SAFETY-CRITICAL HETEROGENEOUS COMPUTING FOR AEROSPACE

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PRINCIPAL INVESTIGATOR
NETWORKS AND EMBEDDED SYSTEMS
UTRC-IRELAND

MARCH 2020

United Technologies Research Center

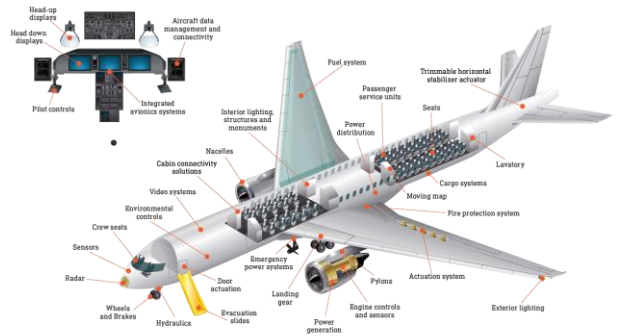
UNITED TECHNOLOGIES CORPORATION

AEROSPACE PORTFOLIO

Collins Aerospace
A United Technologies Company

NET SALES $23 BILLION*

* 2017 pro-forma



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Collins Aerospace

Pratt & Whitney
A United Technologies Company

NET SALES $16.2 BILLION

DOUBLE DIGIT REDUCTION IN FUEL CONSUMPTION

UP TO **75%** REDUCTION IN NOISE FOOTPRINT

UP TO **50%** REDUCTION IN NO_X EMISSIONS FROM CAEP/6

AIRCRAFT:
Airbus A320NEO
Airbus A220
Embraer E-Jets
Mitsubishi MRJ
Irkut MC21

PRATT & WHITNEY
GTF

Global Research

>600 Employees

89% Advanced Degrees

United Technologies Research Center

United Technologies Research Centre, Ireland
Established in 2010, included capabilities in Controls, Decision Support, Networks & Embedded Systems, System Modelling & Optimization, Power Electronics, and System Analysis & Assurance

Berkeley, CA
Established in 2009, focuses on cyber physical systems and embedded intelligence

East Hartford, CT
Founded in 1929, focuses on a broad range of system engineering, thermal, fluid, material, and informational sciences

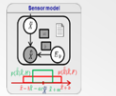
United Technologies Research Centre, Italy
Joined UTC in 2012, focuses on model-based design and embedded systems engineering.

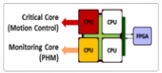
UTRC IRELAND

EUROPEAN HUB

Networks & Embedded Systems

- Hardware embedded systems
- IoT and communications systems
- Software systems
- Sensor technologies
- Autonomous systems



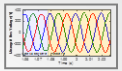



Control & Decision Support

- Model-based control design
- Optimization-based control
- Decentralized / distributed control
- Data analytics / machine learning
- Data- and physics-based diagnostics
- Computer vision

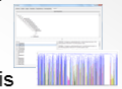
Power Electronics

- EMI modelling and filter design
- Power converter hardware design
- Distributed electrical systems
- Motor drives and converter controls
- HiL, Rapid control prototyping



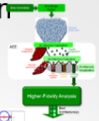

System Analysis & Assurance

- SW/HW Cyber-security
- Formal analysis and Verification
- Model based design of CPS
- Cyber-Physical Systems analysis and Co-simulation


System Modeling & Optimization

- Aircraft systems modeling
- Building systems modeling
- Design Exploration and Optimization
- Thermal modeling and simulation
- Constraint programming and discrete optimization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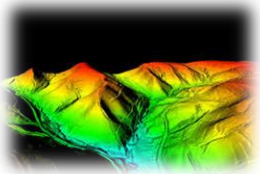
SAFETY CRITICAL APPLICATIONS AT UTC

UTC IS ONE OF THE LARGEST SUPPLIERS OF AEROSPACE SYSTEMS

- Safety-of-life operation is a critical technology differentiator in UTC.
- From Avionics to Engine PHM, Embedded Systems are a critical part of our products.

e.g. Vehicle Management Computer for rotorcraft, fixed-wing and UAS

- Will feature triple multi-core processors, high-speed communications and open architecture for use in high-redundancy flight critical applications.
- Higher processing capability will enable fly-by-wire and autonomous flight.



e.g. Situational awareness for autonomous operations

- Heavy use of image processing and sensor fusion for 3D environment reconstruction, obstacle detection, etc.
- More autonomy, more criticality!

e.g. Run-Time PHM of Engines

- Monitoring is critical.
- Instrumentation limited by physical constraints: space, temperature, etc.

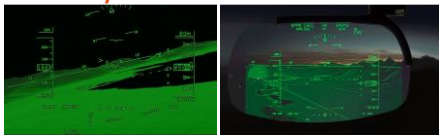
SAFETY CRITICAL & COMPUTING INTENSIVE

CERTIFIED

COLLINS AEROSPACE

https://www.collinsaerospace.com

Vision Systems



- Head Up Displays
- Head Worn Displays
- Helmet mount Displays

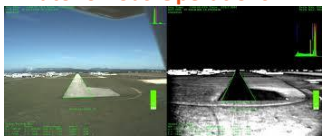
- Enhanced Vision Systems
- Synthetic Vision Systems
- Combined Vision Systems

Flight & Mission Controls

- Configurable FCC
- Fly-by-wire
- Auto-throttle

- Flight Control Computers
- Mission Computers
- Vehicle Management Computers

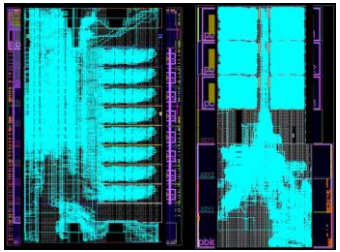
Autonomous Operations



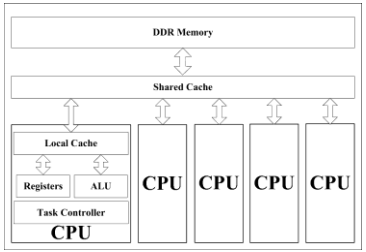
- Auto-Pilot
- Auto-Taxiing
- Auto-Landing

- Situational awareness
- Assured AI
- UAV Modes

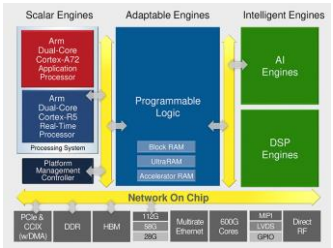
Embedded GPUs



FPGAs



Multicore Platforms



MPSoCs

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CURRENT SOLUTIONS FOR SAFETY-CRITICAL ES

SOLUTIONS ARE EITHER COTS-BASED OR DOMAIN SPECIFIC

- E.g. Vehicle Management Computer for rotorcraft, fixed-wing and UAS: 3 asymmetric commercial multicores, with different HALs.
- E.g. Motor Control Systems for actuation very frequently use dedicated Flash-based FPGAs with dedicated control architectures, redundant or not.
- E.g. Display controls include commercial GPUs and SoCs but the level of criticality is not maximum, if so, they are supported by co-processors like FPGAs.

but…

… for instance a standalone GPU performing a critical task is difficult… kernel co-scheduling?

… how do you ensure time determinism in a COTS multicore? How do you enforce it?

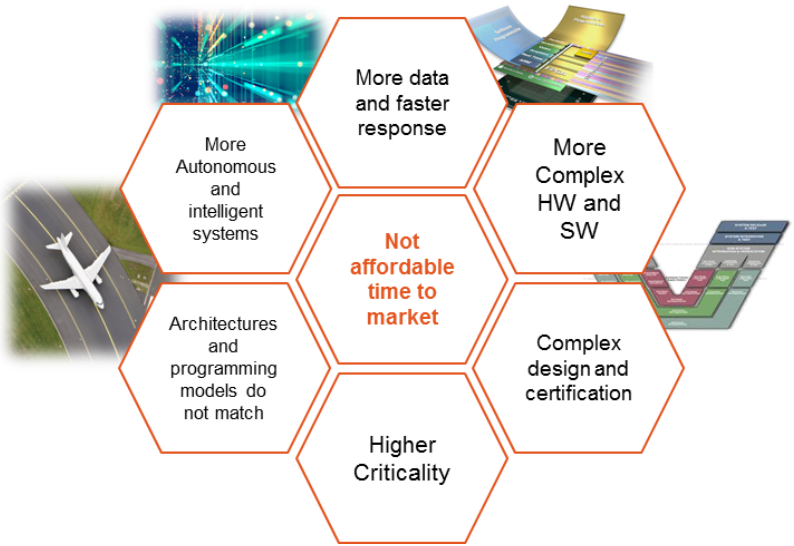
… how long does it take to fully design your system in an FPGA? Who does that?

… which is the best programing model for heterogeneous solutions?

… how can we decrease V&V overhead as complexity increases?

DIFFERENT PATHS

AUTONOMY BRINGS NEW CHALLENGES

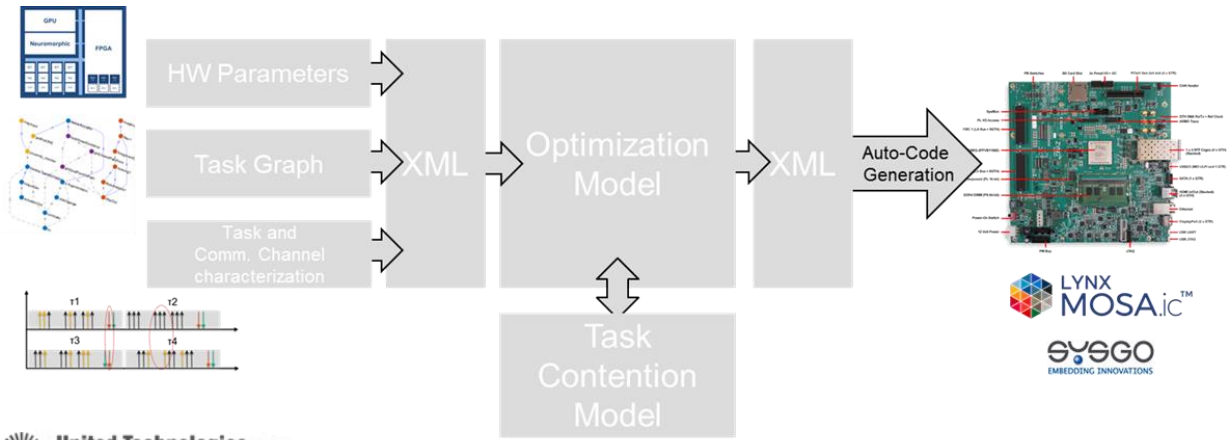


- Commercial of the Shelf (COTS):
  - Characterising platforms to allow certification
  - Enabling faster design iterations using MBD techniques
  - Enabling dynamic adaptability to overcome faults and attacks
- Custom Architectures:
  - RISC-V based architectures
  - Design methodologies and abstract languages
- Beyond Moore technology
  - Photonic Computing

ACCELERATING MULTICORE CERTIFICATION

COLLINS AEROSPACE ALREADY SUBMITTED MC ARTEFACTS TO FAA

- Timing analysis to bound **WCET** is extremely **difficult**.
- **Interference analysis** is very **time consuming** and offering certification guarantees is challenging.
- **Platform Usage Domains** limit platform **performance** enormously: hyper threading, cache disabling, etc.
- **SW architectures** tend to **replicate single core** operations in multicore platforms with huge performance losses.



MASTECS

Barcelona Supercomputing Center
Centro Nacional de Supercomputación

RAPITA SYSTEMS
A Bertrand COMPANY

MARELLI

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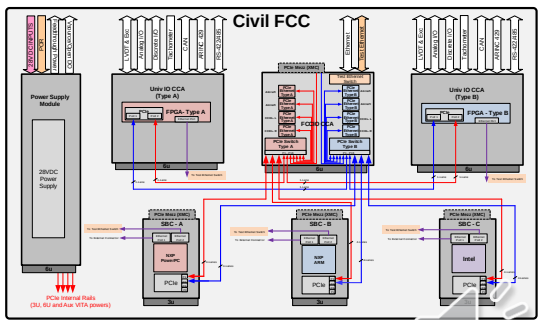
- Fast Track to innovation (FTI)
- **M**ulticore **A**nalysis **S**ervice and **T**ools for **E**mbedded **C**ritical **S**ystems



Civil Certified Vehicle Management Computer

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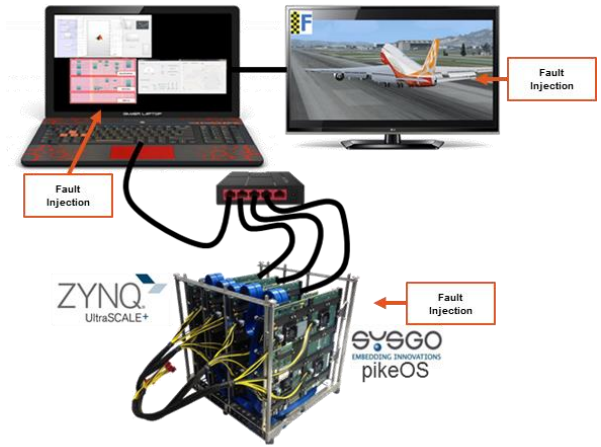
https://utcaerospacesystems.com/utc-aerospace-systems-developing-next-gen-vehicle-management-computer-to-support-autonomous-flight

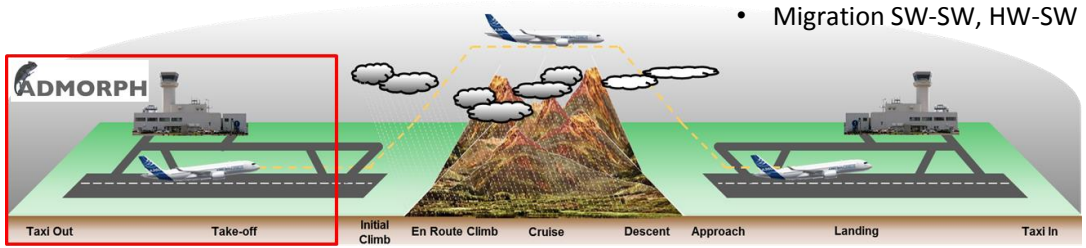
https://blogs.windriver.com/wind_river_blog/2019/12/first-ascent-field-updates-from-wind-river-and-collins-aerospace/

DYNAMICALLY MORPHING EMBEDDED SYSTEMS

OFFER ASSURANCE FOR DYNAMIC ADAPTABILITY IN AVIONICS SYSTEMS



- **Use Case:** Flight Management and braking control systems
- **Setup:** 3D Simulation environment, Matlab-Simulink and Hardware in the Loop.
- **Scenarios:** airport navigation and auto take off.
  - Emergency situation: e.g. rejected take off to stress controls and braking system.
  - Attacks: wrong information from ATC, obstacles, etc.
- **HW/SW adaptability:**
  - Vehicle Management Computer including several PCBs in rack fashion.
  - Multi-core + FPGA implementations
  - PCIe, Ethernet, etc.
  - Migration SW-SW, HW-SW

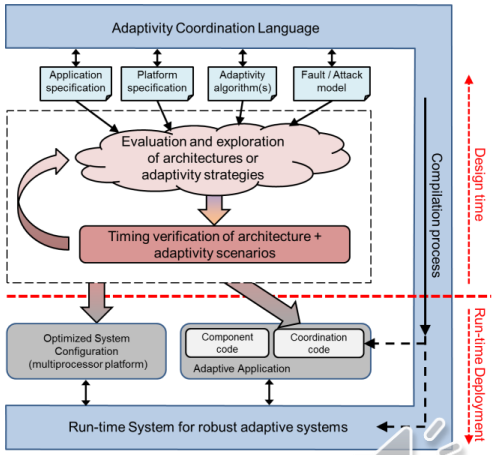


ADMORPH

Dynamically Morphing Embedded Systems (H2020-ICT-01)

Participant organization name	Country
Universiteit van Amsterdam	The Netherlands
Thales Nederland B.V.	The Netherlands
SYSGO AG	France
Université du Luxembourg	Luxembourg
Lund University	Sweden
United Technologies Research Center	Republic of Ireland
Q-media	Czech Republic
FCiências.ID	Portugal

http://admorph.eu/



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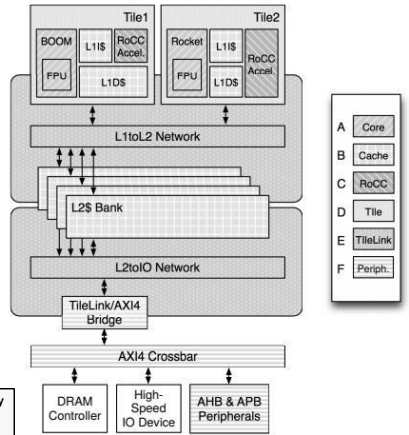
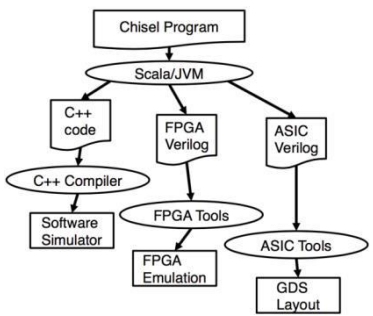
RISC-V BASED ARCHITECTURES

ARCHITECTURES FOR SAFETY-CRITICAL DOMAINS

- **Collins Aerospace** is a **Silver** Member of the **RISC-V Foundation**.
- **Verification** from the very beginning: **Formal** specs for RISC-V (**Kami**, **Sail**, etc.)
- Specifically tailored **instruction extensions**: IO, crypto, monitors, etc.
- **Safety** and **Security** enhancements: redundancies, anomaly detectors, SCA protection, etc.
- **Reusable** building blocks.
- **Customizable Performance Counters** for full observability.



Rocket Chip Generator (Berkeley)

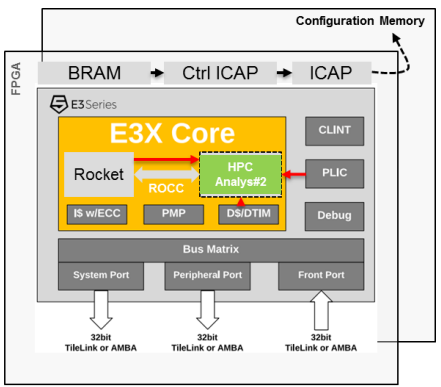


Toolchain Rocket Chip Generator and Chipyard

```
// app.c
Instruction #1
Instruction #2
Instruction #3
Instruction #4
Instruction #5
CUSTOMX() // returns HPC analysis
and launch reconfiguration
Instruction #6
Instruction #7
Instruction #8
CUSTOMX()
Instruction #9
Instruction #10
CUSTOMX()
```

Machine Hardware Performance Monitor Event Register	
Instruction Commit Events, mhpeventX[7:0] = 0	
Bits	Meaning
8	Exception taken
9	Integer load instruction retired
10	Integer store instruction retired
11	Atomic memory operation retired
12	System instruction retired
13	Integer arithmetic instruction retired
14	Conditional branch retired
15	JAL instruction retired
16	JALR instruction retired
17	Integer multiplication instruction retired
18	Integer division instruction retired
Microarchitectural Events , mhpeventX[7:0] = 1	
Bits	Meaning
8	Load-use interlock
9	Long-latency interlock
10	CSR read interlock
11	Instruction cache/ITIM busy
12	Data cache/DTIM busy
13	Branch direction misprediction
14	Branch/jump target misprediction
15	Pipeline flush from CSR write
16	Pipeline flush from other event
17	Integer multiplication interlock
Memory System Events, mhpeventX[7:0] = 2	
Bits	Meaning
8	Instruction cache miss
9	Memory-mapped I/O access

Hardware Performance Counter Registers



System Schematic

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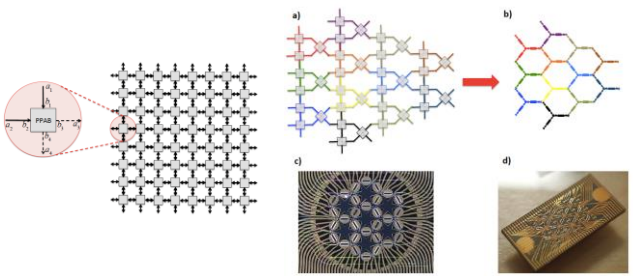
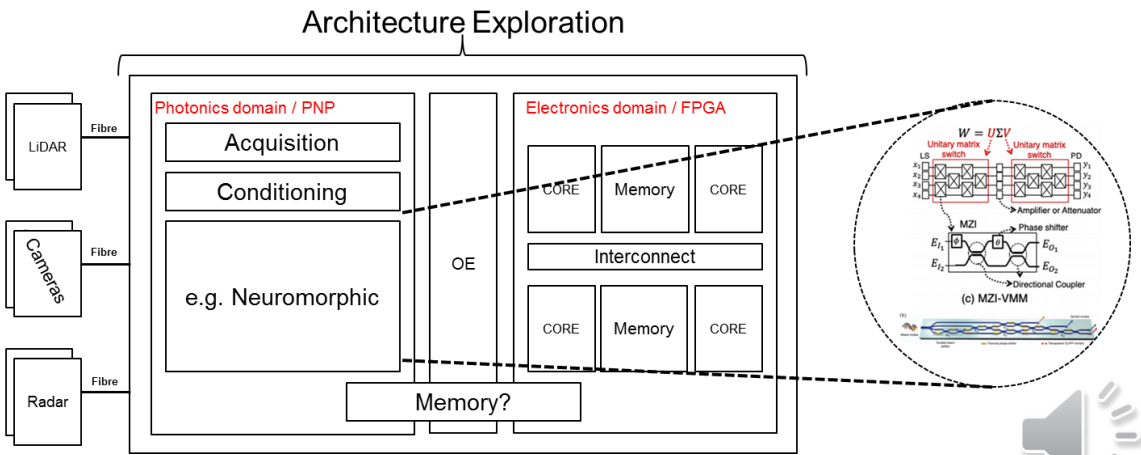
https://utcaerospacesystems.com/utc-aerospace-systems-developing-next-gen-vehicle-management-computer-to-support-autonomous-flight
https://blogs.windriver.com/wind_river_blog/2019/12/first-ascent-field-updates-from-wind-river-and-collins-aerospace/

PHOTONIC COMPUTING

TOWARDS MORE HYBRID PROCESSING ARCHITECTURES

- Prepare for **limitations in conventional electronics**. Death of Moore's Law, etc.
- Optical **sensing** and **communications** are **already used** in commercial products, a **more computing** approach is necessary.
- E.g. Programmable Nano-Photonic Processors (**PNPs**) and Field Programmable Photonic Arrays (**FPPAs**) are already a reality.
- It is proven that photonic circuits can improve **speed** and **energy** consumption although they currently have **limitations** in terms of **scalability and stability**.
- Execution paradigms can change if **photonic memories** or photonic links can be used to alter the **memory hierarchy limitations**.





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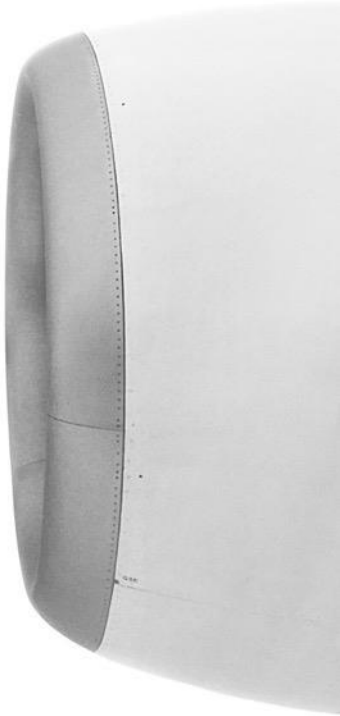
CONCLUSIONS

- **Embedded Systems** are **key** elements of most of our systems: need to **accelerate design**!
- **Certification** still very **expensive** and aerospace is very conservative.
- Aircrafts looking for more **autonomy**, require more intelligence at the edge…. but **assured intelligence**.
- More electric aircraft, fly by wire, WAIC, IMA architectures, run-time monitoring, etc. require **more and more SW for critical functionalities**.
- **COTS** or **custom** architectures?
- Complex **SoCs** are already here, but mostly relying on architectural **redundancies** to be part of critical systems, can we enable adaptability?
- What is **beyond** pure **electronics**?



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THANK YOU.

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valverj@utrc.utc.com

Networks & Embedded Systems,
UTRC Ireland