A Context Analysis Method for Embedded Systems
--- Exploring a Requirement Boundary between a System and Its Context

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Many embedded systems not only affect their context through actuators but also are affected by their context through sensors. It is important to provide a context analysis method for constructing reliable embedded systems.

However, it is difficult to decide the boundary of the context that should be taken into account, which context element should be included as the targets of requirements analysis.
Our approach

- **CAMEmb** (Context Analysis Method for Embedded systems)

- Only the **value-context elements** are extracted as the associated context elements.
  - We can explore only a sequence of context elements affecting the **data value observed or controlled** by sensors/actuators.
  - Other context elements not affecting the system observation and control **are not taken into account** because these context elements do not affect the system behavior.
Contribution 1: CAMEmb

Guide Words for Context Analysis

<table>
<thead>
<tr>
<th>No.</th>
<th>Category of $\textit{Affect}$</th>
<th>Guide word</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>physical phenomena</td>
<td>factor that determines the upper limit</td>
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<tr>
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<td>physical phenomena</td>
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Contribution 2: Model transformation

Model-Driven Requirements Engineering
Outline

- Motivation
- CAMEmb
- CAMEmb-based MDD
- Discussion
- Conclusions
Motivation
Example: an electric pot

Should air pressure be taken into account?

* Boiling point is below 100 Celsius.
* Water evaporates and finally its volume will be empty.
* There may be climbers who use a pot up on high mountains where the air pressure is low.

Requirements
Problems to be tackled

- The boundary of the context should be determined from stakeholders’ requirements.
  - If we consider climbers as customers of the pot, we have to admit that we failed in eliciting requirements.

- It is not easy to define the context boundary even if the target users of the system are determined.
  - A developer will be faced with the frame problem because there are unlimited context elements in the real world.

Our approach

- We provide a systematic way to relax the frame problem by providing the followings.
  - **CAMEmb**
    - procedure for **exploring the context boundary**.
    - validation method for detecting the conflicts between system and its context.
  - **CAMEmb-based MDD** (Model-Driven Development)
    - tool support for **transforming system and context models into the design model** that takes into account the influence of the context within the explored boundary.
CAMEmb

Context Analysis Method for Embedded systems
CAMEmb Overview

CAMEmb is applied after system requirements analysis.
Context analysis using guide words

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Step 1:
Extract directly observed or controlled context elements

UML Profile for Context Analysis

Class
<<Sensor>>
<<Actuator>>
<<Context>>

Association
<<Observe>>
<<Control>>

Value-context element (value object)

System Analysis Model

Context Analysis
Step 2 [Initial boundary]: Extract indirectly observed or controlled context elements

The initial context boundary is an ideal boundary in which system's observing and controlling are not affected by other factors.
Step 3 [intermediate boundary]: Extract impact factors using guide words

Context elements that do not change the values are ignored!

*The frame problem can be avoided!*

Association

<<Affect>>

Guide word

Factor that determines the upper limit
Step 4 [Final boundary]:
Determine the context boundary

Focus on value-context elements

Association
<<Affect>>

Guide word

Factor related to a specific value
CAMEmb-based MDD
Model-Driven Requirements Engineering for Context Analysis
CAMEmbModeler

- Model Editor
- Model Compiler
- Code Generator

Context model of a line trace car

DSL for Context Analysis

Model Compiler + Code Generator

Requirements
Analysis Model

Context
Analysis Model

System
Analysis Model

Design Model

Code

Model-Driven Requirements Engineering
Mapping between context model and design model

Context Analysis Model

We can obtain a design structure by reversing the recognition path.

The context boundary determines the design structure.

The context elements in a context model show the process of context recognition.

Recognition Goal (logical)

Initial context boundary

Sensed Data (physical)

The top module of the design hierarchy corresponds to a context element existing within the initial context boundary.

Design Model (Module structure)

Light Sensor

- -> Reflected Light (light volume)
- -> Ground Color (black or white)
- -> On or outside a line
Discussion
Problem frames

- A context diagram in the **problem frames approach** describes problem domains, a machine, and connections among them.

- The notion of context in CAMEmb corresponds to the real world in the problem frame.

Context analysis with problem frames

### Required Behavior Frame

**Control Machine**
- **Trace Controller (TC)**
- **Body (BD)**

**Controlled Domain**
- **Line Trace**

**Required Behavior**
- **Line Position (LP)**
- **Light Sensor (LS)**

### Transformation Frame

**Transformation Machine**
- **Line recognition Controller (LC)**

**Input**
- a: TC! { Right, Left}
- b: LP! { On, Off}
- c: LC! { Ground Color}
- d: LS! { Reflected Light}
- r: BD! { Run, Return to Course}

**Output**
- a: TC! { Right, Left}
- b: LP! { Line detected, Linemissed}
- c: LC! { Ground Color}
- d: LS! { Reflected Light}
- r: BD! { Run, Return to Course}

On if ground color is black
We consider that it is effective to apply CAMEmb after problem analysis is done.

The problem frames approach is strong in analysing problems in the real world.

CAMEmb provides a systematic way for determining the context boundary and refining the real world model cut off by the boundary into a design model.
Conclusions
Conclusions

- We proposed CAMEmb, a context-dependent requirements analysis method.
- The idea of value-context elements and guide words plays an important role.
- We believe that the essential idea of CAMEmb can be applied to other kinds of context such as security.
- As the next step, we plan to apply CAMEmb to such an application domain.
Thank you for your attention.