

Software variability management

Xavier Devroey <x.d.m.devroey@tudelft.nl>

Office 4.W.740 (4th floor, West side, VMB building 28)



Introduction

Variability in hardware



	Samsung Galaxy S6 Edge	Samsung Galaxy S6	HTC M9	Google/Motorola Nexus 6	Apple iPhone 6 Plus	Apple iPhone 6	Motorola Moto X	Sony Xperia Z3	LG G3
Display size (diagonal)	5.1 in	5.1 in	5.0 in	6.0 in	5.5 in	4.7 in	5.2 in	5.2 in	5.5 in
Resolution (pixels)	577ppi	577ppi	441ppi	493ppi	401ppi	326ppi	423ppi	424ppi	538ppi
Weight	132g	138g	157g	184g	172g	129g	144g	152g	149g
Size, in mm (H x W x D)	142.1 x 70.1 x 7.0	143.4 x 70.5 x 6.8	144.6 x 69.7 x 9.6	159.3 x 83 x 10.1	158 x 77.8 x 7.1	138 x 67 x 6.9	140.8 x 72.4 x 9.9	146 x 72 x 7.3 (mm)	146.3 x 74.6 x 8.9
Operating System	Android 5	Android 5	Android 5	Android 5	iOS 8	iOS 8	Android 5	Android 4.4.4	Android 4.4.2
RAM	3GB	3GB	3GB	3GB	1GB	1GB	2GB	3GB	2/3GB
Processor	2.1/1.5GHz, octa-core	2.1/1.5GHz, octa-core	2.1/1.5GHz, octa-core	2.7GHz quad-core	1.4GHz, dual-core	1.4GHz, dual-core	2.5GHz quad-core	2.5GHz quad-core	2.5Ghz quad-core
Internal storage	32/64/128GB	32/64/128GB	32GB	32/64GB	16/64/128GB	16/64/128GB	16/32GB	16/32GB	16/32GB
Storage expansion	none	none	Up to 128GB, MicroSD	none	none	none	none	Up to 128GB, MicroSD	Up to 128GB, MicroSD
Camera (rear/front)	16MP/5.0MP	16MP/5.0MP	20.7MP/4.0MP	13MP/2MP	8MP/1.2MP	8MP/1.2MP	13MP/2MP	20.7MP/2.2MP	13MP/2.1 MP
Video recording	2160p at 30fps	2160p at 30fps	1080p at 30fps	2160 at 30fps	1080p at 60 fps	1080p at 60 fps	2160p at 30fps	2160p at 30fps	2160p at 30fps
Battery life/ capacity	2600 mAh	2550 mAh	2840 mAh	3220 mAh	2915 mAh	1810 mAh	2300 mAh	3100 mAh	3000 mAh
NFC	yes	yes	yes	yes	yes	yes	yes	yes	yes
Wireless charging	yes	yes	no	yes	no	no	no	no	yes
Water/dust resistant	no	no	no	yes	no	no	yes	yes	no
Launch date	April 2015	April 2015	March 2015	October 2014	September 2014	September 2014	October 2014	September 2014	May 2014

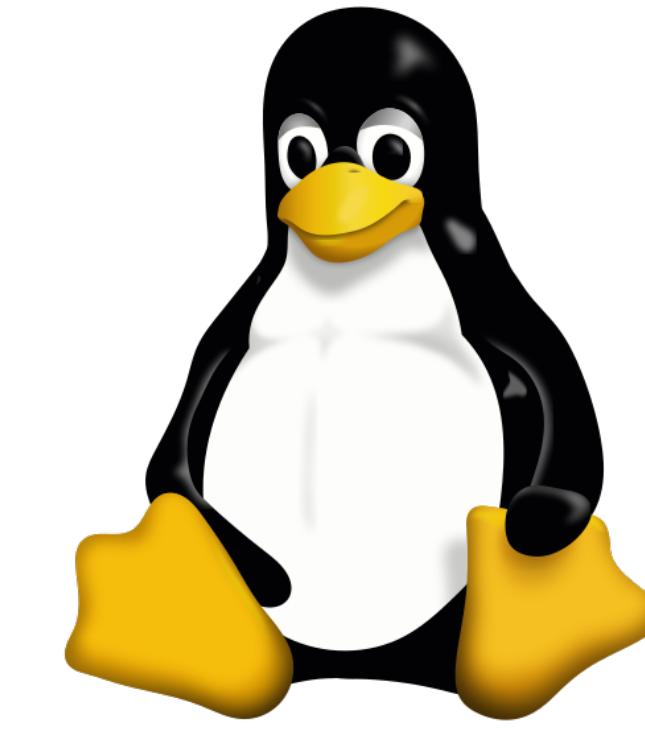
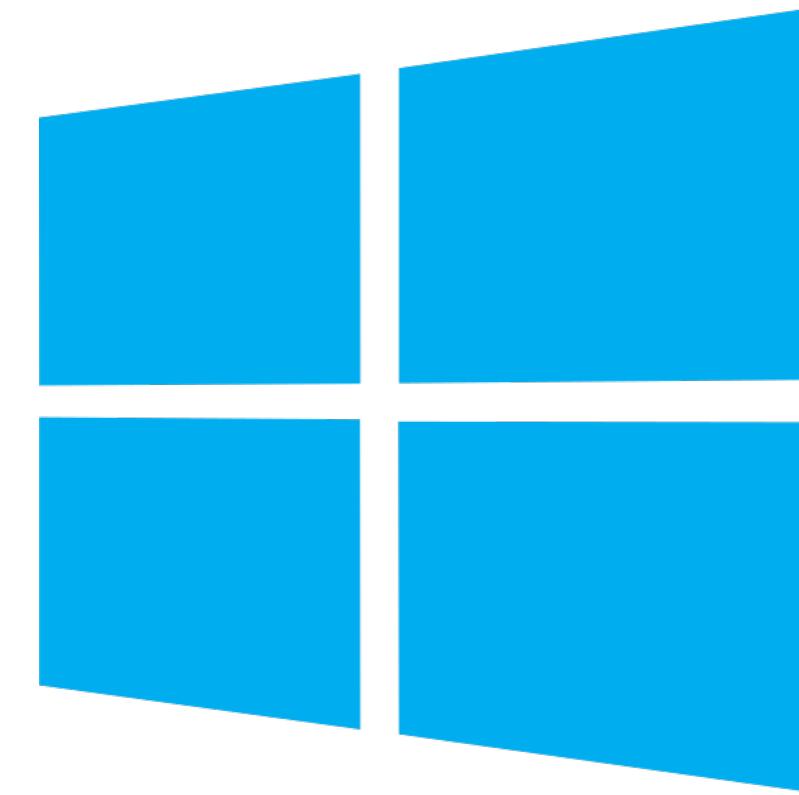
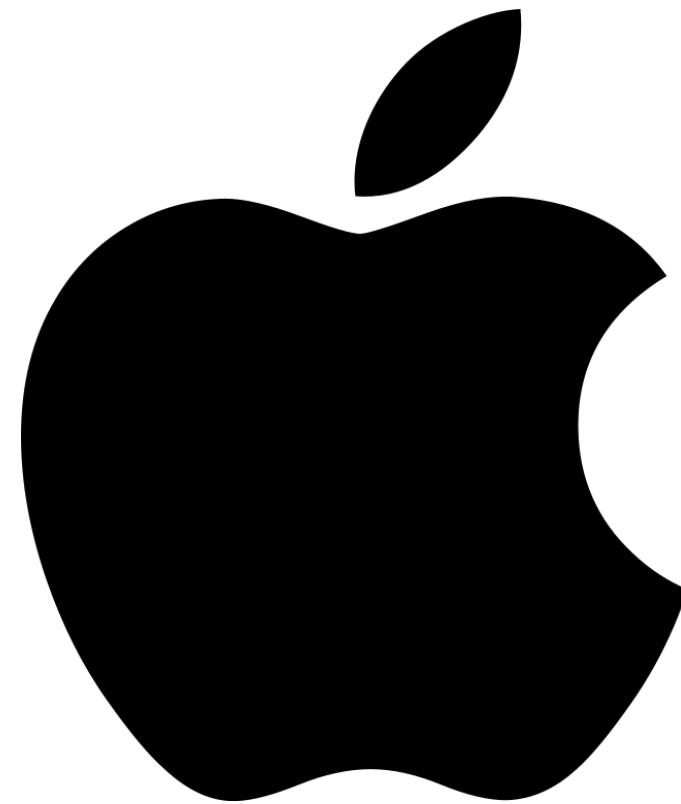
Source: Companies. *Not officially.

C. Inton, 02/03/2015

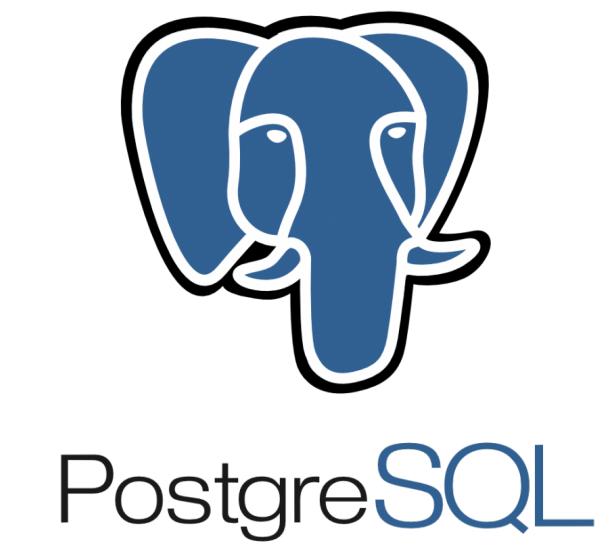
REUTERS

Variability in platforms

Operating System:



Database Management System:



Variability in software



- Bundles

	Java EE	Java	C/C++	PHP	Committees	JavaScript/Web	Java/DSL	Modeling Tools	RCP/RAP	Parallel Application	Testers	Scout
Select packages to compare	<input type="checkbox"/>											
BIRT Framework												
C/C++ Development Tools			✓									✓
Data Tools Platform	✓											
Git integration for Eclipse	✓	✓	✓	✓	✓	✓			✓	✓	✓	✓
Java Development Tools	✓	✓				✓			✓	✓		✓
Java EE Developer Tools		✓										
JavaScript Development Tools		✓				✓						
Jubula Functional Testing												✓
Maven Integration for Eclipse	✓	✓				✓			✓			✓
Mylyn Task List	✓	✓	✓	✓	✓	✓			✓		✓	✓
PHP Development Tools (PDT)						✓						
Parallel Tools Platform												✓
Plug-in Development Environment	✓					✓			✓	✓		
Remote System Explorer	✓		✓				✓					

<https://www.eclipse.org>

Variability in software

- Bundles
- *Command line parameters*

gcc -help

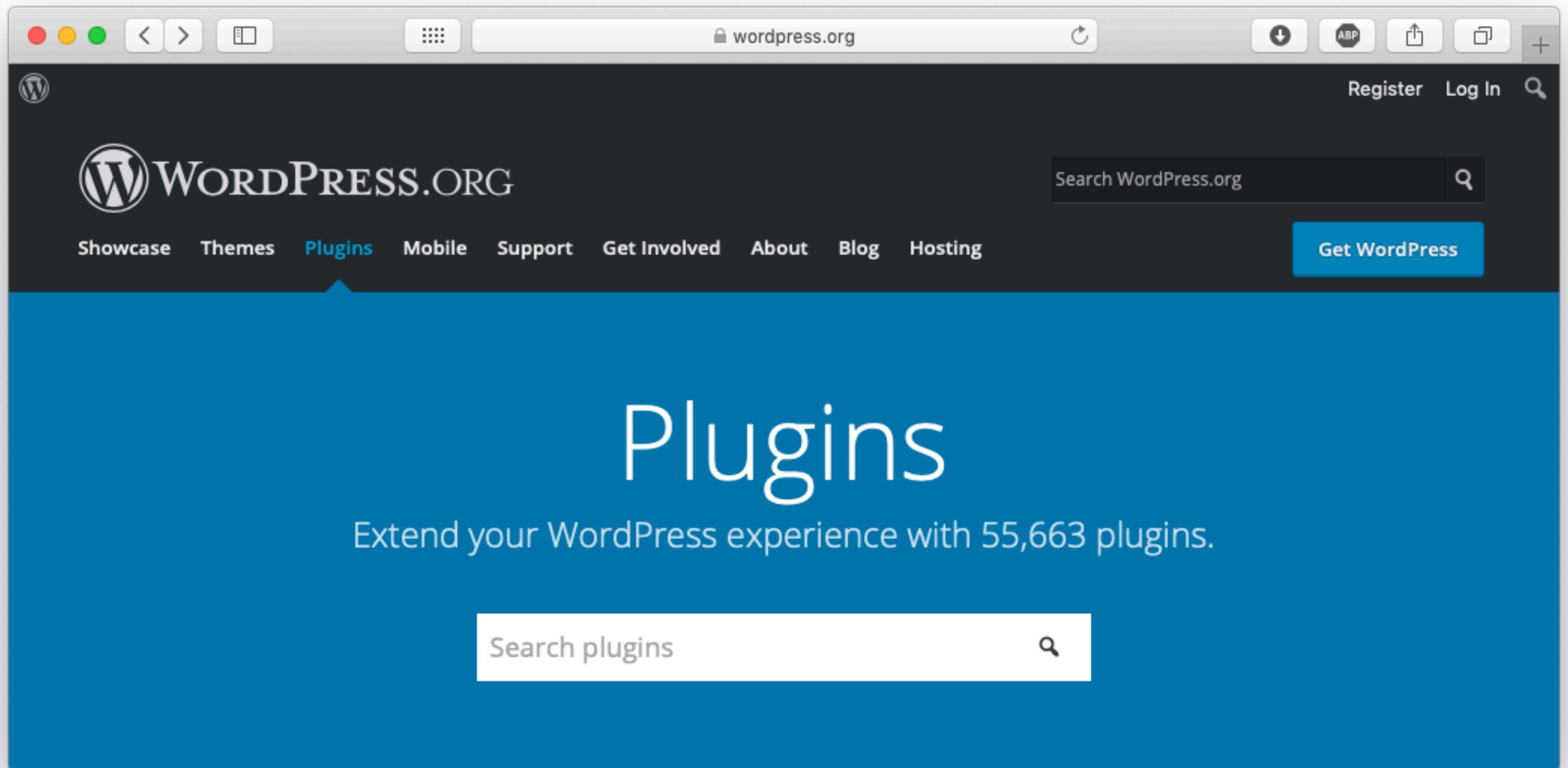
```
OVERVIEW: clang LLVM compiler

USAGE: clang [options] <inputs>

OPTIONS:
-###          Print (but do not run) the commands to run for this compilation
--analyzer-output <value>
               Static analyzer report output format (html|plist|plist-multi|file|plist-html|text).
--analyze      Run the static analyzer
--arcmt-migrate-emits-errors
               Emit ARC errors even if the migrator can fix them
--arcmt-migrate-report-output <value>
               Output path for the plist report
-B <dir>     Add <dir> to search path for binaries and object files used implicitly
-CC           Include comments from within macros in preprocessed output
-cfguard     Emit tables required for Windows Control Flow Guard.
-cl-denorms-are-zero OpenCL only. Allow denormals to be flushed to zero.
-cl-fast-relaxed-math OpenCL only. Sets -cl-finite-math-only and -cl-unsafe-math-optimizations, and defines __FAST_RELAXED_MATH__.
-cl-finite-math-only OpenCL only. Allow floating-point optimizations that assume arguments and results are not NaNs or +Inf.
-cl-fp32-correctly-rounded-divide-sqrt
               OpenCL only. Specify that single precision floating-point divide and sqrt used in the program source are correctly rounded.
-cl-kernel-arg-info OpenCL only. Generate kernel argument metadata.
-cl-mad-enable   OpenCL only. Allow use of less precise MAD computations in the generated binary.
-cl-no-signed-zeros OpenCL only. Allow use of less precise no signed zeros computations in the generated binary.
-cl-opt-disable  OpenCL only. This option disables all optimizations. By default optimizations are enabled.
-cl-single-precision-constant
               OpenCL only. Treat double precision floating-point constant as single precision constant.
-cl-std=<value> OpenCL language standard to compile for.
-cl-strict-aliasing OpenCL only. This option is added for compatibility with OpenCL 1.0.
-cl-uniform-work-group-size
               OpenCL only. Defines that the global work-size be a multiple of the work-group size specified to clEnqueueNDRangeKernel
-cl-unsafe-math-optimizations
               OpenCL only. Allow unsafe floating-point optimizations. Also implies -cl-no-signed-zeros and -cl-mad-enable.
--config <value> Specifies configuration file
--cuda-compile-host-device
               Compile CUDA code for both host and device (default). Has no effect on non-CUDA compilations.
--cuda-device-only Compile CUDA code for device only
--cuda-gpu-arch=<value> CUDA GPU architecture (e.g. sm_35). May be specified more than once.
--cuda-host-only  Compile CUDA code for host only. Has no effect on non-CUDA compilations.
--cuda-include-ptx=<value>
               Include PTX for the following GPU architecture (e.g. sm_35) or 'all'. May be specified more than once.
--cuda-noot-device-debug
               Enable device-side debug info generation. Disables ptxas optimizations.
--cuda-path-ignore-env Ignore environment variables to detect CUDA installation
--cuda-path=<value> CUDA installation path
-cxx-isystem <directory>
               Add directory to the C++ SYSTEM include search path
-C             Include comments in preprocessed output
-c             Only run preprocess, compile, and assemble steps
-dD            Print macro definitions in -E mode in addition to normal output
-dependency-dot <value> Filename to write DOT-formatted header dependencies to
-dependency-file <value>
               Filename (or -) to write dependency output to
-dI            Print include directives in -E mode in addition to normal output
-dM            Print macro definitions in -E mode instead of normal output
-D <macro>=<value> Define <macro> to <value> (or 1 if <value> omitted)
-emit-ast     Emit Clang AST files for source inputs
-emit-llvm    Use the LLVM representation for assembler and object files
-enable-trivial-auto-var-init-zero-knowing-it-will-be-removed-from-clang<value>
               Trivial automatic variable initialization to zero is only here for benchmarks, it'll eventually be removed, and I'm OK with that because I'm only using it to
benchmark
-E             Only run the preprocessor
-faddrsig     Emit an address-significance table
-faligned-allocation Enable C++17 aligned allocation functions
-fallow-editor-placeholders
               Treat editor placeholders as valid source code
-fansi-escape-codes Use ANSI escape codes for diagnostics
-fapinotes-cache-path=<directory>
               Does nothing; API notes are no longer cached separately from modules
-fapinotes-modules Enable module-based external API notes support
```

Variability in software

- Bundles
- Command line parameters
- *Plugins*



Variability in software

- Bundles
- Command line parameters
- Plugins
- *Configuration files*

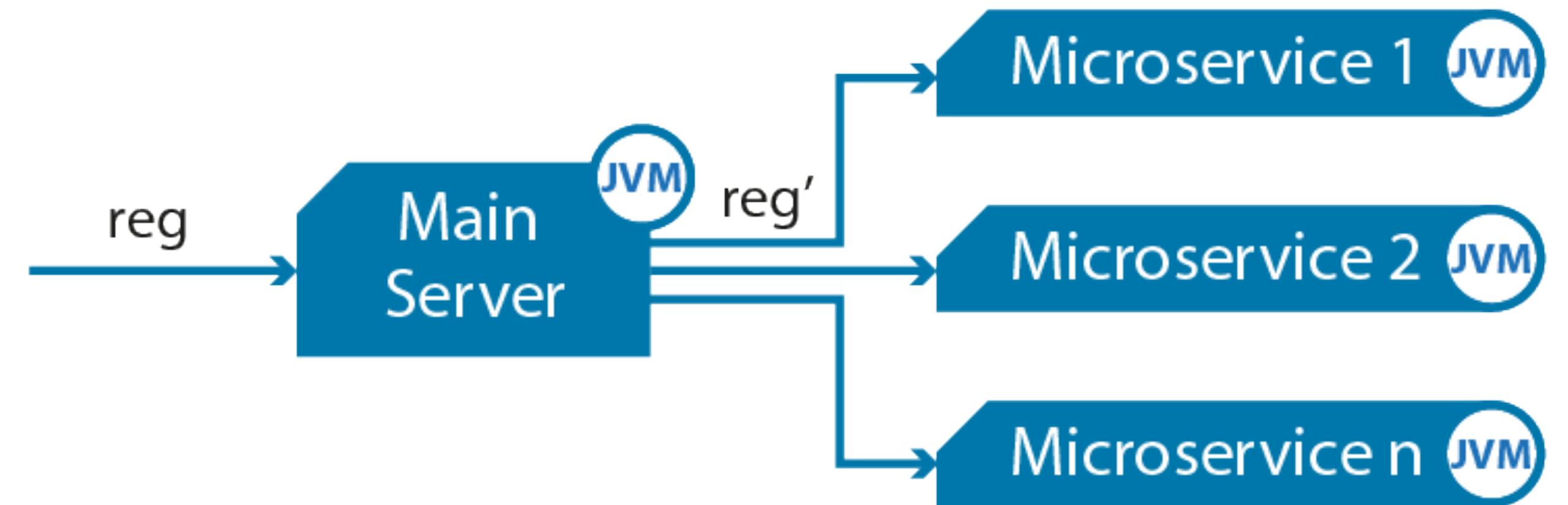


```
<profiles>
  <profile>
    <!-- Define a profile for releases of the application -->
    <!-- mvn release:prepare -P release -DskipTests=true -->
    <!-- mvn release:perform -P release -DskipTests=true -->
    <id>release</id>
    <build>
      <plugins>
        [...]
      </plugins>
    </build>
  </profile>
</profiles>
```

<https://github.com/STAMP-project/botsing/blob/master/pom.xml>

Variability in software

- Bundles
- Command line parameters
- Plugins
- Configuration files
- *Microservices*

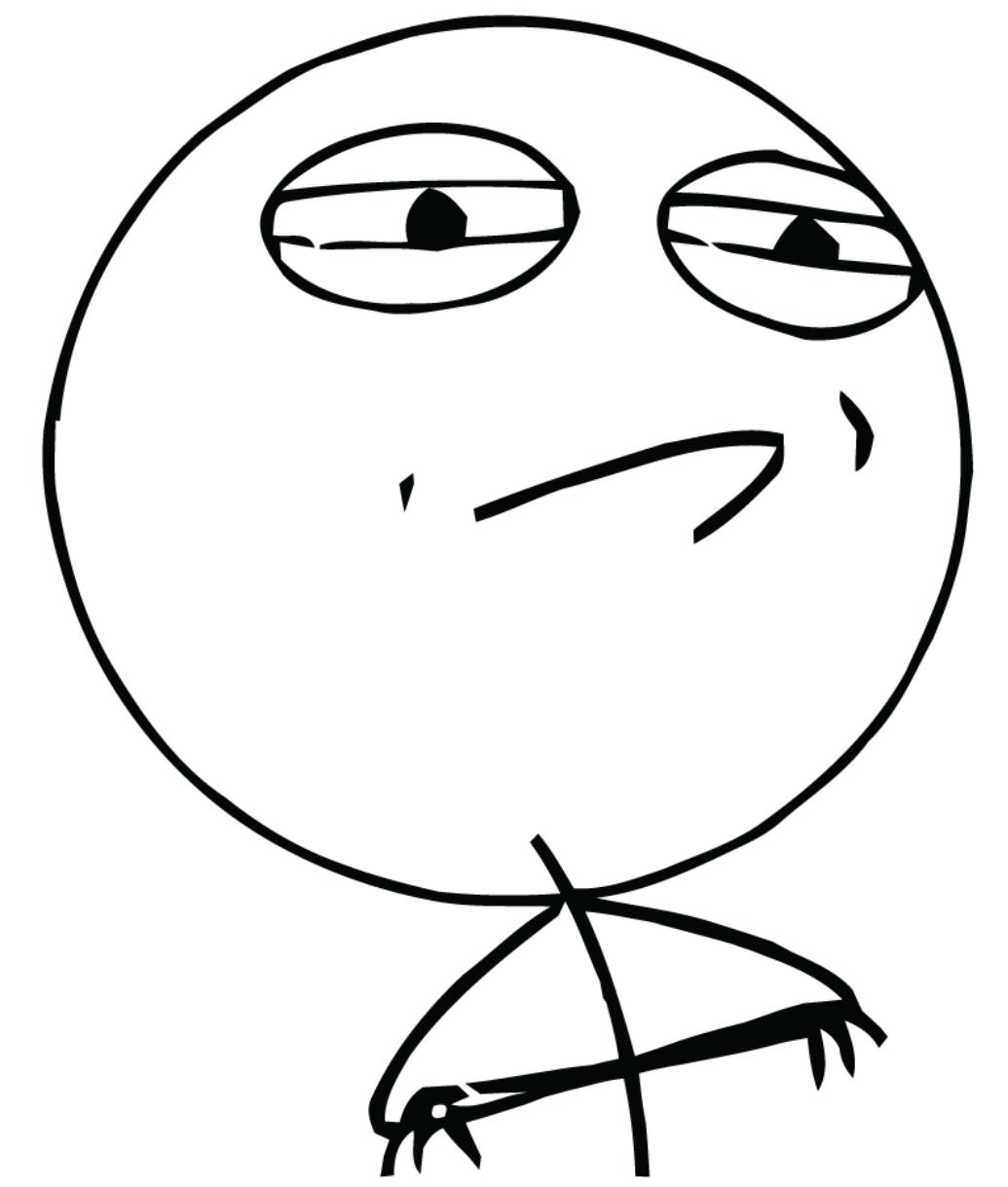


software variability is the ability of a software system or artefact to be efficiently extended, changed, **customised** or configured for use in a **particular context**.

Does your application have variability?

Yes, most probably

- **What kind of variability?**
 - Hardware
 - Platform
 - Software
 - Bundles
 - Plugins
 - Command line options
 - Configuration files
 - Microservices
 - ...



Challenges

<input type="checkbox"/> Option 1	<input type="checkbox"/> Option 2	<input type="checkbox"/> Option 3	<input type="checkbox"/> Option 4
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<input type="checkbox"/> Option 33			



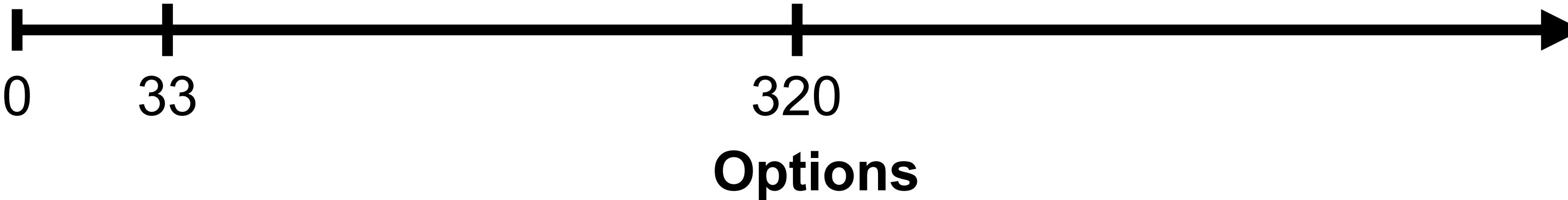
A unique product for every person on this planet
(8,589,934,592 products)

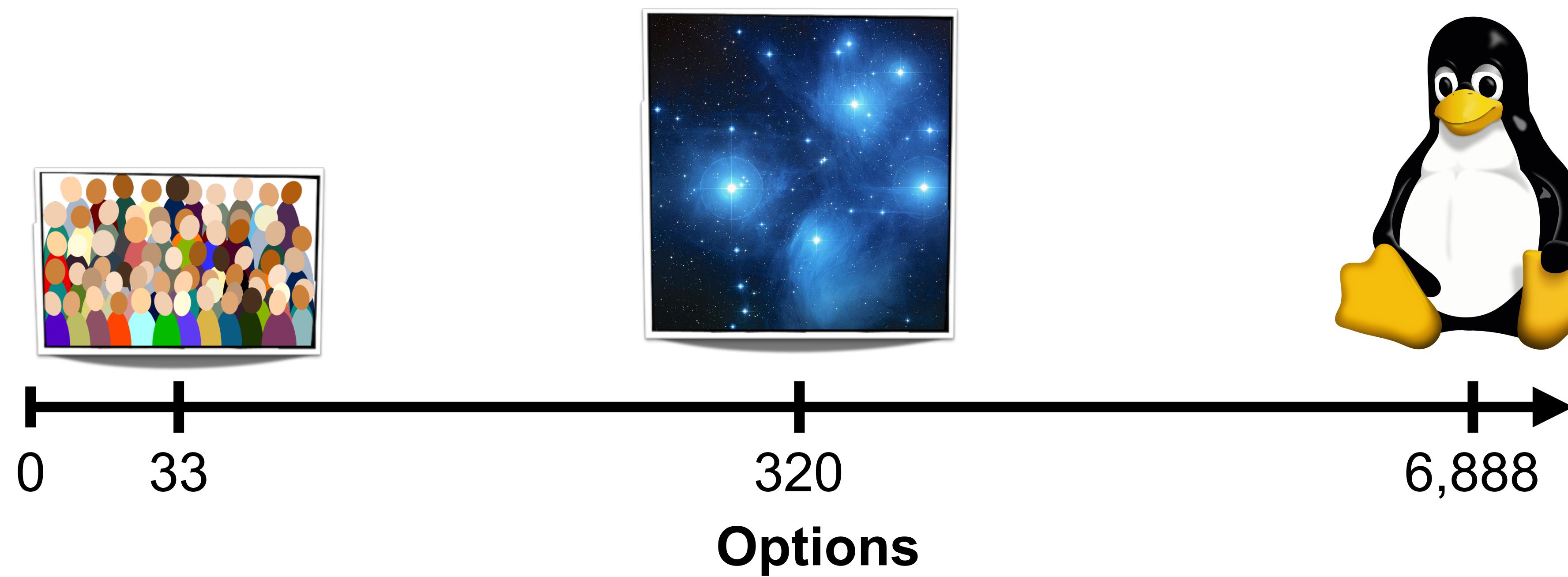
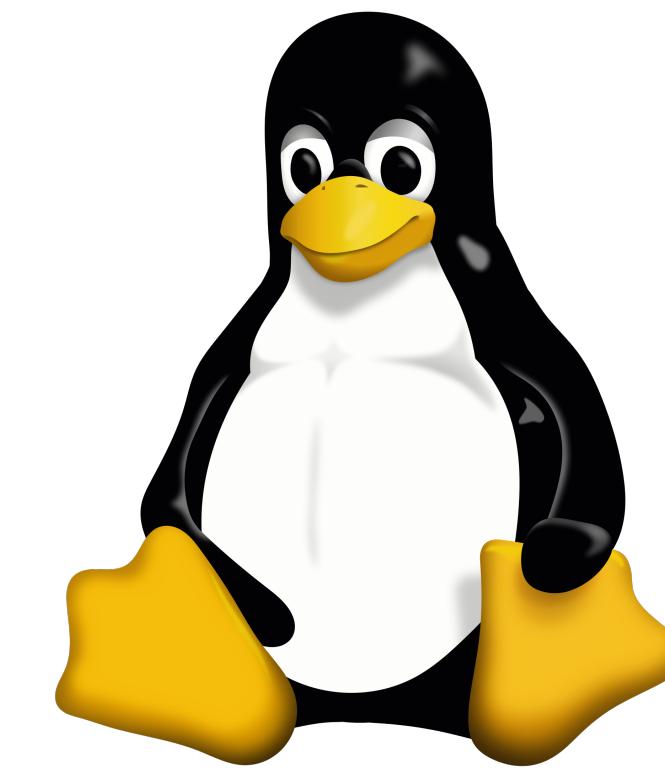


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More products than the estimated atoms in the universe (2.135987e+96 products)





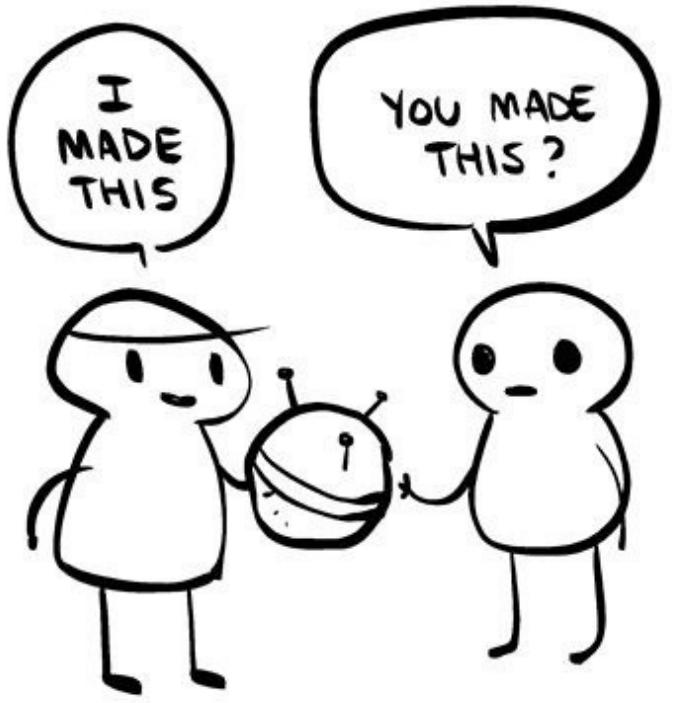
How to...

...define requirements?

...develop?

...test?

...maintain?



Clone and Own

(Variability 101)

zeit / next.js

Used by ▾

64k

Watch ▾

852

Star

45.1k

Fork

6.4k

numpy / numpy

Sponsor

Used by ▾

318k

Watch ▾

485

Star

12.9k

Fork

4.3k

ansible / ansible

Used by ▾

10.2k

Watch ▾

2k

Star

41.8k

Fork

18.4k

ethereum / solidity

Watch ▾

493

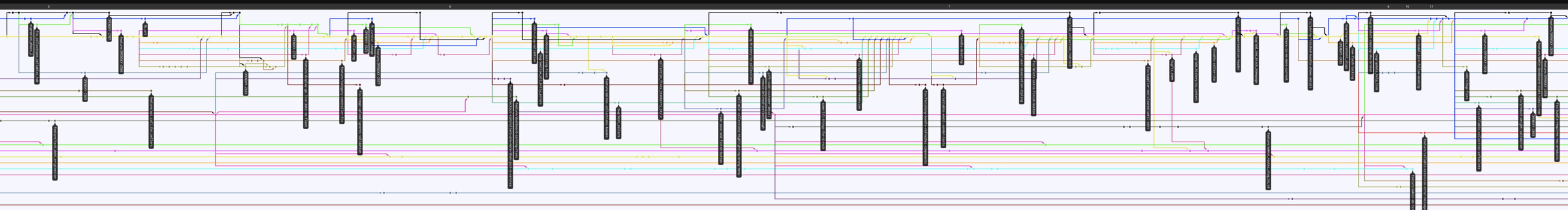
Star

7.7k

Fork

2.1k

Problem: how to manage the evolution of a large number of copies?



Hudson



Hudson - Microsoft Internet Explorer

File Edit View Favorites Tools Help

Address http://kohsuke.sfbay/hudson/ Go

Hudson

Hudson

New Job

Configure

Reload Config

Build Queue

hudson	Idle
jaxb-ri	Idle

Build Executor Status

No.	Status
1	Idle
2	Idle
3	Building javanet-maven-repository-daemon #826
4	Building jaxb-ri #3181
5	Building glassfish #105
6	Idle

All JAX-WS JAXB Tango java.net +

Job	Last Success	Last Failure	Last Duration
Common annotations	4 days (#16)	9 months (#3)	39 seconds
bsh	6 months (#11)	10 months (#2)	59 seconds
dtd-parser	6 months (#8)	N/A	1 minute
fi	28 days (#586)	1 month (#567)	7 minutes
fi (weekly)	6 days (#53)	13 days (#52)	5 minutes
glassfish	4 hours (#104)	1 day (#88)	1 hour
hudson	4 minutes (#201)	N/A	1 minute
istack-commons	12 days (#19)	16 days (#5)	14 seconds
japex	3 days (#55)	9 hours (#64)	1 minute
java-ws-xml community discussion updater	4 minutes (#16146)	10 hours (#16125)	1 minute
java.net acl processor	18 hours (#162)	N/A	0 seconds

ENABLE AUTO REFRESH

Internet



Jenkins

Jenkins

search ? Claudia Meindl | log out

Back to Project

Status

Changes

Console Output

View as plain text

View Build Information

Git Build Data

Previous Build

Console Output

```
Skipping 1.196 KB.. Full Log
KoEttlJQNjBwdnF2sVayAwD4vuoDpQAAAA==[0mskipping: [teamwiesn.com]
TASK [smtp-server : include] ****
skipping: [teamwiesn.com]

TASK [ssl : include] ****
included: /var/lib/jenkins/jobs/Rollout-system/workspace/roles/ssl/tasks/setup.yml for
teamwiesn.com

TASK [ssl : install ssl packages] ****
ok: [teamwiesn.com] => (item=[u'ssl-cert', u'openssl'])

TASK [ssl : Install ssl certificates] ****
ok: [teamwiesn.com] => (item=teamwiesn.crt)

TASK [ssl : Install ssl keys] ****
ok: [teamwiesn.com] => (item=teamwiesn.key)

TASK [ssl : Generate dhparam key] ****
ok: [teamwiesn.com]

TASK [ssl : Check ssl forward secrecy key permission] ****
ok: [teamwiesn.com]

TASK [ssl : include] ****
skipping: [teamwiesn.com]

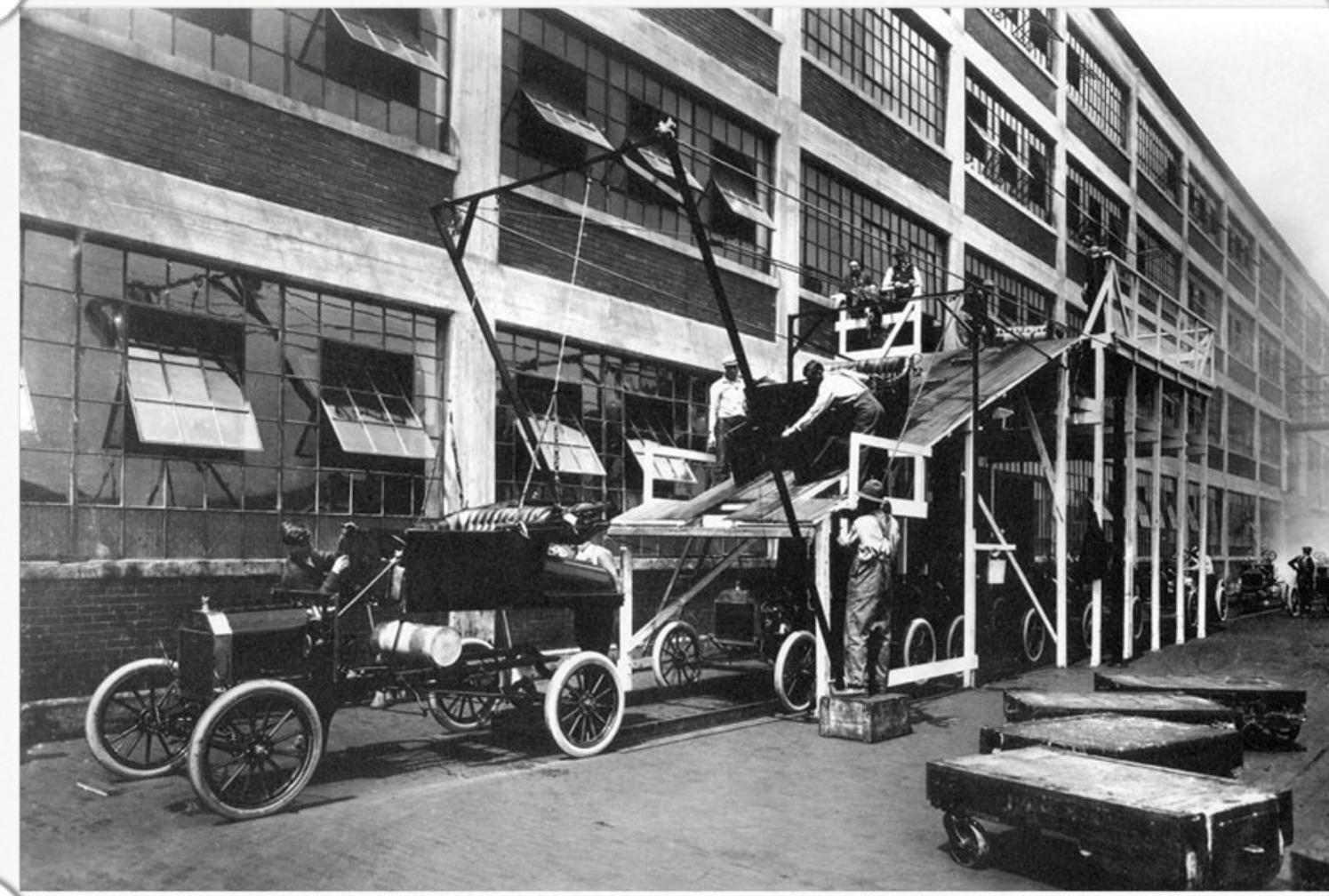
TASK [pip : Check to see if pip is already installed.] ****
ok: [teamwiesn.com]
```

- **Fast**
- **Cheap (at first)**
- **Limited**
 - Manage (large number of) copies
 - Maintenance cost at each evolution
 - Inconsistent evolution of copies

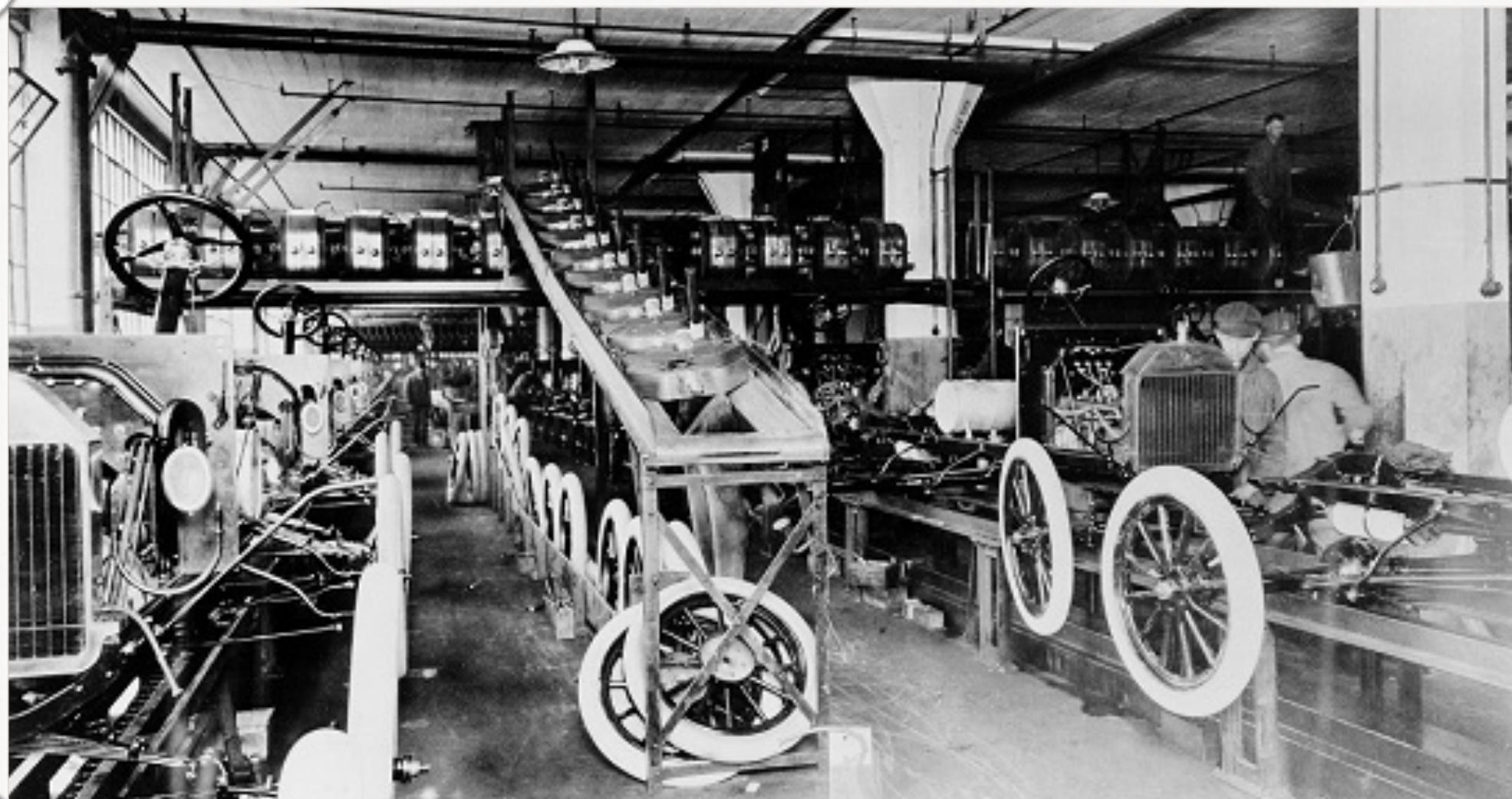


Software Product Line

(Variability level over 9000!)



Henry Ford 1901



Volkswagen

Models

Build your Volkswagen

Locate me Load Filter your Search

Golf From \$19,595¹
Golf GTI From \$30,595¹
Golf R From \$42,065¹
e-Golf From \$36,355¹
Golf SportWagen From \$24,195¹
Golf Alltrack From \$34,345¹
Beetle From \$21,895¹
Beetle Convertible From \$25,895¹

Jetta From \$20,995¹
New Tiguan From \$27,995¹
Passat From \$26,995¹
Atlas From \$35,690¹

Golf GTI

Exterior colour (1/3)

Summary

Gallery 360° View Virtual Reality

Choose your exterior colour

Top coat - metallic

Dark Iron Blue Metallic No additional costs
Platinum Grey Metallic No additional costs

Go to options

Golf GTI

From \$30,595¹

Key Features

- 17" Brooklyn alloy wheels with all-season tires
- Ambient interior lighting
- "App-Connect" smartphone integration (Android Auto, Apple Carplay, and Mirrorlink)
- Leather multi-function sport steering wheel

My standard equipment

Compare trims

Choose your engine and transmission

2.0 TSI 6 speed manual From \$30,595¹

2.0 TSI 6 speed automatic with Tiptronic® From \$31,995¹

Build your Volkswagen

Load from My Garage Load a previous configuration

Compare Golf GTI Trims

Standard Equipment

Compare standard equipment on two trims to find the car that fits you.

Show only differences.

	GTI	Autobahn
17" Brooklyn alloy wheels with all-season tires	●	—
18" Milton alloy wheels with all-season tires	○	●
8 speakers	●	—
Fender® Premium Audio System	○	●
Cloth seating surfaces	●	○
Leather seating surfaces	○	●
Front fog lights	●	—
Front fog lights with static cornering lights	○	●
LED daytime running lights	●	—

Go to Home Page

Notifications 1 Logged in as Davis

Choose a product

All categories > Clothing / Apparel > Women > Tank-tops

All Alternative American Apparel Anvil Bella + Canvas Next Level

Bella + Canvas 3001
Unisex Short Sleeve Jersey T-Shirt with Tear Away Label
Starting from \$13

Anvil 980 Lightweight Fashion Short Sleeve T-Shirt with Tear Away™ Label
Starting from \$17.25

Bella + Canvas 3413
Triblend Short Sleeve T-Shirt with Tear Away Label
Starting from \$13.50

LA Apparel 20001 Fine Jersey Short Sleeve Men T-Shirt w/ Tear Away Label
\$13.95

Choose between hundreds of product variations



IKEA Home Planner FY08 - 1.9.4

You have chosen:
W/G1530
W: 15"
H: 30 3/8"
D: 12 1/4"

Handle: No handle
Decor: No decor
Frame color: #2583:10156
Front Color: ABSTRAKT #2583:10156

Base cabinets 12 7/8" deep
High cabinets
High cabinets 12 7/8" deep
Wall cabinets
30 3/8" high
Corner cabinets
Cabinets with doors
Cabinets with glass door(s)
Cabinets for microwave or
Open shelves

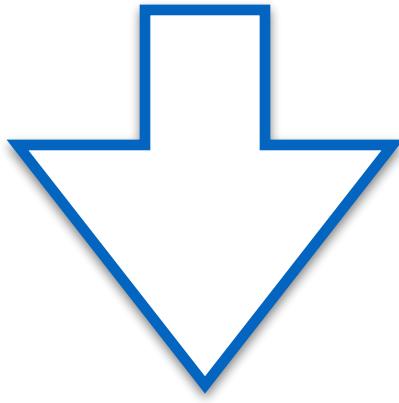
CW2530	W1230	W1530	W1830	W2130	W24301	W2430	W3030
25x25x30"	12x30"	15x30"	18x30"	21x30"	24x30"	24x30"	30x30"

BEN&JERRY'S Products Range

500ml TUBS

LOW FAT FROZEN YOGURT 3% FAT

A product is built by systematically combining
commonalities, common to all products, and
variabilities, specific to some products.



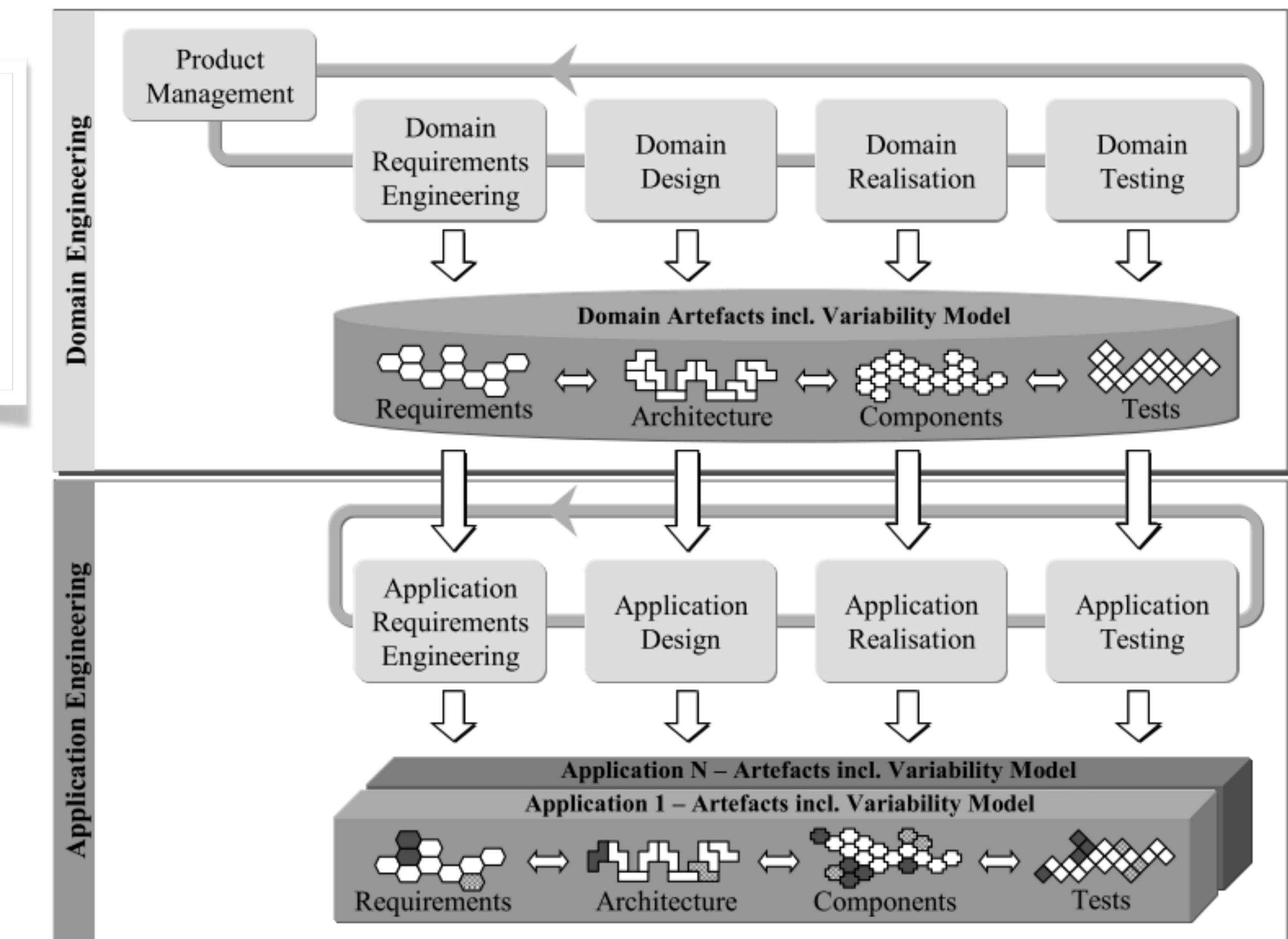
Features

A **feature** is a characteristic
or **end-user-visible behaviour**
of a software system.

The software product line engineering framework

**Commonalities and variabilities
definition and realisation**

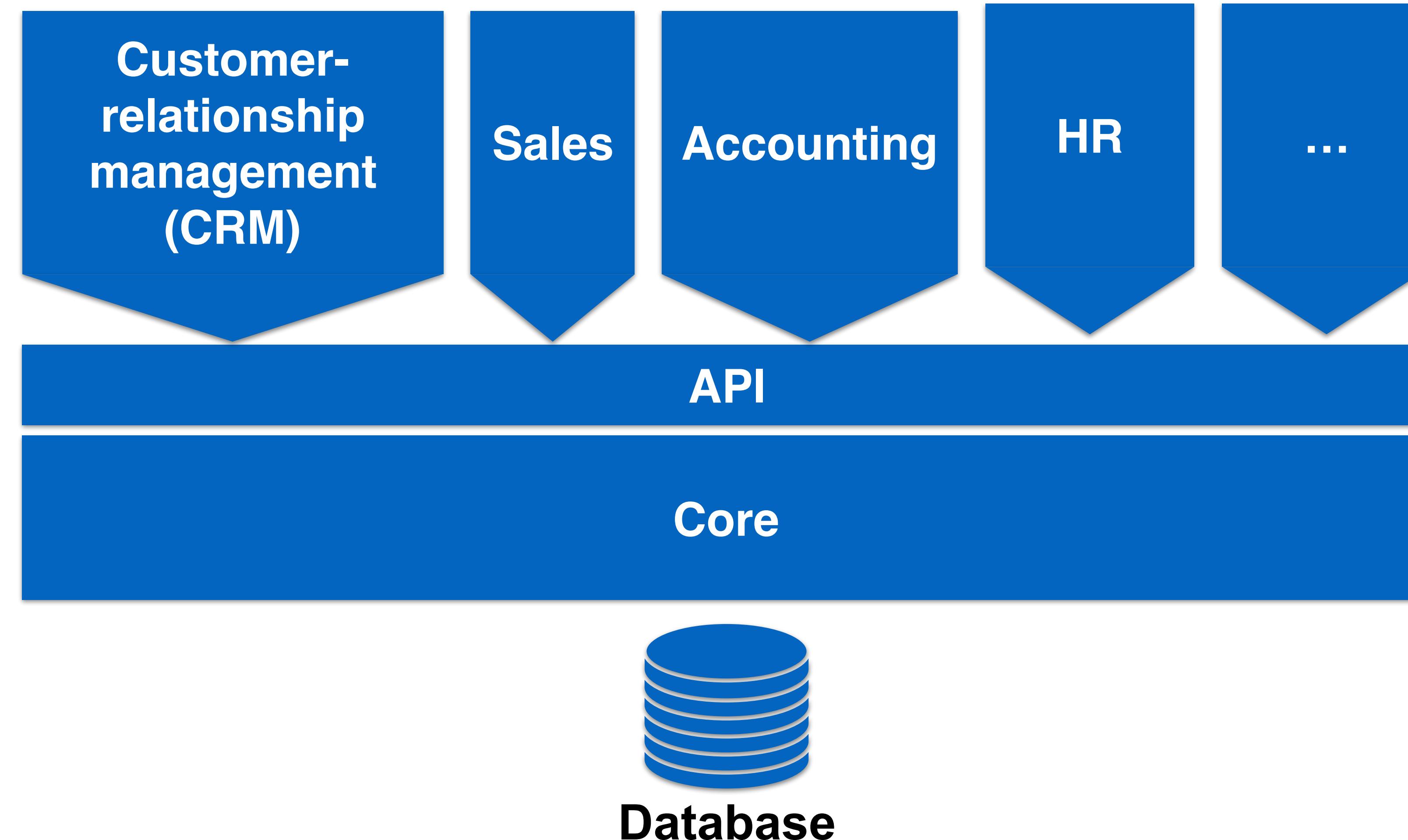
Product derivation





Example: SAP, an Enterprise Resource Planning system (ERP)

Integrated management of business processes and operational data

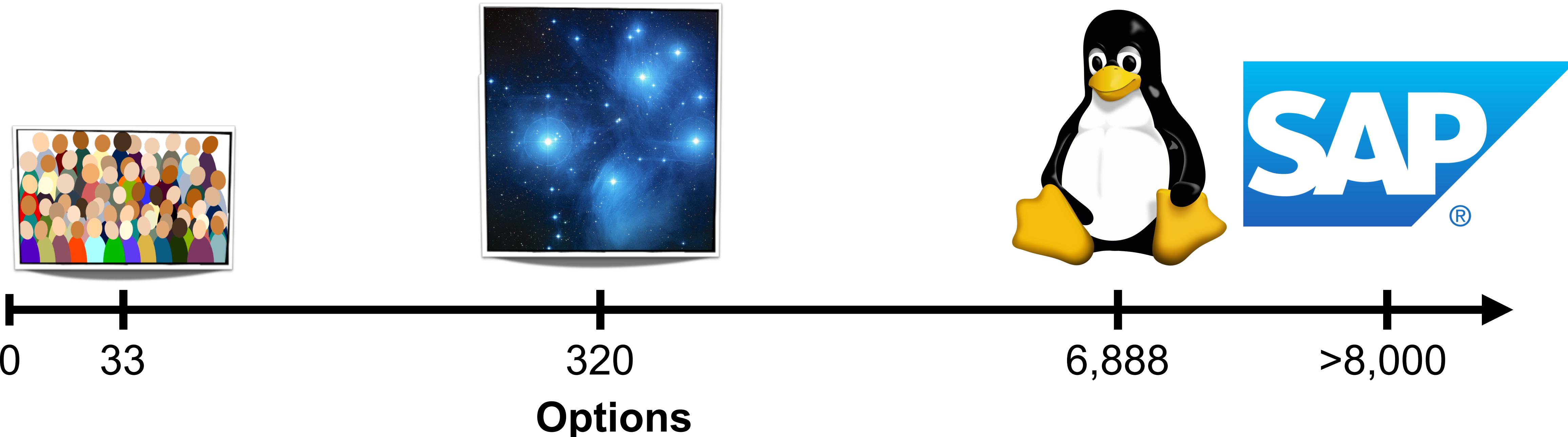


ERPs in numbers

- SAP was founded in 1972
 - Designed to be extensible from the beginning
- Every year (worldwide)...
 - companies spend \$41B on ERPs
 - SAP alone sells for \$25B
 - SAP systems manage 77% of the world's transaction revenue, and 78% of the world's food

A basic SAP installation has 20,000 database tables,
3,000 are configuration tables

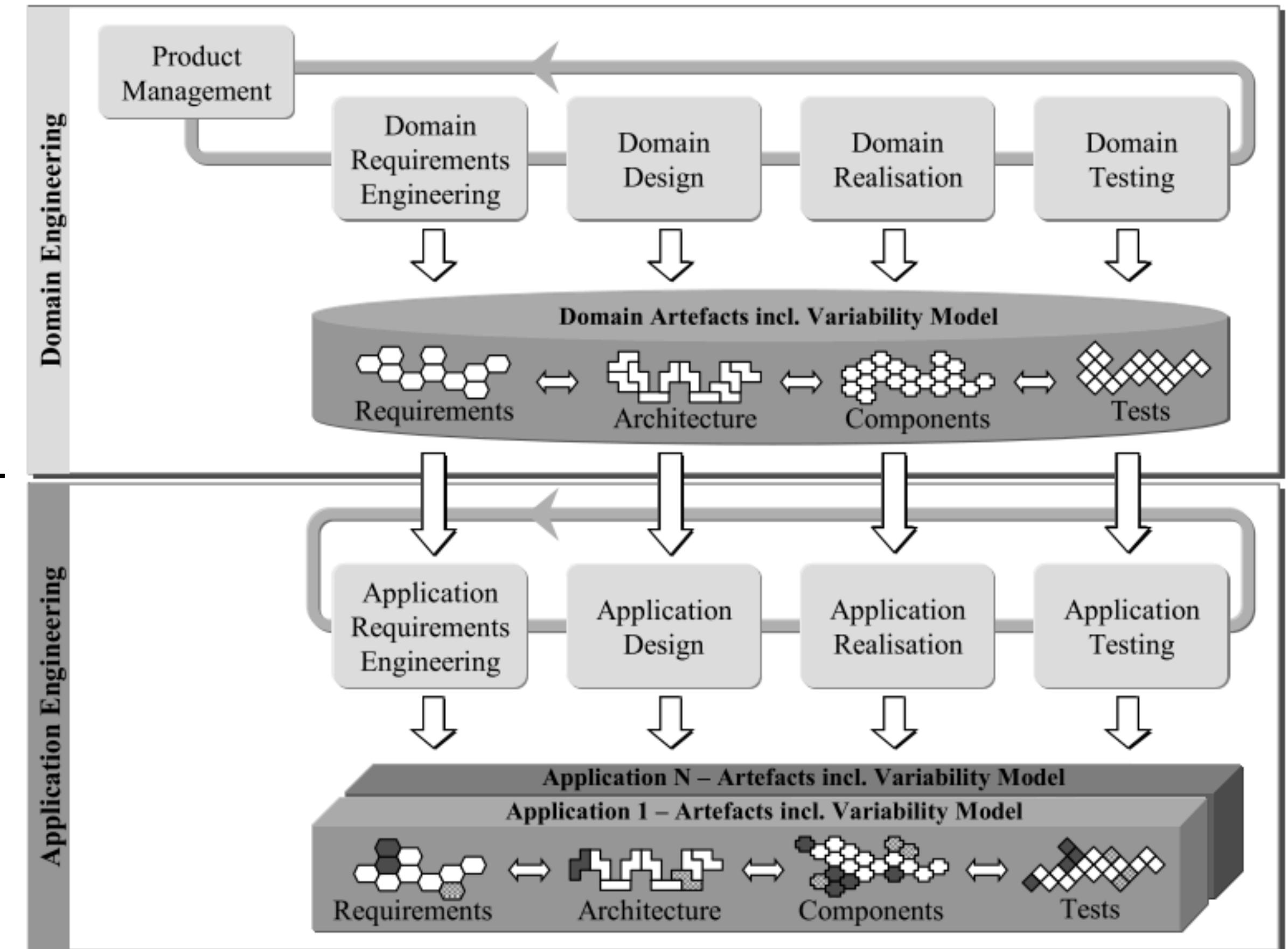
SAP requires ~8,000 configuration decisions at setup
→ *SAP Configuration Specialist* is an actual job title!



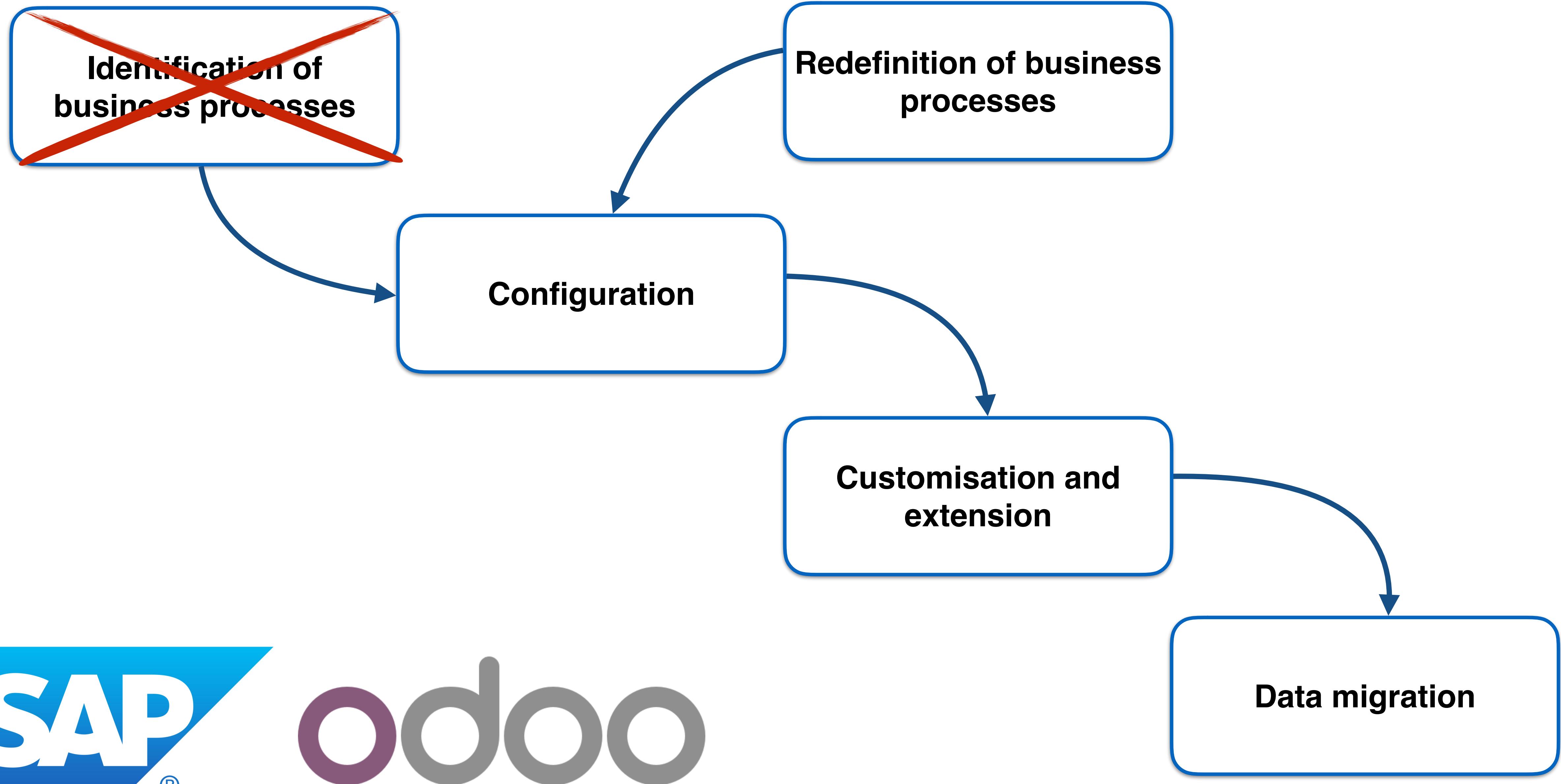
ERPs in numbers

- Switching to an ERP
 - Costs \$100 million to \$500 million
 - \$30 million in software license fees,
 - \$200 million in consulting fees,
 - millions for hardware,
 - and millions to train managers and employees.
 - Takes from four to six years
- Examples
 - Cisco's ERP implementation took 9 months and \$15 million (best case)
 - Dow Chemical's implementation took 8 years and \$1 billion
 - the U.S. navy spent \$1 billion on four different ERP projects that all failed

- Building the ERP platform
 - Core
 - API
 - Modules
 - Configuration workflow
-



Example: Enterprise resource planning systems (ERPs)



Hall of Fame Software Product Line Conference (SPLC)

- Boeing
- Bosch Group
- CelsiusTech Systems AB
- Cummins, Inc.
- Danfoss
- Ericsson AXE
- FISCAN
- General Motors Powertrain (GMPT)
- Hewlett Packard
- HomeAway
- Lockheed Martin
- LSI Logic
- Lucent
- Market Maker
- Nokia
- Philips (Medical Systems)
- Philips (Software for Television Sets)
- Philips (Telecommunication Switching System)
- Salion, Inc.
- Siemens (syngo.via)
- Toshiba
- U.S. Army Live Traning Transformation
- U.S. Naval Research Laboratory

<http://splc.net/hall-of-fame/>

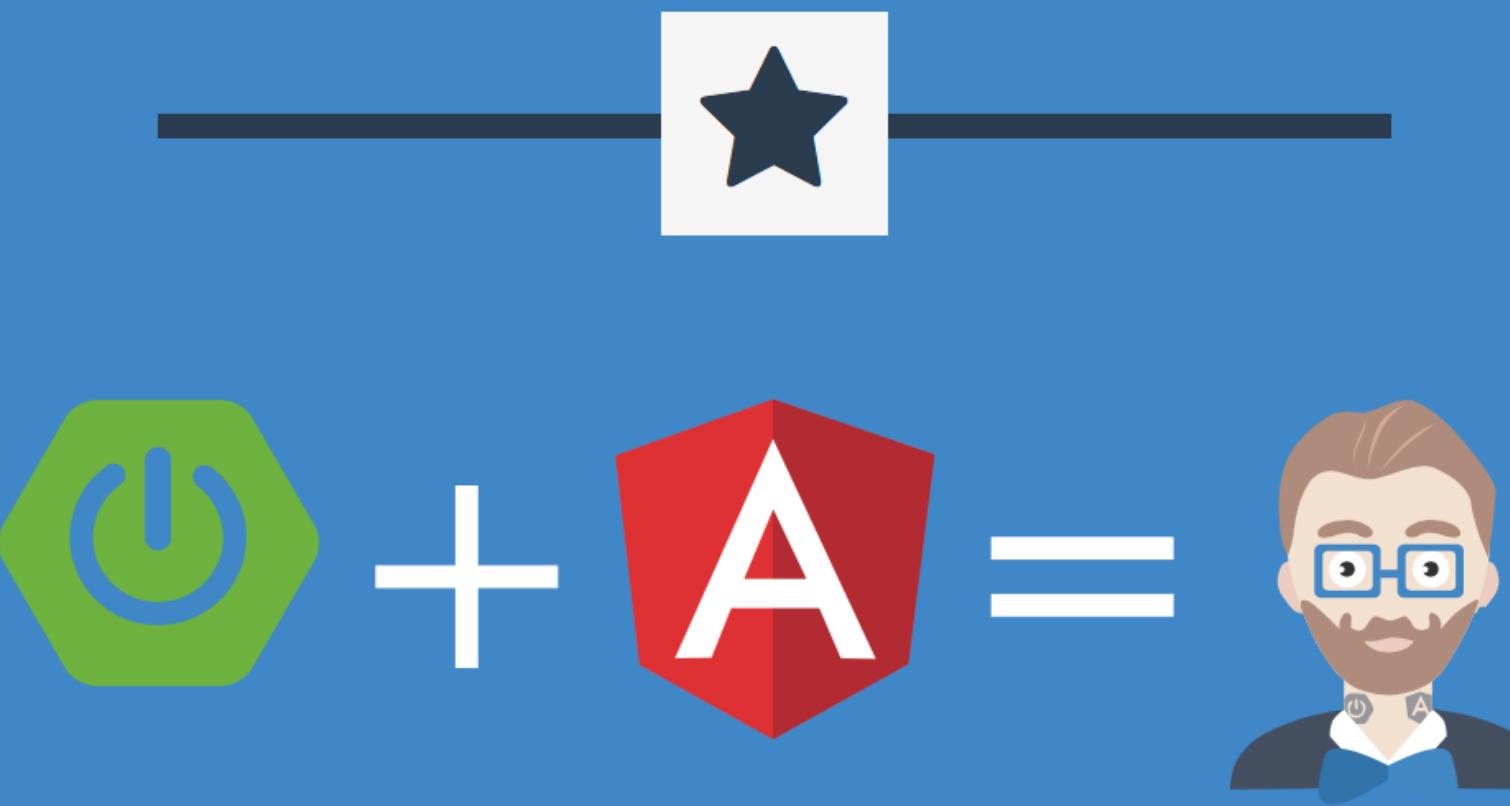
- **Tailor-made**
 - For individual customers
- **Reduced costs**
 - Reusable parts can be combined in different ways
- **Improved quality**
 - Parts can be standardized and checked in isolation and reused and tested in multiple products.
- **Time to market**
 - building on top of existing parts is much faster than developing it entirely from scratch



Greetings, Java Hipster!

Feature Modelling

What Is JHipster?



JHipster is a development platform to generate, develop and deploy Spring Boot
+ Angular Web applications and Spring microservices.



<https://start.jhipster.tech/>

Client Side Options

- HTML5
- CSS3
- Bootstrap
- AngularJS
- Angular
- jQuery
- Websockets
- Yarn
- Webpack
- Bower
- Gulp
- Sass
- Browsersync
- Karma
- Protractor

Server Side Options

- Spring Boot
- Spring Security
- NETFLIX OSS
- Netflix OSS
- Consul
- Gradle
- Maven
- Hibernate
- Liquibase
- MySQL
- MariaDB
- PostgreSQL
- Oracle
- SQL Server
- MS SQL
- MongoDB
- cassandra
- Cassandra
- EhCache
- Hazelcast
- ElasticSearch
- Kafka
- Swagger
- ELK Stack
- ELK Stack
- Prometheus
- Thymeleaf
- Gatling
- Cucumber

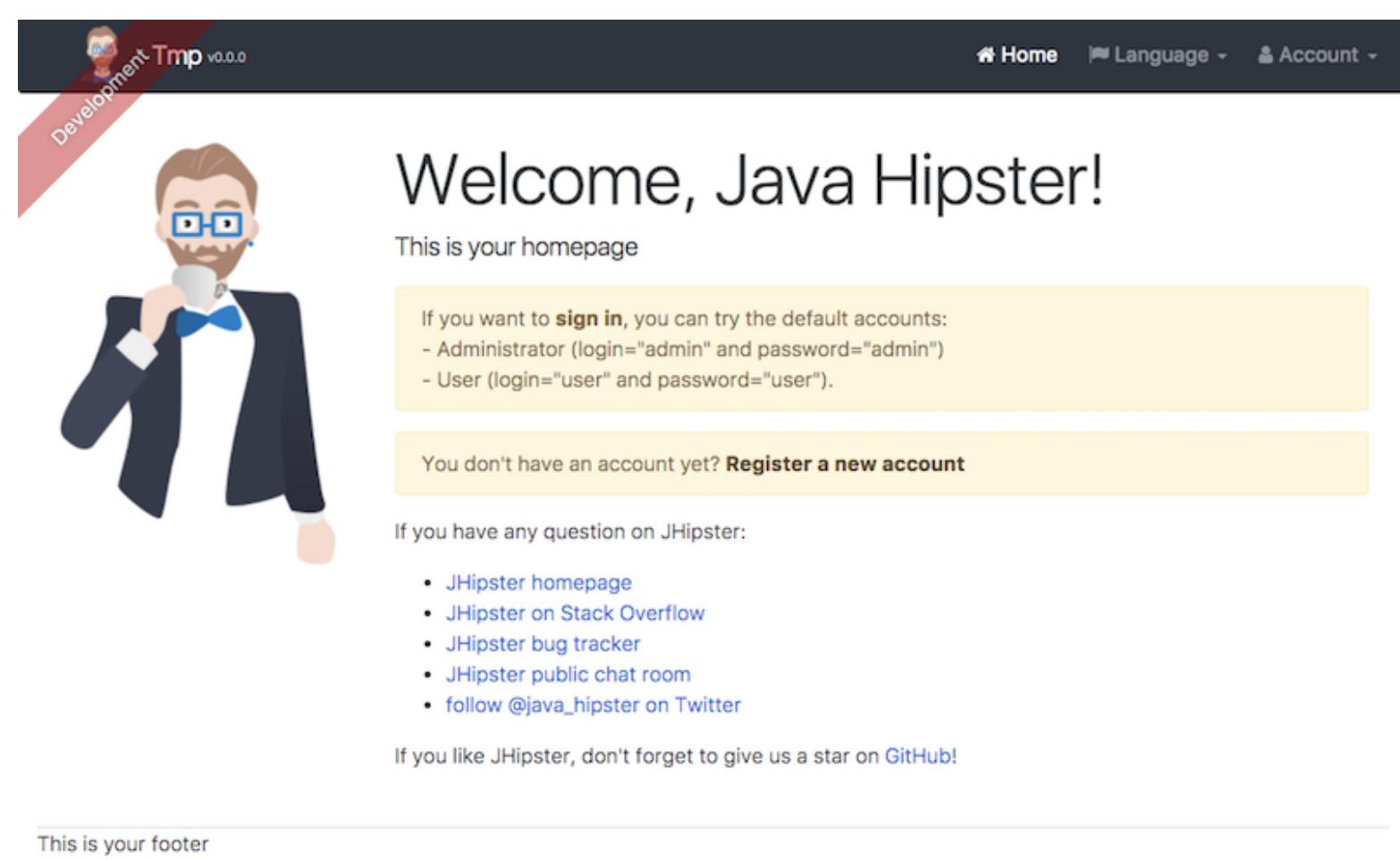
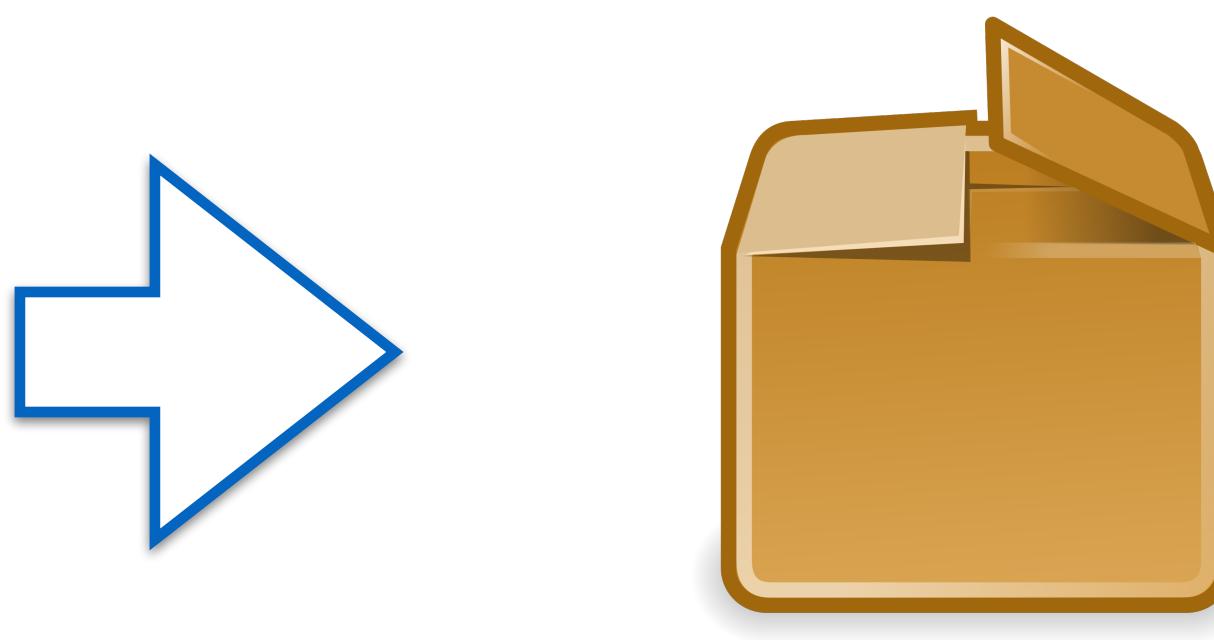
Deployment Options

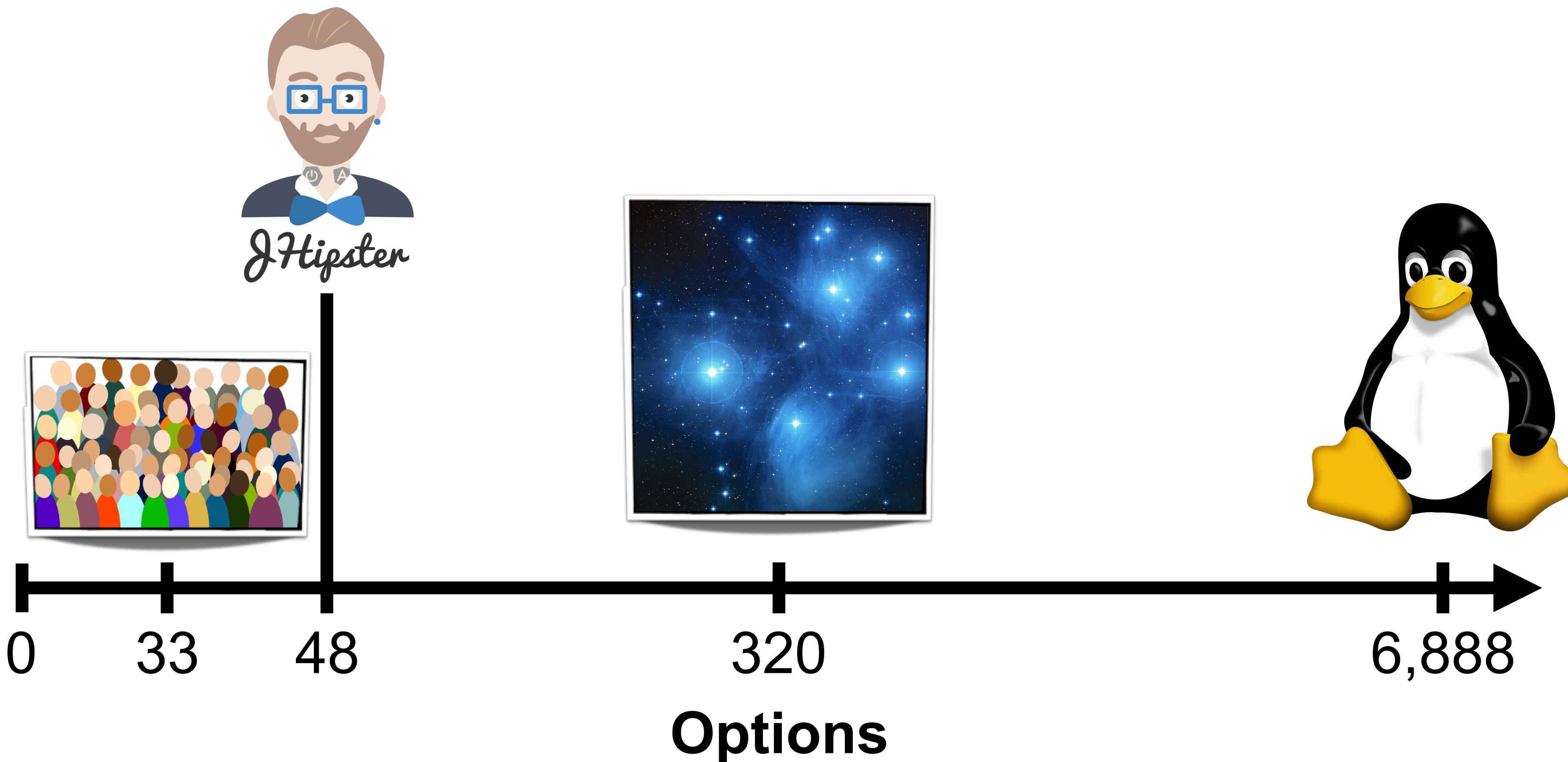
- Docker
- Kubernetes
- Heroku
- CloudFoundry
- AWS
- Boxfuse
- Rancher
- OpenShift

The screenshot shows the NetBeans IDE interface with the following details:

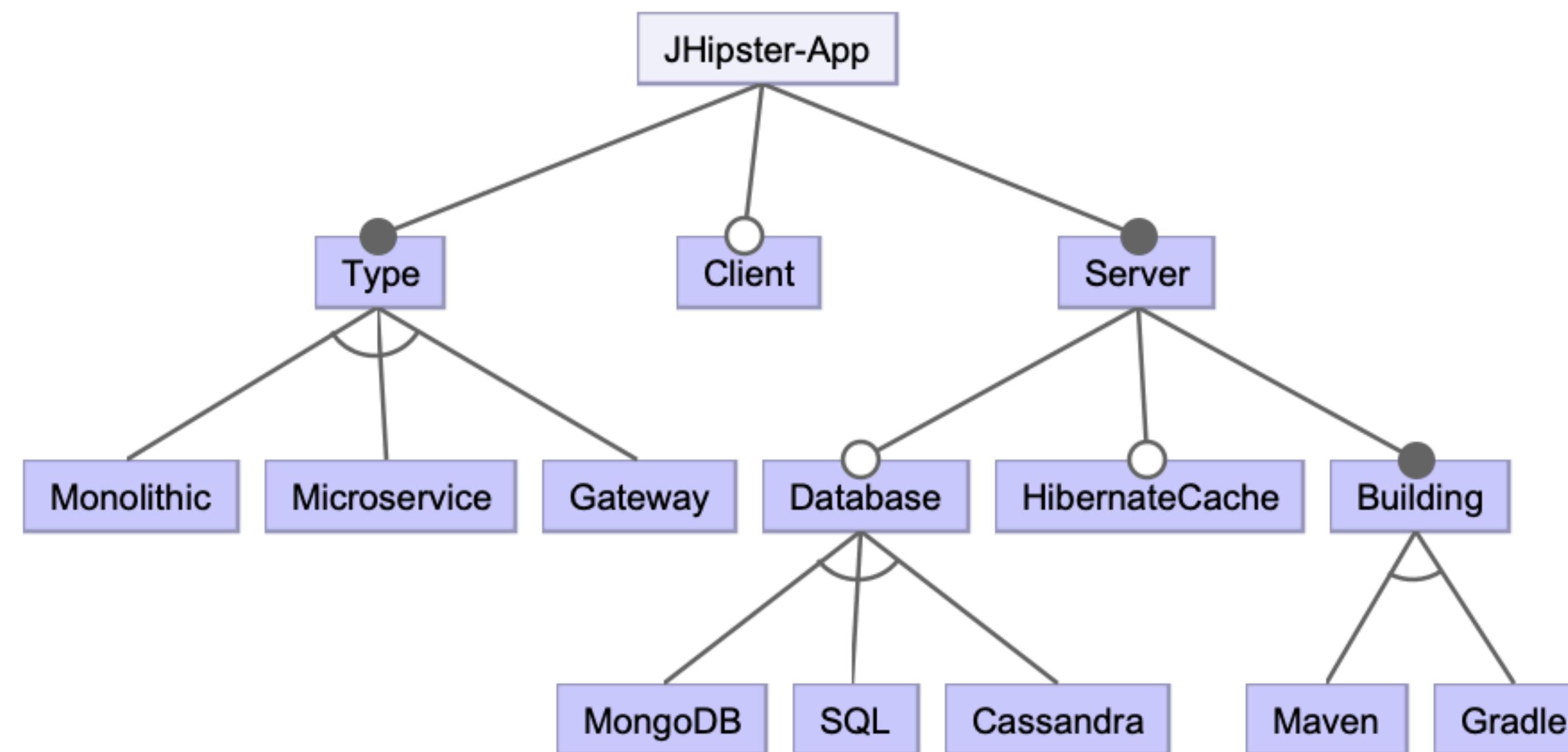
- Title Bar:** be.unamur.testme.jhipster-0.0.1-SNAPSHOT - NetBeans IDE 8.1
- Toolbar:** Standard NetBeans toolbar with icons for file operations, search, and navigation.
- Project Explorer (Left):** Shows the project structure under "Project".
 - be.unamur.info.b314-compiler-0.0.1-SNAPSHOT
 - be.unamur.info.methode-progra2-0.0.1
 - be.unamur.info.methode-progra2-dyna
 - be.unamur.info.methode-progra2-gree
 - be.unamur.info.methode-progra2-tp1-
 - be.unamur.info.methode-progra2-typeS
 - be.unamur.info.workbook-algorithmic-0
 - be.unamur.testme.jhipster-0.0.1-SNAPSHOT
 - Remote Files
 - Source Packages
 - be.unamur.testme
 - ApplicationWeb.xml
 - JhipsterApp.java
 - be.unamur.testme.aop.logging
 - LoggingAspect.java
 - be.unamur.testme.async
 - be.unamur.testme.config
 - be.unamur.testme.config.apidoc
 - be.unamur.testme.config.audit
 - be.unamur.testme.config.locale
 - be.unamur.testme.config.metrics
 - be.unamur.testme.domain
 - be.unamur.testme.domain.util
 - be.unamur.testme.repository
 - be.unamur.testme.security
 - be.unamur.testme.security.jwt
 - be.unamur.testme.service
 - be.unamur.testme.web.filter
 - be.unamur.testme.web.rest
 - be.unamur.testme.web.rest.dto
 - be.unamur.testme.web.rest.error
 - be.unamur.testme.web.rest.util
 - Test Packages
 - Other Sources
 - Other Test Sources
 - Dependencies
 - Runtime Dependencies
 - Test Dependencies
 - Java Dependencies
- Code Editor (Center):** Displays the `JhipsterApp.java` file with Java code for initializing the application and running it.

```
35 /**
36  * Initializes jhipster.
37  * <p>
38  * Spring profiles can be configured with a program arguments --spring.profiles.active=your-active-profile
39  * <p>
40  * You can find more information on how profiles work with JHipster on <a href="http://jhipster.github.io/profiles/">http://jhipster.github.io/profiles/</a>
41  */
42
43 @PostConstruct
44 public void initApplication() {
45     log.info("Running with Spring profile(s) : {}", Arrays.toString(env.getActiveProfiles()));
46     Collection<String> activeProfiles = Arrays.asList(env.getActiveProfiles());
47     if (activeProfiles.contains(Constants.SPRING_PROFILE_DEVELOPMENT) && activeProfiles.contains(Constants.SPRING_PROFILE_PRO
48         log.error("You have misconfigured your application! It should not run " +
49         "with both the 'dev' and 'prod' profiles at the same time.");
50     }
51     if (activeProfiles.contains(Constants.SPRING_PROFILE_DEVELOPMENT) && activeProfiles.contains(Constants.SPRING_PROFILE_CLO
52         log.error("You have misconfigured your application! It should not" +
53         "run with both the 'dev' and 'cloud' profiles at the same time.");
54     }
55
56
57 /**
58  * Main method, used to run the application.
59  *
60  * @param args the command line arguments
61  * @throws UnknownHostException if the local host name could not be resolved into an address
62  */
63 public static void main(String[] args) throws UnknownHostException {
64     SpringApplication app = new SpringApplication(JhipsterApp.class);
65     DefaultProfileUtil.addDefaultProfile(app);
66     Environment env = app.run(args).getEnvironment();
67 }
```
- Output, Notifications, Versioning Output, Javadoc, Test Results, Usages (Bottom):** Standard NetBeans tabs for managing build output and dependencies.





A feature model documents
the **features** of a product line
and their **relationships**.



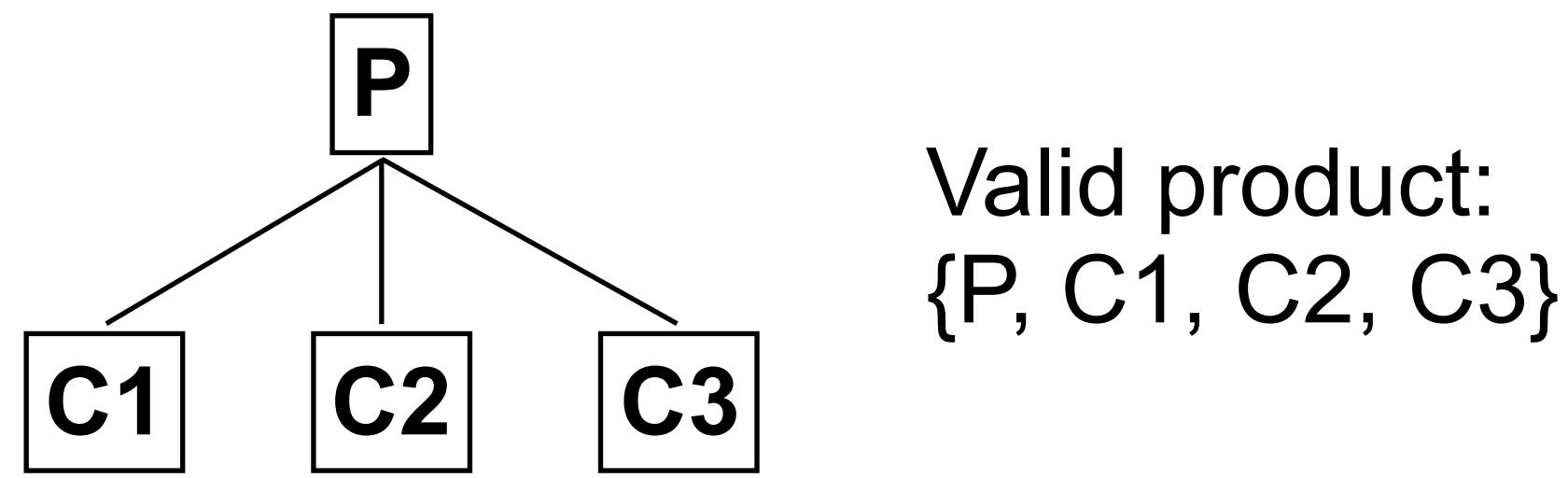
Vocabulary

Feature = Option

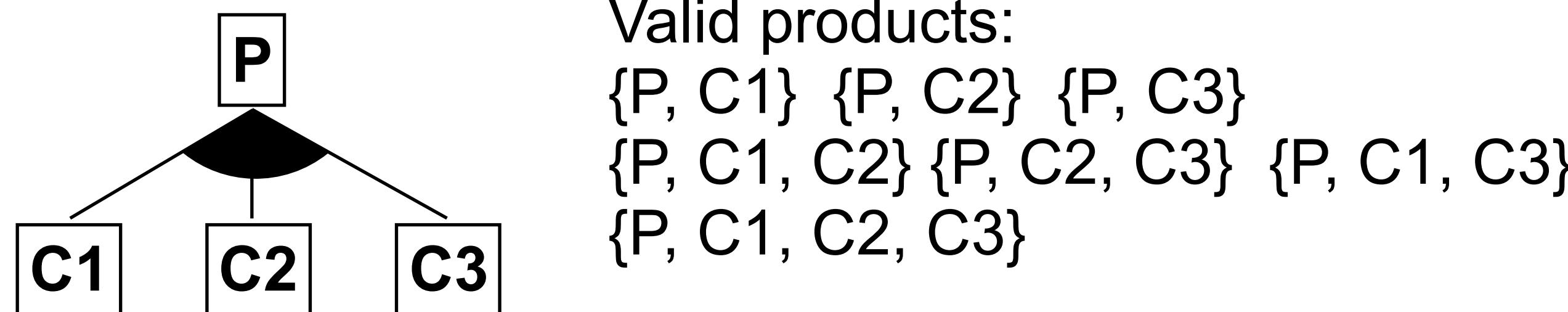
Product = Configuration = Variant

Feature diagram

- **Tree-like** structure (directed acyclic graph).
- A feature is **decomposed** in sub-features
 - **And** decomposition: if the parent is selected then all sub-features must be selected too

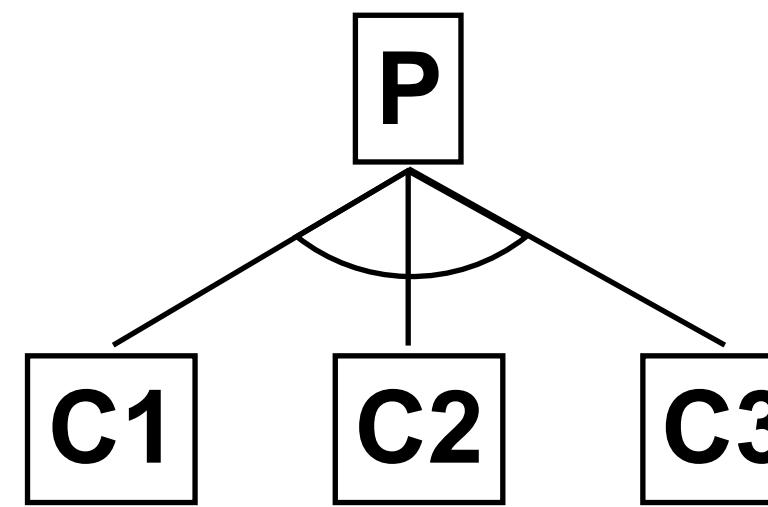


- **Or** decomposition: if the parent is selected then at least one sub-features must be selected too



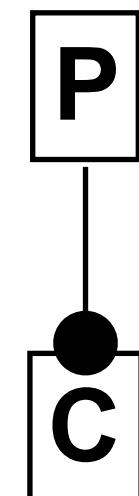
Feature diagram

- **Tree-like** structure (directed acyclic graph).
- A feature is **decomposed** in sub- features
 - **Xor** decomposition: if the parent is selected then exactly one sub-features must be selected too



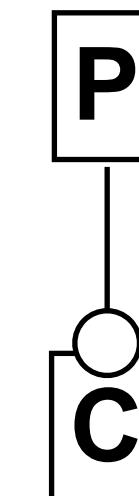
Valid products:
{P, C1}
{P, C2}
{P, C3}

- **Mandatory** feature: if the parent is selected then the feature must be selected



Valid product:
{P, C}

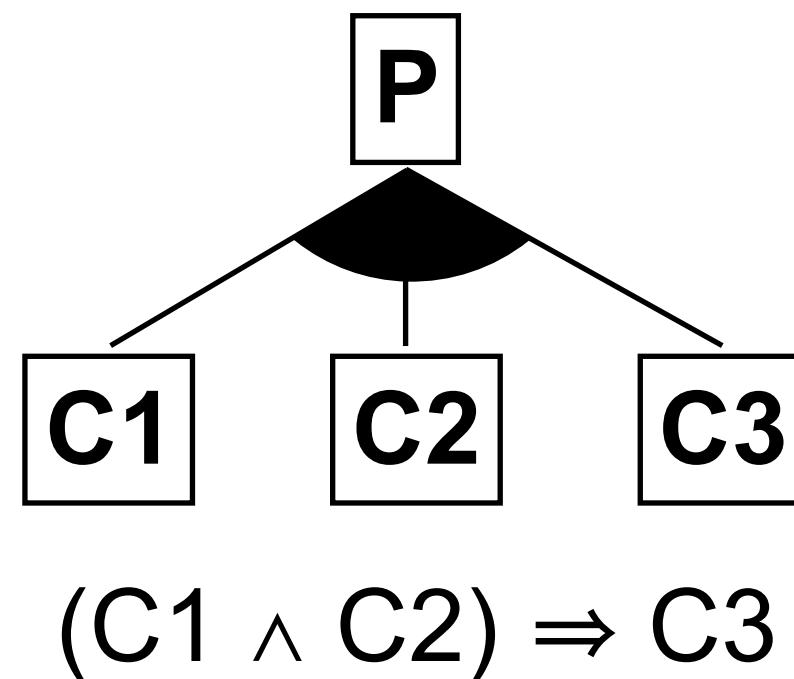
- **Optional** feature: if the parent is selected then the feature must be selected



Valid products:
{P}
{P, C}

Feature diagram

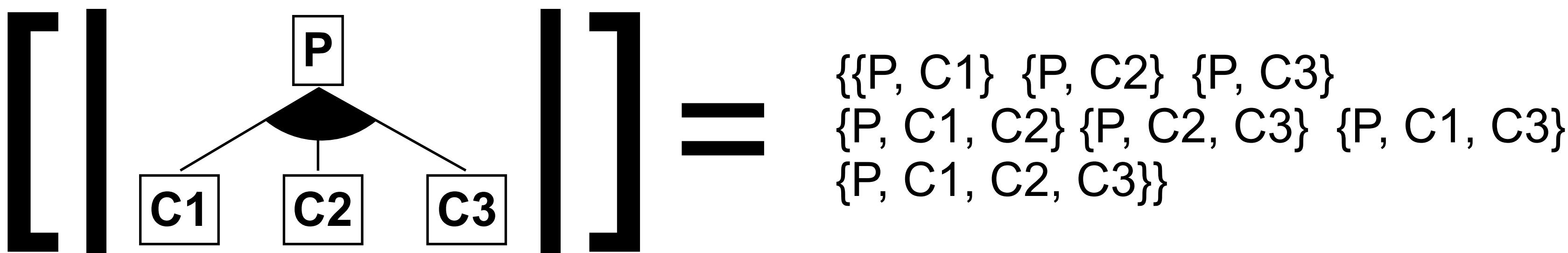
- Cross-tree **constraints** are expressed as boolean expressions over the features.

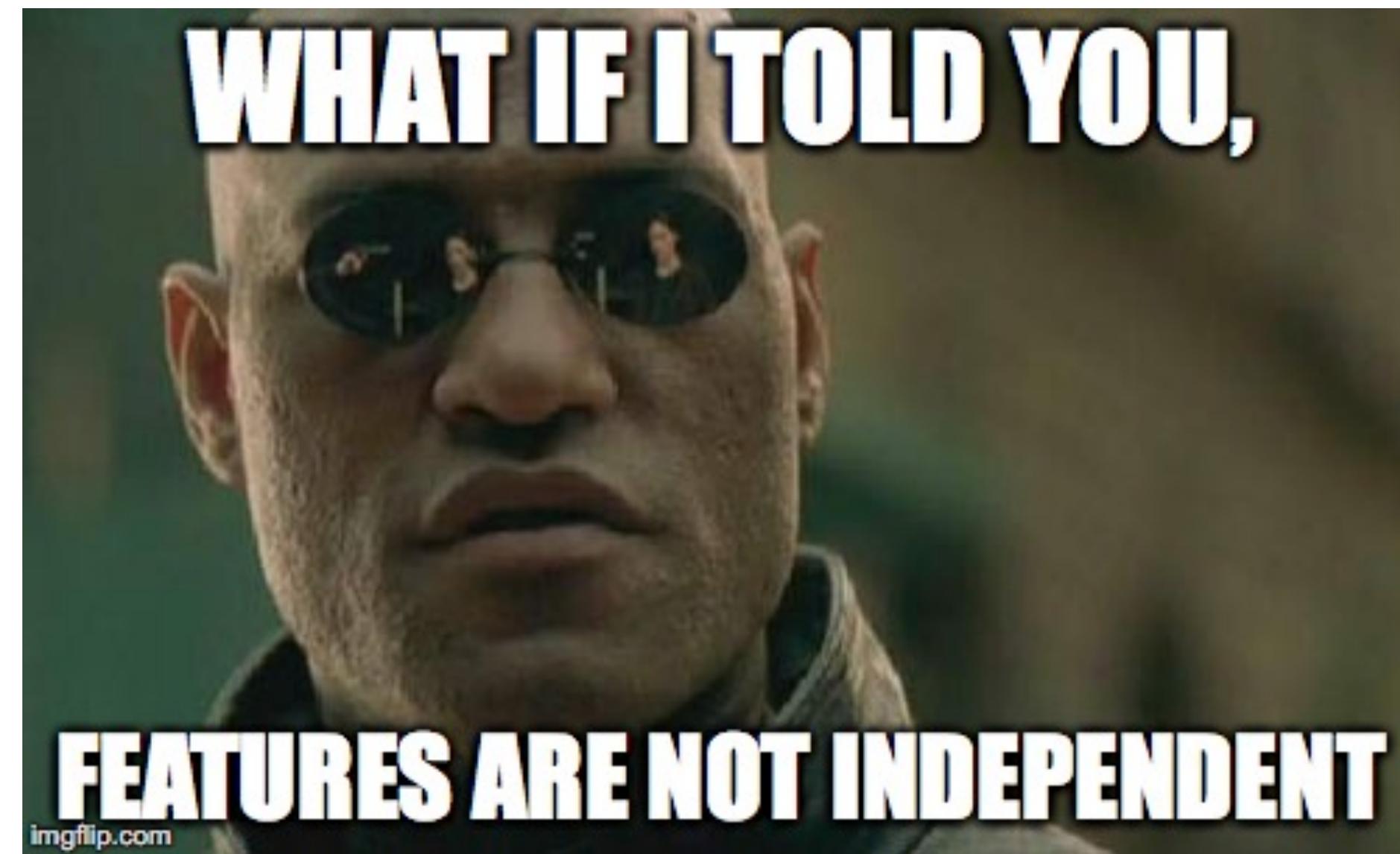


Valid products:

$\{P, C1\}$ $\{P, C2\}$ $\{P, C3\}$
 $\{\cancel{P, C1, C2}\}$ $\{P, C2, C3\}$ $\{P, C1, C3\}$
 $\{P, C1, C2, C3\}$

- The **semantics** of a feature model corresponds to all the **valid products** allowed by the feature model.





Constraints and where to find them

Source: Configurator

Application type

Client side options

Server side options

Which type of application would you like to create?

- Monolithic application (recommended for simple projects)
- Microservice application
- Microservice gateway
- JHipster UAA server (for microservice OAuth2 authentication)

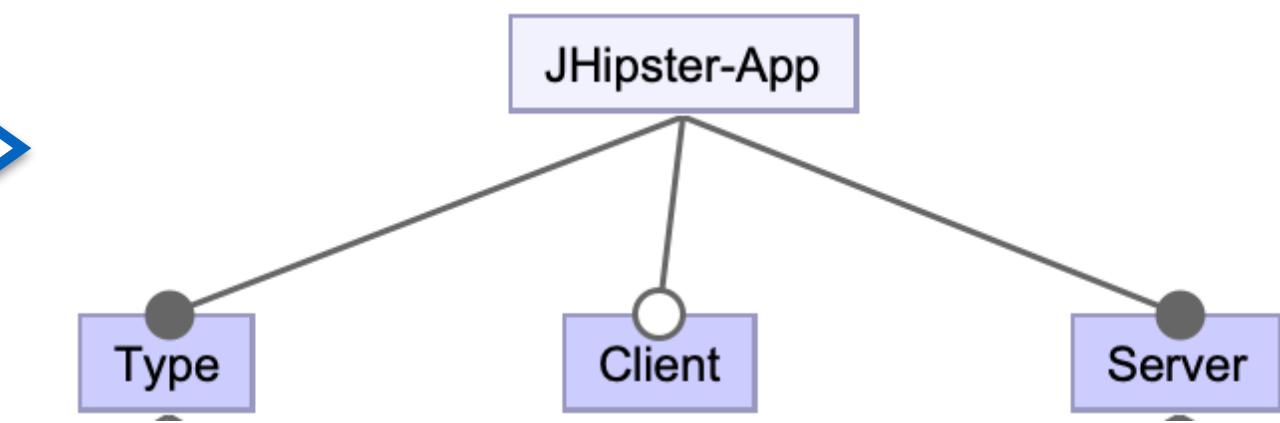
Besides JUnit and Jest, which testing frameworks would you like to use?

- Gatling
- Cucumber
- Protractor

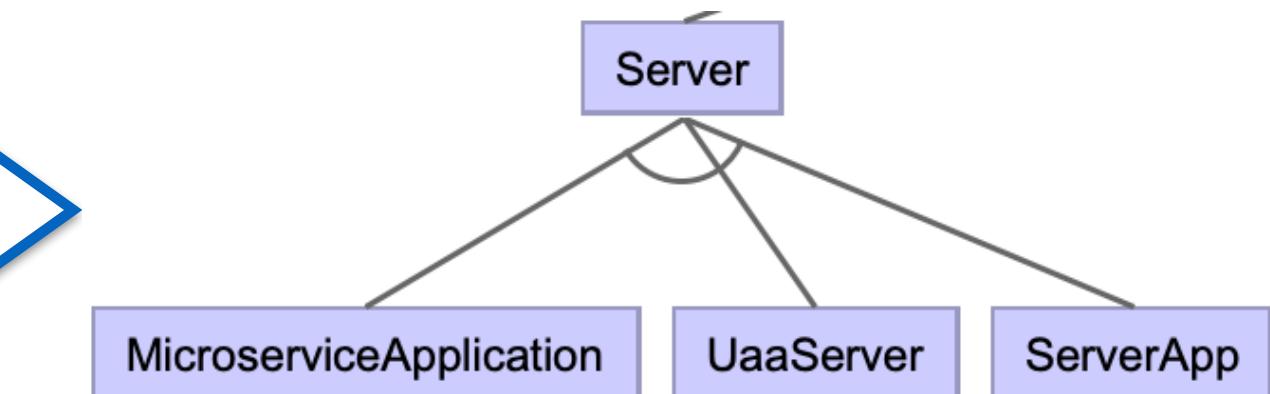
Would you like to enable internationalization support?

- Yes
- No

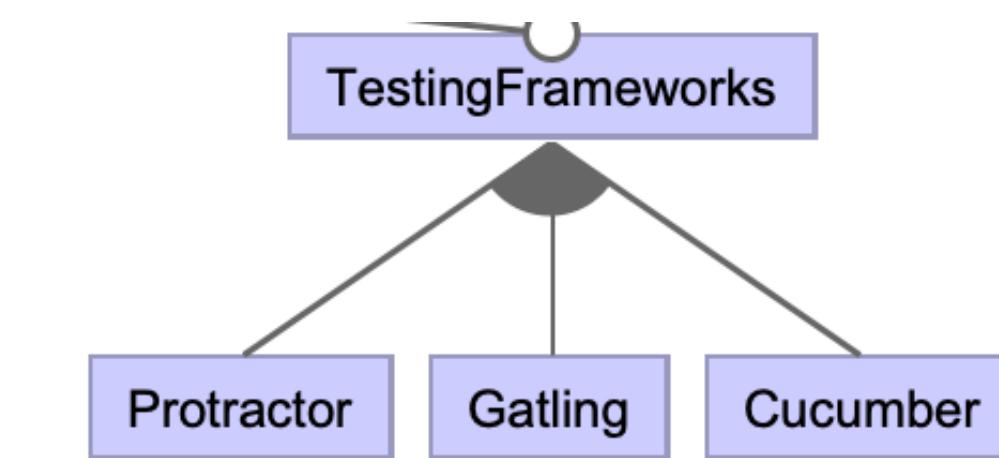
**AND
decomposition**



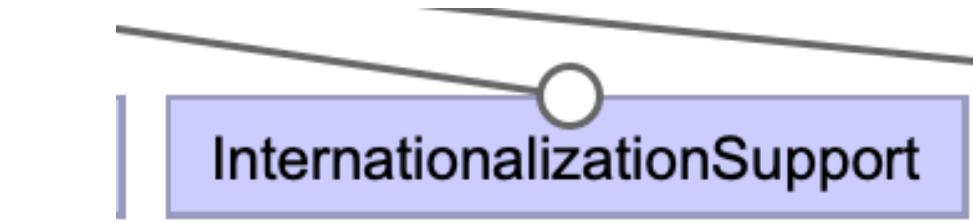
**XOR
decomposition**



**OR
decomposition**



Optional feature



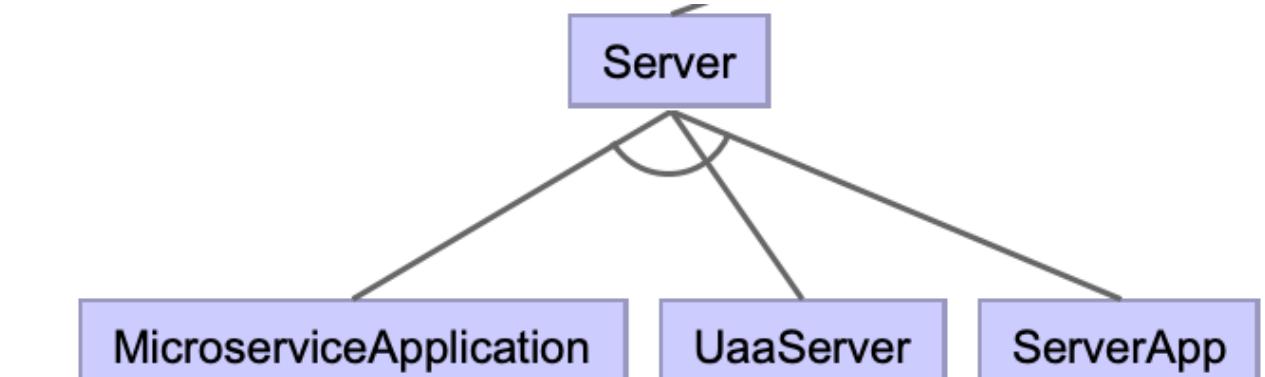
Source: Documentation

Which type of application would you like to create?

You can either use:

- Monolithic application [...]
- Microservice application [...]
- Microservice gateway [...]

XOR decomposition



Which type of database would you like to use?

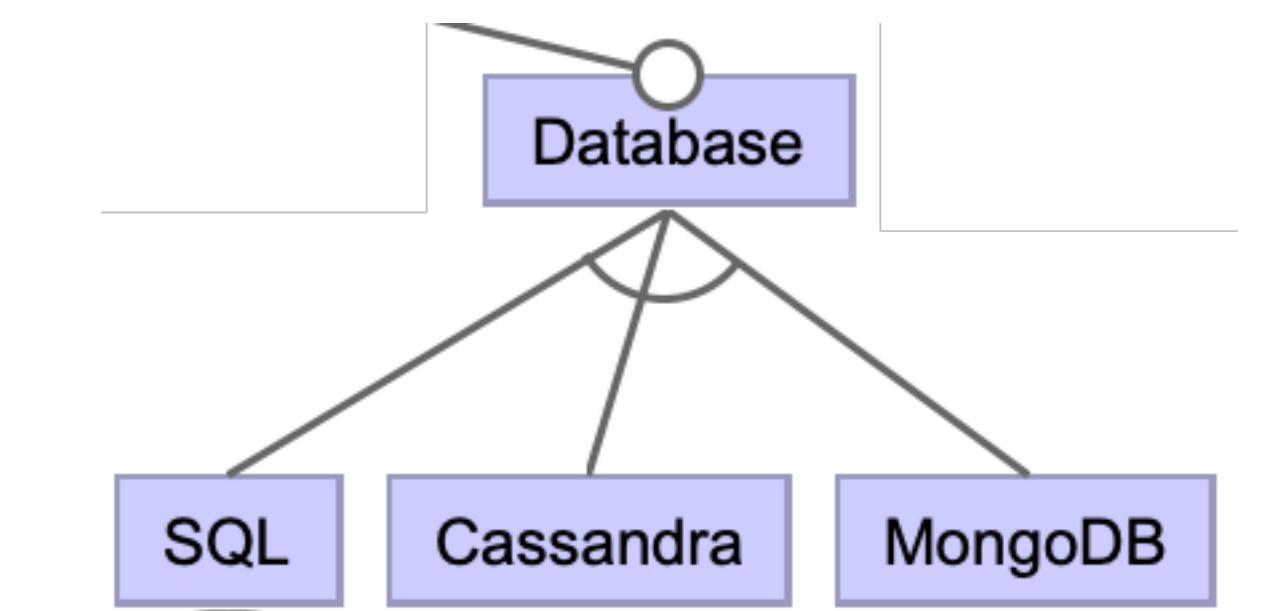
You can choose between:

- No database (only available when using a microservice application)
- An SQL database (H2, MySQL, MariaDB, PostgreSQL, MySQL, Oracle), which you will access with Spring Data JPA
- MongoDB
- Cassandra

Optional feature

XOR decomposition

Additional constraints



$\neg Database \Rightarrow MicroserviceApplication$

$SQL \Rightarrow SpringDataJPA$

Social login (Google, Facebook, Twitter)

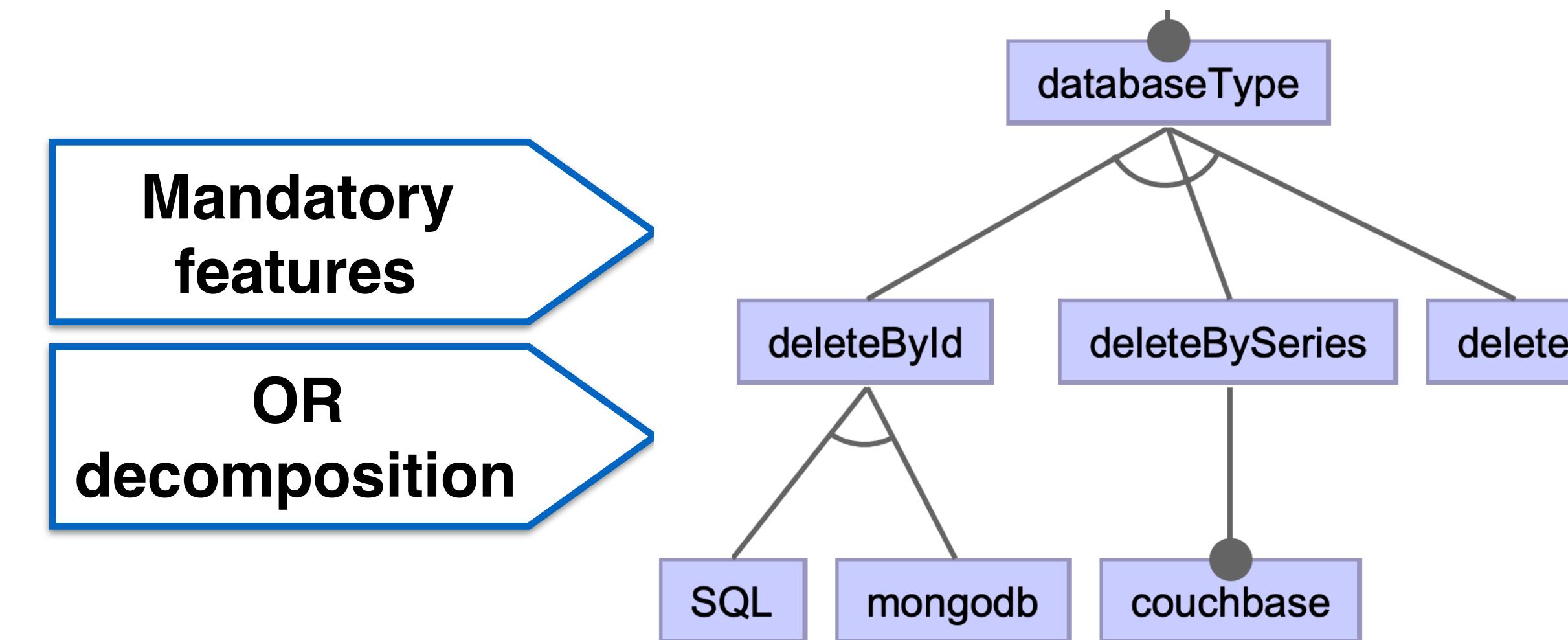
This option is only available if you selected an SQL or MongoDB database.

Additional constraints

$SocialLogin \Rightarrow (SQL \vee MongoDB)$

Source: Source code

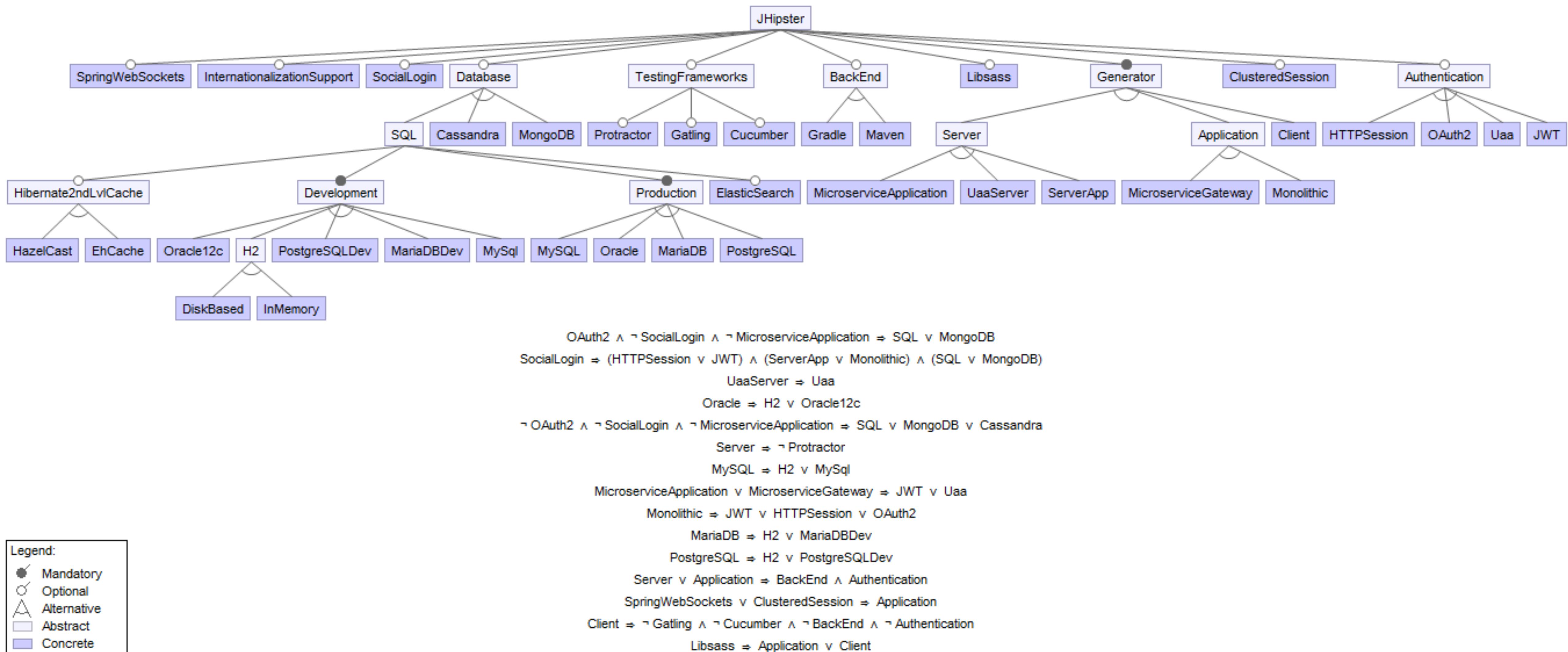
```
public void invalidateSession(@PathVariable String series) throws UnsupportedEncodingException {
    String decodedSeries = URLDecoder.decode(series, "UTF-8");
    SecurityUtils.getCurrentUserLogin()
        .flatMap(userRepository::findOneByLogin)
        .ifPresent(u ->
            persistentTokenRepository.findByUser(u).stream()
                .filter(persistentToken -> StringUtils.equals(persistentToken.getSeries(), decodedSeries))
                <%_ if (databaseType === 'sql' || databaseType === 'mongodb') { _%>
                    .findAny().ifPresent(t -> persistentTokenRepository.deleteById(decodedSeries)));
                <%_ } else if (databaseType === 'couchbase') { _%>
                    .findAny().ifPresent(t -> persistentTokenRepository.deleteBySeries(decodedSeries));
                <%_ } else { _%>
                    .findAny().ifPresent(persistentTokenRepository::delete));
                <%_ } _%>
        }<% } %>
```



f IDE
eature

<http://www.featureide.com>

JHipster v3.6.1



<https://github.com/xdevroey/jhipster-dataset/tree/master/v3.6.1/featuremodel>

Conjunctive Normal Form (CNF)

JHipster-App \wedge (Building $\vee \neg$ Maven) \wedge (Building $\vee \neg$ Gradle) \wedge (Maven \vee Gradle $\vee \neg$ Building) \wedge (\neg Maven $\vee \neg$ Gradle) \wedge (Server $\vee \neg$ Database) \wedge (Server $\vee \neg$ HibernateCache) \wedge (Server $\vee \neg$ Building) \wedge (Building $\vee \neg$ Server) \wedge (JHipster-App $\vee \neg$ Type) \wedge (JHipster-App $\vee \neg$ Client) \wedge (JHipster-App $\vee \neg$ Server) \wedge (Type $\vee \neg$ JHipster-App) \wedge (Server $\vee \neg$ JHipster-App) \wedge (Type $\vee \neg$ Monolithic) \wedge (Type $\vee \neg$ Microservice) \wedge (Type $\vee \neg$ Gateway) \wedge (Monolithic \vee Microservice \vee Gateway $\vee \neg$ Type) \wedge (\neg Monolithic $\vee \neg$ Microservice) \wedge (\neg Monolithic $\vee \neg$ Gateway) \wedge (\neg Microservice $\vee \neg$ Gateway) \wedge (Database $\vee \neg$ MongoDB) \wedge (Database $\vee \neg$ SQL) \wedge (Database $\vee \neg$ Cassandra) \wedge (MongoDB \vee SQL \vee Cassandra $\vee \neg$ Database) \wedge (\neg MongoDB $\vee \neg$ SQL) \wedge (\neg MongoDB $\vee \neg$ Cassandra) \wedge (\neg SQL $\vee \neg$ Cassandra) \wedge (\neg HibernateCache \vee SQL) \wedge (\neg Client \vee Monolithic) \wedge (Client \vee Microservice \vee Gateway) \wedge True $\wedge \neg$ False



- SAT
 - Consistency
 - Valid configurations
 - Dead features
 - ...

JHipster v3.6.1: >26k possible products

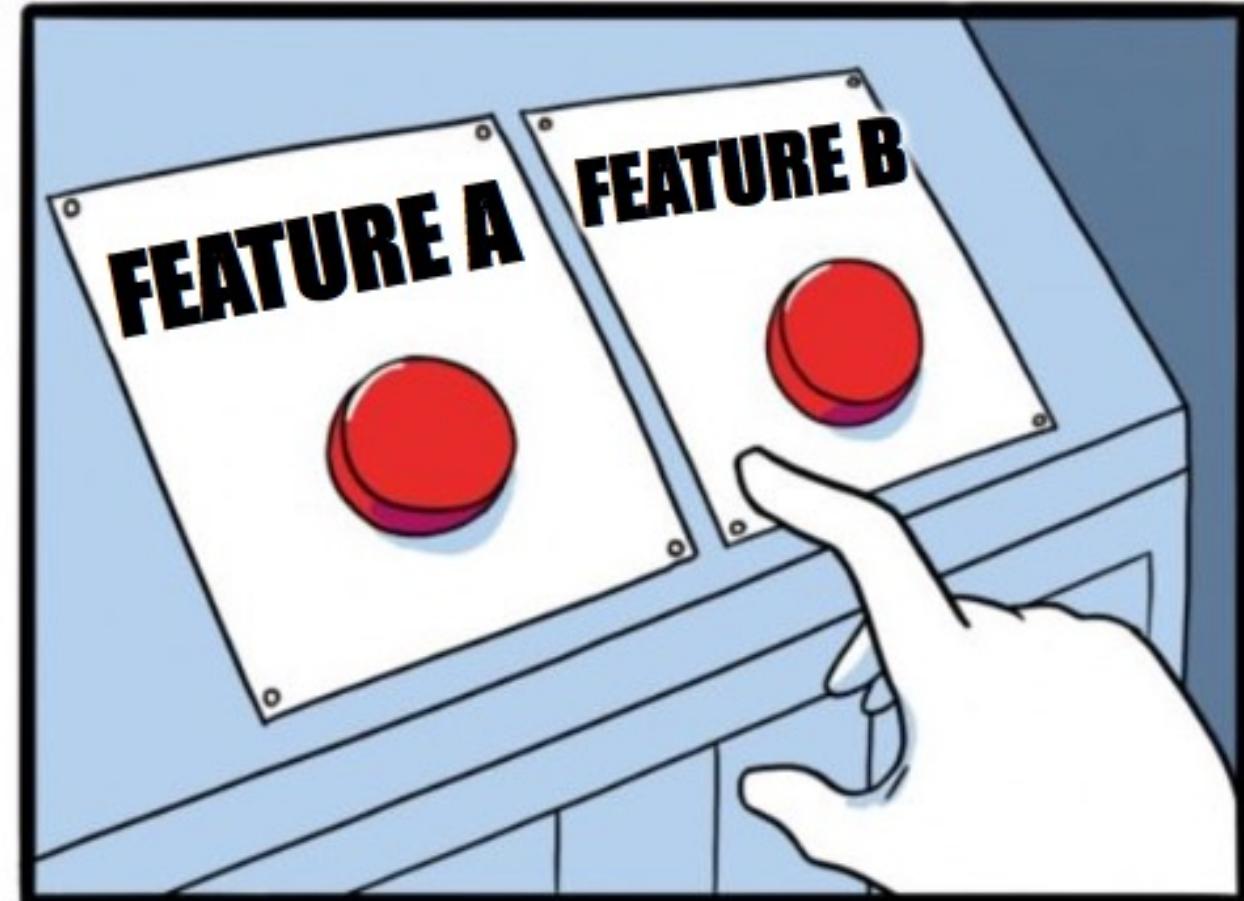
Feature Modelling

- **Compact representation of all products**
 - For instance, using a feature diagram
- **Sources for reverse-engineering**
 - Configurator
 - Documentation
 - Source code
- **Can be formalised for analysis**
 - SAT of a configuration/product
 - Analysis (consistency, dead features, etc.)
 - ...

Does your application have variability?

Yes, most probably

- **What kind of variability?**
 - Hardware
 - Platform
 - Software
 - Bundles
 - Plugins
 - Command line options
 - Configuration files
 - Microservices
 - ...
- **How is it managed (if it is managed)?**
 - For users
 - Documentation only?
 - Configurator (e.g., JHipster)?
 - For developers
 - Documentation only?
 - Model (e.g., feature model)?
 - Planned in the development lifecycle?



imgflip.com

JAKE-CLARK.TUMBLR

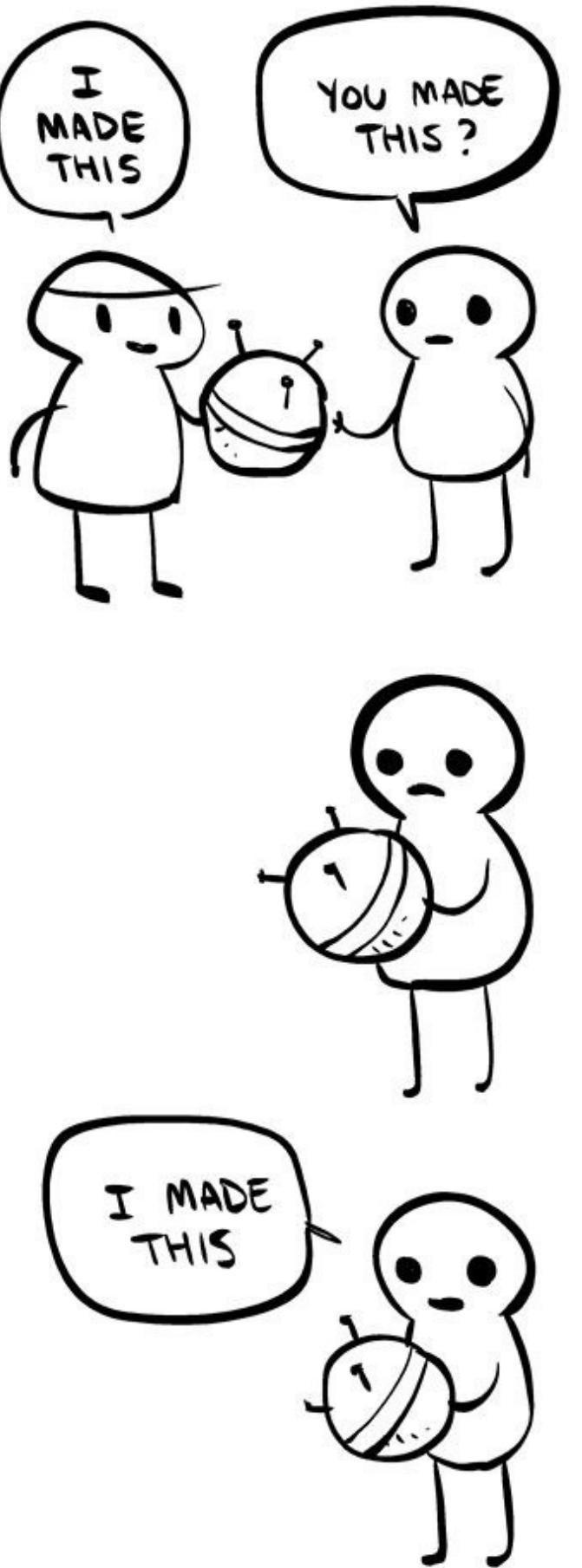
Variability Binding Time

Variability offers choices.

When we derive a product, we make **decisions**; we decide which features will be included in the product or not. We also say that we **bind** a decision.

Design-time binding

- Clone and own



Compile-time Binding

- Decided before or at compile time
- Allows **optimisations**
 - Removes unnecessary code from the product
- Once the product has been generated and deployed, it is **not variable any more**

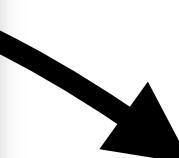
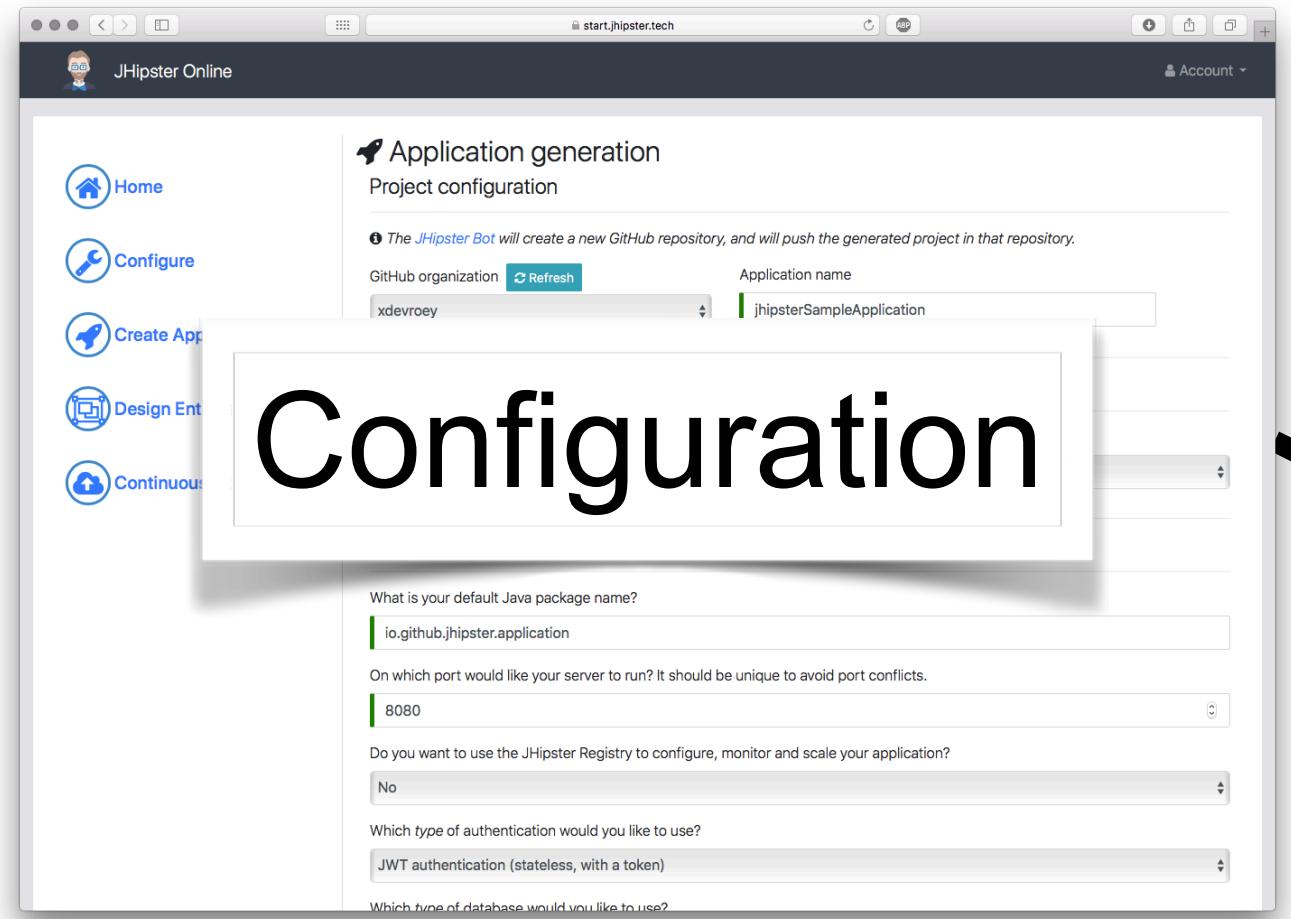
Conditional compiling

- Implements variability with **preprocessors**
- Using **annotated** code (here, templates)

```
<%_ if (databaseType === 'mongodb' || databaseType === 'couchbase') { %>←  
<dependency>  
  <groupId>org.springframework.boot</groupId>  
  <artifactId>spring-boot-starter-data-<%=databaseType%></artifactId>←  
</dependency>  
<%_ } %>  
<dependency>  
  <groupId>org.springframework.boot</groupId>  
  <artifactId>spring-boot-starter-logging</artifactId>  
</dependency>  
  
<% if (databaseType === 'sql') { %>/**  
 * Spring Data JPA repository for the Authority entity.  
 */<% } %><% if (databaseType === 'mongodb') { %>/**  
 * Spring Data MongoDB repository for the Authority entity.  
 */<% } %><% if (databaseType === 'couchbase') { %>/**  
 * Spring Data Couchbase repository for the Authority entity.  
 */<% } %>  
public interface AuthorityRepository extends <% if (databaseType === 'sql') {  
%>JpaRepository<% } %><% if (databaseType === 'mongodb') { %>MongoRepository<% } %><%  
if (databaseType === 'couchbase') { %>N1qlCouchbaseRepository<% } %><Authority, String>  
{  
}
```



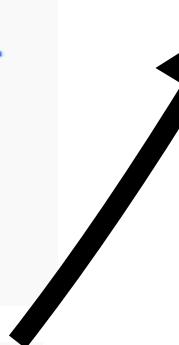
Conditional compiling



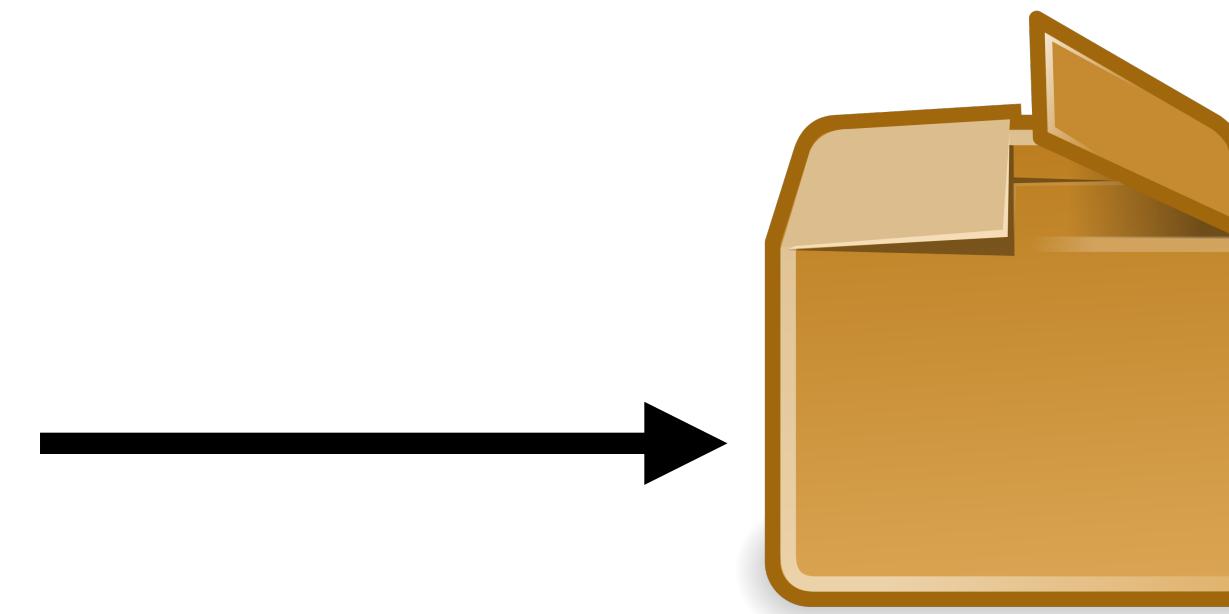
Yeoman

```
<%_ if (databaseType === 'mongodb' || databaseType === 'couchbase') { %>
<dependency>
  <groupId>org.springframework.boot</groupId>
  <artifactId>spring-boot-starter-data-<%=databaseType%></artifactId>
</dependency>
<% } %>
<dependency>
  <groupId>org.springframework.data</groupId>
  <artifactId>spring-data-mongodb</artifactId>
</dependency>
<% if (databaseType === 'couchbase') { %>/*
 * Spring Data Couchbase repository for the Authority entity.
 */<% } %>
<% if (databaseType === 'couchbase') { %>/*
 * Spring Data Couchbase repository for the Authority entity.
 */<% } %>
public interface AuthorityRepository extends <% if (databaseType === 'sql') {
  %>JpaRepository<% } %><% if (databaseType === 'mongodb') { %>MongoRepository<% } %><%
if (databaseType === 'couchbase') { %>N1qlCouchbaseRepository<% } %><Authority, String>
{
}
```

A large callout box highlights the annotated code, specifically the conditional blocks starting with '<% if (databaseType === ...)'.



Annotated code



Source code
without annotations



Load-time Binding

- Decided after compilation when the program is started
- More flexibility for **reconfiguration**
 - ... but Requires a reboot
- Memory and performance **overhead**
 - All variations are compiled into a single binary
 - Consistency conditions must be checked at load time
 - Unnecessary functionality may be considered as potential **security threat**

Parameters and Configuration Files

- Implement variability using conditional statements (such as if and switch)
- Controlled by configuration parameters
 - Passed to the method or module,
 - Set as global variables in a system

Gcc

```
/* Enable -Werror=coverage-mismatch when -Werror and -Wno-error
   have not been set. */
if (!global_options_set.x_warnings_are_errors
    && warn_coverage_mismatch
    && (global_dc->classify_diagnostic[OPT_Wcoverage_mismatch] ==
         DK_UNSPECIFIED))
  diagnostic_classify_diagnostic (global_dc, OPT_Wcoverage_mismatch,
                                 DK_ERROR, UNKNOWN_LOCATION);

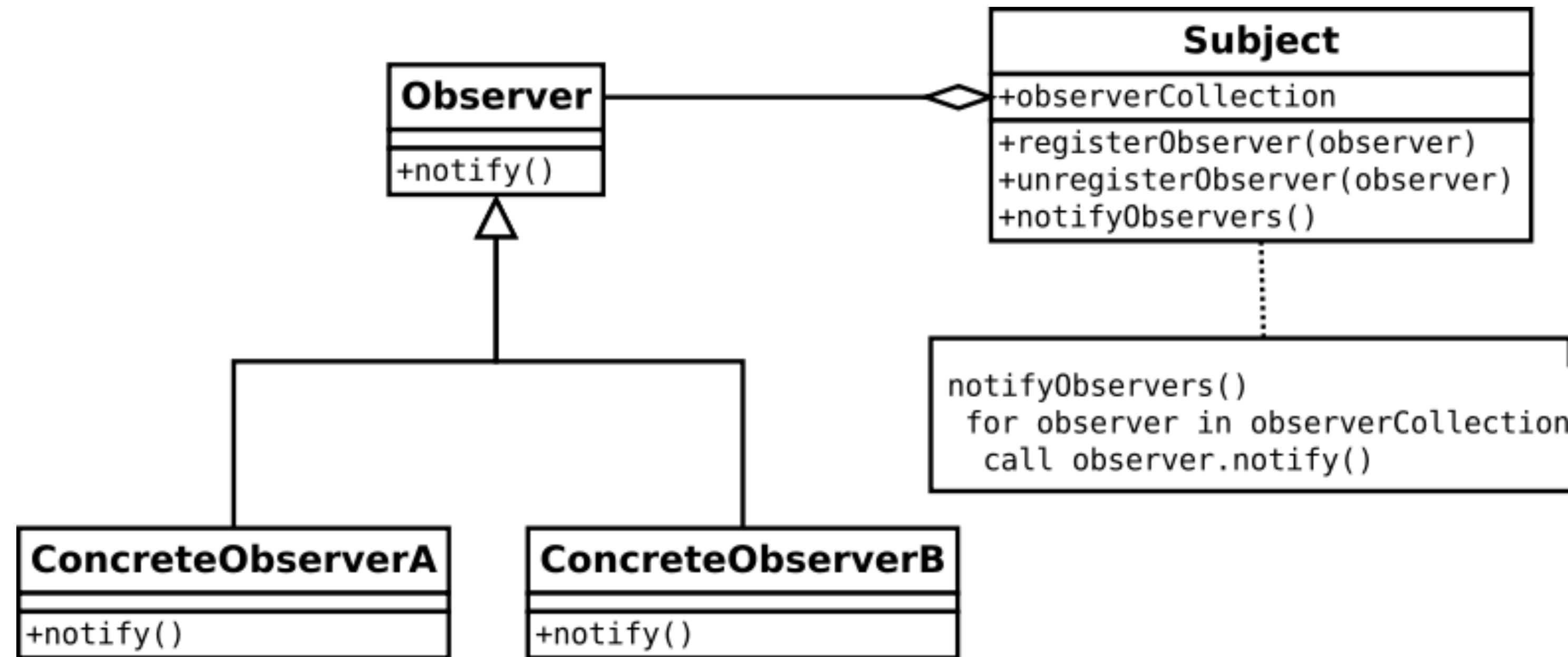
/* Save the current optimization options. */
optimization_default_node = build_optimization_node (&global_options);
optimization_current_node = optimization_default_node;
```

Run-time Binding

- Decided during program execution and may be changed latter
 - Used in dynamic adaptive systems (e.g., robots)
- Most flexible to **reconfigure**
 - Able to react to internal and external stimuli by adapting its behaviour
- Memory and performance **overhead**
 - All variations are compiled into a single binary
 - Consistency conditions must be checked at run time
- Unnecessary functionality may be considered as potential **security threat**

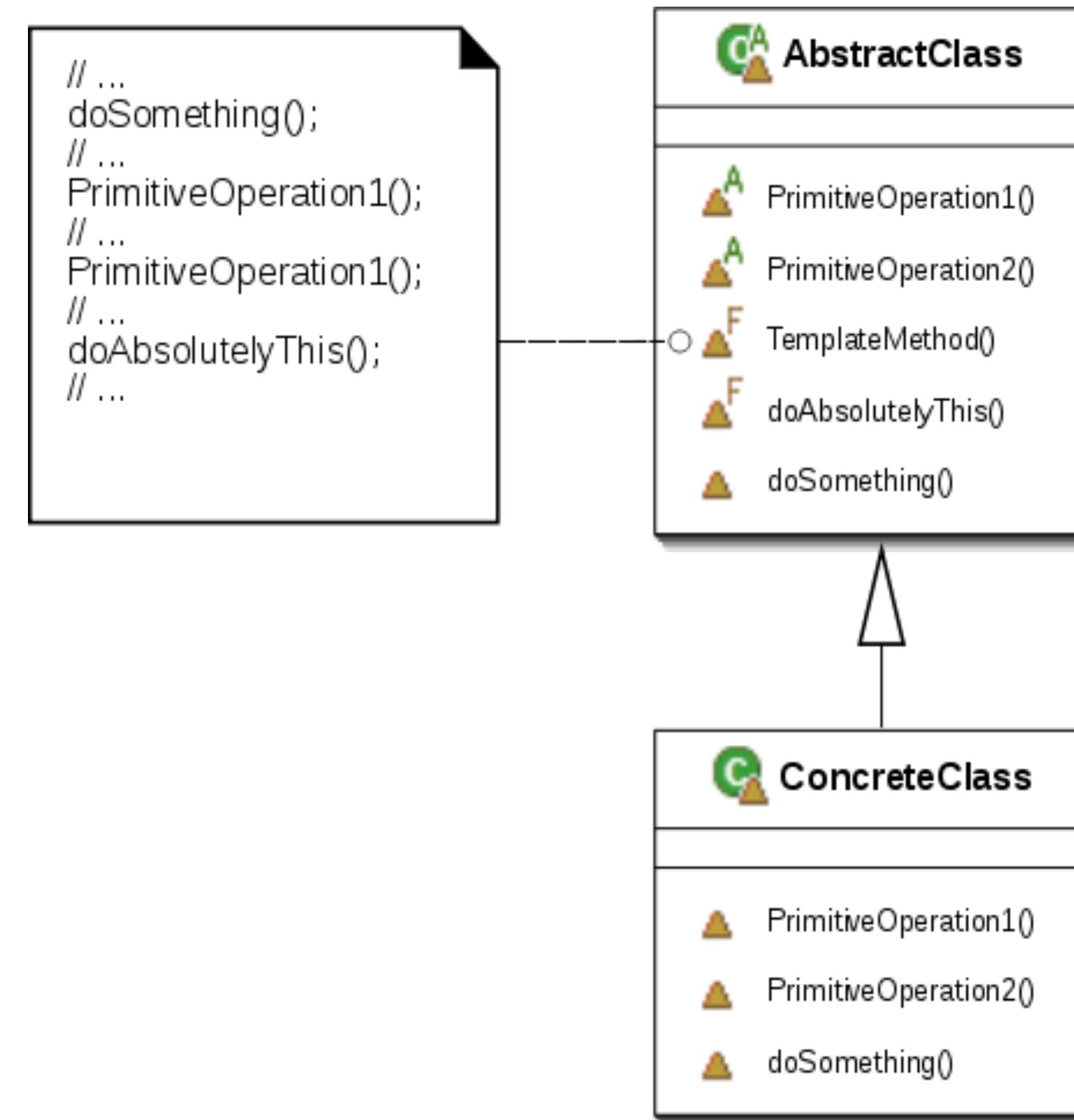
Design Patterns

- Observer pattern (publish/subscribe) to implement distributed event handling
 - Features are implemented as observers
 - Variability is achieved by registering or not registering observers



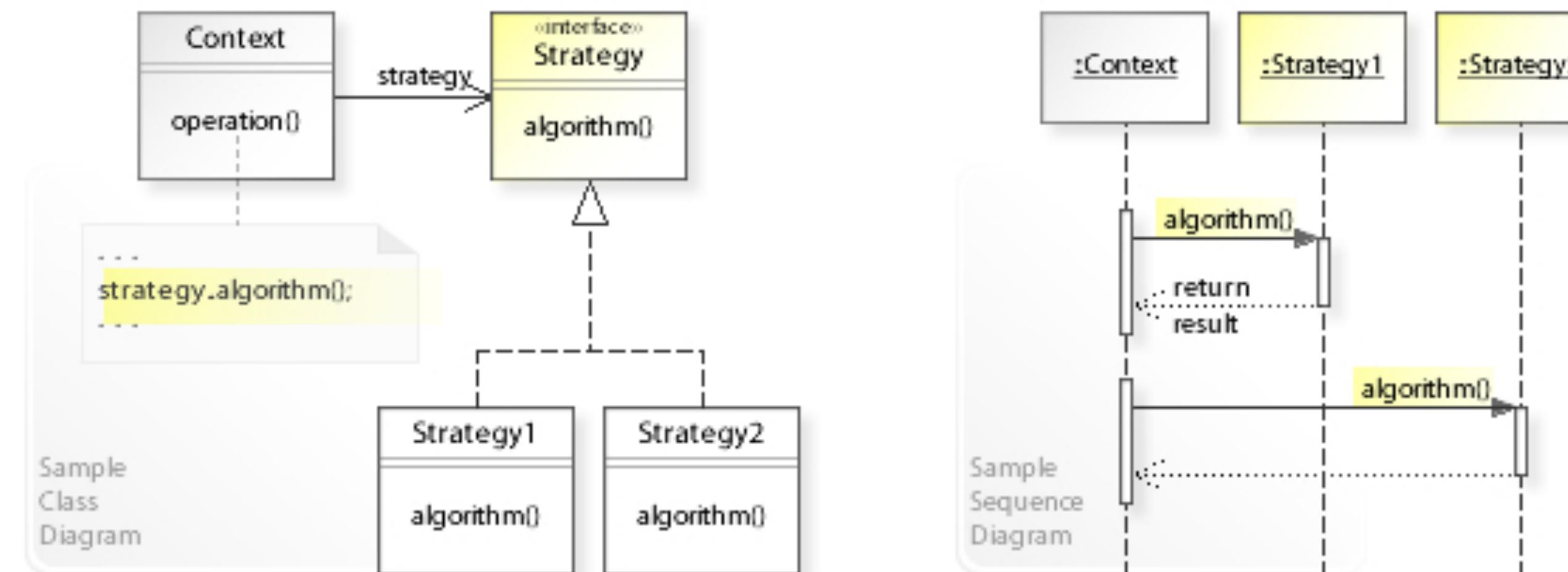
Design Patterns

- Template-method pattern
 - Using an abstract class
 - Implement feature's behaviour using inheritance



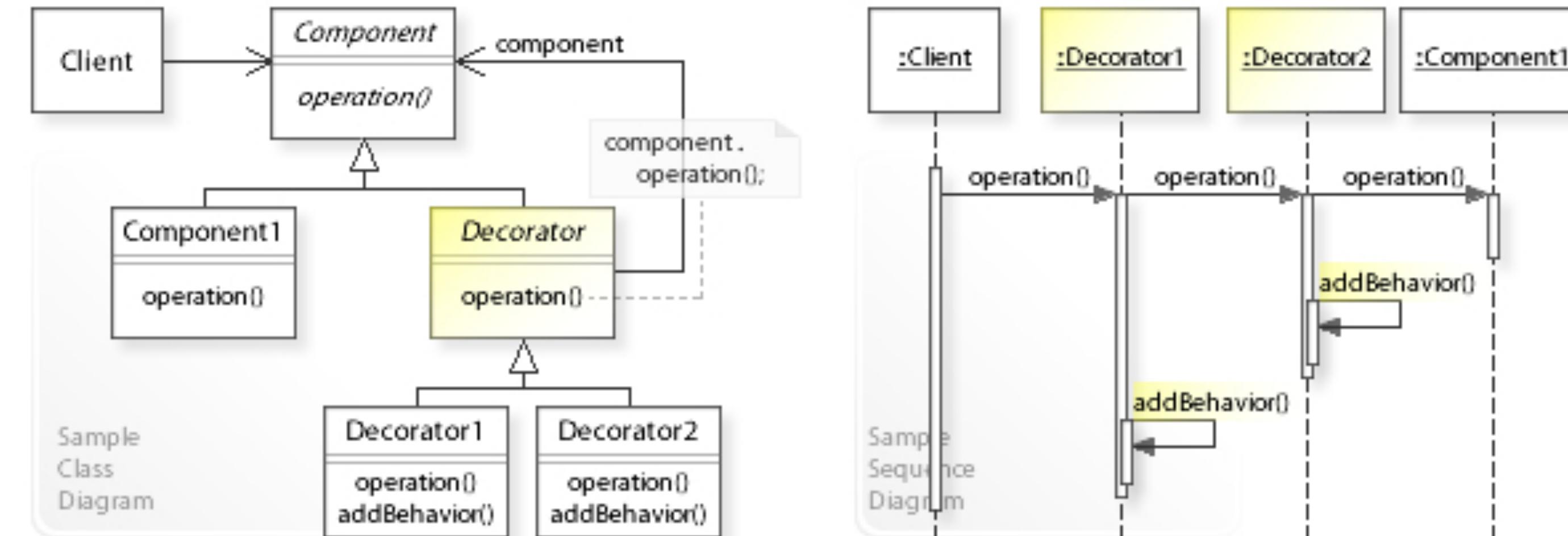
Design Patterns

- Strategy pattern
 - Encodes a callback mechanism
 - Alternative features where each corresponds to one implementation of the algorithm
 - Uses polymorphism instead of conditional statements



Design Patterns

- Decorator pattern
 - Extends object with additional behaviour at run time
 - Optional features and feature groups, of which multiple features can be selected, are implemented as decorators



Variability Binding Time

- **Design-time**

- Clone and own

- **Compile-time**

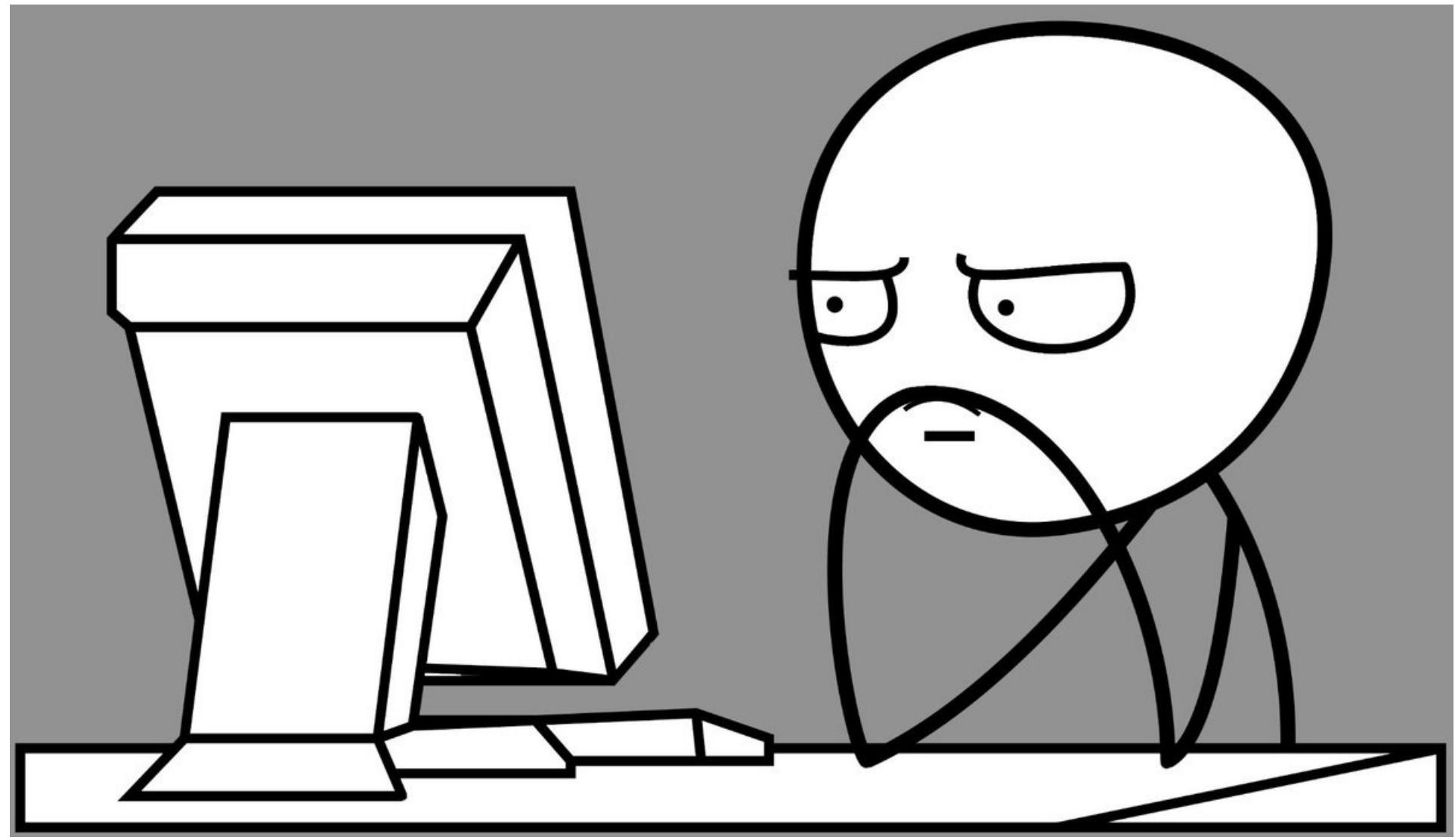
- Conditional compilation

- **Load-time**

- Program parameters and configuration files

- **Run-time**

- Design patterns



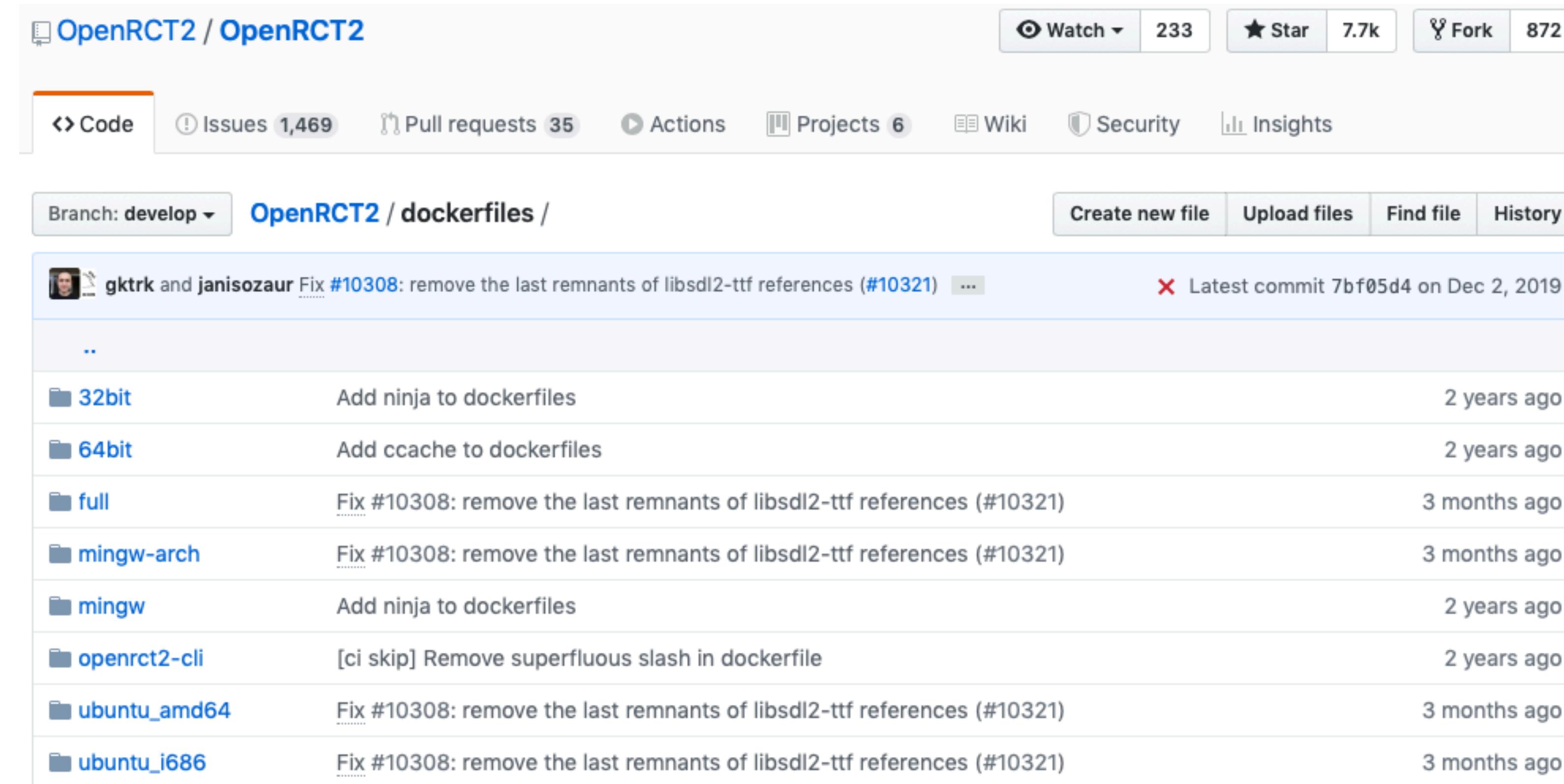
Take-away

Does your application have variability?

Yes, most probably

- **What kind of variability?**
 - Hardware
 - Platform
 - Software
 - Bundles
 - Plugins
 - Command line options
 - Configuration files
 - Microservices
 - ...
- **How is it managed (if it is managed)?**
 - For users
 - Documentation only?
 - Configurator (e.g., JHipster)?
 - For developers
 - Documentation only?
 - Model (e.g., feature model)?
 - Planned in the development lifecycle?

Example: Docker images



The screenshot shows the GitHub repository page for `OpenRCT2 / OpenRCT2`. The repository has 233 watchers, 7.7k stars, and 872 forks. The `Code` tab is selected, showing 1,469 issues and 35 pull requests. Other tabs include Actions, Projects (6), Wiki, Security, and Insights.

The current branch is `develop`, and the specific commit history for the `OpenRCT2 / dockerfiles` folder is displayed. The latest commit was made by `gktrk and janisozaur` on Dec 2, 2019, fixing #10308: remove the last remnants of libsdl2-ttf references (#10321). The commit message also mentions `#10321`.

The commit history lists the following changes:

- 32bit: Add ninja to dockerfiles (2 years ago)
- 64bit: Add ccache to dockerfiles (2 years ago)
- full: Fix #10308: remove the last remnants of libsdl2-ttf references (#10321) (3 months ago)
- mingw-arch: Fix #10308: remove the last remnants of libsdl2-ttf references (#10321) (3 months ago)
- mingw: Add ninja to dockerfiles (2 years ago)
- openrct2-cli: [ci skip] Remove superfluous slash in dockerfile (2 years ago)
- ubuntu_amd64: Fix #10308: remove the last remnants of libsdl2-ttf references (#10321) (3 months ago)
- ubuntu_i686: Fix #10308: remove the last remnants of libsdl2-ttf references (#10321) (3 months ago)

Variability Management section outline

- Examples of variability in your system, and their manifestation in architectural discussions
 - **Variability management**
 - **(Partial) feature model**
 - Current variability **implementation mechanism** of your system
 - Conditional compiling
 - Conditional statements (if-then-else)
 - Design patterns
 - **Variability binding time**
 - Design-time
 - Compile-time
 - Load-time
 - Run-time

Take-aways

- Variability enables **adaptability** to the business domain
 - It should be **planned** and **managed**
 - Identify development **practices**
 - Clone and own
 - Software product line
 - Most probably something intermediate
 - Binding
 - Design, compile, load, and/or runtime binding
 - Variability implementation mechanism(s) (conditional compiling, parameters, design patterns)
 - **Feature modelling** helps to manage variability
 - Analysis on the feature model
 - Sample products to test