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

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Outline

Presentation

1. **Introduction**
2. **Voyager and Our Research Objectives**
3. **ASSL**
4. **ASSL Model for Voyager**
5. **Discussion, Future Work, and Benefits**

Introduction

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**;

Voyager Spacecraft [The Planetary Society, "Space topics: Voyager – the story of the 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;

Voyager and Our Research Objectives

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.

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

- ✓ ASSL tiers - intended to specify different aspects of an AS, but only a few are needed to come up with a working model;
- ✓ an ASS -management policies, en;
- ✓ a comple
  - ✓ is va king tool;
  - ✓ is us l prototype.
- ✓ generate readed event-driven applications with embedded messaging;

ASSL Policy Specification

```
ASSELF_MANAGEMENT {
  SELF_HEALING {
    FLUENT inLosingSpacecraft {
      INITIATED_BY { EVENTS.spaceCraftLost }
      TERMINATED_BY { EVENTS.earthNotified }
    }
    MAPPING {
      CONDITIONS { inLosingSpacecraft }
      DO_ACTIONS { ACTIONS.notifyEarth }
    }
  }
}
```

ASSL Model for Voyager

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.

ASSL Model for Voyager

ASSL Specification

- ✓ 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

- ✓ IMAGE_PROCESSING self-management policy

```
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 Model for Voyager

ASSL Specification – AE Voyager

✓ IMAGE_PROCESSING self-management policy

```
AESELF_MANAGEMENT{
    OTHER_POLICIES{
        POLICY IMAGE_PROCESSING{
            FLUENT inTakingPicture{
                INITIATED_BY{EVENTS.timeToTakePicture}
                TERMINATED_BY{EVENTS.pictureTaken}
            }
            FLUENT inProcessingPicturePixels{
                INITIATED_BY{EVENTS.pictureTaken}
                TERMINATED_BY{EVENTS.pictureProcessed}
            }
            MAPPING{
                CONDITIONS{inTakingPicture}
                DO_ACTIONS{ACTIONS.takePicture}
            }
            MAPPING{
                CONDITIONS{inProcessingPicturePixels}
                DO_ACTIONS{ACTIONS.processPicture}
            }
        }
    }
} // AESELF_MANAGEMENT
```

```
EVENT timeToTakePicture {
    ACTIVATION {
        CHANGED { METRICS.interestingObjects }
            OR
        PERIOD{ 60 SEC }
    }
}
```

```
METRIC interestingObjects {
    METRIC_TYPE{ RESOURCE}
    METRIC_SOURCE{ AEIP.MANAGED_ELEMENTS.
        wideAngleCamera.countInterestingObjects }
    THRESHOLD_CLASS { integer[0~) }
}
```

```
MANAGED_ELEMENT wideAngleCamera{
    ...
    INTERFACE_FUNCTION countInterestingObjects {
        RETURNS{integer}
    } }
```

```
INTERFACE_FUNCTION takePicture{}
```

ASSL Model for Voyager

ASSL Specification – Antenna AEs

- ✓ IMAGE_PROCESSING self-management policy

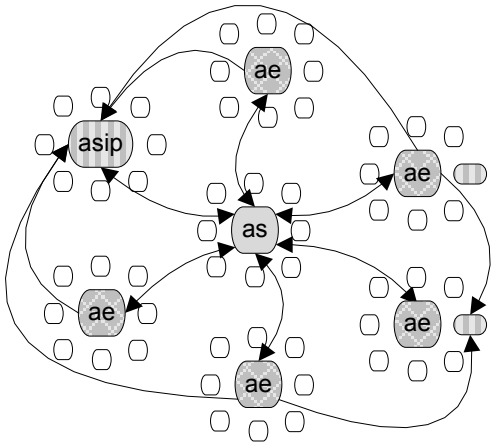
```
FLUENT inStartingGreenImageSession {
    INITIATED_BY { EVENTS.greenImageSessionIsAboutToStart }
    TERMINATED_BY { EVENTS.imageSessionStartedGreen }
}
FLUENT inCollectingImagePixelsBlue {
    INITIATED_BY { EVENTS.imageSessionStartedBlue }
    TERMINATED_BY { EVENTS.imageSessionEndedBlue }
}
```

```
EVENT greenImageSessionIsAboutToStart {
    ACTIVATION { SENT { AES.Voyager.AEIP.MESSAGES.
                        msgGreenSessionBeginAus } }
}
EVENT imageSessionStartedBlue {
    ACTIVATION { RECEIVED { AES.Voyager.AEIP.MESSAGES.
                        msgBlueSessionBeginAus } }
}
```

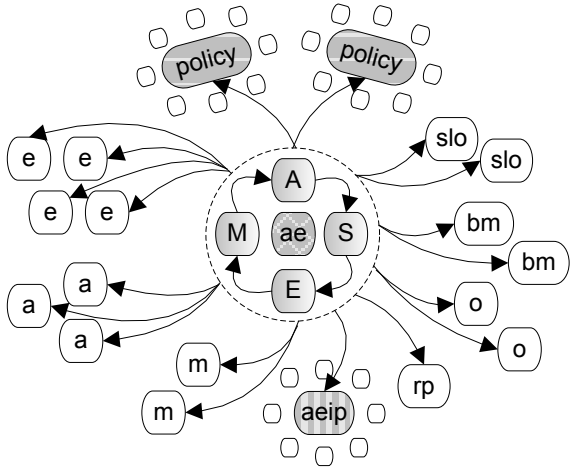
ASSL Model for Voyager

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.



a)



b)

ASSL Model for Voyager

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.*

ASSL Model for Voyager

Behavior of the Generated Prototype

- ✓ log records show important state-transition operations ongoi
- ✓ these ior of the gener

Test resu

The run- del for the Voyager the ASSL

IMAGE_

```
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.
     INPROCESSINGPICTUREPIXELS': 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.BLUEIMAGESESSIONISABOUTTOSTART': has
     occurred
111) EVENT 'as.aes.antenna_spain.events.REDIMAGESESSIONISABOUTTOSTART': has
     occurred
112) FLUENT 'as.aes.antenna_spain.aeself_management.image_processing.
     INSTARTINGREDIMAGESESSION': has been initiated
113) FLUENT 'as.aes.antenna_japan.aeself_management.image_processing.
     INSTARTINGBLUEIMAGESESSION': has been initiated
114) EVENT 'as.aes.antenna_spain.events.BLUEIMAGESESSIONISABOUTTOSTART': has
     occurred
115) FLUENT 'as.aes.voyager.aeself_management.image_processing.
     INPROCESSINGPICTUREPIXELS': has been terminated
     ....
```

Discussion, Future Work, Benefits

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*.

Discussion, Future Work, Benefits

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!