



# Plan Maintenance for Continuous Execution Management

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# Innovation For Application

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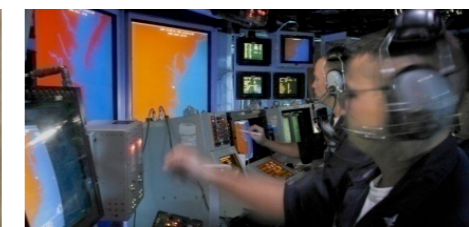


## • Our Purpose

- ATL is a creative, entrepreneurial environment focused on partnering with S&T organizations to attack high-impact CRAD projects, successfully execute them, and when the opportunity is ripe, transition the results to LM Business Units or end users

## • Guiding Principles

- Develop transformational technologies
- Nurture creativity
- Embrace relentless entrepreneurialism
- Build enduring relationships



We do what's right, respect others, and perform with excellence



- The AI planning community has focused on plan generation, typically introducing assumptions that do not hold for operational environments
  - Plans can be executed without encountered unforeseen circumstances
  - Planner has full insight and control of the *actors* executing the plan
- Enabling warfighters to anticipate and rapidly respond to the dynamic battlespace requires architectures oriented towards *Continuous Execution Management*.

***Within Continuous Execution Management, plans are dynamic constructs with structured semantics guiding change.***

DARPA initiative to apply artificial intelligence and other modern modeling and computing technologies to improve the capabilities of the AOC Weapons System in the areas of planning and dynamic replanning

- Reduce time and manpower
- Support continuous operations

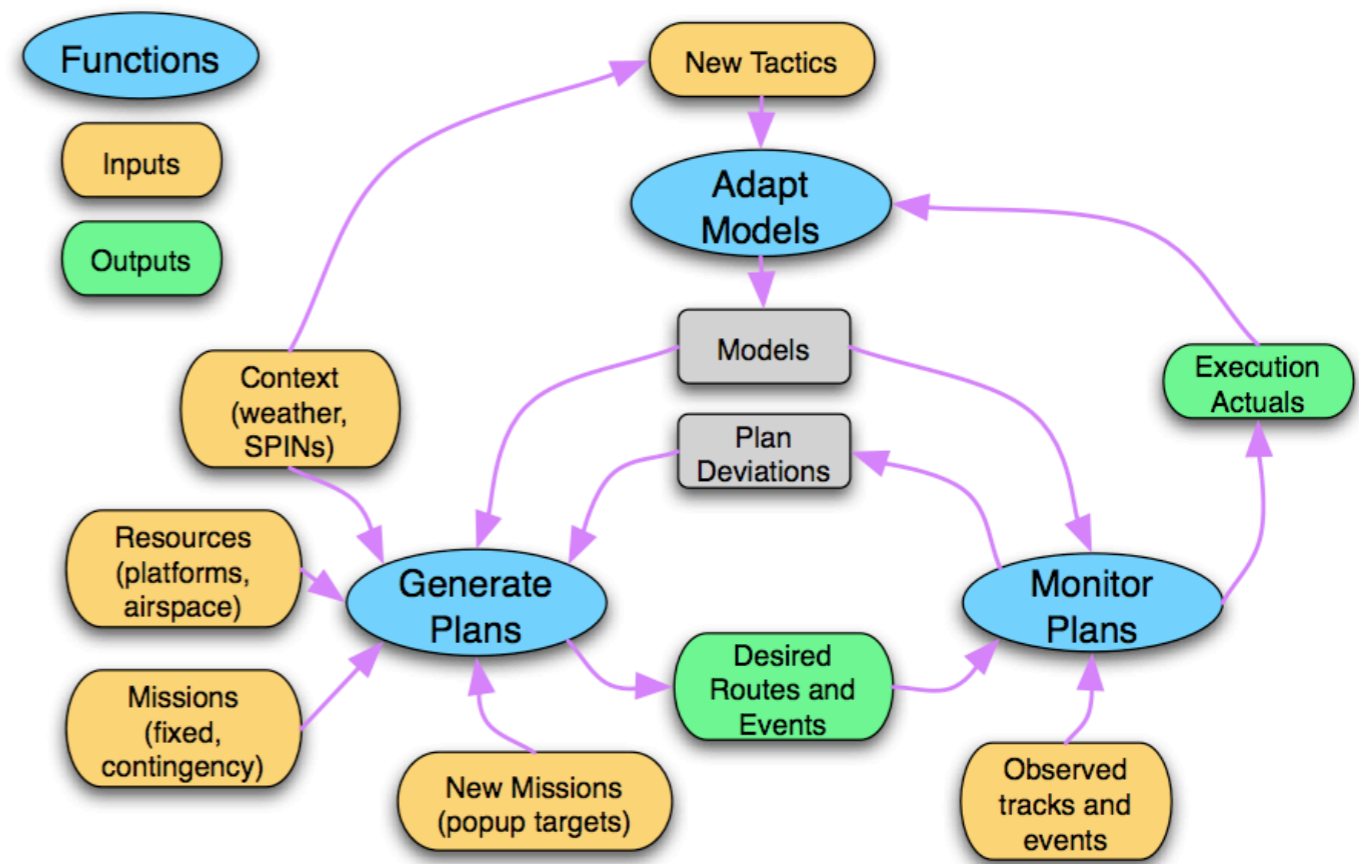


## JAGUAR COMPONENTS

**Plan Generator:** Creates, refines and adjusts air operations plans

**Plan Monitor:** Correlates reports to plans, anticipates downstream problems.

**Model Adaptor:** Updates models of platforms and tactics.







## ***Plan Execution Understanding Service (PLEXUS):***

- A plan maintenance engine:
  - **Plan Structure Maintenance:** splicing new plans and plan repairs into existing structures, maintaining a version history of plan structural revisions.
  - **Plan State Maintenance:** tracking actions through their life cycle, activating propagation algorithms on state changes.
- A reasoner that can be extended for domain-specific processing
- A distributed, query-able engine for plan-related data

(n) plan:

1. A systematic arrangement of elements
2. A diagram showing the structure or arrangement of something.

(n) plexus:

1. A structure in the form of a network
2. A combination of interlaced parts; a network.

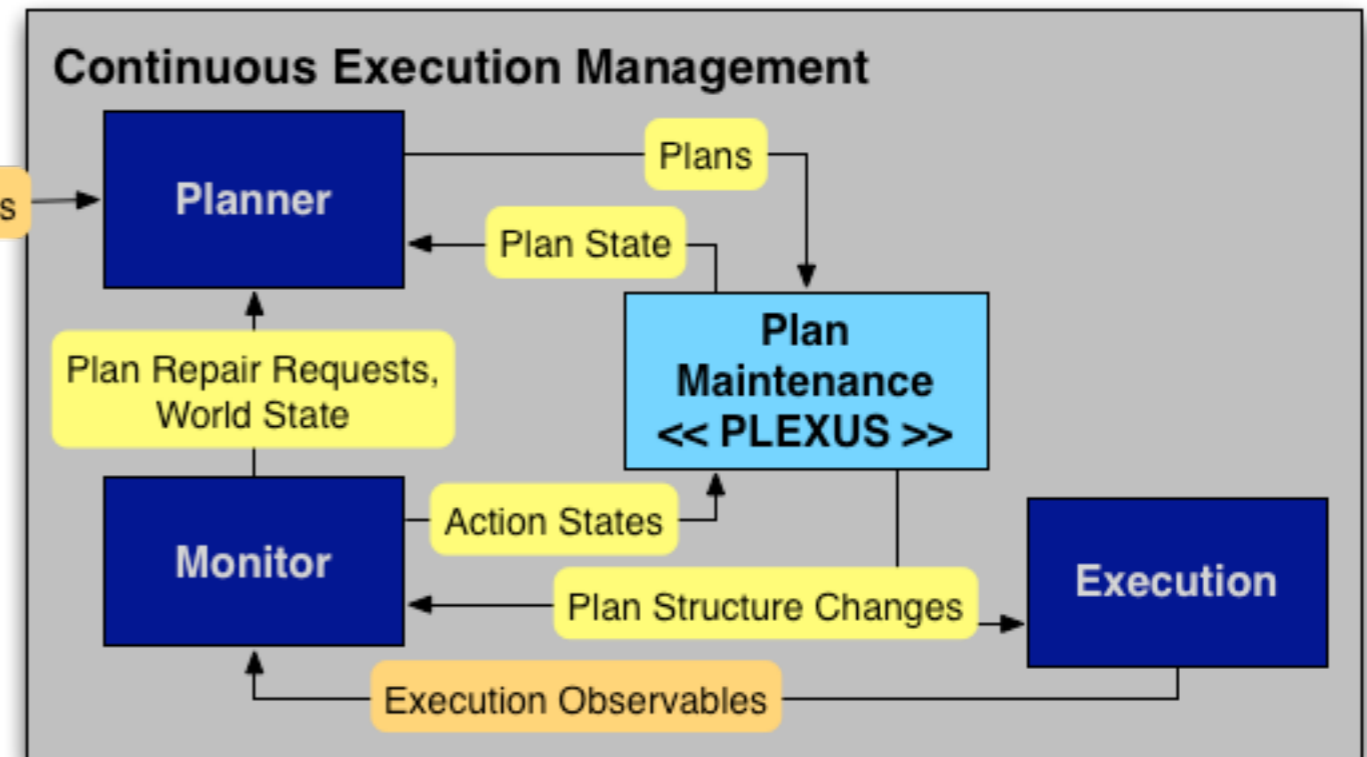
***PLEXUS*** is LM-ATL's reusable software component that maintains and integrates the complex network of: plans, plan elements, and domains.

# Plan Maintenance Role

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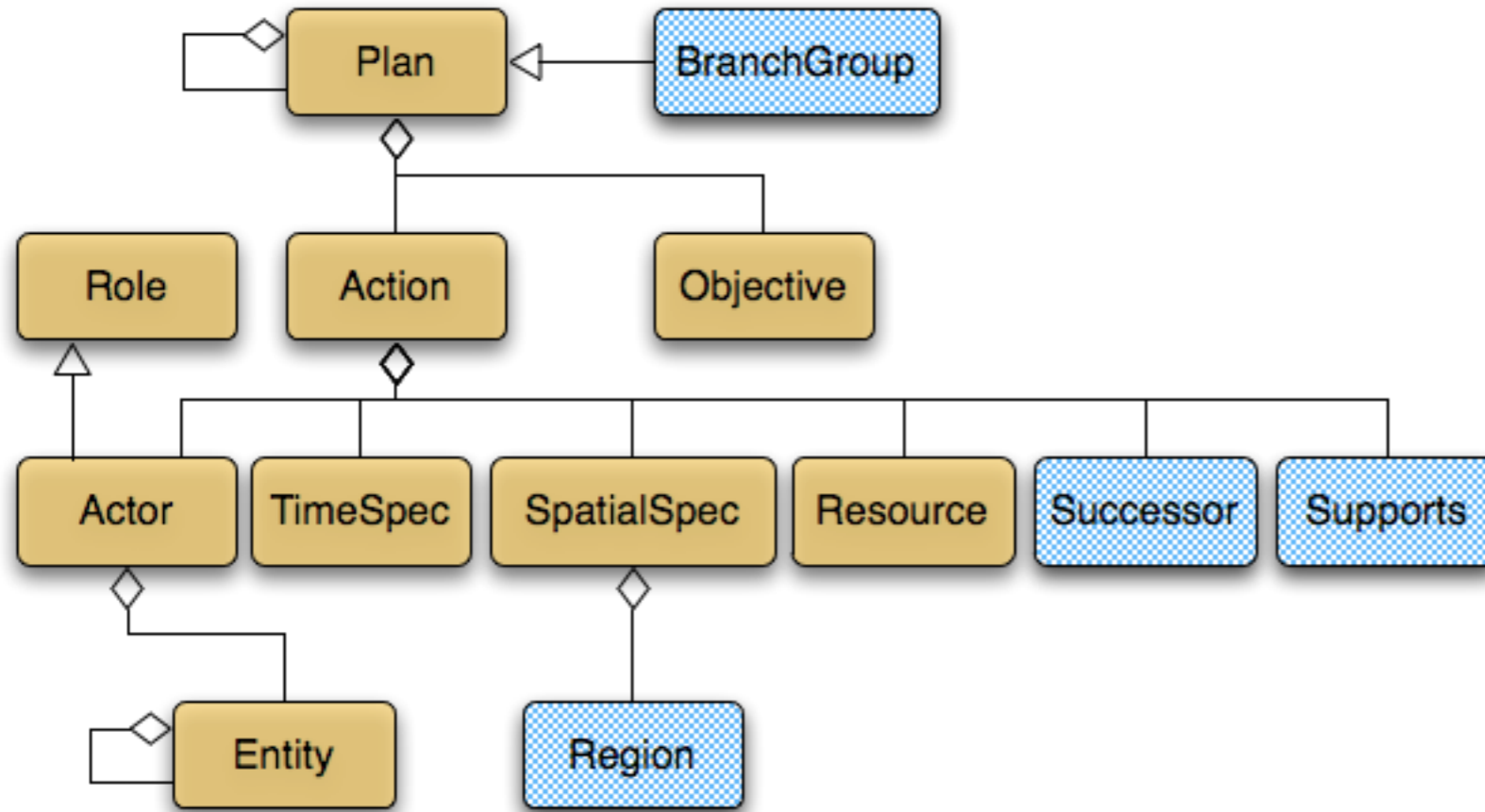


- Tracks execution progress to enforce change management semantics
  - activity state propagation
  - plan modification and repair
  - version history
- Coordinates plan change effects to Monitor and Execution



# Domain Independent Plan Representation

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## Core Plan Representation (CPR)

- DARPA developed domain independent plan representation
- Originally designed for planning systems only

Standard CPR Type

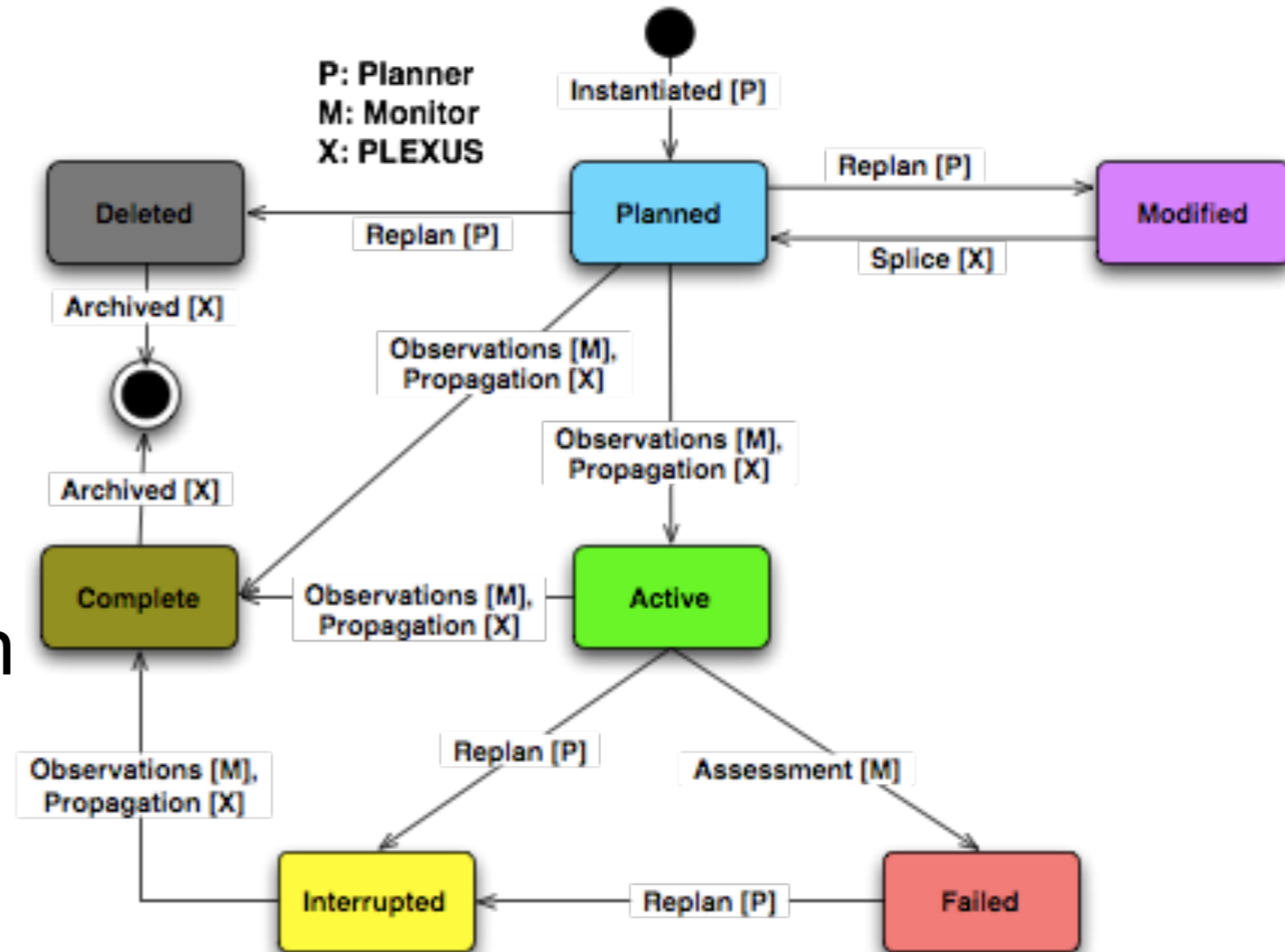
- PLEXUS extends CPR to improve its capabilities for use in *continuous execution management*
  - plan branches
  - inter- and intra-mission dependencies

# Action Life Cycle Maintenance

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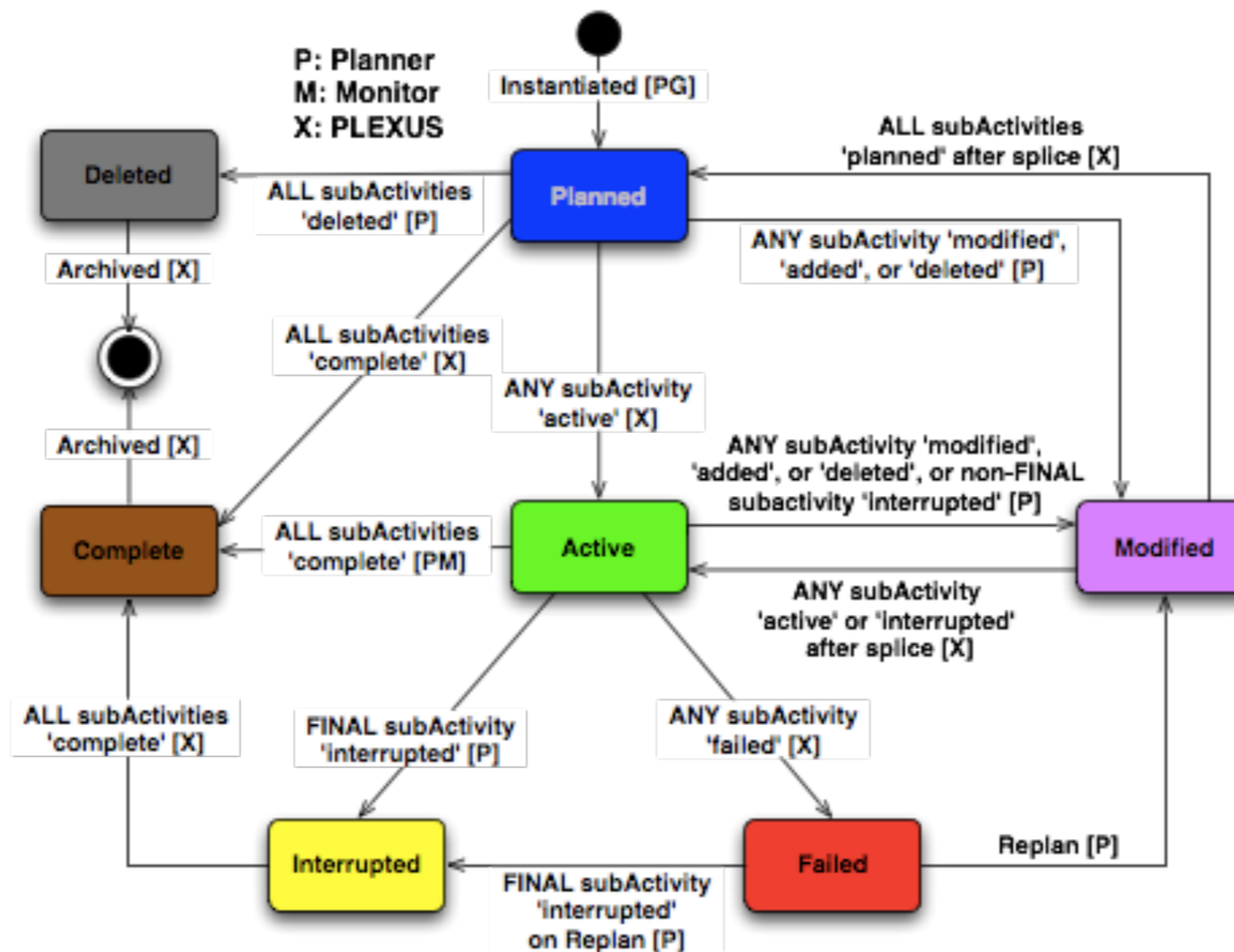


- Track action progress through its state life cycle
  - enforce transition rules
  - transition is driven by observations or directed change
- Action links within a mission allow for state propagation
  - activation of an action triggers completion of all prior actions
- State propagation rules are customizable





# Inferred Action Life Cycle Maintenance

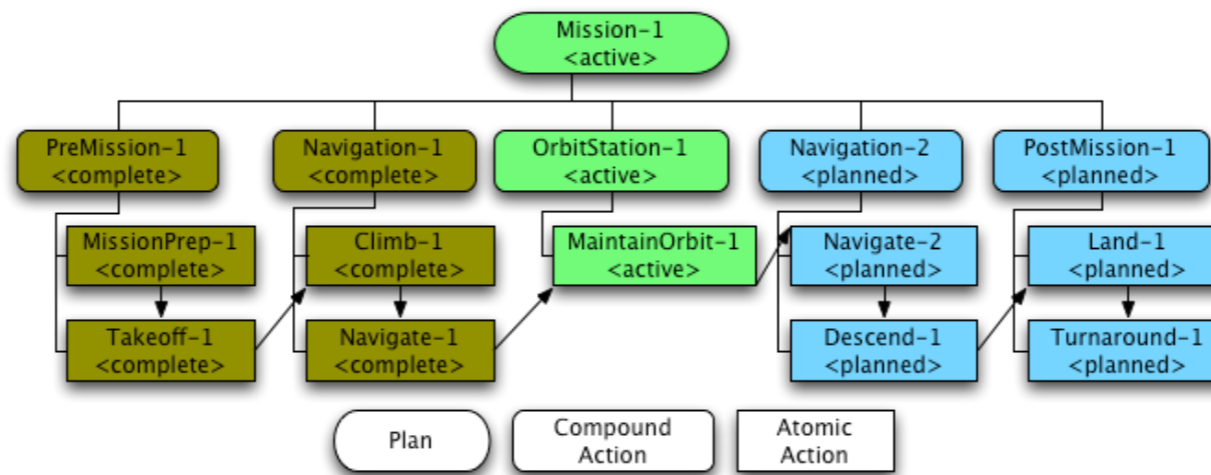
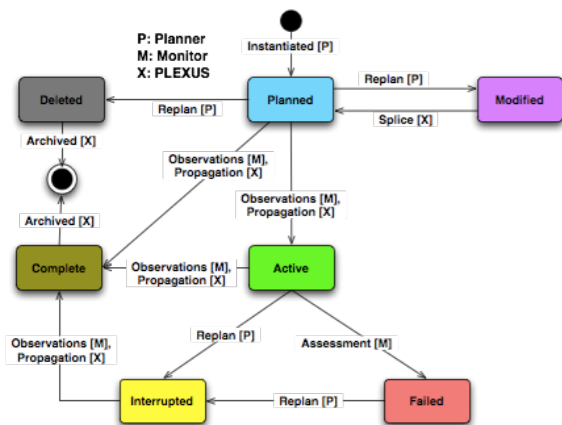


State transitions are accomplished through aggregation and inference

# Plan Modification

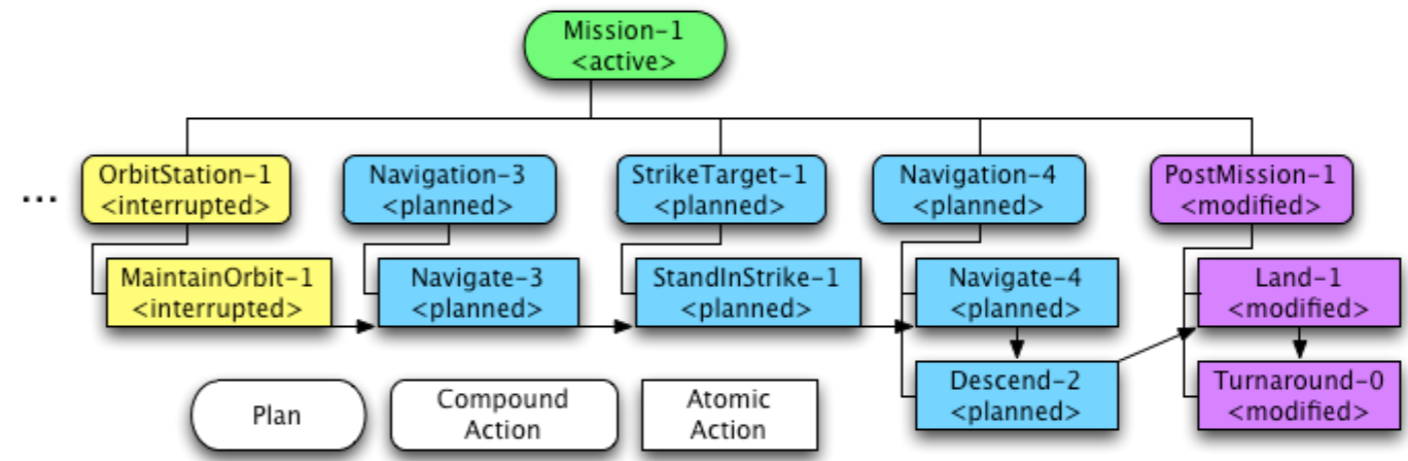


- Changes to plan due to
  - new objectives
  - adjustments as part of a repair (i.e. assign target to air alert)
- Life Cycle semantics inform planner how activities may be changed



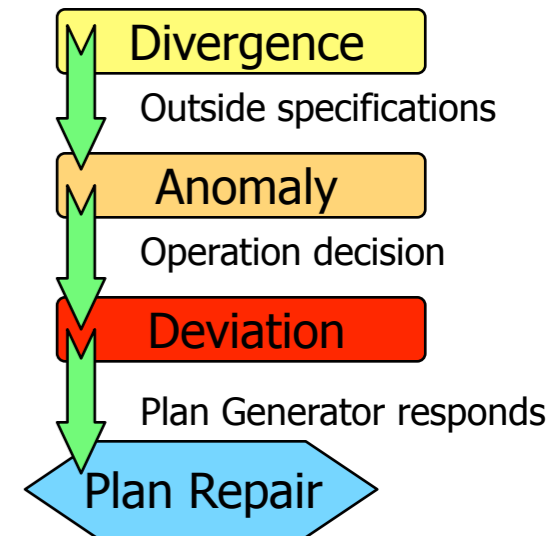
This Air Alert mission is in orbit and capable of being tasked

- by:
1. interrupting the orbit
  2. adding the strike sequence
  3. deleting the obsolete navigation-2 sequence
  4. updating the PostMission





- Triggered by *Monitor* identified failures (deviations)
  - JAGUAR deviation detection set includes
    - Spatiotemporal, consumption, vehicle health, threats, base closure and aircraft diverts
- Scope and Severity
  - Operator-controlled thresholds for anomaly detection
    - Adjustable by mission and/or activity type
  - Causal linkages amongst activities enable impact propagation assessment



***Life Cycle semantics guide changes in identical fashion to plan modification***

# Performance Analysis



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- Evaluate scalability of our Continuous Execution Management system
- PLEXUS satisfies the plan maintenance requirements for CEM on plans at the scale and complexity required of real environments

	Plan 1	Plan 2
Actors	54	450
Activities	1098	7925
Entities	1520	13228
Spatial Specs	1511	10565
Total	4183	32168

The number of actors, activities, entities, and spatial specifications in each test

	Plan 1 Average	Plan 1 Std. Dev.	Plan 2 Average	Plan 2 Std. Dev.
Setup	34.3s	2.8s	44.5s	0.7s
Context Request	4.7s	0.5s	6.0s	0.0s
Problem Statement	5.3s	0.5s	8.0s	0.0s
Plan	101.2s	17.2s	4616.5s	47.4s
Context Request	14.5s	0.7s	159.5s	6.4s
Time Jump	44.2s	17.9s	1108.5s	23.3s
Total	204.2s	19.9s	5943.0s	77.8s

Execution Time of Each Test Step on Each Plan in Seconds



- Plan repair is inevitable in rapidly changing, unpredictable environments
- CEM is key in assessing deviation impact and enabling effective plan repair
- PLEXUS
  - Plan maintenance service that supports CEM
  - Tracks and enforces domain-independent action life-cycle rules



# Acknowledgements



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