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# Accelerometry data: from micro- to macro-level

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## ABSTRACT

Wearable devices, such as accelerometers and heart rate monitors, can now provide objective and continuous measurements of human activity. Such devices have been widely deployed in large observational and clinical studies because they are expected to produce objective measurements that could improve or replace current self-reported activity measuring practices. Modern devices allow collection of high frequency acceleration time series (micro-level data) that provides rich information about device wearers' detailed physical activity characteristics. On the other hand, aggregated summaries of the high frequency acceleration, commonly called "counts data" (macro-level data), are used more often in practice because they are adequate to capture subjects' 24-hour physical activity trajectory. In this talk, I will walk through the typical accelerometry data processing pipeline from the micro- to macro-level and discuss commonly used statistical analysis for the data at different stages of the processing. Accelerometry data from several observational and clinical studies on disparate populations will be used as examples.

# Parameterized exploration

JESSE CLIFTON

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## ABSTRACT

Exploration in reinforcement learning is often accomplished by heuristics which account for neither the time horizon of the decision problem nor the decision-maker's current state of knowledge of the dynamics of the underlying system. Accounting for these features could greatly improve the exploration-exploitation tradeoff (for instance, by avoiding over-exploration in short time horizons), and is computationally feasible in applications such as mobile health (mHealth) in which moderate computing times are acceptable. We introduce Parameterized Exploration (PE), a simple family of methods for tuning the exploration schedule which leverages an estimated model of dynamics of the decision problem and accounts for the time horizon. The proposed methods provides significant empirical gains relative to competing methods in variety of empirical examples and an application the management of type I diabetes using mobile interventions. We show that the proposed method is consistent for the optimal exploration schedule within the class under consideration and show how its estimated sampling distribution can be used to design robust and safe exploration strategies.

# Sample size considerations for precision medicine

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## ABSTRACT

Sequential Multiple Assignment Randomized Trials (SMARTs) are considered the gold standard for estimation and evaluation of treatment regimes. SMARTs are typically sized to ensure sufficient power for a simple comparison, e.g., the comparison of two fixed treatment sequences. Estimation of an optimal treatment regime is conducted as part of a secondary and hypothesis-generating analysis with formal evaluation of the estimated optimal regime deferred to a follow-up trial. However, running a follow-up trial to evaluate an estimated optimal treatment regime is costly and time-consuming; furthermore, the estimated optimal regime that is to be evaluated in such a follow-up trial may be far from optimal if the original trial was underpowered for estimation of an optimal regime. We derive sample size procedures for a SMART that ensure: (i) sufficient power for comparing the optimal treatment regime with standard of care; and (ii) the estimated optimal regime is within a given tolerance of the true optimal regime with high-probability. We establish asymptotic validity of the proposed procedures and demonstrate their finite sample performance in a series of simulation experiments.

# Addressing issues with GPS and tracking data collection: Correction algorithms for understanding movement

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## ABSTRACT

The collection of movement data through geographical positioning and tracking has become increasingly popular as a factor in understanding the physical and mental health of populations. From infectious disease spread to physical activity levels for chronic disease aversion, a population's spatial distribution can significantly affect health outcomes. Positioning error can however be a common occurrence due to topography, user error, receiver positioning and the atmosphere. In this talk, we discuss several algorithms being used to correct this error in a physical activity study where participants are collecting movement data on their mobile phones.

# From real-world evidence to person-centered healthcare: applications of computational behavior science and interpretable AI/ML for minimally disruptive medicine

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## ABSTRACT

Enhancing patient experience has been one of the quadruple aims of healthcare in modern medicine. How to do this while maintaining overall health of the population and reducing per capita cost of care is the key question. To achieve this, recent studies documented the importance of accounting for individuality and heterogeneity through precision health applications. In practice, while care management programs can be effective at times, our knowledge about how to engage patients in care management has been limited due to a lack of systematic analysis of care management history with labeled actions and outcomes. Meanwhile, the recent rise of consumer awareness and the prevalence of e-health technologies (e.g., mobiles, sensors, wearables) have further enabled data curation on personal health status and contexts for interpretation. However, today's care programs are not structured to capture such levels of patient understanding, but rather pre-determined by a set of rules that are based on population-level evidence. What if healthcare professionals can take advantage of the revealed behavioral patterns and responses to further engage target patients and personalize their care plans? What if a stress management advisor can guide the users to recover with regards to their individual preferences and contexts? What if patients themselves can be making more sense of their own health data and goal attainment journey for share decision making or healthy behavior maintenance? Can we start generating real-world evidence from the personal health data to provide hyper-personalization insights of best practice at the individual level (or at least for patients similar to this patient)?

# Entropy learning for dynamic treatment regimes

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## ABSTRACT

Estimating optimal individualized treatment rules (ITRs) in single or multi-stage clinical trials is one key solution to personalized medicine and has received more and more attention in statistical community. Recent development suggests that using machine learning approaches can significantly improve the estimation over model-based methods. However, proper inference for the estimated ITRs has not been well established in machine learning based approaches. In this paper, we propose an entropy learning approach to estimate the optimal individualized treatment rules (ITRs). We obtain the asymptotic distributions for the estimated rules so further provide valid inference. The proposed approach is demonstrated to perform well in finite sample through extensive simulation studies. Finally, we analyze data from a multi-stage clinical trial for depression patients. Our results offer novel findings that are otherwise not revealed with existing approaches.

Despite the high potential, making individualized recommendations from personal health behavioral data incurs multi-level challenges. Recently, novel AI/ML algorithms are being proposed to capture and predict behavioral outcomes from different modalities of personal health data. The goal of this talk is to review the efforts of developing a learning framework to incorporate these algorithms to capture individual predictive care pathways from observational data in a causal inference-inspired way. As the adoption of AI/ML in high-stakes health decision-making scenarios has been slow, in this talk we will address the gap between how humans and machines make decisions and introduce the recent push for model transparency, interpretability and causal explainability to help decision makers understand how machines account for the models they learn. For example, in our own work, we leveraged interpretable AI/ML approaches to induce policies for physical activity recommendations that can reduce a user's perceived stress over a given time horizon. Idiographic N-of-1 models are compared with the traditional nomothetic (one-size-fits-all) model. Moreover, a new form of reinforcement learning method, multi-stage threshold Q-learning (mTQL) is introduced to incorporate behavioral theoretical constructs, such as implementation intention and goal setting, into the modeling process. Results from both the observational and Monte Carlo simulation studies indicate that the mTQL-based learning framework brings out actionable insights from m-health data and can empower patients in precision behavioral intervention and cognitive care management applications. Finally, as medical decisions are never black and white, we introduce a cognitive care management framework that can help incorporate the real-world evidence of patient differential responses in personalized care planning. We will conclude with the challenges we have confronted with its implementation in care flows, as well as the opportunities we observed in the process for future integration of data science and the science of care for patients.

# Contextual multi-armed bandit algorithm for semiparametric reward model

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March 1, 2019

## ABSTRACT

Contextual multi-armed bandit (MAB) algorithms have been shown promising for maximizing cumulative rewards in sequential decision tasks under uncertainty when contextual information is given. Applications include news article recommendation systems, web page ad placement algorithms, revenue management, and mobile health. However, most of the proposed contextual MAB algorithms rely on strong, linear assumptions between the reward and the context of the action. In this talk, we propose a new contextual MAB algorithm for a relaxed, semiparametric reward model that supports nonstationarity. Alternative algorithms have been proposed for the same model (Greenewald et al., 2017; Krishnamurthy et al., 2018). Our proposed algorithm is less restrictive and easier to implement than the existing algorithms. It can be shown that the high-probability upper bound of the regret incurred by the proposed algorithm has the same order as the Thompson sampling algorithm for linear reward models without restricting action choice probabilities. The proposed algorithm and existing algorithms are evaluated via simulation and also applied to Yahoo! news article recommendation log data provided by Yahoo! Webscope.

# Robust tests in online decision-making: testing the utility of data collected by wearables

JANE PAIK KIM

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## ABSTRACT

We describe and introduce the study design of a Stanford led project using Apple watches, in which the goal is to promote physical activity by pushing sequences of notifications on the Apple Watch. We identify issues of the analysis of adaptive sequential decision making that arise from this study that can also be generalized to other mHealth studies in the area. In the Apple Watch study, a focal issue is whether the watch provides useful covariates and testing whether the variables obtained from the wearable device are informative plays an important role in decision-making. The validity of hypothesis testing for the model coefficients is, however, predicated on the correct specification of either policy or value models. We propose a robust test statistic that is valid when either the model of the algorithm or the auxiliary model for the variable collected from the wearable is correctly specified.

# Real world data, real world evidence, and decision analytics for precision medicine and health

TZE LEUNG LAI

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## ABSTRACT

Real world data (RWD) and real world evidence (RWE) have been increasingly used in health care decision-making since the passage of the 21st Century Cures Act on December 9, 2016, which requires the FDA to develop a framework and guidance for evaluating RWD and RWE to support approvals of new drugs or devices, or new indications for previously approved drugs, and to support post-approval studies for monitoring safety and adverse events for regulatory decision-making. Whereas pharmaceutical companies use RWD and RWE to support clinical development activities and to provide evidence to inform health technology assessment (HTA) decisions, the healthcare community uses RWD and RWE to develop guidelines and decisions to support medical practice and to assess treatment patterns, costs and outcomes of interventions. Although high-speed computing tools and machine learning algorithms have been conveniently applied to RWD, there are still substantial challenges in deriving RWE from RWD and using the RWE in healthcare decision-making. We discuss how recent advances in statistical science can be combined with domain knowledge to address these challenges.

# Latent state modeling in mobile health and diagnostic classification: Recent advances in the MCMC approach

TZE LEUNG LAI

*Stanford University, USA*

## ABSTRACT

We first describe the important role of latent state modeling in mobile health and in diagnostic classification/rating, together with hidden Markov models and MCMC methods for these applications. Motivated by applications to adaptive filtering that involves joint parameter and state estimation in hidden Markov models, we describe a new approach to MCMC which uses sequential state substitutions for its Metropolis-Hastings-type transitions. The basic idea is to approximate the target distribution by the empirical distribution of  $N$  representative atoms, chosen sequentially by an MCMC scheme so that the empirical distribution converges weakly to the target distribution as the number  $K$  of iterations approaches infinity, with an optimal rate of convergence. Implementation details and concrete applications are also provided.

# A model-based multi-threshold method for subgroup identification

JIALIANG LI

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## ABSTRACT

Thresholding variable plays a crucial role in subgroup identification for personalized medicine. Most existing partitioning methods split the sample based on one predictor variable. In this paper we consider setting the splitting rule from a combination of multivariate predictors, such as the latent factors, principle components and weighted sum of predictors. Such a subgrouping method may lead to more meaningful partitioning of the population than single variable. In addition our method is based on a change point regression model and thus yields straight forward model-based prediction results. After choosing a particular thresholding variable form, we apply a two stage multiple change point detection method to determine the subgroups as well as to estimate the regression parameters. Our method allows more than two subgroups from multiple change points and proffers an explicit definition for each subgroup. It can be shown that our method can identify the true grouping with high probability and the estimation results enjoy the oracle properties. We carry out extensive simulation studies to assess the performance of the new method. Two real data examples are analyzed to illustrate the applications.

# Challenges in developing learning algorithms to personalize treatment in real time

SUSAN MURPHY

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## ABSTRACT

A formidable challenge in designing sequential treatments is to determine when and in which context it is best to deliver treatments. Consider treatment for individuals struggling with chronic health conditions. Operationally designing the sequential treatments involves the construction of decision rules that input current context of an individual and output a recommended treatment. That is, the treatment is adapted to the individual's context; the context may include current health status, current level of social support and current level of adherence for example. Data sets on individuals with records of time-varying context and treatment delivery can be used to inform the construction of the decision rules. There is much interest in personalizing the decision rules, particularly in real time as the individual experiences sequences of treatment. Here we discuss our work in designing online “bandit” learning algorithms for use in personalizing mobile health interventions.

# Developing mHealth interventions to improve mood, activity, and sleep for medical interns

TIMOTHY NECAMP

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## ABSTRACT

During their internship year, medical interns tend to work long hours, face difficult decisions, undergo stress, and have inconsistent sleep. They are also known to have increased rates of depression. The Intern Health Study (IHS) seeks to improve the interns' mood, activity, sleep, and depression levels through a mobile health intervention. The intervention sends daily messages targeting one of three categories: mood, activity, or sleep. The messages contain either general advice for improving the specific category or personalized historical data summaries about that category. To evaluate, personalize, and optimize these interventions, we designed and implemented a micro-randomized trial, where interns are randomized every day to receive a particular intervention. In this talk, we give an overview of our trial, analyses of our trial data, analysis issues, and present major findings.

# Determining optimal treatments based on complex data

R. TODD OGDEN

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## ABSTRACT

A major goal in precision medicine is to make optimal patient-specific treatment decisions using data observed at baseline. Available data may include clinical and demographic variables and measures of behavioral/cognitive performance, as well as complex imaging or genomics data. In the context of a large randomized trial, I will discuss some methods for treatment selection using imaging and other baseline data. Making the most efficient use of complex data will require dimension reduction, penalization, and other techniques common in functional data analysis. This will allow us to properly take into account the structure of the data. I will describe some new methodological advances and illustrate them with preliminary results using clinical trial data.

# Constructing personalized decision algorithm for mHealth applications

MIN QIAN

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## ABSTRACT

Mental illnesses affect tens of millions of people each year. However, only half of those in need actually receive treatment. This is partly due to the substantial barriers associated with accessing office-based mental health care. As such, there are great needs for providing those who are in need of help with access to efficacious therapies. The use of mobile applications can fill the gap by delivering personalized treatments to patients who will otherwise not have access to the traditional treatments. In this work, we proposed a new analytical framework to develop personalized mobile decision algorithms to optimize immediate goals, such as response to a pushed notification or reminder. The method is evaluated using simulation studies and illustrated using data from a recent mobile health study.

# Statistical inference for online decision-making: in a contextual bandit setting

RUI SONG

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## ABSTRACT

Online decision-making problem requires us to make a sequence of decisions based on incremental information. Common solutions often need to learn a reward model of different actions given the contextual information and then maximize the long-term reward. It is meaningful to know if the posited model is reasonable and how the model performs in the asymptotic sense. We study this problem under the setup of the contextual bandit with a linear reward model. The “epsilon-greedy policy” is adopted to address the classic exploration-and-exploitation dilemma. Using Martingale Central Limit Theorem, we show the online ordinary least squares estimator of the model parameter is asymptotic normal. If the linear model is misspecified, we propose the online weighted least squares estimator using the propensity score and also establish its asymptotic normality. Based on the properties of the parameter estimators, we further show that the in-sample inverse propensity weighted value estimator is asymptotic normal. We illustrate our results using simulated data and the news article recommendation data from Yahoo!.

# Latent variable regression analysis of longitudinal multivariate data with irregular and informative observation times

ZHENKE WU

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## ABSTRACT

In many mobile health studies, phone surveys such as Ecological Momentary Assessments (EMA) are increasingly adopted because they are less susceptible to recall bias and are sensitive to contextual factors. For example, they hold great potentials in smoking cessation studies to probe subjects' time-varying psychological states such as vulnerability (risk for lapse) and receptivity (ability and willingness to engage with self-regulatory activities). Inference and prediction of these states may inform just-in-time adaptive intervention development. However, the observation times of these EMAs may correlate with survey responses. For instance, some EMAs are delivered and answered with lower positive emotions when they were triggered by a recent smoking episode detected by on-body sensors. Such dependence must be accounted for to obtain valid inference. We propose a latent variable regression approach for longitudinal multivariate discrete data analysis with irregular and informative observation times. Our goal is to infer the distribution of scientifically meaningful latent variables over time as a function of covariates. The observed dependence between the survey responses and observation times is assumed to be induced by unobserved random effects and observed covariates. We demonstrate the utility of the proposed model through simulation studies and an analysis of data from Break Free study among African Americans who attempt to quit smoking.

# Reinforced risk prediction with budget constraint

YINGQI ZHAO

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## ABSTRACT

Uncontrolled glycated hemoglobin (HbA1c) levels are associated with adverse events among complex diabetic patients. These adverse events present serious health risks to affected patients and are associated with significant financial costs. A high-quality predictive model that could identify high-risk patients so as to inform preventative treatment thereby has the potential to improve patient outcomes while reducing healthcare costs. Because the biomarker information needed to predict risk is costly and burdensome, it is desirable if such a model collects only as much information is needed on each patient so as to render an accurate prediction. We propose a sequential predictive model that uses accumulating patient longitudinal data to classify patients as: high-risk, low-risk, or uncertain. Patients classified as high-risk are then recommended to receive preventative treatment and those classified as low-risk are recommended to standard care. Patients classified as uncertain are continued to be monitored until a high-risk or low-risk determination is made. We construct the model using claims and enrollment files from Medicare, linked with patient Electronic Health Records (EHR) data. The proposed model uses functional principal components to accommodate sparse longitudinal data and weighting to deal with missingness and sampling bias. The proposed method demonstrates higher predictive accuracy and lower cost than competing methods in a series of simulation experiments and application to data on complex patients with diabetes.