PDF SOLUTIONS™

2023 PDF Users Conference:

AI for tomorrow's manufacturing and R&D

Santa Clara Marriott - 2700 Mission College Boulevard Santa Clara, California 95054 USA

Innovation Focus in Advanced Solutions

24th October 2023

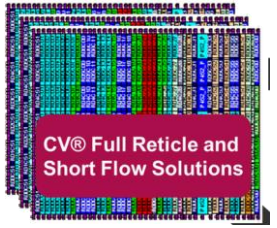
Advanced Solutions Group

PDF's vision and Mission

- **Vision:** To be the world's leading data and analytics platform spans the semiconductor and electronics ecosystems.
- **Mission:** Provide innovative solutions to create, access, and organize data to enable analysis and control for semiconductor and electronics companies to achieve better time-to-market, yields, quality, and operational efficiencies.

Advanced Solutions Group

- ASG develops new methods, tools, and applications to support PDF's vision
- Example innovations from ASG:



Innovation Focus in Advanced Solutions

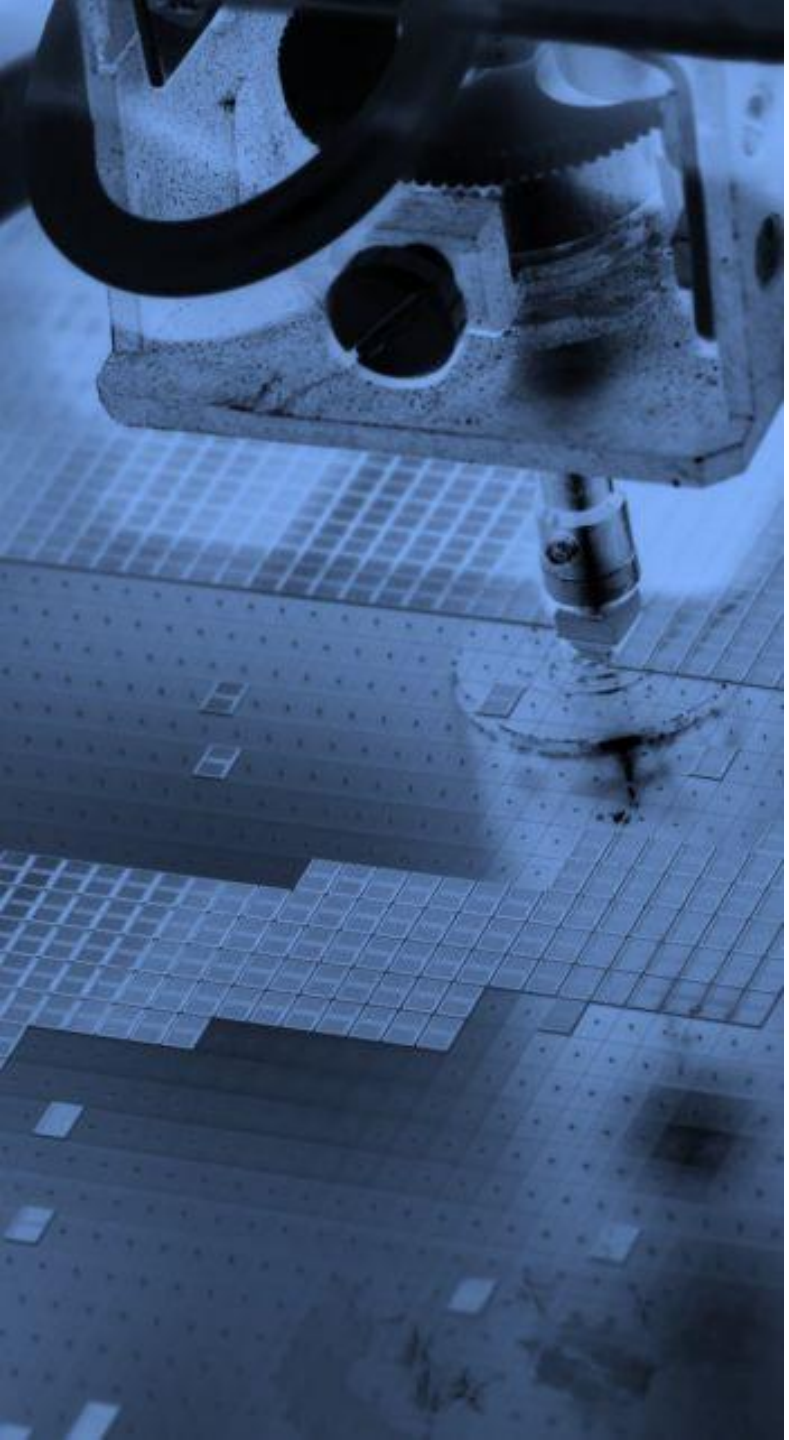
- **Using AI to connect Design, Test, and Analytics (DTA)**

  How to use design information to better drive test and yield diagnostics in Exensio? We are working on various AI algorithm to connect design to test and then to yield diagnostics, especially to address systematic fail modes.

- **Our Generative AI: Generation of unique observation with help of AI**

  It is getting harder to "see" various fail modes in advanced nodes. We use AI to assist the design and measurement of some PDF unique elements to characterization of process & product that are hard to observe by traditional approach. Examples include LLE DOE, CV Core, and dScan-by-FIRE.

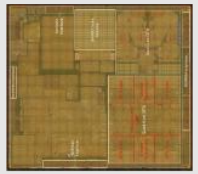
**** Contents include a combination of existing solutions and future roadmap items***



Using AI to connect Design, Test, and Analytics (DTA)

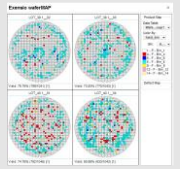
How to use design information to better drive test and yield diagnostics in Exensio? We are working on various AI algorithm to connect design to test and then to yield diagnostics, especially to address systematic fail modes.

2023-2024 R&D Roadmap to Connect Design – Test – Analytics



Design

WAT, WS Assembly, FT



Product Yield

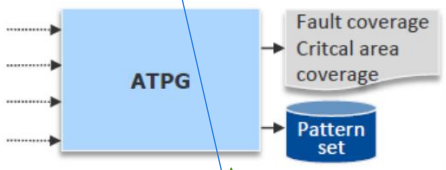
Connect Multiple Products With PLM

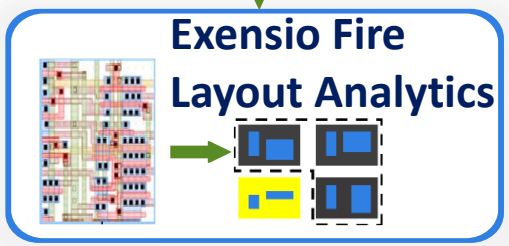
PLM

Exensio Manufacturing Analytics

“Tag” IPs Across Products

Use “DNA” Of Systematic Fail Mode to Optimize Test





Smart Organization of ATPG Test Vector

Exensio Test Ops

See Separate Sessions

Exensio AI Training Engine

Test operations with ModelOps

Released For Deployment

Fabless/IDM

- Multiple Designs
- Multiple Processes
- Multiple Foundries

Exensio®

- End-to-end Analytics With AI/ML And Big Data Technologies
- Automated Analysis
- Direct Tool Control
- Supply Chain Traceability

Tessent®

- Product Specific Root Cause
- Systematic Yield Limiters
- RCD Statistical Analysis Of Diagnosis

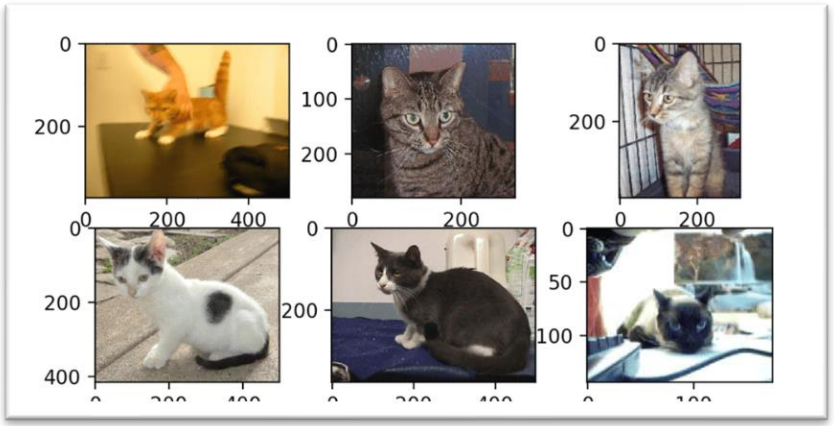
Tessent + Exensio Scan Diagnostic Integrated Solution

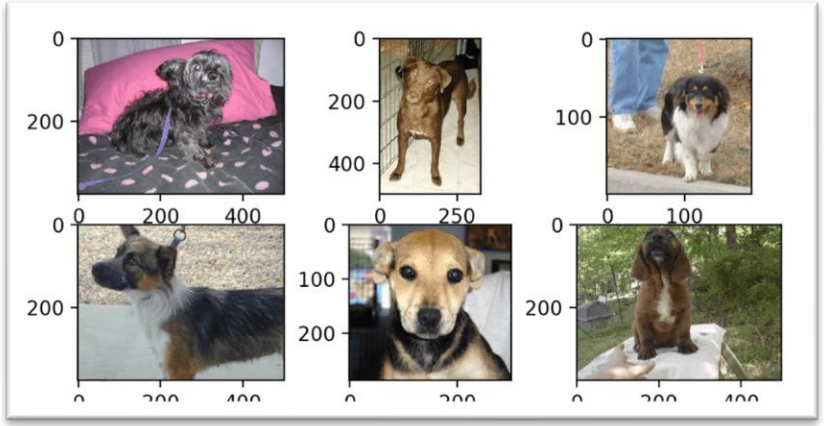
PDF SOLUTIONS™

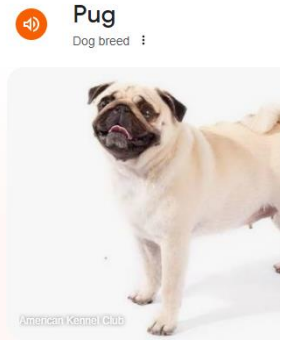
Exensio FIRE Software: Fuzzy Pattern AI

- A given systematic fail mode usually comes from, not one, but a “family” of layout configurations. Traditional rule-based approach is insufficient for the evolving complexity of product design at advanced nodes

- Using fuzzy pattern classification algorithm, PDF’s Exensio FIRE software automatically groups all similar patterns of same fail mode into a “pattern family”.







“How to Classify Photos of Dogs and Cats (with 97% accuracy)“
-- machinelearningmastery.com

PDF Solutions and Siemens EDA accelerating yield

See Siemens technical presentation on Day 2 afternoon

Siemens EDA's Tessent Diagnosis/YieldInsight

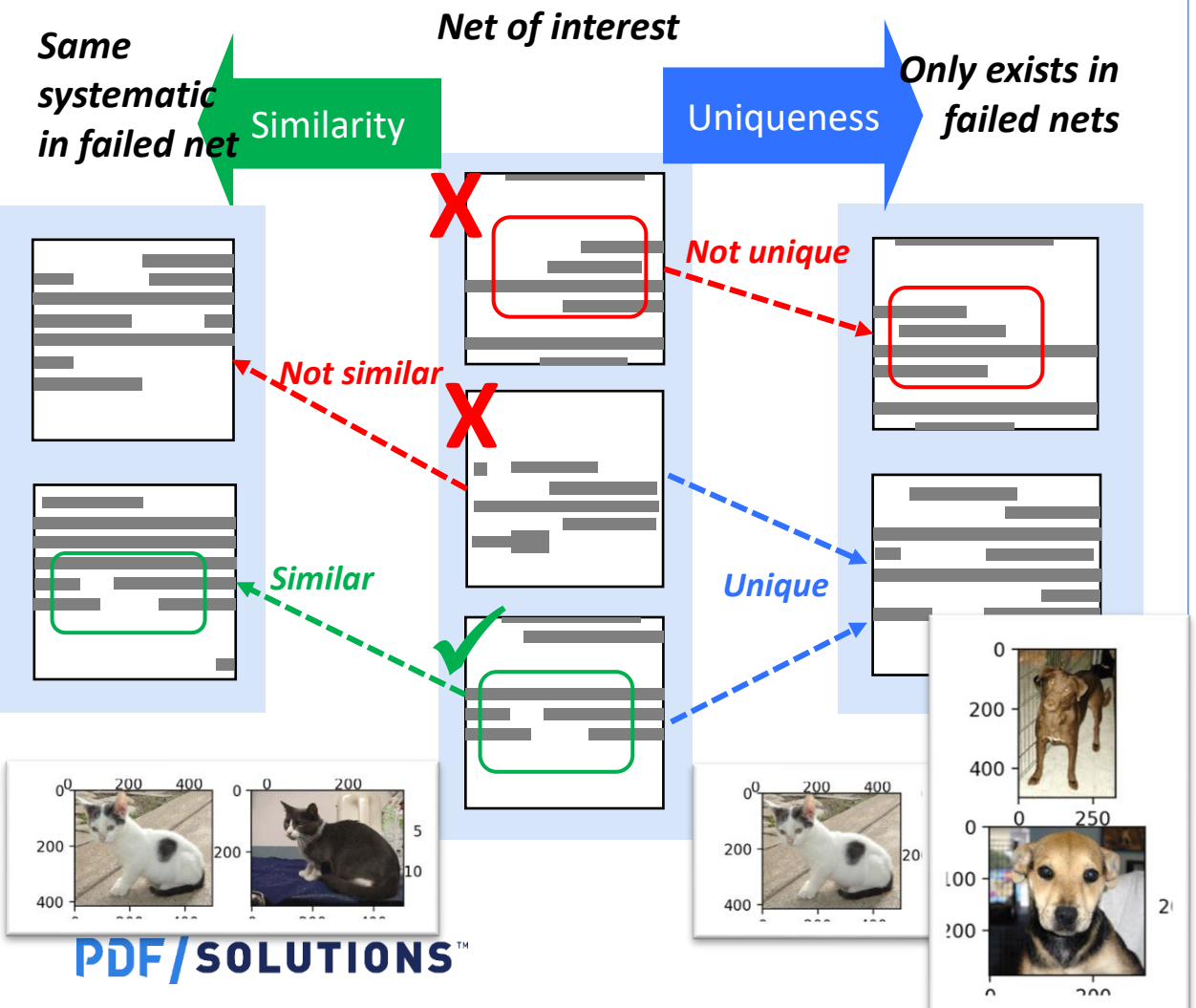
+

PDF's Exensio/FIRE

enabling diagnosis of systematic yield loss

Tessent and Exensio/FIRE working together

Approach: *Similarity vs Uniqueness*

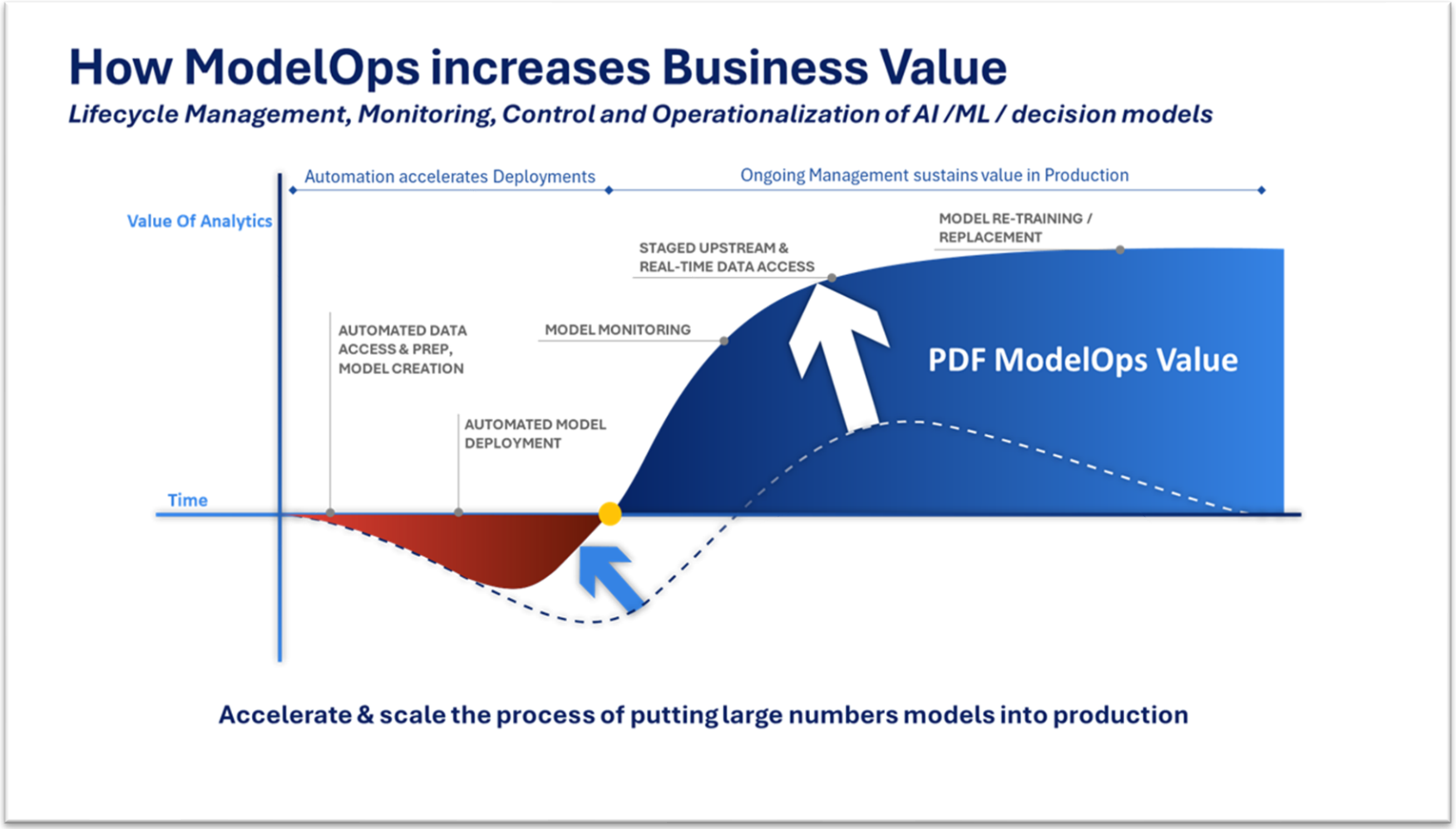


Customer Benefit

For a product in production at advanced node:

- **7x improvement in inspection and/or PFA efficiency**
- **By identifying root causes for ~90% of measured failure**
- **Coming from lower layer and upper layer metals**

ModelOps and Edge Inference for Test



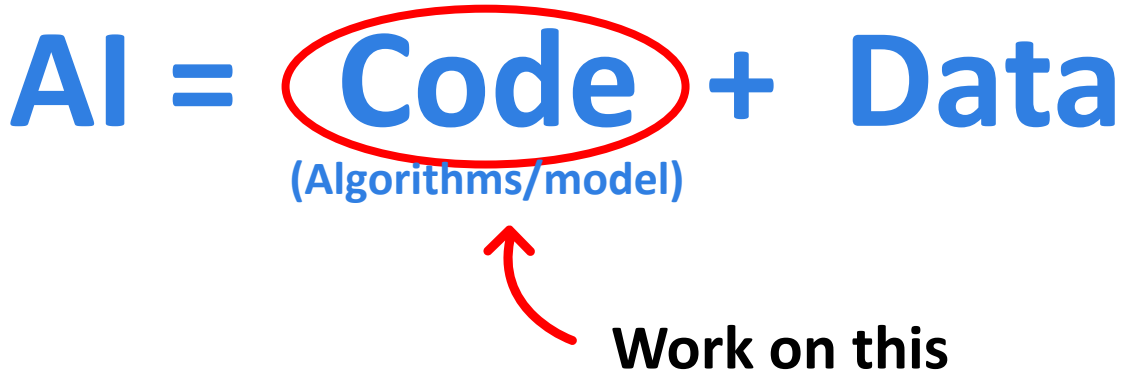
Day 2

Technical Presentations

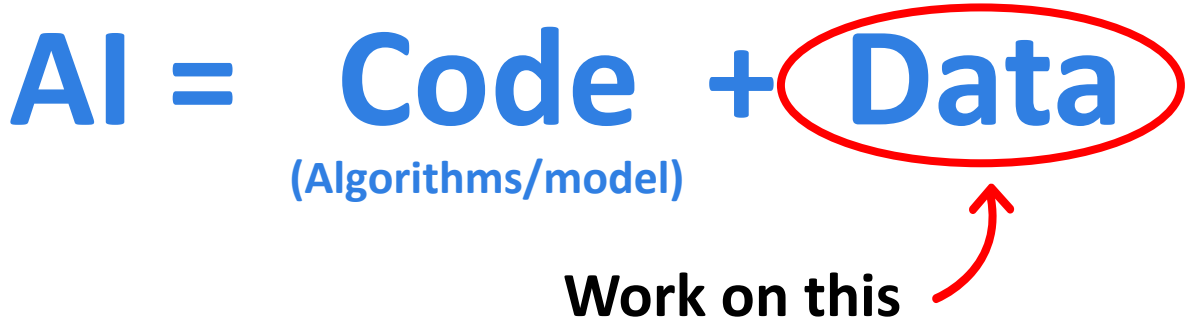
- **Operationalizing and Scaling AI/ML for the Semiconductor Industry, by Jeff David**
- **Edge Inference for Test, by Greg Prewitt**

Shifting from Model-Centric to Data-Centric AI

- **Conventional model-centric approach:**



- **Data-centric approach:**



Credit: **Andrew Ng**, NeurIPS Workshop, Data Centric AI, December 2021

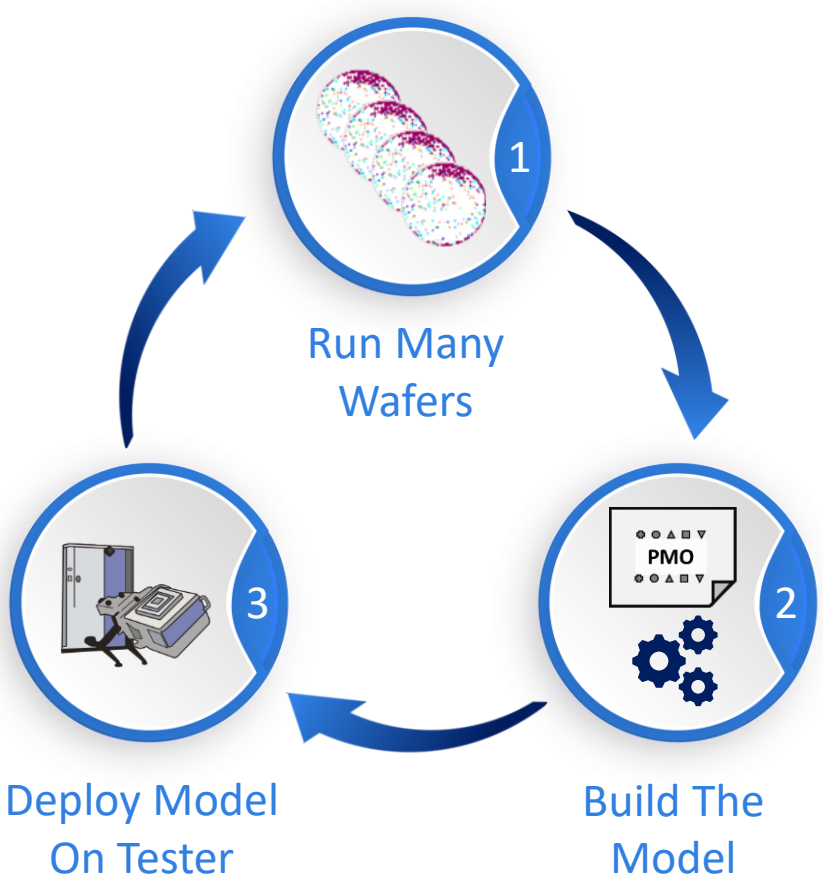
Example of data movement for a model for Final Test:

- Data from Fab
- DFF (Data Feed Forward) of outcome of fab predict model from above
- Data from wafer sort
- DFF of outcome of WS model from above
- (more complexity for multi-chip solution)

PDF's ModelOps pipeline takes care of the complex issues related to data collection, alignment, feature extraction, DFF, validation, corner event treatment, etc, and is integrated with facilities' MES.

AI/ML for Testing Optimization, but …

Current Approach



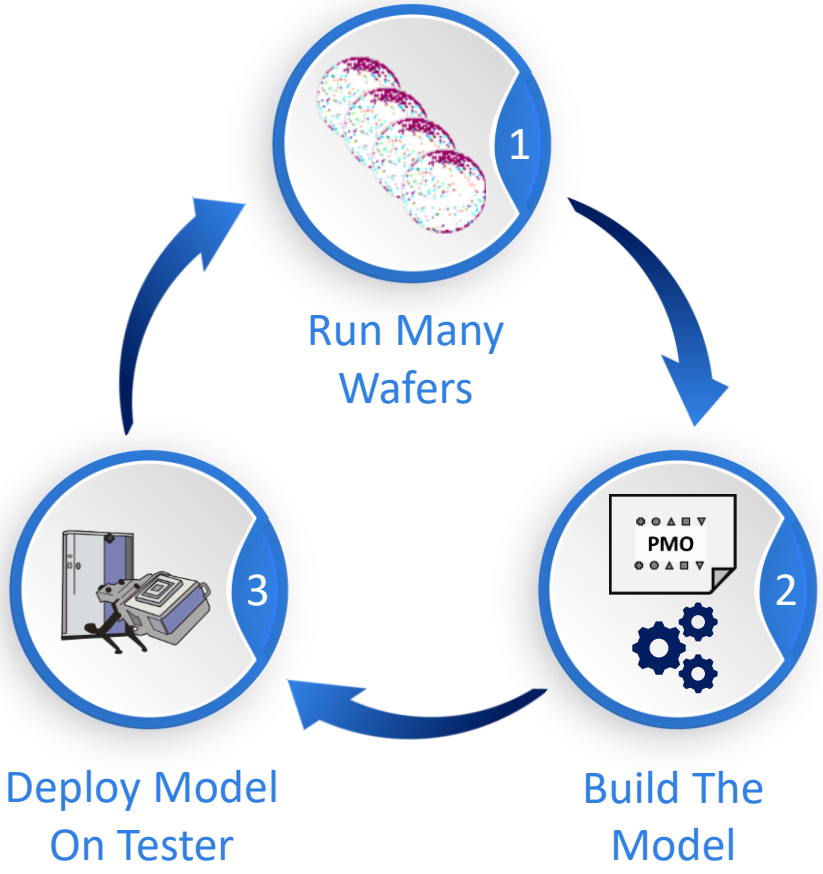
NEW

Goal

Achieve this **without** the training on large test result dataset.

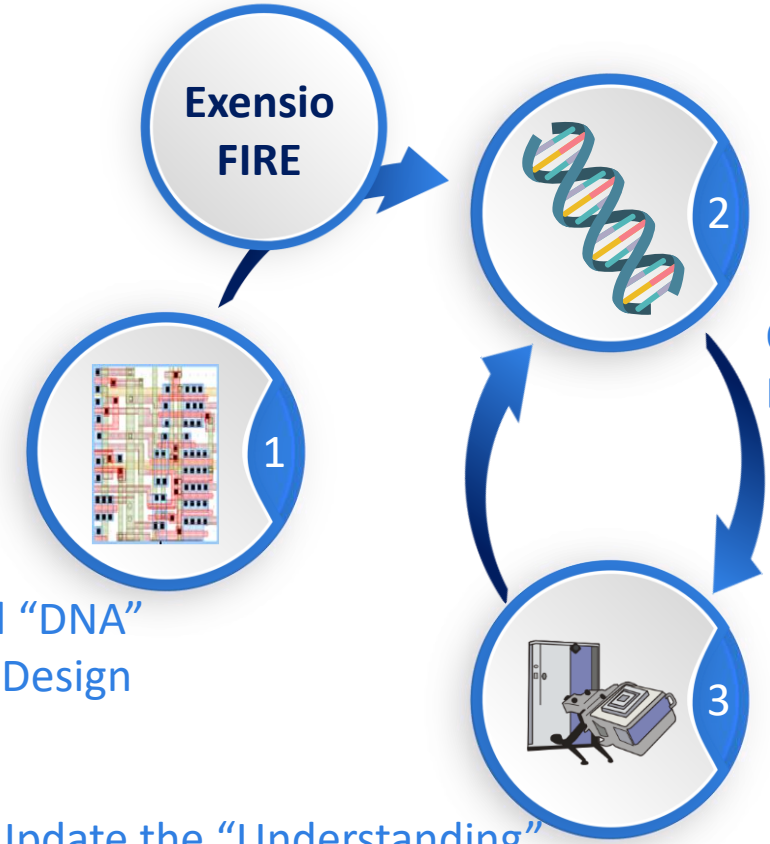
AI/ML for Testing Optimization, but …

Current Approach



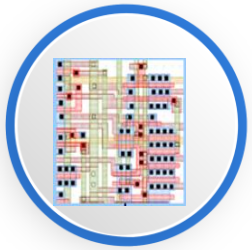
NEW

Use Information from Design

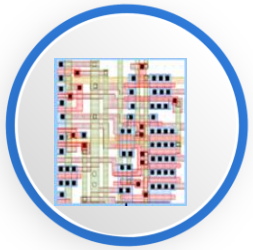


Dealing with Many Product Tape-outs

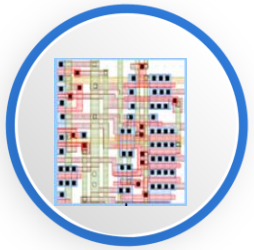
Product A



Product B



Product C



Problem

# of products > # of employees

Dealing with Many Product Tape-outs

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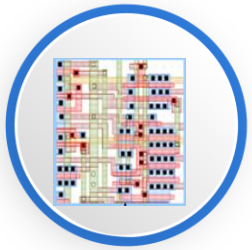

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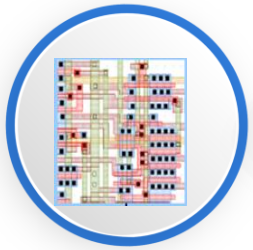

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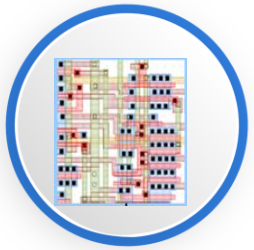

PLM
(With Partner)

Contains product attributes, such as list of IP used.

Exensio Manufacturing Analytics

- **Enable cross product applications**
  - E.g. identify common low yielding IP across products
  - E.g. common systematic yield loss across products
  - E.g. to update “importance” of each gene from existing product to new product introduction

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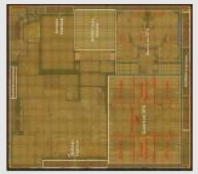

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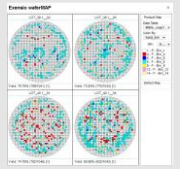

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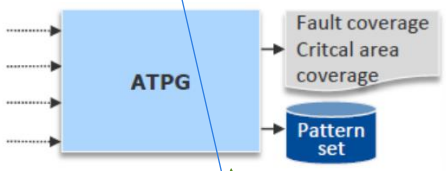

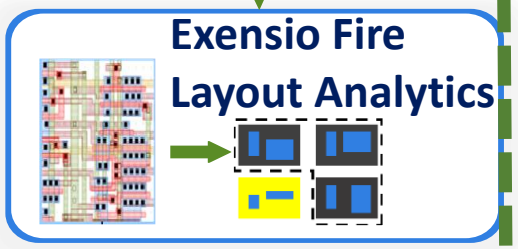

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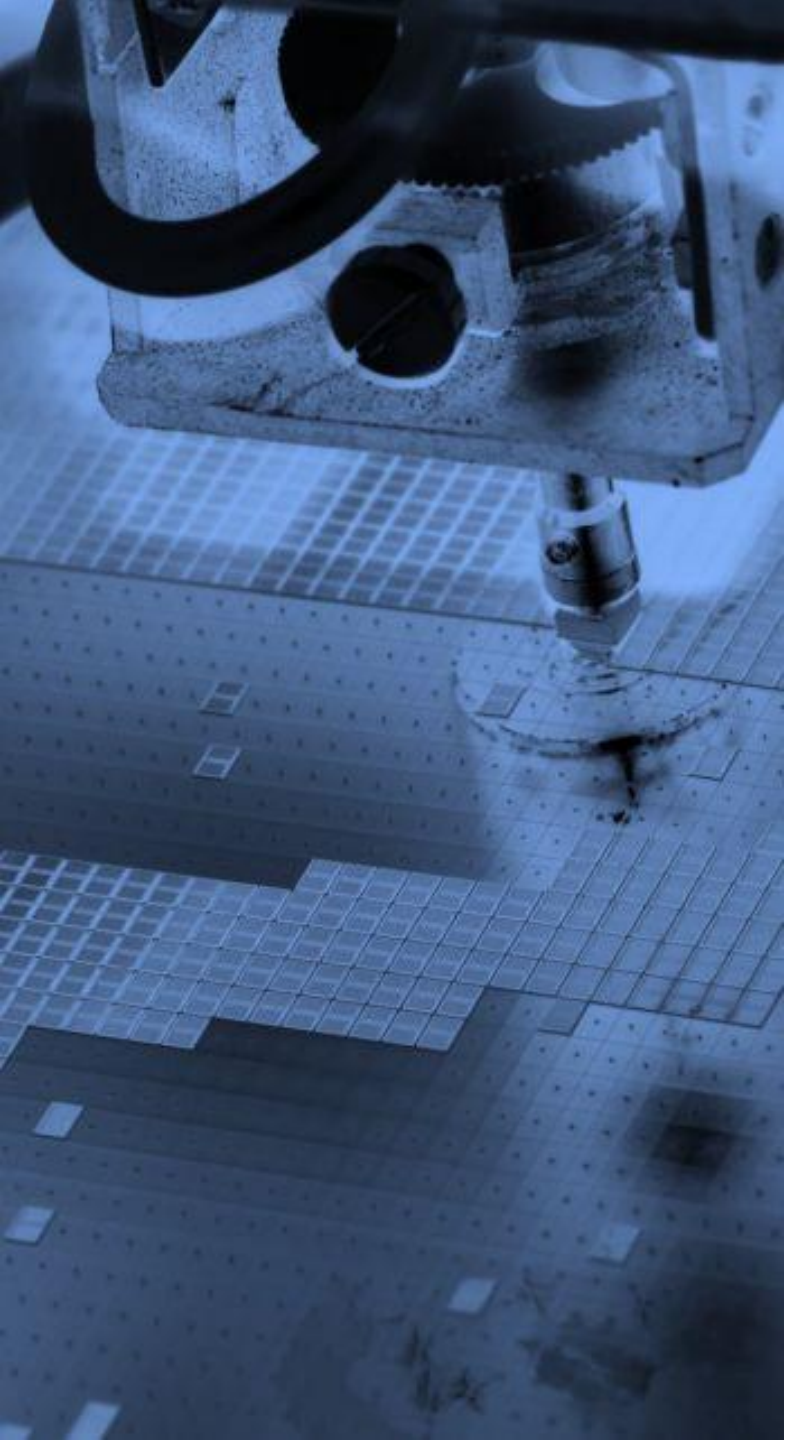
- Product Specific Root Cause
- Systematic Yield Limiters
- RCD Statistical Analysis Of Diagnosis

Tessent + Exensio Scan Diagnostic Integrated Solution

PDF/SOLUTIONS™



Our Generative AI: Generation of unique observation with help of AI

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Use Generative AI to Design CV TestChip: *LLE example*

- **Characterization of local layout effect is critical for products at advanced nodes.**

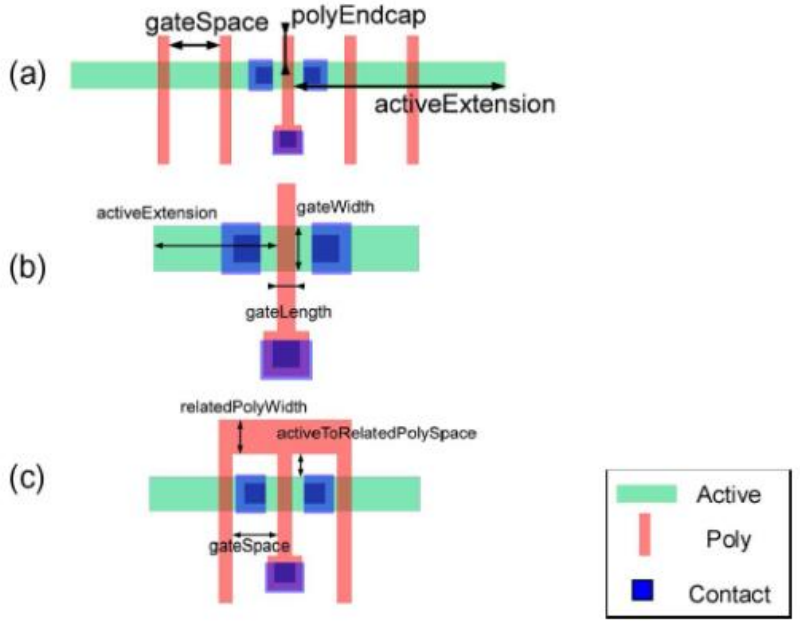
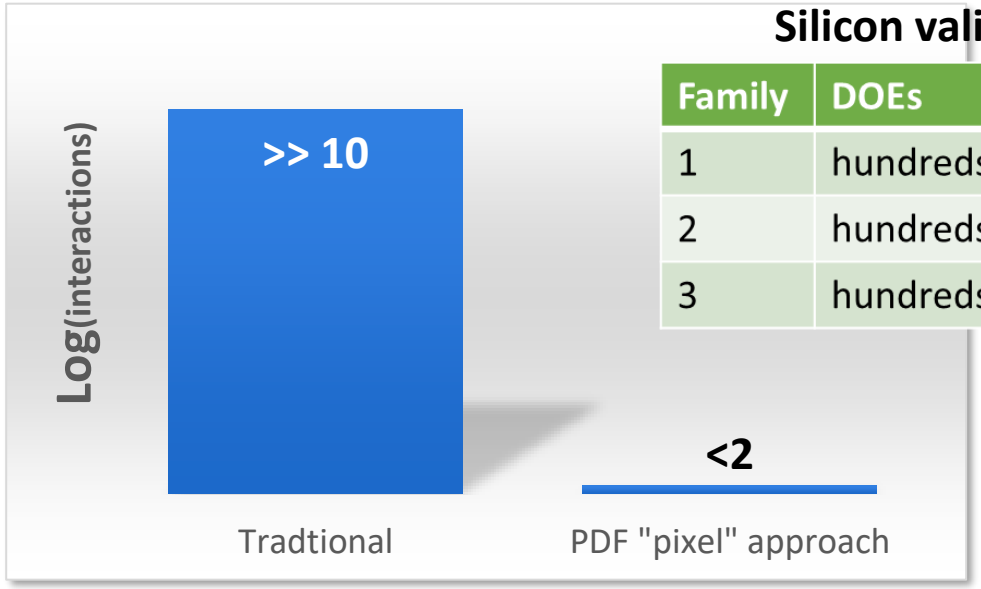


Fig. 5. Example layout patterns for characterizing layout effects: (a) Poly-pitch-induced variation due the to impact of lithography and stress, (b) active-extension-induced variation due to STI stress, and (c) gate-poly-shape-induced variation due to corner rounding.

Variation in Transistor Performance and Leakage in Nanometer-Scale Technologies; IEEE Transactions on Electron Devices, Vol. 55, No. 1, January 2008

- **Traditional approach requires more silicon area than physically possible to characterize all behavior.**
- **Using AI algorithm, PDF can select and create a small set of fundamental components (we call pixels) that represents all LLE effects.**

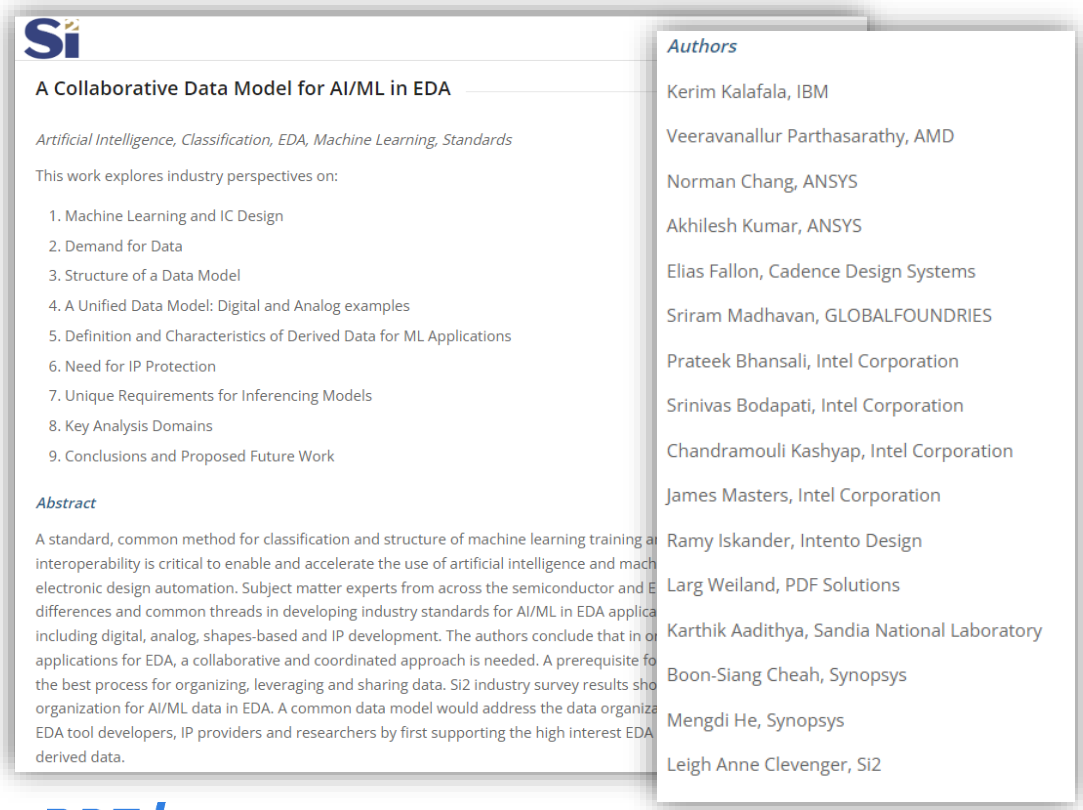


Silicon validation

Family	DOEs	"Pixel"
1	hundreds	8
2	hundreds	17
3	hundreds	9

Large and Effective Dataset is needed to Train AI Algorithm

- **To train Generative AI algorithm for test chip design, large and effective dataset is needed, as also being recognized in the industry.**



Si

A Collaborative Data Model for AI/ML in EDA

Artificial Intelligence, Classification, EDA, Machine Learning, Standards

This work explores industry perspectives on:

1. Machine Learning and IC Design
2. Demand for Data
3. Structure of a Data Model
4. A Unified Data Model: Digital and Analog examples
5. Definition and Characteristics of Derived Data for ML Applications
6. Need for IP Protection
7. Unique Requirements for Inferencing Models
8. Key Analysis Domains
9. Conclusions and Proposed Future Work

Abstract

A standard, common method for classification and structure of machine learning training a
interoperability is critical to enable and accelerate the use of artificial intelligence and mach
electronic design automation. Subject matter experts from across the semiconductor and E
differences and common threads in developing industry standards for AI/ML in EDA applica
including digital, analog, shapes-based and IP development. The authors conclude that in o
applications for EDA, a collaborative and coordinated approach is needed. A prerequisite fo
the best process for organizing, leveraging and sharing data. Si2 industry survey results sho
organization for AI/ML data in EDA. A common data model would address the data organiza
EDA tool developers, IP providers and researchers by first supporting the high interest EDA
derived data.

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- **As the largest independent commercial characterization test chip provider, only PDF's dataset has:**
  - **hundreds** CV test chip for FinFET technologies
  - Up to **1 billion** of DUT per CV test chip design
  - More than **100,000 wafers per year** tested using PDF's pdFasTest tester

Example Whitepapers:
at Silicon Integration Initiative (Si2)
https://si2.org/ai-ml-downloads/

PDF/SOLUTIONS™

CV Core Sensor for Reliability and 3DHI

PDF/SOLUTIONS™

Circuit Performance

Circuit Aging

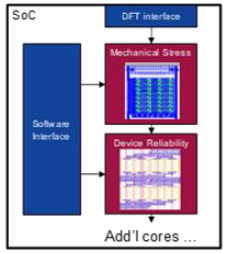
Package Performance

Traditional PVT Sensors

proteanTecs

DESIGN

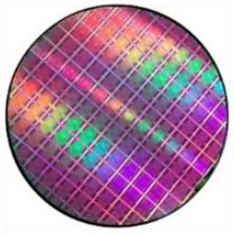
Chip Design



CV Core Insertion

BUILD

Wafer Manufacturing



Sort yield/parametrics correlation
PCM/Spice correlation

PACKAGING

Chip/Module/System Assembly and Test

Sort to FT/SLT correlation for Pkg/Test optimization
Die mission profile based aging readout (t=0)

MONITOR

Field Deployed Systems

Exensio CV Core Edge

In-field performance monitoring and mission profile optimization (t>0)

Exensio CV Core Data Processor

Sensor FOM Results

Configurations

DEX node

DEX node

DEX node

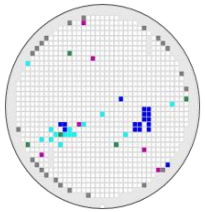
Exensio Manufacturing Analytics

Customer System & Analytics

Using AI/ML on CV Core data for Burn-In Optimization

- **CV Core data based AI model for lookahead prediction (e.g. Wafer Sort to Final Test): 20X improvement of capture rate for burn-in optimization**

Traditional Inking



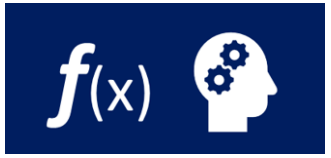
Overkill budget: 0.01%
Capture rate: 0.0%

# of die	Predicted fail	Predicted pass
Actual fail	0	YY,000
Actual pass	0	XXX,000

Overkill budget: 1.0%
Capture rate: 2.3%

# of die	Predicted fail	Predicted pass
Actual fail	Z,000	YY,000
Actual pass	A,000	XXX,000

CV Core based Prediction



Overkill budget: 0.01%
Capture rate: 19%

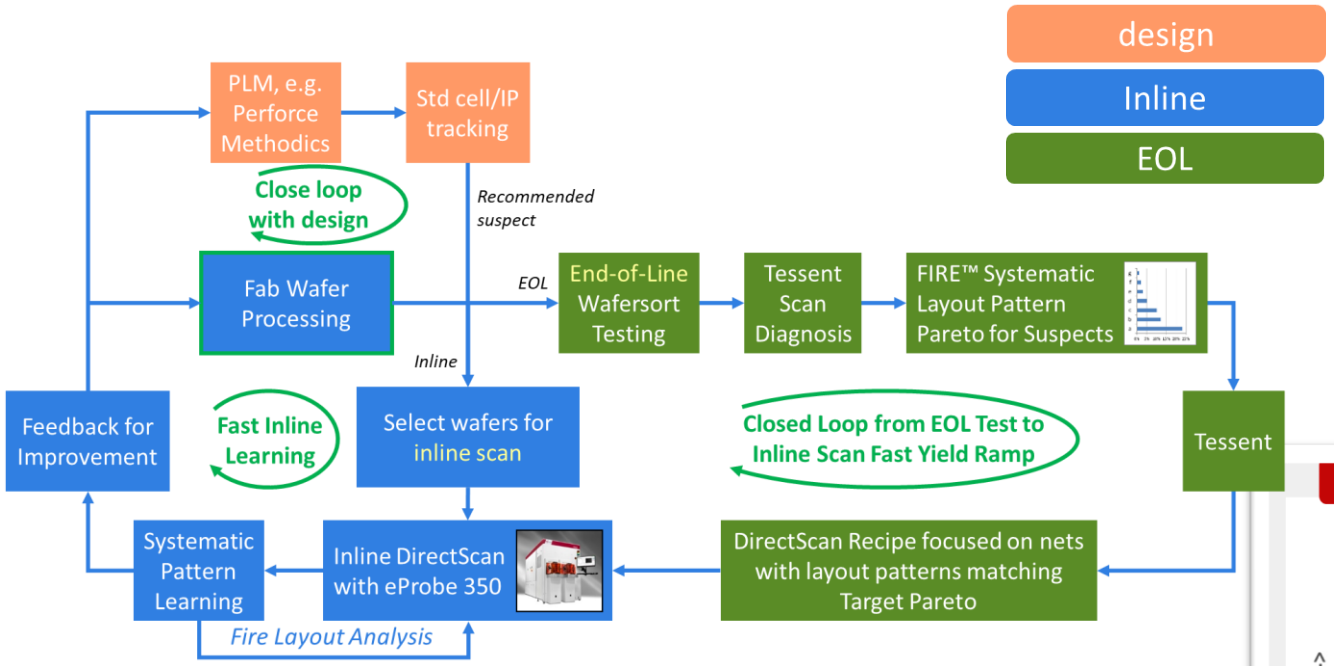
= (# predicted fail but actual pass) / total pass
= (# predicted fail that actual fail) / # actual fail

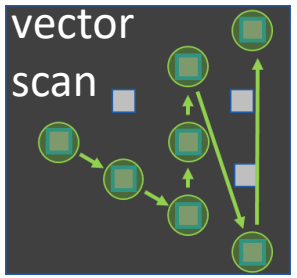
# of die	Predicted fail	Predicted pass
Actual fail	Z',000	YY',000
Actual pass	AA	XXX',000

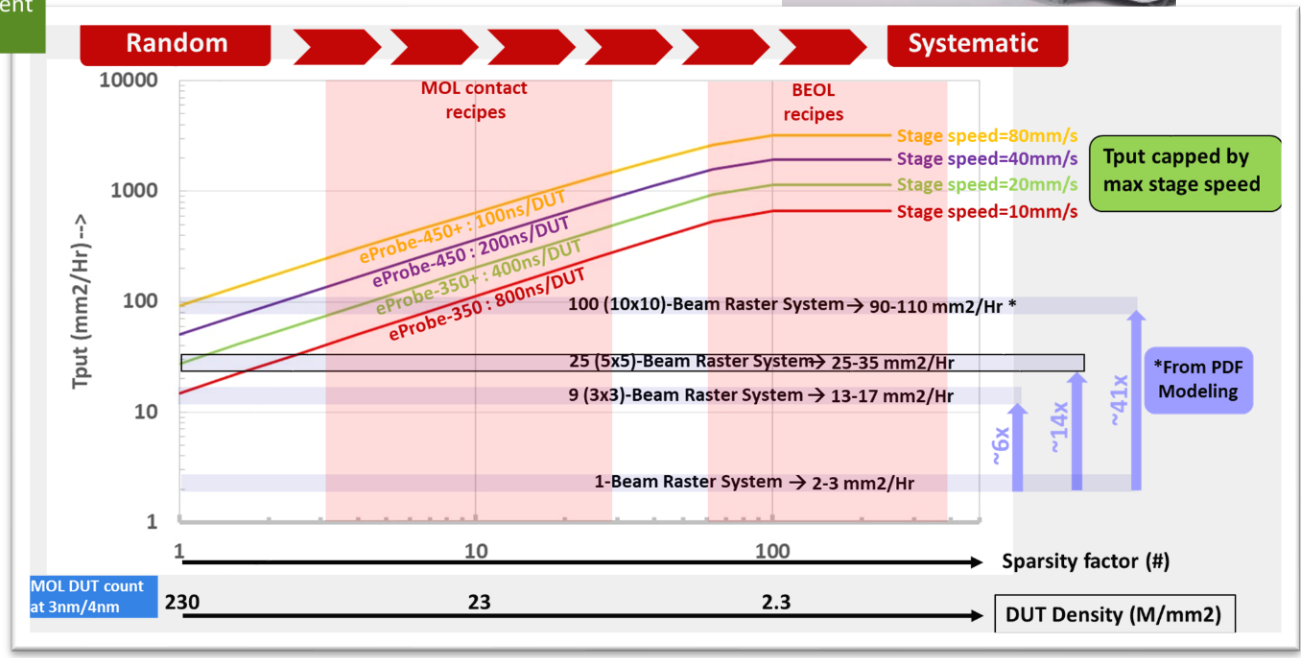
Overkill budget: 1.0%
Capture rate: 52%

# of die	Predicted fail	Predicted pass
Actual fail	ZZ',000	YY',000
Actual pass	A,000	XXX',000

Improve Learning Cycle with DirectScan™



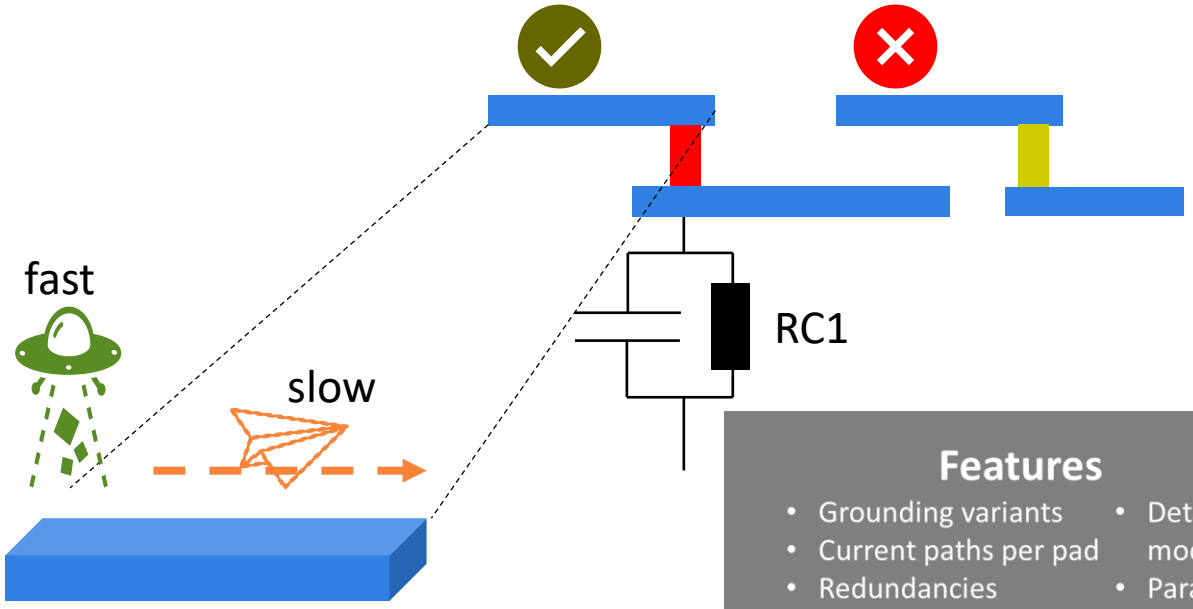




- Systematic failure at advanced nodes requires < 1ppb resolution and often at under layer.
- PDF developed DFI eProbe to address this challenge.

Exensio FIRE to Drive More Efficient Inline eBeam Inspection

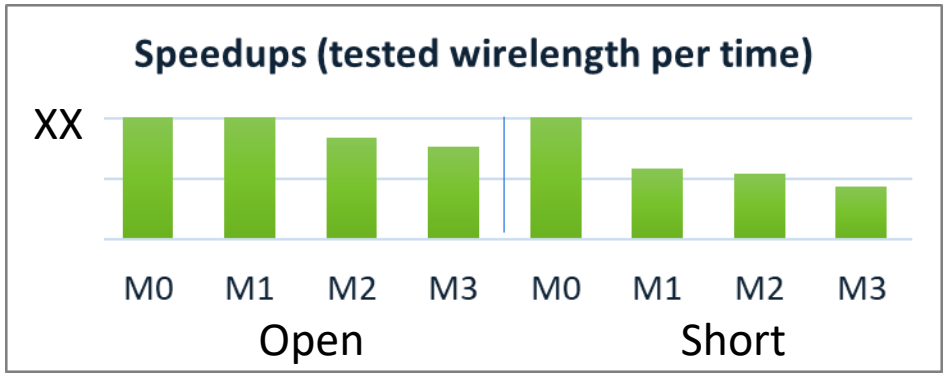
- **FIRE AI algorithm summarize design geometrical, electrical, and expected e-beam characteristics, to enable selection of scan points, to take advantage of HW vector scan capability.**

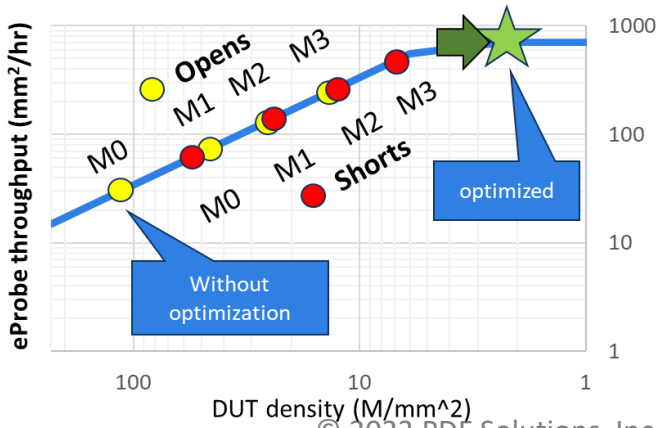


Features

- Grounding variants
- Current paths per pad
- Redundancies
- Leakage modeling
- Detailed failmode modeling
- Parasitic failmodes
- E-beam brightness simulation

- **FIRE created eProbe inspection recipe leads to 10-100X efficiency gain for systematic fail mode measurement.**
  - Example: eProbe-350 on N7 logic block

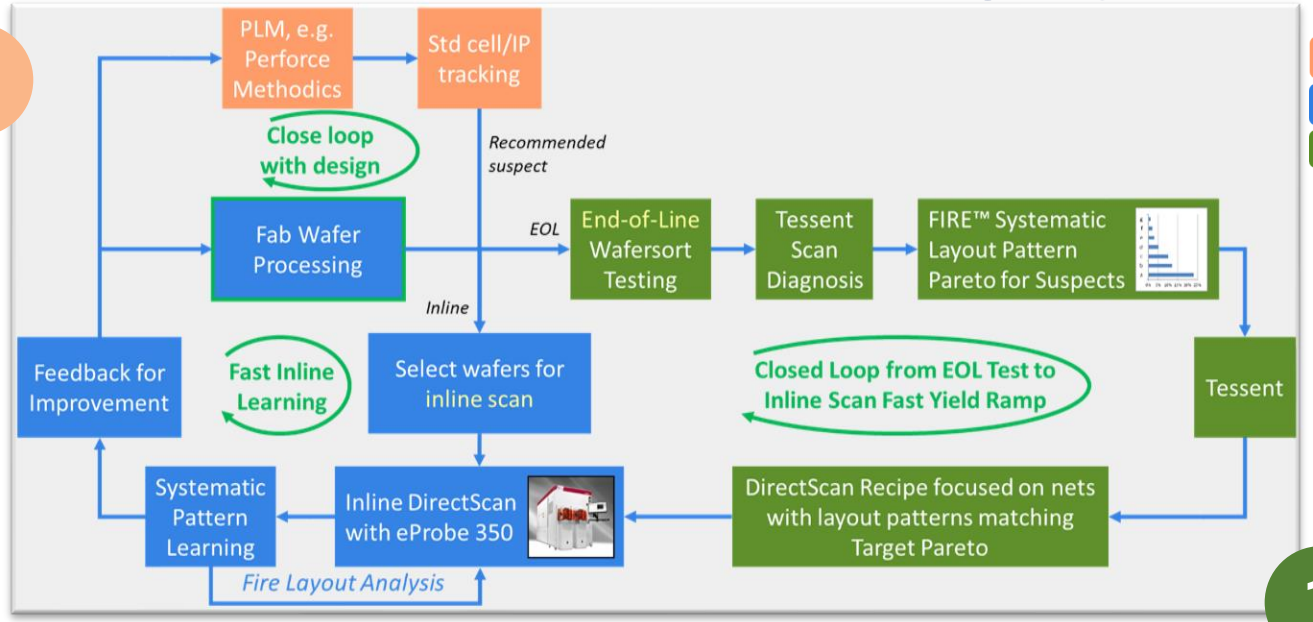




Example Workflow to Shorten Learning Cycle

For subsequent tape-out, inspection recipe can be created at/before tape-out to assist NPI.

3



Direct inline inspections of all locations of this systematic fail mode

2

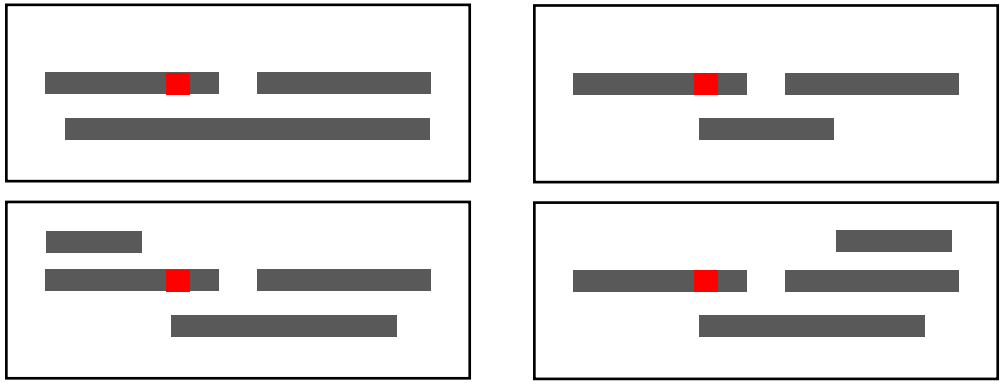
For a given product, FIRE extract all (x,y) locations of this systematic fail mode, and create recipe to drive DirectScan™.

The layout attribute is “tagged” with each location, which allows us to study the relationship of failure with layout attribute (process margin).

1

Offline analytics to identify potential systematic fail mode.

Example one family of fuzzy pattern



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Summary

AI Related Roadmap of PDF Advanced Solution

PDF's vision and Mission

- **Vision:** To be the world's leading data and analytics platform spans the semiconductor and electronics ecosystems.
- **Mission:** Provide innovative solutions to create, access, and organize data to enable analysis and control for semiconductor and electronics companies to achieve better time-to-market, yields, quality, and operational efficiencies.

AI Related Solutions from ASG

- **Available NOW**
  - Siemens Tessent + PDF Exensio/FIRE integrated solution for scan diagnostics
  - Exensio Test with ModelOps
  - CV Core sensors and related apps
  - DirectScan™ eProbe with Exensio FIRE
- **On Deck**
  - ATPG + Exensio FIRE using design DNA
  - PLM + Exensio across multi-products
  - Generative AI for CV test chip design

Thank You

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