Visual Statistics: Exploring a New Way Of Teaching Unintuitive Math

Alex Baroody ‘23, Advised By David Walker

Center for Statistics and Machine Learning, Princeton, NJ

Introduction and Related Work

Statistics is often taught in confusing and verbose ways. The goal of this project is to make a set of tutorials that act as a supplement to classroom instruction on an area of Statistics that I find especially challenging and important: hypothesis testing. I designed and implemented three separate tutorials at different levels of statistical depth, aiming to have a way for all curious or struggling users to learn Statistics, no matter their level of prior experience.

This project was inspired by a Google PAIR tool. This “explorable” looks into how researchers measure fairness in Artificial Intelligence and Machine Learning models [8].

I gathered information regarding type I and type II errors, as well as for the rest of the content of the tutorials, from glossaries, studies, and informational papers. This includes a 2020 CDC study on diagnostic COVID-19 tests [6], along with a 2009 paper from the National Library of Medicine on hypothesis testing [5].

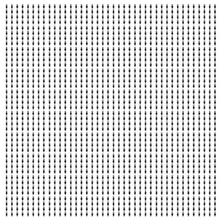
To make this project, I used JavaScript, React, HTML, and CSS. On top of these basic building blocks, I used React [4], Nodemon [2], and MathJax [1], along with code snippets from Dusten Katsen [7] and Eric Terwan [3].

Implementation

Because I designed the website to have only one page, I needed a way to organize and differentiate between the header slide and each tutorial. Further, I needed a way to organize the content inside each tutorial in a standardized, intelligible way. I decided to create a number of customized HTML and React elements with standardized styling to create this organization.

There are a handful of elements that make up the visual portion of the tutorials. The most important is the grid representing the sample population used throughout all 3 tutorials; however, the other visual elements were also necessary to producing an engaging tool.
First, consider the simplest set of elements: the equations used in all three tutorials. They consist of a MathJax React component for every equation necessary for that tutorial, with the equation inline in the HTML code.

This grid represents the population that is used for examples throughout all three tutorials. I chose 1600 avatars because it is a square number that plays well with values for sensitivity and specificity that were both realistic and resulted in simple calculations. Especially for the beginner tutorial, it was paramount that the calculations were as simple as possible—while maintaining some semblance of realism—so that users would not be deterred by complicated decimals or fractions.



The grid used for the main example.

The crux of this project was transitioning from slide to slide. These transitions are managed by a master function, onPageScroll(), which delegates to nested auxiliary functions depending on the user’s scroll height. The main function passes the user’s scroll height, as well as pointers to the elements each tutorial uses. The majority of the slides feature transformations from one state of the grid to another. To accomplish this, we first need to find the appropriate cell(s) or row(s) of the grid component and then move them to the correct position.

Design

In designing this tool, I aimed to be simple and elegant and to create a tool that was easy and intuitive to use. I wanted the user to know exactly how to get around the website with little or no prompting, and I wanted the colors to be contrasting but easy on the eyes. Ideally, every aspect of the design of my tool would serve the user’s experience in learning the material, without any extra frills.

I saw a few ways to improve upon the design of the Google PAIR tutorial on measuring fairness. The most important aspect was to target multiple audiences with multiple levels of tutorials. To improve the transitions between states in the visual portion of the tutorial, I settled on a scroll-based animation system that would keep a single visual element on screen for as long as is pertinent to the example.

$$\mathbb{P}[A|B] = \frac{\mathbb{P}[A \cap B]}{\mathbb{P}[B]}$$

The definition of Conditional Probability

$$\mathbb{P}[A|B] = \frac{\mathbb{P}[B|A] \cdot \mathbb{P}[A]}{\mathbb{P}[B]}$$

The definition of Bayes’ Theorem

When designing the Basic tutorial, I focused entirely on the providing the most utility to the user while assuming as little mathematical and statistical knowledge as possible. When designing the Intermediate tutorial, I spent less time introducing the example than in the Basic tutorial, assuming that the user is familiar with the concepts from either previously taking the Basic tutorial or from some other avenue. The Advanced tutorial is designed to go beyond the visual examples and put users on track to learn more about advanced, research level Statistics.

Evaluation

In order to evaluate the quality of my tool, I chose to both consider my goals at the beginning of the semester and ask others to use the product without having used it throughout development.

Looking back at my project proposal, the final set of tutorials is a good proof of concept for the tool I laid out. I believe that my final product lives up to the goal I proposed at the beginning of the semester. I believe that the tutorials are intuitive and easy to read, use, and understand for people of all skill levels and backgrounds.

The user evaluation consisted of two phases: a focus group of my seminar mates and a set of 6 random users from the University community and beyond, with a wide range of confidence in Statistics. In total, I had 10 users test my product at a thorough level.

The focus group style setting was important to making improvements to the usability of my tool. Because my classmates have similar experience using the development tools that I did, they were able to give specific, accomplishable feedback on the tool.

While the broader call for evaluation did mean there were some vague and unhelpful responses, it also meant that I could hear from people more similar to my target audience. While my classmates were very helpful with the technical and visual components of the tool, these members of the University Community were helpful in making the content clear and easy to follow.

Future Work

The most glaring and immediate piece of future work is rewriting the animation code to move things relatively rather than absolutely. Currently, the site is styled in a hodge-podge of relative and absolute units. Early observation shows that the way I define and use the height of the user’s window should cover animation specific sizing and positioning: that is, the animations should be acting in a relative manner.

In order to make this site a more effective place to learn Statistics, I may choose to develop similar tutorials in other areas of Statistics or Mathematics. One of the stretch goals in my project proposals was to include an example of such a tutorial on Simpson’s Paradox; however, creating the animations took longer than I thought, and I wanted to produce a smaller set of fleshed-out tutorials rather than a larger set of poor-quality ones. However, these other tutorials could span many topics, from Simpson’s Paradox to Statistical Bias. In designing these tutorials, I would try to keep the main goal of the original tool in mind: I would balance visuals and explanations, attempting to have the latter serve the former rather than the other way around.

One of the most surprising parts of research was not being able to find a Scroll-based animation library. In order to create such a library, I could start from my code for this project: much of the required logic is contained in my work. Another important consideration is the scope and platform in which my library exists. For example, if it is a standard HTML or CSS package, it would be easy to write and very portable, but likely not very powerful; if I built a wrote a React specific library, it would be less portable but likely more powerful, as I could take advantage of React’s partial re-rendering [4].

Works Cited

[1] “better-react-mathjax.” [Online]. Available: https://www.npmjs.com/package/better-react-mathjax
[2] “nodemon.” [Online]. Available: https://nodemon.io/
[3] “Pure CSS Hamburger fold-out menu.” [Online]. Available: https://codepen.io/erikterwan/details/EVzeRP
[4] “React–A JavaScript library for building user interfaces.” [Online]. Available: https://reactjs.org/
[5] A. Banerjee, U. B. Chitnis, S. L. Jadhav, J. S. Bhawalkar, and S. Chaudhury, “Hypothesis testing, type I and type II errors,” *Industrial Psychiatry Journal*, vol. 18, no. 2, pp. 127–131, 2009. [Online]. Available: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2996198/
[6] A.Brihn, J.Chang, K.OYong, S.Balter, D.Terashita, Z.Rubin, and N.Yeganeh, “Diagnostic Performance of an Antigen Test with RT-PCR for the Detection of SARS-CoV-2 in a Hospital Setting — Los Angeles County, California, June–August 2020,” *MMWR. Morbidity and Mortality Weekly Report*, vol. 70, 2021. [Online]. Available: https://www.cdc.gov/mmwr/volumes/70/wr/mm7019a3.htm
[7] D. Kasten, “Smooth Scroll behavior polyfill,” Mar. 2022, original-date: 2013-08-08T03:41:53Z. [Online]. Available: https://github.com/iamdustan/smoothscroll
[8] A. Pearce, “Measuring Fairness,” May 2020. [Online]. Available: https://pair.withgoogle.com/explorables/measuring-fairness/

Acknowledgements

I would like to thank Prof. David Walker for teaching an extremely useful seminar and seeming to have the answers to my questions before I needed to ask them; thanks must also be extended to my classmates in his seminar, who consistently gave helpful and constructive feedback on my project, from start to finish. I would also like to thank Jérémie Lumbroso for inspiring my love for using technology for education, in any and all forms. Although I no longer work with Jérémie, his influence is still very much felt. Lastly, I would like to thank my parents, Jim and Karen, for opening endless doors so that I could be here and work on such a project.