AI-4-GNC Airbus DS perspectives

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Current challenges and limitations of GNC and the Functional Avionics chain

Today…

Rosetta

Solar Orbiter

- ✓ Safely and robustly delivered on challenging missions
- ✓ Partial autonomy and decision-making (large cost driver)

JUICE

ExoMars rover

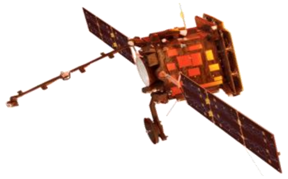
Tomorrow…

Smarter and cheaper (**S&C**)

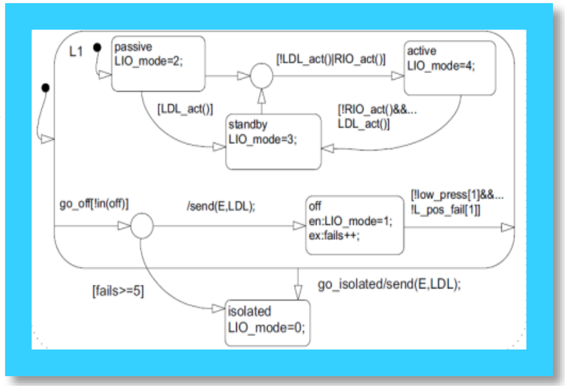
Autonomy (**AU**)

Increased complexity (**IC**)

Current challenges and limitations of GNC and the Functional Avionics chain



Controls systems/GNC



Model-based Knowledge-driven

Do not scale well with complexity…

Guidance, Control and Estimation techniques widely adopted in industry

- ✓ Solid mathematical foundation
- ✓ Widely Explainable and Verifiable (under constraints and hypothesis)
- ✓ Extensive tools for synthesis
- ✓ Backed by decades of use
- ❖ Largely relying on strong hypothesis (e.g. Linearity, time-invariance). **IC**
- ❖ Largely unable to adapt on-line **S&C**/**IC**/**AU**
- ❖ May require prohibitive comp. power **IC**
- ❖ Costly/Expensive **S&C**/**IC**/**AU**

New paradigms developed to overcome drawbacks (e.g. non-linearity or adaptation) yet limited adoption in industry

- ❖ Complexity and cost
- ❖ Computational power
- ❖ Need for models (not always possible)

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The promises of AI

In 1950…

Allan Turing proposes the Turing test

In the 1970s…

AI went through a severe winter

In 2014…

A chatbot called Eugene Goostman passes the Turing test

AI

"Some algorithm to enable computers to perform actions we define as requiring intelligence…"

Search Based Heuristic Optimization (A*)

Logic Programming (inductive logic programming, fuzzy logic)

Evolutionary computation (genetic algorithms)

Probabilistic Reasoning (Bayesian networks)

Machine Learning

Robotics

Computer Vision

Natural Language Processing

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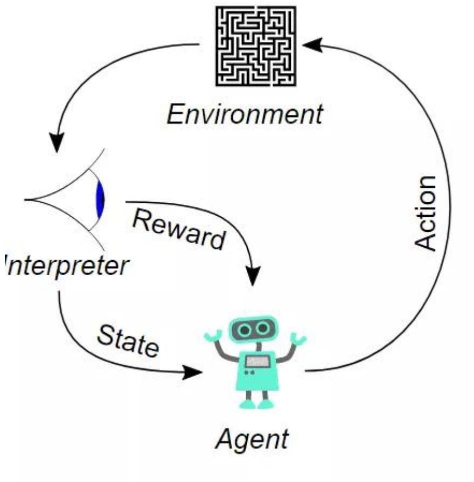
The promises of AI

AI => Machine Learning => (Mostly) Model-based =>

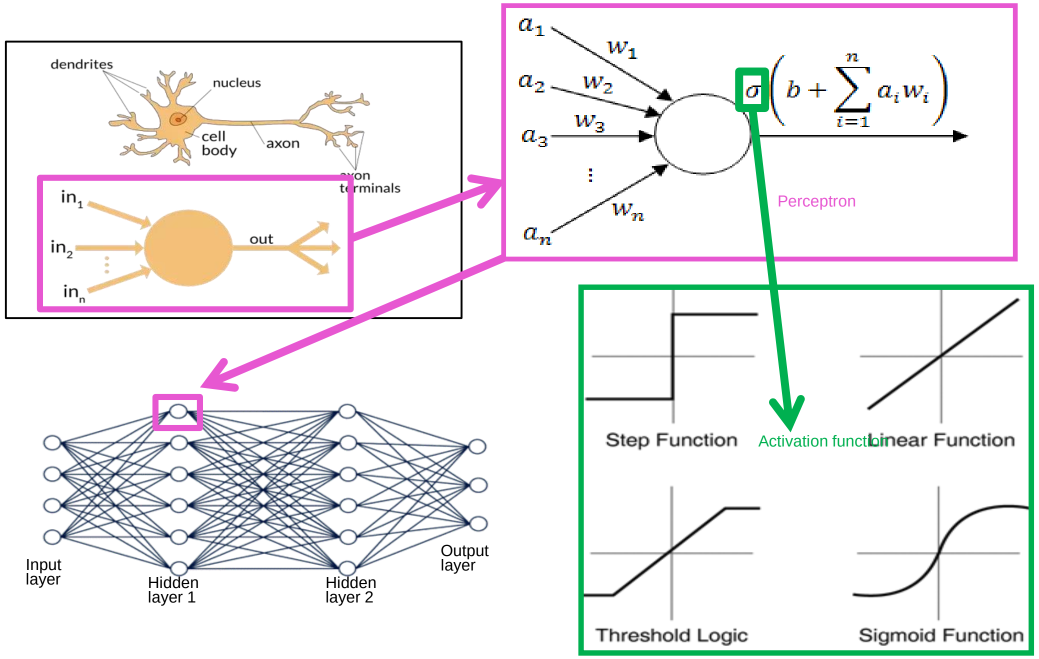
Supervised/Unsupervised
Reinforcement learning



"Machine learning is the field of study that gives computers the ability to learn without being explicitly programmed…" – Arthur Samuel. 1959

The "generic" model learns with data…

The great potential of ANNs as universal approximators…



Potential of Neural Nets:

- ✓ Handling of extremely complex and high dimensional data (e.g. VBN or Decision-Making)
- ✓ Cheaper development processes
- ✓ Efficiently design taking into account non-ideal behaviour
- ✓ Mission enabler (HW and/or SW)
- ✓ Scalable on-line learning and/or adaptation for performance
- ❖ Explainability and Verification
- ❖ Generalisation outside training envelope/robustness
- ❖ Embeddability (for some applications)

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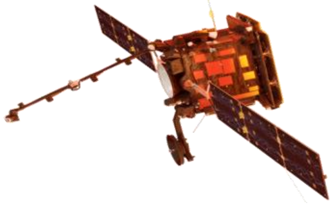
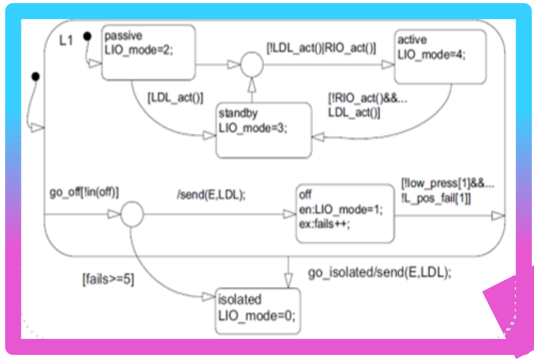
Merging the two worlds (1)



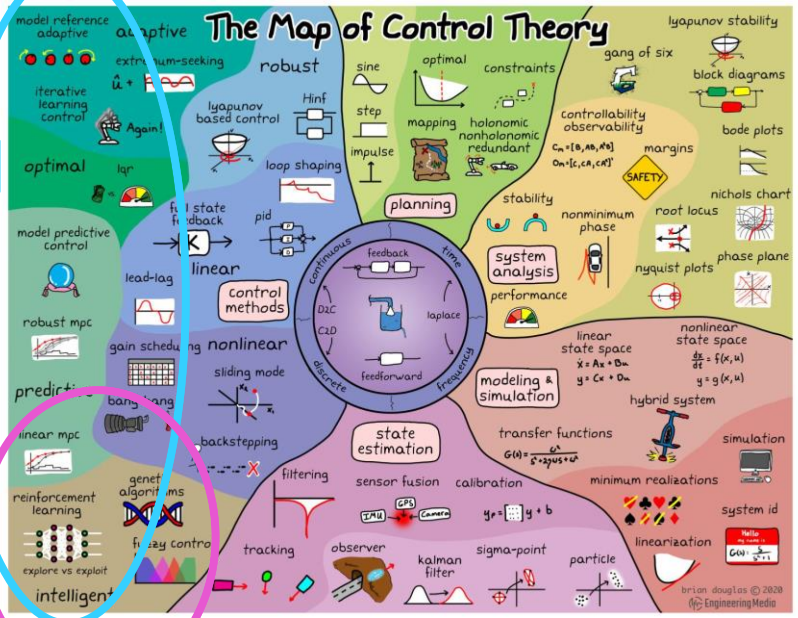
Controls systems/GNC



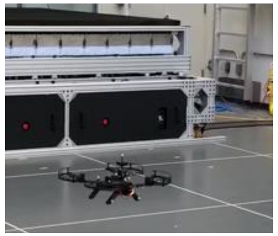
Model-based: Knowledge driven

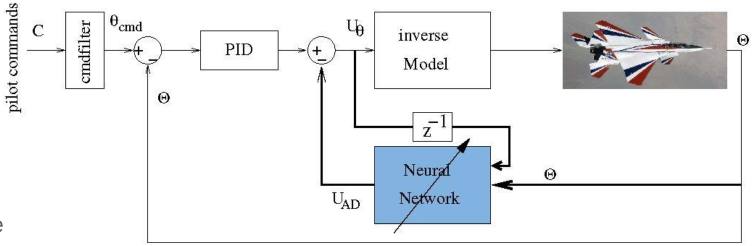
+

Data driven



Very few real life demonstrators





Only successful if…

- ✓ Generic
- ✓ Safe and Robust
- ✓ Efficient
- ✓ Verifiable solutions

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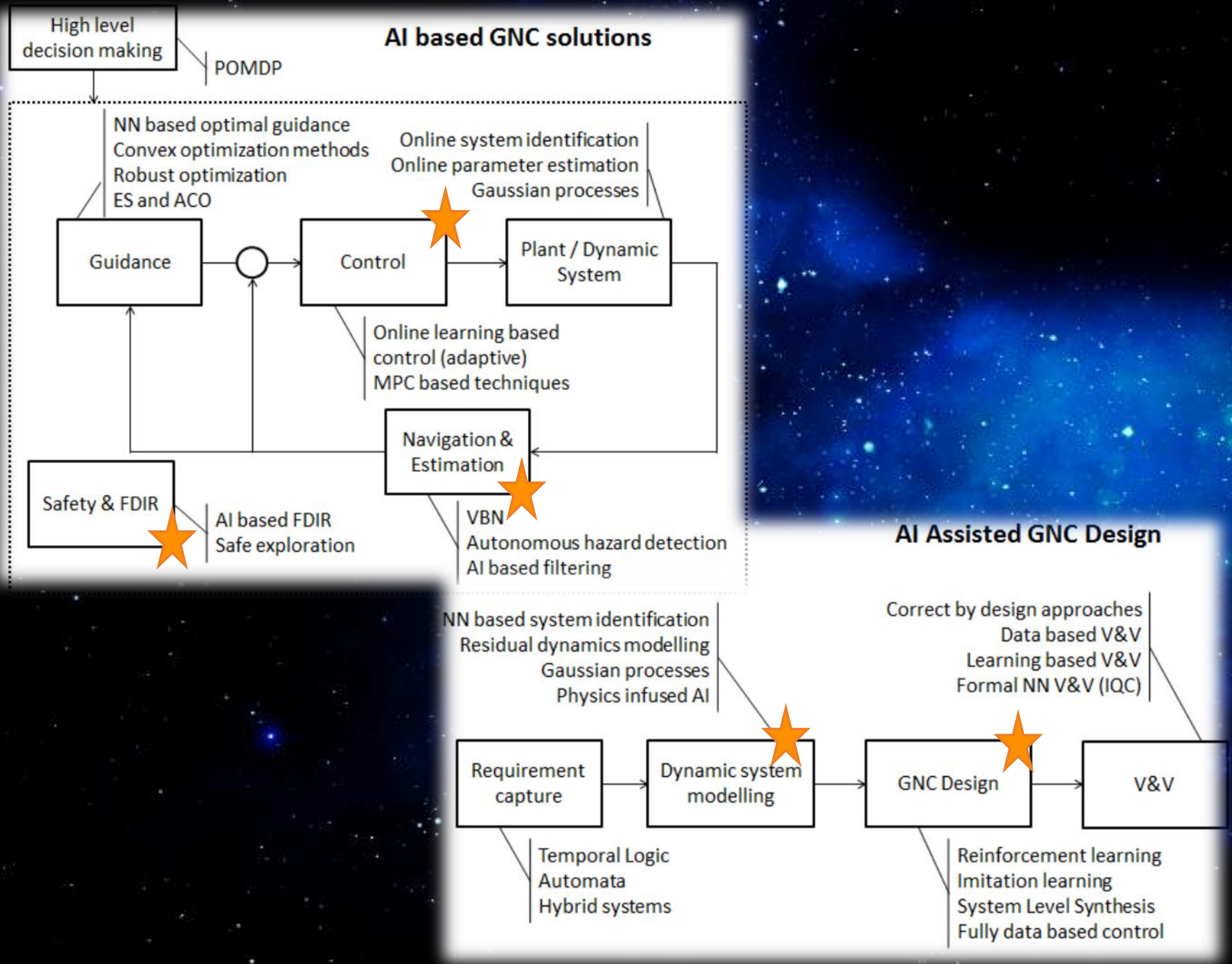
Merging the two worlds (2)



Tomorrow…

Smarter and cheaper (S&C)

Autonomy (AU)

Increased complexity (IC)

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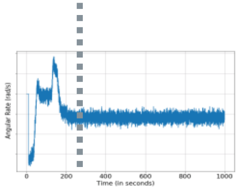
Current efforts…

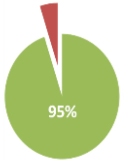
SMART-FDIR & Fly SMART-FDIR IOD

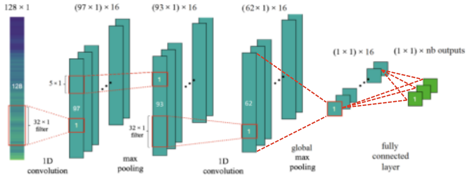
- **Objectives/Value:** Cheaper FDIR design + higher autonomy and availability of the spacecraft
- **Achievements:** In-house algorithm tailored for unsupervised anomaly detection + isolation. First go on embedding the NNs
- **Main conclusions: Increased** Some use cases may be embeddable in future HW (Leon4).

Supervised Learning for GYR-frozen use case in Telecommunication satellites

- **Objectives/Value**: Address classical FDIR design limitation on a “tricky” GYR failure mode
- **Achievements**: CNN trained as a very effective monitor with 95% detections and Zero false triggering
- **Main conclusions**: Supervised methods are very powerful for specific FDIR challenges

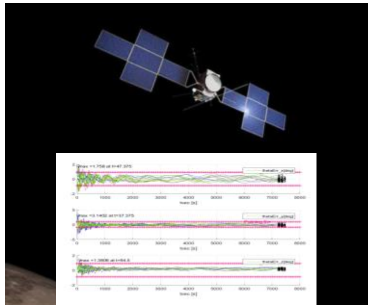


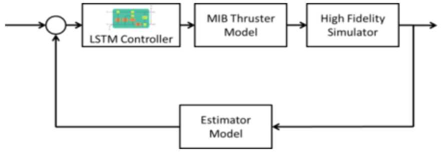




GNC-v.AI

- **Objective/Value:** Algorithms “learnt” by the NNs through interaction on the simulator. Cheaper algorithm design with potential performance improvement
- **Achievements**: First initiatives exploring RL as a GNC algorithm development approach. PG and ES techniques explored. GYM-like env. available
- **Main conclusions:** Domain randomisation successful in achieving robustness to different uncertainties. Unable to beat human design performance



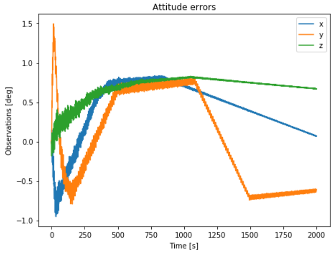


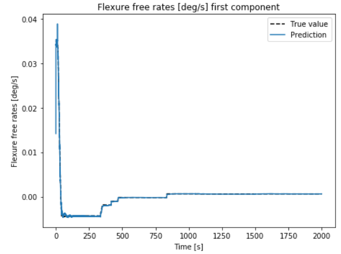
Extension of GNC-v.AI – Deep Estimation

Supervised learning for advanced estimation:
RNN based flexure-free angular rates estimation for highly flexible spacecraft (JUICE, SolO…).

$$\begin{bmatrix} \mathbf{v}^I \\ \omega^I \end{bmatrix}_{\mathbf{flex-free}} = \begin{pmatrix} \mathbf{m}\mathbf{I}_3 & 0 \\ 0 & \mathbf{J}_{\mathbf{CoM}} \end{pmatrix}^{-1} \begin{bmatrix} m\underline{v} + \Gamma\dot{\eta} \\ J\underline{\omega} + \delta\dot{\eta} \end{bmatrix}_{CoM}$$

- Classical solution (e.g. LKF or EKF) never attempted due to model complexity => so far only flexure filters are used
- Early results show **better accuracy than linear filters**





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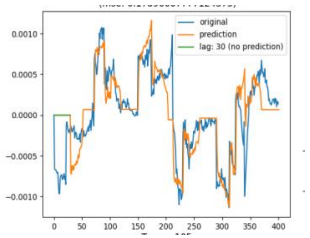
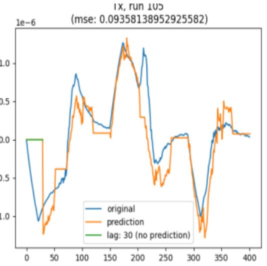
Current efforts…

Sloshing meta-Modelling

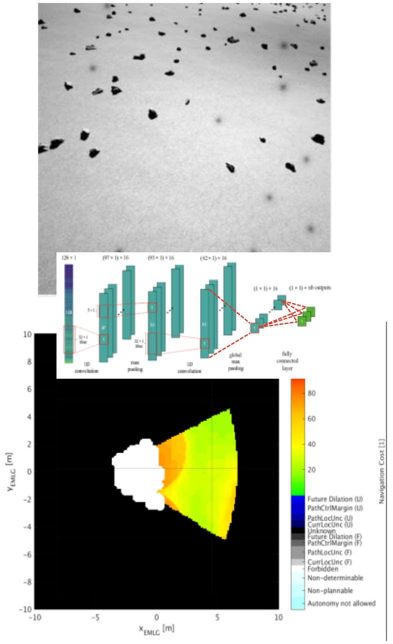
- **Objective/Value:** meta-model of the Sloshing phenomenon in the context of “agile” missions, in order to speed up verification and increase the pointing stability.
- **Achievements:** Promising open-loop predictions have been achieved. Best results encountered for the moment using time spanned MLP.
- **Conclusions/Issues:** Method good enough to capture/approximate fundamental behaviour in open loop. Close-loop validation ongoing





FARNAV

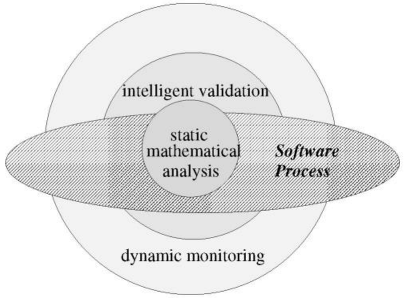
- **Objective/Value:** achieve Fast And Robust NAVigation maps against noise, motion blur or other camera defects for continuous drive. Leverage CNNs robustness to image artefacts and semantic extraction power to produce navigation maps significantly faster
- **Achievements:** Imitation learning/supervised framework setup and relevant dataset specification and generation process ongoing
- **Conclusion/Issues:** study just started



Study on Verification of AI for GNC

- **Objective/Value**: Start tackling the problem of verification of AI-augmented solutions in AOCS/GNC
- **Achievements**:
  - ➢ Reviewed V&V of AI applied to other engineering fields (automotive/aviation)
  - ➢ Reviewed V&V formal methods from control/formal verification
  - ➢ Reviewed V&V statistical/probabilistic methods
  - ➢ Reviewed metrics to quantify safety/robustness for AI

- **Conclusions (so far)**:
  - ➢ Significant efforts in V&V of AI can be leveraged from other fields
  - ➢ Both formal (with severe limitations) and statistical/probabilistic guarantees approaches exist
  - ➢ The techniques are still in their infancy, almost never used in industrial examples
  - ➢ Run time assurance is an interesting concept to



Multi-lyered V&V approach for AI-augmented systems

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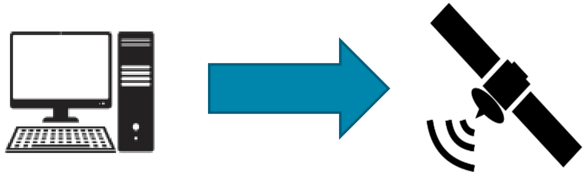
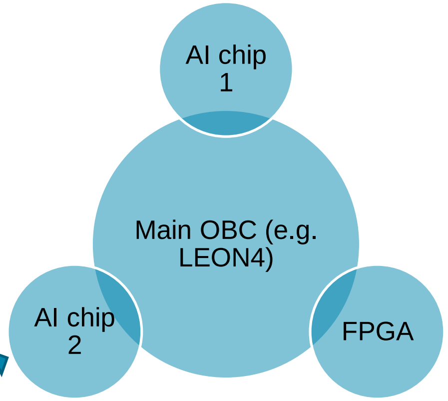
AI in the FA chain… Future challenges



Challenge: <u>Tensorflow Model representation → Specialised Space-grade HW executable representation</u>
Different "Edge" Inference HW options considered:

Device Type	Remarks
GPU	Primarily for cloud training. Not space-grade.
FPGA	Fast. Low power. Payload? Future?
Dedicated AI Chip	Fastest. Low power. Not space-grade. Payload? Future?
Traditional Microprocessor (e.g. SPARC LEONx)	Not ideal, but space-grade and **fastest path to flight for platform application**. "Safest" according to existing ECSS standards.
Combination of options above	More plausible long term solution.Traditional CPU with AI chips/FPGA co-processors

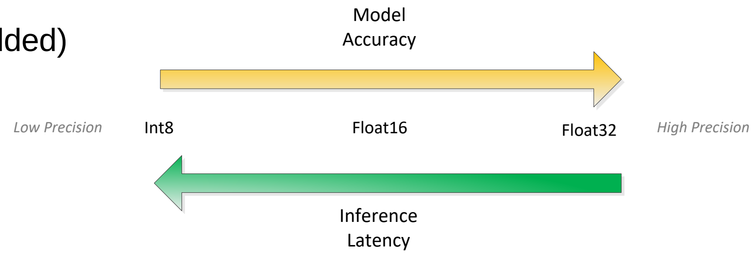


- **Important considerations for embedding DNNs:**

✓ Validation of <u>model conversion</u> (prototype == embedded)
  - After optimisation: Quantisation, Pruning

✓ Build/Integration: Compiling & Linking with OBS

✓ Software Budget:
  - Memory (~Millions of parameters)
  - CPU Latency (Inference time based on FLOPS/MIPS)



✓ Verification
  - Code metrics & Code complexity analysis
  - Unit testing (boundary, coverage, floating point robustness)

✓ Qualification & Licensing
  - 3rd party tools (maths library, conversion tool)

✓ Observability (trainable NN parameters as datapool parameters)

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Conclusions

Controls theory will be stretched to overcome its current limitations and deliver for the challenges of tomorrow

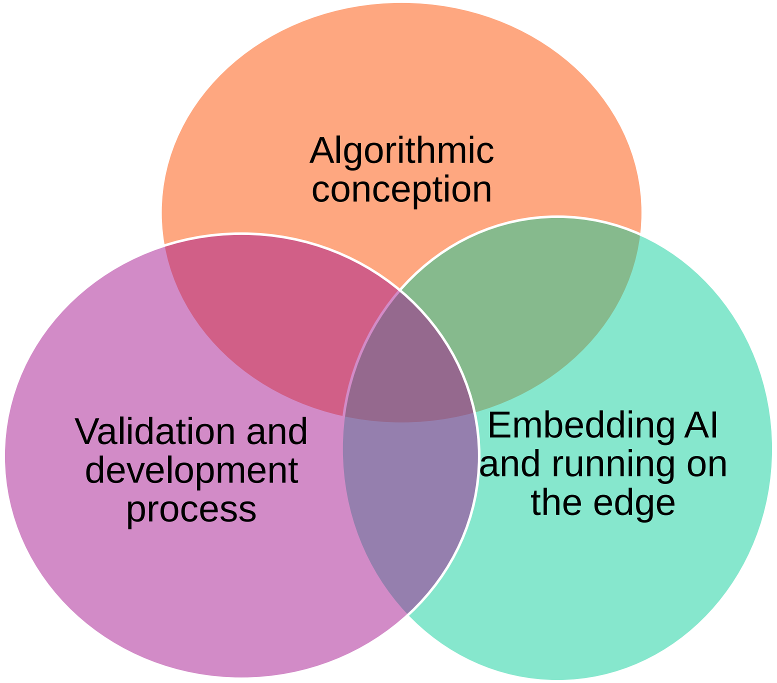
AI and in particular ML offers promising solutions to the above but…
It must remain compatible to current safety/robustness

First interesting Proofs of Concept developed with some further advanced
The Functional Avionics chain (e.g. SMART-FDIR). OBSW embedability
And SMART FA process outlined… but work to do!

The field of Controls/GNC shall and cannot walk alone in this adventure!
Algos + SW + HW intimately related. We need a truly FA joint effort!

In Orbit Demonstrators to play an important role in adoption of AI for
Technical and non-technical reasons

GAPs in current OB AI



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Thank you

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