T H R E A D I N G — *Plotting ionospheric electron density*

## ABSTRACT

*March 2020:*
Sensing I would be spending the foreseeable future locked in the studio, I set out to apply myself to a 'complete' project. I wanted to hybridize all of the disciplines I'm familiar with: computer science, physics, engineering, mathematics, design, and art. My studio became a laboratory. After four months (June), I had a working printer. To make it more interesting, I worked until now to make it function autonomously; observing information and relaying it visually over time.

Conceptually, the system explores input and output (I/O) as being shared by both the human creative process and the digital/mechanical process. The creative mind is driven by imagination, interpretation, emotion, and reaction. In turn it applies those forces to some kind of material. Similarly, a system is driven by matching raw input to a corresponding action. Both respond programmatically —either directly or in a more nuanced way— to a set of inputs and subsequently relay their findings.

The 'input' side of my creative process is informed by things that are really limited these days (e.g.: traveling or going outside). To accommodate that, I existed in a smaller scope; exploring 'input/output' in a synthetic and concrete way. 'The system' —a primitive analog— became a set of eyes, a set of information they look at, and a tiny mind full of its own rules used to interpret and convey what it sees.

## CONCRETE

The paper, or picture plane, represents a map of the Earth using a Platte Carré projection. This simple cylindrical projection converts the globe into a Cartesian grid. The system responds to numeric input data translated to longitudinal (Y axis) and latitudinal (X axis) coordinates and plots/draws the input on the map. The longitudinal zero position (GMT) is determined in advance to capture a full 24 hour cycle of activity legibly. This system's most basic function is to draw a shape corresponding to the excitation (energy level) in the Earth's upper atmosphere due to the energy beaming at us from our Sun. I chose this dataset because it reflects things happening in the interstice between Earth and vacuum of space. I also enjoy the organic nature of the contours and their superimposing over time.

# LEGEND

*Synchronous (happening at a fixed interval of time):*

(1) CTIPE TOTAL ELECTRON CONTENT FORECAST. The Coupled Thermosphere Ionosphere Plasmasphere Electrodynamics (CTIPe) model, from the NOAA Space Weather Prediction Center, measures the concentration of electrons in the upper atmosphere (ionosphere) all over the globe.
The electron density is measured in TECU where 1 TECU = 10^16 electrons/square meter. The system gets this data from NOAA every 30 minutes and the data is interpolated. Once a maximum value for the current TECU measurement is found, a 2 dimensional contour is derived mathematically which reflects 85% of the maximum value. That contour is in turn plotted on the map.
The mathematical center of the contour is labeled with it's iteration number. The location (address) of the contour's center on the globe as well as the energy level of the contour are plotted at the top of the map. In the lower part of the map, a smaller version of the contour is plotted in sequence showing the actual local time of the iteration and its number. At the bottom of the map, the energy level is graphed indicating the normalized average (marked with a diamond shape) and level change and is plotted.

*Asynchronous (happening at a random interval of time):*

(1) SUN. The outline of the Sun as a contour derived from an overlay of the NASA SOHO observatory Extreme Ultraviolet Imaging Telescope and the NASA SOHO observatory Large Angle Spectrometric Coronagraph. The contour is plotted centered at it's approximate scaled longitude and latitude and is labeled "SUN". The position of the sun is also plotted and is labeled "S" followed by the number of the corresponding iteration.

(2) MOON. The position of the Moon is plotted and is labeled "M" followed by the number of the corresponding iteration.

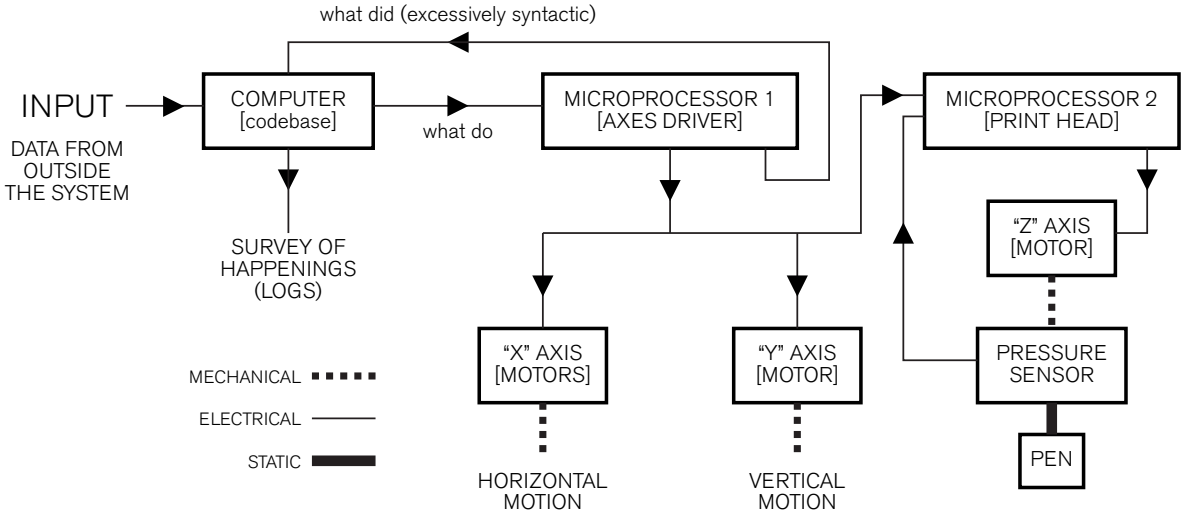
(3) ISS. The position of the International Space Station (ISS) is plotted and is labeled "I" followed by the number of the corresponding iteration. A unit vector indicating the direction of the ISS orbit path is attached to the label terminating in a arrow shape.

(4) LOCATION. Random locations on Earth are plotted.

(5) TIME MARKERS. Centered on equator.
"GMT" Greenwich Meridian Time (0 hours 0° Latitude)
"GMT +1" Greenwich Meridian Time + 1 (1 hours 15° Latitude)
"GMT + 12" Greenwich Meridian Time +12 (12 hours 180° Latitude)
"STUDIO" Location of my studio in Burlington, VT.
"ROYAL OBS." Location of the Royal Observatory (from which GMT is determined)

## TECHNICAL

The mechanics of the system are described in the following diagram:




The computer software is written in the Python programming language. It's several thousands of lines long and is the part of the system that turns input into output. Microprocessor 1 (axes driver) runs GRBL v0.9, an open source software used to power motors based on numeric 3 dimensional coordinates sent from the computer. GRBL code is written in C++. Microprocessor 2 (print head) runs code written in C++ and is responsible for determining the correct pressure and state of the pen that draws the plotted data. The Print Head features a small LCD screen which displays coordinates, number of motor steps and pressure and serial I/O when relevant.

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Integral Python code libraries:

**scikit-image** : Python image processing
*Stéfan van der Walt, Johannes L. Schönberger, Juan Nunez-Iglesias, François Boulogne, Joshua D. Warner, Neil Yager, Emmanuelle Gouillart, Tony Yu, and the scikit-image contributors. scikit-image: Image processing in Python. PeerJ 2:e453 (2014) https://doi.org/10.7717/peerj.453*

**shapely**: Manipulation and analysis of geometric objects in the Cartesian plane.
*There are over 100 active contributors to this project. Major portions of this work were supported by a grant (for Pleiades) from the U.S. National Endowment for the Humanities*

**skyField**: High precision research-grade positions for planets and Earth satellites generator.
*[ascl:1907.024] Rhodes, Brandon. Skyfield computes positions for the stars, planets, and satellites in orbit around the Earth. Its results should agree with the positions generated by the United States Naval Observatory and their Astronomical Almanac to within 0.0005 arcseconds (which equals half a "mas" or milliarcsecond).*

Input data resources:

**NOAA**: Coupled Thermosphere Ionosphere Plasmasphere Electrodynamics (CTIPe) model. Provides raw space weather data in text format for the system. The data is publicly available at:
*https://services.swpc.noaa.gov/experimental/text/ctipe-tec-output.txt*

**geocodeapi.io**: Geocode API enables geoparsing and geocoding at scale. The system uses the API to reverse-lookup the address information associated with a coordinate from the map.

## MADE POSSIBLE BY

**3dhubs, HQ in Amsterdam, Netherlands.**
Supplied 3d-Printed rigid resin components (3) used to translate rotational motion to linear motion (opaque white parts in print head). Integral to the actuation of the print head. 3d models designed using Autodesk Fusion360 with non-commercial license.

**Hayley Wood Products, Essex Junction Vermont.**
Supplied 9mm Baltic Birch Plywood (BB) for parts.

**Sammel Sign Company, Essex Junction Vermont.**
Supplied CNC (Computer Numerical Control) routing of many physical main assembly parts in the system design. Responsible for providing pre-finish milled parts from a substrate of 9mm Baltic Birch Plywood (BB). Sammel was able to prepare CADCAM paths and mill work from parts that were 3d modeled/designed using Autodesk Fusion360 with non-commercial license.

**Vermont Art Supply, Burlington, Vermont.**
Supplied materials essential to the system's development including pens, paper, tape, solidarity, and ongoing moral support.

**Curtis Lumber, Burlington, Vermont.**
Supplied post-assembly parts of the system.

**City Hardware, Burlington, Vermont.**
Supplied post-assembly parts of the system.

**SoapBox Arts, Burlington, Vermont.**
Provided a platform on which this system can be shared with other people.

**SHOUTOUT TO:**
Ngrok, Military Time, MatPlotLib, peer-pressure,  Burlington,  vaccines, the globe, government, moral leadership, challenges, turbulence, priorities, respect,, and work.