Homework 1: Reading Assignment and Essay

Deep Learning Discrete Calculus for Engineering Applications, Special Topics in Mechanical Engineering (MECH-ENG 395-0-1), Prof. W.K. Liu, Spring 2023, Northwestern University.

Klemens Iten, KlemensIten2023@u.northwestern.edu
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Digital Twins and AI

In the last decades, digital twins have emerged as powerful tools in research and industry. A digital twin is a virtual replica of a system which is used to digitally simulate how it reacts and performs in the real world. According to Purdy et al. (2020); IBM, the concept of a digital twin goes further than just a simulation: Rather, it is a digital environment which simulates multiple facets of the real system, ideally all that are relevant. Furthermore, a digital twin benefits from richer information, such as being continuously updated by real-time data from sensors and other sources.

Just as many key technologies in today's world, the history of digital twins can be traced to the space race in the 1960s, when NASA first used them as "living models" of the Apollo mission to train astronauts. However, the actual term "digital twin" has only been coined as recently as the 2010s, even though digitals twins as a concept is not as new. As Allen (2021) notes, what sets apart today's digital twins from technologies used in earlier years is "the scale, ordinality, and non-deterministic nature of the models".

The reason therefor lies in rapid developments in data science, which allows for the collection, processing and analyzation of large amounts of accurate and useful data. In turn, digital twins themselves produce large amounts of data, which can be used to improve the real-world system. Machine learning and AI algorithms can be used to model the behaviour of the digital twin and thus the physical system itself, and optimization algorithms can be used to optimize their performance.

Nowadays, companies all over the world are adopting digital twins. Cabos and Pavone (2018) provide the main use cases for businesses: On one hand, the goal is to improve product design, performance, and health. An example for this is provided by Swiss-Swedish company ABB (Nowak and Stekkeland, 2019), which uses a digital twin of a dieselelectric propulsion system to improve the performance of a ship's on-board DC grid system, which is limited by the rough conditions and limited maintenance options at sea.

Furthermore, Cabos and Pavone (2018) list the possibility of using digital twins to increase manufacturing efficiency, quality, flexibility and competitiveness. In Germany, this has gone as far as industry-wide standards for the implementation of digital factory twins emerging, particularly regarding data management and system architecture (VDI Association of German Engineers, 2008, VDI Standard No. 4499).

Another example is the Swiss CO_2-capturing technology startup CLIMEWORKS, which uses digital twins of their factories in Iceland and the Swiss alps to move "from reactive to proactive issue management", ranging from detecting anomalies of critical components to using real-time weather forecast data for ideal performance balancing of their plant, all from the remote headquarters in Zurich, Switzerland (Accenture Digital X, 2021).

As mentioned, Machine Learning algorithms can aid in the design process of a digital twin, such as in identifying the relevant governing equations. An example for this is deep learning using Artificial Neural Networks, which through the Universal Approximation Theorem (Cybenko, 1989) can approximate any continuous function using nonpolynomical activation functions. Thus, deep learning techniques learned in this class can provide crucial insights into the modeling of digital twins.

As for a possible digital twin project for this course, one could consider a digital twin of a real-world system or asset. One possibility can be attempting to create a digital twin of a system which is present on the NORTHWESTERN campus, say for example one's very own dorm room. In principle, such a dorm room is a thermodynamic system consisting of a radiator steam heating system (which cannot be controlled and has slow dynamics), an A/C cooling system (which can be controlled by the user and has faster dynamics), and external influences (roommate opening the door, sun shining onto the roof).

Using sensors (temperature, humidity, etc), external weather data, and by incorporating the various heat sinks and sources, one could try to model a digital twin of the dorm room. By controlling the A/C cooler through a digital relay system, the goal would be to keep the actual dorm room's temperature and humidity in a desirable range.

In conclusion, digital twins are a powerful tool in the field of data science and AI, enabling the simulation and optimization of physical systems and assets. Companies across various industries are adopting digital twins to optimize their operations and improve their products and services. Data science plays a critical role in creating and using digital twins, providing the tools and techniques to collect, process, and analyze the data required to create accurate and effective digital twins. Lastly, creating a digital twin potentially provides a unique opportunity to apply data science and AI techniques to a real-world problem or application.

Word count: approx. 775

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