Feature Oriented Evolutions for Context-Aware Adaptive Systems

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Variability Dimensions

- Requirement Variability
- Context Variability

System Evolutions

- Requirement Variability: Req 0, Req 1, Req 2, Req 3, ..., Req k
- Context Variability: Context 0, Context 1, Context 2, Context 3, ..., Context z
System and Context

- A Context-Aware Adaptive Application is represented as a set of dynamic units which express functionalities and domain assumptions.
- Context Entities to enable run-time evolutions at the three abstraction levels: requirement, design and implementation.
A unit of behavior is a feature. Feature are triples: 
\[ f_{pickUp} = (R_{pickUp}, W_{pickUp}, S_{pickUp}) \]
where:
- \( R_{pickUp} \) system requirements  
  e.g. *The system shall pick up object of fixed size*
- \( W_{pickUp} \) environment assumptions (conditions)  
  e.g. *The energy is greater than 1 unit and the object appears in the nearby*
- \( S_{pickUp} \) component/service implementing the feature expressed as pseudo-code  
  e.g. *The robot opens the arm; It catches the object; It unloads the object into its container*
Evolution Classification

- Foreseen Evolution
  - addresses context variability dimension
  - evolution logic is embedded inside the system models
  - static analyzed configurations

- Unforeseen Evolution
  - addresses system variability dimension
  - unknown evolution logic (New requirement)
  - dynamically analyzed configurations

- Context Model
  - completely characterized for the foreseen evolution
  - updated as run-time evolution is applied
A robot moves in a predefined path from a source to a destination. He collects objects he may encounter by its arm. Any time the robot picks up an object or move toward the destination he consumes some energy.

**System Goal**: reach the destination while picking up the encountered objects.
\[ A = \{ f_{move}, f_{DetObj}, f_{pickUp}, f_{UnloadObj} \} \]
A = \{f_{move}, f_{DetObj}, f_{pickUp}, f_{UnloadObj}\}

G = \{\{f_{move}, f_{DetObj}\}, \{f_{pickUp}, f_{DetObj}\}\}, \{f_{move}\}, \{f_{DetObj}\},
\{f_{pickUp}\}, \{f_{UnloadObj}\}\}
\[ A = \{ f_{\text{move}}, f_{\text{DetObj}}, f_{\text{pickUp}}, f_{\text{UnloadObj}} \} \]

\[ G = \{ \{ f_{\text{move}}, f_{\text{DetObj}} \}, \{ f_{\text{pickUp}}, f_{\text{DetObj}} \}, \{ f_{\text{move}} \}, \{ f_{\text{DetObj}} \}, \{ f_{\text{pickUp}} \}, \{ f_{\text{UnloadObj}} \} \} \]

**System Configuration**

Given \( F \subseteq A \) a *system configuration* is a triple obtained combining together the features in \( F \):

\[ G_F = (R_F, W_F, S_F) \text{ s.t. } F \subseteq 2^{|A|} \]
The context model enables reasoning upon the environment elements that are relevant for the application.

Feature requirement, feature assumption and feature specification refer to the context elements expressed as Key-Value resources.

In our vision Context Model can be identified following two different perspectives:

- Static Context Model expressed as: resource type (enumerate, boolean, natural) and resource hierarchy (Physical, System, User).
- Dynamic Context Model expresses the variability for Static Context Model instances.
The context model enables reasoning upon the environment elements that are relevant for the application.

Feature requirement, feature assumption and feature specification refer to the context elements expressed as Key-Value resources.

In our vision, Context Model can be identified following two different perspectives:

- **Static Context Model** expressed as: resource type (enumerate, boolean, natural) and resource hierarchy (Physical, System, User).
- **Dynamic Context Model** expresses the variability for Static Context Model instances.
Given the Resource set \( ResId = \{ \text{Energy}, \text{BigObj}, \text{LitteObj} \} \) the structure for each of them is defined as:

\[
R_{\text{Structure}}(\text{Energy}) \rightarrow \text{Energy}(\text{nat}, \text{System}) \\
R_{\text{Structure}}(\text{Obj}) \rightarrow \text{Obj}(\text{bool}, \text{Physical}) \\
R_{\text{Structure}}(\text{Position}) \rightarrow \text{Position}(\text{enum}, \text{Physical})
\]

Each resource has a set of admissible value:

\[\text{Energy} \rightarrow \{0, 1, 2\}, \text{Obj} \rightarrow \{\text{True}, \text{False}\}, \text{Pos} \rightarrow \{0, 1, 2\}\]

Each context state \( \vec{c} \in \text{Energy} \times \text{Obj} \times \text{Pos} \)
The domain assumptions are constraints upon the environment that should be checked in order to evaluate the feature validity.

Pick Up Functionality

\[ \langle W_{\text{pickUp}} \rangle \coloneqq Obj \land Energy \geq 1 \]
Context Assumptions

- The domain assumptions are constraints upon the environment that should be checked in order to evaluate the feature validity.

Detection Functionality

\[ < W_{detObj} > ::= \text{Energy} \geq 1 \]
The domain assumptions are constraints upon the environment that should be checked in order to evaluate the feature validity.

 Movement functionality

\[ < W_{\text{move}} > ::= Energy \geq 1 \land \neg \text{Pos} = 0 \]
The domain assumptions are constraints upon the environment that should be checked in order to evaluate the feature validity

unload functionality

\[ < W_{UnloadObj} > ::= Pos = 0 \land Energy \geq 1 \]
Context Assumptions

- The domain assumptions are constraints upon the environment that should be checked in order to evaluate the feature validity.

Validity Check

$$\text{CheckVal}(W_{Gi}, \vec{c}) = \begin{cases} 
1 & \text{if } W_{Gi}[\vec{c}/\text{ResId}] \text{ is True} \\
0 & \text{Otherwise}
\end{cases}$$
Consider only the context state relevant w.r.t. the configurations which pursue the long-term goal $G$; The process to discover $CS \in \text{Energy} \times \text{Obj} \times \text{Pos}$ consists in:

1. assigning at each context $\overrightarrow{c}$ a subset of features $f_i$ satisfying two conditions:
   - $f_i$ appears in at least one configuration entailed in $G$
   - $f_i$ makes the condition $\text{CheckVal}(W_{f_i}, \overrightarrow{c}) = 1$ valid

2. assigning at each context the configurations in "$G$" that have all the entailed features valid

3. checking the consistency for each configuration $G_{F_k}$ in each state $\overrightarrow{c_j}$ as: $S_{F_k}, W_{F_k}[\overrightarrow{c_j}/x] \vdash R_{F_k}$ (Eligibility)
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2. assigning at each context the configurations in "$G$" that have all the entailed features valid

3. checking the consistency for each configuration $G_{F_k}$ in each state $\vec{c}_j$ as: $S_{F_k}, W_{F_k}[\vec{c}_j/x] \vdash R_{F_k}$ (Eligibility)
Phase 1

Table: Feature Validity Table

<table>
<thead>
<tr>
<th>C(E, O, P)/f_j</th>
<th>f_{move}</th>
<th>f_{DetObj}</th>
<th>f_{pickUp}</th>
<th>f_{UnloadObj}</th>
</tr>
</thead>
<tbody>
<tr>
<td>C_0 = (1, 0, 0)</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>C_1 = (1, 0, 1)</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>C_2 = (1, 0, 2)</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>C_3 = (1, 1, 0)</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>C_4 = (1, 1, 1)</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>C_5 = (1, 1, 2)</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>C_6 = (2, 0, 0)</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>C_7 = (2, 0, 1)</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>C_8 = (2, 0, 2)</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>C_9 = (2, 1, 0)</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>C_{10} = (2, 1, 1)</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>C_{11} = (2, 1, 2)</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>
### Table: Context Based Selection Table

<table>
<thead>
<tr>
<th>$C(E, O, P) / G_k$</th>
<th>${f_{\text{move}}, f_{\text{DetObj}}}$</th>
<th>${f_{\text{pickUp}}, f_{\text{DetObj}}}$</th>
<th>$f_{\text{move}}$</th>
<th>$f_{\text{pickUp}}$</th>
<th>$f_{\text{DetObj}}$</th>
<th>$f_{\text{Unload}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$C_0 = (1, 0, 0)$</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>$C_1 = (1, 0, 1)$</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>$C_2 = (1, 0, 2)$</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>$C_3 = (1, 1, 0)$</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>$C_4 = (1, 1, 1)$</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>$C_5 = (1, 1, 2)$</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>$C_6 = (2, 0, 0)$</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>$C_7 = (2, 0, 1)$</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>$C_8 = (2, 0, 2)$</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>$C_9 = (2, 1, 0)$</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
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<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>$C_{11} = (2, 1, 2)$</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>
Evolution Pattern

- Decision making mechanism is supported by a probabilistic evolution pattern: each state is a context state and each arch expresses the probability to move from a context to another.
- The evolution pattern is based on:
  - user centric information (user mobility, preference, task,...)
  - evolution laws for resources

Table: Steady-state probabilities

<table>
<thead>
<tr>
<th></th>
<th>C0</th>
<th>C1</th>
<th>C2</th>
<th>C3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.3</td>
<td>0.15</td>
<td>0.15</td>
<td>0.4</td>
</tr>
</tbody>
</table>
Decision making mechanism is supported by a probabilistic evolution pattern: each state is a context state and each arc expresses the probability to move from a context to another.

The evolution pattern is based on:
- **user centric information** (user mobility, preference, task,...)
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### Table: Steady-state probabilities

<table>
<thead>
<tr>
<th></th>
<th>C0</th>
<th>C1</th>
<th>C2</th>
<th>C3</th>
</tr>
</thead>
<tbody>
<tr>
<td>P.</td>
<td>0.3</td>
<td>0.15</td>
<td>0.15</td>
<td>0.4</td>
</tr>
</tbody>
</table>
Ranking Process

- Rank each eligible configuration $G_j$ in the current context state $\overrightarrow{c}$

- Each configuration is ranked based on the steady-state probabilities for the evolution automaton and a subpart of the context-based selection matrix.

$$
\begin{bmatrix}
    fd_{G_1} \\
    fd_{G_2} \\
    \vdots \\
    fd_{G_v}
\end{bmatrix}
= 
\begin{bmatrix}
    \vdots & \vdots & \vdots \\
    \text{CheckVal}(\overrightarrow{c_i}, W_{G_j}) & \vdots & \vdots \\
    \vdots & \vdots & \vdots
\end{bmatrix}
\times
\begin{bmatrix}
    p_1 \\
    p_2 \\
    \vdots \\
    p_h
\end{bmatrix}
$$

where $j = 1, .., v$, $i = 1, .., h$
Definition

- System execution: $S_{G_1} \rightarrow S_{G_2} \rightarrow \cdots \rightarrow S_{G_z}$
- The context state is $\overrightarrow{c} \in Energy \times Obj \times Pos$.
- The evolution system is defined as
  $< S_{G_i}, \sigma > \rightarrow < S_{G_{i+1}}, f(\sigma) >$
- The state $\sigma$ is composed by three main components:
  - $\sigma_s$ is completely managed by the system
  - $\sigma_c$ contains the parameter $currAss$ with the current context state $\overrightarrow{c}$
  - $\sigma_e$ contains the parameter $currEv$ which may contain a new required functionality (a new requirement)
Foreseen Evolution Process

- This scenario is based on the Context-Based Selection Table.
- All the configurations have been already analyzed and proved consistent w.r.t. to context states.
- Therefore the current deployed configuration $G_{curr} = \{f_1, \ldots, f_p\}$ running at the context state $\overrightarrow{c_{curr}}$ is consistent by itself:

$$\forall j \in \{1, \ldots, p\} \quad S_j \land (\forall j \in \{1, \ldots, p\} \quad W_j)[\overrightarrow{c_{curr}}/x] \vdash \forall j \in \{1, \ldots, p\} \quad R_j$$

- The process consists in monitoring the current context state in order to discover when it moves towards a different valid assignment of resources.
- As context changes the new best configuration is choosen based on the fitness vector.
High Level Procedure

ForeseenEvolution($< S_{G_i}, \sigma >, < S_{G_{i+1}}, f(\sigma) >)$

IF $\text{monitor}(\text{ResId}, \sigma_c(\text{currAss})) = false$

Evaluate the new Context state $C_{NewState}$

Look-up $C_{NewState}$ in the Context-Based Decision table

Ranking mechanism

Configuration selection based on Rankings

Execute $< S_{G_{i+1}}, (g(\sigma_s), \sigma_c[C_{NewState}/\text{currAss}], \sigma_e) >$

Restart

OTHERWISE

Restart
High Level Procedure

\[
\text{ForeseenEvolution}(\langle S_{G_i}, \sigma \rangle, \langle S_{G_{i+1}}, f(\sigma) \rangle) \\
\quad \text{IF } \text{monitor}(\text{Resld}, \sigma_c(\text{currAss})) = \text{false} \\
\quad \quad \text{Evaluate the new Context state } C_{\text{NewState}} \\
\quad \quad \text{Look-up } C_{\text{NewState}} \text{ in the Context-Based Decision table} \\
\quad \quad \text{Ranking mechanism} \\
\quad \quad \text{Configuration selection based on Rankings} \\
\quad \text{Execute } \langle S_{G_{i+1}}, (g(\sigma_s), \sigma_c[C_{\text{NewState}}/\text{currAss}], \sigma_e) \rangle \\
\quad \text{Restart} \\
\quad \text{OTHERWISE} \\
\quad \text{Restart}
\]
Unforeseen Evolution Process

- A new requirement arises from the user, therefore the system has to be enhanced with a new feature.
- We assume to have a Search Engine that given the requirement $R_{New}$ returns the set of feature:

  $$(R_{new}, W_i, S_i) \text{ such that } S_i, W_i \vdash R_{New}$$

- The current deployed configuration $G_{curr} = \{f_1, ..., f_p\}$, which is already consistent by itself should be checked against each returned feature considering the current context state $c_{curr}$:

  $$\bigwedge_{j=1}^{p} S_j \land S_i, \left( \bigwedge_{j=1}^{p} W_j \land W_i \right)[c_{curr} / x] \vdash \bigwedge_{j=1}^{p} R_j \land R_{new}$$
Example

- Let us suppose that while the system configuration is running $G_{current} = \{f_{DetObj}\}$ at the context state $C_{10}$ a new requirement arises from the user, e.g. $R_{New} = \text{The system shall picks up a new kind of objects}$
- The search engine discovers the triple $f_{pickUpB} = (R_{New}, W_{pickUpB}, S_{pickUpB})$
- Its domain assumption is: $W_{pickUpB} = Energy \geq 1 \land ObjB$
- The context model is enhanced with the new resource $ObjB \rightarrow \{true, false\}$
- Each new context state $\overrightarrow{c} \in Energy \times Obj \times Pos \times ObjB$
- The context model Synthesis process is repeated considering the new configuration $G_6 = \{f_{DetObj}, f_{pickUpB}\}$ and the new context states.
High Level Procedure

UnforeseenEvolution\((< S_{G_i}, \sigma >, < S_{G_{i+1}}, f(\sigma) >)\)

IF \(\sigma_e(currEv) = (R_{new}, \bot, \bot)\) THEN
Query the Search Engine with \((R_{new}, \bot, \bot)\)
\(\forall f_z = (R_{New}, W_z, S_z)\) build \(G_{i+1} = G_i \cup f_z\)
IF \(G_{i+1}\) is Consistent in \(\overleftrightarrow{c_{curr}}\)
    Add \(f_z\) to \(E\)(set of eligible features)
Chose one feature
Context Model Refinement (New States)
Context-Based Selection Table Refinement \((G_{i+1}, \text{New States})\)
Execute \(< S_{G_{i+1}}, (g(\sigma_s), \sigma_c, \sigma_e[(\bot, \bot, \bot)/currEv]) >\)
Restart
OTHERWISE \(\sigma_e(currEv) = (\bot, \bot, \bot)\)
Restart
High Level Procedure

UnforeseenEvolution(< S_{G_i}, \sigma >, < S_{G_{i+1}}, f(\sigma) >)

IF $\sigma_e(currEv) = (R_{new}, \bot, \bot)$ THEN
  Query the Search Engine with $(R_{New}, \bot, \bot)$
  $\forall f_z = (R_{New}, W_z, S_z)$ build $G_{i+1} = G_i \cup f_z$
  IF $G_{i+1}$ is Consistent in $\overrightarrow{c_{curr}}$
    Add $f_z$ to $E$(set of eligible features)
  Chose one feature
  Context Model Refinement (New States)
  Context-Based Selection Table Refinement ($G_{i+1}$, New States)
  Execute $< S_{G_{i+1}}, (g(\sigma_s), \sigma_c, \sigma_e[(\bot, \bot, \bot)/currEv]) >$
  Restart
OTHERWISE $\sigma_e(currEv) = (\bot, \bot, \bot)$
  Restart
Conclusion

Pros

- Unit of behavior modularization
- Static and Dynamic decision making mechanism support
- Explicit Context modeling to drive the evolution

Cons

- No actual implementation
- Prediction model complexity
Questions?