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Syllabus Overview Sample: Digital Twins and AI for Predictive Analytics

Program: AI Engineering- Digital Twins and Analytics Certificate Program

Faculty: Damon Weiss, Professor of Practice, Civil and Environmental Engineering, College of Engineering

Course Number: 12831 **Units:** 12

Zoom Class: Weekday Evening, ET

Course Description

This course explores the transformative power of digital twins to harness data-driven insights and improve decision making with predictive analytics. You will study topics like data analysis, statistical inference, and applied machine learning to understand the process of collecting, cleaning, interpreting, transforming, exploring and analyzing data generated by digital twin models.

Using this process, you will learn how to extract pertinent information, communicate insights, and support decision making based on the predictions of how engineered systems might perform under various conditions. The advantages of using visualization techniques to explore data and communicate outcomes will also be highlighted throughout the course.

Course Learning Objectives

By the end of this course, students will be able to:

- Plan, design, and implement projects using statistical, computational, and quantitative applied machine learning techniques
- Predict system response to support data-driven decision making using digital twins
- Discuss the ethical implications of AI-driven decision making

Faculty Introduction



Damon Weiss is a professor of the practice in the Department of Civil and Environmental Engineering at Carnegie Mellon University. He holds an M.S. in advanced infrastructure systems from Carnegie Mellon and a B.S. in civil engineering from the University of Virginia. With 28 years of applied experience in digital modeling, urban systems, and data-informed design, Weiss helps students connect emerging technologies with real-world infrastructure challenges.

At Carnegie Mellon, he teaches graduate courses on digital twins and advanced infrastructure systems, and helped shape the online certificate program in AI Engineering: Digital Twins & Analytics. The program prepares engineers and planners to apply real-time sensing, simulation, and machine learning to complex infrastructure systems.

In addition to his academic role, Weiss is the co-founder of Ethos Collaborative, a Pittsburgh-based civil and ecological engineering firm specializing in sustainable and community-centered urban design. Through this dual engagement, he integrates thoughtful design with emerging technologies—bridging the tactile, human-scaled aspects of infrastructure with digital twin systems, AI models, and geospatial analytics to elevate decision-making, performance, and public value. His work supports municipal and regional partners in advancing climate resilience, infrastructure equity, and systems-level planning across the built environment.

Course Topics

Topic	Weekly Concepts and Activities
Intro to Digital Twins for Predictive Analytics	● Explain the role of digital twins and AI on predictive analytics. ● Identify the key characteristics distinguishing digital twins from digital models. ● Map real case studies to the course's digital twin modeling framework.
Sensing and Instrumentation	● Explain the role of sensors in digital twins ● Differentiate between static and dynamic characteristics of sensors ● Calculate sampling and quantization requirements ● Understand the limitations of digital signal processing
Measurement Errors	● Distinguish between systematic and aleatory uncertainty ● Describe three different sources of measurement error ● Calculate the design stage uncertainty for an instrument ● Calculate the uncertainty propagated through a function on a set of measurements. ● Understand how measurement uncertainty propagates to and affects controller outputs

Predictive Modeling without Uncertainty	● Predict the behavior of systems over time using different model classes ● Reason about the tradeoffs inherent to choosing between classes of models
Predictive Modeling with Uncertainty	● Understand sources of uncertainty in digital models ● Calculate effects of uncertainty propagation on model outputs ● Perform Monte Carlo simulations to reason about uncertainty
Probabilistic Modeling	● Evaluate different modeling approaches, comparing deterministic and probabilistic models. ● Understand the predictive variance for new samples from the digital twin. ● Draw samples from the predictive (frequentist) distribution of a model.
Probabilistic Modeling : The Bayesian View	● Explain the implications of Bayes theorem on predictive models ● Reason about the effects of priors and evidence on posterior distributions ● Be able to draw samples from posterior predictive distributions.
Other Predictive Models	● Understand the broader scope of predictive models and the specific applications for each kind ● Formally define the processes of data assimilation and model calibration in Digital Twins ● Calibrate and evaluate a classification model for a binary classification task
The Observe, Orient, Decide, and Act (OODA Loop)	● Articulate at least three benefits that Digital Twins provide in OODA loops ● Roughly decompose sequential decision making problems and map the components into the OODA framework ● Explain concepts behind optimal control and robust control
Model-Predictive Control (MPC)	● Identify and explain the four key components of an MPC problem: dynamic models, cost function, constraints, and optimization algorithm ● Analyze case studies that demonstrate both the benefits and drawbacks of MPC in real-world applications ● Map MPC components and their requirements to the Digital Twin modeling framework ● Implement a basic MPC controller for temperature setpoint optimization to minimize energy use
Digital Twin Integration, Interoperability, and Middleware	● Understand the role of middleware in connecting physical and digital twins ● Distinguish between syntactic and semantic interoperability in digital twin systems ● Apply key standards such as ISO 23247, OPC UA, and BIM in digital twin integration ● Analyze practical considerations including scalability, latency, and data security in middleware

	● Design interoperable sensor and simulation systems
Foundation Models, Agentic Workflows and the Future	● Analyze recent advances in AI/ML and evaluate their relevance and potential applications within digital twin frameworks ● Define foundation models and identify state-of-the-art examples across different modalities (text, vision, multimodal), explaining their key characteristics and capabilities ● Explain agentic systems and workflows by describing their definitions and providing examples of how they are applied in different real-world applications ● Envision and propose future digital twin systems that leverage foundation models and agentic workflows, considering both opportunities and challenges
Ethics, Security, and Privacy in Digital Twins	● Understand ethical considerations in managing AI-driven systems in critical infrastructure ● Identify and address privacy concerns when handling sensitive data in digital twins ● Recognize security vulnerabilities and implement protection strategies for digital twin models against cyberattacks ● Apply ethical, security, and privacy principles in the design and evaluation of digital twin systems for real-world applications

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NOTE: This is a sample designed to provide an overview of topics covered in the course based on previous course syllabi. All students will be provided an updated and final syllabus at the start of the course. Faculty, content, and schedule are all subject to change.