Modeling the Image-Processing Behavior of the NASA Voyager Mission with ASSL
Presentation

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AC & Space Exploration

Autonomic Computing (AC) – a solution to software complexity:

- Helps to implement self-adaptive and autonomic systems (ASs);
- Autonomic elements (AEs) – the architectural components of an autonomic system (AS)
- AC may handles complexity in spacecraft computer systems

The new age of space exploration: NASA embarks in AC

- AC software helps to build the next generation of unmanned spacecraft;
- Autonomous Nano-Technology Swarm (ANTS) concept mission;
- Deep Space One (DS1) mission;
Introduction

Our Approach – Prototyping with ASSL

AC-based Voyager-like missions:
✓ Investigate hypotheses about the design and implementation of future Voyager-like missions based on the AC principles.

✓ Build prototype software models:
  ✓ help in the comparison of features and issues of the actual Voyager mission with hypothesized possible autonomic approaches;
  ✓ bring significant benefits to the development of future space-exploration systems.

✓ We experiment with ASSL (Autonomic System Specification Language) to realize these goals.
Voyager and Our Research Objectives

The Voyager Mission

- an extremely successful example for future space missions;
- designed for exploration of the Solar System;
- continue to explore the space: now on the special Voyager Interstellar Mission;

Factors of success:
- rigorous spacecraft design and implementation;
- spacecraft hardware was designed to allow for enhanced remote control programming;
- autonomous behavior persists in the Voyager requirements;

Objectives

Long-term objectives:

- model and implement with ASSL AS prototypes of future Voyager-like missions;
- benchmark experiments - compare prototyped autonomic features and issues with the actual Voyager Mission;
- validate features in question and perform further investigations based on practical results under simulated conditions;

First objective:

- specify with ASSL and generate a prototype model for the *image-processing behavior* observed in the Voyager mission.

Event-driven behavior: *Voyagers are able to detect space objects and take pictures of the same on-the-fly*
Specification Model

I. Autonomic System (AS)
- AS Service-Level Objectives
- AS Self-Management Policies
- AS Architecture
- AS Actions
- AS Events
- AS Metrics

II. AS Interaction Protocol (ASIP)
- AS Messages & Negotiation Protocol
- AS Communication Channels
- AS Communication Functions

III. Autonomic Element (AE)
- AE Service-Level Objectives
- AE Self-Management Policies
- AE Friends
- AE Interaction Protocol (AEIP)
  - AE Messages & Negotiation Protocol
  - AE Communication Channels
  - AE Communication Functions
  - AE Managed Resource Interface
- AE Recovery Protocols
- AE Behavior Models
- AE Outcomes
- AE Actions
- AE Events
- AE Metrics

- scalable specification model;
- provides judicious selection and configuration of infrastructure elements and mechanisms for ASs;
- decomposes an AS in two directions – 1) into levels of functional abstraction; 2) into functionally related sub-tiers;
- presents the system from three different perspectives – 1) AS; 2) ASIP; 3) AE;
- meets the AS builders needs;
- flexible approach to specification.
ASSL

Specifying and Generating Prototypes with ASSL

- ASSL tiers - intended to specify different aspects of an AS, but only a few are needed to come up with a working model;

- an ASSL specification is built around self-management policies, which make that specification AC-driven;

- a complete specification:
  - is validated with a built-in consistency checking tool;
  - is used to automatically generate a functional prototype.

- generated prototypes: fully-operational multithreaded event-driven applications with embedded messaging;
Specifying and Generating Prototypes with ASSL

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generate 

ASSL Policy Specification

ASSELF_MANAGEMENT {
  SELF_HEALING {
    FLUENT inLosingSpacecraft {
      INITIATED_BY { EVENTS.spaceCraftLost }
      TERMINATED_BY { EVENTS.earthNotified }
    }
    MAPPING {
      CONDITIONS { inLosingSpacecraft }
      DO_ACTIONS { ACTIONS.notifyEarth }
    }
  }
}
Specified Image-Processing Behavior

1. The Voyager II spacecraft:
   • uses its cameras to monitor space objects;
   • takes a picture with its cameras;
   • notifies Earth that an image transmission is about to start;
   • applies color filters and sends the stream of pixels to Earth;
   • notifies antennas on Earth for the end of each session.

2. Antennas on Earth:
   • are prompted to receive the image by special messages (one per applied filter);
   • receive image pixels;
   • are prompted to terminate the image sessions by special messages;
   • send the collected images to the Voyager Mission base on Earth.

3. The Voyager Mission base on Earth receives images from antennas.
we specified Voyager at the three main ASSL tiers – AS tier, ASIP tier, and AE tier;

we specified the Voyager II spacecraft and the antennas on Earth as AEs that:

- follow their encoded autonomic behavior;
- exchange predefined ASSL messages over predefined ASSL communication channels.

the Voyager mission autonomic behavior is specified at both AS and AE tiers as a self-management policy:

- the global autonomic behavior is determined by the specification of that policy at each AE and at the global AS tier.
ASSL Model for Voyager

ASSL Specification - AS Tier specification

✓ IMAGEPROCESSING self-management policy

```plaintext
FLUENT inProcessingImage_AntSpain {
  INITIATED_BY { EVENTS.imageAntSpainReceived }
  TERMINATED_BY { EVENTS.imageAntSpainProcessed }
}

MAPPING {
  CONDITIONS { inProcessingImage_AntAustralia }
  DO_ACTIONS { ACTIONS.processImage("Antenna_Australia") }
}

ACTION IMPL processImage {
  PARAMETERS { string antennaName }
  GUARDS {
    ASSELF_MANAGEMENT_OTHER_POLICIES.
    IMAGE_PROCESSING.inProcessingImage_AntAustralia
    OR
    ASSELF_MANAGEMENT_OTHER_POLICIES.
    IMAGE_PROCESSING.inProcessingImage_AntJapan
    ...
  }
  TRIGGERS {
    IF antennaName = "Antenna_Australia" THEN
      EVENTS.imageAntAustraliaProcessed
    END ELSE ...
  }
}

EVENT imageAntSpainReceived {
  ACTIVATION {
    RECEIVED { ASIP_MESSAGES.msgImageAntSpain }
  }
}

EVENT imageAntSpainProcessed {
}
```
ASSL Specification – AE Voyager

✓ IMAGE_PROCESSING self-management policy

ASSL Model for Voyager
ASSL Specification – Antenna AEs

✓ IMAGE_PROCESSING self-management policy

```plaintext
FLUENT inStartingGreenImageSession {
    INITIATED_BY { EVENTS.greenImageSessionIsAboutToStart }
    TERMINATED_BY { EVENTS.imageSessionStartedGreen }
}
FLUENT inCollectingImagePixelsBlue {
    INITIATED_BY { EVENTS.imageSessionStartedBlue }
    TERMINATED_BY { EVENTS.imageSessionEndedBlue }
}

EVENT greenImageSessionIsAboutToStart {
    ACTIVATION { SENT { AES.Voyager.AEIP.MESSAGES. 
                        msgGreenSessionBeginAus } }
}
EVENT imageSessionStartedBlue {
    ACTIVATION { RECEIVED { AES.Voyager.AEIP.MESSAGES. 
                               msgBlueSessionBeginAus } }
}
```
Structure of the Generated Prototype

- a pure software solution – both spacecraft and antennas are implemented as interacting components in a Java application;
- has a multi-granular structure composed of instances (objects) of the specified tiers in the ASSL specification:
  - a hierarchical composition where sub-tier instances are grouped around instances of major tiers.
Behavior of the Generated Prototype

✓ log records show important state-transition operations ongoing in the system;
✓ these records help to trace and evaluate the behavior of the generated prototype model;

Test results:

*The run-time behavior of the generated prototype model for the Voyager II mission strictly followed that specified with the ASSL IMAGE_PROCESSING self-management policy.*
**Behavior of the Generated Prototype**

- Log records show important state-transition operations ongoing in the system.
- These records help to trace and evaluate the behavior of the generated prototype.

**Test results:**

The run-time behavior of the generated prototype model for the Voyager II mission strictly followed that specified with the ASSL IMAGE_PROCESSING self-management policy.

```plaintext
99) EVENT 'as.aes.voyager.events.TIMETOTAKEPICTURE': has occurred
100) FLUENT 'as.aes.voyager.aeself_management.image_processing.INTAKINGPICTURE': has been initiated
101) ACTION 'as.aes.voyager.actions.TAKEPICTURE': has been performed
102) EVENT 'as.aes.voyager.events.PICTURETAKEN': has occurred
103) FLUENT 'as.aes.voyager.aeself_management.image_processing.INTAKINGPICTURE': has been terminated
104) FLUENT 'as.aes.voyager.aeself_management.image_processing.ENPROCESSINGPICTUREPIXELS': has been initiated
105) ACTION 'as.aes.voyager.actions.PROCESSFILTEREDPICTURE': has been performed
106) ACTION 'as.aes.voyager.actions.PROCESSFILTEREDPICTURE': has been performed
107) ACTION 'as.aes.voyager.actions.PROCESSFILTEREDPICTURE': has been performed
108) ACTION 'as.aes.voyager.actions.PROCESSPICTURE': has been performed
109) EVENT 'as.aes.voyager.events.PICTUREPROCESSED': has occurred
110) EVENT 'as.aes.antenna_japan.events.BLUEIMAGESSESSIONISABOUTTOSTART': has occurred
111) EVENT 'as.aes.antenna_spain.events.REDIMAGESSESSIONISABOUTTOSTART': has occurred
112) FLUENT 'as.aes.antenna_spain.aeself_management.image_processing.INSTARTINGREDIMAGESSESSION': has been initiated
113) FLUENT 'as.aes.antenna_japan.aeself_management.image_processing.INSTARTINGBLUEIMAGESSESSION': has been initiated
114) EVENT 'as.aes.antenna_spain.events.BLUEIMAGESSESSIONISABOUTTOSTART': has occurred
115) FLUENT 'as.aes.voyager.aeself_management.image_processing.INPROCESSINGPICTUREPIXELS': has been terminated
```
Discussion & Future Work

- image-processing - programmed as an autonomic policy, but does not extend the original event-driven behavior observed in the Voyager Mission;
- the Voyager’s prototype abstracts most of the spacecraft components;
- the next prototype model:
  - will specify the spacecraft’s radio, antenna, and two cameras as distinct managed elements - this will allow the evaluation of component behavior (via ASSL metrics and events);
  - will extend the IMAGE_PROCESSING policy with other self-management features – two scenarios are planned: remote-assistance self-healing and on-board self-healing.
Future Work Goals

- further prototype development:
  - detailed specification of the Voyager spacecraft components;
  - new autonomic features - self-healing, self-protecting, and self-adapting policies;

- construct an intelligent Voyager-like system able to react automatically to hazards in space by finding possible solutions and applying those on-board with no human interaction;

- a new ASSL model checking mechanism is currently under development – this will allow for automatic feature validation and discovery of design flaws;
Discussion, Future Work, Benefits

Benefits For Space Systems

- both the ASSL specifications and the generated prototypes can be extremely useful for the design and implementation of future Voyager-like missions;
- the ability to compare features and issues with the actual mission and with hypothesized possible autonomic approaches gives significant benefit;
- we develop Voyager prototypes incrementally where each new prototype includes new autonomic features - this helps to evaluate the performance of each feature and gradually construct a model of a future Voyager-like system;
- this approach helps to discover eventual design flaws in both the original system and the prototype models;
Questions

Thank You!