Astronomy in Julia – ESI Optimizations

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***Abstract*—** The purpose of this project is to utilize the Julia language to analyze a sample of NASA's Exo-Planet and make a comparison between 4 variants of the ESI (Earth Similarity Index) equation.

***Index Terms*—** ESI (Earth Similarity Index), Transit, Stellar Flux, Standard ESI, Weighted ESI, Red Dwarf Star, Tidally Locked, Main Sequence Star, Custom ESI, Revised ESI, Julia, Jupyter Notebook, Linear Algebra, Plots, Iterative, XLSL

I. Introduction

In 1992, radio astronomers Aleksander Wolszcan and Dale Frail discovered two planets orbiting the pulsar PSR 1256+12. This discovery became the first of thousands to come in the following years. With the search for a habitable exoplanet now on the horizon, astronomer Schulze- Makuch and his team developed the ESI (Earth Similarity Index) as a means to determine how similar was an exo-planet to Earth [6].

The implementation of the ESI saw the rise of numerous potential Earth-like planets. One major hurdle that plagued the scientists however was the limits in the data they obtained from telescopes. The transit method, the most popular of the observation methods, relied on the finding of a dip in the brightness of the host star. That dip in brightness and the periodical recurrence of that same dip would indicate the existence of a planet [1].

II. NASA's ESI Variants

Early methods of exo-planet discovery provided a limited amount of data. Most of the available information consisted of the stellar flux and planet radius. The stellar flux, the measure of radiation a planet receives from its host star, became the focal point of the first equation, the Standard ESI equation. Earth's radius (Re) and stellar flux (Fe) were used as the baseline for the equation.

Standard ESI [2]:

$$\mathrm{ESI}(F,R) = 1 - \sqrt{\frac{1}{2}\left[\left(\frac{F-Fe}{F+Fe}\right)^2 + \left(\frac{R-Re}{R+Re}\right)^2\right]}$$

Highest ESI: Teegarden's Star B = 0.9502

The integration of two variables in the Standard ESI yielded Teegarden's Star B as the exo-planet with the greatest similarity to Earth. The planet's orbit in Teegarden's Star's habitable zone and its very similar radius to Earth reflect the high ESI score. However many in the scientific community still felt the use of two variables was inadequate. As a consequence, a new Weighted ESI equation was formulated to account for more factors.

The Weighted ESI equation utilizes a total of 5 variables: stellar flux, radius, density, escape velocity, and temperature. Each one of these variables has weights that affect the sensitivity of each factor. Temperature holds the highest weight because of the important role it plays in the habitability of planets.

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Weighted ESI variables [2]:

Variables	Weights
Flux	1
Radius	0.57
Density	1.07
Escape Velocity	0.70
Temperature	5.58

Weighted ESI:

$$\mathrm{ESI}(F,R,D,E,T) = 1 - \sqrt{\frac{1}{5}\left[\left(\frac{F-Fe}{F+Fe}\right)^2 + (0.57)\left(\frac{R-Re}{R+Re}\right)^2 + (1.07)\left(\frac{D-De}{D+De}\right)^2 \right.} \\ \left. (0.70)\left(\frac{E-Ee}{E+Ee}\right)^2 + (5.58)\left(\frac{T-Te}{T+Te}\right)^2 \right]$$

Highest ESI: Teegarden's Star B = 0.9636

The Weighted ESI's 5 variables deem Teegarden's Star B once again as the planet with the greatest similarity to Earth. The planet's similar radius, mass, and density to Earth suggest that the conditions in that world may be very similar to that of our planet. However Teegarden's Star B does have one startling distinction, the planet orbits a red dwarf star with a mass roughly 9 percent that of our Sun [2].

III. Custom ESI Variants

Red dwarf planetary systems are host to a multitude of issues that may prevent the development of life. The first notable problem lies with the range of the habitable zone. Due to the cooler temperature of red dwarfs, planets in the habitable zone often have orbital periods that range from 5 to 12 days. The close proximity of the planet to its star causes the planet to be tidally locked. One side of the planet would always face the star, and the other side would be left in perpetual night. The absence of a day/night cycle would render most of the surface of such planets unsuitable for life.

Another major problem that plagues red dwarf systems is the radiation of the stars. Red dwarf stars have a life cycle that is considerably longer than that of Sun-sized main sequence stars. Sun-massed stars often live 10 billion years. Red dwarf stars can ensure as long as 1 trillion years. Younger stars tend to send out frequent and more solar storms. Every red dwarf star in the universe is in its infancy. As a consequence, many of the planets orbiting such systems are much more irradiated than Earth or even Mercury [8].

Older ESI models fail to take the mass of the star into account. A planet such as Teegarden's Star B perhaps has a temperature comparable to that of Earth. But it will likely have a surface as irradiated as the ruins of Chernobyl. To mitigate this problem, we have formulated two new variants of the ESI equation. The first of these variants takes in a total of 9 variables, star temperature, and star mass among them, all unweighted. We have titled this first equation the Custom ESI. The structure of the equation is similar to that of the Standard ESI. The one notable difference is the use of 9 variables. The equation below is simply a compressed representation of a longer Custom ESI formula.

Variables: Flux, Radius, Gravity, Planet Mass, Temperature, Star Temperature, Star Mass, Orbital Period, Density.

Custom ESI:

$$\mathrm{ESI}(F,R,G,M,T,K,S,O,D) = \prod_{i=1}^{9}\left(1 - \left|\frac{x_i - x_{io}}{x_i + x_{io}}\right|\right)$$

Highest ESI: Venus = 0.7996

One problem that is immediately apparent with the Custom ESI formula is its inaccuracy. As many in the scientific community are aware, Venus is far too hot to be a habitable planet. The reason for this inaccuracy is due to the failure of the equation to weigh its values. The temperature should hold the highest weight. Factors such as star mass should be included, but they should not allow planets such as Venus to be counted as Earth analogs.

Revised ESI variables [8]:

Variables	Weights
Flux	3.2
Radius	0.57
Gravity	4.75
Planet Mass	0.4
Temperature	10.58
Star Temperature	1
Star Mass	1
Orbital Period	1
Density	2.8

Revised ESI:

$$\mathrm{ESI}(F,R,G,M,T,K,S,O,D) = \prod_{i=1}^{9}\left(1-\left|\frac{x_i - x_{io}}{x_i + x_{io}}\right|\right)^{\frac{wi}{9}}$$

Highest ESI: Kepler-452 B = 0.8478

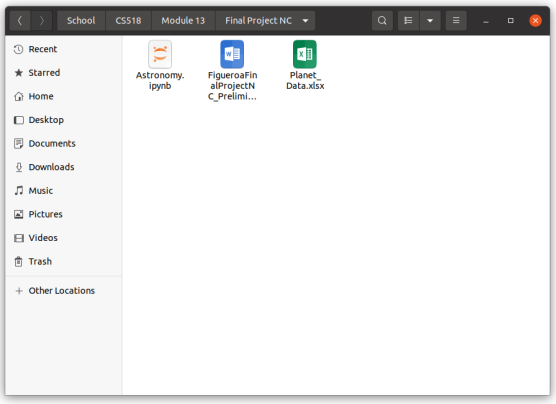
Kepler-452 B orbits a star similar in mass to the Sun. It has a temperature and orbital period similar to that of Earth. The one notable difference is the density of the planet. Earth has a density of 5.51 g/cm3, Kepler-452 B has a density of 4.21 g/cm3. The exo-planet has a larger mass and radius than Earth. The lower density suggests the planet may be a semi-gaseous planet or an ocean planet [3].

The Revised ESI is still not as reliable as it could be. However with further revisions, the Revised ESI could one day become a highly accurate method for determining the habitability of exo-planets. In the time being, this formula, and the other 3 formulas, will serve as the algorithms we will test on NASA's exoplanet catalog [2].

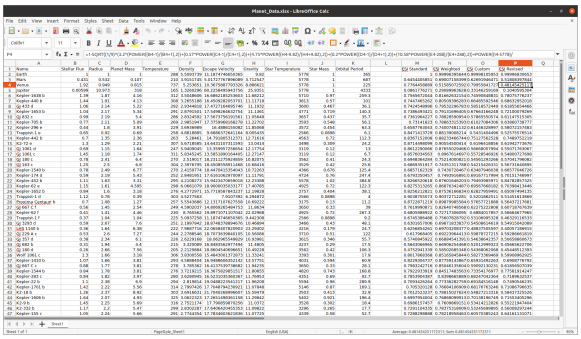
IV. The Setup

We have placed every file relevant to the project in a folder titled "Final Project NC". The Excel file "Planet_Data.xlsx" contains the data we have gathered from a source that lists every known potentially habitable exo-planet.

Project Directory Before Photos:



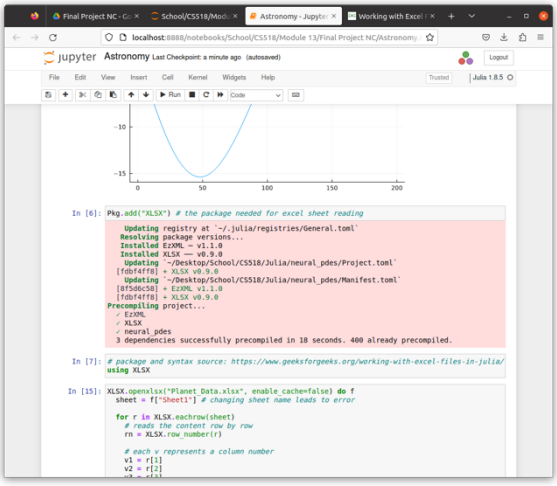
Planet Data Excel Content:



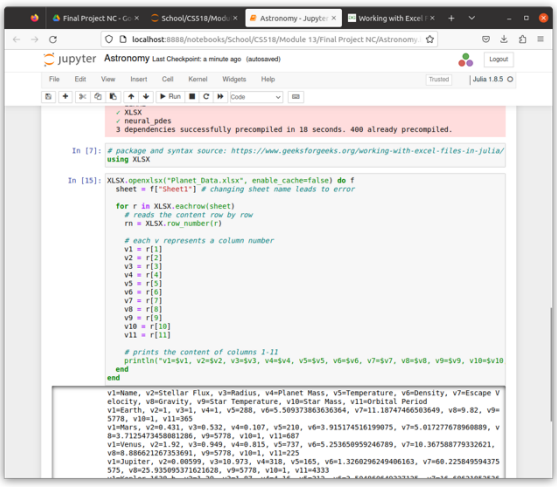
The content of the Planet_Data file displays the list of exo-planets and their attributes. The last 4 columns of the files display the results of the 4 ESI equation variants. Earth serves as the baseline point [9].

Our project directory contains another file titled "Astronomy.ipynb".This Julia Jupyter Notebook file contains a test code that displays the graph of an equation from Module 1, Software Part 2. The file also contains some code that utilizes the "XLSL" package which we will use to read the content of the "Planet_Data" file.

XLSL Package installation:



Data Reading Syntax [12]:



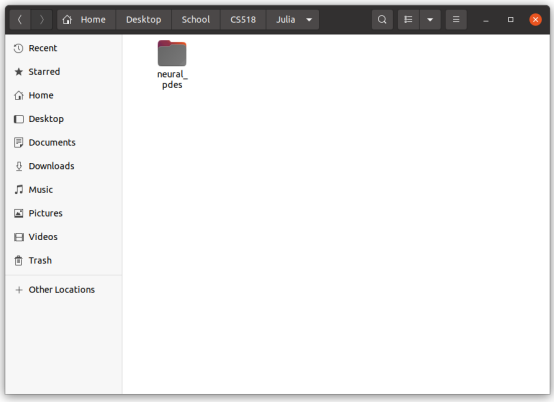
The Julia syntax from the screenshot above was sourced from *Geeksforgeeks.org*. The code snippet from above represents the beginning of the next stage of our project. We have done extensive research on the mathematical models that we intend to recreate. However, have noticed some concerning hurdles as we went through the installation of the packages.

V. Challenges in Coding

The Julia language comes with a vast library of packages that are included in the default installation. These packages have allowed us to successfully complete assignments 1-6 which have not required anything beyond the use of Linear Algebra. However, we ran into a number of setbacks as we made attempts to install additional packages into our Julia environment.

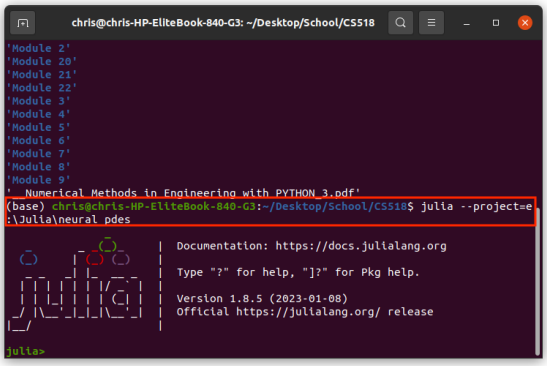
One essential package that we had trouble installing was the Plots package. Our environment titled "neural_pdes" was contained in the directory "e: Home:\\Desktop\\School\\CS518\\Julia". The syntax of the directory follows the Windows format as dictated by the Module 1, Software part 2 class write-up.

Environment directory:

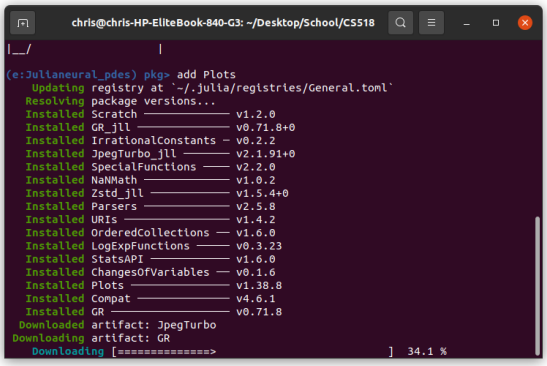


As we continued to follow the instructions of the module, we made an attempt to install the Plots package through the command prompt. The screenshots in the following page represent our unsuccessful attempt at the package installation.

Julia Environment Activation [10]:

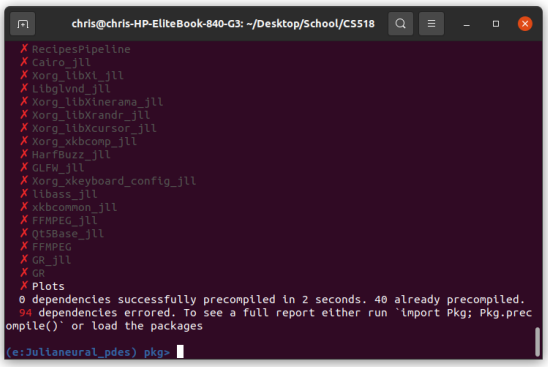


Seemingly Successful installation:



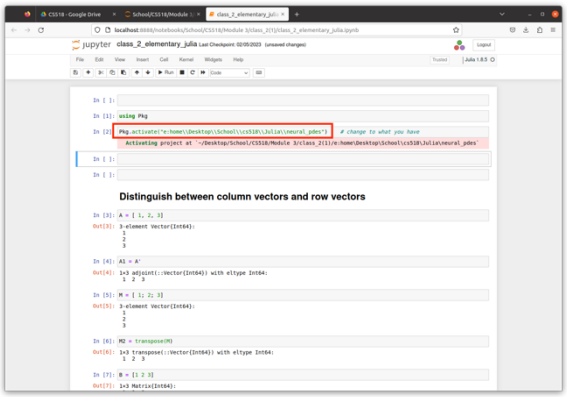
When we activated the environment and set Julia to package mode. The installation process at first appeared to run as it should. However, the moment we make the attempt to install the Plots package in the "neural_pdes" environment, the command prompt displays a dependency error. This same error occurs with a number of other packages as well.

Dependency Error:

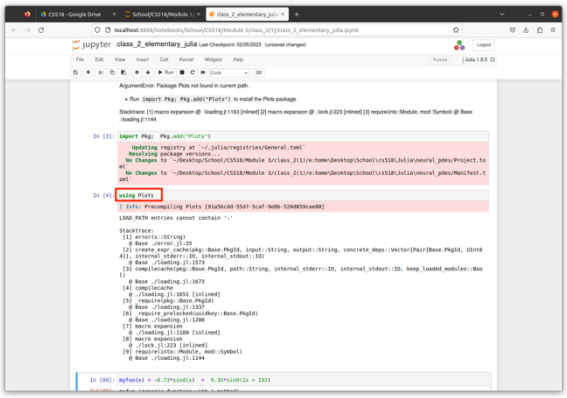


The consequence of an unsuccessful package installation can be seen in Jupyter Notebook. The line in the screenshot below that begins with "Pkg.activate" imports the "neural_pdes" environment onto the Notebook file.

Jupyter Notebook [10]:



Package Error:

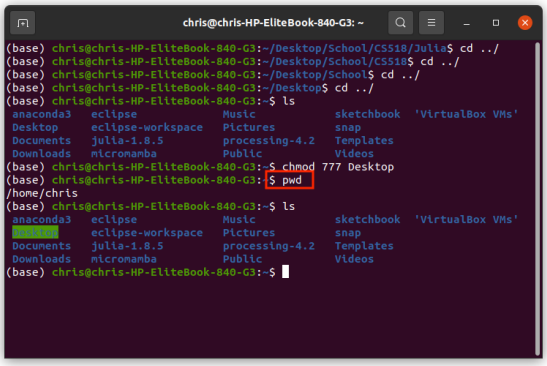


The statement “using Plots” yields an error that is a result of the unsuccessful installation of Plots into the environment. The cause of this error remained a mystery to us for a number of weeks. But there was one crucial detail that I did not take into account, my computer’s operating system.

VI. Overcoming Challenges

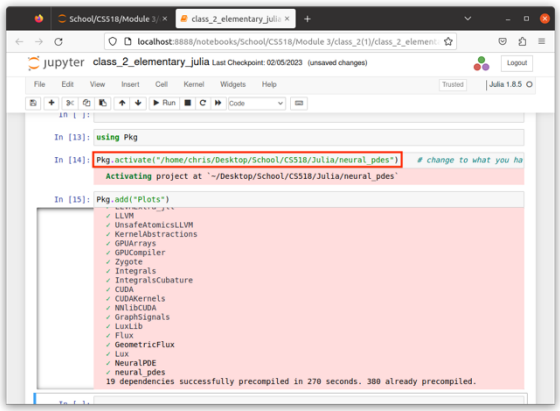
The instructions in Module 1 were meant for a computer that utilizes a Windows operating system. The main computer that my partner and I intend to use for this project runs a Linux system. The Linux operating system in some instances features some hidden folders that can only be found with the command “pwd”. This command reveals the folder “chris” which lies inside a folder titled “home”. The “chris” folder, the hidden folder that I did not spot before my use of the command, is the folder that contains the “Desktop” folder.

Hidden Folder:



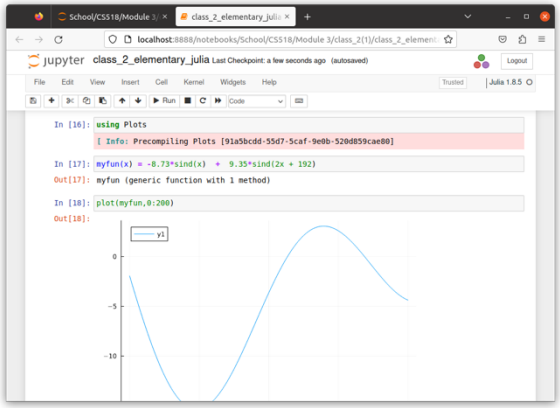
Another detail that we did not initially account for was Linux’s distinct directory syntax. The format of a Windows directory usually includes a double backslash “\\”. The Linux directory format by contrast utilizes a single forward slash “/” between each folder. A typical Linux directory also begins with “/home” rather than the “e:home\\” of a Windows directory.

Corrected Path:



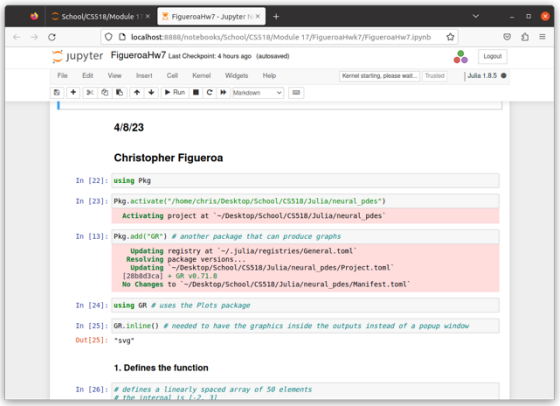
The new corrected directory syntax was “/home/chris/Desktop/School/CS518/Julia/neural_pdes”. This change in syntax allowed the Julia Notebook file to successfully activate the environment. With the path to the environment corrected, we are now able to use the Plots package to generate the graphs that we will need for this project.

Class 2 Graph code [13]:



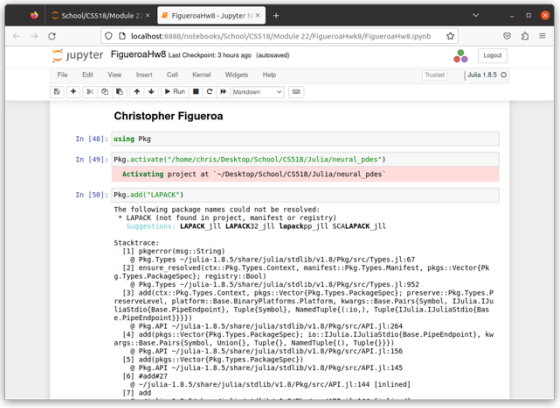
The “Astronomy.ipynb” file we have created contains code sourced from the Class 2 Code snippets. This code tests whether the Plots package works or not. The code in this particular displays the graph successfully. However, we have noticed that some other packages have been more difficult to install than others.

Assignment 7 GR Package:



The “GR” package necessary for Assignment 7 works as needed. The installation of that package into the environment worked as expected. We verified that the directory follows the correct Linux format.

Assignment 8 LAPACK Package:



The “LAPACK” package for Assignment 8 for some unknown reason cannot be installed in the manner that the Plots and GR packages were. Not even the “using LinearAlgebra, LAPACK” line worked for the homework. We may run into a similar issue as we come upon more coding examples that require the installation of additional packages.

VII. Conclusion

The next step in this project will involve more research into the ways numerical computing techniques can be used to find the appropriate variable weights for the Revised ESI equation. The implementation of iterative methods is one example of a technique we plan to use to guess the ideal weight values.

The implementation of iterative methods will rely on neural networks and a series of weights and biases to further refine the accuracy of the Revised ESI formula. This project will implement techniques from this course as well as elements from artificial intelligence, particularly deep learning. We will translate any code we find in our sources into Julia code [11].

The development of this ESI astronomy project began with the idea to create a more reliable way to find habitable Earth-like planets outside the Sol system. The initial research of the ESI equation led us to uncover new factors that affect the habitability of planets. With the discovery of these factors, we have derived the Revised ESI formula, which was a bi-product of the other three ESI variants.

We may have done a lot of research in the mathematical aspects of the project. We may have resolved the initial hurdles we faced with the installation of Julia packages. But now we should shift our efforts to the more practical component of the project. We will utilize the planet data inside our Excel file to generate a .csv file. This new file will serve as the source of the data that will be analyzed in the upcoming stages of the project.

References

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[12] M. Ridul, “Working with Excel Files in Julia”, *Geeksforgeeks.org*, p. 1-3, 2020.

[13] B. Andriamanalimana, “Class 2 Elementary Julia”, *Module 3*, 2023.