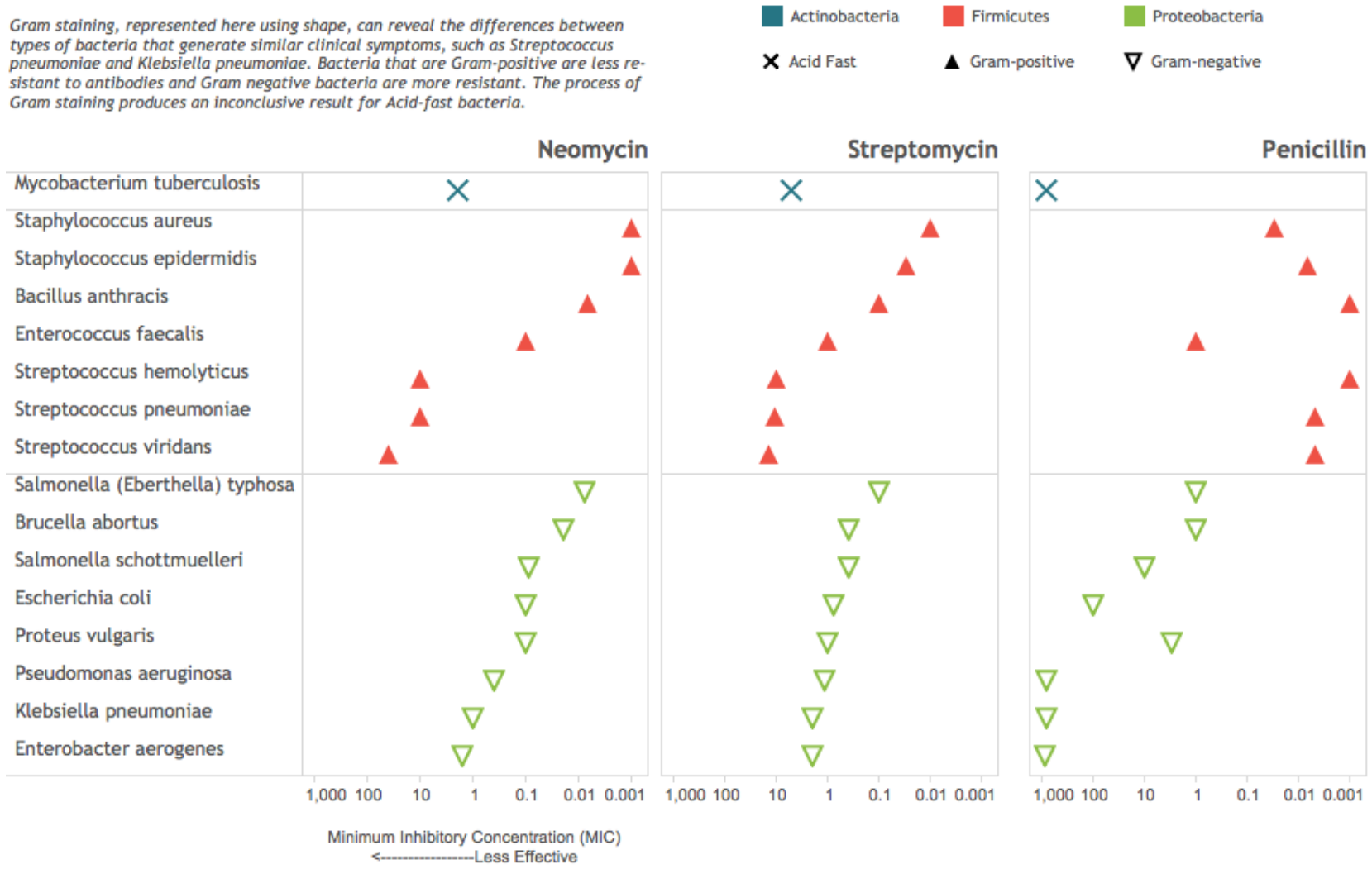
Minimum Inhibitory Concentrations (MIC) of Antibiotics for Gram-negative and Gram-positive Bacteria



The Effectiveness of 3 Popular Antibiotics on 16 Bacteria

These graphs illustrate the minimum inhibitory concentration (MIC), a measure of the effectiveness of an antibiotic, of Neomycin, Streptomycin and Penicillin required to prevent growth of selected bacteria in vitro and the responses of those bacteria to those same antibiotics

Gram staining, represented here using shape, can reveal the differences between types of bacteria that generate similar clinical symptoms, such as Streptococcus pneumoniae and Klebsiella pneumoniae. Bacteria that are Gram-positive are less resistant to antibodies and Gram negative bacteria are more resistant. The process of Gram staining produces an inconclusive result for Acid-fast bacteria.



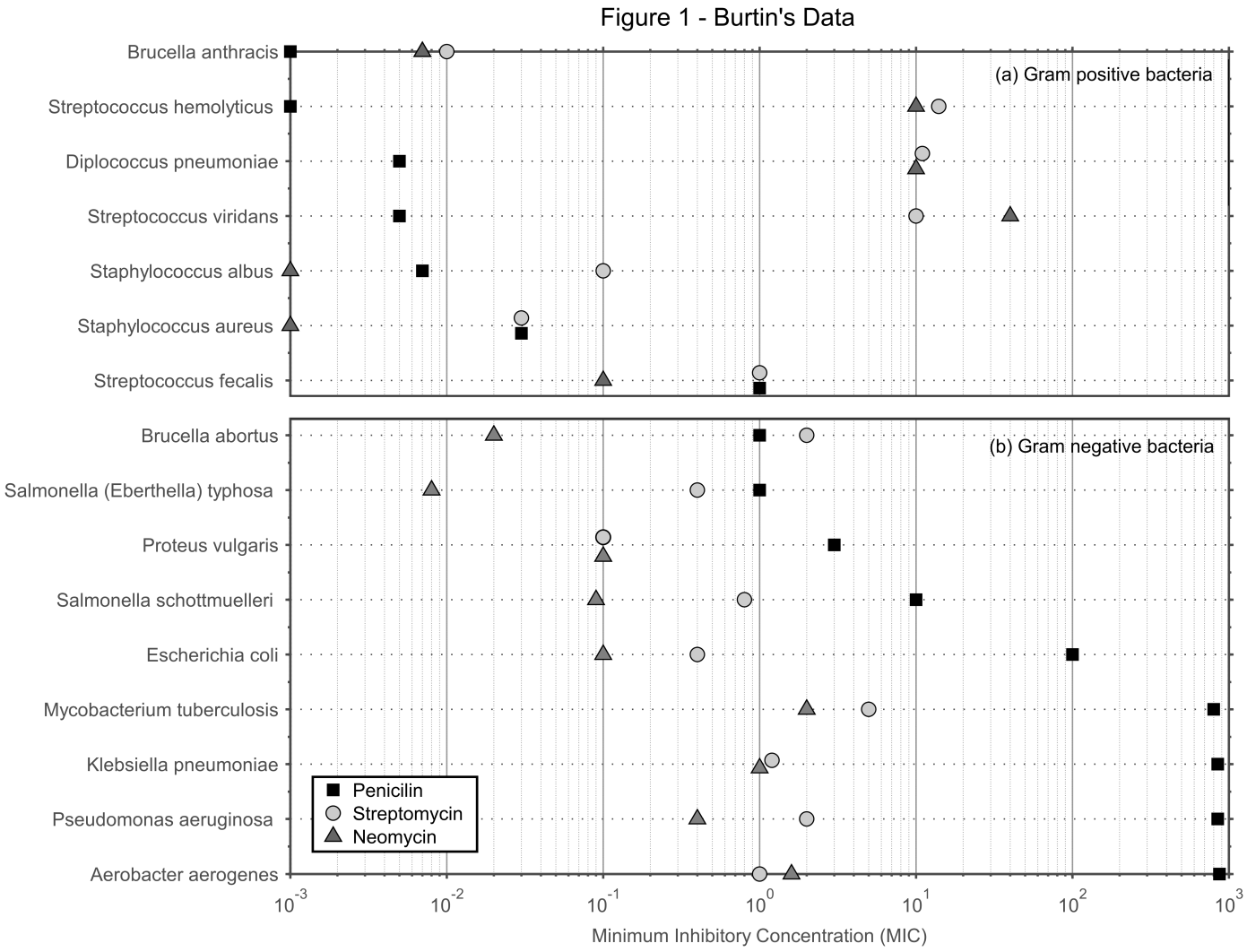
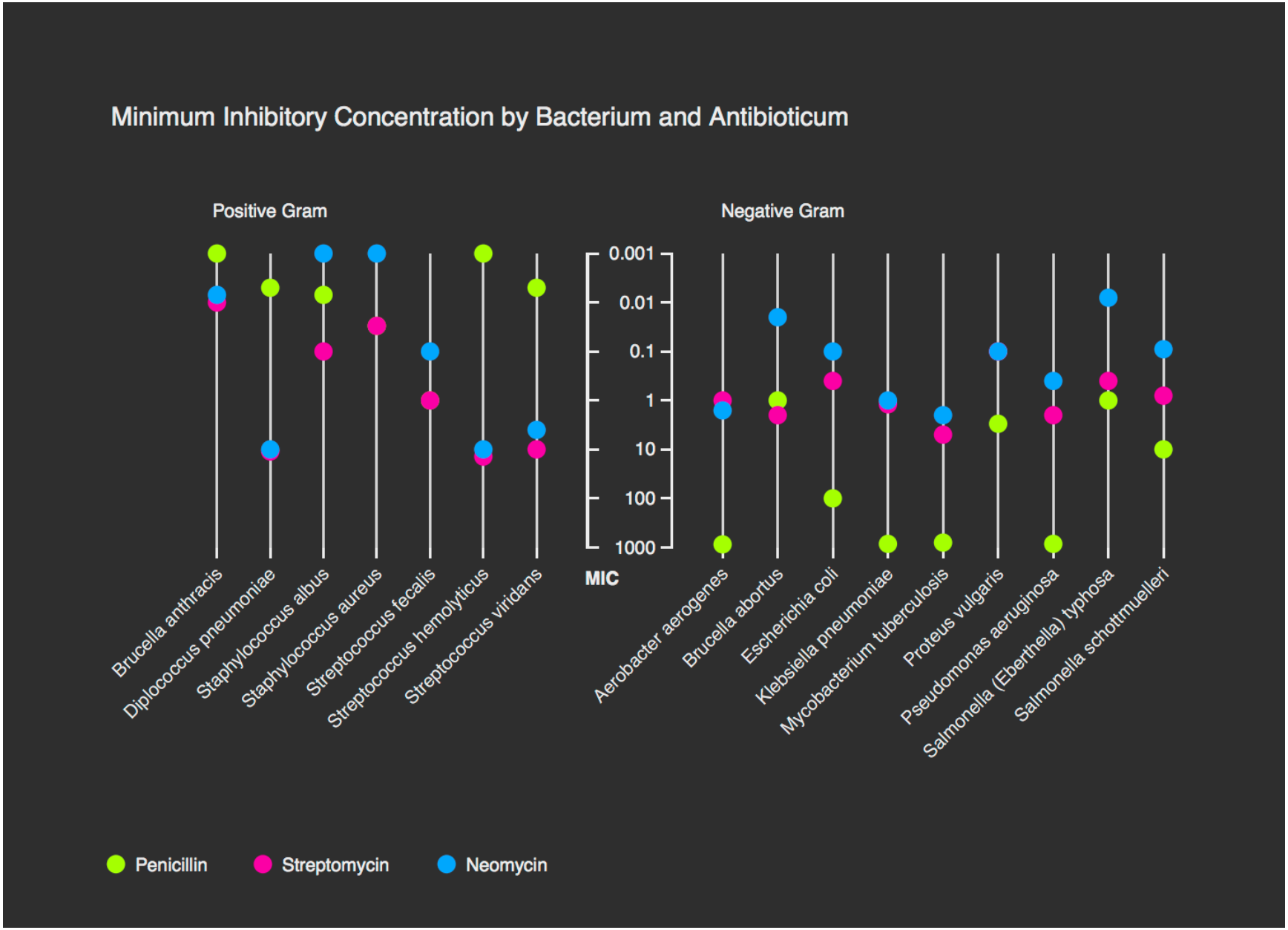
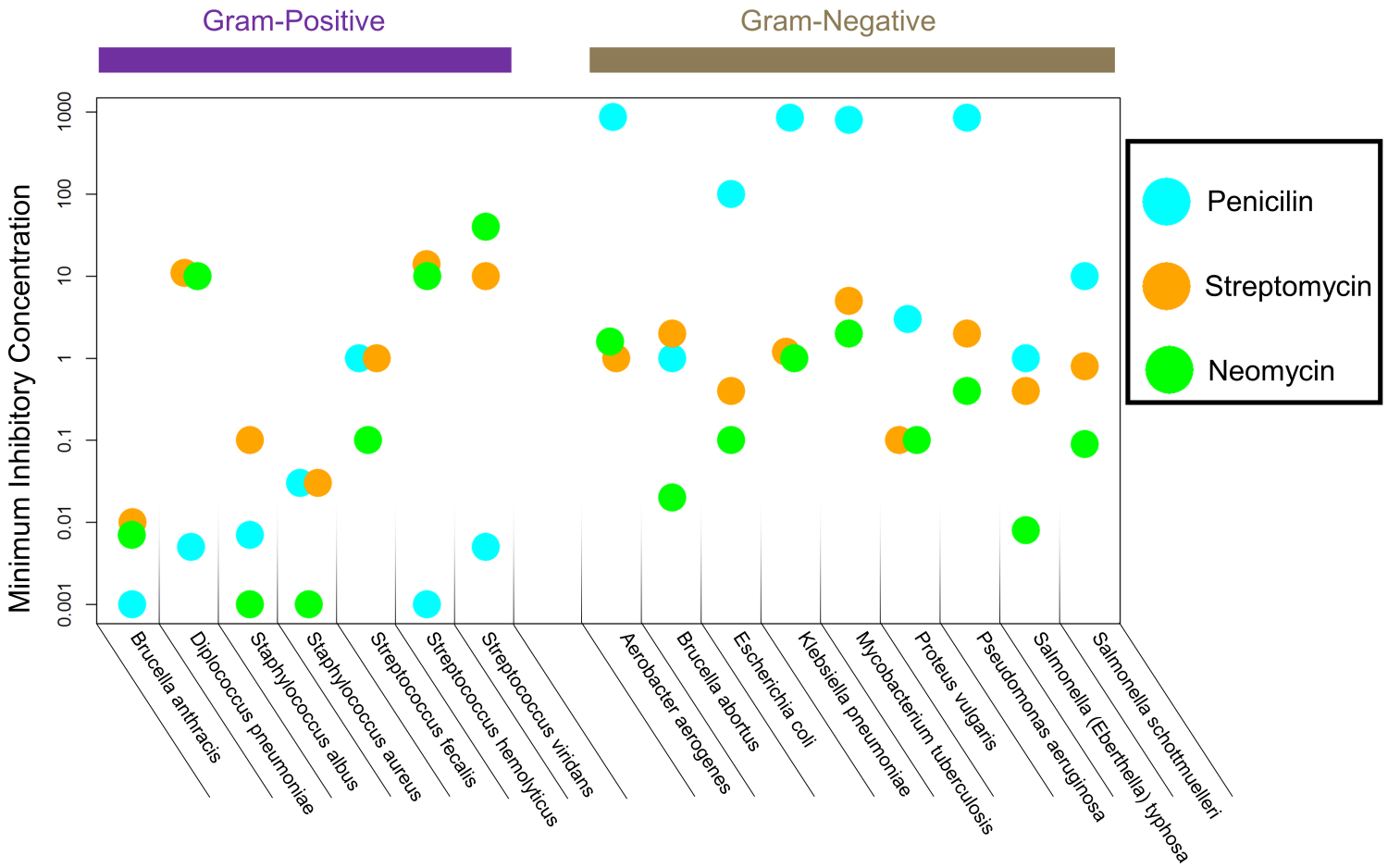


Figure 1 - Burtin's Data
Brucella anthracis
Streptococcus hemolyticus
Diplococcus pneumoniae
Streptococcus viridans
Staphylococcus albus
Staphylococcus aureus
Streptococcus fecalis
(a) Gram positive bacteria
Brucella abortus
Salmonella (Eberthella) typhosa
Proteus vulgaris
Salmonella schottmuelleri
Escherichia coli
Mycobacterium tuberculosis
Klebsiella pneumoniae
Pseudomonas aeruginosa
Aerobacter aerogenes
(b) Gram negative bacteria
Penicilin
Streptomycin
Neomycin
10-3
10-2
10-1
100
101
102
103
Minimum Inhibitory Concentration (MIC)

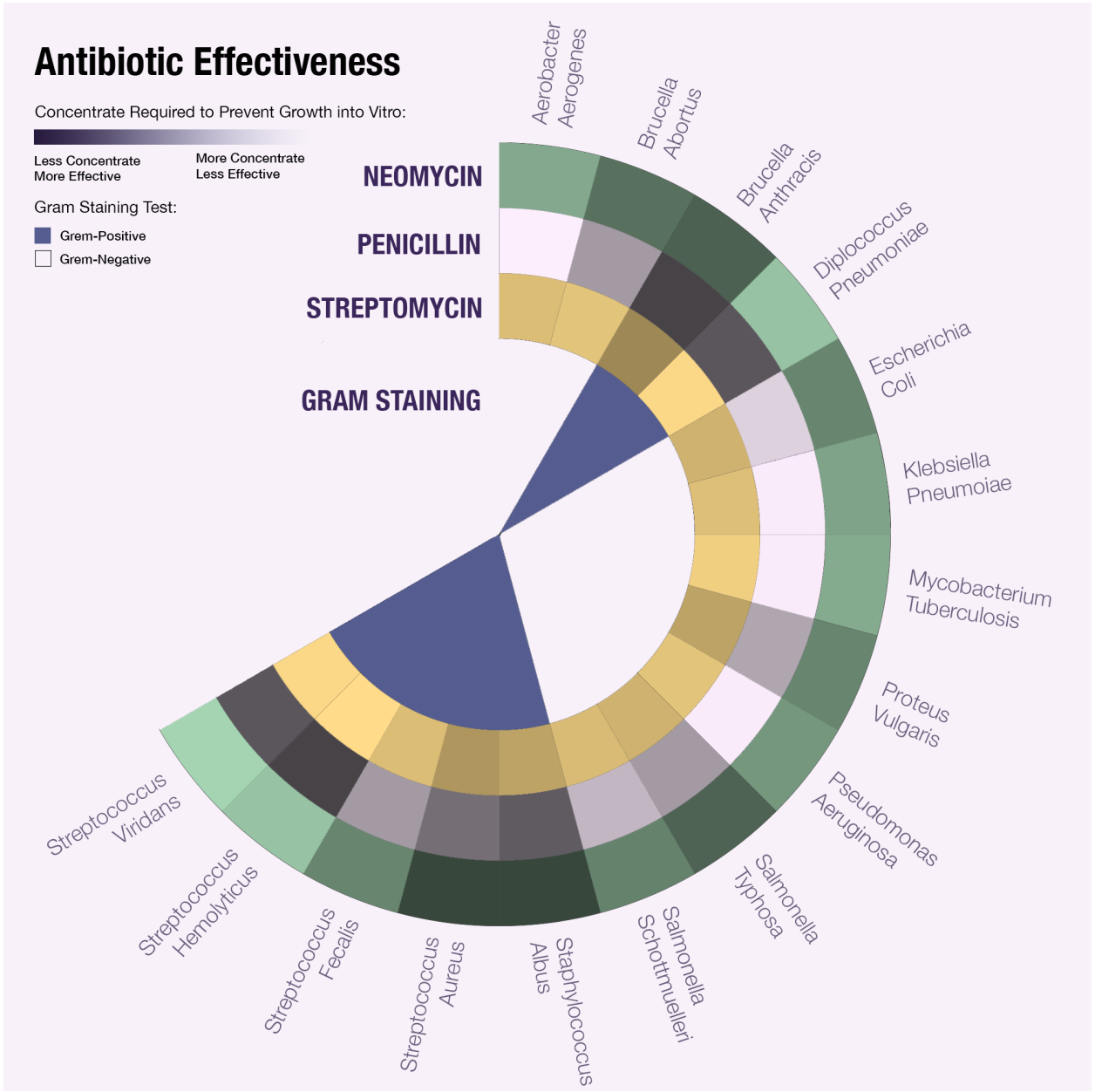

Minimum Inhibitory Concentration by Bacterium and Antibioticum
Positive Gram
Negative Gram
0.001
0.01
0.1
1
10
100
1000
MIC
Brucella anthracis
Diplococcus pneumoniae
Staphylococcus albus
Staphylococcus aureus
Streptococcus fecalis
Streptococcus hemolyticus
Streptococcus viridans
Aerobacter aerogenes
Brucella abortus
Escherichia coli
Klebsiella pneumoniae
Mycobacterium tuberculosis
Proteus vulgaris
Pseudomonas aeruginosa
Salmonella (Eberthella) typhosa
Salmonella schottmuelleri
Penicillin
Streptomycin
Neomycin

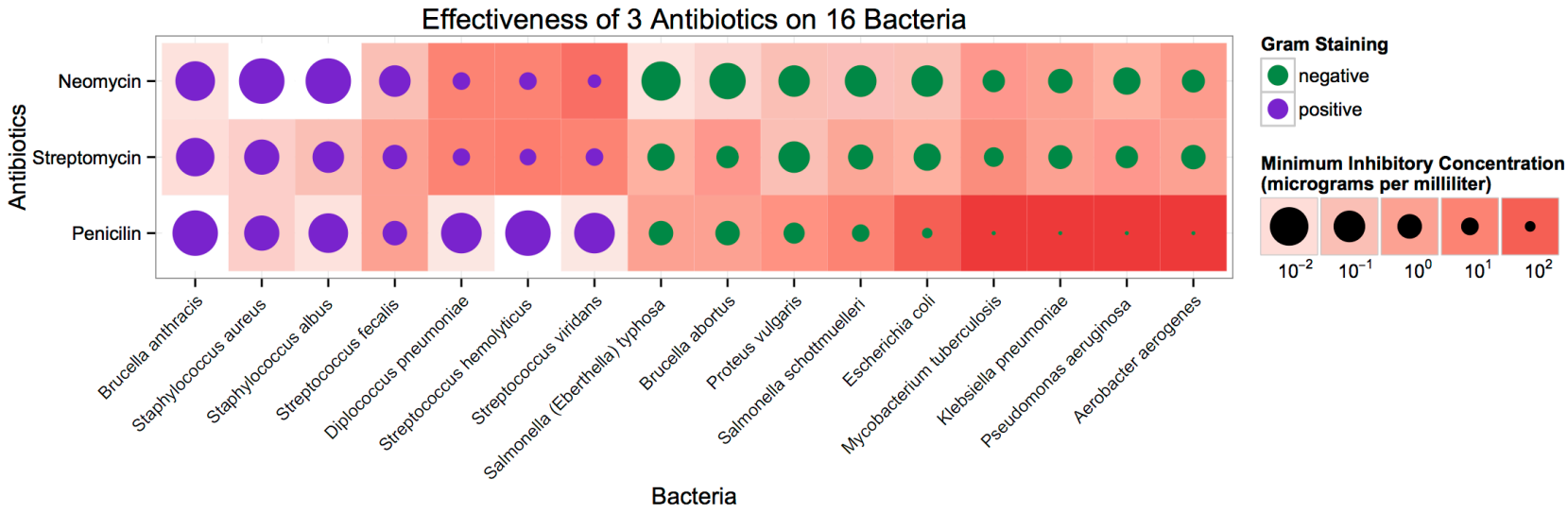
Susceptibility of different bacterial species to three antibiotics



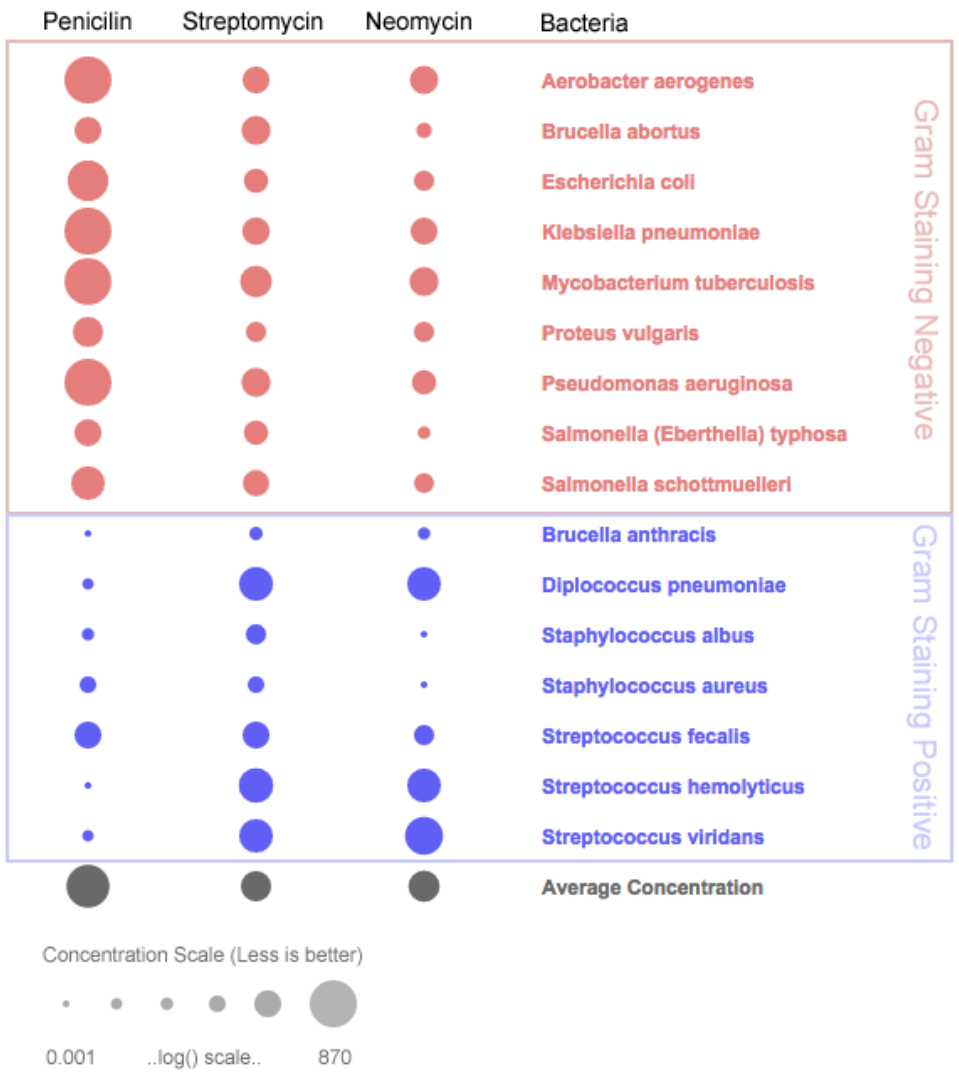
Bars show median MIC per Gram Staining/Antibiotic.

Tables / Heat Maps


Antibiotic Effectiveness
Concentrate Required to Prevent Growth into Vitro:
Less Concentrate
More Effective
More Concentrate
Less Effective
Gram Staining Test:
Grem-Positive
Grem-Negative
NEOMYCIN
PENICILLIN
STREPTOMYCIN
GRAM STAINING
Aerobacter Aerogenes
Brucella Abortus
Brucella Anthracis
Diplococcus Pneumoniae
Escherichia Coli
Klebsiella Pneumoiae
Mycobacterium Tuberculosis
Proteus Vulgaris
Pseudomonas Aeruginosa
Salmonella Typhosa
Salmonella Schottmuelleri
Staphylococcus Albus
Streptococcus Aureus
Streptococcus Fecalis
Streptococcus Hemolyticus
Streptococcus Viridans


Effectiveness of 3 Antibiotics on 16 Bacteria
Antibiotics
Neomycin
Streptomycin
Penicillin
Brucella anthracis
Staphylococcus aureus
Staphylococcus albus
Streptococcus fecalis
Diplococcus pneumoniae
Streptococcus hemolyticus
Streptococcus viridans
Salmonella (Eberthella) typhosa
Brucella abortus
Proteus vulgaris
Salmonella schottmuelleri
Escherichia coli
Mycobacterium tuberculosis
Klebsiella pneumoniae
Pseudomonas aeruginosa
Aerobacter aerogenes
Bacteria
Gram Staining
negative
positive
Minimum Inhibitory Concentration
(micrograms per milliliter)
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}

Minimum Inhibitory Concentrations



Best antibiotic for each bacteria

Gram Staining	Bacteria	Antibiotics		
		Penicilin	Streptomycin	Neomycin
+	Brucella anthracis	0.001	0.01	0.007
	Diplococcus pneumoniae	0.005	11	10
	Staphylococcus albus	0.007	0.1	0.001
	Staphylococcus aureus	0.03	0.03	0.001
	Streptococcus fecalis	1	1	0.1
	Streptococcus hemolyticus	0.001	14	10
	Streptococcus viridans	0.005	10	40
-	Aerobacter aerogenes	870	1	1.6
	Brucella abortus	1	2	0.02
	Escherichia coli	100	0.4	0.1
	Klebsiella pneumoniae	850	1.2	1
	Mycobacterium tuberculosis	800	5	2
	Proteus vulgaris	3	0.1	0.1
	Pseudomonas aeruginosa	850	2	0.4
	Salmonella (Eberthella) typhosa	1	0.4	0.008
	Salmonella schottmuelleri	10	0.8	0.09

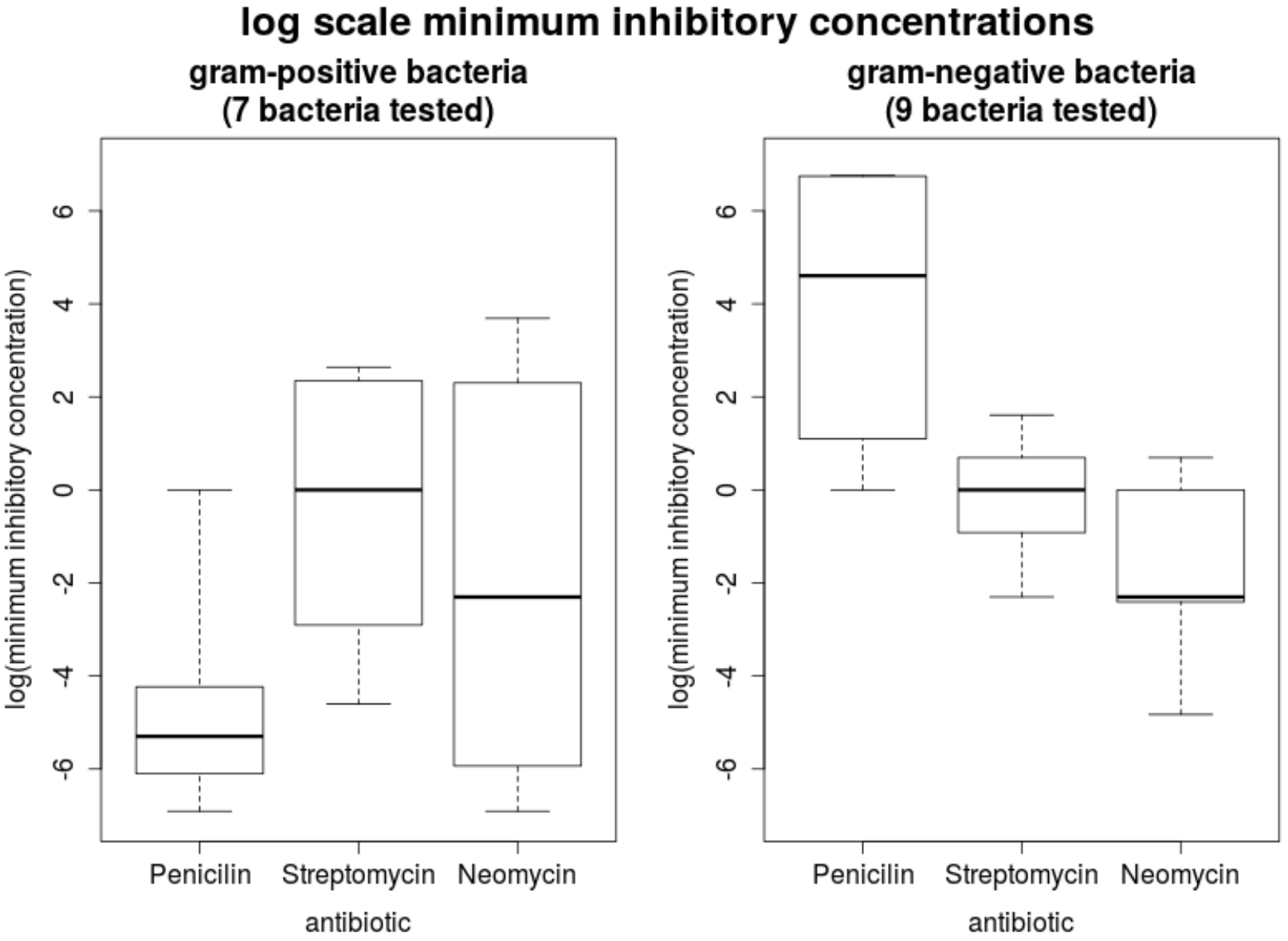
Values in the table represent minimum inhibitory concentration (MIC), where lower is better.
Best antibiotic for each bacteria shaded.

Common Bacteria Identification Chart

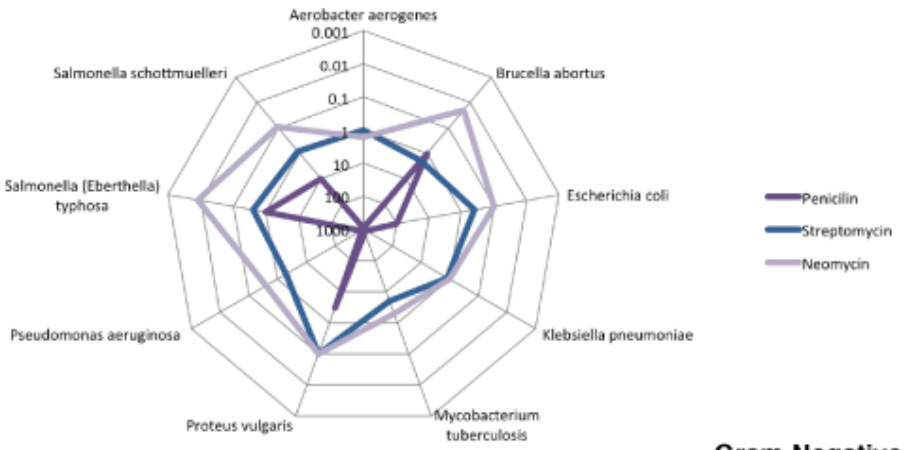
Given 7 culture samples of each antibiotic at MIC concentrations 0.001, 0.01, 0.1, 1.5, 12, 20, 150, tally the count of effective dosages per antibiotic. Each bacteria has a distinct Gram stain and triple of antibiotic tally counts.

Gram Stain	Penicillin	Streptomycin	Neomycin	Bacteria
■	6	5	6	Brucella antracis
■	6	2	3	Streptococcus hemolyticus
■	6	3	3	Diplococcus pneumoniae
■	6	3	1	Streptococcus viridans
■	6	4	6	Staphylococcus albus
■	5	5	6	Staphylococcus aureus
■	4	4	4	Streptococcus fecalis
□	4	3	5	Brucella abortus
□	3	4	4	Pseudomonas aeruginosa
□	3	4	5	Salmonella schottmuelleri
□	1	4	4	Escherichia coli
□	0	3	3	Proteus vulgaris
□	0	4	4	Klebsiella pneumoniae
□	0	3	4	Salmonella (Eberthella) typhosa
□	0	4	3	Aerobacter aerogenes

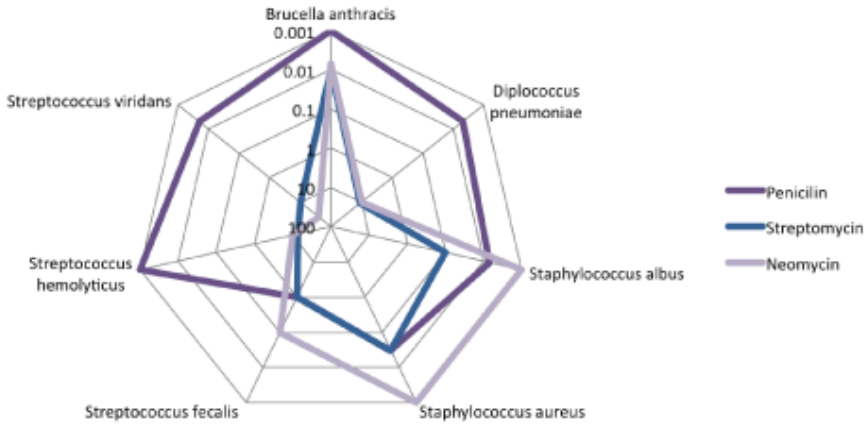
Other


log scale minimum inhibitory concentrations
gram-positive bacteria
(7 bacteria tested)
gram-negative bacteria
(9 bacteria tested)
log(minimum inhibitory concentration)
6
4
2
0
-2
-4
-6
Penicillin
Streptomycin
Neomycin
antibiotic

Performance of three antibiotics on sixteen bacteria

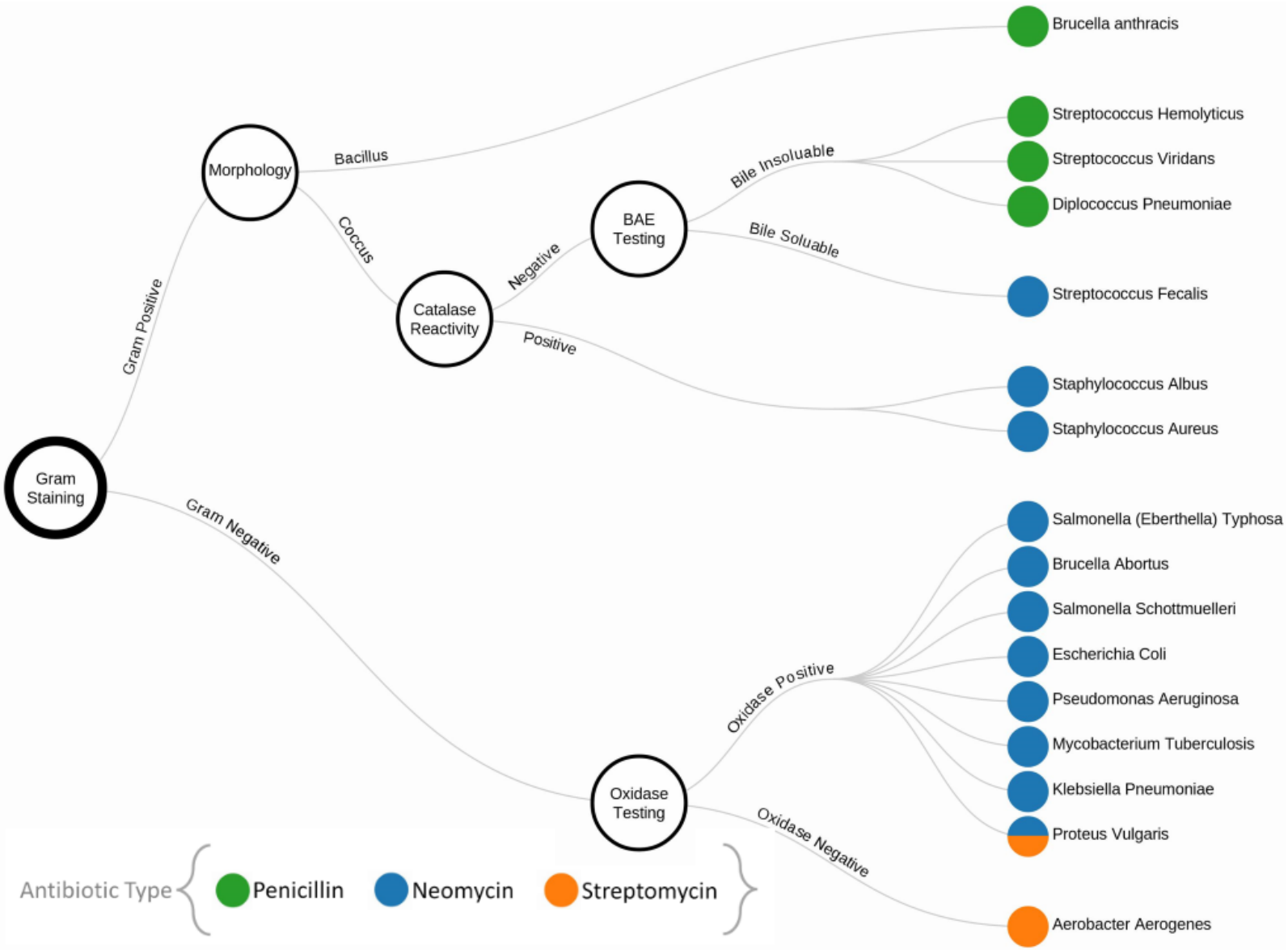


Gram-Negative
Unit: log (1/MIC)



Gram-Positive
Unit: log (1/MIC)

Most effective antibiotic given physical properties



Visualization Design In-Class Exercise

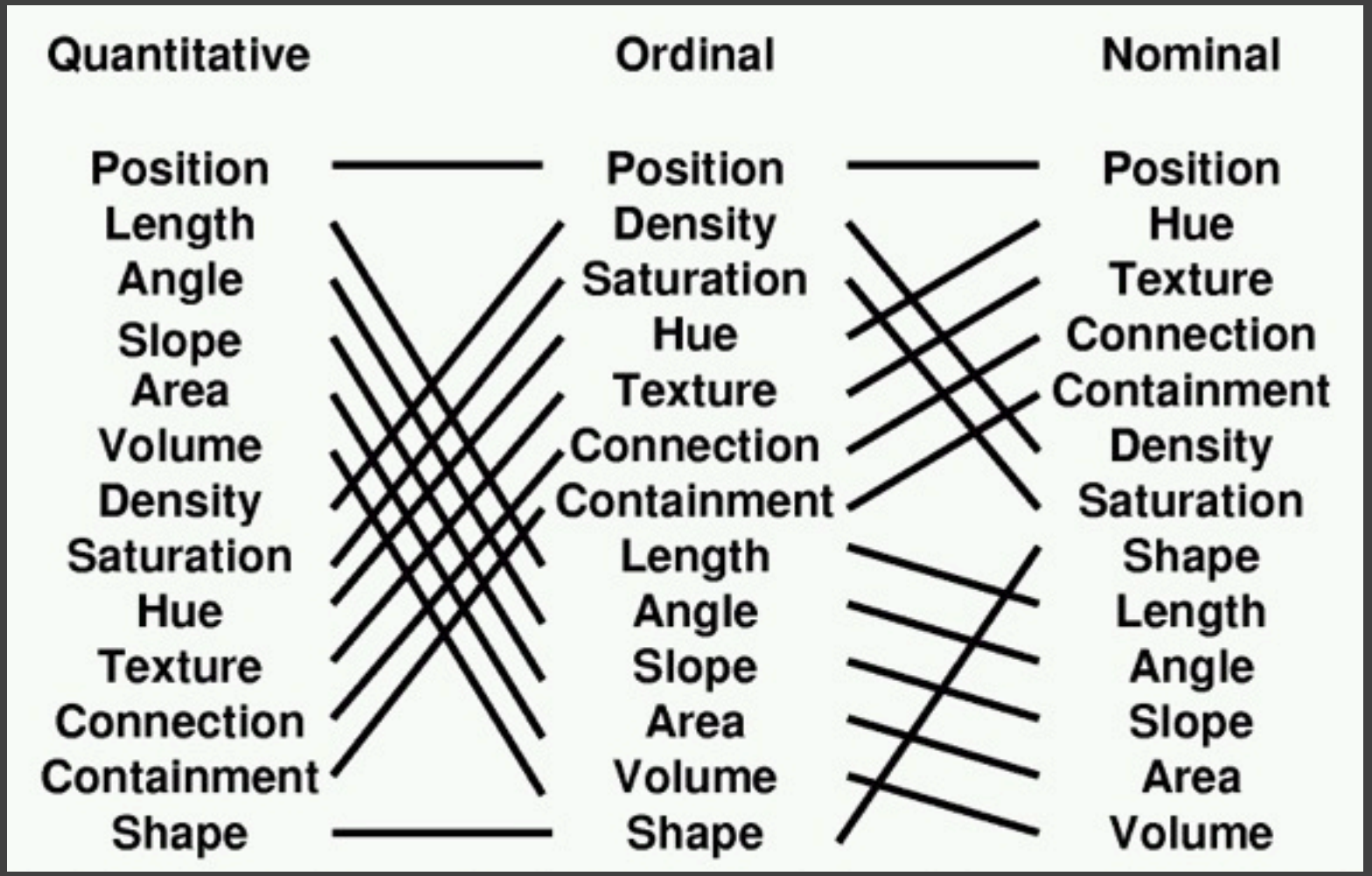
In-Class Design Exercise

Task: Analyze and Re-design visualization

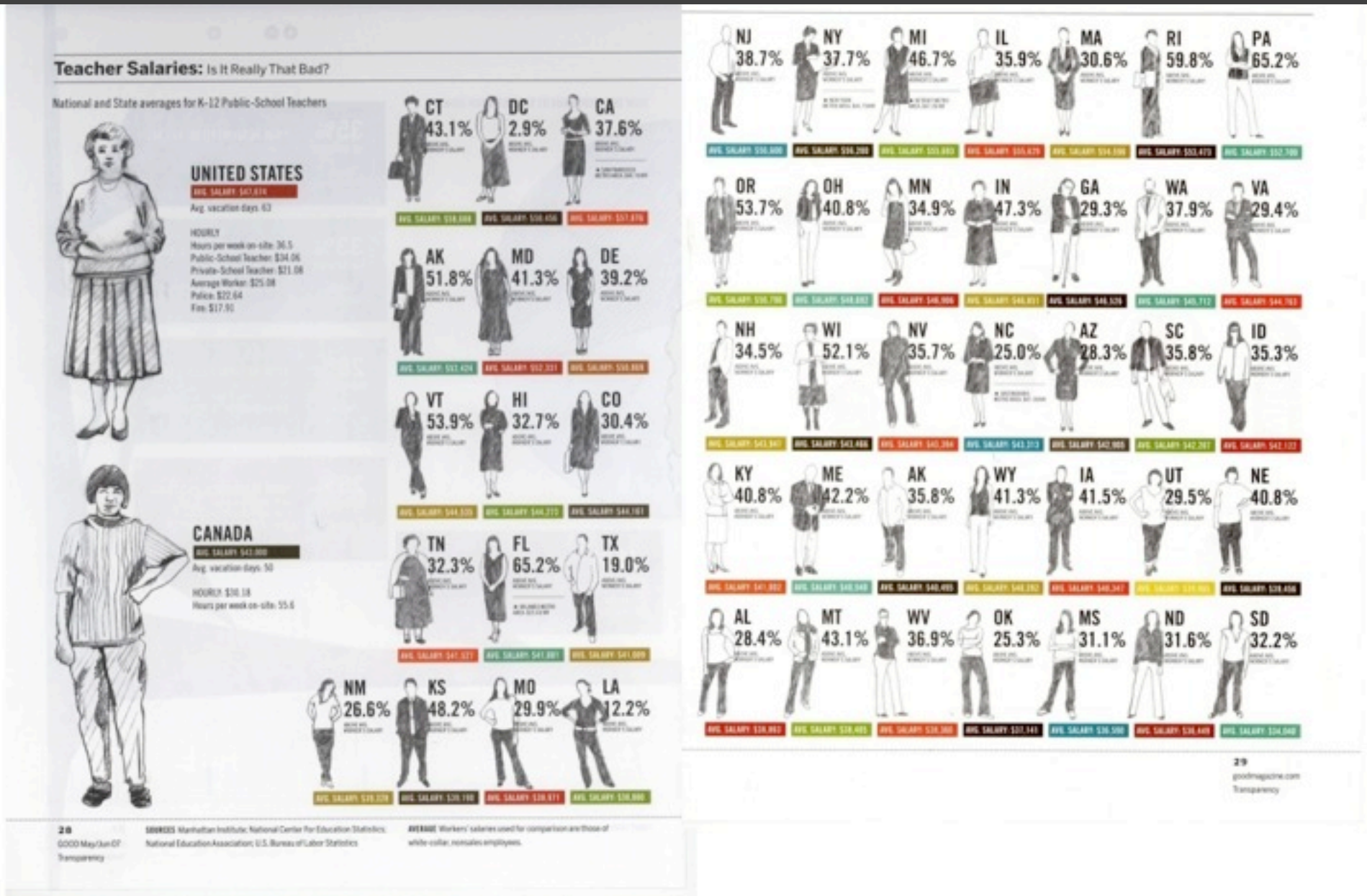
- Identify data variables (n,o,q) and encodings
- Critique the design: what works, what doesn't
- Sketch a re-design to improve communication
- Be ready to share your thoughts with the class

Break into groups with those sitting near you (~4 people per group)

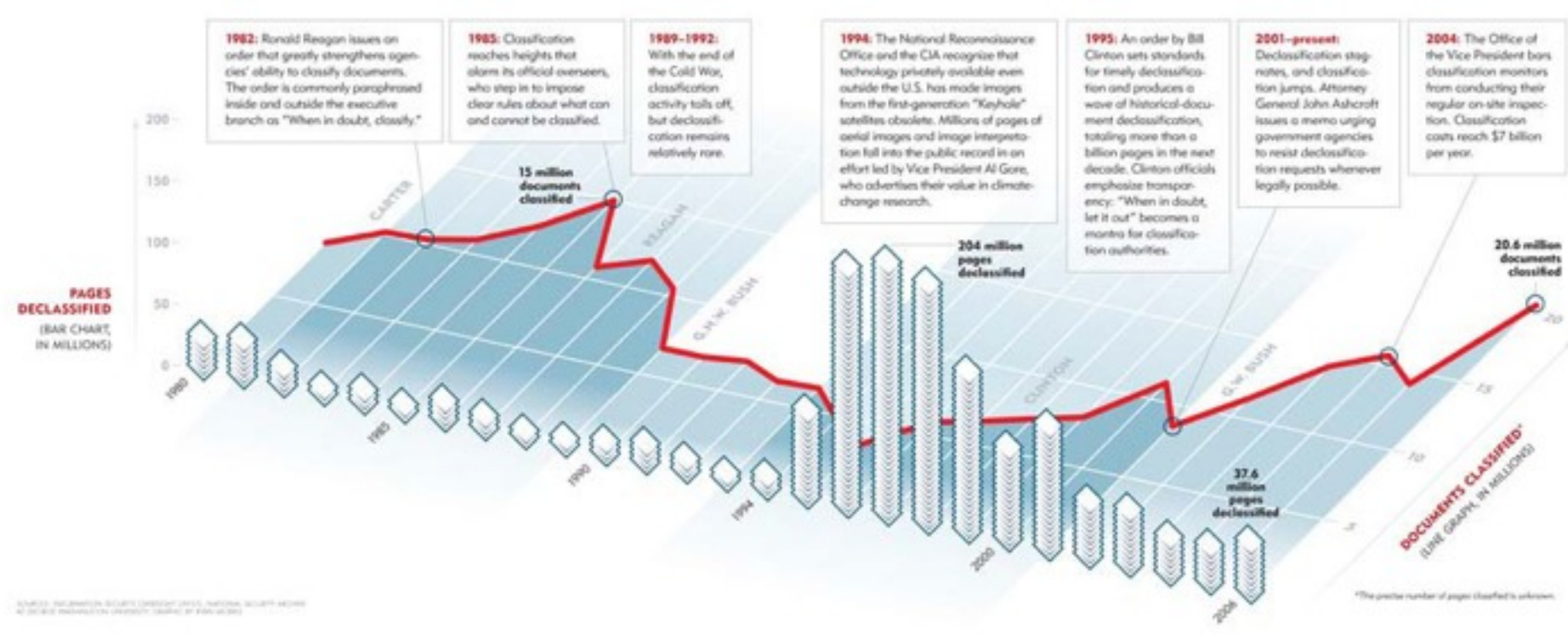
Mackinlay's Ranking



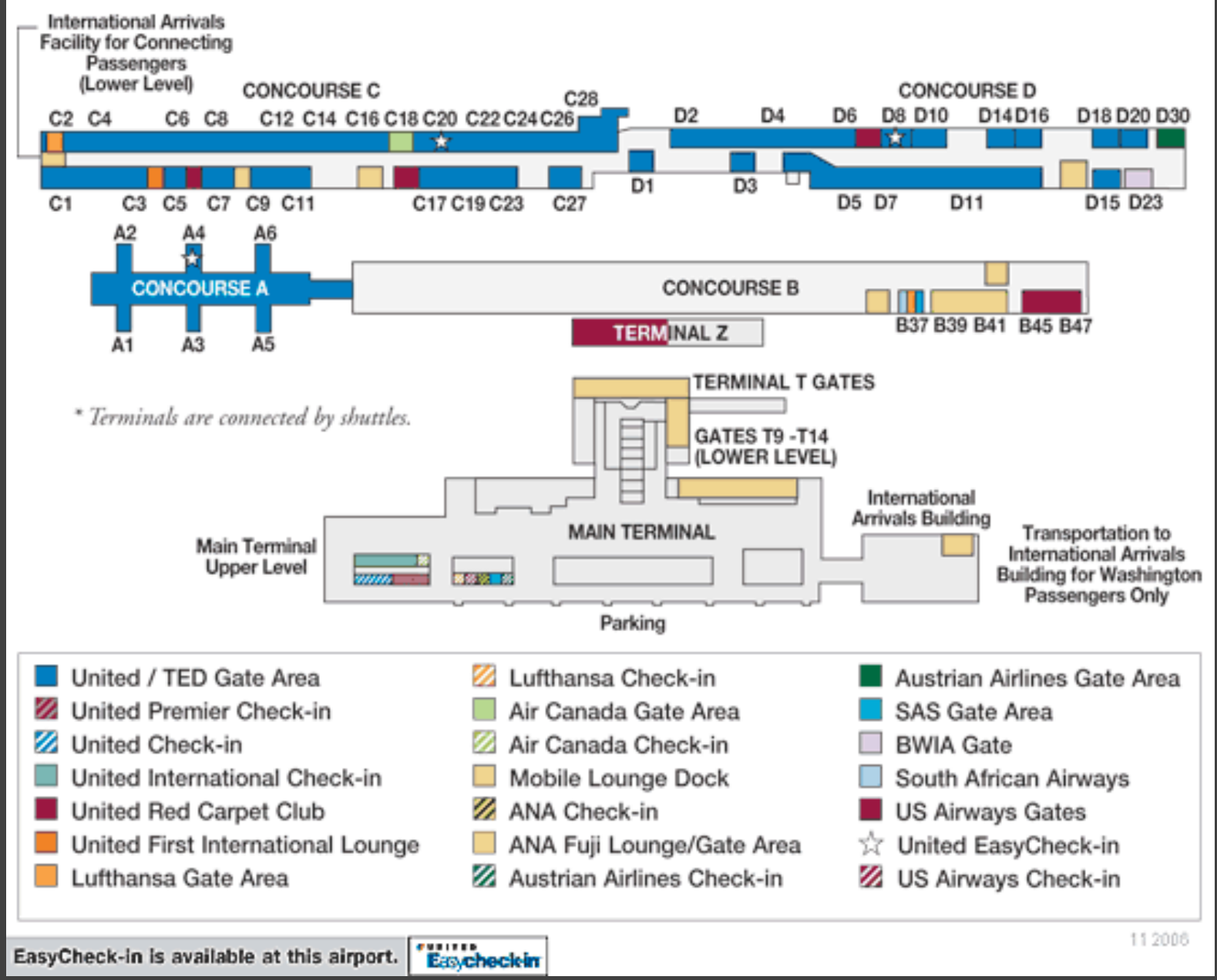
Conjectured *effectiveness* of the encoding



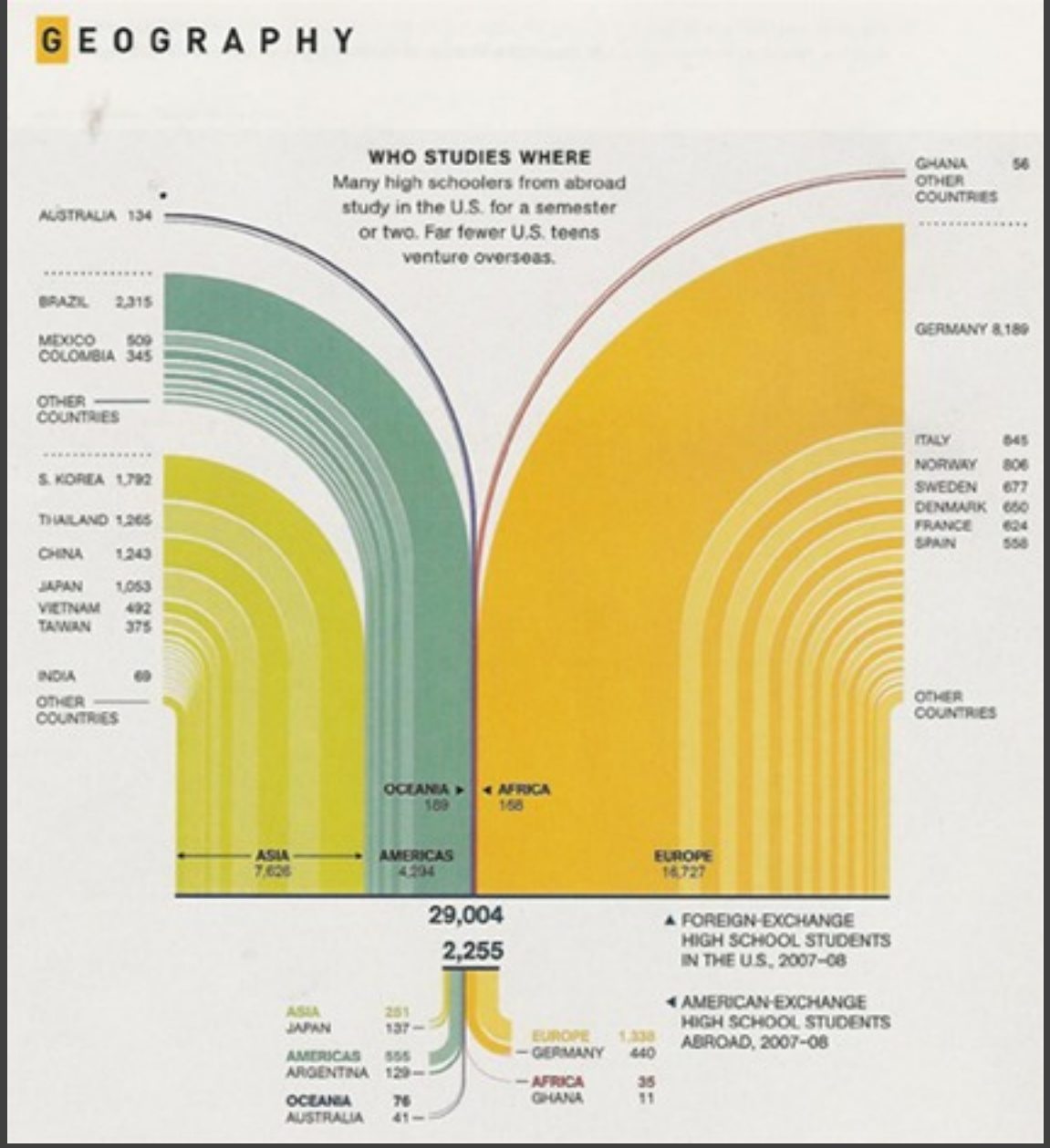
Source: *Good* Magazine



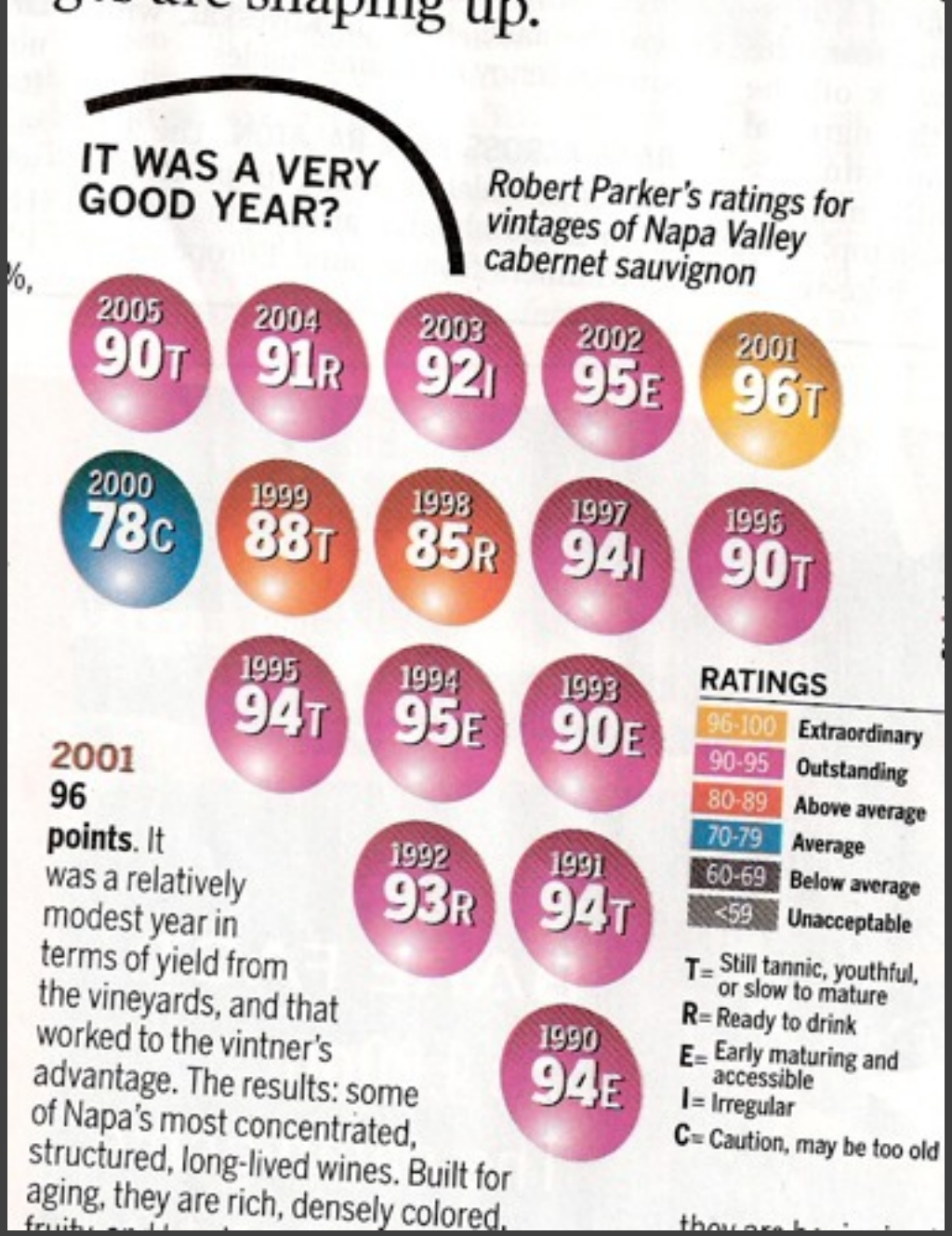
Source: *The Atlantic* 300 no. 2 (September 2007)
Number of Classified U.S. Documents



Washington Dulles Airport Map
Source: United Airlines *Hemispheres*



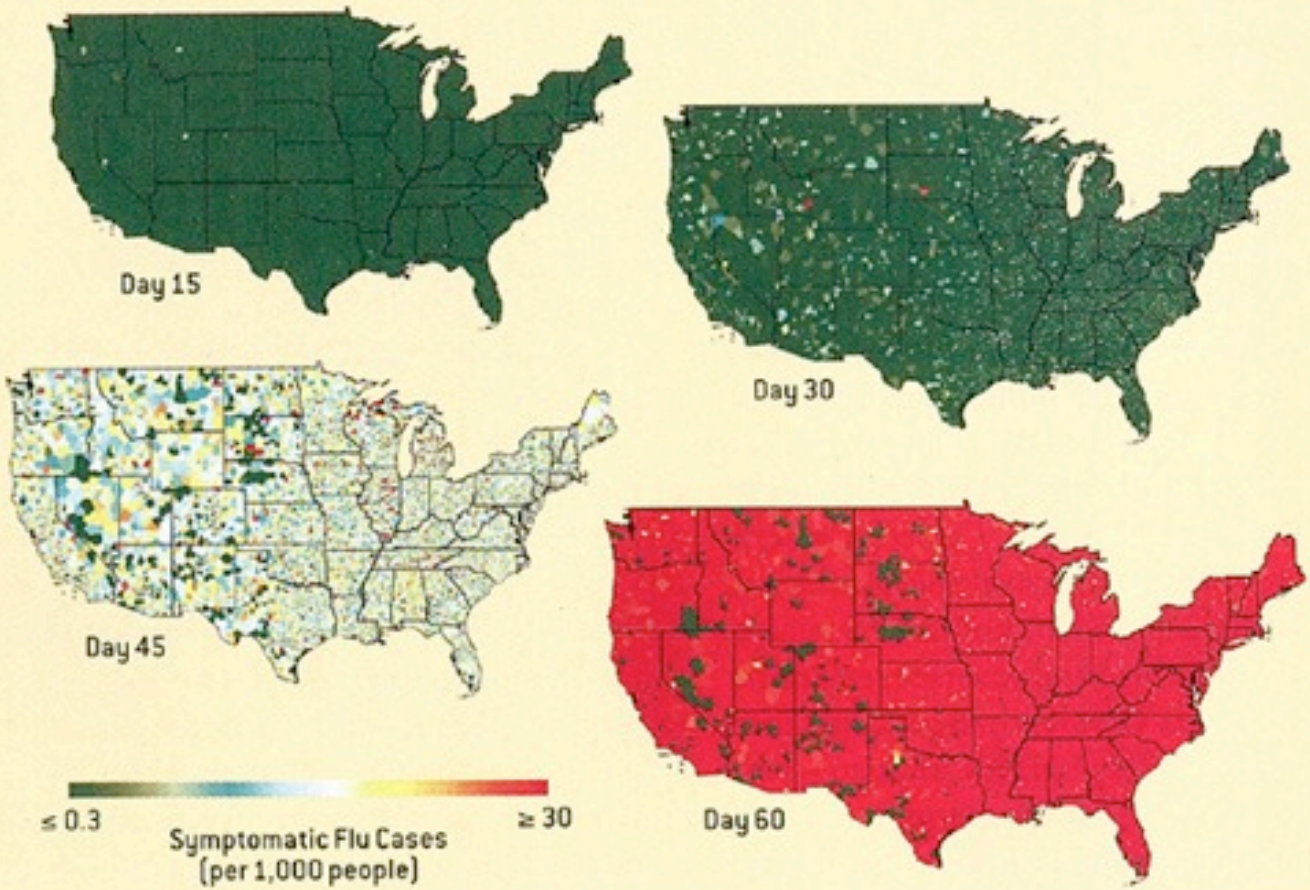
Source: *National Geographic*, September, 2008, p. 22. Silver, Mark. "High School Give-and-Take."



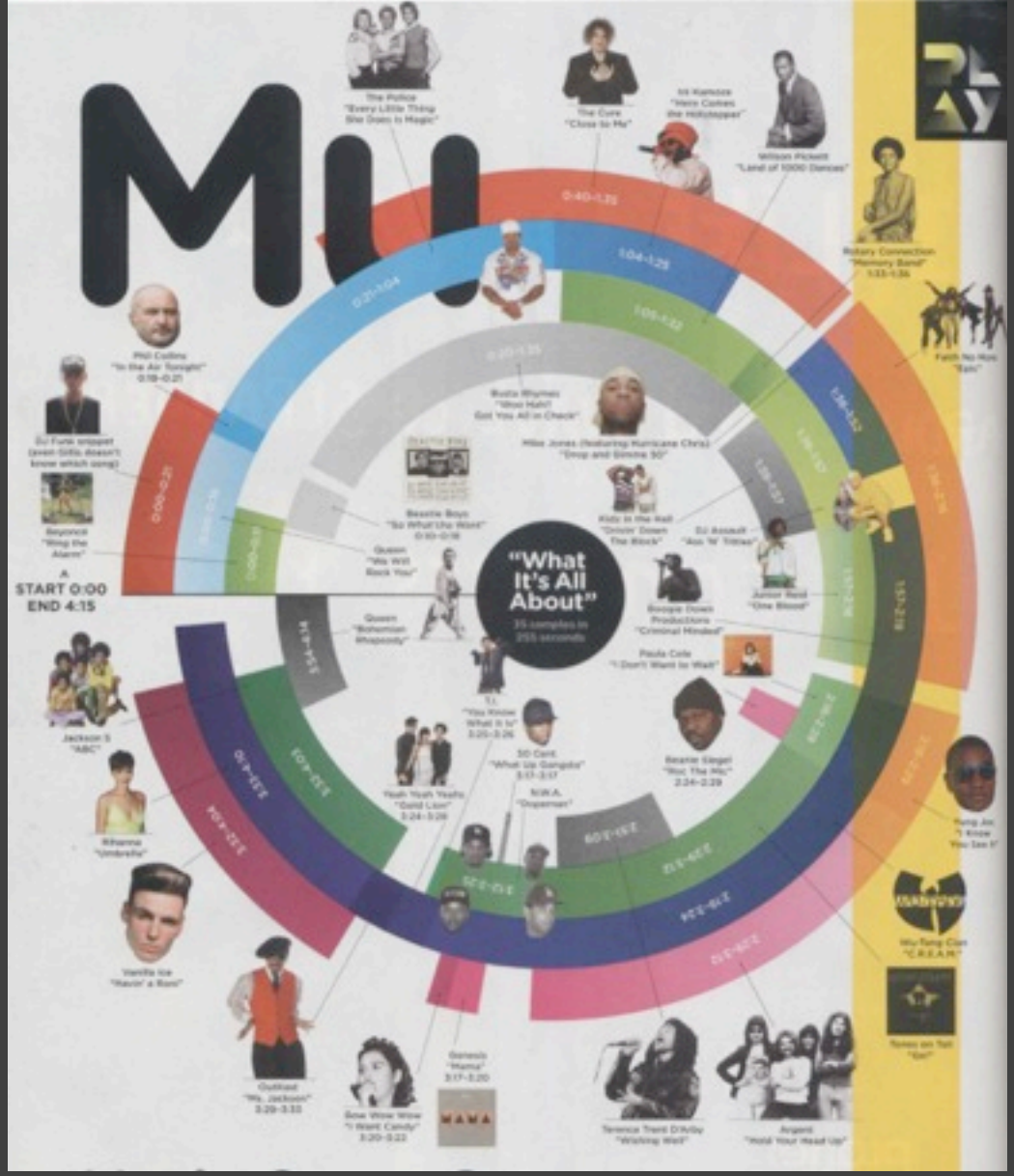
Source: *Business* Week, June 18, 2007

Pandemic Flu Hits the U.S.

A simulation created by researchers from Los Alamos National Laboratory and Emory University shows the first wave of a pandemic spreading rapidly with no vaccine or antiviral drugs employed to slow it down. Colors represent the number of symptomatic flu cases per 1,000 people (*see scale*). Starting with 40 infected people on the first day, nationwide cases peak around day 60, and the wave subsides after four months with 33 percent of the population having become sick. The scientists are also modeling potential interventions with drugs and vaccines to learn if travel restrictions, quarantines and other disruptive disease-control strategies could be avoided.



Preparing for a Pandemic
Source: *Scientific American*, 293(5). November, 2005, p. 50



Source: *Wired Magazine*, September 2008 Edition
Music: Super Cuts (page 92)