Using Computational Intelligence Techniques to Accelerate the Design Automation of Power Electronics

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Abstract

Design Automation techniques for electronics design have become standard practice for many sectors in electronics, however have lagged behind in power electronics, till now.

There has been an explosion of design tools and techniques aligned with the rapid increase in interest in power electronics with the adoption of wide bandgap technology leading to rapid research and innovation in the field.

The term "Computational Intelligence" has been applied to the field of advanced computational techniques ranging from optimization (including heuristics and evolutionary algorithms) to the use of Artificial Neural Networks (ANNs) of various types.

More recently there has been a rapid adoption of a variety of Machine Learning (ML) approaches for both design and analysis of data from simulation and experimental testing.

Rapid advances in computational platforms such as cloud and edge computing, GPUs and AI specific hardware to support significant increases in computational power able to be leveraged to solve these challenges.

This talk will provide an overview of computational intelligence techniques, implementation and platforms, and how they can be applied to power electronics.

Agenda

Overview of Computational Intelligence

Platforms and Deployment – how do we implement and use Computational Intelligence in practice

Concluding Remarks and Questions

Overview	Approaches	Implementation	Examples	Conclusions

Computational Intelligence Approaches – what are they and how do they work?

Some Examples in Power Electronics

Overview of Computational Intelligence

What does this mean and what are the main approaches?

What does "Computational Intelligence" mean?

FROM WIKIPEDIA

"Computational intelligence (CI) is a set of Nature-inspired computational methodologies and approaches to address complex problems of the real world applications to which traditional (first principles, probabilistic, black-box, etc.) methodologies and approaches are ineffective or infeasible. It primarily includes Fuzzy logic systems, Neural Networks and Evolutionary Computation."

WHAT DOES IT MEAN - PRACTICALLY?

CI is a subset of Artificial Intelligence

CI is used to solve real world problems

CI includes "hard computing = binary/logic" and also "soft computing = fuzzy/adaptive" systems

CI techniques include Evolutionary Algorithms, Optimization, Neural Networks, Decision Making Systems, Neural Networks, etc…

Why Use "Computational Intelligence"?

A COUNTER ARGUMENT

Power Electronics is well defined – we know how to solve the equations and Power Electronics Design is simple – we don't need fancy new techniques…

A CASE FOR CI

True in simple cases, however with so many parasitics, environmental factors and variations it can be impossible or at least hugely time consuming to calculate from first principles

Power Electronics design is not really about the topology any more, it is often about everything else! Packaging, Thermal, Parasitics, Devices – all of which have so many unknowns or lack of analytical data we need other approaches

What about Machine Learning?

Machine Learning is a subset of Artificial Intelligence that uses algorithms to improve the performance of computing through the use of learning

Computational Intelligence Approaches

What are they and how do they work?

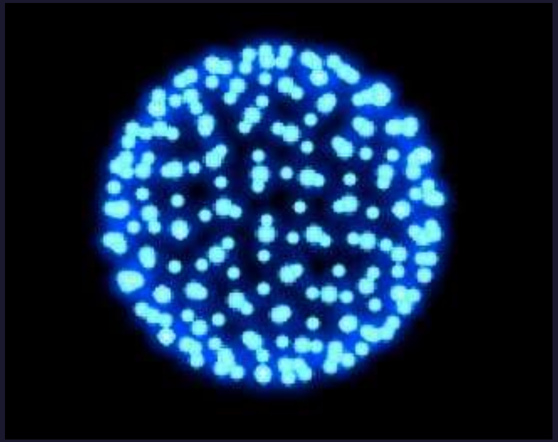
Optimization, Artificial Neural Networks, Learning, Classification

(There are a plethora of approaches and there is not time to cover them all. For a very useful primer see this book:

Computational Intelligence - Concepts to Implementations, 1st Edition - August 10, 2007 **Authors:** Russell Eberhart, Yuhui Shi, Hardback ISBN: 97815586075909, eBook ISBN: 9780080553832)

Optimization: Genetic Algorithms

INITIALIZE A POPULATION



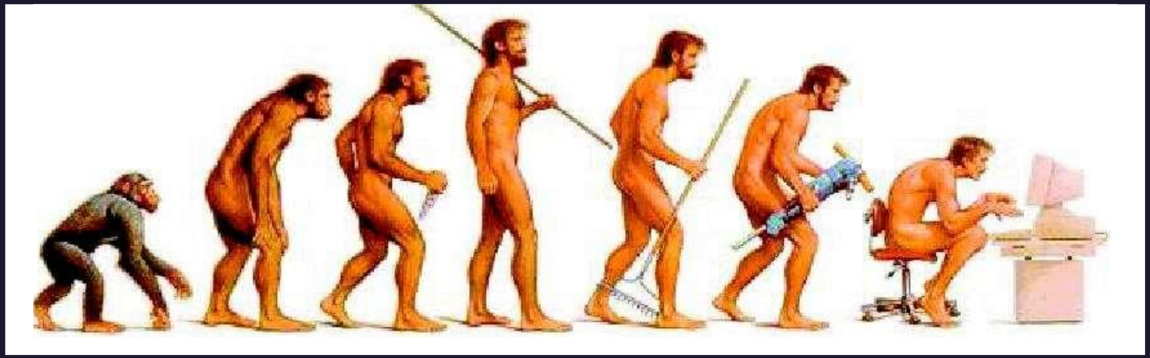
EVALUATE, RANK AND SELECTION

CROSSOVER AND MUTATION

SURVIVAL OF THE FITTEST

Evolutionary (Genetic) Algorithms

GUARANTEED TO GET OPTIMUM OUTCOME, RIGHT?



GENETIC ALGORITHMS CAN BE VERY USEFUL IN TRAVERSING A LARGE DESIGN SPACE – HOWEVER NOT ALWAYS THE BEST TO FIND AN OPTIMAL SOLUTION TO A PROBLEM

STAGNATION IS A POSSIBILITY…

OFTEN “CLASSICAL” TECHNIQUES SUCH AS STEEPEST DESCENT OR SIMULATED ANNEALING CAN BE FASTER AND BETTER AT FINDING SOLUTIONS TO PROBLEMS *AFTER* A GENETIC ALGORITHM HAS FOCUSED THE DESIGN SPACE

Genetic Algorithm outline

1. Randomly generate initial population of n strings (“chromosomes”)
2. Evaluate the fitness of each string in the population
3. Repeat the following steps until next generation of n individual strings produced
    1. Select pair of parent chromosomes from current population according to their fitness, i.e. chromosomes with higher fitness are selected more often
    2. Apply crossover (with probability)
    3. Apply mutation (with probability of occurrence)
4. Apply generational replacement
5. Go to 2 or terminate if termination condition met

Can be implemented in C, C++, C#, Python or other language of your choosing

Artificial Neural Networks (ANN)

FUNDAMENTALLY USED FOR CLASSIFICATION

No iterative procedure.
Parameters of system are the training data.

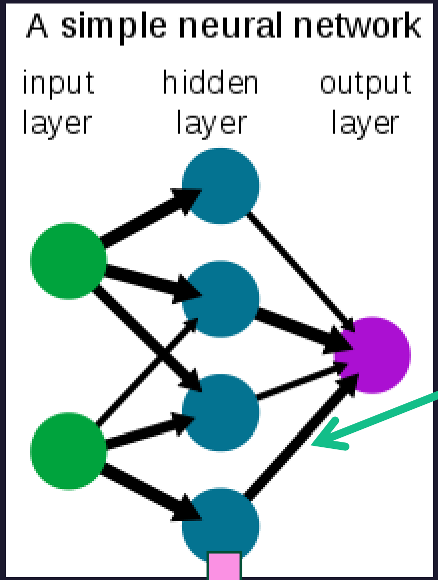
Learning is just ***adding training data***.

AN ATTEMPT TO MIMIC BIOLOGICAL BEHAVIOUR

Artificial neural nets (ANN) attempt to mimic brains

…a collection of biological neurons.

Artificial Neural Networks

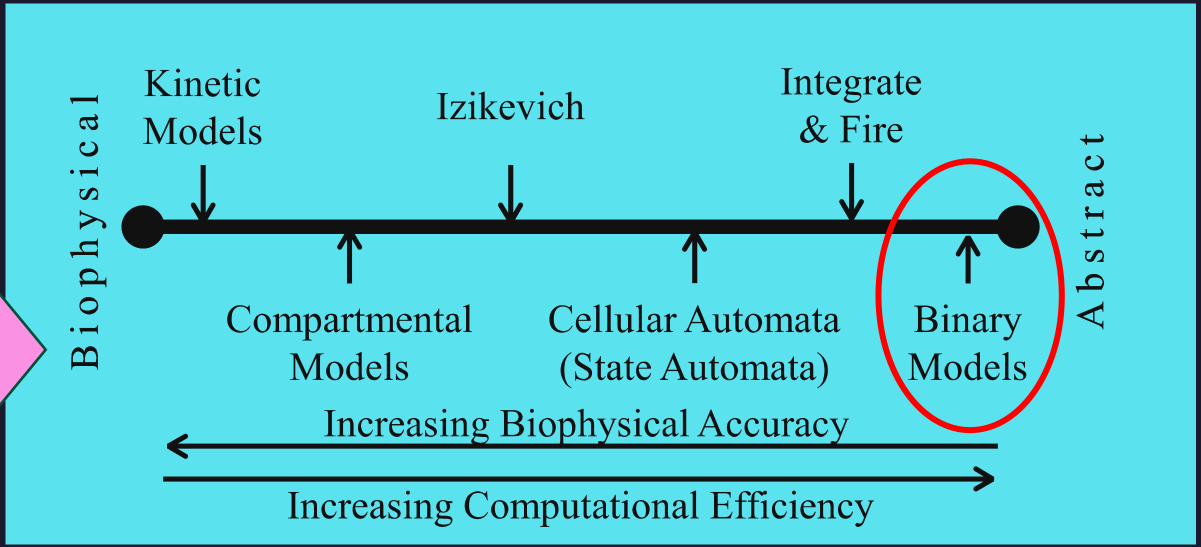


Find the connection weights?

Connection structure defines the Topology

Find topology?

Artificial ***Neural*** Networks generally use a **binary model** for maximum computational efficiency



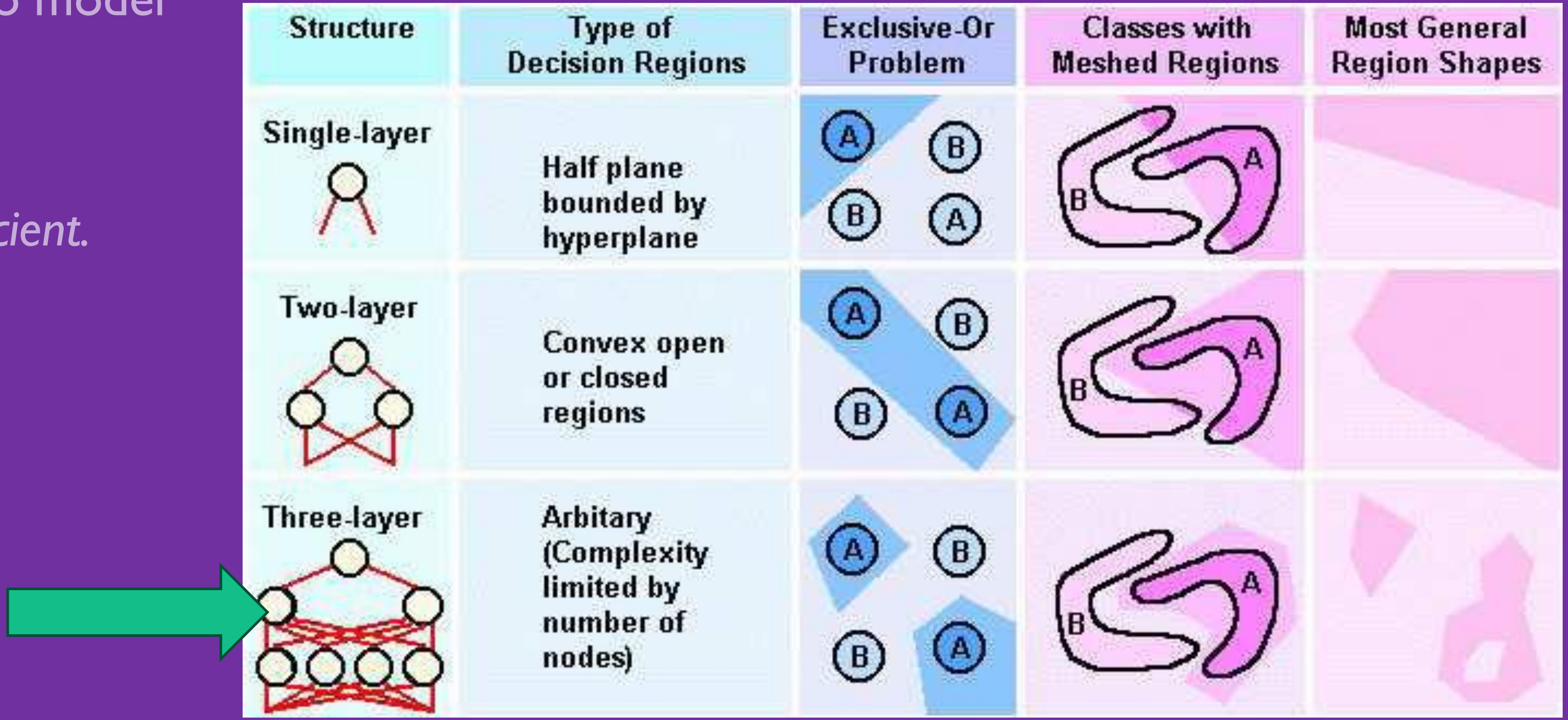
Implementing ANNs in Practice

A single artificial neuron has the limitation that only linearly separable functions can be modelled.

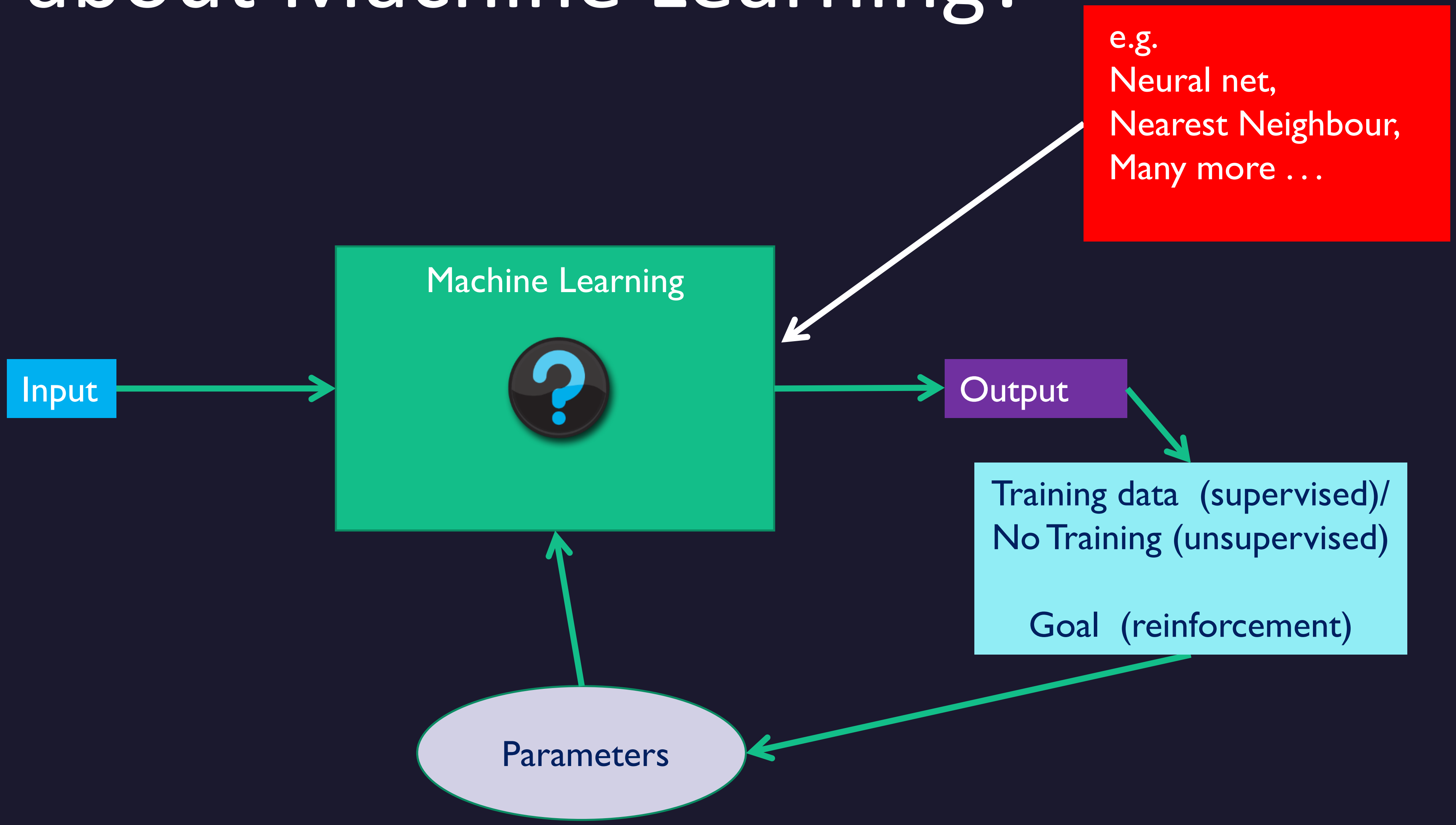
Adding more layers allows arbitrary functions to be modelled.

How many layers are needed to model an arbitrary function ?

It turns out 3 layers are sufficient.



What about Machine Learning?



Types of Machine Learning (ML)

Supervised learning is a type of ML learns from a data set of labelled input-output pairs

Unsupervised learning is a type of ML that learns from unlabelled data sets to identify patterns

Reinforcement learning uses intelligent agents with a reward mechanism

Platforms and Deployment

How can we implement these techniques and deploy them in practical scenarios?

Standalone Implementation - Languages

C/C++/C#	Ubiquitous, Fast, but steep learning curve
Python	Ubiquitous, many tools, excellent libraries
TCL/TK	Often used, focus on GUI and less on mathematical and simulation (low performance)
Javascript	Originally focussed on web development, becoming widely used in applications
Julia	Builds on Python/C++ but has interesting AI/ML capability

There are others, of course, but of these Python and C++ are the primary languages in most Design Automation applications

Getting Started? – head for Python

Very Popular among students and researchers

Huge Variety of libraries

Open source – heavily used by academics and commercial users alike

Object Oriented Approach

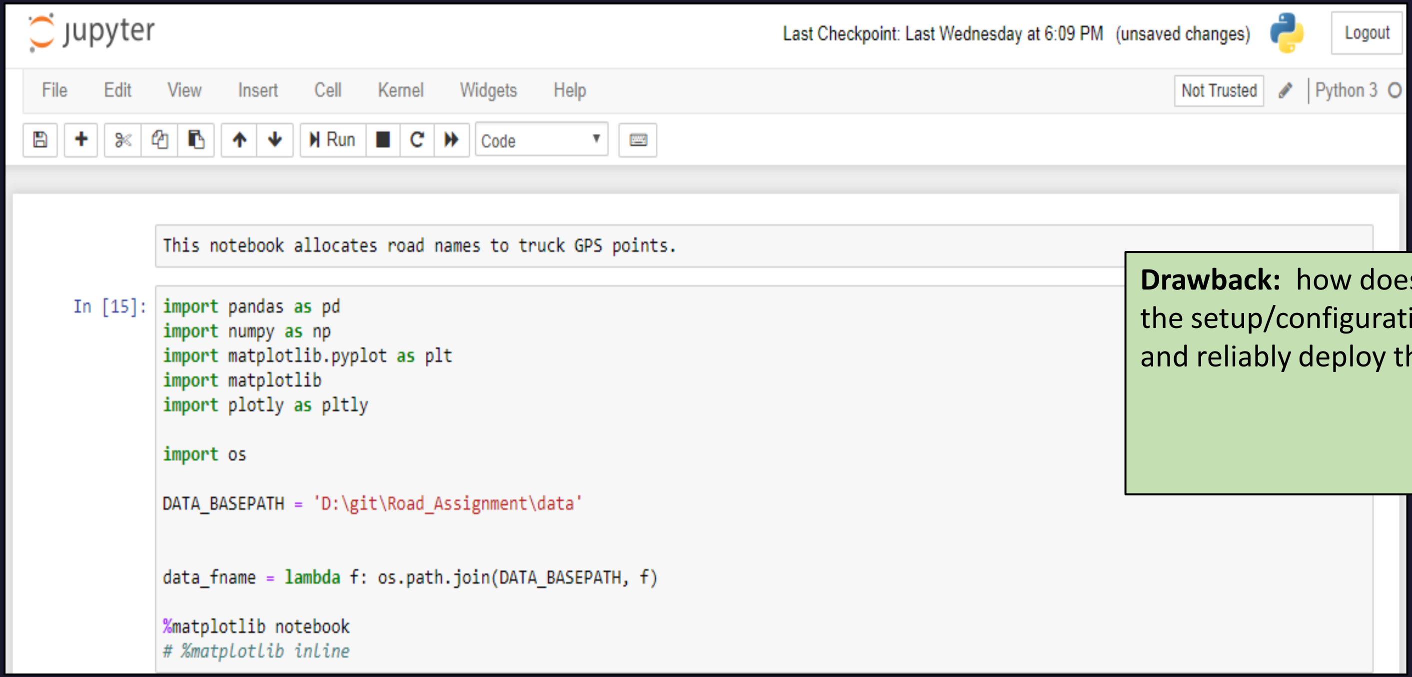
Highly Modular

Performance is "good enough" – ideal for getting started

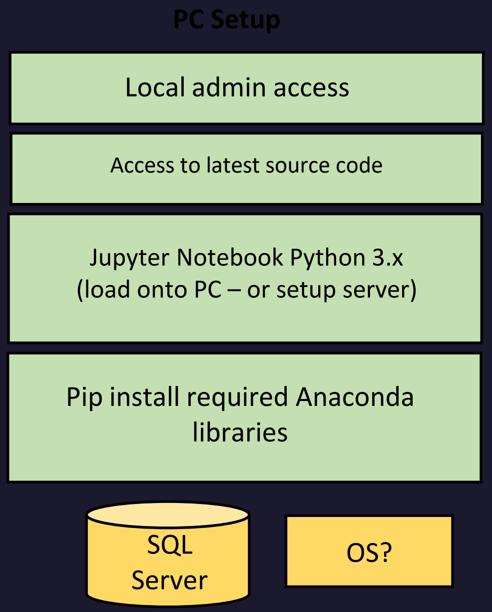
Sharing? Jupyter Notebooks are an option

Jupyter Notebooks are a very useful technology to combine python code, a GUI, and documentation for sharing with customers and/or collaborators.

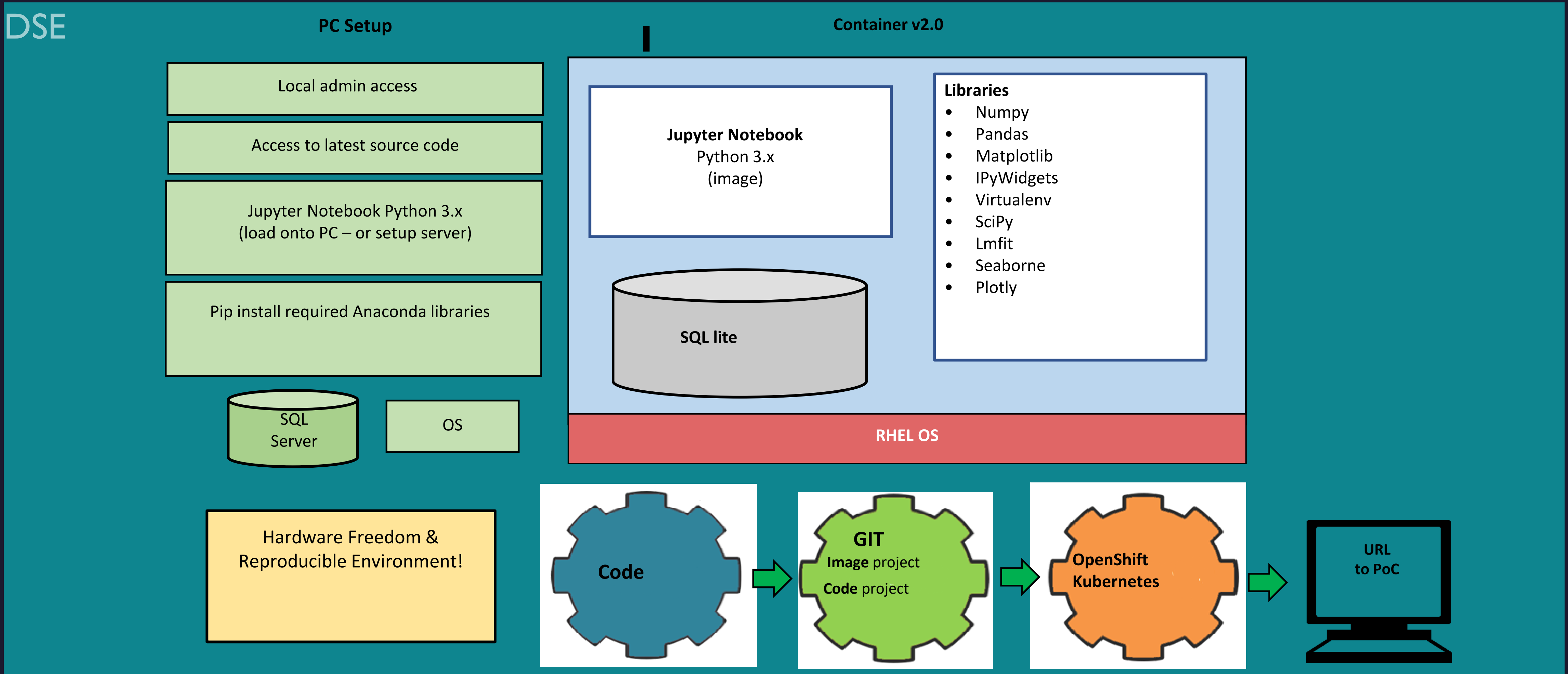
Execute in a browser that can be accessed locally or on a cloud service



Drawback: how does one avoid the setup/configuration issues and reliably deploy the notebook?



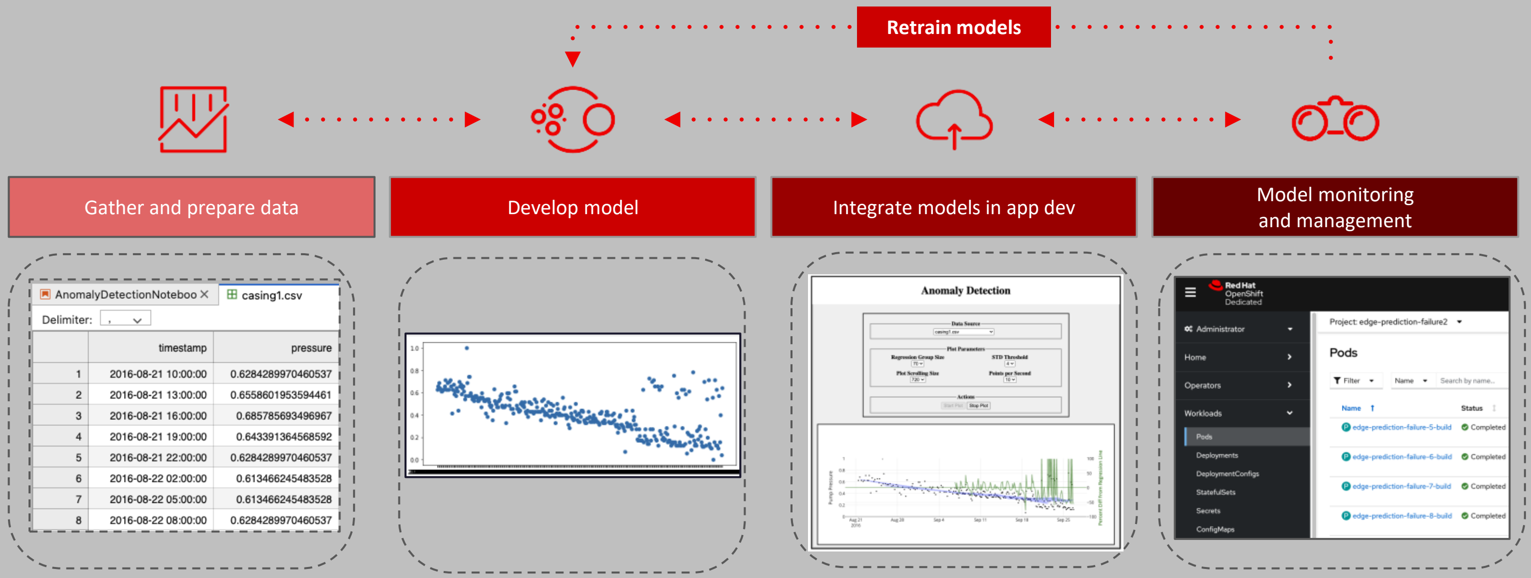
Building a data science environment?



Reproducible Data Science environment that users interact with via Chrome.

Extending to a Cloud Based Data Driven Modeling and Analysis Environment

Models, Applications and Containers – Deployed in the Cloud (e.g. RedHat, AWS, Azure etc…)



Some examples of Computational Intelligence in Power Electronics

Some examples of real-world applications in Power Electronics to advance design automation

For a recent review of applications of AI in power electronics see this paper:
S. Zhao, F. Blaabjerg and H. Wang, "An overview of artificial intelligence applications for power electronics", *IEEE Transactions on Power Electronics*, vol. 36, no. 4, pp. 4633-4658, 2020, doi: 10.1109/TPEL.2020.3024914

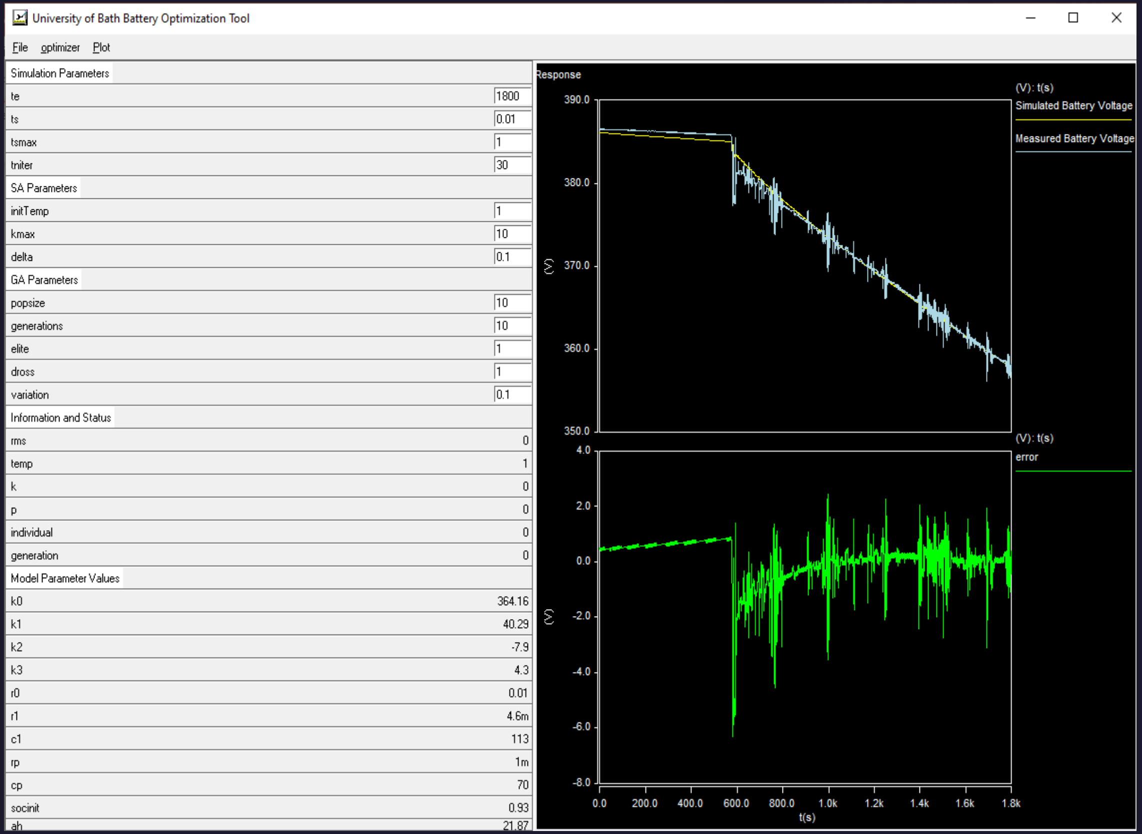
Characterization of Model Parameters

Genetic Algorithm and Simulated Annealing Combined Optimization

Simulation Options Built in Equation Solve and External Simulators (Saber/Spice)

Used for rapid characterization of battery cells, devices, circuits from real-world data

More effective optimization than steepest descent approaches alone and more noise tolerant



P. Wilson and C. Vagg, "Optimization Tool for the Characterization of Electric Vehicle Battery Packs," *DMC 2022*, doi: 10.1109/DMC55175.2022.9906467.

Power Electronics System Design

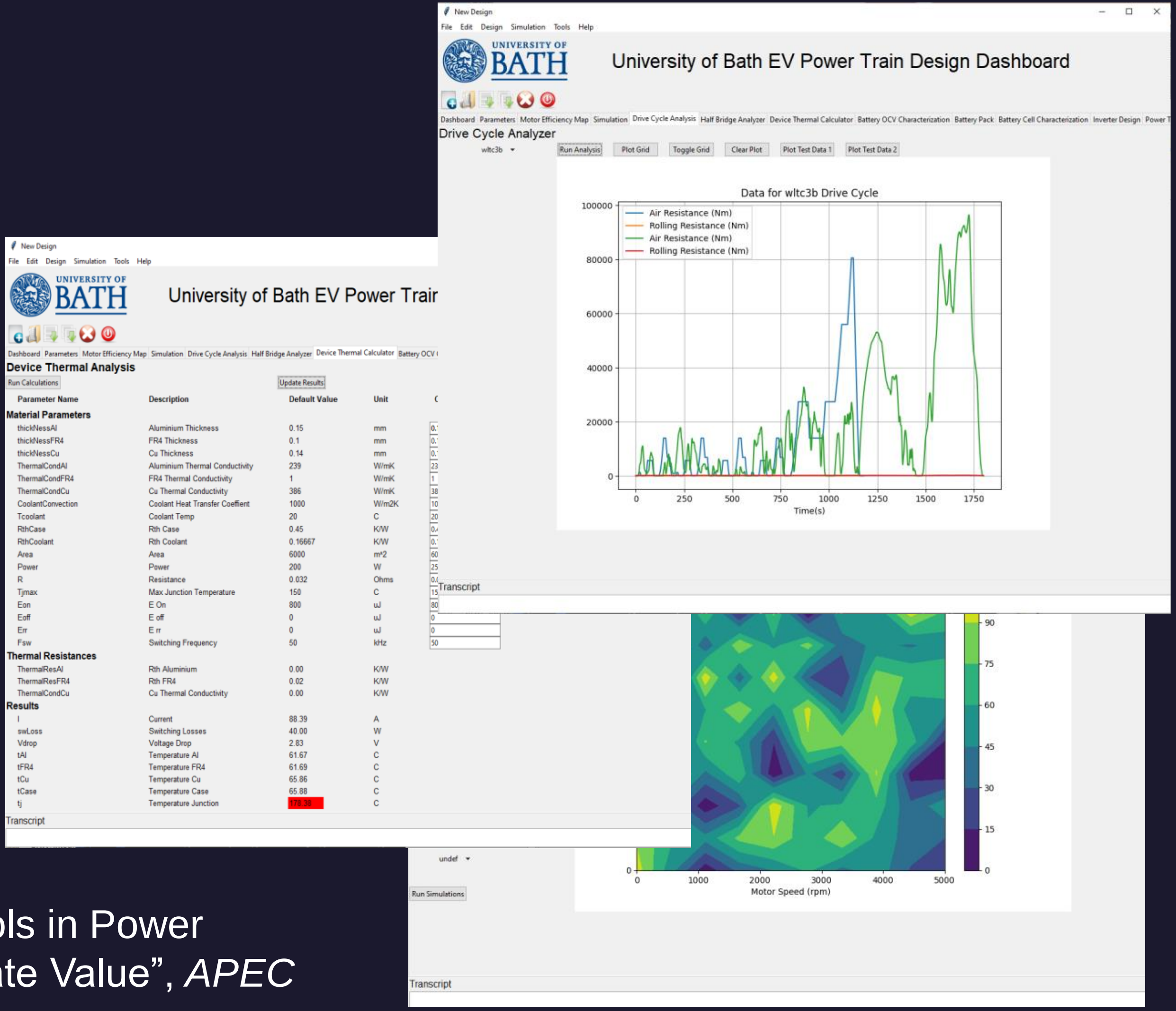
System Level Design of EV Power Trains

Simulation Options Built in Equation Solver or External Simulators

Used for rapid design of EV powertrains, optimization and *data driven models*

Data Driven approaches are ideally suited for ANN and ML approaches

Rapid Design, Mix of analytical and Data Driven Models – reduced time on analytical modelling, simplification of complex systems design



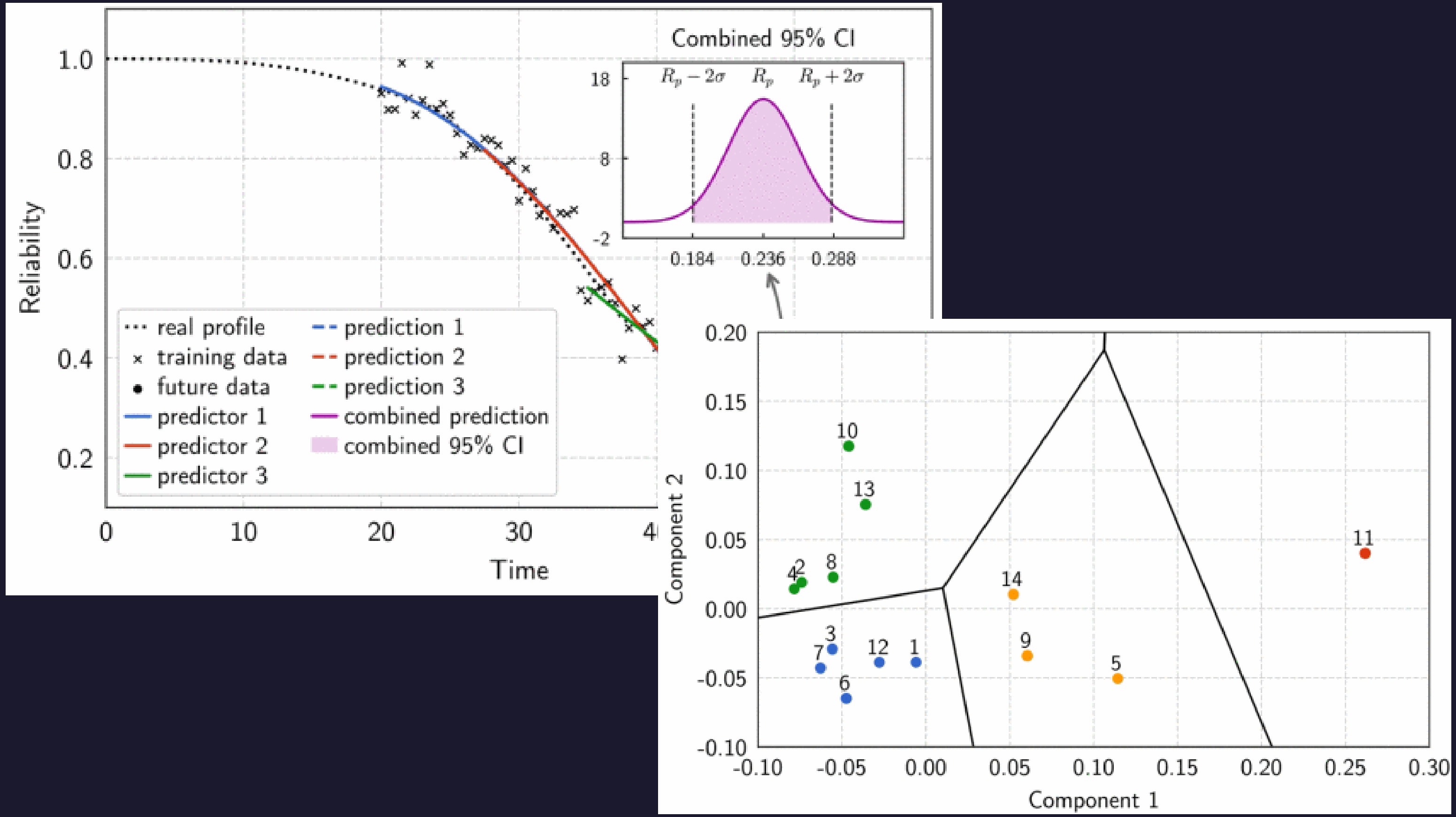
Wilson and Reznik, “Using OpenSource Technology and Tools in Power Electronics To Drive Innovation, Boost Productivity and Create Value”, *APEC 2023*, Industry Session 28.1

Diagnostics and Reliability Prediction

Machine Learning is ideally suited for identification of patterns in large data sets

Monitoring Systems such as power electronic converters or machine drives for behaviour prior to failure is becoming a very common application for Machine Learning

Results show excellent results for predicting reliability and also using PCA for clustering & classification



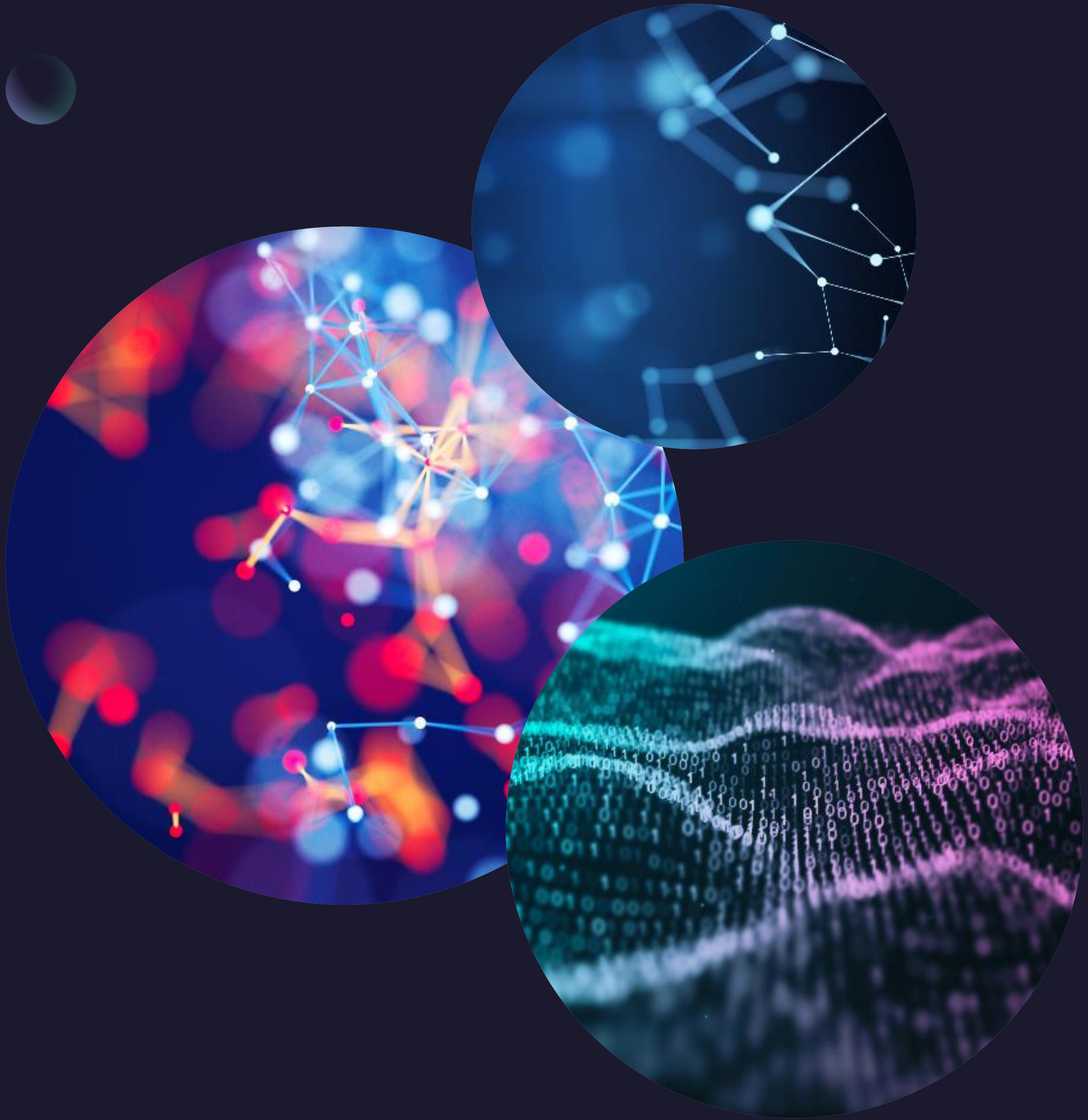
Figures From: Y. Cui, J. Hu, R. Tallam, R. Miklosovic and N. Zargari, "Reliability Monitoring and Predictive Maintenance of Power Electronics with Physics and Data Driven Approach Based on Machine Learning," *2023 IEEE Applied Power Electronics Conference and Exposition (APEC)*, Orlando, FL, USA, 2023, pp. 2563-2568, doi: 10.1109/APEC43580.2023.10131151.

Summary

There are numerous applications of Computational Intelligence already in Power Electronics including

- Optimization
- Control Strategies
- Decision Making
- Reliability Assessment
- Data Driven Modeling

There is huge potential for many further areas of growth, in particular generative design using AI



Summary

Computational Intelligence approaches are more frequently applied to power electronics than perhaps is immediately apparent and in the drive to more data driven and generative approaches will become even more useful as these techniques continue to evolve and new ones emerge.

Thank You & Questions

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