Enhancing GeoHealth

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Enhancing GeoHealth: A step-by-step procedure for spatiotemporal disease mapping

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Abstract

Cartography, or geographical visualization of disease is an essential aspect of the field of GeoHealth, yet there is limited guidance on the visualization of spatiotemporal disease maps. In order to adequately contribute to understanding disease outbreaks, disease maps should be crafted carefully and according to relevant cartographic guidelines. This article aims to increase the understanding of space-time visualization techniques that are relevant to the field of GeoHealth, by providing a step-by-step framework for the creation of space-time disease visualizations. This study introduces a systematic approach to spatiotemporal disease mapping by integrating operations from the Generalized Space Time Cube (GSTC) Framework with established cartographic symbology guidelines. This resulted in an overview table that contains both the relevant GSTC operations and cartographic guidelines, as well as a step-by-step procedure that guides users through the process of creating informative spatiotemporal disease maps. The practical application of this step-by-step procedure is demonstrated with an example using Dutch COVID-19 data. By providing a clear, practical step by step procedure, this study enhances the capacity of public health professionals, policymakers, and researchers to monitor, understand, and respond to the spatial and temporal dynamics of diseases.

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Introduction

The practice of mapping disease data has a long history, serving as an essential element in the field of epidemiology and public health. From John Snow's iconic cholera map in the 19th century, which revolutionized our understanding of disease transmission and spatial epidemiology, to contemporary digital disease surveillance, mapping infectious diseases has been pivotal in identifying outbreaks, understanding their spread, and informing public health interventions. This historical context underscores the critical role that disease mapping plays in safeguarding public health and the continuous evolution of methods to improve its quality and usefulness. The recent COVID-19 pandemic highlighted concerns within the field of GeoHealth, with the large outburst of disease maps. This discourse on disease maps has shown that many attempts at disease mapping have not fully realized their potential (Mooney & Juhász, 2020). Disease maps should serve the purpose of clearly conveying information about health concerns to the public and of providing policymakers with a reliable basis for informed decision-making.

Human infectious disease outbreaks are always occurring within a specific spatio-temporal context. These contexts can vary from a short, localized outbreak to global multi-year pandemics. This affects the process of disease mapping, as something that works in one specific context does not automatically work in another. The spatial and temporal trends in disease maps are relevant, but creating a practical disease map that includes space and time dimensions is challenging. Although there are publications on how to map the spatial dimension of disease and the temporal dimension of spatial phenomena, there is limited attention for effective methods to map spatiotemporal trends of disease outbreaks. The available literature on spatiotemporal disease patterns mainly concerns different analysis methods. The visualization aspect of spatio-temporal disease patterns requires more attention.

During the COVID-19 pandemic, sharing available data in interactive dashboards, animated maps, or data viewers has become increasingly common. These tools can provide great insights and allow for data exploration. However, there are also downsides. The interactive and animated maps are often: "Data Rich but Information Poor" (DRIP). These DRIP maps leave the reader in charge of seeking meaning in the data and interpreting the patterns. Mooney and Juhász (2020) commented on the emergence of these online applications for data exploration. They concluded that many web maps in the early stage of the pandemic were incorrectly using mapping techniques, inadequately classified data, and ultimately were poorly designed. Related to this is the research by Zhang (2021), who found that COVID-19 visualizations are shared not just by governments or public health institutes but primarily by news outlets, independent media, corporations, and social media. These visualizations are thus far-reaching and have broad audiences, highlighting the importance of guidance in spatio-temporal disease mapping. Alongside the dashboards and animated maps, many of the published COVID-19 visualization were static maps, due to the limitations for animation in printed media such as newspapers and journals. These static maps, which aim to show spatio-temporal relationships, will be the focus of this paper.

When creating a disease map, as with all maps, many aspects influence the design. Some essential elements are the *mapping purpose*, *map users*, *user environment,* and *data characteristics* (Kraak, 2014). The map's purpose relates to its usage or the questions it aims to answer. For disease maps, these purposes can vary from monitoring or analysing patterns to predicting disease progression. The map users of disease maps can differ extensively. Doctors and other medical personnel, policymakers, and even the general public all get in contact with disease maps. The place where the maps are used varies as well. Policy-making departments, disease control institutes, newspapers, and social media are the environments in which these disease maps are discussed. It is essential to design the map for the intended target audience. Still, mapmakers should be aware that their map might end up in different contexts, such as on social media or in a newspaper. The final aspect that influences the map design is the data characteristics. In disease mapping, a yearly dataset of cases per country will result in a different map compared to a dataset with individual case points within a city.

Both space and time are of great importance in mapping infectious disease data. It is thus vital to enhance the knowledge of effectively combining these dimensions in a map. In this paper, we aim to increase the understanding of space-time visualization techniques that are relevant to the field of human infectious disease and provide guidelines for creating space-time disease visualizations. This will be achieved by using the Generalized Space Time Cube Framework (GSTC) framework. This framework, developed by Bach *et al.* (2016), assists in the understanding of spatiotemporal data. It provides operations that, combined with existing rules on cartographic compilation, will provide structure and guidance to the creation of spatio-temporal disease maps. In the next section, the relevant literature on both space-time mapping and disease mapping will be discussed. Additionally, the GSTC Framework and the cartographic guidelines relevant to spatiotemporal disease mapping will be introduced.

Space-time mapping

A substantial body of literature is devoted to temporal mapping, of which several key papers will be discussed chronologically. Space-Time mapping emerged at the end of the twentieth century, mostly due to advances in computer technology. Increased computational power allowed for research on larger datasets that included time. Berry (1964) pioneered time geography, as he was among the first to display time on an individual axis, giving it an equal place alongside the spatial dimension. This marked a shift in the handling of time in geography, as time was suddenly viewed as equally important to attribute and space. Tobler (1970) was one of the first to use the computer when mapping time. In his seminal paper on population growth in Detroit, he mapped different stages of Detroit's population. In 1990, Mark Monmonier published an article on the visualization of geographic time-series data, in which he described various techniques for creating time maps, many of which are still used regularly today (Monmonier, 1990). One of the mapping techniques he described is flow maps, also known as line maps, which show progress or direction over time using lines and arrows. Another map type Monmonier described is chess maps, a series of maps showing different time frames. Monmonier also discussed change maps, which show temporal progression as a rate of change in a single map, as well as mapping animations and interactive maps. In the 1992 book: 'Time in Geographic Information Systems,' Gail Langran identified four major classes of temporal mapping techniques: 'Time sequences,' 'Change data,' 'Thematic symbol maps' and 'animations,' which are very similar to the techniques described by Monmonier (1990), indicating a standardization within the field of time mapping (Langran, 1992). At the end of the twentieth century, substantial efforts were made to conceptualize time in GIS, for example, by Donna Peuquet (1994), who introduced the Space-Time Prism framework, a framework for understanding time in relation to space, founded on the research by Hägerstrand (1970). The next major advancement in space-time geography was the practical application of the Space-Time Cube in GIScience by Kraak (2003). The Space-Time Cube is built upon the concept of the space-time prism by Hägerstrand (1970), where individual time series could be mapped in a conceptual space-time framework. The Space-Time Cube was instrumental in the growth of time mapping due to technological advances making it possible to compute these Space-Time Cubes relatively easily. Another progression in time mapping in the early 2000s was the advancement of animated and interactive maps. Increasingly complex and sometimes interactive spatiotemporal maps were being published and becoming available to growing audiences. In more recent work, Zhong *et al.* (2012) highlighted the most important static visualization techniques for spatiotemporal data. They identified temporal symbology, such as timestamps and time labels, the usage of lines for flow rates, image series, and the Space-Time Cube to be the most relevant for mapping spatiotemporal data. In 2019, Rodrigues et al. presented an overview of guidelines for the creation of interactive space-time maps. They identified four important guidelines that deal with the temporal structure, the spatio-temporal changes, the focus of the visualization, and the scale of the data (Rodrigues *et al.*, 2019). These guidelines will be described in more detail here. The first guideline is about the Temporal Structure, which is based on work by Aigner *et al.* (2011). Three types of temporal structures are identified: *ordered time, branching time, and multiple perspectives.* Within ordered time, events occur linearly, from past to present. Branching time consists of a temporal structure where alternative scenarios are considered individually. Multiple perspectives entail a structure where multiple scenarios are happening simultaneously. The second guideline on spatio-temporal changes is based on work by Andrienko *et al.* (2003), which identifies three types of changes: existential, spatial, and thematic. Existential changes are changes characterized by the appearance and disappearance of data, e.g., infection cases. Spatial changes are represented by changes in spatial attributes, such as location, volume, or shape. In thematic changes, values or attributes are changing. The third guideline is about data representation, which is based on work by Peuquet (1994). This guideline centres around the question whether the focus of the visualization is on a certain object in space-time, a location in space-time, or the moments that certain objects appear at certain locations within space-time. The fourth guideline, based on research by Andrienko *et al.* (2010) is on the spatial and temporal scale of the data. On the temporal scale, it is important to know whether the data is collected in e.g. hours or months and if the data are collected as points or intervals. On the spatial scale, it is important to know the extent of the spatial scale. These four guidelines by Rodrigues *et al.* (2019) provide great insight into the important aspects to consider when dealing with spatio-temporal data.

Generalized space time cube framework

In this study, we use the Generalized Space Time Cube framework, a framework for temporal data visualizations created by Bach *et al.* (2016). Central to this framework is a conceptual 3D space-time cube. Within this framework, all data that consists of three dimensions can be visualized within this conceptual 3D space-time cube. An example of a conceptual 3D Space-time cube is presented in Figure 1. In this figure, the dimensions of space and time are shown. The conceptual space-time cube is relevant for many data types, but in this paper, we will investigate its usability with the visualization of spatiotemporal disease data. For example, data on a month-long disease outbreak in a country can be visualized as a 3D space-time cube. The data structure affects how this cube's inner structure looks. Aggregated regions with case data result in a different inner structure compared to GPS logs of individual infected persons. In Figure 2A, examples of different inner structures are shown. With the data conceptualized as a 3D cube, it is possible to conduct operations on this cube. An example of an operation is taking a 'Time Slice'. In the case of a month-long disease outbreak in a region, a time slice could be a map of cases on a single day, see Figure 2B. In this framework, all visualizations of (spatial-) temporal data are different combinations of operations on this conceptual 3D cube. A visualization of a human infectious disease outbreak, thus, consists of multiple operations on the conceptual 3D cube. The GSTC framework is a broad framework applicable to all data sources with at least three dimensions. The framework can thus be applied in various fields, such as information visualization, cinematography, or economics. Since we focus specifically on using the GSTC framework in the visualization of spatio-temporal disease data, the dimensions in the GSTCs in this article are space, time, and disease. It is important to note that the generalized space-time cube is a conceptual starting point, which does not mean the visualizations have to be displayed on an actual space-time cube. The cube is simply the framework on which all transformations are made and where all visualizations can be traced back to.

Disease mapping

There is a large body of research on mapping health and disease. In this section, some key works on disease mapping will be discussed. In their introductory textbook on health geography, Hazen & Anthamatten (2011) describe three types of commonly used thematic health maps. First, point maps, which can be further divided into point distribution maps, dot density maps and graduated symbol maps. Point distribution maps highlight the distribution of the data, often individual case data. Dot density maps appear similar to point distribution maps but differ in that points do not indicate the actual location of the data but represent the density of cases. Regions with more cases will have a higher density of points, which allows the reader to see patterns on the map based on the density of points. Graduated symbol maps, or proportional symbol maps are maps that incorporate an additional dimension. For example, the size of the symbols, often points, can be increased based on the value attributed to the points. Second, line maps, which can be subcategorized into flow maps and contour maps. Flow maps use line symbols, where the lines represent direction or flow rate. Contour maps use isolines to highlight areas with similar values, often using interpolation techniques. Finally, area maps are the last type of disease maps, of which the choropleth map is the most commonly used type. Choropleth maps are a popular mapping type when dealing with data that is aggregated or collected in administrative units. By classifying the data, in combination with visualization techniques such as colour usage, varia-

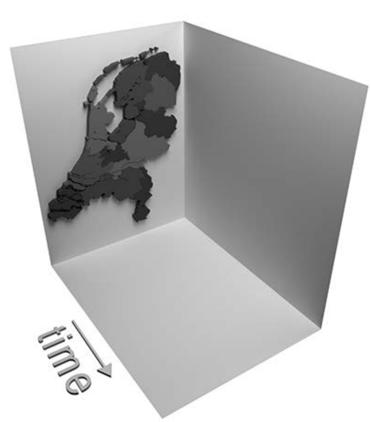

Figure 1. Conceptual space time cube.

tions between administrative units can be observed. These different mapping types are identified as common disease mapping tools by other scholars, *e.g.*, Carroll *et al.* (2014), Cromley & McLafferty (2011), and Souris (2019).

GSTC framework operations

The GSTC framework consists of many operations, not all relevant for space-time disease mapping. In Figure 3, all operations categorized by Bach *et al.* (2016) can be seen. The framework consists of four categories of operations: *extraction*, *flattening*, *geometric transformations,* and *content transformations*. Extraction is the selection of a part of the space-time cube, for example, extracting a GPS trajectory of a single respondent. Flattening is the reduction of a dimension, for example, visualizing a 3D space-time trajectory on a 2D plane. Geometry transformations are operations on the spatial scale without changing the content, and content transformations are operations that transform the content without changing the geometry. These last two categories are, in the context of map making, closely related to cartographic operations such as changing the map scale or projection, and symbology. There is, however, a difference between changing the symbology or geometry within a map or changing the sizing of the different map frames that together make up the visualization. The former is considered within the cartographic guidelines, the latter is part of the GSTC Framework. Within all these categories, there are distinctions between operations on the spatial scale and the temporal scale. For example, flattening operations can reduce a 3D space-time trajectory into a 2D spatial object or a 2D temporal object. When the GSTC is used to create maps, the spatial aspect remains constant because the spatial axis is predefined by the goal of creating a map. For example, when the goal is to make a disease map of an outbreak in Germany, it is irrelevant to take a 'space cut', as this would result in the temporal progression of the disease in a specific slice of the country. When creating a disease map, creating a spatial 2D representation of the conceptual 3D Cube is ultimately the goal. This means that all operations that extract or flatten the spatial scale or extract data in a non-planar manner are not relevant. Therefore, only the operations that are suitable for the creation of a map are considered here. These relevant operations are highlighted in green in Figure 3. It is important to note here that this is a general framework which, to the best of our knowledge, contains all relevant operations. However, there are various other operations that can affect the visualization through changing the geometry or attributes of the data itself, such as the reclassification of attributes,

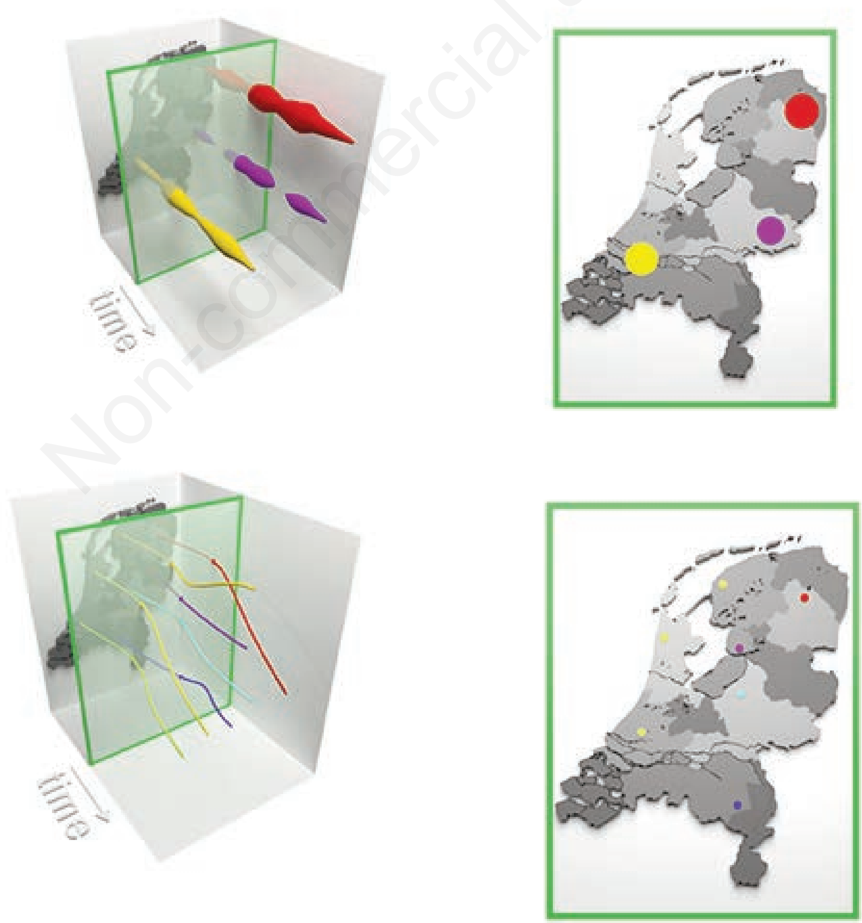

Figure 2. A) Two examples of different inner structures of Conceptual Space-Time Cubes: individual trajectories and aggregated data; **B**) Time slices of the Conceptual Space-Time Cubes in green.

or the generalization of geometry, but these types of operations are not part of the GSTC Framework and thus are not within the scope of this article.

Guidelines for symbolization

When making any map, attention should be paid to cartographic aspects such as visual balance, map projections, or cartographic elements such as a north arrow. These cartographic principles are explained in detail in *e.g.* Buckley *et al.* (2022) or Kraak & Ormeling (2020). All general cartographic aspects of map-making need to be accounted for when creating disease maps, but certain elements require specific attention. The GSTC Framework assists in the understanding and selecting data, yet it is not concerned with the choices made within these visualizations. Cartographic guide-

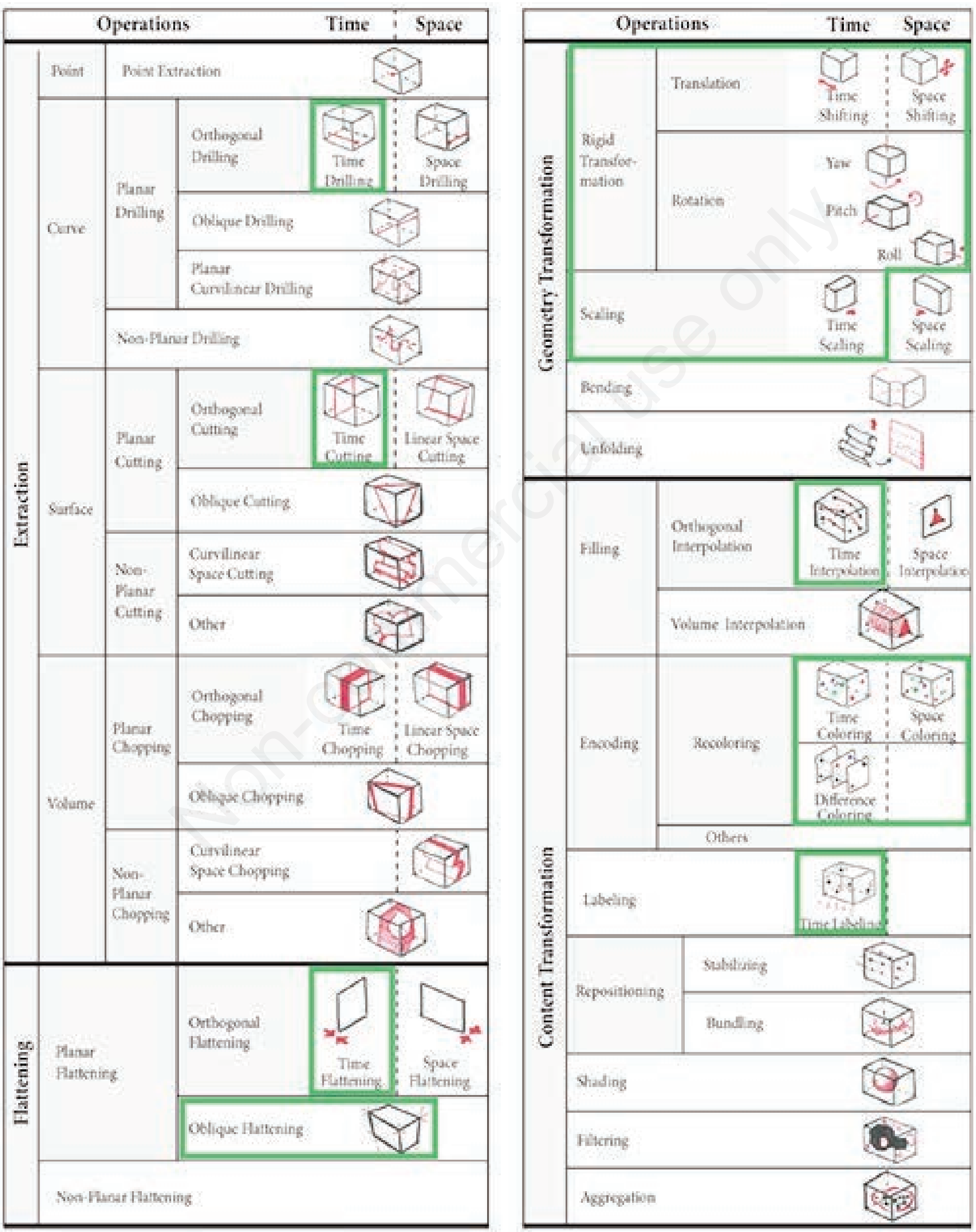

Figure 3. Operations GSTC. Operations relevant to creating static spatiotemporal disease maps are highlighted in green. This figure was adapted from Bach *et al.* (2016) and used with permission from the authors.

lines on symbology should be considered to ensure that the GSTC framework's output is mapped adequately. For this, the cartographic guidelines on symbology by Kraak (2014) will be considered. Central to these cartographic guidelines on symbology are the six visual variables, originally identified by Jacques Bertin in 1967: *Size, Value, Texture, Colour, Orientation & Shape* (Bertin, 1967). These visual variables are the different aspects that a map-maker can adjust to change the symbol's meaning. These six visual variables have specific use cases and are relevant for particular data types. These use cases apply to all kinds of data and symbology, but we will explain them and link them to disease mapping. According to Kraak (2014), different visual aspects work better in certain use cases. *Texture*, *value,* and *size*, primarily suitable for quantitative data, work best with visualizations that show ordering or distance, such as the chronological development of a disease outbreak through a region. Additionally, *Size* helps show proportionality within the data. For example, to highlight differences over time in the number of disease cases, the symbol size can be increased proportionally to the increase in cases. *Colour, orientation*, and shape are suitable for the symbolization of qualitative data and work well for the differentiation of data. For example, to differentiate cases of different diseases or disease types on a map by giving every case of a specific disease or type a particular colour. An overview of the various visual aspects, with the best use cases for different types of symbology can be found in Kraak (2014, p 67.)

Materials and Methods

This study introduces a systematic approach to spatiotemporal disease mapping by integrating operations from the Generalized Space Time Cube (GSTC) Framework with established cartographic symbology guidelines. Our method is designed to enhance the clarity, understanding, and analytical depth of disease maps, addressing the challenges of visualizing complex health data over time and space. This results in an overview table that contains both the relevant GSTC operations and cartographic guidelines, as well as a step-by-step procedure that is demonstrated with a practical example.

Selection of GSTC operations

The GSTC Operations will be selected based on their relevance for map visualization. This means that only operations suited for visualization on the spatial dimension will be included. In practice, this means that the operations that are categorized by Bach et al. (2016) as operations on the temporal dimension will be selected, see Figure 3. The only exception to this rule is the exclusion of 'Time Chopping', a process similar to time cutting, but resulting in a three-dimensional output, which is not suitable for the visualization on a 2D map. Other operations that are conducted on the spatial scale, or a combination of both the spatial and temporal scale, do not result in outputs that can be visualized on a 2D map and will thus not be included in the table.

Integration with cartographic guidelines

The next step is to link the GSTC operations with the various symbology types, to see which symbology is best suited for every GSTC operation. To provide suitable symbology types for the GSTC operations, the GSTC operations were matched with the different use cases as described by Kraak (2014), being: *order*, *distance*, *proportionality* and *differentiation*. This match was based on the common use cases in cartography, based on cartography literature where this is described in more detail, e.g.: Kraak & Ormeling (2020), Calvo *et al.* (2023), Pena-Araya *et al.* (2019) and Buckley *et al.* (2022).

Step-by-step procedure and practical application

A step-by-step procedure, derived from the integration of GSTC operations and symbology guidelines, guides users through the process of creating informative spatiotemporal disease maps. To demonstrate the practical application of this procedure, we present a case study using daily COVID-19 cases in the Netherlands. These data contain the daily and cumulative number of cases per municipality in the Netherlands, from the first of October 2021 until the 31st of March 2022. These data originate from the official register of COVID-19 infections in the Netherlands, maintained by the National Institute for Public Health and the Environment (RIVM, 2024).

Results

Different GSTC Operations and cartographic guidelines on symbology

The combination of the GSTC Framework and the cartographic guidelines are displayed in the Supplementary Table 1. In this table, the different GSTC Operations and cartographic guidelines on symbology are linked. The table contains the following information. The first four columns are related to the GSTC Framework and display the categories of GSTC operations, the relevant operations, a description of these operations and a practical application of these operations. The final three columns are related to the guidelines on symbology and show different use cases for these operations, relevant symbol types and examples of related aspects of symbology.

Step-by-step procedure

In Figure 4, the step-by-step procedure is displayed. It shows the different steps required to create understandable and replicable disease maps. The GSTC Framework and the cartographic guidelines on symbology are shown as input for steps 2, 3 and 4. To highlight the usage of the procedure, the different steps will be described.

Step 1 is to identify the purpose, or the goal of the map. Identifying the goal of the map is an essential part of the mapmaking process and influences the possibilities in the later steps.

Step 2 is the conceptualization of the data as a GSTC. This is achieved by identifying the different data dimensions of the conceptual GSTC: time, space and disease. The spatial dimension consists of a spatial grain and a spatial extent. The temporal dimension consists of a temporal extent and temporal intervals. The disease dimension is related to the structure of the data, for example individual data points or aggregated cases. It is possible that the data does not allow for the creation of a map with the intended goal. In this case, the map-maker should try to find a different dataset which can help achieve the intended purpose. This is indicated in Figure 4 by the dashed line.

Step 3 is to select relevant operations that will contribute to achieving the goal. These operations can be selected using the overview in Supplementary Table 1. By selecting appropriate operations in this table, the relevant data can be extracted from the original dataset.

Step 4 is to visualize the data according to the cartographic guidelines on symbology, also visible in Supplementary Table 1. The intended usage of the map influences the choices in symbology.

Example using COVID-19 data for the Netherlands

In this example, the step-by-step procedure will be followed in order to demonstrate the process of spatiotemporal disease mapping, in a structured manner.

Step 1: Identifying the goal of the map. In this example the goal is to monitor the temporal development of cases in the different municipalities in the province of Groningen, the Netherlands.

Step 2: conceptualize the data as a GSTC and identify the spatial extent, spatial resolution, temporal extent, temporal intervals, and data structure. The spatial extent is the province of Groningen, the spatial resolution is the municipalities in the province of Groningen, the temporal extent is the total time period of six months, and the temporal interval is monthly. The data structure is monthly cases.

Step 3: Select relevant operations. The goal is to monitor the temporal development of cases per municipality, which puts the focus on the individual municipalities. The full temporal extent is

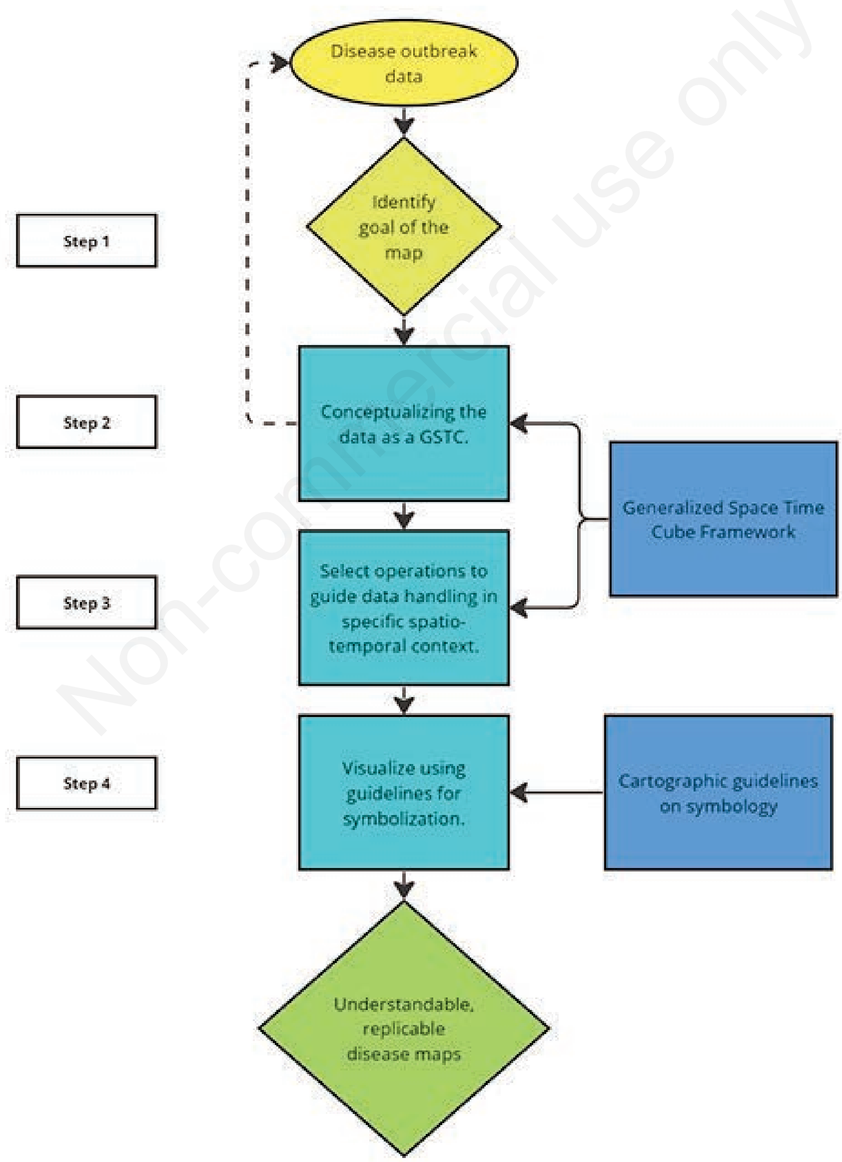

Figure 4. Step-by-step procedure.

relevant to visualize, which makes 'time drilling' a valid operation. These time drills need to be rotated towards the viewer using the 'Rotation' operation in the category Geometry Transformation.

Step 4: Symbolizing the selected data. In the case of this map, there will be one symbol in every municipality representing the temporal progress of the region. The goal of the symbology is to show ordering. There are various options for the symbology here, such as graphs, bar charts, or pie charts. In order to adequately compare the municipalities on the temporal trends, a bar chart will be selected. An example of a mapping result is provided in Figure 5.

Discussion

In this study, we engaged with both the fields of time mapping and disease mapping to understand the different techniques and guidelines in practice in both space-time mapping and disease mapping. The motivation for this study was the limited available guidance on visualization within the field of spatio-temporal disease mapping. The field of spatio-temporal disease mapping is mainly concerned with specific analysis techniques and there is limited attention for data visualization. There was a need for guidance in the visualization of space-time disease data for multiple reasons. First, as we saw during the COVID-19 pandemic, there was an explosion of data visualizations. Second, not all of these visualizations were crafted carefully. The interactive maps and visualizations were sometimes described as Data Rich but Information Poor (DRIP), leaving the reader in charge of identifying what is important.

Our study presented a step-by-step procedure for the creation of spatiotemporal disease maps. This step-by-step procedure was created by combining relevant aspects from the GSTC Framework, in combination with cartographic guidelines on symbology. It is important to note here that the step-by-step procedure does not result in one uniform map and there are many ways in which the goal of a map can be achieved. However, the value of this step-by-step procedure is in the provided structure under which this map is created, as it is based upon a good understanding of the data structure and guided considerations of different options within the different steps of the map-making process.

The GSTC Framework is a framework that is suited for the visualization of all kinds of data. Due to the relevancy of the space-time cube to the field of mapping, it is very well suited for the representation of geographical temporal data. By selecting the relevant operations for mapping disease, the framework became a

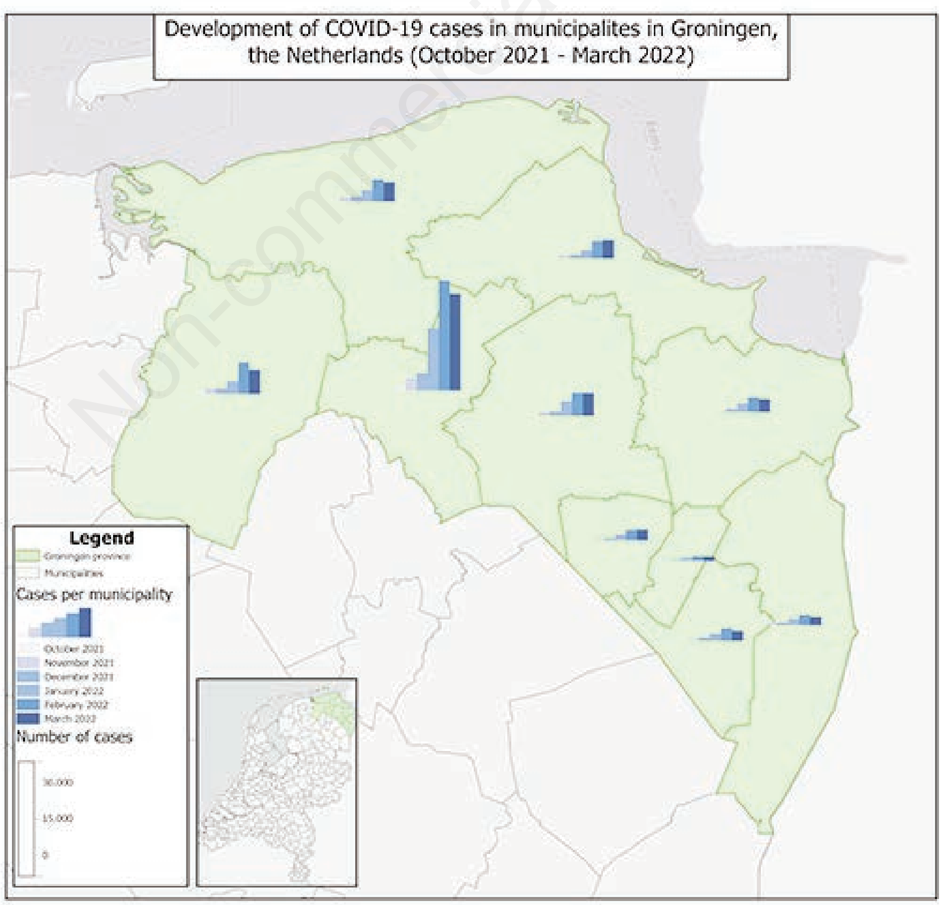

Figure 5. A Example map created using the step-by-step procedure.

valuable tool for understanding and selecting spatiotemporal data. However, more than conceptualizing the data and utilizing the GSTC operations is required to create understandable disease maps, as specific visualization requirements have to be met when creating maps. To address this, we made use of the cartographic guidelines on map symbology. The GSTC framework combined with the guidelines on map symbology resulted in a step-by-step procedure to guide the visualization of spatiotemporal disease data.

Another relevant aspect of the GSTC Framework is that it can be applied to existing visualizations. Analysing existing visualizations through the lens of the GSTC Framework makes it possible to identify the different operations that make up the visualization. This can be beneficial in understanding how a disease map was made and what aspects were deemed necessary during the creation of the map. Another relevant aspect of the framework is that it moves away from nomenclature. Instead of using names like 'chess map' or 'flow map', it is possible to distinguish different visualizations by naming the individual operations of the visualization. This article provides guidance for the visualization of spatiotemporal disease data in a static map. Conversely, in recent years there has been a large increase in the number of interactive online disease maps, mainly due to the COVID-19 pandemic. There are downsides to interactive maps, such as potentially suffering from the 'DRIP' syndrome, as mentioned by Mooney and Juhász (2020). On the other hand, interactive or animated maps are being applauded (Lan *et al*., 2021). Research that compared interactive animated maps with static maps found that both had different strengths. For example, Andrienko *et al.* (2010), found that static maps were more suited for identifying spatial patterns, while animated maps were better in observing changes and events. Additionally, Boyandin *et al.* (2012) found that static flow maps were useful in identifying patterns over long time periods, while animated maps were useful in identifying patterns between subsequent years. Ultimately, the choice between creating an interactive or static map should be informed by the intended purpose or goal of the visualization. The step-by-step procedure presented in this article can contribute to the creation of clearer and more insightful spatiotemporal disease maps.

Conclusions

This study has successfully established a comprehensive step-by-step procedure for the creation of spatiotemporal disease maps, effectively integrating the GSTC framework with established cartographic guidelines. Our approach addresses a critical gap in the field of GeoHealth— the challenge of visualizing complex disease data in a manner that is both informative and accessible to diverse stakeholders. By providing a clear, practical step-by-step procedure, this study enhances the capacity of public health professionals, policymakers, and researchers to monitor, understand, and respond to the spatial and temporal dynamics of diseases. By facilitating the creation of clearer, more insightful spatiotemporal maps, our methodology aids in the early detection of disease outbreaks, the monitoring of disease spread, and the assessment of public health interventions. Further research could explore the integration of additional datasets, such as demographic and socioeconomic data. Additionally, the benefits and opportunities of interactive visualizations could be explored.

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Online supplementary materials

Supplementary Table 1. Overview table of relevant GSTC Operations and symbology guidelines.