Fundamentals of Computational Psychophysiology: Theory and Methodology

WELCOME to the second issue of IEEE TRANSACTIONS ON COMPUTATIONAL SOCIAL SYSTEMS (TCSS) in 2022. In this issue, we are going to present 25 regular articles. After the "scanning the issue," I would like to share some of my opinions and perspectives on the fundamentals of computational psychophysiology: theory and methodology.

I. SCANNING THE ISSUE

1. "An Agent-Based Modeling Approach to Brain Drain" by *Furkan Gürsoy and Bertan Badur*

This study provides an agent-based model for the emigration dynamics of skilled workers. A few abstract variables are proposed to represent the variables employed in the related literature, capturing the main factors. The proposed computational model is validated with qualitative and quantitative pattern matchings, respectively, via calibration to real data and visual inspection. Various what-if analyses, including extremely supportive and unsupportive scenarios, the impact of different degrees of network effects, and different socioeconomic trends of the countries are conducted, and findings are presented. Moreover, response surface models are built to both predict and explain the brain drain dynamics.

2. "Integrated Timetable Rescheduling for Multidispatching Sections of High-Speed Railways During Large-Scale Disruptions" by *Min Zhou, Hairong Dong, Xuan Liu, Hongjie Zhang, and Fei-Yue Wang*

This article focuses on the timetable cooperative rescheduling problem with multidispatching sections of high-speed railways (HSRs) from a macroscopic perspective in the case of large disruptions. The problem is formulated as a mixed-integer linear program (MILP) model on the objectives of minimizing the weighted sum of the arrival delay time of trains, the delay time of depart trains at the handover station, and the number of delays of trains at all stations. The strategies of retiming and reordering are adopted to generate the rescheduling scheme and reduce delay propagation by making full use of three kinds of buffer time reserved in the timetable.

3. "The Coevolution of Social Networks and Cognitive Dissonance" by *Roger M. Whitaker, Gualtiero B. Colombo, Liam Turner, Yarrow Dunham, Darren K. Doyle, Eilish M. Roy, and Cheryl A. Giammanco*

In this article, the authors explore the network implications from individuals reconciling cognitive friction when their neighbors hold alternative views. Through agent-based modeling, they introduce a framework to explore the sensitivity of behavior on social network structure, in response to vicarious dissonance. Alternative response behaviors are each found to be highly effective in reducing the cognitive dissonance felt across a population but with wide-ranging outcomes for the population as a whole. The results highlight the important role of neutrality and tolerance in retaining social cohesion while showing how easily this can be disrupted.

4. "Linking COVID-19 Perception With Socioeconomic Conditions Using Twitter Data" by *Egemen Sert, Oral Okan, Alper Özbilen, Şeyda Ertekin, and Suat Özdemir*

In this study, the authors investigate the topic dynamics of Twitter content sharing for the Republic of Turkey. They have analyzed 1.3 million tweets containing the keyword "korona" shared between February 24, 2020, and May 2, 2020. They aim to explore the relationship between socioeconomic conditions and topic usage by inspecting 1.3 million tweets collected over two months.

5. "Disjoint and Overlapping Community Detection in Small-World Networks Leveraging Mean Path Length" by *Arnab Kumar Ghoshal, Nabanita Das, and Soham Das*

In this article, a comprehensive two-phase approach based on a genetic algorithm (GA) is proposed, which can be applied to any small-world network to generate the disjoint community set (DCS) and the overlapping community set (OCS) very quickly without any prior knowledge of the community structure. In the first phase, an upper bound on the mean path length of a community is applied, relative to the equivalent Erdős–Rényi (E-R) random graph that expedites the convergence significantly. In the second phase, the search space is reduced considerably, by selecting a smaller subset of boundary nodes of the DCS generated in the first phase, to be manipulated probabilistically.

6. "Explainable AI in Deep Reinforcement Learning Models for Power System Emergency Control" by *Ke Zhang, Jun Zhang, Pei-Dong Xu, Tianlu Gao, and David Wenzhong Gao*

The interpretability issue in deep reinforcement learning (DRL) models in power system emergency control is discussed in this article. The proposed interpretable method is a backpropagation deep explainer based on Shapley additive explanations (SHAPs), which is named the deep-SHAP method. The deep-SHAP method is adopted to provide a reasonable interpretable model for a DRL-based emergency control application. For the DRL model, the importance of input features has been quantified to obtain contributions for the outcome of the model.

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7. "Composite Behavioral Modeling for Identity Theft Detection in Online Social Networks" by *Cheng Wang, Hangyu Zhu, and Bo Yang*

The authors investigate the feasibility of building a ladder from low-quality behavioral data to a high-performance behavioral model for user identification in online social networks (OSNs). By deeply exploiting the complementary effect among OSN users' multidimensional behaviors, we propose a joint probabilistic generative model by integrating online and offline behaviors. When the designed joint model is applied to identity theft detection in OSNs, its comprehensive performance, in terms of the detection efficacy, response latency, and robustness, is validated by extensive evaluations on real-life OSN datasets.

8. "A Survey of Community Detection in Complex Networks Using Nonnegative Matrix Factorization" by *Chaobo He, Xiang Fei, Qiwei Cheng, Hanchao Li, Zeng Hu, and Yong Tang*

To facilitate research on nonnegative matrix factorization (NMF)-based community detection, in this article, the authors make a comprehensive review on NMF-based methods for community detection, especially the state-of-the-art methods presented in high prestige journals or conferences. First, they introduce the basic principles of NMF and explain why NMF can detect communities and design a general framework of NMF-based community detection. Second, according to the applicable network types, they propose a taxonomy to divide the existing NMF-based methods for community detection into six categories. Finally, they summarize the common problems faced by all methods and potential solutions and propose four promising research directions.

9. "Understanding Social Biases Behind Location Names in Contextual Word Embedding Models" by *Fangsheng Wu, Mengnan Du, Chao Fan, Ruixiang Tang, Yang Yang, Ali Mostafavi, and Xia Hu*

In this article, the authors first employ the concept of counterfactual fairness to investigate the social biases encoded in training data. Then, they quantify the biases in the contextual embeddings (BERT and ELMo). They report a high correlation between biases in the training data and embeddings. Next, they introduce a novel bias mitigation algorithm that customizes bias representations for any location name. The method yields debiased location name vectors for various social attributes simultaneously.

10. "Collaborative Human Decision Making With Heterogeneous Agents" by *Baocheng Geng, Xiancheng Cheng, Swastik Brahma, David Kellen, and Pramod K. Varshney*

From a distributed detection and information fusion perspective, the authors show that promoting heterogeneity enhances the performance of collaborative human decision-making. First, they assume that the independent local decisions are modeled via the binary symmetric channel (BSC) model, and the final result is aggregated through the likelihood ratio test (LRT)-based decision rule. Next, they consider the more practical scenario where humans have similarities in their behavioral properties so that they make correlated local decisions.

11. "A New Method for Measuring the Behavioral Consistency Degree of WF-Net Systems" by *Fang Zhao, Dongming Xiang, Guanjun Liu, and Changjun Jiang*

This article uses workflow nets (WF-nets) to model workflow systems and re-explore their behavioral relations to guarantee consistency between different systems. Then, their behavioral relation matrices (BRMs) are constructed. Based on BRMs, some new measurement methods are proposed to calculate the behavioral consistency degree of two WF-net systems. Finally, a group of experiments is done to show the effectiveness of our methods. The article formalizes general modules and special modules in WF-net systems based on behavioral relations, refines the existing correspondence relations into nine kinds, and proposes methods to measure the behavioral consistency degree of two WF-net systems, especially with special modules.

12. "Influence Maximization Through Scheduled Seeding in a Real-World Setting" by *Tomer Lev, Irad Ben-Gal, and Erez Shmueli*

The article first proposes methods for analyzing historical data to quantify the infection probability of a node with a given set of properties in a given time and assess the potential of a given seeding strategy to infect nodes. The article uses the proposed methods to demonstrate the existence of two important effects in their dataset: a complex contagion effect and a diminishing social influence effect and compares a number of benchmark seeding strategies to a scheduled seeding strategy that ranks nodes based on a combination of the number of infectious friends (NIF) they have, as well as the time that has passed since they became infectious. Results of the analyses show that for a seeding budget of 1%, the scheduled seeding strategy shows a better result.

13. "A Multitask Multimodal Ensemble Model for Sentiment- and Emotion-Aided Tweet Act Classification" by *Tulika Saha, Apoorva Upadhyaya, Sriparna Saha, and Pushpak Bhattacharyya*

This article hypothesizes that the association between emotion and sentiment will provide a clearer understanding of the tweeter's state of mind, aiding the identification of tweet acts (speech acts in Twitter, TAs). This article creates a new multimodal, emotion-TA, EmoTA dataset collected from the open-source Twitter dataset. The authors propose a multitask ensemble adversarial learning framework for multimodal TA classification (TAC) to incorporate these multiple aspects. In addition, this article also incorporates a joint embedding network, with bidirectional constraints to capture and efficiently integrate the shared semantic relationships across modalities and learn generalized features across multiple tasks. The experimental results indicate that the proposed framework boosts the performance of the primary task TAC.

14. "Sequential Attacker–Defender Game on Complex Networks Considering the Cascading Failure Process" by *Yuxuan Huang, Jiajing Wu, Chi K. Tse, and Zibin Zheng*

This article proposes a multiround attacker–defender game model on complex networks based on the concept of the Stackelberg competition, allowing high flexibility in the available actions for both sides in the game. The model proposed allows the two sides to specify certain parameters of the

network to attack/defend and further allocate a certain amount of resources for the attack/defense. Such flexibility allows the model to capture the actions of the attackers and defenders more precisely and simulate the attack process in a more realistic manner. This article also proposes an iterative search algorithm to search for desirable strategies with systematic experiments on various types of networks and associated parameters and in terms of different relative resources owned by the attacker and defender.

15. "Social Bots and Their Coordination During Online Campaigns: A Survey" by *Tuja Khaund, Baris Kirdemir, Nitin Agarwal, Huan Liu, and Fred Morstatter*

This article presents a detailed survey of social bots, their types and behaviors, and how they impact social media, identification algorithms, and their coordination strategies in OSNs. The survey also discusses coordination in areas such as biological systems, interorganizational networks, and coordination games. Existing research extensively studied bot detection, but bot coordination is still emerging and requires more in-depth analysis. The survey covers existing techniques and open research issues on the analysis of social bots, their behaviors, and how social network theories can be leveraged to assess coordination during online campaigns.

16. "Stakeholder Utility Measures for Declarative Processes and Their Use in Process Comparisons" by *Mark Dukes*

This article presents a method for calculating and analyzing stakeholder utilities of processes that arise in, but are not limited to, social sciences. These areas include business process analysis, healthcare workflow analysis, and policy process analysis. This method is quite general and applicable to any situation in which declarative-type constraints of a modal and/or temporal nature play a part. This article also derives a measure for stakeholder utility that can be applied in a very general setting. This derivation is achieved by listing a collection of properties that they argue such a stakeholder utility function ought to satisfy and then using these to show that a very specific form must hold for such a utility.

17. "Evolution of Ethereum Transaction Relationships: Toward Understanding Global Driving Factors From Microscopic Patterns" by *Dan Lin, Jialan Chen, Jiajing Wu, and Zibin Zheng*

This article discusses the evolution mechanism of Ethereum transactions. First, it collects the transaction data of Ethereum and builds network models from a microlevel view and then uses a link-prediction-based framework to quantify the impact of network characteristics on Ethereum evolution. Next, it explores the graph structure properties and the driving factors of newly generated transaction relationships. The experimental results show that the local and microscopic structure of Ethereum networks is star-shaped, and the transaction frequency of addresses has a great impact on the evolution of Ethereum transaction relationships. First-layer nodes of microstructures dominate the network evolution.

18. "Fostering Peer Learning With a Game-Theoretical Approach in a Blended Learning Environment" by *Seyede Fatemeh Noorani, Mohammad Hossein Manshaei, Mohammad Ali Montazeri, and Behnaz Omoomi*

This study proposes a mechanism and an instructional design in order to foster well-organized peer learning based on game theory (PD_PL). The proposed mechanism uses prisoner's dilemma (PD), the most widely known example of game theory in a dynamically blended and collaborative learning environment. PD_PL maps the strategy and payoff concepts found in PD onto a peer learning (PL) atmosphere. This article uses paired Hotelling's T-square function to analyze the pretests and posttests and investigate the impacts of PD_PL and the proposed instructional design on students' learning improvement. The results of paired Hotelling's T-square indicate that PD_PL is a successful mechanism for encouraging the active participation of students in the PL process.

19. "Potent Real-Time Recommendations Using Multimodel Contextual Reinforcement Learning" by *Anubha Kabra, Anu Agarwal, and Anil Singh Parihar*

This article proposes multimodel contextual reinforcement learning (MMCR) constituting three novel features for real-time and customized recommendations. The first feature is user-item interactive state embedding which not only uses item information but also assigns weightage to this information according to its usage history. It gives higher importance to the newly clicked items by the users than the older ones. Second, this article devises a contextual cluster exploration (CCE) strategy. This strategy enhances the item-choice recommendations by consistently reducing the randomness during exploration. The third novelty is an item-based multiagent framework that can tackle the case of sparsely chosen items.

20. "Social Influence Network Simulation Design Affects Behavior of Aggregated Entropy" by *Michael J. Garee, Hong Wan, and Mario Ventresca*

This article creates opinion data using agent-based simulation and experimental design. By viewing opinion changes as an information-generating process, opinion dynamics can be studied using entropy. This work explores the relationships between aggregated entropy and five simulation design factors. Three entropy measures are calculated on continuous-valued opinions and are analyzed using a main effects model and cluster analysis. Overall, the choices of influence model and error distribution are most important to the entropy measures, activation regime is important to some measures, and population size is unimportant. In addition, design variation can be detected using time-series cluster analysis.

21. "Maintaining Social Distancing in Pandemic Using Smartphones With Acoustic Waves" by *Vaibhav Rupapara, Manideep Narra, Naresh Kumar Gunda, Swapnil Gandhi, and Kaushika Reddy Thipparthy*

This article describes a solution using smartphones which delivers near-field peer-to-peer communication using the present hardware to convert the messages into sound waves. The proposed system uses audio waves for detecting nearby devices and creates communications among the host and surrounding nearby devices. The system can control the reachability of waves by increasing or decreasing sound waves' frequency. The proposed technique is multipurpose and harmonious with any devices

that sustenance sound processing as it only requires a microphone and speakers. Finally, ultrasound does not require internet connectivity or other hardware like near-field communication (NFC).

22. "Collaborative Detection of Community Structure in Multiple Private Networks" by *Wenjian Luo, Binyao Duan, Li Ni, and Yang Liu*

In this article, from the view of secure multiparty computation, the authors present two methods to detect the community structure of the multiple networks without directly exchanging edges' information. These two methods are developed from the fast modularity algorithm (fast modular) and the label propagation algorithm (LPA), and they are called Cofast-Modular and CoLP A, respectively. Both methods can detect the community structure within multiple networks without the need to directly exchange the edges' information. Experiments are conducted on several real-world and synthetic networks. The experimental results show that CofastModular and CoLPA could effectively identify the community structure.

23. "Detecting Ethereum Ponzi Schemes Based on Improved LightGBM Algorithm" by *Yanmei Zhang, Wenqiang Yu, Ziyu Li, Salman Raza, and Huaihu Cao*

This article proposes a smart contract Ponzi scheme identification method based on the improved LightGBM algorithm. The experiments conducted on the real dataset of Ethereum prove that their proposed method has improved accuracy dramatically in terms of the F-score index and the AUC index compared with the state-of-the-art methods. In addition, model training speed is significantly improved. Therefore, the method more accurately identifies Ponzi schemes in smart contracts, thus reducing investment risk.

24. "Latent Personality Traits Assessment From Social Network Activity Using Contextual Language Embedding" by *Pavan Kumar K. N. and Marina L. Gavrilova*

This article proposes a novel input representation mechanism to process tweets by converting them into real-valued vectors using frequency, co-occurrence, and context (FCC) measures. A GA approach is proposed to reduce the feature set and increase the efficacy of the features extracted. The developed system outperforms the state-of-the-art research by reliably estimating the user's latent personality traits while using 50 or fewer tweets per user.

25. "Green Computing: A Future Perspective and the Operational Analysis of a Data Center" by *S. P. Raja*

This article discusses the functioning of green businesses that are environment-friendly and cut carbon emissions and transportation costs. This article also presents the various measurements of power usage, water usage, and carbon footprint of a Vellore Institute Computing Center. Little steps taken to adopt green computing measures result in a most congenial environment, while computers and their applications are ubiquitous, so too is a rising awareness of the cost and scarcity of the energy needed to power them, as well as the materials needed to make them in the first place.

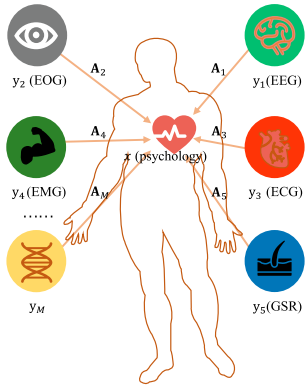

Fig. 1. Inverse solution of CPP.

II. Fundamentals of Computational Psychophysiology: Theory and Methodology

Since 2015, computational psychophysiology (CPP) has been stated out in the community of computational social systems [7]. Over the last decade, on one hand, we have witnessed a plethora of efforts being given to leverage the power of artificial intelligence (AI) to assess the psychophysiological status of subjects in a quantitative paradigm. On the other hand, an in-depth exploration of the fundamentals of CPP is still lacking. To this end, we present our opinions and perspectives on the fundamentals of CPP in terms of theory and methodology.

A. Theory

It is well-known that the psychological variables cannot be measured directly [6]. Nevertheless, the peripheral physiological measurements are viewed as the overt symptoms of psychological variables. It is an accessible way to infer psychological variables from physiological measurements [1]. This is a typical mathematical issue—psychophysiological inverse problem as

$$\min_{x} \sum_{m=1}^{M} \|\mathbf{A}_m(x) - y_m\|^2 + \alpha \cdot \mathbf{R}(x) \tag{1}$$

and Fig. 1, where m is modality, $\mathbf{A}_m(x)$ is the unknown mapping from psychological variable x onto physiological responses, y is the known physiological measurements, and α and $\mathbf{R}(x)$ are the weight and regularization terms, respectively. The objective function is to estimate the optimized psychological variables and the corresponding inverse of $\mathbf{A}_m(x)$, i.e., $\mathbf{A}_m^{-1}(y_m)$. If $\mathbf{A}_m^{-1}(\cdot)$ is constructed, we can naturally infer the psychological variables. It is essential to build a series of inverse solution theories for the psychology theory evolution.

B. Methodology

1) Paradigm Design and Data Acquisition: Paradigm design and data acquisition are the key steps to construct psychophysiological models for solving the inverse problem of CPP. Since physiological signals are unspecific to psychological variables, inverse validation paradigm design requires manipulation of experimental conditions that differ in only

one dimension, namely, the psychological variable of interest. Then, the impact on the peripheral measures can be evaluated, that is, predictive validity [1]. Paradigm controls the process of the psychological variable x and makes its variation as small as possible to meet the requirements of regularization term $\mathbf{R}(x)$ [9]. In the phase of data acquisition, we should guarantee that the acquired multimodal physiological signals y can represent the same psychological semantics to evaluate the psychological states accurately. The quality of the acquired data determines whether we can effectively infer the mapping $\mathbf{A}^{-1}$ from physiological responses to a psychological variable through the data-driven machine learning method.

2) Advanced Signal Processing: Traditional signal processing techniques, e.g., the Fourier transformation (FT), have been widely applied to the field of CPP for the purpose of signal enhancement and feature extraction. Nevertheless, considering the psychophysiological signals are highly complicated, nonlinear and nonstationary by nature, more advanced signal processing approaches are needed. For instance, short-time FT (STFT) cannot optimize the Heisenberg-like trade-off in time–frequency analysis [4]. Instead, wavelet transformation (WT) [2] can provide us a multiresolution analysis paradigm, which can make it quite suitable to extract representations from physiological signals that cannot be well characterized by FT. Furthermore, empirical mode decomposition (EMD) [8], a novel signal processing method, has been demonstrated to be efficient in depression detection tasks by extracting features from the EEG signals [10].

3) Data Modeling: Data modeling of CPP mainly leverages physiological signals or behavioral data to infer psychological states and predict their dynamic changes. Different from the traditional modeling physiological signals, modeling of CPP needs to build a strong corresponding relationship between the psychological states and the physiological signals. This is due to the asynchronous correlation mechanism between psychological activities and physiological responses. Different individuals usually demonstrate different physiological changes in the same psychological condition. Even the physiological signals from the same person are different at different times. Furthermore, one's psychological states normally cause multiple types of signals to change simultaneously. Therefore, modeling of CPP should first alleviate the difficulties brought by individual differences in building the relationship between the psychological states and the physiological responses. Among this process, minimizing the interindividual differences is an effective scheme. Second, modeling of CPP should explore the patterns and characteristics of the psychological states and the physiological responses over time which aims to establish dynamic psychophysiological alignment in latent space. Psychological states-oriented dynamic semantic alignment and temporal change representation of physiological responses can effectively solve this problem. Finally, modeling of CPP should solve two scientific problems. The first one is about semantic synchronization between psychological state and its asynchronously triggered multidimensional and multimodal physiological signals. The second problem is how to construct the common semantic representation among different physiological signals and

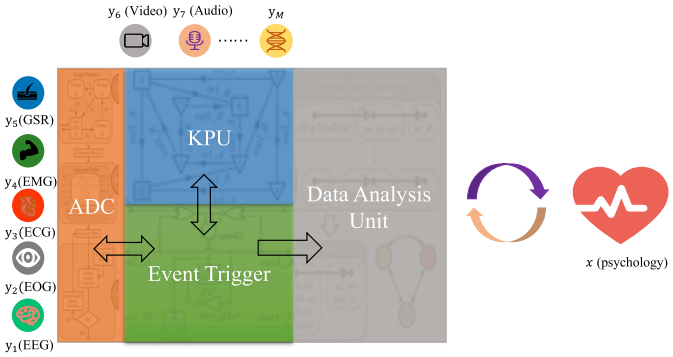

Fig. 2. Framework of the PPU.

establish the synchronous correlation mechanism of asynchronous information. Psychosemantic alignment and coordinate representation of multiple physiological signals can effectively improve the performance of physiological signals modeling and bring new vigor and vitality into accurate psychological semantic recognition. Recently, CPP has provided an important modeling basis in the fields of depression detection [11], AD pathology detection [5], and emotion recognition [12].

4) Psychophysiology Processing Unit: The human's psychophysiological activities naturally occur in an asynchronous pattern [3]. Therefore, it is necessary to adopt chips with asynchronous architecture to simulate psychophysiological activities. As depicted in Fig. 2, we propose a psychophysiological processing unit (PPU) framework which leverages an event-triggered asynchronous structure and can be applied to simulate psychophysiological activities. The PPU consists of four modules: analog-to-digital converter (ADC), knowledge processing unit (KPU), event trigger module, and data analysis unit. The ADC can capture physiological electric signals, including electroencephalogram (EEG), electrocardiogram (ECG), electromyogram (EMG), and electrooculogram (EOG). The KPU can process audio and video information. The event trigger is connected with the ADC and KPU, which can simulate psychological states and control the asynchronous acquisition of multimodal physiological signals related to the states. Note that the working mode of the trigger is asynchronous. In particular, by computing the relationship between psychological states and physiological signals, the PPU can help us further explore and reveal the mechanism of human psychophysiological activities. The data analysis unit is composed of numerous neural computing units with strong computing power [3], which can be used to preprocess raw signals, extract and analyze features, and fuse multimodal physiological information.

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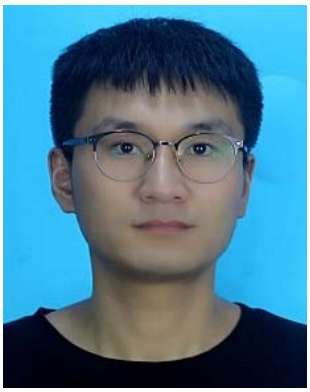

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