An Ontology for Resource Sharing

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Outline

- The Need
- Ontology Objectives
- Ontology Overview
- Simple RLC Example
- Resource Consumption Example
- Hybrid Vehicle Example

The Need

- Want to reduce development time of large cyber-physical systems
  - System and service integration challenges.
  - Interoperability.
  - Move experimental analysis into design phase.

- Want to be able to reason about and make certification arguments about highly dynamic systems-of-systems.
  - Incorporate interoperability in its gory detail.

- Main challenge is resource sharing.
  - Unintended interactions.
  - Certification challenges.
    - No shared memory access in civil air vehicles.

Certification Challenges for Highly Dynamic Systems

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- Certification process involves convincing an authority that a system
  - Adheres to its requirements
  - Does not exhibit incorrect behavior
- Techniques involved for certification are methodology, analysis and testing
  - State explosion makes exhaustive testing prohibitively expensive
- Challenge is to develop techniques to convince a certifying authority without relying on exhaustive testing and complex design
  - Sweet spot between better techniques and augmented certification rules

More Complications…

- Sometimes intended cures causes more problems.
- Distributed control interactions.
- More extensive and expensive testing.

Ontology Overview

- Resource related objects
  - Resources
  - Resource Consumers
  - Resource Allocators
  - Resource Providers
- Assessment related objects
  - Measurements
  - Equations
- Coordination objects
  - Timing
  - Threshold Pass

Ontology Overview

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Attributes:

- Resource provisioning attributes
  - How the resources are allocated.
- Resource availability attributes
  - How the availability of the resources may change after provisioning.
- Resource consumption attributes
  - How the resources are consumed by component operation.
- Resource assessment attributes
  - How the consumption of the resources are typically evaluated.

Ontology Overview

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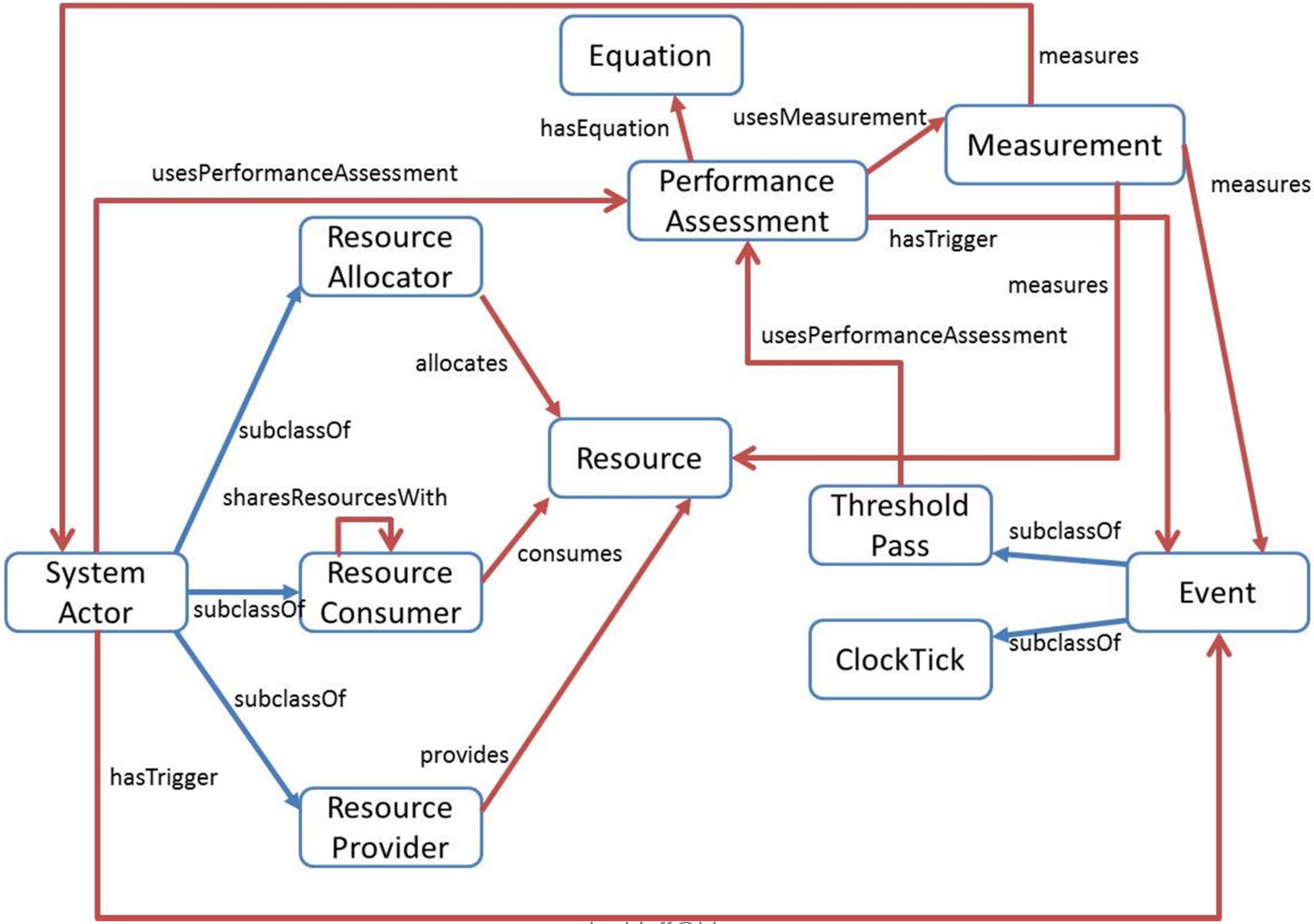

Ontology Overview

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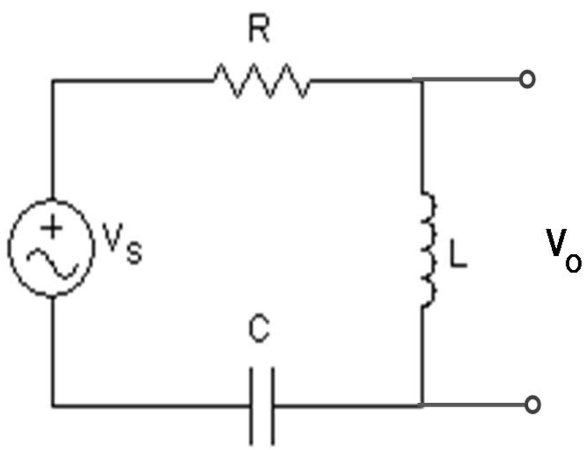
- Thing
  - Equation
  - Measurement
  - PerformanceAssessment
  - Resource
    - ExclusiveResource
    - SharedResource
  - Event
    - ClockTick
      - PeriodicClockTick
      - SingleClockTick
    - NonRepeatedEvent
      - SingleClockTick
    - RepeatedEvent
      - PeriodicClockTick
    - ThresholdPass
  - SystemActor
    - ResourceAllocator
      - Controller
      - SystemDesigner
      - SystemInfrastructure
      - SystemUser
    - ResourceConsumer
      - SystemInfrastructure
      - SystemUser
    - ResourceProvider
      - SystemInfrastructure

- allocates
  - exclusivelyAllocates
- allocatesTo
- availabilityPartiallyObservableTo
  - availabilityObservableTo
- consumes
  - exclusivelyConsumes
- hasEquation
- hasTrigger
  - assessedOnEvent
  - degradesOn
  - reallocatesOn
  - updatesMissionOn
- isAllocatedBy
  - isExclusivelyAllocatedBy
- isCalibratedBy
- isConsumedBy
  - isExclusivelyConsumedBy
  - isPredictablyConsumedBy
- isMeasuredBy
- isProvidedBy
- measures
- partiallyObservesAvailabilityOf
  - observesAvailabilityOf
- provides
- receivesAllocationsFrom
- sharesResourceWith
  - explicitlySharesresourceWith
  - implicitlySharesResourceWith
- usedByPerformanceAssessment
- usesMeasurement
- usesPerformanceAssessment

Example – RLC circuit



For the non-EEs:

- Resistor, Inductor, Capacitor

Objects

- Resource: Power
- Resource Provider: Vs
- Resource Consumers: R, Vo
- Measurements:
  – Voltages, Currents
- Equations: Ws=Vs*Is, etc…

Resource Contention Extension

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- Underlying Theory
  - Contention Complexity represents propensity for resource contention
  - Applicable to design, manufacturing, and usage processes
    - Operational consumers use resources
    - Contention when resources insufficient for consumers' needs
- Approach
  - Contention Complexity (overall) is sum of Resource Contention Complexities for all resources
  - Resource Contention Complexity is proportional to
    - Number of consumers that could request that resource
    - Expected amplitude and length of consumer resource use
    - Variance in amplitude and length of consumer resource use
    - Criticality of the consumer resource use

Contention Complexity

Contention Complexity metric is a function of

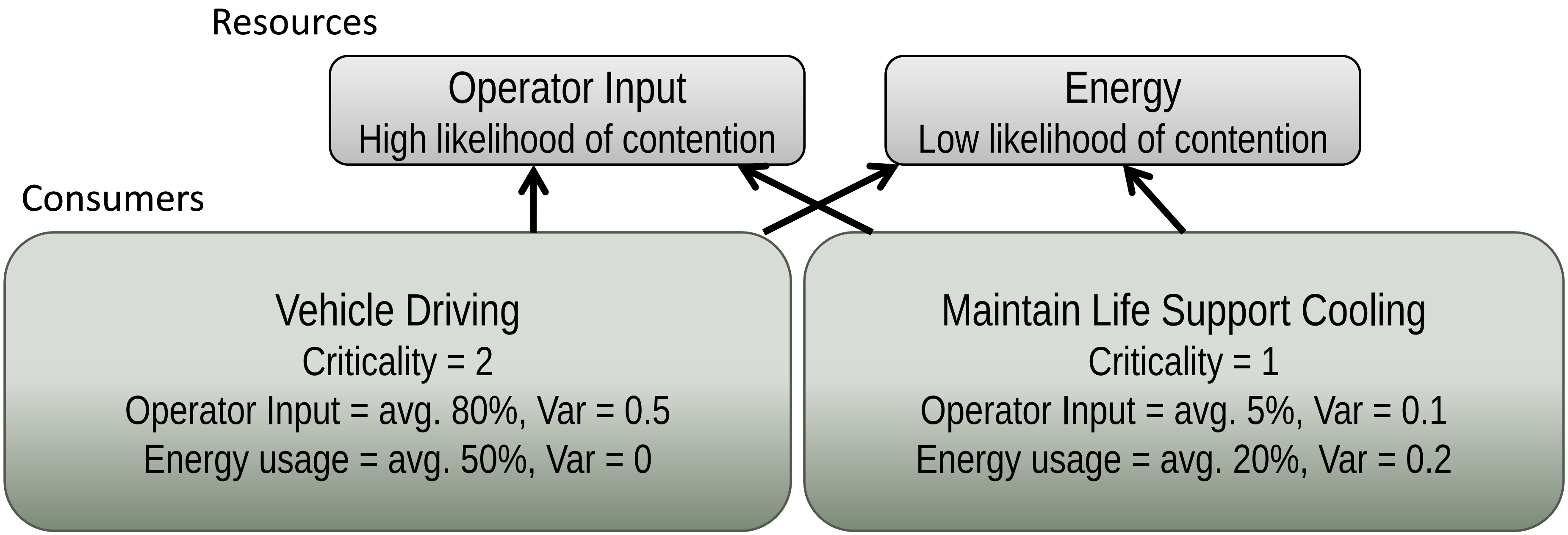
- ***%level(c,r)*** magnitude of consumer (c) use of resource (r).
- ***criticality(c,r)*** criticality of consumer's use of resource. (1 is very critical, 10 is not critical at all.)
- ***E[ ]*** is expected value and ***var( )*** is variance. (Evaluated numerically if needed.)

Contention Complexity of a resource:

$$ContentionComplexity(r) = \sum_{c \in DependsOn(r)} \frac{E[\%level(c,r)]\, var(\%level(c,r))}{criticality(c,r)}$$

Contention complexity represents a "propensity" for contention of resources.

Contention Complexity



- ContentionComplexity(OperatorInput) = 0.8*0.5/2+0.05*0.1/1
  = 0.2 + 0.005
  = 0.025
- ContentionComplexity(Energy) = 0.5*0/2 + 0.2*0.2/1
  = 0.0 + 0.04
  = 0.04
- ContentionComplexity = 0.025 + 0.04 = 0.065 (approx)

Larger Example – Hybrid Vehicle

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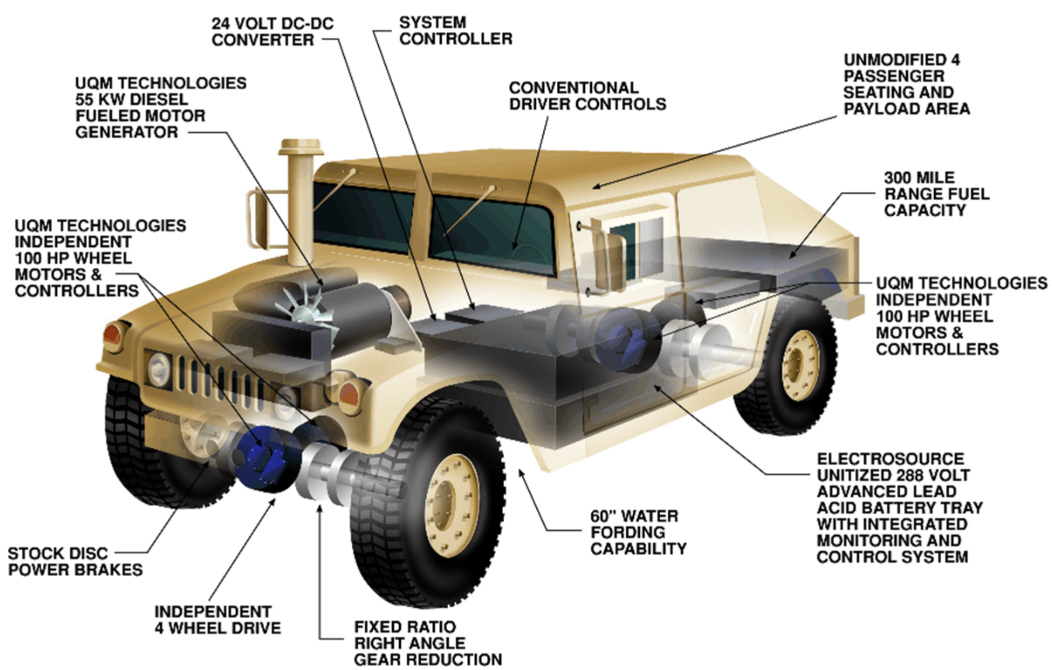
Analysis Question:

What battery configuration minimizes maintenance resource contention complexity on hybrid-electric HMMWV?



We want to select a battery and control parameters to minimize contention complexity of maintenance resources.

Resources:

- Power, Labor, Replacement Cost

Resource Consumers:

- Vehicle Movement, Maintenance

Battery Selection

- Battery Types: Lead Acid, NiCad, Li-Ion
  - Variations in:
    - Replacement cost (Lead Acid is cheap!)
    - Power density (Li-Ion is powerful.)
    - Robustness (Lead Acid can take more abuse and can sometimes be serviced in the field.)

- Depth-of-Discharge (DoD) parameter selection
  - DoD represents how “deep” battery is discharged.
  - Large DoD mean you get more power on every charge.
  - Deep DoD changes battery chemistry and reduces number of charging cycles a battery can support.

Experimental Setup – Contention Complexity

Complexity Simulation Model:
- Monte Carlo simulation of hybrid HMMWV moving at 20mph over US terrain model.
- Representative control model of battery charging/discharging while moving.
- Assuming regenerative braking.

Model Output:
- Over multiple runs, model estimates number of hours until battery failure and maintenance cost for various battery types and depths-of-discharge.
- We compute maintenance resource contention compexity from assessments of expectations and variances over simulation runs.

Analysis Output

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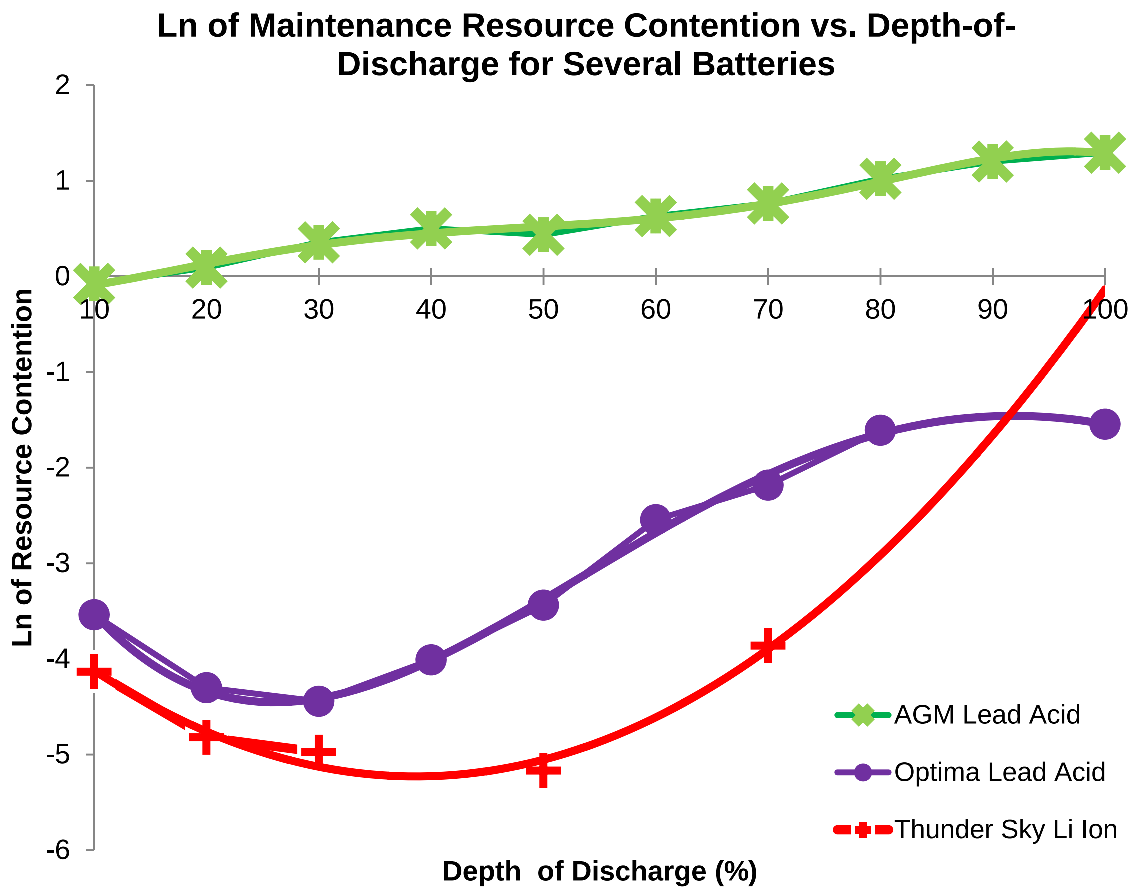

Li-Ion battery with 30%-50% DoD minimizes maintenance resource contention complexity.

This aligns well with "real-world" results from carmakers.

Conclusions

- Certification as a limitation
  – Develop Certification Arguments for interoperability
- Resource Sharing Ontology
  – Driven by resource Interactions
- Support for contention complexity assessment
  – Coupling with assessment tools

Thanks!
Questions?

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