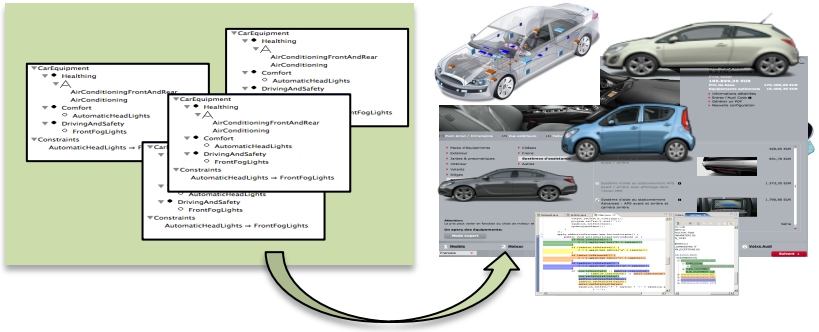


Model-based Software Product Lines

Overview and Principles

Mathieu Acher

Maître de Conférences

mathieu.acher@irisa.fr

UNIVERSITÉ DE RENNES 1

istic Informatique Électronique

Material

http://mathieuacher.com/teaching/M2R/

Plan

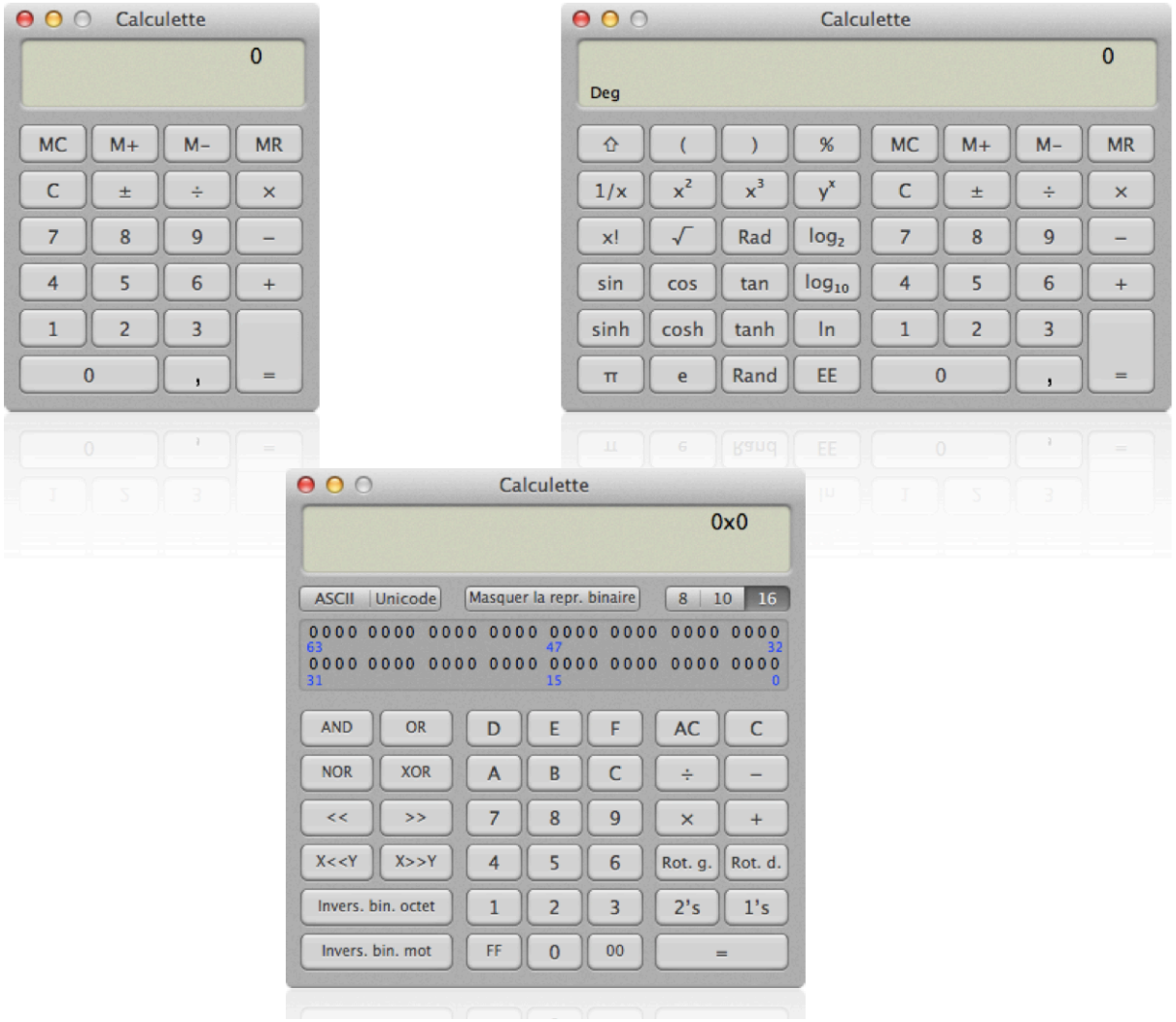
- Challenges and Overview
  - Developping billions of software product is hard but now a common practice
- Implementing Variability
  - Revisit of existing techniques and curriculum
- Specificity of Product Line Engineering
  - Process, methods
- Feature Models
  - Defacto standard for modeling product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

Contract

- The idea of software product lines and variability
  - You will be able to recognize this class of systems
  - Aware of the complexity
  - Aware of the specific development process
  - Aware of existing techniques and theory
  - Open issues
- Feature modeling
  - A widely used formalism for modeling product lines and configurable systems in a broad sense
  - Language and theory
  - Open issues

Software Product Line and Variability Engineering

Overview


Calculette
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4 5 6 +
1 2 3 =
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Calculette
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1/x x² x³ yˣ C ± ÷ ×
x! √ Rad log₂ 7 8 9 −
sin cos tan log₁₀ 4 5 6 +
sinh cosh tanh ln 1 2 3 =
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Masquer la repr. binaire
8 | 10 | 16
0000 0000 0000 0000 0000 0000 0000 0000
63 47 32
0000 0000 0000 0000 0000 0000 0000 0000
31 15 0
AND OR D E F AC C
NOR XOR A B C ÷ −
<< >> 7 8 9 × +
X<<Y X>>Y 4 5 6 Rot. g. Rot. d.
Invers. bin. octet 1 2 3 2's 1's
Invers. bin. mot FF 0 00 =

« A set of programs is considered to constitute a **family**, whenever it is worthwhile to study programs from the set by **first studying the common properties** of the set and then determining the **special properties** of the individual family members »

aka **Variability**

David L. Parnas — "On the design and development of program families" in Transactions on Software Engineering, SE-2(1):1–9, 1976

	 Starter	 Home Premium Upgrade $119.99* Buy	 Professional Upgrade $199.99* Buy	 Ultimate Upgrade $219.99* Buy
Communication				
Bluetooth support	✓	✓	✓	✓
Join a homegroup	✓	✓	✓	✓
Internet Explorer 8	✓	✓	✓	✓
View Available Networks	✓	✓	✓	✓
Windows Connect Now (WCN)	✓	✓	✓	✓
Create a homegroup		✓	✓	✓
Location and other sensors support		✓	✓	✓
Support for joining domains			✓	✓
Entertainment				
DirectX 11	✓	✓	✓	✓
Gadgets	✓	✓	✓	✓
Games Explorer	✓	✓	✓	✓
Play To	✓	✓	✓	✓
Windows Media Player 12	✓	✓	✓	✓
Create and play DVDs		✓	✓	✓
Internet TV		✓	✓	✓

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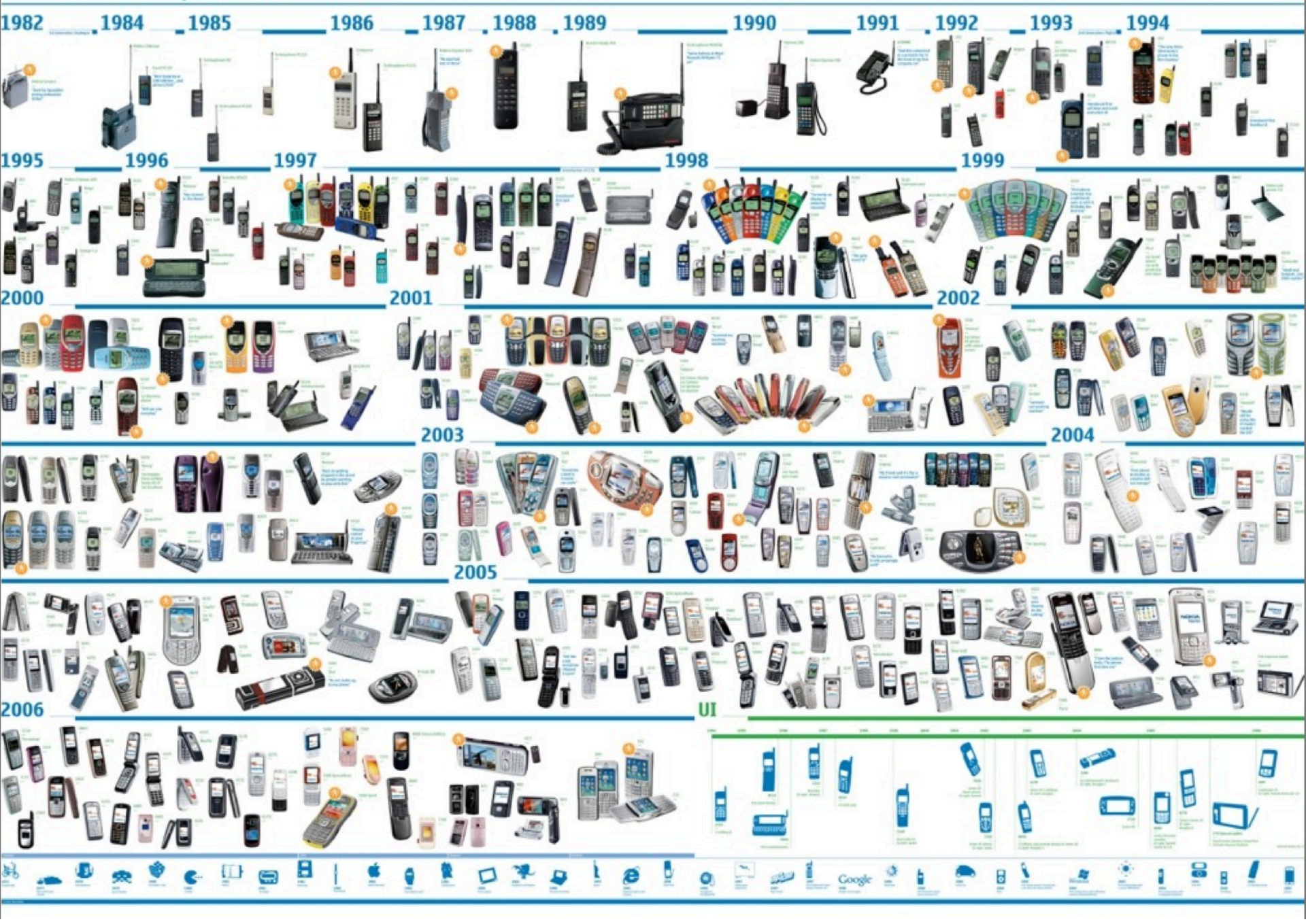
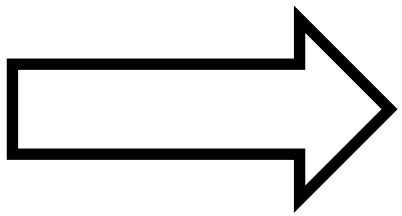


Software-intensive systems

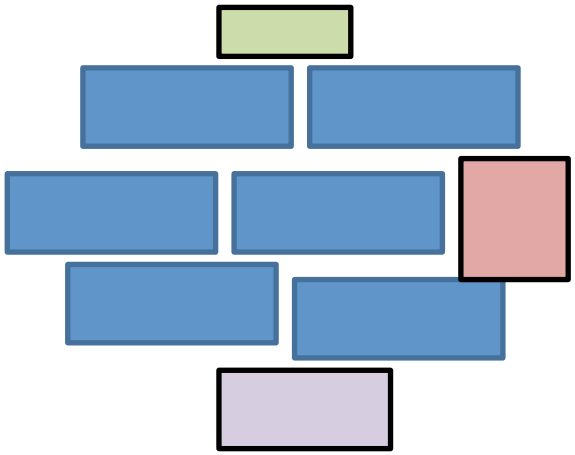


come in many **variants**

Software Product Line Engineering

Factoring out **commonalities**

for **Reuse** [Krueger et al., 1992] [Jacobson et al., 1997]



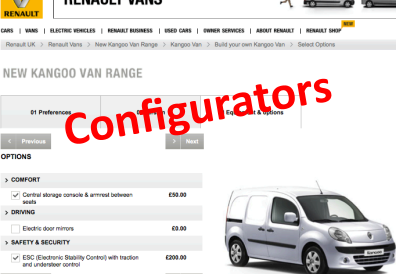
Managing **variabilities**

for Software **Mass Customization** [Bass et al., 1998] [Krueger et al., 2001], [Pohl et al., 2005]

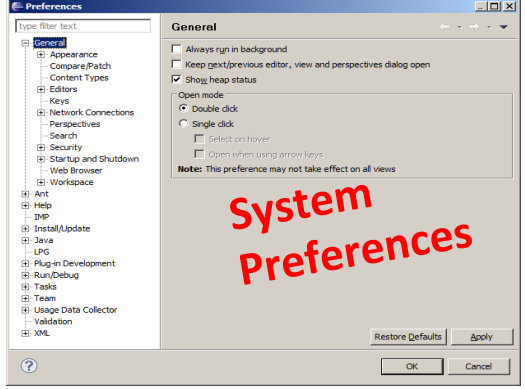
Variability

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

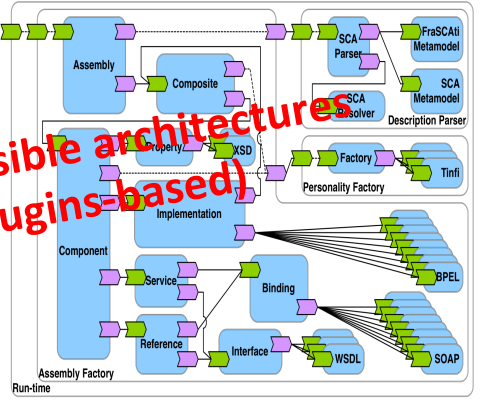
Mikael Svahnberg, Jilles van Gurp, and Jan Bosch (2005)



Configurators



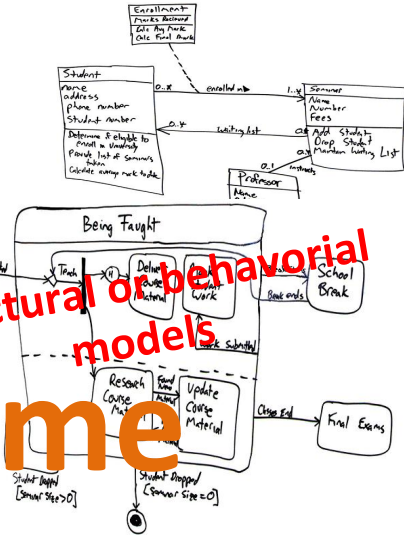
System Preferences



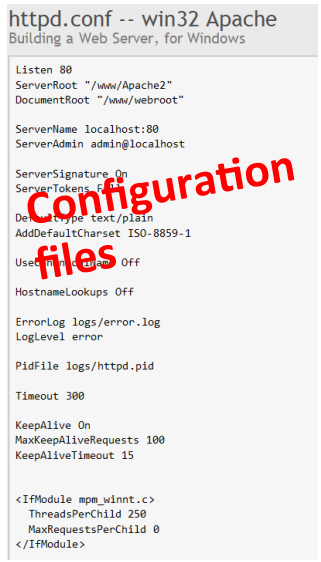
Extensible architectures (eg plugins-based)

Comparison of *

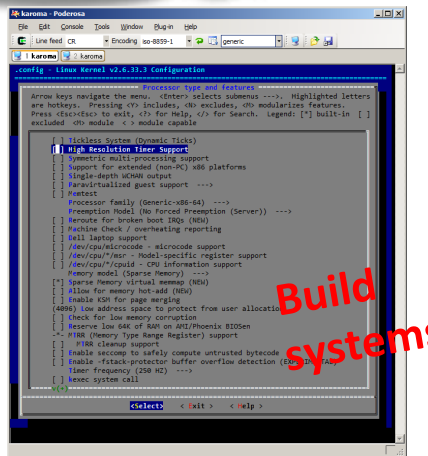
External Variability
Internal Variability
Variability @ run.time



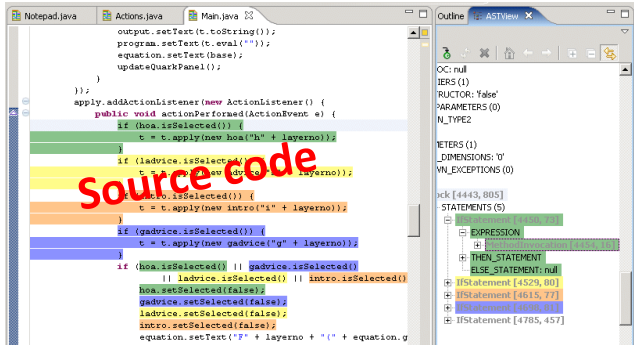
Structural or behavorial models



Configuration files



Build systems



Source code

Developer Tools
Development
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DTP/Prepress
Educational
Finance
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Games
Graphics
HTML Tools
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Spot t Plug Utilities
System ilities
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Word Processing

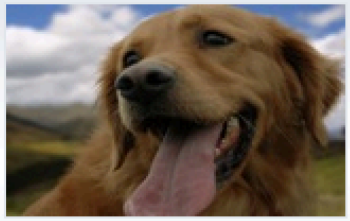
LOBAL PAGES >>
EWS ARCHIVE >>
OFTPEDIA REVIEWS >>
EET THE EDITORS >>

Power Matte 2 1.3 update

Adobe Ar plugin that can extract a ect in an i e

[read

Size:	13.20 MB
Platform:	Mac OS X 10.5 or later
License:	Trial
Rating:	Good (3.0/5)
Downloads:	1,504
Updated:	June 20th, 08:21 UTC



Grid 1.1 update

Helps you generate perspective grids

[read more >]

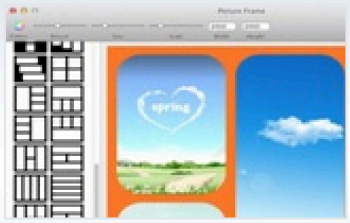
Size:	102 KB
Platform:	Mac OS X 10.8 or later
License:	Commercialware
Rating:	NOT RATED
Downloads:	21
Updated:	June 20th, 07:56 UTC

Picture Frame 2.2 update

Quickly generate multi-frame photos using your Mac

[read more >]

Size:	716 KB
Platform:	Mac OS X 10.6.6 or l...
License:	Commercialware
Rating:	Excellent (5.0/5)
Downloads:	297
Updated:	June 20th, 07:53 UTC

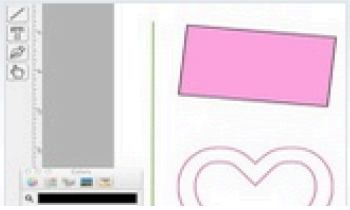


FashionLab Studio 1.1 update

Makes it easy to design your own T-shirt using a Mac

[read more >]

Size:	3.10 MB
Platform:	Mac OS X 10.6.6 or l...
License:	Commercialware
Rating:	NOT RATED
Downloads:	3
Updated:	June 20th, 07:49 UTC



Variability

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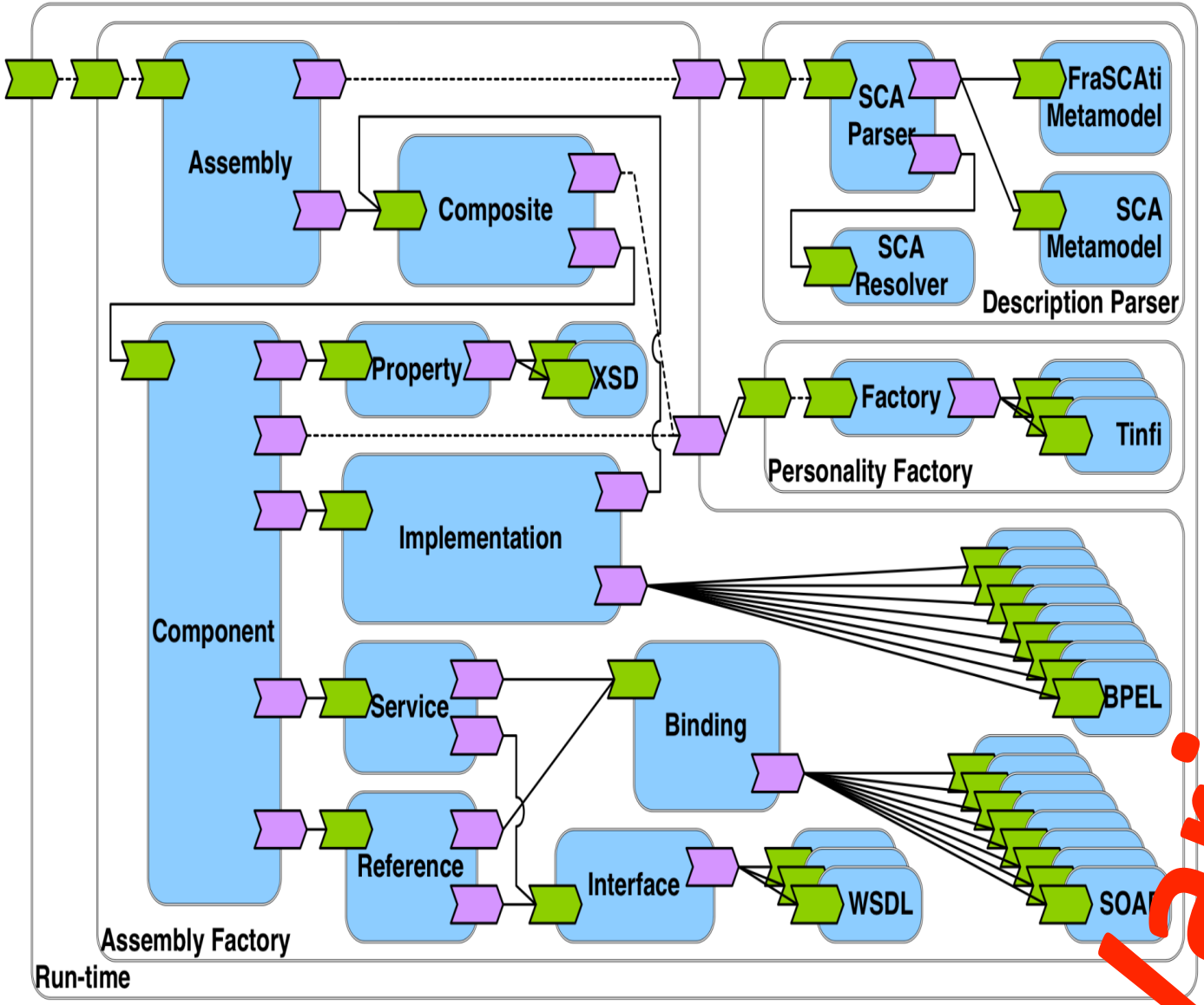
Variability



Variability

Variability Patterns

Features (C)

Service name (A)	Automatic forwarding	E-mail client access[14]	client E-mail for other server	Integration with IM service (B)	Domain Name customization	Interface script technique
AOL Mail	No	Yes (POP3, IMAP, SMTP)	Yes[0]	AOL Instant Messenger	No[1]	JavaScript/ Ajax (4)
Bigfoot Communications	Premium account only	Yes (POP3, IMAP, SMTP)	Yes (POP3 only)	XMPP (3)	Yes	HTML/ JavaScript/ CSS/Ajax
FastMail.FM	Paid accounts only	Yes (IMAP)[7] (2)	Paid accounts (POP3, Hotmail)	XMPP	Enhanced and group (Business/ Family) accounts	HTML/ JavaScript/ CSS/Ajax (Optional user supplied custom css+JavaScript)
Gmail	Yes	Yes (POP3, IMAP) SSL/TLS supported SMTP restricted[18]	Yes (POP3 only)	Google Talk[beta] (XMPP), AOL Instant Messenger	Yes (Google Apps $5.00 monthly/ $50.00 annually)	HTML/ JavaScript/ Ajax[2]
GMX Mail	No	Yes (POP3, IMAP[17], SMTP) SSL/TLS supported	Yes (POP3 only)	XMPP	Yes	HTML/ JavaScript/ Ajax
Hushmail	No	Extra cost[8]	? (5)	No	$1.99/$3.99 monthly through Hushmail Business	Java or HTML
Mail.com	No	Yes (POP3, IMAP, SMTP) SSL/TLS supported	Yes (POP3 only)	Google Talk (XMPP)	No	HTML/ JavaScript/ Ajax[2]
Mail.ru	Yes	Yes (POP3, IMAP)	Yes (POP3 only)	custom (7)	?	HTML/ Ajax (Beta)
rediff	No	Plus members only	?	Rediff Bol	Yes (1)	JavaScript/ Ajax[2]
Runbox	Yes	Yes (IMAP, POP, SMTP) SSL/TLS supported	Yes (POP3, Hotmail, Gmail) SSL/TLS supported	XMPP, Google Talk, AOL Instant Messenger, MSN, ICQ, IRC[41]	Yes	HTML/ JavaScript/ CSS/Ajax
Seznam.cz	Yes	Yes (POP3, IMAP, SMTP) SSL/TLS supported	Yes (POP3 only)	No	No	HTML/ JavaScript
Windows Live Hotmail	Yes	Partial (POP3, SMTP)[3]	Yes (POP3 only)	Windows Live Messenger	Yes[4]	HTML/ JavaScript/ CSS/Ajax
Yahoo! Mail	Plus accounts only	Yes (POP3-Plus members only, but free in some countries, IMAP SSL/TLS supported)	(6)	Yes (POP3 only)	Yahoo! Messenger, Windows Live Messenger	$35 yearly (7)
Yandex Mail	Yes	Yes (POP3, IMAP, SMTP, SSL)	Yes (POP3 only)	Ya Online, any XMPP IM	Yes (Free, Yandex PDD supports up to 1000 mailboxes without verification of legal use)	HTML/ JavaScript/ CSS/Ajax

1. Boolean yes/no answers
2. Partial/constrained yes/no answers
3. Single-value answers
4. Multiple values answers
5. “Unknown” answers
6. Empty cells
7. Inconsistent cells
8. Additional / Extra information

WIKIPEDIA
The Free Encyclopedia

Variability

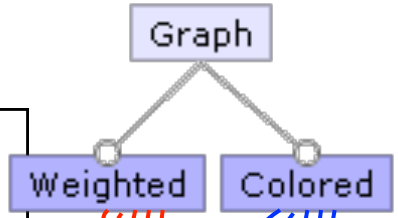
```
class Graph {
  Vector nv = new Vector(); Vector ev = new Vector();
  Edge add(Node n, Node m) {
    Edge e = new Edge(n, m);
    nv.add(n); nv.add(m); ev.add(e);
    e.weight = new Weight();
    return e;
  }
  Edge add(Node n, Node m, Weight w)
    Edge e = new Edge(n, m);
    nv.add(n); nv.add(m); ev.add(e);
    e.weight = w; return e;
  }
  void print() {
    for(int i = 0; i < ev.size(); i++) {
      ((Edge)ev.get(i)).print();
    }
  }
}
```

```
class Node {
  int id = 0;
  Color color = new Color();
  void print() {
    Color.setDisplayColor(color);
    System.out.print(id);
  }
}
```

```
class Edge {
  Node a, b;
  Color color = new Color();
  Weight weight;= new Weight();
  Edge(Node _a, Node _b) { a = _a; b = _b; }
  void print() {
    Color.setDisplayColor(color);
    a.print(); b.print();
    weight.print();
  }
}
```

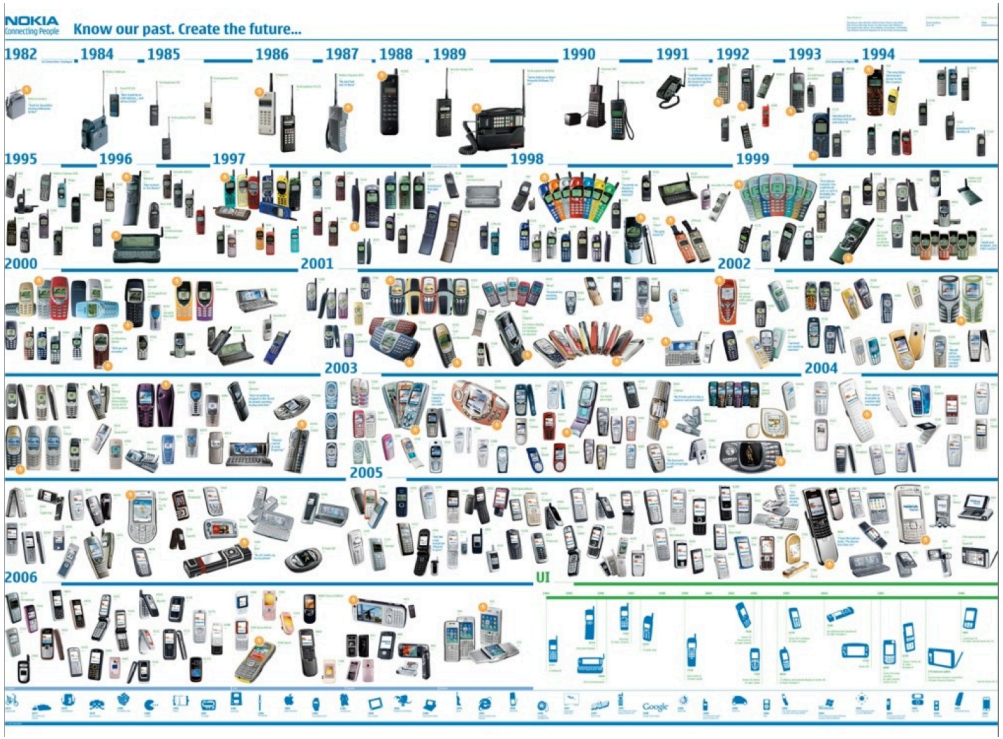
```
class Color {
  static void setDisplayColor(Color c) { ... }
}
```

```
class Weight { void print() { ... } }
```



Variability in time vs in space

- **Variability in Time (releases)**
  - the existence of different versions of an artifact that are valid at different times
- **Variability in Space (variants)**
  - the existence of an artifact in different shapes at the same time

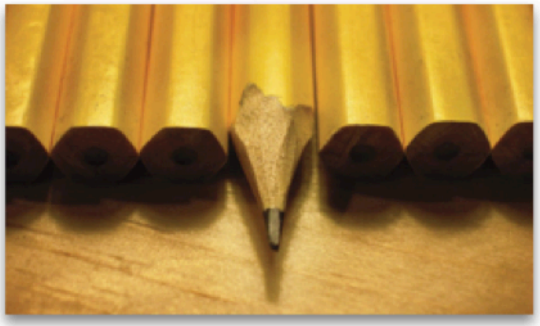


Benefits

Improve product reliability

Improve usability

Improve consistency across products...



Benefits

Reduce production costs

Reduce certification costs

Shorten time-to-market

Hall of Fame

splc.net/fame.html

BOSCH
Invented for life

PHILIPS

ERICSSON

NOKIA
Connecting People

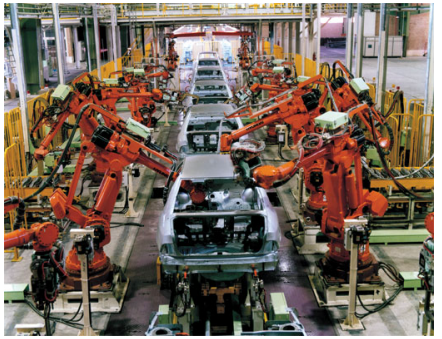
CelsiusTech

Lucent Technologies
Bell Labs Innovations

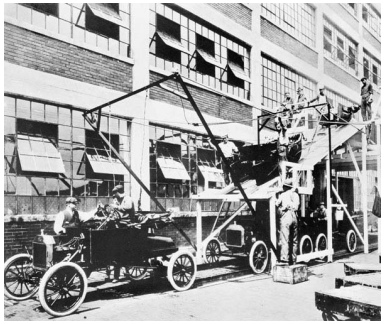
Printer Firmware

- Production cost reduced by 75%
- Development time reduced by 33%
- Reported defects reduced by 96%

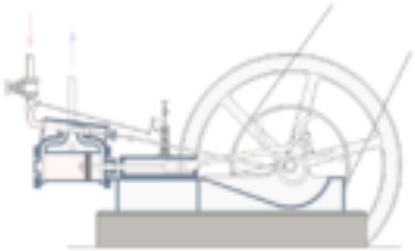
A Bit of History: Industrial Revolution



1980s



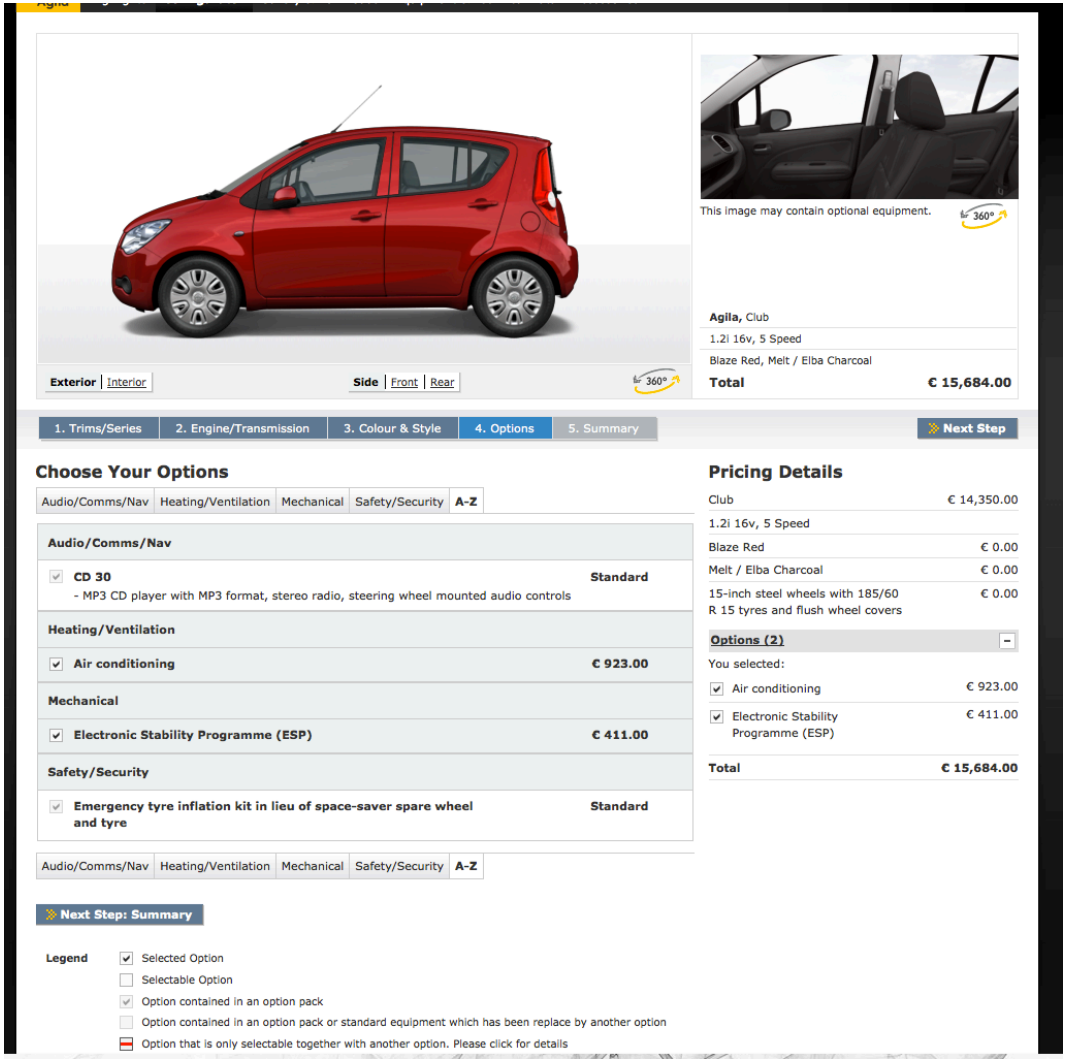
1901
Henry Ford



1698
Thomas Savery

Nowaday: Product Lines Everywhere

Product Lines of Cars

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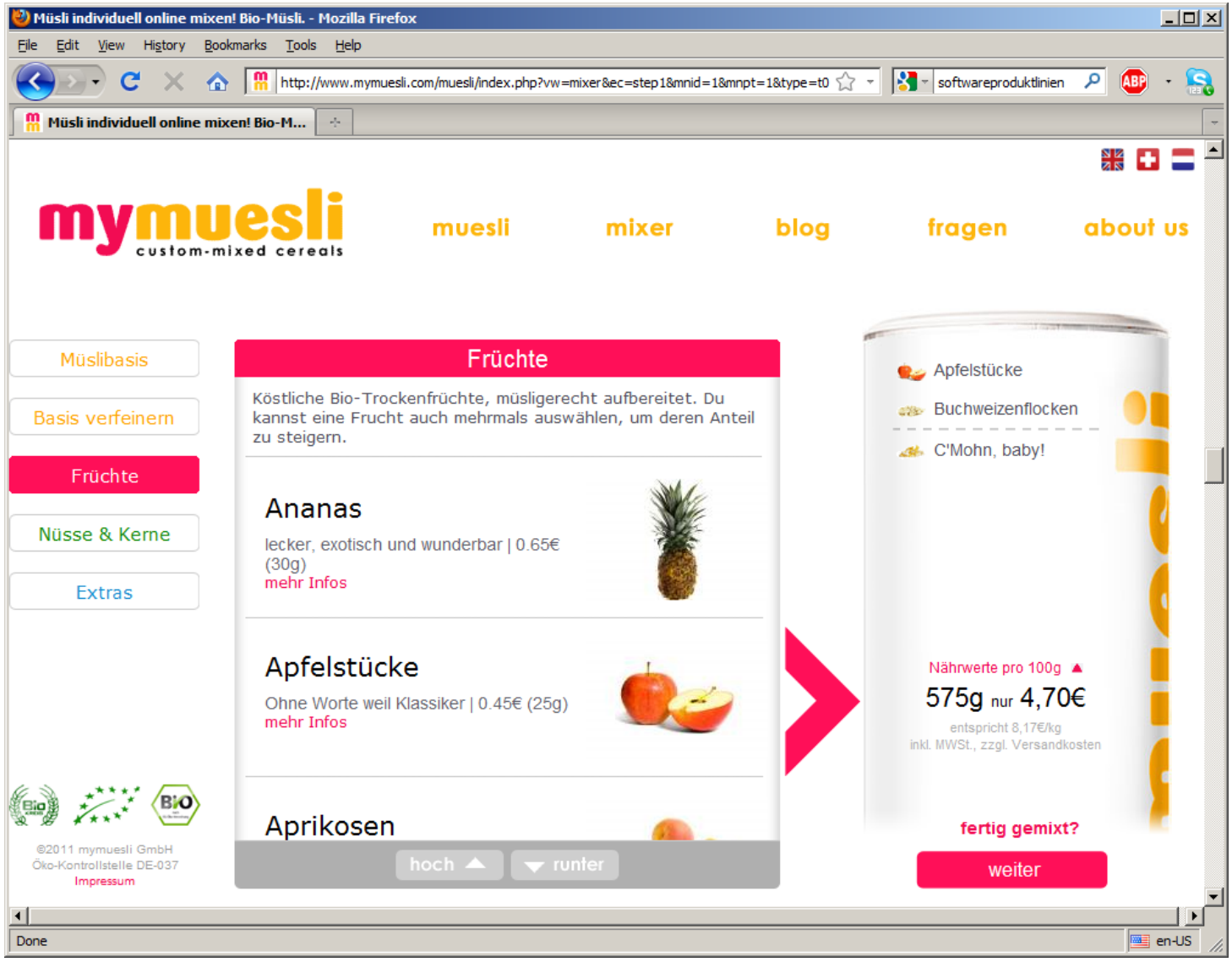
FUSSTYP
MYSELVE
INFO
HOME
MODELLE
LOOKBOOK
SELVE ID
PASSWORT
>>ANMELDEN
selve
selve Kollektion -> Style: casuals -> Modell: Opal
modell-details
>>hier clicken
>>SELVE SCHUHREGAL
inhalt: 0
>>SHOPPING BAG
inhalt : 0
A. Erstes Oberleder
Velours leder Sand
Velours leder Bordeaux
Velours leder Cognac
Velours leder Sand
C. Futterleder
Beige
D. Absatz
Hufeisen Braun
E. Sohle
Gummisohle
>>ÄNDERN
>>ZURÜCKLEGEN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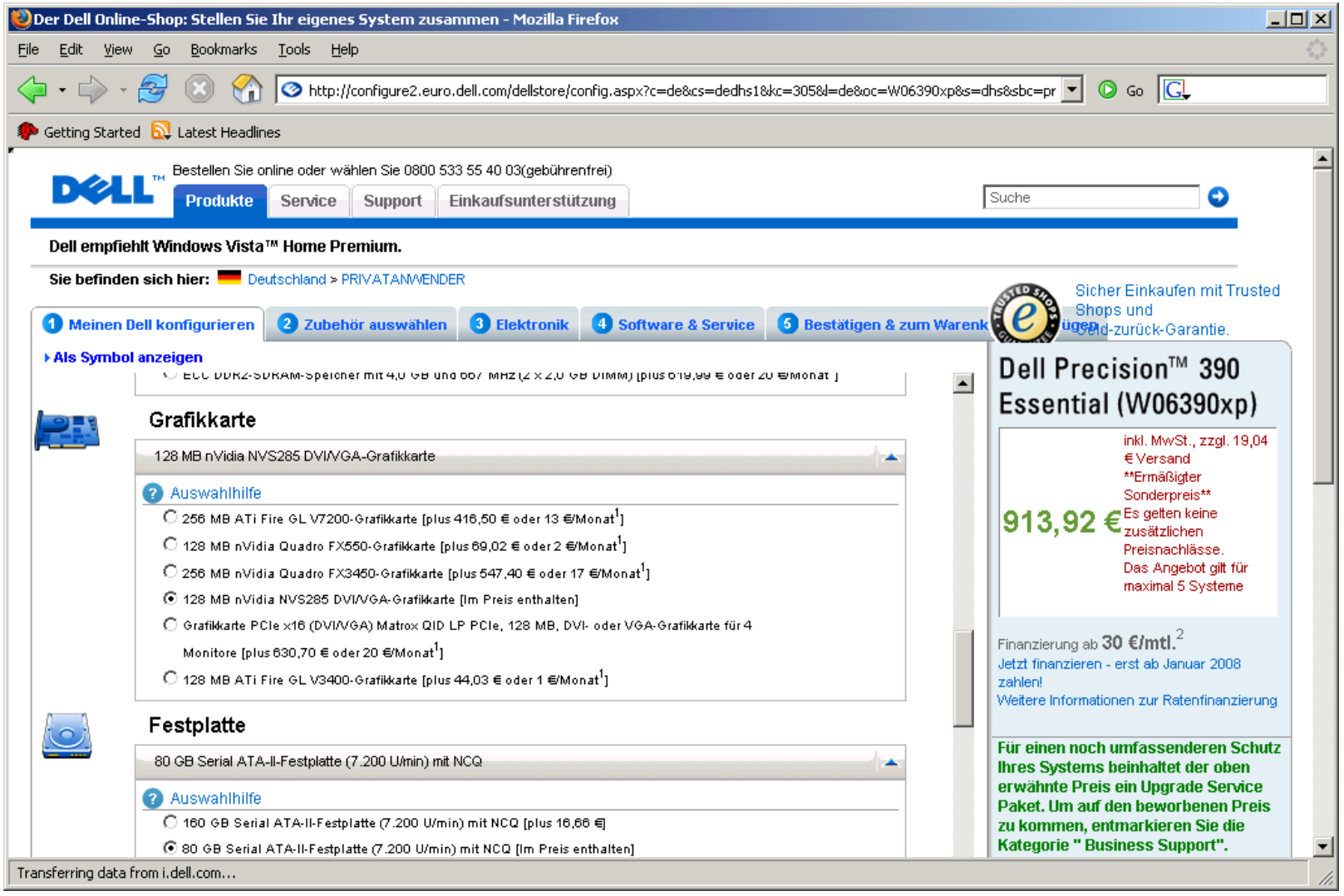
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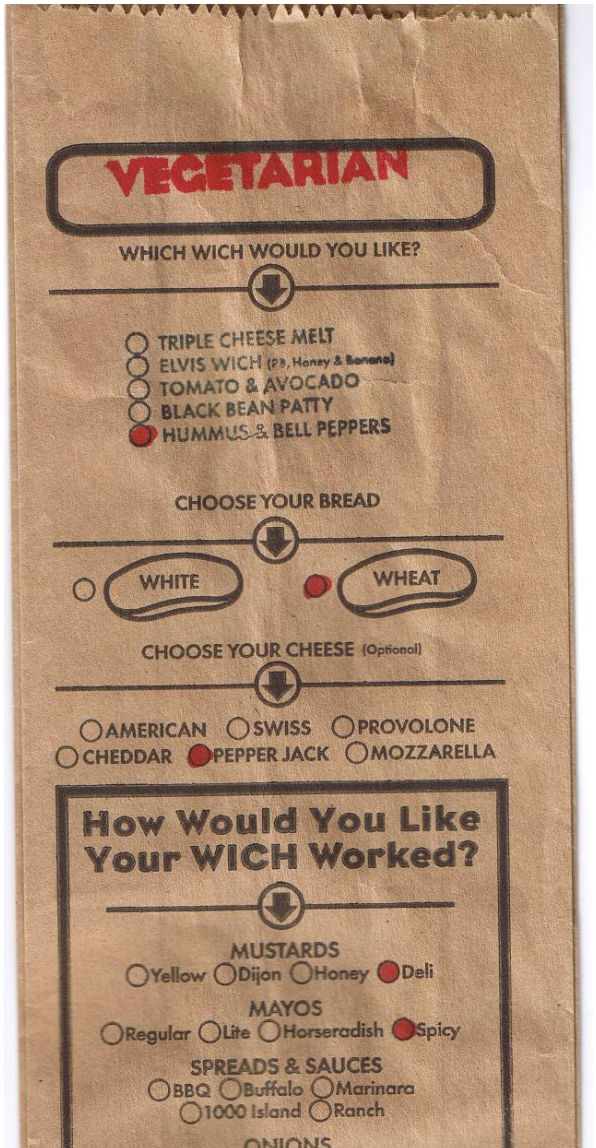
Transferring data from i.dell.com...

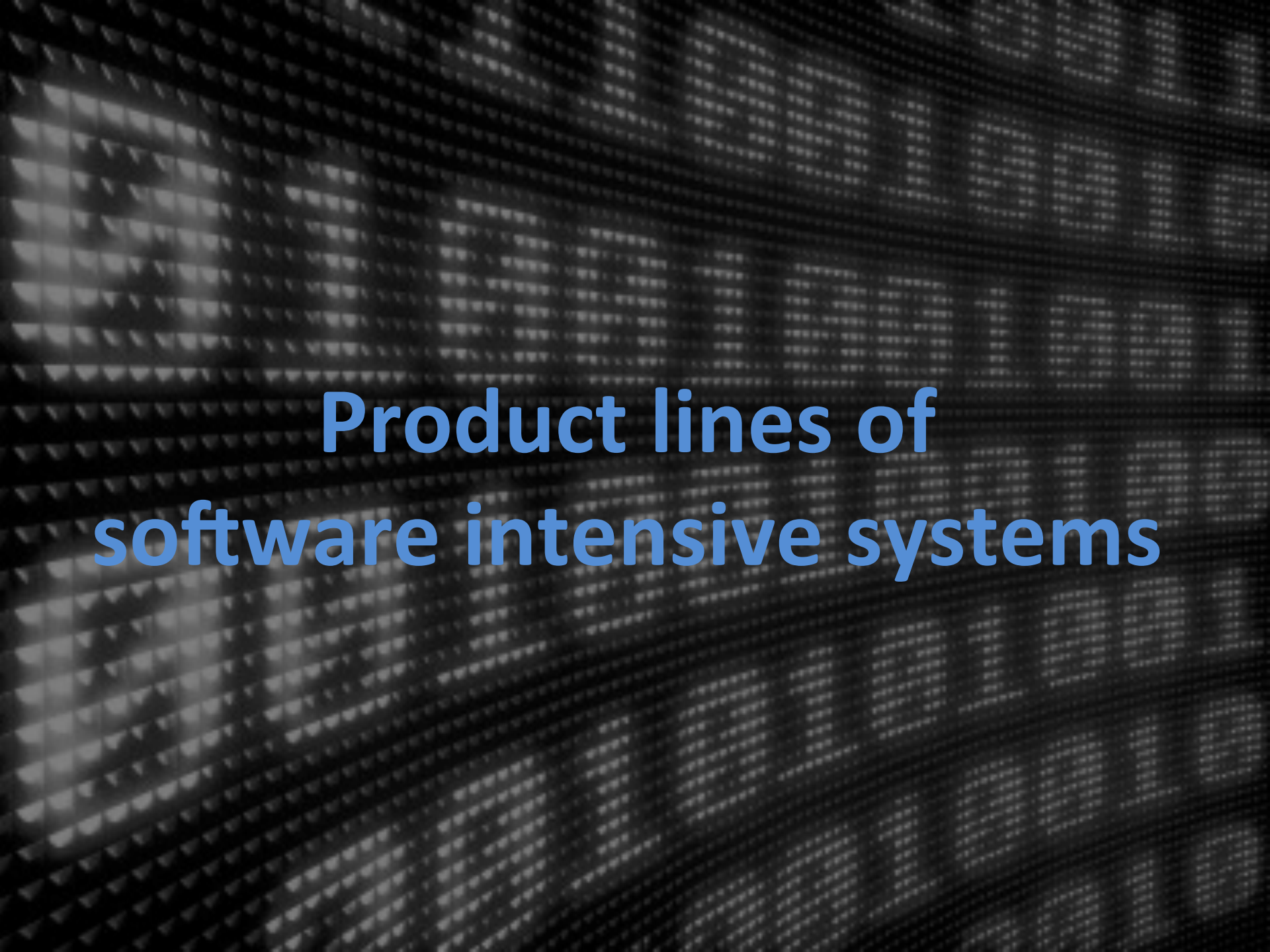
Food? Product lines!




VEGETARIAN
How Would You Like Your WICH Worked?
VEGETARIAN
How Would You Like Your WICH Worked?

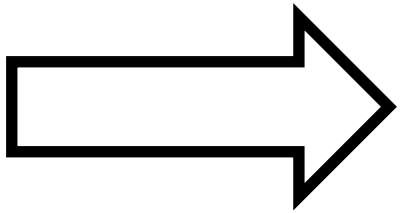
Mass production

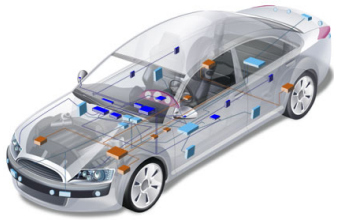
What about software?


Product lines of
software intensive systems

Software intensive systems

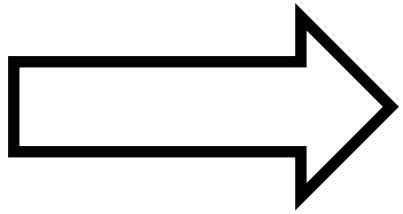
are declined in many **variants**





Software intensive systems

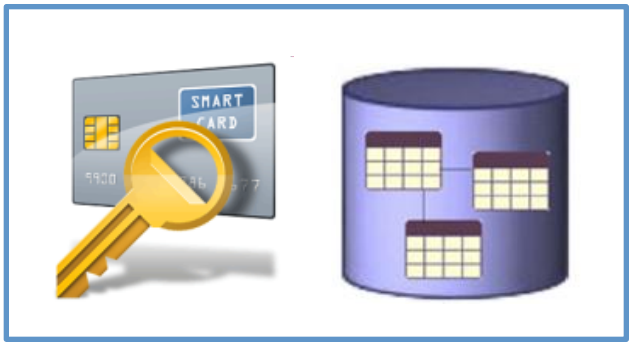
are declined in many **variants**



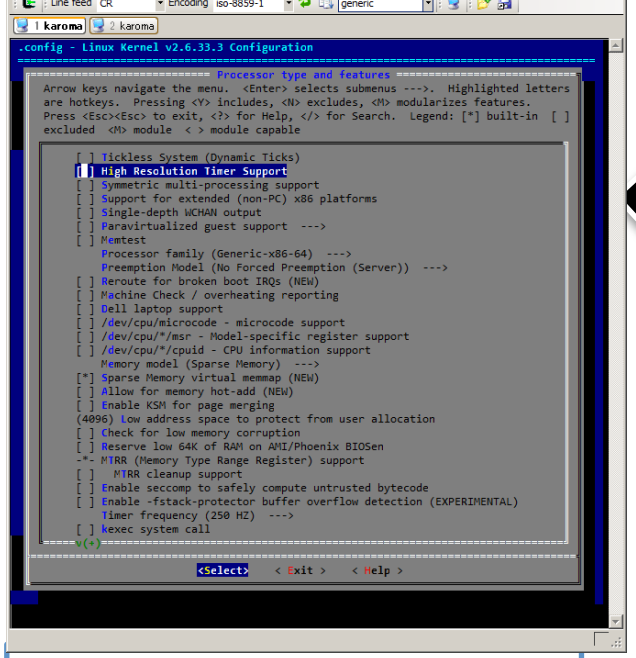
Software Product Lines

Car

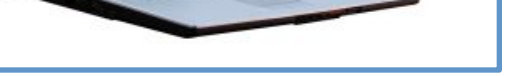
Database Engine



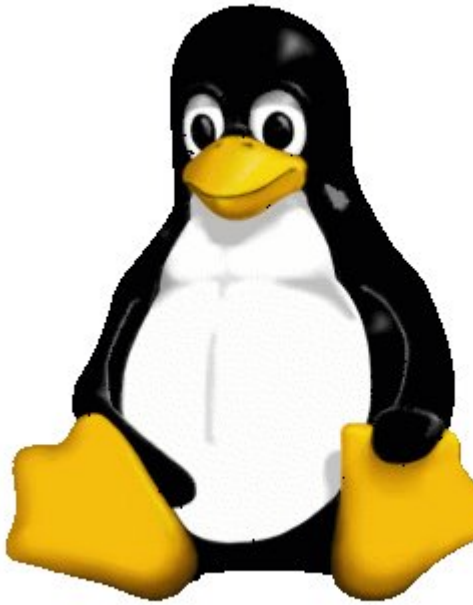
Printer Firmware



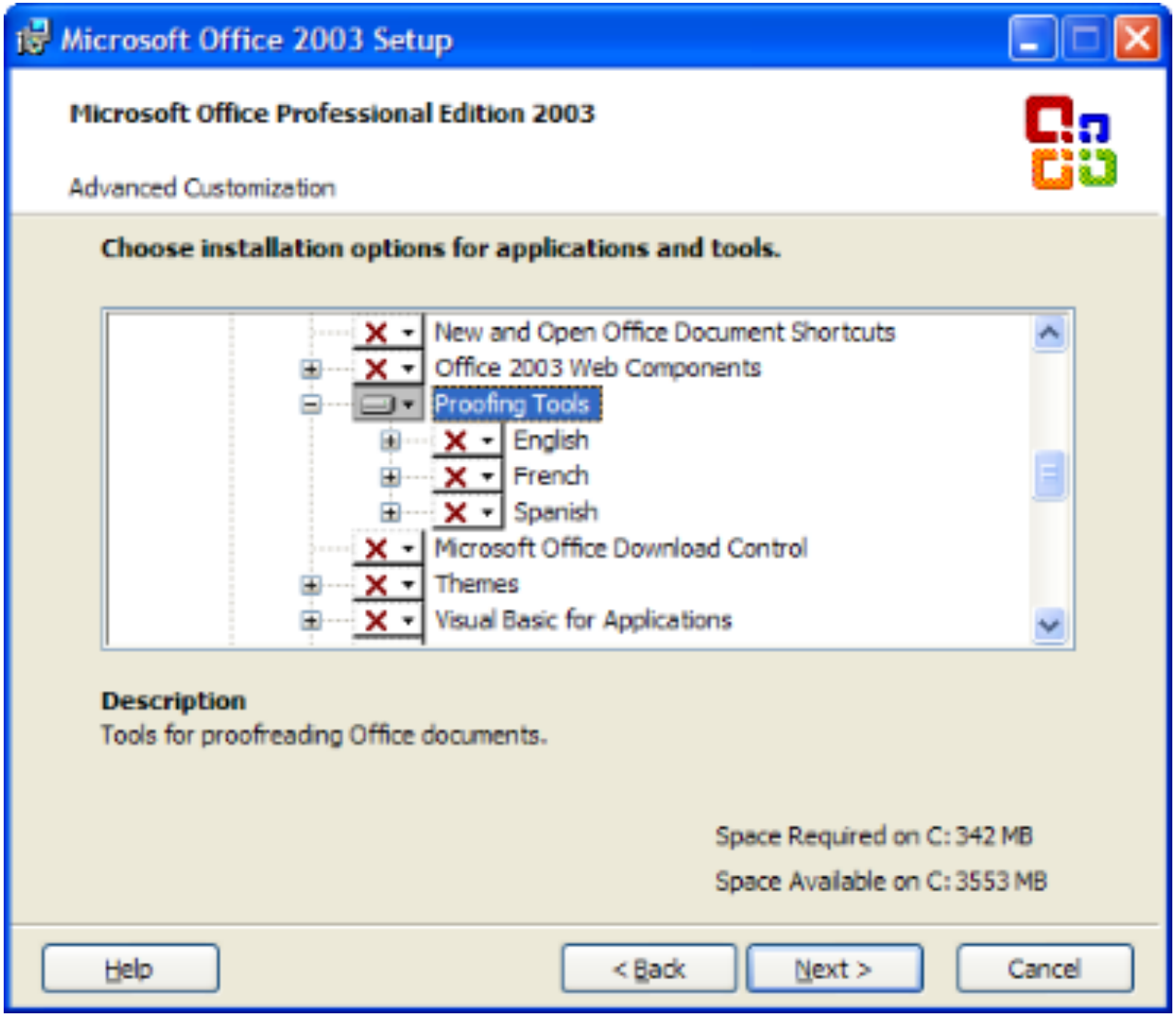
Linux Kernel



Linux-Kernel



Features in Microsoft Office



The development of a

family of software systems

is much more challenging than the development of

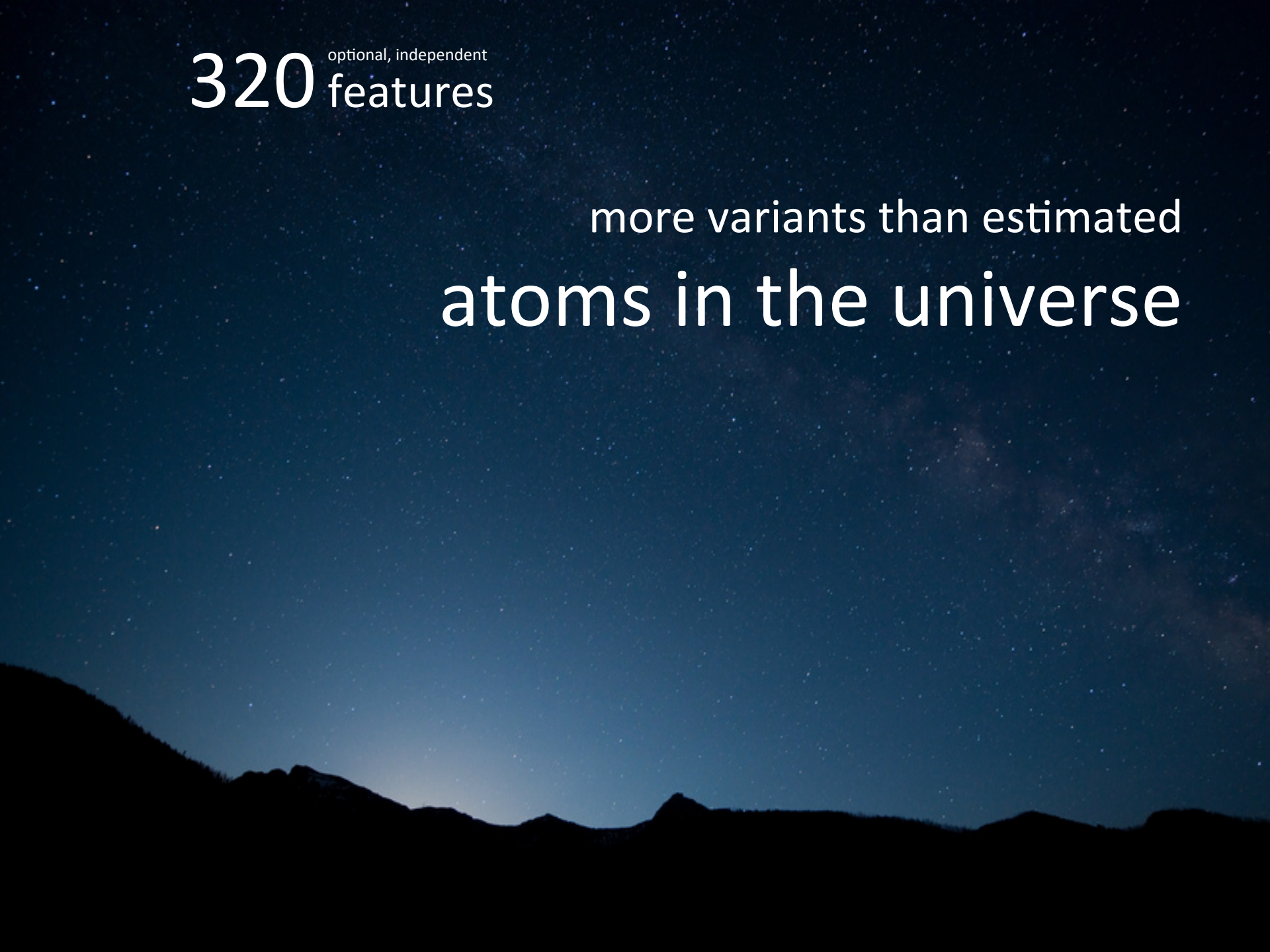
a single software system


Variability = Complexity

33 optional, independent features

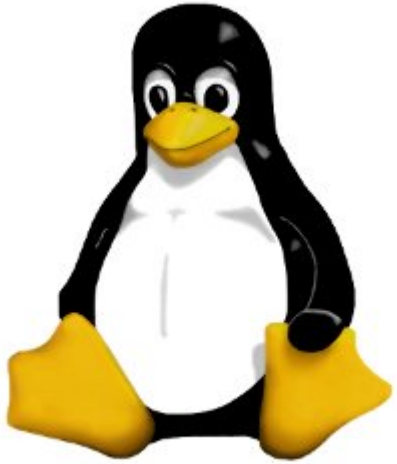
a unique variant for every

person on this planet

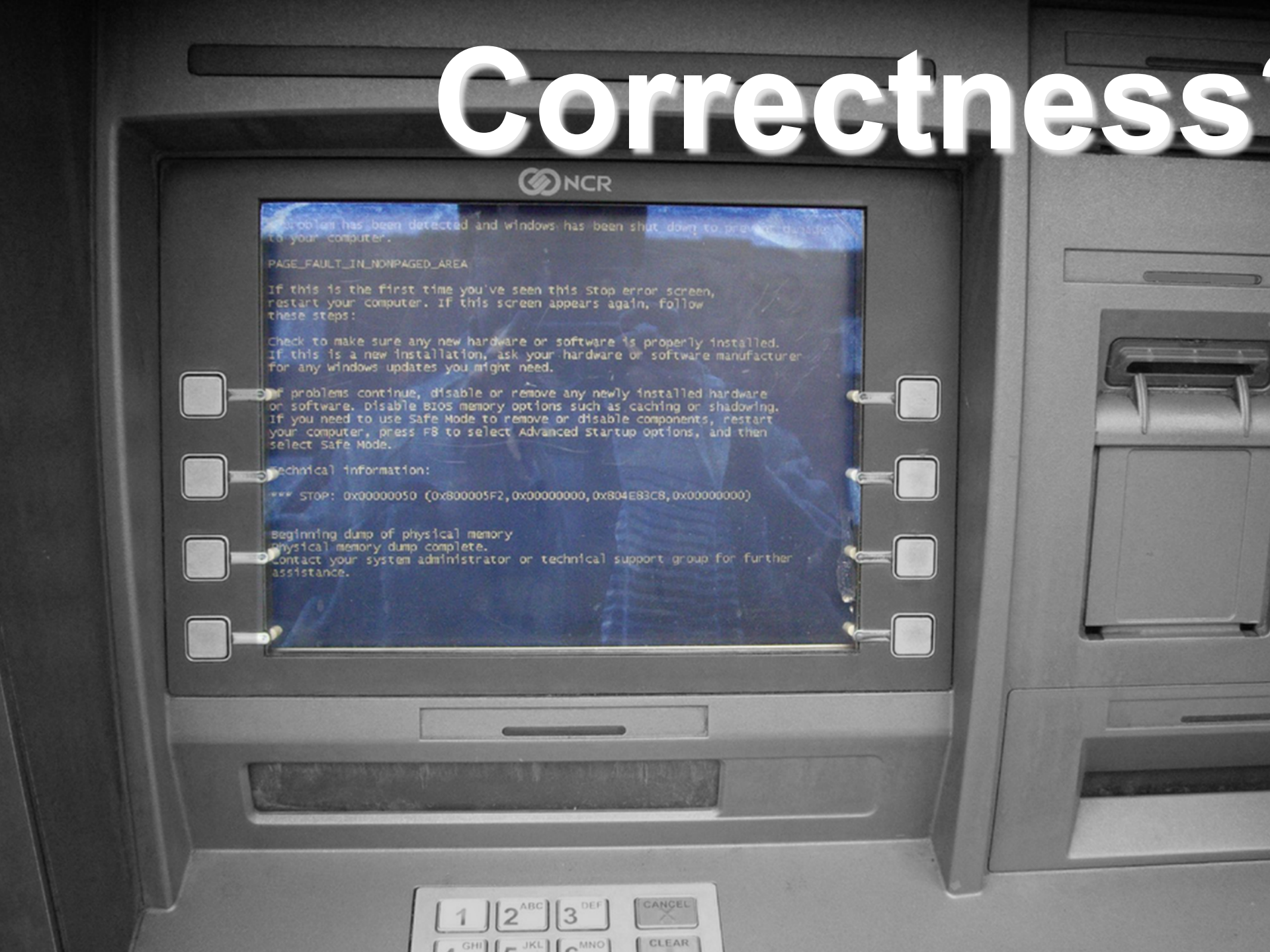

320 optional, independent features
more variants than estimated
atoms in the universe

2000 features

10000 features




Automation?
Avoid solving the same problem!
2, 3…n times


Correctness
NCR
PAGE_FAULT_IN_NONPAGED_AREA
If this is the first time you've seen this Stop error screen,
restart your computer. If this screen appears again, follow
these steps:
Check to make sure any new hardware or software is properly installed.
If this is a new installation, ask your hardware or software manufacturer
for any windows updates you might need.
If problems continue, disable or remove any newly installed hardware
or software. Disable BIOS memory options such as caching or shadowing.
If you need to use Safe Mode to remove or disable components, restart
your computer, press F8 to select Advanced Startup options, and then
select Safe Mode.
Technical information:
*** STOP: 0x00000050 (0x800005F2,0x00000000,0x804E83C8,0x00000000)
Beginning dump of physical memory
Physical memory dump complete.
Contact your system administrator or technical support group for further
assistance.
1
2 ABC
3 DEF
CANCEL
CLEAR

Maintenance?
Comprehension?

Checking **Products**

2000 Features
100 Printers
30 New Printers per Year

Printer Firmware

Checking **Products**

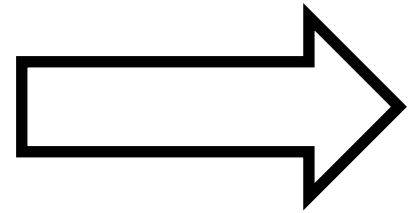
8000 Features

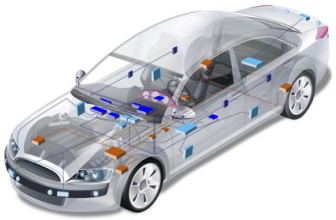
? Products

Linux Kernel

Software product line engineering

= modeling and managing variability





The development of a

family of software systems

differs from the development of

a **single** software system

THANKS CAPTAIN
OBVIOUS

« The development of a **family** of software systems differs from the development of a **single** software system »

Reuse

Customization

Automation

Commonality

Variability

Assembly Line and Mass Customization

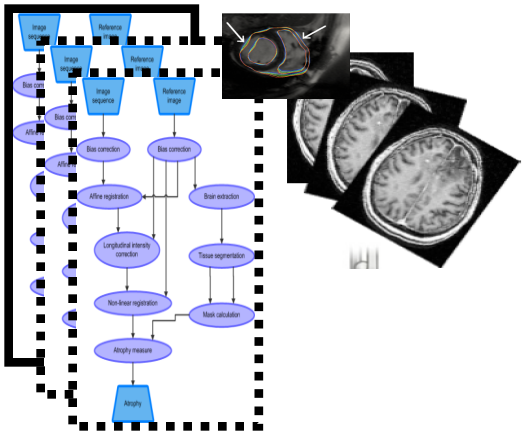
Reuse and Mass Customization

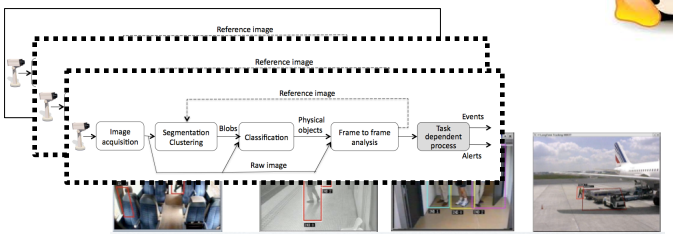

Starting from scratch?


You cannot start from scratch

"a set of software- intensive systems that share a common, managed set of features satisfying the specific needs of a particular market segment or mission and that are developed from a common set of core assets in a prescribed way" **[Clements et al., 2001]**

Software Product Lines

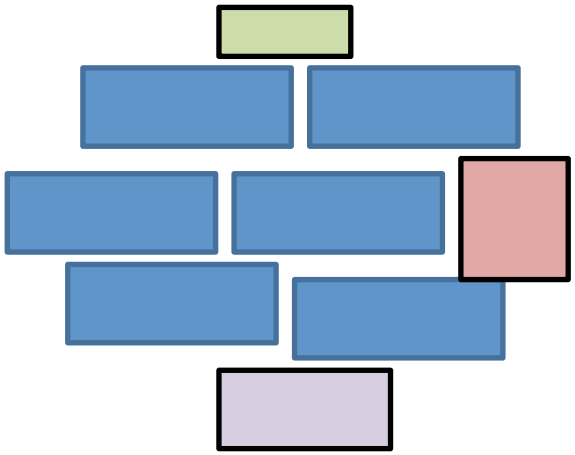




Software Product Line Engineering

Factoring out **commonalities**

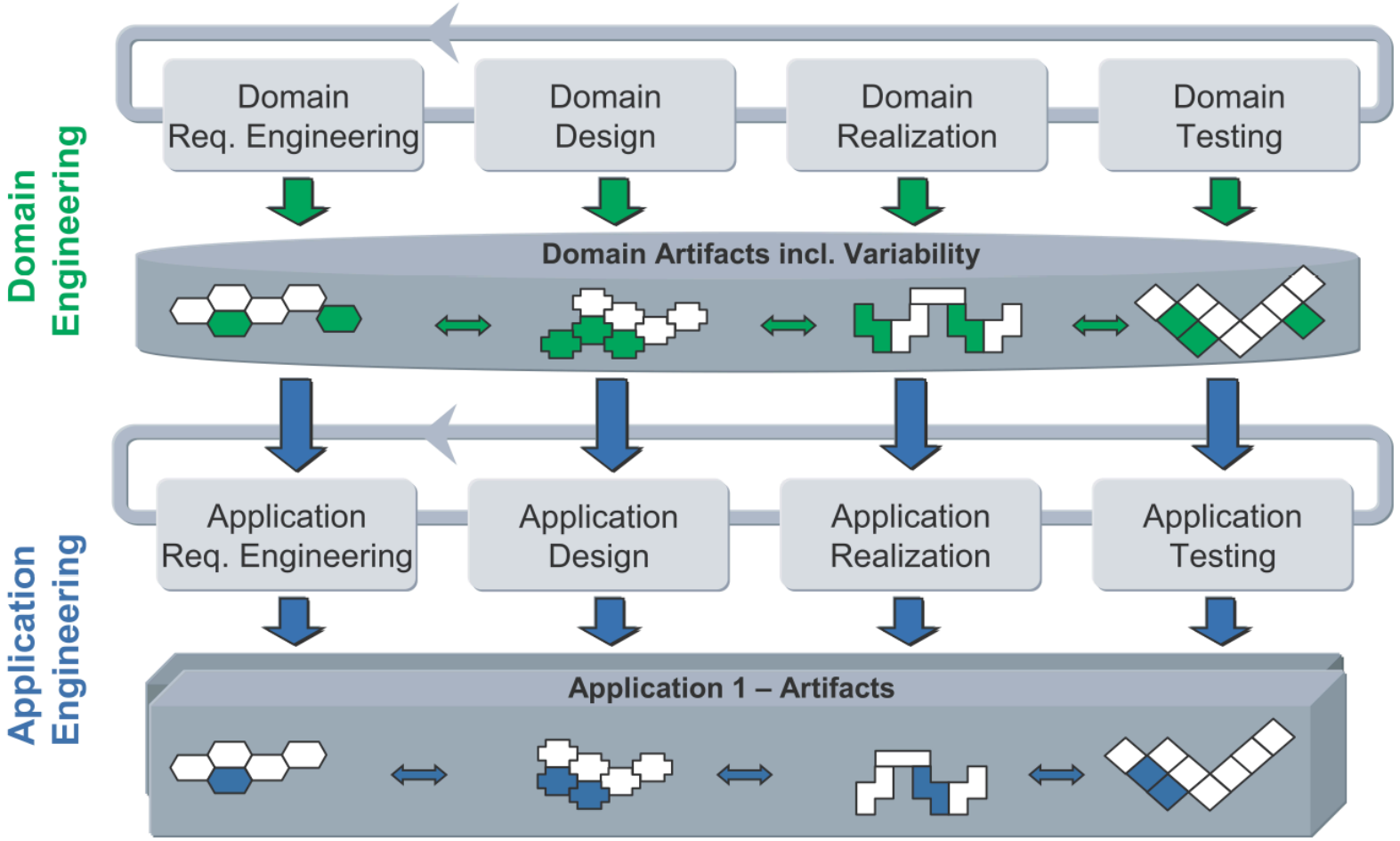
for **Reuse** [Krueger et al., 1992] [Jacobson et al., 1997]



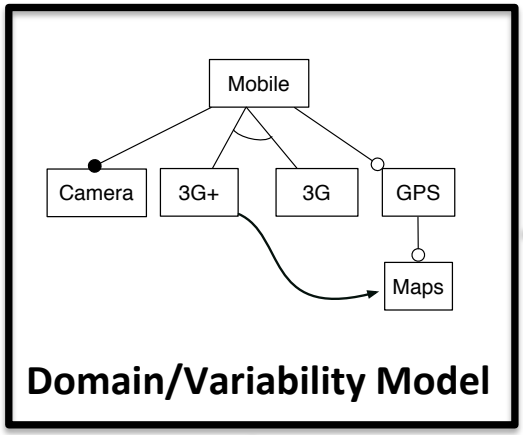
Managing **variabilities**

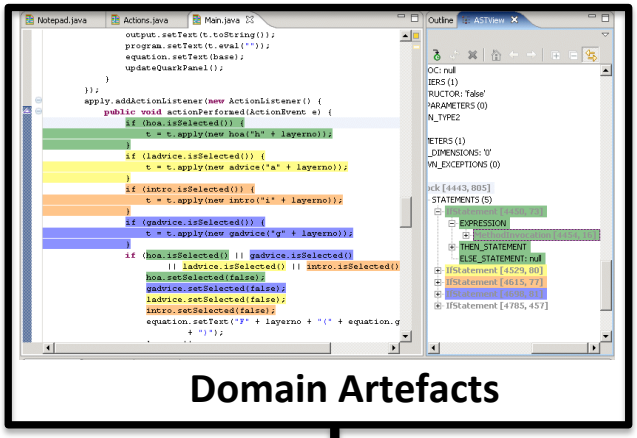
for Software **Mass Customization** [Bass et al., 1998] [Krueger et al., 2001], [Pohl et al., 2005]

Software Product-Line Engineering

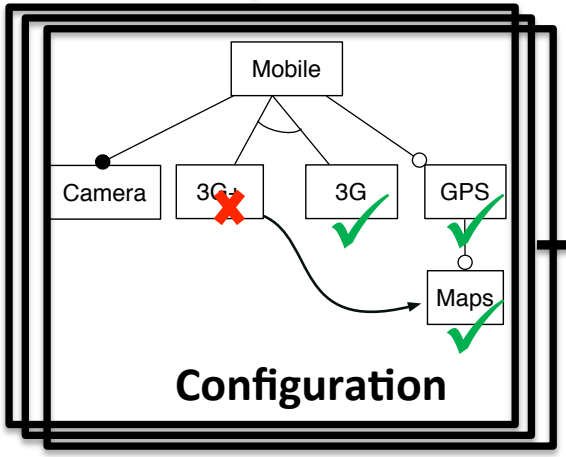


Domain Engineering



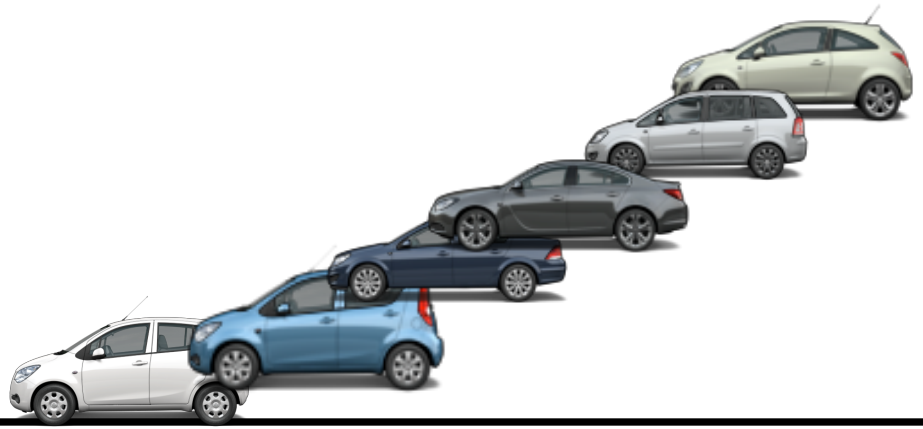


Application Engineering



*« 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)



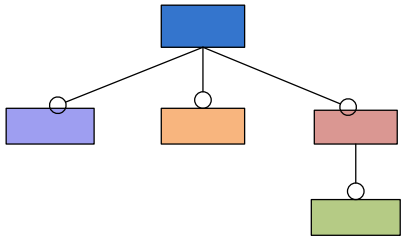
"Reuse-in-the-large works best in families of related systems, and thus is domain dependent." [Glass, 2001]

Domain engineering

Domain Analysis

(problem)

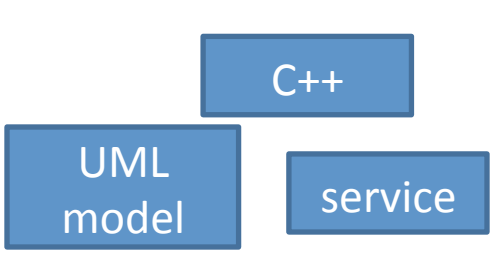
- elicitate requirements and scope the line
- variability modeling: determine commonalities and variabilities usually in terms of features



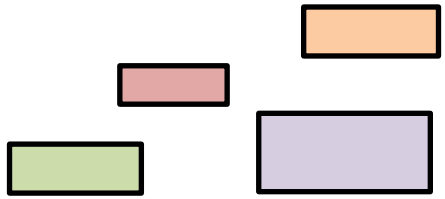
Variability Model (Feature Model)

Domain Implementation

(solution)



Common assets

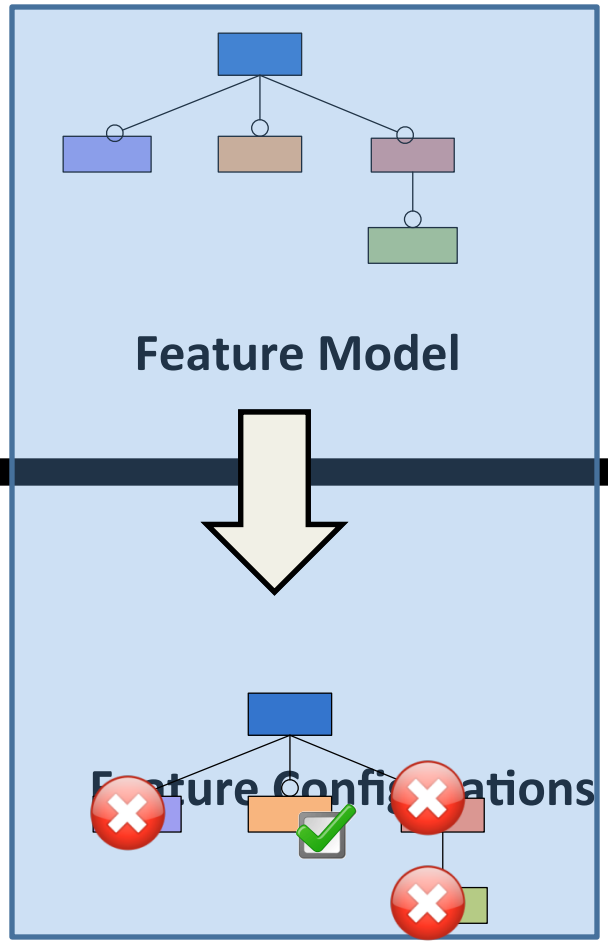


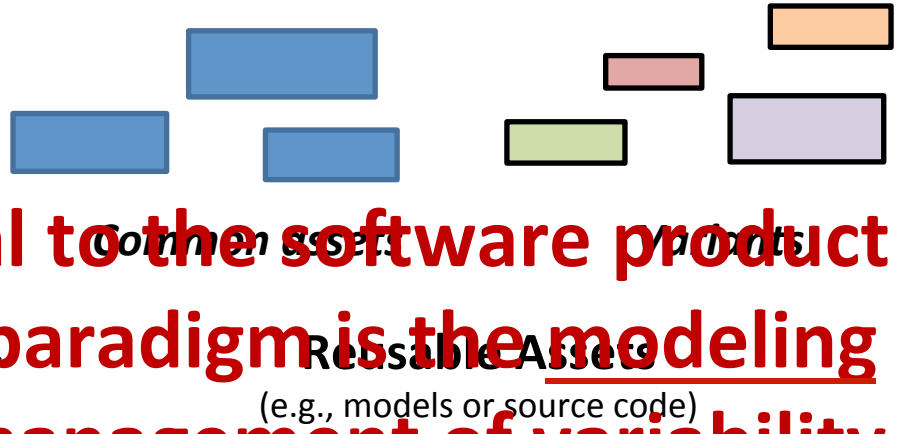
Variants

Reusable Assets

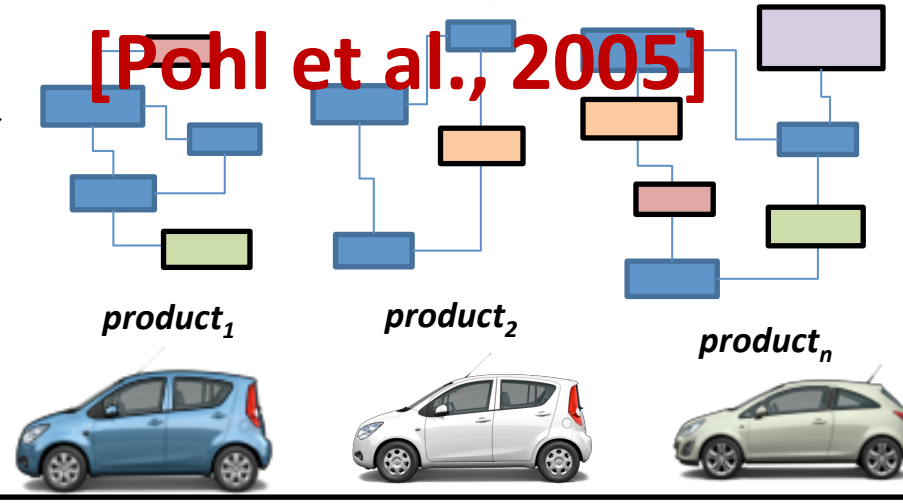
(e.g., models or source code)

Domain engineering (development for reuse)

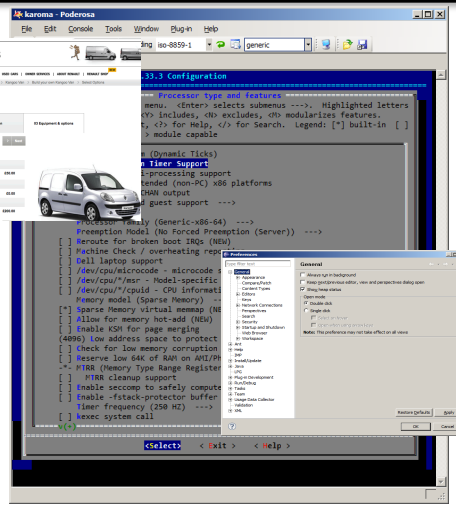




"central to the software product line paradigm is the modeling and management of variability, that is, the commonalities and differences in the applications" [Pohl et al., 2005]

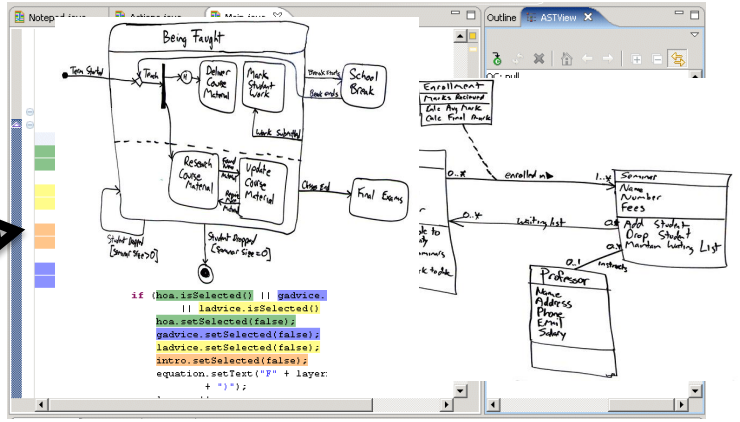


Application engineering (development with reuse)

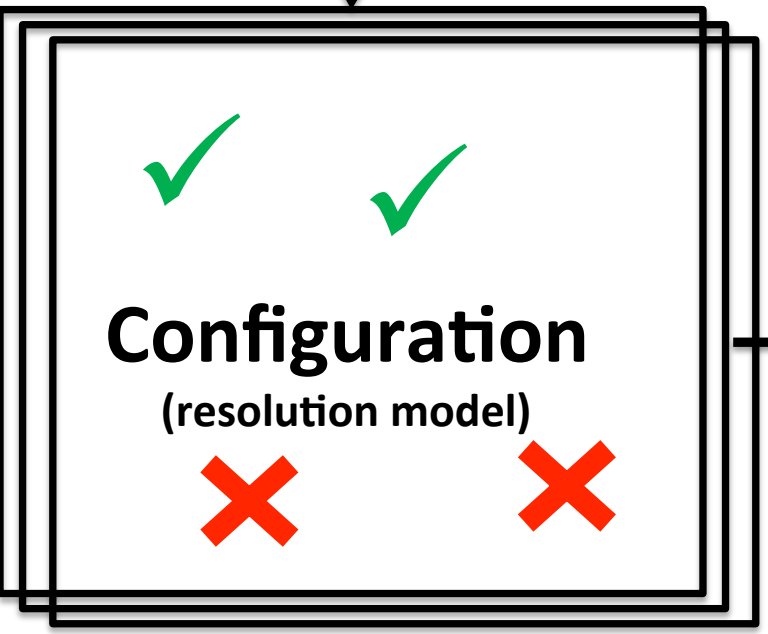


Variability Abstraction Model (VAM)

Variability Realization Model (VRM)



Domain Artefacts (e.g., models)



Configuration

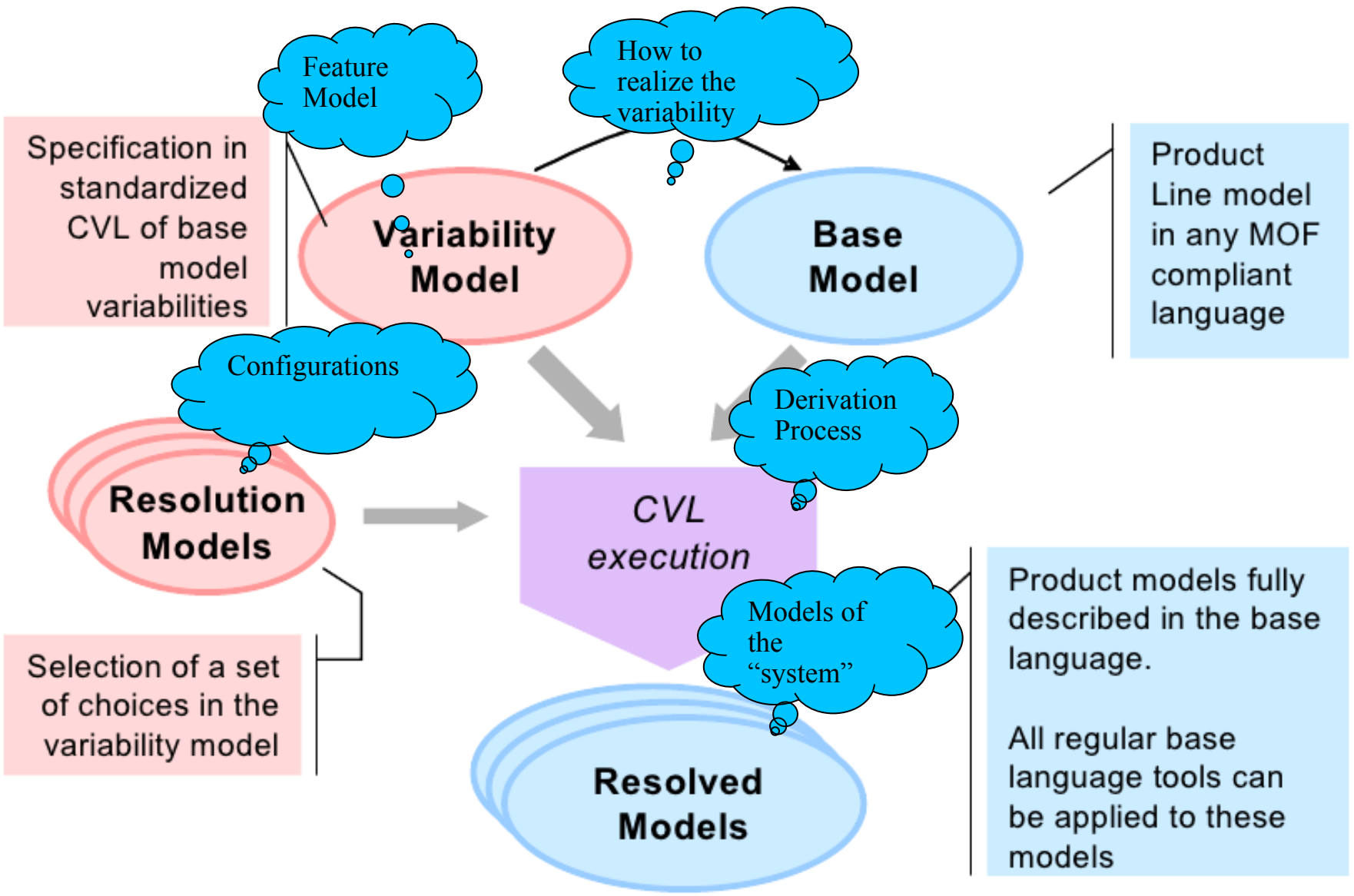
(resolution model)

Software Generator

(derivation engine)

COMMON VARIABILITY LANGUAGE

FAMiliAR

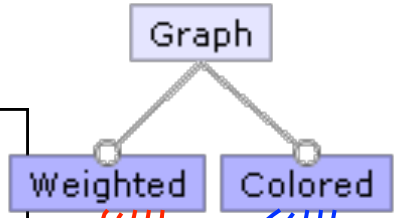


Variability Models and Mappings: Examples

Mapping: an example

```
class Graph {
  Vector nv = new Vector(); Vector ev = new Vector();
  Edge add(Node n, Node m) {
    Edge e = new Edge(n, m);
    nv.add(n); nv.add(m); ev.add(e);
    e.weight = new Weight();
    return e;
  }
  Edge add(Node n, Node m, Weight w)
    Edge e = new Edge(n, m);
    nv.add(n); nv.add(m); ev.add(e);
    e.weight = w; return e;
  }
  void print() {
    for(int i = 0; i < ev.size(); i++) {
      ((Edge)ev.get(i)).print();
    }
  }
}
```

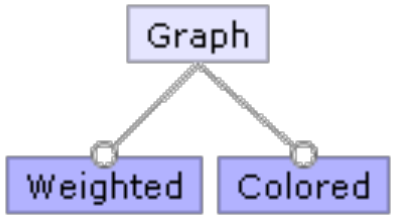
```
class Node {
  int id = 0;
  Color color = new Color();
  void print() {
    Color.setDisplayColor(color);
    System.out.print(id);
  }
}
```




```
class Edge {
  Node a, b;
  Color color = new Color();
  Weight weight;= new Weight();
  Edge(Node _a, Node _b) { a = _a; b = _b; }
  void print() {
    Color.setDisplayColor(color);
    a.print(); b.print();
    weight.print();
  }
}
```

```
class Color {
  static void setDisplayColor(Color c) { ... }
}
```

```
class Weight { void print() { ... } }
```



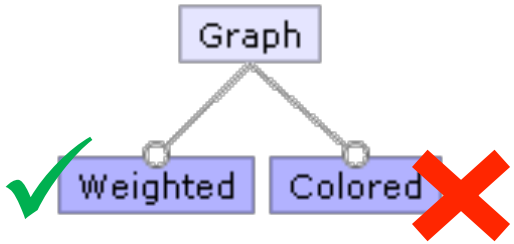

```
class Graph {
  Vector nv = new Vector(); Vector ev = new Vector();
  Edge add(Node n, Node m) {
    Edge e = new Edge(n, m);
    nv.add(n); nv.add(m); ev.add(e);
    /*if[WEIGHT]*/
    e.weight = new Weight();
    /*end[WEIGHT]*/
    return e;
  }
  /*if[WEIGHT]*/
  Edge add(Node n, Node m, Weight w)
    Edge e = new Edge(n, m);
    nv.add(n); nv.add(m); ev.add(e);
    e.weight = w; return e;
  }
  /*end[WEIGHT]*/
  void print() {
    for(int i = 0; i < ev.size(); i++) {
      ((Edge)ev.get(i)).print();
    }
  }
}
```

```
/*if[WEIGHT]*/
class Weight { void print() { ... } }
/*end[WEIGHT]*/
```

```
class Edge {
  Node a, b;
  /*if[COLOR]*/
  Color color = new Color();
  /*end[COLOR]*/
  /*if[WEIGHT]*/
  Weight weight;
  /*end[WEIGHT]*/
  Edge(Node _a, Node _b) { a = _a; b = _b; }
  void print() {
    /*if[COLOR]*/
    Color.setDisplayColor(color);
    /*end[COLOR]*/
    a.print(); b.print();
    /*if[WEIGHT]*/
    weight.print();
    /*end[WEIGHT]*/
  }
}
```

```
/*if[COLOR]*/
class Color {
  static void setDisplayColor(Color c) { ... }
}
/*end[COLOR]*/
```

```
class Node {
  int id = 0;
  /*if[COLOR]*/
```

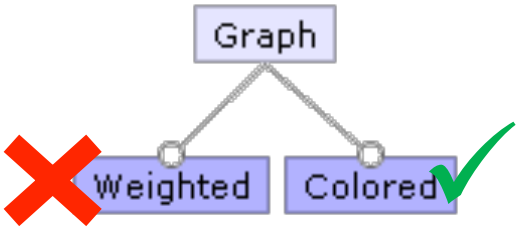



```
class Graph {
  Vector nv = new Vector(); Vector ev = new Vector();
  Edge add(Node n, Node m) {
    Edge e = new Edge(n, m);
    nv.add(n); nv.add(m); ev.add(e);
e.weight = new Weight();
return e;
  }
Edge add(Node n, Node m, Weight w)
    Edge e = new Edge(n, m);
    nv.add(n); nv.add(m); ev.add(e);
    e.weight = w; return e;
  }
void print() {
    for(int i = 0; i < ev.size(); i++) {
      ((Edge)ev.get(i)).print();
    }
  }
}
```

```
class Edge {
  Node a, b;
  Weight weight;
  Edge(Node _a, Node _b) { a = _a; b = _b; }
  void print() {
   a.print(); b.print();
   weight.print();
}
}
```

```
class Node {
  int id = 0;
  void print() {
   System.out.print(id);
  }
}
```

```
class Weight { void print() { ... } }
```



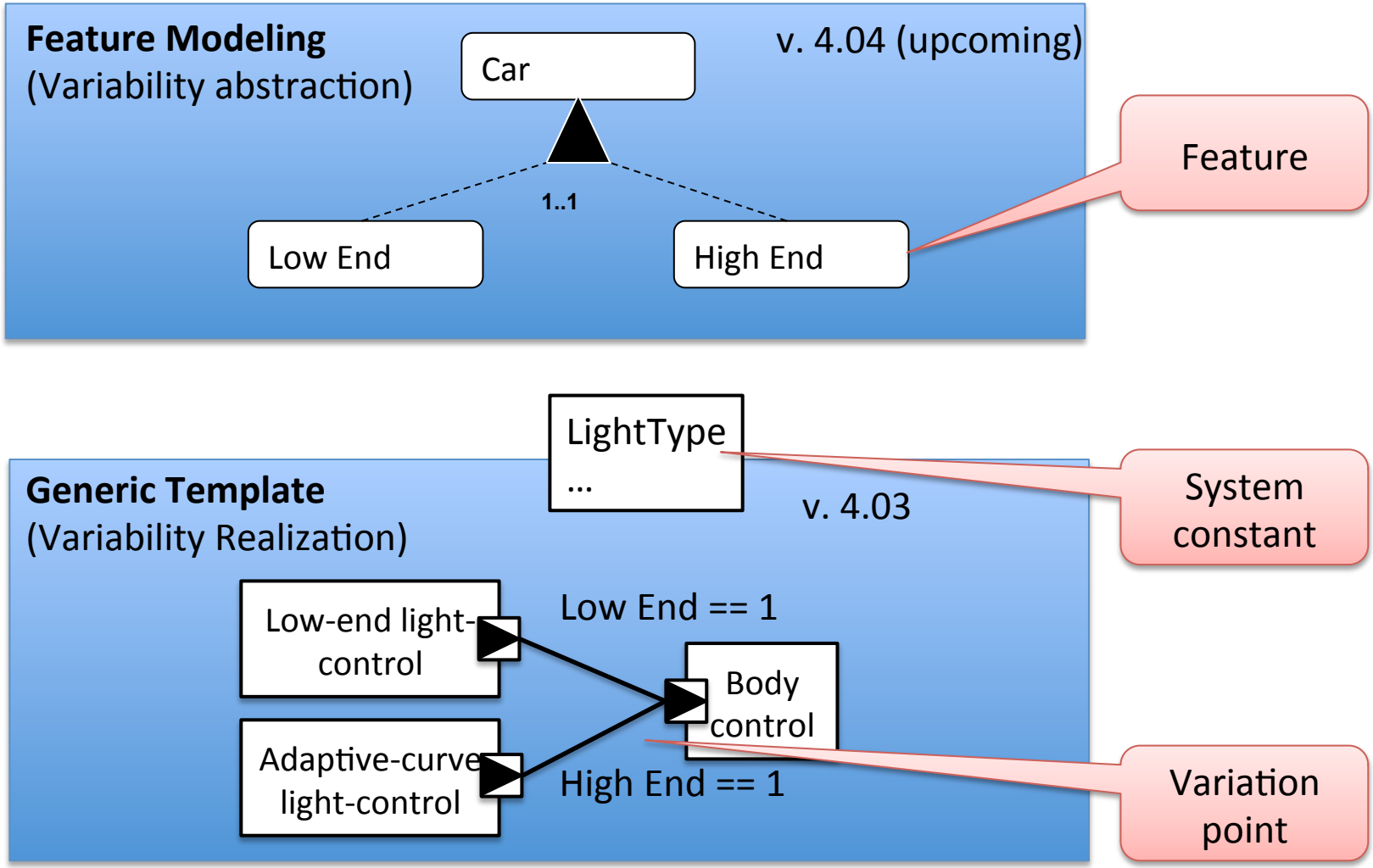

```
class Graph {
  Vector nv = new Vector(); Vector ev = new Vector();
  Edge add(Node n, Node m) {
    Edge e = new Edge(n, m);
    nv.add(n); nv.add(m); ev.add(e);
return e;
  }
void print() {
    for(int i = 0; i < ev.size(); i++) {
      ((Edge)ev.get(i)).print();
    }
  }
}
```

```
class Edge {
  Node a, b;
  Color color = new Color();
Edge(Node _a, Node _b) { a = _a; b = _b; }
  void print() {
Color.setDisplayColor(color);
a.print(); b.print();
}
}
```

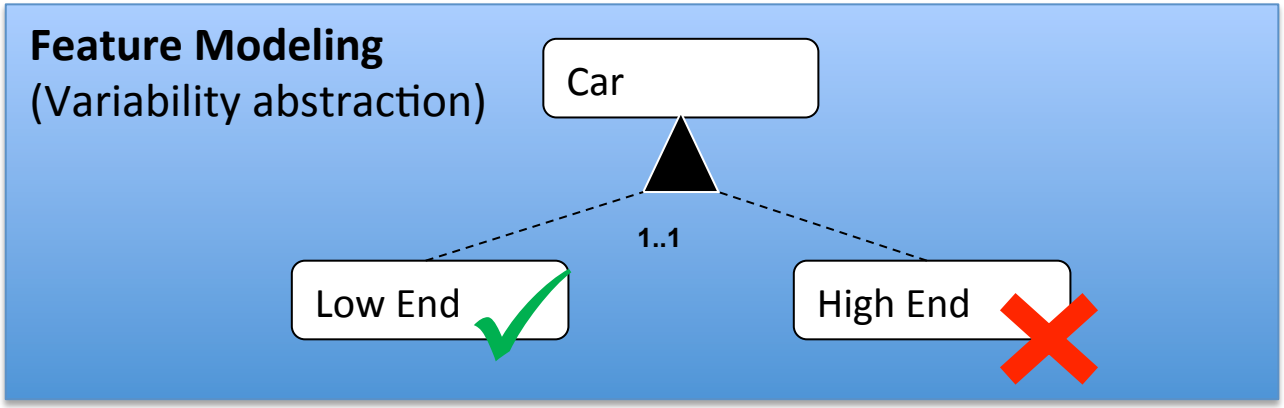
```
class Color {
  static void setDisplayColor(Color c) { ... }
}
```

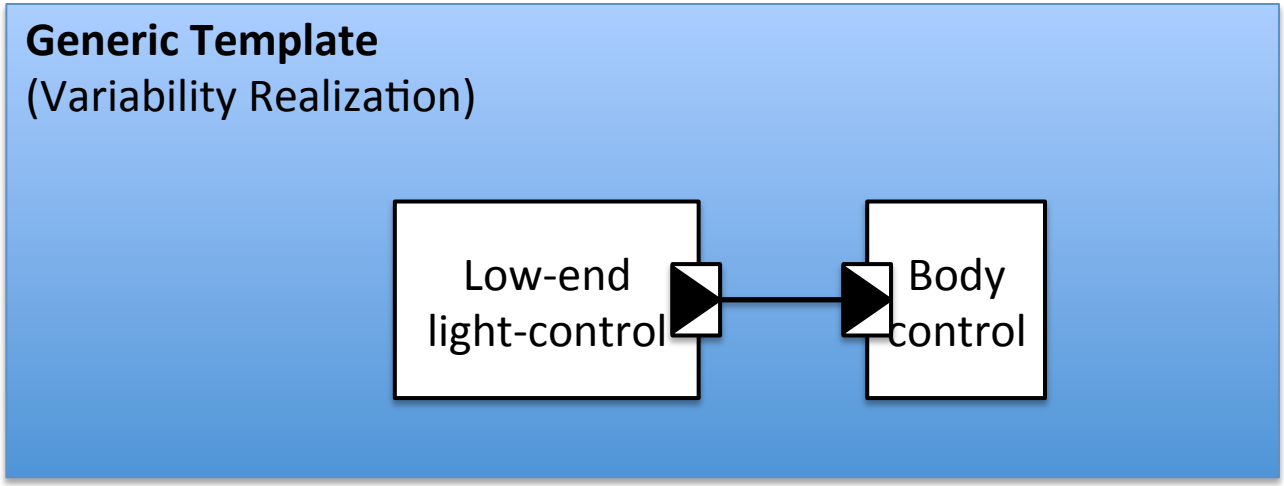
```
class Node {
  int id = 0;
Color color = new Color();
void print() {
Color.setDisplayColor(color);
System.out.print(id);
  }
}
```

Variability Handling in AUTOSAR

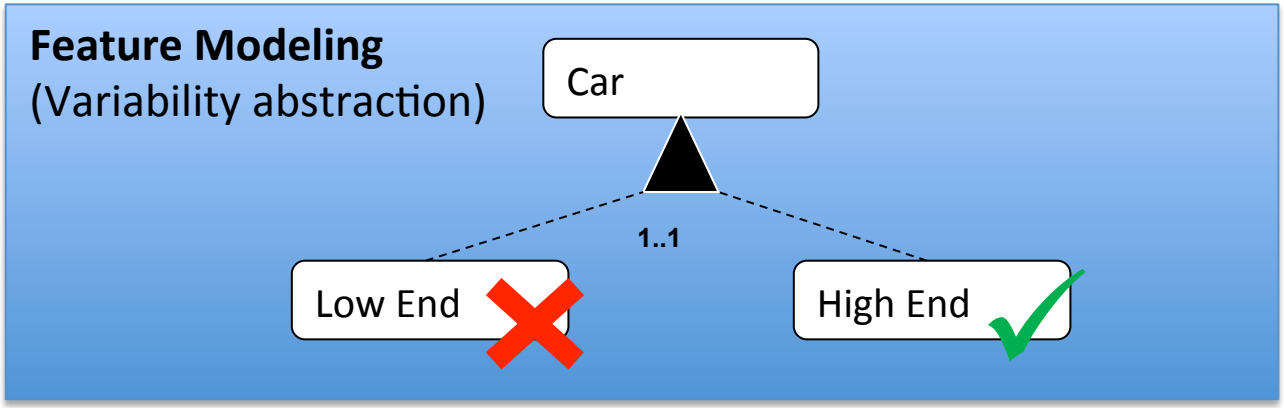


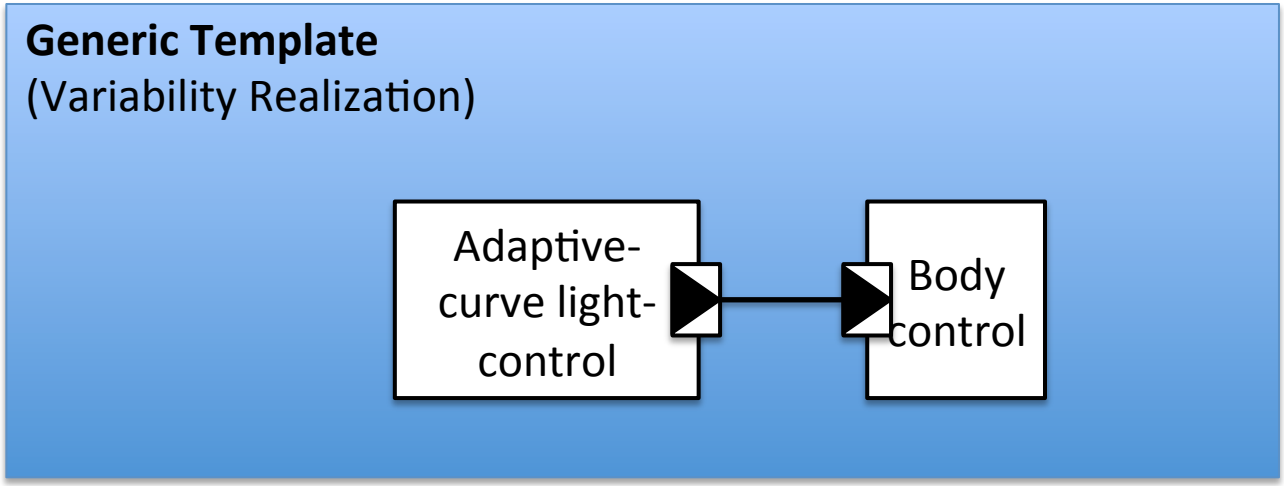
Variability Handling in AUTOSAR (2)





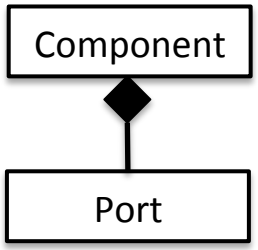
Variability Handling in AUTOSAR (3)

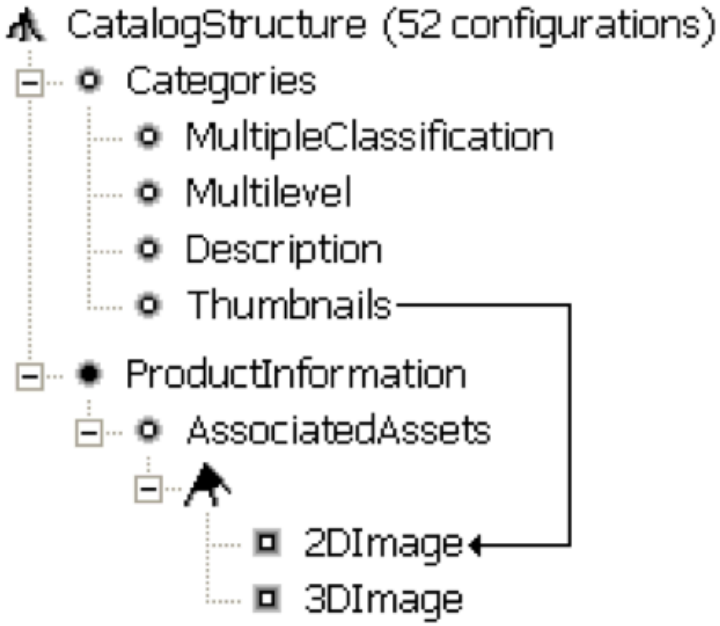


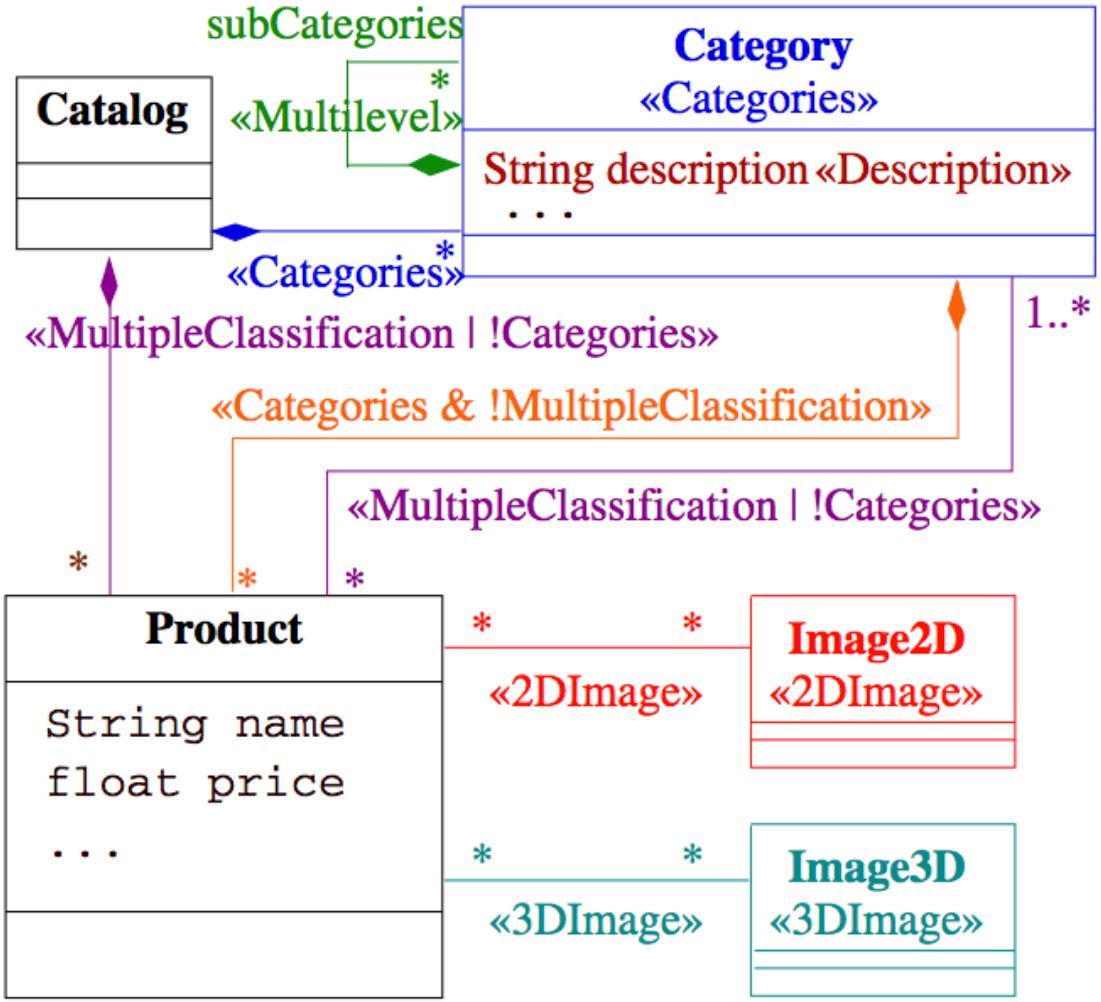


Variation Point Types

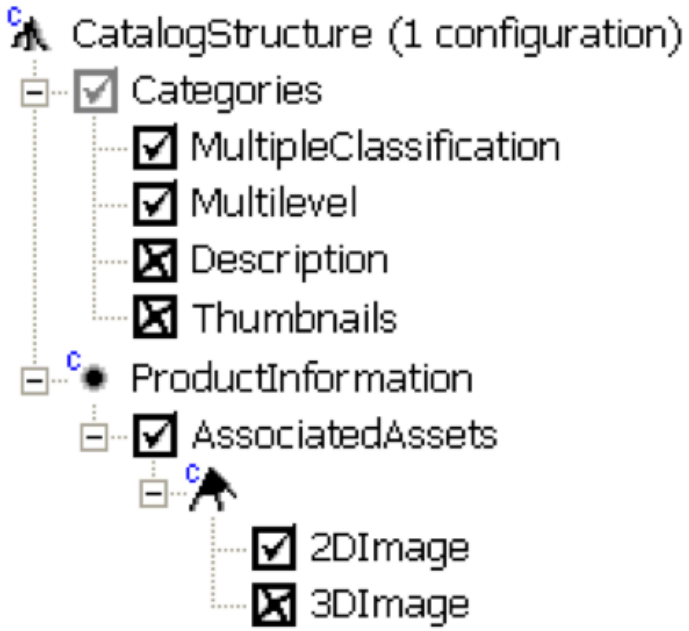
- Variability is applied to different parts of the metamodel
  - Aggregation, association, attribute value, property set
- Resulting variability
  - Optional component
  - Optional port
  - Optional connector
  - Parameter variability

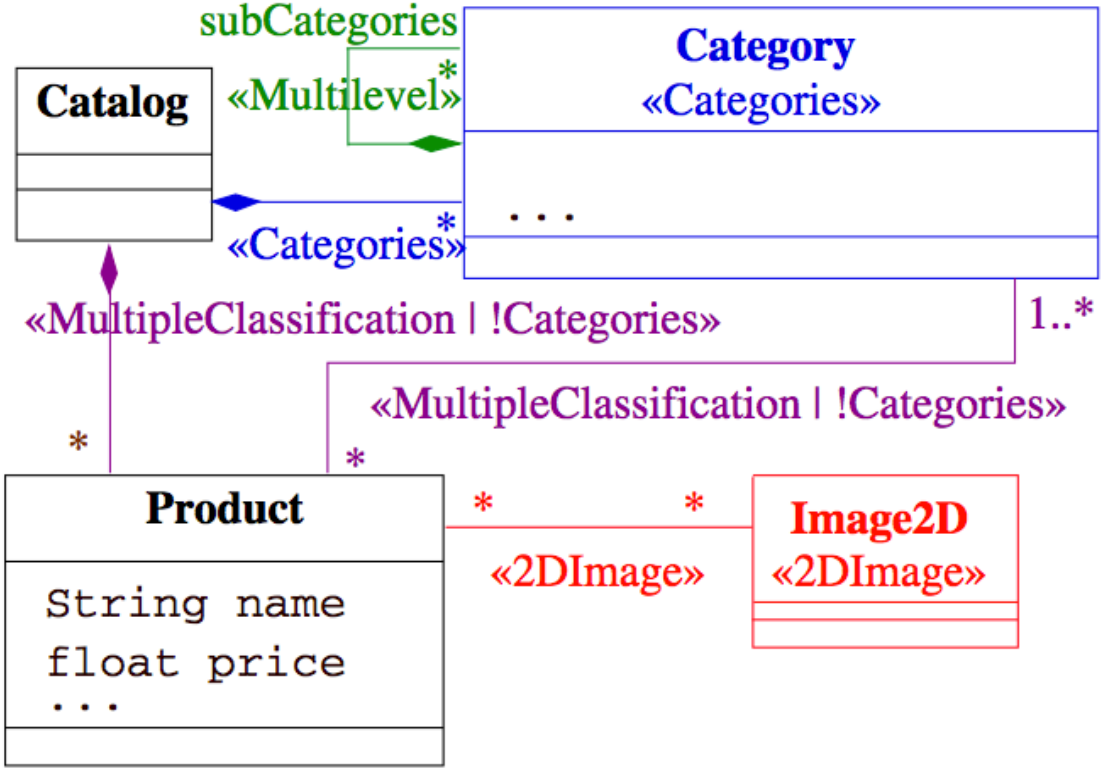






« Mapping Features to Models: A Template Approach Based on Superimposed Variants»
Krzysztof Czarnecki and Michal Antkiewicz GPCE'05





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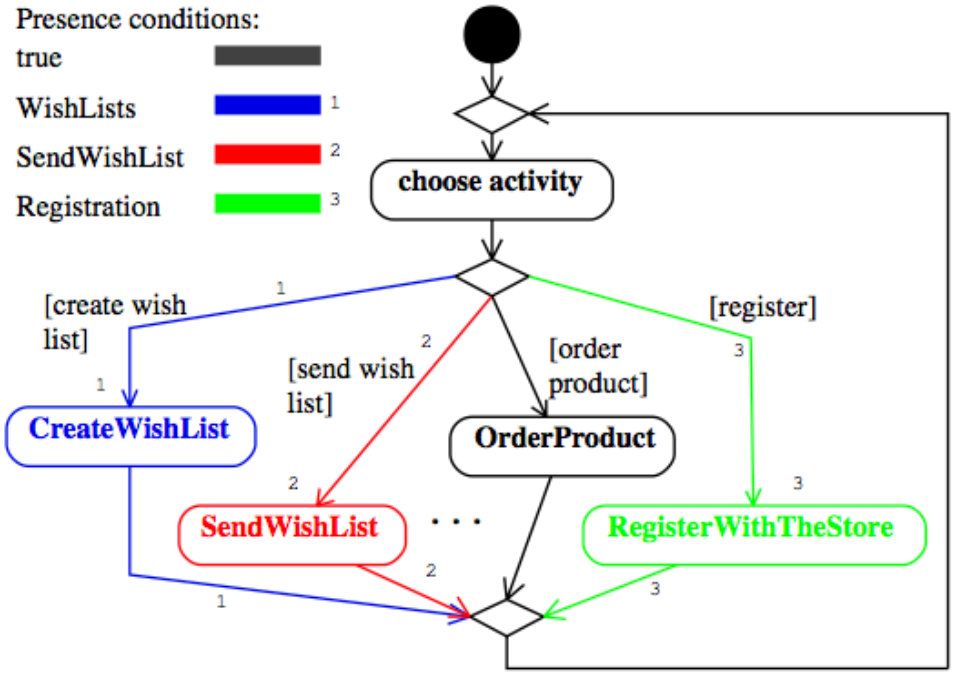
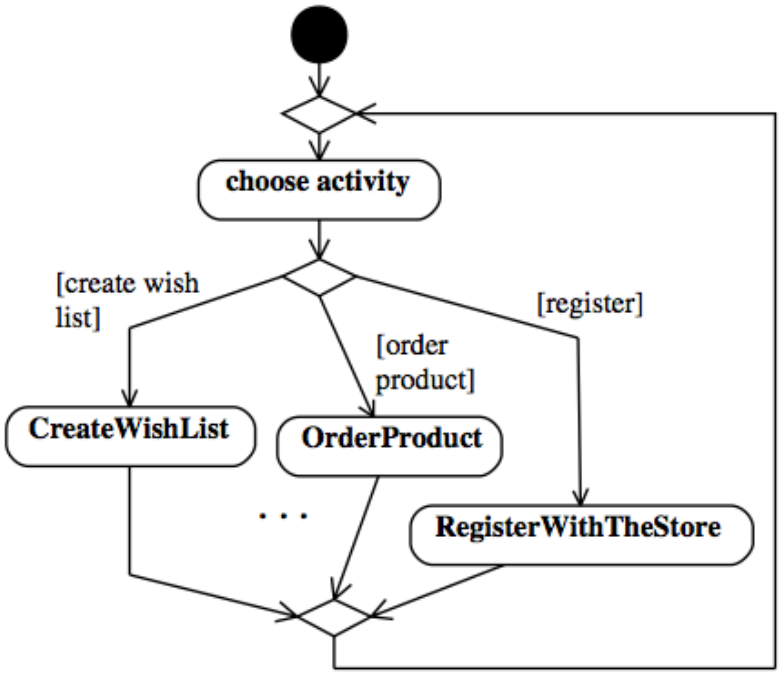


(a) Storefront template



(b) Storefront instance

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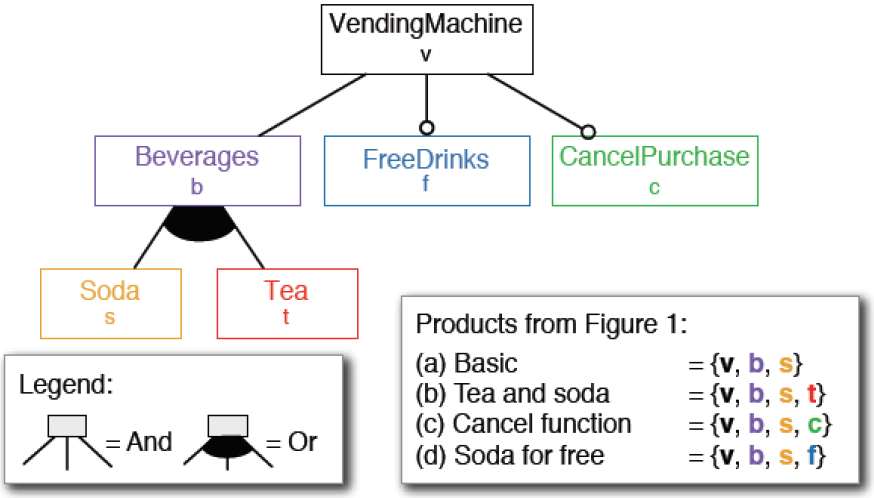


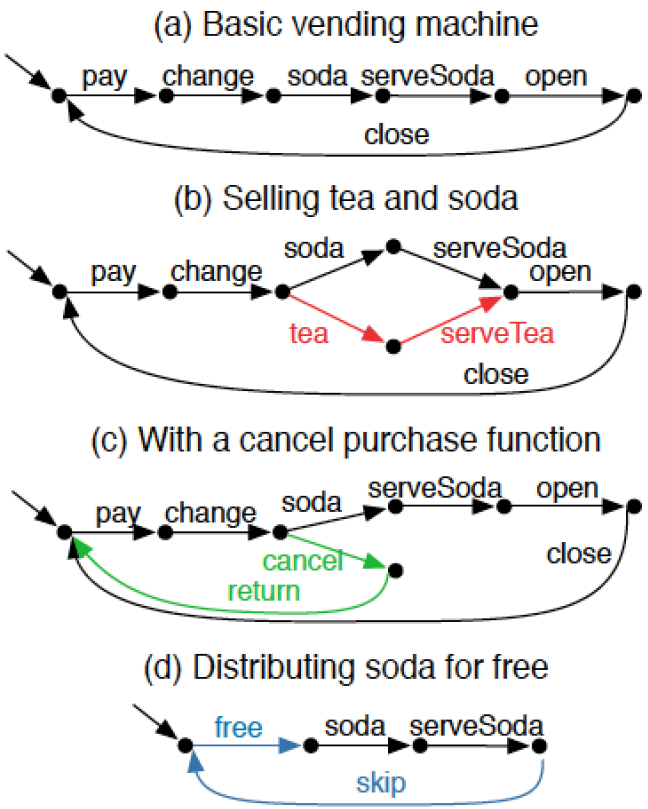
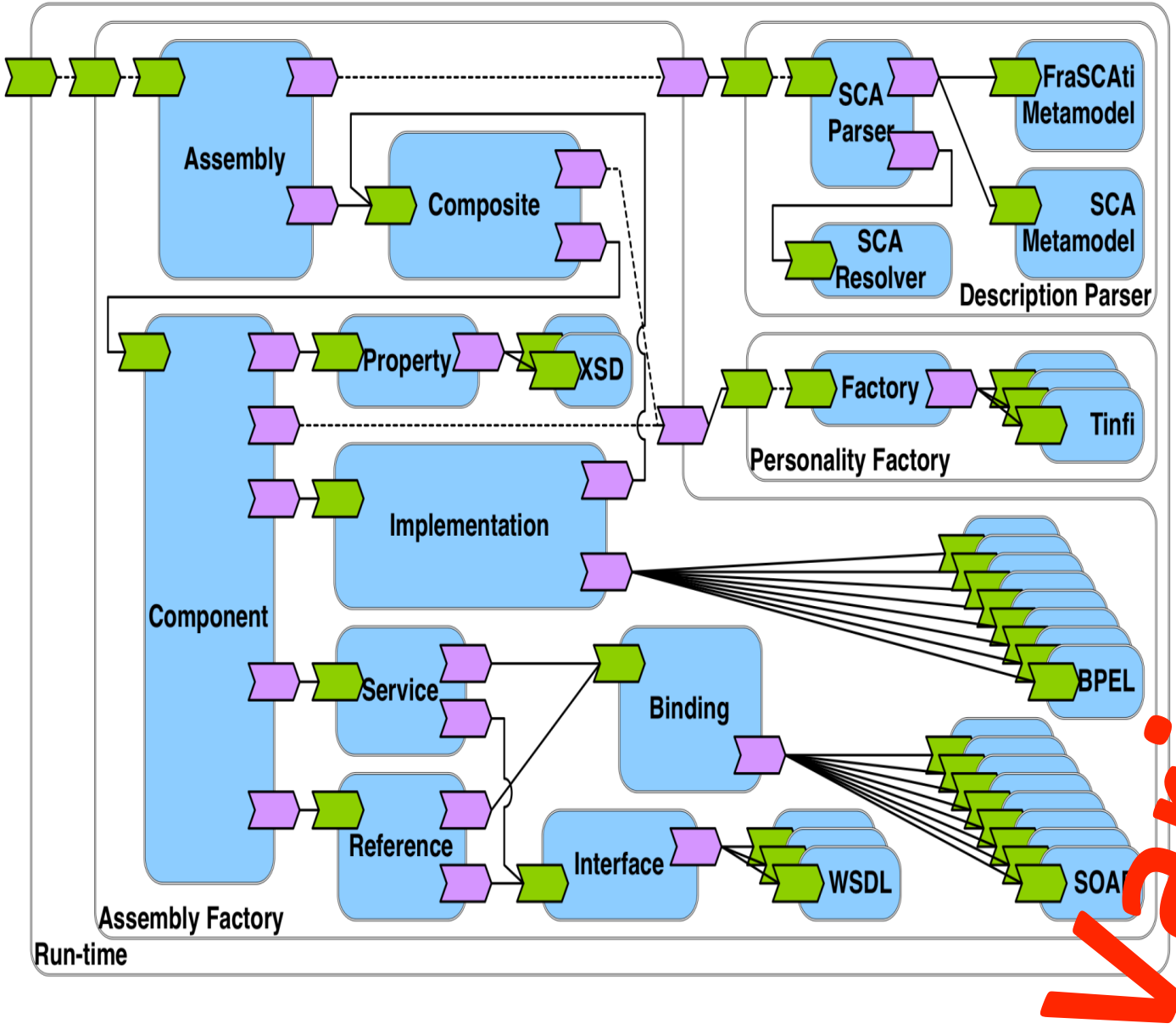
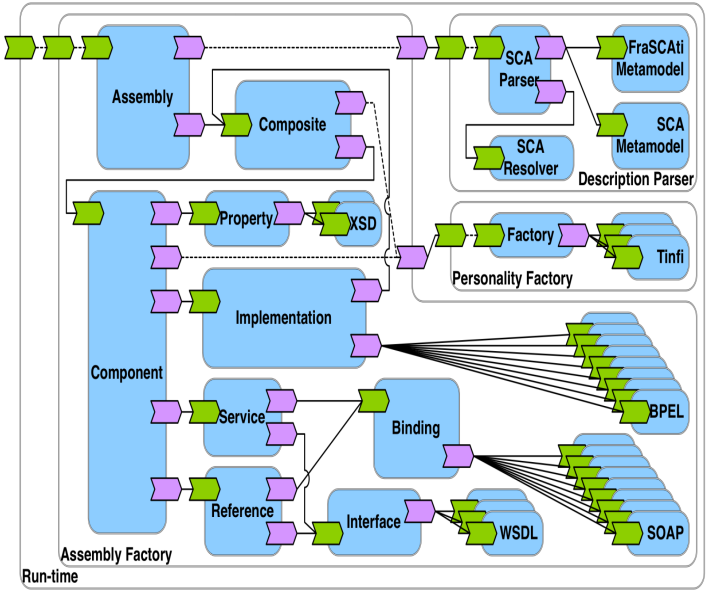


Figure 1: Several variants of a vending machine.

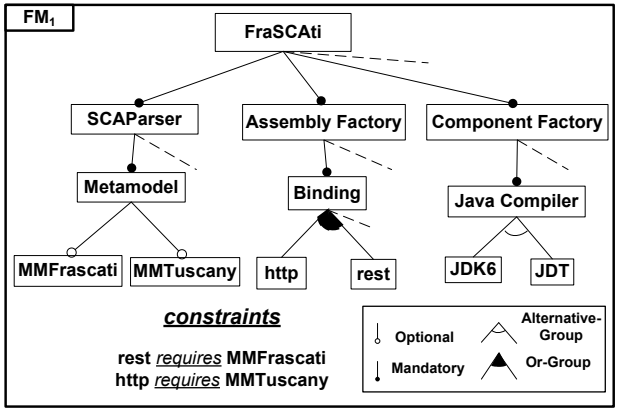


Variability

« Extraction and Evolution of Architectural Variability Models in Plugin-based Systems »
Mathieu Acher, Anthony Cleve, Philippe Collet, Philippe Merle, Laurence Duchien, Philippe Lahire ECSA/SoSyM'13



maven



Variability Model

« Extraction and Evolution of Architectural Variability Models in Plugin-based Systems »
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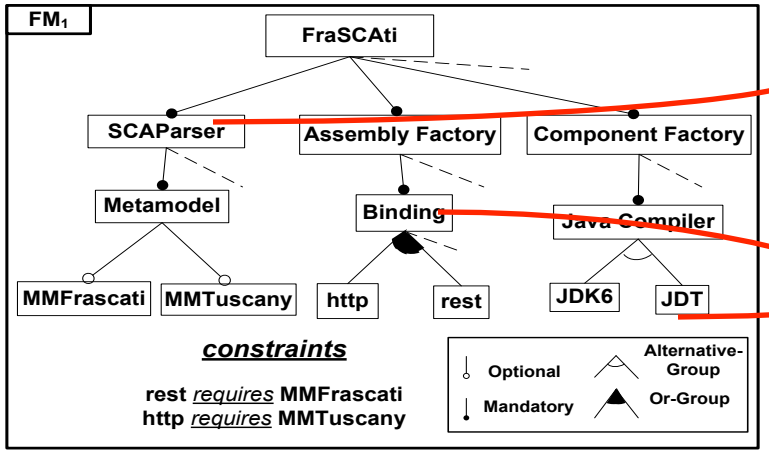
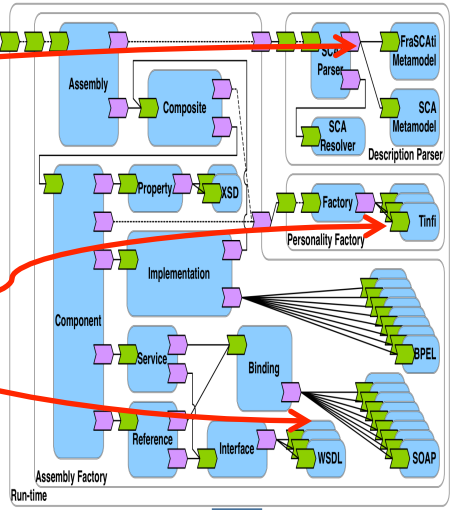
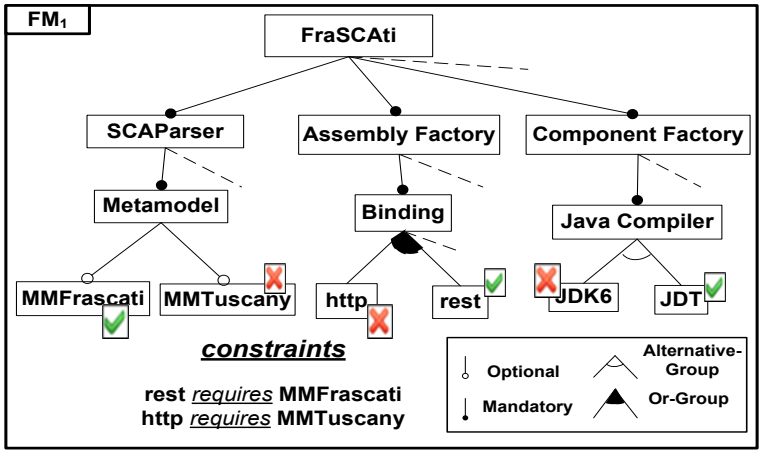
Feature Model



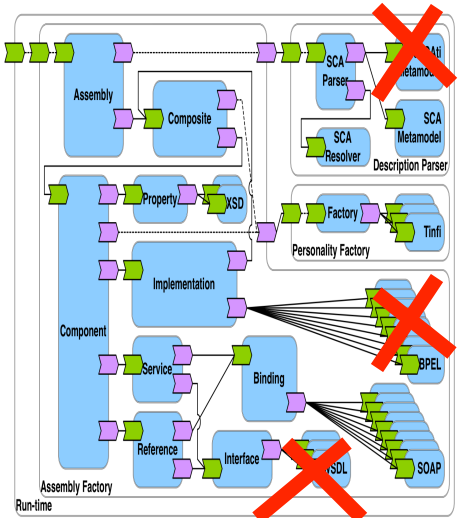
FraSCAti Architecture



Configuration



Derived FraSCAti Architecture



Software Product Line and Variability Engineering

A revisit of your cursus

What is new?

Family vs single systems

Focus on reuse

Domain engineering

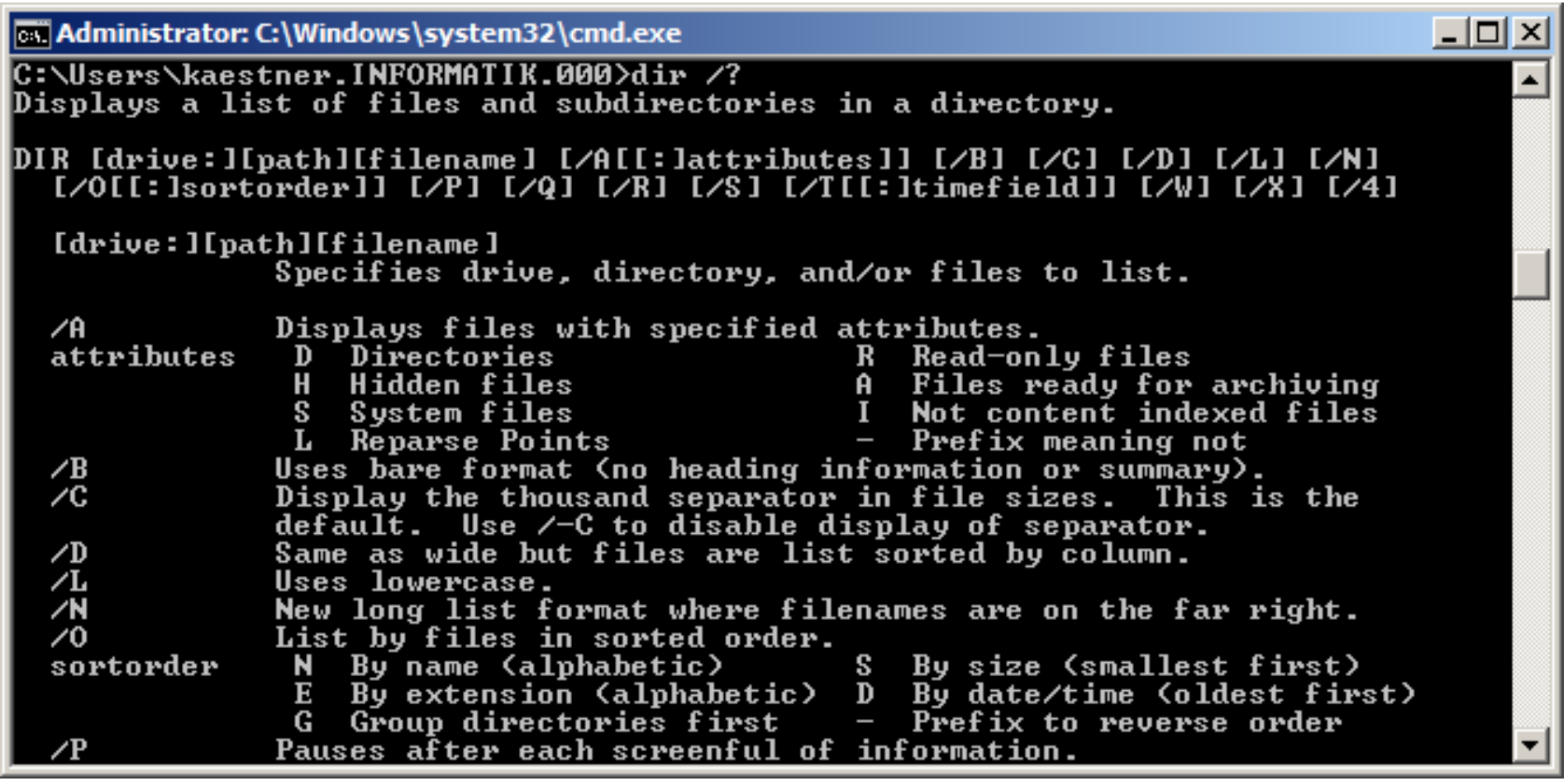
Factoring out commonality

Managing variability

« variability »

Is it really new?

Parameter


Administrator: C:\Windows\system32\cmd.exe
C:\Users\kaestner.INFORMATIK.000>dir /?
Displays a list of files and subdirectories in a directory.
DIR [drive:][path][filename] [/A[[:]attributes]] [/B] [/C] [/D] [/L] [/N]
[/O[[:]sortorder]] [/P] [/Q] [/R] [/S] [/T[[:]timefield]] [/W] [/X] [/4]
[drive:][path][filename]
Specifies drive, directory, and/or files to list.
/A
attributes
Displays files with specified attributes.
D Directories
H Hidden files
S System files
L Reparse Points
R Read-only files
A Files ready for archiving
I Not content indexed files
- Prefix meaning not
/B
Uses bare format (no heading information or summary).
/C
Display the thousand separator in file sizes. This is the
default. Use /-C to disable display of separator.
/D
Same as wide but files are list sorted by column.
/L
Uses lowercase.
/N
New long list format where filenames are on the far right.
/O
List by files in sorted order.
sortorder
N By name (alphabetic)
E By extension (alphabetic)
G Group directories first
S By size (smallest first)
D By date/time (oldest first)
- Prefix to reverse order
/P
Pauses after each screenful of information.

Parameter –i in grep

```
1  int match_icase;
2
3  int main (int argc, char **argv)
4  {
5    [...]
6    while ((opt = get_nondigit_option (argc, argv, &default_c
7      switch (opt)
8        {
9        [...]
10       case 'i':
11         match_icase = 1;
12         break;
13       }
14   }
15
16
17 static const char *
18 print_line_middle (const char *beg, const char *lim,
19                    const char *line_color, const char *match_color)
20 {
21   [...]
22   if (match_icase)
23     {
24       ibeg = buf = (char *) xmalloc(i);
25       while (--i >= 0)
26         buf[i] = tolower(beg[i]);
27     }
```

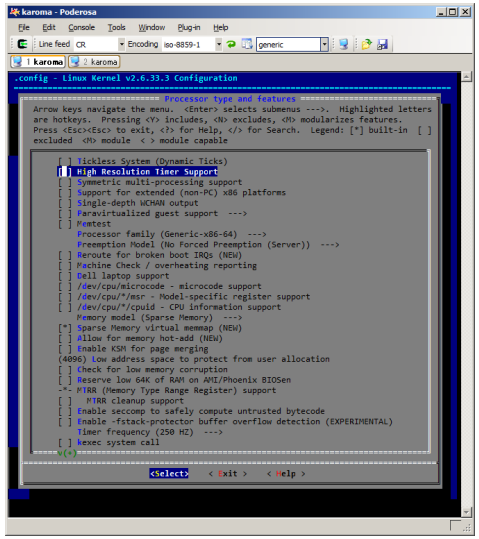
Global configuration

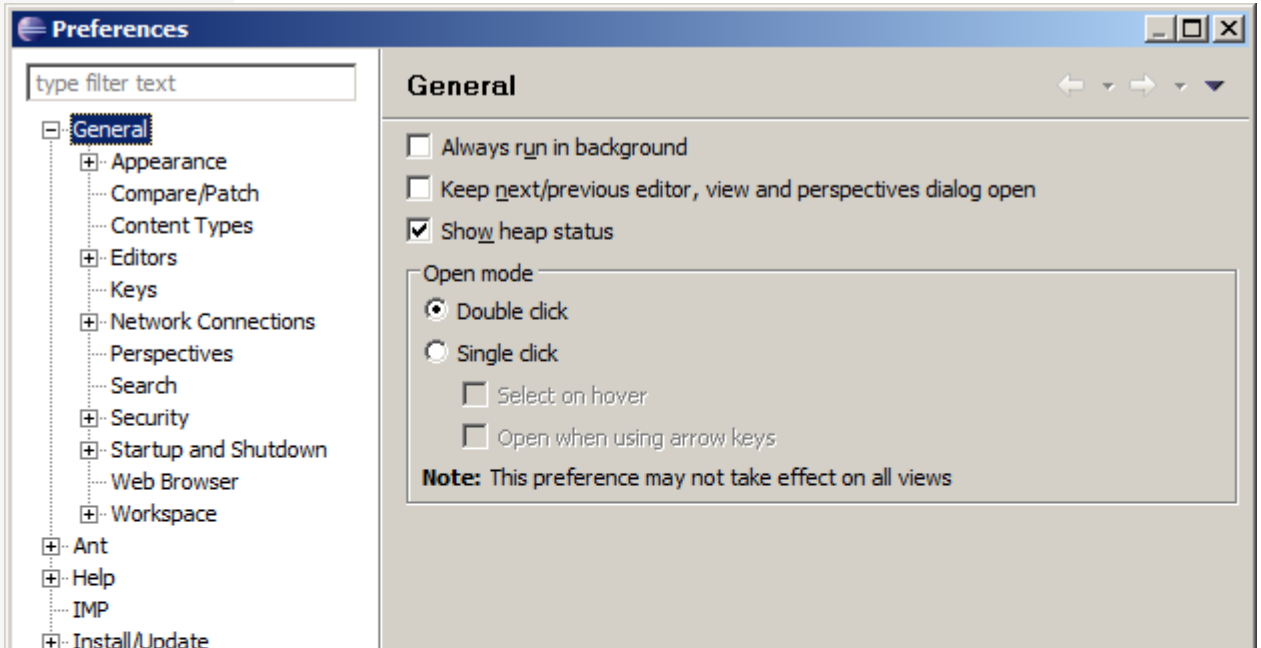
```
class Config {
  public static boolean isLogging = false;
  public static boolean isWindows = false;
  public static boolean isLinux = true;
}
class Main {
  public void foo() {
    if (isLogging)
      log(„running foo()“);
    if (isWindows)
      callWindowsMethod();
    else if (isLinux)
      callLinuxMethod();
    else
      throw RuntimeException();
}
```

Configuration

httpd.conf -- win32 Apache
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
```





Conditional compilation #ifdef (Berkeley DB)

```
static int __rep_queue_filedone(dbenv, rep, rfp)
                    DB_ENV *dbenv;
                    REP *rep;
                    __rep_fileinfo_args *rfp; {
#ifndef HAVE_QUEUE
                    COMPQUIET(rep, NULL);
                    COMPQUIET(rfp, NULL);
                    return (__db_no_queue_am(dbenv));
#else
                    db_pgno_t first, last;
                    u_int32_t flags;
                    int empty, ret, t_ret;
#ifdef DIAGNOSTIC
                    DB_MSGBUF mb;
#endif
                    // over 100 lines of additional code
}
#endif
```

Intentional Code Cloning

~ Copy & Paste

Code Cloning (example, Linux driver)

cyberstorm.c

```
....
static void dma_dump_state(struct NCR_ESP *esp)
{
        ESPLOG(("esp%d: dma -- cond_reg<%02x>\n",
                esp->esp_id, ((struct cyber_dma_registers *)
                                        (esp->dregs))->cond_reg));
        ESPLOG(("intreq:<%04x>, intena:<%04x>\n",
                custom.intreqr, custom.intenar));
}

static void dma_init_read(struct NCR_ESP *esp, __u32 addr, int
        length)
{
        struct cyber_dma_registers *dregs =
                (struct cyber_dma_registers *) esp->dregs;

        cache_clear(addr, length);

        addr &= ~(1);
        dregs->dma_addr0 = (addr >> 24) & 0xff;
        dregs->dma_addr1 = (addr >> 16) & 0xff;
        dregs->dma_addr2 = (addr >>  8) & 0xff;
        dregs->dma_addr3 = (addr      ) & 0xff;
        ctrl_data &= ~(CYBER_DMA_WRITE);
.......
```

cyberstormII.c

```
....
static void dma_dump_state(struct NCR_ESP *esp)
{
        ESPLOG(("esp%d: dma -- cond_reg<%02x>\n",
                esp->esp_id, ((struct cyberII_dma_registers *)
                                        (esp->dregs))->cond_reg));
        ESPLOG(("intreq:<%04x>, intena:<%04x>\n",
                custom.intreqr, custom.intenar));
}

static void dma_init_read(struct NCR_ESP *esp, __u32 addr, int
        length)
{
        struct cyberII_dma_registers *dregs =
                (struct cyberII_dma_registers *) esp->dregs;

        cache_clear(addr, length);

        addr &= ~(1);
        dregs->dma_addr0 = (addr >> 24) & 0xff;
        dregs->dma_addr1 = (addr >> 16) & 0xff;
        dregs->dma_addr2 = (addr >>  8) & 0xff;
        dregs->dma_addr3 = (addr      ) & 0xff;
}
.........
```

Replicate & Specialize

Clone to reuse and adapt existing solutions

+ Less effort needed

- Long-term cost outweighs short-term benefit

~ Cost of refactoring rises over time

Platform Variations

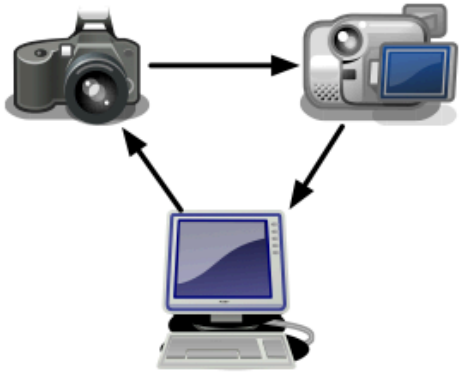
Clone existing code and fix low level platform interaction

+ Avoid complexity of virtualization layer

- Hard to propagate bug fixes

~ Ensure consistent behavior of all clones

Hardware Variations



Clone existing driver

+ No risk of changing existing driver
- Code growth
~ Dead code can creep into system

Inheritance (OOP)

Base Class encapsulate commonalities

Derive classes specialize peculiarities

Generic Programming

C++ template

```
template <typename T>
T max(T x, T y)
{
   return x < y ? y : x;
}
```

Generics in Java

```
public interface List<E> {
void add(E x);
Iterator<E> iterator();
}
public interface Iterator<E> {
E next();
boolean hasNext();
}
```

Design Patterns

Template Method

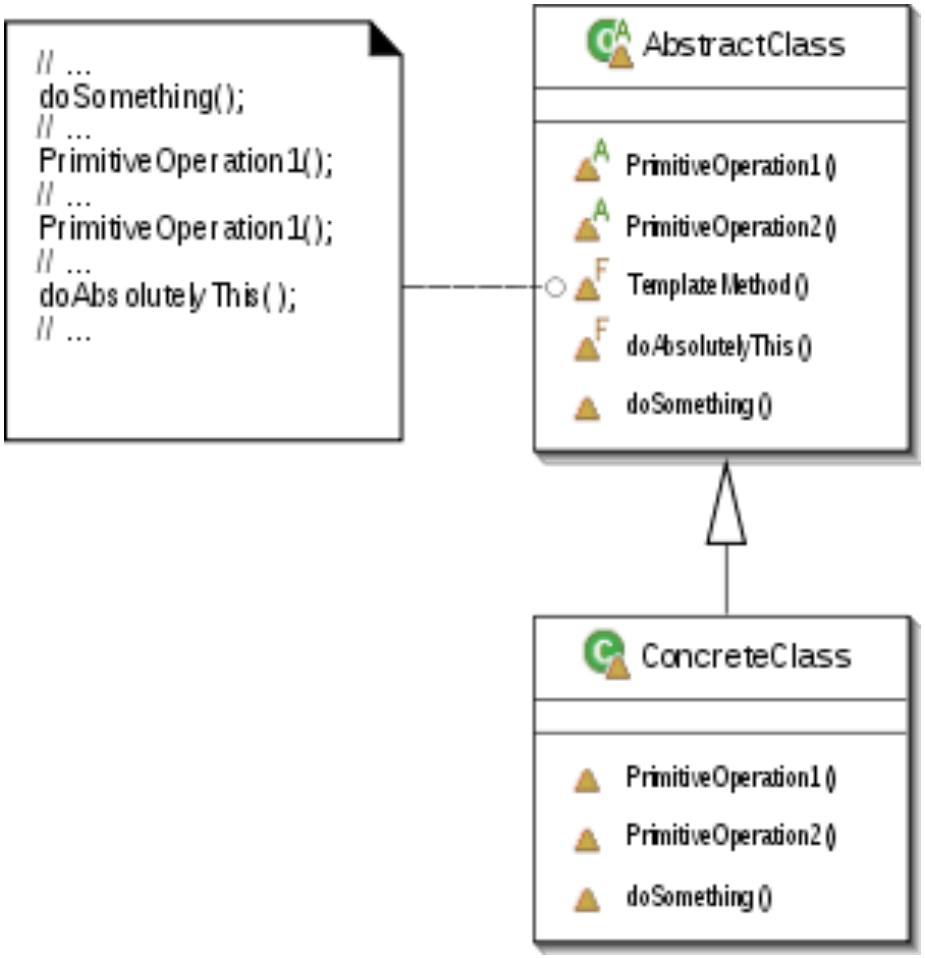
Factory

Strategy

Decorator

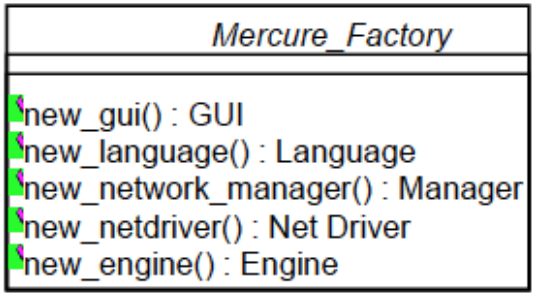
....

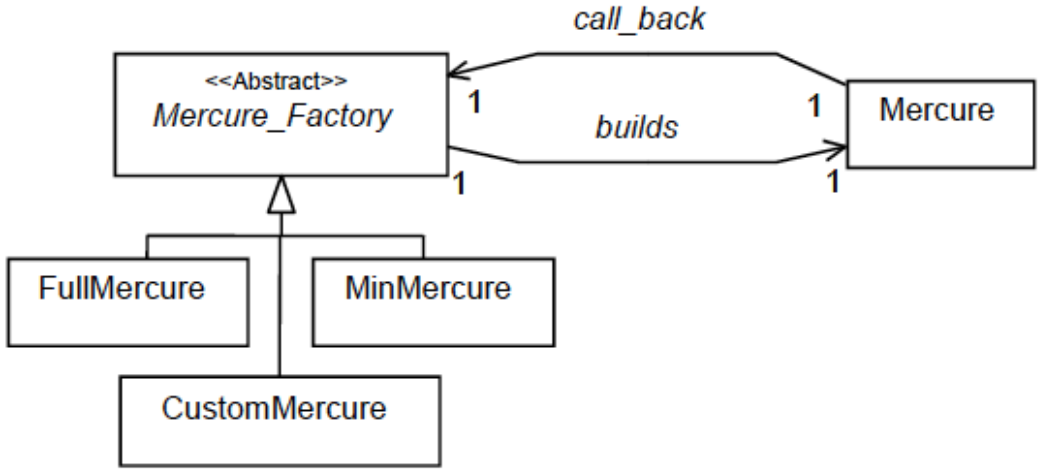
Template Method

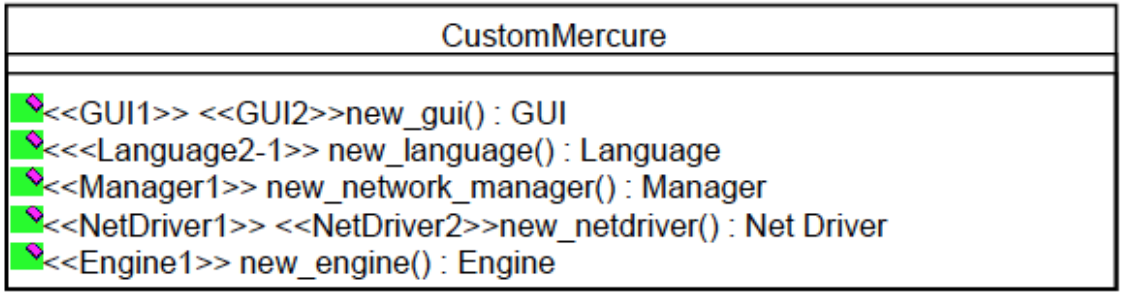


The decision model

- The Abstract Factory Design Pattern
  - [Gamma et al 95]







API

Framework

Plugin-based systems

(Active) Annotations

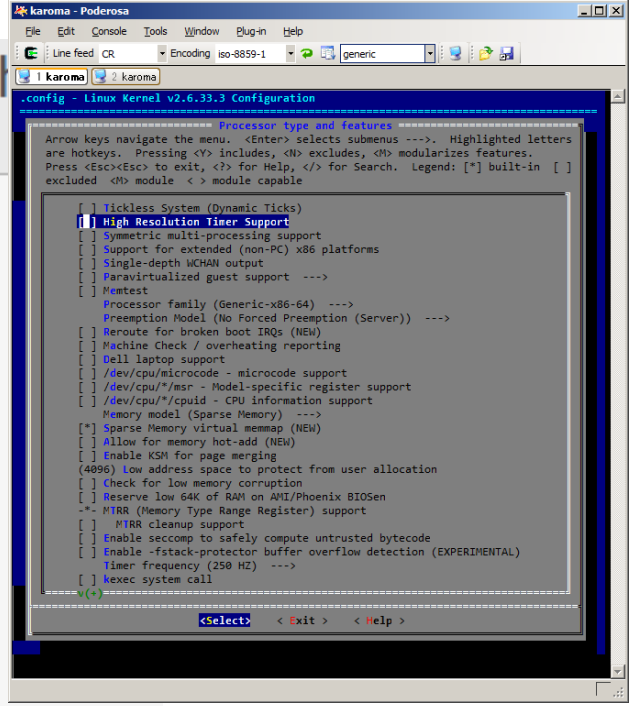
can have parameters

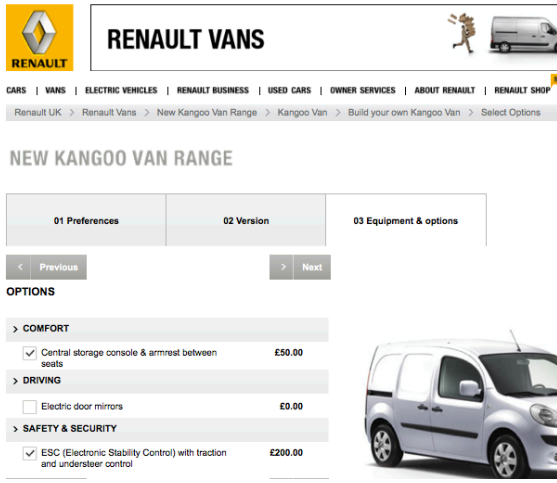
Metamodeling and Domain-Specific Languages

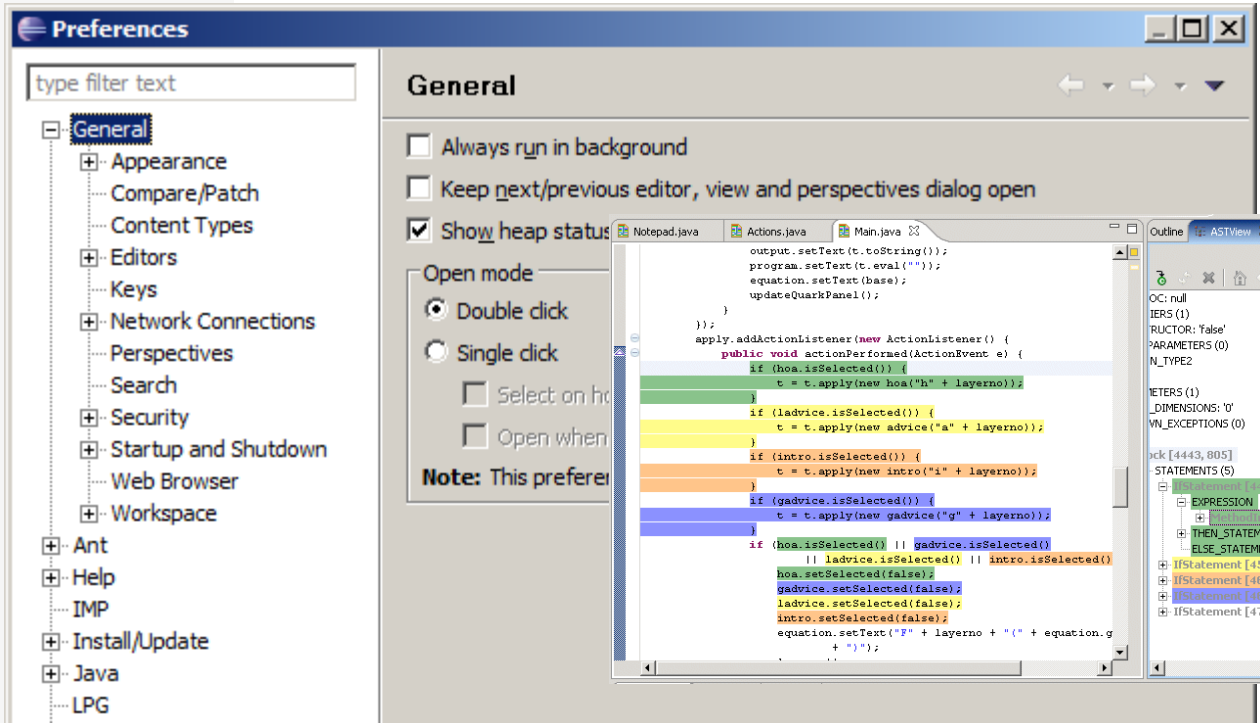
httpd.conf -- win32 Apach

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>
```



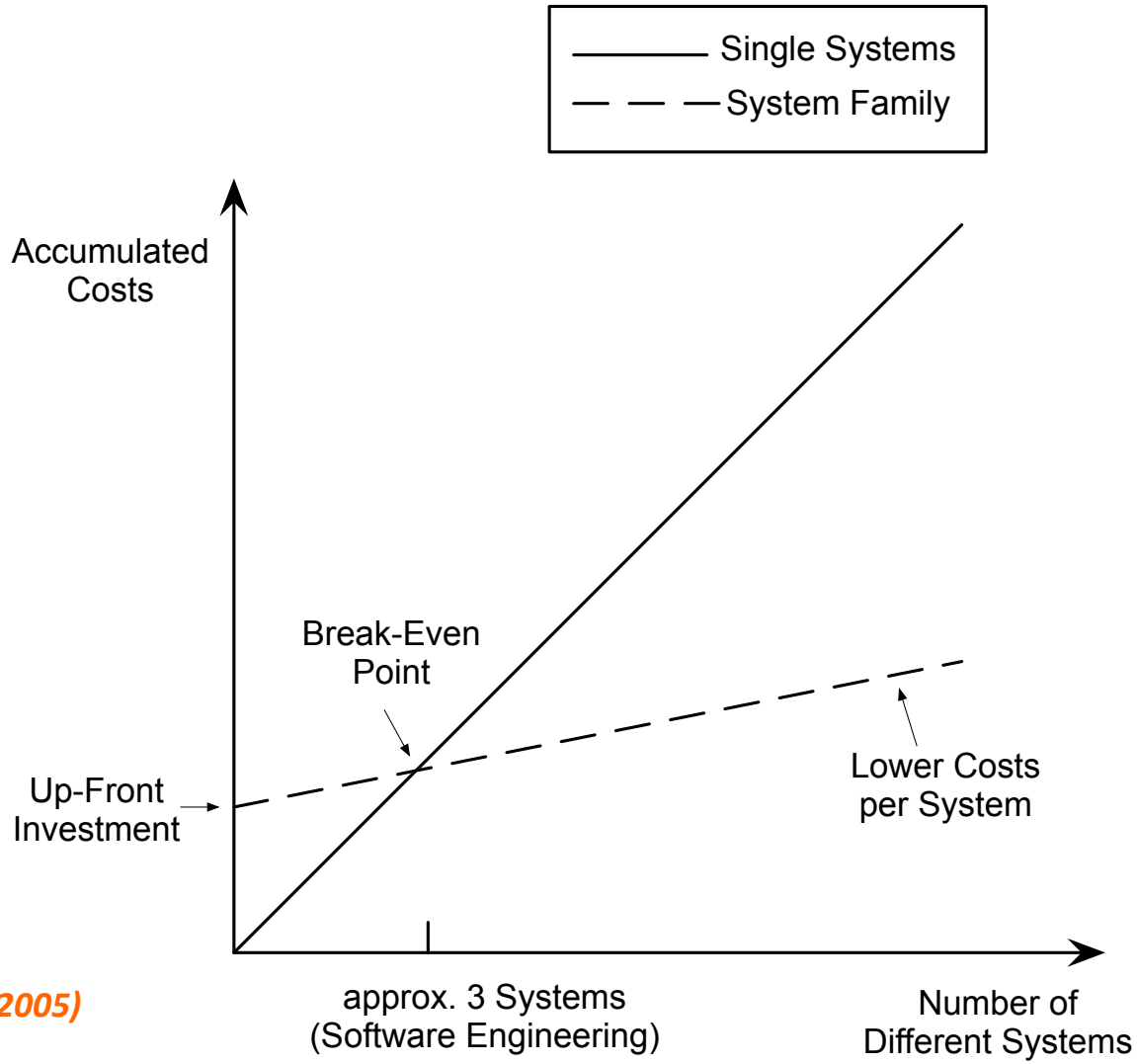




The specificity of

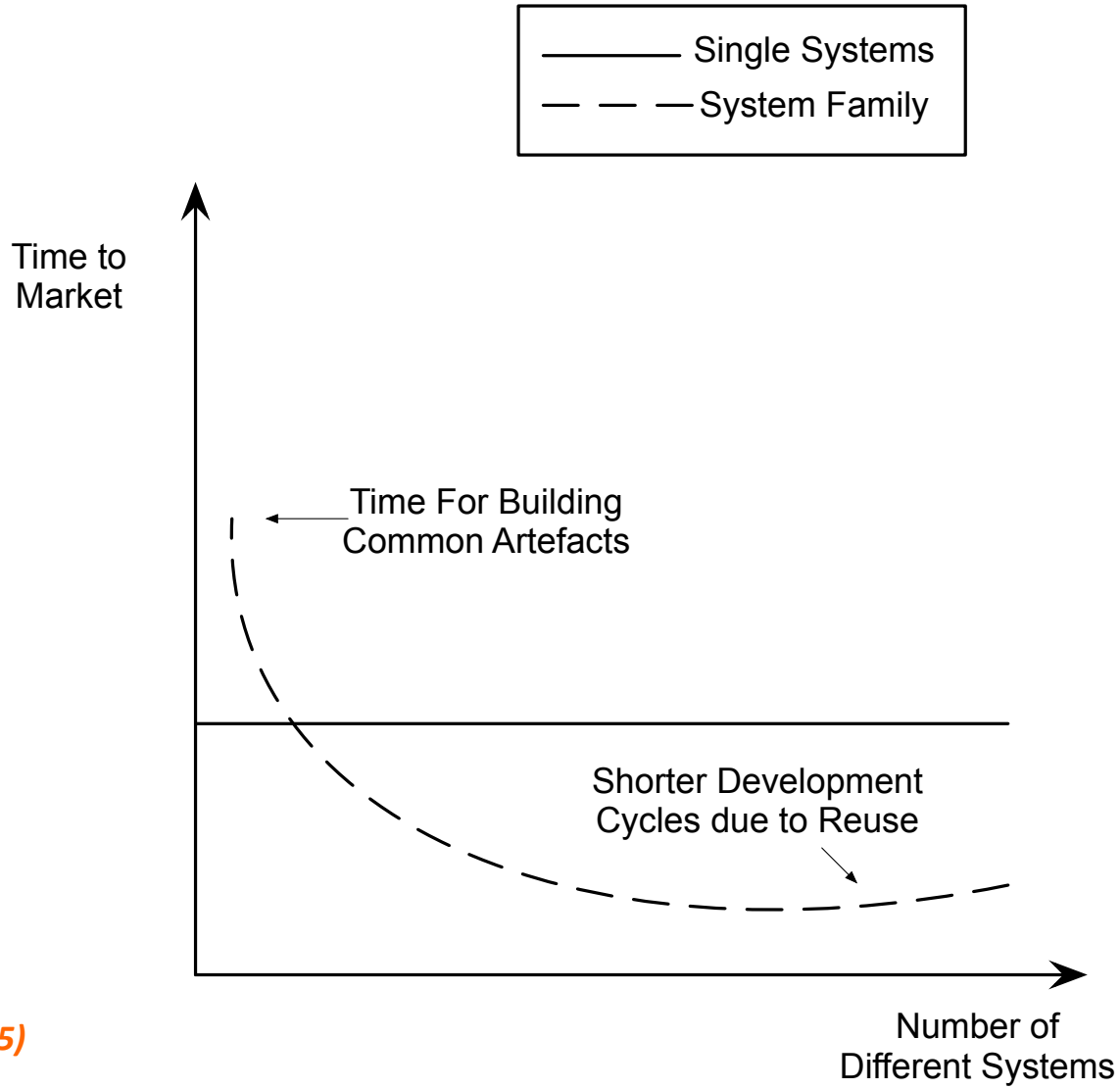
Software Product Line Engineering

Promises of Software Product Line Engineering



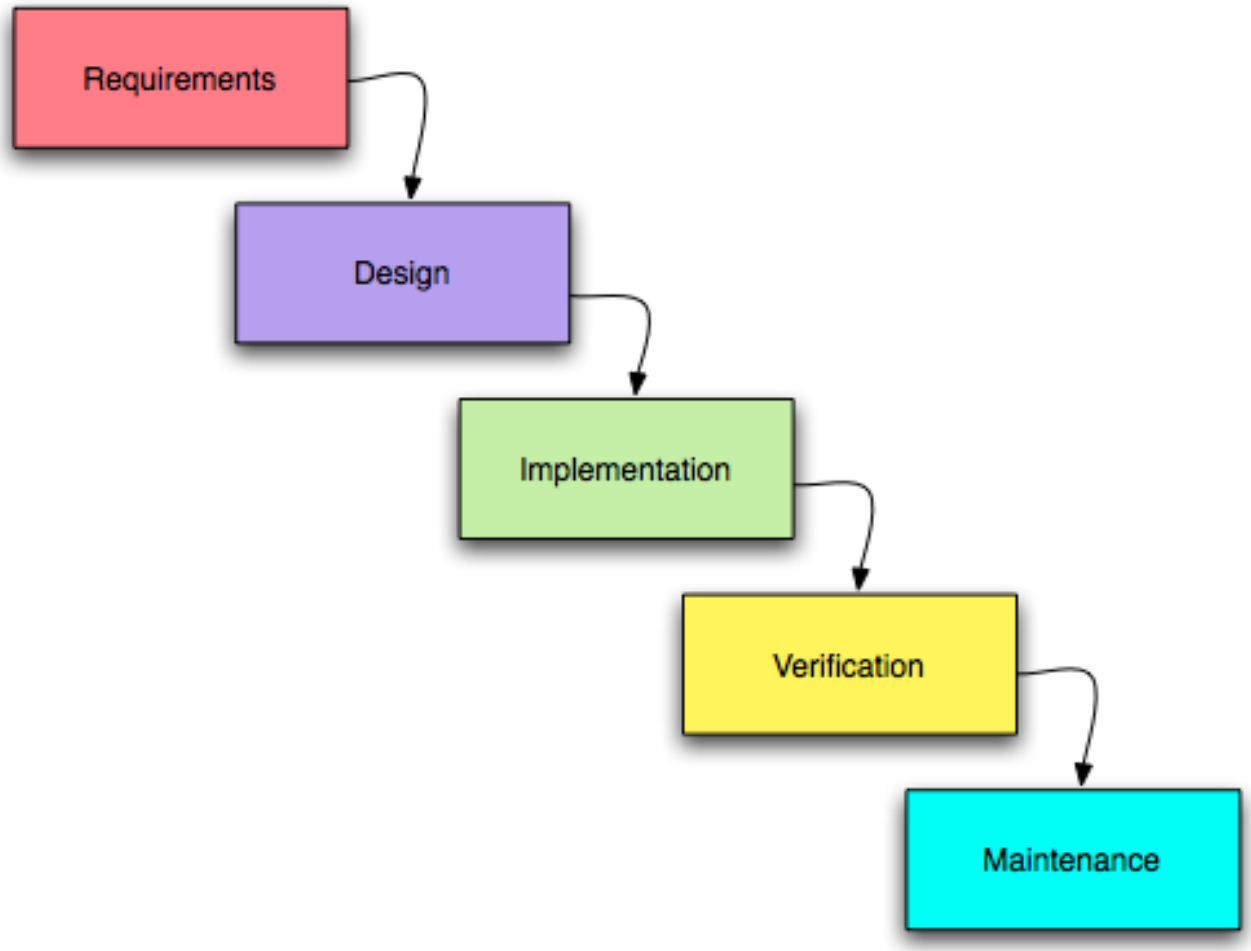
Klaus Pohl (2005)

Promises of Software Product Line Engineering

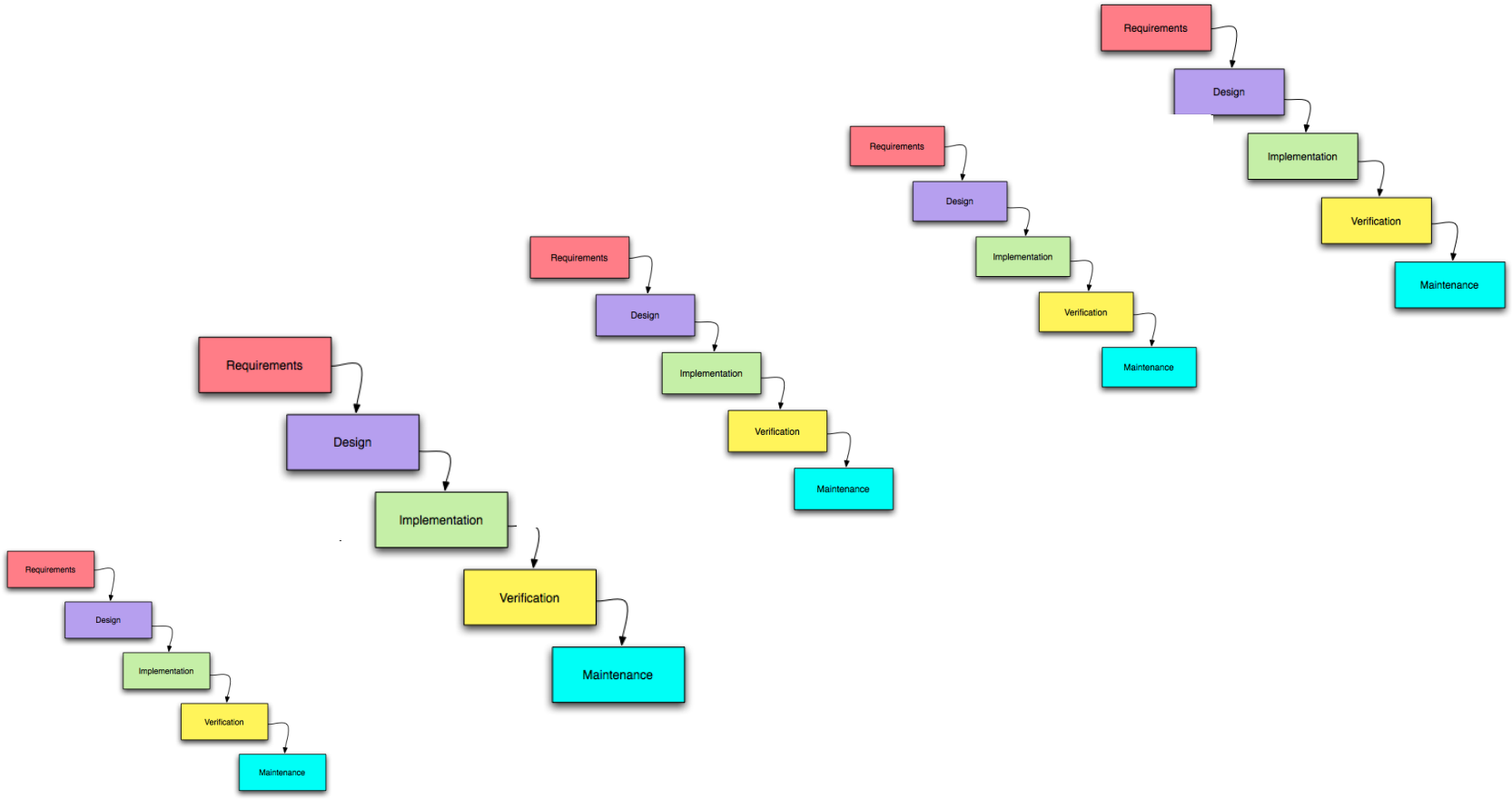


Klaus Pohl (2005)

Single Software Development



Software Product Line Development?



Time and Effort: not scalable!

We need an **engineering process specific** to **software product lines**

Observation: "Reuse-in-the-large works best in families of related systems, and thus is domain dependent." [Glass, 2001]

Domain Engineering

[...] is the activity of collecting, organizing, and storing past experience in building systems [...] in a particular domain in the form of reusable assets [...], as well as providing an adequate means for reusing these assets (i.e., retrieval, qualification, dissemination, adaptation, assembly, and so on) when building new systems.

K. Czarnecki and U. Eisenecker

Domain Engineering

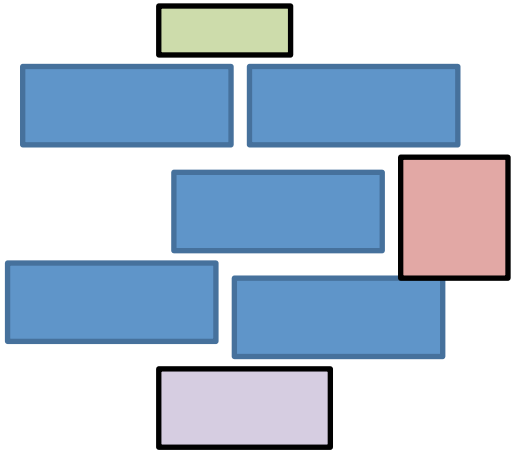
~=

Product Line Engineering

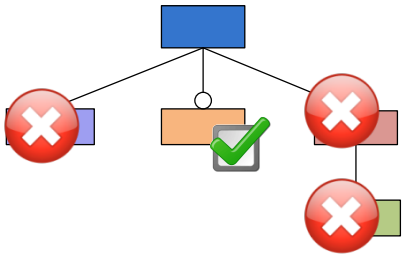
The conventional software engineering concentrates on satisfying the requirements for a **single** system

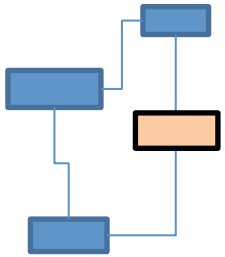
Domain Engineering concentrates on providing **reusable** solutions for **families** of systems.

Key idea: building a reusable platform during domain engineering

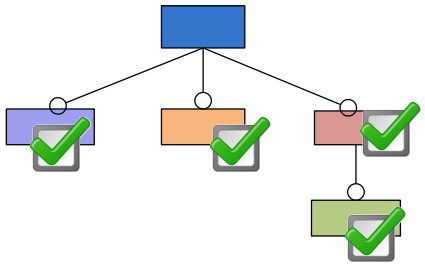


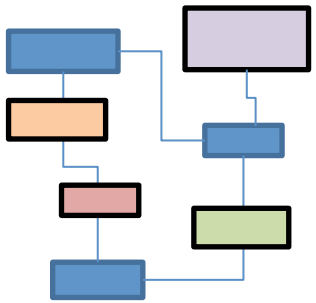
Specific requirements



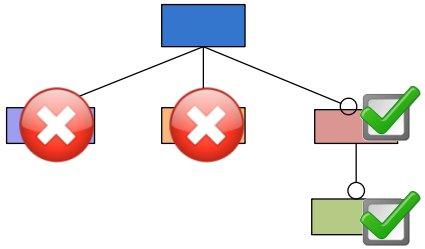


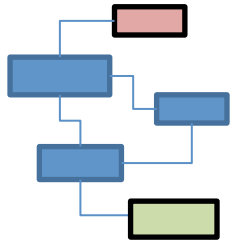
$product_2$





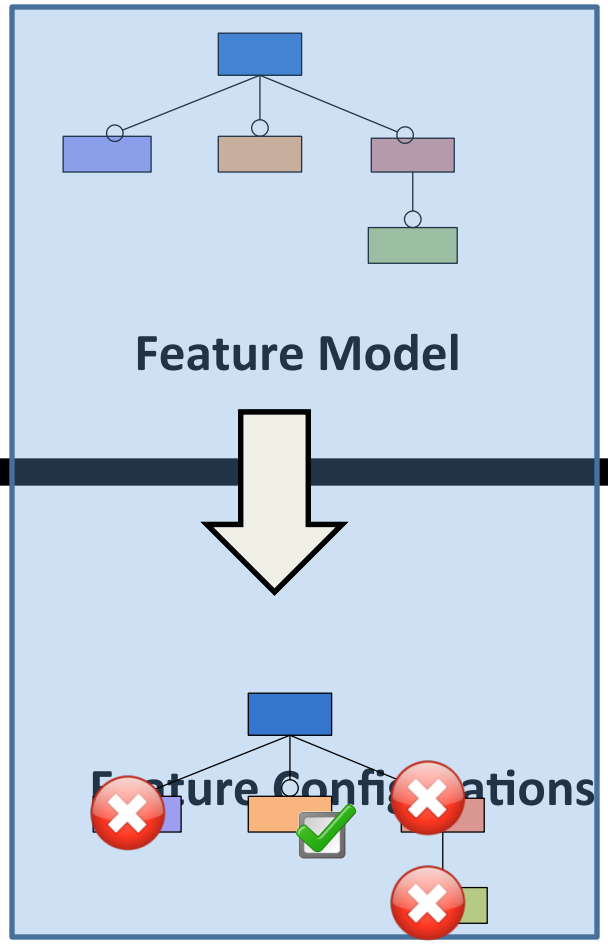
$product_n$

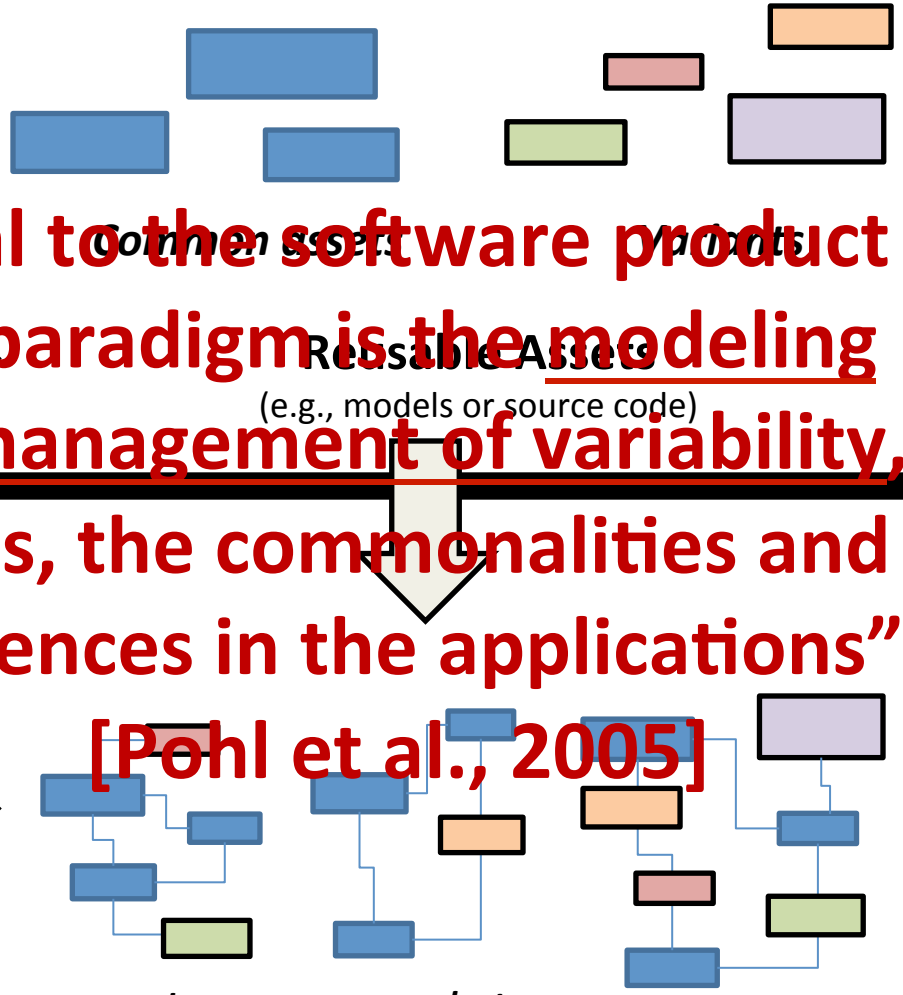




$product_1$

Domain engineering (development for reuse)

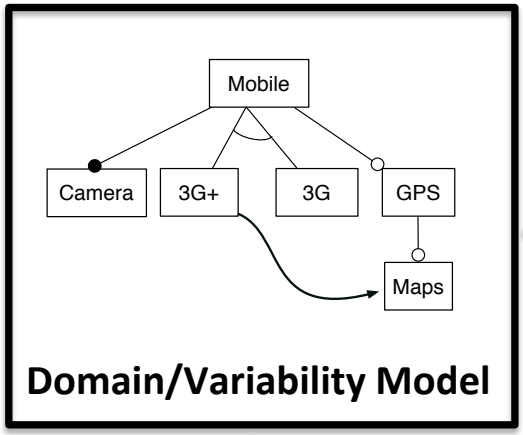


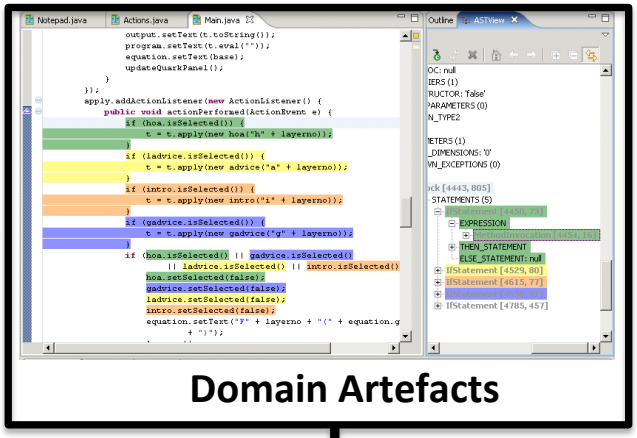


"central to the software product line paradigm is the modeling and management of variability, that is, the commonalities and differences in the applications" [Pohl et al., 2005]

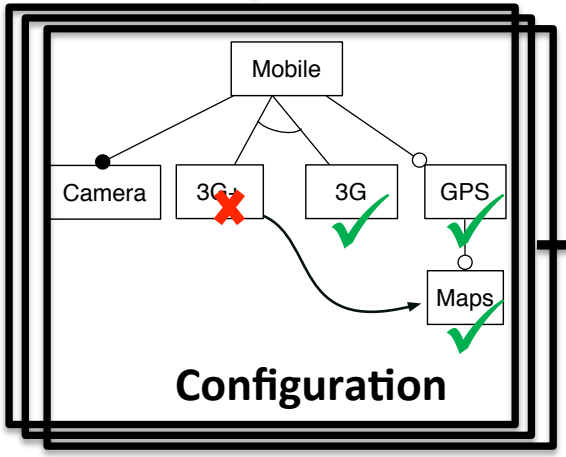
Application engineering (development with reuse)

Domain Engineering





Application Engineering

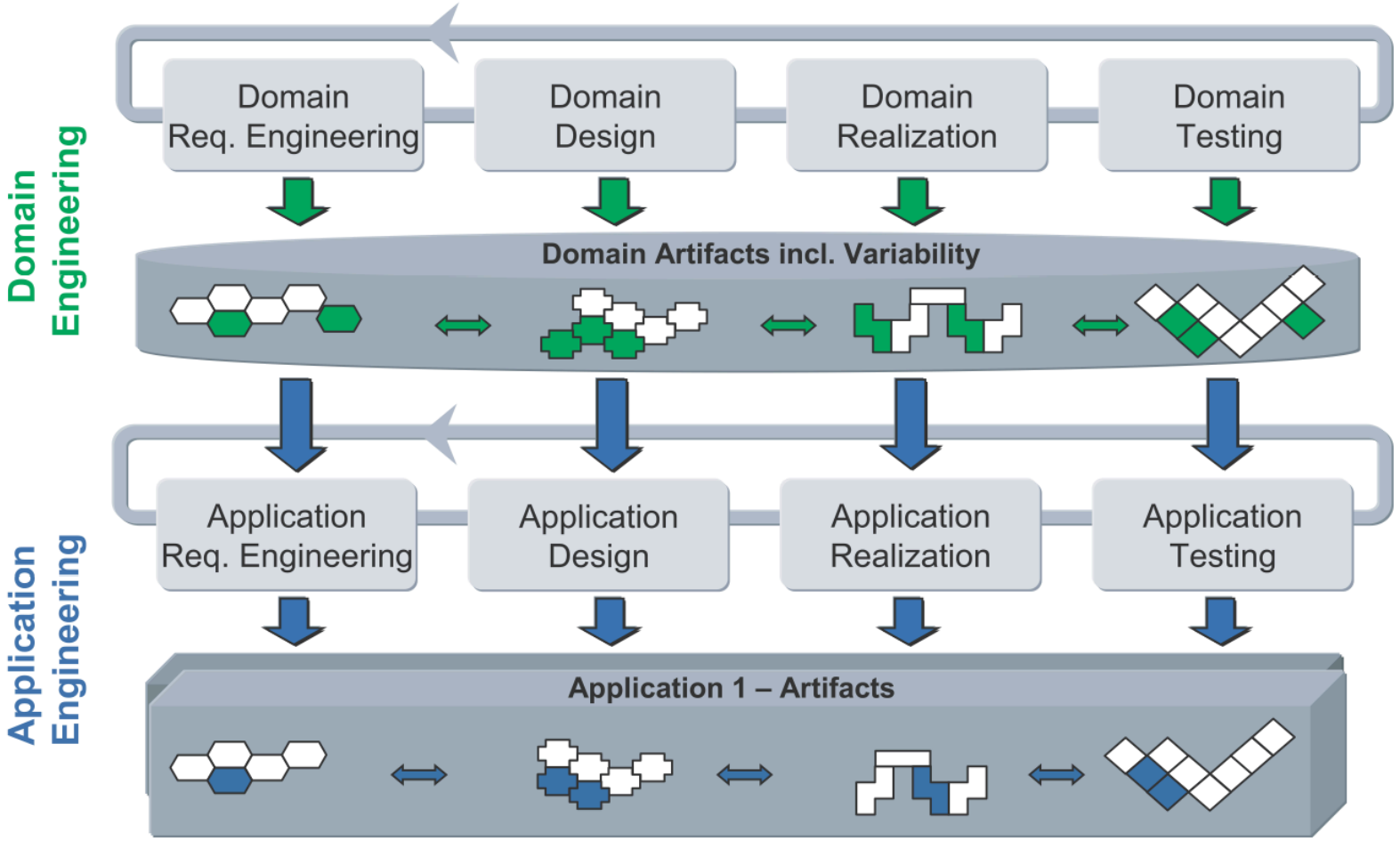


*« the investments required to develop the reusable artifacts during **domain engineering**, are outweighed by the benefits of deriving the individual products during **application engineering** »*

Jan Bosch et al. (2004)

Activities related to domain engineering and application engineering

Software Product-Line Engineering



Domain Analysis

- Collect relevant domain information
  - domain experts (interviews, workshops)
  - system handbooks, textbooks, prototyping, experiments,
  - already known requirements on future systems
  - Creative activity
- Domain Definition
  - examples of systems in a domain,
  - counterexamples (i.e. systems outside the domain),
  - generic rules of inclusion or exclusion (e.g. “Any system having the capability X belongs to the domain.”).
- Domain vocabulary
- Domain concepts
- and integrate it into a coherent *domain model*
  - more or less formal

Czarnecki and Eisenecker (2000)

Domain Modeling (aka Metamodeling)

- Ontology, ER, UML, Ecore, Feature Model

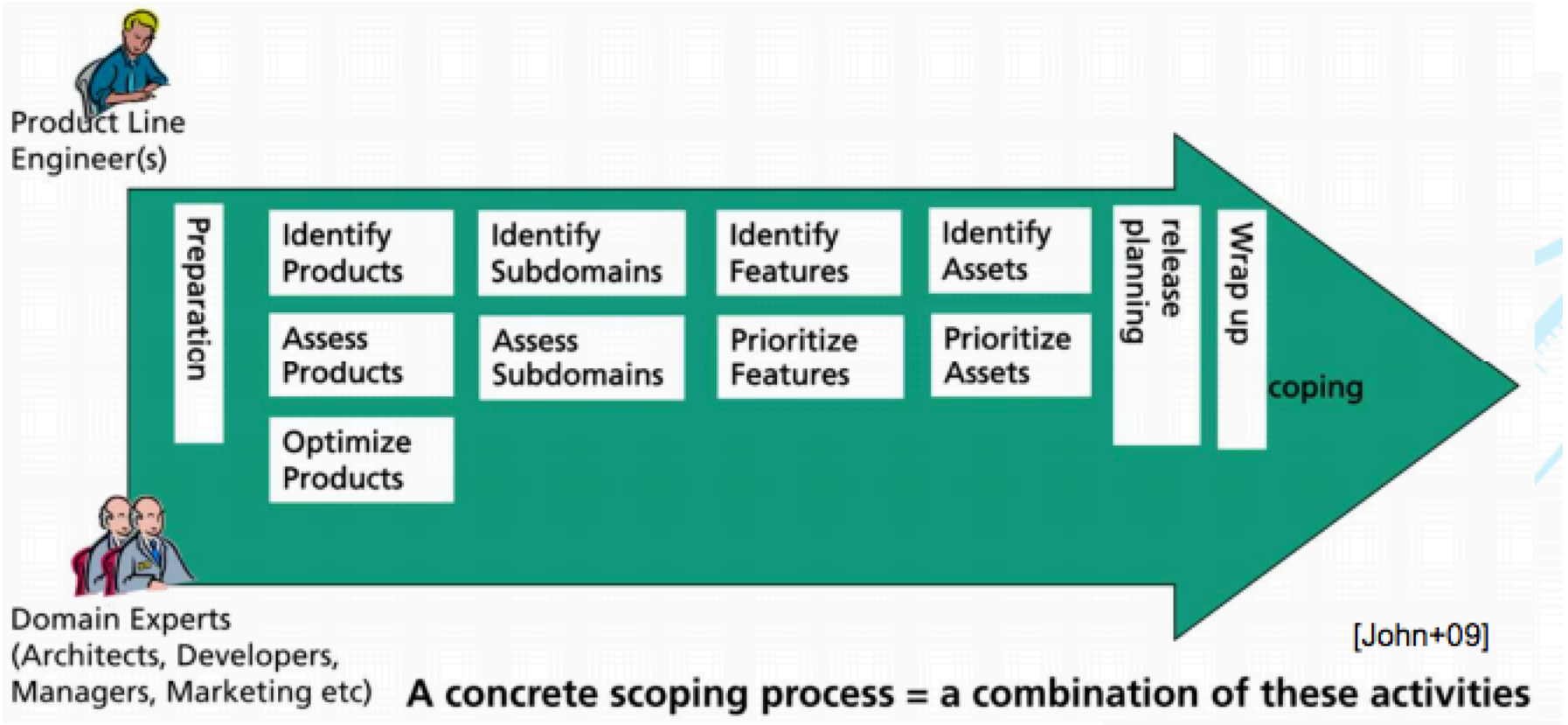
- Analysis of similarity
  - Analyze similarities between entities, activities, events, relationships, structures, etc.
- Analysis of variations
  - Analyze variations between entities, activities, events, relationships, structures, etc.

- Clustering
- Abstraction
- Classification
- Generalization
- Vocabulary construction

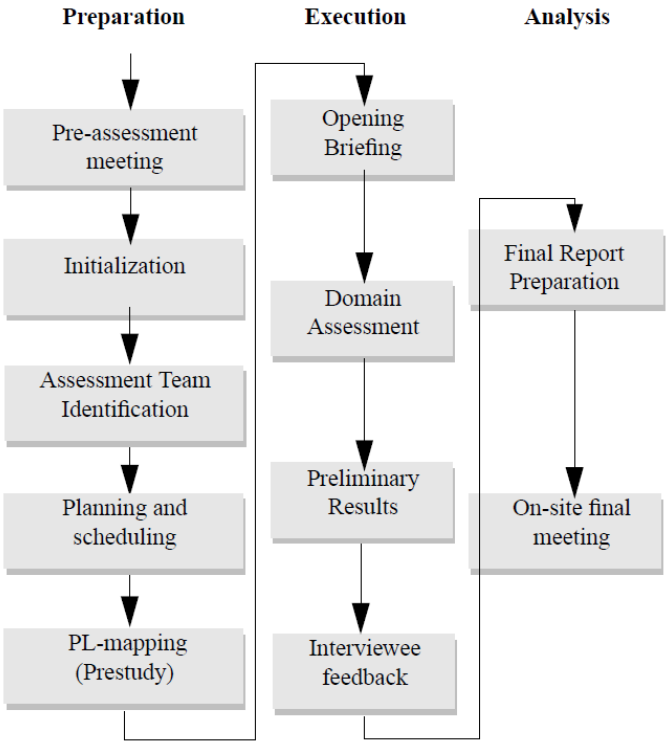

Unused flexibility


Illegal variant

Scoping Activities



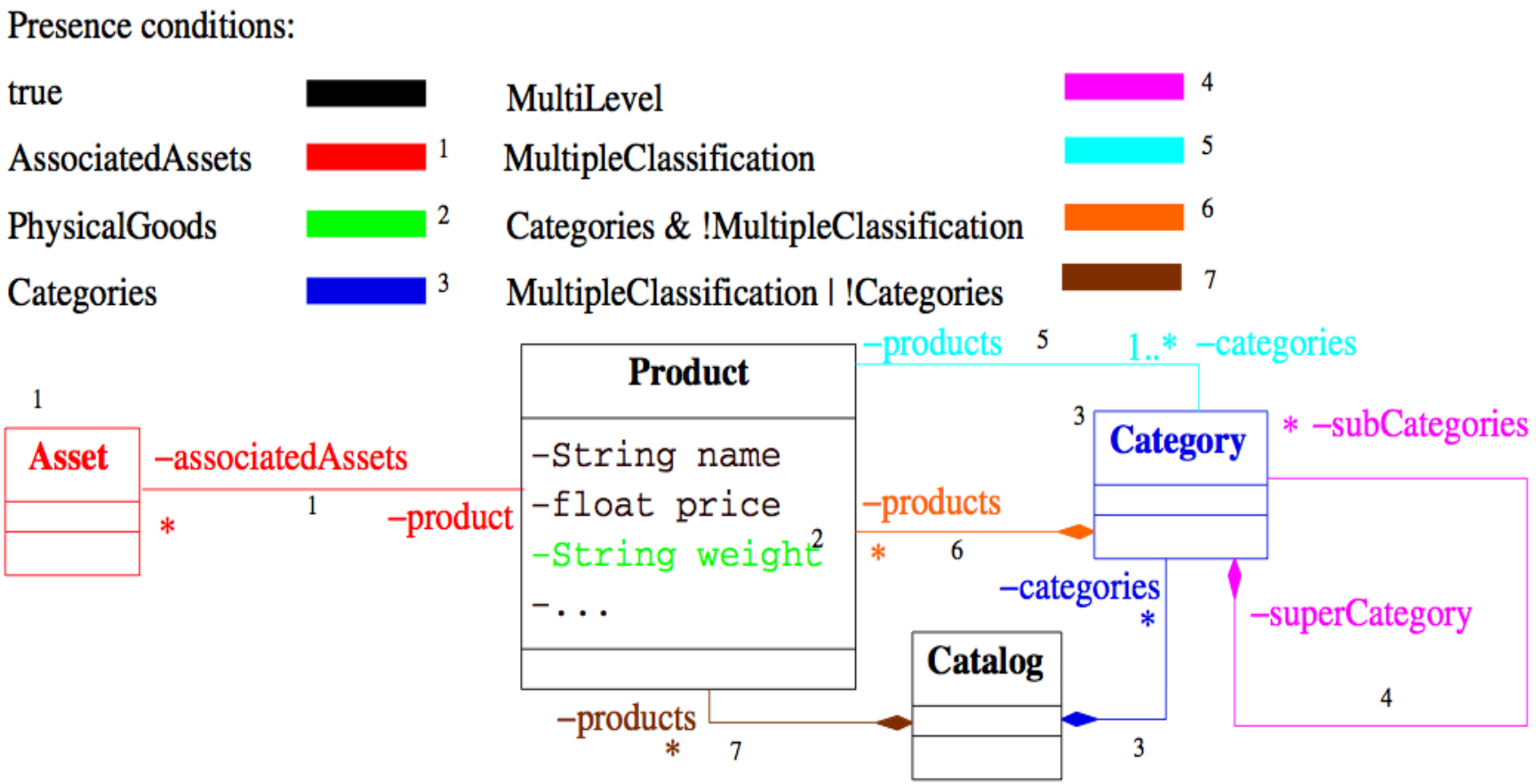
Domain/Product Line **Scoping**



Schmid 2002

			exist.	planned		potent.
			P1	P2	P3	P4
Domain 1	Sub-Domain 1.1	Feature 1.1.1	X	X	X	X
		Feature 1.1.2	—	X	X	X
		Feature 1.1.3	X	X	—	X
	...	...	...	...	...	...
	Sub-Domain 1.n	Feature 1.n.1	X	—	X	X
		...	...	...	...	...
Domain 2	Sub-Domain 2.1	Feature 2.1.1	—	X	X	—
	...	...	...	...	...	...
...	...	...	...	...	...	...
...	...	Feature m.1.1	—	X	—	X

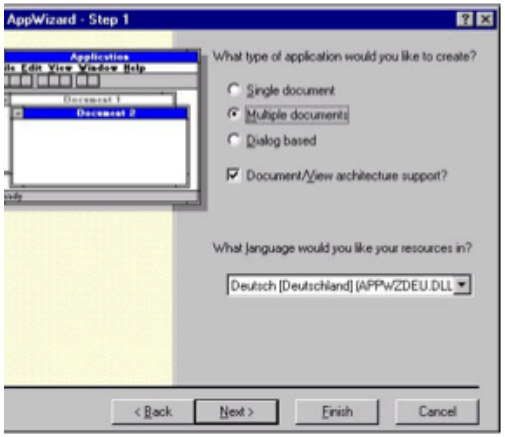
Domain Design



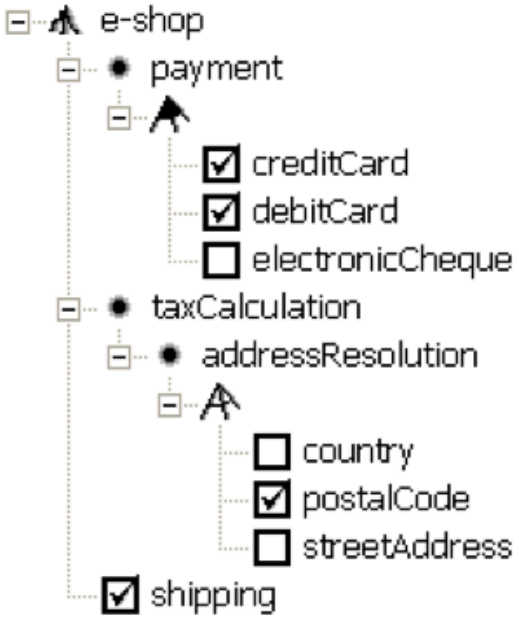
Czarnecki et al. (GPCE'05)

Czarnecki et al. (2005) DSLs for customizing

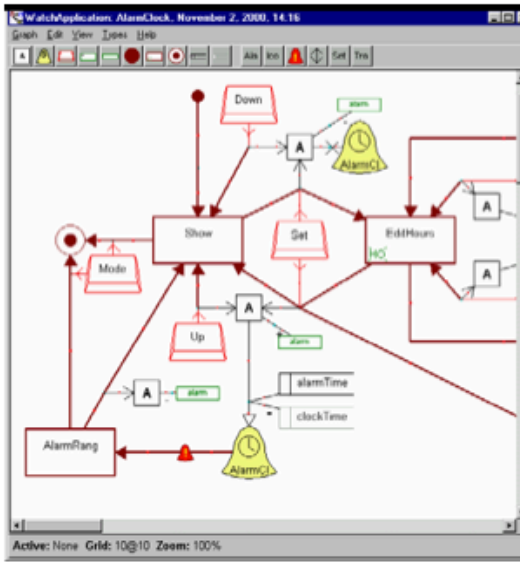
Routine configuration ⟷ *Creative construction*



Wizard



Feature-based configuration



Graph-like language

Dummy Feature Model

```
feature runtimeCalibration : false
feature bumper : true
feature sonar : false
feature debugOutput : true
```

Voelter (SPLC'11)

Configuring Models and Code

```
{sonar} task sonartask cyclic prio = 2 every = 100 {
          int s = ecrobot_get_sonar_sensor(SENSOR_PORT_T::NXT_PORT_S2);
          sonarHistory[sonarIndex] = s;
          sonarIndex = sonarIndex + 1;
          if ( sonarIndex == 10 ) {
            sonarIndex = 0;
          }
          int ss = 0;
          for ( int i = 0; i < 10; i = i + 1; ) {
            ss = ss + sonarHistory[i];
          }
          currentSonar = ss / 10;
          { {debugOutput} { debugInt(2, "sonar:", currentSonar); } }
        }
```

```
doc This is the cyclic task that is called every 1ms to do the actual control of th
task run cyclic prio = 2 every = 2 {
  stateswitch linefollower
    state running
      {bumper} int bump = ecrobot_get_touch_sensor(SENSOR_PORT_T::NXT_PORT_S3);
      {bumper} if ( bump == 1 ) {
        {debugOutput} { debugString(3, "bump:", "BUMP!"); }
        event linefollower:bumped
        terminate;
      }
      {sonar} if ( currentSonar < 150 ) {
        event linefollower:blocked
        terminate;
      }
      int light = ecrobot_get_light_sensor(SENSOR_PORT_T::NXT_PORT_S1);
      if ( light < ( WHITE + BLACK ) / 2 ) {
        updateMotorSettings(SLOW, FAST);
      } else {
        updateMotorSettings(FAST, SLOW);
      }
      {debugOutput} { debugInt(4, "light:", light); }
    {sonar} state paused
              updateMotorSettings(0, 0);
              if ( currentSonar < 255 ) {
                event linefollower:unblocked
              }
    {bumper} state crash
               updateMotorSettings(0, 0);
    default
      <noop>;
}
```

Preprocessor for Java code (Munge)

```
class Example {
        void main() {
                System.out.println("immer");
                /*if[DEBUG]*/
                System.out.println("debug info");
                /*end[DEBUG]*/
        }
}
```

java Munge –DDEBUG –DFEATURE2 Example.java

configuration option

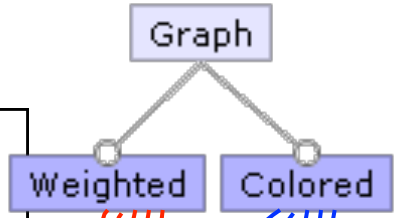
Kastner's slide

http://weblogs.java.net/blog/tball/archive/2006/09/munge_swings_se.html

Mapping: an example

```
class Graph {
  Vector nv = new Vector(); Vector ev = new Vector();
  Edge add(Node n, Node m) {
    Edge e = new Edge(n, m);
    nv.add(n); nv.add(m); ev.add(e);
    e.weight = new Weight();
    return e;
  }
  Edge add(Node n, Node m, Weight w)
    Edge e = new Edge(n, m);
    nv.add(n); nv.add(m); ev.add(e);
    e.weight = w; return e;
  }
  void print() {
    for(int i = 0; i < ev.size(); i++) {
      ((Edge)ev.get(i)).print();
    }
  }
}
```

```
class Node {
  int id = 0;
  Color color = new Color();
  void print() {
    Color.setDisplayColor(color);
    System.out.print(id);
  }
}
```




```
class Edge {
  Node a, b;
  Color color = new Color();
  Weight weight;= new Weight();
  Edge(Node _a, Node _b) { a = _a; b = _b; }
  void print() {
    Color.setDisplayColor(color);
    a.print(); b.print();
    weight.print();
  }
}
```

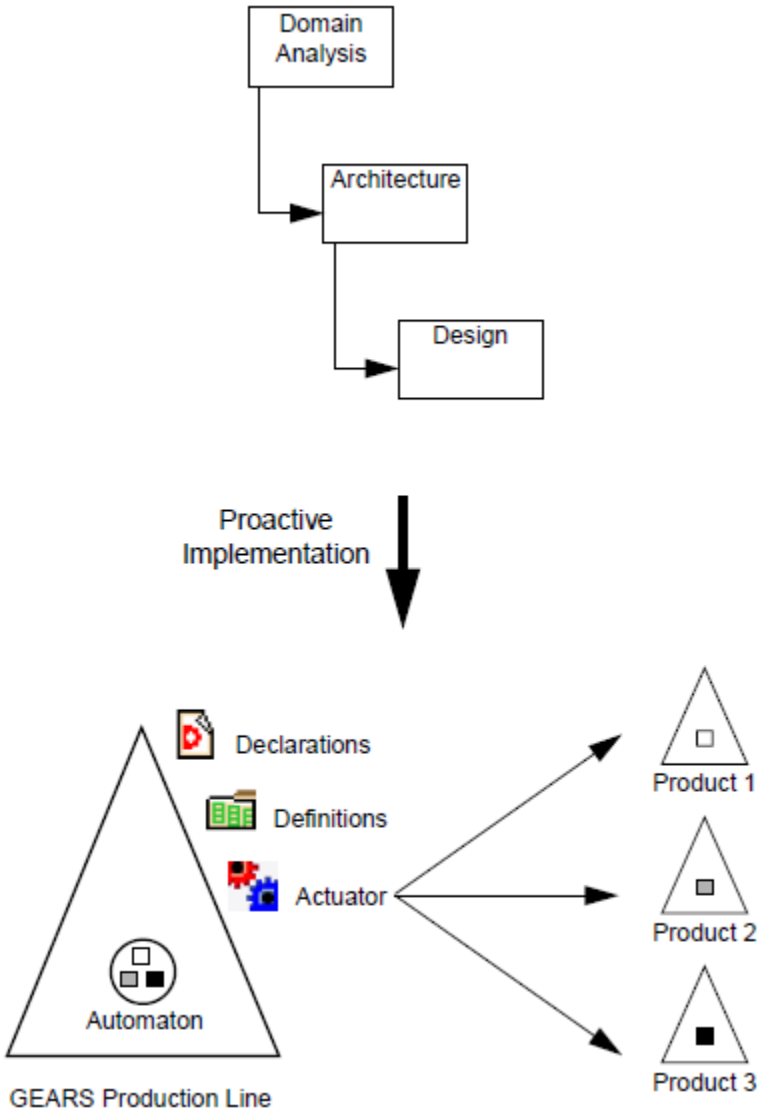
```
class Color {
  static void setDisplayColor(Color c) { ... }
}
```

```
class Weight { void print() { ... } }
```

Adoption and Strategies

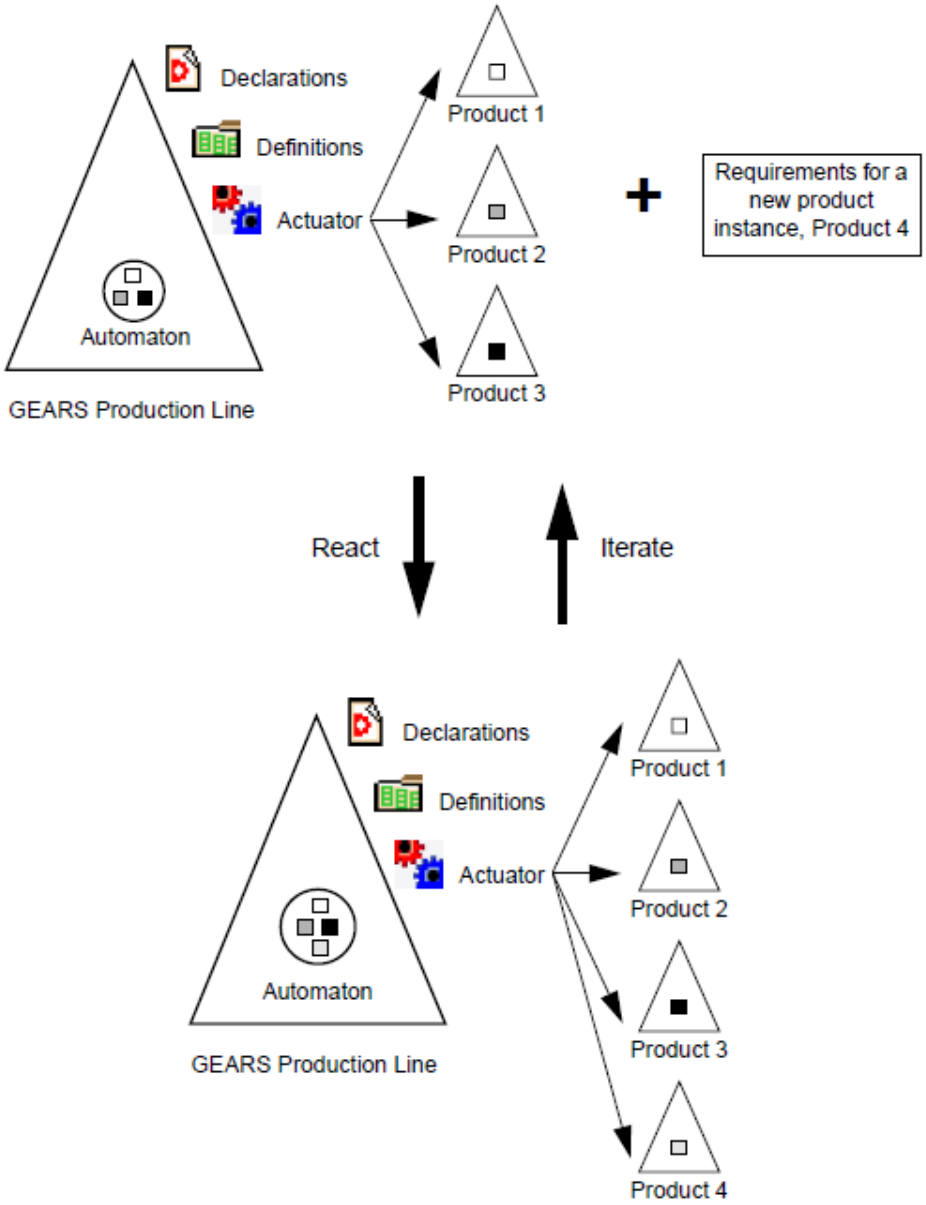
- **Proactive (starting from scratch)**
- **Extractive (re-engineering, from products to product line)**
- **Reactive (hybrid)**

Proactive



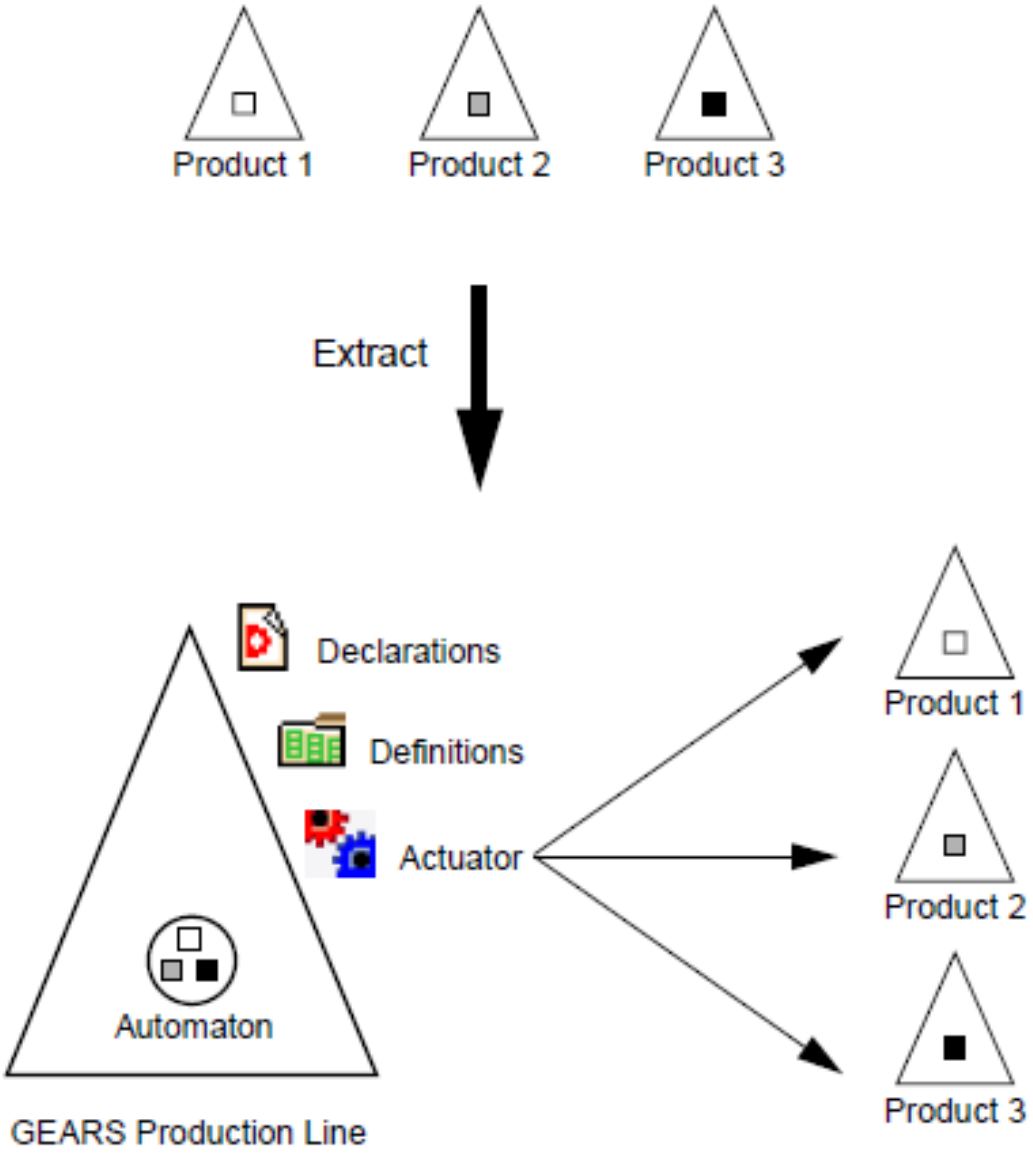
[Krueger 2002]

Reactive



[Krueger 2002]

Extractive



[Krueger 2002]

How MDE can help

Software Product Line Engineering

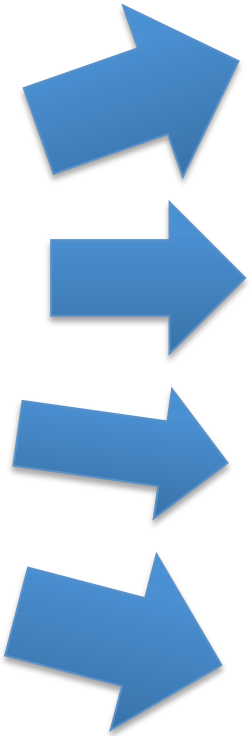
Generative approach

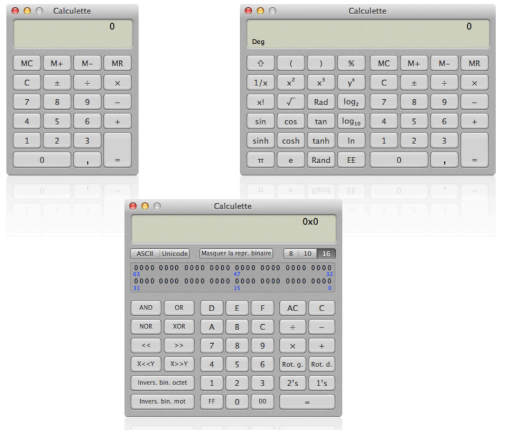
- Programming the generation of programs
  - Very old practice
  - Metaprogramming: generative language and target language are the same
    - Reflection capabilities

- Generalization of this idea:
  - from a specification written in one or more textual or graphical domain-specific languages
  - you generate **customized variants**

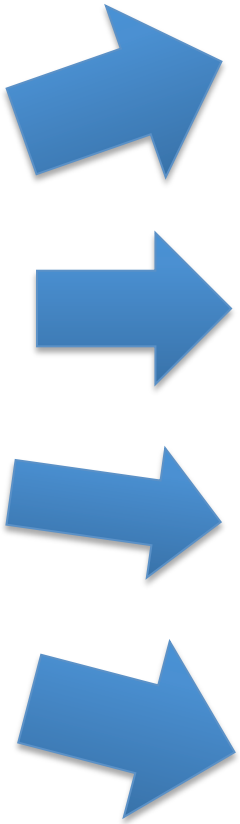
Modeling and implementing system families such that a desired system can be automatically generated from a specification written in one or more textual or graphical domain-specific languages.

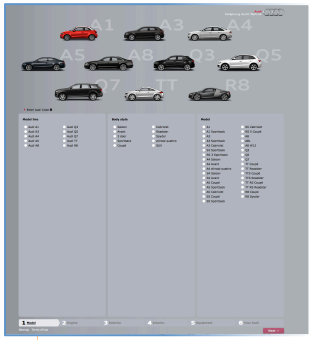
Models And Languages

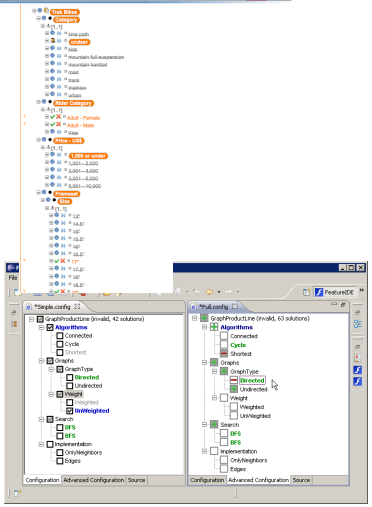


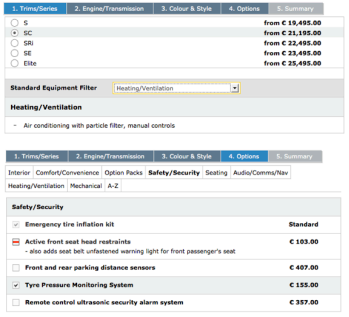


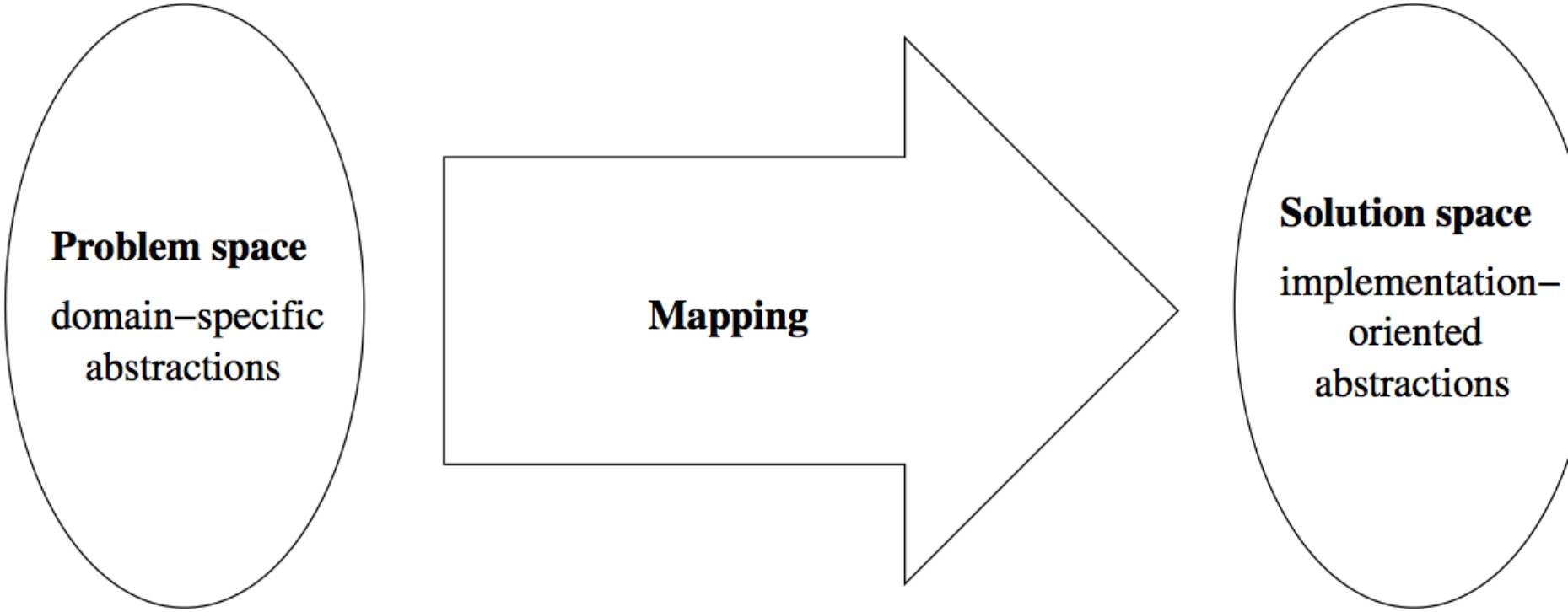
Models And Languages



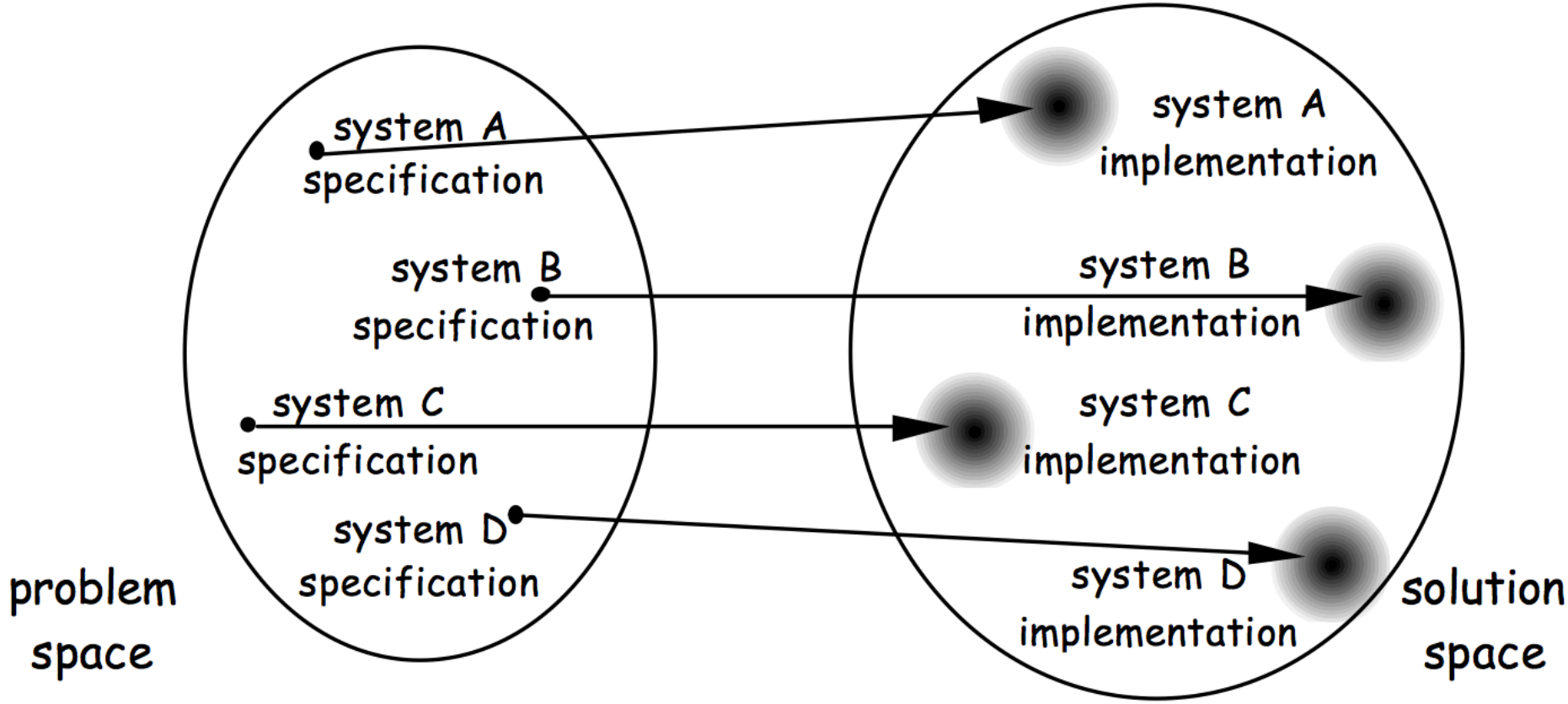




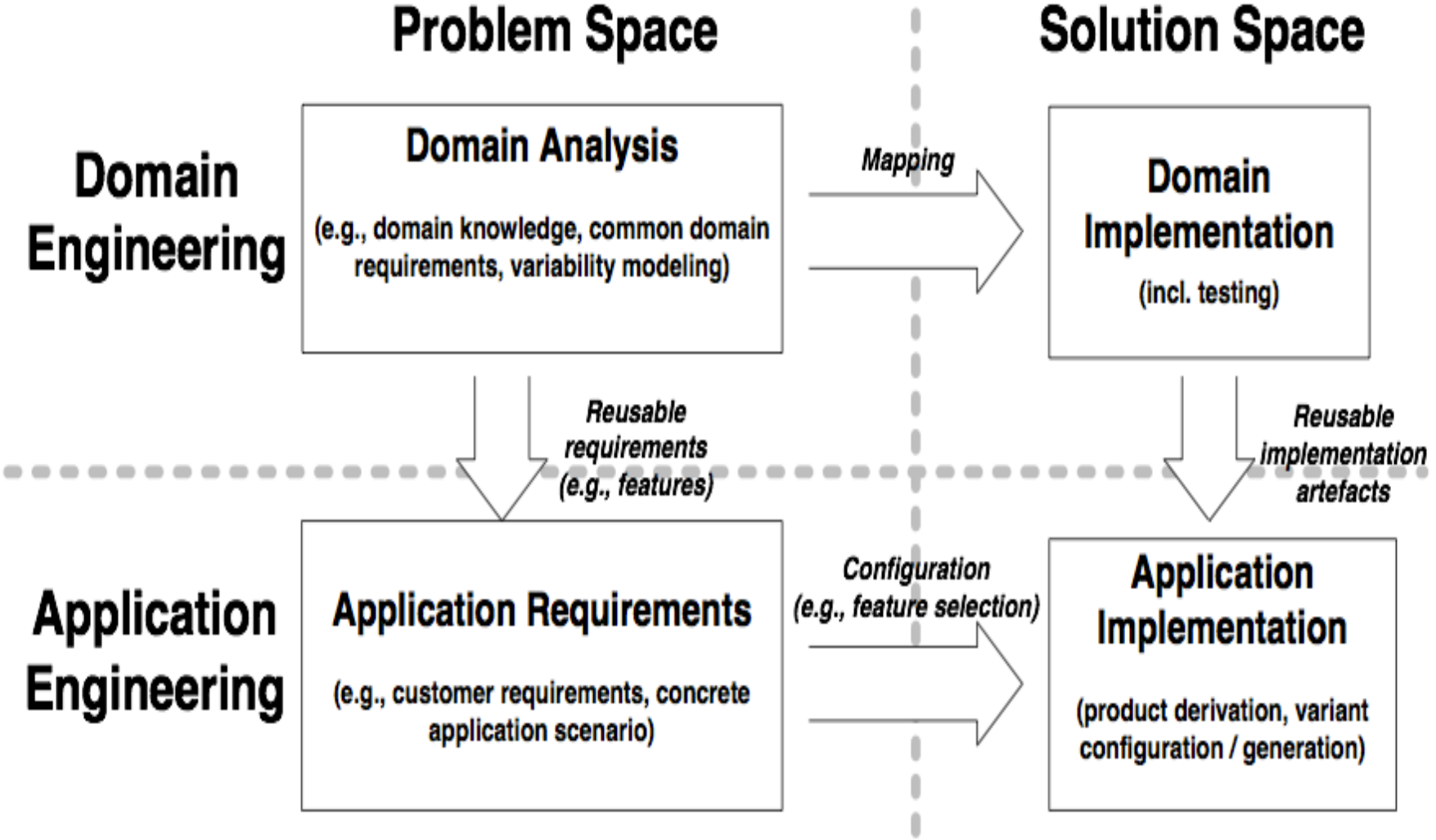




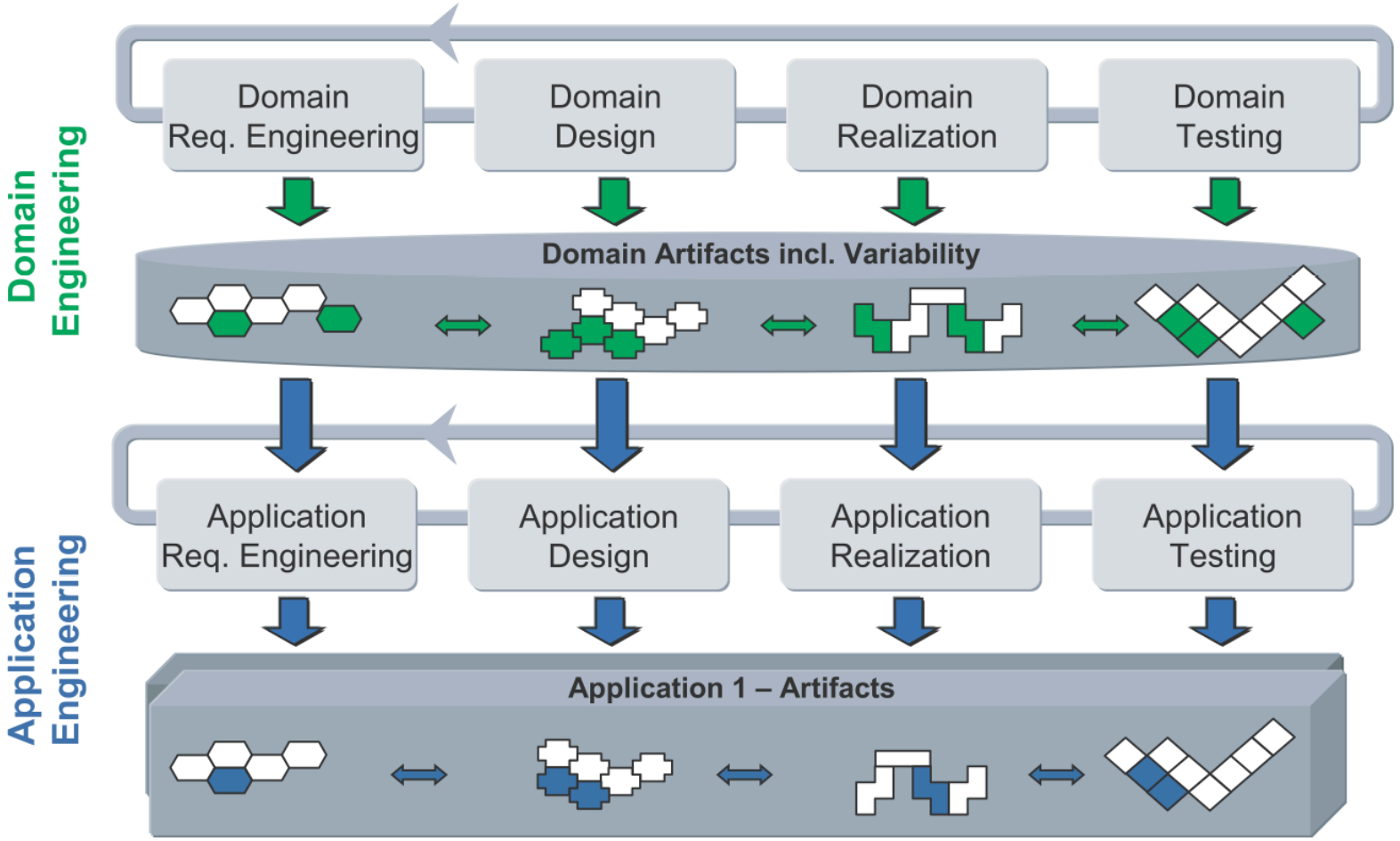
[Czarnecki and Eisenecker 2000]



[Czarnecki, PhD thesis]


Problem Space
Solution Space
Domain Engineering
Domain Analysis
(e.g., domain knowledge, common domain requirements, variability modeling)
Mapping
Domain Implementation
(incl. testing)
Reusable requirements (e.g., features)
Reusable implementation artefacts
Application Engineering
Application Requirements
(e.g., customer requirements, concrete application scenario)
Configuration (e.g., feature selection)
Application Implementation
(product derivation, variant configuration / generation)

Software Product-Line Engineering



Developing Product Lines
Metamodels, DSLs, and Transformations to the rescue

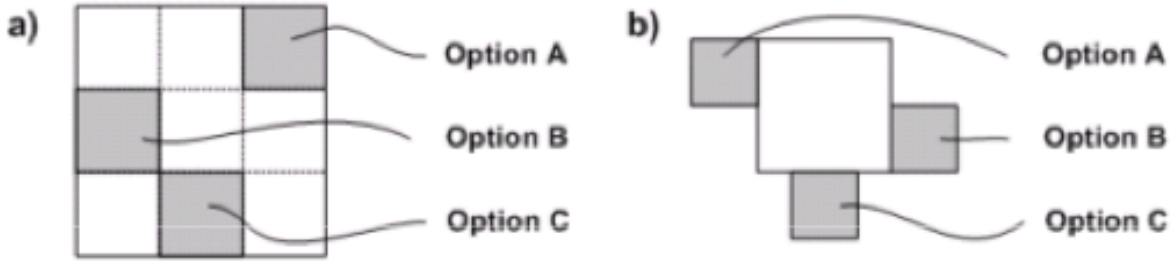
- Domain Engineering
  - Domain Models
  - Level of abstraction
  - Domain-specific modeling languages
    - (visual or textual) syntacs, precise semantics
    - analyzed (verification)
  - Traceability between the artefacts
- Application Engineering
  - Model transformations (automation)
- Reduce the gap

[Voelter et al., SPLC'07)]

Realizing variability

- Negative Variability (pruning, annotative)
  - **takes optional parts away** from an „overall whole“
- Positive Variability (merging, compositional)
  - **adds optional parts** to a minimal core

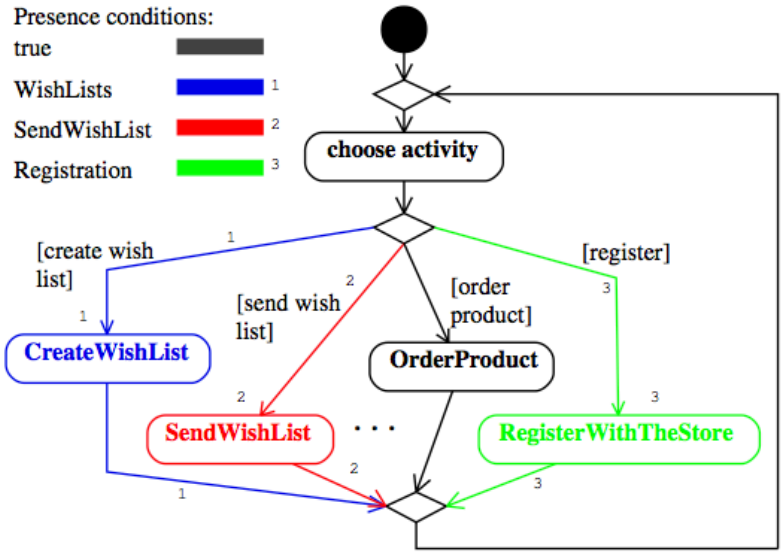
Negative vs. Positive Variability



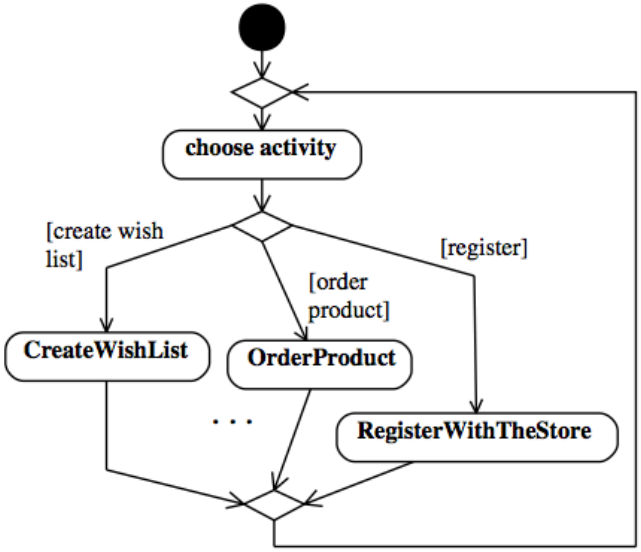
- Both in practice!

[Czarnecki et al. (GPCE'05)]

Feature-based Model Templates



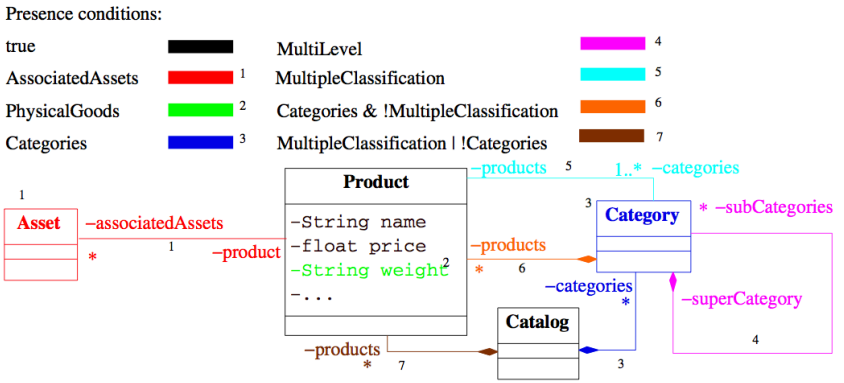
(a) Storefront template



(b) Storefront instance

[Czarnecki et al. (GPCE'05)]

Approach



Refers to features through annotations

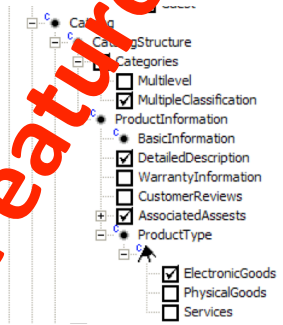
Feature model

Model template expressed in target notation and annotated with presence conditions and meta–expressions

Manual configuration process

Features/Options

Feature configuration

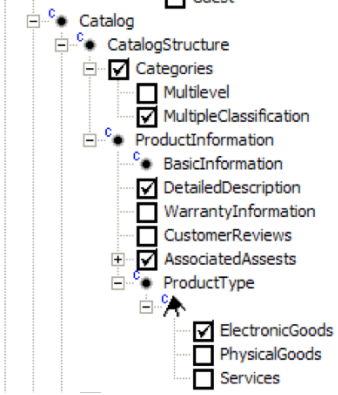


Automatic template instantiation
- Evaluation of presence conditions and meta–expressions
- Element removal
- Post–processing

Template instance

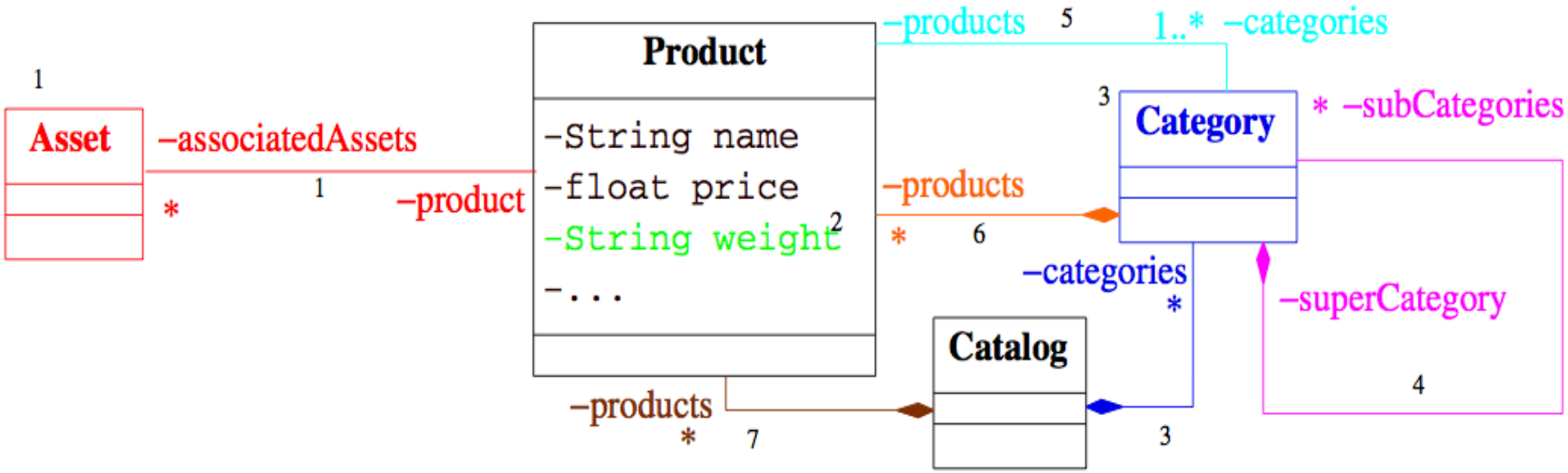
Product Model

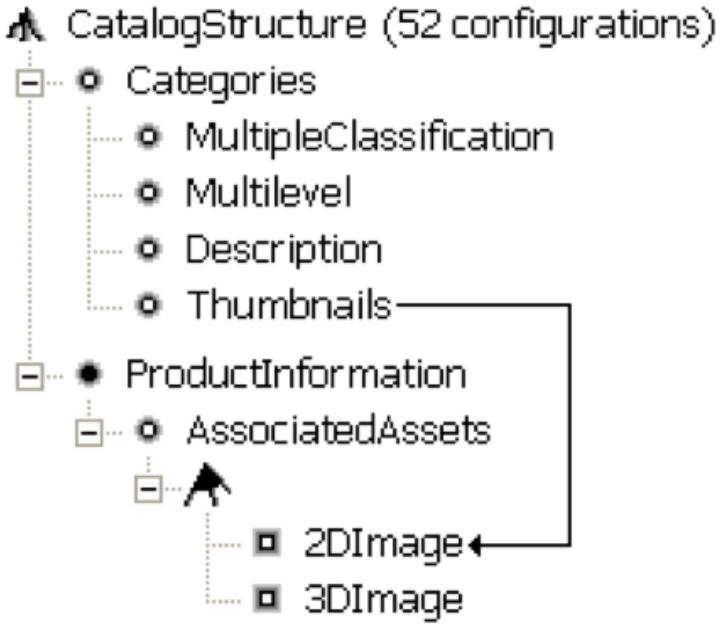
[Czarnecki et al. (GPCE'05)]

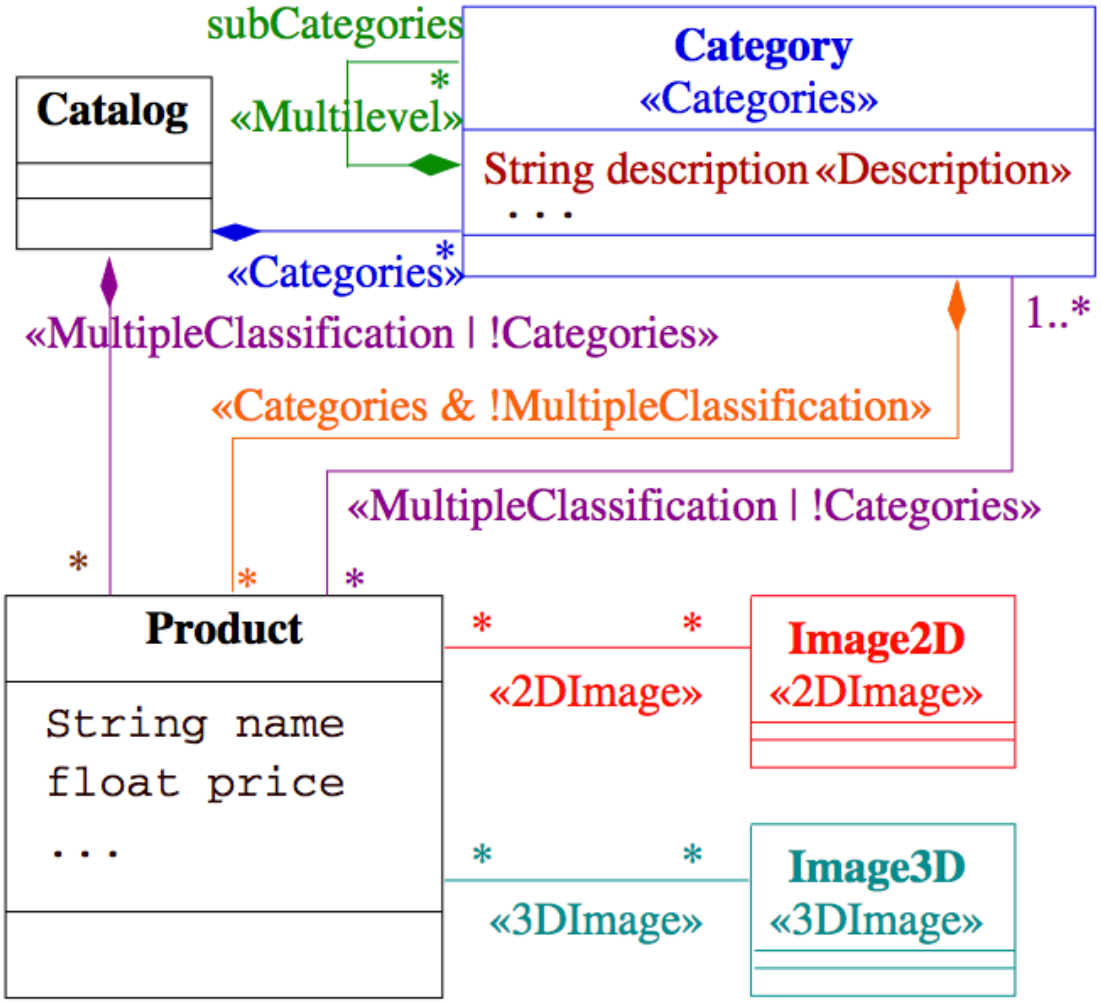


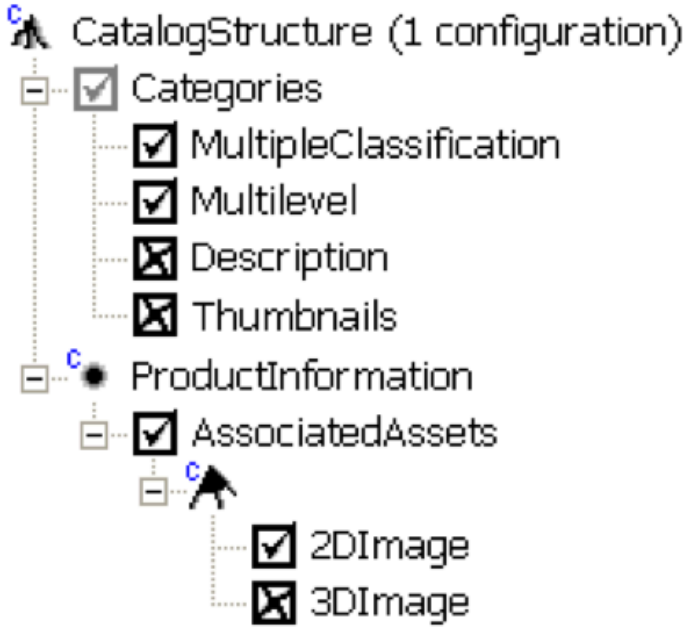
Presence conditions:

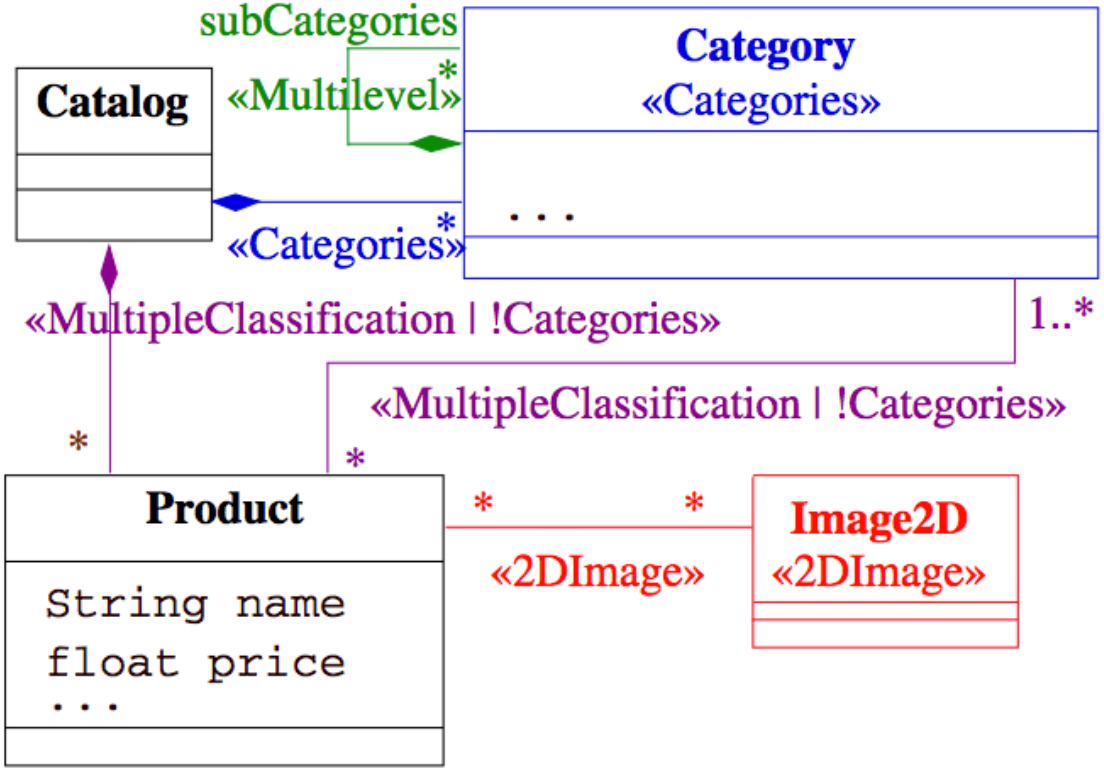
true		MultiLevel	4
AssociatedAssets	1	MultipleClassification	5
PhysicalGoods	2	Categories & !MultipleClassification	6
Categories	3	MultipleClassification | !Categories	7



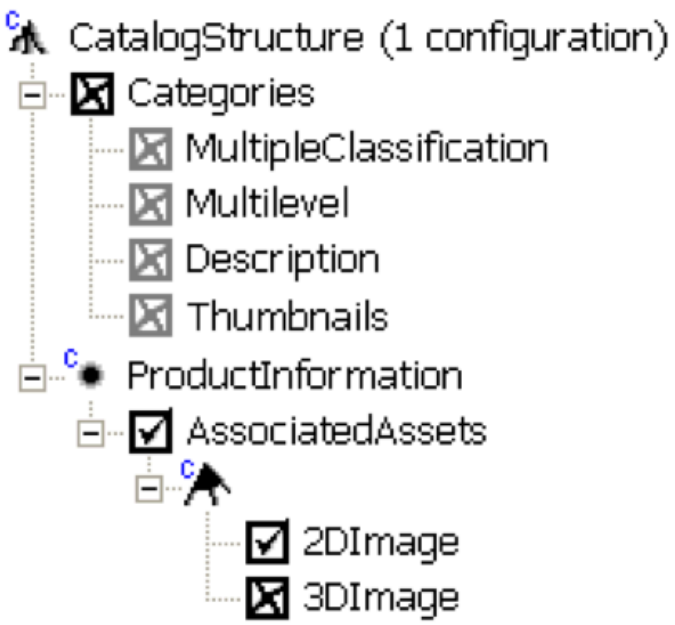

CatalogStructure (52 configurations)
Categories
MultipleClassification
Multilevel
Description
Thumbnails
ProductInformation
AssociatedAssets
2DImage
3DImage

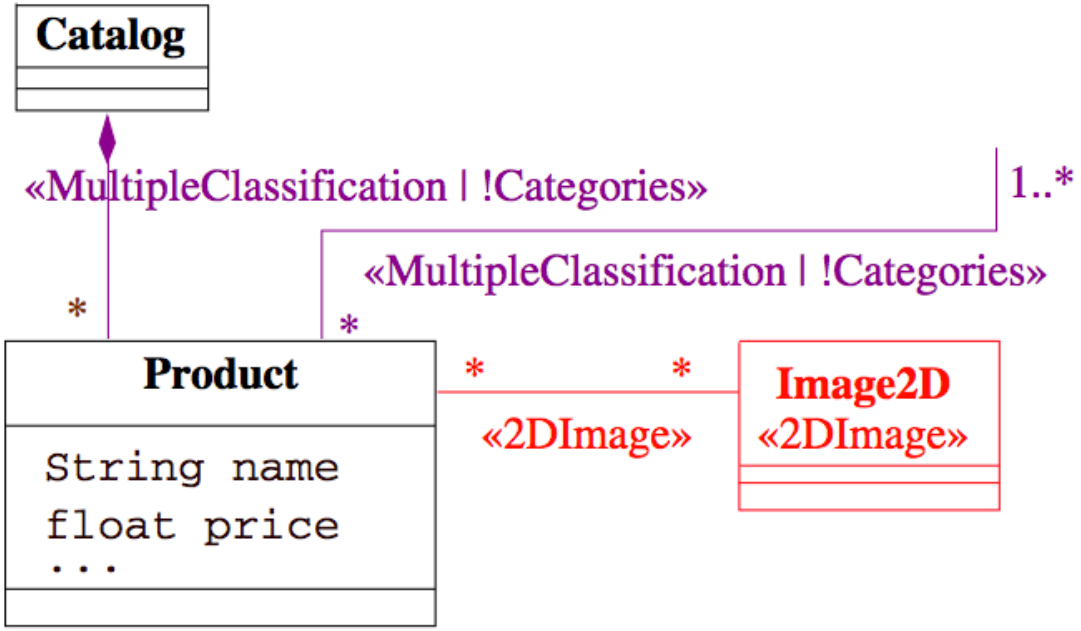

subCategories
Catalog
«Multilevel»
Category
«Categories»
String description «Description»
. . .
«Categories»
«MultipleClassification | !Categories»
«Categories & !MultipleClassification»
«MultipleClassification | !Categories»
1..*
Product
String name
float price
. . .
«2DImage»
Image2D
«2DImage»
«3DImage»
Image3D
«3DImage»


CatalogStructure (1 configuration)
Categories
MultipleClassification
Multilevel
Description
Thumbnails
ProductInformation
AssociatedAssets
2DImage
3DImage

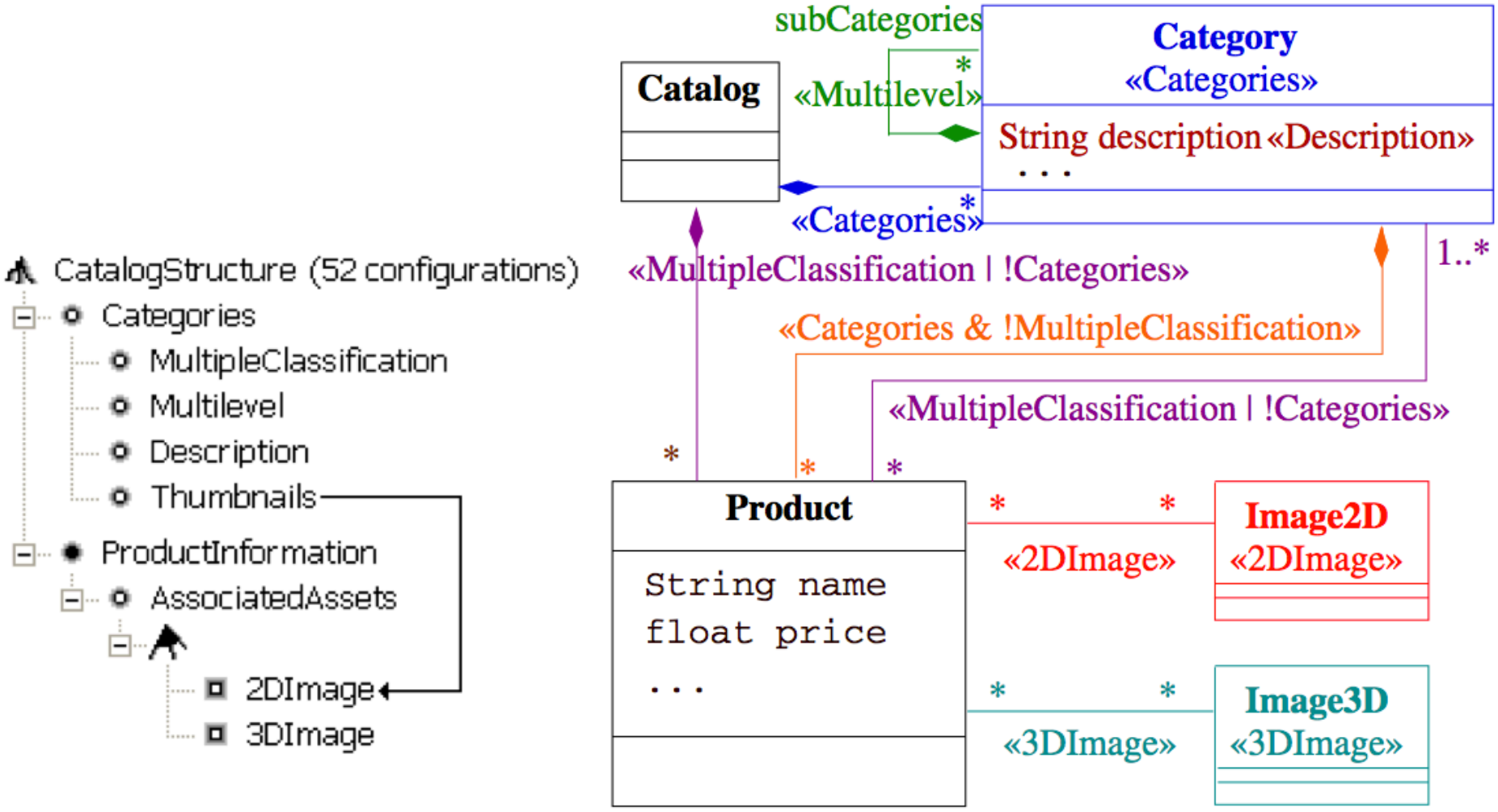

subCategories
Catalog
«Multilevel»
Category
«Categories»
...
«Categories»
«MultipleClassification | !Categories»
1..*
«MultipleClassification | !Categories»
Product
String name
float price
...
«2DImage»
Image2D
«2DImage»

Ooops


CatalogStructure (1 configuration)
Categories
MultipleClassification
Multilevel
Description
Thumbnails
ProductInformation
AssociatedAssets
2DImage
3DImage

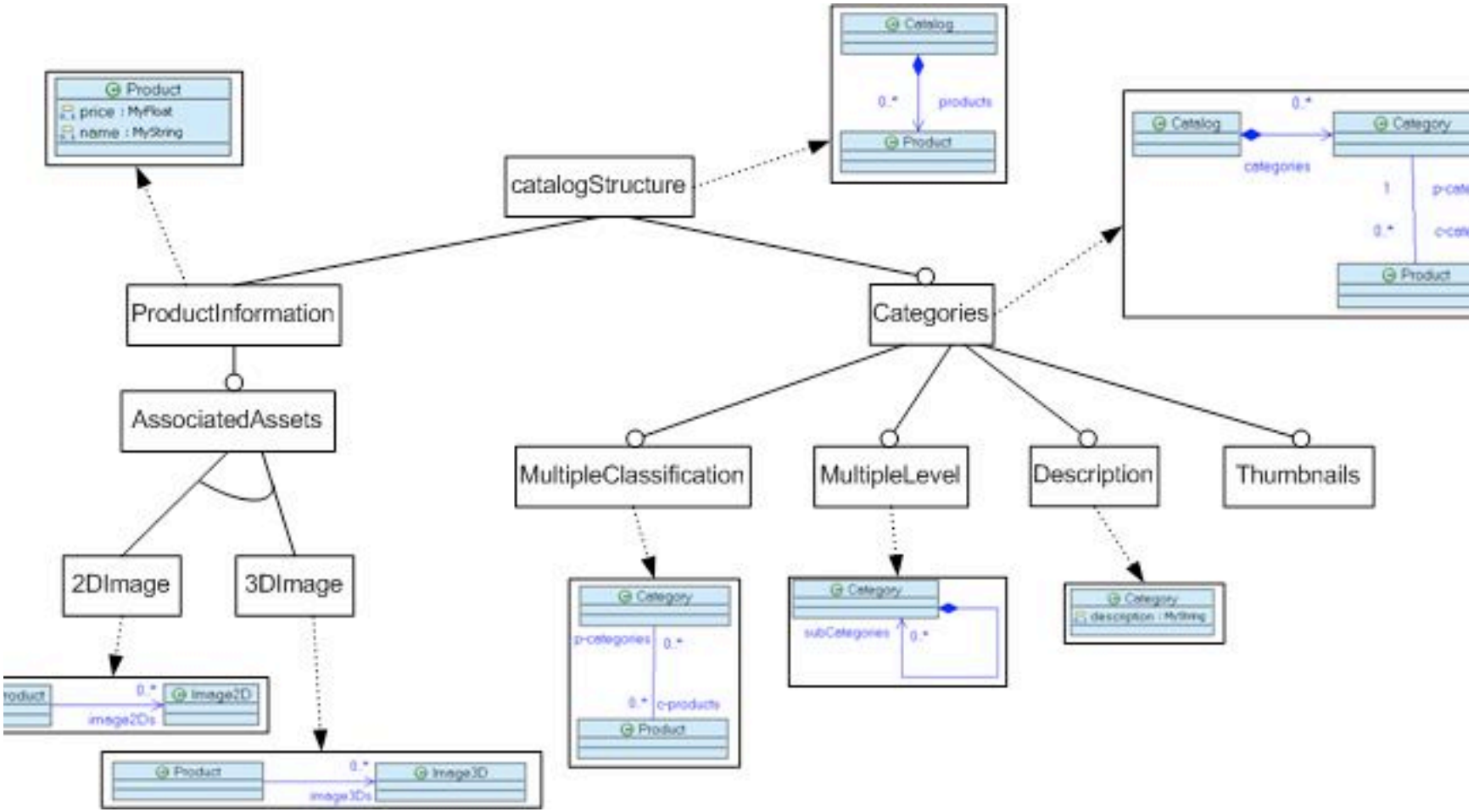

Catalog
«MultipleClassification | !Categories»
1..*
«MultipleClassification | !Categories»
*
*
Product
String name
float price
...
*
*
«2DImage»
Image2D
«2DImage»

Safe composition? No!



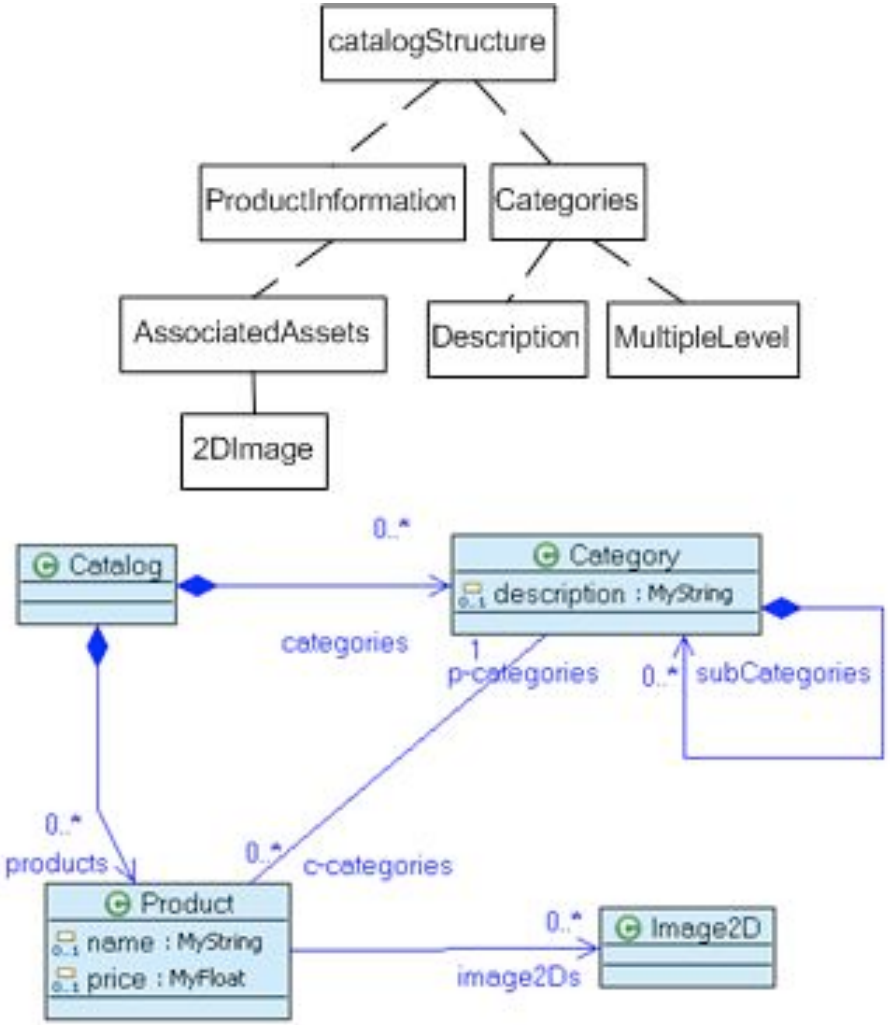
[Perrouin et al. (SPLC'08)]

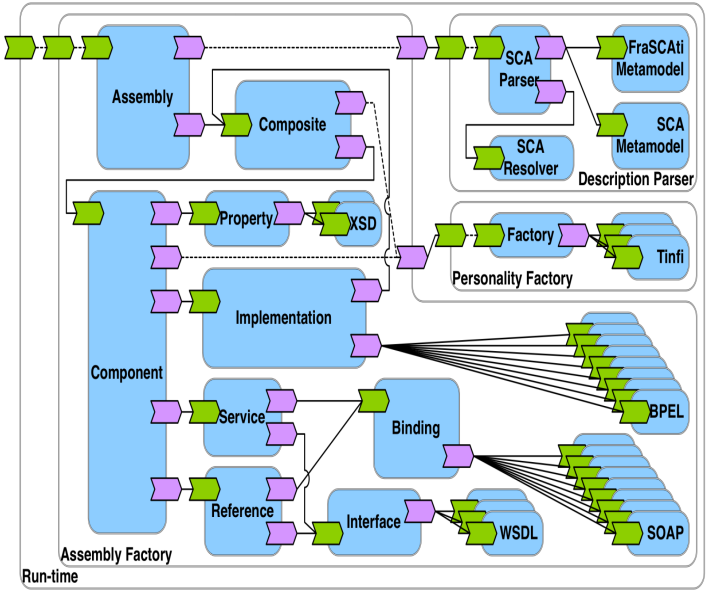
Another approach (compositional)



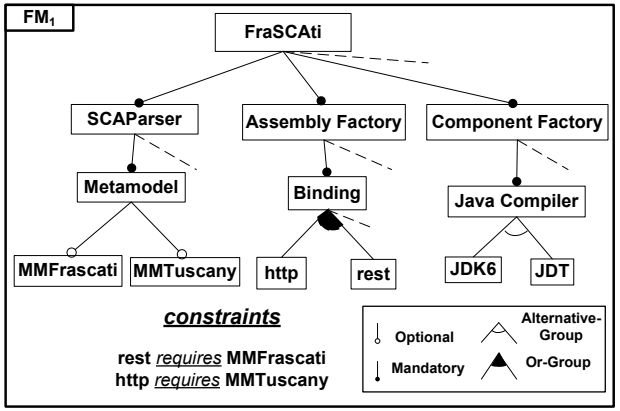
Composition of models

for deriving the product model





maven



Variability Model

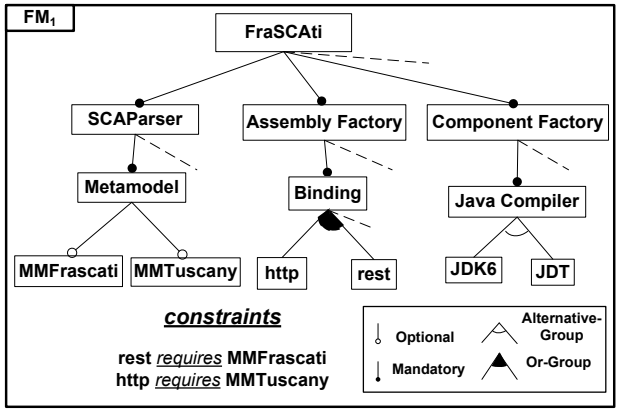
« Extraction and Evolution of Architectural Variability Models in Plugin-based Systems »
Mathieu Acher, Anthony Cleve, Philippe Collet, Philippe Merle, Laurence Duchien, Philippe Lahire ECSA/SoSyM'13

Scope is too large

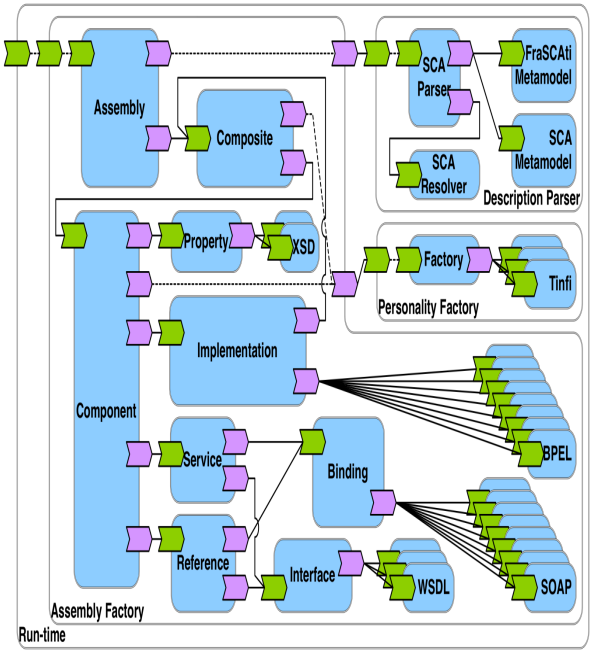
Not all combinations of architectural elements are valid

Implementation_BPEL "requires" Interface_WSDL ;
Implementation_Spring "requires" MM_SCA ;

Variability Model

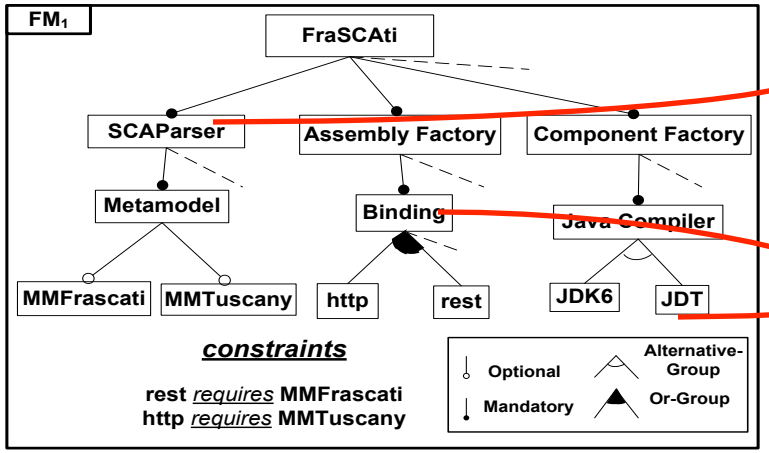


FraSCAti Architecture

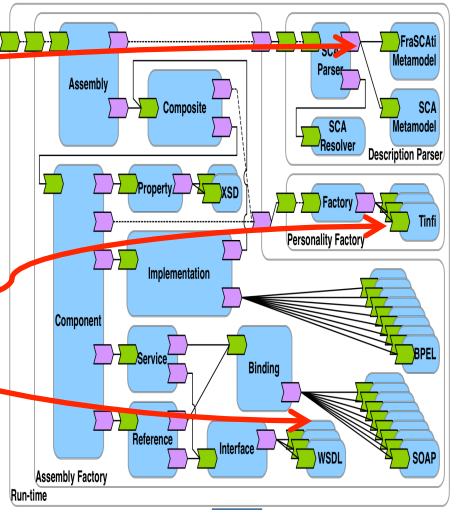


Illegal Variant

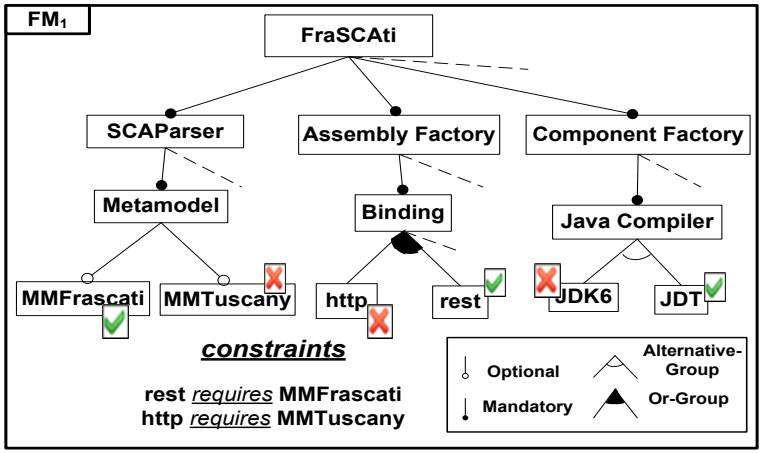
Feature Model



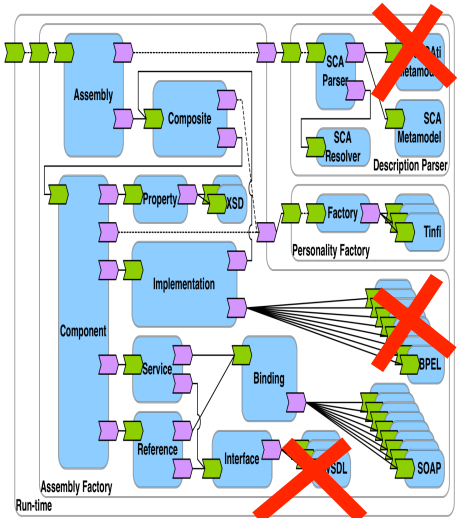
FraSCAti Architecture



Configuration

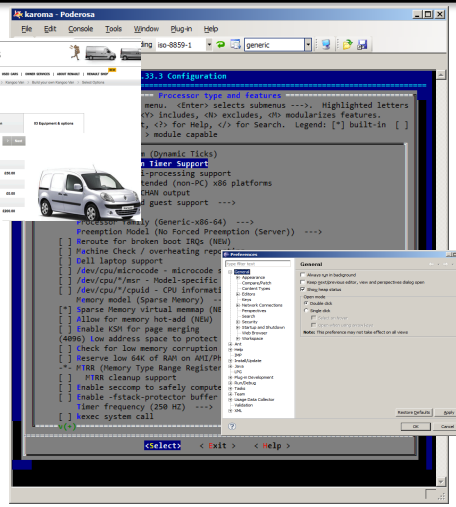


Derived FraSCAti Architecture



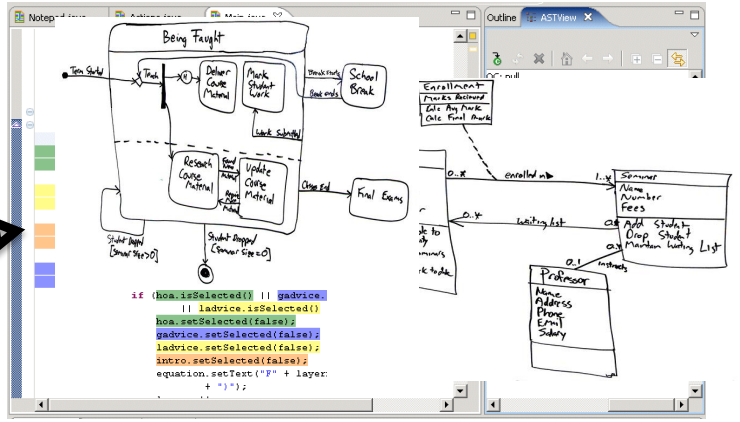
Common Varaibility Language (CVL)

(back to examples)

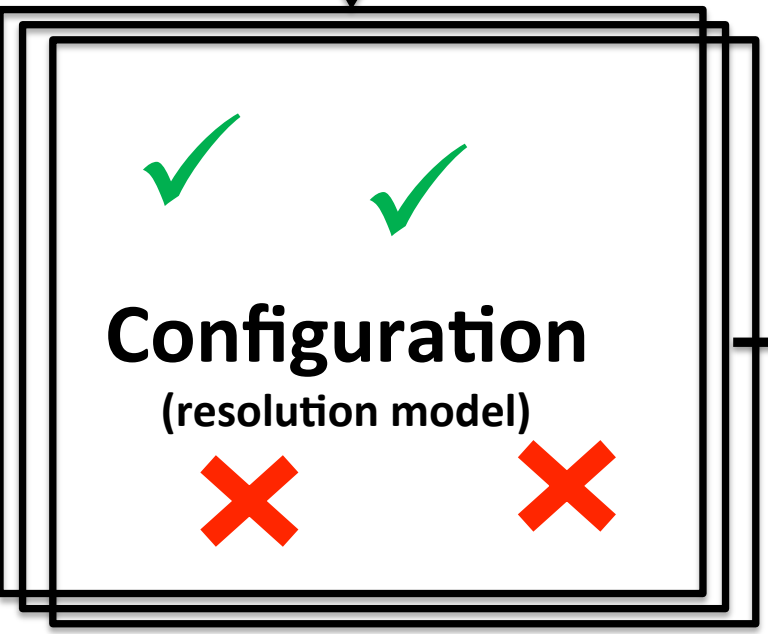


Variability Abstraction Model (VAM)

Variability Realization Model (VRM)



Domain Artefacts (e.g., models)



Configuration

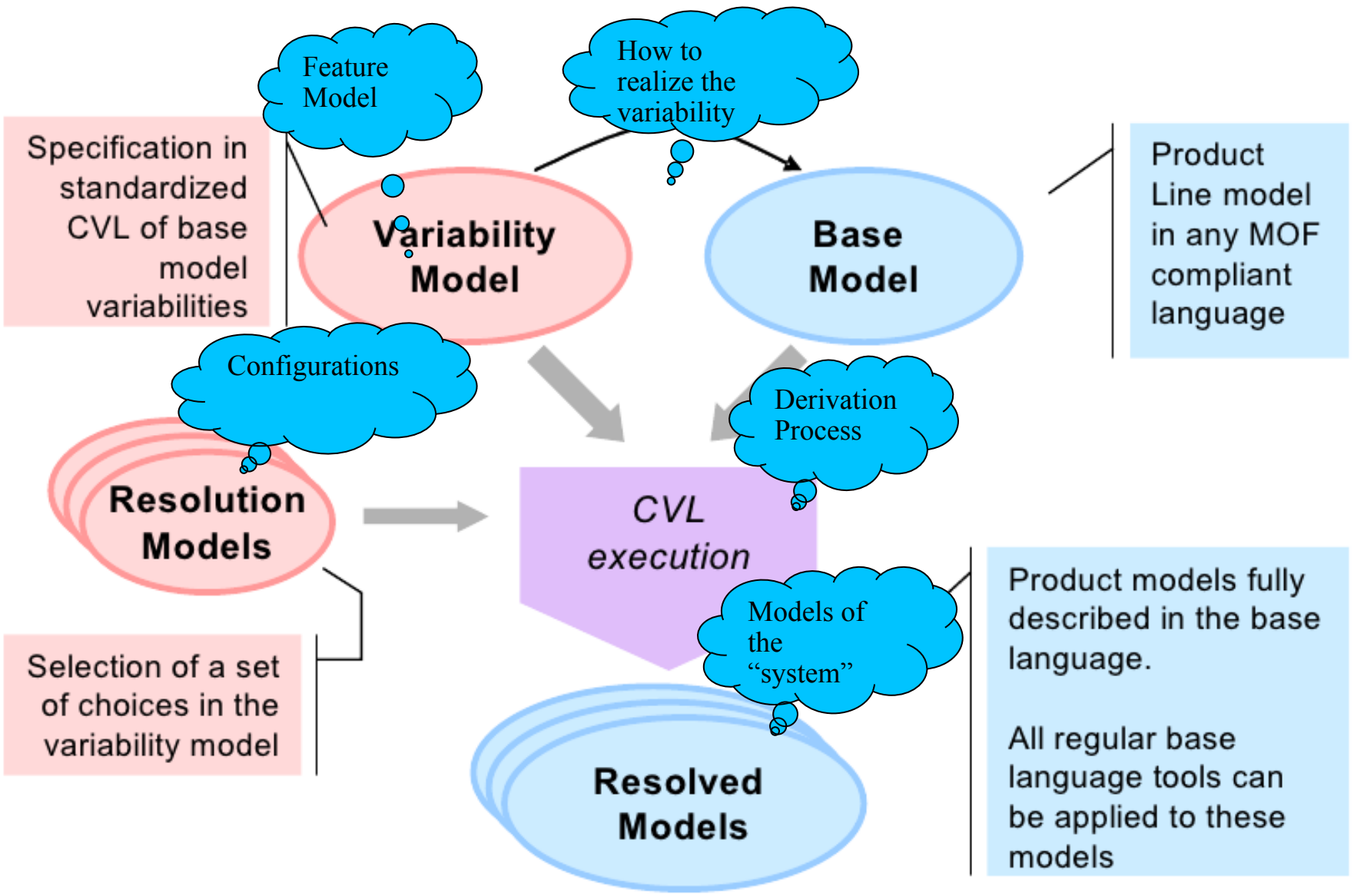
(resolution model)

Software Generator

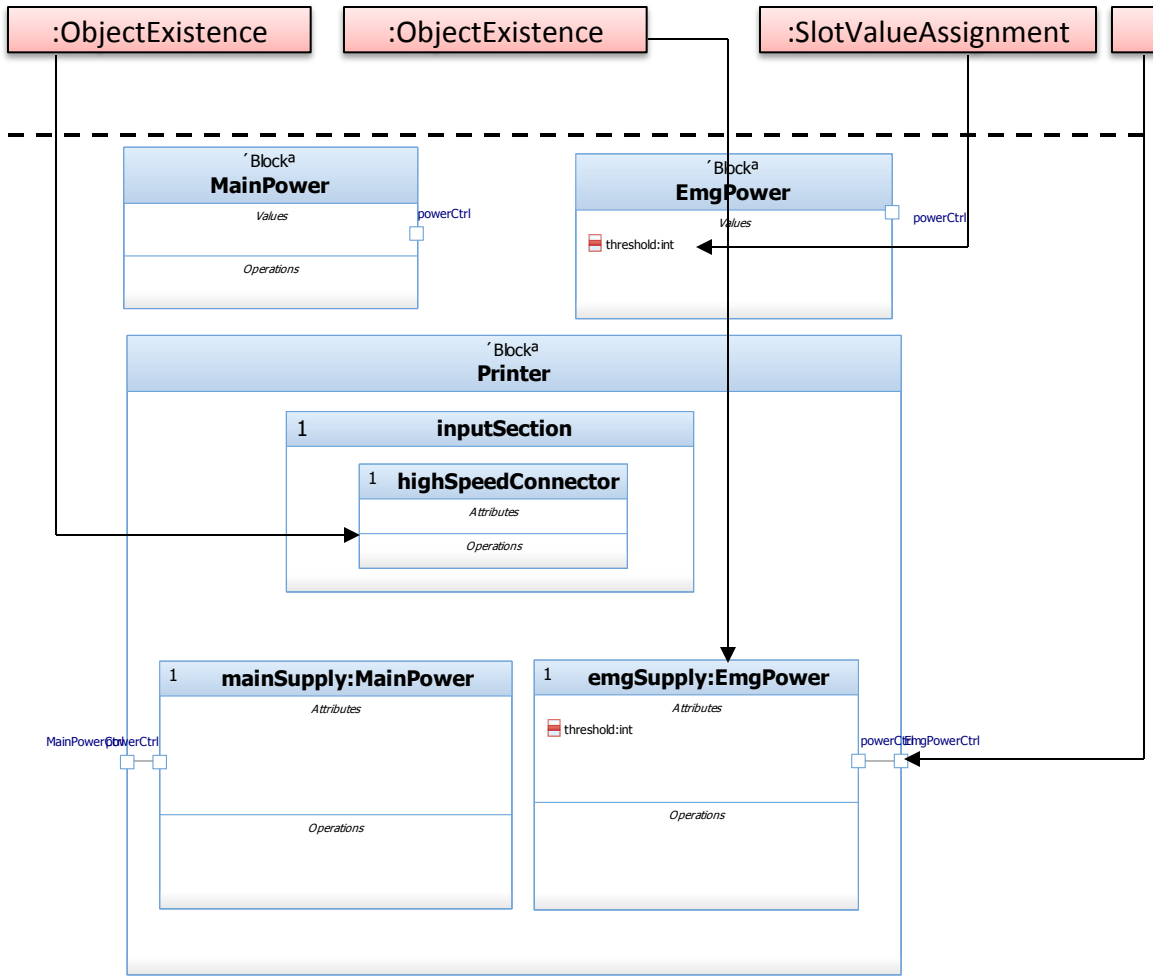
(derivation engine)

COMMON VARIABILITY LANGUAGE

FAMiliAR

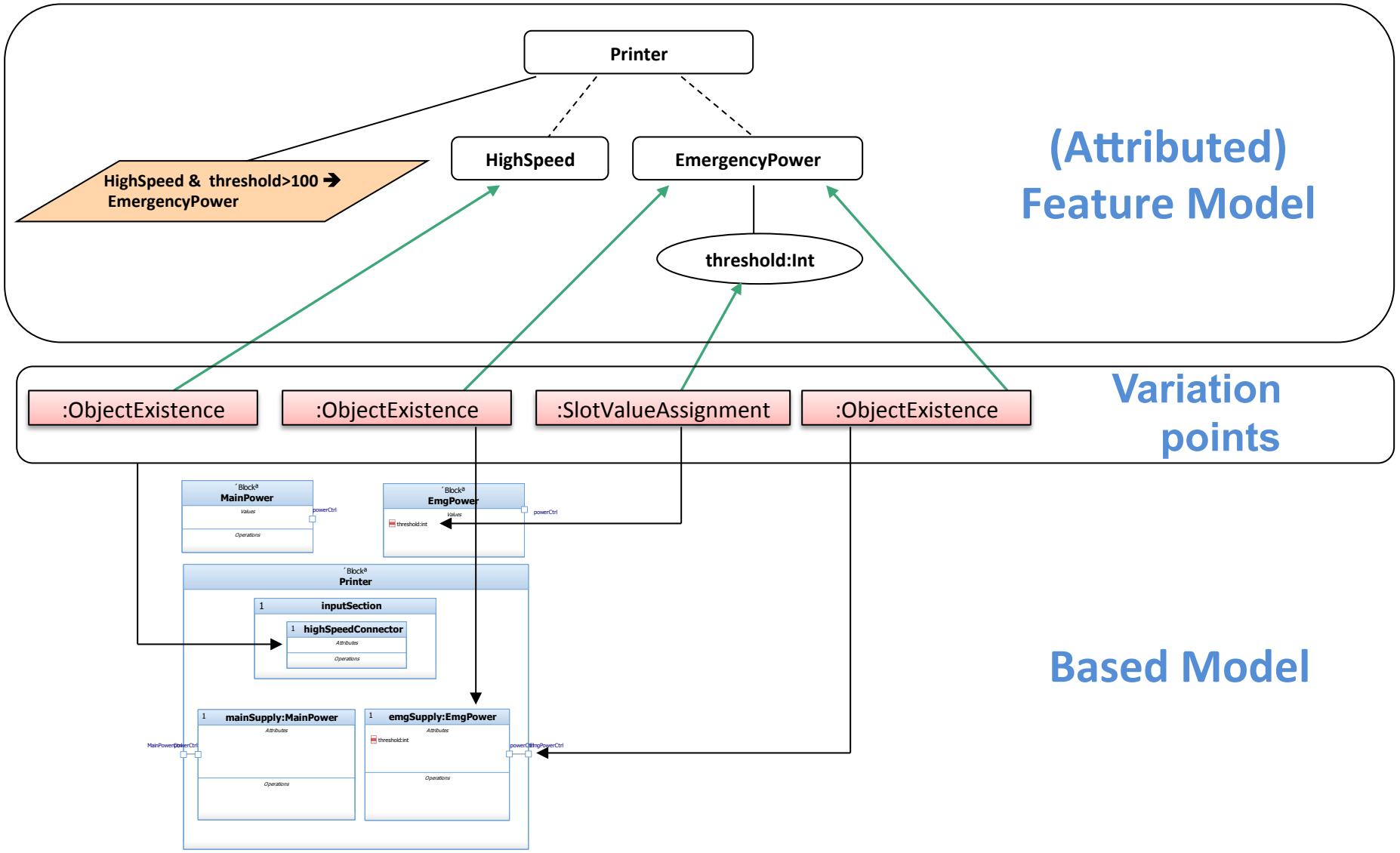


Variation Points over base model



- Variability in this example:
  - Part **EmergencySupply** is optional
  - Part **HighSpeedConnector** is optional
  - Port **EmgPowerCtrl** on block **Printer** is optional
  - Value of attribute **threshold** in block **EmergencyPower** is variable

Adapted from the CVL tutorial at SPLC'12 by Oystein Haugen, Andrezj Wasowski, Krzysztof Czarnecki



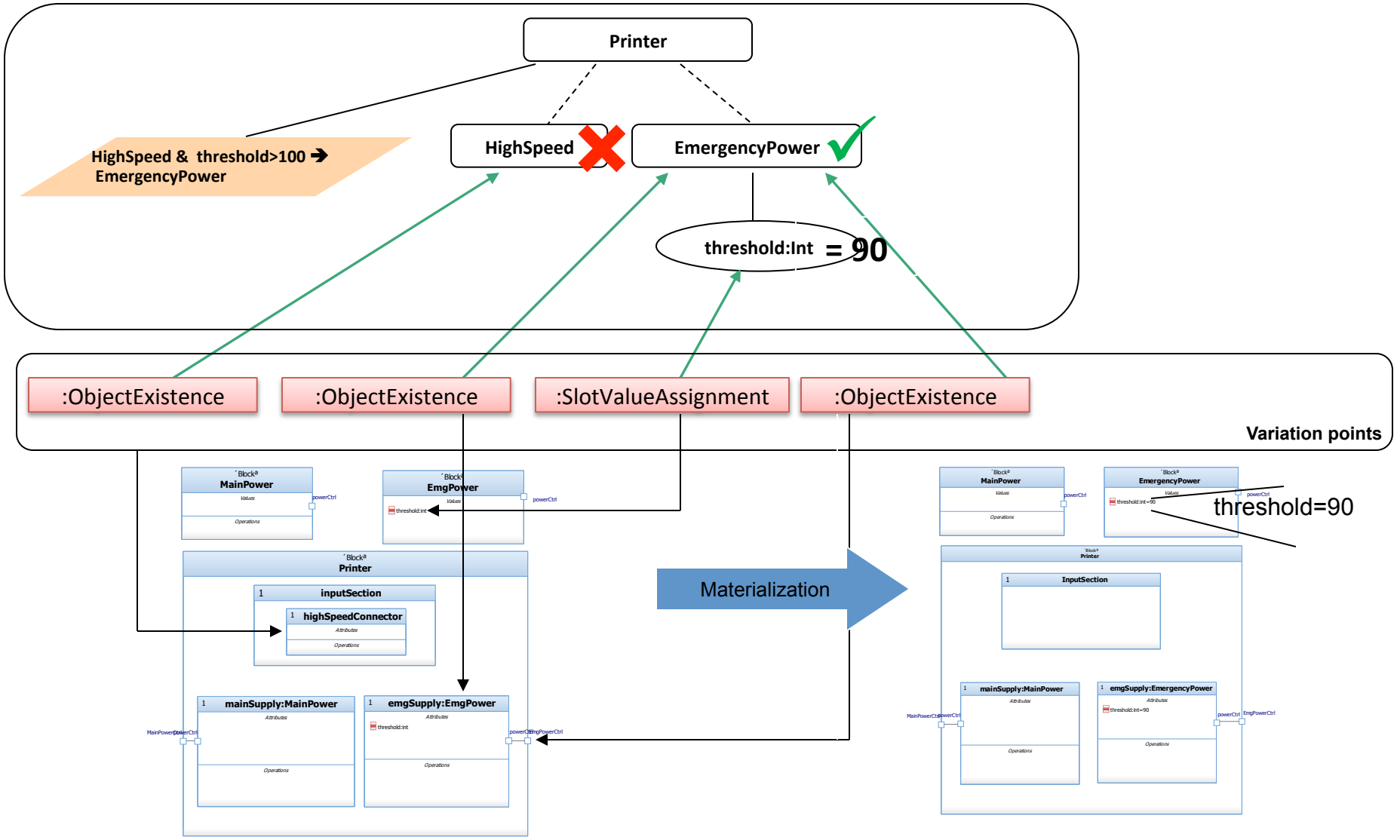
Adapted from the CVL tutorial at SPLC'12 by Oystein Haugen, Andrezj Wasowski, Krzysztof Czarnecki

Variability Realization Layer

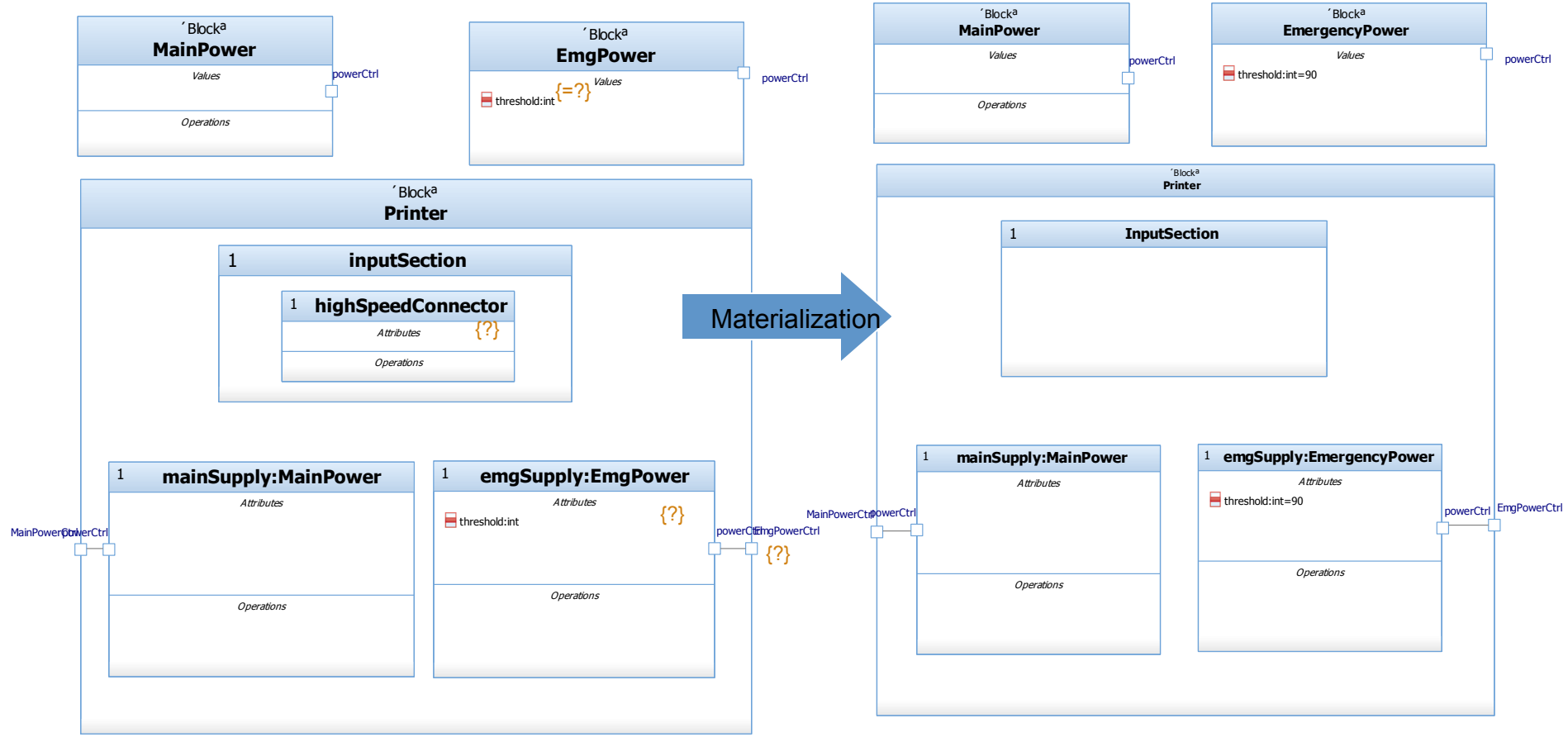
Variation points in CVL

- Variation Points refer to Base objects
- Variation Points define the base model modifications precisely
- There are different kinds of Variation Points
  - Existence (object or link)
  - Value assignment
  - Substitution
  - Opaque variation point
  - Configurable Unit

Configuration and Product Derivation



Another syntax for specifying the mapping (annotations)

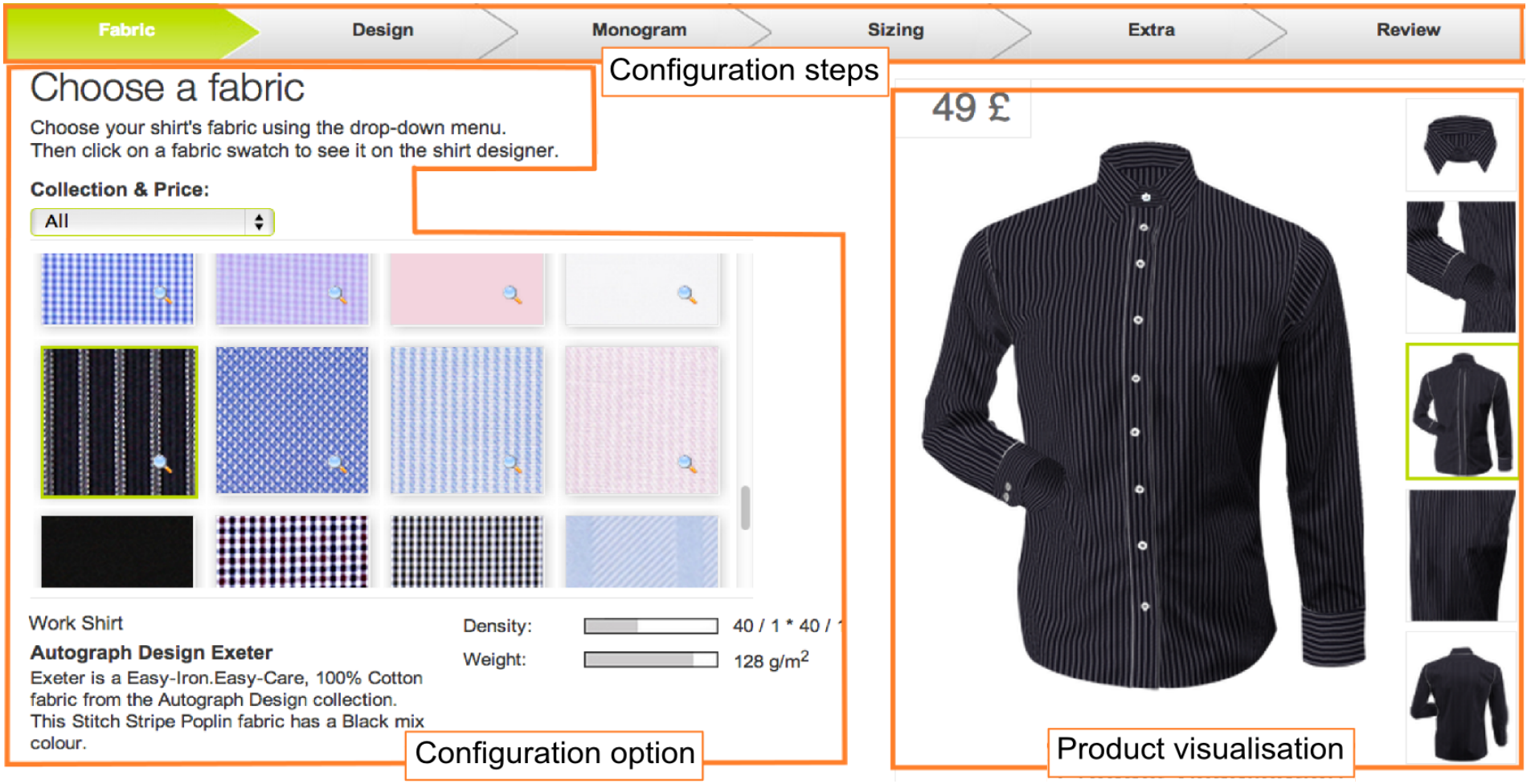


Product Line Model

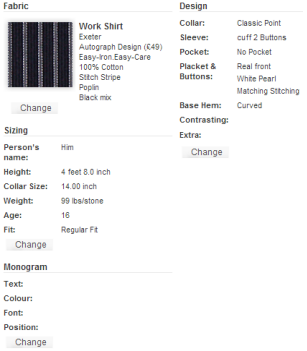
Product Model (materialized model)

Common Varaibility Language (CVL)

(another example)

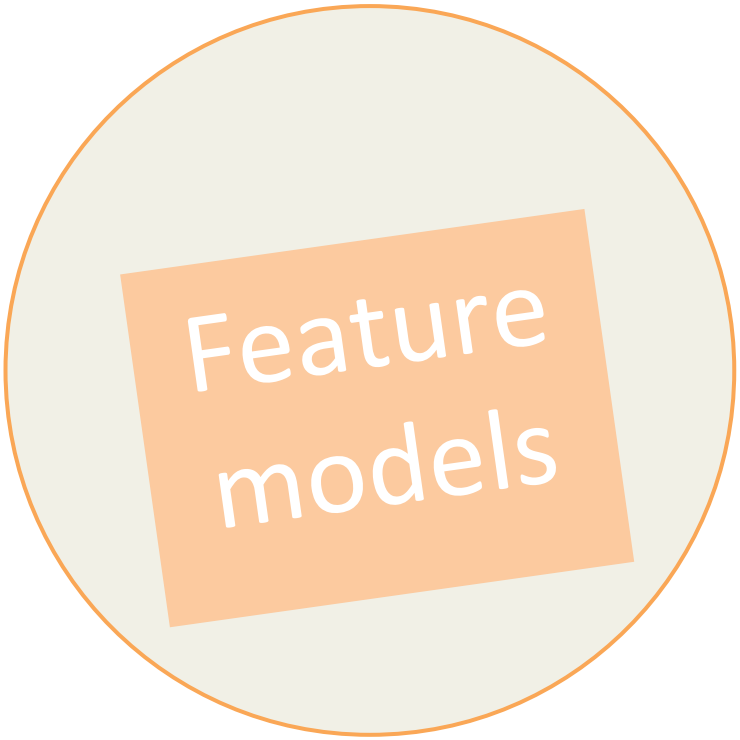


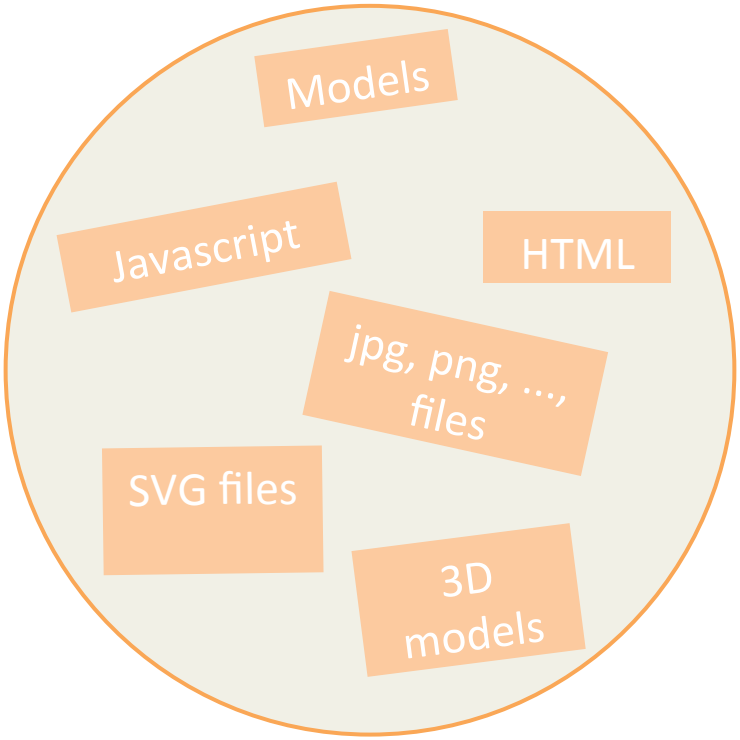
Marks & Spencer web configurator



PRODUCT CONFIGURATION

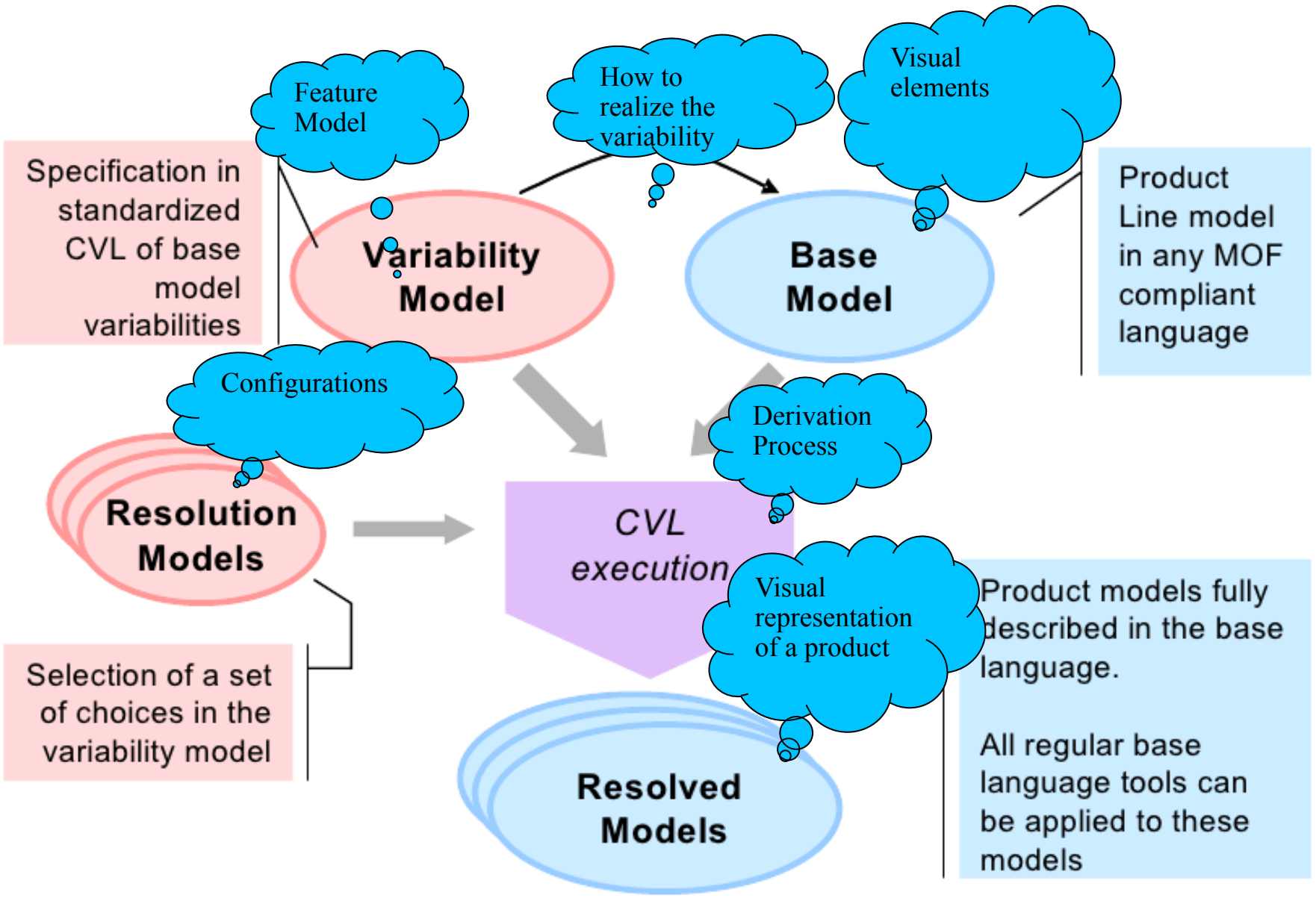
VISUAL REPRESENTATION



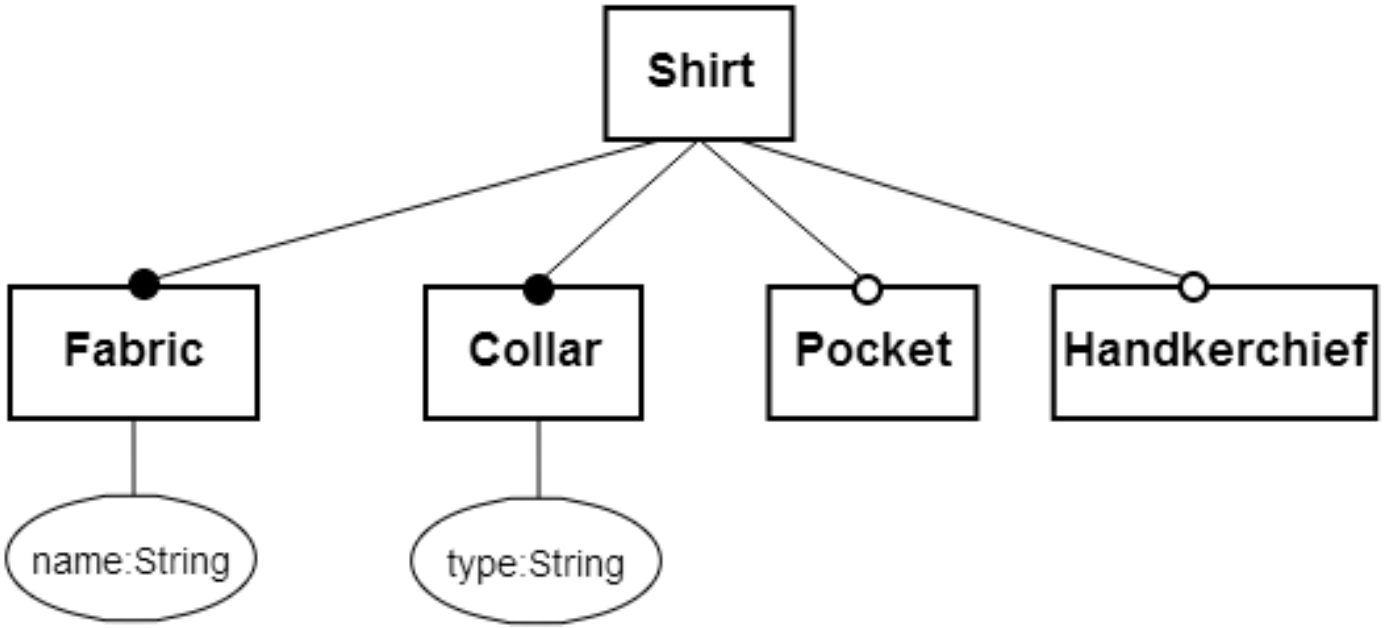


COMMON VARIABILITY LANGUAGE

FAMiliAR



Feature model



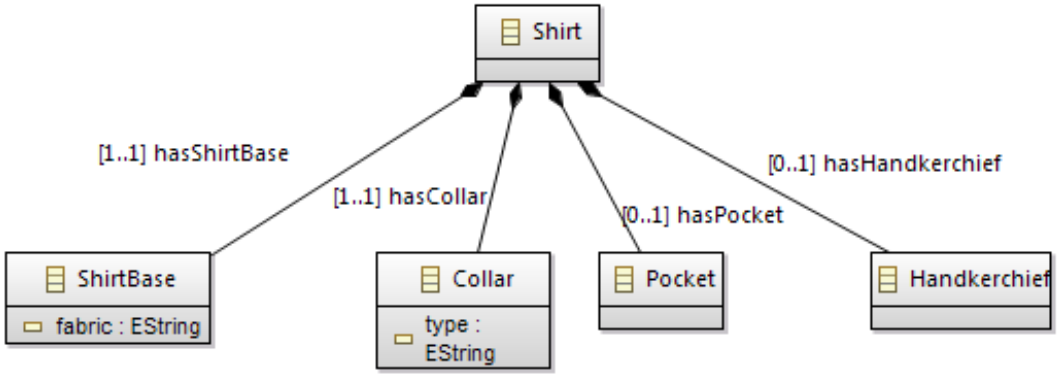
- Implicit boolean attribute *existence*
- No constraints

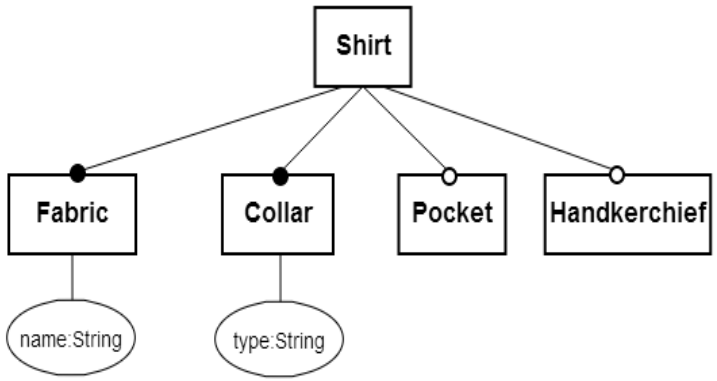
DSL metamodel

ShirtModel.ecore

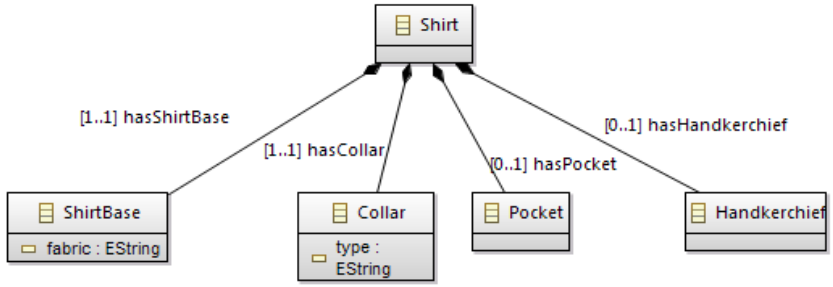
- platform:/resource/ShirtModel/model/ShirtModel.ecore
  - ShirtModel
    - Shirt
      - hasShirtBase : ShirtBase
      - hasCollar : Collar
      - hasPocket : Pocket
      - hasHandkerchief : Handkerchief
    - ShirtBase
      - fabric : EString
    - Collar
      - type : EString
    - Pocket
    - Handkerchief

ShirtModel.ecore | ShirtModel package entities





ShirtModel.ecore | ShirtModel package entities



ShirtsConfigurator.cvl

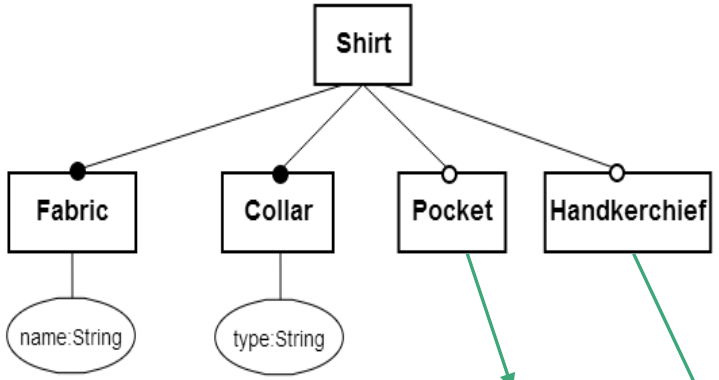
Resource Set

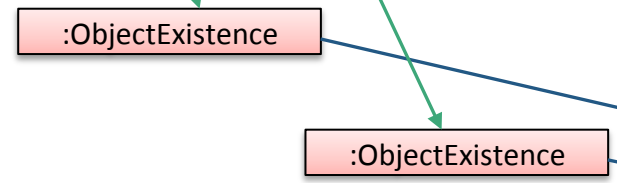
- platform:/resource/ShirtsConfigurator/ShirtsConfigurator.cvl
  - VPackage ShirtsConfigurator
    - VPackage Variable types
      - Primitve Type String
    - VPackage VAM
      - Choice Shirt
    - VPackage Resolution Model
      - Variable Value Assignment FabricName
      - Variable Value Assignment CollarType
    - VPackage VRM
      - Parametric Slot Assignmet FabricName
        - Object Handle Fabric
      - Parametric Slot Assignmet CollarType
        - Object Handle Type
      - Object Existence Pocket
        - Object Handle Pocket
      - Object Existence Handkerchief
        - Object Handle Handkerchief
  - platform:/resource/ShirtsConfigurator/baseModel.shirtmodel

baseModel_new.shirtmodel

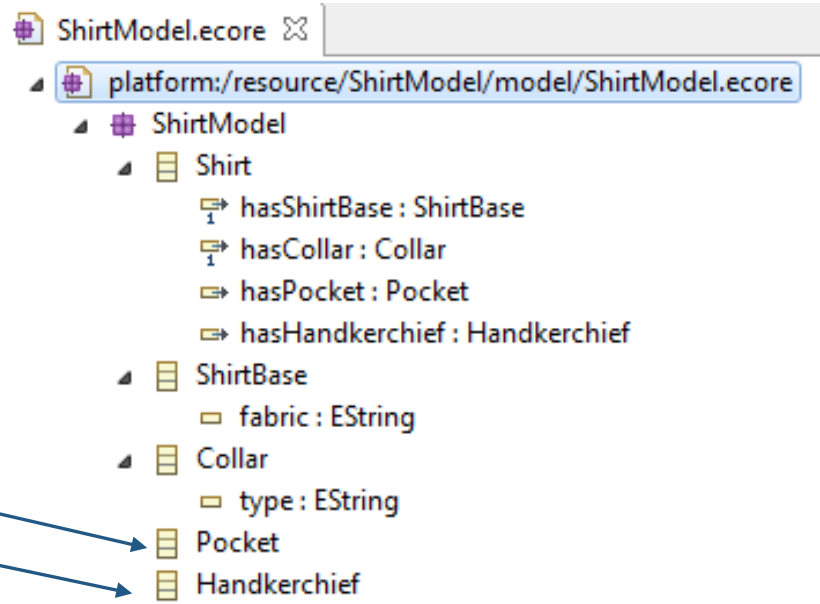
Resource Set

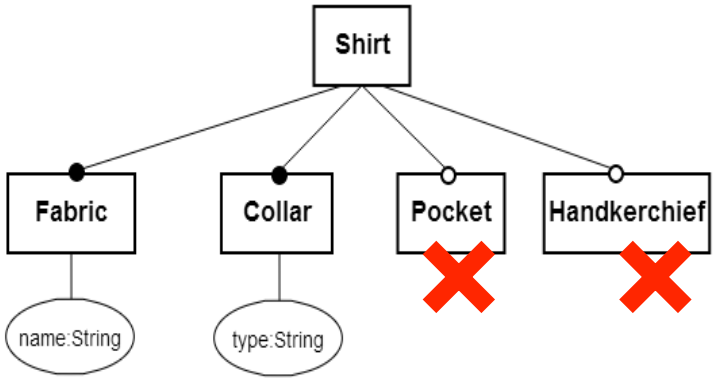
- platform:/resource/ShirtsConfigurator/baseModel_new.shirtmodel
  - Shirt
    - Shirt Base Florida
    - Collar ClassicPoint

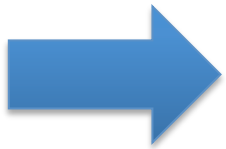

Shirt
Fabric
Collar
Pocket
Handkerchief
name:String
type:String

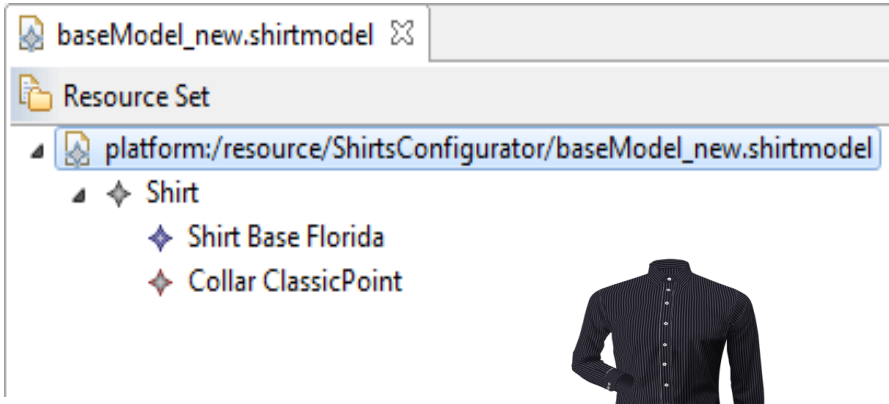

:ObjectExistence

:ObjectExistence


ShirtModel.ecore
platform:/resource/ShirtModel/model/ShirtModel.ecore
ShirtModel
Shirt
hasShirtBase : ShirtBase
hasCollar : Collar
hasPocket : Pocket
hasHandkerchief : Handkerchief
ShirtBase
fabric : EString
Collar
type : EString
Pocket
Handkerchief


Shirt
Fabric
Collar
Pocket
Handkerchief
name:String
type:String




baseModel_new.shirtmodel
Resource Set
platform:/resource/ShirtsConfigurator/baseModel_new.shirtmodel
Shirt
Shirt Base Florida
Collar ClassicPoint