\section{Application Implementation}

We developed an application to be used by LEAs that outlines a standard process for generating crime maps utilizing NIBRS data as input variables, open-source software, and design strategies that best promote transparency with the public. Law enforcement agencies at the state and local levels are held to criminal and civil law compliance by the U.S. Department of Justice. For example, these include laws that ensure all law enforcement officers do not deny any individual in the U.S. of rights set forth by the U.S. constitution\footnote{Addressing Police Misconduct laws enforced by the Department of Justice, U.S. Department of Justice, https://www.justice.gov/crt/addressing-police-misconduct-laws-enforced-department-justice} . Standards for the delivery of service by LEAs remain mostly self-regulated. In 1979 the Commission on Accreditation for Law Enforcement Agencies (CALEA) was created as an independent credentialing authority that works to create standardized practices âto improve the delivery of public safety servicesâ\footnote{The Commission, CALEA, http://www.calea.org/content/commission}. In 2017 there were just over 1,000 LEA enrolled in the CALEA accreditation program. With at least 30,000 LEAs servicing the U.S. this leaves many agencies without a standard practice for the delivery of crime incident data to the public.

\par This application includes practical guidelines and an example website with the goal of being easily replicable and enhancing legitimacy and trust with the public. The application description below is spilt into subsections of Time, Interactivity, Color, Basemap Selection, Map Types, and Variables. The subsections of the application description are put into place to act as a guide for novice mapmakers.

\subsection{Time}

Time or temporal analysis in maps has been in use with thematic maps for many years. Like space, time is heterogeneous [6]. We see day differences in terms of weekdays and weekends. The analysis of spatiotemporal data can be complex with many numbers of distinct planes. This can cause in the example of a dot map to display too much information and leaving the user with no knowledge to be gained from the map. To help with this interactive maps should be time bound. Users of Opencrimemapping.org are able to switch between time periods to obtain knowledge.

\par Time in most visualization methods is considered linear. Most visualizations that incorporate time do so based on a timeline [7]. Actions in time can occur in cycles. With burglaries in Dallas weekdays display higher densities of instances than on weekends.

\par In crime mapping, victims, offenders, and property managers adjust densities over time around specific places. Using the drop down to select different years on our tool the user can see differences in density as displayed in figure 1. The user can recognize that less burglaries happened in 2017 verse prior year in 2016.

\begin{figure}

\includegraphics[width=0.85\textwidth]{timeFigA.png}

\caption{This dot map has been zoomed in a location in Dallas with a high density of burglaries. Using the drop-down button the user is able to see the difference in density from one year to the other.} \label{fig.1}

\end{figure}

\subsection{Interactivity}

Growth in computer processing speed and Internet technologies have help lead the to the growth of interactive map availability, design and consumption. Cartographic interaction is the use of a digital map by a user facilitated by a computer. This creates a dialog between user and map.

\par Maps manifest themselves as knowledge from the mapmaker about the map's variable of interest. The goal of a map whether successful or not is the transfer of geographic insight from the mapmaker to the map user [8]. In User-Centered Design for Interactive Maps: A Case Study in Crime Analysis by Roth et. al. an interactive framework for maps is presented in which focuses on the needs of the user when conceptualizing and implementing an interface [9]. This application focuses heavily on ease-of-use. The User-Centered Design (UCD) framework is designed around three U's.

\par \textit{Usability} describes the ease of using an interface to complete the user's objective. Opencrimemapping.org's user interface is set up from Shiny. Through Shiny we provide tools for the user to select through parts of framework. We use a drop-down button, so the user can move through periods of time easily. The user is also has the ability to pan, zoom in and zoom out with the map displayed in figure 2. We also provide the user with the ability to hover-over specific instances. When the user hovers-over they are presented with more detailed information about the incident.

\begin{figure}

\includegraphics[width=0.85\textwidth]{interactiveFigA.png}

\caption{This heat map uses Shiny to create interactive interfaces so users can select different periods of time by selecting the drop down button on the upper right.} \label{fig.2}

\end{figure}

\par The usefulness of an interface for completing the user's desired task is called utility. \textit{Utility} taxonomy essentially breaks down to identifying one data element. Opencrimemapping.org uses color themes that are well thought out to ensure a user can find data elements on a map. The second taxonomy of utility is being able to search for information through space and time to help answer "when" and "where" questions.

\par Finally, to complete the UCD loop is the \textit{user}. The targeted user is often not an expert in the field that the tool focuses on. Target user's needs will change over time and cause an iterative process in designing a user interface. This application did not use a formal research method to identify user needs. Instead our tool was developed through a qualitative process of trial and error with users that were not part of the tool's development.

\subsection{Color}

Thematic maps through history have used color to communicate activity within a geography. With early maps the information was imprecise. The imprecise nature of maps led map makers to choose between pictorial or abstract representation of more accurate data[10]. Color in early maps was more colorful than in early production maps when printed color had limited selection of color mixes. By the 19th century printing improved enough to allow expansion in the role of color again [10].

\par The start of modern color in thematic maps can be traced to Jacques Bertinâs 1983 Book “Semiology of Graphics”. Bertin presents the goal of giving the reader of a map a clear visual indication of what is happening on the surface of the earth [11]. One way this is accomplished is through using color to show the difference between entities.

ColorBrewer developed by Mark Horrower and Cynthia Brewer in 2003 helps in choosing appropriate color schemes for mapping needs. The authors point out that choosing color schemes can be very difficult when designing thematic maps. Most GIS software have color schemes, but they don’t provide direction on the use of color.

\par When a thematic is displayed on a laptop LCD it may not print the same way. The ColorBrewer system suggest color schemes if an agency needs to have the maps available through multiple media types. There is a total of 35 color schemes or sets. They are divided into three groups: qualitative, sequential and diverging. Sequential schemes work well when order is needed in data from low to high. Diverging colors are good for separation variables. Qualitative color schemes use differences in hue to create a set that does not imply order [12]. In opencrimemapping.org we use a diverging scheme two show the difference between residential burglaries and business burglaries on a dot map shown in figure 3.

\begin{figure}

\includegraphics[width=0.7\textwidth]{colorFigA.png}

\caption{This dot map uses diverging colors selected from ColorBrewer.org to display different burglary types. The color selection in this map also takes advantage of ColorBrewer's option for managing color blindness.} \label{fig.3}

\end{figure}

\par Colors in thematic maps also need to take into consideration users with impaired color-vision. Pastel like colors were found to be more confusing to color-vision impaired users than darker colors. This is an important consideration to consider when in a group of 25 at least one person is likely to be color-vision impaired [13].

Finally, color selection needs to take into account considerations such unintended bias. When mapping crime data using a color scheme that may match skin tones could create a perception that areas may be more heavily populated by a specific ethnicity.

\par It’s important that the map maker make a careful and well-thought-out choice in the data colors that are displayed on a map. Failure to do so could lead to the user not gaining new information from the map.

\subsection{Base Map Selection}

A basemap is GIS data that has been planimetrically corrected. A planimetric image has had the effects of tilt and perspective removed and only displays the horizontal surface features of the Earth's surface. The basemap is what we think of when we imagine the boundary lines defining countries and states, it provides the setting. A basemap can be as simple as a few boundary lines. However, with GIS technology base maps can include intricate details about natural and cultural surface features.

\par Leaflet maps use 'tiles' like most digital maps\footnote{Using Basemaps, Leaflet for R, https://rstudio.github.io/leaflet/basemaps.html} . Tiles are individual map images that are joined along invisible seams when called. This preserves computational efficiency while enabling zoom. The process of building a map in Leaflet is described as stacking layers. For example, the first layer is the generally the base map so markers showing the location of police stations would be layered on top. This layering capability provides flexibility to selecting a basemap because even basemaps can be layered together assuming a level of opacity is used to allow the bottom basemap to show through the top basemap.

\par With Leaflet one does not need to build their own basemap, but that is still an option. Leaflet provides pre-designed basemaps created by Leaflet as well as third parties that can be printed to a screen in 3 lines of code or less\footnote{Leaflet-providers preview, Leaflet, http://leaflet-extras.github.io/leaflet-providers/preview/index.html}. There are many impressive open source basemap tile designs available. Before choosing a basemap for crime display it is important to ask, "Who are these maps for and how will these maps be used?" and to remember that the quality of these maps also reflects on the LEA as a professional entity. The 1999 U.S. DOJ publication Mapping Crime: Principle and Practice, described the process of using maps as creating abstractions of reality. As the abstraction increases the further from reality we move. However, abstraction allows a complex story to be told simply [DOJ]. The process of selecting a basemap is a balance between abstraction and reality. The goal of police transparency revolves around telling what is true as best as possible. Transparency also depends on the ability of citizen users to understand. The figure below shows a basemap of Dallas, TX that has a watercolor design and a basemap that has a more realistic topographical details. While the watercolor map is appealing, it does not allow a user to easily determine locations of interest in Dallas. On the other end of the spectrum, a basemap could potentially show so many details that when using the zoom feature incident depictions get easily lost in the chaos. For example, a web-based test of basemap usability conducted by KoneÄnÃœ et al. found that all tasks completed with a topographic basemap took longer to complete and suggest that topography can be cognitively challenging [15]. Ultimately, the selection of a basemap should minimize frustration for the user.

\begin{figure}

\includegraphics[width=0.85\textwidth]{baseMapFigA.png}

\caption{These basemaps illustrate artistry verses clarity in the selections of basemap options within Leaflet.} \label{fig.4}

\end{figure}

\subsection{Map Types}

There are a variety of major map types that can be used to display crime incidents. Digital maps can be extended well beyond push pins in a hanging map. In combination, map types can paint both images of individual incidents and overall trends. If not carefully constructed, digital crime maps can also be misleading.

\subsubsection{Dot Maps}

Dot maps are a traditional mapping style where each dot represents a discrete object. Dot maps can be effective at showing where individual crime incidents occur and the distribution of many incidents across space.

\par Individual dots will be most accurately represented using a coordinate system such as latitude and longitude or state coordinates. When using data from different sources it is essential to use a single coordinate system. State coordinates cannot be accurately placed on a map developed using latitude and longitude because state map coordinates represent physical distances on the ground.

\par Dot size is also important. Dot sizes too large can oversaturate a map and lead to lots of overlap. Dot sizes too small can be hard to perceive. On the other hand, larger dots may be preferred to obfuscate the exact location of incidents. If a dot overlaps a few residencies rather than pointing to a single residence it will offer some protection of privacy to victims and/or accused. If a formal algorithm for selecting dot size is not used, it is best to compare several dot sizes to determine the most accurate and useful representation of a single incident. With leaflet, dot sizes can increase upon zoom to retain their relative size to the geographical area they represent. This is an important feature to have so that upon closer inspection the location of a single dot still appears to be in the correct coordinate space.

\par Dot maps can be used to look for trends. If dots are displayed with opacity, it is possible to see density more clearly for highly populated maps or maps with strong clustering. The patterns in a crime map are both an important investigative tool as well as possible source of misleading information. A cluster of incidents may appear to be a hot spot, but they may also represent a more highly populated area [Mapping Crime: Principle and Practice https://www.ncjrs.gov/pdffiles1/nij/178919.pdf].

\par Dot maps can be used to look for trends and patterns. If dots are displayed with opacity, it is possible to see density more clearly for highly populated maps or maps with strong clustering. The patterns in a crime map are both an important investigative tool as well as possible source of misleading information. A cluster of incidents may appear to be a hot spot, but they may also represent a more highly populated area [Mapping Crime: Principle and Practice https://www.ncjrs.gov/pdffiles1/nij/178919.pdf]. Dot maps are advantaged because they can display segments of incidents or totally distinct incidents. Crime maps often include an assortment of icons to map many distinct types of incidents. The limitation of mapping many incident types at once is over saturation. The time frame for a map may need to be significantly reduced to fit many types of incidents onto a map. Furthermore, many incident types can be so busy it is difficult to interpret the map or use it as an investigative tool.

\begin{figure}

\includegraphics[width=0.85\textwidth]{dotMapDrawbacks.png}

\caption{This dot map shows the challenge of balancing appropriate dot map size in both a zoomed-out and zoomed-in view.} \label{fig.5}

\end{figure}

\subsubsection{Cluster Maps}

Cluster maps are an extension of dot maps. Cluster maps represent the collection of incidents for defined surrounding areas. Cluster maps are more computationally efficient than dot maps. With Leaflet, a cluster is labeled with the number of incidents represented within each single cluster. A mouse over effect allows the user to highlight the area captured by a single cluster. When a cluster is clicked on the map zooms in toward the area captured by the cluster and pulls smaller clusters and individual markers out of the first cluster. Figure 6 shows the mouse over effect and the 'spiderfy' effect of clusters as the zoom increases.

\begin{figure}

\includegraphics[width=0.85\textwidth]{clusterMaps.png}

\caption{The left cluster map shows the mouse over feature in leaflet that highlights the area captured by a cluster. The right cluster map shows a zoom view with smaller clusters and some individual markers representing single incidents} \label{fig.6}

\end{figure}

\subsubsection{Heat Maps}

Heat maps in simple terms are fluid density projections placed on top of a basemap to indicate where incidents are most clustered. Heat maps use colors to represent a scale of numbers. Usually, as colors become darker they represent increasing numbers. A heat map is useful for a big picture view of the distribution of a single type of incident. If incidents are combined for a density analysis they should be related or grouped together and defined as a larger category.

\par Heat maps are considered distinct from hot spot maps. Heat maps do not use statistical significance to distinguish between density. Hot spot maps are projected into polygons that represent statistically different densities. When using a heat map it is important to consider this difference because there is a greater potential for misrepresenting data. If a density projection is too dark it may overemphasize crime incidents and if a projection is too faint it may be difficult to find any patterns.

\subsection{Variable Selection}

The selection of variables to be represented in crime maps for the public is a business problem. Police departments serve as public safety agents and crime maps are an extension of this service and a peek into the role of the police department. To continue along the theme of trust and legitimacy, departments should consider asking citizens what types of crimes they are interested in. They should also balance sensitivity. Some crimes, such as those related to sexual offenses or offenses involving children need more privacy and careful consideration before being shared with the public.

Also, the display of multiple incidents at once may imply to the user that they are related in ways that they may not be. The correlation between incidents of specific types may be legitimate, but if causation or further research into correlations is not well understood the public interpretation could be incorrect.