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Integrating Artificial Intelligence and Simulation Modeling

PwC Artificial Intelligence Accelerator

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PwC Artificial Intelligence Accelerator is working with AnyLogic simulation and other AI technologies to create a new generation of simulation models

- The pervasive adoption of AI technology in business and society means that our simulation models must reflect and adopt AI as well

- In the foreseeable future all but the simplest simulation models will incorporate AI tech either in the model itself or in the development of the model

Agenda

- Impact of AI and key AI technologies
- Survey of AI and simulation integrated applications
- Example Problem: Autonomous Vehicle behavior using Deep Reinforcement Learning
- Making it real: Integrating AI directly into AnyLogic simulation

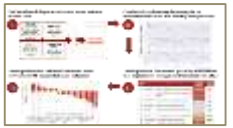
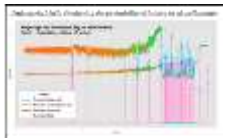
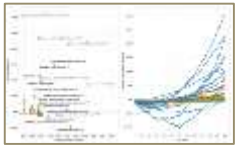
Application of AI ranges from automating existing processes to disrupting markets and business models

AI Game Changing Impact

Disrupting your Core Business	Innovating with New Services	Redesigning your Business Model
Automate your business processes & augment your decision making before other disruptors do it to you	*Innovate with new products and services for your customers based on big data, analytics and AI*	*Fundamentally redesign your business model or disrupt adjacent markets based on your core capabilities*
Example: Legal and accounting firms are using robotic and cognitive process automation, and blockchain to disrupt and re-engineer their business processes (e.g., Ross as a disruptor, PwC)	**Example:** Electronic retailers are using their extensive transactional and behavioral data of their customers to offer them new ways of trying, experiencing and purchasing their products (e.g., Amazon with Alexa, Baidu with Chatbots)	**Example:** Auto manufacturers are fundamentally rethinking their business model as 'Personal Mobility' service providers instead of manufacturers of vehicles to exploit autonomous cars and car share/ride share trends (e.g., GM with MAVEN, BMW with DriveNow)

Automating business processes with AI will soon become table-stakes, leaving the differentiation to those using AI to change the way they interact with customers

Artificial Intelligence is not a single technology. Here are five key areas that PwC is focusing on. We consider simulation to be an AI technology.

	Application Areas	Success Stories	
Machine Learning	• Workflow automation • Decision support • Anomaly detection	• Consumer fraud behavior anomalous activity detection using unsupervised methods • Deals asset reclassification automation support	
Deep Learning	• Unstructured data analysis for audio, image, and text • Automation and learning systems	• Audio analysis used to identify sales call features and assess traits of effective conversations • Deep reinforcement learning used to learn optimal operating policies for a rideshare business	
Natural Language Understanding	• Information extraction, workflow automation, and text generation • Insights from unstructured data • Chat bots and IPA	• Tax workflow automation that could save the client ~$65M annually • Customer contact center complaint analytics platform • Comprehensive chat bot study	
Data at Scale	• Industrial IoT • Streaming and real time data • Large scale data processing architecture	• Predictive maintenance applying ML on oil/gas pump sensor streaming data in a scalable manner	
Simulation	• Operations analysis • Strategy support • Consumer behavior modelling • New market entry analysis	• Designed a go to market strategy for a new personal mobility service • Patent for autonomous vehicle resource management in a rideshare environment	

Survey of AI and simulation integrated applications

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Digital supply chain, smart factory, and other industrial processes all incorporate AI technology. Simulation models of these systems will necessarily include AI components as well.

AI Application	AI and Simulation Integration Approach	Objective
• Material routing • Loading plans • Real-time decision making based on sensor data • Real-time “control tower”	AI components from the real system are **embedded** in the simulation model	Near real-time digital twins, “what-if” system analysis
	AI components for the real system are **developed** using simulation model	System design

Deep learning components can replace rules based models of human behavior and decision making in new service and strategic simulation models

AI Application	AI and Simulation Integration Approach	Objective
• Neural nets that describe consumer choice • Competitive reaction • Modelling other human behaviors	AI components trained in other environments are embedded in the simulation model	Testing of alternative business models
	Self generation of data to train neural nets	Strategy identification and development

AI techniques can address crippling optimization/calibration problems in large scale agent based models

- Large-scale ABM simulation models have
  - Lots of parameters to calibrate
  - Long run times
- Traditional optimization approaches often fail because they take much too long
- Machine learning and intelligent sampling approaches can be used to create meta models that dramatically speed up calibration
  - Meta models run much faster than the full simulation model
  - Machine learning makes it possible to capture the non-linear behavior and discontinuities in agent based models

Example Problem: Autonomous Vehicle behavior using Deep Reinforcement Learning

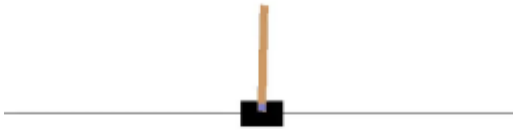
A common application for simulation is develop “optimal” decision rules for agents in a complex system. This is a problem that can be tackled with AI technologies combined with simulation.

- Many business problems consist of multiple decisions makers either collaborating or competing towards a particular goal
- PwC is working with a team at a large car company that is looking to roll out autonomous vehicles for the purpose of transporting customers
- Using a very complex AnyLogic AB/DE model simulated vehicles that follow hand coded rules to make their decisions
- As an experiment we used “Deep Reinforcement Learning” to train AV to maximize fleet efficiency while satisfying customer trip demand

Reinforcement Learning - an area of machine learning focused on teaching a computer an optimal decision policy over time using rewards and penalties as signals

Simple Physics RL Examples

Cart Pole



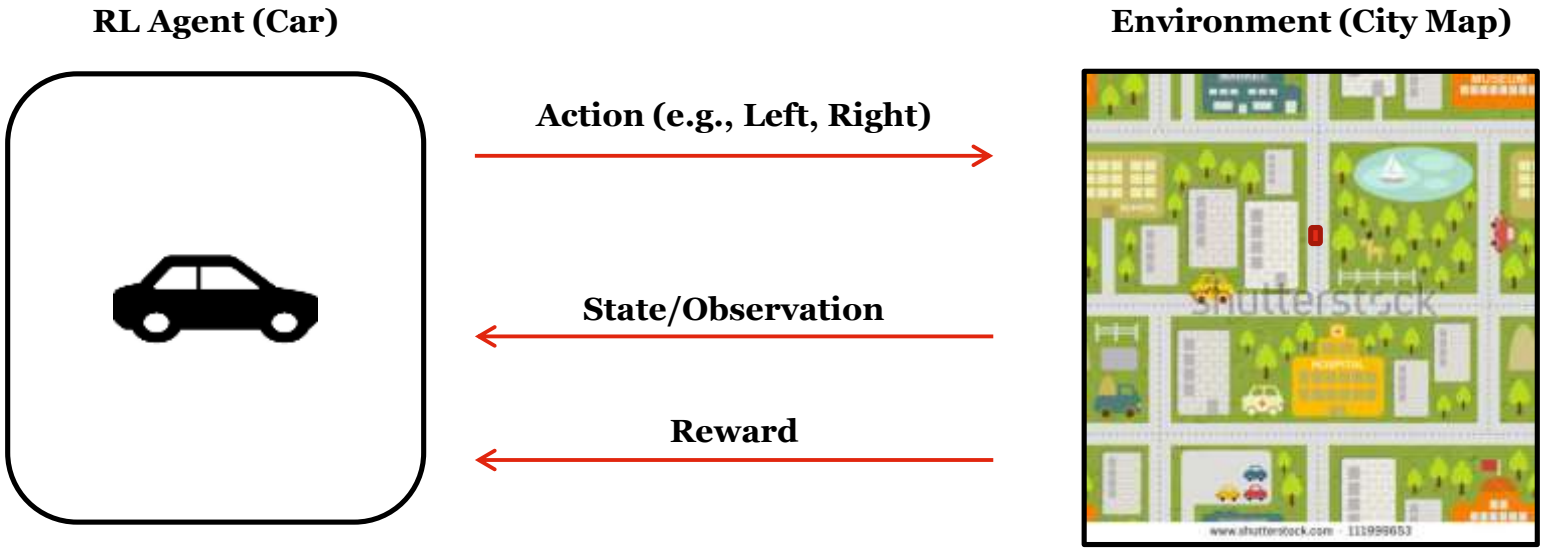
Pendulum Balance

Mountain Car Hill

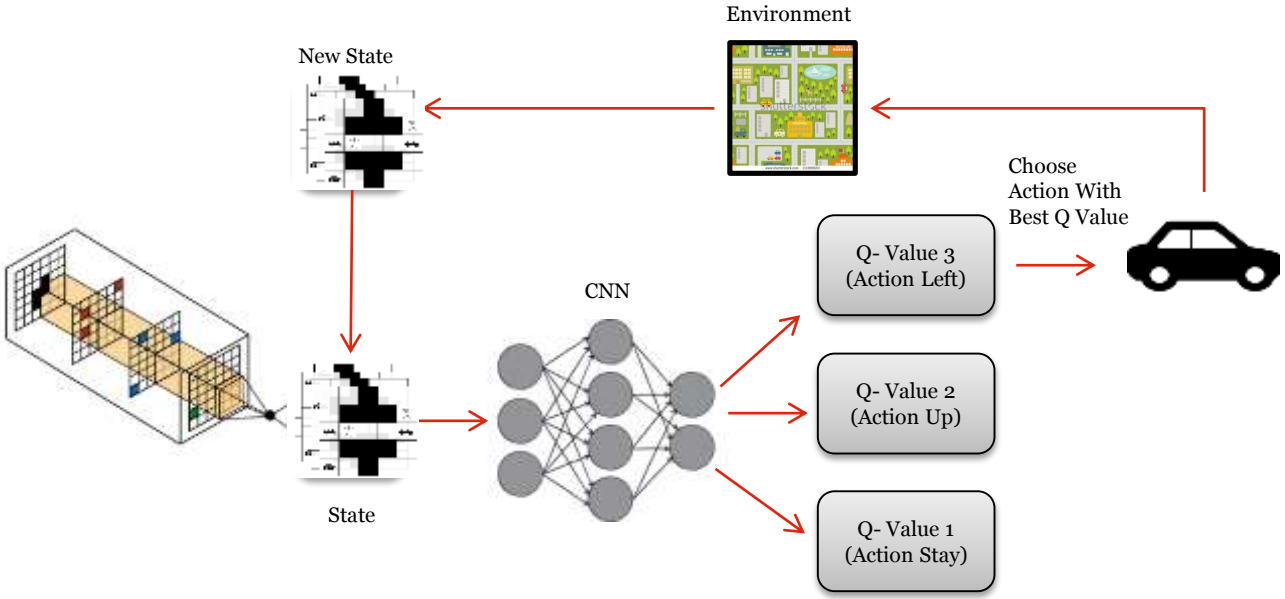
Key Takeaways

- The agent's goal is to select actions that maximize the future reward
- Representative model of how humans learn from experiences
- Lies in between supervised and unsupervised learning
- We implement Deep Reinforcement Learning for more complex problems using Deep Neural Networks

RL Agent Vs Environment – RL is composed of two entities, the agent making decisions and the world it is acting in. An Agent (Car) will communicate actions to the world and as a result it will recieve a reward and a new observation.



Deep Q Network – The CNN acts as a value function for a particular state and outputs a Q-Value for each action. Depending on the action policy, the action that yields the highest value is chosen by the agent and then performed in the environment.



DQN Attributes

- *Bellman's Updates:* iteratively used to train the neural network to represent the Q function
- Prioritized *Experience Replay:* used to store all experiences in a replay memory in order of importance and it s sampled in minibatches during training
- *Exploration–Exploitation:* ε-greedy exploration is used *where with probability* ε choose a random action, otherwise go with "greedy action
- *Target Networks:* Training is stabilized with a second network that is only updated with the weights every X training period

Making it real: Integrating AI directly into AnyLogic simulation

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Specialized AI toolsets are fine for developing specific components but to model entire systems we need to integrate AI directly into AnyLogic

Python is well known as the prominent language for data science toolkits. However, we needed a java-based library to achieve our goal of integrating AI into an AnyLogic simulation.

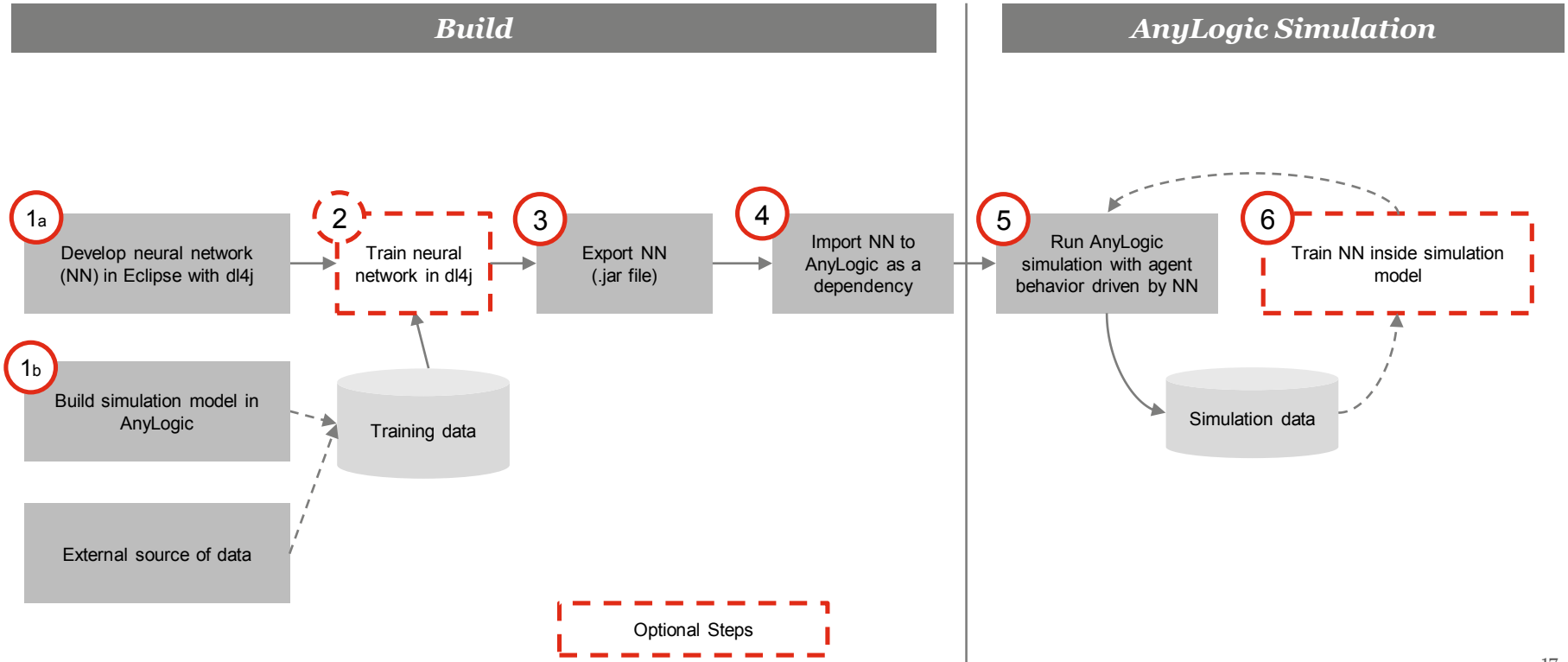
We looked for a library that met these requirements:

- Java based to allow for integration with AnyLogic
- Well supported by an engaged community to keep up with AI trends
- Designed for scale as our applications are likely to be for big businesses
- Interfaces with a variety of data stores as is the likely in a commercial scenario

With these requirements, we landed on Deeplearning4j (dl4j). Deeplearning4j is a commercial grade library designed for data scientists in business environments. Whilst it is always recommended to research libraries for each use case, here are some dl4j highlights:

- JVM-based distributed deep learning framework
- Dl4j leverages ND4J for data management which is also distributed
- Integrates with Hadoop, Spark and Kafka
- Strong documentation and community

The deep learning model is constructed externally and may be trained before integrating into AnyLogic



To explore this process we modified the “Schelling Segregation model” to train and utilize a simple neural net that replaces the rules based agent decision

Schelling Segregation model
Agents have a minimum threshold for ‘like-minded’ neighbors and are placed in a random location.

Rule-based simulation

Agents evaluate whether there are enough like-minded neighbors each time they move or a neighbor changes. Agents can also move randomly for no reason

- If there are enough like-minded agents, they stay in their current location
- If there are not enough like-minded agents, they move to a random location

Neural-network driven simulation

The neural network is trained on ‘historical movement data’ i.e. data generated from the rule-based simulation

→ Given the number of like-minded individuals and threshold, the neural network makes a decision to move or not move

Both models converge but in the neural-network driven simulation, we arrive at the result **without prior knowledge** of the relationship between threshold and like-minded neighbor count

AI can also be embedded into AnyLogic and used in replacement of manually encoded behaviors or processes

Objective: Demonstrate direct integration of AI and AnyLogic

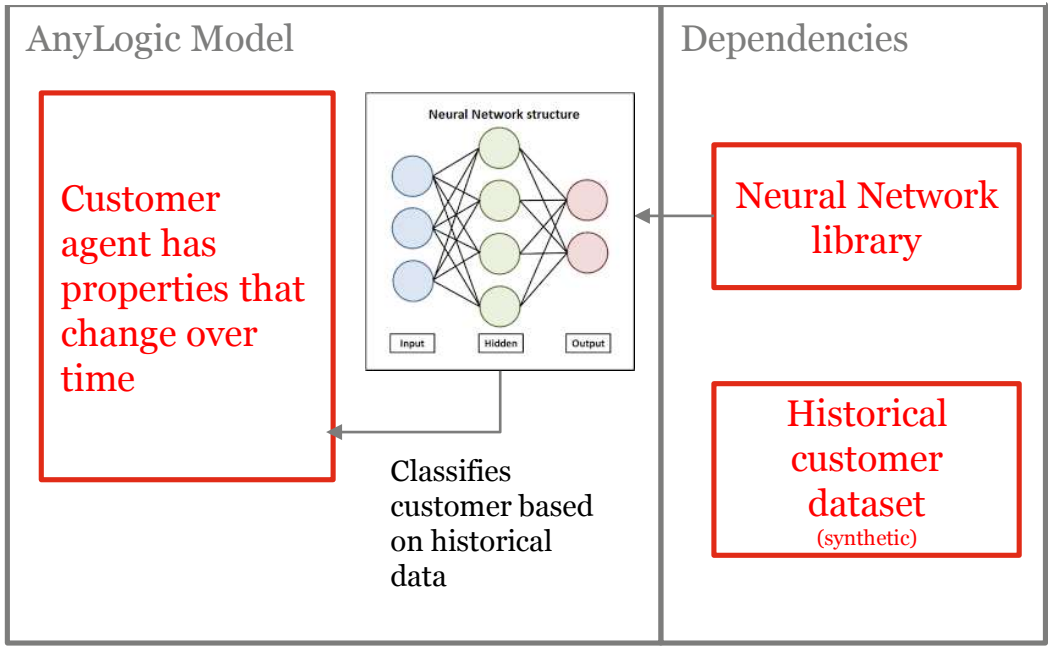
Direct integration means we are able to:

- Instantiate and configure a neural network in the AnyLogic environment
- Train the neural network with data during runtime
- Replace manually coded rules that govern agent behavior with the neural network

In our example model:

- A neural network is trained on historical customer data that contains some characteristics of the customers and whether or not they are a priority customer
- In replacement of business rules to approximate priority status, the neural network detects trends in the data and classifies each customer

Example model: Classifying priority customers



Concluding Thoughts

- Pervasive AI in the real world means that we will have pervasive AI in our simulated world as well
- AI will not only appear in our models but will help us build them as well
- AnyLogic's architecture makes it practical to integrate AI components directly into simulations

Thank you

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