

Yelp Ratings and Crime Distribution

Kenneth Lin, Sid Naik, Tom McCormick

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1 Problem Statement and Background

For our CS 194 final project, we decided to investigate the potential relationship between the City of San Francisco public safety data set and the data set provided by the Yelp API. With the recent civil unrest both inside and outside of the United States, and more recently, right here in Berkeley, we thought that it would be interesting to look into the factors that promote crime. One of our team members (Kenneth Lin) had also been robbed recently, so the problem is one that is dear to our hearts. Perhaps the most well-known correlation with crime rate is the income level of a neighborhood – the lower the income level, the higher the crime rate [1, p.93-94]. However, we wanted to show something more interesting. In particular, Yelp restaurants, in our experience, often reflect the wealth and well-being of its surrounding neighborhood – the presence of many highly rated restaurants, we believed, reflect the optimism in the economy of a neighborhood, as well as the wealth and “goodness” of that neighborhood. Therefore, we had conjectured that crime would negatively impact restaurant ratings, or that low restaurant ratings would be correlated with areas of high crime. We worked to show this throughout our project.

In particular, we wanted to know

- ✓ the effect of crime on restaurant ratings (or vice versa)
- ✓ the distribution of crime vs. the distribution of ratings

We had also wanted to predict crime density / severity using restaurant ratings or vice versa, but along the way we ran into issues of determining or implying causation in any of the methods we used. By using one to predict the other and trying to draw useful conclusions from this, we run the risk of assuming causation without definitive proof. There are many other problems that may arise as a result of this, which will be discussed in the **Lessons Learned** section.

1.1 City of San Francisco Public Safety Data Set

The City of San Francisco public safety data set is a record, written by the San Francisco Police Department, of incoming incident reports, either via phone call, in person, or otherwise. These incidents, reported via the SFPD CABLE crime

incident reporting system, cover the span of more than 11 years, from 1/1/2003 to present. Incidents are recorded when a police report is filled out during or after a crime incident. Crimes range from aggravated assault to vandalism to death reports.

A sample of records in the data set looks like the following:

	IncidentNum	Category	Descript	DayOfWeek	Date
0	140001966	NON-CRIMINAL	DEATH REPORT, CAUSE UNKNOWN	Wednesday	01/01/2014
1	140003025	NON-CRIMINAL	DEATH REPORT, CAUSE UNKNOWN	Thursday	01/02/2014
2	140004487	NON-CRIMINAL	DEATH REPORT, CAUSE UNKNOWN	Thursday	01/02/2014
3	140000059	NON-CRIMINAL	AIDED CASE	Wednesday	01/01/2014
4	140000071	VANDALISM	MALICIOUS MISCHIEF, VANDALISM OF VEHICLES	Wednesday	01/01/2014

Time	PdDistrict	Resolution	Location	X	Y
16:21	TENDERLOIN	NONE	400.0 Block of ELLIS ST	-122.413794	37.784772
02:00	MISSION	NONE	500.0 Block of JERSEY ST	-122.438235	37.750203
14:30	BAYVIEW	NONE	100.0 Block of CORAL CT	-122.371925	37.727898
00:17	SOUTHERN	NONE	1500.0 Block of MISSION ST	-122.417566	37.773892
00:30	SOUTHERN	NONE	0.0 Block of MARKET ST	-122.393966	37.795028

Figure 1: Sample of San Francisco crime data set

The majority of the fields are self-explanatory. However, there are a few things to note:

1. Category and descript are both categories, but category is more general. There are only 36 different “Categories” while there are 499 different “Descript”s in the year of 2014.
2. Resolution, though none are shown in the sample above, denote whether any action was taken and what that action was.
3. X denotes longitude, while Y denote latitude.

A more detailed analysis is in the attached `analysis.ipynb`.

1.2 Yelp Data Set

Yelp.com is a platform which publishes crowd-sourced reviews about local businesses. On Yelp, customers who have used the services of local businesses may write reviews of these businesses and provide ratings of their satisfaction. Reviewers may select from between 1 to 5 stars for each review they make, and a business’s average rating is the average of the ratings of each of the reviews it has received. Yelp supplies a platform for all kinds of local businesses ranging from restaurants to barbers to museums; however, for the purpose of our research, we will look primarily at restaurants as they are a very large majority of the reviews on Yelp.

There are two primary ways to access the data on Yelp. First, we can utilize the search / business API (<http://www.yelp.com/developers/documentation>). The API provides a way to search for local businesses matching a particular key term (“restaurants”, for example) near a geographical location, and get all the rating / review information about that restaurant. The API further allows us to narrow the search to only the geographically closest restaurants (not ranked by rating). This gives us a way to link the geographical location of crime incidents to the types of restaurants near that incident.

The other way of accessing Yelp data is through the academic data set (https://www.yelp.com/academic_dataset). The Yelp academic data set provides all the data and associated reviews of the 250 closest businesses to each of 30 universities, including UC Berkeley. Although not a random sample of all businesses on Yelp, the academic data set provides a much better estimate of all businesses in the Yelp data set population. For the purposes of the analysis, we will assume for now that this data set is a perfect sample of the entire Yelp data set, and that its average is indicative of the Yelp-wide average. Issues with this assumption will be addressed in the **Lessons Learned** section.

2 Methods

2.1 Data Fetching

The bulk of our work was done in trying to get data from Yelp. As mentioned, there were two main ways that Yelp provides to access data, and those are the API and the academic data set.

To access the Yelp API, Yelp provided sample Python code (<https://github.com/Yelp/yelp-api/tree/master/v2/python>). However, as we found out, the sample code was buggy – not only did the code fail on certain calls, it even failed on the default call when the search term was “dinner” and the location was “San Francisco, CA”. We contacted Yelp API support about this issue, but it seemed that the API wasn’t well-maintained, and Yelp engineers didn’t have time to update or fix the sample code. Therefore, we decided to fix the bug ourselves.

After much investigation, we figured out that whereas Python’s `urllib` library encoded spaces into “+” characters, Yelp’s server-side authentication ex-

pected the OAuth-signed URLs to use “%20” as the proper encoding for space. In this context (the query arguments in a URL), both should be valid, but Yelp’s authenticator only expected the latter. After figuring this out, we let the Yelp engineers know of the bug, and were able to build a temporary work-around to fetch our data.

We also encountered other problems in data fetching. In addition to the bugs in the API, there were rate limiting and quantity limiting issues as well. In particular, we could only access 20 results at a time, and a maximum of 40 total results for searches that sorted the results by only distance or rating. With searches not by distance or rating, Yelp enforced its own ranking to its results. Results further down the results page became so varied that they no longer matched the keyword (for example, Yelp may provide a gym even though “food” was specified simply because the gym was much closer than any other “food” locations). All of the above limited the ways in which we could obtain and analyze Yelp data.

For us, the ideal way to get Yelp data would be to have a data set containing data on every single restaurant in San Francisco. This would have been the most ideal solution as

1. we could then compare the *properties of restaurants* near crimes to the general population of restaurants in San Francisco properly. The way we do this instead is to use the academic data set, but that includes data from other cities
2. the data we had would be the *entire population* of restaurants in San Francisco (that Yelp has in their database)
3. we could then compare any other *location-based data* (like population density) and determine any confounding factors in our statistical model. This wasn’t discovered until after our t-test results. The way we had to access the data instead introduced bias towards high-crime areas into the data set.

Further, we weren’t able to get as much data as we needed (because of Yelp’s rate limiting). However, it was still possible to search for the closest restaurants near any location specified by longitude and latitude. As a result, we decided to search for the 20 closest restaurants near each crime and look at the characteristics of this set of restaurants.

In the end, we were able to build a fault-tolerant work-around to Yelp’s broken authentication system. We queried Yelp’s API for the 20 closest restaurants near each crime in the City of San Francisco crime data set for a total of 12,000 crimes (9704 unique incidents due to multiple criminal offenses per incident). These results were stored in the MongoDB instance that we installed on our EC2 server.

2.2 Visualization

After fetching the data, we wanted to explore the nature of each data set first. A lot of the data is location-based, so the natural next step was to visualize, either via heatmap or plots on a map, the spatial distribution of restaurants or crimes. After testing around, we decided to create a heatmap for crime density and a plot of Yelp ratings.

To create the heatmap for crime density, we took the map and created a 100 x 100 grid where we assigned a value to each spot on the grid based on the amount of crimes in the area. We calculated a normal distribution at each crime location to create a Gaussian kernel density estimator, and calculated the final values of the KDE at each of the 10000 points. Then, we exported this data structure as a CSV with fields longitude, latitude, and density. Then, using heatmap.js, a JavaScript library, we were able to create a heatmap layer over the Google Map, which we got using the Google Maps API, of the region.

To create the plot of the average Yelp rating for crimes, we had to first get our data in a CSV file with the fields longitude, latitude, and density. Once these fields were found, we used the D3 library in JavaScript to plot circles on a Google Map based on their rating. We used the colors red, yellow, green and blue for each of the four quartiles. Lastly, to create the last plot of just the restaurants that were near crime, the method was very similar to the plot of all the Yelp ratings, except that the amount of data was less and the gradient was slightly different.

The results of the visualizations can be seen in the **Results** section.

2.3 Looking for Correlations

Our primary purpose (initially) was to determine how crime affected restaurant ratings. Specifically, given the limitations of the data we could get from Yelp, we wanted to see whether Yelp restaurant ratings were any different when they were near crime hotspots.

At this point, we could access two data sets – the data set of “near-crime” restaurants, obtained through querying for restaurants near crime incident locations via the Yelp API, and the Yelp academic data set. Given this data, we had a few options to draw a correlation:

1. We could look at the “average rating” of a crime – that is, we could take the average rating of the 20 closest restaurants to a crime incident and call that the average rating of restaurants near that crime. Then, we could compare that rating with the Yelp-wide average from the academic data set.
2. We could look at all the *restaurants* near any of the crime incidents in the crime data set. Then, we can put these together as a set of “near-crime” restaurants, and look at the rating distribution of these compared to the academic data set.

We had originally planned to execute option 1. However, as we realized from exploring the crime data set, crime density is very different for different areas of San Francisco. If we look at the average rating of each crime, it is likely that the results would be very heavily weighted by the ratings of restaurants in high crime density areas (ie. Market Street). Although our very purpose was to show that high crime density areas were prone to different kinds of Yelp ratings, we did not want to artificially induce this by weighting the results by the crime density itself. Therefore, we chose the second option. Surprisingly, we discovered that in the 9704 unique incidents we looked at and the 194080 restaurants near those incidents, there were only a total of 658 unique restaurants. This implies that the crimes were indeed very clustered, and that use of the “average rating of a crime” method (option 1) would have resulted in significant bias to restaurants near the clustered areas. A further examination of the visualizations indicate that crime was indeed highly clustered near Market Street. This will be discussed more in the **Results** section.

To determine whether there were any significant differences between the two data sets, we used a Student’s t-test as our statistical hypothesis test. In this case, the null hypothesis was that the two data sets, both of Yelp ratings in San Francisco, have identical expected values (means). The t-test results are more thoroughly discussed in the **Results** section. Through the analysis, however, we learned instead that restaurants near high-crime areas actually had higher ratings than the Yelp-wide average. This indicates that our hypothesis was wrong. However, we also realized around this time that any correlation, positive or negative, does not imply causation.

2.4 Accounting for Population Density

In an effort to learn why our hypothesis was wrong, we began considering confounding factors. The two heatmaps we created seem to indicate that population density was key.

To gather the data on population density, we found a database file (.dbf) from data.sfgov.org that contained a table that mapped tract (a unit of area used by the census) to population density. We were also able to find another data set that contained the tract centers (longitude and latitude) for each tract. By associating each longitude and latitude pair with the closest tract center (using great-circle distance for the Earth), and then joining the population-density-by-tract-table on tract, we could estimate which tract each restaurant or crime was in, and find an associated population density for a restaurant or crime. The result allowed us to look for a possible correlation between crime density and population density. The data sets looked like the following:

	Tract2010,N,9,0	Pop2010,N,9,0	Area_smi,N,13,11	Pop_psmi,N,13,11
0	16500	5083	0.143014	35542.0
1	16400	3778	0.119325	31661.4
2	16300	4293	0.094915	45229.9
3	16100	5366	0.142413	37679.0
4	16000	2465	0.061086	40352.7

Figure 2: Sample of population density data set

	TRACTCE10,C,6	INTPTLAT10,C,11	INTPTLON10,C,12
0	21300	37.750066	-122.441075
1	21300	37.750196	-122.438933
2	20500	37.756794	-122.436270
3	21200	37.753529	-122.437050
4	21100	37.755758	-122.433400

Figure 3: Sample of census tract data set

One difficulty we had with integrating this data was that the data was given to us divided up into tracts, which are standardized regions of land used by the government to collect census data. However, the crime data, and therefore the Yelp data, were based on specific latitude and longitude coordinates. A better way to have done it would have been to look at crimes density by tract as well as average yelp data by tract. This would have possibly allowed us to draw correlations with more conviction as well as allow us to implement other statistical tools such as a regression. Alas, we happened to collect the crime and Yelp data before the population density, and it would have been too time consuming to recollect all the crime density and Yelp ratings.

3 Tools

- ✓ pandas – Pandas was our primary means of manipulating data sets. We used Pandas in our data fetching, data cleaning, and data analysis process.
- ✓ MongoDB – We installed MongoDB on the EC2 server and used it primarily for storing Yelp data. MongoDB was a great choice because the document-based nature of MongoDB was perfect for storing all the JSON documents we received from the Yelp API. In addition, we weren't sure what kind of data we needed to store when we first began fetching data, so using Mongo allowed us to easily keep all of the data in case we needed more than what we had thought.
- ✓ pymongo – pymongo was our choice Python interface to MongoDB.
- ✓ numpy – NumPy was used in conjunction with both Pandas and SciPy.

- ✓ scipy – We used SciPy mostly for its large library of statistical methods (t-tests, etc.).
- ✓ D3.js – We used D3 in conjunction with other frameworks when visualizing the data.
- ✓ Google Maps API – The Google Maps API provided a base for many of the location-based visualizations we needed to create. In addition, the Google Maps API also had a heatmap plugin, which we tried in addition to heatmap.js.
- ✓ heatmap.js – We primarily used heatmap.js for our heatmap visualizations.

4 Results

A preliminary analysis of just the public safety data set is available in the attached `analysis.pynb`. Below follows our results and conclusions from looking at Yelp restaurant rating data near crime hotspots.

4.1 Visualizations

Below are the visualizations we created from the two data sets.

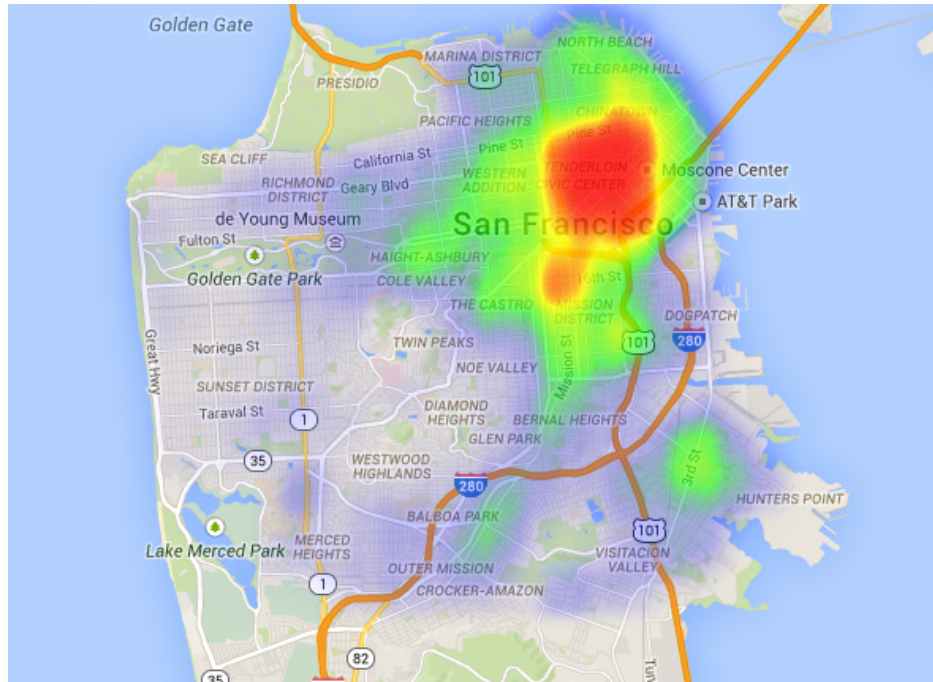


Figure 4: Heatmap of crime density

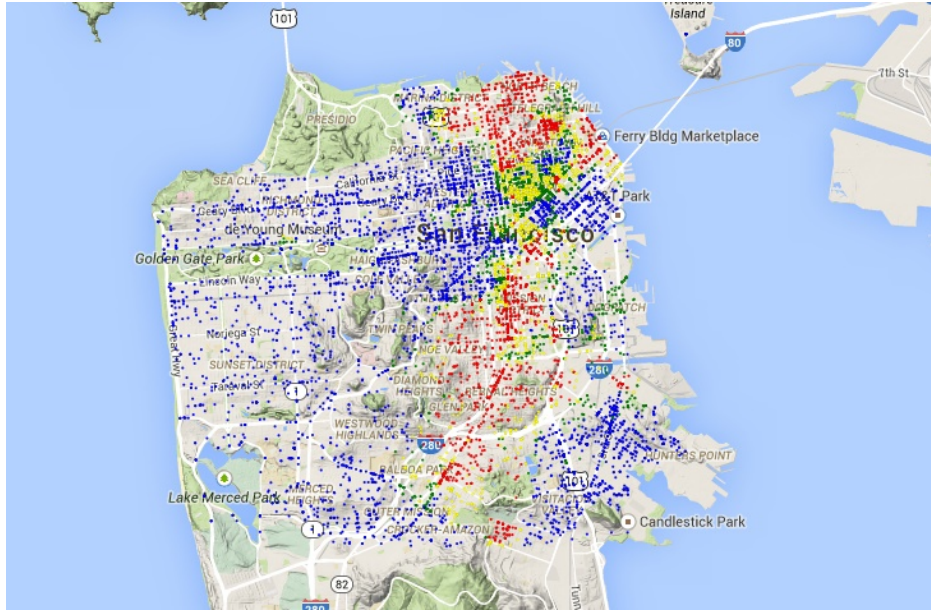


Figure 5: Plot of “average Yelp rating of crimes”. Each point corresponds to a crime, and the color corresponds to the average rating of the closest 20 restaurants to that crime.

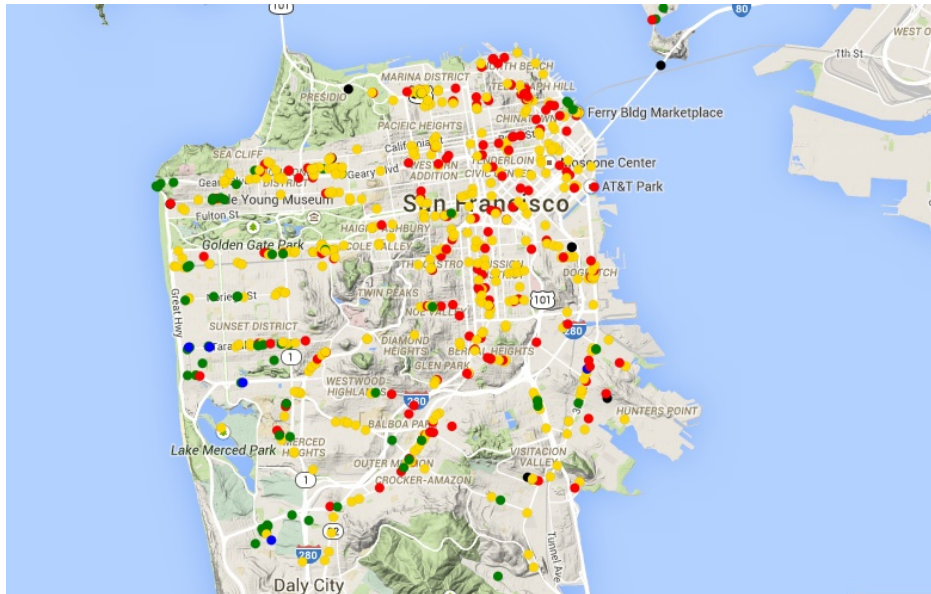


Figure 6: Plot of Yelp ratings for restaurants in the near-crime data set. Black = 5.0; red = 4.5; yellow = 4.0; green = 3.5; blue = 3.0

As can be seen, crime seemed to be clustered near Market Street. The plot of “average Yelp rating of crimes” is also telling – a significant number of crimes were close to highly rated restaurants, especially along Market Street, near Fisherman’s Wharf, and down to Bernal Heights and Balboa Park. Although the number of unique restaurants fetched makes it difficult to see the same correlation with the plot of just restaurants, it is still easy to see that the majority of restaurants that are “inland” are decently rated, compared to those that were on the East or South side of San Francisco. These plots aided in us drawing our conclusions from the t-test we performed.

4.2 Putting it together

The results of the t-test between the near-crime data set and subsets of the academic data set are detailed in Table 1.

Data set	Mean	Std	t-statistic*	p-value*
Near-crime	4.072	0.327		
All businesses (all)	3.618	0.933	-12.441	2.39×10^{-35}
All businesses (Berkeley)	3.629	0.837	-12.390	3.43×10^{-33}
All businesses (Stanford)	3.696	0.846	-8.310	4.34×10^{-16}
All businesses (Los Angeles)	3.571	0.988	-12.542	1.66×10^{-34}
Restaurants only (all)	3.482	0.739	-20.291	7.10×10^{-89}
Restaurants only (Berkeley)	3.413	0.618	-20.490	9.34×10^{-77}
Restaurants only (Stanford)	3.307	0.520	-14.367	3.30×10^{-41}
Restaurants only (Los Angeles)	3.431	0.773	-18.797	2.28×10^{-68}

Table 1: t-test results against “near-crime” data set

* against the “near-crime” data set

The “all businesses” data sets refer to all the businesses provided by the academic data set, whereas the “restaurants only” data sets filtered out only the businesses in the academic data set that had “Food” or “Restaurants” as one of the items in its category field.

From the p-values of each t-test it is clear that the null hypothesis can be rejected, and that the “near-crime” data set does not have the same average Yelp rating as the other data sets. The following two plots provide a better picture of the actual distribution of each data set.

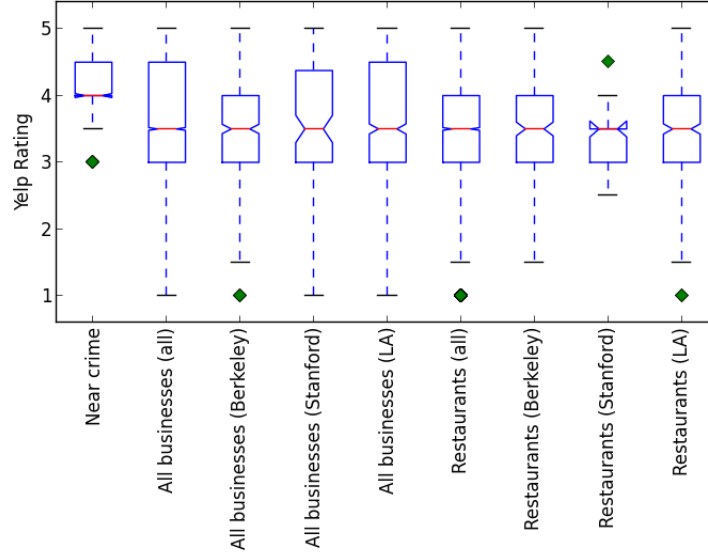


Figure 7: Box-and-whiskers plot of distribution of the ratings of different data sets

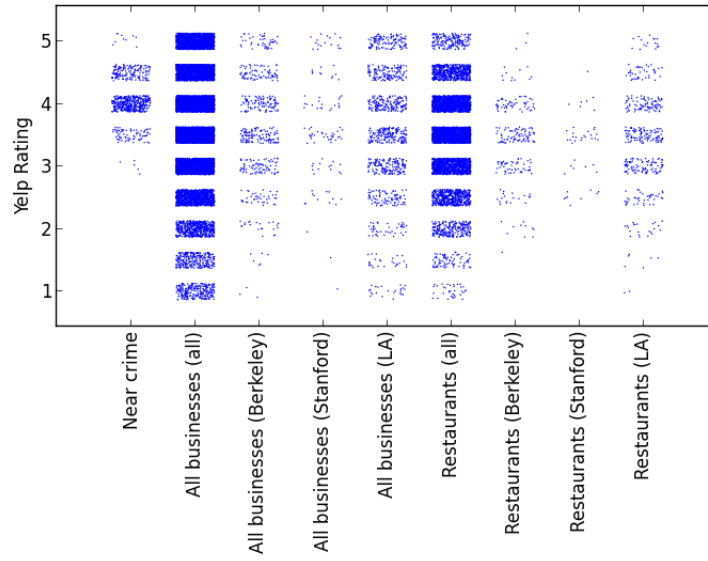


Figure 8: Scatter plot of distribution of the ratings of different data sets.

Points plotted with certain randomness to show distribution of points.

However, the data indicates that our initial hypothesis was also wrong – we found instead that the restaurants near crimes were actually *higher* rated than the general population of restaurants. To us, this was extremely counterintuitive. Our original hypothesis was that crime would negatively affect restaurant ratings. However, the data seems to show that crime was instead positively correlated with ratings. As we were looking for explanations, we also realized that the tests we have been doing would not prove causation anyways. It’s possible that crime positively affects restaurant ratings, or that restaurant ratings increase the crime rate, but it’s also possible that both are correlated with a third confounding factor. In particular, from the visualizations we created earlier, it’s very likely that population density would be a factor. Areas near Market Street are known to be the most popular areas in San Francisco, for work, shopping, and many other things. A high population density would spark growth and increase competition, so any restaurants that are able to stay in the area must be high quality. A high population density would also attract crime, as there are more targets, and the chaos of the busy streets may make it easier to get away. As we were not familiar with these statistical notions when we formulated our problem statement, we had not thought of problems like these when we started.

Due to the limitations of the Yelp API, we could not get Yelp data with an even distribution across all of San Francisco. Given what we had, we wanted to compare the population density of the areas of near-crime restaurants to the population density of the restaurants in the other sets. However, because our academic data set had restaurants all across the United States where we didn’t have ready access to population density data, it was impossible to calculate population density for these areas. Further, population varies more by city than areas within the city, so variations in those restaurants are not telling at all.

The best alternative was to instead compare the population density of the areas of near-crime restaurants to the total population density of San Francisco. Although the results of this test would not be directly related to the test performed above, it would provide exploratory insight into the reason behind why our hypothesis was wrong.

Using the methods described in the **Methods** section, we decided to also compare the population density of those areas.

4.3 Population Density

Another simpler t-test was performed in order to see how high-crime areas were correlated with population density. From the population density data, we found that the total population density of the city of San Francisco was 17143.59 people per square mile. We conducted a one-sample t-test to determine whether either of the following two data sets were significantly different from the city of San Francisco mean population density. The first data set is that of the population

density of the near-crime restaurant data set. That is, it is the population densities of tracts containing the Yelp restaurants which were found to be close to crime incidents. The next is the data set of the population density of crime itself. In other words, it is the population densities of the tracts of 9704 distinct crimes. We will call the first one the “restaurants” data set and the second one the “crimes” data set.

Data set	Mean	Std	t-statistic*	p-value*
Restaurants	25437.36	15694.58	13.56	4.34×10^{-37}
Crimes	34488.61	30239.04	62.83	≈ 0.0

Table 2: t-test results against known population density mean

* against known population density mean of 17143.59 people per square mile

The results indicate that the restaurants and crimes were indeed correlated with a significantly higher population density. This confirms our suspicion that population density, or another similar confounding factor, played a role in the correlation between crime density and Yelp ratings. However, again, as we lack the data and tools to prove this definitively, we can only say that further investigation into the relationships between crime density, Yelp rating distribution, and population density would be a profitable cause.

5 Lessons Learned

Our project was nowhere near perfect, but through our project, we learned many, many valuable lessons that will no doubt benefit any future data science projects we perform.

5.1 The Problem Statement

Perhaps the most important thing that we learned is to formulate a clear problem statement from the very beginning. When we began the project, we were looking to find interesting correlations between Yelp restaurant ratings and crime occurrences. However, as we didn’t have experience with data science projects, we weren’t used to formulating rigorous statistical hypotheses. As a result, we forgot about the fact that correlation did not imply causation. Furthermore, we did not think through what data we can access, how to combine the data together, and other confounding factors in our model. If we had thought clearly through our entire problem statement and formulated a plan of attack, then given the limitation of the Yelp API, we might have changed our project to be geared towards other APIs or data sets that could give us a picture of the entirety of San Francisco.

5.2 Let the Data Speak

Having a clear problem statement, however, does not mean assuming a certain hypothesis before we see the data. In this project, we realized that we had held

our hypothesis as fact throughout the course of most of our investigation. A lot of our plans to visualize the data, for example, were made before we even looked at the data, and they were made to show that a correlation did indeed exist. On a similar note, if we could had tried to get the data and conduct the tests of significance first, we would have realized the problem with correlations vs. causation earlier on, and that would have given us more leeway in planning our next steps.

5.3 The Yelp API

The Yelp API was a huge problem for us in this project. There were multiple issues with it. First, and most importantly, was that we couldn't get a evenly distributed sample of restaurants in San Francisco. Ideally, we would be able to get the entire data set of all restaurants in San Francisco, but even if that was not possible, an truly random sample of the restaurants in San Francisco would have been much nicer. If we had this data, we would then be able to correlate restaurants with location without any bias, and then we could use any location-based data in our model (such as population density). The way we were forced to access data meant that we were only able to find restaurants that were near crimes in the first place. This makes our data set inherently biased. Given this bias, we were only able to analyze the data in a particular way (compare near-crime restaurants vs. the general population of restaurants).

Because of this limitation, we had to use the academic data set as a representative sample of the entire Yelp restaurant population. Because the academic data set was of restaurants outside of San Francisco, this posed two major problems:

1. All the data we obtained for other purposes do not pertain to the academic data set. Because of this, we could only use the academic data set in a separate analysis from all the other data with which we were working.
2. The academic data set is not necessarily a representative sample of the entire Yelp restaurant population. For one thing, it's just a sample of the closest 250 businesses to certain universities. Aside from the fact that businesses near universities themselves may be biased, the fact that the data set spans different cities may be bias in itself. San Francisco's restaurant rating distribution may vary highly from those of Berkeley, Stanford, Los Angeles etc.

Furthermore, we also had technical issues with the Yelp API. We had found many bugs in the Yelp API and sample code, both of which were no longer maintained. Aside from the authentication bug mentioned, the Yelp API also had issues handling Unicode. The rate limiting and the slow response rate of the Yelp API also meant that we couldn't query every single location in San Francisco to obtain data for every single restaurant in Yelp's database. Data fetching was tedious and marginally better than scraping at best. Furthermore, the API lacked some of the properties displayed on the website such as price

range (denoted by a number of dollar signs from 1 to 4). Characteristics like this may have been better correlated with crime density, or would at least have given us a clearer picture of the reason behind why our hypothesis was wrong. Keyword search with location was also a strange idea, because due to the way search is implemented there are necessarily restaurants that may not be included in a search result (false negatives in the search). Usually, for the purposes of a human user, this would not be a problem, but if the search filters out actual restaurants because it doesn't match the keyword as well, then this process introduces bias into our data. Finally, in hindsight, Yelp rating data was too limited to be informative. The API only provides rating data accurate to 0.5 increments, so there are only a total of 10 different ratings a restaurant could have. We had asked Yelp developers through email to provide us with a separate data set with more resolution in ratings, but they weren't able to provide us with anything.

5.4 Causation

As mentioned above, our biggest problem by the end of the project was that, given the data we could access and the limitations we had, we weren't able to show causation or lack thereof. This is partly because we didn't have a clear problem statement to begin with, but is also because we didn't have the statistical background to think rigorously about the process by which we do data science, and the implications of finding a correlation. We also didn't realize that confounding factors were something that almost definitely had to account for, as our original plan was just to predict crime density using restaurant ratings by utilizing machine learning. In the end, we didn't have the data or tools necessary to show causation in either direction. However, we learned interesting correlations along the way.

6 Conclusion

Unfortunately, we weren't able to show any definitive causation between Yelp ratings and crime. However, we were able to find a significant correlation between the two, as well as between each of them and population density. Further work into investigating these correlations could prove to be very interesting and beneficial.

References

- [1] S. D. Levitt, "The Changing Relationship between Income and Crime Victimization," September 1999. [Online]. Available: <http://pricetheory.uchicago.edu/levitt/Papers/LevittTheChangingRelationship1999.pdf>