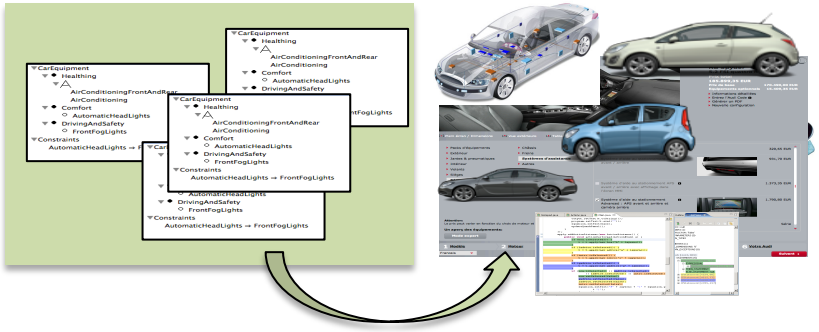


Model-based Software Product Lines

Overview and Principles

Mathieu Acher

Maître de Conférences

mathieu.acher@irisa.fr

UNIVERSITÉ DE RENNES 1

istic Informatique Électronique

Material

http://mathieuacher.com/teaching/MDE/

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

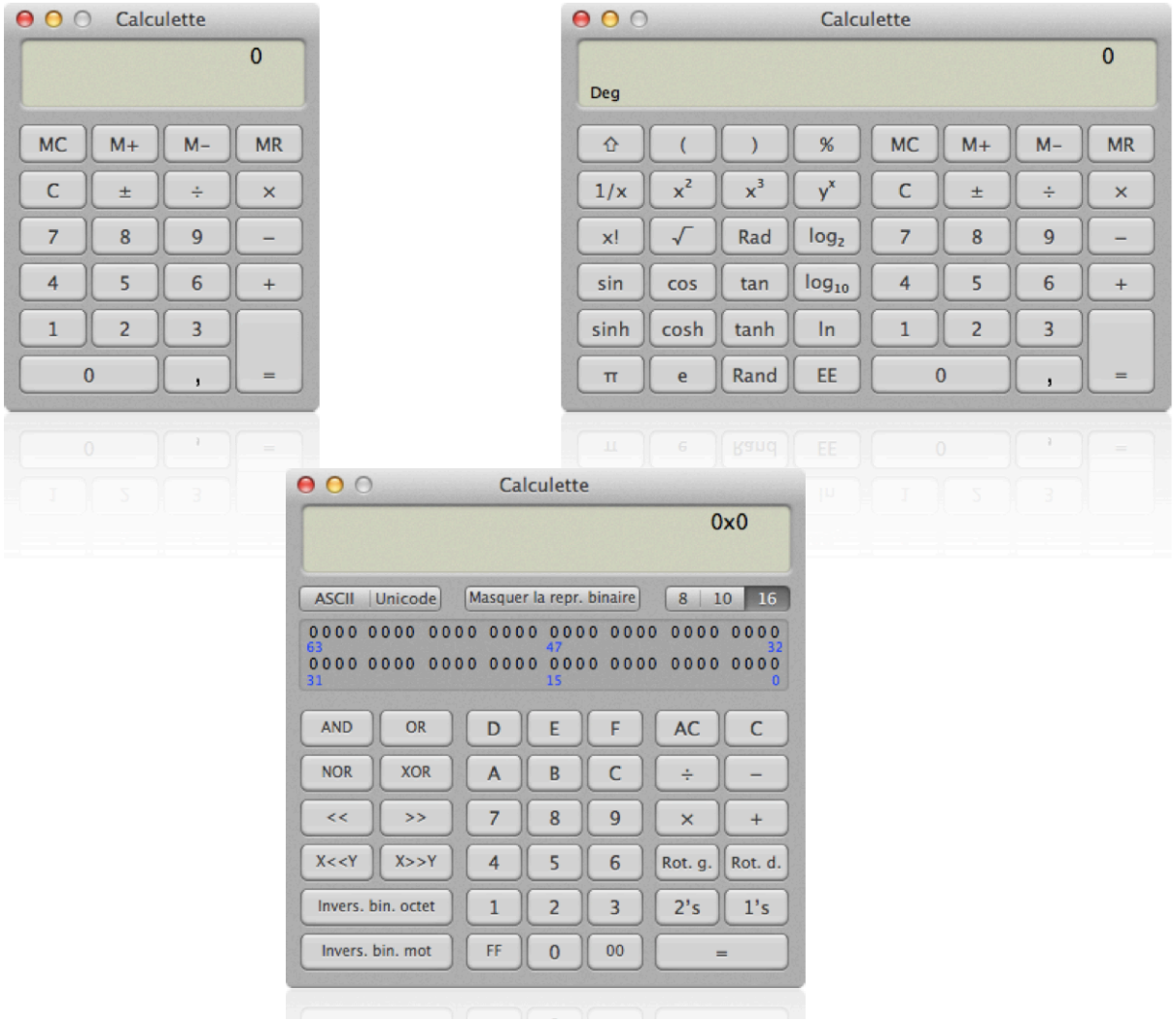
Contract

- 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

- Feature modeling
  - A widely used formalism for modeling product lines and configurable systems in a broad sense

Software Product Line and
Variability Engineering

Challenges and Overview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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		✓	✓	✓

NOKIA
Connecting People

Know our past. Create the future...

1982 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994

1995 1996 1997 1998 1999

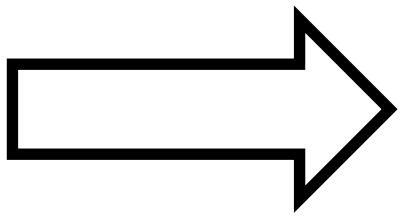
2000 2001 2002

2003 2004

2005

2006 UI

Software-intensive systems

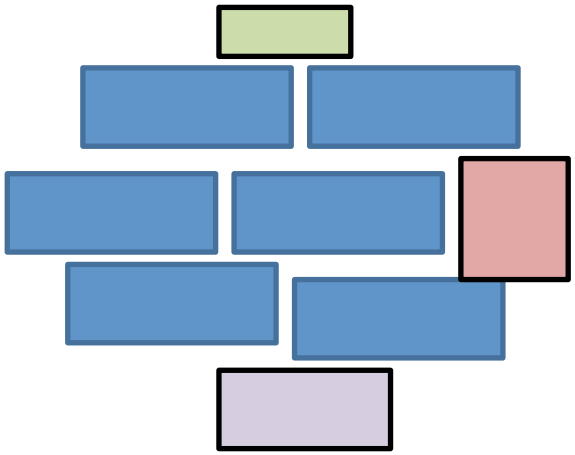


come in many **variants**

Software Product Line Engineering

Factoring out **commonalities**

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



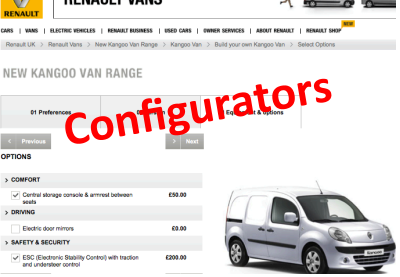
Managing **variabilities**

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

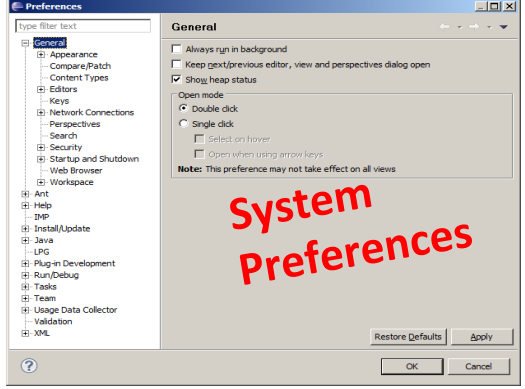
Variability

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

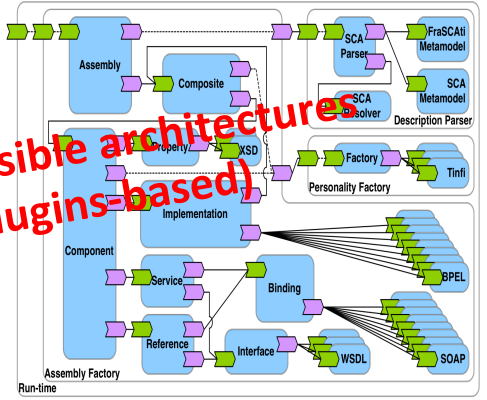
Mikael Svahnberg, Jilles van Gurp, and Jan Bosch (2005)



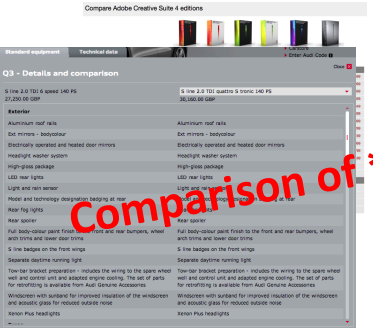
Configurators



System Preferences

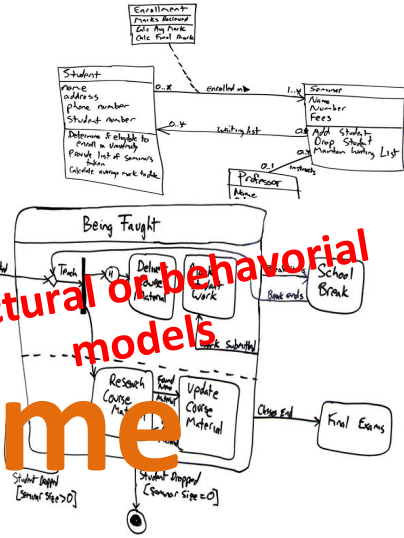


Extensible architectures (eg plugins-based)

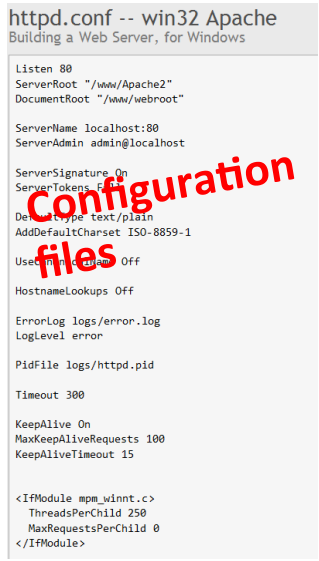


Comparison of *

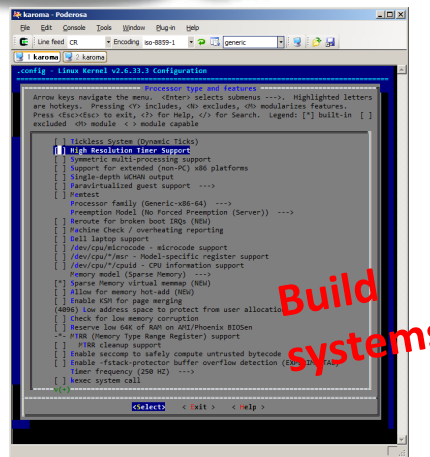
External Variability
Internal Variability
Variability @ run.time



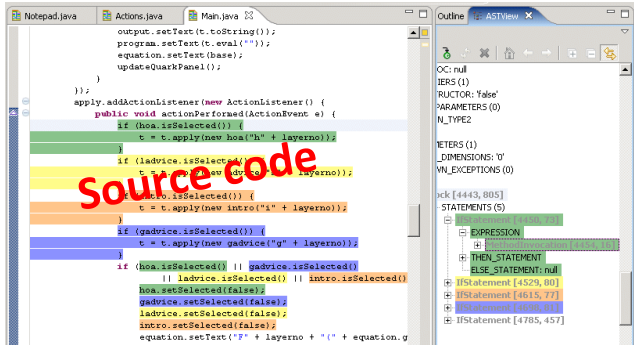
Structural or behavorial models



Configuration files



Build systems



Source code

Developer Tools
Development
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DTP/Prepress
Educational
Finance
Font Tools
Games
Graphics
HTML Tools
Internet Utilities
IPhone Applications
IPod Tools
Math/Scientific
Multimedia
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Screensave
Security
Spot t Plug Utilities
System ilities
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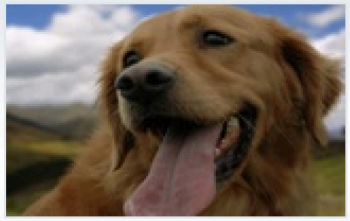
EET THE EDITORS >>

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 >]

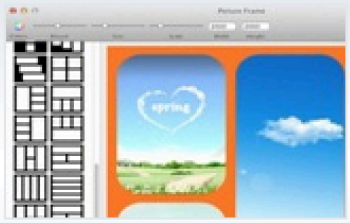
Size:	102 KB
Platform:	Mac OS X 10.8 or later
License:	Commercialware
Rating:	NOT RATED
Downloads:	21
Updated:	June 20th, 07:56 UTC

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

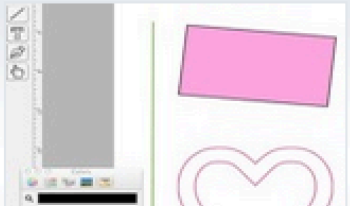


FashionLab Studio 1.1 update

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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Previous Next

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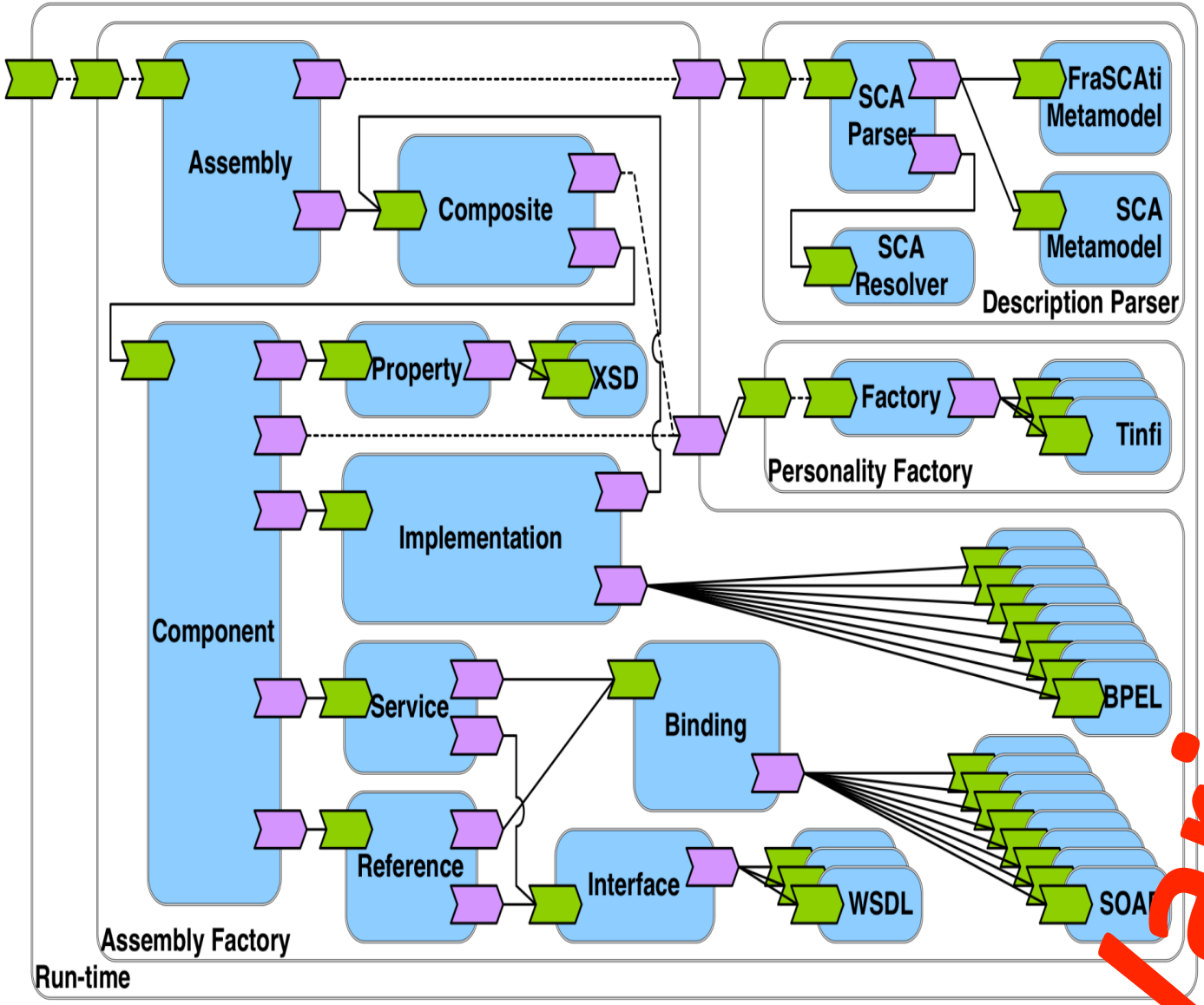
☑ ESC (Electronic Stability Control) with traction and understeer control	£200.00

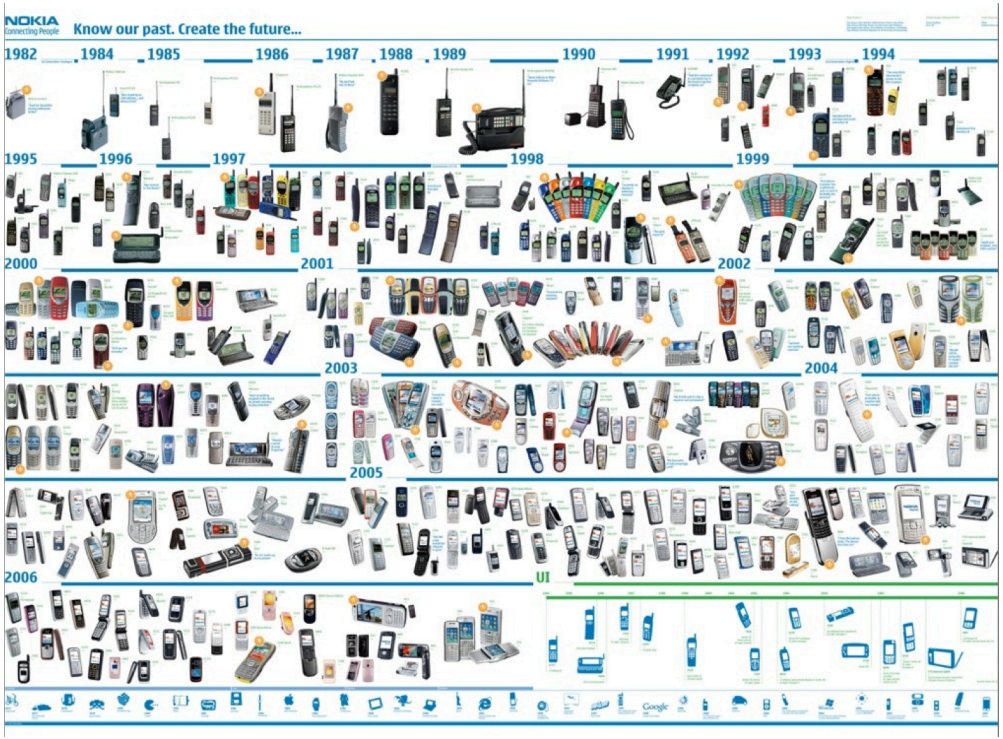
Variability



Variability

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**

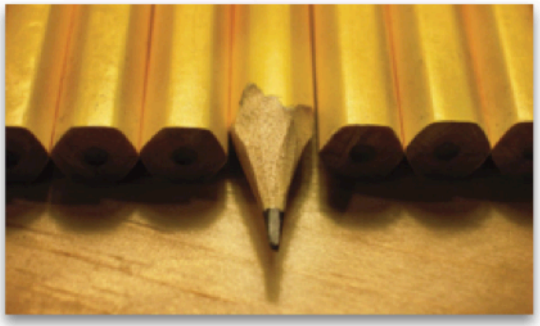


Benefits

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

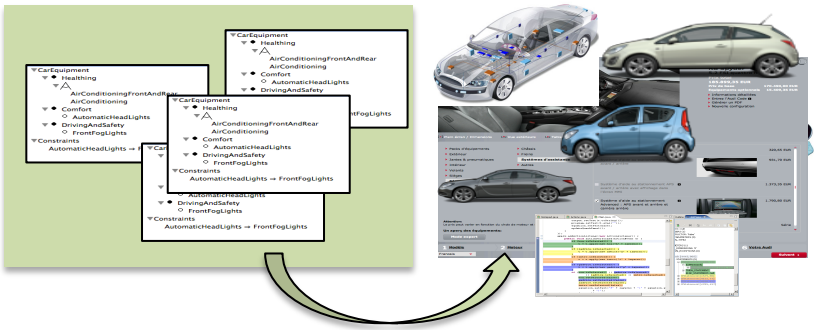
Lucent Technologies
Bell Labs Innovations

Printer Firmware

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

Objectives

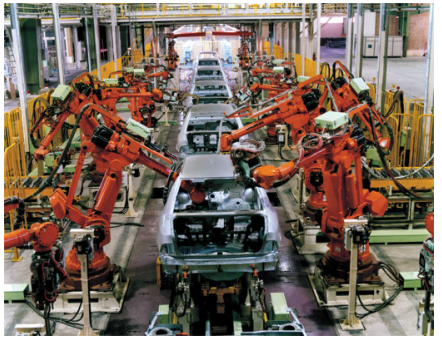
- Variability and Software Product Line Engineering
  - Overview
  - Challenges



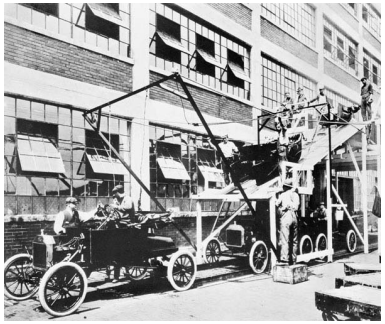
- The (possible) role of Model-Driven Engineering

- Overview of techniques

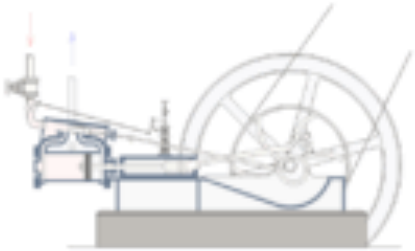
A Bit of History: Industrial Revolution



1980s



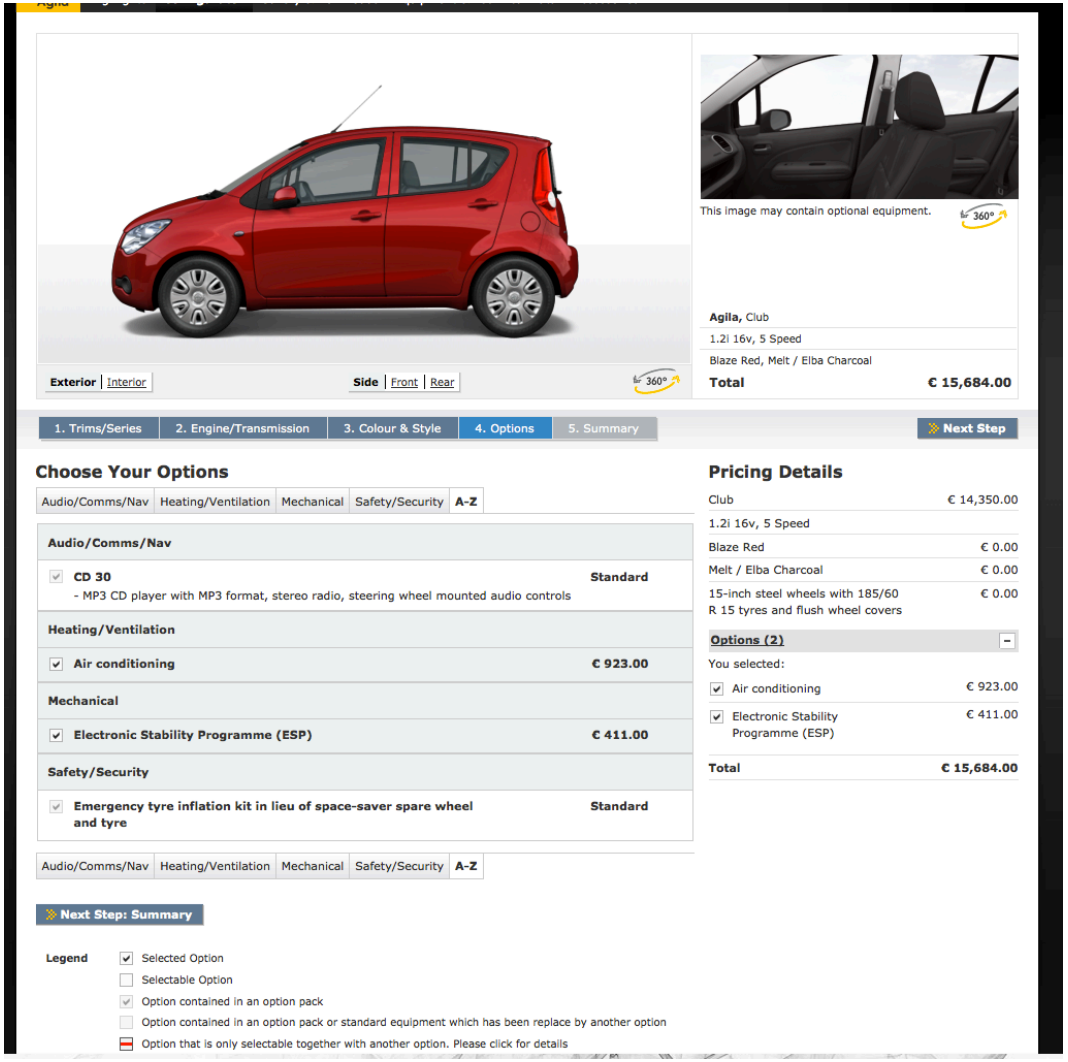
1901
Henry Ford



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
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modell-details
>>hier clicken
>>SELVE SCHUHREGAL
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>>SHOPPING BAG
inhalt : 0
A. Erstes Oberleder
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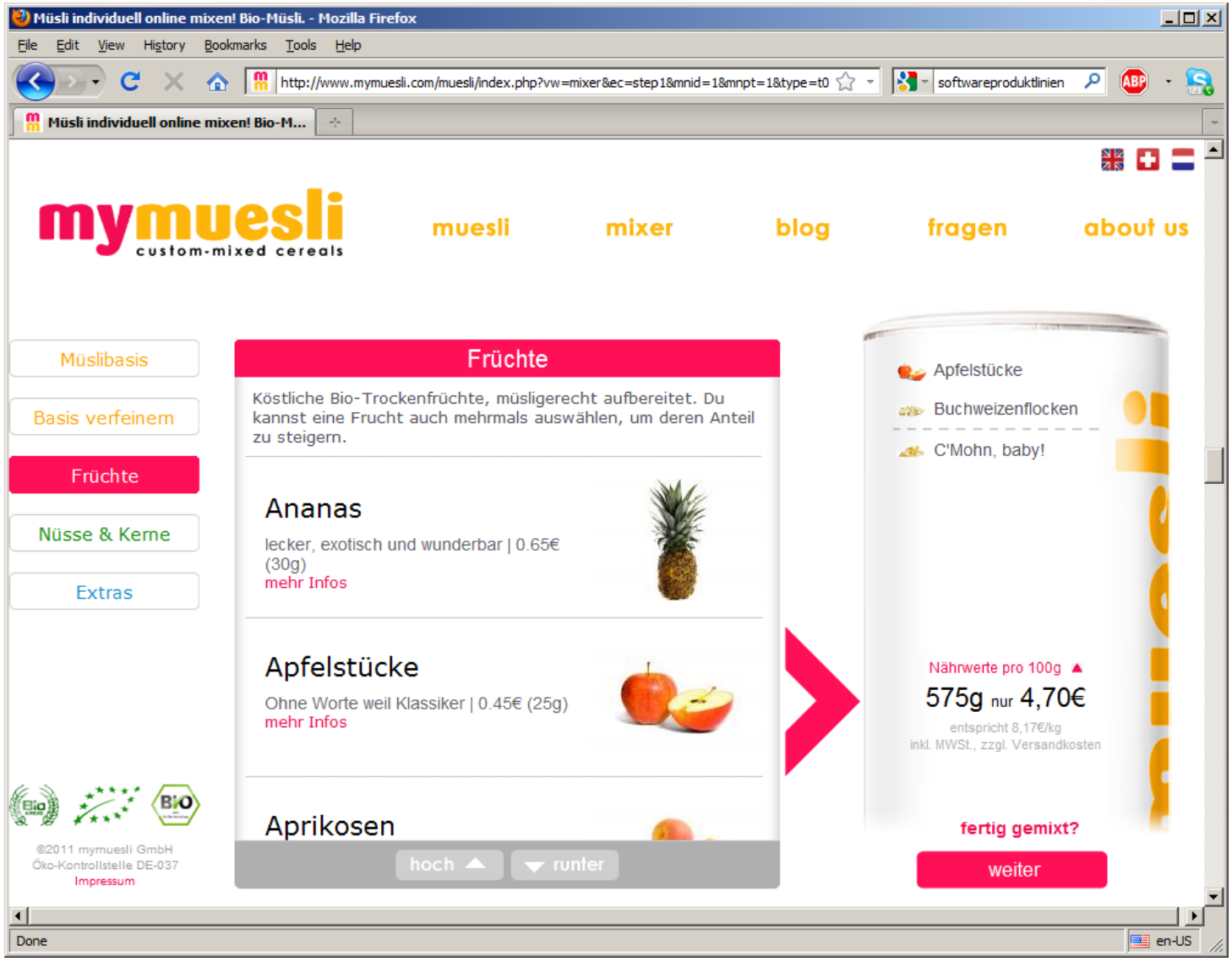
Velours leder Bordeaux
Velours leder Cognac
Velours leder Sand
B.
C. Futterleder
Beige
D. Absatz
Hufeisen Braun
E. Sohle
Gummisohle
>>ÄNDERN
>>ZURÜCKLEGEN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Köstliche Bio-Trockenfrüchte, müsligerecht aufbereitet. Du kannst eine Frucht auch mehrmals auswählen, um deren Anteil zu steigern.
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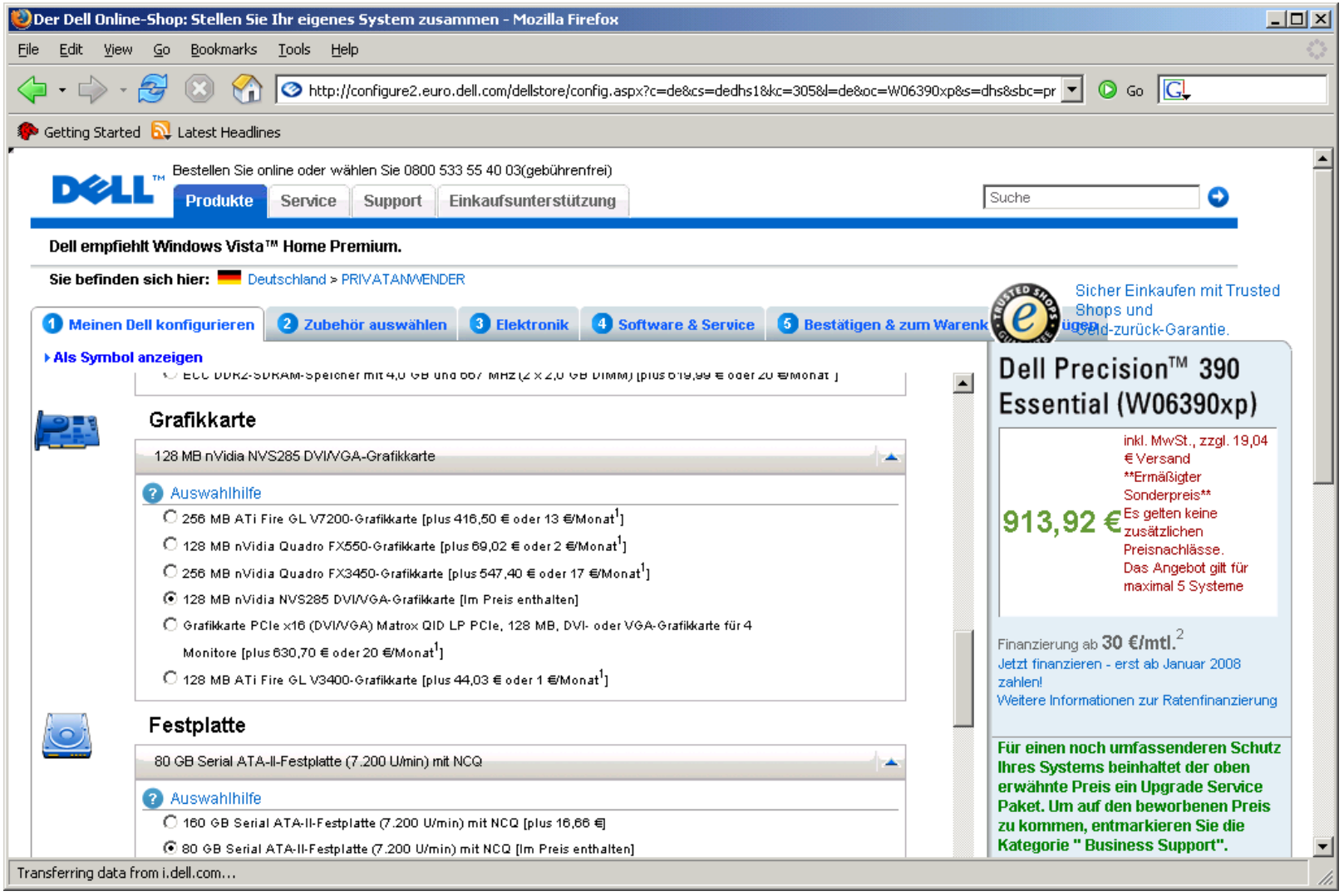
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160 GB Serial ATA-II-Festplatte (7.200 U/min) mit NCQ [plus 16,66 €]
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Ermäßigter Sonderpreis
Es gelten keine zusätzlichen Preisnachlässe.
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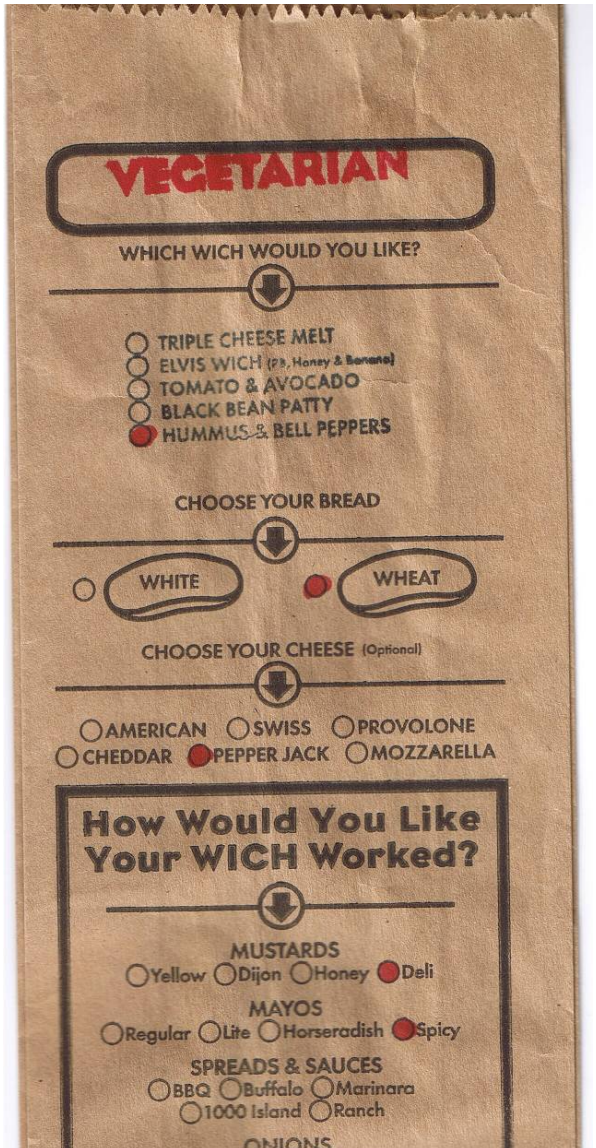
Transferring data from i.dell.com...

Food? Product lines!




VEGETARIAN
How Would You Like Your WICH Worked?


VEGETARIAN


How Would You Like Your WICH Worked?

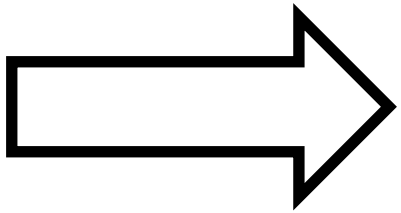
Mass production

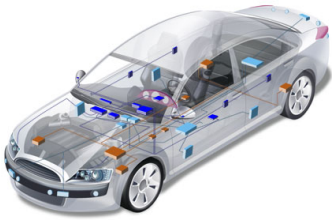

What about
software?

Product lines of software intensive systems

Software intensive systems

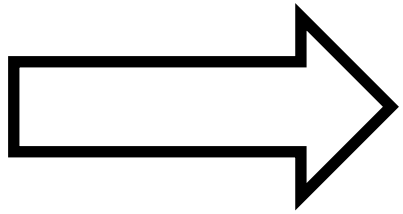
are declined in many **variants**





Software intensive systems

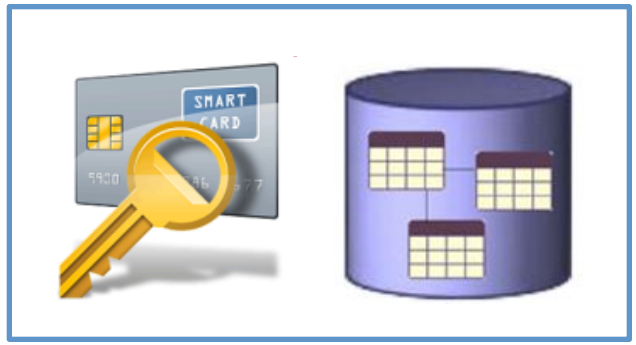
are declined in many **variants**



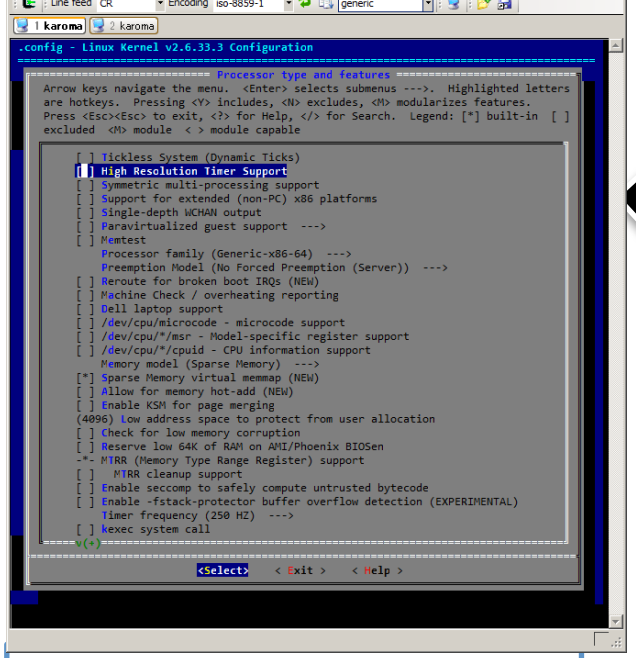
Software Product Lines

Car

Database Engine

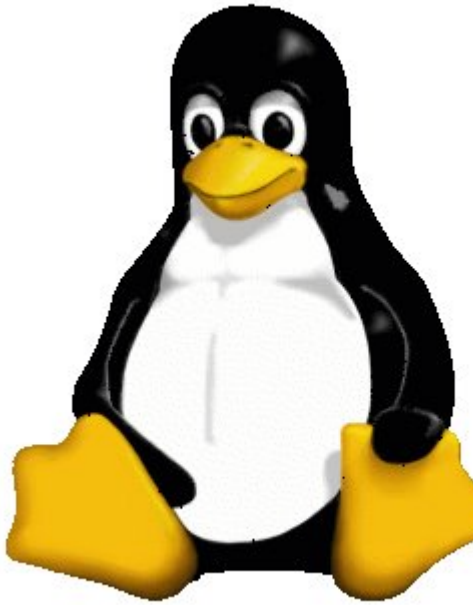


Printer Firmware

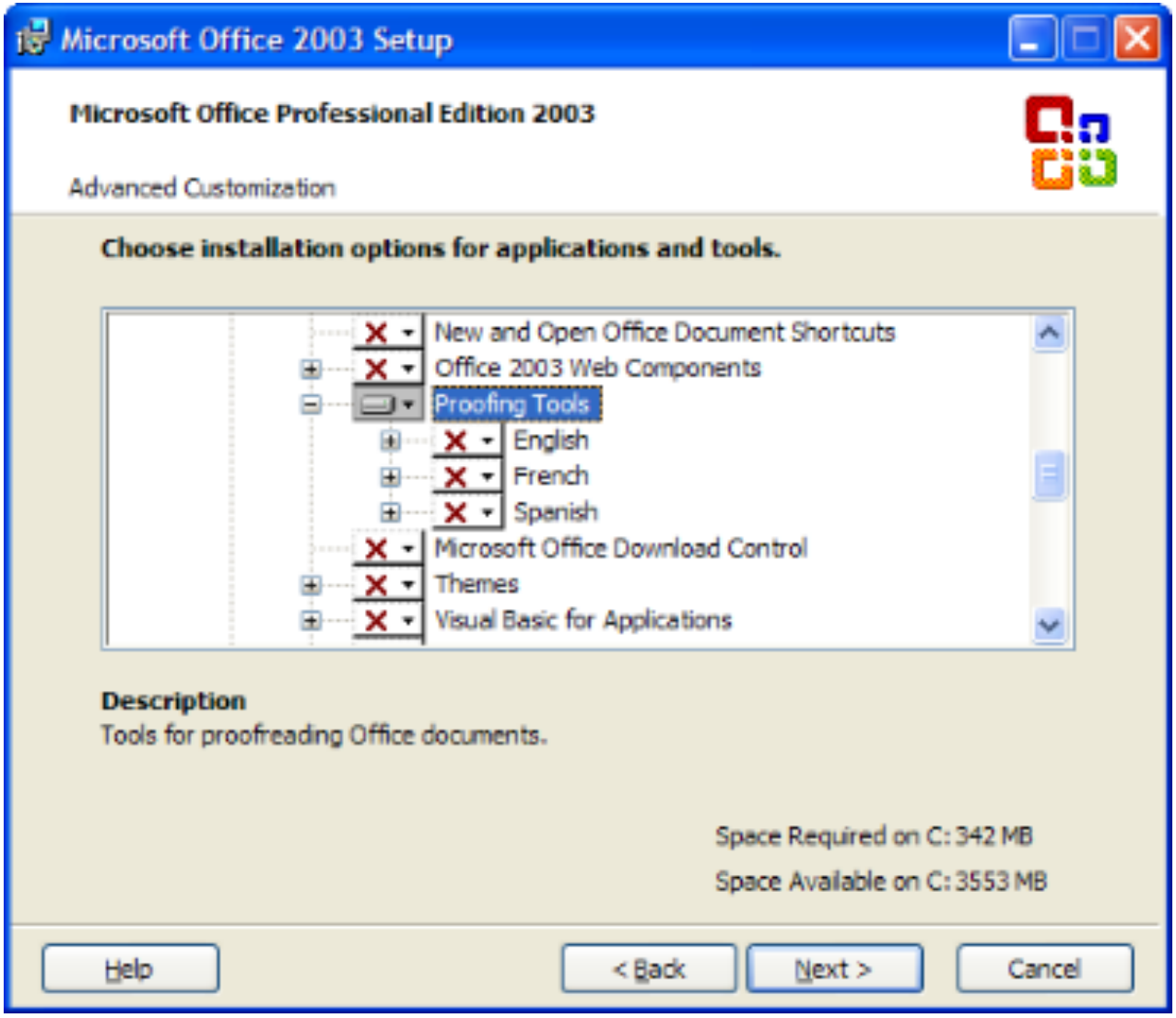


Linux Kernel

Linux-Kernel



Features in Microsoft Office



The development of a

family of software systems

is much more challenging than the development of

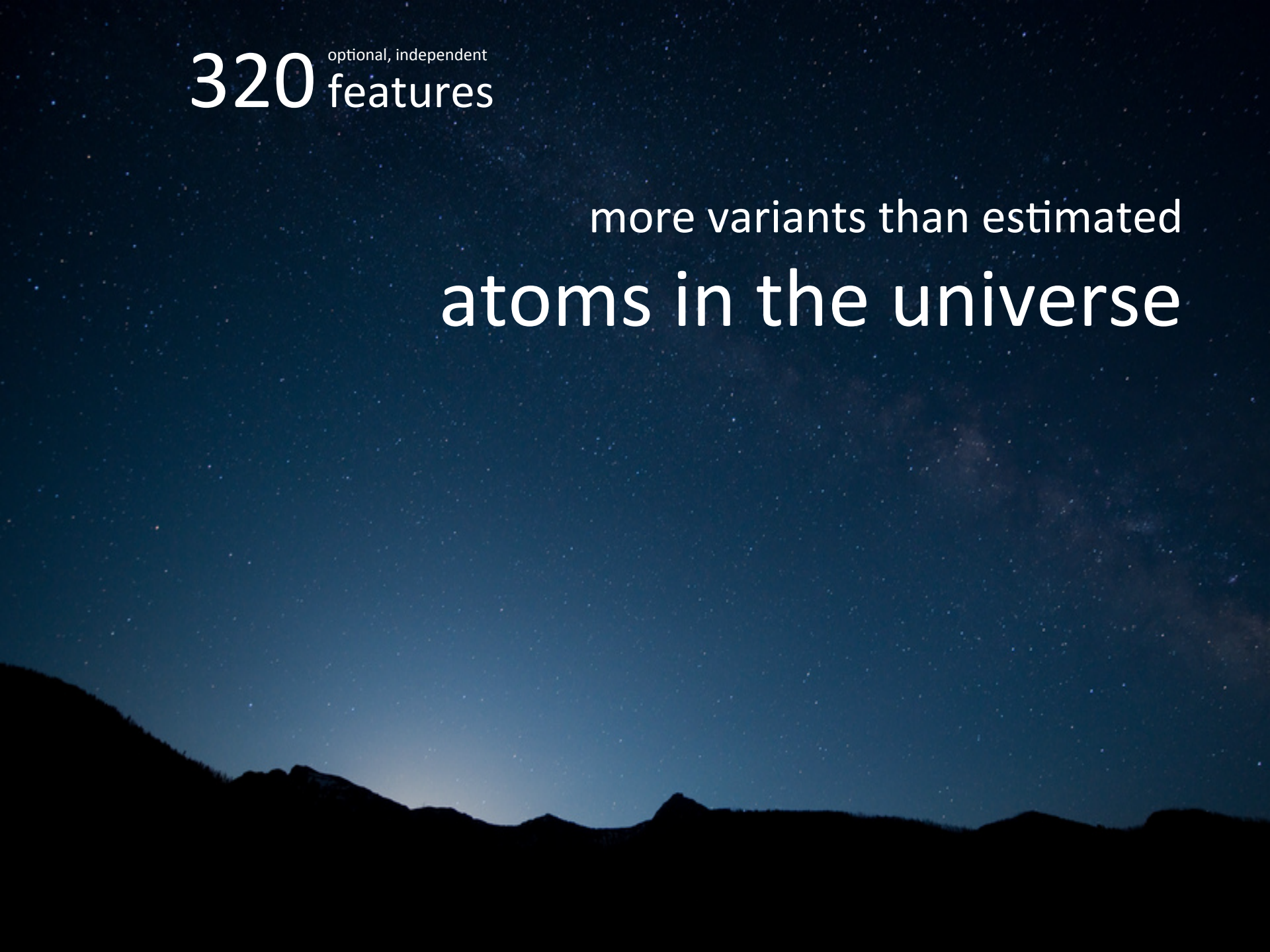
a single software system


Variability = Complexity

33 optional, independent features

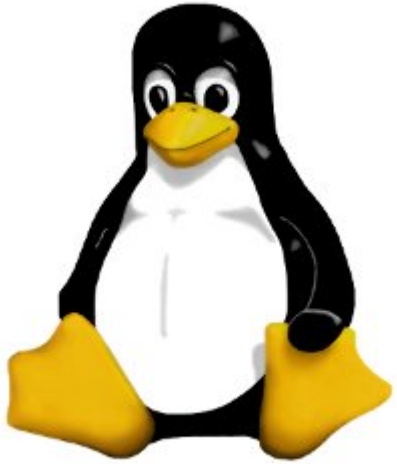
a unique variant for every

person on this planet

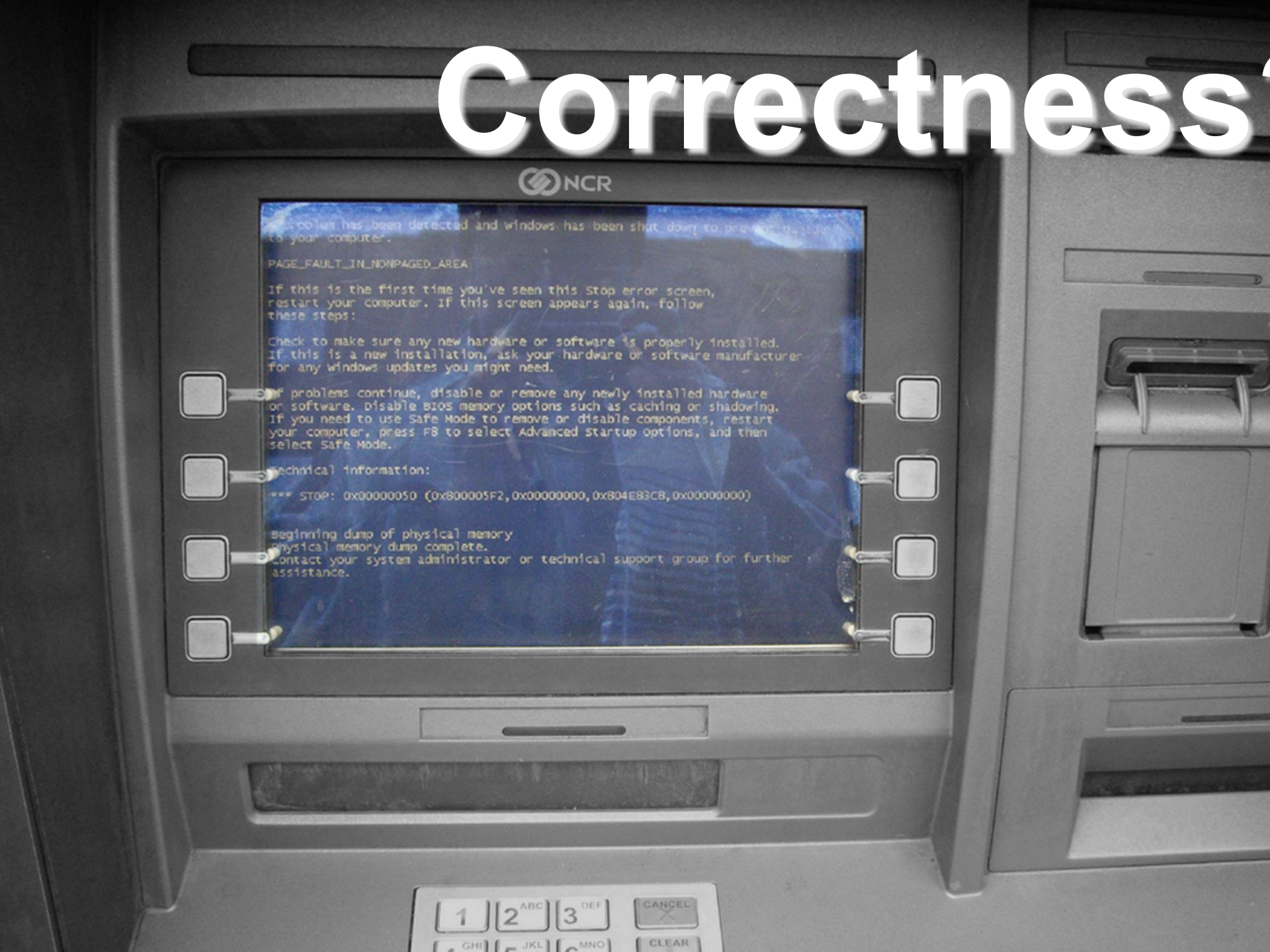

320 optional, independent features
more variants than estimated
atoms in the universe

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**

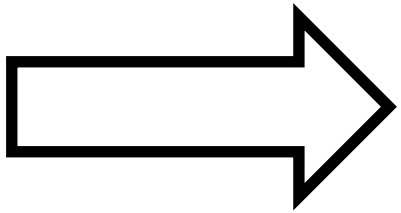
8000 Features

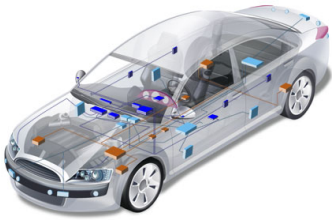
? Products

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

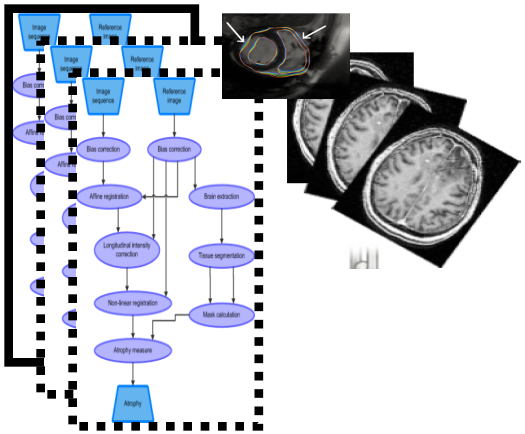
Reuse and Mass Customization

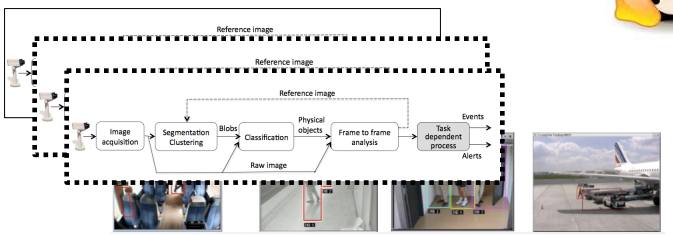

Starting from scratch?


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

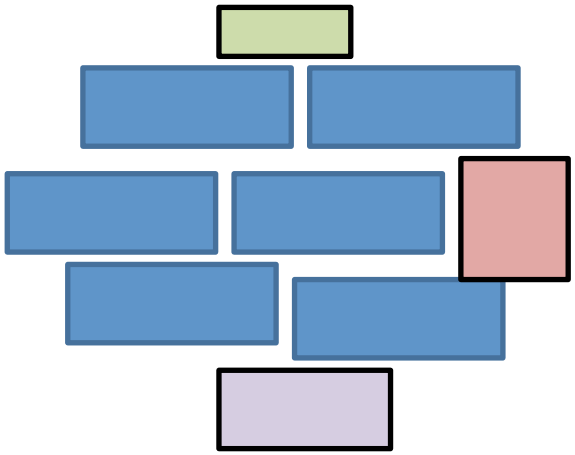




Software Product Line Engineering

Factoring out **commonalities**

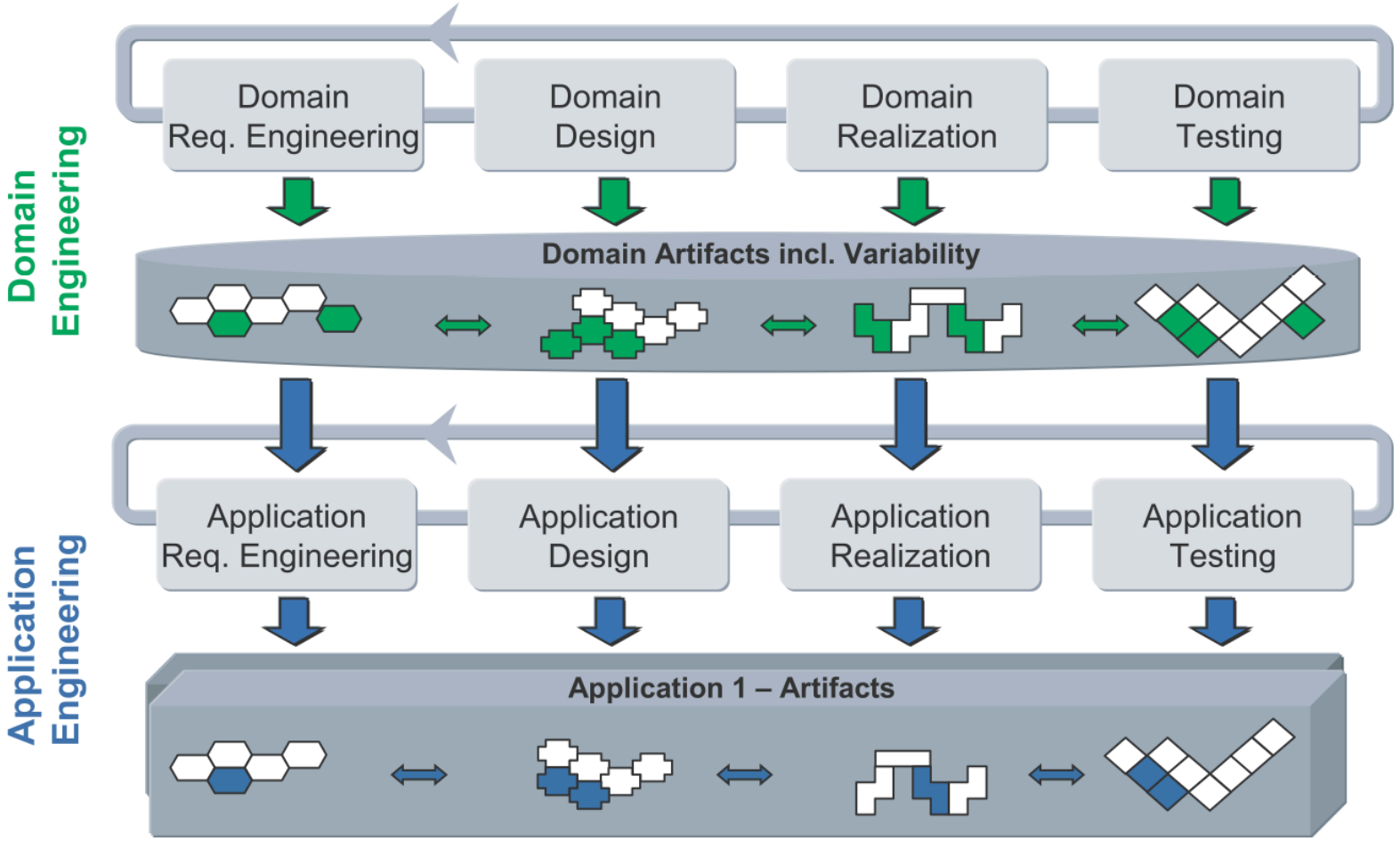
for **Reuse** [Krueger et al., 1992] [Jacobson et al., 1997]

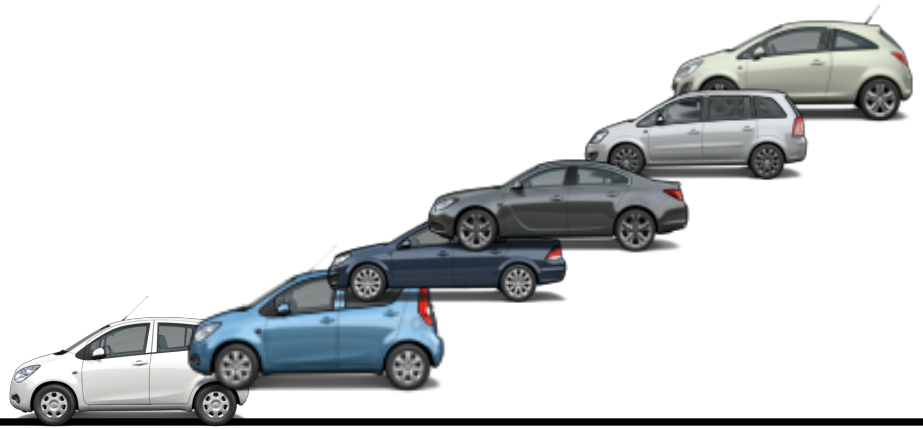


Managing **variabilities**

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

Software Product-Line Engineering





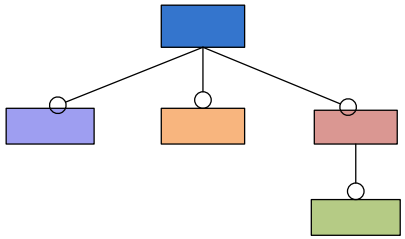
"Reuse-in-the-large works best in families of related systems, and thus is domain dependent." [Glass, 2001]

Domain engineering

Domain Analysis

(problem)

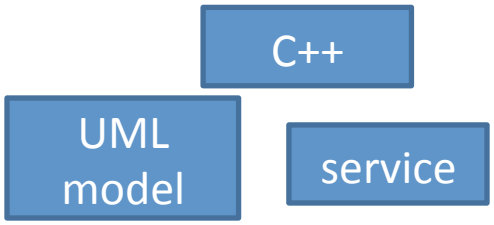
- elicitate requirements and scope the line
- variability modeling: determine commonalities and variabilities usually in terms of features



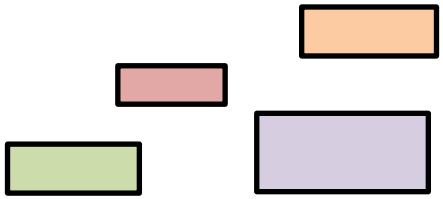
Variability Model (Feature Model)

Domain Implementation

(solution)



Common assets

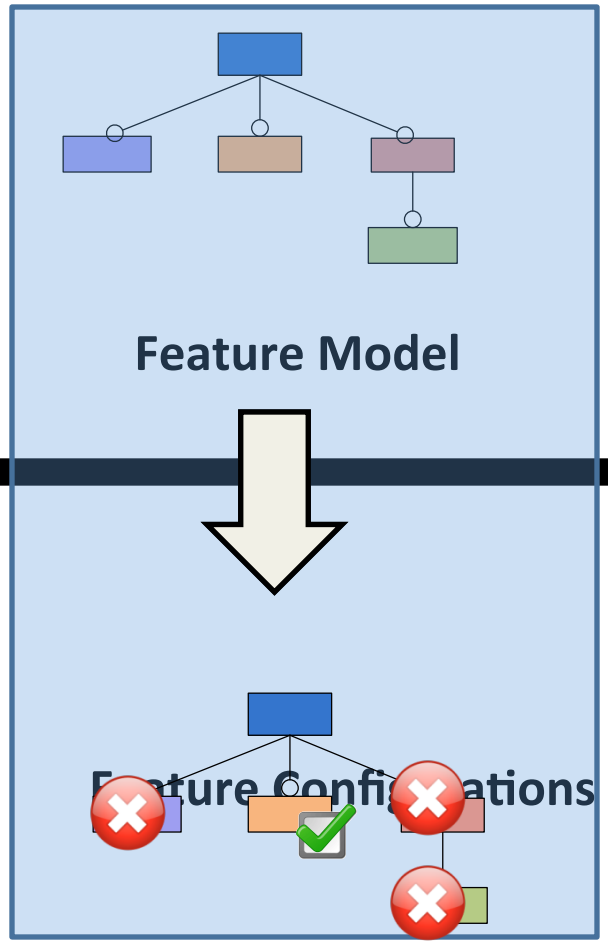


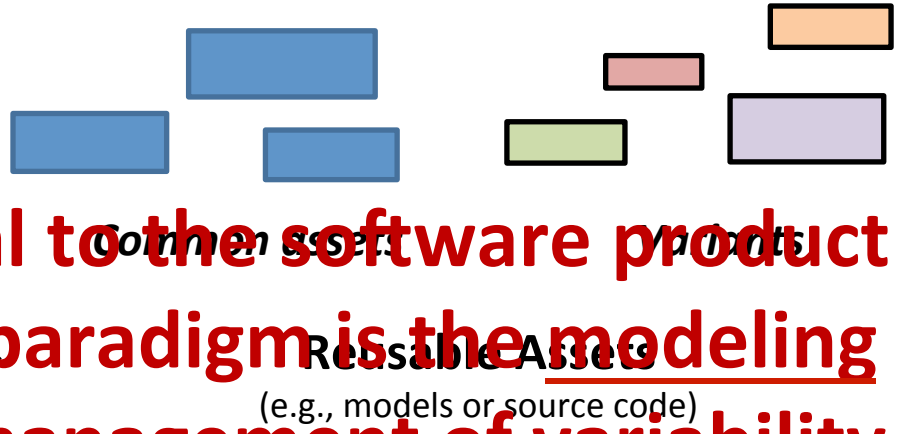
Variants

Reusable Assets

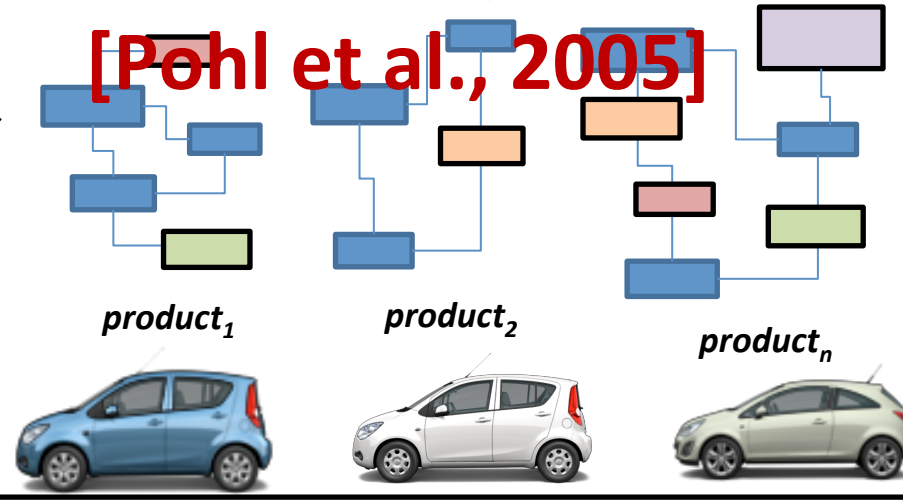
(e.g., models or source code)

Domain engineering (development for reuse)

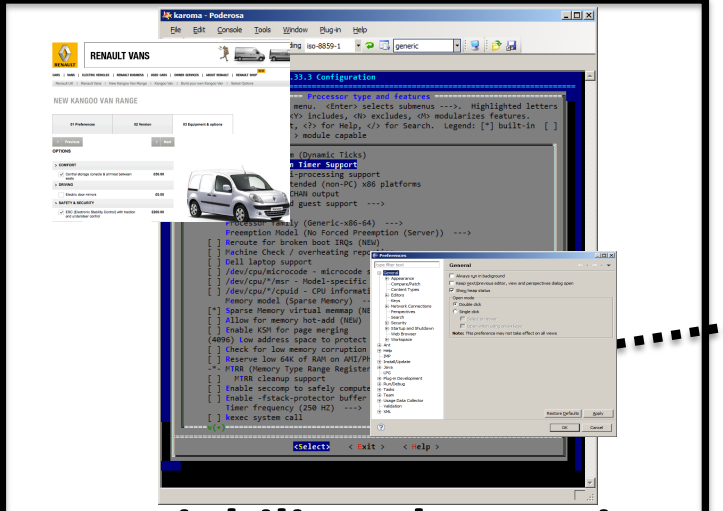




"central to the software product line paradigm is the modeling and management of variability, that is, the commonalities and differences in the applications" [Pohl et al., 2005]

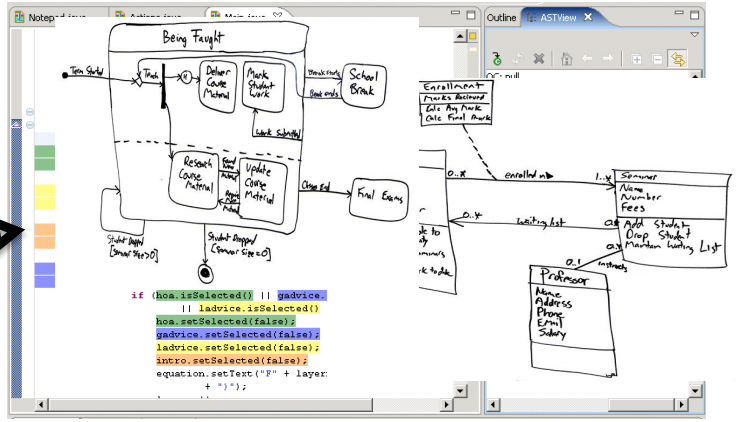


Application engineering (development with reuse)

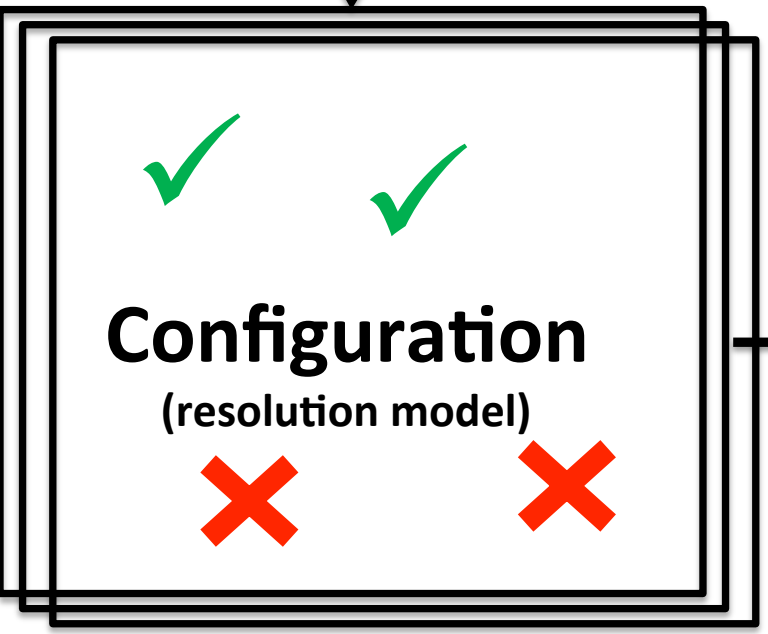


Variability Abstraction Model (VAM)

Variability Realization Model (VRM)



Domain Artefacts (e.g., models)



Configuration

(resolution model)

Software Generator

(derivation engine)

Software Product Line and Variability Engineering

A revisit of your cursus

What is new?

Family vs single systems

Focus on reuse

Domain engineering

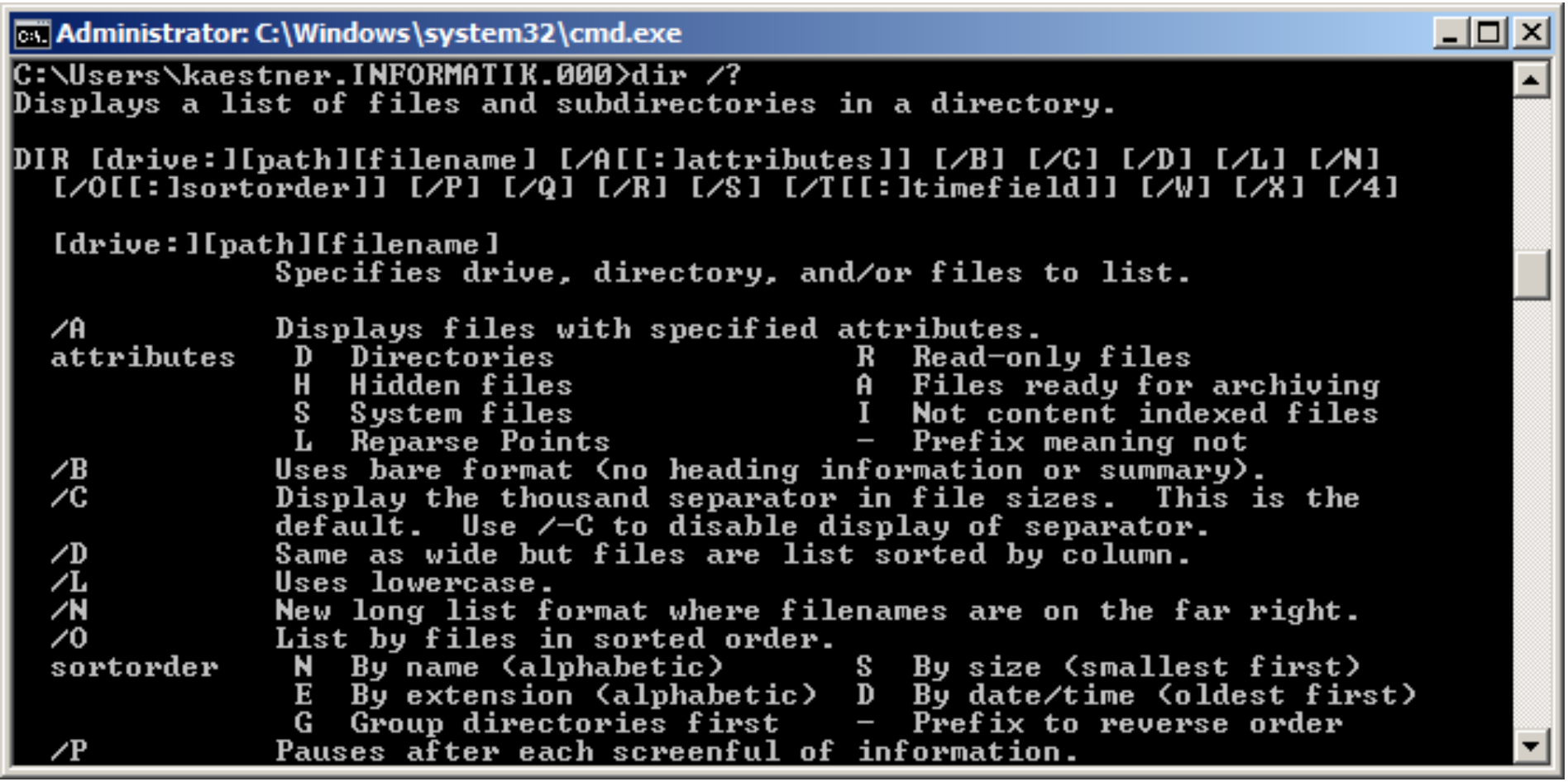
Factoring out commonality

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     }
```

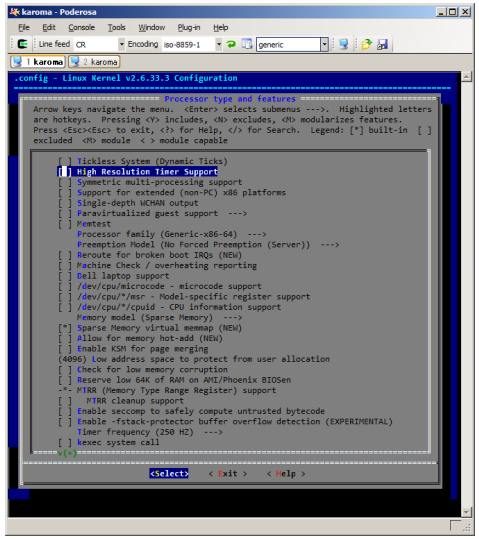
Global configuration

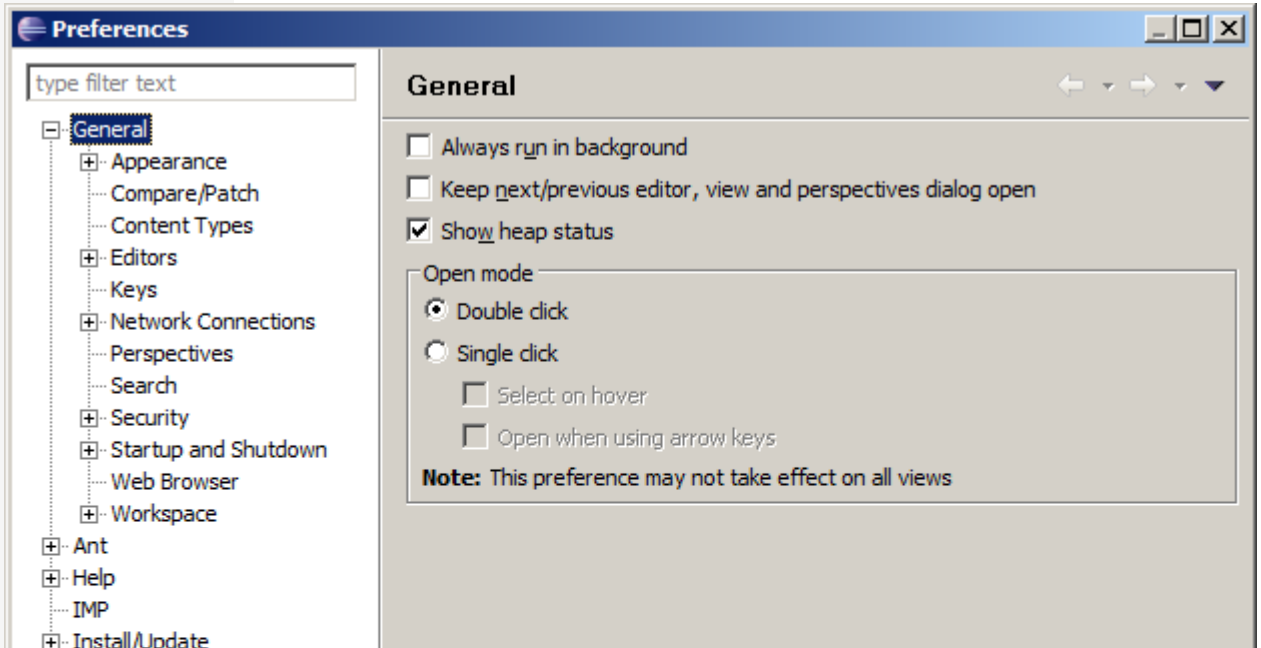
```
class Config {
  public static boolean isLogging = false;
  public static boolean isWindows = false;
  public static boolean isLinux = true;
}
class Main {
  public void foo() {
    if (isLogging)
      log(„running foo()“);
    if (isWindows)
      callWindowsMethod();
    else if (isLinux)
   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

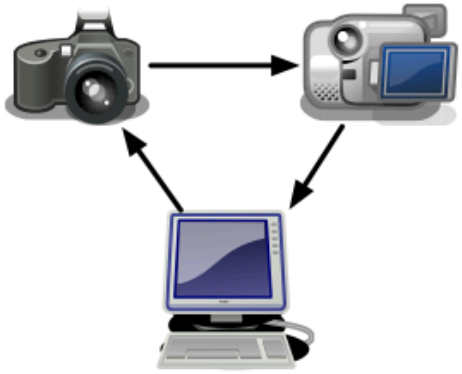
Clone existing code and fix low level platform interaction

+ 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

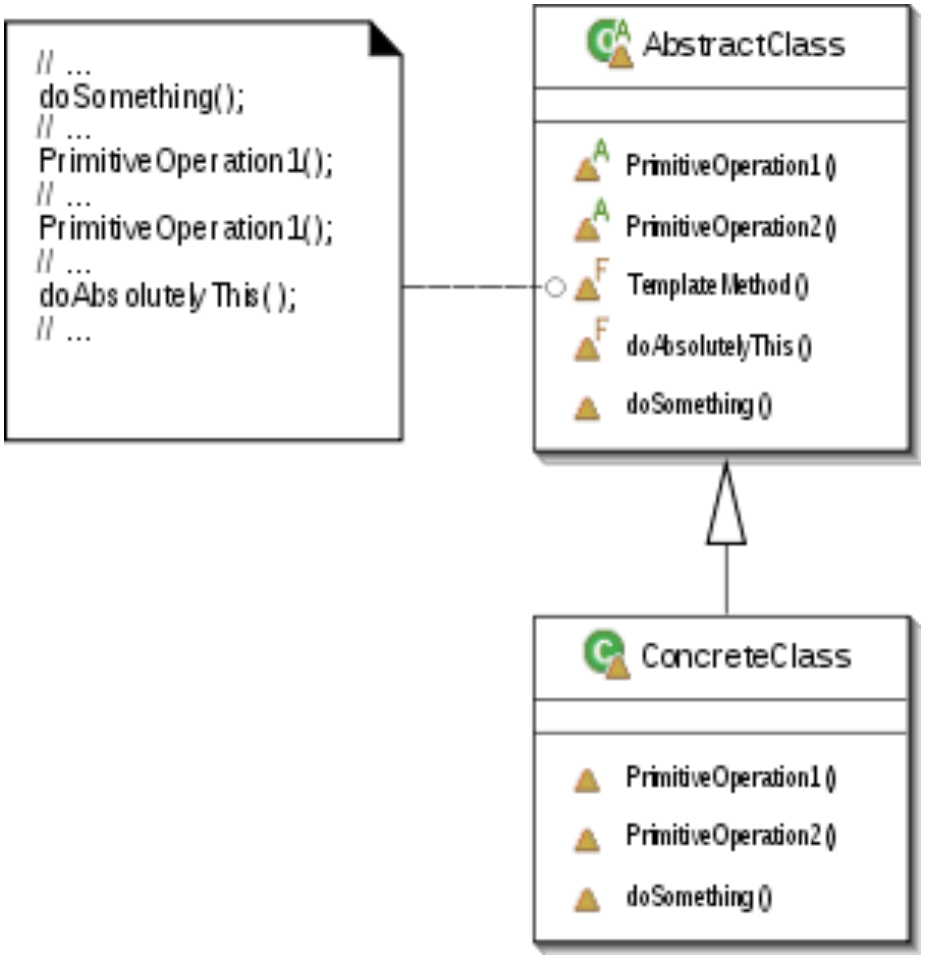
Factory

Strategy

Decorator

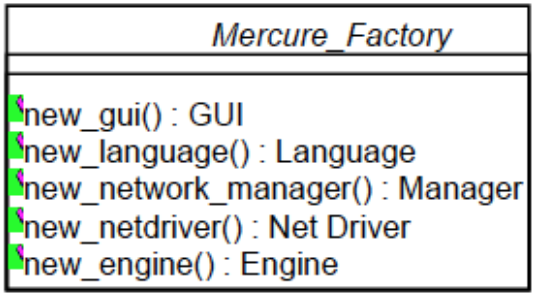
....

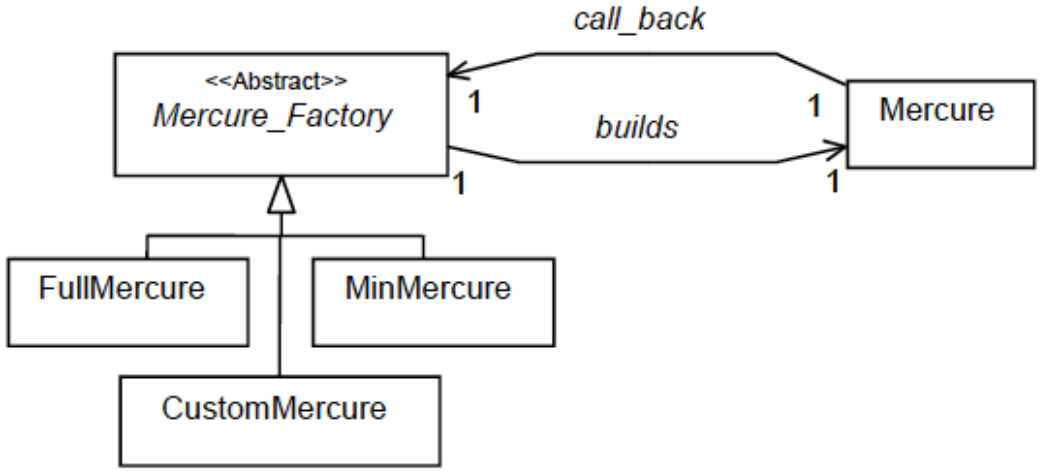
Template Method

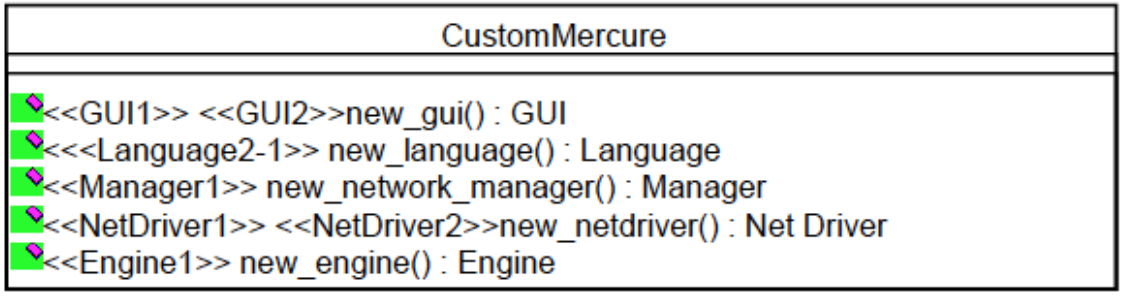


The decision model

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







API

Framework

Plugin-based systems

(Active) Annotations

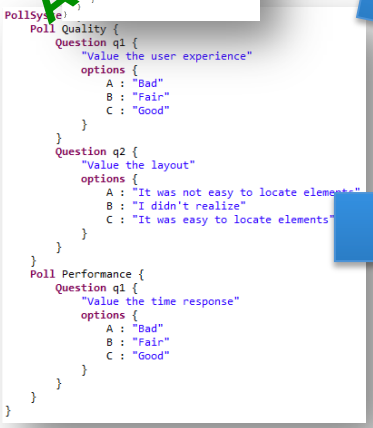
can have parameters

Metamodeling and Domain-Specific Languages

Commonalities

TP 3

Another DSL



```
PollSystem
    Poll Quality {
        Question q1 {
            "Value the user experience"
            options {
                A : "Bad"
                B : "Fair"
                C : "Good"
            }
        }
        Question q2 {
            "Value the layout"
            options {
                A : "It was not easy to locate elements"
                B : "I didn't realize"
                C : "It was easy to locate elements"
            }
        }
    }
    Poll Performance {
        Question q1 {
            "Value the time response"
            options {
                A : "Bad"
                B : "Fair"
                C : "Good"
            }
        }
    }
}
```

Questionnaire.xtext

TP 2

Model-to-Model

TP 4

Pivot MM

TP 3

UI model

Generator

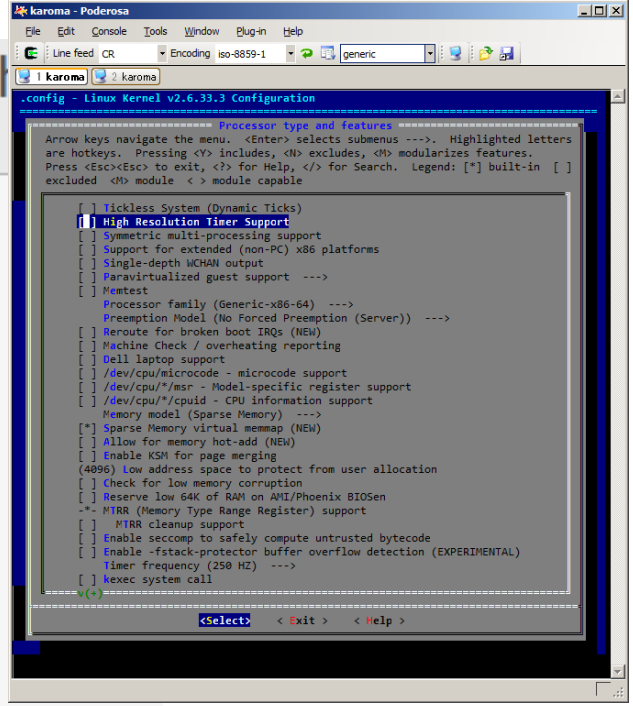
TP 5

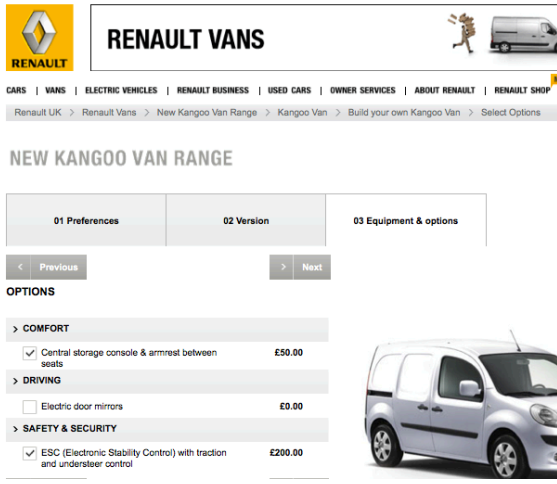
Model-to-Text

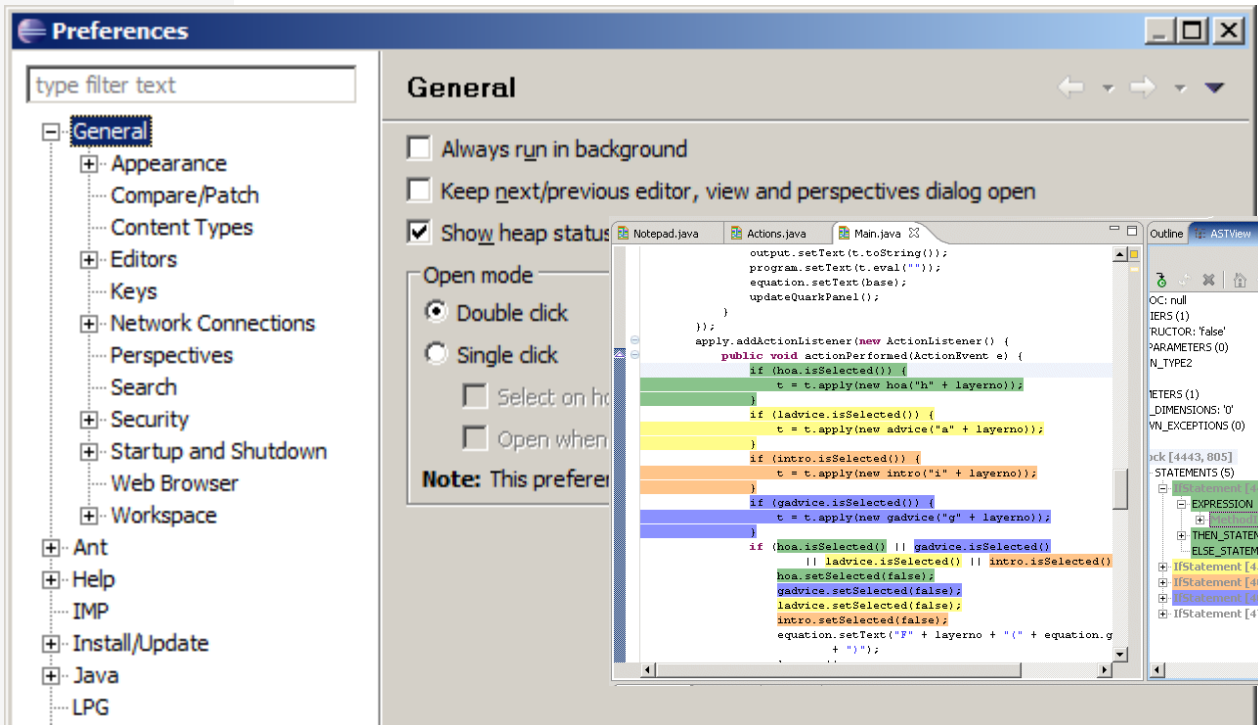
httpd.conf -- win32 Apach

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>
```



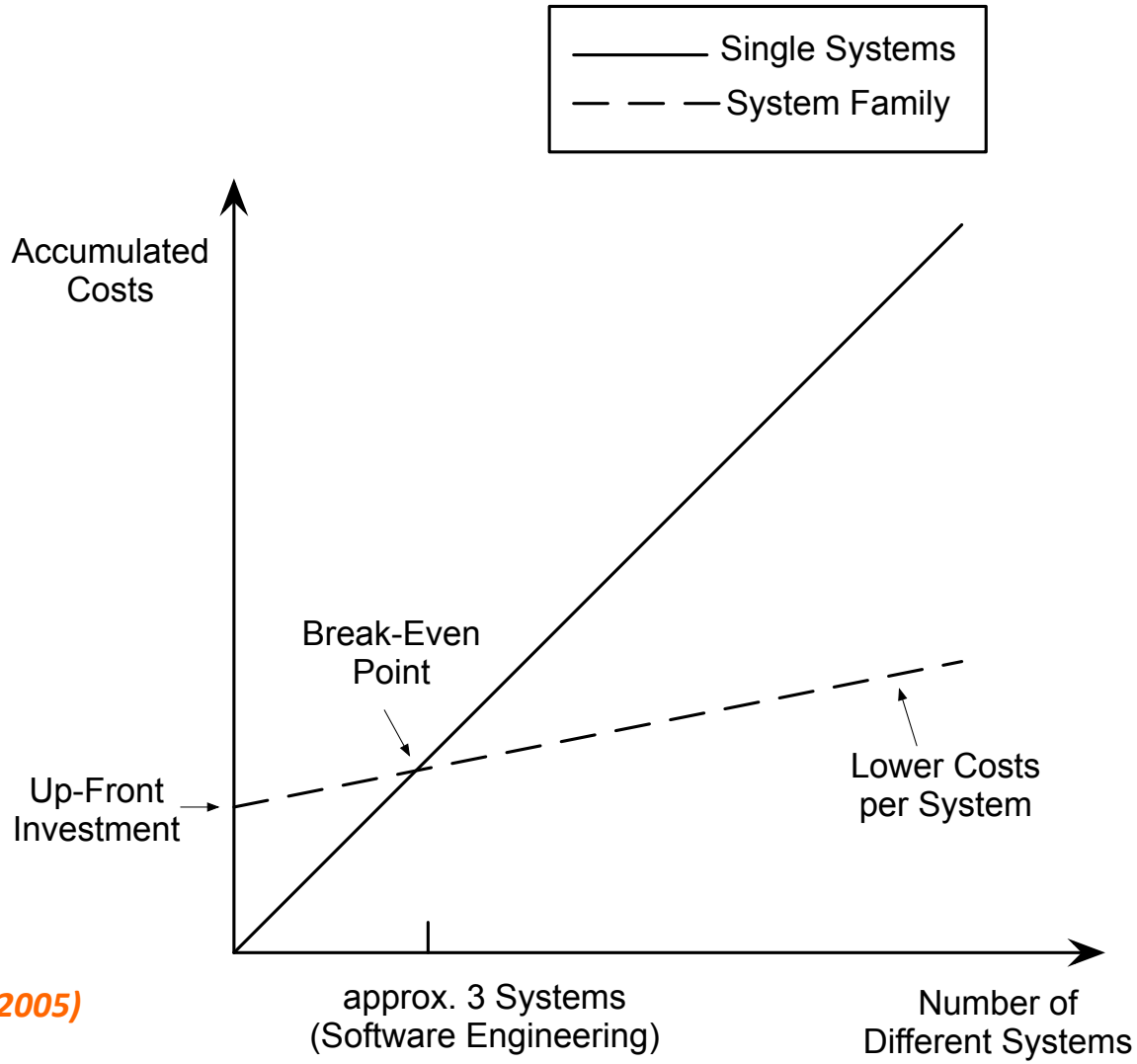




The specificity of

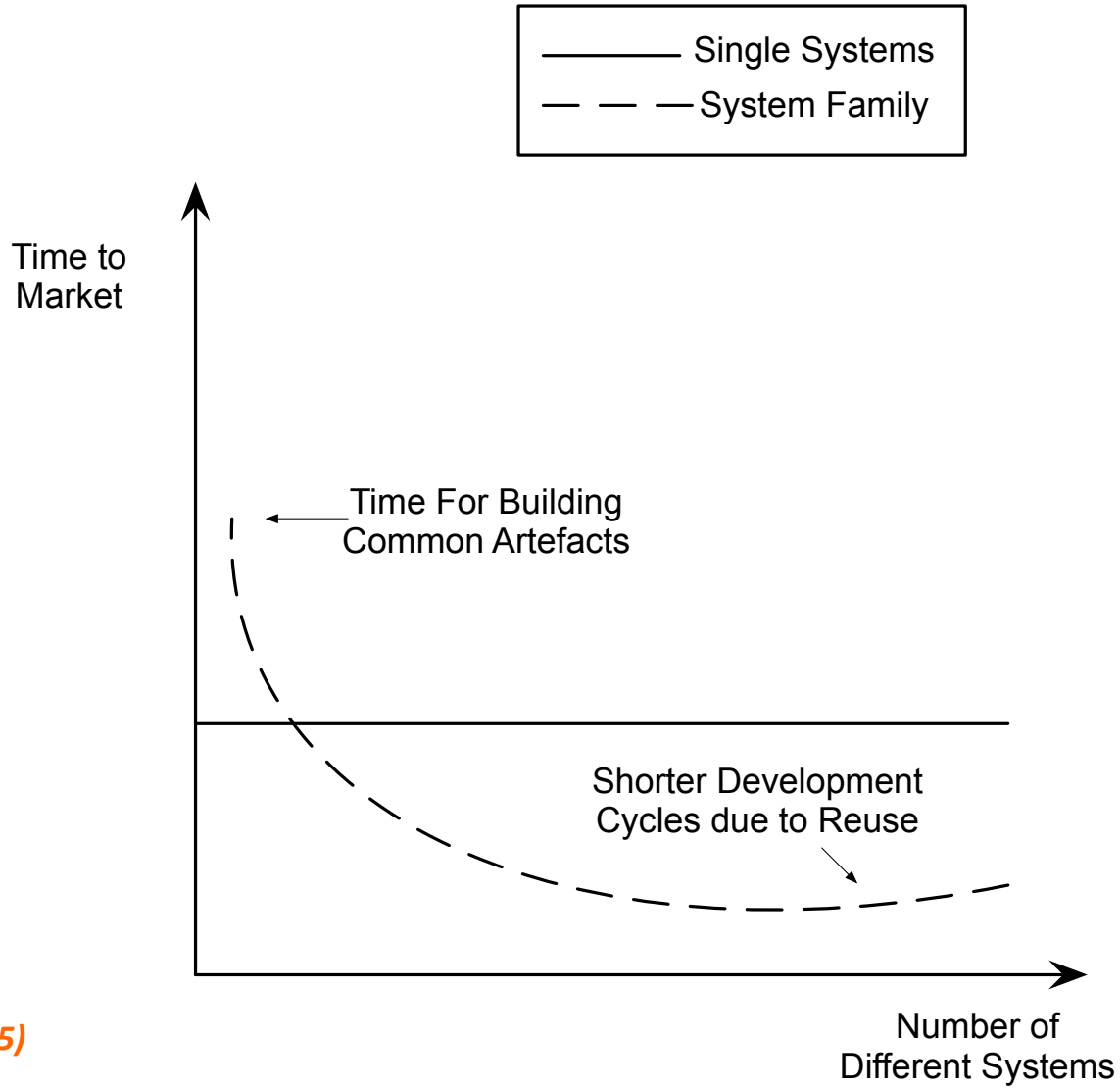
Software Product Line Engineering

Promises of Software Product Line Engineering



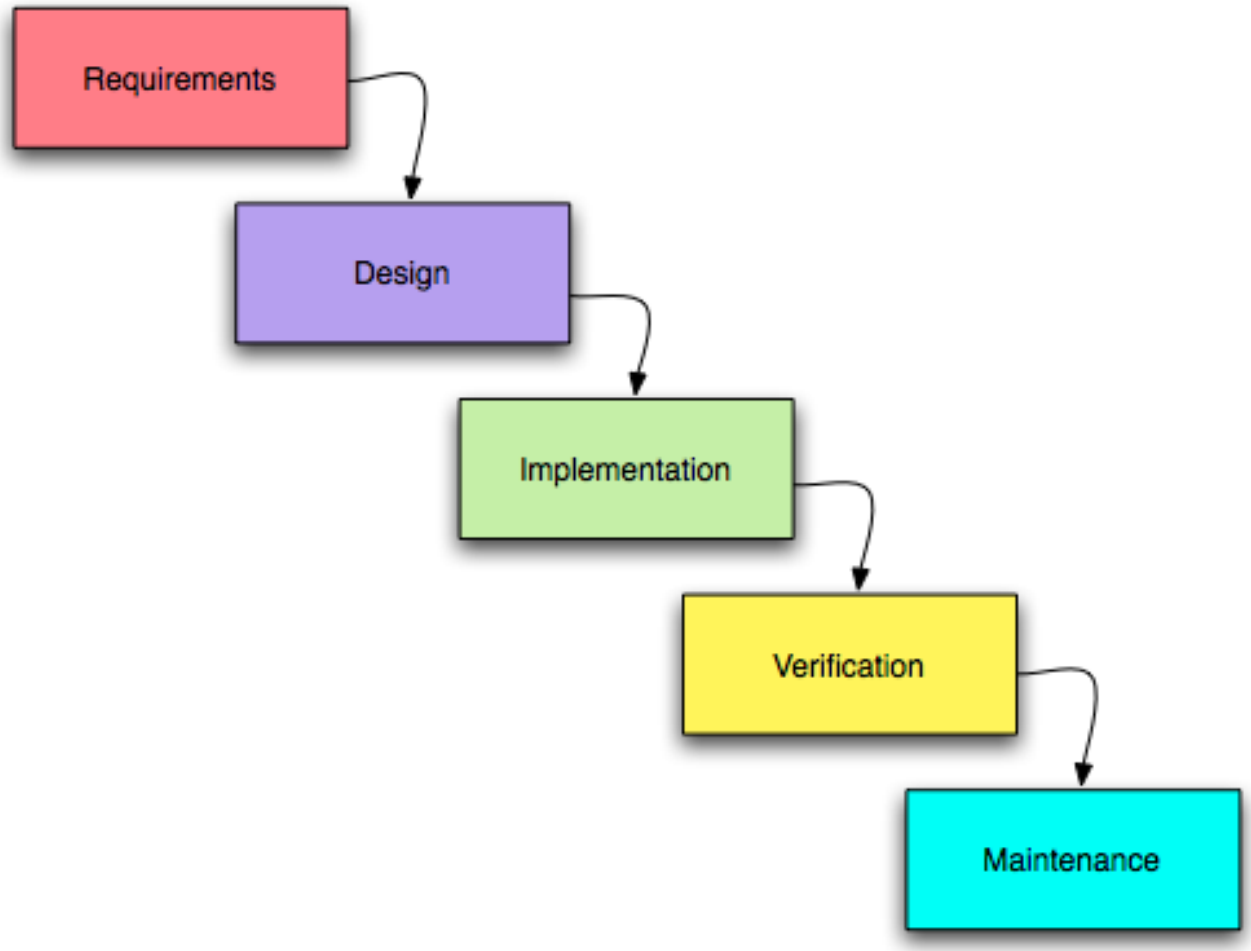
Klaus Pohl (2005)

Promises of Software Product Line Engineering

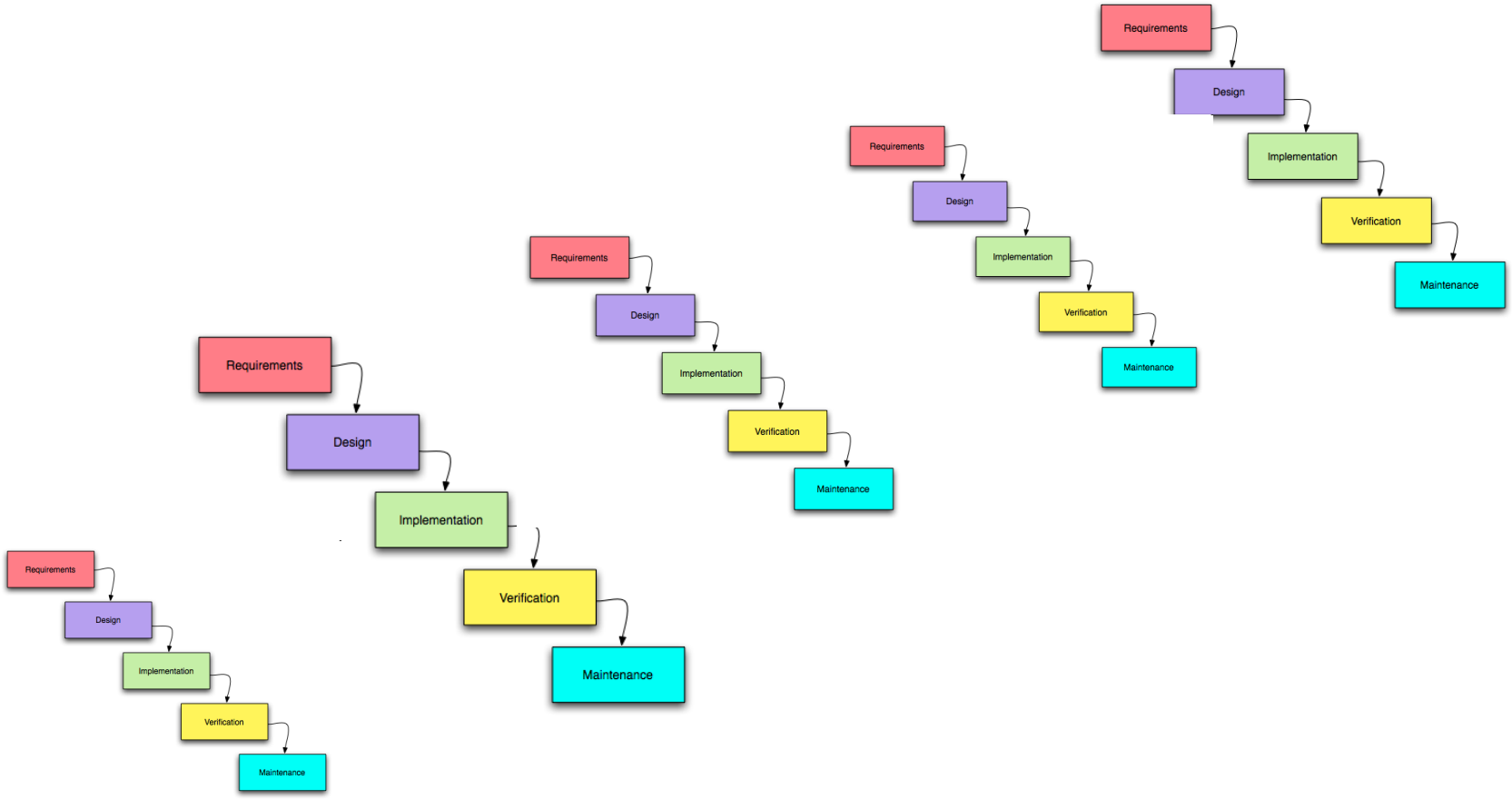


Klaus Pohl (2005)

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

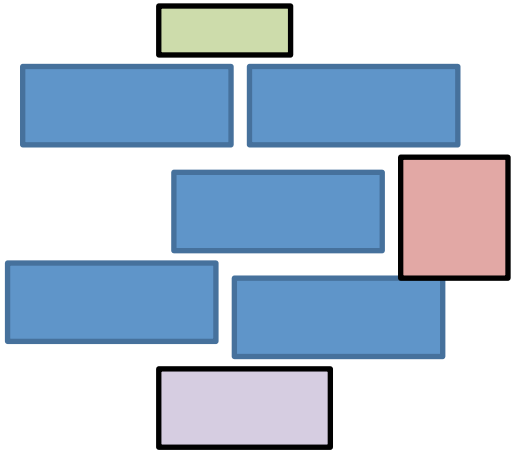
~=

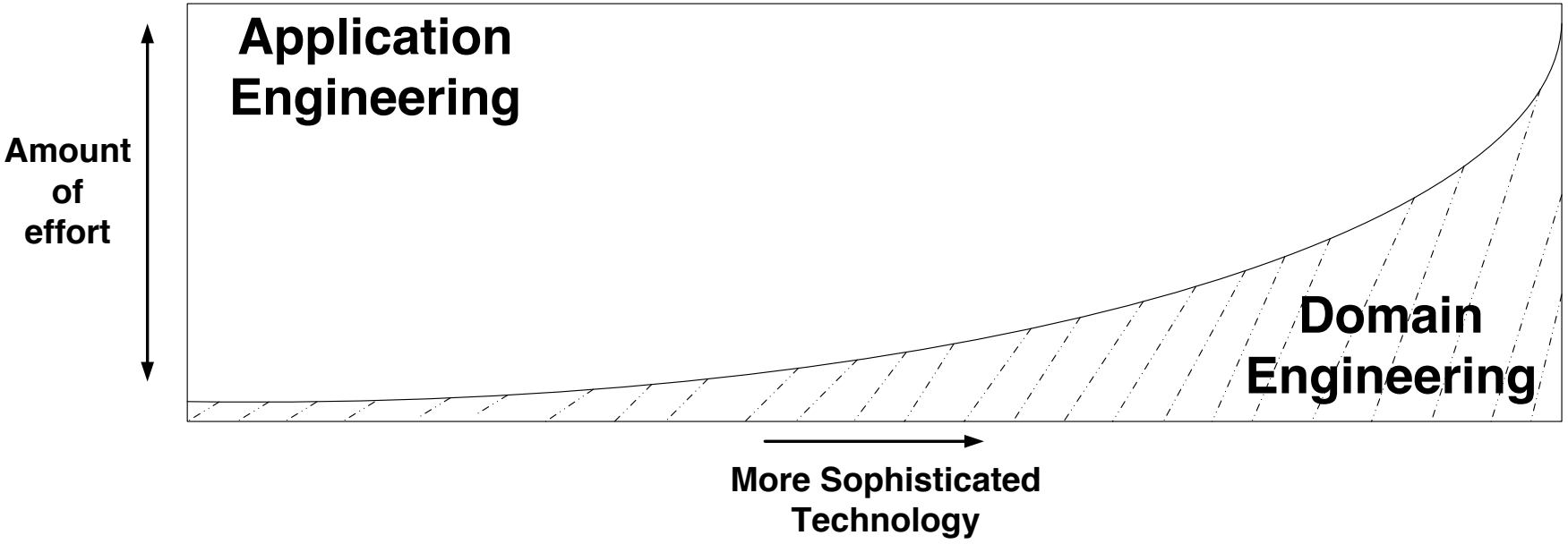
Product Line Engineering

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



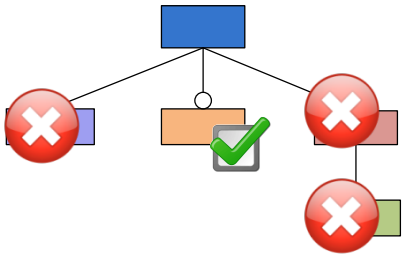


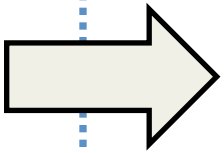
99% domain engineering,

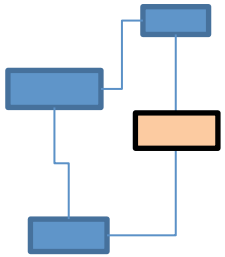
1% application engineering?

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

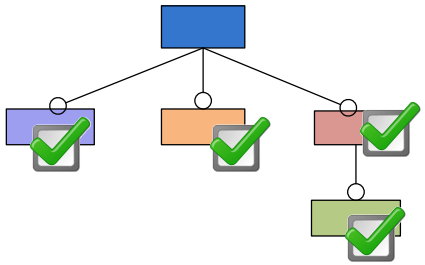
Specific requirements

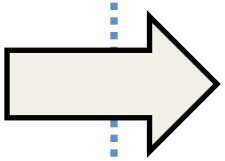


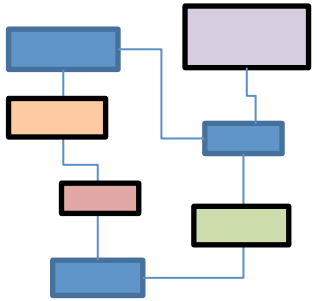




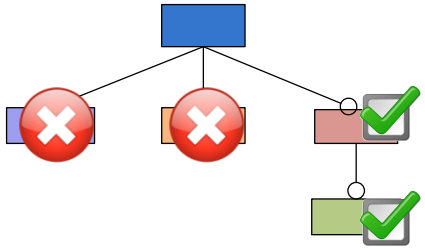
$product_2$

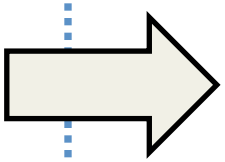


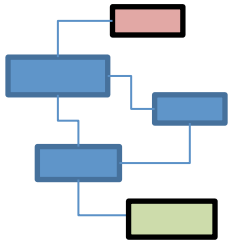




$product_n$

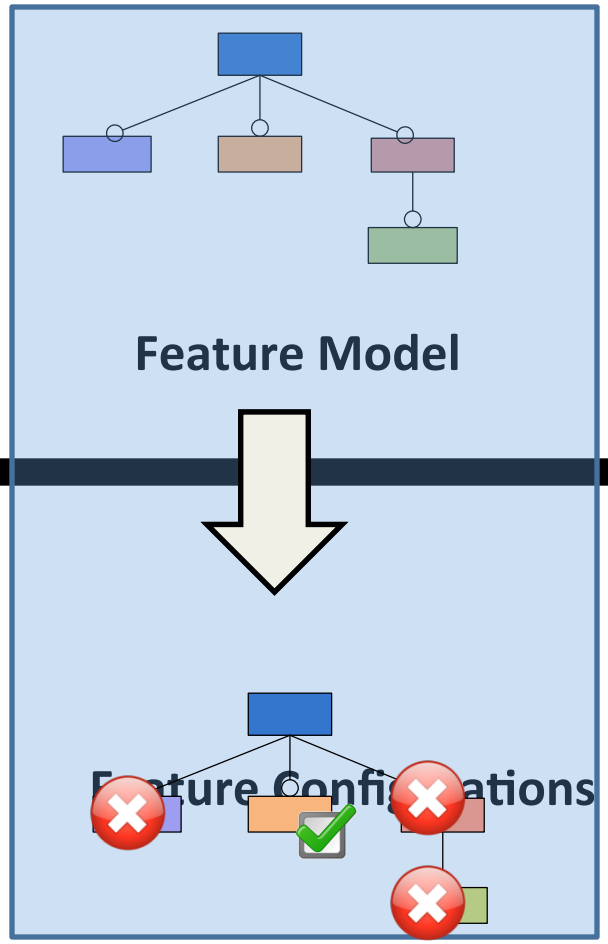


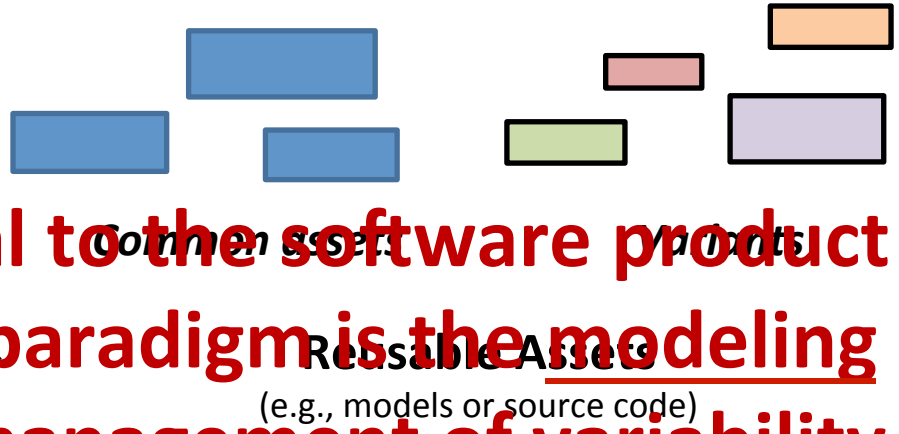




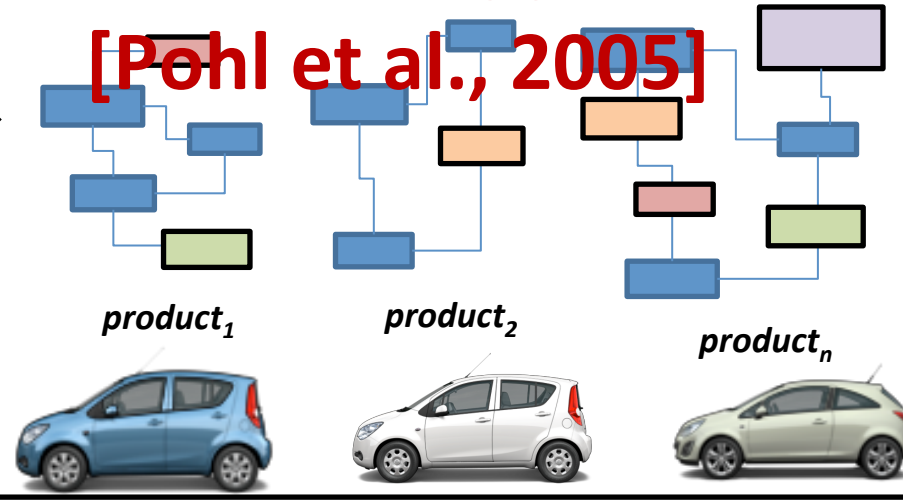
$product_1$

Domain engineering (development for reuse)



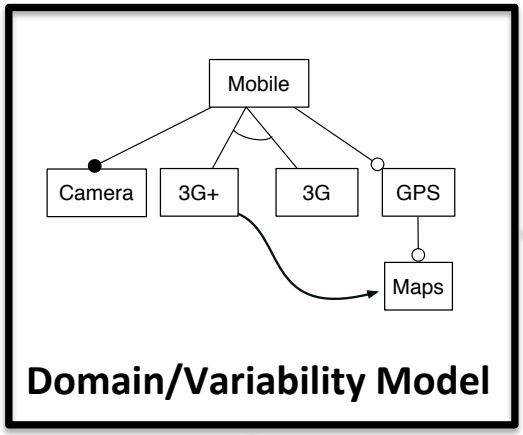


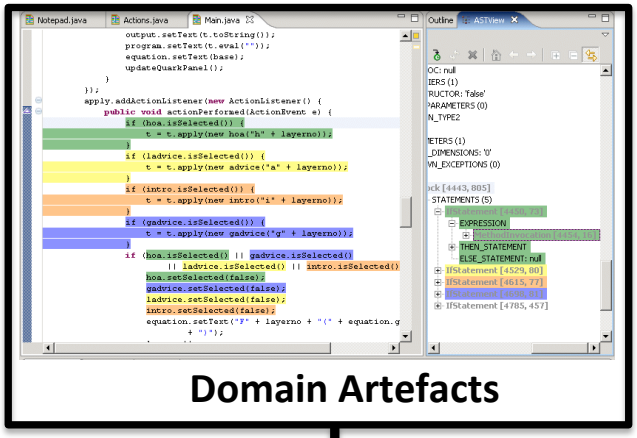
"central to the software product line paradigm is the modeling and management of variability, that is, the commonalities and differences in the applications" [Pohl et al., 2005]



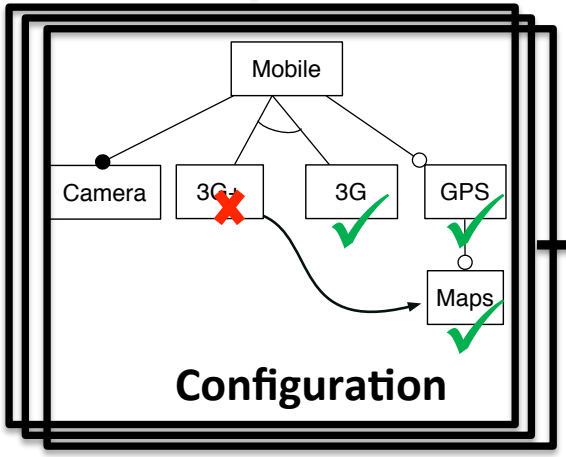
Application engineering (development with reuse)

Domain Engineering





Application Engineering

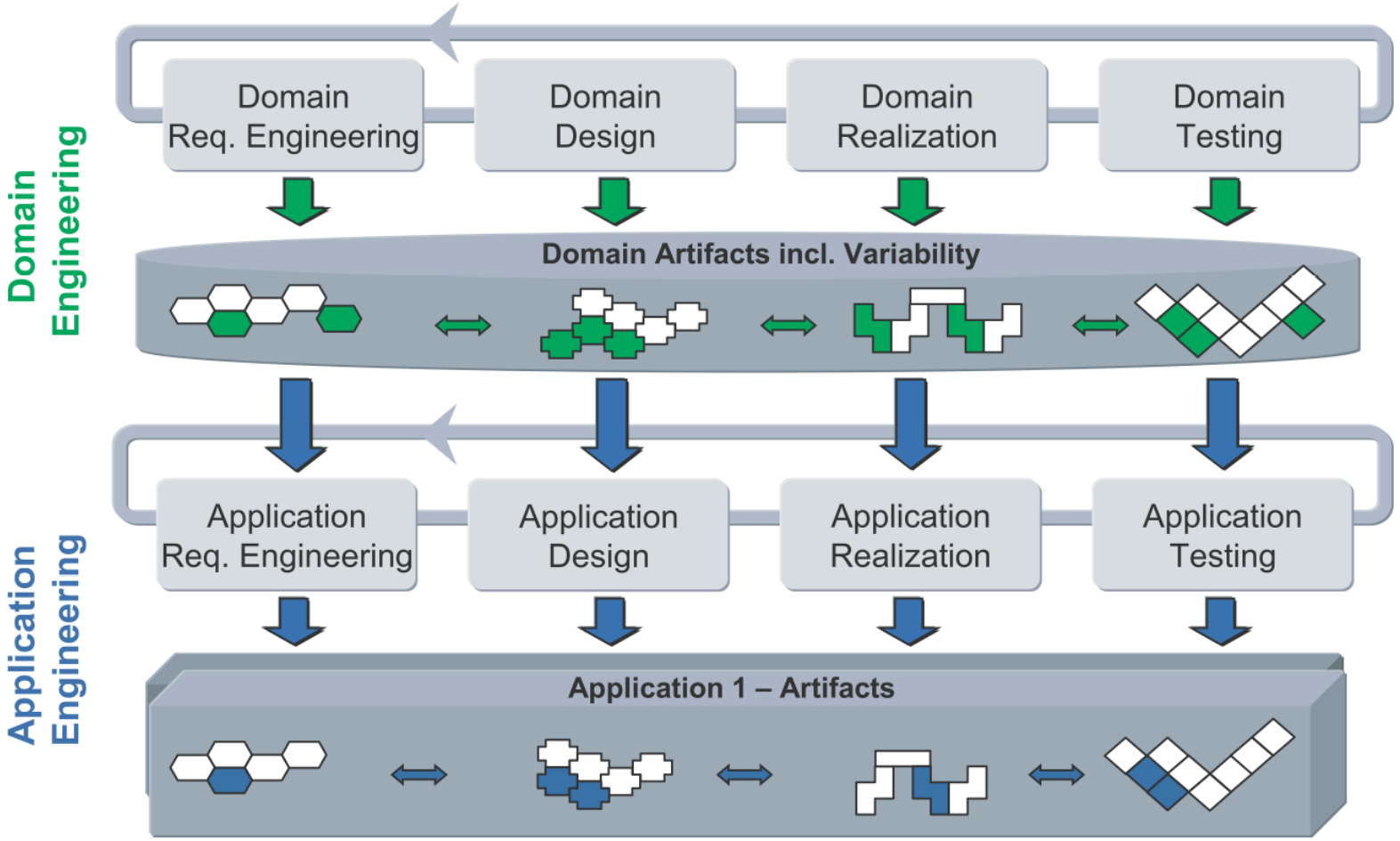


*« the investments required to develop the reusable artifacts during **domain engineering**, are outweighed by the benefits of deriving the individual products during **application engineering** »*

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

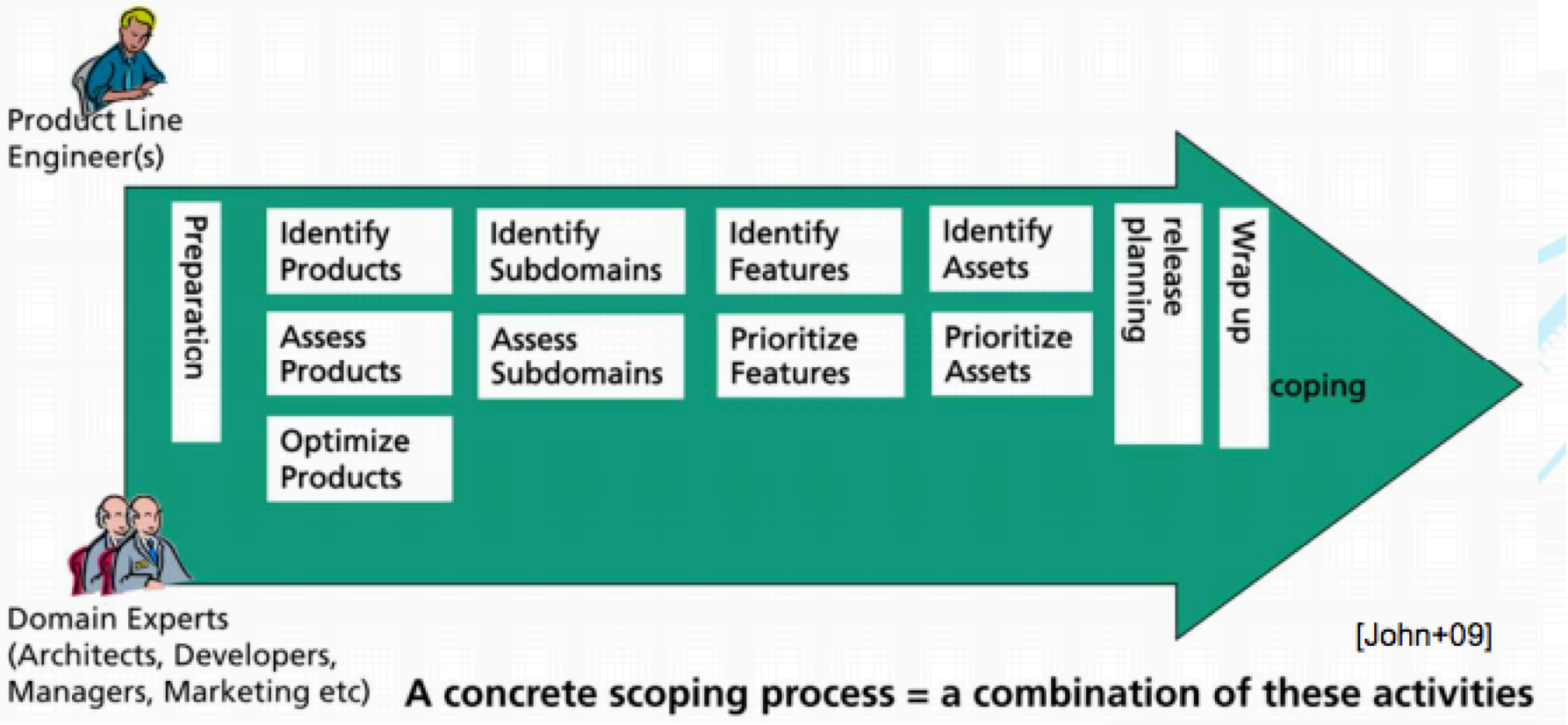
- Analysis of similarity
  - Analyze similarities between entities, activities, events, relationships, structures, etc.
- Analysis of variations
  - Analyze variations between entities, activities, events, relationships, structures, etc.

- Clustering
- Abstraction
- Classification
- Generalization
- Vocabulary construction


Unused flexibility

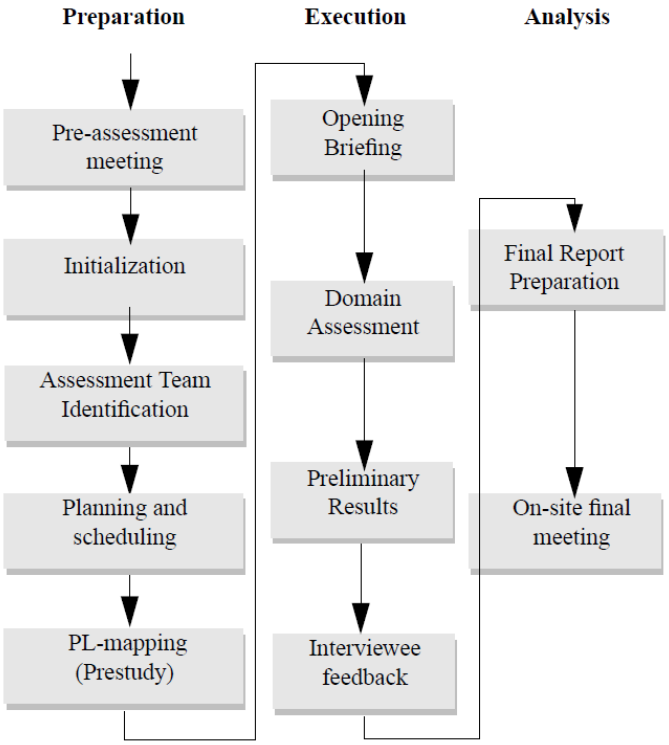

Illegal variant

Scoping Activities



A concrete scoping process = a combination of these activities

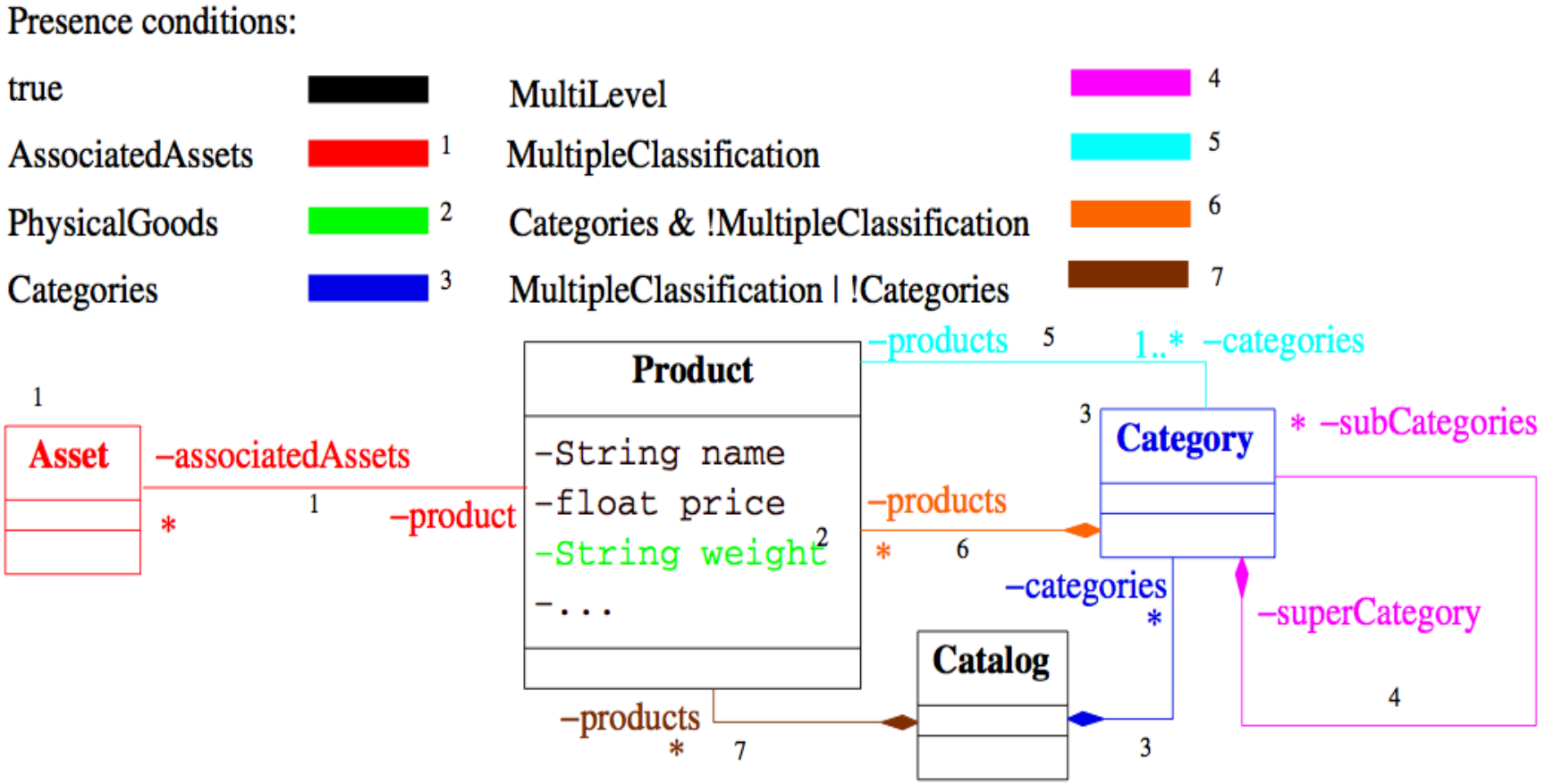
Domain/Product Line Scoping



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

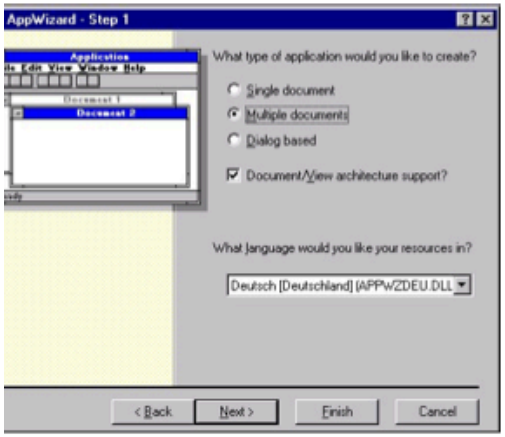
Domain Design



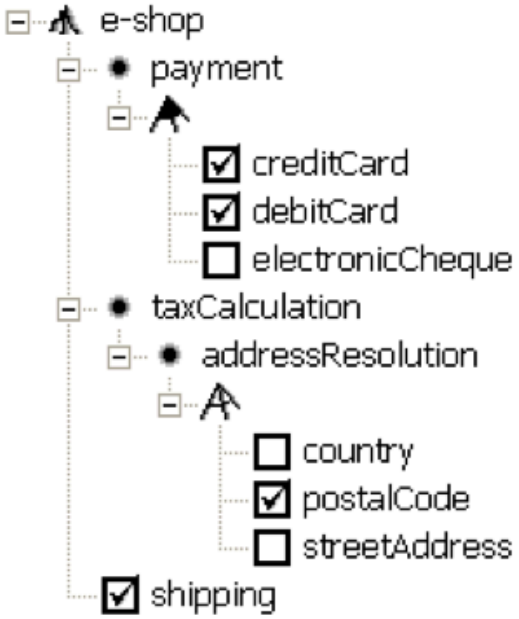
Czarnecki et al. (GPCE'05)

Czarnecki et al. (2005) DSLs for customizing

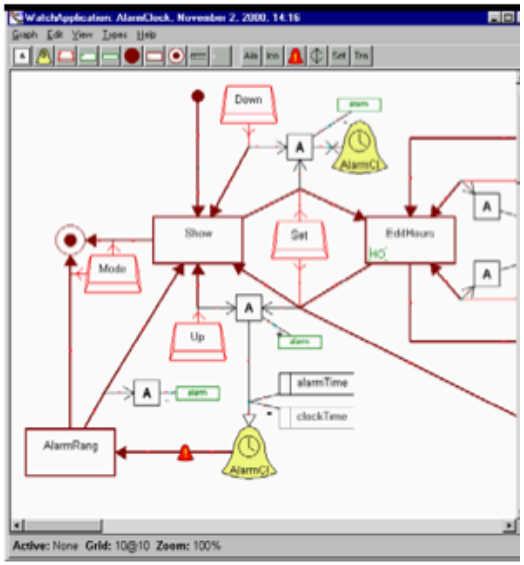
Routine configuration ⟷ *Creative construction*



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

```
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() { ... } }
```

Kastner's slide

Mapping: an example

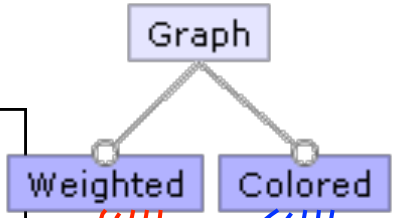
```
class Graph {
  Vector nv = new Vector(); Vector ev = new Vector();
  Edge add(Node n, Node m) {
    Edge e = new Edge(n, m);
    nv.add(n); nv.add(m); ev.add(e);
    e.weight = new Weight();
    return e;
  }
  Edge add(Node n, Node m, Weight w)
    Edge e = new Edge(n, m);
    nv.add(n); nv.add(m); 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]*/
  }
}
```

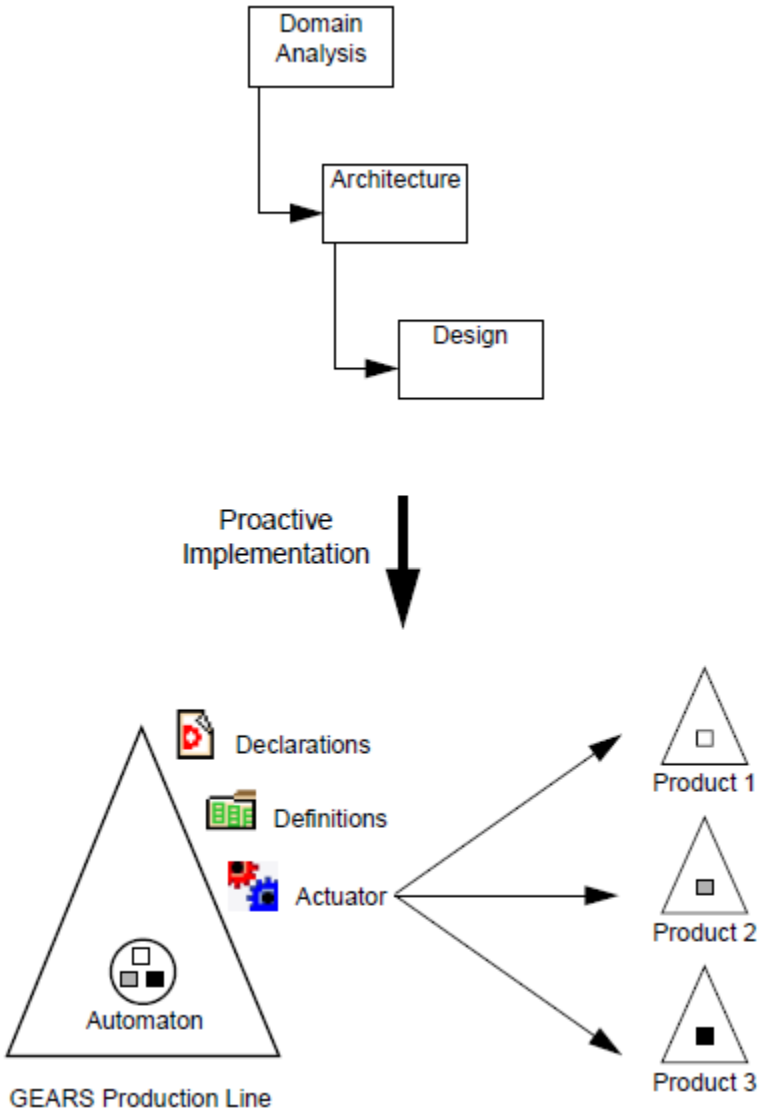
```
/*if[COLOR]*/
class Color {
  static void setDisplayColor(Color c) { ... }
}
/*end[COLOR]*/
```

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

Adoption and Strategies

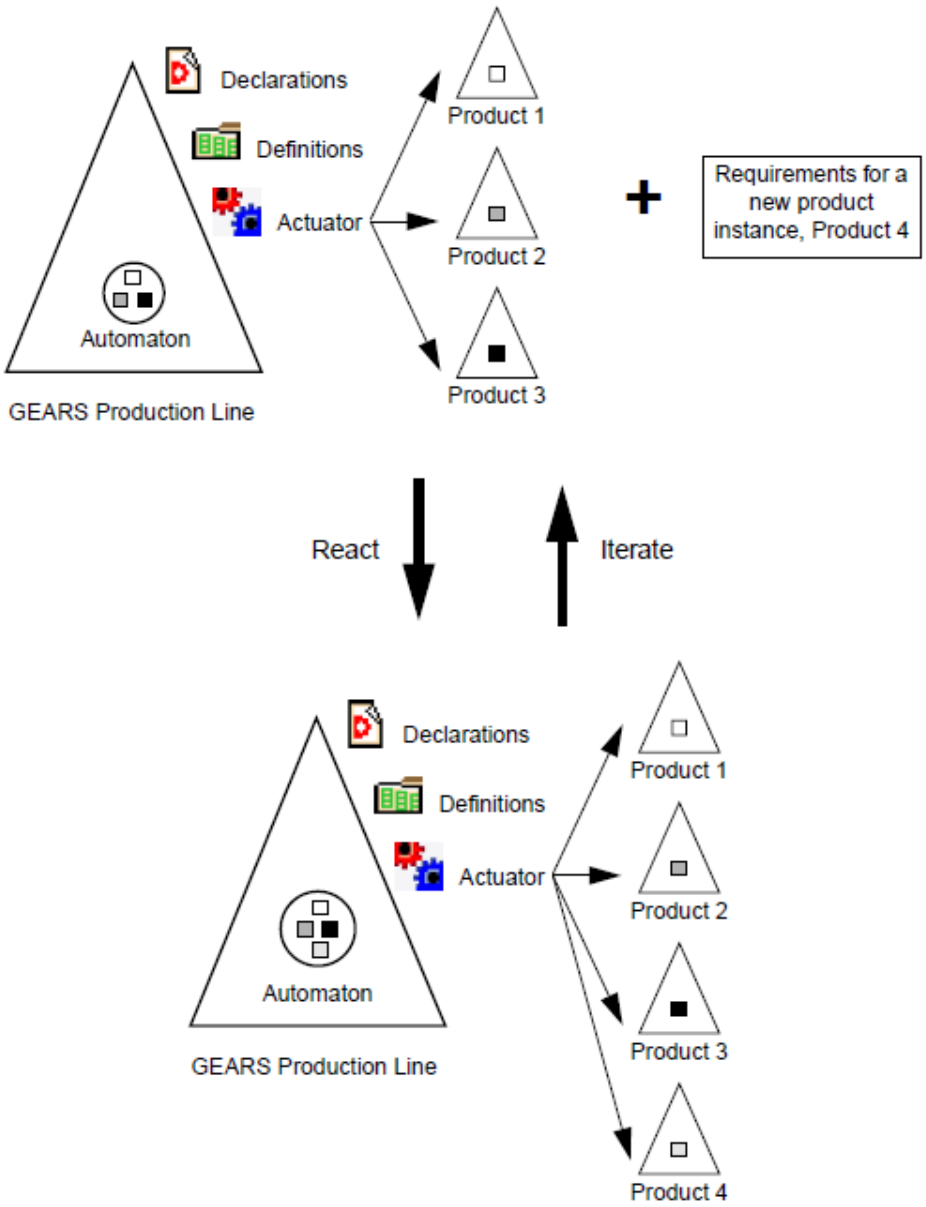
- **Proactive (starting from scratch)**
- **Extractive (re-engineering, from products to product line)**
- **Reactive (hybrid)**

Proactive



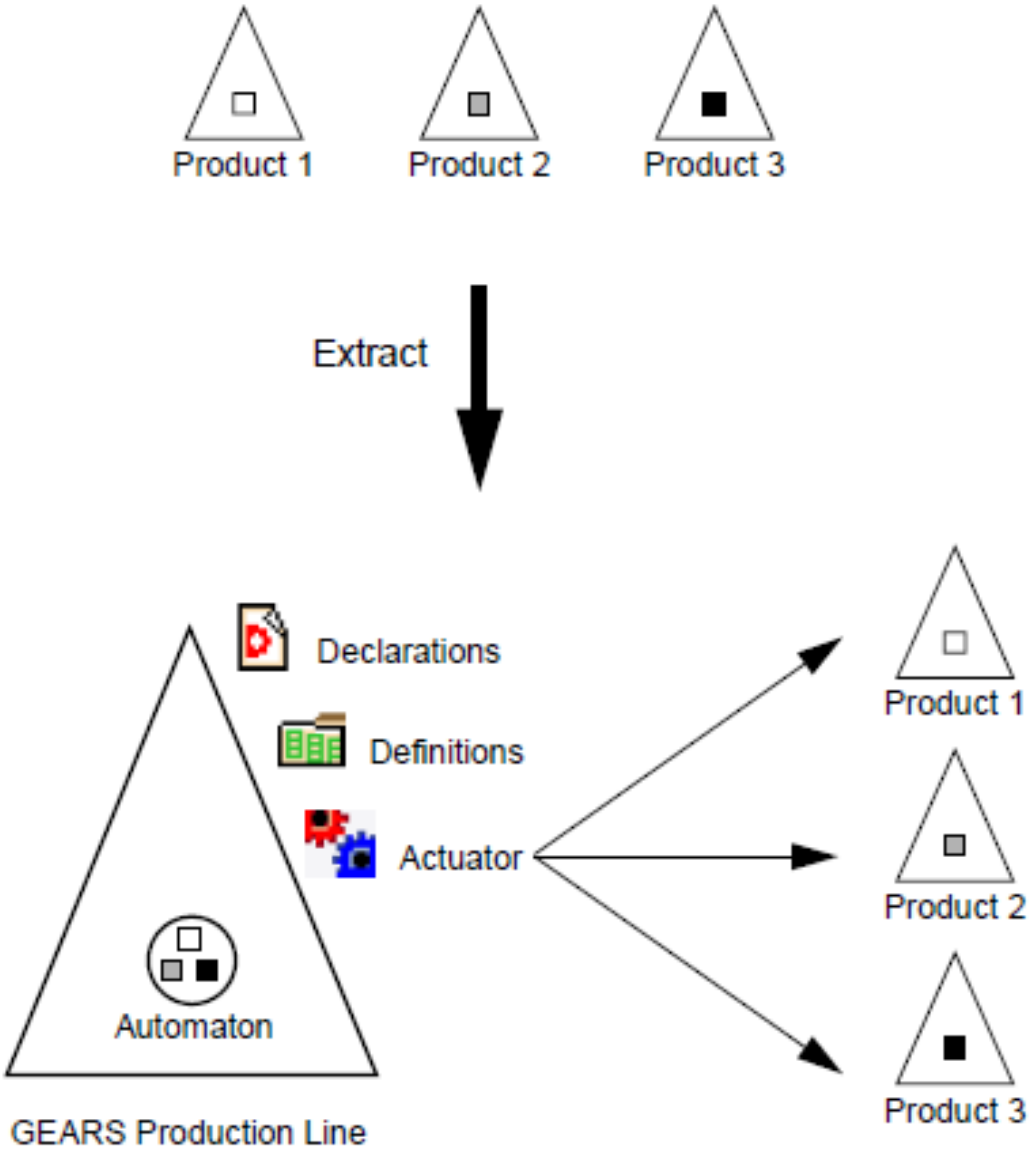
[Krueger 2002]

Reactive



[Krueger 2002]

Extractive



[Krueger 2002]

How MDE (IDM) can help

Software Product Line Engineering

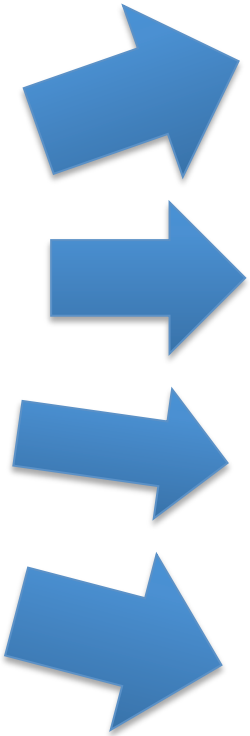
Generative approach

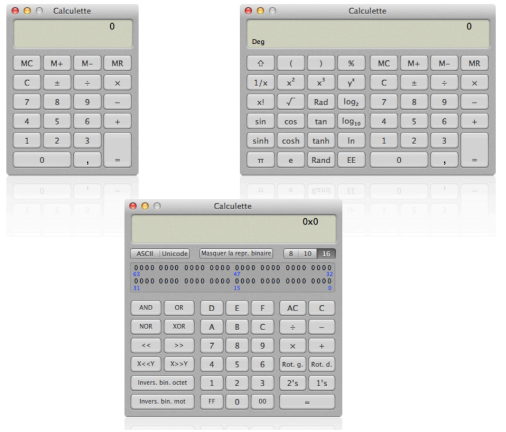
- Programming the generation of programs
  - Very old practice
  - Metaprogramming: generative language and target language are the same
    - Reflection capabilities

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

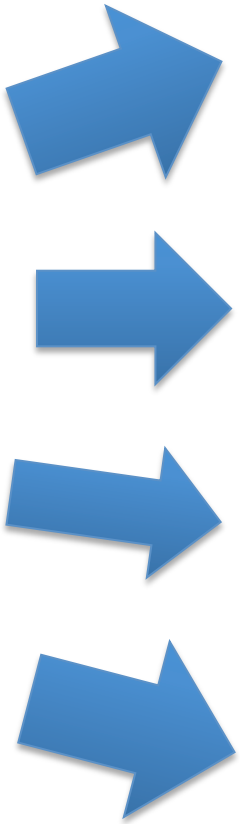
Modeling and implementing system families such that a desired system can be automatically generated from a specification written in one or more textual or graphical domain-specific languages.

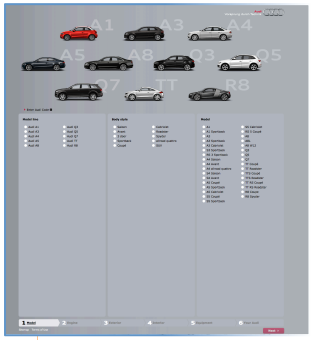
Models And Languages

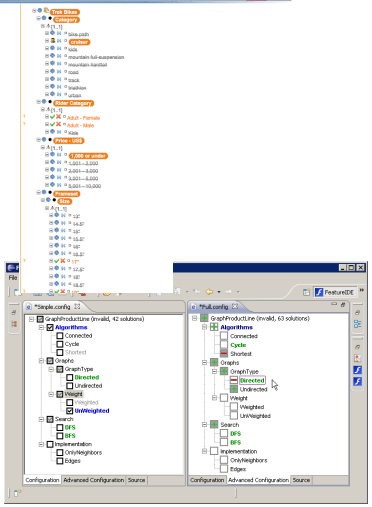


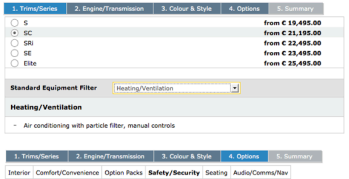


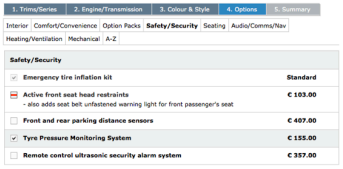
Models And Languages

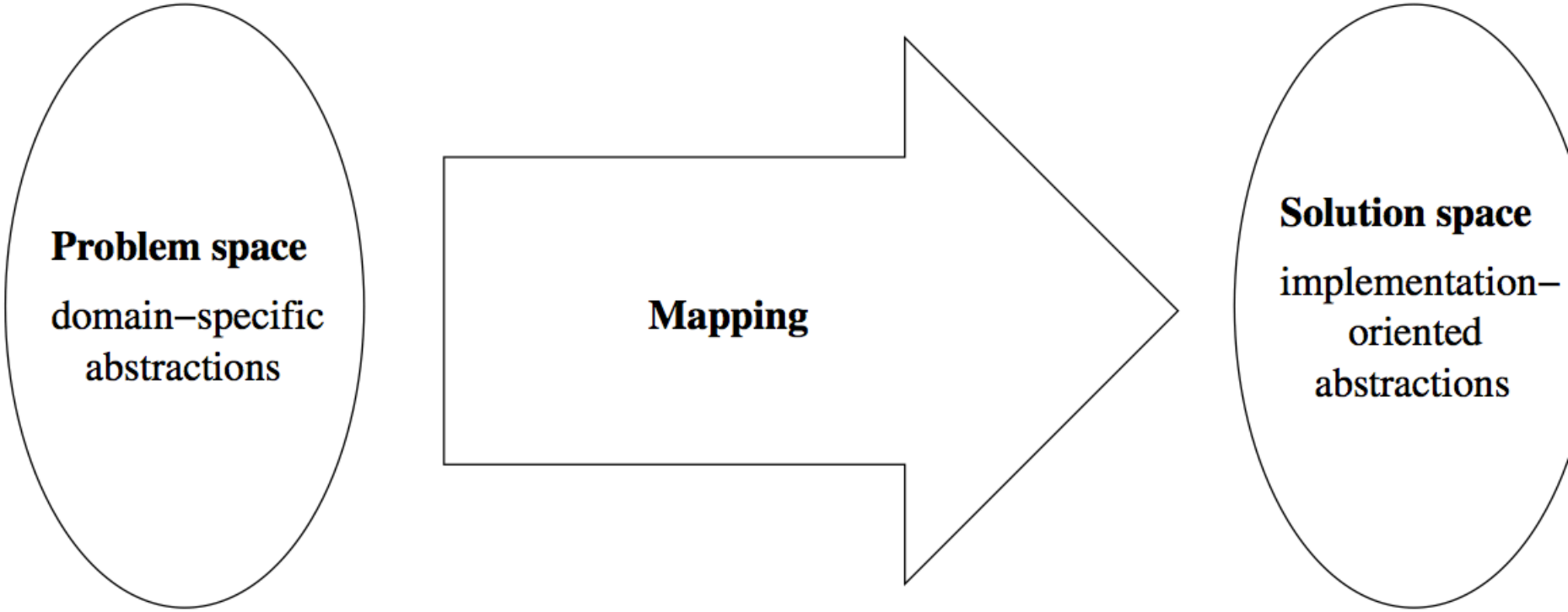




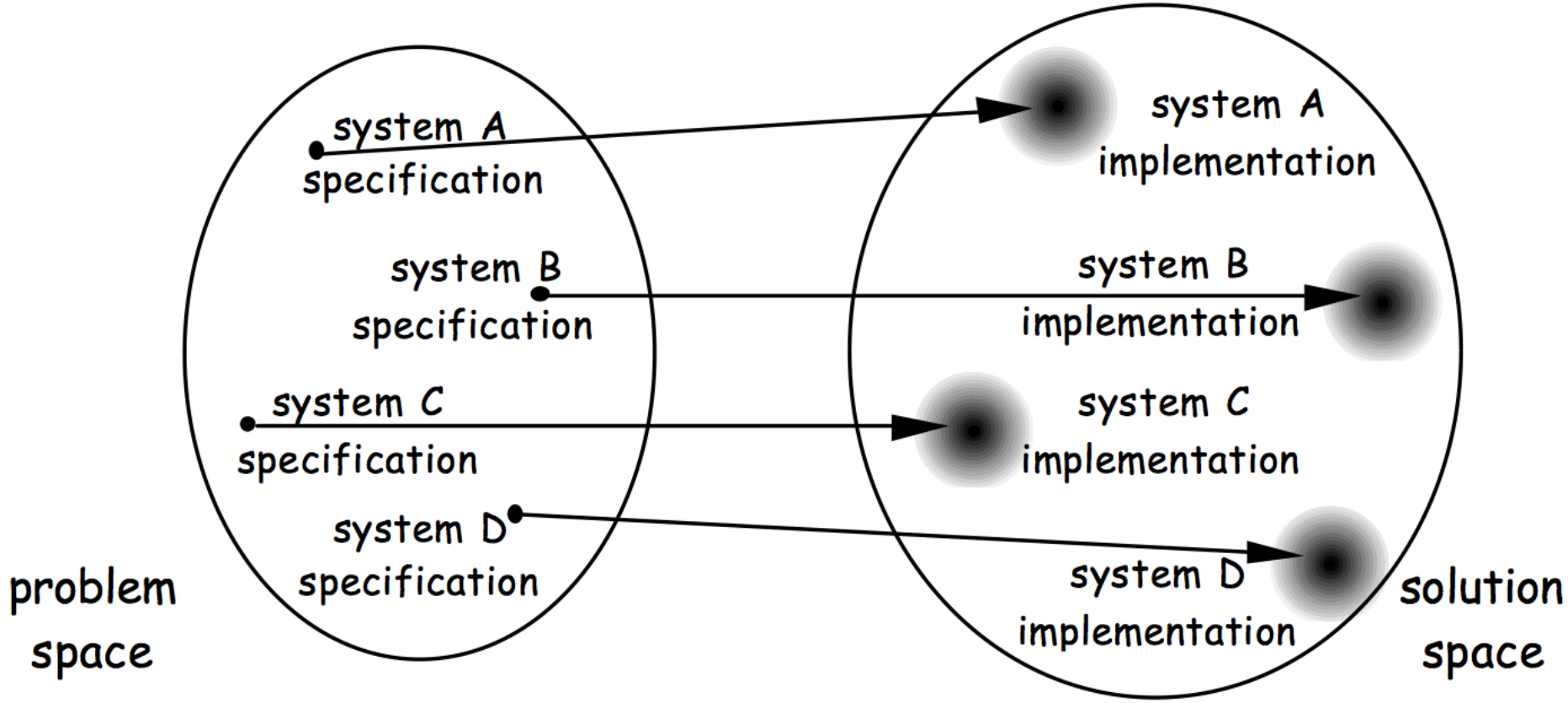




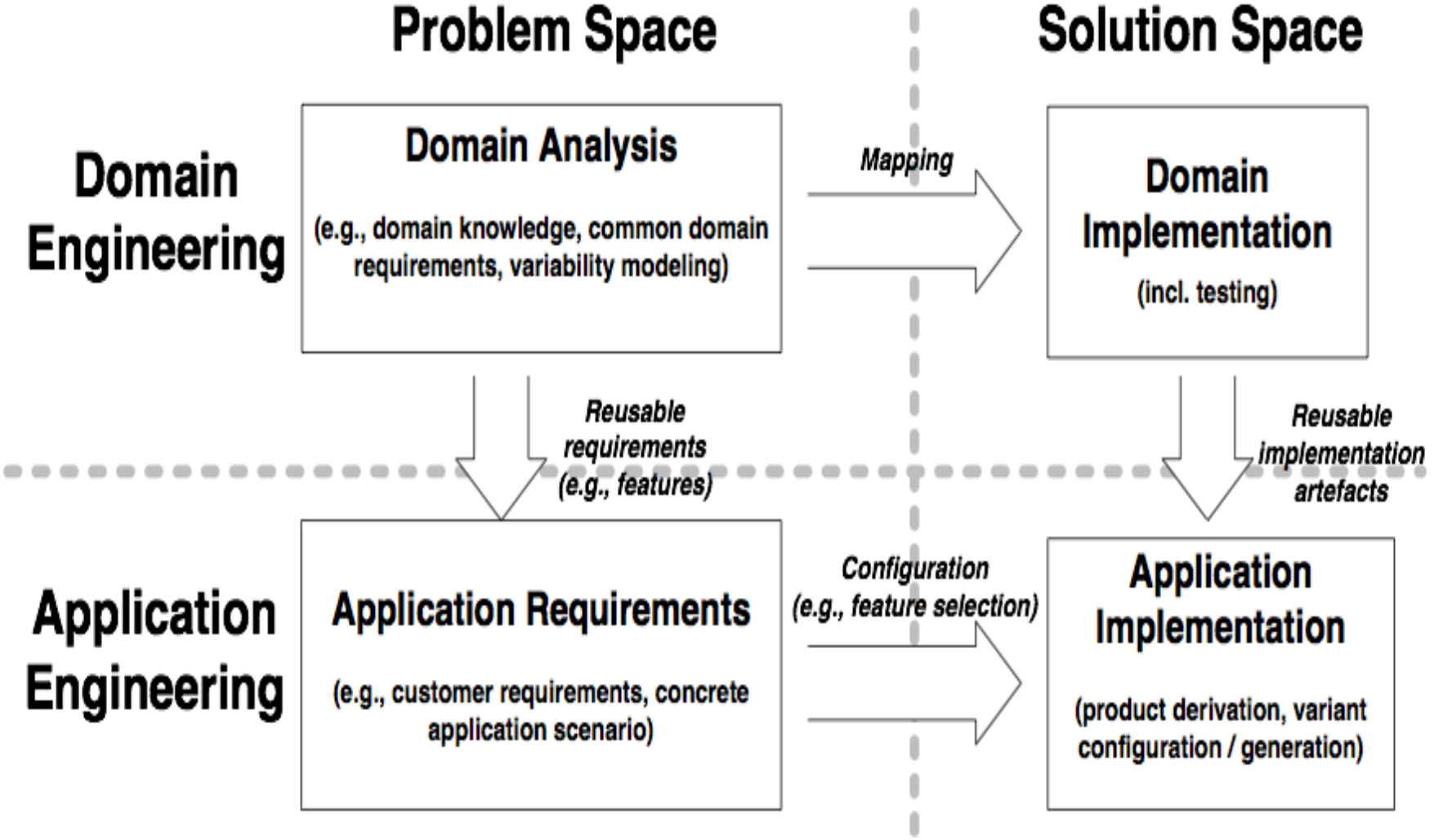




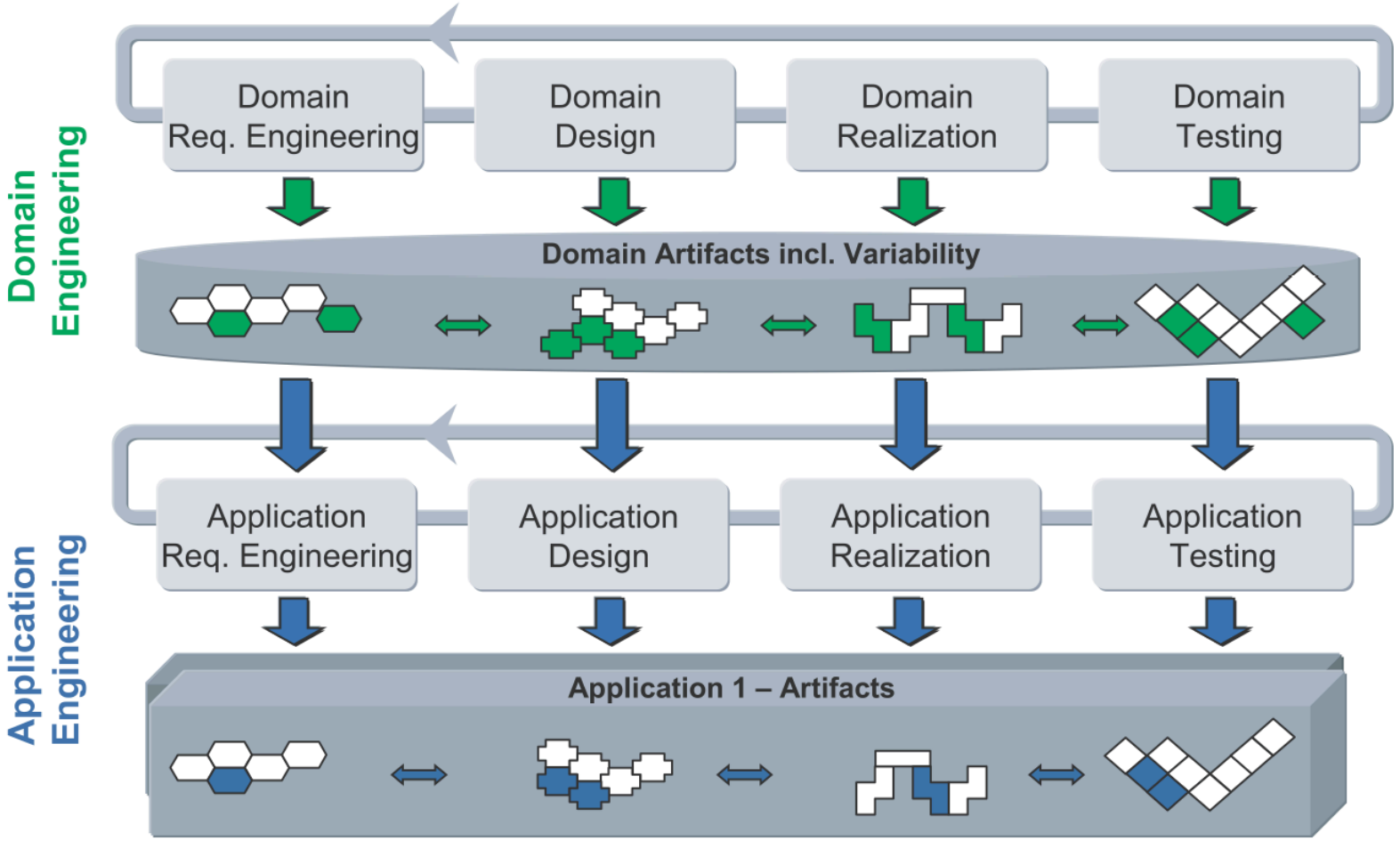
[Czarnecki and Eisenecker 2000]



[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

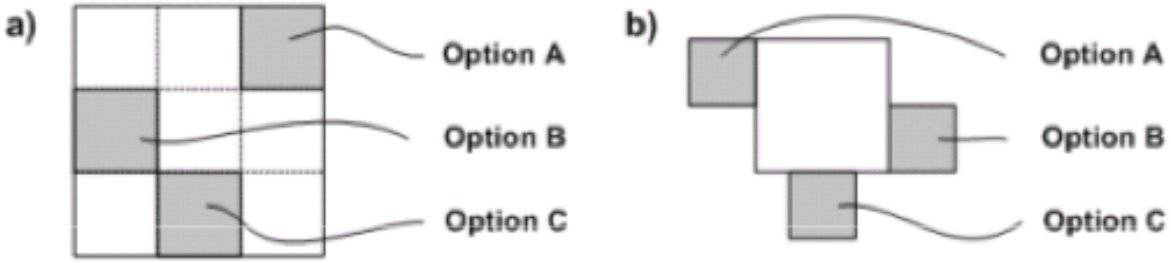
- Domain Engineering
  - Domain Models
  - Level of abstraction
  - Domain-specific modeling languages
    - (visual or textual) syntacs, precise semantics
    - analyzed (verification)
  - Traceability between the artefacts
- Application Engineering
  - Model transformations (automation)
- Reduce the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

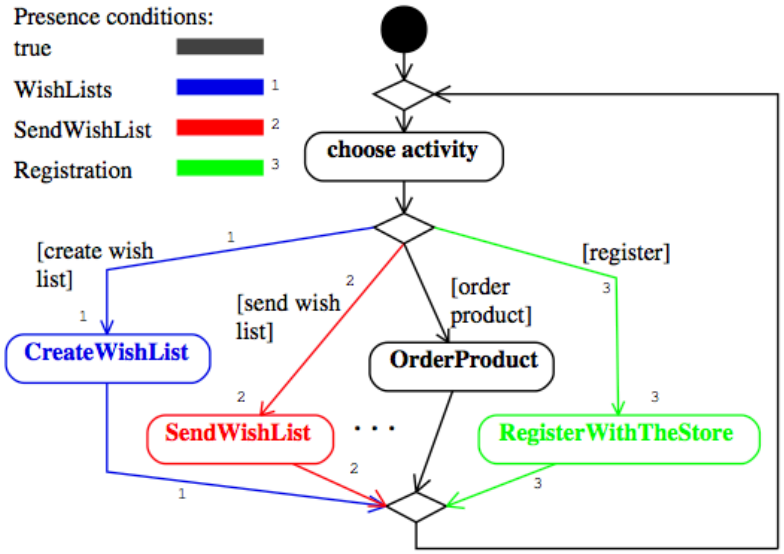
Negative vs. Positive Variability



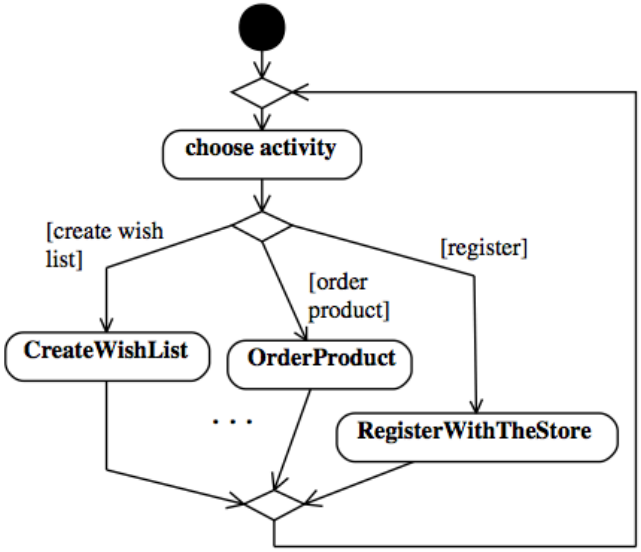
- Both in practice!

[Czarnecki et al. (GPCE'05)]

Feature-based Model Templates



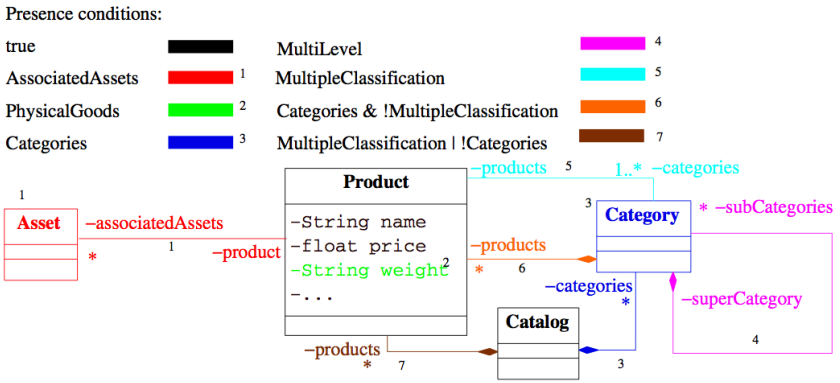
(a) Storefront template



(b) Storefront instance

[Czarnecki et al. (GPCE'05)]

Approach



Refers to features through annotations

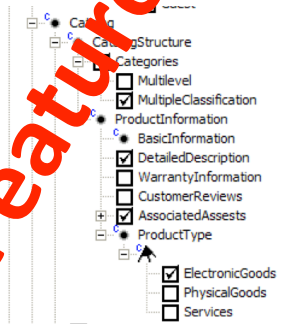
Feature model

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

Manual configuration process

Feature configuration

Features/Options

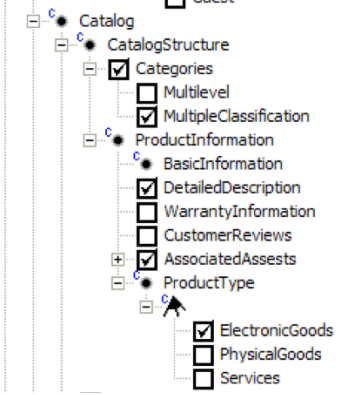


Automatic template instantiation
- Evaluation of presence conditions and meta–expressions
- Element removal
- Post–processing

Template instance

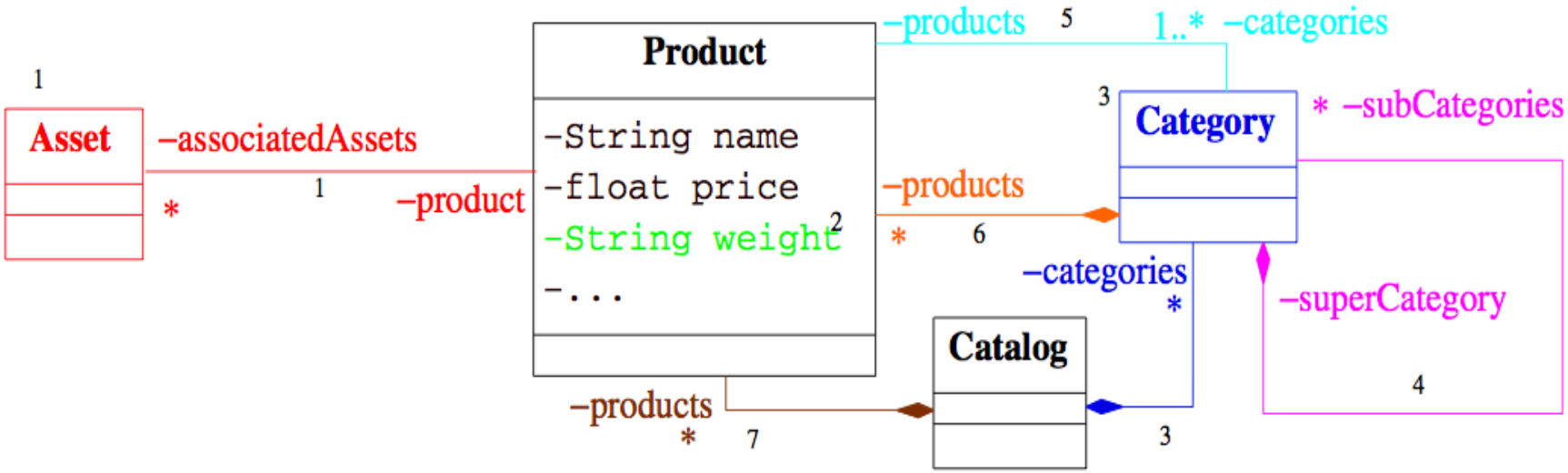
Product Model

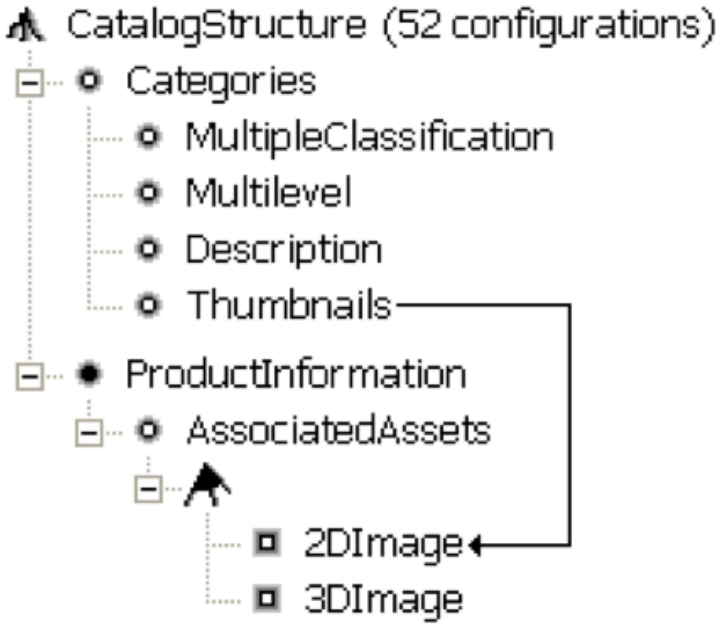
[Czarnecki et al. (GPCE'05)]

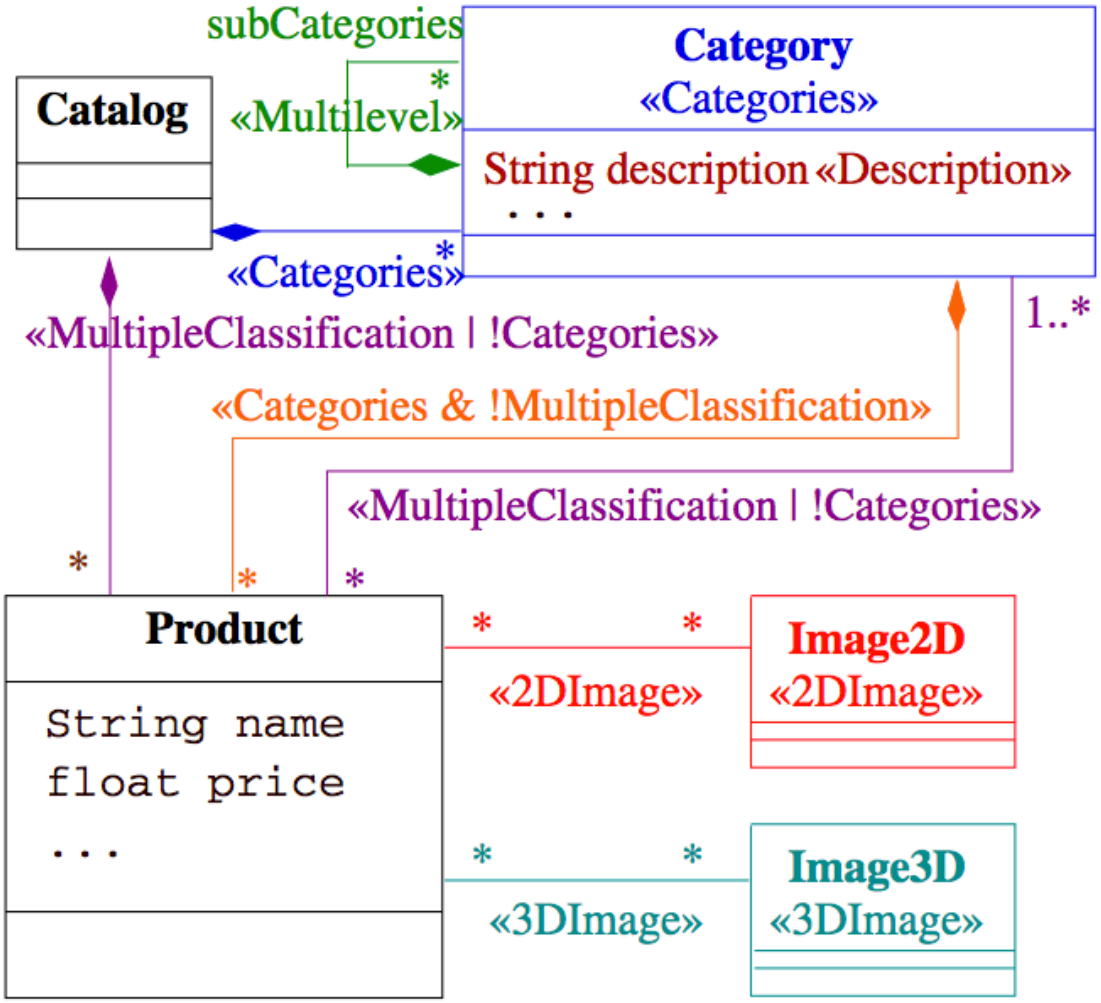


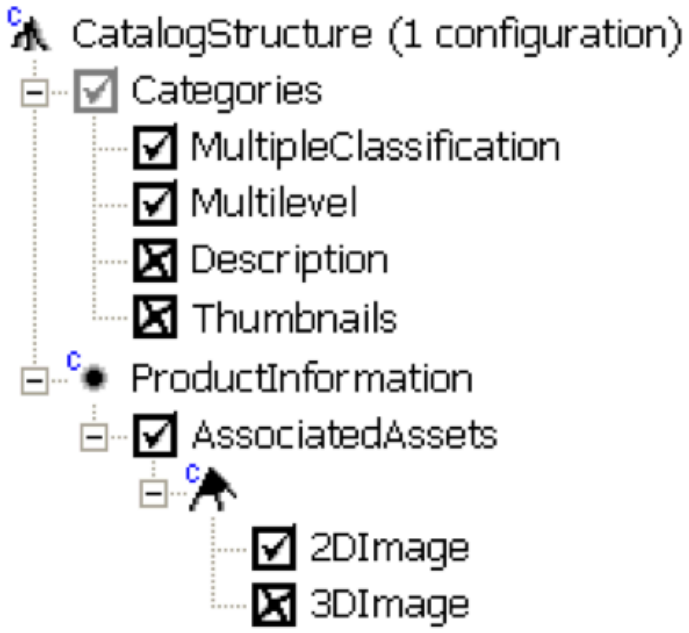
Presence conditions:

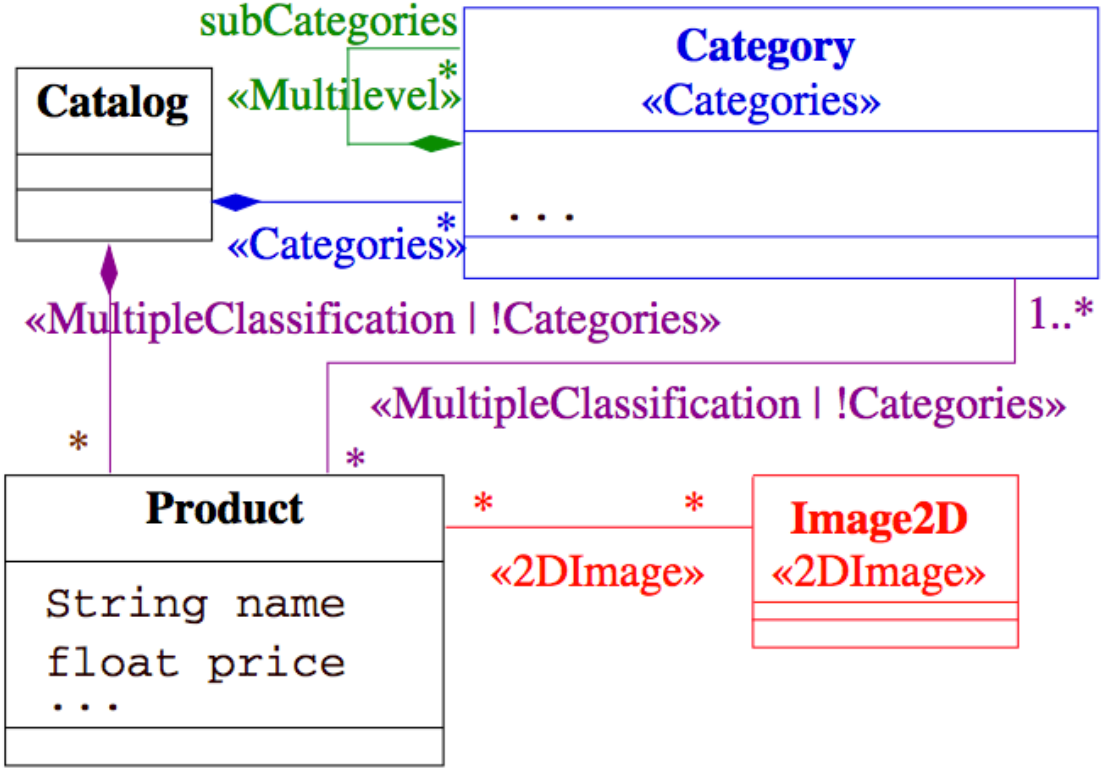
true		MultiLevel	4
AssociatedAssets	1	MultipleClassification	5
PhysicalGoods	2	Categories & !MultipleClassification	6
Categories	3	MultipleClassification | !Categories	7



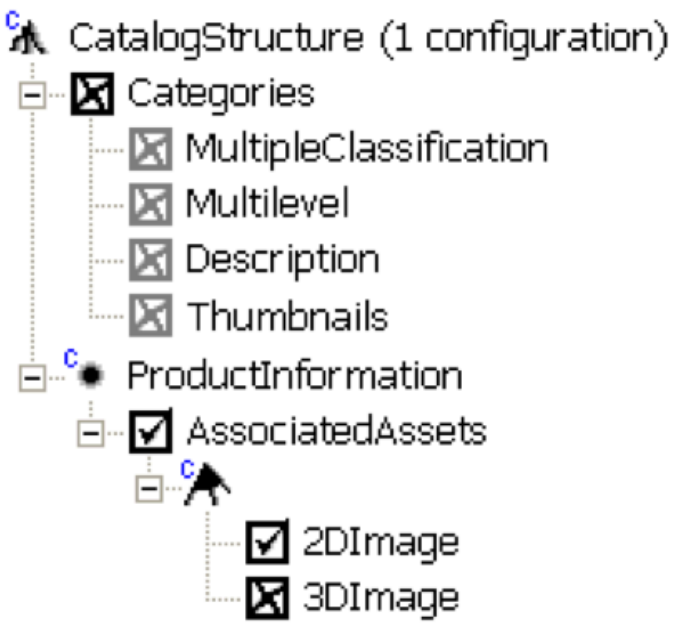

CatalogStructure (52 configurations)
Categories
MultipleClassification
Multilevel
Description
Thumbnails
ProductInformation
AssociatedAssets
2DImage
3DImage

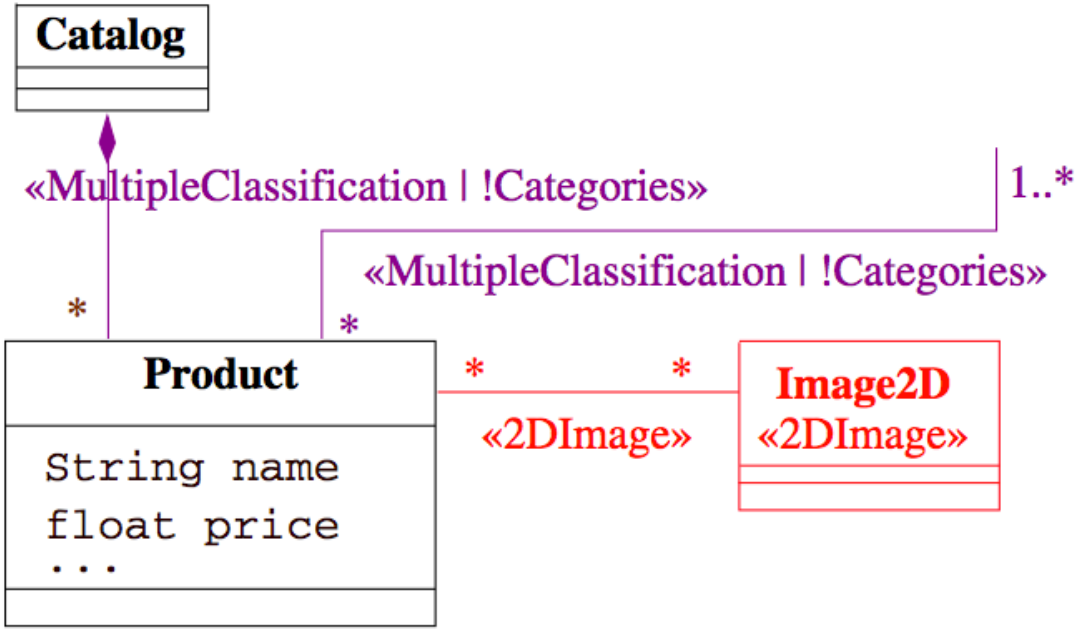

subCategories
Catalog
«Multilevel»
Category
«Categories»
String description «Description»
. . .
«Categories»
«MultipleClassification | !Categories»
1..*
«Categories & !MultipleClassification»
«MultipleClassification | !Categories»
Product
String name
float price
. . .
«2DImage»
Image2D
«2DImage»
«3DImage»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


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

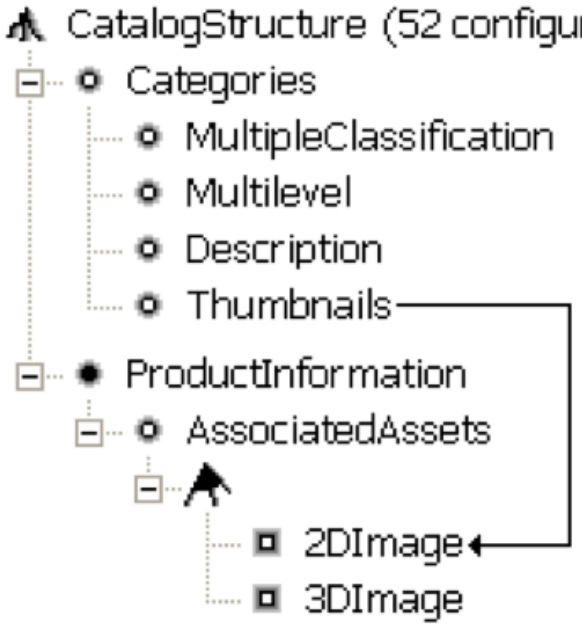

subCategories
Catalog
«Multilevel»
Category
«Categories»
...
«Categories»
«MultipleClassification | !Categories»
1..*
«MultipleClassification | !Categories»
Product
String name
float price
...
«2DImage»
Image2D
«2DImage»

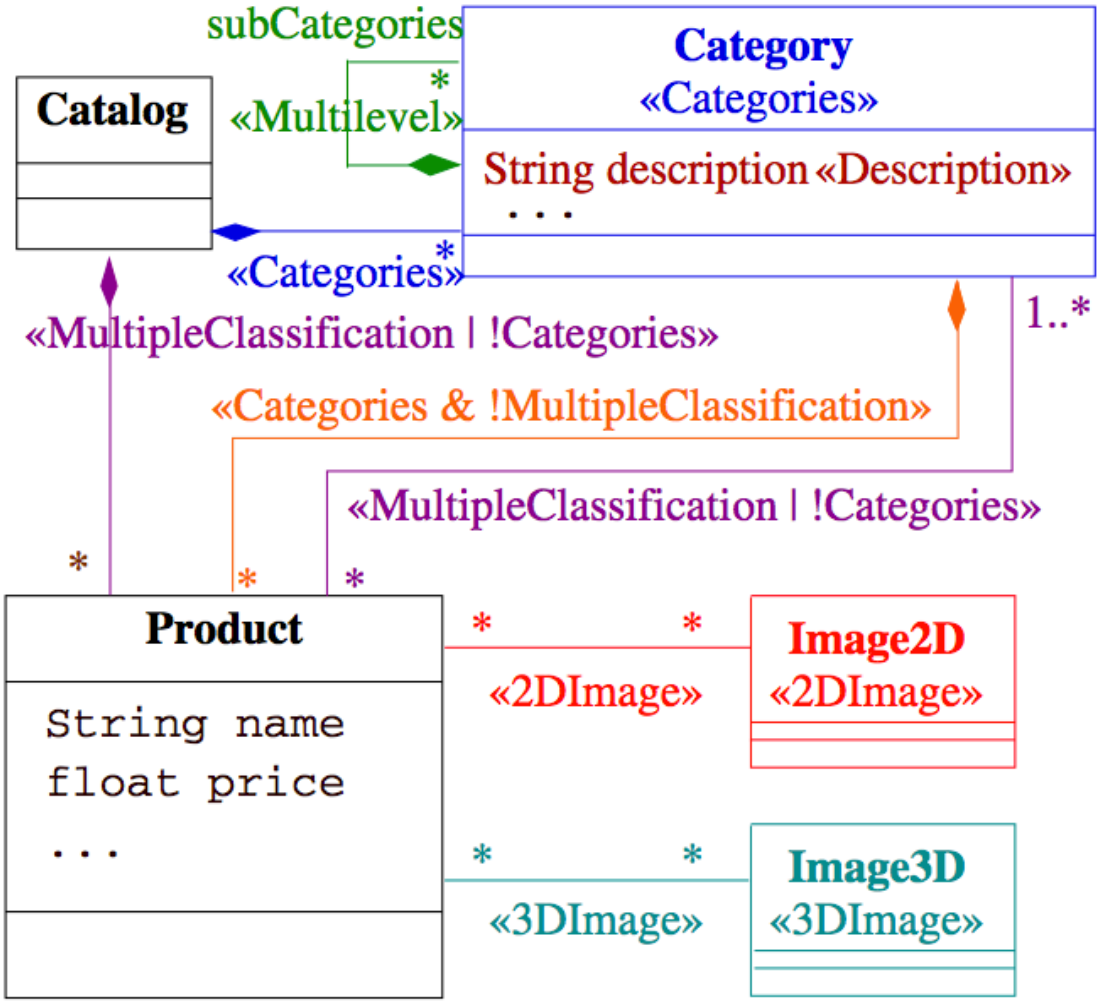
Ooops


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»

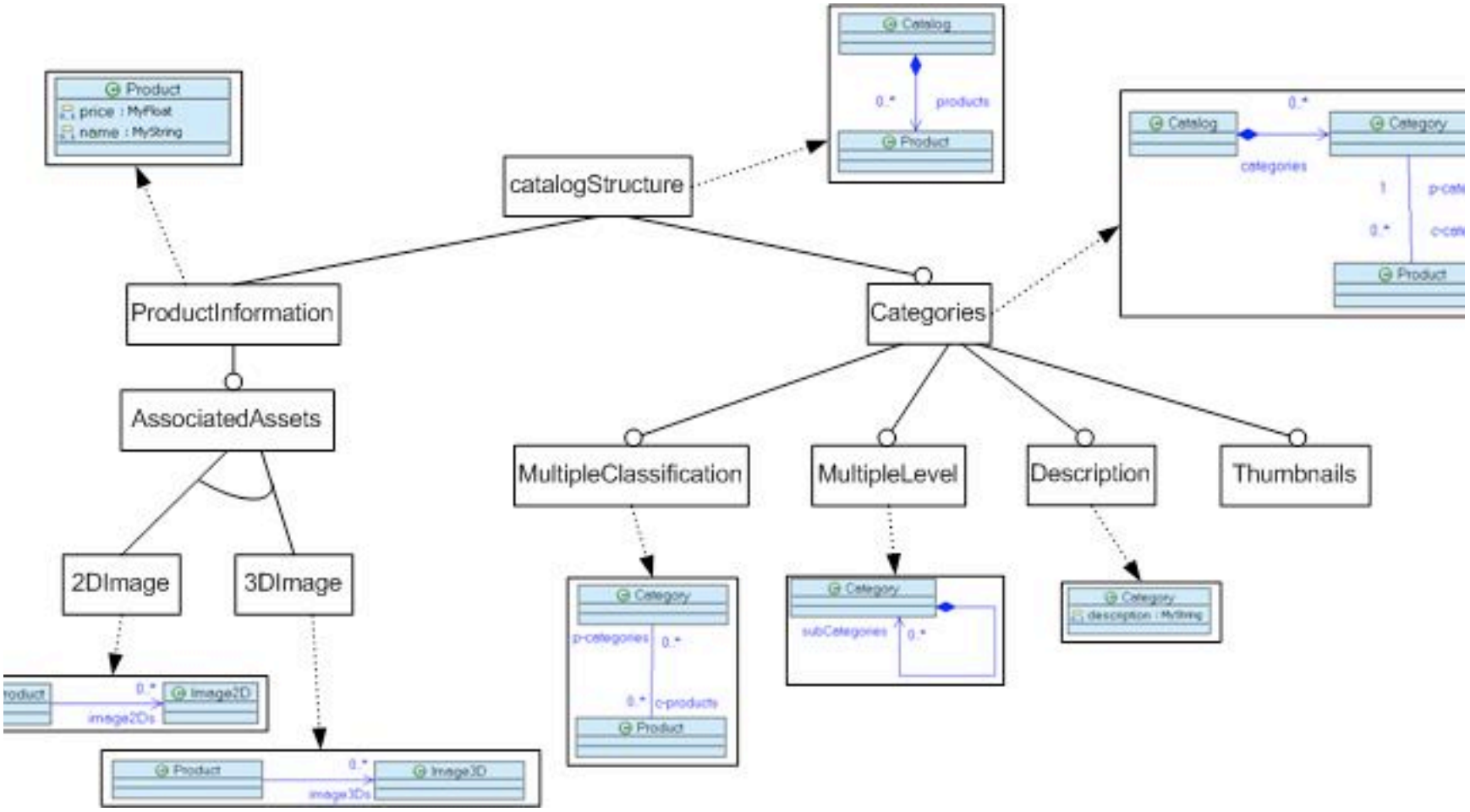
Safe composition? No!





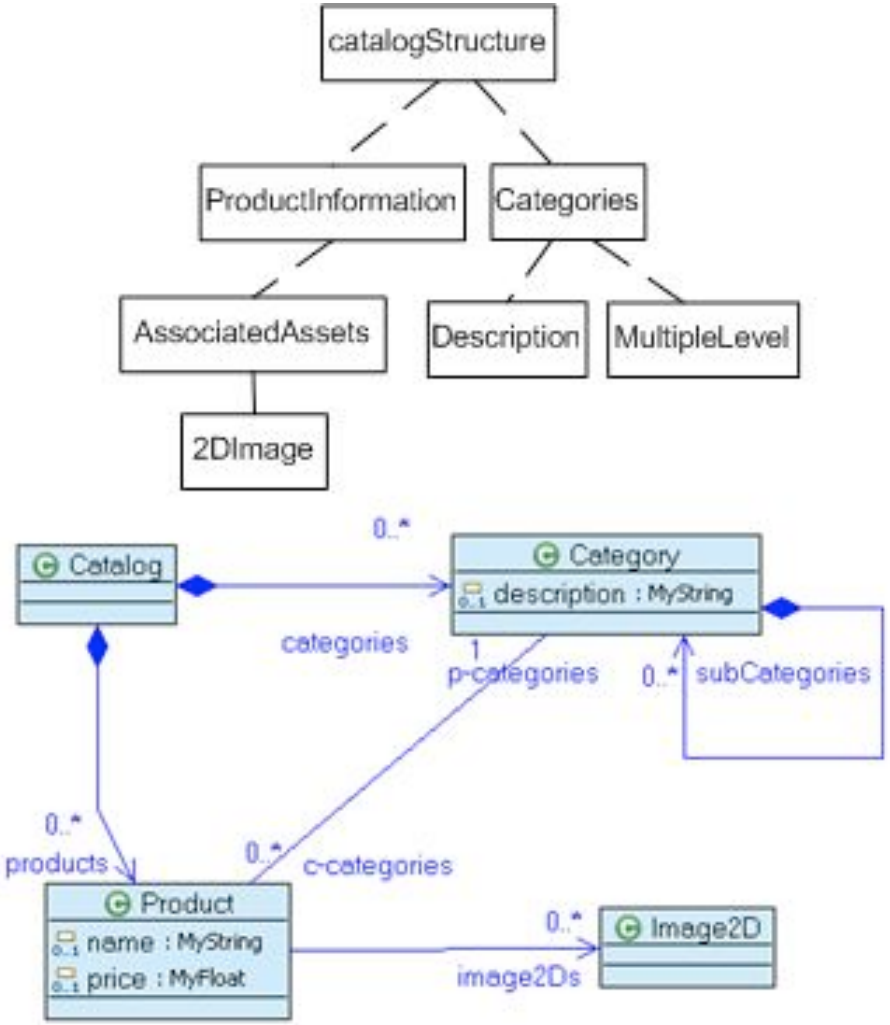
[Perrouin et al. (SPLC'08)]

Another approach (compositional)

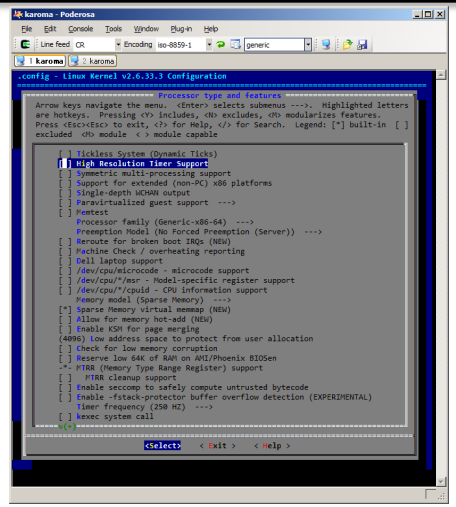


Composition of models

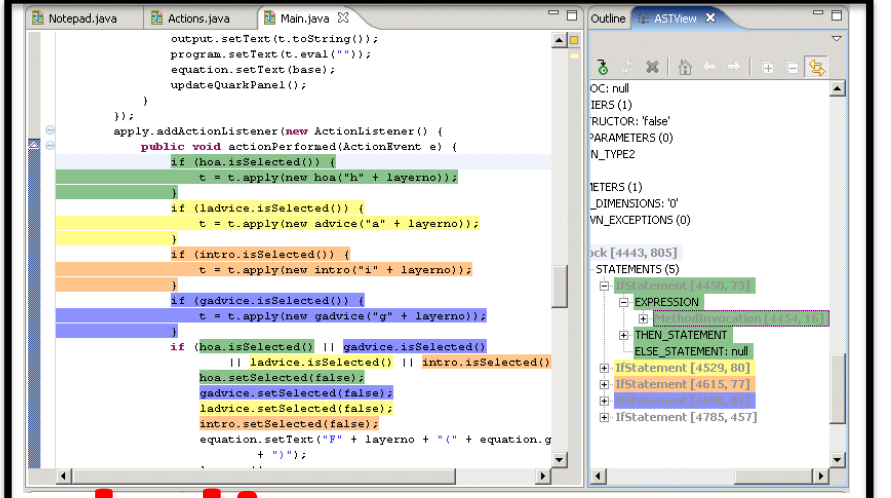
for deriving the product model



Feature Models



Variability Model



Domain Artefacts (e.g., source code)

Modeling variability is crucial

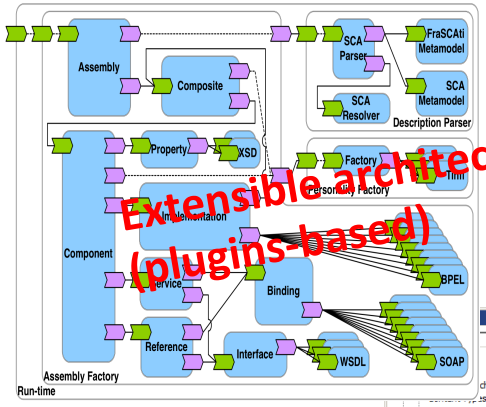
Configuration

Software Generator

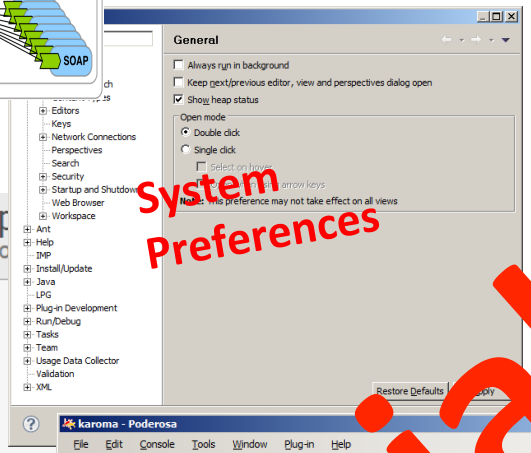

Unused flexibility


Illegal variant

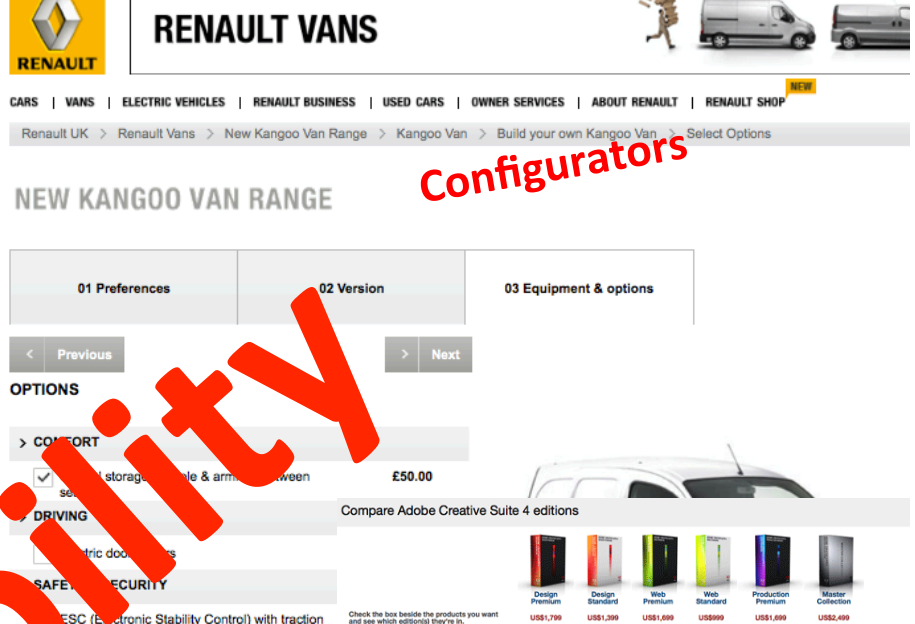
Variability



Extensible architectures (plugins-based)

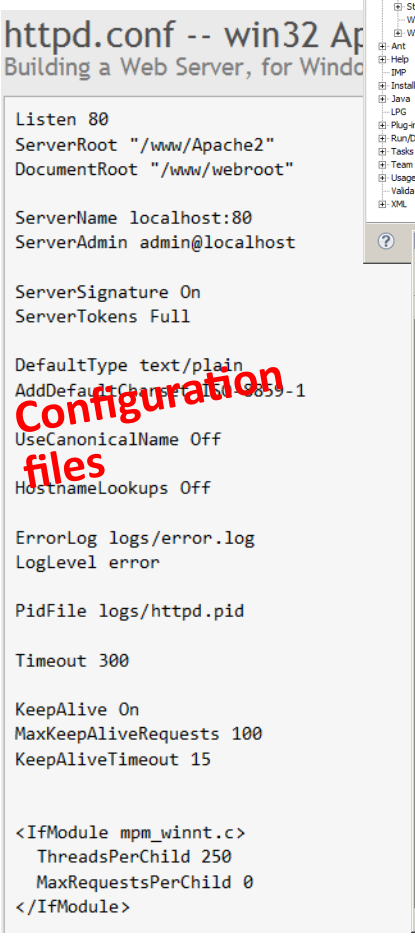


System Preferences

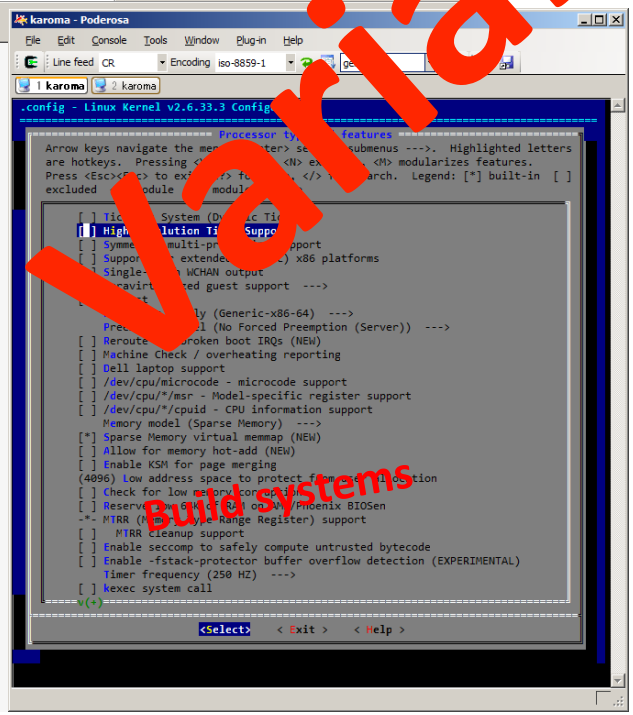


Configurators

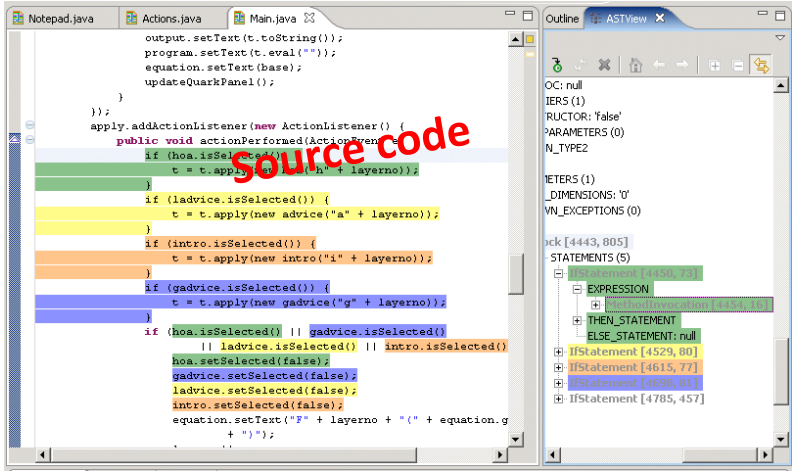
Comparison of Product



Configuration files



Built systems



Source code

Variability Management

Common features

print – connect with computer…

Variable features

fax – scan – USB port…

Product-specific features

serial port

Feature modeling is…

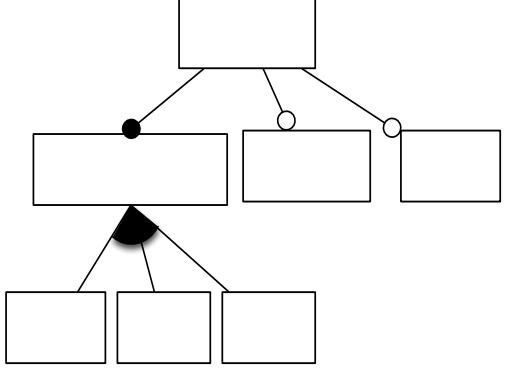
- … about identifying
  - common features of concepts
  - variable features of concepts
  - and their dependencies
- and documenting them in a coherent model, called a **feature model**
- Feature modeling is a core activity of important domain-engineering methods

What's a **feature**? (survey excerpt)

- *[Kang et al.]* "a prominent or distinctive **user-visible aspect, quality** or **characteristic** of a software system or systems"
- *[Kang et al.]* "distinctively identifiable **functional abstractions** that must be implemented, tested, delivered, and maintained"
- *[Eisenecker and Czarnecki]*. "**anything users** or client programs might want to **control about a concept**"
- *[Bosch et al.]* "A **logical unit of behaviour** specified by a set of **functional** and **non-functional requirements**."
- *[Chen et al.]* "a **product characteristic** from user or customer views, which essentially consists of a cohesive **set of** individual **requirements**"
- *[Batory]* "an elaboration or augmentation of an entity(s) that introduces a **new service**, **capability** or relationship"

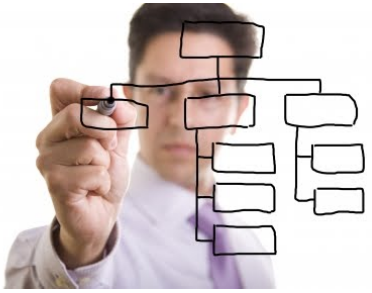
Requirements to Code

Feature Model

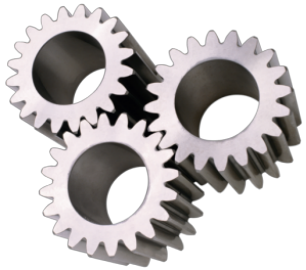


not, and, or, implies

Communicative



Analytic



Generative

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),
- Common Variability Language (CVL)

Audi
Vorsprung durch Technik

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

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

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:

☑ GPS Plus avec disque dur		2.934,25 EUR

Voici les équipements complémentaires possibles:

○ Ordinateur de bord en couleur avec programme efficiency **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		181,50 EUR
○ 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

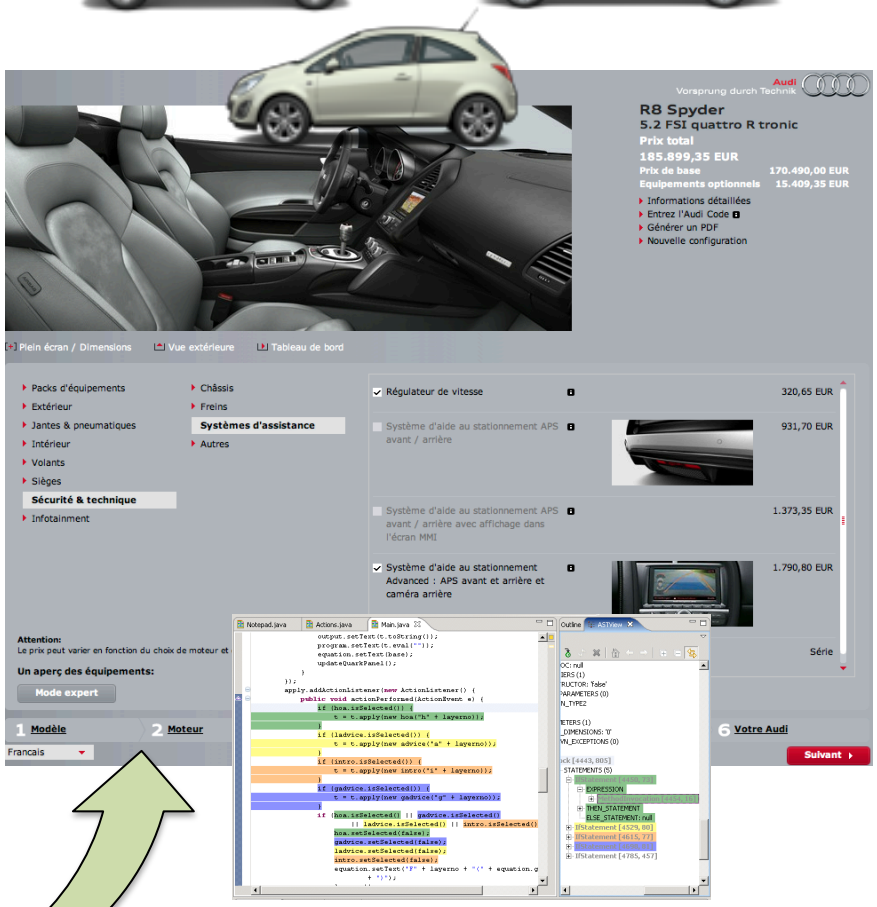
1 Modèle | 2 Moteur | 3 Extérieur | 4 Intérieur | 5 Option | 6 Votre Audi

Francais

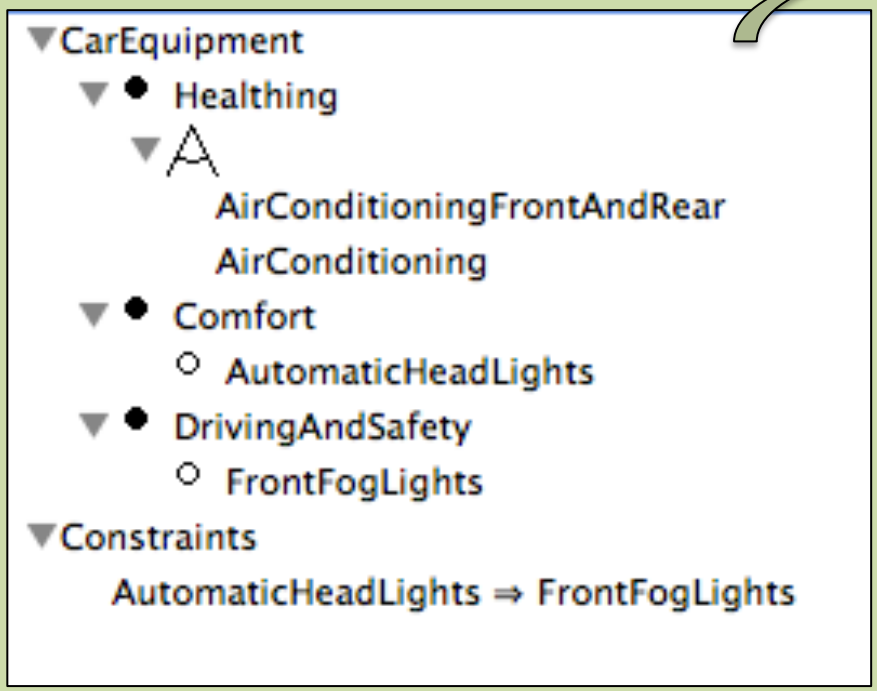
Suivant

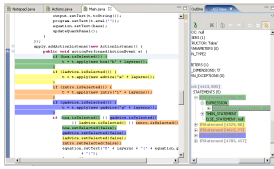
Feature Models

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



Feature Models (Background)

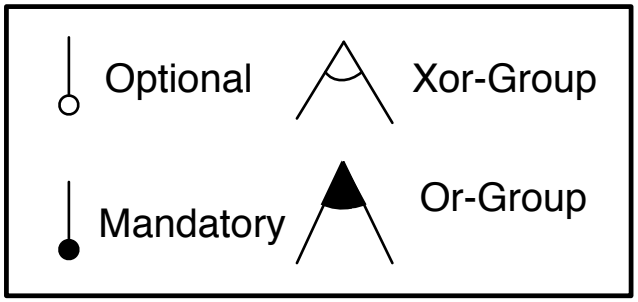




Hierarchy: rooted tree

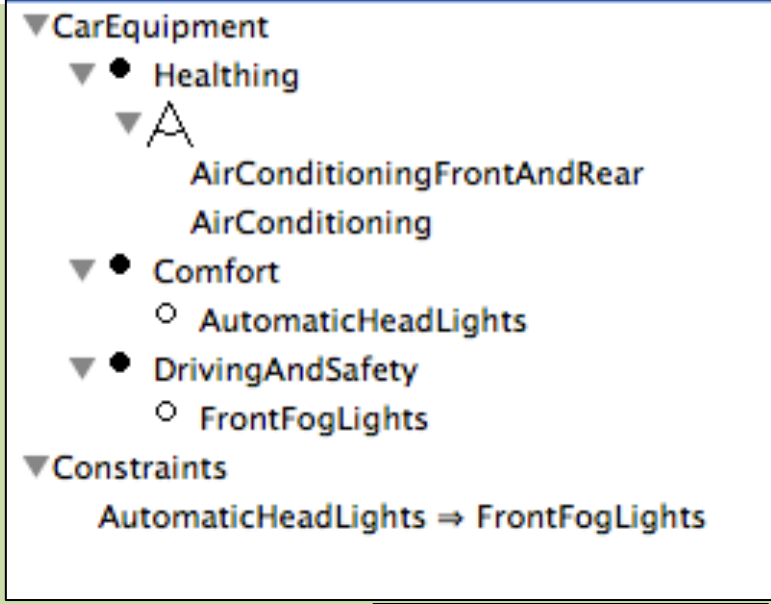
Variability:

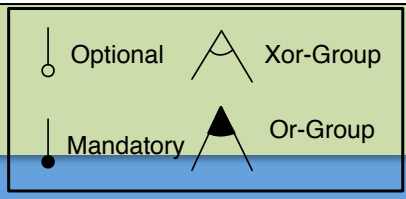
- mandatory,
- optional,
- Groups: exclusive or inclusive features
- Cross-tree constraints



SPLC12Scripts Model | SPLC12Scripts.config

- CarEquipment (valid, 1 possible configurations)
  - Healthing
    - AirConditioningFrontAndRear
    - AirConditioning
  - Comfort
    - AutomaticHeadLights
  - DrivingAndSafety
    - FrontFogLights





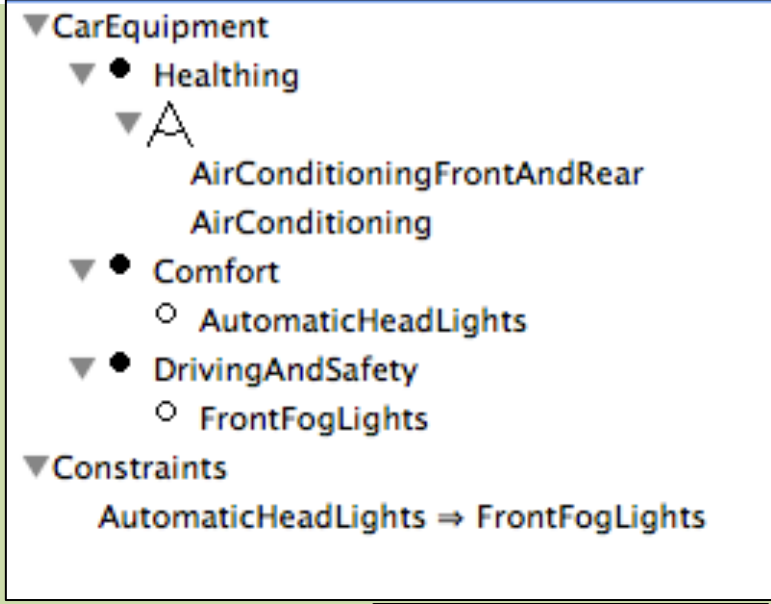
Hierarchy + Variability
=
set of valid configurations

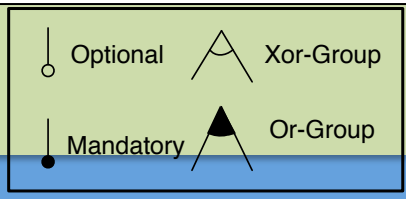
configuration = set of features selected

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

SPLC12Scripts Model | SPLC12Scripts.config

- CarEquipment (valid, 1 possible configurations)
  - Healthing
    - AirConditioningFrontAndRear
    - AirConditioning
  - Comfort
    - AutomaticHeadLights
  - DrivingAndSafety
    - FrontFogLights

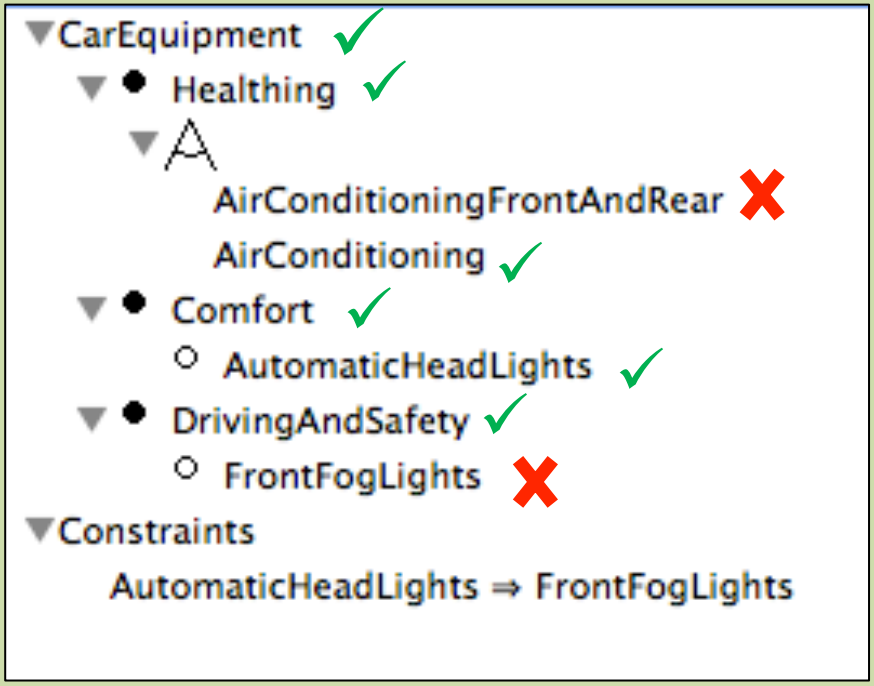


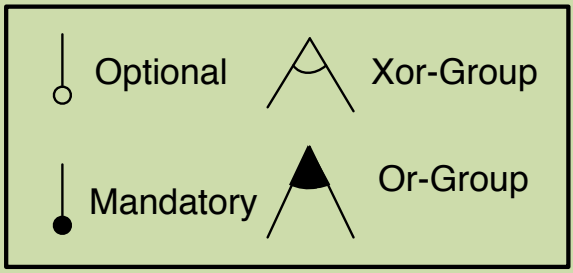


Hierarchy + Variability
=
set of valid configurations

configuration = set of features selected

{CarEquipment, Comfort, DrivingAndSafety, Healthing, AirConditioning}

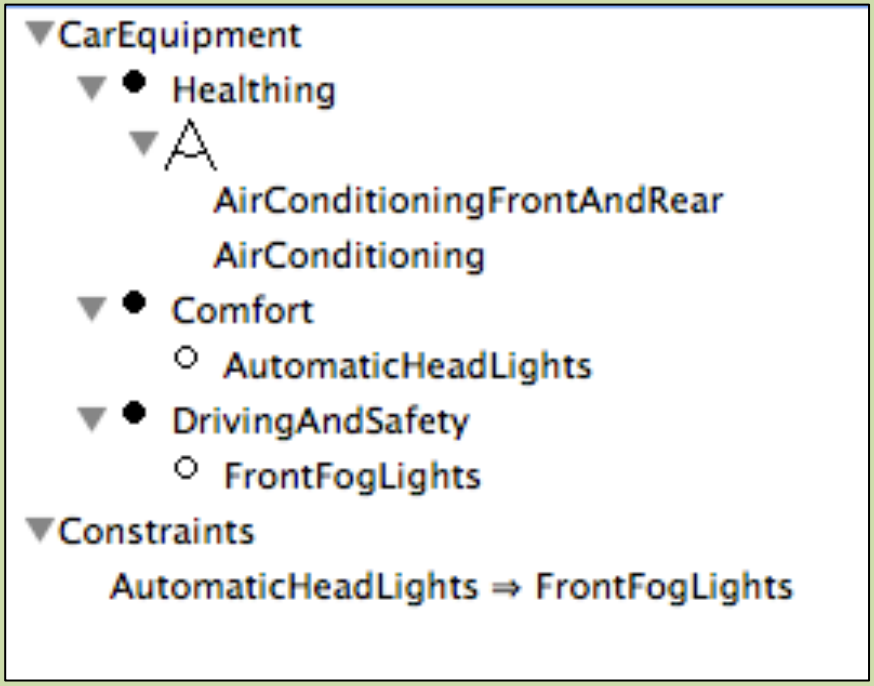


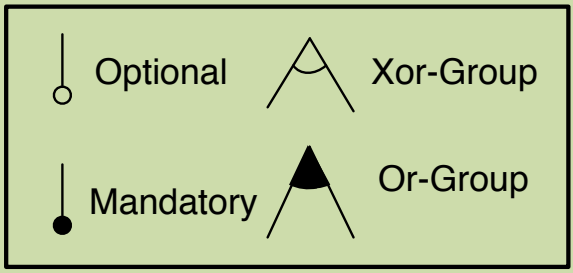


Hierarchy + Variability
=
set of valid configurations

configuration = set of features selected

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





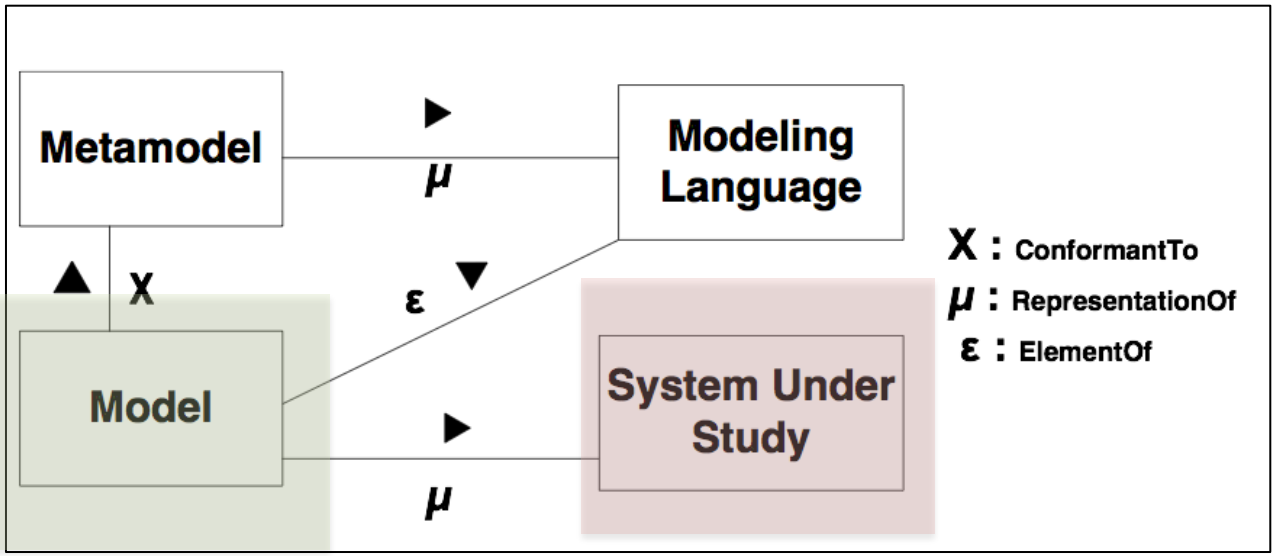
Hierarchy + Variability
=
set of valid configurations

{CarEquipment, Comfort, DrivingAndSafety, Healthing}

X

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

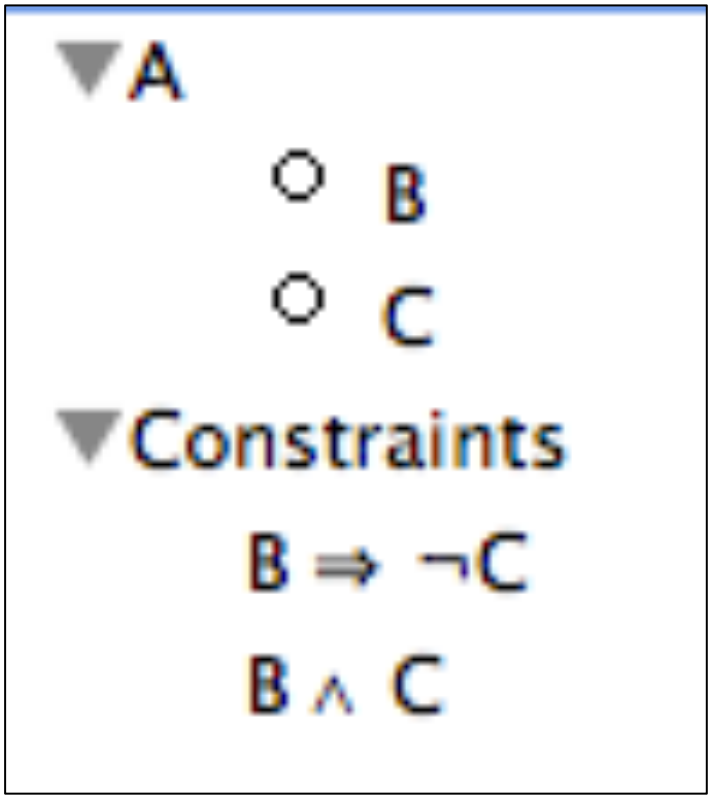
Feature Models



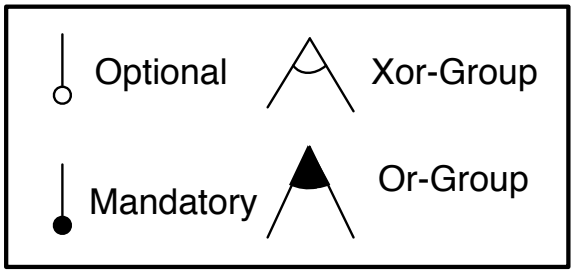
- CarEquipment
  - Healthing
    - AirConditioningFrontAndRear
    - AirConditioning
  - Comfort
    - AutomaticHeadLights
  - DrivingAndSafety
    - FrontFogLights
- Constraints
  - AutomaticHeadLights ⇒ FrontFogLights

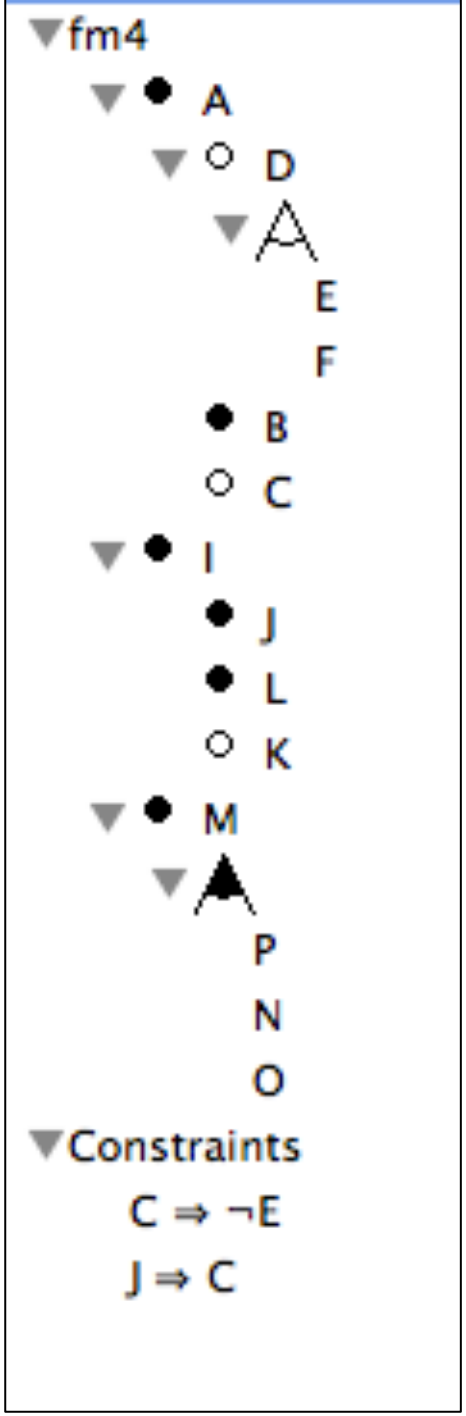
Feature Model Analysis

semantics and automated reasoning



Empty set of configurations





Dead feature

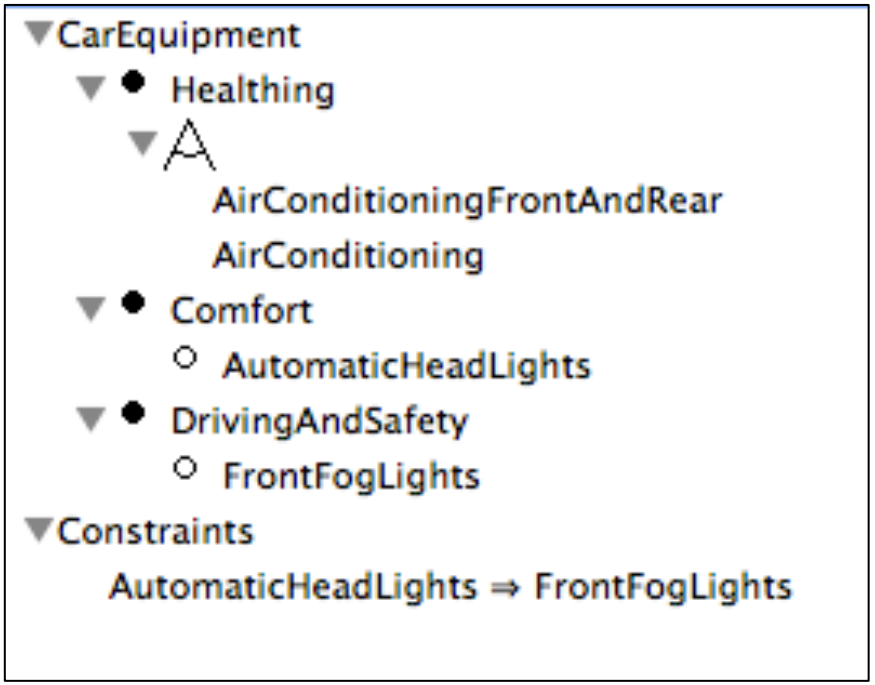
False optional feature

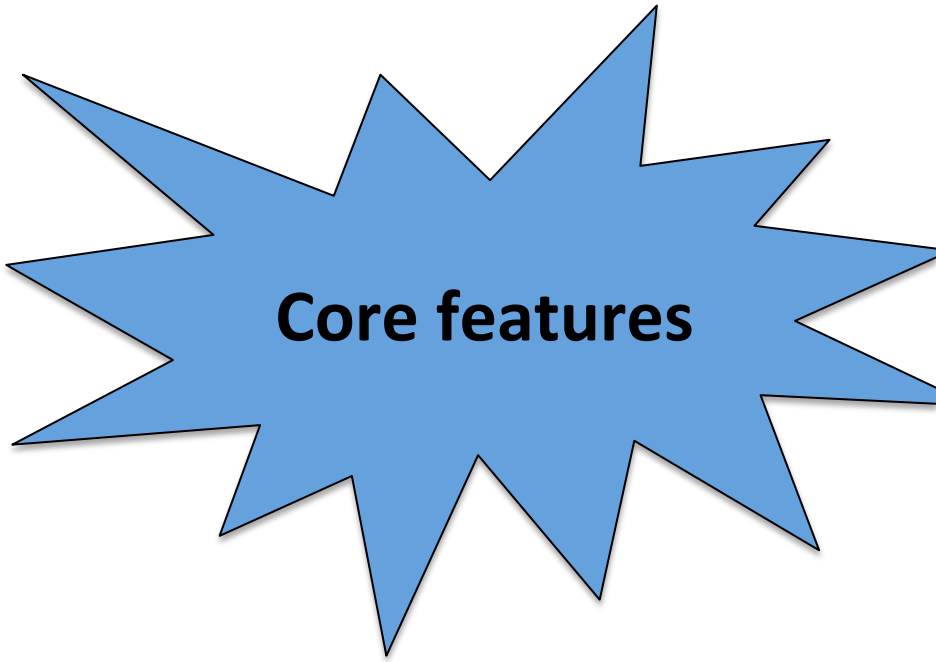
Optional

Xor-Group

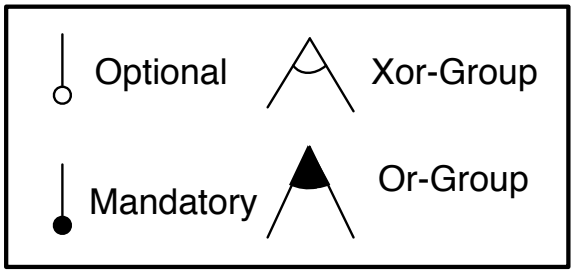
Mandatory

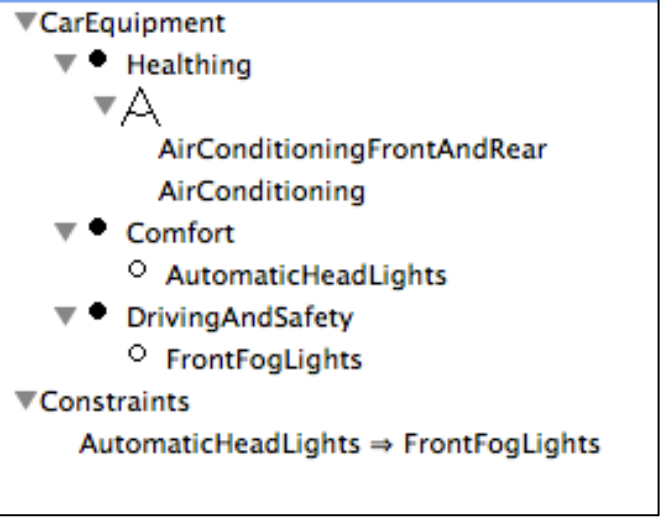
Or-Group

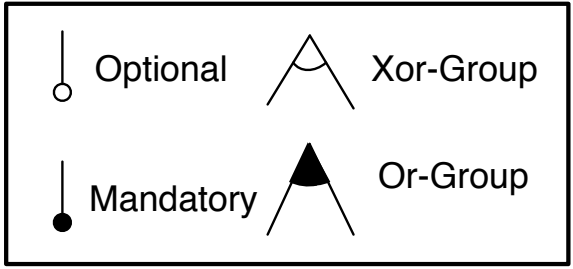


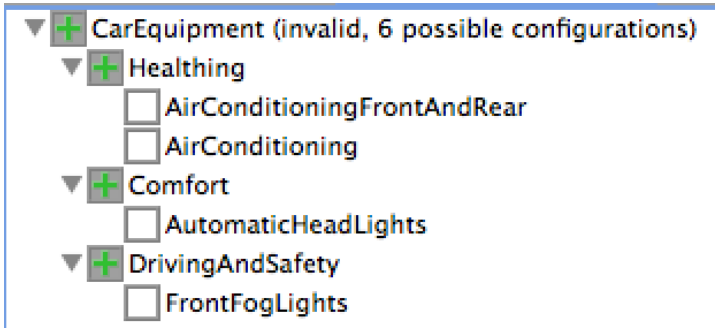


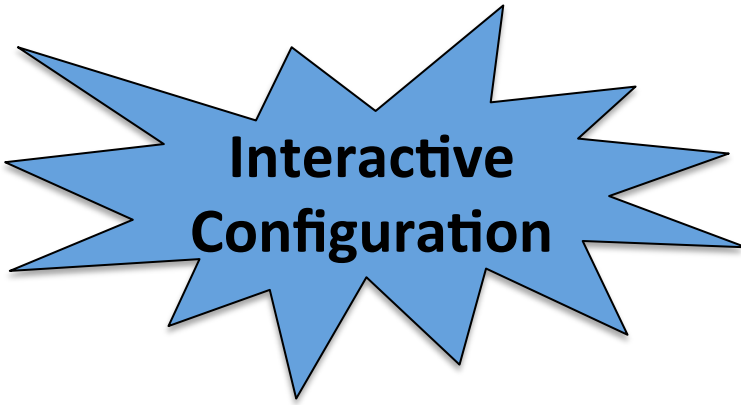
{CarEquipment, Comfort, DrivingAndSafety, Healthing}

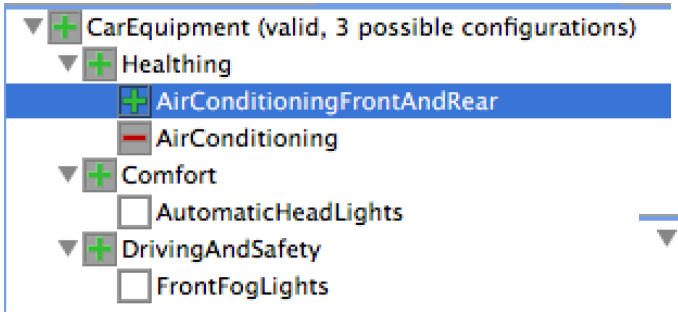


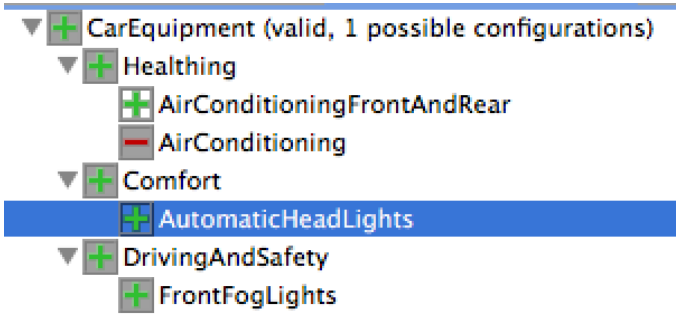

CarEquipment
Healthing
AirConditioningFrontAndRear
AirConditioning
Comfort
AutomaticHeadLights
DrivingAndSafety
FrontFogLights
Constraints
AutomaticHeadLights ⇒ FrontFogLights


Optional
Xor-Group
Mandatory
Or-Group


CarEquipment (invalid, 6 possible configurations)
Healthing
AirConditioningFrontAndRear
AirConditioning
Comfort
AutomaticHeadLights
DrivingAndSafety
FrontFogLights


Interactive
Configuration

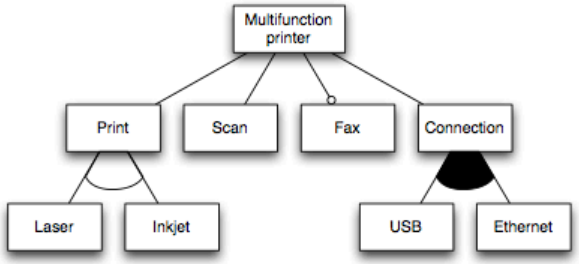

CarEquipment (valid, 3 possible configurations)
Healthing
AirConditioningFrontAndRear
AirConditioning
Comfort
AutomaticHeadLights
DrivingAndSafety
FrontFogLights


CarEquipment (valid, 1 possible configurations)
Healthing
AirConditioningFrontAndRear
AirConditioning
Comfort
AutomaticHeadLights
DrivingAndSafety
FrontFogLights

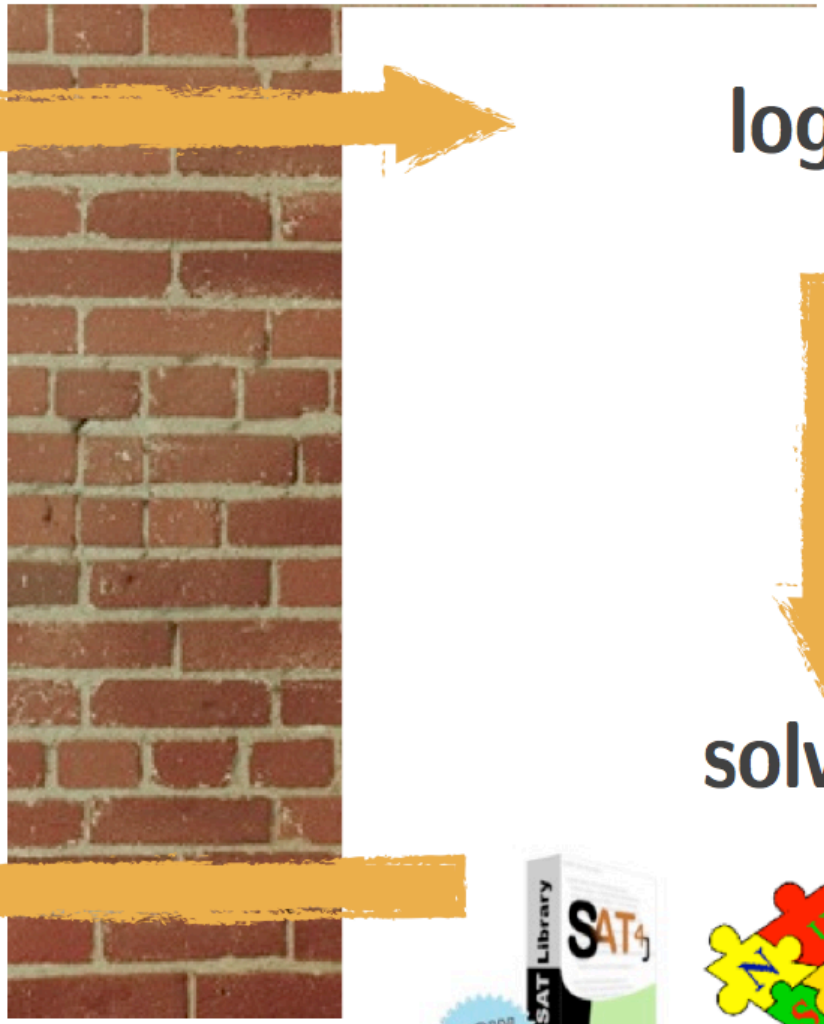
Decision problems and complexity

- Validity of a feature model
- Validity of a configuration
- Computation of dead and core features
- Counting of the number of valid configurations
- Equivalence between two feature models
- Satisfiability (SAT) problem
  - NP-complete

Typical implementations



result

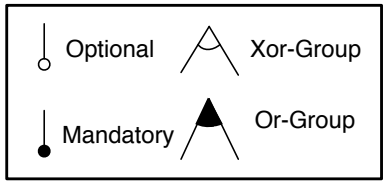


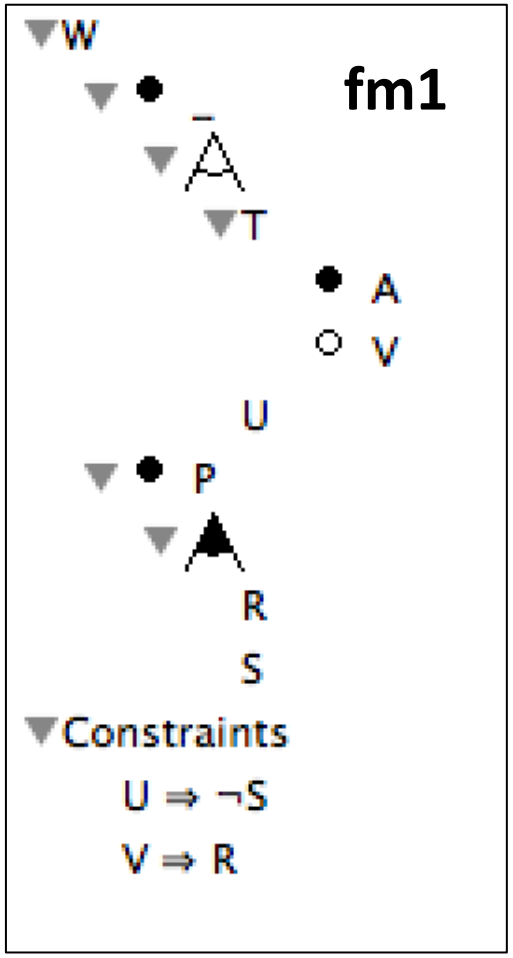
logics

solvers

(Boolean) Feature Models

Hierarchy + Variability = set of valid configurations

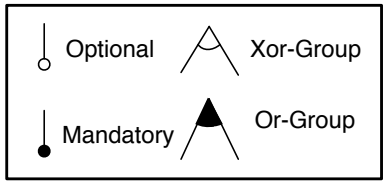


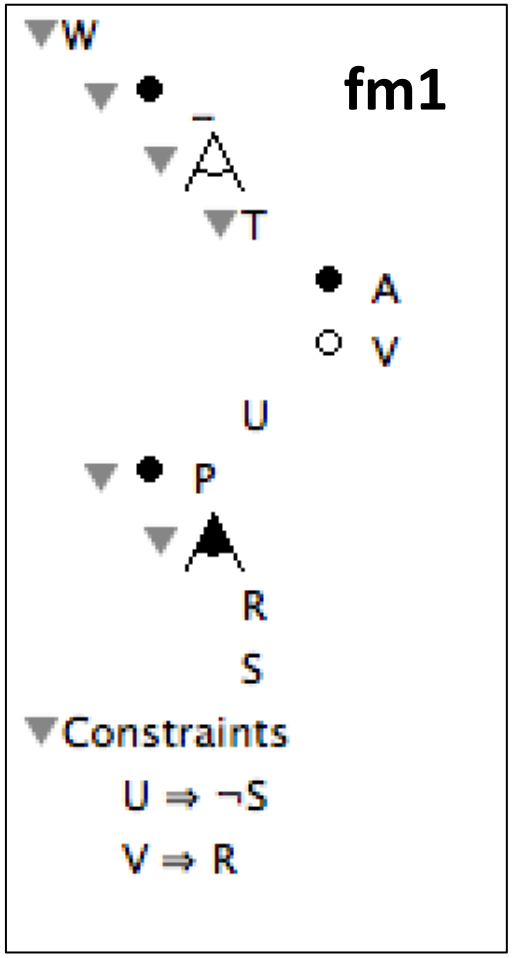


$$[\![fm1]\!] = \{$$
$$\{W, P, R, S, T, A, V\},$$
$$\{W, P, S, T, A\},$$
$$\{W, P, R, T, A\},$$
$$\{W, P, R, U\},$$
$$\{W, P, R, T, V, A\},$$
$$\{W, P, R, S, T, A\},$$
$$\}$$

(Boolean) Feature Models

~ Boolean formula

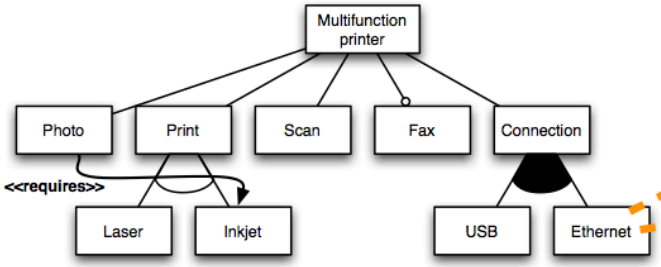




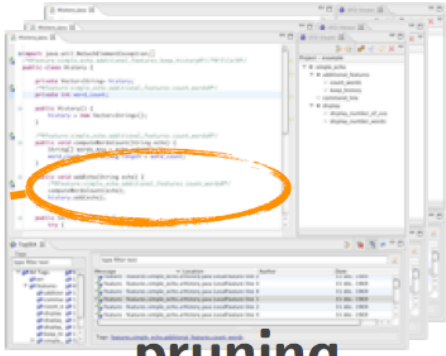
$$
\begin{aligned}
&\phi_{fm_1} = W \;//\; \text{root} \\
&\wedge\, W \Leftrightarrow P \;//\; \text{mandatory} \\
&//\; \text{Or-group} \\
&\wedge\, P \Rightarrow R \vee S \\
&\wedge\, R \Rightarrow P \wedge\; S \Rightarrow P \\
&\wedge\, V \Rightarrow T \;//\; \text{optional} \\
&\wedge\, A \Leftrightarrow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

Product Derivation

feature model



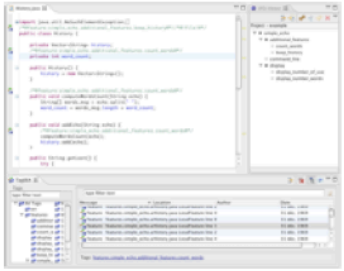
variable model and code assets



pruning,
composition,
weaving,
transformation
...

configuration

{ MP, Photo, Print, Inkjet, Scan,
Fax, Connection, USB, Ethernet }

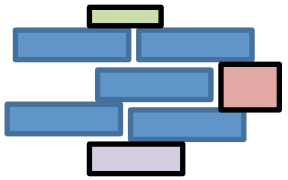


product spec

product

Summary

- **Software product line engineering**
  - Mass customization
  - Family of software intensive systems
  - Systematic reuse
  - Domain engineering
  - Variability management



- **Variability** everywhere
  - Applied and applicable to many industries and domains

- **Modeling** and **implementing** variability: an overview