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# Syphilis Trigram: a domain-specific visualisation to combat syphilis epidemic and improve the quality of maternal and child health in Brazil

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RESEARCH

# Syphilis Trigram: a domain-specific visualisation to combat syphilis epidemic and improve the quality of maternal and child health in Brazil

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**Abstract**

**Background:** The Brazilian health system is a large and complex system, especially considering its mixed public and private funding. The number of syphilis cases has been increasing greatly in the last four years, even though it has a cheap and simple treatment. Syphilis notification is compulsory by law, and public health surveillance pays great importance to syphilis notification during pregnancy. Syphilis infection can cause severe newborn conditions, premature births, and abortions.

**Methods:** The Action Research methodology was applied to deal with the complex syphilis surveillance reality in Pernambuco, Brazil. Iterative learning cycles were used, totalling six cycles with a formal validation of an operational version of the Syphilis Trigram visualisation at the end of the process. The original data source was analysed and prepared for use without any new data or changes in the ordinary procedure of the current system.

**Results:** The main result of this study is the Syphilis Trigram, a domain-specific infographic for presenting gestational and birth data. The second contribution of this study is the Average Trigram, an organised pie chart which synthesises the Syphilis Trigram relationship in an aggregated manner. Both visualisations are presented in an Infographic User Interface, a tool that gathers an infographic broad visualisation sense for data visualisation. These interfaces also gather selection and filter tools to assist and refine the presented information. The user can experience a specific case-by-case view and an aggregated perspective by any city monitored by the system.

**Conclusions:** The proposed domain-specific visualisation amplifies the understanding of each syphilis case and the overall case characteristics of a city. This new information produced by the Trigram can clarify the reinfection/relapse cases, optimise resource allocation, and enhance syphilis healthcare policies without any new data. Therefore, health surveillance professionals can see the broad tendency, understand the key patterns through visualisation, and take action in a feasible time.

**Keywords:** syphilis; congenital syphilis; data visualisation; poverty

## Introduction

Sexually transmitted diseases (STDs) are considered a public health problem and are among the most common transmissible diseases [1], negatively affecting people's quality of life and health. Among them, syphilis is a systemic infection exclusively caused by the bacterium *Treponema pallidum*, transmitted in three ways: sexual,

congenital, or via blood transfusion. Sexual transmission is predominant [2], followed by congenital, which is the result of the transmission of *Treponema pallidum* present in the bloodstream of the pregnant woman to the conceptus via the placenta or, occasionally, through direct contact with the syphilitic lesion at the time of delivery.

The adverse outcomes of untreated gestational syphilis are early pregnancy loss (4%), foetal death (11%), and preterm or low weight (12% to 13%). Furthermore, at least 20% of newborns have signs suggestive of early congenital syphilis [3]. In newborns, congenital syphilis can manifest either early or late. The main consequences of early congenital syphilis are preterm and low birth weight, in addition to various skin lesions, periostitis, radiographic abnormalities, limp pseudoparalysis, and respiratory distress. On the other hand, in late congenital syphilis, symptoms appear after the second year of birth and, in this case, owing to the longer development time of treponemas, more tissue and bone damage and cognitive losses may occur, such as saber blade tibia, Clutton's joints, Olympic forehead, saddle nose, deformed upper middle incisor teeth (Hutchinson's teeth), blackberry molars, short jaw, raised palatal arch, interstitial keratitis, sensory hearing loss, and learning difficulties [2].

Congenital syphilis is very much combated precisely because of these severe consequences in newborns. In addition to being a condition with easy and accessible treatment, it is objectively eradicable. The increase in the number of tests, especially in primary health care (PHC), after 2017, allowed a better understanding of the scenario of gestational and congenital syphilis in Brazil. According to the Syphilis Epidemiological Bulletin 2020 of the Ministry of Health of Brazil [1], Brazil has been facing a syphilis epidemic since 2016, despite being a treatable disease with an affordable and low-cost medication, such as penicillin. In 2019, the syphilis detection rate in Brazil was 72.8 cases per 100,000 population; the detection rate of syphilis in pregnant women was 20.8/1,000 live births, the incidence rate of congenital syphilis was 8.2/1,000 live births, and the mortality rate from congenital syphilis was 5.9/100,000 live births [1]. According to the Epidemiological Bulletin, in the last ten years, there has been a progressive increase in the incidence rate of congenital syphilis: from 2.1 cases/1,000 live births in 2009 to 8.2 cases/1,000 live births in 2019. Recife had the highest incidence rate in 2019 (with 25.6 cases/1,000 live births), a rate three times higher than that in Brazil (Figure 1). Based on the rate of mortality because of congenital syphilis in children under one year per 1,000 live births, Pernambuco appears in the 7th place, at a rate of 7.2 (Figure 2).

Despite the numbers presented and unlike many neonatal infections, congenital syphilis is a preventable condition, as long as the pregnant woman is identified (through effective prenatal care) and appropriate treatment is carried out. According to Macedo et al. [4], "with relatively simple and oriented interventions for the case of mothers and newborns, it is possible to obtain a great reduction in congenital syphilis".

In this context, it is necessary to create and update public policies in the area of maternal and child health to improve this scenario. There have already been several efforts by public administrators at different levels to reduce maternal and child deaths . Among these efforts, there are specific guidelines for assistance to pregnant women with syphilis (and other STIs) in PHC. An example is the *Mãe Coruja Pernambucana* Program (PMCP) [5], a Brazilian social program of reference in the

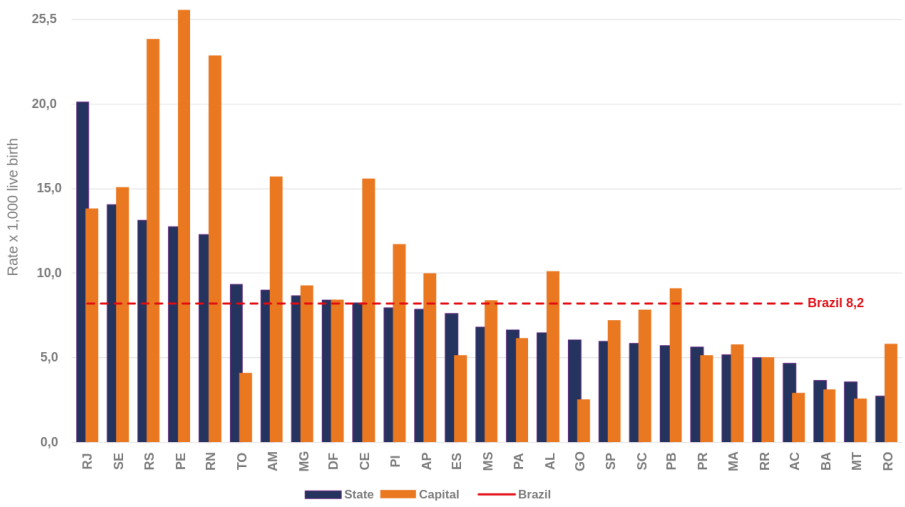



**Figure 1** Incidence rates of congenital syphilis (per 1,000 live births) in 2019.

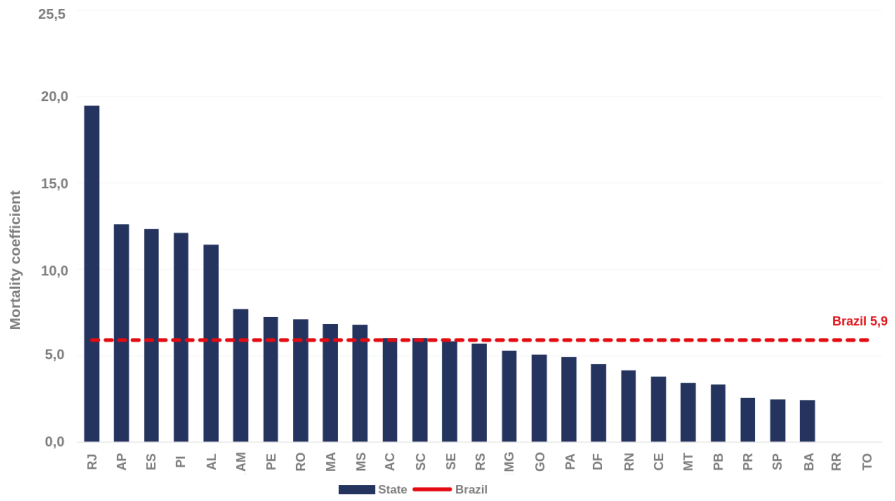



**Figure 2** Infant mortality rates due to congenital syphilis (per 1,000 live births) in 2019.

maternal and child area, implemented in October 2007, recognised and awarded by the United Nations (UN) and the Organization of American States (OAS), as a public policy management model. The PMCP is a priority program of the government of Pernambuco, which aims to ensure comprehensive care for pregnant women using the Unified Health System (SUS) and their children up to 5 years of age, creating a solidarity network to reduce maternal and child mortality, in addition to contributing to the improvement of social indicators. Currently, the PMCP is present in the 105 most vulnerable municipalities in the state of Pernambuco[1].

[1]https://maecoruja.pe.gov.br/cantos-mae-coruja/

However, the scarcity of communication and information channels, and the existence of stigmatisation by the society about STIs, especially in the context of vulnerable populations, weakens awareness and access to preventive measures and, consequently, to treatment for these diseases. According to Macedo et al. [4], "among the sociodemographic factors, low education, low income, and material status (stable or non-stable union) are identified as risk situations and an expression which syphilis is related to poverty, although it is not limited to it". Additionally, although the rapid test for syphilis is available free of charge to the entire Brazilian population [6], its scarcity in PHC is common and can contribute to masking the real number of positive diagnoses and, consequently, to a decrease in the number of people who should be under treatment and follow-up [7].

According to Santos et al. [7], knowing the trends in syphilis and identifying the main factors related to PHC and the sociodemographic structure of a locality can guide new strategies for health promotion and disease prevention, as well as direct resources that significantly influence the reduction of a possible epidemic. In this way, the main goal of this study is to present the Syphilis Trigram, a visualisation system that represents the narrative of an individual pregnant woman with syphilis. The solution offers quality information for analysis, comparisons with a short learning curve, providing inputs to improve the care of pregnant women, and to understand cases of reinfection, recurrence, or lack of exams. Moreover, the Syphilis Trigram is applicable to data provided by the PMCP without the need to add or modify the primary data.

## Methods

### Context and data

Initially, the data set used in this work was composed of information from four cities of Pernambuco (Aliança, Araçoiaba, Bonito, and Petrolina) from 2016 to 2017, with 1,552 records of pregnancies and 10,185 records of prenatal care. To study the scalability of the solution, another data set covering all cities of Pernambuco served by the PMCP was made available. This dataset contained information from 2016 and 2017 of 43,938 pregnancies with 217,444 prenatal care, 39,309 births, and 38,559 children.

### Action Research methodology

This research was conducted using an Action Research methodology approach [8]. Among the various methodological views of the Action Research, the chosen one was proposed by Peter Checkland, the Soft System [9]. It is a methodology for the analysis and development of systems in which researchers and stakeholders participate jointly in the process of designing and developing the system in an iterative manner. The soft system appears as an alternative to the systems engineering concept of hard systems. Hard systems are systems which, given an explicit definition of an objective, the conceived system will be engineered for that particular purpose under various constraints (budget, legal, environmental, etc.). In many scenarios, this approach can be applied to troubleshooting. However, real-world systems with multi-layered processes, such as SUS, are much more complex. Another factor for choosing the soft system methodology is its integrated relationship with human actors in the systems. For Checkland [8], there is a special kind of system, the human

activity system, which is intrinsically linked to human action and so cannot be reduced in its complexity to create a model. Systematic human action, as in a health system, does not behave like a natural or autonomous system.

The analysis for this study is based on Checkland's iterative learning cycles [8], and the activities of each cycle are presented in Figure 3. Initially, it is necessary to produce a clear picture of the business process. This is a multi-perspective system analysis with a diagrammatic system representation called "rich picture" as the output. Some root definitions have been proposed, representing a core need to meet an actual and specific systematic complexity. After this cycle, researchers and stakeholders build together a concept model for the system. This model was validated formally and within its interaction with other related systems. Further, the model is compared with the initial state of the problem and validated if it fits the overall needs of the system. At the end of each cycle, there is a small output (new product, tool, or concept) that helps to solve the issues elucidated in the previous cycle. Therefore, this new reality (a new rich picture) is the input for the next cycle.

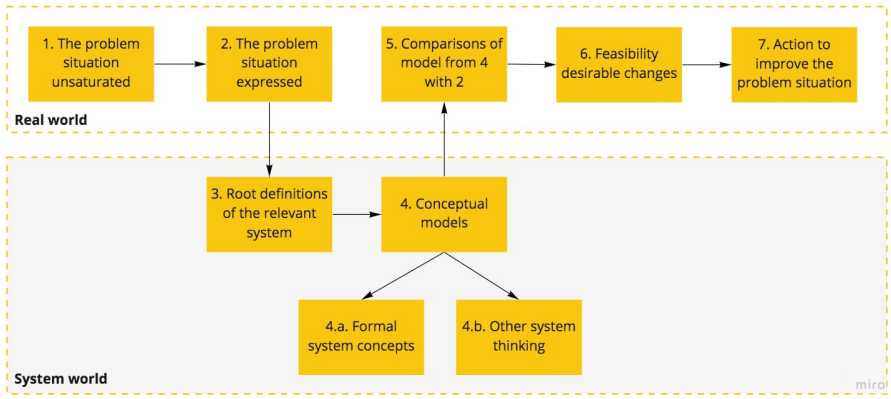



**Figure 3** Activities of cycles. Adapted from McManus [10].

Figure 4 presents the six learning cycles resulting from the interaction between researchers and stakeholders to elucidate and solve the target problem. Each cycle has its specificity and own contributions.

### 1st Cycle - Data understanding

The first iterative development cycle started with a wish-to-change. This was followed by a stage of description and presentation of the problem and context to understand the entire relationship between the use and roles of the stakeholders. This stage was built using two strategies: a CATWOE analysis to create a root definition and a mind map of hierarchy relations called a rich picture [11].

CATWOE is an acronym for customers, actors, transformation processes, weltanschauung, ownership, and environmental constraints. These elements must be contained within a root definition so that throughout the development process, it is clear who it is intended for and who evaluates any system resource. The CATWOE defined for this first cycle is:

- **(C) Customers:** pregnant women attended by PMCP;

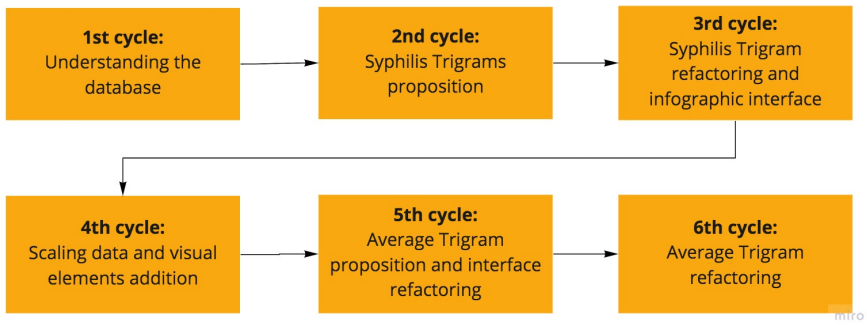



**Figure 4** Software System iterative learning cycles.

- **(A) Actors:** regional and board managers of PMCP;
- **(T) Transformation:** acquire more information for decision-making in actions to combat syphilis within the scope of PMCP;
- **(W) Weltanschauung:** consider the board managers and data analysts, who have a different view of what the problem is and how to select the data;
- **(O) Owner:** board managers of PMCP;
- **(E) Environmental constrains:** do not restructure the database or collect new primary data.

Therefore, we summarise these elements of CATWOE in the following root definition, defined with the stakeholders: "*Create a visualisation system that interprets the current data of pregnant women with syphilis from the PMCP, segmented by social and context variables (gestational risk, age group, race/colour, education, income, place of residence, type of population, among others) for production of quality information, without the need to add or modify forms or primary data, for analysts and the board of the PMCP, to help the decision-making to improve the care of pregnant women*".

The main contribution of this investigation is the identification of the variables correlated with the appearance of syphilis in pregnant women assisted by the PMCP; in particular, to understand which factors could be more important for the initial detection of syphilis and faster care for pregnant women with an indicated profile, based on sociodemographic data.

A rich picture is the strategy of an organic mind map of hierarchies and power relations in the organisational environment. It should be organic by definition and should not be based on visual models of formal diagrams. In Figure 5, we represent the PMCP domain, where an important characteristic is that the action is performed by the basic health network. The PMCP team is composed of an articulator and a healthcare agent who do not work directly in health care. In addition, the PMCP has hierarchies from the community centre to the board of the program.

Accordingly, based on the definition of the root definition, the analysis of data from a sample of the SIS-MC (the database from the PMCP that uses PostgreSQL) began. The initial sample had data from four cities (Aliança, Araçoiaba, Bonito, and Petrolina) from 2016 to 2017, with 1,552 records of pregnancies and 10,185 records of prenatal care.

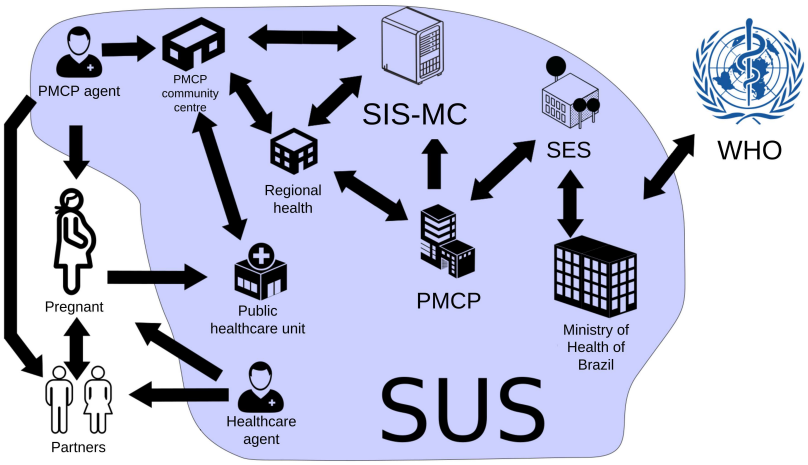



**Figure 5** Rich picture of PMCP domain. Source: author.

However, even during the conceptual modelling process, it is necessary to create a new root definition. As an alternative, it focused on visualising data that had a certain level of completeness (greater than 70% of recorded data), which could be supported by the syphilis test data, both during pregnancy and at delivery. Therefore, a new root definition version presented to the stakeholders was: "*Create a visualisation system that represents the PMCP narrative about pregnancy with syphilis without the need to add or modify forms or primary data for the analysts and the board of the PMCP, to help the decision-making to improve the service to pregnant women*".

The addition of the narrative concept was crucial in the development of this cycle, as it changed the perspective of punctual information (like in reports with simple queries) to an interrelationship between present and absent data. Focusing on the perception of the pregnancy narrative, we focused on adjusting and recognising the missing data as information to be considered.

The main contributions of this first cycle are as follows:

- Understanding the database and its filling characteristics, data quality, and evolutionary history;
- Understanding that it is not always possible to answer all the questions initially elucidated in the root definition as the quality of data available for analysis must be assessed;
- Understanding the health domain of the PMCP, especially about specific terms and meanings.

### 2nd Cycle - Syphilis Trigram proposition

From the results of the data preparation from the first cycle, the process of selecting SIS-MC data for visual representations was started with the main focus on understanding syphilis cases. Data selection and categorisation depend on the presence of syphilis in some pregnancies until the outcome. The main expected contribution of this cycle is the application of domain data for a visualisation that represents the dynamics of syphilis.

The elements of the CATWOE analysis remain the same as in the first cycle and the following root definition was defined: "*Define a visualisation that represents the narrative of the individual data of pregnancies present in the PMCP database and produce quality information that allows comparison and with a short learning curve*".

The purpose of this iteration is to show, through visualisation, an individual narrative of pregnancies. This visualisation should serve to understand or signal cases of reinfection, recurrence, or not performing sufficient examinations. Based on this definition, several visual forms of data representation were analysed, and a Trigram was proposed.

### 3rd Cycle - Syphilis Trigram refactoring and infographic interface proposition

The third iterative development cycle focuses on visualisation, as isolated Trigrams were not a tool for analysis. A graphical interface that grouped the Trigrams and had filter tools would be necessary. In addition, the usability issue in the accessibility aspect should be included in the visualisation. Therefore, in this third iterative development cycle, the following root definition was agreed: "*Improve Trigrams, making them more accessible and with less eyestrain, and develop a Graphical User Interface (GUI) that supports them and allows refinement of information and filters, with easy comparison and a short learning curve.*".

The main contributions of this cycle were as follows:

- Creation of the Trigrams results matrix to represent the number of cases according to the Venereal Disease Research Laboratory (VDRL) results at birth and the mother's last test;
- Development of the first version of the GUI containing the Trigrams and the Trigrams results matrix;
- Trigrams improvement with colour adjustment, which is better for people with colour vision problems, and mild intensity to prevent eyestrain.

However, in the evaluation, it was noticed that the data provided did not have enough scale to explore and challenge the model proposed by the Trigrams. The number of occurrences was too low (n=21) to challenge the view scale. After the approval of this first prototype, it was agreed to expand the database with a larger segment of the SIS-MC database.

### 4th Cycle - Scaling data and visual element addition

This cycle begins with the availability of a more complete SIS-MC database for study, intending to validate whether the visualisation is scalable. Therefore, the data analysis process was restarted, now with a range of data covering all cities served by the PMCP in the years 2016 and 2017. The amount of data available for analysis jumped from 1,552 pregnancies to 43,938 pregnancies, with 217,444 prenatal care, 39,309 births, and 38,559 children in the new database made available by the PMCP. With the increase in the data scale, it was necessary to reassess the quality of the data proposed for visualisation. Thus, the following root definition was agreed upon: "*Improve Trigrams through greater use of data, develop and validate its graphical interface allowing system actors to produce quality information, easy to compare, and with a short learning curve*".

Thus, the main contributions of this cycle were as follows:

- Pre-processing of the new database with a larger number of cases for analysis and visualisation;
- Addition of a new element to the Trigram to represent the gestational age at delivery, and the division of the Trigram into trimesters;
- Adaptation of the GUI to accommodate more viewing data, resulting in a density reduction with interface elements and addition of navigational elements.

### 5th Cycle - Average Trigram proposition and interface refactoring

After increasing the scale of the data, the visualisation system was validated to be closer to the actual use of stakeholders. The suitability of Trigrams to increase the data scale raises the need for new data selection, grouping, and analysis tools. In this cycle, new ways to expand the infographic space for information production will be developed. In addition, the language applied to visualisation was not coherent with the common domain of the PMCP, as assessed in the previous cycle. The adjustment of the representation language for the domain was considered during the process of specifying the root definition of this cycle. The method of visualising the data impressed the stakeholders, but the noise of the terms caused many problems in the evaluation. Thus, the following root definition was defined with stakeholders: "*Propose a data visualisation of a location that maintains the Trigrams narrative, but in a grouped manner, and standardise the terms of all interfaces with terms close to the PMCP domain.*".

The main contributions of this cycle were as follows:

- Change of terms that define the lack of data to a language closer to the reality of the stakeholders;
- Proposition of the Mean Trigram to connect, compare and synthesise the mean distribution of the narratives of three variables relevant to the context: first test, last test, and test in childbirth;
- Graphical interface update with new elements, such as year selector and Average Trigram.

During the assessment, the relationship between prenatal care and the impact on syphilis care increased. One of the premises of PMCP is to encourage an increase in the amount of prenatal care. In the infographic interface, viewing the relationship between successful or unsuccessful narratives and the amount of prenatal care would be important information for the stakeholder analysis.

### 6th Cycle - Average Trigram refactoring

In this iterative cycle, the greatest demand is an adjustment of the mean Trigram for greater accuracy of the data representation. Another increase in visualisation is the relationship between prenatal care and the narrative of syphilis examinations. It is necessary to evaluate the profusion of elements at the interface to avoid adding noise. The mean Trigrams present an improved analysis of the data, but it is necessary to validate their accuracy and reliability for representation. The root definition defined in this cycle was: "*Improve the Mean Trigrams and the infographic view as a whole, considering the representation of prenatal care within the infographic interface.*".

The main contributions of this cycle were as follows:

- Visualisation of prenatal care in the series of Trigrams, allowing comparison between test results and care for pregnant women; and

- Improvement of Trigram to visualise the information about the latest syphilis exams.

## Results

Considering the multivariable nature of pregnancy and the need raised by the CATWOE analysis presented in the first cycle, an infographic perspective was chosen for the visual representation of this system. Infographics are diagrammatic representations of data [12], which are more complex than a series of data displayed together or a story presented through images. In essence, an infographic representation has a distribution for each piece of information that has a purpose and meaning within the visual space [13]. Furthermore, infographics have an exploratory nature through interaction, which is one of the main goals of data visualisation [14]. One of the elements favoured by interactive infographics is dual cognitive experience. The human brain responds well to the simultaneous use of motor (hands) and visual (graphics) elements simultaneously in the same context [15] [16]. The consciousness part (vision-to-perception) and call to action (vision-to-action) are activated simultaneously in infographic interfaces. This dual mental stimulus is especially useful in systems that rely on high specificity and precision from users, such as healthcare systems. The ability to communicate large amounts of data and multiple variables visually, and allow exploration is critical to the greater usefulness of a healthcare system, enabling the end-user to notice events and act as desired in a complex data environment [15].

Based on the three pillars of data consistency, relevant statistics, and design, we defined the following principles for the infographic visualisation system:

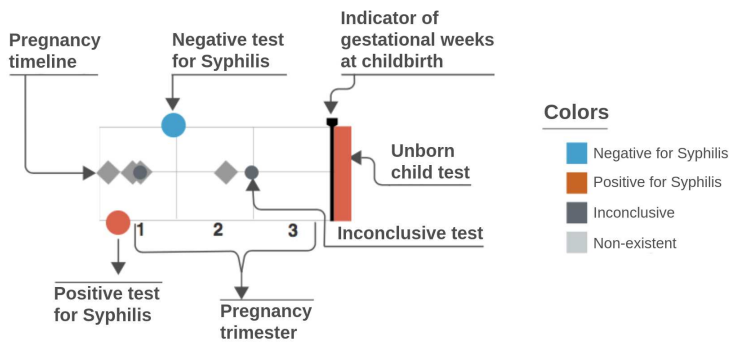
1. The data must be appropriate to the user in terms of relevance, quantity, and temporality;
2. The infographics must allow for accurate comparison in the same viewing context;
3. The design narrative must be consistent and meaningful throughout the infographic;
4. The infographic must allow the user to explore, expand and compare data and information in the same interface;
5. The infographic visualization system must allow refinements to a level of data that the user wants to see, according to their context of use, allowing new visualisations and analysis.

### The evolution of the Trigram

Based on the principles presented above, an adequate representation of the problem domain called **Trigram** was proposed, as shown in Figure 6. Trigrams are an infographic representation of the narrative of pregnancy through a time series. Each Trigram presents a comparable view of pregnancy in relation to syphilis, considering tests and outcomes. By definition, it is a multivariate and interactive series that visually compares data from pregnancy.

The Trigram was inspired in the form of a musical pentagram, and each element represented in the time series was positioned horizontally in time in relation to the birth date and gestational weeks. On these lines, circles are positioned vertically

**Figure 6** Visual structure of the Trigram.




related to the result of the pregnant woman's syphilis tests, and can be classified as positive (circle positioned in the first line, from the bottom to the top), unavailable/null (second line), or negative (third line). The second line of the Trigram is also used as a basis for prenatal care using diamonds. This representation proved to be resilient; they could be occluded by the examination, but they did not lose time series information. They can be grouped and, even with a few days of difference, they still show the quantity and its value in the time series.

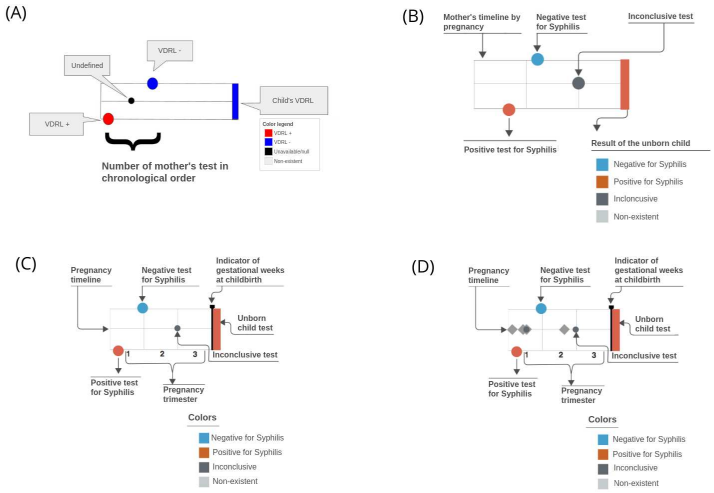
At the end of the time series, there is a rectangle that represents the result of the outcome, indicated by a colour, to reinforce the meaning and facilitate the user's reading. The line with a small arrow pointing downward represents the gestational age at delivery to assess the loss or not of the gestational age. Within pregnancy care, the loss of gestational days or weeks is valuable information to guide the action of health care. A loss can severely impact the development of unborn children [17].

The Trigram series is divided into three parts, each representing a trimester as the Ministry of Health of Brazil [18] recommends that the first syphilis test be performed in the first trimester of pregnancy and another one is repeated at the beginning of the third quarter if there is no positive. In particular, the third trimester test focuses on reducing vertical transmission (mother-to-child transmission). Thus, users of the visual system can easily measure and compare the ratio of examinations within a significant time series for the monitoring of pregnant women.

However, the final design of the Trigram shown in Figure 6 was based on cycles, as described in the previous section. Figure 7 shows the evolution of the Trigram.

Several improvements were made during the development of the Trigram. For example, in the third cycle (B), the colour pattern was adjusted. The chosen colours are safe for people with colour vision problems and have a soft intensity to avoid eyestrain. Positive tests for syphilis are coloured orange-red, negative light blue, and undefined dark grey. When endpoints are classified as non-existent, they are coloured in light grey. To make it easier to read and reduce the learning curve, a Trigram colour and reading legend were added.

**Figure 7** Evolution of the Trigram versions. Source: author.




Therefore, a visual solution was designed that was easy to learn, was part of a common user repertoire (music), and supported the multivariable and temporal complexity of the data, allowing for quick comparison and interpretation of a pregnancy. One of Trigram's visual advantages is the composition of the pregnancy narrative. Previously, through the existing systems in the PMCP, the reports showed whether syphilis was present in a given pregnancy but did not indicate when or how many times per pregnancy or if there was reinfection, which are important information for health surveillance. With Trigrams, it became possible to evaluate this narrative construction of pregnancy in relation to syphilis, including mapping optimal, ideal, and undesirable situations.

## Evolution of the Mean Trigram

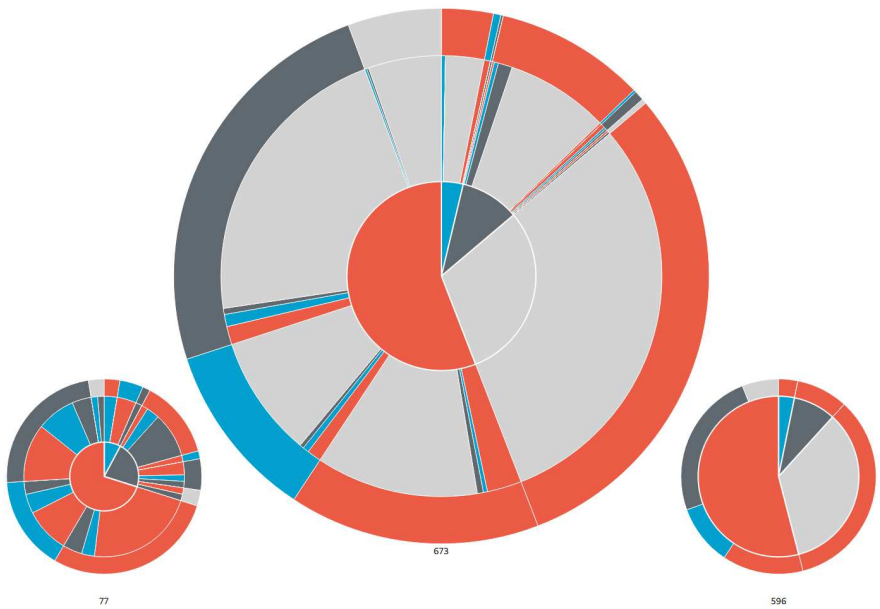
The grouped view facilitates the choice of data observation. It is difficult to obtain a general idea of a city from the individual Trigrams presented previously. The major challenge is how to represent it in a clear, comparable way and with the refinement needed by users. In the proposed Trigrams, the temporal representation of the exams helps to understand the relationship of the pregnancy narrative, considering reinfections, false negatives, and even care failures. For an aggregated view, it is important to maintain this structure, which presents the narrative of outcomes.

After studying the technical manuals for notification and surveillance of syphilis [18] and [19], it was determined that the grouped view should understand the last phase of the narrative from pregnancy to the outcome. One of the main actions proposed by the visualisation system is to reduce the number of cases of congenital syphilis. Analysing the first and last exams during pregnancy would be a way to see how the treatment occurred during prenatal care. If the first test is positive for syphilis, it is expected that there will be another test with a negative result. Moreover, if the last test was positive, there was a high chance of having congenital syphilis. Thus, concentrating on these two variables would enable a grouped synthesis of pregnancy. To close the entire narrative, the outcome must be represented.

One of the expressive results of the assistance policy for pregnant women is the result of the test during childbirth. A positive test can indicate a lack of assistance, relapse, drug resistance, or even false negatives. Thus, the visual representation must contain at least these three variables (first test, last test, and test at delivery) to synthesise the narrative of the Trigrams with the coarsest granularity.

The visual composition of a pie chart with three concentric rings is called the **Mean Trigram** (Fig 8). The main idea of this visual element is to synthesise the average distribution of the narratives among the three variables analysed. Each sector is coloured with the same Trigram colour palette and has the same meaning as the exams. The innermost circle represents the pregnancies, the intermediate represents the latest exams, and the outermost circle represents the outcome.

**Figure 8** Mean Trigram expanded with two Mean sub-Trigrams. The mean Trigram on the left represents pregnancies that have more than one test, and the right one only represents pregnancies with one test. Source: author.




The central mean Trigram is the mean Trigram of the location and year chosen by the user. The lower mean sub-Trigram on the left represents a segment of pregnancies that have more than one test. The lower mean sub-Trigram on the right represents those who only have one test (that is why there is no intermediate ring between the pregnancy test and the outcome). Note that the number of pregnancies for each chart represents a different amount. The ideal is when the majority of the cases are in the Mean sub-Trigram on the left, which is not the case for the analysis of the presented sample.

The central part of the chart is sectioned between mothers with at least one test confirming syphilis (represented in red) and mothers who do not have tests that confirm syphilis (represented as blue, in the absence of a positive test for syphilis), but in both cases, the mothers had syphilis. These two initial sectors are directly

related to their outcomes, represented by the outermost ring. Thus, pregnancies with positive tests for syphilis are subdivided into an outcome with a positive test for syphilis, an outcome with a negative test for syphilis (ideal), an inconclusive outcome (with no data in the system), and no information (there is no record of the outcome in the database).

The sector of mothers who do not have a positive test for syphilis (blue sector in the middle of the mean Trigram) is defined by its outcome, and so all outcomes have a positive test for syphilis. Therefore, this group is also syphilitic, defined by the outcome at the time of delivery, owing to the absence of positive tests before pregnancy.

Finally, for the intermediate sector between pregnancies and outcomes, for each outcome section, there is a representation for the last exam. Thus, it can be observed whether a pregnancy that started as positive for syphilis had the result changed before the outcome or if this situation was confirmed. In the case of mothers who did not have a positive test, the greatest information comes from false negatives (represented by blue), inconclusive data (dark grey), and lack of prenatal tests (represented by light grey).

Section (A) of Figure 9 represents a case in which the mother had the first positive test, and irrespective of whether she had a second positive test, the test at delivery was negative. Thus, it shows the number of mothers who were assisted by the health system but did not have a test to confirm the treatment. Section (B) of Figure 9 represents a Trigram that has no test. This category was a domain discovery learned during the generation of the mean Trigram. A large group of mothers did not have any tests registered during pregnancy, but the test at birth indicated that they had syphilis. Section (C) of Figure 9 shows a case in which there is an inconclusive outcome record for a pregnancy that had one or more positive tests for syphilis. Section (D) of Figure 9 represents a false negative, serologic scarring, or infection very close to delivery. Thus, despite having a test that is proven to be negative for syphilis, the outcome has an unfavourable result, with a positive test for syphilis.

One of the characteristics of the mean Trigrams, in addition to the narrative and quantitative representation, is the power of comparison. The mean Trigram allows comparison between regions and rapid assessment of the results of public policies over a given period of time. Thus, it serves as a tool for individual and comparative evolution (benchmarking). In Figure 10, there is a comparison between the mean Trigrams of the state of Pernambuco, by years and in total years with the city of Recife.

Note that, despite the different sample quantities, it is possible to evaluate the distribution of cases, considering the chosen time interval. A noteworthy piece of information is the increase in the number of false negatives (a negative test before delivery positive for syphilis). This is exactly a differential feature between non-treponemal (rapid test) and treponemal tests. Non-treponemal tests within the syphilis treatment protocol [19] should be used for initial screening in pregnant women but confirmed with other treponemal tests. Therefore, this section of the Trigram points to false negatives of rapid tests and, at the same time, the possible lack of tests with a more accurate technique.

**Figure 9** Reading of the Mean Trigram. Each transverse slice represents one or more Trigrams according to the three analysed variables. Source: author.

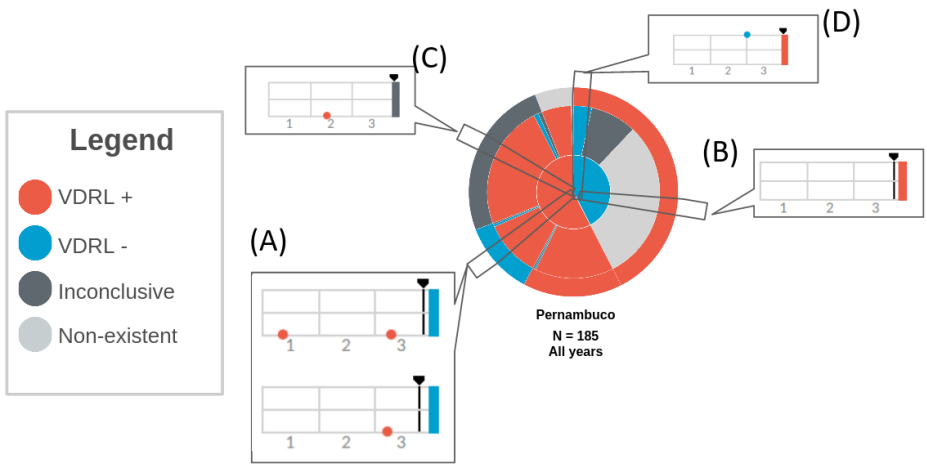
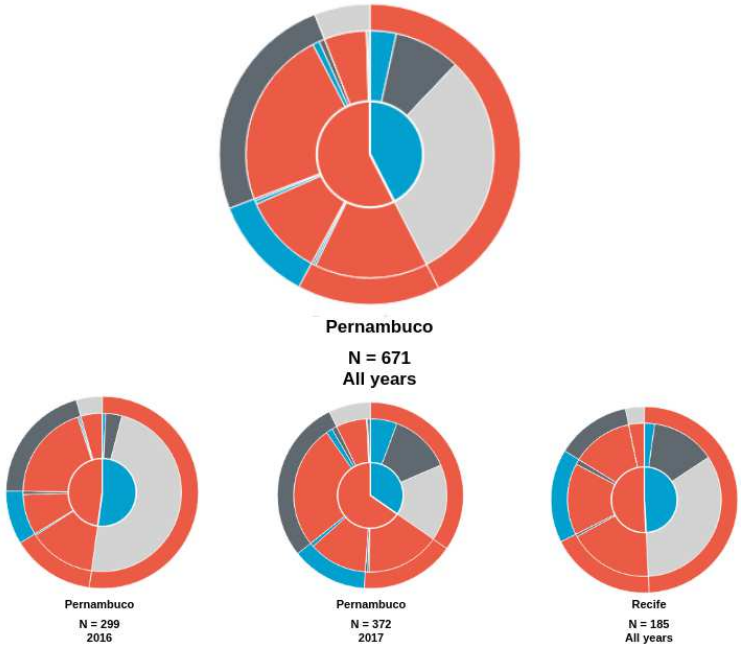



**Figure 10** Comparison between Mean Trigrams of the State of Pernambuco, for different years and the city of Recife.

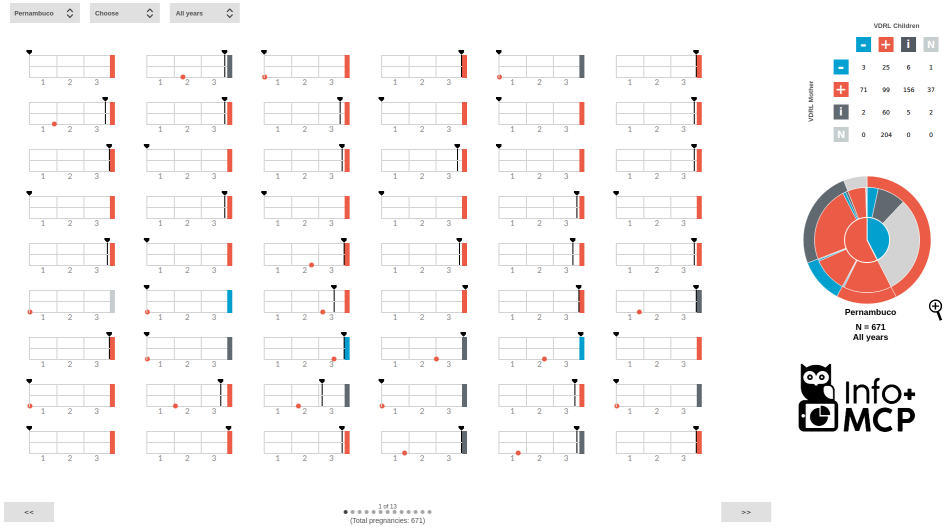



## The evolution of the User Interface

The complete infographic interface is shown in Figure 11. A year selector was used to segment the data for visualisation. The user can filter by city and year, and all Trigrams and the mean Trigrams interface will respond to these filters.

One of the important elements of visual clarity is the ability to compare Trigrams using vertical alignment. Thus, when choosing a column as an element of perception, it is possible to compare how the Trigrams are distributed in the test and gestational

**Figure 11** Complete infographic interface, with Mean Trigram. Source: author.




age with each other in the visualised sample. This comparative view, added to the selected filters of the last pregnancy test and the birth test, allows users to produce context information through a broad perception of the Trigrams. The comparative view is completed with a case-by-case focus on the narrative of each pregnancy by the Trigram. Thus, there is a comparable infographic view of the situation in a given location.

There is also a **matrix of the Trigram results**. Considering that one of the main goals of care for pregnant women with syphilis is to avoid the various damages caused by vertical transmission, it was decided to filter by the last pregnancy test and the birth test. The $4 \times 4$ matrix numerically represents the quantitative value according to the following parameters: VDRL result at birth (positive, negative, indefinite, and non-existent) and the mother's last test (positive, negative, and indefinite). In addition to the individual data of pregnancies in the Trigram, it is possible to consult the numerical quantity by comparing the last test and the outcome. This double view of the data reinforces the infographic approach, as the Trigrams show a finer granularity of pregnancies, while the matrix presents a development grouped by a combination of factors. This double vision improves the perception of reality in general and specific narratives. In this way, the analyst can filter whether the test result of the mother is transferred to the child at birth. In particular, this filter helps to understand cases of false negatives and failure to perform or report a test to prove the cure for syphilis. The test state indicators (represented by a "+", "-", "i", and "n") are interactive buttons that when activated, filter the Trigrams by one variable at a time or a combination of two from different axes.

Furthermore, given the variation in the data, the mean Trigram has a zoom tool in the visualisation interface. Some slices in cities with more population or the total state have a representation that is difficult to perceive within the applied size of the mean Trigram at the interface. With the zoom, the user can better understand these thin slices and use the mouse interaction over/hover for more information.

In this version, the pagination system and matrix are already integrated with the complete SIS-MC base. As mentioned before, the matrix now also represents the Trigrams that do not have any test to be filtered in the execution.

## Discussions

One of the important factors of domain-specific infographics is their interactive and exploratory nature. Although normally presented separately, data visualisation, interaction, and analysis are not mutually exclusive. Its integration is one of the main goals of data visualisation [14]. Unlike the exploratory approach of [20], because infographics are domain-specific, users can make good exploratory use of them. The exploitation is controlled within what is expected to be found. It is not by trial and error; it is an investigation of situations that are within the scope of the domain, the data, and the views.

One of the potential applications of domain-specific infographics is the ability to explain phenomena at a managerial and strategic level. It does not represent the data nominally; it expands the understanding of the data by comparing and relating the various visual elements. Far beyond the "what happened", is promoting a "how it happened" or "how to investigate what happened". In this aspect, the infographic interface makes it possible to go from general epidemiological data to specific data on pregnancies.

As an example, the epidemiological bulletins of syphilis in Brazil in 2017 and 2018 were selected for analysis. These bulletins correspond to the data range of the PMCP database, referring to the years 2016 and 2017. The limitations of this analysis come from the form of notification of the Notifiable Diseases Information System (SINAN) compared to the SIS-MC, as the SIS-MC data are not from all the pregnant women in the state. On the other hand, the care provided by the PMCP is considered to be superior to the average SUS owing to the focus and reinforcement of care for pregnant women. Therefore, the pregnant women analysed in this comparison would be the best possible scenario in the SUS of the state.

The number of notifications of syphilis cases in pregnant women in the state in 2016 and 2017 were 888 and 1,648, respectively. The PMCP assisted 141 and 235 pregnant women, respectively, during the same period. One of the problems of the comparison is that in SIS-MC, the notification data are consolidated by pregnancy, but in SINAN, which serves as the basis for the bulletin, it is based on notifications. If the same pregnant woman has two positive tests during the same pregnancy, for SINAN, it will be counted as two notifications, but in the SIS-MC, it will appear as a pregnant woman with syphilis. This point will be important for understanding how data are amplified by infographic analysis with Trigrams. Considering the unborn children with detection of syphilis in less than seven days (which is the PMCP notification interval), the numbers reported in 2016 and 2017 were 1,465 and 1,860 notifications, respectively. Of this total, 13.5% and 10.2% were born at the PMCP, respectively. In this case, it can be attributed to the children being a part of the PMCP because there is no way to have more than one notification within seven days.

Two important pieces of information from the analysed bulletins are the detection rate of gestational syphilis and the incidence rate of congenital syphilis. These rates

represent the total number of notifications per thousand people in the population at that time. These are interesting rates because they are comparable over the years, as they are proportional to the population at that time. This information is presented in Figures 12, 13, 14, and 15.

**Figure 12** Syphilis detection rates in pregnant women according to Federation Unit and capital. Brazil, 2016. Source: SINAN, updated on 06/30/2017.

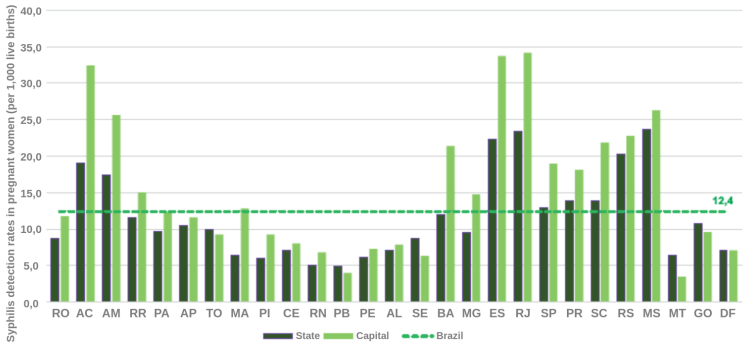
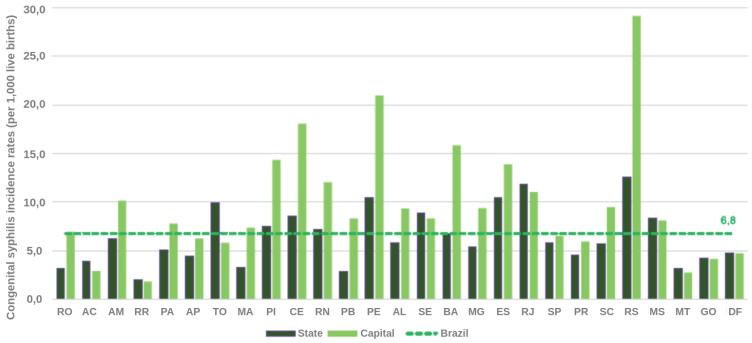



**Figure 13** Congenital syphilis incidence rates by State and capital. Brazil, 2016. Source: SINAN, updated on 06/30/2017.




The details are analysed when comparing the rates of gestational syphilis and congenital syphilis. Boards and comment on the relationship between these rates (highlighted on the board). At the epidemiological level, this relationship is indicative of a phenomenon. However, during the analysis of the Trigrams, it was noticed that it is a much more complex phenomenon.

Section of the epidemiological bulletin 2017.

> **Syphilis Epidemiological Bulletin 2016** *When comparing the detection rates of syphilis in pregnant women with the incidence rates of congenital syphilis in each of the capitals, it is noted that in Teresina, Fortaleza, Natal, João Pessoa,* ***Recife****, Maceió, Aracaju, and Porto Alegre presented in 2016, the incidence rates of congenital syphilis were higher than syphilis detection rates in pregnant women, which leads to possible* ***gaps in the diagnosis during pregnancy, misreporting as acquired syphilis, and/or the epidemiological surveillance system*** *in these cities.*

Section of the epidemiological bulletin 2018.

**Figure 14** Congenital syphilis incidence rates by State and capital. Brazil, 2017. Source: SINAN, updated on 06/30/2018.

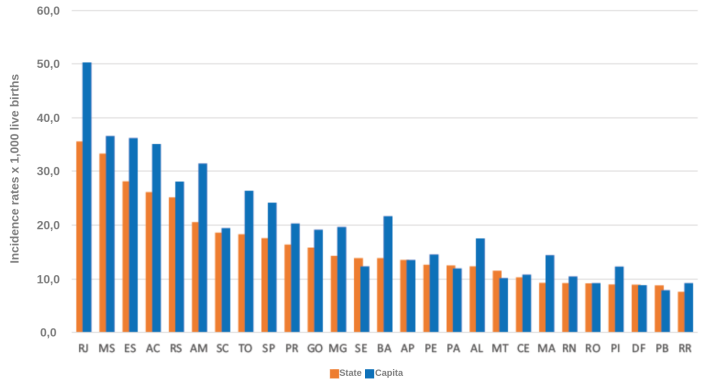
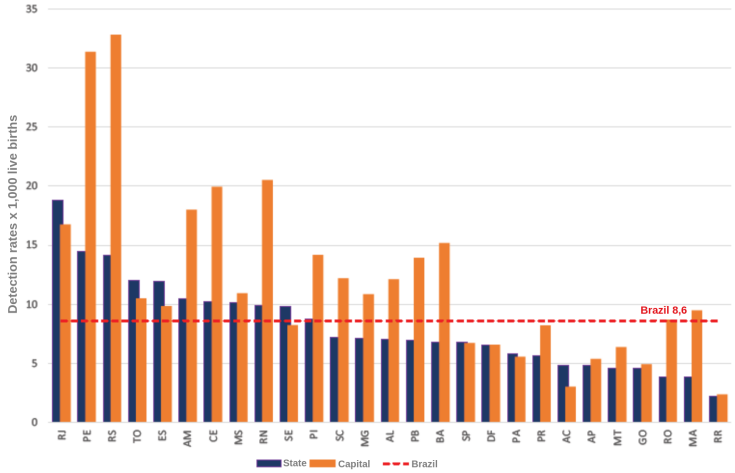



**Figure 15** Syphilis detection rates in pregnant women according to State and capital. Brazil, 2017. Source: SINAN, updated on 06/30/2018.



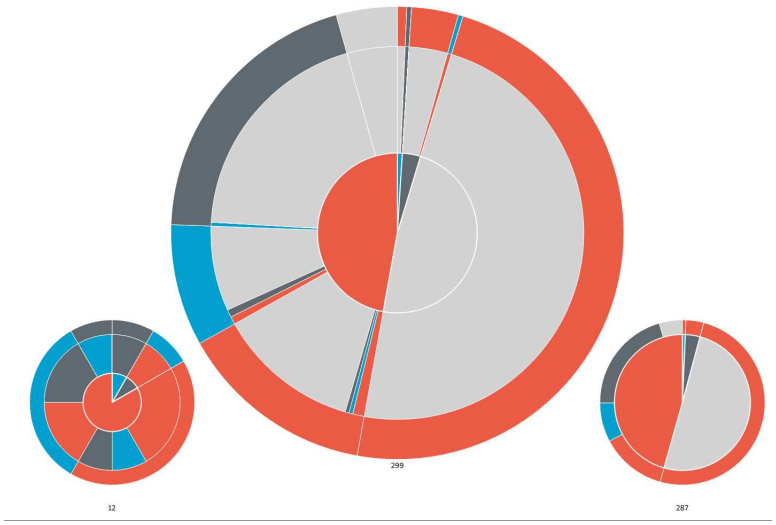

**Syphilis Epidemiological Bulletin 2017** *When comparing the detection rates of syphilis in pregnant women with the incidence rates of congenital syphilis in each of the capitals, it is noted that in Teresina, Fortaleza, Natal, João Pessoa,* ***Recife****, and Porto Alegre presented, in 2017,* ***incidence rates of congenital syphilis were higher than the syphilis detection rates in pregnant women, which points to probable gaps in prenatal care and in the epidemiological surveillance system*** *in these cities.*

Considering the limitations of the analysis presented at the beginning of this section, the mean Trigrams show a different viewpoint on the relationship between the detection of gestational syphilis and the incidence of congenital syphilis. Figures 16 and 17 show the mean Trigrams of the state of Pernambuco in the PMCP in 2016 and 2017. In the epidemiological bulletins, the syphilis detection rate in Pernambuco more than doubled between 2016 and 2017 (from 6.1% to 12.6%). This was reflected in the Trigrams, as the grey slice of the innermost circle was significantly reduced. However, the relationship between pregnant women diagnosed with syphilis and outcomes with syphilis did not change significantly. The unfinished tests of the unborn child have a greater relationship with the detection rate than the rate of

congenital syphilis. Both charts are at the management level, but the granularity of the mean Trigrams allows us to understand, in addition to the phenomenon represented in the rates, others that happen around them.

For example, we considered the relationship between rapid test false negative results and cases of gestational syphilis. In the Mean Trigram for 2017, there was a significant proportion of pregnant women who tested negative for syphilis, but the outcome was unfavourable. This slice hardly appears in the 2016 mean Trigram. The absence of confirmation tests, as provided in the Technical Manual for the Diagnosis of Syphilis [19], is one of the most important factors in the notification of congenital syphilis. As explained previously, there is no direct relationship between pregnant women with syphilis and syphilis outcomes. There is a misalignment between these two data points in the samples analysed in this study. Probably with more data and with the breadth of the entire state, this relationship would change. However, within this period of two years, the comparison is very clear.

**Figure 16** Mean Trigrams of the state of Pernambuco in 2016. Source: Author

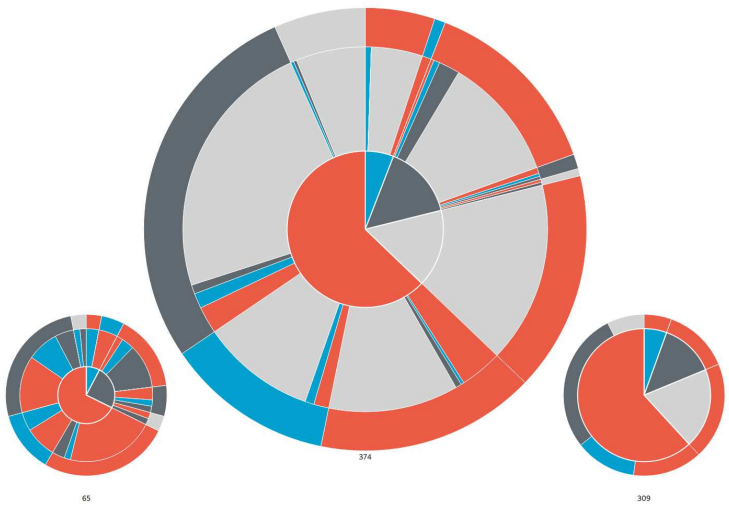



The infographic analysis promoted by the infographic interface allows for this alternation between broad epidemiological data for a case-by-case refinement. This vision and other implementations of this development also aim to meet the recommendations of the World Health Organization (WHO).

## Conclusions

The Syphilis Trigram represents the complexity of gestational syphilis and congenital syphilis in a time series. The Syphilis Trigram allows analysis of the pregnancy narrative for cases of gestational syphilis, representing in a comparable way the relationship between prenatal care, examinations, and pregnancy outcomes with or without congenital syphilis. Aided by other visual elements, such as the mean Trigram and selection matrix, it comprises an infographic interface for the analysis of gestational syphilis and congenital syphilis at the managerial and information executive level.

**Figure 17** Mean Trigrams of the state of Pernambuco in 2017. Source: Author




The main contribution of this study is the proposition of infographics in a specific health domain. These infographics are quantitative representations that allow to understand a health phenomenon at both the macro and micro scales through visual synthesis. The great advantage of this view is that it allows this change in scope (macro and micro) in the same visual context to help users investigate complex phenomena through consistent and comparable views. Therefore, in addition to having a general idea about a sample, users can see and understand the individual motivators that might influence the overall result. These views generated new information and forms of analysis for stakeholders, allowing a greater and better understanding of their data.

This study proposed a contribution to the Brazilian SUS analysis and decision-making process through data visualisation. The contributions presented are far from being the definitive solution for the SUS process, but it is believed that there is an increase in the way information is produced in some specific spheres, with even greater possibilities for expansion. However, in the specific domain in which they were designed, these visualisations can help improve the health care system, optimise resources, and be used as a learning tool to avoid past mistakes.

The continuation of similar research can, even in small steps, greatly improve the quality of SUS. Considering the complexity of the SUS and the reality of Brazil, any improvement has the potential to greatly enhance the lives of Brazilians.

**Declarations**

Ethics approval and consent to participate

This work has ethics approval under protocol 12438019.2.0000.5208.

Consent for publication

Not applicable.

Availability of data and materials

The datasets during and/or analysed during the current study available from the corresponding author on reasonable request.

Competing interests
The authors declare that they have no competing interests.

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Authors' contributions
CMM was the main contributor in proposing and designing the Syphilis Trigram infographic, processed the data, and performed the analysis. IVT and PTE were involved in the critical revision of manuscript. PTE was a major contributor in writing the manuscript. JK helped in the drafting and revision of manuscript. All authors read and approved the final manuscript.

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