Laying a Foundation for Reusability of Knowledge Bases in Spacecraft Ground Systems

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Outline

– MVP-CA Motivation
– MVP-CA Objective & Approach
– Characteristics of Satellite Systems
– MVP-CA’s Relevance in Satellite Systems
– Telemetry Systems Analyzed to date
  • SEAES
  • XTE
  • UES
– MVP-CA Capabilities with focus on Reusability
– Related Work
– Conclusions

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Characteristics of Satellite Systems

• Spacecraft satellite telemetry (sub)systems have multiple configurable roles
• Similar rule bases in existence for different satellite subsystems
• Number of such rule bases with similar structure keeps growing as new missions get planned
• Number of rules in each such rule base keeps growing as knowledge evolves
• Complexity of a rule base depends on the:
  – number of rules, and
  – complexity of each pattern in the rule.

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Motivation

Software Engineering of Large and Complex KBS is Difficult

• Built by multiple teams
  – ambiguities and interpretation problems

• Knowledge evolves
  – knowledge-base changes frequently

• Scaling up problems for rapid prototyping systems

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Multi-ViewPoint Clustering Analysis (MVP-CA) Technology
Objective

The objective of the MVP-CA technology is to facilitate:

- Verification, Validation & Testing
- Reusability of Software Components across Missions
- Adaptability of Software Components across Missions
- Maintenance & Management of Large KBS

Approach

- Use agglomerative clustering algorithms to obtain semantically-related rule clusters
- “Similarity” defined by a set of heuristic distance metrics for determining distance between rules
- Zero-in on meaningful clusters with the aid of statistical and semantics-based cluster information

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MVP-CA Technology for Mission Rule Set Management

- Legacy expert systems can be clustered into rule sets of semantically related rules.
- CBR tools can then use the *Cluster Interface Definitions (CID)* of these rule sets for intelligent management, adaptation and assimilation of these rules across missions.

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Telemetry Systems Analyzed

• Spacecraft Environmental Anomalies
  -- SEAES (Aerospace)

• X-Ray Timing Explorer
  -- XTE (NASA Goddard)

• Unexpected Events System Rule Base
  -- UES (ICS - part of the FUSE Project)
**XTE**

*X-Ray Timing Explorer* *(NASA Goddard)*

- **Problem Description**
  - Generic Spacecraft Analyst Assistant (GenSAA) - superset of Clips
  - Health & Safety Monitoring Rule base for various onboard subsystems

- **MVP-CA tool adapted for**
  - processing GenSAA rules

- **MVP-CA Tool discovered**
  - rule naming problems
  - reusable software components across the subsystems

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XTE Anomalies

Duplicate rule name:

<table>
<thead>
<tr>
<th>Rule#</th>
<th>Rule Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>23</td>
<td>sa_status_check</td>
</tr>
<tr>
<td>27</td>
<td>xpndr_status_check</td>
</tr>
<tr>
<td>29</td>
<td>gsace_status_check</td>
</tr>
<tr>
<td>33</td>
<td>tam_status_check</td>
</tr>
<tr>
<td>35</td>
<td>tam_status_check</td>
</tr>
<tr>
<td>25</td>
<td>sds_status_check</td>
</tr>
<tr>
<td>31</td>
<td>rwa_status_check</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Rule#</th>
<th>Rule Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>24</td>
<td>sa_limit_check</td>
</tr>
<tr>
<td>28</td>
<td>xpndr_limit_check</td>
</tr>
<tr>
<td>30</td>
<td>gsace_limit_check</td>
</tr>
<tr>
<td>34</td>
<td>tam_limit_check</td>
</tr>
<tr>
<td>36</td>
<td>pca_limit_check</td>
</tr>
<tr>
<td>26</td>
<td>sds_limit_check</td>
</tr>
<tr>
<td>32</td>
<td>rwa_limit_check</td>
</tr>
</tbody>
</table>

:Rule 35
(defrule tam_status_check ""
  (LimitStatus PAPCU1TMP2T#XTE_DECOM ?x1)

  ...

  ?o1 <- (Inferred PCA-Temp-Status ?cur_stat)
  (Inferred valid-telemetry valid)

  => ...

  (if (neq ?cur_stat ?new_stat) then

    ....
    then (SendMessage "MessageWindow" Status
      (str-cat "PCA Temperatures changed from " ?cur_stat " to " ?new_stat))
    else (SendMessage "MessageWindow" Warning
      (str-cat "PCA Temperatures changed from " ?cur_stat " to " ?new_stat))

    ...

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Objective:

To identify and store rule clusters which can be reused, possibly with adaptation, for new situations.

Issues:

• Identification of reusable component or rule clusters
• Specifying features which represents these clusters succinctly through Cluster Interface Definitions (CID)
• Retrieval of these clusters based on CIDs
• Adaptation of these clusters based on parameterizeable templates

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Example Reusable Set: XTE

76 rcvr-1-lock2search
77 rcvr-1-search2lock
78 rcvr-2-lock2search
79 rcvr-2-search2lock

(defrule rcvr-1-lock2search ""
(Mission XA1CARLK#XTE_DECOM
  ?r1&:(neq ?r1 LOCK))
?x1 <- (Inferred SC-Rcvr-1-Lock
  ?r3&:(neq ?r3 Search))
=>
  ...
  (SendMessage "MessageWindow" Status
   "Reciever 1 went from Locked to Search")
)

(defrule rcvr-1-search2lock ""
(Mission XA1CARLK#XTE_DECOM
  LOCK)
(Mission XA1RCVlk#XTE_DECOM
  LOCK)
?x1 <- (Inferred SC-Rcvr-1-Lock
  Search)
(Inferred valid-telemetry valid)
=>
  ...
  (SendMessage "MessageWindow" Status
   "Reciever 1 went from Search to Locked")
)

(defrule rcvr-2-lock2search ""
(Mission XA2CARLK#XTE_DECOM
  ?r1&:(neq ?r1 LOCK))
?x1 <- (Inferred SC-Rcvr-2-Lock
  ?r3&:(neq ?r3 Search))
=>
  ...
  (SendMessage "MessageWindow" Status
   "Reciever 2 went from Locked to Search")
)

(defrule rcvr-2-search2lock ""
(Mission XA2CARLK#XTE_DECOM
  LOCK)
(Mission XA2RCVlk#XTE_DECOM
  LOCK)
?x1 <- (Inferred SC-Rcvr-2-Lock
  Search)
(Inferred valid-telemetry valid)
=>
  ...
  (SendMessage "MessageWindow" Status
   "Reciever 2 went from Search to Locked")
)

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Example Reusable Set: XTE

<table>
<thead>
<tr>
<th></th>
<th>tsm-0-22-watch</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>tsm-0-22-watch</td>
</tr>
<tr>
<td>65</td>
<td>tsm-62-64-watch</td>
</tr>
<tr>
<td>12</td>
<td>tsm-24-watch</td>
</tr>
<tr>
<td>13</td>
<td>tsm-25-watch</td>
</tr>
<tr>
<td>39</td>
<td>tsm-68-watch</td>
</tr>
<tr>
<td>14</td>
<td>tsm-26-32-watch</td>
</tr>
<tr>
<td>17</td>
<td>tsm-65-66-watch</td>
</tr>
</tbody>
</table>

(defrule tsm-0-22-watch ""
  ?o1 <- (TSM-FAIL ?etime "ACS" ?id&:(and (>= ?id 0) (<= ?id 16)) ?thresh)
  ?o2 <- (acs-tsm-status ?)
  ?o3 <- (Inferred POWER-TSM-STATUS ?)
  ...;
**************************************************************************
(defrule tsm-24-watch ""
  ?o1 <- (TSM-FAIL ?etime "SC" 24 ?thresh)
  ?o2 <- (Inferred POWER-TSM-STATUS ?)
  ...;
**************************************************************************
(defrule tsm-25-watch ""
  ?o1 <- (TSM-FAIL ?etime "SC" 25 ?thresh)
  ?o2 <- (Inferred POWER-TSM-STATUS ?)
  ...;
**************************************************************************
(defrule tsm-26-32-watch ""
  ?o2 <- (Inferred POWER-TSM-STATUS ?)
  ...;
**************************************************************************
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Retrieval & Adaptation of Rule Sets: CBR Tools

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Representation of Rule Sets

- **Indexes** in CBR tools are used to represent & retrieve relevant cases.
- Indexes should be:
  - predictive - of the intended functionality of the cluster
  - abstract - to cover generality for incorporation of future cases in the case base
  - concrete - to be extracted efficiently for reuse
- Index repertoire should cover all dimensions of the domain.
- In this project, “cases” are software components, i.e., rule sets which perform a given function.
- Hence we require indexes which can capture all key aspects of the functionality of the rule sets.
Adaptation of Rule Sets

- Exact match of new scenarios will not be found always
- Thus rule sets will need to be adapted for reuse
- One mechanism is to store parameterized templates representing the rule set.
- Such templates would abstract the structure of the rule set and can be used for generation of new rule sets.

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Sample Reusable Set

;CONTINUOUS BGM RULE DESCRIPTION: Trigger when MF_QUALITY is Good
(defrule tlm_qual1
  (bgm-rule tlm_qual1 on)
  (Mission MF_QUALITY#XTE_DECOM ~Nodata)
  (Inferred fsync_lock_occurred yes)
  =>
  (AssertFact "Inferred Telem_Quality Good")
  (SendMessage "MessageWindow" Status "MF_QUALITY indicates Telem quality is Good.")
)

;CONTINUOUS BGM RULE DESCRIPTION: Trigger when MF_QUALITY is Bad
(defrule tlm_qual2
  (bgm-rule tlm_qual2 on)
  (Mission MF_QUALITY#XTE_DECOM ~Good)
  (Inferred fsync_lock_occurred ~yes)
  =>
  (AssertFact "Inferred Telem_Quality Bad")
  (SendMessage "MessageWindow" Warning "MF_QUALITY indicates Telem quality is not Good.")
)

;CONTINUOUS BGM RULE DESCRIPTION: Trigger when MF_QUALITY drops out
(defrule tlm_qual3
  (bgm-rule tlm_qual3 on)
  (Mission MF_QUALITY#XTE_DECOM ~Good)
  (Inferred fsync_lock_occurred ~yes)
  (Inferred Telem_Quality Good)
  =>
  (AssertFact "Inferred Telem_Quality Bad")
  (SendMessage "MessageWindow" Warning "MF_QUALITY indicates Telemetry has dropped out.")
)
Possible Template for BGM Rules

defrule <name-of-rule>
    (bgm-rule <name-of-rule> on)
    (Mission MF_QUALITY#XTE_DECOM <data-quality-value>)
    (Inferred fsync_lock_occurred <f-l-value>)
=>
    (AssertFact "Inferred Telem_Quality <i-t-value>")
    (SendMessage "MessageWindow" <status-value>
        "MF_QUALITY indicates Telem quality is <t-value>."))

Cluster-identification: Input data-quality derives telemetry-quality

Parameters:
- Mission-name: MISSION
- Process-name: XTE-DECOM
- Input-data-source: MF-Quality
- Output: Telem-quality

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Conclusions

• MVP-CA tool is applicable to
  – many types of telemetry expert systems, and
  – many expert system development platforms.

• It is scalable to large operational systems.

• Human-in-the-loop allows semantics of the KBS to be utilized in the clustering process.

• The tool aids in:
  – V & V - exposing anomalies and incompleteness
  – reusability.