# Inferring Patterns of Neural Response with STL Learning
(Technical Paper)

# The Role of Informational Ubiquity in Belief Formation

(STS Paper)

A Thesis Prospectus Submitted to the

Faculty of the School of Engineering and Applied Science
University of Virginia • Charlottesville, Virginia

In Partial Fulfillment of the Requirements of the Degree
Bachelor of Science, School of Engineering

Robert Michaels
Spring, 2020

On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

Signature _______________________________________ Date __________
Robert Michaels

Approved _______________________________________ Date __________
Lu Feng, Department of Computer Science

Approved _______________________________________ Date __________
Michael Gorman, Department of Engineering and Society

# Technical Prospectus

## Introduction/STL Overview

Signal temporal logic (STL) is form of mathematical expression which incorporates symbolic logic and temporal constraints to determine whether a  changing system of various metrics or conditions satisfies certain criteria. As opposed to standard symbolic logic which can only determine if a set of variables satisfies logical formulae at a particular state, temporal logic includes operators accounting for time-based criteria such as variables eventually reaching some satisfactory condition, always satisfying some condition within a specified time frame, and so on. Signal temporal logic in particular employees the usage of temporal logic formulae with a stream of variable data over time which can be either analyzed after data has been collected, or run in-line with live data to see if a system fits the criteria in real time. Additionally, instead of a qualitative satisfaction requirement, STL formulae can be implemented in a quantitative manner with a robustness score which indicates to what degree a set of variables satisfy the parameters of the STL system (Bartocci, 2018).

STL has potential to be of particular use within the field of cyber-physical systems. Since this type of system is one which provides several types of biometric data over time, STL can be used to create monitoring systems in order to attempt to classify when metrics would indicate some sort of overall state outside of normal parameters. The group I am working with has done previous research on incorporating STL with data monitored from diabetic patients in order to potentially classify anomalous changes in blood glucose levels or detect when a patient may have forgotten to record a meal in relevant monitoring software (Young, 2018).

## Genetic STL Learning

While STL provides a framework for satisfiability conditions given a signal, deriving STL formulae is not necessarily a straightforward affair. Instead of trying to assess data for patterns, genetic STL learning provides an algorithmic approach for creating STL formulae and parameters.

Nenzi et al provide an algorithm for defining such formulae (2018). The essential pattern of this algorithm is generating formula patterns, best fitting parameters to the data set at hand, then taking the most robust formulae for classification and mutating/combining these to develop a new generation of formulae. This pattern can be repeated any number of times with the intention of developing more descriptive formulae at each generation.

Practically, this involves dividing a group of temporal signals into a labeled set as to whether a given set of variables describes a particular set of data. In the example of the diabetic assessment application previously mentioned, this would be a physiological state of components such as blood glucose at odds with reported data of meal intake. This step is not automated and performed by the data analyst who knows about the actual state of the system (ie. knowing an individual failed to record a meal in the diabetic monitoring case).

Formula generation is initially performed by randomly assigning conjunctions of one or more variables using STL formulae (ie. glucose levels being above a certain level within some future time given that a certain amount of carbohydrates have been ingested at a time). These formulae then have their robustness values (the extent to which they discriminate between the labeled cases and other states) and the best formulae are chosen for inclusion in the next generation of the algorithm. The STL properties of included formulae are then used with some degree of random change to create formulae for the next generation. These new formulae are then assessed for robustness and mutated/combined for however many generations are specified.

**Application to Neurological Data**

This sort of genetic algorithm has the potential for novel applications in analysis of neurological data. For this particular project, I plan on using neurological data provided through UC Berkeley's Collaborative Research in Computational Neuroscience (CRCNS) program. Specifically, I will be doing analysis on the pvc-3 data set, which is based upon recording neuronal activity in the primary visual cortex in response to a variety of stimuli (CRCNS, 2020). Since this data tracks individual neuronal activity in a sensory region of the brain, STL learning has the potential to map incoming stimuli to the activity of a particular neuron or combinations of multiple neurons firing in groups.

As a brief overview, the concept of receptive fields has been used for decades in neurophysiology to make this sort of sensory stimulus response mapping on the neuronal level (Ringach, 2004). These receptive fields in the context of visual stimuli include perception of particular shapes, as well as perception of patterns in motion. There have been studies performed confirming that the visual cortex of various animals does, in fact, follow these sort of direct response to geometric visual perceptions of their environment (Donner, 1981) (Camarda, 1976). While these sort of correlations have traditionally been made using statistical inference on the level of individual neurons, STL learning provides the potential for more complex associations and combinations of neural activity from a particular stimulus to be expressed.

Part of the difficulty in accurately mapping brain activity to stimuli is the sheer complexity of connections within the brain. While individual neurons may be responding to particular retinal stimuli in the case of visual stimuli, there are also a vast number of interconnections between downstream sensory neurons. STL learning may have the potential to create more robust stimulus mapping over a variety of neurons, and may be more generalizable to other activity within the brain. As this is an application yet to be explored in the field of computational neuroscience, there is a great deal of potential future application which should be investigated to some degree if any sort of compelling results are derived from this experiment.

## **Works Cited**

Bartocci, E., & Falcone, Y. (2018). Specification-Based Monitoring of Cyber-Physical Systems: A Survey on Theory, Tools and Applications. In *Lectures on Runtime Verification* (pp. 135–175). New York, United States: Springer Publishing.

Camarda, Rosolino, and Giacomo Rizzolatti. "Visual Receptive Fields in the Lateral Suprasylvian Area (Clare-Bishop Area) of the Cat." *Brain Research*, vol. 101, no. 3, 1976, pp. 427–443., doi:10.1016/0006-8993(76)90469-8.

"Collaborative Research in Computational Neuroscience - Data Sharing." *Collaborative Research in Computational Neuroscience - Data Sharing*, 2020, crcns.org/data-sets/vc/pvc-3.

Donner, K. "Receptive Fields of Frog Retinal Ganglion Cells: Response Formation and Light-Dark-Adaptation." *The Journal of Physiology*, vol. 319, no. 1, Jan. 1981, pp. 131–142., doi:10.1113/jphysiol.1981.sp013896.

Nenzi, L., Silvetti, S., Bartocci, E., & Bortolussi, L. (2018). A Robust Genetic Algorithm for Learning Temporal Specifications from Data. *Quantitative Evaluation of Systems Lecture Notes in Computer Science*, 323–338. doi: 10.1007/978-3-319-99154-2_20

Ringach, Dario L. "Mapping Receptive Fields in Primary Visual Cortex." *The Journal of Physiology*, vol. 558, no. 3, 2004, pp. 717–728., doi:10.1113/jphysiol.2004.065771.

Young, W., Corbett, J., Gerber, M. S., Patek, S., & Feng, L. (2018). DAMON: A Data Authenticity Monitoring System for Diabetes Management. *2018 IEEE/ACM Third International Conference on Internet-of-Things Design and Implementation (IoTDI)*. doi: 10.1109/iotdi.2018.00013

## STS Prospectus

### Introduction

The internet has fundamentally changed the way in which we gather information on an individual level. Whereas in the past the majority of people's world-views were largely shaped by formal education and the communities around us and it would require concerted, dedicated effort to be exposed to new information, the internet provides us with the opportunity to connect with the sum of all human knowledge in seconds with a simple search engine query.

While this widespread informational access provides opportunities never seen before in human history, it does come at a cost. Even though internet access allows for self-driven education and the possibility for marginalized groups to connect to similar individuals, this cuts both ways. The onus of parsing information lies on the individual, which has directly led to the resurgence of fundamentally anti-scientific concepts such as flat earth theory and anti-vaccination, as well as recruitment for extremist political organizations such as ISIS and various ethnonationalist entities worldwide.

For my STS topic, I hope to explore the factors at play for belief formation in the information age, as well as efforts which may be taken to reduce the spread of misinformation and potentially dangerous politically extreme rhetoric.

### Patterns of Internet Usage

We are rapidly approaching a society which is ubiquitously connected to the internet. According to the Pew Research Center (2019), 90% of Americans had consistent access to the internet in 2019, as opposed to 52% of the population in 2000. At the global scale, statistics from the World Bank (2017) indicate that worldwide internet adoption rates rose from 6.7% in 2000 to 49.7% in 2017.

This widespread trend of increased internet access has fundamentally changed how individuals both receive and process information. A combination of an increased rate of informational dispersal and a system of globally available information has led us to an age where any individual has the ability to both access content and disseminate their ideas at a global scale.

With this adoption of new media, there is an observable shift in how the average person is forming their worldview. As of 2017, the proportion of Americans who "often received news from" social media surpassed print (Shearer, 2018). Additionally, the reduction of barriers to dispersing one's ideas through social media, blogs, and video platforms means that whoever can post whatever whenever with minimal overhead required to disseminate their ideas to the public. With more and more people forming their beliefs from fundamentally different (and frequently less reliable) media than generations past, it is important to investigate the patterns of how individuals are forming their worldview through the content they choose to consume.

## Psychological Patterns of Belief Formation

In order to explain emerging patterns in belief formation, it's important to understand the underlying psychological mechanisms at play in content consumption. The psychological constructs of confirmation bias and the Dunning-Kruger effect can explain much of the spread of misinformation, whereas the concept of filter bubbles provides a framework more specifically tailored to the internet.

A driving psychological concept in modern media consumption is confirmation bias, the concept that an individual is more likely to accept information confirming previously held beliefs. R. Nickerson summarizes the general phenomenon of confirmation bias as "people do not naturally adopt a falsifying strategy of hypothesis testing. Our natural tendency seems to be to look for evidence that is directly supportive of hypotheses we favor." This concept goes hand-in-hand with that of filter bubbles, the concept that the sheer volume of content on the internet allows us to pick and choose the information we consume based on preexisting notions (Pariser, 2009). The fact is that when there is an excess of information, particular wording of search engine can lead to obtaining any desired result on a particular subject. Not to mention specific social media groups which are dedicated to content pushing a certain point of view which may not hold objective truth. When individuals are given the option of consuming an effectively unlimited amount of information on any given topic, there's no reason (and frequently no desire) for them to branch out and investigate conflicting points of view.

Additionally, the Dunning-Kruger effect is the recurring pattern that people tend to have a disproportionately sharp increase in their confidence regarding understanding a subject when they know only a small amount about the subject (Dunning, 2011). This explains many argumentative patterns one may observe online with the spread of fringe apolitical beliefs, as well as disinclination for individuals to change their minds on subjects they know very little about. Combined with confirmation bias and the sheer amount of available content, individuals can easily fall into a content consumption pattern where they are consistently receiving the same, limited information on a subject and becoming increasingly self-confident regarding their knowledge, potentially going on to propagate their absorbed misinformation and misinterpretations into their social networks at large.

## Anticipatory Governance to Mitigate Misinformation Spread

In regards to mitigating the spread of misinformation, a useful STS framework may be that of anticipatory governance, "a broad-based capacity extended through society that can act on a variety of inputs to manage emerging knowledge-based technologies while such management is still possible" (Guston, 2013).

As obvious technique which has been applied on many social media platforms is that of removing content which may be misinformation or inciting extremist responses. Though this does prevent particular instances of such content from spreading in the short term, the sort of individuals espousing this sort of content often end up migrating to other platforms which may specifically cater to their interests. The censorship of their ideas, no matter how damaging they may be, is frequently viewed within these groups as justification for a more confrontational approach. Additionally, once within these sort of echo chambers, it's unlikely any such individuals would return to a platform where they may receive push-back from conflicting ideas.

I believe that it is of utmost importance to prepare future generations for responsible internet usage in the information age. Concepts such as having licensing to use the internet in a responsible manner may reduce the spread of misinformation if implemented, but this would inevitably run at odds with the egalitarian nature that makes the internet such a valuable tool. I believe that an emphasis should be placed on education of internet usage, techniques used by bad actors to manipulate individuals, and critically parsing information one may encounter on the internet. Perhaps education needs to be formally addressing this from an early stage, since even young children now frequently have access via smart phones.

Though misinformation is a fundamentally human problem, in that we will never be a planet full of perfect responsible beings without some degree of misconceptions about our universe, steps can be made to improve our overall usage of this amazing emergent technology. Any satisfactory solution will require to some degree individual responsibility, and I believe that we can make great strides in teaching people the tools they need to make their own decisions in an improved manner.

**Works Cited**


Demographics of Internet and Home Broadband Usage in the United States. (2019, June 12). Retrieved from https://www.pewresearch.org/internet/fact-sheet/internet-broadband/.

Dunning, D. (2011). The Dunning–Kruger Effect. Advances in Experimental Social Psychology, 247–296. doi: 10.1016/b978-0-12-385522-0.00005-6

Guston, D. H. (2013). Understanding 'anticipatory governance.' *Social Studies of Science*, *44*(2), 218– 242. doi: 10.1177/0306312713508669

Individuals using the Internet (% of population). (n.d.). Retrieved from https://data.worldbank.org/indicator/it.net.user.zs.

Nickerson, R. S. (1998). Confirmation bias: A ubiquitous phenomenon in many guises. Review of General Psychology, 2(2), 175–220. doi: 10.1037//1089-2680.2.2.175

Pariser, E. (2012). The filter bubble: how the new personalized web is changing what we read and how we think. New York, NY: Penguin Books.

Shearer, E. (2018, December 10). Social media outpaces print newspapers in the U.S. as a news source. Retrieved from https://www.pewresearch.org/fact-tank/2018/12/10/social-media-outpaces-print-newspapers-in-the-u-s-as-a-news-source/.