A Hands-on Application-Based Tool for STEM Students to Understand Differentiation

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Abstract - **The main goal of this project is to illustrate to college students in science, technology, engineering, and mathematics (STEM) fields some fundamental concepts in calculus. A high-level technical computing language – MATLAB, is the core platform used in the construction of this project. A graphical user interface (GUI) is designed to interactively explain the intuition behind a key mathematical concept: differentiation. The GUI demonstrates how a derivative operation (as a form of kernel) can be applied on one-dimensional (1D) and two-dimensional (2D) images (as a form of vector). The user can interactively select from a set of predetermined operations and images in order to show how the selected kernel operates on the corresponding image. Such interactive tools in calculus courses are of great importance and need, especially for STEM students who seek an intuitive and visual understanding of mathematical notions that are often presented to them as abstract concepts. In addition to students, instructors can greatly benefit from using such tools to elucidate the use of fundamental concepts in mathematics in a real world context.**

Index Terms - Applications of derivatives, Derivative kernel, Image processing, Math in STEM fields

INTRODUCTION

In a perceptual manner, this project explores an educational tool for students and instructors in science, technology, engineering, and mathematics (STEM) fields in order to perceive how differentiation can be used in image processing. The motivation of this work has stemmed from the need to enable STEM students to actively understand fundamental concepts in mathematics and apply such knowledge to a tangible interface with all benefits of computer technology. Our presented tool focuses on showing the fundamental idea behind one of the many applications of derivatives in the real world. It demonstrates how the core concept learned in calculus becomes relevant by applying it to an image through a filter. Students who have a background in calculus already possess the basic understanding of differentiation. However, despite seeing various applications-based examples (mainly in physics), these individuals often miss out on the whole purpose as to why derivatives are taught and how they hold significance in relation to the world. Once the conceptual aspect of differentiation is understood, its uses and applications become more clear. However, there is a missing step where students can use technology to interact with these rather abstract mathematical notions. Our proposed tool allows users to visually see a derivative in action along with the mathematics that accompanies it. We strongly believe such tool will improve students' comprehension and understanding more deeply and lastingly.

In order to create the proposed interactive tool, MATLAB (MathWorks, Natick, MA) is used as the main platform to build a graphical user interface (GUI). It should be noted that the actual GUI is still a work-in-progress, but it will be ready to be presented at the 2016 IEEE Integrated STEM Education Conference, in Princeton, NJ. This project has been primarily designed and developed by two non-math major undergraduate students under a Sokol Faculty-Student Research Award, and it will be of great use and interest to STEM students who have taken (or currently taking) their first calculus course. In addition to reinforcing the mathematical concept of derivative, we believe this tool can trigger students' interest in related application fields, under the STEM umbrella, such as image processing, pattern recognition, or computer vision. Calculus instructors will also benefit from incorporating this interface into their lectures to demonstrate one of the many valuable applications of derivatives in the real world through a hands-on approach.

METHODS

I. Mathematical Representation of a Digital Image

To keep simplicity in this project, only black and white images in which pixel values are based on a grayscale are considered. Using a grayscale instead of a red, green, and blue (RGB) color scale allows for an easier understanding of how pixels relate to an image and how transformations affect each pixel.

Digital images are made up of pixels. Each pixel holds a value that correlates to the color or gray intensity of that pixel. These pixel values can be represented in a table, which allows an image to be expressed mathematically. The table that respectively holds pixel values is called a vector on a one-dimensional (1D) and a matrix on a two-dimensional (2D) space. A 1D image is essentially a line/strip and can be represented as a single row of pixel values. 1D images are used in this project to emphasize the basic concept behind applying a filter to an image. The 1D example serves the purpose to display an image

transformation on the most basic scale possible and enables the user to easily visualize what is being done to the image. Once the understanding is grasped on a 1D level, the 2D level transformation can be comprehended more clearly.

Indexing is also an important aspect to take into consideration when dealing with digital images. Essentially, the index of a pixel is the location of the pixel within the image [1]. In 1D, such location can be represented in a vector whereas in 2D, the indexes are stored in a matrix format. This will be of importance when transformations are performed on an image.

II. Linear Image Transformation

In essence, the terms filter and kernel are commonly used interchangeably because both refer to the expression of a fundamental change to an image. To be more specific, filter is the term more frequently used when dealing with the subject of image processing. Kernel is used more explicitly when referring to the direct mathematics that goes into the process.

A filter is generally known as an effect that alters an image. Filters can change an image through various effects, such as, blurring, sharpening, and edge detection. Essentially, a kernel is a vector or matrix consisting of predetermined values that causes a change (transformation) to occur on an image [1]. Specifically, a derivative kernel is used in image processing to determine the rate at which the pixels in an image are changing in a certain direction. In other words, derivative kernels allow the detection of edges by taking the change in the intensity with respect to the change in position [2]. Each pixel in an image holds a specific value that is represented in a matrix. When a derivative kernel is applied to an image, it takes into consideration the value of the indexed pixel and also the values of the pixels on either side. It measures the amount of difference on both sides and a new value, the derivative, is assigned to the new indexed pixel (transformed image).

III. Graphical User Interface

To demonstrate the transformation that is performed on a one-dimensional (1D) image, the user has the option to select from a list of predetermined images (grayscale strip) or enter their own input values of a vector that will be displayed as a grayscale strip. A kernel is then selected and applied to the vector. The user has the option to slide the selected kernel across the vector in order to visually see the transformation. The default kernel is the derivative filter, but in order to take the concept even further, other types of filters such as blurring and sharpening are also available.

The use of a kernel on a two-dimensional (2D) image is also demonstrated through an interactive tool which allows the user to select from a set of options. The interface is set to a default design that most effectively shows the use of the derivative filter. From there, a set of predetermined images (grayscale pictures of objects as well as some medical images) or an arbitrary image can be selected from a drop down menu. The user can then select the desired filter and apply it to the image. For comparison purposes, the original image along with the new image and their corresponding pixel values in a matrix form are displayed.

DISCUSSION AND FUTURE WORK

Engineering students who are just beginning their studies may use this tool in their math courses as a means of being introduced to filters from a mathematical point of view rather than solely learning about filters in engineering courses. For life science majors, there is often a disconnect between science courses and mathematics courses. The tool that is being developed enables these students to see both subjects come together and function in unison. This allows for the realization of the importance of mathematics in all fields of study. Although this specific tool is not novel, it bears a powerful impact from both the teaching and learning viewpoints because it allows professors and students to engage themselves in a hands-on way. The use of technology in the classroom holds a large significance when enhancing education. Interactive tools allow students to take a hands-on approach when dealing with the material being presented to them. Having this tool in classrooms allows for instructors to enrich the learning experience altogether for students.

Derivative filters serve as a basis for edge detection in image processing, and it consists of identifying areas within a digital image where the brightness changes sharply [3]. Edge detection is significant in determining and analyzing features of an image obtained for different applications such as photography or scientific imaging (medical imaging, microscopy, remote sensing, etc.) Basing this project off of the mathematical concept behind derivative kernels, while also intuitively showing how such operation can be applied to an image as a filter, allows students not only to see another applications of differentiation, but also provides them an opportunity for hands-on learning. One of the major problems contributing to the STEM crisis is the lack of student engagement in STEM courses [4]. That is particularly the case in college-level math courses, such as Calculus, where non-math major students are required to take at least a few math courses, but generally have an indifferent or even negative attitude towards the subject. That is mainly due to the students' lack of understanding the connection between what they are passionate about (their major) and what is taught to them in their math courses. Our proposed interactive interface is a an example of a tool that can hold an impact on STEM education by enabling students to recognize the value of rather abstract mathematical concepts in the real world applications, in addition to gain a more intuitive and deeper understanding of differentiation. It also helps instructors increase the level of engagement in the classroom by creating an active-learning environment.

It should be noted that both students who are involved in this project were taking pre-calculus in Fall 2014, when the initial desire for doing research was started. Together they explored the features of MATLAB as well as programming and various aspects of image processing. The

research continued while the students advanced in their non-major mathematics course requirements such as calculus, which stimulated the interest to begin a project involving the derivative kernel. Motivation has also stemmed from the desire to enable students to actively understand what they have learned about derivatives and apply this knowledge to a tangible medium. Also during this time, the students were awarded the 2015-16 Montclair State University Sokol Faculty/Student Research grant with Dr. Golnabi. Having a professor from the mathematics department working with undergraduate students in STEM majors is particularly advantageous because it allows both faculty and students share valuable perspectives.

When the GUI creation is completed, we plan to implement its use in our Calculus course for biology majors at Montclair State University. We aim to conduct further studies and observe the direct impact such interactive tool can have on STEM education. Our goal is to use those results as a "stepping-stone" in order to develop more mathematical interactive tools for students in STEM fields.

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