White Paper for DARPA Seedling Grant

Dopamine Expression Tracking (DExTra)

Submitted by: Arrow Analytics, LLC (service disabled veteran owned small business)

ABSTRACT

This white paper outlines a proposed effort for a DARPA seedling grant aimed at developing a minimally viable product (MVP) that integrates eye-tracking and facial expression recognition technologies into a comprehensive Government Purpose Rights (GPR) software tool. There are three applied use-cases for this tool: 1) assessing adversarial malign propaganda or testing friendly psychological operations campaigns at lower cost and risk with fewer participants; 2) a diagnostic tool for humans with dopamine deficiencies (e.g. substance use disorder, Parkinson's disease), and 3) establishing a proof of concept for future automated testing of propaganda without participants. This project seeks to conduct rigorous scientific experiments to validate and extend the capabilities of this tool, while also pioneering a prototype dopamine measurement model that utilizes signals from eye tracking and facial expression recognition. Additionally, the proposed research aims to validate this model through use of a proven laboratory protocol for generating experimentally controlled spikes in dopamine and the University of Central Florida's rapid dopamine measurement blood test.

1. INTRODUCTION:

In an era marked by the relentless evolution of information warfare, the development of cutting-edge technologies capable of deciphering the intricate interplay between the human brain and propagandistic stimuli has become imperative. This white paper outlines a pioneering initiative proposing the integration of neuroscience technologies, specifically eye-tracking and facial expression recognition, to revolutionize the measurement of brain responses to propaganda, fake news, and disinformation. The technology envisioned seeks to mitigate risks inherent in traditional assessment methods by leveraging deep brain responses to media, which are inherently physiological and exhibit reduced variance across subjects. By employing these advanced tools, our aim is to enable effective assessments with significantly fewer respondents, streamlining the evaluation process. This not only reduces the cost to assess adversarial and friendly media content, but also reduces the risk incurred with such a test.

Beyond its immediate application in influence operations, this groundbreaking technology holds promise for medical diagnostics, particularly in identifying impaired dopamine conditions such as substance abuse disorders, Parkinson's Disease, and other neurological conditions. We aim to empower decision-makers with unparalleled insights into cognitive and emotional responses, fostering a more resilient and informed response to the complex challenges of the contemporary information landscape. The proposed effort responds to the growing need for advanced tools supporting full-spectrum operations. Integrating eye-tracking and facial expression recognition into a unified platform aims to provide a multifaceted approach to understanding human behavior, with an innovative extension into dopamine measurement for a more nuanced assessment.

The foundational theory for this effort is known as the James-Lange Theory[1], which is one of the oldest in neuroscience. James and Lange describe the sequence of neural responses to stimuli. The first stage is physiological, where people experience a conditioned physiological response to stimuli. For example, a person that sees a wasp may experience elevated heart rate or begin to perspire. The second stage is emotional, where people experience emotions in response to the physiological changes in their body. For example, the person with elevated heart rate and perspiration may feel fear and anxiety. The third state is conscious rationalization, where the person is aware of and rationally explains their emotion.

We posit that at each stage in the James-Lange model, error can be introduced. Dr. Christophe Morin of SalesBrain, a consumer neuromarketing firm, uses a two-stage model in their commercial work, based off system one and two thinking proposed by Nobel laureate Daniel Kahneman[2]. Morin argues that there is a primal brain (system 1) that is primarily responsible for our actions and

[1] Lange, C. G. E., & James, W. E. (1922). The emotions, Vol. 1.
[2] Kahneman, D. (2011). *Thinking, fast and slow*. Macmillan.

decisions and there is a rational brain (system 2) that rationally justifies and explains our actions[3]. They achieve much stronger and more accurate results of consumer behavior and response to marketing campaigns with far fewer human research participants by measuring brain reactions in the primal brain regions. They call this the "buy" button of the brain. Their typical technologies for measuring primal brain response include EEG, galvanic skin response, eye-tracking, pupillometry, among others. Recently, they have been using facial expression recognition during COVID to approximate primal brain response to stimuli to include reaching target audiences in Ukraine and Russia for assessing Avon advertisements. Their use of facial expression recognition has been proven to be comparable in performance to traditional EEG and other neuroscientific measurements. The current tool used by SalesBrain is not extensible, has high license costs, and can only be deployed through a non-secure cloud. Our proposed MVP will extend the two-stage SalesBrain model to a three-stage model based on James-Lange to be more extensible, and deliver a GPR solution that preserves government security and flexibility in deployment.

The importance of neuroscience to information warfare is not new. McCulloh published a neurocognitive influence model with the DoD Strategic Multi-Layer Assessment (SMA) conference[4]. In his model, he notes that people are often unable to accurately report their intended behavior or reactions to influential stimuli and provides empirical evidence to show that neural response is a stronger predictor of behavior. The DoD has funded work to effectively assess neural response to psychological operations videos and content with success. The work to date, however, has focused on measuring activity in the prefrontal cortex, which measures the rational brain as it mobilizes to explain deeper, primal brain responses. Through the proposed technology, we aim to more precisely target the brain regions that matter. Moreover, we intend to do it with a tool that can be safely deployed in semi-permissive environments with low risk and cost to service members.

2. TECHNOLOGY INTEGRATION:

The MVP will seamlessly combine eye-tracking and facial expression recognition technologies, enabling real-time analysis of human responses. This integrated tool will serve as a foundational platform for subsequent scientific experiments and the development of the dopamine measurement model. Partial development of this tool has already begun and can be tested at http://brain-gaze.com. The current prototype is an AWS-hosted tool that captures eye-tracking data via webcam for a single video media file. We are extending the tool to capture users' facial images to allow training a facial expression recognition model. The tool can be used with a number of deployment protocols to include crowdsourcing thru Amazon Mechanical Turk (AMT).

The seamless integration and transition of this web-based software promise transformative applications across diverse sectors. For the US Global Engagement Center (GEC), this technology offers a cost-effective and risk-mitigated approach to assess foreign malign disinformation by testing potentially threatening content among small virtual focus groups. Similarly, the US Army Psychological Operations community can utilize this tool to enhance the effectiveness of their coordinated campaigns by testing products and series. In the realm of healthcare, the Brain Rise Foundation, a non-profit organization, will harness this innovative technology to equip their network of first-line treatment centers with advanced capabilities for combatting substance use disorders. Furthermore, SalesBrain and other neuromarketing companies stand to benefit from the tool's application in assessing commercial advertisements, offering valuable insights into consumer responses and preferences. This technology, with its broad-ranging utility, is poised to become a pivotal asset in addressing complex challenges across information warfare, psychological operations, healthcare, and marketing domains.

3. SCIENTIFIC EXPERIMENTATION:

This project will consist of three phases. In phase 1, the Brain-Gaze application will be further developed to create a user interface for the analysis of eye-tracking and facial expression data. This will be tested and validated using FeelPix[5], an open source resource for validating facial expression recognition tools available at https://github.com/ludovicalamonica/FeelPix. We may also validate

[3] Morin, C. (2011). Neuromarketing: the new science of consumer behavior. *Society*, *48*(2), 131-135.

[4] McCulloh, I. (2016). Neuroscience of Influence. *White Paper on Bio Psycho Social Applications to Cognitive Engagement*. Washington DC: Office of Secretary of Defense-Strategic Multilayer Assessment.

[5] La Monica, L., Cenerini, C., Vollero, L., Pennazza, G., Santonico, M., & Keller, F. (2023). Development of a Universal Validation Protocol and an Open-Source Database for Multi-Contextual Facial Expression Recognition. *Sensors*, *23*(20), 8376.

the tool against previously collected content from SalesBrain. This will establish an initial MVP that can be used for evaluating the effectiveness of both adversary and friendly influential content.

The second phase will involve a slight modification to the Brain-Gaze application to modify the stimulus presentation to consist of the dopamine stimulating computer game used by Ken Kishida at Wake Forest University[6]. Dr. Kishida has used fast-scan cyclic voltammetry, an electrochemical technique, paired with machine learning, to detect and measure dopamine levels in real-time on patients undergoing invasive procedures such as deep brain stimulation. Kishida's protocol demonstrates the ability to create reliable changes in dopamine levels in a laboratory setting without the need for invasive surgical procedures. We will use this protocol within the Brain-Gaze application to collect eye-tracking and facial expression data for training new computer vision machine learning algorithms.

Depending on available resources, we may be able to utilize an innovative technology for non-invasive rapid dopamine measurement developed by Debashis Chanda at University of Central Florida. The problem with dopamine measurement from blood is that it detects general dopamine in the body and may not be as temporally responsive to changing stimuli and associated brain activity.

The third phase will test the Brain-Gaze application on dopamine-compromised individuals and healthy controls to create a proof of concept for dopamine detection. This will be limited to testing the tool's ability to measure changing dopamine levels in individuals. We may be able to test retrospective facial expressions collected by SalesBrain to test whether dopamine detection provides a better measure of neuromarketing success than current emotion detection. At this time, it is unclear if the data will lend itself to this type of test and whether we will be permitted to use the data due to client restrictions on their content.

Arrow Analytics LLC often uses a third party IRB service for human subjects testing and all employees are certified in human subject research. Depending upon our collaboration with partners at the University of Central Florida and Wake Forest University, we may use one of the university IRBs. Human subjects research will follow all ethical guidelines for this type of research.

4. DOPAMINE MEASUREMENT MODEL:

The proposed prototype dopamine measurement model will leverage signals from eye-tracking and facial expression recognition to infer dopamine levels. This innovative approach aims to enhance our understanding of cognitive and emotional states, providing valuable insights for a range of applications. During the development of dopamine detection models, we may set-up a laboratory environment with multiple cameras with higher resolution than expected with a typical webcam. This will be used to create better baseline computer vision models that may be fine-tuned for webcam application later.

6. EXPECTED OUTCOMES:

The technology's practical applications include assessing adversarial malign propaganda, conducting psychological operations campaigns with fewer participants, serving as a diagnostic tool for dopamine deficiencies, and laying the groundwork for automated propaganda testing without participants. This lays the foundation for a future DARPA program that has the benefit of dual-use application. On the public-facing side, this technology provides a diagnostic capability for physicians treating a wide range of medical conditions from substance abuse disorder to neurological conditions such as Parkinson's or Huntington's disease. On the close-hold side, this technology provides a capability to test both friendly and adversarial influence products in a more effective way. It will allow unprecedented capability to test whether a malign meme or video is likely to achieve effects and require a response or be ignored. Moreover, we can reverse engineer influential effects and design more effective campaigns while assuring decision makers that those campaigns are of reduced risk. This is a game-changing technology that can help the US regain lost symmetry in the information domain.

7. KEY PERSONNEL:

Dr. Ian McCulloh will be the PI. He founded Arrow Analytics almost 10 years ago to conduct neuroscience and data science research and consulting. He is a retired Army officer, culminating as the Chief of Strategy and Assessments for the US Central Command's Information Operations Division (J39). He is a veteran of Afghanistan and Iraq, West Point professor (Math, Comp. Sci), established the

[6] https://newsroom.wakehealth.edu/news-releases/2023/12/research-shows-human-behavior-guided-by-fast-changes-in-dopamine-levels

Army Network Science Center, and has been a PI on 37 competitive federal research programs to include 3 DARPA programs. He was faculty at Johns Hopkins University with joint appointments in computer science, public health, and the Applied Physics Lab. He maintains an adjunct faculty position teaching graduate AI/ML and neuroscience courses. He established Accenture's Federal AI practice, growing it from 36 to 1200 people between 2019-2023, established an $80M competitive research program, and delivered five of the largest at-scale AI programs in the US Government. He holds a PhD in computer science from Carnegie Mellon, has authored three books and over 100 peer-reviewed academic papers.

Dr. Christophe Morin will be the co-PI. With over 30 years of experience in consumer research and advertising strategy, Christophe's passion is to understand and predict consumer behavior using cutting-edge science. Christophe has run and started many businesses as well as held senior positions in several publicly traded companies. Christophe holds an MBA from Bowling Green State University, an MA in Media Psychology and a Ph.D. in Media Psychology from Fielding Graduate University in Santa Barbara, California. He joined the Adjunct Faculty of the Media Psychology department of Fielding in 2013 as a professor of Media Neuroscience. Christophe has received numerous awards during his career as a speaker (Vistage 2011 and 2013) and a consumer researcher (ARF 2011, 2014 and 2015). He has given over 1200 talks and lectures on the subject of neuromarketing and consumer neuroscience since 2003. Most recently, Christophe published The Persuasion Code in 2018, the first book decoding the effect of advertising messages on the brain. His latest book is entitled The Serenity Code (9/2020). In it, Christophe unveils a unique model to help millions of people rewire their brains to experience life without stress, anxiety and depression.

Arrow Analytics may employ additional junior data scientists under the supervision of Dr. McCulloh to clean and explore the data at a more cost-effective rate.

8. BUDGET & DURATION:

Total Request: $1,000,000 for a period of 12 months.

Allocation: Software development, testing, human subjects recruiting/compensation, model development, research publication.

9. CONCLUSION:

This DARPA SBIR proposal outlines a comprehensive effort to advance government rights technology through the integration of eye-tracking, facial expression recognition, and a pioneering dopamine measurement model. The proposed research will not only yield a groundbreaking MVP but also contribute valuable insights and applications in the fields of national security, psychology, and healthcare.