Opportunities and Challenges for Digital Twins in Biomedical Sciences - A Workshop

THIS WORKSHOP WILL BE HELD VIRTUALLY—REGISTER HERE

MONDAY, JANUARY 30, 2023*

10:00–10:20	**Welcome and Housekeeping**
	Rebecca Willett (the University of Chicago)
	Michelle Schwalbe (National Academies) delivering sponsor remarks (NIH and NSF)

10:20–11:20	**Opening Plenary**
	Definition of Digital Twins (DT) in general and in the context of biomedical science, vision of DT in this application area and in decision-making, overall challenges, opportunities, and successes. Moderated by Irene Qualters (Los Alamos National Laboratory)
	Reinhard Laubenbacher (University of Florida)
	Karissa Sanbonmatsu (Los Alamos National Laboratory)

11:20–11:30	**Break**

11:30–12:15	**Panel 1: Digital Twins at the Cellular and Molecular Scale**
	Moderated by Ines Thiele (National University of Ireland, Galway)
	Jeff (Jeffrey R.) Sachs (Merck & Co., Inc., Rahway, NJ, USA)
	Mikael Benson (Karolinska Institute)
	Juan Perilla (University of Delaware)
	Rommie Amaro (University of California, San Diego)

12:15–12:45	**Lunch Break**

12:45–1:30	**Panel 2: Digital Twins at the Organ, Tumor, and Microenvironment Scale**
	Moderated by Caroline Chung (MD Anderson Cancer Center)
	Tom Yankeelov (University of Texas at Austin)
	Jayashree Kalpathy-Cramer (University of Colorado Denver)
	James A Glazier (Indiana University)
	Petros Koumoutsakos (Harvard University)

*All times in ET

1:30–2:15   **Panel 3: Digital Twins at the Whole Human, Multisystem, and Population Scale**

Moderated by Ines Thiele (National University of Ireland, Galway)

Aldo Badano (Food and Drug Administration)

David Miller (Unlearn.AI)

Todd Coleman (Stanford University)

Heiko Enderling (H. Lee Moffitt Cancer Center)

2:15–2:30   **Break**

2:30–3:15   **Panel 4: Connecting Across Scales**

Moderated by Rebecca Willett (The University of Chicago)

Bissan Al-Lazikani (MD Anderson Cancer Center)

Liesbet Geris (University of Liège)

Gary An (University of Vermont)

3:15–3:45   **Panel 5: Special Session on Privacy, Ethics, and Data Issues**

Moderated by Irene Qualters (Los Alamos National Laboratory)

Jodyn Platt (University of Michigan)

Nathan Price (Thorne HealthTech)

Lara Mangravite (HI-Bio)

3:45–4:00   **Summary and Convergence**

Caroline Chung (MD Anderson Cancer Center)

MEETING ADJOURNED

COMMITTEE BIOS

Karen E. Willcox (Chair) is Director of the Oden Institute for Computational Engineering and Sciences, Associate Vice President for Research, and Professor of Aerospace Engineering and Engineering Mechanics at the University of Texas at Austin. She is also External Professor at the Santa Fe Institute. At UT, she holds the W. A. "Tex" Moncrief, Jr. Chair in Simulation-Based Engineering and Sciences and the Peter O'Donnell, Jr. Centennial Chair in Computing Systems. Before joining the Oden Institute in 2018, she spent 17 years as a professor at the Massachusetts Institute of Technology, where she served as the founding Co-Director of the MIT Center for Computational Engineering and the Associate Head of the MIT Department of Aeronautics and Astronautics. Prior to joining the MIT faculty, she worked at Boeing Phantom Works with the Blended-Wing-Body aircraft design group. She is a Fellow of the Society for Industrial and Applied Mathematics (SIAM), a Fellow of the American Institute of Aeronautics and Astronautics (AIAA), and in 2017 was appointed Member of the New Zealand Order of Merit (MNZM) for services to aerospace engineering and education. In 2022 she was elected to the National Academy of Engineering (NAE). Willcox is at the forefront of the development and application of computational methods for design, optimization and control of next-generation engineered systems. A number of her active research projects and collaborations with industry are developing core mathematical and computational capabilities to achieve predictive digital twins at scale.

Derek Bingham is a Professor and Chair of the Department Statistics and Actuarial Science at Simon Fraser University. He received his PhD from the Department of Mathematics and Statistics at Simon Fraser University in 1999. After graduation he joined the Department of Statistics at the University of Michigan. He moved back to Simon Fraser in 2003 as the Canada Research Chair in Industrial Statistics. He has recently completed a three-year term as Chair for the Natural Sciences and Engineering Research Council of Canada's Evaluation Group for Mathematical and Statistical Sciences. The focus of his current research is developing statistical methods for combining physical observations with large-scale computer simulators. This includes new methodology for Bayesian computer model calibration, emulation, uncertainty quantification and experimental design. Dr. Bingham's work is motivated by real-world applications. Recent collaborations have been with scientists at U.S. national laboratories (e.g., Los Alamos National Lab), U.S. Department of Energy sponsored projects (Center for Exascale Radiation Transport), and Canadian Nuclear Labs.

Caroline Chung is vice president and Chief Data Officer and is an associate professor in Radiation Oncology and Diagnostic Imaging. Her clinical practice is focused on CNS malignancies and her computational imaging lab has a research focus on quantitative imaging and computational modeling to detect and characterize tumors and toxicities of treatment to enable personalized cancer treatment. Internationally, Dr. Chung is actively involved in multidisciplinary efforts to improve the generation and utilization of high quality, standardized imaging to facilitate quantitative imaging integration for clinical impact across multiple institutions, including Vice Chair of the Radiological Society of North America (RSNA) Quantitative Imaging Biomarker Alliance (QIBA) and Co-Chair of the Quantitative Imaging for Assessment of Response in Oncology Committee of the International Commission on Radiation Units and Measurements (ICRU). Beyond her clinical, research and administrative roles, Dr. Chung enjoys serving as an active educator and mentor with a passion to support the growth of diversity, equity and inclusion in STEM, including her role as Chair of Women in Cancer (http://www.womenincancer.com), a non-for-profit organization that is committed to advancing cancer care by encouraging the growth, leadership and connectivity of current and future oncologists, trainees and medical researchers. Her recent publications include work on building digital twins for clinical oncology.

Julianne Chung is an Associate Professor in the Department of Mathematics at Emory University. Prior to joining Emory in 2022, she was an Associate Professor in the Department of Mathematics and part of the Computational Modeling and Data Analytics Program at Virginia Tech. From 2011-2012, she was an Assistant Professor at the University of Texas at Arlington and from 2009-2011 an NSF Mathematical Sciences Postdoctoral Research Fellow at the University of Maryland at College Park. She received her PhD in 2009 in the Department of Math and

Computer Science at Emory University, during which she was supported by a Department of Energy Computational Science Graduate Fellowship. She has received many prestigious awards including the Frederick Howes Scholar in Computational Science award, an NSF CAREER award, and an Alexander von Humboldt Research Fellowship. Her research interests include numerical methods and software for computing solutions to large-scale inverse problems, such as those that arise in imaging applications.

Carolina Cruz-Neira is a pioneer in the areas of virtual reality and interactive visualization, having created and deployed a variety of technologies that have become standard tools in industry, government and academia. She is known world-wide for being the creator of the CAVE virtual reality system. She has dedicated a part of her career to transfer research results into daily use by spearheading several Open Source initiatives to disseminate and grow VR technologies and by leading entrepreneurial initiatives to commercialize research results. She has over 100 publications as scientific articles, book chapters, magazine editorials and others. She has been awarded over $75 million in grants, contracts, and donations. She is also recognized for having founded and led very successful virtual reality research centers, like the Virtual Reality Applications Center at Iowa State University, the Louisiana Immersive Technologies Enterprise and now the Emerging Analytics Center. She has been named one of the top innovators in virtual reality and one of the top three greatest women visionaries in this field. BusinessWeek magazine identified her as a "rising research star" in the next generation of computer science pioneers; she has been inducted as a member of the National Academy of Engineering, an ACM Computer Pioneer, received the IEEE Virtual Reality Technical Achievement Award and the Distinguished Career Award from the International Digital Media & Arts Society among other national and international recognitions. She had given numerous keynote addresses and has been the guest of several governments to advise on how virtual reality technology can help to give industries a competitive edge leading to regional economic growth. She has appeared in numerous national and international TV shows and podcasts as an expert on her discipline and several documentaries have been produced about her life and career. She has several ongoing collaborations in advisory and consulting capacities on the foundational role of virtual reality technologies with respect to digital twins.

Conrad J. Grant is the Chief Engineer for the Johns Hopkins University Applied Physics Laboratory, the nation's largest University Affiliated Research Center, performing research and development on behalf of the Department of Defense, the intelligence community, the National Aeronautics and Space Administration, and other federal agencies. He previously served for over a decade as the Head of the APL Air and Missile Defense Sector where he led 1200 staff developing advanced air and missile defense systems for the U.S. Navy and the Missile Defense Agency. Mr. Grant has extensive experience in the application of systems engineering to the design, development, test and evaluation, and fielding of complex systems involving multi-sensor integration, command and control, human-machine interfaces, and guidance and control systems. Mr. Grant's engineering leadership in APL prototype systems for the Navy is now evidenced by capabilities on board over 100 cruisers, destroyers, and aircraft carriers of the U.S. Navy and its Allies. He has served on national committees including as a technical advisor on studies for the Naval Studies Board (NSB) of the National Academies as well as membership on the U.S. Strategic Command Senior Advisory Group (SAG). He is a member of the program committees for the Department of Electrical and Computer Engineering (ECE) and the Engineering for Professionals Systems Engineering Program of the Johns Hopkins University Whiting School of Engineering. Mr. Grant earned a Bachelor of Science in Physics from the University of Maryland, College Park, a Master of Science in Applied Physics and a Master of Science in Computer Science from the Johns Hopkins University, Whiting School of Engineering.

James L. Kinter is Director of the Center for Ocean-Land-Atmosphere Studies (COLA) at George Mason University (GMU), where he oversees basic and applied climate research conducted by the Center. Dr. Kinter's research includes studies of atmospheric dynamics and predictability on intra-seasonal and longer time scales, particularly the prediction of Earth's climate using numerical models of the coupled ocean-atmosphere-land system. Dr. Kinter is a tenured Professor of Climate Dynamics in the Atmospheric, Oceanic and Earth Sciences (AOES) department of the College of Science at GMU, where he has responsibilities for teaching climate predictability and climate change. After earning his doctorate in geophysical fluid dynamics at Princeton University in 1984, Dr. Kinter served as a

National Research Council Associate at NASA Goddard Space Flight Center, and as a faculty member of the University of Maryland prior to helping to create COLA. Dr. Kinter, a Fellow of the American Meteorological Society, has served on many national and international review panels for both scientific research programs and supercomputing programs for computational climate modeling. Dr. Kinter has served on three previous National Academies committees.

Ruby Leung is a Battelle Fellow at Pacific Northwest National Laboratory. Her research broadly cuts across multiple areas in modeling and analysis of climate and water cycle including orographic precipitation, monsoon climate, extreme events, land surface processes, landatmosphere interactions, and aerosol-cloud interactions. Dr. Leung is the Chief Scientist of the U.S. Department of Energy's Energy Exascale Earth System Model (E3SM), a major effort involving over 100 earth and computational scientists and applied mathematicians to develop state-of-the-art capabilities for modeling human-Earth system processes on DOE's next generation high performance computers. She has organized several workshops sponsored by Department of Energy, National Science Foundation, National Oceanic and Atmospheric Administration, and National Aeronautics and Space Administration to define gaps and priorities for climate research. She is a member of the Board on Atmospheric Sciences and Climate (BASC), National Academies of Sciences, Engineering, and Medicine and an editor of the AMS Journal of Hydrometeorology. She has published over 450 papers in peer-reviewed journals. Dr. Leung is an elected member of the National Academy of Engineering and Washington State Academy of Sciences. She is also a fellow of the American Meteorological Society (AMS), American Association for the Advancement of Science (AAAS), and American Geophysical Union (AGU). She is the recipient of the AGU Global Environmental Change Bert Bolin Award and Lecture in 2019, the AGU Atmospheric Science Jacob Bjerknes Lecture in 2020, and the AMS Hydrologic Sciences Medal in 2022. She was awarded the DOE Distinguished Scientist Fellow in 2021. She received a BS in Physics and Statistics from Chinese University of Hong Kong and an MS and PhD in Atmospheric Sciences from Texas A&M University.

Parviz Moin (NAS/NAE) is the Franklin P. and Caroline M. Johnson Professor of Mechanical Engineering and the director of the Center for Turbulence Research (CTR) at Stanford University. He was the founding director of the Institute for Computational and Mathematical Engineering and he directed the Department of Energy's ASCI and PSAAP centers. Dr. Moin pioneered the use of direct numerical simulation and large eddy simulation techniques for the study of the physics, and reduced order modeling of multi-physics turbulent flows. His current research interests include predictive simulation of aerospace systems, hypersonic flows, multi-phase flows, propulsion, numerical analysis for multi-scale problems, and flow control. Dr. Moin is the co- editor of the Annual Review of Fluid Mechanics and associate editor of the Journal of Computational Physics. Amongst his awards are the American Physical Society (APS) Fluid Dynamics Prize and AIAA Fluid Dynamics Award. Dr. Moin is a member of the National Academy of Sciences, National Academy of Engineering, and the Royal Spanish Academy of Engineering. He is a fellow of APS and AIAA, and the American Academy of Arts and Sciences. Dr. Moin received a Ph.D. in mechanical engineering from Stanford University.

Lucila Ohno-Machado, MD, PhD, MBA, has been appointed deputy dean for biomedical informatics and will lead the newly created free-standing Section for Biomedical Informatics and Data Science at Yale School of Medicine starting 1/1/23. She is currently health sciences associate dean for informatics and technology, founding chief of the Division of Biomedical Informatics in the Department of Medicine, and distinguished professor of medicine at the University of California San Diego (UCSD). She also is founding chair of the UCSD Health Department of Biomedical Informatics and founding faculty of the UCSD Halicioğlu Data Science Institute in La Jolla, California. She received her medical degree from the University of São Paulo, Brazil; her MBA from the Escola de Administração de São Paulo, Fundação Getúlio Vargas, Brazil; and her PhD in medical information sciences and computer science at Stanford University. She has led informatics centers that were funded by various NIH initiatives and by agencies such as AHRQ, PCORI, and NSF. Dr. Ohno-Machado organized the first large-scale initiative to share clinical data across five UC medical systems and later extended it to various institutions in California and around the country. Prior to joining UCSD, she was distinguished chair in biomedical informatics at Brigham and

Women's Hospital, and faculty at Harvard Medical School and at MIT's Health Sciences and Technology Division. She is an elected member of the National Academy of Medicine, the American Society for Clinical Investigation, the American Institute for Medical and Biological Engineering, the American College of Medical Informatics, and the International Academy of Health Sciences Informatics. She is a recipient of the American Medical Informatics Association leadership award, as well as the William W. Stead Award for Thought Leadership in Informatics. She serves on several advisory boards for national and international agencies.

Colin James Parris has achieved great academic and professional success while attending and leading some of the most prestigious academic and business institutions in America and the world. His career has been centered on the development and enhancement of digital transformation across multiple industries (telecommunications, banking, retail, aviation, energy) in billion-dollar companies, as well as advocating/evangelizing STEM advancement across minority communities. As GE Digital's Chief Technology Officer, Dr. Parris leads teams that work to leverage technologies and capabilities across GE to accelerate business impact and create scale advantage for digital transformation. He also champions strategic innovations and identifies and evaluates new, breakthrough technologies and capabilities to accelerate innovative solutions to solve emerging customer problems. Dr. Parris created and leads the Digital Twin Initiative across GE. He previously held the position of Vice President, Software and Analytics Research at GE Research in Niskayuna, NY. Prior to joining GE, Dr. Parris worked at IBM where he was an executive for 16 years in roles that spanned research, software development, technology management, and P&L management. He was the Vice President, System Research at the IBM Thomas J. Watson Research Division, the Vice President Software Development for IBM's largest system software development lab (6,000+ developers worldwide), Vice President of Corporate Technology, and the Vice President and General Manager of IBM Power Systems responsible for the company's $5B+ Unix System and Software business. Dr. Parris holds a PhD, Electrical Engineering from the University of California, Berkeley; an MS from Stanford University; an MS, Electrical Engineering and Computer Science from the University of California, Berkeley and a BS, Electrical Engineering from Howard University.

Irene Qualters serves as the Associate Laboratory Director for Simulation and Computation at Los Alamos National Laboratory, a U.S. Department of Energy national laboratory. She previously served as a Senior Science Advisor in the Computing and Information Science and Engineering (CISE) Directorate of the National Science Foundation (NSF), where she had responsibility for developing NSF's vision and portfolio of investments in high performance computing, and has played a leadership role in interagency, industry, and academic engagements to advance computing. Prior to her NSF career, Irene had a distinguished 30-year career in industry, with a number of executive leadership positions in research and development in the technology sector. During her 20 years at Cray Research, she was a pioneer in the development of high-performance parallel processing technologies to accelerate scientific discovery. Subsequently as Vice President, she led Information Systems for Merck Research Labs, focusing on software, data and computing capabilities to advance all phases of pharmaceutical R&D.

Ines Thiele is the principal investigator of the Molecular Systems Physiology group at the University of Galway, Ireland. Her research aims to improve the understanding of how diet influences human health. Therefore, she uses a computational modelling approach, termed constraint-based modelling, which has gained increasing importance in systems biology. Her group builds comprehensive models of human cells and human-associated microbes; then employs them together with experimental data to investigate how nutrition and genetic predisposition can affect one's health. In particular, she is interested in applying her computational modelling approach for better understanding of inherited and neurodegenerative diseases. Dr. Thiele has been pioneering models and methods allowing large-scale computational modelling of the human gut microbiome and its metabolic effect on human metabolism. She earned her PhD in bioinformatics from the University of California, San Diego, in 2009. She was an Assistant and Associate Professor at the University of Iceland (2009 - 2013), and Associate Professor at the University of Luxembourg (2013-2019). In 2013, Dr. Thiele received the ATTRACT fellowship from the Fonds National de la Recherche (Luxembourg). In 2015, she was elected as EMBO Young Investigator. In 2017, she was awarded the prestigious ERC starting grant. In 2020, she was named a highly cited researcher by Clarivate, and

received the NUI Galway President's award in research excellence. She is an author of over 100 international scientific papers and reviewer for multiple journals and funding agencies.

Conrad Tucker is an Arthur Hamerschlag Career Development Professor of Mechanical Engineering at Carnegie Mellon University and holds courtesy appointments in Machine Learning, Robotics, Biomedical Engineering, and CyLab Security and Privacy. His research focuses on employing Machine Learning (ML)/Artificial Intelligence (AI) techniques to enhance the novelty and efficiency of engineered systems. His research also explores the challenges of bias and exploitability of AI systems and the potential impacts on people and society. Dr. Tucker has served as PI/Co-PI on federally/non-federally funded grants from the National Science Foundation, the Air Force Office of Scientific Research, the Defense Advanced Research Projects Agency, the Army Research Laboratory, the Bill and Melinda Gates Foundation, among others. In February 2016, he was invited by National Academy of Engineering (NAE) President Dr. Dan Mote, to serve as a member of the Advisory Committee for the NAE Frontiers of Engineering Education Symposium. He is currently serving as a Commissioner on the U.S. Chamber of Commerce Artificial Intelligence Commission on Competitiveness, Inclusion, and Innovation. Dr. Tucker received his Ph.D., M.S. (Industrial Engineering), and MBA degrees from the University of Illinois at Urbana-Champaign, and his B.S. in Mechanical Engineering from Rose-Hulman Institute of Technology.

Rebecca Willett is a Professor of Statistics and Computer Science at the University of Chicago. Her research is focused on machine learning, signal processing, and large-scale data science. Willett received the National Science Foundation CAREER Award in 2007, was a member of the DARPA Computer Science Study Group, received an Air Force Office of Scientific Research Young Investigator Program award in 2010, was named a Fellow of the Society of Industrial and Applied Mathematics in 2021, and was named a Fellow of the IEEE in 2022. She is a co-principal investigator and member of the Executive Committee for the Institute for the Foundations of Data Science, helps direct the Air Force Research Lab University Center of Excellence on Machine Learning, and currently leads the University of Chicago's AI+Science Initiative. She serves on advisory committees for the National Science Foundation's Institute for Mathematical and Statistical Innovation, the AI for Science Committee for the US Department of Energy's Advanced Scientific Computing Research program, the Sandia National Laboratories Computing and Information Sciences Program, and the University of Tokyo Institute for AI and Beyond. She completed her PhD in Electrical and Computer Engineering at Rice University in 2005 and was an Assistant then tenured Associate Professor of Electrical and Computer Engineering at Duke University from 2005 to 2013. She was an Associate Professor of Electrical and Computer Engineering, Harvey D. Spangler Faculty Scholar, and Fellow of the Wisconsin Institutes for Discovery at the University of Wisconsin-Madison from 2013 to 2018.

Xinyue Ye is Fellow of American Association of Geographers (AAG) and Fellow of Royal Geographical Society (with IBG), holding Harold L. Adams Endowed Professorship in Department of Landscape Architecture and Urban Planning & Department of Geography at Texas A&M University-College Station (TAMU), USA. He directs the focus of transportation in the PhD program of Urban and Regional Science at TAMU, and is the Interim Director of Center for Housing and Urban Development. His research focuses on geospatial artificial intelligence, geographic information system, and smart cities. Prof. Ye won the national first-place research award from University Economic Development Association. He was the recipient of annual research awards from both computational science (New Jersey Institute of Technology) and Geography (Kent State University) as well as AAG Regional Development and Planning Distinguished Scholar Award. He was one of the top 10 young scientists named by The World Geospatial Developers Conference in 2021. His work has been funded by National Science Foundation, National Institute of Justice, Department of Commerce, Department of Energy, and Department of Transportation. Prof. Ye is Editor-in-Chief of Computational Urban Science, an open access journal published by Springer. He also serves as the co-editor of Journal of Planning Education and Research, the flagship journal of Association of Collegiate Schools of Planning.

PANELIST BIOS

Bissan Al-Lazikani FRSB MBCS is a data scientist and drug discoverer with experience in academia and industry. She is Professor, Genomic Medicine; Director of Discovery Data Science and founding faculty of the Data Science Institute at MD Anderson Cancer Center. Prior to this, she was Head of Data Science at the Institute of Cancer Research, London. She is formally trained in biology and computer science: BSc Molecular Biology from University College, London; MSc Computer Science from Imperial College, London; PhD Computational Biology from the University of Cambridge, and Howard Hughes postdoctoral fellowship Biophysics, Columbia University, NY. She co-led the creation of the groundbreaking ChEMBL database. Then she led the creation of the world's largest public drug discovery knowledgebase, canSAR, integrating vast multidisciplinary data; and leading suite of AI-driven drug discovery analysis algorithms. She applies these to discovery novel drugs and optimize therapy for adult and pediatric cancers.

Rommie E. Amaro holds the Distinguished Professorship in Theoretical and Computational Chemistry at the Department of Chemistry and Biochemistry at the University of California, San Diego. She grew up on the south side of Chicago, and received her B.S. in Chemical Engineering (1999) and her Ph.D. in Chemistry (2005) from the University of Illinois at Urbana-Champaign. Rommie was a NIH postdoctoral fellow with Prof. J. Andrew McCammon at UC San Diego from 2005-2009, and started her independent lab at the University of California, Irvine in 2009. In 2011 she moved to UC San Diego. She is the recipient of an NIH New Innovator Award, the Presidential Early Career Award for Scientists and Engineers, the ACS COMP OpenEye Outstanding Junior Faculty Award, the ACS Kavli Foundation Emerging Leader in Chemistry, the Corwin Hansch Award, and the 2020 ACM Gordon Bell Special Prize for COVID19. Rommie's scientific interests lie at the intersection of computer-aided drug discovery and biophysical simulation. Her scientific vision revolves around expanding the range and complexity of molecular constituents represented in atomic-level molecular dynamics simulations, the development of novel multiscale methods for elucidating their time dependent dynamics, and the discovery of novel chemical matter controlling biological function.

Dr. Gary An is a Professor of Surgery and Vice-Chairman for Surgical Research in the Department of Surgery at the University of Vermont Larner College of Medicine. He is a clinically active trauma/critical care surgeon who has worked on the application of complex systems analysis, agent-based modeling and in silico trials to study sepsis, inflammation, wound healing, host-pathogen interactions and cancer since 1999. He is one of the co-founders of Translational Systems Biology, a discipline that promotes the use of multi-scale mechanistic simulation models to cross the Valley of Death of Drug Development. He asserts that the biggest bottleneck in drug development/repurposing is the inability to effectively predict the effect of a molecular manipulation of cellular behavior (e.g. a drug) demonstrated to be effective in pre-clinical studies or with existing clinical usage when it is then applied in a novel clinical context. His work consists of the development of multiscale, cell-based computer simulations and the integration of machine learning and artificial intelligence with such models to represent the individual diversity within clinical populations (e.g. populations of medical digital twins for in silico trials) and for discovery and development of therapeutic control modalities.

Opportunities and Challenges for Digital Twins in Biomedical Sciences

Aldo Badano joined FDA in 2001 and was appointed to the Senior Biomedical Research Service in 2012. Aldo is currently the Director of the Division of Imaging, Diagnostics, and Software Reliability, Office of Science and Engineering Laboratories, Center for Devices and Radiological Health, FDA. He received a MEng in Radiological Health Engineering and a PhD in Nuclear Engineering from the University of Michigan in 1999 and 1995 after obtaining a ChemEng degree from the Universidad de la República, Montevideo, Uruguay in 1992. His primary research interests are in the characterization and modeling of medical imaging acquisition and visualization systems. Aldo is a fellow of SPIE, AAPM, and AIMBE.

Mikael Benson, MD, PhD, leads the Medical Digital Twin Group at the Karolinska Institute in Stockholm, and the Swedish Digital Twin Consortium (publications and a recorded talk at Harvard can be found at our website: sdtc.se). The overall aim is to develop digital twins of individual patients for predictive preventive and personalised medicine. The twins are constructed based on integrating routine clinical and genome-wide data down to the single cell level. Each twin is computation are treated with thousands of drugs to find the drug that is optimal for the patient.

Todd P. Coleman received B.S. degrees in electrical engineering (summa cum laude), as well as computer engineering (summa cum laude) from the University of Michigan. He received M.S. and Ph.D. degrees from MIT in electrical engineering and did postdoctoral studies at MIT in neuroscience. He previously held faculty positions in Electrical & Computer Engineering and Neuroscience at the University of Illinois and in Bioengineering at UC San Diego. He is currently an Associate Professor in the Department of Bioengineering at Stanford University. Dr. Coleman's research is very multi-disciplinary, using tools from applied probability, physiology, and bioelectronics. He has been selected as a National Academy of Engineering Gilbreth Lecturer, as a Fellow of IEEE, and a Fellow as the American Institute for Medical and Biological Engineering. He is currently the Chair of the National Academies Standing Committee on Biotechnology Capabilities and National Security Needs.

Dr. Heiko Enderling, FSMB, is Senior Member & Director for Education and Outreach in the Department of Integrated Mathematical Oncology at Moffitt Cancer Center, with courtesy appointments in the Departments of Radiation Oncology and Genitourinary Oncology. He currently serves as president of the Society for Mathematical Biology. Dr. Enderling received his Undergraduate degree in Computer Visualization applied to Human Medicine from the University of Magdeburg, Germany, in 2003, before earning his PhD in Mathematical Biology at the University of Dundee, Scotland, in 2006. He trained as a postdoc and instructor before advancing to Assistant Professor at the Center of Cancer Systems Biology at Tufts University School of Medicine. Since 2013, He is a Moffitt, where he directs a research group with focus on Quantitative Personalized Oncology. He develops calibrated and validated mathematical model driven by clinical data to aid patient-specific treatment decisions, with major focus on radiation therapy and mathematical biomarkers for treatment personalization. Dr. Enderling has published over 100 peer-reviewed articles, and his laboratory is funded by multiple NCI and several foundation funding awards.

Opportunities and Challenges for Digital Twins in Biomedical Sciences

Liesbet Geris is Research Professor in Biomechanics and Computational Tissue Engineering at the university of Liège and KU Leuven in Belgium. Her research focusses on the multi-scale and multi-physics modeling of biological processes. Together with her team and their clinical and industrial collaborators, she uses these models to investigate the etiology of non-healing fractures, to design in silico potential cell-based treatment strategies and to optimize manufacturing processes of these tissue engineering constructs. Liesbet is scientific coordinator of the Prometheus platform for Skeletal Tissue Engineering (50+ researchers). She has edited several books on computational modeling and tissue engineering. She has received 3 prestigious ERC grants (starting in 2011 and consolidator in 2017 and 2023) to finance her research and has received a number of young investigator and research awards. She is a former member and chair of the Young Academy of Belgium (Flanders) and member of the strategic alliance committee of the Tissue Engineering and Regenerative Medicine Society. She is the current executive director of the Virtual Physiological Human Institute and in that capacity she advocates the use of in silico modeling in healthcare through liaising with the clinical community, the European Commission and Parliament, regulatory agencies (EMA, FDA) and various other stakeholders including patients. She is the coordinator of the EDITH coordination and support action that aims to develop the ecosystem and roadmap for the integrated virtual human twin (www.edith-csa.eu). Besides her research work, she is often invited to give public lectures on the challenges of interdisciplinary in research, women in academia and digital healthcare.

Dr. James Glazier is Professor of Intelligent Systems Engineering and Director of the Biocomplexity Institute at Indiana University, Bloomington. He received his B.A. in Physics and Mathematics from Harvard University in 1983 and his Ph.D. in Physics from the University of Chicago in 1989. His research focuses on applying mechanistic, multiscale virtual-tissue computer simulations to understand embryonic development, homeostasis, toxicity and disease and to develop and optimize disease treatments. He leads the collaborative development of the open-source CompuCell3D (www.compucell3d.org) framework for the construction of mechanistic biomedical digital twins and actively disseminates these methods, He is a fellow of the American Physical Society and the Institute of Physics (London) and has served as Chair of the Division of Biological Physics of the American Physical Society. He co-leads the IMAG/MSM Working Group on Multiscale Modeling and Viral Pandemics and is active in the development of infrastructure and community for the creation of biomedical digital twins.

Jayashree Kalpathy-Cramer is an endowed chair in Ophthalmic data sciences and the founding chief of the Division of Artificial Medical Intelligence in the Department of Ophthalmology at the University of Colorado (CU) School of Medicine. Previously, she was an associate Professor of Radiology at Harvard Medical School where she was actively involved in data science activities with a focus on medical imaging. Her research interests span the spectrum from novel algorithm development to clinical deployment. She is passionate about the potential that machine learning and mathematical modeling have to improve the access and the quality of healthcare in the US and worldwide. Dr. Kalpathy-Cramer has authored over 200 peer-reviewed publications and has written over a dozen book chapters.

Opportunities and Challenges for Digital Twins in Biomedical Sciences

Petros Koumoutsakos is Herbert S. Winokur, Jr. Professor of Engineering and Applied Sciences and Area Chair for Applied Mathematics at Harvard's John A. Paulson School of Engineering and Applied Sciences (SEAS). He studied Naval Architecture (Diploma-NTU of Athens, M.Eng.-U. of Michigan), Aeronautics and Applied Mathematics (PhD-Caltech) and has served as the Chair of Computational Science at ETH Zurich (1997-2020). Petros is elected Fellow of the American Society of Mechanical Engineers (ASME), the American Physical Society (APS), the Society of Industrial and Applied Mathematics (SIAM). He is recipient of the Advanced Investigator Award by the European Research Council and the ACM Gordon Bell prize in Supercomputing. He is elected International Member to the US National Academy of Engineering (NAE). His research interests are on the fundamentals and applications of computing and artificial intelligence to understand, predict and optimize fluid flows in engineering, nanotechnology, and medicine.
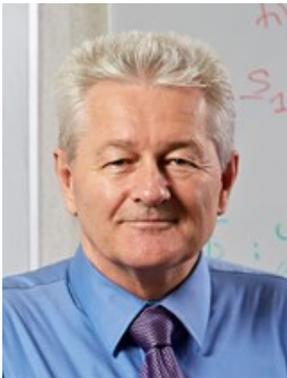
Dr. Reinhard Laubenbacher joined the University of Florida in May 2020 as a professor in the Department of Medicine, Division of Pulmonary, Critical Care, and Sleep Medicine. He is the director of the Laboratory for Systems Medicine. Prior to joining UF, he served as director of the Center for Quantitative Medicine and Professor in the Department of Cell Biology in the University of Connecticut School of Medicine. Concurrently, he held an appointment faculty appointment at the Jackson Laboratory for Genomic Medicine. He is a fellow of AAAS, the Society for Mathematical Biology, and the American Mathematical Society. Dr. Laubenbacher is a mathematician by training, and his broad research interests lie in computational and mathematical systems medicine, with applications to lung immunology and cancer.
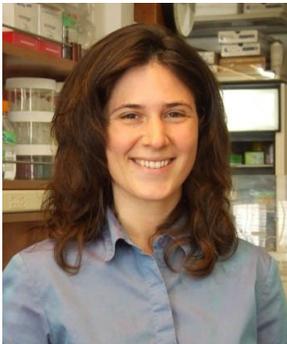
Lara Mangravite, PhD, is a data strategist focused on the development, management and use of multi-scalar human data resources. She currently serves as VP of Data Strategy, Partnerships, and Translational Genetics at HI-Bio, a clinical-stage biotech company focused on precision immunology. Dr. Mangravite trained in Physics at the Pennsylvania State University (BS), in Pharmaceutical Chemistry from the University of California, San Francisco (PhD), and completed a postdoctoral fellowship in cardiovascular pharmacogenomics at the Children's Hospital Oakland Research Institute. She spent the majority of her early career as President of Sage Bionetworks, a nonprofit research institute that worked closely with institutes, foundations and research communities to improve data and information flow, benchmark analytical practices, and establish reliable outcomes to support translational research.

Dave Miller is the Chief Science Officer at Unlearn, overseeing the Clinical, Regulatory, and Biostatistics function. He is a biostatistician with expertise in prognostic models, clinical trials, observational studies, and diagnostic devices. Prior to joining Unlearn, Dave was Head of Biostatistics & Epidemiology for Verily Life Sciences. Other past roles include Lead Program Biostatistician at Genomic Health and Sr Dir of Medical Affairs Statistical Analysis at ICON Clinical Research. Dave received his bachelors and masters in Statistics from Carnegie Mellon. He has co-authored over 100 peer-reviewed papers in medical journals.

Opportunities and Challenges for Digital Twins in Biomedical Sciences

Dr. Juan Perilla is a biophysical chemist, and is an Assistant Professor of Chemistry & Biochemistry at the University of Delaware. He obtained his Ph.D. in 2011 at the Johns Hopkins University, researching transition state theory applied to large conformational changes in proteins. He then moved to the University of Illinois at Urbana-Champaign (late Klaus Schulten's group), where he studied entire viruses and bacterial organelles under physiological conditions. Prof. Perilla develops physical and chemical based methodologies for the understanding of biological processes related to life and disease. In particular, his research spans from quantum-mechanical calculations to mesoscale simulations and leverages the computational power of petascale and exascale super computers. Prof. Perilla has conducted some of the largest simulations ever performed, which allowed him to develop a robust statistical analysis framework for such big datasets. He has authored over 50 peer-reviewed articles, 11 journal covers and three book chapters. Dr. Perilla enjoys sports like squash, golf, long-distance road cycling, as well as playing chess and the violin.

Jodyn Platt, PhD, MPH is an Associate Professor of Learning Health Sciences at the University of Michigan. Trained in medical sociology and health policy, her research focuses on issues at the intersection of informatics and ethics. She is interested in understanding what makes data-driven health trusted and the pathways for earning, achieving, and sustaining trust across stakeholders. Dr. Platt is the AcademyHealth Senior Scholar in Residence advising on issues of measuring and building trust. Her recent work, largely funded by NIH, examines public, patient, and other stakeholder perspectives on policy for data and information in precision oncology and the use of AI/ML in Clinical Decision Support. The goal of this work is to identify factors that influence trust in complex information systems and to develop evidence-based and actionable recommendations that can inform issues of institutional, state, and federal health policy.

Dr. Nathan Price is Chief Scientific Officer of Thorne HealthTech (NASDAQ: THRN) and author of The Age of Scientific Wellness. Previously he was CEO of Onegevity, an AI health intelligence company that merged with Thorne prior to the IPO in 2021. In 2019, he was named as one of the 10 Emerging Leaders in Health and Medicine by the National Academy of Medicine, and in 2021 he was appointed to the Board on Life Sciences of the National Academies of Sciences, Engineering, and Medicine. He spent much of his earlier career as Professor and Associate Director of the Institute for Systems Biology (now on leave), co-director with biotechnology pioneer Lee Hood of the Hood-Price Lab for Systems Biomedicine, and is Affiliate Faculty at the University of Washington in Bioengineering and Computer Science & Engineering. He is a Camille Dreyfus Teacher-Scholar, received the 2016 Grace A. Goldsmith award for his work pioneering 'scientific wellness', was a co-founder of Arivale, and received a Healthy Longevity Catalyst Award from the National Academy of Medicine in 2020. He has co-authored more than 200 peer-reviewed scientific publications and given over 200 talks and keynotes. He also served as Chair of the NIH Study Section on Modeling and Analysis of Biological Systems (MABS) and is a Fellow of the American Institute for Biological and Medical Engineering.

Jeff (Jeffrey R.) Sachs, PhD is a Distinguished Scientist in the Quantitative Pharmacology and Pharmacometrics Department ("QP2") in Merck Research Laboratories (Merck & Co., Inc., Rahway, NJ, USA), where he is responsible for modeling and simulation for vaccines from early discovery through late-stage clinical development. His publication areas include methods for and applications of pharmacometrics, biotechnology, and pattern recognition. Dr. Sachs received his BS and MS in Applied Math from Brown University and his PhD in Math at MIT where he worked with Alan Grodzinsky on the electromechanochemistry of articular cartilage, supporting design of a minimally-invasive arthroscopic diagnostic device. After postdoctoral appointments in Applied Physics (Univ. Tokyo), Biomedical Engineering (Northwestern Univ.), and Biotechnology (N.I.S.T.), he developed two successful biotechnology consulting businesses. He came to Merck in 1999 and worked on gene expression analysis, data mining, and SAR integration platforms. He was lead inventor of Merck's proteomics and metabolomics technology platforms. He led the therapeutic area-aligned modeling and simulation group, and lead the design, implementation, and global deployment of a web-based tool providing a user-friendly, non-technical, modeling interface for internal and external decision makers. That tool, used across many programs and therapeutic areas, helped Merck gain recommendations for compounds in over 40 countries. He led the department's efforts in infectious diseases, oncology, and strategy for digital health/adherence. He is currently the QP2 Therapeutic Area Lead for vaccines, and the QP2 Program Lead for the Dengue vaccine program.

Dr. Karissa Sanbonmatsu is a structural biologist and fellow of Los Alamos National Laboratory, where she leads the Sanbonmatsu Laboratory established in 2001. She received her B.A. in Physics from Columbia University in 1992 and Ph.D. in Astrophysical, Planetary and Atmospheric Sciences from University of Colorado at Boulder in 1997. Her team uses computational and experimental approaches to understand the mechanism of a diverse array of epigenetic and non-coding RNA systems, including chromatin, ribosomes, riboswitches and long non-coding RNAs. She is a fellow of the American Physical Society and an advocate for LGBT scientists. Her TED talk, The biology of gender, from DNA to the brain, has over 2.5 million views on TED.com.

Tom Yankeelov received an MA in Applied Mathematics and an MS in Physics from Indiana University, and a PhD in Biomedical Engineering at SUNY @Stony Brook. He completed his post-doc at Vanderbilt University and climbed the ranks to Full Professor in 2010. He then joined The University of Texas at Austin in 2016 where he is now the Moncrief Chair of Computational Oncology and Professor of Biomedical Engineering, Diagnostic Medicine, and Oncology. Dr. Yankeelov is the founding Director of the Center for Computational Oncology, and also serves as Director of Cancer Imaging Research within the Livestrong Cancer Institutes at UT Austin. He is also an Adjunct Professor of Imaging Physics at MD Anderson Cancer Center. The overall goal of Dr. Yankeelov's research is to develop tumor forecasting methods by integrating advanced imaging technologies with predictive models of tumor growth to optimize therapy. This is accomplished by dividing his efforts between mathematical modeling, pre-clinical development, and implementation in clinical trials.