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MC2 Challenges for Mission Management of Unmanned Systems

An industry perspective

Second TCRTS Workshop on Certifiable Multicore Avionics and Automotive Systems (CMAAS)

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Motivation

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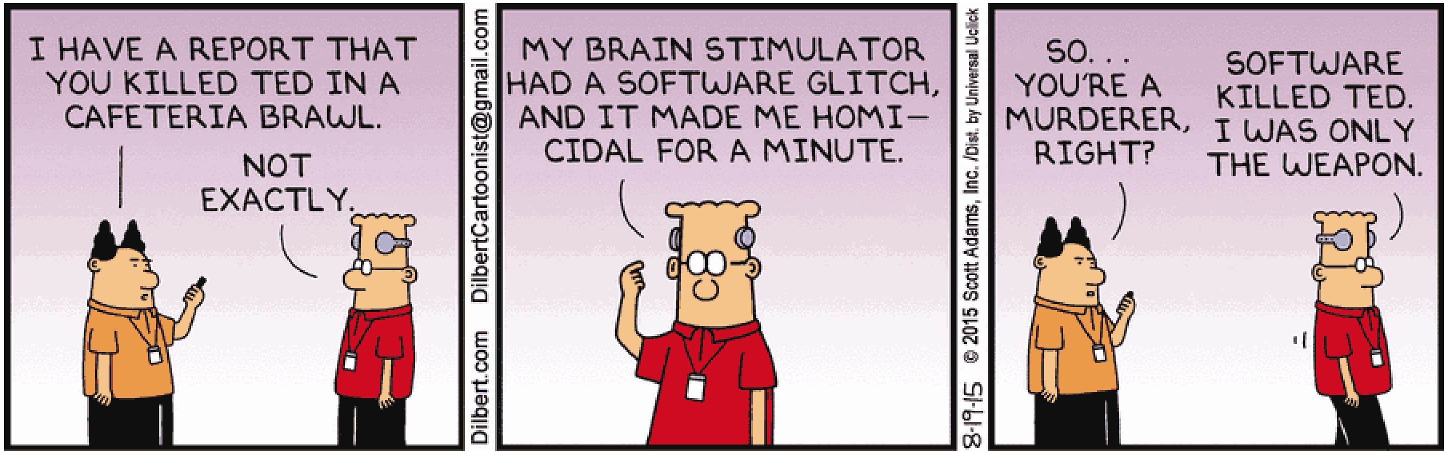
- Enhancing and Ensuring Safety (Behavior Assurance)
- Ensuring Affordability
- Managing Complexity
- {Avionics} + {DecisionCapability} + {Sensing} + {Actuation} $\Rightarrow$ **CPS**

Increasing Mission Complexity

Goal: Provide insights into CPS drivers for unmanned systems


I HAVE A REPORT THAT YOU KILLED TED IN A CAFETERIA BRAWL.
NOT EXACTLY.
MY BRAIN STIMULATOR HAD A SOFTWARE GLITCH, AND IT MADE ME HOMI-CIDAL FOR A MINUTE.
SO. . . YOU'RE A MURDERER, RIGHT?
SOFTWARE KILLED TED. I WAS ONLY THE WEAPON.
Dilbert.com DilbertCartoonist@gmail.com
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Autonomous Operations Challenges

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- Autonomy Spectrum
  - "A thrown stone is a perfectly autonomous system" (zero control response)
  - Manned fighter is also an autonomous system (lots of intelligent control!)
- Autonomy
  - is not a useful scale! (Flawed by definition), but is a vital system trait for UxVs
  - Better to think of autonomous operations in terms of req.s and design functions
  - Not inherently unsafe, just harder to understand and determine outcome
- Key Challenges
  - Mixed Initiative Transparency and Communications (Trust, Explanations)
  - Self-Assessment and Reflection (Oracles/Monitors)
  - Bounded Functional Characterization (?)

Frozen Double Shot Macchiato Skinny with no Ice…

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Role of Resiliency in Autonomous Operations

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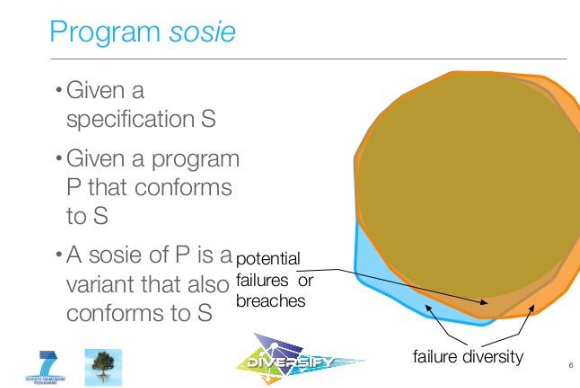
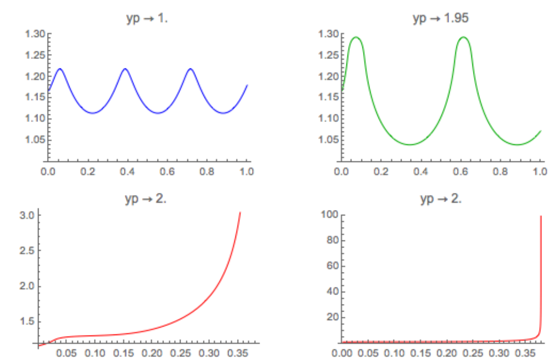
- Flexibility / Rigidity
- Stiff Systems
- Diversity
- Originality /Creativity





Resiliency Essential to be Mission Effective under off-nominal conditions

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Mission Drivers

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- Dynamic
  - Tasking changes throughout mission
  - Actors (Blue/Red) change as well
  - Environment is dynamic in that both the operating conditions and the relevant situation are continually subject to change.
- Uncertain
  - Integrity of sensed data is often very limited
  - Expectations of operating conditions is limited to short timescales
  - Blue and Red Actor (human) responses exhibit a high degree of uncertainty
- Adverse
  - In Theater operations have to contend with an active adversary
  - Some basic strategy and tactics will need to be modeled and extant as part of the unmanned system

Challenges of complex missions drive CPS capability set

Avionics Constraints

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- Embedded Processing is limited by SWAP and Flight qualification
  - Small number of embedded boards available that are flight qualified
  - Significant limitation on available processing power due to SWAP constraints
  - Additional constraints placed for special operating conditions such as Carrier (CV) Suitability (E3, Shock and Vibration)
- Architecture
  - Avionics Architecture subject to Interoperability standards such as FACE
  - Architecture is constrained by its integration (usually tight coupling) with other safety critical components (flight controls, navigation, stores)
  - This impacts memory, available data bus, physical interfaces
- Integration
  - Vertical integration often drives the form and function of the avionics processing trade space

Reliability and SWAP drive onboard processing requirements

Safety Challenges for UxV: 1…2…3…

1. Why is this hard?
   - Consensus on the right _safe_ behavior
   - No integrated tools/framework to establish assurance
   - Doing more -> More Autonomy -> More complexity

2. Why is this costly?
   - Current verification relies primarily on exhaustive testing ($$$)
   - Software complexity (combinatorial) $\propto$ Testing cost ($$$$)
   - Input Space $\otimes$ Decision Space $\otimes$ Output Space $\Rightarrow$ Infeasible Test Size

3. Why is this so murky?
   - No objective / functional framework for Safety Characterization
   - "Do no wrong" - Prove that UAV will avoid situations in which it cannot cope with or handle
   - Regulatory Uncertainty further complicates these issues

Safety is hard, but should you care?

Safety Drivers: Lifecycle Approach

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- What's out there?
  - Requirements Specification/Analysis/Validation Tools
  - Formal Methods: Model Checking, Reachability sets, syntactic parsing, automated case generation …
  - Design for safety: Composability contracts, stability/safety bounds, oracles, safety controllers, monitors …
  - Safety guidance for implementation (MILSTD882/JSSSEH/AOP52…), Simplex Architectures (multicore), adaptive scheduling
  - Verification Tool chains: coverage tools,

- What do we need?
  - Requirements/Arguments/Formalism
  - Design for safety certification guidance, models, sw constructs
  - Build/Implementation guidelines
  - Test/Verifications process, evidence collection
  - Making the certification case/licensure

A holistic approach to Safety demands resiliency

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Security Drivers

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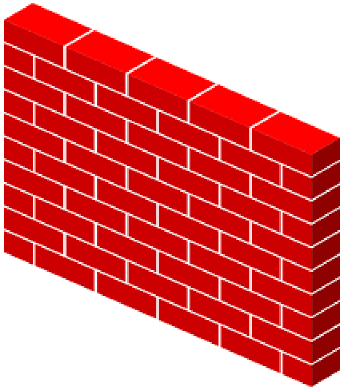
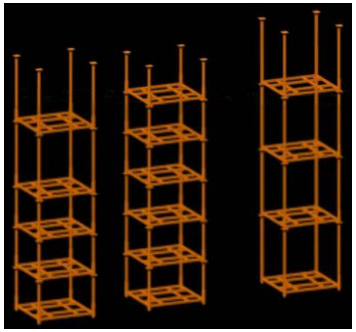
- Time and Space Partitioning (SWAP, Architecture)
- Multiple Enclaves (SWAP, Data availability)
- Virtualization/Partitions (Data movement constraints)
- Security Principal / Kernel (Latency, data movement)





Can't Live without it, Cannot live with it …

Affordability & Interoperability Desirements

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- Interoperability Standards
  - FACE, UCI, STANAG 4586, JAUS, IOPs
  - Cross-Domain Standards
  - Open Architecture – OASIS, RedHawk
  - Generalization of Data Models
- Affordability
  - Product Line approach + SOA
  - Common/Core Components + Variants/Custom Components
  - Open Business Model

Interoperability is desirable but hard to achieve for unmanned CPS

Unmanned Edge Cases of current relevance

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- Case 1: Loss of Communications
  - Latency, Bandwidth/Throughput, Reliability, Loss, Adverse Action
  - Knowing (detect/perceive), Planning(problem-solving), Doing(fuzzy-execution)
- Case 2: Subsystem Failure
  - Prognostics, Diagnostics, Detection, Isolation
  - Respond/Rework, Switch/Swap/Substitute, Change/Alter, Assess Impact
- Case 3: Cooperative Operations
  - Mission Lifecycle – SA, Plan, Act = Teaming?
  - Planned / Unplanned ?
  - Good Samaritan vs. Greedy Approaches

Run-of-the-mill ? Real Challenge for Unsupervised Operations

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Putting it together

Building a case for UxV Certification

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- Tesla, Ravens, Quadbots, Remus, iRobots : UxVs coming home to roost…
- UxV proliferation is a real problem – in the air, underwater and on the ground
- Potential issues include controlled space conflicts, loss of control, loss of privacy, parking conflicts
- Potential hazards range from UxV pile-ups, property incursions, package rain, falling debris…
- Resilient and Self-Aware systems can greatly accelerate development of Safe Behavior Bounds for CPS systems, but pose real challenges for Schedulability

"UxV's" are very real and now in a neighborhood near you!

Implications for Schedulability and Scheduling

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Desired Capability		Impact
• Respond to Dynamic Environment	→	• Unpredictable events trigger bounded set of behaviors
• Dynamic Decision Making	→	• Any selected behavior response can/will change over its implementation
• Enhanced Situation Awareness	→	• SA can give a heads up on impending changes
• Resilient Response to adversity	→	• In a degraded system solution, decision making should include an assessment of schedulability

Challenges inherent in unmanned CPS are multi-disciplinary and cross-layer

In a future CMAAS …

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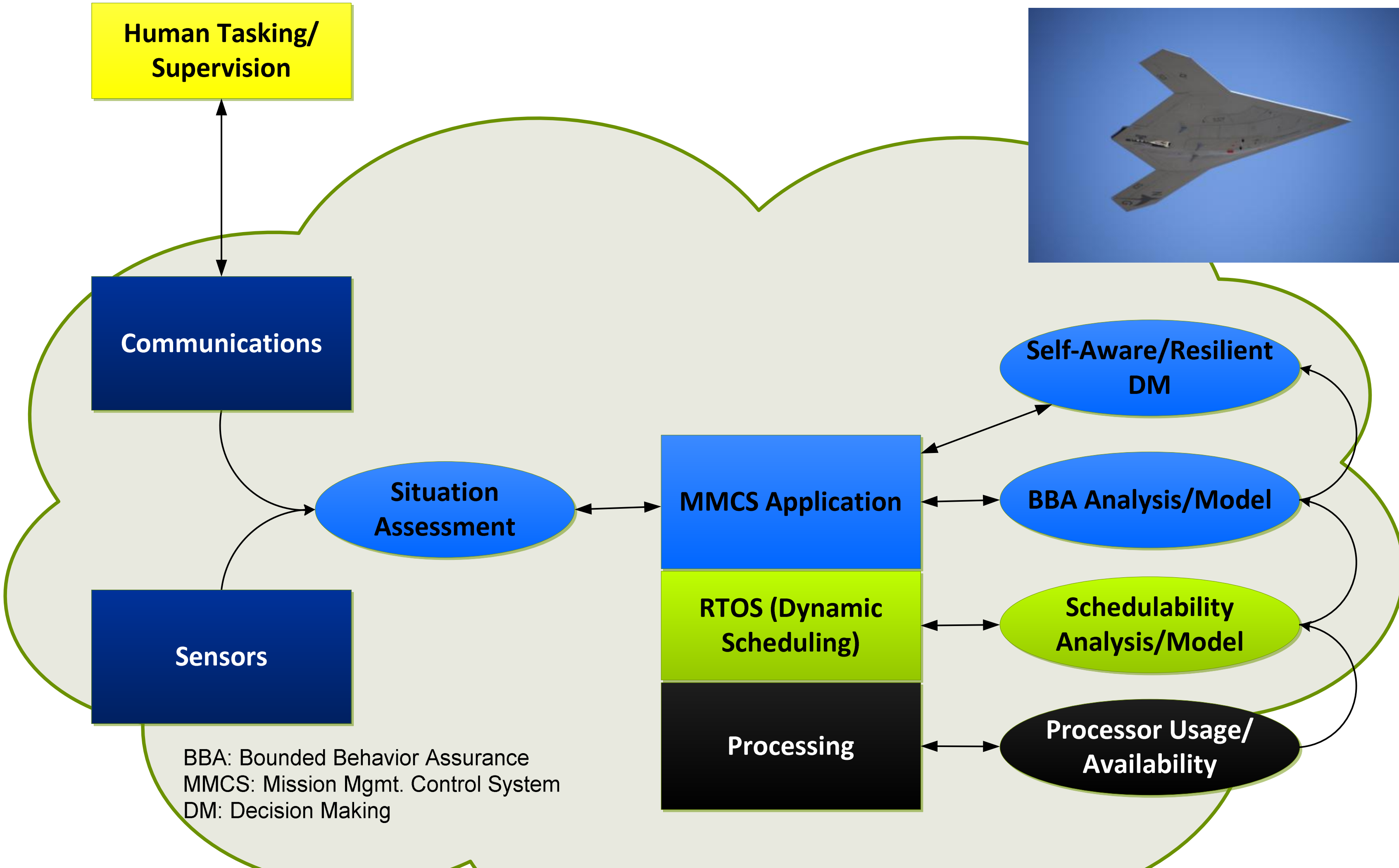

Realizing Assured Mission Management Avionics will need your help!

NGC Collaboration with Jim Anderson UNC

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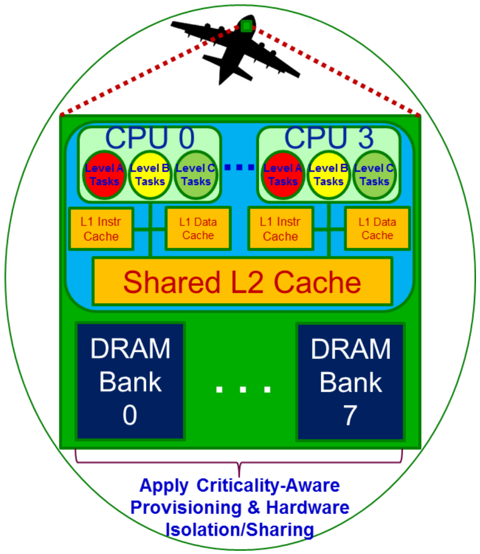
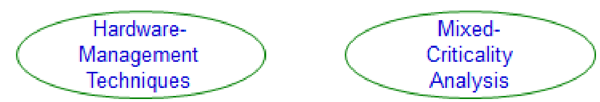


Our Solution Strategy

- W.r.t. lessening capacity loss generally (even on uniprocessors), two orthogonal approaches have been investigated previously:
  - » **Hardware-management techniques** that reduce hardware interference.
  - » **Mixed-criticality analysis techniques** that enable less critical tasks to be provisioned less pessimistically.

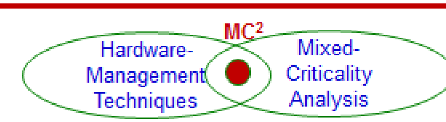


Future Work

- Our future plans include:
  - » Investigating other forms of IPC such as pipes and message queues.
  - » Conducting a definitive schedulability study that fully considers all options and allocation choices.
  - » Extending page coloring to fully deal with dynamically allocated pages.
  - » Enabling dynamic task-system adaptations, mode-change protocols, and synchronization.

Our Solution Strategy

- Our work focuses broadly on research questions that arise when applying both approaches together.
  - » We are addressing such questions in the context of a resource-allocation and analysis framework developed by us called **MC² (mixed criticality on multicore).**



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Path Forward

- A broad spectrum of needs and drivers for unmanned CPS have been discussed
- The challenges posed need a comprehensive approach, both functional and non-functional, to make inroads
- A foundational construct that can have wide ramification is to la prior and online schedulability models to inform dynamic responses to external events
- Such a multi-level resilient system when informed by schedulability and implemented by advanced scheduling approaches, can produce assured desirable behavior under dynamic, uncertain and adverse conditions

Thank You

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