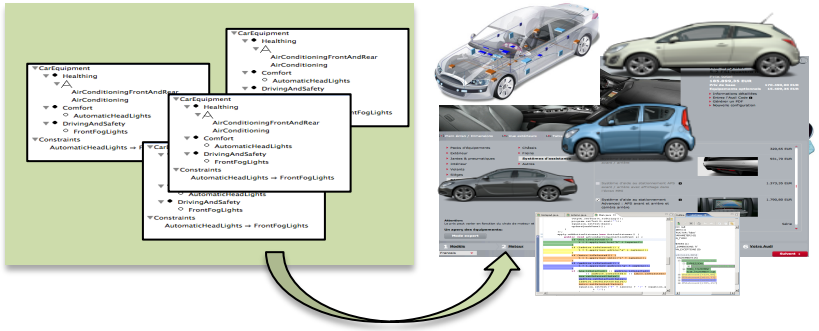

MODELS 2012
innsbruck

Next-Generation Model-based Variability Management: Languages and Tools

Mathieu Acher (Associate Professor, Rennes)

Patrick Heymans (Professor, Namur / Lille)

Philippe Collet (Associate Professor, Nice)

Philippe Lahire (Professor, Nice)

Acknowledgments

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  - Raphaël Michel, Quentin Boucher, Ebrahim Abbasi, Arnaud Hubaux (PhD), Gilles Perrouin (PhD), Assoc. Prof. Anthony Cleve
- Contributors of FAMILIAR
  - Robert B. France (Colorado State University)
  - Students
    - Aleksandar Jakšić (Colorado State University)
    - Foudil Bendjabeur (Université Nice Sophia Antipolis)
    - Master students in Namur (variability management course)

Audience

- No pre-requisite background!
- Targeted Audience
  - Academics or practitioners
  - Curious guys: e.g., PhD students or modellers unaware of…
    - Variability and software product lines (SPLs)
    - Variability modelling
    - Configuration
  - MDE guys: people involved or interested in the development of model management tools
    - e.g., model composition/decomposition
  - SPL guys: advances that want to learn new technique

At the end of the tutorial…

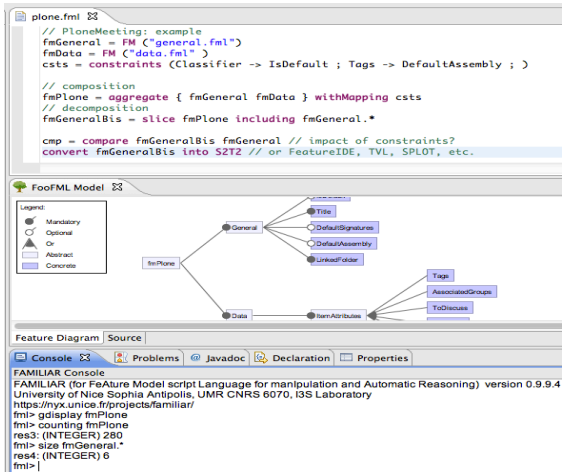
- You will have an overview of what's going on in the field of variability and model-based software product line engineering
- You will be able to go further with the languages and modelling techniques
  - so to reuse them in practical or academic contexts

- Supporting material: https://nyx.unice.fr/projects/familiar/wiki/MODELS12-tutorial
  - slides of the tutorial
  - related articles,
  - TVL models,
  - FAMILIAR scripts,
  - and packaged tools to interactively play with the models during the tutorial.

Plan

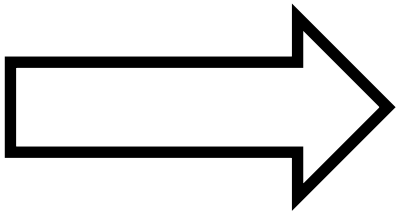
- Why managing **Variability** does matter (30’)
- **Modelling** variability with TVL (60’)
- **Managing** variability models with FAMILIAR (90’)

```
root PloneMeeting {
    group allof {
        General,
        Data,
        WorklowSec,
        Interface,
        Email,
        Tasks,
        Advices,
        Votes
    }
}

General {
    group allof {
        Title ,
        opt DefaultAssembly,
        opt DefaultSignatures,
        LinkedFolder,
        opt IsDefault,
        NumberLastItemLastMeeting {
            int number;
        },
        opt NumberLastMeetingConfig {
            int number;
        },
        opt MeetingConfigID
    }
}
```



Why managing **Variability** does (and will) matter

Software-intensive systems



come in many **variants**

Exterior | Interior

Side | Front | Rear

360°

This image may contain optional equipment. 360°

Agila, Club

1.2i 16v, 5 Speed

Blaze Red, Melt / Elba Charcoal

Total **€ 15,684.00**

1. Trims/Series | 2. Engine/Transmission | 3. Colour & Style | 4. Options | 5. Summary

Next Step

Choose Your Options

Audio/Comms/Nav | Heating/Ventilation | Mechanical | Safety/Security | **A-Z**

Audio/Comms/Nav	
☑ **CD 30** - MP3 CD player with MP3 format, stereo radio, steering wheel mounted audio controls	**Standard**
Heating/Ventilation	
☑ **Air conditioning**	**€ 923.00**
Mechanical	
☑ **Electronic Stability Programme (ESP)**	**€ 411.00**
Safety/Security	
☑ **Emergency tyre inflation kit in lieu of space-saver spare wheel and tyre**	**Standard**

Audio/Comms/Nav | Heating/Ventilation | Mechanical | Safety/Security | **A-Z**

Next Step: Summary

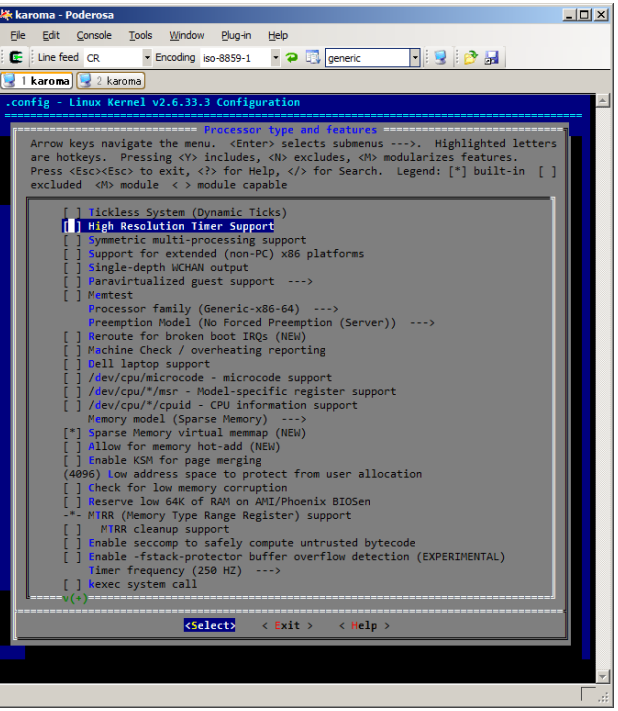
Legend

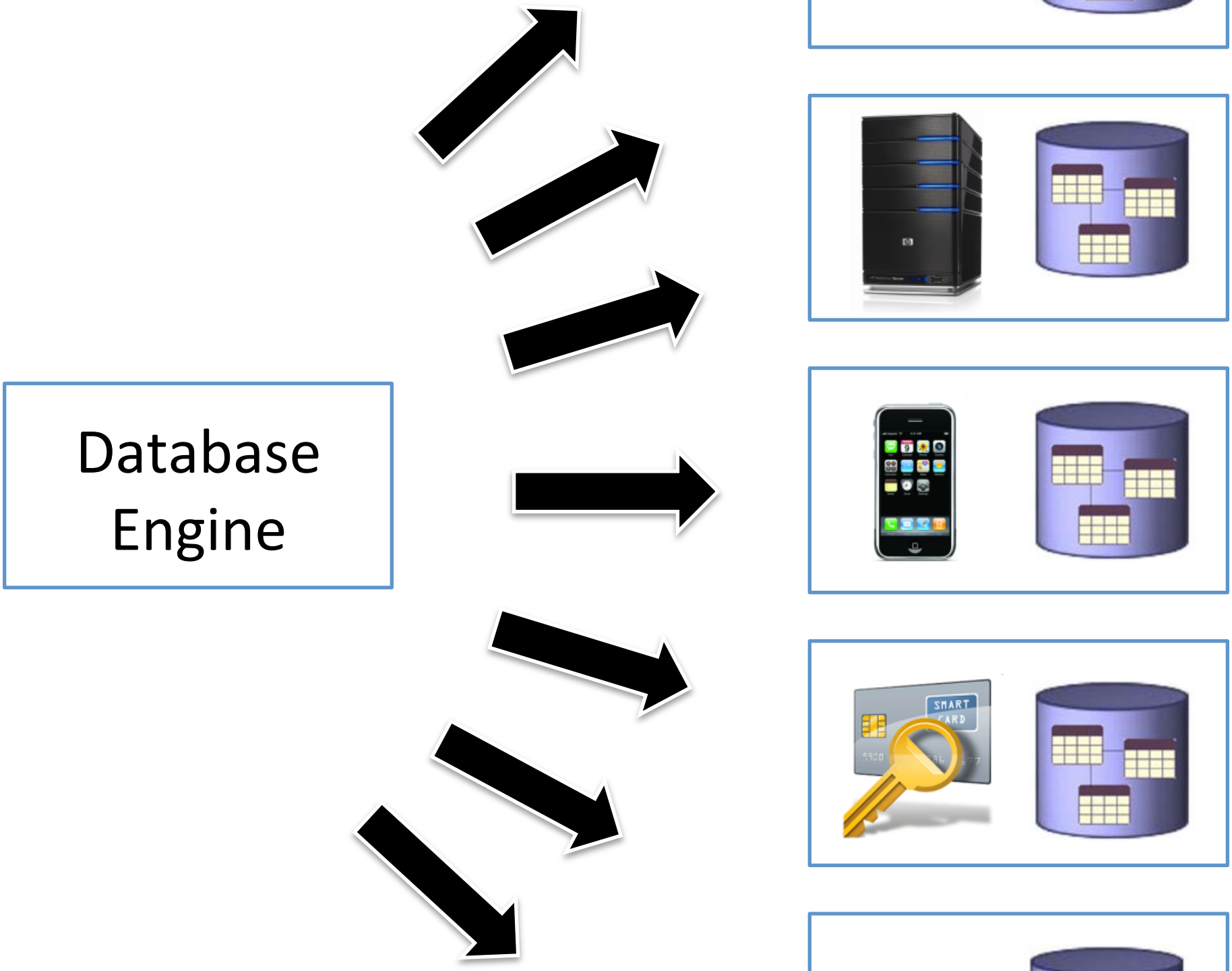
- ☑ Selected Option
- ☐ Selectable Option
- ☑ Option contained in an option pack
- ☐ Option contained in an option pack or standard equipment which has been replace by another option
- ⊟ Option that is only selectable together with another option. Please click for details

Pricing Details

Club	€ 14,350.00
1.2i 16v, 5 Speed	
Blaze Red	€ 0.00
Melt / Elba Charcoal	€ 0.00
15-inch steel wheels with 185/60 R 15 tyres and flush wheel covers	€ 0.00
Options (2)	−
You selected:	
☑ Air conditioning	€ 923.00
☑ Electronic Stability Programme (ESP)	€ 411.00
Total	**€ 15,684.00**

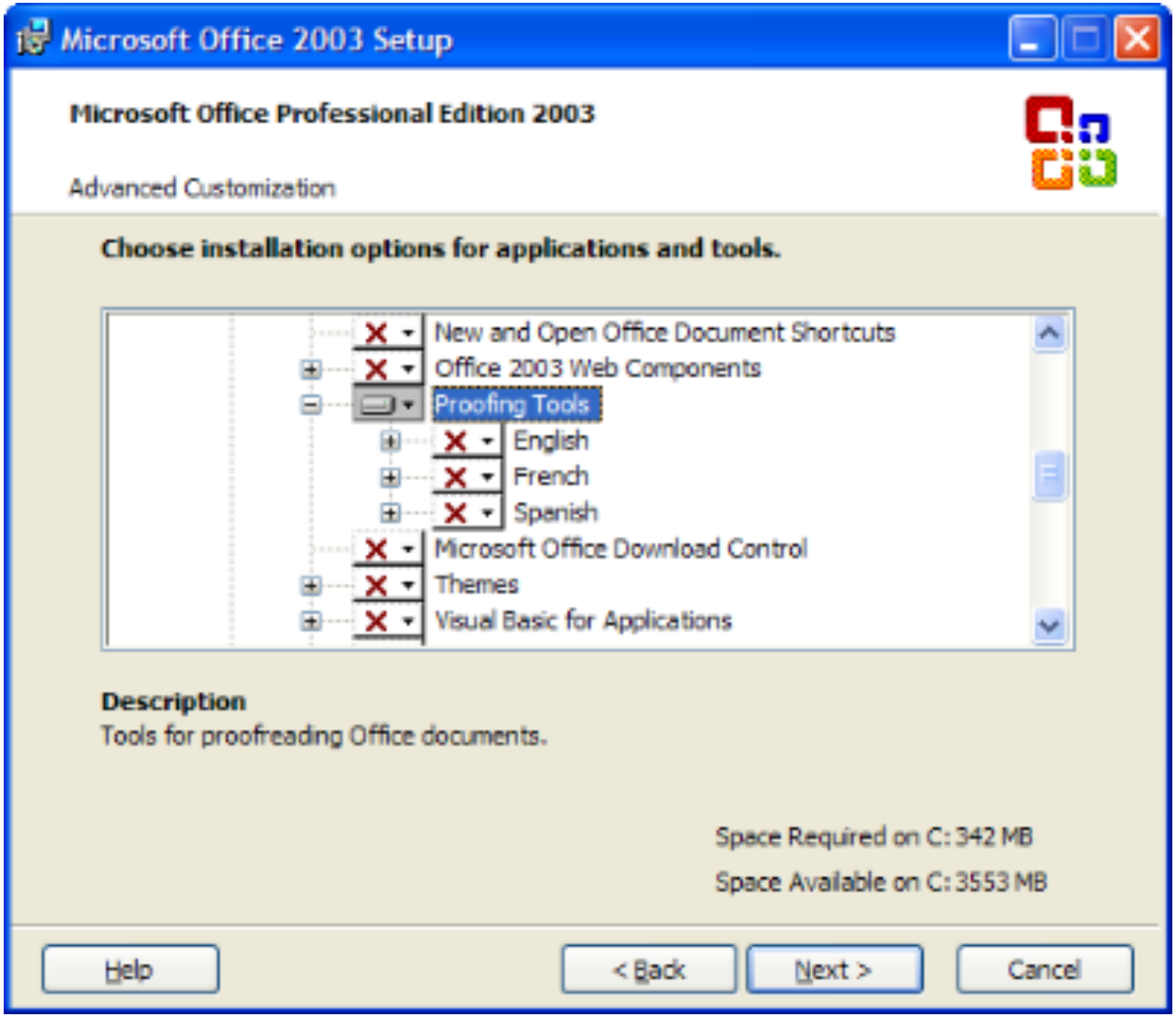
Linux Kernel




Database Engine
SMART CARD

Printer Firmware

Features in Microsoft Office



Variability

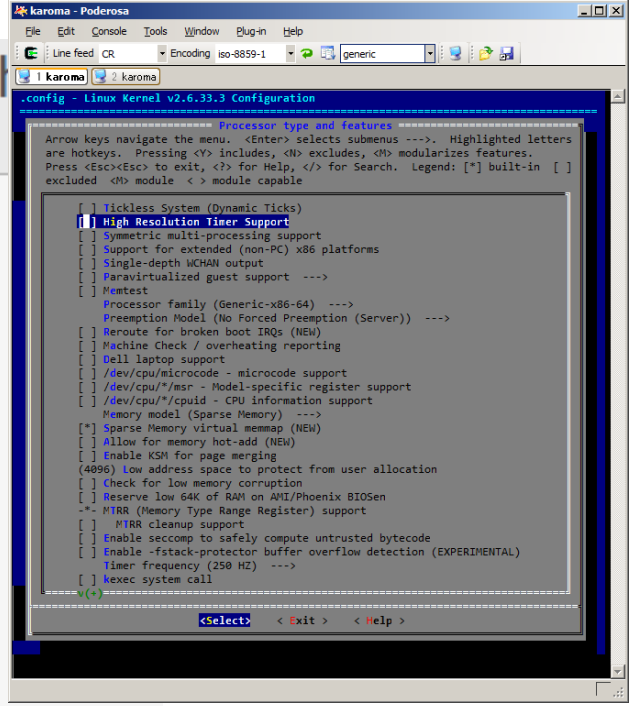
"the ability of a system to be efficiently extended, changed, customized or configured for use in a particular context"

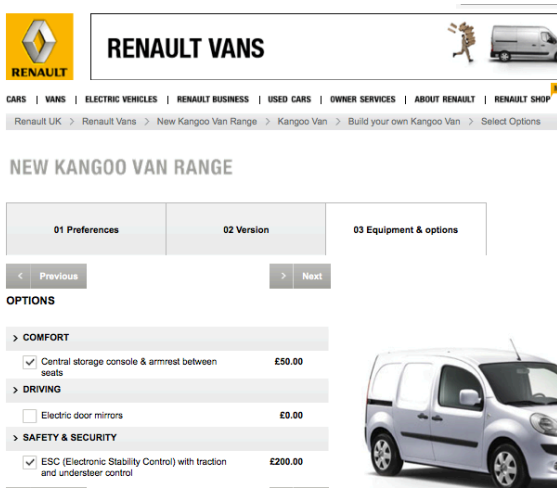
Mikael Svahnberg, Jilles van Gurp, and Jan Bosch (2005)

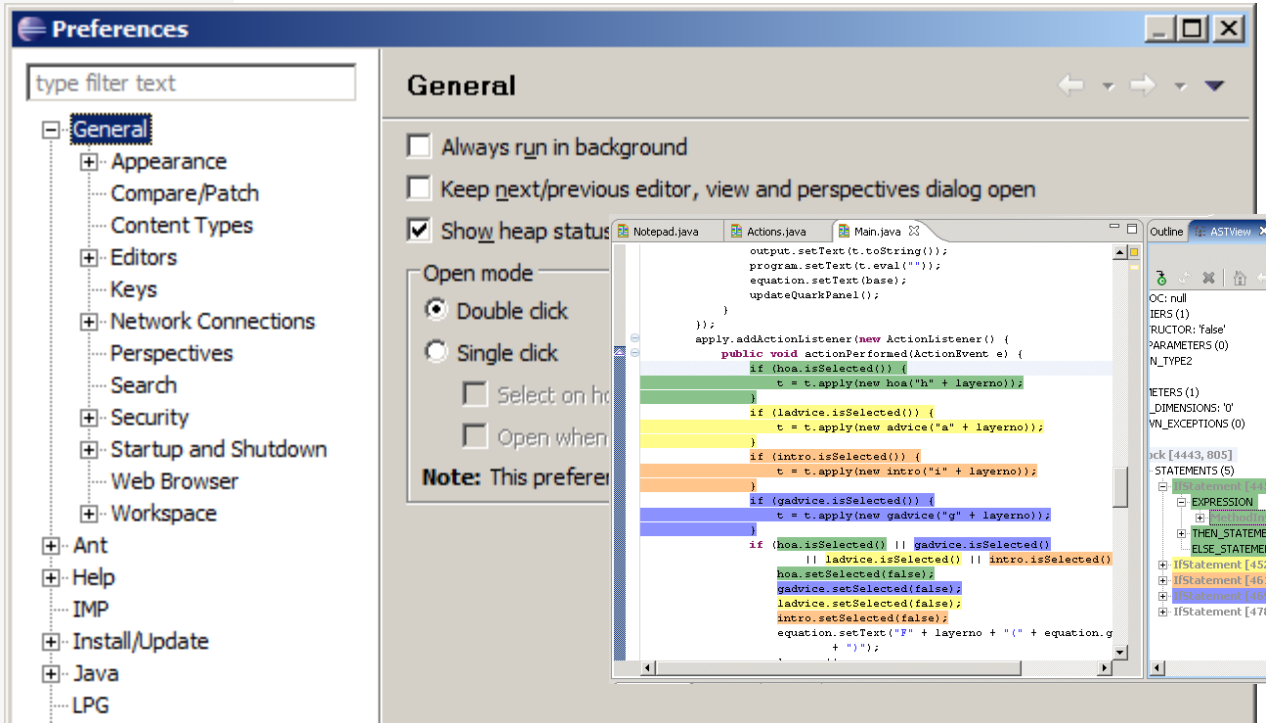
httpd.conf -- win32 Apach

Building a Web Server, for Windows

```
Listen 80
ServerRoot "/www/Apache2"
DocumentRoot "/www/webroot"

ServerName localhost:80
ServerAdmin admin@localhost

ServerSignature On
ServerTokens Full

DefaultType text/plain
AddDefaultCharset ISO-8859-1

UseCanonicalName Off

HostnameLookups Off

ErrorLog logs/error.log
LogLevel error

PidFile logs/httpd.pid

Timeout 300

KeepAlive On
MaxKeepAliveRequests 100
KeepAliveTimeout 15


<IfModule mpm_winnt.c>
  ThreadsPerChild 250
  MaxRequestsPerChild 0
</IfModule>
```







If you're able to master variability…

- Reduce development costs
- Reduce certification costs
- Shorten time-to-market

- But, are you able?
  - developing, verifying, certifying billions of variants is challenging!

Variability = Complexity

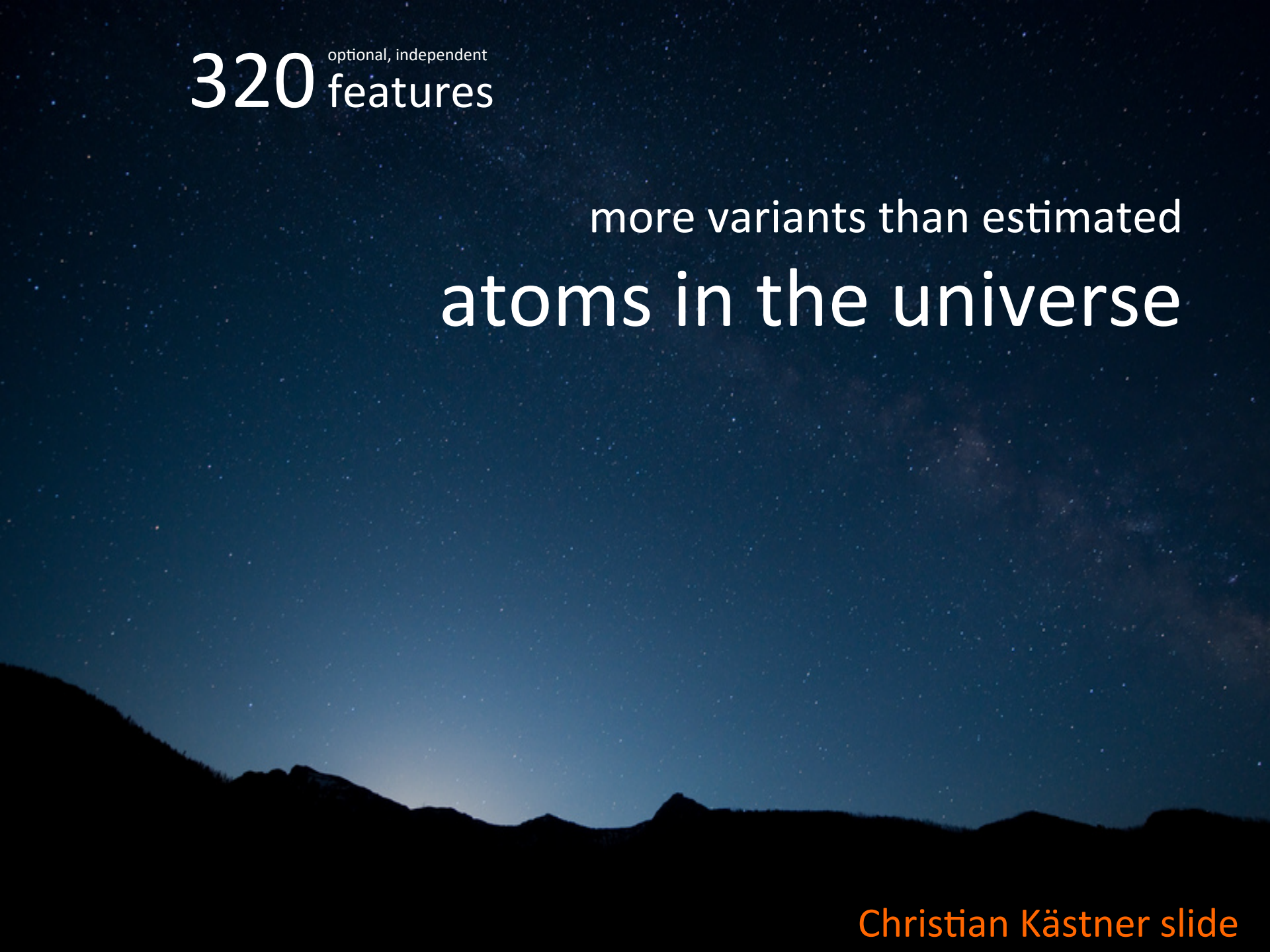
Christian Kästner slide

33 optional, independent features

a unique variant for every

person on this planet

Christian Kästner slide


320 optional, independent features
more variants than estimated
atoms in the universe
Christian Kästner slide

2000 features

10000 features

Christian Kästner slide

Automation?

Avoid solving the same problem!

2, 3…n times

Correctness?

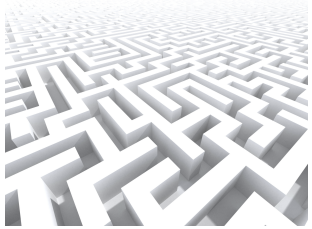
Christian Kästner slide


Link-Belt
Maintenance?
Comprehension?

Why managing Variability does (and will) matter

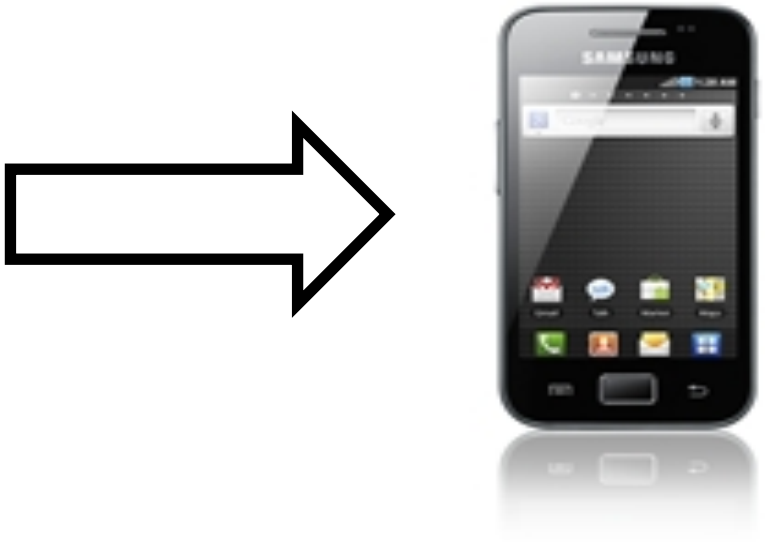
Goal: Software mass customization / Adaptive and configurable systems

Problem: Variability = Complexity

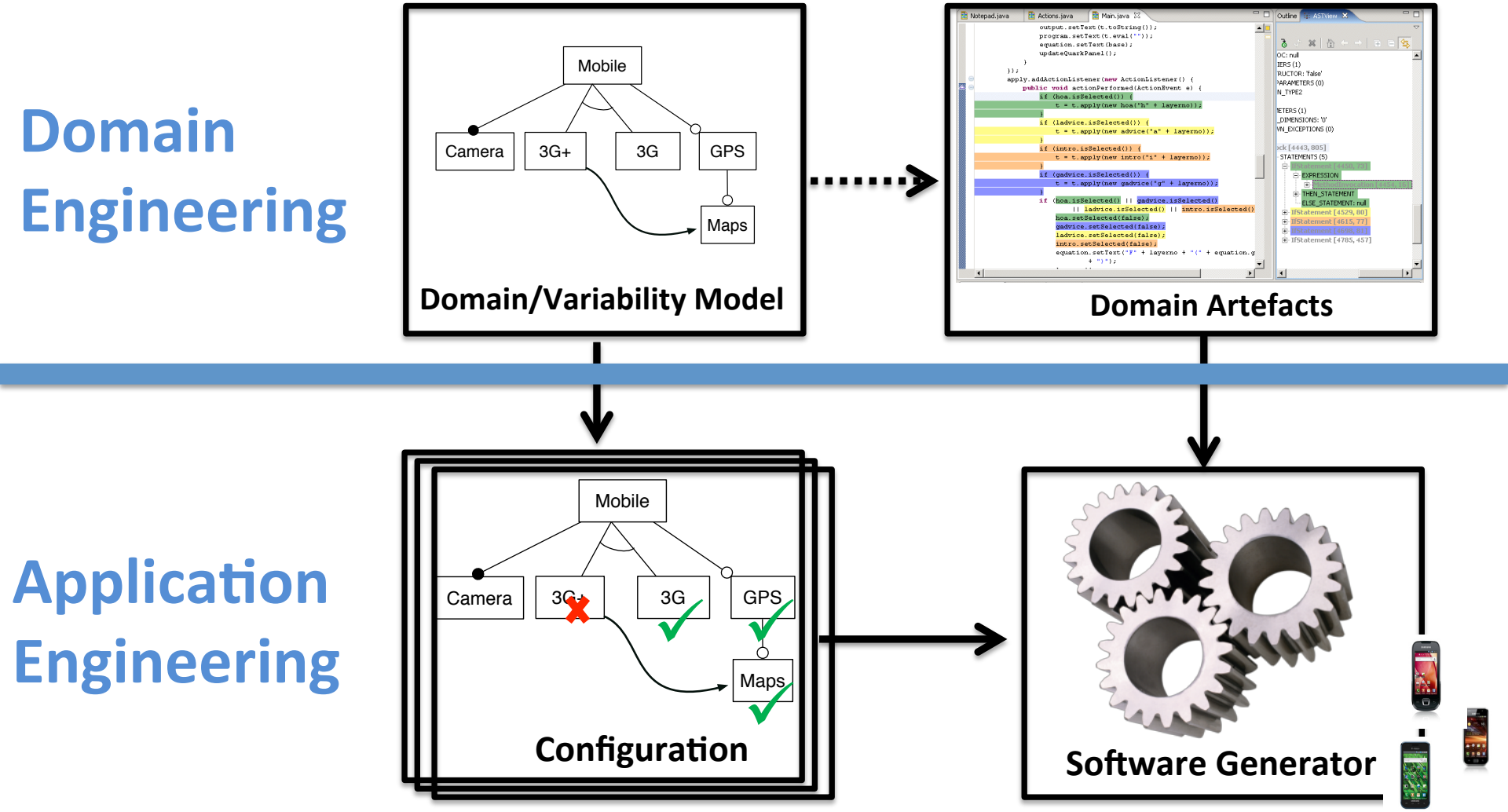


Approach: Model-based variability management

Software-intensive systems come in many **variants**

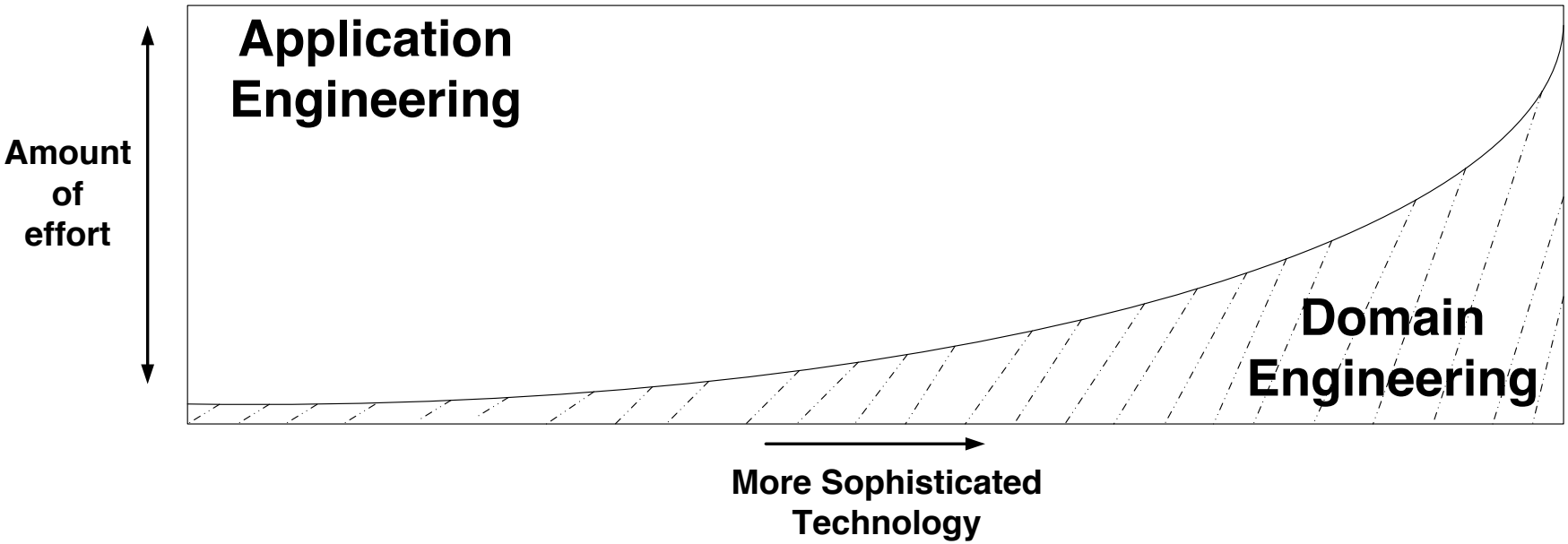


Model-based Variability Management



*« the investments required to develop the reusable artifacts during **domain engineering**, are outweighed by the benefits of deriving the individual products during **application engineering** »*

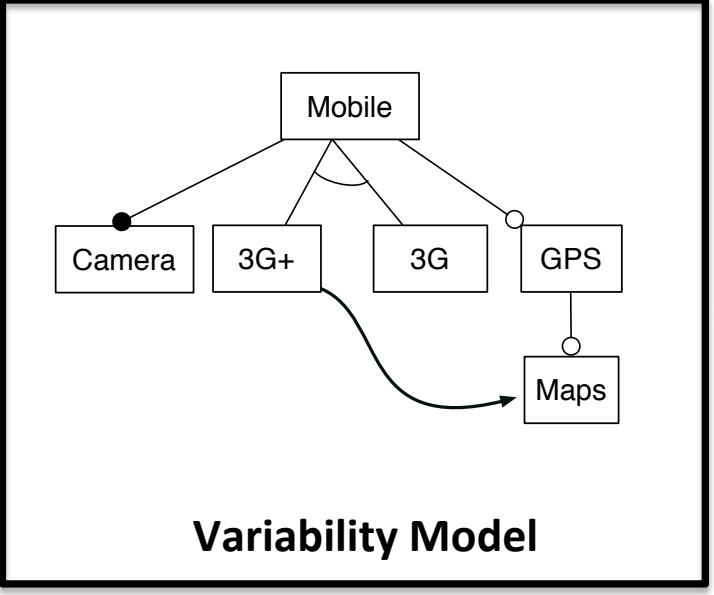
Jan Bosch et al. (2004)

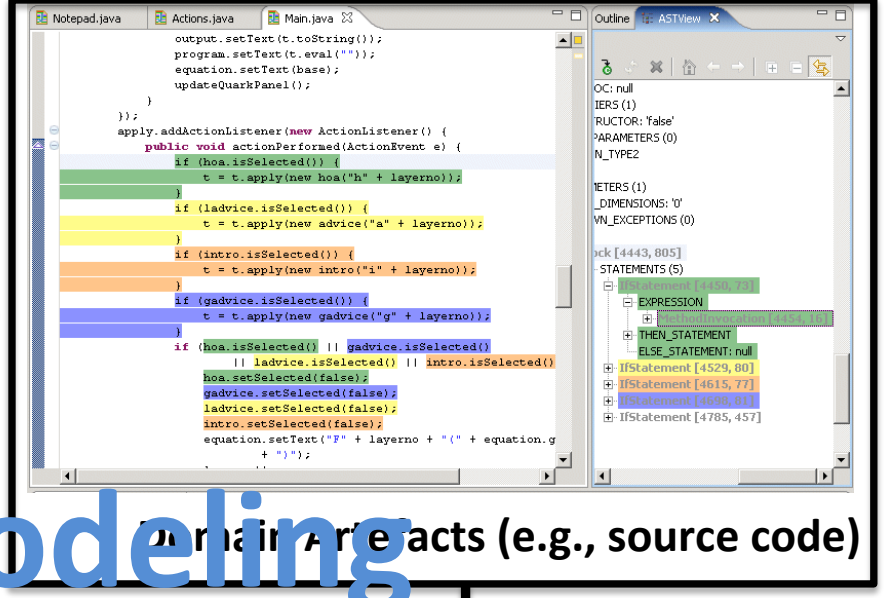


99% domain engineering,

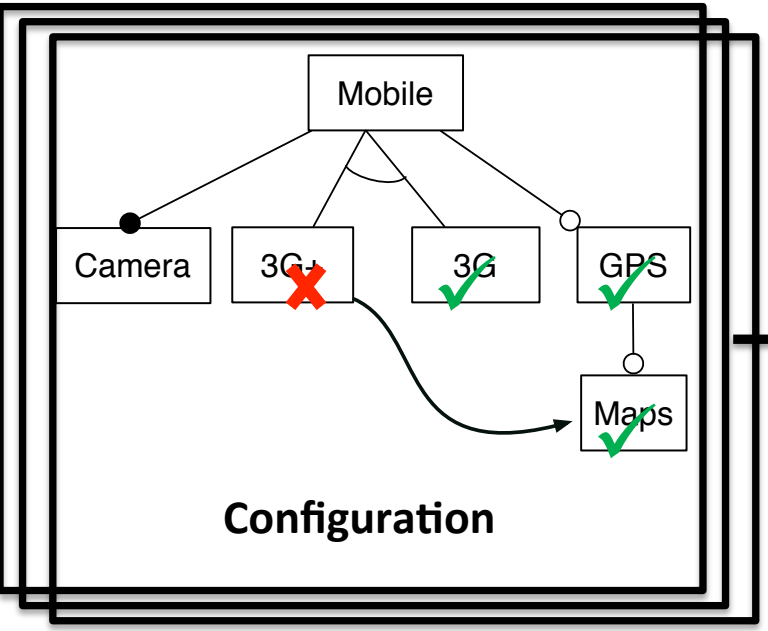
1% application engineering?

- specifies what you want (click, click, click) a customized product is automatically built for you
- Iterate the process for *n* products





Modeling variability is crucial



Unused flexibility

Illegal variant

Variability Model

Feature Model: *de facto* standard

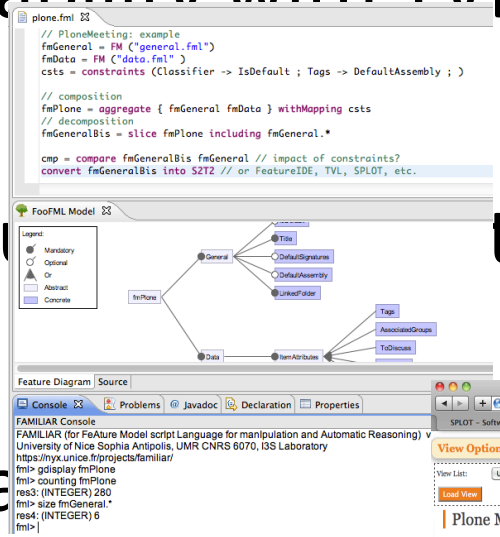
- Research
  - 2500+ citations of [Kang et al., 1990] on Google Scholar
  - Central to many generative approaches
    - at requirements or code level
  - Tools & Languages (GUIDSL/FeatureIDE, SPLOT, FaMa, etc.)

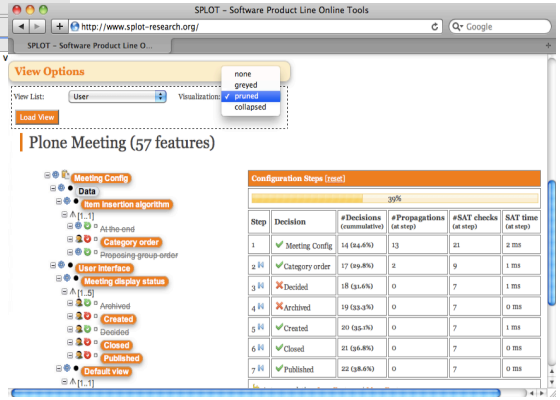
- Industry
  - Tools (Gears, pure::variants),
  - Will be Part of Common Variability Language (CVL), future OMG standard

Plan

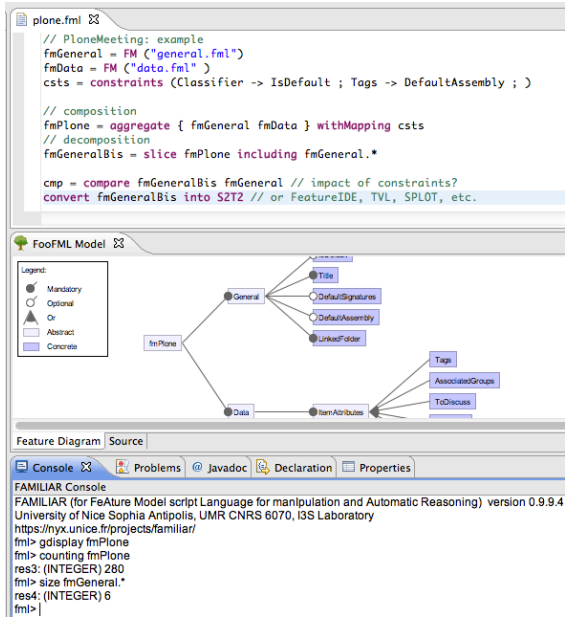
- W g Variability does matter
- M iability with TVL
- M th FAMILIAR
- Configuring fea

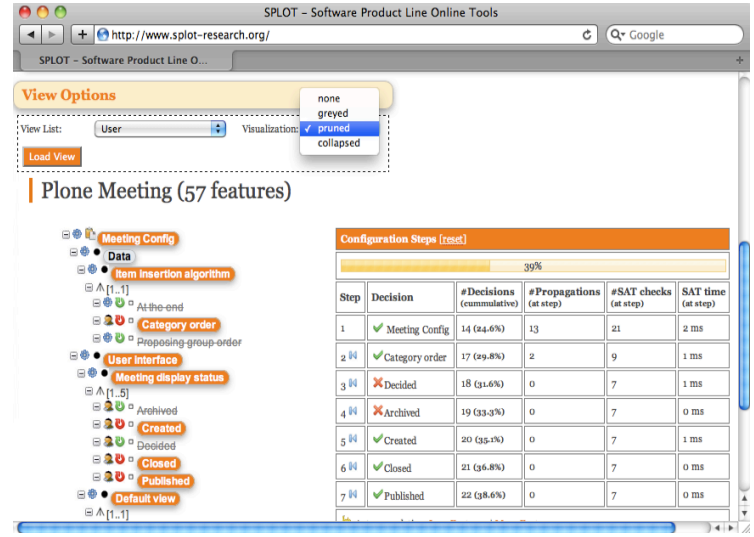
```
root PloneMeeting {
    group allof {
        General,
        Data,
        WorklowSec,
        Interface,
        Email,
        Tasks,
        Advices,
        Votes
    }
}

General {
    group allof {
        Title ,
        opt DefaultAssembly,
        opt DefaultSignatures,
        LinkedFolder,
        opt IsDefault,
        NumberLastItemLastMeeting {
            int number;
        },
        opt NumberLastMeetingConfig {
            int number;
        },
        opt MeetingConfigID
    }
}
```





```
root PloneMeeting {
    group allof {
        General,
        Data,
        WorklowSec,
        Interface,
        Email,
        Tasks,
        Advices,
        Votes
    }
}

General {
    group allof {
        Title ,
        opt DefaultAssembly,
        opt DefaultSignatures,
        LinkedFolder,
        opt IsDefault,
        NumberLastItemLastMeeting {
            int number;
        },
        opt NumberLastMeetingConfig {
            int number;
        },
        opt MeetingConfigID
    }
}
```





Formally define the scope of your product line with a textual language

Edit, compose, decompose, compare, reason about your variability specifications

Configure your product line with a collaborative, distributed and dependable feature-based configuration

Modelling variability with TVL

(Text-based Variability Language)

R8 Spyder

5.2 FSI quattro R tronic

Prix total

171.216,00 EUR

Prix de base	**170.490,00 EUR**
Equipements optionnels	**726,00 EUR**

- Informations détaillées
- Entrez l'Audi Code
- Générer un PDF
- Nouvelle configuration

[+] Plein écran / Dimensions ▸ Fermer la capote ▸ Habitacle ▸ Tableau de bord

Packs

Aucun pack n'est proposé pour ce modèle.

Couleurs

Blanc Ibis
Noir
Prix: 0,00 EUR

Couleurs métallisées à partir de 0,00 EUR

Couleurs à effet perlé à partir de 0,00 EUR

Couleurs personnalisées Audi exclusive

Audi exclusive

Couleur capote

Noir

Jantes

4 Jantes alu 5 BRANCHES ROTOR finition titane 8,5 x 19 à l'avant, 11 x 19 à l'arrière. Pneus 235/35 R19 à l'avant et 305 /30 R19 à l'arrière
Prix: 726,00 EUR

19" à partir de 0,00 EUR

Audi
Vorsprung durch Technik

R8 Spyder
5.2 FSI quattro R tronic

Prix total
185.899,35 EUR

Prix de base	**170.490,00 EUR**
Equipements optionnels	**15.409,35 EUR**

- Informations détaillées
- Entrez l'Audi Code
- Générer un PDF
- Nouvelle configuration

[+] Plein écran / Dimensions Vue extérieure Tableau de bord

- Packs d'équipements
- Extérieur
- Jantes & pneumatiques
- Intérieur
- Volants
- Sièges
- **Sécurité & technique**
- Infotainment

- Châssis
- Freins
- **Systèmes d'assistance**
- Autres

excludes

☑ Régulateur de vitesse		320,65 EUR
☐ Système d'aide au stationnement APS avant / arrière		931,70 EUR
☐ Système d'aide au stationnement APS avant / arrière avec affichage dans l'écran MMI		1.373,35 EUR
☑ Système d'aide au stationnement Advanced : APS avant et arrière et caméra arrière		1.790,80 EUR
● Audi hill assist : assistance au démarrage en côte		Série

Attention:
Le prix peut varier en fonction du choix de moteur et des équipements.

Un aperç des équipements:

Mode expert

Réinitialiser la sélection

1 Modèle 2 Moteur 3 Extérieur 4 Intérieur 5 Option 6 Votre Audi

Audi
Vorsprung durch Technik

A5 Sportback
3.0 TDI quattro S tronic

Prix total
54.460,15 EUR

Prix de base	50.570,00 EUR
Equipements optionnels	3.890,15 EUR

- Informations détaillées
- Entrez l'Audi Code
- Nouvelle configuration

[+] Plein écran / Dimensions

Vérification de votre sélection

Cet équipement nécessite un équipement complémentaire:

- [x] GPS Plus avec disque dur — 2.934,25 EUR

Voici les équipements complémentaires possibles:

- ( ) Ordinateur de bord en couleur avec programme efficiency — 181,50 EUR
  Remarque: uniquement sur les modèles avec système Start-Stop et uniquement disponible en combinaison avec l'autoradio Concert, l'autoradio Symphony ou un système de navigation
- ( ) Pack Intenso Plus — 3.100,00 EUR

- Extérieur
- Jantes & pneumatiques
- Intérieur
- Volants
- Sièges
- Sécurité & technique
- **Infotainment**

2.934,25 EUR

Sans appareil de navigation — Série

Attention:
Le prix peut varier en fonction du choix de moteur et des équipements.

Un aperç des équipements:

Mode expert

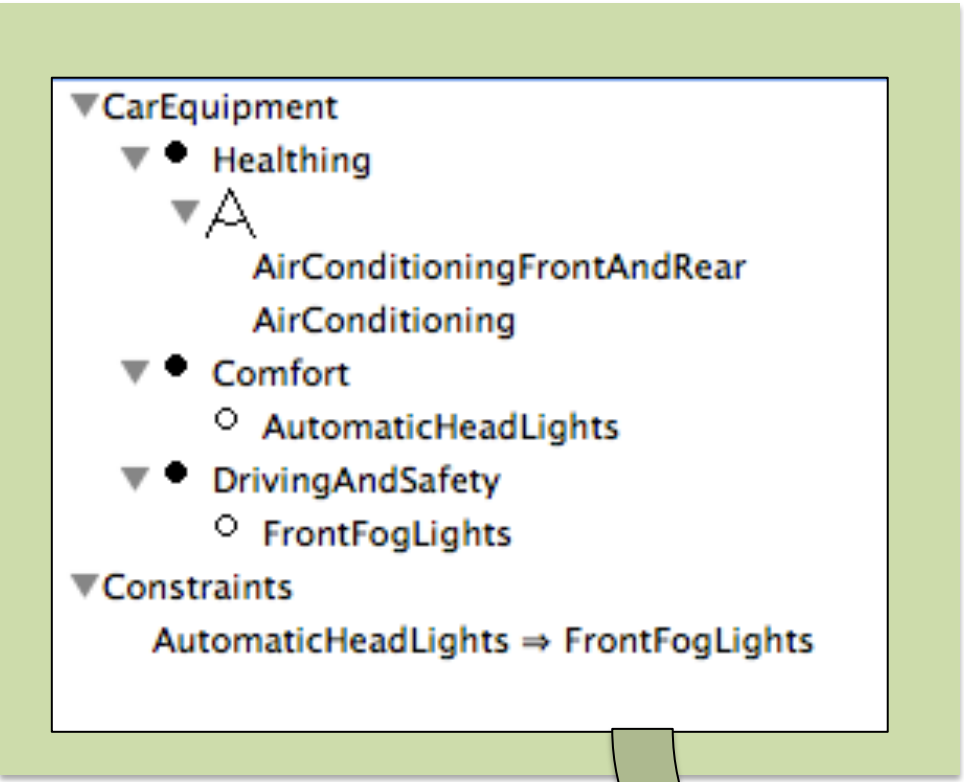
Réinitialiser la sélection

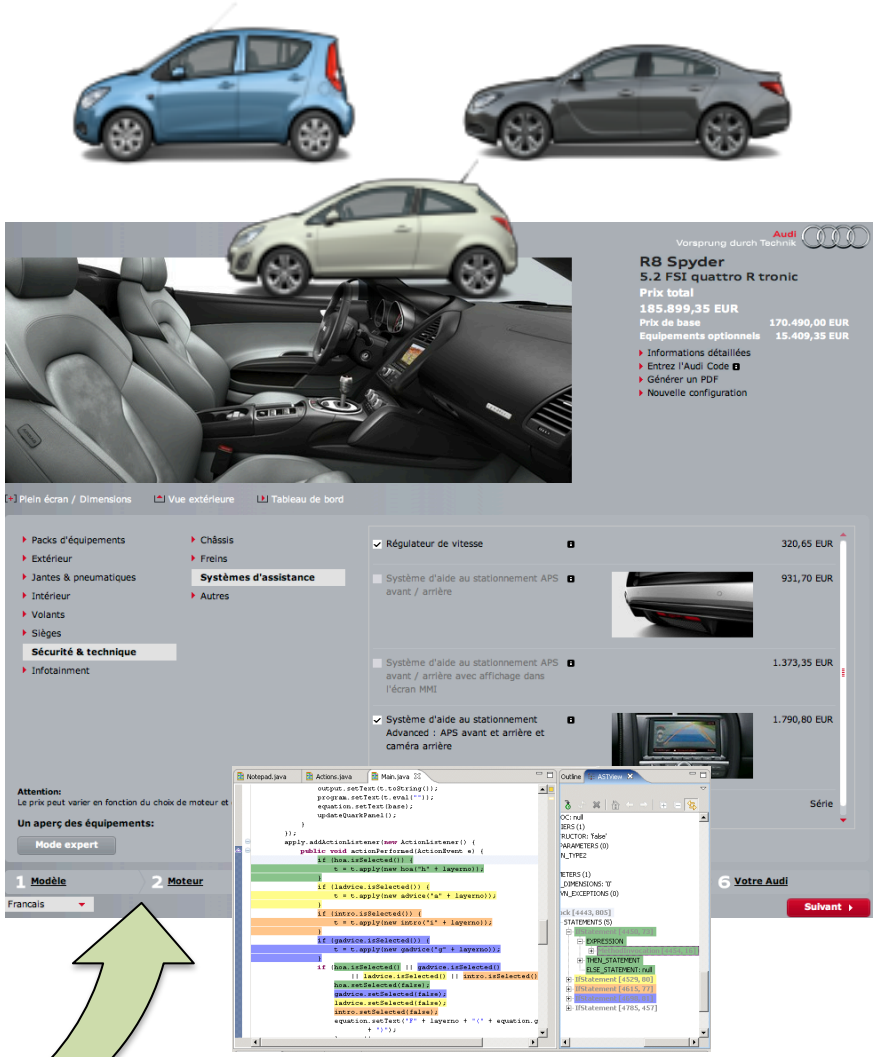
1 Modèle | 2 Moteur | 3 Extérieur | 4 Intérieur | 5 Option | 6 Votre Audi

Francais

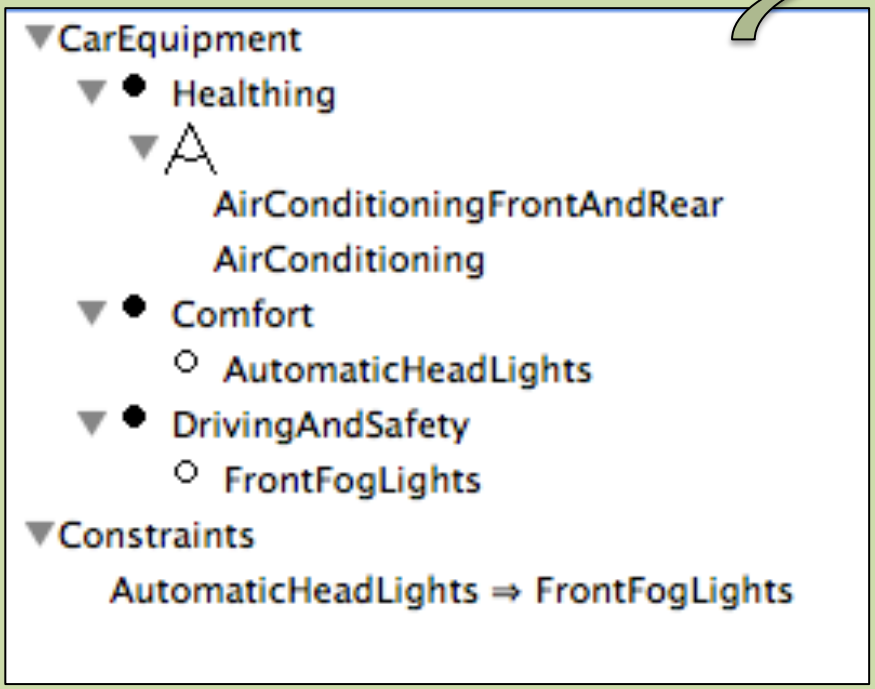
Suivant

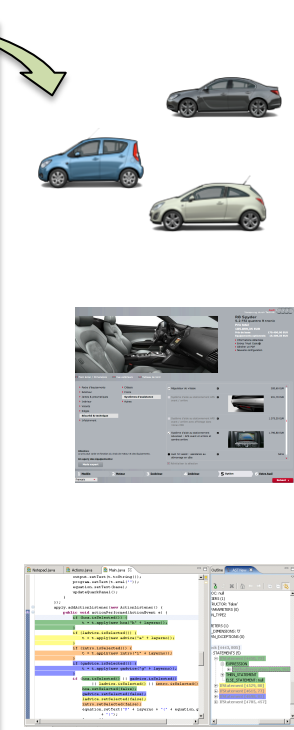
Feature Models

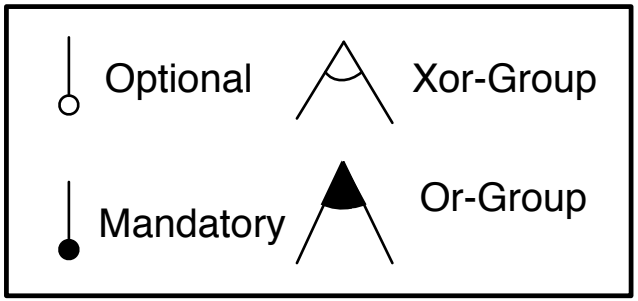




Feature Models (Background)



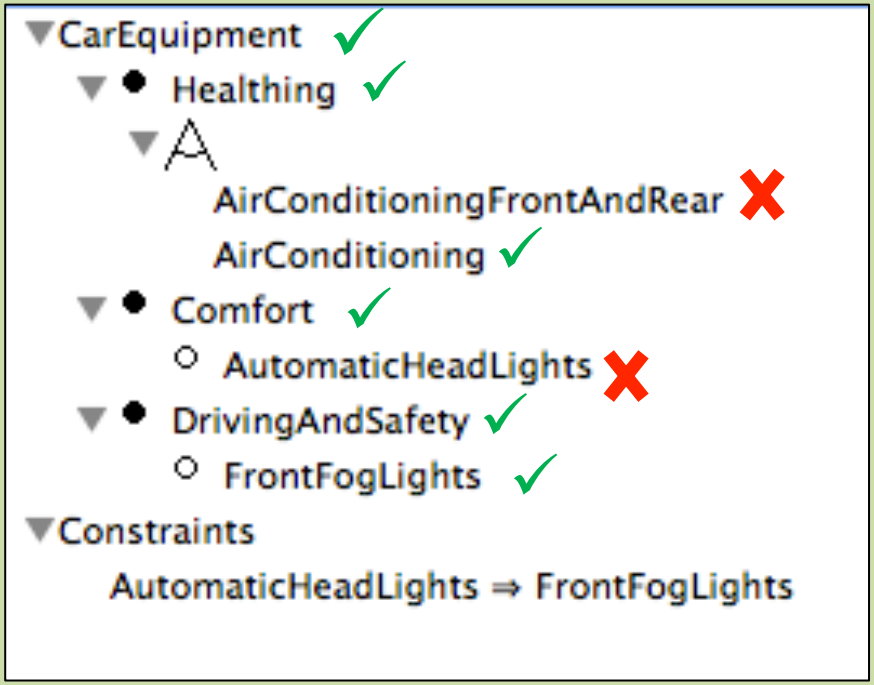


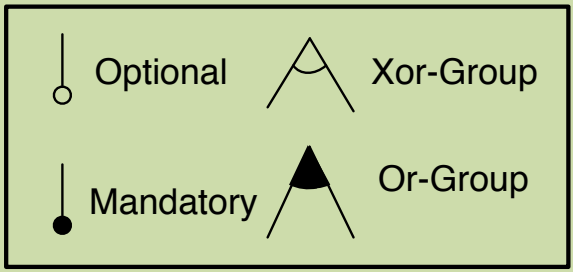


Hierarchy: rooted tree

Variability:

- mandatory,
- optional,
- Groups: exclusive or inclusive features
- Cross-tree constraints

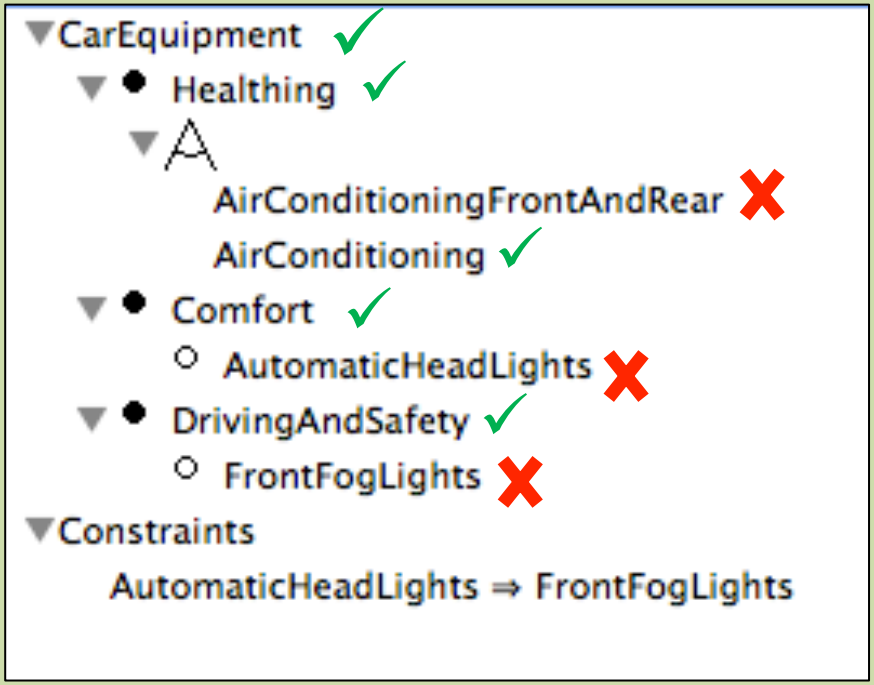


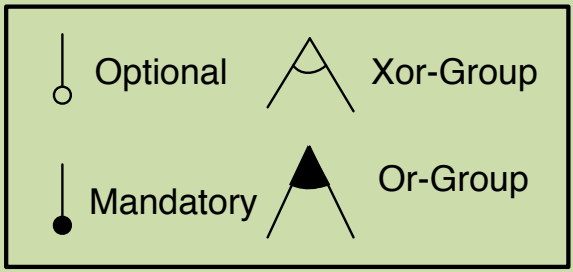


Hierarchy + Variability
=
set of valid configurations

configuration = set of features selected

{CarEquipment, Comfort, DrivingAndSafety, Healthing, AirConditioning, FrontFogLights}

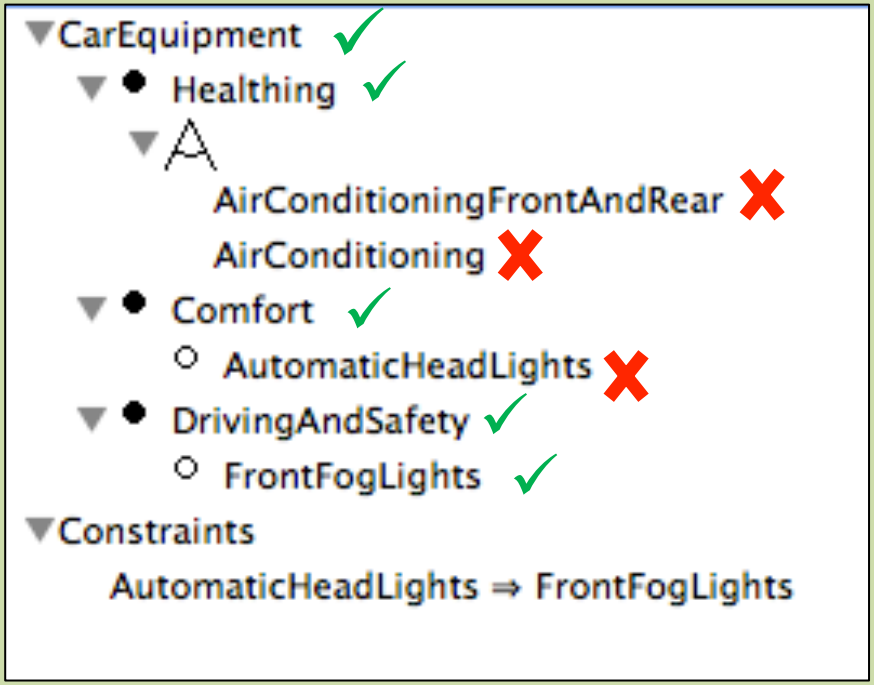


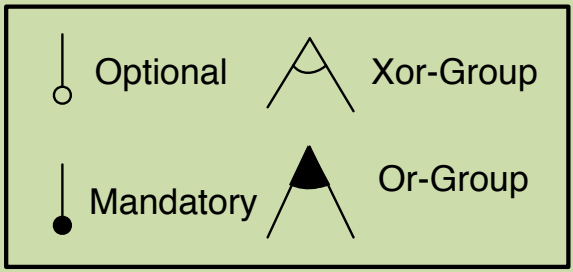


Hierarchy + Variability
=
set of valid configurations

configuration = set of features selected

{CarEquipment, Comfort, DrivingAndSafety, Healthing, AirConditioning}

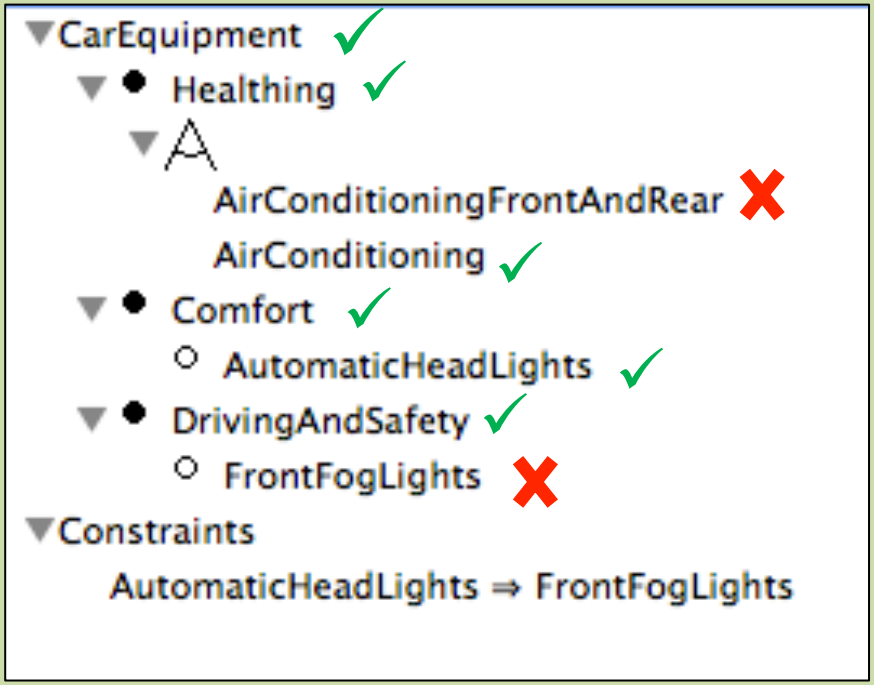


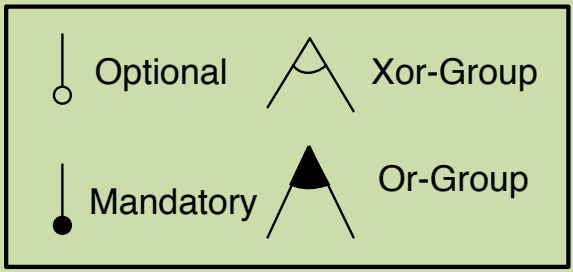


Hierarchy + Variability
=
set of valid configurations

configuration = set of features selected

{CarEquipment, Comfort, DrivingAndSafety, Healthing, AirConditioning, AirConditioningFrontAndRear, FrontFogLights}

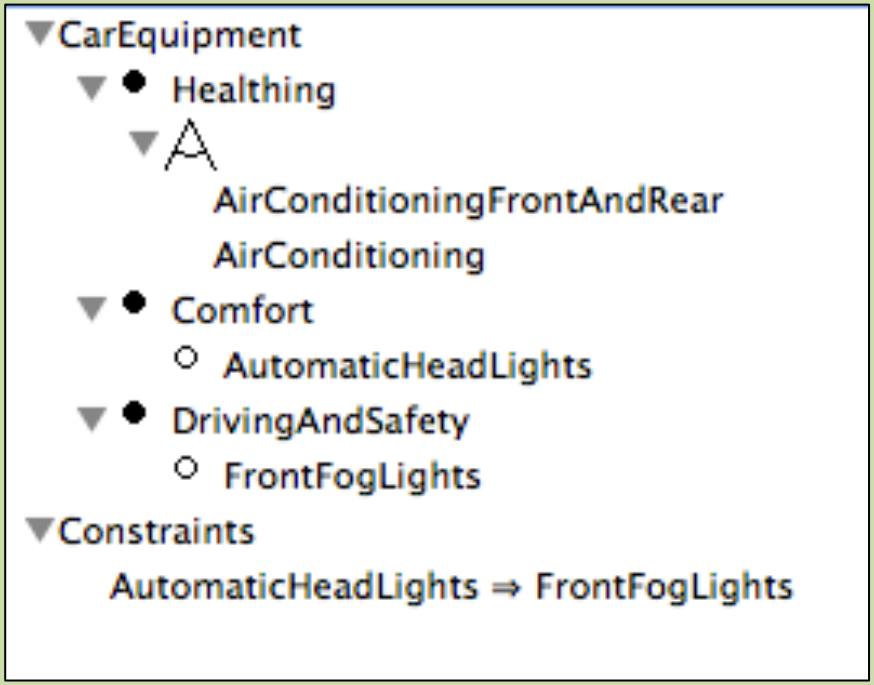


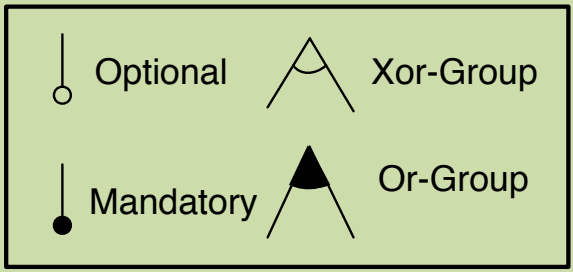


Hierarchy + Variability
=
set of valid configurations

configuration = set of features selected

{CarEquipment, Comfort, DrivingAndSafety, Healthing, AirConditioning, AutomaticHeadLights}





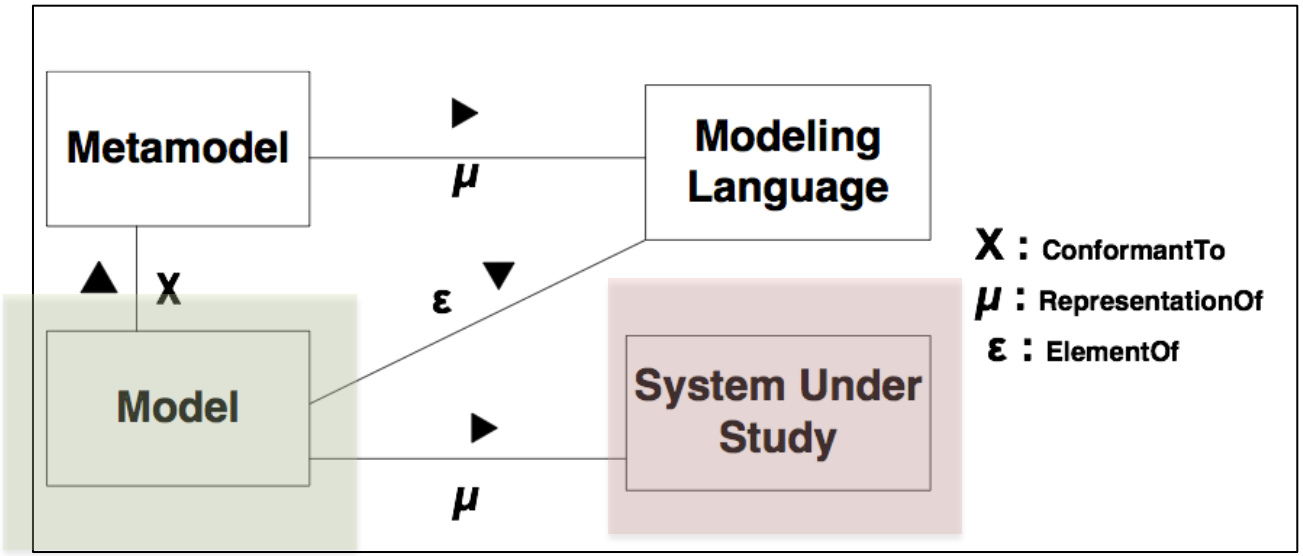
Hierarchy + Variability
=
set of valid configurations

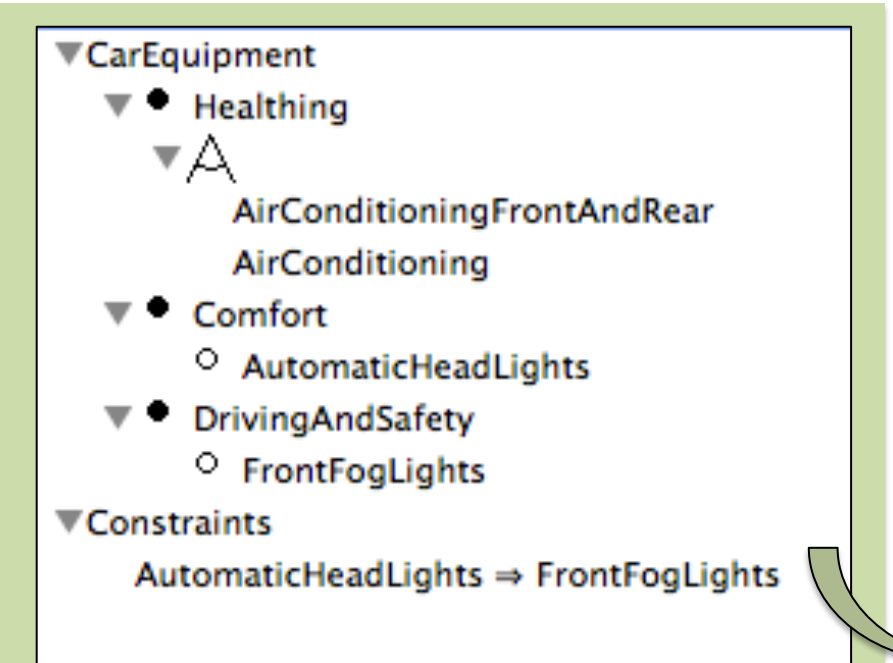
{CarEquipment, Comfort, DrivingAndSafety, Healthing}

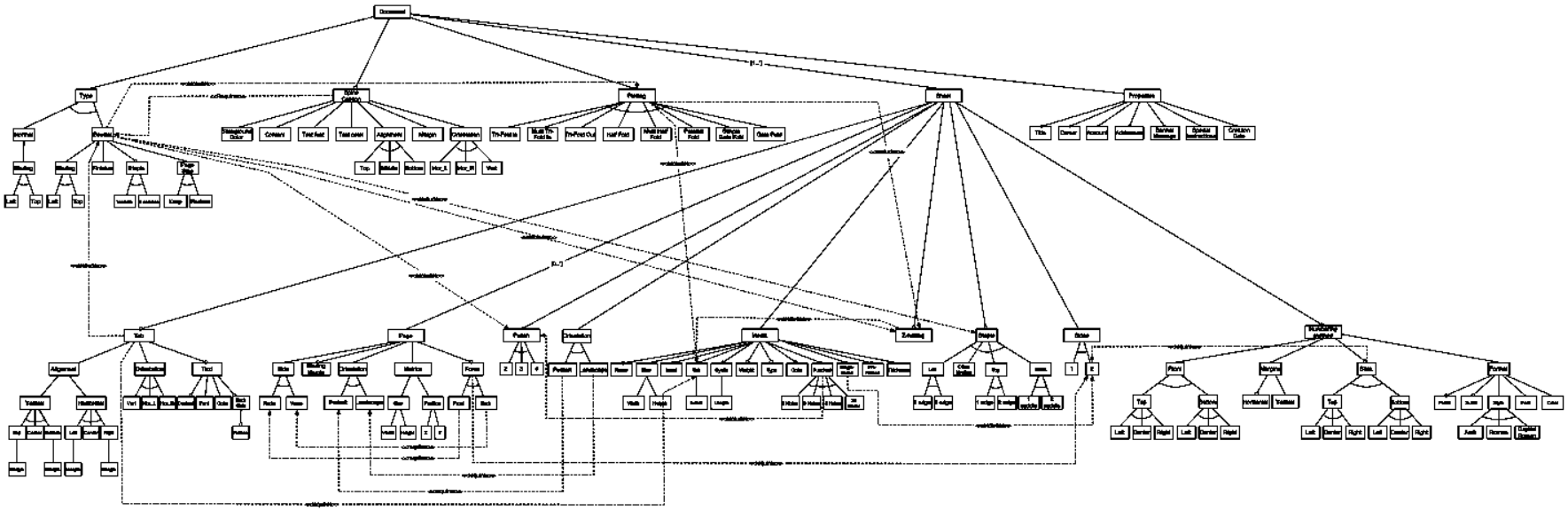
X

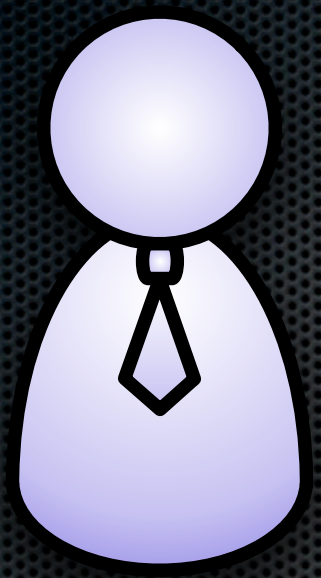
{AirConditioning, FrontFogLights}
{AutomaticHeadLights, AirConditioning, FrontFogLights}
{AutomaticHeadLights, FrontFogLights, AirConditioningFrontAndRear}
{AirConditioningFrontAndRear}
{AirConditioning}
{AirConditioningFrontAndRear, FrontFogLights}

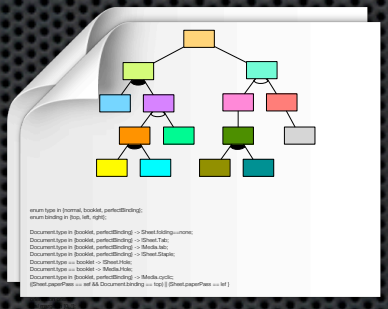
Feature Models

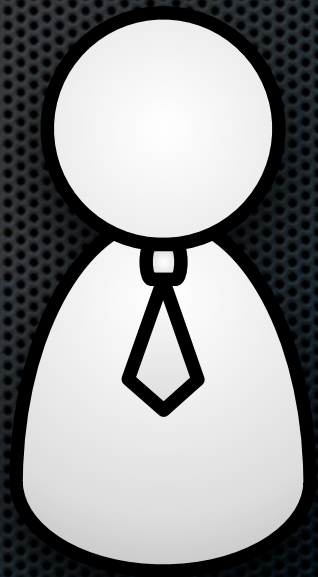


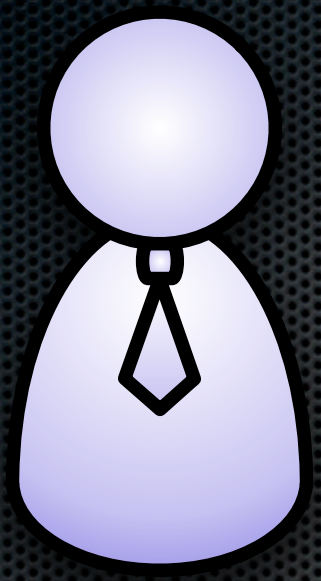


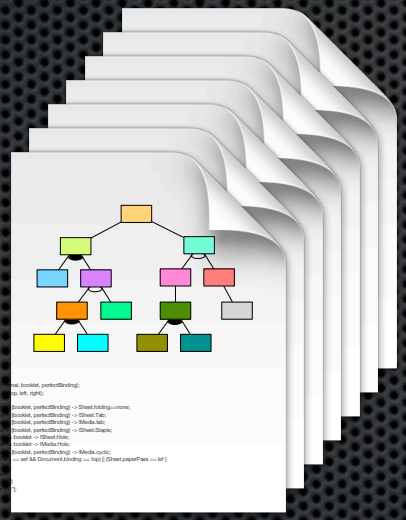





enum type in {normal, booklet, perfectBinding};
enum binding in {top, left, right};
Document.type in {booklet, perfectBinding} -> Sheet.folding == none;
Document.type in {booklet, perfectBinding} -> Sheet.Tab;
Document.type in {booklet, perfectBinding} -> Media.tab;
Document.type in {booklet, perfectBinding} -> Sheet.Staple;
Document.type == booklet -> Sheet.Hole;
Document.type == booklet -> Media.Hole;
Document.type in {booklet, perfectBinding} -> Media.cyclic;
{Sheet.paperPass == lef && Document.binding == top} {Sheet.paperPass == lef }







Visualisation will help, right ?

- Tools create their own problems
- Lock-in, dependance
- Some information is inevitably textual
  - OCL constraints in UML
  - Minispecs in StateCharts
  - Attributes and constraints in FD

Why not use text altogether ?

- There are powerful tools for that
- Helps with
  - Editing
  - Transformation
  - Versioning
  - Information exchange
  - …
- Graphical views can be generated anyway

Not a new idea

Language	User Friendly	Attributes	Cardinalities	Cross tree constraints	Modula-risation
Van Deursen et al.	✔				
GUIDSL (AHEAD)	✔				
SXFM	✔				
XML-based (FAMA etc.)		✔	✔	✔	

+ CML
+ VSL

Furthermore

- Intuitive C-like syntax
- Formal semantics
- Statically typed
- Implemented

TVL : allOf – and decomposition

root feature

and decomposition

all subfeatures must be present in the product

```
root AudiCar {
        group allOf {
        ModelLine,
        BodyStyle,
        Model,
        Engine,
        Exterior,
        Interior,
        Equipment }

}
```

sub features

TVL : optional features

```
Exterior{
    group allof {
            Wheels,
            Paint,
            opt BlackStylingPack
    }
}
```

all subfeatures

must be present in the product

except this one

it is optional

TVL : one of – xor decomposition

feature definition

xor decomposition

one and only one subfeature must be present in the product

```
ModelLine {

        group oneof {
                AudiA1 {
                        AudiA1 -> (A1 || A1Sportback);
                        AudiA1 -> (Door3 || Sportback);
                },
                AudiA3
                {
                        AudiA3 -> (A3 || A3Sportback || A3Cabriolet
                                || S3 || S3Sportback || RS3Sportback);
                        AudiA3 -> (Door3 || Sportback || Cabriolet);
                },
                AudiA4
                {
                        AudiA4 -> (A4Avant || A4AllroadQuattro || S4Avant);
                        AudiA4 -> (Avant || AllroadQuattro);
                },
        }

}
```

constraints definition

Boolean expressions in terms of features that must remain true

TVL : someOf – or decomposition

feature definition

or decomposition

one or more subfeatures must be present in the product

```
Equipment{
        group someof {
                Package,
                EquipExterior,
                Tyres,
                EquipInterior,
                SteeringWheels,
                Seats,
                SafetyAndTechnology,
                AudiAndCommunication,
                Warranty
        }
}
```

TVL : Cardinalities

```
Fuel {
        group [1..2] {
                Diesel,
                Gas,
                LPG,
                Electricity
        }
    LPG -> Gas
    Diesel excludes Gas
    LPG excludes Electricity
}
```

or decomposition

the minimum and maximum number of features that must be present in the product are specified

additional constraints

more restrictive than cardinalities alone

TVL : Attributes

numerical attribute

```
Exterior {
  group allof {
          Wheels {
              int size in [17..19]
          }
  }
}
```

value range

TVL : Constants

```
const int minSize is 17;
const int maxSize is 19;

Exterior {
  group allof {
      Wheels {
           int size in [minSize..maxSize]
      }
  }
}
```

constants can be reused

constants are allowed in cardinalities, expressions, etc.

TVL : Attributes

```
Car {
    int price is sum(children.price);

    Equipment {
        int price is sum(selectedChildren.price);

        group someof {
           NavigationSystems {
               int price is 605;
           },
           Telephone {
               int price is 300;
           },
           Speakers {
               int price is 690;
           },
           Other {
               int price is 385;
           }

        }
}
```

aggregation function

aggregation functions : sum, mul, min, max

built-in selectors

TVL : Attributes

```
Car {
   int engineSize in {1300, 1500, 1900, 2200};
   enum bodyType in {Sedan, Coupe, Break, Cabriolet};
   bodyType type;
   type == Break -> ...
}
```

enumeration of possible values

enumerated type definition

enumerated attribute

TVL : ifIn / ifOut

```
Infotainment {
     group someof {
           NavigationSystem {
              int price;
              group oneof {
                 DVDBased {
                      ifIn: NavigationSystem.price == 1620;
                 },
                 HDDBased {
                      ifIn: NavigationSystem.price == 2045;
                 }
              }
           },
           ...
    }

}
```

conditional constraint

ifIn : applies only if the feature is selected

ifOut : applies if the feature is not selected

TVL : Ternary operator

```
Infotainment {
    group someof {
            NavigationSystem {
               int price = DVDBased ? 1620 : 2045;
               group oneof {
                       DVDBased,
                       HDDBased
               }
            },
            ...
    }

}
```

condition
a feature is true if it is selected

value if condition is false

value if condition is true

TVL : Modularity

```
root Car {
          group allOf {
          BodyStyle,
          Model,
          Engine,
          Equipment }

}

include(BodyStyle.tvl);
include(Model.tvl);
include(Engine.tvl);
include(Equipment.tvl);
```

Split model in reusable parts using external files

TVL : Modularity

BodyStyle.tvl

```
BodyStyle {
    group oneof {
            Avant,
            Door3,
            Sportback,
            Coupe,
            Cabriolet,
            Roadster,
            Spyder,
            SUV
     }

}
```

Model.tvl

```
Model {
    group oneof {
            A1,
            A3,
            S3,
            A4,
            S4,
            A5,
            S5,
            RS5,
            A6,
            A7,
            A8,
            A8L,
            R8
            Q3,
            Q5,
            Q7,
            TT,
            TTS,
            TT RS
     }
}
```

Engine.tvl

```
Engine {
   group oneof {
      SE12TFSI,
      CE14TFSI,
      CE14TFSI119,
      Sport12TFSI,
      Sport14TFSI,
      Sport14TFSI119,
      BlackEdition14TFSI,
      SLine12TFSI,
      SLine14TFSI,
      SE16TDI,
      CE16TDI,
      CE20TDI,
      ...
     }

}
```

TVL : Tools

- Key references
  - Classen, A.; Boucher, Q. and Heymans, P. A Text-based Approach to Feature Modelling: Syntax and Semantics of TVL. In Science of Computer Programming (SCP), Special Issue on Software Evolution
  - Hubaux, A.; Boucher, Q.; Hartman, H.; Michel, R. and Heymans, P. Evaluating a Text-based Feature Modelling Language: Four Industrial Case (SLE 2010)
  - http://info.fundp.ac.be/tvl/
- Support
  - Parser / Syntactic and semantic checker
  - SAT-based checker for Boolean models

- Ongoing
  - SMT-based checker for models with numerical attributes (ongoing)
  - Eclipse editor (ongoing)

Managing variability models with FAMILIAR

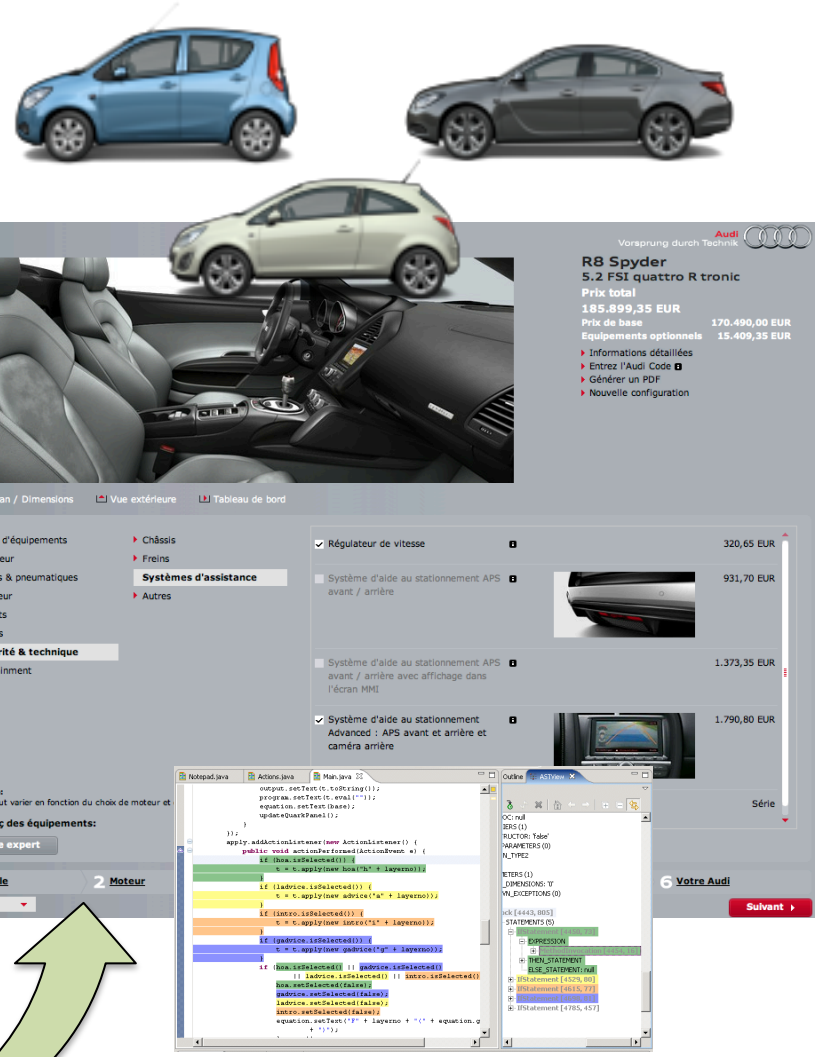
At the end of the tutorial (bis)

- You will have an overview of what's going on in the field of variability and model-based software product line engineering
- You will be able to go further with the languages and modelling techniques
  - reuse them in practical or academic contexts

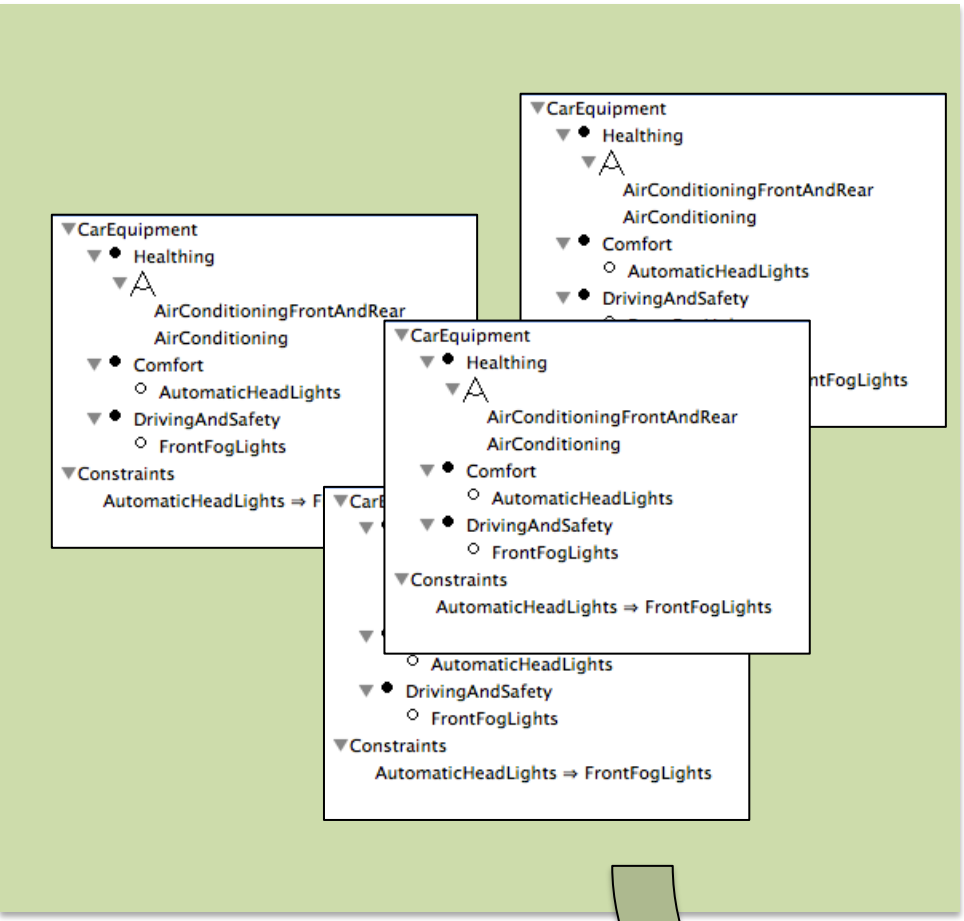
- Supporting material: https://nyx.unice.fr/projects/familiar/wiki/MODELS12-tutorial
  - slides of the tutorial
  - related articles,
  - TVL models,
  - FAMILIAR scripts,
  - and packaged tools to interactively play with the models during the tutorial.

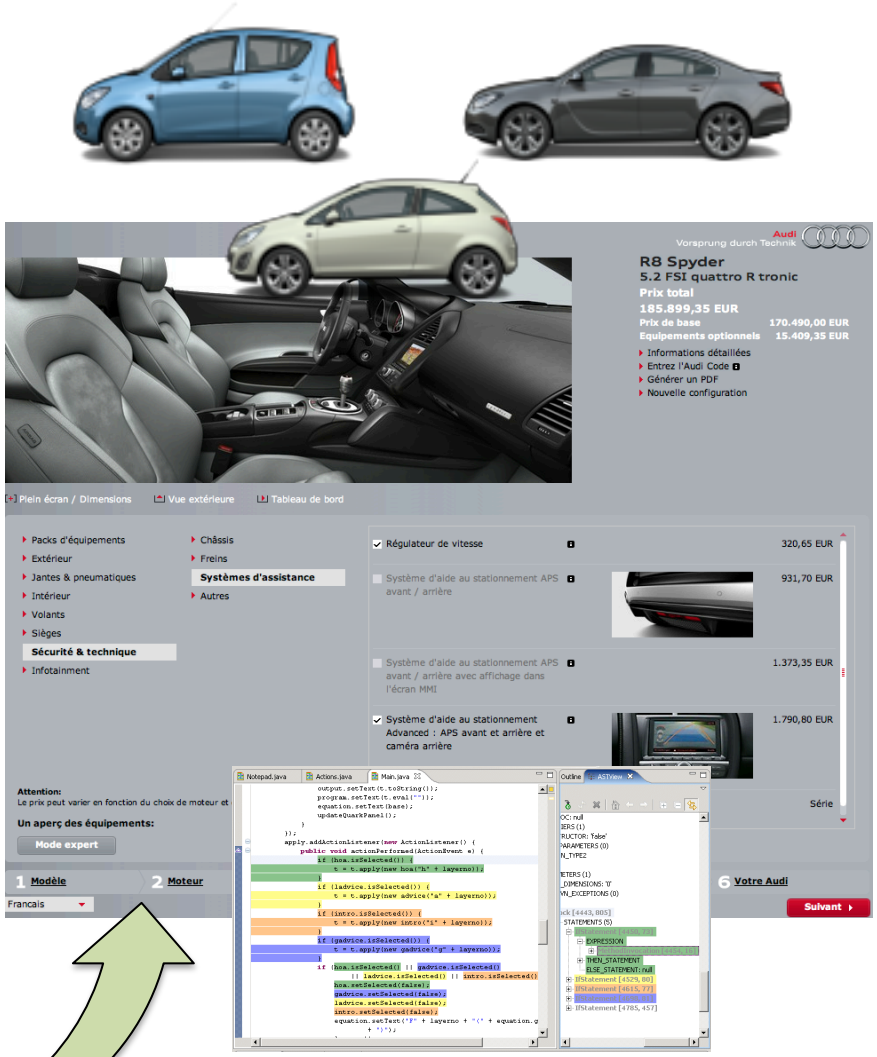
#1 Automated Analysis

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

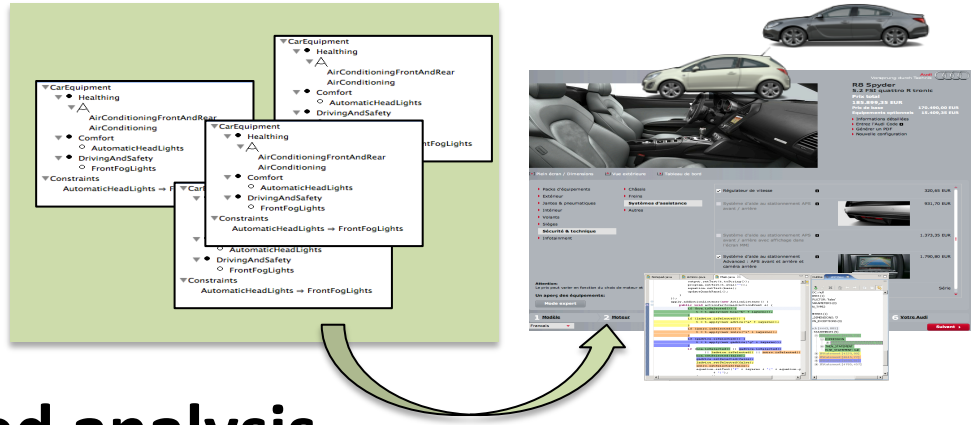


#2 Multiple Feature Models





Two Key Requirements



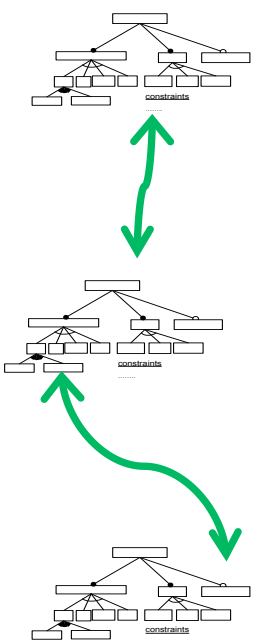
- **#1 Automated analysis**
  - Aka support to better understand and play with your feature model (TVL model)

Automated analysis of feature models 20 years later: A literature review☆

David Benavides *, Sergio Segura, Antonio Ruiz-Cortés

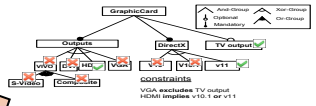
- **#2 Managing <u>multiple</u> feature models**
  - Composing / Decomposing / Diff and Reasoning about their relationships
  - Combining these operators

FAMILIAR language and environment

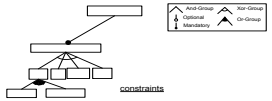



```
// foo.fml
fm1 = FM ("foo1.tvl")
fm2 = FM ("foo2.m")
fm3 = merge intersection { fm1 fm2 }
c3 = counting fm3
renameFeature fm3.TV as "OutputTV"
fm5 = aggregate { fm3 FM ("foo4.xml") }
assert (isValid fm5)
fm6 = slice fm5 including fm5.TV.*
export fm6
```

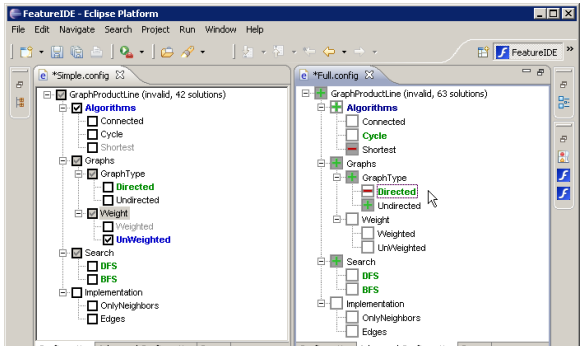
FAMILIAR

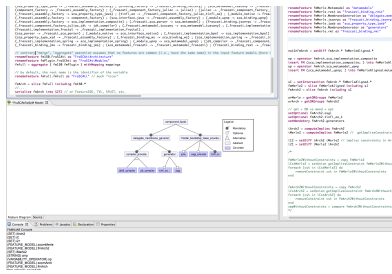


True/False
8759
"OutputTV", "TV"



Interoperability **Language facilities** **Environment**





FAMILIAR … features

Interoperability

fm1 = FM("foo.tvl")
fm2 = FM ("foo.m")
fm3 = FM ("foo.xmi")
fm4 = FM (A : B ….)

serialize fm4 into SPLOT
serialize fm1 into featureide

Reasoning

isValid
counting
configs
cores
deads
configuration
select
deselect
asFM
falseOptionals
cleanup
compare

De/Composition

merge
diff
intersection
sunion
insert
aggregate
map
unmap
extract
slicing

Editing

renameFeature
removeFeature
accessors
copy
setOptional
setMandatory
setAlternatives
setOr

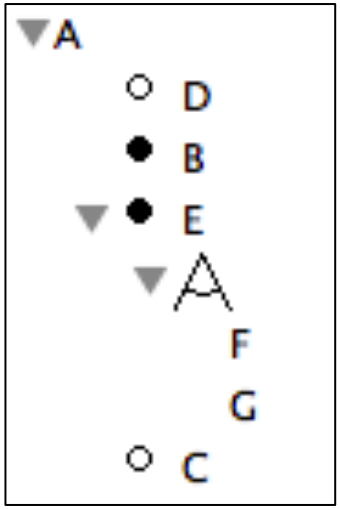
Language Facilities

fm1.*
fm1.B
iterator/conditional
assertion
modular mechanisms
restricted set of types

helloworld.fml

Hello World

```
fm1 = FM ("foo1.tvl")
s = "hello world"
c = counting fm1
n = size fm1.*
println s
```




```
MacBook-Pro-de-Mathieu-2:FML-scripts macher$ java -jar -Xmx1024M ../FML-0.9.9.6.jar helloworld.fml
hello world

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
(DOUBLE) c
(FEATURE_MODEL) fm1
(INTEGER) n
(STRING) s
fml>
```

basics2.fml

Typed language

- Domain-specific types
  - Feature Model,
  - Configuration,
  - Feature,
  - Constraint
- Other types include
  - Set
  - String
  - Boolean,
  - Enum,
  - Integer and Real.

```
fm1 = FM ("foo1.tvl")
ft1 = root fm1
ft2 = fm1.B
fts = fm1.*
n = size fts
n2 = cores fm1

cf = configuration fm1
select B in cf
deselect C in cf

cst1 = constraint (B -> !C)
addConstraint cst1 to fm1
```

- A set of operations, called **operators**, are defined for a given type.

basics2.fml

Typed language

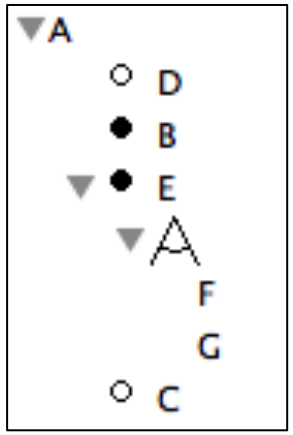
```
fm1 = FM ("foo1.tvl")
ft1 = root fm1
ft2 = fm1.B
fts = fm1.*
n = size fts
n2 = cores fm1

cf = configuration fm1
select B in cf
deselect C in cf

cst1 = constraint (B -> !C)
addConstraint cst1 to fm1
```

```
fml> ls
(FEATURE_MODEL) fm1
(SET) fts
(FEATURE) ft2
(CONSTRAINT) cst1
(INTEGER) n
(CONFIGURATION) cf
(SET) n2
(FEATURE) ft1
```

basics2.fml

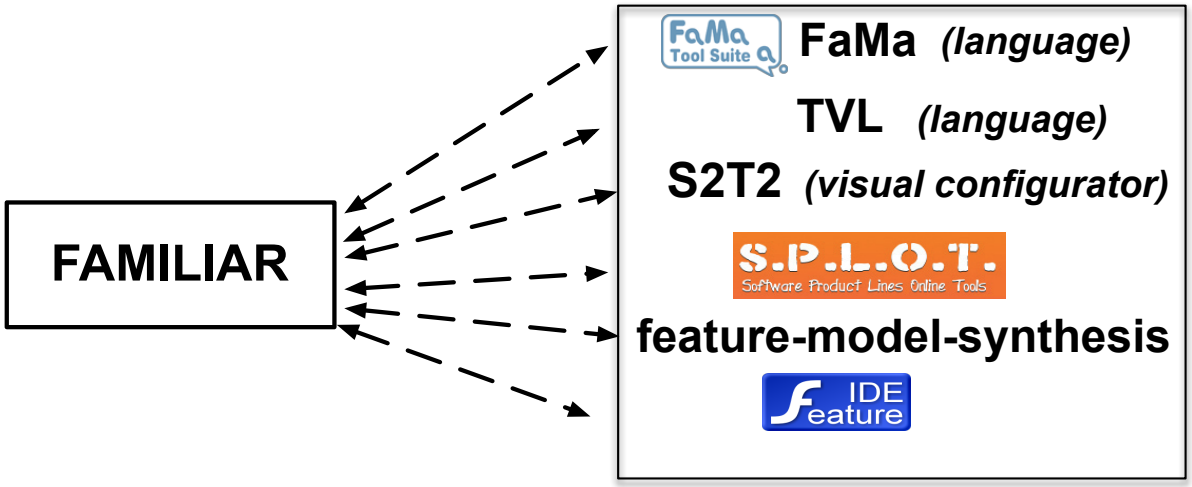
Typed language

```
fm1 = FM ("foo1.tvl")
ft1 = root fm1
ft2 = fm1.B
fts = fm1.*
n = size fts
n2 = cores fm1

cf = configuration fm1
select B in cf
deselect C in cf

cst1 = constraint (B -> !C)
addConstraint cst1 to fm1
```




```
fml> ft1
ft1: (FEATURE) A
fml> ft2
ft2: (FEATURE) B
fml> fts
fts: (SET) {G;E;D;F;C;A;B}
fml> n
n: (INTEGER) 7
fml> n2
n2: (SET) {E;A;B}
fml> cf
cf: (CONFIGURATION) selected: [E, A, B]          deselected: [C]
fml> cst1
cst1: (CONSTRAINT) (B -> !C)
fml> fm1
fm1: (FEATURE_MODEL) A: [D] B E [C] ;
E: (F|G) ;
(B -> !C);
```

Importing/Exporting feature models



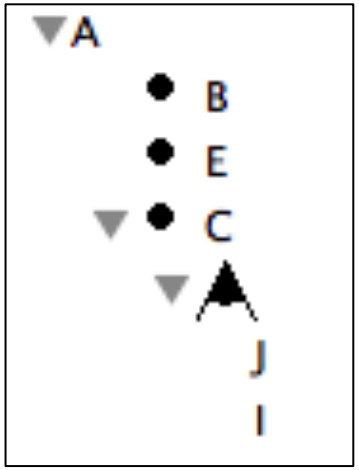
Internal notation *or* by "filename extensions"

```
fm1 = FM ("foo1.tvl")
fm2 = FM (A : [B] [C] D ; )
fm3 = FM ("foo2.m")
serialize fm2 into SPLOT // export
```

ftAccessors.fml

Feature Accessors (1)

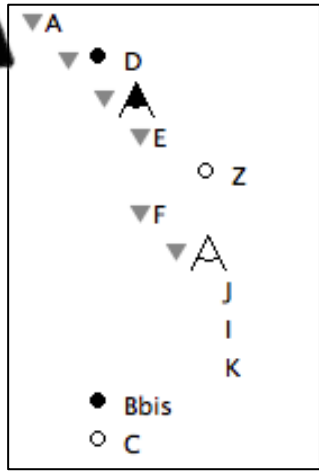
```
fm1 = FM (A : B [C] ; B : E F ; C : (I|J) ; )

r1 = root fm1
s = children r1
s1 = children fm1.A
assert (s eq s1) // equality of the two sets
ft1 = parent fm1.F
str1 = name ft1
ft2 = parent F // parent fm1.F

// another FM
fm2 = FM (A : B C E ; C : (I|J)+ ; )
ft3 = fm2.B
ft4 = name B // ambiguity
```



ftAccessors2.fml

Other constructs

```
fm1 = FM (A: B [C] D; D : (E|F)+; F : (I|J|K); E : [Z]; )
fm1bis = copy fm1 // save the original version

renameFeature fm1.B as "Bbis"
s1 = fm1.* // set of features of fm1
foreach (ft1 in s1) do
        println ft1
end
```

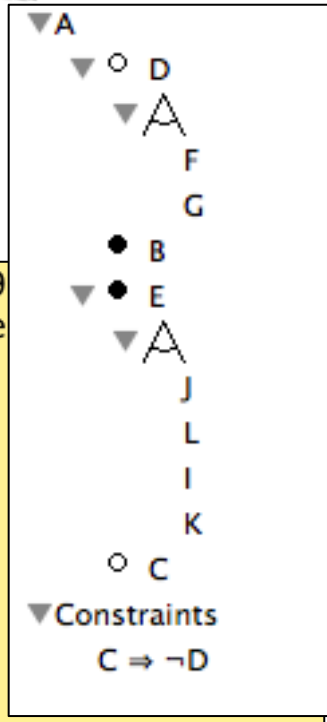



```
acher-scr:FML-scripts macher$ java -jar -Xmx1024M ../FML-0.9.9.5.jar ftAccessors2.fml
Bbis

D

E

A

Z

I

C

J

K

F

FAMILIAR (for FeAture Model scrIpt Language for manIpulation and Automatic Reasoning)  version 0.9.9.5 (bet
University of Nice Sophia Antipolis, UMR CNRS 6070, I3S Laboratory
https://nyx.unice.fr/projects/familiar/
fml> exit
Bye, FAMILIAR user!
```

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!
```

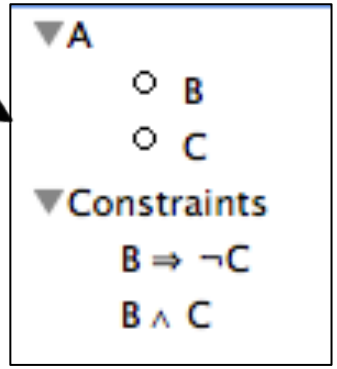



```
MacBook-Pro-de-Mathieu-2:FML-scripts macher$ java -jar -Xmx1024M ../FML-0.9.9
FAMILIAR (for FeAture Model scrIpt Language for manIpulation and Automatic Re
University of Nice Sophia Antipolis, UMR CNRS 6070, I3S Laboratory
https://nyx.unice.fr/projects/familiar/
fml> cFM1
cFM1: (FEATURE_MODEL) A: 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);
```

operatorsFM.fml

Operations for Feature Models (1)

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



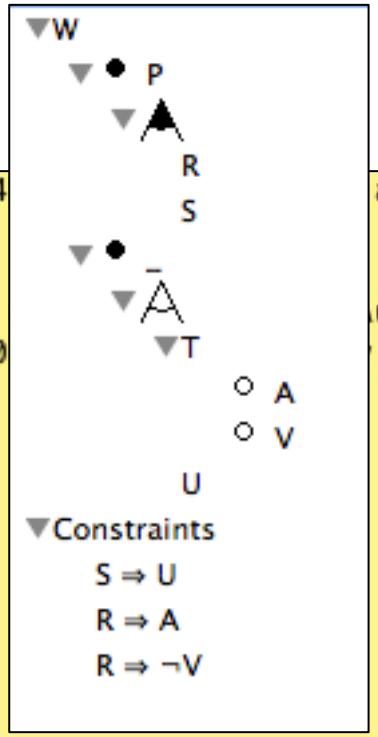

```
acher-scr:FML-scripts macher$ java -jar -Xmx1024M ../FML-0.9.9.5.jar operatorsFM.f
FAMILIAR (for FeAture Model scrIpt Language for manIpulation and Automatic Reasoni
University of Nice Sophia Antipolis, UMR CNRS 6070, I3S Laboratory
https://nyx.unice.fr/projects/familiar/
fml> ls
(FEATURE_MODEL)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

φ

operatorsFM2.fml

Operations for Feature Models (2)

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



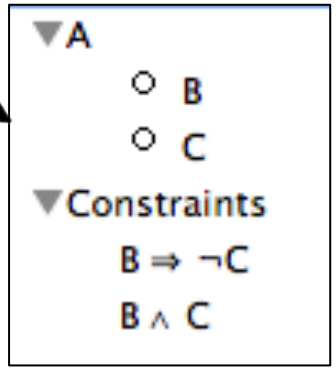

```
acher-scr:FML-scripts macher$ java -jar -Xmx1024                    ar operatorsFM2.fml
cores: {P;W}

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

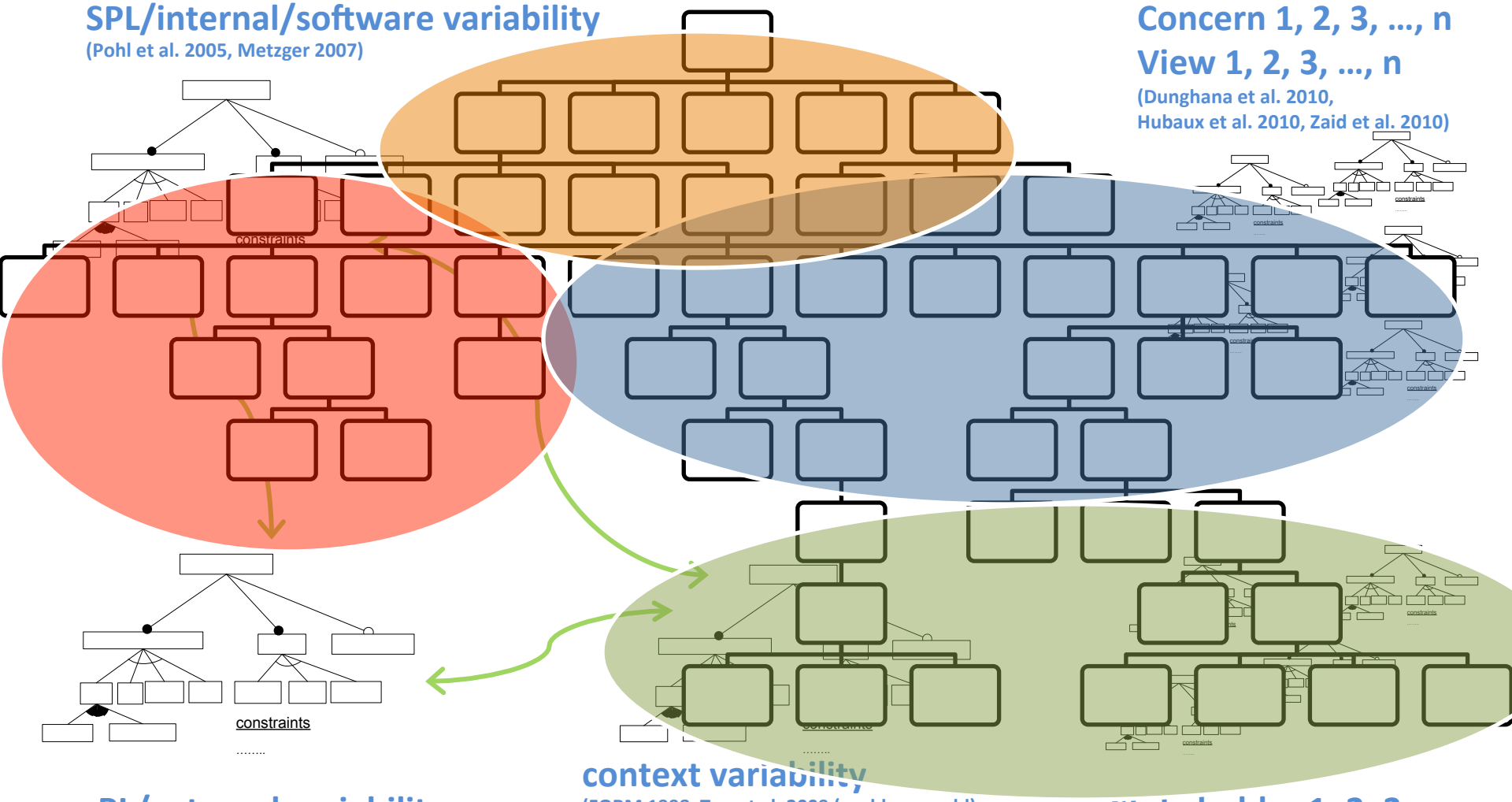
Operations for Feature Models (3)

```
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
```

Multiple Feature Models



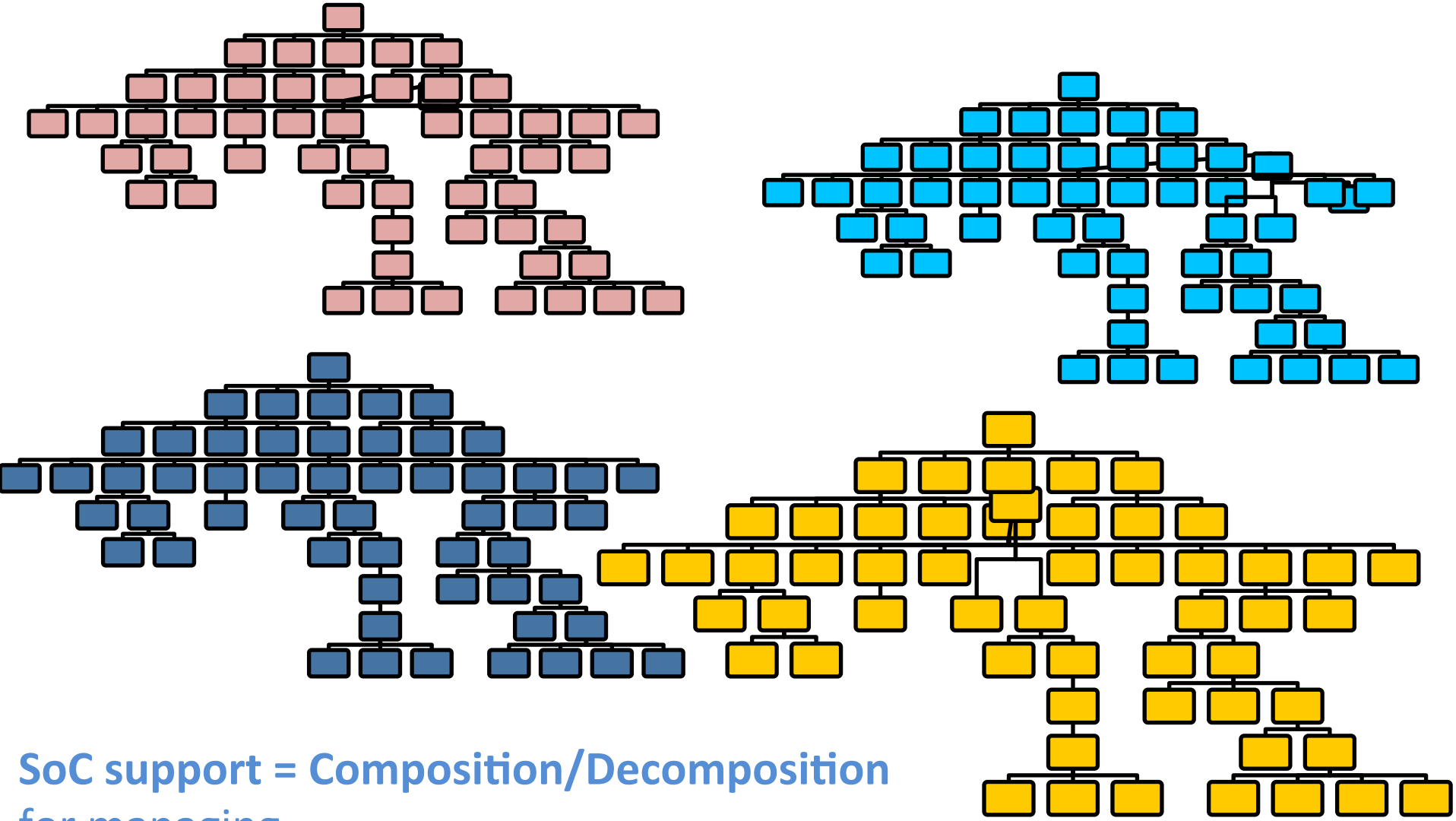
SPL/internal/software variability
(Pohl et al. 2005, Metzger 2007)

Concern 1, 2, 3, …, n
View 1, 2, 3, …, n
(Dunghana et al. 2010,
Hubaux et al. 2010, Zaid et al. 2010)

PL/external variability
(Pohl et al. 2005, Metzger 2007)

context variability
(FORM 1998, Tun et al. 2009 (problem world),
Hartmann 2008 (CVM), Lee et al. 2010

Stakeholder 1, 2, 3, …, n
(Czarnecki 2005, Reiser et al. 2007,
Hartmann et al. 2009, Classen et al. 2009,
Mendonca et al. 2010)



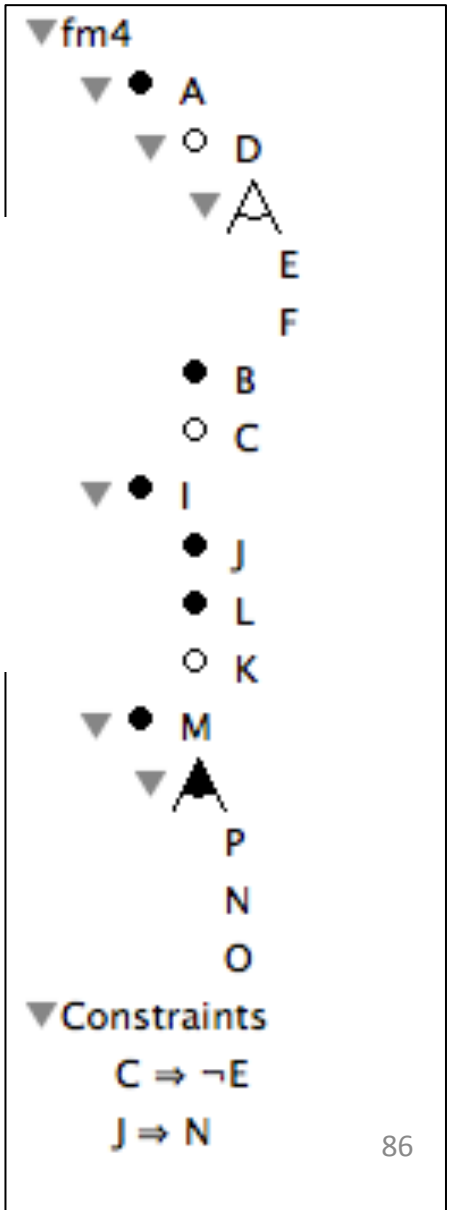
SoC support = Composition/Decomposition
for managing
large, complex and multiple
feature models

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.

aggregateBasics.fml

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

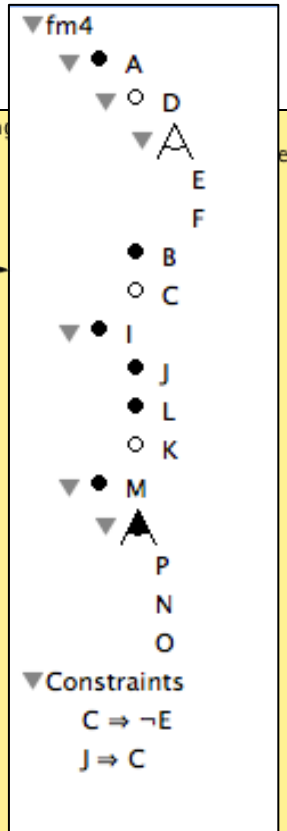
Composing Feature Models (2)

```
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
```

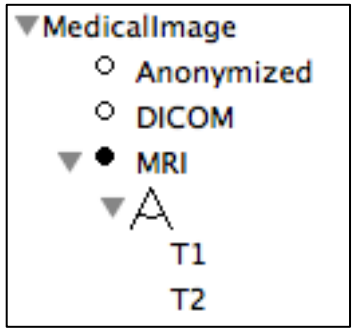
Previous version

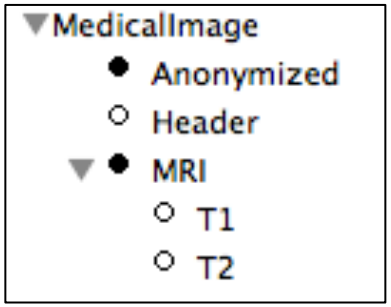
```
MacBook-Pro-de-Mathieu-2:FML-scripts macher$ java -jar -Xmx1024M ../FML-0.9.9.5.jar a
FAMILIAR (for FeAture Model scrIpt Language for manIpulation and Automatic Reasoning)
University of Nice Sophia Antipolis, UMR CNRS 6070, I3S Laboratory
https://nyx.unice.fr/projects/familiar/
fml> cores fm4
res0: (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);
```

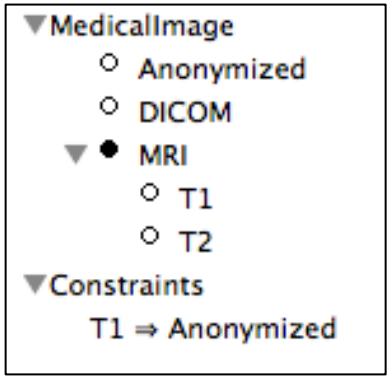


mergeMI.fml

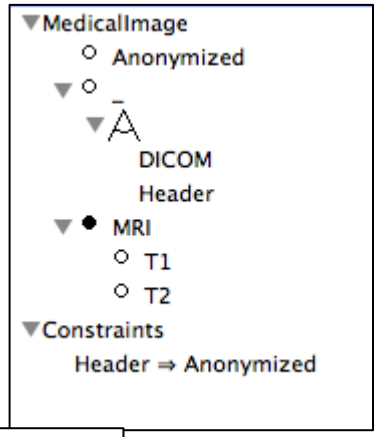
Merging Feature Models

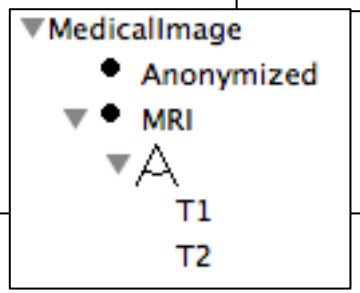







```
fmsupp1 = FM (MedicalImage : [Anonymized] MRI [DICOM] ; MRI : (T1|T2) ;  )
fmsupp2 = FM (MedicalImage : Anonymized MRI [Header] ; MRI : [T1] [T2] ; )
fmsupp3 = FM (MedicalImage : [Anonymized] MRI [DICOM] ; MRI : [T1] [T2] ; T1 -> Anonymized; )

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
```



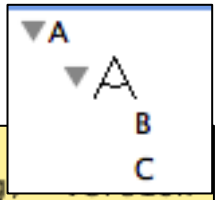


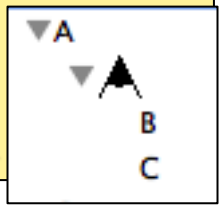
compare.fml

Comparing Feature Models

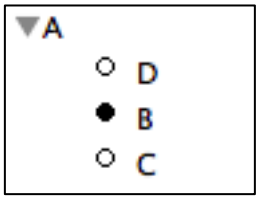
```
fm0 = FM (A: (B|C) ; )
fm1 = FM (A: (B|C)+ ; )
```

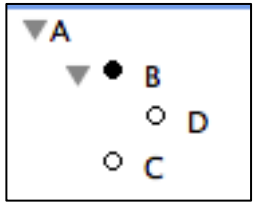
```
MacBook-Pro-de-Mathieu-2:FML-scripts macher$ java -jar -Xmx1024M ../FML-0.9.9.5.jar
FAMILIAR (for FeAture Model scrIpt Language for manIpulation and Automatic Reasoning)
University of Nice Sophia Antipolis, UMR CNRS 6070, I3S Laboratory
https://nyx.unice.fr/projects/familiar/
fml> cmp23
cmp23: (STRING)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

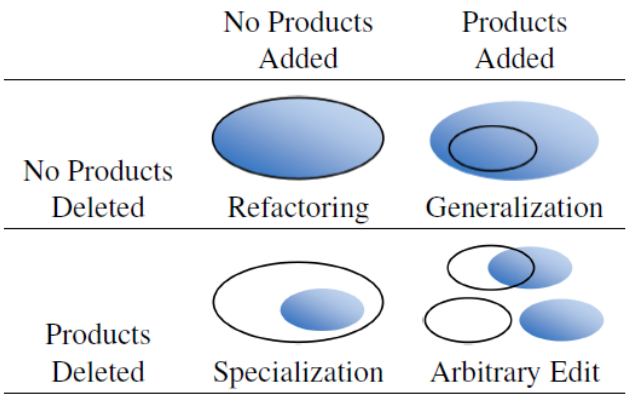





```
assert (cmp10 eq GENERALIZATION)

// 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

Putting all together: Example 1

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?

$\oplus$ $\cap$

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

$\oplus$ $\cap$

- 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

$\oplus_U$

- Registration
  - Header
    - v3
    - v2
    - v1
  - Modality
    - PET
    - CT
    - MRI
  - Affine
    - 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

Yes!

Can suppliers provide *all* products?

"compare"

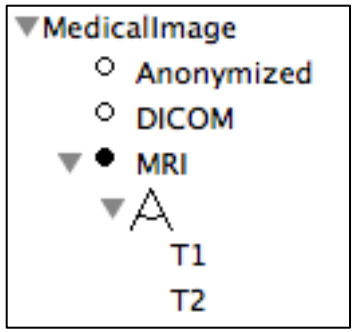
- Registration
  - Header
    - v1
  - Modality
    - CT
    - MRI
  - Format
    - DICOM
    - Nifti
- Constraints
  - DICOM ⇒ ¬MRI

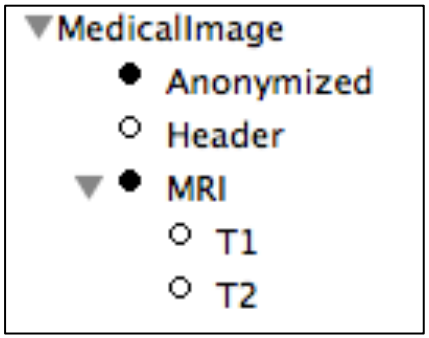
suppliersExample.fml

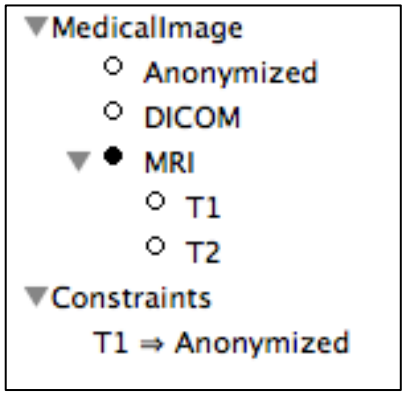
In FAMILIAR

```
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)
```

Anonymized v Header v DICOM v ~T1 v ~T2

Merging operation: semantic issues (2)

φ

$s_0 = \{$

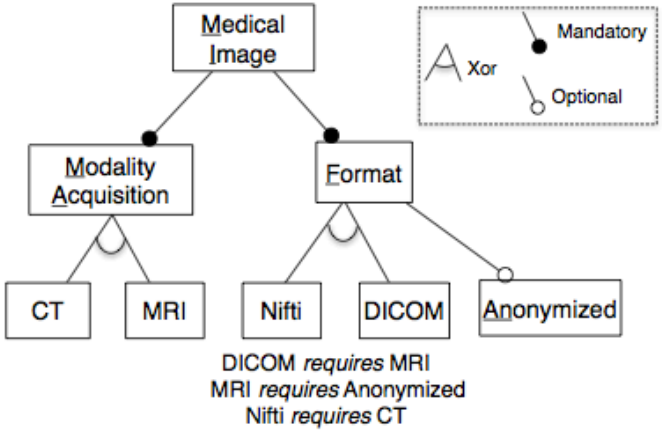
$\{MI, MA, F, CT, Nifti\},$

$\{MI, MA, F, CT, Nifti, AN\},$

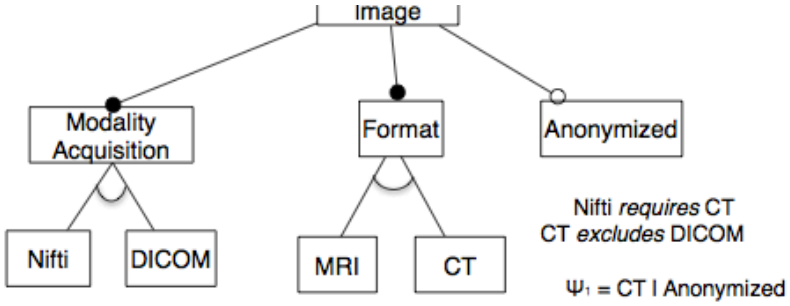
$\{MI, MA, F, DICOM, MRI, AN\}$

$\}$

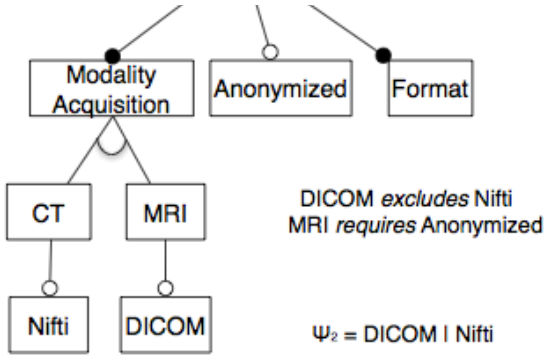
Union
Intersection
Diff



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



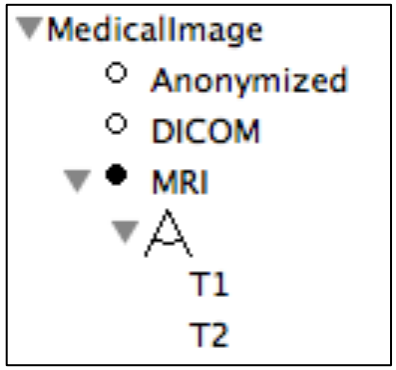
(c) fm_1



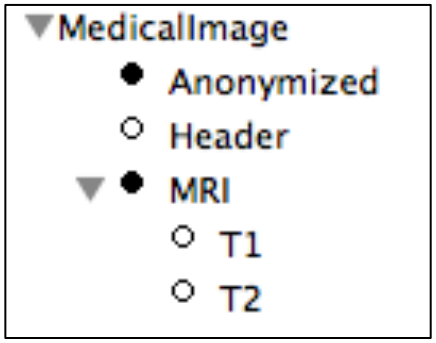
(d) fm_2

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

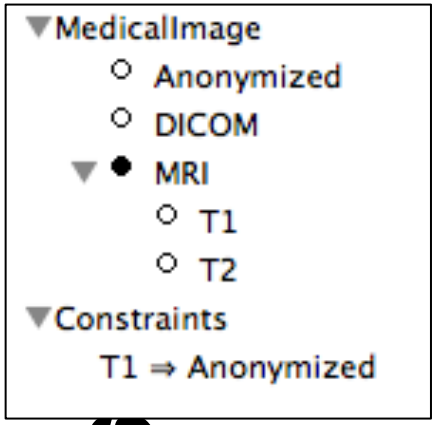
Merging operation: algorithm



φ_1



φ_2



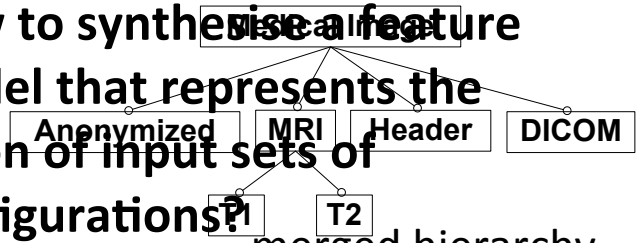
φ_3

φ_{123}

merged propositional formula

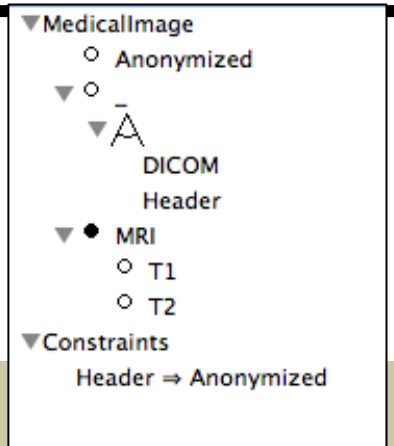
+

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

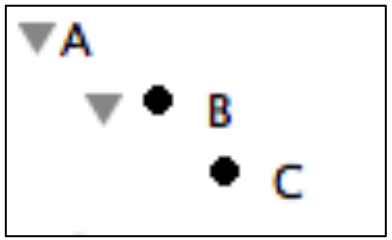


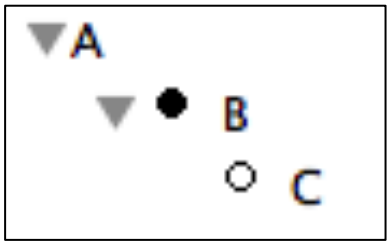
see also [Czarnecki SPLC'07 or SPLC'12]

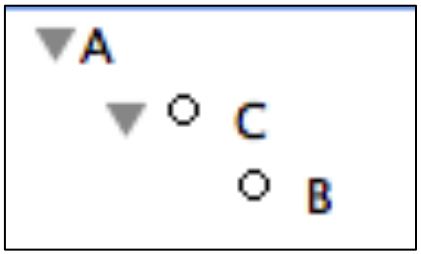
mergeNonPC.fml

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}}

?

see also [Acher PhD thesis]

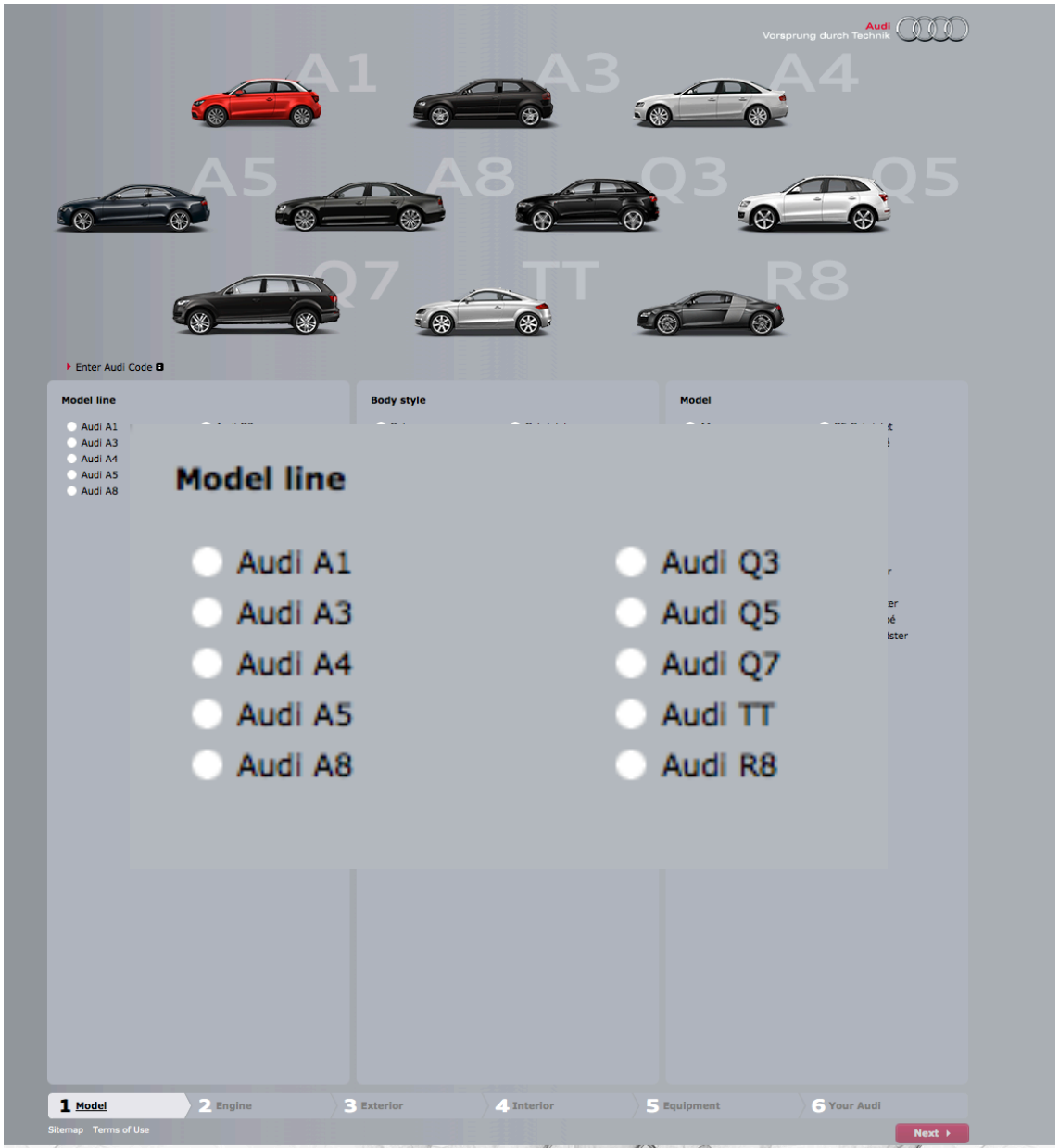
Related Works

- 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'12/AOSD'12/PhD thesis]

Another Example

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

- 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

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

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“

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

#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

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

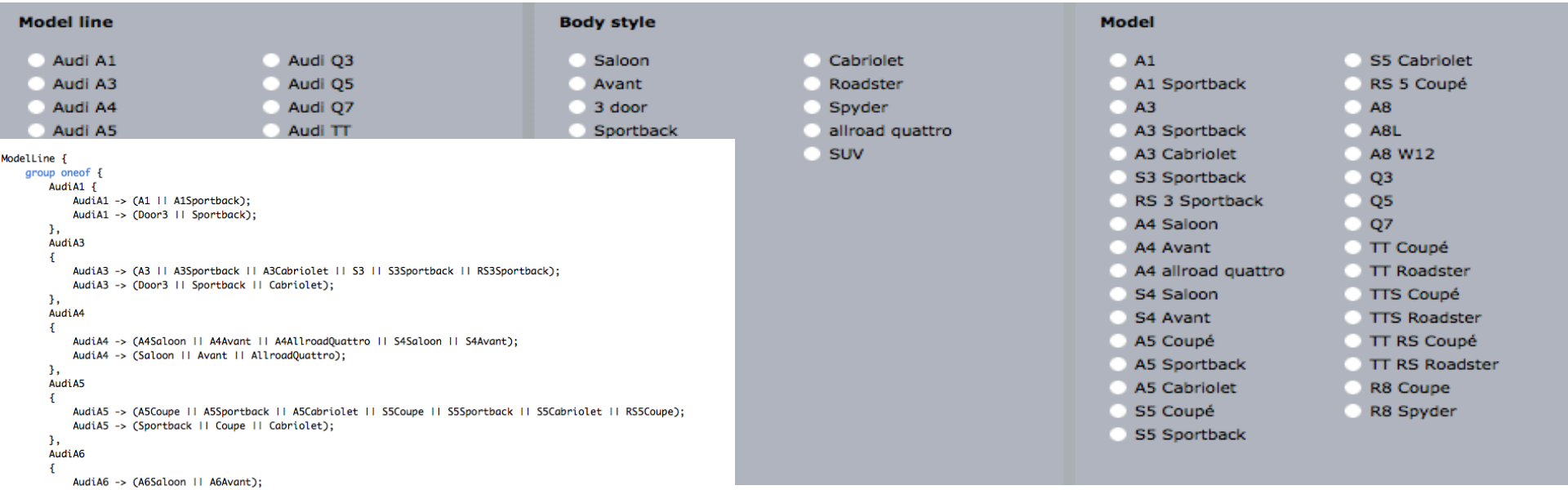
Body style

- 3 door
- Sportback

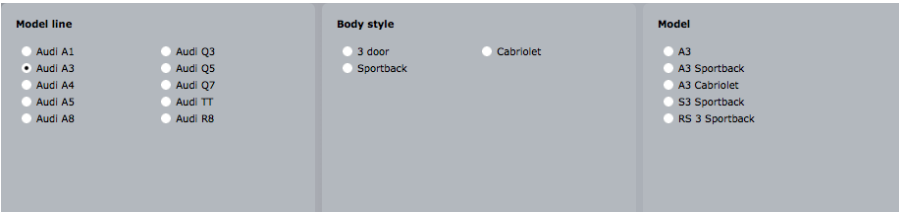
Model

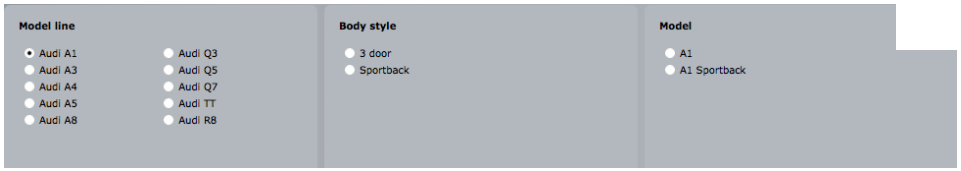
- A1
- A1 Sportback

#1 top-down



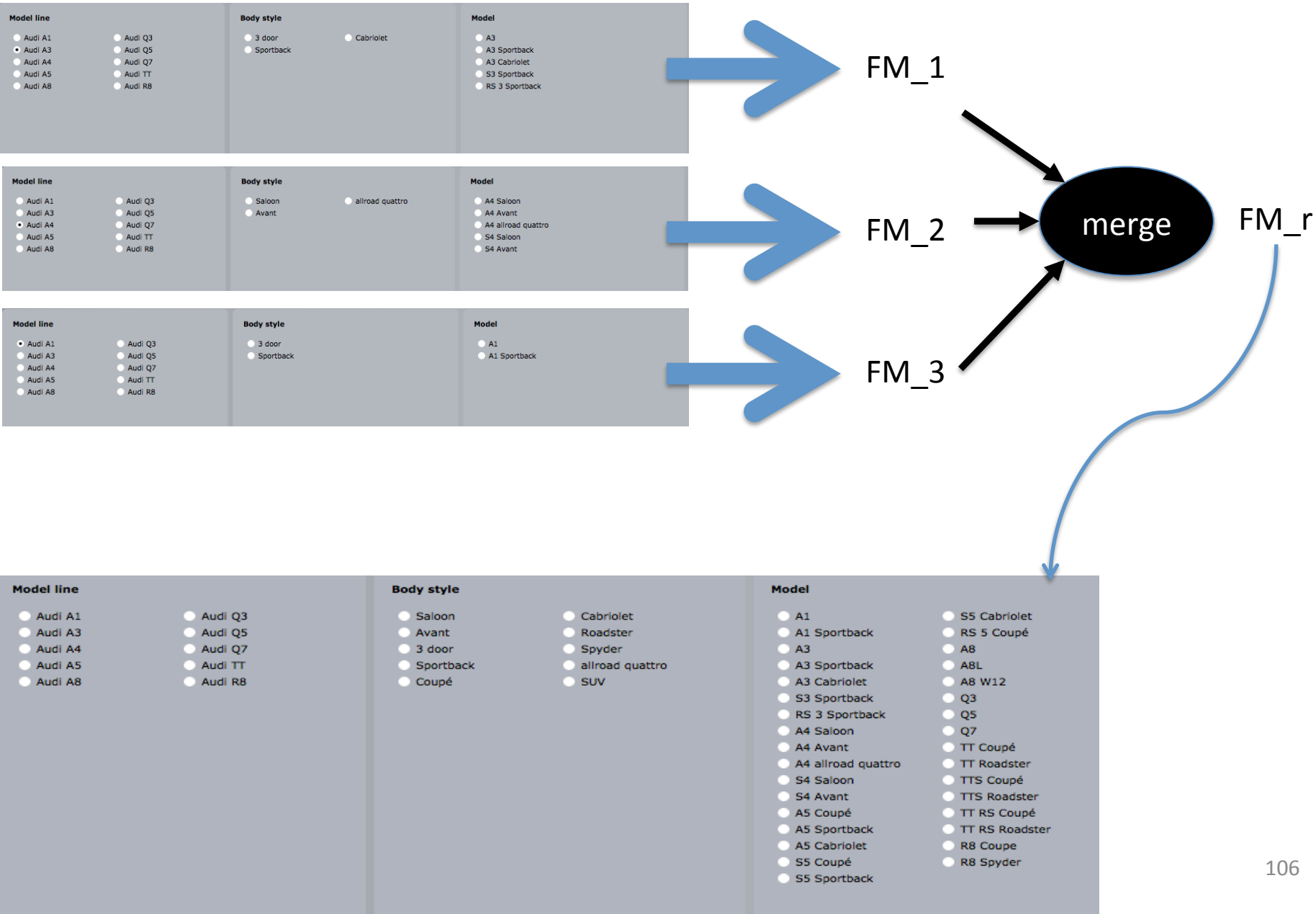

```
ModelLine {
    group oneof {
        AudiA1 {
            AudiA1 -> (A1 || A1Sportback);
            AudiA1 -> (Door3 || Sportback);
        },
        AudiA3
        {
            AudiA3 -> (A3 || A3Sportback || A3Cabriolet || S3 || S3Sportback || RS3Sportback);
            AudiA3 -> (Door3 || 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);
        },
```





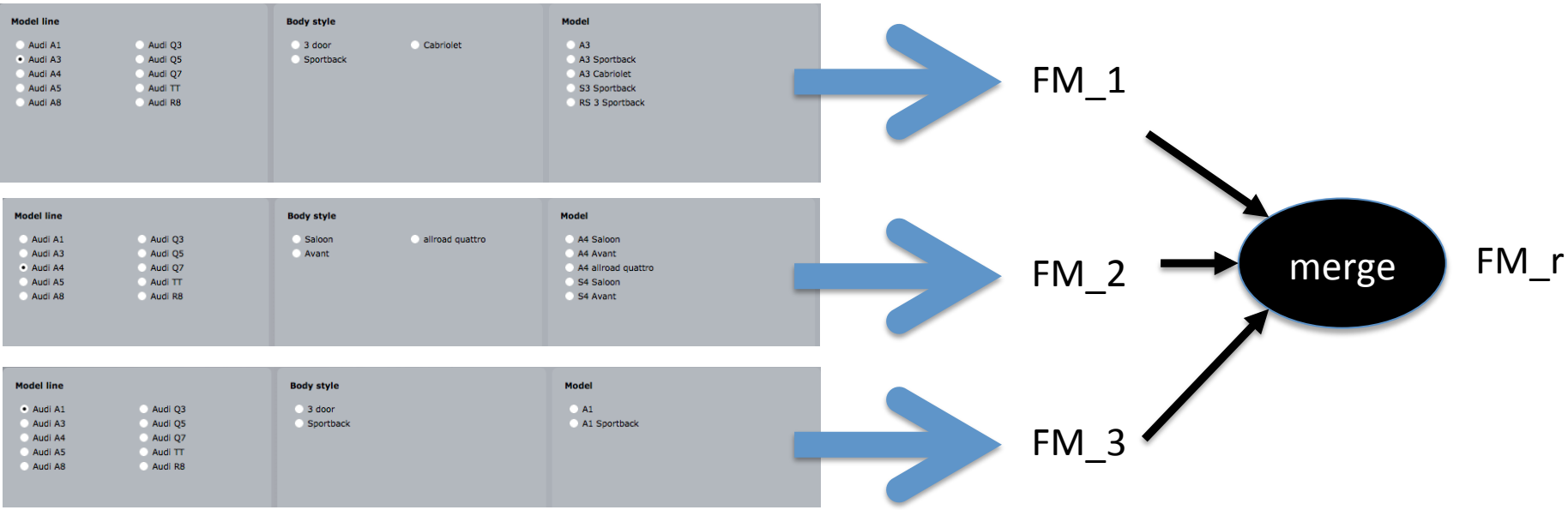

```
BodyStyle {
    group oneof {
        Saloon
        {
            Saloon -> (A4Saloon || S4Saloon || A6Saloon || A8 || A8L || A8W12);
        },
        Avant
        {
            Avant -> (A4Avant || S4Avant || A6Avant);
        },
        Door3
        {
            Door3 -> (A1 || A3 || S3);
        },
        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
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
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
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

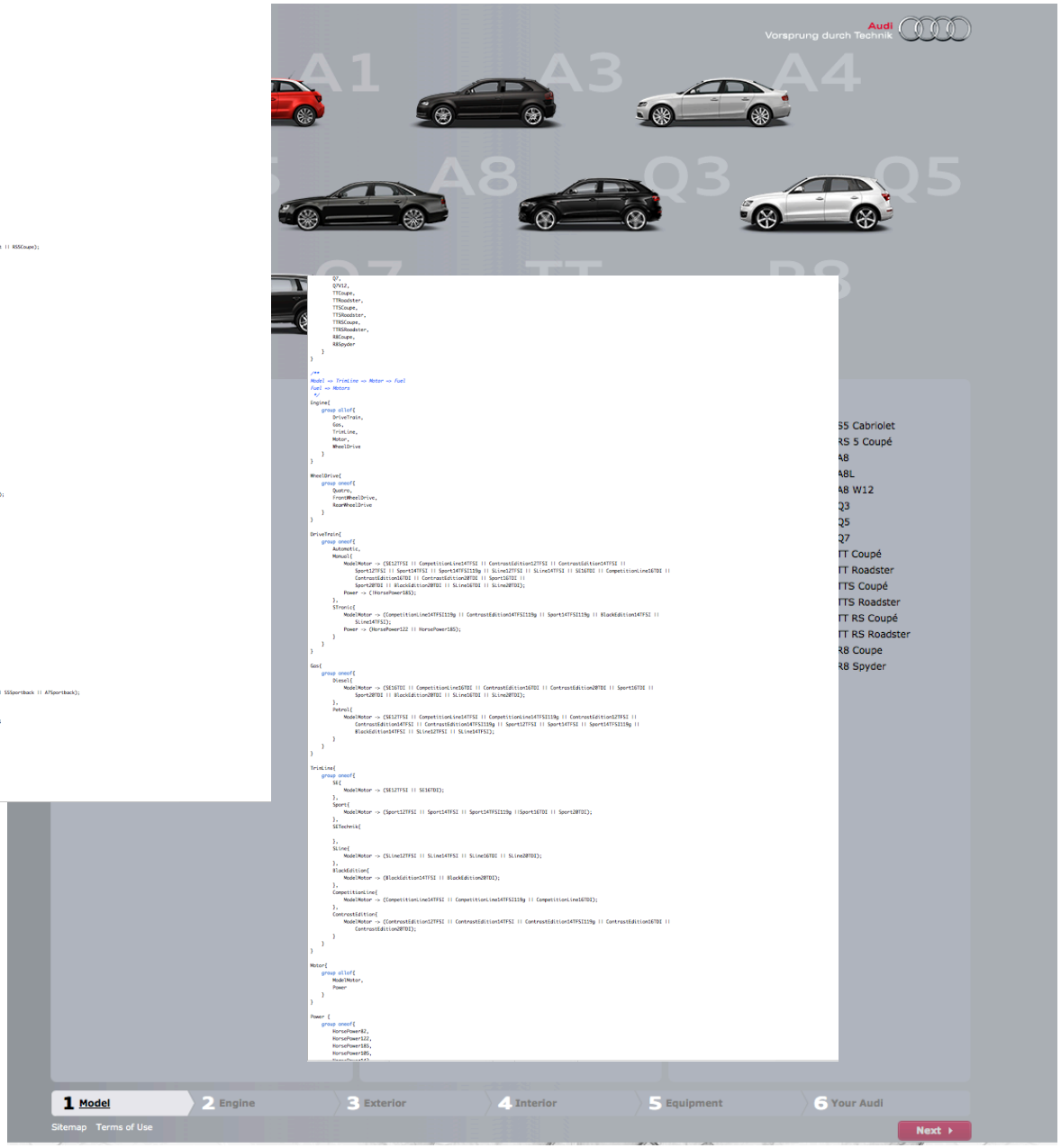
#1 bottom-up (FAMILIAR)




```
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);
```

Building “views” of a feature model

```
root AudiCar {
    group allof{
        ModelLine,
        BodyStyle,
        Model,
        Engine,
        Exterior,
        Interior,
        Equipment
    }
}

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);
        },
        AudiA7
        {
            AudiA7 -> (A7Sportback);
            AudiA7 -> (Sportback);
        },
        AudiA8
        {
            AudiA8 -> (A8 || A8L || A8W12);
            AudiA8 -> (Saloon);
        },
        AudiQ3
        {
            AudiQ3 -> (Q3);
            AudiQ3 -> (SUV);
        },
        AudiQ5
        {
            AudiQ5 -> (Q5);
            AudiQ5 -> (SUV);
        },
        AudiQ7
        {
            AudiQ7 -> (Q7 || Q7V12);
            AudiQ7 -> (SUV);
        },
        AudiTT
        {
            AudiTT -> (TTCoupe || TTRoadster || TTSCoupe || TTSRoadster || TTRSCoupe || TTRSRoadster);
            AudiTT -> (Coupe || Roadster);
        },
        AudiR8
        {
            AudiR8 -> (R8Coupe || R8Spyder);
            AudiR8 -> (Coupe || Spyder);
        }
    }
}

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 || A7Sportback);
        },
        Coupe
        {
            Coupe -> (A5Coupe || S5Coupe || RS5Coupe || TTCoupe || TTSCoupe || TTRSCoupe || R8Coupe);
        },
        Cabriolet
        {
            Cabriolet -> (A3Cabriolet || A5Cabriolet || S5Cabriolet);
        },
        Roadster
        {
            Roadster -> (TTRoadster || TTSRoadster || TTRSRoadster);
        },
        Spyder
        {
```



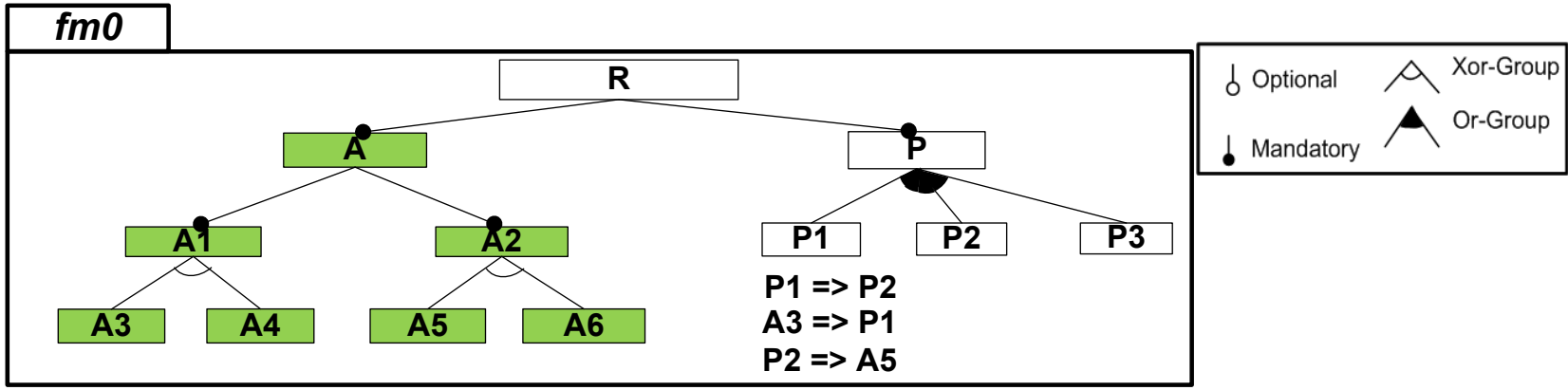

```
        Q7,
        Q7V12,
        TTCoupe,
        TTRoadster,
        TTSCoupe,
        TTSRoadster,
        TTRSCoupe,
        TTRSRoadster,
        R8Coupe,
        R8Spyder
    }
}

/**
Model => TrimLine => Motor => Fuel
Fuel => Motors
 */
Engine{
    group allof{
        DriveTrain,
        Gas,
        TrimLine,
        Motor,
        WheelDrive
    }
}

WheelDrive{
    group oneof{
        Quatro,
        FrontWheelDrive,
        RearWheelDrive
    }
}

DriveTrain{
    group oneof{
        Automatic,
        Manual{
            Model!Motor -> (SE12TFSI || CompetitionLine14TFSI || ContrastEdition12TFSI || ContrastEdition14TFSI ||
                Sport12TFSI || Sport14TFSI || Sport14TFSI119g || SLine12TFSI || SLine14TFSI || SE16TDI || CompetitionLine16TDI ||
                ContrastEdition16TDI || ContrastEdition20TDI || Sport16TDI ||
                Sport20TDI || BlackEdition20TDI || SLine16TDI || SLine20TDI);
            Power -> (HorsePower185);
        },
        Tronic{
            Model!Motor -> (CompetitionLine14TFSI119g || ContrastEdition14TFSI119g || Sport14TFSI119g || BlackEdition14TFSI ||
                SLine14TFSI);
            Power -> (HorsePower122 || HorsePower185);
        }
    }
}

Gas{
    group oneof{
        Diesel{
            Model!Motor -> (SE16TDI || CompetitionLine16TDI || ContrastEdition16TDI || ContrastEdition20TDI || Sport16TDI ||
                Sport20TDI || BlackEdition20TDI || SLine16TDI || SLine20TDI);
        },
        Petrol{
            Model!Motor -> (SE12TFSI || CompetitionLine14TFSI || CompetitionLine14TFSI119g || ContrastEdition12TFSI ||
                ContrastEdition14TFSI || ContrastEdition14TFSI119g || Sport12TFSI || Sport14TFSI || Sport14TFSI119g ||
                BlackEdition14TFSI || SLine12TFSI || SLine14TFSI);
        }
    }
}

TrimLine{
    group oneof{
        SE{
            Model!Motor -> (SE12TFSI || SE16TDI);
        },
        Sport{
            Model!Motor -> (Sport12TFSI || Sport14TFSI || Sport14TFSI119g ||Sport16TDI || Sport20TDI);
        },
        SETechnik{

        },
        SLine{
            Model!Motor -> (SLine12TFSI || SLine14TFSI || SLine16TDI || SLine20TDI);
        },
        BlackEdition{
            Model!Motor -> (BlackEdition14TFSI || BlackEdition20TDI);
        },
        CompetitionLine{
            Model!Motor -> (CompetitionLine14TFSI || CompetitionLine14TFSI119g || CompetitionLine16TDI);
        },
        ContrastEdition{
            Model!Motor -> (ContrastEdition12TFSI || ContrastEdition14TFSI || ContrastEdition14TFSI119g || ContrastEdition16TDI ||
                ContrastEdition20TDI);
        }
    }
}

Motor{
    group allof{
        Model!Motor,
        Power
    }
}

Power {
    group oneof{
        HorsePower82,
        HorsePower122,
        HorsePower185,
        HorsePower105,
```

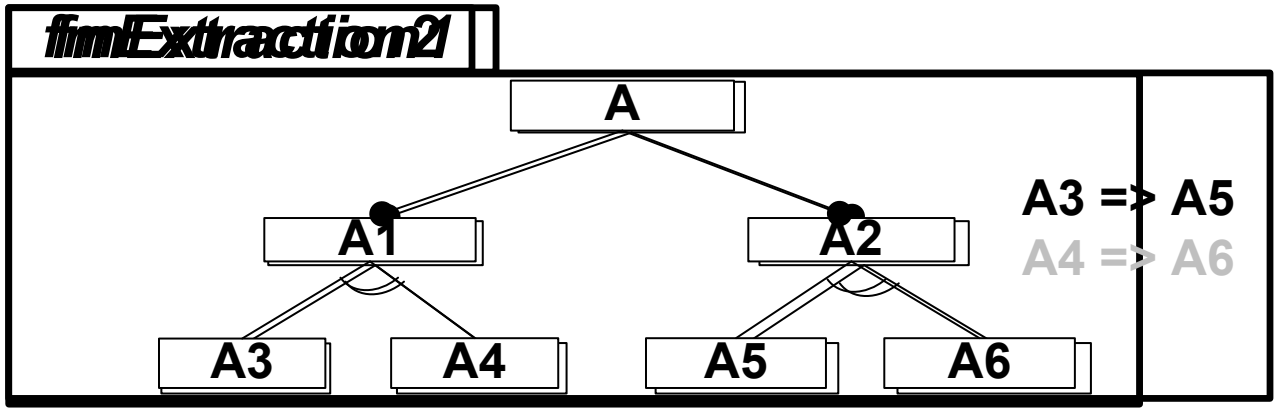
Building "views" of a feature model

- 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



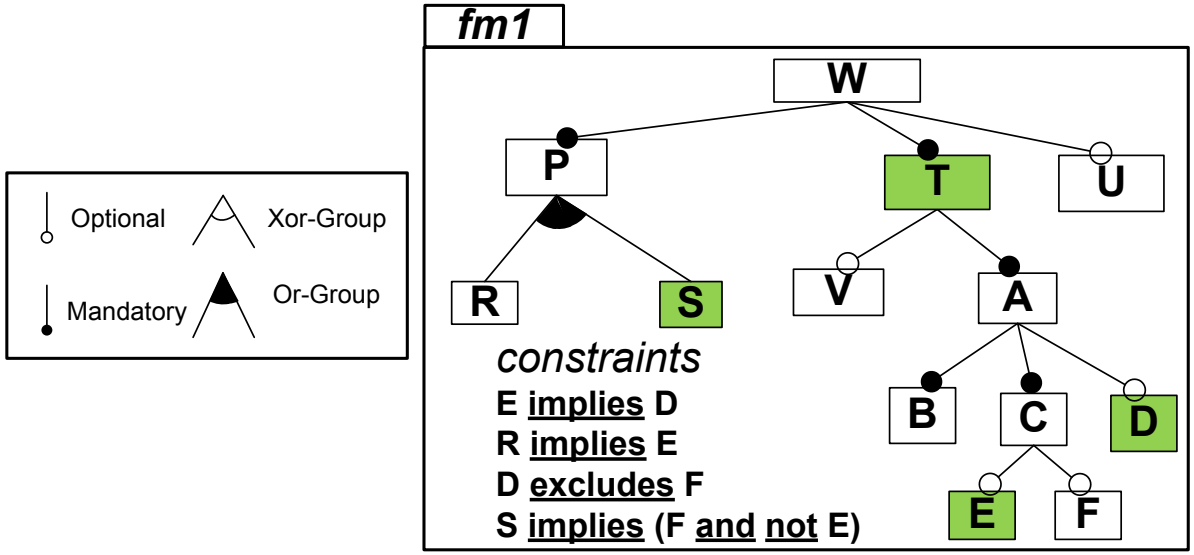


Problem: You can select **A3** without **A5**

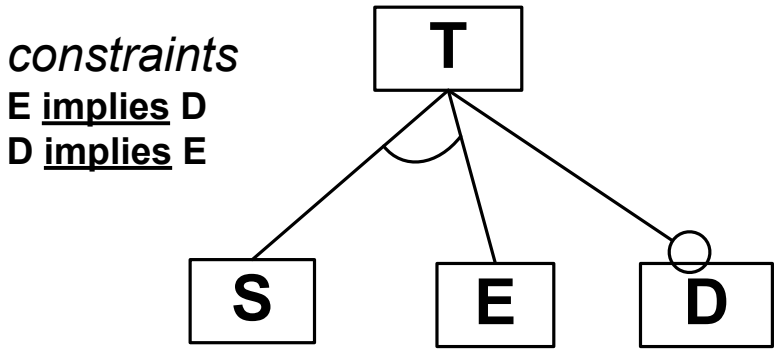
Hierarchy and <u>Configuration</u> matter!

Slicing Operator

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

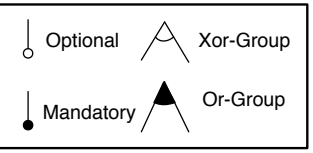


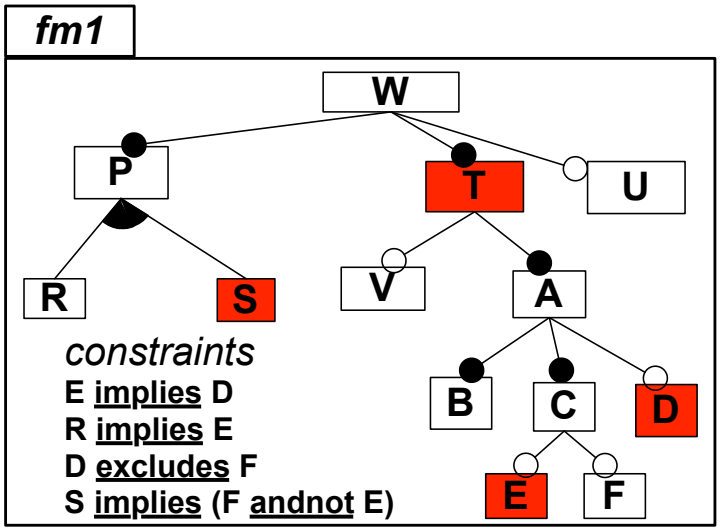
slice : a new feature model, representing a projected set of configurations



Slicing operator: going into details

projected set of configurations



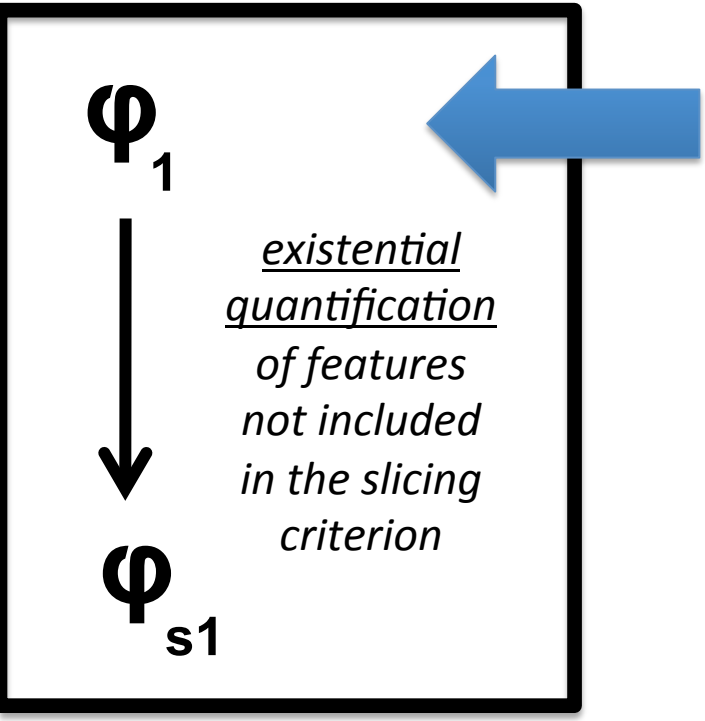


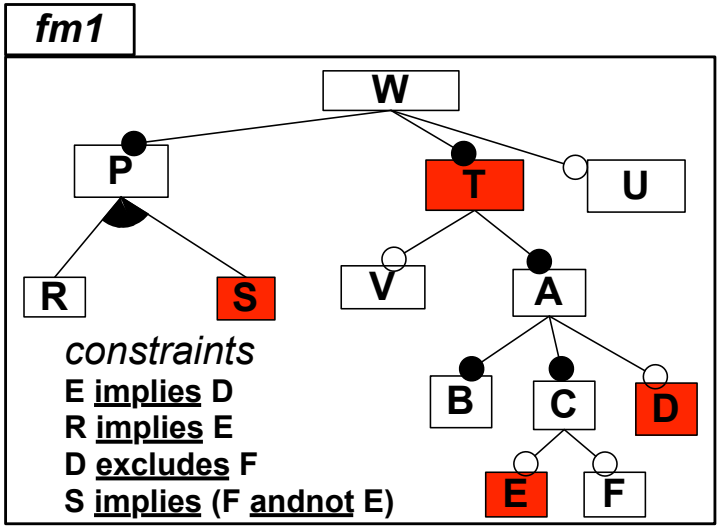
fm1 = {
{A,B,C,D,E,P,R,T,U,W},
{A,B,C,E,P,S,T,U,W},
{A,B,C,D,E,P,R,T,V,W},
{A,B,C,E,P,S,T,V,W},
{A,B,C,E,P,S,T,U,V,W},
{A,B,C,E,P,S,T,V,W},
{A,B,C,D,E,P,R,T,V,W},
} }

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

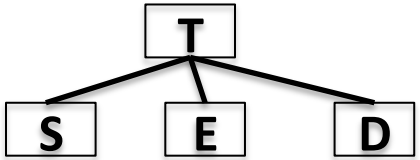
Slicing operator: going into details

synthesizing the corresponding feature model

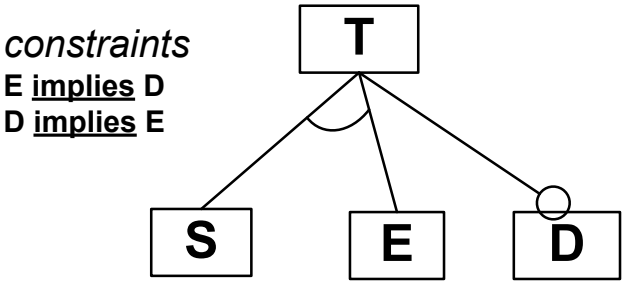




+



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

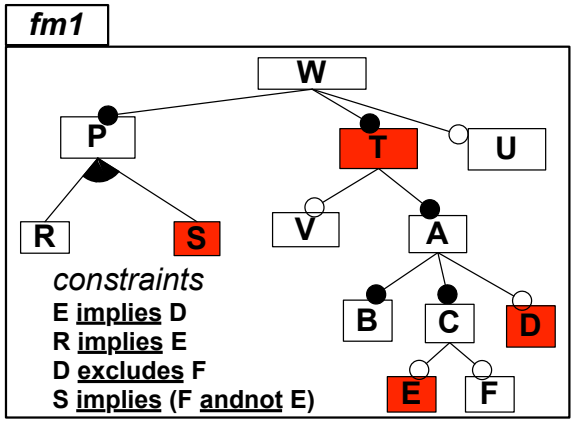


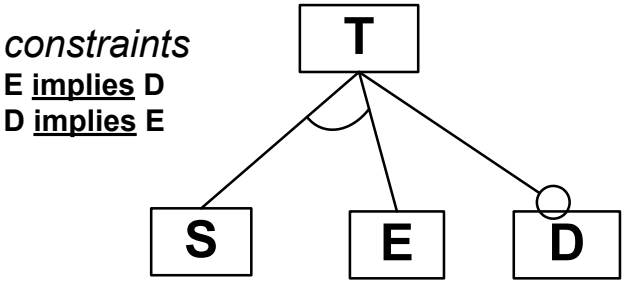
see also [Acher et al., ASE'11/AOSD'12]

slicingOp2.fml

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
```

Revisiting Merge and Slice: AggregateMerge

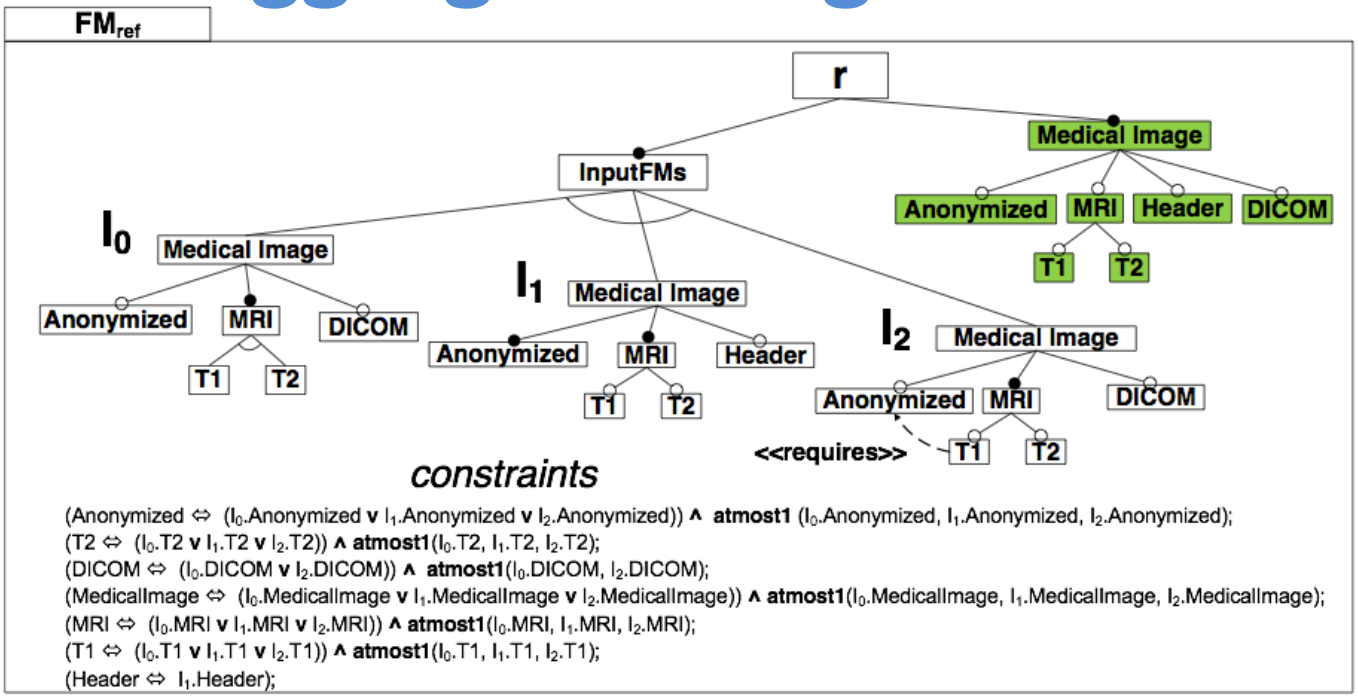
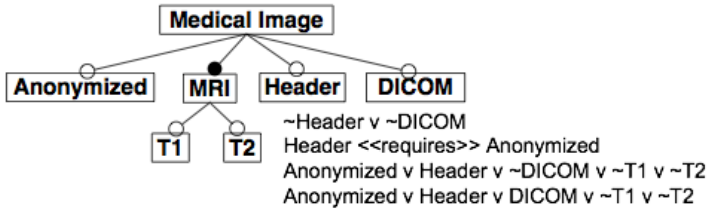


Figure 7.10: Merge of three feature models, I_0, I_1 and I_2 using the slicing operator

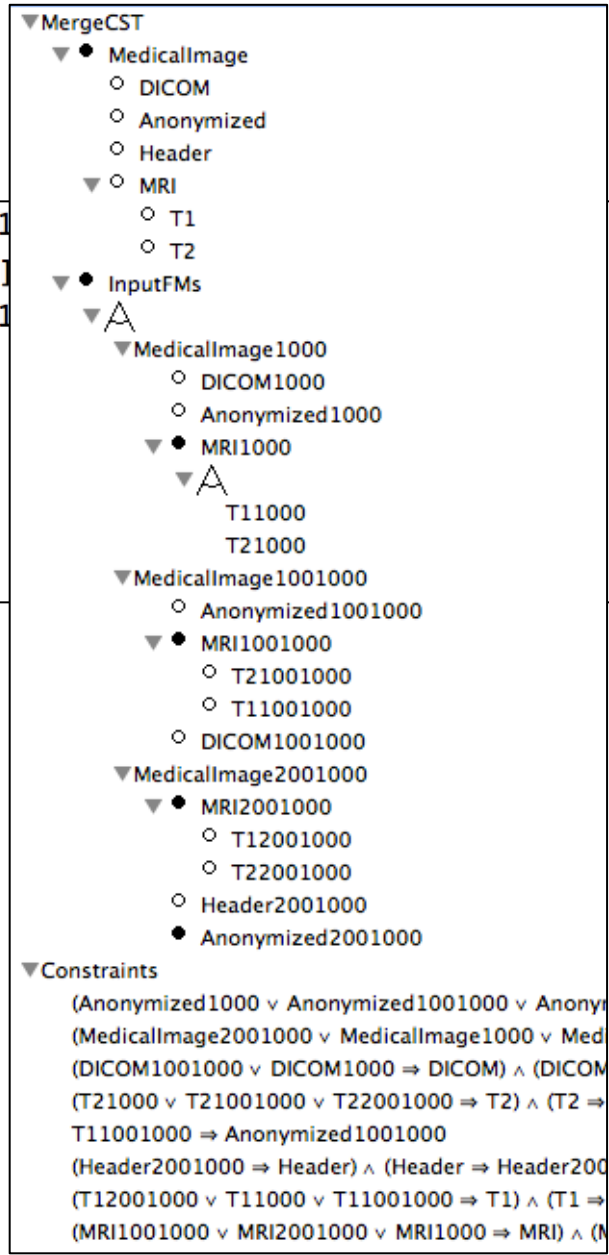


mergeWithAggregateMI.fml

Revisiting Merge and Slice: AggregateMerge

```
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.*
```

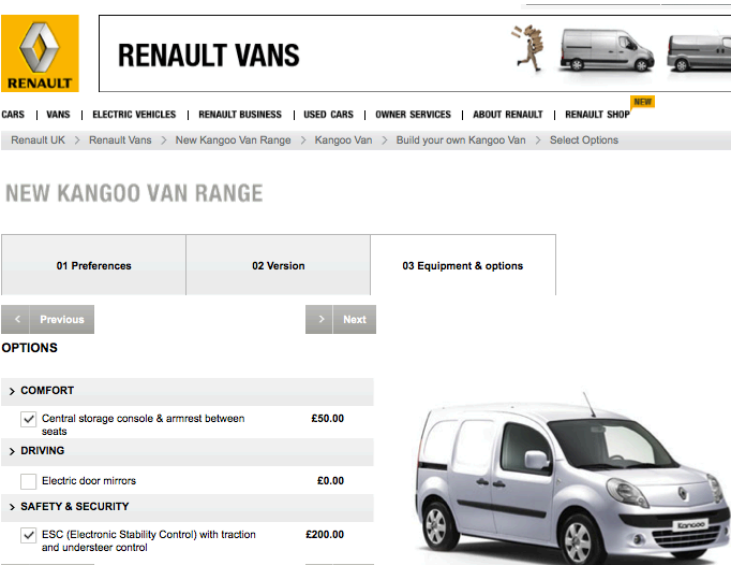
```
fml> compare fmSuppAggSlice fmSupp
res4: (STRING) REFACTORING
```

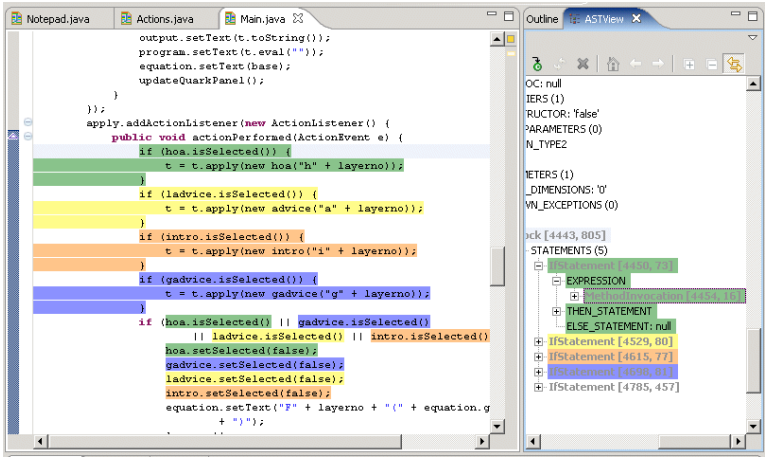


Putting all together: Example 2

From marketing, customers, product management

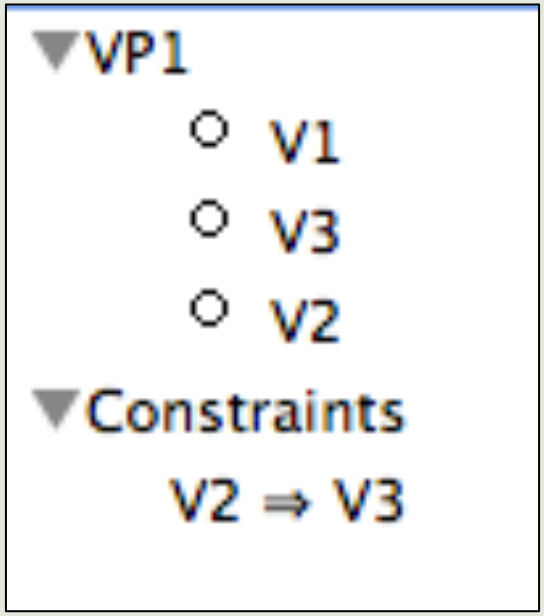
From existing software assets (technical variability)



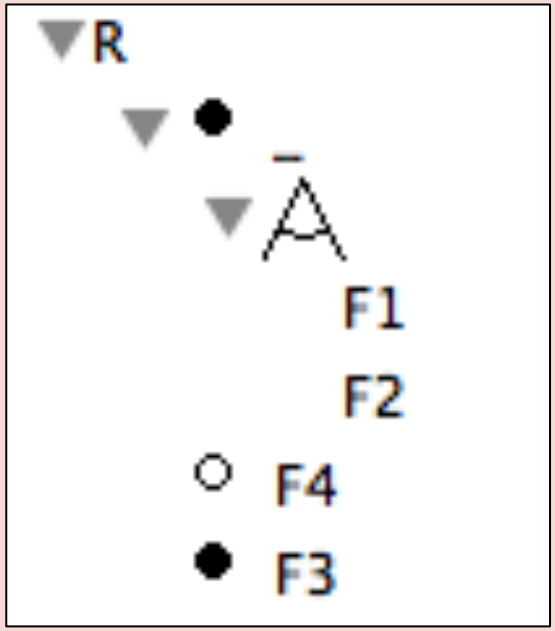


Metzger, Heymans et al. "Disambiguating the Documentation of Variability in Software Product Lines: A Separation of Concerns, Formalization and Automated Analysis" (RE'07)

usefulness



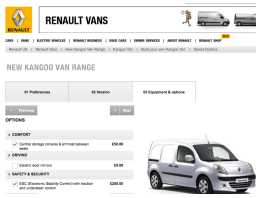
V1 ⇔ f1
V2 ⇔ f2
V3 ⇔ f3

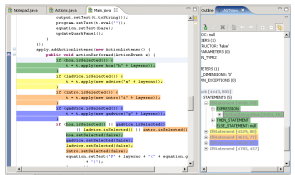


From marketing, customers, product management

From existing software assets

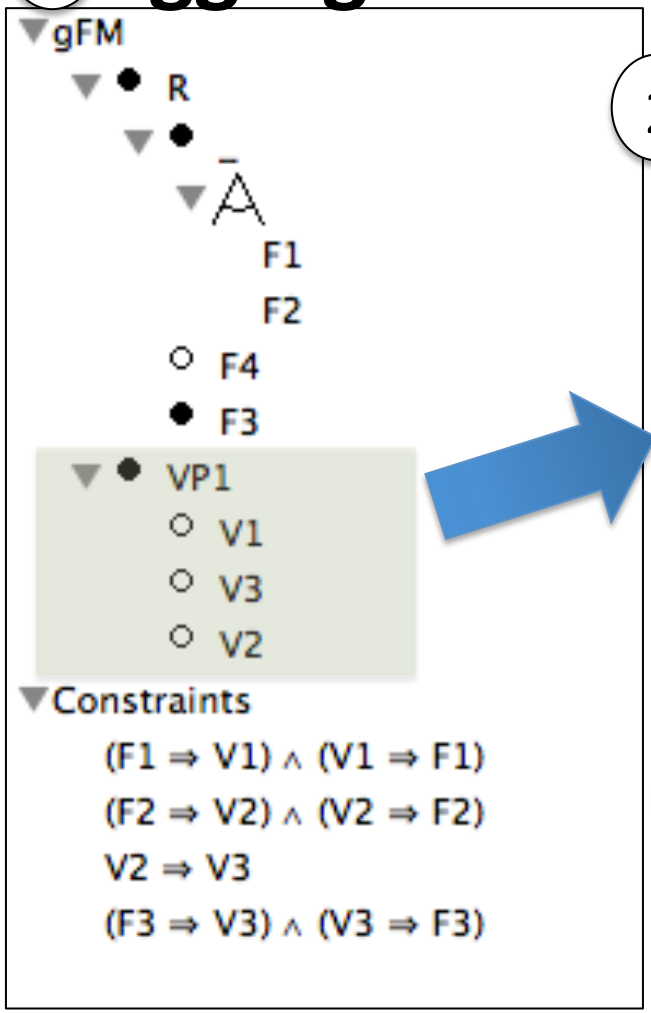
realizability



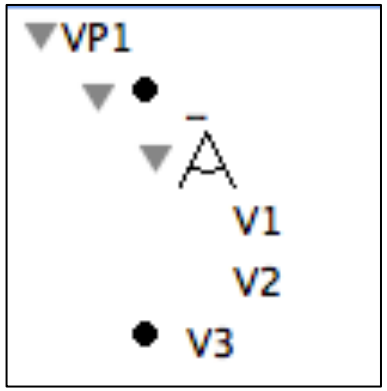


Realizability checking

1 **aggregate**



2 **slice** (“realizable part”)



φ

3 **compare**

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

4 **merge diff**

(“unrealizable products”

see also [Acher et al. AOSD’12 and CAiSE’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}}
```

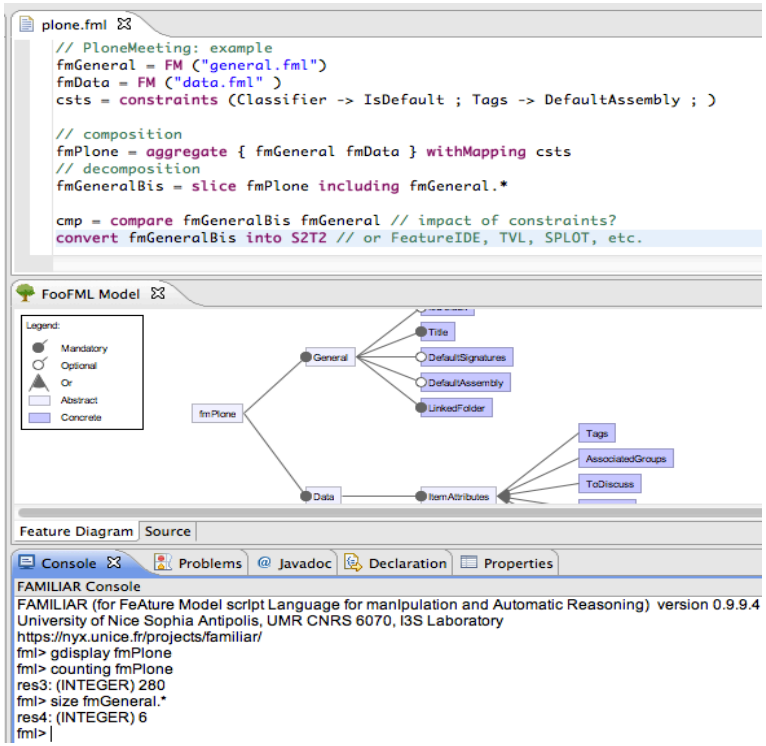
Model-based Variability Management:

Summary

What’s next?

Summary

```
root PloneMeeting {
    group allof {
        General,
        Data,
        WorklowSec,
        Interface,
        Email,
        Tasks,
        Advices,
        Votes
    }
}

General {
    group allof {
        Title ,
        opt DefaultAssembly,
        opt DefaultSignatures,
        LinkedFolder,
        opt IsDefault,
        NumberLastItemLastMeeting {
            int number;
        },
        opt NumberLastMeetingConfig {
            int number;
        },
        opt MeetingConfigID
    }
}
```



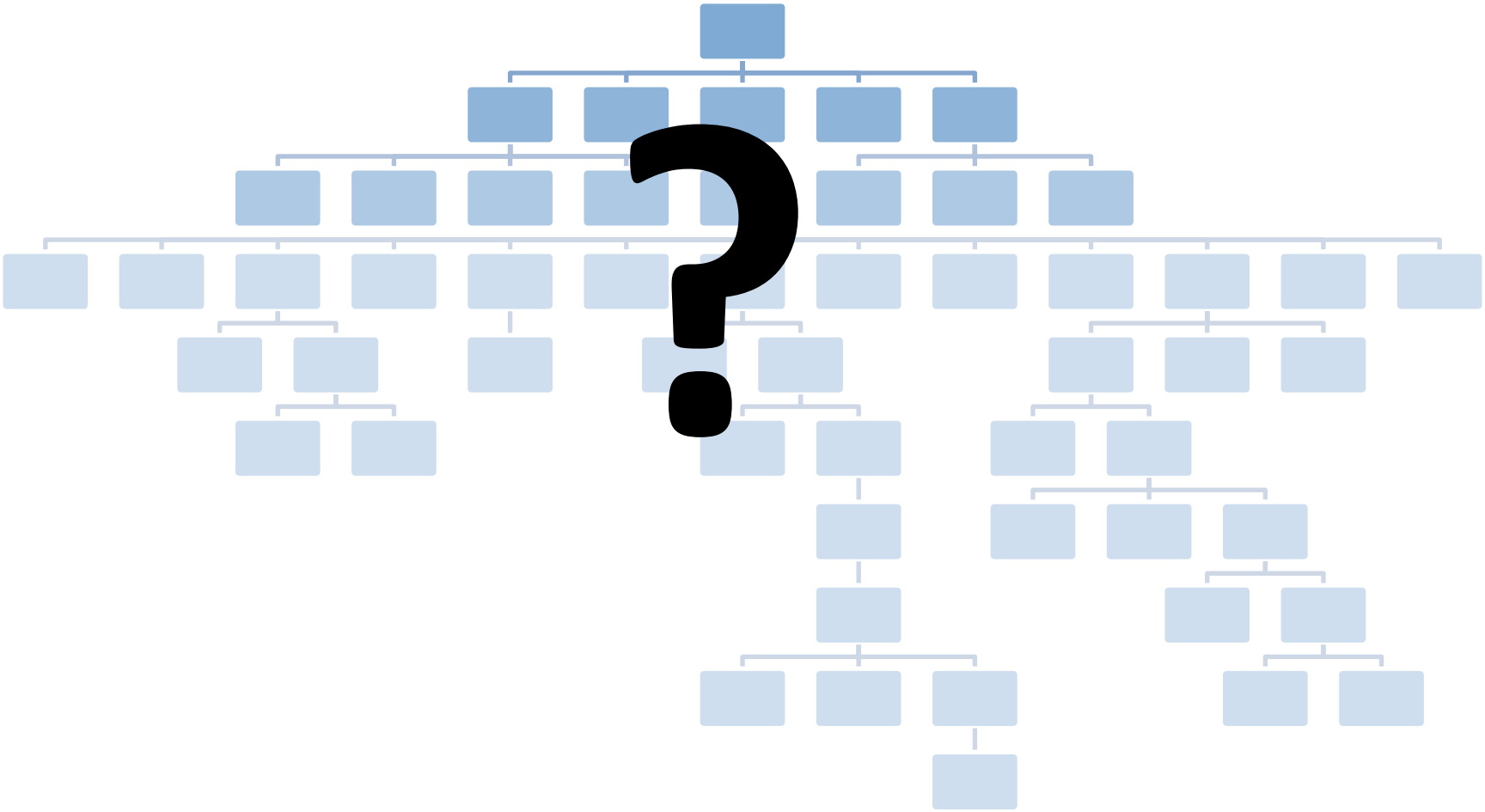
Text-based variability language with formal semantics & support (Boolean form)

A domain-specific language for Importing, exporting, editing, composing, decomposing, computing differences, comparing, reasoning about (multiple) feature models

What's next?

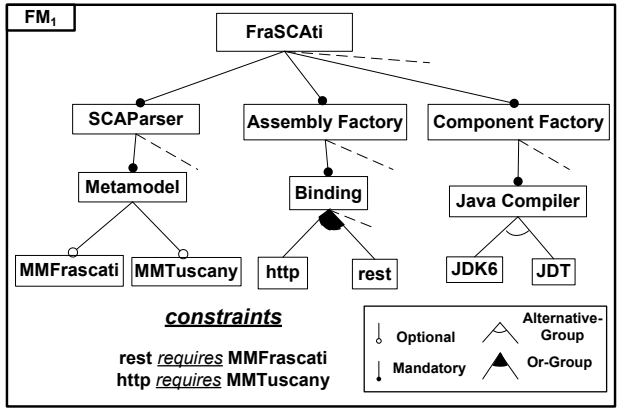
- Increasing further the adoption of the languages
  - You're the future users!
- TVL
  - Comprehensive support for non Boolean constructs
  - Satisfiability Modulo Theory (SMT) solver
- FAMILIAR
  - Applicability, Learnability, Expressiveness, Usability

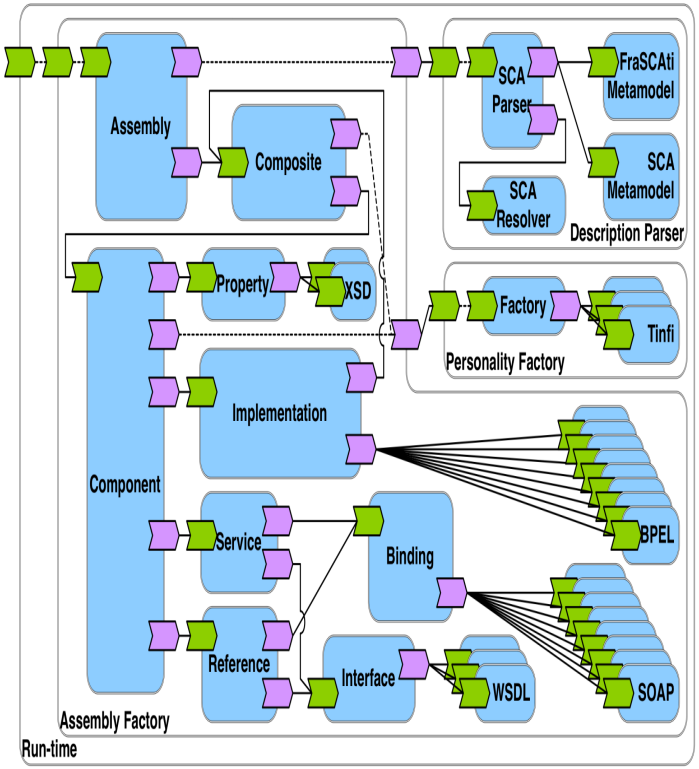
- Connection of feature models to other artefacts
  - Automated product derivation
  - Verification & Certification



#1 Reverse Engineering Architectural Feature Models

Case Study: FraSCAti Architecture

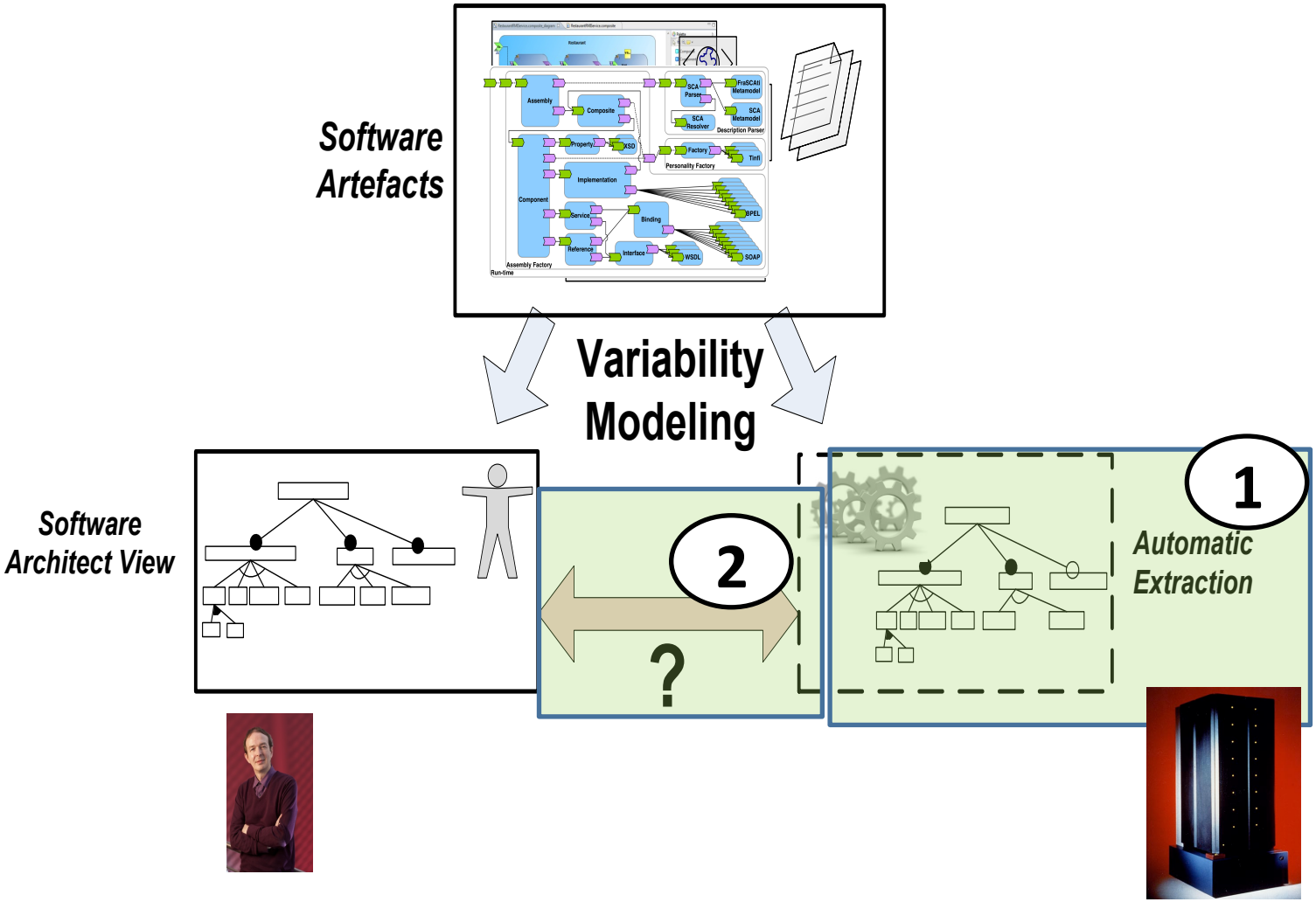




[Acher et al., ECSA'11]
[Acher et al., BENEVOL'11]
[Acher et al., GDR GPL'12]

Collaboration with Anthony Cleve (University of Namur / PRECISE, Belgium), Philippe Collet and Philippe Lahire (University of Nice Sophia Antipolis), Philippe Merle and Laurence Duchien (University of Lille / INRIA)

Extraction process



Philippe Merle,
software architect of FraSCAti

Combination of plugin dependencies and hierarchical component model to synthesise a feature model

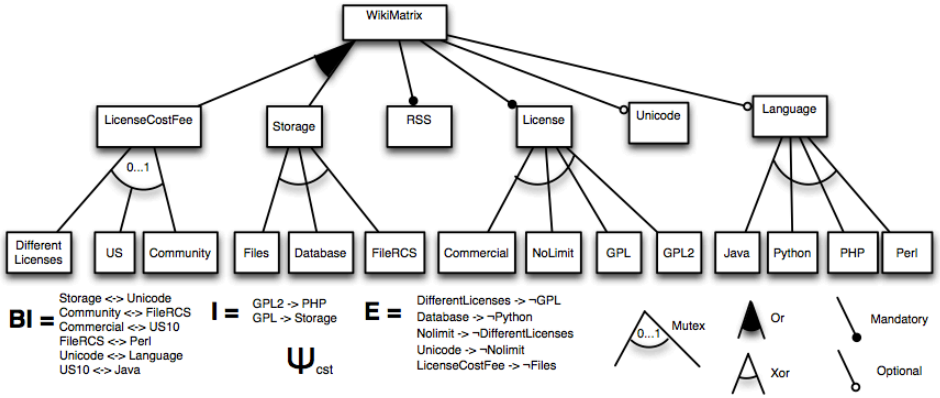
Highlights

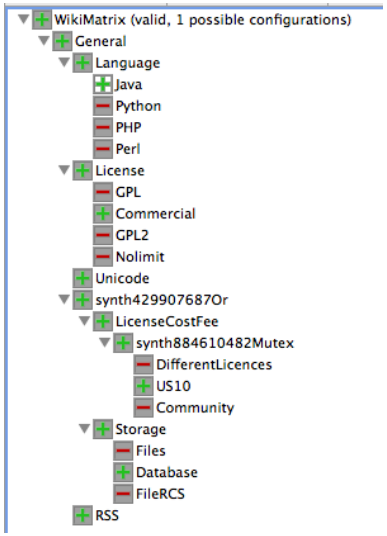
- Automated Procedure
  - Extracting and Combining Variability Sources

  (incl. software architect knowledge)
  - Advanced feature modeling techniques have been developed (tool supported with FAMILIAR)
- Lessons Learned
  - Extraction procedure yields promising results
  - Essential role of software architect
    - To validate the extracted feature model
    - To integrate knowledge
- Ongoing Work
  - Evolution of FraSCAti (v1.3, v1.4, etc.)
  - Applicability to other software architectures

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

#2 from product descriptions to feature models



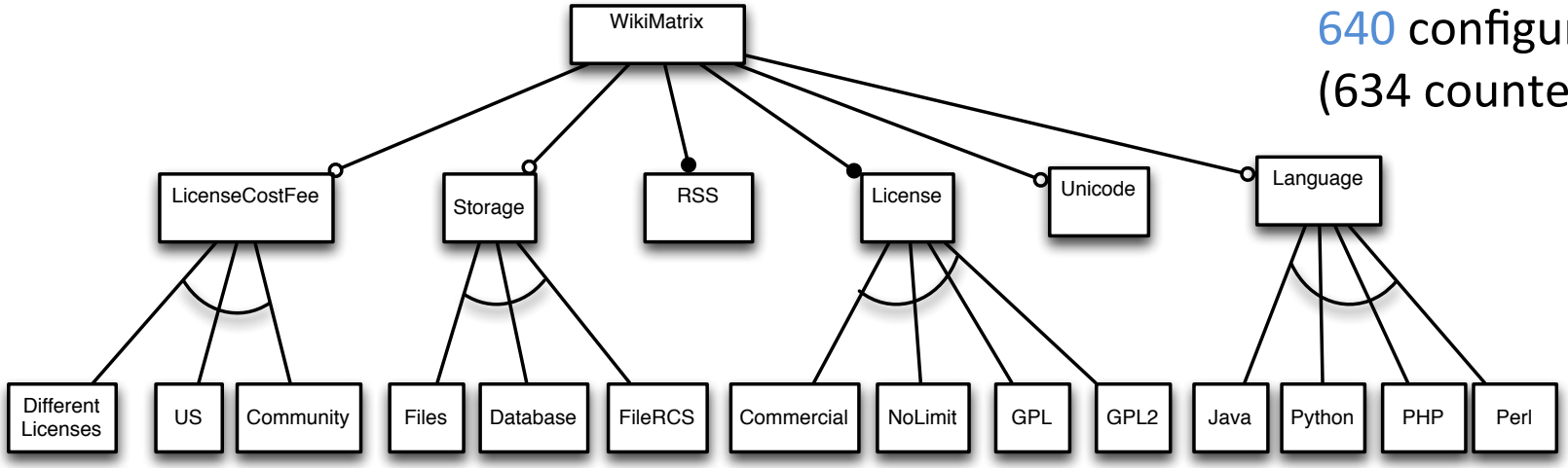


[Acher et al., VaMoS'12]

Collaboration with Patrick Heymans, Anthony Cleve, Gilles Perrouin (University of Namur / PRECISE, Belgium), Philippe Collet and Philippe Lahire (University of Nice Sophia Antipolis),

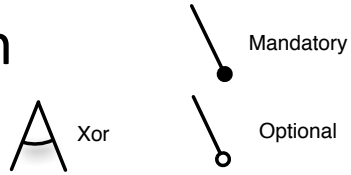
Manual extraction of a feature model from product description(s) is not possible

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



640 configurations
(634 counter examples)

Exact set of configurations, each configuration corresponding to at least one product

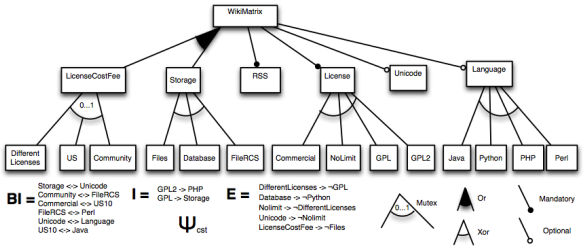


Automation

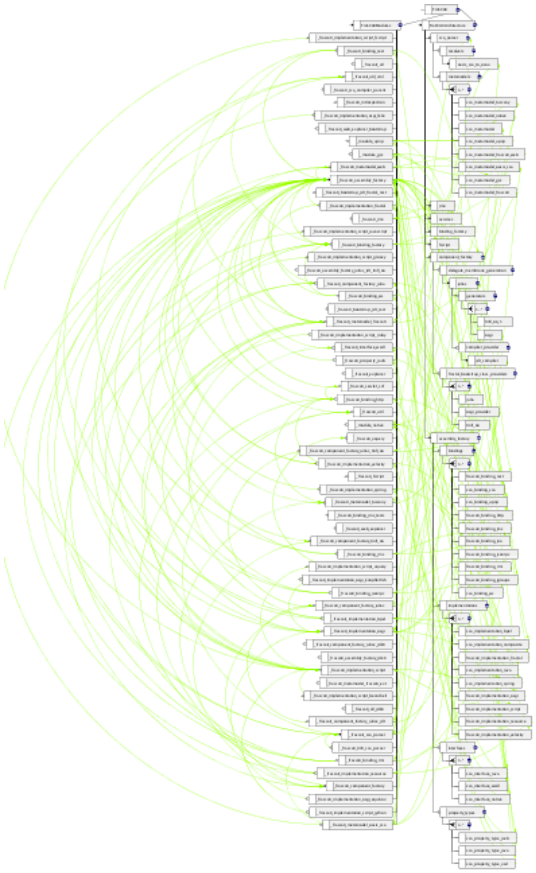
- Each product description is encoded as a feature model

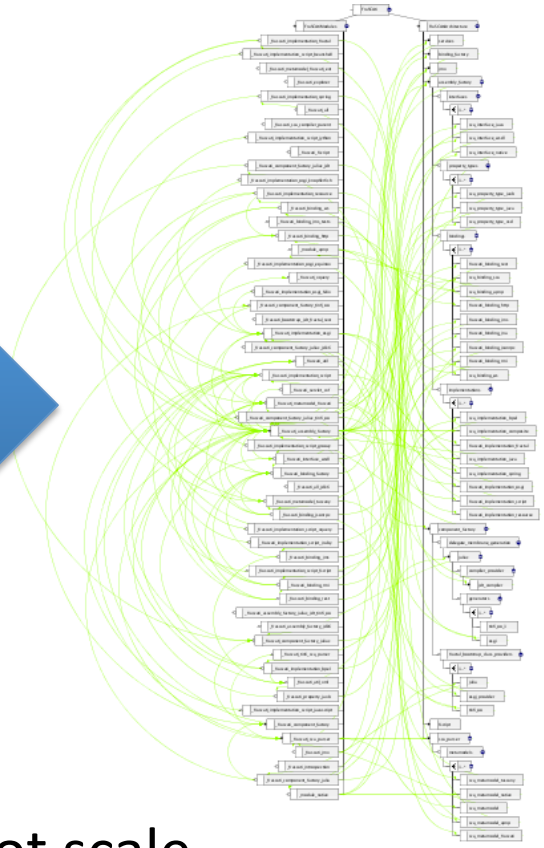
Identifier	License	Language	Storage	LicenseCostFee	RSS	Unicode	
Confluence	Commercial	Java	Database	US10	Yes	Yes	→ fm1
PBwiki	Nolimit	No	No	Yes	Yes	No	→ fm2
MoinMoin	GPL	Python	Files	No	Yes	Yes	→ fm3
DokuWiki	GPL2	PHP	Files	No	Yes	Yes	→ fm4
PmWiki	GPL2	PHP	Files	No	Yes	Yes	→ fm5
DrupalWiki	GPL2	PHP	Database	Different Licences	Yes	Yes	→ fm6
TWiki	GPL	Perl	FilesRCS	Community	Yes	Yes	→ fm7
MediaWiki	GPL	PHP	Database	No	Yes	Yes	→ fm8

- Feature models {fm1, fm2,…,fm8} are **merged**
  - Output: a new feature model
    - Configuration: union of input sets of configurations
    - Hierarchy: by default, we exploit the structure of the tabular data
      - Can be overridden by specific user directive
  - VariCell
    - DSL built on top of FAMILIAR



Feature Model Differences



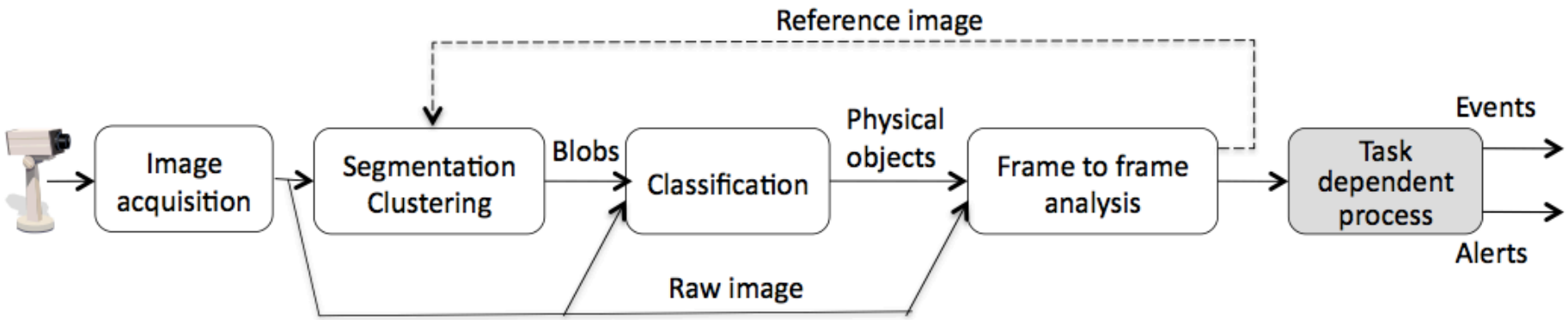


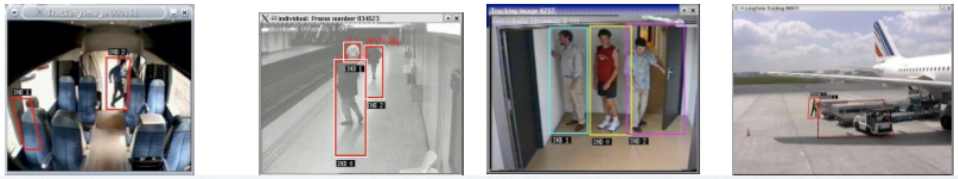
Syntactic differences do not scale

see [Acher et al., CAiSE'12]

Modeling Variability From Requirements to Runtime

The case of video surveillance processing chains





large number of software configurations

Adaptive systems

for a large number of requirements

Collaboration with Sabine Moisan and Jean-Paul Rigault (INRIA)

Contributions

- Separation of Concerns
  - Software variability is distinguished from requirements variability
- A systematic approach to specify and reason about variability of adaptive systems
  - Variability requirements are step-wised specified at design time
    - Some variability choices are kept for runtime adaptation (e.g., Day/Night)
  - Reduction of software configurations to be considered at runtime
- Reasoning operations
  - Consistency checking
  - "Reachability" property
    - for all valid requirements (e.g., contexts), there exists at least one valid software configuration
  - Specialization checking
  - Choices Propagation
- Language support
  - aggregate + slice + compare + editing facilities
  - Reuse of feature models and analysis procedures in 6 scenarios

See also [Acher et al., ICECCS'11] or Demonstration (screencast)