

# **Software Product Lines**

## **Advanced concepts**

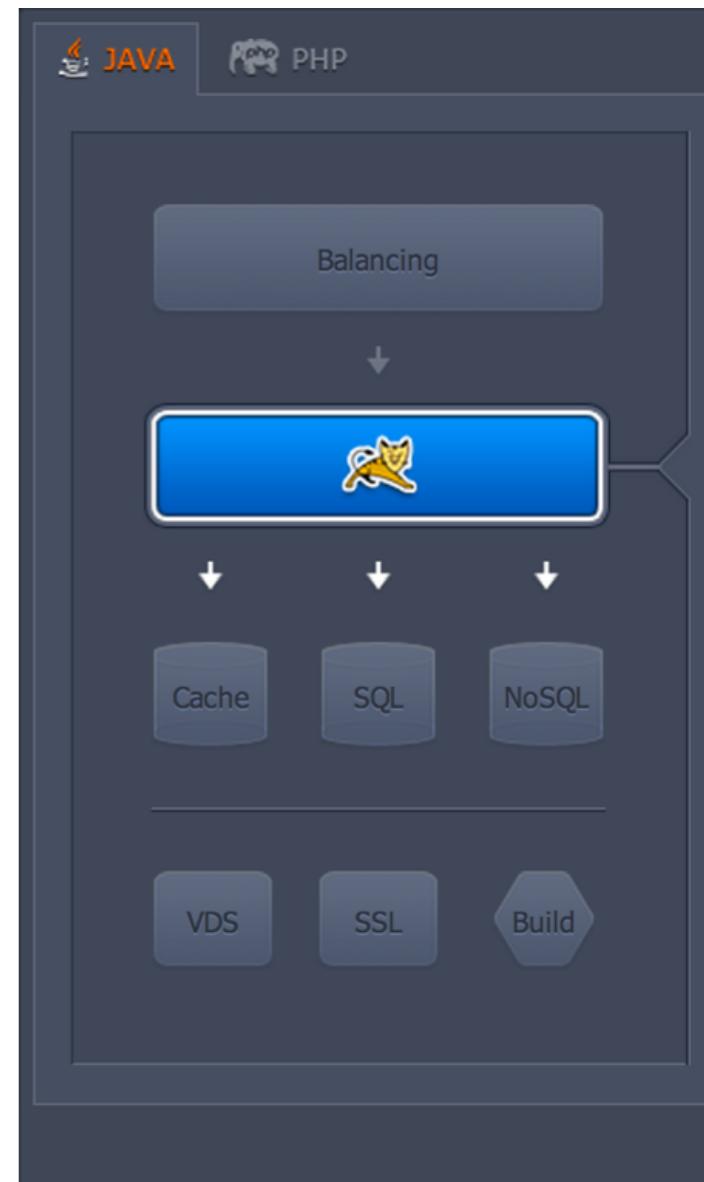
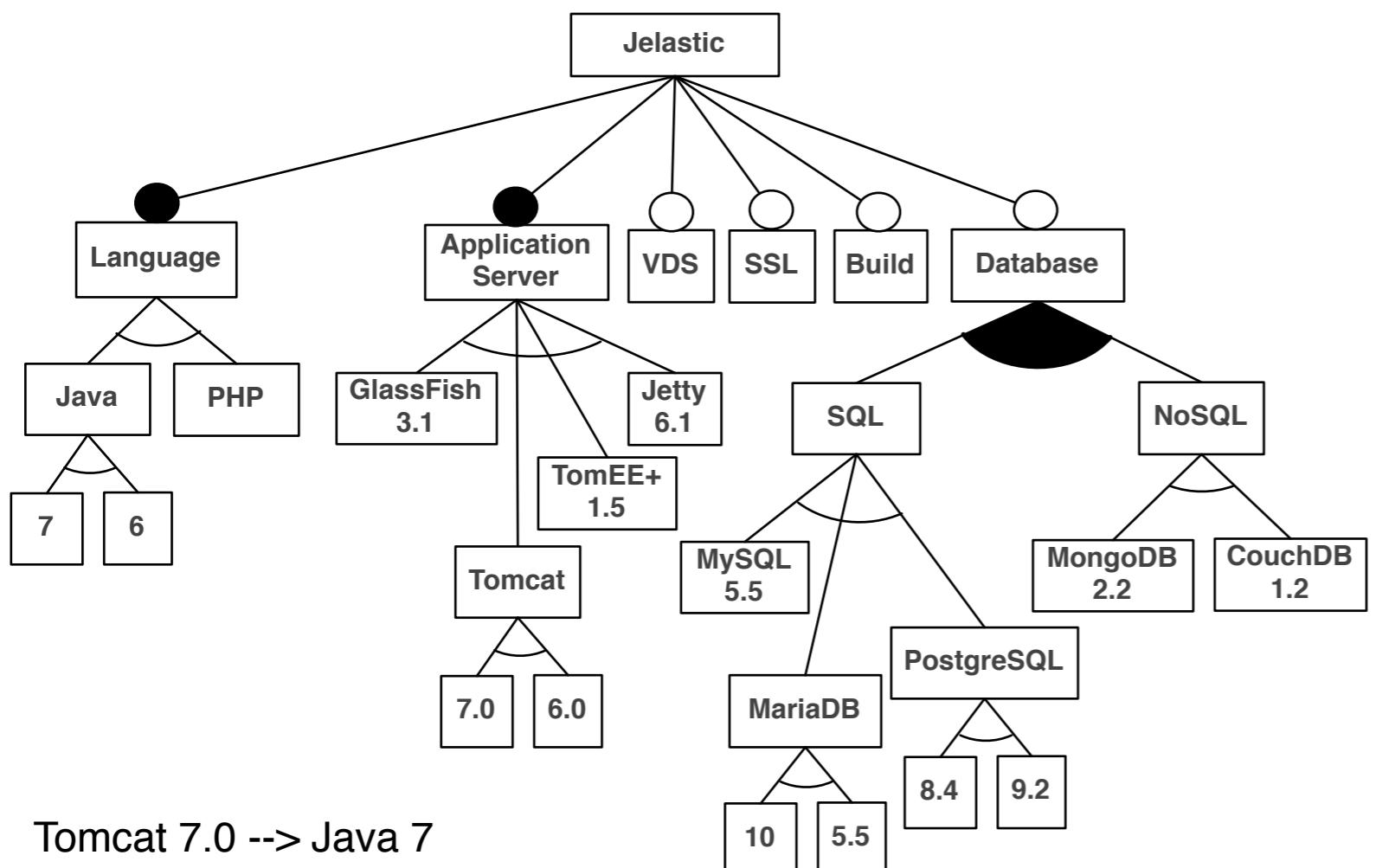
# Product lines

---

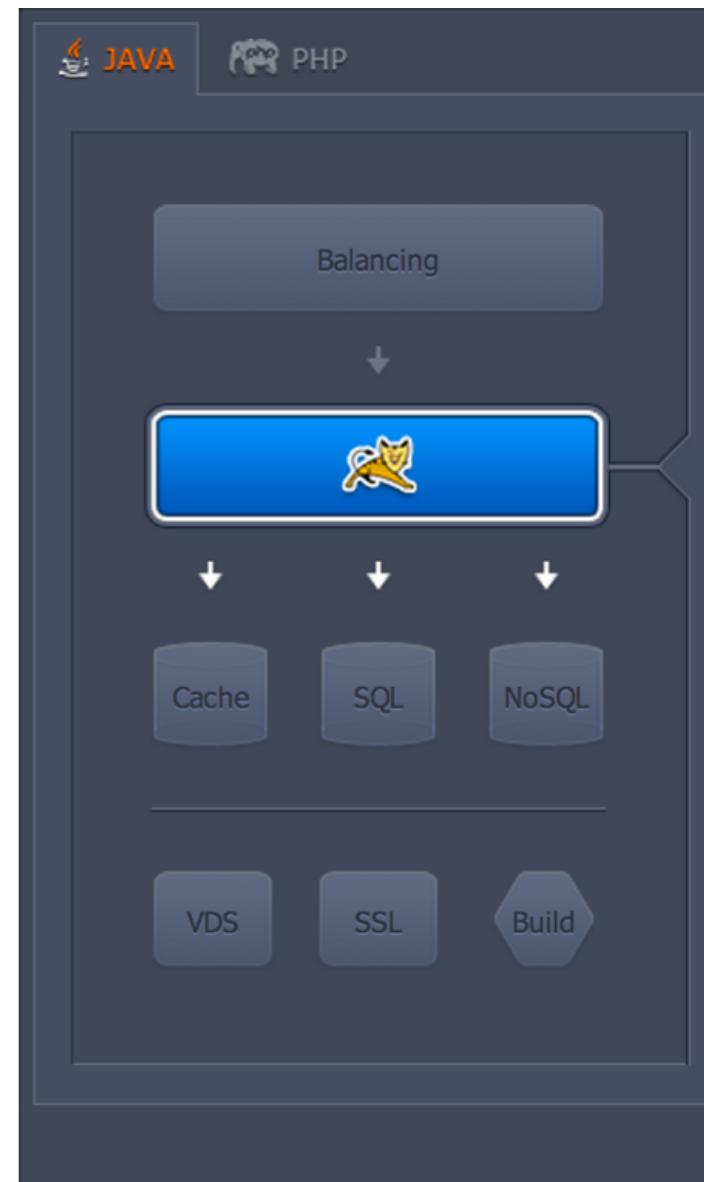
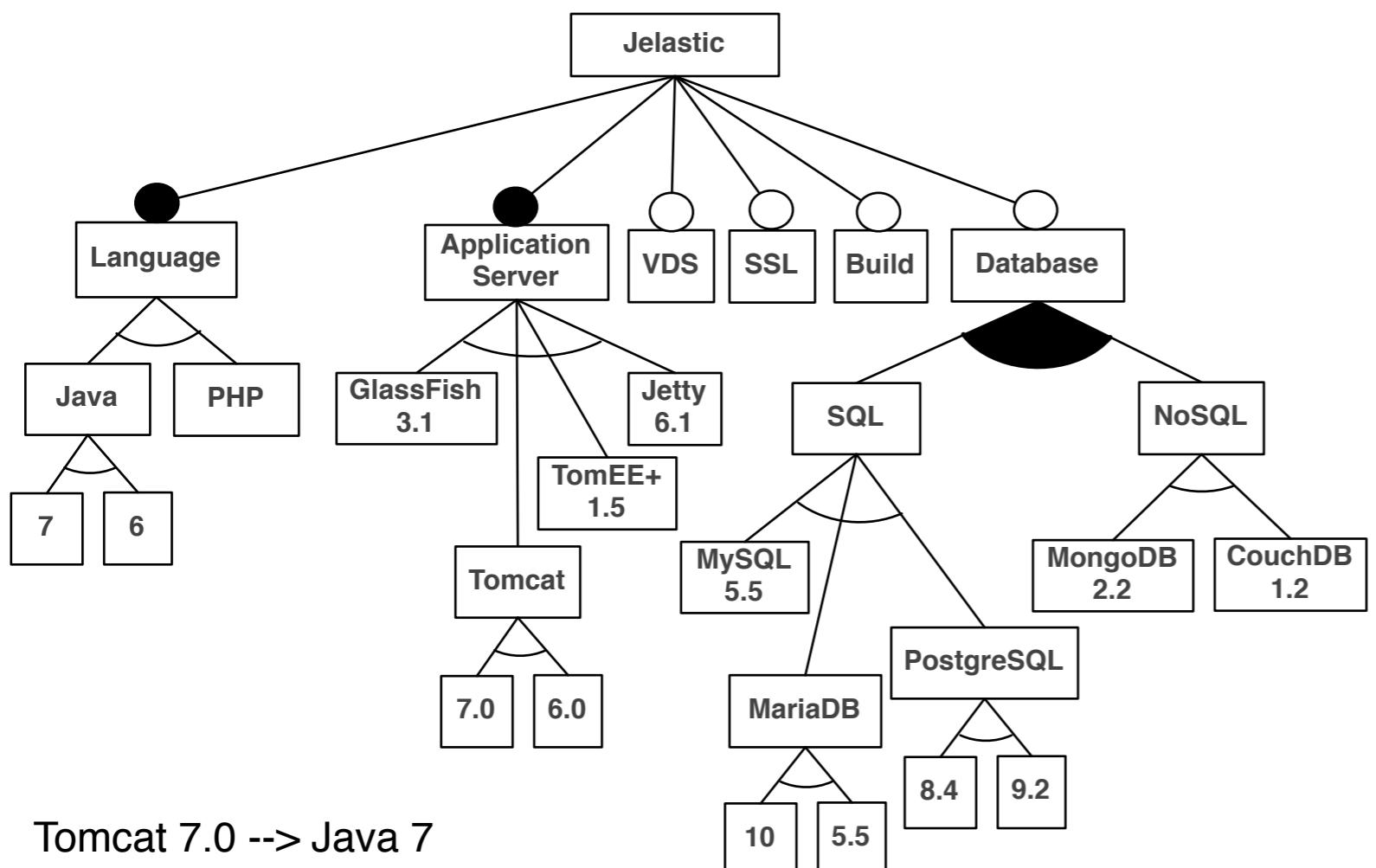
- ▶ Extended feature models
- ▶ Evolution
- ▶ From design time to runtime
- ▶ Evolution @runtime

**Are boolean feature models  
expressive enough?**

# Back to our cloud example



# Back to our cloud example



# Back to our cloud example

The screenshot shows the Jelastic cloud configuration interface for Java applications. It includes a sidebar for Java and PHP, a main application servers section, and a resources section.

**Sidebar:** JAVA (selected), PHP

**Application Servers:** ON

- Vertical scaling per node:** Reserved 1 cloudlet(s) (128 MB, 200 MHz, 0.0085 EUR per.., Discount: 15%)
- Horizontal scaling:** 1 node(s)
- Software stack:** Tomcat 7.0, Java 7
- Cloudlet settings:** High-availability (OFF), Public IPv4 (OFF)

**Resources (cloudlets):**

- Reserved cloudlets:** Now: 1, Next: 8, Discount: 15% (Discount: 25%)
- Total Reserved Cloudlets:** €6 per month (You're saving €1/month by using Reserved Cloudlets)
- Total monthly cost:** €6\* (Free of charge for the trial period.)

**Environment name:** env-2897066.jelastic.dogado.eu

**Buttons:** Cancel, Create

# Back to our cloud example

The screenshot shows the Jelastic cloud configuration interface for Java application servers. The interface is divided into several sections:

- Top Navigation:** JAVA (selected) and PHP tabs.
- Application Servers:** A section showing a central server icon with a cat logo, connected to a "Balancing" box above it and three boxes below labeled "Cache", "SQL", and "NoSQL".
- Vertical scaling per node:** Shows "Reserved 1 cloudlet(s)" with "128 MB, 200 MHz" and "0.0085 EUR per..". A discount of "15%" is applied.
- Horizontal scaling:** Shows a slider from 0 to 64, currently set at 1, with a red box highlighting the "1 node(s)" button.
- Software Selection:** "Tomcat 7.0" and "Java 7" dropdown menus.
- Advanced Options:** "High-availability" and "Public IPv4" checkboxes, both currently off.
- Resources (cloudlets):** Shows "Reserved cloudlets" with "Now: 1" and "Discount: 15%". It also shows "Next: 8" and "Discount: 25%" for the next level. A progress bar indicates the current level.
- Total Reserved Cloudlets:** €6 per month. A note says "You're saving €1/month by using Reserved Cloudlets".
- Total monthly cost:** €6\*. A note says "\*Free of charge for the trial period."
- Links:** "Cost details" and "Quotas & pricing".
- Environment name:** "env-2897066" and ".jelastic.dogado.eu" with a checked checkbox.
- Buttons:** "Cancel" and "Create" buttons.

# Back to our cloud example

The screenshot shows the Jelastic cloud configuration interface for Java application servers. The left sidebar has tabs for JAVA (selected) and PHP. The main area displays a stack diagram with layers: **nginx** (green), **Tomcat 7.0** (blue), **Cache**, **SQL**, **NoSQL**, **VDS**, **SSL**, and **Build**. The Tomcat layer is highlighted with a yellow cat icon.

**Application Servers** (ON)

**Vertical scaling per node**

Reserved 1 cloudlet(s)  
128 MB, 200 MHz  
0.0085 EUR per..  
Discount: 15%

Horizontal scaling: 2 node(s)

Tomcat 7.0 ▾ Java 7 ▾

High-availability OFF

Public IPv4 OFF

**Resources (cloudlets)**

**Reserved cloudlets**

Now: 3 Next: 8  
Discount: 15% Discount: 25%

Total Reserved Cloudlets €18 per month  
You're saving €3/month by using Reserved Cloudlets

**Total monthly cost** from €18\* to €109\*

\*Free of charge for the trial period.

**Cost details**

**Quotas & pricing**

**Environment name**  
env-2897066 .jelastic.dogado.eu

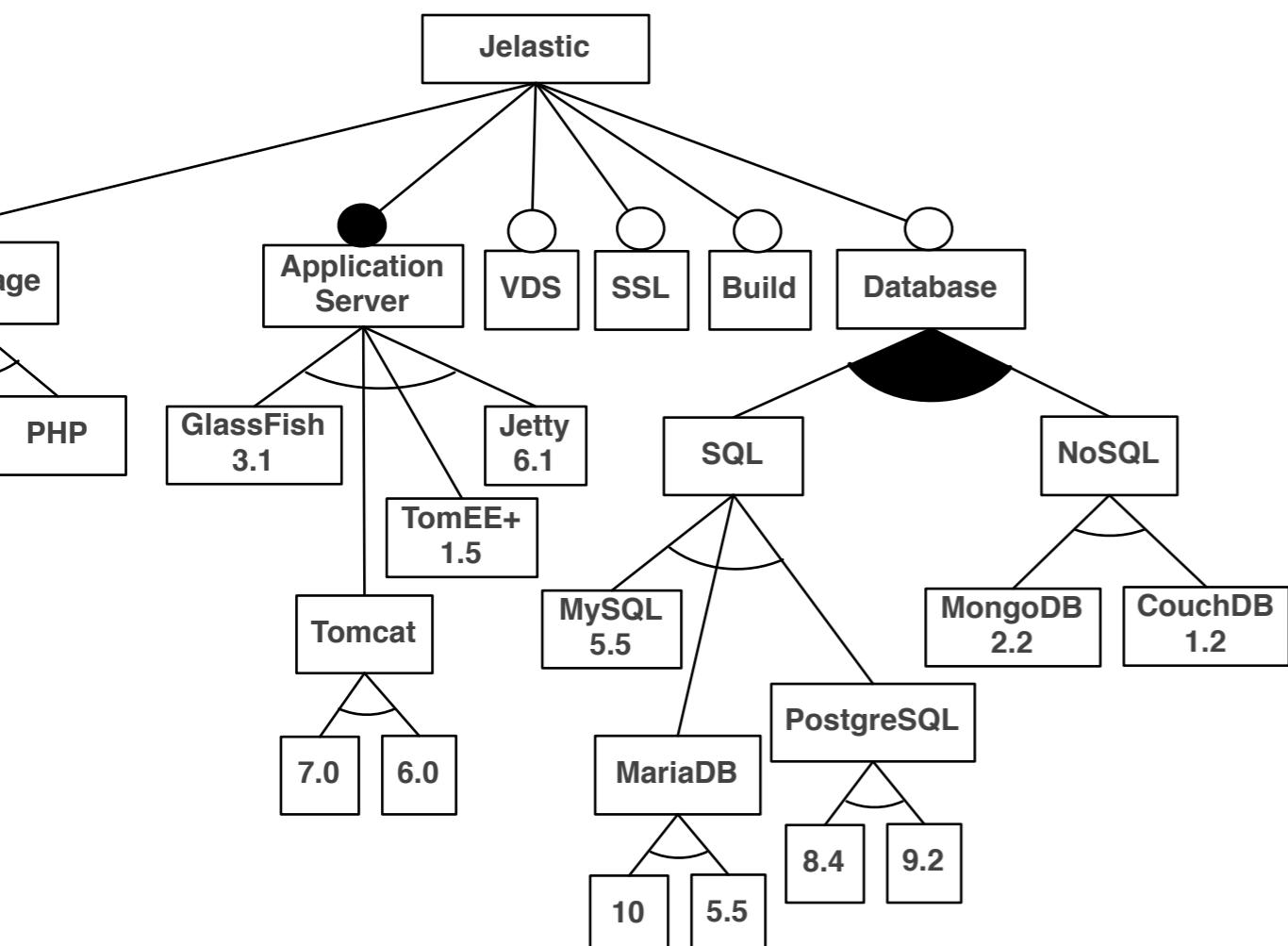
**Create**

# Back to our cloud example

Load balancer

The screenshot shows the Jelastic cloud interface for deploying an application. On the left, there's a stack editor with Java and PHP tabs. A red arrow points from the text "Load balancer" to the "nginx" component in the stack. The stack consists of several layers: a bottom layer with Cache, SQL, and NoSQL services; a middle layer with VDS, SSL, and Build services; and a top layer with an "nginx" component, followed by a "Tomcat 7.0" node and a "Java 7" node. The "Tomcat 7.0" node has a dropdown menu showing "2 node(s)". To the right, the "Application Servers" section is open, showing "Vertical scaling per node" with 1 reserved cloudlet at 128 MB, 200 MHz, and a 0.0085 EUR per month discount of 15%. It also shows "Horizontal scaling" with 2 nodes. The "Resources (cloudlets)" section indicates 3 reserved cloudlets now and 8 next, with discounts of 15% and 25% respectively. The "Total Reserved Cloudlets" cost is €18 per month, with a note about saving €3/month. The "Total monthly cost" is shown as €18\* to €109\*. Buttons for "Cost details" and "Quotas & pricing" are available. The "Environment name" is set to "env-2897066.jelastic.dogado.eu". At the bottom are "Cancel" and "Create" buttons.

# Back to our cloud example

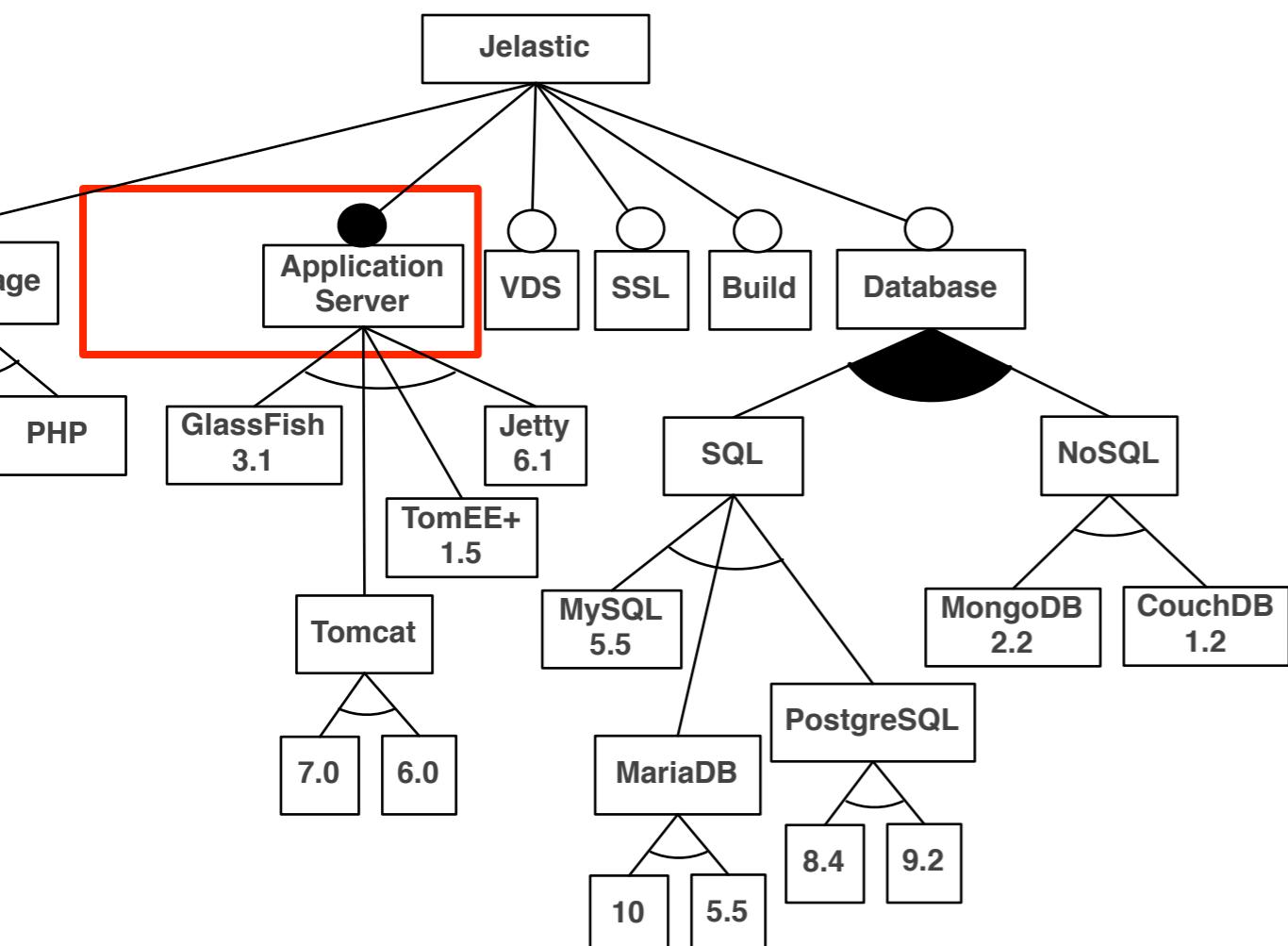


The interface shows a configuration for a Java application. It includes tabs for JAVA and PHP, with JAVA selected. A red arrow points from the "JAVA" tab to the "Tomcat" icon. The configuration panel on the right shows:

- Application Servers**: Vertical scaling per node, Reserved 1 cloudlet(s), 128 MB, 200 MHz, 0.0085 EUR per.., Discount: 15%.
- Horizontal scaling**: 2 node(s) (with a plus sign to add more).
- High-availability**: OFF.
- Public IPv4**: OFF.

Icons for VDS, SSL, and Build are also present in the configuration area.

# Back to our cloud example



A screenshot of the Jelastic application configuration interface. A red arrow points from the 'Load balancer' label to the 'Application Servers' section. The interface shows a Java application stack with Tomcat 7.0 and Java 7 selected. It includes sections for Application Servers (with a 15% discount), Horizontal scaling (2 nodes), and High-availability. Buttons for VDS, SSL, and Build are visible at the bottom.

Load balancer

JAVA PHP

Application Servers

Vertical scaling per node

Reserved 1 cloudlet(s)  
128 MB, 200 MHz  
0.0085 EUR per..  
Discount: 15%

Horizontal scaling

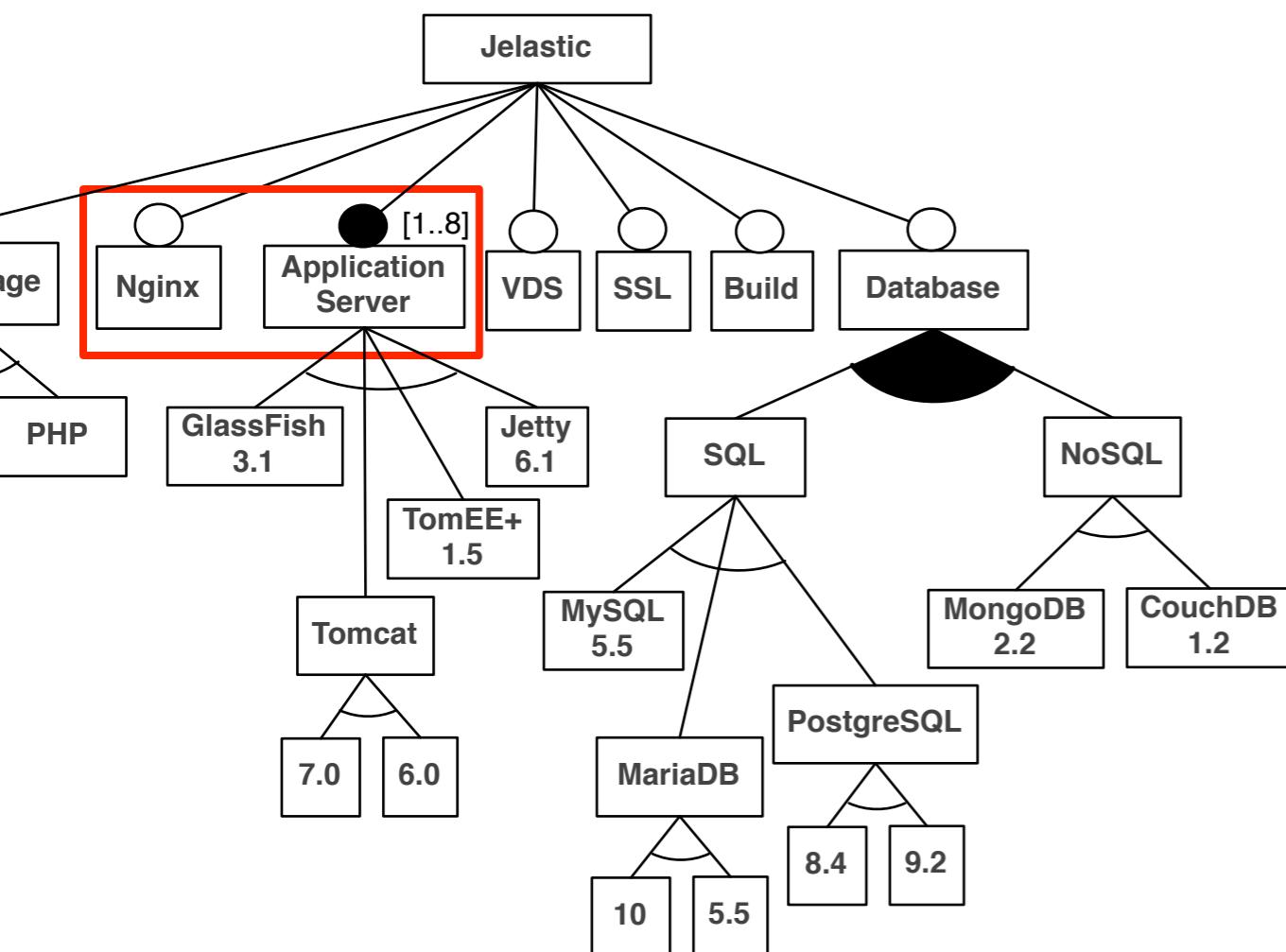
2 node(s)

Tomcat 7.0 Java 7

High-availability

Public IPv4

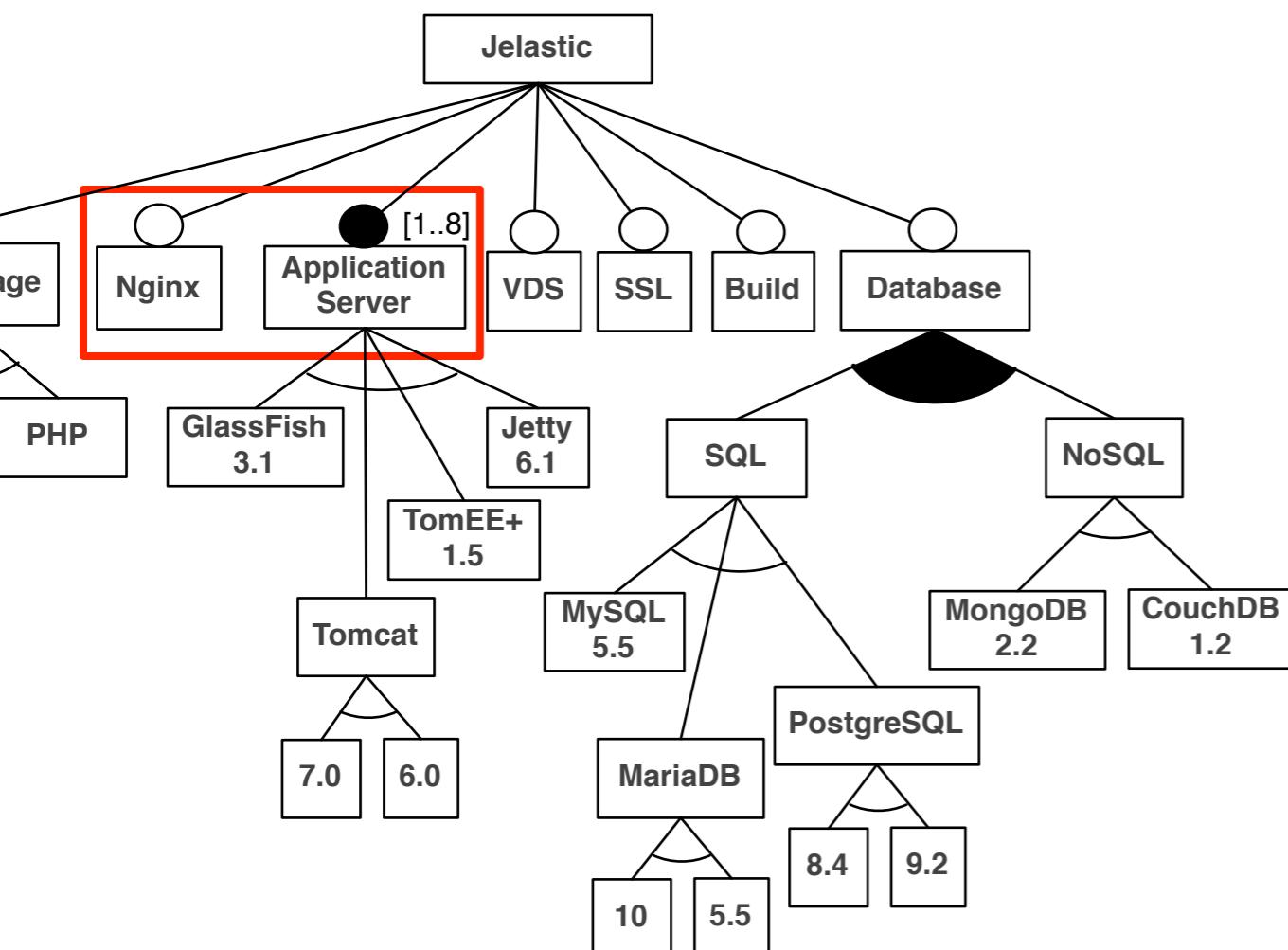
# Back to our cloud example



A screenshot of the Jelastic application configuration interface. On the left, there's a sidebar with tabs for "JAVA" and "PHP". A red arrow points from the "JAVA" tab to a green button labeled "Nginx". Below the sidebar, there's a section titled "Application Servers" with a "Vertical scaling per node" button. It shows "Reserved 1 cloudlet(s)", "128 MB, 200 MHz", "0.0085 EUR per..", and a "Discount: 15%". There are three application server instances listed: "Tomcat 7.0" (selected), "Java 7", and another "Tomcat 7.0" instance. Each instance has a "High-availability" and "Public IPv4" toggle switch, both of which are off. Below the application servers are sections for "Horizontal scaling" (with a "2 node(s)" button and a plus/minus icon) and "Build" (with a "Build" button and a plus/minus icon).

Load balancer

# Back to our cloud example



Tomcat 7.0 --> Java 7

if (nb Application Server >= 2) --> Nginx

The screenshot shows the Jelastic cloud interface for configuring a 'Tomcat 7.0' application. The interface includes:

- Java tab:** Selected.
- PHP tab:** Unselected.
- Application Servers:** Set to 'Tomcat 7.0' (2 nodes).
- Vertical scaling per node:** Reserved 1 cloudlet(s), 128 MB, 200 MHz, 0.0085 EUR per.., Discount: 15%.
- Horizontal scaling:** 2 node(s).
- High-availability:** OFF.
- Public IPv4:** OFF.

A red arrow points from the 'Load balancer' text in the top right to the 'Nginx' button in the configuration panel.

# Back to our cloud example

The screenshot shows the Jelastic cloud configuration interface for Java. The top navigation bar has tabs for JAVA (selected) and PHP. On the left, there's a sidebar with icons for NGINX, Cache, SQL, NoSQL, VDS, SSL, and Build. The main area is divided into two sections: Application Servers and Resources (cloudlets).

**Application Servers** (ON)

- Vertical scaling per node**: Reserved 1 cloudlet(s), 128 MB, 200 MHz, 0.0085 EUR per.., Discount: 15%.
- Horizontal scaling**: 2 node(s) (with a slider from 0 to 64).
- Tomcat 7.0** and **Java 7** dropdown menus.
- High-availability** and **Public IPv4** toggle switches (both OFF).

**Resources (cloudlets)**

- Reserved cloudlets**: Now: 3, Next: 8, Discount: 15% (15%), Discount: 25% (25%). A progress bar shows the discount range.
- Total Reserved Cloudlets**: €18 per month. You're saving €3/month by using Reserved Cloudlets.
- Total monthly cost**: €18\* → €109\*. \*Free of charge for the trial period.
- Cost details** and **Quotas & pricing** links.
- Environment name**: env-2897066.jelastic.dogado.eu (with a checked checkbox).

At the bottom right are **Cancel** and **Create** buttons.

# Back to our cloud example

The screenshot shows the Jelastic cloud configuration interface for Java applications. The left sidebar has tabs for JAVA (selected) and PHP. The main area displays a stack diagram with layers: nginx (green), application (blue with a cat icon), Cache, SQL, and NoSQL (grey boxes). Below the stack are buttons for VDS, SSL, and Build.

**Application Servers** (ON)

Vertical scaling per node:

- Reserved: 1 cloudlet(s)  
128 MB, 200 MHz  
0.0085 EUR per..  
Discount: 15%

Horizontal scaling (highlighted with a red box):

- 2 node(s)
- Tomcat 7.0
- Java 7
- High-availability
- Public IPv4

**Resources (cloudlets)**

Reserved cloudlets:

- Now: 3
- Next: 8
- Discount: 15%
- Discount: 25%

Total Reserved Cloudlets: €18 per month

You're saving €3/month by using Reserved Cloudlets

Total monthly cost: €18\* → €109\*

\*Free of charge for the trial period.

[Cost details](#)

[Quotas & pricing](#)

Environment name: env-2897066 .jelastic.dogado.eu

Buttons at the bottom: Cancel (grey), Create (green with checkmark).

# Back to our cloud example

The screenshot shows the Jelastic cloud configuration interface for Java applications. The top navigation bar has tabs for JAVA (selected) and PHP. On the left, there's a diagram showing the application stack: NGINX (green box), followed by a blue box containing a cat icon, then Cache, SQL, and NoSQL databases, and finally VDS, SSL, and Build services. The main configuration area is titled "Application Servers" (ON). It shows "Vertical scaling per node" with 1 reserved cloudlet (128 MB, 200 MHz, 0.0085 EUR per.., 15% discount). Below this is "Horizontal scaling" where 4 nodes are configured (Tomcat 7.0, Java 7, High-availability ON, Public IPv4 OFF). A red box highlights this horizontal scaling section. To the right, under "Resources (cloudlets)", it shows "Reserved cloudlets" (Now: 5, Next: 8, Discount: 15%, 25%), "Total Reserved Cloudlets" (€31 per month), and a note about saving €5/month. It also shows "Total monthly cost" (from €31\* to €107\*), "Cost details", and "Quotas & pricing". At the bottom, the environment name is set to "env-2897066.jelastic.dogado.eu" with a checked checkbox. The "Create" button is at the bottom right.

**Application Servers** **ON**

Vertical scaling per node

Reserved 1 cloudlet(s)  
128 MB, 200 MHz  
0.0085 EUR per..  
Discount: 15%

Horizontal scaling

4 node(s)

Tomcat 7.0 Java 7

High-availability **ON**

Public IPv4 **OFF**

**Resources (cloudlets)**

Reserved cloudlets

Now: 5 Next: 8  
Discount: 15% 25%

Total Reserved Cloudlets **€31 per month**

You're saving **€5/month** by using Reserved Cloudlets

Total monthly cost from **€31\*** to **€107\***  
\*Free of charge for the trial period.

**Cost details**

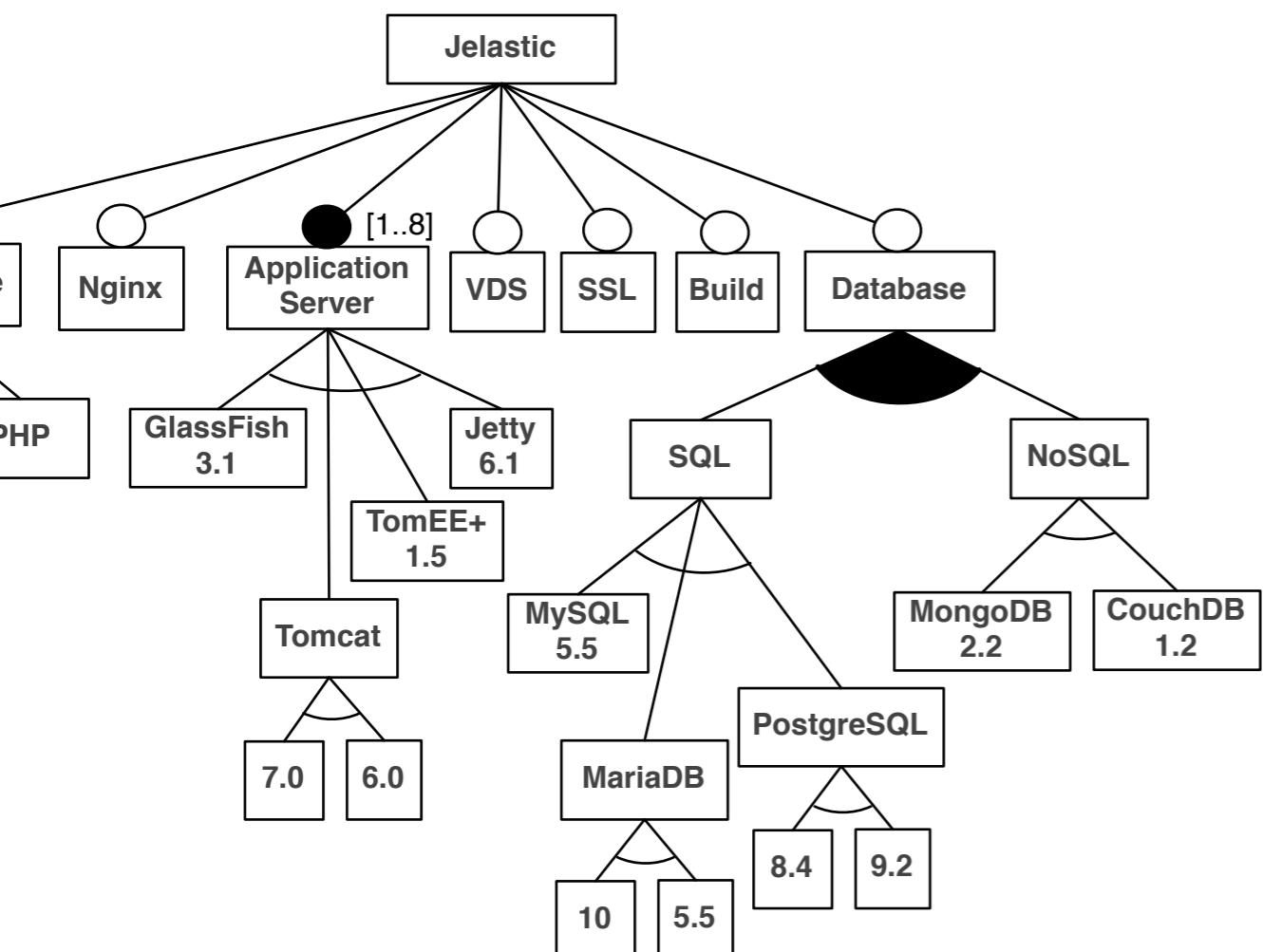
**Quotas & pricing**

Environment name

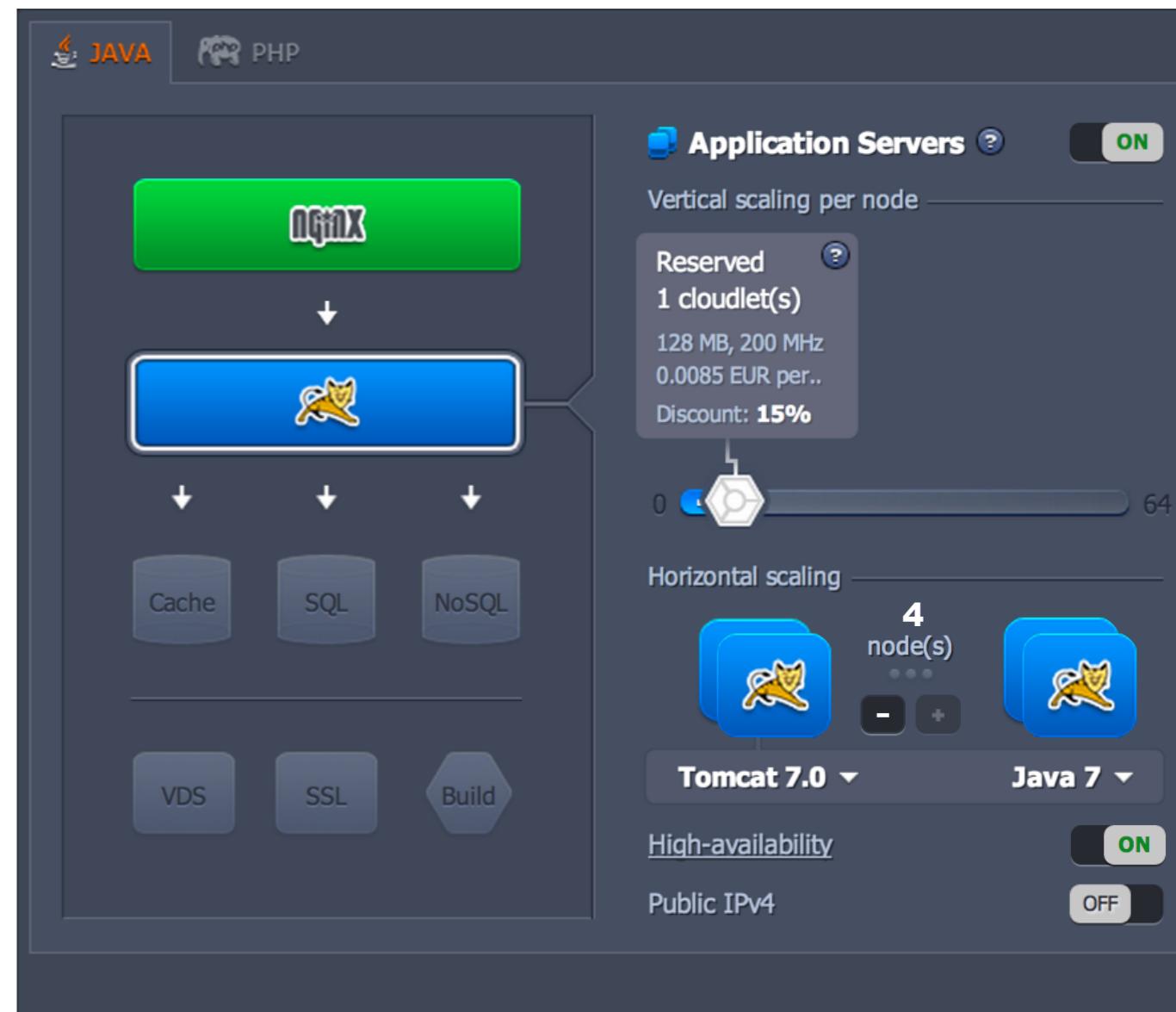
env-2897066.jelastic.dogado.eu

**Create**

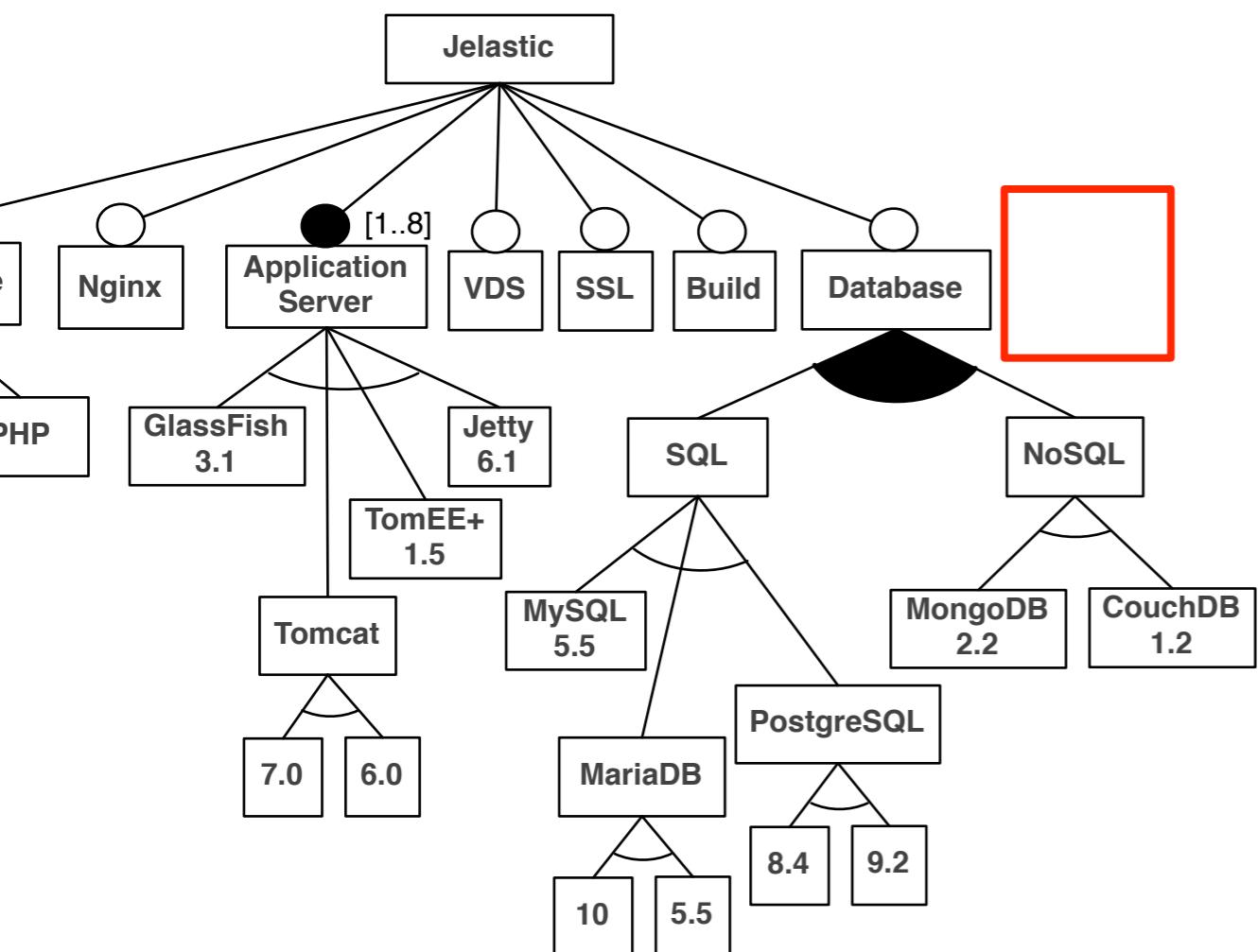
# Back to our cloud example



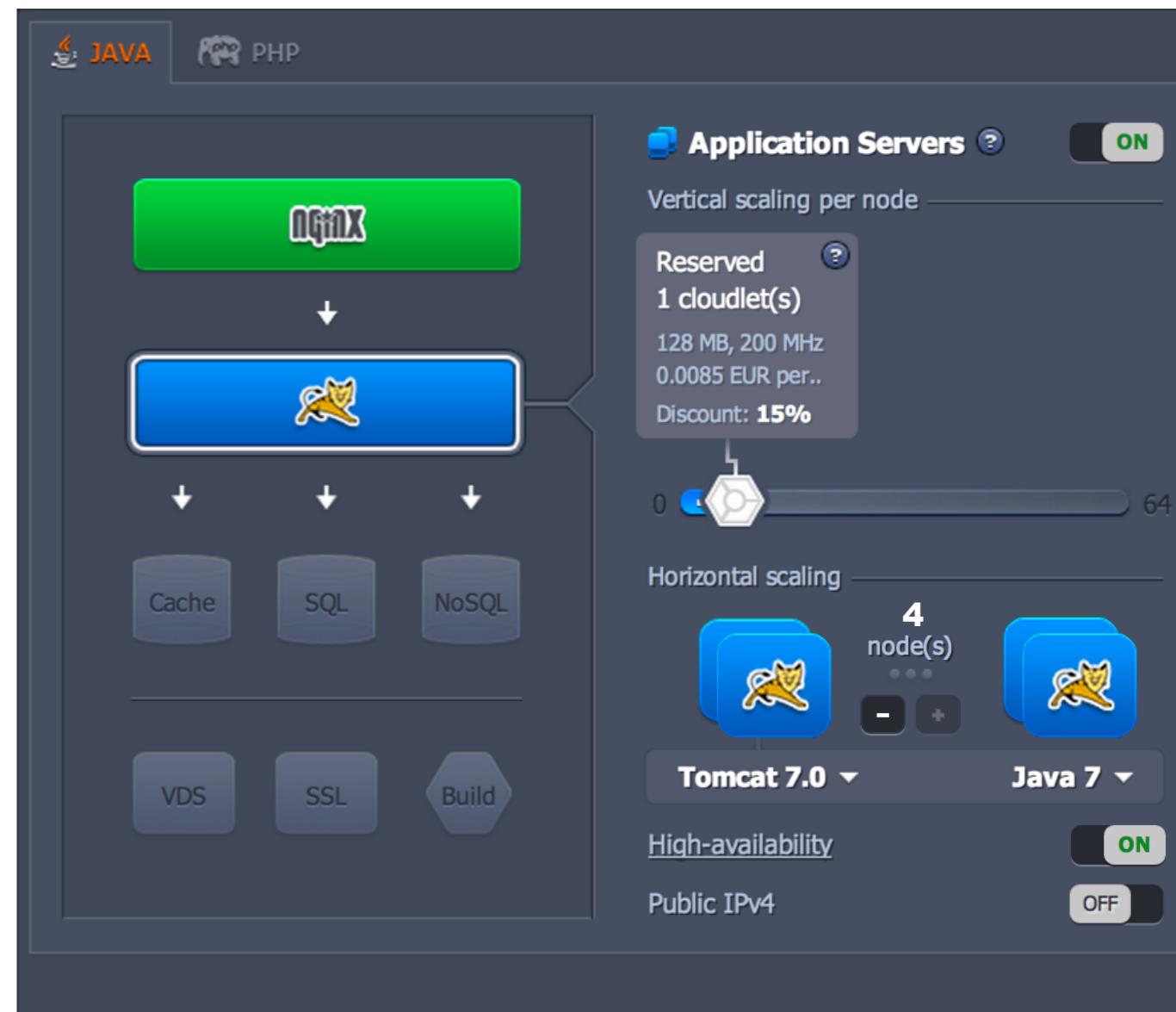
Tomcat 7.0 --> Java 7  
if (nb Application Server >= 2) --> Nginx



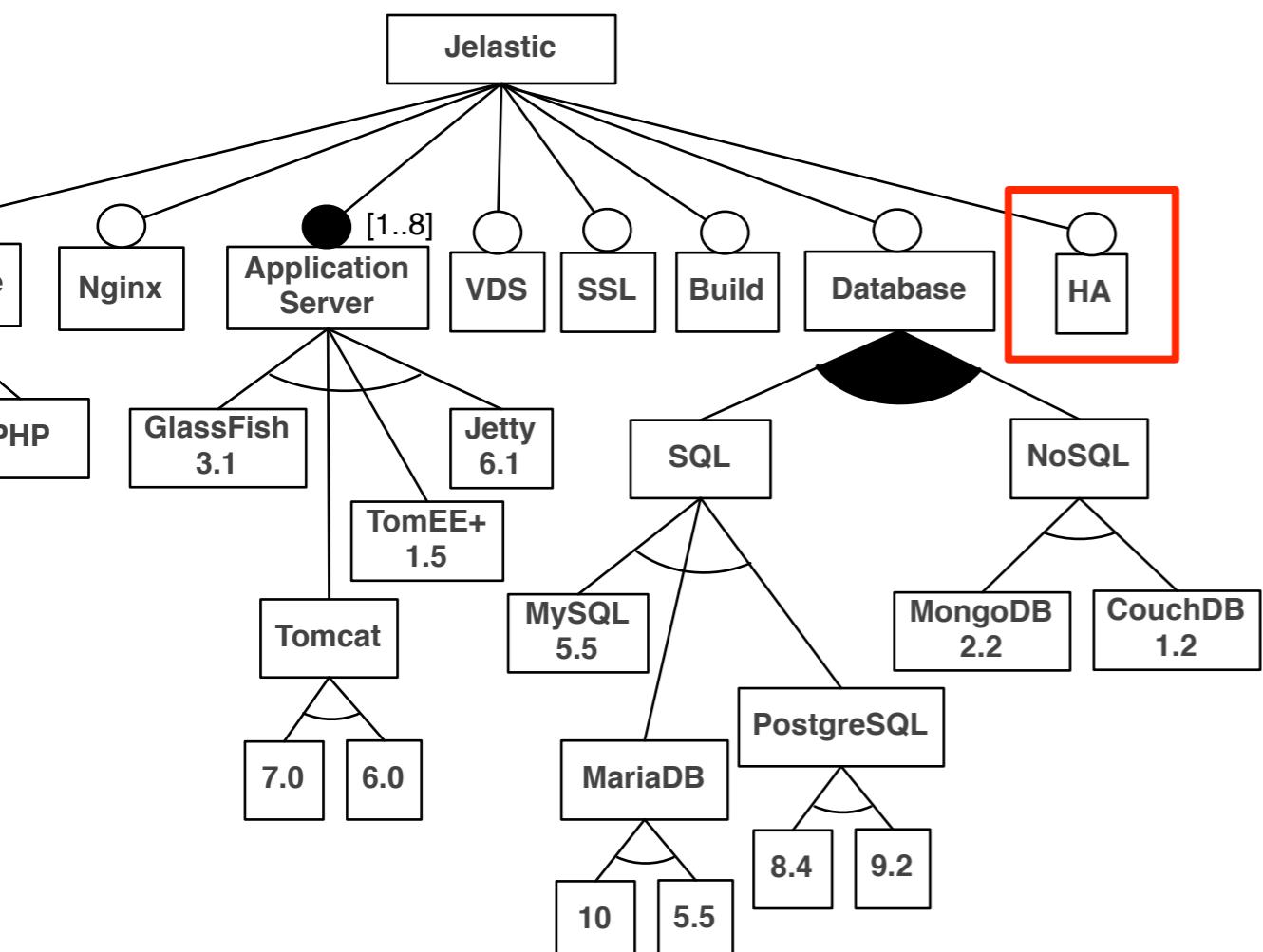
# Back to our cloud example



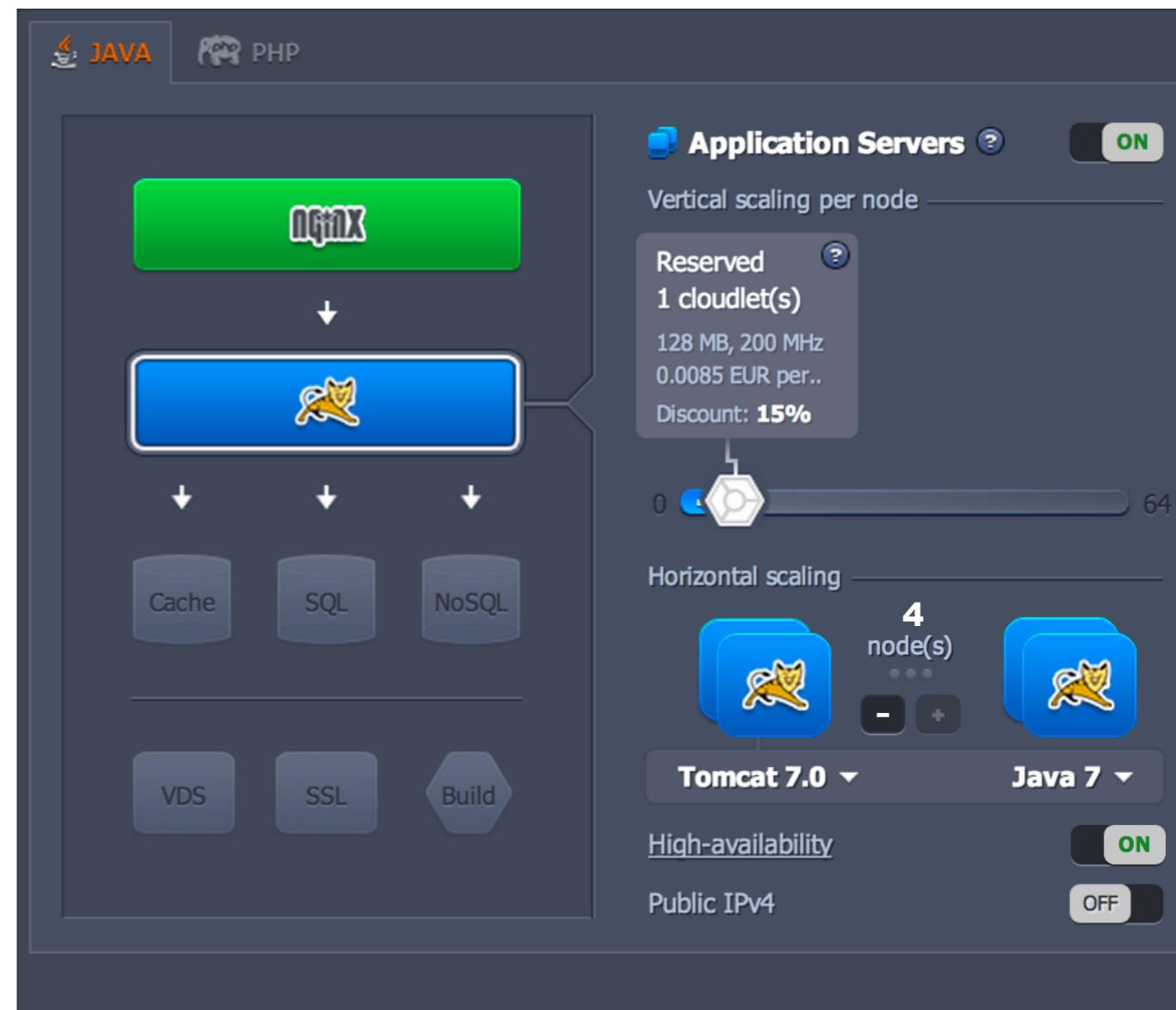
Tomcat 7.0 --> Java 7  
if (nb Application Server >= 2) --> Nginx



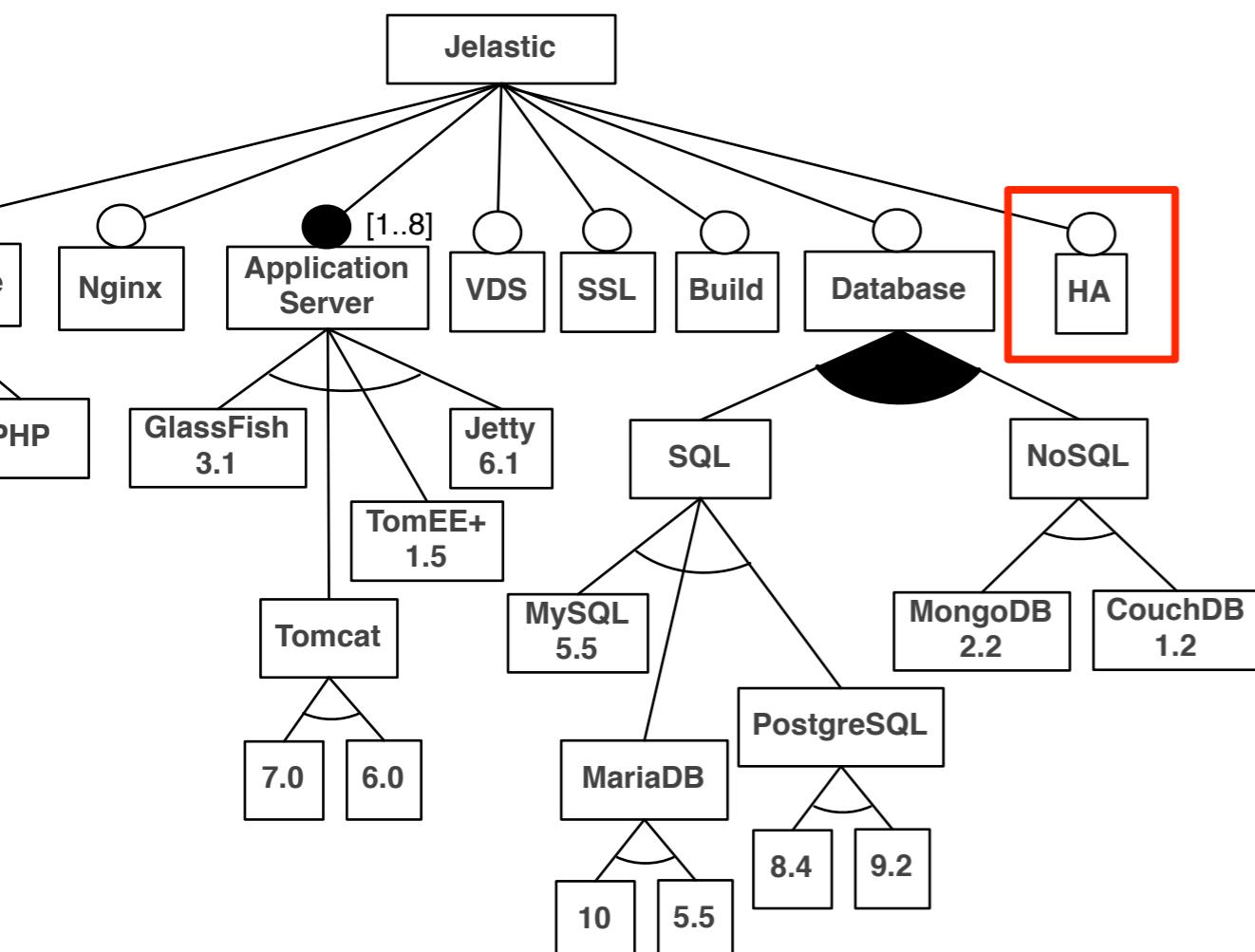
# Back to our cloud example



Tomcat 7.0 --> Java 7  
if (nb Application Server >= 2) --> Nginx



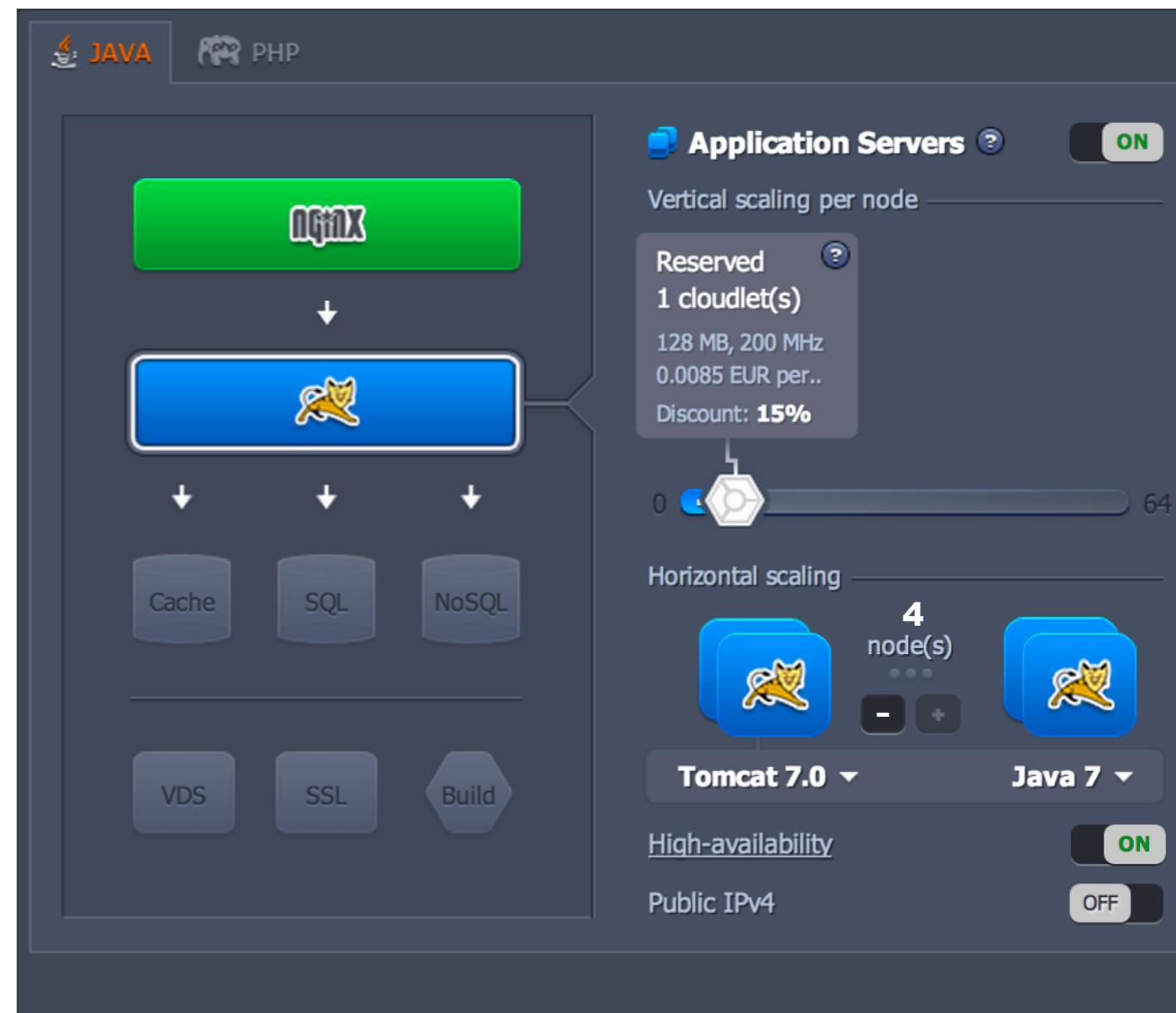
# Back to our cloud example



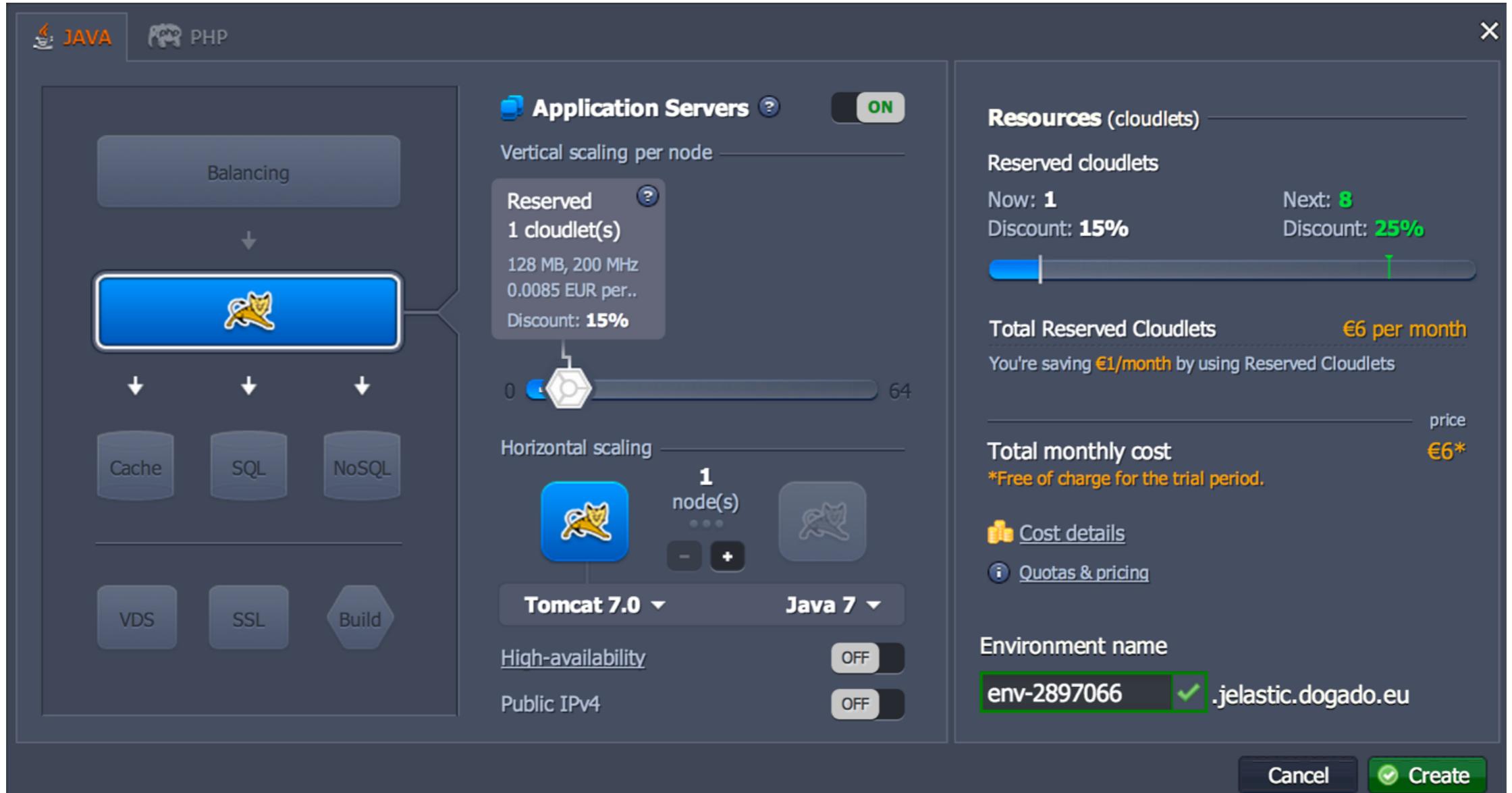
Tomcat 7.0 --> Java 7

if (nb Application Server >= 2) --> Nginx

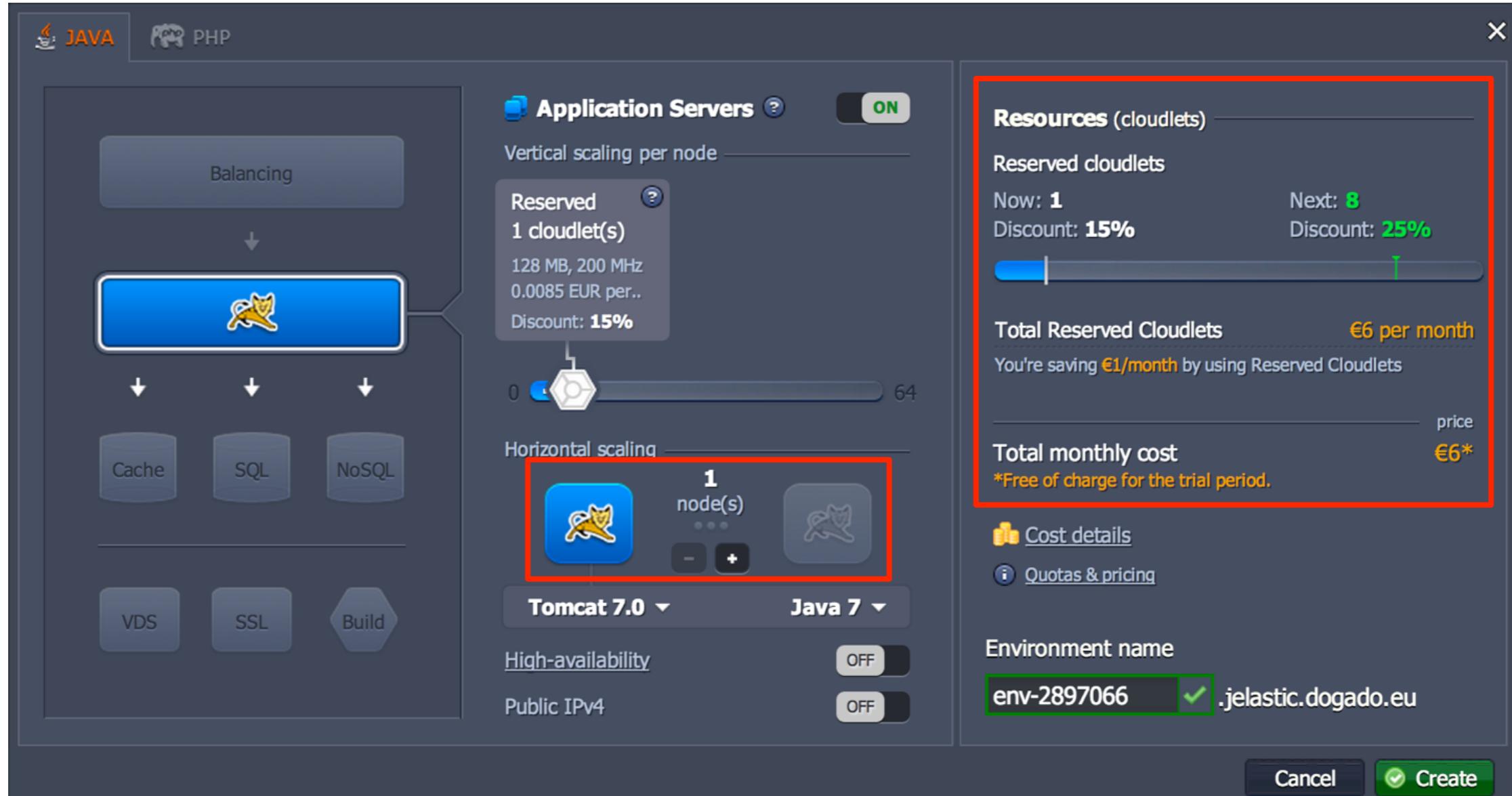
if HA --> nb Application Server \* 2



# Back to our cloud example



# Back to our cloud example



# Back to our cloud example

The screenshot shows a cloud configuration interface for a Java application. On the left, there's a stack diagram with layers: NGINX (green), Application (blue with a cat icon), Cache, SQL, and NoSQL (grey boxes). Below the stack are buttons for VDS, SSL, and Build.

**Application Servers** (ON)

**Vertical scaling per node**

- Reserved: 1 cloudlet(s) (128 MB, 200 MHz, 0.0085 EUR per.., Discount: 15%)
- Horizontal scaling: 2 node(s) (Tomcat 7.0, Java 7)
- High-availability and Public IPv4 options are OFF.

**Resources (cloudlets)**

**Reserved cloudlets**

- Now: 3 (Next: 8)
- Discount: 15% (25%)
- Total Reserved Cloudlets: €18 per month
- You're saving €3/month by using Reserved Cloudlets

**Total monthly cost**: €18\* → €109\*

\*Free of charge for the trial period.

**Cost details** and **Quotas & pricing** links are available.

**Environment name**: env-2897066 .jelastic.dogado.eu

**Create** button (with checked checkbox).

# Back to our cloud example

The screenshot shows a cloud configuration interface for Java applications. On the left, there's a diagram of the application stack: NGINX (green box) at the top, followed by a blue box containing a cat icon, Cache, SQL, and NoSQL databases, and finally VDS, SSL, and Build services at the bottom. To the right, under 'Application Servers', the 'ON' switch is turned on. It shows 'Vertical scaling per node' with 1 reserved cloudlet(s) (128 MB, 200 MHz, 0.0085 EUR per.., Discount: 15%) and a slider from 0 to 64. Below that is 'Horizontal scaling' with 2 node(s). Underneath are dropdown menus for 'Tomcat 7.0' and 'Java 7'. At the bottom are 'High-availability' and 'Public IPv4' options, both set to OFF. On the far right, a red box highlights the 'Resources (cloudlets)' section. It shows 'Reserved cloudlets' with 'Now: 3' and 'Next: 8', 'Discount: 15%' and 'Discount: 25%', and a progress bar. It also displays 'Total Reserved Cloudlets' at '€18 per month' and a note 'You're saving €3/month by using Reserved Cloudlets'. Below this is 'Total monthly cost' with a range from '€18\*' to '€109\*', noting '\*Free of charge for the trial period.' At the bottom right are 'Cost details' and 'Quotas & pricing' links, and an 'Environment name' field containing 'env-2897066 .jelastic.dogado.eu' with a checked checkbox. At the very bottom are 'Cancel' and 'Create' buttons.

Resources (cloudlets)

Reserved cloudlets

Now: 3      Next: 8

Discount: 15%      Discount: 25%

Total Reserved Cloudlets      €18 per month

You're saving €3/month by using Reserved Cloudlets

Total monthly cost      from €18\* to €109\*

\*Free of charge for the trial period.

Cost details

Quotas & pricing

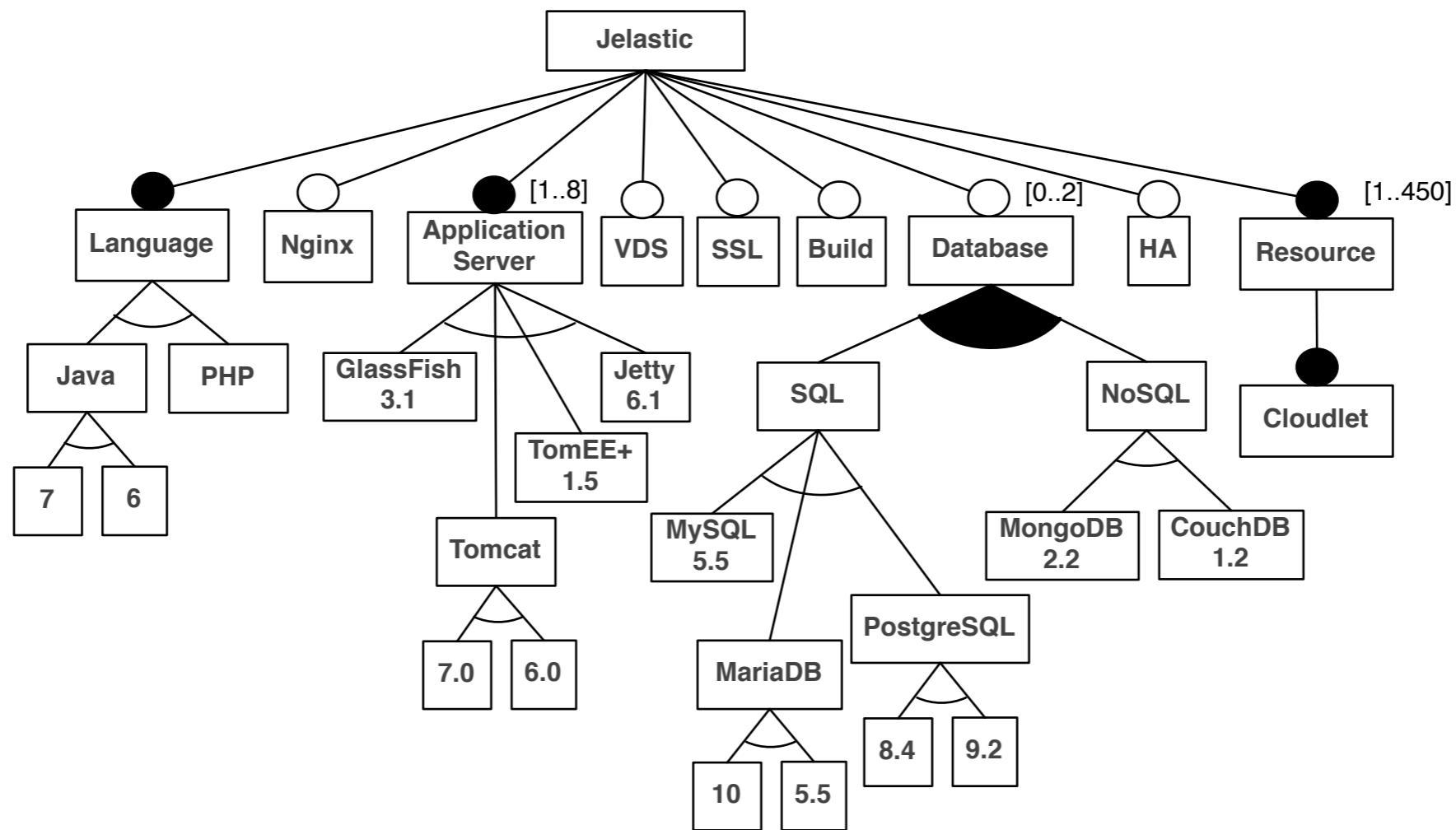
Environment name

env-2897066 .jelastic.dogado.eu

Cancel      Create

each application server instance --> 1 Cloudlet

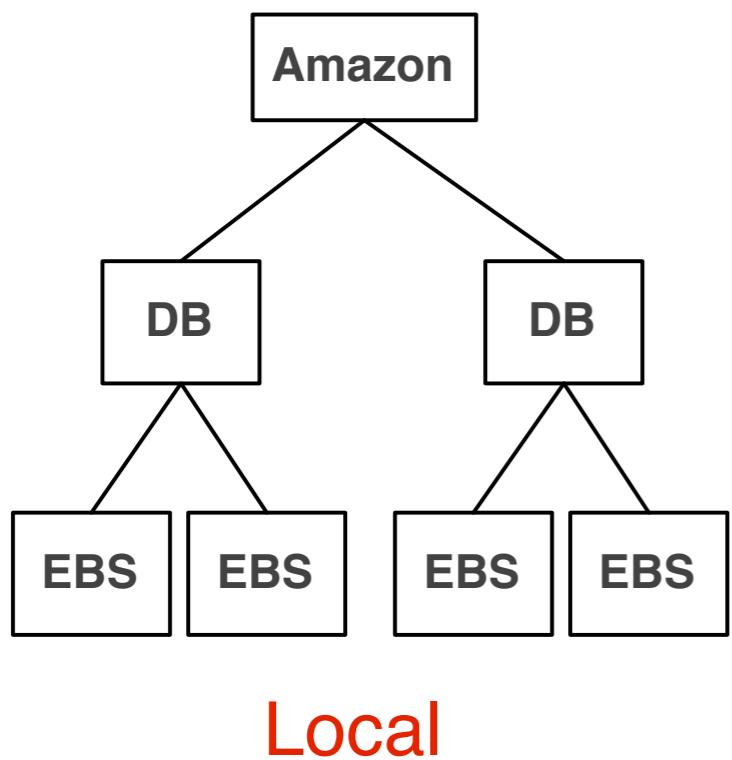
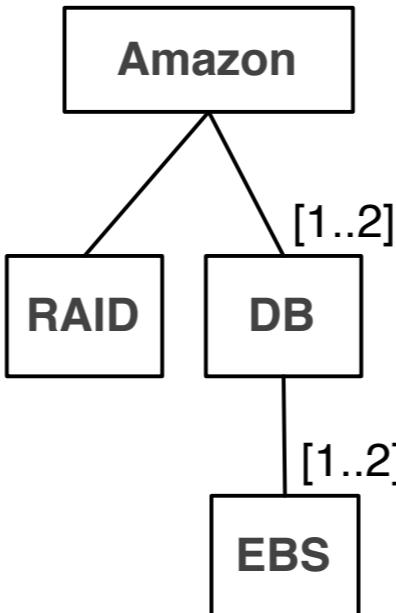
# Back to our cloud example



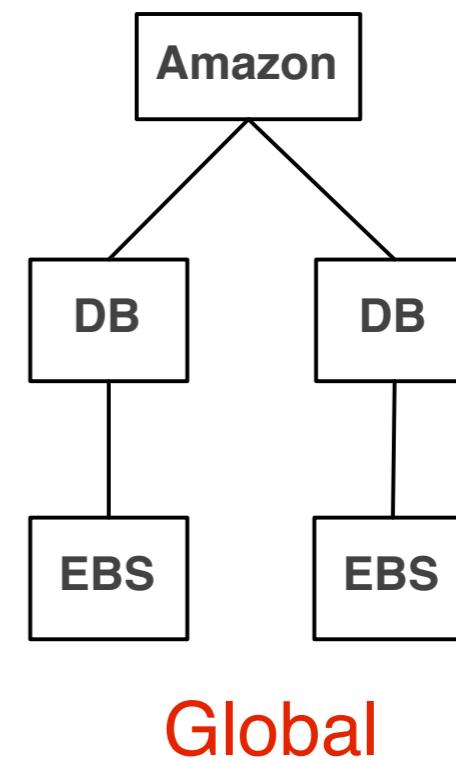
Tomcat 7.0 --> Java 7  
if (nb Application Server >= 2) --> Nginx  
if HA --> nb Application Server \* 2  
Application Server --> +1 Cloudlet

...

# Cardinalities: scope



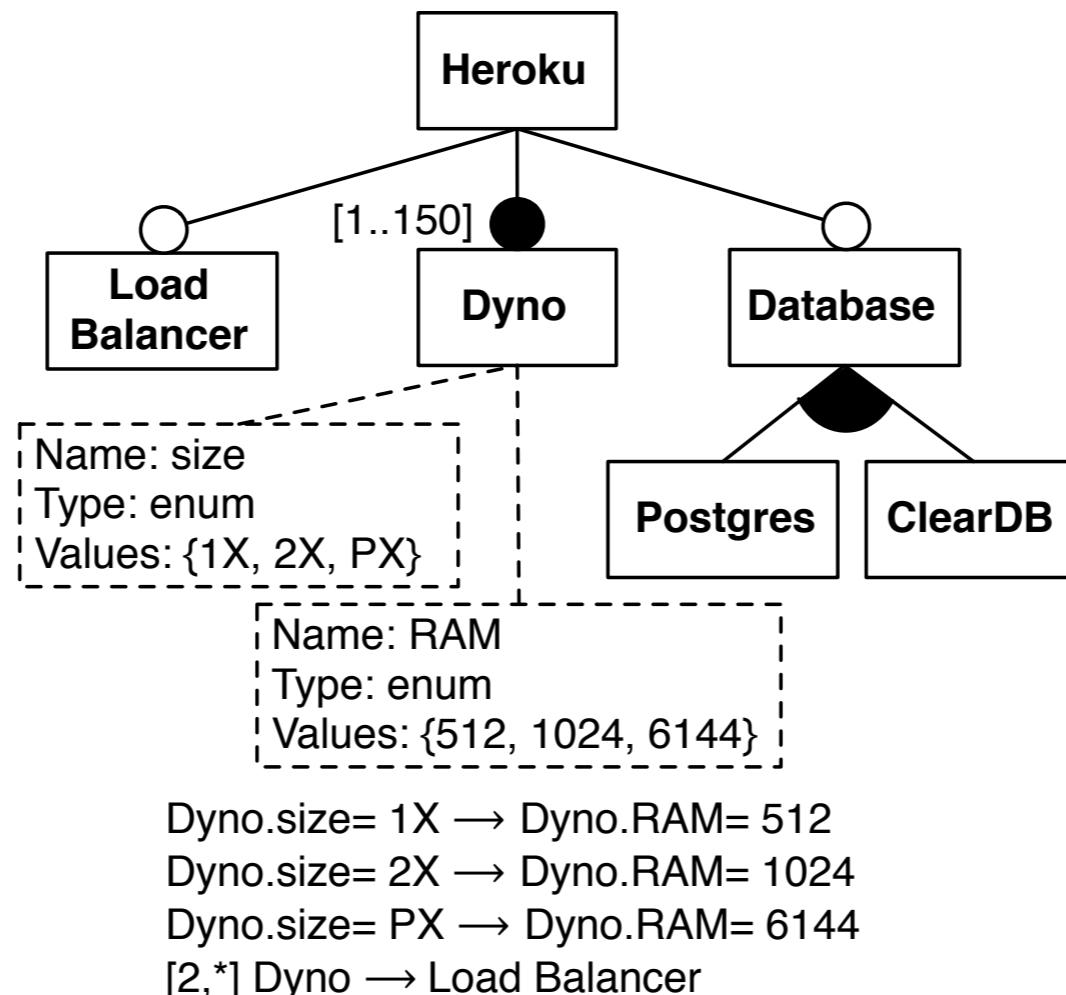
Local



Global

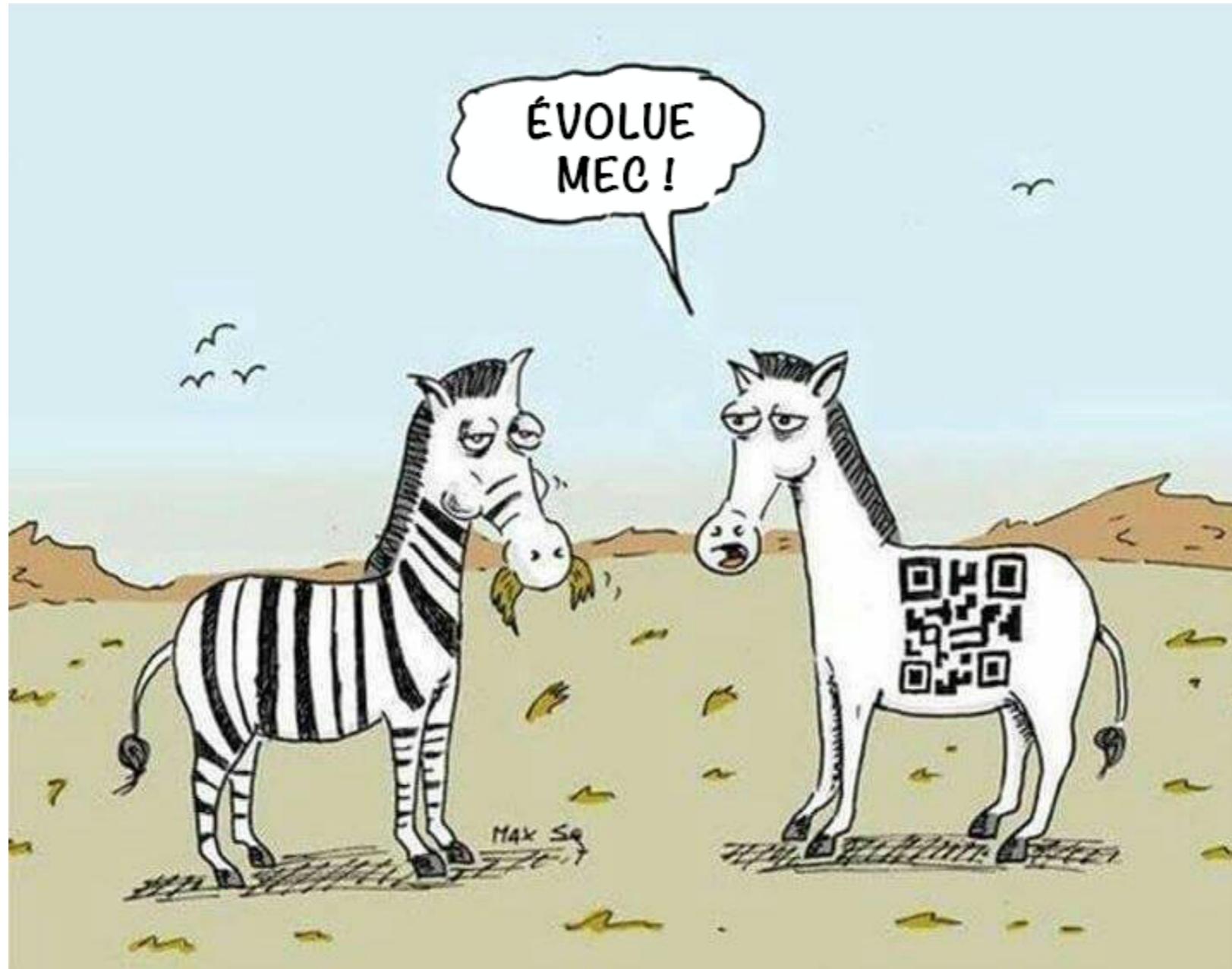
# Another extension: attributes

---



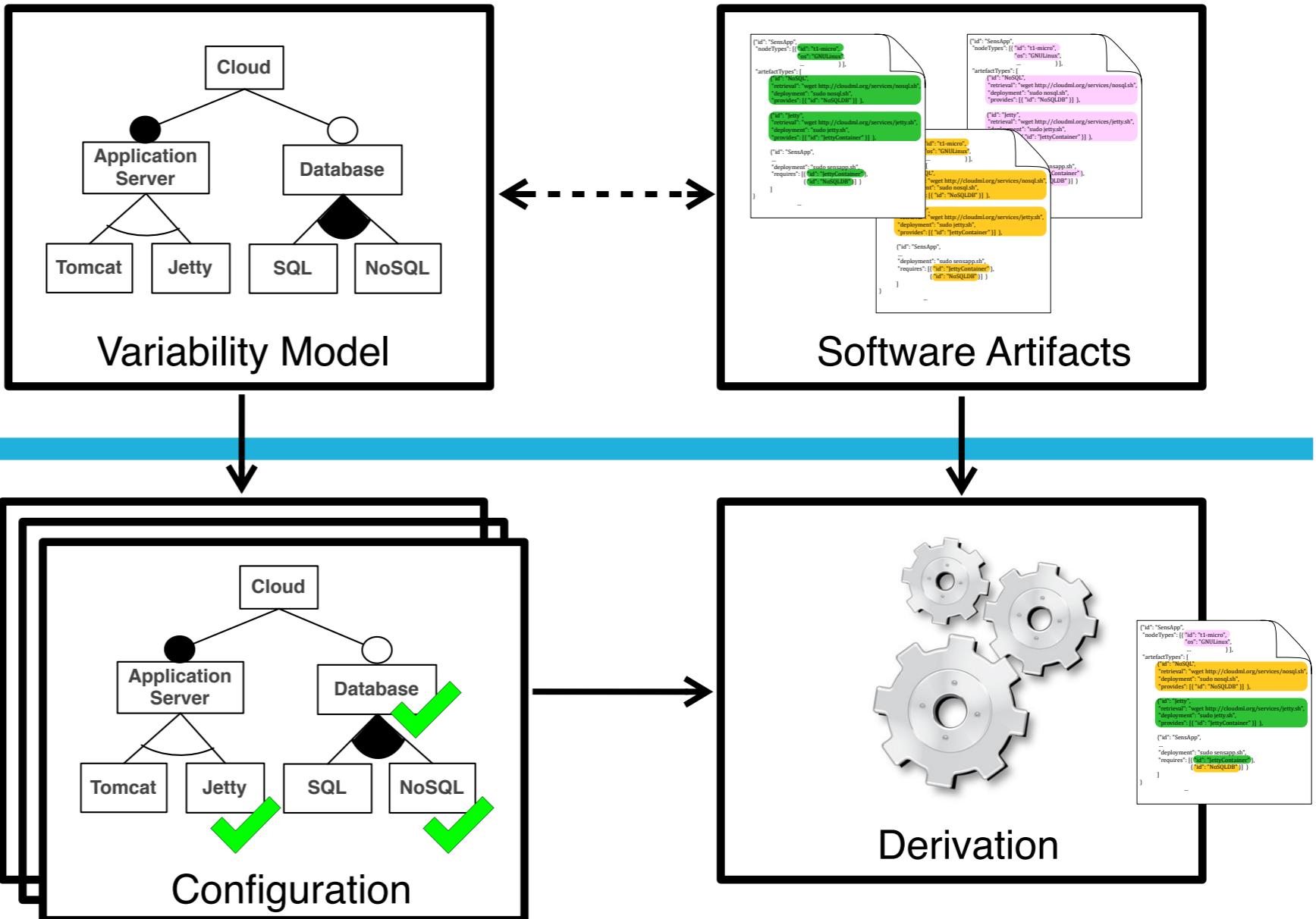
# “Design evolution is absolutely inevitable”

Kent Beck, The Inevitability of Evolution, IEEE Software, 2010



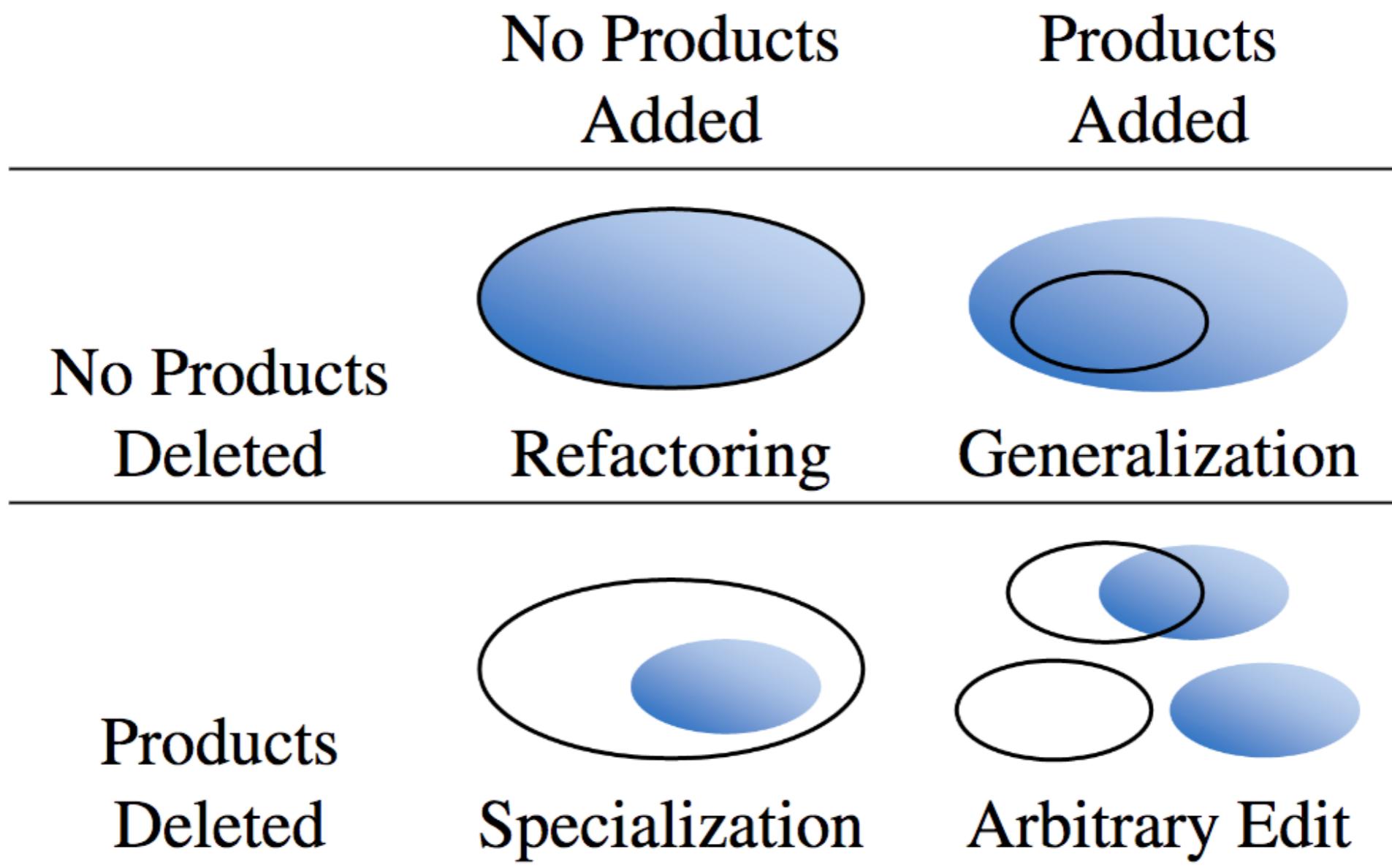
# Evolution

## Domain Engineering



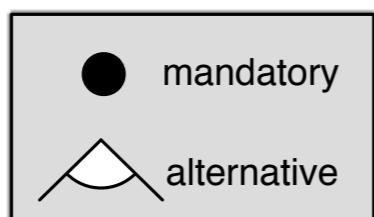
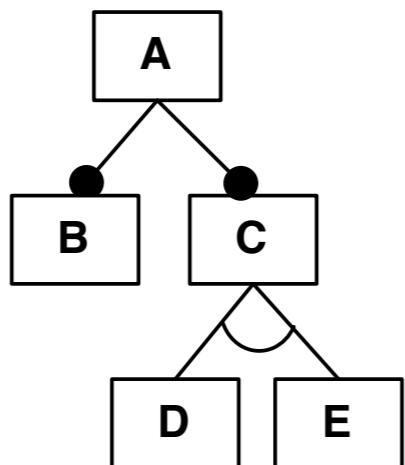
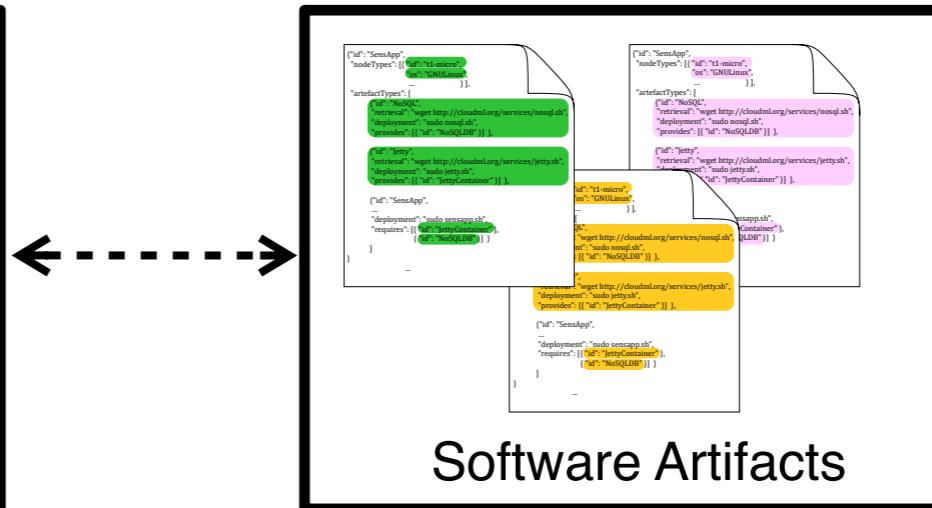
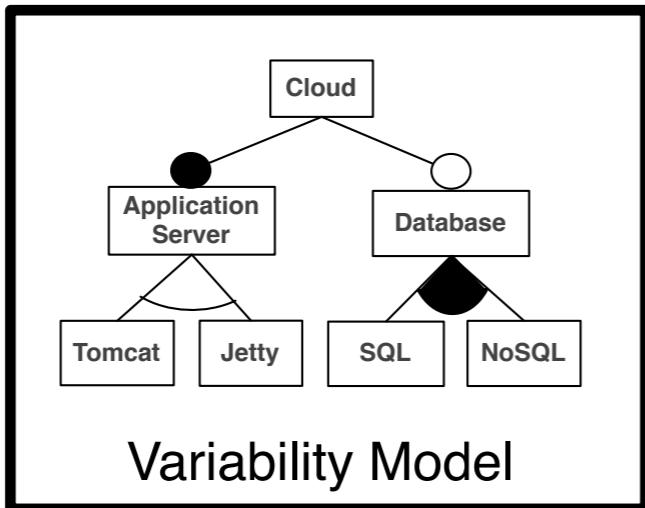
# Different kinds of evolution

---



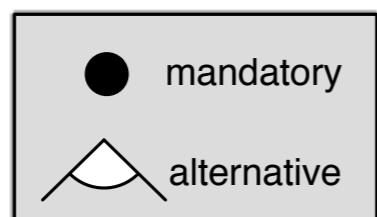
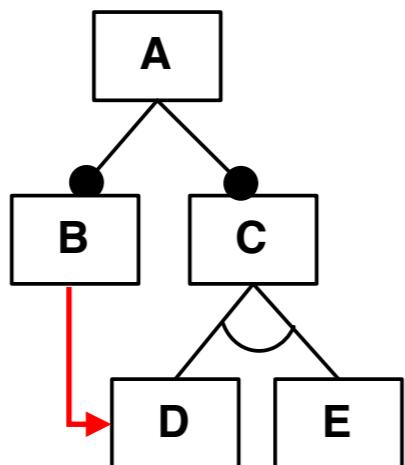
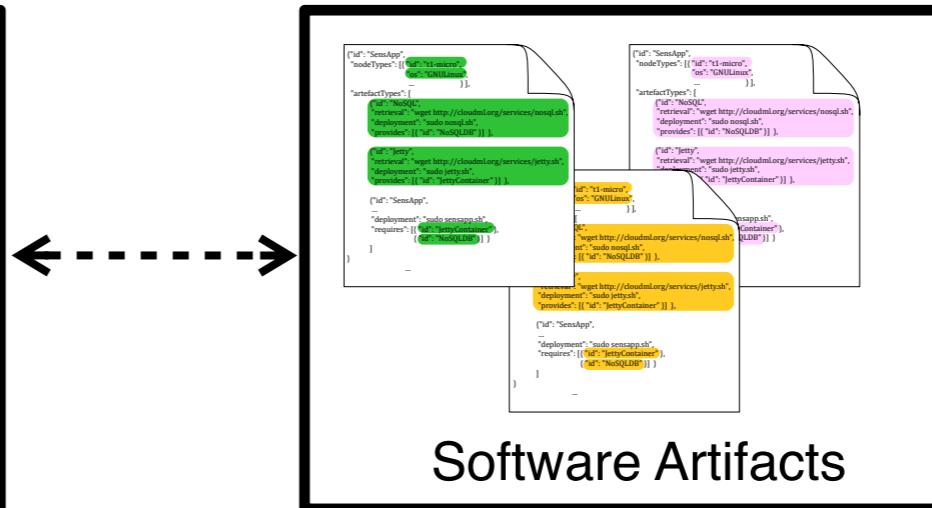
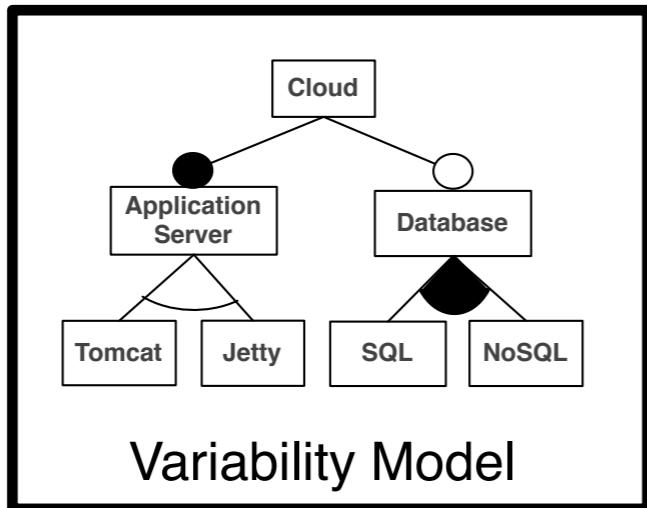
# Evolution and consistency

Problem  
Space



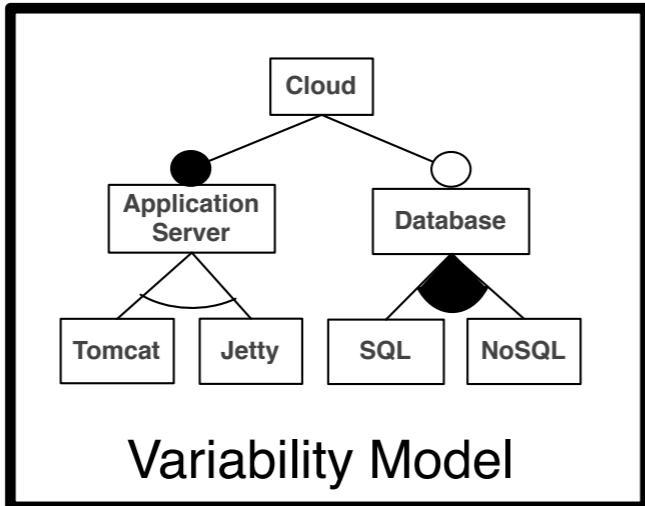
# Evolution and consistency

Problem  
Space

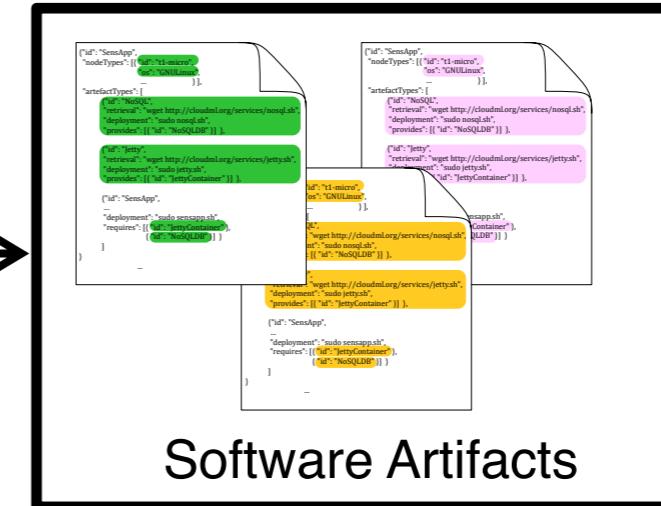


# Evolution and consistency

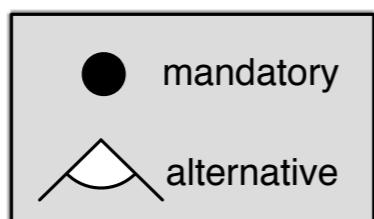
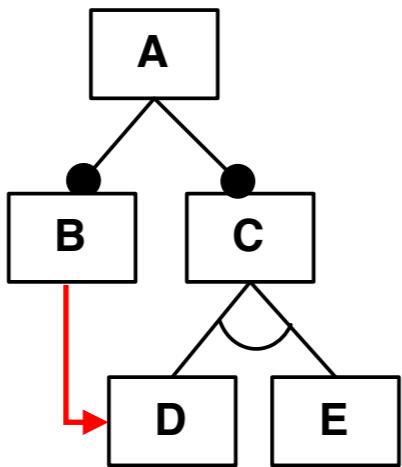
Problem Space



Solution Space

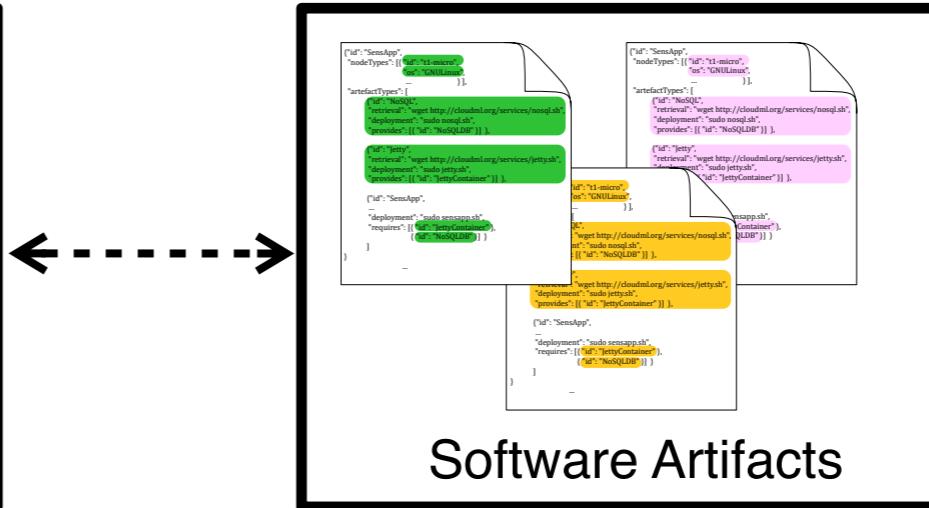
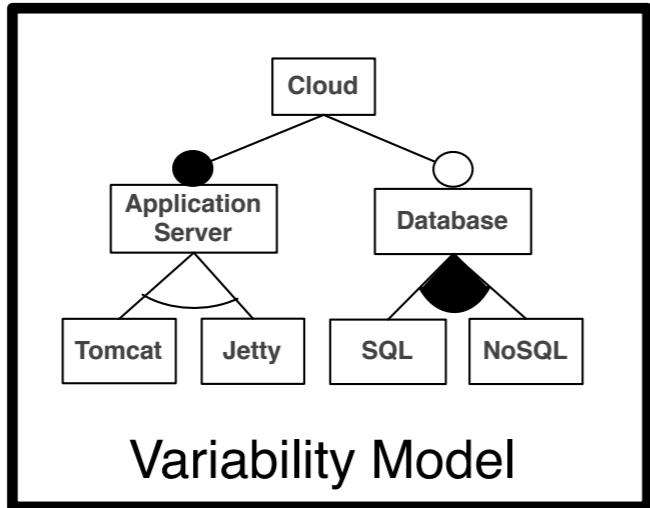


E is a dead feature

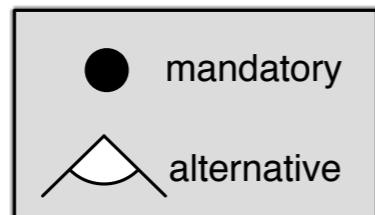
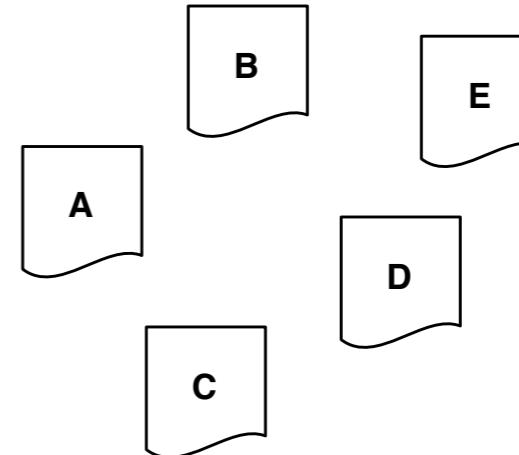
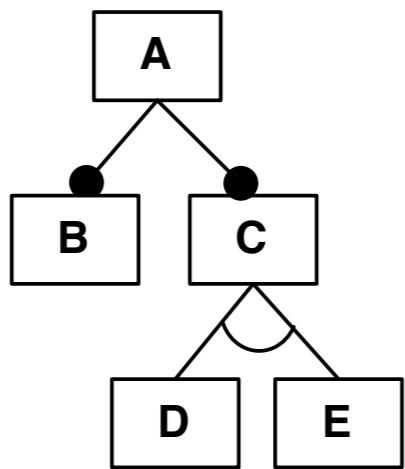


# Evolution and consistency

Problem  
Space

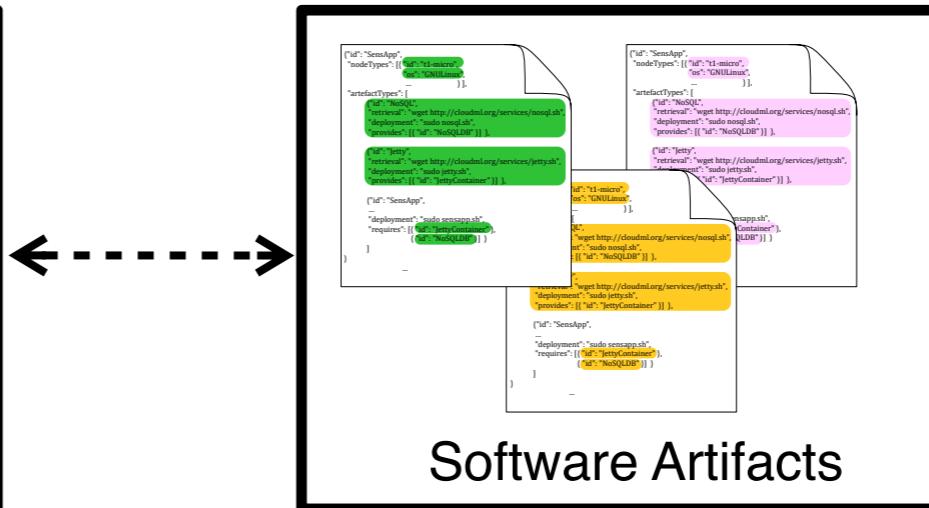
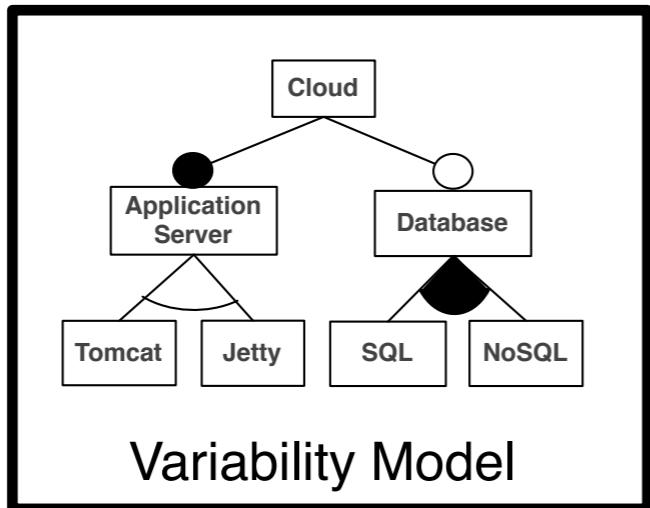


Solution  
Space

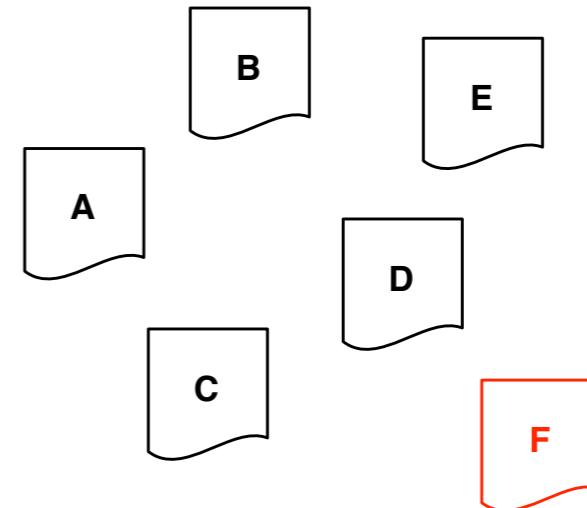
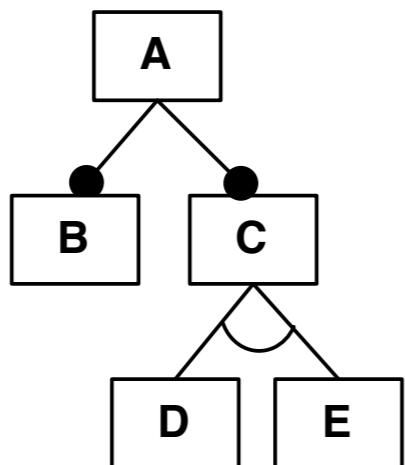


# Evolution and consistency

Problem  
Space

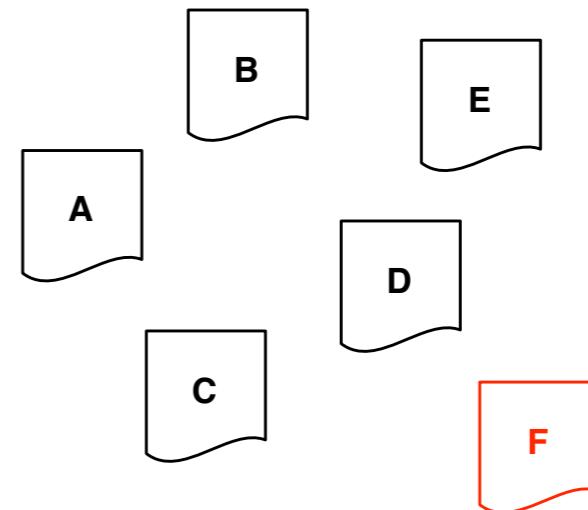
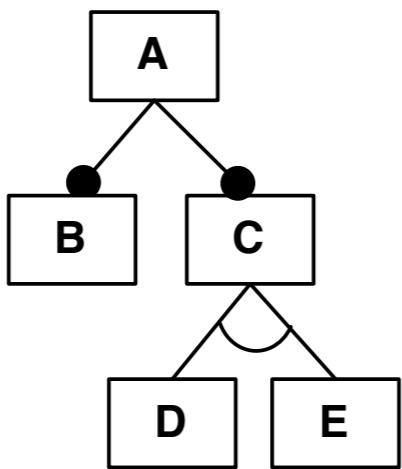
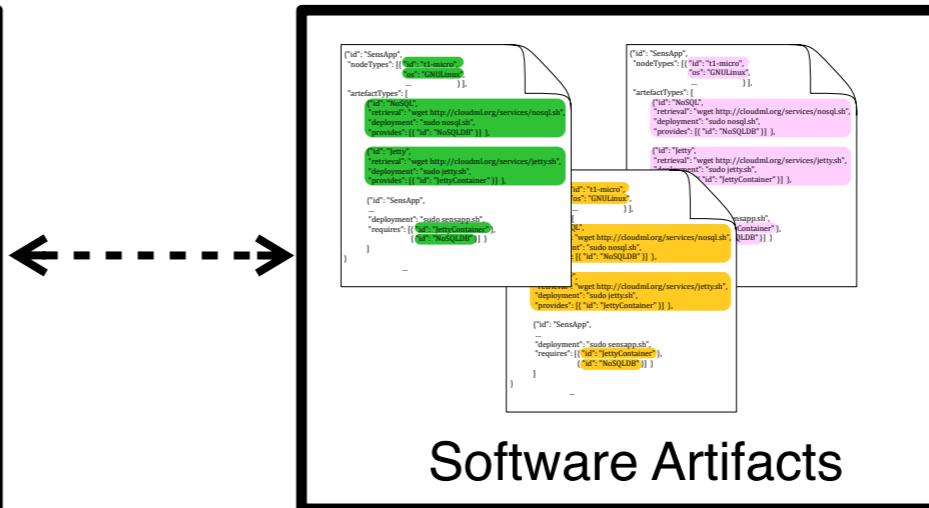
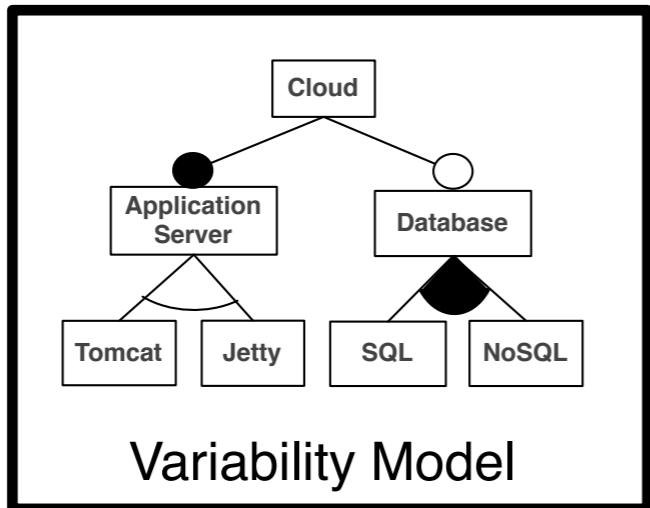


Solution  
Space



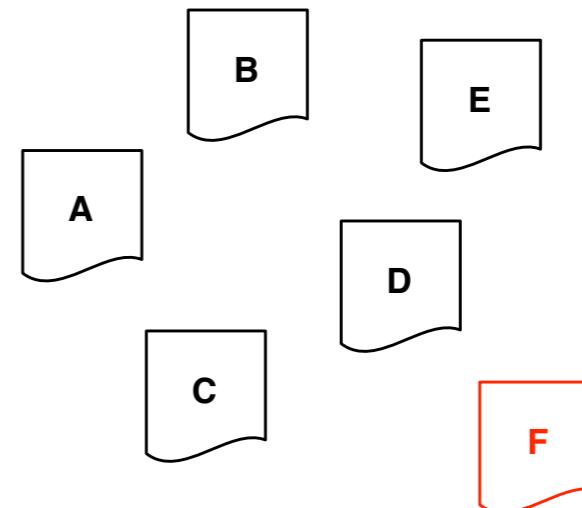
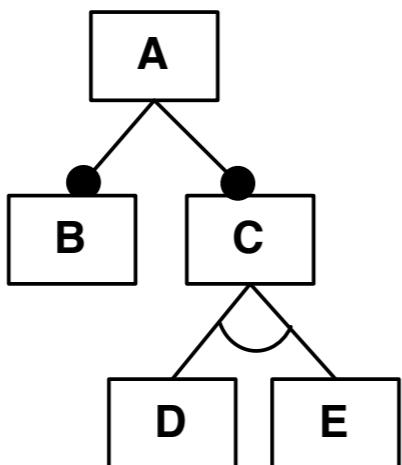
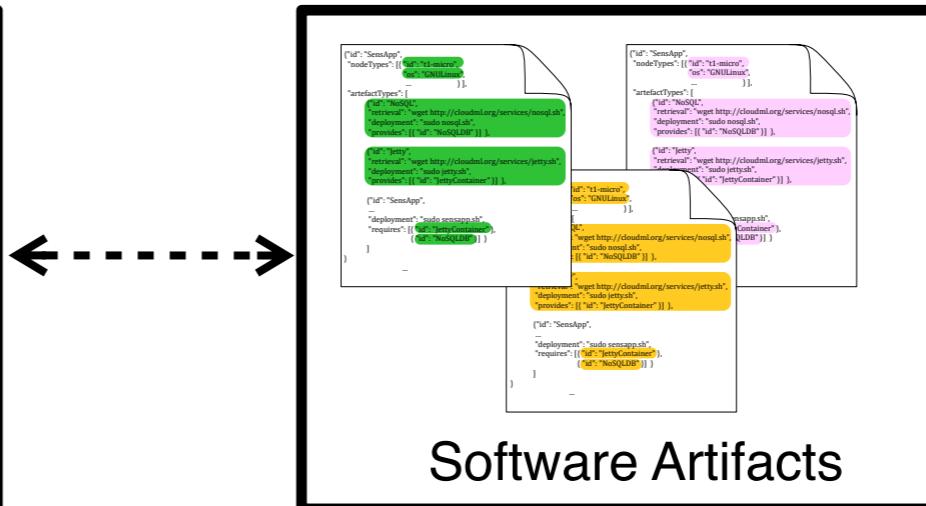
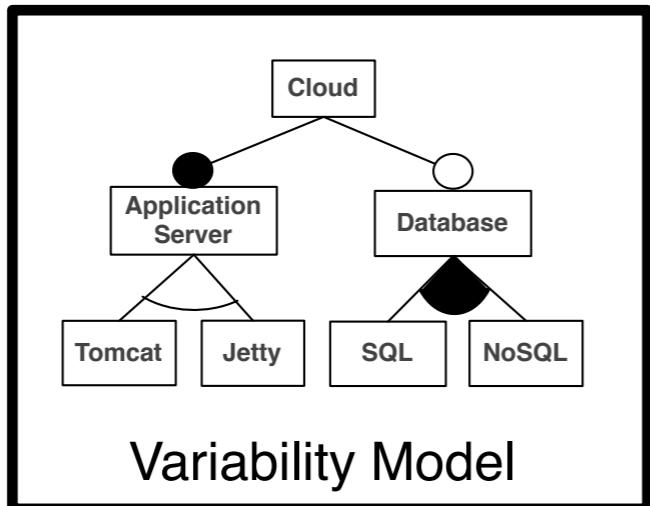
# Evolution and consistency

Problem Space



# Evolution and consistency

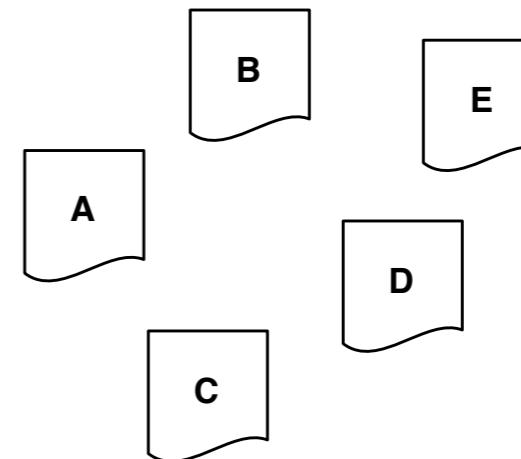
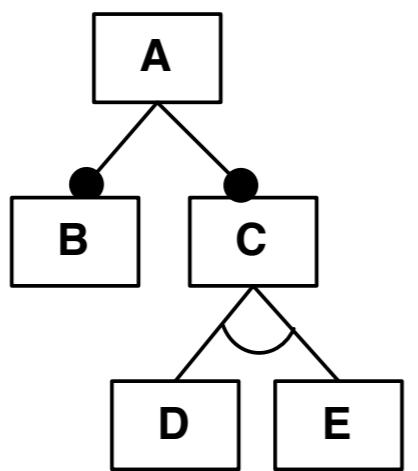
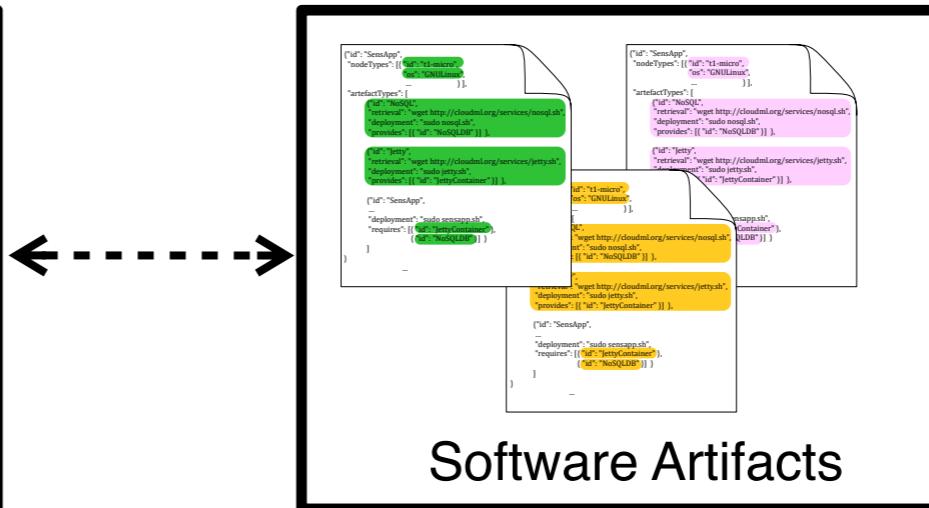
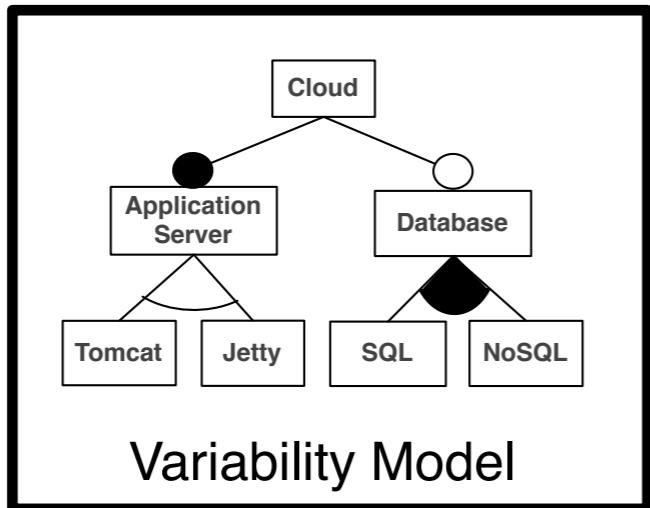
Problem Space



Incompatibilities between  
- packages (e.g. Linux)  
- plugins (e.g. Eclipse)

# Evolution and consistency

Problem Space

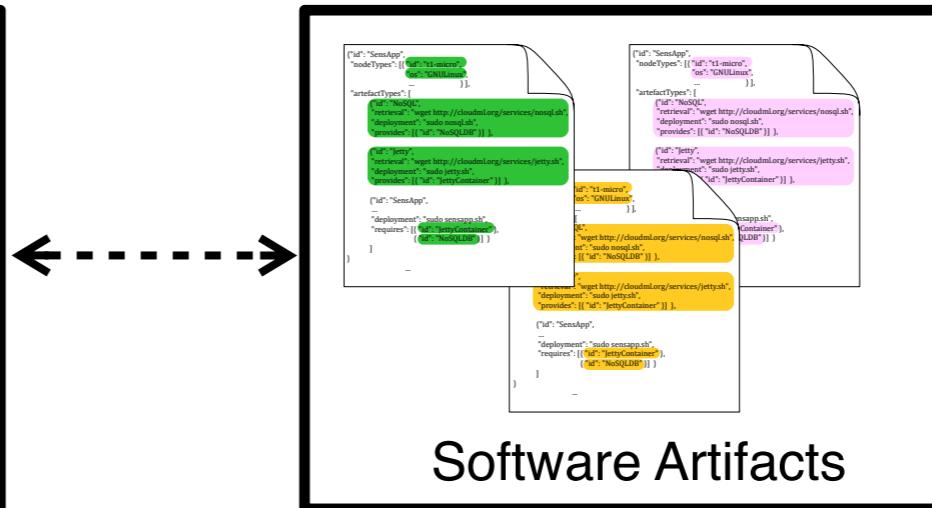
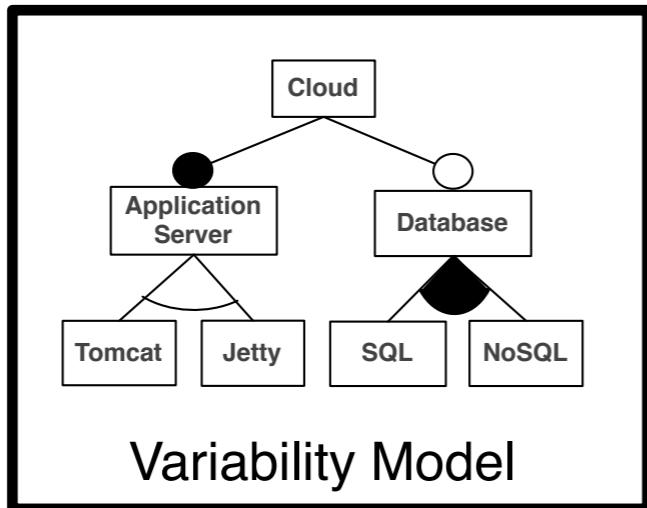


A → B  
A → C  
C → D  
C → E

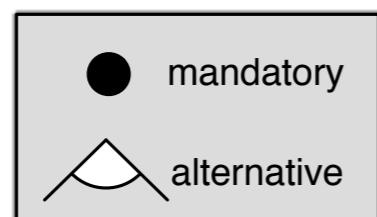
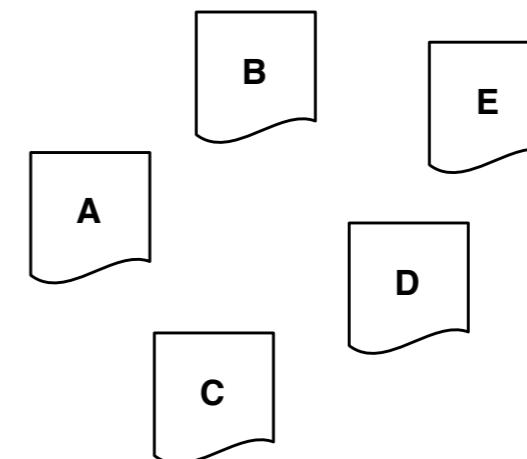
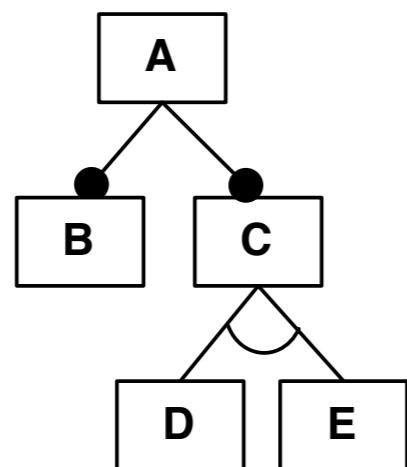


# Evolution and consistency

Problem Space



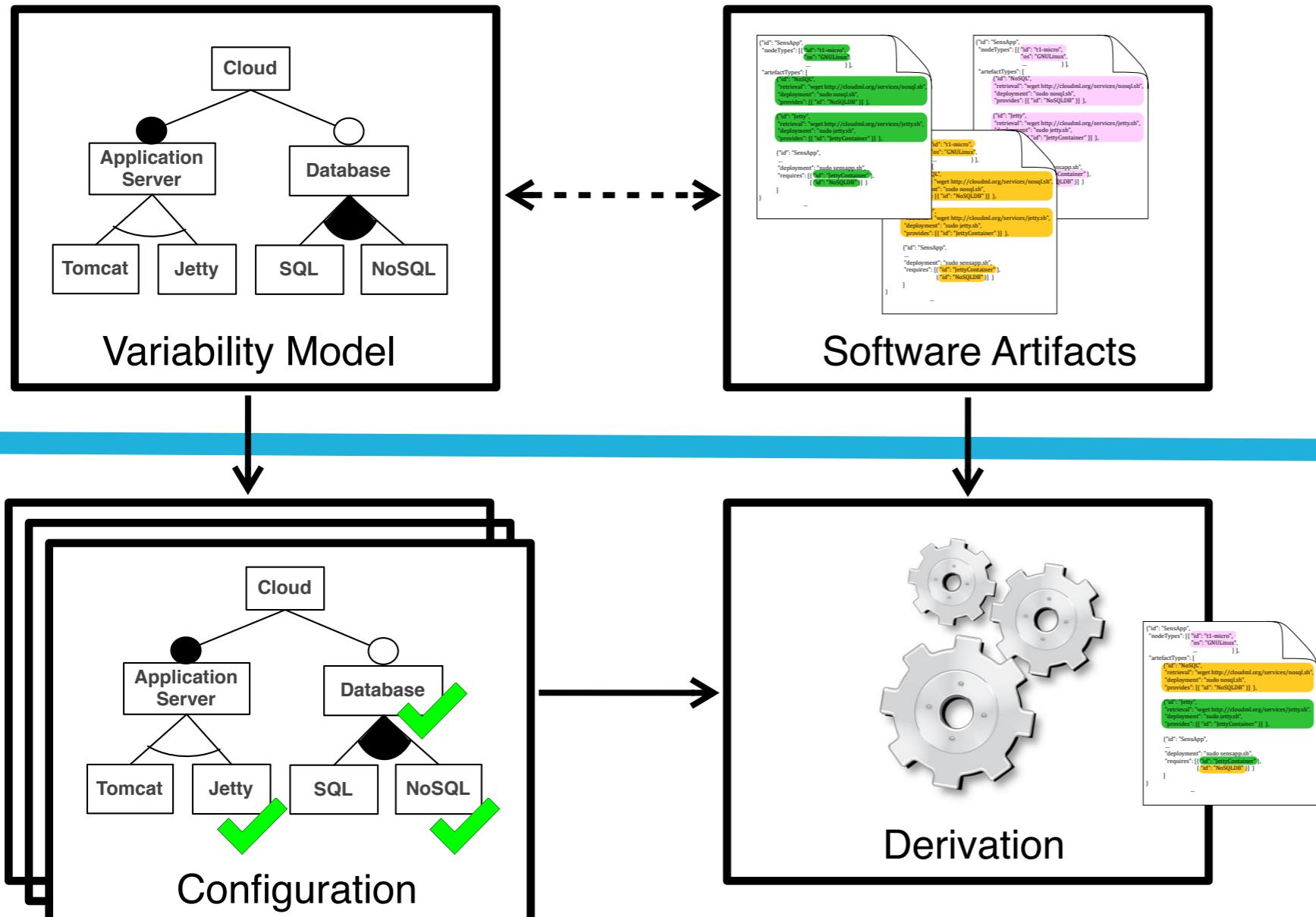
Solution Space



**What about variability  
at runtime?**

# Software product lines

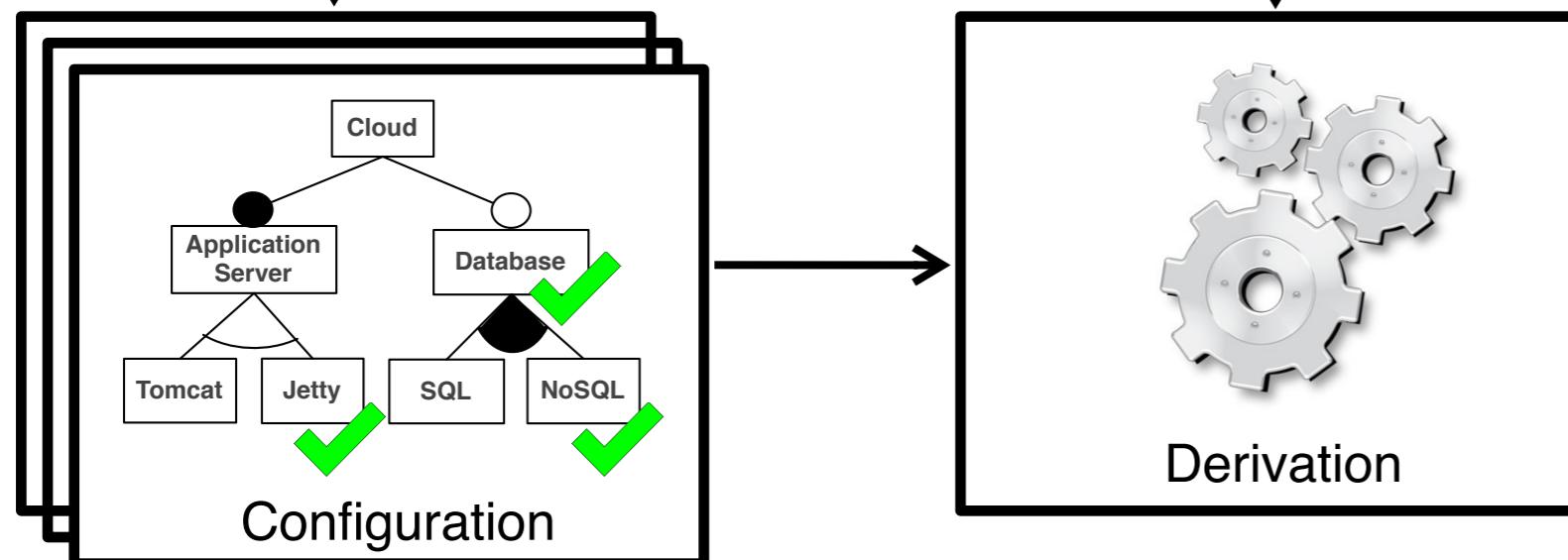
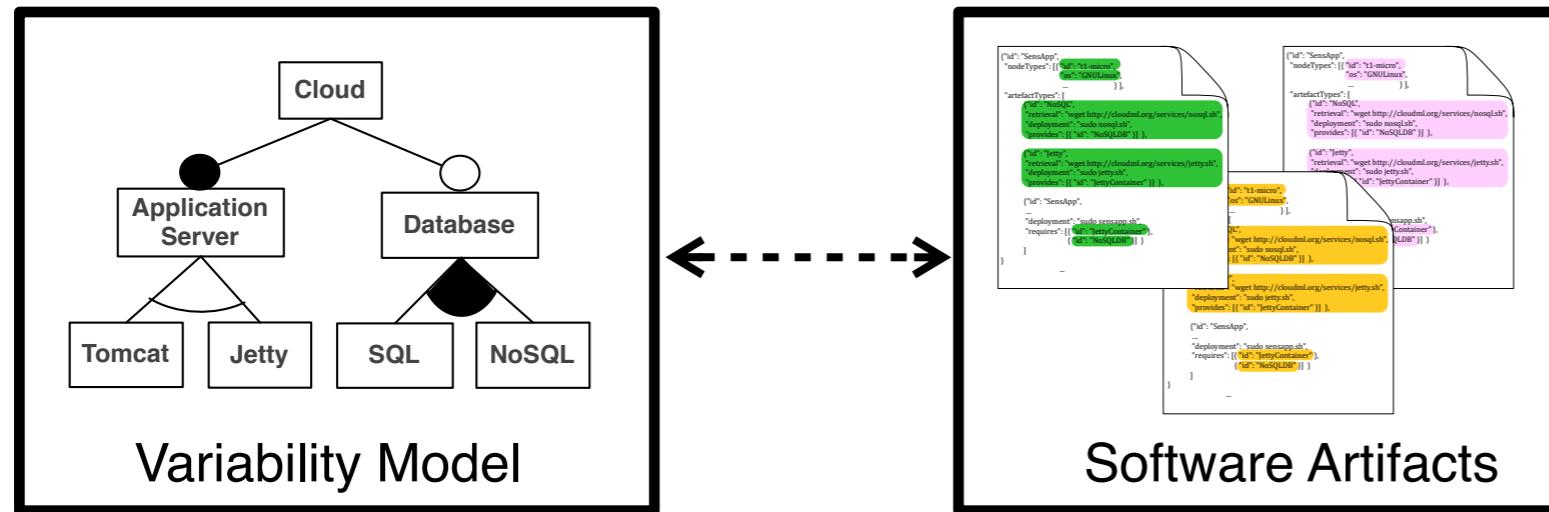
## Domain Engineering



## Application Engineering

# Software product lines

## Domain Engineering



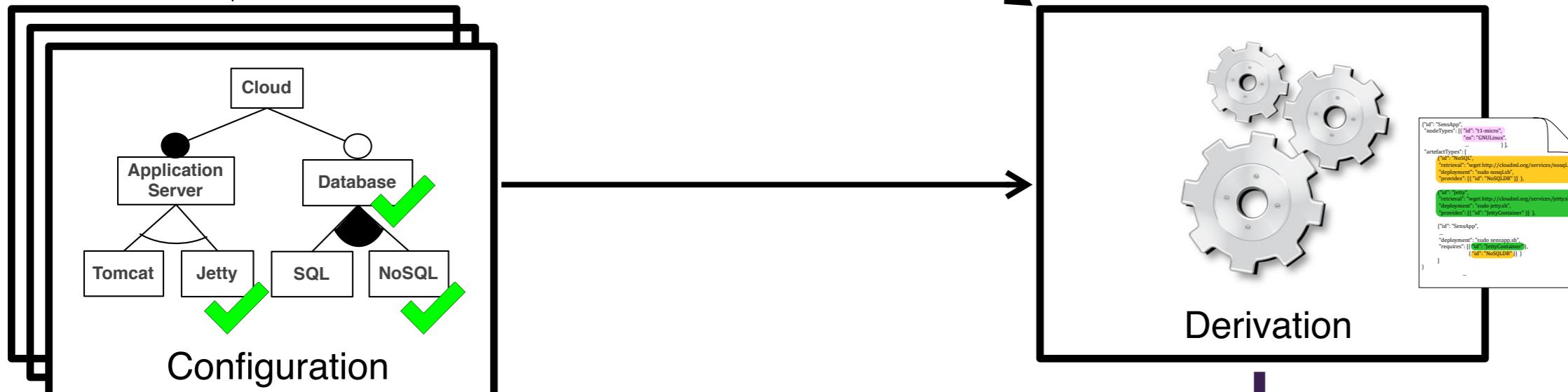
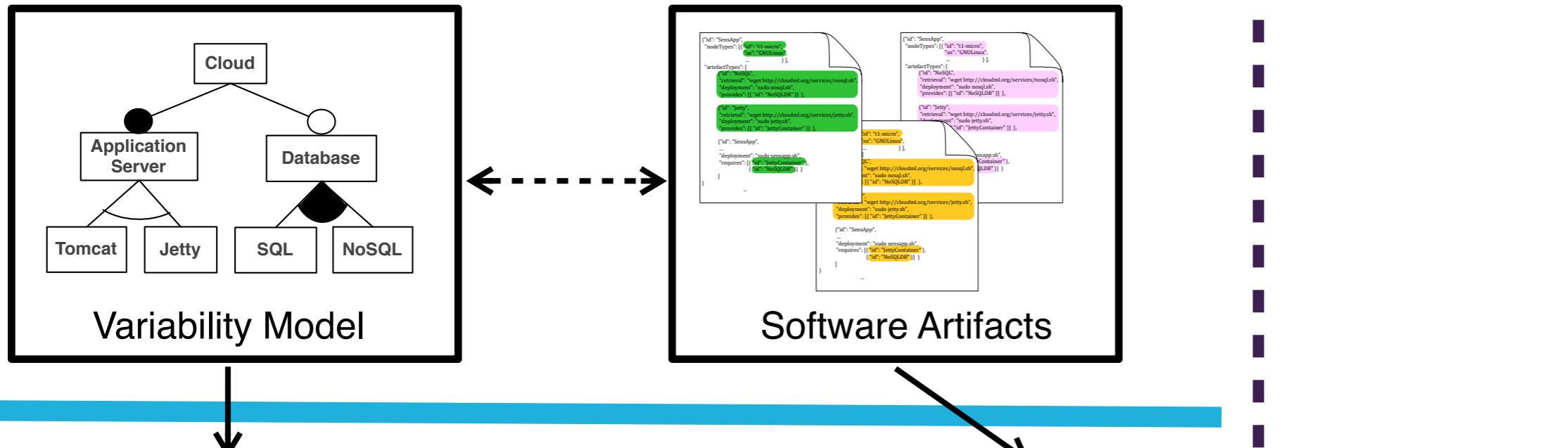
Application  
Engineering

Design  
Time



# Dynamic software product lines

## Domain Engineering



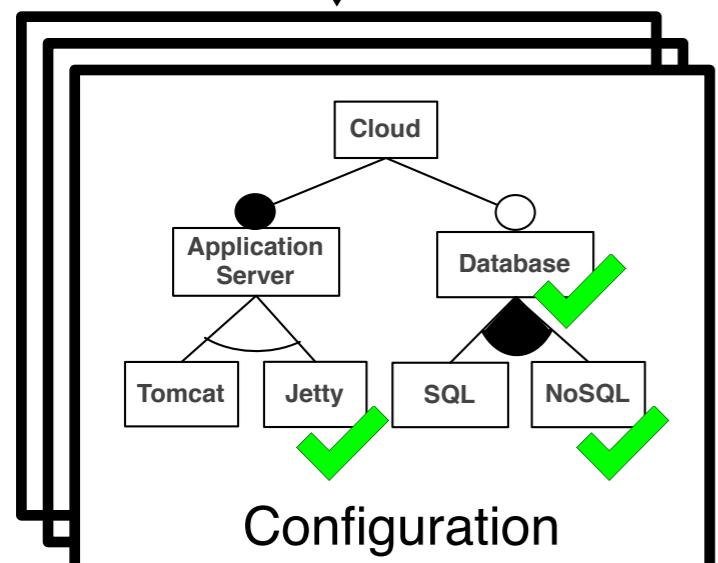
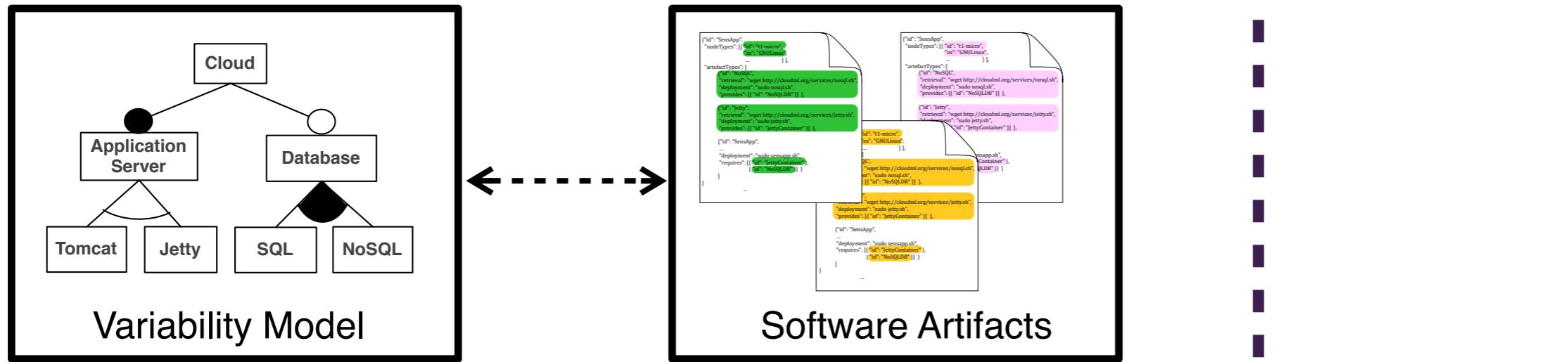
## Application Engineering

Design Time

Runtime

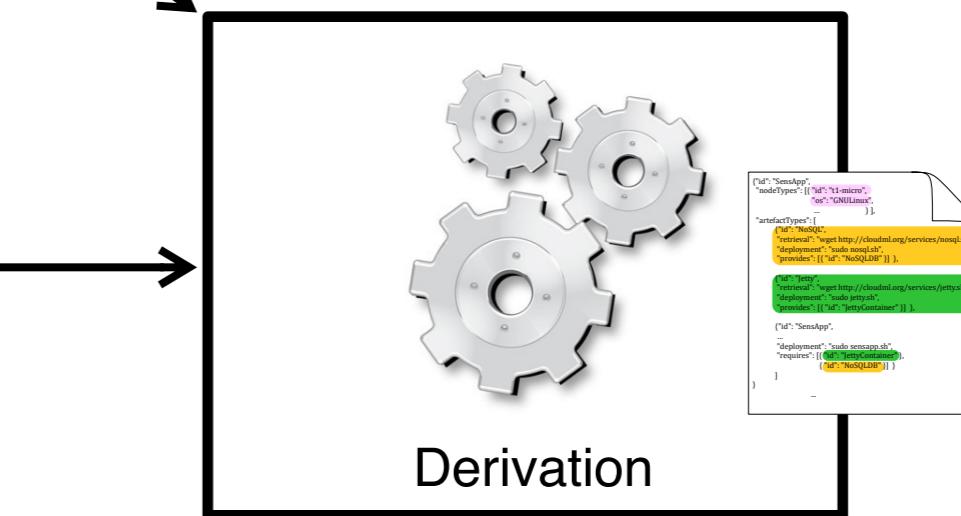
# Dynamic software product lines

## Domain Engineering



## Application Engineering

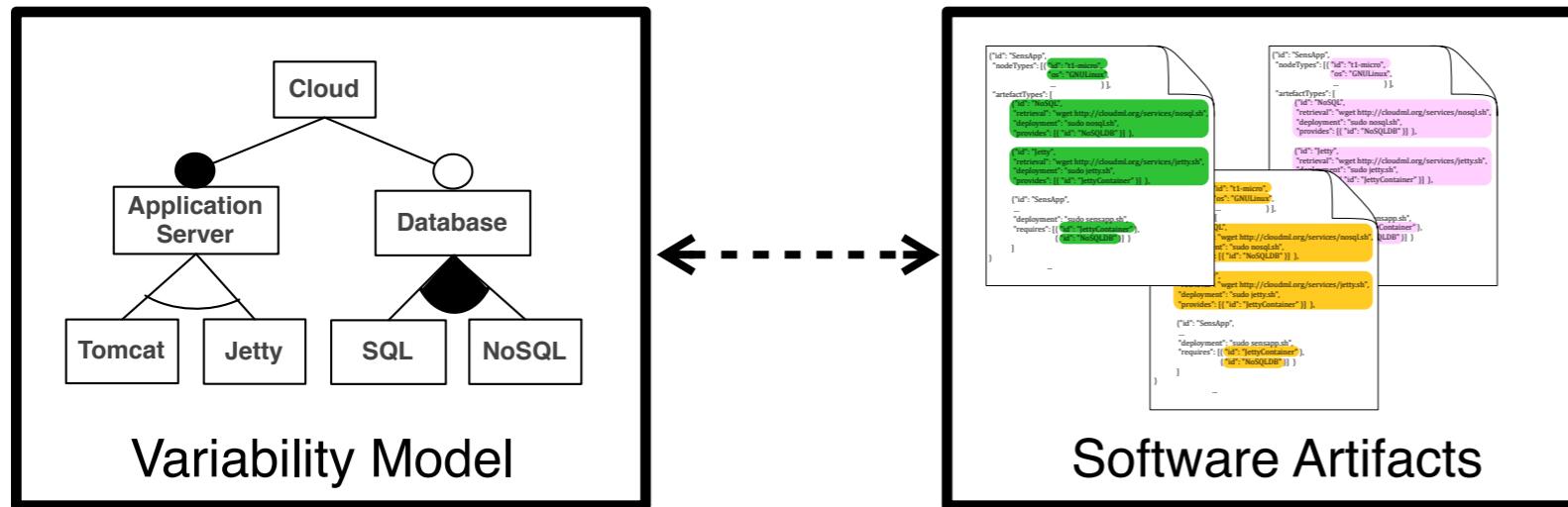
Design Time



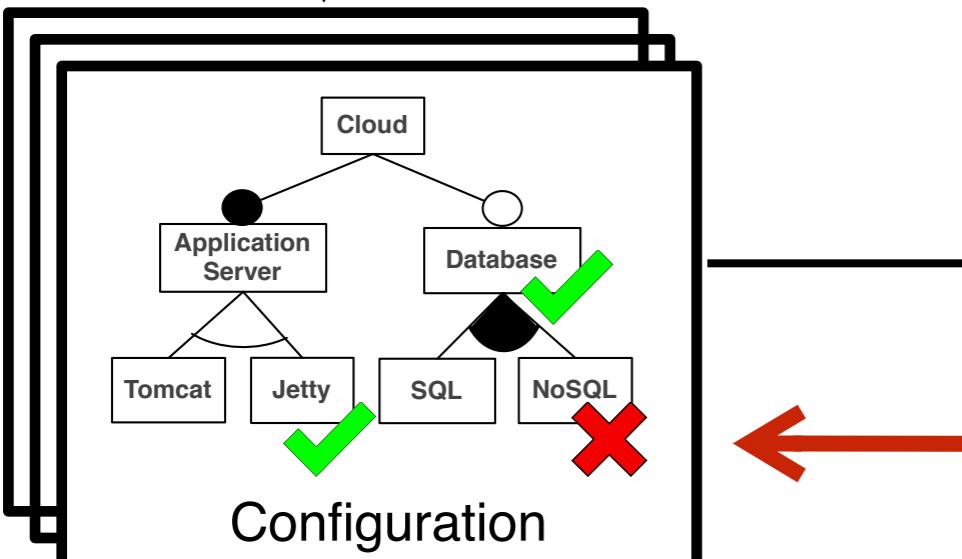
Runtime

# Dynamic software product lines

## Domain Engineering

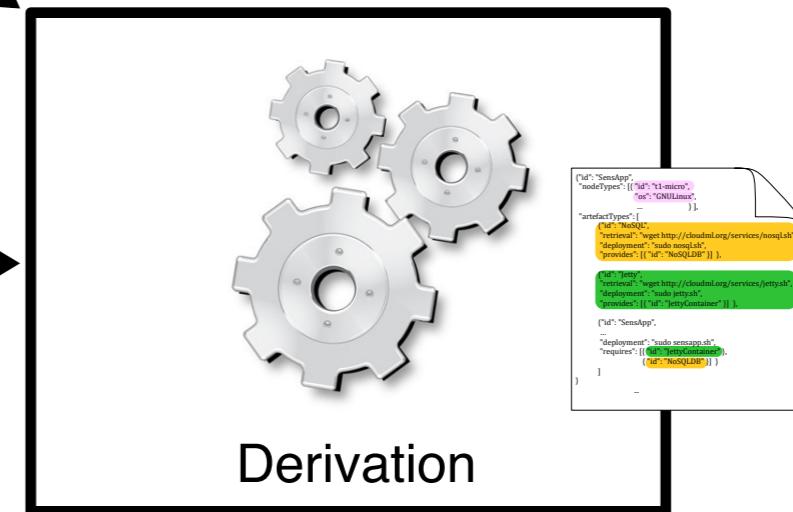


Software Artifacts



## Application Engineering

Design Time



Adaptation

Runtime

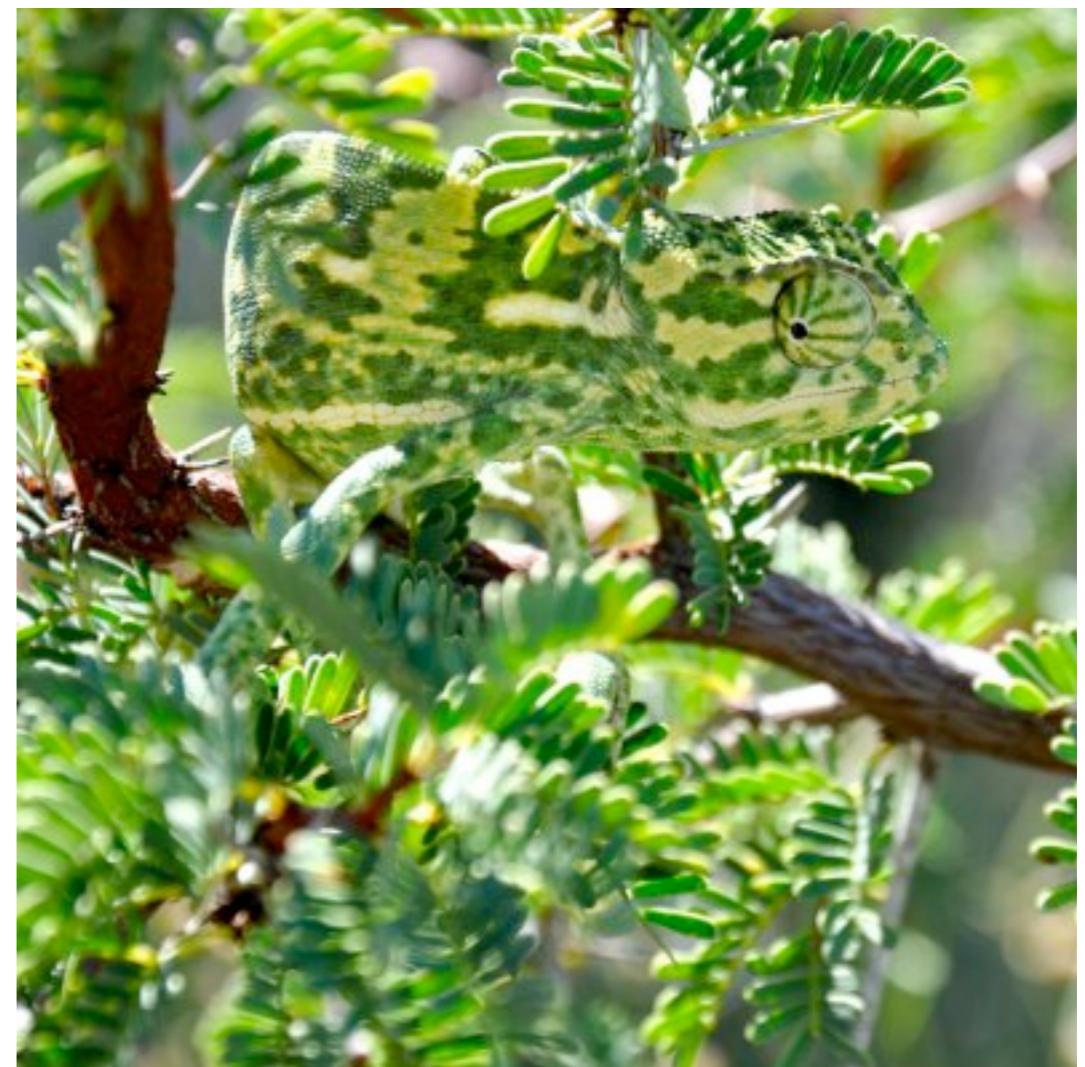
# DSPL for self-adaptive systems

---

**The ability of a system (S) to adapt itself to its environment (E) to meet a set of requirements (R)**



© Alex Hyde / Barcroft Media



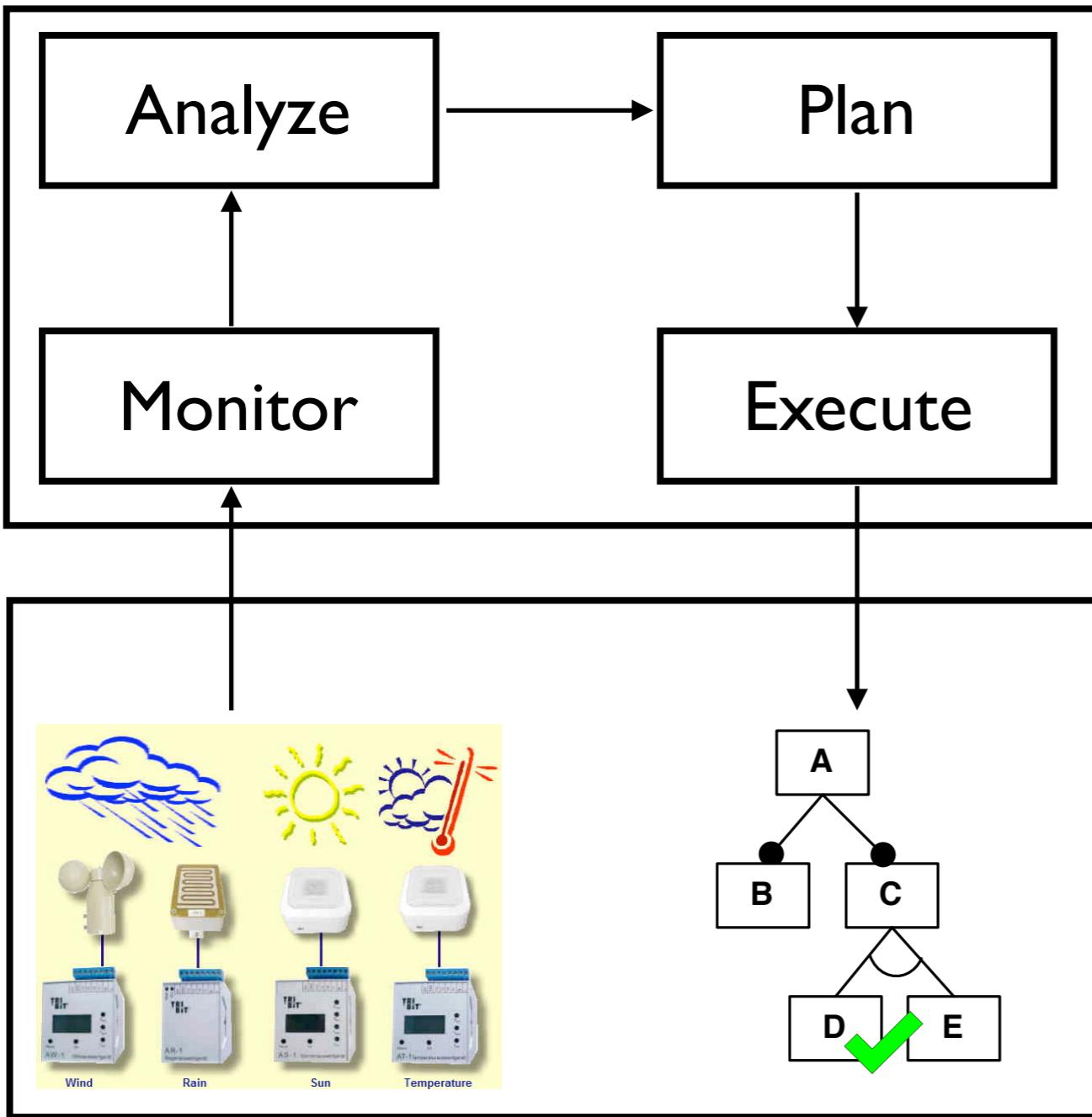
$$E, S_i \models R$$

$$E', S_j \models R$$

# DSPL for self-adaptive systems

Adaptation

Execution



Scenario

$$E, S_i \models R$$

$$E'$$

$$\text{Plan}(E', S_i) = S_j$$

$$\text{AR}: S_i \rightarrow S_j$$

$$\text{Execute(AR)}$$

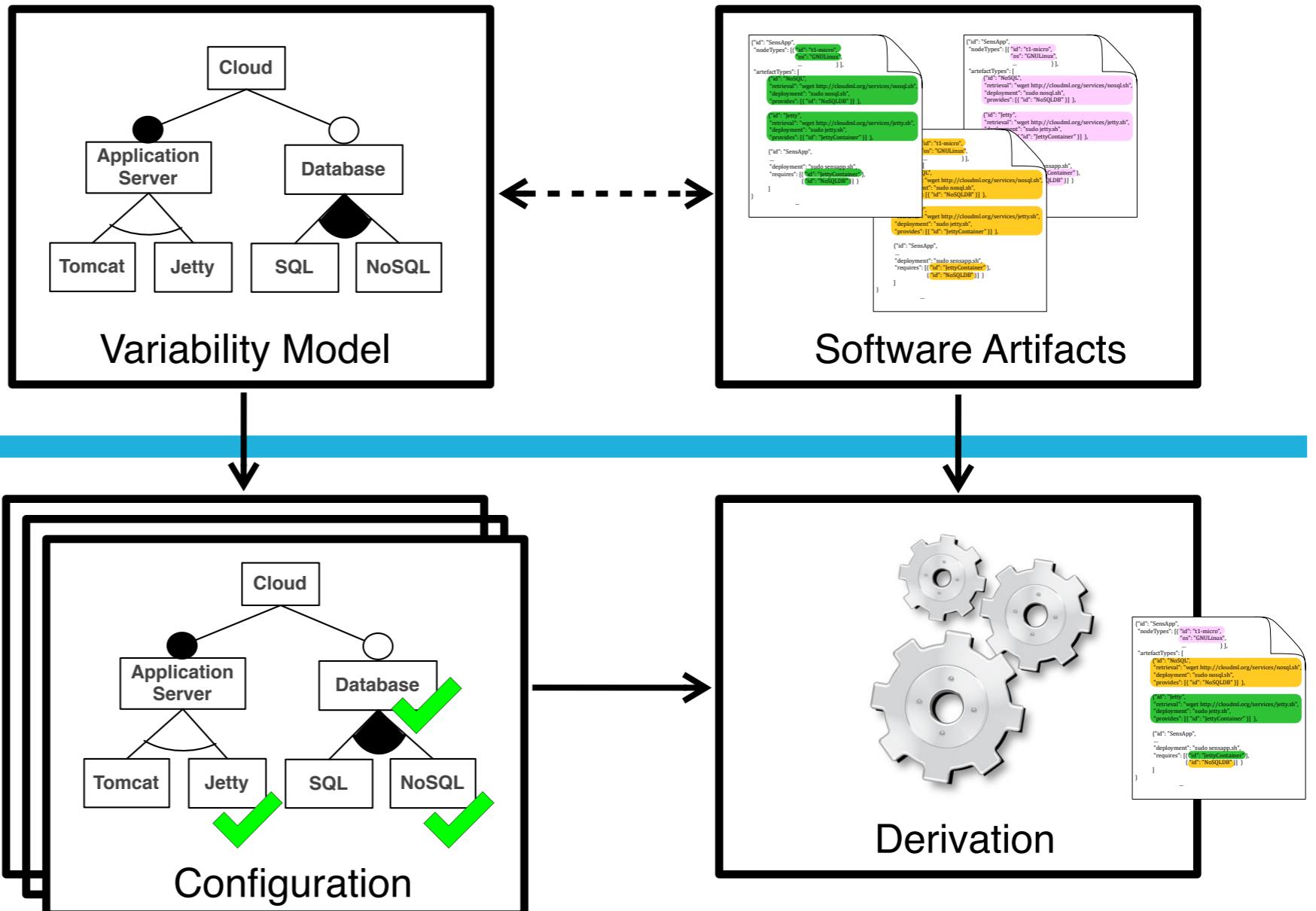
$$E', S_j \models R$$

# DSPL for self-adaptive systems

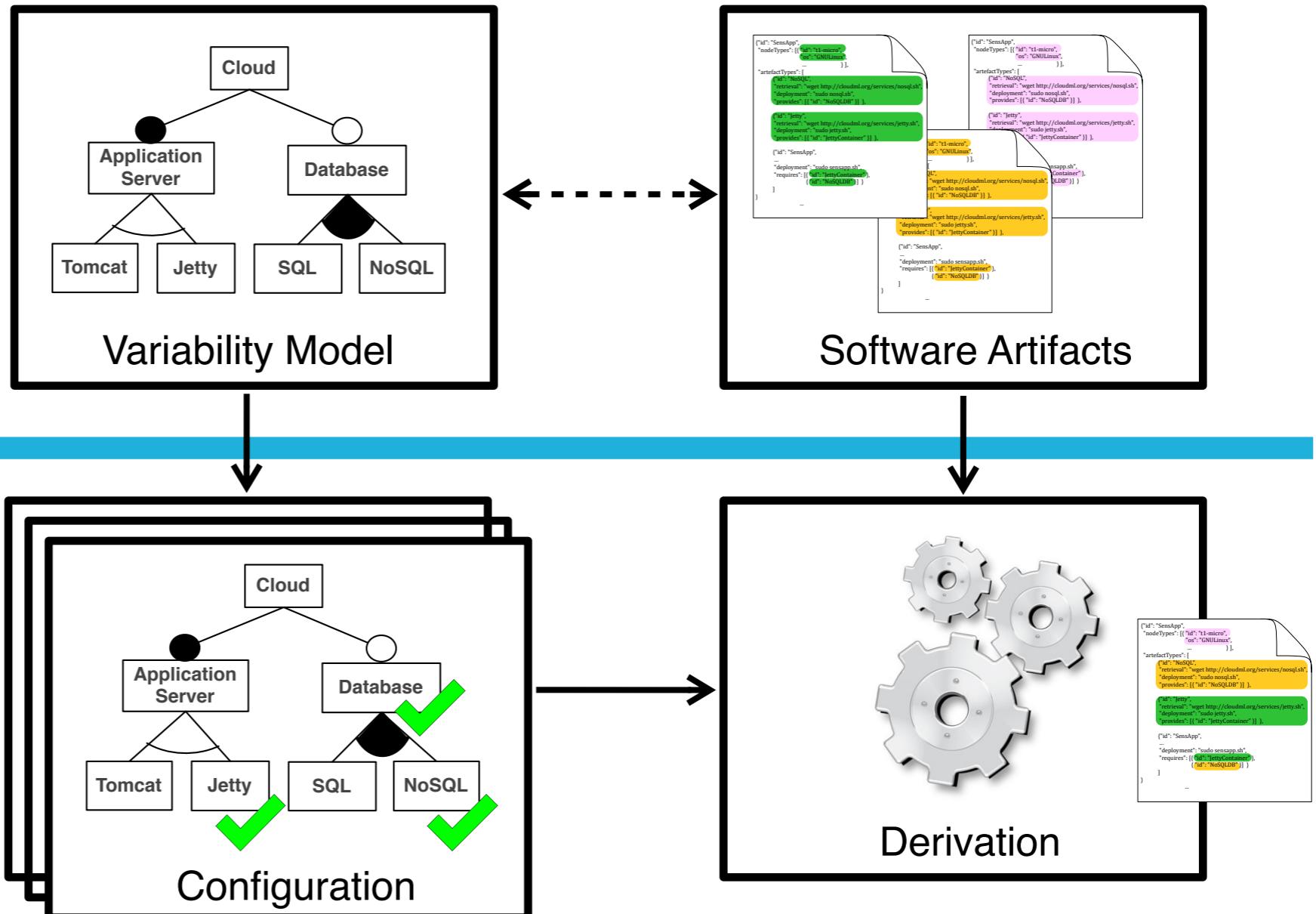
---

- ▶ Service-oriented DSPL
- ▶ Component-based DSPL
- ▶ Java-based?

# Domain Engineering



# Domain Engineering



<http://researchers.lille.inria.fr/cquinton/SPL/TP2.pdf>