Extended Validation and Verification for Situation-Aware Middleware Architectures

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Today’s Agenda

Situation-Aware Middleware Architecture: Introduction
- Scenario
- Research Issues
- Project Goal and Overview

EVS: A Solution Approach

Summary
TSCE: A Scenario

Situation-Awareness
Research Issues

- How to provide timely and transparent support in middleware
  - for application adaptations that are triggered by different situations?
  - for situation-aware, open-standard communication

- How to generate an open middleware framework
  - for generating new and/or reusing 3rd party components?
  - for multiple QoS management mechanism that is tied with various situations of a given mission?

- How to provide efficient, secure services to application developers
  - especially in an multicast and wireless environment in a manner that is survivable and efficient
Project Goals

Adaptive, Situation-Aware Middleware (SAM) Architectures

- As the next generation of distributed real-time and embedded (DRE) middleware
- Adaptable, Secure, Reliable architectures

(Collaboration with Dr. Stephen Yau, Arizona State University)
Overview of Situation-Aware Middleware Architecture

Situation-Aware Middleware Framework (Task 3)

SA-CSL Compiler (Task 1)

MCL Compiler (Task 1)

Target Middleware Configuration Specification using our MCL (Task 1)

Resource Trade-off Analysis (Task 6)

Validation and Verification (Task 7)

TD/OEP/US Naval Research Lab: Core middleware components (e.g. TAO ORB, RCSM context processor, scheduler, persistency service, etc.) optimized for specific platform. Possibly available from other TDs and OEPs.

TD/OEP/US Naval Research Lab: 3rd-party QoS providers and agents. Possibly available from other TDs and OEPs.

Dynamic Instrumentation (Task 5)

Meta-Programming Context-Processor and Secure Agent Deployment

Target Middleware Model Generator (Task 4)

Target Middleware Component Generator (Task 4)

Target Middleware Integrator (Task 4)

Customized core components

Core components

Reusable Component Block

New Component Block

Aspect component generator

Interceptor model generator

Context-Processor generator

Core component customizer

Aspect component model generator

Target middleware

Naval Research Lab’s Secure Agents Middleware (SAM)

Overview of Situation-Aware Middleware Architecture
Innovation of SAM

- Situation-awareness.
- Separation of aspects components and middleware core components.
- Automated component integration for combining crosscutting aspects.
- Meta-programmable dynamic instrumentation.
- Trade-off analysis for application and target middleware model optimization.
- Validation and Verification Framework.
- Security and survivability mechanisms utilizing software agents.
V&V: Focus of This Talk

Difficult to apply traditional V&V technique to situation-awareness applications
- State explosion problem (huge number of state space)
- Redundant, unnecessary constraints related to dynamic changing of situations

Lack of scalability
- BDD (Binary Decision Diagram)/OBDD (Ordered BDD)
- Common data types
  - enumerations, integer, real types
Today’s Agenda

Situation-Aware Middleware Architecture: Introduction

EVS: A Solution Approach
  – Overview
  – Examples

Summary
EVS: A Solution Approach

EVS (Extended Validation & Verification System)

- Combination of model checking and theorem proving (salsa)
- Automatic property-driven abstraction method

SS (Situation Specification)
- AM (Abstraction Mechanism)
- QoSmon (QoS monitor)
- TEVS (Translator for EVS)
- EVS (Extended Validation and Verification System)
- RG (Report Generator)
Predator: An Example

Total Ship Computing Environment (TSCE)

Predator’s mission is to take reconnaissance pictures and send back the pictures to the carrier.

Predator command and control in the carrier.
Step 1. Situation Specification

Mission 1: Destroy an enemy target.

Resources:
missile, radar, fuel, etc.

Actions: launch missile(), guide missile()

QoS:
1) The missile should be launched within \( n \) seconds after the command is received from the carrier.

Situations:
Situation 2: If it receives a “destroy” command, the drone should launch missile.
Situation 3: After the missile is launched and before it hits the target, the radar system should guide the missile.

Mission 2: Reconnaissance

Resources:
radar, communication system, fuel, etc.

Actions: scan(), send-information()

QoS:
1) Each scan action has to be completed by \( m \) seconds.
2) The information sent back to the carrier should not be tampered.

Situations:
Situation 1: If the drone is in enemy territory, then every \( k \) seconds \((k > m)\), the radar should perform a scan action and a send-information action.
Situation Specification (Continued)

QoS-Security {
    Entity goal; Action in;
    Action out; Mechanism m1;
    out.input = m1(in.result);
} Sec1;

QoS-RealTime {
    Int Duration;
    Int Importance;
} RTC1;

RTScan = new RTC1 (m, 0);
RTLaunchMissile = new RTC1 (n, 1);
RTGuideMissile = new RTC1 (null, 1);
SecureSendInfo = new Sec1 (Carrier, scan, sendInfo, PublicEncryption);

Resource {
    Int Missile; Int Communication;
    Int Radar; Int[] getResourceAvailable();
} DroneResource;

ResrScan = new DroneResource (0, 0, 1);
ResrSendInfo = new DroneResource (0, 1, 0);
ResrLaunchMissile = new DroneResource (1, 0, 0);
ResrGuideMissile = new DroneResource (1, 0, 1);

QoS-Security {
    Entity goal; Action in;
    Action out; Mechanism m1;
    out.input = m1(in.result);
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    Int Radar; Int[] getResourceAvailable();
} DroneResource;

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ResrSendInfo = new DroneResource (0, 1, 0);
ResrLaunchMissile = new DroneResource (1, 0, 0);
ResrGuideMissile = new DroneResource (1, 0, 1);

Situation-aware-object {
    Situation1: Location is in enemy territory, every k seconds Situation1 is true;
    Situation2: Drone receives “destroy” command, and missile has not been launched yet;
    Situation3: Missile has been launched and it has not hit the target yet.

    [local] [Activate at Situation1] scan ()
        RequireResources ResrScan
        withQoSConstraint RTScan;

    [outgoing] [Activate at Situation1] sendInfo ()
        RequireResources ResrSendInfo;
        withQoSConstraint SecureSendInfo;

    [local] [Activate at Situation2] launchMissile ()
        RequireResources ResrLaunchMissile
        WithQoSConstraint RTLaunchMissile;

    [outgoing] [Activate at Situation3] guideMissile ()
        RequireResources ResrGuideMissile
        WithQoSConstraint1 RTGuideMissile;
        WithQoSConstraint2 ... ... another security QoS

    } DroneControl;

    QoSExceptionHandler {
        fail RTScan do action1;
        fail SecureSendInfo do action2;
        ... ...
    }
}

DroneExceptionHandler;
Step 2. Abstract Mechanism

AM1: Remove irrelevant information
- Based on analysis of relationship between variables

Dependency graph
### Abstract Mechanism (Continued)

#### AM2: Spatial Information Reduction

- Based on spatial analysis based on spatial relationships

<table>
<thead>
<tr>
<th>Spatial Relationship</th>
<th>Diagram</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. touching</td>
<td><img src="Diagram" alt="Circle Touching" /></td>
</tr>
<tr>
<td>2. overlapping</td>
<td><img src="Diagram" alt="Circle Overlapping" /></td>
</tr>
<tr>
<td>3. crossing</td>
<td><img src="Diagram" alt="Circle Crossing" /></td>
</tr>
<tr>
<td>4. containing/inside_of</td>
<td><img src="Diagram" alt="Circle Containing/Inside" /></td>
</tr>
<tr>
<td>5. covering/covered_by</td>
<td><img src="Diagram" alt="Circle Covering/Covered By" /></td>
</tr>
<tr>
<td>6. disjoint</td>
<td><img src="Diagram" alt="Circle Disjoint" /></td>
</tr>
<tr>
<td>7. equal</td>
<td><img src="Diagram" alt="Circle Equal" /></td>
</tr>
</tbody>
</table>

Let:
- $L_{\text{BattleField}} = \{\text{zone1, zone2, zone3}\}$
- $L_{\text{Enemy}} = \{\text{zone1, zone2}\}$
- $\text{Loc} = \{L_{\text{Enemy}}, L_{\text{BattleField}}\}$
- $L_1 \text{ Loc}; L_2 \text{ Loc};$

Scan:
- $(L_1 == L_{\text{Enemy}} \text{ AND } L_2 == L_{\text{BattleField}});$  
  $\Rightarrow$ scan $(L_1 == L_{\text{Enemy}});$
### Abstract Mechanism (Continued)

**AM3: Temporal Information Reduction**

- Based on temporal analysis based on temporal relationship

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<tbody>
<tr>
<td><img src="image1" alt="Diagram" /></td>
<td><img src="image2" alt="Diagram" /></td>
<td><img src="image3" alt="Diagram" /></td>
<td><img src="image4" alt="Diagram" /></td>
<td><img src="image5" alt="Diagram" /></td>
<td><img src="image6" alt="Diagram" /></td>
</tr>
</tbody>
</table>

- **Example 1:** scan(); AFTER launchMissile(); launchMissile(); AFTER guideMissile();
- **Example 2:** \( \Rightarrow \) scan(); AFTER guideMissile()
Step 3. EVS

Situation-aware Salsa
- Invariant checker for situation-aware specifications

\[
\text{SAL Specification } S \\
\text{Potential Invariant } I \\
\text{New } I = I \land L
\]

<Process for applying Salsa>
module TSCE_drone

type definitions
    OnOff : {On, Off};

monitored variables
    Missile, Radar, Control_System : OnOff;

controlled variables
    TSCE_drone : OnOff;

internal variables
    launchMissile, guideMissile, scan, sendInfo : bool;
    Situation1, Situation2, Situation3 : bool;
    Mission1, Mission2 : bool;

guarantees
    /* true properties */
    Property1 = @T(Radar = On) when (Situation1) => scan';
    Property2 = (Missile = On and Radar = On) => guideMissile;
    /* false properties */
    Property3 = (Missile = On and launchMissile) => not scan;
    Property4 = (Radar = On and guideMissile) => Missile = Off;

definitions
    var launchMissile initially false :=
        ev
        [] @F(scan) -> false
        [] @T(scan) when (Missile = On) -> true
        [] @T(guideMissile) when (not scan) -> false
    ve

    var guideMissile initially false :=
        ev
        [] @F(scan) -> false
        [] @T(scan) when (Missile = Off or Radar = Off) -> false
        [] @T(scan) when (Missile = On and Radar = On and launchMissile) -> true
    ve

    var scan initially false :=
        ev
        [] @T(Radar = On) when (Situation1) -> true
        [] @T(Radar = On) when (not Situation1) -> false
    ve

end module
Analyzing SAL specification in file: tcse.sal.
Checking disjointness of all modules.
Checking module TSCE_drone
Number of Nontrivial Atoms: 0
Checking launchMissile ... disjoint.
Checking guideMissile ... disjoint.
Checking scan ... disjoint.
All checks passed.
Number of failed/passed verification conditions: 0/7
Time (total) : 0.226
Rewriting : 0.078
Partitioning : 0.000
Integer solving : 0.000
Bdd ops(total,gc) : 0.058, 0.000
BDD statistics.
  Number of variables : 25
  Number of nodes
    User : 96
    Total : 467
  Table size : 65536

Checking coverage of all modules.
Checking module TSCE_drone
Number of Nontrivial Atoms: 0
All checks passed.
Number of failed/passed verification conditions: 0/0
Time (total) : 0.076
Rewriting : 0.013
Partitioning : 0.000
Integer solving : 0.000
Bdd ops(total,gc) : 0.000, 0.000
BDD statistics.
  Number of variables : 25
  Number of nodes
    User : 1
    Total : 2
  Table size : 65536

Checking guarantees in all modules.
Checking module TSCE_drone
Number of Nontrivial Atoms: 0
Checking Property1 ... pass
Checking Property2 ... fail
Checking Property3 ... fail
Checking Property4 ... fail
Checks failed for: Property4, Property3, Property2
Number of failed/passed verification conditions: 3/1
Time (total) : 0.315
Rewriting : 0.131
Partitioning : 0.000
Integer solving : 0.000
Bdd ops(total,gc) : 0.072, 0.000
BDD statistics.
  Number of variables : 25
  Number of nodes
    User : 119
    Total : 528
  Table size : 65536
Salsa: Extension to Situation-Aware

Extension for Spatial Relationship

definitions

......

var TSCE_drone=
    case Mission1
        [] @T(launchMissile) CROSSING @T(enemy_area) ->
            if []true -> true []false -> false fi
    esac
    case Mission2
        [] @T(scan) -> if []true -> true []false -> false fi
    esac

Extension for Temporal Relationship

definitions

......

var TSCE_drone=
    case Mission1
        [] @T(launchMissile) BEFORE @T(guideMissile) ->
            if []true -> true []false -> false fi
    esac
    case Mission2
        [] @T(scan) -> if []true -> true []false -> false fi
    esac
EVS: Extension to OBDD

BDD (Binary Decision Diagram) and OBDD (Ordered BDD) for property 1

- \( (\text{Radar} = \text{On AND Situation1}) \Rightarrow \text{scan} \);
Check a CTL formula,
- \( \text{AG} (\text{scan} \rightarrow \text{AF} \, \text{guideMissile}) \)

<Step 1>
\( \text{AG} (\text{scan} \rightarrow \text{AF} \, \text{guideMissile}) \equiv \neg \text{EF} (\text{scan} \land \neg \text{guideMissile}) \)

<Step 2>
- \( \text{S(scan)} = \{1\} \)
- \( \text{S(\neg \text{guideMissile})} = \{1,2,3\} \)
- \( \text{S(EG \, \neg \text{guideMissile})} = \{1,2,3,5\} \)

<Step 3>
- \( \text{S(scan} \land \text{EG \, \neg \text{guideMissile})} = \{1\} \)
- \( \text{S(EF (scan} \land \text{EG \, \neg \text{guideMissile}))} = \{1,2,3,4,5\} \)

<Step 4>
- \( \text{S(\neg \text{EF (scan} \land \text{EG \, \neg \text{guideMissile}))} = \emptyset \)
Extended V&V for Situation-Aware Middleware Architectures

- Redundant, unnecessary constraints related to dynamic changing of situations
  - Represent by Situation Specification
  - Reduce by Situation-aware Abstract Mechanisms (Spatial and Temporal).
- Reduce the number of state space for V&V
  - By salsa (combining model checking and theorem proving)
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