CIVA DS and Simulation for Data Science

CIVA USERS
COMMUNITY EVENT

DS
DATA SCIENCE

Outline

- **Introduction to CIVA DS**
- Key Features of CIVA DS
- Use Case Examples
- Roadmap and Future Perspectives

Introduction to CIVA DS

- ***AI and Data Science are transforming industries****: The rise of AI and machine learning is revolutionizing industrial applications, including Non-Destructive Testing (NDT).*

- ***NDT can greatly benefit from AI****: AI-assisted diagnosis and automation can improve detection capabilities and efficiency.*

- **Challenges remain**: *Key obstacles to overcome include* :

    - Data availability,
    - Reliability,
    - Explainability

Why CIVA DS ?

- **High-quality synthetic data generation**: CIVA can provide well-labelled data through fast and advanced simulations, reducing reliance on costly experimental data.

- **Flexible numerical experiments**: Users can design and test AI models with controlled parameters, allowing fast iteration and optimization, on large datasets

- **Powerful post-processing tools**: thanks to CIVA generic functionalities, CIVA DS allows data extraction, signal and images processing, advanced reconstruction tools, and structuring adapted for AI applications.

- **Connects simulation and real-world use:** CIVA DS helps ensure AI models are applicable and practical in production environments through its compatibility with acquisition system file formats and the ability to process performance demonstration studies considering a wide set of variables

Outline

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- **Key Features of CIVA DS**
- Use Case Examples
- Roadmap and Outlook

DESK of CIVA DS

CIVA N·D·E 2025

Data Science

Data bases & Metamodels

Data bases Fusion

Python Notebooks

Classification

Outliers Detection

Inversion

User manual

Video

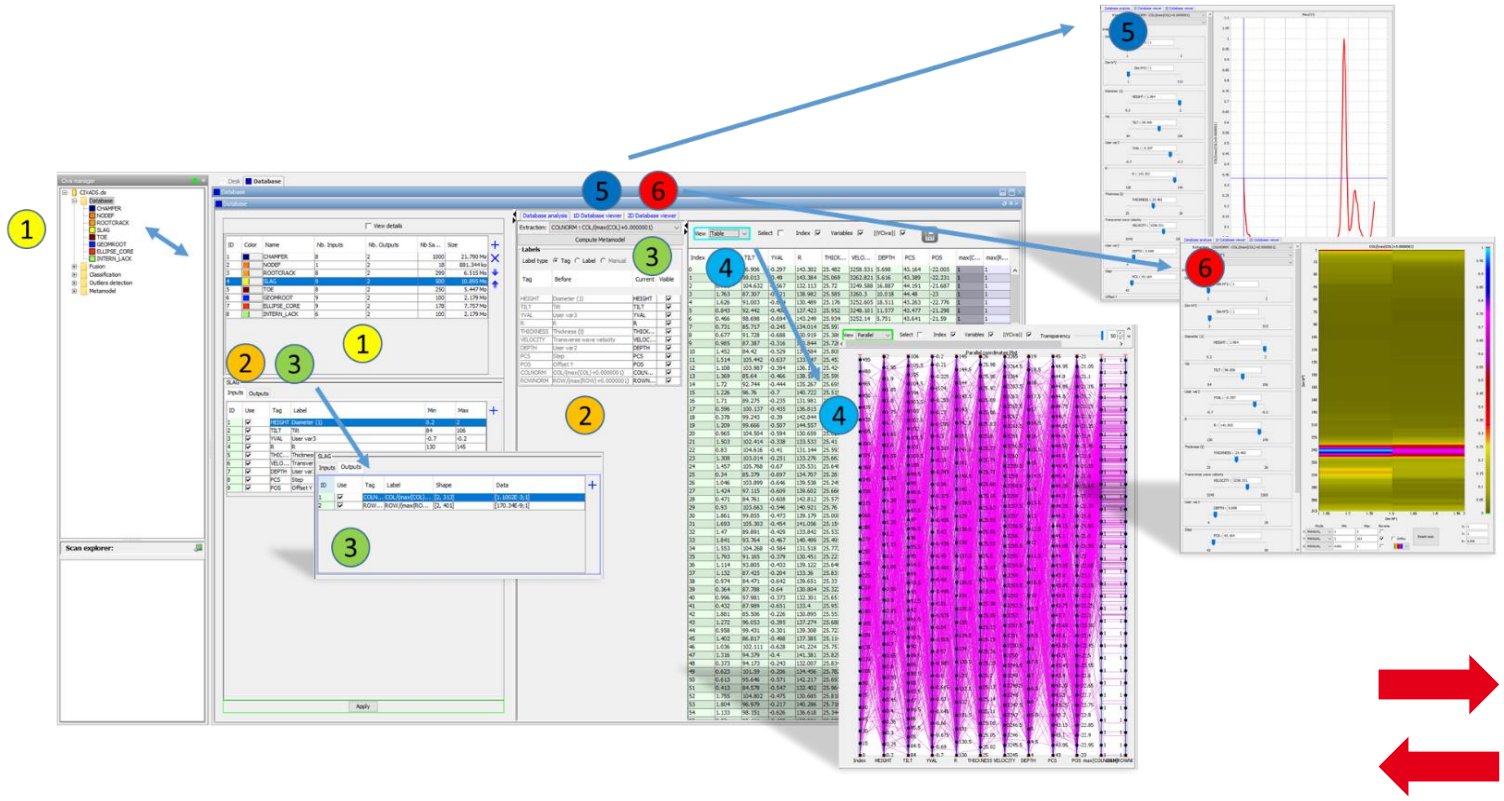
EXTEND CIVA

About CIVA

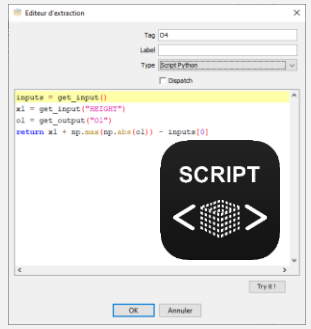
Import and Manage Data

Data bases & Metamodels

- Import data from multiple sources (.var, .cck, .txt, .hdf5, experimental data).
- Customize inputs and outputs for better structuring
- Data visualization for easy interpretation and verification



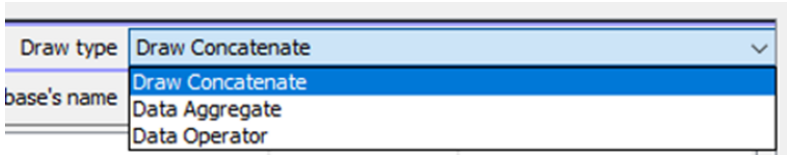
1. List of imported databases
2. List of inputs
3. List of outputs (data) and selection of output visualized
4. Global Visualization (Table or Parallel Plot are available)
5. 1D Visualization of outputs
6. 2D Visualization of outputs (available only for outputs with 2 or more dimensions)



Process your data using a simple formula or **CIVA Script** (python)

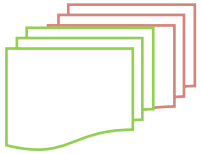
Data Fusion

- Combine multiple datasets for *enhanced learning*.
- Merge experimental and simulated data.



Combine your Data

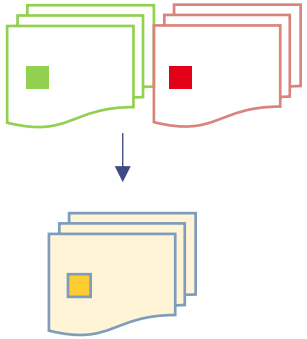
Draw concatenation allows to concatenate samples from several databases in one.



Data concatenation coming from different databases in one new output result of a concatenation of all outputs selected

Data Aggregation allows to concatenate outputs linked to same set of inputs values from several databases in one database

Data fusion allows to merge data from several databases.

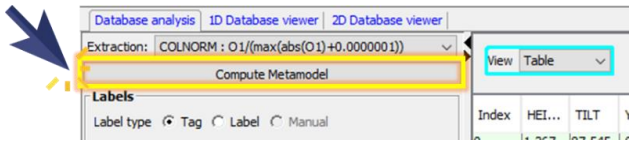


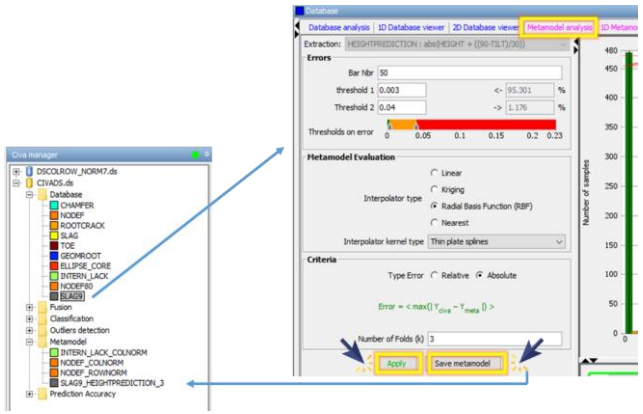
Metamodeling

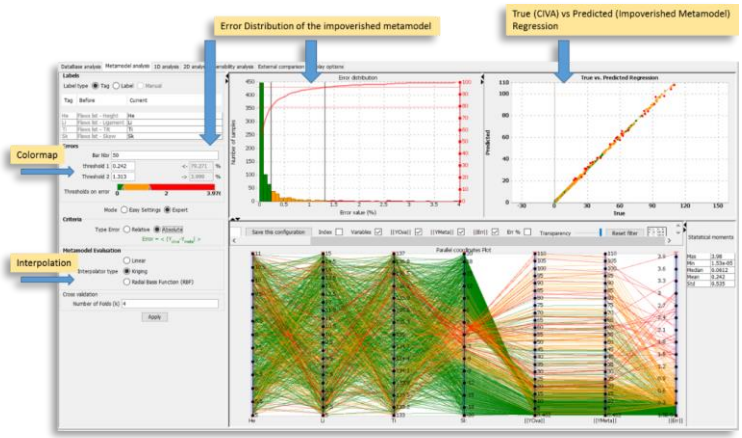
Data bases & Metamodels

- Build a metamodel from any database (customized outputs, fusion, experimental data)
- Access to all metamodels feature (Accuracy Analysis, Sensitivity Analysis, POD, Prediction Accuracy)

Build Metamodels from any type of Data

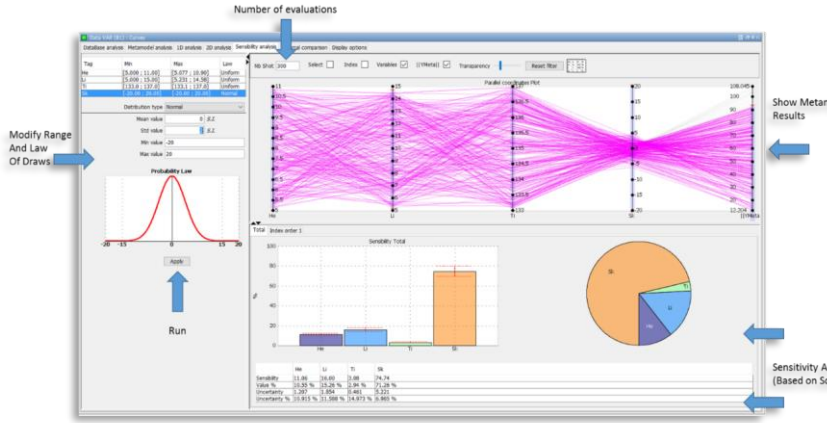




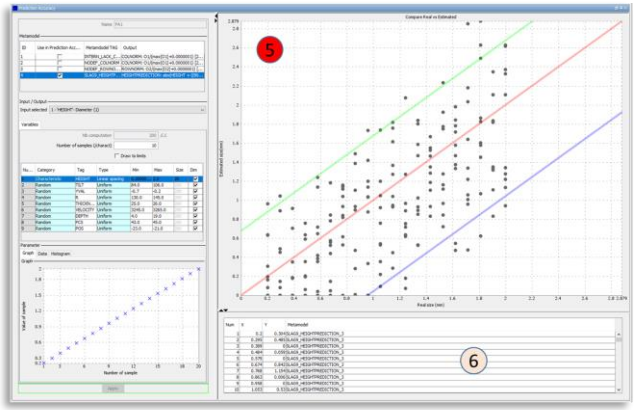


Metamodel Accuracy Analysis

POD



Sensitivity Analysis

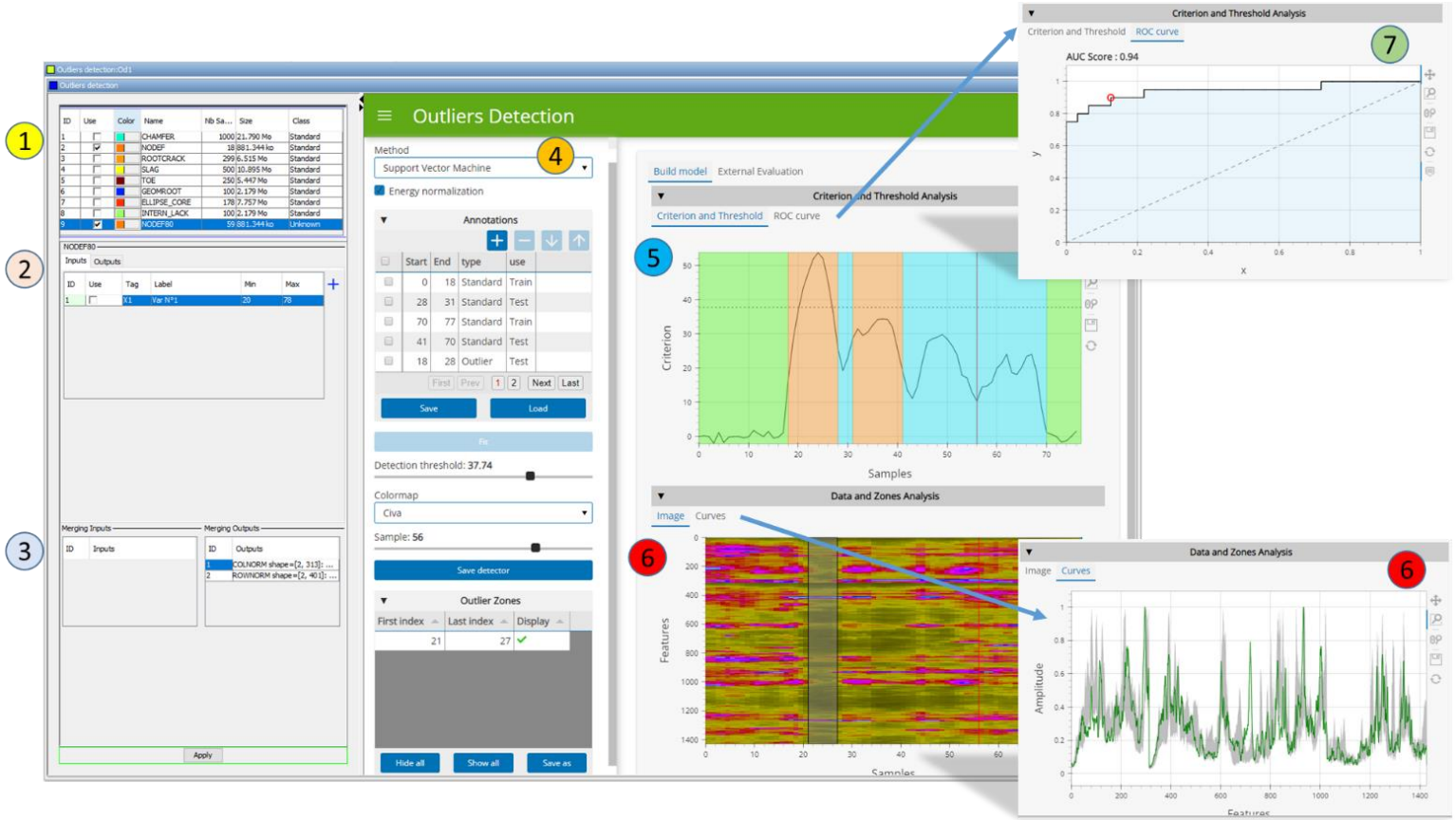


Prediction Accuracy

Machine Learning for Detection

Outliers Detection

- Detect deviations from standard defect-free conditions.
- Binary discrimination for anomaly detection
- ROC curve analysis for performance evaluation.

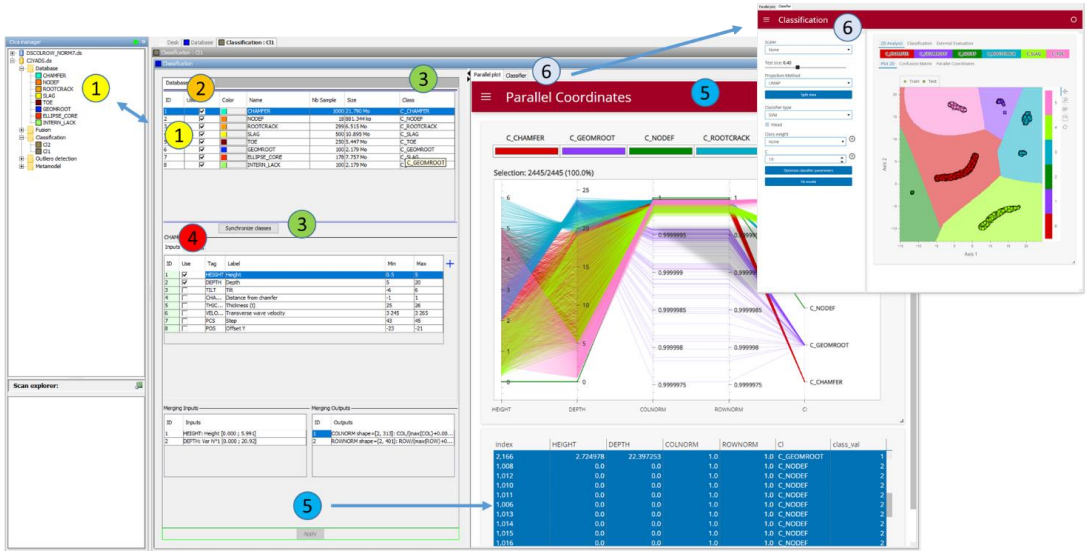


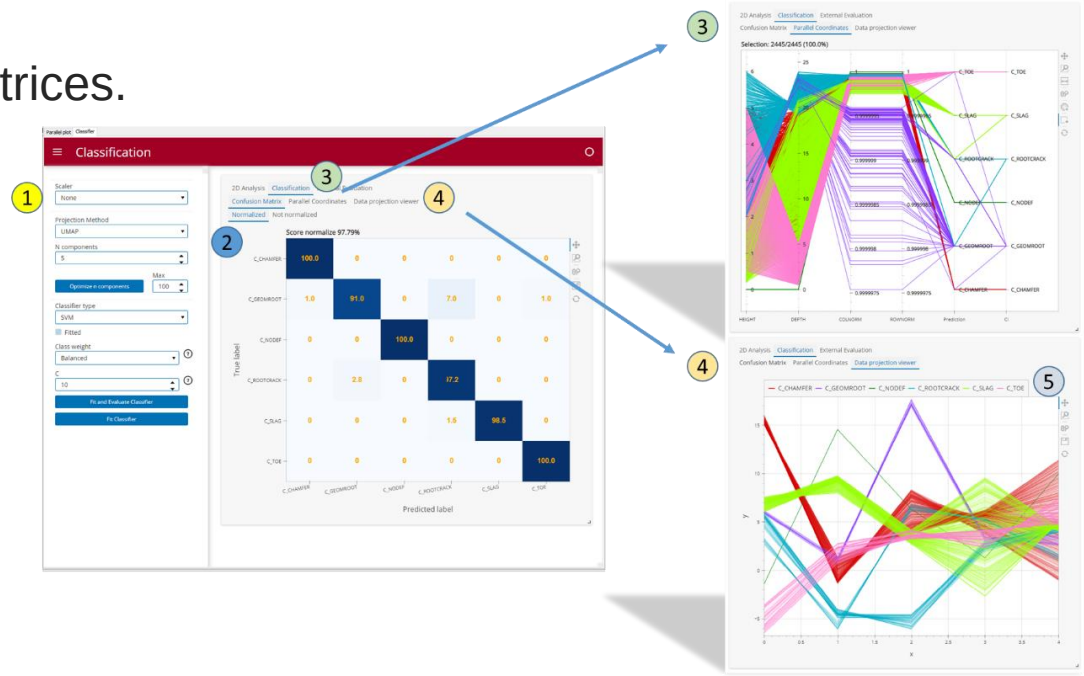
The outliers detection module allows to use databases for a "single class" training. The main idea is to learn "one situation" (for example "no defect situation") and to detect outlier cases (for example "with defect situation")

Machine Learning for Classification

Classification

- Select and structure data for classification models.
- Organize your data by class
- Compare algorithms for optimal performance.
- Visualize results using parallel plots and confusion matrices.





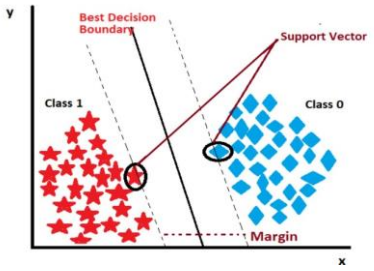
Unified Algorithm Testing Environment: A single platform for evaluating both standard algorithms and specific advanced algorithms with Plug-in capabilites

Machine Learning for Classification

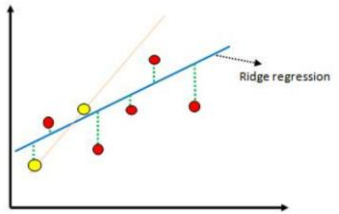
Classification

Classification Algorithms available in CIVA DS

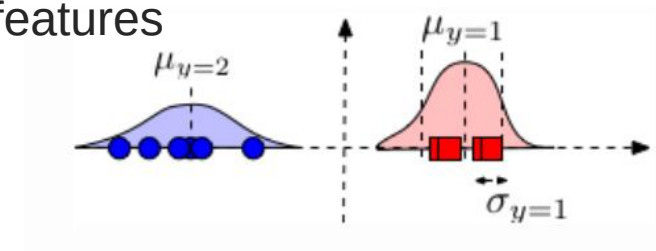
- **SVM** : Support Vector Machines
  Find the optimal hyperplane that separates the data into different classes, while maximizing the margin between the classes.



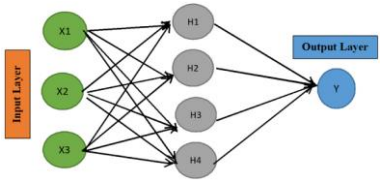
- **Ridge** :
  Converts the label data into [-1, 1] and solves the regression method's problem



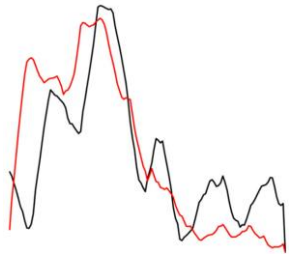
- **Naïve Bayes** :
  Look at how likely each feature is to belong in that category, assuming those features don't affect each other



- **MLP** : Multi Layer Perceptron
  Artificial neural network that learns to make predictions by adjusting connections between layers of artificial neurons



- **Time Series Correlation**
  finds how much two sets of data that change over time are related



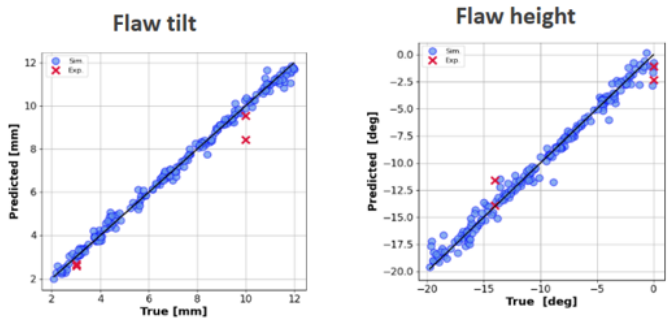
Machine Learning for Inversion / Regression

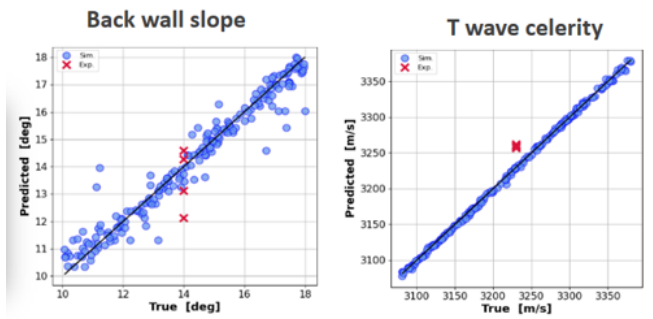
Train regression models to predict continuous values.
Utilize simulated or experimental data to create accurate estimators

- Select parameters to invert
- Select and structure data for inversion models.
- Compare algorithms for optimal performance.
- Visualize results using scatter plot with 95% and 5% percentiles of residuals.

In progress …

- Inversion results



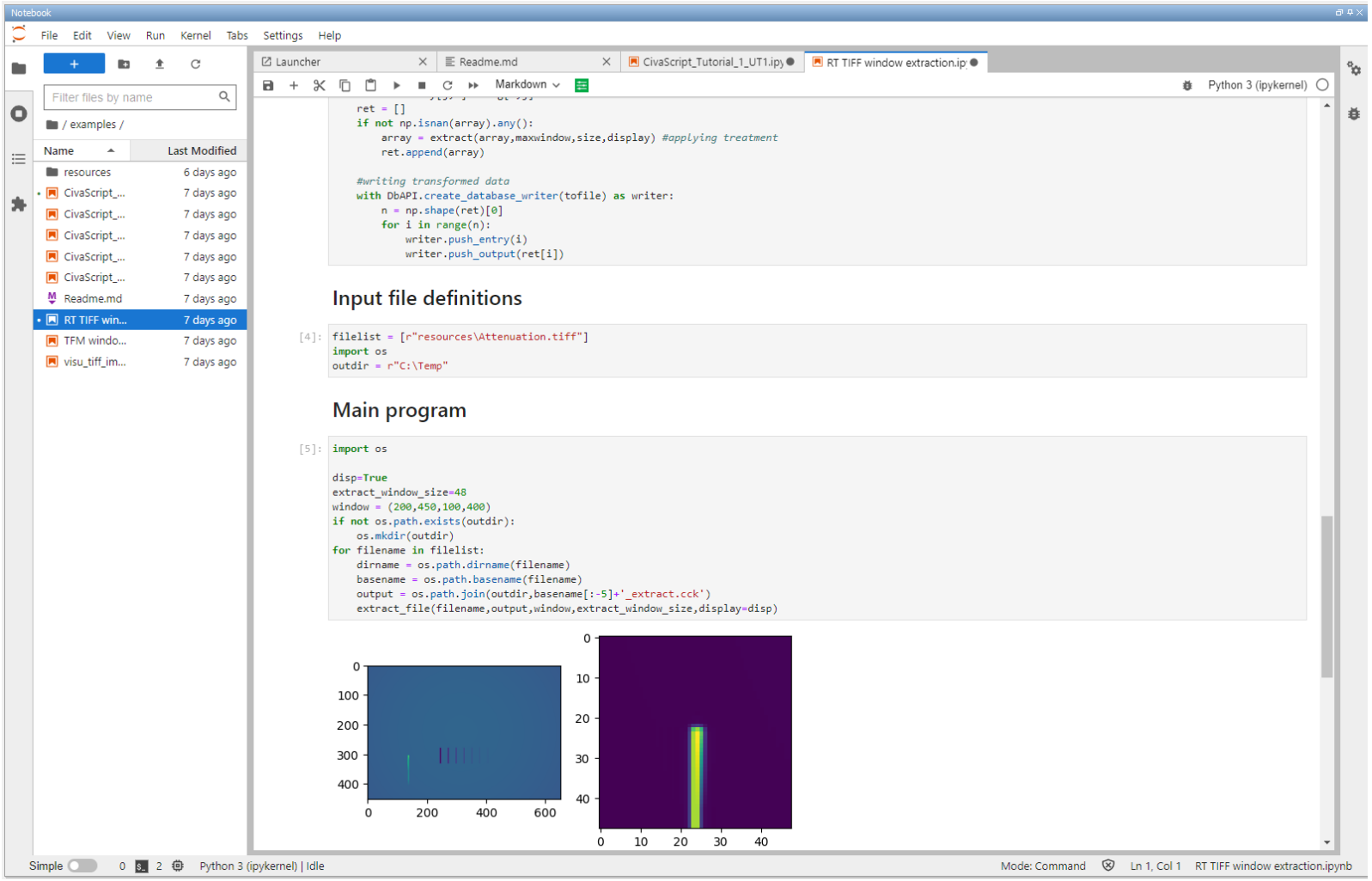


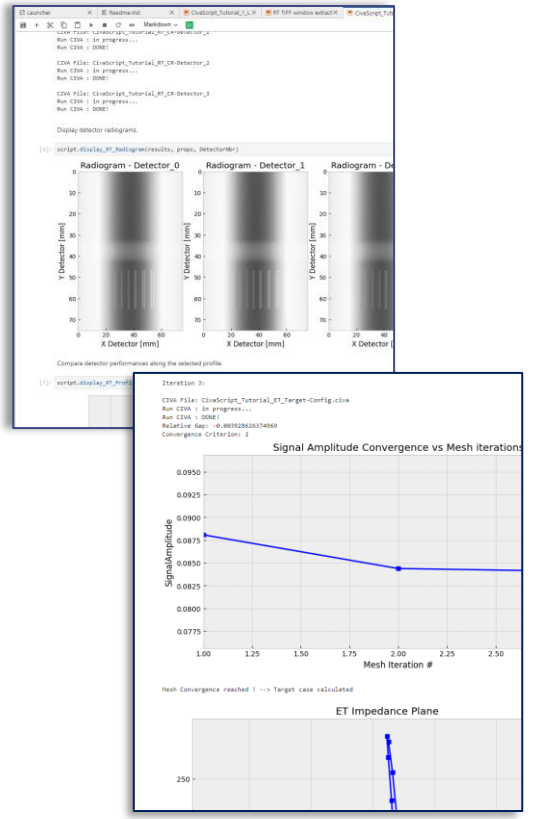
Notebooks

The CIVA DS Python notebooks allow to offer a simple access for user to specific and advanced features not available through CIVA GUI
User can define its own notebook using CIVA Python API for easy data access , post processing and data base generation

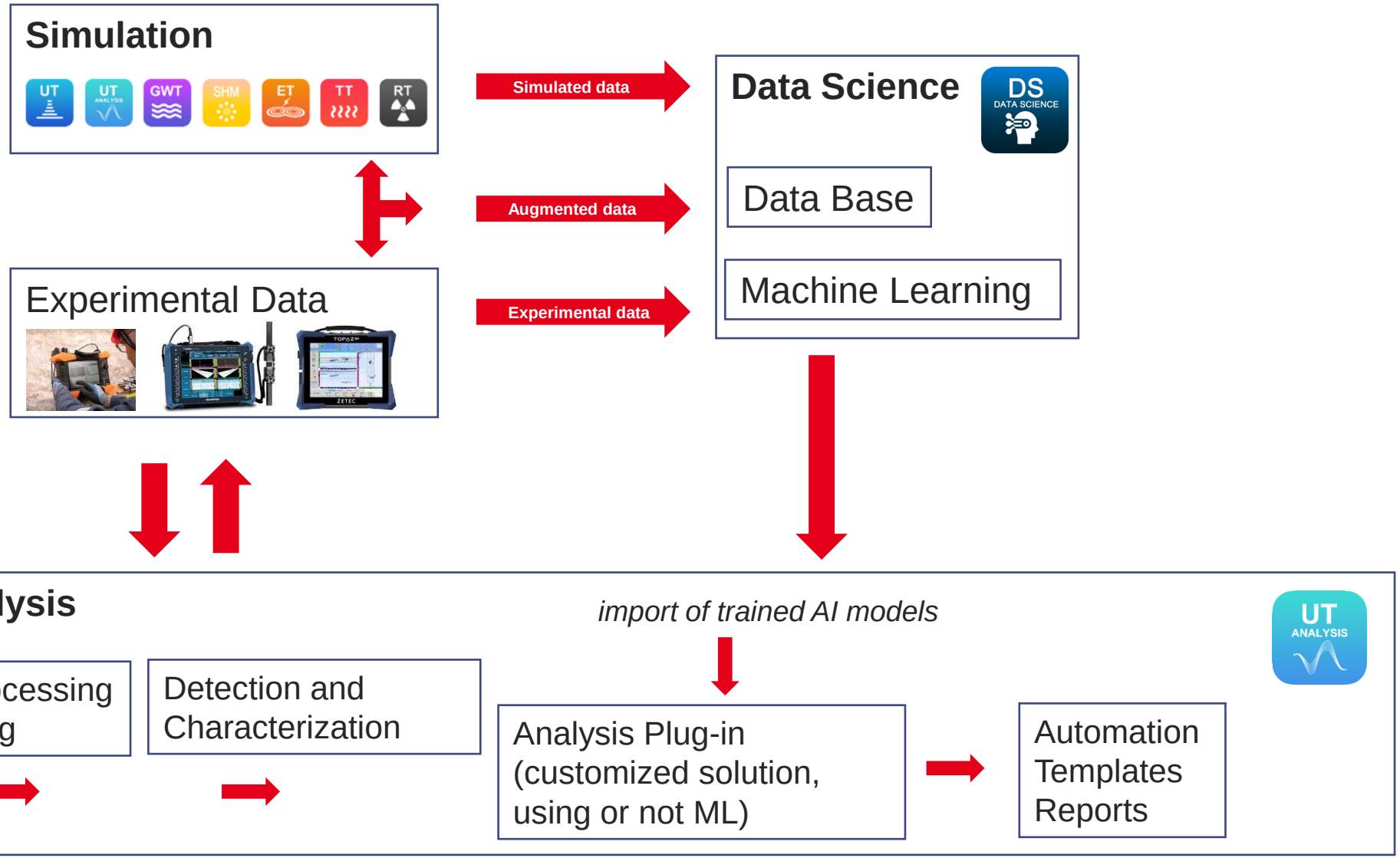
Python Notebooks

SCRIPT





In Summary


Simulation
UT
UT ANALYSIS
GWT
SHM
ET
TT
RT
Simulated data
Augmented data
Experimental data
Experimental Data
Data Science
DS DATA SCIENCE
Data Base
Machine Learning
CIVA Analysis
Signal Processing PA Imaging
Detection and Characterization
import of trained AI models
Analysis Plug-in (customized solution, using or not ML)
Automation Templates Reports
UT ANALYSIS

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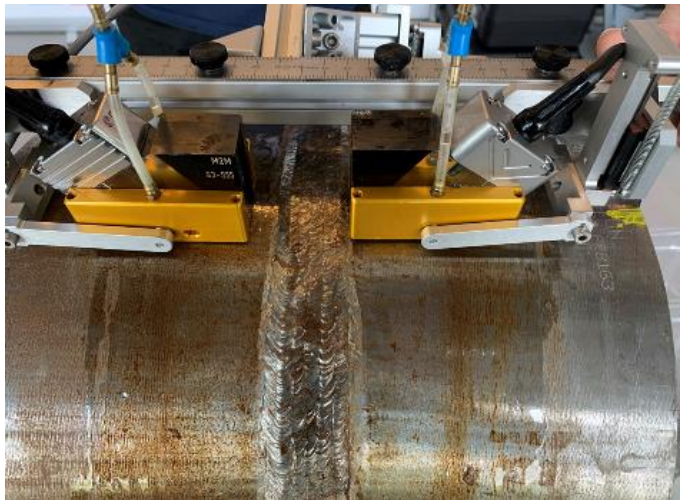
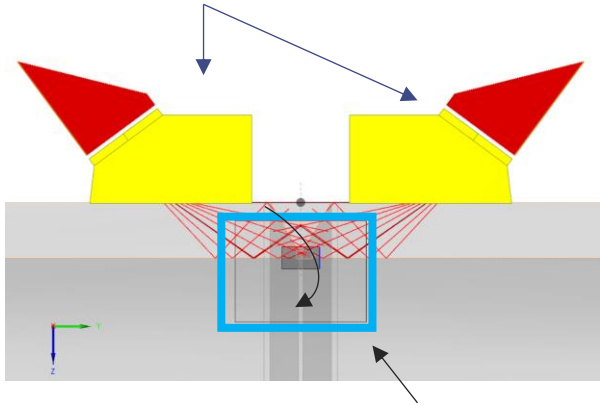
- Roadmap and Outlook

AI and simulation-based diagnosis



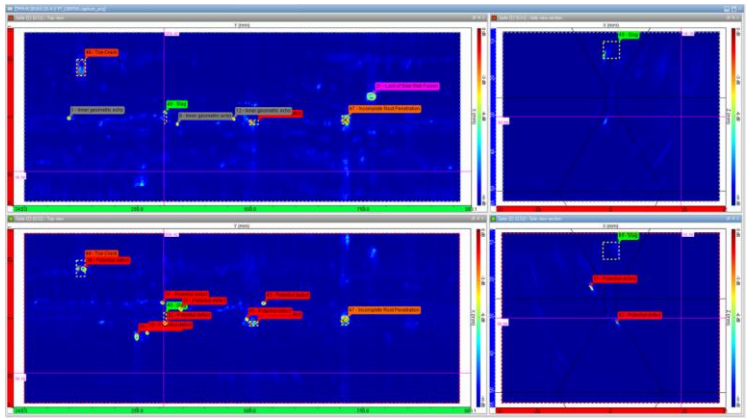
V-Weld 30°
Thickness 25.4mm
Steel tube
Diameter 300mm

2 PA Probes (US and DS) : 5MHz 64 elements : 38 mm x 10 mm
TFM-PWI inspection 43° to 79°, 6 angles



Optimized TFM zone for direct reconstruction (the echoes from the CAP zone will be detected after reflection => visible at the bottom of the zone).

Detection Threshold-12dB

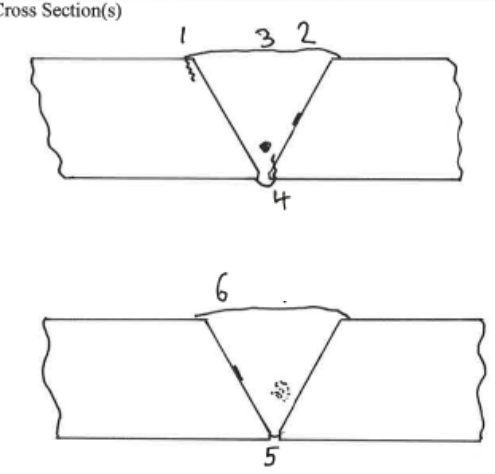


NDE INSPECTION REPORT

ULTRASONIC

Customer	CEA Saclay		Date	28/03/19
Specimen ID	P 28163		Specimen Type	Pipe
Dimensions	25 THK. x 300 DIA.	mm	Acceptance Spec.	SI/08/88

Weld/Specimen Cross Section(s)



To Scale

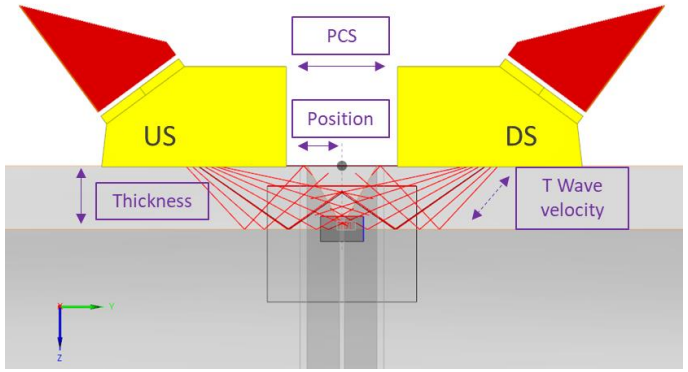
Flaw No	Flaw Type	Flaw Length mm	Distance from 0 mm	Max UT Indication dB	Max UT Indication Angle
1	Toe Crack	24	113	+ 0	45
2	Lack of Side Wall Fusion	22	248	+ 11	60
3	Slag	16	307	- 6	60
4					70
5	Incomplete Root Penetration	18	709	+ 10	70
6	Lack of Side Wall Fusion	15	766	+ 11	60

Comments:
Misalignment noted.

Inspector	Sam Berriman	Signed

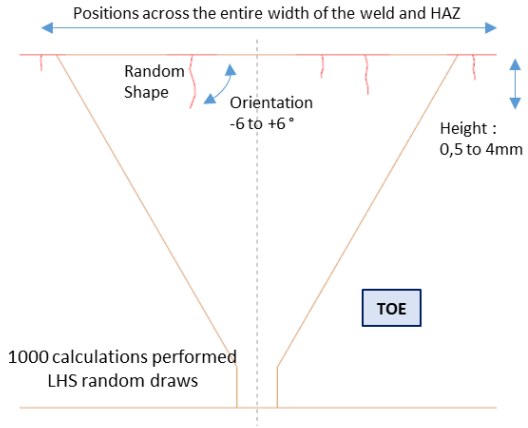
AI and simulation-based diagnosis

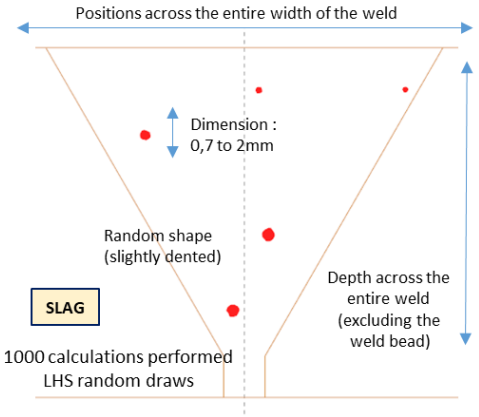
Learning from simulated data
=> Numerical experimental design

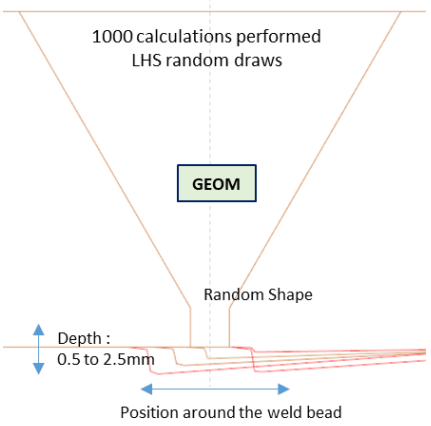


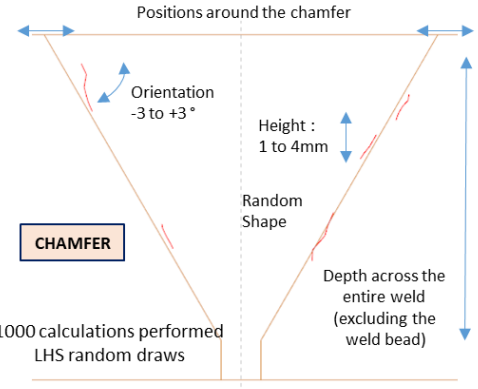
Essential Variables

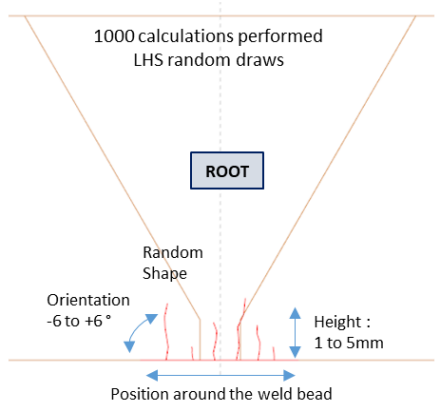
- PCS : +/- 2mm
- Probe misalignment with respect to the weld: +/-2mm
- Thickness : +/- 1mm
- T-wave velocity : +/- 20 m/s

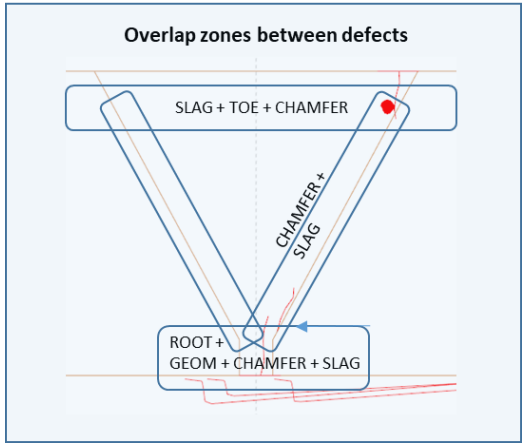




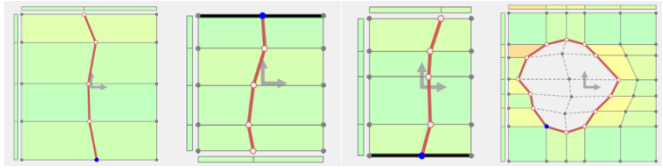






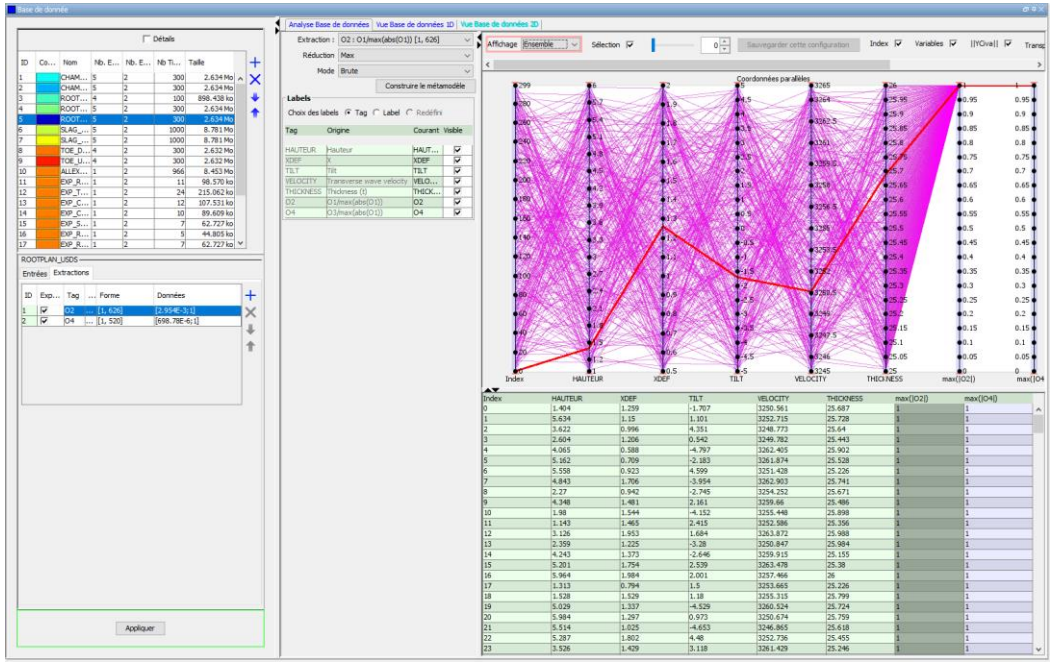


Defects (types, dimensions, positions, orientations, random shape)



AI and simulation-based diagnosis

Data Importation in CIVA DS

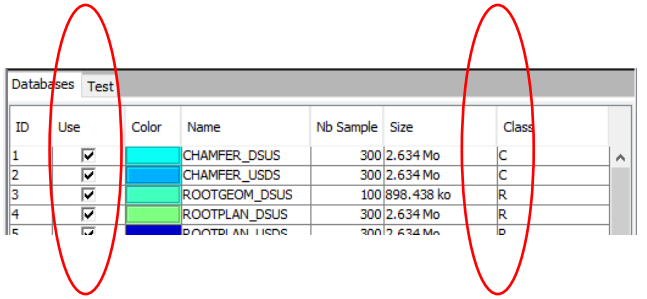


Consolidation and preparation of training data

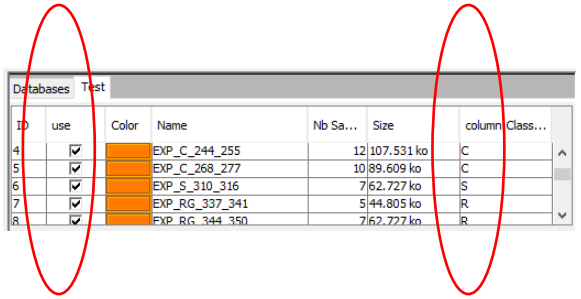
Fusion of Upstream and Downstream channel (using Fusion module)

Normalization of the data [0;1] through “Output Formula Tool”
In this case, we decided to normalize the data in order to bypass the calibration steps between simulation and experiment, and to eliminate the dependency on the defect size (which significantly impacts the amplitude) in a classification context

Selection and labeling (name of the class) for each datadase



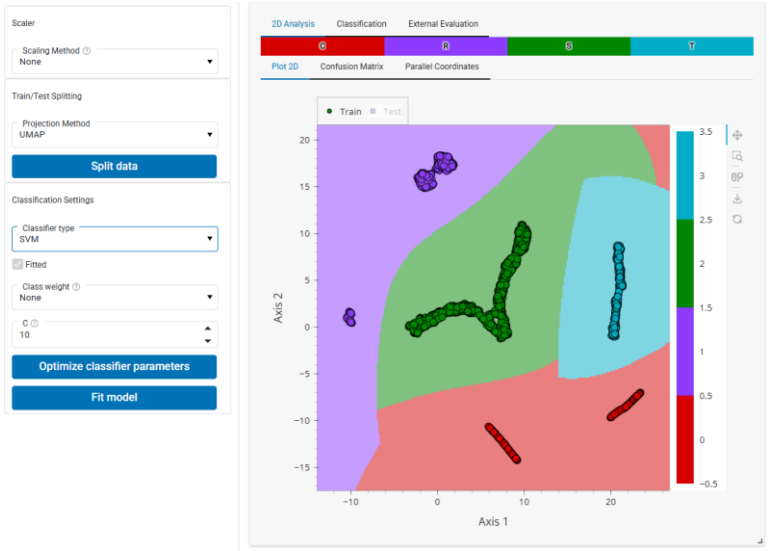
Training datasets
(Simulated data)



Test datasets
(here experimental data)

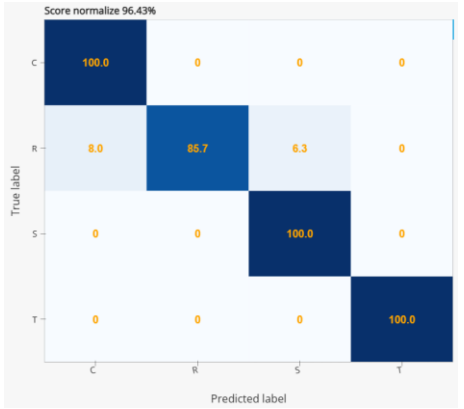
AI and simulation-based diagnosis

Previsualization (2D Projection)

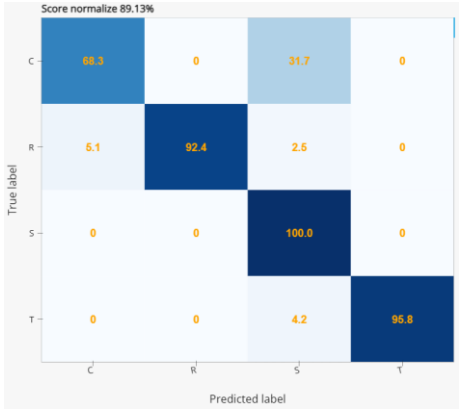


This first step allows to check the separation capabilities of the data
Evaluation is applied by cross validation

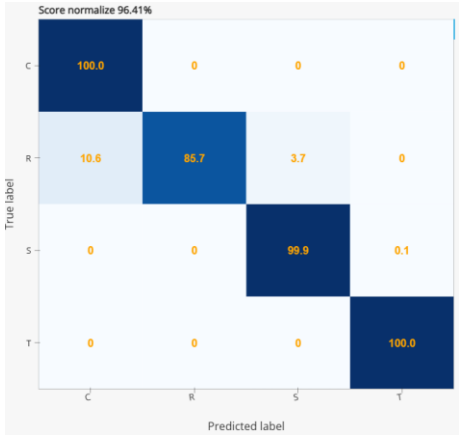
Classification and evaluation



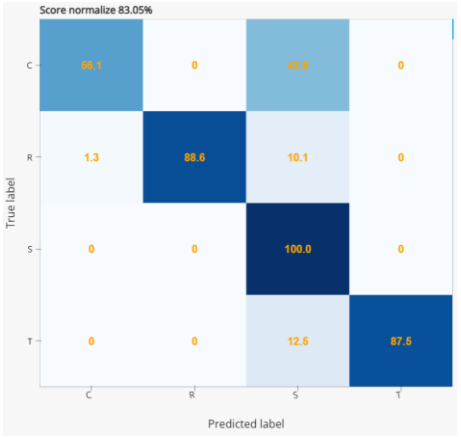
SVM CROSS-VALIDATION



SVM on TEST BASE (EXP.)



MLP CROSS-VALIDATION



MLP on TEST BASE (EXP.)

Search for the best parameters and algorithmic choices

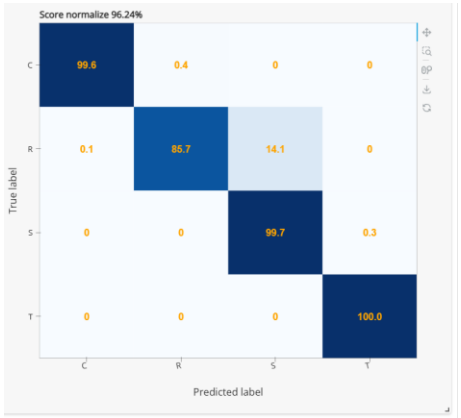
Prediction assessment
of trained models using cross-validation techniques

Prediction assessment of trained models using a dedicated test base

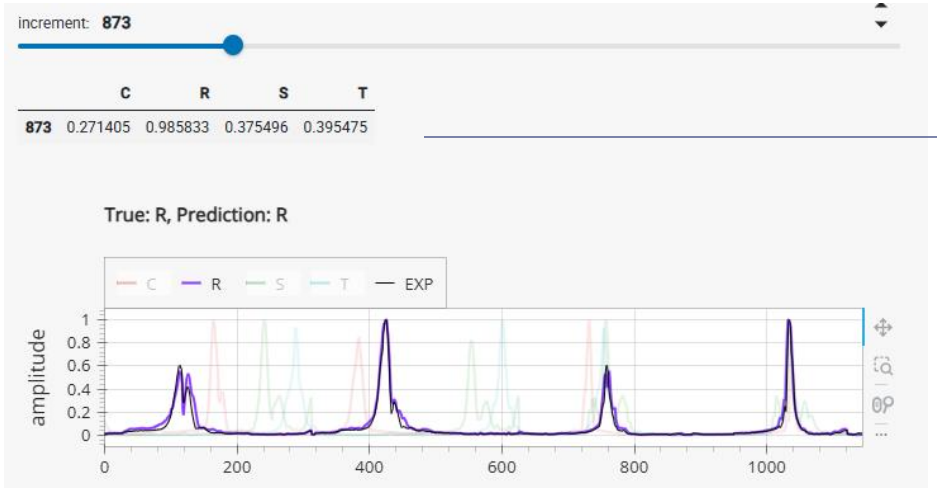
AI and simulation-based diagnosis

Focus on Time Series Correlation (TSC) (CIVA 2025)

Nearest neighbor search using a similarity measure based on signal cross-correlation.

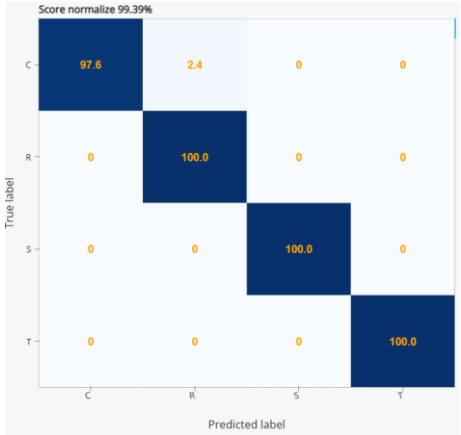


TSC CROSS-VALIDATION

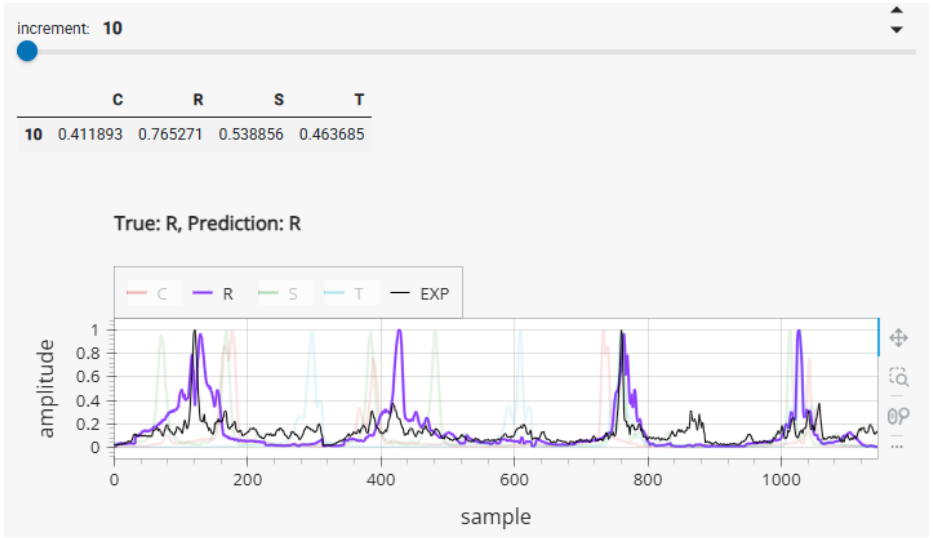


SCORE PER CLASS FOR EACH PREDICTION

TSC CROSS-VALIDATION – SUPERPOSITION DATA TO EVALUATE VS CLOSEST TRAINING DATA FOR EACH CLASS



TSC on TEST BASE (EXP.)



TSC on TEST BASE (EXP.) – SUPERPOSITION DATA TO EVALUATE VS CLOSEST TRAINING DATA FOR EACH CLASS

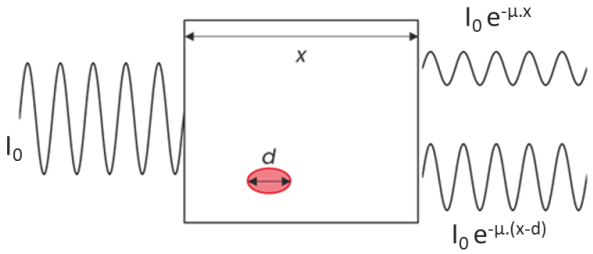
Augmented Simulation for ML

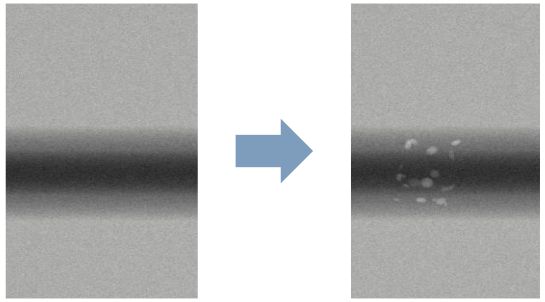
Objective : most realistic simulation results

RT Use Case

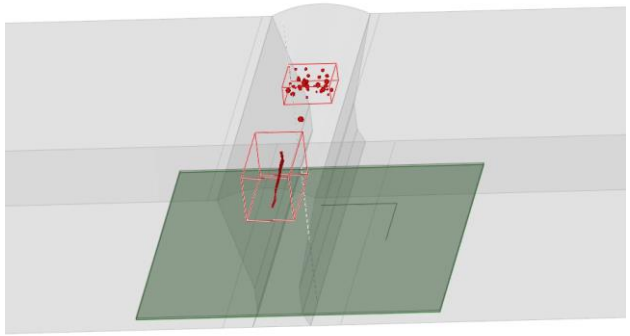
- Experimental image without defect $I_{exp} = I_0 \,.\, e^{-\mu.x} + B$
- **Recalibration :** B → max range of thicknesses

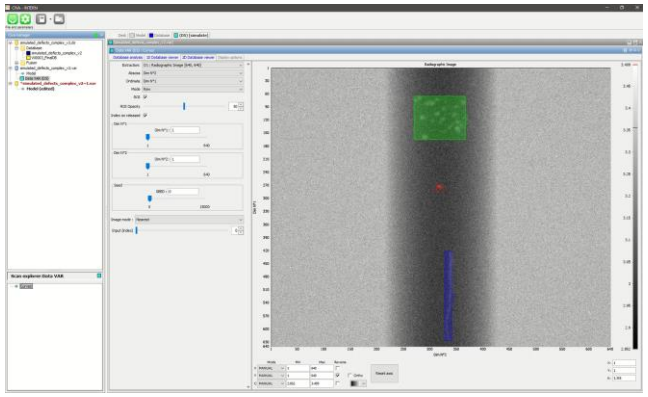
$$I_{aug} = (I_{exp} - B) \,.\, e^{\mu.d} + B$$





Parametric Study for data base generation

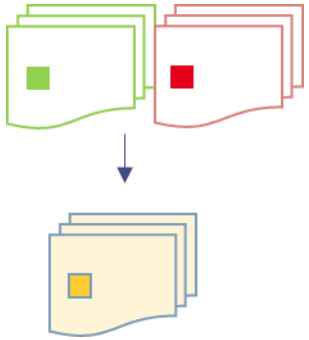




Augmented Simulation for ML

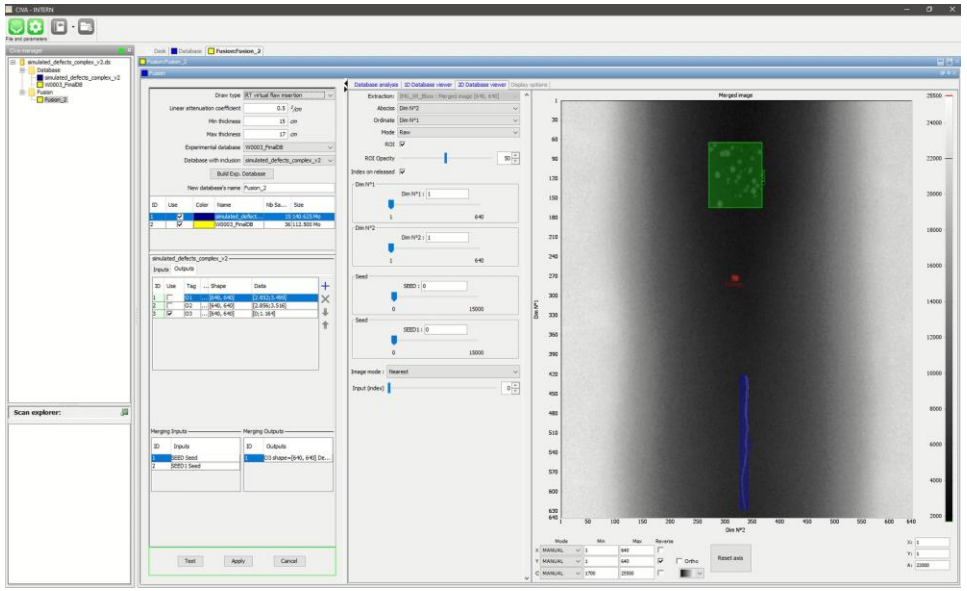
CIVA DS Fusion :

Parametric study + set of experimental images



For each simulated image, random drawing of an experimental image and fusion

Realistic data base with annotations (region of the defect, class name)



Database Ready to be used for Machine Learning (Object Detection on Image)

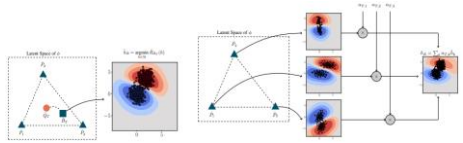
Possibility to adapt the format in Python Notebook thanks to CIVA Script

Outline

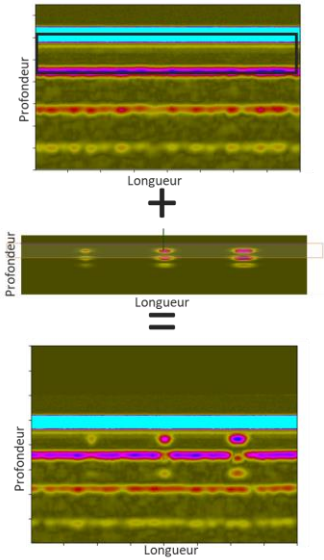
- Introduction to CIVA DS
- Key Features of CIVA DS
- Use Case Examples
- **Roadmap and Outlook**

Roadmap

- Inversion and Optimization Modules with AI Integration
- Augmented Simulation will be extended to other techniques (UT, ET, TT…)
- AI domain adaptation



- *New algorithms based on Explainable AI (XAI) and Trusted AI*
- Bridge to Convolutional Neural Networks in Deep Learning
- Export of AI models for
  - CIVA Analysis Plug-in
  - External use (including real-time embedded integration)



UT Augmented Simulation

Embedded AI

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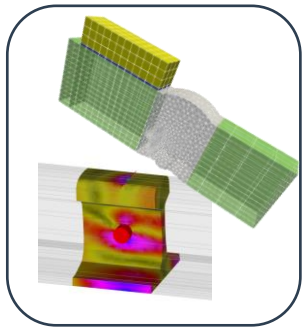
CIVA USERS COMMUNITY Suggestions are welcome !

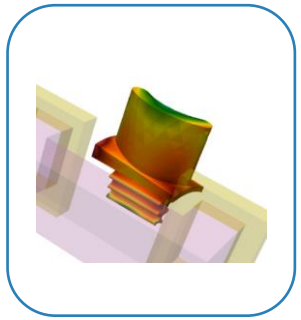
CIVA Strategic Roadmap

MULTI-MODEL



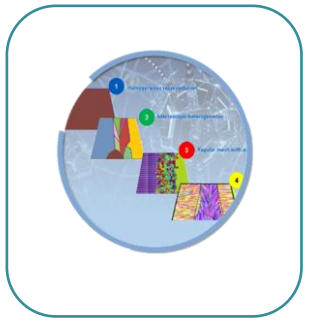
- Semi-Analytical
- Digital
- Hybrid
- Materials

MULTI-TECHNIQUE



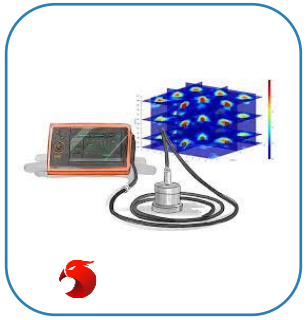
- Thermography
- UT Laser
- Additive Manufacturing
- Trusted and Reliable Simulation

MULTI-SCALE



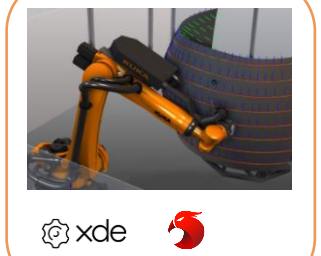
- Materials
- Simulation for Analysis
- Cloud Computing

DATA AND PROCESSING



- Data Science
- Trusted AI (ExpressIf)
- Augmented Imaging
- Reconstruction

DIGITAL TWIN



- Digital Twin (DT)
- Real-time Simulation
- Planning (ExpressIF)

2020 → **2022** → **2024** → **2026** → **2028** → **2030**

CIVA 2021

- Simulation for SHM (numerical model)
- Hybrid models (SA/EF)
- Metamodels
- Robotic control for Nozzle inspections

CIVA 2023

- Thermography
- Numerical calculation for ET
- Demonstration of performance
- Data Science

CIVA 2025

- FE Computation
- RT complete model Fluorescence Bremsstrahlung
- Augmented Simulation
- Data Science

CIVA 2027

- UT : Complex structures and materials
- TT and ET: on 3D CAD Specimens
- Characterization of materials
- Trusted Simulation

CIVA 2030

- CIVA Robotics and DT
- Real-time simulation And AI diagnostics
- Additive manufacturing
- UT laser

+ Continuous updates and improvements to all modules