University of Namur

University of Duisburg-Essen

Cross-checking Disambiguated Product Line Variability Models

P. Heymans, A. Metzger, P-Y. Schobbens,
K. Pohl, G. Saval, A. Hubaux

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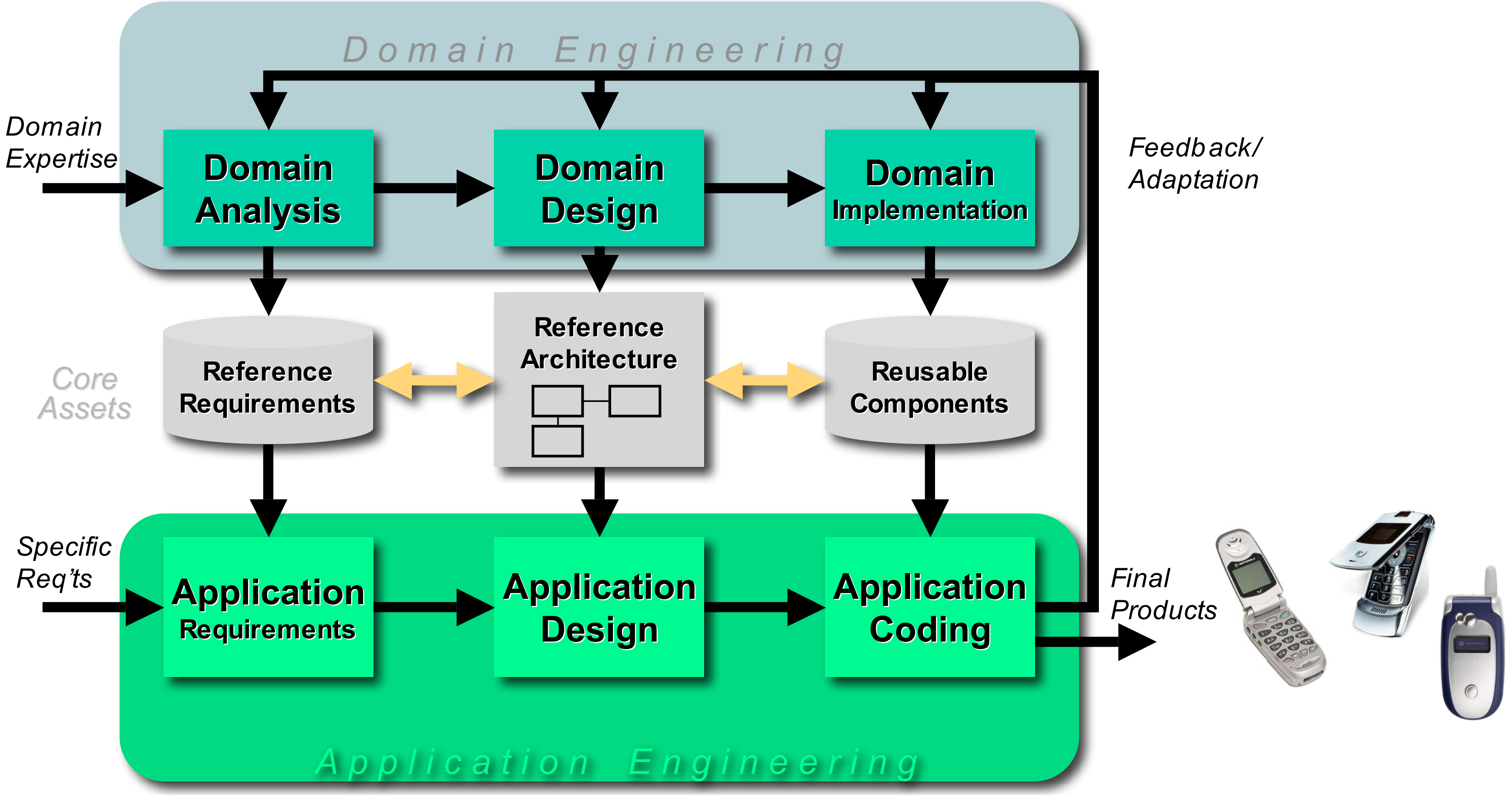
Presentation outline

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

Software Product Line Engineering (SPLE)



www.sei.cmu.edu/productlines

Key SPLE benefits & challenges

- Benefits
  - Scale economies
  - Shorter time to maket
  - 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

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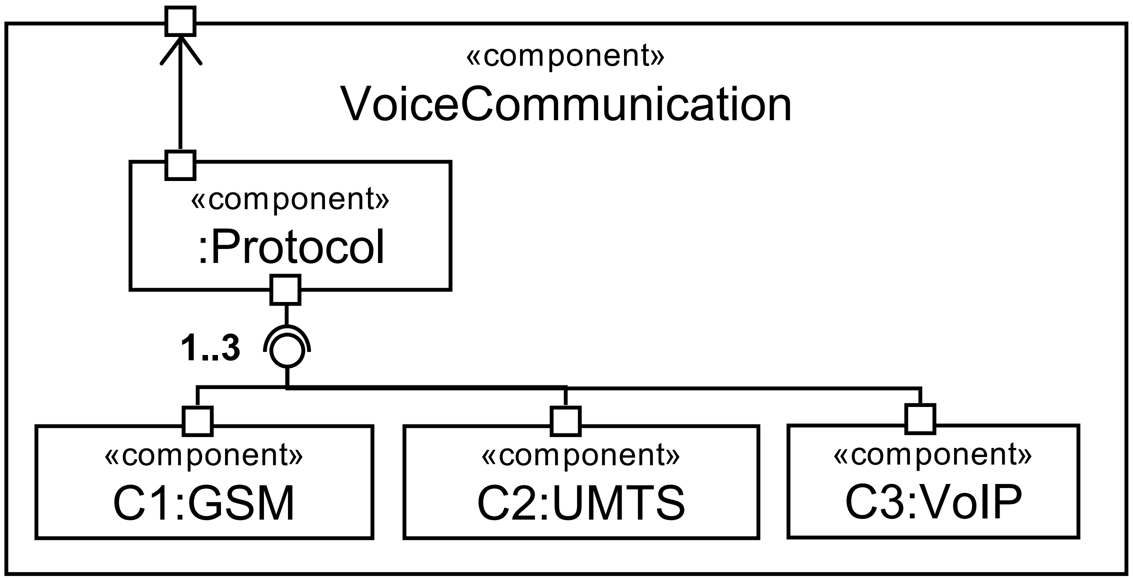
Two kinds of variability

> ☛ **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:



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]

is realized through

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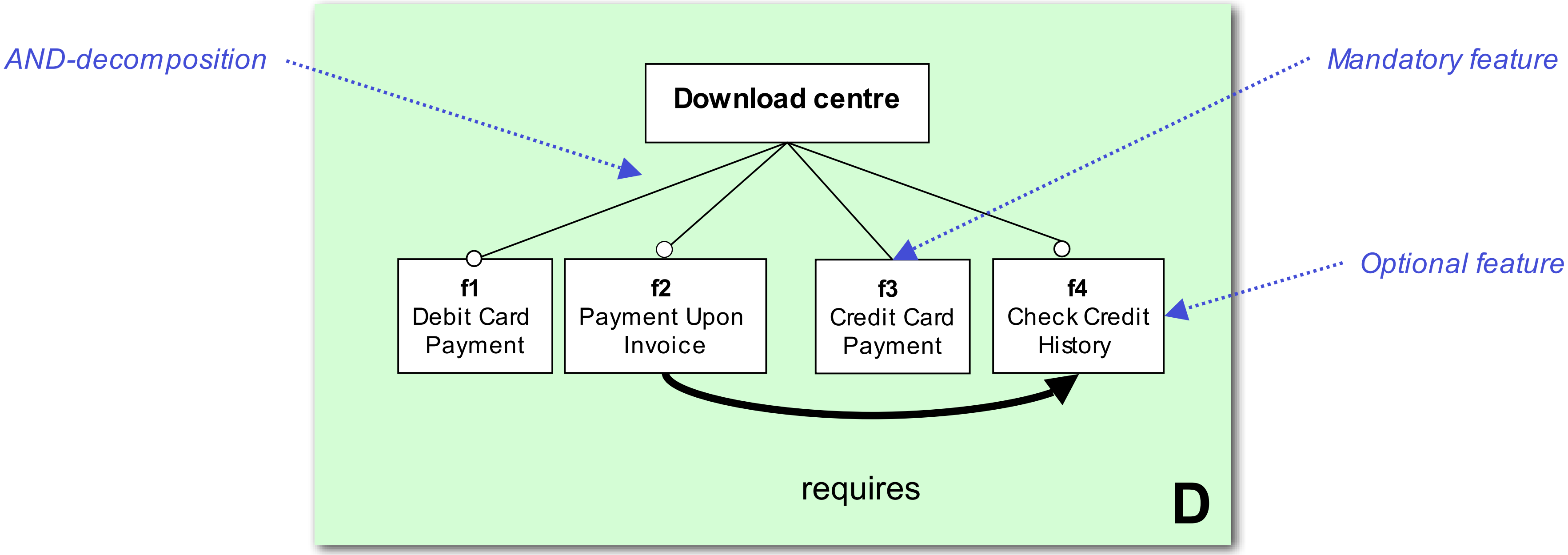
Our objective

- 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 *[RE'06]*



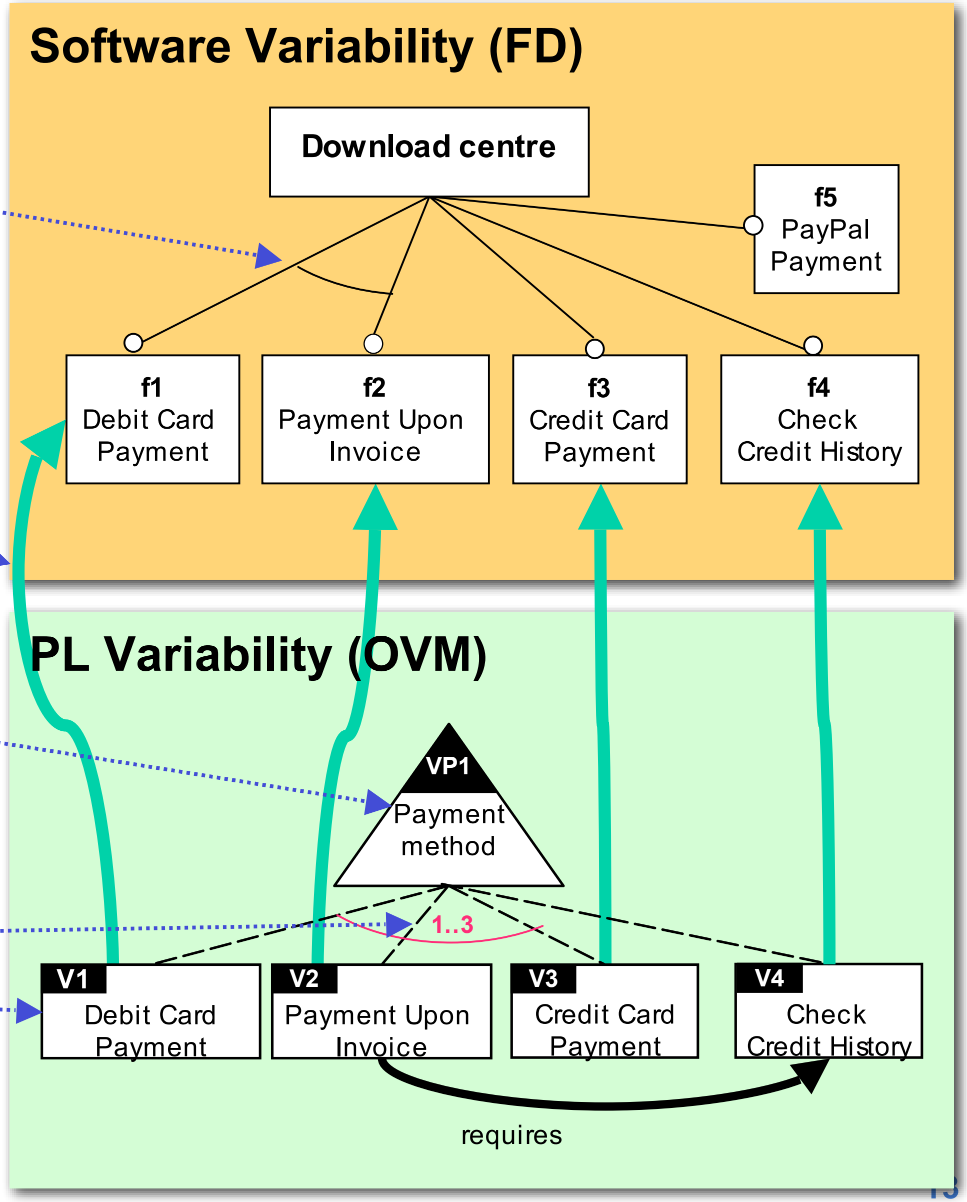
$$[\![D]\!] = \{ \ \{ f3 \}, \{ f1,f3 \}, \{ f3,f4 \}, \{ f2,f3,f4 \}, \{ f1,f3,f4 \}, \{ f1,f2,f3,f4 \} \ \}$$

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



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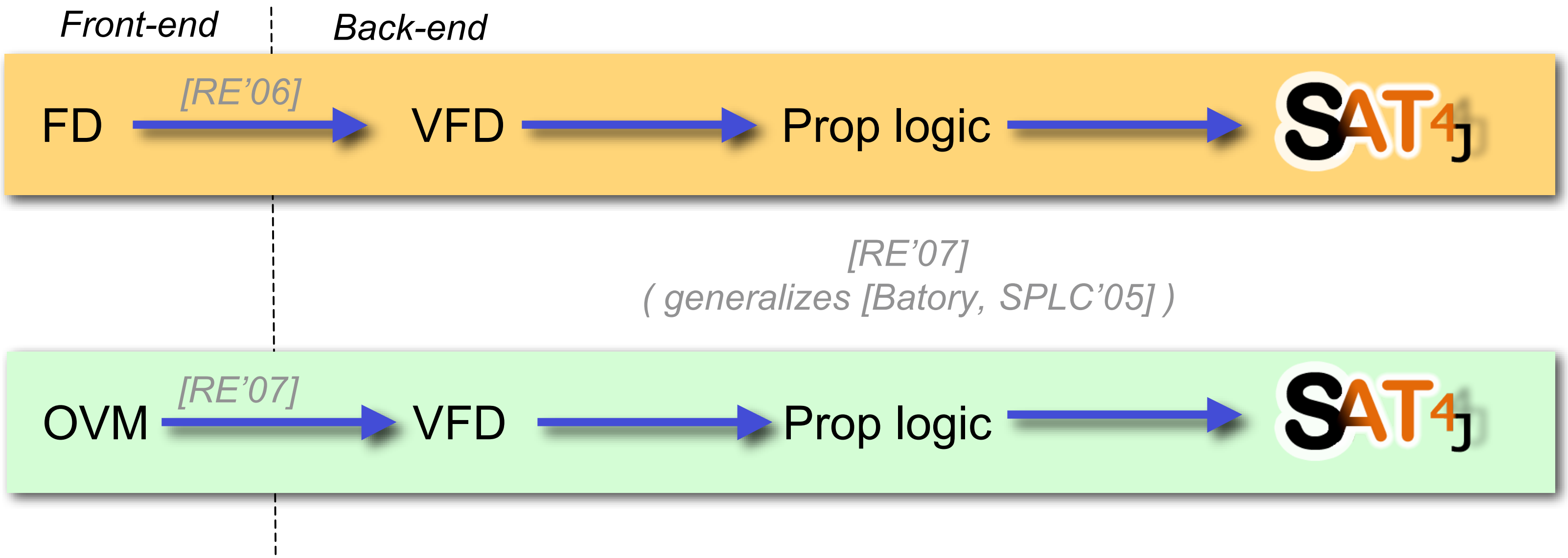
Internal model verification



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**: $\cup [\![D]\!]_{VFD}$

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X-links and their semantics

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

  $\{\boldsymbol{V1}, V3, f3, V4, f4\} \notin [\![G]\!]$

  $\{V1, \boldsymbol{f1}, V3, f3, V4, f4\} \in [\![G]\!]$

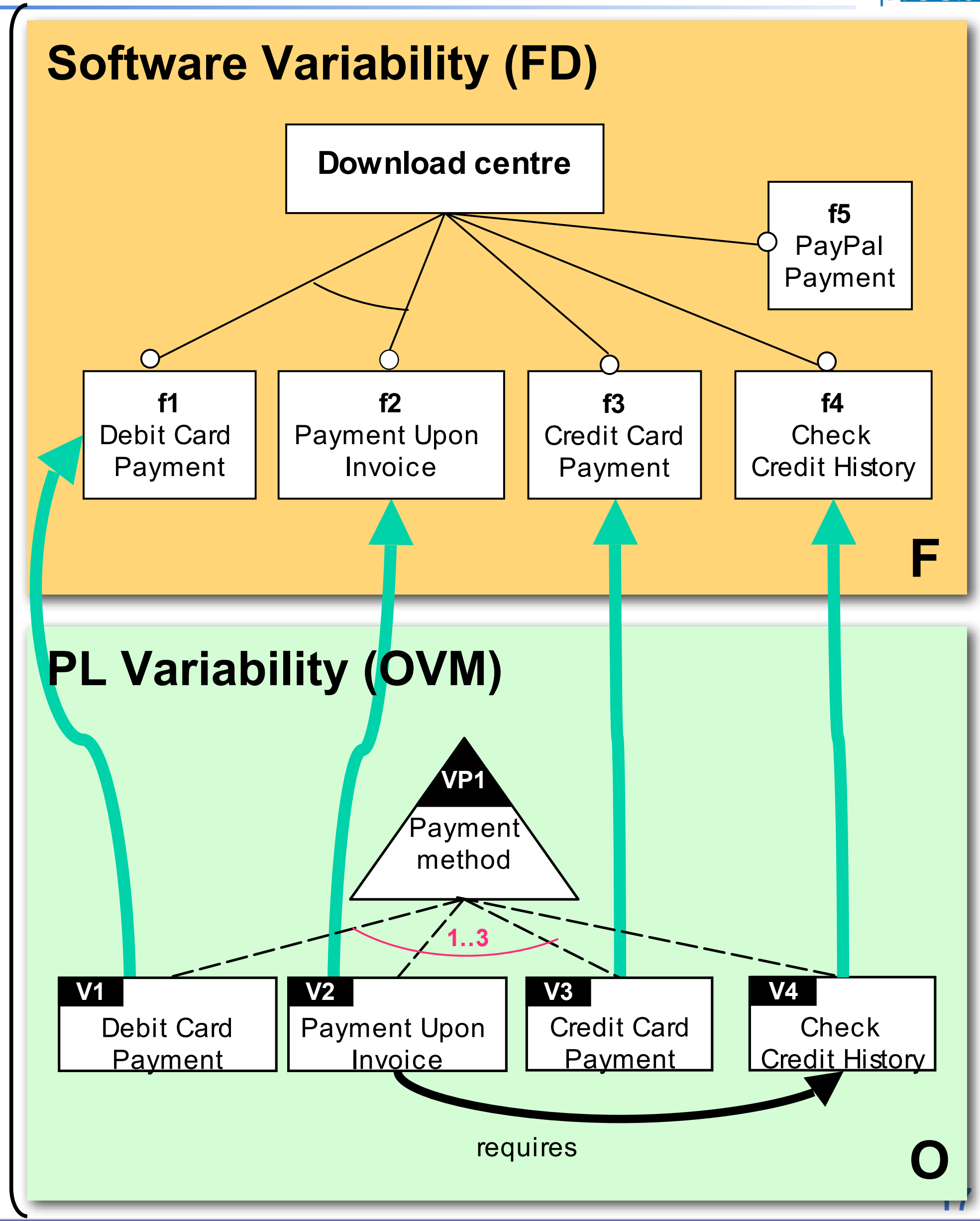
- *"An X-linked feature requires at least one*
  X-linked variant (justification) to be chosen"
  e.g.

  $\{\boldsymbol{f1}, V3, f3, V4, f4\} \notin [\![G]\!]$

  $\{\boldsymbol{V1}, f1, V3, f3, V4, f4\} \in [\![G]\!]$

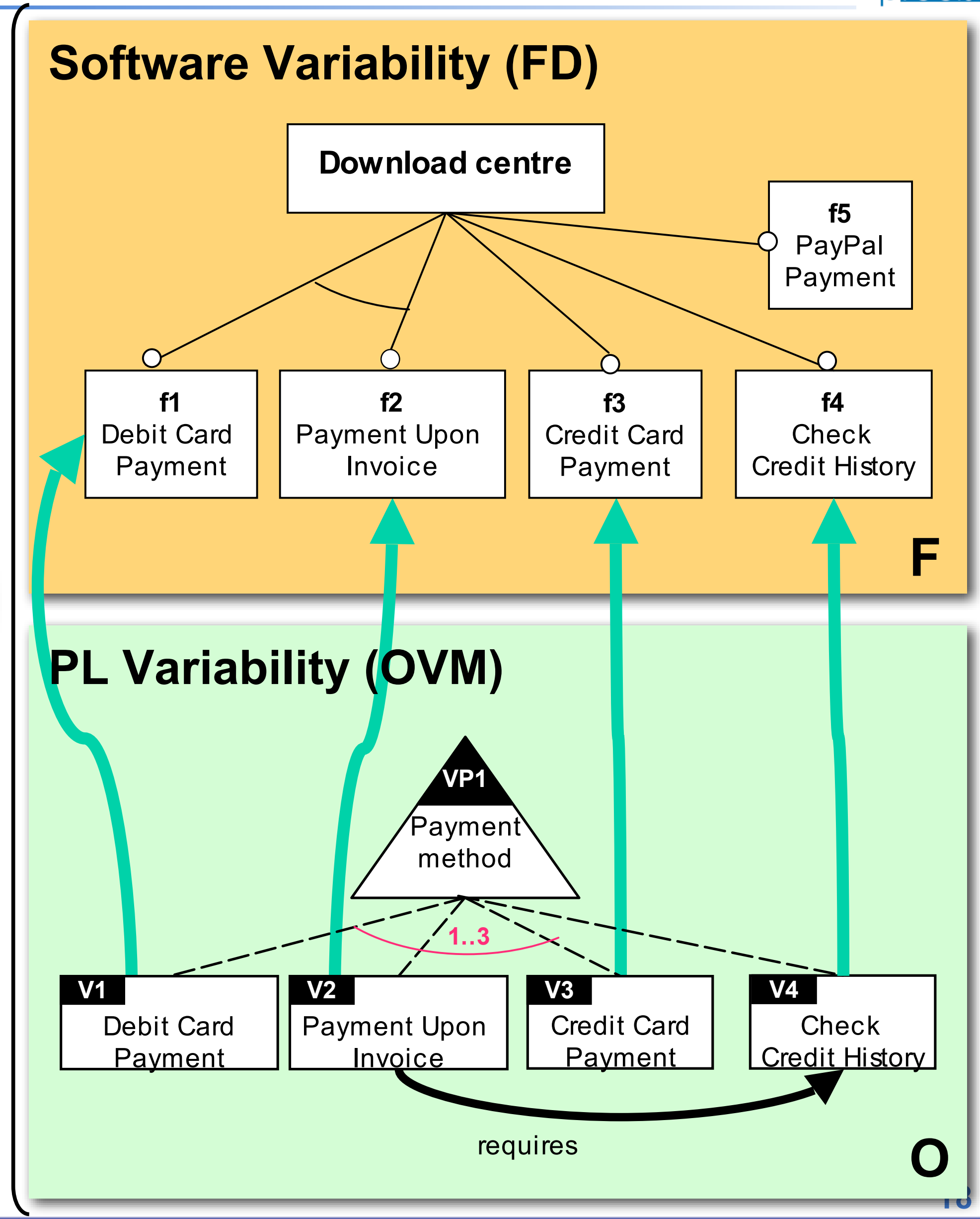
  $\{V1, f1, V3, f3, V4, f4, \boldsymbol{f5}\} \in [\![G]\!]$

G =



Global model's semantics

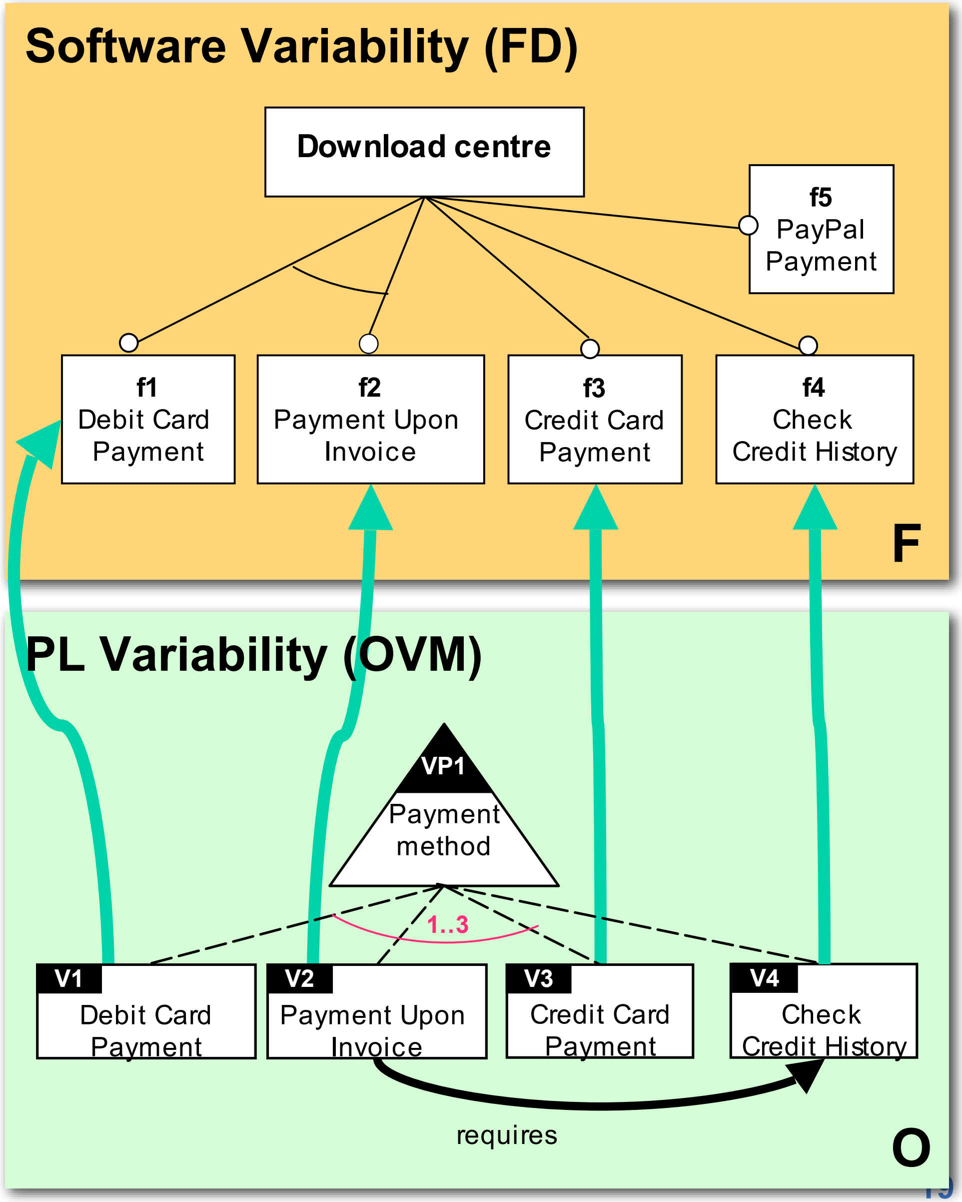
G =



⟦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*

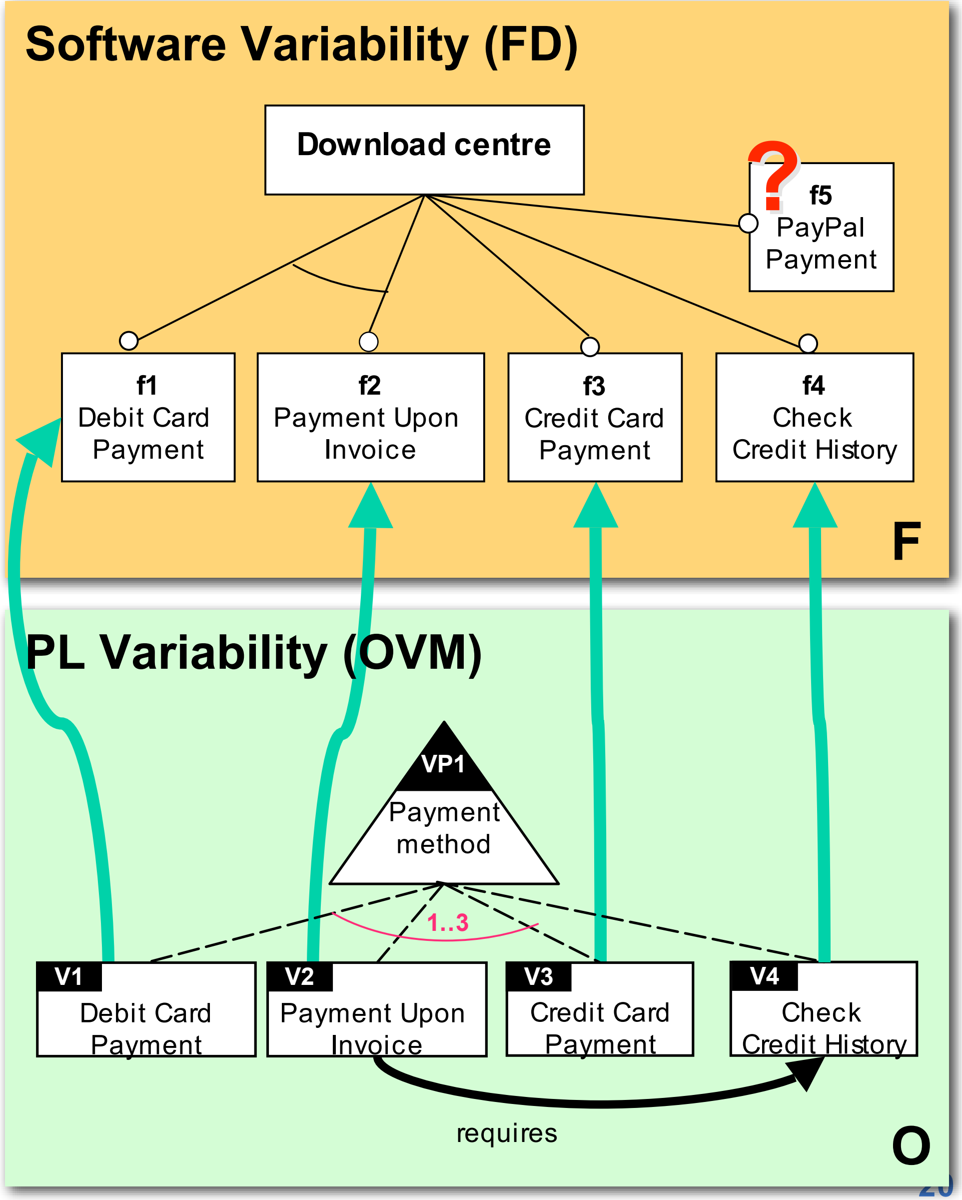


Simple syntactic X-checks (warnings)

- Suspect cases

  ☒ *Features not hit by an X-link*

  ☑ *Variants with no departing X-link*



Simple syntactic X-checks (warnings)

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  - ✓ *Features not hit by an X-link*
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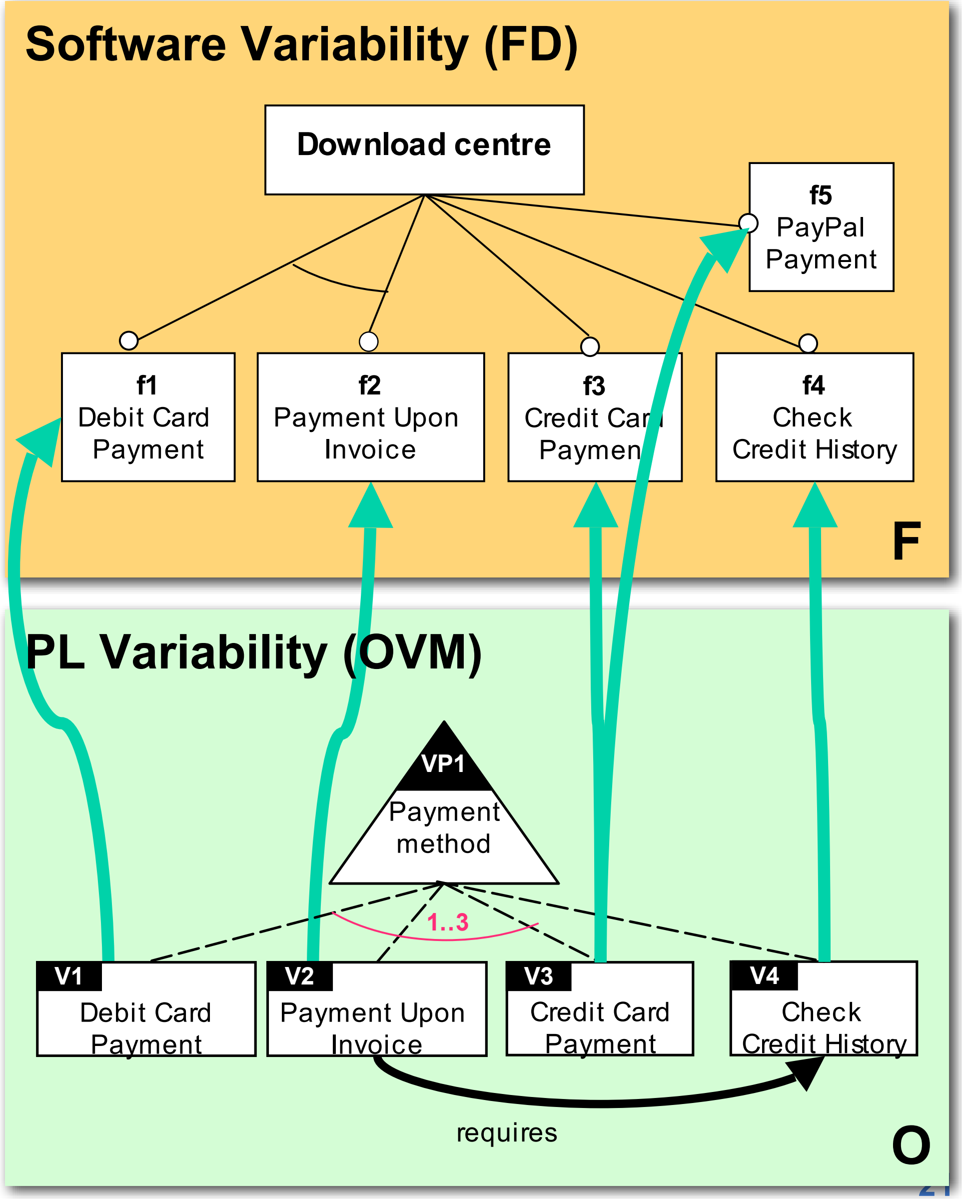

Simple syntactic X-checks (warnings)

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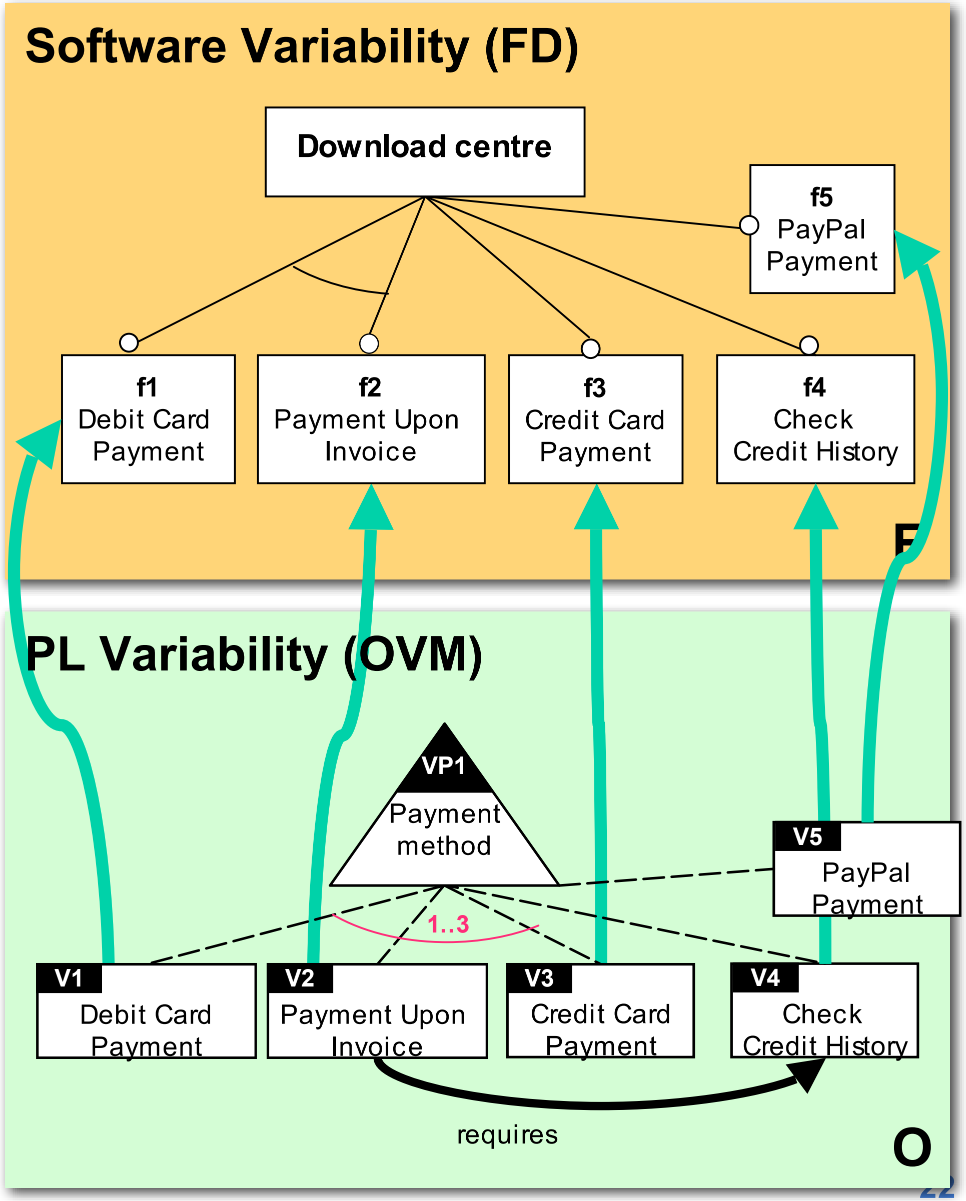

Simple syntactic X-checks (warnings)

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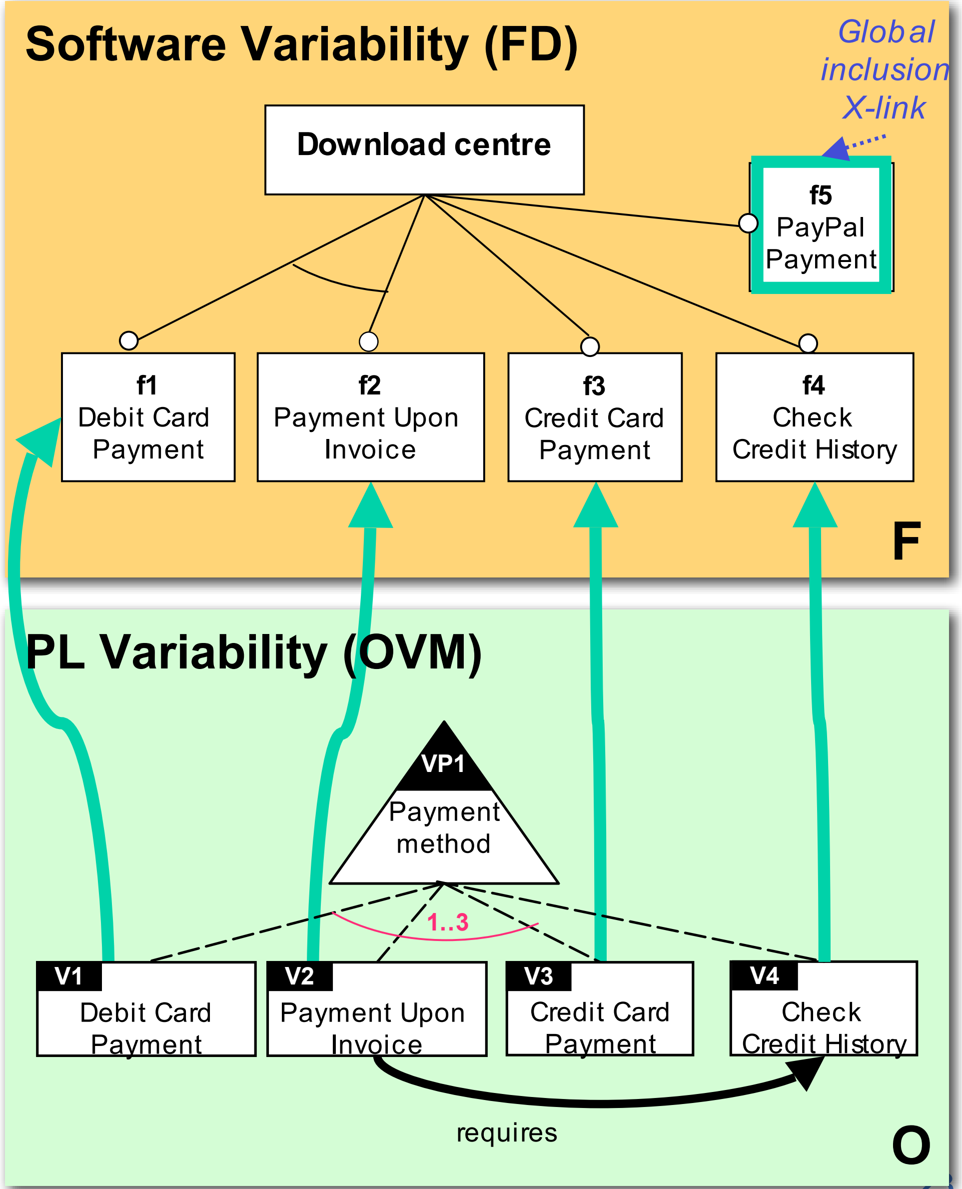
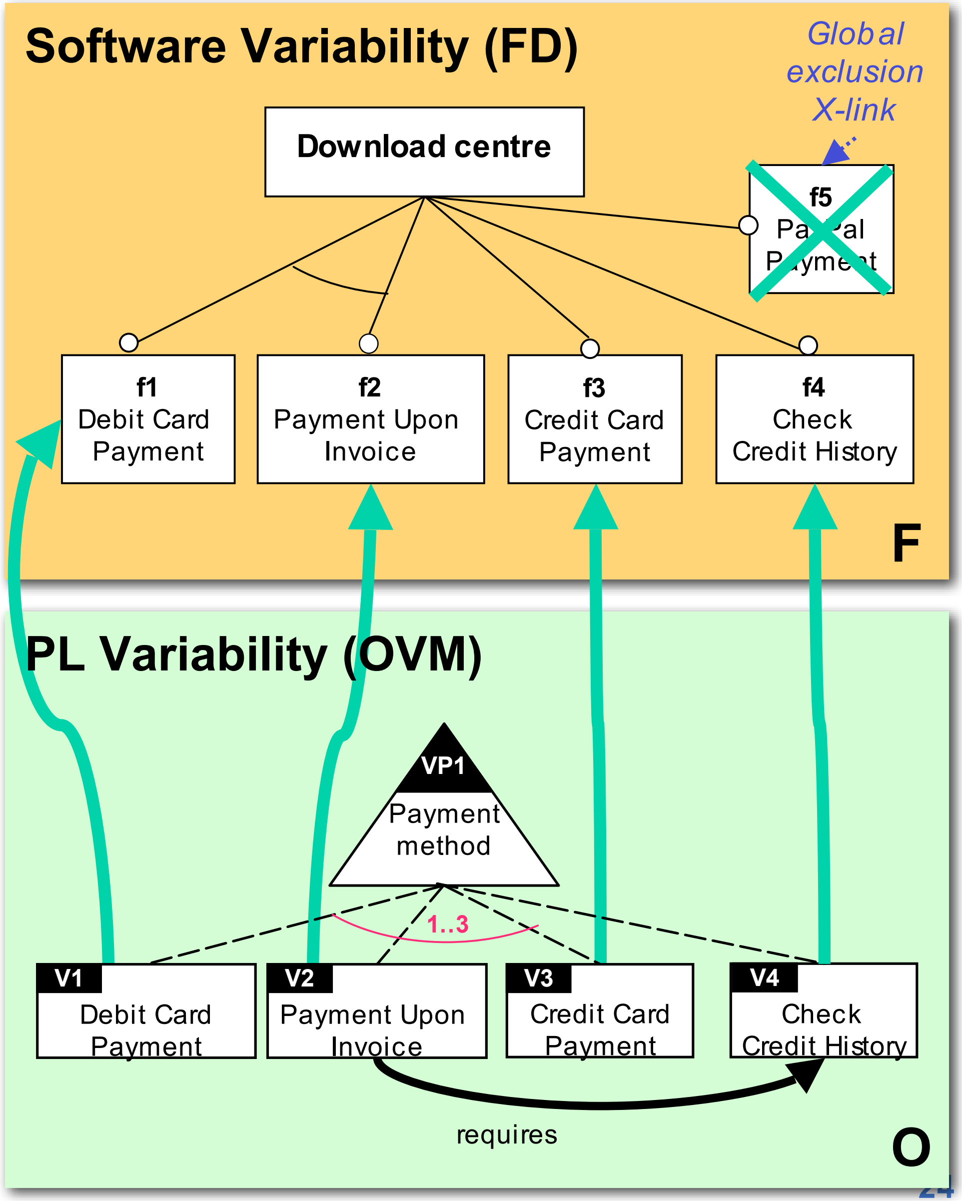


Simple syntactic X-checks (warnings)

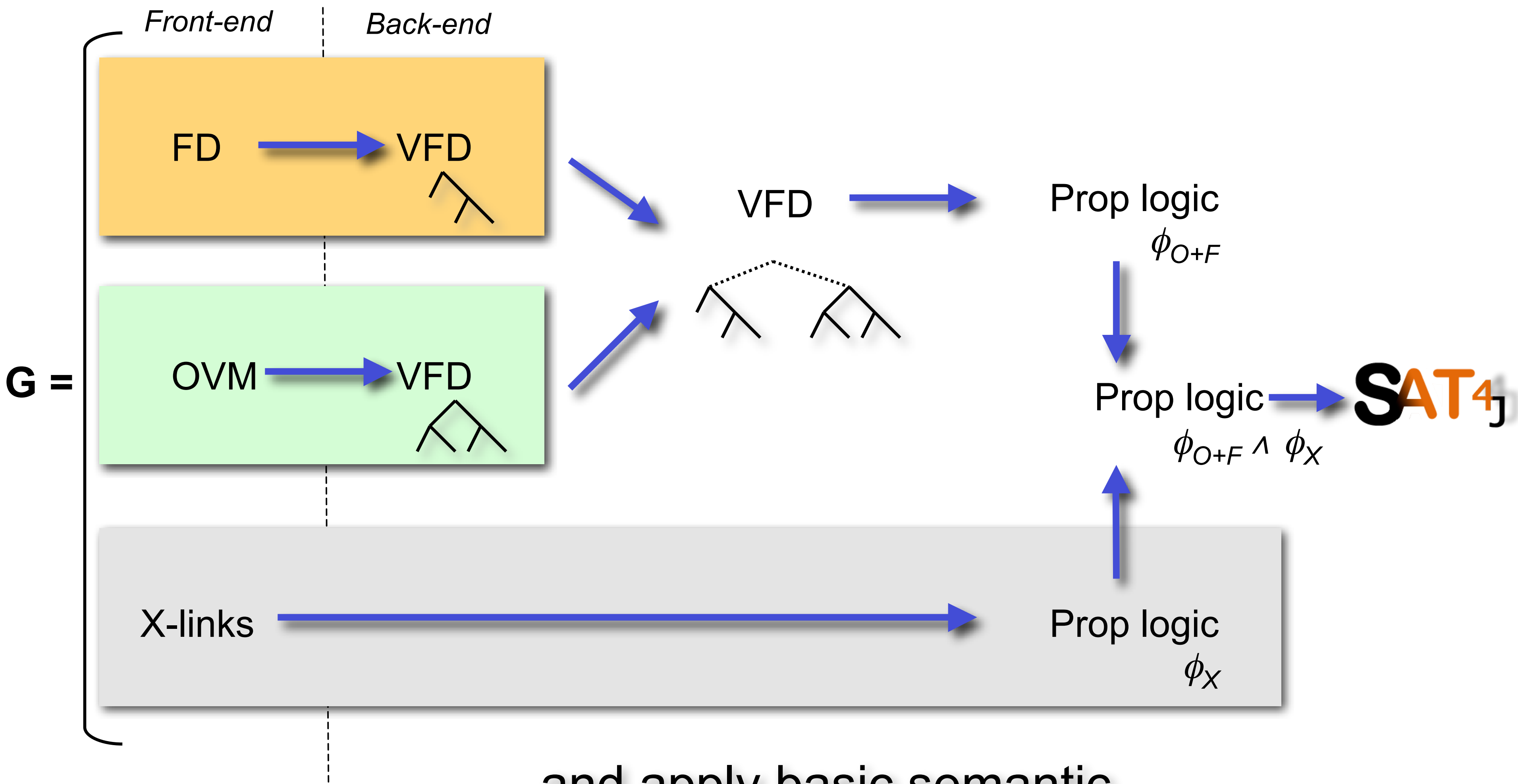
- Suspect cases

  ✓ *Features not hit by an X-link*

  ✓ *Variants with no departing X-link*



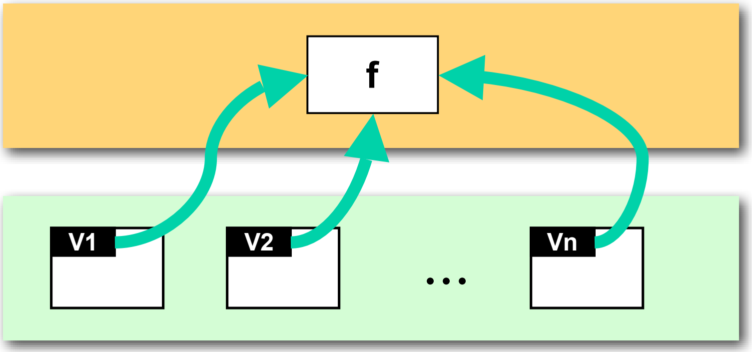
Towards semantic X-checks



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

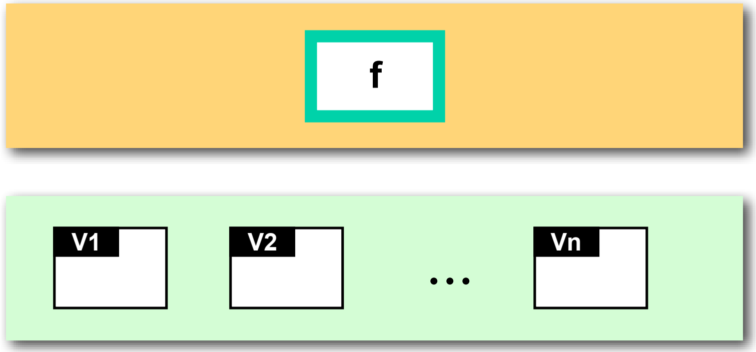
X-links → prop logic

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



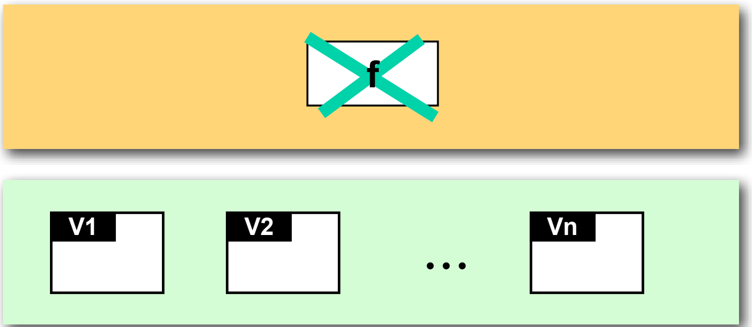
$\rightarrow f \Leftrightarrow v_1 \vee v_2 \vee \ldots \vee v_n$

***Pattern 2** — global **in**clusion X-link*



$\rightarrow f$

***Pattern 3** — global **ex**clusion X-link*



$\rightarrow \neg f$

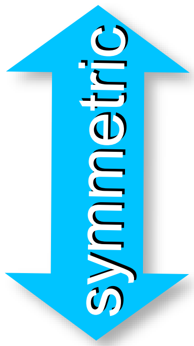
No specific pattern

Use any formula in

$\mathbb{B}$ ($\{f1,\ldots,fm\} \cup \{V1,\ldots,Vn\}$)

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
  - $\{V1, V2, V3, V4\} \in [\![O]\!]$
  - $\{V1, V2, V3, V4\} \notin [\![G]\!]|_O$
  - Hence, $\{V1, V2, V3, V4\} \in [\![O]\!] \backslash [\![G]\!]|_O$
- Solution
  - *either* restrict the PL scope
  - *or* increase the flexibility of the software platform

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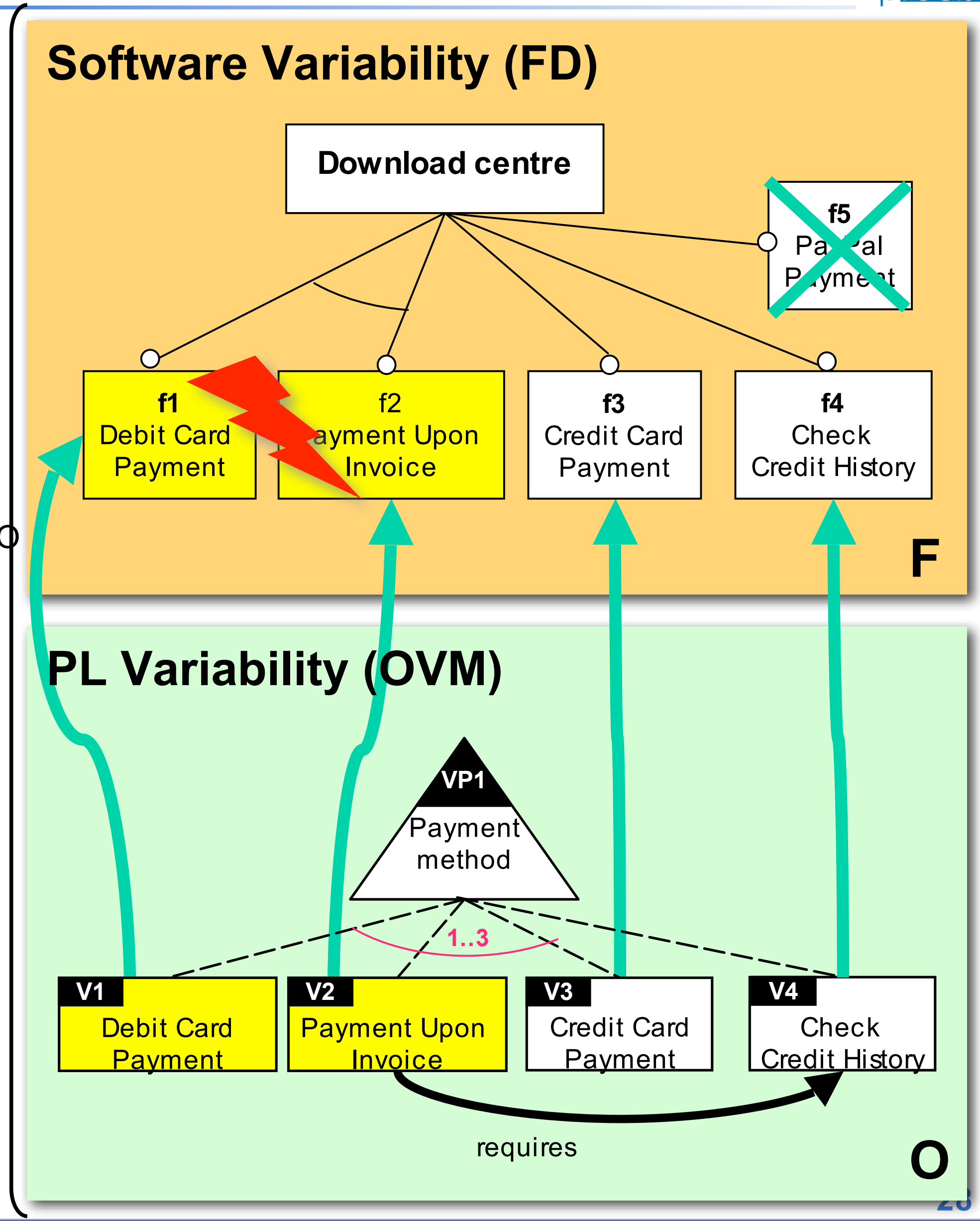
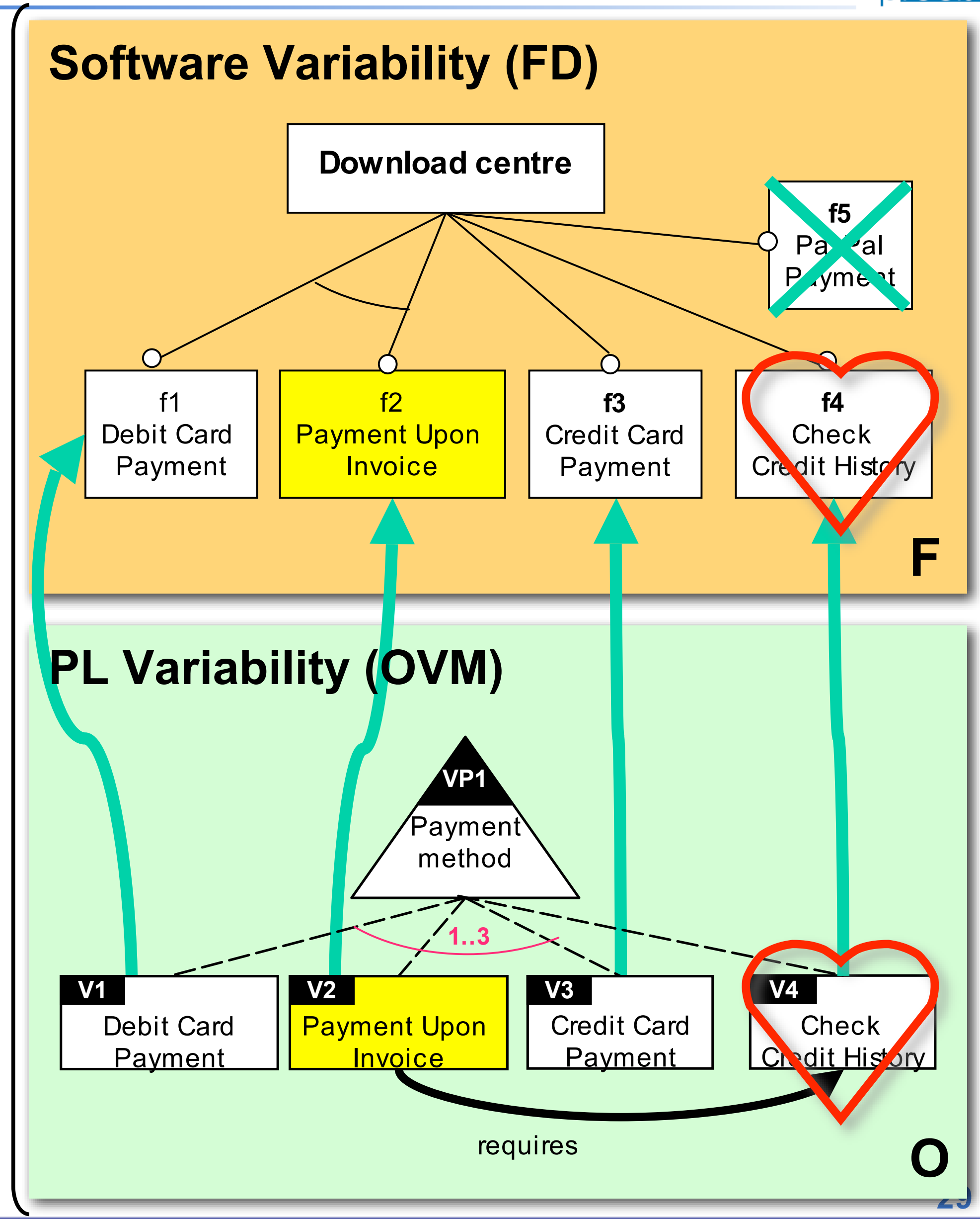


Usefulness — example

- Detected issue
  - $\{f2\} \in [\![F]\!]$
  - $\{f2\} \notin [\![G]\!]|_F$
  - Hence, $\{f2\} \in [\![F]\!] \setminus [\![G]\!]|_F$
- Possible optimization
  - *either* expand the PL scope (for free)
  - *or* remove the flexibility of the software platform

G =



More advanced semantic checks

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

symmetric

- **Check2’. Unloyalty to customer** — 2 distinct products realizing the same PL member?
  - $(po \cup pf_1) \in [\![G]\!] \wedge (po \cup pf_2) \in [\![G]\!] \wedge (pf_1 \neq pf_2)$
  - 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 SAT4J
- Application to non-toy (but not real-size) exemplar
  - Private Branch eXchange *[Lee, Kang et al., 2006]*

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Current & future work

- Apply approach to real-size project
  - transitioning OSS PloneGov.org 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