

# Software Product Line Engineering

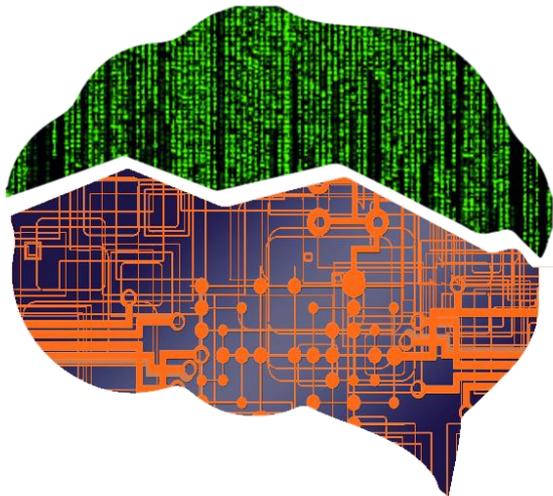
## Introduction and Motivation

Christian Kästner (Carnegie Mellon University)

Sven Apel (Universität Passau)

Norbert Siegmund (Bauhaus-Universität Weimar)

Gunter Saake (Universität Magdeburg)



**Bauhaus-Universität  
Weimar**

# Agenda

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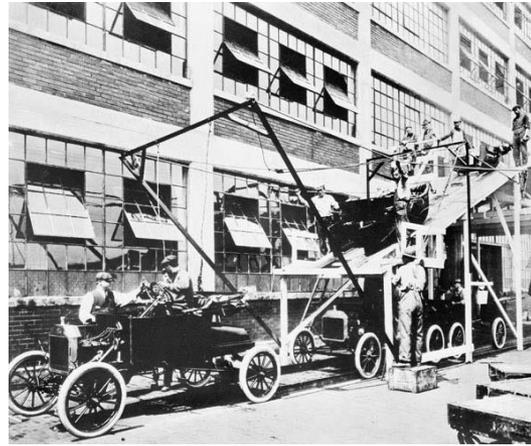
- ▶ Organization
- ▶ Introduction and motivation

# Background

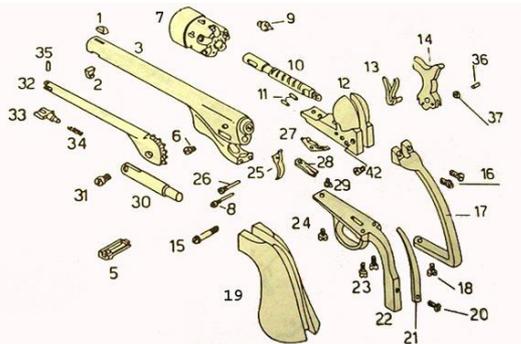
# Industrial Revolution



1980s  
Automated assembly line  
(first industrial robots 1961  
from General Motors)



1901  
Assembly line  
(Ransom Olds/Henry Ford)



1826  
First spare parts  
(John Hall, after 25 years)

[Czarnecki & Eisenecker 2000]

# Product Lines in Industry



# Automotive Product Lines

BMW Deutschland - Mozilla Firefox

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 Grundausstattung Farbe, Interieur + Felgen Editionen + Pakete **Sonderausstattungen** Zusammenfassung

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

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

Suchen Alle

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

Waiting for ecom.bmwgroup.com...

# Variant-rich Systems

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Example: BMW X3



90,000 variants  
for the ceiling

3,000 variants  
for the doors

324 variants  
for rear suspension

***„Variants are a main source for economical success.“***  
— Franz Decker, Leader: Program Variant Management, BMW Group

# Automotive Product Lines 20 Years Ago

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- ▶ Choice of car was limited to the type and some small extras, such as cassette deck
- ▶ One single variant (Audi 80, 1.3l, 55PS) was responsible for 40% of the sales



# Automotive Product Lines Now

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- ▶  $10^{20}$  variants of a single Audi;  
 $10^{32}$  variants of a single BMW
- ▶ Nearly no identical car leaves production
- ▶ Just the base platform has 100 different variants for a single model depending on engine and extras
- ▶ There are 50 different steering wheels (3 vs. 4 spokes, wood vs. plastic vs. leather, heating, colors, etc.)



# More Product Lines

ALTERNATE.de - Apple, Nc X

Suchbegriff eingeben...

Mein Konto

Hardware PC Notebook Tablet Software Gaming TV & Audio Foto & Video Telefonie Apple Haushalt Garten Werkzeug Spielzeug Outlet

Topseller Wearables Drohnen PC-Konfigurator Markenportale **ZACKZACK**

Meine Konfiguration  
€ 0,-\*  
» Details ansehen

**1-2-3-Konfigurator**

In 3 Schritten zum Wunsch-PC! Jetzt starten ▶

**Alles perfekt!**  
Der PC nach meinen Wünschen.

Basis-Komponenten	Optionale Komponenten	Software & Service	
<b>Prozessor</b> neue Auswahl	<b>Mainboard</b> neue Auswahl	<b>Prozessorlüfter</b> neue Auswahl	<b>Arbeitsspeicher</b> neue Auswahl
<b>Grafikkarte</b> neue Auswahl	<b>Festplatte</b> neue Auswahl	<b>Gehäuse</b> neue Auswahl	<b>Netzteil</b> neue Auswahl
<b>Betriebssystem</b> neue Auswahl	<b>Optisches Laufwerk</b> neue Auswahl		

▼ Zuletzt angesehen (0)

# More Product Lines

Willkommen bei selve - the shoe individualizer

http://www.selve.net/index\_js.html

KOLLEKTION FUSSTYP MYSELVE INFO HOME

MODELLE  
LOOKBOOK

SELVE ID  
PASSWORT  
>>ANMELDEN

**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

Müsli individuell online mixen! Bio-Müsli. - Mozilla Firefox

File Edit View History Bookmarks Tools Help

http://www.mymuesli.com/muesli/index.php?vw=mixer&ec=step1&mid=1&mnpt=1&type=t0

Müsli individuell online mixen! Bio-M...

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](#)

Done en-US

# More Product Lines

**VEGETARIAN**

WHICH WICH WOULD YOU LIKE?

TRIPLE CHEESE MELT  
 ELVIS WICH (P.B., Honey & Banana)  
 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?**

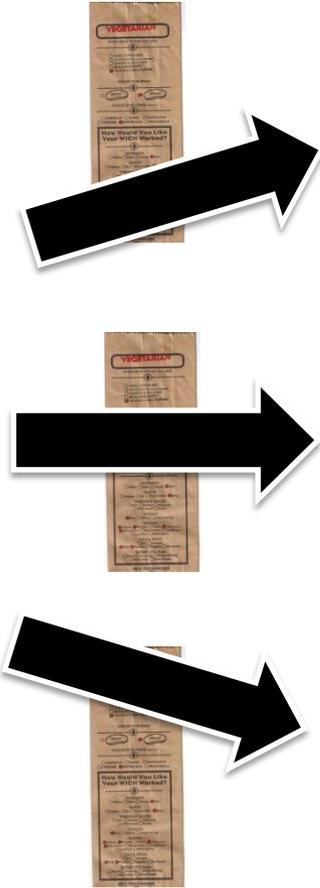
MUSTARDS  
 Yellow  Dijon  Honey  Deli

MAYOS  
 Regular  Lite  Horseradish  Spicy

SPREADS & SAUCES  
 BBQ  Buffalo  Marinara  
 1000 Island  Ranch

ONIONS





# And in Software?

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- ▶ Modern software applications are „Eier-legende Wollmilchsäue“ (all-in-one systems)
  - ▶ Example: Windows, Libre Office, Oracle, SAP myERP, Adobe Photoshop, Mozilla Thunderbird, Gimp
- ▶ Specialized, tailor-made software becomes more important, such as embedded systems' software
  - ▶ Smartphone, sensor networks, TVs, weather station, cars, chip cards, router, ubiquitous computing
  - ▶ 98% of all deployed systems are embedded systems
  - ▶ Resource scarcity and heterogenous hardware requires tailor-made solutions
  - ▶ Often reimplementations, long development times, and high costs

# Why to Tailor Software Systems?

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- ▶ **Personalization**

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

- ▶ **Resource limitations**

- ▶ Energy consumption, performance, memory consumption, ....

- ▶ **Software and product quality**

- ▶ Usability
- ▶ Unused functionality as security risk
- ▶ Maintenance and testing increases with increasing functionality

- ▶ **Costs, effort, flexibility, competitors, ...**



# Features in Microsoft Office

Office



Microsoft Office Customization Tool - custom\_office\_2016.MSP

File Edit View Help

## Microsoft Office Customization Tool

Welcome

**Setup**

- Install location and organization name
- Additional network sources
- Licensing and user interface
- Remove previous installations
- Add installations and run programs
- Office security settings
- Modify Setup properties

**Features**

- Modify user settings
- Set feature installation states

**Additional content**

- Add files
- Remove files
- Add registry entries
- Remove registry entries
- Configure shortcuts**

Outlook

- Outlook profile
- Add accounts
- Export settings

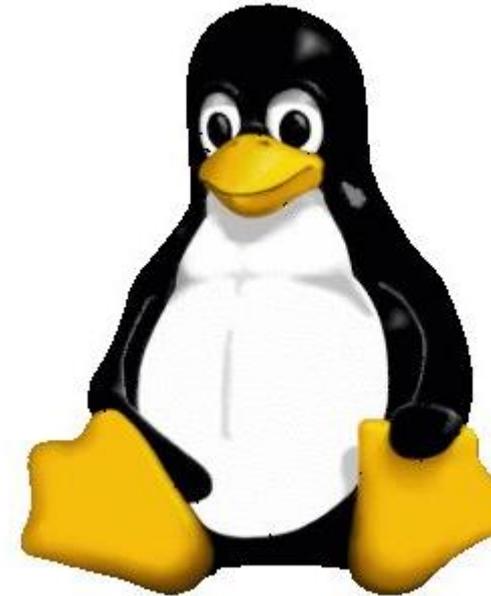
Modify or remove existing shortcuts to Microsoft Office applications, or add new shortcuts to Microsoft Office applications or other applications

Shortcut name	Location
Access 2016	[ProgramMenuFolder]\Microsoft Office 2016
Database Compare 2016	[ProgramMenuFolder]\Microsoft Office\Microsoft Office Tools
Excel 2016	[ProgramMenuFolder]\Microsoft Office 2016
Excel 2016	[DesktopFolder]
Office 2016 Language Preferences	[ProgramMenuFolder]\Microsoft Office\Microsoft Office Tools
Office 2016 Upload Center	[ProgramMenuFolder]\Microsoft Office\Microsoft Office Tools
OneDrive for Business	[ProgramMenuFolder]\Microsoft Office 2016
OneNote 2016	[ProgramMenuFolder]\Microsoft Office 2016
Outlook 2016	[ProgramMenuFolder]\Microsoft Office 2016
PowerPoint 2016	[ProgramMenuFolder]\Microsoft Office 2016
PowerPoint 2016	[DesktopFolder]
Publisher 2016	[ProgramMenuFolder]\Microsoft Office 2016
Skype for Business 2016	[ProgramMenuFolder]\Microsoft Office 2016
Skype for Business Recording Manager	[ProgramMenuFolder]\Microsoft Office\Microsoft Office Tools
Spreadsheet Compare 2016	[ProgramMenuFolder]\Microsoft Office\Microsoft Office Tools
Telemetry Dashboard for Office 2016	[ProgramMenuFolder]\Microsoft Office\Microsoft Office Tools
Telemetry Log for Office 2016	[ProgramMenuFolder]\Microsoft Office\Microsoft Office Tools
Word 2016	[ProgramMenuFolder]\Microsoft Office 2016

# Linux-Kernel

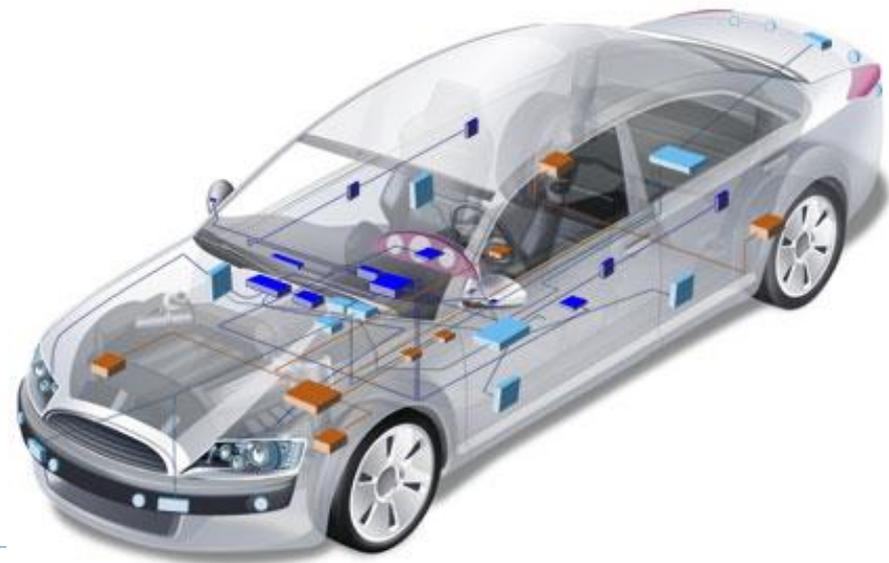
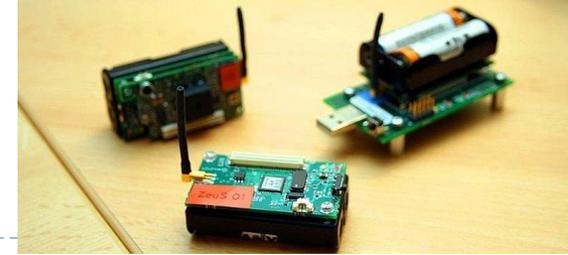
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- About 6.000.000 lines of code
- Highly configurable
  - > 10.000 configuration options! (x86, 64bit, ...)
  - Nearly all the source code is *optional*



# Database Systems

- ▶ Continuous increasing data
- ▶ Often embedded with resource limitations



# Printer Firmware



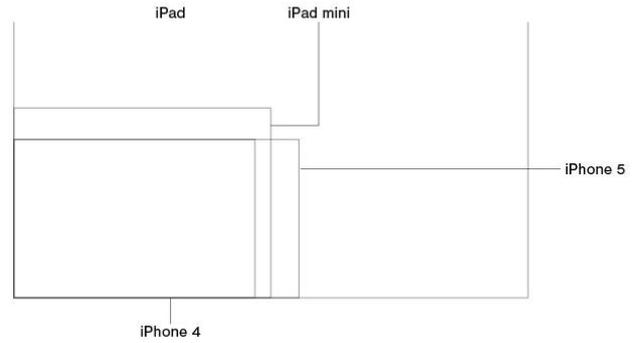
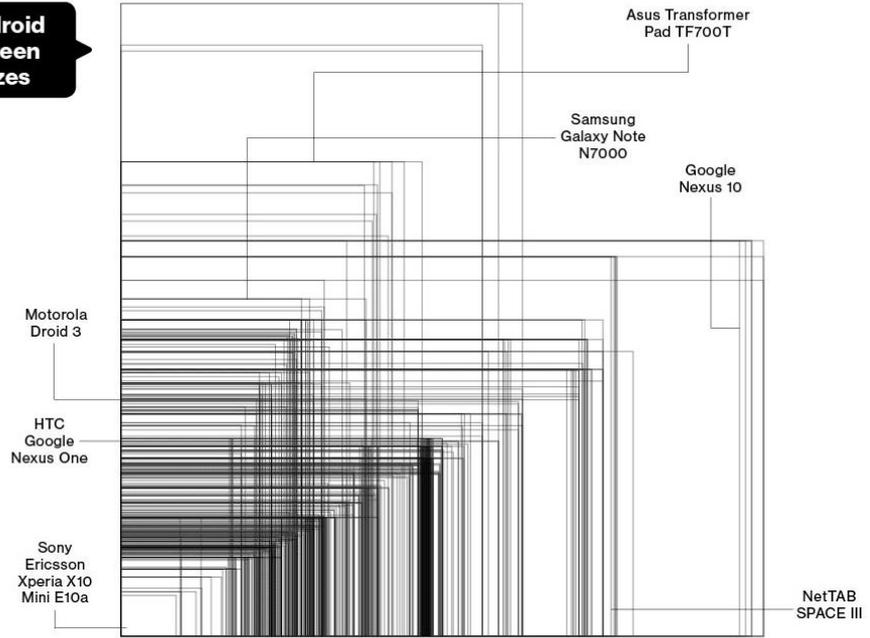
# Games



# Windows Phone



## Android Screen Sizes



# Software Product Lines in Industry

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- ▶ HP: printer driver and firmware
- ▶ Nokia: smart phone software, browser
- ▶ Phillips: high-end TVs, medical technologies, ...
- ▶ TomTom: embedded navigation system
- ▶ Cummins: diesel engine control software
- ▶ LG: elevator control software
- ▶ Ericsson: telecommunication switches
- ▶ General Motors: powertrains
- ▶ May more: gas turbines, train control, ship control, frequency converter, internet payment gateway, helicopter avionics software, ...

# Goal of this Course

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- ▶ Techniques to develop tailor-made software systems that contain exactly the functionality that is actually needed
- ▶ Variants for different application scenarios
  - ▶ New variants are easy to develop; fast and efficient development due to reuse of well-proven functionality
  - ▶ Customer-specific product; specialization
  - ▶ Customization to available resources
- ▶ Software product lines (SPLs): Configuration (customization) via the selection of features (German: Merkmale)

# Estimation

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*About 80% of all software systems today are software product lines or can at least profit from product line technologies.*

# Challenges

**Variability = Complexity**



# 33 optional, independent features



one tailor-made variant for  
**each human on the planet!**

---



320<sup>optional, independent</sup> features

more variants than  
atoms in the whole universe!



2000 features

10000 features



# Are all Combinations Sensible?

The image shows two overlapping windows. The background window is a terminal titled ".config - Linux/arm 3.8.13 Kernel Configuration". It displays a menu of kernel options with "Device Drivers" highlighted. The foreground window is "FeatureIDE - Eclipse Platform", showing a tree view of configuration options for "GraphProductLine".

**Linux/arm 3.8.13 Kernel Configuration**

Arrow keys navigate the menu. <Enter> selects submenus --->. Highlighted letters are hotkeys. Pressing <Y> includes, <N> excludes, <M> modularizes features. Press <Esc><Esc> to exit, <?> for Help, </> for Search. Legend: [\*] built-in [ ] excluded <M> module < > module capable

- General setup --->
- [\*] Enable loadable module support --->
- [\*] Enable the block layer --->
- System Type --->
- Bus support --->
- Kernel Features --->
- Boot options --->
- CPU Power Management --->
- Floating point emulation --->
- Userspace binary formats --->
- Power management options --->
- [\*] Networking support --->
- Device Drivers --->**
- File systems --->
- Kernel hacking --->
- Security options --->
- Cryptographic API --->
- Library routines --->

<Select> < Exit >

**FeatureIDE - Eclipse Platform**

\*Simple.config

- GraphProductLine (invalid, 42 solutions)
  - Algorithms
    - Connected
    - Cycle
    - Shortest
  - Graphs
    - GraphType
      - Directed
      - Undirected
    - Weight
      - Weighted
      - UnWeighted
  - Search
    - DFS
    - BFS
  - Implementation
    - OnlyNeighbors
    - Edges

\*Full.config

- GraphProductLine
  - Algorithms
    - Connected
    - Cycle
    - Shortest
  - Graphs
    - GraphType
      - Directed
      - Undirected
    - Weight
      - Weighted
      - UnWeighted
  - Search
    - DFS
    - BFS
  - Implementation
    - OnlyNeighbors
    - Edges

# 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, 0x804E83CB, 0x00000000)

Beginning dump of physical memory  
Physical memory dump complete.

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

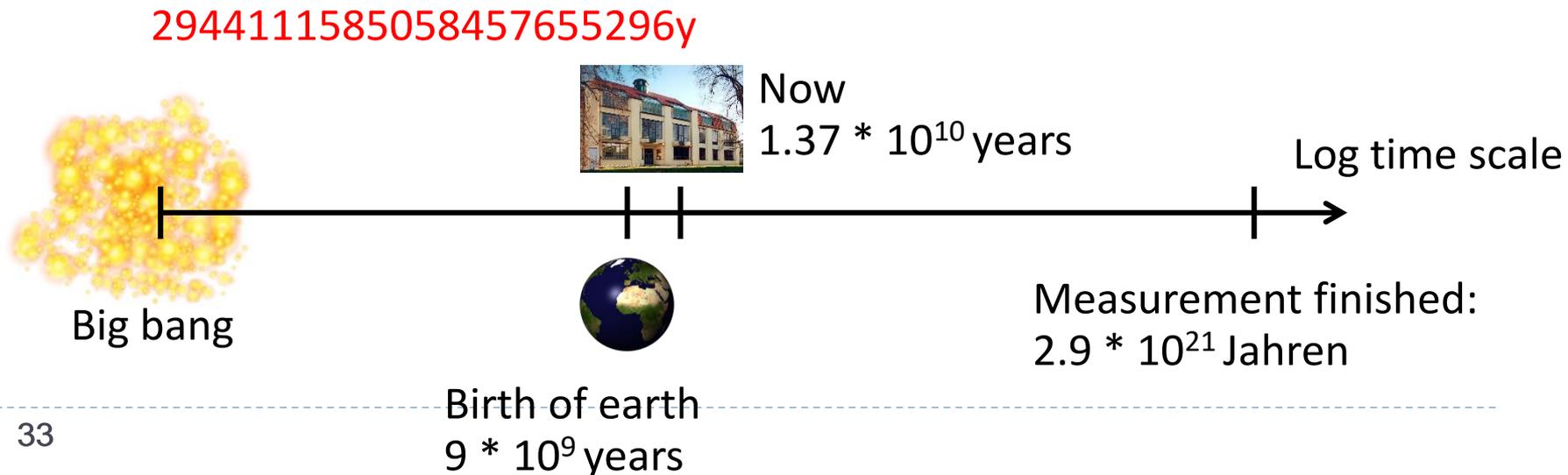


# Performance?



# Optimization of Non-Functional Properties

- ▶ SQLite is an embedded, customizable database system
  - ▶ About 500 million deployments
  - ▶ Provides about 88 compiler options to configure
- ▶ Assuming we measure each variant of SQLite:
  - ▶  $2^{88}$  variants and 5 min per measurement (compile + benchmark) =  $2^{88} * 5\text{min} / 60 (\text{per h}) / 24 (\text{per d}) / 365 (\text{per y}) =$



# Implementation: State of the Art

- ▶ If variability management exists, it relies often on `#ifdef`, templates, make, CVS
- ▶ 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
```

# Effects on Maintainability?

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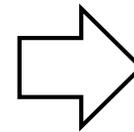
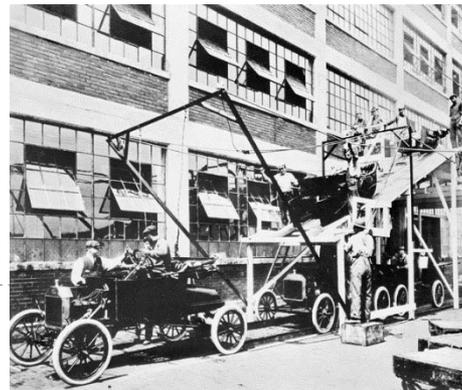
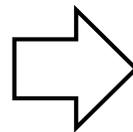
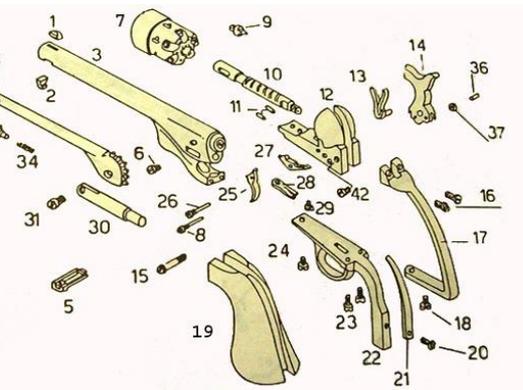
```
class Stack {
void push(Object o
#ifdef SYNC
, Transaction txn
#endif
) {
    if (o==null
#ifdef SYNC
        || txn==null
#endif
        ) return;
#ifdef SYNC
    Lock l=txn.lock(o);
#endif
    elementData[size++] = o;
#ifdef SYNC
    l.unlock();
#endif
    fireStackChanged();
}
}
```



# Idea: Systematic Development of Software Product Lines

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- ▶ Starting the implementation always from scratch is not economical and risky
- ▶ Instead, tailor software based on a product line
  - ▶ Based on reusable parts
  - ▶ Which might have alternative implementations
  - ▶ Which are customizable to specific use cases
  - ▶ Which are usable even for heavily constrained resources



# SPL-Implementation

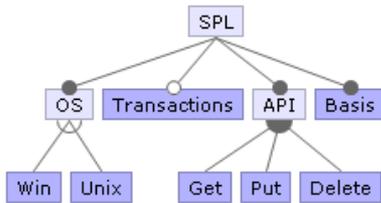
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- ▶ Different approaches to implement SPLs
- ▶ In this course, we consider:
  - ▶ Runtime parameters, version control systems, preprocessors, components, frameworks/plugins
  - ▶ Feature-oriented programming, aspect-oriented programming
- ▶ ...and additional topics:
  - ▶ Feature interactions
  - ▶ Product line analysis
  - ▶ Virtual separation of concerns
  - ▶ Optimization of non-functional properties

# Design and Implementation of Features

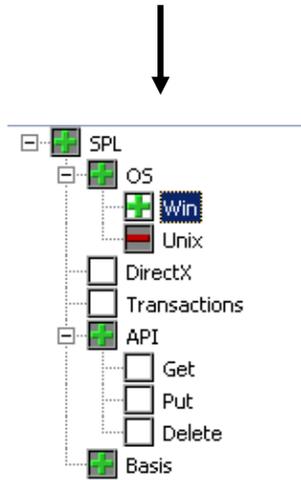
Domain Eng.

Feature model



Reusable implementation artifacts

Application Eng.



Feature selections = configuration



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	Wyu	(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	Misato	Misato	3 000 77

Deployable software system