

Distributed Autonomy

(Continual Coherent Team Planning)

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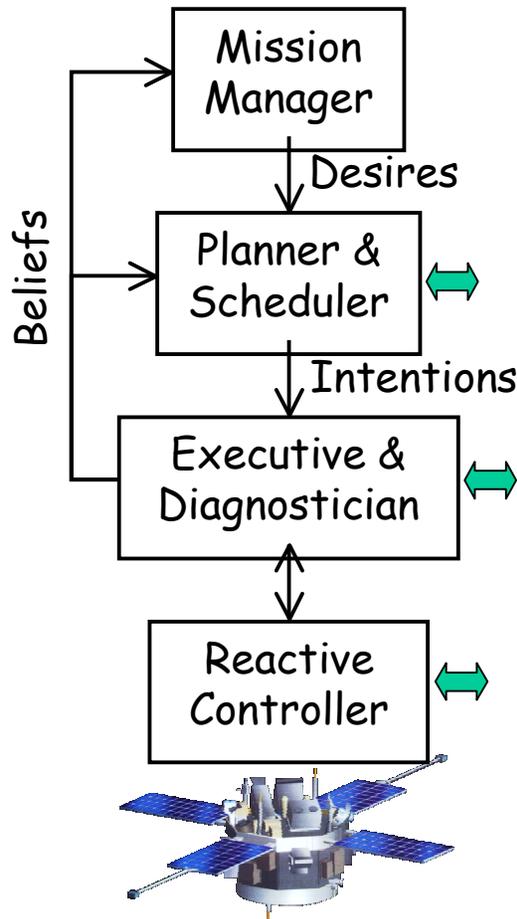
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Summary of Objectives

- To extend continual planning based autonomy to multiple spacecraft missions.
- Target Mission Class: Missions with spacecraft that cannot continually communicate during normal operations.
 - Highly separated formations like Constellation-X and LISA.
 - Signal space covering sensor webs like Magnetospheric Multiscale and Magnetospheric Constellation.

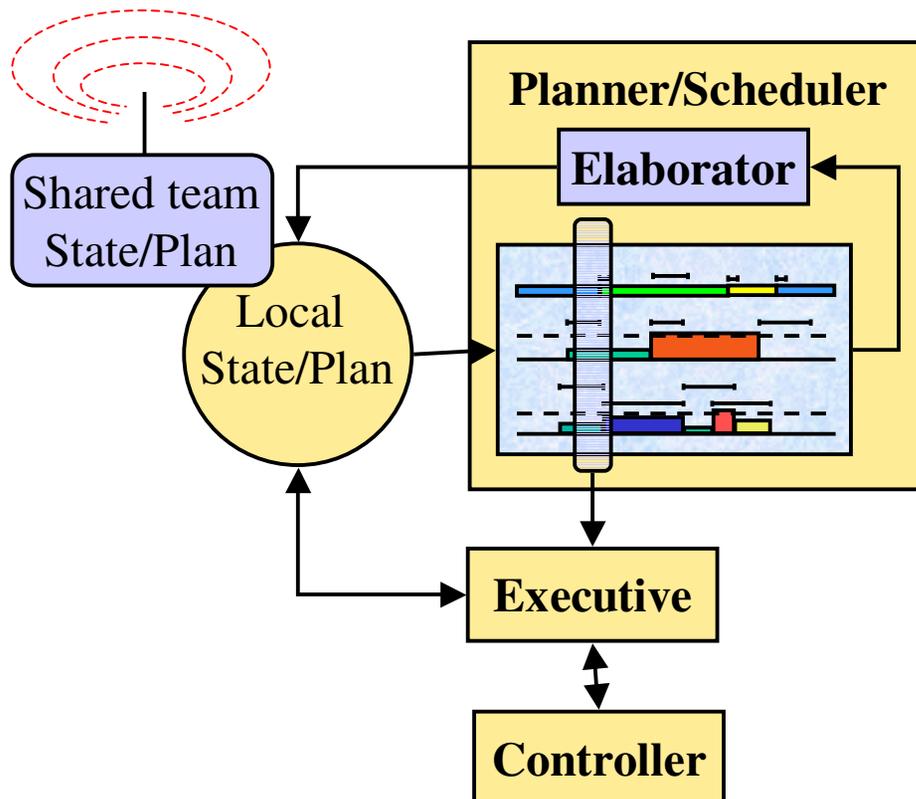
Types of Plan Coordination



- Goal distribution (planner comm.)
 - Each spacecraft satisfies goals in isolation
- Interaction avoidance (planner comm.)
 - Each spacecraft schedules its activities to avoid interactions
- Joint goals (planner and executive comm.)
 - Spacecraft work together to satisfy a joint goal
- Joint actions (communication at all levels)
 - Spacecraft have joint actions, like formation flying

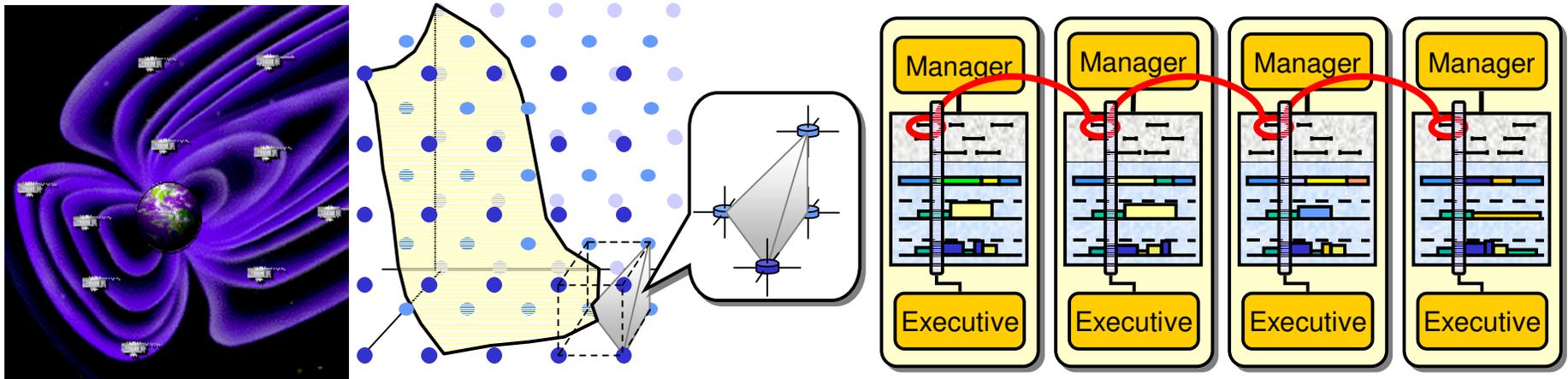
Approach

Change Negotiation



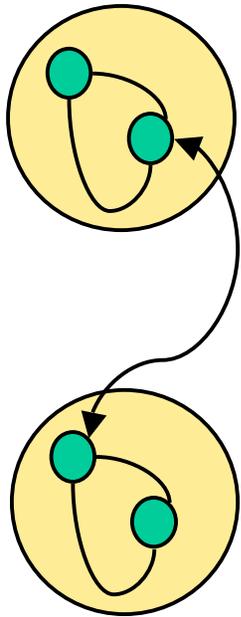
- Continual planning operates on each spacecraft.
- Points of coordination are modeled as shared “team” activities.
- Changes to the shared team activities are negotiated among teammates (a DCSP)
- Negotiation strategies are dynamically adapted to meet real-time deadlines by trading solution quality for negotiation convergence speed.

Obtained Results



- Developed a plan coordination infrastructure based on shared activities. (infused in MISUS)
- Developed a theory for predicting the performance of a DCSP resolution strategy.
- Designed protocol for mapping DCSP into distributed continual planning.

Argumentation Strategies



- Argumentation as Distributed CSP
 - When an agent communicates local variable assignments, it also communicates constraints leading to local assignments.
 - Other agents accelerate DCSP resolution by exploiting communicated constraints.
- DCSP strategies
 - **Max. cooperation:** choose local assignment that *maximizes* the flexibility of neighboring agents.
 - **Min. cooperation:** choose local assignment that *minimizes* the flexibility of neighboring agents.

Papers

- “Continual Coordination of Spacecraft through Shared Activities,” accepted by NASA Planning and Scheduling Workshop.
- “Enabling Efficient Conflict Resolution in Multiple Spacecraft Missions via DCSP,” accepted by NASA Planning and Scheduling Workshop.

Current/Future Activity

- Coordination framework currently coordinates static planning/scheduling, currently debugging the extension to interleaved execution in continual planning.
- Future activities involve dynamic negotiation strategy adaptation to enable sacrificing solution quality for improved response time and scaling issues.

Continual Coherent Team Planning

Anthony Barrett/JPL and Milind Tambe/USC

Goal: Enable distributed autonomy for missions with closely coordinated spacecraft (including formation fliers).

Objectives: Develop techniques that make multiple closely coordinated spacecraft continually manage their local plans while coherently scheduling and performing team activities in dynamic partially understood environments.

Key Innovations:

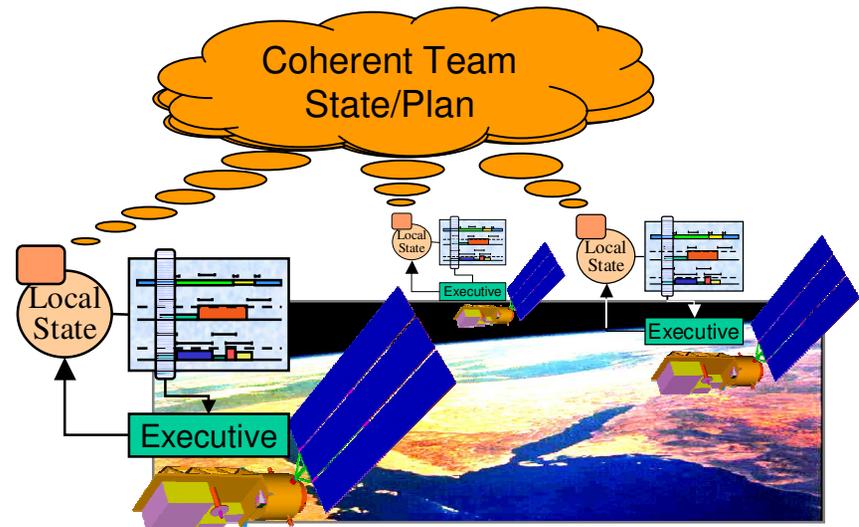
- *Dynamic Team Planning* will let agents delete, reschedule, and add team activities to adapt a team plan to the environment.
- *Negotiation by argumentation* will let agents negotiate to overcome incompatible models of their environment.
- *Negotiation strategy adaptation* will let the agents alter their approaches to negotiation based on real-time deadlines.

NASA Relevance:

- Enable missions with multiple spacecraft that coordinate *while responding to anomalies and opportunistic science data collection opportunities*. Such missions include: Bidirectional Reflectance Distribution Function (BRDF) S/C Clusters; Synthetic Aperture Radar (SAR) S/C Clusters; Radio and Optical Interferometers; and Robotic Outposts & Explorers
- Reduce Operations Tedium and Costs.

Accomplishments to date:

- Papers: “Planning with Resources at Multiple Levels of Abstraction,” ECP-01; “Continual Coordination of Spacecraft through Shared Activities,” To appear; “Enabling Efficient Conflict Resolution in Multiple Spacecraft Missions via DCSP,” To appear



Schedule:

- FY01: Investigate the convergence rate and real-time performance of various collaborative argumentation strategies and develop a continual planner that manages team plans.
- FY02: Develop negotiation strategies for coordinating continual team planners spread across multiple S/C.
- FY03: Protocols for dynamically adapting planning and negotiation strategies among multiple S/C.

Negotiation via Argumentation

- Observation: sending rationale for negotiated changes reduces communication overhead.
- CONSA Algorithm
 - Initial Phase: Agents recognize conflict.
 - Argumentation:
 - Propose resolutions with supporting justifications.
 - Strengthen or refute justifications of received resolutions.
 - Termination: Accept a resolution once its justification becomes strong enough.