From Logics to Feature Models

(syntax, semantics, and synthesis of feature models)

Mathieu Acher

Maître de Conférences

mathieu.acher@irisa.fr

UNIVERSITÉ DE RENNES 1

istic Informatique Électronique

Material

https://github.com/FAMILIAR-project/HackOurLanguages-SIF

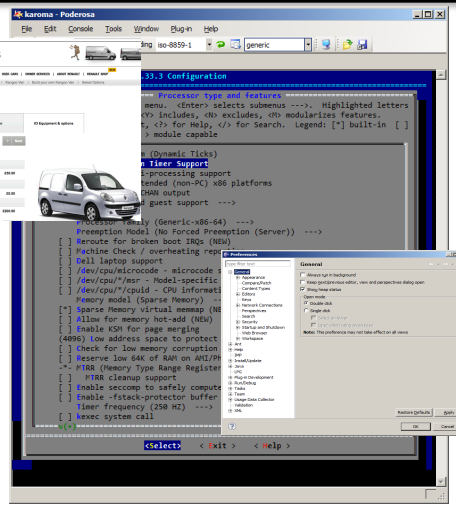
Plan

- Challenges and Overview
  - Developping billions of software product is hard but now a common practice
- Implementing Variability
  - Revisit of existing techniques and curriculum
- Specificity of Product Line Engineering
  - Process, methods
- **Feature Models**
  - **Defacto standard for modeling product lines and variability**
  - **Syntax, semantics, automated reasoning, synthesis**

Contract

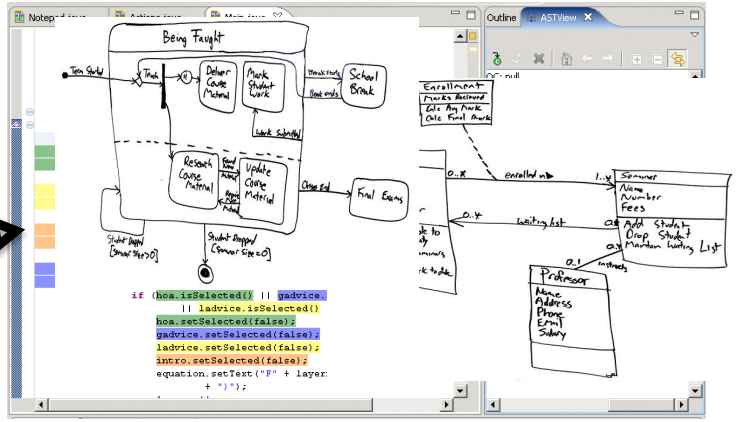
- The idea of software product lines and variability
  - You will be able to recognize this class of systems
  - Aware of the complexity, the specific development process, and existing techniques
- **Feature modeling**
  - **A widely used formalism for modeling product lines and configurable systems in a broad sense**
- **Composing/Decomposing feature models with a domain-specific language**
- **Reverse engineering variability models**

Previously

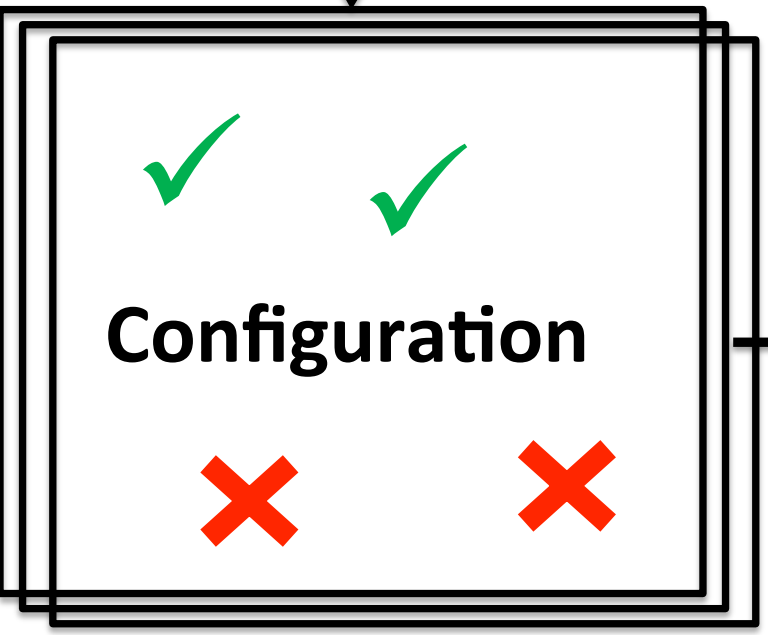


Variability Model

mapping

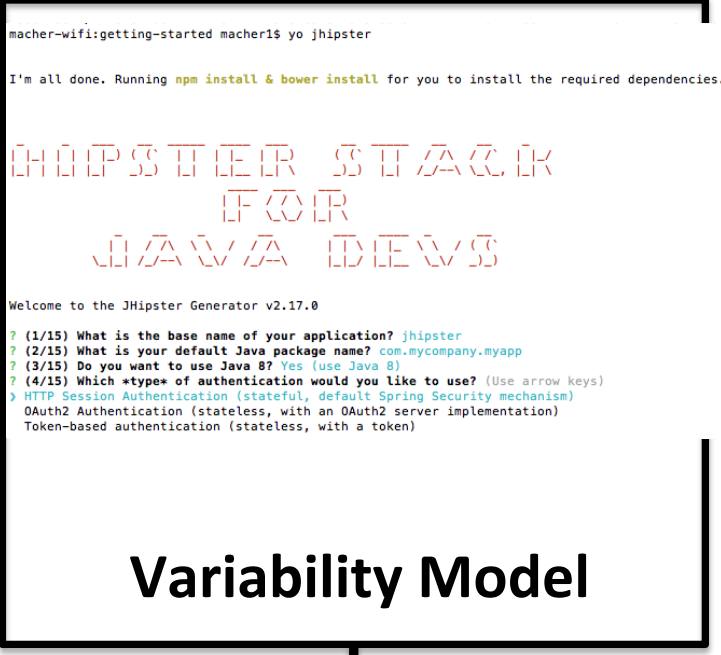


Base Artefacts (e.g., models)



Configuration

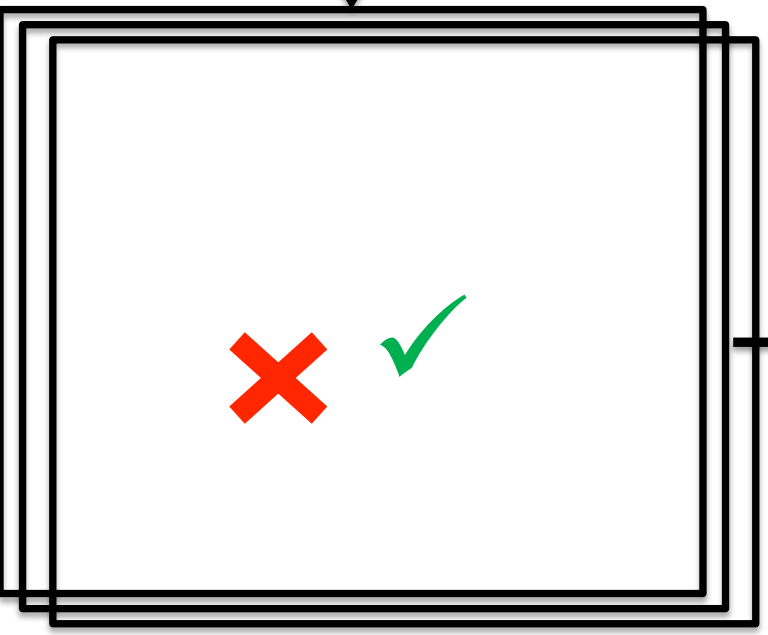
Software Generator
(derivation engine)



Variability Model

mapping

Base Artefacts



Software Generator
(derivation engine)

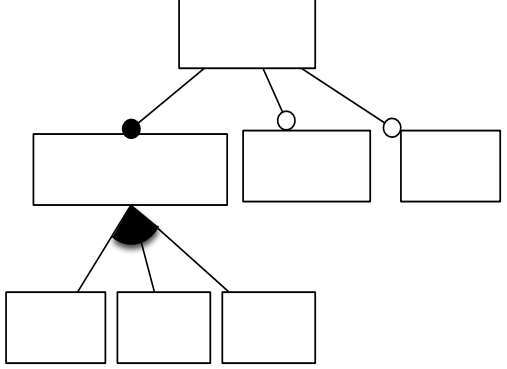

Illegal variant


Unused flexibility

Feature Models

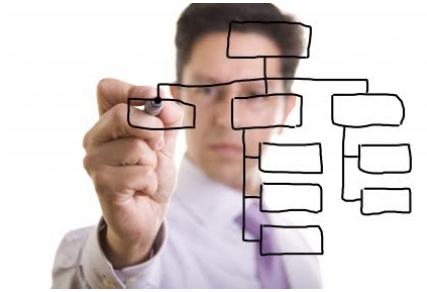
Syntacs, Semantics
Feature diagram, Formula

Feature Model

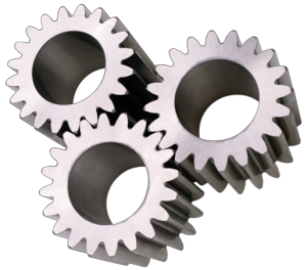


not, and, or, implies

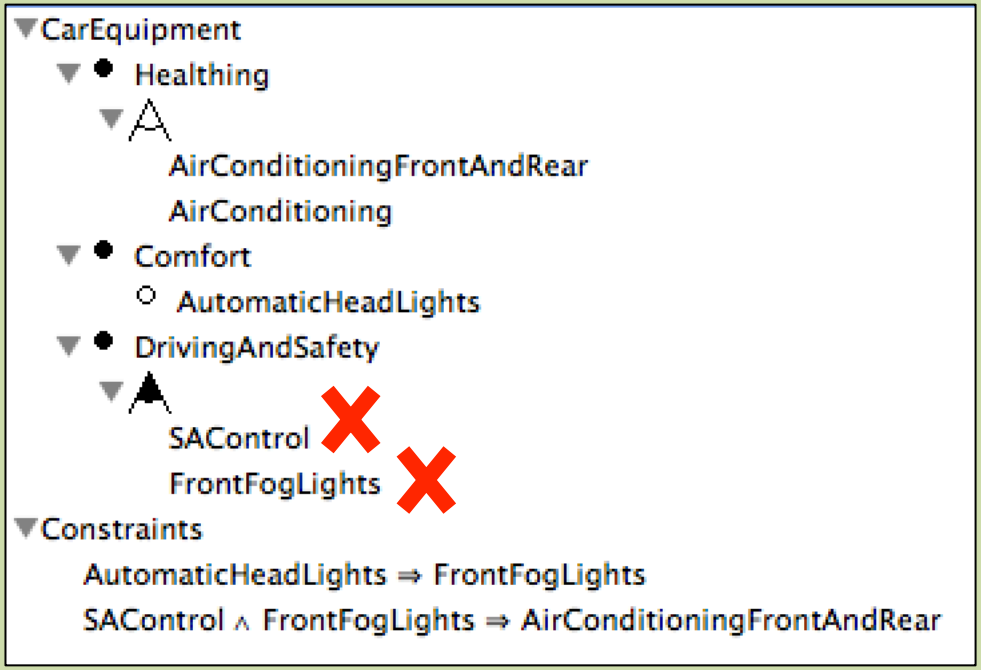
Communicative

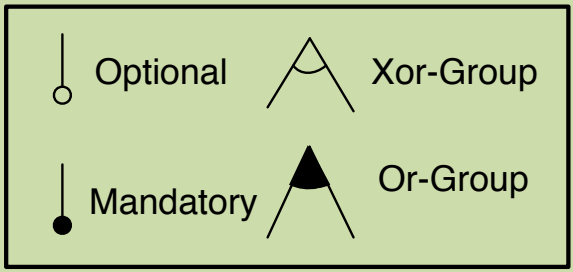


Analytic



Generative



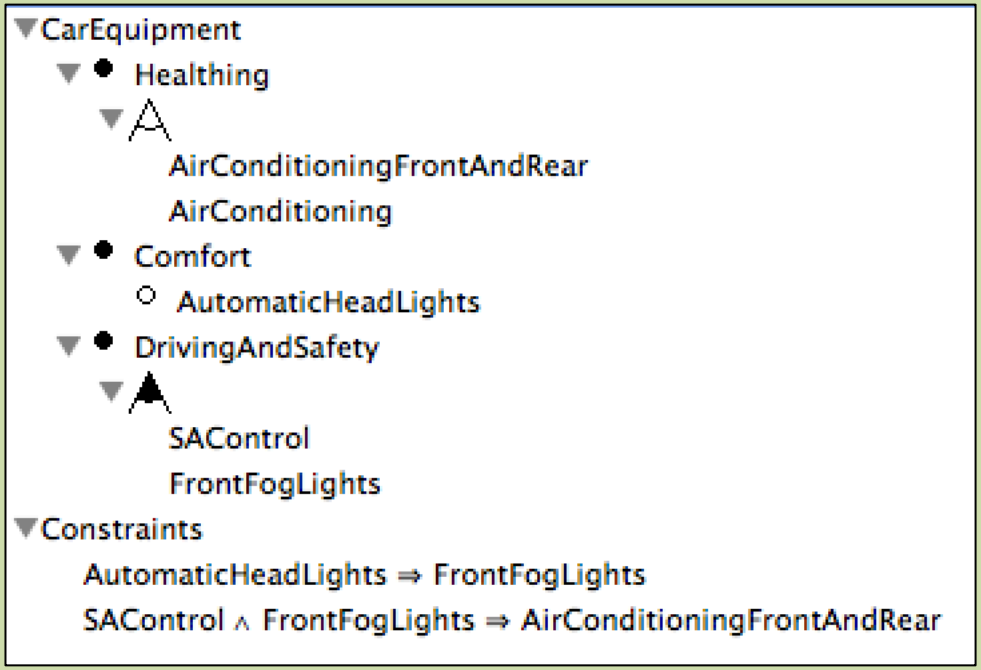


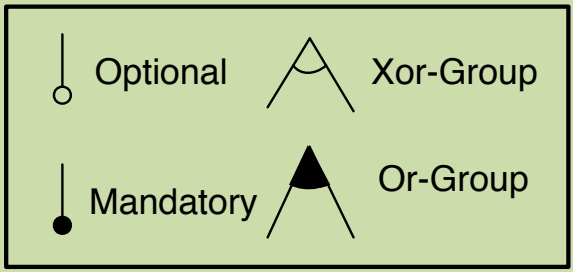
Hierarchy + Variability

=

set of valid configurations

Or-group: at least one!





Hierarchy + Variability
=
set of valid configurations

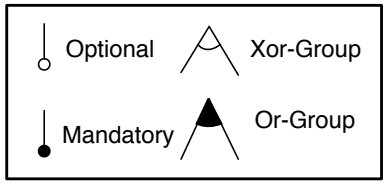
{CarEquipment, Comfort, DrivingAndSafety, Healthing}

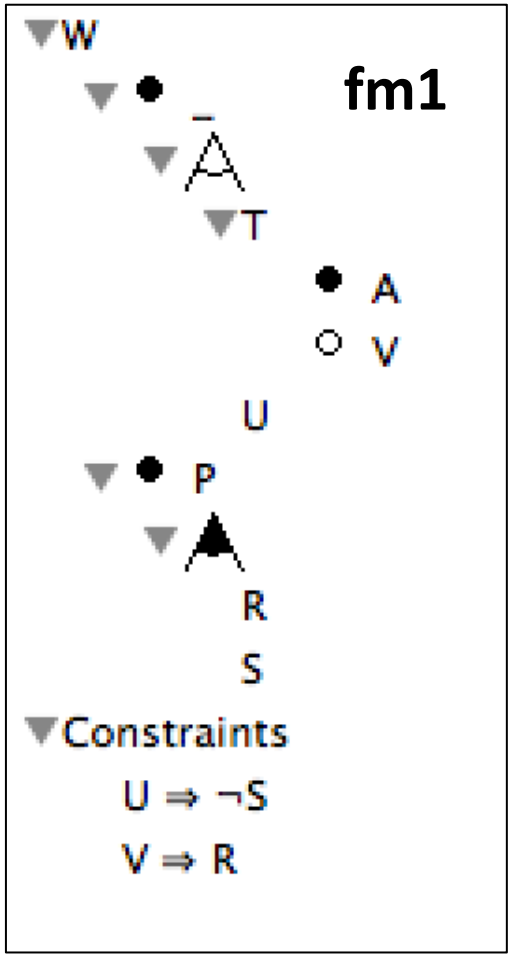
X

{AirConditioningFrontAndRear, FrontFogLights, SAControl}
{AirConditioningFrontAndRear, SAControl}
{AutomaticHeadLights, AirConditioning, FrontFogLights}
{AirConditioningFrontAndRear, SAControl, AutomaticHeadLights, FrontFogLights}
{FrontFogLights, AirConditioning}
{AutomaticHeadLights, AirConditioningFrontAndRear, FrontFogLights}
{FrontFogLights, AirConditioningFrontAndRear}
{SAControl, AirConditioning}

(Boolean) Feature Models

Hierarchy + Variability = set of valid configurations

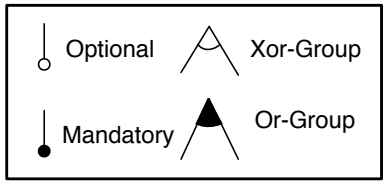


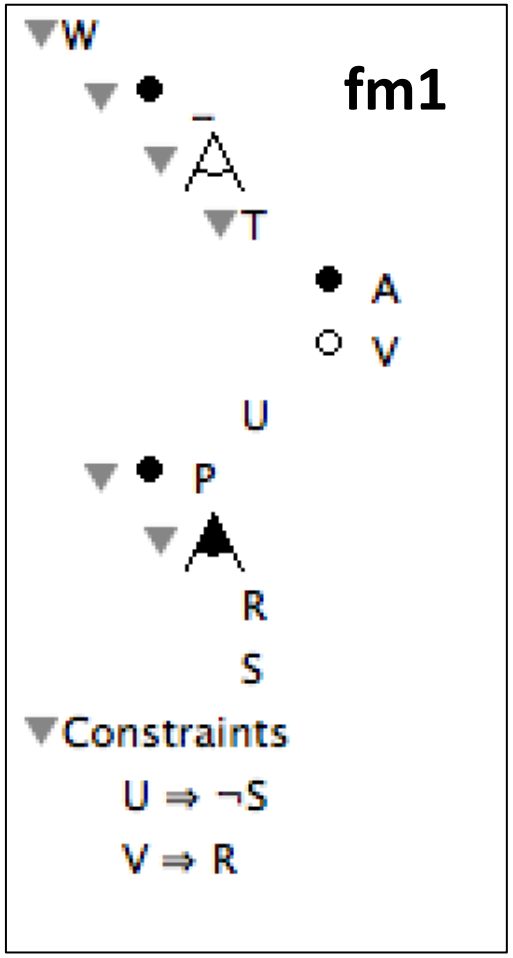


$$[\![fm1]\!] = \{$$
$$\{W, P, R, S, T, A, V\},$$
$$\{W, P, S, T, A\},$$
$$\{W, P, R, T, A\},$$
$$\{W, P, R, U\},$$
$$\{W, P, R, T, V, A\},$$
$$\{W, P, R, S, T, A\},$$
$$\}$$

(Boolean) Feature Models

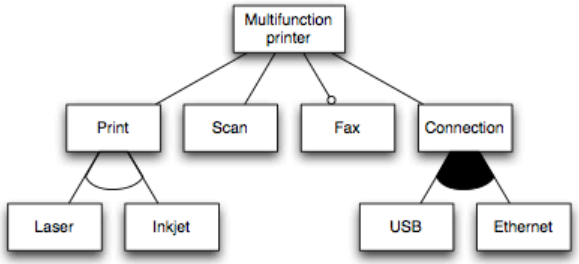
~ Boolean formula



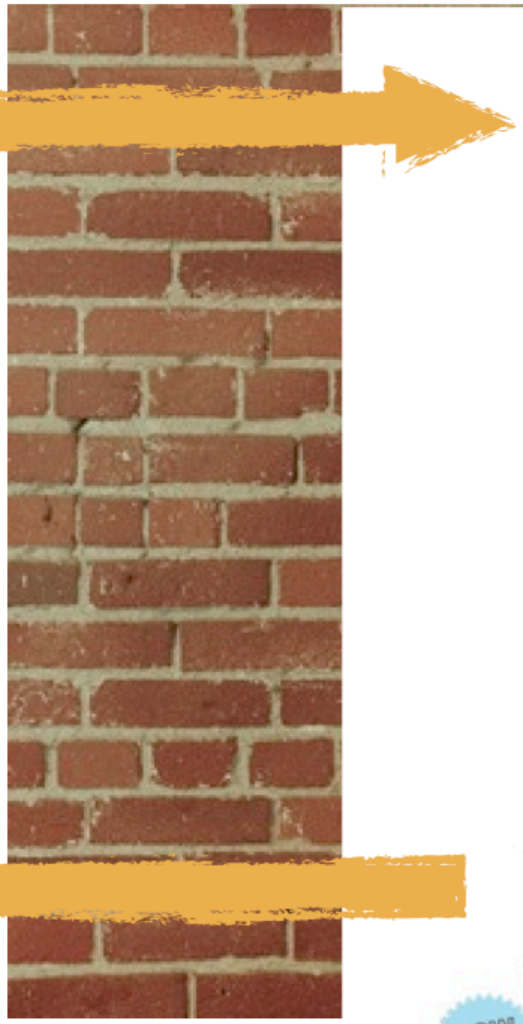


$$
\begin{aligned}
&\phi_{fm_1} = W \;//\; \text{root} \\
&\wedge\, W \Leftrightarrow P \;//\; \text{mandatory} \\
&//\; \text{Or-group} \\
&\wedge\, P \Rightarrow R \vee S \\
&\wedge\, R \Rightarrow P \wedge\, S \Rightarrow P \\
&\wedge\, V \Rightarrow T \;//\; \text{optional} \\
&\wedge\, A \Leftrightarrow T \;//\; \text{mandatory} \\
&//\; \text{Xor-group} \\
&\wedge\, T \Rightarrow W \\
&\wedge\, U \Rightarrow W \\
&\wedge\, \neg T \vee \neg U \\
&//\; \text{constraints} \\
&\wedge\, V \Rightarrow R \;//\; \text{implies} \\
&\wedge\, \neg U \Rightarrow \neg S \;//\; \text{excludes}
\end{aligned}
$$

Typical implementations



result



logics

solvers

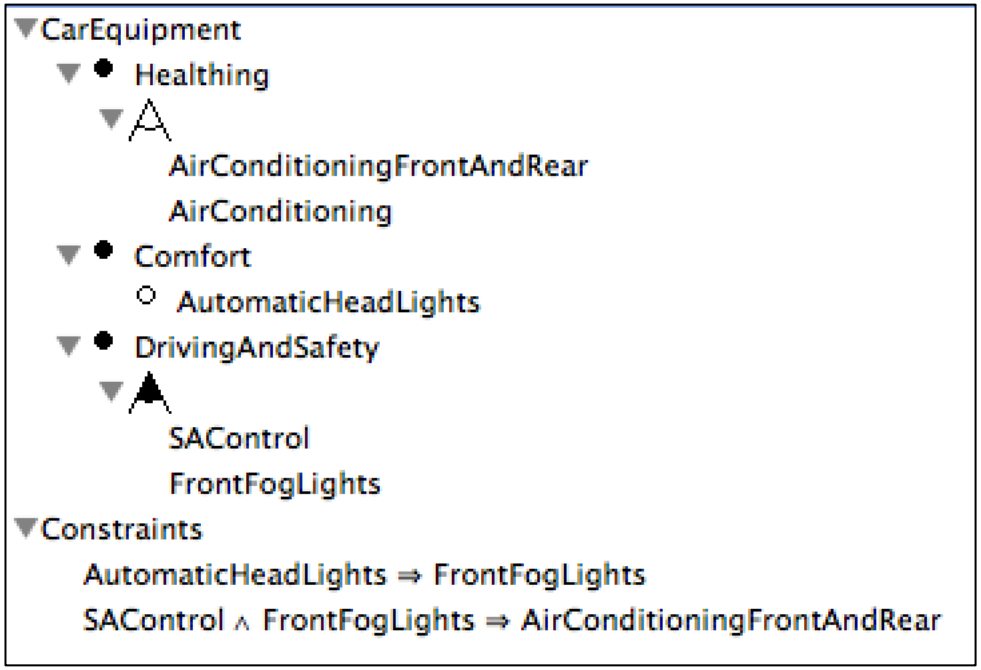
Formal semantics of a language

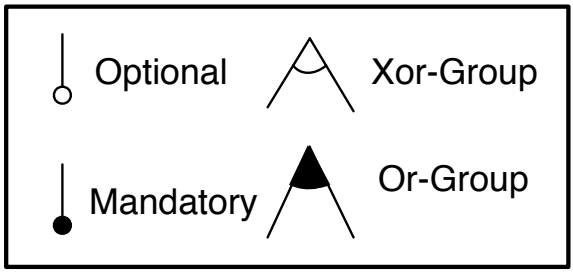
– **formal syntax** (L) – clearcut syntactic rules defining all legal diagrams, a.k.a. syntactic domain

– **semantic domain** (S) – a mathematical abstraction of the real-world concepts to be modelled

– **semantic function** (M: L ⟶ S) – clearcut semantic rules defining the meaning of all legal diagrams

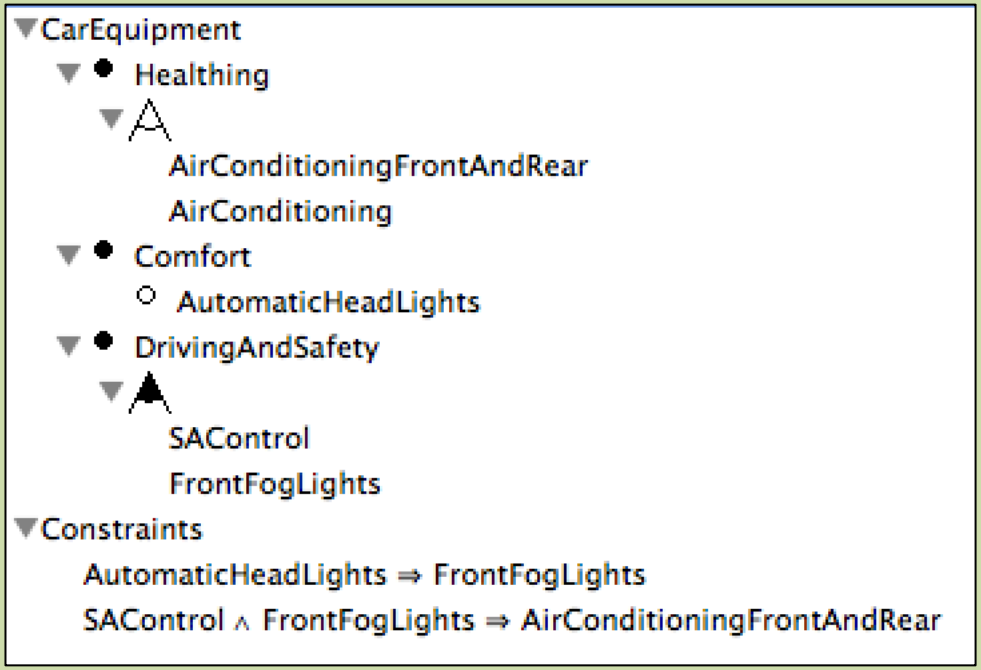
[Harel & Rumpe, IEEE Computer, 2004]

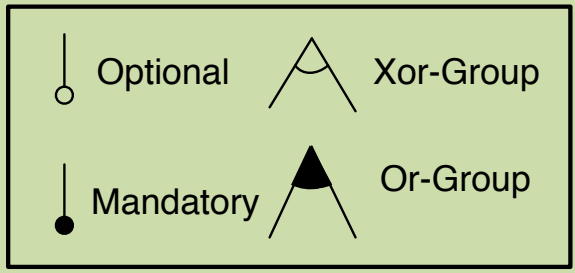




Definition 2 (Feature Diagram) *A feature diagram* $FD = \langle G, E_{MAND}, G_{XOR}, G_{OR}, I, EX \rangle$ *is defined as follows:* $G = (\mathcal{F}, E, r)$ *is a rooted, labeled tree where* $\mathcal{F}$ *is a finite set of features,* $E \subseteq \mathcal{F} \times \mathcal{F}$ *is a finite set of edges and* $r \in \mathcal{F}$ *is the root feature ;* $E_{MAND} \subseteq E$ *is a set of edges that define mandatory features with their parents ;* $G_{XOR} \subseteq \mathcal{P}(\mathcal{F}) \times \mathcal{F}$ *and* $G_{OR} \subseteq \mathcal{P}(\mathcal{F}) \times \mathcal{F}$ *define feature groups and are sets of pairs of child features together with their common parent feature ;* I *a set of implies constraints whose form is* $A \Rightarrow B$, EX *is a set of excludes constraints whose form is* $A \Rightarrow \neg B$ $(A \in \mathcal{F}$ *and* $B \in \mathcal{F})$.

Definition 3 (Feature Model) *An FM is a tuple* $\langle FD, \psi \rangle$ *where* FD *is a feature diagram and* ψ *is a propositional formula over the set of features* $\mathcal{F}$.





Definition 1 (Configuration Semantics) *A configuration of an FM fr*
defined as a set of selected features. $[\![fm_1]\!]$ *denotes the set of valid configura*
of fm_1 *and is a set of sets of features.*

{CarEquipment, Comfort, DrivingAndSafety, Healthing}

X

{AirConditioningFrontAndRear, FrontFogLights, SAControl}
{AirConditioningFrontAndRear, SAControl}
{AutomaticHeadLights, AirConditioning, FrontFogLights}
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{FrontFogLights, AirConditioning}
{AutomaticHeadLights, AirConditioningFrontAndRear, FrontFogLights}
{FrontFogLights, AirConditioningFrontAndRear}
{SAControl, AirConditioning}

Quizz

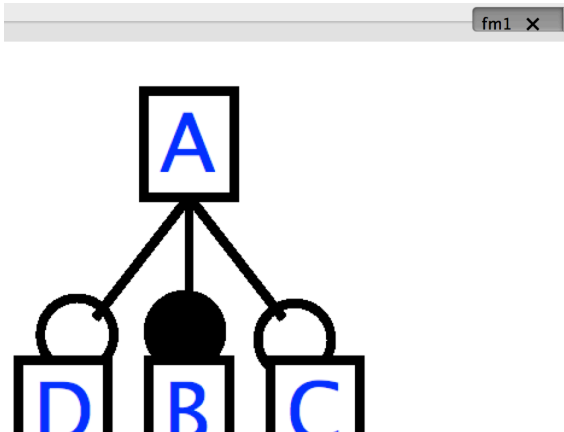
1) Give two feature models with the same configuration semantics but with different syntax

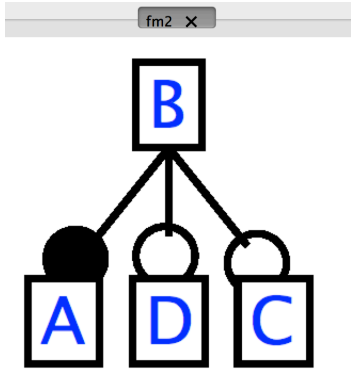
2) Does it matter ?

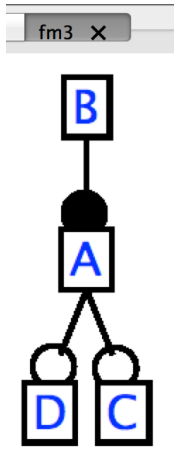
A ^
A ⇔ B ^
C => A ^
D => A

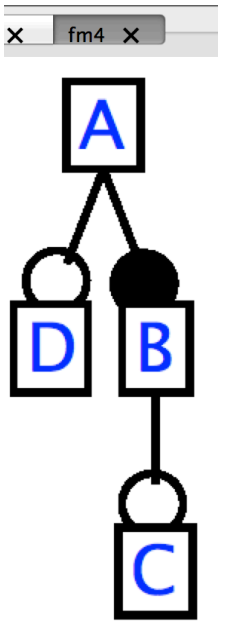
Feature Model Synthesis Problem

[Czarnecki et al., SPLC'07]
[She et al., ICSE'11]
[Andersen et al., SPLC'12]










```
fm2 = FM (B : A [C] [D] ; )
fm3 = FM (B : A ; A : [C] [D] ; )
fm4 = FM (A : B [D] ; B : [C] ; )
fm5 = FM (A : B [C] ; B : [D] ; )

b12 = compare fm1 fm2
b13 = compare fm1 fm3
b14 = compare fm1 fm4
b15 = compare fm1 fm5
assert (b12 eq REFACTORING)
```

#1 Reverse Engineering Scenarios

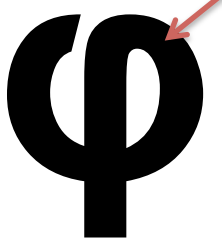
- [Haslinger et al., WCRE'11], [Acher et al., VaMoS'12]

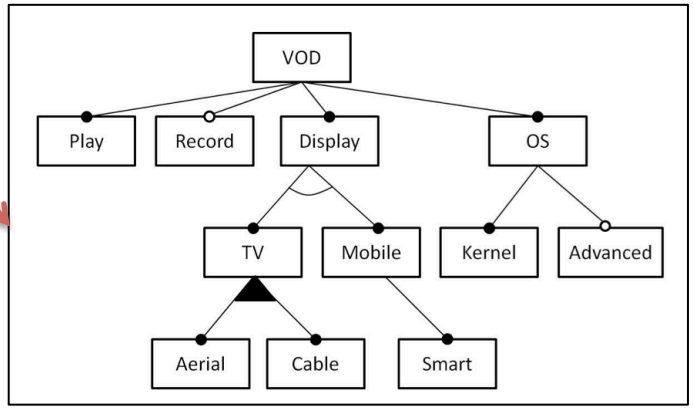
P	V	P	R	D	O	T	M	S	K	Ad	Ae	C
P1	✓	✓	✓	✓	✓	✓			✓	✓	✓	
P2	✓	✓	✓	✓	✓	✓			✓		✓	
P3	✓	✓		✓	✓	✓			✓	✓	✓	
P4	✓	✓		✓	✓	✓			✓		✓	
P5	✓	✓	✓	✓	✓	✓			✓	✓	✓	✓
P6	✓	✓	✓	✓	✓	✓			✓	✓		✓
P7	✓	✓	✓	✓	✓	✓			✓		✓	✓
P8	✓	✓	✓	✓	✓	✓			✓			✓
P9	✓	✓		✓	✓	✓			✓	✓	✓	✓
P10	✓	✓		✓	✓	✓			✓	✓		✓
P11	✓	✓		✓	✓	✓			✓		✓	✓
P12	✓	✓		✓	✓	✓			✓			✓
P13	✓	✓	✓	✓	✓		✓	✓	✓	✓		
P14	✓	✓	✓	✓	✓		✓	✓	✓			
P15	✓	✓		✓	✓		✓	✓	✓	✓		
P16	✓	✓		✓	✓		✓	✓	✓			

```
// from product descriptions to feature models
// typically something generated by VariCell (see VaMoS'12 paper or the dedicated web page)
fm_1 = FM (VOD: R Ae T D P Ad K V O ; )
fm_2 = FM (VOD: R Ae T D P K V O ; )
fm_3 = FM (VOD: Ae T D P Ad K V O ; )
fm_4 = FM (VOD: T Ae D P V K O ; )
fm_5 = FM (VOD: R T Ae D P Ad K V O C ; )
fm_6 = FM (VOD: R T D P Ad V K O C ; )
fm_7 = FM (VOD: R T Ae D P V K O C ; )
fm_8 = FM (VOD: R T D P K V O C ; )
fm_9 = FM (VOD: Ae T D P Ad V K O C ; )
fm_10 = FM (VOD: T D P Ad K V O C ; )
fm_11 = FM (VOD: Ae T D P V K O C ; )
fm_12 = FM (VOD: T D P K V O C ; )
fm_13 = FM (VOD: R S D P Ad V K O M ; )
fm_14 = FM (VOD: R S D P K V O M ; )
fm_15 = FM (VOD: S D P Ad V K O M ; )
fm_16 = FM (VOD: S D P V K O M ; )

// fmR represents the union of configurations/products
// characterized by fm_1, fm_2, ..., fm_16
fmR = merge sunion fm_*

fmR2 = ksynthesis fmR with hierarchy= VOD : V P R D O ; O : K Ad ; D : T M ; T : Ae C ; M : S ;
```

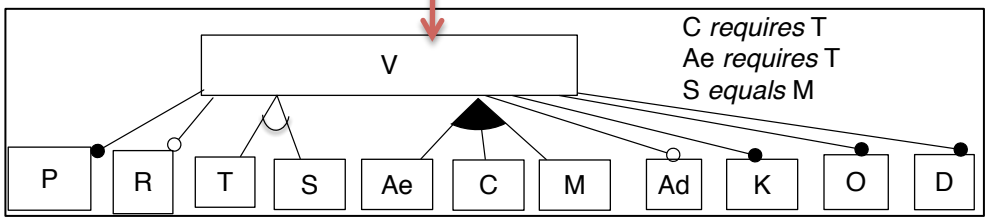


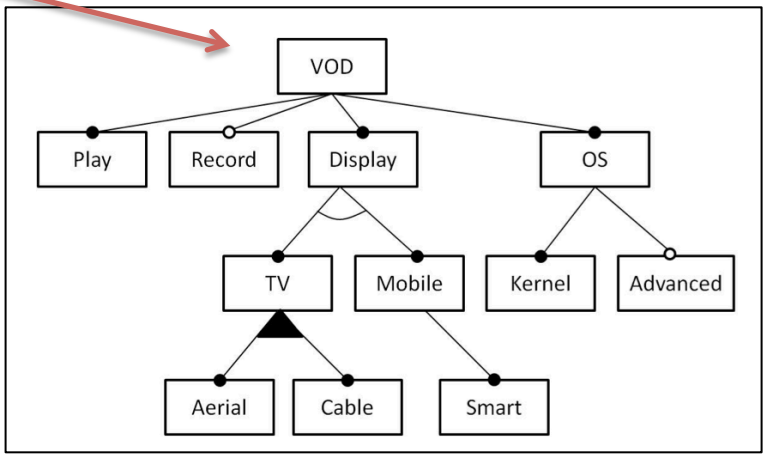


#2 Refactoring

- [Alves et al., GPCE'06], [Thuem et al., ICSE'09]

```
// refactoring!
fmR2 = ksynthesis fmR with hierarchy= VOD : V P R D O ; O : K Ad ; D : T M ; T : Ae C ; M : S ;
```





φ

```
fml> compare fmR fmR2
res0: (STRING) REFACTORING
```

Feature Model SemanticS

- As configuration semantics is not sufficient…

- **Ontological** semantics
  - Hierarchy
  - And feature groups

Quizz (Class Diagram)

1) Give two class diagrams with the same semantics but with different syntax

   – (preliminary) what is the semantic domain of CDs?

2) Does it matter ?

3.1 Class diagrams language

As a concrete CD language we use the class diagrams of UML/P [29], a conceptually refined and simplified variant of UML designed for low-level design and implementation. Our semantics of CDs is based on [11] and is given in terms of sets of objects and relationships between these objects. More formally, the semantics is defined using three parts: a precise definition of the syntactic domain, i.e., the syntax of the modeling language CD and its context conditions (we use MontiCore [16, 24] for this); a semantic domain - for us, a subset of the System Model (see [7, 8]) OM, consisting of all finite object models; and a mapping $sem : CD \rightarrow \mathcal{P}(OM)$, which relates each syntactically well-formed CD to a set of constructs in the semantic domain OM. For a thorough and formal account of the semantics see [8].

Note that we use a *complete* interpretation for CDs (see [29] ch. 3.4). This roughly means that 'whatever is not in the CD, should indeed not be present in the object model'. In particular, we assume that the list of attributes of each class is complete, e.g., an `employee` object with an `id` and a `salary` is not considered as part of the semantics of an `Employee` class with an `id` only.

The CD language constructs we support include generalization (inheritance), interface implementation, abstract and singleton classes, class attributes, uni- and bi-directional associations with multiplicities, enumerations, aggregation, and composition.

Maoz et al. CDDiff: Semantic Differencing for Class Diagrams, ECOOP'11

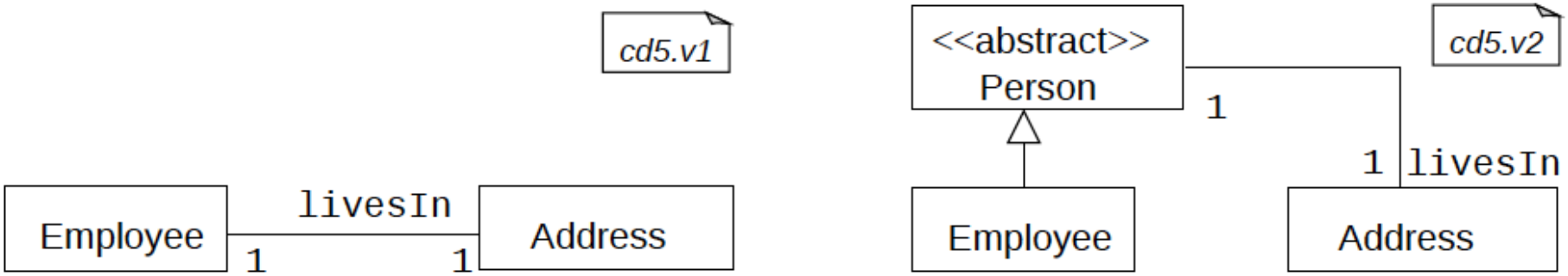


Fig. 4. *cd5.v1* and its revised version *cd5.v2*. The two versions have equal semantics.

Maoz et al. CDDiff: Semantic Differencing for Class Diagrams, ECOOP'11

Quizz (back to Feature Model)

Definition 2 (Feature Diagram) *A feature diagram* $FD = \langle G, E_{MAND}, G_{XOR}, G_{OR}, I, EX \rangle$ *is defined as follows:* $G = (\mathcal{F}, E, r)$ *is a rooted, labeled tree where* $\mathcal{F}$ *is a finite set of features,* $E \subseteq \mathcal{F} \times \mathcal{F}$ *is a finite set of edges and* $r \in \mathcal{F}$ *is the root feature ;* $E_{MAND} \subseteq E$ *is a set of edges that define mandatory features with their parents ;* $G_{XOR} \subseteq \mathcal{P}(\mathcal{F}) \times \mathcal{F}$ *and* $G_{OR} \subseteq \mathcal{P}(\mathcal{F}) \times \mathcal{F}$ *define feature groups and are sets of pairs of child features together with their common parent feature ;* I *a set of implies constraints whose form is* $A \Rightarrow B$, EX *is a set of excludes constraints whose form is* $A \Rightarrow \neg B$ $(A \in \mathcal{F}$ *and* $B \in \mathcal{F})$.

Definition 3 (Feature Model) *An FM is a tuple* $\langle FD, \psi \rangle$ *where* FD *is a feature diagram and* ψ *is a propositional formula over the set of features* $\mathcal{F}$.

Given a set of configurations *s*, can we always characterize *s* with a feature diagram *fd* ?

ie [[fd]] = s

In other words: is the formalism of feature diagram expressive enough wrt Boolean logic?

Feature Diagram ?

s = {{A},
{A,C,B},
{B,A},
{C,D,A},
{D,A},
{A,D,B},
{A,C}
}

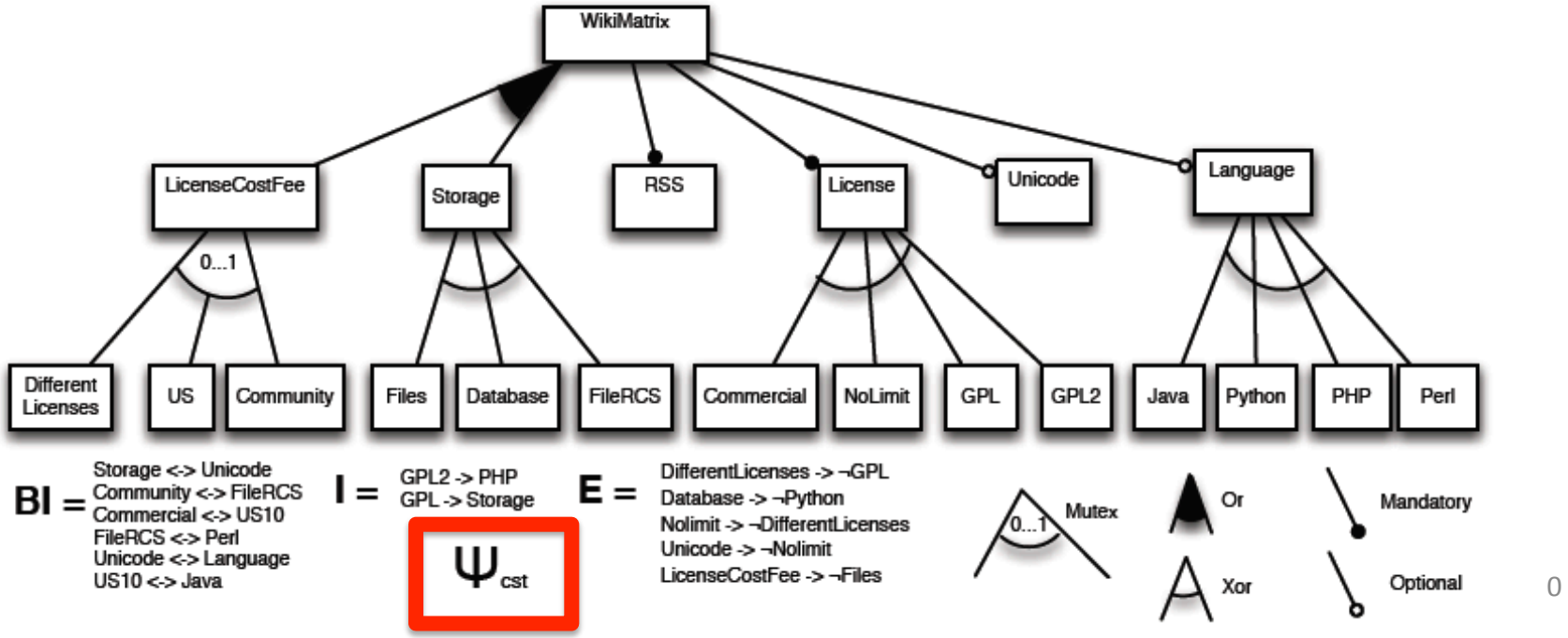
fm1 = FM (A : [B] [C] [D] ^
// B, C and D are optional features of A

((B & C) -> !D)

)

Feature Diagram ?

Identifier	License	Language	Storage	LicenseCostFee	RSS	Unicode
Confluence	Commercial	Java	Database	US10	Yes	Yes
PBwiki	Nolimit	No	No	Yes	Yes	No
MoinMoin	GPL	Python	Files	No	Yes	Yes
DokuWiki	GPL2	PHP	Files	No	Yes	Yes
PmWiki	GPL2	PHP	Files	No	Yes	Yes
DrupalWiki	GPL2	PHP	Database	Different Licences	Yes	Yes
TWiki	GPL	Perl	FilesRCS	Community	Yes	Yes
MediaWiki	GPL	PHP	Database	No	Yes	Yes



Quizz

Feature Model (bis)

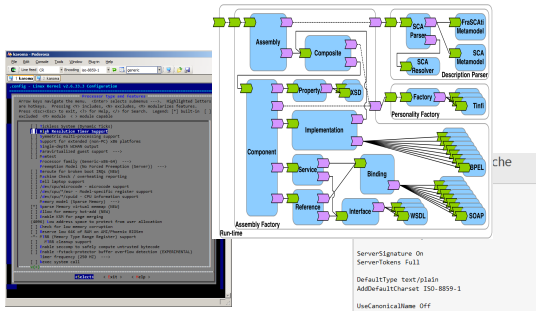
s = {{A}, {B}}

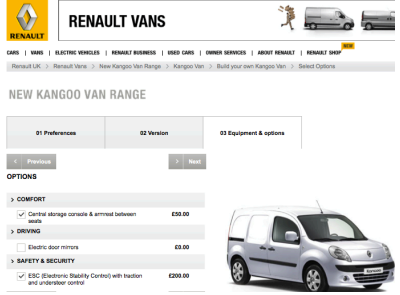
fd = ?

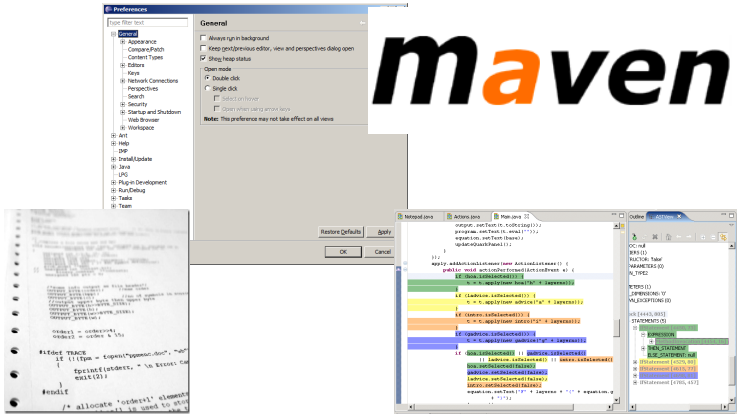
Feature Model: Key Insights

- Semantics
  - Configuration and ontological
- Syntax
  - Feature diagram vs Feature Model
  - Feature diagram not expressively complete
- Feature models are a (syntactical) view of a propositional formula

Synthesising Feature Models (from semantics to syntacs)



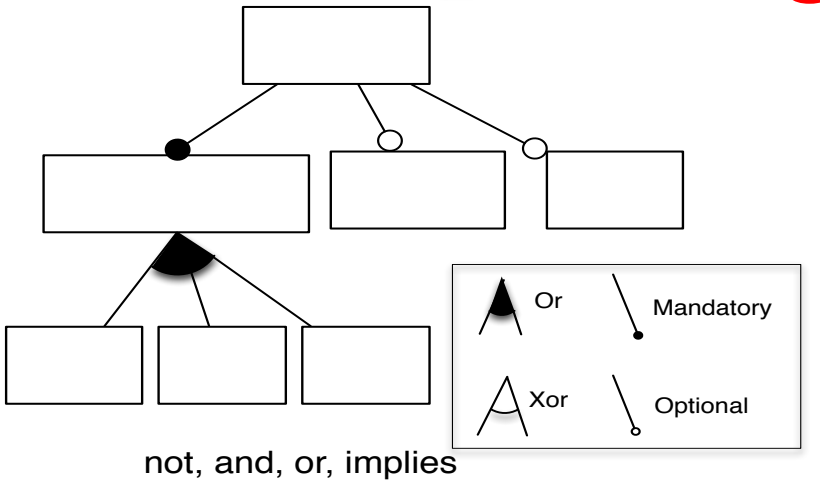




Mining/Extracting

Encoding/Formalizing

Synthesising



not, and, or, implies

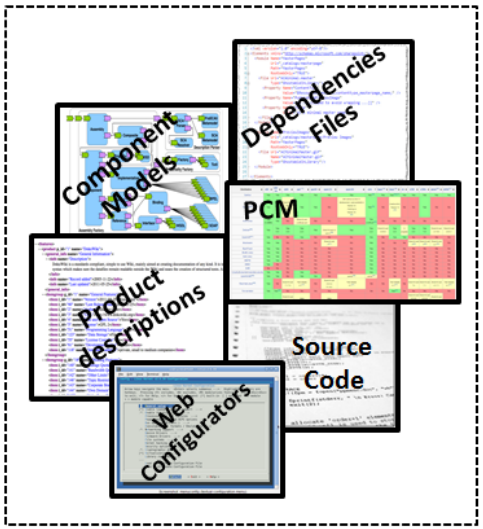
FAMiliAR

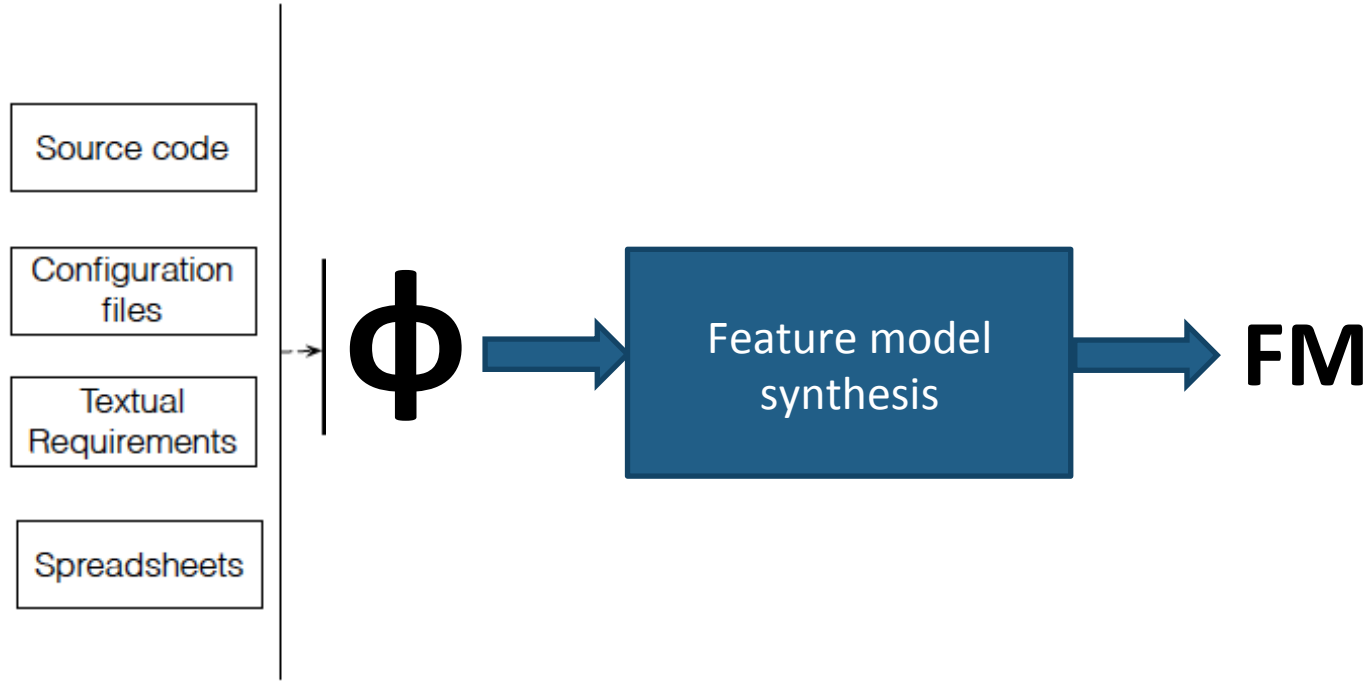
Variability Models (feature models)

- CarEquipment
  - Healthing
    - AirConditioningFrontAndRear
    - AirConditioning
  - Comfort
    - AutomaticHeadLights
  - DrivingAndSafety
    - FrontFogLights
- Constraints
  - AutomaticHeadLights ⇒ FrontFogLights

φ

Product	CarEquipment	Comfort	DrivingAndSafety	Healting	AirConditioning
Find	Yes / No	Yes / No	Yes / No	Yes / No	Yes / No
Car1	yes	yes	yes	yes	yes
Car2	yes	yes	yes	yes	yes
Car3	yes	yes	yes	yes	no
Car4	yes	yes	yes	yes	no
Car5	yes	yes	yes	yes	yes
Car6	yes	yes	yes	yes	no





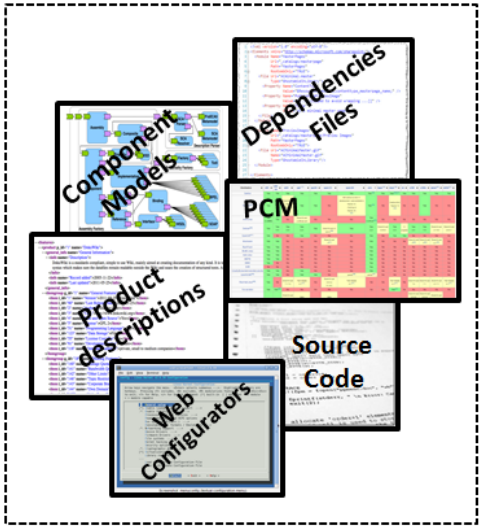
Feature model synthesis problem

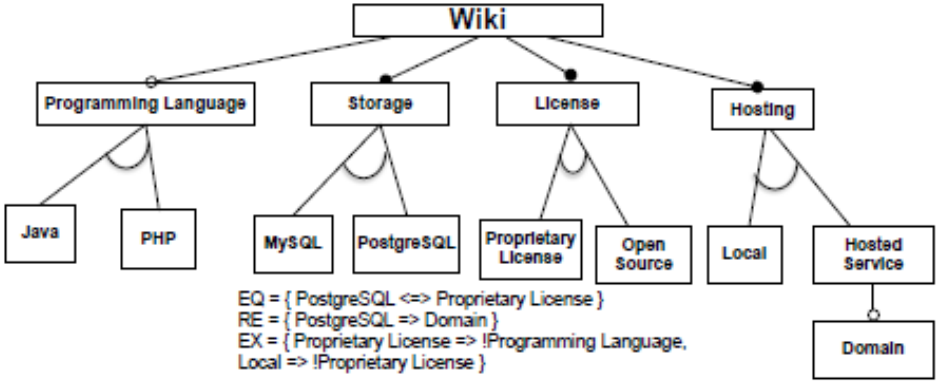
Input: ϕ, a propositional formula representing the **dependencies** over a set of features *F*.

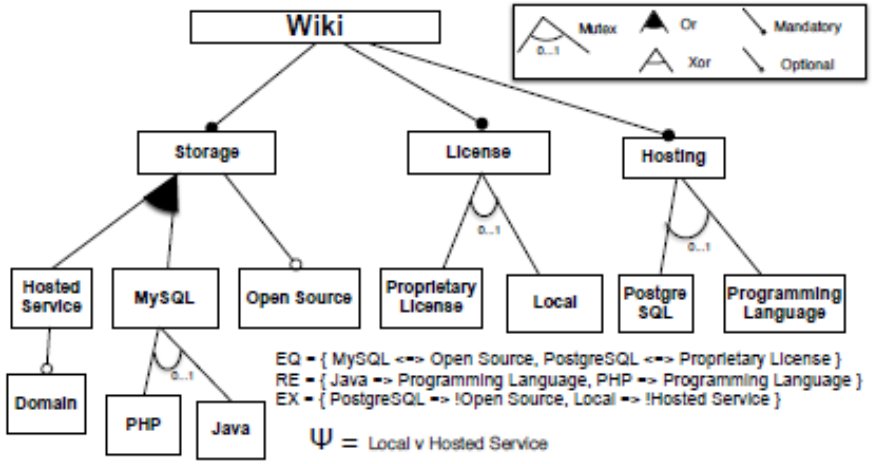
Output: a maximal feature model with a **sound configuration semantics**

For a given configuration set,

many (maximal) feature diagrams

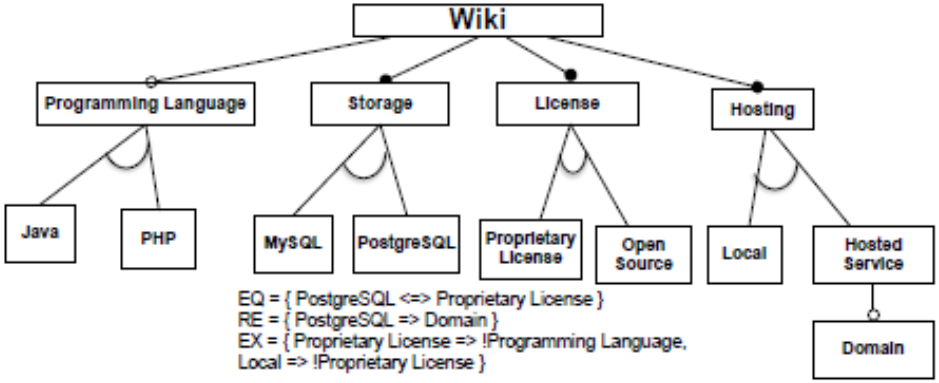


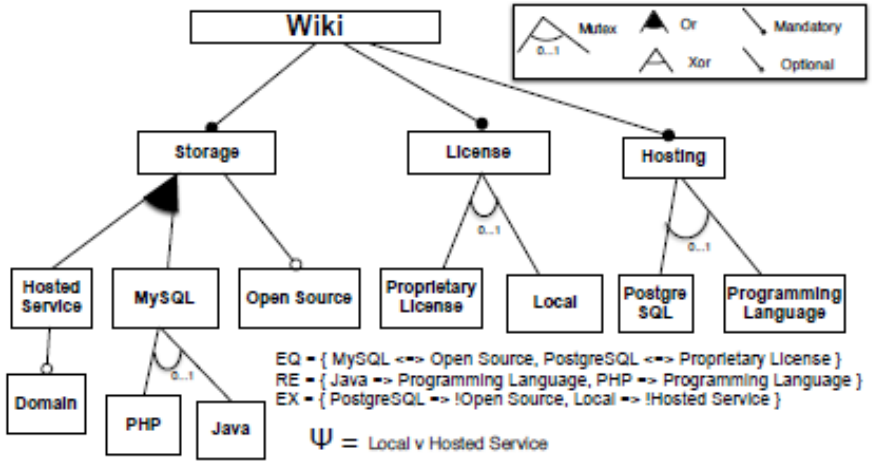




Maximal feature diagrams

~ “as much logical information as possible is represented in the diagram itself, without resorting to the constraints”



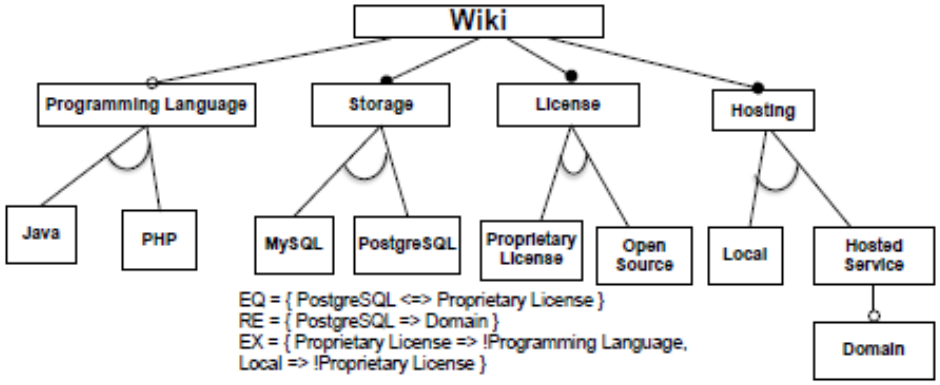


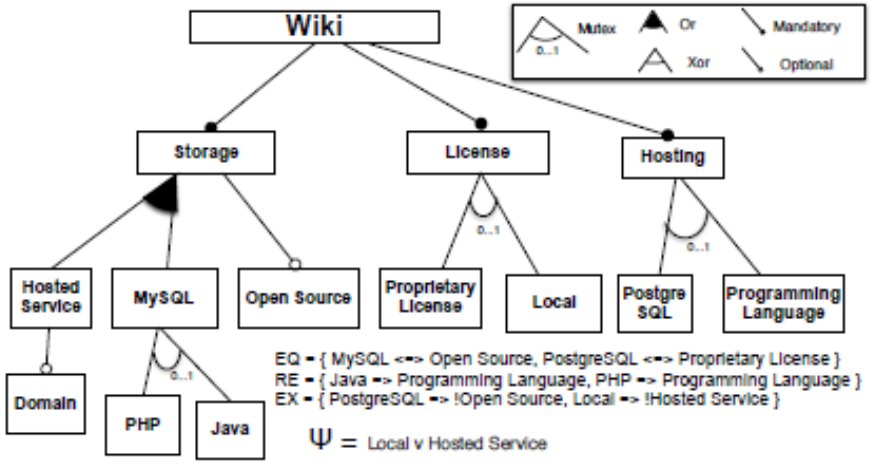
Maximal feature diagrams

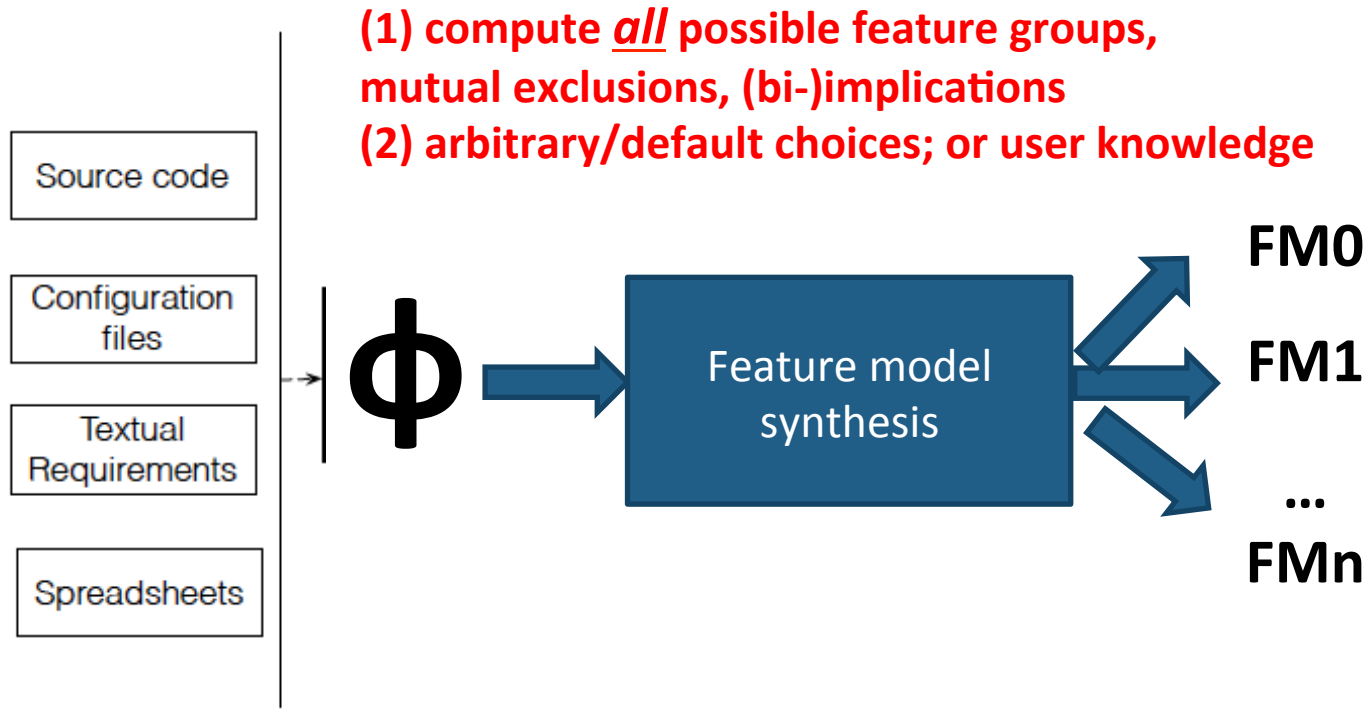
~ “as much logical information as possible is represented in the diagram itself, without resorting to the constraints”

Quizz:

give a non maximal feature diagram







Feature model synthesis problem

Input: ϕ, a propositional formula representing the **dependencies** over a set of features *F*.

Output: a maximal feature model with a **sound configuration semantics**

$(\varphi$: formula over F rooted in r, $r \in F)$

▷ Find and remove all dead features

1 $D = \{f \in F \mid \varphi \wedge r \rightarrow \neg f\}$

2 $\varphi = \varphi[d \mapsto 0]_{d \in D}$

▷ Compute the implication graph $G(V, E)$

3 $V = F \setminus D$

4 $E = \{(u, v) \in V \times V \mid \varphi \wedge u \rightarrow v\}$

▷ Compute strongly connected components

5 $V' = \{S \subseteq V \mid S$ is a SCC of $G\}$

▷ Make edges between SCCs creating a DAG

6 $E' = \{(u, v) \in V' \times V' \mid u \neq v$ and

7 $\exists u' \in u, v' \in v.\ (u', v') \in E\}$

▷ Compute the mutex graph $M(V, E_{\mathrm{x}})$

8 $E_{\mathrm{x}} = \{\{u, v\} \subseteq V' \mid \exists u' \in u, v' \in v.\ \varphi \wedge u' \rightarrow \neg v'\}$

▷ Compute mutex-groups

9 $G_{\mathrm{m}} = \{\{(f_1, p), \ldots, (f_k, p)\} \mid \{f_1, \ldots, f_k\}$ is

10 a maximal clique in M and $\forall f_i.\ (f_i, p) \in E'\}$

▷ Compute or-groups

11 $G_{\mathrm{o}} = \{\{(f_1, p), \ldots, (f_k, p)\} \mid f'_1 \vee \cdots \vee f'_k$ is

12 a prime implicate of $\varphi \wedge p'$ and

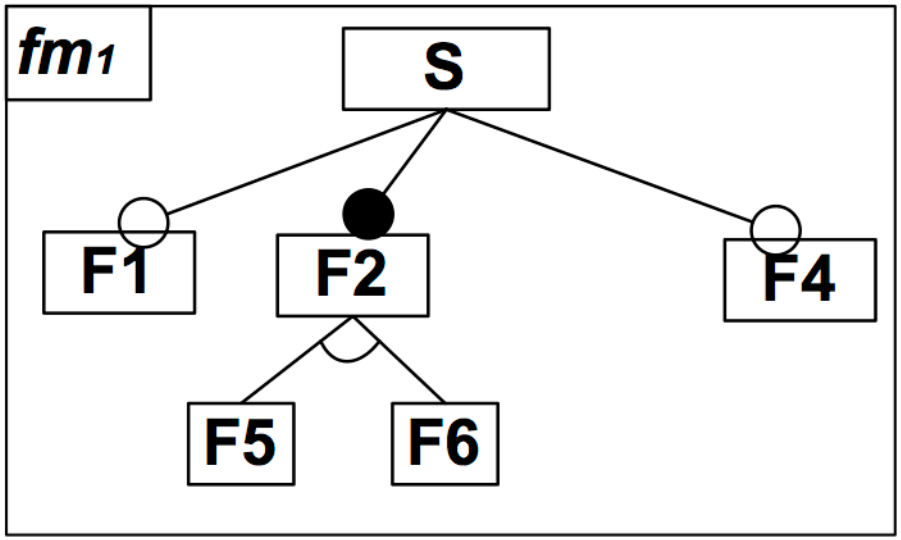
13 $p' \in p$ and $\forall f_i.\ f'_i \in f_i \wedge (f_i, p) \in E'\}$

▷ Compute xor-groups

14 $G_{\mathrm{x}} = \{\{(f_1, p), \ldots, (f_k, p)\} \in G_{\mathrm{o}} \mid \forall\, i \neq j.\ (f_i, f_j) \in E_{\mathrm{x}}\}$

Andersen et al. « Efficient Synthesis of Feature Models », SPLC'12

(F5 -> F2) ^ (F2 -> S) ^ SYNTETIC_ROOT_FEATURE ^ (F6 -> !F5) ^ (F1 -> S) ^ (SYNTETIC_ROOT_FEATURE -> S) ^ (F4 -> S) ^ (S -> F2) ^ (F6 -> F2) ^ ((!F2 | F6) | (!F2 | F5)) ^ (S -> SYNTETIC_ROOT_FEATURE)



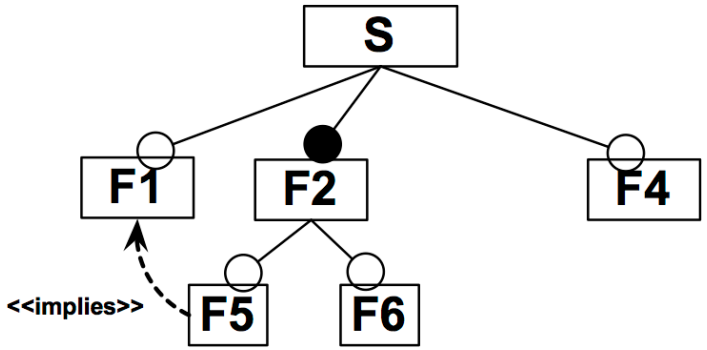

```
fml> computeImplies fm1
computeImplies fm1 ===> {(F1 -> F2);(F5 -> S);(S -> F2);(F6 -> F2);(F4 -> S);(F1 -> S);(F5 -> F2);(F4 -> F2);(F2 -> S);(F6 -
fml> cliques fm1
cliques fm1 ===> {{S;F2}}
fml> computeXORGroups fm1
computeXORGroups fm1 ===> {[F6, F5] -> S (XOR);[F6, F5] -> F2 (XOR)}
fml> computeMUTEXGroups fm1
computeMUTEXGroups fm1 ===> {}
fml> computeExcludes fm1
computeExcludes fm1 ===> {(F5 -> !F6)}
```

Quizz

There and Back Again

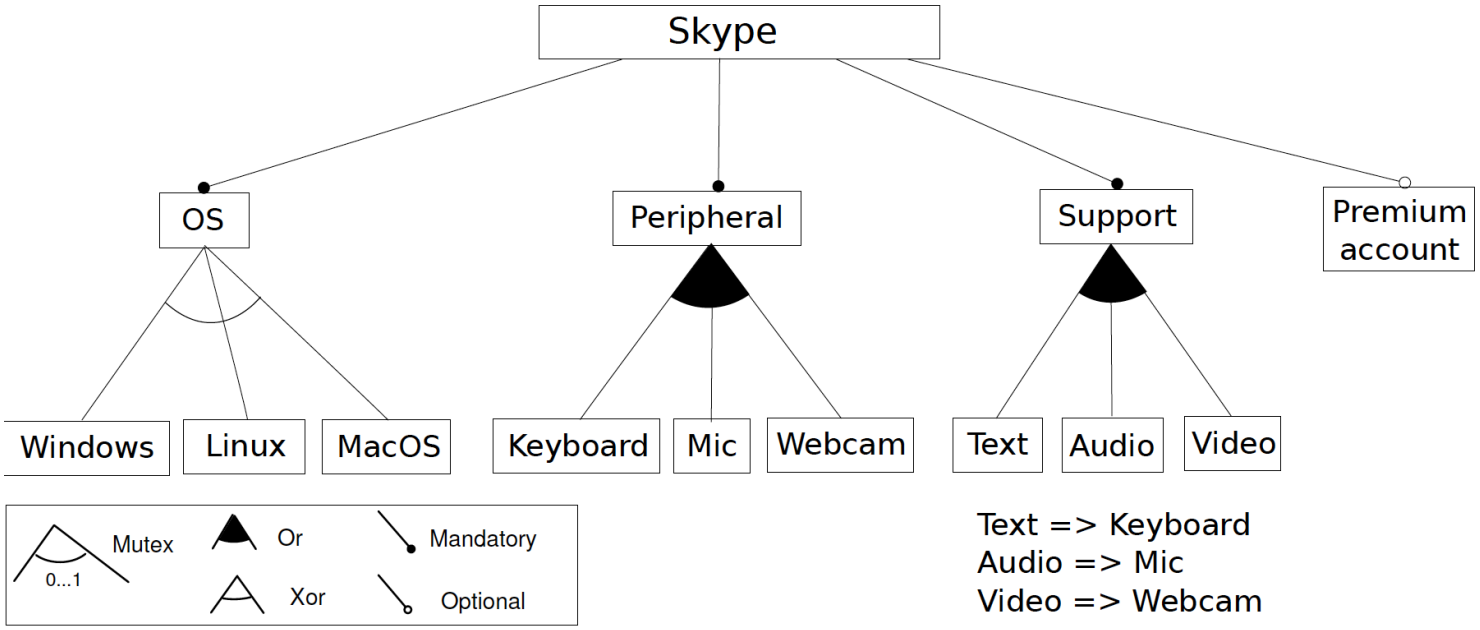
1) Translate this feature model to a propositional formula

2) Compute the synthesis « structures »

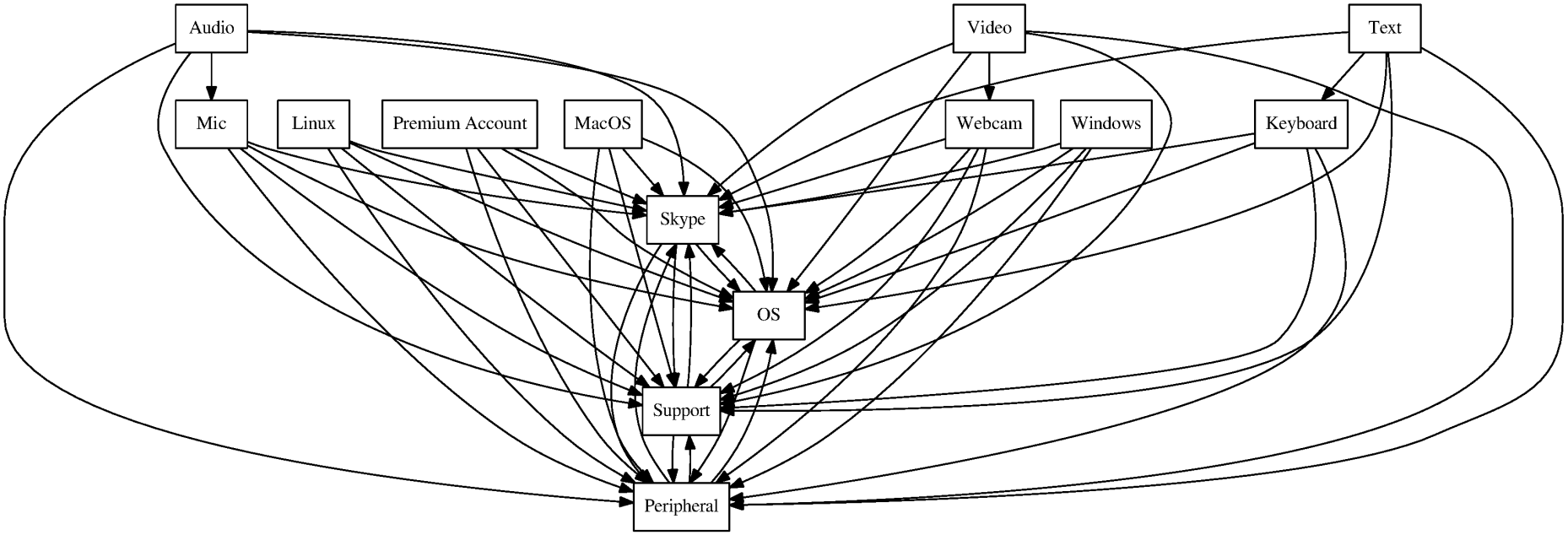


Key: Binary Implication Graph

Sound and complete representation of possible hierarchies



Sound and complete representation of possible hierarchies

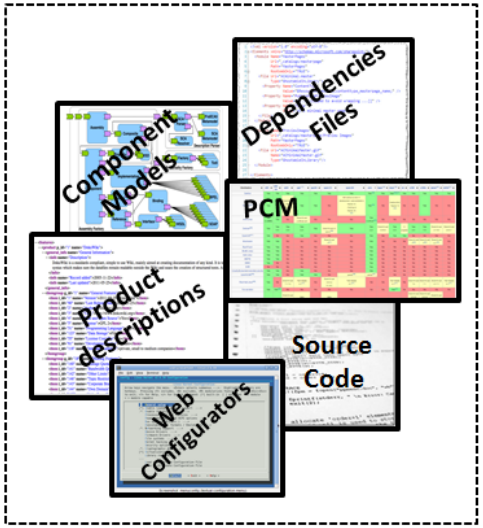


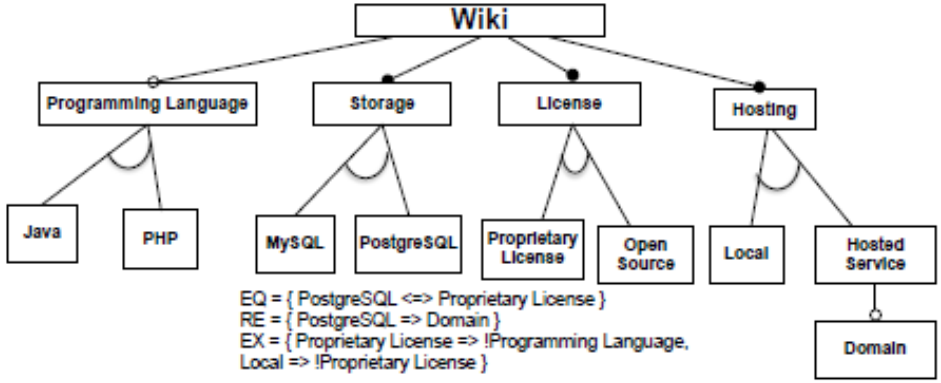
For a given configuration set,

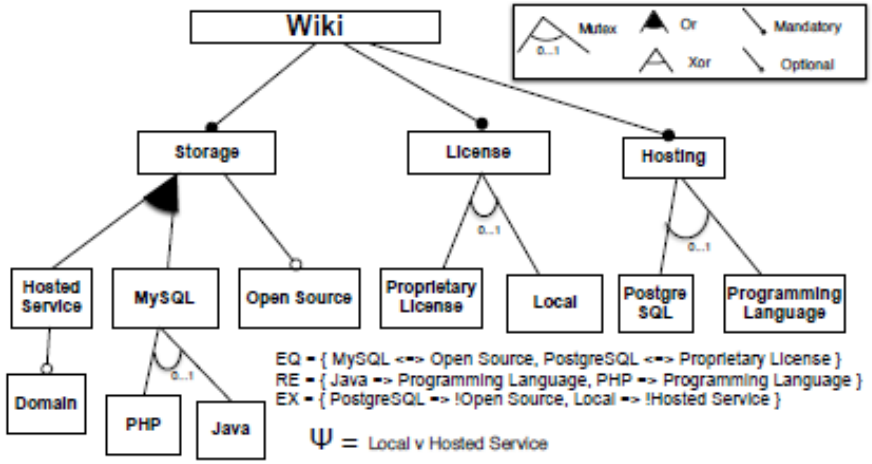
many (maximal) feature diagrams

with different ontological semantics

[She et al. ICSE'11, Andersen et al. SPLC'12, Acher et al. VaMoS'13]



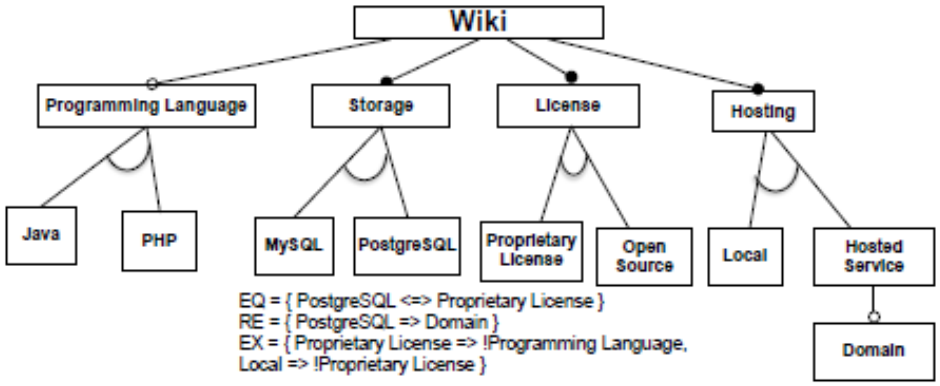


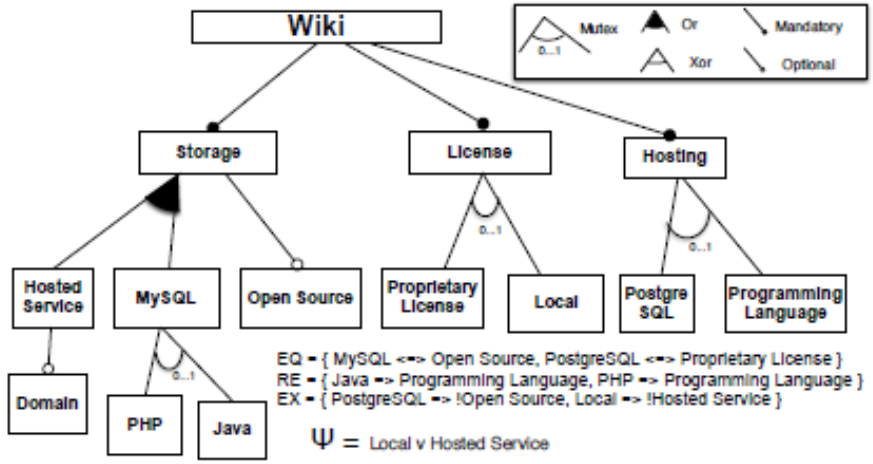


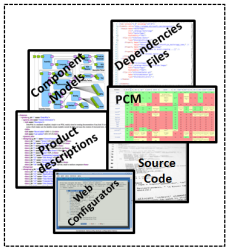
For a given configuration set, many (maximal) feature diagrams with different ontological semantics [She et al. ICSE'11, Andersen et al. SPLC'12, Acher et al. VaMoS'13]

	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
PostgreSQL	✓	×	×	×	×	×	×	×	×	×
MySQL	×	✓	✓	✓	✓	✓	✓	✓	✓	✓
License	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Domain	✓	×	×	×	×	✓	×	✓	✓	×
Proprietary License	✓	×	×	×	×	×	×	×	×	×
Local	×	×	✓	×	✓	×	×	×	×	✓
Programming Language	×	✓	×	×	✓	✓	✓	✓	×	✓
Java	×	✓	×	×	×	✓	×	×	×	✓
Storage	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
PHP	×	×	×	×	✓	×	✓	✓	×	×
Open Source	×	✓	✓	✓	✓	✓	✓	✓	✓	✓
Wiki	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Hosting	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Hosted Service	✓	✓	×	✓	×	✓	✓	✓	✓	×

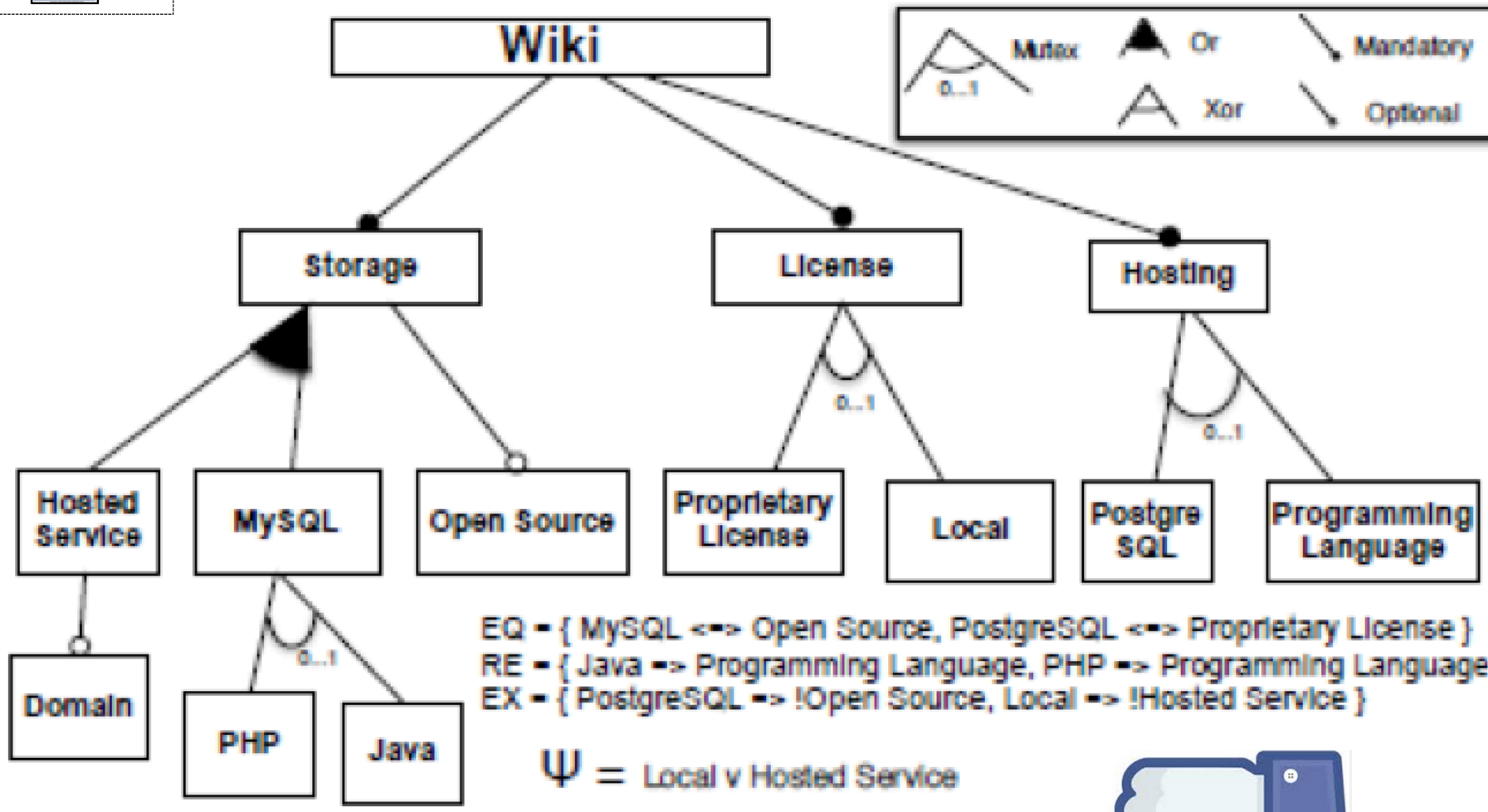
(a) Product comparison matrix (✓ feature is in the product ; × feature is not in the product)

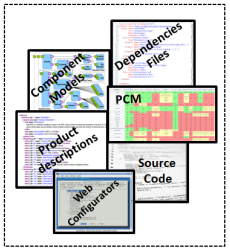






Importance of ontological semantics (1)





Importance of ontological semantics (2)

Wiki Wizard

Choose your Wiki

Storage

Do you want to choose Open Source as your storage system?

- (•) Yes, I want.
- ( ) No.

Should your hosted service provide a Domain ?

- (•) Yes.
- ( ) No.

Choose your MySQL database:

- (•) JAVA
- ( ) PHP
- ( ) None.

License

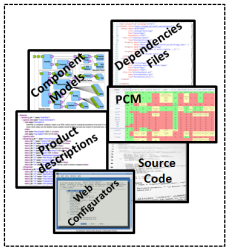
Select your License:

- ( ) Proprietary License
- (•) Local
- ( ) None

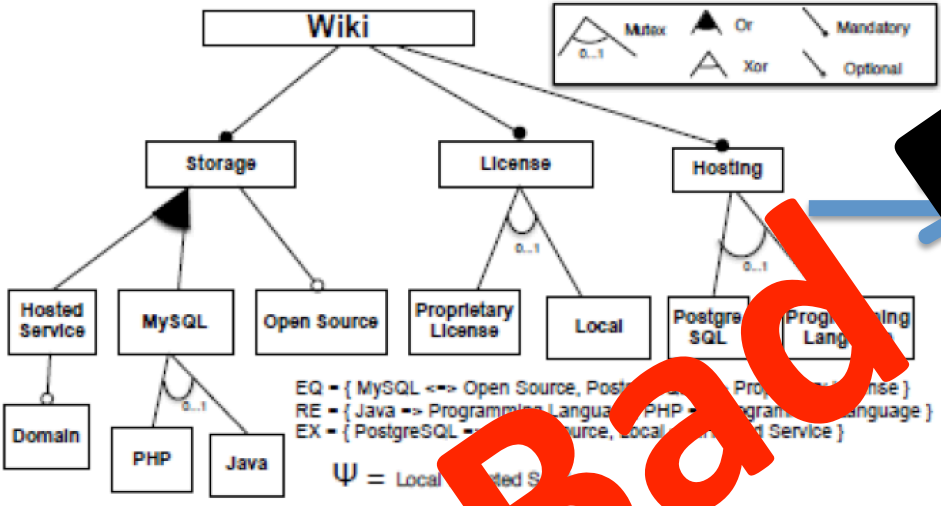
Hosting

What would you like to choose?

- ( ) PostgreSQL
- (•) Programming Language
- ( ) None.

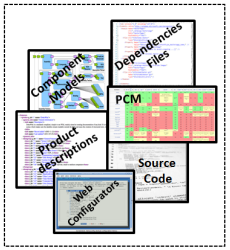


Importance of ontological semantics (3)



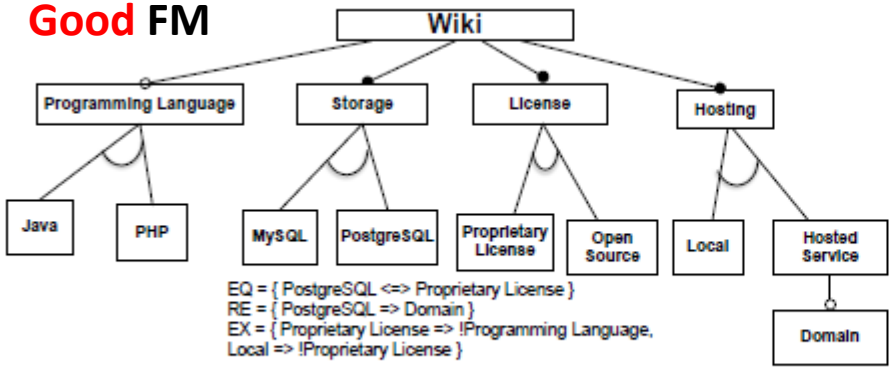
Bad FM

Communication
Comprehension
Forward engineering (e.g., generation)

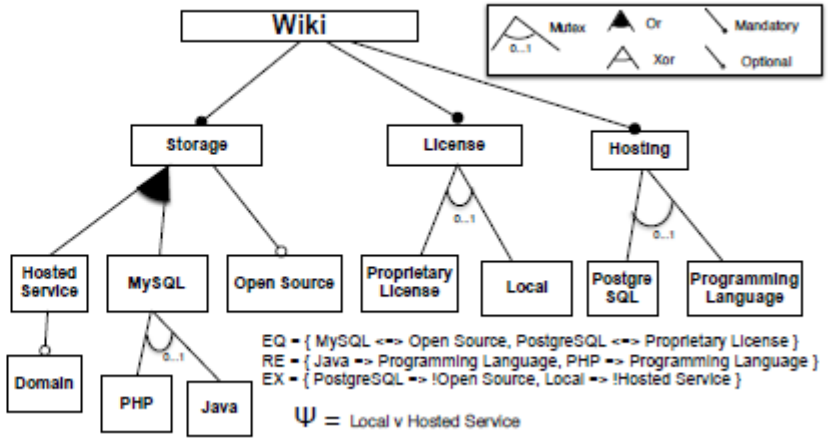


Importance of ontological semantics (4)

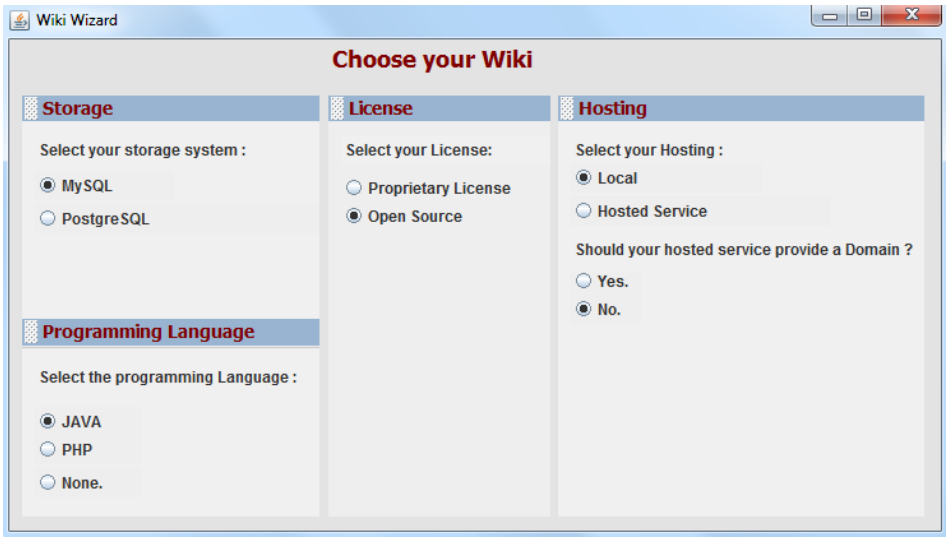
Good FM



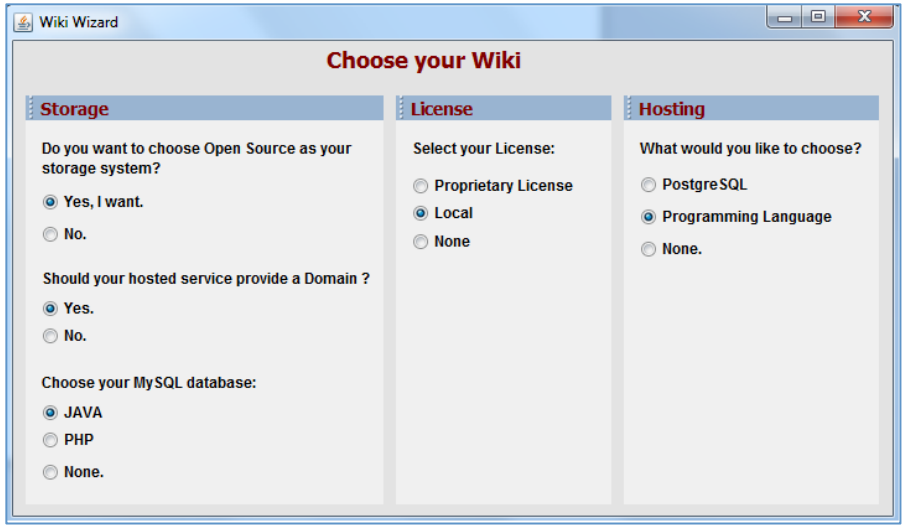
Bad FM



Good configuration interface

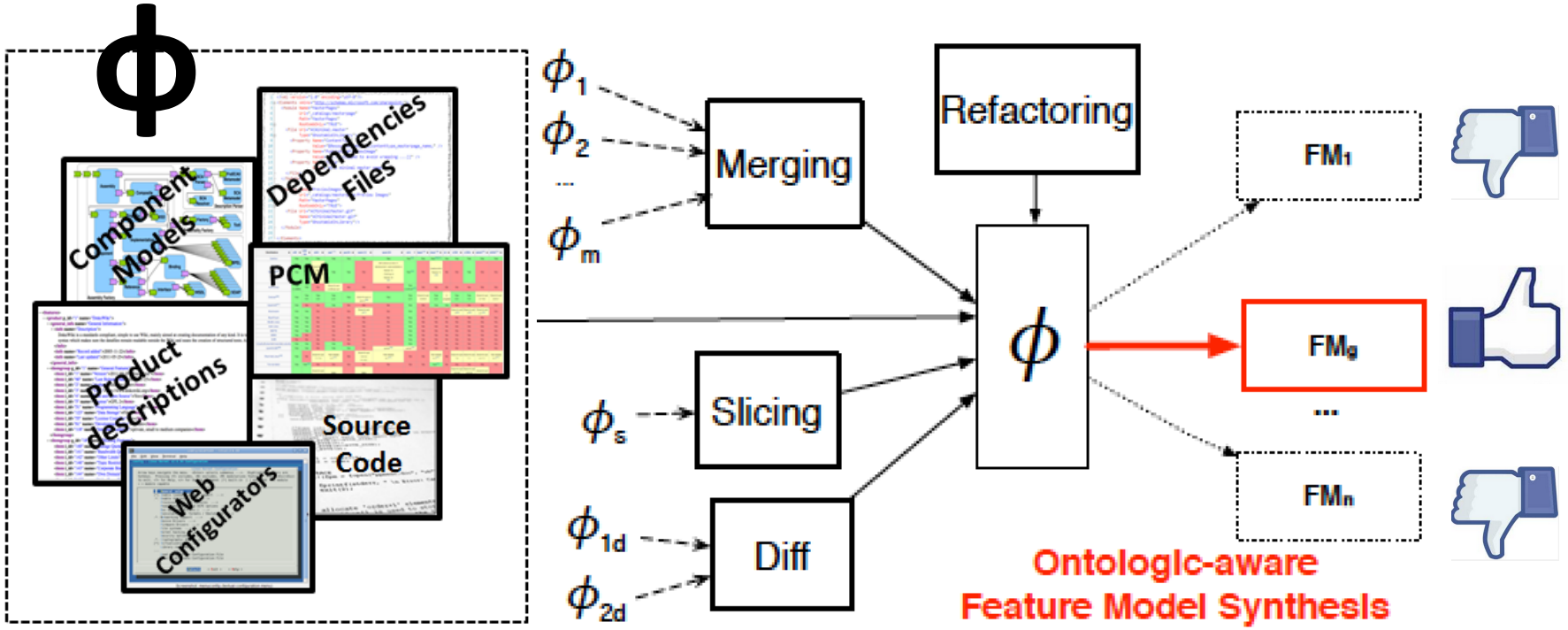


Bad configuration interface



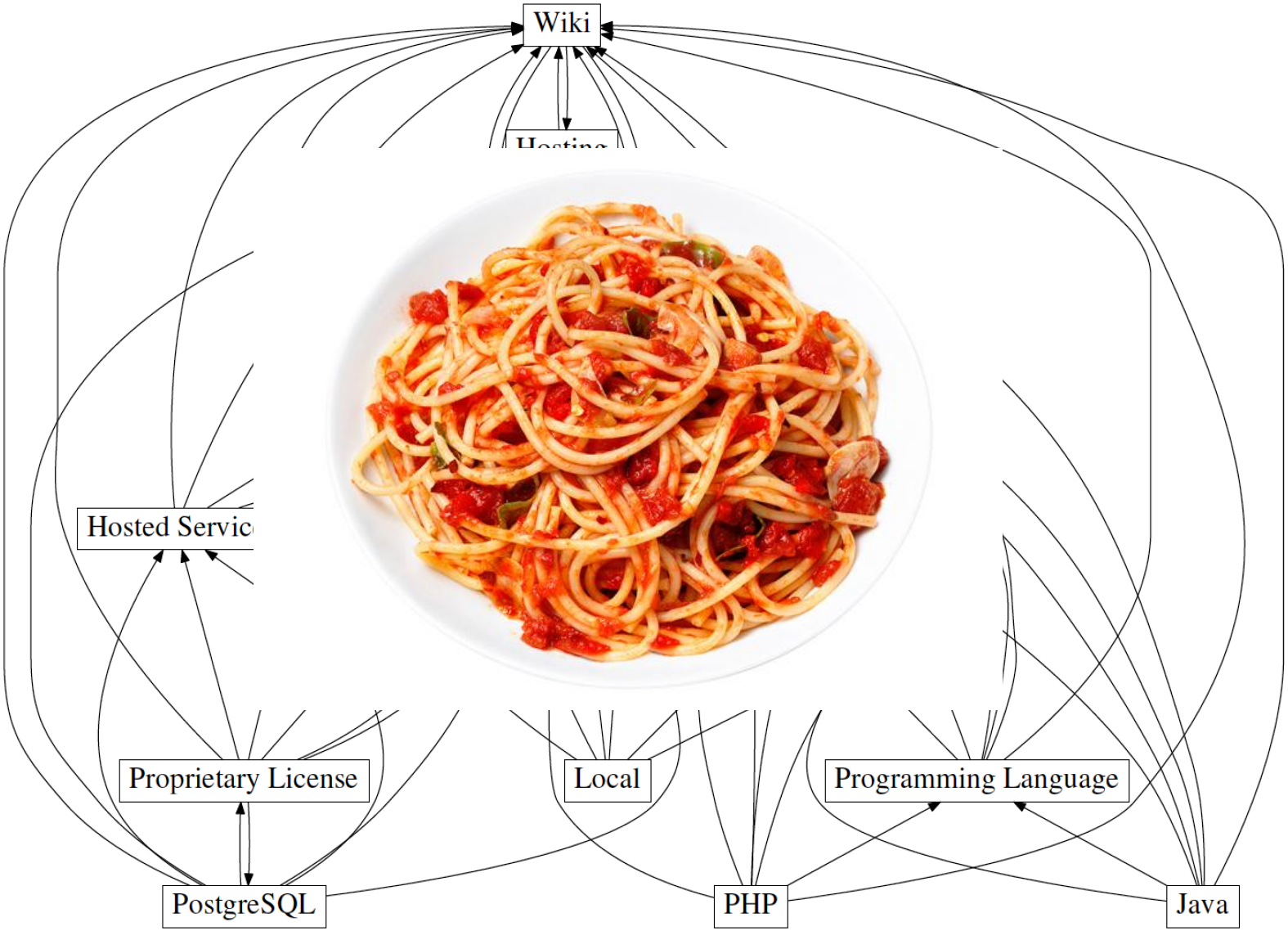
Two product configurators generated from two FMs with the same configuration semantics but different ontological semantics.

Most of the existing approaches neglect either configuration or ontological semantics. We want both!



Fundamental Problem

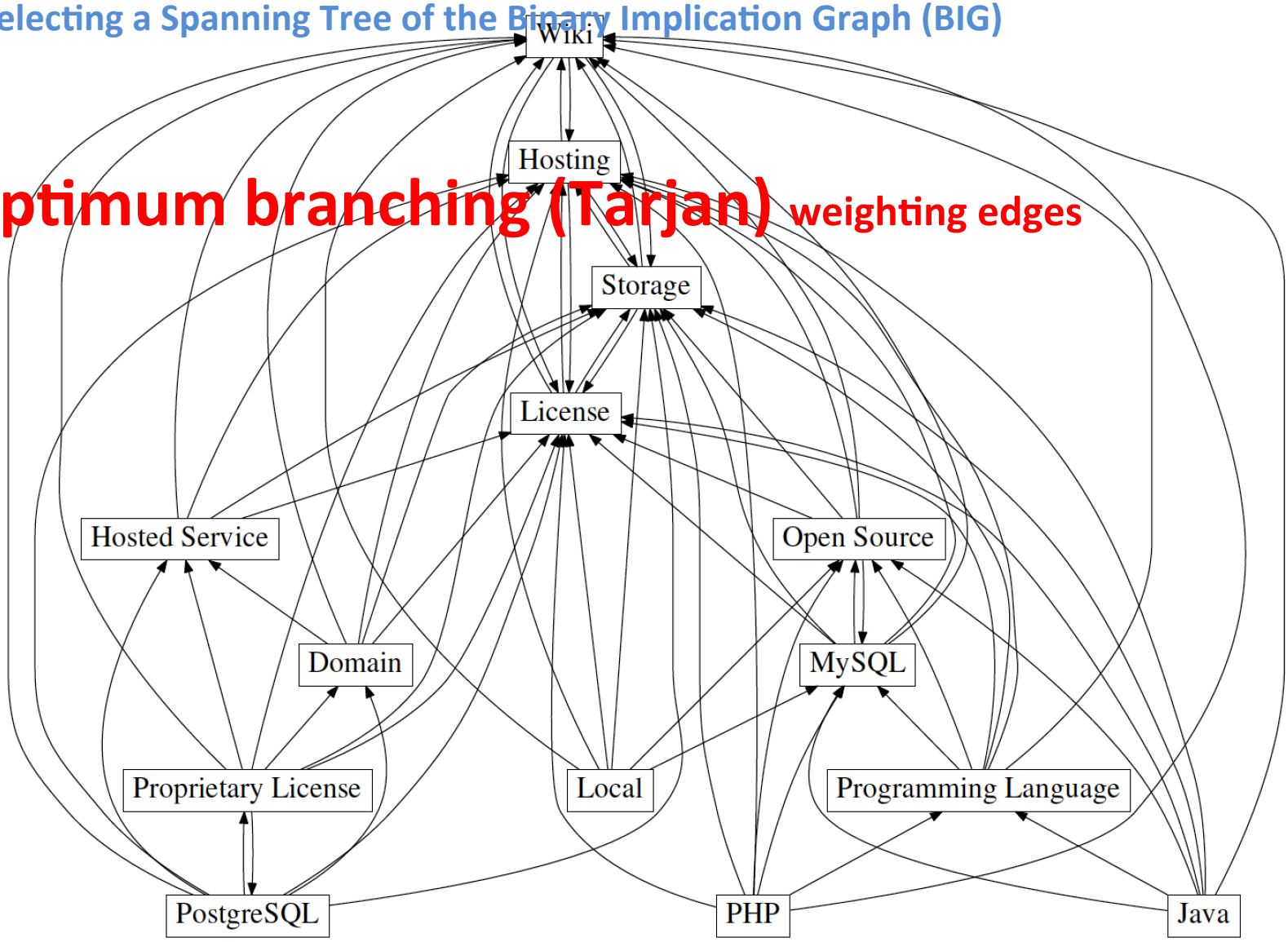
Selecting a Spanning Tree of the Binary Implication Graph (BIG)



Fundamental Problem

Selecting a Spanning Tree of the Binary Implication Graph (BIG)

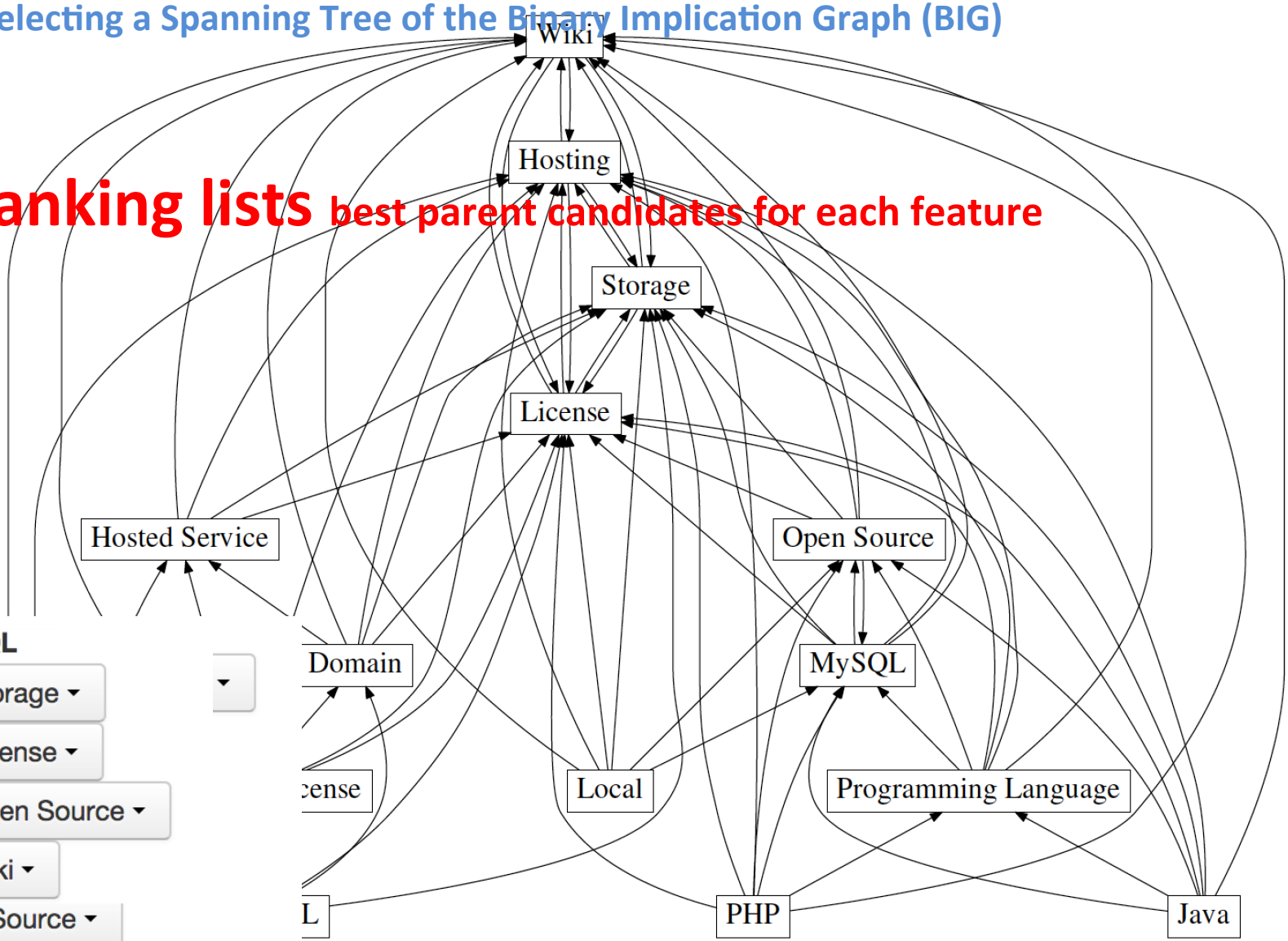
#0 Optimum branching (Tarjan) weighting edges



Fundamental Problem

Selecting a Spanning Tree of the Binary Implication Graph (BIG)

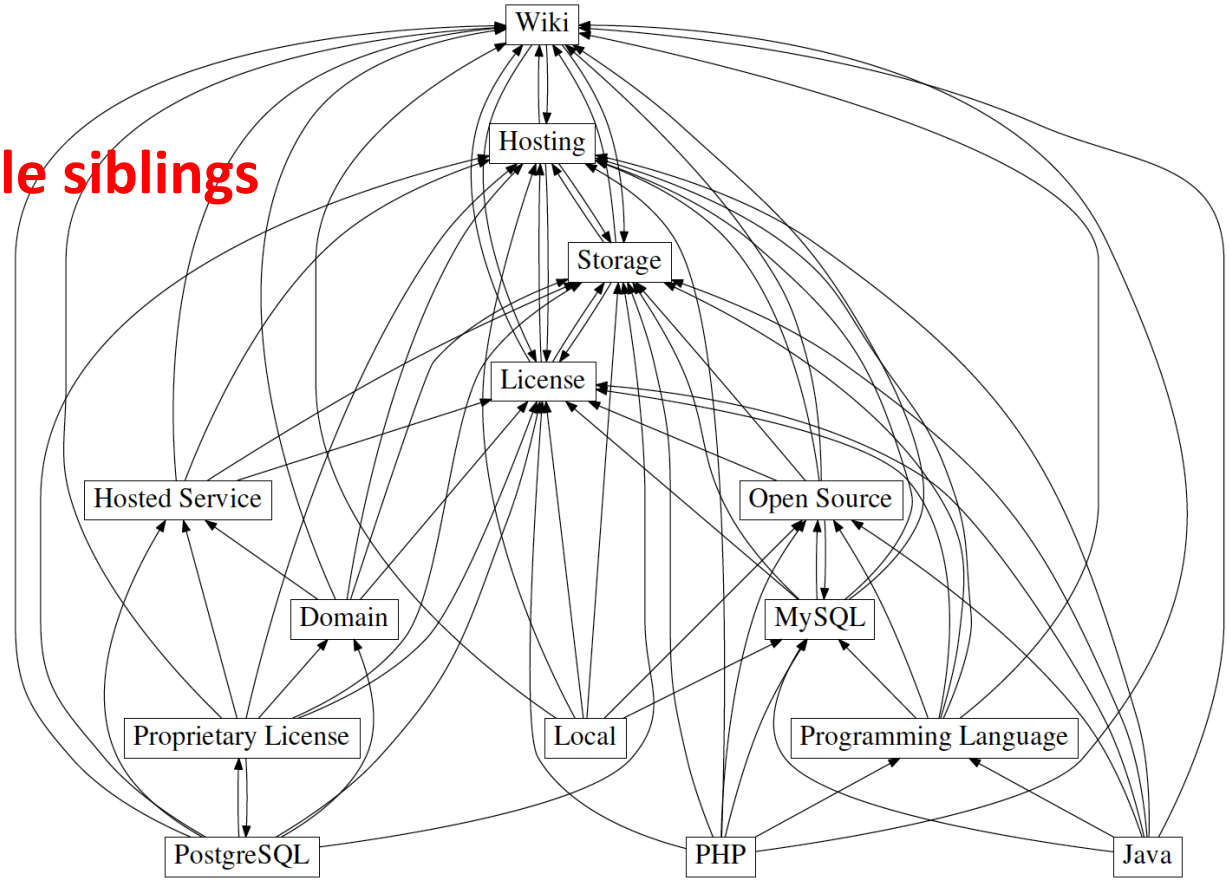
#1 Ranking lists best parent candidates for each feature



Fundamental Problem

Selecting a Spanning Tree of the Binary Implication Graph (BIG)

#2 Clusters ~possible siblings



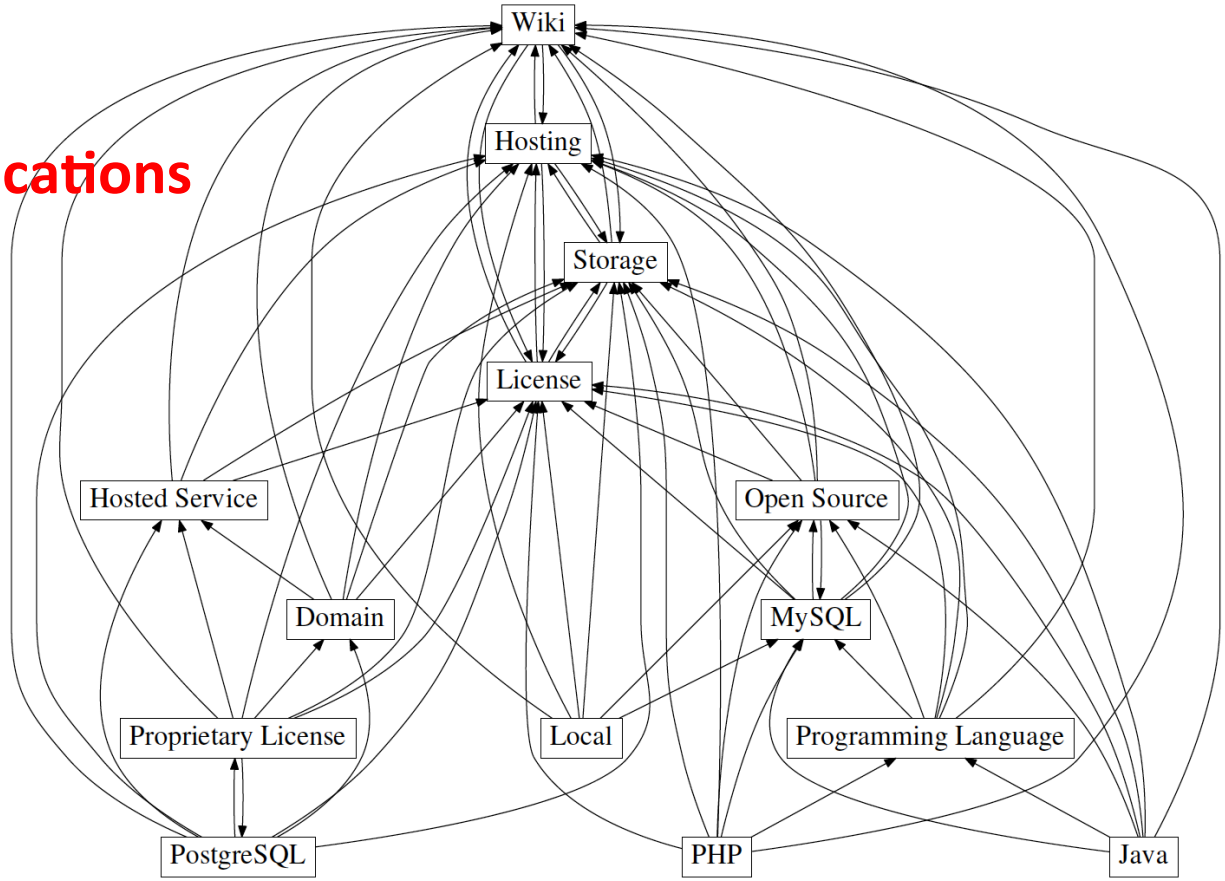
Clusters

- License
- Proprietary License
- PostgreSQL
- MySQL

Fundamental Problem

Selecting a Spanning Tree of the Binary Implication Graph (BIG)

#3 Cliques ~bi-implications

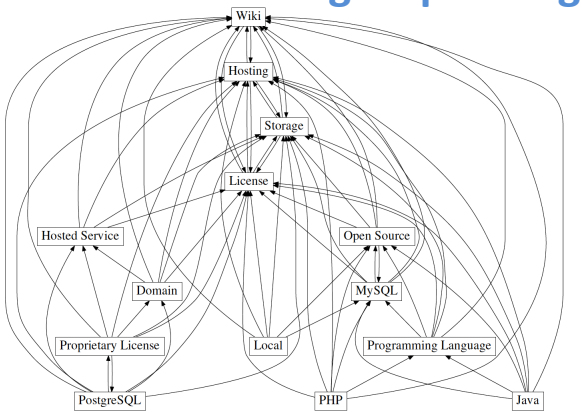


Cliques

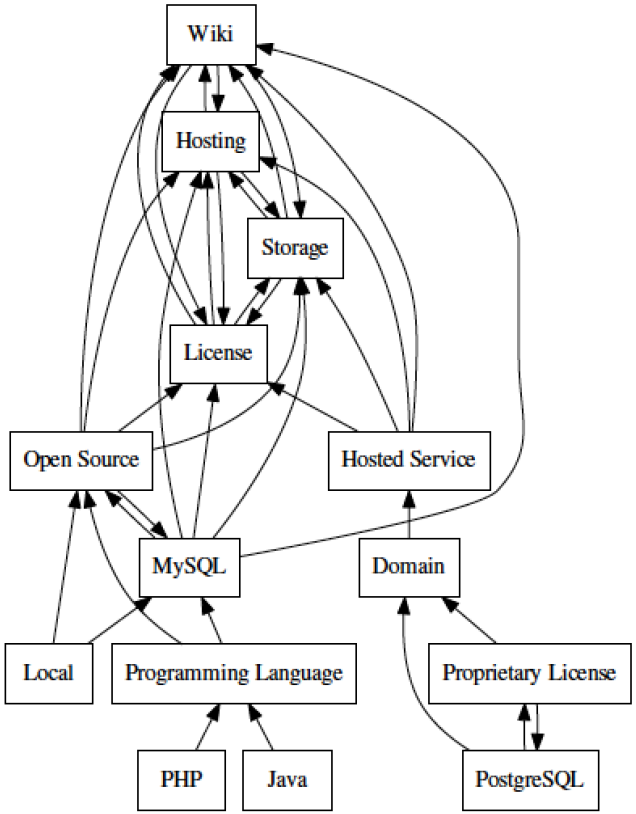
- Storage
- License
- Wiki
- PostgreSQL
- Proprietary License
- MySQL
- Open Source

Fundamental Problem

Selecting a Spanning Tree of the Binary Implication Graph (BIG)

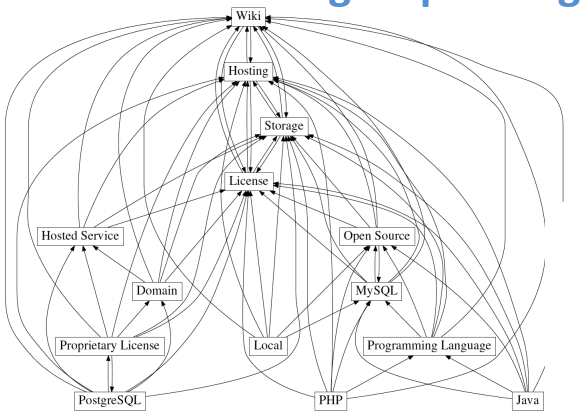


#4 small BIG



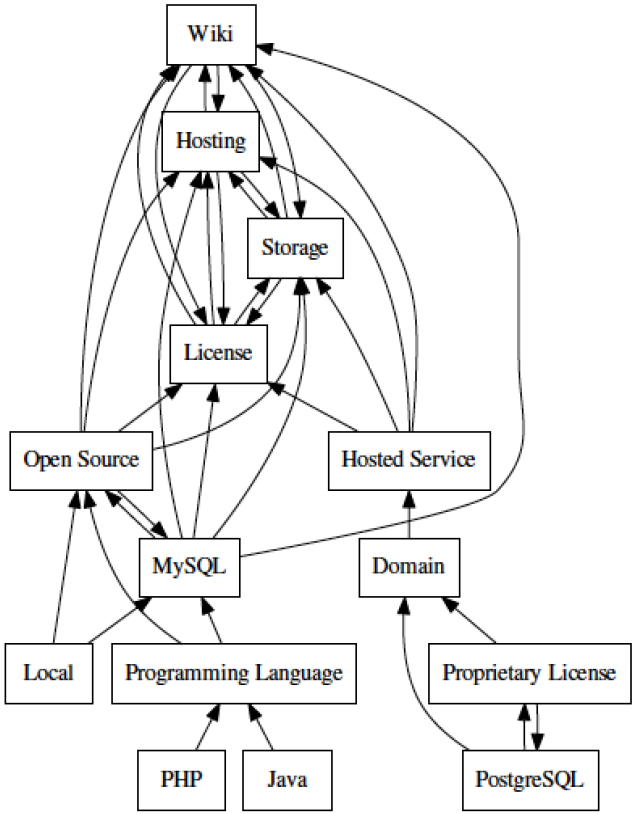
Fundamental Problem

Selecting a Spanning Tree of the Binary Implication Graph (BIG)



#4 reduced BIG

incomplete but dramatically reduce the problem



Ontological Heuristics

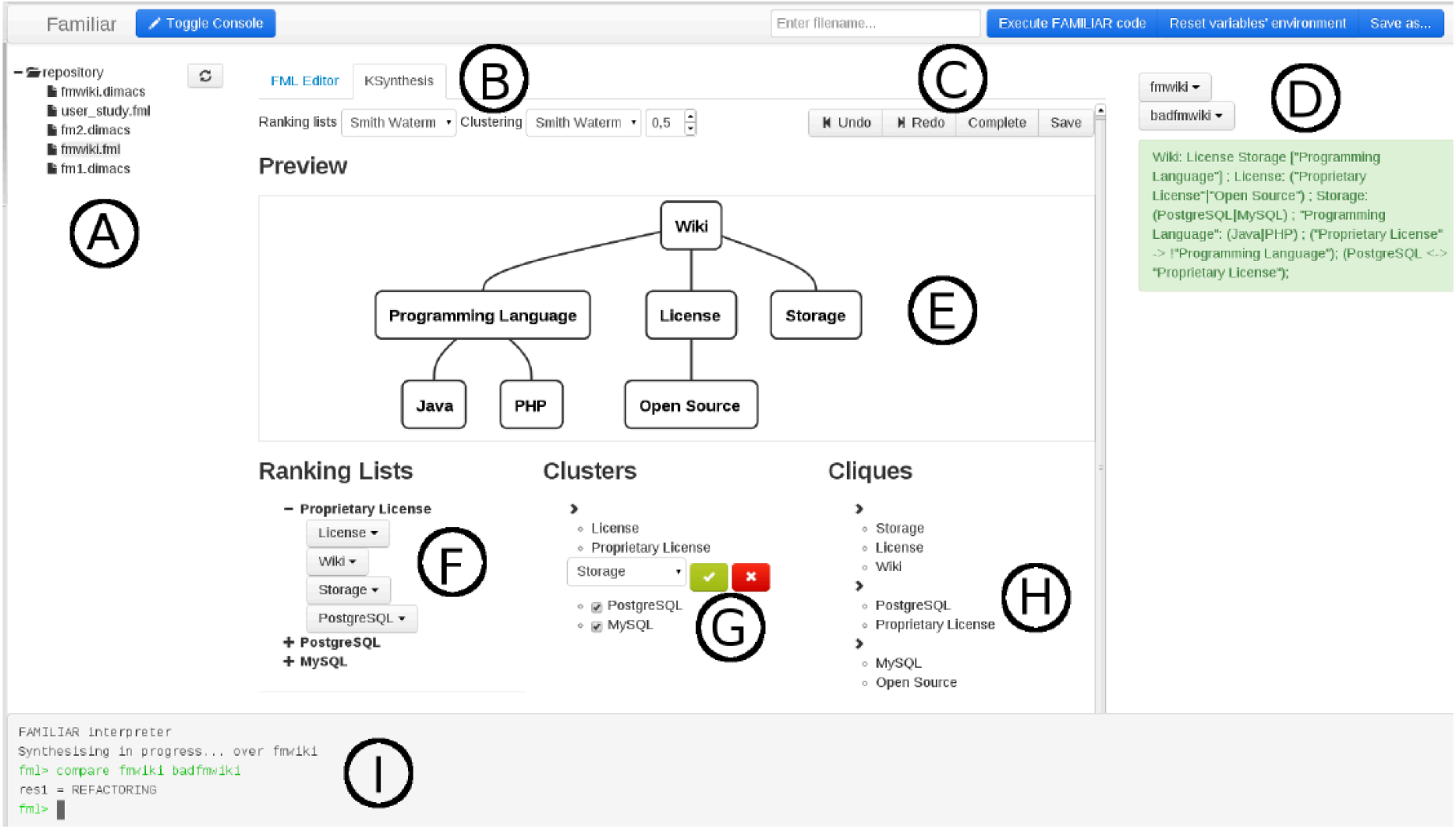
- For optimum branching, computing ranking lists and clusters
  - ~ « closedness » of features based on their names

- Syntactical heuristics
  - Smith-Waterman (SW) and Levenshtein (L)
- Wordnet
  - PathLength (PL) and Wu&Palmer (WP)
- Wikipedia Miner offers an API to browse Wikipedia's articles and compute their relatedness
  - Wiktionary (Wikt)

40 GB!

Milne, D.N., Witten, I.H.: An open-source toolkit for mining wikipedia. Artif. Intell. 194, 222{239 (2013)

WebFML


Familiar
Toggle Console
Enter filename...
Execute FAMILIAR code
Reset variables' environment
Save as...
repository
fmwiki.dimacs
user_study.fml
fm2.dimacs
fmwiki.fml
fm1.dimacs
A
FML Editor
KSynthesis
B
C
Ranking lists
Smith Waterm
Clustering
Smith Waterm
0,5
Undo
Redo
Complete
Save
fmwiki
badfmwiki
D
Wiki: License Storage ["Programming Language"] ; License: ("Proprietary License"|"Open Source") ; Storage: (PostgreSQL|MySQL) ; "Programming Language": (Java|PHP) ; ("Proprietary License" -> !"Programming Language"); (PostgreSQL <-> "Proprietary License");
Preview
Wiki
Programming Language
License
Storage
Java
PHP
Open Source
E
Ranking Lists
Clusters
Cliques
Proprietary License
License
Wiki
Storage
PostgreSQL
PostgreSQL
MySQL
F
License
Proprietary License
Storage
PostgreSQL
MySQL
G
Storage
License
Wiki
PostgreSQL
Proprietary License
MySQL
Open Source
H
FAMILIAR interpreter
Synthesising in progress... over fmwiki
fml> compare fmwiki badfmwiki
res1 = REFACTORING
fml>
I

Support and Empirical Study (1)

Goal: evidence and empirical insights of what heuristics are effective and what support is needed in WebFML

- Dataset
  - 120+ feature models of SPLOT
  - 30+ product comparison matrices from Wikipedia (see Becan et al. ASE'14 and ASE'13)
  - Ground truths are known
- Effectiveness of techniques (reduced BIG + ontological heuristics)
  - One shot synthesis
  - Quality of the ranking lists (top 2), clusters
  - Comparison with randomized and existing techniques

Support and Empirical Study (2)

Default heuristics/support has been determined through an empirical study

- Dataset
  - 120+ feature models of SPLOT
  - 30+ product comparison matrices from Wikipedia (see Becan et al. ASE'14 and ASE'13)
  - Ground truths are known
- Effectiveness of techniques (reduced BIG + ontological heuristics)
  - One shot synthesis
  - Quality of the ranking lists (top 2), clusters
  - Comparison with randomized and existing techniques

Support and Empirical Study (3)

Default heuristics/support has been determined through an empirical study

- One-step synthesis is far from the ground truth
  - despite state-of-the-art techniques we have developed
  - interactive support is thus crucial
- State-of-the-art heuristics for ranking lists and clusters
- Empirical insights on « cliques » and BIG reduction
  - e.g., support for unfolding of cliques

Support and Empirical Study (3)

Breathing Ontological Knowledge Into Feature Model Synthesis: An Empirical Study

Guillaume Bécan, Mathieu Acher, Benoit Baudry, Sana Ben Nasr

▶ **To cite this version:**

Guillaume Bécan, Mathieu Acher, Benoit Baudry, Sana Ben Nasr. Breathing Ontological Knowledge Into Feature Model Synthesis: An Empirical Study. Empirical Software Engineering, Springer Verlag (Germany), 2015, pp.51. <10.1007/s10664-014-9357-1>. <hal-01096969>

FAMILIAR-pl

branch: **master**

gbecan on 11 Jul Update links to KSynthesis

2 contributors

37 lines (26 sloc) | 2.867 kb | Raw | Blame | History

Empirical Evaluation of Ontologic-aware Feature Model Synthesis

How to reproduce the experiments

To reproduce the experiments you have to clone two github repositories:

- KSynthesis repository (version used: ESE-evaluation).
- FAMILIAR (version used: ESE-evaluation)

The first repository contains the algorithms and heuristics for synthesizing a correct and meaningful FM. It also contains an **Evaluation** project with the two FM datasets (SPLOT and PCM) and the necessary code to run the experiments. The second repository is a dependency for the algorithms.

The SPLOT dataset contains 126 FMs encoded in *SXFM* format. The PCM dataset contains 30 FMs encoded in *fmlbdd* format.

To use heuristics based on Wikipedia, you need to install additional files.

https://hal.inria.fr/hal-01096969

http://tinyurl.com/OntoFMExperiments

She et al.
Reverse Engineering Feature Models ICSE'11 (Linux/eCos/FreeBSD case study)

Configuring FreeBSD:

```
# IPI_PREEMPTION relies on the PREEMPTION option

# Mandatory:
Device apic                # I/O apic

# Optional:
options MPTABLE_FORCE_HTT #enable HTT CPUs ...
options IPI_PREEMPTION
```

Code:

```
MODULE_DEPEND(at91_twi, iicbus, …);
#ifdef A … #endif
```

Features and dependencies are scattered through code and documentation.

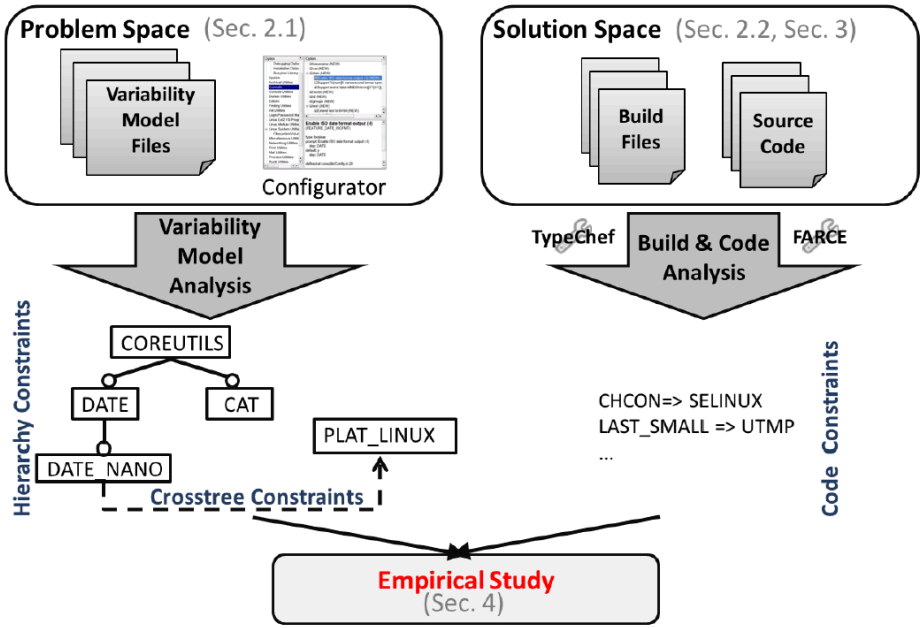
Mining Configuration Constraints: Static Analyses and Empirical Results

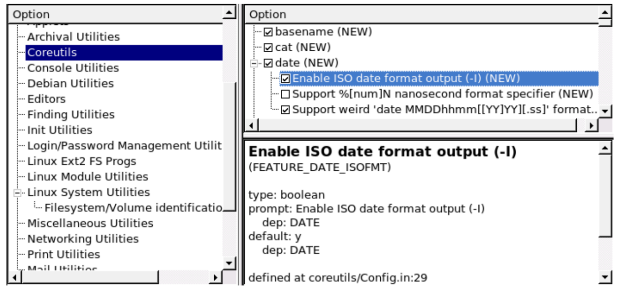
Sarah Nadi
University of Waterloo, Canada

Thorsten Berger
IT University of Copenhagen, Denmark

Christian Kästner
Carnegie Mellon University, USA

Krzysztof Czarnecki
University of Waterloo, Canada

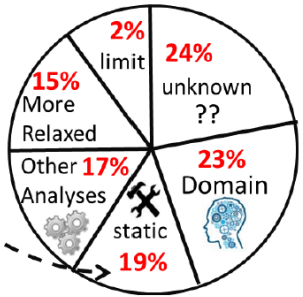




Obj. 1
Accuracy & Scalability
Spec. 1: **93%** accurate
Spec. 2: **77%** accurate

Obj. 2
Recoverability
19 %

Obj. 3
Constraint Classification




```
1 #ifndef Y
2 void foo() { ... }
3 #endif
4
5 #ifdef X
6 void bar() { foo(); }
7 #endif
```

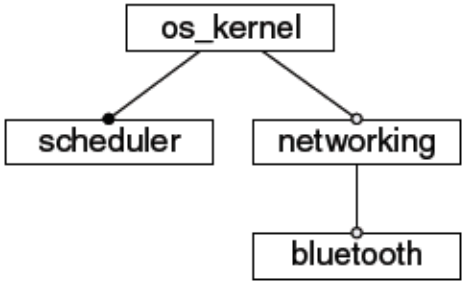
```
1 #if defined(Z)&&defined(X)
2  ...
3 #ifdef W
4  ...
5 #endif
6  ...
7 #endif
```

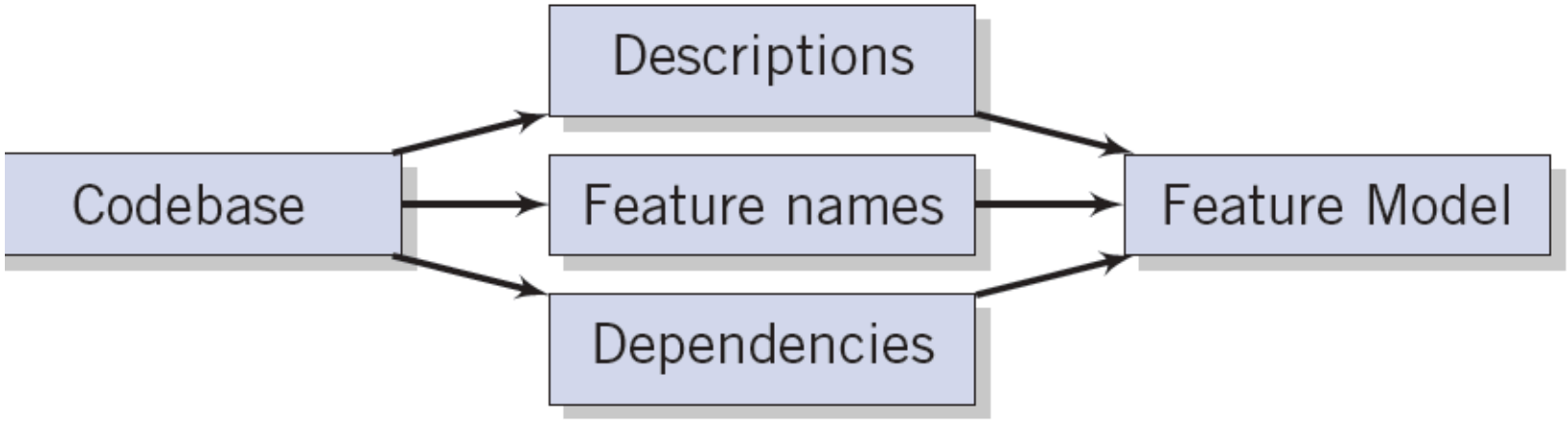
She et al. Reverse Engineering Feature Models ICSE'11

```
#ifdef A
   #ifndef B
      #error ...
    #endif
#endif
```

scheduler ↔ os_kernel
networking → os_kernel
bluetooth → networking

bluetooth is a network driver.





Leverage both names and descriptions for additional domain knowledge.

She et al. Reverse Engineering Feature Models ICSE'11

```
#ifdef A
  #ifndef B
    #error ...
  #endif
#endif
```

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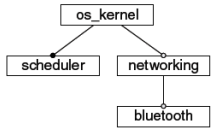

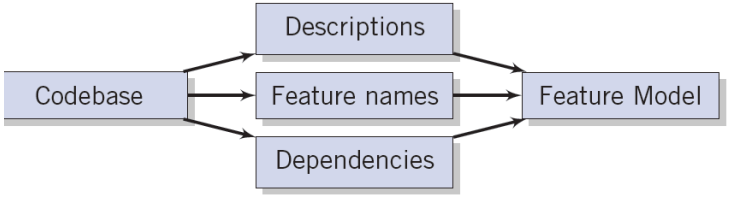

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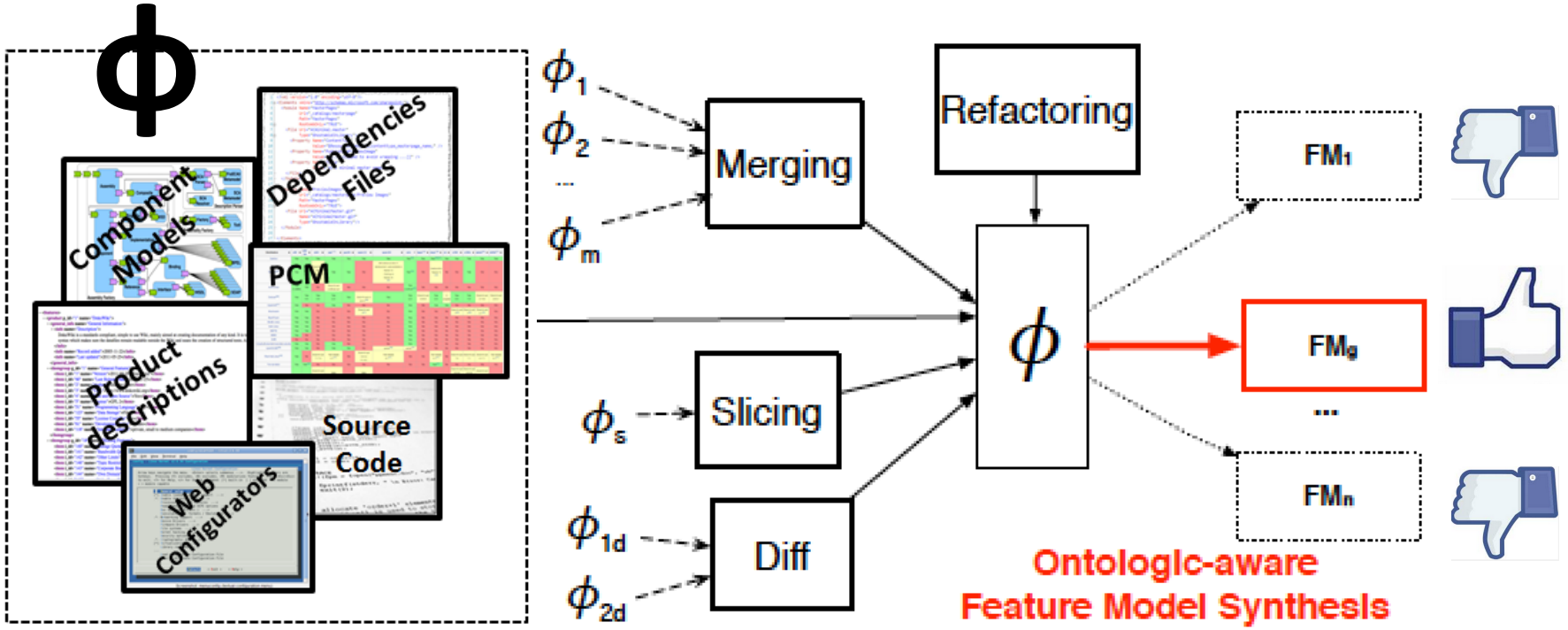

Ontological heuristics (based on feature descriptions)

Feature similarity.

Feature names and descriptions

os_kernel	Operating system.
scheduler	I/O scheduling.
networking	Networking drivers.
ethernet	Type of local area networking.

Selecting a parent for:

bluetooth, a network driver.

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Ontological heuristics (based on feature descriptions)

Feature similarity.

Ranked list

Feature names and descriptions

1. networking Networking drivers.
2. ethernet Type of local area networking.
3. os_kernel Operating system.
4. scheduler I/O scheduling.

Selecting a parent for:

bluetooth, a network driver.

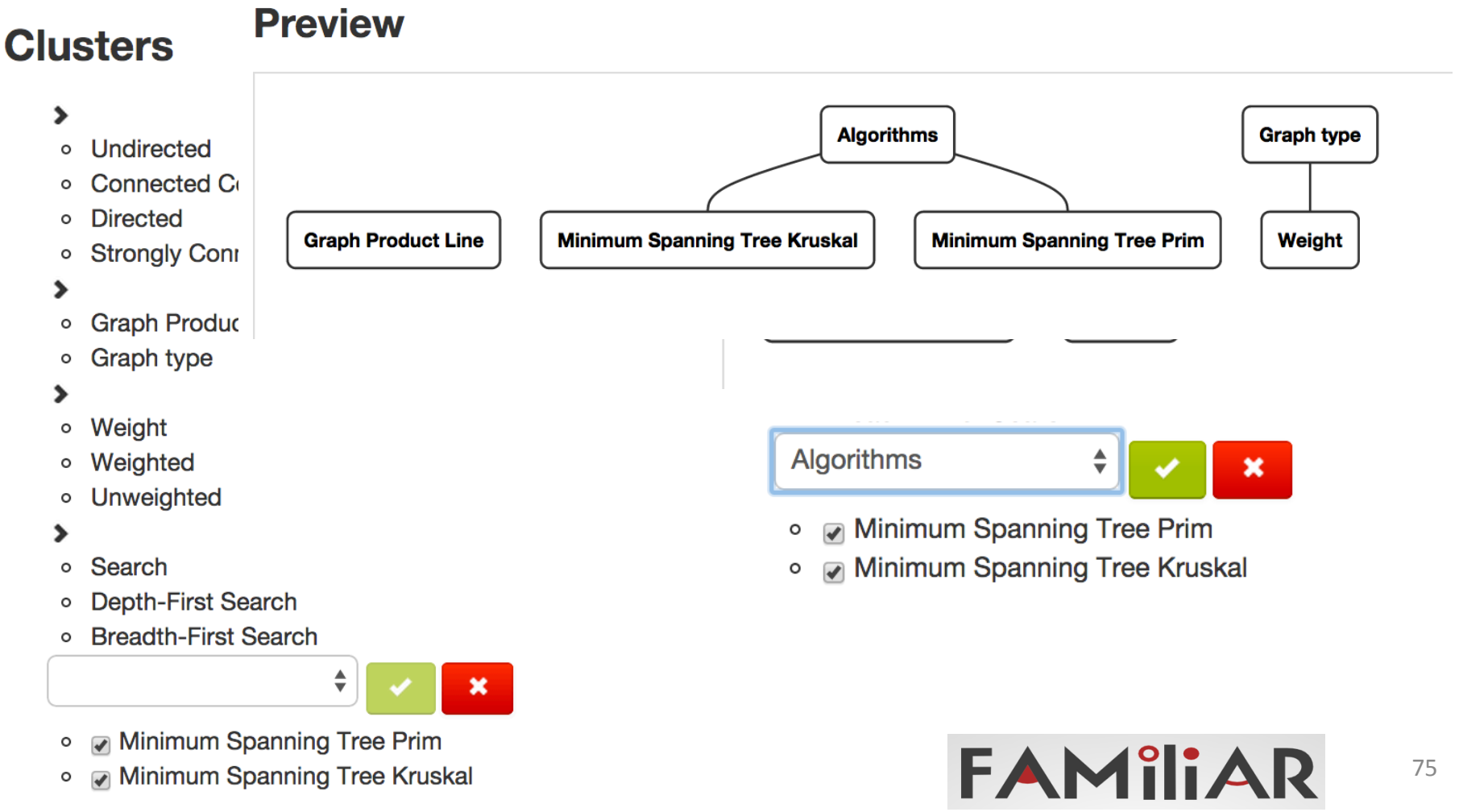
Empirical results

How many features have their reference parents ranked in the top 5 of our RIFs?

- Linux: 76% of features, eCos: 79% of features.
- Ignoring root features, 90% for Linux and 81% for eCos.
- For incomplete descriptions, At least 50% of words needed for good results (roughly 10 words in Linux).

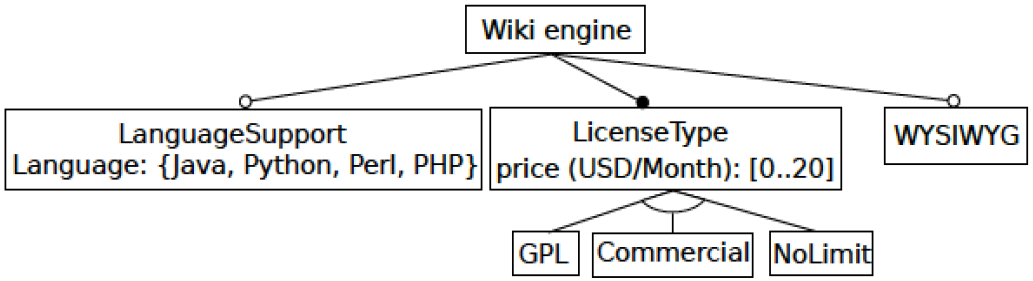
Guillaume Bécan, Mathieu Acher, Benoit Baudry, and Sana Ben Nasr. Breathing Ontological Knowledge Into Feature Model Synthesis: An Empirical Study (2015). In Empirical Software Engineering (ESE)

WebFML: Synthesizing Feature Models Everywhere (SPLC'14)



FAMiliAR

Synthesising Attributed Feature Models



Commercial <=> LicenseType.price = 10
Commercial <=> Java
GPL => LicenseType.price <= 10
NoLimit <=> ¬LanguageSupport

GPL => LanguageSupport
NoLimit => LicenseType.price >= 10
¬PHP => WYSIWYG
Python => LicenseType.price = 0

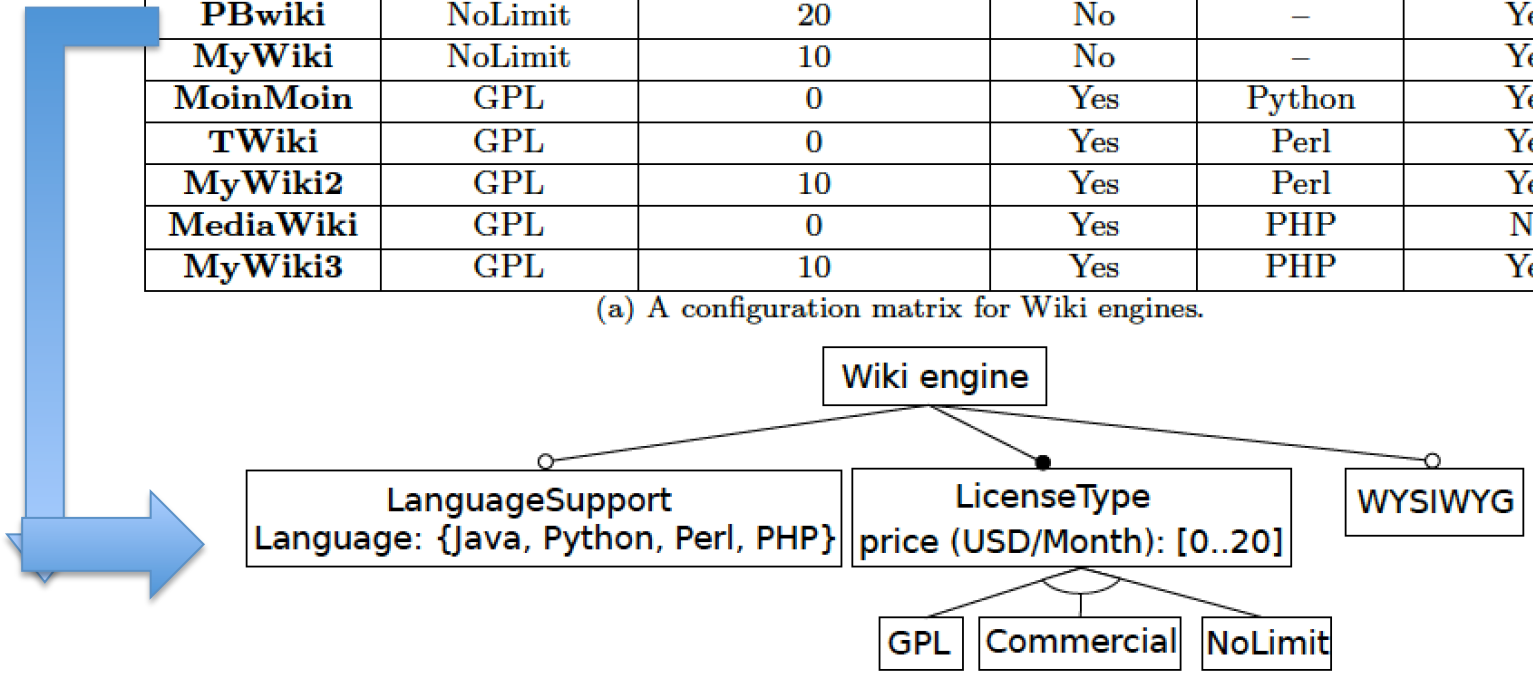
$\Phi = \neg WYSIWYG <=> PHP \wedge LicenseType.price = 0$

Product	License	Price	Language Support	Language	WYSIWIG
W1	Commercial	10	Yes	Java	Yes
W2	NoLimit	20	No		Yes
W3	NoLimit	10	No		Yes
W4	GPL	0	Yes	Python	Yes
W5	GPL	0	Yes	Perl	Yes
W6	GPL	10	Yes	Perl	Yes
W7	GPL	0	Yes	PHP	No
W8	GPL	10	Yes	PHP	Yes

Guillaume Bécan, Razieh Behjati, Arnaud Gotlieb, and Mathieu Acher. Synthesis of Attributed Feature Models From Product Descriptions (2015). In 19th International Software Product Line Conference (SPLC'15) (research track, long paper)

Identifier	LicenseType	LicenseType.price	Language Support	Language	WYSIWYG
Confluence	Commercial	10	Yes	Java	Yes
PBwiki	NoLimit	20	No	–	Yes
MyWiki	NoLimit	10	No	–	Yes
MoinMoin	GPL	0	Yes	Python	Yes
TWiki	GPL	0	Yes	Perl	Yes
MyWiki2	GPL	10	Yes	Perl	Yes
MediaWiki	GPL	0	Yes	PHP	No
MyWiki3	GPL	10	Yes	PHP	Yes

(a) A configuration matrix for Wiki engines.



Commercial <=> LicenseType.price = 10
Commercial <=> Java
GPL => LicenseType.price <= 10
NoLimit <=> ¬LanguageSupport
GPL => LanguageSupport
NoLimit => LicenseType.price >= 10
¬PHP => WYSIWYG
Python => LicenseType.price = 0

Φ = ¬WYSIWYG <=> PHP ∧ LicenseType.price = 0

(b) An attributed feature model representing the configuration matrix in Figure 2(a)

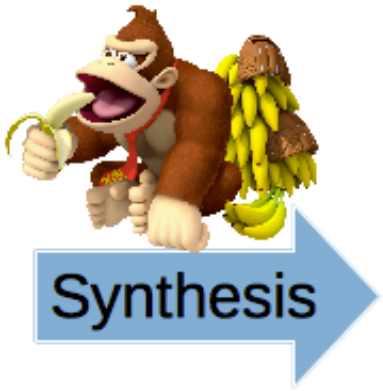
Guillaume Bécan, Razieh Behjati, Arnaud Gotlieb, and Mathieu Acher. Synthesis of Attributed Feature Models From Product Descriptions (2015). In 19th International Software Product Line Conference (SPLC'15) (research track, long paper)

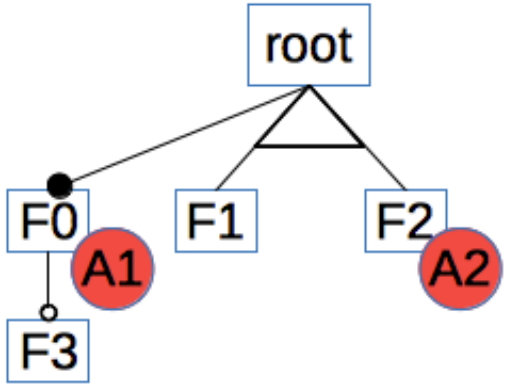
Upload a Matrix | Features Attributes | Hierarchy | Feature Groups | Constraints | AFM

Next

#	root Feature Null value	F0 Feature Null value	F1 Feature Null value	F2 Feature Null value	F3 Feature Null value	A1 Attribute 0	A2 Attribute 0
0	Yes	Yes	Yes	No	Yes	3	0
1	Yes	Yes	No	Yes	Yes	2	2
2	Yes	Yes	Yes	No	No	2	0
3	Yes	Yes	No	Yes	No	0	8

root	F0	F1	F2	F3	A1	A2
Yes	Yes	Yes	No	Yes	3	0
Yes	Yes	No	Yes	Yes	2	2
Yes	Yes	Yes	No	No	2	0
Yes	Yes	No	Yes	No	0	8



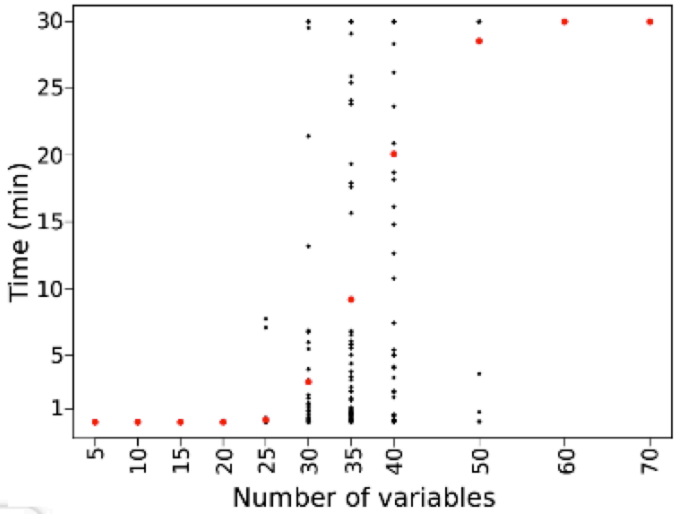


A2 < 8 => A1 >= 2
A1 > 0 => A2 <= 2

Scalability

Random dataset

- Generator of configuration matrices
  - Number of variables (features + attributes)
  - Number of configurations
  - Maximum domain size (number of distinct values in a column)
- Execution time of or-group computation




= default heuristics only

- 1000 configurations
- max domain size of 10

Timeout always reached with more than 60 variables

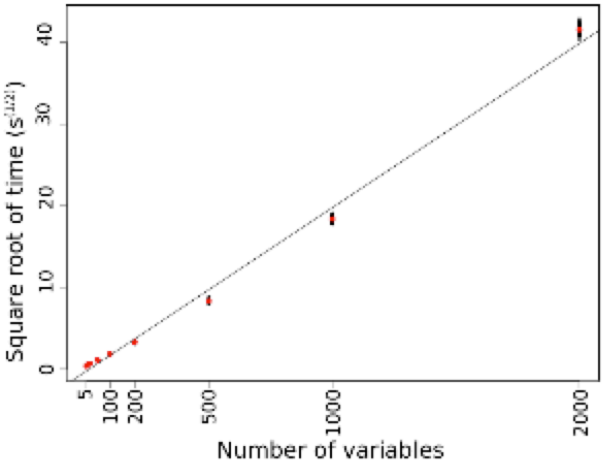
Or groups do not scale !

Scalability

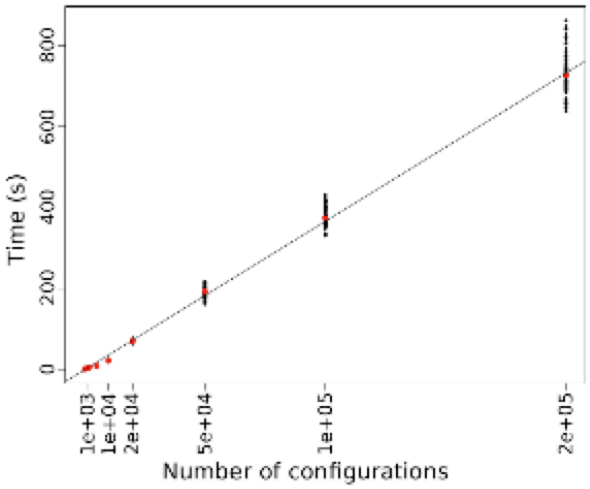
Random dataset

- Execution time (no or-groups)

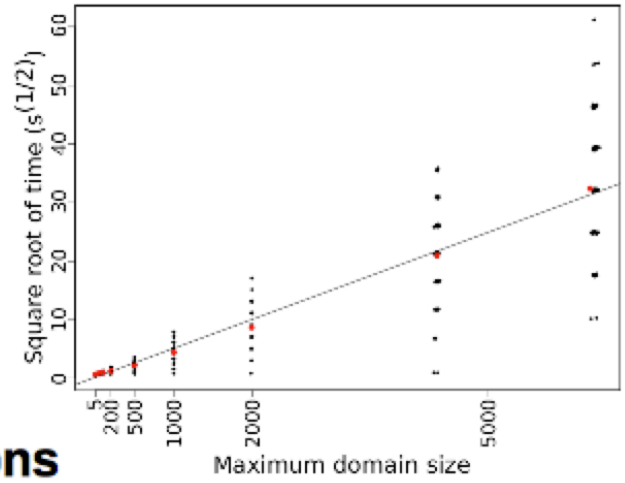
= default heuristics only



- **Up to 2,000 variables**
- 1,000 configurations
- Max domain size of 10



- 100 variables
- **Up to 200,000 configurations**
- Max domain size of 10



- 10 variables
- 10,000 configurations
- **Up to 6000 distinct values**

On all experiments:
Average: 2.6 min
Max: 62 min

Scalability

Best Buy dataset

- 242 matrices
- < 25% of empty cells
- Interpretation of empty cells

= default heuristics only

Media Card Reader	Yes	Yes	Yes
Number Of Ethernet Ports	1	1	
Number Of HDMI Outputs	1	1	1
Number Of USB Port(s)	3	3	3
Number Of VGA Ports	1		
Operating System	Windows 8.1	Windows 8.1	Windows 8.1

Execution time of 2.1s for the most challenging matrix:

- 77 variables
- 185 configurations
- Maximum domain size of 185

Execution time is similar to the random dataset

Managing Feature Models

FAMiliAR

(FeAture Model scrIpt Language for manIpulation and Automatic Reasoning)

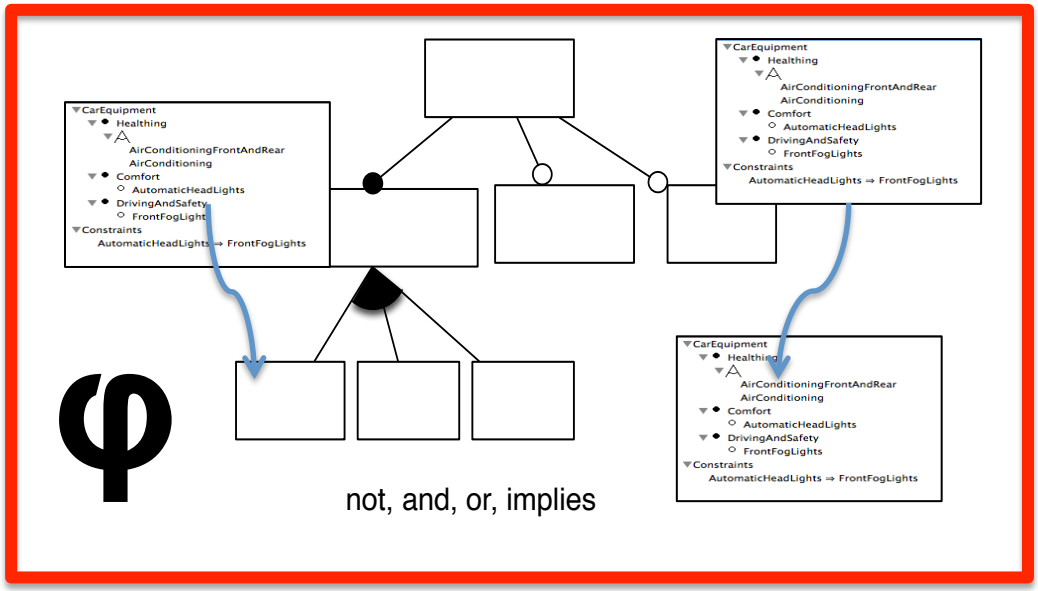
http://familiar-project.github.com/

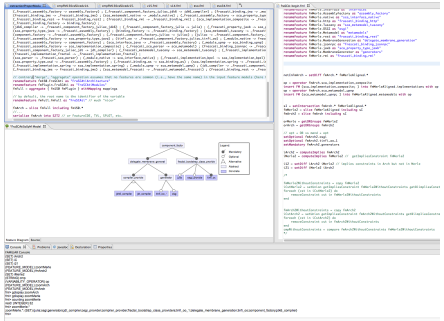
COMMON VARIABILITY LANGUAGE

S.P.L.O.T. Software Product Lines Online Tools

IDE Feature

TVL
DIMACS



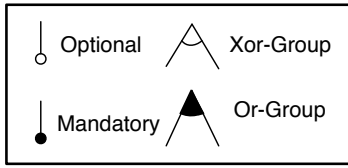


importing, exporting, composing, decomposing, editing, configuring, reverse engineering, computing "diffs", refactoring, testing, and reasoning about (multiple) variability models

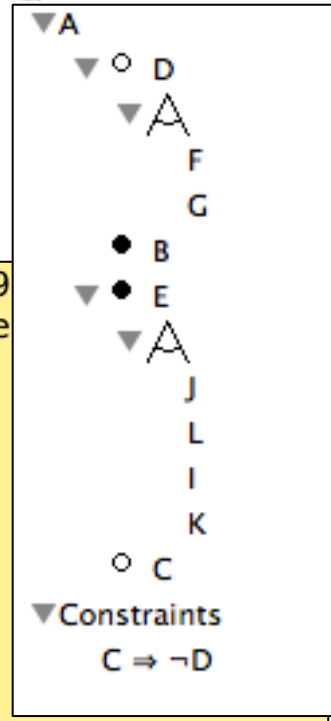
Mathieu Acher, Philippe Collet, Philippe Lahire, Robert B. France « A Domain-Specific Language for Large-Scale Management of Feature Models » Science of Computer Programming (SCP), 2013

conf.fml

Configuration



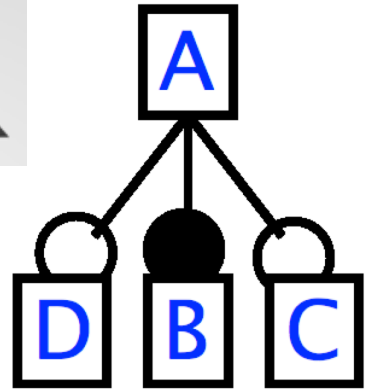

```
fm1 = FM (A: B [C] [D] E; D : (F|G) ; E : (I|J|K|L) ; C -> !D ; )
c1 = configuration fm1
select C in c1
sc1 = selectedF c1 // accessors
cFM1 = asFM c1 // configuration and FM: back!
```



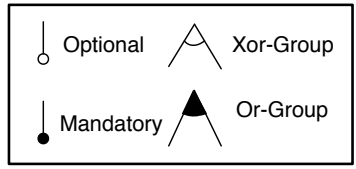

```
MacBook-Pro-de-Mathieu-2:FML-scripts macher$ java -jar -Xmx1024M ../FML-0.9.9
FAMILIAR (for FeAture Model scrIpt Language for manIpulation and Automatic Re
University of Nice Sophia Antipolis, UMR CNRS 6070, I3S Laboratory
https://nyx.unice.fr/projects/familiar/
fml> cFM1
cFM1: (FEATURE_MODEL) A: B E C ;
E: (J|L|I|K) ;
E;
A;
B;
C;
fml> fm1
fm1: (FEATURE_MODEL) A: [D] B E [C] ;
D: (F|G) ;
E: (J|L|I|K) ;
(C -> !D);
```

A ^
A ⇔ B ^
C => A ^
D => A

FAMiliAR



FM



φ

```
fml> fm1 = FM ("output/fm1.tvl")
root A {
    group [ 3..3 ] {
        opt D {
        },
        B {
        },
        opt C {
        }
    }
}
fm1: (FEATURE_MODEL) A: [D] B [C] ;
```

```
fm1bis = FM ("foo3.dimacs")
fm1bisbis = FM ("foo3.constraints")
```

```
fml> c1 = cores fm1
c1: (SET) {B;A}
fml> c1bis = cores fm1bis
```

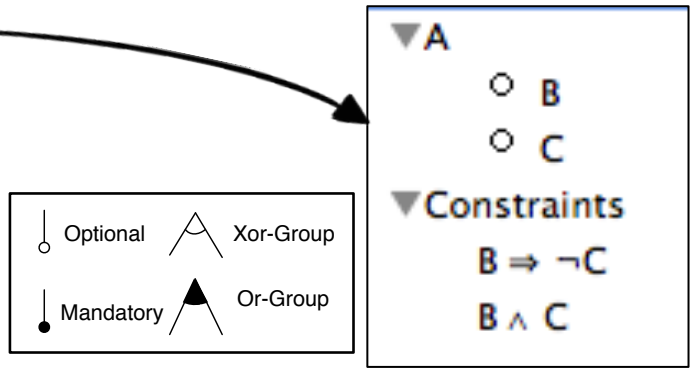
```
fml> compare fm1 fm1bis
res7: (STRING) REFACTORING
fml> compare fm1bis fm1bisbis
res8: (STRING) REFACTORING
```

```
fml> c1 eq c1bisbis
res6: (BOOLEAN) true
```

operatorsFM.fml

Operations for Feature Models (1)

```
fm1 = FM (A : [B] [C] ; B -> !C ; B and C ; )
b1 = isValid fm1
```

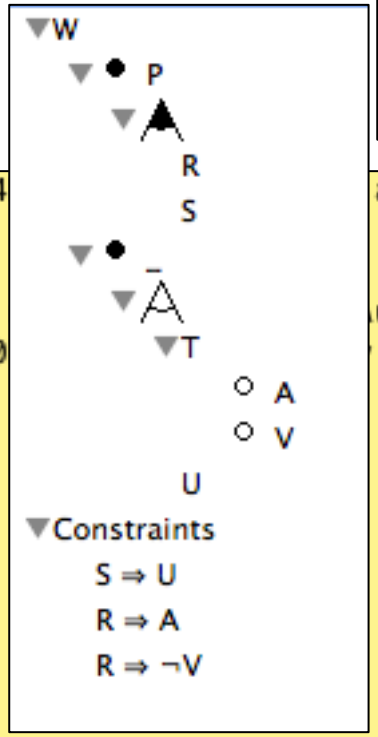


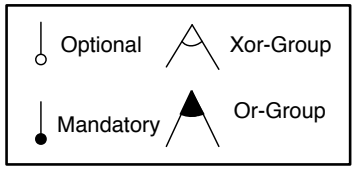

```
acher-scr:FML-scripts macher$ java -jar -Xmx1024M ../FML-0.9.9.5.jar operatorsFM.f
FAMILIAR (for FeAture Model scrIpt Language for manIpulation and Automatic Reasoni
University of Nice Sophia Antipolis, UMR CNRS 6070, I3S Laboratory
https://nyx.unice.fr/projects/familiar/
fml> ls
(FEATURE_MODEL) fm1
(BOOLEAN) b1
fml> b1
b1: (BOOLEAN) false
fml> configs fm1
res0: (SET) {}
```

operatorsFM2.fml

Operations for Feature Models (2)

```
1 fm1 = FM (W : P (T|U); P : (R|S)+ ; T : [V] [A] ; R -> !V ; S -> U ; R -> A ; )
2 b1 = isValid fm1
3 s1 = configs fm1
4 c1 = counting fm1
5 dfm1 = deads fm1
6 println "cores: ", cores fm1
7 fo1 = falseOptionals fm1
```



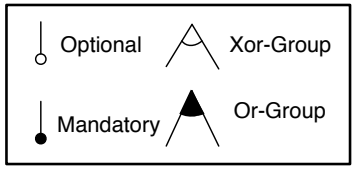



```
acher-scr:FML-scripts macher$ java -jar -Xmx1024                    ar operatorsFM2.fml
cores: {P;W}

FAMILIAR (for FeAture Model scrIpt Language for                     utomatic Reasoning)
University of Nice Sophia Antipolis, UMR CNRS 60
https://nyx.unice.fr/projects/familiar/
fml> ls
(SET) fo1
(SET) dfm1
(SET) s1
(DOUBLE) c1
(BOOLEAN) b1
(FEATURE_MODEL) fm1
fml> c1
c1: (DOUBLE) 2.0
fml> fo1
fo1: (SET) {A}
fml> dfm1
dfm1: (SET) {V}
```

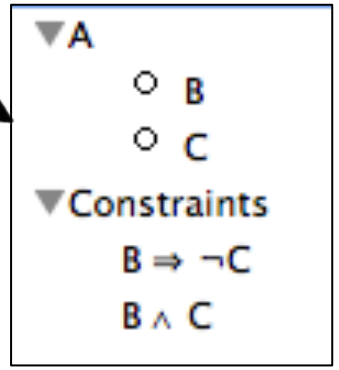
φ

operatorsFM3.fml

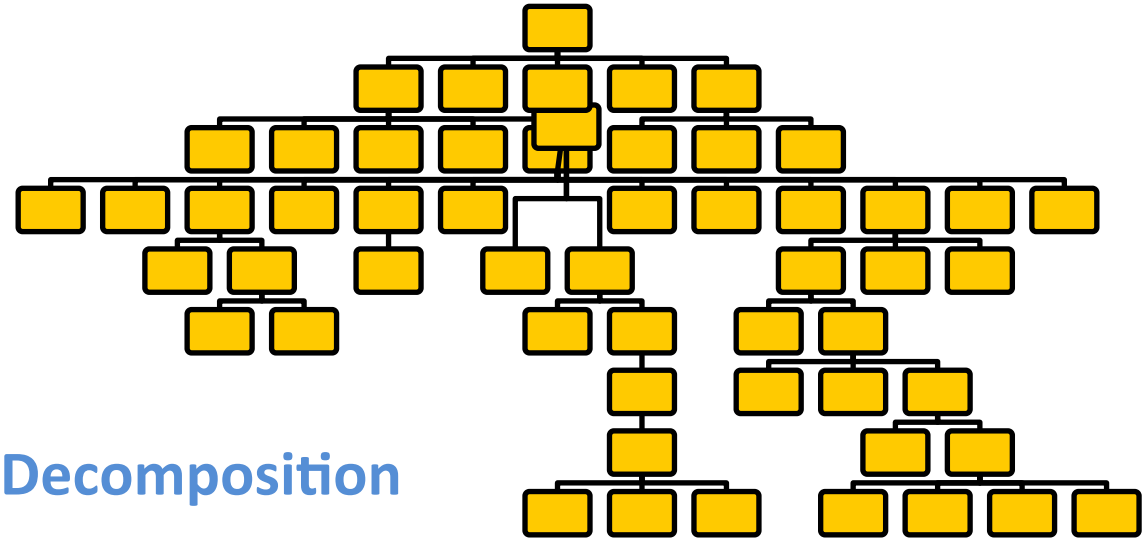
Operations for Feature Models (3)




```
fm1 = FM (A : [B] [C] ; B -> !C ; B and C ; )
b1 = isValid fm1

csts1 = constraints fm1
foreach (cst in csts1) do
        println "removing constraint... ", cst
        removeConstraint cst in fm1
        c = counting fm1
        println "now the number of valid configurations is... ", c
end
```




```
MacBook-Pro-de-Mathieu-2:FML-scripts macher$ java -jar -Xmx1024M ../FML-0.9.9.5.jar operatorsFM3.fml
removing constraint... (B & C)

now the number of valid configurations is... 3.0

removing constraint... (B -> !C)

now the number of valid configurations is... 4.0
```

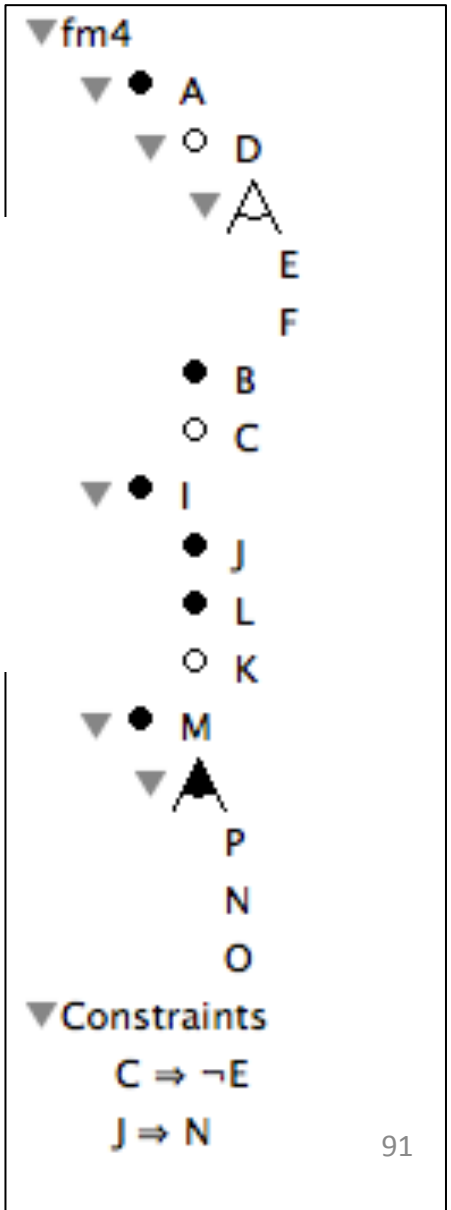


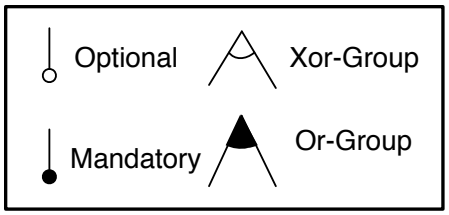
SoC support = Composition/Decomposition
for managing
large, complex and multiple
feature models

FORM 1998, Tun et al. 2009 (SPLC), Hartmann 2008 (SPLC), Lee et al. 2010, Czarnecki 2005, Reiser et al. 2007 (RE journal), Hartmann et al. 2009 (SPLC), Thuem et al. 2009 (ICSE), Classen et al. 2009 (SPLC), Mendonca et al. 2010 (SCP), Dunghana et al. 2010, Hubaux et al. 2011 (SoSyM), Zaid et al. 2010 (ER), She et al., 2011 (ICSE), etc.

Composing Feature Models (1)

```
fm1 = FM (A : B [C] [D] ; D : (E|F) ; C -> !E; )
fm2 = FM (I : J [K] L ; )
fm3 = FM (M : (N|O|P)+ ; )
cst = constraints (J implies N ; )

// equivalent to aggregate { fm1 fm2 fm3 }
fm4 = aggregate fm* withMapping cst
```





aggregate1.fml

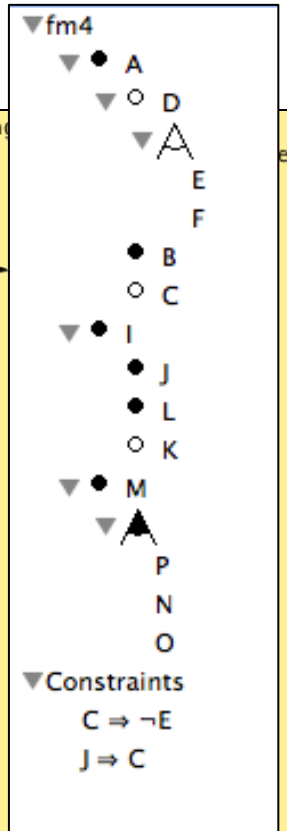
Composing Feature Models (2)

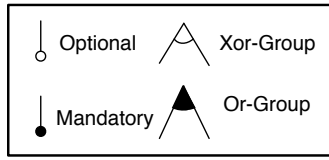
```
fm1 = FM (A : B [C] [D] ; D : (E|F) ; C -> !E; )
fm2 = FM (I : J [K] L ; )
fm3 = FM (M : (N|O|P)+ ; )
cst = constraints (J implies C ; )

// equivalent to aggregate { fm1 fm2 fm3 }
fm4 = aggregate fm* withMapping cst

// composition sometimes leads to "anomalies"
dfm4 = deads fm4
```

```
fm1 = FM (A : B [C] [D] ; D : (E|F) ; C -> !E; )
fm2 = FM (I : J [K] L ; )
fm3 = FM (M : (N|O|P)+ ; )
cst = constraints (J implies N ; )

// equivalent to aggregate { fm1 fm2 fm3 }
fm4 = aggregate fm* withMapping cst
```

Previous version

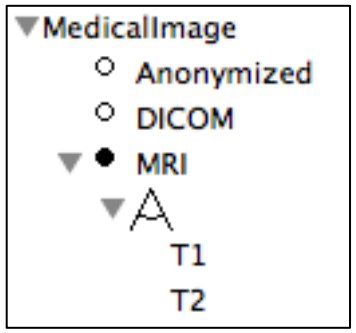
```
MacBook-Pro-de-Mathieu-2:FML-scripts macher$ java -jar -Xmx1024M ../FML-0.9.9.5.jar ag
FAMILIAR (for FeAture Model scrIpt Language for manIpulation and Automatic Reasoning)
University of Nice Sophia Antipolis, UMR CNRS 6070, I3S Laboratory
https://nyx.unice.fr/projects/familiar/
fml> cores fm4
res0: (SET) {C;fm4;A;J;I;B;L;M}
fml> falseOptionals fm4
res1: (SET) {F;C}
fml> operator fm4.C
res2: (VARIABILITY_OPERATOR) OPTIONAL
fml> operator fm4.F
res3: (VARIABILITY_OPERATOR) ALTERNATIVE
fml> sibling fm4.F
res4: (SET) {E}
fml> deads fm4
res5: (SET) {E}
fml> operator fm4.E
res6: (VARIABILITY_OPERATOR) ALTERNATIVE
fml> fm4
fm4: (FEATURE_MODEL) fm4: A I M ;
A: [D] B [C] ;
I: J L [K] ;
M: (P|N|O)+ ;
D: (E|F) ;
(C -> !E);
(J -> C);
```

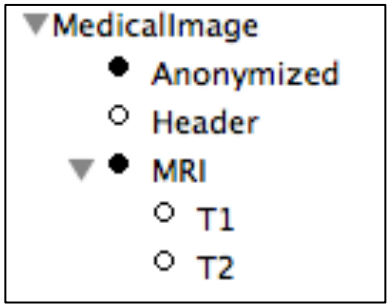


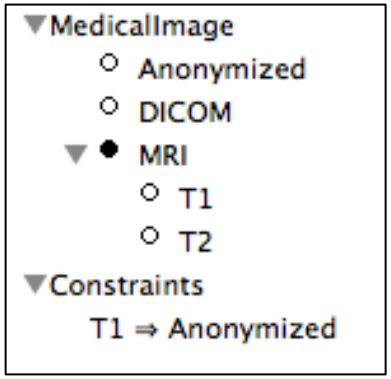


mergeMI.fml

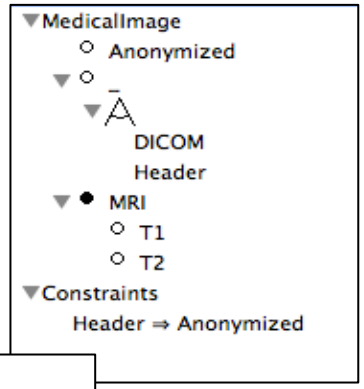
Merging Feature Models (1)

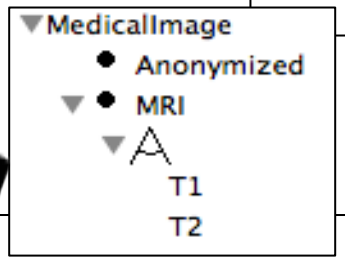







```
fmsupp1 = FM (MedicalImage : [Anonymized] MRI [DICOM] ; MRI : (T1|T2) ;  )
fmsupp2 = FM (MedicalImage : Anonymized MRI [Header] ; MRI : [T1] [T2] ; )
fmsupp3 = FM (MedicalImage : [Anonymized] MRI [DICOM] ; MRI : [T1] [T2] ; T1 -> Anonymized; )

s1 = configs fmsupp1
s2 = configs fmsupp2
s3 = configs fmsupp3

s123 = setUnion s3 setUnion s1 s2

fmSupp = merge sunion fmsupp*

assert (size s123 eq counting fmSupp)

fmCommon = merge intersection { fmsupp1 fmsupp2 }
sC = configs fmCommon
sC2 = setIntersection s1 s2
```

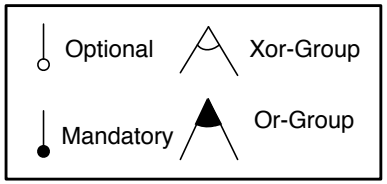


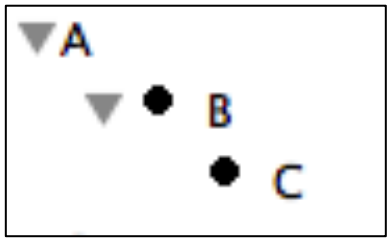


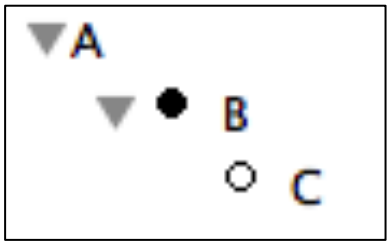
Mathieu Acher, Philippe Collet, Philippe Lahire, Robert B. France « Comparing Approaches for Implementing Feature Model Composition » ECMFA'10

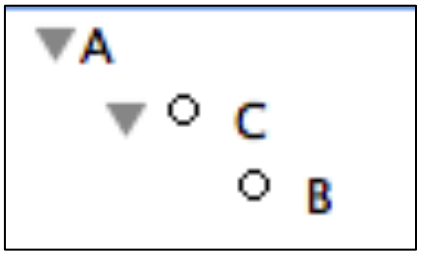
Merging operation (2)

```
fm1 = FM (A : B ; B : C ;)
fm2 = FM (A : B ; B : [C] ;)
fm3 = FM (A : [C] ; C : [B] ; )
fm4 = merge sunion { fm1 fm2 fm3 }
```









> configs fm4
> res12: (SET) {{C;A};{A;B};{A};{A;B;C}}

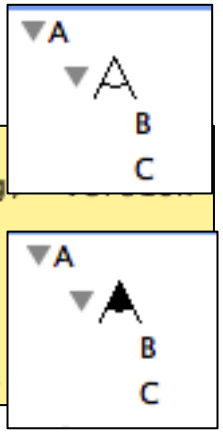
?

compare.fml

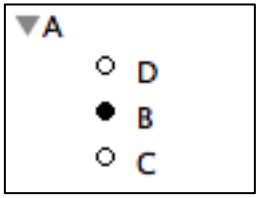
Comparing Feature Models

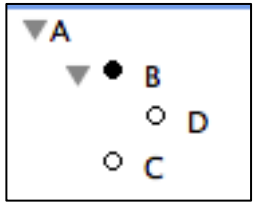
```
fm0 = FM (A: (B|C) ; )
fm1 = FM (A: (B|C)+ ; )
```

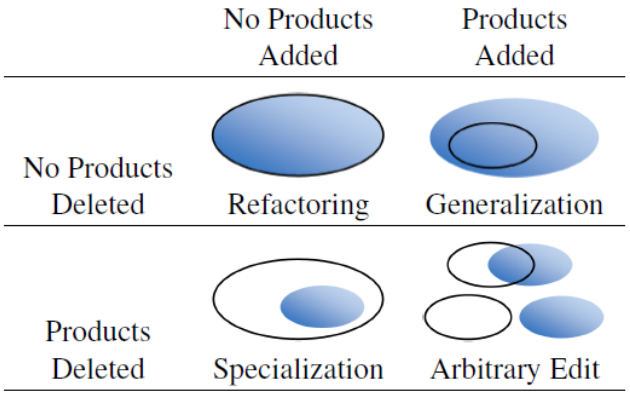
```
MacBook-Pro-de-Mathieu-2:FML-scripts macher$ java -jar -Xmx1024M ../FML-0.9.9.5.jar
FAMILIAR (for FeAture Model scrIpt Language for manIpulation and Automatic Reasoning)
University of Nice Sophia Antipolis, UMR CNRS 6070, I3S Laboratory
https://nyx.unice.fr/projects/familiar/
fml> cmp23
cmp23: (STRING) REFACTORING
fml>
```

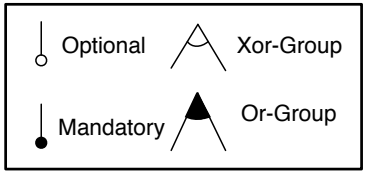



```
assert (cmp10 eq GENERALIZATION)

// example taken from Automated Analysis of Feature Models
fm2 = FM (A: B [C] [D]; )
fm3 = FM (A: B [C]; B : [D]; )
cmp23 = compare fm2 fm3
```









see also Thuem, Kastner and Batory, ICSE'09

Combining operators: an example

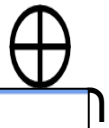
Merge Intersection: Available Suppliers

- Registration
  - Affine
  - Header
    - v3
    - v1
  - Modality
    - CT
  - Format
    - DICOM
    - Nifti

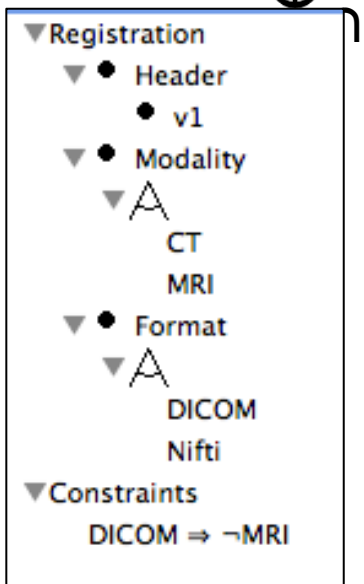
- Registration
  - Affine
  - Header
    - v2
    - v1
  - Modality
    - MRI
  - Format
    - Nifti
    - GE

- Registration
  - Rigid
  - Header
    - v3
    - v2
  - Modality
    - PET
    - MRI
  - Format
    - Nifti

Suppliers?
Products?



- Registration
  - Header
    - v1
  - Modality
    - CT
  - Format
    - DICOM
    - Nifti



- Registration
  - Header
    - v1
  - Modality
    - CT
    - MRI
  - Format
    - DICOM
    - Nifti
- Constraints
  - DICOM ⇒ ¬MRI

A customer has some requirements

suppliersExample0.fml

In FAMILIAR

```
REGsupp1 = FM (Registration : Header Format Modality [Affine] ;
                                                    Header : (v1|v3);
                                                    Format : (DICOM|Nifti) ;
                                                    Modality : CT; )

REGsupp2 = FM (Registration : Header [Affine] Format Modality ;
                                                    Header : (v1|v2);
```

```
MacBook-Pro-de-Mathieu-2:FML-scripts macher$ java -jar -Xmx1024M ../FML-0.9.9.6.jar suppliersExample0.fml
FAMILIAR (for FeAture Model scrIpt Language for manIpulation and Automatic Reasoning)  version 0.9.9.6 (beta)
University of Nice Sophia Antipolis, UMR CNRS 6070, I3S Laboratory
https://nyx.unice.fr/projects/familiar/
fml> ls
(FEATURE_MODEL) REGsupp3
(FEATURE_MODEL) REGsupp2p
(FEATURE_MODEL) REGrequired
(FEATURE_MODEL) REGsupp3p
(FEATURE_MODEL) REGsupp1p
(FEATURE_MODEL) REGsupp2
(FEATURE_MODEL) REGsupp1
fml> REGsupp3p
REGsupp3p: (FEATURE_MODEL) False
fml> REGsupp1p
REGsupp1p: (FEATURE_MODEL) Registration: Header Modality Format ;
Header: v1 ;
Modality: CT ;
Format: (DICOM|Nifti) ;
```

```
REGsupp1p = merge intersection { REGrequired REGsupp1 }
REGsupp2p = merge intersection { REGrequired REGsupp2 }
REGsupp3p = merge intersection { REGrequired REGsupp3 }
```

Merge Union: Availability Checking

Registration
- Affine
- Header
  - v3
  - v1
  - odality
  - CT
  - rmat
  - DICOM
  - Nifti

Registration
- Affine
- Header
  - v2
  - v1
- Modality
  - MRI
- Format
  - Nifti
  - GE

Registration
- Rigid
- Header
  - v3
  - v2
- Modality
  - PET
  - MRI
- Format
  - Nifti

Registration
- Header
  - v3
  - v2
  - v1
- Modality
  - PET
  - CT
  - MRI
- ○ _
  - Affine
  - Rigid
- Format
  - DICOM
  - Nifti
  - GE
- Constraints
  - GE ⇒ MRI
  - GE ⇒ ¬v3
  - CT ⇒ ¬v2
  - Rigid ⇒ Nifti
  - DICOM ⇒ CT
  - v1 ⇒ ¬Rigid
  - CT ⇒ ¬Rigid
  - v1 ⇒ ¬PET
  - PET ⇒ ¬Affine

⊕U

Yes!

Can suppliers provide *all* products?

"compare"

Registration
- Header
  - v1
- Modality
  - CT
  - MRI
- Format
  - DICOM
  - Nifti
- Constraints
  - DICOM ⇒ ¬MRI

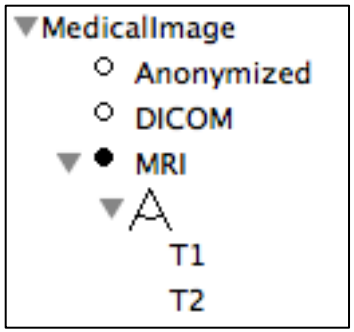
Optional | Xor-Group | Mandatory | Or-Group

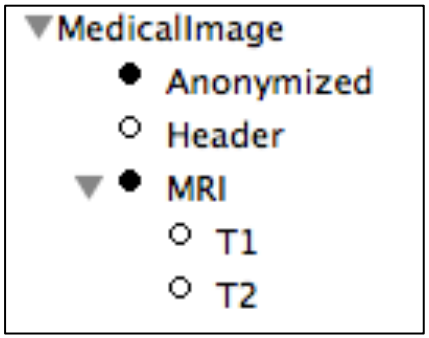
suppliersExample.fml

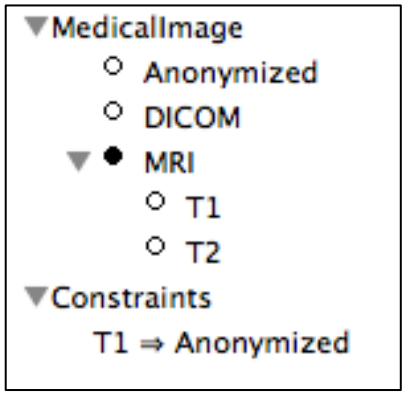
In FAMILIAR

```
REGsupp1 = FM (Registration : Header Format Modality [Affine] ;
                                                    Header : (v1|v3);
                                                    Format : (DICOM|Nifti) ;
                                                    Modality : CT; )

REGsupp2 = FM (Registration : Header [Affine] Format Modality ;
                                                    Header : (v1|v2);
                                                    Format : (Nifti|GE) ;
                                                    Modality : MRI; )

REGsupp3 = FM (Registration : Header [Rigid] Format Modality ;
                                                    Header : (v2|v3) ;
                                                    Format : Nifti ;
                                                    Modality : (MRI|PET); )


REGrequired = FM (Registration : Header Format Modality ;
                                                    Header : v1 ; //v3;
                                                    Format : (DICOM|Nifti) ;
                                                    Modality: (MRI|CT);
                                                    !DICOM or !MRI;
                                                    )

REGmspl = merge sunion REGsupp*          // merge all FMs whose variable identifier starts w

cmp = compare REGrequired REGmspl
//missingSPL = merge diff { REGrequired REGmspl }
```

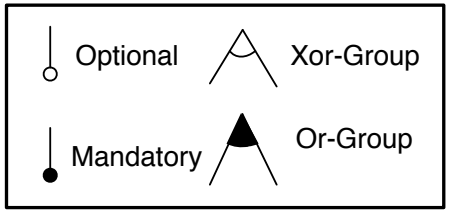
Merging operation: implementation issues

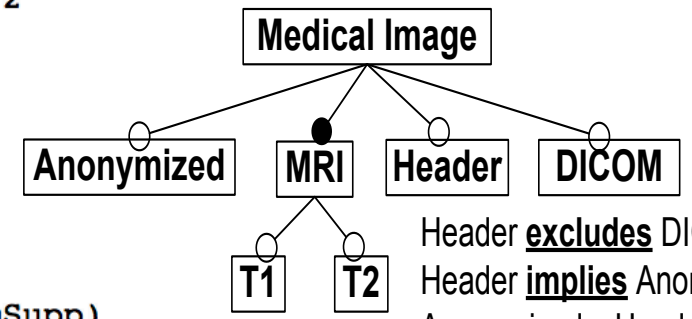







```
fmsupp1 = FM (MedicalImage : [Anonymized] MRI [DICOM] ; MRI : (T1|T2) ;  )
fmsupp2 = FM (MedicalImage : Anonymized MRI [Header] ; MRI : [T1] [T2] ; )
fmsupp3 = FM (MedicalImage : [Anonymized] MRI [DICOM] ; MRI : [T1] [T2] ; T1 -> Anonymized; )

// computing the union of sets of configurations like this is COSTLY
s1 = configs fmsupp1
s2 = configs fmsupp2
s3 = configs fmsupp3

s123 = setUnion s3 setUnion s1 s2

// you WONT scale
//...

fmSupp = merge sunion fmsupp*

assert (size s123 eq counting fmSupp)
```





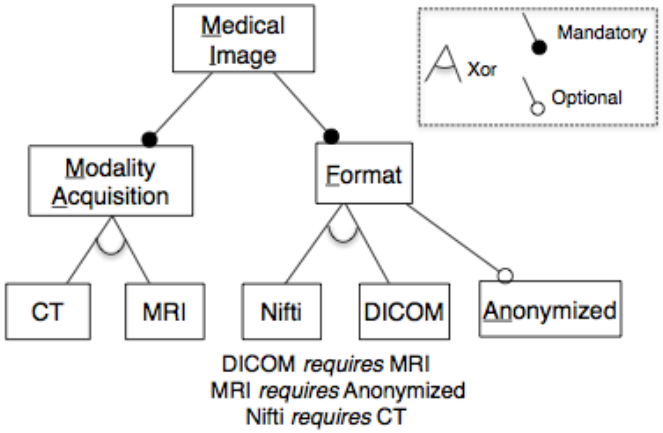
Header **excludes** DICOM
Header **implies** Anonymized
Anonymized v Header v ~DICOM v ~T1 v ~T2
Anonymized v Header v DICOM v ~T1 v ~T2

Merging operation: semantic issues (2)

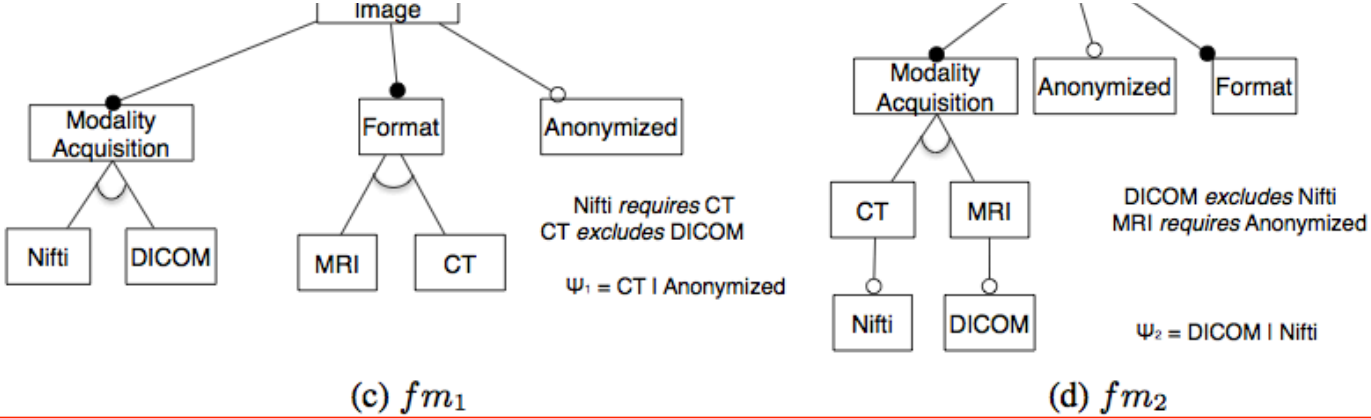
φ

$$s_0 = \{$$
$$\{MI, MA, F, CT, Nifti\},$$
$$\{MI, MA, F, CT, Nifti, AN\},$$
$$\{MI, MA, F, DICOM, MRI, AN\}$$
$$\}$$

Union
Intersection
Diff



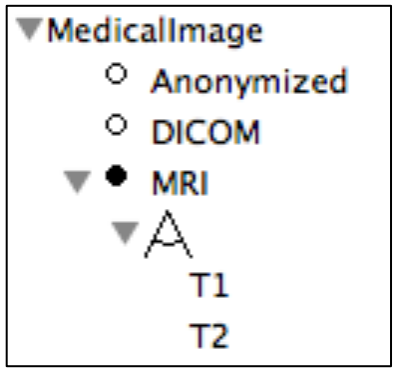
How to synthesise a feature model that represents the union of input sets of configurations?



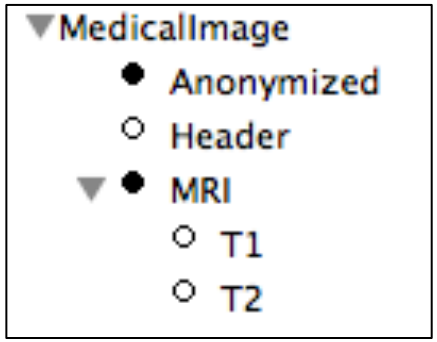
(c) fm_1 (d) fm_2

Fig. 2: For a given set of configurations, three possible yet different FMs ($s_0 = [\![fm_0]\!] = [\![fm_1]\!] = [\![fm_2]\!]$)

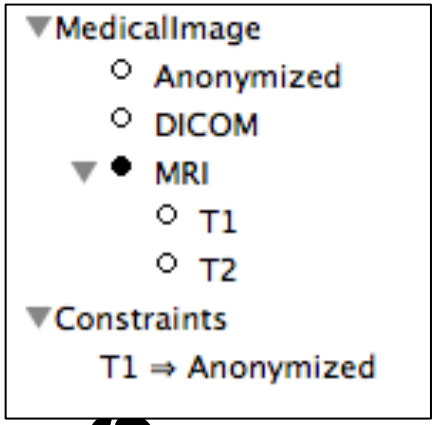
Merging operation: algorithm



φ_1



φ_2



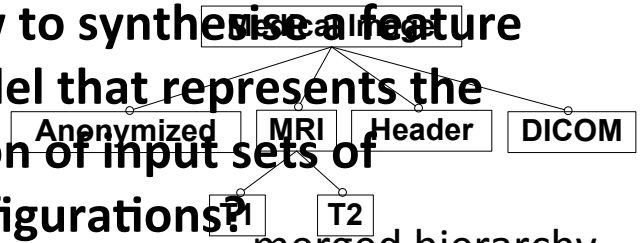
φ_3

φ_{123}

merged propositional formula

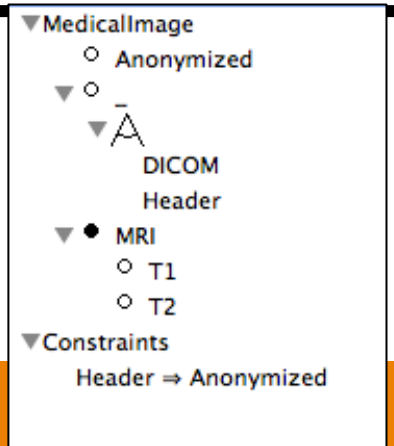
+

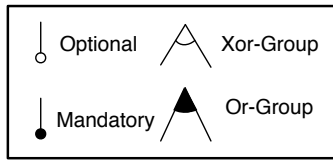
How to synthesise a feature model that represents the union of input sets of configurations?



merged hierarchy

Set mandatory features
Detect Xor and Or-groups
Compute "implies/excludes" constraints



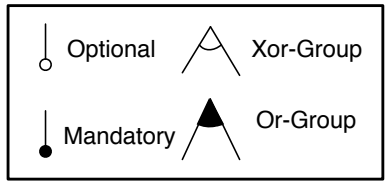


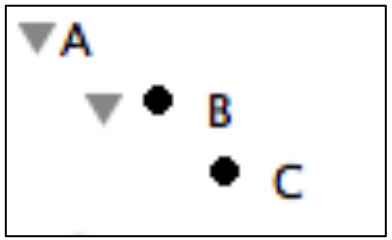
see also [Czarnecki SPLC'07 or SPLC'12]

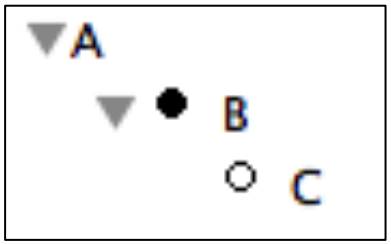
mergeNonPC.fml

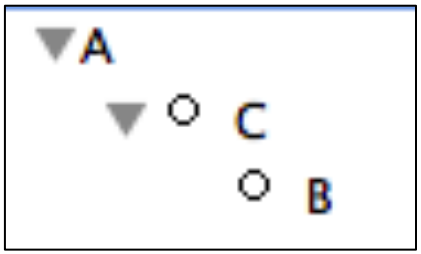
Merging operation: back to hierarchy

```
fm1 = FM (A : B ; B : C ;)
fm2 = FM (A : B ; B : [C] ;)
fm3 = FM (A : [C] ; C : [B] ; )
fm4 = merge sunion { fm1 fm2 fm3 }
```









> configs fm4
> res12: (SET) {{C;A};{A;B};{A};{A;B;C}}

?

Related Works

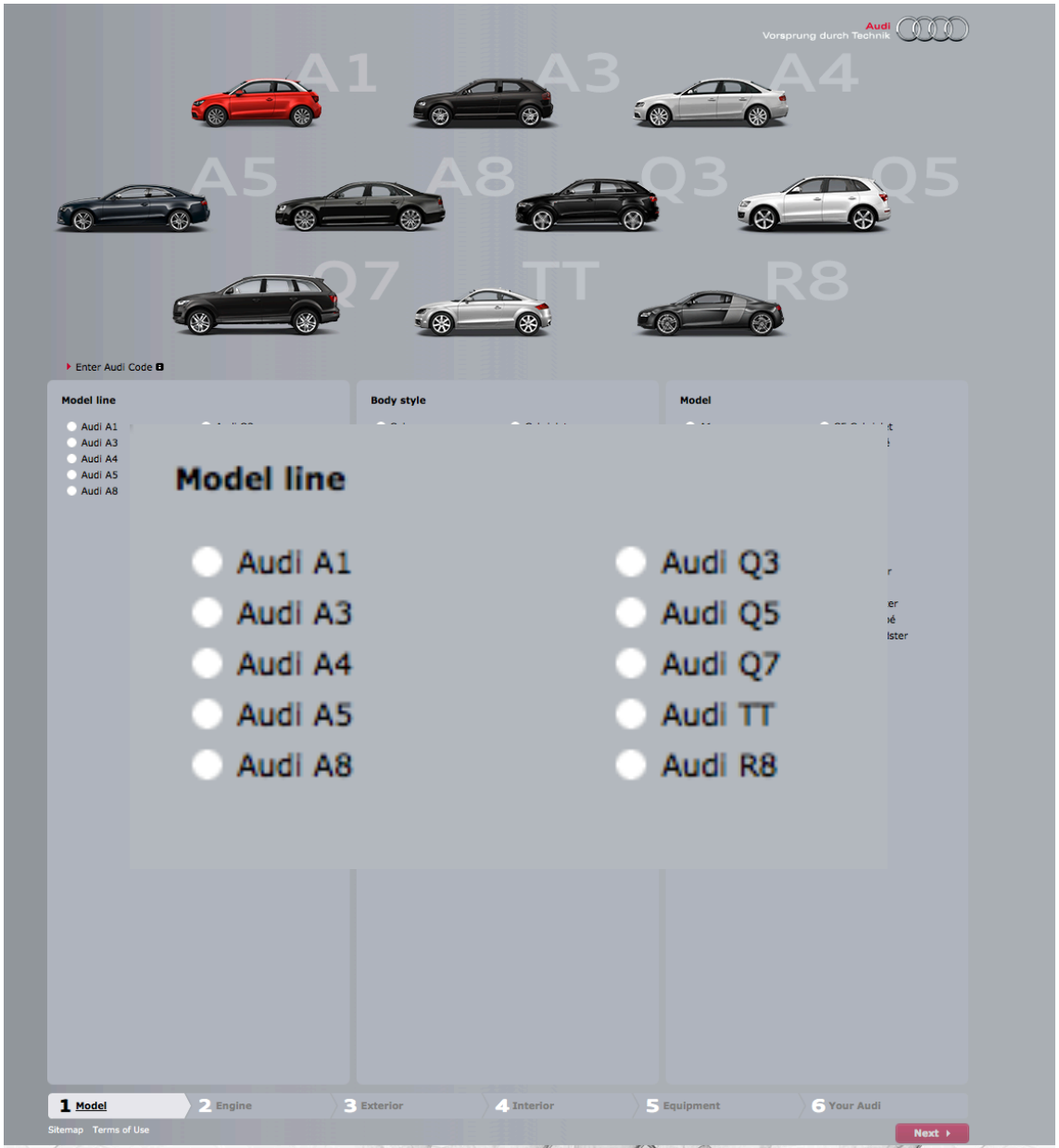
- Well-defined semantics
- Guarantee semantics properties by construction
- More compact feature models than reference-based techniques [Schobbens et al., 2007], [Hartmann et al., 2007]
  - Easier to understand
  - Easier to analyze (e.g., compare with another)
- Applicable to any propositional feature models
  - Full support of propositional constraints
  - Different hierarchies [Van Den Broek et al., SPLC'2010/2012]
- Syntactical strategies fail [Alves et al., 2006], [Segura et al., 2007]

see also [Acher et al., ECMFA'10 / MODELS'13]

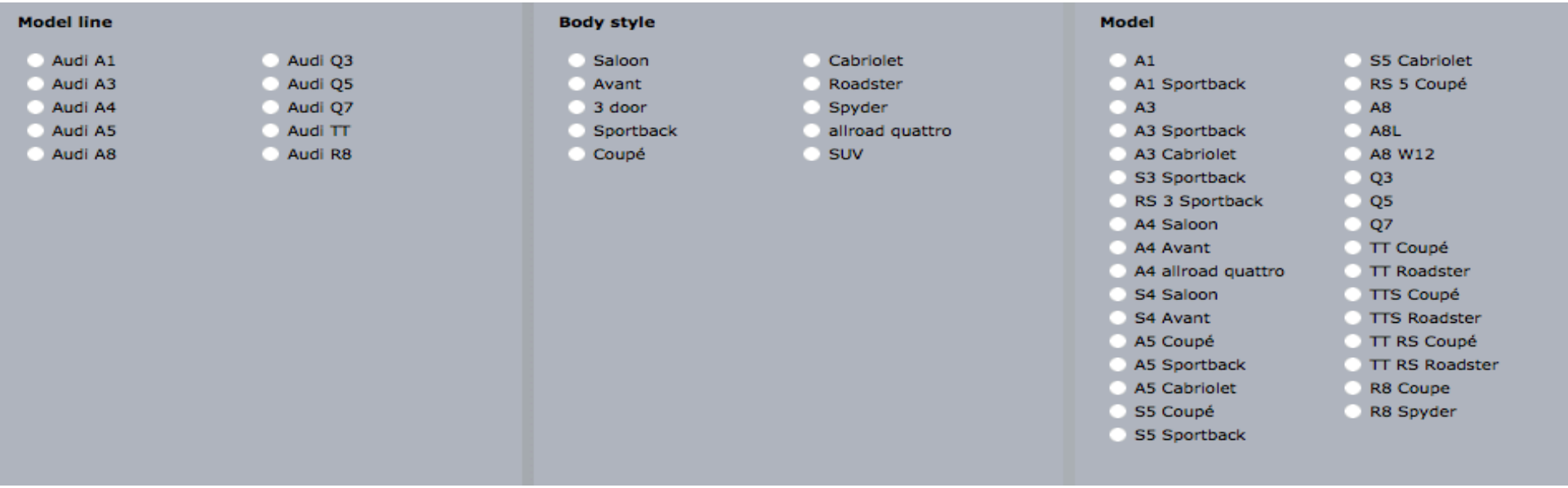
Another application of composing feature models

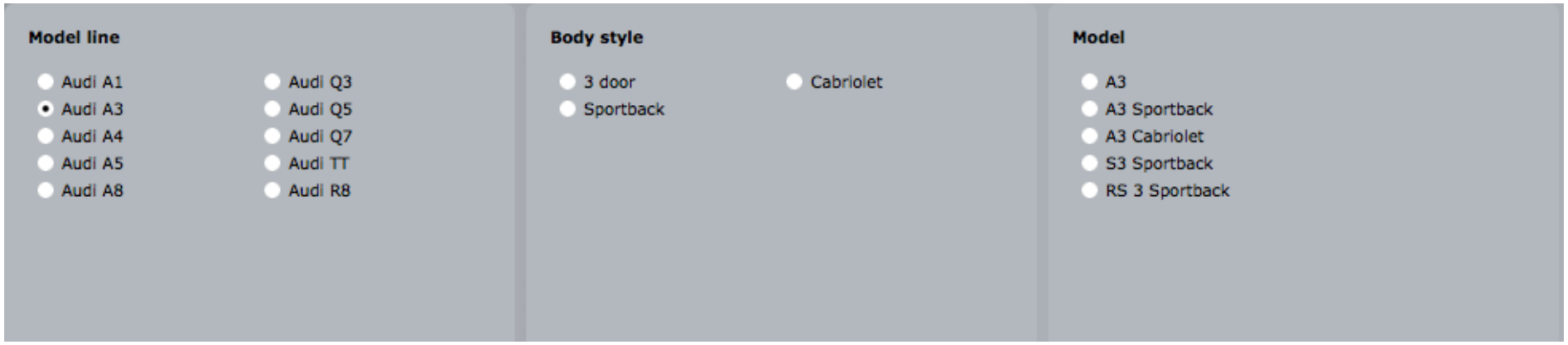
(purpose: automated synthesis of feature models)

Problem: multiple „car models“



Problem: multiple „car models“





Problem: multiple „car models“

Model line

- ○ Audi A1
- ◉ Audi A3
- ○ Audi A4
- ○ Audi A5
- ○ Audi A8
- ○ Audi Q3
- ○ Audi Q5
- ○ Audi Q7
- ○ Audi TT
- ○ Audi R8

Body style

- ○ 3 door
- ○ Sportback
- ○ Cabriolet

Model

- ○ A3
- ○ A3 Sportback
- ○ A3 Cabriolet
- ○ S3 Sportback
- ○ RS 3 Sportback

Model line

- ○ Audi A1
- ○ Audi A3
- ◉ Audi A4
- ○ Audi A5
- ○ Audi A8
- ○ Audi Q3
- ○ Audi Q5
- ○ Audi Q7
- ○ Audi TT
- ○ Audi R8

Body style

- ○ Saloon
- ○ Avant
- ○ allroad quattro

Model

- ○ A4 Saloon
- ○ A4 Avant
- ○ A4 allroad quattro
- ○ S4 Saloon
- ○ S4 Avant

Model line

- ◉ Audi A1
- ○ Audi A3
- ○ Audi A4
- ○ Audi A5
- ○ Audi A8
- ○ Audi Q3
- ○ Audi Q5
- ○ Audi Q7
- ○ Audi TT
- ○ Audi R8

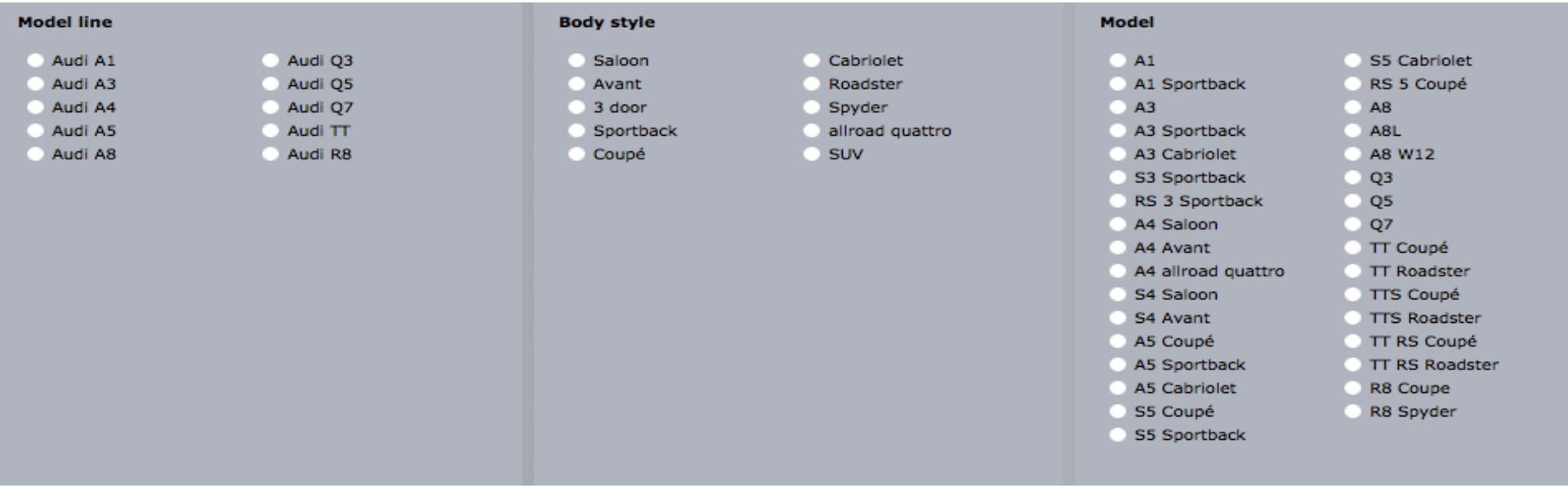
Body style

- ○ 3 door
- ○ Sportback

Model

- ○ A1
- ○ A1 Sportback

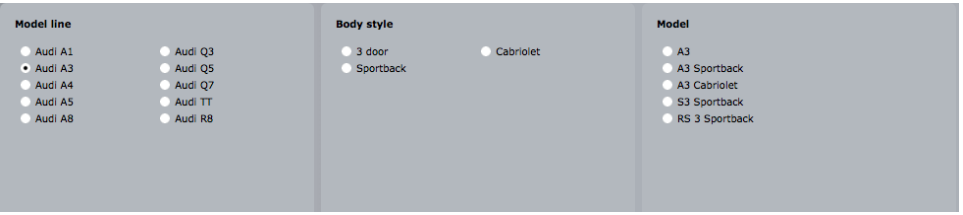
Problem: multiple „car models“

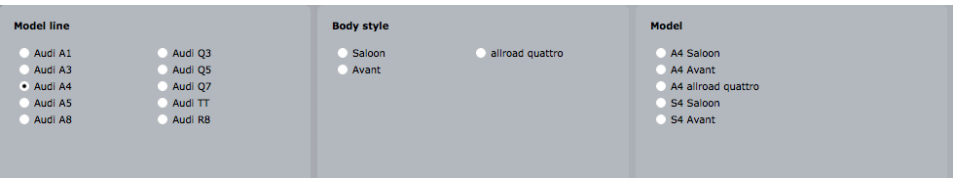


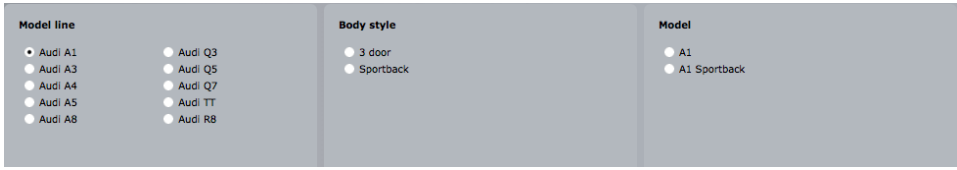
#1 – top-down: specify constraints (e.g., excludes) of all model lines upfront

Two modeling approaches

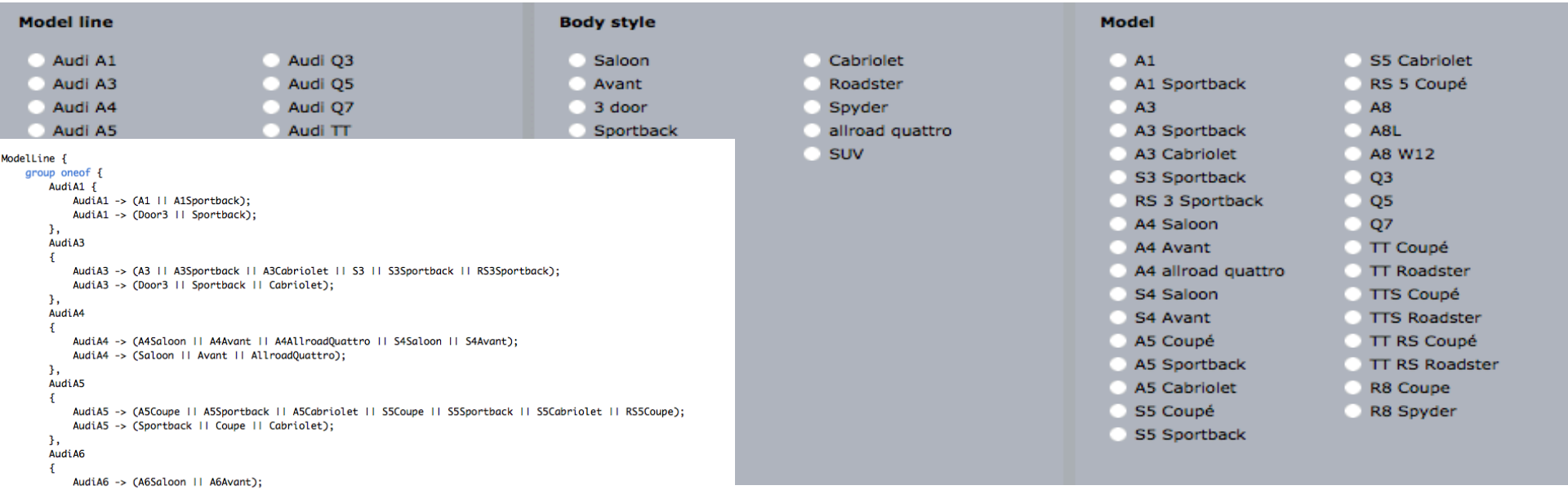
#2 – bottom-up: elaborate a feature model for each model line and merge them



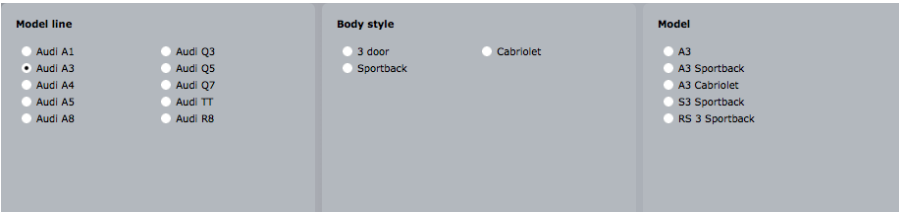


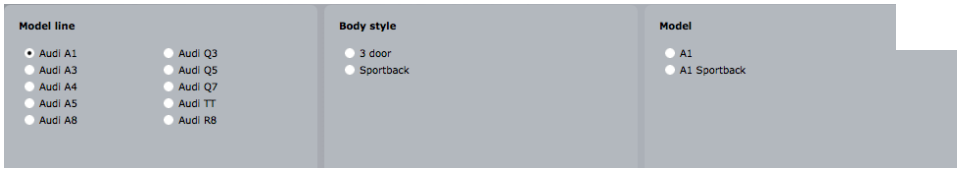


#1 top-down



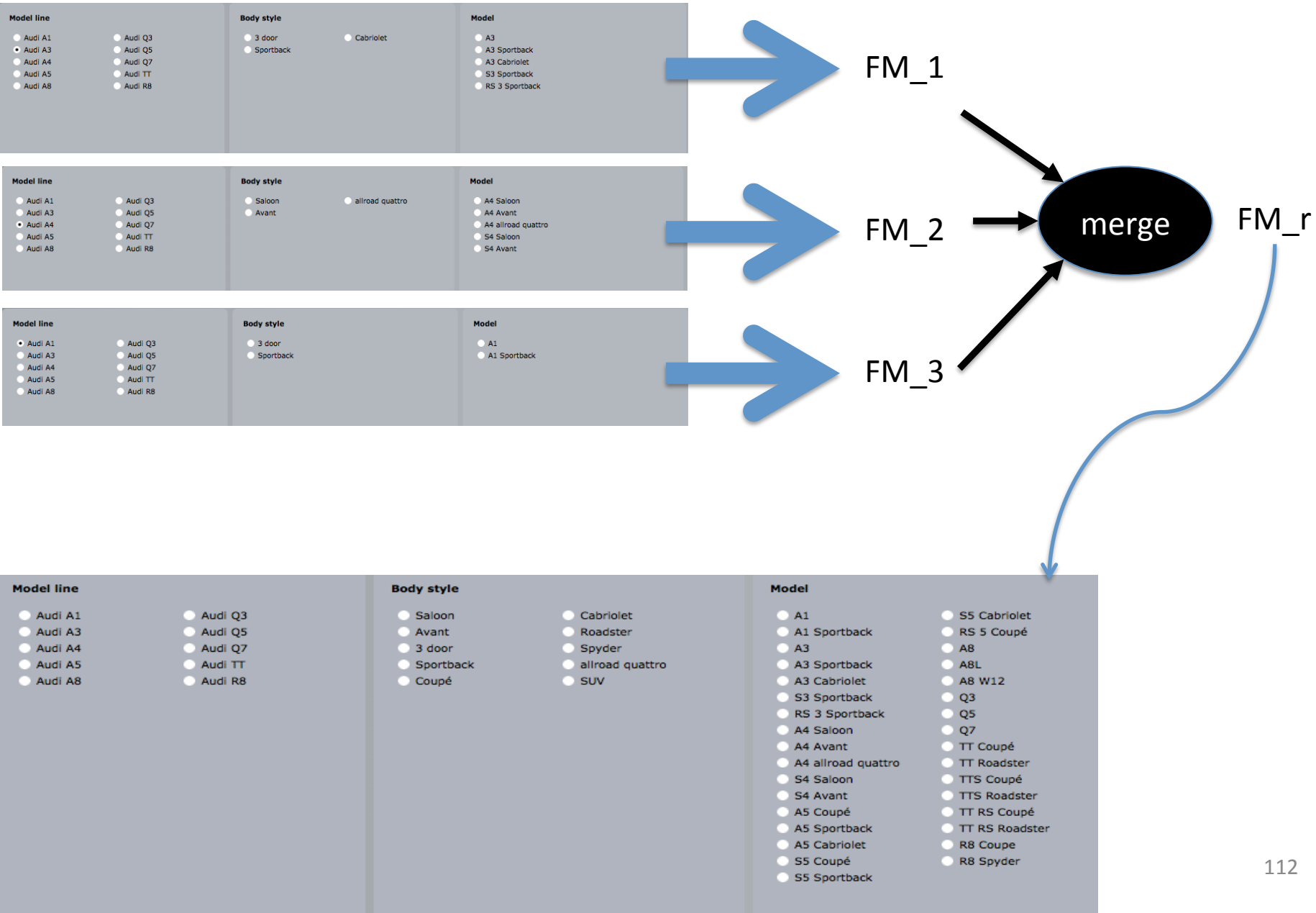

```
ModelLine {
    group oneof {
        AudiA1 {
            AudiA1 -> (A1 || A1Sportback);
            AudiA1 -> (Door3 || Sportback);
        },
        AudiA3
        {
            AudiA3 -> (A3 || A3Sportback || A3Cabriolet || S3 || S3Sportback || RS3Sportback);
            AudiA3 -> (Door3 || Sportback || Cabriolet);
        },
        AudiA4
        {
            AudiA4 -> (A4Saloon || A4Avant || A4AllroadQuattro || S4Saloon || S4Avant);
            AudiA4 -> (Saloon || Avant || AllroadQuattro);
        },
        AudiA5
        {
            AudiA5 -> (A5Coupe || A5Sportback || A5Cabriolet || S5Coupe || S5Sportback || S5Cabriolet || RS5Coupe);
            AudiA5 -> (Sportback || Coupe || Cabriolet);
        },
        AudiA6
        {
            AudiA6 -> (A6Saloon || A6Avant);
            AudiA6 -> (Saloon || Avant);
        },
```





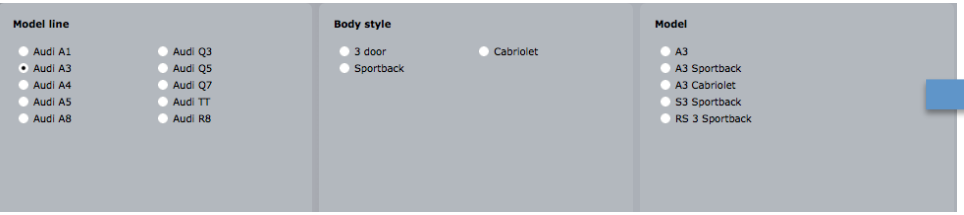

```
BodyStyle {
    group oneof {
        Saloon
        {
            Saloon -> (A4Saloon || S4Saloon || A6Saloon || A8 || A8L || A8W12);
        },
        Avant
        {
            Avant -> (A4Avant || S4Avant || A6Avant);
        },
        Door3
        {
            Door3 -> (A1 || A3 || S3);
        },
        Sportback
        {
            Sportback -> (A1Sportback || A3Sportback || S3Sportback || RS3Sportback || A5Sportback || S5Sportback || A7Spor
        },
        Coupe
        {
            Coupe -> (A5Coupe || S5Coupe || RS5Coupe || TTCoupe || TTSCoupe || TTRSCoupe || R8Coupe);
        },
```

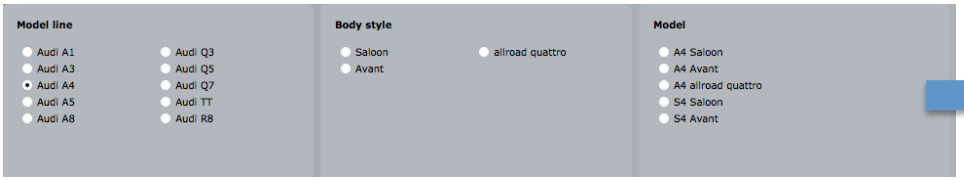
#1 bottom-up

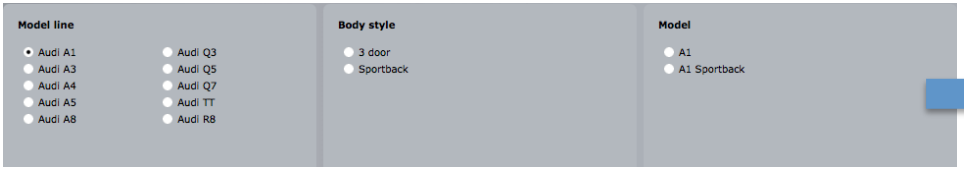

Model line
Audi A1
Audi A3
Audi A4
Audi A5
Audi A8
Audi Q3
Audi Q5
Audi Q7
Audi TT
Audi R8
Body style
3 door
Sportback
Cabriolet
Model
A3
A3 Sportback
A3 Cabriolet
S3 Sportback
RS 3 Sportback
FM_1
Model line
Audi A1
Audi A3
Audi A4
Audi A5
Audi A8
Audi Q3
Audi Q5
Audi Q7
Audi TT
Audi R8
Body style
Saloon
Avant
allroad quattro
Model
A4 Saloon
A4 Avant
A4 allroad quattro
S4 Saloon
S4 Avant
FM_2
merge
FM_r
Model line
Audi A1
Audi A3
Audi A4
Audi A5
Audi A8
Audi Q3
Audi Q5
Audi Q7
Audi TT
Audi R8
Body style
3 door
Sportback
Model
A1
A1 Sportback
FM_3
Model line
Audi A1
Audi A3
Audi A4
Audi A5
Audi A8
Audi Q3
Audi Q5
Audi Q7
Audi TT
Audi R8
Body style
Saloon
Avant
3 door
Sportback
Coupé
Cabriolet
Roadster
Spyder
allroad quattro
SUV
Model
A1
A1 Sportback
A3
A3 Sportback
A3 Cabriolet
S3 Sportback
RS 3 Sportback
A4 Saloon
A4 Avant
A4 allroad quattro
S4 Saloon
S4 Avant
A5 Coupé
A5 Sportback
A5 Cabriolet
S5 Coupé
S5 Sportback
S5 Cabriolet
RS 5 Coupé
A8
A8L
A8 W12
Q3
Q5
Q7
TT Coupé
TT Roadster
TTS Coupé
TTS Roadster
TT RS Coupé
TT RS Roadster
R8 Coupe
R8 Spyder

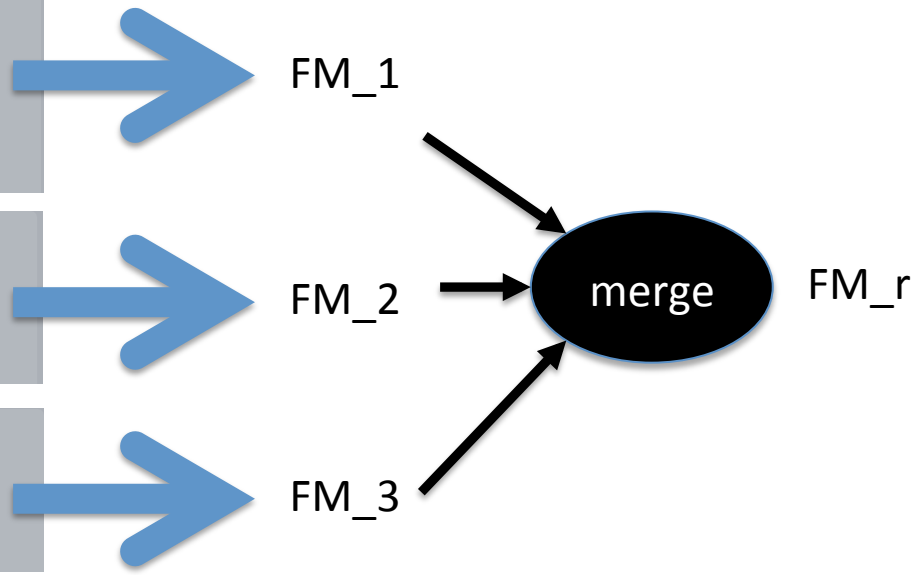
audiMerge.fml

#1 bottom-up (FAMILIAR)










```
fml> fmAudiS = merge sunion { fm1 fm2 fm3 }
fmAudiS: (FEATURE_MODEL) Audi: ModelLine BodyStyle ;                    9.9.4 (beta)
ModelLine: (A1|A4|A3) ;
BodyStyle: (Saloon|Door3)? (Cabriolet|AllroadQuattro)? (Sportback|Avant)? ;
(A4 -> !Sportback);
(A1 -> !Avant);
(A1 -> !Saloon);
(A3 -> !Saloon);
(A4 -> !Cabriolet);
(A1 -> !AllroadQuattro);
(A1 -> !Cabriolet);
(A4 -> !Door3);
(A3 -> !Avant);
(A3 -> !AllroadQuattro);
```

Decomposition support

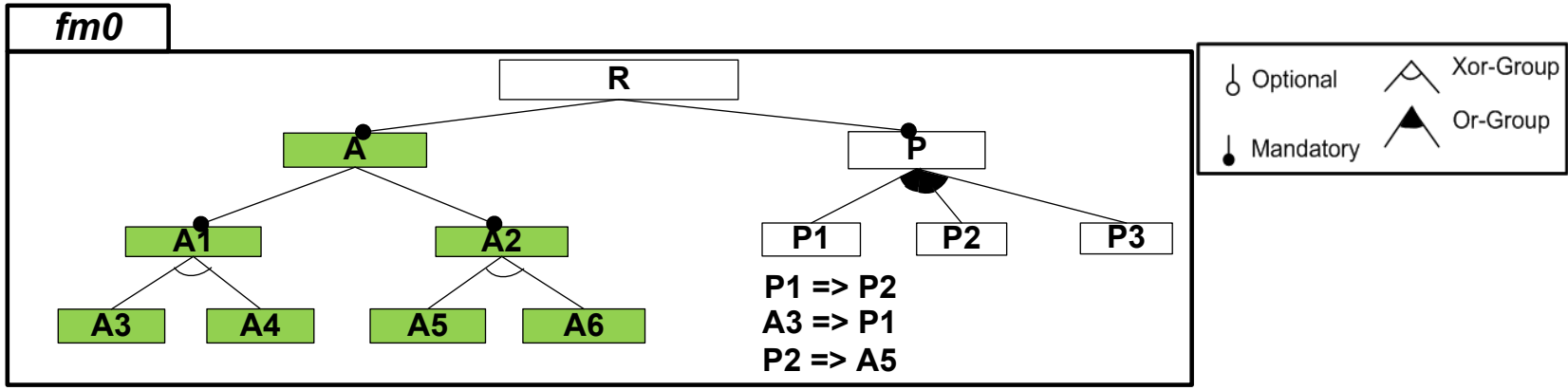
(and its combination with other operators)

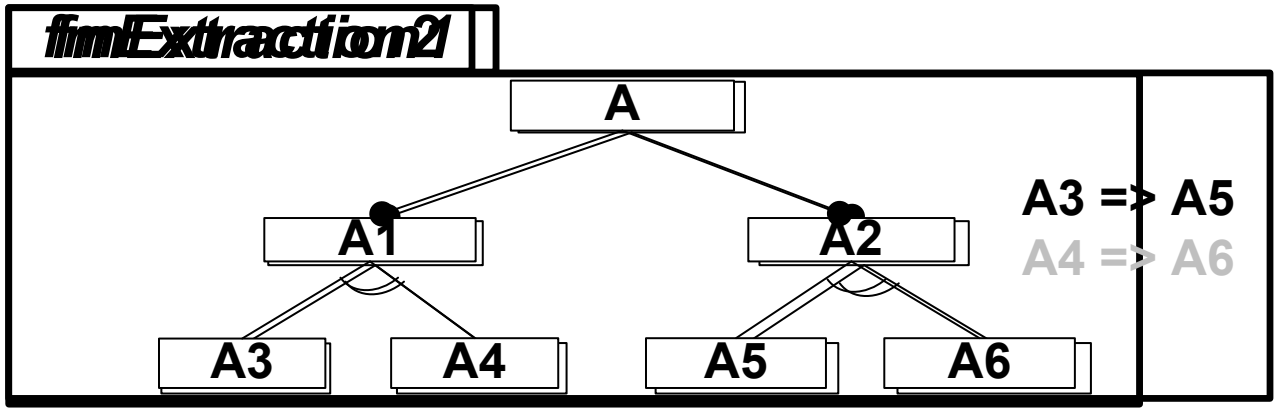
Building "views" of a feature model

- Problem: given a feature model, how to decompose it into smaller feature models?

- Semantics?
  - What's the hierarchy
  - What's the set of configurations?

A first try



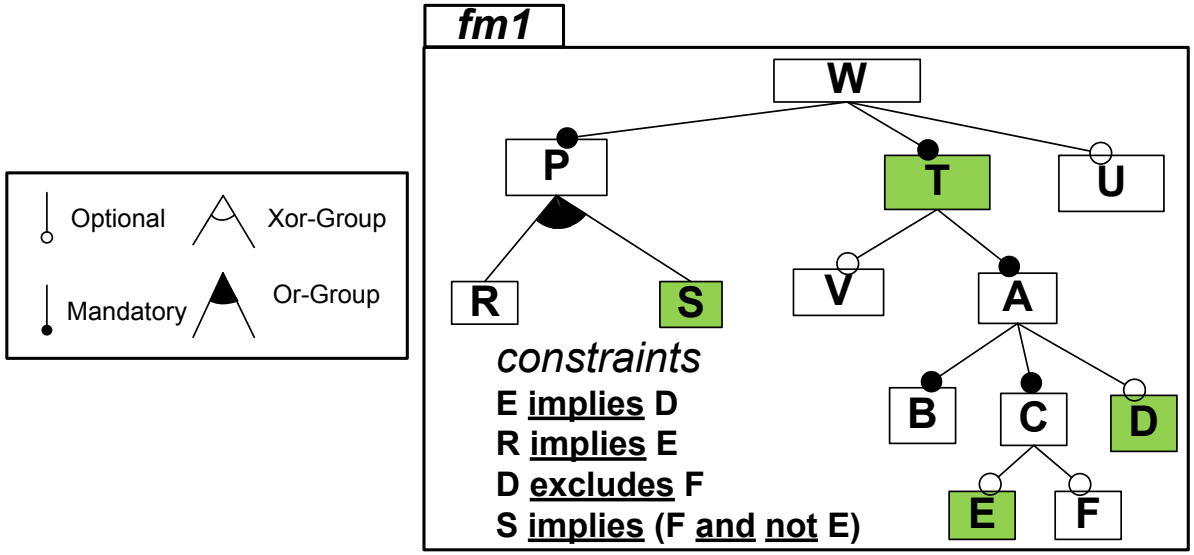


Problem: You can select **A3** without **A5**

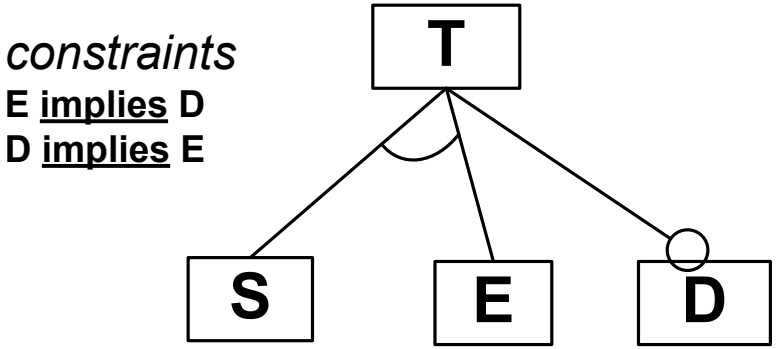
Hierarchy and Configuration matter!

Slicing Operator

slicing criterion : an arbitrary set of features, relevant for a feature model user

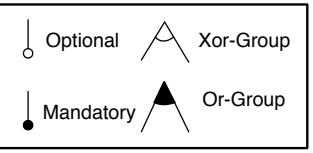


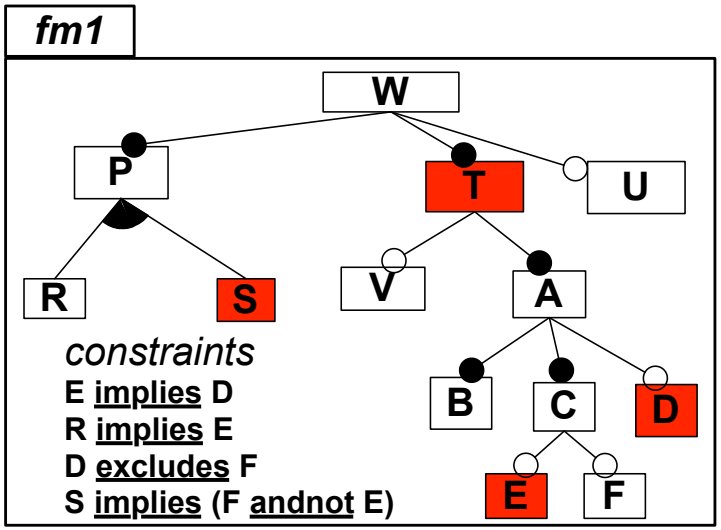
slice : a new feature model, representing a projected set of configurations



Slicing operator: going into details

projected set of configurations



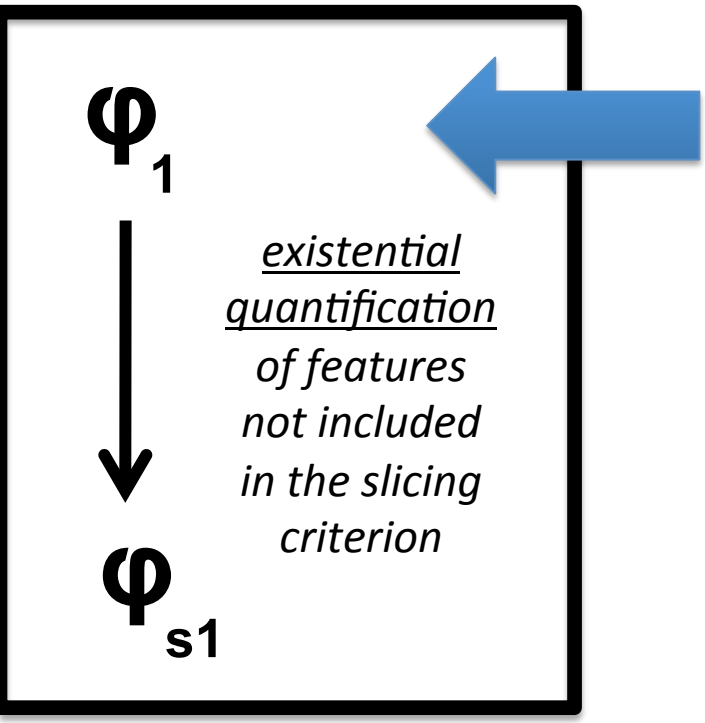


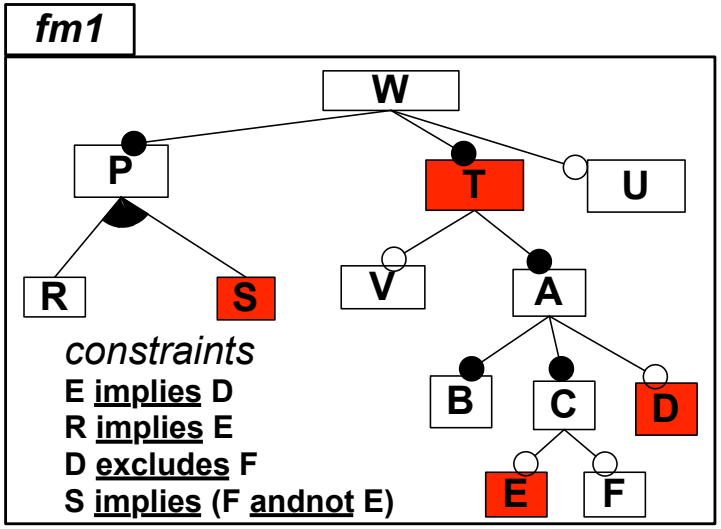
fm1 = {
{A,B,C,D,E,P,R,T,U,W},
{A,B,C,E,P,S,T,U,W},
{A,B,C,D,E,P,R,T,W},
{A,B,C,E,P,S,T,V,W},
{A,B,C,E,P,S,T,U,V,W},
{A,B,C,E,P,S,T,W},
{A,B,C,D,E,P,R,T,V,W},
} }

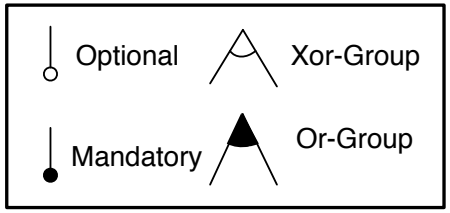
fm1p = {
{D,E,T},
fm1p = {
{S,T},
{D,E,T},
{D,E,T},
{S,T},
{S,T},
{S,T},
{S,T},
{D,E,T}
}

Slicing operator: going into details

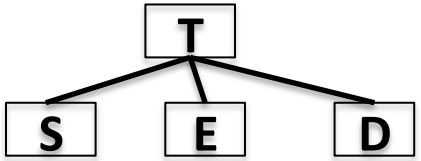
synthesizing the corresponding feature model



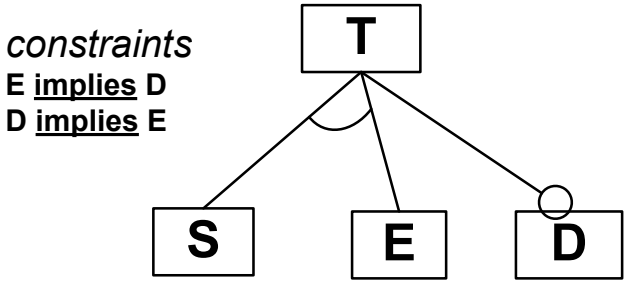




+



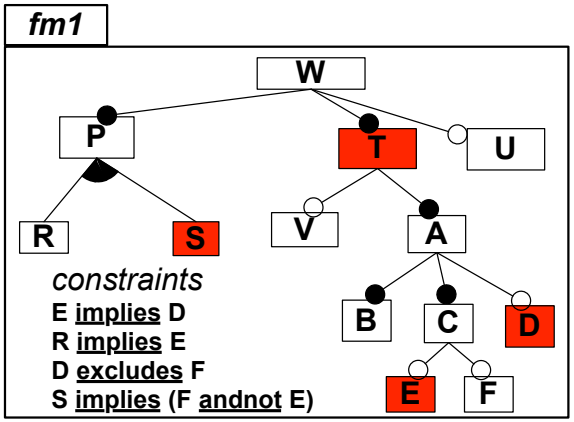
fm1p = {
{D,E,T},
{S,T}
}

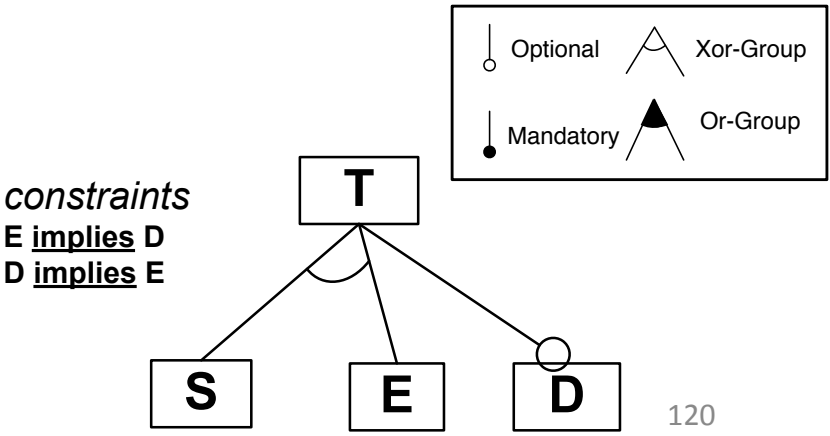


Mathieu Acher, Philippe Collet, Philippe Lahire, Robert B. France « Separation of Concerns in Feature Modeling: Support and Applications » AOSD'12

Slicing operator with FAMILIAR (1)

```
fm1 = FM (W : P T [U] ; T : [V] A ;
                          A : B C [D] ;
                           C : [E] [F] ;
                           P : (R|S)+ ;
                           E implies D ; R implies E ;
                           S implies (F and !E) ; D implies !F ; )

fm2 = slice fm1 including { S T E D }
fm2bis = slice fm1 excluding { W P R V A B C F U }

cmp = compare fm2 fm2bis
assert (cmp eq REFACTORING)
```





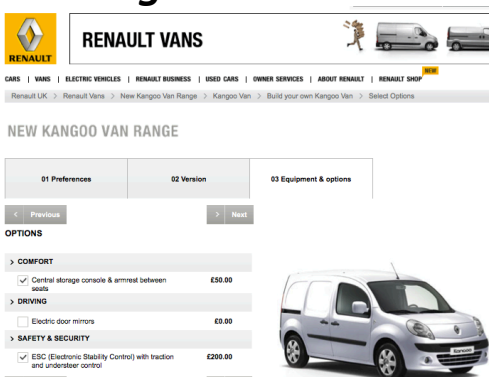
slicingOp.fml

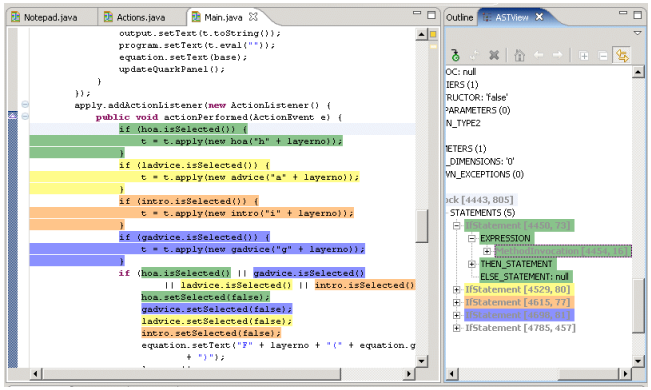
Slicing with FAMILIAR (2)

```
fm1 = FM (W : P T [U] ; T : [V] A ;
                          A : B C [D] ;
                           C : [E] [F] ;
                           P : (R|S)+ ;
                           E implies D ; R implies E ;

                           S implies (F and !E) ; D implies !F ; )

fm2 = slice fm1 including fm1.A.* ++ { fm1.A }

fm3 = slice fm1 including fm1.P.* ++ { fm1.P }
//fm3bis = slice fm1 including { fm1.P fm1.R fm1.S } // equivalent to fm3

fm4 = slice fm1 including { fm1.E fm1.D fm1.F }

fts5 = { fm1.P fm1.W } ++ fm1.P.*
fm5 = slice fm1 including fts5
```

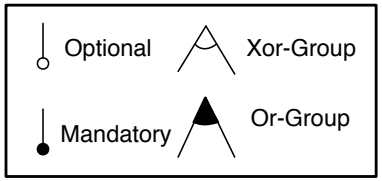
From marketing, customers, product management

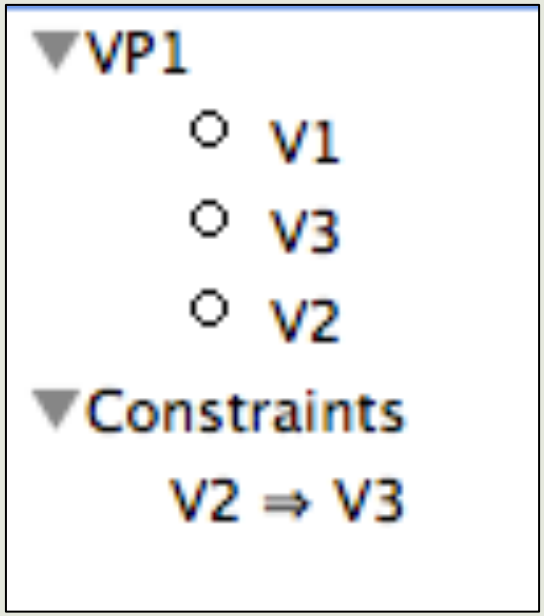
From existing software assets (technical variability)





Metzger, Heymans et al. "Disambiguating the Documentation of Variability in Software Product Lines: A Separation of Concerns, Formalization and Automated Analysis" (RE'07)



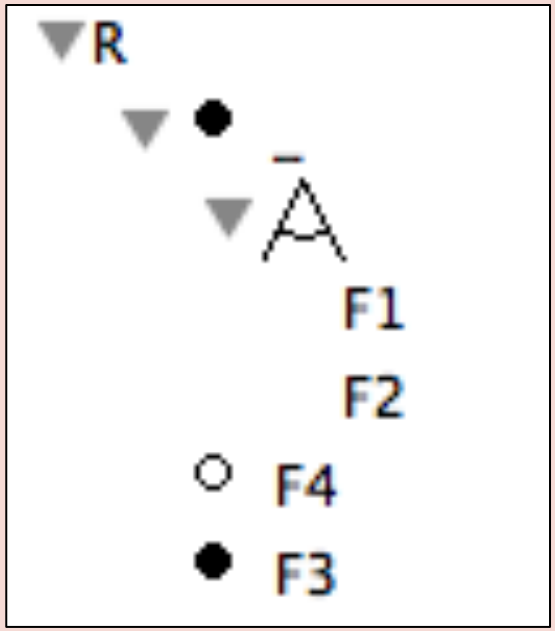


From marketing, customers, product management

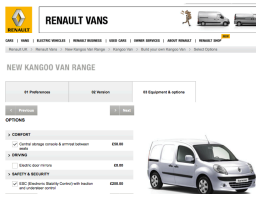
usefulness

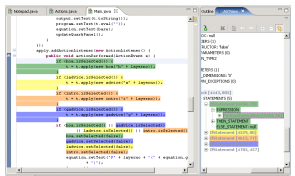
V1 ⇔ f1
V2 ⇔ f2
V3 ⇔ f3

realizability

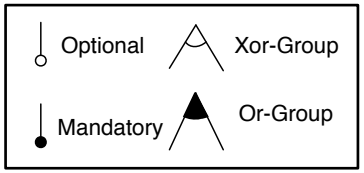


From existing software assets

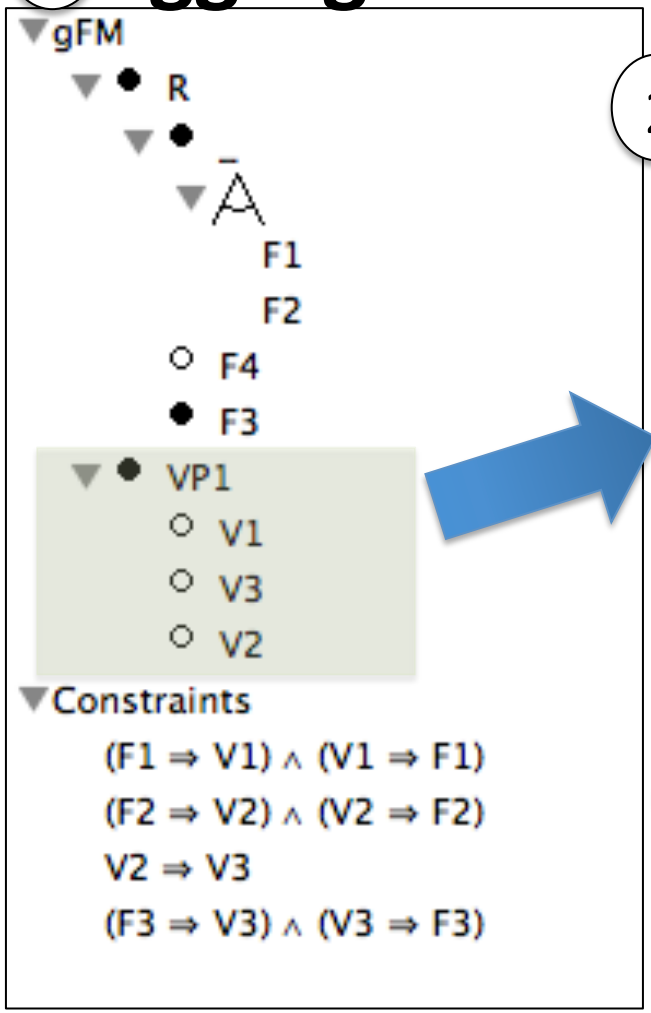




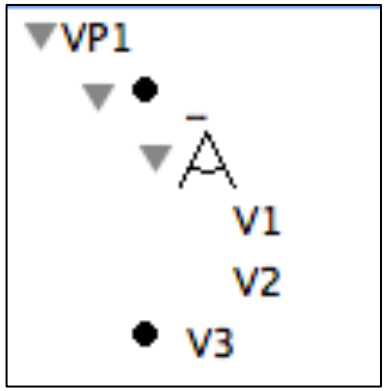
Realizability checking



1 **aggregate**



2 **slice** (“realizable part”)



φ

3 **compare**

{{V1,V3,V2,VP1},
{V1,VP1},
{V3,VP1},
{VP1}}

4 **merge diff**

(“unrealizable products”)

Mathieu Acher, Philippe Collet, Philippe Lahire, Robert B. France « Separation of Concerns in Feature Modeling: Support and Applications » AOSD’12

realizibility.fml

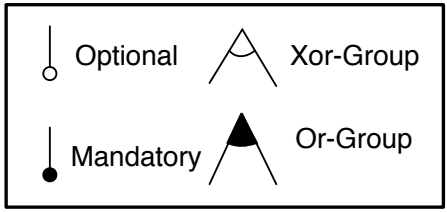
With FAMILIAR

```
/*
* Metzger et al. 2007, RE'07
* Disambiguating the .....
* Figure 1, Section 3
*/
```

```
fmSoftware = FM (R : (F1|F2) F3 [F4] ; )
```

```
MacBook-Pro-de-Mathieu-2:FML-scripts macher$ java -jar -Xmx1024M ../FML-0.9.9.6.jar realizability.fml
FAMILIAR (for FeAture Model scrIpt Language for manIpulation and Automatic Reasoning)  version 0.9.9.6
University of Nice Sophia Antipolis, UMR CNRS 6070, I3S Laboratory
https://nyx.unice.fr/projects/familiar/
fml> ls
(FEATURE_MODEL) gFM
(FEATURE_MODEL) fmSoftware
(FEATURE_MODEL) fmPLDiff
(FEATURE_MODEL) fmPLPrime
(FEATURE_MODEL) fmPL
(SET) xLink
fml> configs fmPLDiff
res1: (SET) {{VP1;V1};{VP1;V3};{VP1};{V3;V1;VP1;V2}}
```

Revisiting Merge: Aggregate + Slice



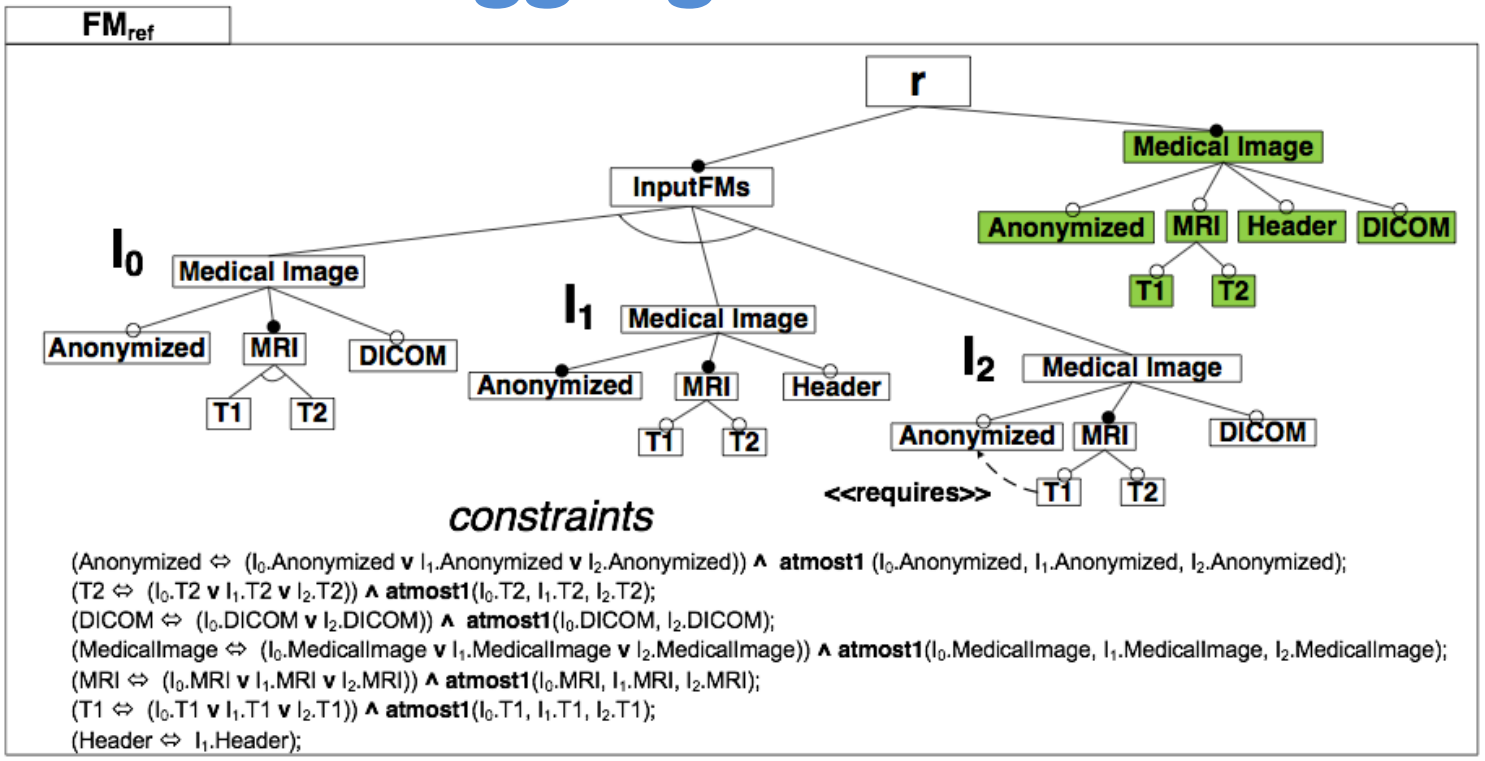
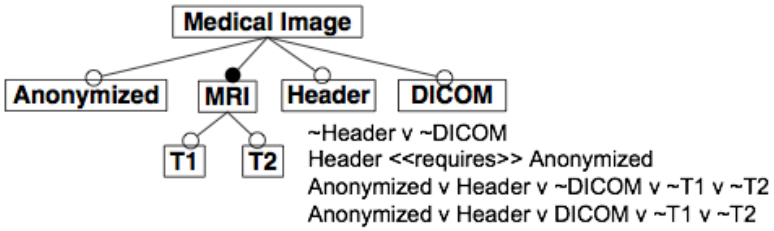


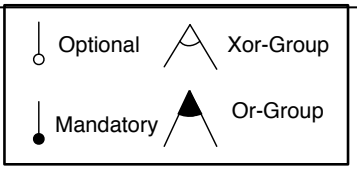
Figure 7.10: Merge of three feature models, I_0, I_1 and I_2 using the slicing operator



mergeWithAggregateMI.fml

Revisiting Aggregate, Merge and Slice:

```
fmsupp1 = FM (MedicalImage : [Anonymized] MRI [DICOM] ; MRI : (T1
fmsupp2 = FM (MedicalImage : Anonymized MRI [Header] ; MRI : [T1]
fmsupp3 = FM (MedicalImage : [Anonymized] MRI [DICOM] ; MRI : [T1

fmSupp = merge sunion fmsupp*
fmSuppAgg = aggregateMerge sunion fmsupp*

fmSuppAggSlice = slice fmSuppAgg including fmSupp.*
```




```
fml> compare fmSuppAggSlice fmSupp
res4: (STRING) REFACTORING
```

- MergeCST
  - MedicalImage
    - DICOM
    - Anonymized
    - Header
    - MRI
      - T1
      - T2
  - InputFMs
    - MedicalImage1000
      - DICOM1000
      - Anonymized1000
      - MRI1000
        - T11000
        - T21000
    - MedicalImage1001000
      - Anonymized1001000
      - MRI1001000
        - T21001000
        - T11001000
      - DICOM1001000
    - MedicalImage2001000
      - MRI2001000
        - T12001000
        - T22001000
      - Header2001000
      - Anonymized2001000
- Constraints
  - (Anonymized1000 ∨ Anonymized1001000 ∨ Anonyr
  - (MedicalImage2001000 ∨ MedicalImage1000 ∨ Medi
  - (DICOM1001000 ∨ DICOM1000 ⇒ DICOM) ∧ (DICOM
  - (T21000 ∨ T21001000 ∨ T22001000 ⇒ T2) ∧ (T2 ⇒
  - T11001000 ⇒ Anonymized1001000
  - (Header2001000 ⇒ Header) ∧ (Header ⇒ Header200
  - (T12001000 ∨ T11000 ∨ T11001000 ⇒ T1) ∧ (T1 ⇒
  - (MRI1001000 ∨ MRI2001000 ∨ MRI1000 ⇒ MRI) ∧ (M

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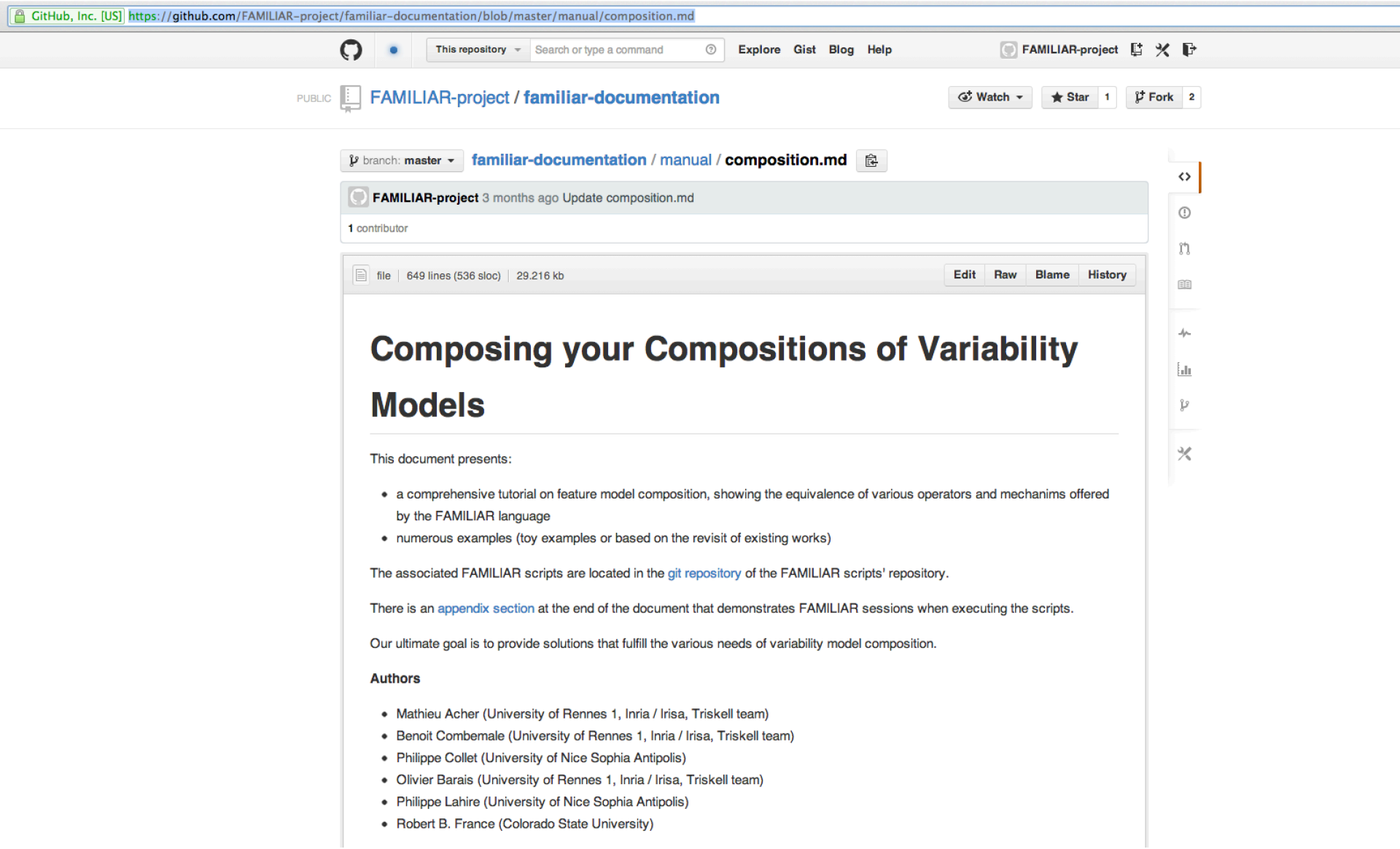

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Quizz (open problem)

Composition of attributed feature models

Conclusion

- Implementing variability (code clones, preprocessor, generative programming, …, DSLs)
- Modeling variability
  - Syntax and semantics of feature models; synthesis (from semantics to syntax)
  - Reasoning and operations for feature models
- Reverse engineering variability
  - Code base, textual inputs, tabular data, configuration files, “variants”