

Software Product Lines

Part 1: Introduction and Overview

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with courtesy of: **Sven Apel**, **Christian Kästner**, **Gunter Saake**

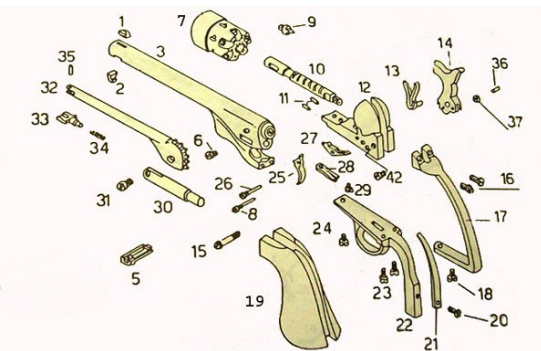
Agenda

- ▶ Formal and organizational matters
- ▶ A short introduction to the topic
 - ▶ Product lines in industry
 - ▶ Software product lines
 - ▶ Challenges to software product lines

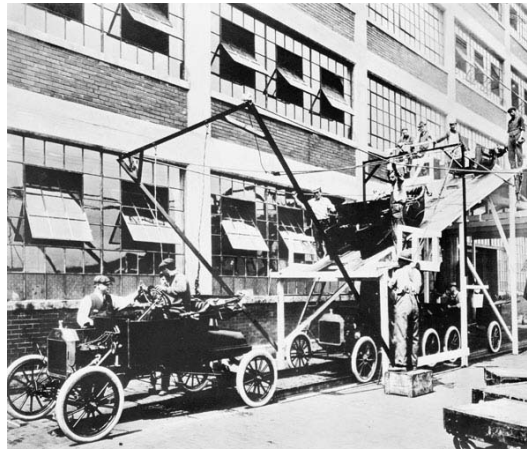


Background

Industrial revolution



1826
exchangeable parts
(John Hall, after 25 years of trying)



1901
conveyor belt
(Ransom Olds/Henry Ford)



1980s
automated production line
(first industrial robot 1961
at General Motors)

[Czarniecki & Eisenecker 2000]

Product lines in industry



Car product line

BMW Deutschland - Mozilla Firefox

File Edit View Go Bookmarks Tools Help

http://www.bmw.de/de/de/index_narrowband.html?content=.../de/de/general/configurations_center/configurator.htm

Getting Started Latest Headlines


Home 1 3 5 6 7 X3 X5 Z4 M Gebrauchte Automobile Service & Zubehör Faszination BMW

Mein BMW Kontakt **BMW Konfigurator** BMW Händler & Service Partner Finanzieren & Versichern Shops Direktabnehmer

BMW Konfigurator

Zurück

BMW Konfigurator



318i Touring
Gesamtpreis | Monatliche Rate
34.970,00 EUR

Fahrzeugdaten ausdrucken
Finanzierung und Leasing
Beenden und Speichern
Hinweis zu Preisangaben

Tipps zum Car Configurator

Modell Grundausrüstung Farbe, Interieur + Felgen Editionen + Pakete **Sonderausstattungen** Zusammenfassung

Getriebe | Klima, Heizung | Komfort/Nutzen | Optik innen/außen | Polsterungen, Sitze | Radio, Audio, Kommunikation, Info | Sicherheit | Sportlichkeit

Suchen Alle

Ausstattung	Code	Preis
Getriebe		
<input checked="" type="checkbox"/> Automatic Getriebe	Bild-1 205	2.160,00 EUR
Klima, Heizung		
<input checked="" type="checkbox"/> Standheizung mit Fernbedienung	Bild-1 536	1.340,00 EUR
<input type="checkbox"/> Sonnenschutzverglasung, Individual	1 761	390,00 EUR
<input checked="" type="checkbox"/> Klimaautomatik mit Fondausströmern	Bild-1 534	770,00 EUR Preis-1
Komfort/Nutzen		
<input type="checkbox"/> Ablagenpaket	Bild-1 493	110,00 EUR
<input type="checkbox"/> Armauflage vorn, verschiebbar	Bild-1 4AE	150,00 EUR Preis-1
<input type="checkbox"/> Außenspiegelpaket	Bild-1 313	240,00 EUR

Suche Sitemap Website Einstellungen Weitere BMW Websites Rechtlicher Hinweis / Impressum Zur Video-Version

Waiting for ecom.bmwgroup.com...

Diversity of variants

Example: BMW X3



Ceiling:
90.000
variant options

Car doors:
3.000
variant options

Rear axle:
324
variant options

„Variants are a significant leverage for our operating results.“

— **Franz Decker**, head of variant management programme, BMW Group

Car product lines 20 years ago

- ▶ Choice was restricted to models and a few extras, like roof-mounted luggage rack or alternative CD player
- ▶ One variant (Audi 80, 1.3l, 55PS) = 40% of sales



Car product lines today

- ▶ 10^{20} possible variants of an Audi
 10^{32} possible variants of a BMW
- ▶ Hardly a car leaves the production plant with the same features as the one before it
- ▶ 100 different floor units for one model, based on engine and equipment
- ▶ 50 different steering wheels (3 vs. 4 spokes, wood vs. plastic vs. leather, heating, colors)



Not just cars....



Create and buy your own unique bike



More product lines

Willkommen bei selve - the shoe individualizer

http://www.selve.net/index_js.html

KOLLEKTION FUSSTYP MYSELVE INFO HOME selve

MODELLE
LOOKBOOK

selve

selve Kollektion -> Style: casuals -> Modell: Opal

modell-details
>>hier klicken

>>SELVE SCHUHREGAL
inhalt: 0

>>SHOPPING BAG
inhalt: 0

A. Erstes Oberleder
Veloursleder Sand

B. Veloursleder Bordeaux
Veloursleder Cognac
Veloursleder Sand

C. Futterleder
Beige

D. Absatz
Hufeisen Braun

E. Sohle
Gummisohle

>>ÄNDERN
>>ZURÜCKLEGEN

More product lines



More product lines

The screenshot shows the mymuesli website in a Mozilla Firefox browser window. The website has a clean, modern design with a white background and orange accents. The main navigation bar includes links for 'muesli', 'mixer', 'blog', 'fragen', and 'about us'. On the left side, there is a sidebar with buttons for 'Müslibasis', 'Basis verfeinern', 'Früchte' (highlighted in pink), 'Nüsse & Kerne', and 'Extras'. The main content area is titled 'Früchte' and lists three fruit options: 'Ananas' (Pineapple), 'Apfelstücke' (Apple pieces), and 'Aprikosen' (Apricots). Each option includes a description, price, and a 'mehr Infos' link. A large pink arrow points from the 'Apfelstücke' section to a detailed product view on the right. This view shows a cylindrical container of the selected muesli mix, listing the ingredients: 'Apfelstücke', 'Buchweizenflocken', and 'C'Mohn, baby!'. It also displays the price '575g nur 4,70€' and a 'weiter' button. The footer includes logos for 'Bio' and 'Öko-Kontrollstelle DE-037'.

mymuesli
custom-mixed cereals

muesli mixer blog fragen about us

Müslibasis
Basis verfeinern
Früchte
Nüsse & Kerne
Extras

Früchte

Köstliche Bio-Trockenfrüchte, müsligerecht aufbereitet. Du kannst eine Frucht auch mehrmals auswählen, um deren Anteil zu steigern.

Ananas
lecker, exotisch und wunderbar | 0.65€ (30g)
[mehr Infos](#)

Apfelstücke
Ohne Worte weil Klassiker | 0.45€ (25g)
[mehr Infos](#)

Aprikosen

[hoch](#) [runter](#)

Apfelstücke
Buchweizenflocken
C'Mohn, baby!

Nährwerte pro 100g ▲
575g nur 4,70€
entspricht 8,17€/kg
inkl. MWSt., zzgl. Versandkosten

fertig gemixt?
[weiter](#)

©2011 mymuesli GmbH
Öko-Kontrollstelle DE-037
[Impressum](#)

More product lines

Der Dell Online-Shop: Stellen Sie Ihr eigenes System zusammen - Mozilla Firefox

File Edit View Go Bookmarks Tools Help

http://configure2.euro.dell.com/dellstore/config.aspx?c=de&cs=dedhs1&kc=305&l=de&oc=W06390xp&s=dhs&sbc=pr

Getting Started Latest Headlines

Bestellen Sie online oder wählen Sie 0800 533 55 40 03(gebührenfrei)

DELL™ Produkte Service Support Einkaufsunterstützung

Suche

Dell empfiehlt Windows Vista™ Home Premium.

Sie befinden sich hier: Deutschland > PRIVATANWENDER

1 Meinen Dell konfigurieren 2 Zubehör auswählen 3 Elektronik 4 Software & Service 5 Bestätigen & zum Warenkorb

Als Symbol anzeigen

ELC DDR2-Speicher mit 4,0 GB und 667 MHz (2 x 2,0 GB DIMM) [plus 019,99 € oder 20 €/Monat¹]

Grafikkarte

128 MB nVidia NVS285 DVI/VGA-Grafikkarte

Auswahlhilfe

- ☐ 256 MB ATI Fire GL V7200-Grafikkarte [plus 416,50 € oder 13 €/Monat¹]
- ☐ 128 MB nVidia Quadro FX550-Grafikkarte [plus 69,02 € oder 2 €/Monat¹]
- ☐ 256 MB nVidia Quadro FX3450-Grafikkarte [plus 547,40 € oder 17 €/Monat¹]
- ☒ 128 MB nVidia NVS285 DVI/VGA-Grafikkarte [Im Preis enthalten]
- ☐ Grafikkarte PCIe x16 (DVI/VGA) Matrox QID LP PCIe, 128 MB, DVI- oder VGA-Grafikkarte für 4 Monitore [plus 630,70 € oder 20 €/Monat¹]
- ☐ 128 MB ATI Fire GL V3400-Grafikkarte [plus 44,03 € oder 1 €/Monat¹]

Festplatte

80 GB Serial ATA-II-Festplatte (7.200 U/min) mit NCQ

Auswahlhilfe

- ☐ 160 GB Serial ATA-II-Festplatte (7.200 U/min) mit NCQ [plus 16,66 €]
- ☒ 80 GB Serial ATA-II-Festplatte (7.200 U/min) mit NCQ [Im Preis enthalten]

Transferring data from i.dell.com...

Sicher einkaufen mit Trusted Shops und 30-tägige Geld-zurück-Garantie.

Dell Precision™ 390 Essential (W06390xp)

inkl. MwSt., zzgl. 19,04 € Versand
Ermäßigter Sonderpreis
913,92 €
Es gelten keine zusätzlichen Preisnachlässe.
Das Angebot gilt für maximal 5 Systeme

Finanzierung ab **30 €/mtl.**²
Jetzt finanzieren - erst ab Januar 2008 zahlen!
Weitere Informationen zur Ratendifinanzierung

Für einen noch umfassenderen Schutz Ihres Systems beinhaltet der oben erwähnte Preis ein Upgrade Service Paket. Um auf den beworbenen Preis zu kommen, entmarkieren Sie die Kategorie "Business Support".

More product lines

VEGETARIAN

WHICH WICH WOULD YOU LIKE?

☐ TRIPLE CHEESE MELT
☐ ELVIS WICH (P.B., Honey & Bananas)
☐ TOMATO & AVOCADO
☐ BLACK BEAN PATTY
☒ HUMMUS & BELL PEPPERS

CHOOSE YOUR BREAD

☐ WHITE ☒ WHEAT

CHOOSE YOUR CHEESE (Optional)

☐ AMERICAN ☐ SWISS ☐ PROVOLONE
☐ CHEDDAR ☒ PEPPER JACK ☐ MOZZARELLA

How Would You Like Your WICH Worked?

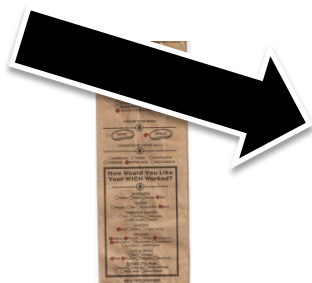
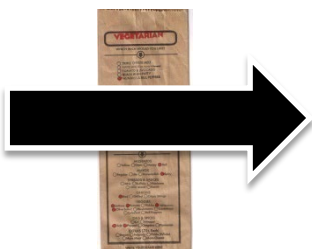
MUSTARDS
☐ Yellow ☐ Dijon ☐ Honey ☒ Deli

MAYOS
☐ Regular ☐ Lite ☐ Horseradish ☒ Spicy

SPREADS & SAUCES
☐ BBQ ☐ Buffalo ☐ Marinara
☐ 1000 Island ☐ Ranch

ONIONS





And Software?

- ▶ Modern application software systems are Swiss army knives
 - ▶ Bsp.: Windows 10, Open Office, Oracle, SAP myERP, Adobe Photoshop, AutoCAD
- ▶ Specialized software und systems for embedded systems more and more important
 - ▶ Bsp.: phones, sensor networks, microwaves, TVs, weather stations, cars, chip cards, on-board computers, routers, ubiquitous computing
 - ▶ 98% of computing systems in use are embedded systems
 - ▶ Resource constraints and heterogenous hardware require custom-tailored solutions
 - ▶ Frequent from-scratch development, long time-to-market, high development costs

Why custom-tailored software?

- ▶ Personalization

- ▶ Individual requirements, Look-and-Feel, special algorithms, law settings, hardware, ...

- ▶ Resource constraints

- ▶ Energy consumption, performance, memory use,

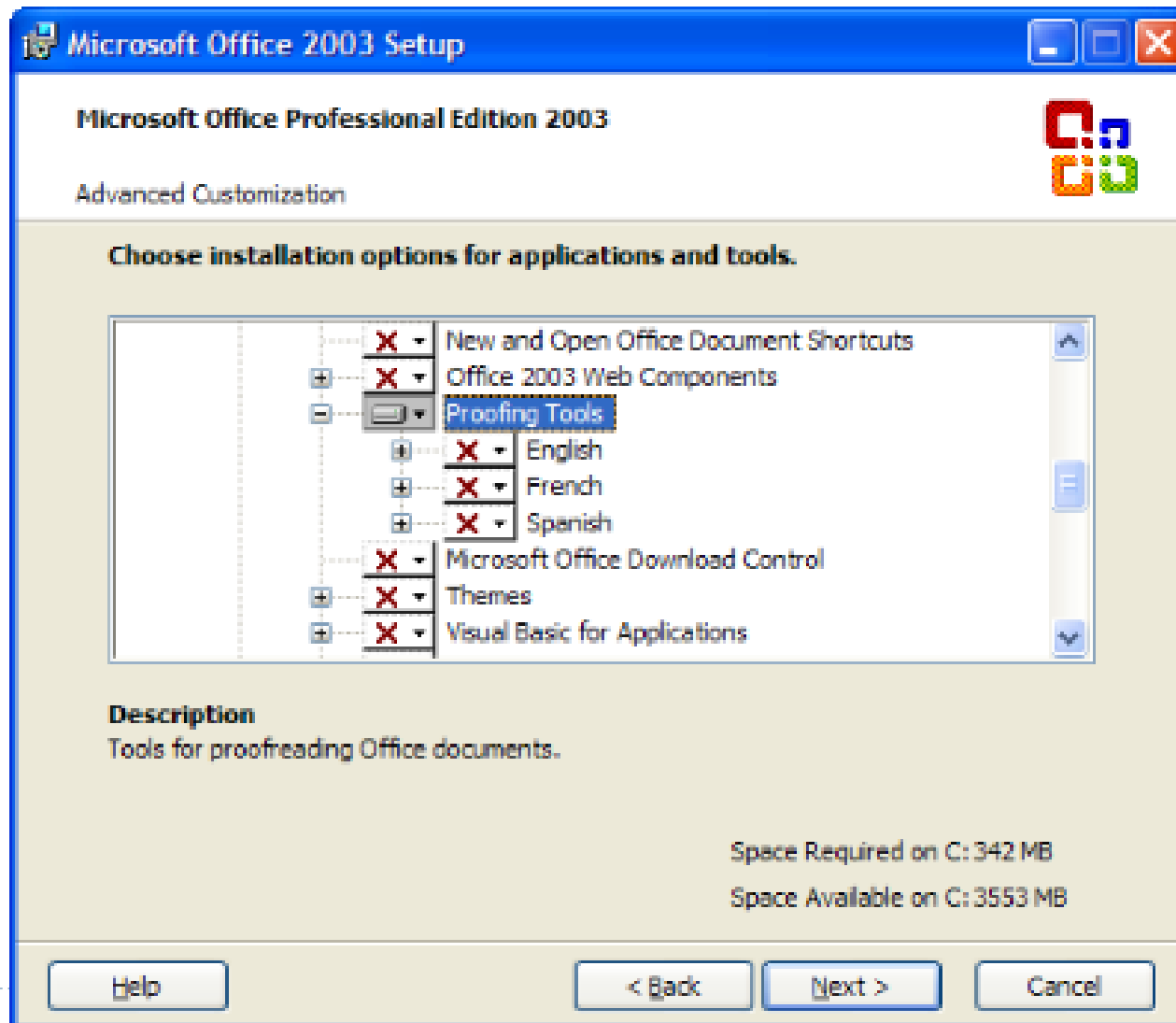
- ▶ Software and product quality

- ▶ Usability
 - ▶ Unused functionality as a risk
 - ▶ Maintenance and testing effort grows with amount of functionality

- ▶ Costs, effort, flexibility, competition...

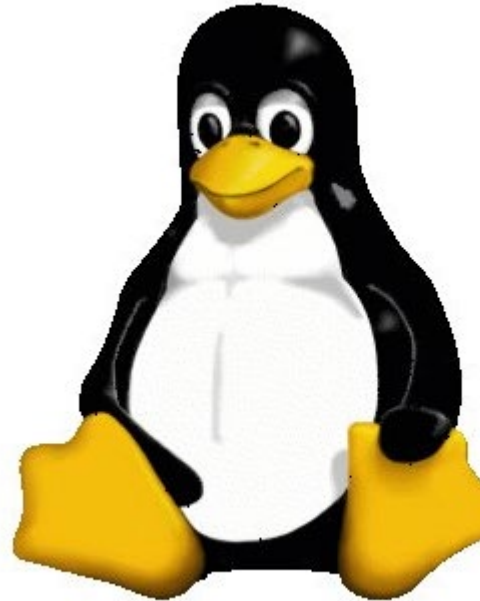


Features in Microsoft Office



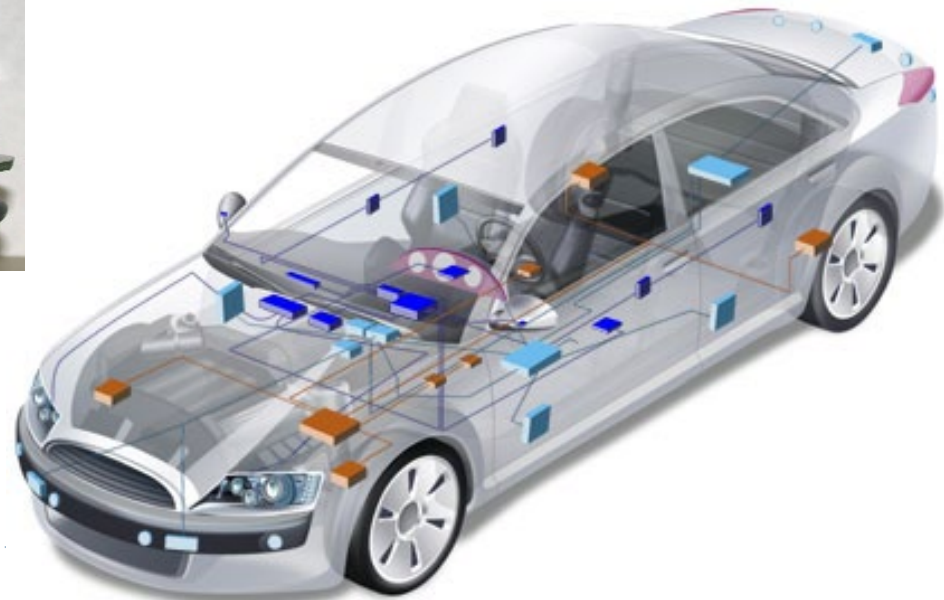
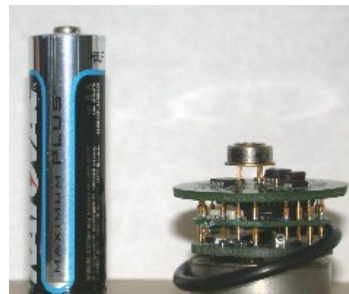
Linux kernel

- about 6.000.000 lines of source code
- highly configurable
 - > 10.000 configuration options! (x86, 64bit, ...)
 - almost all source code is „optional“



Databases

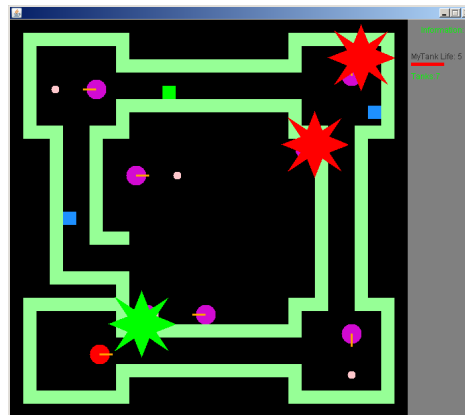
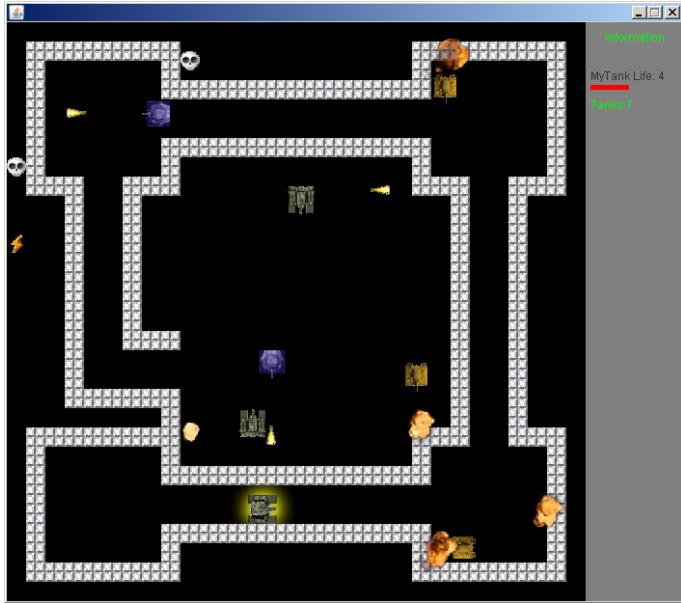
- ▶ Continuously increasing amounts of data
- ▶ Often embedded into contexts with resource constraints



Printer firmware



Games



Software product lines in industry

- ▶ HP: printer drivers/firmware
- ▶ Nokia: phone software, browser
- ▶ Phillips: high-end TVs, medical technology, ...
- ▶ TomTom: embedded navigation systems
- ▶ Cummins: Diesel engine control software
- ▶ LG: lift control software
- ▶ Ericsson: telecommunication switches
- ▶ General Motors: powertrains
- ▶ Many more: gas turbines, train control, ship control, frequency converter, internet payment gateway, helicopter avionics software, ...

Goal of course

- ▶ Techniques for developing custom-tailored software that contains exactly the required functionality
 - ▶ Variants for different use-cases
 - ▶ Can easily add new variants, fast further development, reuse of proven functionality
 - ▶ Customer-specific production, specialization
 - ▶ Customization to available resources
- ▶ Software product lines (SPLs):
Configuration by selection of features (Dutch: kenmerken)

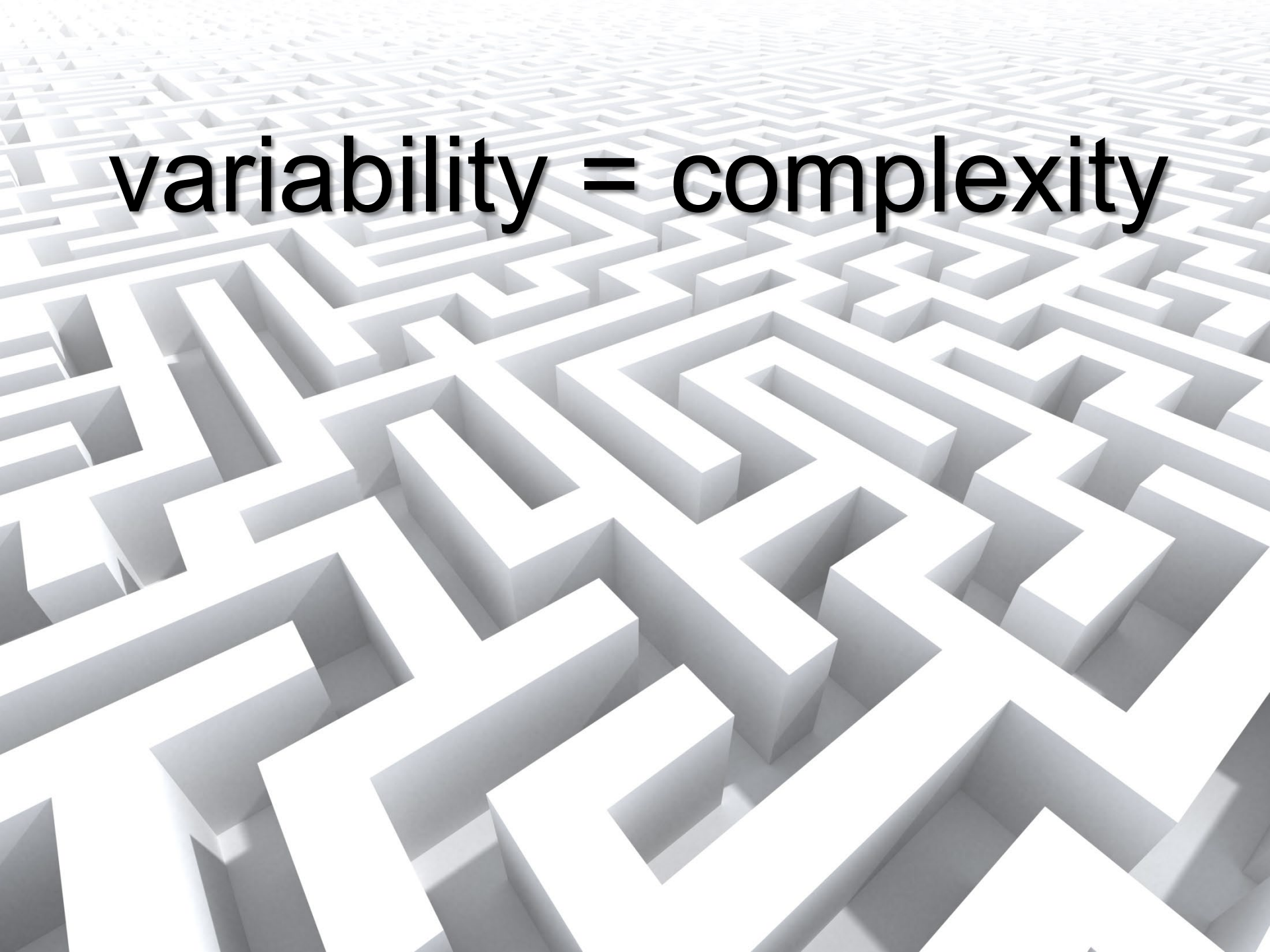
Estimation

about 80% of all software systems are software product lines or can benefit from software product line technology



Challenges

variability = complexity



VEGETARIAN

WHICH WICH WOULD YOU LIKE?



- ☐ TRIPLE CHEESE MELT
- ☐ ELVIS WICH (P.B., Honey & Bananas)
- ☐ TOMATO & AVOCADO
- ☐ BLACK BEAN PATTY
- ☒ HUMMUS & BELL PEPPERS

CHOOSE YOUR BREAD



- ☐ WHITE
- ☒ WHEAT

CHOOSE YOUR CHEESE (Optional)



- ☐ AMERICAN
- ☐ SWISS
- ☐ PROVOLONE
- ☐ CHEDDAR
- ☒ PEPPER JACK
- ☐ MOZZARELLA

How Would You Like Your WICH Worked?



MUSTARDS

- ☐ Yellow
- ☐ Dijon
- ☐ Honey
- ☒ Deli

MAYOS

- ☐ Regular
- ☐ Lite
- ☐ Horseradish
- ☒ Spicy

SPREADS & SAUCES

- ☐ BBQ
- ☐ Buffalo
- ☐ Marinara
- ☐ 1000 Island
- ☐ Ranch

ONIONS

- ☒ Red
- ☐ Grilled
- ☐ Crispy Strings

VEGGIES

- ☒ Lettuce
- ☒ Tomato
- ☐ Pickles
- ☒ Jalapenos
- ☒ Olive Salad
- ☐ Mushrooms
- ☐ Sauerkraut
- ☐ Coleslaw
- ☐ Bell Peppers

OILS & SPICES

- ☐ Oil
- ☐ Vinegar
- ☒ Salt
- ☒ Pepper
- ☐ Oregano
- ☐ Parmesan

EXTRAS (.75¢ Each)

- ☐ Bacon
- ☐ Avocado
- ☐ Pickle (Whole)
- ☐ More Meat
- ☐ More Cheese

33 optional, independent
features



one custom-tailored variant for
every human on the planet



320^{optional, independent} features

more variants than
atoms in the universe!



2000 features

10000 features



correctness?



A problem has been detected and windows has been shut down to prevent damage to your computer.

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:

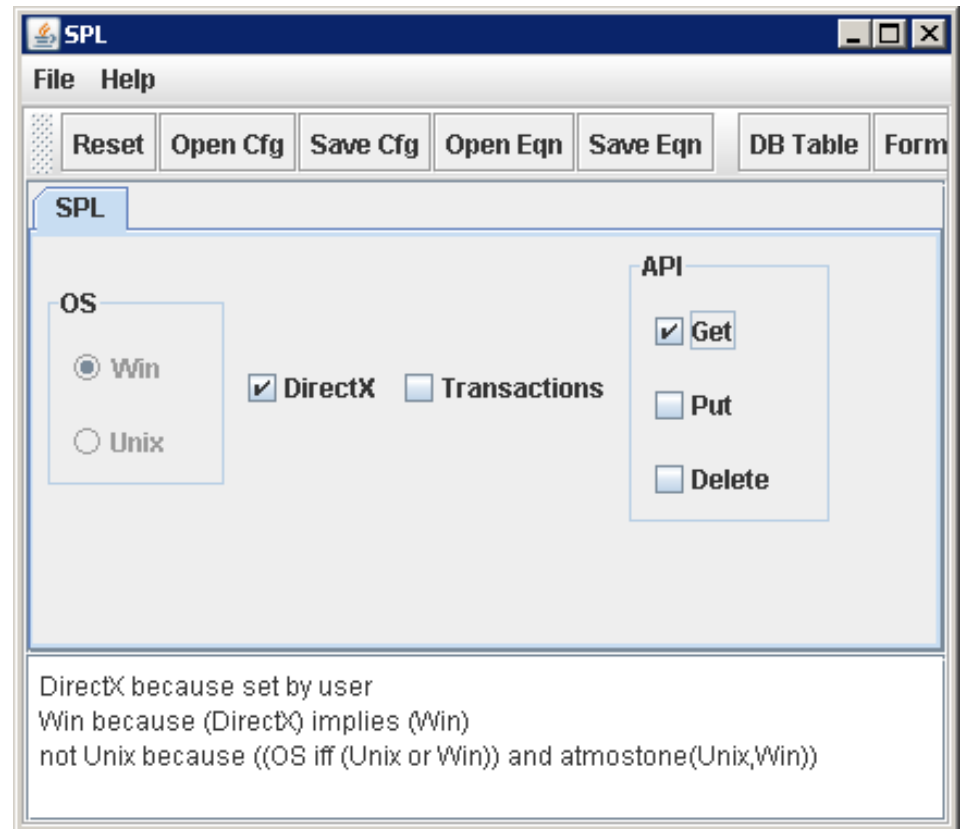
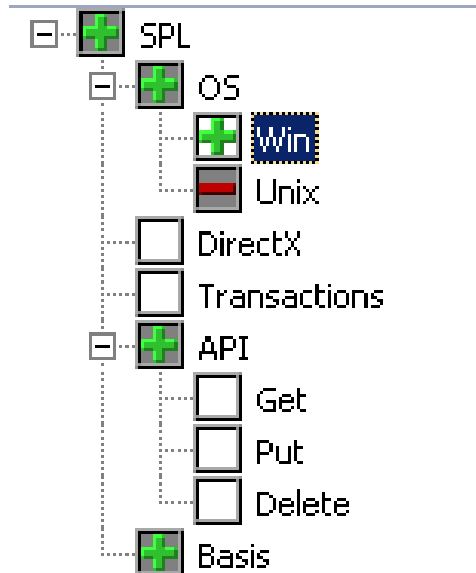
*** STOP: 0x00000050 (0x800005F2, 0x00000000, 0x804E83C8, 0x00000000)

Beginning dump of physical memory
Physical memory dump complete.

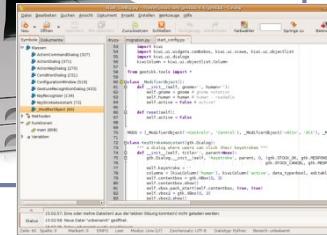
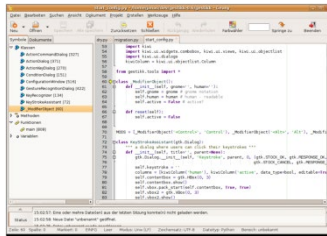
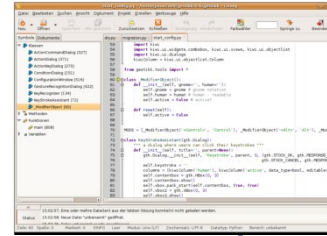
Contact your system administrator or technical support group for further assistance.



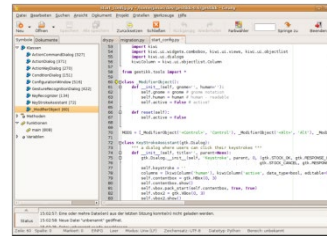
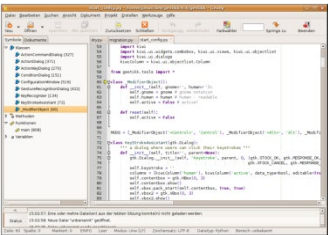
are all combinations useful?



Reuse during implementation?



Where correct errors?



Idee: Systematic development process

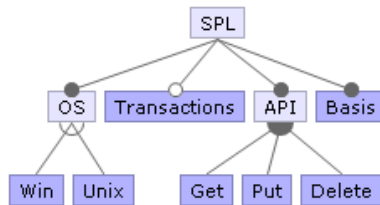
- ▶ Developing new variants from scratch is not economically feasible
- ▶ Creating variants by „clone and own“ is a possibility, but comes with many problems in practice
- ▶ Therefore: Custom-tailored software based on software product lines
 - ▶ From reusable parts
 - ▶ That can have alternative implementations
 - ▶ Customizable for specialized use-cases
 - ▶ Even usable in presence of extreme resource constraints



Design and implementation of features

Domain Eng.

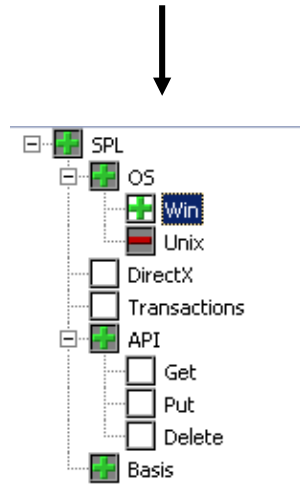
Feature model



Reusable implementation artifacts



Application Eng.



Feature selection



Generator

	CUST_NO	CUSTOMER	CONTACT..	CONTACT..	PHONE
1	1,001	Signature ..	Dale J.	Little	(619) 531
2	1,002	Dallas Tec ..	Glen	Brown	(214) 961
3	1,003	Buttle, Griff ..	James	Buttle	(617) 481
4	1,004	Central Bank	Elizabeth	Brocket	61 211 9
5	1,005	DT Systems	Tai	Wiu	(852) 851
6	1,006	DataServe ..	Tomas	Bright	(613) 221
7	1,007	Mrs. Beauv ..		Mrs. Beauv ..	
8	1,008	Anini Vacat ..	Lellani	Briggs	(809) 831
9	1,009	Max	Max		22 01 23
4	1,010	MDM Corp	Munster	Munster	2 000 77

Record 1 of 15

Final program

Non-functional properties

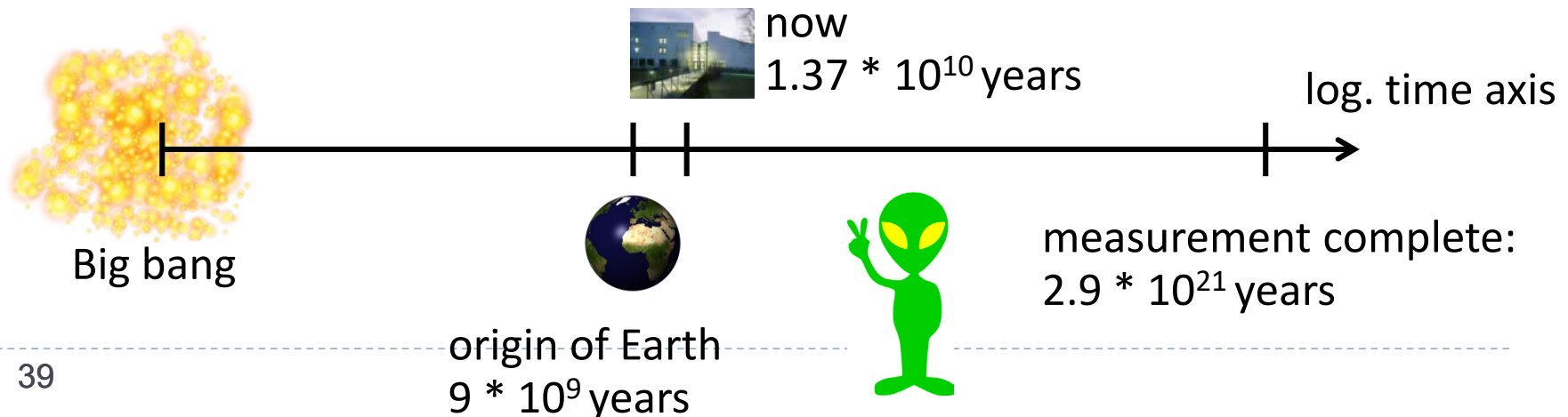
- ▶ Constraints and optimisation
- ▶ Optimisation for low energy consumption
- ▶ Optimisation for high performance
- ▶ Optimisation for low footprint
- ▶ Special implementation
(e.g., no RAM; few writing accesses)
- ▶ Security



Optimisation of non-functional properties

- ▶ SQLite ist an embedded and customizable system
 - ▶ Used in more than 500 million systems
 - ▶ Configurable with 88 compilation options
- ▶ Assuming we experiment with every SQLite variant:
 - ▶ 2^{88} variants and 5 min. per experiment (compile + benchmark)
 $= 2^{88} * 5\text{min} / 60 (\text{per h}) / 24 (\text{per d}) / 365 (\text{per y}) =$

2944111585058457655296y



Implementation: State of the Art

- ▶ If variant management is done, then mostly with `#ifdef`, templates, make, Git
- ▶ Example: Berkeley DB (`mutex_int.h`)

```
#ifndef _DB_MUTEX_INT_H_
#define _DB_MUTEX_INT_H_

#ifdef HAVE_MUTEX_PTHREADS
#include <pthread.h>

#define MUTEX_FIELDS
pthread_mutex_t mutex; /* Mutex. */
pthread_cond_t cond; /* Condition variable. */
#endif

#ifdef HAVE_MUTEX_UI_THREADS
#include <thread.h>
#endif

#ifdef HAVE_MUTEX_SOLARIS_LWP
#include <synch.h>

#define MUTEX_FIELDS
lwp_mutex_t mutex; /* Mutex. */
lwp_cond_t cond; /* Condition variable. */
#endif

#ifdef HAVE_MUTEX_UI_THREADS
#include <thread.h>
#include <synch.h>

#define MUTEX_FIELDS
mutex_t mutex; /* Mutex. */
cond_t cond; /* Condition variable. */
#endif

#ifdef HAVE_MUTEX_AIX_CHECK_LOCK
#include <sys/atomic_op.h>
typedef int tsl_t;

#ifdef LOAD_ACTUAL_MUTEX_CODE
#define MUTEX_INIT(x) 0
#define MUTEX_SET(x) (!_check_lock(x, 0, 1))
#define MUTEX_UNSET(x) _clear_lock(x, 0)
#endif
#endif
#endif
```

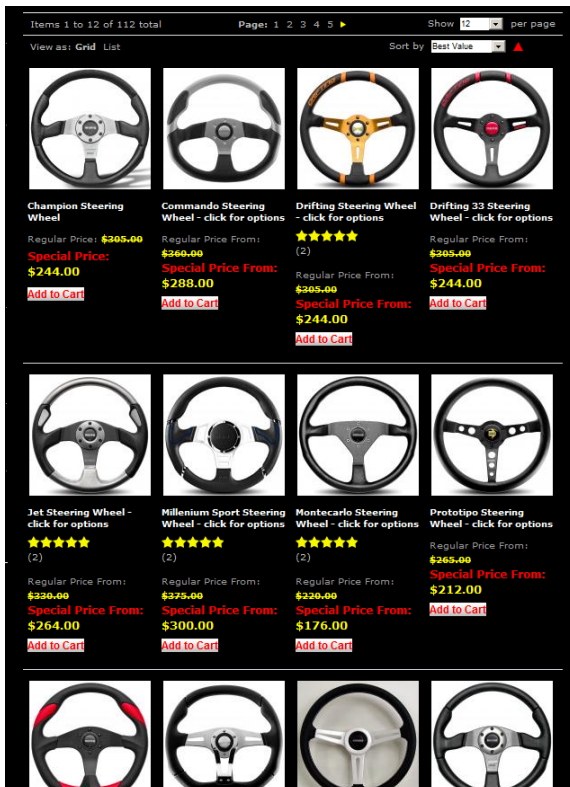

Implementation and maintainability?

```
class Stack {
void push(Object o
#ifdef SYNC
, Transaction txn
#endif
) {
    if (o==null
#ifdef SYNC
        || txn==null
#endif
        ) return;
#ifdef SYNC
    Lock l=txn.lock(o);
#endif
    elementData[size++] = o;
#ifdef SYNC
    l.unlock();
#endif
    fireStackChanged();
}
}
```

SPL implementation

- ▶ Different methods for implementing SPLs
- ▶ In this course we consider, t.ex.:
 - ▶ Versioning systems
 - ▶ Preprocessors
 - ▶ Components
 - ▶ Frameworks/plugins
 - ▶ Feature-oriented programming
 - ▶ Aspect-oriented programming
- ▶ ...and further important topics
 - ▶ Feature interactions
 - ▶ Analysis and testing of software product lines
 - ▶ Virtual separation of concerns

What's a reasonable amount of variability?



Development cost
Investment cost
Maintenance cost
Logistical cost
Product cost (small quantities)

Focus

- ▶ Goal: Custom-tailored software
- ▶ Central concept: Features
- ▶ Focus on implementation of features
- ▶ Much source code, diverse paradigms and language extensions