Detecting Developmental Delays

New Mexico

SuperComputing Challenge

Final Report

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Team 1

Academy for Technology and the Classics

Team Members:

Etta Pope, 11th Grade

Shyla Sharma, 12th Grade

Odin Frostad, 11th Grade

Teacher:

Jenifer Hooten

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Executive Summary

A developmental delay is categorized as a child's inability to reach a developmental milestone within a set period of time, determined by the average amount of time it takes a child to read this milestone. Developmental delays can present in 5 areas: fine motor, gross motor, social, language, and cognitive. As of a 2008 study, one in six children is affected by a developmental delay, with the prevalence of developmental delays increasing by almost 20% since 1997. In counts, this means that 1.8 million more children have developmental delays. Because of the extreme relevance of developmental delays, it is important to be able to diagnose them as early and as efficiently as possible, as to avoid further complications that arise from undiagnosed delays.

Our code aims to provide not only a more efficient but also more accurate means of detecting these delays in children. The code, written in Java using the program jGrasp, takes in a T2-weighted magnetic resonance image (MRI) of a brain, and analyzes the image pixel by pixel. The selected MRI is compared to a MRI with no known abnormalities, and, if any abnormalities are found, the user is alerted. This code both eliminates the need for doctors to individually read each MRI, freeing up a large amount of resources and greatly reducing the amount of time spent per MRI, and reduces the introduction of human error in detecting abnormalities, of which accounts for between 60% and 80% of all error in the entire field of radiology [NCBI, 2016], lowering the amount of brain abnormalities that go undetected.

Introduction

All background information needed, as well as the premise for the project, will be detailed in the following section.

Problem Statement

Neurological disorders are an issue that affect over one billion people throughout the world. Though many of these disorders can be detected from abnormalities in the brain, finding these abnormalities can at times prove difficult. Brain abnormalities can be seen in brain MRIs, which show where the white brain matter is located in each individual brain. Using these brain MRIs, medical professionals can determine where these abnormalities are and what they correlate to with a pretty high success rate.

Still, there is room for improvement. Though there is a high success rate, it is still far from perfect. Many brain abnormalities go undetected, preventing these people from receiving the care and assistance they not only need, but deserve. Additionally, the entire process of finding abnormalities in brain MRIs is incredibly time consuming and requires medical professionals to spend valuable time reading each individual MRI.

Background Research

I. MRI Scans (Magnetic Resonance Imaging)

As technology has advanced, Magnetic Resonance Imaging (MRI) Scans have become more common. Each year, “approximately 10 million patients undergo MRI procedures” [ISMRM: 2017]. These scans typically last 20 - 90 minutes, depending on the body part being imaged. The cost of an MRI scan ranges from “ $1,200 to $4,000” [AAFM: 2017] on average. One of the reasons that these scans are so popular among doctors is that they create images that compare healthy and unhealthy tissue, which are then used to determine numerous potential problems in various parts of the body, ranging from the brain to joints. MRI Scans can be used to diagnose a wide variety of conditions, such as tumors, heart damage, lung damage, sport injuries, and brain abnormalities.

Another reason that doctors prefer MRI Scans is that they do not rely on the ionizing radiation used for an x-ray or CT Scan. Instead, “the MRI examination requires specialized equipment that uses a powerful, constant magnetic field, rapidly changing local magnetic fields, radiofrequency energy, and dedicated equipment including a powerful computer to create very clear pictures of internal body structures” [ISMRM: 2017]. When the patient is placed in the MR System, an electric current is passed through coiled wires, which creates a “temporary magnetic field in a patient’s body” [FDA: 2018]. This magnetic field then aligns with the protons present in the body’s tissues. When radiofrequency energy is applied, these protons produce signals that are specially characterized and processed to produce images of a body part. “For some MRI exams, intravenous (IV) drugs, such as gadolinium-based contrast agents (GBCAs) are used to

change the contrast of the MR image" [FDA: 2018]. This contrast agent provides a clearer distinction between healthy and unhealthy tissues.

There are five types of MRI Scans: Functional MRI (fMRI), Breast MRI, Magnetic Resonance Angiography (MRA), Magnetic Resonance Venography (MRV), and Cardiac MRI. A functional MRI is used to map the brain. "During an fMRI, the patient is asked to perform certain activities to help the neurosurgeons map the functional areas of the brain before surgery takes place." [Stanford: 2019]. A Breast MRI is used to examine patients at high risk for breast cancer by using a "a powerful magnetic field, radio frequency pulses and a computer to create detailed images of the breast tissue and any abnormalities that may present themselves" [Stanford: 2019]. An MRA Scan is used to examine the heart and other soft tissues. It uses a combination of a typical MRI Scan and an intravenous contrast dye in order to view blood vessels. This type of MRI Scan is very similar to an MRV Scan. An MRV Scan also uses magnetic resonance technology and an intravenous contrast dye, but uses it to visualize the veins. This procedure produces "detailed images of organs and structures within the body" [Stanford: 2019]. A Cardiac MRI "uses a combination of a large magnet, radio frequencies, and a computer to produce detailed images of heart structures" [Stanford: 2019].

In addition to the many types of MRI Scans, there is a variety of MRI machines. The most basic type is the traditional closed MRI machine, which is a large tube that a patient lays in. It requires that the patient be very still, as movement can result in inaccurate readings. This scanner produces high quality images, but can be an issue for claustrophobic patients. An open MRI machine is "ideal for people who have claustrophobia, or fear of small, enclosed spaces who are looking to have digital imaging done" [MVA: 2017]. A true open MRI Scanner is open

on all four sides and still requires the patient to lie down, though they don't completely enclose the patient. A Wide Bore MRI Scanner is the middle ground between a closed MRI and an open MRI. In a Wide Bore MRI, “the size of the ‘hole’ (or bore) where the patient lies is 70 cm, providing more headroom than a true open MRI” [Shields: 2019]. It is typically more spacious than an open MRI, but is not open on all sides. There is also a standing or sitting MRI, which was developed to improve patient comfort. , but unfortunately does not produce high quality images. “While these machines help with patient comfort, they currently don’t provide a good image quality” [IBJI: 2017].

Various machines also include different parameters in order to enhance image quality. “The image quality of an MRI depends on signal and field strength” [Shields: 2019]. Currently, the standard signal for MRI in a clinical setting is a 1.5T MRI. A 1.5T machine is faster than lower strength MRIs and is ideal for abdomens and chest MRIs. A 1.2 machine is able to produce diagnostic images, but it inherently has less signal than a 1.5 magnet, causing the image quality to be much lower. “Where there is more signal with a 1.5T magnet than a 1.2T magnet, there are great options as to what can be done with the extra signal”[Shields: 2019]. An example of these options could be decreased scan time. The newest and most powerful MRI Machine is the 3T Highfield Wide Bore MRI. This machine has a “higher field and signal strength than others, allowing it to be a faster scan and higher-quality image” [MVA: 2017].

II. Magnetic Resonance, Functional (fMRI) - Brain

A functional magnetic resonance imaging (fMRI) is used to map the brain by measuring the small changes in blood flow that occur during brain activity. “Oxygen is delivered to neurons

by haemoglobin in capillary red blood cells.When neuronal activity increases there is an increased demand for oxygen and the local response is an increase in blood flow to regions of increased neural activity" [NDCN: 2019]. Blood oxygenation varies according to the levels of neural activity, meaning that brain activity can be detected using differences in blood flow. Haemoglobin is diamagnetic when oxygenated, meaning that its atoms are slightly repelled by a magnetic field. However, haemoglobin is also paramagnetic when deoxygenated, meaning that its atoms are slightly attracted by a magnetic field. For this reason, when a patient is asked to perform a simple task during an fMRI examination, such as viewing pictures, it " causes a small change in the magnetic field, and thus the MRI signal, in the active region" [HNL: 2010]. "This difference in magnetic properties leads to small differences in the MR signal of blood depending on the degree of oxygenation" [NDCN: 2019].

"fMRI is becoming the diagnostic method of choice for learning how a normal, diseased or injured brain is working, as well as for assessing the potential risks of surgery or other invasive treatments of the brain" [RadiologyInfo: 2019]. These scans can be used to examine the functional anatomy of the brain, determine which part of the brain is handling critical functions, help assess the effects of disease on brain function, monitor the growth and function of brain tumors, and guide the planning of brain treatments.

III. Interpreting MRI Scans

An MRI Map is "based on the magnetization properties of atomic nuclei. A powerful, uniform, external magnetic field is employed to align the protons that are normally randomly oriented within the water nuclei of the tissue being examined" [Preston: 2006]. External Radio

Frequency (RF) energy that is a result of the MRI machine is then used to disrupt the alignment. The nuclei then return to their original alignment and emit RF energy. The emitted signals are then measured after the initial emission of RF energy. Fourier transformation (takes a time-based pattern, measures every possible cycle, and returns the he amplitude, offset, & rotation speed for every cycle that was found) "is used to convert the frequency information contained in the signal from each location in the imaged plane to corresponding intensity levels, which are then displayed as shades of gray in a matrix arrangement of pixels" [Preston: 2006].

Different types of images can be created by changing the sequence of RF pulses applied. This is accomplished by varying the Repetition Time (TR), the amount of time between successive pulse sequences applied to the same slice, and Time to Echo (TE), the time between the delivery of the RF pulse and the receipt of the echo signal. The contrast and brightness of an MRI image is dependent on which sequence is used. The most common MRI sequences are T1-weighted and T2-weighted scans. A T1 -weighted image is produced by using short TE and TR times. A T2 - weighted image is produced by using longer TE and TR times. Another commonly used sequence is the Fluid Attenuated INversion Recovery (Flair). In this sequence, the TE and TR times are very long.

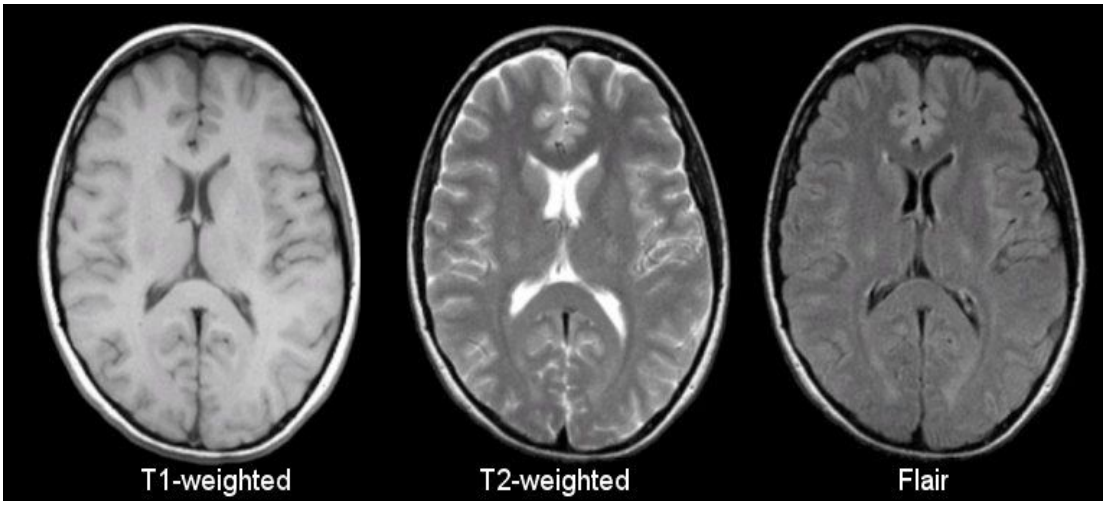

Image 1: Comparison of T1 vs. T2 vs. Flair (Brain)

Tissue	T1-Weighted	T2-Weighted	Flair
CSF	Dark	Bright	Dark
White Matter	Light	Dark Gray	Dark Gray
Cortex	Gray	Light Gray	Light Gray
Fat (within bone marrow)	Bright	Light	Light
Inflammation (infection, demyelination)	Dark	Bright	Bright

Chart 1: Chart 1: Comparison of T1 vs. T2 vs. Flair (Brain)

VI. Developmental Delays

Child development refers to the cognitive and physiological changes that occur from infancy to adolescence. During this time period, children are expected to develop certain physical, cognitive, and social skills within a specific range of time. A developmental delay "refers to a child who is not achieving milestones within the age range of that normal variability" [DPHHS]. A developmental delay can be due to a variety of causes, ranging from a genetic cause to a complication with pregnancy or birth. Unfortunately, the specific cause is often unknown.

Developmental delays can impact several areas of childhood development. These skills are communication skills, social and emotional skills, gross and fine motor skills, and cognitive skills. A child's inability to communicate can be due to a speech delay. A speech delay can either be a receptive language disorder, "in which a child has difficulty understanding words or concepts" [NYULH: 2019], or an expressive language disorder, "in which a child has a reduced vocabulary of words and complex sentences for his or her age." [NYULH: 2019]. A child can also have a combination of both receptive and expressive delays. Speech delays can be due to physiological causes, such as brain damage or genetic syndromes, but in most instances, the cause of a speech delay is unknown. A child with a developmental delay often has issues with their social and emotional skills. "Children with developmental delays, including those with related neurobehavioral disorders such as autism spectrum disorder and attention deficit hyperactivity disorder, often also have social, emotional, or behavioral delays"[NYULH: 2019]. Due to the differences in their brain development, they may react to their environment differently than children of the same age. These delays often impact a child's ability "to learn, communicate, and interact with others" [NYULH: 2019]. A motor delay can impact a child's gross and fine motor skills by interfering "with a child's

ability to coordinate large muscle groups, such as those in the arms and legs, and smaller muscles, such as those in the hands"[NYULH: 2019]. Motor delays can result from genetic conditions, conditions that affect muscles, or even structural problems. "Cognitive delays may affect a child's intellectual functioning, interfering with awareness and causing learning difficulties that often become apparent after a child begins school" [NYULH: 2019]. The cause of this delay is often unknown, though it can result from a brain injury or a disorder that affects intellectual development. A developmental delay often impacts more than one area of a child's development. A global developmental delay occurs when a child has delays in many or all of these areas.

VII. MRI Scans and Developmental Delays

With developmental delays, early intervention is vital. The earlier a child is diagnosed, the earlier parents are able to monitor their child's progress and determine potential areas of concern. Depending on the cause of the developmental delay, especially with a motor delay, early intervention can even reverse a developmental delay. There are also resources available for students with developmental delays. Most states provide special programs to aid students with delays, which can have a significant impact on the child's education. Students with developmental delays tend process information in different ways, which can impact their behavior and emotional state. Being placed in a specialized program can improve the quality of education that they are receiving.

MRI Scans can be very useful in detecting developmental delays early on. "The main causes of delay in development include a range of various diseases from which the large number associate with specific findings in brain MRI" [Momen: 2011]. As neuroimaging provides information regarding brain tissue structures, "the magnetic resonance imaging (MRI) scans were able to

determine abnormalities in the white matter and gray matter of the brains of very preterm infants, those born at 30 weeks or less" [Miller: 2006]. MRI scans are also able show lesions on infant's brains, which can show which region of the brain is affected. Researchers were then able to use this information to predict the risk of severe cognitive delays and other impairments by age 2. "Using this method could be effective in diagnosis, management, and almost prognosis determination processes" [Momen: 2011]. An MRI can provide evidence of previous injuries or specific abnormalities that could indicate a group or a particular disease.

VIII. New Mexico and Developmental Delays

Identification of Children with Disabilities Chart

STUDENT ENROLLMENT, AGES 6 THROUGH 21

Student Category	State Students (#)	State Students (%)	Nation Students (#)	Nation Students (%)
All students	303,454		45,056,472	
Children with disabilities (IDEA)	41,534	13.7	5,789,884	12.9

Explanatory Note: The number and percentage of total students enrolled in public schools in the state and nation as of October 1, 2010 (or the closest day to October 1) for all grade levels from grade 1 through grade 12, as well as ungraded. The number and percentage of children with disabilities (IDEA) in the state and nation as of the state- designated child count date (between October 1 and December 1, 2011). Children with disabilities (IDEA) are served under the Individuals with Disabilities Education Act (IDEA). Data reported for IDEA 2011 Child Count and the 2010-11 Common Core of Data (CCD). National data represent the US and Outlying Areas. (Data Sources:http://www.ideadata.org and http://nces.ed.gov/ccd/elsi/).

PERCENT OF POPULATION WHO ARE CHILDREN WITH DISABILITIES (IDEA), AGES 3 THROUGH 21

Age	State (%) SY 2009-10	State (%) SY 2010-11	State (%) SY 2011-12	Nation (%) SY 2011-12
3 through 5	7.6	6.0	5.7	6.0
6 through 21	8.9	8.9	8.9	8.4

xplanatory Note: The percentage of the population who are children with disabilities (IDEA) in e state and nation as of the state designated special education child count date, for the age ranges 3 through 5 and 6 through 21. National data represent the 50 states, DC, PR, and BIE. Data ported for IDEA 2011 Child Count and Census. (Data Source: http://www.ideadata.org).

In New Mexico, developmental delays are a prevalent issue. The state's average percentage of students with developmental delays was higher than the nation's by 0.8%. Due to the amount of children with these delays, New Mexico has created several programs designed to aid children with special developmental needs. These programs include Early Childhood Special Education, Developmental Disabilities Support Division, and BabyNet.

Methods

In the following section, the code will be broken down piece by piece, with an explanation above each section of code, to offer an in-depth explanation of the methods utilized. The full code can be found under *Appendix*.

The code begins with the importation of several libraries, all of which are common in Java programs. Both ImageIO and BufferedImage are used to read any entered image, in this case being the selected MRI.

```
import java.io.*;
import java.awt.*;
import javax.imageio.ImageIO;
import java.awt.image.BufferedImage;
```

Next, the picture was taken in, made into a file, with the file then being converted into an image using the BufferedImage class. The methods getWidth and getHeight from the BufferedImage class were then used to get the dimensions of the image. These are checked against the dimensions the code uses. If the dimensions match, the code will run, but if they do not, the user will be informed that they must resize the MRI. A boolean variable is initialized to store whether or not an abnormality has been found. The programs starts out assuming that the MRI has abnormalities present.

```
public class ATCCode
{
  public static void main(String args[]) throws IOException
   {
      File file= new File("20YABrainMRIAxialT2Dark.jpg");
      BufferedImage image = ImageIO.read(file);
      //Shadow, Black (2014) GetPixelColor [Source code]
```

```
//<https://stackoverflow.com/questions/22391353/get-color-of-each-pixel-of-an-image-using-bufferedimages>.

     boolean noAbnormalityDetected = false;
     int width = image.getWidth()-1;
     int height = image.getHeight()-1;
     System.out.println("The width is " + width + " and the
height is " + height + ".");

      if(width!=529||height!=639)
         {
          System.out.println("The dimensions of the choosen MRI
do not match the specifications of the program. Please format
the MRI to 529X610 and re-compile.");
         }
```

Next, using a nested for loop, the code parses through each pixel of the MRI. The first for loop increases the x value of the pixels one by one once the end of the row of pixels had been reached. This process repeats until the program reaches the pixel in the lower right corner of the image. The value of the variable holding the information about whether an abnormality is present is reset for each pixel, as to avoid skipping over any possible areas with abnormalities present. For each pixel, the red, green, and blue hexadecimal values of its color are gathered. This information will be used to determine whether or not the pixel contains white brain matter.

```
for(int i = 0; i <= width; i++)
      //Increases width by one.
         {

            for(int j = 0; j<= height; j++)
            //Increases height by one.
               {
                  noAbnormalityDetected =  false;
           //Resets the variable that checks for abnormalities
for each pixel.
```

```
                    int color=  image.getRGB(i,j);
                    int  red   = (color & 0x00ff0000) >> 16;
                    int  green = (color & 0x0000ff00) >> 8;
                    int  blue  =  color & 0x000000ff;
//Shadow, Black (2014) GetPixelColor [Source code]
//<https://stackoverflow.com/questions/22391353/get-color-of-eac
h-pixel-of-an-image-using-bufferedimages>.
```

The red, green, and blue values are gathered in the lines

```
int  red   = (color & 0x00ff0000) >> 16;
int  green = (color & 0x0000ff00) >> 8;
int  blue  =  color & 0x000000ff;
```

All three colors are stored together in the variable ‘color’. In the first of the three lines,

```
0x00ff0000
```

is used to extract the red value from the three values (red, green, blue) being stored together. The zeros are used to mask all the other color values, and the two ff’s, which are hexadecimal for the number 256, allow the full value of red to be present. The

```
>>16
```

is used to move the value to right 16 positions so there is no blank space left over from where the other values were previously. The two other lines follow the same process, just masking out the other values so that specific color is the only one that can be seen. Because the blue value is already at the end, there is no need to shift it over either 16 or 8 spaces, so

```
>> 16
```

or

```
 >>8
```

is not present in that line of the code.

Next, the code determines whether the red, green, and blue values of the pixel are associated with the color white, whether it be bright white, dull white, or off white. All of these variations of the color are accounted for in the chosen parameters. If the pixel is discovered to fit within these parameters, it is then sent through a series of tests to determine if the pixel is in a place where white brain matter should not be present. It should be noted that in the type of MRI being used, white brain matter is represented by a black or dark gray pixel. An example of some of the tests the pixel is put through can be found below.

```
if((red>228&&red==green&&green==blue)||(red>=240&&green>245&&blu
e>240)||(red>=217&&red<228)&&(green==red)&&(blue==green))

            {
                    if((i==120)&&(291<=j&&j<=233))
                    {
                    noAbnormalityDetected =  true;
                    }
                    else if((159<=i&&i<=162)&&(426<=j&&j<=431))
                    {
                  noAbnormalityDetected =  true;
                    }
```

If the pixel is determined to not have an abnormality, the variable chosen the represent the presence of abnormalities will be changed to reflected this. For each pixel, a message will be printed if an abnormality is detected, by way of altering the user. The user will recieve multiple messages if multiple abnormalities are detected. Nothing will be printed for the user if no abnormalities are discovered.

```
if(noAbnormalityDetected=false)
                        {
                        System.out.println("An abnormality has been
detected. Please review the MRI.");
```

Results

We verified our code by testing it with brain MRIs both with and without abnormalities. On both counts, the code was effective, alerting the user when an abnormality was present, and not inaccurately alerting the user when an abnormality was not present. Because of the lack of real MRIs with and without abnormalities available in the public domain, specifically within the desire age range, it proved challenging to prove the code worked beyond a reasonable doubt. Though the code was accurate with the MRIs it received, this in no way guarantees that the code would be effective in a real world situation.

In order to obtain results that more reasonably prove the reliability of the code, a much greater amount of MRIs within the parameters of the project will need to be run through the code and used as a more accurate basis for determining where white brain matter should be found on the MRI. For this reason, as well as others that are explained in the *Future Work* section of this report, we plan on elongating this project into a two year project with the two members who will not have yet graduate from high school. Suggestions for future adaptations to the code that would make it more accurate are also detailed in the *Future Work* section of the report. Also, a more in-depth explanation of the challenges and successes associated with finding usable MRI images can be found in the *Personal Statement* section.

Conclusion

The applications of the code and all suggested future work are detailed in the following section of the report.

Real World Application

Currently, the majority of MRIs are examined by hand by a medical professional. This is an incredibly resource-draining process, requiring an immense amount of time dedicated to looking at each MRI. The introduction of a code like the one detailed above would almost entirely eliminate the time spent reading MRIs, with only the ones determined to have an abnormality need to be read. Though similar codes already exist, none are reliable enough to entirely eliminate the need for a medical professional to look at each MRI. Additionally, the finished code would also help to avoid brain MRIs going undiagnosed, which occur in some cases from human error.

Another effect would be the overall price reduction in MRIs, making it affordable to more families, and allowing more children to be diagnosed and receive the assistance they deserve. Because there would be no need for copious amounts of medical professionals to read each MRI, the expense of each individual one would go down.

Our code, with all of the adjustments detailed in the *Future Work* section of this report made, would not only be fast, but more effective than the current system. The code would be able to catch more minute abnormalities not always visible to the human eye, and would prevent children from not receiving treatment because of an overlooked abnormality.

Personal Statement

The most significant accomplishment of the project was overcoming the difficulty associated with finding appropriate MRIs to use for the project. Finding MRIs, both with and without abnormalities, was imperative to the completion of the project. They were not only necessary to check the validity of the code, but they were also necessary to find the areas that should be composed of white brain matter, the entire premise of the code. Multiple setbacks were endured, and, after experiencing fears that it would be necessary to change the topic of the project, usable MRIs were finally found. Not only did this allow for completion of the project, it also generated a great boost in morale.

Future Work

Because of the incredibly useful nature of a code with the ideal abilities of the one mentioned above, future work can be recommended to get the code in question up to the standards necessary for its implementation in the appropriate medical field. In order to continue working on and perfecting the code, we have decided to carry this project on into a second year. Although one team member will be graduating, preventing her from continuing on with the project, the other two plan on persisting, eliciting new mentors and other support in order to achieve full completion of the project.

When fully completed, our code will determine where white brain matter should be from a database of thousands of brain MRIs without abnormalities, making the parameters on which

the code is based more accurate. This will greatly decrease the probability of falsely altering medical professionals to a brain MRI, as well as decreasing the probability of brain abnormalities passing through the program without being recognized. This is a necessary step in the process of making the code usable and scientifically reputable.

Future work is also necessary as to creating many similar codes devoted specifically to the brain MRIs of patients of specific ages. As one of our main goals is catching developmental delays as early as possible, it is important to have a code aim directly at patients of young ages. The young brain is still developing, meaning that it is growing and changing drastically until approximately age two. Though our code is accurate for the brain MRIs of patients over the age of two, more code needs to be created specifically for patients whose age falls in between the range of birth and two years. There is not a one-fits-all code for this age range, but it is feasible to create code that addresses each major milestone of brain growth in this range.

Additionally, time could be put towards determining exactly where in the MRI the abnormality was found. Currently, the code tells the user whether or not an abnormality is present, but, in the event that an abnormality was found, the user is not told where the abnormality was discovered. Adding this capability to the code would both reduce the amount of time the user spends looking for the abnormality and allows for an increase in the overall capabilities of the code. If the location of the abnormalities is known, the code itself can determine what the abnormality is correlated to, reducing the amount of time required to be put in by the user to an even greater extent. This also allows for use of the code outside the realm of developmental delays, and as a general brain abnormality-determining program.

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Appendix

```
import java.io.*;
import java.awt.*;
import javax.imageio.ImageIO;
import java.awt.image.BufferedImage;

public class ATCCode
{
  public static void main(String args[]) throws IOException
   {
      File file= new File("20YABrainMRIAxialT2Dark.jpg");
      BufferedImage image = ImageIO.read(file);

//Shadow, Black (2014) GetPixelColor [Source code]

//<https://stackoverflow.com/questions/22391353/get-color-of-eac
h-pixel-of-an-image-using-bufferedimages>.
      boolean noAbnormalityDetected = false;

      int width = image.getWidth()-1;

//One is subtracted from the width because pixels start at 0,0.
      int height = image.getHeight()-1;

//One is subtracted from the height because pixels start at 0,0.
```

```
      System.out.println("The width is " + width + " and the
height is " + height + ".");

    if(width!=529||height!=639)
      System.out.println("The dimensions of the choosen MRI do
not match the specifications of the program. Please fit the MRI
to 5291X6101 and re-compile.");
    else
    {


      for(int i = 0; i <= width; i++)

//Increases width by one.
         {


            for(int j = 0; j<= height; j++)

//Increases height by one.
               {

noAbnormalityDetected =  false;

int color=  image.getRGB(i,j);

//Width goes first, then height.

int  red   = (color & 0x00ff0000) >> 16;
```

```
//Masks all colors except for red, then moves the value 16
spaces over.

int  green = (color & 0x0000ff00) >> 8;

//Masks all colors except for green, then moves the value 8
spaces over.

int  blue  =  color & 0x000000ff;

//Masks all colors except for blue.

//Shadow, Black (2014) GetPixelColor [Source code]
//<https://stackoverflow.com/questions/22391353/get-color-of-eac
h-pixel-of-an-image-using-bufferedimages>.

//System.out.println("The pixel at " + i + "," + j + " has a red
value of " + red + ", a green value of " + green + ", and a blue
value of " + blue + ".");

                  //Values associated with the color white

if((red>228&&red==green&&green==blue)||(red>=240&&green>245&&blu
e>240)||(red>=217&&red<228)&&(green==red)&&(blue==green))
                  {

if((i==120)&&(291<=j&&j<=233))
                  {
```

```
noAbnormalityDetected =  true;
                  }
                    else if((159<=i&&i<=162)&&(426<=j&&j<=431))
                    {
                   noAbnormalityDetected =  true;
                    }

                    else if((179<=i&&i<=181)&&(894<=j&&j<=501))
                    {
                   noAbnormalityDetected =  true;
                    }

                    else if(i==235&&j==386)
                    {
                  noAbnormalityDetected =  true;
                    }

                    else if((236<=i&&i<=241)&&(381<=j&&j<=395))
                    {
               noAbnormalityDetected =  true;
                    }

                    else if(i==241&&j==402)
                    {
                  noAbnormalityDetected =  true;
                    }

                    else if((242<=i&&i<=243)&&(383<=j&&j<=409))
```

```
      {
     noAbnormalityDetected =  true;
      }

      else if(244==i&&(384<=j&&j<=414))
      {
  noAbnormalityDetected =  true;
      }

      else if((245<=i&&i<=246)&&(385<=j&&j<=420))
      {
noAbnormalityDetected =  true;
      }

      else if((247<=i&&i<=252)&&(398<=j&&j<=428))
      {
     noAbnormalityDetected =  true;
      }

      else if((253<=i&&i<=257)&&(407<=j&&j<=416))
      {
     noAbnormalityDetected =  true;
      }

      else if((253<=i&&i<=255)&&(430<=j&&j<=433))
      {
  noAbnormalityDetected =  true;
      }
```

```
  else if((259==i)&&(393<=j&&j<=394))
  {
noAbnormalityDetected =  true;
  }

  else if((260==i)&&(325<=j&&j<=326))
  {
noAbnormalityDetected =  true;
  }

  else if((260<=i&&i<=264)&&(392<=j&&j<=406))
  {
 noAbnormalityDetected =  true;
  }

  else if((262<=i&&i<=264)&&(348<=j&&j<=353))
  {
 noAbnormalityDetected =  true;
  }

  else if((265<=i&&i<=266)&&(134<=j&&j<=136))
  {
noAbnormalityDetected =  true;
  }

  else if((265<=i&&i<=277)&&(402<=j&&j<=426))
  {
 noAbnormalityDetected =  true;
  }
```

```
                    else if((271<=i&&i<=282)&&(380<=j&&j<=393))
                    {
                 noAbnormalityDetected =  true;
                    }

                    else if((i==406)&&(j==268))
                    {
                noAbnormalityDetected =  true;
                    }

                        }


if(noAbnormalityDetected=false)
                        {

 System.out.println("An abnormality has been detected. Please
review the MRI.");

                        }
                }
          }
          }
     }
  }
```