

# Artificial Intelligence In MATLAB: From Research To Implementation And Production

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**Christoph Stockhammer**  
**Senior Application Engineer**  
**MathWorks**

# Artificial Intelligence

*The capability of a machine to imitate intelligent human behavior*

# Artificial Intelligence

*The capability of a machine to **match or exceed** intelligent human behavior*

# Artificial Intelligence Today

*The capability of a machine to **match or exceed** intelligent human behavior  
by training a machine to learn the desired behavior*

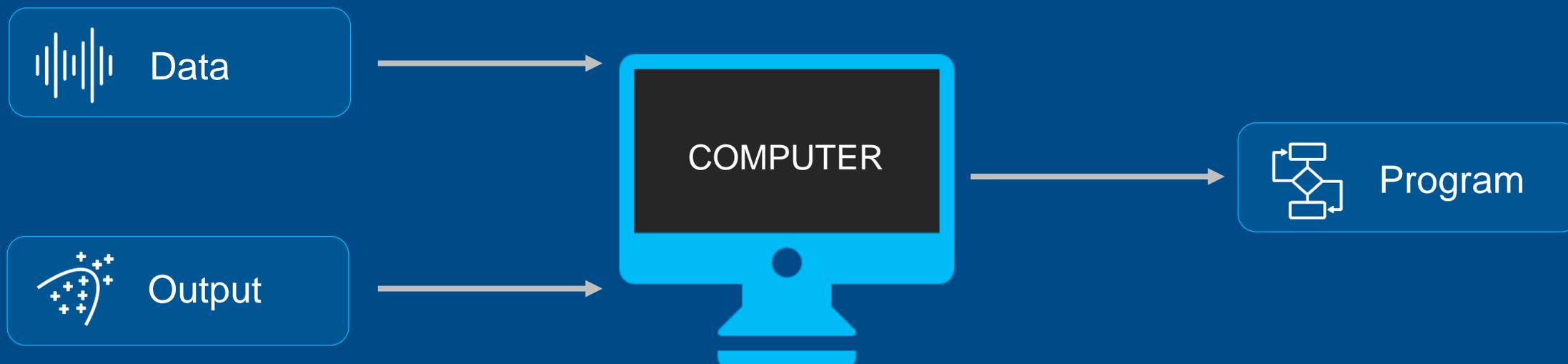
# There are two ways to get a computer to do what you want

## Traditional Programming



# There are two ways to get a computer to do what you want

## Machine Learning



# There are two ways to get a computer to do what you want

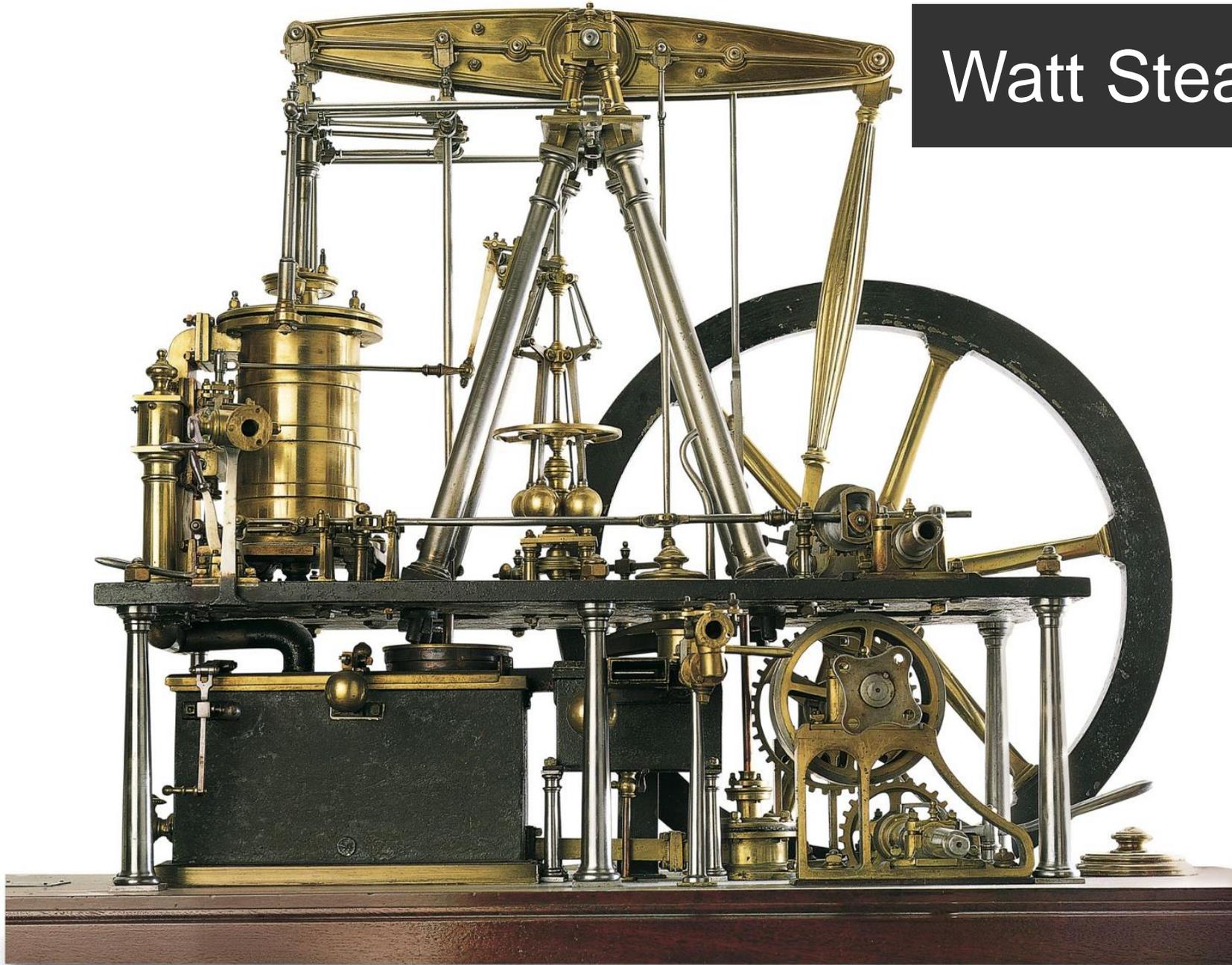
## Machine Learning



Artificial Intelligence

Machine Learning

# Watt Steam Engine



# Artificial intelligence is a transformative technology

McKinsey Global Institute

## Notes from the AI frontier: Modeling the impact of AI on the world economy

September 2018 | Discussion Paper

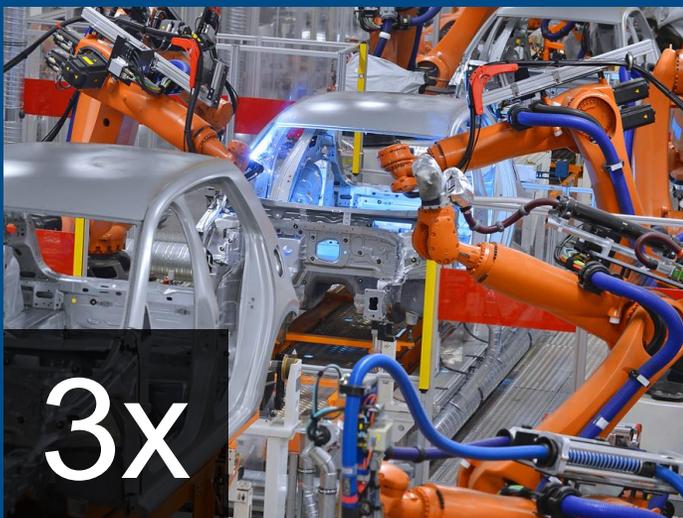
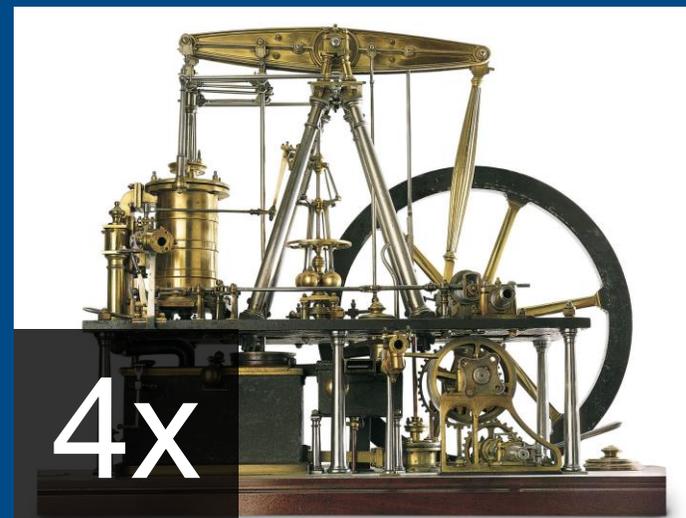
**AI will create \$13 trillion in value by 2030**

based on McKinsey's latest AI forecast – September 2018

# AI has tremendous potential to increase productivity



=



# Yet AI is struggling



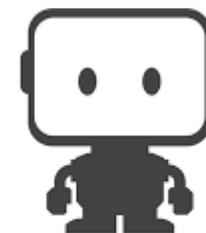
Most AI Projects Fail. Here's How to Make Yours Successful.

July, 2018



3 Common Reasons Artificial Intelligence Projects Fail

May, 2018



**DataRobot**

Why Most AI Projects Fail

Oct, 2017

# There are many ways Artificial Intelligence can **fail**

No data  
scientists

Too much data

Poor ROI

Not enough data

Beyond the skill  
of the team

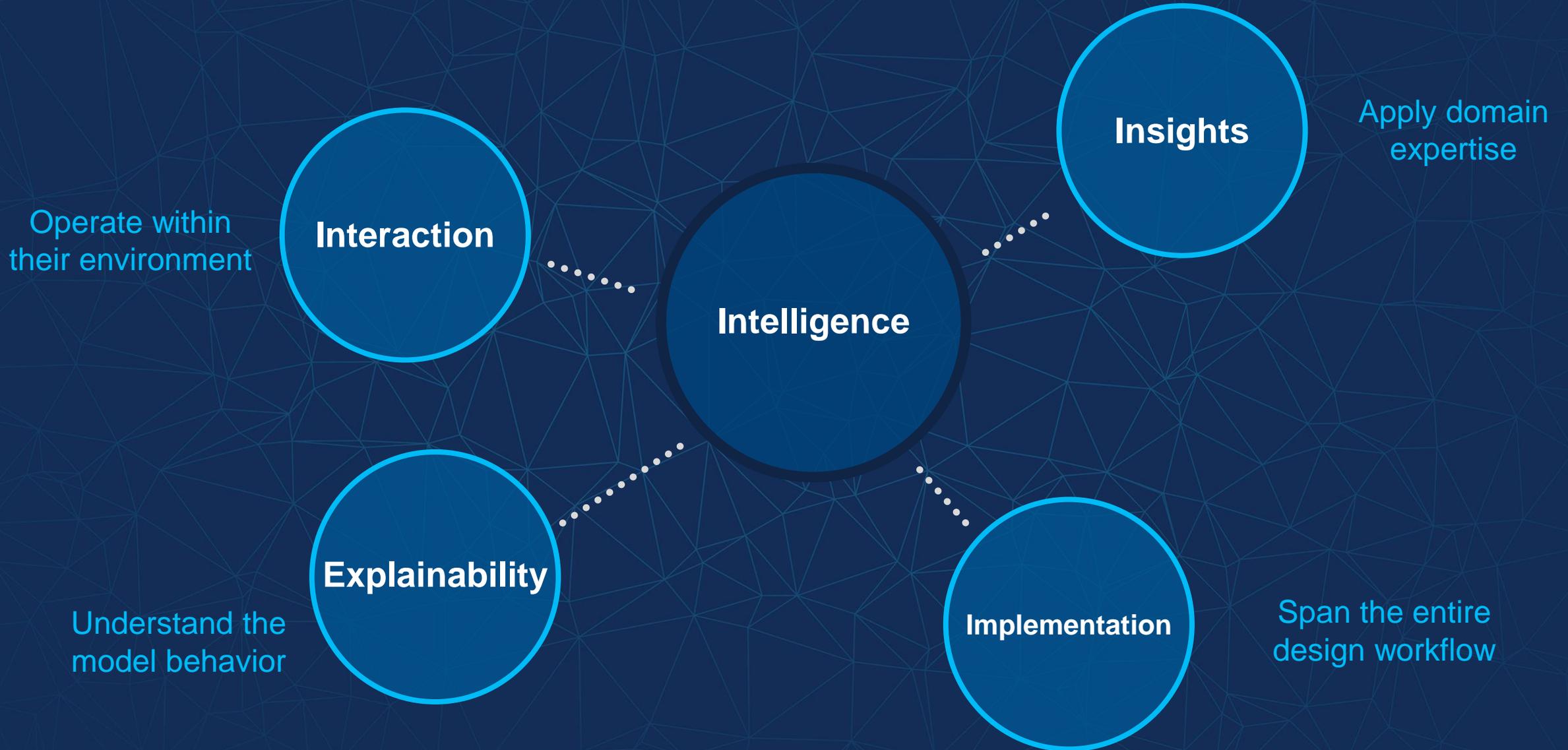
Incomplete  
tools

Problem is a  
poor fit for AI

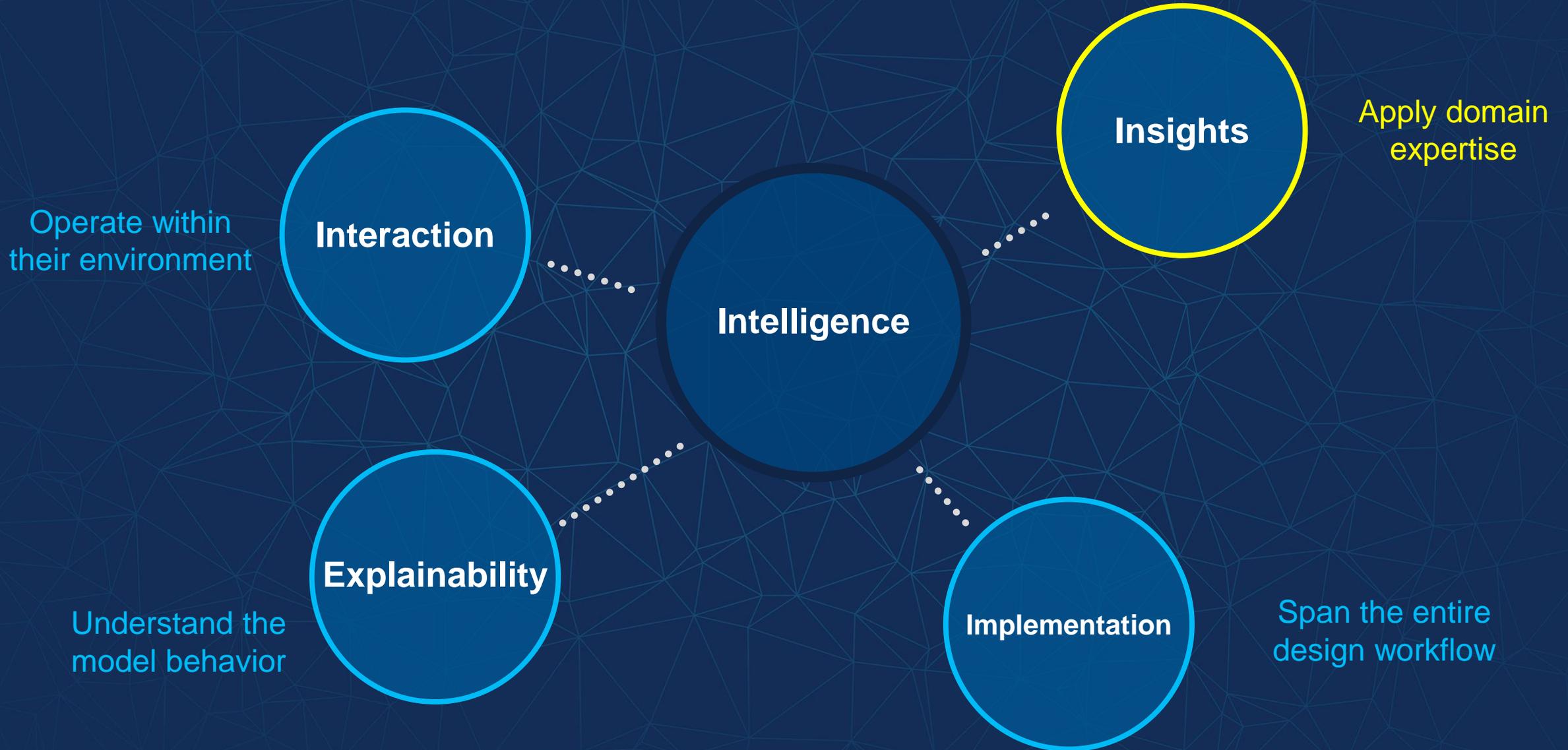
Can't interact with  
other systems

Problem is  
unsolvable

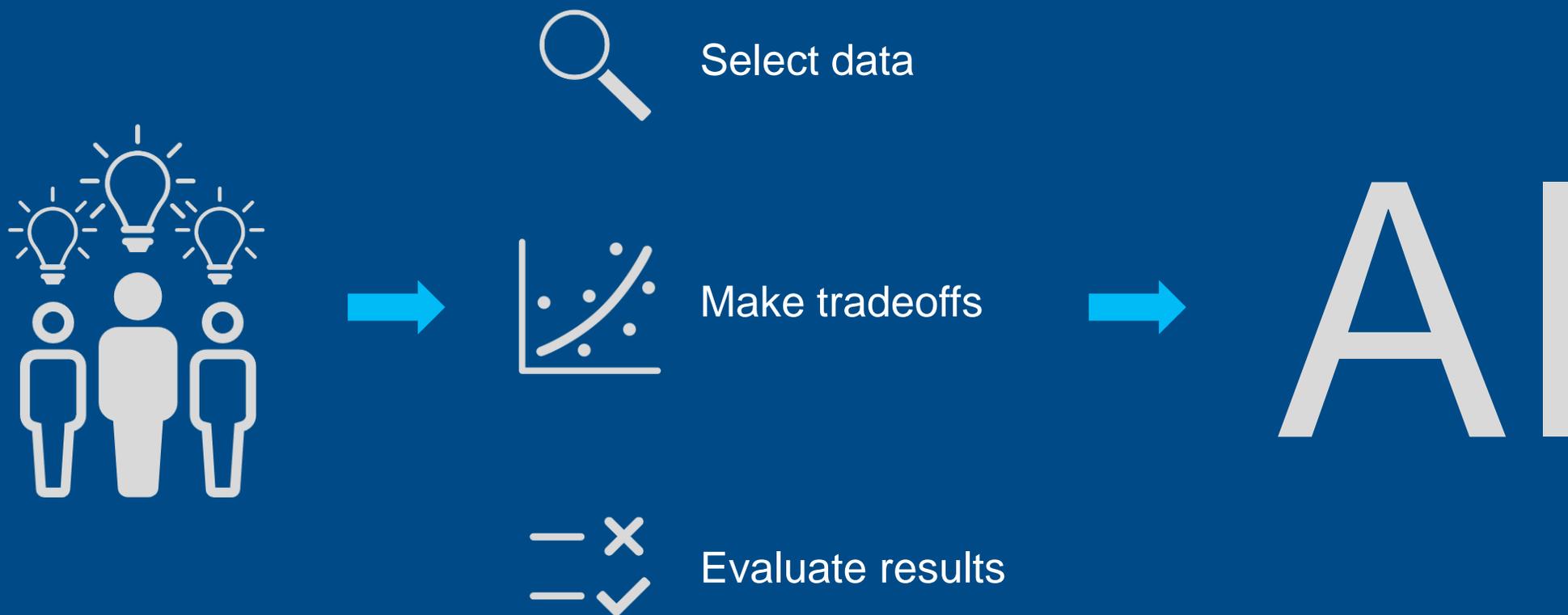
# AI is more than just the intelligence of the algorithm



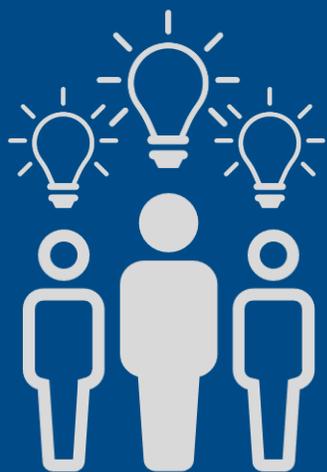
# AI is more than just the intelligence of the algorithm



# Bring human insights into AI



# Bring human insights into AI



- We are the domain experts
- Shortage of data scientists
- We need the right tools

# Improving New Zealand Dairy Processing

- University of Auckland
- Auckland University of Technology



# Wanted to detect a bad product earlier

## Continuous Plant Process

Raw Milk

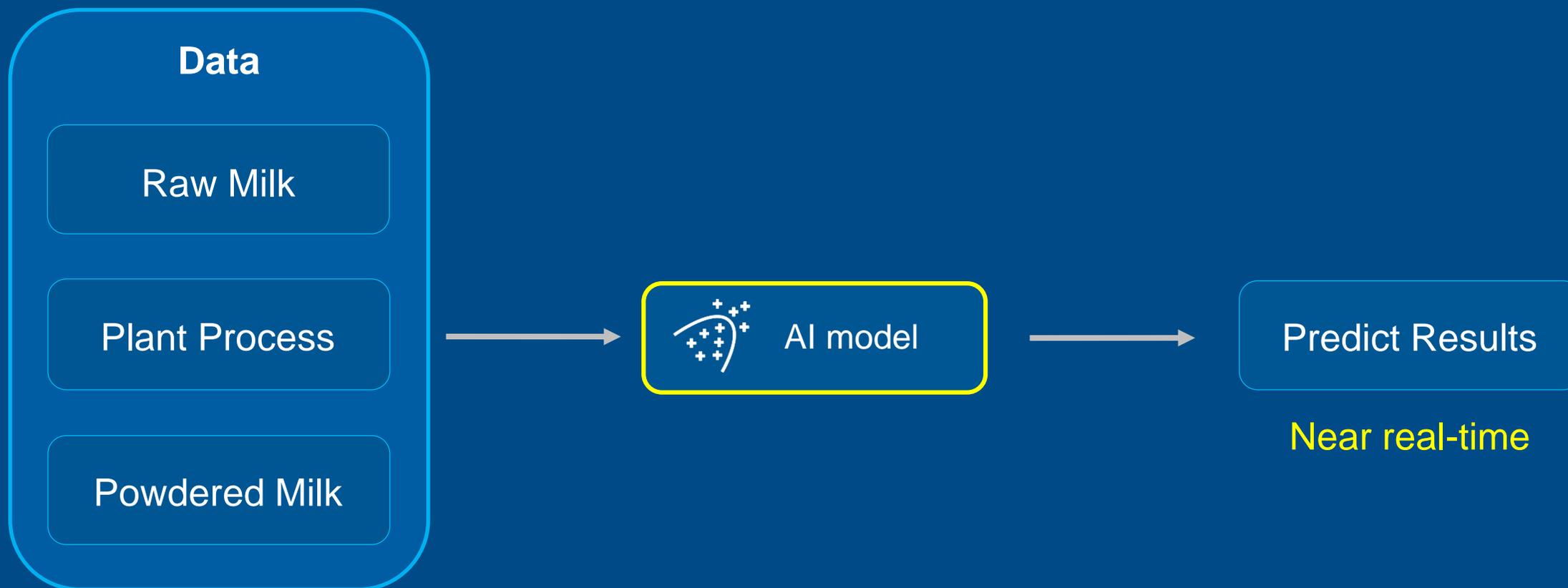


Powdered Milk



Days later

# Wanted to detect a bad product earlier

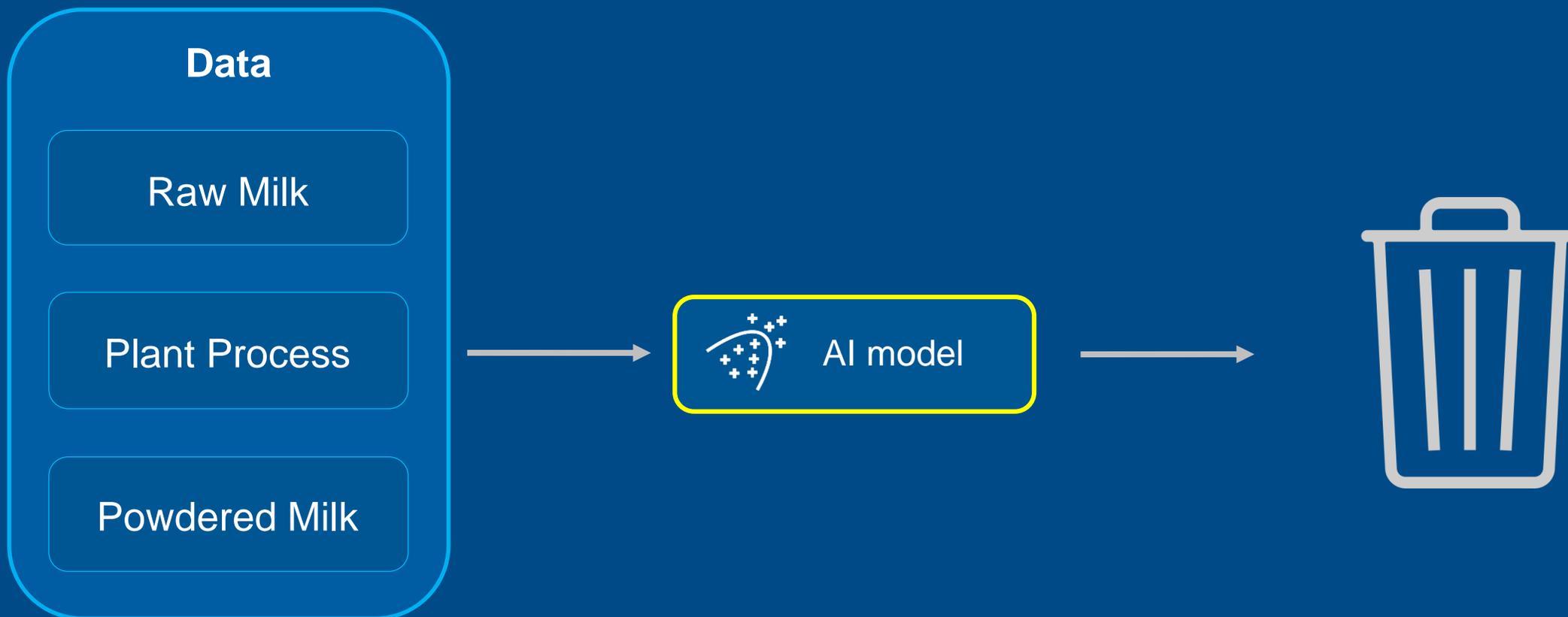


# They had **lots** of data



- Millions of data points
- 6 years
- 3 plants

# But...



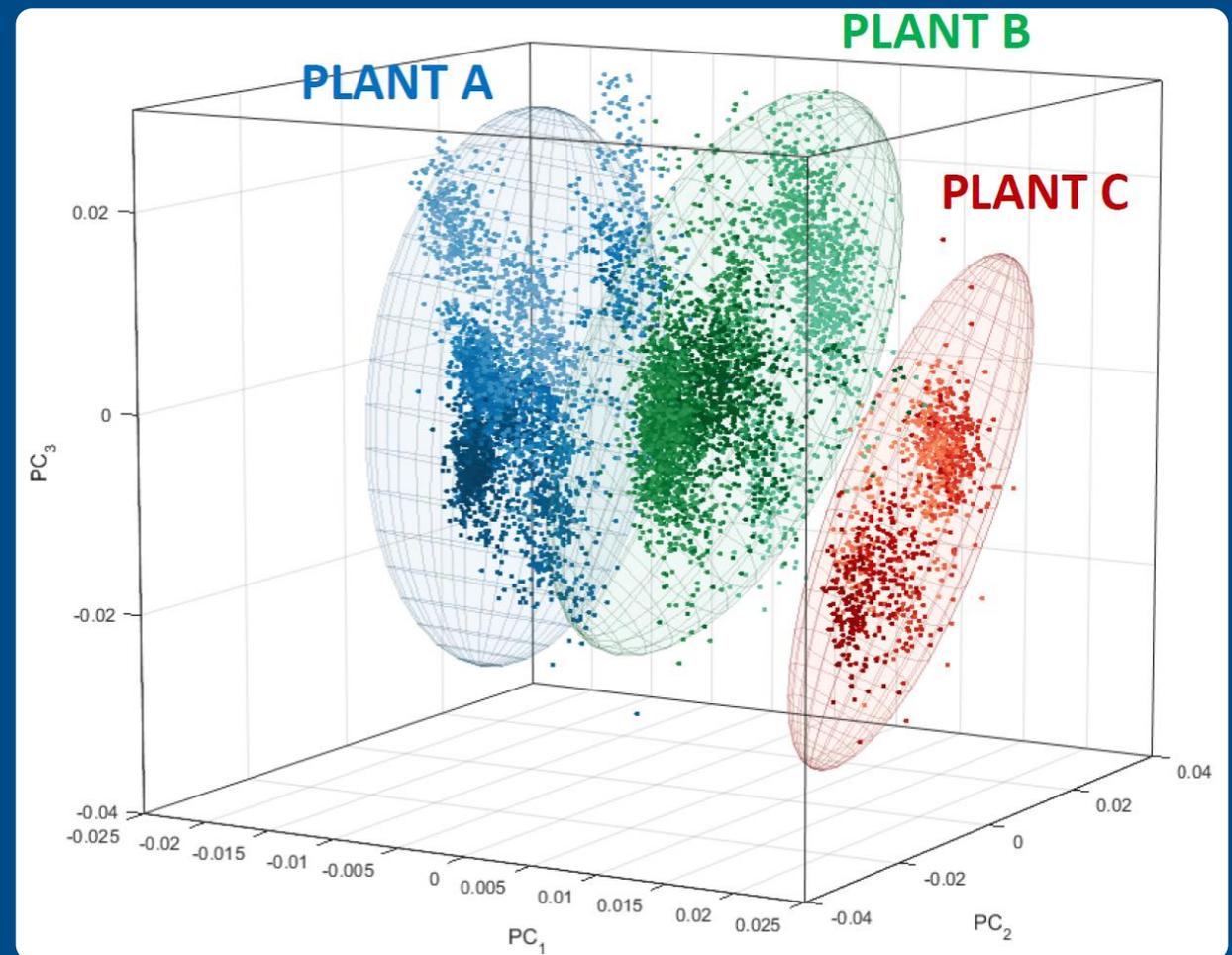
# They made several key insights

1. Results were wrong

# They made several key insights

1. Results were wrong
2. Need to build a separate model for each plant

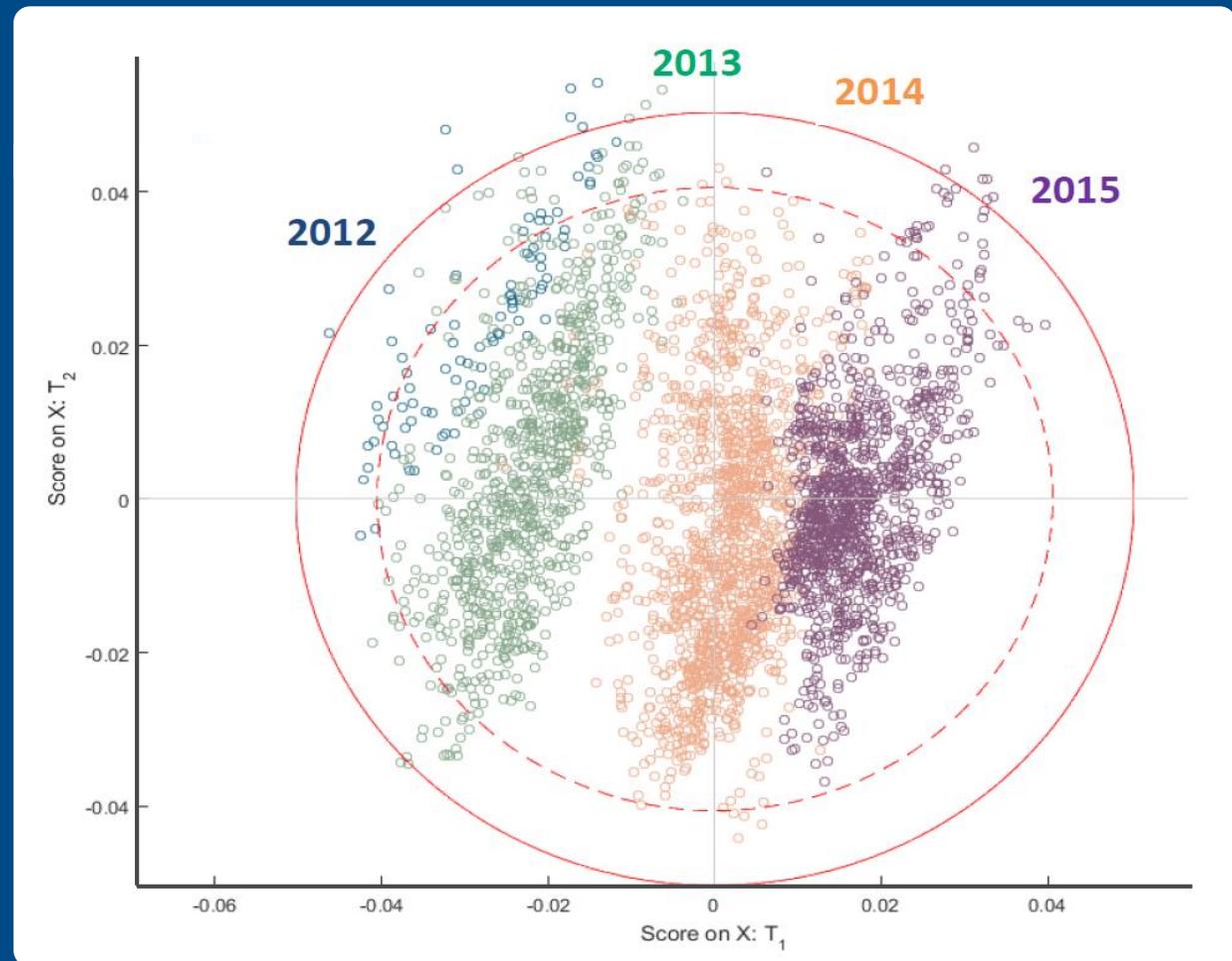
Plants **behaved differently**  
from each another



# They made several key insights

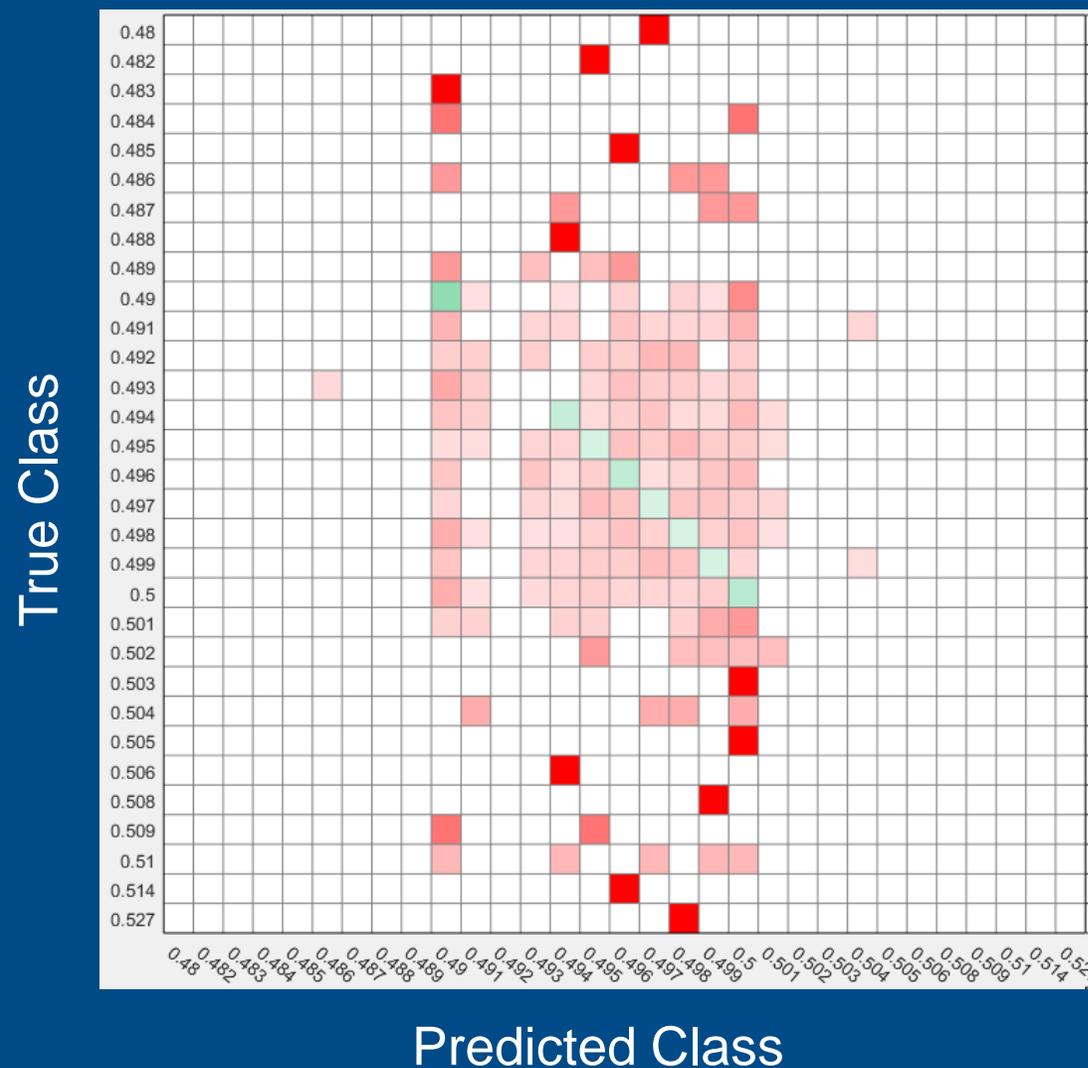
1. Results were wrong
2. Need to build a separate model for each plant
3. Plant's operating state changes each year

Each year was like a **completely different plant**



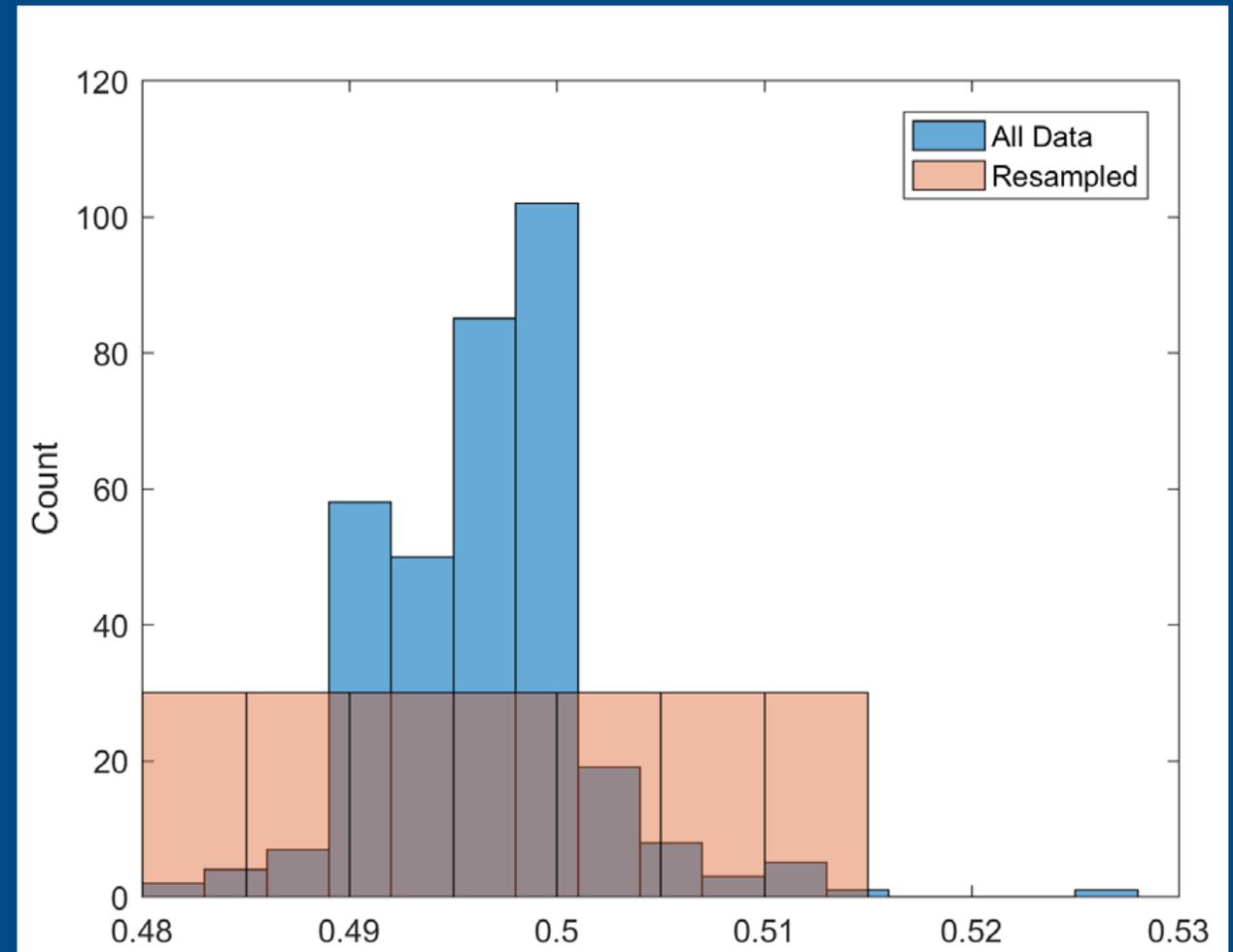
# Bulk density prediction results were inaccurate

- Many false positives
- Unused classes



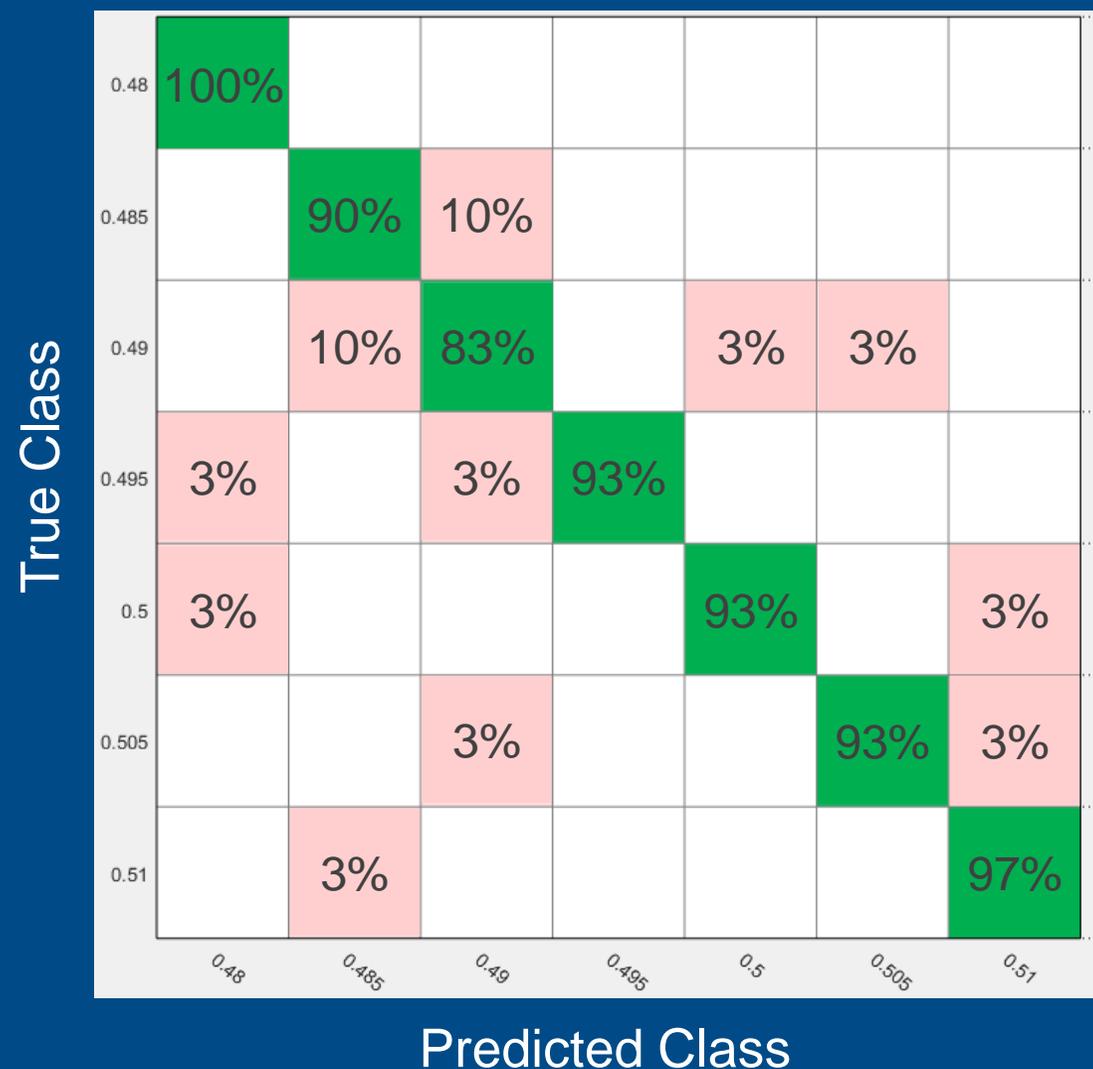
# They made several key insights

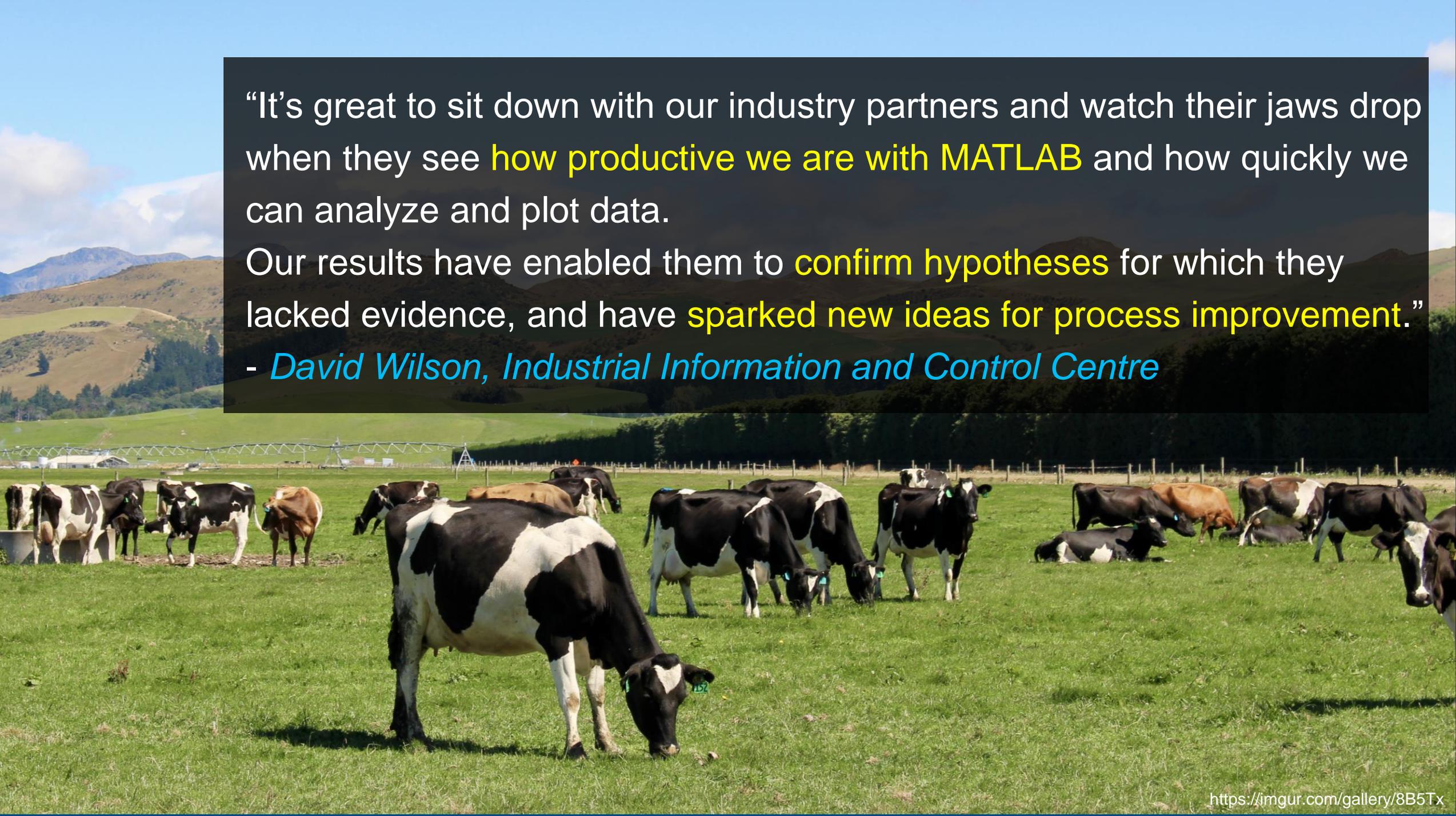
1. Results were wrong
2. Need to build a separate model for each plant
3. Plant's operating state changes each year
4. Training data was biased



# Resampling data resulted in higher predictive accuracy

- Resampled data
- Reduced the number of bins



A photograph of a herd of cows grazing in a lush green field. In the background, there are rolling hills and mountains under a blue sky with some clouds. The cows are of various colors, including black and white, brown, and white. Some are standing and grazing, while others are lying down. A fence is visible in the distance, and there are some farm buildings and a large irrigation system structure in the background.

“It’s great to sit down with our industry partners and watch their jaws drop when they see **how productive we are with MATLAB** and how quickly we can analyze and plot data.

Our results have enabled them to **confirm hypotheses** for which they lacked evidence, and have **sparked new ideas for process improvement.**”

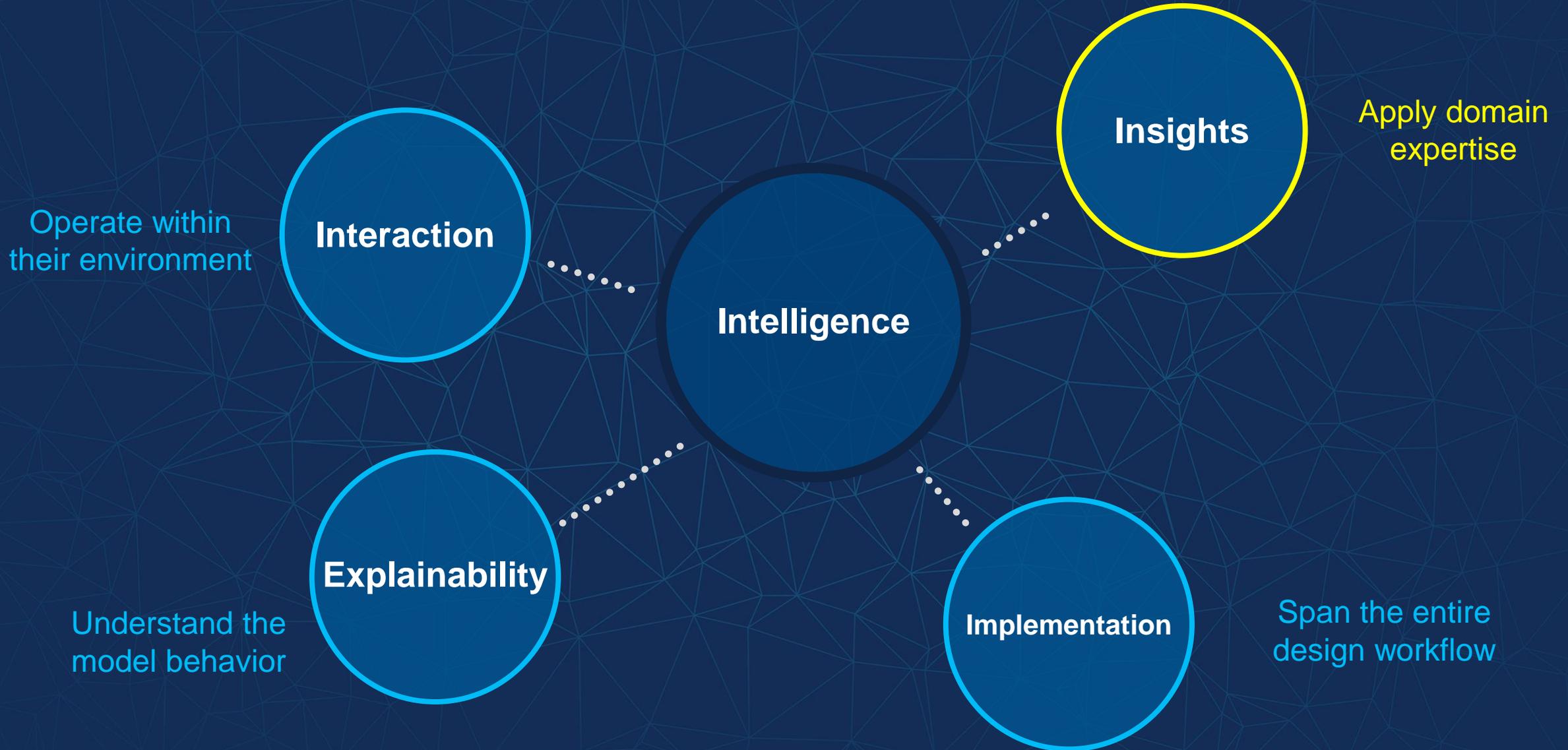
- *David Wilson, Industrial Information and Control Centre*

To be successful with AI, we must ...

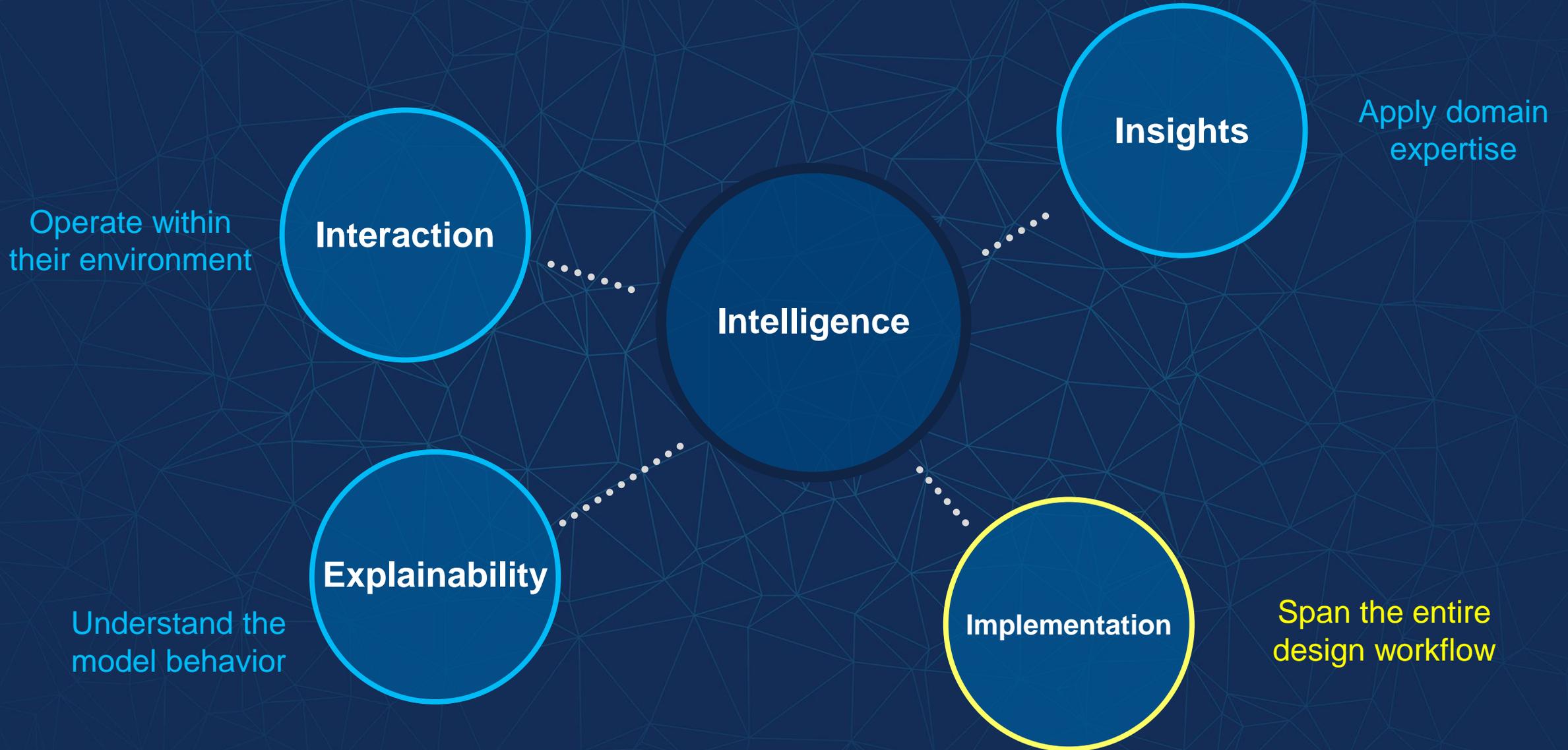
Combine AI model building  
with **scientific and engineering insights**

Along with **tools** that span  
both the **science and engineering** and the **data science**

# AI is more than just the intelligence of the algorithm



# AI is more than just the intelligence of the algorithm



# Implementation is about designing the solution

## Research



Testing  
Data analysis  
Reporting

## Manufacturing



Developing concept  
Prototyping  
Deployment

## Autonomous System



Requirements building  
Modeling and simulation  
Verification and validation

“Deliver on the promise of self-driving cars **today.**”



# Voyage's goal was to quickly get to market

1. Target retirement communities



# Voyage's goal was to quickly get to market

1. Target retirement communities
2. Use off-the-shelf components wherever possible



# Voyage's goal was to quickly get to market

1. Target retirement communities
2. Use off-the-shelf components wherever possible
3. Bring in the right software tools across the entire workflow



The LUMINAR logo, with the word 'LUMINAR' in a black sans-serif font. The letters 'U' and 'I' are highlighted in red and green respectively.

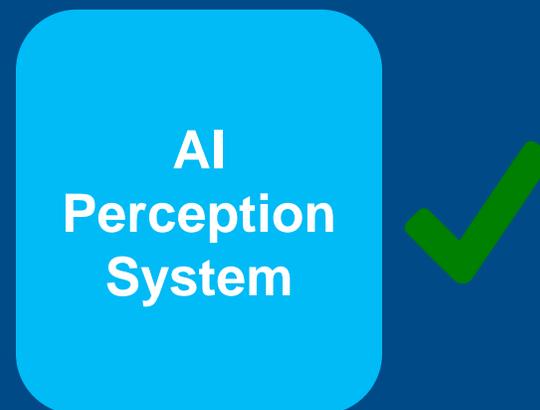


The CARMERA logo, featuring a stylized infinity symbol in orange and purple above the word 'CARMERA' in a black sans-serif font.

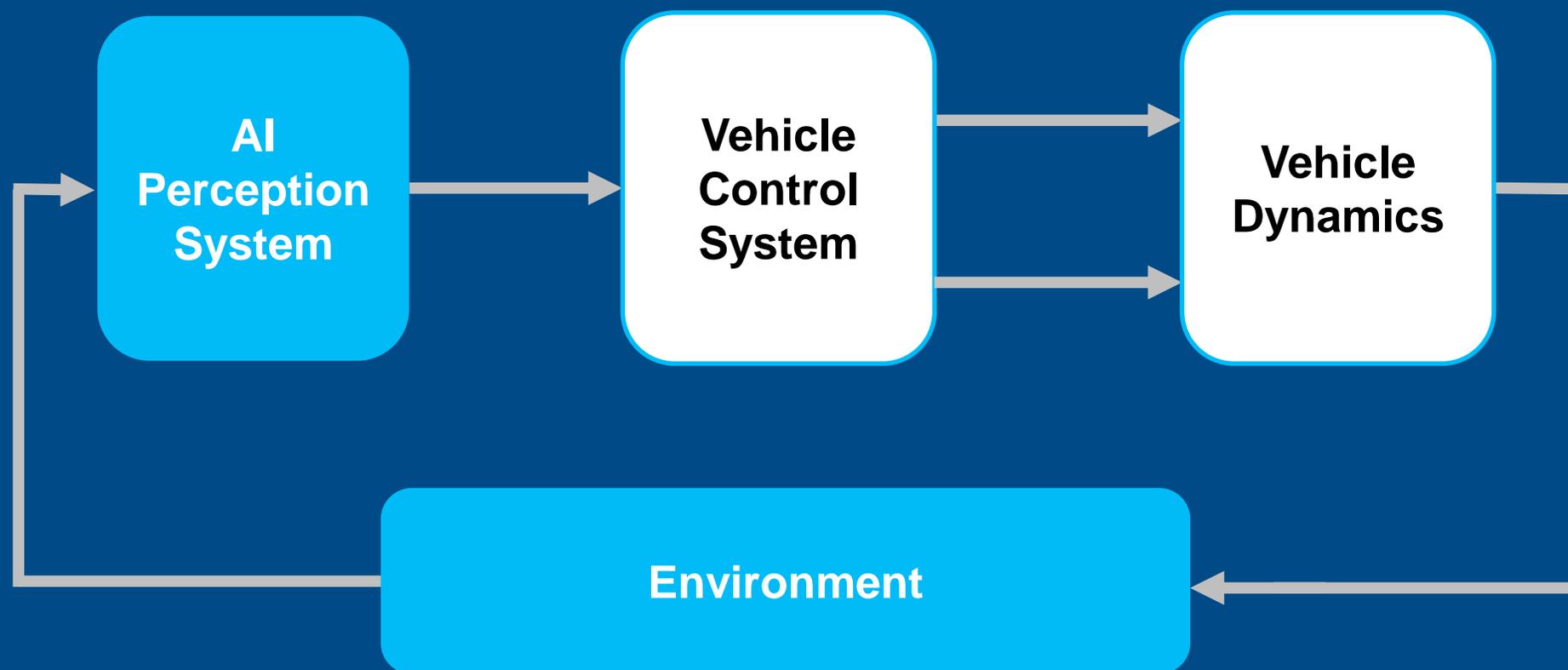
The ROS logo, featuring a grid of dots above the text 'ROS' in a large black sans-serif font, with 'Robot Operating System' in a smaller font below it.



# Voyage completed their AI system first



# But they needed to connect the AI to the rest of the system



# Started with Simulink example that they could build upon

The screenshot shows the MathWorks MATLAB Examples page. At the top left is the MathWorks logo. Below it is a dark blue header with 'MATLAB Examples' in white. To the right of the header is a search bar labeled 'Search Examples' and a dropdown menu labeled 'Examples' with a search icon. Below the header is a breadcrumb trail: 'Examples Home > MATLAB Family > Control Systems > Model Predictive Control Toolbox > Automated Driving Applications'. The main content area features the title 'Adaptive Cruise Control with Sensor Fusion' in orange. Below the title is a paragraph: 'This example shows how to implement a sensor fusion-based automotive adaptive cruise controller for a vehicle traveling on a curved road using sensor fusion.' This is followed by the text 'In this example, you will:' and a list of three steps. On the right side, there is a sidebar with the text 'By MathWorks' and a MathWorks logo. Below this is the section 'Explore:' with a link to 'Model Predictive Control Toolbox'. Underneath is the section 'This example also uses:' with links to 'Embedded Coder', 'Simulink', and 'Simulink Control Design'. At the bottom of the sidebar is a blue button that says 'Try it in MATLAB'.

MathWorks®

## MATLAB Examples

Search Examples Examples

Examples Home > MATLAB Family > Control Systems > Model Predictive Control Toolbox > Automated Driving Applications

### Adaptive Cruise Control with Sensor Fusion

This example shows how to implement a sensor fusion-based automotive adaptive cruise controller for a vehicle traveling on a curved road using sensor fusion.

In this example, you will:

1. Review a control system that combines sensor fusion and an adaptive cruise controller (ACC). Two variants of ACC are provided: a classical controller and an Adaptive Cruise Control System block from Model Predictive Control Toolbox.
2. Test the control system in a closed-loop Simulink model using synthetic data generated by the Automated Driving System Toolbox.
3. Configure the code generation settings for software-in-the-loop simulation and automatically generate code for the control algorithm.

By MathWorks

Explore:

[Model Predictive Control Toolbox](#)

This example also uses:

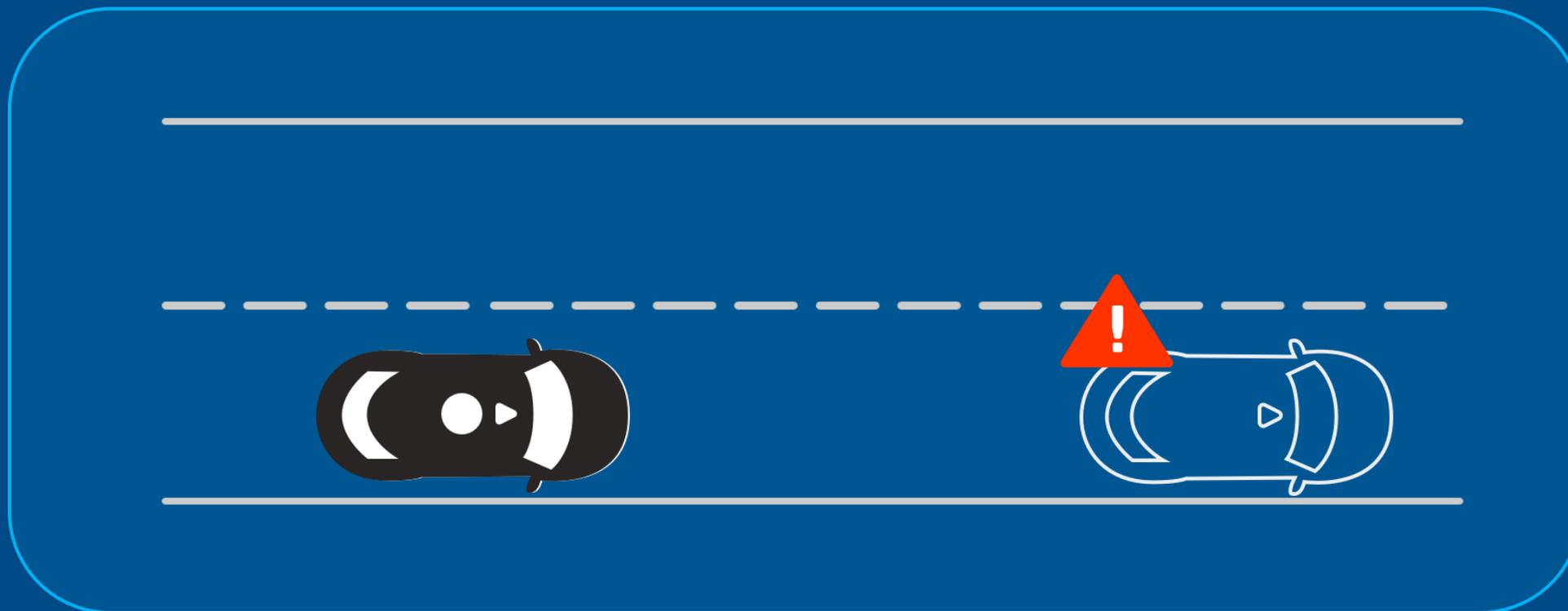
[Embedded Coder](#)

[Simulink](#)

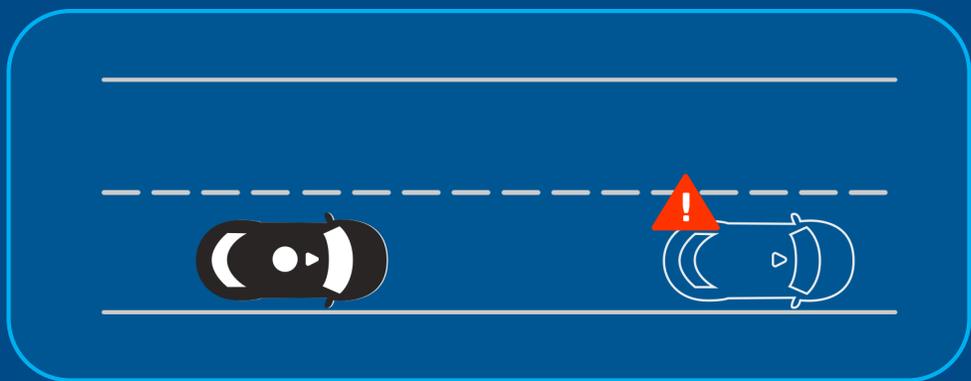
[Simulink Control Design](#)

Try it in MATLAB

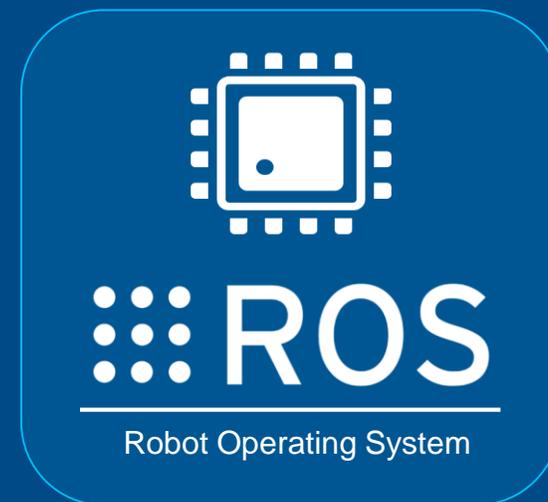
# Injected simulated vehicles to interact with while driving



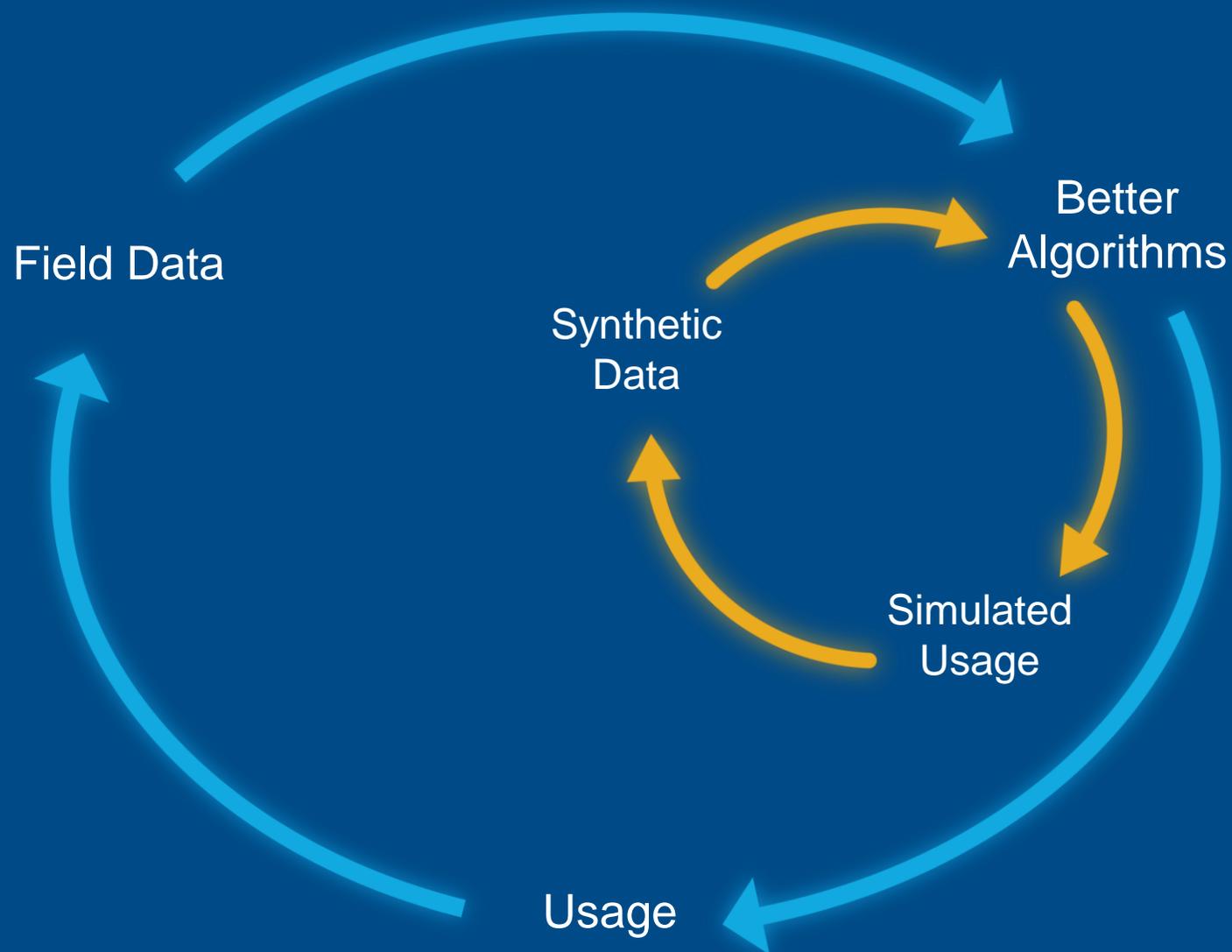
# Deployed controller as ROS node and generated code



Robotics System Toolbox  
Embedded Coder



# Train your AI faster with tight simulation loops

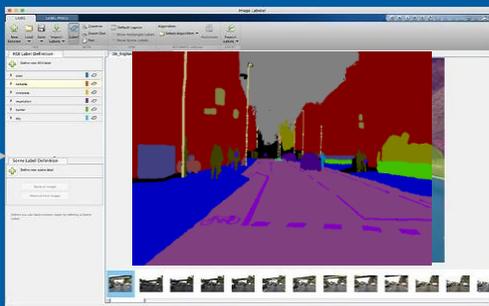


# One example of leveraging simulation for data synthesis

## Traditional deep learning workflow



Record



Label



AI model

## Simulation-based workflow



Simulate



Auto-label



***“Simulink + ROS allowed us to deploy a Level 3 autonomous vehicle in less than 3 months.”***

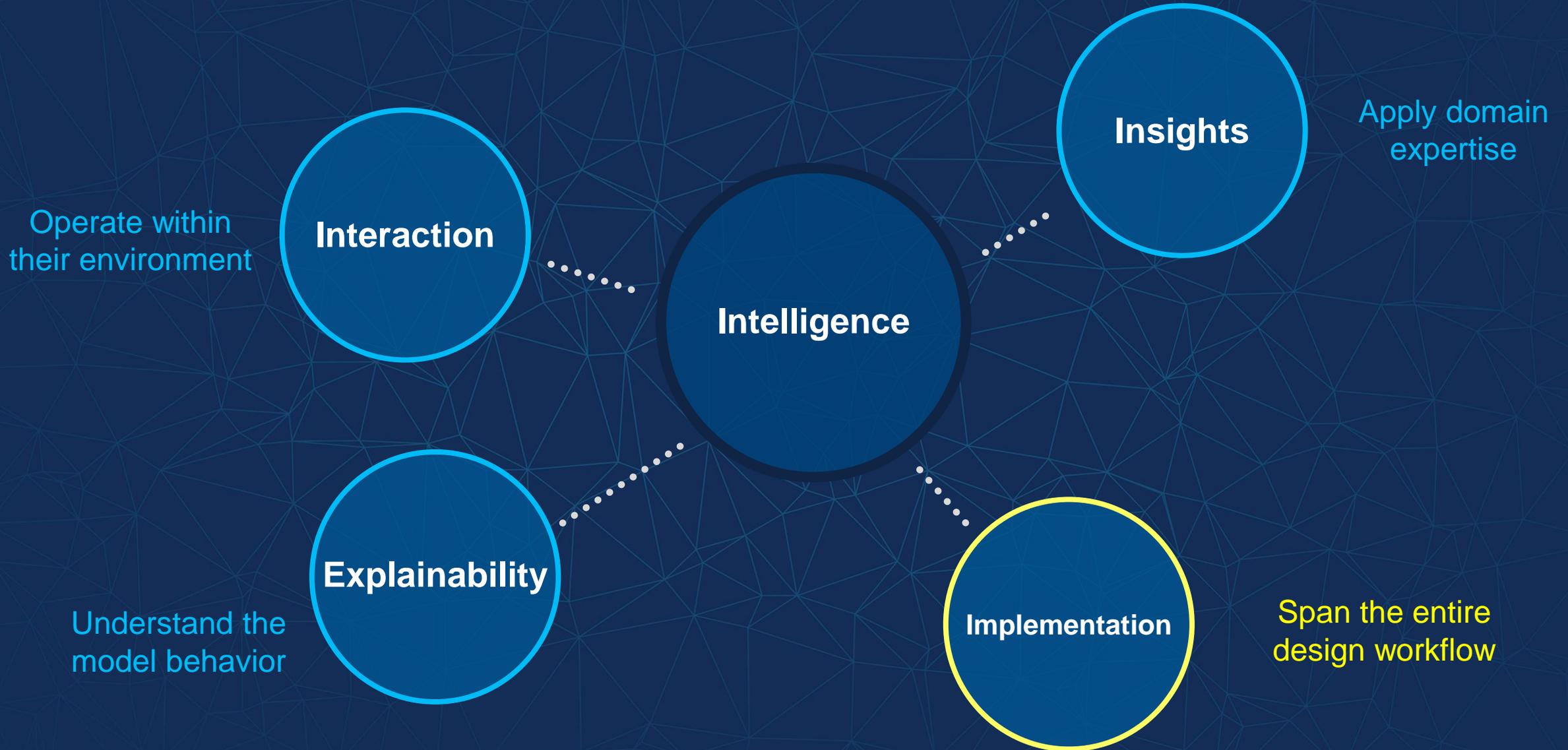
***– Alan Mond, Voyage***



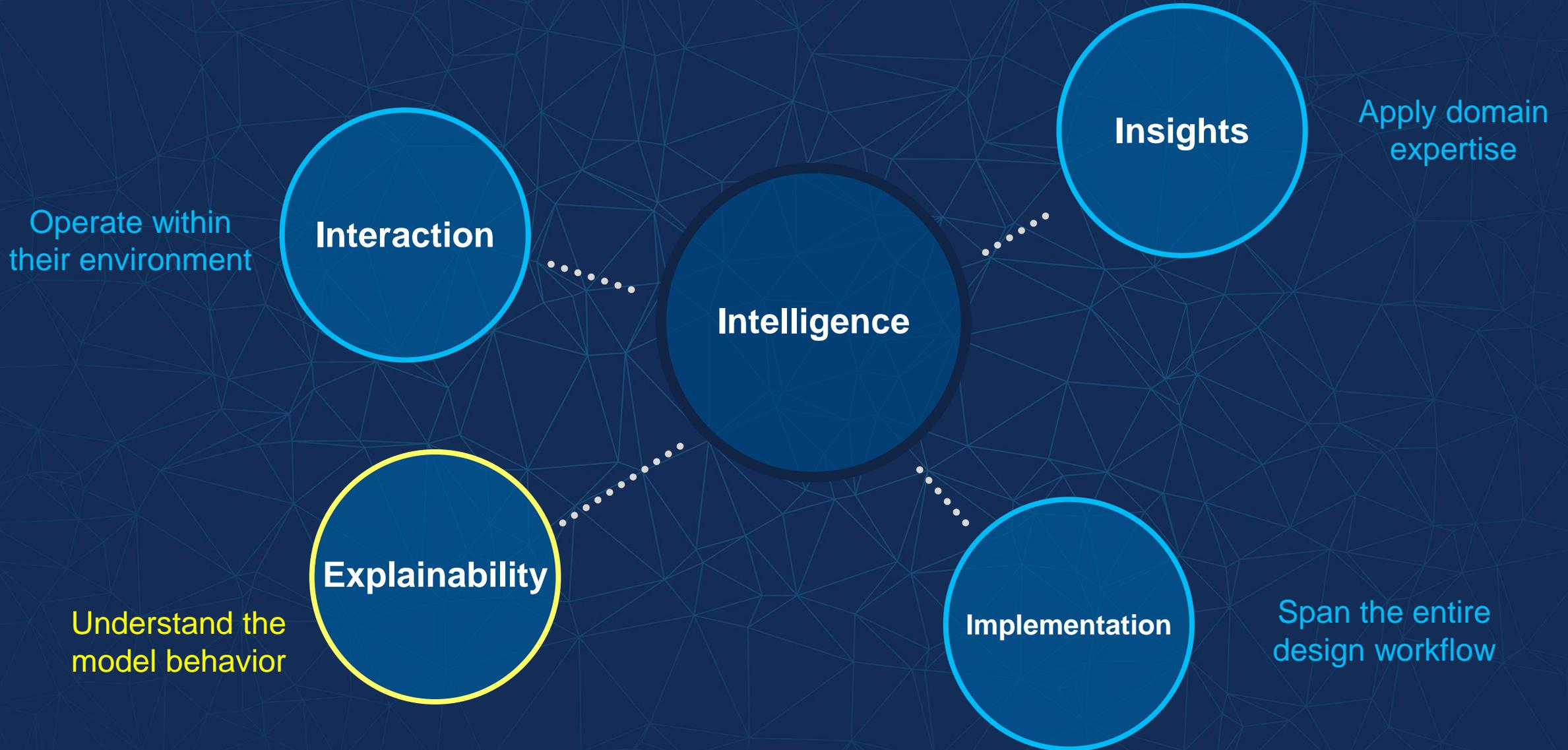
# To be successful with AI, we must ...

Use tool chains that **span**  
the **entire design workflow**

# AI is more than just the intelligence of the algorithm



# AI is more than just the intelligence of the algorithm

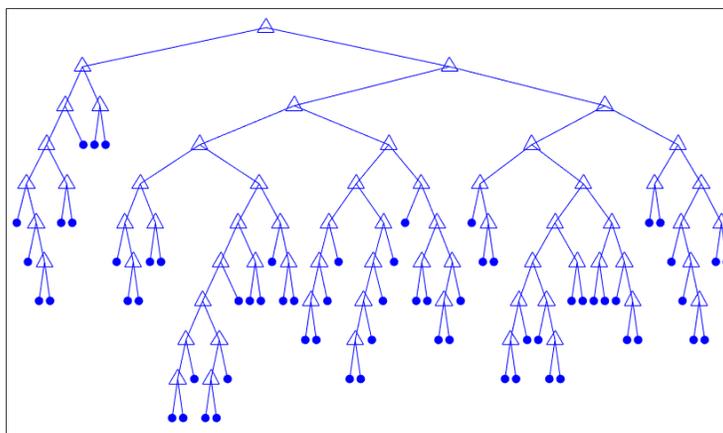


# AI should be “explainable”

How did the model come the decision?

What do you want from me?

Why was my loan application denied?



Why did it fail?



# The community is realizing the importance of explainable AI

## GOOGLE's What-If Tool ([Link](#))

Introducing the What-If Tool for Cloud AI Platform models



## IBM Toolkit for Developing Explainable AI ([Link](#))

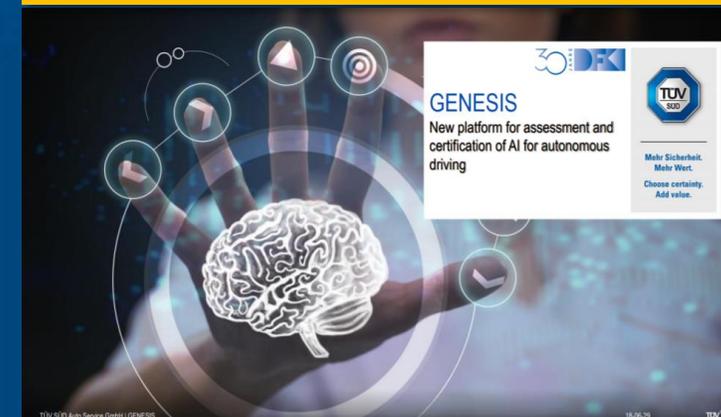
OPEN PROJECT

### AI Explainability 360

An open source software toolkit that helps you comprehend how machine learning models predict labels

[Get the code](#)

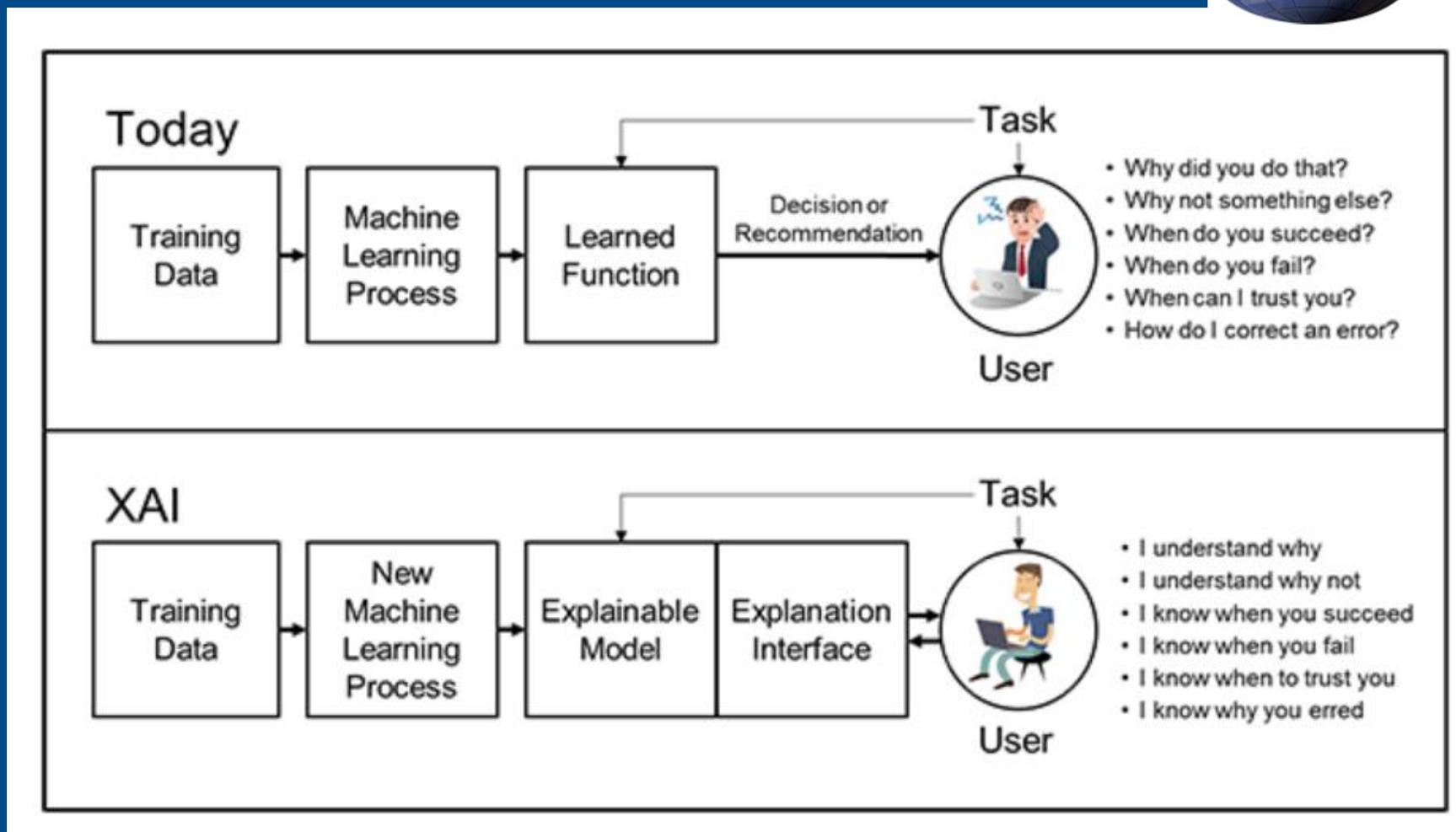
## GENESIS – Funded by German Govt. ([Link](#))



# The community is realizing the importance of explainable AI



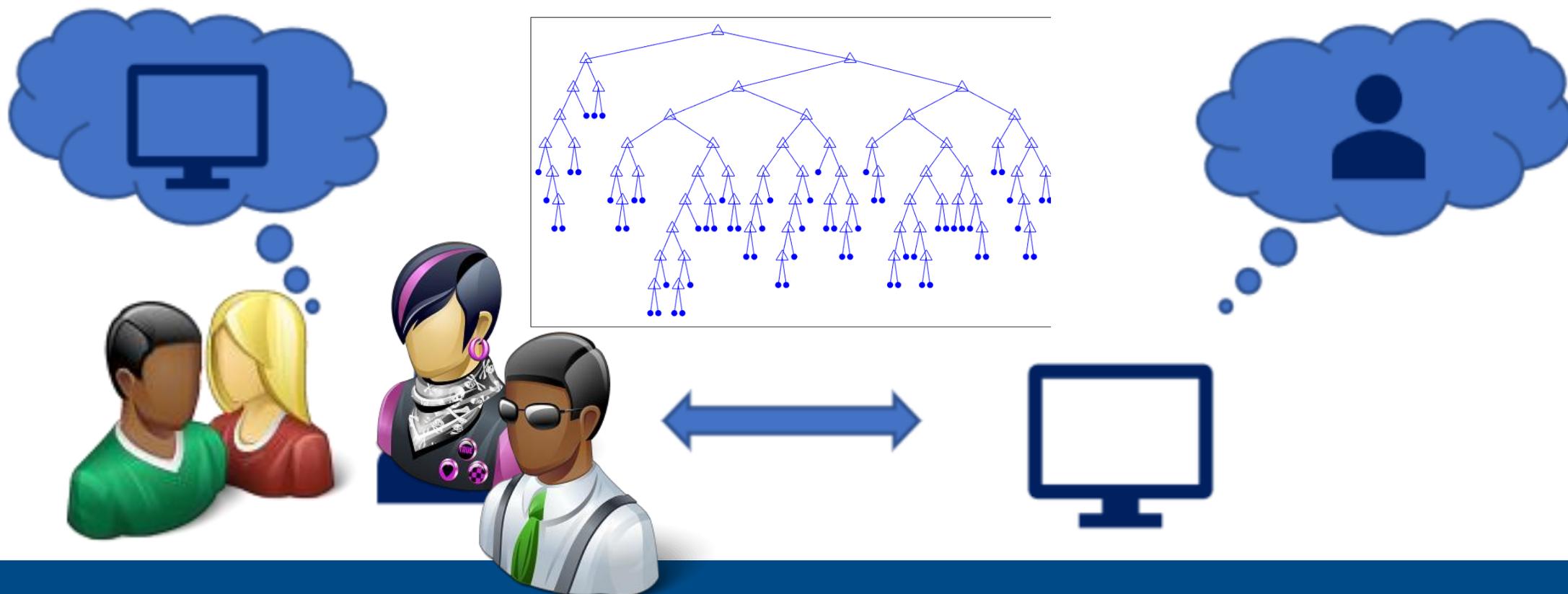
DEFENSE ADVANCED  
RESEARCH PROJECTS AGENCY



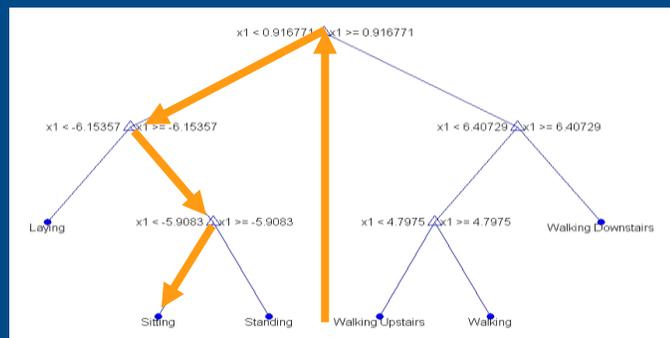
# AI should be “explainable”

Explainable to everyone

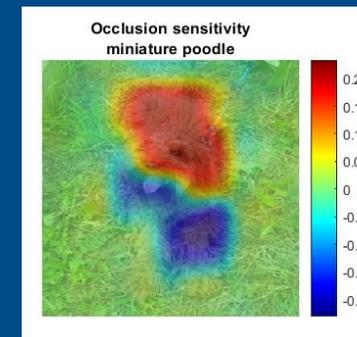
Interpretable



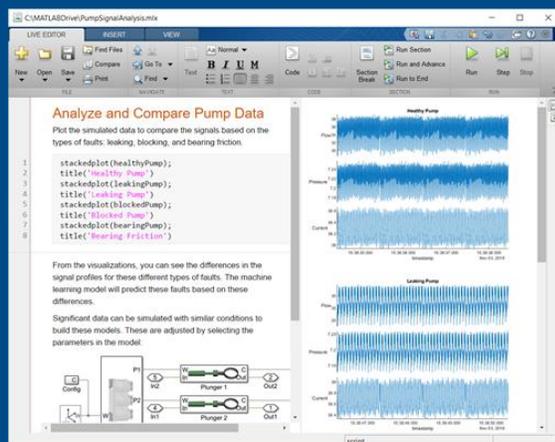
# Model explainability can be improved



Simpler models



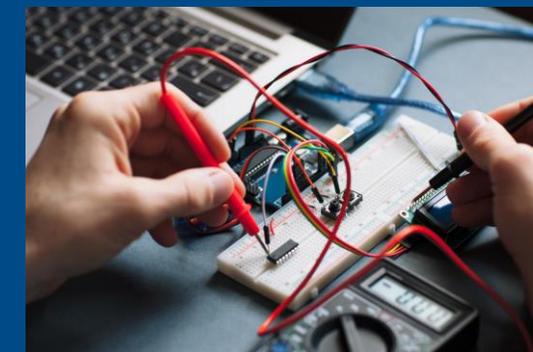
Visualizations



Documentation

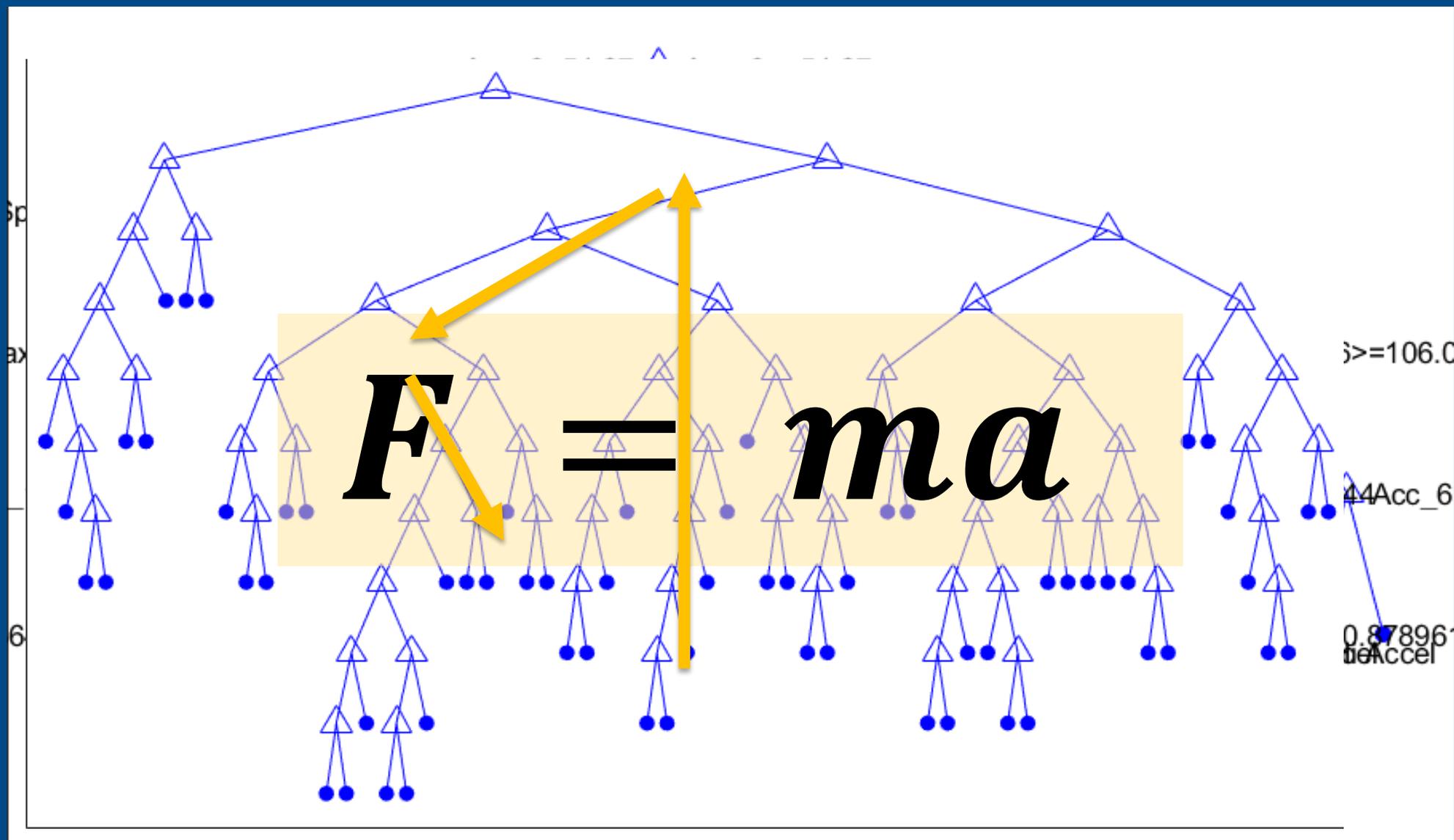


Simulations

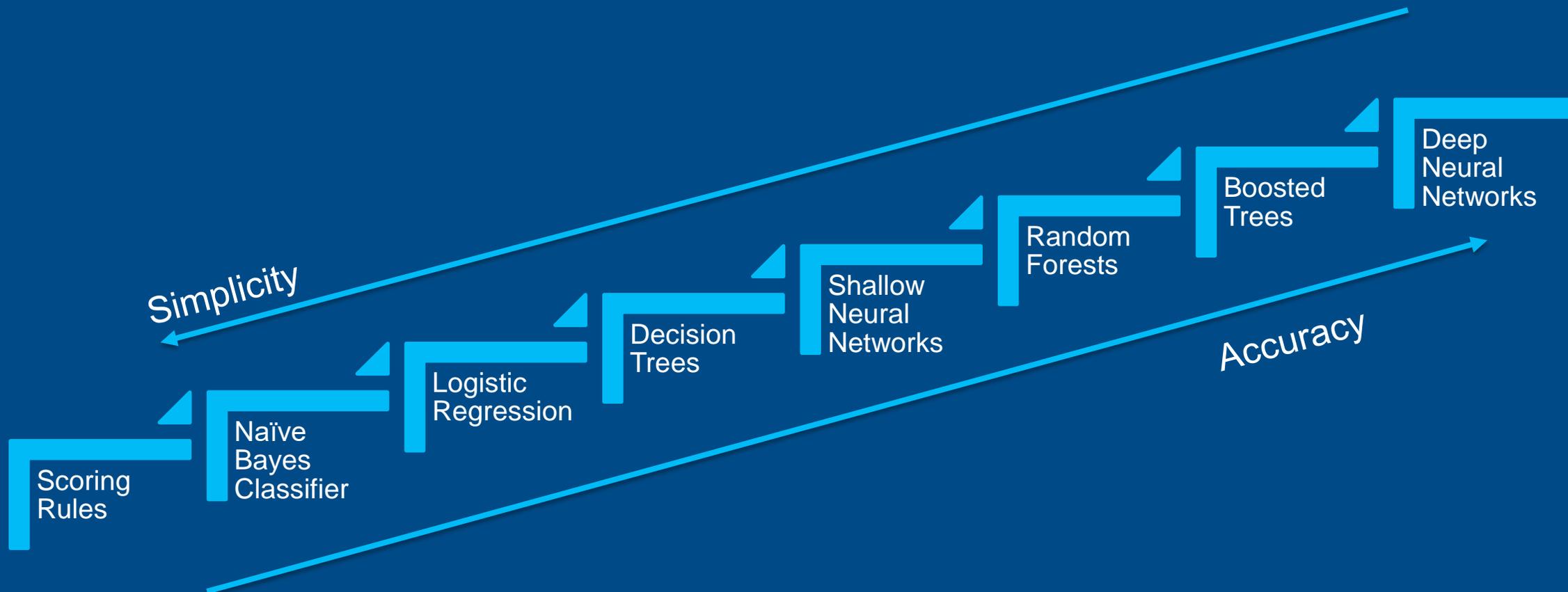


Rigorous testing

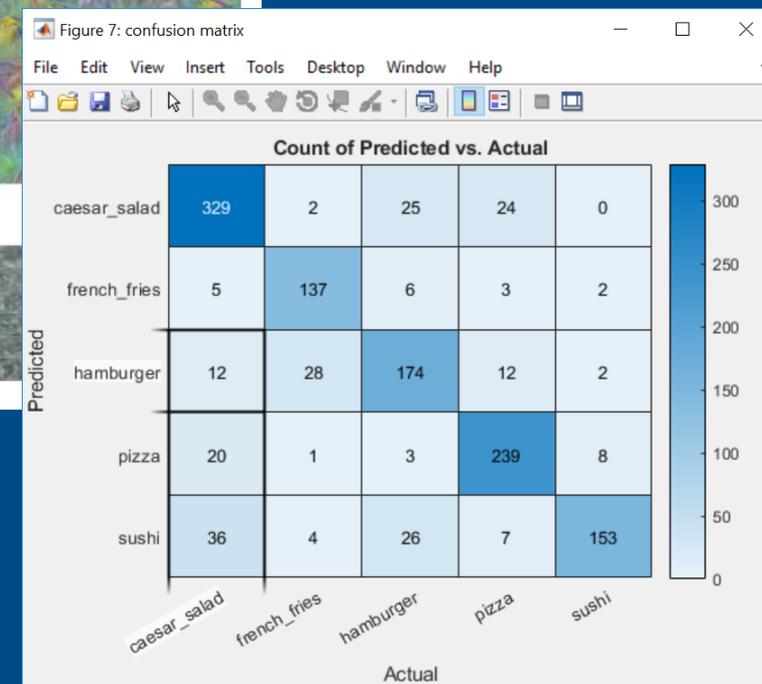
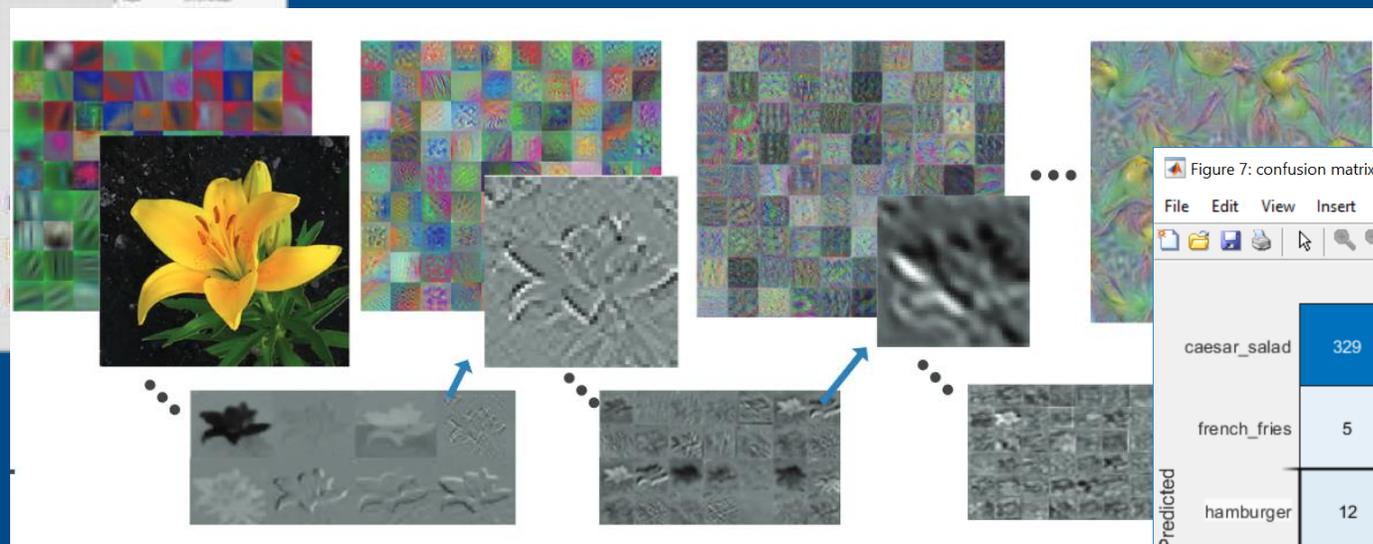
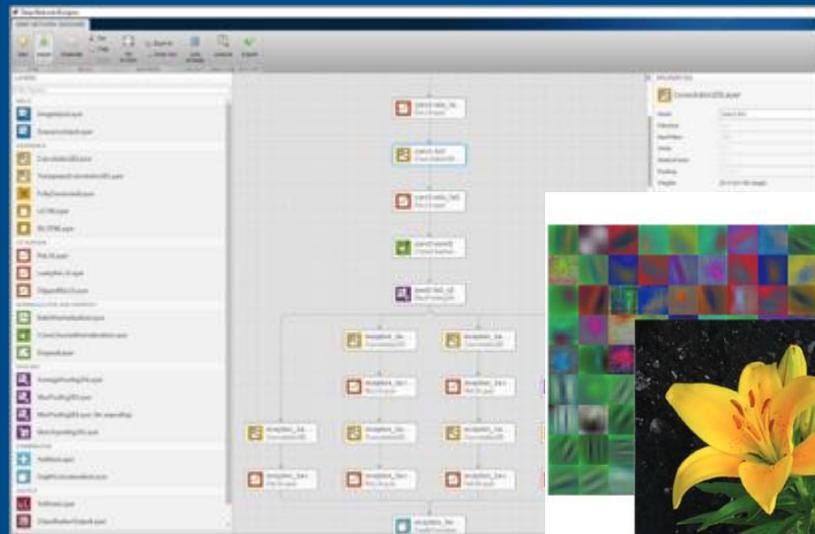
# Use simpler, interpretable models



# Use simpler, interpretable models

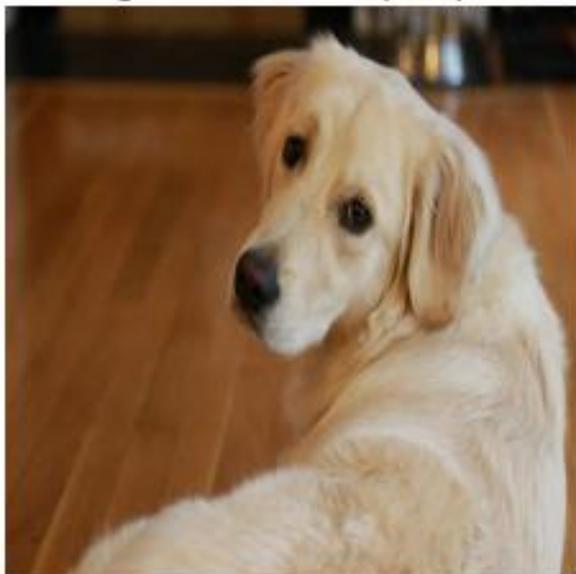


# Visualize throughout the entire process



# Use visualizations to understand predictions

golden retriever (0.55)



Grad-CAM

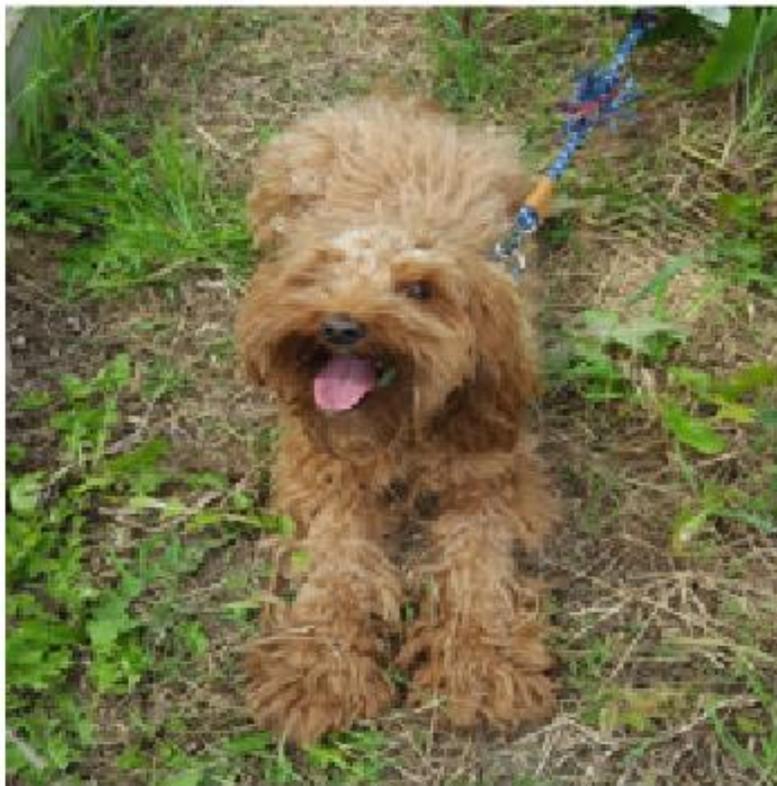


# Visualize which parts of the image influence the classification

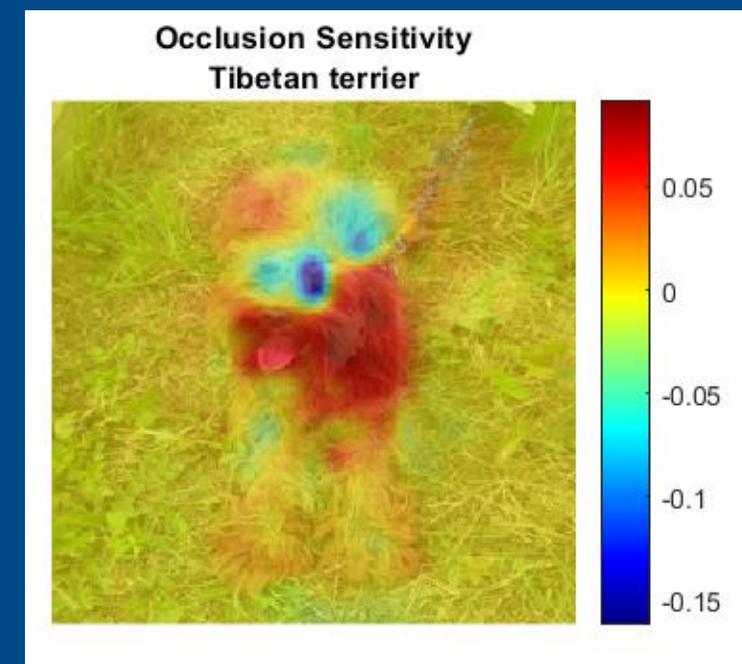
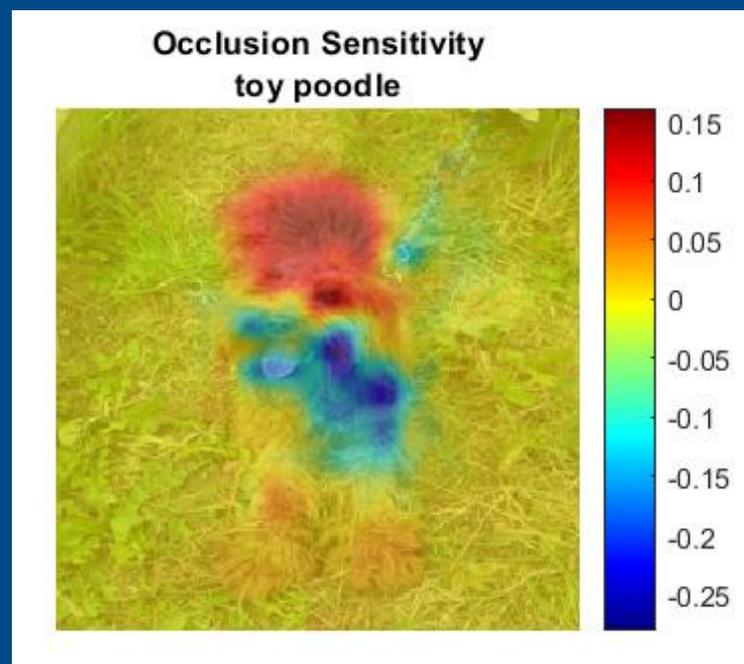
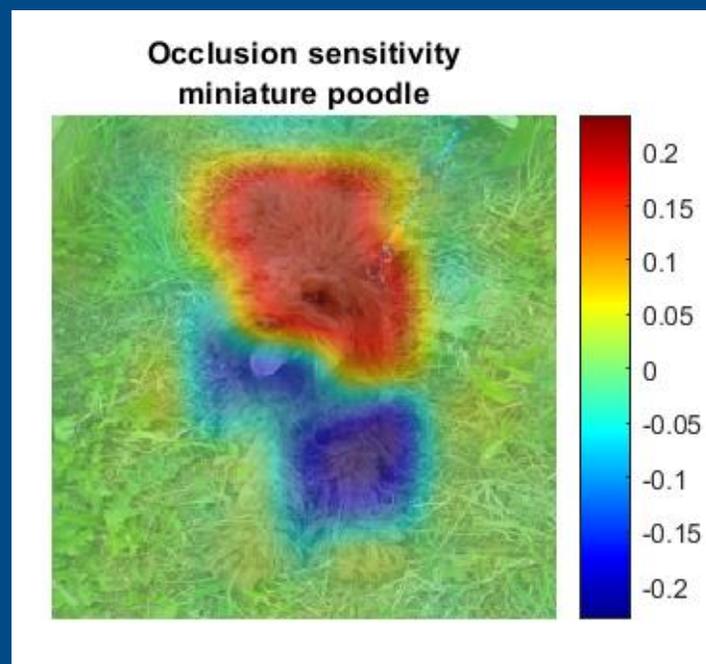
miniature poodle (0.23)

toy poodle (0.17)

Tibetan terrier (0.11)

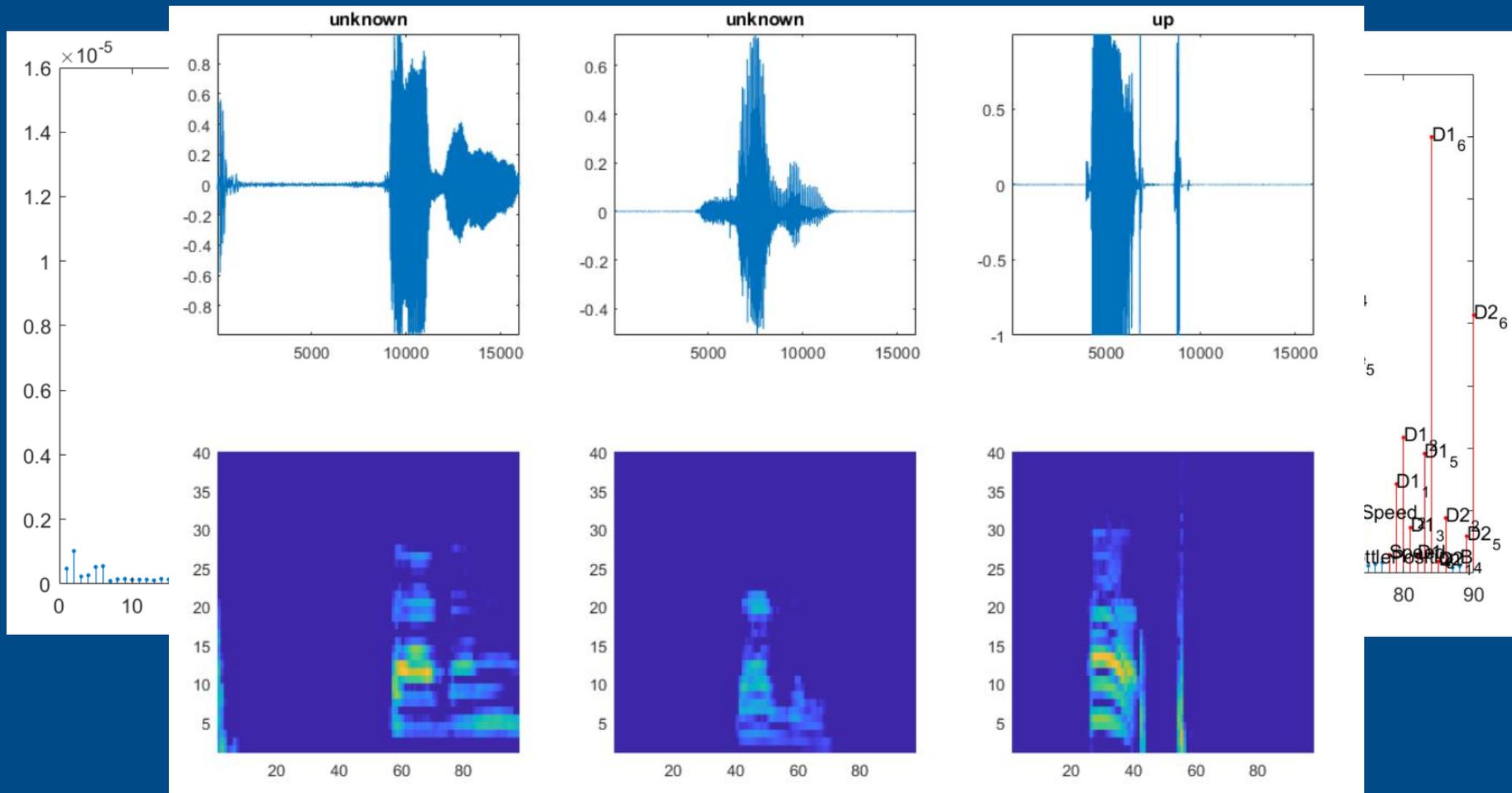


# Visualize which parts of the image influence the classification



<https://www.mathworks.com/help/deeplearning/ref/occlusionsensitivity.html>

# Visualize feature importance



# Document everything

MATLAB R2019b

HOME PLOTS APPS LIVE EDITOR INSERT VIEW

C:\Users\hgorr\Demos\HowsMyDrivingDemo\09\_HowsMyDrivingModel

Live Editor - C:\Users\hgorr\Demos\HowsMyDrivingDemo\09\_HowsMyDrivingModel\BuildDrivingModel.mlx \*

BuildDrivingModel.mlx \* ImprovingTheModel.mlx WorkWithImbalancedClasses.mlx Untitled.mlx \*

## Develop Predictive Model

### Table of Contents

- Develop Predictive Model
- Build Model
  - Build machine learning model
  - Predict for new data
  - Save results
- Improve the model
- Use Model in the Stream

---

## Build Model

```
1 load('preprocessedTT.mat')
```

Create a table of predictor and response variables for classification. This is a table, so we will use a subset of data to train the model and test it with the remaining data.

```
2 results = timetable2table(tt);
3 rng(1234)
4 cv = cvpartition(results.Event,'Holdout',0.3);
5 trainData = results(cv.training,:);
6
```

C:\MATLABDrive\PumpSignalAnalysis.mlx

LIVE EDITOR INSERT VIEW

FILE NAVIGATE TEXT CODE SECTION RUN

New Open Save Print Find Files Compare Go To Find Text Normal B I U M Code Section Break Run Section Run and Advance Run to End Run Stop

## Analyze and Compare Pump Data

Plot the simulated data to compare the signals based on the types of faults: leaking, blocking, and bearing friction.

```
1 stackedplot(healthyPump);
2 title('Healthy Pump');
3 stackedplot(leakingPump);
4 title('Leaking Pump');
5 stackedplot(blockedPump);
6 title('Blocked Pump');
7 stackedplot(bearingPump);
8 title('Bearing Friction');
```

From the visualizations, you can see the differences in the signal profiles for these different types of faults. The machine learning model will predict these faults based on these differences.

Significant data can be simulated with similar conditions to build these models. These are adjusted by selecting the parameters in the model.

script

# Simulate real data

“Need **11** billion miles of testing to demonstrate with **95%** confidence that failure rate is **20%** better than human drivers”

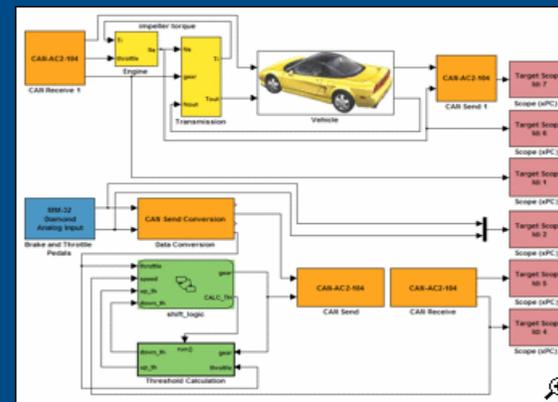
Source: RAND



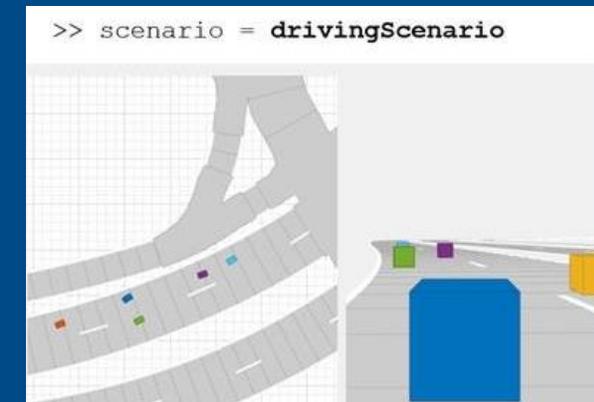
X 1,000,000's



Model Confidence



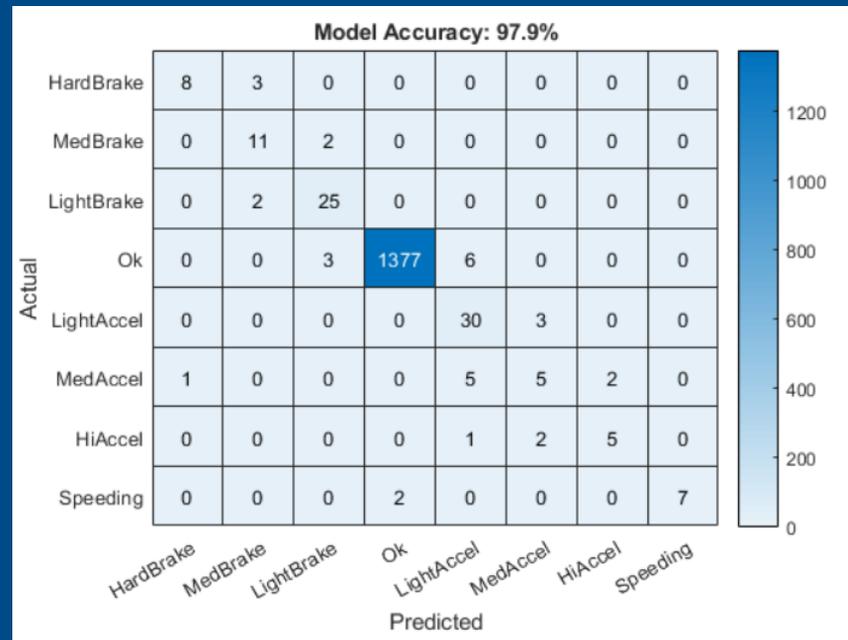
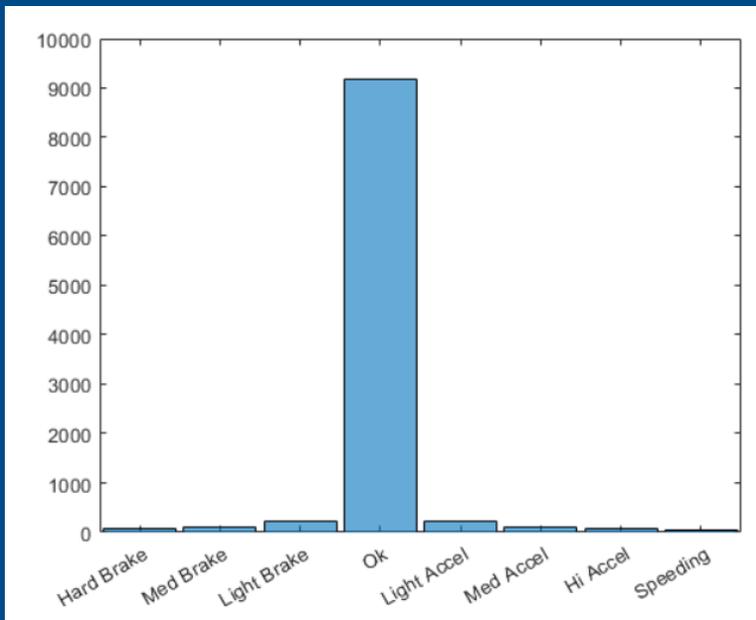
Components, Systems



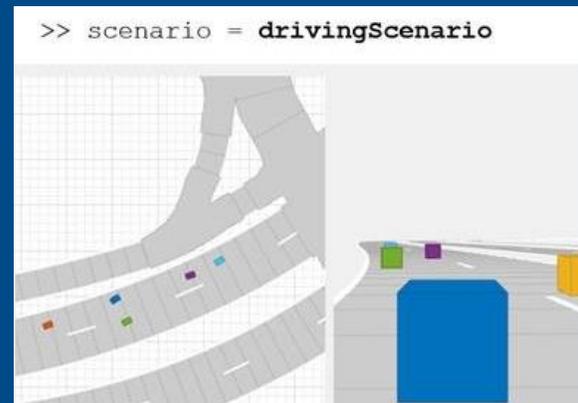
Test Scenarios

# Simulate data for more confidence

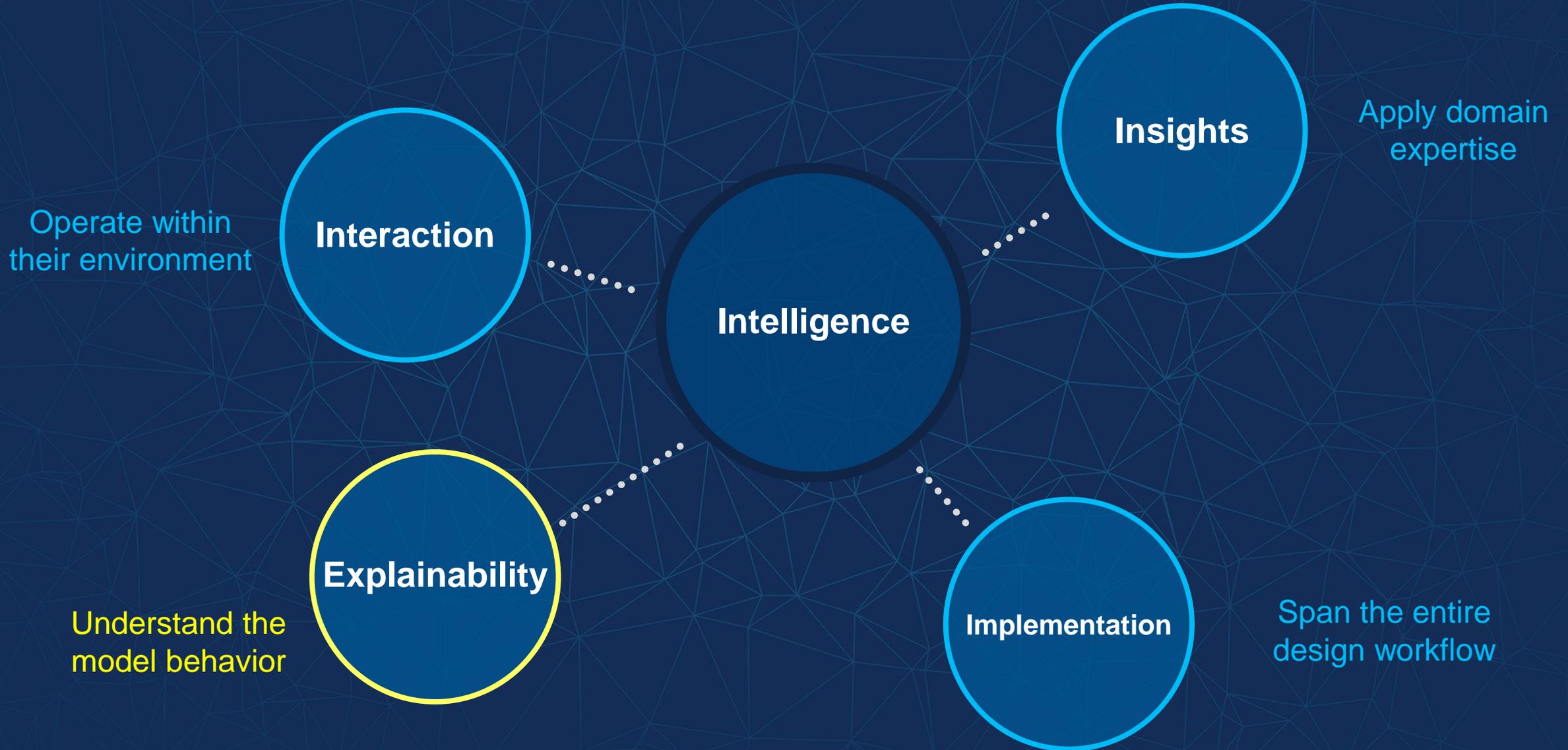
Model



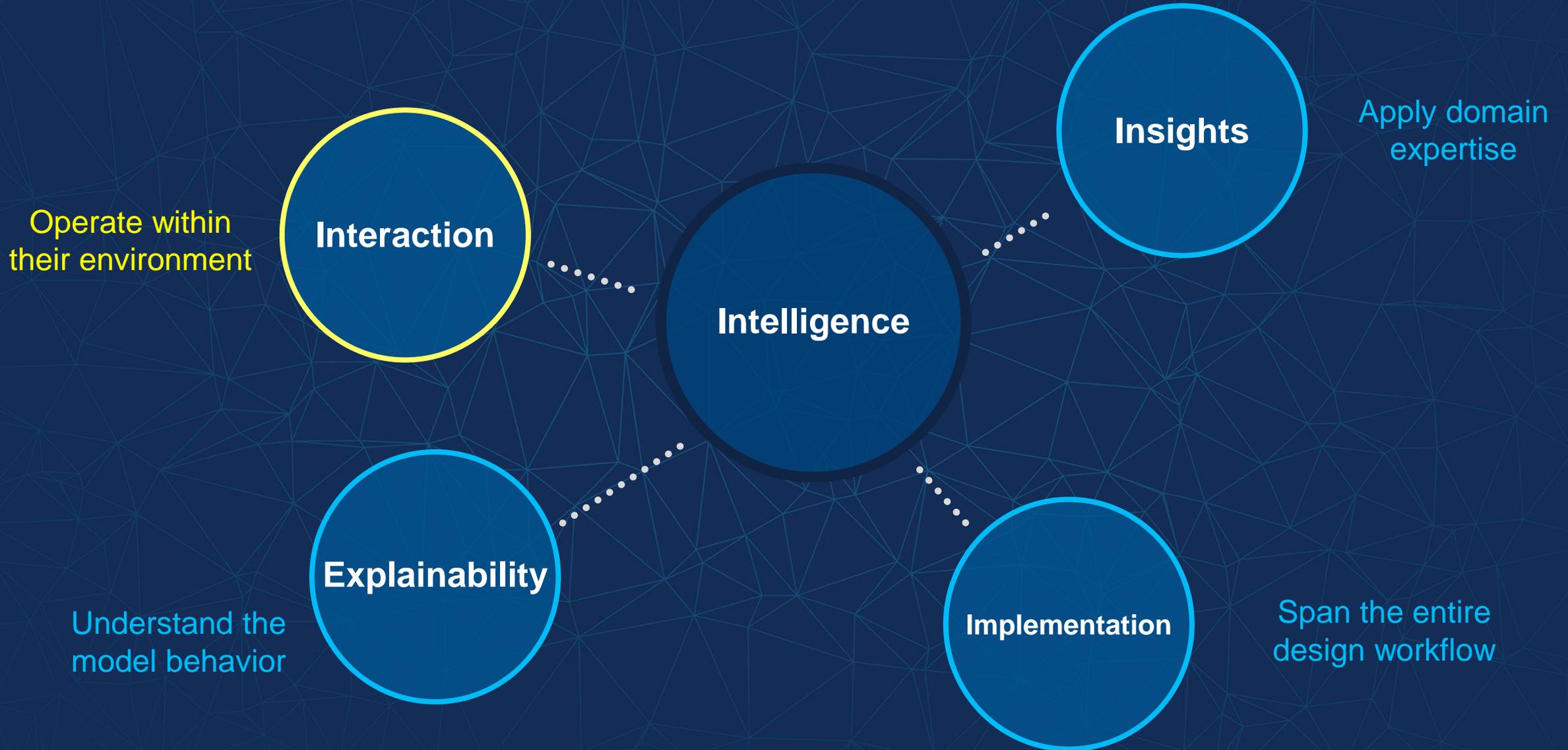
System



# AI is more than just the intelligence of the algorithm



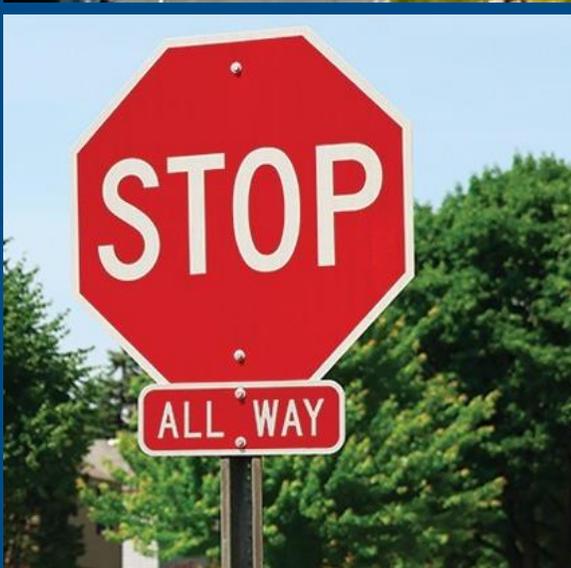
# AI is more than just the intelligence of the algorithm





Interaction within complex environments

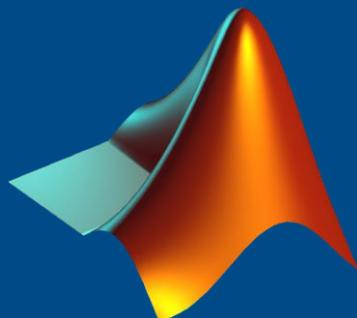
# What was the larger system the vehicle had to operate in?



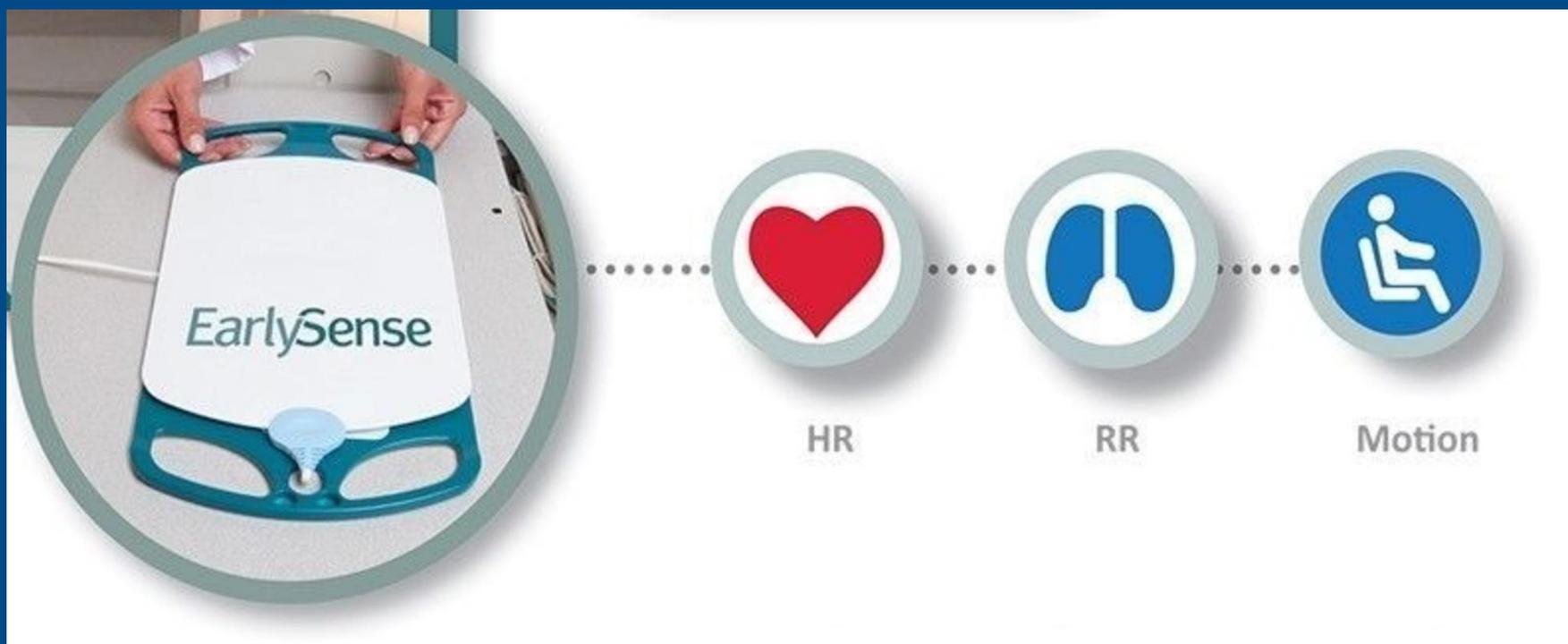
# EarlySense



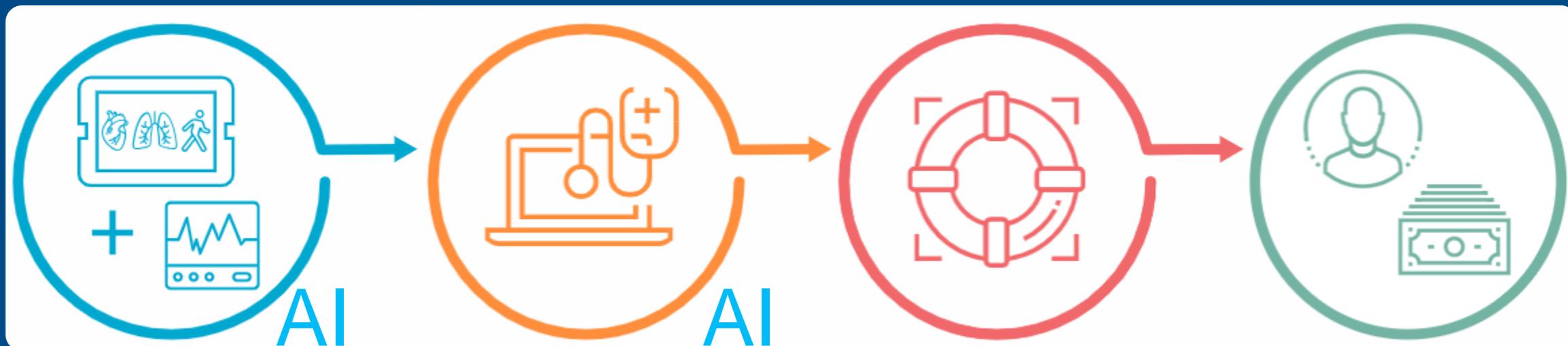
“Proactive patient care”



Statistics and Machine Learning Toolbox  
Signal Processing Toolbox  
MATLAB Coder  
Embedded Coder



# EarlySense's AI can **predict critical events** before they happen



Continuous  
Monitoring

Early  
Detection

Early  
Intervention

Better  
Outcomes

# Dashboards at nurses' stations and on hallway monitors



Alerts on hand-held  
devices carried by staff





Address problems before they become emergencies

To be successful with AI, we must ...

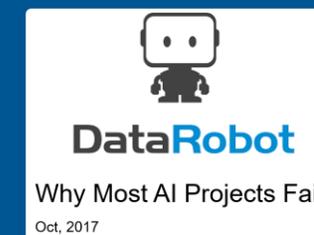
Design how our systems will integrate  
and **interact within their environment**

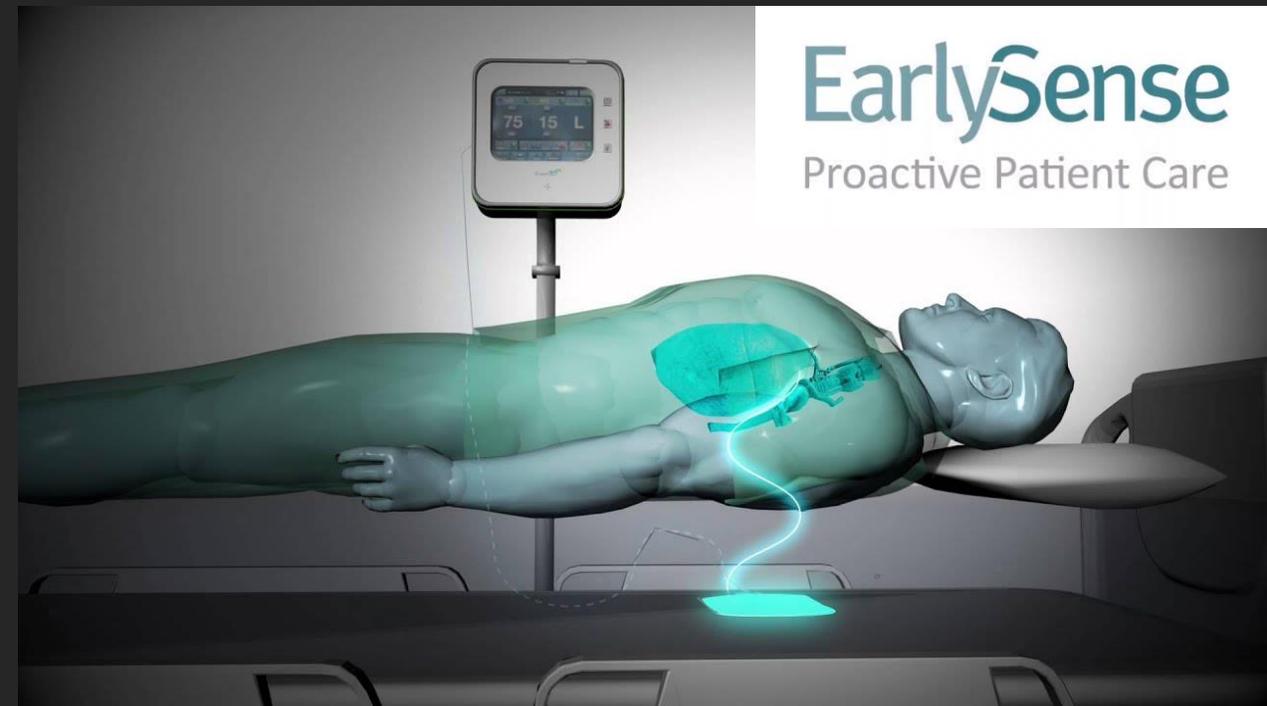
# Success requires more than just intelligence

AI is a transformative technology



But AI projects can and do fail





EarlySense  
Proactive Patient Care

Operate within  
their environment

**Interaction**

Understand the  
model behavior

**Explainability**

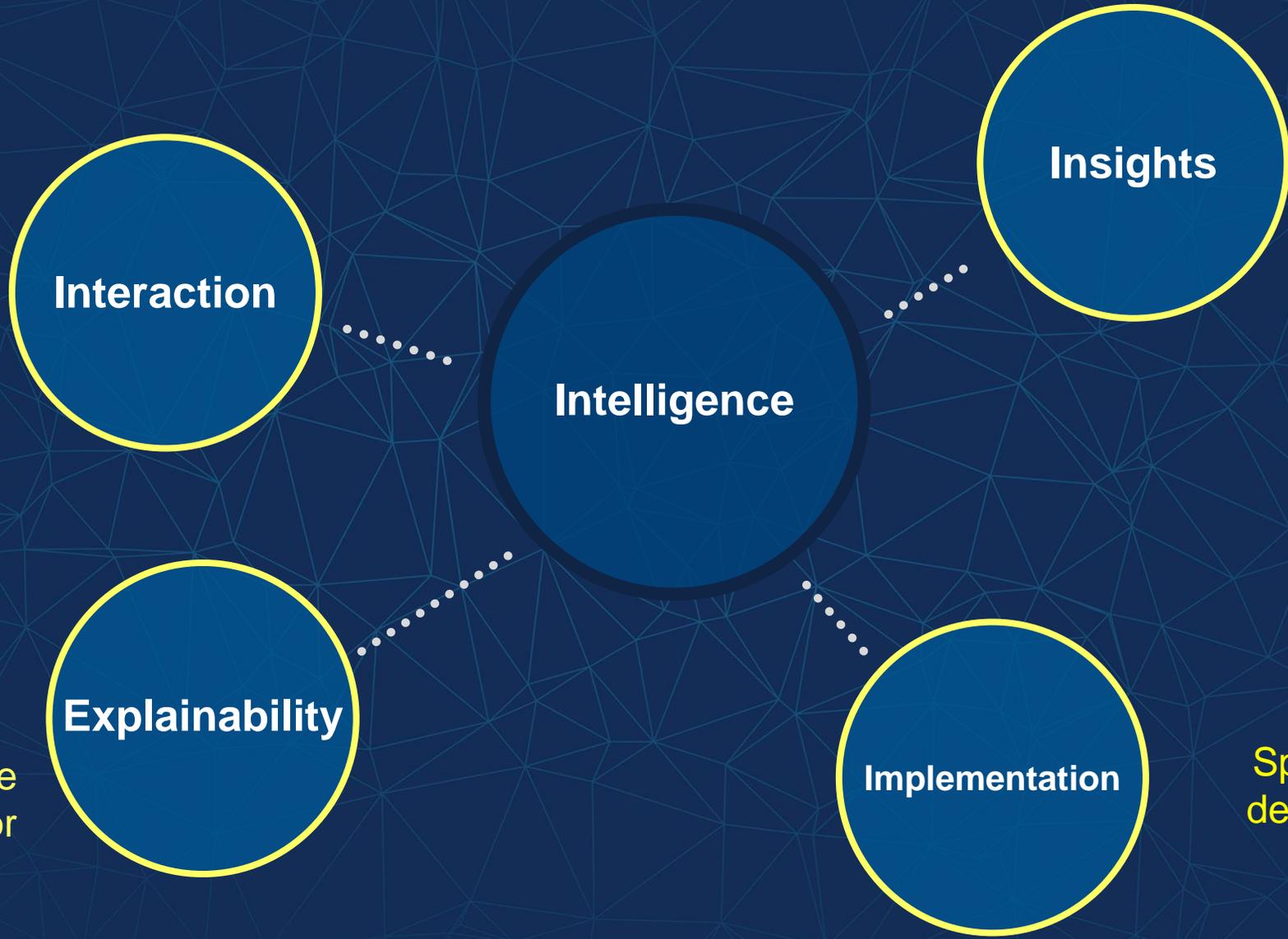
**Intelligence**

**Implementation**

**Insights**

Apply domain  
expertise

Span the entire  
design workflow



# How will you apply AI to your projects?

