Cross-checking Disambiguated Product Line Variability Models

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Presentation outline

1. Software Product Lines Engineering
2. Two kinds of variability
3. Objectives and approach overview
4. Internal model verification
5. Cross-model verification
6. Summary of contributions
7. Current & future work
1. **Software Product Lines Engineering**

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Software Product Line Engineering (SPLE)

Domain Engineering

Domain Analysis → Domain Design → Domain Implementation

Reference Requirements → Reference Architecture → Reusable Components

Application Requirements → Application Design → Application Coding

Feedback/Adaptation → Final Products

www.sei.cmu.edu/productlines
Key SPLE benefits & challenges

- **Benefits**
  - Scale economies
  - Shorter time to market
  - Less risky development

- **Challenges**
  - High upfront adoption costs
  - Requirements are even more crucial
    - they determine the success of the whole family
  - Manage the variation between products
1. Software Product Lines Engineering
2. Two kinds of variability
3. Objectives and approach overview
4. Internal model verification
5. Cross-model verification
6. Summary of contributions
7. Current & future work
Two kinds of variability

Software Variability refers to the **ability of a software system or artefact** to be efficiently extended, changed, customized or configured for use in a particular context. [Svahnberg et al. 2005]

- **descriptive** statements about the existing software assets
- relevant to both SPLE and single product development
- example:

```plaintext
VoiceCommunication

- «component»: Protocol
- 1..3
- «component»: C1: GSM
- «component»: C2: UMTS
- «component»: C3: VoIP
```
Two kinds of variability

**Product Line Variability** describes the **variation (differences)** between the systems that belong to a product line in terms of properties and qualities (like features that are provided or requirements that are fulfilled).

[Coplien et al., 1998] [Kang et al., 2002] [Pohl et al., 2005]

- *prescriptive* statements about the products to be built
- explicit **decisions** made by product management
- specific to SPLE
- example:
  - “Every mobile phone in the PL shall support the GSM protocol, the UMTS protocol, or both (but not VoIP or other protocols)”
Relationship between the two variabilities

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[Coplien et al., 1998] [Kang et al., 2002] [Pohl et al., 2005]

**Software Variability** refers to the ability of a software system or artefact to be efficiently extended, changed, customized or configured for use in a particular context.  

[Svahnberg et al. 2005]
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Our objective

- Support PL business and software engineers in
  - Making PL variability decisions that are aware of
    - the software asset’s capabilities
    - the software adaptation costs
  - Developing software assets that allow
    - to realize all PL variability
    - but not too much more

- Current practice
  - information is not documented
  - or documented informally
  - or software & PL variability are not distinguished

[Metzger & Heymans, TR, 2006]
Use formal variability models

Use formal variability models

\[ \mathbb{D} = \{ \{ f_3 \}, \{ f_1,f_3 \}, \{ f_3,f_4 \}, \{ f_2,f_3,f_4 \}, \{ f_1,f_3,f_4 \}, \{ f_1,f_2,f_3,f_4 \} \} \]

**Formal, but still ambiguous:**

- are these the realizable software products?
- are these the PL members to be offered to customers?
- or an entangled mixture of each?
The proposed approach

- The 2 variabilities are
  - Documented **separately**
  - **Related** through X-links

- Using popular concrete syntaxes in the front-end
  - OVM  [Pohl et al., 2005]
  - any FD dialect

- Using formal semantics in the back-end
  - less ambiguity
  - automated reasoning support
1. Software Product Lines Engineering
2. Two kinds of variability
3. Objectives and approach overview
4. Internal model verification
5. Cross-model verification
6. Summary of contributions
7. Current & future work
**Internal model verification**

**Basic semantic checks** [Benavides et al. 2006] [RE’06], e.g.

- **Satisfiability**: $[D]_{VFD} \neq \emptyset$
- **Product (resp. PL member) enumeration**: list all $p_i$ s.t. $p_i \in [D]_{VFD}$
- **Product (resp. PL member) checking**: $p_i = \{f_{i,1}, \ldots, f_{i,n}\} \in [D]_{VFD}$
- **Dead features (resp. variants)**: $\{f_1, \ldots, f_m\} \setminus \cap [D]_{VFD}$
- **Commonality**: $\cup [D]_{VFD}$
1. Software Product Lines Engineering
2. Two kinds of variability
3. Objectives and approach overview
4. Internal model verification
5. Cross-model verification
6. Summary of contributions
7. Current & future work
X-links and their semantics

- “Whenever a variant is chosen, all its X-linked features must be in”
  e.g.

\[
\{V_1, V_3, f_3, V_4, f_4\} \notin \mathcal{G}
\]
\[
\{V_1, f_1, V_3, f_3, V_4, f_4\} \in \mathcal{G}
\]

- “An X-linked feature requires at least one X-linked variant (justification) to be chosen”
  e.g.

\[
\{f_1, V_3, f_3, V_4, f_4\} \notin \mathcal{G}
\]
\[
\{V_1, f_1, V_3, f_3, V_4, f_4\} \in \mathcal{G}
\]
\[
\{V_1, f_1, V_3, f_3, V_4, f_4, f_5\} \in \mathcal{G}
\]
Global model’s semantics

\[G\] is the set of realizable PL members (incl. their features)
Simple syntactic X-checks (warnings)

- Suspect cases
  - Features not hit by an X-link
  - Variants with no departing X-link
Simple syntactic X-checks (warnings)

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- Suspect cases
  
  ✔ Features not hit by an X-link

  ✔ Variants with no departing X-link
Simple syntactic X-checks (warnings)

- Suspect cases

  - Features not hit by an X-link
    - ✔️
  - Variants with no departing X-link
    - ✔️
Towards semantic X-checks

...and apply basic semantic checks (satisfiability, product checking...) for a start

Front-end

Back-end

G =

FD → VFD

OVM → VFD

X-links

Prop logic

\( \phi_{O+F} \)

\( \phi_{O+F} \land \phi_X \)

Prop logic

\( \phi_X \)

Prop logic

SAT

University of Namur (FUNDP)
X-links $\rightarrow$ prop logic

**Pattern 1 — one-to-one inclusion X-link**

\[ f \iff V_1 \lor V_2 \lor \ldots \lor V_n \]

**Pattern 2 — global inclusion X-link**

\[ f \]

**Pattern 3 — global exclusion X-link**

\[ \neg f \]

**No specific pattern**

Use any formula in

\[ B(\{f_1,\ldots,f_m\} \cup \{V_1,\ldots,V_n\}) \]
Advanced semantic checks

- **Check1. Realizability** — are there non-realizable PL members?
  - PL member $po \in [O]$ is **realizable** if $po \in [G]_o$
  - non-realizable PL members are given by $[O] \setminus [G]_o$

- **Check1’. Usefulness** — are there useless products?
  - product $pf \in [F]$ **useful** if $pf \in [G]_F$
  - useless products are given by $[F] \setminus [G]_F$
Realizability — example

- Detected issue
  - \( \{V1, V2, V3, V4\} \in \square \)
  - \( \{V1, V2, V3, V4\} \not\in \square \circ \)
  - Hence, \( \{V1, V2, V3, V4\} \in \square \setminus \\square \circ \)

- Solution
  - *either* restrict the PL scope
  - *or* increase the flexibility of the software platform
Detected issue
- \( \{f2\} \in [F] \)
- \( \{f2\} \notin [G]|_F \)
- Hence, \( \{f2\} \in [F]\backslash[G]|_F \)

Possible optimization
- *either* expand the PL scope
  (for free)
- *or* remove the flexibility of the software platform
More advanced semantic checks

- **Check2. Internal competition** — 2 distinct PL members realized by 1 product?
  - \( (po_1 \cup pf) \in [G] \land (po_2 \cup pf) \in [G] \land (po_1 \neq po_2) \)
  - i.e. several ways for the customer to get the same features, maybe at different prices...

- **Check2’. Unloyalty to customer** — 2 distinct products realizing the same PL member?
  - \( (po \cup pf_1) \in [G] \land (po \cup pf_2) \in [G] \land (pf_1 \neq pf_2) \)
  - i.e. two customers could choose the same PL member, and get different features
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Summary of contributions

- Disambiguation of variability models
  - Separation of concerns — software vs. PL variability
  - Formal models — FD (not new), OVM, X-links

- Automated verification
  - Internal model consistency
    - not new, but now (more) meaningful!
  - Cross-model consistency

- Proof-of-concept prototype using SAT

- Application to non-toy (but not real-size) exemplar
  - Private Branch eXchange [Lee, Kang et al., 2006]
1. Software Product Lines Engineering
2. Two kinds of variability
3. Objectives and approach overview
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5. Cross-model verification
6. Summary of contributions
7. Current & future work
Current & future work

- Apply approach to real-size project
  - transitioning OSS into a SPL
    
    [Delannay et al., OSSPL’07] [Hubaux et al., SPLC’08]

- Validate and improve notations
  - modularize variability models [Classen et al., VaMoS’07]
  - more X-link patterns needed?
  - further formalization and separation of concerns
Current & future work

- Validate and improve tools
  - optimize verifications
    - less naive use of SAT solver
  - identify more checks
  - towards an integrated tool chain for SPLE