Planning Autonomously in Mobile Swarms (PAMS)

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Overview

- **Presentation goal:**
  - To present an innovative approach to planning in complex space systems
- **Structure:**
  - Complex space systems
  - Planning problem and solution approaches
  - Application to constellations (PACT)
  - Distributed planning algorithm
  - Application to swarms (PAMS)

Complex space systems

- **Market trends:**
  - **more challenging missions**
  - **need to reduce costs**
- **Effects on complexity:**
  - **increasing autonomy**
  - **multi-element space systems:**
    - **constellations and formations**
    - **mobile swarms**

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The planning problem (1)

- **Current approach:**
  - **off-line, deliberative planning**
  - **centralised, on-ground**
  - **safety first and foremost**
- **Tool support:**
  - **spreadsheet/database and word proc.**
  - **AI-based tools emerging:**
    - **only expert systems operational**

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The planning problem (2)

- **Imagine:**
  - Darwin interferometry formation
  - Arthur C. Clarke mission
  - swarm of 20+ mobiles on Mars
- **Consequences:**
  - understanding on-board autonomy
  - communication and co-ordination
  - mission planning and scheduling

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The planning problem (3)

- **Existing approach:**
  - undermines autonomy
  - OR techniques not true match
  - impractical for > 20 elements
- **Clues to solution:**
  - autonomy drives on-board solution
  - existing approach does not scale up
  - centralisation is bottleneck

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Solution approach: trade-offs and choices

- **Trade-offs:**
  - on-ground vs. on-board
  - central vs. decentral
  - analytical vs. simulated
  - deliberative vs. reactive
  - off-line vs. on-line
- **Technologies:**
  - manual
  - OR
  - knowledge-based

- **Choices:**
  - OG -> OB
  - central -> decentral
  - analytical -> simulated
  - deliberative
  - off-line -> on-line
- **Choices:**
  - manual -> knowledge-based

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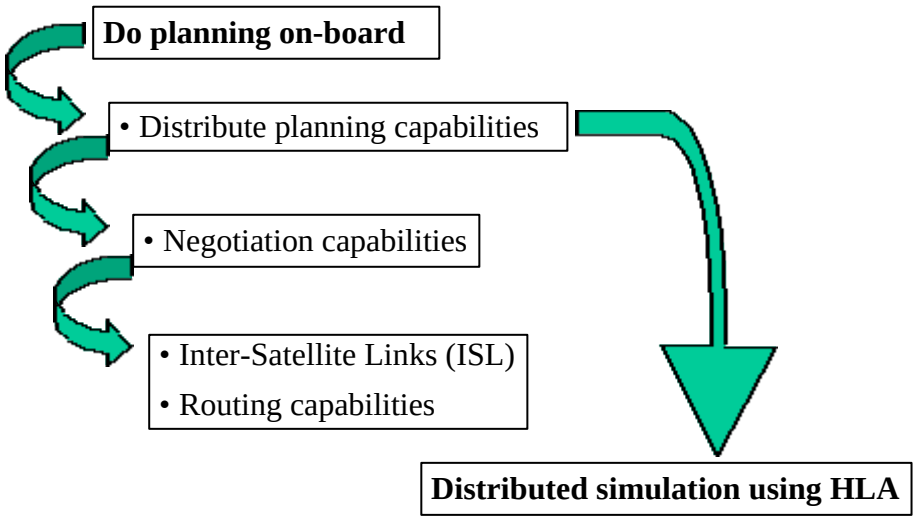
Solution approach: the Big Idea



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Applications: constellations (1)

- **Constellation application (PACT):**
  - **illustrative mission:**
    - **remote sensing**
    - **diverse instruments on smallsats**
    - **smallsats co-ordinate observations**
  - **issues:**
    - **planning co-ordinated activities**
    - **contention for downlinking**

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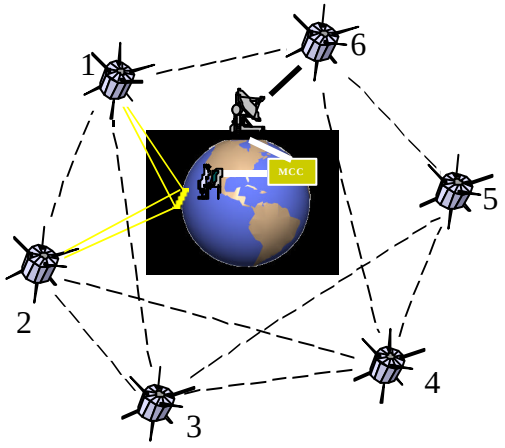
Applications: constellations (2)



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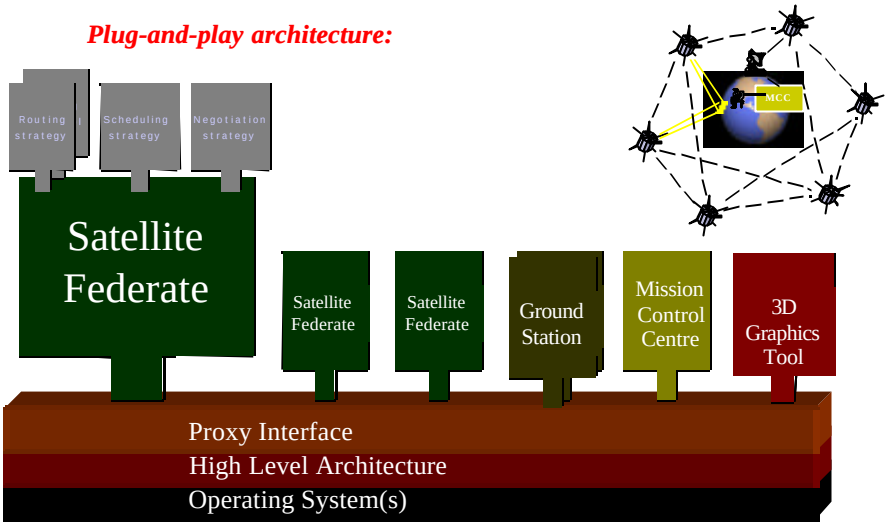
Applications: constellations (3)

Plug-and-play architecture:



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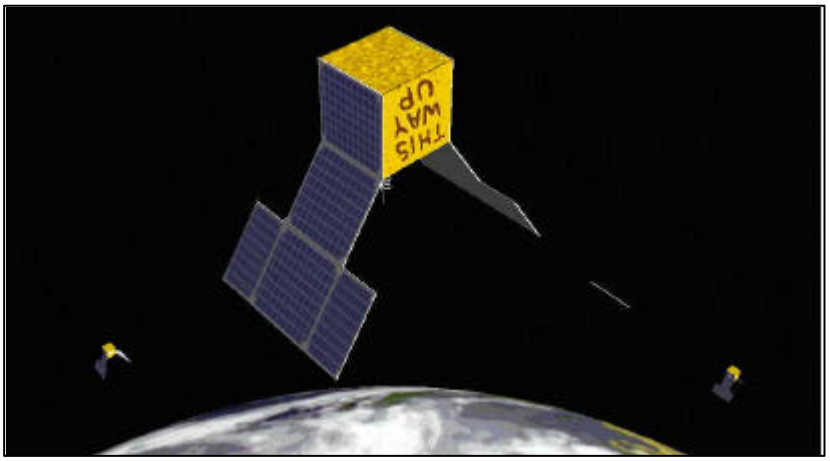
Applications: constellations (4)

Screendump from "PACT: the movie":



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Applications: constellations (5)

- **PACT project:**
  - **nationally-funded (NIVR)**
  - **two phases:**
    - **distributed planning (1998)**
    - **distributed scheduling (1999)**
  - **implementation:**
    - **up to 10 smallsats, over 4 PCs**
  - **total effort: one man-year**

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Distributed planning algorithm (1)

- **Key features:**
  - **mixes planning and negotiation**
  - **exchange of partial schedules**
  - **no "master" planner:**
    - **all elements capable of everything**
    - **"Solver" is *role* of element that first reaches complete solution**
    - **no element *needs* to maintain knowledge of others' capabilities**

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Distributed planning algorithm (2)

- **How it works:**
  - **Mission Control Centre:**
    - **OKs user's High Level Command**
  - **Ground station:**
    - **Uplinks HLC to nearest element**
  - **Elements (of constellation/swarm):**
    - **Decompose HLC into sub-goals**
    - **Negotiate "who-does-what"**
    - **Schedule and execute actions**

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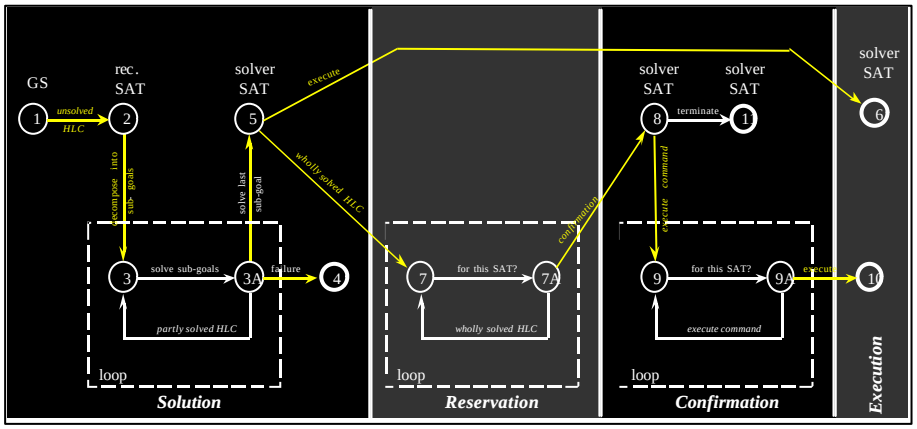
Distributed planning algorithm (3)

State-transition network for planning process:



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Distributed planning algorithm (4)

- **AI planning aspects:**
  - **(monolithic) algorithm split into parts**
  - **communication between parts**
  - **search tree becomes tree of messages**
  - **parallel search**
  - **breadth-first, no pruning, no heuristics**
    - ***in current implementation***

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Distributed planning algorithm (5)

- **It works, but …**
- **Limitations:**
  - **assumes perfect communications**
    - **only inter-element visibility modelled**
  - **diverse solutions developed**
  - **same solution can be duplicated**
  - **first (not “best”) solution adopted**

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Applications: swarms (1)

- **Mobiles application (PAMS):**
  - **illustrative mission:**
    - **Mars sample return**
    - **diverse instruments on micro-robots**
    - **mobiles co-ordinate for sampling**
  - **issues:**
    - **planning co-ordinated activities**
    - **relative navigation**

Applications: swarms (2)

Applications: swarms (3)

- **PAMS challenges:**
  - **suitable illustrative application:**
    - **interacting mobiles**
  - **suitable partnerships**
  - **technical issues:**
    - **esp. hardware interfacing**
- **PAMS status:**
  - **awaiting funding**

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Applications: others

- **Other applications:**
  - **complex space systems:**
    - **multiple robot arms**
    - **robots + astronauts**
    - **multiple astronauts**
    - **astronaut(s) + PI team**
  - **non-space systems:**
    - **air/road/rail traffic management**

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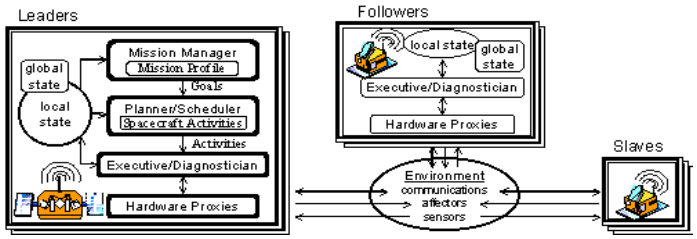
JPL's approach (1)

- **JPL's approach:**
  - **distributed spacecraft and rovers**
  - **three architectures identified:**
    - **master-slave, leader-follower, peer-to-peer**



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JPL's approach (2)

- **Comparison:**
  - **what we have in common with JPL:**
    - **on-board planning**
  - **but JPL architectures all centralised:**
    - **"master", "leader", "auctioneer"**
    - **becomes bottleneck when scaling up**
  - **by contrast, our approach:**
    - ***decentralised* peer-to-peer**

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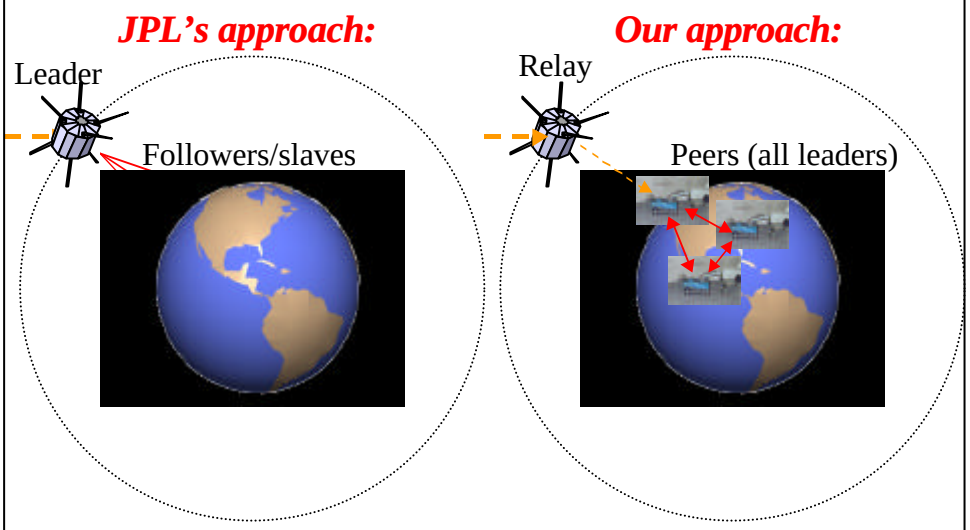
JPL's approach (3)



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Conclusions

- **Status:**
  - **innovative concept**
  - **feasibility proven**
- **Needs:**
  - **illustrative application to mobiles**
  - **partnerships**
  - **address technical issues**

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