June 2020

Artificial Intelligence and Simulation

System Dynamics Conference

Lyle Wallis & Mark Paich

Headlines make it clear that AI is a hot topic…

“

What does that mean for simulation?

“

AI is one of the most important things humanity is working on. It is **more profound** than, I dunno, electricity or fire.

- Sundar Pichai
Google CEO

“

The trajectory of AI and its **influence on society** is only beginning.

- Satya Nadella
Microsoft CEO

“

Artificial Intelligence Is Likely to Make a Career in Finance, Medicine or Law a Lot **Less Lucrative**

- Entrepreneur
August 2017

“

Just as electricity transformed almost everything 100 years ago, today I actually have a hard time thinking of an industry that I don’t think **AI will transform** in the next several years.

- Andrew Ng

Google Brain, Baidu, Stanford University

AI is a collection of techniques and technologies across a number of domains:

Natural Language

- Natural Language processing and text mining
- Natural Language generation
- Chatbots and discourse understanding
- Sentiment & emotion analysis
- Speech-to-text and text-to-speech

Machine Learning

- Regression & classification
- Bayesian learning
- Probabilistic programming
- Anomaly detection
- Optimization techniques
- Support Vector Machines
- Various supervised, semi-supervised, and unsupervised techniques

Deep Learning

- Convolutional Neural Nets
- Recursive Neural Nets
- Capsule Networks
- Generative Adversarial Networks
- Deep reinforcement learning
- Hybrid learning models

Simulation@Scale

- Cloud simulation
- Big data architecture
- Cloud ML – AWS, GCP, Azure
- Machine Learning deployment
- DRL Toolchains

Automated ML

- Automated data preparation
- Automated feature engineering
- Automated algorithm selection
- Automated explanation generation
- Meta-model inference

Simulation & RL

- System dynamics modeling
- Agent-based simulation
- Digital Twins
- Reinforcement learning
- Augmented and synthetic data generation
- Calibration of models

Embodied AI

- IoT and Industrial IoT – Edge computing and Smart sensors
- Drone – Autonomy & Image analytics
- Robots – Navigation & Learning
- Brain-Machine Interfaces

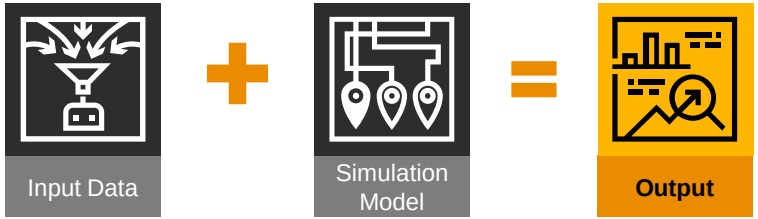
Responsible AI

- Explainable AI
- Beneficial AI
- ‘Black box’ Interpretability
- Maturity models
- Ethics and Law
- AI Governance
- AI Controls framework

Simulation Development and ML/NLP Model Development

...are fundamentally different

Causal



Human defines set of rules (simulation) which transform the input data into the output

Correlational

Machine infers the model based on large amounts of input and output examples

BodyLogical Meta-Modeling

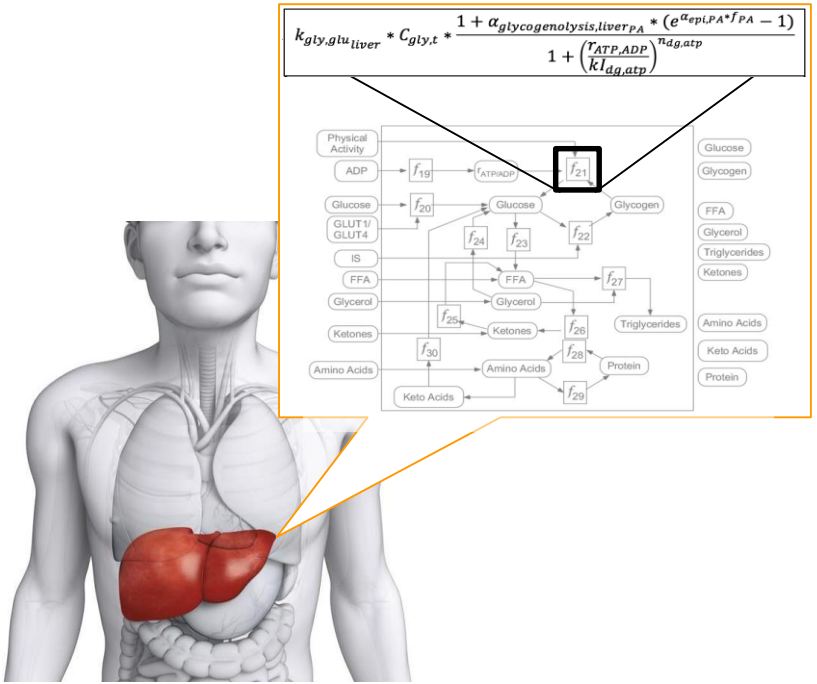
Combining Simulation and ML

BodyLogical

An individual level, ODE-based, simulation model of the human body used to predict the progression of chronic diseases such as metabolic syndrome

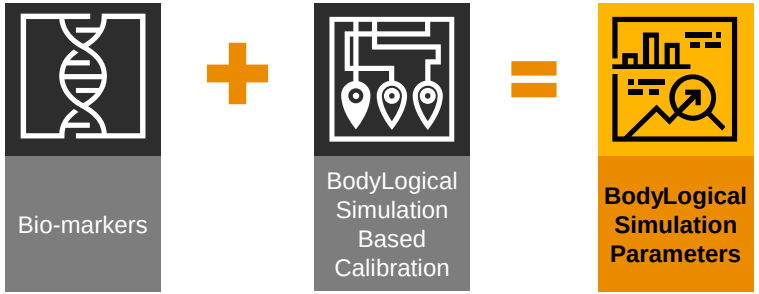
Using BodyLogical requires calibration for thousands of individuals in a selected population

- BodyLogical is calibrated to clinical biomarkers (eg: blood pressure, glucose level, etc) at an individual level.
- Full calibration for an individual uses a differential evolution algorithm that is very time consuming
  - **Multiple days for a 15000 person population**

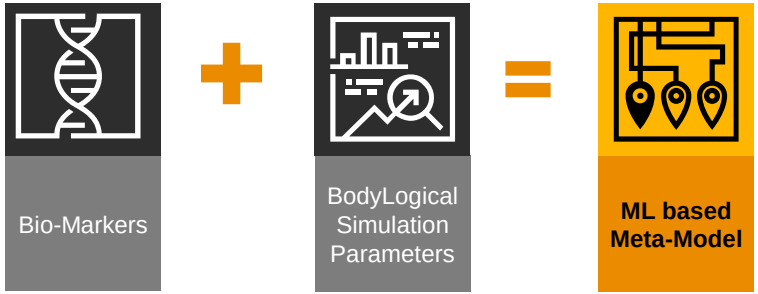


Combining **Simulation** and **Machine Learning** approaches to create a Meta-Model accelerates the calibration process

BodyLogical Simulation

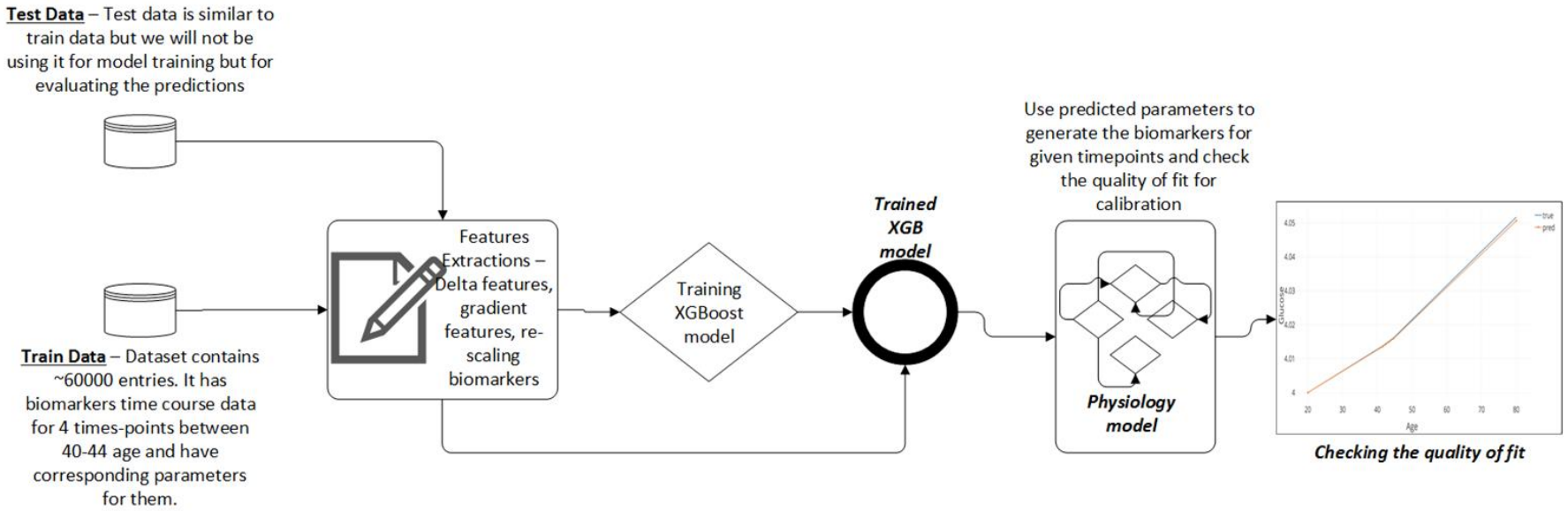


Meta-Model using ML



How it works

Using Machine Learning to relate individual bio-markers to previously estimated model parameters, the meta-model accelerates the calibration process



Performance

The meta-model provided an excellent fit between patient biomarkers and previously estimated model parameters

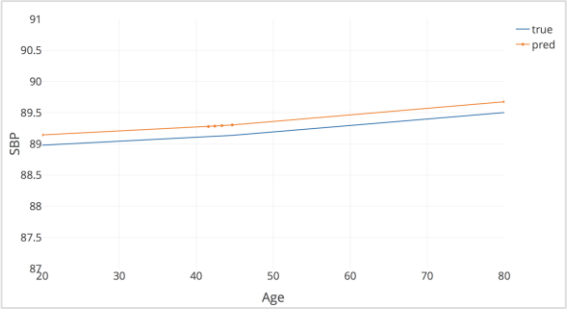
The meta-model was extremely fast. Parameters for 15,000 individuals could be estimated in *3 seconds*.

There were some cases where the meta-model didn't perform as well. Generally, these were cases where the patient had a major health intervention.

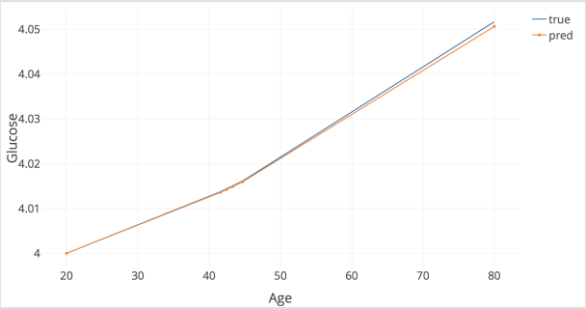
Approach is very promising and is continuing to be pursued.

Example Results

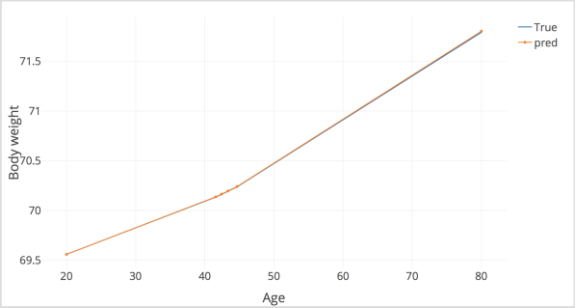
Data without intervention
(Best fit example)



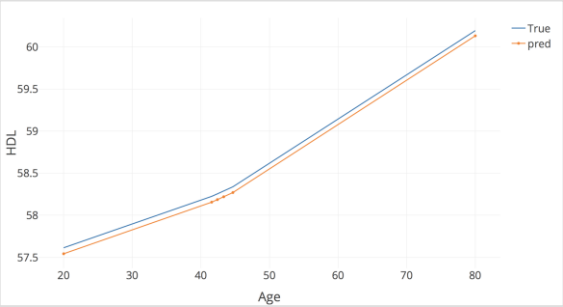
SBP



Glucose



Body weight



HDL cholesterol

Getting an answer to “**So What?**”

Combining Simulation with **Deep Reinforcement Learning**

Deep Reinforcement Learning (DRL) gives us a promising way to do simulation model policy analysis and answer **“So What?”**

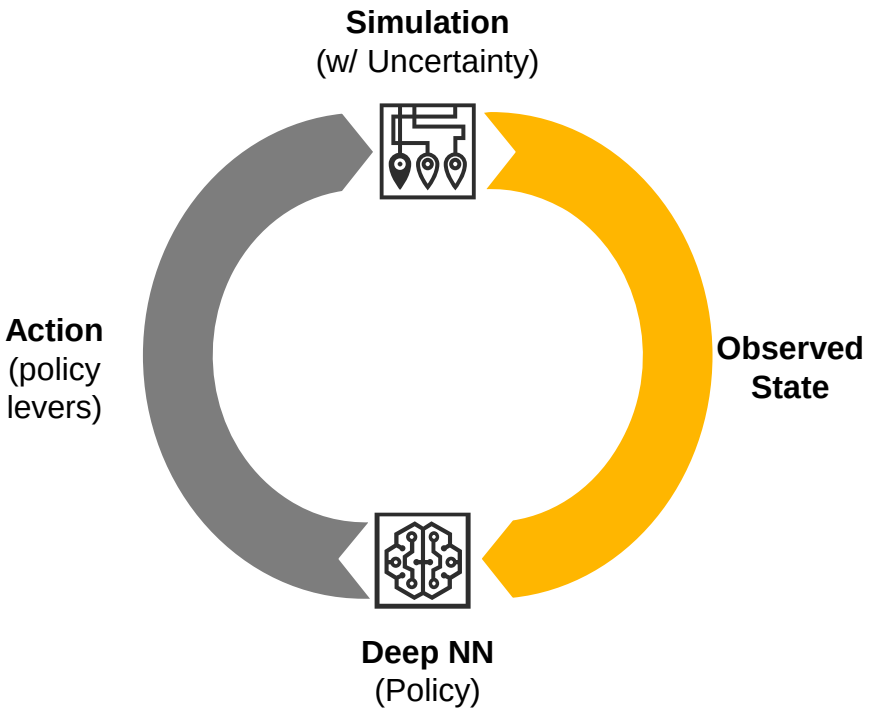
Simulation is great for describing systems, creating shared mental models, and predicting system behavior.

However, we often are challenged with **“so what?”**

Answering “So What?” requires a prescriptive response that in the SD world we call **“policy.”**

DRL combined with **simulation** gives us a new way to generate good policies and integrate them into the fabric of the systems themselves.

DRL solves problems that require a complex sequence of actions to optimally reach a desired goal state

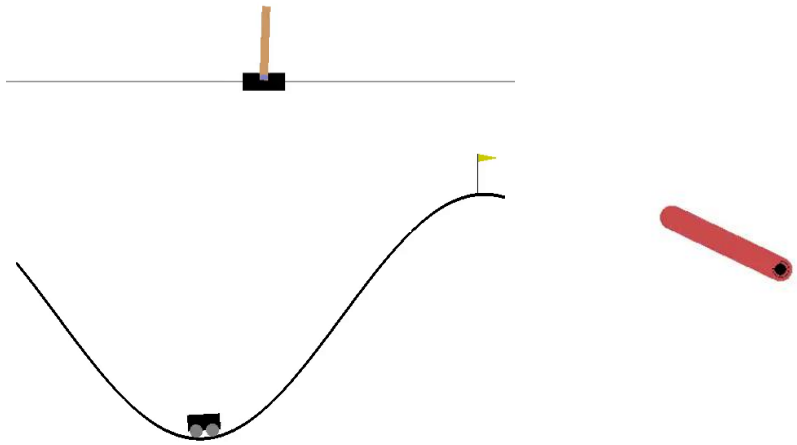


- Actions are generated periodically (eg, every minute, day, year) or a-periodically based on the system reaching a specific state (condition)
- The outcome (ie: the next observed state of the system) of each action taken is **uncertain**
- For every system state the policy Deep NN generates the best action to ultimately reach a goal state, even if that goal state is many decisions (actions) in the future
- DRL is effective even for systems with immense state spaces
- This is a **Markov Decision Process** implemented with simulation, neural nets, and reinforcement learning

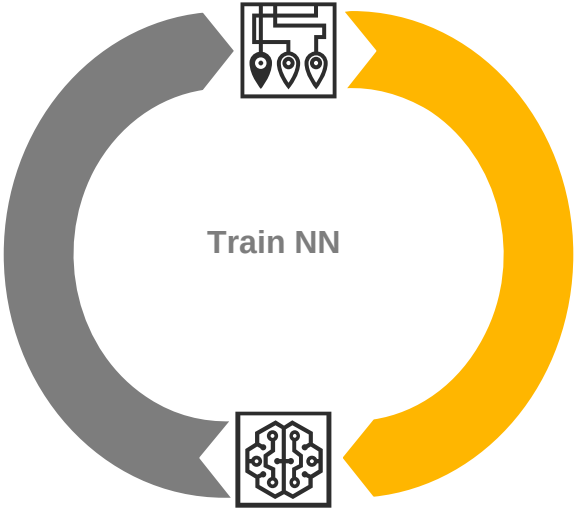
Once a system simulation has been created the **Deep NN "Brain"** is trained using reinforcement learning (RL)

- RL works similarly to how humans learn – through exploration and exploitation (**aka: trial and error**)
- The process is guided by a system of **rewards and penalties** towards the desired goal state
- As a rule of thumb it can take **~1 million simulations** to train the Deep NN. This requires a high performance tool chain to train the NN in reasonable time.

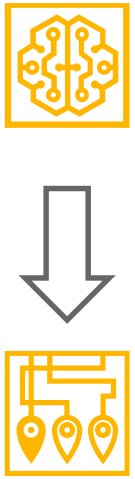
Simple Physics RL Examples



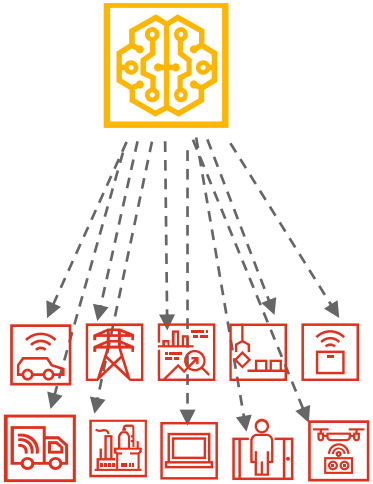
Trained Deep NNs (“brains”) embed the entire **state-action space** of the system and can be deployed independently of the simulation



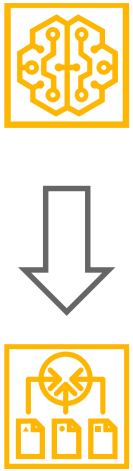
Insert NN into simulation



Insert NN into embodied systems



Insert NN into enterprise systems



Advanced Simulation + DRL tool chains create the capability to deploy and embed policies into operational systems

Strong prescriptive insights combined with deployment options expands the range of application for system simulation and systemic thought

Embodied Systems

- Robotics
- Drones
- Industrial Control

Operational Systems

- Supply Chain
- Scheduling
- Logistics
- Inventory

Strategy

- Dynamic and Resilient Strategy
- Pricing
- Production
- Promotion
- Competitive response

DRL can be advantageous over other techniques for policy analysis in situations where the system is highly non-linear and/or uncertain

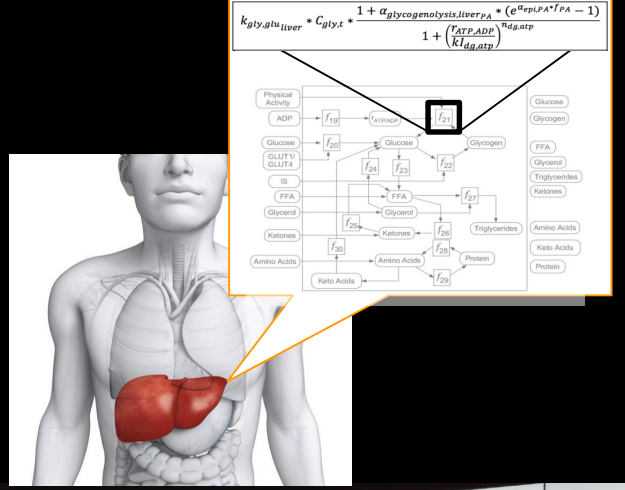
Advantages

- Inherently multi-period
- Generates adaptive policies
- Effectively handles uncertainty
- Effectively handles non-linear systems
- Scales to very complex systems with very large state spaces
- Computationally cheap once the policy is created
- Policies can be evaluated by observing the state-action response in simulation

Disadvantages

- Computationally expensive to create the policy
- Complex tool chains
- Multi-disciplinary set of skills required to execute and deliver
- Policies must be evaluated by observing the state-action response in simulation

Simulation is an integral part of the AI landscape. As AI technologies advance, the opportunities for simulation will increase.



Thank you.

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