

Modeling Distributed Situation Awareness in Resilience-based Design of Complex Systems

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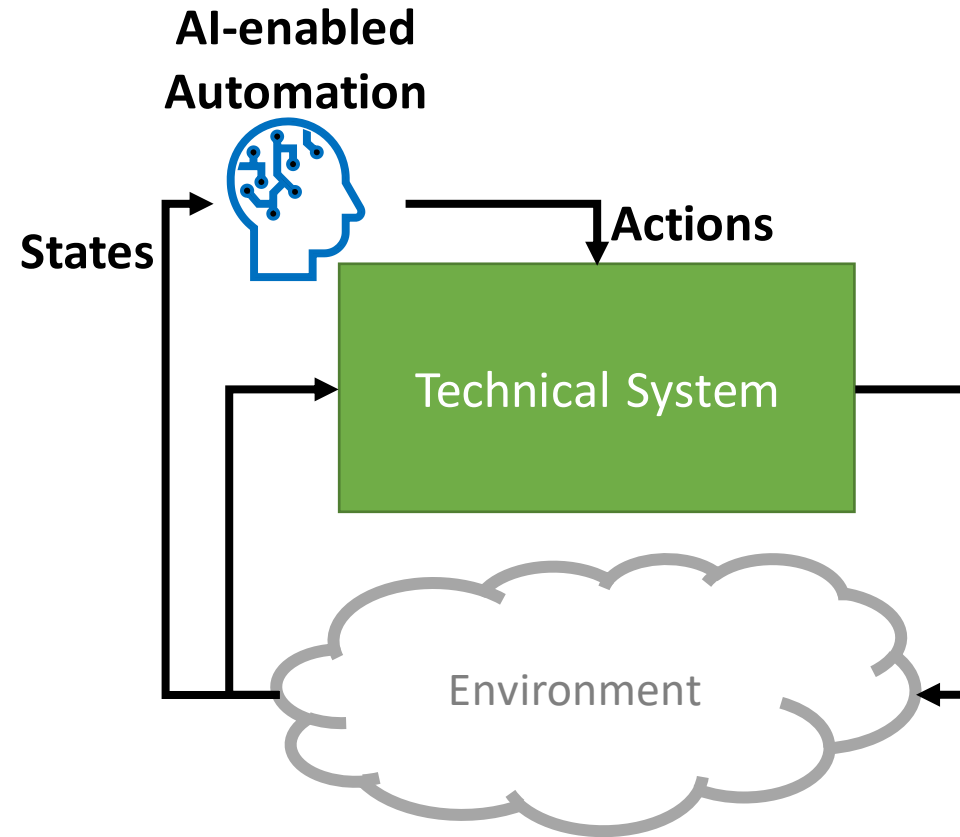
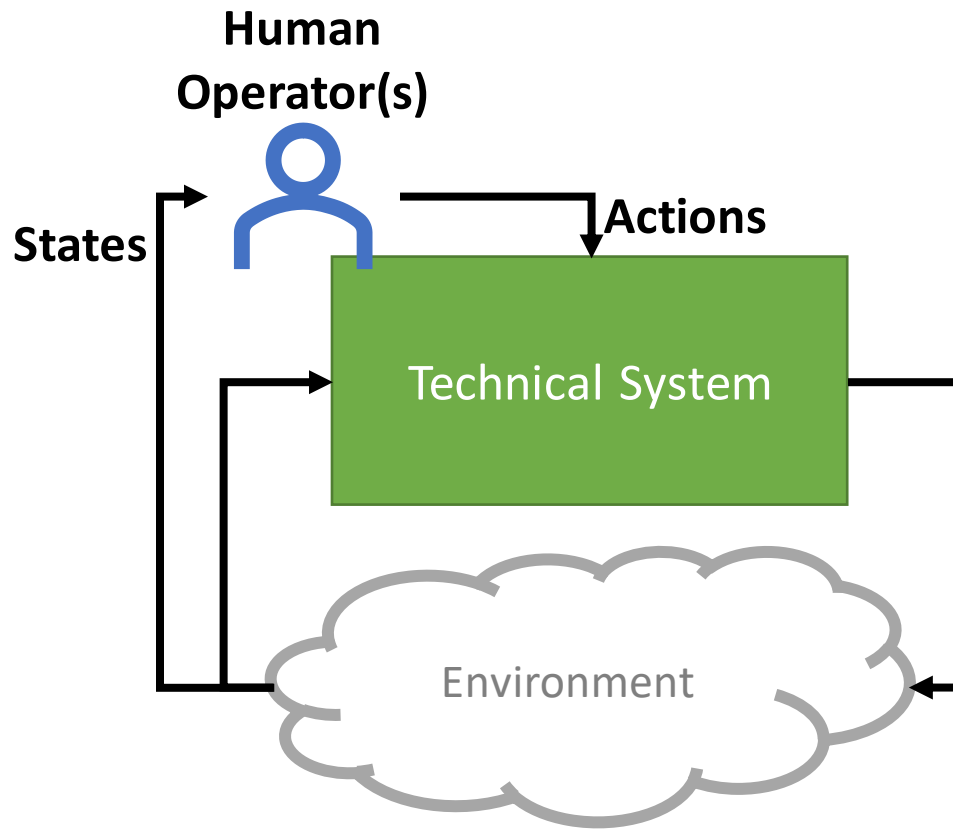
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Motivation

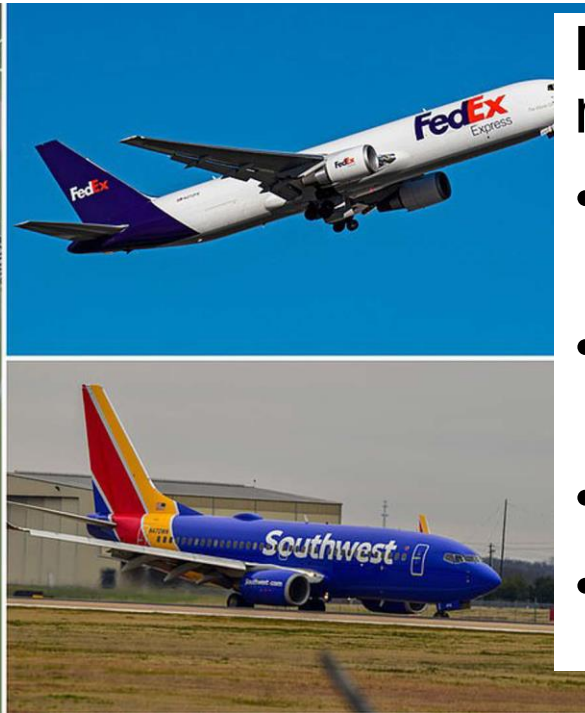


How do we compare human contributions to resilience with AI-enabled automated systems?



Distributed Situation Awareness

- Key aspect of human resilience in complex systems
- Property of distributed agents with local perceptions and communications to **collectively understand system state to function as a whole**
- Understood as a loosely-coupled information network between agents

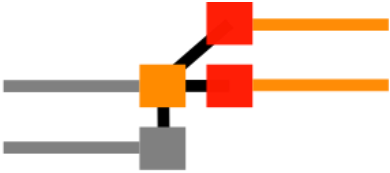


Example: 2023 FedEx/Southwest near miss

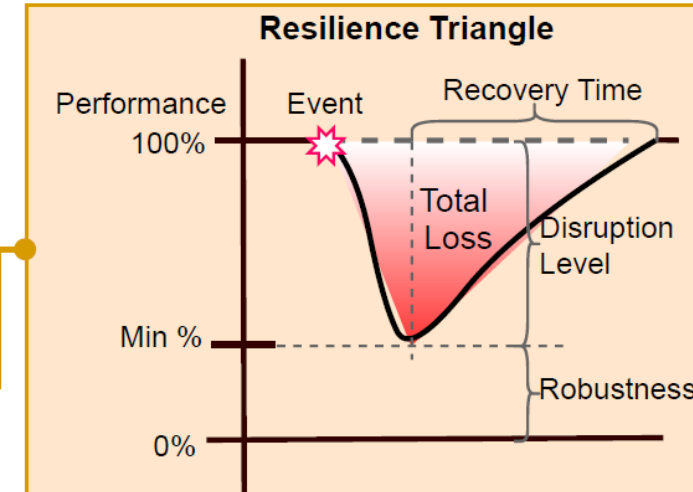
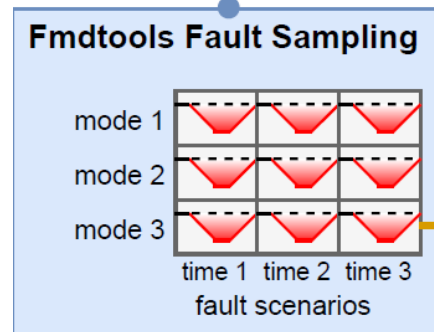
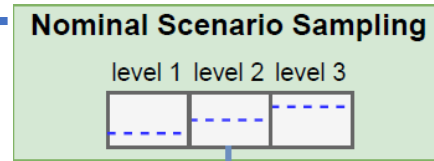
- Dense fog led ATC to clear simultaneous landing and takeoff
- FedEx pilot aborts landing and notifies Southwest/ATC
- Caused by DSA degradation (ATC)
- Mitigated by DSA redundancy (FedEx)



Resilience Modelling in fmdtools



fmdtools
Python library to support
resilience assessment.



Features:

- Able to understand and visualize dynamic system behavior over time
- Explicit quantification of metrics (risk, recovery, etc.) and parameters to inform decision-making

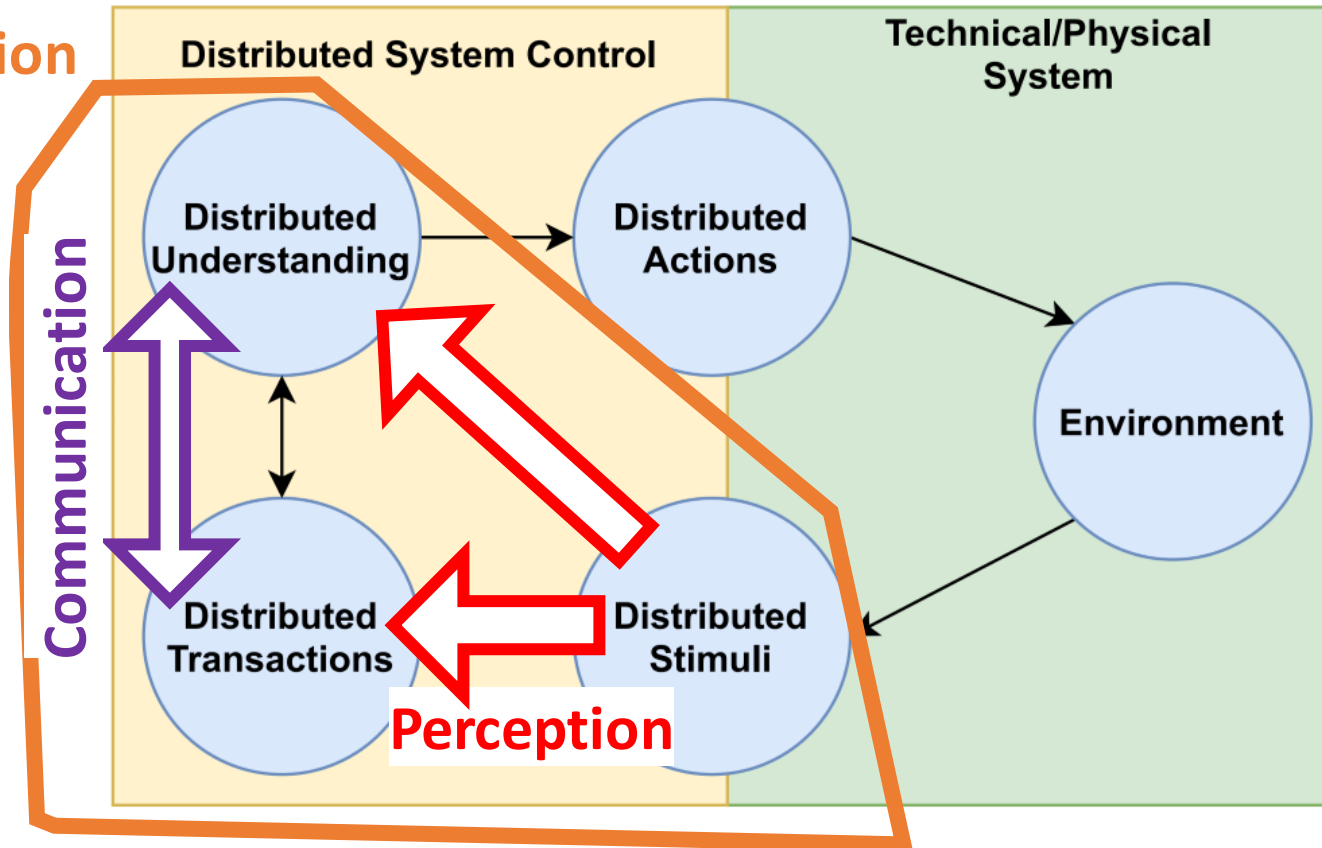
Limitations (v1.4):

- Tricky to set up for large distributed systems
- Difficulty understanding information and communications networks
- Not capable of modelling DSA

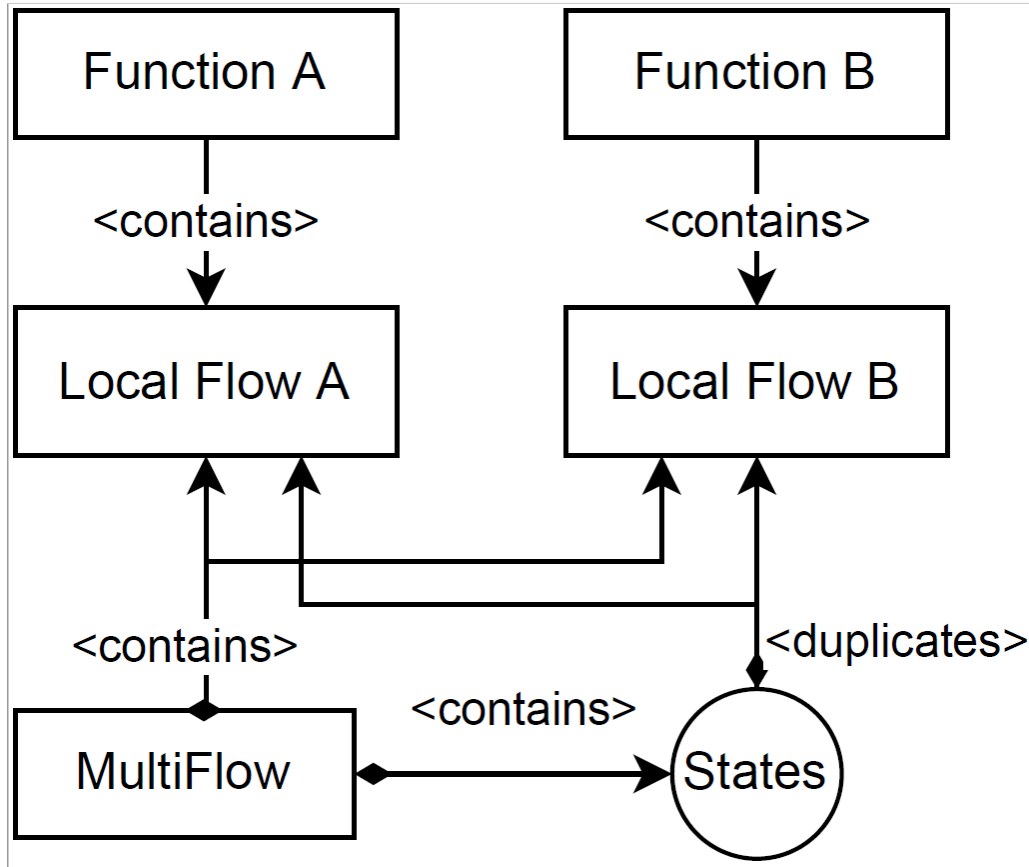


DSA Modelling Framework

Distributed Situation
Awareness



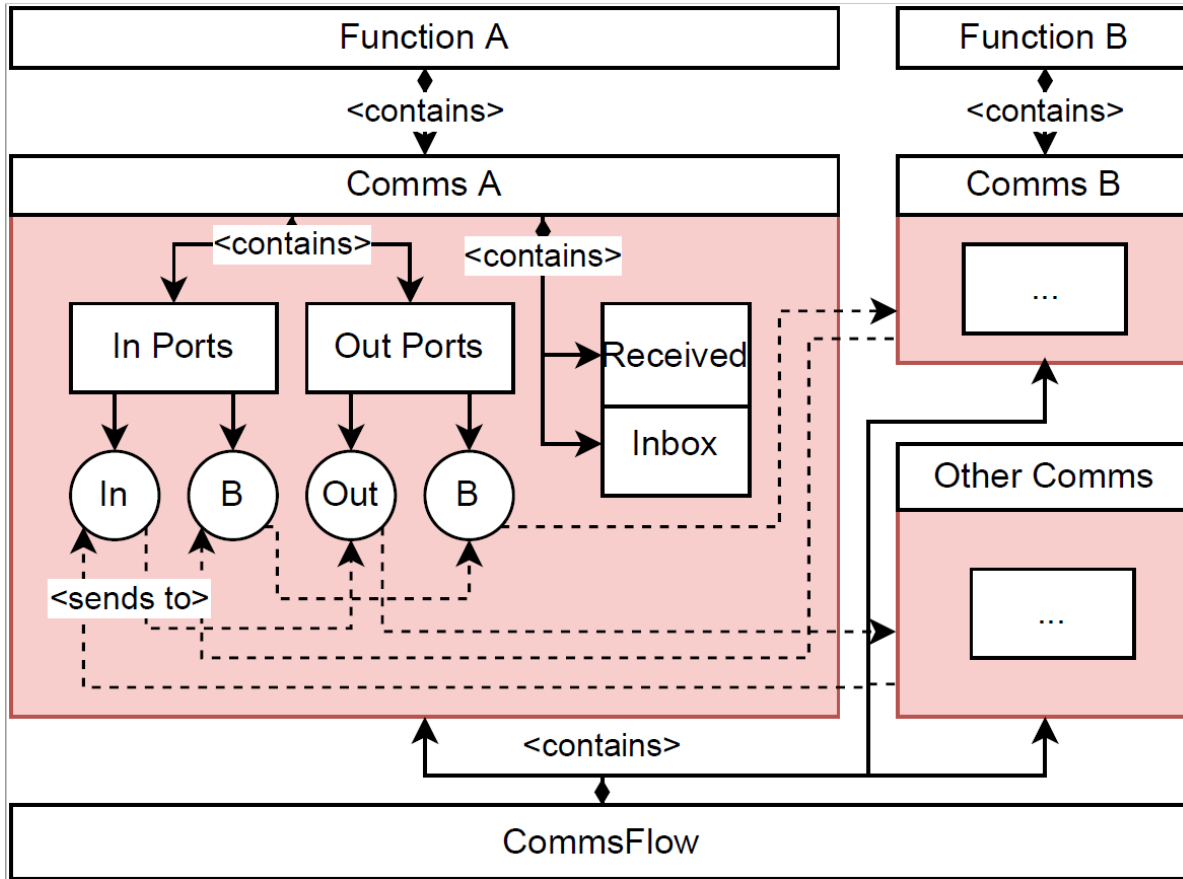
DSA Model Constructs - MultiFlow



- Enables representation of **perception**:
 - Each Agent has its own “local” state representing its perceived state
 - e.g., each agent may have an **individual location** as well as their own “**perceived**” **location** and a “**perceived**” **location** for nearby agents
 - MultiFlow connects this information in an overall information graph



DSA Model Constructs- CommsFlow

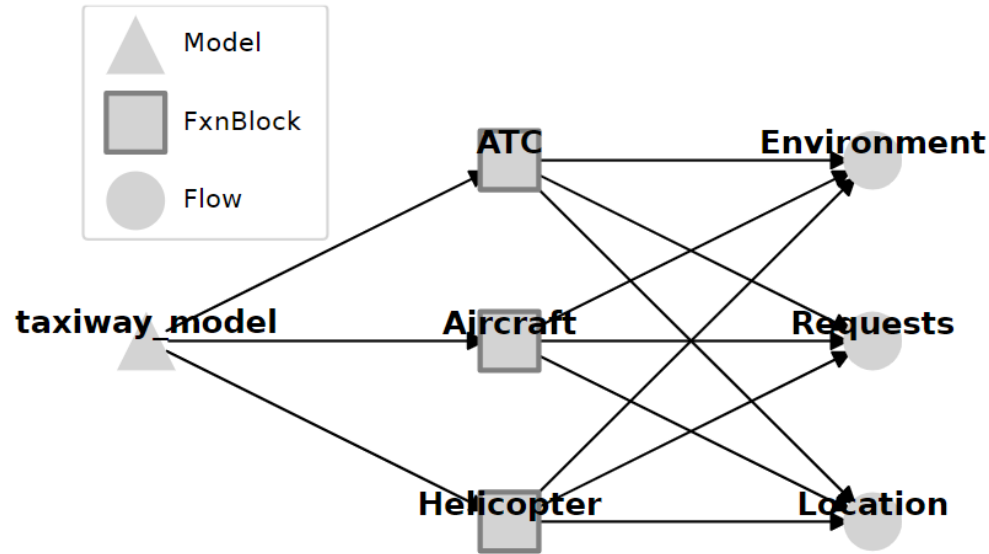


- Extension of MultiFlow to enable representation of **communications**

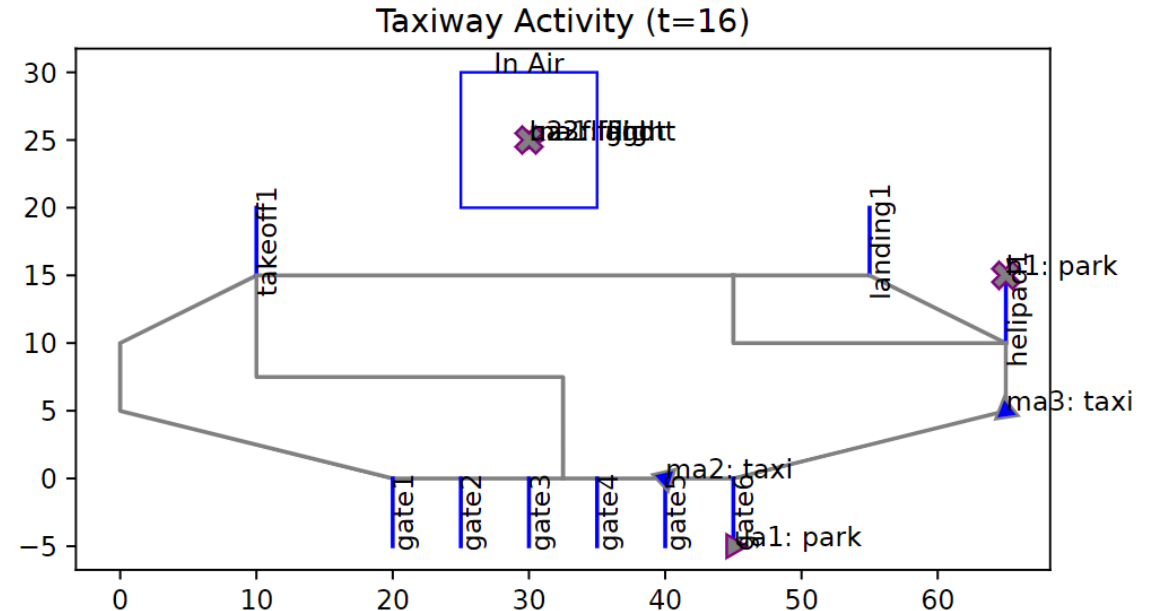
- Inbox to enable asynchronous, 1-to-X and X-to-1 communications
- Ports to enable dedicated fields between agents
- e.g., Agent 1 may have a port for Agent 2 and Agent 3 which lets it send and receive different location updates to/from each



Taxiway Case Study



- Assets taxi to/from gates and takeoff and land
 - Clearance/direction from ATC
 - VLOS to other assets
- ATC coordinates landing and taxiing

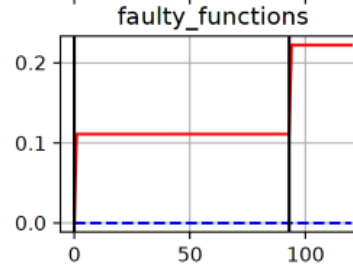
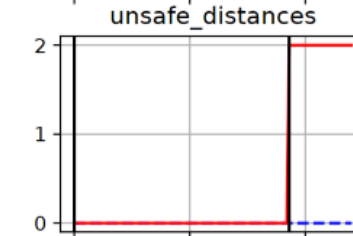
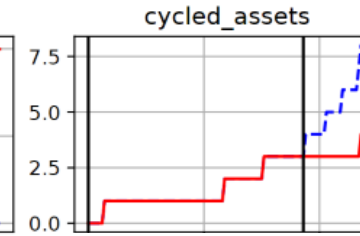
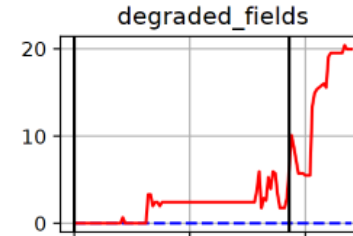
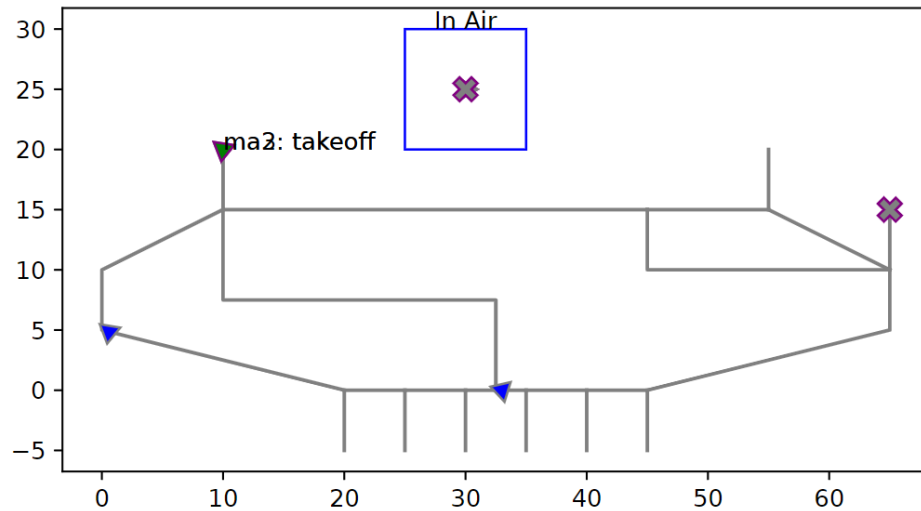


- Interact on taxiway
 - Dedicated landing and takeoff runways/taxiways
 - Helipad only used by one AC at a time
 - If too close, assets crash

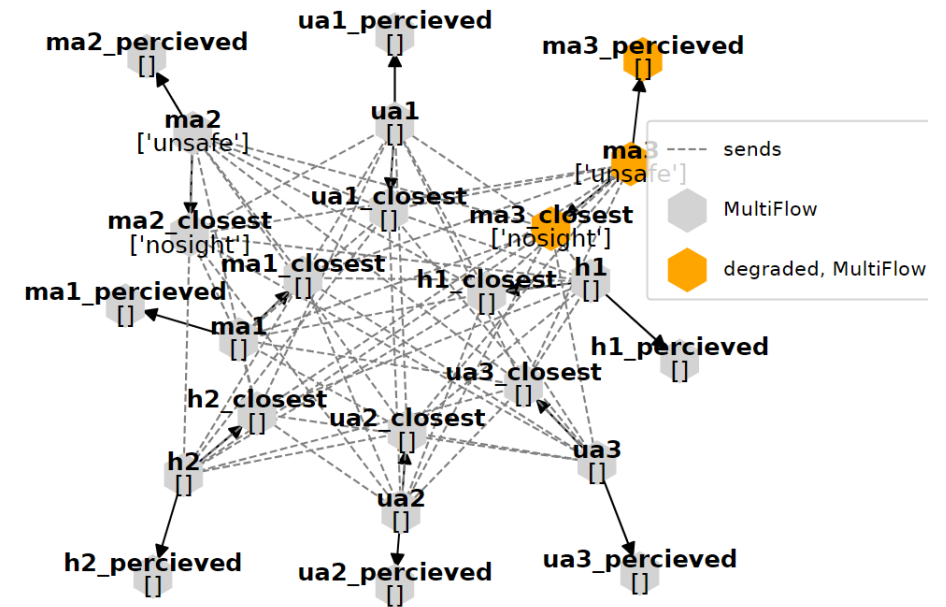


Taxiway Vision Fault Example

MA3 approaches MA2 with no vision cone (t=93)



Perception Graph



- Scenario: AC loses VLOS to other aircraft in the taxiway
- No immediate effects until it gets close to other AC (queuing for takeoff)

- Unsafe distance causes crash with other AC
- Crash immobilizes taxiway



Taxiway Clearance Fault Example

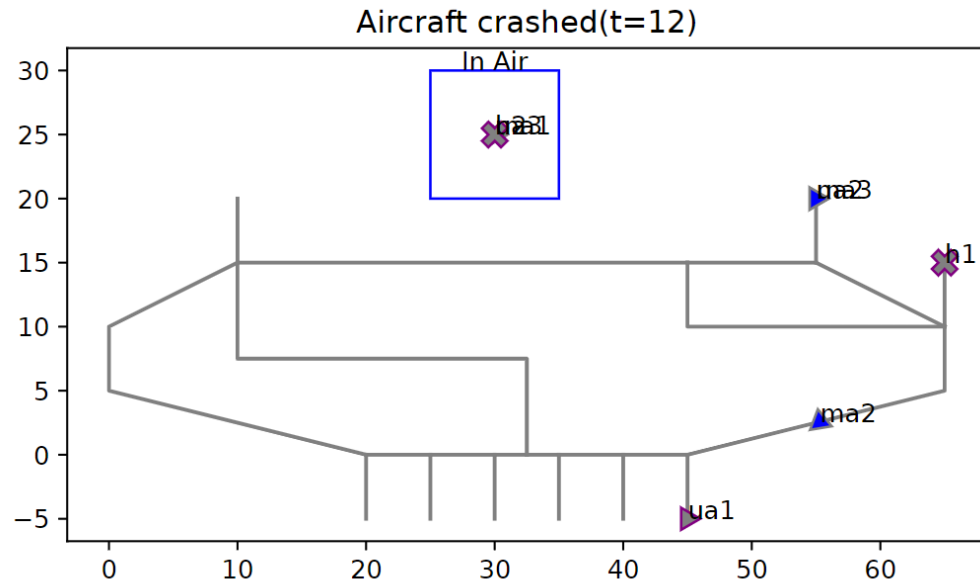
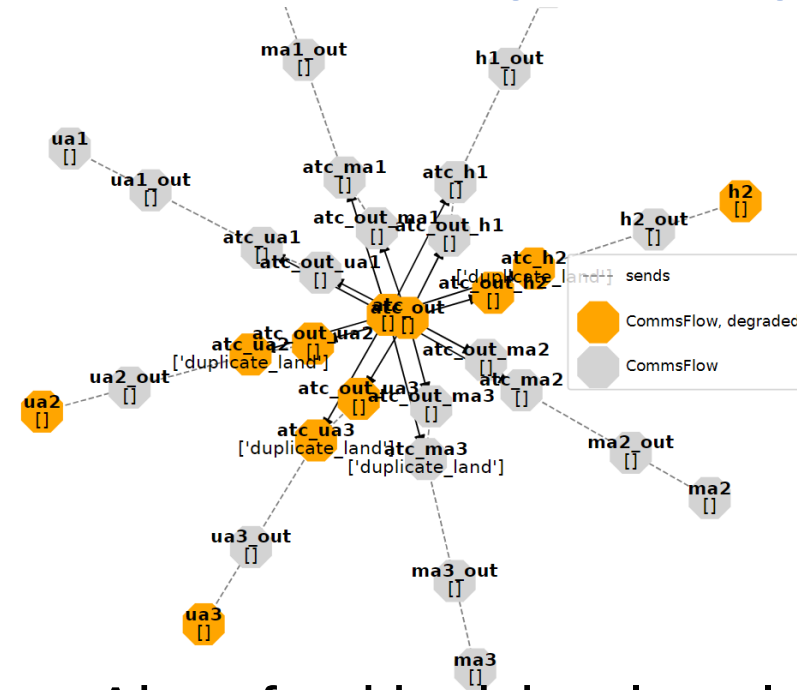


Fig. 15 Resulting clearance fault asset allocation—three aircraft are incorrectly permitted the landing runway.

- Scenario: ATC clears all airborne AC to land and one AC loses VLOS
- AC with VLOS attempt and abort landing

Clearance/Requests Graph



- Aircraft with vision loss lands on just-landed aircraft, crashing both
- All other aircraft unable to land



Discussion and Conclusions

Takeaways

- Developed **capability to represent DSA** in dynamical system resilience models
- Taxiway demo shows the richness of this approach for **modeling perception and communications errors**
- In the future, we would like to **extend number of scenarios** and/or explore **hazard sampling techniques**

Limitations/Difficulties

- **Distributed understanding** is difficult to represent and not really addressed here.
- **Metrics used** in this work are limited to risk/hazard metrics and “degraded fields,” which don’t offer much insight into DSA



Questions?

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Fmdtools Simulation Package

repo: github.com/nasa/fmdtools
documentation: nasa.github.io/fmdtools/

