19th IEEE Conference on Business Informatics

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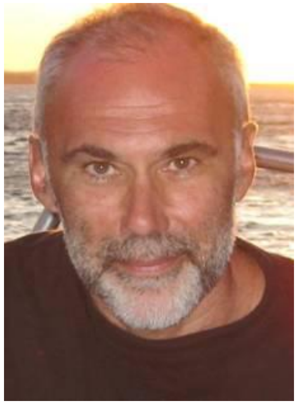
Developing the Data-Driven Proactive Enterprise

Prof. Gregoris Mentzas

Gregoris… who?

About me



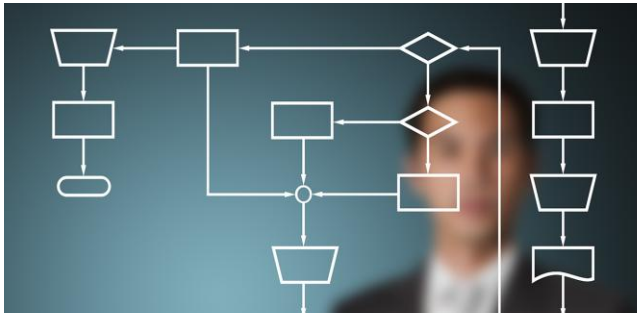
- Professor at the School of Electrical and Computer Engineering of the National Technical University of Athens (NTUA)
- Director of the Information Management Unit (IMU)
- Research by IMU led to 3 internet technology companies
- Published 4 books and more than 200 papers
- (co-)Chair or PC Member in > 55 international conferences
- 4 best papers awards
- Associate Editor of 5 international journals
- Led or contributed in 47 R&D projects
- Google Scholar estimates more than 3,500 citations (h=31)
- Always a learner (and a beginner)

IMU - Information Management Unit

- IMU is a **multi-disciplinary unit** engaged in research and technology development activities in **Information Technology Management**.
- Our mission is **to enable the development of knowledge-driven organisations**
- **Operates within ICCS (Institute of Communication and Computer Systems)**
- **IMU is a member of:**
  - Big Data Value Association (BDVA) , a fully self-financed non–for-profit organization, which aims to boost European Big Data Value research, development and innovation and to foster a positive perception of Big Data Value
  - **NESSI** the European Technology platform dedicated to Software and Services

Technologies we work with

- **Knowledge and semantic technologies**
  - Ontology engineering and management
  - Linked Data Management and the Web of Data
  - Text mining and Latent Semantic Analysis
  - Personalization and Recommender Systems
  - Context awareness and Situation management



- **Service and Process Engineering**
  - Business process modeling, management and integration
  - Event-driven and context-aware business processes
  - Service modeling, analysis and design
  - Semantic web services
  - Cloud service management and composition
  - Value Creation in Service Systems

- **Decision Management**
  - Mathematical programming, simulation, optimisation
  - Multiple Criteria Decision Making
  - Probabilistic, fuzzy and linguistic techniques
  - Predictive business analytics
  - Information aggregation and prediction markets
  - Crowdsourcing and human computation

Research activities

- Since its establishment IMU contributed actively in **forty seven (47) research and development projects**
  - Forty (40) projects were completed during the 1997-2015 period
  - Seven (7) projects are active during the 2016-2018 period
- The total funding of IMU since 1997 exceeds **12,0 million euros**

- Our work is funded by these programs and institutions:
  - **Horizon 2020 (previously FP5, FP6, FP7)** the research Framework Programs of the European Union
    - http://ec.europa.eu/programmes/horizon2020/
  - Operational Program for the **Information Society** of the Greek Ministry of Economy and Finance
    - www.infosoc.gr
  - Research programs of the **General Secretariat for Research and Technology** of the Greek Ministry of Development
    - www.gsrt.gr

Our Research Areas

Research area

”Small” and “Big” Data-driven Persuasive Technologies

- **We use Personal and Collective Big Data…**

➢ Urban sensing, resource consumption, environmental sensors aggregate social media data

➢ **Quantified self data**
  - self-tracking of biological, physical, behavioral, or environmental information
  - IoT and wearable sensors, mobile apps, online communities

- **… to support behavioral change**

➢ for **sustainability** and **well being**
  - *Indicative domains:* health, diet, exercise, energy efficiency, waste reduction, green mobility, water conservation

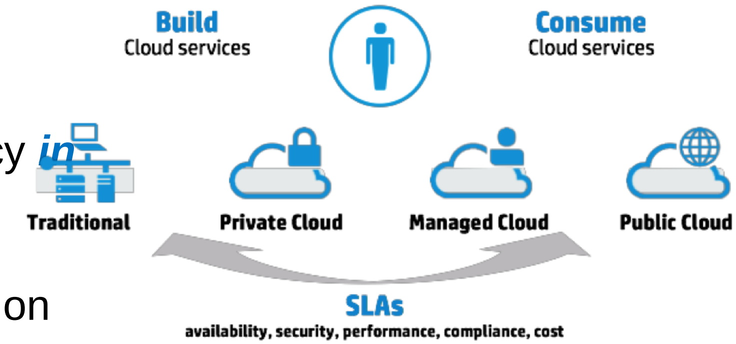
➢ delivering **timely, personalized and context aware interventions**

➢ coupling **data science, HCI and psychology research**
  - machine learning, personalization & recommendation systems
  - intelligent user interfaces and visualizations
  - persuasive techniques (rewards, goal-setting, social comparison, choice architecture, suggestions, self-monitoring)

Research area

Optimising Data-intensive multi-Cloud computing

- **Cloud Computing & data-intensive applications**
  - Research topics
    - Cloud service brokerage, resource allocation, location-aware processing, security and privacy ***in hybrid multi-cloud environments***
  - Software and open-source frameworks
    - Intelligent recommenders, Multi-Criteria Decision Making approaches, Probabilistic, fuzzy and linguistic preference modelling systems
    - PULSAR, Data-intensive reasoners and adaptation managers

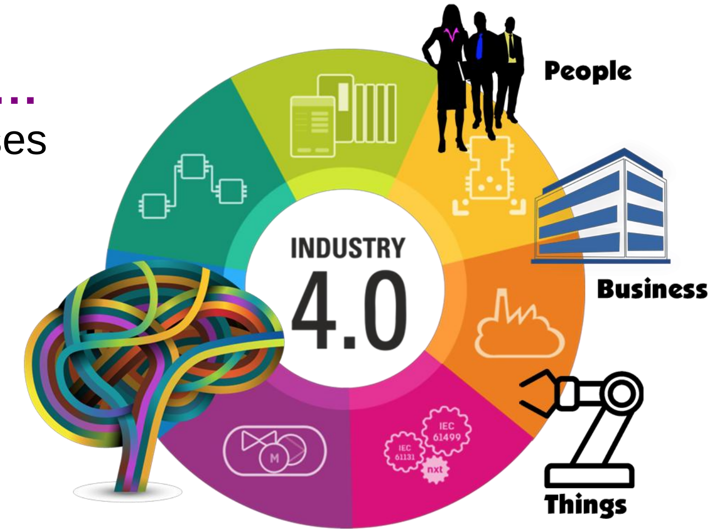


  - Indicative data-intensive application areas
    - xRM (anything Relationship Management), crisis management, genome data analysis



Research area

Big Data-driven Smart Industry



- **Turn big manufacturing data into insights…**
  - Integrate predictive analytics in operational processes to
    - fuel continuous **situation awareness**
    - **predict** what is likely to happen
    - recognize **possible undesired situations** (e.g. breakdowns)
    - **before** these actually happen

- **…and use them for proactive decision making**
  - Advanced probabilistic decision methods to
    - **alter the likelihood** that undesired situations will occur
    - and/or **mitigate their effect**
    - by **intervening prior** to their occurrence
    - proactively recommend **what action** to take and **when**

From reactive to proactive

“anticipatory systems”

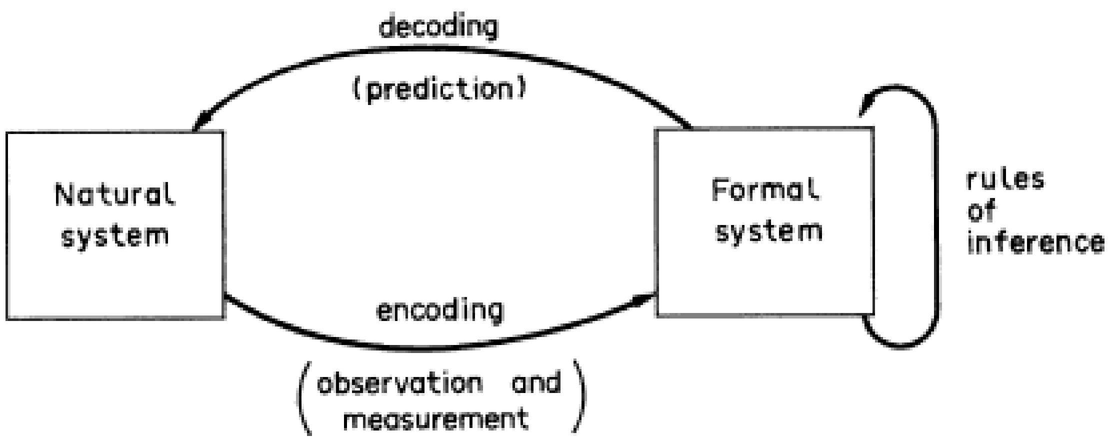
From reactive to proactive

- Science has advanced the **understanding** of the reactive characteristics of the physical world
  - expressed in the cause-and-effect sequence
  - a machine can represent the functional characteristics of reality

- Computer programs are **descriptions** that capture details of a homogenous reality
  - Based on the deterministic understanding of the world
  - the corresponding reductionist model fails to capture the defining characteristic of life: the ability to anticipate.

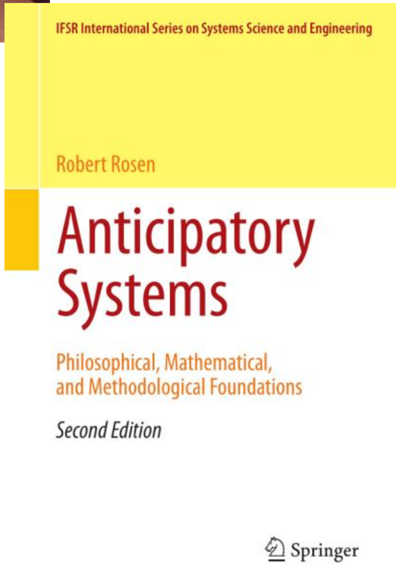
- Inferring from a rapidly increasing body of data to an integrated understanding of change, and its possible anticipation, assumes that we know **how anticipation is defined**

Anticipatory system



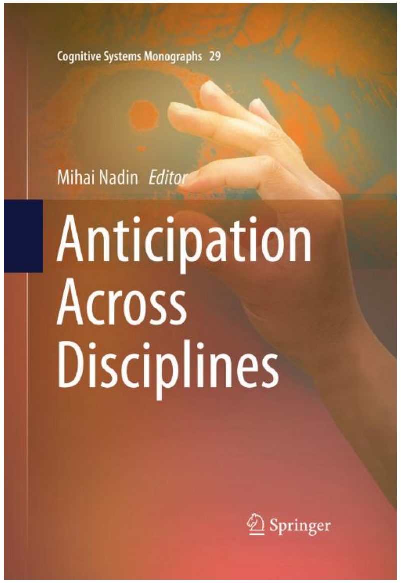
- “A system containing a predictive model of itself and/or its environment, which allows it to change state at an instant in accord with the model’s predictions pertaining to a later instant”
  - [Rosen 1985]

Robert Rosen (1934-1998)



- Mathematical biologist
- Professor of Biophysics at Dalhousie University

Mihai Nadin



- Professor of computer science and interactive media, UT Dallas
- http://www.nadin.ws

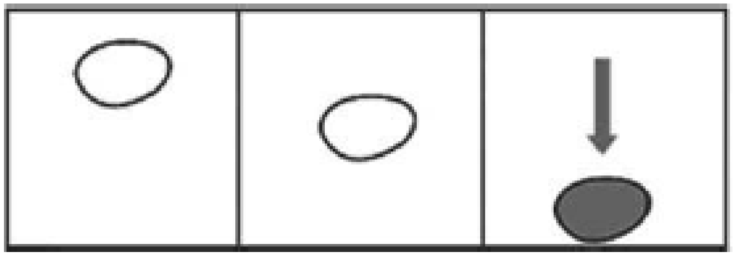
The concepts

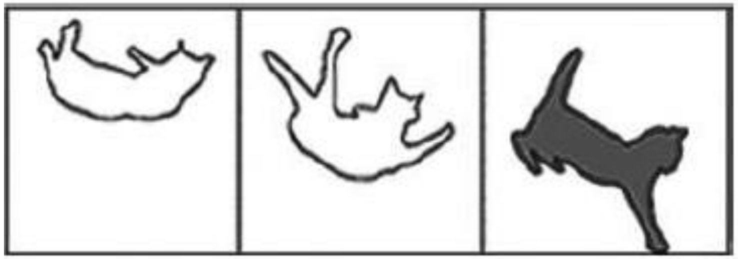
- To **predict** *(from the Latin prae: before and dicere: to say)* to state something about a sequence: what follows in time, and in space
  - Predictions can be time-independent, pertinent to simultaneous occurrences, or can be inferred from data describing a previous state or the current state of the world to a future state.

- **Anticipation** (from the Latin ante: ahead and capere: to understand) provides the basis for an action (avoiding danger, reaching a goal) informed by a possible future state
  - The premise of predictive or anticipatory performance is the perception of reality.
  - Data about it, acquired through sensors, as well as generated within the subject, drive the predictive effort or inform anticipatory action.

Nadin, M. (2017) Predictive and Anticipatory Computing, Encyclopedia of Computer Science and Technology, Second Edition DOI: 10.1081/E-ECST2-120054027

All falls are subject to gravity…





but not all of them are the same!

Apple's "active fall protection system"

- Apple U.S. Patent No. 8,903,519 for a "Protective mechanism for an electronic device"
  - filing date Sep 16, 2011

- Apple's system relies on sensors to monitor physical device activity and positioning.

- Accepted embodiments leverage onboard accelerometers, gyroscopes and GPS which are already incorporated in the latest iPhone and iPad models

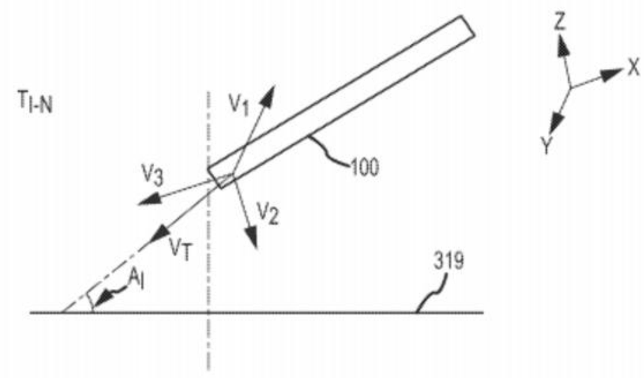


FIG.5C

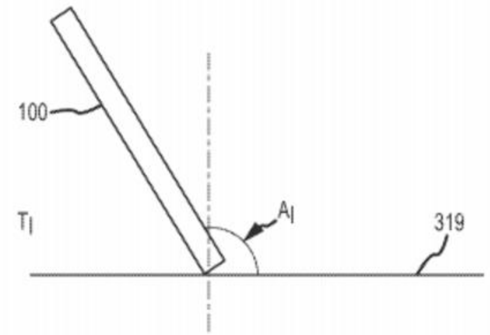
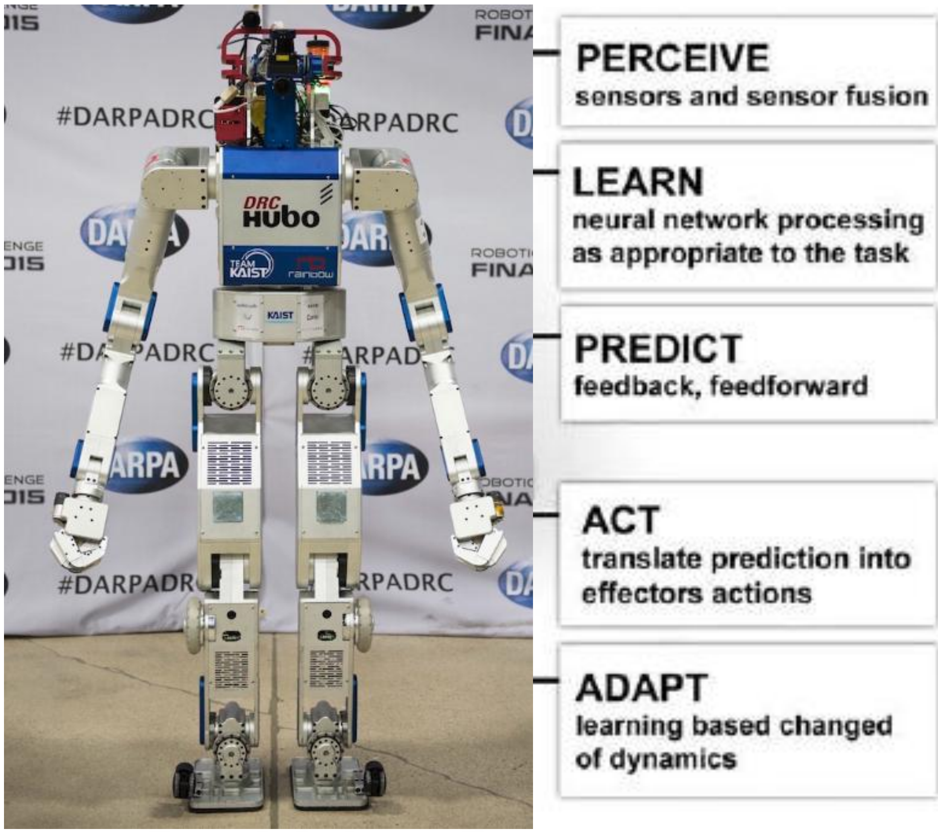


FIG.5D

http://appleinsider.com/articles/14/12/02/apple-patents-active-fall-protection-system-that-shifts-iphones-in-midair

Applications of anticipatory computation



- Extremely varied sensory feedback as a requirement similar to that of the living is a prerequisite, but not a sufficient, condition.
- Robot designers provide a forward model together with feedback.
  - The forward(prediction of how the robot moves) and inverse (how to achieve the desired speed) kinematics are connected to path planning.
- The uncertainty of the real world has to be addressed predictively
  - advancing on a flat surface is different from moving while avoiding obstacles

[South Korea's DRC-HUBO Robot Won the DARPA Robotics Challenge (2015)](http://spectrum.ieee.org/automaton/robotics/humanoids/how-kaist-drc-hubo-won-darpa-robotics-challenge)
http://spectrum.ieee.org/automaton/robotics/humanoids/how-kaist-drc-hubo-won-darpa-robotics-challenge

Probability space and anticipation

- “**Uncertainty is the shadow projected by each prediction**”

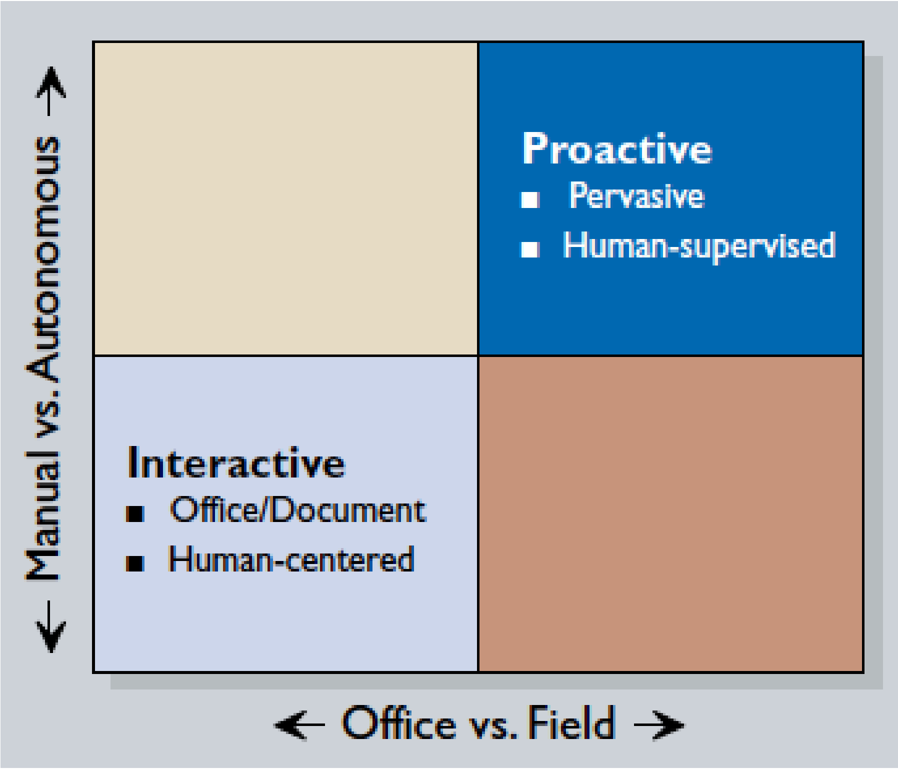
- Uncertainty is fought with plenty of data

- The increasing amount of sensors can be considered as the source of data
  - provided that sensor fusion is achieved and
  - the aggregate data can be associated with meaning.

- **Sensor data do not entail predictivity**, but are necessary conditions for achieving it.
  - Integrated sensors generate high-level, multidimensional representations.
  - Their **interpretation**, by individuals or intelligent agents, emulates the machine model of neuronal activity

Proactive Computing

- Getting **physical**
  - Proactive systems will be intimately connected to the world around them
    - using sensors and actuators to both monitor and shape their physical surroundings
- Getting **real**
  - Proactive computers will routinely respond to external stimuli
    - at faster-than-human speeds.
- Getting **out**
  - Interactive computing deliberately places human beings in the loop
    - Shrinking time constants and sheer numbers demand research into proactive modes of operation in which humans are above the loop.



Tennenhouse, David. "Proactive computing." *Communications of the ACM*43.5 (2000): 43-50.

Proactive enterprise capabilities

- Capability to **reveal insights and extract** - previously hidden **– meaningful patterns from structured and unstructured data** from a multitude of sources
    - sensors and actuators embedded in objects
    - customer transactions
    - social interactions, GPS trails, etc.

- Capability **to develop predictions and implement respective actions**
    – recognize possible opportunities or threats
    – before these actually happen and
    – trigger appropriate actions

(Big) Data
is the new oil

Emergence of Big Data

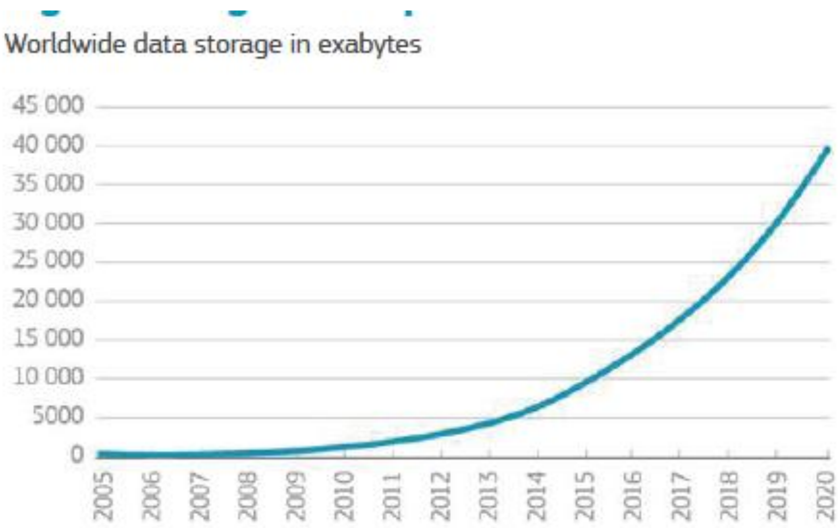
Data as the new economic asset

- Data is rapidly becoming the lifeblood of the global economy

- Gartner estimates there are currently about **4.9 billion connected devices** generating data
  - This is expected to reach 25 billion by 2020.

- The real value is no longer in the product, as such, but in the **opportunities** it can offer to users in terms of accessing information and experiences

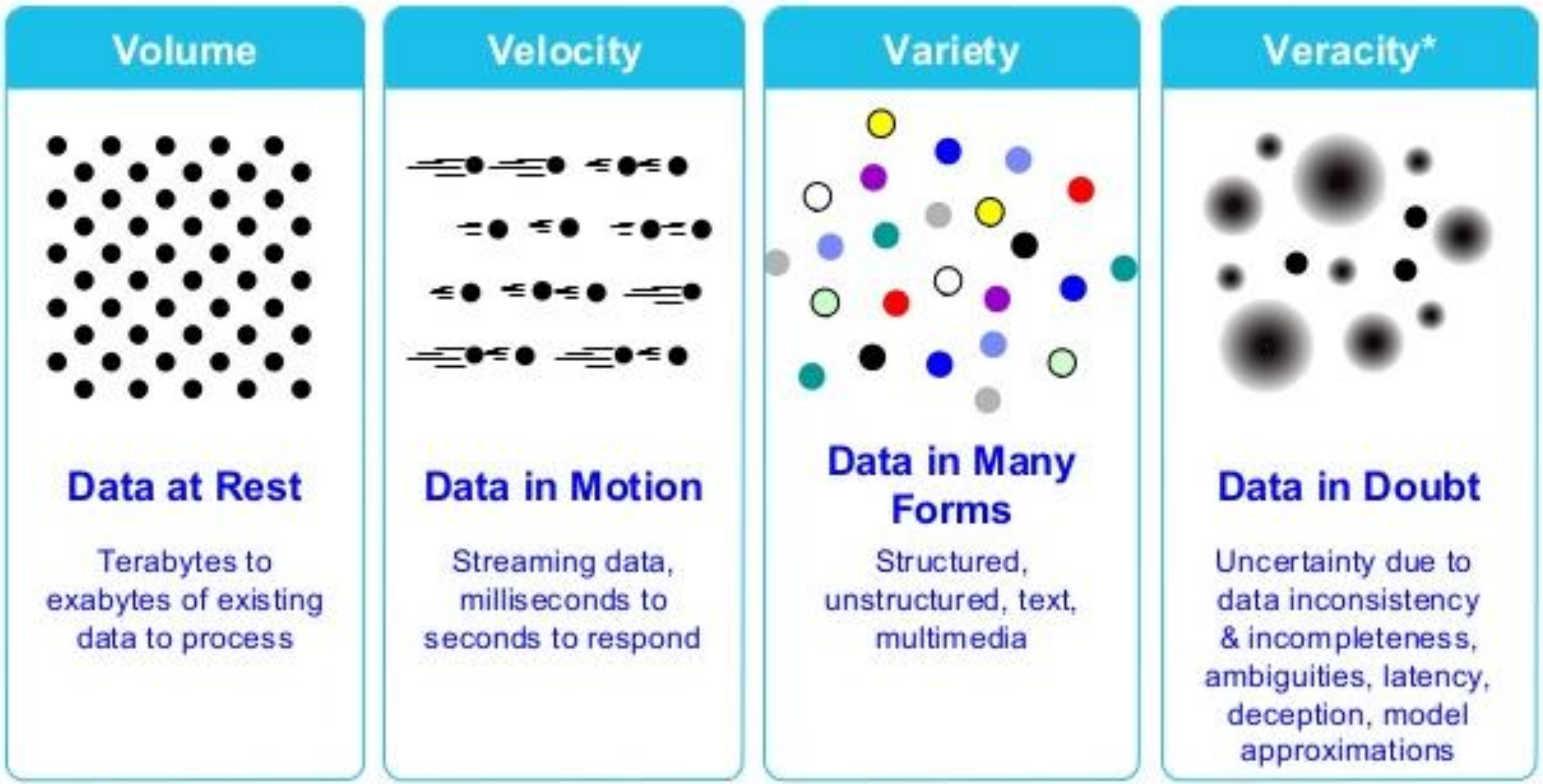
Global Explosion of data



Source: International Data Corporation Digital University Study

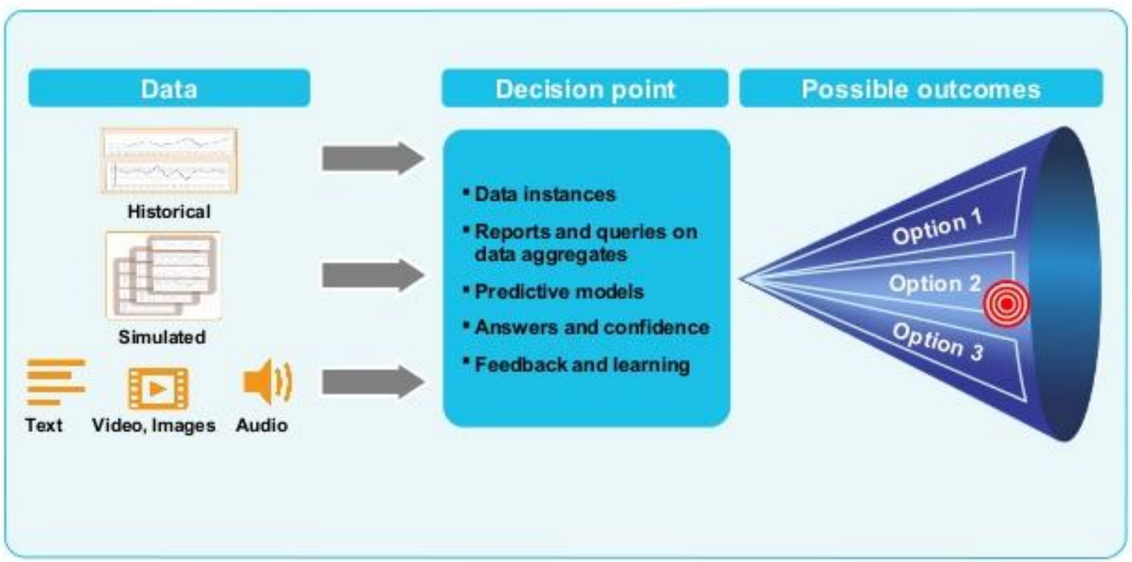
European Political Strategy Centre (EPSC) (2017) Enter the Data Economy, Issue 2.1, January 2017.

The 4 Vs of Big Data



Source: IBM Smarter Business - “Building Confidence in Big Data”

80% of all available data are uncertain



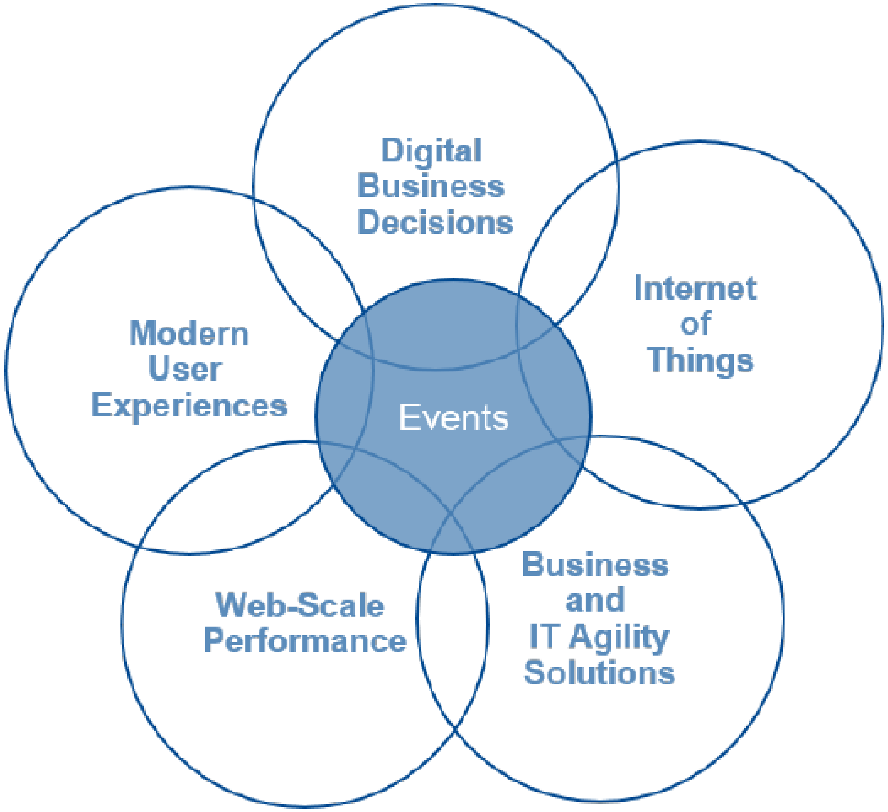
Source: IBM Smarter Business - “Building Confidence in Big Data”

	Descriptive	Diagnostic	Predictive	Prescriptive
Questions Answered	• What happened? • What is happening?	• Why did it happen? • What are key relationships?	• What will happen? • What if? • How risky is it?	• What should happen? • What is the best option? • How can I optimize?
Use Cases	• Performance Measurement • Performance Management	• Understanding outliers, relationships, leading indicators, and drivers of variability • Customer Scoring and Segmentation • Market Basket Analysis • Customer Profiling • Classification of email as spam	• Forecasting • Hypothesis Testing • Risk Modeling • Propensity Modeling	• Customer Cross-Channel Optimization • Best Action/Offer • Portfolio Optimization • Business Optimization • Risk Management
Sample Technologies	• Reporting • Dashboards • Scorecards	• OLAP • Interactive Visualization • Data Mining and Modeling • Statistics • Machine Learning • Content Analytics	• Machine Learning • Forecasting • Simulation • Predictive Modeling • Machine Learning Statistics • Visualization • Content Analytics	• Modeling • Simulation • Optimization • Visualization
Sample Analytical Methods (See Acronym Key and Glossary of Terms for definitions)	Key Performance Indicators Cause and Effect	• Cluster Analysis • Link Analysis • Association Rules • Classification • Principle Component Analysis • Decision Trees	• Decision Trees • Monte Carlo Simulation • Regression • Neural Networks	• Decision Trees • Monte Carlo Simulation • Linear and Non-Linear Programming • Game Theory

Source: Gartner (2012) “Advanced Analytics: Predictive, Collaborative and Pervasive” Feb. 2012

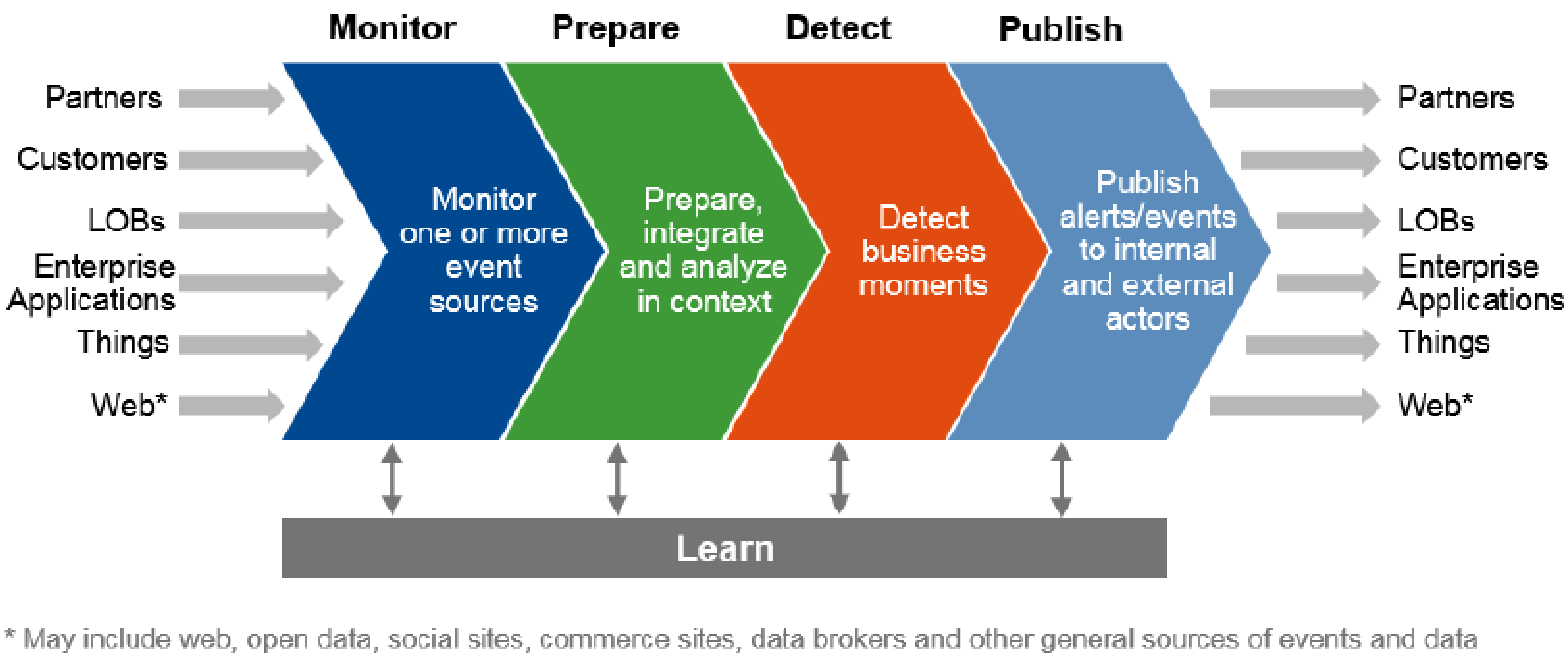
~~(Big) Data~~
Events
is the new oil

Forces that Drive Event-Driven Architectures



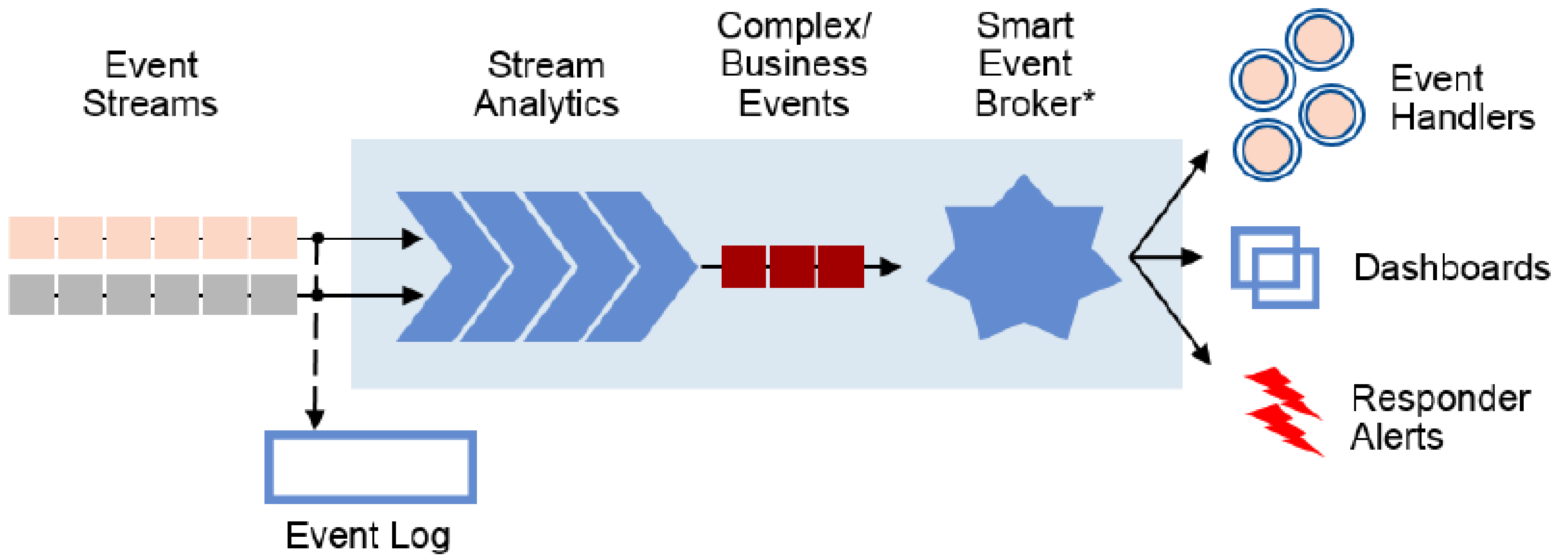
Source: Gartner (February 2017)

Business Event and "Business Moments"



Source: Gartner (May2017)

“Sense & Respond” Event-driven Architectures

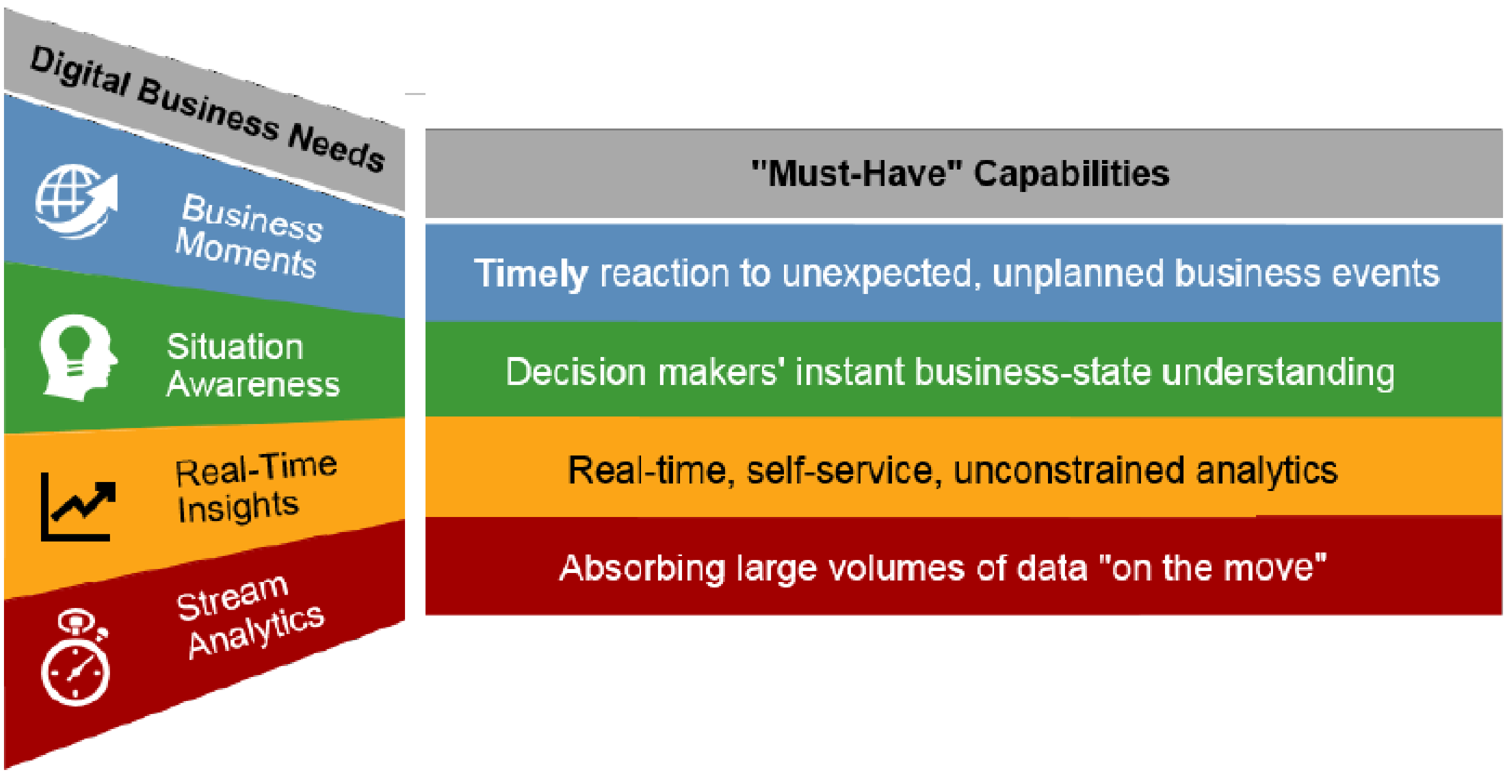


* May include analytics, logging, integration, other mediation and routing of events to subscribers

Source: Gartner (May2017)

“Data-in-motion”
(Big data + events)
is the new oil

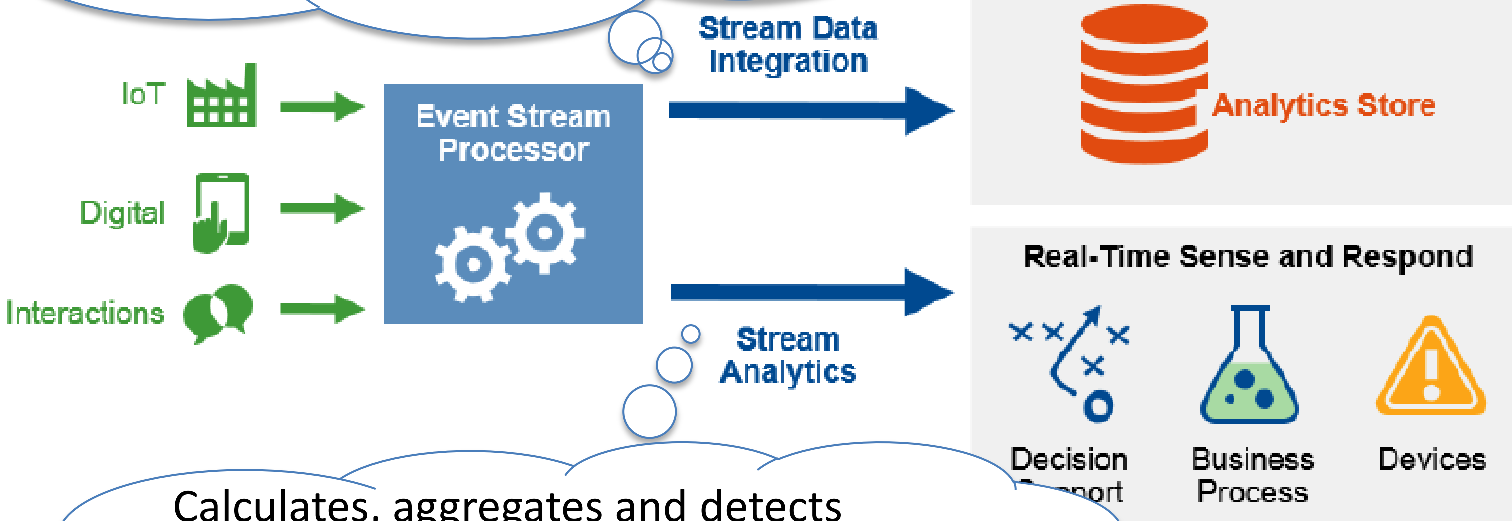
Data and event stream processing



Source: Gartner (April 2017)

Processing Data in Motion

Focuses on the ingestion and processing of data sources targeting real-time extract-transform-load (ETL) and data integration



Calculates, aggregates and detects patterns to generate higher-level, more relevant summary information (complex events)

Plethora of platforms

- Event processing
  - Esper (EsperTech)
  - Drools (Red Hat)
  - Apama (Software AG)
  - Business Events (Tibco)
  - IBM Streams …
- Stream Computing
  - Apache Storm
  - Apache Flink
  - Apache Spark Streaming
  - Apache Samza
  - Twitter Heron …
- Stream Data integration Platforms
  - Apache Kafka Streams
  - Apache Beam
  - Google Cloud Dataflow
  - Apache Gearpump
  - …

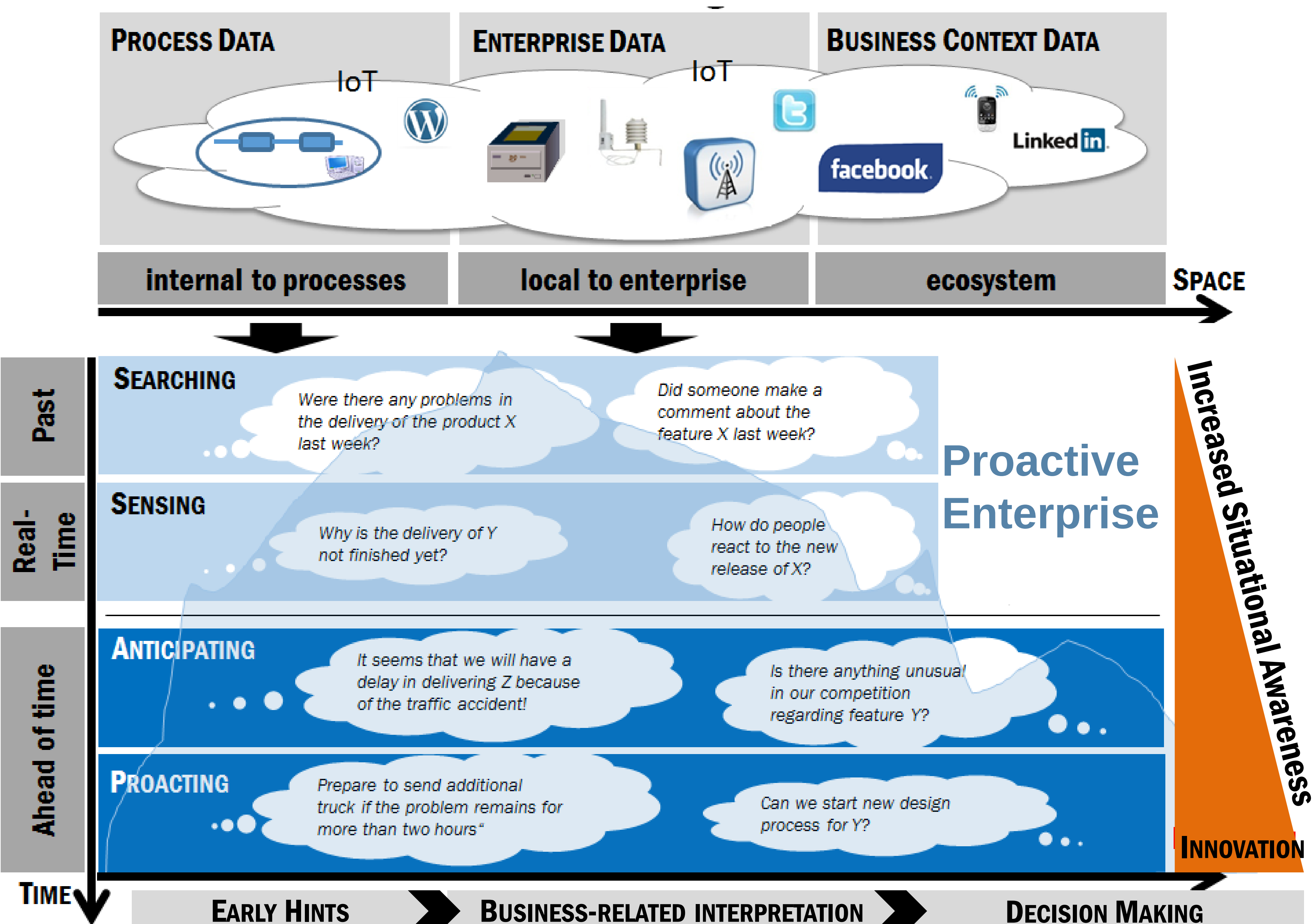
The Technology Landscape is flourishing

- More than 35 vendors in this market segment

- Trends
  - Open source
    - E.g. Confluent (Apache Kafka), data Artisans (Apache Flink), Databricks (Apache Spark Streaming), DataTorrent (Apache Apex) etc.
  - Hybrid products
    - E.g. FICO Data Management Integration Platform (DMIP), Hortonworks DataFlow, Impetus Technologies StreamAnalytix, Rapidminer Streams, and Salesforce Thunder leverage Apache Storm
  - Cloud-enablement
    - Amazon Kinesis Stream Analytics, Microsoft Azure Stream Analytics and Salesforce now offer similar services

Source: Gartner (May 2017)

towards the proactive enterprise



Process Data
IoT
Enterprise Data
IoT
Business Context Data
facebook
Linked in
internal to processes
local to enterprise
ecosystem
Space
Searching
Were there any problems in the delivery of the product X last week?
Did someone make a comment about the feature X last week?
Sensing
Why is the delivery of Y not finished yet?
How do people react to the new release of X?
Anticipating
It seems that we will have a delay in delivering Z because of the traffic accident!
Is there anything unusual in our competition regarding feature Y?
Proacting
Prepare to send additional truck if the problem remains for more than two hours"
Can we start new design process for Y?
Proactive Enterprise
Increased Situational Awareness
Innovation
Past
Real-Time
Ahead of time
Time
Early Hints
Business-related interpretation
Decision Making

proasense
The Proactive Sensing Enterprise

The Proactive Sensing Enterprise

- Vision: a new class of **proactive enterprises** that will be continuously aware of that **what “might happen”** in the relevant business context and optimize their behaviour to achieve **what “should be the best action”**

- ProaSense’s core goal is to pave the way for an **efficient transmission from Sensing into Proactive enterprises**.

- From 01/11/2013 to 31/01/2017
- url: http://www.proasense.eu/

SINTEF FZI ICCS UNINOVA Instituto de Desenvolvimento de Novas Tecnologias Nissatech innovation centre

Institut "Jožef Stefan", Ljubljana, Slovenija mhwirth HELLA

ProaSense Vision

Main Objective

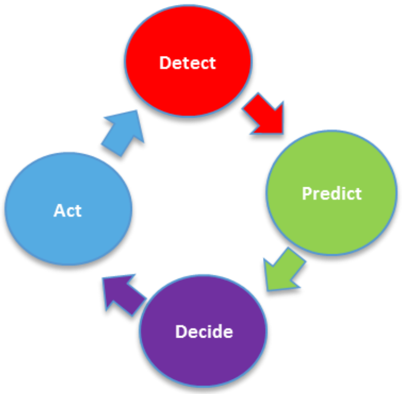
Support a transition from **Sensing** enterprises into **Proactive** sensing enterprises

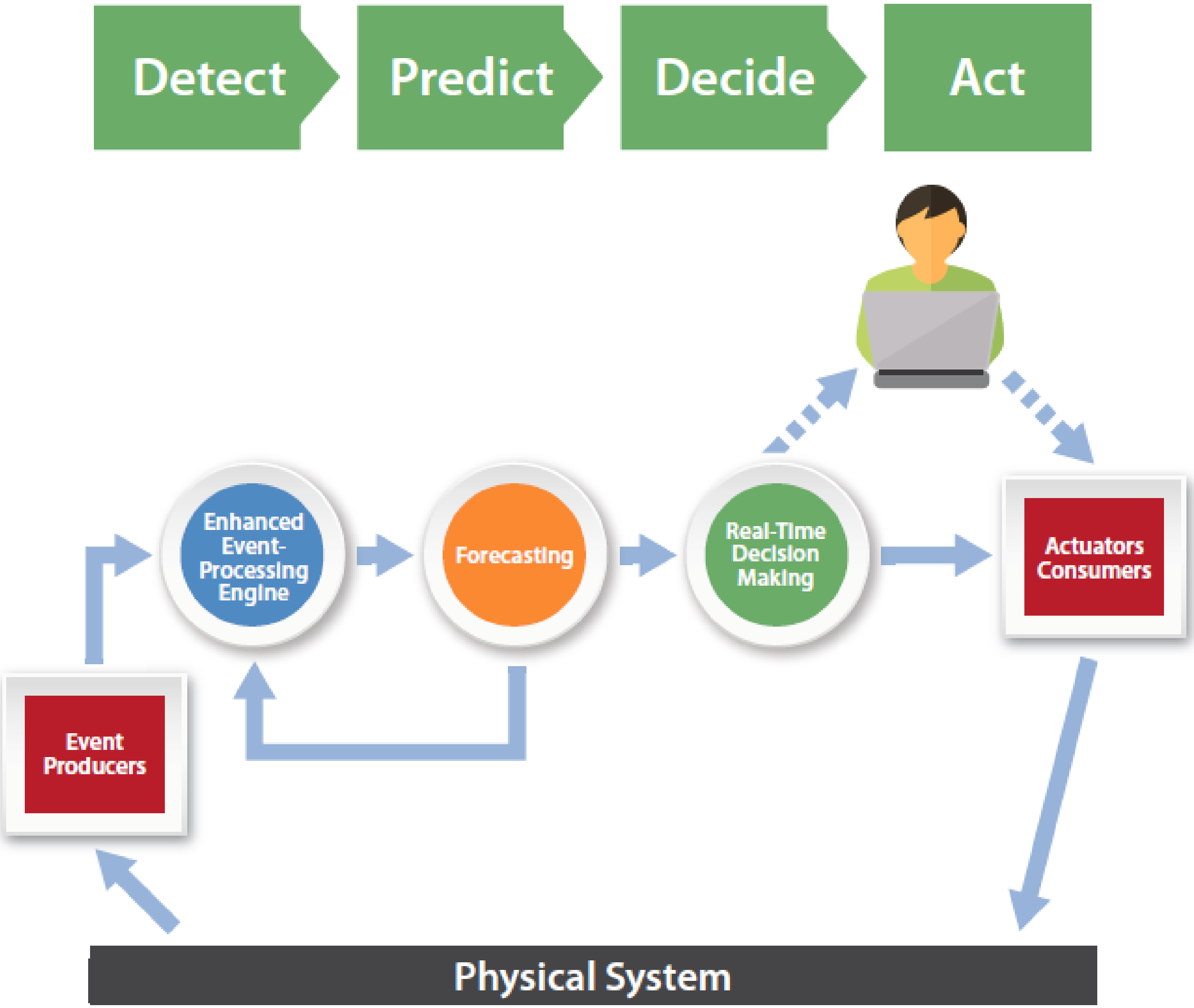
- to go from **reactive** to **proactive computing** in order to prevent problems or capitalize on opportunities before they even occur

Approach

Adoption of the Detect-Predict-Decide-Act loop of situational awareness and development of corresponding technologies:

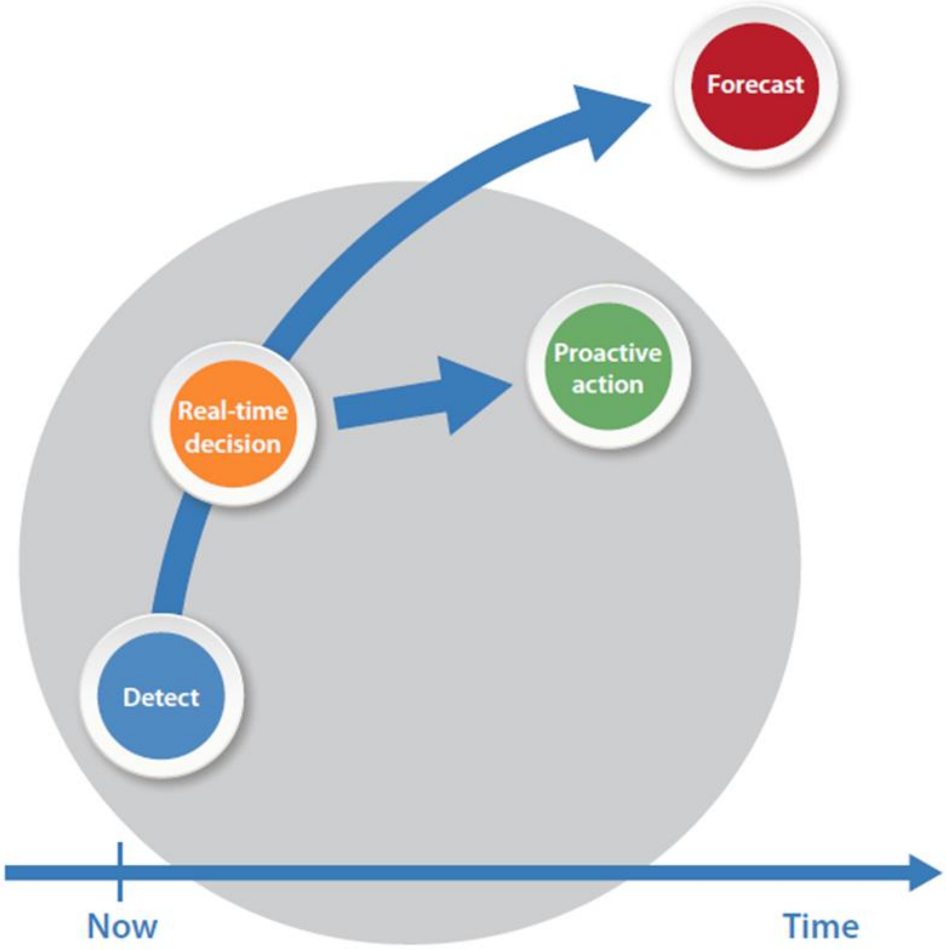
- a scalable, distributed architecture for the management and processing of IoT big-data that will enable
- continuous monitoring, detection of the need for service adaptation and propose corresponding changes in a (semi-) automatic way





Source: Etzion O. (2016). Proactive Computing: Changing the Future. RTInsights.

Framework for Proactive Decision Making



- Proactive information systems aim to enable business analysts to create and configure decision method instances for mitigating a future undesired event, which lays outside the desired states space.

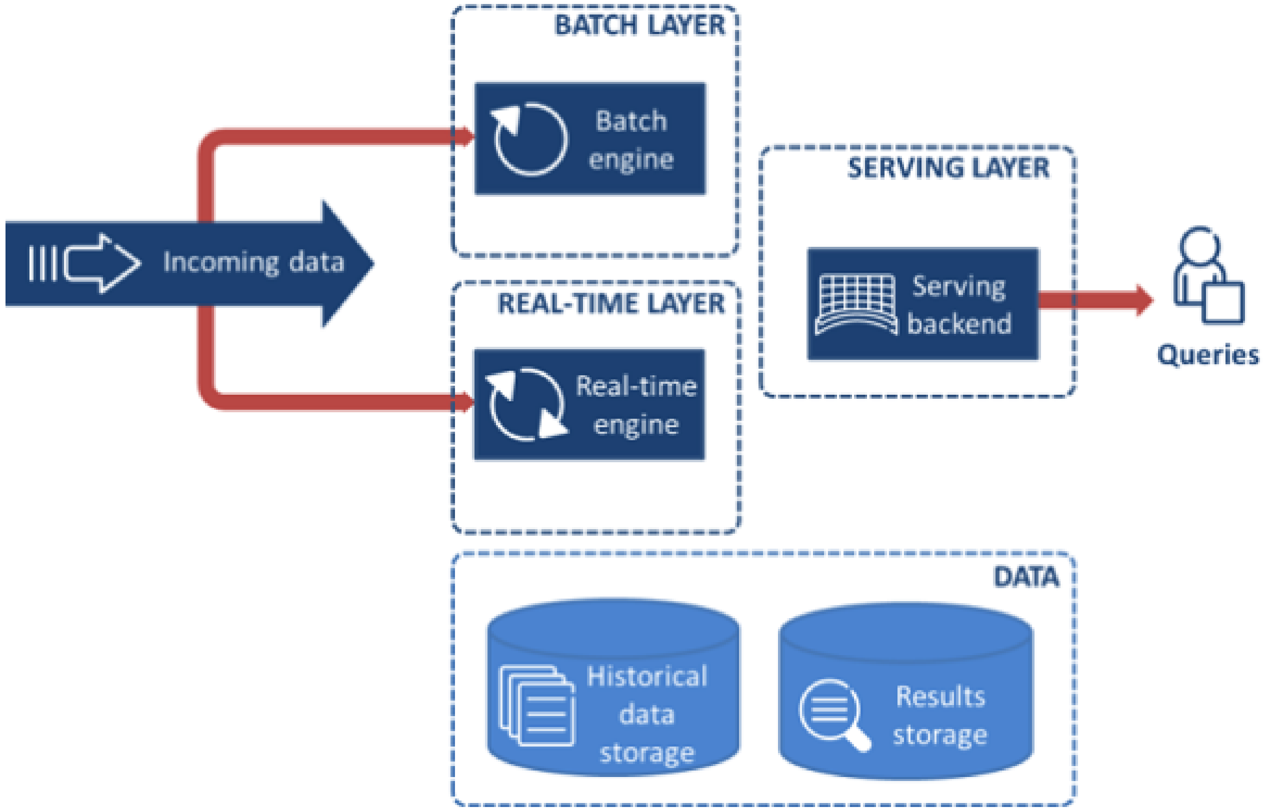
- Based on the predictions for undesirable situations derived on the basis of streaming data, decision methods instances are enacted online to generate mitigating action recommendations and optimal time of action implementation.

Source: Etzion O. (2016). Proactive Computing: Changing the Future. RTInsights.

which architecture for ProaSense?

Lambda, Kappa and other Greek letters

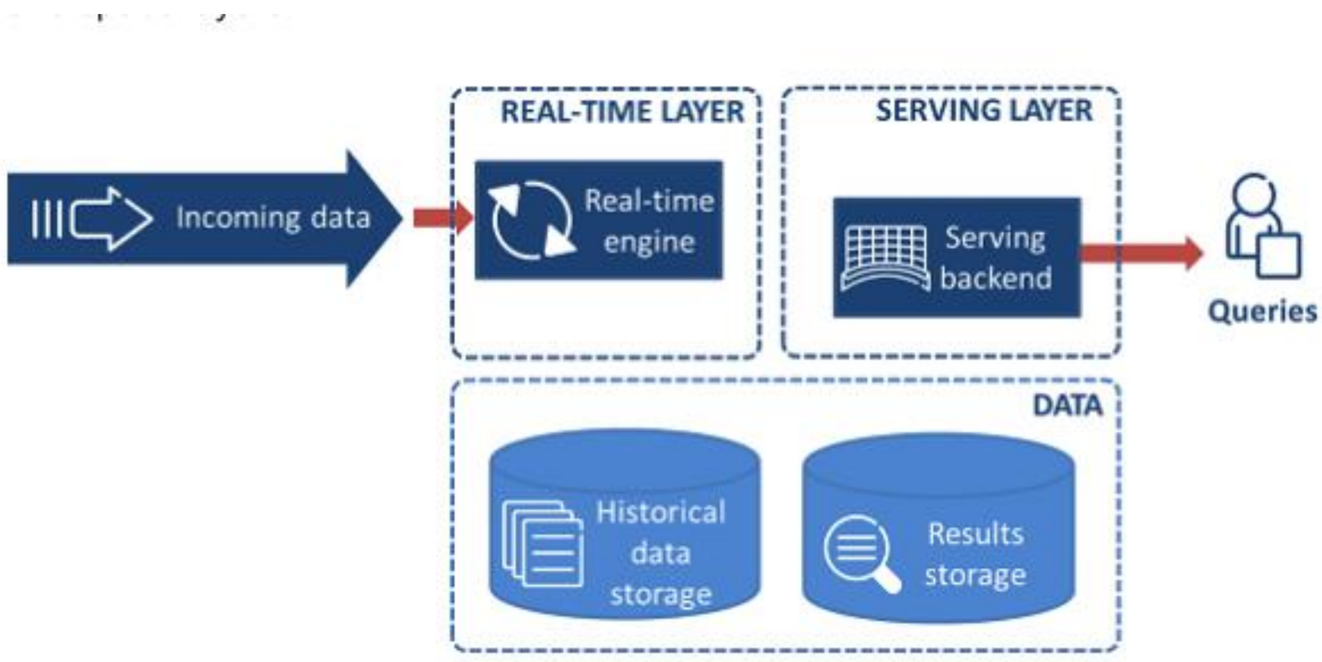
Lambda architecture



- Developed by Nathan Marz, creator of Apache Storm (2011)
- Used by Twitter and Spotify

Source: Julien Forgeat (2015) Data processing architectures – Lambda and Kappa, Ericsson Research Blog.

Kappa architecture



- Developed by Jay Kreps, creator of Apache Kafka (2014)
- Used by LinikedIn and Yahoo

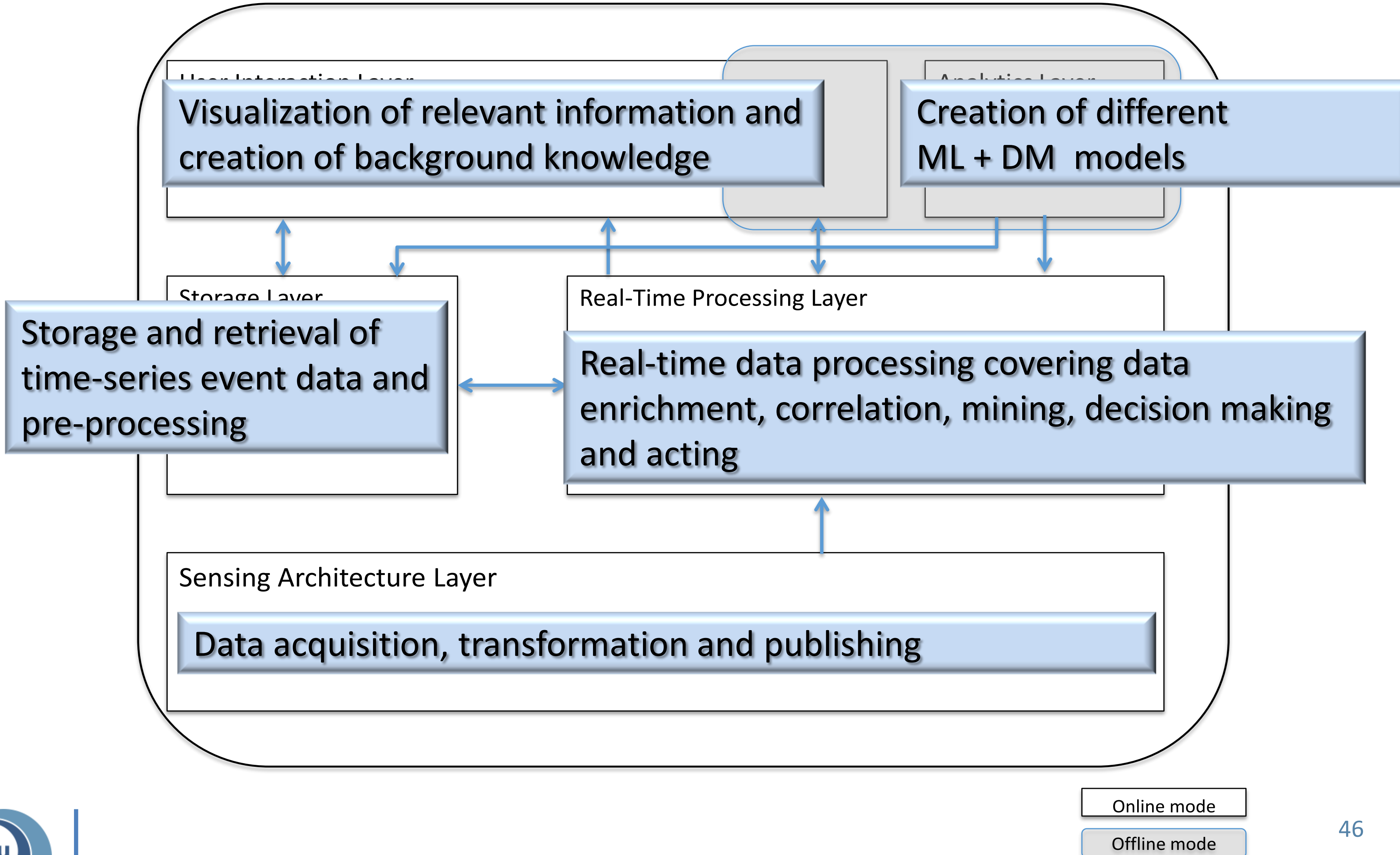
Source: Julien Forgeat (2015) Data processing architectures – Lambda and Kappa, Ericsson Research Blog.

Lambda vs. Kappa

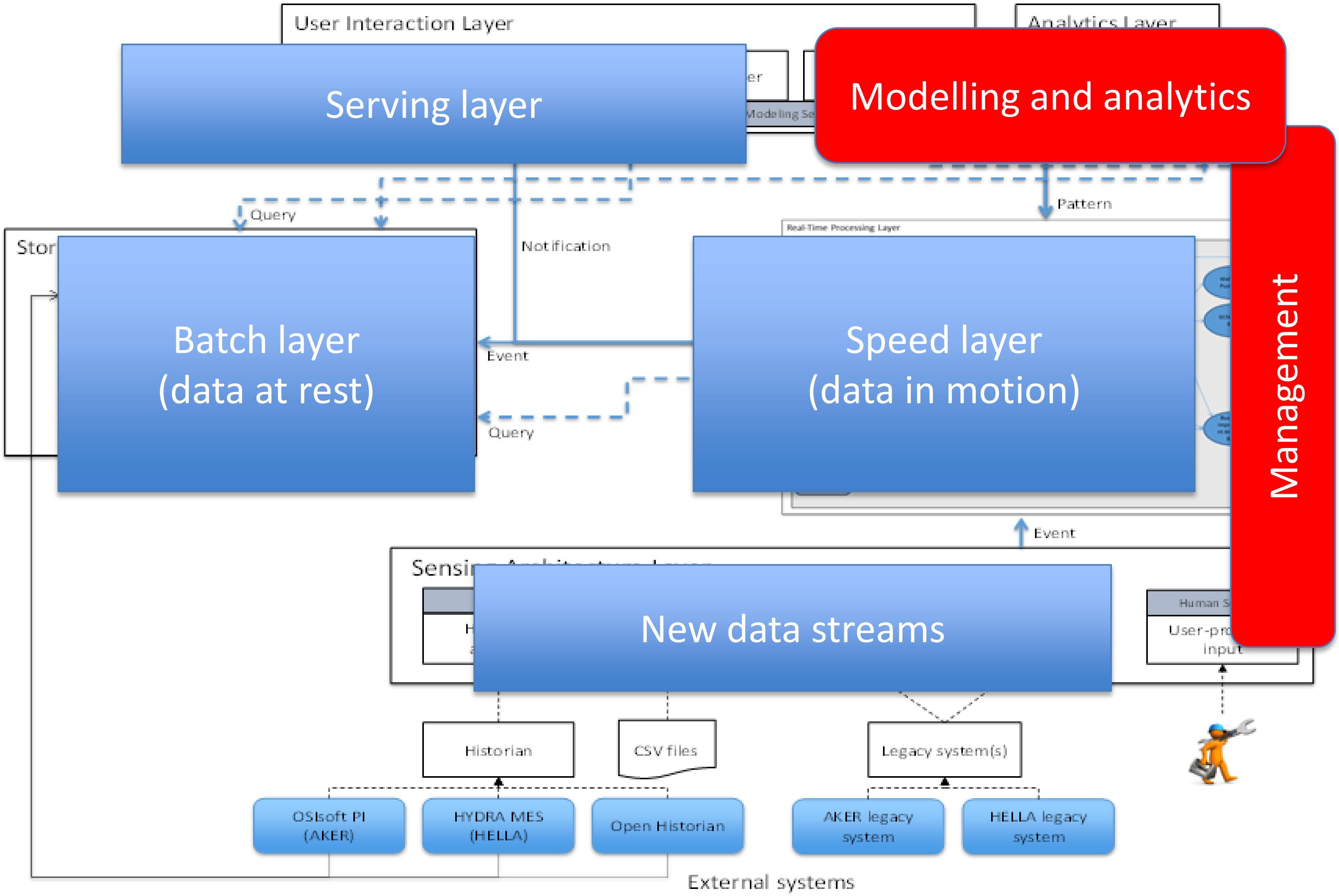
	λ	K
Processing paradigm	Batch + Streaming	Streaming
Re-processing paradigm	Every Batch cycle	Only when code changes
Resource consumption	Function = Query (All data)	Incremental algorithms, running on deltas
Reliability	Batch is reliable, Streaming is approximate	Streaming with consistency (exactly once)

Source: http://www.slideshare.net/DanielMarcous/big-data-real-time-architectures-51967547

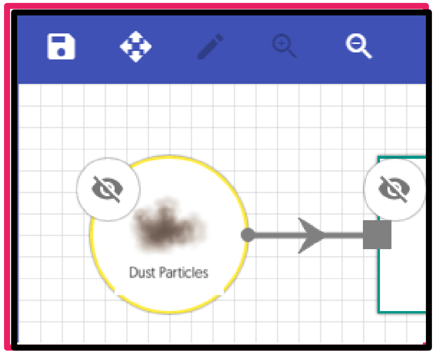
Conceptual architecture of Proasense

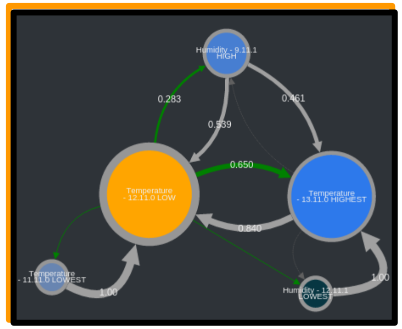


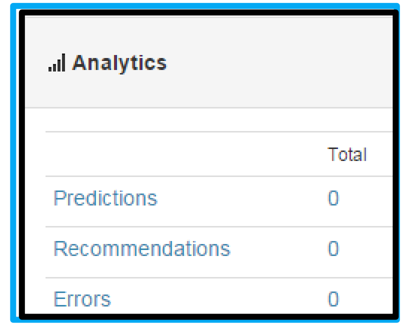
ProaSense vs. Lambda Architecture

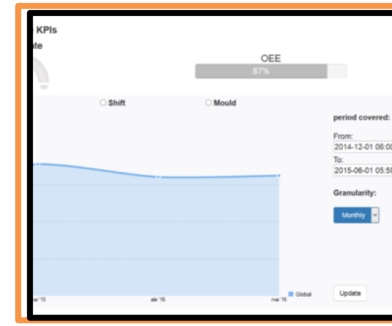


ProaSense Software Components









StreamPipes	StreamStory	PANDDA	KPI Modeler
Flexible modeling toolkit for data processing pipelines targeted at business users	Advanced data exploration platform capable of producing online outputs	Semi-automatic proactive decision making by providing recommended actions based on predictions.	Modeling tool to define and visualize KPIs and target values

ProaSense Adapter Library & Storage

Detect → Predict → Decide → Act

Detect → Predict → Decide → Act

StreamPipes

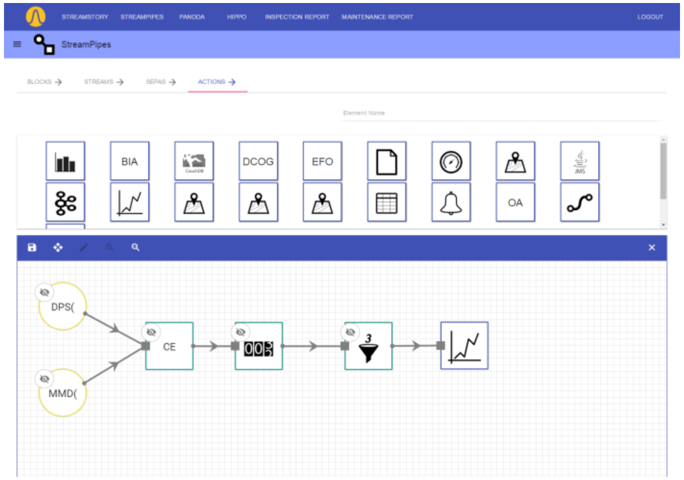
Semantics-based Stream Processing Pipelines

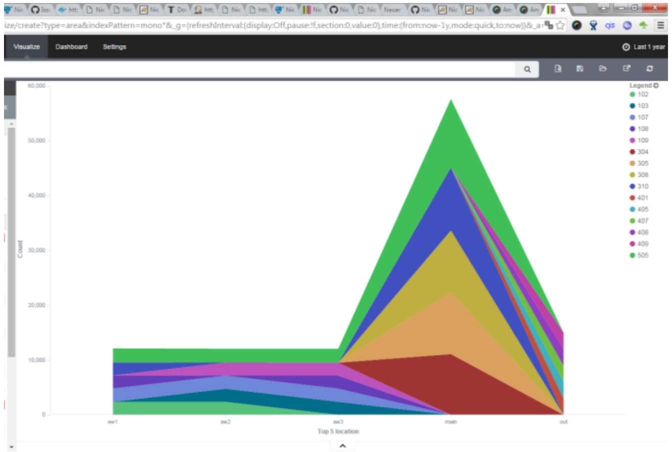
Scope

Self-service modeling framework to allow business analysts to quickly define and execute data stream processing pipelines.

Features

- Integrated Monitoring & Situation Detection
  - Deviations and threshold violations
  - Correlate different data streams
  - Pattern detection (e.g., Sequences)
- Continuous Data Ingestion
  - Filters, enrichment, transformations
  - Ingest data into third party applications



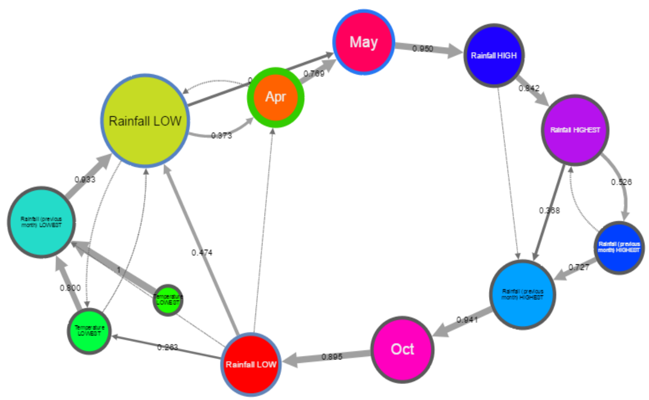


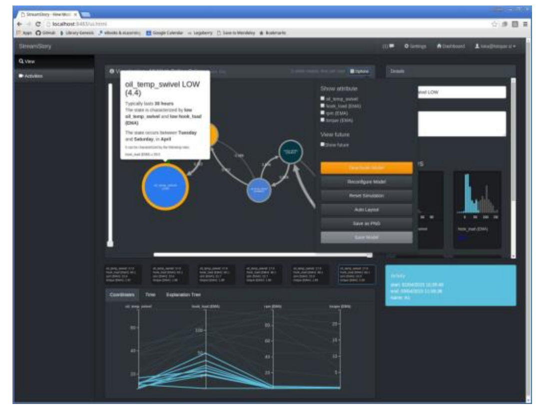
Detect → Predict → Decide → Act

StreamStory

A tool for analysis of multivariate time series

- Identifies typical states in the observed data on multiple levels of granularity
- Represents data as a hierarchy of states and transitions
- Using hierarchical Markov chains





Summarizes the long term qualitative and quantitative properties of the modelled data

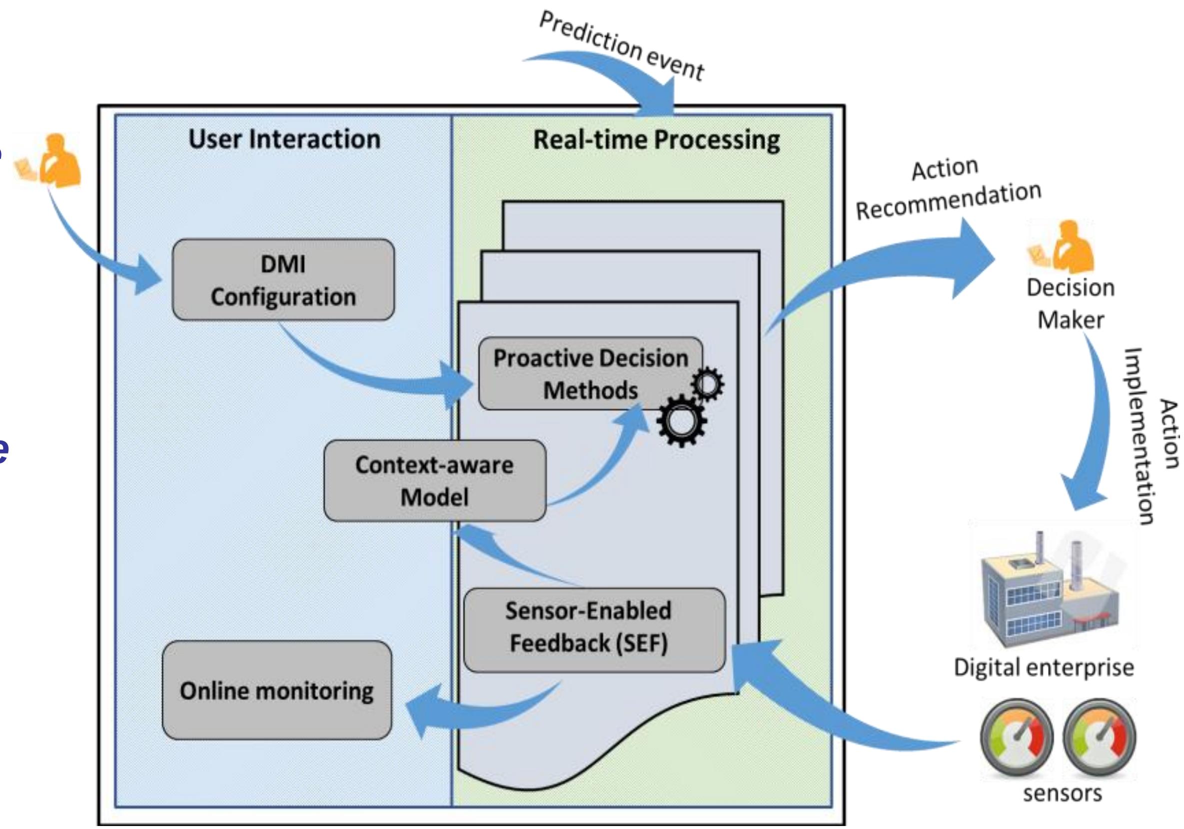
- States and transitions are explained by several mechanisms

Connects to real-time data to produce outputs

Detect Predict Decide Act

Pandda

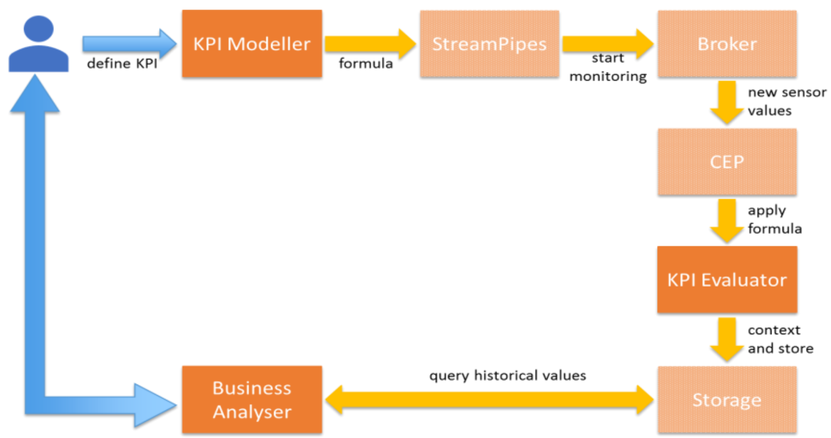
- **Configuration role**
  - to allow business analysts create ***decision method instances*** and ***configure*** them by editing possible mitigating actions and other ***domain knowledge***.
- **Processing role**
  - to support ***decision-making ahead of time***
    - on the basis of real-time observations and anticipation of future undesired events
  - to ***inform users online*** about the estimated cost of action during action implementation
  - ***to update the cost function*** and use it in the next recom-mendation cycle



Detect › Predict › Decide › Act

KPI Modeller

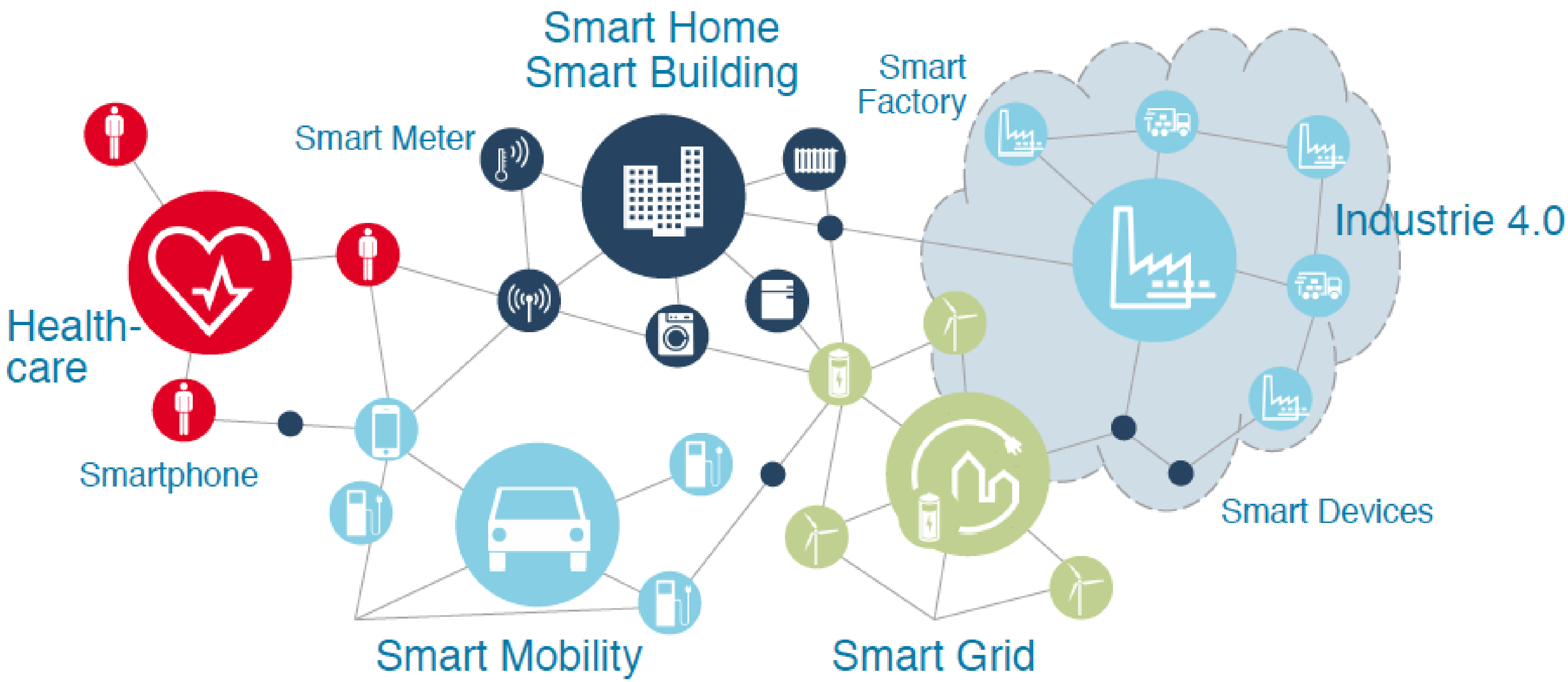
- KPI Analysis
  - Bringing together data from sensors, software systems and company.
  - Defining contextualized target values for KPIs.
  - Plotting statistical process control charts.
- KPI Prediction



which data?
which events?

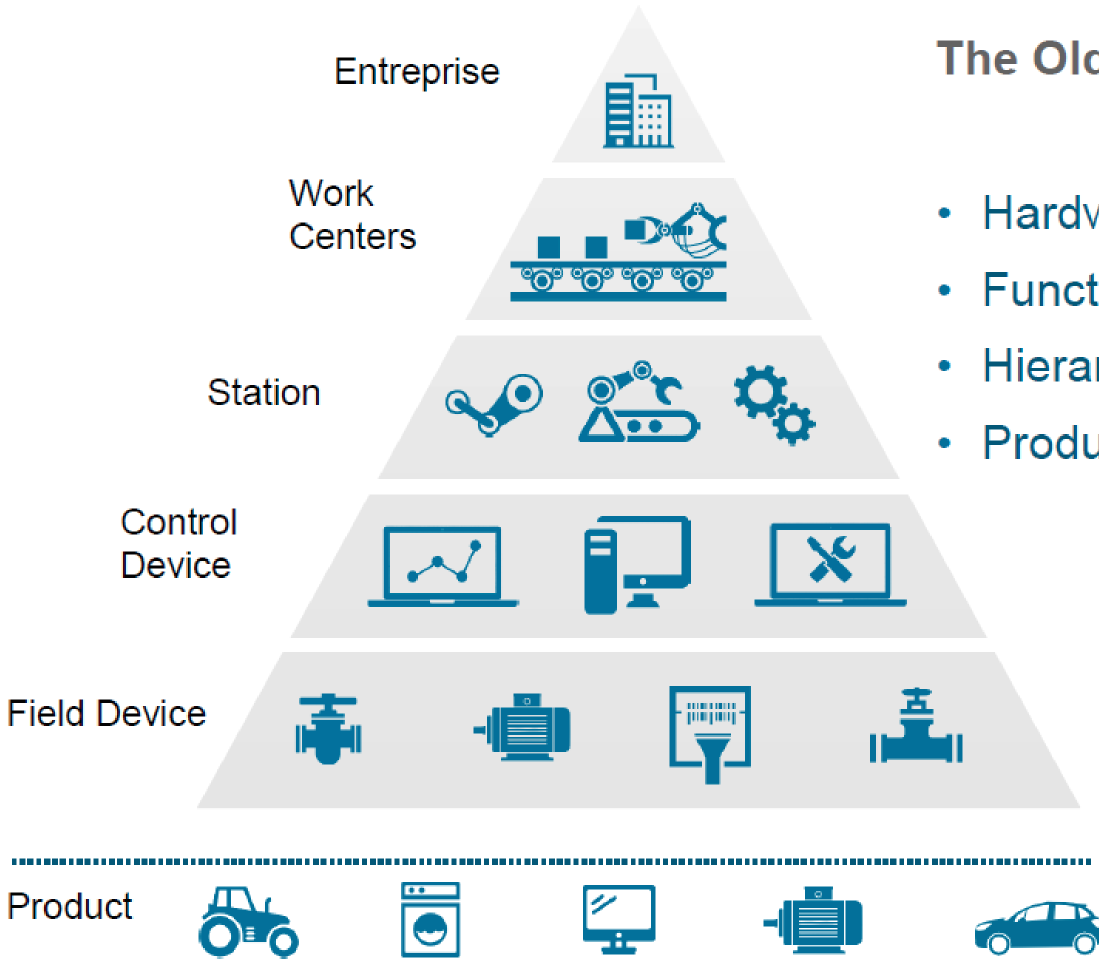
IIoT + Industrie 4.0

Internet of Things and Services



http://www.plattform-i40.de/

From the “old” industry…



The Old World: Industrie 3.0

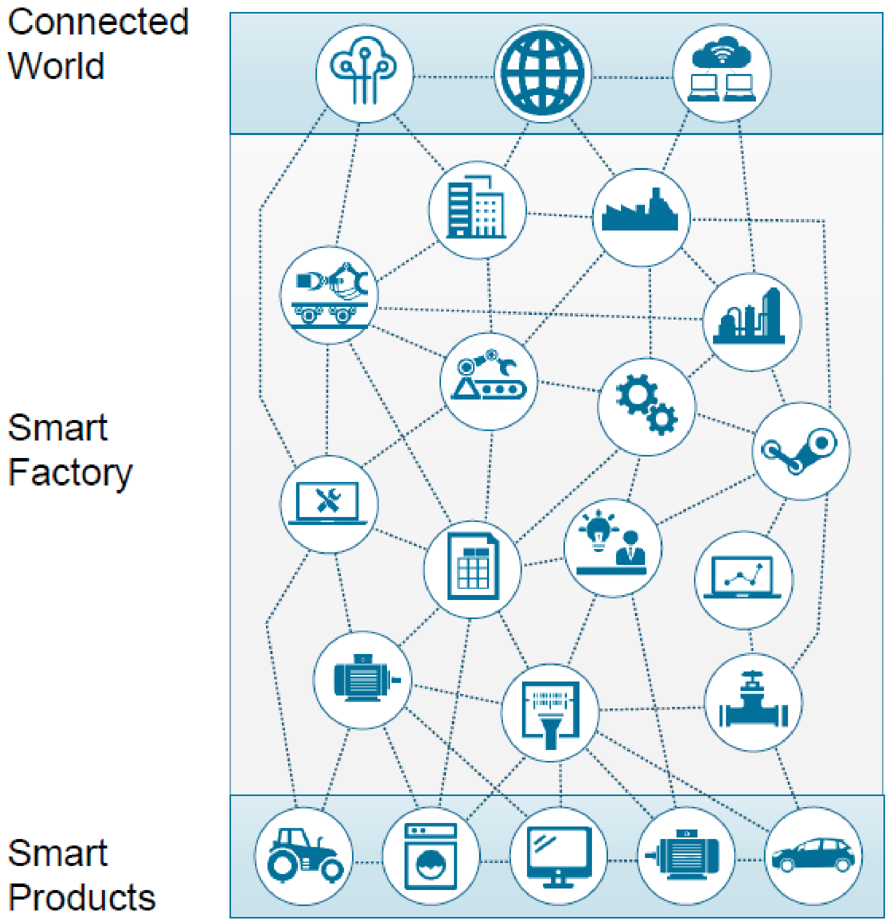
- Hardware-based structure
- Functions are bound to hardware
- Hierarchy-based communication
- Product is isolated

Source: Plattform Industrie 4.0

... to the “new” industry

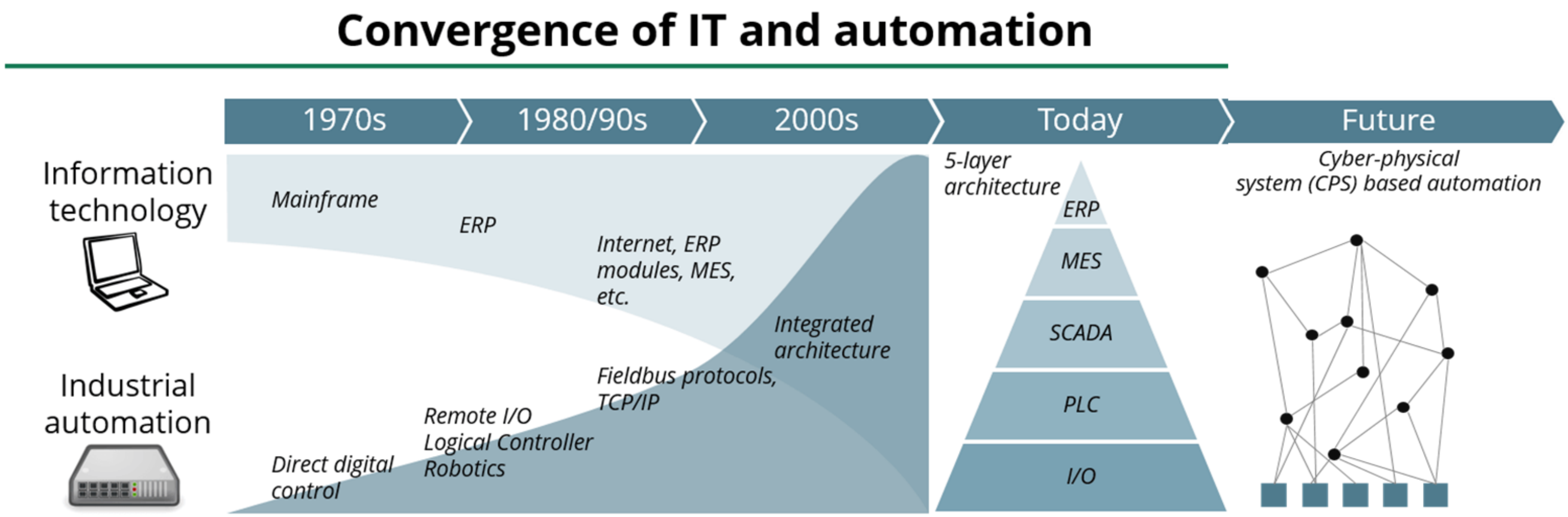
The New World: Industrie 4.0

- Flexible systems and machines
- Functions are distributed throughout the network
- Participants interact across hierarchy levels
- Communication among all participants
- Product is part of the network



Source: Plattform Industrie 4.0

Convergence of IT and Automation



Source: www.iot-analytics.com: Market Insights for the Internet of Things

Proasense Users: MHWirth and HELLA

- MHWirth is a leading global provider of first-class drilling solutions and services.
- Global span covering 5 continents with offices in more than 20 countries and employs 4,300 professionals.
- Its revenue is approx. 1 billion dollars.

- Hella Saturnus (Ljubljana, Slovenia) is a part of the Hella Group.
- Core business is the production of lighting equipment for motor vehicles
- 95% of sales are exported worldwide.
- The last annual revenue was 257 mEUR
- Employs approx. 2,800 people.

Towards proactive maintenance

- Maintenance is related to all the processes of a manufacturing firm
  - focuses not only on avoiding breakdown but also on improving performance
- Existing strategies
  - breakdown maintenance
  - time-based, preventive
  - condition-based (predictive) maintenance
- Sensor-generated real-time big data processing enable proactive maintenance

mhwirth

- A typical day rate for an oil rig is around USD 500,000
  - One hour of saved downtime is typically worth USD 20,000.
- Reducing undesired downtime is of outmost importance

HELLA

- A reduction of scrap rate by just 1%, results in savings of the order of 100,000 Euro per year

Proactive maintenance of headlamp production in Hella Saturnus

Automotive Lighting Equipment Scenario

- The production process includes the **production of the headlamps' components** and their **assembly** with automated transporting

  - **The scrap rate of the moulding machine**
    - The machine starts **cooling down** and at restart produces certain amount of **scrap** – dependent on downtime
    - Scrap rate can be predicted and **eliminated**

- **Sensors measure parameters** that are known to affect the function of the moulding machine and therefore, the scrap rate of cover lens:
  - the **dust levels** in the shop floor
  - **environmental factors**, i.e. temperature and humidity

Application of proactivity in the scenario

- **Detect**: a Complex Event Processing (CEP) engine detects a complex pattern that indicates an abnormal behaviour of the equipment (StreamStory)

- **Predict**: an online predictive analytics service provides a prediction about the scrap rate exceeding 25% (StreamPipes)

- **Decide**: proactive recommendations about the optimal time for cleaning and the optimal time for ordering the moulds (PANDDA)

- **Act**: continuous monitoring of Key Performance Indicators and adaptation of the whole cycle, leading to the continuous business performance improvement (KPI Modeler)

The case of Hella

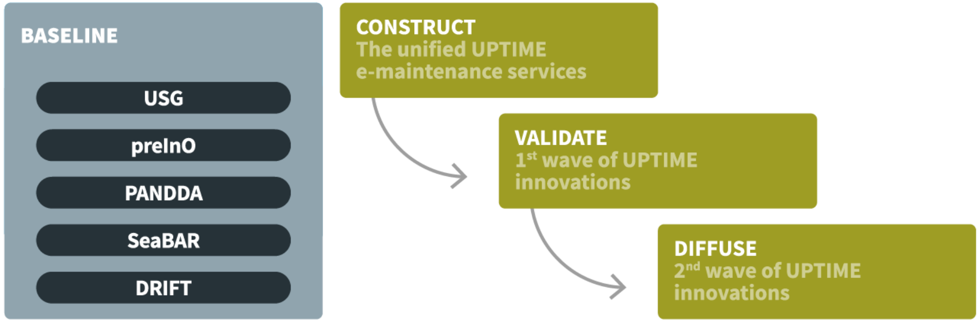
UPTIME

Unified Predictive Maintenance System

UPTIME will provide a unified predictive maintenance framework and an associated unified information system in order to enable predictive maintenance strategy in manufacturing firms

Validation in 3 industrial cases: (a) White Goods - Home appliances (b) Steel Industry - Cold rolling (c) Aviation Industry

- From 01/09/2017 to 31/08/2020



BIBA - Bremer Institut für Produktion und Logistik GmbH

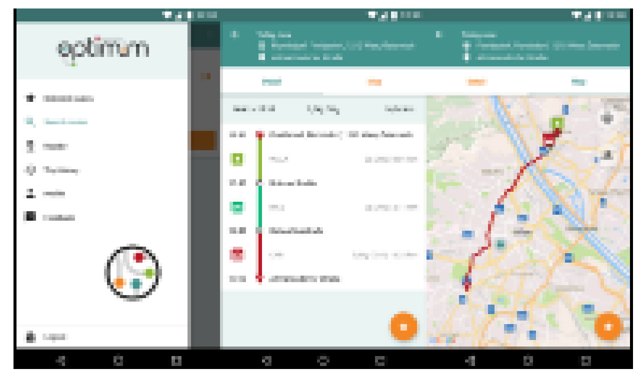
Is proactivity applicable only to manufacturing?

Multi-source Big Data Fusion Driven Proactivity for Intelligent Mobility

- OPTIMUM aims to unveil state-of-the-art solutions to improve transit, freight transportation and traffic connectivity throughout Europe.

- OPTIMUM is striving to bring proactive mobility to modern transport systems by introducing and promoting interoperability, adaptability and dynamicity

- From 01/05/2015 to 30/04/2018
- Url: http://www.optimumproject.eu



Mobile Therapeutic Attention for Patients with Treatment Resistant Schizophrenia

- During the m-resist project, a model of analysis will be implemented, in order to move forward in **understanding resistant schizophrenia**.

- M-Resist will help to **predict patient's behaviour** and allow the establishment of a **reaction alert system**, as well as draw up protocols and recommendations to give **doctors support in the clinical decisions**.

  - From 01/01/2015 to 31/12/2017
  - url: http://www.mresist.eu

Proactive Cloud Resources Management at the Edge for efficient Real-Time Big Data Processing

- PrEstoCloud targets a dynamic and distributed software architecture that **manages proactively cloud and fog resources**, while reaching the extreme edge of the network for an efficient real-time Big Data processing.
- Three use cases will demonstrate pro-activeness, self-adaptation, orchestration of distributed processing nodes and processing on the edge: (a) vehicle fleet management (b) media prosumer platform (c) surveillance solution

- From 01/01/2017 to 31/12/2019
- url: http://prestocloud-project.eu

Challenges ahead

Limitations and Challenges

- Scope and timing of proactivity
  - Proactive systems should be aware of the scope and limit their liability to a specific time horizon and events within that scope.
    - Decision whether to bring an umbrella or not is useless if made once we are already away from home
    - Decision to bring an umbrella on a day which is a year from now is likely to be inaccurate
- Context capture and filtering
  - Problem of selecting useful features from a myriad of extracted sensor data
  - Machine learning tools often implicitly filter out unimportant signals
    - for example, a regression model weights factors according to their influence on the target variable.
- Non-deterministic behaviour
  - Anticipation is unlikely to be deterministic.
    - While biological systems consider multiple possible futures in parallel, for a computer-based system to mimic biological systems remains a challenge
  - “In so far as the propositions of mathematics are certain, they do not apply to reality; and in so far as they apply to reality, they are not certain”
    - Einstein, A. (1921)

Proactive computing αs a grand challenge

- Proactive computing is inherently interdisciplinary
  - Research fields: predictive analytics, human-computer interaction (HCI), machine learning, context prediction and intelligent decision making

- *One can imagine the underpinning of computer science taking a leap from deterministic to probabilistic models, with hidden Markov models or Bayesian networks supplanting finite state machines, in much the way that physics moved from classical to quantum mechanics*.
  - David Tennenhouse "Proactive computing." *Communications of the ACM* (2000)

- The hope is to create momentum for further investigation of proactive computing throughout the computing community

More info?

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