Smart Plants

Autonomy In Plant Operations

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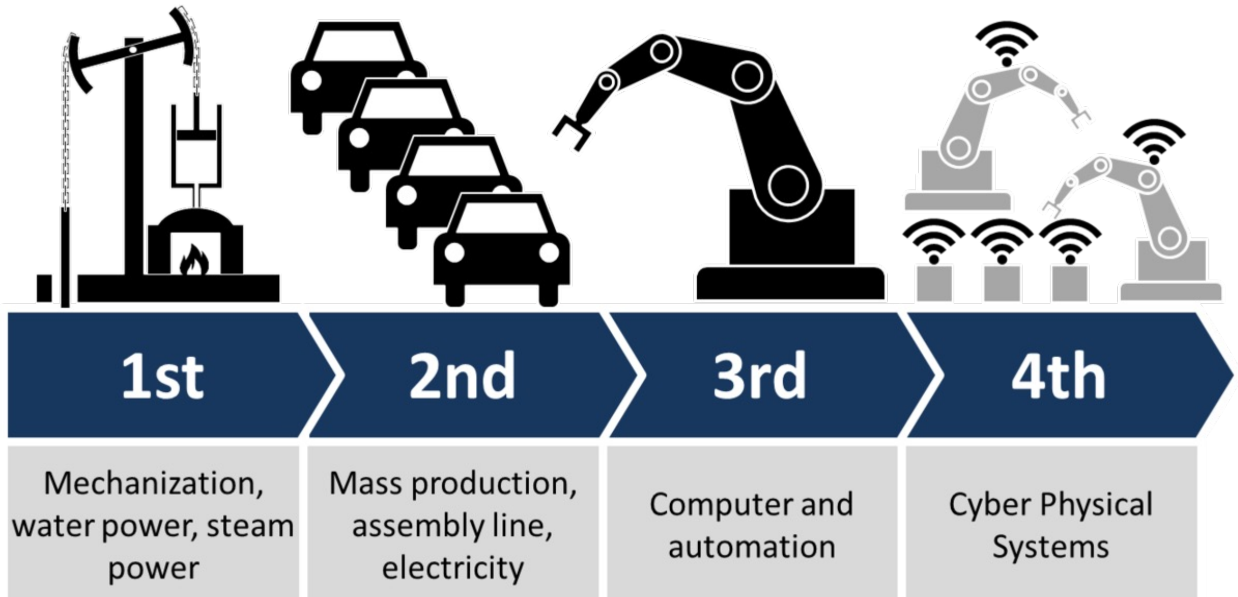
4th Industrial Revolution (*)



1780 Steam

1870 Electricity

1970 Computing

Intelligence (AI)

From Automation (Digitization) to Autonomy (Digitalization)

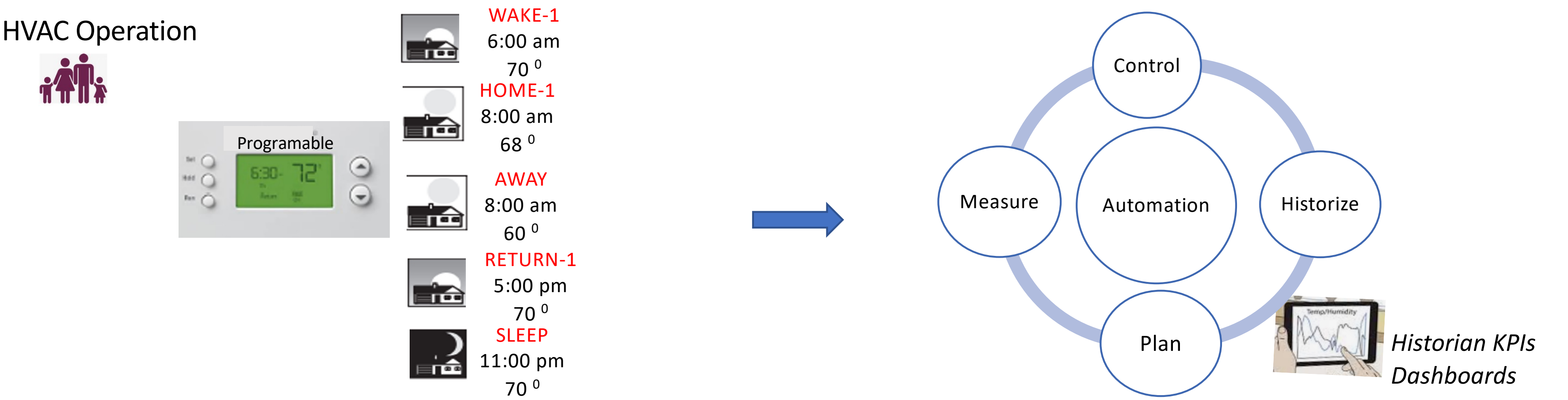
Industry 4.0 Trends & Exponential Growth of

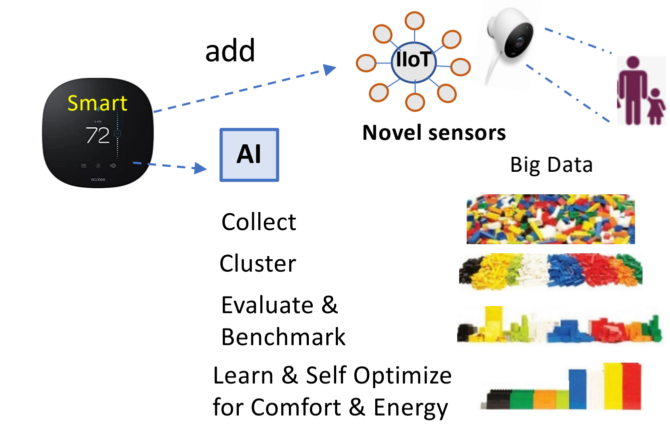
- Industrial Internet of Things (IIoT)
- Low-cost & novel sensors
- Cloud Computing
- Mobility
- Analytics & Numerical/Statistical AI
    - Big Data
    - Machine Learning
- Cognitive & Semantic AI
- IT/OT Systems Integration
    - Operational Data Pipelines
- Autonomous Operations

Graphic Credit & Reference:

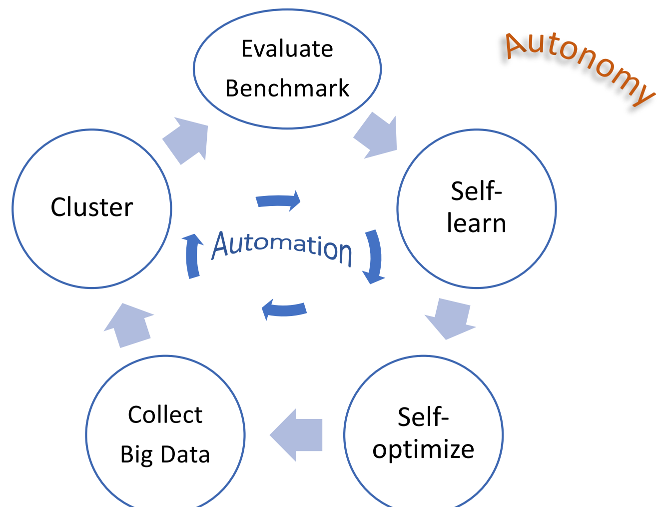
[(*) Ten Years of Industry 4.0-Quo Vadis? | AllAboutLean.com](#)

From Automation to Autonomy (*)





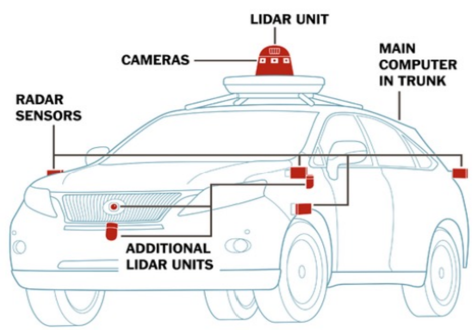
Graphic Credit: (99+) Post | Feed | LinkedIn



(*) Transformation from Automated to Autonomous | ARC Advisory (arcweb.com)
Lawrence on Twitter: "The Power of AI - From Automated to Autonomous - Apostolis Georgiou, ExxonMobil #ARCForum https://t.co/yRhKo25UjP" / Twitter

From Autonomous Cars *To* *Autonomous Operations* (*)

- Multi & variable Operation (i.e., speed, path)
- Multiple disturbances to detect/infer online
- Requires online optimization (best route, dynamic route)



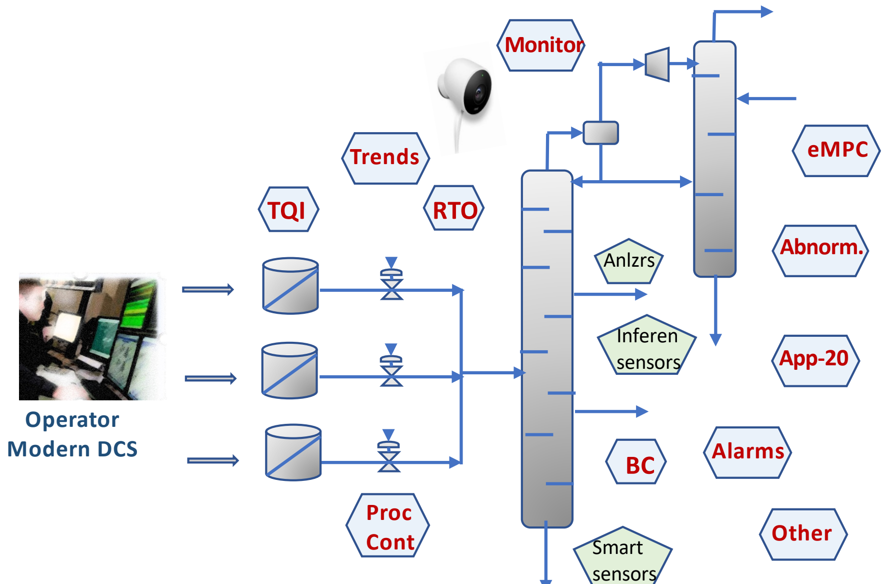
Graphic credit: [Google self driving car | Self driving, Mini cars, Driving (pinterest.com)]

SAE Levels of Autonomy: [Automated Vehicle Safety | NHTSA]

Driver/Operator Involvement

- L0: You Drive, You Monitor
- L1: foot off (adaptive cruise control)
- L2: hands off (now) for limited modes/areas
- L3: eyes off (you are available to take over)
- L4: mind off
- L5: drive off

- Multi-mode operations;
- Complex disturbances (short/long-term disturbances) and manipulated variables.
- Requires online optimization for various unplanned conditions (weather, equip. failures, supply chain disruptions)



Impact of (Human) Operational errors (**)

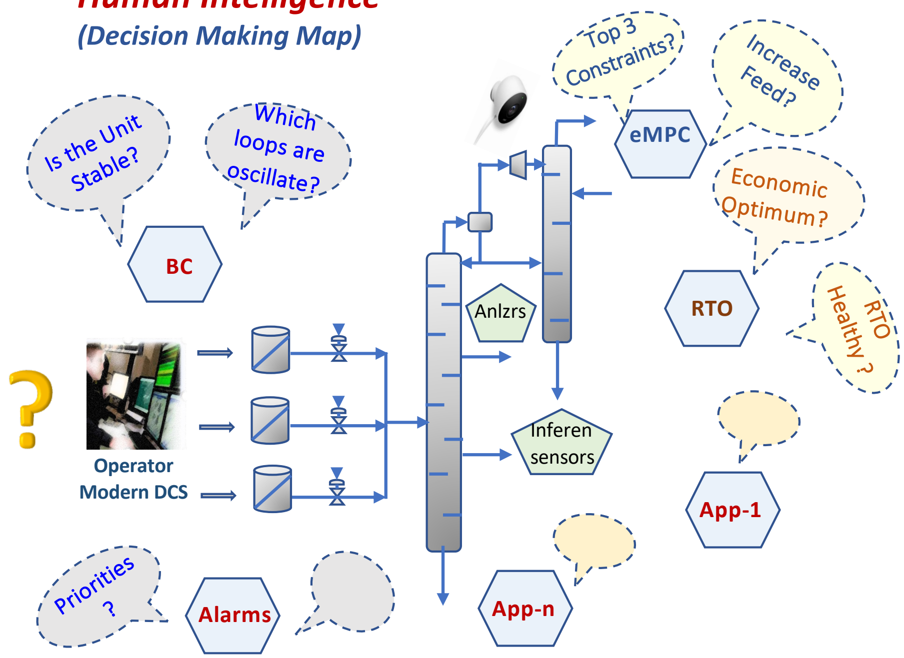
"The biggest "losses" in our industry are a result of our own mistakes..
This is why we believe in #autonomousoperations ....."
(KBC/YKG; "Survey of Dollar Loss per Major Incident" by J&H& MCLenna, Inc)

(*) [Transformation from Automated to Autonomous | ARC Advisory (arcweb.com)]

(**) [(99+) Post | Feed | LinkedIn]

Human Intelligence

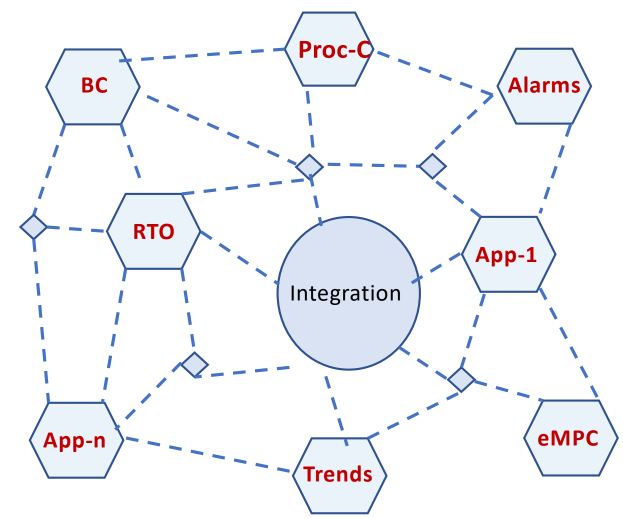
(Decision Making Map)



- Human analysis & actions are based on <u>experience and limited key variables</u>
  - Detects plant health, modes, states by previous (knowledge) patterns
  - Makes decisions/actions for safety & stability & minimal optimization

Computer Intelligence

(Network of Agents)

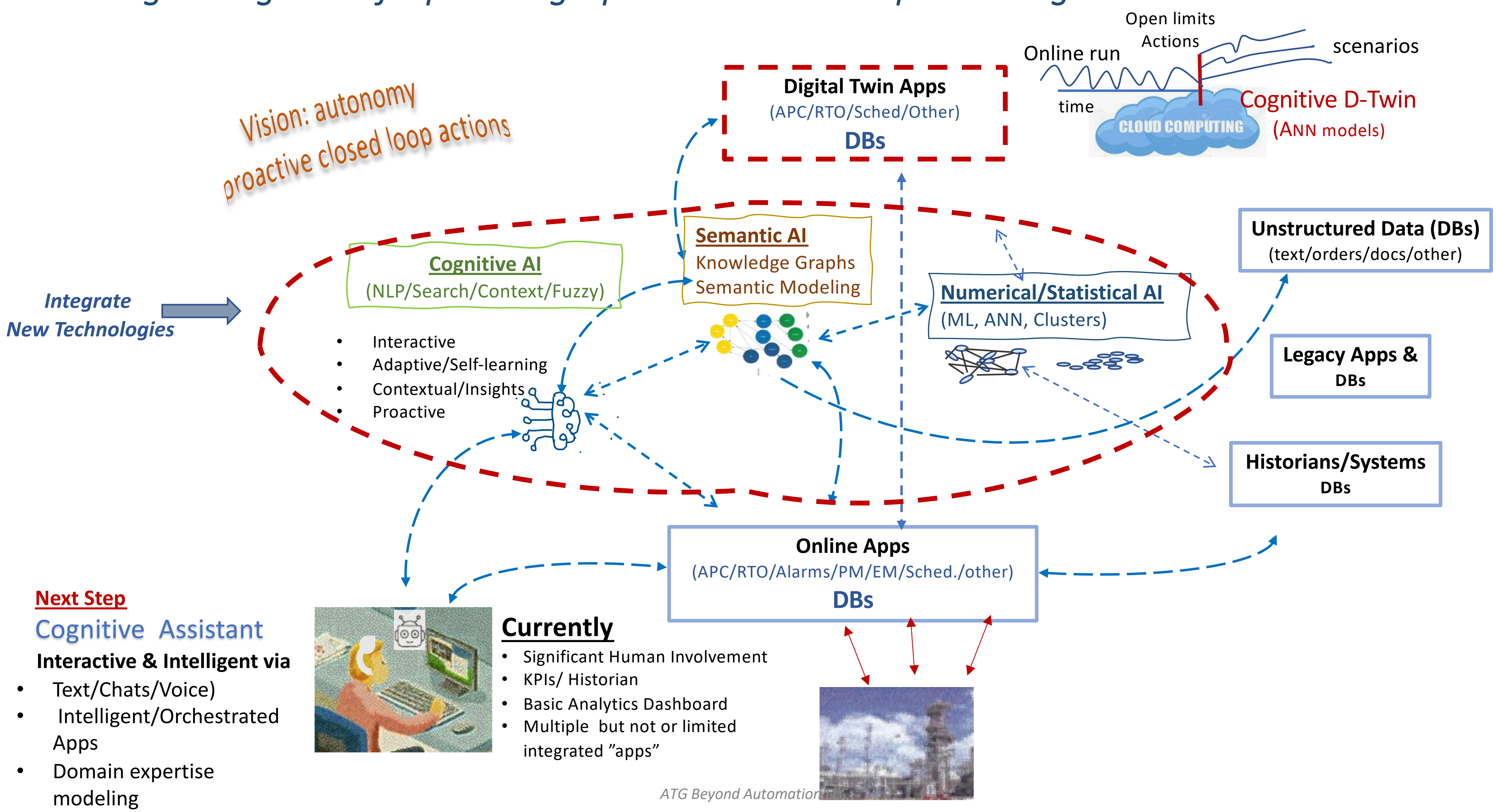


- <u>Scans millions</u> of data in mins; Structured & Unstructured Data
  - Connect different DBs – detect modes and instruments
  - Run scenarios
  - Can find a true (global) economic optimum
  - Leverage unconventional measurements such as videos

"Autonomy" Objective: Enhance operator decision making by AI to minimize human errors *(Intelligent Self-optimizing)*

- Safe, reliable, and consistent operation. Achieve economic optimum at all operating modes
- Continuously evaluate constraints and performance and finds the new optimum

Achieving Intelligent Self-Optimizing Operations: A conceptual Design



Challenges & Thoughts

Big Data, Modeling, & Expert Knowledge: Partners in the Journey to Autonomy

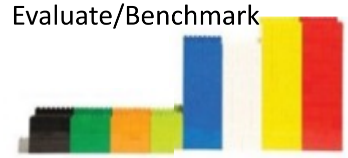
Big Data

Collect/Clean

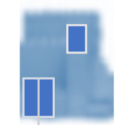
Organize/cluster

Label

Evaluate/Benchmark



Explain/Recommend



Graphic Credit: (99+) Post | Feed | LinkedIn

Modeling is the Core of the Applications

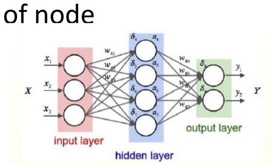
Fundamental ("Mechanistic" & Explainable) Models

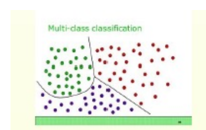
- Fundamental knowledge of how things work
- Mechanistic based casual understanding and explanations
- Reduced models

$$J_{\theta_s}(x_m) = -\frac{1}{M}\left[\sum_{m=1}^{M}\sum_{k=1}^{K} 1\{u_m = k\}\log\frac{e^{\theta_{sk}^T x_m}}{\sum_{k=1}^{K} e^{\theta_{sk}^T x_m}}\right]$$

Data Driven Models – Machine/Deep Learning (Numerical/Statistical AI)

- Based on historical Data. Active learning based on excitation and guided experimental
- Learning comes from data resulting in networks of weighted links between inputs and outputs via layers of node

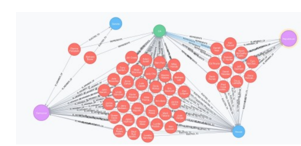




i.e., SVM, DM, CNN, Markov/Decision Models, LSTM, Autoencoder, SOM, Reinforcement Learning

Cognitive & Semantic AI type Models

- Cognitive models (i.e., NLP models)
- Interactive Intelligence
- Text modeling & Semantic (based on concepts) modeling & reasoning
- Fusion of structured & unstructured data
- Embedded domain expertise Knowledge Graph Models



Challenge: Represent business problem by integrating "domain expertise" with math and statistics.

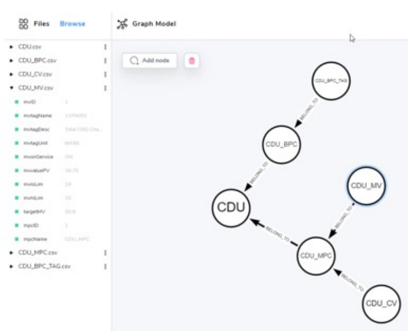
Opportunity: The recent advances in Cognitive/Semantic Technologies (i.e., "unstructured data/text" modeling, semantic reasoning) present an enormous opportunity to move "intelligence" in the math environment towards intelligent & autonomous operations

Challenge: Integration of Domain Expertise Knowledge; Structured and Unstructured Data

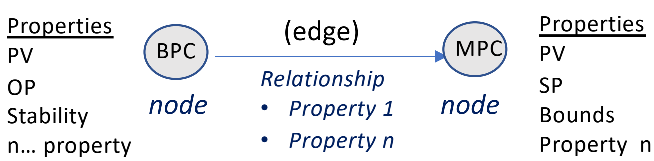
AI: Semantic Modeling/Knowledge Graphs

- Modeling of "*concepts*" (semantics), hierarchy, and data relationships. Can combine structured & unstructured data
- Can provide real-time recommendations, based on
  - "*Collaborative*" filtering such as similarity of behaviors and operations or best practices
  - "*Content*" filtering such as patterns of constraints and interactions among entities/concepts (i.e., between apps)

"KG on interaction of "control" apps (domain expertise)

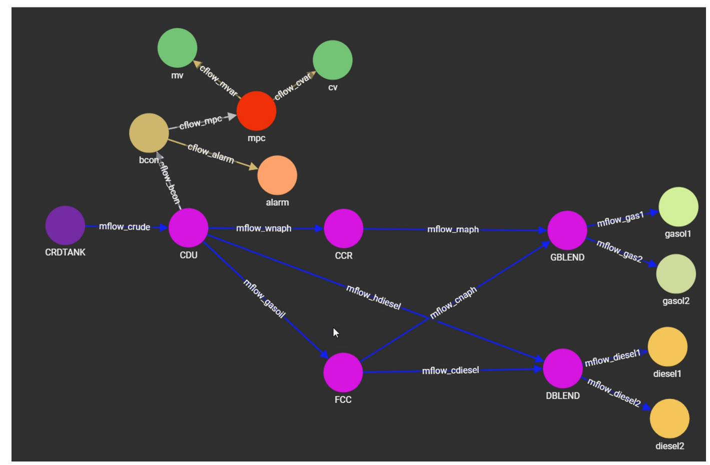


i.e., KG of "Base Process Control (BPC)" and MPC



Schema

"KG on interaction of Units for process control

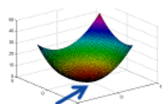


Challenge: Contextualization of Data is a Key for Intelligent Systems

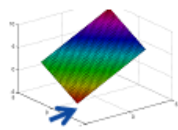
→ 38.8 deg C ←

has different meaning

- The "context" of data is usually defined by the "receiver" of the data and defines the implementation
  - Example: MPC receives "set-points" from RTO. Every set-point has a "context". Depending on the "context" each set-point is implemented differently
  - Context of a "set-point"



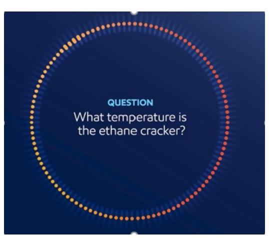
RTO Minimum



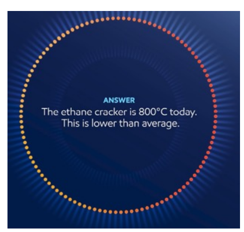
- How to contextualize data (i.e., Knowledge Graph and "metadata")
- Where to contextualize (i.e., real-time analytics at the interface (edge devices/computing)) ?)

Contextualization Enhances Human Decision Making

Example (*)



→ Intelligent app



Data: 800 deg C
Context: " This is lower than average"

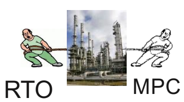
(very useful "context" for a new operator to make a decision)

(*) Graphic Credit:
https://energyfactor.exxonmobil.com/energy-innovation/smart-technologies-intelligent-operations/

Challenge: Integration vs Orchestration of Applications (*)

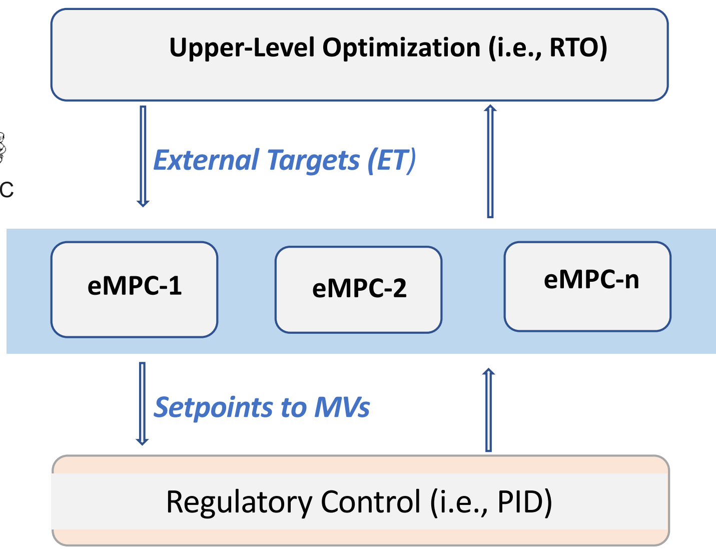
Integration : Communicate **data** (i.e., values)
Orchestration : Communicate **data** and **context.** Achieves a better synchronization towards a common objective

Example (**)



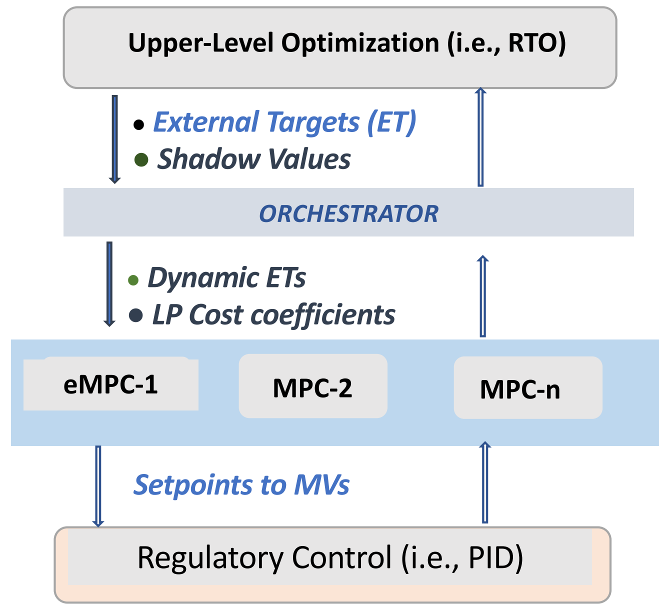
Integration of Applications

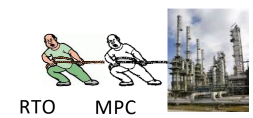
- **Sends just data**



Orchestration of Applications

- **Sends data with CONTEXT (i.e. "active set" of constraints)**





Graphic Credit:

(**) https://www.focapo-cpc.org/pdf/Georgiou.pdf

(*)Transformation from Automated to Autonomous | ARC Advisory (arcweb.com)

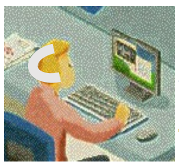
Towards Autonomous Operations: Components of An AI System

Interactive
with multiple devices, people, roles, services (i.e., cloud)

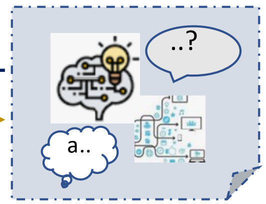
Iterative Process
To solve problems which are ambiguous, or info/data exists across different APPs and DBs.

Knowledgeable Stateful & Contextual. Adaptive
- Provides expert insight that is suitable for the specific question at the present time
- Identify and extract contextual elements
- Learns and adapt the environment

Automated & Scenario Based Solutions Multiparametric Analysis

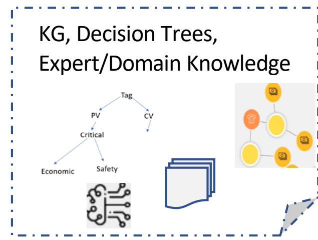


Interacts
with
Devices & Services

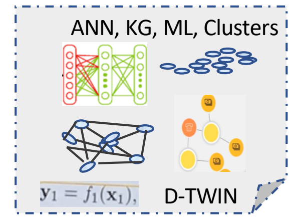


Cognitive AI
(NLP), QnA, etc.)
Converts general questions (utterances) to intents

i.e., MS Azure Cognitive Services
- (LUIS), STT, TTS, etc.

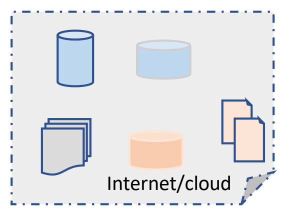


Semantic AI (and Cognitive Services)
(Expert Domain)



Engineering Apps
(Microservices)

(i.e., run different scenarios on cognitive D-Twin based on KG schema, Decision trees)



Data Bases
(Structured & Unstructured

Benefits

Enhance operator decision making to minimize human errors

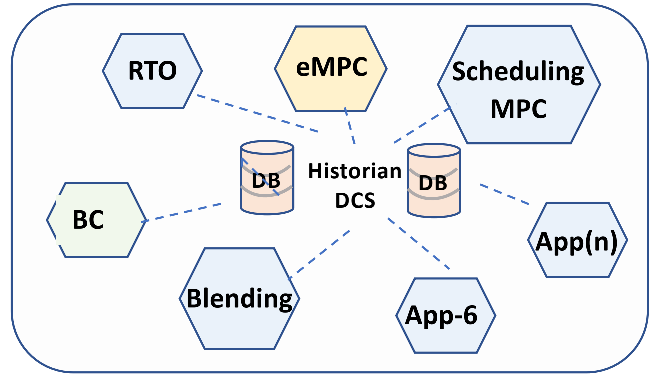
- Safe, reliable, consistent operation and close to the optimum at all operating modes
- Continuously evaluate constraints and optimum

New Flexible & Sustainable System Architectures Enable the Journey to Autonomy

- Hard to accommodate various technology advancements
- Hard to make changes
- Unreliable framework (sustainment)
- Limited Scalability

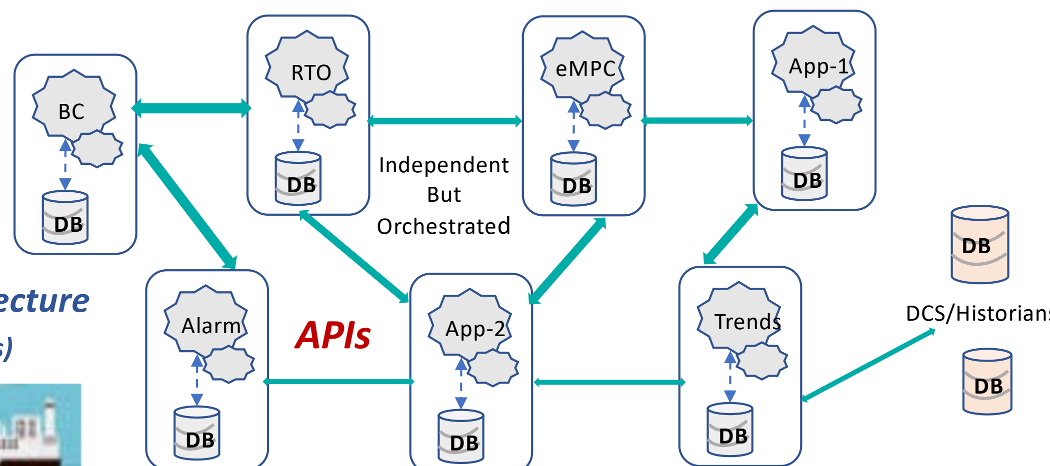
From

Monolithic Architecture



- Flexible and easy to add new technologies
- Easy updates
- Easy deployment & sustainment
- Can be scaled independently
- Agnostic to platforms

To



Microservices Architecture
(Containers, Dockers)

Data Driven AI Systems Guide Operators: Industrial Examples

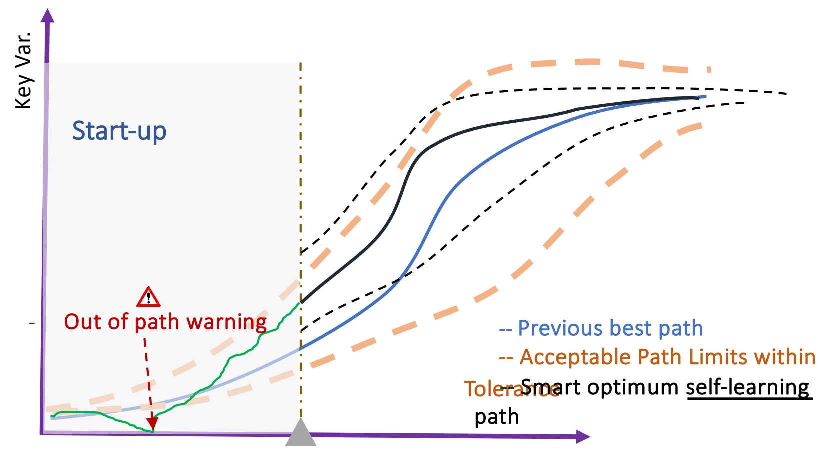
- ***EM "SmartLane" AI Optimizes Transients*** [1,2]

Graphic Credit

https://energyfactor.exxonmobil.com/energy-innovation/smart-technologies-intelligent-operations/

Intelligent Optimization of Reactor Transient Operations

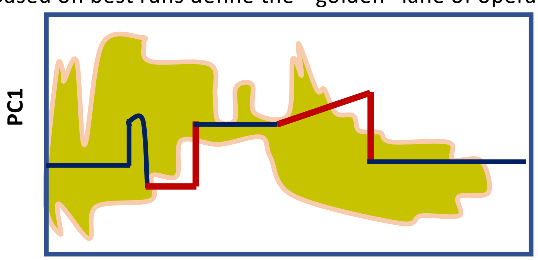
Clustering & Benchmarking
- Find best achieved operation
- Self-learning & Optimizing



Graphic Credit & reference [1]

- ***H L Golden Lane*** [3]

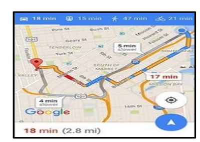
Based on best runs define the "golden" lane of operation

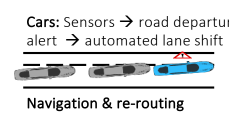


Time of Run (batch)

- Outside of the "Golden Zone" or "Smart Lane"
  - Indicates a higher probability of failure
  - If close to the boundary, the uncertainty is high

- An Intelligent system should "re-route" the operation if an unplanned event occurs (like GPS for traffic accidents)





(1) *A. Georgiou, and O. Onel, "Towards Autonomous Manufacturing Operations", Presented at 2020 ARC Industry Forum", Orlando, FL, 2020*
A. Georgiou and O. Onel, " Towards Autonomous Operations" Presented at 2020 Aspentch Advisory Committee", June, TX, 2020
(2) [US20210240175A1 - Methods and systems for performing transient processes - Google Patents]
(3) [(672c) Data-Driven Predictive Monitoring and Operation Support for Change-over Processes in Biopharmaceutical Drug Product Manufacturing | AIChE]

Summary (1/2)

Autonomy: Systems that – without manual (human) intervention – can change their behavior in response to unanticipated events during operations (Watson & Scheidt (2005))

- Don't confuse autonomy with automation system which "performs" defined instructions within a limited scope of operations.

- **Key Characteristics:**
  - Self-managing : collects, organizes data & automates decisions
  - Self-learning : improves over time, and self-adapts
  - Self-optimizing : more than automation, controls, and optimizes itself (continuously evaluate the data/patterns)

Human stills needs to define goals & objectives and specify the boundaries

Summary (2/2): Autonomy is a Journey of Integrating AI and Automation/Optimization Technologies

Enhance **Automation**	***To*** **Autonomous/Smart Operations**
Process Control (currently reacting to known problems)	Detect situations that can neither be modeled by design nor have been experienced before
Data Values	Data Contextualization/New Formats
Supervised Learning (Data Recon./Regression)	Clustering, Pattern Recognition, Unsupervised Learning ("Feature" Engineering)
Predefined Learning/Knowledge	Iterative Learning (Cognitive), Self-learning, Knowledge Graphs (KG)
Numerical/Statistical Modeling	Semantic Modeling AI (Structured & Unstructured Data, KG)
Integrated Applications	Orchestrated Applications
Monolithic Architectures	Microservices (Independent but Coordinated Systems)

From Computer aided to Compute Science based Chemical Engineering