2011 15th International Software Product Line Conference

Families (of products) in Space

Extended Abstract

Mike Hinchey
Lero–the Irish Software Engineering Research Centre
University of Limerick
Limerick, Ireland
mike.hinchey@lero.ie

Abstract

NASA is developing plans for innovative and novel approaches to future (unmanned) space exploration missions. Future missions involve sending spacecraft and robots to harsh environments, where resilience is necessary for the survival of the mission. In addition, distances and communication lead times between the spacecraft and Earth necessitate much of the mission operation being autonomous.

We have been conducting research on the development of autonomous space exploration missions based on principles from Autonomic Computing (AC), whereby the mission is imbued with self-management capabilities. Such missions will involve several, rather than single, spacecraft, robots or other devices, operating in collaboration.

We describe one such concept mission, ANTS (Autonomous Nano-Technology Swarm), which involves a number of sub-missions that are self-similar. Our work in this, and other future missions, has involved the use of techniques from AC for building in self-management, and ultimately self-governance. We have also explored the use of formal methods to gain confidence in the correct behavior of the mission. Since both the physical devices which will be used for exploration, and the software that is essential for their successful deployment, lend themselves to a product-line approach, we have been exploiting techniques from software product-line engineering, in particular Multi-Agent System Product Lines (MAS-PL) and Dynamic Software Product Lines (DSPL).

I. Introduction

NASA is investigating the use of swarm technologies for the development of sustainable exploration missions that will be autonomous and exhibit autonomic properties [1].

The idea is that biologically-inspired swarms of smaller spacecraft offer greater redundancy (and, consequently, greater protection of assets), reduced costs and risks, and the ability to explore regions of space where a single large spacecraft would be impractical.

ANTS is a NASA concept mission, a collaboration between NASA Goddard Space Flight Center and NASA Langley Research Center, which aims at the development of revolutionary mission architectures and the exploitation of artificial intelligence techniques and the paradigm of biological inspiration in future space exploration. The mission concept includes the use of swarm technologies for both spacecraft and surface-based rovers, and consists of several sub-missions [2]:

- SARA: The Saturn Autonomous Ring Array will launch 1000 pico-class spacecraft, organized as ten sub-swarms, each with specialized instruments, to perform in situ exploration of Saturn's rings, by which to understand their constitution and how they were formed. Additionally, autonomous operation is necessary for both manoeuvring around Saturn's rings and collision avoidance.
- PAM: Prospecting Asteroid Mission will also launch 1000 pico-class spacecraft, but here with the aim of exploring the asteroid belt and collecting data on particular asteroids of interest for potential future mining operations.
- LARA: Lander Amorphous Rover Antenna will exploit new NASA-developed technologies in the field of miniaturized robotics, which may form the basis of remote landers to be launched to the moon from remote sites, and exploit innovative techniques to allow rovers to move in an amoeboid-like fashion over the moon's uneven terrain.
- ALMA: Autonomous Lunar Manual Assistant, tethered to another rover will collect samples from the lunar surface, or potentially from other planets or planetoids.

II. Software Product Line Engineering

While the ANTS sub-missions may sound very different—one involves flying through the gaseous rings of Saturn, one involves collecting data from the Asteroid Belt, and the others involve robotic devices that will collect data from the moon's surface—they have much in common:

978-0-7695-4487-8/11 $26.00 © 2011 IEEE
DOI 10.1109/SPLC.2011.49

- Each of the physical devices will be built using the same carbon nanotube technology and reliant on solar sails, or equivalents, for power provision.
- The core functionality of the software involves navigation (albeit either "flying" or "crawling" on a lunar surface), achieving resilience through self-protection in a harsh environment (mainly achieved through suspending activity in times of threat), conducting a mission involving science data collection, its processing, and planning for future data collection based on the data collected to date.
- Each of the swarms used in the sub-missions, while varying in size and physical appearance, will achieve its goals through software that exhibits properties of an Autonomic System.

There are, of course, also variabilities. A device that "flies" will not use exactly the same software as one that "crawls". Protection from Saturn's radioactive rings poses other challenges above and beyond those of collision avoidance with asteroids, which is in turn far more complex than avoiding obstacles on a planet or planetoid surface. They must also operate various miniaturized instruments.

The sub-missions will exhibit self-(re-)configuration, self-healing, self-organization and self-protection (plus several others self-★ properties) in various forms and will achieve these in various ways.

The sub-missions, therefore, are prime examples for software product line engineering.

They must exhibit high levels of autonomy due to the complex nature of their activities, the need for resilience in harsh environments, and the need to adapt to damage from collisions and solar storms in order to continue their work. As such, they exhibit the properties of a Dynamic Software Product Line (DSPL) [3], which will be highlighted in the talk.

Since these sub-missions involve the use of agent-based technology (while there is no requirement that AC systems use agents, the trend is in that direction) [4], we have been investigating the use of Multi-Agent System Product Lines (MAS-PL) as a means of structuring these concept exploration missions and exploiting the benefits of software product line engineering [5].

III. Conclusion

Future space exploration missions will offer many challenges. They will need to be resilient in space, and essentially self-managing in order to achieve their science goals and ensure the longterm "health" of the mission. Such missions will require the use of techniques from Autonomic Computing, and likely formal methods in order to be able to prove that inappropriate behavior will not emerge.

These are concept missions that may ultimately inspire all future NASA (unmanned) missions with the use of swarms (or at least large numbers of) very similar spacecraft becoming commonplace.

Software product line engineering, and in particular Dynamic Software Product Lines, also has a potential role to play in reducing the amount of development effort, providing for economies, and enabling higher levels of assurance in these complex missions.

Acknowledgement

The research described in this talk involved collaboration with a number of colleagues, most notably: Svein Hallsteinsen, Sooyong Park, Joaquin Peña, Jim Rash, Chris Rouff, Klaus Schmid, Roy Sterritt, Walt Truszkowski, and Emil Vassev. This work was supported in part by Science Foundation Ireland grant 03/CE2/I303_1 to Lero—the Irish Software Engineering Research Centre and by the NASA Office of Systems and Mission Assurance (OSMA) through its Software Assurance Research Program (SARP), administered by the NASA IV&V Facility, Fairmont, WV.

References

1. Truszkowski, W.F., Hinchey, M.G., Rash, J.L., Rouff, C.A.: "Autonomous and autonomic systems: A paradigm for future space exploration missions." IEEE Trans. on Systems, Man, and Cybernetics, Part C 36(3):279–291, 2006.
2. Hinchey, M.G., Sterritt, R.: "99% (Biological) Inspiration." In *Biologically Inspired Cooperative Computing*, IFIP International Federation for Information Processing, Volume 216, Pan, Y, Rammig, F., Schmeck, H., Solar, M., eds., pp. 7-20, Springer, Boston, 2009.
3. Hallsteinsen, S., Hinchey, M., Park, S.-Y. and Schmid, K., "Dynamic Software Product Lines." *Computer*, 41(4):93-95, April 2008.
4. Hinchey, M.G., Sterritt, R.: "Self-managing software." *Computer*, 39(2):107–109, February 2006.
5. Peña, J., Hinchey, M.G., Cortes, A.R.: "Multi-agent system product lines: challenges and benefits." *Comm. of the ACM*, 49(12):82–84, December, 2006.