1 Introduction

With the rise in exposure of police-community interactions through video and audio media, community members are showing greater interest in bringing awareness to how these interactions unfold through social media. Thus, studying these encounters between law enforcement and community members is a growing area of interest in research. We build on previous work studying these encounters through body-warn camera (BWC) footage from a police agency. We aim to use statistics on a collection of BWC videos to produce visuals that reveal insights on unique subsets of patterns and characteristics within these encounters. We use topological data analysis (TDA) rather than traditional methods of statistical analysis to study these encounters. The goal is to produce visual representations of these interactions that capture the several variables impacting their outcomes, while also providing insight on what motivates and drives the decision-making processes of both police officers and suspects.

2 Background Analysis of Police-Community Interactions

Prior methods of statistical analysis have been done to study police-community interactions, including the study of Supplementary Homicide Reports (SHR), Systematic Social Observations (SSO), and Regression Analysis. These methods have been critiqued, however for not taking into account the several variables that tend to drive these encounters. SHR are written reports sent to the FBI by law enforcement agencies describing encounters between police officers and community members. Klinger (2012) critiques this method of analysis, as it is limited to lethal studies only rather than all possible cases with less severe force. Klinger & Brunson (2009) and Phillips (2018) also argue that this method relies solely on recall by officers, which can be inaccurate due to reliance on memory, especially during emotionally charged encounters. SSOs are written reports that are created during live ride-alongs by researchers. Worden & McLean (2014) critique that this method of interaction-analysis is also limited in the number of observations able to be collected for an encounter at one time, as well as for its reliance on notes and memory. Regression analysis is a mathematical method used to determine which variables in a study impact the future outcome of a given event, and which variables do not. Thus, regression analysis provides us a way to predict the outcome of these police-community interactions for a given variable. Berk (2004) argues that this method does not identify distinct subsets of data that reveal patterns of outcomes during these socially complex encounters.

Variables:	Description:
Gender	1 if male, 2 if female
Race	Categorical; 1 if white, 2 if black, greater than 2 if unknown
Arrests	1 if arrest made, 0 if not
Aggression	1 if level 1, 2 if level 2, 3 if level 3
lof max	Maximum level of force applied during the encounter (1-4)
Uses of force (UofF)	Number of times force is used on the suspect
Time to force (TtoF)	Length of time between contact with suspect and first use of force
UofF seconds	Time (in seconds) when first use of force occurs
end_uof_seconds	Time (in seconds) when last use of force occurs
Duration of force (DofF)	Length of time that force lasts (end_uof_seconds-UofF seconds)

Figure 1: Variables used for annotation and analysis of UofF and TtoF Mappers (Makin & Willits et al. (2018)).

TDA is a method that Broussard et al. (2018) use to study body-warn camera videos (BWCs) of police-community encounters. TDA is able to alleviate some of the limitations of traditional analysis, by producing visuals of data that take as input all of the variables that impact the outcomes of these encounters, and by producing subsets of encounters that reveal interesting patterns for their outcomes. Studying video footage rather than written reports also avoids reliance on recall and memory during emotionally heightened encounters, as well as allows us to re-watch these encounters as necessary. Therefore TDA is comparatively unique to these traditional methods. It doesn't limit

the visual representation of data to just a few variables, and rather than solely predicting future outcomes, it provides a visual that preserves all of the variables that impact these interactions, as well as reveals unique subsets of data that reveal interesting characteristics within them. We build off of the work of Broussard et al. (2018), by producing different mapper graphs of the same data set that provide new insights and unique patterns within the data collected on police-community encounters.

3 Methods

3.1 Data Collection & Pre-processing

We received data of 288 annotated body-warn camera (BWC) videos from one police agency.

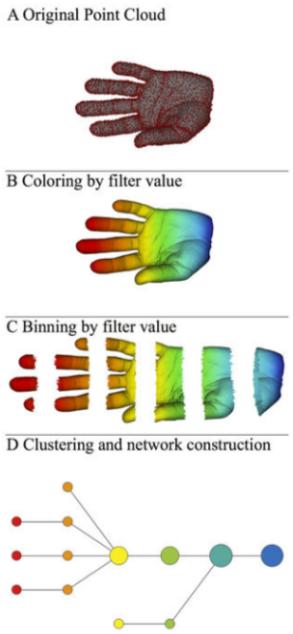

Figure 2: Mapper of Point Cloud Data of a Hand (Lum et al. 2013) with height from wrist as its filter. Its pullback cover is displayed in the third image as color bins (color values) assigned to points on the hand based on their image under the filter value.

Each video was annotated by Maken et al. (2018) using event modeling methods to create objective markers for the events within them. The collection of all markers in a given video is one complete annotation. Maken et al. use time to force (TtoF, the amount of time in seconds from the start of the encounter to the first application of force), duration of force (DofF, the amount of time from the first application of force to the last application of force), level of force (the degree of force used on a suspect), and uses of force (UofF, the number of times force is applied by an officer) as key variables for annotating these interactions. See Figure 1 for a complete list of variables collected during annotation.

The levels of force used by Maken et al. for annotation are defined as follows: 0=no force, 1=minor force (i.e. verbal threats), 2=medium force (i.e. grappling with the suspect), 3=high force (i.e. strikes and grappling applied to the suspect), and 4=instrument-based force (i.e. batons, chemical agents, bean bag rounds). We provide a table below defining these annotation variables.

3.2 Mapper

Before we describe how to use Mapper on our data, we first describe how this algorithm works on two point clouds. We provide two examples in Figures 2 and 3. Mapper is an effective algorithm for topological data analysis, as it takes as input a multi-dimensional point cloud of data, and produces a 1-skeleton (2D) image of that data that can provide useful insights about the structures and unique subsets within it. The ability of Mapper to provide low-dimensional representations that still capture

the high-dimensional structure of the data makes this form of data analysis unique compared to traditional methods discussed in Section 2.

We begin with a point cloud set of data points in $\mathbb{X}$. We create a cover or filter variable of this data $f : \mathbb{X} \to \mathbb{R}^d$. We can choose as many filters up to dimension as is preferred, however we use one for both of our examples. We define a range of our cover Z. Once we select our filter, we choose the number of intervals we want to make up this cover (n), and the percent that we want each of these intervals to overlap (p). Then for each interval I_i in the range of f, we compute the pre-image $f^{-1}(I_i)$, the set of all points in our data space $\mathbb{X}$ whose values under the filter variable are in I_i.

The union of all of these pre-images defines our pullback cover of data. Then we create the nerve of our pullback cover. The nerve is computed by clustering neighboring points of each pre-image into nodes using a distance metric, and defining edges between nodes who share data points in their intersection. The resulting nerve is our 1-skeleton mapper graph of our data. Kepler Mapper distinguishes pre-images by assigning a color value to each data point based on its image under the filter f, and then assigning each node a color based on the mean color value (by default) of all samples within it. Each node contains a member distribution that represents the color values within the node, and the node distribution represents the mean value of the points within each node under the filter.

3.3 Applying Mapper

Now that we have established the theory behind Mapper, we discuss its applications on our data set. Recall that our aim in using Mapper is to provide a unique way to identify subsets of patterns within our high-dimensional data using a low-dimensional visualization, while still preserving the several complex variables factoring into each interaction. We begin with our 28-dimensional set of annotated police-community encounters. We produce two mappers of our data. We select UofF as a filter function for our first mapper analysis, and then TtoF for our second. We then test each filter over a wide range of n and p to look for mappers that produce stable features. Features we looked for included branching to or from nodes and homology. A mapper feature is considered stable if it persists over a range of n and p. The larger this range is, the more stable the feature. We not only look for stable features, but also unique features that provide some unique structure in our data. We created a course grid to keep track of these unique subsets of mappers, and colored each cell within it according to its unique mapper type. Once we identified subsets of mappers that produced interesting characteristics, we created a smaller refined course grid to cover all possible values of n and p that produced them. We describe our choices of n and p for both mappers in sections 4 and 5 below. Once we

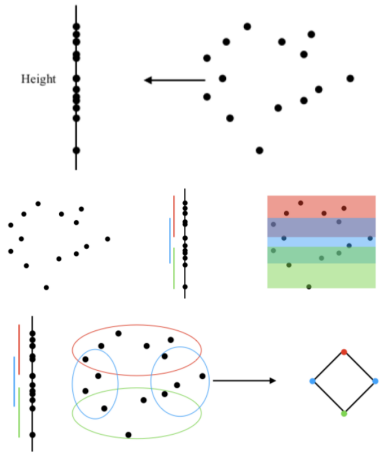

Figure 3: Mapper of the Point Cloud of a Circle from Broussard et al. (2018). The first image displays height as the filter with a line shown as its cover. The second image shows the pullback cover of the data. The last image shows the clustering algorithm.

selected our interval and percent overlap values, Mapper clustered neighboring points in the pullback cover into nodes using the DBSCAN clustering algorithm. DBSCAN defines any two points in the pullback together to be neighbors if they are within ϵ distance of each other, and computes clusters for all subsets of data containing the minimum number of neighbors. We chose these ϵ and minimum sample values. Once Mapper clustered our sample data points, it kept track of pre-images in the pullback cover by assigning each sample within a given cluster a color based on its value under UofF or TtoF. Then it assigned each node a color based on the average value under UofF or TtoF of all of the samples within it. Once both mappers were produced, the members within each node were studied for their racial and gender distributions, aggression levels by suspects, amount of arrests, uses of force, times to force, and durations of force. We provide tables of these results in Figure 4 below. We refer to each cluster in these tables by their size.

4 Use of Force

We naturally select Uses of Force ($UofF$) as a filter, as we are interested in studying police-community interactions, and the amount of times force is applied by an officer could potentially have an active role in how these encounters play out. We projected $UofF$ onto our data set over a wide range of resolution and gain values, n and p, respectively. We found stable features in our graph across $n \in [16, 18]$ and $p \in [.64, .66]$, $n \in [10, 12]$ and $p \in [.59, .63]$, and $n \in [11, 13]$ and $p \in [.64, .68]$. We selected a mapper for analysis from the two choices with median values $n = 11$ and $p = .61$, and $n = 12$ and $p = .66$, as these mappers persist over larger ranges of p. These two mappers are identical, so we selected one of them for analysis with $n = 12$ and $p = .66$. This $UofF$ mapper is displayed in Figure 5 below. Each node in our mapper contains sample points from our data set. Each sample point represents an annotated police-community encounter. The population of each node is the amount of encounters it contains. We display this population size below each node, denoted as P. Each node is displayed as a pie chart in order to reveal the racial distributions of the individuals in each cluster of encounters. Our mapper contains nodes with mean $UofF$ over three ranges, denoted μ; $0 \leq \mu \leq 1.4$, $1.4 < \mu \leq 2.8$, and $2.8 < \mu \leq 4.2$. The mean μ for each node is computed by taking the average uses of force over all encounters within it. We first compare nodes within each of these three ranges of $UofF$, and then between each set of ranges, as each range represents three different types of experiences. Assume that all percentages in the analyses below are referenced respectively (in the same order that the nodes are mentioned).

Nodes in $0 \leq \mu \leq 1.4$:
For easier reference, we name the nodes by their population size P. This portion of our Uses of Force graph displays encounters with little to no force used. Node 23 captures encounters with no uses of force, as it has a mean use of force equal to 0, while node 193 captures encounters with very few uses of force with mean 0.0155. Lower levels of aggression were displayed by suspects in node 23 compared to node 193. That is, 13.5% of individuals in 193 use level 2 of aggression, compared to 8.7% at level 2 by individuals in node 23. More arrests occurred in node 23 at 47.8% compared to the 20.2% of arrests in node 193.

Cluster	Cube 2 Cluster 1	Cube 0 Cluster 1	Cube 1 Cluster 0	Cube 2 Cluster 0	Cube 1 Cluster 1	Cube 0 Cluster 2	Cube 0 Cluster 0
size	8	7	13	11	5	23	193
mean UofF	2.25	1.57	1.85	2.82	2.6	0	0.0155
lof=1	37.50%	57.10%	53.80%	9.10%	20%	N/A	N/A
lof=2	50%	42.90%	38.50%	54.50%	40%	N/A	N/A
lof=3	12.50%	0%	7.70%	9.10%	0%	N/A	N/A
lof=4	0%	0%	0%	27.30%	40%	N/A	N/A
arrests	25%	57.10%	38.50%	45.50%	20%	47.80%	20.20%
aggression level 1	12.50%	12.50%	15.40%	18.20%	20%	91.30%	86.50%
aggression level 2	87.50%	87.50%	84.60%	81.80%	80%	8.70%	13.50%
aggression level 3	0%	0%	0%	0%	0%	0%	0%
white	75%	71.40%	69.20%	72.70%	80%	78.30%	77.20%
black	0%	14.30%	15.40%	9.10%	0%	8.70%	8.30%
other	25%	14.30%	15.40%	18.20%	20%	13 %	14.50%
male	75%	87.50%	77%	90.90%	80%	73.90%	67.40%
female	25%	12.50%	23%	9.10%	20%	26.10%	32.60%

Cluster	Cube 1 Cluster 2	Cube 0 Cluster 1	Cube 1 Cluster 1	Cube 0 Cluster 0	Cube 1 Cluster 0	Cube 2 Cluster 0	Cube 3 Cluster 0	Cube 20 Cluster 0
size	6	7	8	17	9	8	6	214
mean TtoF	29.67	25.43	37.75	30.24	37.75	157	171.17	1400
mean UofF	2.5	2.43	3.5	2.82	2.67	3.63	3.67	0
arrests	66.70%	57.10%	62.50%	52.90%	33.30%	37.50%	33.30%	22.90%
aggression level 1	16.70%	28.60%	12.50%	11.80%	11.10%	25%	16.70%	86%
aggression level 2	50%	42.90%	87.50%	88.20%	77.80%	50%	66.70%	12.60%
aggression level 3	33.30%	28.50%	0%	0%	11.10%	25%	16.60%	1.40%
white	100%	85.70%	75%	70.60%	77.80%	87.50%	83.30%	77.60%
black	0%	14.30%	25%	17.60%	11.10%	12.50%	16.70%	8.40%
other	0%	0%	0%	11.80%	11.10%	0%	0%	14%
male	100%	100%	87.50%	88.20%	88.90%	75%	66.70%	67.80%
female	0%	0%	12.50%	11.80%	11.10%	25%	33.30%	32.30%
DofF Range	[0,58]	[0,58]	[3,110]	[0,110]	[0,43]	[3,67]	[3,67]	N/A

Figure 4: Data calculations for each node in UofF Mapper on the top, and TtoF mapper on the bottom.

Nodes in $1.4 < \mu \leq 2.8$**:**

Nodes 5, 7, 8, and 13 all have encounters with average uses of force between 1.4 and 2.8. We observe that nodes 7 and 13 both have slightly less uses of force with means 1.57 and 1.85 compared to nodes 5 and 8 with means 2.6 and 2.25. Nodes 7 and 13 also contain encounters with more arrests at 57.1% and 38.5%, compared to 25% and 20% arrests in nodes 5 and 8. Nodes 7 and 13 also had relatively lower percentages of white and black suspects at 69.2%-71.4% white and 14.3%-15.4% black compared to 75%-80% white and 20%-25% black in nodes 5 and 8. Node 7 also has a lower maximum level of force applied at 42.9% level 2, compared to nodes 5,8, and 13 with 40% of encounters at level 4, 12.5% at level 3, and 7.7% at level 3. Node 7 also has a smaller range for the duration that force is applied to the suspect, with force lasting anywhere between 0

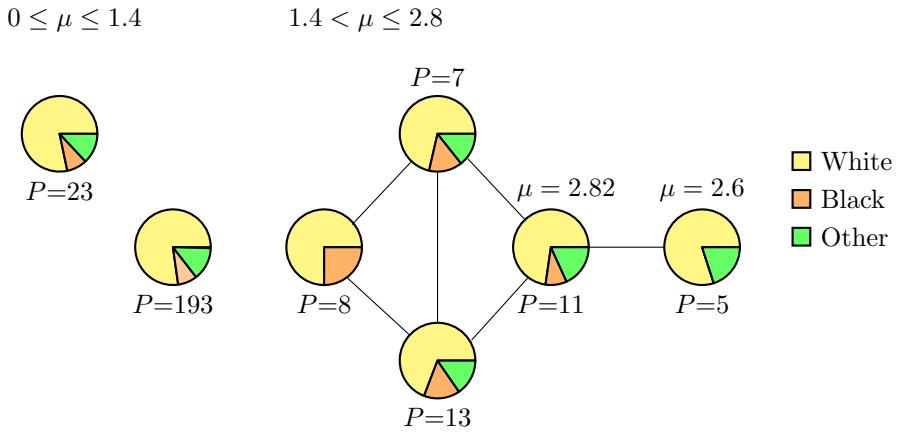

Figure 5: Mapper with uses of force (UofF) as filter variable. Each pie chart represents a node in the mapper, and the number of samples from the data within each node is listed below it as its population, P. The mean UofF ranges for the node distribution are written as μ. The first two nodes contain encounters with mean in $0 \leq \mu \leq 1.4$, the next three nodes and node $P = 5$ contain encounters with mean in $1.4 < \mu \leq 2.8$, and node $P = 11$ contains encounters with mean $\mu = 2.82$ in range $2.8 < \mu \leq 4.2$. The racial distributions within each node are shown as colors in the pie charts. See the legend for how to define these.

and 9 seconds, while nodes 5, 8, and 13 all have longer durations in ranges [2,23], [6,24], and [0,24] seconds, respectively. There are also slightly less black suspects in node 7 encounters at 14.3% compared to 20%, 25%, and 15.4% in nodes 5, 8, and 13. Node 5 also contained relatively lower times until force was applied in each encounter, with $TtoF$ between 7 and 26 seconds, compared to ranges [0,116], [32,196], and [0,261] seconds in nodes 7, 8, and 13, respectively.

Nodes in $1.4 < \mu \leq 2.8$ **vs Node** 11**:**

We compare nodes in both of these ranges, as they all have relatively close mean values for use of force applied, and notably each of these clusters contain 100% of encounters with force applied at some level. Nodes 5 and 11 are connected by an edge, indicating an overlap or sharing of sample points and have only a .22 difference in μ, thus we are interested in comparing these two clusters. Node 11 has a slightly higher mean use of force at 2.82 compared to 2.6 in node 5. Node 11 also has more arrests at 45.5% compared to 20% in node 5. There are also more males and black suspects in node 11 at 90.9% and 9.1%, respectivetly, compared to 80% males and 0% black suspects in node 5. On the ohter hand, nodes 5 and 11 both have the largest maximum level 4 of force applied at 40% and 27.3%, compared to 0% at level 4 in nodes 7, 8, and 13. Node 11 also has similar levels of aggression by suspects in each encounter as nodes 5, 7, 8, and 13, with all five nodes having between 80% to 90% at level 2 and between 12% to 20% at level 1.

Nodes in $0 \leq \mu \leq 1.4$ **vs** $1.4 < \mu \leq 4.2$**:**

We observe that nodes in the larger two ranges of μ contain 100% of encounters with force applied, while nodes 23, 192, and 193 in the lowest range of μ together contain nearly zero uses of

force. Thus we study the differences between these two types of experiences. Lower levels of aggression overall are seen in nodes 23, 192, and 193, in which suspects display over 84% of level 1 aggression and under 16% level 2 aggression. On the other hand, much higher levels of aggression are seen in nodes 5, 7, 8, 11, and 13, whom all contain over 80% of suspects displaying level 2 aggression and under 21% level 1. This suggests that higher levels of aggression by individuals could be a potential response to increased uses of force by officers. One interesting similarity across these ranges is shown in nodes 192, 193, and 5, as they all contain encounters in which around 20% of suspects were detained, while these clusters also all contain encounters with a maximum level of force applied equal to four.

5 Time to Force Mapper One

We also select Time to Force (TtoF) as a filter for our data, as the amount of time until force is used on a suspect by an officer could provide insights on how these interactions unfold. Out of all 288 encounters, 218 of them had no force used, and 70 of them had force used. Our time to force range (in seconds) for all encounters is $[0, 1831]$. We selected a smaller TtoF value of 1400 seconds for all 218 encounters without force applied (Broussard et all., 2018). This is because, when applying the distance function to the pullback cover of our data set, 1400 was a large enough filter value that all sample points with no force used were clustered together, yet small enough so that all of the sample points with force used would not be clustered together into one big node. Choosing a maximum TtoF value in this way thus allows us to produce a mapper that distinguishes encounters that involve use of force from those that don't, while also generating nodes that distinguish different types of UofF experiences based on their TtoF values.
Once we assigned 1400 seconds to all 214 encounters without force used, this subset of our data was clustered into one large node P=214. See the Time to Force mapper in Figure 6 for reference. The remaining subset of our data capturing all encounters where force was applied is represented by the 7 nodes in the first two ranges of mean time to force: $0 \leq \mu \leq 140$ and $140 < \mu \leq 280$. Now that we have a mapper that distinguishes TtoF in this way, we have a more representative graph of our data that we can use to compare how TtoF and UofF come into play during these interactions. We again refer to the nodes by their population size P for easier reference. Assume that all calculations are stated respectfully (in the order that their nodes are mentioned).

Node 214 **vs nodes in** $0 \leq \mu \leq 280$**:**

We first compare the nodes containing encounters with force to the node containing encounters without force. 214 has much longer TtoF (1400 seconds) with 0% of its encounters involving force applied by an officer, while each node in $0 \leq \mu \leq 280$ has much shorter TtoF (between 25.43-37.75 seconds) with 100% of its encounters involving uses of force. 214 also has lower levels of aggression displayed by suspects. Suspects displayed 86% level 1, 12.6% level 2, and 1.4% level 3 of aggression in 214, whereas suspects in nodes with force used displayed below 28.6% level 1, between 42.9%-87.5% level 2, and between 0%-33.3% level 3 aggression. The least amount of arrests occurred in node 214 interactions at 22.9%, whereas encounters in nodes with force used all had between 33.3%-66.7% arrests.

Nodes in $0 \leq \mu < 140$ **vs** $140 < \mu \leq 280$**:**

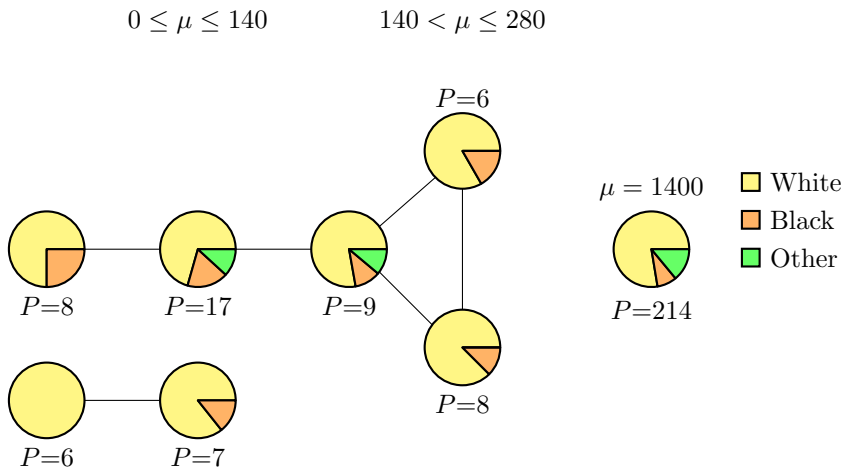

Figure 6: Mapper with time to force (TtoF) as filter variable. Each pie chart represents a node in the mapper, and the number of samples from the data within each node is listed below it as its population, P. The mean TtoF ranges (in seconds) for the node distribution are written as μ. The first five nodes contain encounters with mean in $0 \leq \mu \leq 140$, the next two nodes contain encounters with mean in $140 < \mu \leq 280$, and node $P = 214$ contains all encounters with mean $\mu = 1400$ in range $1260 < \mu \leq 1400$ and zero uses of force. The racial distributions within each node are shown as colors in the pie charts. See the legend for how to define these.

Nodes 6 and 8 in TtoF range $140 < \mu \leq 280$ both contain encounters with similar average time until force is applied at 157 and 171.17 seconds, whereas nodes in TtoF range $0 \leq \mu < 140$ all contain encounters with lower average TtoF between 25.43-37.75 seconds. These two subsets of nodes represent two distinct types of police-community interactions. Thus we are interested in studying the similarities and differences between these encounters. Nodes 6 and 8 in the second range $140 < \mu \leq 280$ both have less male suspects, more white suspects, relatively higher levels of aggression, relatively less arrests, and greater mean UofF than nodes in the first range $0 \leq \mu < 140$. Both nodes in the second range contain samples with 66.7% and 75% males, and 83.3% and 87.5% white suspects, whereas nodes in the first range contain samples with between 87.75%-100% males and 70.6%-77.8% white suspects. Suspects displayed higher levels of aggression in nodes 6 and 8 of the second range compared to nodes 8, 9, and 17 of the first range. Suspects in 6 and 8 of range 2 displayed 16.6% and 25% level 3 aggression, whereas suspects displayed 0% level 3 aggression in nodes 8 and 9 and 11.1% level 3 aggression in node 17. Both nodes in range 2 contain samples with relatively less arrests than nodes in range 1. Particularly, 6 and 8 in the second range contain encounters with 33.3% and 36.5% arrests, whereas nodes in the first range contain encounters with between 33.3%-66.7% arrests. Range 2 nodes have greater mean uses of force by officers compared to range 1 nodes. Encounters in nodes 6 and 8 of range 2 contain 3.67 and 3.63 mean UofF, whereas nodes in range 1 contain between 2.43 and 3.5 mean UofF. Interactions in 6 and 8 from $140 < \mu \leq 280$ also have the same duration of force, lasting between 3-67 seconds.

Nodes in $0 \leq \mu < 140$:

The interactions captured in nodes 8, 9, and 17 all have mean TtoF above 30 seconds, whereas interactions within nodes 6 and 7 have mean TtoF below 30 seconds. Nodes 6 and 7 are also shared by a separate edge from nodes 8, 9, and 17. Therefore we are interested in comparing the interactions in 8, 9, and 17 with the interactions in 6 and 7. Clusters 8, 9, and 17 all have longer mean time to force, more average uses of force, lower levels of aggression, and less white male suspects than nodes 6 and 7. Nodes 8 and 9 both have mean TtoF 37.75 seconds and 17 has mean 30.24 seconds, whereas 6 and 7 have mean TtoF 29.67 seconds and 25.43 seconds. Officers display greater average UofF in encounters of nodes 8, 9, and 17 compared to nodes 6 and 7. Officers apply force to suspects an average of 3.5, 2.67, and 2.82 times in nodes 8, 9, and 17, compared to 2.5 and 2.43 times in nodes 6 and 7. Individuals also exhibit lower levels of aggression in 8, 9, and 17 compared to 6 and 7. Individuals in 8 and 17 use 0% level 3 aggression and individuals in 9 use 11.1% level 3 aggression. On the other hand, 33.3% and 28.5% level 3 aggression is displayed by individuals in nodes 6 and 7. Nodes 8, 9, and 17 have between 70.6%-66.8% white suspects and 87.5%-88.9% males, whereas 6 and 7 have more white males in there encounters, with 100% and 85.7% white suspects, and 100% males in each.

6 Time to Force Mapper Two

We generated another mapper with time to force using the same methods for selection of resolution and gain as before. That is, we created a course grid to test several values of resolution and gain for mappers with interesting and stable features. We found another stable TtoF mapper graph with resolution in range $[25, 26]$ and gain in $[0.56, 0.58]$. We selected the mapper with resolution $n = 25$ and gain $p = 0.57$ for detailed analysis. For reference, since there are two nodes with size 7, we will refer to the node 7 that is node connected by an edge to the rest of the nodes in $0 <= \mu < 280$ as an "isolated node". We will continue to refer to the rest of the nodes in our graph by their population size. See figure 7 for our table of node calculations and figure 8 for our mapper graph.

Cluster	Cube 0 Cluster 1	Cube 0 Cluster 0	Cube 1 Cluster 0	Cube 3 Cluster 0	Cube 2 Cluster 0	Cube 18 Cluster 0
size	7	17	10	7	9	213
mean TtoF	25.4	24.5	74.5	184	155.3	1400
mean UofF	2.4	2.9	3.8	3.3	4.8	0
arrests	57.14%	52.94%	40.00%	42.86%	44.44%	23.00%
aggression level 1	28.57%	11.76%	10.00%	28.57%	22.22%	86.38%
aggression level 2	42.86%	88.24%	70.00%	57.14%	44.44%	12.68%
aggression level 3	28.57%	0.00%	20.00%	14.29%	33.34%	0.94%
white	100.00%	70.59%	70.00%	71.43%	77.78%	77.93%
black	0.00%	17.65%	10.00%	14.29%	0.00%	8.45%
other	0.00%	11.76%	20.00%	14.28%	22.22%	13.62%
male	100.00%	88.24%	90.00%	71.43%	77.78%	68.08%
female	0%	11.76%	10.00%	28.57%	22.22%	31.92%
DofF Range	[0,58]	[0,120]	[0,128]	[0,67]	[3,128]	N/A

Figure 7: Data calculations for each node in TtoF Mapper Two.

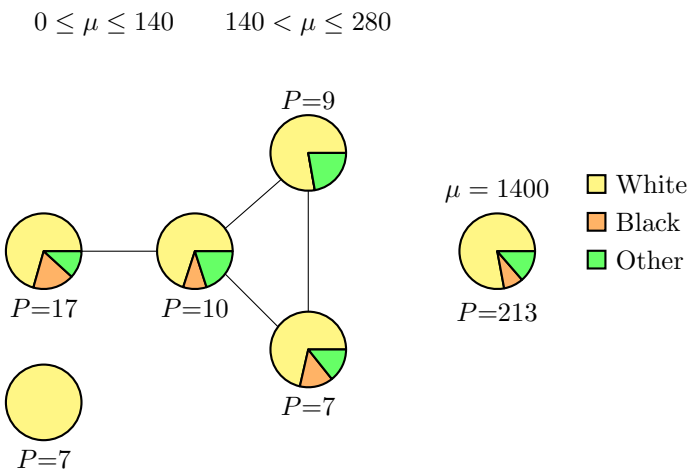

Figure 8: Second mapper with time to force (TtoF) as filter variable. Each pie chart represents a node in the mapper, and the number of samples from the data within each node is listed below it as its population, P. The mean TtoF ranges (in seconds) for the node distribution are written as μ. The first three nodes contain encounters with mean in $0 \leq \mu \leq 140$, the next two nodes contain encounters with mean in $140 < \mu \leq 280$, and node $P = 213$ contains all encounters with mean $\mu = 1400$ in range $1260 < \mu \leq 1400$ and zero uses of force. The racial distributions within each node are shown as colors in the pie charts. See the legend for how to define these.

Encounters with force used (nodes in $0 \leq \mu < 280$) **VS encounters with no force used (node 213):**

Node 213 reveals that encounters with no force used had the least amount of arrests compared to all other encounters with uses of force. Node 13 depicts 23% of interactions ending in arrests, while all other nodes containing use-of-force encounters had a higher percentage of arrests between 40-57.14%.

Node 213 also reveals that encounters with no force used involved suspects displaying lower levels of aggression compared to encounters with force used. That is, node 213 reveals that 86.38% of its encounters contain suspects displaying level 1 aggression, 12.68% displaying level 2, and only 0.94% displaying level 3. Oppositely, all other nodes containing use-of-force interactions contain suspects that displayed much higher levels of aggression. Nodes in this range ($0 \leq \mu < 280$) had between 10-28.57% level 1 aggression displayed by individuals, between 42.86-88.24% level 2 aggression displayed, between 0-33.4% level 3 aggression displayed.

As well as this, node 213 shows that encounters with no force used involved slightly less males at 68.08% than those with use of force. Nodes 17, 10, 7, and 9 are all interactions containing use of force, and all involve between 71.43-90% males.

Lastly, node 213 shows that encounters with no force contained slightly less nonwhite suspects than encounters with force applied. Node 213 contains interactions with 22.07% nonwhite individuals, while nodes 17, 10, 9, and 7 all contain interactions with between 22.22-30% nonwhite

suspects.

Isolated node compared to other nodes with uses of force ($0 \leq \mu < 280$):

Of all of the nodes capturing encounters with force applied by officers, one of them is isolated with population size 7. Naturally, it makes sense to investigate what makes these use-of-force encounters unique from the rest of the nodes containing force.

Firstly, this isolated node contains more arrests than other use of force nodes and the most amount of white suspects. This isolated node contains encounters with 57.14% arrests and 100% white suspects, while the rest of the nodes 7,9,10, and 17 containing use-of-force interactions contain between 40-52.94% arrests and only between 70-77.78% white individuals.

This isolated node also contains the most amount of male suspects relative to the other use-of-force nodes. The isolated node contains 100% male suspects in its encounters, while nodes 7,9,10, and 17 have between 71.43-90% of male individuals.

Nodes in $0 \leq \mu < 140$ **compared to nodes in** $140 \leq \mu < 280$:

Because the isolated node and nodes 10 and 17 in the lowest mean TtoF range all contain TtoF less than 75 seconds, and the two nodes in the longer mean TtoF range contain encounters in which it takes longer than 150 seconds until force is applied, it makes sense to look into the differences between these two types of use-of-force experiences.

Nodes in the lower mean TtoF range contain relatively more arrests in their encounters than nodes in the larger mean TtoF range. The isolated node and node 17 both contain encounters with 57,14% and 52.94% arrests, respectively, whereas encounters in nodes 7 and 9 contain only 42.86% and 44.44% arrests, respectfully.

Nodes 10 and 17 in the lower mean TtoF range also contain interactions with slightly more nonwhite suspects. Nodes 10 and 17 contain encounters with 29.41% and 30% nonwhite suspects, while nodes 7 and 9 in the longer mean TtoF range contain encounters with 28.57% and 22.22% nonwhite suspects.

Nodes 10, 17, and the isolated node also contain encounters with more male suspects than nodes 7 and 9 with longer time until force is applied. Nodes 10, 17, and the isolated node in the less mean TtoF all contain 90%, 88.24%, and 100% males, respectfully. Nodes 7 and 9 with longer mean TtoF contain only 71.43% and 77.28% male individuals, respectfully.

7 Discussion

7.1 Use of Force in Police-Community Encounters

Our UofF mapper in Figure 5 reveals overall subsets of patterns within our set of encounters. Encounters with less uses of force contained relatively lower levels of aggression from suspects, as discussed for nodes 23 and 193 with less force used compared to nodes 5, 7, 8, 11, and 13 with more force used. Interactions in nodes 23 and 193 with less force used also had slightly less non-white individuals in them compared to interactions in nodes 7, 8, 11, and 13 with more force used. Encounters in nodes 23 and 193 with less force used also involved less male suspects than encounters

in nodes in 5, 7, and 11 with more force used, as shown by our data table in Figure 4. Thus for our data set, more force was typically used in encounters with slightly more nonwhite male individuals, and more aggression was typically used by suspects in these interactions.

7.2 Time to Force in Police-Community Encounters

Our first TtoF Mapper in Figure 6 also reveals interesting characteristics about these interactions in our data. Encounters in node 214 with no force used had lower levels of aggression exhibited by suspects than encounters in the remaining nodes with force used. These encounters also involved the least amount of arrests by officers than encounters with force used. Interactions in nodes with less time until force was applied typically contained more nonwhite males, relatively lower levels of aggression, relatively more arrests, and lower average uses of force than interactions in nodes with more time until force was applied, as discussed when comparing nodes 6 and 8 with more TtoF and less UofF with nodes 8, 9, and 17 in the lowest range of TtoF. Thus in our data set, less TtoF was typically seen in encounters with more nonwhite males, and suspects in these encounters showed relatively lower levels of aggression than suspects in encounters with longer time until force.

Our second TtoF mapper reveals similar patterns as our first one. That is, encounters with force used involved slightly more nonwhite male suspects displaying higher levels of aggression than encounters with no force used. Oppositely, encounters with no force used involved slightly less nonwhite male suspects displaying lower levels of aggression than encounters with force used. Deeper analysis of the nodes with UofF encounters revealed that force was applied by police officers more quickly during interactions containing slightly more nonwhite male suspects, and ended in more arrests compared to interactions with longer time until force was used.

8 Limitations and Future Work

Our work is limited in the number of encounters studied. To get a more holistic view on patterns within police-community interactions, working with more than 280 BWC videos (and with more than 70 encounters with UofF) from more than one law enforcement agency in the future would be ideal. We are also interested in using other variables as filters for our BWC data, such as duration of force and maximum level of force used. We'd like to study how these other variables impact the outcomes of these interactions.

The goal of our research is to provide a unique way to study the interactions between law enforcement and community members that avoids the limitations of traditional statistical analysis on the subject. We use Mapper to visually represent the nuanced complexity of these interactions, and the many variables that impact how these social encounters play out. Our mapper graphs provide unique representations of these social exchanges by revealing unique subsets of encounters that identify patterns in which variables effect the outcomes of these interactions. This quality of Mapper is one that traditional statistical analysis is typically not capable of. Our mappers take as input a high-dimensional set of encounters, and produce a low-dimensional image that preserves the multiple variables that impact each interaction, and reveals hidden structure that other statistical graphics cannot do. By applying Mapper to our data set of annotated video encounters between police and suspects, we were able discover insights on patterns revealed in the graphs. We discovered patterns revealing how variables such as time to force and use of force impact the outcome of these interactions, and how other variables such as race and gender played a role in their outcomes.

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Sample 1	Sample 2	Sample 3	Sample 4
Cu_0Cl_2 (23)	Cu_2Cl_1 (8)	Cu_0Cl_1 (7)	Cu_2Cl_1 (8)
Cu_0Cl_0 (192)	Cu_0Cl_1 (7)	Cu_1Cl_0 (13)	Cu_0Cl_1 (7)
	Cu_1Cl_0 (13)	Cu_2Cl_0 (11)	Cu_1Cl_0 (13)
	Cu_2Cl_0 (11)		Cu_2Cl_0 (11)
	Cu_1Cl_1 (5)		

Figure 9: Samples for T-Tests in Uses of Force Mapper. We compared concentrations and averages between Samples 1 and 2, Samples 1 and 3, and Samples 1 and 4.

Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
Cu_0Cl_1 (7)	Cu_18Cl_0 (213)	Cu_0Cl_1 (7)	Cu_3Cl_0 (7)	Cu_0Cl_0 (17)
Cu_0Cl_0 (17)		Cu_0Cl_0 (17)	Cu_2Cl_0 (9)	Cu_1Cl_0 (10)
Cu_1Cl_0 (10)		Cu_1Cl_0 (10)		
Cu_3Cl_0 (7)				
Cu_2Cl_0 (9)				

Figure 10: Samples for T-Tests in Time to Force Mapper. We compared concentrations and averages between Samples 1 and 2, Samples 3 and 4, and Samples 5 and 4.

	Sample 1 (no UofF) Pop=215	Sample 2 (UofF) Pop=44	Difference (p) increase(+) decrease(-)	p-value
UofF	0.014	2.205	2.191	4.08E-22
TtoF	1387.31	69.18	-1318.13	5.40E-114
White	0.78	0.73	-0.05	0.48
Black	0.18	0.09	-0.09	0.14
Other	0.04	0.18	0.14	6.34E-04
Non-white	0.22	0.27	0.05	0.48
Males	0.68	0.82	0.14	0.07
Females	0.32	0.18	-0.14	0.07
Low_Agg	0.86	0.16	-0.7	3.68E-22
Med_Agg	0.13	0.84	0.71	3.91E-23
High_Agg	0.01	0	-0.01	0.52
L1_force	0.0047	0.36	0.3553	1.94E-18
L2_force	0	0.36	0.36	6.95E-20
L3_force	0	0.09	0.09	8.37E-06
L4_force	0.0093	0	-0.0093	0.52
Arrests	0.23	0.39	0.16	0.03

	Sample 1 (no UofF) Pop=215	Sample 3 (UofF) Pop=31	Difference increase(+) decrease(-)	p-value
UofF	0.014	2.129	2.115	4.24E-14
TtoF	1387.31	66.23	-1321.08	1.49E-70
White	0.78	0.71	-0.07	0.41
Black	0.18	0.18	0	0.47
Other	0.04	0.16	0.12	7.29E-03
Non-white	0.22	0.29	0.07	0.41
Males	0.68	0.84	0.16	0.08
Females	0.32	0.16	-0.16	0.08
Low_Agg	0.86	0.16	-0.7	3.98E-18
Med_Agg	0.13	0.84	0.71	5.13E-19
High_Agg	0.0093	0	-0.0093	0.59
L1_force	0.0047	0.4194	0.4147	1.50E-04
L2_force	0	0.26	0.26	3.65E-14
L3_force	0	0.0968	0.0968	4.44E-06
L4_force	0.0093	0.0645	0.0552	0.02
Arrests	0.23	0.45	0.22	7.64E-03

	Sample 1 (no UofF) Pop=215	Sample 4 (UofF) Pop=39	Difference increase(+) decrease(-)	p-value
UofF	0.014	2.15	2.136	7.90E-19
TtoF	1387.31	76.1	-1311.31	2.20E-94
White	167/215=0.78	28/39=0.72	-0.06	0.42
Black	40/215=0.18	4/39=0.1	-0.17	0.2
Other	8/215=0.04	7/39=0.18	0.014	5.25E-04
Non-white	48/215=0.22	11/39=0.28	0.06	0.42
Males	147/215=0.68	32/39=0.82	0.14	0.08
Females	68/215=0.32	7/39=0.18	-0.14	0.08
Low_Agg	185/215=0.86	6/39=0.15	-0.71	5.41E-21
Med_Agg	28/215=0.13	33/39=0.85	0.72	6.02E-22
High_Agg	2/215=0.0093	0	-0.0093	0.55
L1_force	1/215=0.0047	31/39=0.79	0.79	1.29E-42
L2_force	0	20/39=0.51	0.51	7.43E-28
L3_force	0	4/39=0.1	0.1	2.21E-06
L4_force	2/215=0.0093	3/39=0.08	0.07	5.16E-03
Arrests	50/215=0.23	16/39=0.41	0.18	0.02

Figure 11: Table of averages/concentrations and their differences for Samples compared in Uses of Force Mapper.P-values for each difference are listed in the right column of each table.

	Sample 1 (UofF) Pop=50	Sample 2 (No UofF) Pop=213	Difference increase (+) decrease (-)	p-value
UofF	3.4	0	-3.4	2.10E-11
TtoF	80.52	1400	1319.48	5.30E-64
White	0.74	0.78	0.04	0.55
Black	0.12	0.09	-0.03	0.5
Other	0.14	0.13	-0.01	0.87
Non-white	0.26	0.22	-0.04	0.55
Males	0.86	0.68	-0.18	0.01
Females	0.14	0.32	0.18	0.01
Low_Agg	0.18	0.86	0.68	2.14E-22
Med_Agg	0.66	0.13	-0.53	1.60E-15
High-Agg	0.16	0.01	-0.15	5.41E-07
L1_force	0.84	N/A	N/A	N/A
L2_force	0.56	N/A	N/A	N/A
L3_force	0.24	N/A	N/A	N/A
L4_force	0.18	N/A	N/A	N/A
Arrests	0.48	0.23	-0.25	3.82E-04

	Sample 3 (Quicker TtoF) Pop=34	Sample 4 (Slower TtoF) Pop=16	Difference increase (+) decrease (-)	p-value
UofF	3.06	4.13	1.07	0.27
TtoF	39.41	167.88	128.47	7.02E-12
White	25/34=0.74	12/16=0.75	0.01	0.91
Black	5/34=0.15	1/16=0.06	-0.09	0.39
Other	4/34=0.12	3/16=0.19	0.07	0.51
Non-white	9/34=0.26	4/16=0.25	-0.01	0.91
Males	31/34=0.91	12/16=0.75	-0.16	0.12
Females	3/34=0.09	4/16=0.25	0.16	0.12
Low_Agg	5/34=0.15	4/16=0.25	0.1	0.38
Med_Agg	25/34=0.74	8/16=0.5	-0.69	0.1
High-Agg	4/34=0.12	4/16=0.25	0.13	0.23
L1_force	28/34=0.82	14/16=0.88	0.06	0.64
L2_force	22/34=0.65	6/16=0.38	-0.27	0.03
L3_force	5/34=0.15	7/16=0.44	0.29	2.00E-02
L4_force	7/34=0.21	2/16=0.13	-0.08	0.49
Arrests	17/34=0.5	7/16=0.44	-0.06	0.68

	Sample 5 (Quicker TtoF) Pop=27	Sample 4 (Slower TtoF) Pop=16	Difference increase (+) decrease (-)	p-value
UofF	3.22	4.13	0.91	0.37
TtoF	43.04	167.88	124.84	1.50E-11
White	19/27=0.7	12/16=0.75	0.05	0.74
Black	4/27=0.15	1/16=0.06	-0.09	0.4
Other	4/27=0.15	3/16=0.19	0.04	0.74
Non-white	8/27=0.3	4/16=0.25	0.22	0.74
Males	24/27=0.89	12/16=0.75	-0.06	0.23
Females	3/27=0.11	4/16=0.25	0.14	0.23
Low_Agg	0	4/16=0.25	0.25	6.37E-03
Med_Agg	22/27=0.81	8/16=0.5	-0.76	0.03
High-Agg	5/27=0.19	4/16=0.25	0.06	0.61
L1_force	23/27=0.85	14/16=0.88	0.03	0.83
L2_force	17/27=0.63	6/16=0.38	-0.25	0.11
L3_force	2/27=0.07	7/16=0.44	0.37	4.63E-03
L4_force	6/27=0.22	2/16=0.13	-0.09	0.43
Arrests	13/27=0.48	7/16=0.44	-0.04	0.78

Figure 12: Table of averages/concentrations and their differences for Samples compared in Time to Force Mapper.P-values for each difference are listed in the right column of each table.