Self-Organizing MPS for Dynamic EO Constellation Scenarios

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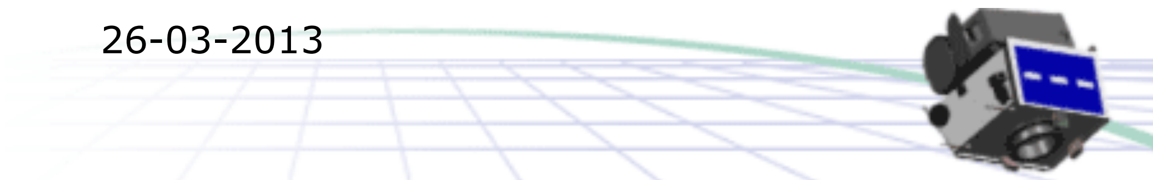


Context

- Multiple platform scenarios
  - constellation
  - cluster
  - swarm
- Coordination ➔ planning
- Current examples
  - Autonomous Operations (Lenzen et a. 2011)
  - Disaster management: Sensorweb (Chien et al., 2011) EO (Pralet et al., 2011)
  - Coordination as optimization (Grasset-Bourdel et al., 2011; De Florio 2006)

Outline

- Case Study: DMC Constellation
- Proposed Approach
  - Technical Background: Ant Colony Optimization
- Empirical Evaluation
- Conclusions & Future Work

Case Study: DMC constellation

Case Study:
Disaster Monitor Constellation

Ground-based Automated System for the Campaign Imaging Planning & Scheduling of the DMC constellation. This platform is composed of 6 Earth Observation mini-satellites.

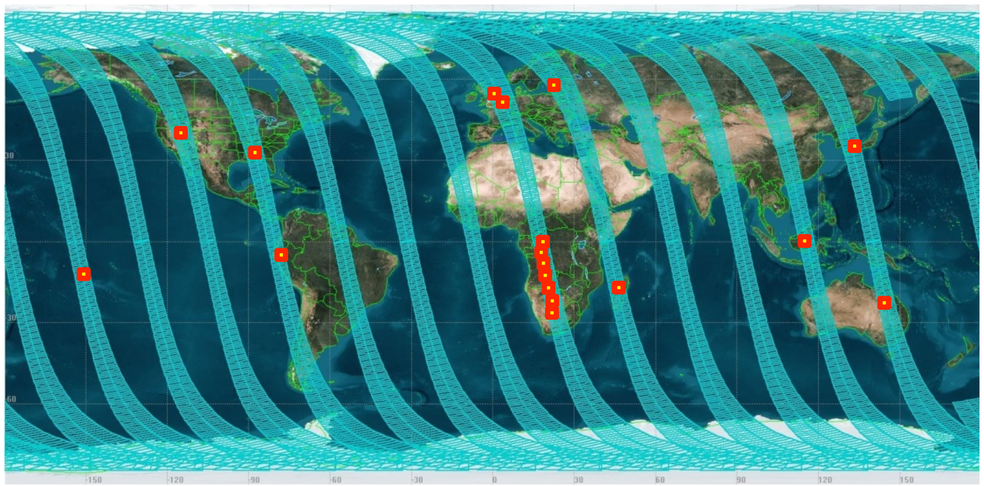
Requirements:

- **Efficiency**, maximizing the performance to serve the highest number of user.
- **Adaptability**, reacting to the new requests with the minimum impact on the current plan.
- **Coordination**, avoiding duplications of the targets among the satellites' plans.

Constraints Considered:

- Total Memory Available
- Temporal constraints between imaging requests

UK-DMC2



Case Study: Disaster Monitor Constellation

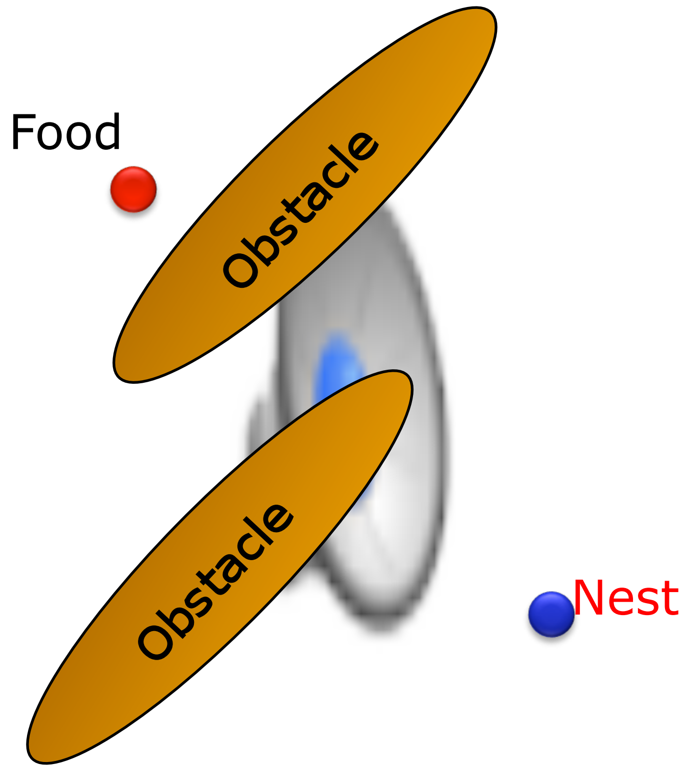
- Constellation should respond to a number of image requests
  - # of allocated requests
  - returning time
  - dynamic asynchronous requests
- Conflicting requirements
  - e.g., adaptability vs. efficiency
  - e.g., coordination vs. scalability

Proposed Approach

Ant Foraging Pattern

While looking for food, ants leave traces of pheromones along the path. These traces influence the following ants to get on the same path.

However only the shortest path will end having the strongest pheromone distribution as is the one that requires the minimum travelling time.



Engineering benefits:

- Efficiency
- Adaptability
- Self-Organizing Coordination

Ant Colony Optimization - ACO

Family of stochastic techniques for solving combinatorial optimization problems reduced in finding good paths through graphs, Dorigo 1996.

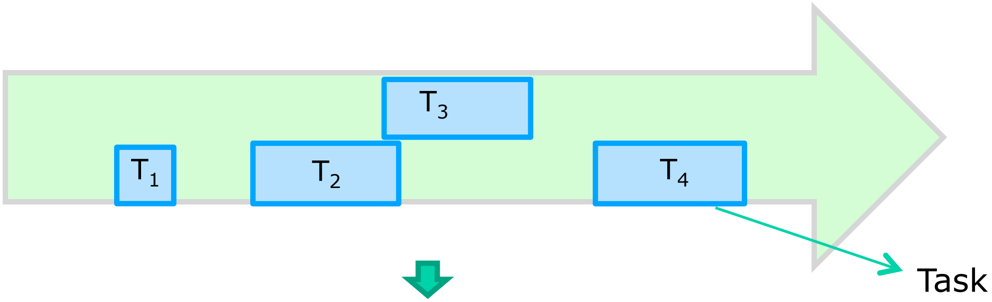
ACO workflow

- **Construction Phase**: the ant navigates the graph using a probabilistic rule, function of the pheromone trail.
- **Objective Function Evaluation**: the path quality is determined using an objective function.
- **Depositing Phase**: the ant deposits on its path an amount of pheromones, function of the path quality.

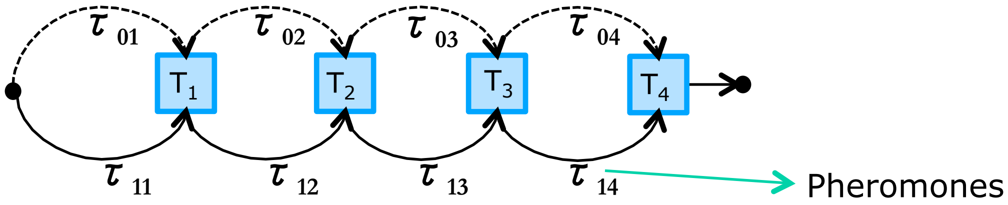
Automated Planning & Scheduling Systems

Problem modelling

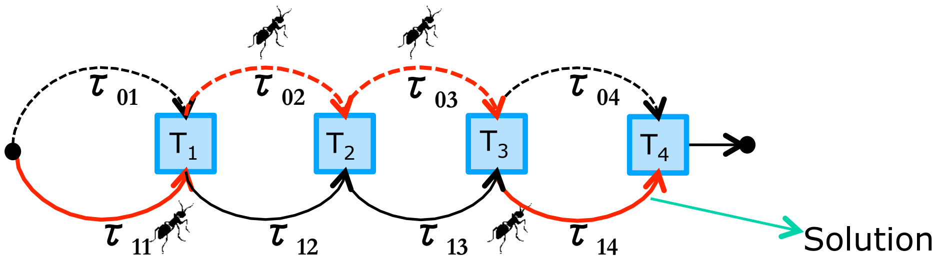
Planning Problem Timeline:



Binary Chain:



Ant Colony:



System Output:

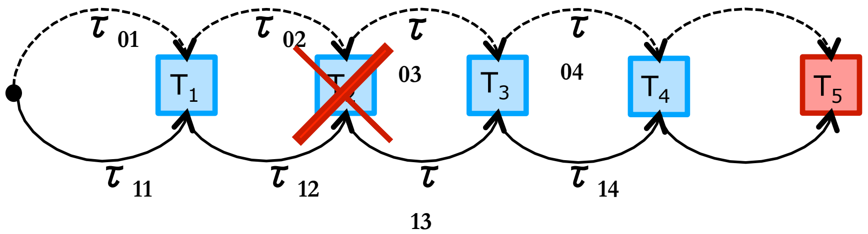
Binary representation: **1001**

Tasks scheduled: $\mathbf{T_1, T_4}$

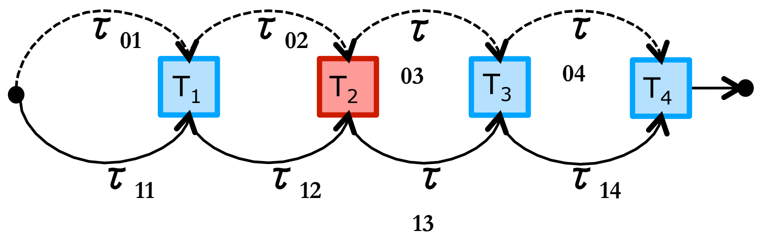
Facing Dynamic Problems
Dynamic Binary Chain

Event modelling:

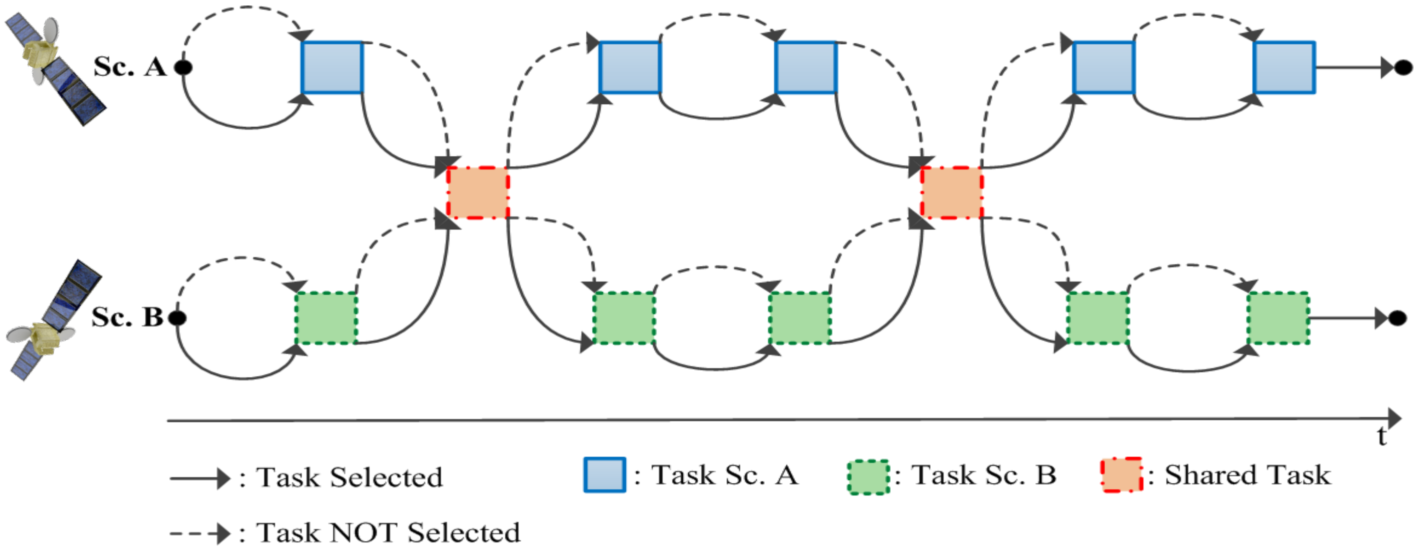
- **Add or Remove a task**



- **Change task's properties**



Problem modelling: multiple spacecrafts



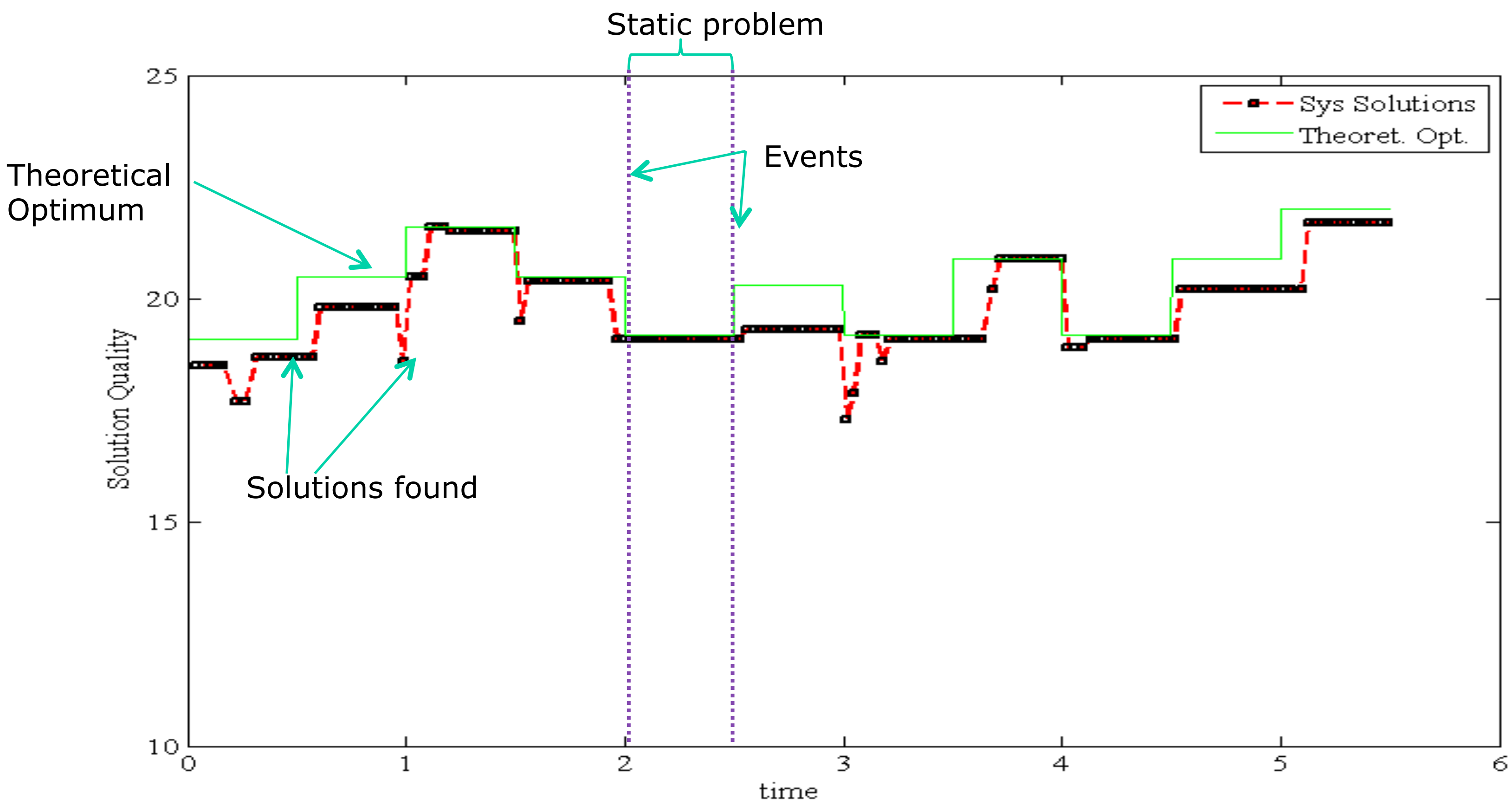
- Each spacecraft is associated with a **binary chain**, representing the imaging targets requested.

- Coordination between satellites based on pheromones
  - Tasks shared among the satellites are modelled as intersections among the satellites' binary chains.
  - The pheromone field of one spacecraft inhibits the ants of the other spacecraft, avoiding duplications.

Empirical Evaluation

Adaptability Example

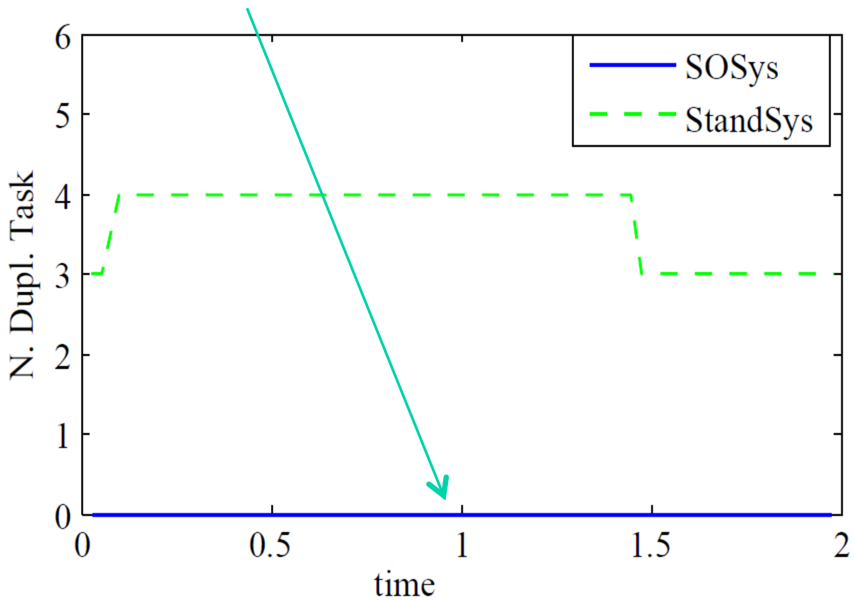
- Single run on a **single** spacecraft **dynamic** problem (10 events on one run).
- Events: change number of tasks, change task's properties.
- Theoretical optimum calculated using a complete determinist algorithm.
- A new plan is obtained every time the system converges on a new path (black dots)



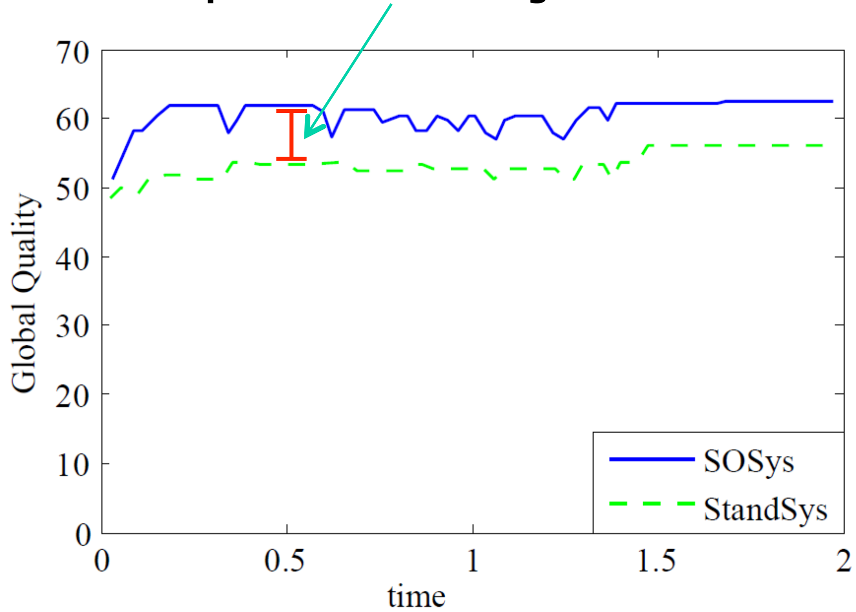
Coordination Example

- Single run on a **multi**-spacecraft **static** problem (3 spacecraft).
- 20% of the tasks are shared.
- Comparison between generic system allowing duplication (StandSys) and a system implementing our coordination mechanism (SOSys).

Never Duplications

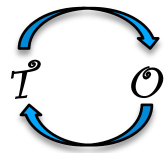


Improvement at the global level



Conclusions & Future work

Conclusions



- Novel concept for an automated P&S system applied to dynamic scenarios based on natural-inspired problem solving strategies.

- The technique presented shows the following benefits:
  - **Reliable**, it is based on a solid mathematical model.
  - **Efficiency**, it is able to offer a near-optimal solution at any time.
  - **Adaptability**, it is able to adapt the solution to asynchronous events.
  - **Scalability**, it offers high scalability in terms of number of satellites.

- Aspects to be considered:
  - **Problem Modelling**, translating the problem in a binary chain.
  - **Black box**, reasoning chain not available.
  - **Stochastic nature**, nondeterministic system.
  - **Cost & Operational feasibility**, change in the Operational workflow.

Conclusions & Future work

Future Work

- Quantitate analysis of the system's performance in multiple scenarios and comparison with other techniques
- System integration on the DMC constellation MPS
- Transferability evaluation on ESA missions

More info..

Publications:

- Journal paper "The Dynamics of Ant Colony Optimization Algorithms Applied to Binary Chains" Swarm Intelligence 6, no. 4 (2012), Springer.
- Conference paper "A Novel ACO Algorithm for Dynamic Binary Chains Based on Changes in the System's Stability" at 2013 IEEE Swarm Intelligence Symposium.
- Conference paper " Highly Responsive MPS for Dynamic EO Scenarios" at the 12th International Conference on Space Operations, SpaceOps 2012. Stockholm.

Questions