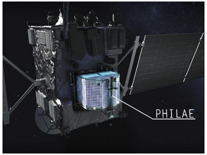
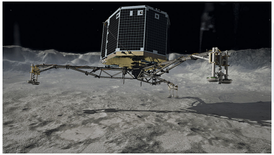
LAAS Days
Research & Technology

”Des plans sur la comète”: the Contribution of Combinatorial Optimization to Rosetta/Philae

Christian Artigues, Emmanuel Hebrard, Pierre Lopez, Gilles Simonin





Rosetta: mission timeline & science campaign scheduling

Goal : To rendezvous with Comet 67P/Churyumov-Gerasimenko and to study the nucleus of the comet and its environment for nearly two years, and land a probe on its surface.

nov 1993 Mission approved by ESA

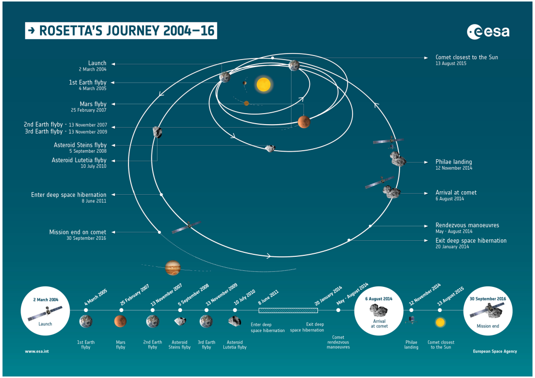
mar 2004 Rosetta launched by Ariane 5G+

aug 2014 Arrival at comet

nov 2014 Philae's landing and science campaign
An algorithm designed at LAAS was used to schedule Philae's scientific experiments

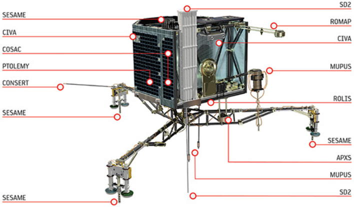
dec 2014 Rosetta's science campaign
Rosetta's scientific activities scheduled by ASPEN, a NASA JPL software
[Chien S. et al., Activity-based scheduling of science campaigns for the Rosetta Orbiter, in IJCAI'15]

sep 2016 Rosetta landed on 67P. End of the mission



Philae's scientific experiments on comet 67P

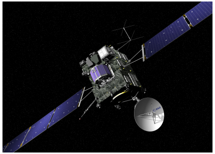
- 10 instruments / 18 experiments
- Designed by 14 European Countries
- Limited resources :
  1kWh battery & 6Mb Mass memory (!)



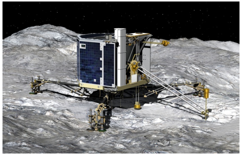
LAAS R&T Days

Experiment planning and scheduling process

Rosetta



Philae



SONC

CNES - Toulouse

Software:
Mission Operation Scheduling Tool (MOST)

$\simeq$ 50 min (500,000,000km)

LCC

DLR - Cologne

ESOC

ESA - Darmstadt

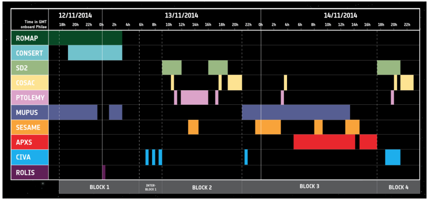
Ground station

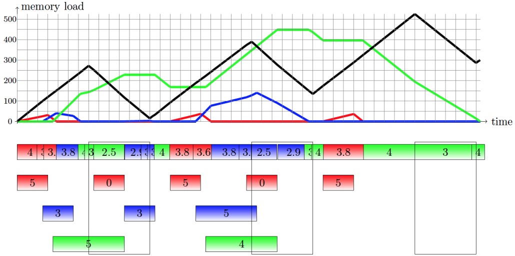
ESA - New Norcia

A complex resource-constrained scheduling problem

- Each experiment is made of one or several elementary tasks
- Each task has to be scheduled
- Precedence constraints
- Maximum power usage constraints
- Memory usage & Data transfer constraints (depending on Rosetta's visibility!)

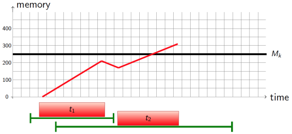
Objective: make the maximum number of experiments with the available energy and without data loss

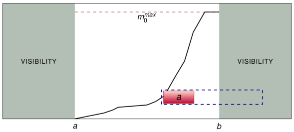




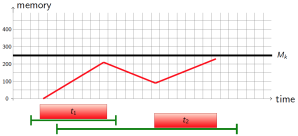
Good and bad schedules

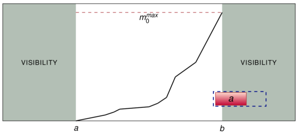
Bad schedule





Good schedule



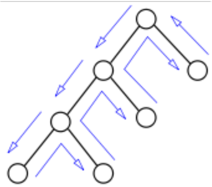


- an NP-hard Combinatorial Optimization problem with a possibly huge search space
- Enumerating with a computer able to performed 10^{10} instructions per second all solutions to schedule 10 tasks on 100 time slots would take 325 years

Issues in the first version of the MOST algorithm

A first version of the MOST algorithm was designed from 1998 to 2011 by CNES IT subcontractors

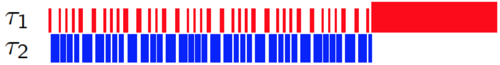
- Constraint Programming Technology: integration of Operations Research and Artificial Intelligence
- Data Transfers were naively modeled: huge number of dummy transfer tasks
- Exhaustive enumeration of schedules on the time horizon (250 000 seconds)



Realistic scenarios could not be solved within hours. LAAS was involved in 2011 in a collaboration with CNES/SONC to analyse the algorithm weaknesses and propose an alternative solution.

Our solution: a fast constraint programming algorithm

- A more accurate "bandwidth" model for data transfers and memory usage.
  a global data transfer constraint
- A fast $O(n \log n)$ "sweep" algorithm to check that a partial schedule is data loss-free
- Constraint propagation algorithms : enforcing necessary conditions for avoiding bad schedules

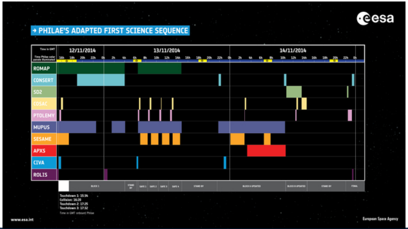


CPU Time comparison for scheduling all experiments

about 11000 seconds (previous algorithm), about 5 seconds (our algorithm)

Now what eventually happened...

- Unexpected rebound after touch down due to harpoon failure
- Recourse schedule had to be rebuilt in a short time frame,...
- ...which was made possible thanks to the reactivity of the algorithm

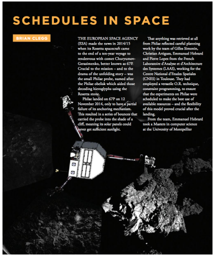


The first ever landing on a comet was finally a success !

Questions?

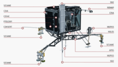
Gilles Simonin, Christian Artigues, Emmanuel Hebrard, Pierre Lopez: Scheduling scientific experiments for comet exploration. Constraints 20(1): 77-99 (2015)

Best Application Paper Award CP 2012 – ACP success story “CP has landed on a comet” – Euro Excellence in Practice Award 2016 Finalist



SUCCESS STORIES

CP Has Landed on the Comet



On June 13th 2015, the robot-lab Philae woke up on the comet 67P/Churyumov-Gerasimenko to resume a series of experiments interrupted seven months ago. These experiments were scheduled using Constraint Programming, and researchers of the team ROC

Thus LAAS had an important contribution in the tool set up. It made it much more reactive and indeed operable in the critical phase of the First Science Sequence. This was especially fortunate because the unexpected rebound after the first touch-down forced the SONC team to adapt the science operational sequence to the new Philae location within a very tight time frame. The LAAS implication was highly appreciated by the MOST operational experts and by the SONC operational manager. I can personally deem that P. Lopez’s team deserves an award for this work.

The Rosetta project manager at CNES,

Philippe GAUDON