University of Amsterdam
Multi-scale Networked Systems Research Group

Data-Centric Analysis of Complex Industrial Systems

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Why data-centric solutions?

- Modern systems in many domains are **data-rich ecosystems**
  => Lots of **sensors**

- Computerisation
  => Everything is a **computing platform**
  => Strong presence of **software**

- Systems are continuously evolving during their lifecycle

- Dealing with **non-determinism**
  => A common trait of CPS

There are challenges …

- Data scarcity
  => Sometimes there is not enough data
  => Not of the kind we need
  => Gaps in data streams

- Data deluge
  => Because of: Transfer limitations, processing limitations, latency

- Knowledge incorporation (more on this at the end …)

- How to generalise?
  => Oftentimes solutions are use-case specific

Example use-case:
Anomaly detection/identification

for semiconductor photolithography machines


20
10
0
x100
min-1
60
70
80
km/h
60
40
20
0
140
160
180
200
ABS

iDAPT Project

- *Interactive DSL for Composable EFB Adaptation using Bi-simulation and Extrinsic Coordination*
- National project funded by NWO
- Main project user: ASML Netherlands B.V.
- Other users: TNO, Thales, Radboud University Nijmegen

Robustness

- Things go wrong, no matter how good the design (**design is not static**)

- This is about **detecting** that something is going wrong
  => Unwanted behaviour
  => Light turns on …

- This is also about **distinguishing** between different unwanted behaviour
  => Different things can go wrong in a complex system
  => Different lights, different modes

- If we know about it, we can **fix** it, or reduce its effects
  => Increased robustness

This is exactly what the solution is about!

Robustness: Anomaly detection/identification

- Anomaly: A **readily** detectable deviation in system's normal behaviour
  => A symptom
- Anomaly detection
  => Behaviour is not as intended
- Anomaly identification
  => What sort of trouble are we talking about?
  => Which part? (subsystem)
  => How bad? (severity)
- Predicting anomalous behaviour

It is all about normal behaviour vs anomalous behaviour.

Industrial CPS and phases

- Industrial CPS are **purpose-built**
  => A limited domain of activities and tasks

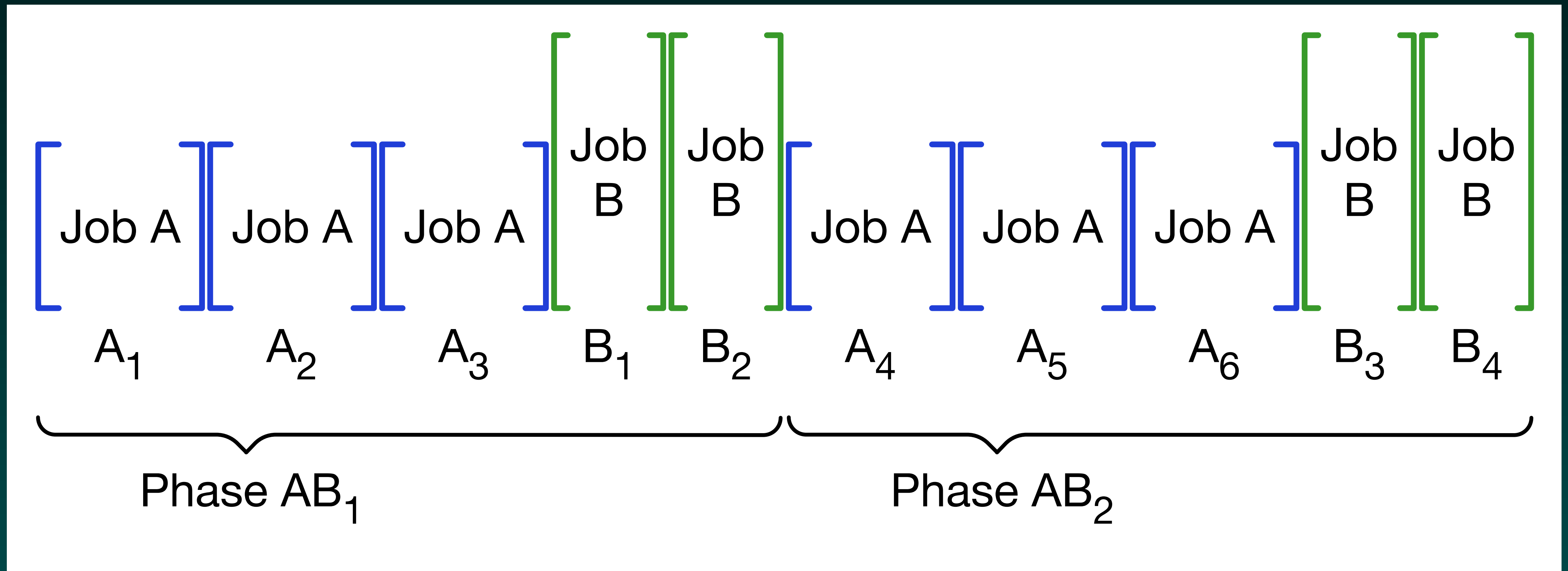
- We want to exploit this repetitiveness for behavioural monitoring

- Execution phases => **Units of execution**

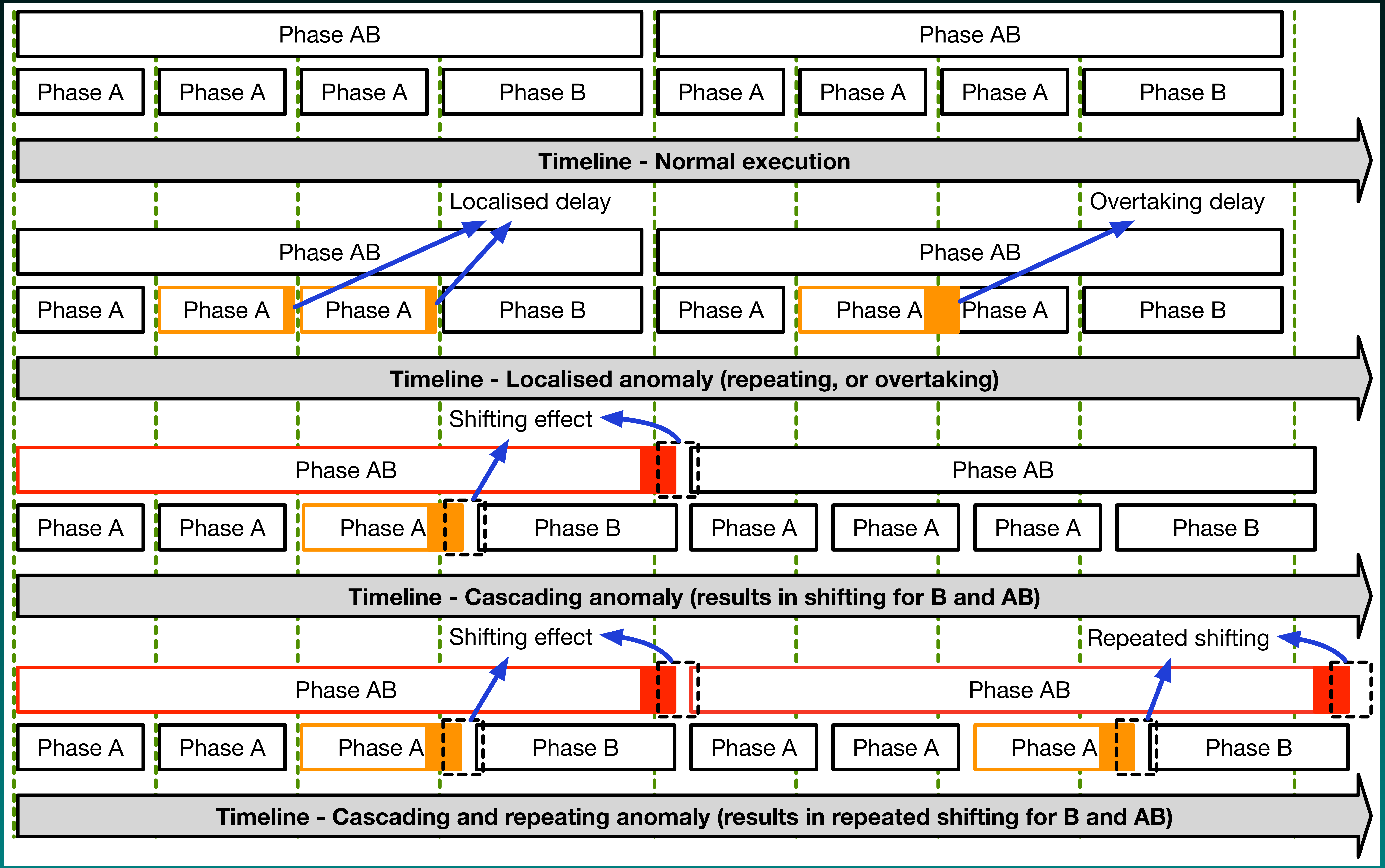
  ➡ Atomic phases: Smallest **repetitive** unit of execution behaviour

  ➡ Combo phases: **Repetitive** combinations of a collection of atomic phases

- Observation and analysis needs will determine phase granularity



Anomalies and their effects



Our subject: Industrial CPS

- We are not dealing with cars, or engines
- We are dealing with industrial machinery
  => But, a specific breed, controlled by computers
- Characteristics of industrial CPS
  => Bunch of computers working together, collectively!
  => Different types of computers, heterogeneous
  => Interaction with the environment
  => Software, software, software, software, software, …

Industrial Cyber-Physical Systems (CPS) are highly repetitive systems

Semiconductor photolithography machines

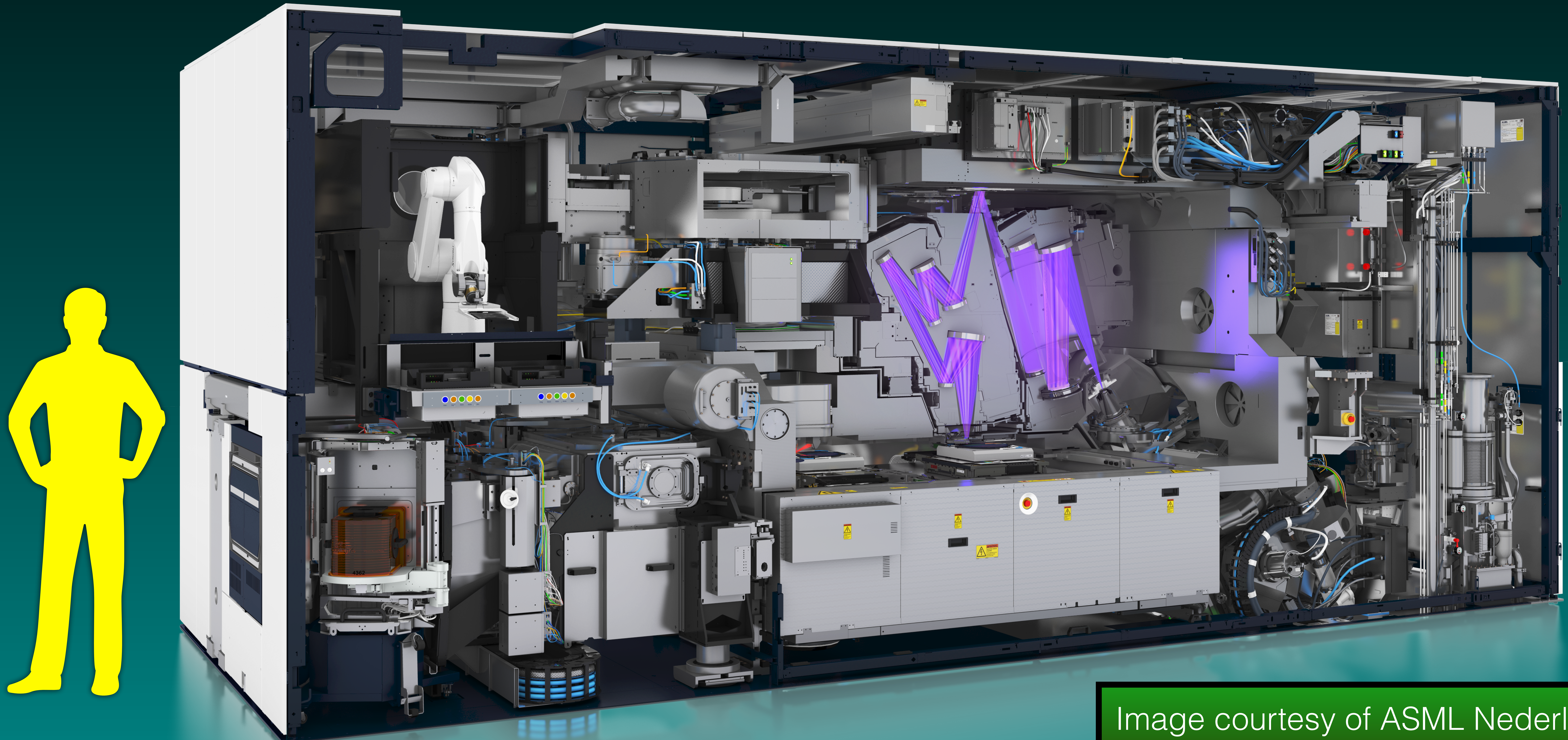
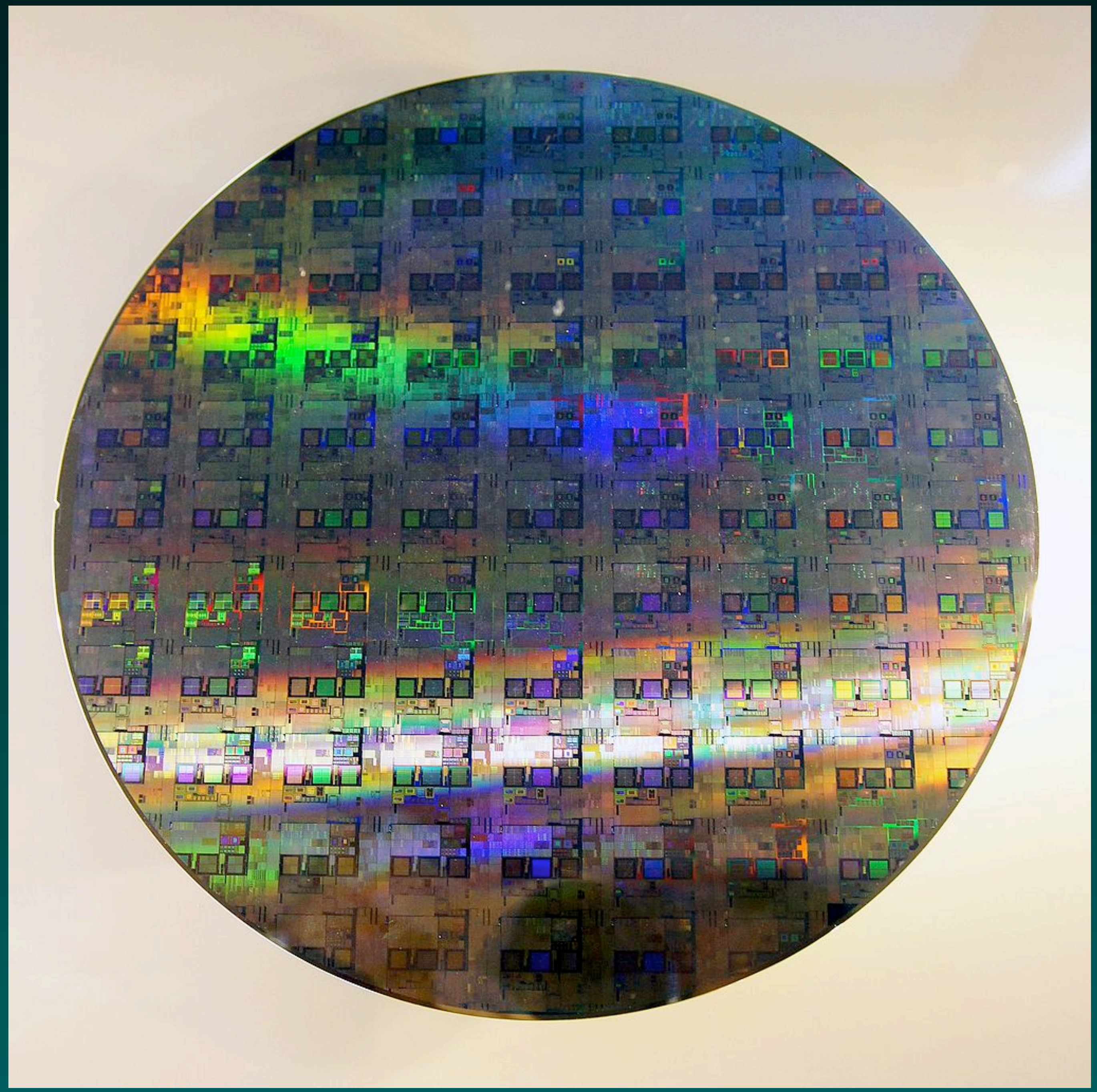


Image courtesy of ASML Nederlands B.V.

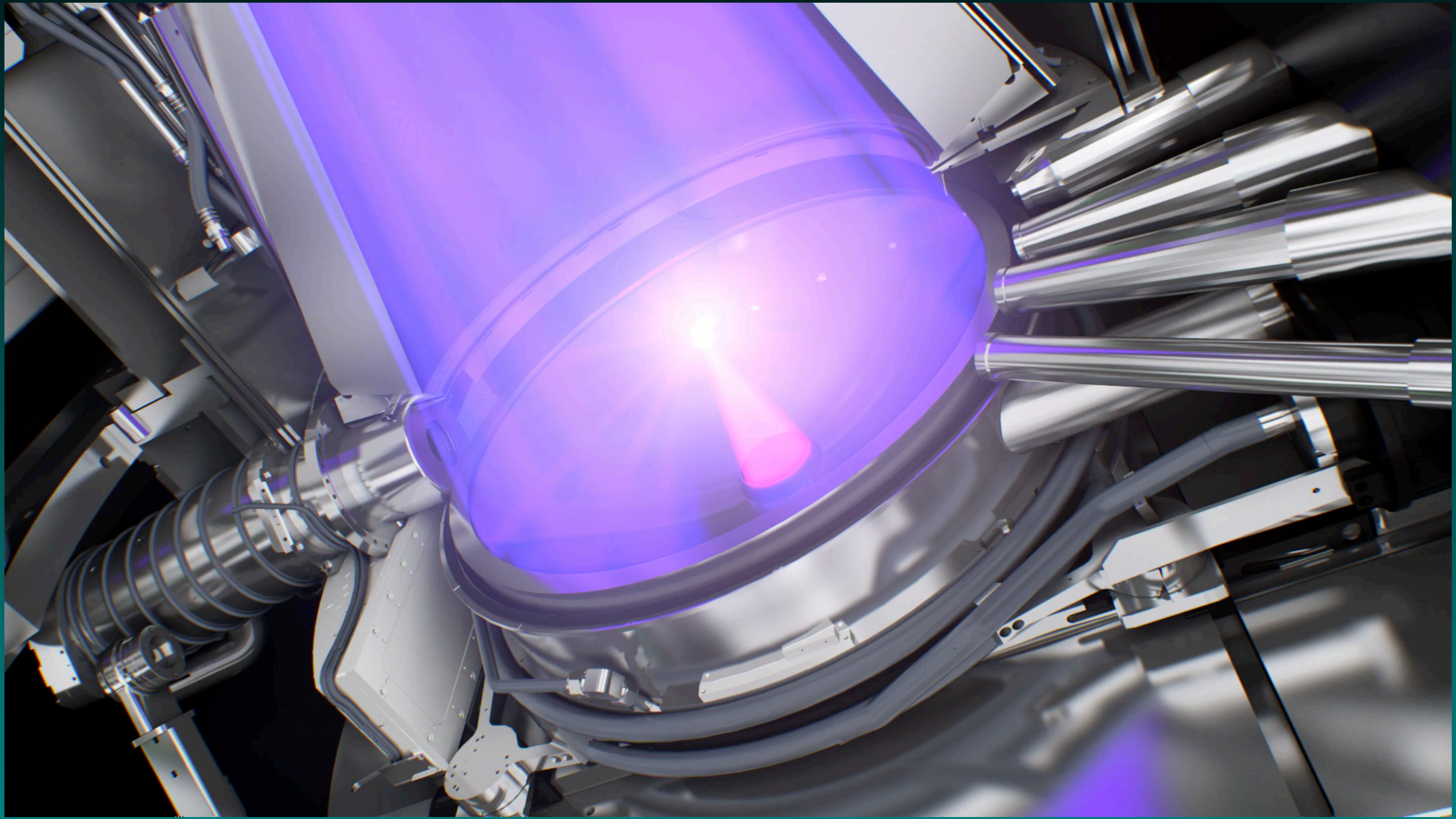
Semiconductor photolithography machines

- Very similar to photography
- Involves light (EUV) and therefore, a **light source**
- Involves film (**wafer**) with **photosensitive material**
- Involves patterns to be applied (**reticle**)
- Involves chemical developers
- Has to be done at scale, otherwise a smartphone will cost €10000 …



Photolithography

EUV generation - The light source



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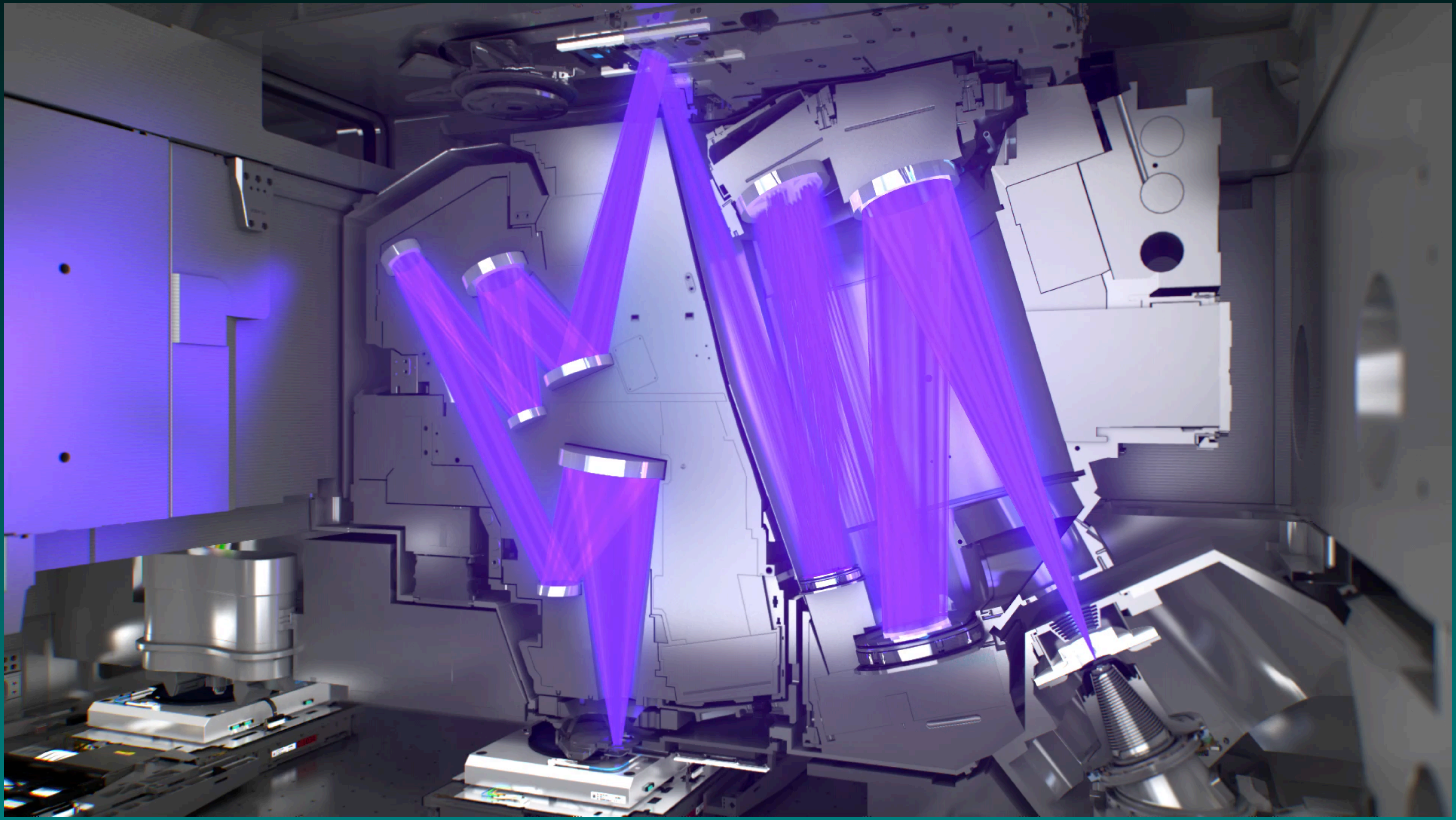
Photolithography

Light path and patterns



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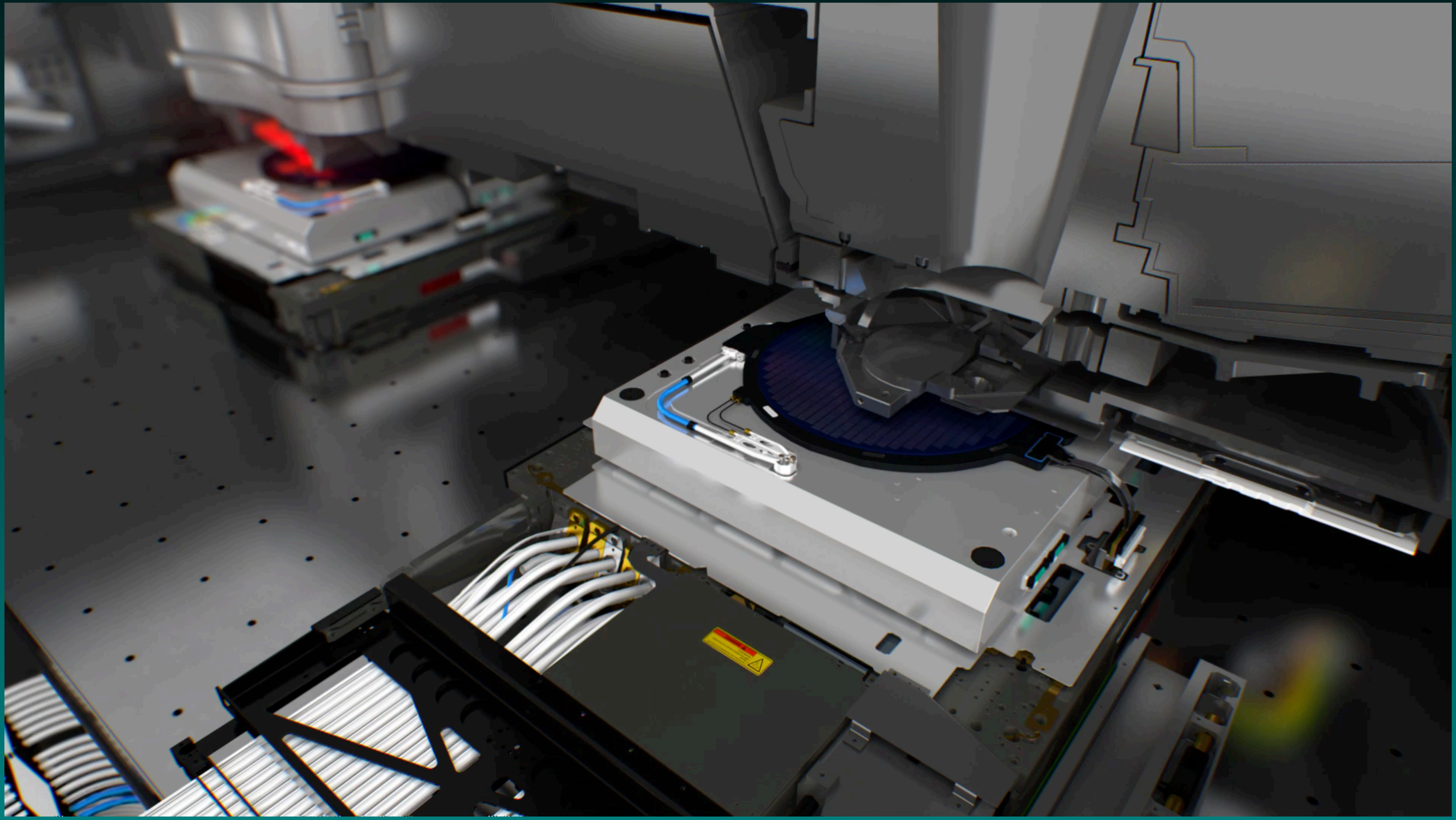
Photolithography

Stepper unit exposing photosensitive material



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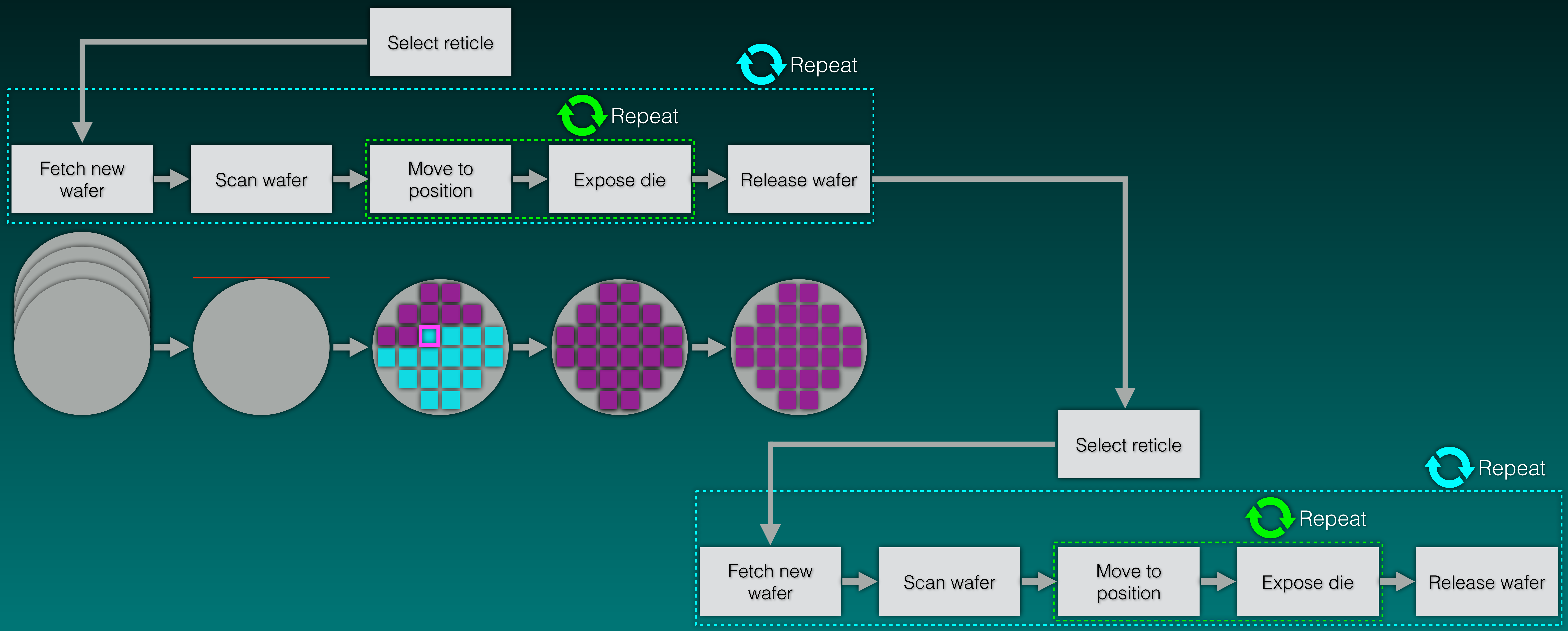
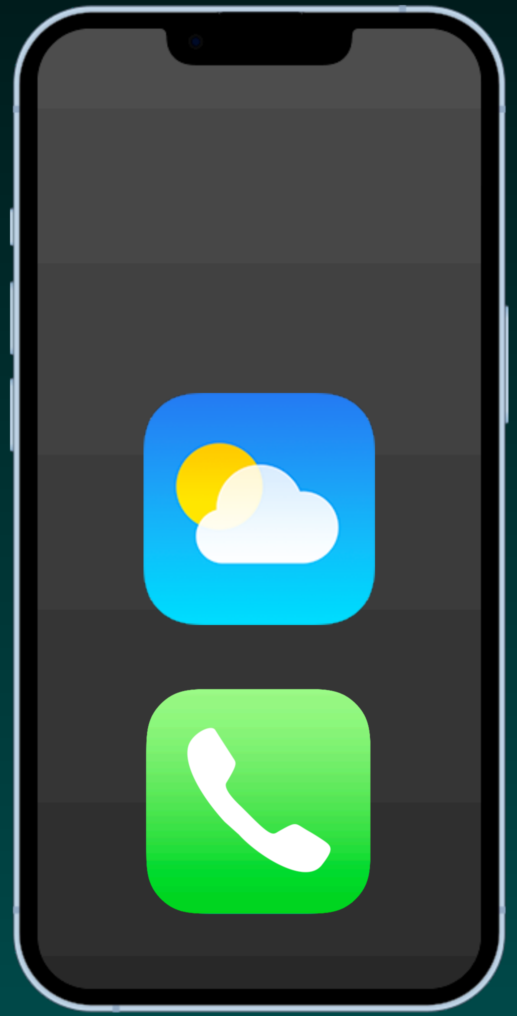
Characteristics of industrial CPS

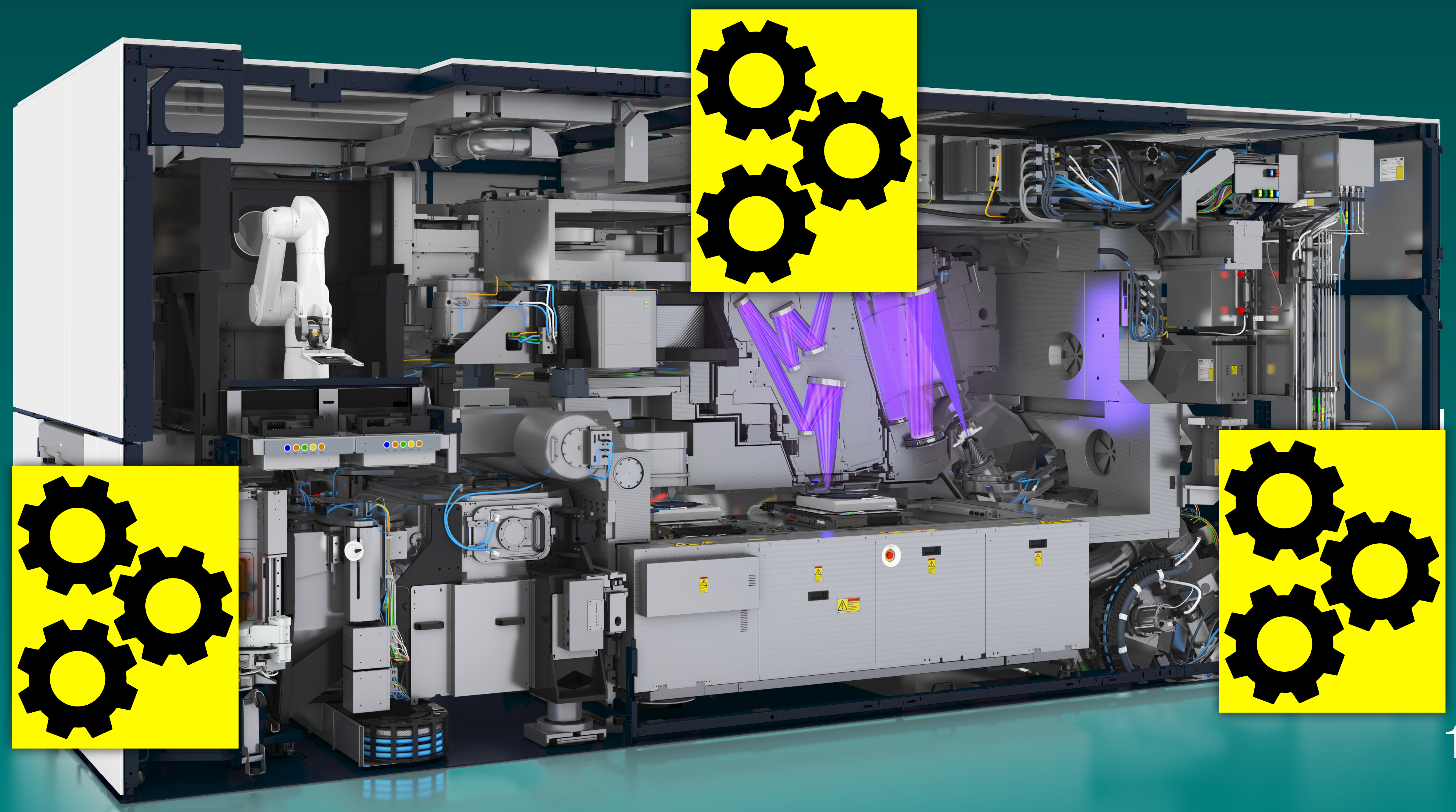
Repetition in a semiconductor photolithography machine



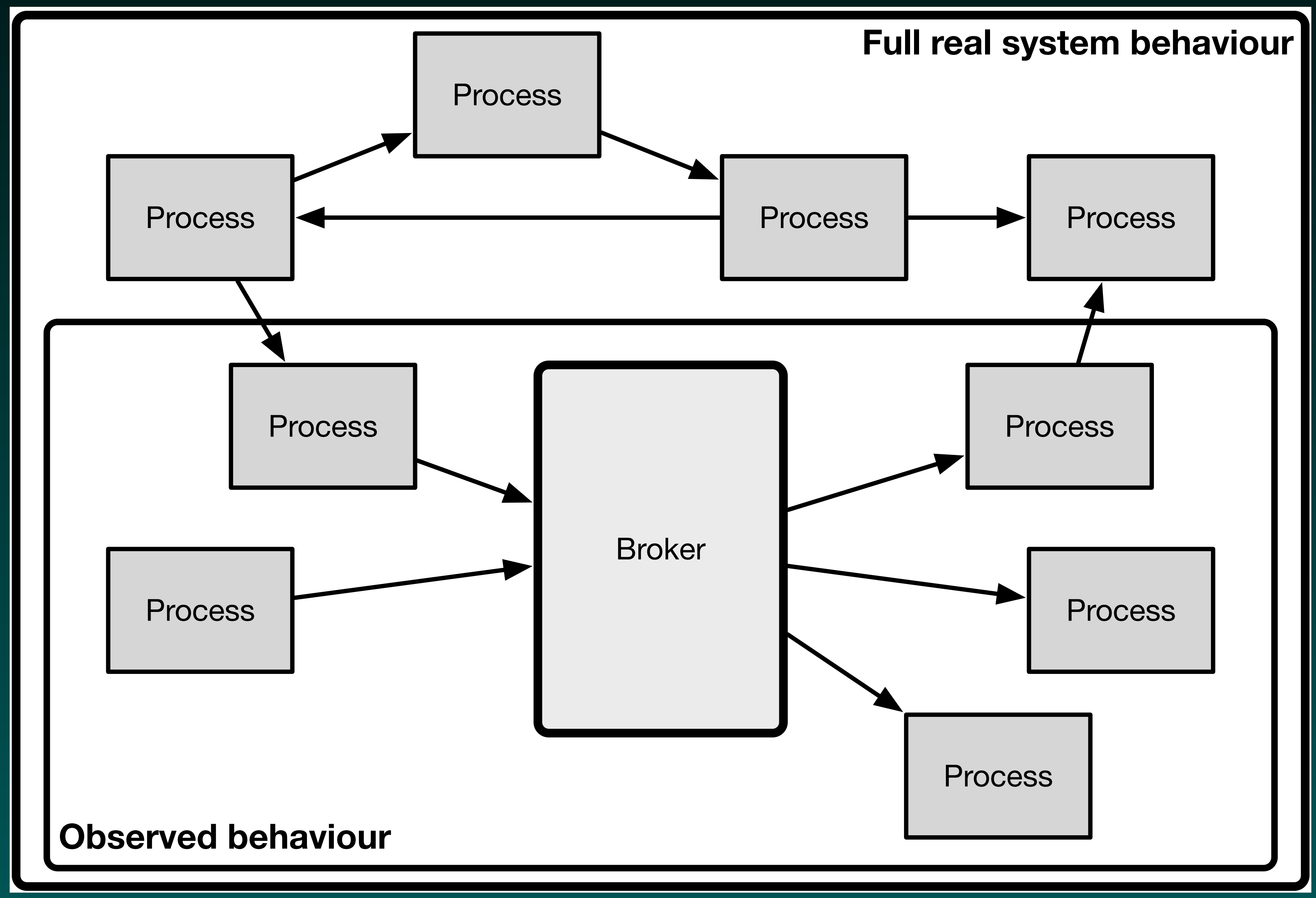
Software is taking over

- Everything is being computerised, industrial CPS included
- Computers are platforms for software
  => Software can be added or removed
  => New or extended software, extended functionality
- Software is a big source of data
  => We can take advantage of sensors and collect
- Software is getting too large
  => Complexity, extremely costly to get it right at design time





Minimal, but extensive enough data

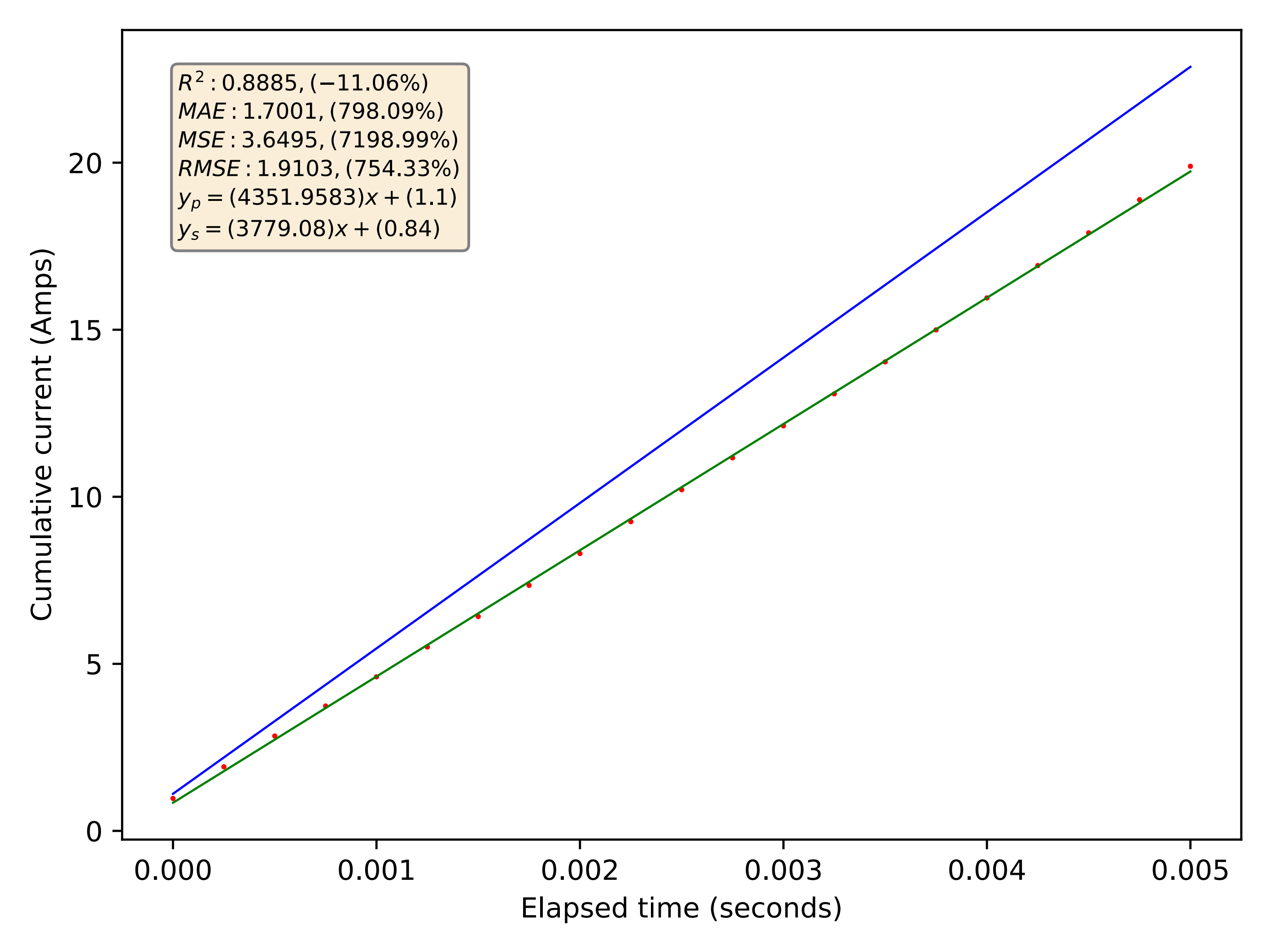


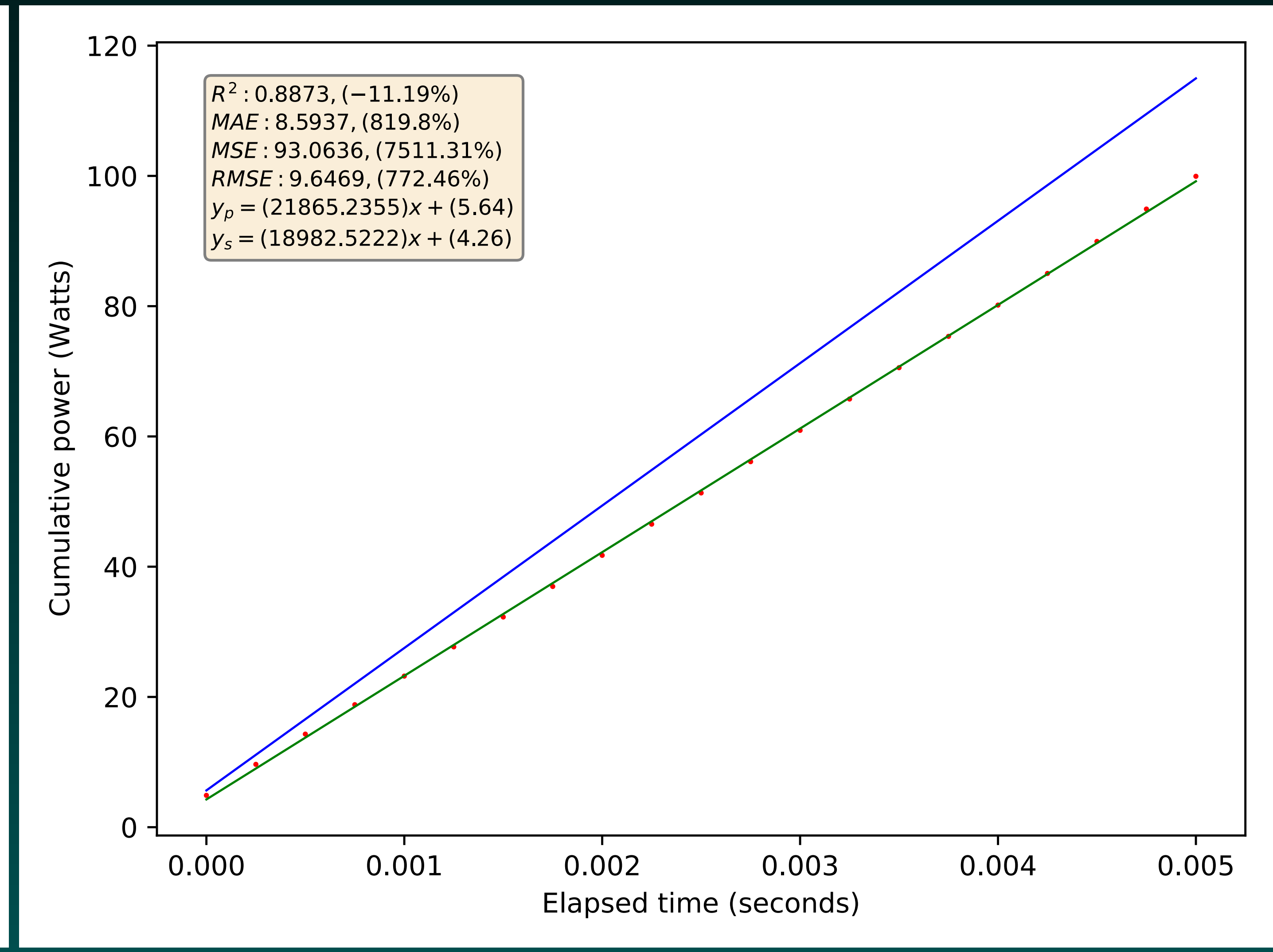
- We look into efficient collection of data
  => Enough to understand what is going on (understand the behaviour)
  => Be efficient, not too much data

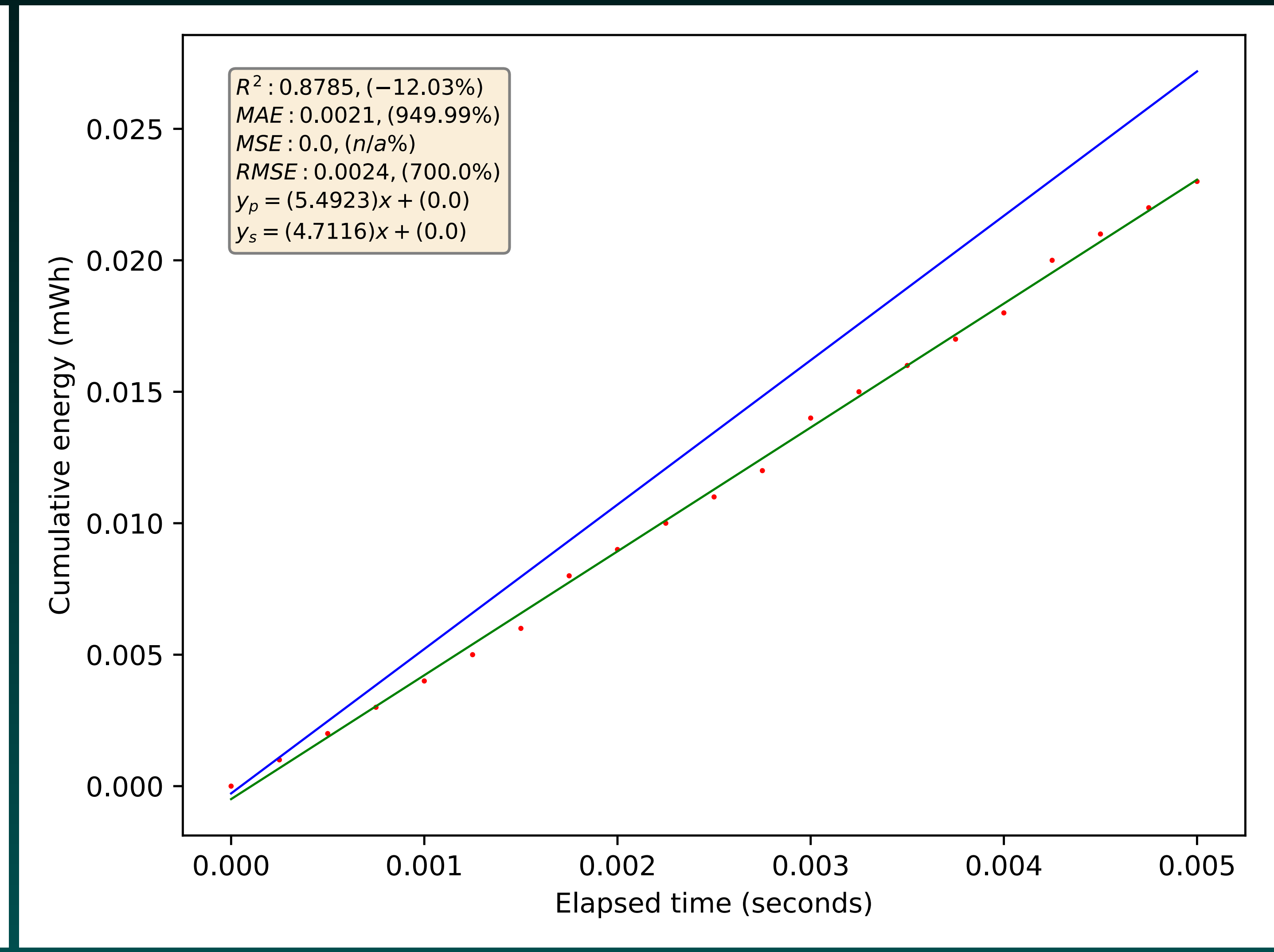
- Process the data in different ways
  => Ability to generate **fingerprints** for the behaviour
  => Ability to compare different fingerprints
  => Take advantage of Artificial Intelligence (AI)

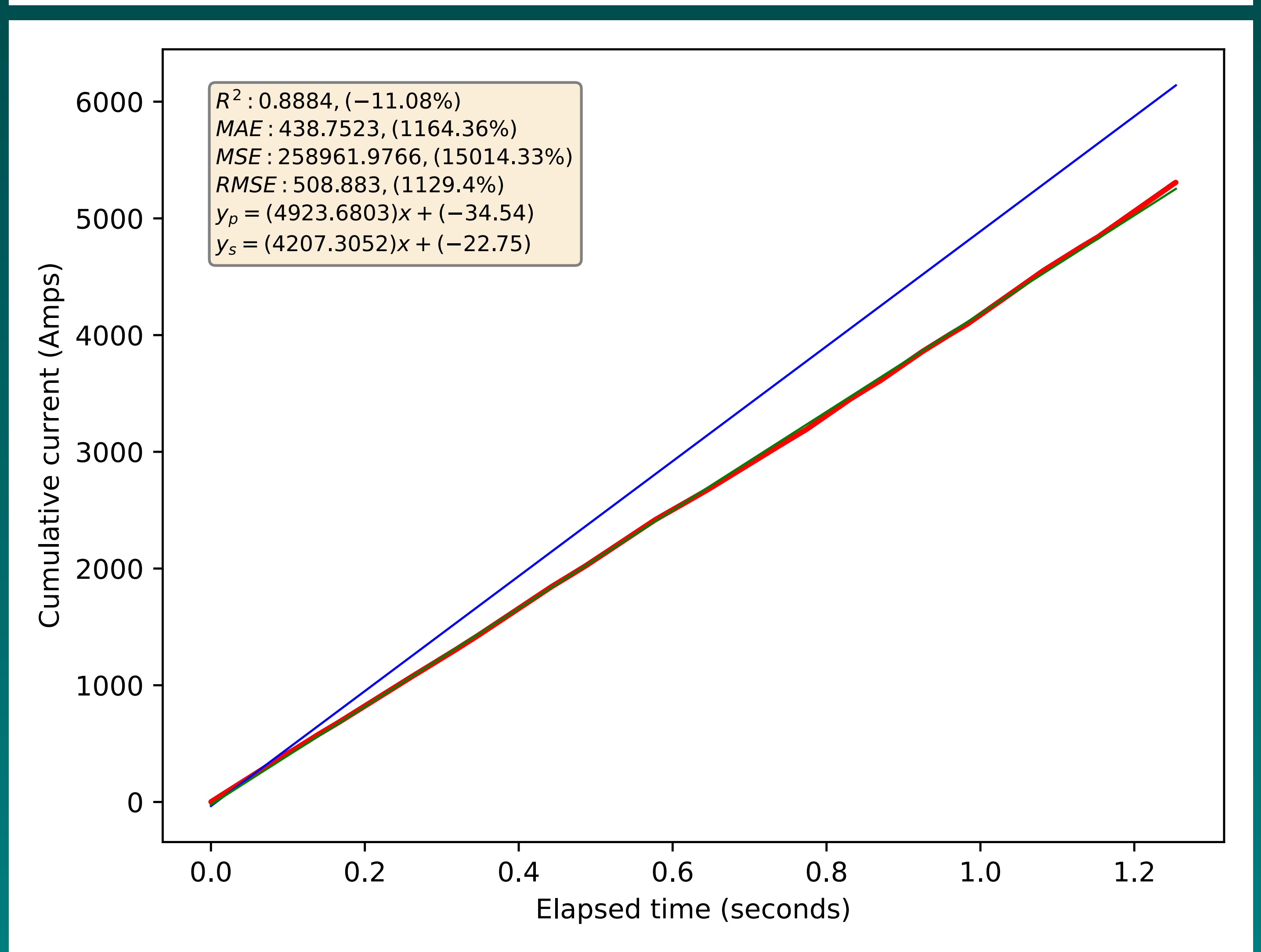
It is all about data and what we can learn from it.

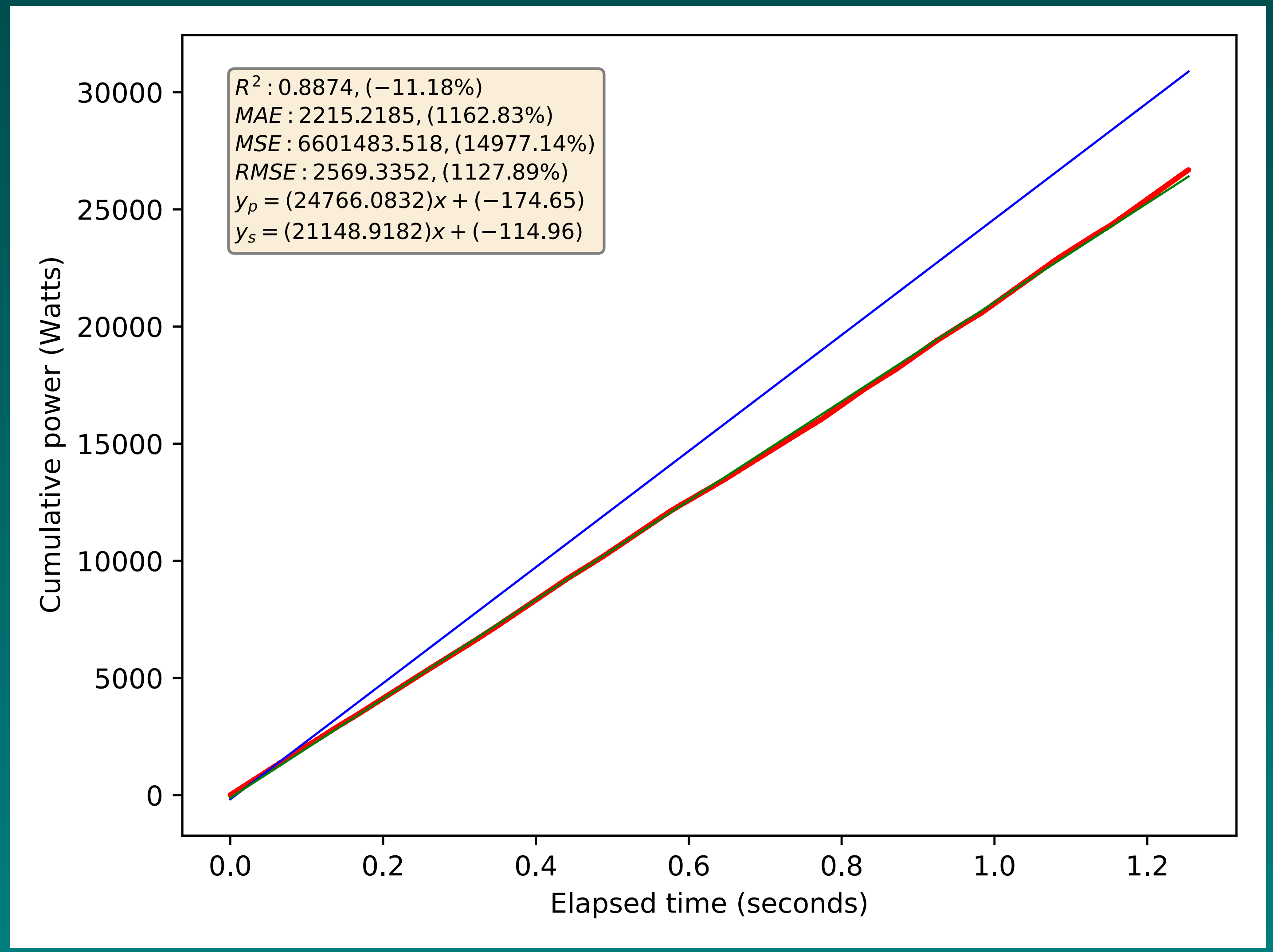
How about those fingerprints?

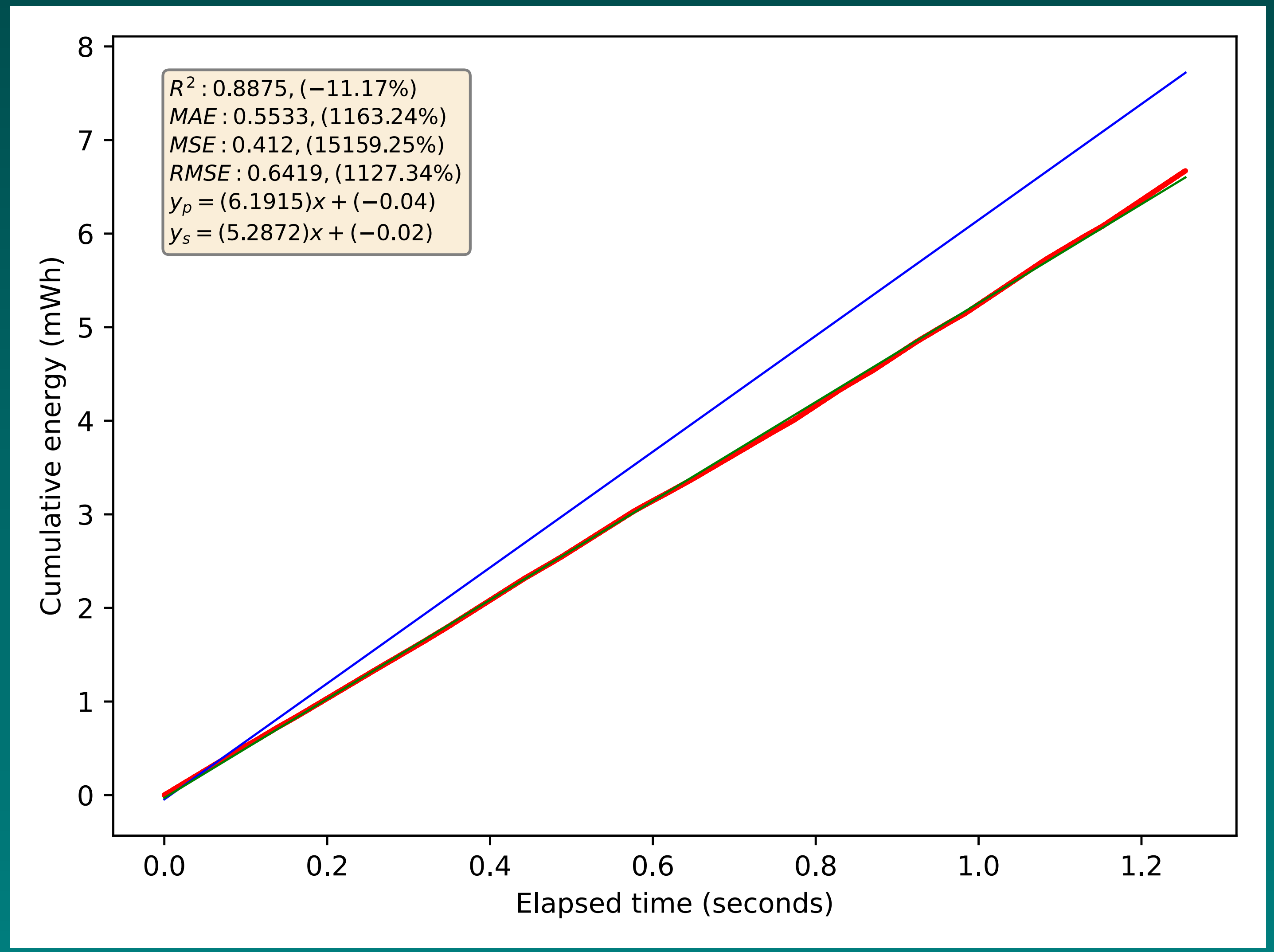










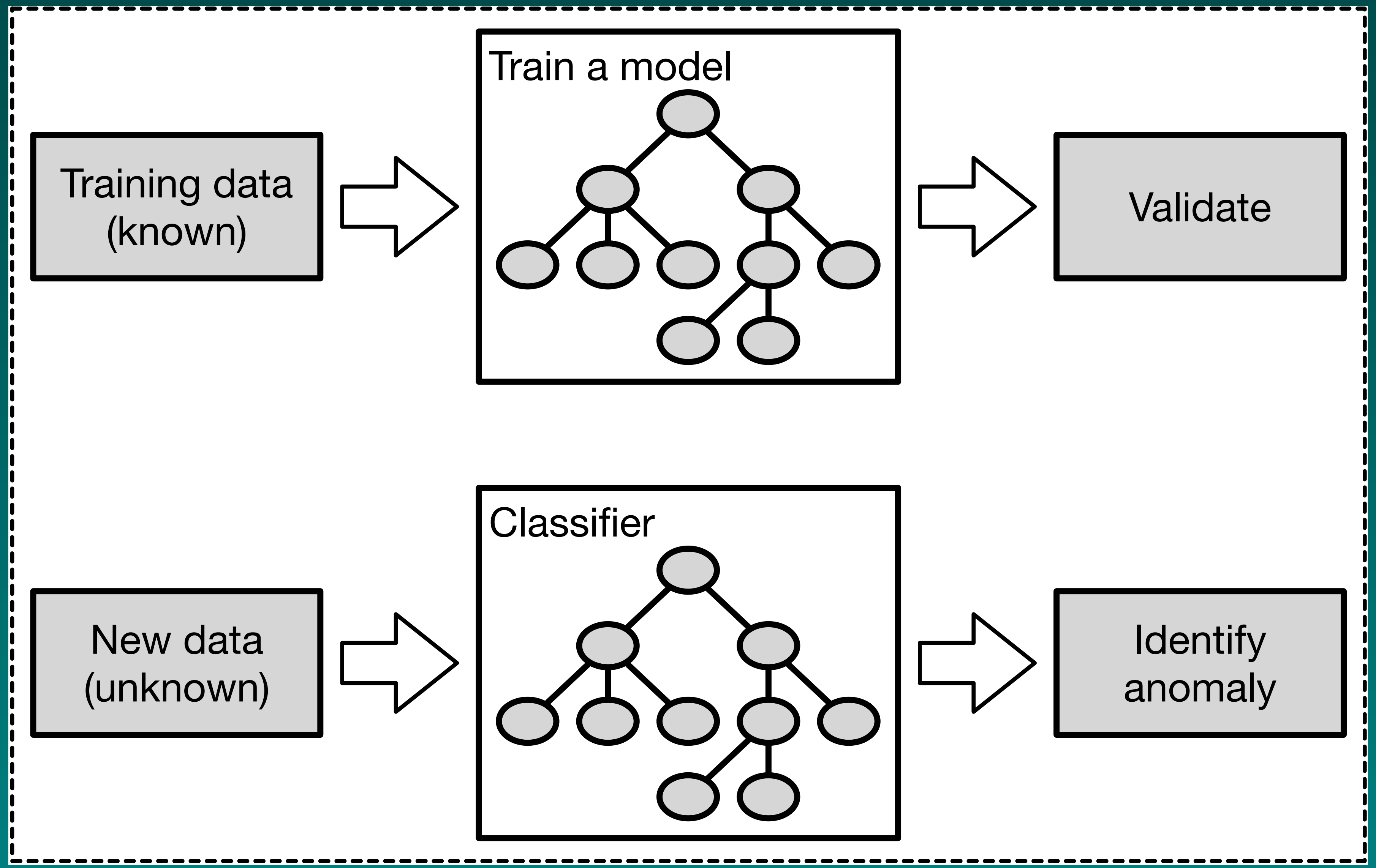


Where there is data, there is AI

- AI models are trained with known data and can react to unknown data
  => Based on what they have learned

- Specifically for us: Classifiers
  => Use known data to train the model
  => Teach it different behavioural categories
  => Use the model to classify unknown behaviour

- There are different types of classifiers
  => Traditional models, e.g., Decision Trees
  => And deep learning models, specifically, Convolutional Neural Networks (CNN)



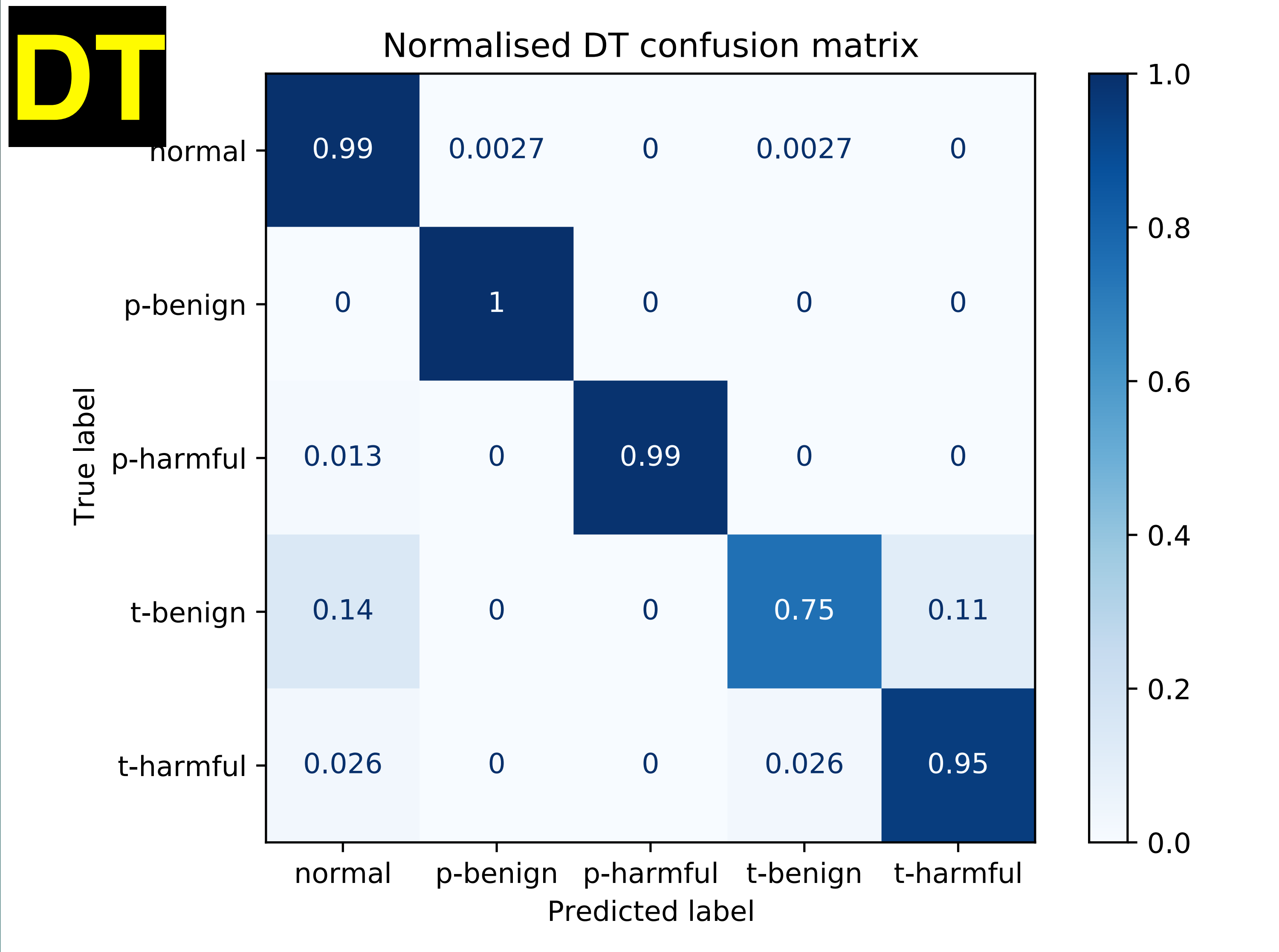
Where there is data, there is AI

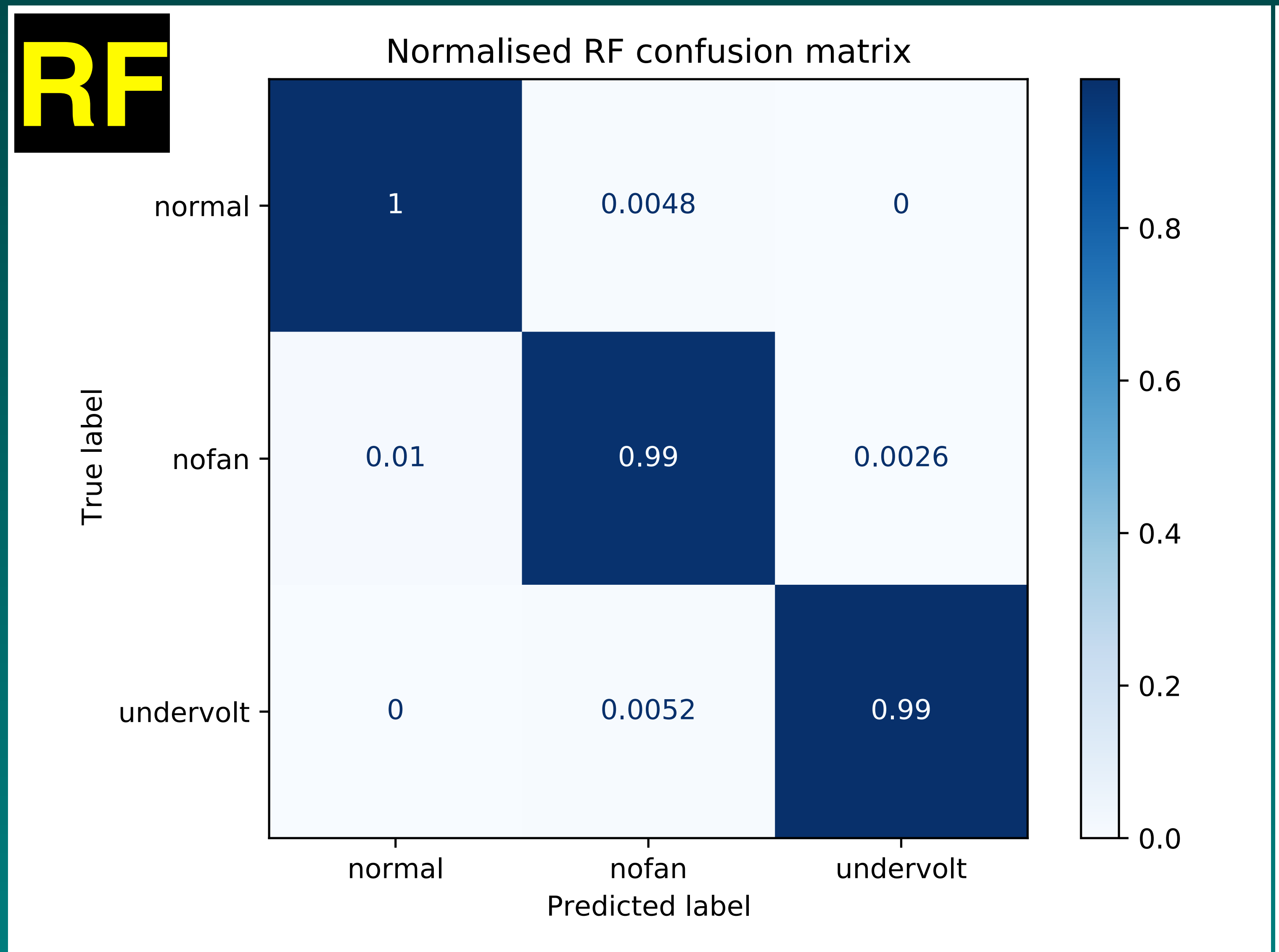
- How good is a classifier?
  => This is evaluated by the accuracy of its predictions
  => Classifiers learn from known data
  => Learning performance varies

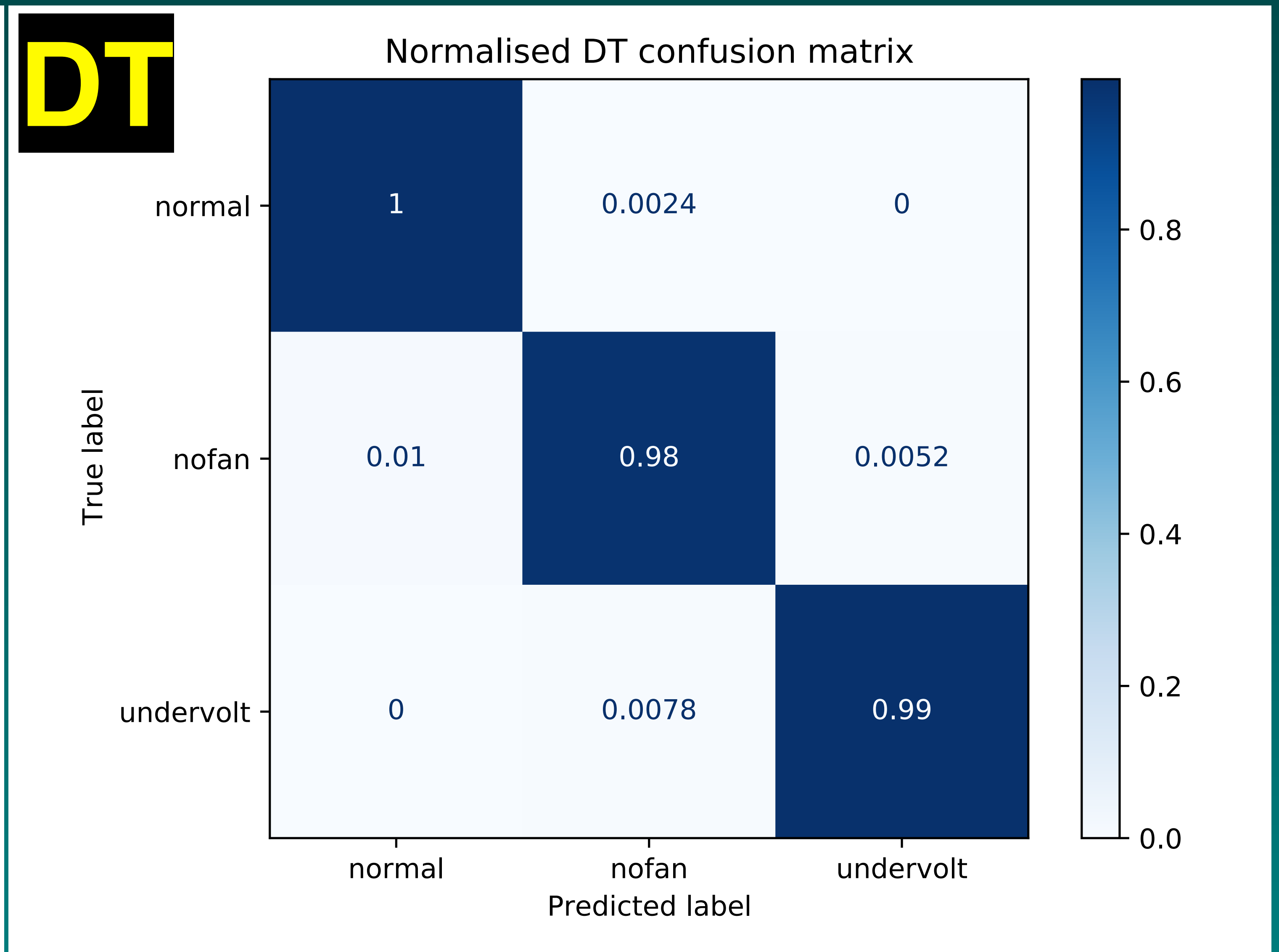
- Correct classification rates:
  => Solution using traditional ML: **99.23%**
  => Solution using DL with CNN: **94.85%**
  (with room to improve …)

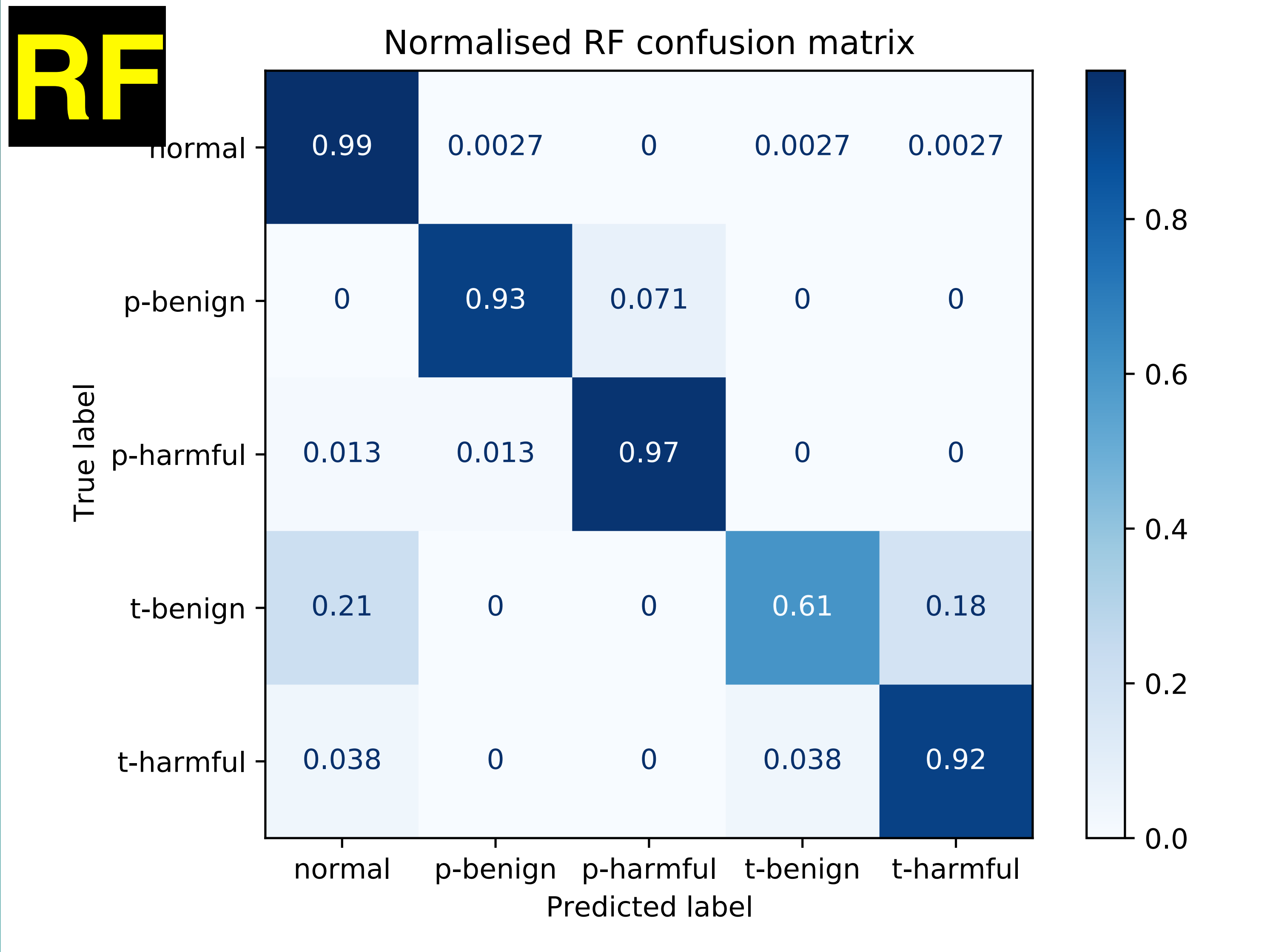
Where there is data, there is AI

- How good is a classifier?
  => Evaluated by the accuracy of predictions
  => Classifiers learn from data
  Known data for supervised …
  => Learning performance varies





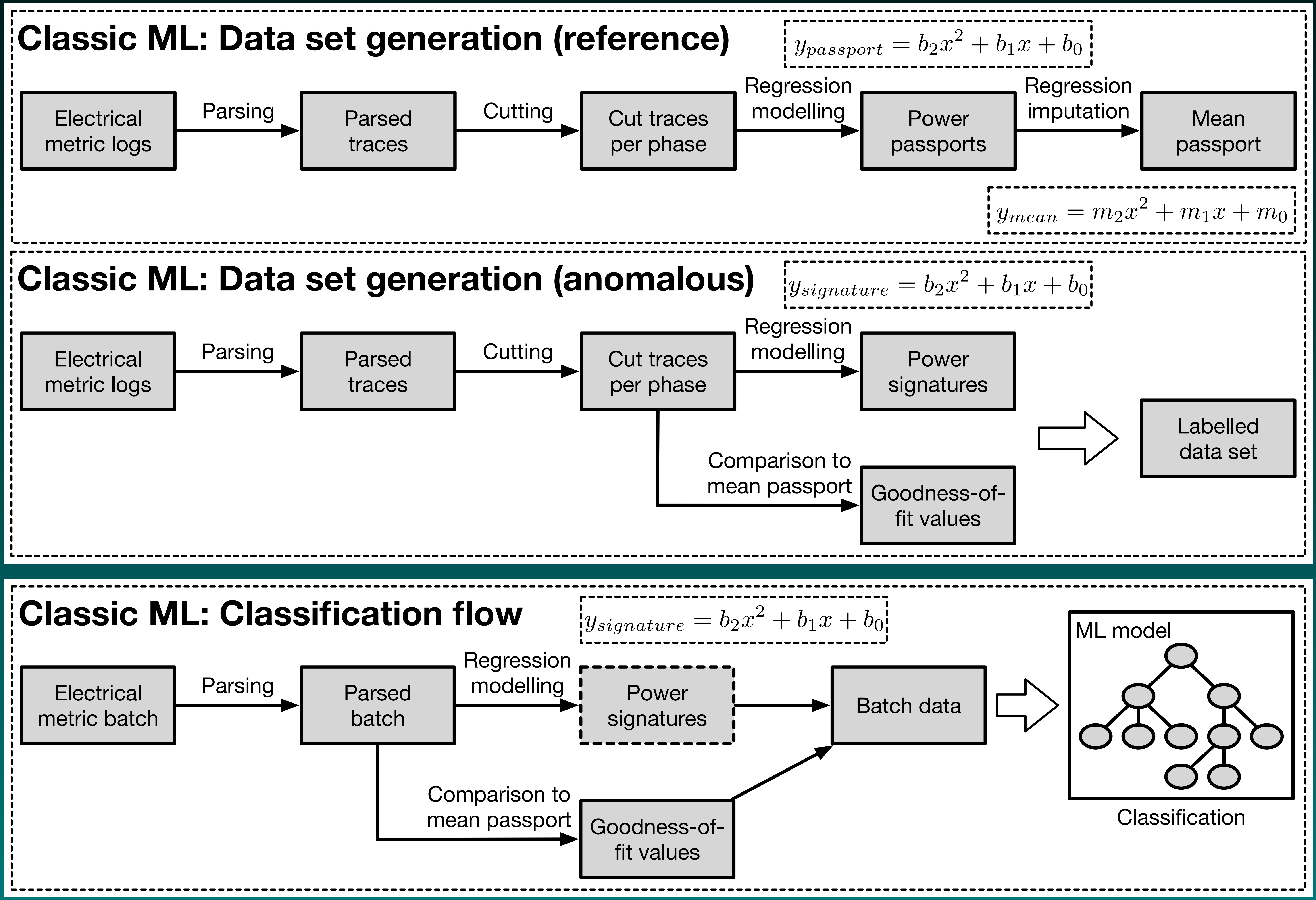




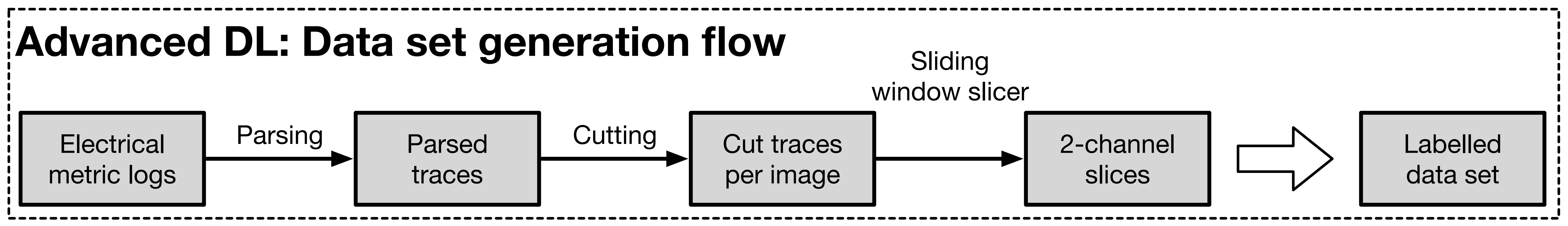
Complete solution 1

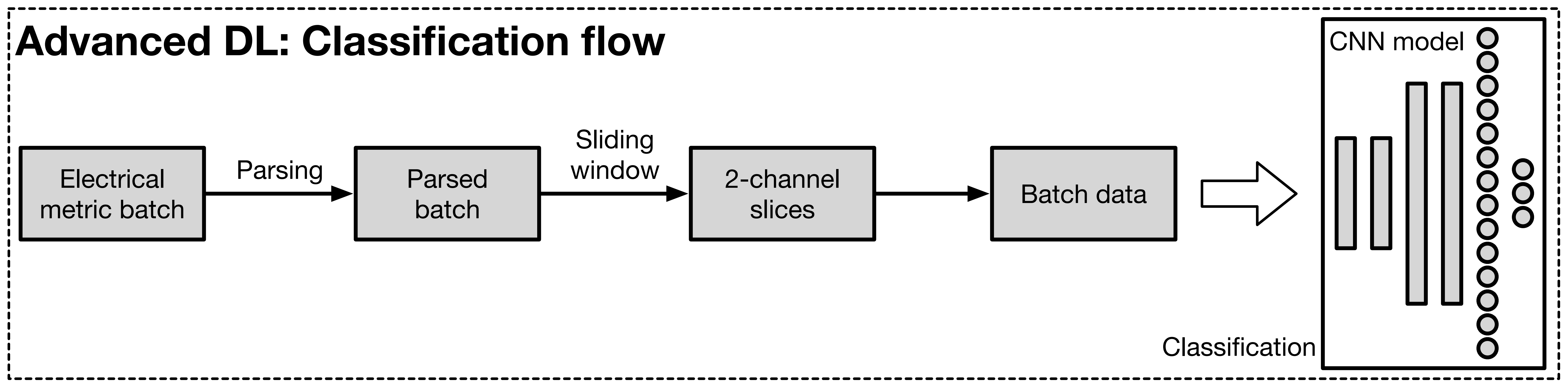
- The solution combines fingerprinting techniques with AI techniques

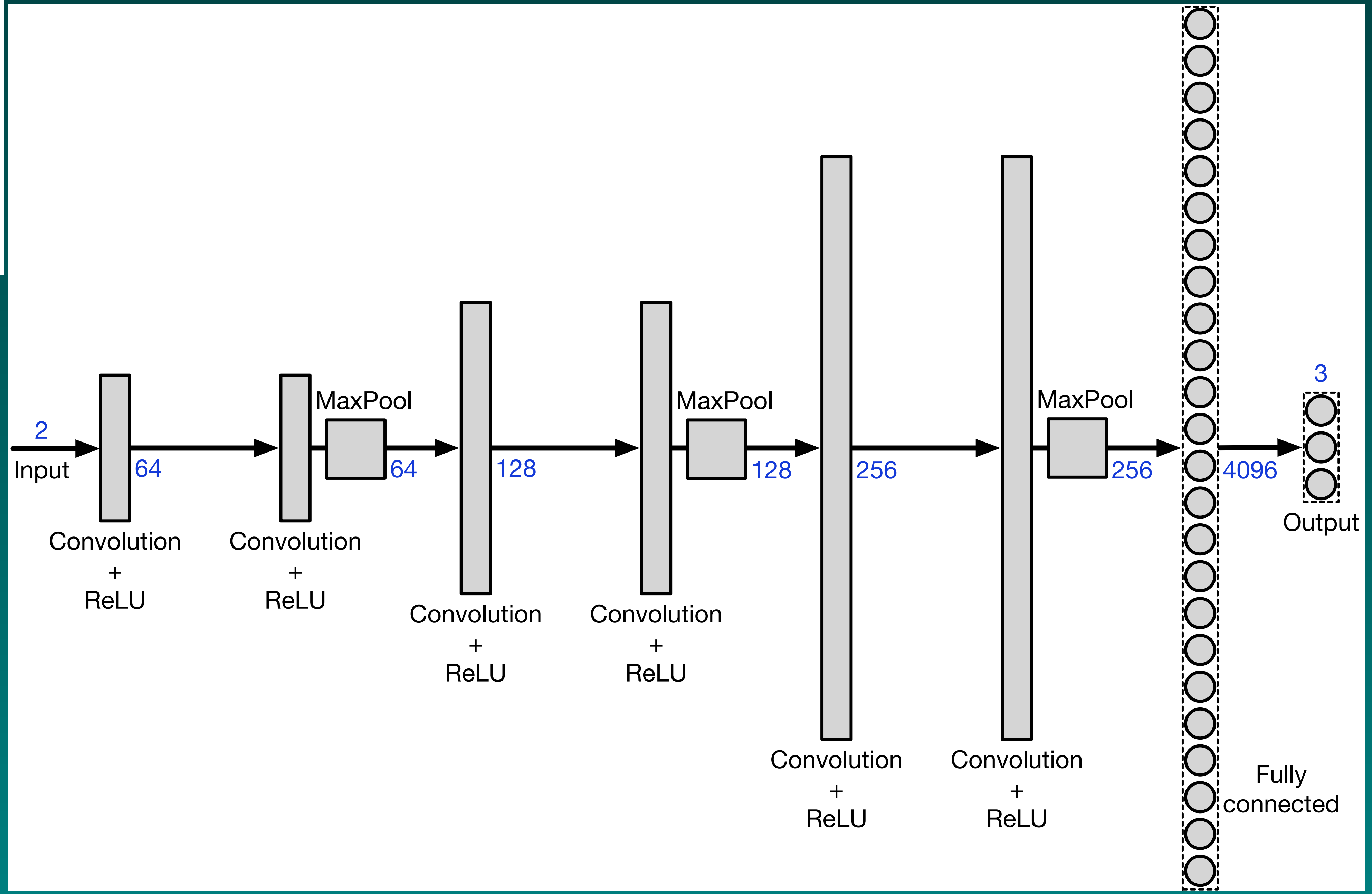
- Different solutions addressing different information positions



Complete solution 2







Comparison

Classic ML vs Advanced DL

- Classic ML advantages:
  => Exceptional accuracy -> **99.23%**
  => Very fast training and inference (after preprocessing)
  => Explainable output (take a look at the DT and backtrack)

- Advanced DL:
  => Good accuracy -> **94.85%** (can be even better)
  => Minimal preprocessing (just proper formatting)
  => Can be relatively quickly put together

To be compared:

- Training speed, classification speed, accuracy, overhead
- Reduction in feature engineering, CNN model design effort

Incorporation of knowledge

- Different information positions will define:
  => Solution specifics
  => Type of model
  => Achievable performance
  (model performance, speed, …)

- Two types of knowledge
  => **Readily** available
  => **Extracted** from data

- Can we develop a framework? Generalise?

		Knowledge position		
		White	**Grey**	**Black**
Data position	**White**	White-White (WW)	White-Grey (WG)	White-Black (WB)
	Grey	Grey-White (GW)	Grey-Grey (GG)	Grey-Black (GB)
	Black	Black-White (BW)	Black-Grey (BG)	Black-Black (BB)

Science does not happen in vacuum

- **UvA:**
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  prof. dr. Andy D. Pimentel
  dr. Hugo Meyer
  Simon Polstra
  Julius Roeder
  Dolly Sapra

- **ASML:**
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  dr. Ignacio Gonzalez Alonso

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Thank you!