Panel:
Autonomy Control at Work: Cars, Robots, Drones, Satellites and all other resources
(Main Features, Vision, Sensing, Trustfulness, Stability, ...)

Chair

Roy Sterritt, Ulster University, Northern Ireland. r.sterritt@ulster.ac.uk

Panellists

Petr Skobelev, Knowledge Genesis Group / Samara Technical University, Russia petr.skobelev@gmail.com
Mario Döller, Fachhochschule Kufstein, Austria Mario.Doeller@fh-kufstein.ac.at
Petre Dini, IARIA, EU/USA petre@iaria.org
Claudius Stern, biozoom services GmbH - Kassel | FOM University of Applied Sciences - Essen, Germany Claudius.Stern@gmx.net
Giulia De Masi - Zayed University, UAE Giulia.DeMasi@zu.ac.ae
Timothy Patten, Automation and Control Institute, TU Wien, Austria patten@acin.tuwien.ac.at
Pedro Forero, Naval Information Warfare Center Pacific, USA pedro.a.forero@navy.mil

Panel:

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ICAS 2020

Panellist Position

Towards Industry 5/0: Adaptive Managing of Autonomous Swarms in Real Time

Peter Skobelev, Knowledge Genesis Group / Samara Technical University, Russia petr.skobelev@gmail.com

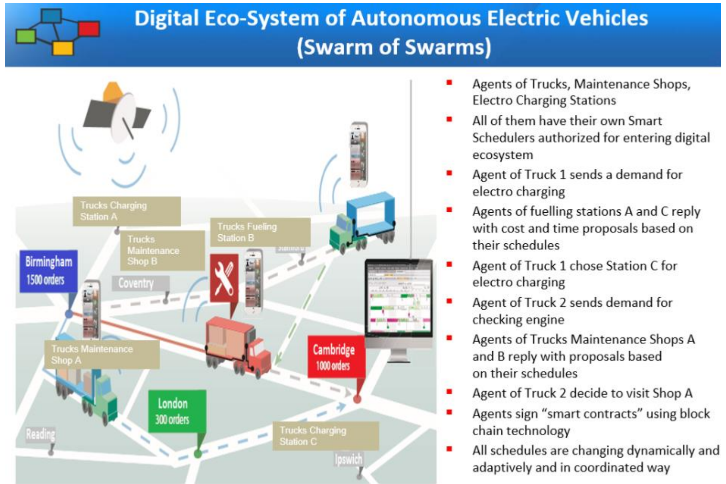
Analysis of enterprise management problems shows that resource management is a complex multi-criteria problem that requires coordinated solution according to the situation and interaction of many participants (customers, managers dispatchers etc.) with their own interests, decision criteria, preferences and restrictions.

The complex problem posed must also be solved adaptively in the course of continuous changes in the initial conditions according to events in real time. Multi-agent system help to solve the problem using collective "swarm intelligence".

The new challenge is to manage adaptively not just one fleet of trucks or factory workshop but to form digital eco-systems of smart schedulers for managing resources (swarm of swarms).

Have a look on "Swarm of Satellites" based on multi-agent technology:

- Short version: https://youtu.be/JOjhaIRBVdI (5 min)
- Extended version: https://www.youtube.com/watch?v=r7vKK9XnTCE (10 min)



Panellist Position

Data processing pipeline for automated multimodal mobility

Mario Döller University of Applied Sciences Kufstein Tirol, Austria Mario.Doeller@fh-kufstein.ac.at
and colleagues: Kris Raich, Robert Kathrein

Automated vehicles will become a reality in the future in several dimensions (e.g. 2D: street, sea, railway / 3D: UAS). A prerequisite for automated mobility is the establishment and long-term management of a stable and sufficient communication (C), navigation (N) and surveillance (S) infrastructure. In our research projects, we develop together with several industry partners a mobile CNS infrastructure including a real time data processing engine in order to support safe and secure mobility applications. For simplicity, in our first focus, we are concentrating on UAS and its secure operation. However, our approach is designed to be multimodal in order to manage automated vehicles across several traffic domains by one real time data processing engine and its visualization. In the core of our system a digital twin represents the operational environment.

https://owncloud.fh-kufstein.ac.at/index.php/s/sSi3exBV7pqI3Ww

Panellist Position

Managing Fleets of Drones and Driverless Cars

Petre Dini, IARIA, EU/USA petre@iaria.org

- Mobility-as-a-Service
- Fleet cognition plan
- Fleet member adaptability
- Fleet embedded monitoring
- Fleet-as-a-Service (hospitals, wars, property security, emergency services on vast areas)

→ Private cars will become obsolete

→ Hybrid fleet harmonization (underwater, terrestrial, aerial) for a complex service delivery

→ Fleets of fleets

Panel:
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ICAS 2020

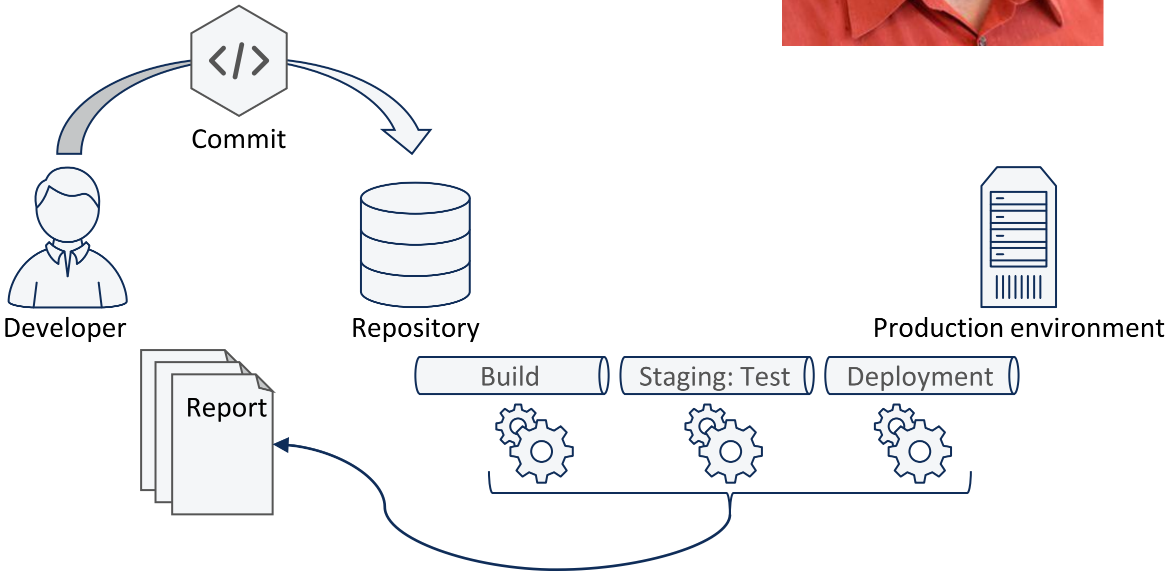
Panellist Position

Autonomy @ Work

Claudius Stern, biozoom services GmbH - Kassel | FOM University of Applied Sciences - Essen, Germany Claudius.Stern@gmx.net

Today's megatrend "Digitalization" comes with many challenges in different areas: private households, ubiquitous devices connected to the internet and last but not least business processes in small and medium enterprises. This causes traditional workflows to get scattered between traditional and digital processes. Autonomous systems may help to cope with those challenges, taking load from the user. Robotic Process Automation (RPA) is one (renewed) approach to cope with scattered workflows.

The digitalization trend raises expectations regarding transparency, reliability, quality and time to delivery. Therefore, another approach being currently in focus is Continuous Integration / Continuous Deployment (CI/CD) which uses automated processes to take reiterating tasks from the user.



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Panellist Position

Swarm robotics: how it will help in the near future for real world applications.

Giulia De Masi *- Zayed University, UAE* *Giulia.DeMasi@zu.ac.ae*

Giulia De Masi is a PhD in Physics, with 15+ years of experience both in Academia and Industry.
Always oriented to multidisciplinary applications, she led several Research and R&D projects in Machine Learning and Robotics.

Currently she is Principal Scientist in the Autonomous and Robotics Research Center (TII) in Abu Dhabi.

Her main scientific interests are Swarm Robotics, Statistical Physics, Stochastic Processes, Machine Learning.

Panellist Position

Robot vision in the wild: Towards Lifelong Learning

***Tim Patten**, Automation and Control Institute, TU Wien, Austria* patten@acin.tuwien.ac.at

Vision is a key component for autonomous systems to understand their surroundings. A strong limitation, however, is the common closed-set assumption, which prevents general and robust deployment. Two aspects, namely, anomaly detection and open-set recognition, aim to address this limitation by exploring methods that enable machines to not only realise what they do not know but to react in a safe and appropriate manner. Such techniques are essential for developing the next generation of robots that can adapt and continuously learn over their operational life.

Dr. Timothy Patten received his PhD from the Australian Centre for Field Robotics at the University of Sydney, Australia. He is now a postdoctoral researcher with the Vision for Robotics laboratory at the Technical University of Vienna, Austria. He has been involved in a number of research and industry sponsored projects in which he worked on object segmentation, recognition, grasping and task planning. Currently, he is the principal investigator at TU Wien in the CHIST-ERA project InDex, for which he is developing methods for object tracking and semantic grasping..

Panellist Position

Autonomy Challenges for Long-endurance AUV Deployments – Trust and Reliability

Pedro A. Forero, *Naval Information Warfare Center Pacific, USA* pedro.a.forero@navy.mil

Claudius

Advances on autonomous underwater vehicle (AUV) technologies will extend the duration of and reduce the requirements for frequent human intervention in a wide range of undersea missions. Although autonomy advances in the terrestrial and air domains have translated into broad technology adoption, a similar trend has not been observed for AUVs. Cost and limited access to the operational domain considerations aside, two major roadblocks for the adoption of autonomy technologies remain for civilian and military communities that operate regularly undersea, namely trust and reliability. In the undersea domain, these roadblocks are exacerbated by the limited communication options that operators have available to interact with AUVs after deployment. Thus, additional emphasis is needed to explore and develop effective human-on-the-loop autonomy solutions that enable the operator to have insight into the AUV as it executes the mission and fault management autonomy able to adjust the AUV mission goals, within the scope defined by the AUV operator, in response to AUV faults and payload performance degradation.

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ICAS 2020

Panel Chair

Autonomy @ work via Autonomicity

Roy Sterritt, Ulster University, Northern Ireland. r.sterritt@ulster.ac.uk

From a software engineering perspective, to achieve autonomy we need a separation of concerns;

autonomicity deals with the self-management of the actual systems (of systems) to enable autonomy of the task/mission/user oriented goals.

From this perspective, autonomicity is a specialization of autonomy, where the task is the management of the system (self-healing, self-configuring, self-optimizing, self-protecting).

As an example, a PhD study by ***Clement Gama****, into specifying capability levels of autonomicity for cubesats that can assist in the autonomy (and capability) of such missions from single craft, to constellations and towards swarms, is presented.*

https://gama-c.wixsite.com/smartsats/intro

Roy's main focus of research is Systems and Software Engineering of Autonomic (Self-Managing Computer-Based) Systems, essentially a research area developed from a call from industry to deal with the complexity and total cost of ownership of our systems of systems (IBM 2001). To date he has 200+ publications in the field including research collaborations with NASA, IBM TJ Watson Center, BT, SAP, HP and Core Systems as well as many academic partners. The research with NASA also lead to 16 US patents. He was the founding chair of the IEEE Task Force and subsequently Technical Committee on Autonomous & Autonomic Systems and elected chair of IEEE Technical Committee on Engineering of Computer-Based Systems. He has held many other IEEE roles such as; IEEE CS Publications board member, chair of the Conference Publications Operations Committee (CPOC); served on the IEEE CS Technical & Conferences Activities Board (T&C Excom and Opcom) and chaired the Conference Advisory Committee (CAC). He has been appointed to the many editorial boards including the NASA Journal on Innovations in Systems and Software Engineering, ACM Transactions on Autonomous and Adaptive Systems (TAAS), AIAA Journal of Aerospace Computing, Information, and Communication, Journal of Autonomic and Trusted Computing, and Multiagent and Grid Systems - An International Journal; and served on steering and/or program committees of the majority of the conferences in his field at some stage during the last 20 years.

IARIA

TOWARDS INDUSTRY 5.0:
ADAPTIVE MANAGING OF AUTONOMOUS SWARMS IN REAL TIME

Prof. Petr Skobelev – Founder and President of Knowledge Genesis Group,
ad of Department of Samara State Technical University (skobelev@kg.ru)

KNOWLEDGE GENESIS®
Group of companies

27 September 2020

Smart Solutions
Multi-Agent Technology for Resource Management

Prof. Petr Skobelev – Introduction

Prof. Petr Skobelev is well-known computer scientist (h-index 14), entrepreneur and software developer, specialized in developing **Artificial intelligence** (AI) for solving extremely complex problems with the use of multi-agent technology.

Multi-agent technology is a new mathematics and information technology based on bio-inspired fundamental principles of self-organization and evolution (as swarms of bees). The solution of any complex problem is formed by self-organization of agents reaching a consensus in swarms through detecting of conflicts and solving them by negotiations.

Key distinctions:

- ✓ We spent about 20 years of R&D to develop first industrial multi-agent systems for managing resources in real time based on new models and methods of self-organization
- ✓ It was proven that multi-agent technology provide 15-40% increase of enterprise resource efficiency under conditions of high uncertainty, complexity and dynamics
- ✓ Time is coming for the next generation of autonomous swarms of multi-agent systems (swarms of swarms) formed as an open digital eco-systems

More on multi-agent systems – in our book “Managing Complexity” by Prof. George Rzevski (UK) and Petr Skobelev (Russia), published by WIT Press (UK), available on Amazon: http://www.amazon.com/Managing-Complexity-G-Rzevski/dp/1845649362

Introduction of Knowledge Genesis Group








- Knowledge Genesis Group of Companies (Skolkovo) - 2010
- Development of Smart ERP systems for adaptive resource management based on multi-agent technology:
  - **Smart Aerospace** (RSC Energia) – managing the ISS RS cargo flow, shifts of control center, etc.
  - **Smart Factory** (Airbus, Axion-Holding, Kuznetsov, Irkut) - management of aircrafts assembly
  - **Smart Projects** (Energia, Ministry of economic development, Progress) – project management
  - **Smart Trucks** (Lorry, Trasko, Monopoly, etc.) - cargo transportation
  - **Smart Service** (gas workers, water utilities, online shops) - management of mobile teams and deliveries
  - **Smart Railways** (Russian Railways) – operational control of the dispatch office (Moscow-St.Petersburg, Nevel, Finland) and capacity planning (Baikal-Amur Mainline), Moscow metro circle
  - **Smart Supply Chains** (Lego, Coca-Cola Germany, Gazpromneft) - supply chain management
  - **Swarms of Satellites** (Rocket and Space Center, Skoltech) – managing a swarm of satellites
- **Resource efficiency growth by 15-40%**
- **One of the 10-best innovative Hi-Tech companies in Russia**
- **New pioneering developments: "swarms of swarms"**

Key Challenges of Real-Time Economy

That Was Then

- Batch
- Optimizers
- Rules Engines
- Constraints
- Visualize

This is Future

- Real-time/ Autonomous
- Manage Trade-offs
- Decision-Making Logic
- Cost/value equation
- Learn, Simulate
  Adapt and Forecast

The solution is multi-agent systems able to adapt in real time to unforeseen events

Multi-Objective Situation-Driven Resource Scheduling and Optimization

Analysis of enterprise management problems shows that resource management is a **complex multi-criteria problem** that requires coordinated solution according to the situation and interaction of many participants (customers, managers, dispatchers, etc.) with their own interests, decision criteria, preferences and restrictions.

Examples of planning criteria, the importance of which can change due to the situation:

- Provide high quality of work performed
- Execute all orders on time
- Minimize the cost
- Balanced load of resources
- Minimize risks
- Minimize expenses
- Equipment utilization

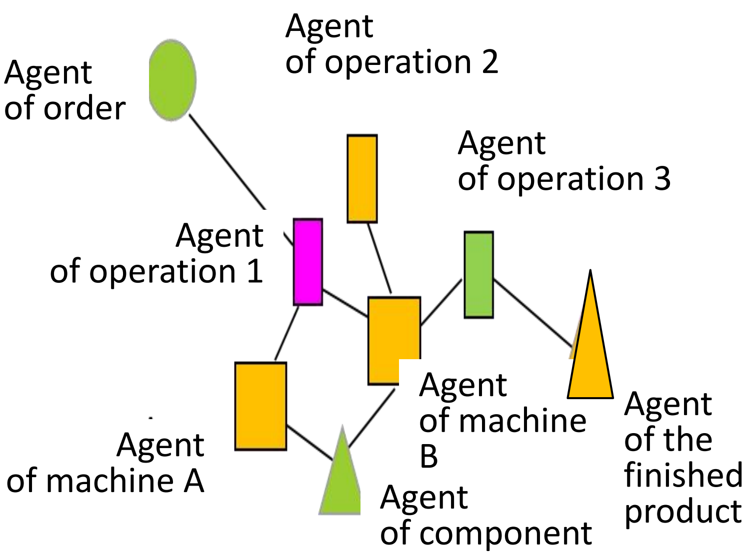
The complex problem posed must also be solved adaptively in the course of continuous changes in the initial conditions **according to events in real time**.

In addition, while solving the problem, both the importance and even the composition of criteria can also change for each participant.

Multi-Agent Technology and Knowledge Bases

Multi-agent Technology

Software agents of demands and resources (DR-network) help construct a solution for any complex problem of resource planning as a dynamic network of links, flexibly changing in real time



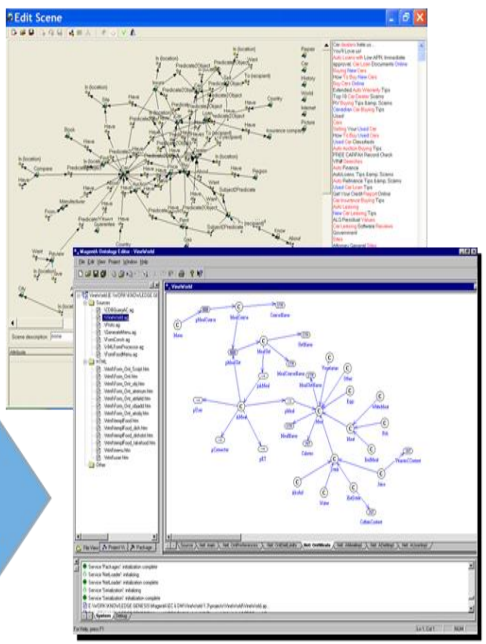
Planning is carried out as parallel asynchronous auctions

Knowledge Base

Traditional forms of data representation (reports, books, tables, etc.)

- Tables of reference books
- Analytical reports
- Conditions of use
- Results of field tests
- Advice and recommendations
- Practical examples

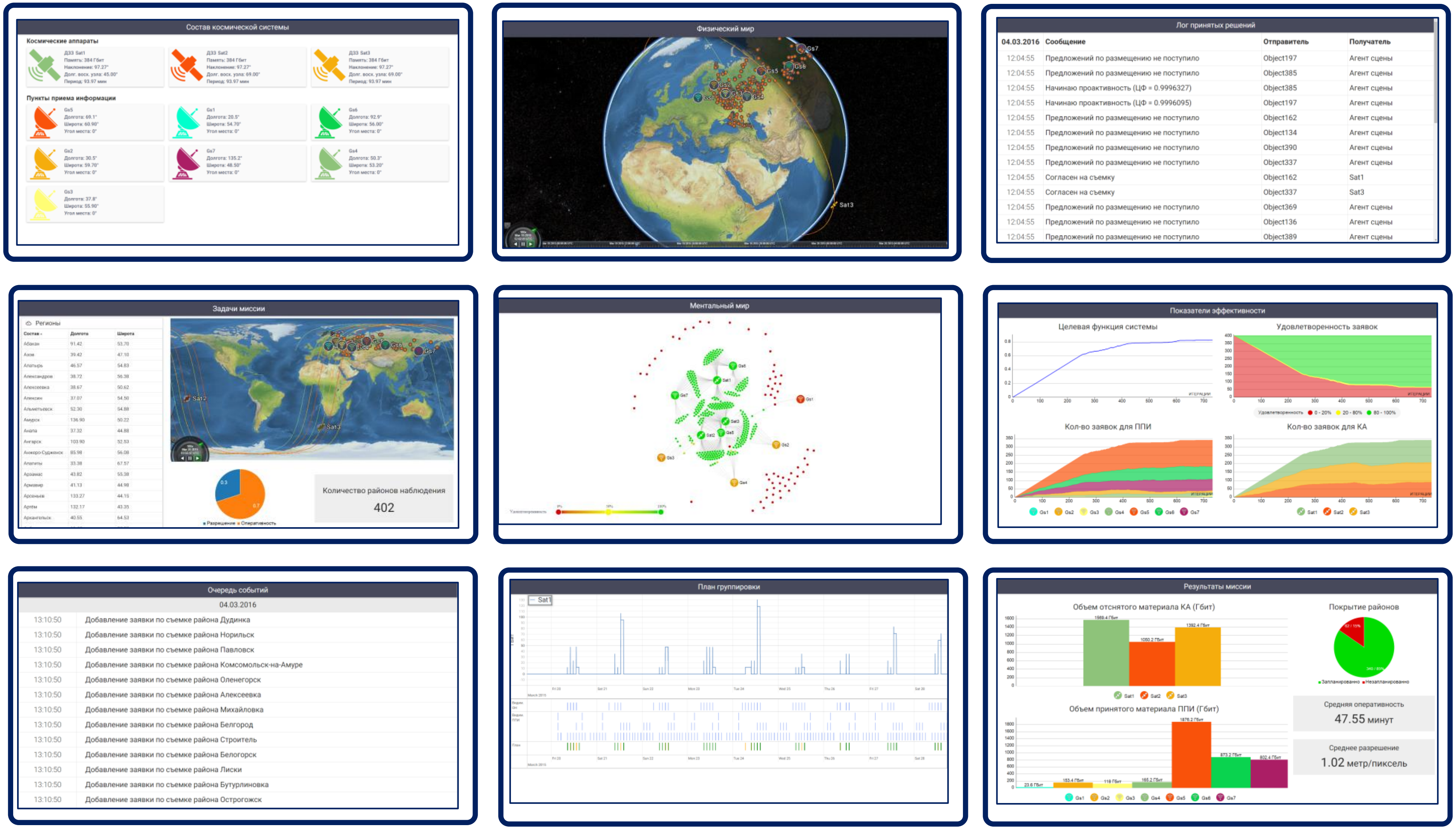
Semantic networks of ontology – computer models of domain knowledge



Examples of screens from ontology editor

Helps tune up the logic of agents to specifics of each enterprise taking into account its products, technologies, etc.

Swarm of Satellites: Multi-Agent System for Adaptive Scheduling



Full Demo: https://www.youtube.com/watch?v=r7vKK9XnTCE

Short Demo: https://youtu.be/JOjhaIRBVdI

Results of Industry Deliveries

Smart Factory (Workshop management)

- **Customers:** Airbus, AviaAgregat, Irkut
- Production schedule for up to 2 years – in 30-45 minutes
- **Increasing total product volume of a workshop by 5-10%** with the same number of workers and equipment
- Saving no less than **1163 man-hours a month, or 7 man-months a month, which equals to 40-105 thousand dollars a year**

Smart Projects (Project management)

- **Customers:** Energia Rocket and Space Corporation, etc.
- Full **transparency** of expenses during planning and implementation
- **Adaptive planning and increasing efficiency of resource use** (reducing downtime and shortage)
- Reducing time for plan construction **by 5-7 times**

Smart Supply (Supply management)

- For LEGO (USA, a network of shops in Chicago) – after pilot implementation – **increase of profit by 18%**
- For Coca-Cola (Germany) – increase of **order execution by 7%** and reducing **transportation costs by 20%**
- International practice shows that the potential for **savings from reducing enterprise costs** for supply logistics can be **up to 25%**

Smart Services (Mobile teams management)

- **Customers:** Middle-Volga gas company. Volgograd water utility, etc.
- **Reduction of reaction time** to unforeseen events **by 5-10 times**
- **Increased efficiency** of work of teams **by 40%** (12 orders instead of 7 per day)
- Support of flexible real-time planning

Smart Taxi (Taxi management)

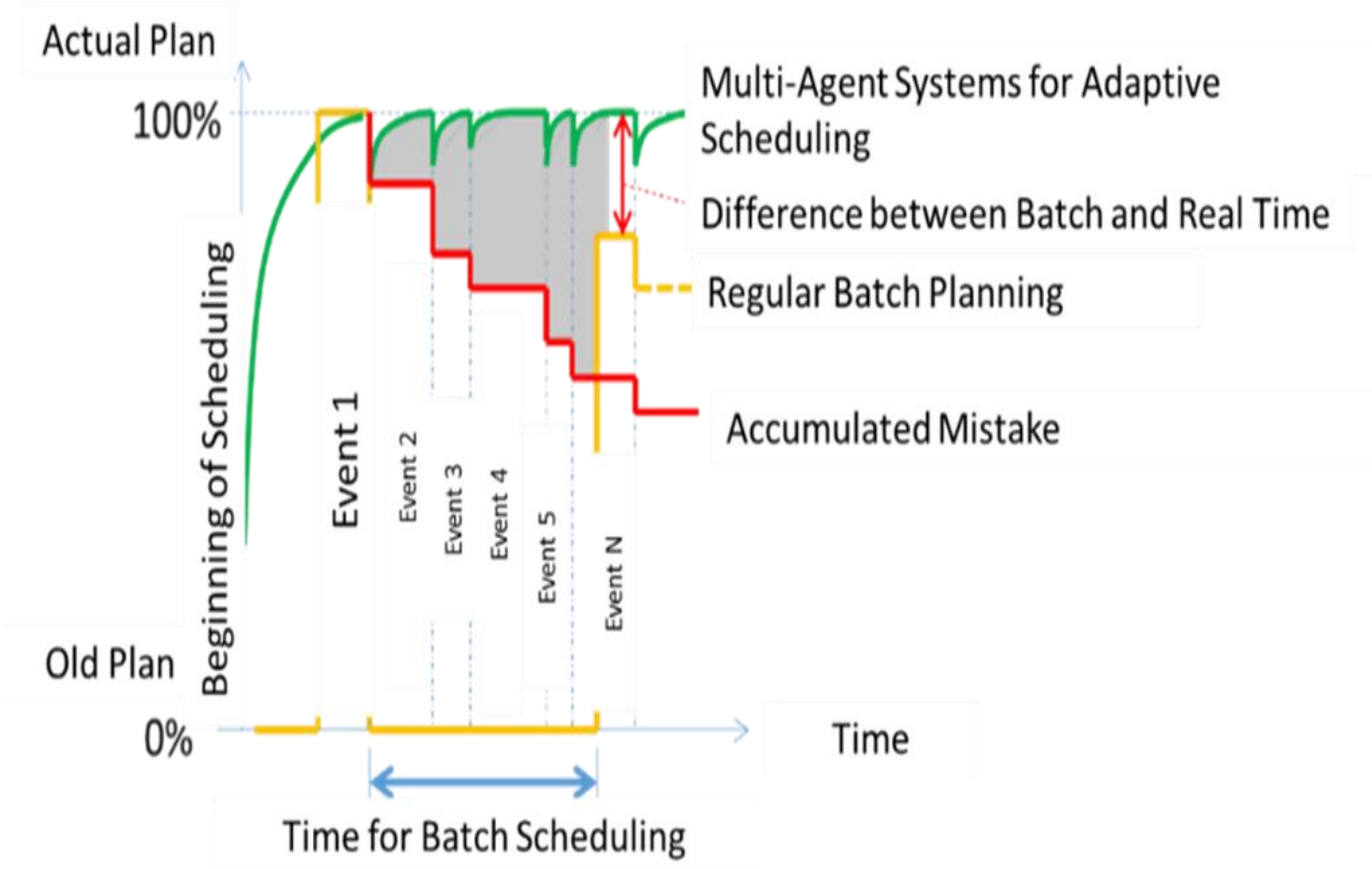
- **Customers:** Addison Lee (UK), etc.
- Number of **processed orders** increased **by 7%** with the same fleet
- **Automatic planning** of **98.5%** of orders
- **Lost orders decreased** by 2% **to 3.5%**
- **Empty mileage** decreased **by 22.5%**
- **Profitability** increased **by 4.8%**, while **driver income** increased **by 9%**, and there appeared an opportunity to expand the fleet

Smart Railways (Railways management)

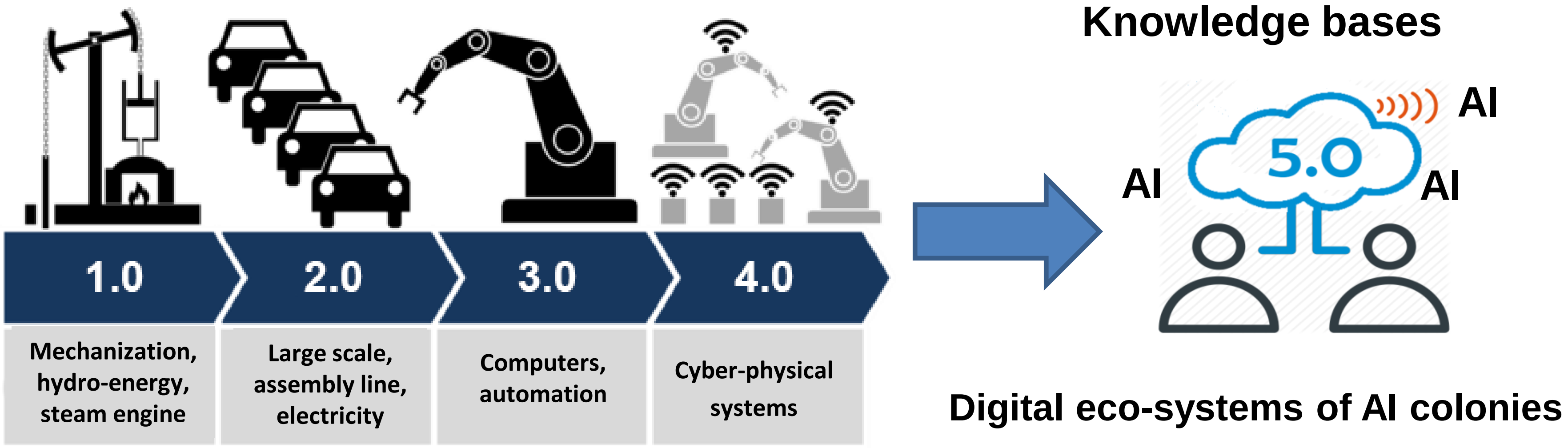
Expected results (under development)

- **Customer:** Russian Railways
- **Increase of speed** of freight trains on BAM (Baikal-Amur Mainline) **by 3-5%**
- **Time of recalculation** of traffic charts - **less than 30 seconds**
- **Increasing efficiency** of dispatching office and regaining the schedule - **by 1.5-2 times**
- **Decreasing dependence** on human factor

High Adaptability of Adaptive Resource Management



What is Next Step for Future?

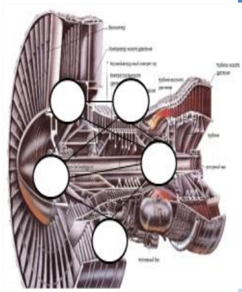


Industry 4.0 solves problems of industrial automation and integration of physical processes with control systems, ERP, BI and accounting systems.

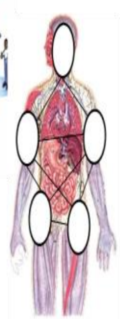
Industry 5.0 is focused on digitalization of knowledge and automation of collective decision making processes.

The new future vision includes formation of **digital eco-systems** with colonies of autonomous artificial intelligence (AI) solutions (autonomous swarms of swarms).

Shift of paradigm: from centralization and hierarchies - to self-organization of smart things

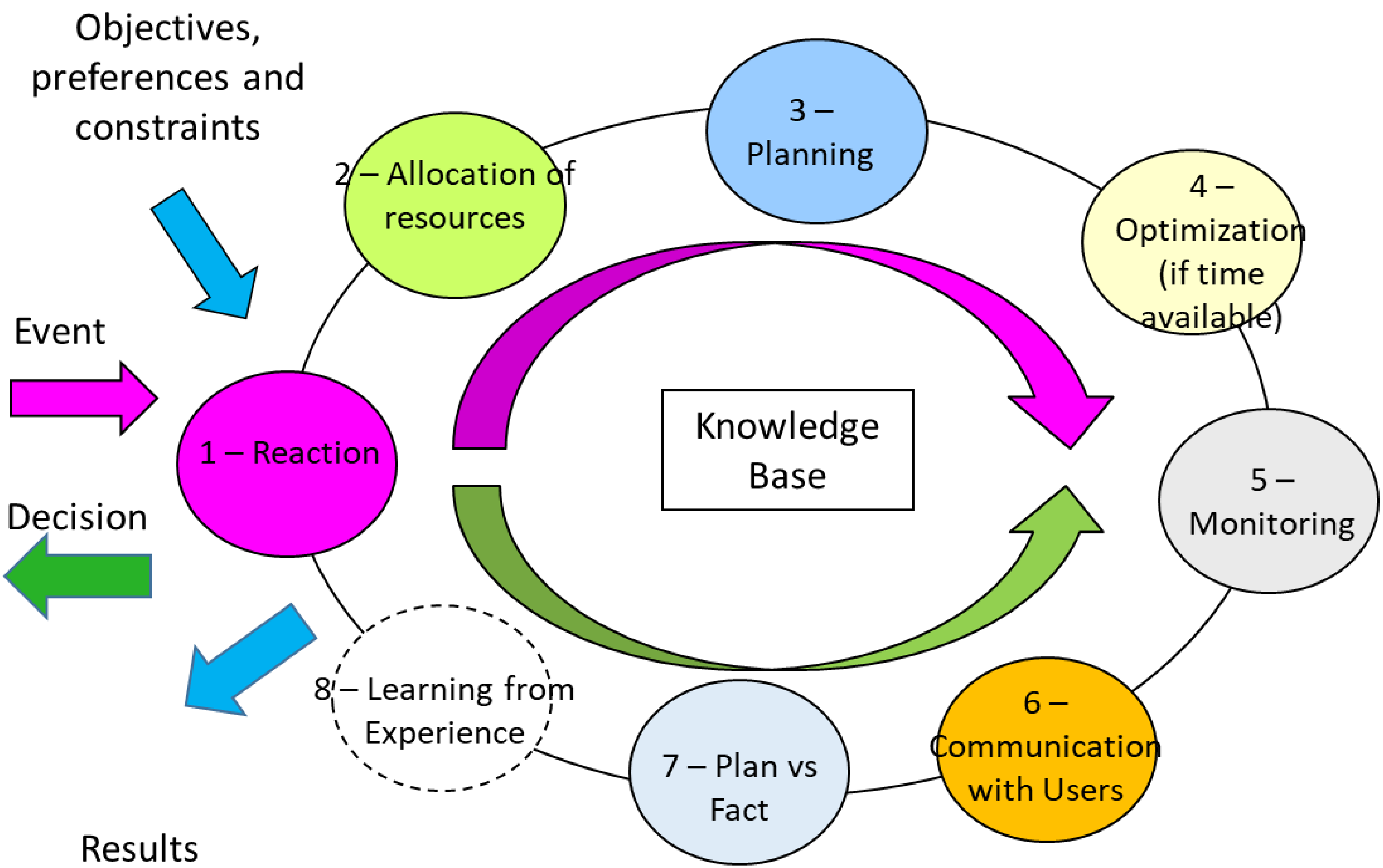





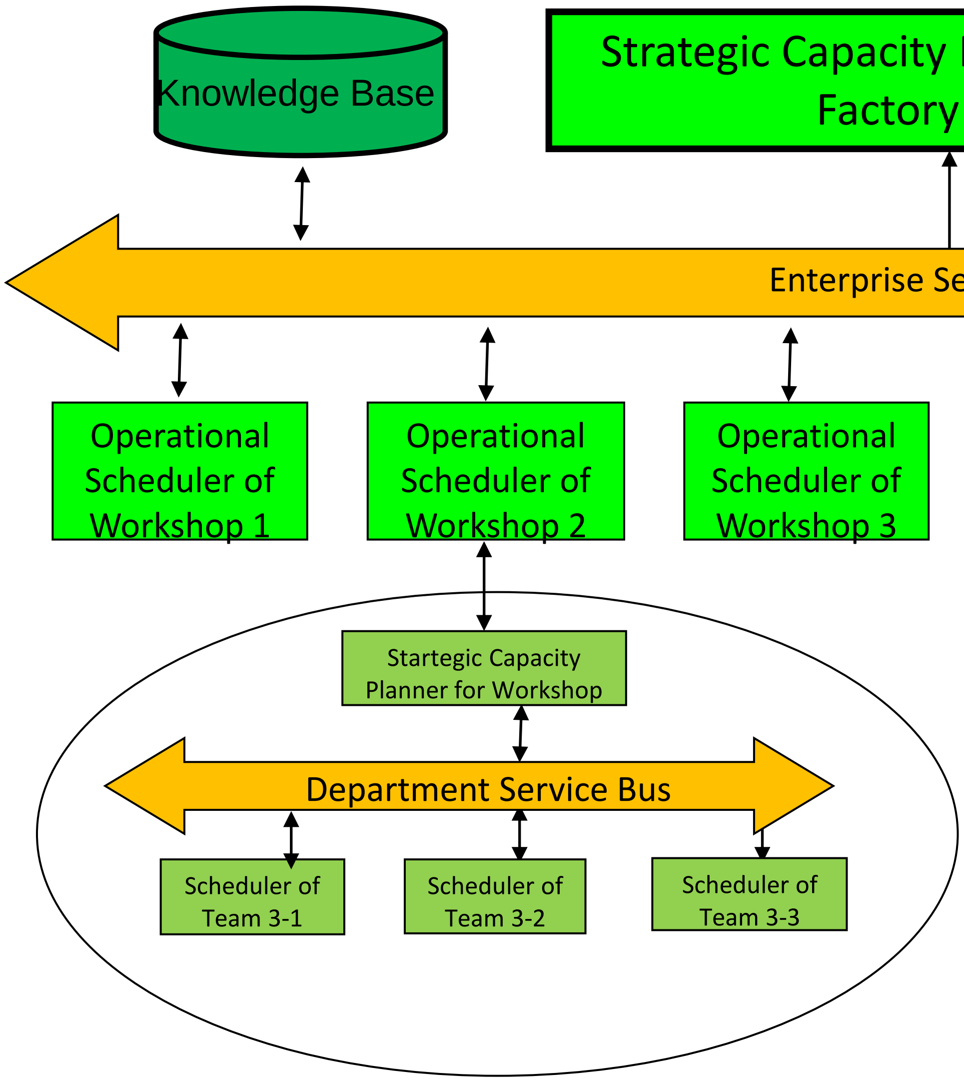


Swarms examples	Field of application	Why is it a swarm organization with highly intense interaction
Smart products	Space Aviation Engines	• An airplane as a network of >100 thousand interconnected agents of "smart parts" • A new engine as a network of agents of negotiating "smart blades" • "Cellular wing" with agents of small "smart wings"
Smart robotics	Satellites and drones	Swarm of aircraft agents such as satellites and drones - high flexibility and efficiency, survivability
Smart infrastructure	Transport	Interaction of agents of cars, roads and traffic lights for ensuring safety
Smart organizations	Project management	Agents of people, projects, tasks, etc. - smart, flexible, efficient management
Biological objects (people, plants, etc.)	Medicine Agriculture	Network of agents of organs, biocenosis, etc. Plant growth management Treatment of the whole organism, not just organs!

Full Cycle of Autonomous Resource Management



Smart Factory as a Digital Eco-System of Workshop Schedulers (Swarm of Swarms)



Draft plan for years horizon on enterprise level

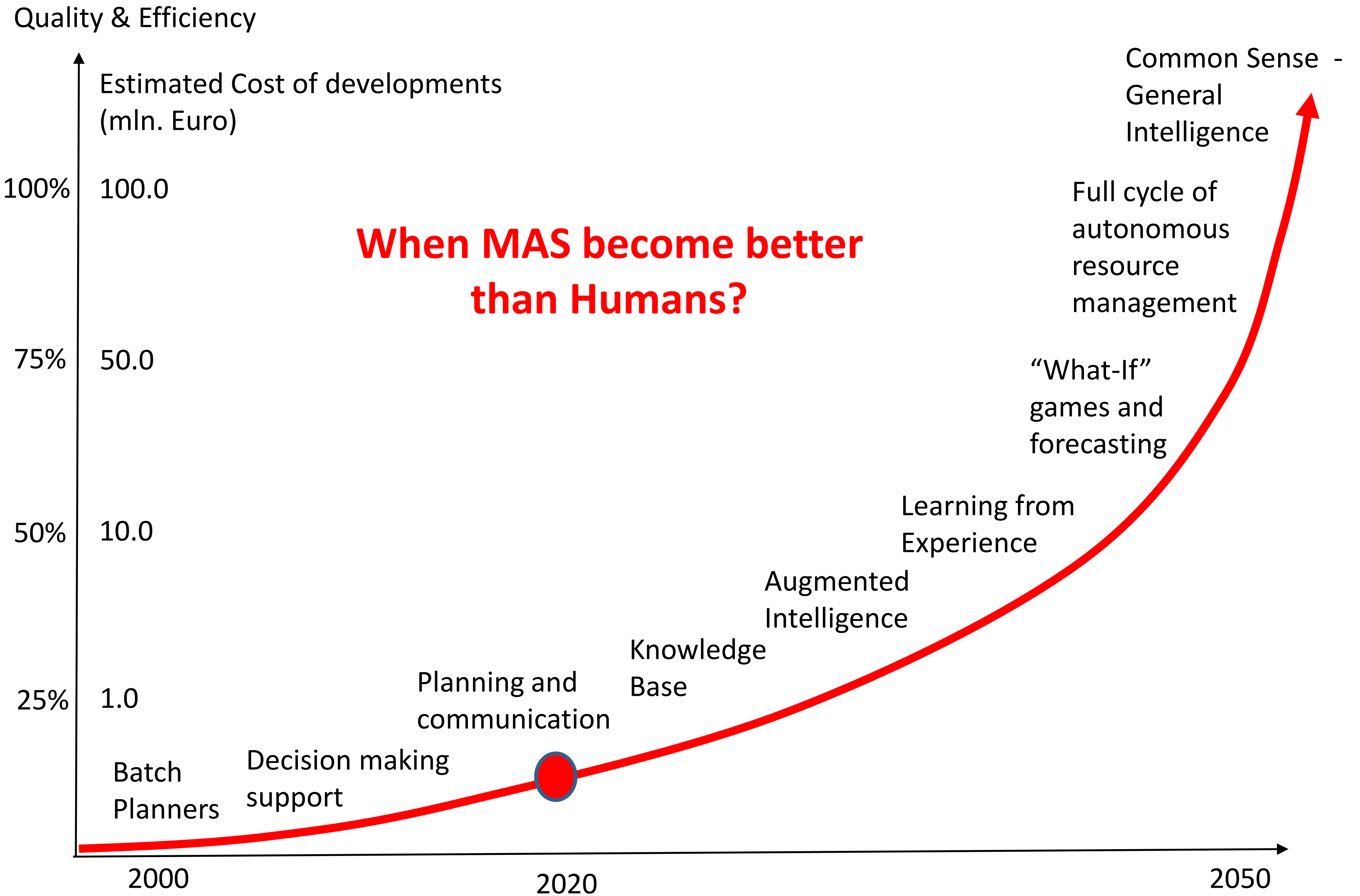
Detailed plans for month horizon on workshops levels

Detailed plans for days horizon on workers levels

Digital Eco-System of Autonomous Electric Vehicles (Swarm of Swarms)

- Agents of Trucks, Maintenance Shops, Electro Charging Stations
- All of them have their own Smart Schedulers authorized for entering digital ecosystem
- Agent of Truck 1 sends a demand for electro charging
- Agents of fuelling stations A and C reply with cost and time proposals based on their schedules
- Agent of Truck 1 chose Station C for electro charging
- Agent of Truck 2 sends demand for checking engine
- Agents of Trucks Maintenance Shops A and B reply with proposals based on their schedules
- Agent of Truck 2 decide to visit Shop A
- Agents sign “smart contracts” using block chain technology
- All schedules are changing dynamically and adaptively and in coordinated way

Expected Levels of Autonomy of Swarms in Real Time Resource Management



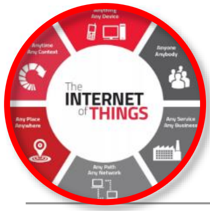
What will INDUSTRY 5.0 bring for enterprises?

New Management – for transition from centralism and hierarchies to flexible network structures with an internal virtual market of business centers and knowledge centers

Smart solutions for “uber”-like resource management based on multi-agent technology - a shift of IT paradigm to principles, methods and means of supporting self-organization. A person becomes an arbiter and is involved in decision-making only if agents of participants cannot come to an agreement

Knowledge bases in the form of a smart Wikipedia of the enterprise for knowledge integration and support of decision making by both people and intelligent systems. This helps develop possible solutions in case of problem situations

Digital eco-systems (swarms of swarms) – for implementation of network-centric systems (“systems of systems”) for competition and cooperation of smart services and implementation of new systems “on the fly” (Plug&Play)



Smart Internet of agents of people, things and documents, where each object shows its state, constructs plans and forecasts, evaluates its indicators and coordinates the decision made with other objects or people

Conclusions

- Smart systems for autonomous resource management is the new innovative direction in AI.
- Such systems are designed with the use of multi-agent technology and knowledge bases - to ensure semantics of automated collective decision making based on consensus.
- Intelligent systems for resource management are already providing increase of business efficiency by 15-40%.
- Besides, multi-agent technology is the new area for R&S in the field of self-organizing and evolving systems of “emergent intelligence”.
- Future developments require digital eco-systems of autonomous AI for resource management (“Swarms of swarms”).

Questions and discussion

Thank you!

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In EU: Multi-Agent Technology, Ltd (Helsinki, Finland)

Enjoy the beauty of self-organized systems for solving complex problems

Data processing pipeline for automated multimodal mobility

Mario Döller, Krispin Raich, Robert Kathrein

Interreg
Österreich – Bayern 2014 – 2020
Europäische Union – Europäischer Fonds für Regionale Entwicklung

fh Kufstein Tirol
UNIVERSITY OF APPLIED SCIENCES

Introduction

- Automated vehicles will become reality in multiple dimensions (2D: road, railway, sea, 3D: air)
- A prerequisite for automated mobility is the establishment and long-term management of a stable and sufficient communication (C), navigation (N) and surveillance (S) infrastructure as well as data management

- our approach is designed to be multimodal in order to manage automated vehicles across several traffic domains by one real time data processing engine and its visualization. In the core of our system a digital twin represents the operational environment.

Related Work

- several EU projects (SESAR CORUS [1], EDA TRAWA [2], SESAR AIRPASS [3]) are working on concepts and technology to setup up unmanned traffic management systems (UTM)

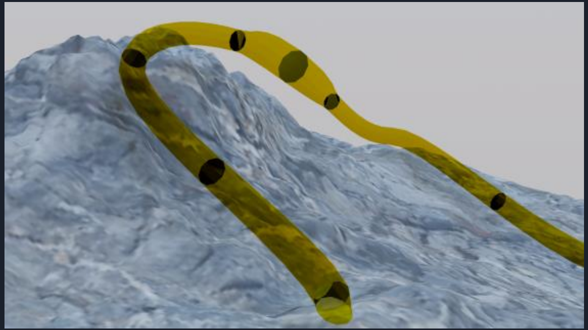
- every UTM relies on an underlying communication (C), navigation (N) and surveillance (S) infrastructure. Such an CNS-infrastructure is necessary to guarantee a safe and secure operation of UAVs in different use cases [4]

- several UTM or U-Space concept proposals can be found in literature [5, 6, 7]

Data Model for multimodal traffic management

Spatial extension model for multimodal traffic management: **SpatialJSON [8]**

- Multimodal
- GeoJSON as platform
- Three-dimensional
- Suitable for unstructured data
- Created 2 new types
  - Corridor to define a traffic corridor
  - Area to define an geographical Area of operation
- Fast to process compared to GM
- Can be enriched with heterogeneous data



Data Model: SpatialJSON Definition

Corridor = <id, shape, coordinates>

- Based on LineString
- Shape defines the basic geometry (D)
- Coordinates holds a list of WayPoints
  - WayPoint = <Position, Size, Junctions>
  - Junctions = <TargetId, TargetType>
- Each WayPoint (B) defines the size of a segment (A)
- Added curve and size interpolation

Area = <id, elevation, height, coordinates, junctions>

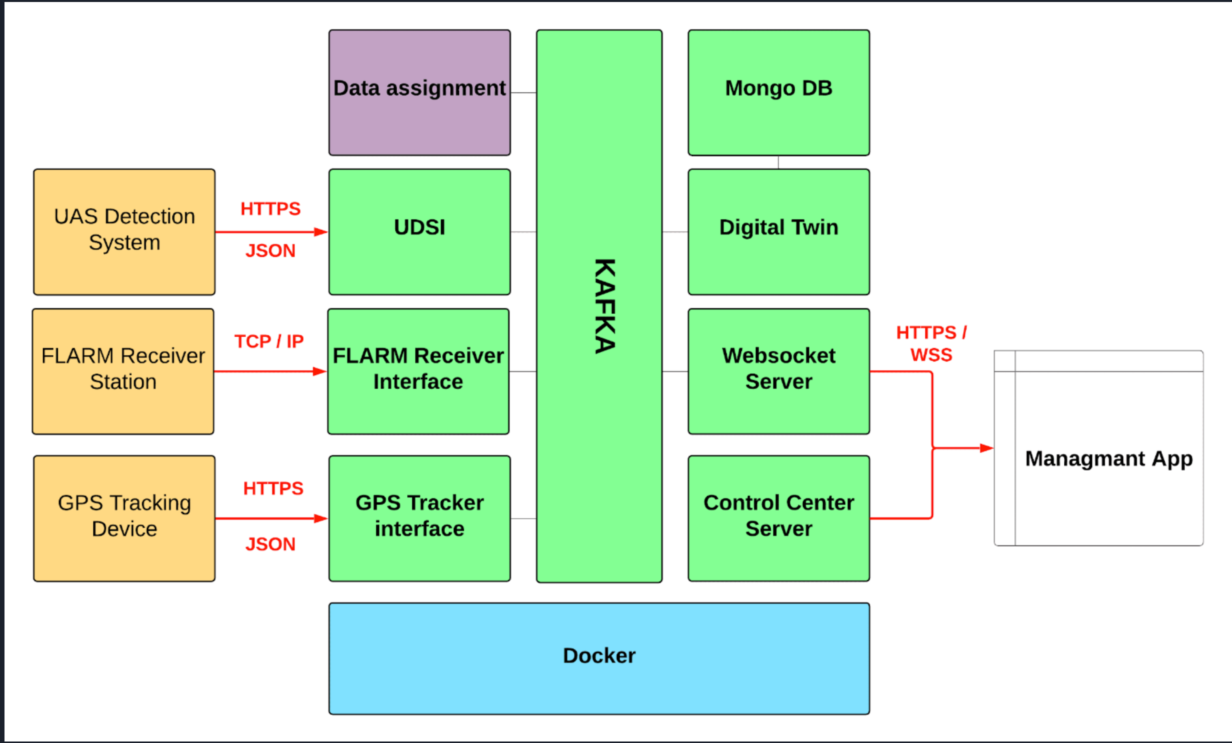
- Based on Polygon
- Added spatial dimensions (elevation & height)
- Coordinates holds a list of GeoJSON Points
- Junctions list intersecting Corridors

Service Oriented Architecture for Real time Data Processing

- Geo based subscribe / publish via Apache Kafka
- Provides realtime and historical traffic information
- Fusion of multi sensor input
- Stream processing interface (Kafka) for BigData processing (Apache Flink and Spark)
- Low latency processing(<20ms)
- Data processing steps:
  - Data Ingestion: dedicated interface for each type of data source.
  - Data assignment: Data is assigned to its origin traffic participant.
  - Data homogenization: Data is transformed to a common data format (**SpatialJson)**
  - Information distribution: Data is distributed to other micro services and subscribers of target Aera or Corridor
  - Value creation: Data is processed in an end-use application.

Service Oriented Architecture for Real time Data Processing

- Data source specific endpoints (UDSI, FLARM Receiver Interface, GPS Tracker interface)
- Apache Kafka as central data Hub (Message broker)
- Data processing Microservices (Digital Twin, Data assignment, Management App)
- Every service in a separate Docker container



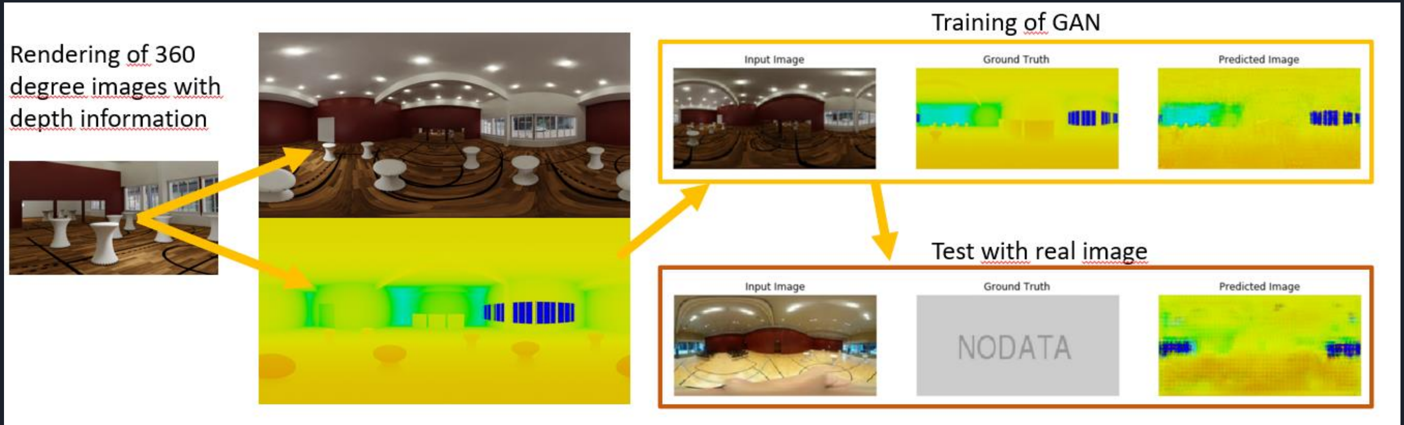
Visual based Depth Detection for Automated Flying

Besides other sensor informations of an UAV (unmanned aerial vehicle) which are creating a kind of awareness of the vehicles state, like location sensores (Compass, GPS), battery status, gyro and accelerometer, a surrounding 360 degree camera could be used as close range detection sensor itself by using AI (artificial intelligence).

To create a proper dataset for training purposes, a 3D model of a drone lab environment was created with a open source rendering software.

Visual based Depth Detection for Automated Flying

To create this local awareness within the drone systems, a Generative Adversarial Network was created and tested to generate the depth informations [9]. The 360 degree renderings of a virtual world was used to train the network to proof the concept of training by a fully artificial training dataset. Furthermore the test images used are photos taken by a real 360 degree camera.



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[5] Mikko Tapani Huttunen. 2019. The U-Space Concept. Air and Space Law, 44(1), 69–89.

[6] Parvez Mahmood. 2014. Integration of UAVs in to ATC System. Journal of Air Traffic Control, 56(2), 54–58.

[7] Steve Henriksen. 2008. Unmanned Aircraft System Control and ATC Communications Bandwidth Requirements NASA/CR—2008-214841

[8] Krispin Raich, Robert Kathrein, Michael Erharter, Mario Döller, Spatial Extension model for multimodal traffic management, In Proceedings of the International Conference on Intelligent Vehicles (ICoIV 2020), Berlin, Germany, 2020.

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[9] Daniel Stanley Tan, Chih-Yuan Yao, Conrado Ruiz, Jr. and Kai-Lung Hua - Single-Image Depth Inference Using Generative Adversarial Networks, CVPR 2018

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PANEL

Autonomy Control at Work: Cars, Robots, Drones, Satellites and all other resources

Challenges in Managing Fleets of Drones and Driverless Cars

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petre@iaria.org

https://www.iaria.org/fellows/PetreDini.pdf

Facts I

- http://money.cnn.com/2016/02/29/autos/google-self-driving-car-accident/
- **"… on February 14, a Lexus 450 hybrid SUV with Google's self-driving technology had a scrape with a city bus in Mountain View, California, the company's hometown. It said no one was injured in the accident. "**

  "Google said the car was in the right lane of a city street, and was about to turn right. But after initially moving to the right side of the lane, it moved back to the center of the lane to avoid sandbags that had been placed around a storm drain. The bus, coming from behind, hit the left side of the car. "

  ""From now on, our cars will more deeply understand that buses (and other large vehicles) are less likely to yield to us than other types of vehicles, and we hope to handle situations like this more gracefully in the future," said the company. "

Facts II

- mini-drone fleet: Perdix
  http://adevarul.ro/international/statele-unite/video-ultima-arma-pentagonului-roiul-drone-mici-dimensiuni-perdix-pregatit-lupta-1_5874fa115ab6550cb8513c7b/index.html
  https://www.defense.gov/News/News-Releases/News-Release-View/Article/1044811/department-of-defense-announces-successful-micro-drone-demonstration

- home protection: Sunflower Home Awareness System
  http://www.digitaltrends.com/cool-tech/sunflower-home-awareness-system/
- http://money.cnn.com/2016/11/03/technology/drone-home-alarm-system/

- self-driving bus: OLLI

  http://www.cnn.com/2016/10/20/world/ollis-electric-bus/

  helsinki: http://www.curbed.com/2016/8/31/12691516/self-driving-bus-vehicles-finland-helsinki-transportation

  singapore: http://www.cnbc.com/2016/10/19/all-aboard-singapore-now-to-try-out-self-driving-buses.html

  tokyo: http://www.wsj.com/articles/japans-dena-says-get-on-the-self-driving-bus-1467884109

  usa; michigan, Ann Arbor: http://www.nbcbayarea.com/on-air/as-seen-on/Self-Driving-Shuttle-Bus-Makes-its-Debut-406048596.html

  las vegas: olli jan 7 | http://www.reviewjournal.com/business/self-driving-bus-olli-still-its-way

  germany: https://www.dezeen.com/2016/07/19/mercedes-benz-self-driving-future-bus-autonomous-vehicle/

Prediction: Fleets at Horizon

- **Mobility-as-a-Service**
- **Fleet cognition plan**
- **Fleet member adaptability**
- **Fleet embedded monitoring**
- **Fleet-as-a-Service (hospitals, wars, property security, emergency services on vast areas)**

→ Private cars will become obsolete

→ Hybrid fleet harmonization (underwater, terrestrial, aerial) for a complex service delivery

→ Fleets of fleets

Being a fleet member

Separation - Avoid crowding neighbors (short range repulsion)

Alignment - Steer towards average heading of neighbors

Cohesion - Steer towards average position of neighbors (long range attraction)

In flocking simulations, there is no central control; each bird behaves autonomously. In other words, each bird must decide for itself which flocks to consider as its environment.

Usually environment is defined as a circle (2D) or sphere (3D) with a certain radius (representing ‘reach’).

On flocking: birds vs. drones

Birds:

- Group behavior vs. Individual behavior
- Environmental observation
- Security distance vs. movement parameters

Fleets:

- Flocking rules

or/and

- Leader-based coordination

or/and

- Central coordination

Starting points: step-by-step

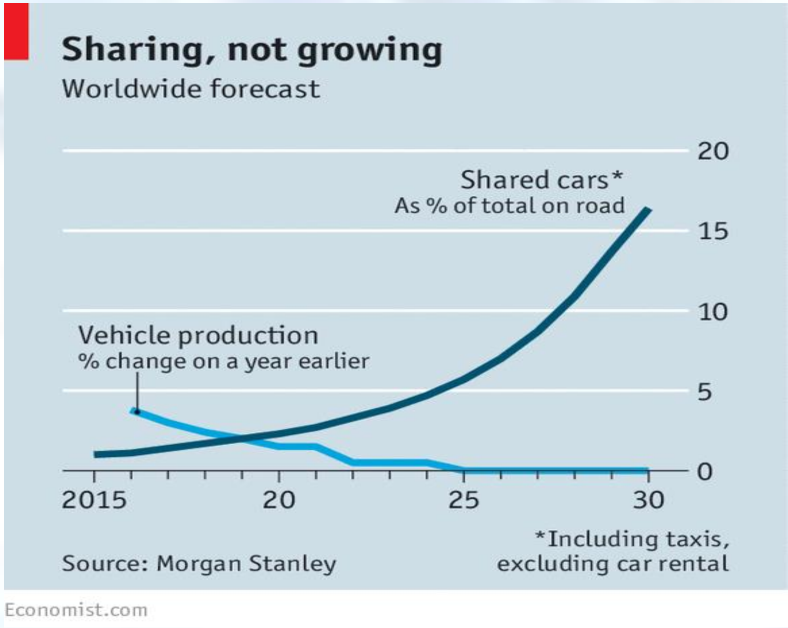
- Cities
- Dedicated Regions
- Student Campus
- Delivery Service
- Business/Cost Model
- Customer Adoption/Luring/Training/Incentives
- Government Support

Self-driving I *Legal aspects*

- **Driverless car journey starts in Las Vegas**
- ***Published 7:59 pm, Friday, May 30, 2014***
- **http://www.timesunion.com/business/article/Driverless-car-journey-starts-in-Las-Vegas-5517869.php#photo-6379150**
- **The Nevada Legislature and the Department of Motor Vehicles have enacted legislation and regulations to enable the testing and operation of autonomous vehicles in the Silver State. Currently, the DMV is accepting applications for testing only. Autonomous vehicles are not available to the general public.**
- **http://www.dmvnv.com/autonomous.htm**

Self-driving II | *Partnership and Incentives*

Partnership
http://www.economist.com/news/business/21685459-carmakers-increasingly-fret-their-industry-brink-huge-disruption
"A rumored tie-up between Ford and Google to produce driverless cars failed to materialize at the show, but even the rumors underlined the disruption that tech firms are bringing to the motor industry. And other partnerships were announced: Ford is teaming up with Amazon to connect its cars to sensor-laden smart homes. It was also revealed at CES that Toyota would adopt Ford's in-car technology, which is a competitor to Apple's CarPlay and Google's Android Auto, to access smartphone apps and other features."



"So when will the fully autonomous car hit the showrooms? Google, whose cars have done 1.3m test miles (2.1m km) on public roads, once promised 2018, whereas most analysts reckoned the 2030s more plausible as carmakers introduced automated-driving features in stages.
Barclays, another bank, forecasts that the fully driverless vehicle will result in the average American household cutting its car ownership from 2.1 vehicles now to 1.2 by 2040. A self-piloting car may drop off a family's breadwinner at work, then scuttle back to pick up the kids and take them to school. The 11m or so annual sales of mass-market cars for personal ownership in America may be replaced by 3.8m sales of self-driving cars, either personally owned or part of taxi fleets, Barclays thinks.
Driverless cars still have problems in bad weather. They may struggle to recognize that light shining off a puddle is harmless or guess that a pedestrian is about to step into the traffic without looking. But sophisticated systems for hands-free driving on motorways, and for automated parking, are already available on a number of manufacturers' models. Fully driverless cars will ferry workers round GM's technical centre in Detroit in late 2016."

Self-driving III | *Drones + IoE*

- **CES 2016: drones, driverless cars and smart brewers**
- **http://www.telegraph.co.uk/technology/ces/12081995/CES-2016-drones-driverless-cars-and-smart-brewers.html**
- **Beyond the Internet of Everything, drones took centre-stage. The Telegraph's picks of drones on the showfloor include winner of the CES 2016 Innovation Award, Lily Robotics which makes a "throw-and-shoot camera" – a 2.8 pound camera drone ($799, shipping begins in February 2016), which follows the user via a tracking device.**

"Chinese drone giant DJI showcased its new Phantom 3 4K – its first-ever sub-$1000 drone with a 4K camera and WiFi transmission upto 1.2km.
And finally, popular drone-maker Parrot showed its giant Disco Drone – a 50-miles-per hour sleek fixed-wing aircraft with a 1080p camera onboard, weighing just 700 grams. When the show opens officially on Wednesday, there will be an Unmanned Systems marketplace, with 26 different exhibitors."

Self-driving IV | *Computing for vehicles*

Connected cars

http://www.telegraph.co.uk/technology/ces/12081995/CES-2016-drones-driverless-cars-and-smart-brewers.html

- **That prophecy has already started to fulfill itself – GPU chip maker Nvidia kicked off the week's keynote speeches with the announcement of its "supercomputer" for driverless cars. This new system apparently has power equivalent to 150 Macbook Pros, squeezed into a lunchbox-sized case and can tell apart cars, humans and street signs.**
- **Its supercomputer is already being tested in cars by companies ranging from Volvo to BMW, Daimler, Ford and Audi, which managed to train its cars to read German road signs better than any other computer, and even humans could.**
- **Nvidia wants to supercharge the self-driving car phenomenon by launching a supercomputer designed specifically for the vehicles.**

The Faraday Future Zero 1 concept car was unveiled at the Consumer Electronics Show in Las Vegas, Jan. 4, 2016. Photo: David Gilbert

Drive and Steer by Web / *e-Vehicle*

http://www.altreonic.com/content/steer-web-kurt

Altreonic has demonstrated for the first time "steer by web" capability for its KURT vehicle.

Using a camera input and a smartphone, the vehicle was remotely steered over Internet using a web application. Even with the application server and the vehicle being widely apart (about 3000 km) and using a standard ADSL connection, the control was with minimal delay.

This brings KURT in the domain of Internet of Things, enabling semi-autonomous driving for a fleet of KURT vehicles.

Events (March 2016+)

http://www.citycarsummit.com/ http://www.autotechnica.be/en

→ urban mobility (uncontrolled behavior of the pedestrian crowd, driverless, drones,…)

→ driverless cars, e-vehicle, exceptions handling

→ special regulations

To be done

- Legal back-up and regulations
- Social acceptance
- Fleet adherence
- Fleet monitoring and control
- Cognition/adaptation advanced theory/algorithms
- Encouraging partnership/incentives
- Specialized/high performance computing devices
- Appropriate monitoring/surveillance infrastructures
- Urban fleets to be carefully supported
- Continuously revisiting progress/issues
- Governmental enforced regulations

Thanks

Thanks

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Autonomy @ Work

ICAS 2020 Panel

Claudius Stern <Claudius.Stern@gmx.net>

Autonomy @ Work

Panelist’s Elevator Pitch

Today’s work is multifaceted

> Digitalization is today’s megatrend
> Transitional phase characterized by scattered workflows
> Workplaces evolving into virtual platforms
> Handle cooperation in large-scale projects

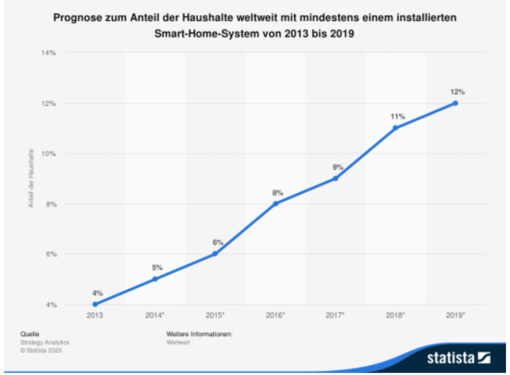
Make use of autonomous technology to cope with today’s challenges

> Robotic Process Automation (RPA) can reduce scattered workflows
> Using Continuous Integration / Continuous Deployment (CI/CD)

Some examples follow.

Megatrend: Digitalization

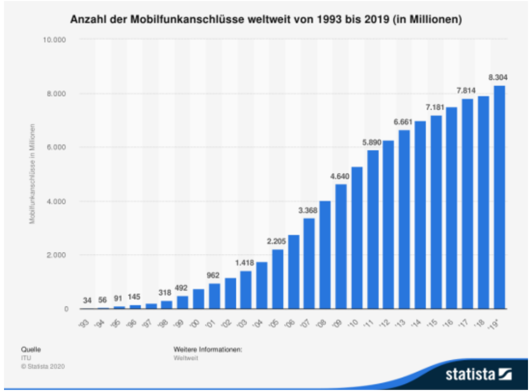
Ubiquitous computing is reality!



Strategy Analytics. (16. Juli, 2014). Prognose zum Anteil der Haushalte weltweit mit mindestens einem installierten Smart-Home-System von 2013 bis 2019 [Graph]. In *Statista*. Zugriff am 23. September 2020, von https://de.statista.com/statistik/daten/studie/318062/umfrage/prognose-zum-anteil-der-haushalte-weltweit-mit-smart-home-systemen/

Digitalization is a megatrend

- > Private: ~12% of households worldwide will have a Smart-Home system
- > Private: More mobile connected devices than people on Earth in 2019
- > Business: Transition from traditional to digital processes ongoing



ITU. (5. November, 2019). Anzahl der Mobilfunkanschlüsse weltweit von 1993 bis 2019 (in Millionen) [Graph]. In *Statista*. Zugriff am 23. September 2020, von https://de.statista.com/statistik/daten/studie/2995/umfrage/entwicklung-der-weltweiten-mobilfunkteilnehmer-seit-1993/

Managing the digitalization transition

Robotic Process Automation for scattered workflows

Robotic Process Automation (RPA)

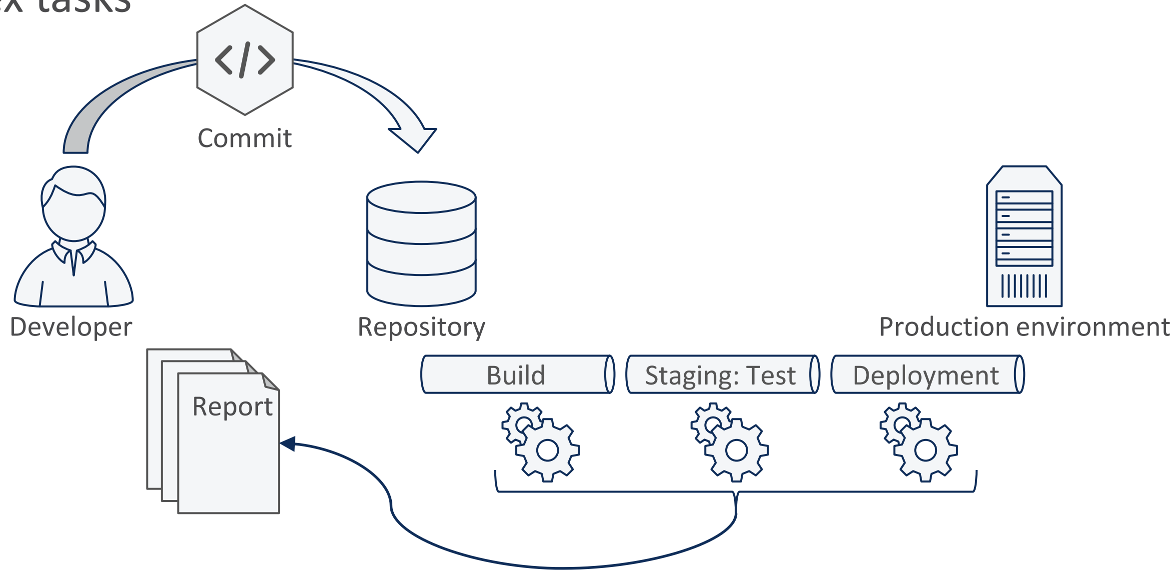
- > Technology spreads into SMEs
- > Transition causes scattered workflows with change of medium
- > Utilizing RPA to ease the workflow
- > Combine with artificial intelligence / machine learning
- > Combine with knowledge management

Continuous Integration / Continuous Deployment

Code quality in large-scale projects

Using CI/CD to ensure code quality and rapid deployment

- Defined pipeline of complex tasks
- Commit as trigger
- Automated process of build, test and deployment
- Only fully pipeline-proofed code is deployed
- One-time effort to establish the pipeline



[1] S. Mysari and V. Bejgam, "Continuous Integration and Continuous Deployment Pipeline Automation Using Jenkins Ansible," *2020 International Conference on Emerging Trends in Information Technology and Engineering (ic-ETITE)*, Vellore, India, 2020, pp. 1-4, doi: 10.1109/ic-ETITE47903.2020.239.

Swarm Robotics:
How it will help in the Near Future for Real World Applications

InforSys 2020 Panel

Giulia De Masi Giulia.demasi@tii.ae

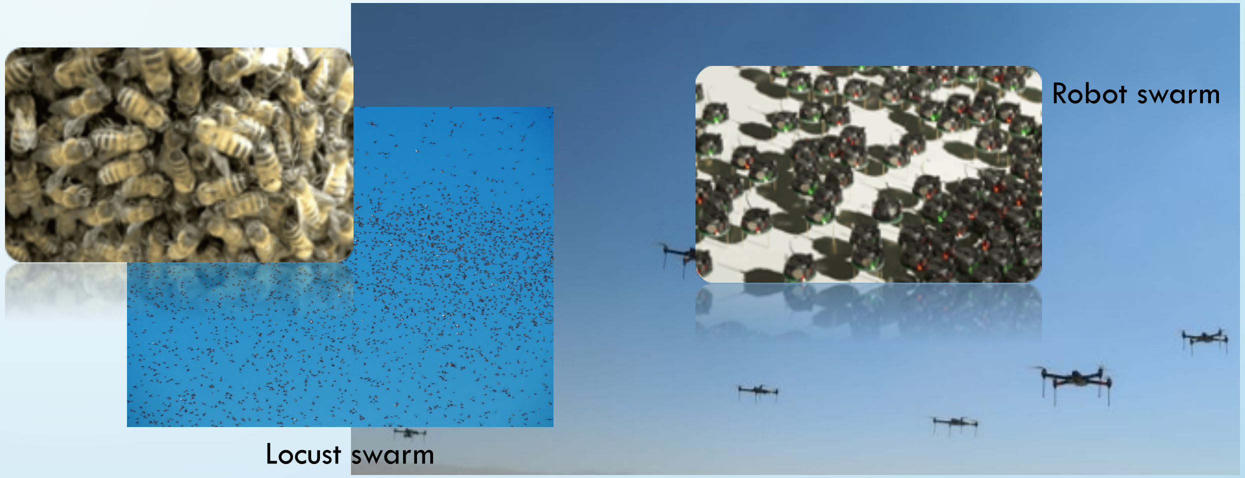
Technology Innovation Institute

Autonomous Robotics Research Centre

IARIA

GROUP OR SWARM OF ROBOTS?

A robot swarm is a self-organizing multi-robot system, imitating the behaviour of social animals.
There is no central control: the system is completely decentralized.

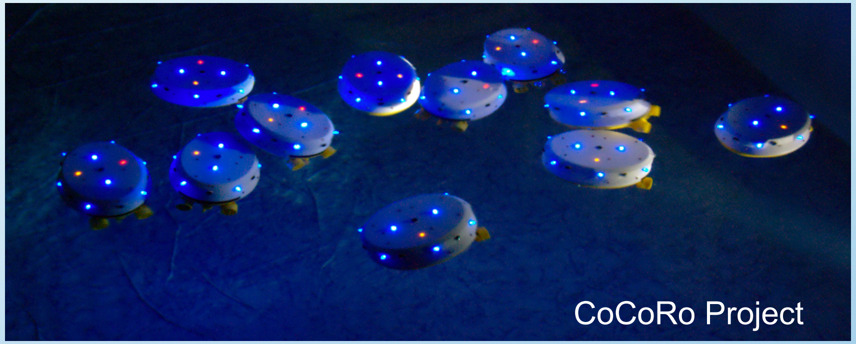


Robots' sensing and communication capabilities are local and robots do not have access to global information.

The collective behavior of the robot swarm emerges from the interactions of each individual robot with its peers and with the environment. The collective intelligence of the swarm is larger that the intelligence a single robot.

WHY A SWARM IS BETTER THAN ONE DRONE

- ✓ more resilient
- ✓ more flexible
- ✓ more scalable
- ✓ cheaper (the failure of a drone is less costly than the damage of a unique big drone)
- ✓ Using local interactions, It is working also in GPS-denied regions



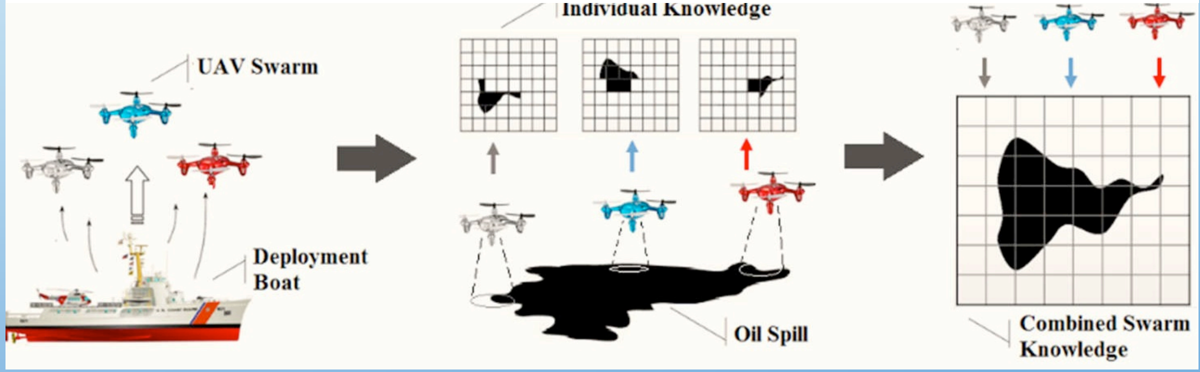
PROMISING APPLICATIONS - I

- Emergency response:
  - beside conventional teams (police, fire brigades etc.), a swarm of robot (terrestrial or aerial) can collaborate with humans.
  - For robots is easier navigate human hostile environments, remove obstacles, gather data

- Smart traffic:
  - In autonomous driving, thousands of carswith different levels of autonomy cooperate to find a common solution

- Environmental monitoring:
  - Aerial
  - Terrestrial
  - Underwater

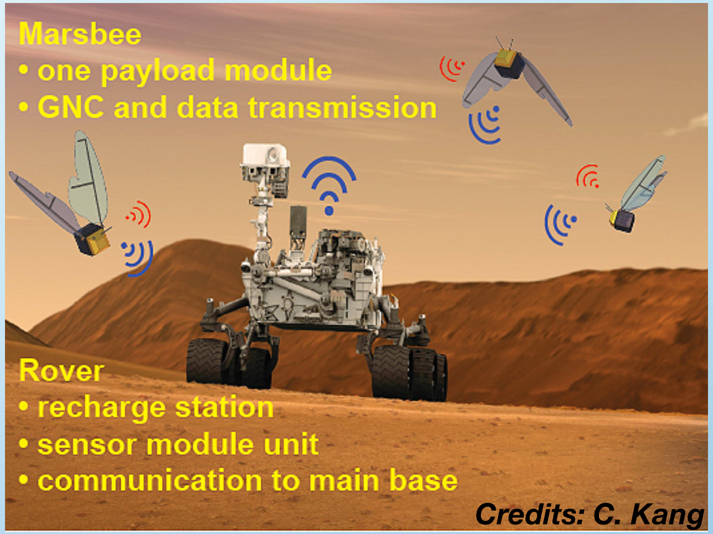
Example in oil spill mapping (Odonkor et al. 2019)



PROMISING APPLICATIONS - II

- Electric energy grids (swarm intelligence paradism):
  - Coordinating houses in neighbourhood
  - Increasing households' internal pv consumption and offering control power with distributed batteries
  - Decentralized smart grid scheduling

- Space missions:
  - Explore the environment and collect data (NASA: Marsbee – Swarm of Flapping Wing Flyers for Enhanced Mars Exploration)
  - Fully automated construction machinery for building facilities on Mars and the moon for long-term human stays (Japan Aerospace Expl.Agency)



- Medicine:
  - Boost Diagnostics: achieving better precision in locating bones metastases and pre-cancerous pathologies in the gastrointestinal lumen
  - Treat Cancer: swarming nanobots might interact with cancerous cells and destroy the tumor injecting the drug directly, without any impact on healthy tissue.

FUTURE CHALLENGES OF SWARM ROBOTICS

- Robustness, scalability, flexibility→ Flexibility is under-achieved
- Fast information transfer within swarms as in fish schools or bird flocks → Collective response and awareness
- Field swarm robotics → Achieving swarms outside of laboratory conditions in wild environments
- Predictability and controllability → Currently hard to control groups of UAVs without precise positioning (tracking or GNSS)
- Security and safety of swarms → As swarms are inherently "open to adaptation" and new individuals, how to identify attacks?
- Verifiability → Noise and stochasticity is inherent in swarms, so how to guarantee certain performance (e.g. for certifications)
- Efficient power consumption → Increased autonomy for self-deployment (e.g. recharge)

Robot Vision in the Wild: Towards Lifelong Learning

Panel: Autonomy Control at Work

Timothy Patten
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Robot Vision in the Wild

Panelist's Elevator Pitch

Vision is integral for robotic systems to understand the world, however, ...

> still mostly evaluated on datasets or in laboratory conditions
> often does not generalise beyond training samples
> performs underwhelmingly in new settings

Robots should realise their limitations:

> report results when confident and acknowledge when not
> determine what is known and unknown
> exploit the realisation and self-supervise to extend operational life

Challenges in the Real World

The limits of vision and learning

Learning-based methods unreliable outside of training distribution

> avoid overconfidence for anomalies or novelties

  > trustworthiness

Autonomous systems operate in an open world

> no fixed classes or instances, cannot consider everything

  > generality

Data and annotation are always necessary

> manual intervention is expensive and time consuming

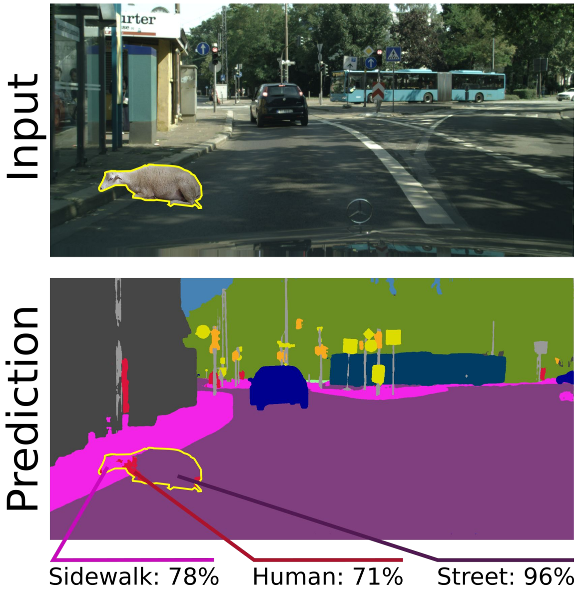
  > efficiency

Anomaly Detection

Addressing unexpected events

What should a robot do when something unexpected happens?

> Detect the outliers (out of distribution)
  > e.g., woman in wheelchair chasing a duck with a broom
> Provide an estimate of its uncertainty
  > know the reliability of its own predictions
> Account for uncertainty
  > Take confidence of predictions with a "grain of salt"



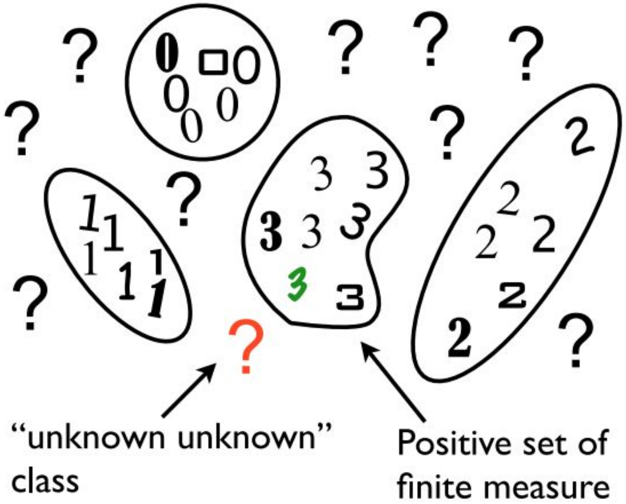
Blum et al., FishyScapes Benchmark
https://fischscapes.com

Open-set Recognition

The limited scope of knowledge

What does a robot know and not know?

- > The "known" classes (closed set)
  - > those that are common and expected
- > The "known unknown" classes
  - > those that are known not to be common or expected
- > The "unknown unknown" classes (open set)
  - > those that are not considered and for which no data exists



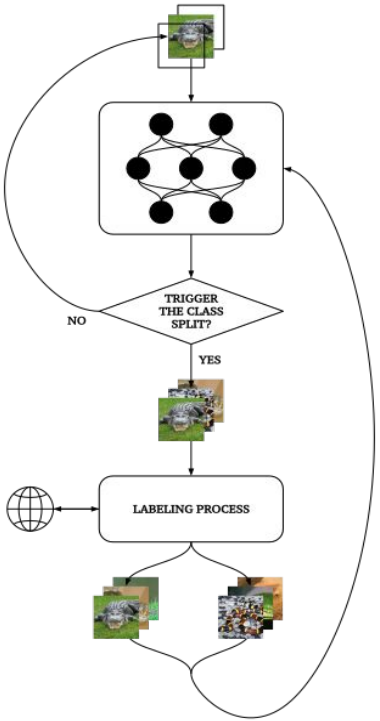
Scheirer et al. "Probability Models for Open Set Recognition," TPAMI, 2014

Lifelong Learning

Extending the operational life

How should a robot extend its operational life in the face of what it does not know?

- Metric to quantify intra-class variability
  - know when classifier limits are reached
- Trigger mechanism to update model
  - adapt class definitions to more precisely represent the environment
- Data retrieval and labelling process by exploiting the web
  - self-supervise learning to automate the process



Autonomy Challenges for Long-endurance AUV Deployments - Trust and Reliability

ICAS 2020 Panel

Pedro A. Forero
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San Diego CA, 92152

Naval Information Warfare Center

PACIFIC

UUV Missions

- Now:
  - Uptempo driven by battery and endurance limitations
  - Require significant operator support
- Future:
  - Increased endurance + better battery technologies = longer, more frequent mission deployments
- Challenges:
  - Less frequent interactions with operator
  - Higher impact of AUV failure and payload performance degradation on the mission outcome

UUV Autonomy

- Focused on navigation and platform survivability
- Some integration with sensor payloads
  - Detection and classification tasks impact AUV mission-execution plan
- AUVs are unable to react to sensor-payload degradation or failure
  - Often operators identify issues during post mission analysis phase
- Minimal interaction with human operators during mission execution
  - Difficult for operators to build trust on AUV autonomy
  - Underwater communications challenges limit observability of AUV during mission

Naval Information Warfare Center PACIFIC

Why Trust?

- Needed to accelerate technology adoption in most application domains
- Trust is built based on interdependencies and interpretations
- Operators have limited observability and controllability of AUVs while in mission
  - A classical operator-on-the-loop autonomy paradigm is challenging to implement
- Modeling and simulation tools offer opportunities for operators to interact with AUV autonomy prior to deployment
- Autonomy itself can help build trust with the operator during deployment by:
  - Managing communication opportunities with the operator as part of the mission execution
  - Prioritizing information to be presented to the operator
  - Deciding when the operator should be given control authority over the AUV
  - Using operator feedback when available

Naval Information Warfare Center PACIFIC

Why Reliability?

- Autonomy can increase AUV mission reliability
  - Not every payload performance degradation or failure should translate into a failed mission
- AUV fault management has been traditionally responsible for guaranteeing the AUV survivability only
- Artificial intelligence/Machine learning methods are able to identify payload degradation and failures
- Autonomy able to update the AUV's mission plan based on the effective sensor payload performance and availability
  - Maximize mission effectiveness using operator-defined metrics
  - Use operator goal decomposition into AUV performance and configuration requirements to assess impact of payload performance degradation and failure
  - Sacrifice AUV mission performance to maintain reliability

Panel:
Autonomy Control at Work: Cars, Robots, Drones, Satellites and all other resources
(Main Features, Vision, Sensing, Trustfulness, Stability, ...)

ICAS 2020

Panel position: Autonomy @ work via Autonomicity …
an example study with CubeSats

Towards a CubeSat Autonomicity Capability Model (CACM)

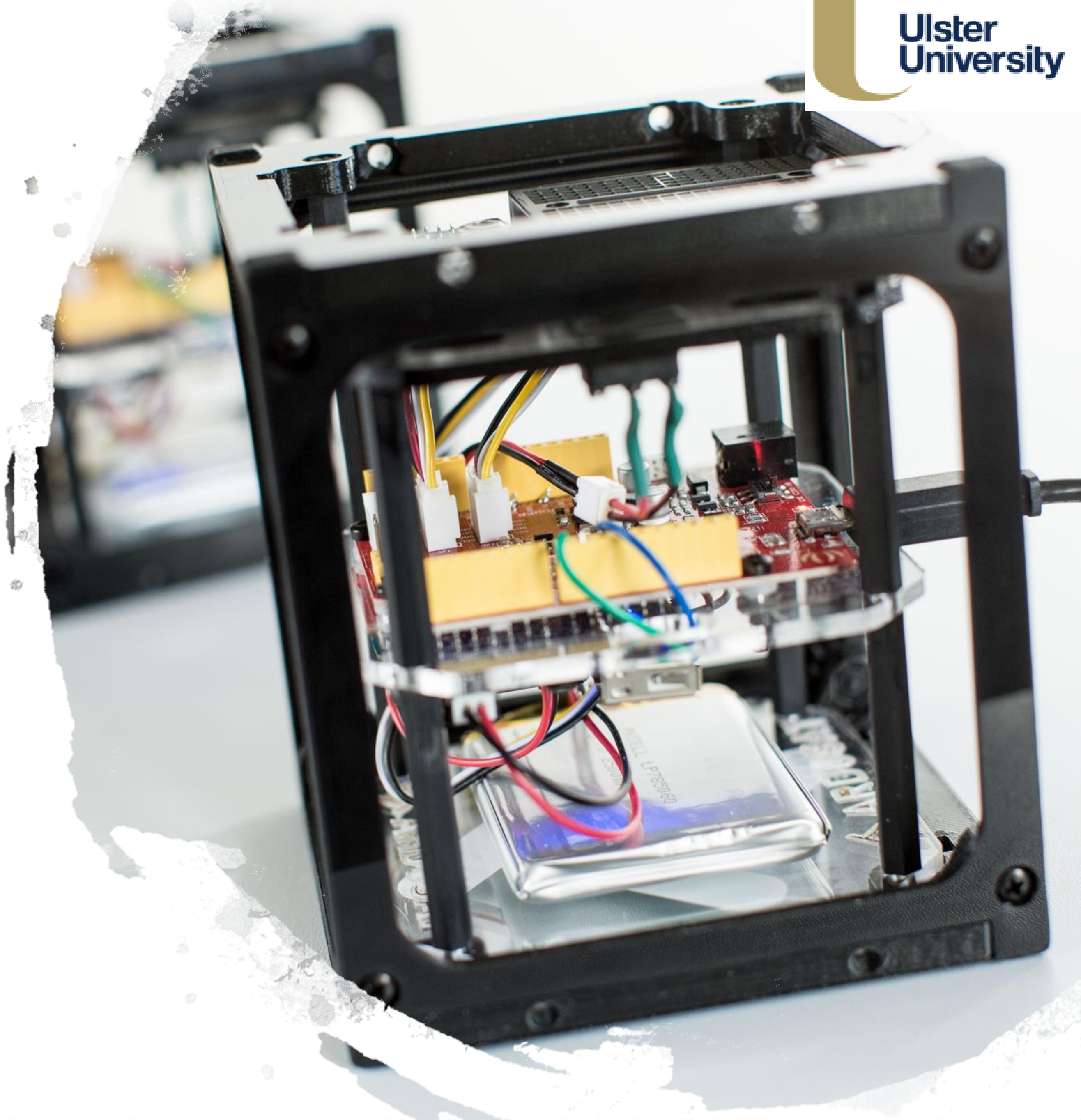
Updated from Adaptive 2018

Gama, C., Sterritt, R., Wilkie, G., & Hawe, G. (2018). "Towards a Cubesat Autonomicity Capability Model A Roadmap for Autonomicity in Cubesats." Proc. The Tenth International Conference on Adaptive and Self-Adaptive Systems and Applications (ADAPTIVE 2018) - Barcelona, Spain., Feb 2018 (pp. 34-43). International Academy, Research, and Industry Association.
https://pure.ulster.ac.uk/en/publications/towards-a-cubesat-autonomicity-capability-model-a-roadmap-for-aut

Towards a Cubesat Autonomicity Capability Model (CACM) v2

- **By: Clement Gama**
- Gama-C1@ulster.ac.uk

- ***Supervisors:***
- **Roy Sterritt –** R.Sterritt@ulster.ac.uk
- **George Wilkie –** Fg.Wilkie@ulster.ac.uk
- **Glenn Hawe –** Gi.Hawe@ulster.ac.uk



Overview

- Introduction
- Background Context
- Research Hypotheses
- Roadmap for Autonomicity in Cubesats
- Kill Switch – Exemplar Application
- Summary

Introduction

To investigate the applicability of autonomic computing in cubesats, and introduce a roadmap for future autonomic cubesat development (a Cubesat Autonomic Capability Model (CACM))

- Autonomous systems are also known as Unmanned Systems, Unmanned Aerial Vehicles, Unmanned Underwater Vehicles and Unmanned Ground Vehicles.
- CACM inspired by:
  - IBM 2001 autonomic computing model (incorporating 5 levels)
  - Autonomy Levels Framework (ALFUS)
  - Automotive Driving Automation Levels Model
  - Capability Maturity Model Integration

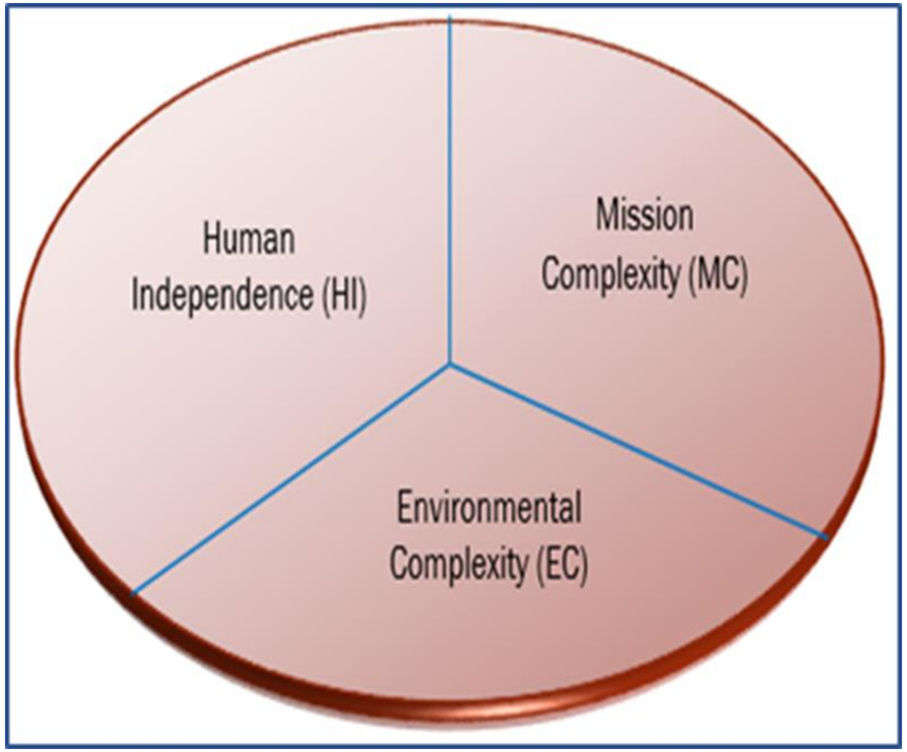
IBM 2001 Autonomic Model

Levels	Characteristics	Skills	Benefits
Level 5 Autonomic	Integrated IT components are collectively and dynamically managed by business rules and policies	IT staff focuses on enabling business needs	Business policy drives IT management Business agility
Level 4 Adaptive	IT components, individually and collectively, able to monitor, correlate, analyse and take action with minimal human intervention	IT staff manages performance against SLAs	Balanced human / system interaction IT agility and resiliency
Level 3 Predictive	Individual IT components and systems able to monitor, correlate and analyse the environment and recommend actions	IT staff approves and initiates actions	Reduced dependency on deep skills Faster / better decision making
Level 2 Managed	Management software in place to provide consolidation, facilitation and automation of IT tasks	IT staff analyses and takes actions	Greater system awareness Improved productivity
Level 1 Basic	Rely on system reports, product documentation, and manual actions to configure, optimize, heal and protect individual IT components	Requires extensive, highly skilled IT staff	Basic requirements addressed

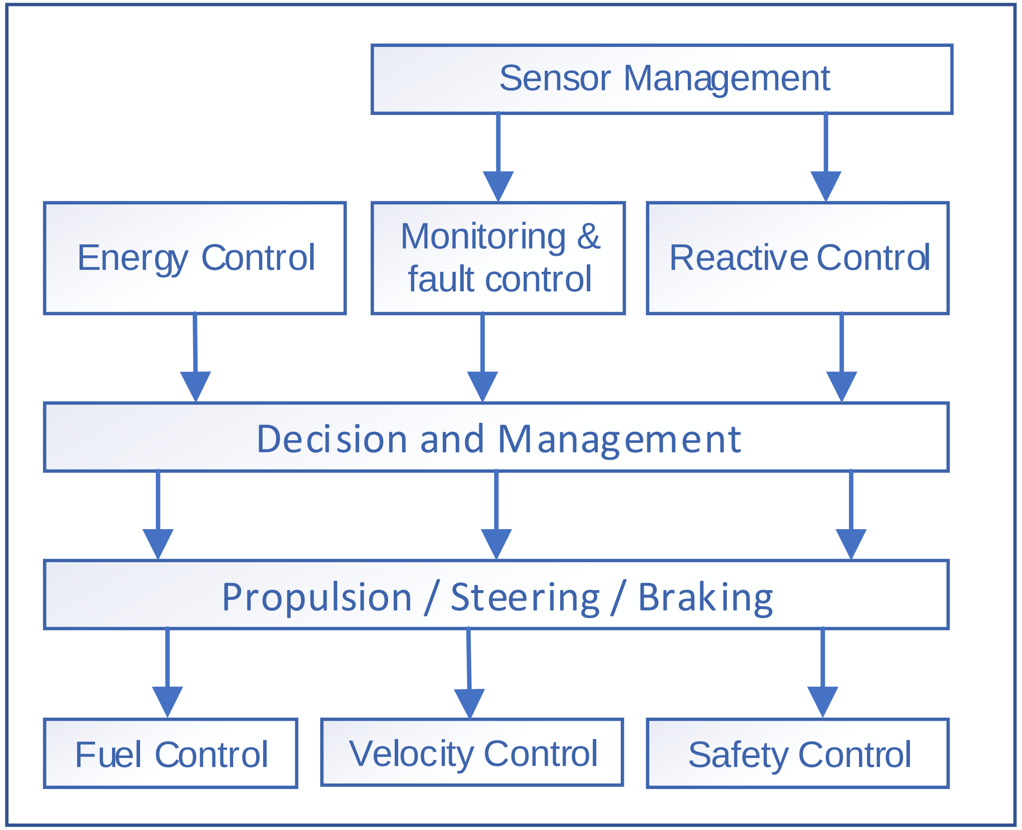
Derived from the IBM 2001 Autonomic Computing Adoption Levels

Autonomy Levels Framework

- IBM Model suitable for stationary computing systems
  - Dedicated environment – lots of processing power
- Model does not work for mobile computing: UMSs & spacecraft
- Ad-Hoc Working group developed: Autonomy Levels For Unmanned Systems (ALFUS) Framework.
- Customised version of AC to address underwater, aerial & over ground AC issues using the following categories:
  - Mission Complexity (MC)
  - Environmental Complexity (EC)
  - Human Independence (HI)



Autonomy in the Automotive Industry



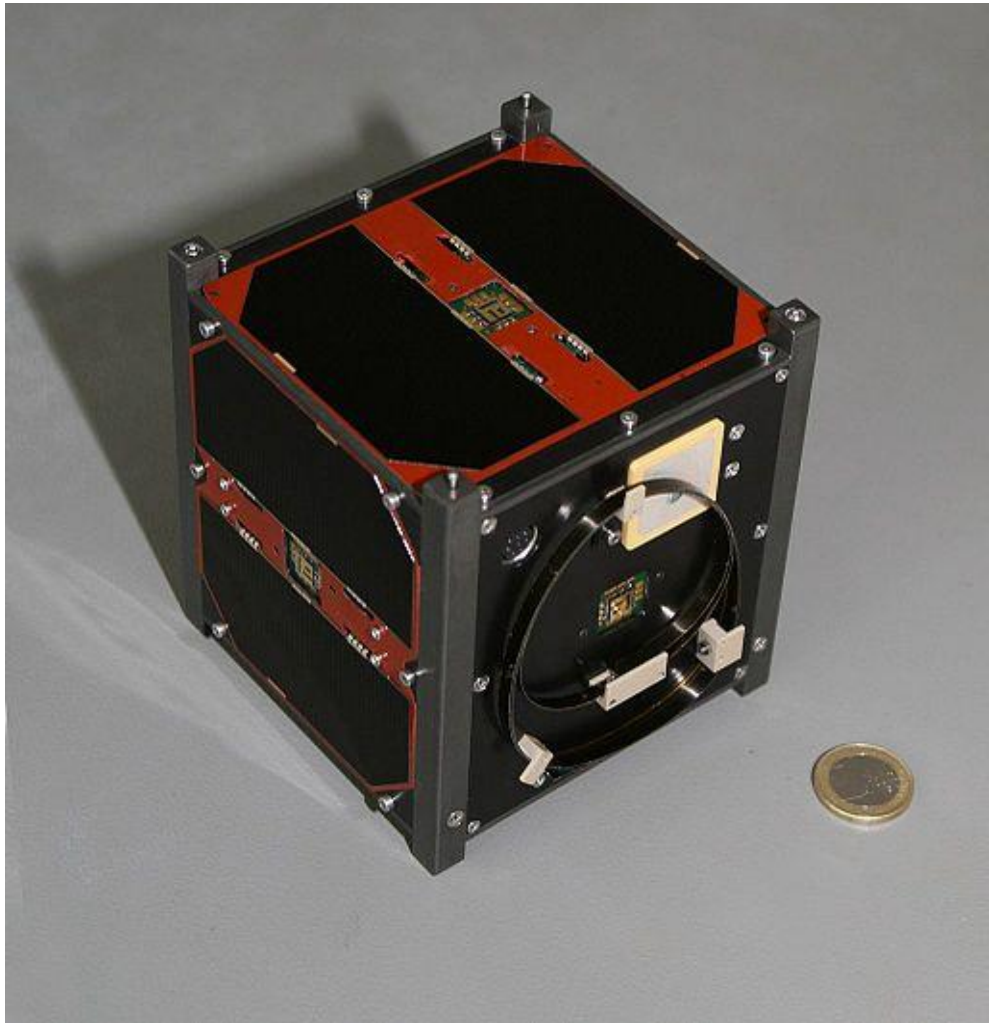
An adapted modular architecture of an autonomous car

- Working on self-driving cars
- Autonomous cars control: steering wheel, acceleration, brakes, gears & clutch
- Autonomy still a major problem
  - An autonomous car failed every 3 hours in California in 2016
  - DMV published 2,500 autonomic cars failed in 2016
- Autonomic cars mimic a human driver
  - they use live streaming of sensory values to understand the current situation

Capability Maturity Model Integration (CMMI)

- Industry best practices model – roadmap giving guidance for improvement specifically in the area of software engineering via a layered approach
- CMMI has associate appraisal tools and training materials, which help motivate, inspire and support software engineers - Successful example
- The models contain 16 process areas which are essential to software engineering (e.g. Organisational Training, Project Planning) – **what are the equivalent areas in the satellite domain?**
- Each process area decomposes into goals and practices – **can equivalent areas in the satellite domain decompose similarly?**

Cubesats



An example of a 1U cubesat

- Cubesats are microsatellites / nanosatellites that came out of a collaborative endeavour between California Polytechnic State University and Stanford University in 1999.
- Original goal: develop skills for creating LEO satellites with a limited number of scientific instruments on-board.
- Form factors: 1U (10cm x 10cm x 10cm), 2U, 3U, etc.
- No standardized autonomic features
- Becoming mainstream in test environments

Research Hypothesis 1

- An autonomic capability model can be used as a tool to educate and motivate cubesat developers on the relevance and areas of application of autonomicity in space missions.
- Follow the
  - IBM 2001 maturity model
  - Automotive Industry Autonomic Model
  - CMMI structure levels
- Develop a CACM that can form the basis for specifying autonomic features of relevance to future cubesat missions

Research Hypothesis 2

- An autonomic and apoptotic solution can address the needs of cubesats in complying with the requirements associated with space debris and will act as a suitable demonstrator to illustrate the architecture of the CACM.

- Using the tenets of the CACM, cubesats can be designed to comply with the international requirement to clean-up space debris by de-orbiting cubesats at the end of their mission or by executing the kill-switch if a cubesat develops irrecoverable error condition(s) before the end of its mission.

Roadmap for Autonomicity in Cubesats – Inspiration from Existing Models

- Cubesats are designed from the ground up for specific missions
- Mission type and goals determine size and capabilities
- Current research shows there is a lack of autonomicity in cubesats
- A proposed draft Cubesat Autonomic Capability Model (CACM) with 5 levels

Roadmap for Autonomicity in Cubesats

CUBESAT AUTONOMIC CAPABILITY MODEL (CACM)	
AC Level	Autonomic Cubesat Level Description
AC1 **Cubesat Managed from Ground Station**	Mission type is fixed – the cubesat mission parameters are hard coded. Limited on-board capability – No propulsion Always transmitting telemetry data Constellation: Participation if for information only – cannot be manoeuvred.
AC2 **Ground Station (GS) & Cubesat Shared Control**	Basic autonomicity – cubesat reports it health status to the Ground Station Default functions: Apoptotic feature, minimal propulsion Mission is pre-scheduled, mission operations on-board. Transmits data to ground station on a schedule. Constellation: Ground Station can manoeuvre cubesat.
AC3 **Single Cubesat Full Autonomic Control**	Single Cubesat Full Autonomicity – GS can intervene if deemed necessary Mission is pre-scheduled, mission operations on-board. Transmits data to ground station on line of sight Kill switch autonomously (apoptotic) executed and or by ground station. Mission goals can be adapted mid-mission
AC4 **Basic Constellation Management**	ONLY applies to Constellations Constellation cubesat missions implement Self-CHOP Execution of goal-oriented mission operations on-board. Individual members have to be at AC Level 3 - Autonomic internal systems operations. Send health status to ground station and constellation. Allows ground station to veto kill-switch execution.
AC5 **Full Autonomic Constellation Management**	ONLY applies to Constellations Goal-oriented mission operations on-board. Can self-re-initialize OS and internal systems – no human intervention Sends health status to ground stations. Only receives new mission from ground station. Kill switch notification with error details Ground Station can always intervene as and when necessary

Roadmap for Autonomicity in Cubesats – CACM Functional Areas

Equivalent to CMMI process areas in our evolving CACM are Functional Areas:

- Mission Control (MC)
- Communication and Data Transmission (C&DT)
- Health Monitoring (HM)
- Ground Station (GS)
- Management
- Launch and Deployment (L&D)
- Electric Power Supply (EPS)
- Attitude Determination and Control System (ADCS)
- Orbit Determination and Control (ODC)
- Position Control (PC)
- Scientific Instrumentation (SI)
- Kill Switch (KS)
- De-Orbit Control
- Constellation

Space Debris

Space debris is one possible exemplar application area which would be drawn from the cubesat autonomic capability model.

- Cubesats and other small space debris - becoming a danger to larger satellites and to other cubesats
  - LEO collisions probability very high
  - 25year satellite orbit life span not adhered to by some space agencies
- NASA Orbital Debris Program Office - advocates for the removal of at least 5 large debris objects per year & mitigate Kessler Syndrome
- ESA to use cubesats to create In Orbit Demonstrations (IOD) for Active Debris Removal (ADR) technologies
- Issues: debris ownership & responsibility
  - Space weaponization - Prevention of an Arms Race in Outer Space (PAROS)

Space Debris

- Europe has debris mitigation standards:
- Outer Space Treaty: *The exploration and use of outer space shall be carried out for the benefit and in the interests of all countries, irrespective of their degree of economic or scientific development, and shall be the province of all mankind... Outer space shall be free for exploration and use by all States... There shall be freedom of scientific investigation in outer space*
- Treaty also refers to “harmful contamination” – high velocity debris
- Space companies opt to adhere to the treaty – not enforceable

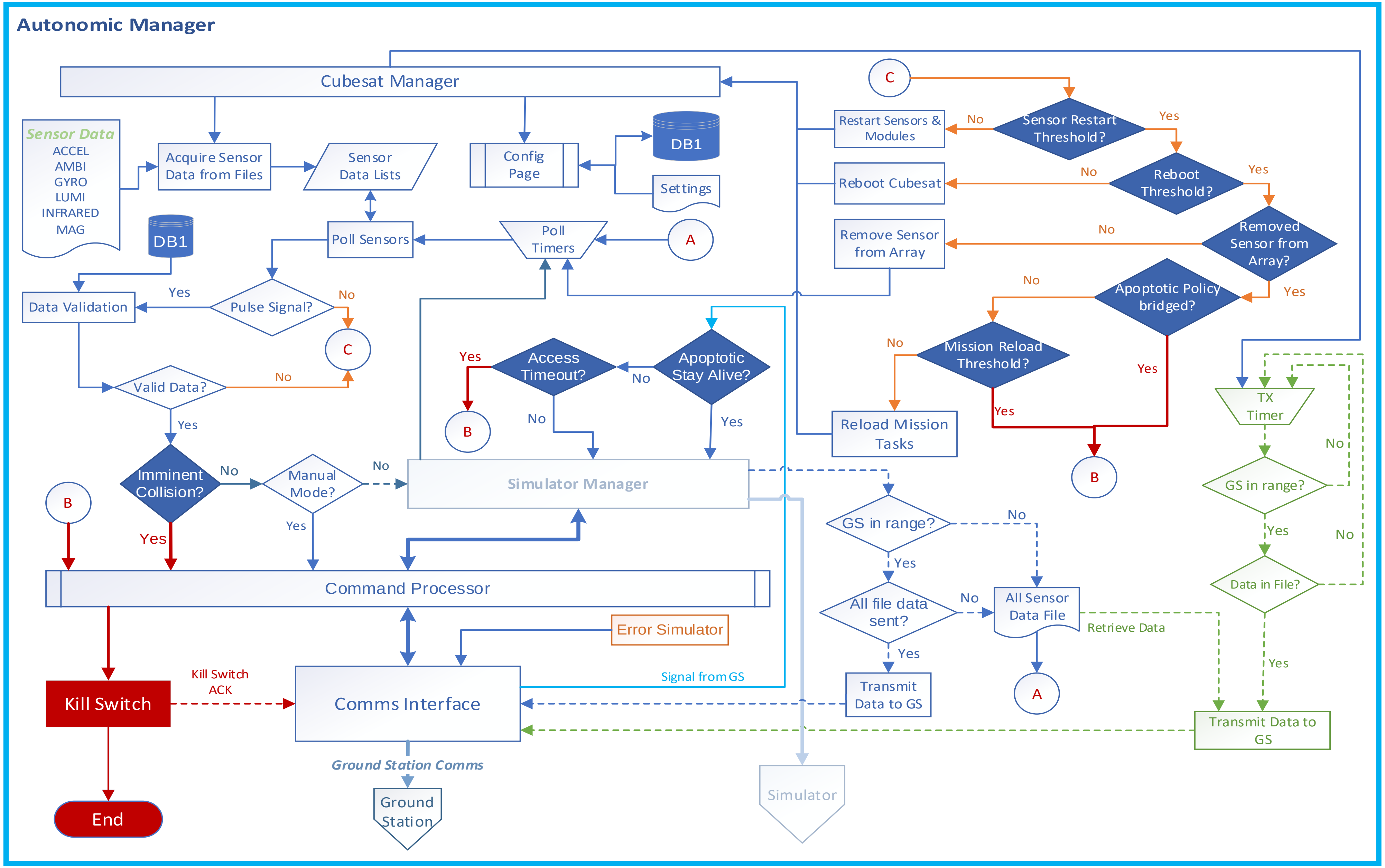
Kill Switch – Exemplar Application

Ulster University

- Functional area: designed to address the space debris problem of defunct satellites remaining in active orbit for many years after their missions have ended
- All cubesats should implement a form of kill switch – deorbit cubesat to burn up in the atmosphere or graveyard orbit
- Highest autonomic level for a single cubesat is Level 3
- Levels 4 & 5 require a constellation configuration

Kill Switch – Exemplar Application

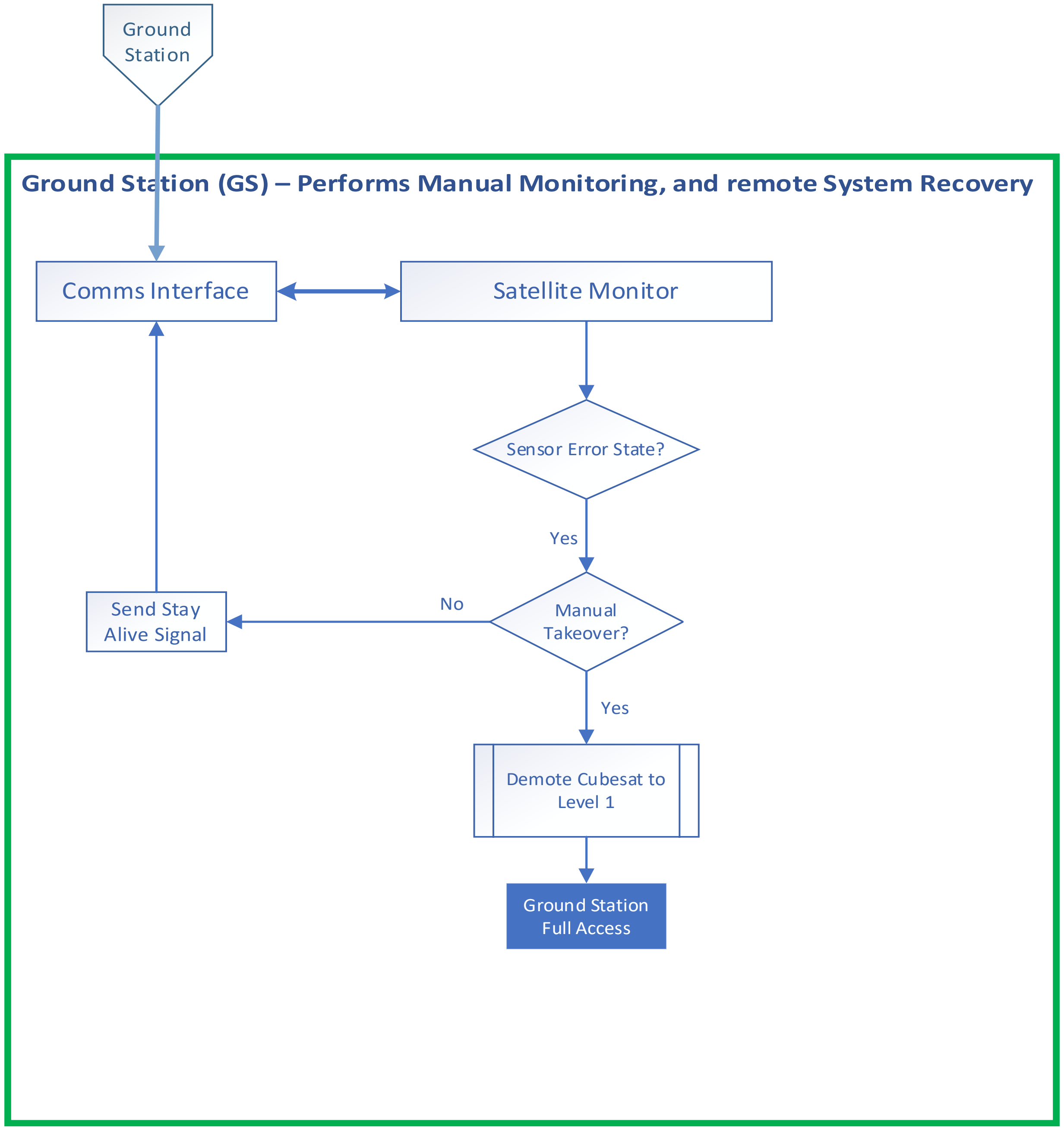
Cubesat Autonomic Capability Model Level 3

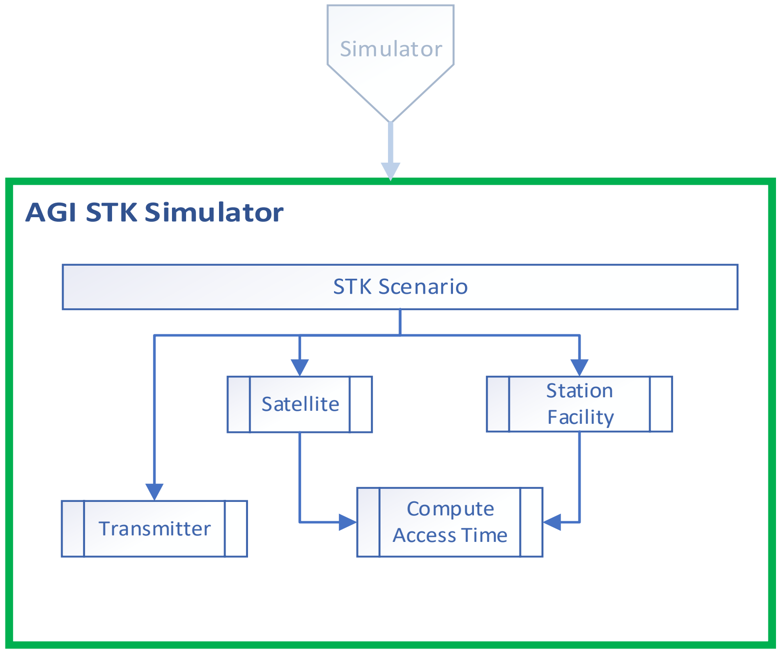


Exemplar Kill Switch application at CACM Level 3.

This is the highest level a single cubesat can implement.

Kill Switch – Exemplar Application





Exemplar Kill Switch application at CACM Level 3.

The Ground Station part is optional, only used as and when necessary

Summary

- Reviewed:
  - Autonomic Computing – defined by IBM in 2001
  - ALFUS Model
  - Autonomy in the automotive industry
  - CMMI
- Proposed and presented a brief summary of an autonomic capability model geared towards advancing cubesats and their functionality
- Further development of the CACM is being carried out in conjunction with developing an exemplar application.
- Exemplar application will be a feedback mechanism to improve the CACM

Can you help this PhD Study and give feedback?

- Please go to:
- https://www.surveymonkey.com/r/G8XH6RJ
- https://gama-c.wixsite.com/smartsats/intro
- MANY THANKS.