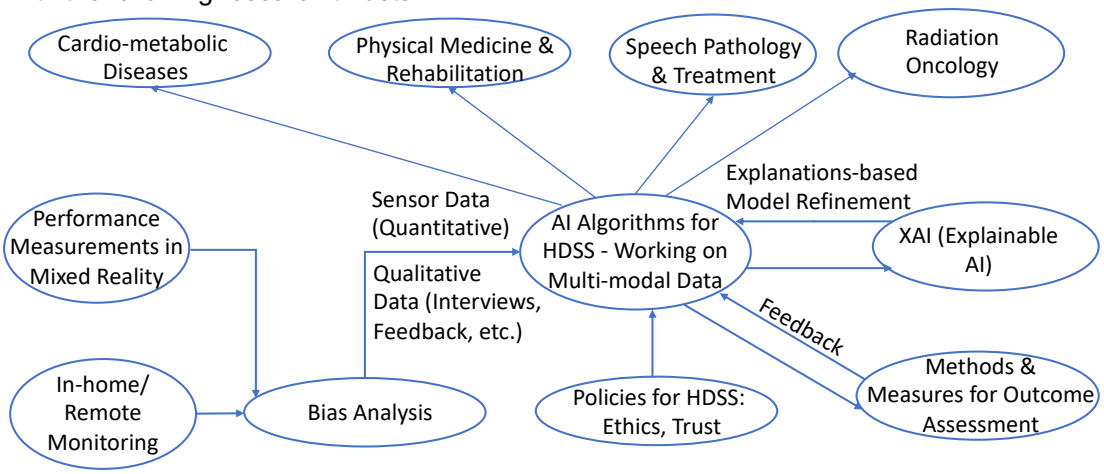
AI-based Healthcare Decision Support Systems (AI-HDSS) - **Prabha (Balakrishnan) Prabhakaran**

With my multi-faceted experience in inter-disciplinary research, managing large research programs and federal public policy, I am working on ***AI-based Healthcare Decision Support Systems (AI-HDSS)***. AI and ML (Machine Learning) are increasingly being used for clinical decision support, remote monitoring, and self-management of various healthcare decision support systems (HDSS) such as cardio-metabolic diseases, physical medicine & rehabilitation, speech pathology & treatment, and radiation oncology. AI-based systems, such as AI-HDSS, deployed in societal applications, need to recover from uncertainties (i.e., be resilient) even if they lack the policies to handle them (i.e., be robust). These systems need to exhibit responsible behavior protecting the privacy of citizens, in an unbiased/fair and ethical manner, and explain its behavior should the need arise. With these factors in mind, my research vision is to build AI-HDSS with the following research thrusts.



Components of the Proposed AI-based Decision-support-systems (AI-HDSS)

1. XAI (Explainable AI) for HDSS: Recently, we have been working on EFACCT (Explainable, Fair, Accountable and Transparent), a framework for body sensor data driven decision support systems, primarily targeted towards cardio-metabolic diseases. As part of the EFACCT, we targeted ECG signals and developed CEFEs [2] to explain how Convolutional Neural Networks (CNNs) classify ECG signals and used the CEFEs based explanations for core-set selection [1]. Prior to EFACCT, our research addressed personalized pattern discovery [4] and association rule mining [3] for healthcare time-series data. Following is some of the peer-reviewed publications related to this activity:

1. "Core-set Selection Using Metrics-based Explanations (CSUME) for multiclass ECG", Sagnik Dakshit, B. M. Maweu, Sristi Dakshit, B. Prabhakaran, Proceedings for IEEE (International Conference on Health Informatics) ICHI 2022, June 2022.
2. "CEFEs: A CNN Explainable Framework for ECG Signals", Barbara Maweu, Sagnik Dakshit, R. Shamsuddin, and B. Prabhakaran, Artificial Intelligence in Medicine, Volume 115 (102509), May 2021.
3. "Association Rule Mining in Multiple, Multidimensional Time Series Medical Data", G.N. Pradhan and B. Prabhakaran, Journal of Healthcare Informatics Research (Springer), Volume 1, Issue 1, June 2017, pp. 92-118.
4. "Discovering Multidimensional Motifs in Physiological Signals for Personalized Healthcare", A. Balasubramanian, J. Wang, and B. Prabhakaran, IEEE Journal of Selected Topics in Signal Processing, Volume 10, Number 5, August 2016, pp. 832-841.

2. Addressing Data Imbalance and Bias in AI for HDSS: AI and ML algorithms' performance depend very much on the quality of data and get influenced by data imbalance and bias (systemic, statistical, and human). To address some of these challenges, we have been developing a bias analysis framework (BAHT [5]) to address fairness and accountability in the EFACCT framework. We have also designed genetic algorithm-based and ML-based approaches to generate "synthetic data" that mimic the characteristics of healthcare multimodal sensor data [6, 7]. We have shown that the quality of these synthetic data is highly comparable to the patient generated data, based on exhaustive analyses. Synthetic data generation

methodologies can also be viewed as an "ethical supplement" for data hungry deep learning algorithms, helping address the issues of data imbalance and bias.

5. "Bias Analysis in Healthcare Time-Series (BAHT) Decision Support Systems from Meta Data", Sagnik Dakshit and B. Prabhakaran, Submission under review.
6. "Generating Healthcare Time Series Data for Improving Diagnostic Accuracy of Deep Neural Networks," B. M. Maweu, R. Shamsuddin, S. Dakshit and B. Prabhakaran, IEEE Transactions on Instrumentation and Measurement, vol. 70, pp. 1-15, 2021, Art no. 2508715, 2021. https://doi.org/10.1109/TIM.2021.3077049.
7. "Virtual Patient Model: An Approach for Generating Synthetic Healthcare Time Series Data", Rittika Shamsuddin, Barbara Maweu, B. Prabhakaran, and Ming Li, *Proceedings of IEEE ICHI (International Conference on Health Informatics) 2018,* New York, June 4-7, 2018.

3. In-home / Remote Activity and Physiological Monitoring: We have worked with various types of body sensors for in-home and remote human activity monitoring. We have been carrying out research in this area [8 – 12], working on various aspects of body sensor data analyses: multi-factor analysis (MFA), fuzzy clustering, supervised machine learning, and personalized rehabilitation. These studies involved sensor deployment in the patients' home (following IRB (Institutional Review Board) protocols). Sensor-based in-home activity monitoring also served as a valuable digital diary, compensating for the inaccuracies in patient's self-reported activities.

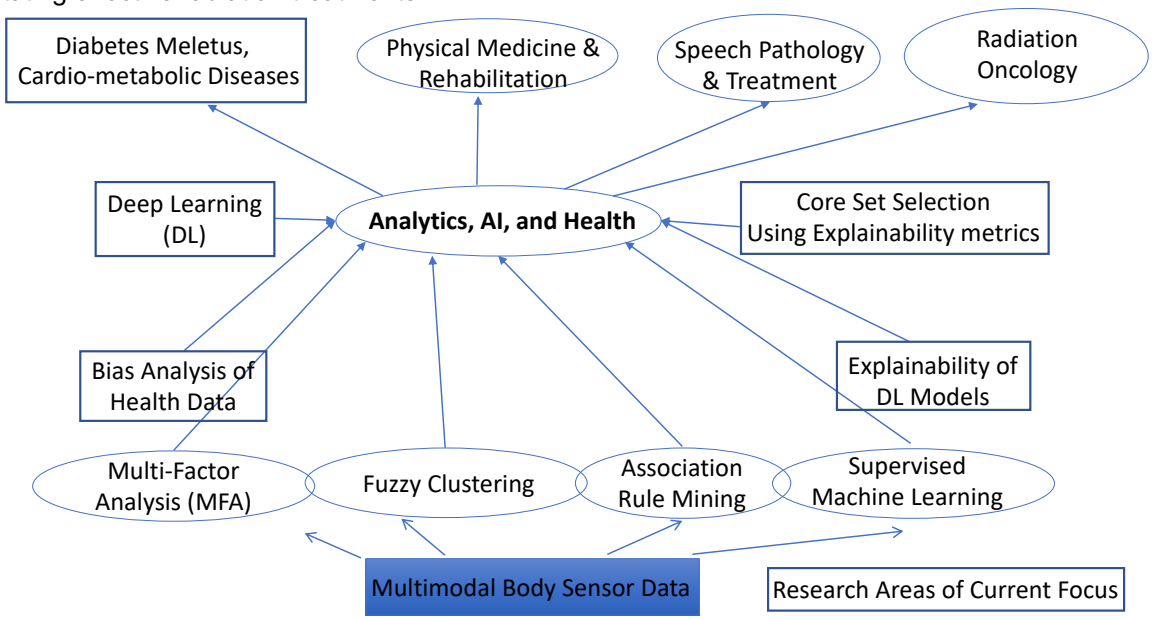
8. "Using Biometric Technology for Telehealth and Telerehabilitation", Thiru M Annaswamy, Gaurav N Pradhan, Keerthana Chakka, Ninad Khargonkar, Aleks Borresen, B. Prabhakaran, Physical Medicine and Rehabilitation Clinics (Elsevier Publications), 32 (2), 437-449, May 2021. https://www.sciencedirect.com/science/article/pii/S104796512030111X.
9. "Personalized 3D exergames for in-home rehabilitation after stroke: a pilot study", Kevin Desai, B. Prabhakaran, Nneka Ifejika, Thiru M AnnaswamyDisability and Rehabilitation: Assistive Technology, (Taylor & Francis Publishers), 1-10, April 2021.
10. "A Body Sensor Network with Electromyogram and Inertial Sensors: Multi-modal Interpretation of Muscular Activities," H. Ghasemzadeh, R. Jafari, and B. Prabhakaran, IEEE Transactions on Information Technology in Biomedicine, Vol. 14, No. 2, pp. 198-207, March 2010.
11. "Analyzing and Visualizing Jump Performance Using Wireless Body Sensors", G.N. Pradhan and B. Prabhakaran, *ACM Transactions on Embedded Computing Systems*, Volume 11, Issue S2, Article No. 47, August 2012.
12. "Exploring unconstrained mobile sensor-based human activity recognition", Luis Gerardo Mojica de La Vega, Suraj Raghuraman, Arvind Balasubramanian, Balakrishnan Prabhakaran, Proceedings of 3rd International Workshop on Mobile Sensing, Co-located with IEEE IPSN'13 and CPSWEEK, April 8, 2013, Philadelphia, PA, USA.

4. Federal public health policy and administrative experiences: From a public health policy perspective, I am serving as a Member of the Interagency Working Group (IWG), Digital Health Research & Development (DHRD) (https://www.nitrd.gov/coordination-areas/dhrd/; formerly, Health Information Technology Research & Development). DHRD membership is restricted to Federal employees from 15 agencies such as NSF, NIH, NIST, and helps coordinate research activities in the broad healthcare arena.

As part of my job at NSF (National Science Foundation), I took up leadership positions: (a) Co-Lead of Smart and Connected Health (SCH) in cooperation with NIH (National Institute of Health); (b) Theme Lead for National AI Institutes on Human-AI Interaction; (c) Co-Chair of Future of Work at the Human-Technology Frontier (FW-HTF), one of the NSF's Big Ideas programs. Currently, I am also involved in programs such as National AI Institutes on multiple themes: "Intelligent Agents for Next-Generation Cybersecurity" and "Trustworthy AI" (in cooperation with NIST (National Institute of Standards and Technology), Fairness in AI (in cooperation with Amazon), Machine Learning for Wireless Networks (MLWiNS, in cooperation with Intel), Multimodal Sensor Systems for Precision Health Enabled by Data Harnessing, Artificial Intelligence, and Learning (SenSE) and SaTC (Secure and Trustworthy Cyberspace) Frontiers, NSF's nation-wide Cybersecurity programs.

My Past Research Background

My funded research career started in 1997 as a tenure-track faculty in Singapore. In the USA, I started my funded research from a database perspective of storing and retrieving human motion sequences, through my NSF (USA National Science Foundation) CAREER Award on Animation Databases. Subsequently, I worked on 3D tele-immersion and collaborative mixed reality (MR) systems, by incorporating networking aspects such as Quality of Service (QoS) requirements and Quality of Experience (QoE) for multimodal streaming. Using the data generated from human interactions in these MR systems, I addressed human motion/gesture understanding/quantification from multiple aspects: (a) gait analysis and gesture recognition; (b) limb motions in stroke-patients and amputees; (c) tongue motion for speech production (especially stroke afflicted persons), and (d) lung tumor motion for profiling human breathing nature and facilitating effective radiation treatments.



Overview of my Research: Explainable AI, Analytics and Health

For understanding human motions/gestures, I worked on various aspects of body sensor data analyses: multi-factor analysis (MFA), fuzzy clustering, association rule mining, and supervised machine learning. More recently, I have been working on synthetic data generation, deep learning (DL), explainability of DL models (used for body sensor data), and core set selection based on explainability metrics. All along, I have been pursuing a research agenda that includes designing innovative algorithms, incorporating them into experimental systems, and deploying them for use in different healthcare domains such as physical medicine & rehabilitation, speech pathology & treatment, robotics for critical care, and radiation oncology.

Generating Multimodal Body Sensor Data: High quality, annotated datasets are required to answer the research questions related to various aspects of understanding and quantifying human interactions, gesture, and performance. For this, my research group has used 3D motion capture systems, on-body sensors such as EMG, and collaborative multimodal mixed reality (MR) systems. MR systems merge real and virtual worlds generating immersive environments, where physical and digital objects co-exist and interact in real time. Activities in such MR systems take place in an immersive continuum of real and virtual worlds. By using 3D/RGB-D cameras that capture both RGB (normal 2D video) and depth information, our research facilitates real-time generation of 3D video avatars (i.e., “live” 3D models of human in the real-world scene) that can interact with objects in the virtual world. The objects in the virtual world can be 3D computer graphics generated; they can also be other 3D video avatars of humans in remote sites, thereby providing a collaborative immersive environment. For multimodal interactions, we have used different types of sensors such as high-stiffness haptic devices, vibro-tactile sensors, accelerometers, gyroscopes, etc.

Deploying Systems for Healthcare: We have successfully deployed some of our collaborative mixed reality-based systems for generating human performance data in healthcare domains such as:

Collaborative Mixed Reality Systems for Physical Medicine and Rehabilitation:

- **Haptic-enabled Mixed Reality for Musculo-skeletal Examination:** This system (https://youtu.be/mVc-fa_Ytso) was used in to remotely diagnose the problems in 15 patients with upper-arm disabilities in the Dallas Veterans Affairs (VA) Hospital. The results of this remote diagnosis showed high degree of correlation with in-person diagnosis of these patients.
- **Mixed Reality for Managing Phantom Limb Pain:** Phantom Limb Pain or simply, Phantom Pain is a severe chronic pain that is experienced as a vivid sensation of the pain in missing body part. We developed a novel Mixed Reality based system for MAnaging Phantom Pain (Mr.MAPP) using the 3D video avatars of the amputees (https://youtu.be/5Fjud10gEzQ, https://youtu.be/JMO4MIav34w).

  Impacts: (a) Research paper describing haptics-based remote musculo-skeletal examination approach was presented in ACM Multimedia 2017 and won the Best Student Paper award. (b) We demonstrated this system in the Arc of Science: From Research to Results, NSF – Capitol Hill Event (invited demonstrations to Congressmen and Senators), February 2017 https://www.nsf.gov/news/news_summ.jsp?cntn_id=191047; (c) Annaswamy, T.M., Prabhakaran, B., and Chung, Y.Y., "High Fidelity Mixed Reality System for Managing Phantom Pain", U.S. Provisional Patent Application No.: 63/325,410, Mar 30, 2022; (d) Annaswamy, T.M., Prabhakaran, B., Desai, K., and Khargoankar, N.A. "VIRTEPEX: Virtual Remote Tele-Physical Examination System", U.S. Provisional Patent Application No.: 63/351,671, June 13, 2022; (e) ACM (Association for Computing Machinery) awarded "Results Replicated" badge for the work on phantom pain management after testing by a third party.

Mixed Reality for Speech Impairments: Opti-Speech is an interactive system that integrates tongue, lip, and jaw motion capture from 3D Electromagnetic Articulography (EMA) systems to animate a 3D tongue model (https://youtu.be/r9NwcDlqAMU). Persons with speech impairments get real-time visual feedback of their tongue and jaw movements during speech therapy.

Impacts: (a) "Opti-Speech", Technology Licensed to Vulintus Inc., by the University of Texas, Dallas. https://www.vulintus.com/optispeech *Inventors:* B. Prabhakaran, Thomas Campbell, Eric Farrar, William Katz, Robert Rennaker, Jennell Vick, and Jun Wang; (b) Opti-speech is being used by the school districts in Cleveland, OH and Dallas, TX.

Experience with Inter-disciplinary Collaborations: My track record in establishing partnerships across disciplines and institutions complements my research contributions. My research spans multiple areas such as multimedia databases, networking, computer vision, graphics, robotics, biomedical sensing, and HCI (Human-Computer Interaction). Hence, throughout my research career, I have been collaborating with researchers from various disciplines: mechanical/biomedical engineers, Physical Medicine & Rehabilitation, Speech Pathologists, Psychologists, Oncologists/Medical Physicists, as well as researchers from Arts, Technology, and Emerging Communication (ATEC) in UT Dallas. For some of these collaborations, I have held formal joint appointments as well. I have been actively collaborating with other institutions such as Dallas Veterans Affairs Medical Center (DVAMC) and the University of Texas Southwestern Medical Center. I have formal, joint appointments as well. For instance, I have Work Without Compensation (WOC) appointment at the DVAMC and an Affiliate Faculty appointment with the UT Dallas Bio-Medical Engineering Department (details are in my CV).