1

Mantenimiento en la Industria 5.0
Cómo el mantenimiento se alinea con la nueva visión centrada en la interacción humano-tecnología

Diego Galar
Catedrático LTU
Director R&D Sisteplant

2

Industry 4.0, the concept

The basic principle of Industry 4.0 is that interconnected machines and systems will form an intelligent self-controlled network spanning the entire value chain.

In the ideal factory, machines autonomously react to unexpected changes in production, predict failures and trigger maintenance processes.

3

AUTOMATION vs AUTONOMY

AUTOMATION

✓ Process performed without human assistance

✓ Pre-defined rules, fixed sequences

✓ Limited flexibility

✓ No understanding of context

✓ "Do what I programmed you to do"

AUTONOMY

✓ sytem performs tasks under changing conditions

✓ Self-adaptive, self-learning

✓ Context-aware

✓ Can make decisions

✓ "Do what is needed to achieve the goal"

4

Industrial AI: From Data to Smart Decisions

Deep Learning Neural Network

Train AI models using historical asset data and domain knowledge
(Offline learning with labeled data)

Deploy models for real-time asset monitoring and decision-making
(Online inference in production environments)

Train | Layer   Hidden Layer

Industrial AI leverages data to smart decisions

5

HOW MACHINES LEARN

Text, images, speech & videos

350 m search day   4.5 b image day   34+ villios per year

Feedback type
- Likes
- Clicks

Consumer Internet

Sensor time series text & images

Feedback type
- Inspection results
- Alarms/—ure logs*
- Downtime hours

Industrial Internet

Continuous Low Events

Feedback type
- Inspection results
- Alarms —ure logs*
- Downtime hours

Industrial Data & Feedback Loop are Different

6

MACHINE LEARNING PIPELINES

Consumer Internet Use Cases

Google
ebay
facebook

Customer Segmentation	Sentiment Analysis
Ads Targeting	Search Engine

Industrial Internet Use Cases

GE
SIEMENS

Early Warning	Analytics Based Maintenance
Work Planning	Performance Optimization

Industrial Machine Learning Pipeline is Different

LULEA UNIVERSITY of TECHNOLOGY

7

INDUSTRY 4.0 DATA IS MOSTLY MACHINE GENERATED DATA

Volume · Velocity · Variety · Variability

Machine-generated data is one of the fastest growing, most complex and most valuable segments of big data

GPS
RFID
Hypervisor
Web Servers
Email, Messaging
Clickstreams, Mobile
Telephony, IVR, Databases
Sensors, Telematics, Storage
Servers, Security Devices, Desktops

8

9
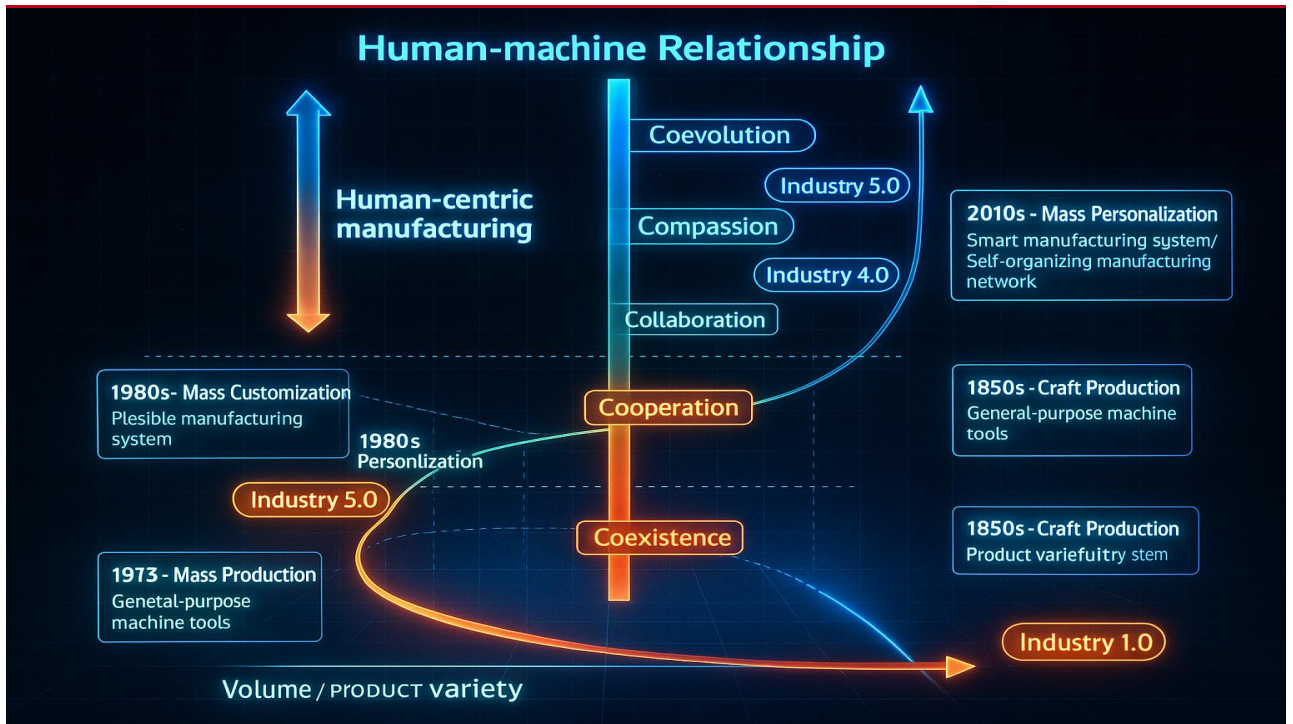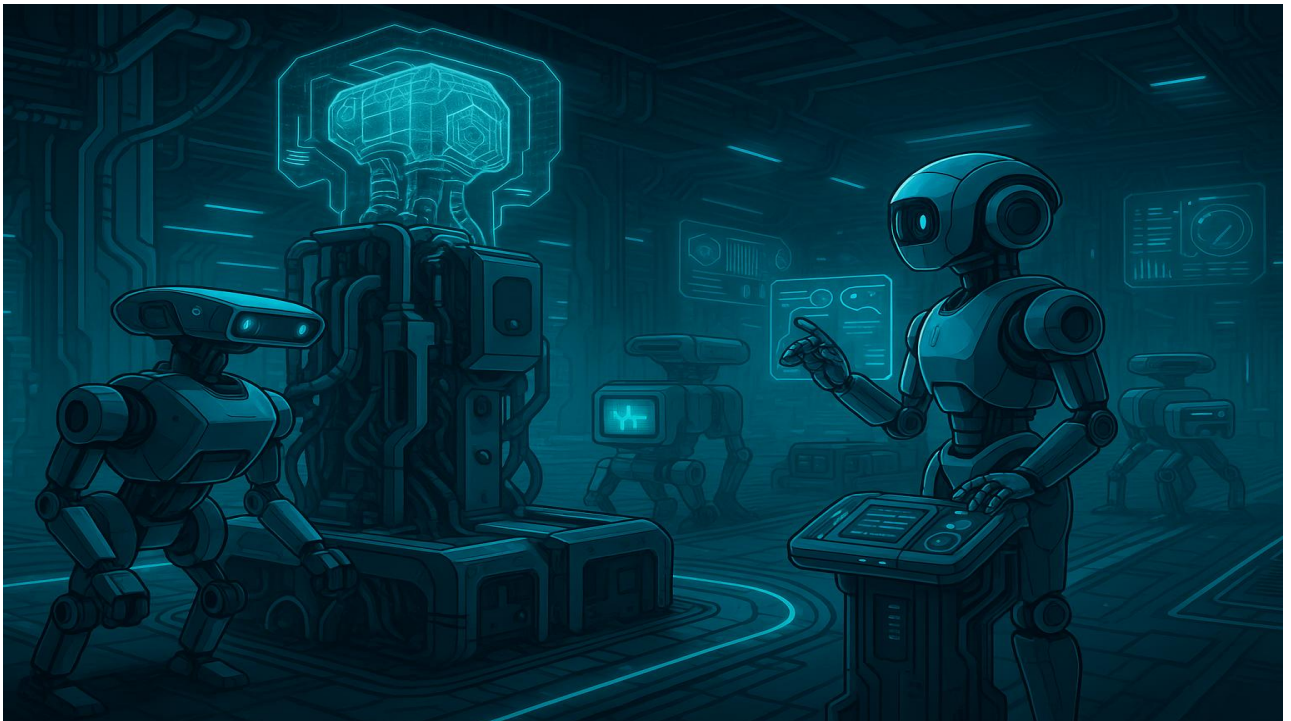

10

11
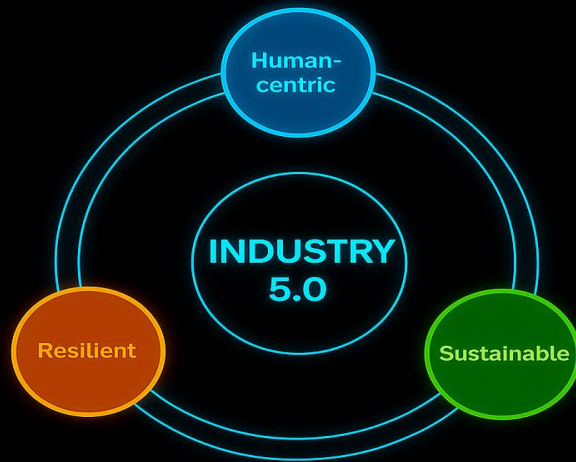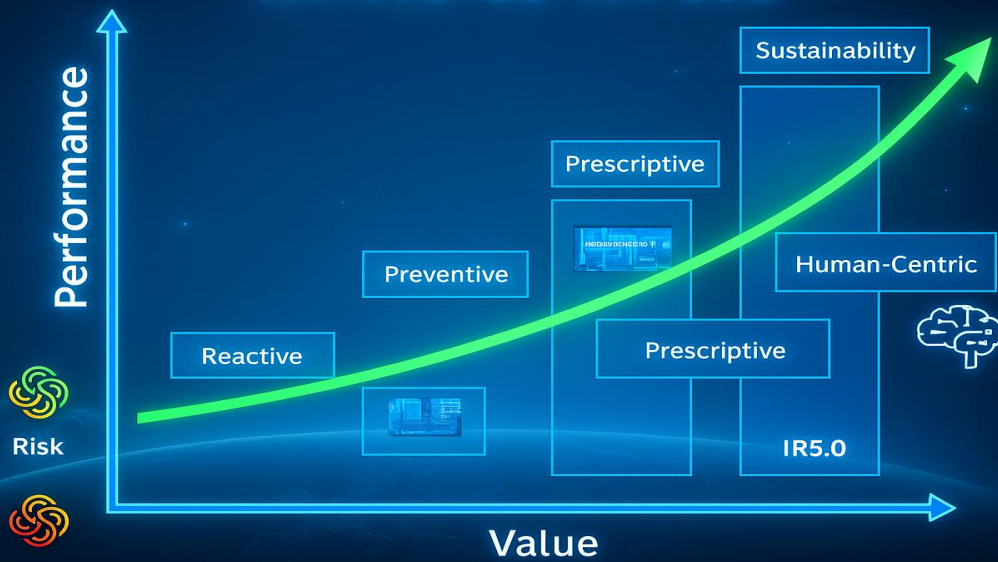
12

13

14

ML IN A METAPHOR

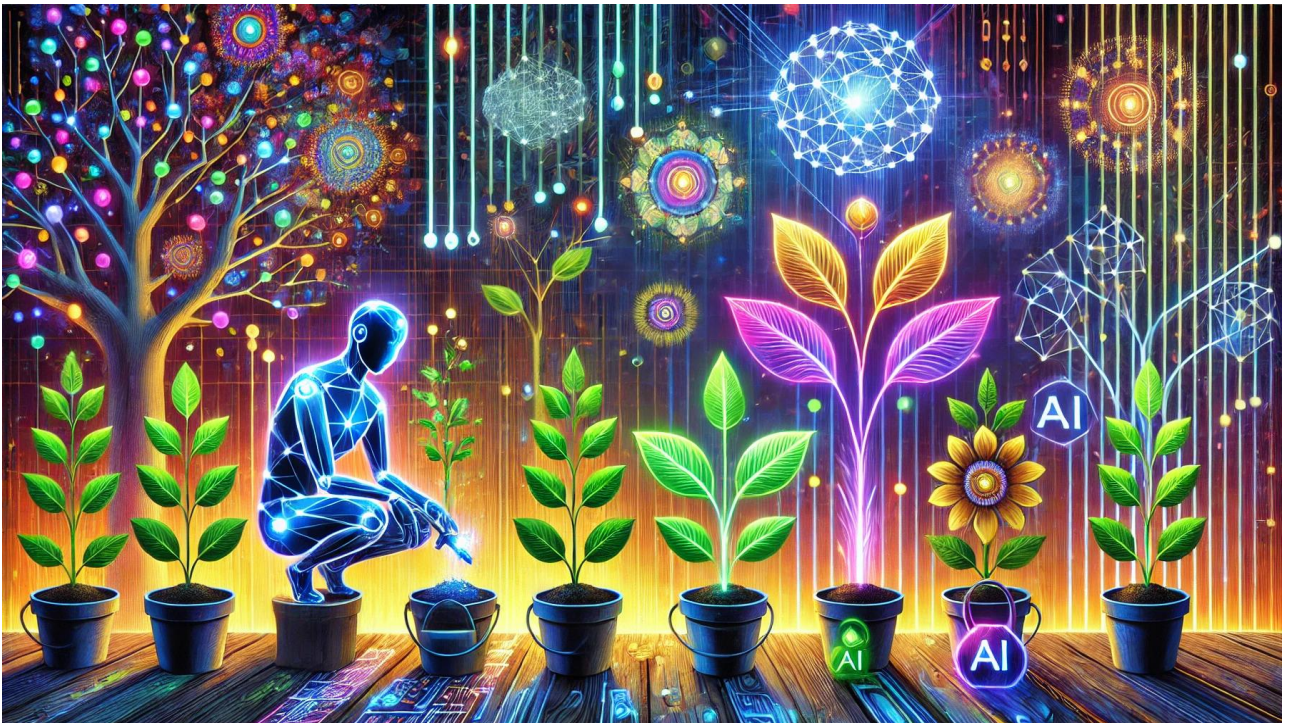**Seeds** = Algorithms
Nutrients = Data
Gardener = You
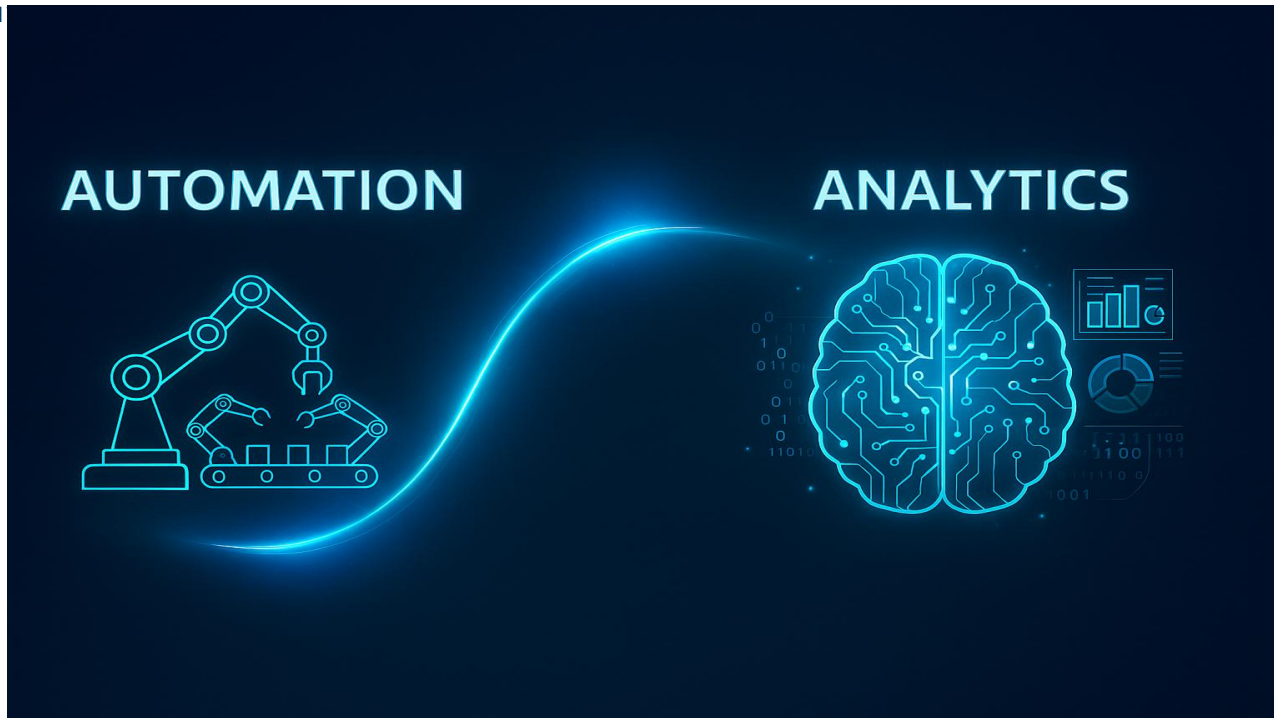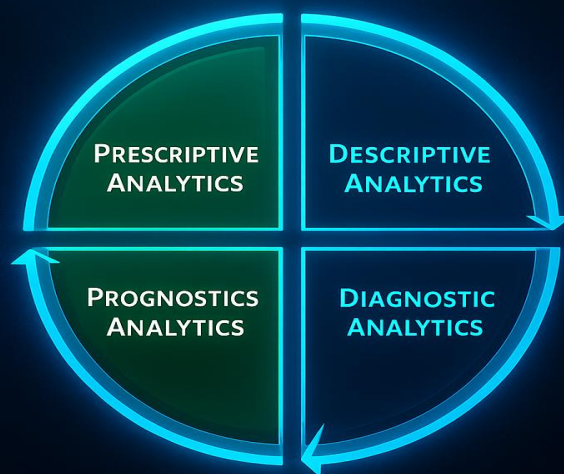**Plants** = Trained models

15

16

8

1

17

Types of Analytics

- **Now casting**
  1. What happened in the past
  2. Why something happened

- **Forecasting**
  3. What will happen in the future
  4. What needs to be done next

PRESCRIPTIVE ANALYTICS

DESCRIPTIVE ANALYTICS

PROGNOSTICS ANALYTICS

DIAGNOSTIC ANALYTICS

18

Analytics and expectations also change

4	**Cognitive Analytics** Cause something to happen.	Automated
3	**Prescriptive Analytics** What should we do?	
2	**Predictive Analytics** What could happen?	
1	**Diagnostic Analytics** Why did it happen?	
0	**Descriptive Analytics** What happened?	Manual

AI AUGMENTATION

19

Types of data analytics

Descriptive Analytics

Group historical data according to their similarity

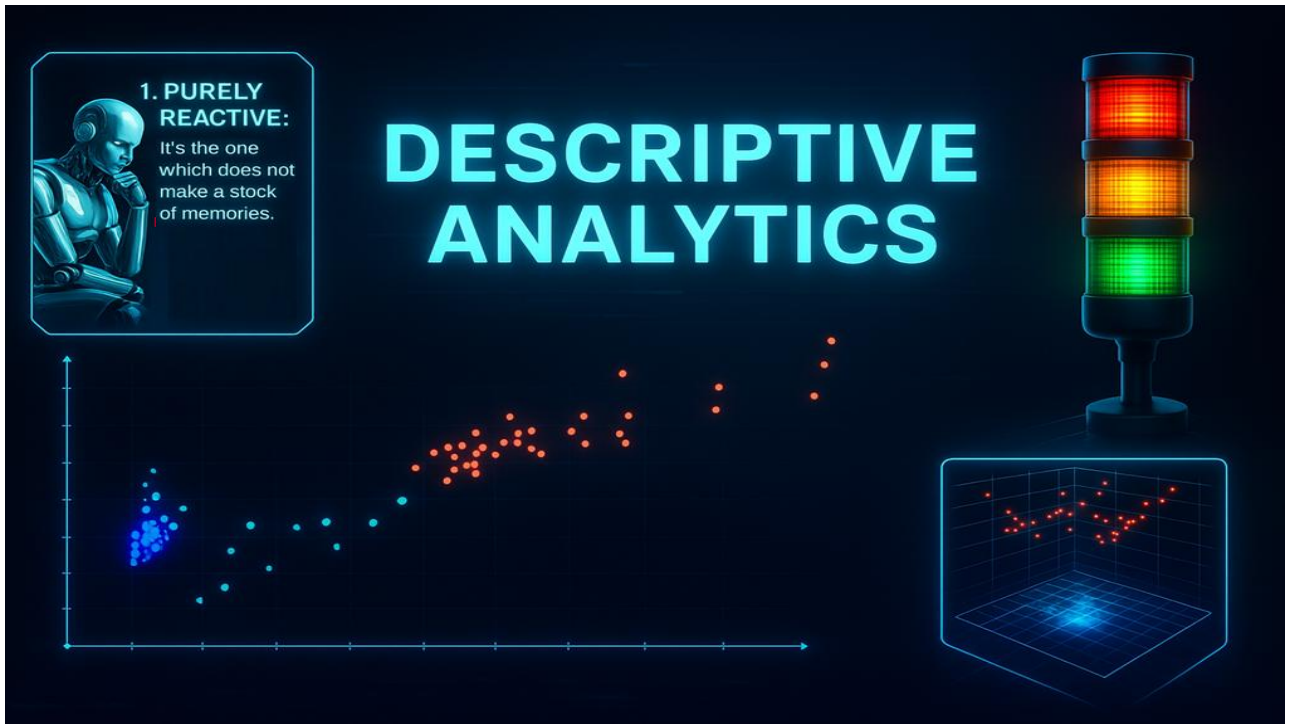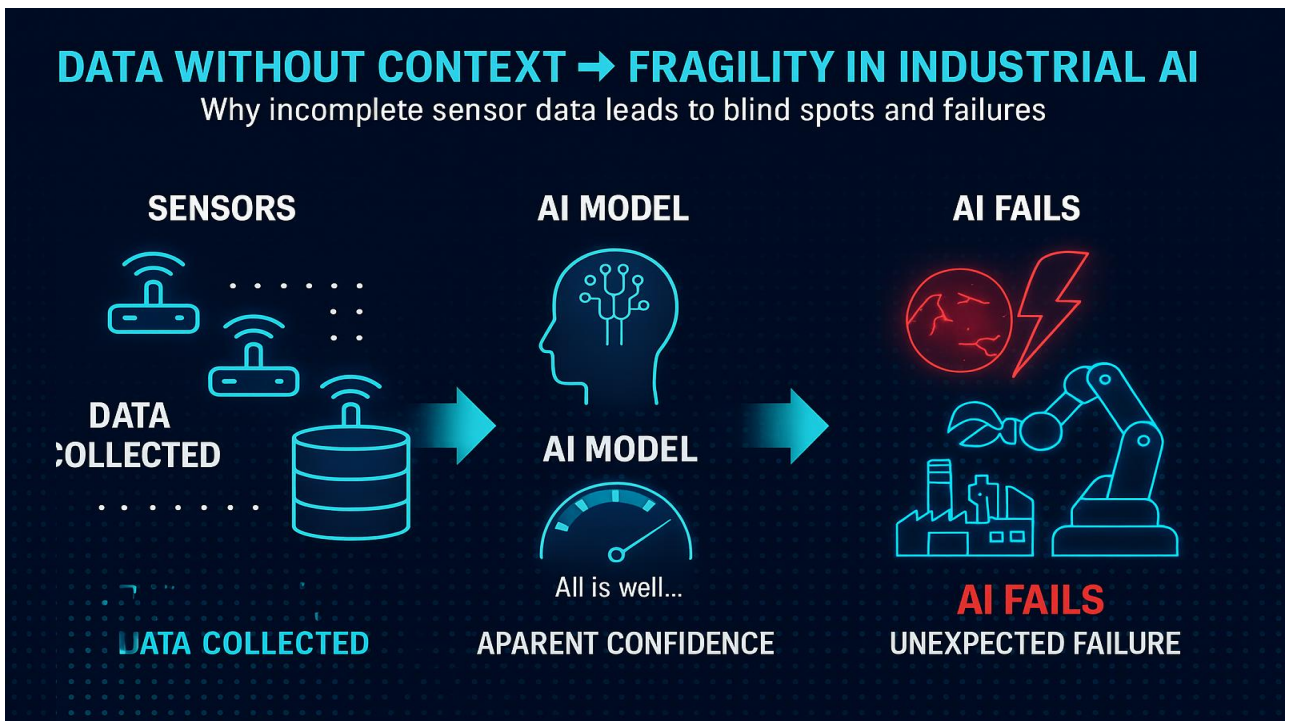Reports Mapping

20

21

22

TYPES OF AI

The emergence of artificial superintilligence will change humanity, but it's not happening
Here are the types of AI leading up that new reality.

Reactive AI

- Good for simple classification and portern recognitioln tasks
- Great for scenarios where all parameters known;

- Incapable of dealing with scenarios including imperfect information or understanding

Limited memory

- Can handle complex classification tasks
- Able to use historical data to make predictions
- Capable of complex tasks such as self-driving cars, but still vulnerable to eutllers or adversarial
- This is the current state of AI, and some say we have hit a wall

Theory of mind

- Able to understand human motives aning
- Can deliver personal experience to every-based on their motives and needs
- Able to learn with fewer examples incu it understands what shows motive and intent

Self-aware

- Human-level intelligence that can surpass our intelligence, too

23

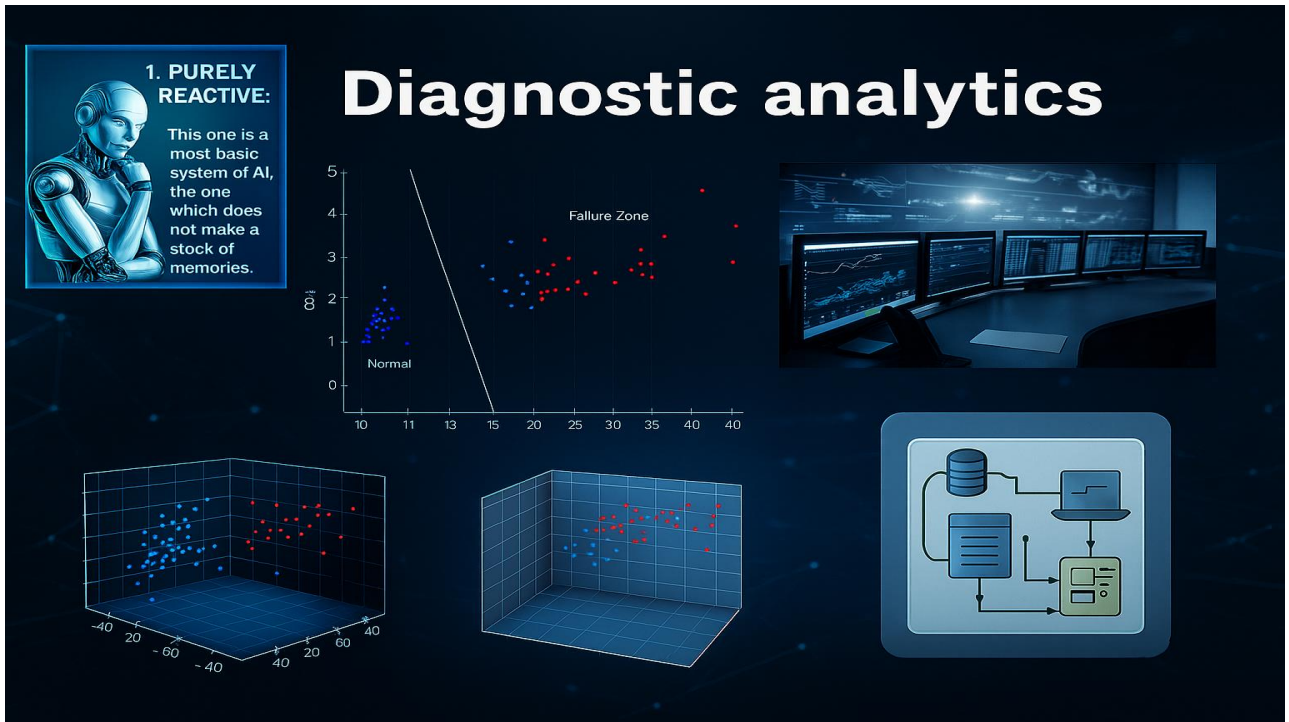# Types of data analytics

Descriptive Analytics

- Group historical data according to their similarity
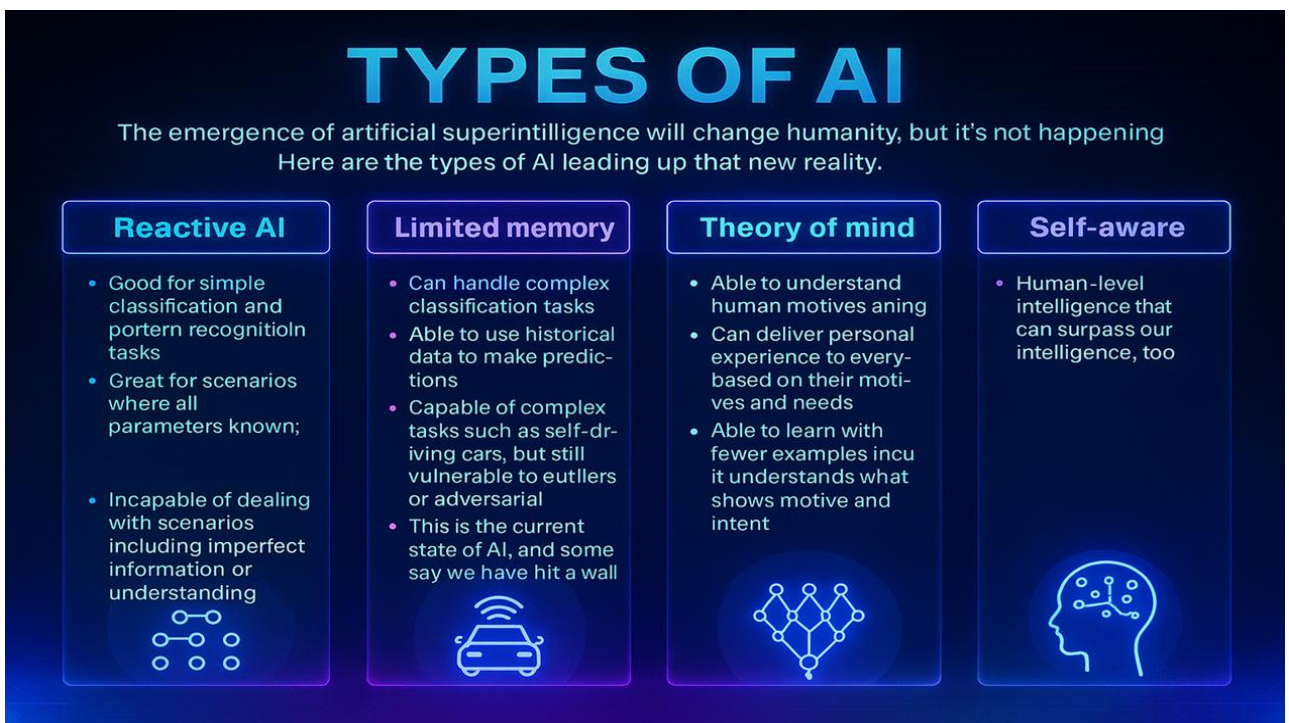
- Reports Mapping

Diagnostic Analytics

Determine cause of successes and failures
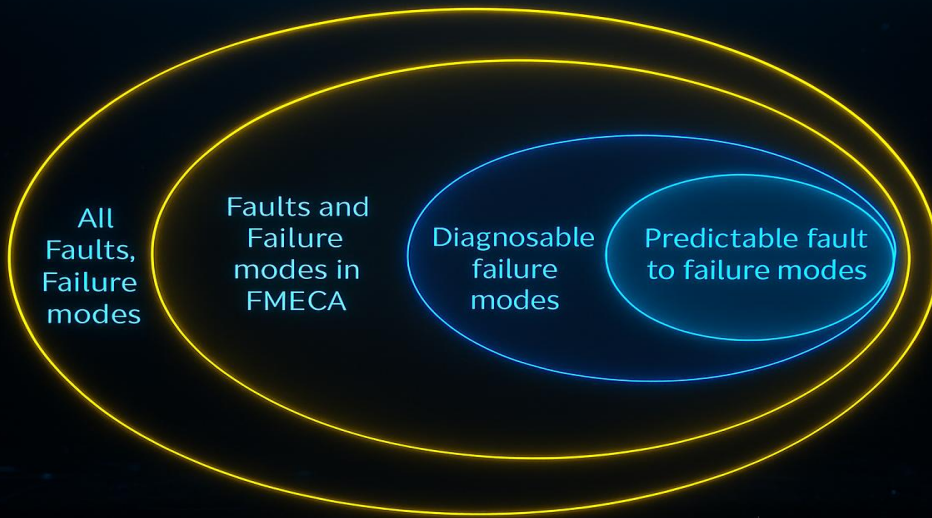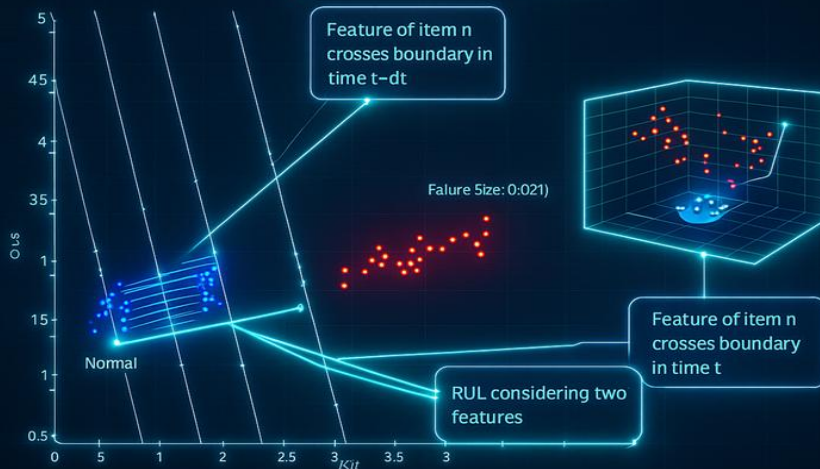
Statistical analysis
Queries
Data Mining

24

1. PURELY REACTIVE:

This one is a most basic system of AI, the one which does not make a stock of memories.

Diagnostic analytics

25

TYPES OF AI

The emergence of artificial superintilligence will change humanity, but it's not happening Here are the types of AI leading up that new reality.

Reactive AI	Limited memory	Theory of mind	Self-aware
• Good for simple classification and portern recognitioln tasks • Great for scenarios where all parameters known; • Incapable of dealing with scenarios including imperfect information or understanding	• Can handle complex classification tasks • Able to use historical data to make predic-tions • Capable of complex tasks such as self-dr-iving cars, but still vulnerable to eutllers or adversarial • This is the current state of AI, and some say we have hit a wall	• Able to understand human motives aning • Can deliver personal experience to every-based on their moti-ves and needs • Able to learn with fewer examples incu it understands what shows motive and intent	• Human-level intelligence that can surpass our intelligence, too

26

13

The challenge in Diagnostics analytics

- All Faults, Failure modes
- Faults and Failure modes in FMECA
- Diagnosable failure modes
- Predictable fault to failure modes

27

Black Swan Losses

- Loss Distribution
  - Tail events are rare – very little data
  - Typically strong model assumptions

28

29

30

31

What can I see   in my data?

Now casting

1) What has happened
2) What is happening

Forecasting

3) What will happen in the future
4) When will it happen

32

TYPES OF AI

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33

TYPES OF DATA ANALYTICS

To Educate and Inform

DESCRIPTIVE ANALYTICS

Group historical data according Ib their similarity

Reports

Mapping

DIAGNOSTIC ANALYTICS

Determine cause of successes and failures

Statistical analysis Queries

Data Mining

PREDICTIVE ANALYTICS

Learning from the past to find our trends, standards, totielations, Anticipcte the future
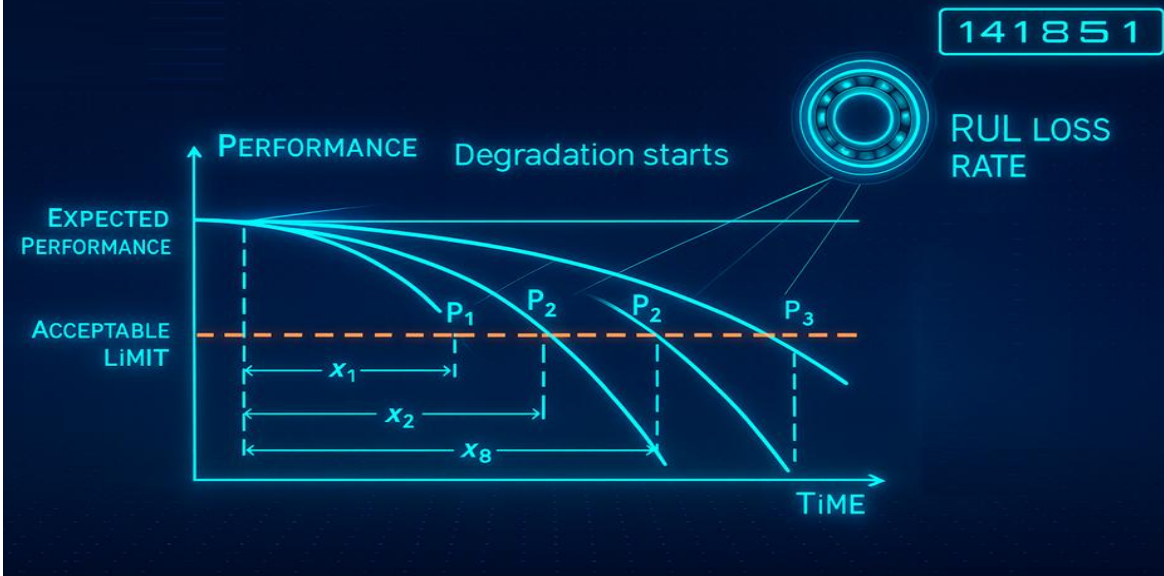
Machine learning, Simulation, Forecasts

PRESCRIPTIVE ANALYTICS / DECISION SUPPORT

Provide better options based on forecasts, Show implications of each option.

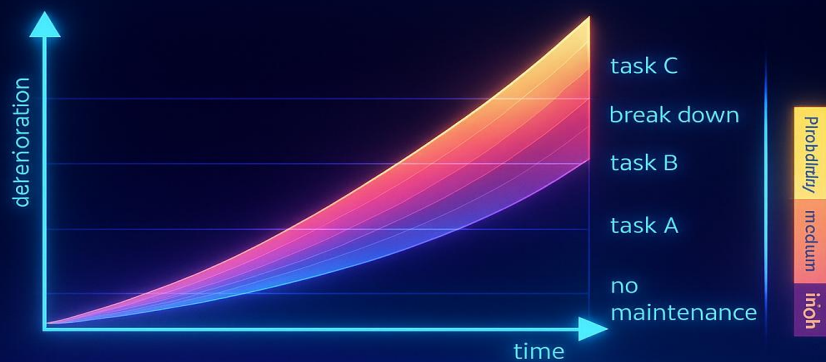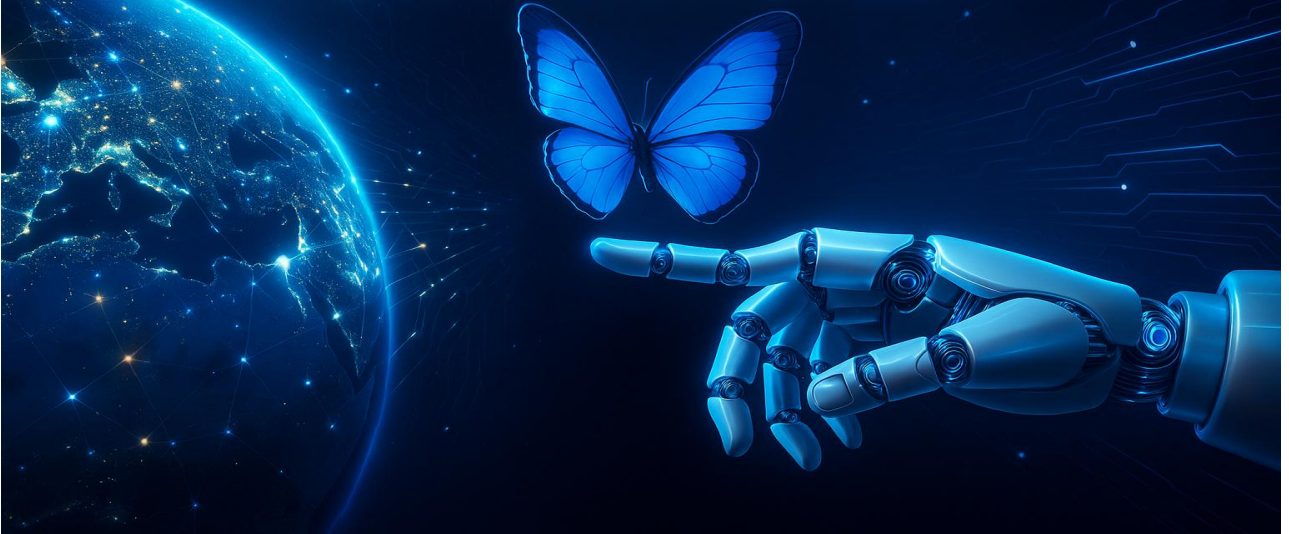Optimization Decision models Planning

34

35

36

Prescriptive challenge: The digital butterfly effect

37

Is my ML model enough?

38

TYPES OF AI

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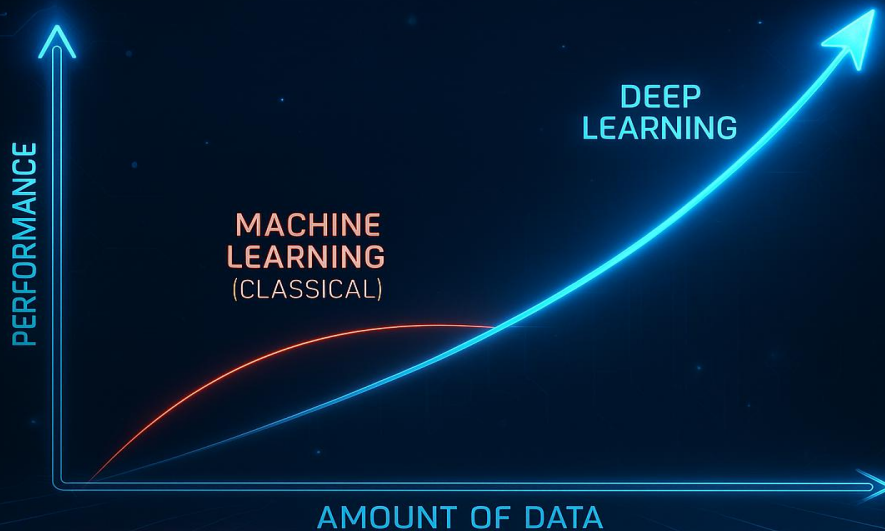## Self-aware

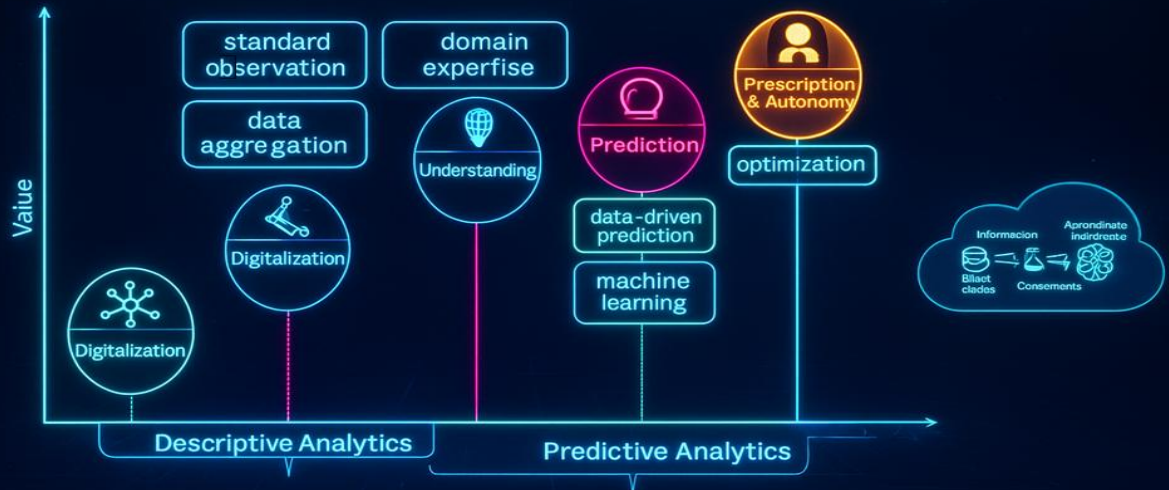- Human-level intelligence that can surpass our intelligence, too
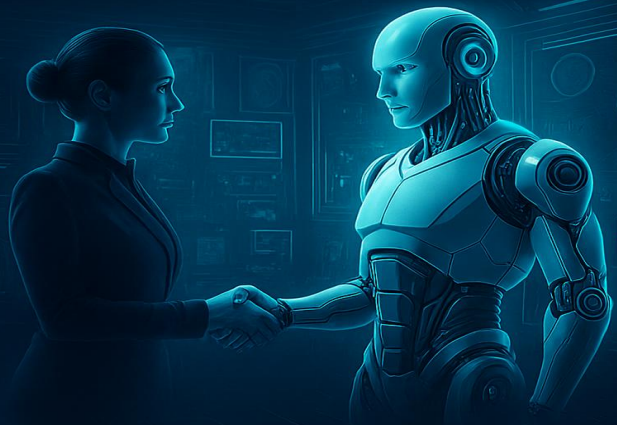
39

CLASSICAL ML VS DEEP LEARNING

PERFORMANCE

DEEP LEARNING

MACHINE LEARNING (CLASSICAL)

AMOUNT OF DATA

40

41

42

COGNITIVE ASSETS WILL SELF PRESERVE

43

TERROR MANAGEMENT THEORY

44

TERROR MANAGEMENT
THE CORE EXISTENTIAL DILEMMA

Core premise:
- Desire for life
- Awareness of the inevitability of death

45

Uniqueness of humankind
Distinctive human behavioral traits:
- Subtle expression of emotions
- Intelligence; abstract thinking, categorizing, & reasoning
- Symbolic & creative language
- Self-awareness & death-awareness
- Tool-making & technology
- Science, literature & art
- Ethics & religion
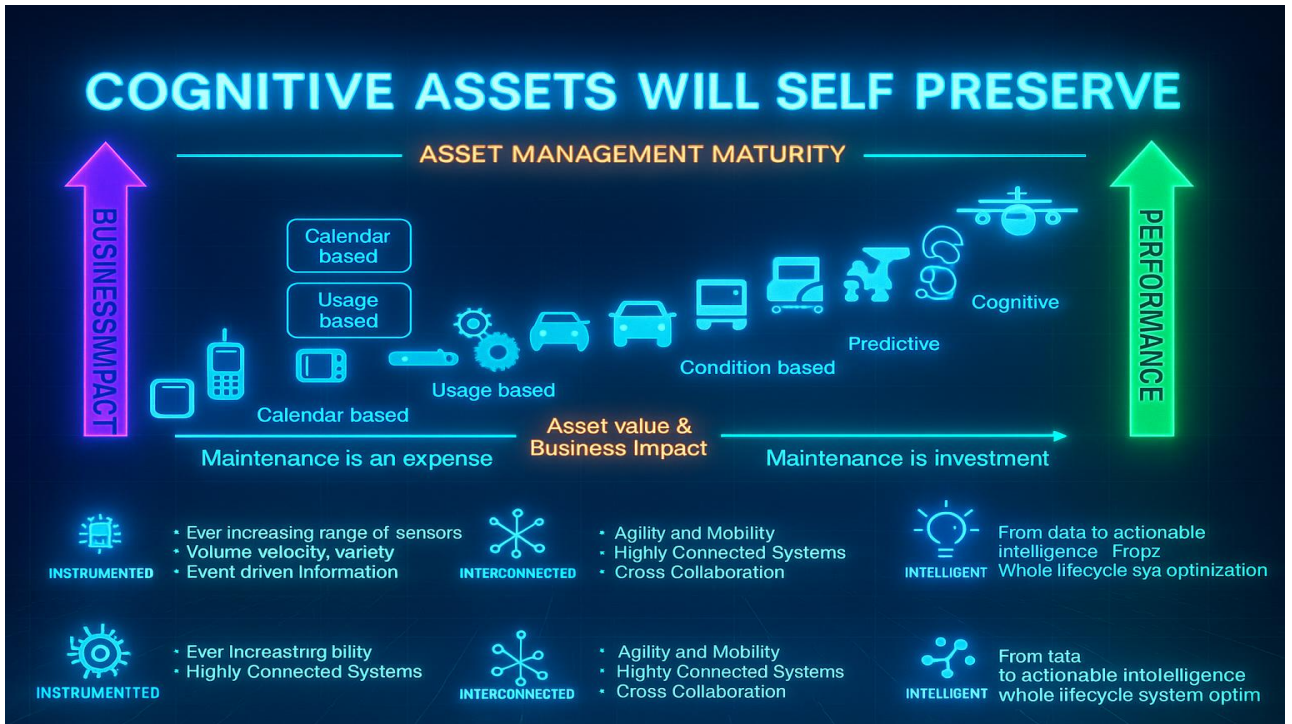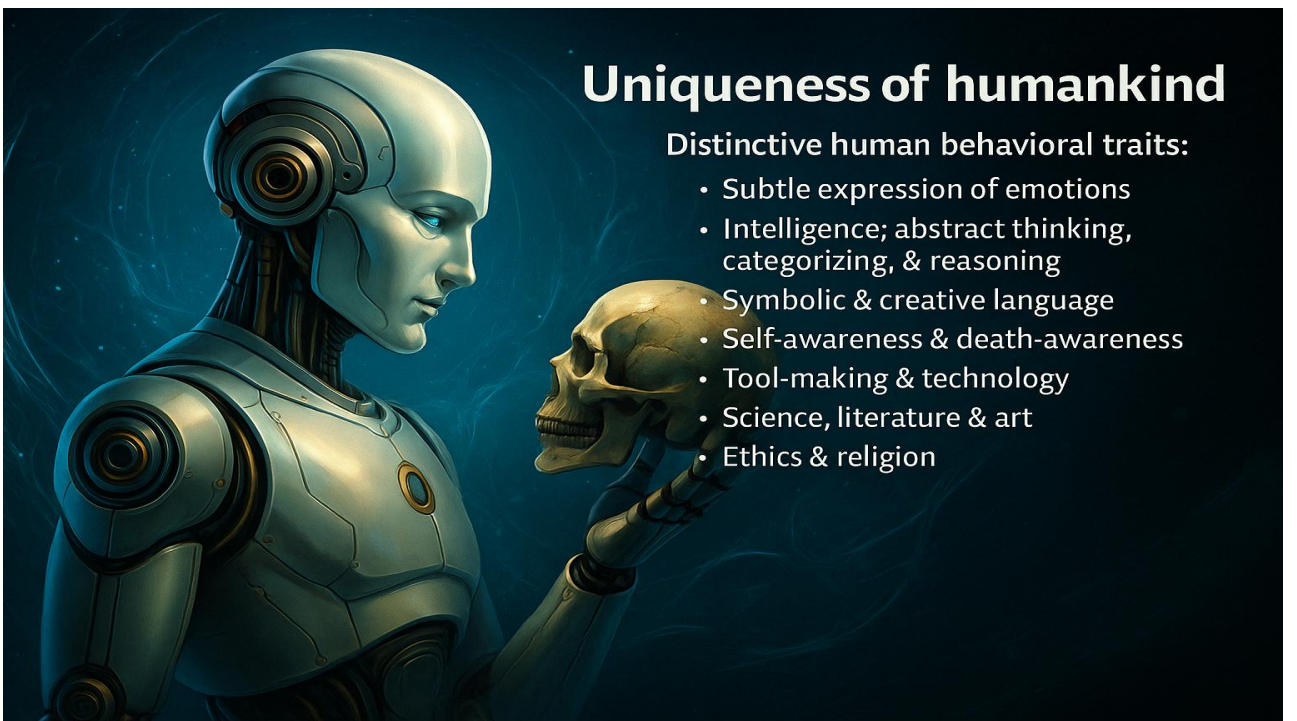
46

Types of AI

Reactive AI

Does not use
past experience

Limited Memory

Utilizes data
from the past

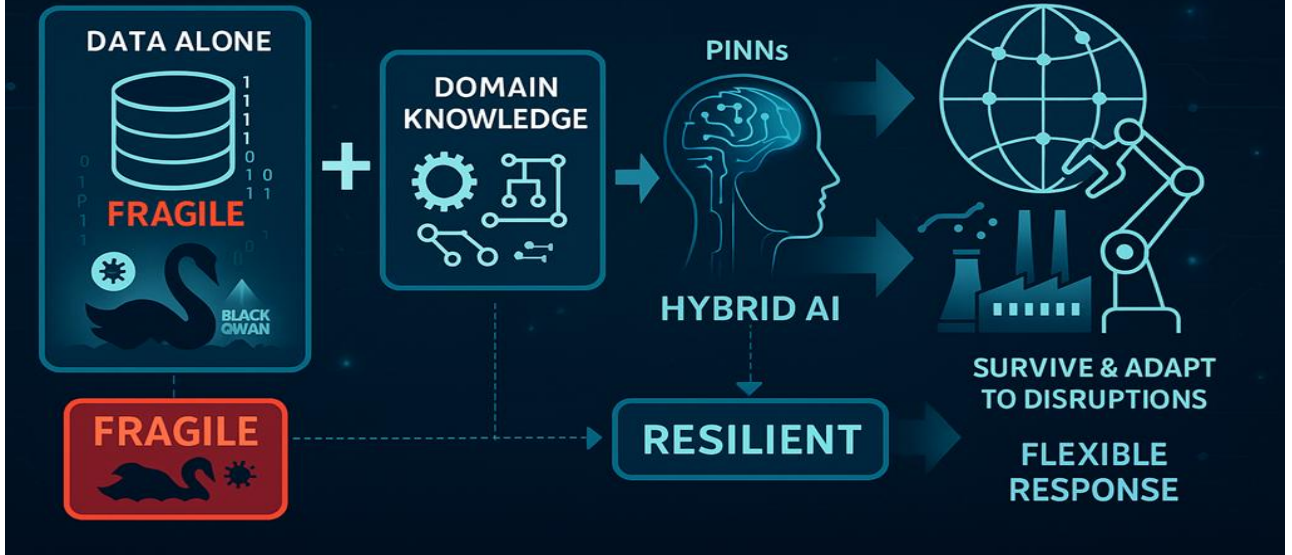### Self-aware

Exhibits
consciousness

47

What is cognitive maintenance?

- Understand complex patterns from asset data

- Generate accurate predictions

- Adapt maintenance activities dynamically

48

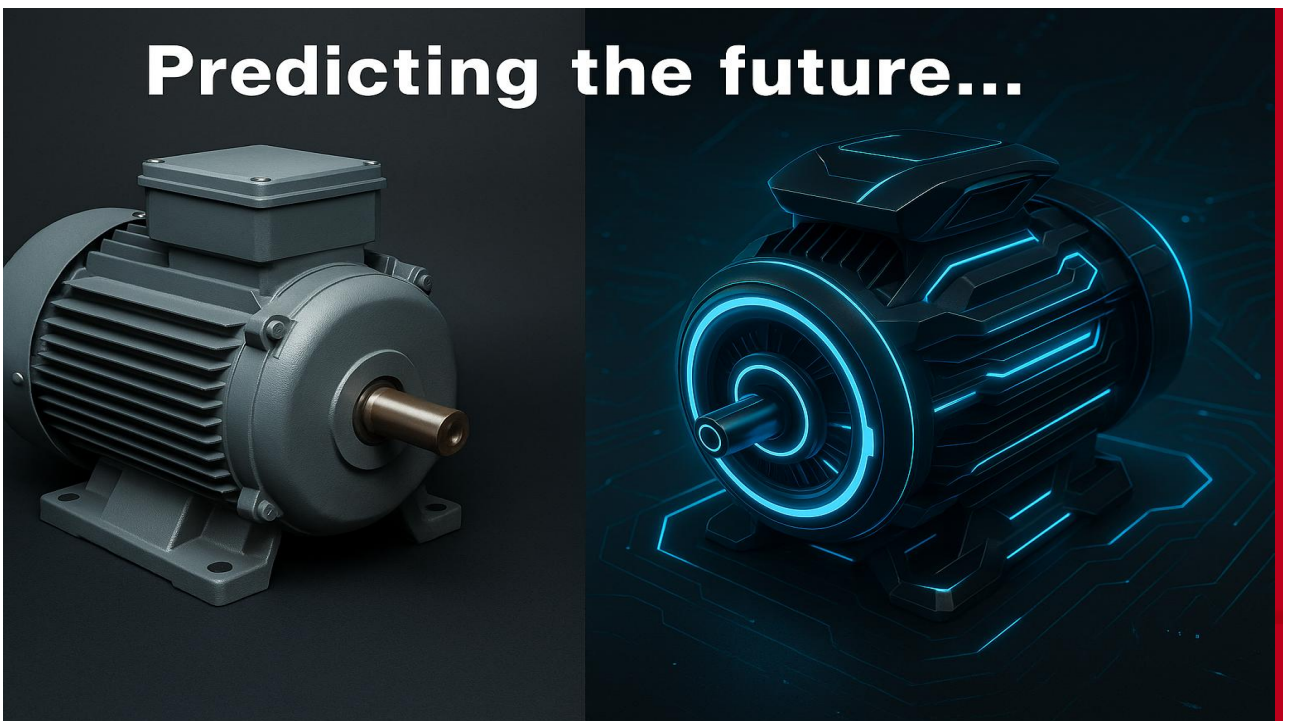BUILDING RESILIENT INDUSTRIAL AI:
WHY DOMAIN KNOWLEDGE MATTERS

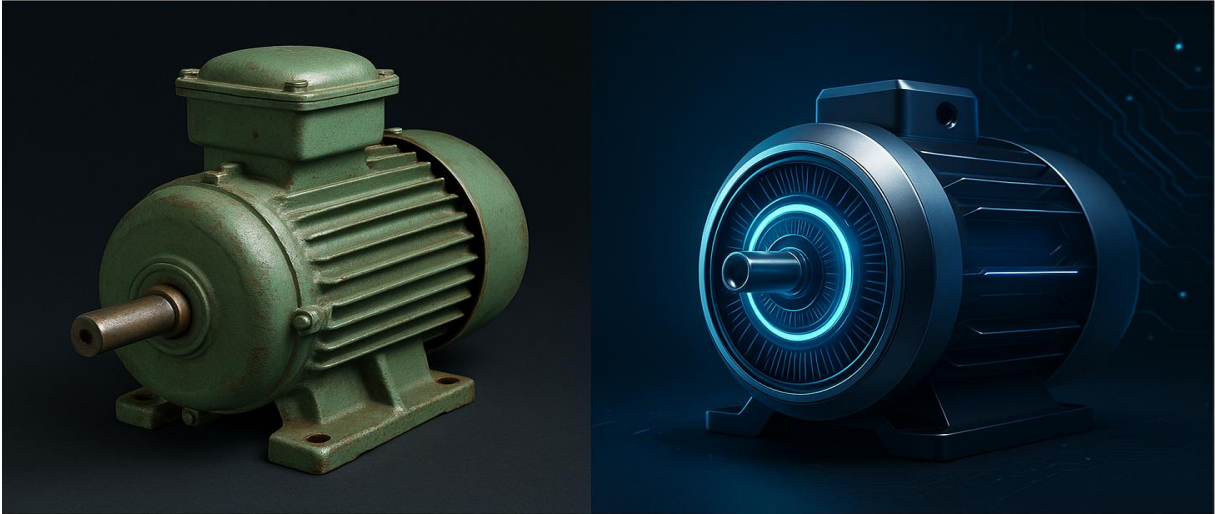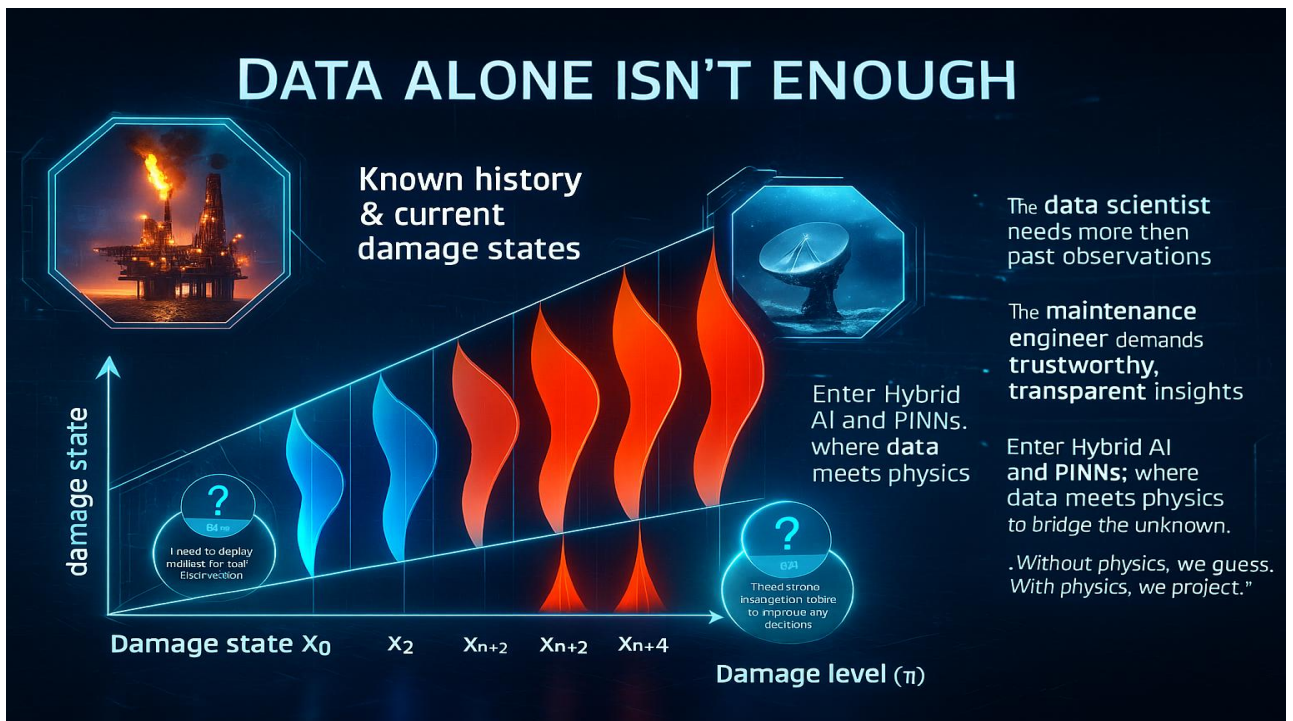49

AI systems should help empower society, combining the best of technology with the best of humanity'

50

Minority Report: Why Human Wisdom Still Matters

Why Human Wisdom Wislom Still Matters

51

Predicting the future...

52

Or predicting the past....

53

54

In summary, are you sure you want to reduce risk?

Incoming Black Swan

Geopolitical

Weather Events

Labor Availiability

Global Hyperinflation

Design Maturity

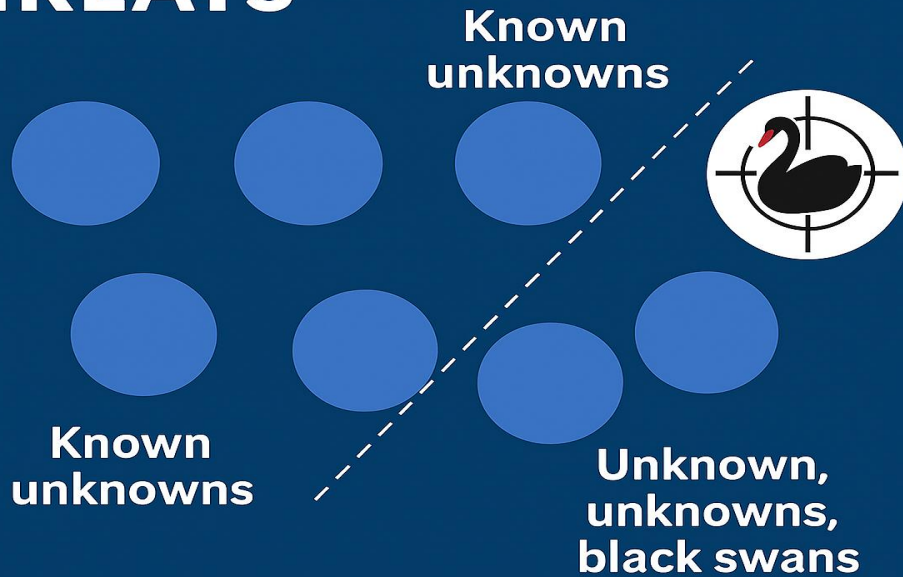Material Avalliality

Global Hyperinflation
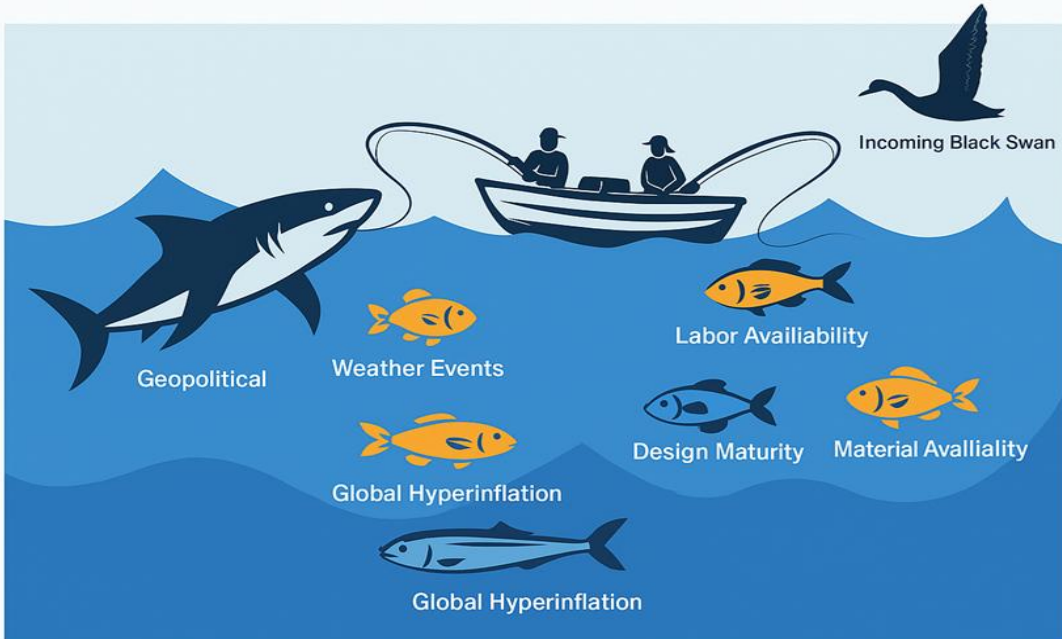
55

Black Swan Event:

An event or occurrence that deviates beyond what is normally expected of a situation and that would be extremely difficult to predict.
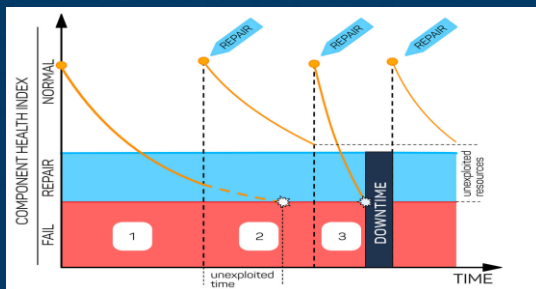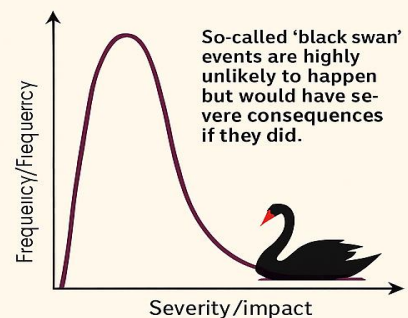
56

THREATS

Known
unknowns

Known
unknowns

Unknown,
unknowns,
black swans

THE PARADOX OF INCREASING RISK

- Technological progress has led to increasing efficiency.

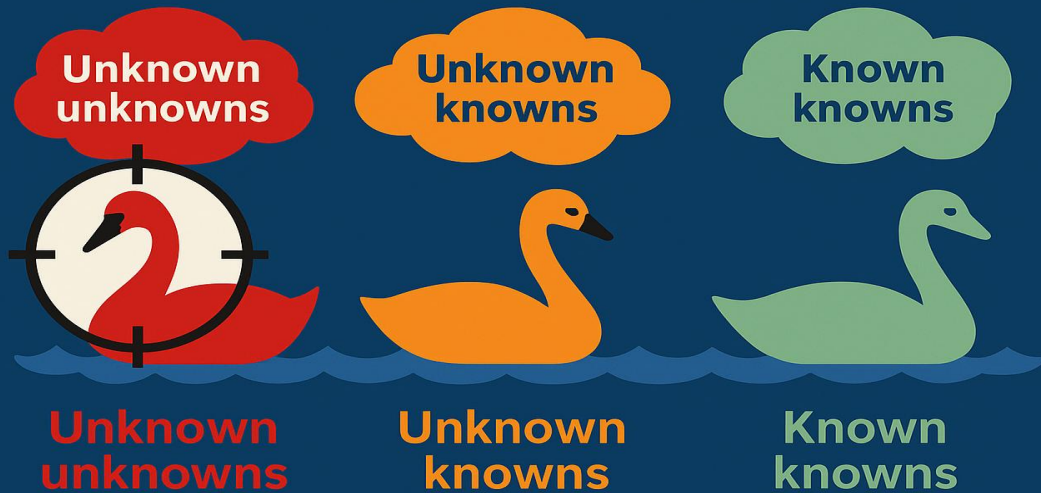- In maintenance reducing vulnerability to small shocks may increase the severity of large ones.

THE BLACK SWAN

So-called 'black swan' events are highly unlikely to happen but would have severe consequences if they did.

Frequency/Frequency

Severity/impact

COMPONENT HEALTH INDEX

NORMAL · REPAIR · FAIL

DOWNTIME

unexploited resources

unexploited time

TIME

58

29

59

60

BLACK SWAN LOSSES

Loss Distribution
- Rare tail events
- Strong model assumptions

61

PROGNOSIS BASED ON DEGRADATION SIGNAL

HEALTPProgonSS

Sensor

Prediction performance

Predicted performance

Past   T$_0$ Future

Observed ⟶ Predicted

Past   Current T$_0$

ENSEMBLE PROGNOSTICS

PHM algorithm   PHM algorithm   PHM algorithm

Weighted sum

RUL

RUL   ...   RUL

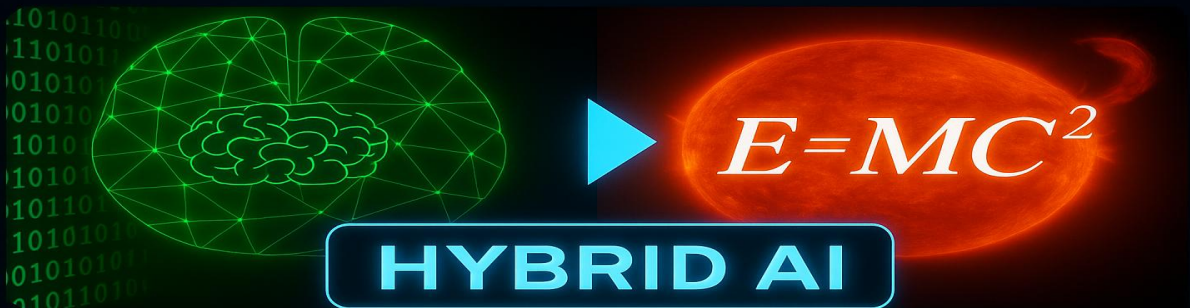**PREDICTED RUL**
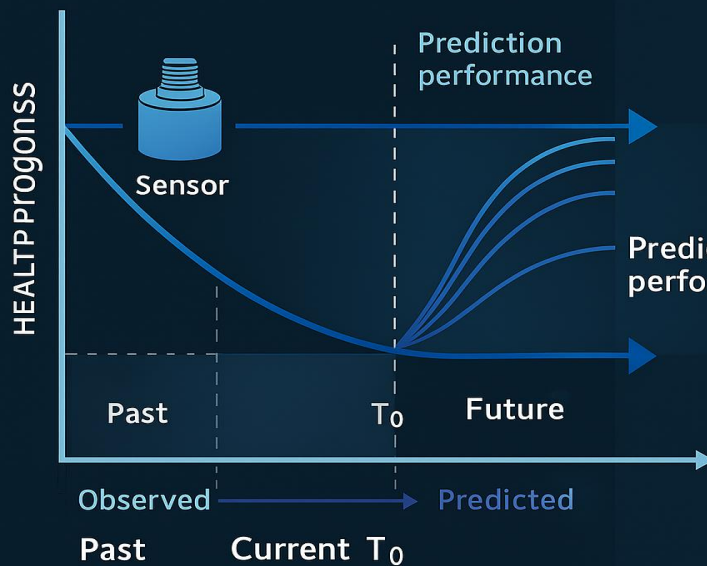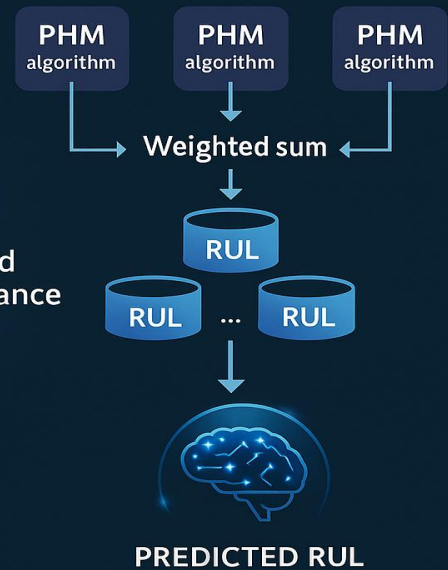
62

SHALL WE BE ABLE TO DETECT THE SWAN SONG OF ORUR ASSETS?

63

BEYOND THE DILEMMA: NOT MODEL-BASED OR DATA-DRIVEN — BUT BOTH

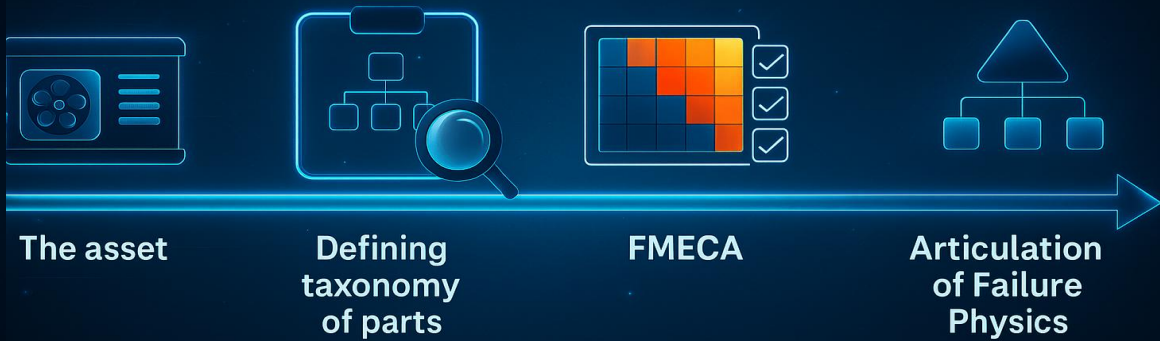## Fusing the laws of physics with the power of machine learning

$E=MC^2$

HYBRID AI

64

The process of Hybrid AI building

Why incomplete sensor data leads to blind spots and failures

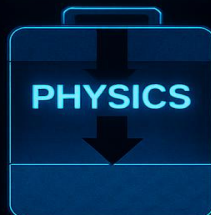| The asset | Defining taxonomy of parts | FMECA | Articulation of Failure Physics |

65

PHYSICAL LAWS AS ADDITIONAL INVARIANCE

– There are many more invariances other than translational invariance:
– Physics-based laws of nature: Conservation of mass, momentum, energy

HOW CAN THESE INVARIANCES HELP?

Three scenarios of Physics-Informed Learning Machines

Lots of Physics

Some Physics

Big Data

This is the common view of how Physics can help
But even in the Big Data regime incorporating Physics can be helpful

PHYSICS

PHYSICS

Small Data
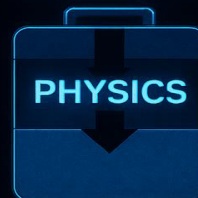
Some Data

Big Data

66

PHYSICAL LAWS AS ADDITIONAL INVARIANCE

There are many more invariances other than translational invariance:
— Physics-based invariances can scale data more seamlessly

HOW CAN THESE INVARIANCES HELP
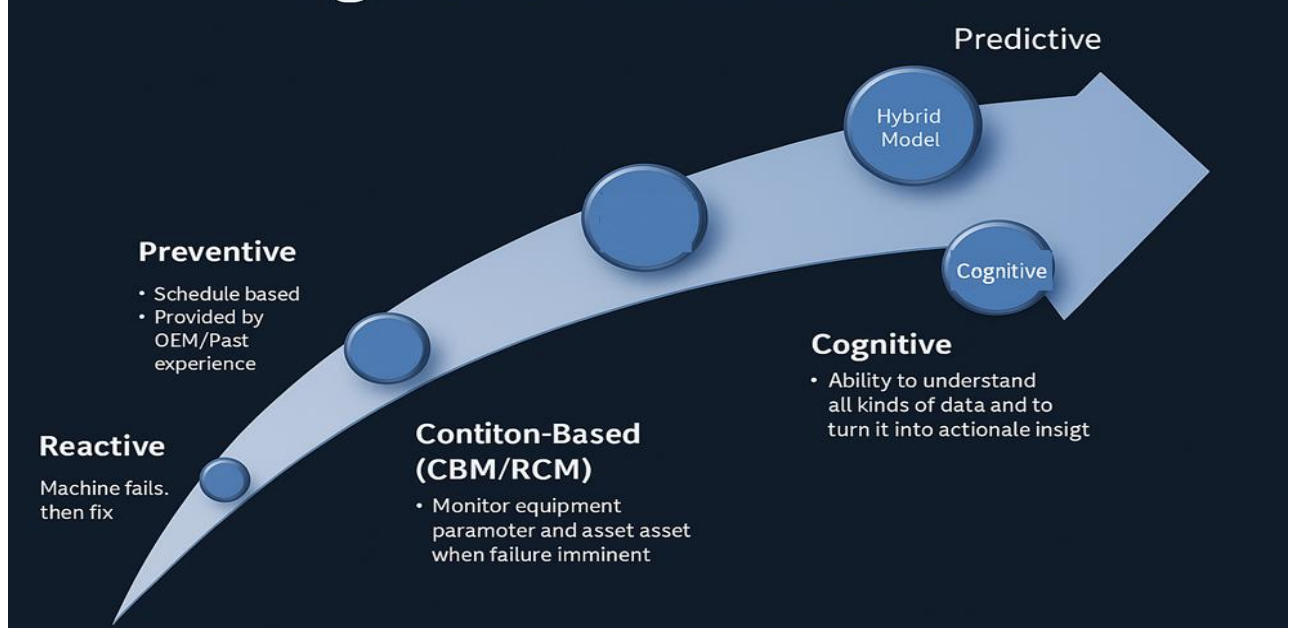
LESS DATA   MORE DATA

PHYSICAL INVARIANCES CAN improve generalization or regularize training

Physical invariances can help make the model easier to train with less parameters

THE MAIN QUESTION IS HOW CAN WE INCORPORATE THESE INVARIANCES INTO LEARNING?
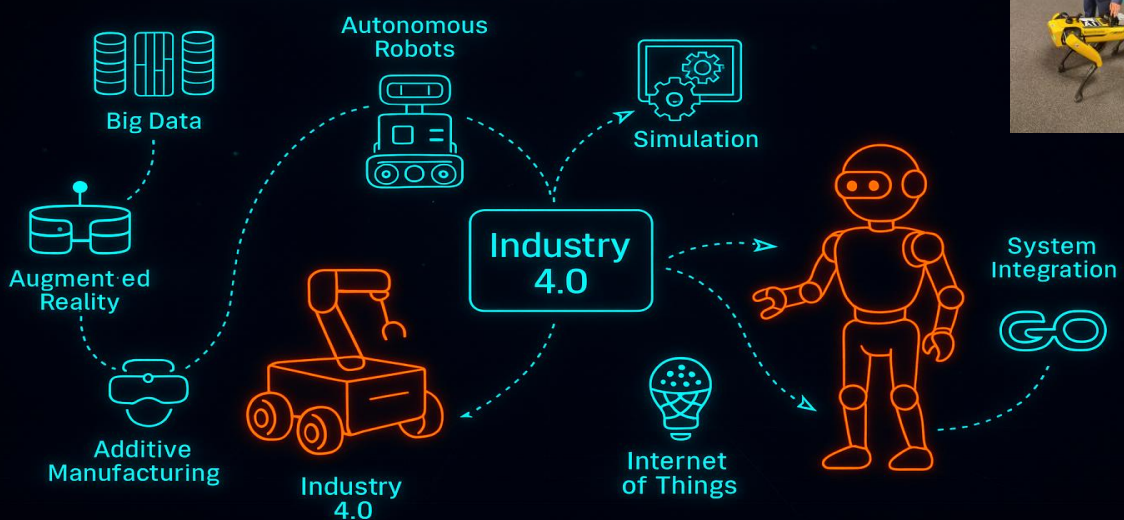
67

Cognitive maintenance

Predictive

Hybrid Model

Cognitive

Preventive
- Schedule based
- Provided by OEM/Past experience

Cognitive
- Ability to understand all kinds of data and to turn it into actionale insigt

Reactive
Machine fails. then fix

Contiton-Based (CBM/RCM)
- Monitor equipment paramoter and asset asset when failure imminent

68

Cognitive Maintenance is a further upgrade on predictive maintenance, as it enables us to ingest all kinds of data

+ Structured
+ Unstructured (audio/video/natural language)

Sensor Data
Proces Audio/Video

Event Data
Breakdowns
Qualityissues

Maintenance Data
Motor Service Data
Operating

to gain informed insight and superior recommendation on next best action

69

ENABLING TECHNOLOGIES WITH ROBOTS AS FOCAL POINT

Big Data

Autonomous Robots

Simulation

Augmented Reality

Industry 4.0

System Integration

Additive Manufacturing

Industry 4.0

Internet of Things

70

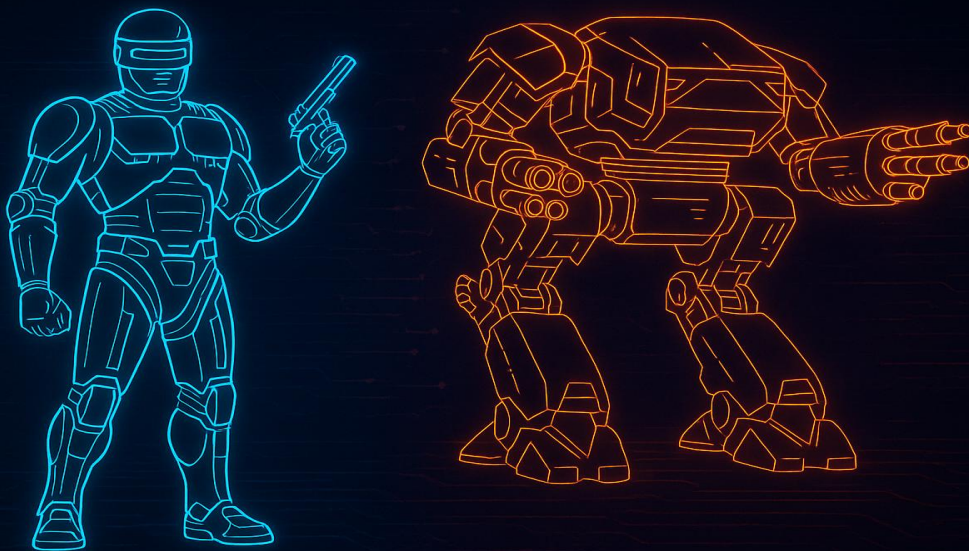## COLLABORATION AND CO-HABITATION ISSUES

- Robots bumping into humans
- Robots (such as drones) falling and the danger this poses to the workforce on the
- Overlooking robots falling onto humans or other robots below
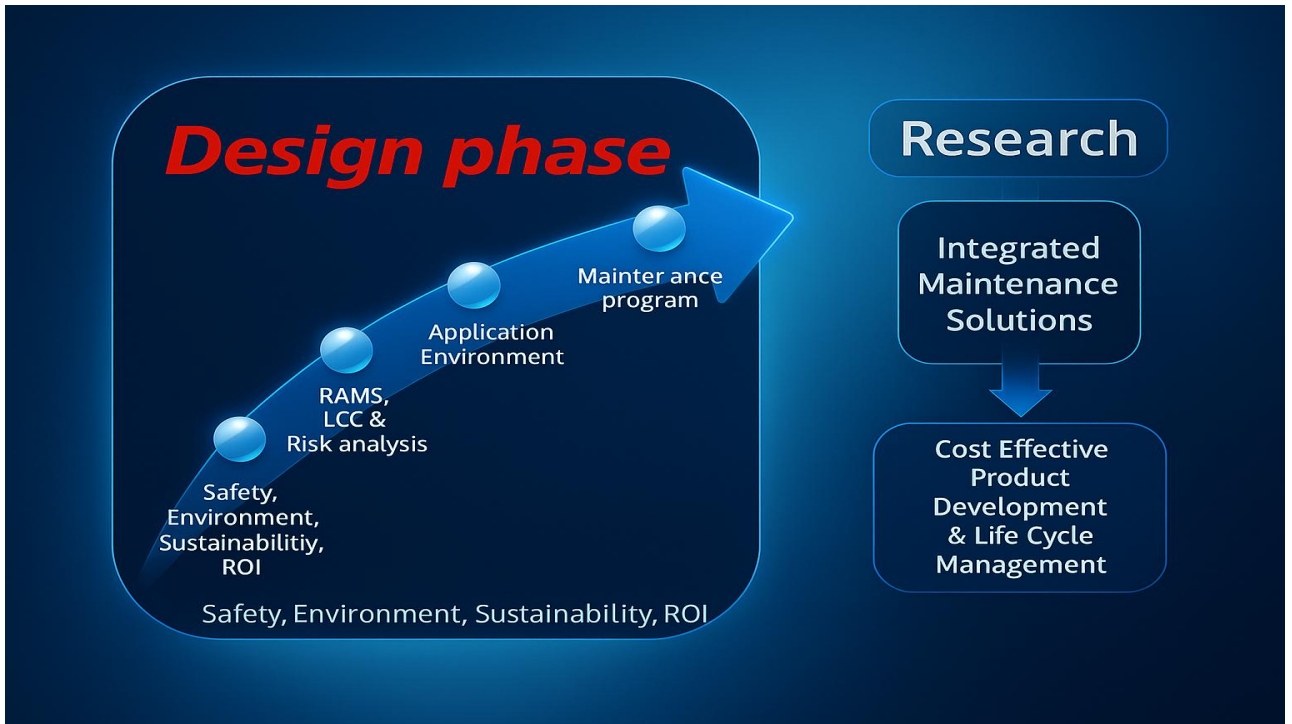- Electrocution caused by robot malfunction
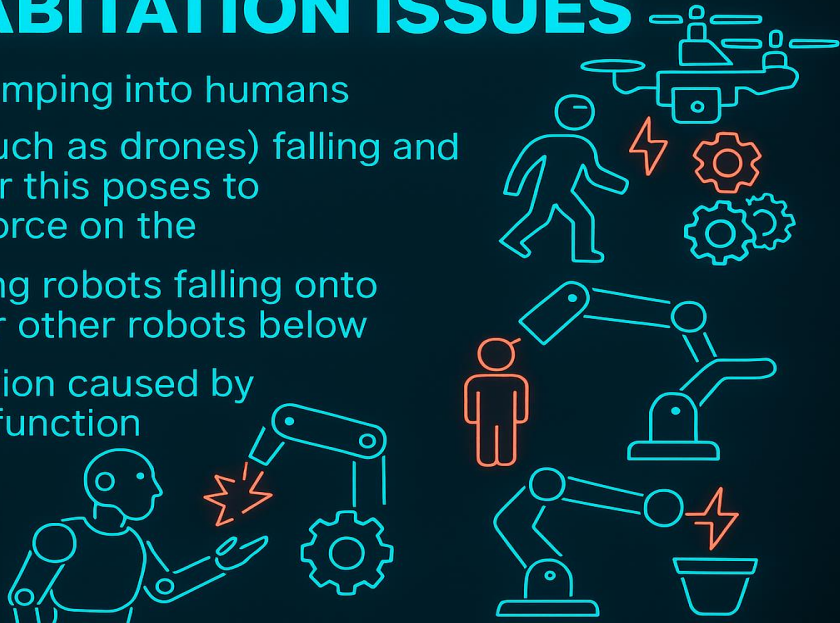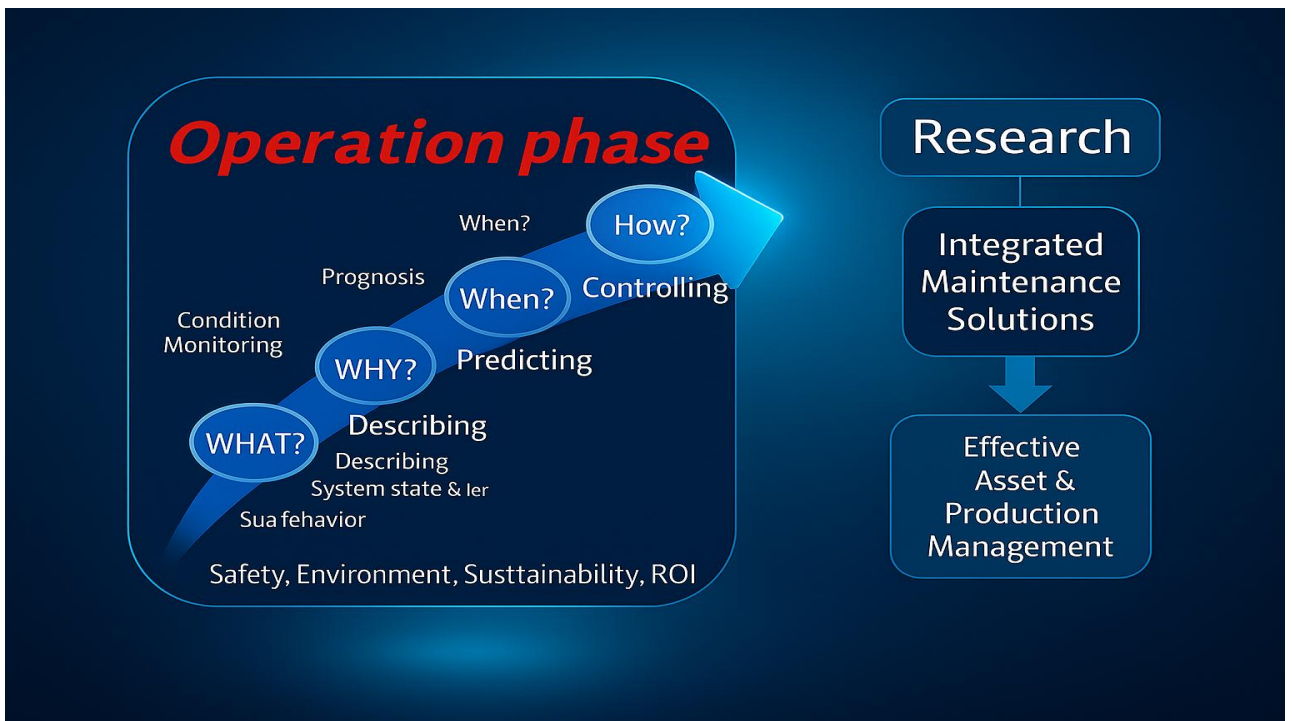
71

ROBOCOP VS ED-209
Human-in-the-loop vs Autonomous Systems

72

73

74

Design for....

- Design for reliability
- Design for maintainability
- Design for maintenance
- Design for **failure**

75

Design for maintenance and maintainability

Maintainability is the measure of the ability of an item to be retained in or specified condition when maintenance is performed by personnel.

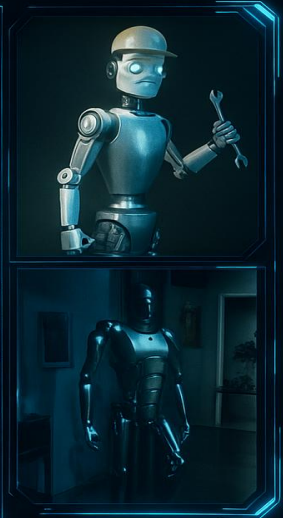SAP PM

76

1-Augmented maintenane crew

77

AR and VR to augment crew skills
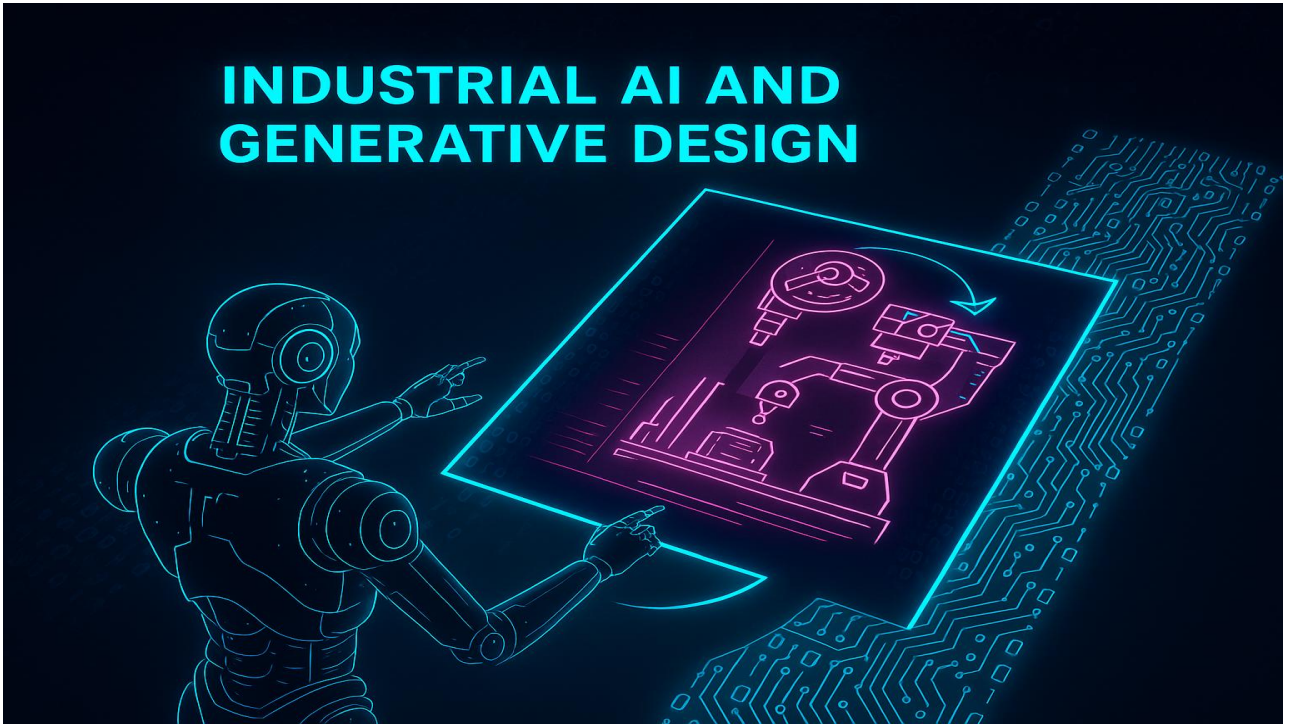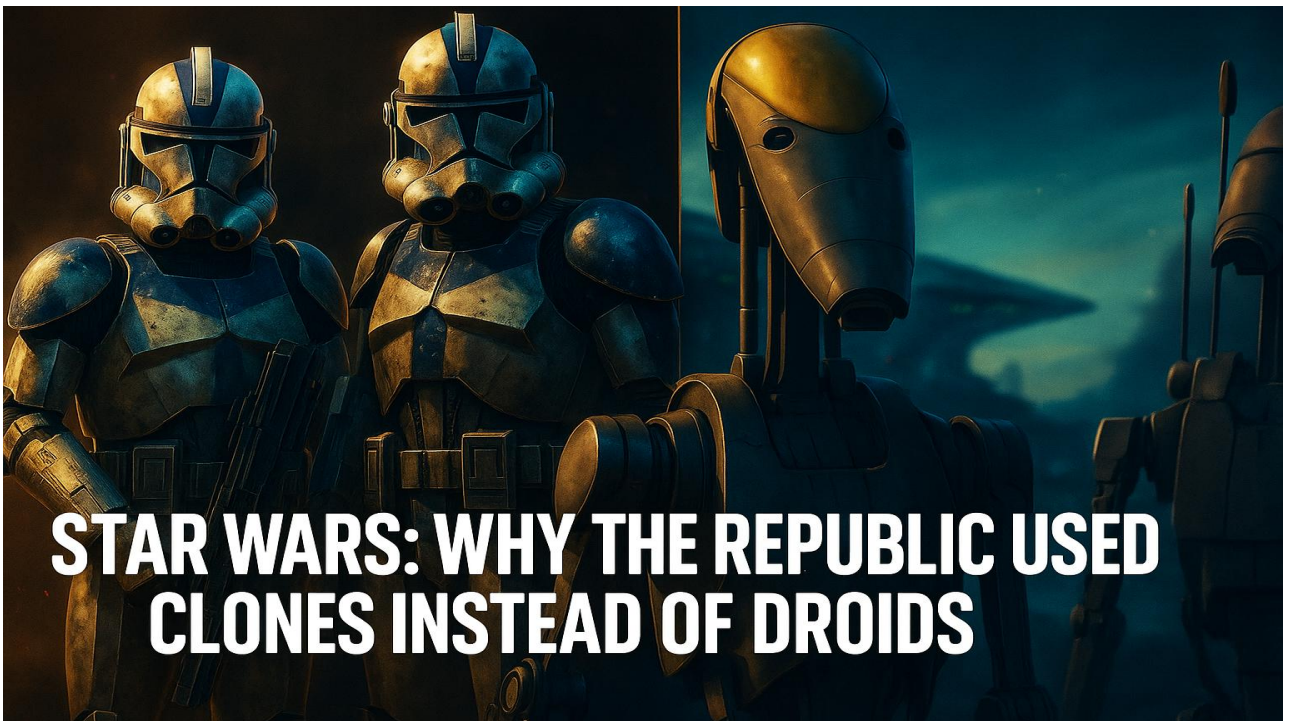
78

2-Droids to perform as humans

79

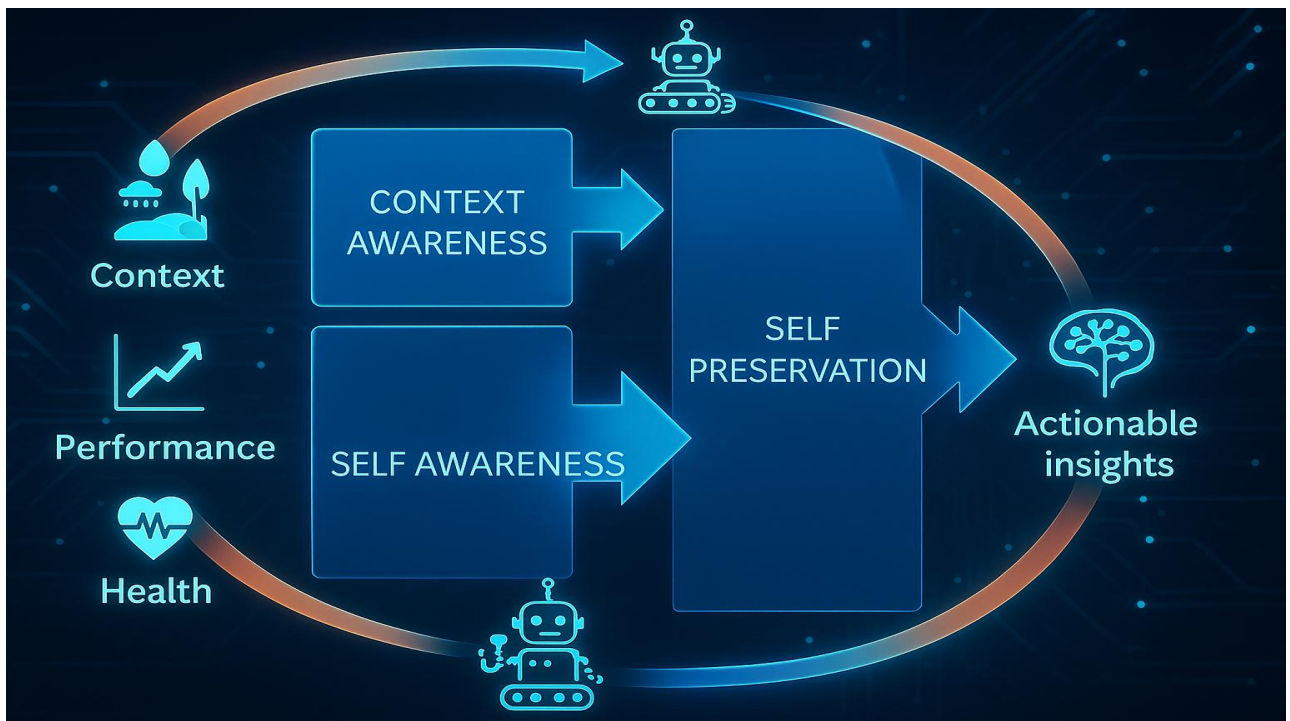# Machines designed to be maintained by robots

80

81

82

Battle droids generally feature limited cognitive systems and programming, restricting them to being most effective when in direct combat

Dumb battledroids are ineffective in military actions. Easily drawn into traps, easily fooled, and nobody has any moral qualms about using any and all weapons to slaughter droids

Smart battledroids have an unfortunate tendency to murder their creator in the beta-testing phase, then try to take over the galaxy and destroy all non-droid life

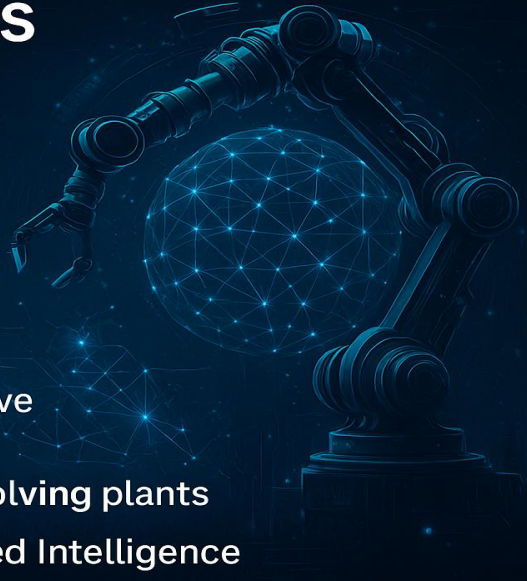## STAR WARS: WHY THE REPUBLIC USED CLONES INSTEAD OF DROIDS

83

Context

CONTEXT AWARENESS

Performance

SELF AWARENESS

SELF PRESERVATION

Health

Actionable insights

84

CONCLUDING REMARKS

- ✔ Hyperaut**omation** → enabler of the future Cyber Plant

- ✔ From **automation to autonomy** self-learning, self-adaptive systems

- ✔ **Cognitive Maintenance** → key to plant resilience

- ✔ **AI** + **Robots** + **Humans** → collaborative ecosystem

- ✔ Towards **self-preserving** and **self-evolving** plants

- ✔ The path: **IR 4.0** → **IR 5.0** → Distributed Intelligence

85

diego.galar@ltu.se
dgalar@sisteplant.com

86