Autonomic Computing for Autonomous Vehicles

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Autonomic Computing Systemization of Knowledge Session

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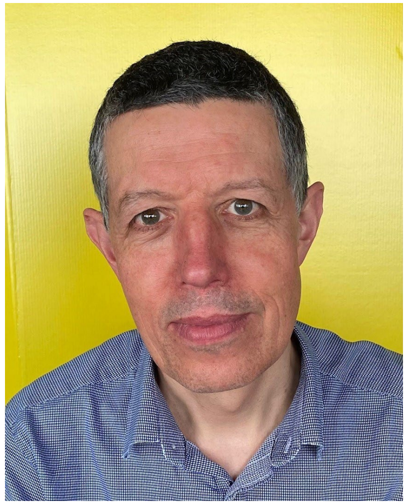
- MSc A.I. Candidate at Ulster University
- Autonomic Computing interest from MSc A.I. module: COM760 Autonomic Computing and Robotics

- I've worked in software for the last 36 years, as a developer, designer and architect. Prior to that I got a BA in Electrical Engineering and Information Science from Cambridge University.

- I'm a keen cyclist, and I guess my interest in Autonomous Vehicles might come from a desire to make the roads safer for all users!



Introduction – Autonomous Vehicles (AV)

By 2016, the Society of Automotive Engineers (SAE International) had defined a 6-level scale of automation, known as SAE J3016 [].

Level 0 – No automation. The driver is responsible for being aware of the environment, and for all driving tasks on a continuous basis. Some warning and emergency assist systems do fall into this category, e.g., park distance control, and anti-lock brakes.

Level 1 – Driver assistance. Some tasks involving speed and steering are executed by the car, e.g., Adaptive Cruise Control (ACC) and Lane Keeping Assist (LKA). But the driver is responsible for all other aspects of driving.

Level 2 – Partial Automation. The driver can "take their hands of the wheel" for some operations, e.g., Advanced automatic parking and Traffic Jam Assist. But the driver must still activate and deactivate the systems, and must monitor the environment at all times and be prepared to take full control at any point.

Level 3 – Conditional Automation. The AV can manage all aspects of driving and safety in some circumstances, e.g., "Highway Chauffeur". The driver does not need to constantly monitor the driving tasks, but does need to be able to take over control at short notice if conditions require it.

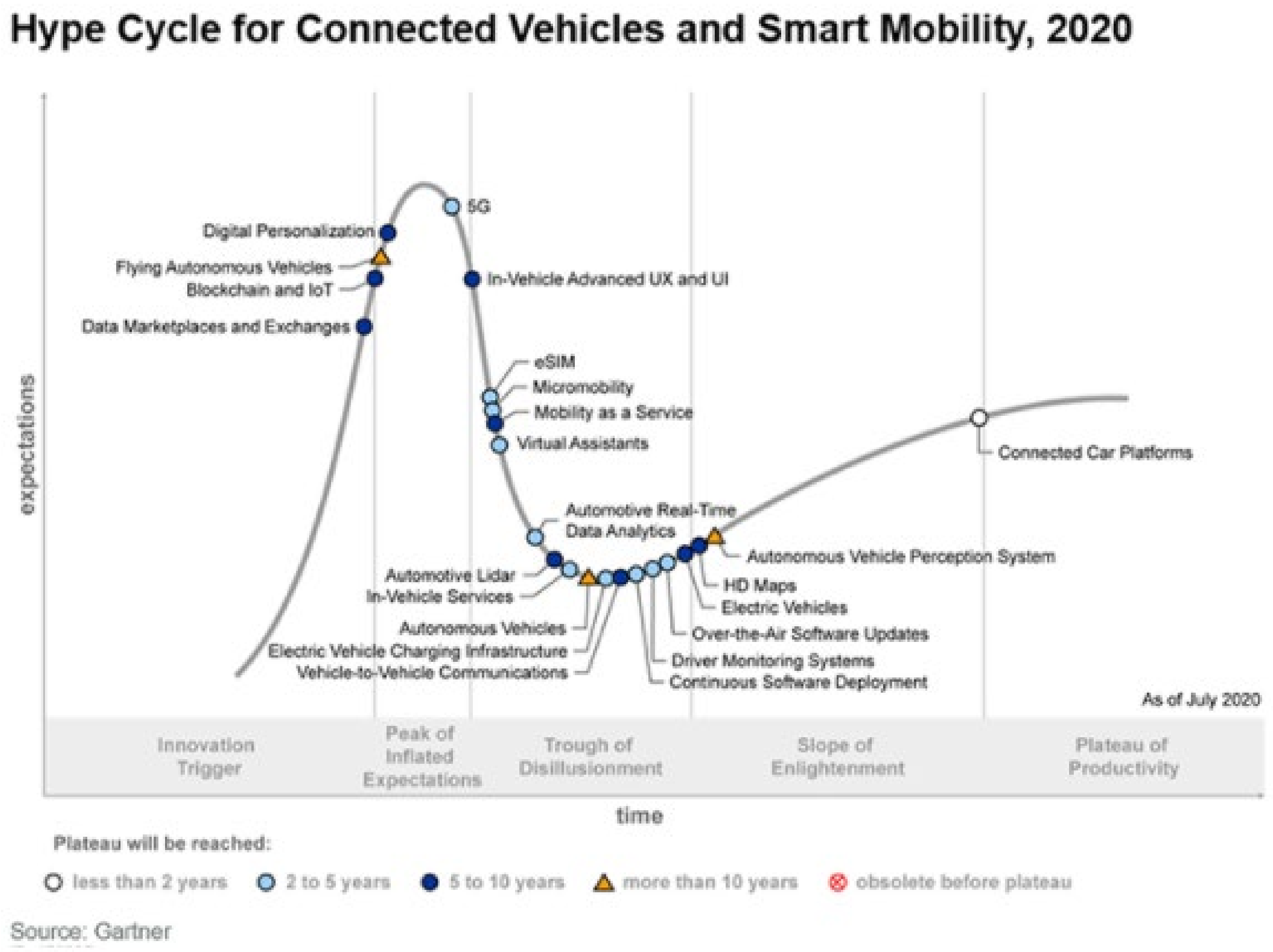
Level 4 – High Automation. Similar to Level 3, but doesn't need the human driver to provide a fall back because the AV can slow or safely stop if necessary.

Level 5 – Full Automation. The AV is capable of performing all driving tasks in all conditions. A human driver does not need to be present.

[] SAE, "J3016C: Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles", Society Automotive Engineers International (sae.org), 2021. [retrieved Oct. 2023]

Autonomous Vehicles (AV)

Cars at level 1 are now widely available. Cars with level 2 capabilities are also on sale, although some functionality may be disabled depending on local regulations – it can be switched on via “over the air update”. Vehicles with higher levels of autonomous behaviour are still in development. The latest Gartner hype cycle for Connected Vehicles and Smart Mobility (see Figure) shows many of the key enabling technologies are in the trough of disillusionment. The SAE [1] is upbeat about this, suggesting it means that “the hard work of commercializing many significant technologies is underway. Over the next five years or so, many technologies on this Hype Cycle will become productive parts of the automotive and smart-mobility ecosystem”[2].



[1] SAE, “J3016C: Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles”, Society Automotive Engineers International (sae.org), 2021. [retrieved Oct. 2023]
[2] B. Visnic, “2020 Gartner Hype Cycle for Connected Vehicles and Smart Mobility”, Society Automotive Engineers International, (sae.org), 2020. [retrieved Oct. 2023]

Introduction - Autonomic Computing (AC)

The goals of AC are to reduce the costs of managing and maintaining complex systems, and reducing the likelihood and impact of faults and issues.

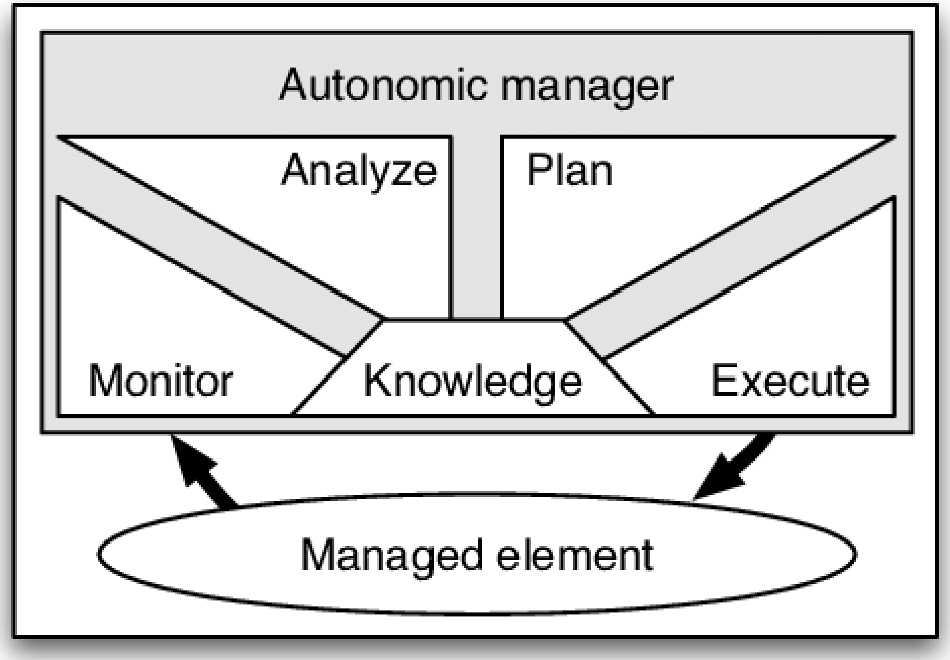
“Self-managing” is often split into four autonomic system objectives [] –

Self-configuration – the system re-adjusts itself to support a change in circumstances or new objectives.

Self-Healing – the system can recover automatically when a fault occurs, or proactively avoid health problems.

Self-Optimisation – the system can measure current performance, adjust to improve and react to policy changes.

Self-Protection – the system can defend itself against accidental or malicious attacks, is aware of threats and can defend itself against them.

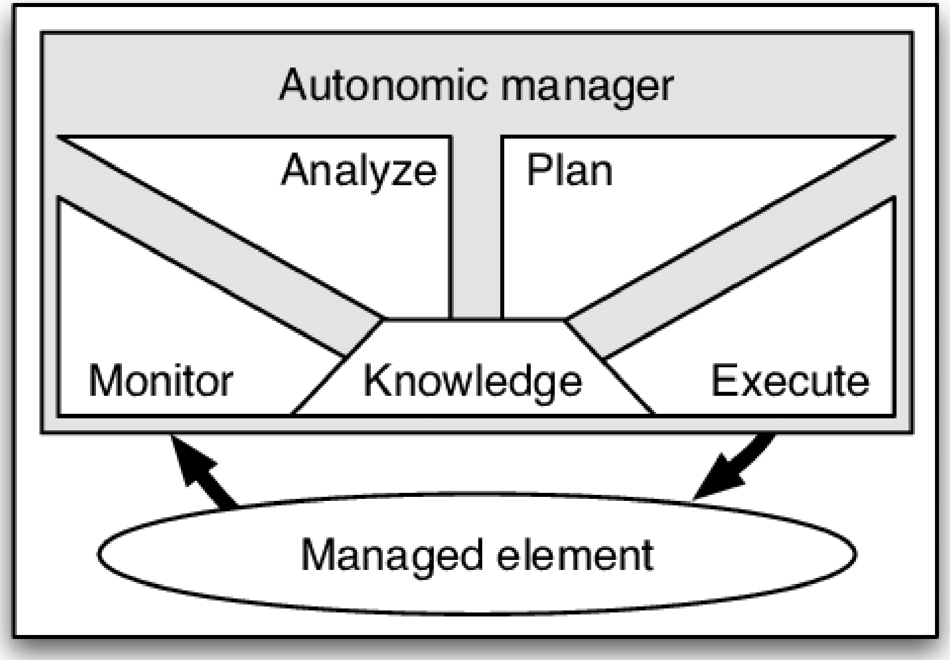


[] M. G. Hinchey and R. Sterritt, “Self-managing software”, IEEE Computer, 39(2), pp107-109, 2006. https://doi.org/10.1109/MC.2006.69

Autonomic Computing

To achieve these objectives, an AC system needs to be self-aware, aware of its environment, and have the ability to monitor and adjust. An AC system, and in particular the policies that drive monitoring and adjustment, can be designed and built, or can learn and adapt using AI.

IBM did some of the initial work on AC. In 2003, they proposed the idea of an autonomic element, consisting of a managed element and an autonomic manager [], see Figure. The autonomic element runs a continuous control loop that Monitors the managed element via sensors and Analyses, Plans and Executes updates based on Knowledge about the element. This is known as MAPE-K.



[] J. O. Kephart and D. M. Chess, "The vision of autonomic computing", IEEE Computer, 36(1), pp. 41–50, 2003.

Current State of the AV Tech

An Autonomous Vehicle architecture is made up of three functional blocks [1]:

Data Acquisition. This can be through sensors like RADAR, LIDAR and camera, and via communication with other cars or the internet.

Data processing. This takes in the data and uses it for situational and environmental awareness. It then merges that with navigation and path planning logic to determine the next actions to take.

Actuation. Carry out the actions to ensure a safe and smooth journey.

There are two basic architectural approaches [2] –

Centralised System Architecture, where the sensors and data inputs feed into a single computation unit, which in turn drives the actuators.

Distributed System Architecture, where functional subcomponents of the overall system are implemented in separate local units, and are connected using a shared communications bus.

[1] R. Hussain and S. Zeadally, "Autonomous Cars: Research Results, Issues, and Future Challenges", IEEE Communications Surveys & Tutorials, 21(2), pp. 1275-1313, 2019, doi:10.1109/COMST.2018.2869360.
[2] K. Jo, J. Kim, D. Kim, C. Jang, and M. Sunwoo, "Development of Autonomous Car—Part I: Distributed System Architecture and Development Process," IEEE Transactions on Industrial Electronics, 61(12), pp. 7131-7140, Dec. 2014, doi:10.1109/TIE.2014.2321342.

Current State of the AV Tech

In spite of rapid progress, and broad consensus on the best architecture, numerous challenges still need to be overcome before AVs will be ready for commercial roll out. These include –

Software reliability. A recent Which? report [] found that electric car manufacturer Tesla – a major AV innovator – was the least reliable car brand in the UK in 2021. And most of the faults reported were "software problems" and not problems with the electric motors or batteries. This suggests that major improvements in the design, implementation and operation of vehicle software systems will be needed before more complex, safety critical AV solutions can be launched.

Interpretable and Verifiably Safe solutions. AVs must be safe and efficient. Rule based systems, designed manually by humans, are explainable and testable, but tend to behave overly cautiously. On the other hand, solutions based on machine learning often give better results but are hard to explain and do not offer any formal safety guarantees.

Reliability of Communications. AVs require fast and reliable communications, and will place large and unique demands on the emerging 5G network.

Legal and regulatory issues. Some countries and states allow limited testing of AVs on the public road, but the wider legal and regulatory framework for public use of AVs still needs to be sorted out. In particular, insurance and legal liability in the case of accidents remain difficult areas.

[] J.Loughran, "Electric vehicle reliability survey paints bad picture for Tesla owners", E&T Magazine (theiet.org), Engineering & Technology, 3 March 2022.

Current State of the AV Tech

Data Privacy. AVs collect huge amounts of data about their own vehicle and other road users, and this can lead to complex ethical issues. Two examples highlighted in [1] are –

- If an AV detects another car that is owned by a driver that the insurance company knows has had multiple accidents, should the AV take an alternative route to avoid the risky car?
- If an AV detects another car performing a dangerous or illegal manoeuvre, should it report it to the police? Or to their insurance company?

These issues need more debate, and potentially some sort of industry wide ethical framework, to resolve.

Public perception. AVs are already much safer than human controlled cars in terms of accidents per million kilometres driven. But there have been some high profile incidents that have dented public confidence in computer based solutions. These include one in 2016, when a Tesla in automatic mode crashed into a truck killing the driver, and one in 2018, when an Uber autonomous car hit and killed a pedestrian [2].

[1] R. Zallone, "Artificial Intelligence vs Autonomous Cars vs General Data Protection Regulation", 2020 AEIT International Conference of Electrical and Electronic Technologies for Automotive (AEIT AUTOMOTIVE), 2020. Doi:10.23919/AEITAUTOMOTIVE50086.2020.9307410.[2] K. Jo, J. Kim, D. Kim, C. Jang, and M. Sunwoo, "Development of Autonomous Car—Part I: Distributed System Architecture and Development Process," IEEE Transactions on Industrial Electronics, 61(12), pp. 7131-7140, Dec. 2014, doi:10.1109/TIE.2014.2321342.
[2] D. Wakabayashi, "Uber's Self-Driving Cars Were Struggling before Arizona Crash." The New York Times, 23 Mar. 2018, www.nytimes.com/2018/03/23/technology/uber-self-driving-cars-arizona.html [retrieved Oct. 2023]

Future: Applying AC Principles to AVs

The similarities between AV technology and AC are striking. At the core of both is the need to collect data on their environment, interpret that data and then plan and take appropriate action. Both have evolved towards a distributed architecture, and to using AI to improve the analyzing and planning stages of the process. And both have worked to balance the potential of machine learning against the need for explainable and verifiable solutions. It therefore makes sense that AC should be at the core of AV design, and that AVs should look to AC for ideas and inspiration.

The following outline some future AV trends and possible areas where AC principles could add value.

Internet of Things

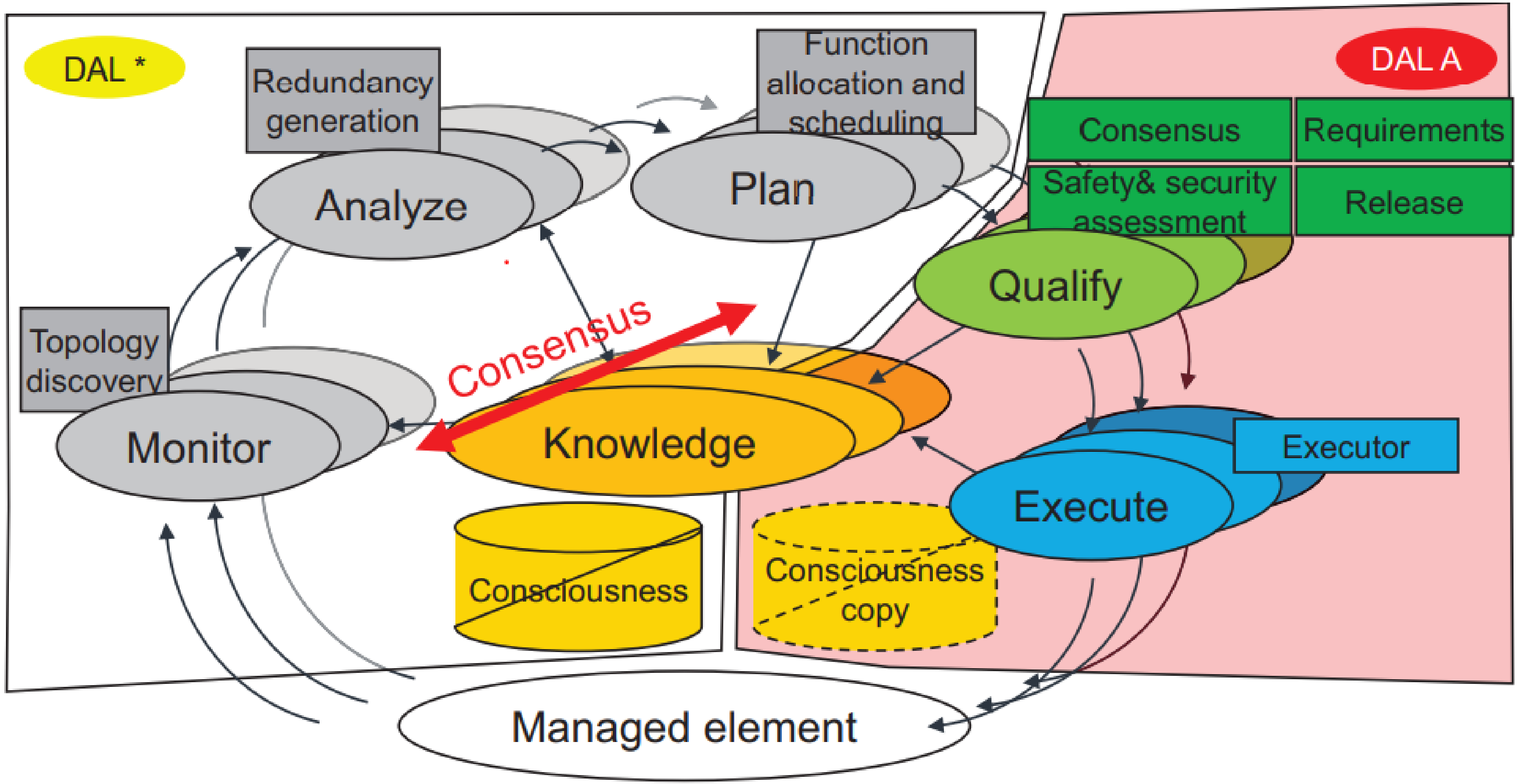
5G Mobile Communications

Safety Critical Engineering and MAPQE-K

Reinforcement Learning

***Other areas inc.* Swarm intelligence**

Future: Applying AC Principles to AVs



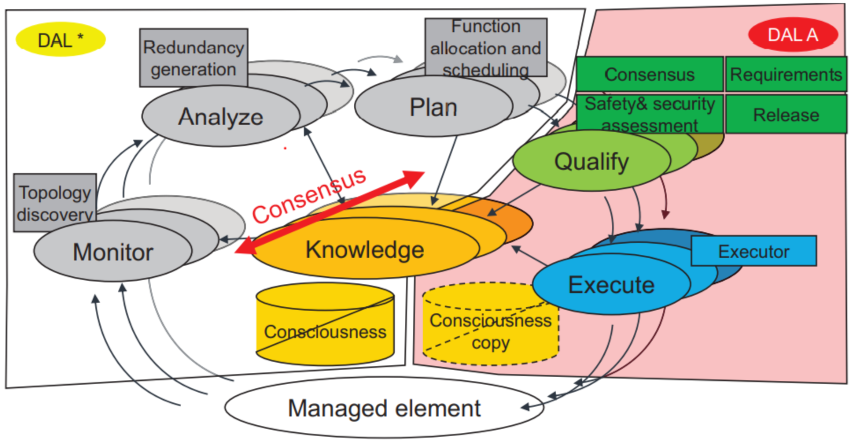
MAP-QE-K with DALs (from [])

[] B. Annighoefer, J. Reinhart, M. Brunner, and B. Schulz, "The Concept of an Autonomic Avionics Platform and the Resulting Software Engineering Challenges", 2021 International Symposium on Software Engineering for Adaptive and Self-Managing Systems (SEAMS), 2021, pp. 179-185, doi:10.1109/SEAMS51251.2021.00031.

Future: Applying AC Principles to AVs

There is a view that Autonomic Computing is not an entirely new concept, but is related to existing concepts like dependability, and builds on existing engineering principles like fault tolerance and safety critical systems standards and design [1].

Safety and dependability are critical considerations in the aircraft industry, and the increasing complexity of aircraft suggests that the self.* properties of AC could be desirable in avionics software platforms. But the rigid aircraft certification processes, and the current requirements for static and pre-determined behaviour, are at odds with the flexible, adaptive nature of AC.



MAP-QE-K with DALs (from [2])

One paper [2] proposes a novel architecture that modifies the typical AC MAPE-K approach by adding in a “Qualifier” step – creating MAP-QE-K. Safety critical aircraft systems are based on Design Assurance Levels (DAL). The proposal is that the M, A and P steps could be low level DAL, but the new Qualifier step along with (E)xecute would be high level DAL, and would act as a robust gatekeeper for any changes being carried out on the managed element. By isolating the complex MAP stages in a low DAL partition, with only the simpler Q and E steps requiring high DAL, it is hoped that an acceptable solution could be reached. The updated architecture is outlined in Figure.

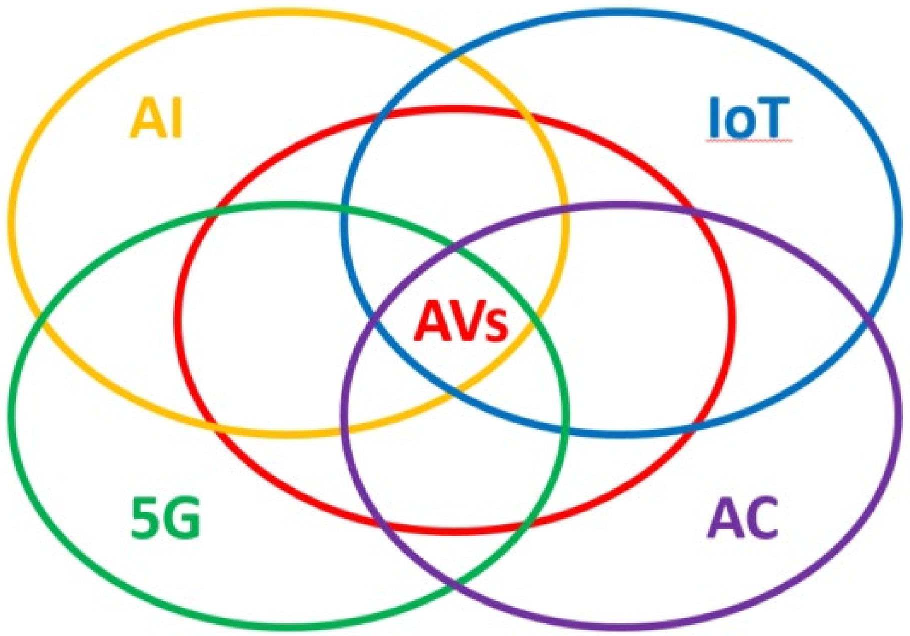
[1] R. Sterritt and M. Hinchey, "Autonomicity - an antidote for complexity?", 2005 IEEE Computational Systems Bioinformatics Conference - Workshops (CSBW'05), 2005, pp. 283-291, doi: 10.1109/CSBW.2005.28.
[2] B. Annighoefer, J. Reinhart, M. Brunner, and B. Schulz, "The Concept of an Autonomic Avionics Platform and the Resulting Software Engineering Challenges", 2021 International Symposium on Software Engineering for Adaptive and Self-Managing Systems (SEAMS), 2021, pp. 179-185, doi:10.1109/SEAMS51251.2021.00031.

Conclusion and Discussion

Autonomous Vehicle technology is hugely complex and ambitious, but there are big potential rewards in terms of safety, business opportunities and better customer experiences.

There is a lot of overlap between AVs and other big technical areas, particularly Artificial Intelligence (AI), Internet of Things (IoT) and Fifth Generation Mobile Networks (5G). To this list we should add Autonomous & Autonomic Computing (Figure).

This paper has outlined the current state of AVs and some of the challenges that still need to be overcome before AVs are ready for "prime time". These include technical, ethical and legal challenges. The paper has also highlighted the similarities and overlaps between AV technology and AC, and has identified several areas where AC techniques and practices could help address AV challenges (and in some cases there has already been progress). Many more examples exist, and more research and development are needed, but it is clear that AC principles will need to be a central part of AV technology if it is to be a success.



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Thank You

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