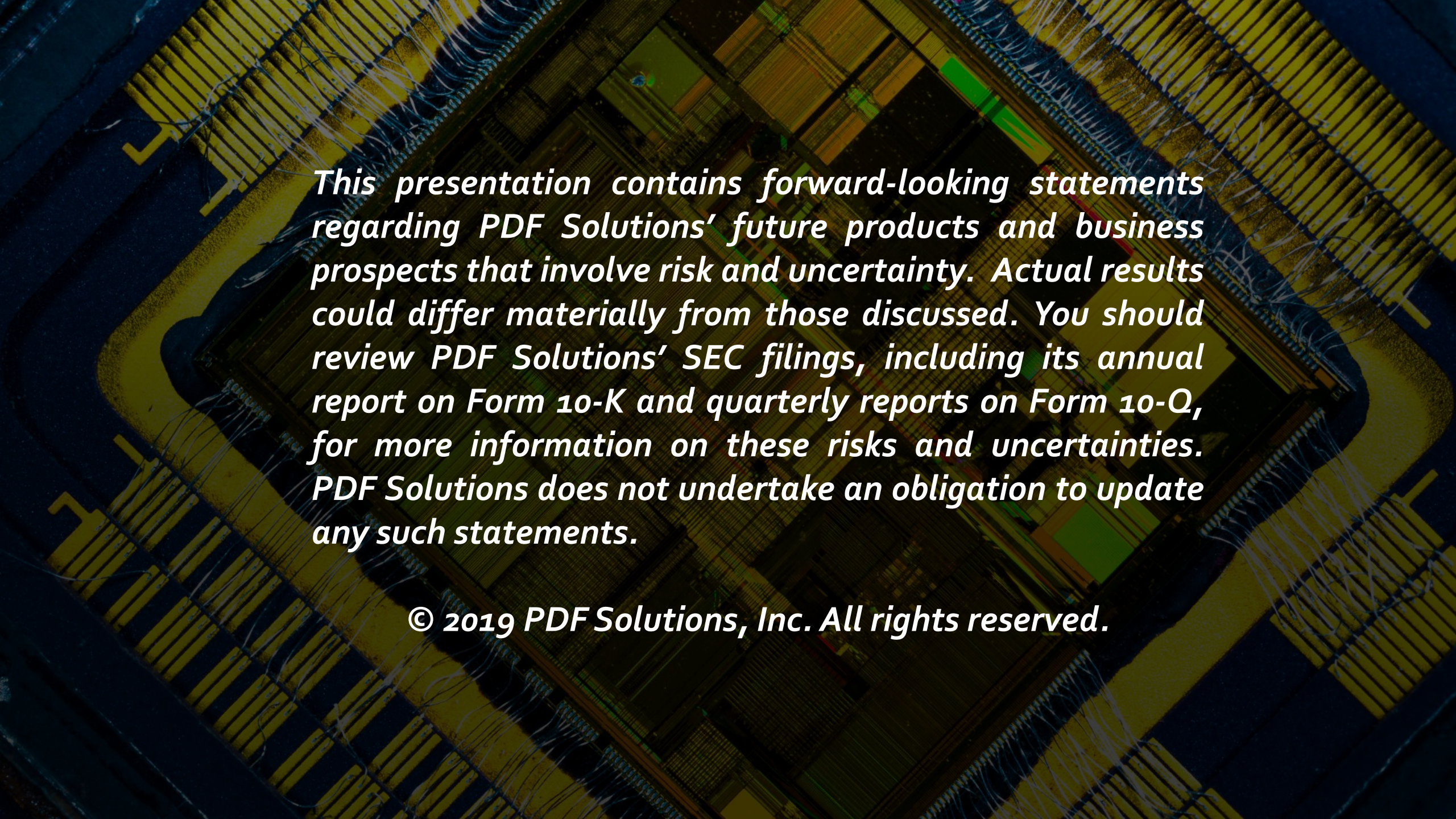
16th Annual
PDF Solutions
Users Conference

PDF/SOLUTIONS™

S1.3 - Machine Learning in Exensio®

October 15, 2019

Jeff David, VP of AI Solutions



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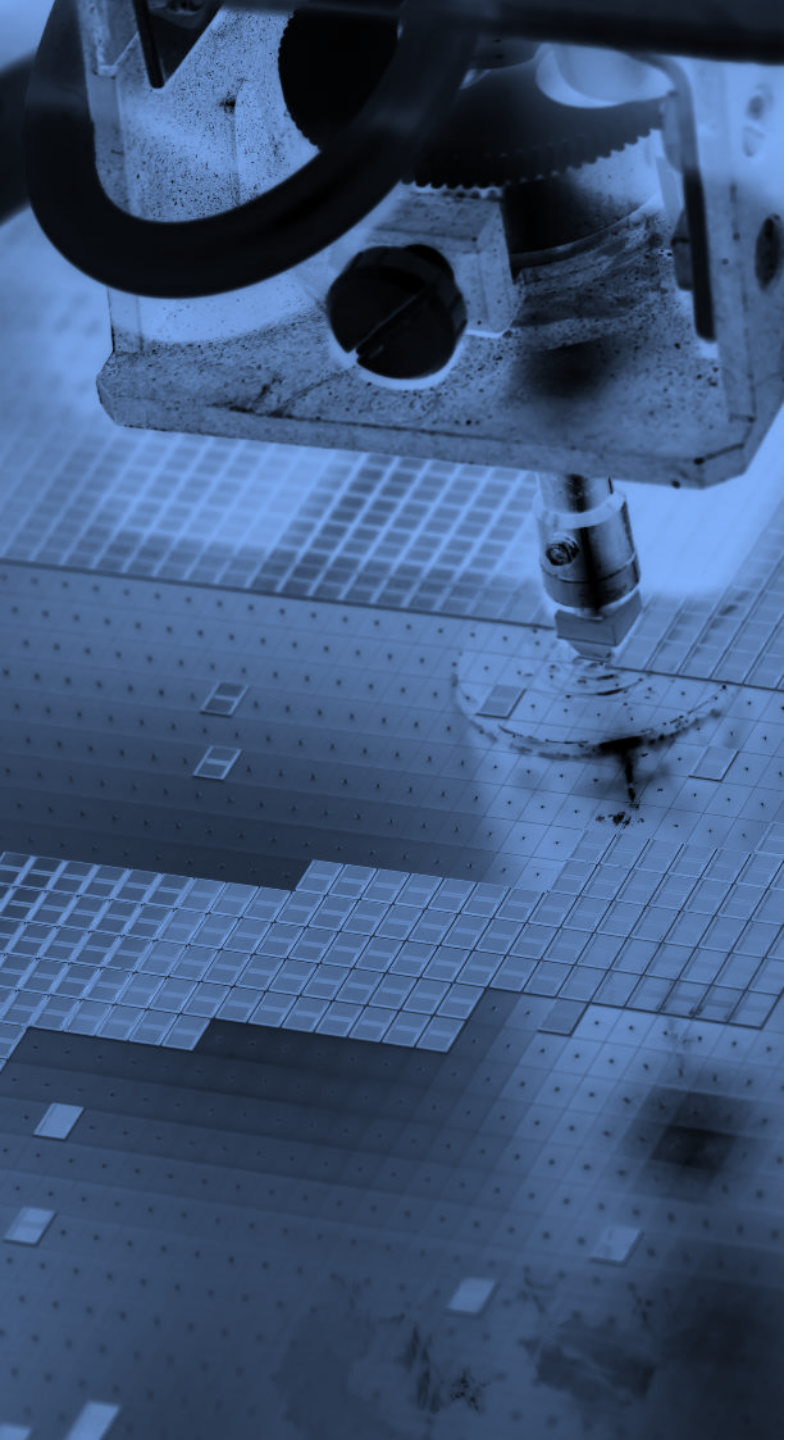
What is Machine Learning??

- *Algorithms that iteratively learn from data to find hidden insights*
- *Allows for automatic generation of models that can analyze massive amounts of data to deliver faster, more accurate predictions*
- *"Learns" complex correlations between incoming data and outputs.*

Everyday Examples of ML

- ❑ *Optical character recognition*
- ❑ *Face detection: Facebook*
- ❑ *Banking: Mobile Check deposits / Fraud detection*
- ❑ *Traffic Prediction: Waze / Google Maps*
- ❑ *Recommendation Engines: Netflix / YouTube / Google*
- ❑ *Spam filtering: identify emails as spam or non-spam*
- ❑ *Self Driving Cars: Google, Tesla*



Agenda

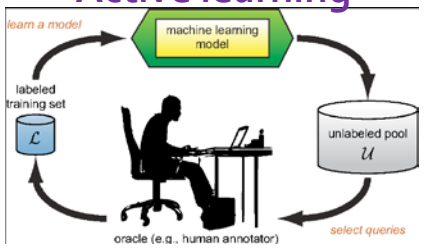
- *Why is implementing machine learning so difficult in the semiconductor industry??*
- *PDF is UNIQUELY positioned to deliver the promise of AI to the industry*
- *Augmenting analytics with AI/ML to improve results and make it easier to use*

Other industries have more sophisticated AI than the semiconductor industry

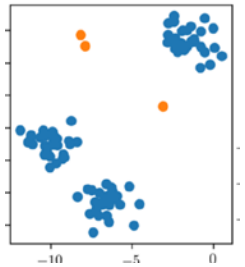
Why is that?

Model Pipeline: a Collection of Steps, Methods and Best-Known Practices that Solve the Problem

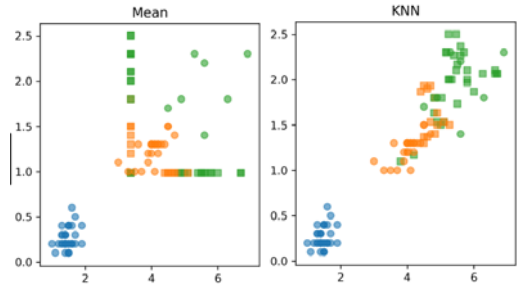
Active learning



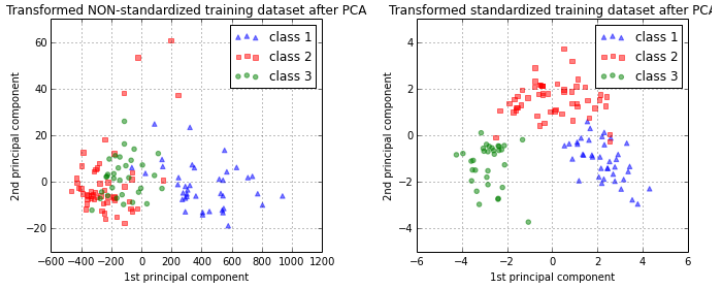
Outlier detection



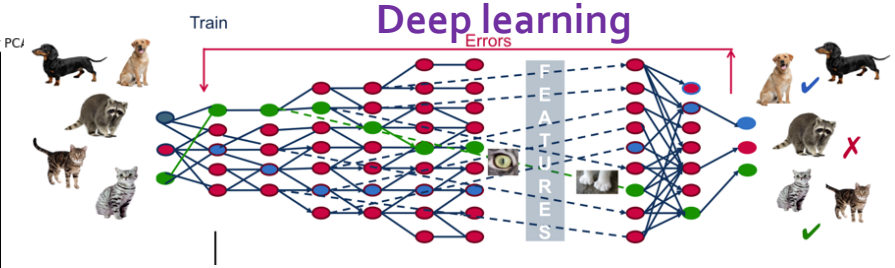
Imputation



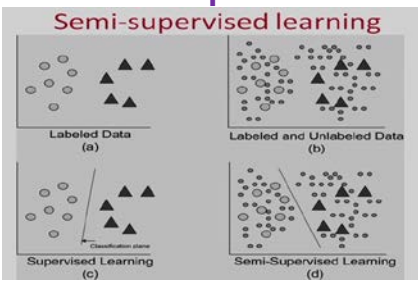
Scaling / Normalization



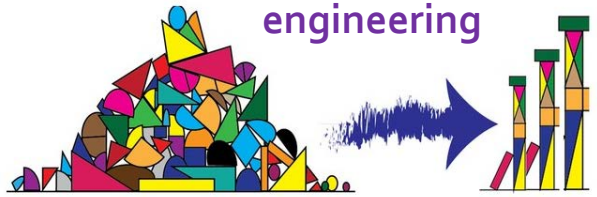
Deep learning



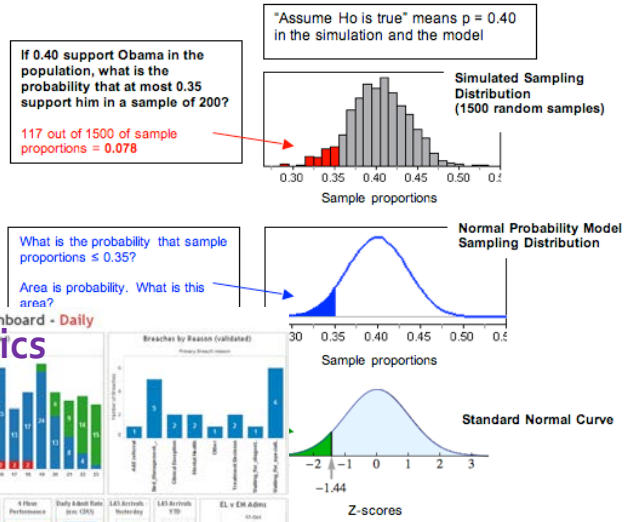
Semi-Supervised



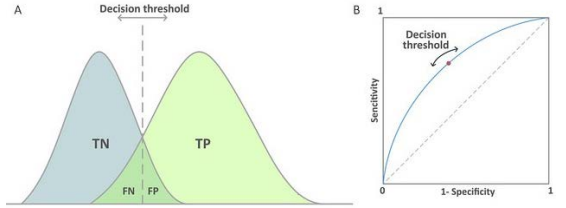
Feature selection & engineering



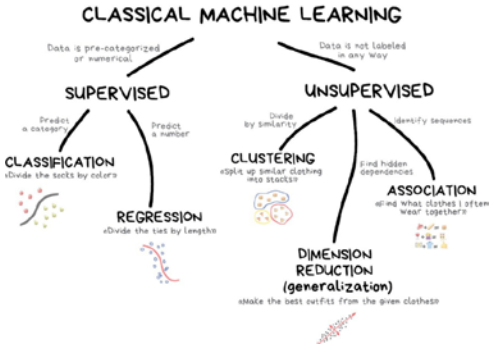
Statistical tests & uncertainty estimation



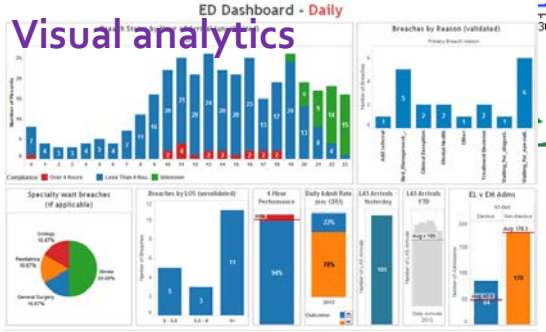
Threshold selection



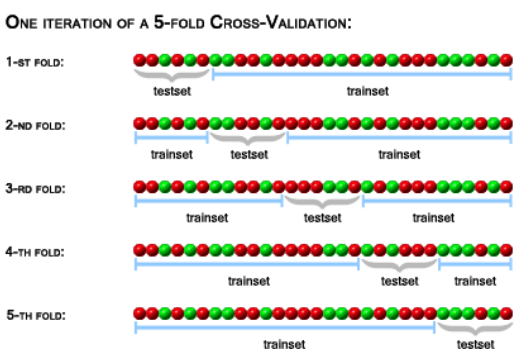
Algorithms / ML



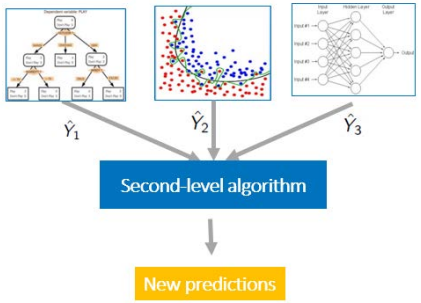
Visual analytics



Hyper-parameter tuning Stratified K-fold cross validation



Ensemble



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Model Pipeline: a Collection of Steps, Methods and Best-Known Practices that Solve the Problem

Outlier detection

Imputation

Scaling / Normalization

Active learning

Deep learning

Nature of the problem dictates what type of algorithm and what order of various methods to use

Use appropriate tools strategically.

Exensio® has a large library of tools to leverage, including open source technologies

We enable our customers to deploy their own models and ML in our platform

Exensio® enables sharing of results across your enterprise

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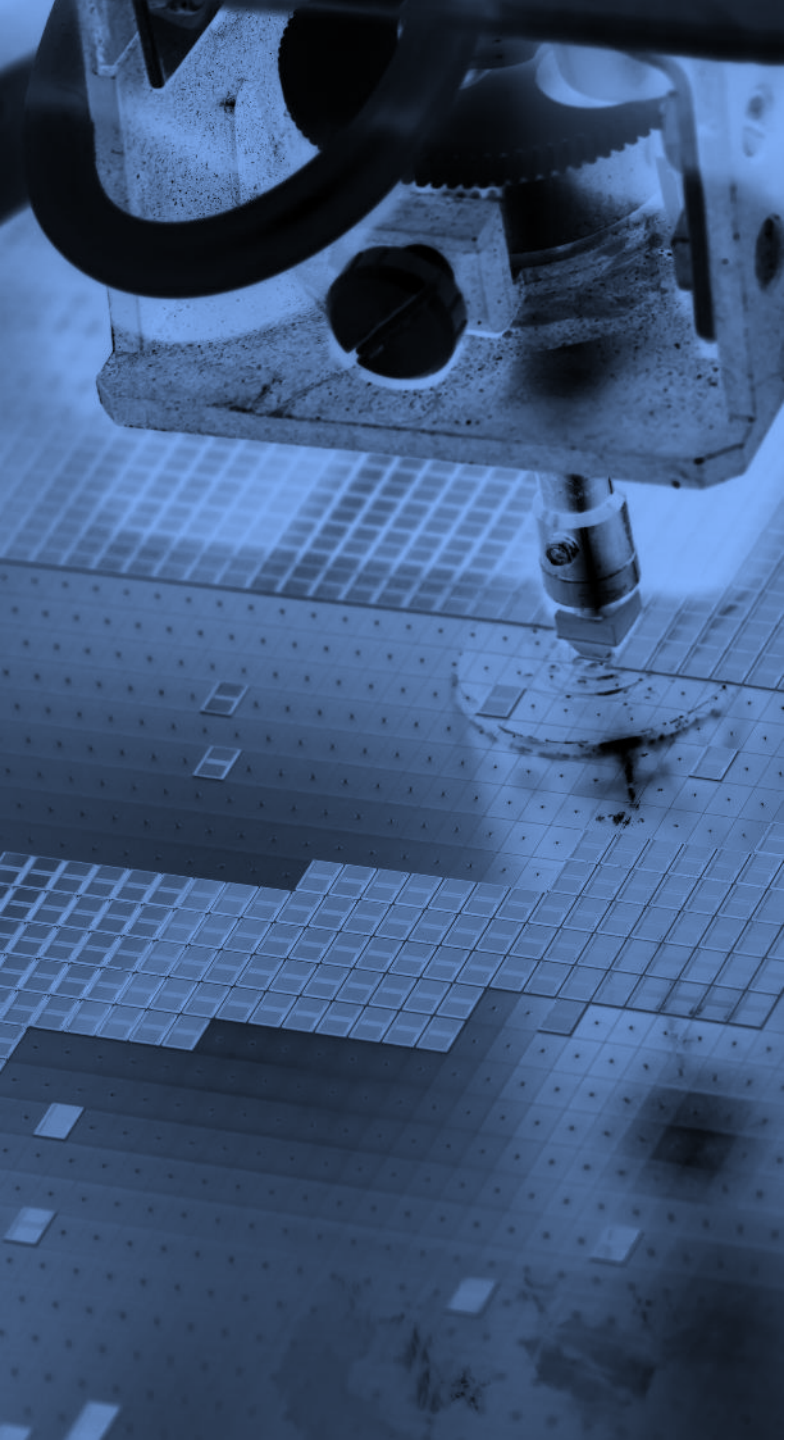
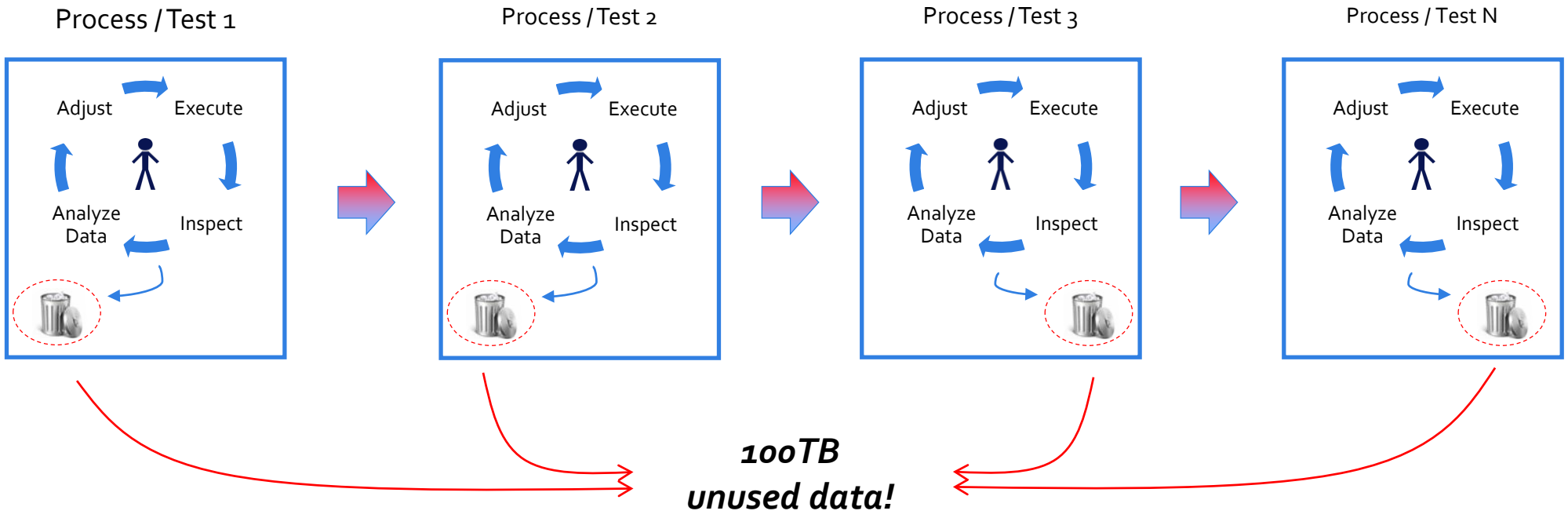


Some Challenges for ML in the Semiconductor Industry

- Multimodal batch trajectories due to product mix
- Test program changes
- Process drift and shift, tool recalibration
- Changing failure modes
- Small amount of training data
- Lack of labels
- Lack of data for emerging technologies
- Lack of traceability for root cause

- *What happens when your data doesn't arrive?*
- *What do you do if it is corrupt?*
- *What kind of prediction do you make?*

Today's Struggle: Silos and Local Optimization



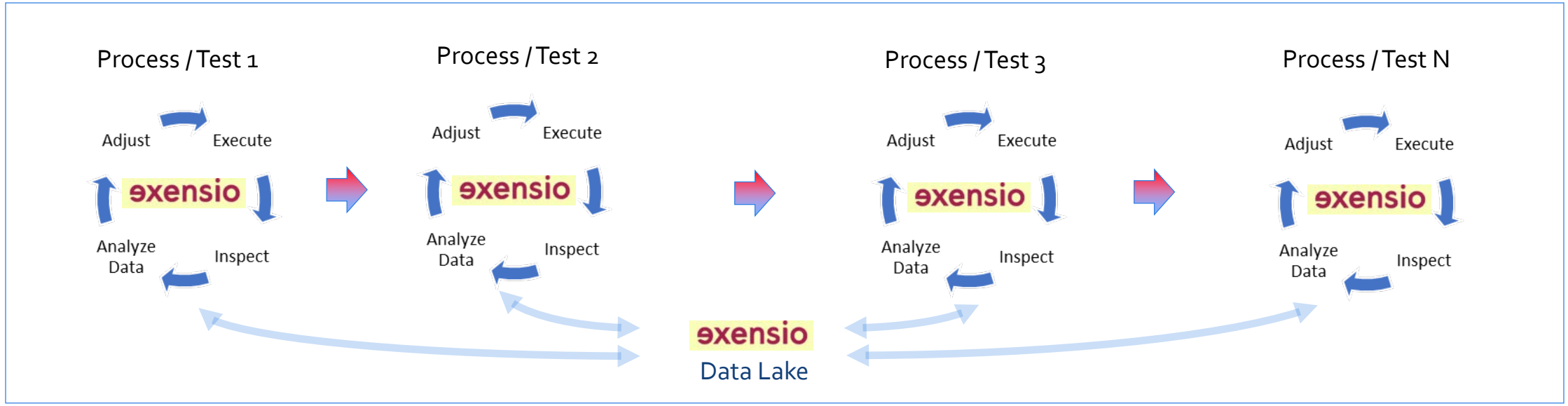
Our customers want to be able to do something better than humans stuck in silos

- One step learning
- One step adjustment
- Data used once
- Human heavy

→ Higher cost
Lower quality
Falling yields

By integrating data and applying ML, our customers can achieve better results

Exensio®: Global and Local Optimization

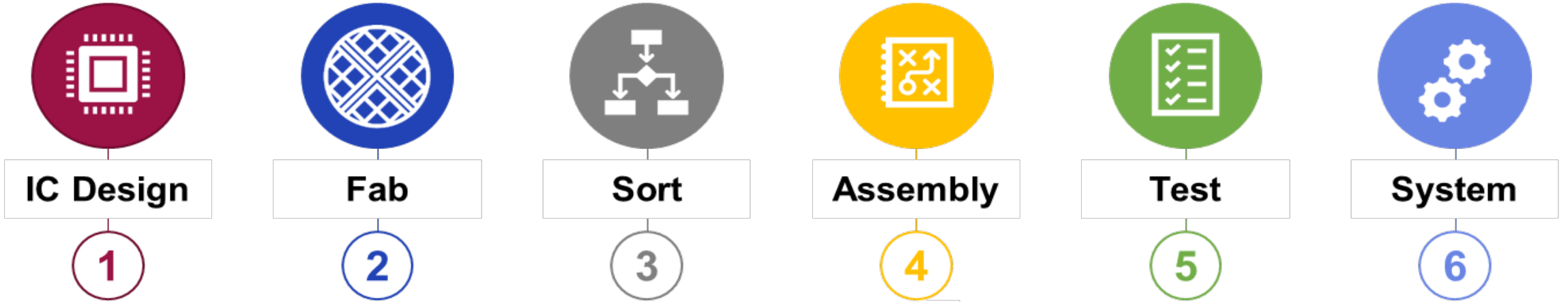


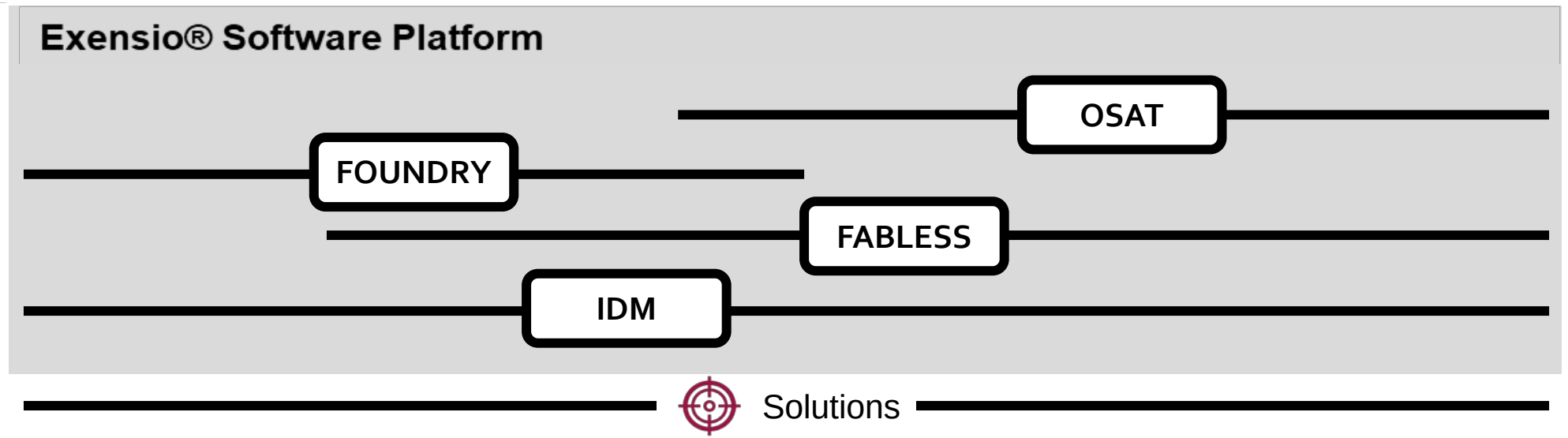
- Multi-step learning
- Multi-step adjustment
- Uses in-situ, upstream & historical data
- Human light, machine learning

Lower cost
Improved quality
Higher Yield

PDF is UNIQUELY Positioned to Deliver the Promise of AI to the Industry

PDF Solutions: Spanning the Supply Chain

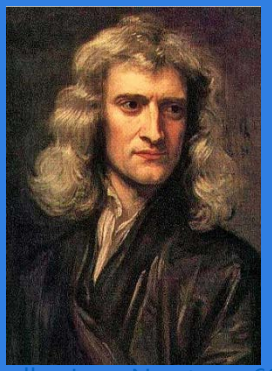




PDF Solutions: Spanning the Supply Chain

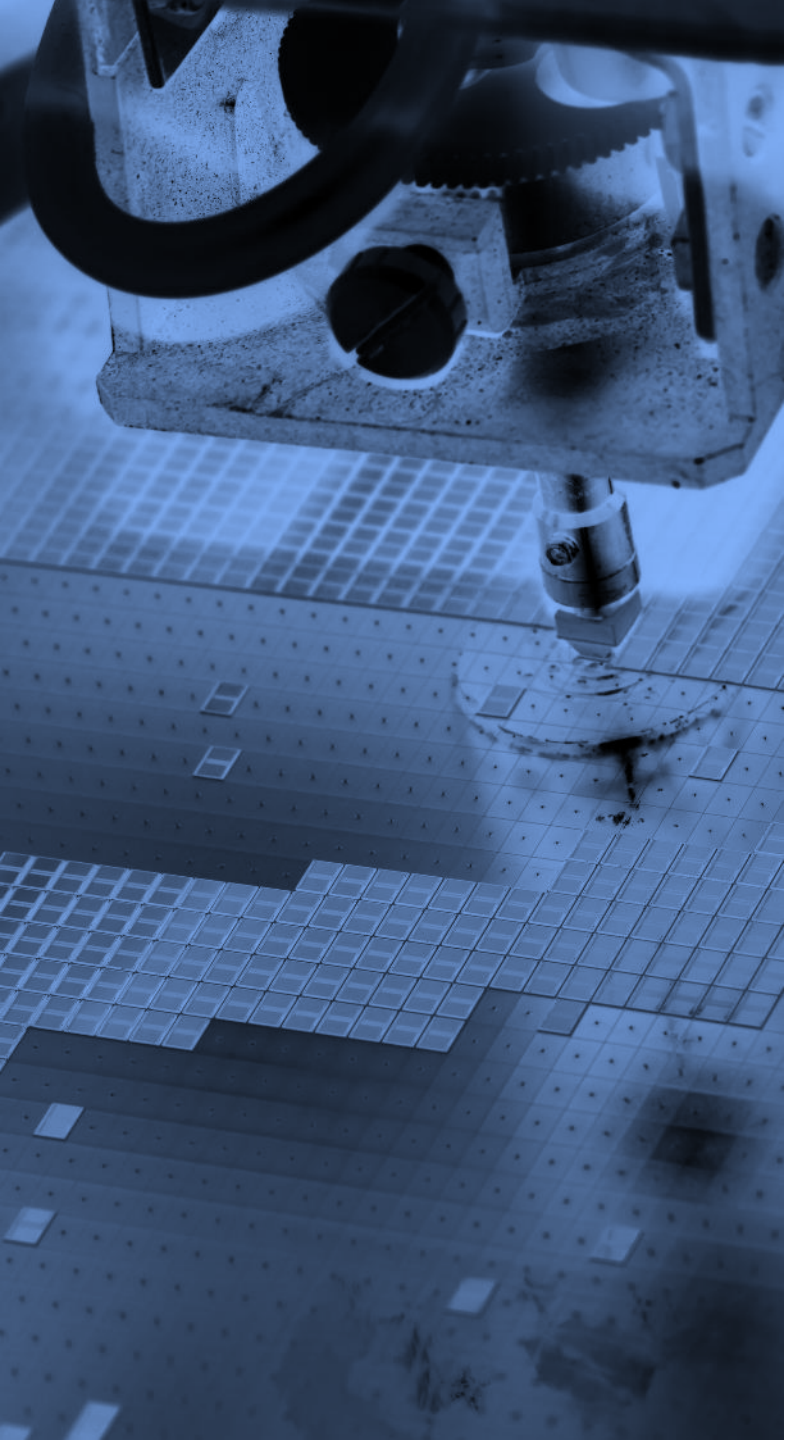
- ✓ PDF has access to the RIGHT data, including new types of data
- ✓ PDF has access to a breadth of data across the supply chain. PDF aligns this data to make it relevant.
- ✓ PDF has the infrastructure built up to integrate and leverage all of this data to deliver on the promise of AI
- ✓ "If I have seen further, it is by standing upon the shoulders of giants"

–Sir Isaac Newton



https://en.wikipedia.org/wiki/Isaac_Newton#/media/File:GodfreyKneller-IsaacNewton-1689.jpg

Solutions



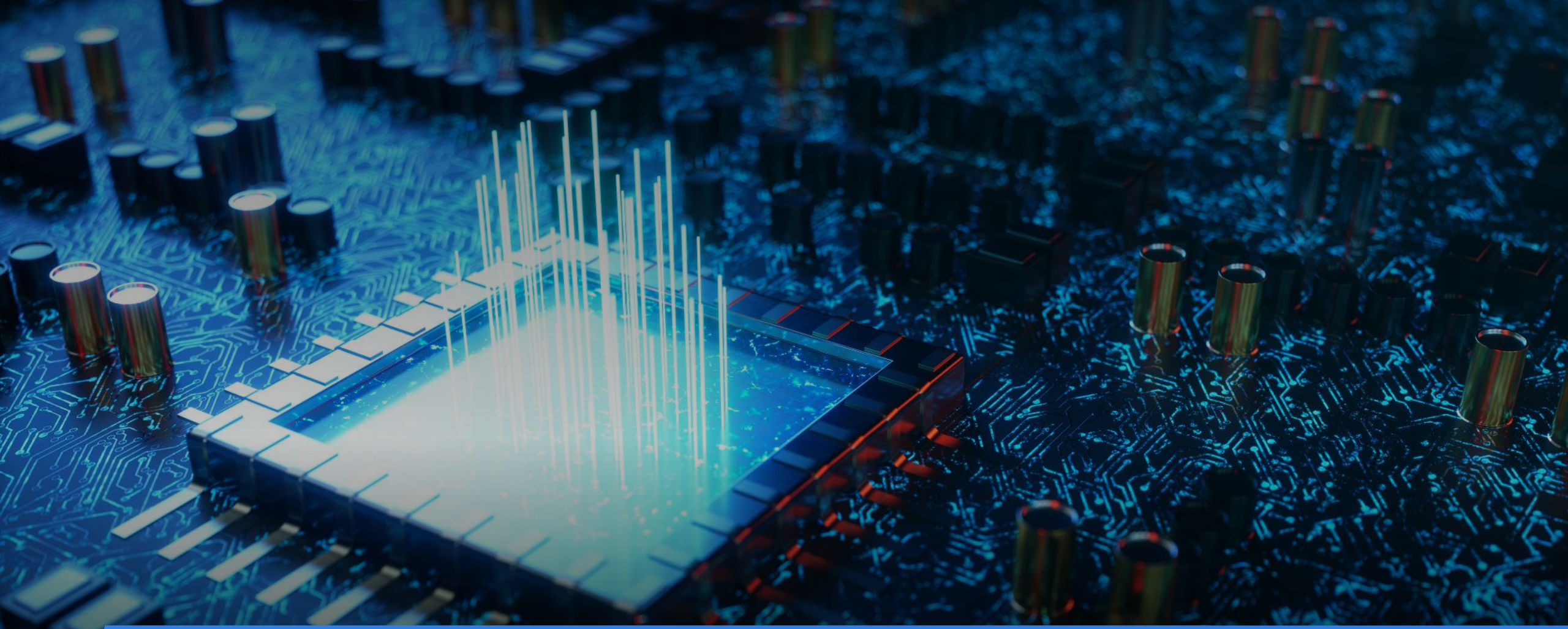
Semantic Models: A Key Element for Applying Machine Learning

- The semantic data model is a method of structuring data in order to represent it in a specific logical way. It is a conceptual data model that includes semantic information that adds a basic meaning to the data and the relationships that lie between them.

  https://www.techopedia.com/definition/30489/semantic-data-model

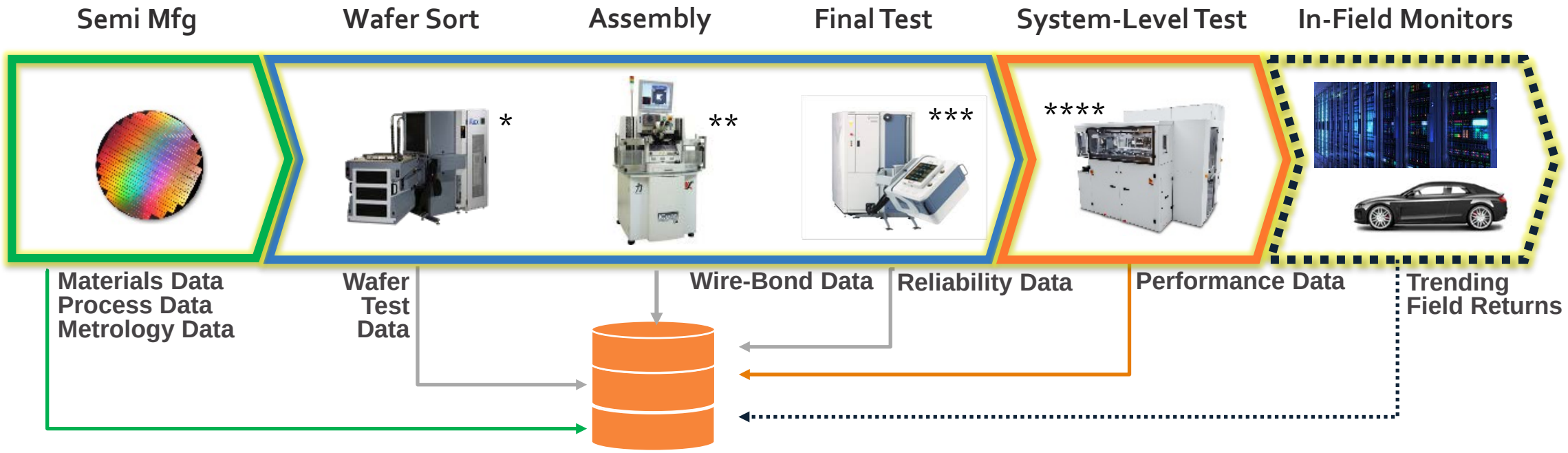
- Examples:
  - Aligning events in a fab with wafer data to answer question like "which wafers were processed with the new batch of resist"?
  - Mapping equipment signals across a fleet of tools to account for configuration differences
  - Meaningful merging of chip data as the chips flow through wafer sort, assembly, and final test

Semantic models allow our customers to deploy machine learning to production



Augmenting Analytics with ML to Improve Results and Make it Easier to Use

A Unified View of Semiconductor Data is Needed



Wafer-level grading and disposition

Test reduction and adaptation

Die quality and RMA prediction

Virtual metrology

Yield prediction

Predictive maintenance

Fault detection and classification

Capacity and efficiency improvement

* Teradyne UltraFLEX
** KnS Iconn
*** Advantest V93000
**** Astronics ATS 5034

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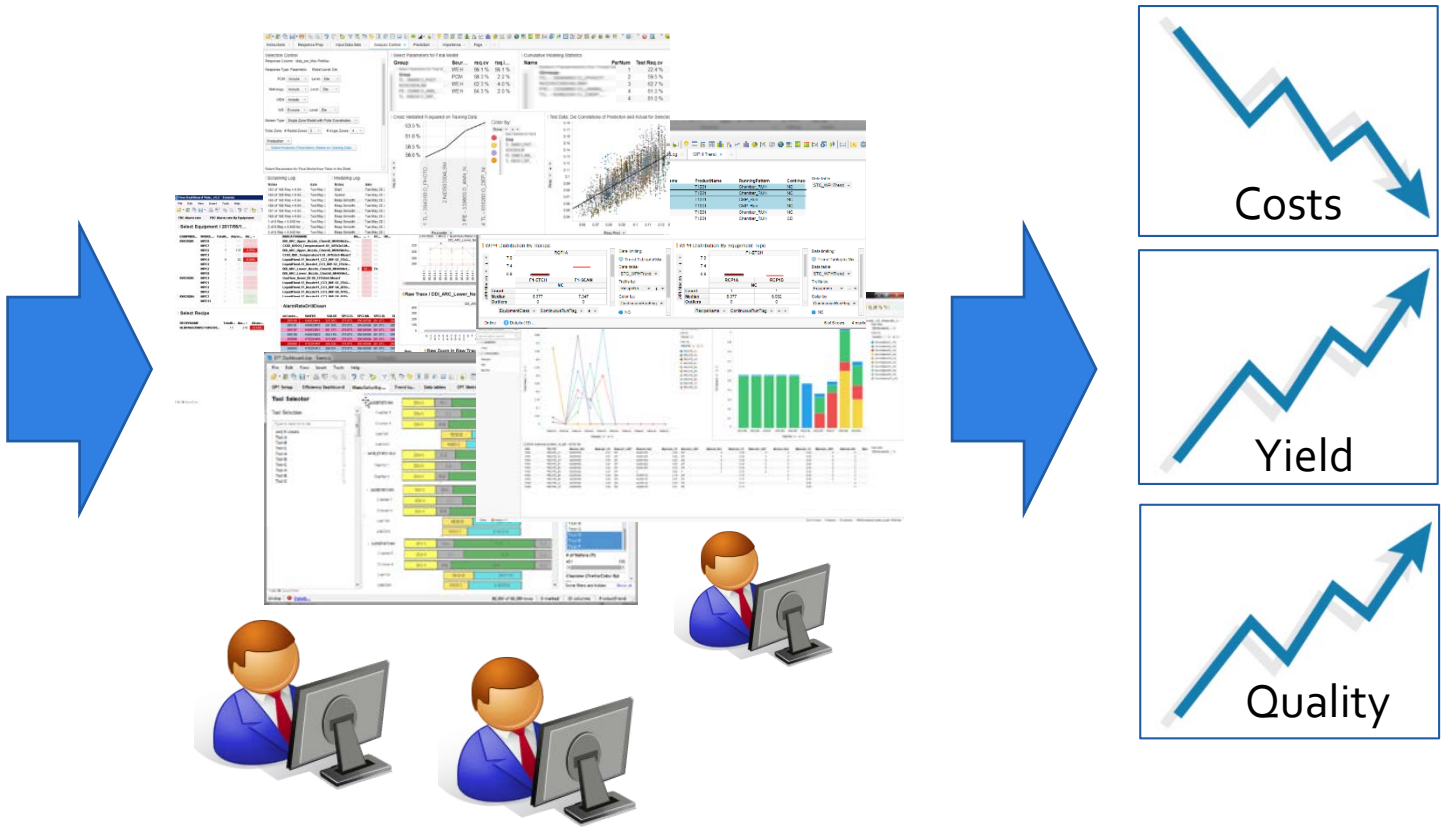
Lots of Great Modules in Exensio® that Incorporate 20 Years of PDF Expertise, but Requires all the Right Skills to get the Needed Results

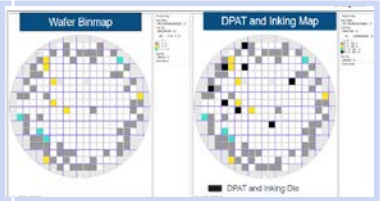
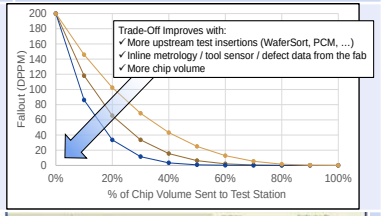
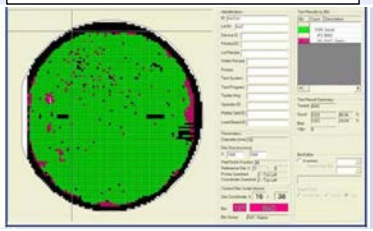
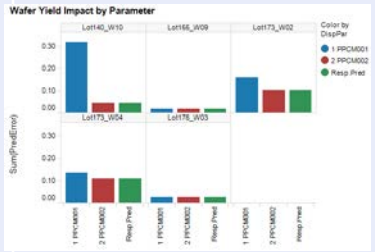
EXENSIO®
Modules

- Rule Ensemble Engine (REE)
- Spatial Signature Analysis (SSA)
- Fail Signature Detection and Analysis (FSDA)
- Product Sensitivity Analysis (PSA)
- Parameter Screening Report (PSR)
- Indicator Screening Report (ISR)
- Automatic Spatial Classification (ASC)

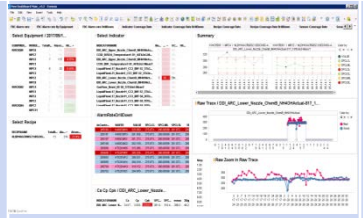


Results require Data Science expertise and understanding of semiconductor manufacturing

AIM Solutions Overview (Fabless/IDM)

Solution	Description	ROI
1. **IMD** – Intelligent Material Disposition (aka MRB)		Wafer level grading & disposition with near real time execution	✓ Reduce engineering disposition time by > 50% ✓ Improves quality of disposition
2. **ST** - Smart Testing – Predict Final Test & Burn-in		Prediction of test requirements based on electrical wafer Sort parametrics	✓ Reduce test or burn-in requirements by 20-60%
3. **ELF** – Early Life Failure detection (die level MRB)		Comprehensive Die Quality Grading - Classify risk based on Sort parametrics	✓ Prevent quality and reliability escapes by detecting high risk die at Sort
4. **FPM** – Fab & Final Test Predictive Modeling		Predict wafer and die level yield & parametric prior to Sort & Final Test operations (or other responses).	✓ Improved inventory management ✓ Reduce yield loss & excursions ✓ Reduces engineering investigative resource

AIM Solutions Overview (Foundry/IDM)

Solution		Description	ROI
5. **FDC –** Fault Detection and Classification		FDC to YMS AI modeling & prediction for yield variability reduction & control plan upgrade	✓ 8% Yield Improvement ✓ 40% excursion reduction ✓ 7% Faster NPI Ramp Learning Rate
6. **CEI** – Capacity & Efficiency Improvement (aka OEE)		Improve OEE, Fab Capacity, & wafer through-put by matching tools & chamber operations	✓ 10% improvement in bottleneck tool capacity ✓ >20% improvement in efficiency (thru-put)
7. **ASD** – Adaptive Signature Diagnostics (Smart Analysis)		Uses spatial signature analysis, ML, to classify Sort failures and auto-diagnose likely root cause of yield loss	✓ Identify sources of yield loss immediately after Sort. ✓ 5x Reduction in engineering investigative resources.
8. **TEP** – Trace based Excursion Prevention		Use AI to identify abnormal tool operation via text log & raw FDC sensor trace data	✓ Prevent large scale excursions at the tool through trouble prevention

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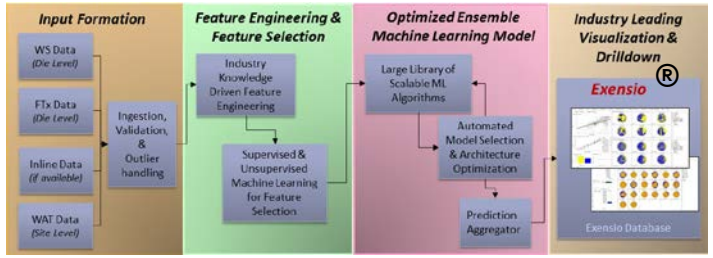
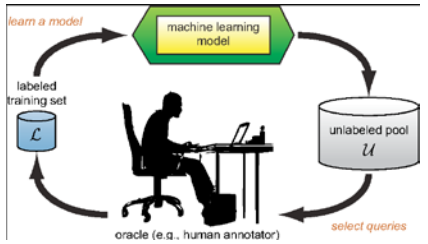
AIM Solutions with AI Makes it Easier to Obtain Optimal Results

EXENSIO®
AIM SOLUTIONS

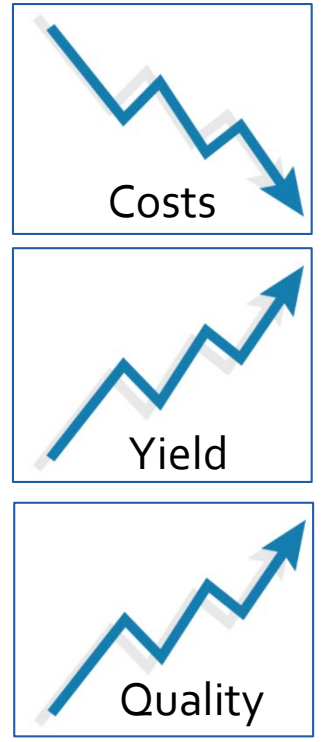
- Intelligent Material Disposition (IMD)
- Smart Testing (ST)
- Early Life Failure Prediction (ELF)
- Fab Predictive Modeling (FPM)
- Fault Detection and Classification (FDC)
- Capacity & Efficiency Improvement (CEI)
- Adaptive Signature Diagnostics (ASD)
- Trace-based Excursion Prevention (TEP)

ML Pipeline





Collaborative Learning



AIM Solutions with AI Makes it Easier to Obtain Optimal Results

EXENSIO®
AIM SOLUTIONS

- Intelligent Material Disposition (IMD)
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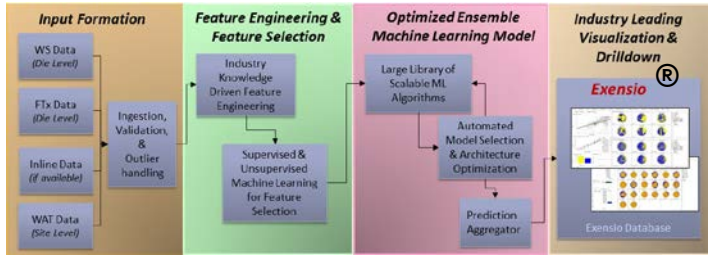
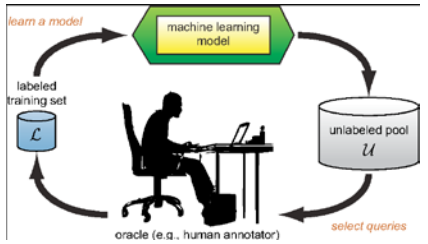
ML Pipeline





Collaborative Learning

- ✓ ***Human light, Better results***
- ✓ ***Data Science enabled in the tool – you don't have to be a data scientist to set it up or maintain it***
- ✓ ***1000's of virtual experts – enabled by AI***

With AI, 20 years of PDF expertise is applied in more productive ways

Augmenting Analytics with ML to Make it Easier to Use and Deploy

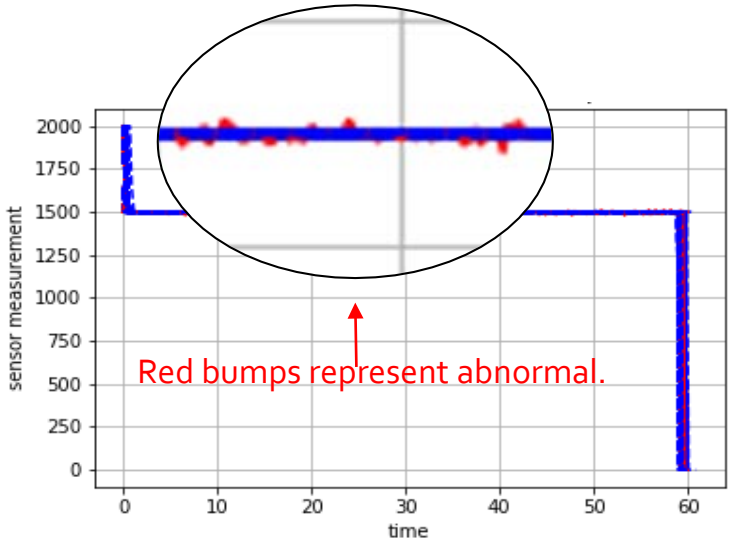
- ***Our systems make it easy for our customers to incorporate their knowledge to improve performance***
  - Allow customer to deploy their own models
  - Allow user to implement their own feature engineering and transformation
  - Collaborative Learning – scalable across different use cases and datasets
    - Provides capability such that you don't need to be a semi expert and data scientist
    - Includes our customer knowledge in the training and refinement of the models.

- ***Using ML, we automate the work performed by our customers for their use cases***
  - ETL – Dynamic Schema
  - Automatic model training designed to be insensitive to product/tool type
  - Allow users to choose models to deploy based on confusion matrix response
  - *Aside:* we want to be careful how many knobs we add as this dilutes the automated nature of the model training

FDC – RESULTS on Large Volume of Production Wafers Across Multiple Process Steps

Process Step	True Positive Rate (actual = normal, prediction = normal)	True Negative Rate (actual = abnormal, prediction = abnormal)
Process Step 1	100.00%	100.00%
Process Step 2	99.82%	99.90%
Process Step 3	97.12%	99.38%
Process Step 4	99.86%	99.23%

- ❑ **Single Machine Learning Pipeline produced accurate model for multiple processes**
- ❑ **No user modification of algorithm settings from process to process**
- ❑ **Many tools and recipes per process step**
- ❑ **Test results on a large volume of advanced device node production wafers**



- ✓ **Data Science enabled in the tool – you don't have to be a data scientist to set it up or maintain it**
- ✓ **1000's of virtual experts – enabled by AI**
- ✓ **Better IP security – distributed knowledge remains in the tool itself**

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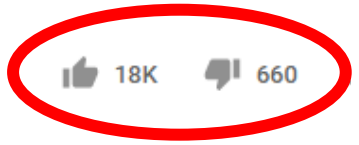
Collaborative Learning: Captures User Knowledge in the System

- Final report provides the user a way to assign a new class per wafer, and retrain the model
- Human interaction via Collaborative Learning allows the user to continually improve and validate wafer classifications, building user confidence in the system.

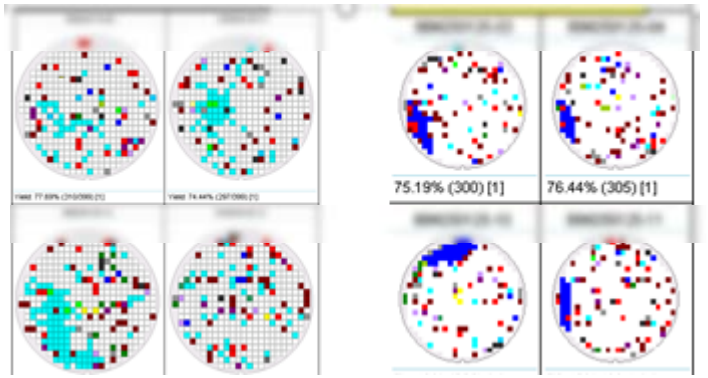


Similar to the "like" button

6 columns from MRBWaferTable

LOT	WAFER	Partial Wafers	RB Class	CL Class	User Class
		True	A	A	A
		True	A	A	A
		True	C	B	A
		True	A	B	Untagged
		True	B	B	B
		True	C	C	B
		False	A	C	C
		True	B	B	Untagged
		True	B	B	Untagged
		True	B	B	Untagged
		True	C	B	Untagged
		True	C	B	Untagged
		True	A	A	A
		True	C	A	A
		True	A	A	Untagged
		True	A	A	Untagged
		True	B	B	B
		True	B	B	A
		True	A	A	A
		True	C	C	A
		True	A	A	A
		True	C	C	A

The user can modify the classifications to continuously improve the model



Method	Hit Rate
Standard Statistics	58%
Fab Model (semantic model)	71%
Collaborative Learning	91%

You don't need to be a data scientist or know statistics to use AI

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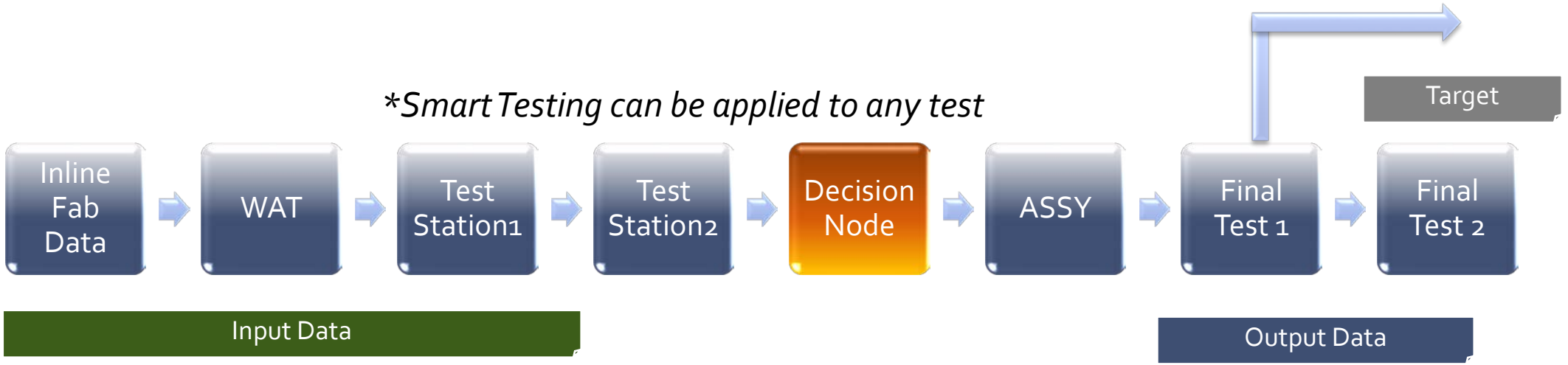
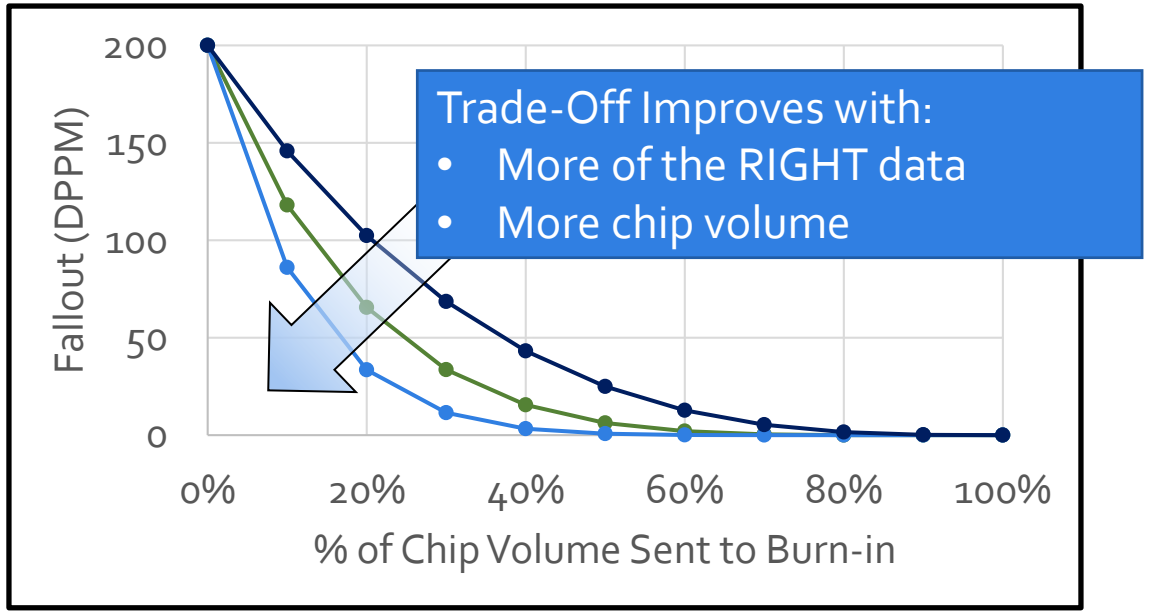
Smart Testing

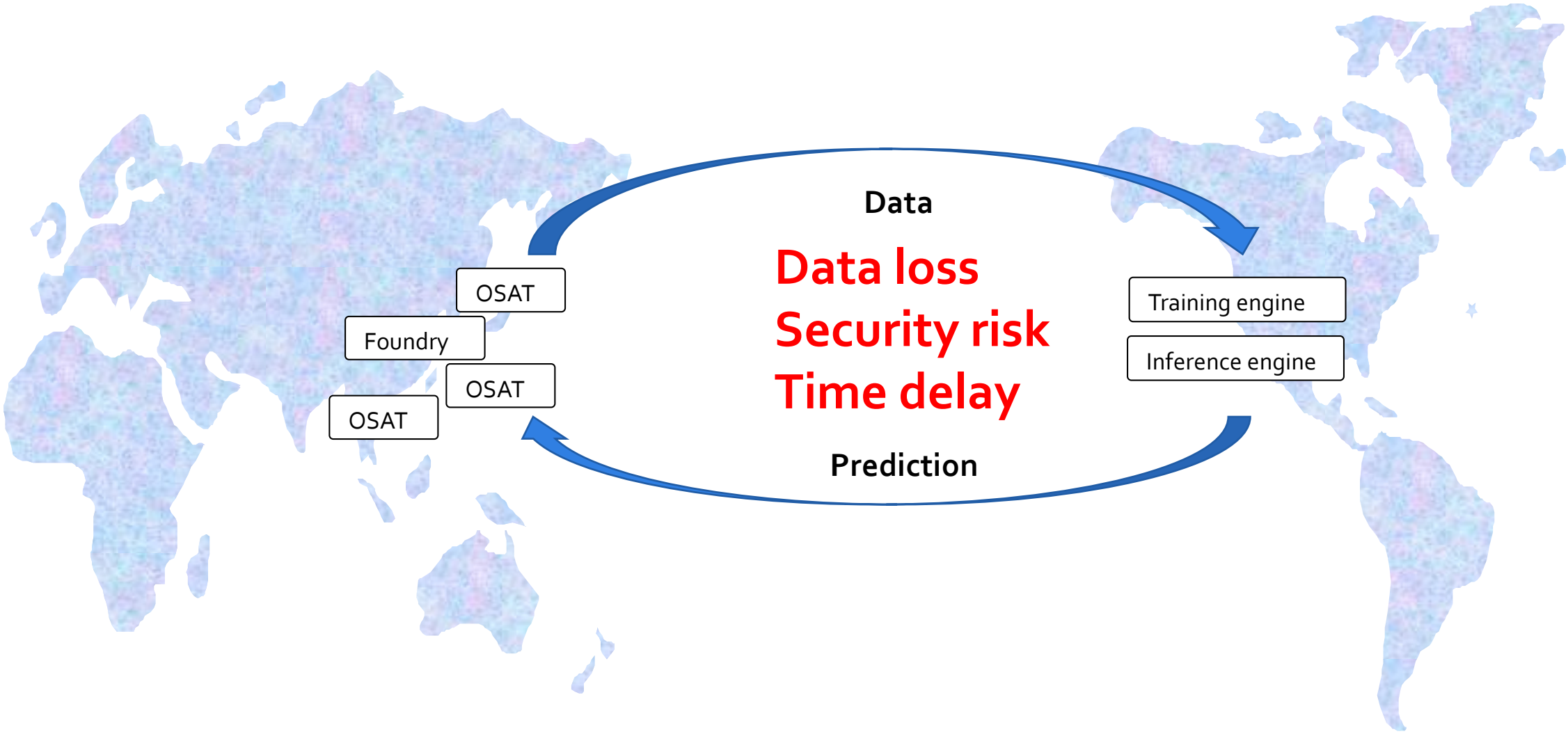
**Smart Testing can be applied to any test*



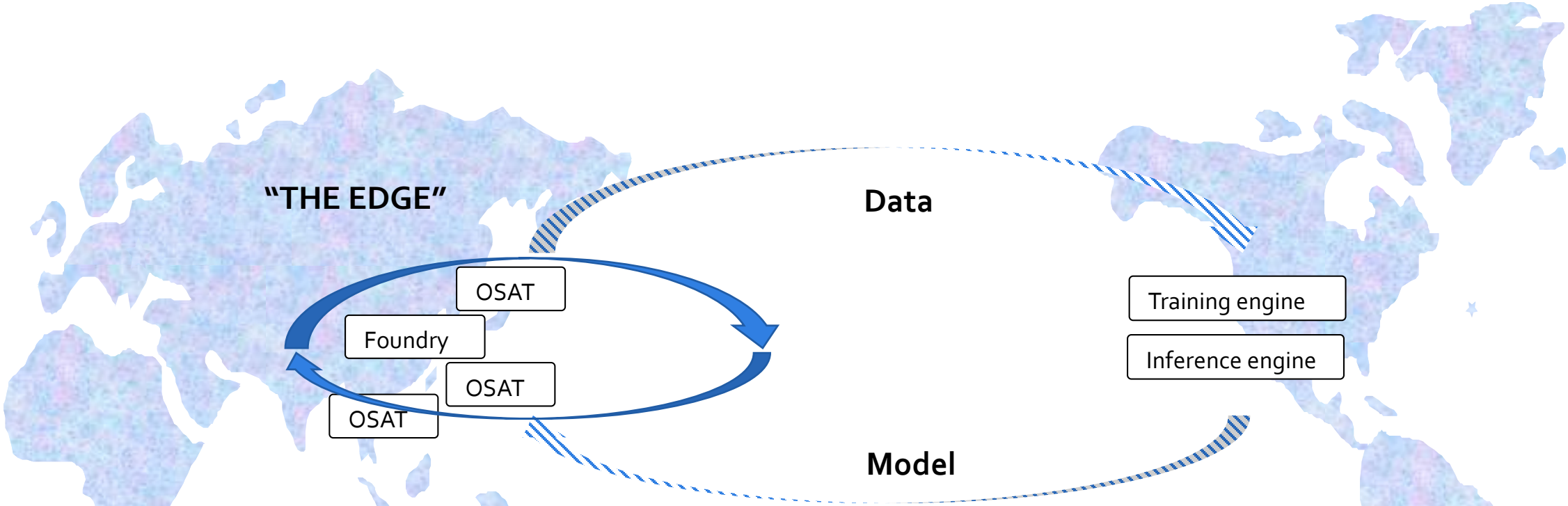
- Goal: No risky chips to field, while diverting chips from expensive tests
- Goal: Improve quality and reliability by quickly identifying the root cause of field returns
- Goal: Focus test resources on product that are at the highest risk for failure
- Goal: Reduce test cost by diverting low-risk product volume away from expensive tests
- Goal: Smarter product binning by quality



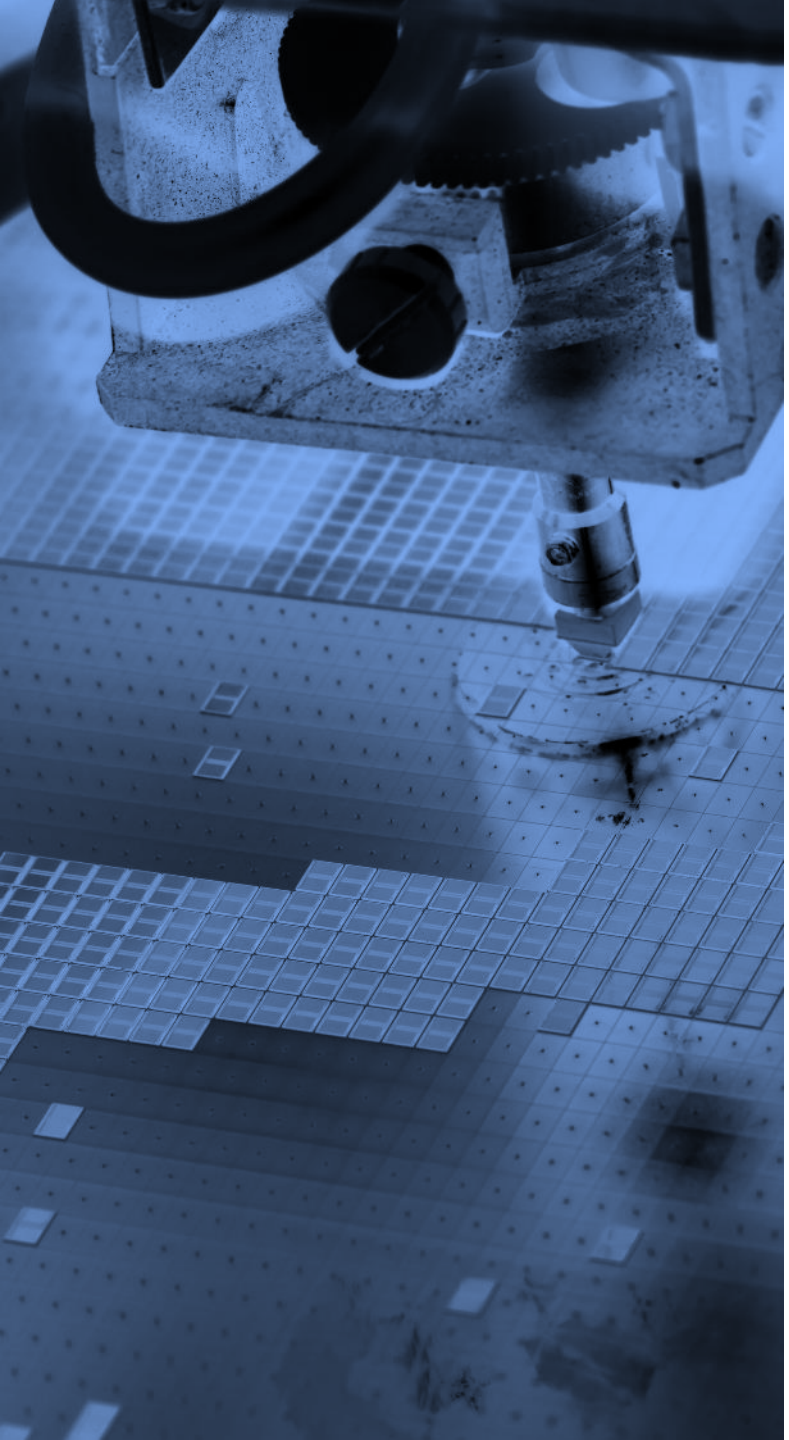
Deployment Challenges



DEX™ Enables Edge Deployment Architecture

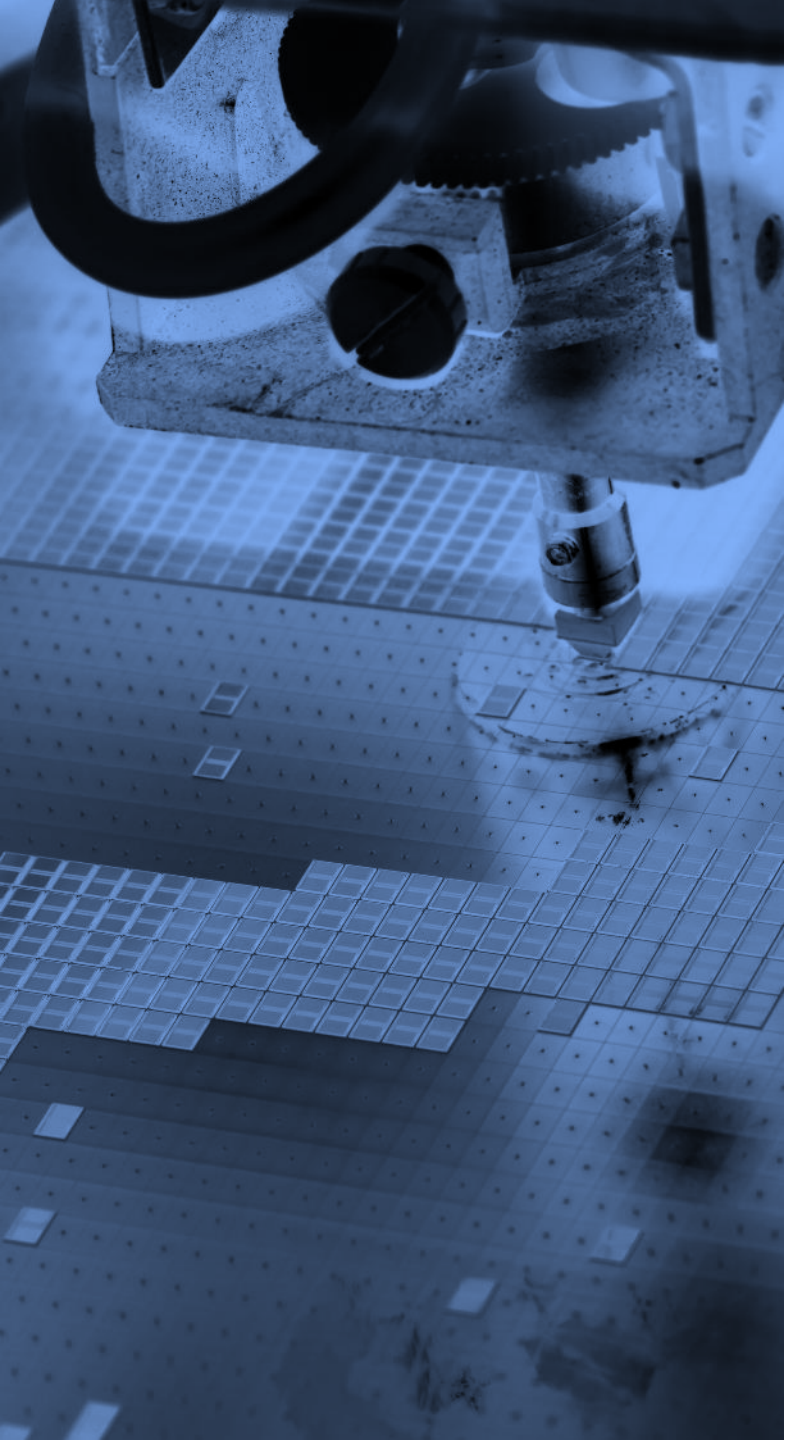


- ✓ **Edge Analytics – fast turnaround times on predictions, making ACTIONABLE predictions a reality**
- ✓ **Reduced data loss**
- ✓ **Brings advanced ML capabilities to Adaptive Testing**
- ✓ **Allows user to develop their own models using latest ML technologies**



Overall Benefits

- Access to a breadth of data, and access to the RIGHT data
- Infrastructure already built up across the supply chain
- Data Science enabled in the tool – you don't have to be a data scientist to set it up or maintain it
- Our systems are designed to make it easy for our customers to incorporate their knowledge to improve performance
- We leverage state-of-the-art AI technologies intended to bring significant ROI to our customers
- Architected for production-worthiness



In Summation…

- The semiconductor industry has been slower to adopt AI technologies than other industries
- Given those challenges, PDF is **UNIQUELY** positioned to deliver the promise of AI to the industry
- PDF's goal is to make it easier to adopt AI – you don't need to be a data scientist
- …the AI enablement provided by PDF is targeted to bring significant value to our customers

Thank You

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