Considering Feature Interactions in Product Lines
Towards the Automatic Derivation of Dependencies Between Product Variants

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Outline

- Introduction
- Variability in Software Product Lines
- Deriving Dependencies between Product Variants
- Conclusion
Introduction: Software Product Line Engineering

- Development approach for customer specific software
  - Systematic reuse
    → Reduction of development cost and time; Increase in Quality

- Two development processes

  Domain Engineering:
  - Domain Req. Engineering
  - Domain Design
  - Domain Realization
  - Domain Testing

  Application Engineering:
  - Application Req. Engineering
  - Application Design
  - Application Realization
  - Application Testing

Introduction: The Concept of Variability (1)

- Variability
  - “Ability of an artefact to be adaptable”

- Employing variability
  - Domain engineering:
    - Modelling of “generic” domain artefacts
  - Application engineering:
    - Binding the variability of the domain artefacts

- Variation point (VP)
  - Point at which an artefact can vary

- Variant (V)
  - Concrete instances or alternatives for variable parts
  - associated to one VP
Introduction: The Concept of Variability (2)

- Example: “Small Building Control System Family”

- Problem: Variants can influence each other

- Consider dependencies during application requirements engineering
  - Example: artificial cooling hinders heating

- customer is aware that “artificial cooling” will impact “heating”
- choice of alternatives is possible (e.g., natural ventilation, integrated HVAC, …)

- Problem: Dependencies have to be known before application requirements engineering
  - otherwise: frustration of customers
Introduction: Dependencies between Variants (2)

- **Solution**: Identify dependencies in domain engineering
  - All possible applications have to be considered

- **Problem**: Number of possible combinations of variants
  - Small example: 5 variants \( (3+2+1) \times (2+1) = 18 \) applications
  - Large example: 14 variants \( 639 \) applications
  - In practical contexts: > 100 variants \( >> 1000 \) applications

  -> Manual identification of dependencies does not scale!

- **Our solution**: Semi-automatic approach based on feature interaction detection
  - Feature interaction between \( V_j \) and \( V_k \) \( \rightarrow \) dependency between \( V_j \) and \( V_k \)

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Variability in Software Product Lines:
Variability Model (1)

- Variation point (VP)
  - Point at which the artefact can vary
- Variant (V)
  - Concrete instances or alternatives for variable parts
  - associated to one VP

- VP-V Dependency
  - Variant Group (VG)
    - Constrains selection of variants for VP

- V-VP Dependency
  - Allows hierarchical refinement

- V-V Dependency
  - Dependencies between variants
    - hard: excludes / requires
    - subtle: hints / hinders

- similarities with feature diagrams

Variability in Software Product Lines:
Variability Model (2)

- Example: “Building Control System Family (BCSF)”

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Deriving Dependencies between Product Variants: Basic Approach

1. **Automatically** determine **feature interactions** for all possible applications
   1.1 Select **representatives** from all possible combinations
      → Tackling the problem of scale

   *for each representative:*
   1.2 Derive “application” by binding variants
   1.3 Detect feature interactions
      - using algorithm from single system development

2. **Manually** derive and model **dependencies**
   2.1 Determine relevant feature interactions
      → Relevance cannot be derived from input models
   2.2 Model dependencies between variants
Deriving Dependencies between Product Variants:
1.1 Select Representatives (1)

- Number of possible \textit{variant combinations} for one VG

\[ K(j,k,n) = \sum_{i=j}^{k} \binom{n}{i} \]

- BCSF Example: 639 combinations

- Assumption: \textbf{no} \textit{m-way feature interactions}
  
  - \textit{m-way feature interaction} :=
    feature interaction that does not occur between \(1 < r < m\) features but occurs among \(m\) features
  
  - interaction between features \(F_1, \ldots, F_m\)
    \[ \Rightarrow \text{interactions between all features } F_{i_1}, \ldots, F_{i_r} \in \{F_1, \ldots, F_m\} \text{ with } 1 < r < m \]

\[ \Rightarrow \textbf{Select} \text{ combination with largest possible number of variants:} \]

- “worst case”: false positives \(\Rightarrow\) more interactions to check manually

\[ K(j,k,n) = \binom{n}{k} \]

- BCSF Example: 639 \(\rightarrow\) 3

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Deriving Dependencies between Product Variants:
1.1 Select Representatives (2)

- \textbf{Selection Algorithm} (“Outline”)

1. Start with root VP

2. Resolve VP by adding maximum number of variants
   - considering alternatives if \(k < n\)

3. Resolve hierarchical variants (replace by VP)

4. Repeat at 2. until no more VPs are contained
Deriving Dependencies between Product Variants:

1.1 Select Representatives (3)

- **Selection Algorithm**
  - BCSF Example:
    ```
    {V1.1, V1.2, V2, V3, V4.1, V4.2, V4.3, V4.4, V5.1} \\
    {V1.1, V1.2, V2, V3, V4.1, V4.2, V4.3, V4.4, V5.3} \\
    {V1.1, V1.2, V2, V3, V4, V5} \\
    {V1.1, V1.2, V2, V3, VP1, VP3, VP4, VP5} \\
    {V1.1, V1.2, V2, V3, V4.1, V4.2, VP4, VP5} \\
    {V1.1, V1.2, V2, V3, V4.1, V4.2, V4.3, V4.4, VP5} \\
    {V1.1, V1.2, V2, V3, V4.1, V4.2, V4.3, V4.4, V5.2} \\
    VP1 \\
    VP3 \\
    V4.1 \\
    V4.2 \\
    1..* \\
    VP2 \\
    V4.3 \\
    V4.4 \\
    1..* \\
    VP4 \\
    V4.5.1 \\
    VP5 \\
    1..1 \\
    V5.2 \\
    VP5 \\
    VP5 \\
    1..1 \\
    V5.3 \\
    ```
```
```

1.2 Derive “Application” (2)

- **Bind variants in GRL (Goal Oriented Requirements Language) models**
  - Each variant is assigned to one goal
  - BCSF Example (Excerpt):
    ```
    {V1.1, V1.2, V2, V3, V4.1, V4.2, V4.3, V4.4} \\
    {V1.1, V1.2, V2, V3, V4.1, V4.2, V4.3, V4.4, V5.1} \\
    {V1.1, V1.2, V2, V3, V4.1, V4.2, V4.3, V4.4, V5.2} \\
    ```
```
```
Deriving Dependencies between Product Variants:
1.3 Detect Feature Interactions

- Detect points of interaction (cf. [Metzger et al. 2003], [Metzger 2004])
  - **Point of interaction**: task that
    - contributes to the realization of more than one goal
    - has more than one direct parent
    - does not realize goals only
  - Recursive algorithm on GRL metamodel instance
  - BCSF Example:

- Interaction between **NaturalLighting**, **Glare** \(\Rightarrow\) Interaction between V1.2, V2

- Extension for embedded systems:
  - Additionally consider environment

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Deriving Dependencies between Product Variants:
2. Manually Derive and Model Dependencies

2.1 Determine relevant feature interactions

- BCSF example:
  1. \(\{V1.2, V2\}\) @ Task
  2. \(\{V1.1, V1.2, V2, V3, V4.2\}\) @ Task
  3. \(\{V1.1, V1.2, V2\}\) @ Task
  4. \(\{V1.2, V2, V3, V5.2\}\) @ environment
  5. \(\{V1.2, V2, V3, V5.1\}\) @ environment
  6. \(\{V4.1, V5.3\}\) @ environment
  7. \(\{V1.2, V2, V3, V5.3\}\) @ environment

2.2 Model dependencies between variants

- BCSF example:
Conclusion

- Semi-automatic approach
  - Reduction of complexity/effort
    - Automatic selection of representatives: 639 → 3
    - Automatic detection of interactions: 37 goals/tasks, 39 means-end-links → 7 interactions

- Model-based approach
  - Inputs/outputs are models
  - Model-based implementation of detection tool
    - Core: 175 manually implemented Java LOCs

- Generality of approach
  - Variability model → feature diagrams could also be used
  - Requirements model (GRL) → other detection approaches are applicable

“Positive” use of Feature Interactions for Product Line Engineering
→ Selection of alternatives to “avoid” undesired interactions

Further Information …

… Text Book:

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… Questions?