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GF Machining Solutions

AI Application in Machine Tools

S. Schurov, U. Maradia, R. Perez

Bern, May 2019

Transition to Industrial Reality

We are industrial pioneers

Founded +200 years ago

On the Swiss Stock Exchange since 1931

Johann Conrad Fischer
1773-1854

Georg Fischer I
1804-1888

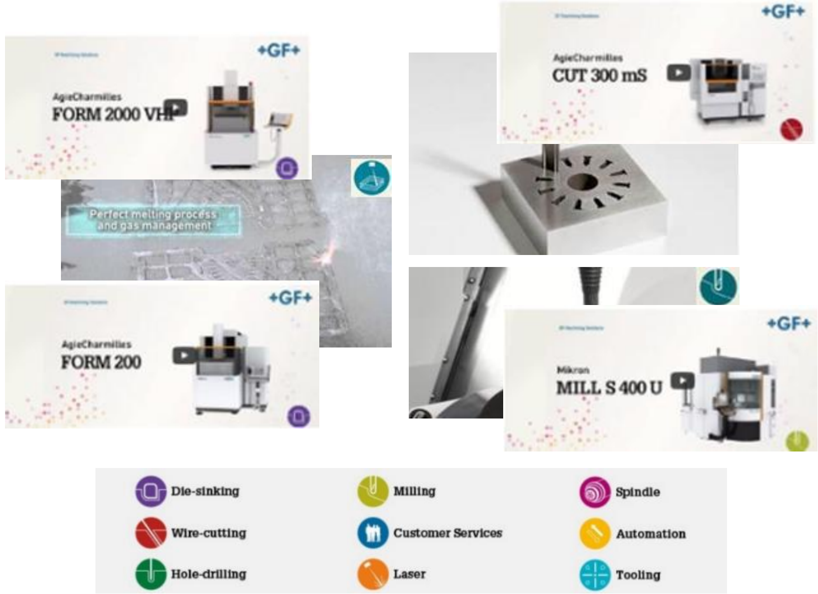
Georg Fischer II
1834-1887

Georg Fischer III
1864-1925

Georg Fischer was among the first to transition from hand production methods to machines

… through “Build to Stock” serial production methods to present day adaptive “On-demand” manufacturing

“People can have the Model T in any color - so long as it’s black”
Henry Ford (1913)



From “Standardized Products” …

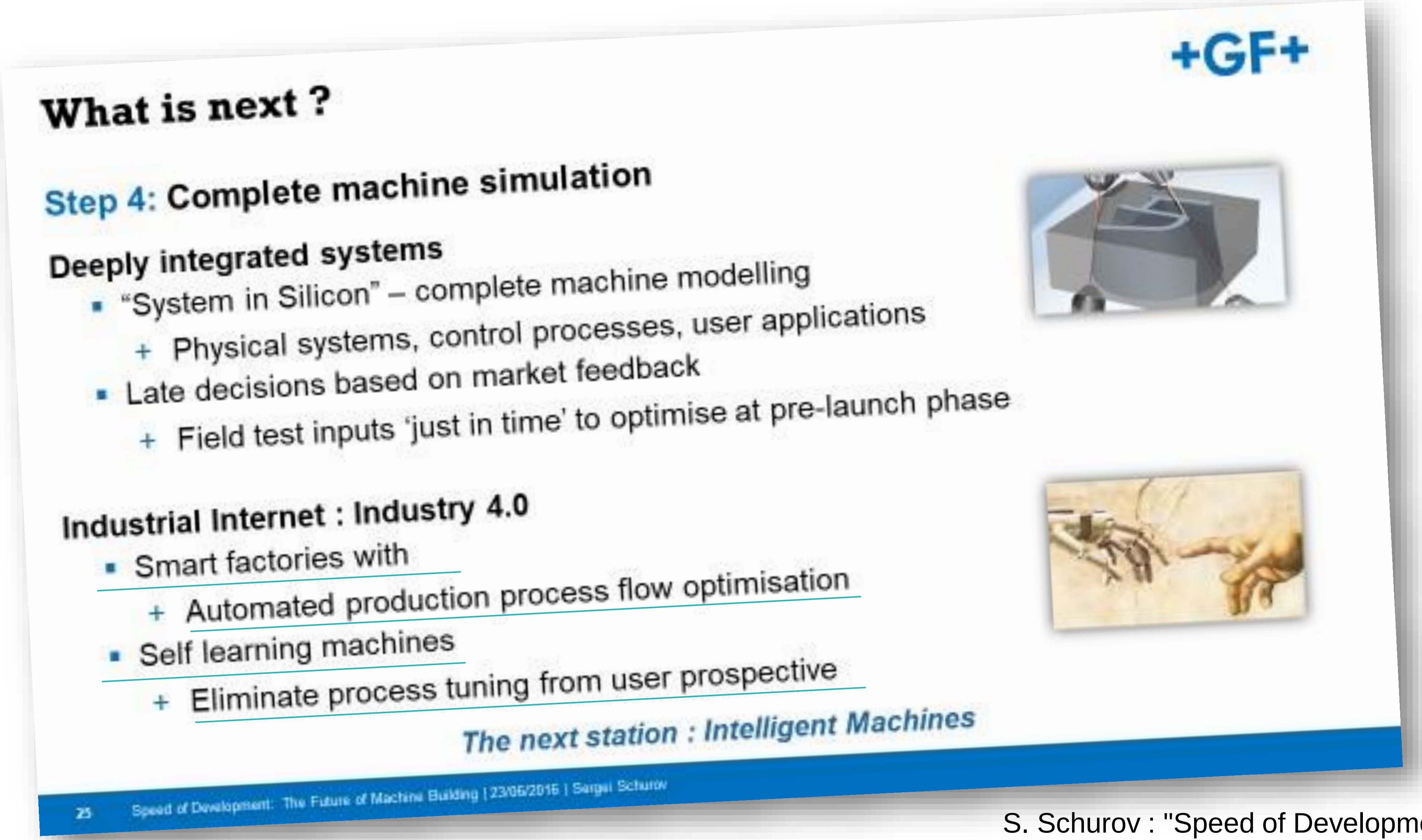
Few materials and technologies, lengthy to establish, costly to move from pre-defined set up …

… to “Mass Customization”

Seemingly limitless choice of materials and technologies with growing sophistication and flexibility

Conventional manufacturing methods no longer meet expectations of fast product cycles

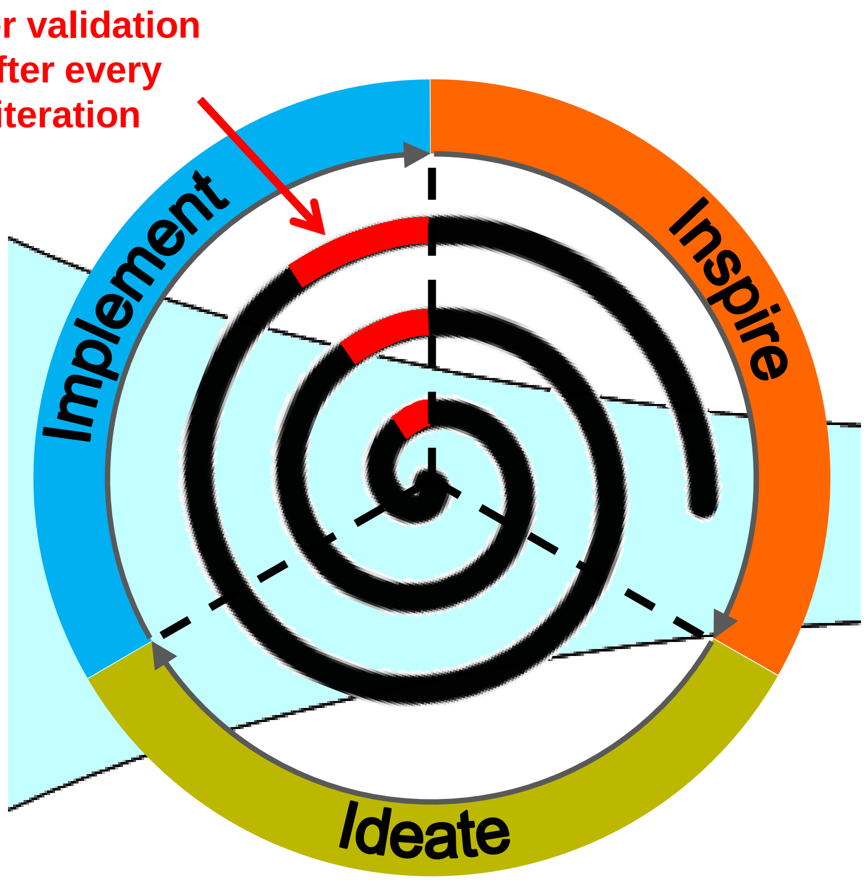
Our Expectations in 2016



S. Schurov : "Speed of Development"
Presentation at Matlab World Expo 2016

4th industrial revolution not only brings connectivity, it transforms organizations and value creation chain

- **Agile everywhere**
  - Each development is a “mini-cycle” or short “sprint"
  - Delivers functional solution ready for user testing
- **Design Thinking**
  - Iterations help validate multiple ideas in rapid succession
  - Specifications are continuously refined based on agreed use-cases and customer feedback
- **Modelling and simulation**
  - Mode order reduction techniques cut simulation times transforming modeling into design tool, not just validation
  - AI and ML reinforce models with powerful algorithms using both EDGE and cloud-based technologies

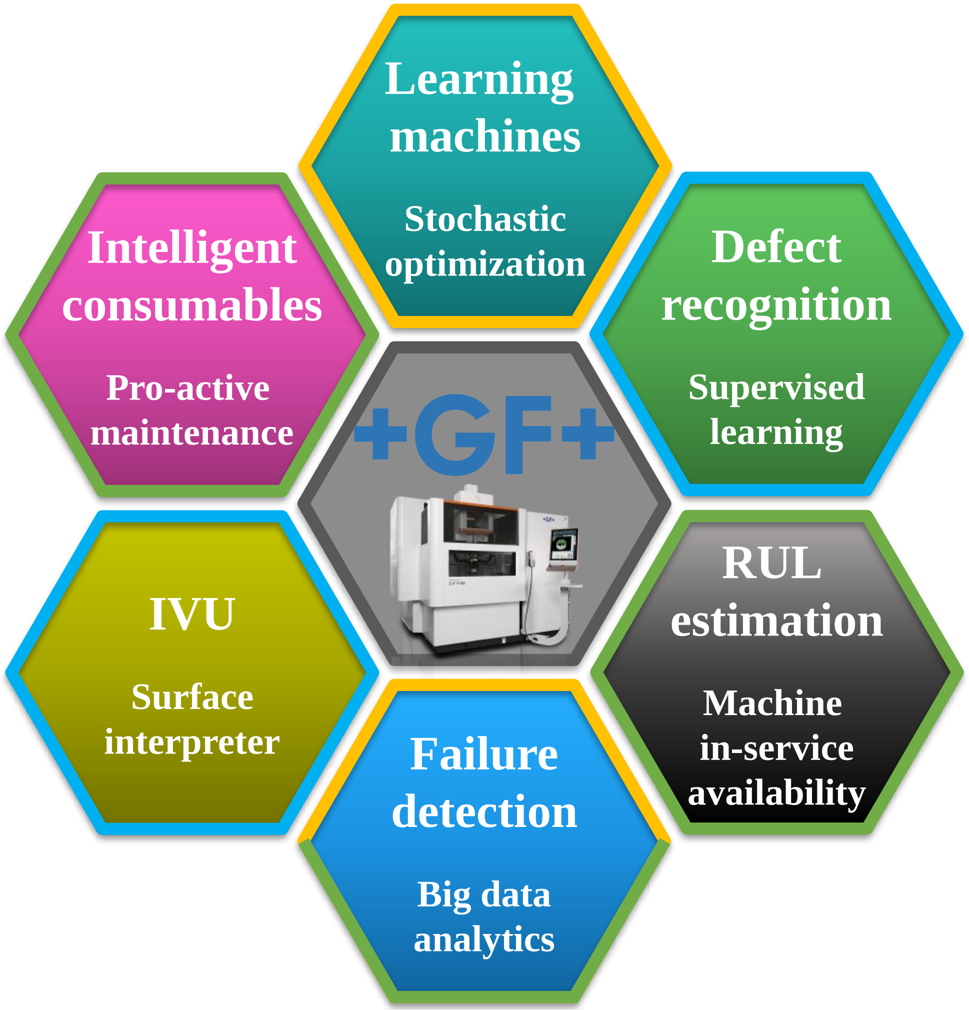


ITERATIVE IDEA DEVELOPMENT

Development cycles defined by numerical models, less by mechanical prototypes

Smart adaptive solutions as process building blocks

Smart adaptive solutions as process building blocks



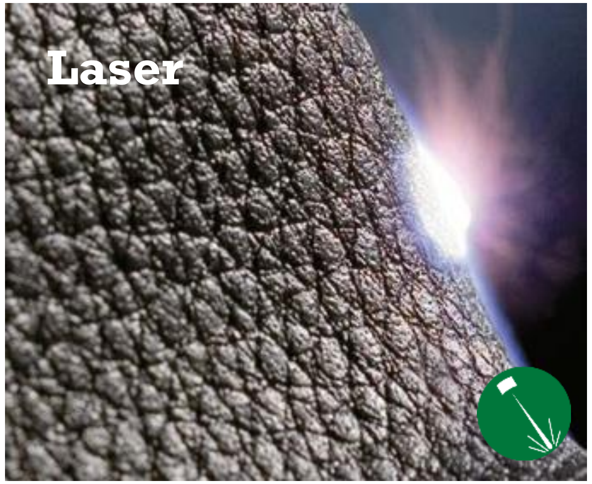
DEVELOPMENT

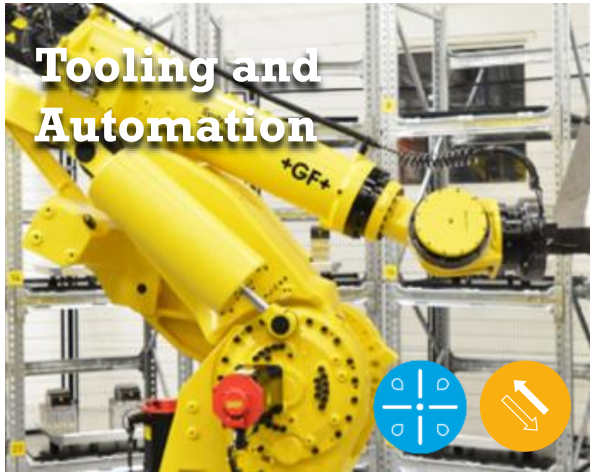
OPERATION

MAINTENANCE

AI brings value across entire manufacturing value chain

Unique Technology Portfolio





Key figures (2018)

Founded	Headquartered	Employees worldwide	Sales CHF million
1802	**Switzerland**	**15 027**	**4 572**

Key figures (2018)

Countries	Companies, service and sales centres	Productions plants
33	140	57

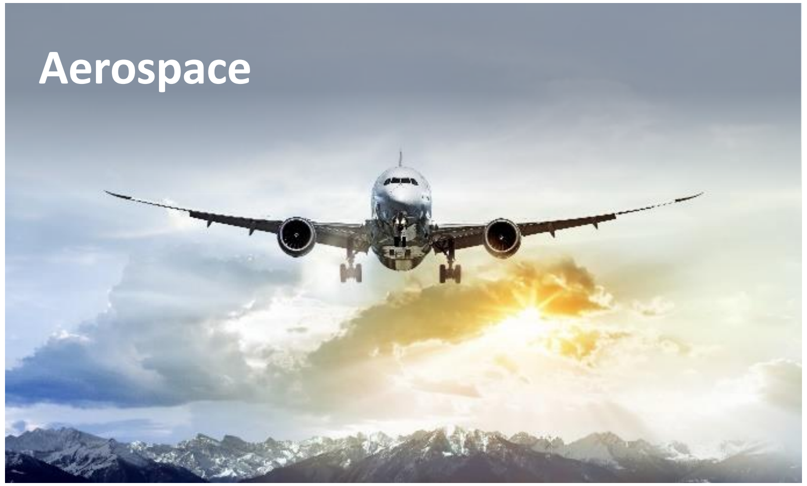
Three divisions

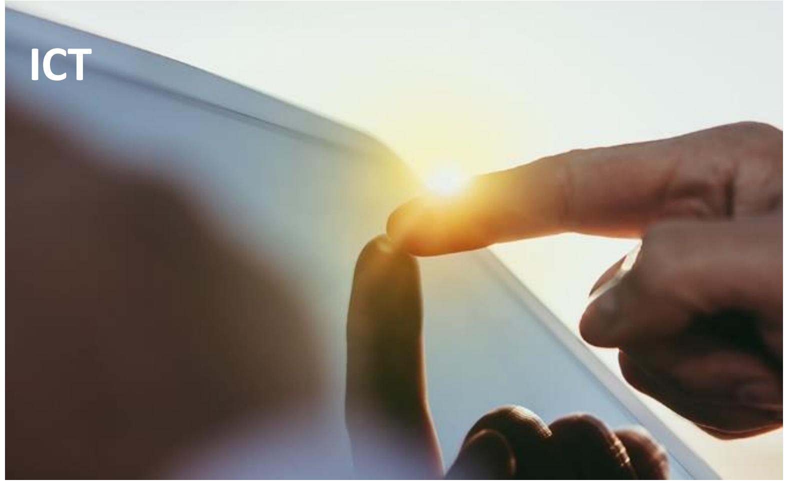
GF Piping Systems

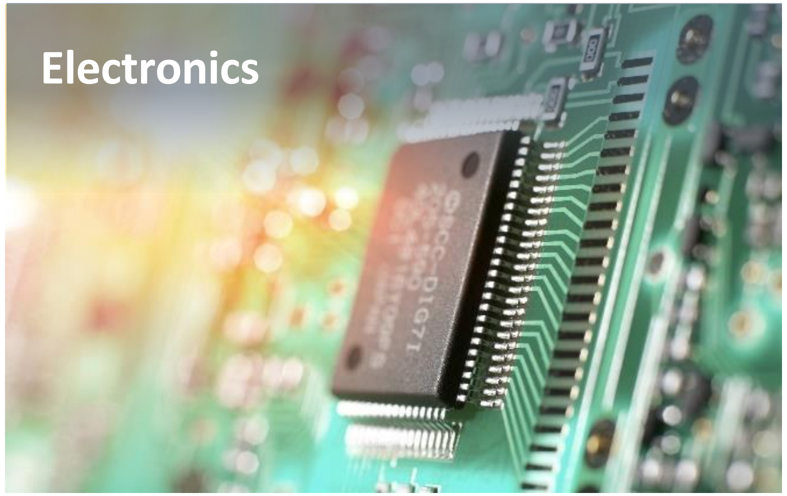
GF Casting Solutions

GF Machining Solutions

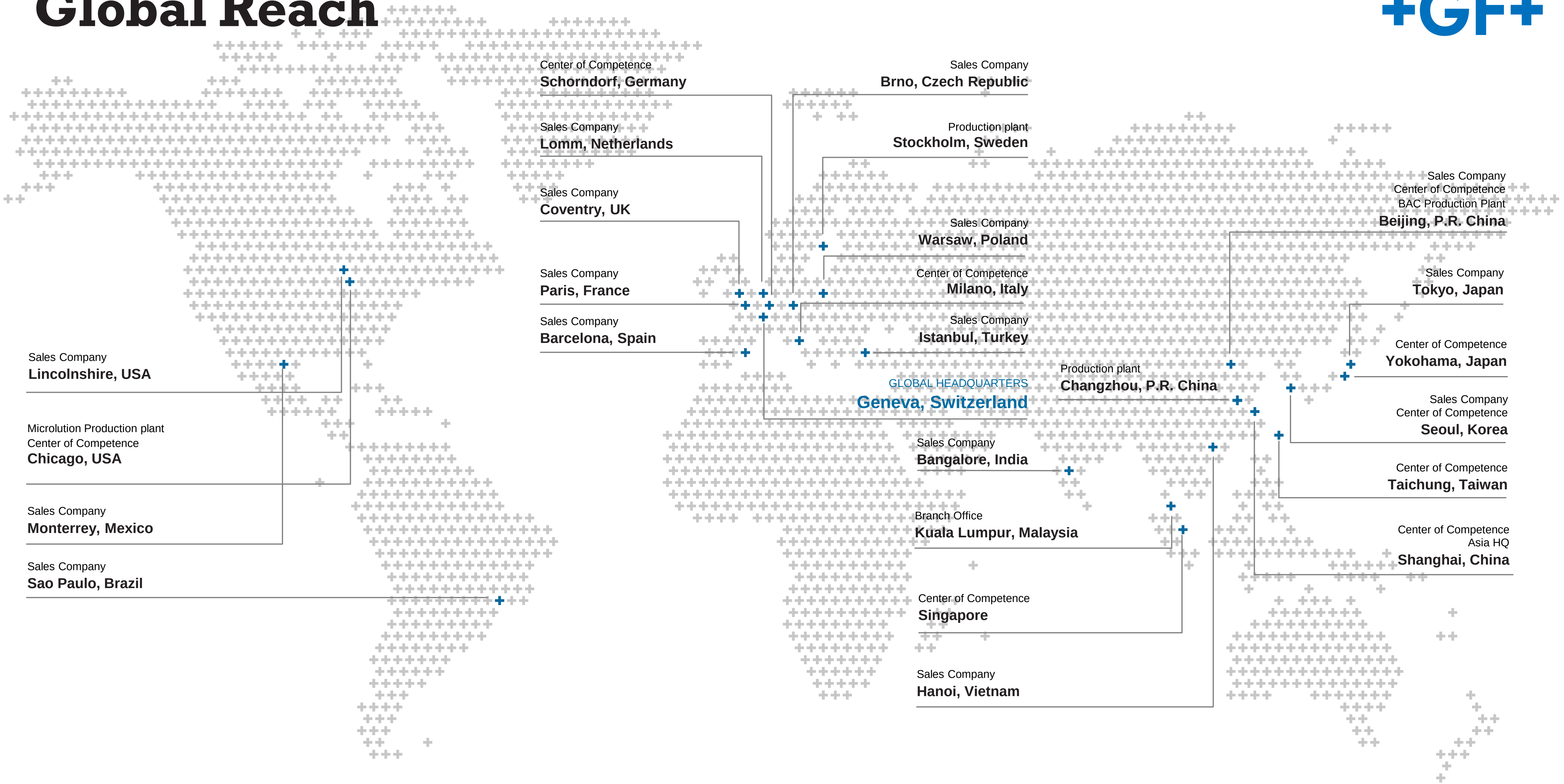
Value-Added Solutions across Market Segments

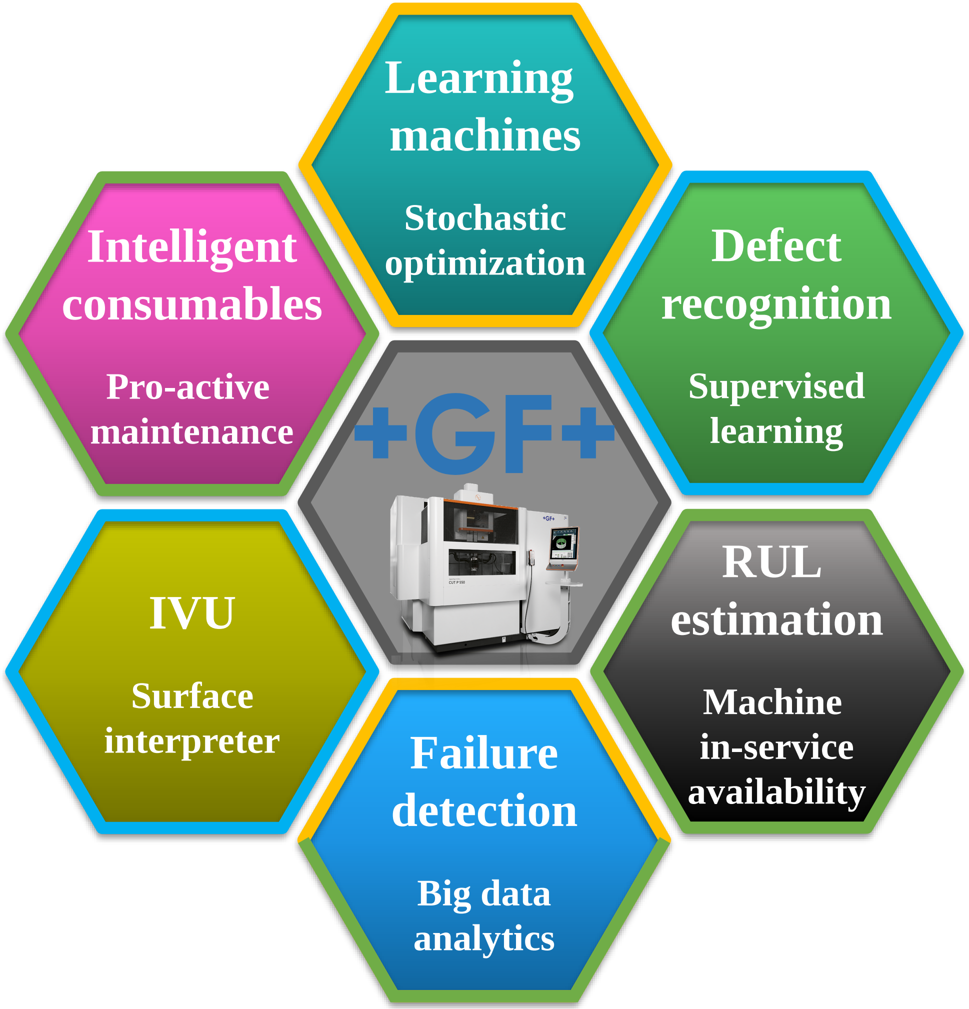






Global Reach





DEVELOPMENT

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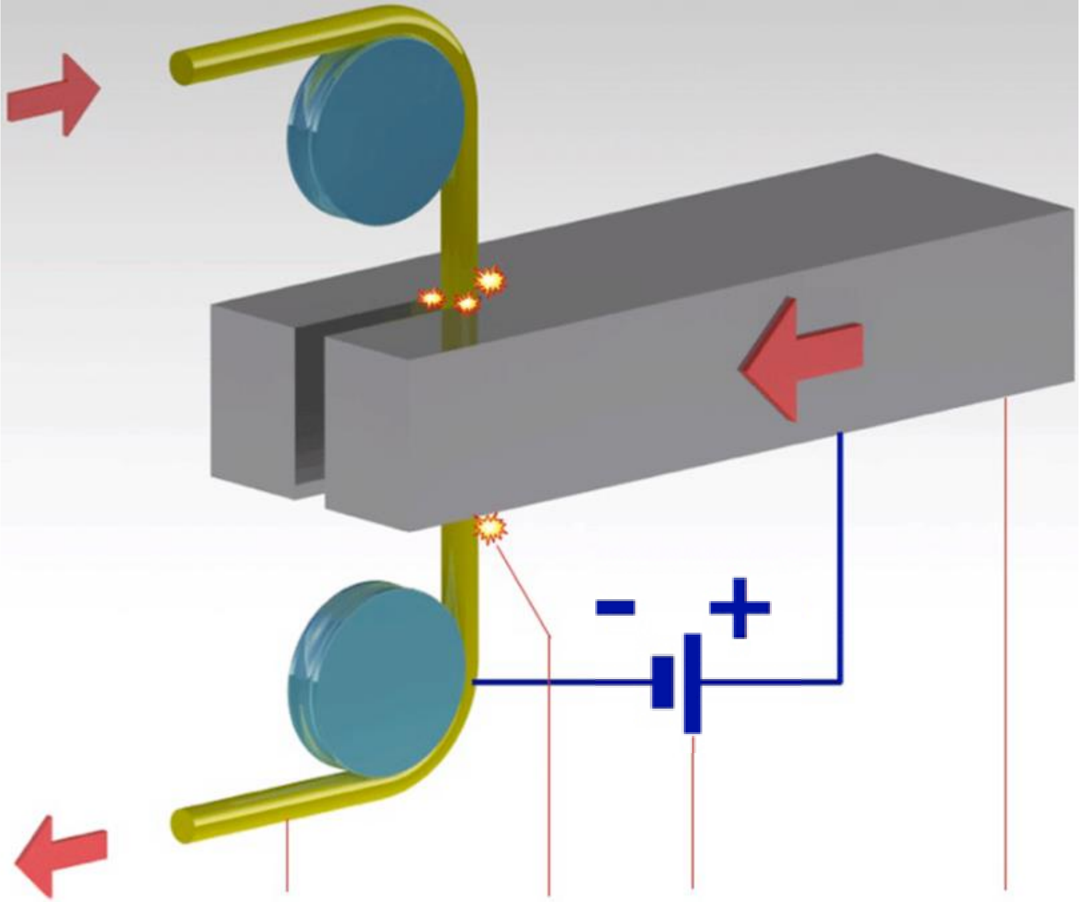
AI for Zero Defect Manufacturing

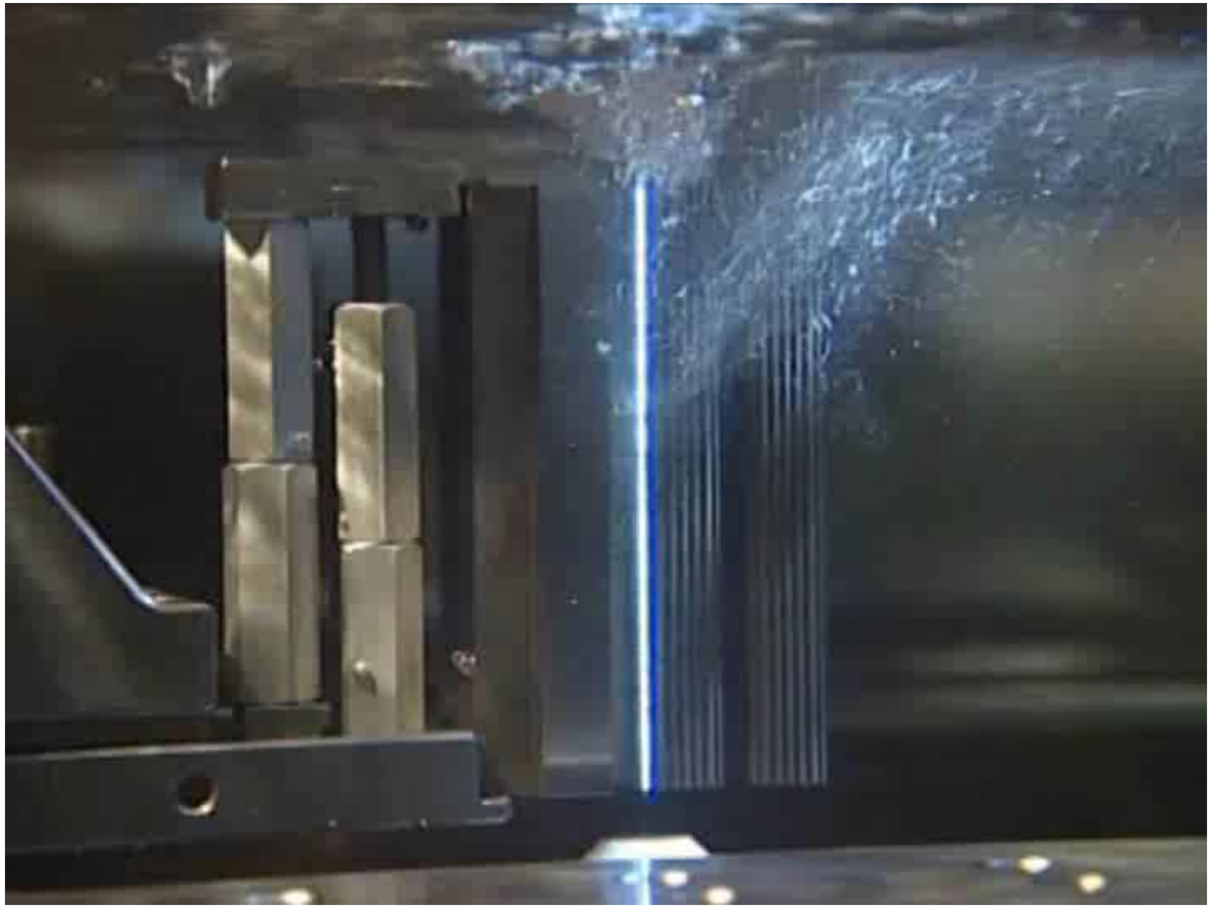
Defect recognition

Supervised learning

OPERATION

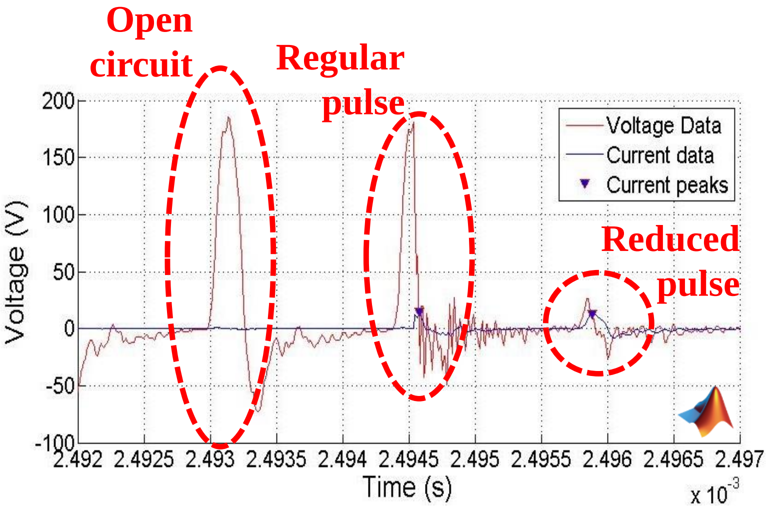
EDM is preferred technology for tough materials



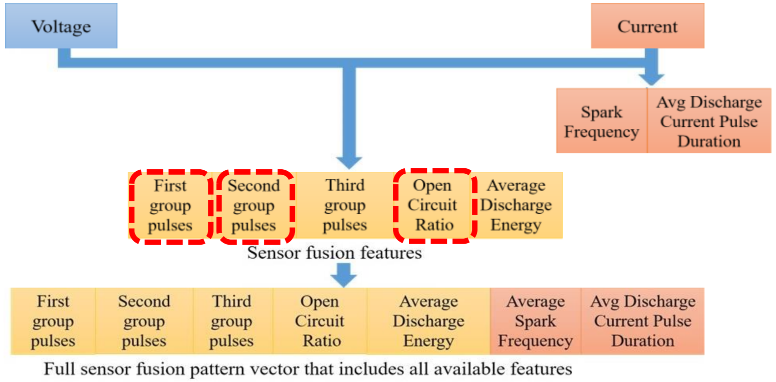


Process abnormalities must be identified in advance for correction to avoid failures later

Our approach : Neural Networks analytics

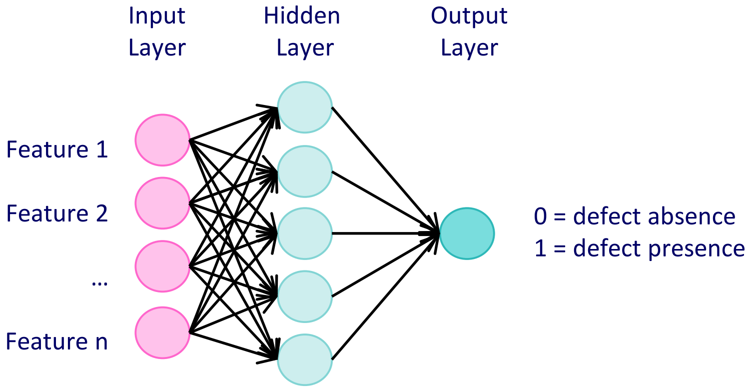


- Direct pattern analysis does not correlate automatically with surface defects
- Features must be extracted by grouping data of different type or source



- Full feature set from 50 parts (example) divided into training and test sets

Training Set	Test Set
30 parts	20 parts



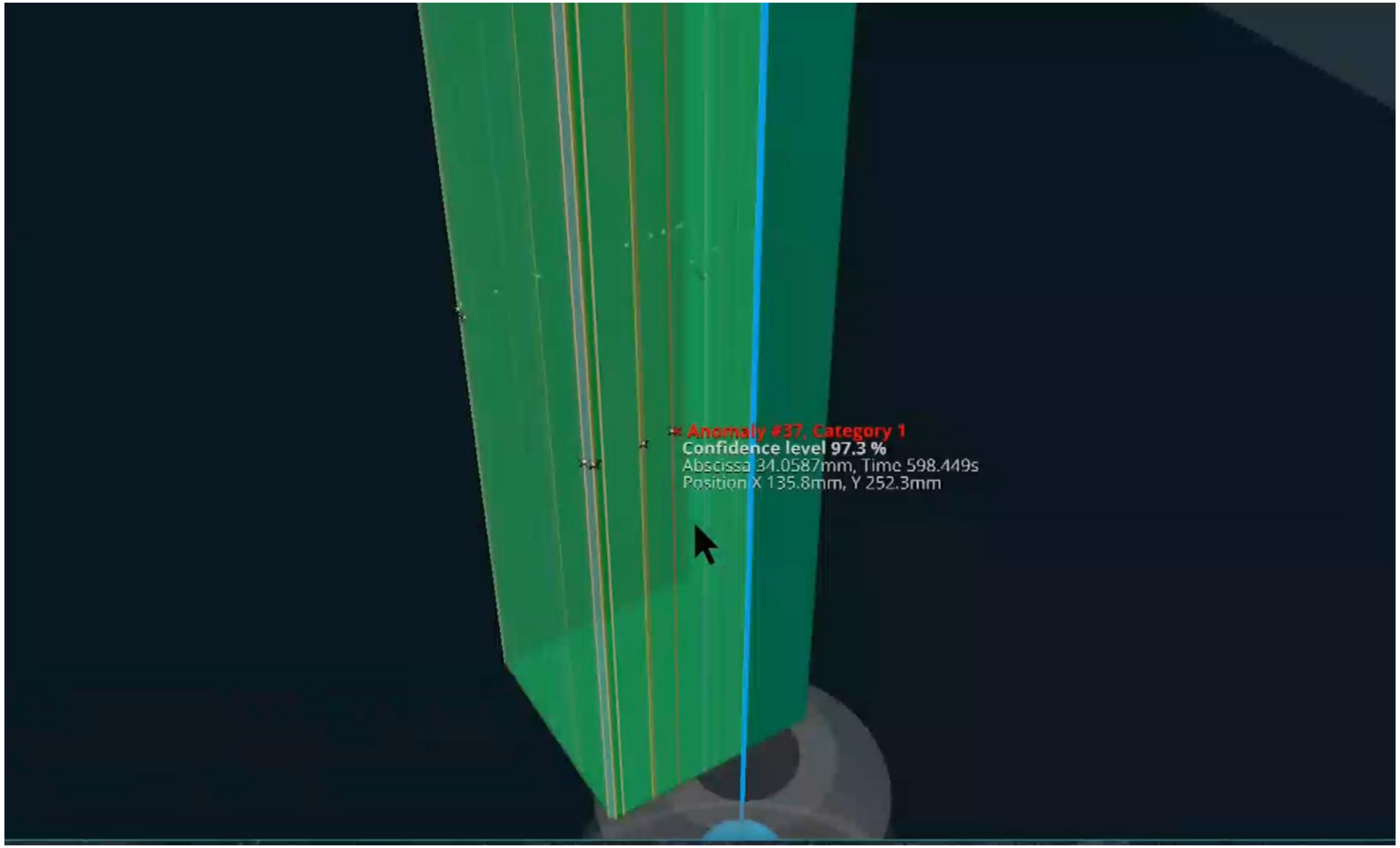
- Apply three-layer feed forward back-propagation neural network: RBF

- Success rate with control data

NN Architecture	Segment size		
	20ms	50ms	100ms
7-7-1	88%	97%	96%
7-14-1	81%	96%	97%
7-21-1	87%	97%	96%
6-6-1	87%	100%	96%
6-12-1	87%	96%	93%
6-18-1	86%	99%	97%

- Optimise nodal architecture and segment size to find best accuracy

Anomalies visualised by superimposing on the CAM image of the part



- Each machine has its unique ML signature
  - Training required for each new geometry and specific for each machine
- Neural Network algorithms evolve with increasing dataset
  - The best accuracy of the model does not always increase with node count

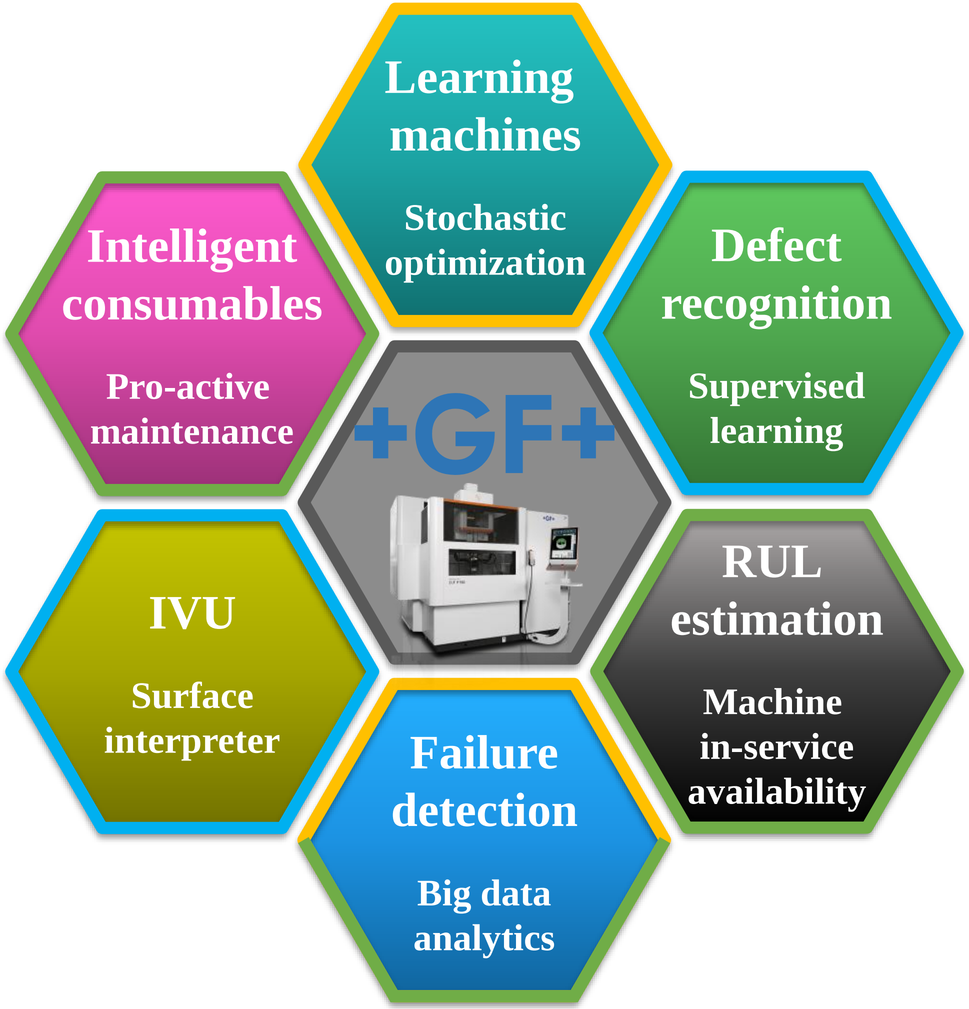
ML correlates abnormal conditions with defects by NN analytics of the fused sensor data

AI for Zero Defect Manufacturing

Defect recognition

Supervised learning

OPERATION



DEVELOPMENT

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AI for Customized Applications

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Learning machines

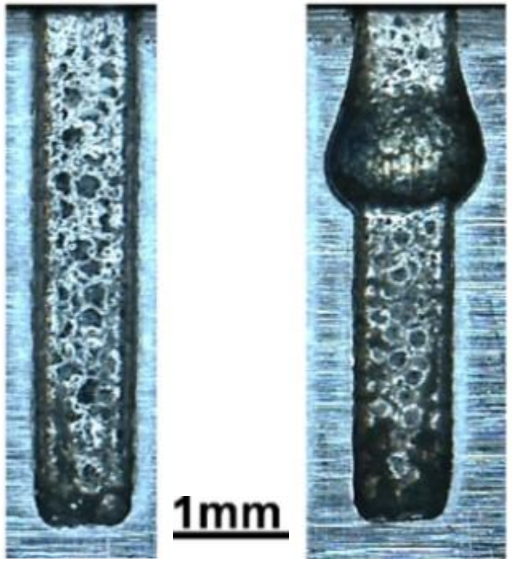
Stochastic optimization

DEVELOPMENT

EDM Drilling: A unique solution for hard materials

- Turbine blades can exceed 1200ºC unless cooled
- Each part: 250+ cooling holes x 40+ blades x 8+ stages
- Machining time ~10s per hole – every second counts

- EDM process has over 100 interdependent variables
- DOE unreliable, full factorial unrealistic
  - n=15, n^3 = 3375 (brute force)
  - n=200, n*3=600 (parsimonious gridding)



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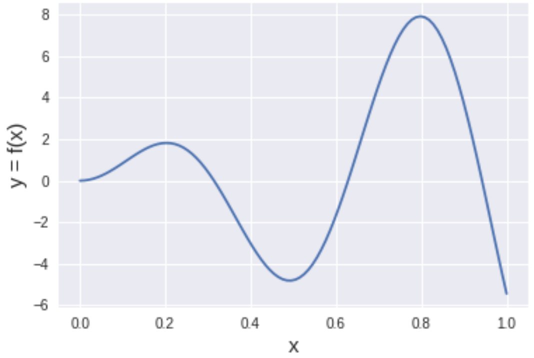
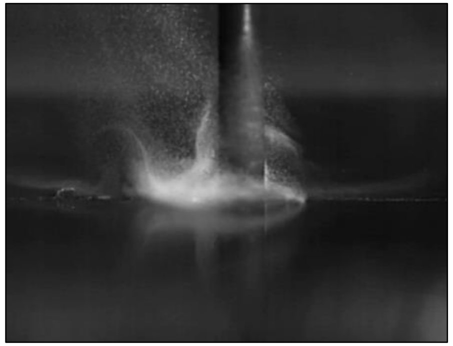


Local minima

☹☹

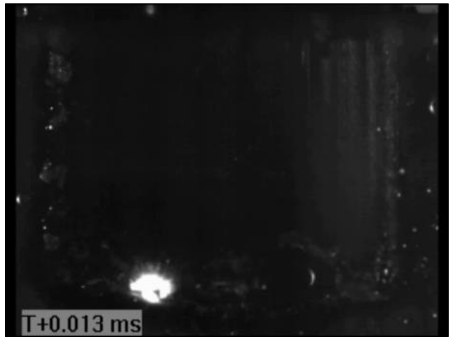
Process noise

☹☹



Material specific

☹☹☹



Unpredictable behavior

The process must be optimized to maximize cutting speed without loss of quality

Our approach: Learning Machines

- EDM Process
  - Expert system
  - Adaptive control

MACHINE OPERATOR

OPERATING APPLICATION FIELD
- *Basic process parameters*
- *Protection algorithms*

EXPERIMENTAL FEEDBACK FIELD
- *Real-time data acquisition*
- *Process output results*

FUSION RULE
Virtual Operator with
Self-Learning Algorithms

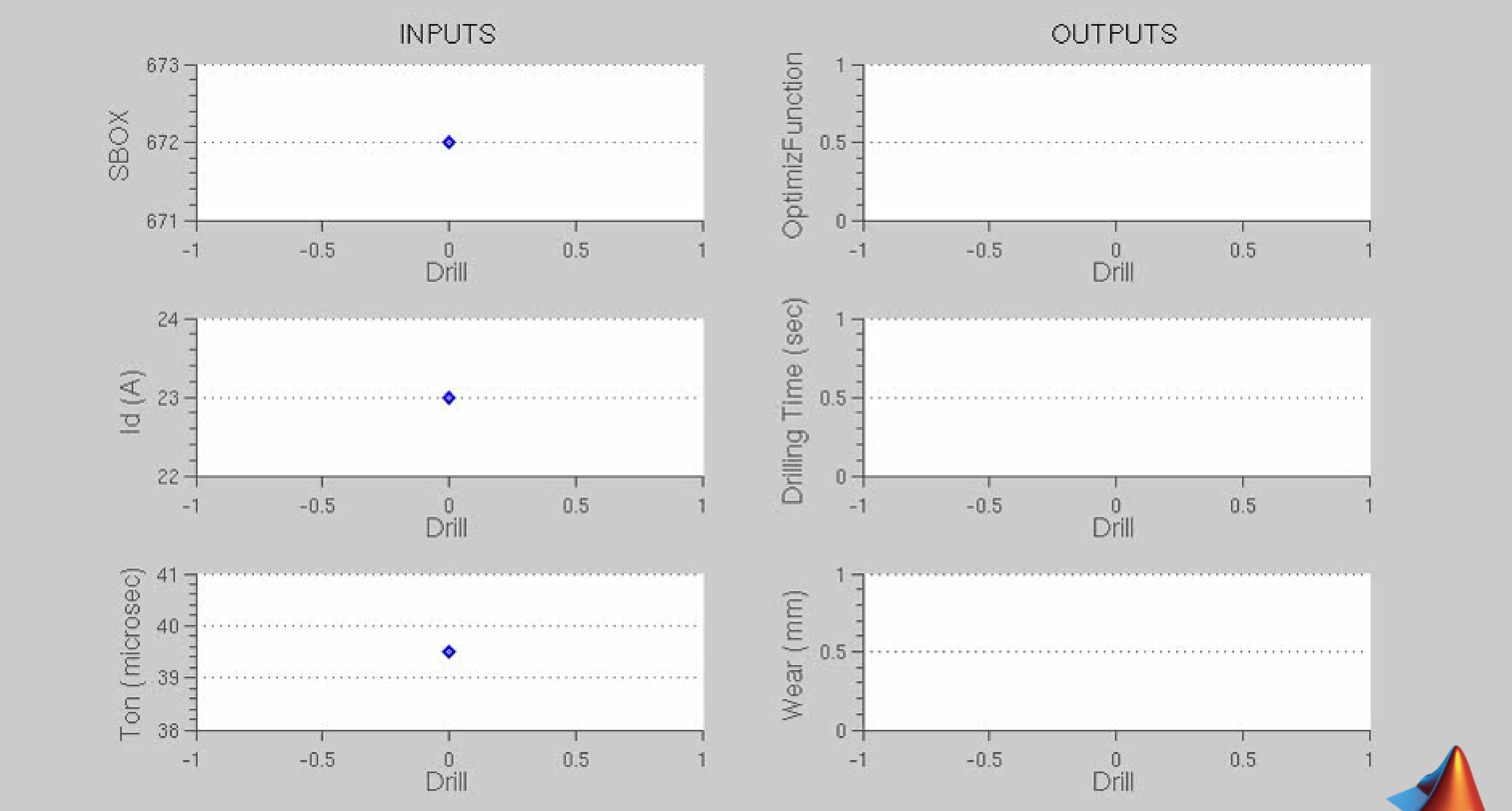
DATA ANALYTICS
(experimental results)

APPLICATION EXPERT
(specialist at GF Machining Solutions)

- ML Input
  - Self-learning algorithms
  - Fusion rules

Stochastic optimization algorithm finds process optima

Results: Improvement over expert set-up



Maradia et.al. EDM Drilling Optimisation using Stochastic Techniques

For three main process inputs, the AI algorithm requires ~40 iterations

AI for Customised Applications

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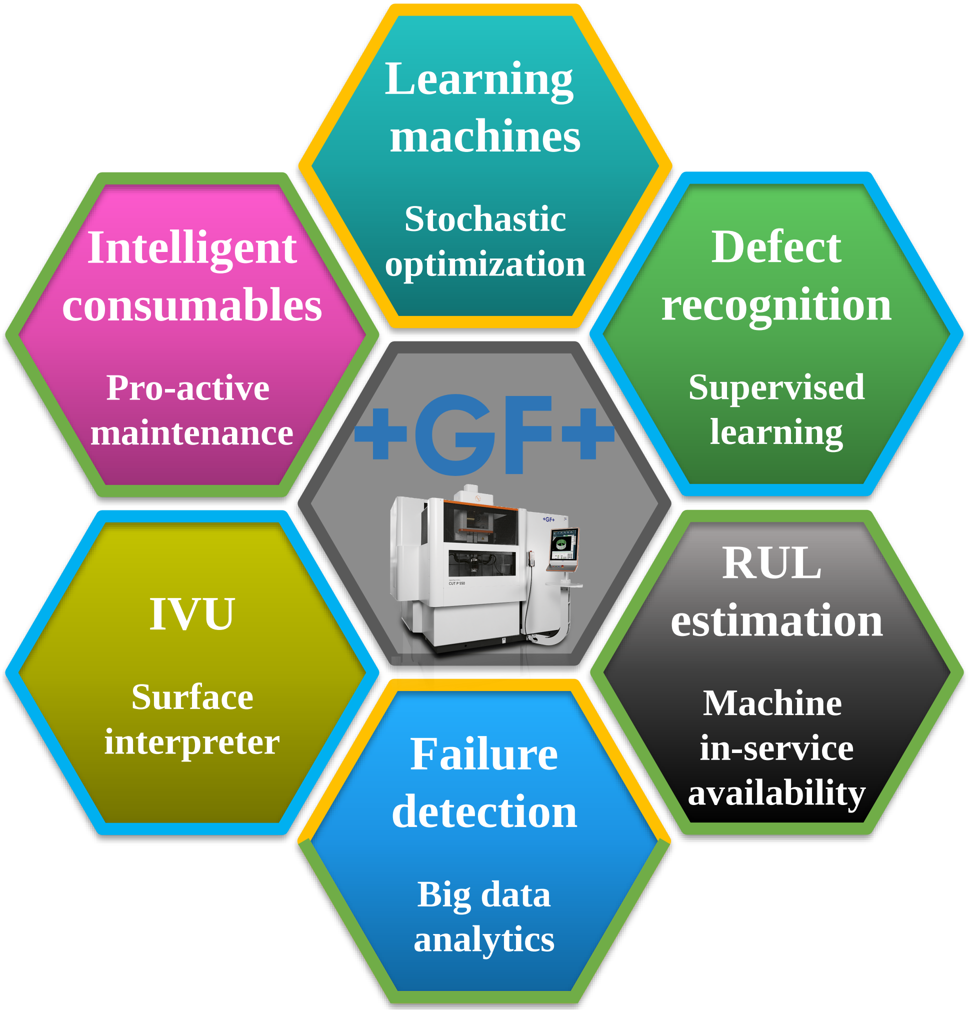
Learning machines

Stochastic optimization

DEVELOPMENT



DEVELOPMENT

OPERATION

MAINTENANCE

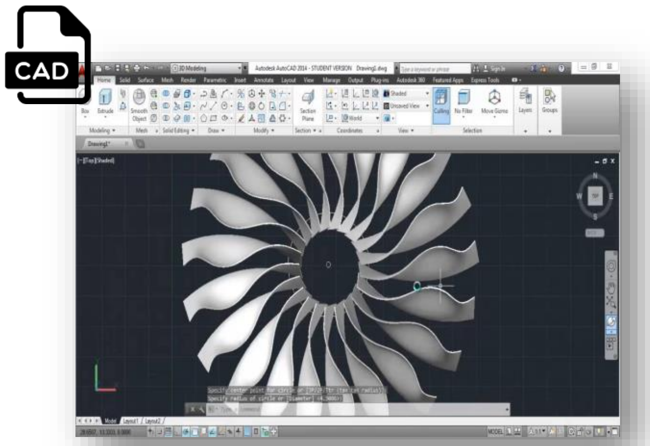
AI in Proactive Maintenance

RUL estimation

Machine in-service availability

MAINTENANCE

Preventive maintenance: mandatory for reliability

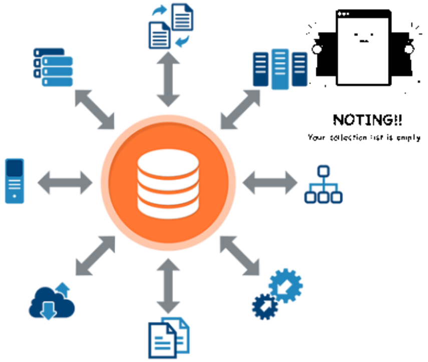


- From CAD/CAM to final product: workflow planning relies on guaranteed machine availability for uninterrupted process

User Expectations

Pro-active advice on m/c maintenance periods

No extra costs: service fees included in the purchase contract



OEM Constraints

No maintenance annotation → Limited options for data analytics

Heterogeneous data sources → Difficulty of data fusion/processing

Interventions ahead of time increase costs unnecessarily

Our approach: Hybrid Condition Monitoring

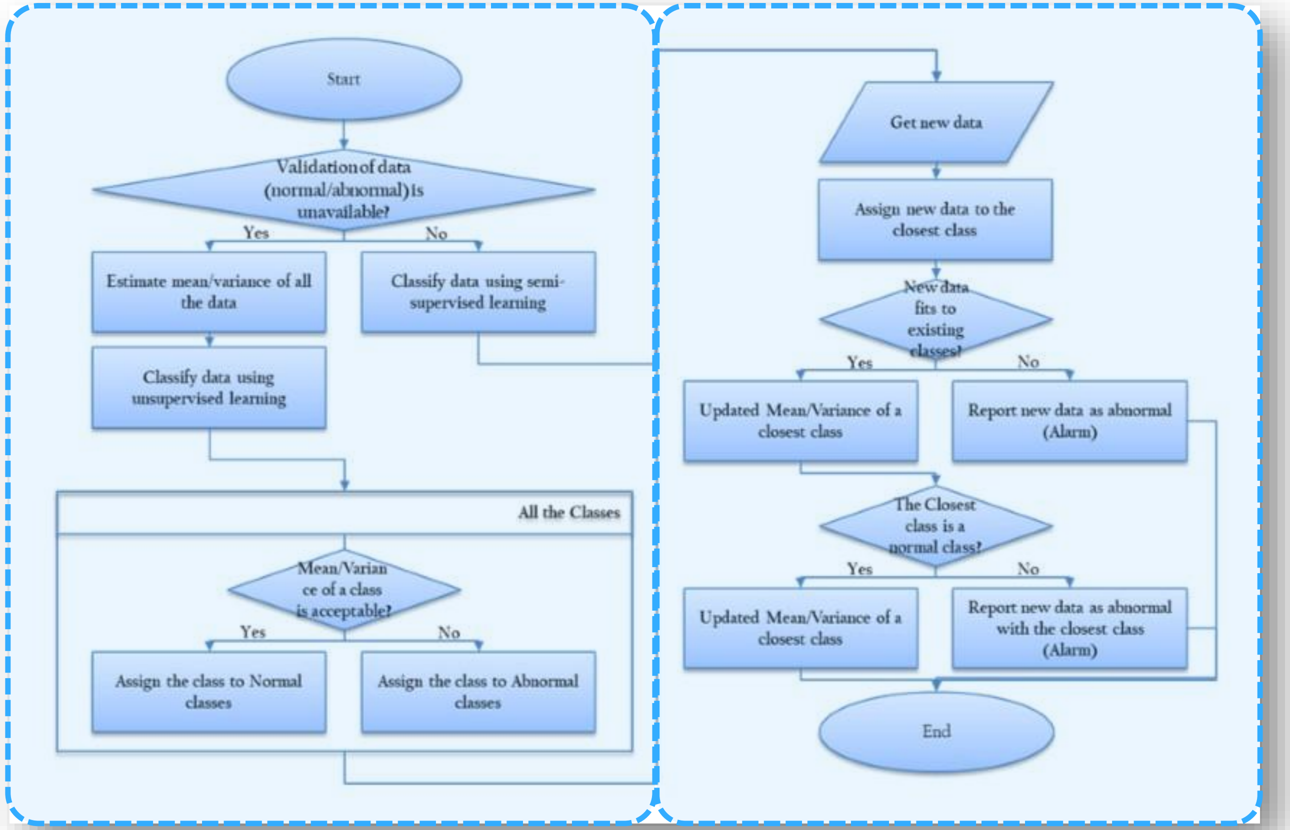
Path 1: Maintenance annotation available :
Supervised learning

- Main purpose : Data classification and Estimation of Residual Useful Lifetime (RUL)
- Hard assignment – maintenance assumptions can not be changed with upcoming data

Path 2 : Maintenance annotation *not* available :
Unsupervised learning

- Main purpose : Anomaly detection
- Soft assignment – maintenance assumptions can change depending on upcoming data

Combine two analytical paths

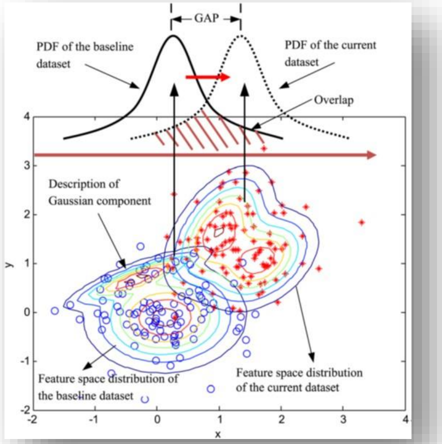


Both methods can run concurrently to calculate RUL and detect early failures

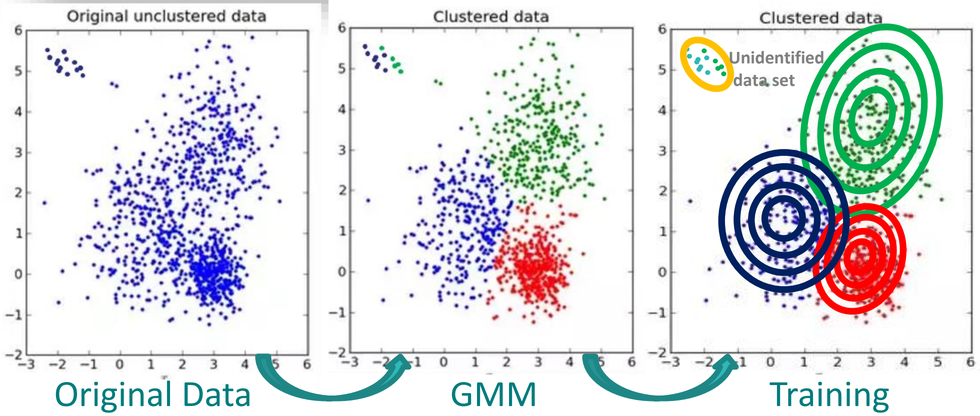
Apply Adaptive Gaussian Model to visualise deviation from normal

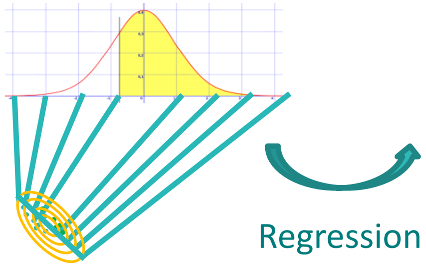
- **Step 1: Gaussian Mixture Model (GMM)**
  - Convert symmetrical Gaussian “Bell Curve” distribution to probabilistic “Mixture Model"
- **Step 2: Predictive Maintenance Algorithm**
  - Apply GMM to original dataset using semi-supervised learning to cluster data
- **Step 3: Calculate Residual Useful Lifetime (RUL)**
  - Calculate Mahalanobis Distance-Residual from regression calculated mean as a failure probability measure

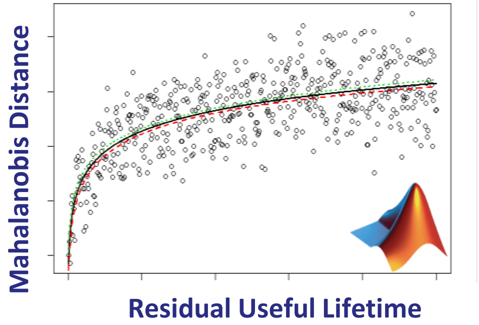
Model accuracy improves with larger datasets



Yu, J., 2012. Machine tool condition monitoring based on an adaptive Gaussian mixture model. *Journal of Manufacturing Science and Engineering*, *134*(3), p.031004. https://ict4sm.epfl.ch/

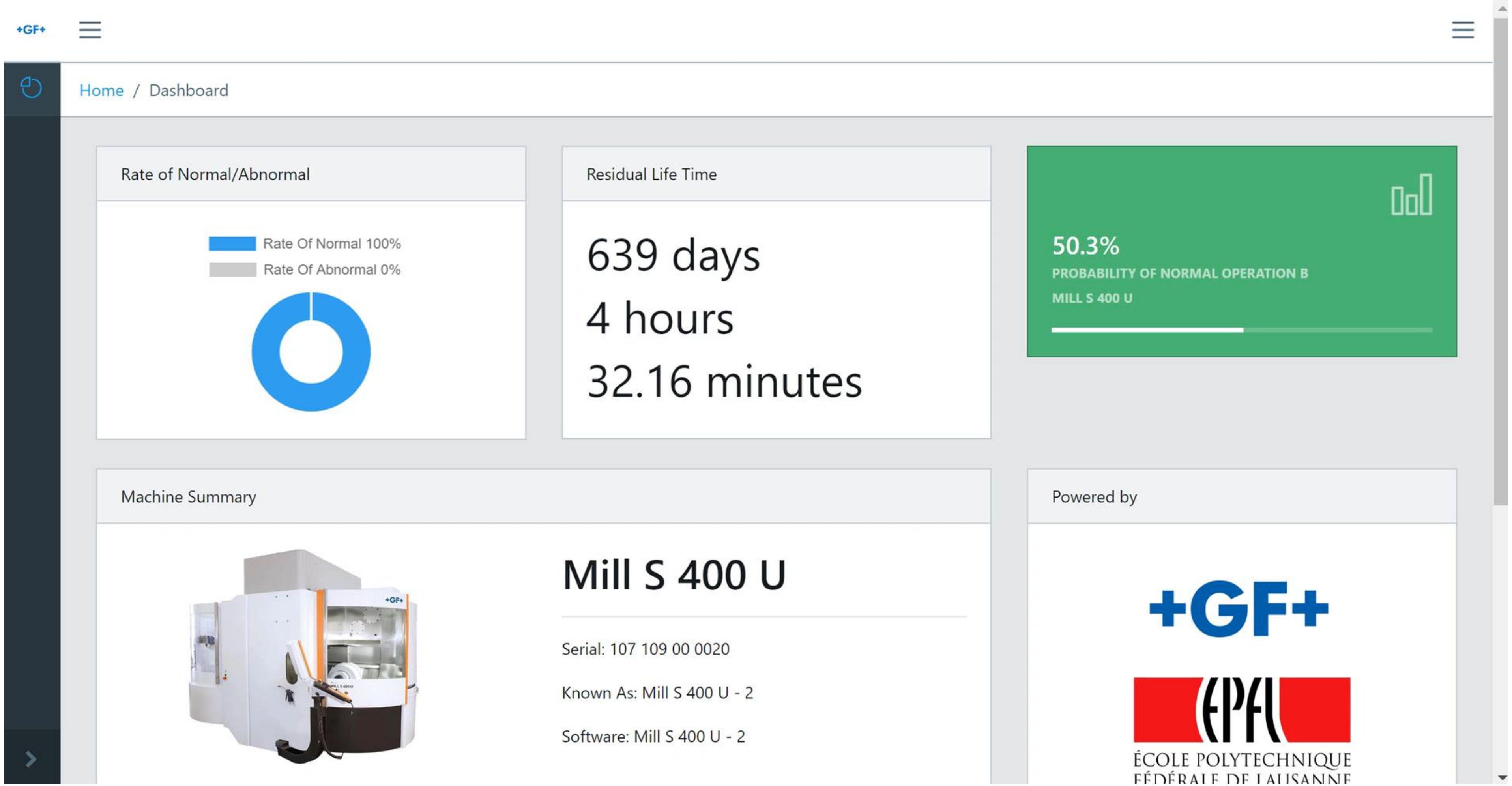






Dashboard to visualize maintenance needs

RUL



Customer can see maintenance alerts as well as accompanying process data

AI in Proactive Maintenance

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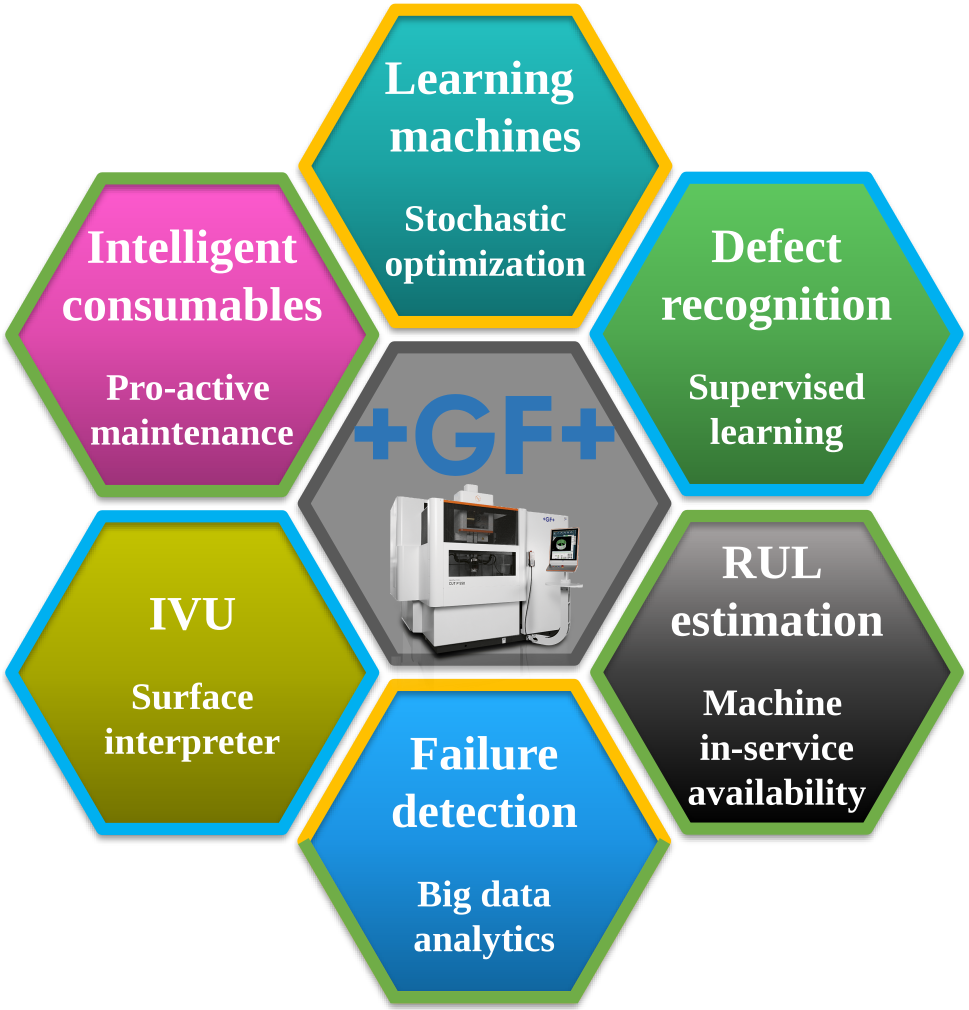
RUL estimation

Machine in-service availability

MAINTENANCE



DEVELOPMENT

OPERATION

MAINTENANCE

AI for Integrated Metrology

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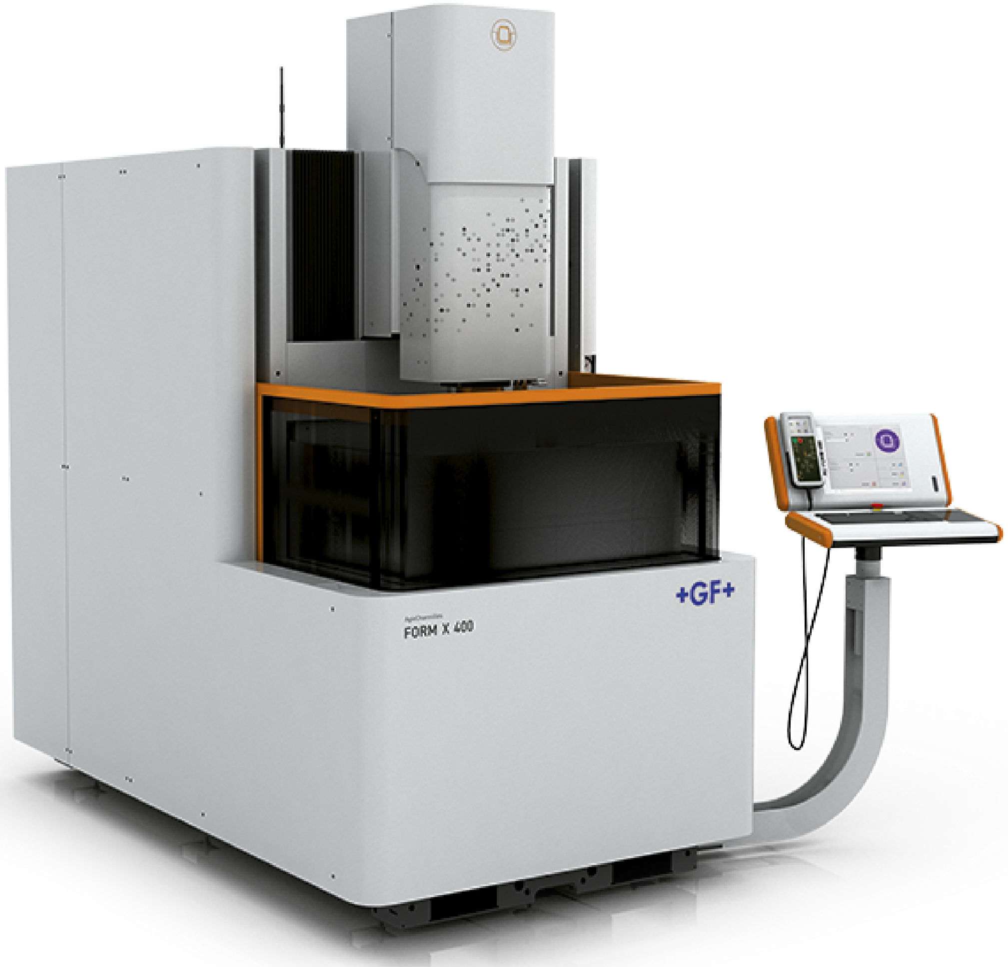
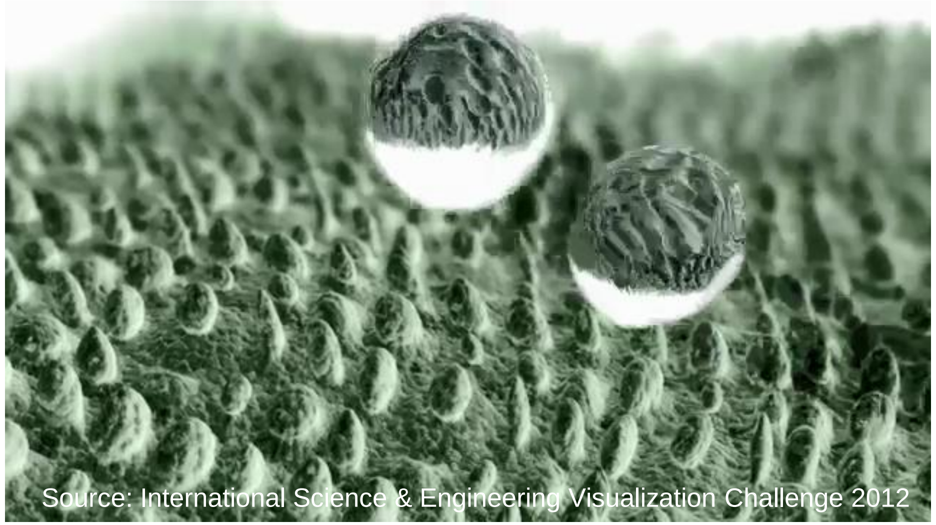
IVU

Surface interpreter



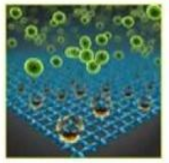
OPERATION

Functional Surfaces – Mother Nature's Magic



Hydrophobic Surface example : **Lotus Leaf**

Self cleaning
- Domestic appliances
- Automobile
- Turbine/Jet engine



Anti-microbial
- Medical

Anti-icing
- Aerospace and defense

Anti-adhesion
- Domestic appliances
- Turbine/Jet engine
- Manufacturing

- Classical methods measure roughness (Ra)

- Similar Ra value, different behavior
- Measure workpiece without removing it from the machine allows:
  - Detect defects: micro cracks, burns, pitting
  - Correct errors automatically
  - Optimize using self-learning automation

In-situ surface characterization is required to achieve desired properties

Our approach : Surface Interpreter

IVU +GF+

Image | Known Ra

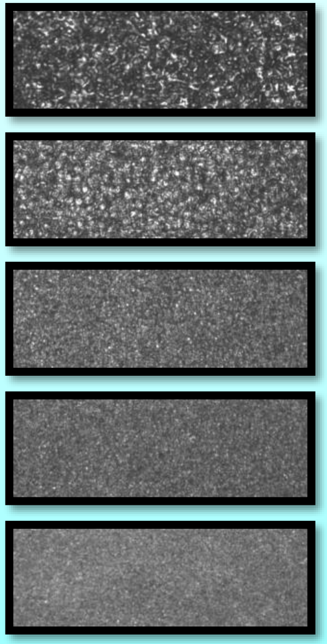


Image	Known Ra
	2.09
	1.21
	0.64
	0.37
	0.17

Prepare Training set

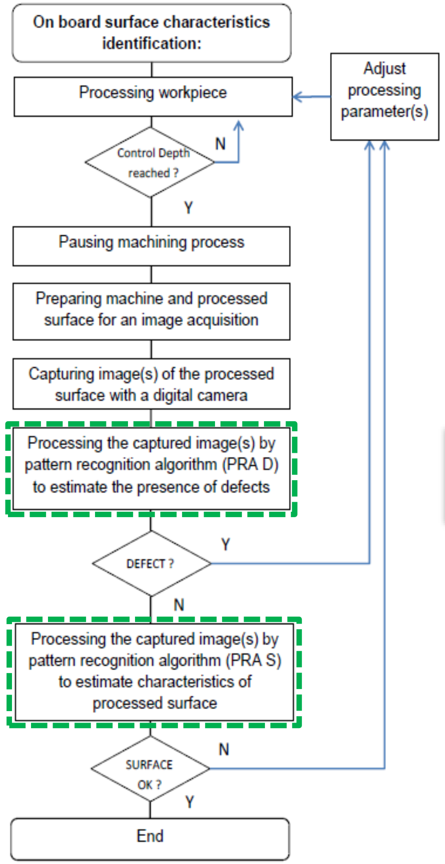
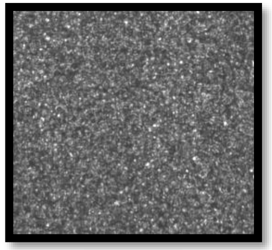


Fig. 10

Process image pattern

New image input



Regressor
or
Classifier

Ra = 0.69 ± 0.11 µm

Output

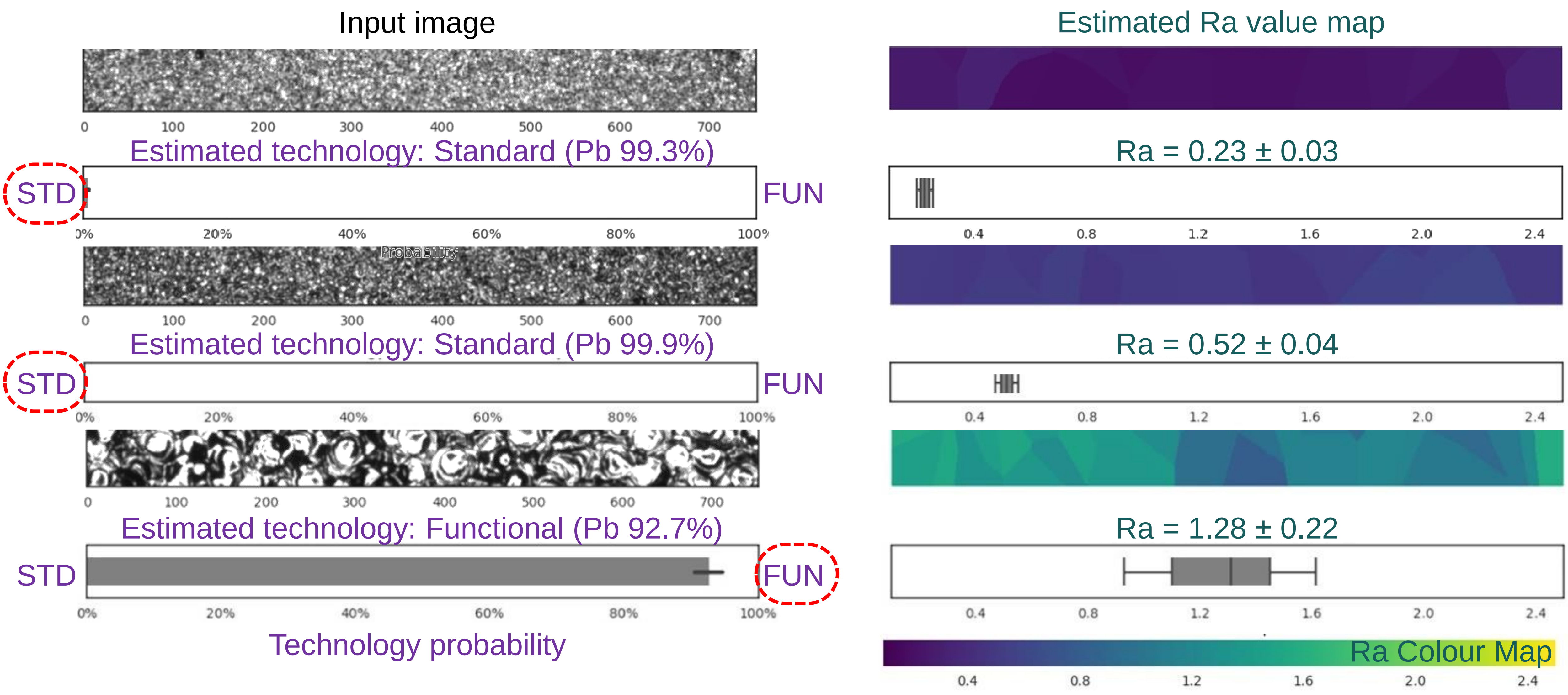
Classify results

Regressor derives surface roughness using training data

Classifier estimates the technology used to produce a surface and identifies defects

Image analysis use Convolutional Neural Networks to recognize fingerprints

Image captured using built-in CCD – then classified



Data processed using EDGE PC with access to cloud-based machine learning data set

AI for Integrated Metrology

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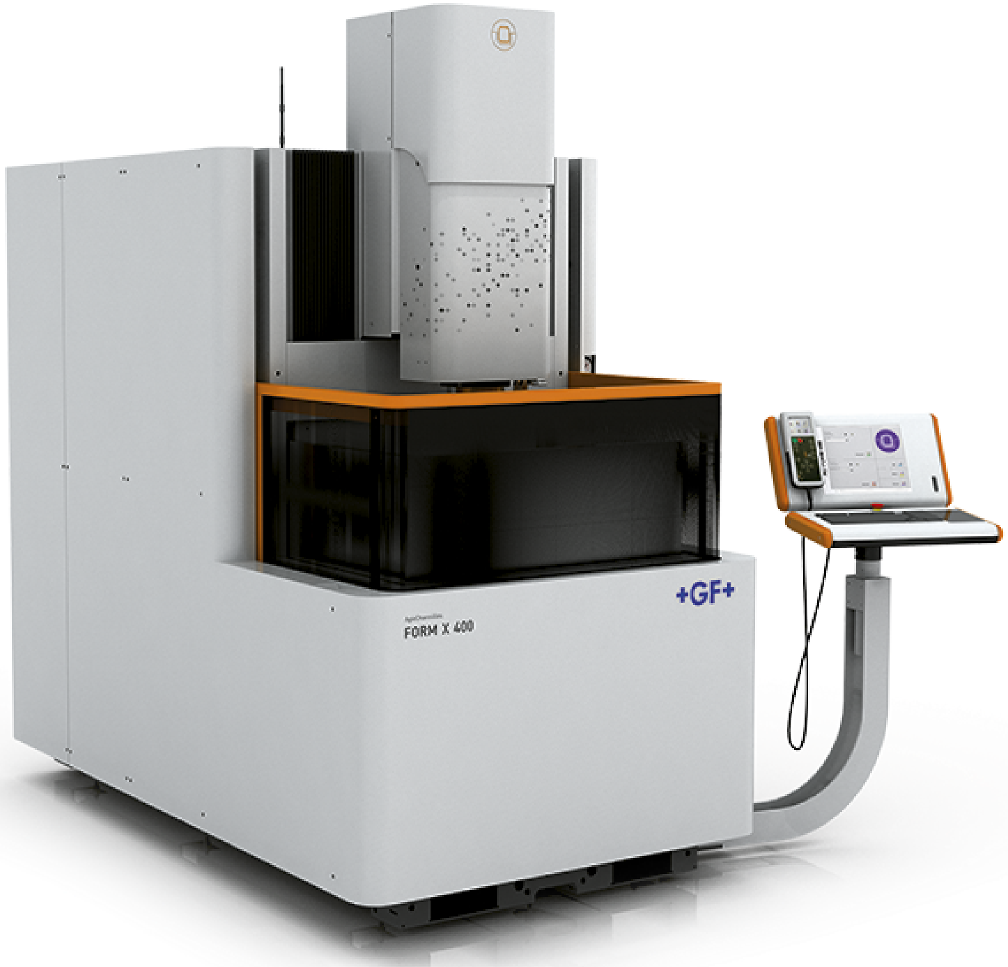
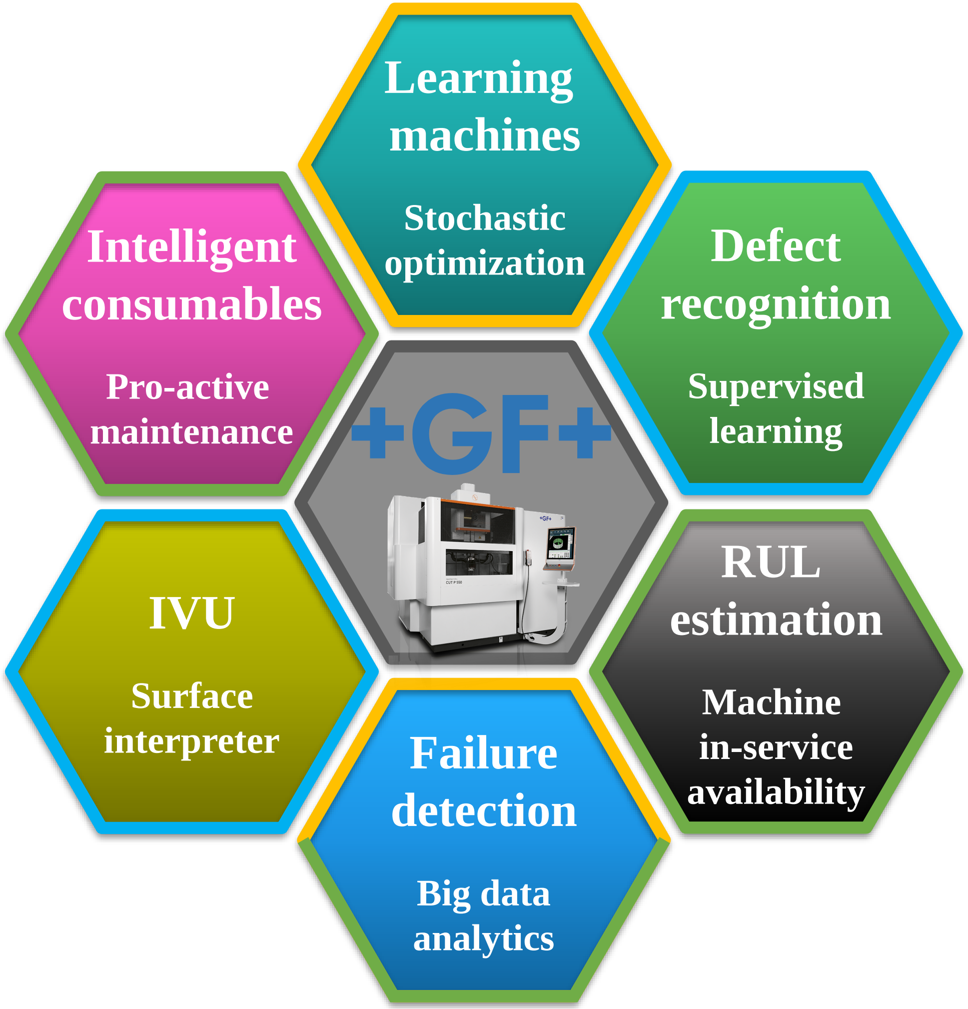
IVU

Surface interpreter



OPERATION



DEVELOPMENT

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AI applications find use across entire manufacturing value chain

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- R&D Development team applies ML to **fast-track** technology development
  - Make customised applications a reality
  - Technology adaptation on-demand
- AI applications in the field improve customer **flexibility** and operational **effectiveness**
  - Eliminate setting errors by using built-in metrology
  - Instant defect recognition with process data analytics
- Customer care teams support end users throughout product **lifetime** with proactive maintenance tools
  - Anticipate issues before they become a problem
  - Intelligent consumables “just in time”

DEVELOPMENT

OPERATION

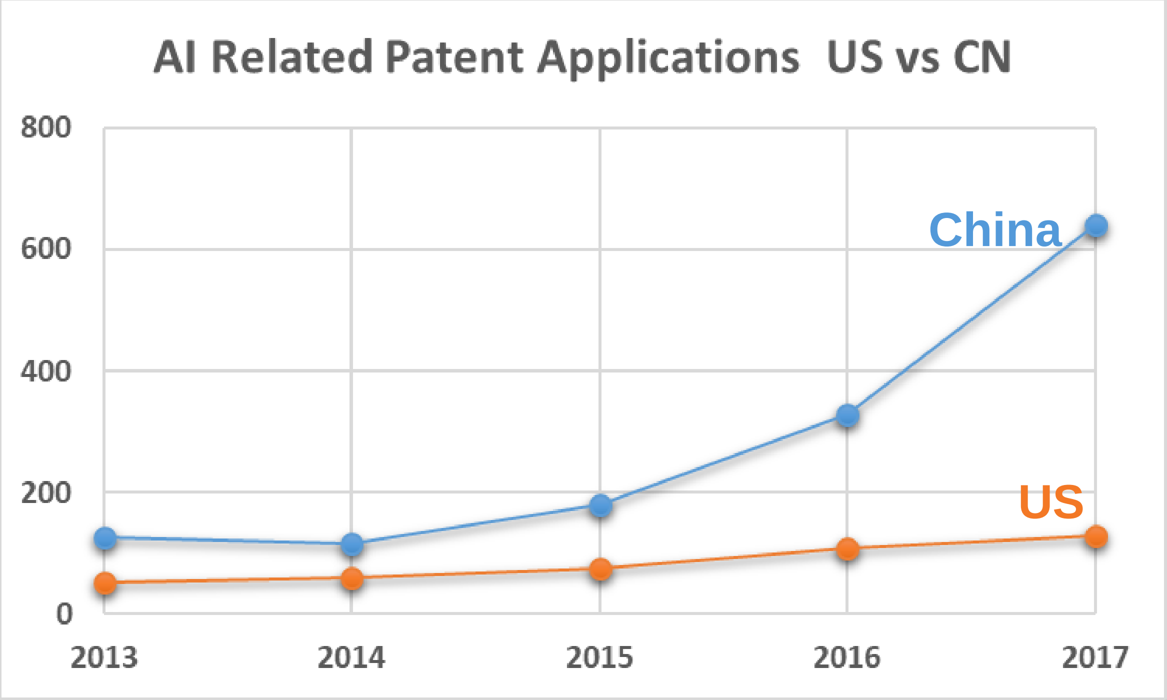
MAINTENANCE

All three domains share AI competencies and tools

Conclusions

Can we afford *not* to AI ?

1. Accelerating customer demands for application-specific solutions and on-demand configurations
2. Manufacturing value chains growing in complexity and need to be adaptive
3. Relentless push for higher performance/productivity without costly (and error-prone) human intervention
4. AI empowered by IOT tools has proven its capabilities; enables huge worldwide investments into this field
5. Competitors in Asia driving ahead at full speed



Data: CB Insights

The choice already made: AI is self-enabling and accelerating !

What comes next ?

Industry 5.0
is already here !

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Thank you

GF Machining Solutions

Passion for Precision