**Travail de Bachelor**

**Analysis and deployment of an observability framework for micro-services-based applications**

Non confidentiel

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| **Étudiant :** | **Wènes Limem** |
| **Travail proposé par :** | Graf Marcel |
| **Enseignant responsable :** | **Graf Marcel** |
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Wènes Limem

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# Introduction

In modern technology, applications development has known entirely different strategies.

User number have grown, and monolithic architectures have shown multiple insufficiencies in serving these users. So, the developer community decided we need a new way to develop more suited applications to answer to users’ needs and growth.

Monitoring and logging have always been significant help for us to understand the system's state. Not only for being able to talk to the system, but also the ability to quickly troubleshoot and find out bugs in short times.

However, applications development has taken a different road now. The micro-services approach came to existence to answer the growing numbers of the users and their needs. But at the same time, debugging has become harder.

# Observability

## What is Observability?

In IT and cloud computing, observability is the ability to measure a system's current state based on the data it generates, such as logs, metrics, and traces. It relies on telemetry derived from instrumentation that comes from endpoints and services in your multi-cloud computing environments. In these modern environments, every hardware, software, and cloud infrastructure component and every container, open-source tool, and microservice, generates records of every happening activity.

The goal of Observability is to understand what is happening across all these environments and among the technologies, so you can detect and resolve issues to keep your systems efficient and dependable.

Developers’ teams inside an organization, usually implement observability using a combination of instrumentation methods and tools. They do also adopt an observability solution to help them detect and analyze the significance of events to their ops, development lifecycle, application security and end-user experience. [1]

## Monitoring vs Observability

**Graphical user interface

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Figure ‎2—1 Monitoring vs Observability

At first, we may think that observability is merely another name for sophisticated monitoring, but no. While the two terms share a lot in common, and can even complement each other, they are different concepts.

One the one hand, *monitoring* allows us to watch and understand the state of our systems. It is based on gathering predefined metrics and logs. Thus, it can only show us what we have expected to occur. Furthermore, the questions we can answer with monitoring are: What’s the state of my system? Is my system working?

On the other hand, *observability* allows us to actively debug our system. It is based on understanding how the system works. When it first emerged, the term indicated that if a system generates enough meaningful data that human operator can understand its internal state based on external output, then such system is observable. Therefore, systems provide insights, contexts and debugging data (like logs, metrics, and traces: they will be explained further) so that the system’s administrator is able to answer the questions: Why my system failed? What is my system doing?

To illustrate better, let’s consider a scenario where our system design pattern is based on micro-services. If we encounter a service-disrupting incident, monitoring won’t be able to show us where is the incident occurred, it will just tell us that something is off. So, to fix this incident, we must find where the anomaly is occurring and why. However, if our system was designed to be observable, such incident will be detected and debugging it will not take long.

## Benefits of Observability

In enterprise environments, observability helps cross-functional teams understand and answer specific questions about what is happening in highly distributed system. It enables us to understand what slow or broken and what actions is are needed to be taken to improve performance. With an observability solution in place, teams can receive alerts about issues and pro-actively resolve them before they affect users.

Due to the dynamic nature of cloud environments, most problems are neither predictable nor monitored. Observability addresses this common issue, enabling us to understand new types of problems continuously and automatically as they rise.

The value of observability does not stop at IT use cases. Once you begin collecting and analyzing observability data, you have an invaluable window in the business impact of our digital services. Such visibility allows us to optimize conversions, validate releases and meet business goals.

Observability benefits IT teams, organizations, and end-users alike.

Some use cases that Observability eases:

- **Application performance monitoring,** full end-to-end observability enables organizations to get to the root of application performance issues much faster, including issues that arise from cloud-native and micro-services environments.

- **Infrastructure, Cloud and Kubernetes monitoring**, Infra and Ops teams can use the enhanced context an observability solution offers to improve application uptime and performance, cut down the time required to pinpoint and resolve issue, detect cloud latency issues, optimize cloud resource utilization, and impose administration of their Kubernetes environments and modern architectures.

- **End-use experience**, a good user experience can enhance a company's reputation and increase users’ number, delivering an edge over the competition. By detecting and resolving issues well before the end-user notices and making improvement before it is requested. There is also the possibility to optimize the latency exactly as they see it, so everyone can quickly agree on where to make improvements.

- **DevSecOps**, observability is not just the result of implementing advanced tools, but a foundational property of an application and its supporting infrastructure. DevSecOps integrates three disciplines Development, Security and Operations. The three disciplines share their need for visibility so they can perform actions and reach desired goals. Observability offers view to the actual actions the system takes, its performance and its issues, in near real-time. Architects and developers who create the software must design it to be observed. Then DevSecOps teams can use and interpret the observable data during the software delivery life cycle to build better, more secure, and more resilient applications. [1]

- **Business Intelligence,** observability can be extended to application level, more precisely to business logic layer. In such context, we can observe what is happening inside the application, the where and when of every occurring transaction. To interpret, we can consider an example of an e-commerce web application. We would be interested to know the impact of a publicity campaign for the application. In that case, we need to observe the number of registered users. We can conclude the impact of the campaign based on the evolution of the observed variable.

## Diagram, venn diagram Description automatically generatedObservability pillars

Based on what we have seen so far, we can characterize a successful observable system based on the measurement collected from these three: Logs, Metrics and Distributed traces are the key pillars to achieving success. Although, we can gather such data from back-end components, we cannot have a full picture of how our system is behaving based on the raw form of these data.

Figure ‎2—2- Observability pillars

The three pillars mentioned previously can be defined as follows:

- **Logs**, structured or unstructured text records of events that occurred at a specific time. [1]

- **Metrics**, numeric values that represents counts or measurements that are often calculated or aggregated over a temporal period. Metrics can originate from a variety of sources, including infrastructures, hosts, services, application-level metrics, cloud platforms, external resources.

- **Distributed** **tracing**, activity of a transaction or request as it flows through applications and shows how services connect, may include code-level-details. Distributed tracing uses spans and alerts to notify admin systems of what is going on.

### Diagram Description automatically generatedLogs

Figure ‎2—3 Logging process in a distributed system

As defined above, logs are records of events that took place at a given time.

Logging is a mechanism to collect logs from various input sources. Usually, logs are in raw format [2]. To gain real insights, we must parse these logs and query-type them. Often, logs are sent to an output tool which organizes and stores them in a central database. Ergo the user can search, analyze, these logs. To push the matter further, we can even create alerts based on logs.

This process defines *what to log*, *how it should be logged* and *how logs are shipped to an external system for aggregating and centralized storage*.

Figure ‎2—4 Distributed logging process

### Metrics

Graphical user interface, diagram

Description automatically generatedMetrics are the measurements of resource usages that be observed and collected through a system. These can be low-level summary usage (CPU, Memory, Storage, Network, I/O throughputs, etc.) or high-level types of data (Requests served, number of sold articles in a certain shop, etc.)

Usually, the most common metrics are the ones provided by the operating system. These metrics covers the usage of the underlying physical resources. Data related to these components are made available by the OS and might be forwarded to a metrics collection point.

Moreover, any application can provide metrics, it is called instrumentation. As a matter of fact, it is becoming necessary and a good coding practice to instrument the application. This allows monitoring tool to gather metrics if the search mechanism, is pull based, or push metrics in the other case to metrics endpoint. Which explains the existence of large number of libraries that helps developers instrument their applications.

Figure ‎2—5 – Metrics possible classification

Even though instrumenting one’s code is a tin action compared to an application development process, it has a beneficial effect. For starters, the insight provided by the metrics allows the exterior observer to the system to understand, not only its health, but also its behavior.

### Spans & Distributed tracing

A trace is a mark, object, or other indication of the existence or passing of something. Projecting the linguistic definition of the term in our environment, we should be able to observe each request made between application’s services from user’s interaction till database action, with every detail (runtime, service name, annotations, tags).

External monitoring only tells us the overall the response time, and in best cases, the number of invocations. However, in our case, each service manages a request by executing one or multiple operations. Hence the need for observing each service at a close range, since each service can execute database queries, generate logs, publishes messages. Diagram

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Tracing is a very important piece of Observability. It traces the calls between various micro-services. Priorities defined to different failures of service and the one with the highest priority caught and alerted in near real-time. A Trace is composed of one to multiple spans.

The initial request is called a parent span (or root span) it stores the end-to-end response time of the request. To dive deeper in the subject, let’s consider an example. As shown in figure 5, we can consider user’s action as root span.

Figure ‎2—6 - Tracing mechanism

The request is initiated by the front-end service (if there is only one), the action will trigger other actions that will need interaction with other services of the application, for example, when a user request requires data from database, a series of services will be crossed till the database. Now each service will contribute a span as soon as it responds to a request of the parent span. It is called a child span.

Diagram

Description automatically generatedLinguistically speaking, a span the full extent of something from end to end. In our case, Spans are the primary building block of a distributed trace, representing an individual unit of work done in a distributed system. Each component of the distributed system contributes a span: a named, timestamped operation representing a step of the workflow.

Spans are identified by tags in addition of the name. Tags allows us to query, filter and comprehend trace data. A span context identifies the request’s root span. It can provide request, service name, and duration metrics. Information like this can help us understand which service taking longer than it should, and from there we can suggest different solutions depending on the found inconsistency.

Figure ‎2—7 - Illustration of Spans and their tags

# Micro-Services architecture

## Monolithic… A relic of the past

General Motors CEO, Mr. J. Welch said, “Change before you have to”. For a long time, desktop clients ruled the IT world, monolithic design patterns were satisfying the need of the existing number of clients and serving them with reliable performance. Thanks to the revolution in the gadget development, clients are not only desktop client (known as thick clients) anymore, but every connected device (Smartphones, tablets, IoT objects, also known as thin clients). Such diversity has pushed the number of clients to increase drastically. As consequence, our applications must be scaled so it can serve client requests with reliable performance. Monolithic designs are not well fit for scaling, that scaling in monolithic designs requires multiple instances of the application to run. As a result, we would need to tweak the application because of the future potential inconsistencies

Graphical user interface, application

Description automatically generatedBesides, adding features has become a necessity for most applications. Unfortunately, the monolithic design pattern does not fit properly the feature addition process. Since the application runs as a whole entity; from one side, we need to stop the application, add the feature, run the tests, reproduce the application, and redeploy it, this will cause a failure in availability. From another side, adding a feature is not as easy as it is said, in worst-case scenario, we might run into a variety of inconsistencies that obliges us to re-architect the whole application, otherwise we would run into stability or consistency issues.

Figure ‎3—1 Illustration of monolithic architecture

Furthermore, cloud-computing services unlocked new solutions. These new solutions allow us to run our application on a rentable infrastructure (a brochure of variety infrastructure customization is provided by all cloud providers). Deploying tremendous codebase, adopting it to new technologies and keeping it up to date with market changes can be a challenging task.

To conclude, monolithic design pattern is quite useful in a lot of other use-cases but have shown insufficient to keep up with the evolving technology.

## Micro-services design architecture

As stated by Mr. Robert C. Martin’s definition of the **Single Responsibility Principle** *“Gather together those things that change for the same reason and separate those things that change for different reasons* “, micro-services design is modularizing an application to small modules, so that each module focuses on a certain service of an application. In fact, these modules will be coupled loosely together to respond to a certain request. From a developer point of view, we can view our application as a collection of orchestrated small applications working together, hence the name micro-services. In contrast, from a client point of view, the application is still viewed as single entity. The figure 3-2 represents the design of a famous web application named *sock-shop*[[1]](#footnote-2) developed and maintained by *Weave-Works*[[2]](#footnote-3).

Such approach gave us numerous advantages over the monolithic pattern.

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First, scalability is not an issue anymore. In fact, services run independently of each other, if one of them has reached its load limit, we simply scale it up by adding another instance of it.

Secondly, since the application is not a single point of failure anymore, pushing updates to a certain service of the application would not cause a downtime for the whole application, but the service in question. Such advantage will allow us to increase our updates from 2-3 updates per week to 2-3 updates per day.

Lastly, modularizing the application will also affect the codebase of each service. With lighter codebase and environment, it will be possible to deploy each of our services on a lightweight virtual machine called containers. In cloud environments, destroying & deploying an instance of a container won’t exceed the seconds.

Figure ‎3—2 Microservices design of sock-shop web application

In conclusion, micro-services architecture, beneficial as it looks, is not a silver-bullet pattern. As a matter of fact, it increases the application complexity and requires the developer teams to have certain skills that they do not necessarily have.

## Containers

A container is a standard unit of software that packages up code and all its dependencies, so the application runs quickly and reliably from one computing environment to another. [3]

Concisely, containers are lightweight, standalone, executable package of software. In addition, these dependencies include libraries, binaries & required configurations. In depth, a container runs on a host OS like a virtual machine with two key differences: First it shares the OS kernel, so it boots faster using less memory. Second, it is hosted on a container runtime giving us the possibility to run multiple containers (several MB in size for each container) in a single server.

The name was not chosen loosely, as a matter of fact, shipping containers standardized globally cargo transportation globally. Applying this to our field, it is safe to say that containers are also a standardization of application packaging over the cloud-environment despite the nature[[3]](#footnote-4)& the provider[[4]](#footnote-5) of the cloud.

It is only natural that questions like, *what is the link between micro-services pattern and container technology? How does the one fit the other?* comes to one’s mind.

To answer these questions, let us agree on the fact that containers are a technology for packaging applications and micro-services is a design pattern. With that said, it is not always fit to choose the micro-service pattern when one is charged with the task of architecting an application. But if we are bound to opt for it, to fully benefit from the technology and the design pattern, we should consider the following: deploying an entire application to a single virtual machine represents a risk of a single point of failure independently of the design pattern chosen. However, modularizing the application to services that will later be deployed over containers is more beneficial on many levels, such us: scalability, availability, specific-targeted improvements.

To conclude, both *the single responsibility* principle and *the* *single application per container* principle align to fit the couple micro-services design deployed on cloud.

## Orchestration

S. Newman explained, in his book *Building microservices*, orchestration as follows: [4] “[…] With orchestration, we rely on a central brain to guide and drive the process, much like the conductor in an orchestra […]”. Orchestration is one of many architectural patterns for distributed systems that plays a crucial role in architectural readability and workload management. For that reason, it can fit software development environment that is focused on long-term scalability. In orchestration-driven architecture, software transactions are translated into workflows, managed, and identified by the orchestrator. In addition to these two tasks, the orchestrator handles payload construction, transformation, and protocol interoperability.

Furthermore, the orchestration pattern aims to centralize workflow management. Developers can query these workflows to identify individual service responsibilities without knowing the rest of the overall application architecture. In addition, this pattern offers more flexibility around deployments and changes, as it allows the different services of an application to start communicating synchronously and switch to asynchronous communication after that. An orchestrator manages transforming payload inter-services. Since all payloads are managed centrally, not only changes are easy to track, locate and manage but also data can be converted to any needed format.

To achieve operational transparency, the orchestrator must be able to check and report system health of each service. Such information is much needed for system administrators. Let’s consider an application with 3 services, in a scaled-up environment, each service will have 10 replicas. Unless we did setup observability principles for our distributed system, it can take forever to find out the faulty replica of a service deployment.

### Kubernetes

“Kubernetes, also known as K8s, is an open-source system for automating deployment, scaling, and management of containerized applications.” [5]

Kubernetes is the most used container orchestration tool. It was initially developed by engineers at Google, then it was donated as an open-source project to the Cloud Native Computing Foundation. Kubernetes is a framework for managing micro-services architecture patterns at scale. It allows us to design our application around services, which will run on multiple containers, schedule these containers across a cluster, scale them, and manages their health overtime. These clusters can span across all cloud nature (public, private & hybrid clouds).

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Description automatically generated To look closer to Kubernetes use case, we need to consider a developer creating a multi-container application. He also needs to plan out how the parts fit and work together, what should happen in case of failure, what should happen in case of high load, etc. The following files represents an example of a multi-container application configuration files.

Figure ‎3—3 Products micro-service pod configuration file

Figure ‎3—4 Users micro-service pod configuration file

Figure ‎3—5 Carts micro-service pod configuration file

To deploy the application we need pods, the smallest unit building unit of Kubernetes. The above files contain the configuration of such said components. These containerized applications are then stored (via YAML[[5]](#footnote-6) config files) in a container registry. Next step will be to apply them to Kubernetes.

Kubernetes will then analyze the configuration, aligning the requirements of each pod. Next, it will locate the appropriate requested resources for running the container. As a last step of mounting the application, it will then pull the images from the registry hub, starts the container, and helps them connect to one another and to system resources.

The orchestrator work does not end here, in the contrary, this is but the end of the first task. Kubernetes will, afterwards, monitor everything and when events diverge from a certain desired state, it will try to fix it and adapt the change. For example, if a container crashes, K8s will restart it, if the Kubernetes node is out of resources, it will look for another node to run the containers, if application load spikes, Kubernetes will locate the service in question and make it scale up.

### Service registry and microservices addressability in Kubernetes

As we mentioned previously, to deploy an application we need a set of pods. The next step will be to configure services to expose these pods and making the communication between them possible.

Each microservice has a unique identifier (name) that is used to resolve its location (IP address). If we must keep a list where to find each service things can catch fire quickly. To avoid this, we have a look-like DNS mechanism that translates service names to addresses. For that, services must have a unique name independent of the infrastructure it is deployed on, so that its location is discovered. Such approach implies that there is an interaction between the way a microservice is deployed and its discovery.

Along the same vein, when a container fails the orchestrator will automatically launch a new instance, and the service registry entry will be updated so that it shows where the service is running and what IP address was attributed to it. Service registry is a key part of service discovery. The registry is a database holding network locations of service instances. A service registry must be highly available and near real-time updated.

In conclusion, a service registry is a cluster of servers that use a replication protocol to keep consistency.

### Communication between microservices in Kubernetes

Communication between microservices is a crucial process when it comes to orchestrating containers.

Client and services can communicate through distinct types of communications. Each one targeting a certain scenario, architecture, and goals. To supply such communications, we can consider four axes:

* **Synchronous**: Client sends request and waits for response from the service (client's code execution has nothing to do with this whether it is synchronous (thread blocking) or asynchronous (response will reach a callback event eventually)). Most known protocol for this is ***HTTP*.**
* **Asynchronous:** Client's code (or message sender in general) does not wait for a response. It just sends the message to a message broker queue (like ***RabbitMQ*** for example).
* **Single receiver:** One receiver only must process each request.
* **Multiple receivers:**  Each request can be processed by zero to multiple receivers. This type of communications requires Asynchronous communication types. Based on message broker when propagating data updates between multiple microservices.

A micro-service-based application will often use a combination of these communication styles.

Most common tools for synchronous communication are ***HTTP REST APIs***, and ***RabbitMQ*** as an asynchronous message broker for asynchronous communication. [6]

### Kubernetes & Observability

Distributed systems with many interconnected micro-services, are systems that requires orchestration to ease its management. Although Observability’s pillars are relevant in Kubernetes; just collecting from these data points and analyzing it; it is not enough to reach observability as we need it. It does not allow us to fully understand what is happening inside the containers.

A Kubernetes cluster is a complex multi-layered, ever-changing web of resources and services., finding the root cause of an error and fixing it would be a hard job, and a waste of resources.

For example, let’s consider a 404 – Not found error. It was generated from a front-end service which runs on a certain pod of containers. The error might have been caused by a back-end service that runs on another pod of containers. In this case, finding exactly which pod is unhealthy among the large pool of pods, would be achievable by analyzing Kubernetes metrics. However, if the error does not stop the service from running, from Kubernetes point of view the container would still be healthy. This is exactly why; Kubernetes metrics are not enough to reach the observability as we defined it above.

This can be avoided if we have deployed an observability framework. This framework will provide us with visibility (through collected metrics and spans visualization) and information (through collected logs) that will help us track the error and fix it.

# Observability Tools

What is an observability tool?

An observability tool is a tool designed to gather information that are relevant to understanding system behavior. and application via monitoring metrics, logs, and traces. In contrast with individual monitoring tools, observability tools enable a system administrator to have constant insight and receive continuous feedback from their systems. This approach to monitoring and logging provides actionable information to system administrators faster than tools limited to monitor or gather logs.

Observability platforms help administrators understand system behavior and predict outages or problems before they occur. They use observability tools to act proactively and prevent system problems.

## Prometheus

### What is Prometheus?

Prometheus is an open-source monitoring and alerting toolkit originally built at SoundCloud. It is now an independent project since it joined the CNCF as the second hosted after Kubernetes. It is written in Go. It provides a multi-dimensional data model, a query language called PromQL, and integrates different parts of the application. [7]

In a nutshell, Prometheus collects and stores timestamped metrics alongside optional labels. To manage such huge amount of data, it uses a time-series database and stores corresponding labels as key value pairs.

#### Components & architecture

Most of Prometheus’s components are written in Go language, for its easiness of build and deployment as static binaries. Prometheus distributed components are as follows:

**Prometheus server**, this entity represents the main server of Prometheus. Its main activity is to scrape and stores time series data.

**Client libraries**, these are the libraries that clients need to integrate in their code environments to make their applications expose metrics available for scraping. Metrics can be exposed via HTTP endpoint on each service instance. CL[[6]](#footnote-7) are available in multiple programming languages (Go, Java, Python, .NET, Node.js, Bash, C, etc.)

**Push gateway**, some components cannot be scraped, due to their short-lived jobs (batch jobs or service-level jobs), they might not live long enough to be scraped.So, we must push metrics making them available at some endpoint[[7]](#footnote-8) for scraping.

**Exporters,** this component is what makes Prometheus widely used. There are libraries and servers that helps third party systems export their metrics as Prometheus metrics, hence the name exporters.

**Alert Manager**, since Prometheus scrapes metrics, it also allows us to configure alerts on these measurements.

To manage data in time-series formats in an effective way, Prometheus dev teams developed PromQL. A Prometheus’s original query language offering the possibility of aggregating and filtering data, thus providing a very important pieces of information. PromQL is designed to work with time-series databases. Therefore, it provides time-related query functionalities.

Now, as we research Prometheus, we expect it provides visualization. However, there is no technical evidence that supports it. Prometheus uses Grafana to visualize its stored data. The couple provides necessary insight to reach observability.

Graphical user interface

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Figure ‎4—1 - Prometheus Architecture (source: https://prometheus.io/docs/introduction/overview/)

Prometheus scrapes metrics in two manners, directly through pulling metrics from instrumented jobs or from the push gateway. Then it stores scraped samples locally and apply rules over it either to aggregate it and store new time series, or to generate alerts and push them to alert manager. Grafana or other visualization tool can visualize collected data.

#### Key Features

Initially, Prometheus uses multi-dimensional data model with time series data identified by metric name and key/value pairs. It stores streams of timestamped values of the same metric and the same labeled dimensions. Prometheus might also generate temporary derived timeseries as a response to users’ queries.

Secondly, PromQL, a Prometheus flexible query language, invented to leverage the data dimensionality provides users with the possibility to aggregate and query over data to get more focused and enhanced visibility at of the desired metrics. Prometheus will retain a minimum of three write-ahead log files. High-traffic servers may retain more than three WAL[[8]](#footnote-9) files to keep at least two hours of raw data. [8]

Thirdly, Prometheus storage is based on an autonomous single server nod, thus no distributed storage. In other words, time series databases store data formatted under an optimized format for longer retention. Although the default Prom release uses local storage, it also provides interfaces to integrate remote storage systems. However, this approach has several drawbacks such us, lowering data retention policy to avoid costly volumes, each Prom’s server had to have a big enough dedicated volume to operate (increases costs) and any increase in metrics pushes central Prom’s server to scrape more data which leads to timeouts.

Prometheus is effective in some use cases, but if the environment scales up high enough, managing it becomes challenging.

### Contribution to Observability

As mentioned in Observability chapter, one of the three pillars of observability is metrics. Prometheus is the most widely used open-source metrics collection tool.

Prometheus client collects default metrics such us, CPU consumption, I/O throughput, HTTP requests rate, etc.; But it also gives us the possibility to create our own metrics and register them to a registry. With this said, we can consider collecting metrics of higher level, metrics that do not belong to infrastructure level, but to application level. This metrics can be, the rate of registered users, the rate of dropped carts, etc.   
 Prometheus does not only scrape these metrics, but also it visualizes them onto variety of dashboards in a near real-time. Furthermore, we also have the possibility to configure alerts on these metrics.

To conclude, Prometheus with the right configuration, customized metrics and set alerts, can be the right tool to cover the metrics pillar to reach system observability. In the last chapter, we will learn more about Prometheus configuration, how add customized metrics, how to visualize these metrics.

### Glance at Prometheus’ & Grafana’s dashboard

A screenshot of a computer

Description automatically generated

Figure ‎4—2 - Prometheus Interface for managing alerts

A screenshot of a computer

Description automatically generated with medium confidence

Figure ‎4—3 - Prometheus Interface for viewing endpoints status

## Thanos

### What is Thanos?

On its website Thanos is defined as an Open source highly available Prometheus setup with long term storage capabilities [9].

Thanos linguistically comes from Greek “Athanasios”, which means immortal. Thanos is not a monitoring and logging tools by itself, but it is a set of components that can be composed into a highly available Prometheus with unlimited storage capacity.

Thanos was brought to existence by the British gaming technology company “Improbable” as a CNCF project. On their blog, they revealed the project goal saying: *"to seamlessly transform existing Prometheus deployments in clusters around the world into a unified monitoring system with unbounded historical data storage”* [10]*.* With that said, it is safe to say that by adding Prometheus to Thanos, system administrators can build highly available metric systems with almost unlimited storage. Once deployed, Thanos provides global query vision, access to historical data and high accessibility as we can see on the following illustration (figure 4-4).

A picture containing text, businesscard

Description automatically generated

Figure ‎4—4 Thanos : a Prometheus federation

To explain better what Thanos does offer more than Prometheus we are going to detail the feature we mentioned above. First, global query view; Prometheus uses sharding[[9]](#footnote-10) approach so it can access all our data in the same API or UI, Thanos does the same thing by collecting metrics from multiple Prometheus instances and allows us to visualize & query them. Second, historical data storage; one of Thanos’s sidecar responsibilities is to watch new block scraped and added by Prometheus instances then adds the block in question to storage bucket to be uploaded to a cloud of our choice, this way the metrics persistence challenge is solved. Third, high availability; this is reached by Thanos sidecar and querier, if we watch closely the figure 4-4, we can notice that the querier can de-duplicate Prometheus metrics from each sidecar and merge them together.

### Components & architectures

Diagram

Description automatically generated

Figure ‎4—5 – Overview of Thanos architecture (Source: https://thanos.io/v0.6/thanos/getting-started.md/)

**Thanos sidecar,** the sidecar is the main component of Thanos. As we can see, Thanos is deployed alongside existing Prometheus server. This component’s task is to collect Prometheus data and upload it to storage component.

**Thanos ruler**, the ruler’s role is to push alerts to alert manager and ship logs to storage component. It provides a Web UI (same as Prometheus)

**Thanos querier,** it is a layer added upon Prometheus’s PromQL API. This component has its own web UI. Also, it has a store API (gRPC API is used instead of HTTP API) to provide near-real time metrics.

**Thanos Store Gateway,** it is the official communicator to Object storage third party component (it can be S3 buckets if AWS or under other bucket formats for other cloud storages).

**Thanos compactor,** this component controls three data aspects: Retention, compaction[[10]](#footnote-11), and down sampling[[11]](#footnote-12). For example, depending on our application’s nature and traffic we can schedule retention configuration change to optimize our storage use. Back to the compaction point, for the same situation, the process of compaction helps reduce number of blocks to store and index indices.

### Contribution to Observability

Thanos transforms Prometheus into a highly available metrics platform with unlimited metrics storage. Since the latter is a metrics collection and visualization tool, Thanos is, with no doubt, the same. To sum up what have been said before, both Prometheus and Thanos cover the metrics pillar of Observability getting us one step closer to a fully observable system.

## Jaeger

### Text Description automatically generatedWhat is Jaeger?

Jaeger is a German word that means Hunter. Jaeger is a distributed tracing system developed by Uber Technologies. It is used for monitoring and troubleshooting applications through collecting spans. [11]

The system focuses on 5 main areas as follows:

* **Distributed context propagation**, to understand this, we need first to define what a context is. As we mentioned in previous chapters, spans are created when requests are made or answered to. As a result, a context can be a micro-service name or an operation type (database interaction, cloud interaction, business-logic, etc.). A request will most likely cross multi micro-services to finally comeback to original sender, and with each micro-service it crosses, multiple spans will be generated with different context, so the context needs to be propagated with the request that we are able to trace it, hence distributed context propagation. The figure below is an example of distributed context propagation in an e-commerce application, based on three micro-services. The application will be explored in the next chapter.

Figure ‎4—6 Illustration of distributed context propagation

Graphical user interface, application

Description automatically generated

* **Distributed transaction monitoring**, a transaction in our field is an end-to-end operation. As spans can contain a lot of information useful for understanding how the micro-services are doing their job, we can also add request response attributes (successes or errors), events, logs, and customed tags. Afterwards, we can query over our spans through all these options.
* **Root cause analysis**, as we mentioned above, a span can contain pieces of information that might be useful to understand an error if it happens. With that said, mixed with the two above, even if our system is scaled-up, localizing an error would take seconds thanks to distributed context propagation and distributed transaction monitoring. Analyzing what is wrong, becomes a matter of minutes thanks to the traces and the contents of the collected spans.
* **Service dependency analysis,** in a micro-services design pattern, the services are meant to communicate with each other. Any communication will issue a request and response therefore a dependency. The following figures illustrates the service dependency.

Diagram

Description automatically generated

Figure ‎4—7 Service dependency analysis of e-shop minimal application

A typical Jaeger installation at Uber processes around several billion spans per day. So the figure is really a 0,0001% of the real capacity of this Jaeger feature.

### Jaeger components

Jaeger is composed of three main components. An agent, a collector, and a service for querying over collected data.

Diagram

Description automatically generated

Figure ‎4—8Illustration of Jaeger components architecture. Source: https://www.jaegertracing.io/docs/1.36/architecture/

**Jaeger-agent**, client libraries included in the application’s code to generate spans and build traces, expects a local jaeger-agent process on each host. The agent work is to expose endpoints for data collection. It also provides the ability to configure static list of collector addresses, as for the possibility to connect point to point to a single collector. [11]

**Jaeger-collector,** stateless components giving us the capability to run multiple parallel instances. Except for storage locations, collectors do not require any further configuration. Jaeger provides two possibilities for storage: local in-memory storage, as the name suggests, such a storage would not be able to hold for long in a production environment, however useful for testing environments. Second is the cloud persistent storage required by collectors. Jaeger supports multiple distributed storage backends like Cassandra[[12]](#footnote-13) or Elasticsearch[[13]](#footnote-14). [11]

**Jaeger-query,** for this component has two tasks: Querying over data and visualizing it. This service is also stateless and so often run behind a load balancer such as NGINX. [11]

### Contribution to Observability

Jaeger is distributed tracing system that collects and analyze spans to provide us with enough information so that we can understand what the system is doing at every step. As we have mentioned, in the Observability chapter, spans are one of its three pillar. Jaeger is a tool that covers the spans pillar.

Designing our system to generate distributed propagated spans is crucial to reach full observability. For example, if we want to see the most followed paths by users so we can qualify the navigation of our web application, querying over spans can help us do this.

## Logo Description automatically generatedDatadog

### What is Datadog?

Datadog is a software proprietary to Datadog, Inc. that was founded by Olivier Pomel and Alexis Lê-Quoc in 2010.

Datadog is a monitoring, security, and analytics platform for cloud application. It brings together the three pillars of observability: logs, metrics, and spans so it makes our application, infrastructure, and third-party services entirely observable. This software can be useful for practically any IT cloud application. In addition to its capacity to enable observability, it also provides analytics of all layers of an application, starting from infrastructure, arriving at real time BI[[14]](#footnote-15).

Besides, Datadog is used also by DevOps teams that it enables them to configure alerts based on issue level. The alerts notifications can be received on variety of tools such us PagerDuty, Slack, or e-mail. Likewise, it also enhances CI[[15]](#footnote-16) visibility, event tracking and anomalies detection.

Moreover, Datadog uses a REST API allowing it to integrate with a variety of services, tools, and programming language including Kubernetes, Puppet, Ansible[[16]](#footnote-17), Ruby, NodeJS, .NET, PHP[[17]](#footnote-18), etc.

Furthermore, the software centralizes everything into one highly customizable platform making the system administrators observe the entirety of the system with less clicks, in some cases, on one dashboard.

A picture containing logo

Description automatically generatedDatadog platform has a canvas of modules as the figure below shows:

Figure ‎4—9 Datadog platform modules. Source: https://docs.datadoghq.com/

### Deployment Strategies & Pricing

Datadog is available for deployment on premises as it supports multiple operating systems such as Linux based distributions, Windows, OpenStack, and Oracle cloud. As well as it is deployable as a SaaS[[18]](#footnote-19). When deployed as a SaaS it eliminates the tools maintenance, capacity scaling, updating or management operations. These benefits the team to focus more the core product. [12]

Since Datadog is proprietary, it is interesting to detail pricing. As a matter of fact, Datadog does not charge for the whole software, but each module or integration might or might not be charged. This figure presents the plans as suggested by the company:

A picture containing echinoderm, electronics, honeycomb

Description automatically generated

Figure ‎4—10 Datadog suggested pricing plans Source: https://docs.datadoghq.com/pricing

To give an overview of the pricing model followed, we will pick 3 modules. Starting with the infrastructure module, for 15$ per host monthly, we have all standard features, plus 15 months of data retention, unlimited alerts, 10 per host monitored containers (automatic selection), 100 custom metrics, 100 event. However, for the enterprise version of the same model, for 23$ per host monthly, 20 per host monitored containers (custom selection), 200 per host custom metrics, 1000 event.

For Log management module, Datadog charges 0.10$ per GB ingested or scanned, $2.50 for a month period retention per million log event per month.

For APM[[19]](#footnote-20) & Continuous Profiler, the company charges 31$ per month per host for APM only. To benefits of both features the cost increases to 40$ per month per host.

In conclusion, Datadog is a useful and affordable tool for big company with no financial pressure, on the other hand, it can be quite expensive for startup companies. [13]

## Comparing Observability tools

To wrap up the four tools & software we have seen so far, we have elaborated these two charts. The charts compare the previously presented tools and compare them based on many criteria.

Graphical user interface

Description automatically generated

Figure ‎4—11 Comparison Chart part 01/02

Graphical user interface

Description automatically generated

Figure ‎4—12 Comparison Chart part 02/02

# Observable systems

## Sock-shop

### Overview

Sock-shop is, as the name suggests, a user-facing part of an e-commerce website that sells socks. It is micro-services-based web-application developed by Weaveworks in 2017 as a demonstration application for micro-services design architecture and cloud-native technologies. It is maintained by Weaveworks and Containers Solutions. It is registered under the Apache License, Version 2.0 [14]. The figure below is a screenshot of the user-interface of the sock-shop application while it was deployed on local Kubernetes node.

Graphical user interface, website

Description automatically generated

Figure ‎5—1 Sock-shop user-interface screenshot

### Design & Layers

Diagram

Description automatically generatedThe application was modularized to micro-services as the next figure shows

Micro-services are not written in one language, and that is the interest behind this design pattern. As a matter of fact, Frontend micro-service is written in JavaScript, whereas Order & Catalogue micro-services were written In Go-Lang.

Figure ‎5—2 Sock-shop application micro-services

Some microservices are connected to databases, such us Order, User, Catalogue and Cart. However, the Sessions database is a standalone micro-service that a session is stored and treated independently of the user.

The services communicate with each other using REST APIs over HTTP protocol for synchronous communications and RabbitMQ for asynchronous communications.

### Infrastructure & Deployment

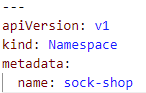
Sock-shop is deployable over Kubernetes. The deployment files can be found at their official GitHub repository. We are using Docker Desktop node for Kubernetes, but it should work on any Kubernetes cluster.

#### Sock-shop namespace deployment

A namespace is a Kubernetes unit used to isolate containers from other namespaces. Kubernetes own containers runs in an isolated namespace named *kube-system* and *kube-node-lease.*

The namespace is created as follows:

Kubernetes API version



Metadata contains the name that will be attributed to namespace

The nature of the configuration we are applying

Figure ‎5—3 Sock-shop namespace deployment YAML file

#### Sock-shop micro-services deployments

To deploy micro-service, we need to create a pod and then expose it with a service at certain port. In Kubernetes, deployments allow us to describe a desired state and let the deployment controller manage the state changes. We can use deployments to create replica-sets, declare new state of pods, scale-up the deployment.

A picture containing graphical user interface

Description automatically generated First, let’s start with the deployment file:

Figure ‎5—4 Deployment file for carts micro-service

Kubernetes API version

The nature of the configuration we are applying

Deployment metadata: includes a name, labels to be matched with other components labels, and the namespace where the deployment will run.

Deployment specs: includers number of replicas, selector type and the corresponding labels, and the template data.

Container specs: includes the container’s name, the image that is supposed to run in the container, environment variables, container’s ports, security context (execution contexts for example), attached volumes (external resources), and a node selector (so the pod can run on a node with the same label).

With that applied to Kubernetes, next step is to expose the deployment with a service as the following file shows:

Graphical user interface, text, application

Description automatically generated

Kubernetes API version

Figure ‎5—5 Carts service YAML file deployment

The nature of the configuration we are applying

Service metadata includes service’s name, its labels, and its annotations (used to attach arbitrary non-identifying metadata to objects).

Service specs including container ports and selector name.

As we have seen in the previous figure 5-2, some micro-services are connected to database, such as the carts micro-service. For that, we need to deploy a container containing the database related to the service. The following file contains a deployment example of carts database.

A picture containing table

Description automatically generated

Kubernetes API version

Figure ‎5—6 Carts database YAML file deployment

The nature of the configuration we are applying.

Deployment metadata: includes a name, labels to be matched with other components labels, and the namespace where the deployment will run.

Deployment specs: includers number of replicas, selector type and the corresponding labels, and the template data.

Container specs: includes the container’s name, the image that is supposed to run in the container, environment variables, container’s ports, security context (execution contexts for example), attached volumes (external resources), and a node selector (so the pod can run on a node with the same label).

Following the same strategy, we can deploy the rest of the application. To do that, we have two possibilities:

Graphical user interface, application

Description automatically generatedFirst deployment files can be found in *sock-shop* => deploy => Kubernetes => manifests to deploy components separately as the next tree shows:

Figure ‎5—7 Tree of sock-shop repo folder part 01

Second, using one file that has all the configuration summed up together. The file can be found at sock-shop repo => deploy => complete-demo.yaml .

Graphical user interface, application

Description automatically generated

Figure ‎5—8 Tree of sock-shop repo folder part 02

Text

Description automatically generated Once the application is deployed, we can check on the deployment status using a terminal. The output should look like the following figure:

Figure ‎5—9 Sock-shop deployment status - Terminal view

We notice that the command prints out the various information depending on the object kind. For example, for pods, we have the pod’s readiness, the number of restarts, and the status. For services, the service type, cluster attributed IP and port mappings. For deployments, we have the readiness & update status and its availability.

### Amazing… But hardly customizable

Sock-shop is a good application to demonstrate the micro-services design pattern and deployment over Kubernetes. However, this is not the only reason behind choosing it as a demonstration application, it is also due to the instrumentations it has.

Since the application was for demonstration purposes, the instrumentation was not configured across the whole collection of services, but only some of them.

Text, application

Description automatically generated Let’s start with micro-services generating traces. As we said before, Jaeger is a trace collection tool, so it is going to be used to capture the traces generated by the services. To enable the sock-shop traces, the Kubernetes manifests will be found at *microservices-demo => deploy => manifests => Kubernetes => manifests-jaeger.* The content of this folder is as the figure 5-10 shows. Once we apply these files to Kubernetes, we notice that only 3 micro-services deployments (catalogue, payment & user) will be update, and 1 deployment will be added (Jaeger all-in-one deployment).

Figure ‎5—10 manifest-jaeger content

Graphical user interface, text, application, email

Description automatically generatedGraphical user interface, application

Description automatically generatedTo explain what happened, we will compare the two manifests of catalogue micro-service deployment. Figure 5-11 presents the catalogue deployment file without the Zipkin exporter as environment variable name.

Figure ‎5—11 Catalogue micro-service deployment with Zipkin to export Jaeger traces

Figure ‎5—12 Catalogue micro-service as deployed previously

Once that is added, the application will know where to push these spans using Zipkin exporter to the correct URI (<http://zipkin.jaeger.svc.cluster.local:9411/>) using the first version of the spans API at port 9411.

At the same time, the Jaeger deployment manifest has the same port configured to receive those spans as the following figure shows.

Graphical user interface, text, application

Description automatically generated

Figure ‎5—13 Jaeger deployment file

Both figures show Jaeger user interface capturing traces generated by the user micro-service. The figure 5-14 shows the health check spans, however the figure 5-15 shows the login spans.

Graphical user interface, application, email, website

Description automatically generated

Figure ‎5—14 Jaeger UI capturing health check spans from user micro-service

Graphical user interface, text, application

Description automatically generated

Figure ‎5—15 Jaeger UI capturing login spans from user micro-service

The previous figures show spans of operation in happening in the same micro-service. An operation as a login, does not require to go out of the user micro-service to login the user. In fact, the login function reads the username and password form the front-end micro-service, issues the authentication token, and passes it along to other micro-services, but the login itself does not go out of the user context.

As the title of the section suggests, sock-shop application is an amazing application for a lot of demonstrations. However, the application’s instrumentation does not show the real power of traces, such us: distributed context propagation, and system dependencies analysis.

Furthermore, the metrics exposed by the Cart micro-service are only the default ones (CPU consumption, opened connections count, etc.). Even when we tried to tweak the micro-service so that it exposes our custom metrics, the whole application stopped working. At first, we tried to debug the errors, but the errors seemed to be originated by old version of Springboot framework.

In conclusion, to demonstrate micro-services, tracing technology, monitoring tools over a cloud-type infrastructure, Sock-shop is the go-to application. But when it comes to demonstrating the effect of observability, we decided to develop our own micro-services-based application named E-shop minimal that will be analyzed in the next chapter.

## E-shop minimal

### Overview

E-shop minimal is an e-commerce basic application. The application is modularized to 3 micro-services: Users, Carts, and Products, hence the name minimal. It was developed in the purpose of demonstrating the span distributed context propagation allowing us to track every request across the system, and default & custom metrics exportation providing us with real-time insights of different layers of the application. Each of the micro-services has its own REST API to communicate with other micro-services.

The application was decided, designed, and developed in two weeks. To demonstrate the observability principles, we opted to show it on back-end component that they will be a very good case-study. As a result, the application does not have a front-end, only API calls are available to interact with the system.

Even though the micro-services design pattern allows us to use different languages and frameworks in one application, we decided otherwise. In fact, the totality of micro-services was written in JavaScript with Express[[20]](#footnote-21) framework and run on NodeJS[[21]](#footnote-22).

Graphical user interface, application

Description automatically generatedFurthermore, the application can run either on a bare-OS or over Kubernetes. Kubernetes manifests are found in *K8s-Infra*. This will be discussed more in the last section of this chapter.

Kubernetes manifests

Grafana dashboard folder

Micro-services folders

Figure ‎5—16 E-shop minimal root folder content

### Design

Graphical user interface

Description automatically generated

Figure ‎5—17 E-shop minimal application micro-services

As we mentioned before, the application is micro-services based. Each of the micro-services is developed as a standalone application and uses REST API for communication.

#### Users micro-service

Users micro-service is the service that executes operations related to user account, such as, registration, login, edit profile information and place an order. Each of these operations has a route defined in the application API. In addition, once these operations are executed, spans and metrics will be generated providing us with real-time events happening in the users-service.

The following figure represents the possible operation for user micro-service as seen from Postman[[22]](#footnote-23) interface.

**Graphical user interface, application

Description automatically generatedUser backend page**, used as a health-check endpoint, to verify whether the application is running or not.

Figure ‎5—18 User Micro-service API from Postman UI

**User register**, it registers users, requires an email and a password. The response should include an ID will be used afterwards to create orders or get user details.

**User login,** this is the login endpoint, it requires an email and a password. The response should include a JWT token required as a bearer token for some of the carts micro-service operations.

**Create order**, this operation requires a payment method to be added to the user account info. To do so we need to use the *update user info* endpoint. It also requires a cart Id and user id.

Text

Description automatically generatedThis micro-service has two MongoDb[[23]](#footnote-24) databases (users and orders) on an Atlas[[24]](#footnote-25) cluster. The user database is as follows:

Figure ‎5—19 User database code snippet

The Card Schema is a nested database to hold payment card details such us: name of the card holder, card number, cvc number and expiration date.

The following figure represents the orders database.

Text

Description automatically generated

Figure ‎5—20 Order database code snippet

In this part, we are going to explore the metrics and the spans and how we instrumented these micro-services. First, as we analyzed some of the tracing and metrics collections tools in the first part of this document, it is only logic to use them in this demonstration.

OpenTelemtry is a collection of tools, APIs and SDKs used to instrument, generate, and collect telemetry data [15]. The OpenTelemetry is the standard for spans creation and formatting. For that reason, we are going to use it in the micro-services to generate the spans. Furthermore, we need to create a tracing module and export it so that it can be used throughout the micro-service. The module file is *tracing.js* and it can be found at the root folder of the micro-service.

Graphical user interface, text, application, Teams

Description automatically generatedThe following figure is a screenshot of the Postman interface registering new user.

Figure ‎5—21 Screenshot of Postman registering new user

Graphical user interface, text, application, email

Description automatically generatedTo illustrate what have been said, the figure 5-21 represents the spans generated by the application at the user registration moment and captured by Jaeger.

Figure ‎5—22 Span captured during registration operation

A screenshot of a computer

Description automatically generated with medium confidenceIt is only logical that the same operation will increment a custom counter metric (named users) that we defined to count the number of registered users. Such metric provides us with real-time insight of user’s interaction with the micro-service. The following figure represents the metric visualized by Grafana and exported to Prometheus.

Figure ‎5—23 Grafana visualizing users metric

#### Carts micro-service

The carts micro-service is the service responsible for executing the carts related operations, such as, cart creation and deletion, adding an item to cart, updating cart content. This micro-service usually communicates often with Products micro-service, so it gets the item details and User micro-service, so it gets the user ID and verifies authentication tokens. Same as in the Users micro-service, the carts also provide a REST API to interact with the application. The following figure represents the service’s endpoint. Some of the interesting endpoints will be explored afterwards.

Graphical user interface, application

Description automatically generated

Figure ‎5—24 Postman view of Carts micro-service's API

This micro-service has a MongoDB database on an Atlas cluster. The following figure represents the code snippet of the database.

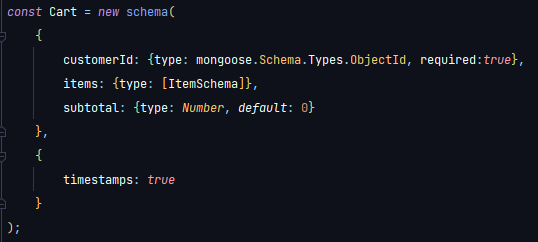


Figure ‎5—25 Cart schema code snippet

### Technology stack

### Running the application

# Conclusion

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1. The application will be analyzed in a later section of the report. [↑](#footnote-ref-2)
2. Weave-works: One of the first members of the Cloud Native Computing Foundation, founded in 2014, specialized in infrastructure management. [↑](#footnote-ref-3)
3. Cloud nature: Public, Private, or Hybrid [↑](#footnote-ref-4)
4. Cloud provider : AWS, GC, Azure, etc. [↑](#footnote-ref-5)
5. YAML: stands for Yet Another Markup Language, however it is not a markup language, but a data serialization language that is often used for writing configuration files. [↑](#footnote-ref-6)
6. CL: Client libraries [↑](#footnote-ref-7)
7. Scrapable endpoint: Prometheus endpoint usually are named /metrics [↑](#footnote-ref-8)
8. WAL: stands for write-ahead log. A mechanism used by Prometheus to secure memory against crashes. [↑](#footnote-ref-9)
9. Sharding: It divides the targets Prometheus scrapes into multiple groups, small enough for a single Prometheus instance to scrape [↑](#footnote-ref-10)
10. Data compaction: reduction of data elements. [↑](#footnote-ref-11)
11. Down sampling: cutting the data to smaller chunk blocks. [↑](#footnote-ref-12)
12. Cassandra is an open-source NoSQL distributed, scalable and highly available database developed by Apache [↑](#footnote-ref-13)
13. Elasticsearch is a scalable search and analytics engine. It is the heart of the Elastic-stack [↑](#footnote-ref-14)
14. BI: Business Intelligence [↑](#footnote-ref-15)
15. CI: Continuous Integration [↑](#footnote-ref-16)
16. Puppet & Ansible are automatization & configuration management tools [↑](#footnote-ref-17)
17. Famous programming languages & frameworks [↑](#footnote-ref-18)
18. SaaS stands for Software as a Service [↑](#footnote-ref-19)
19. APM stands for Application Platform Management [↑](#footnote-ref-20)
20. Express is a JavaScript is a back-end web application framework for Node.js. [↑](#footnote-ref-21)
21. NodeJS is an open-source, cross-platform, back-end JavaScript runtime environment that runs on the V8 engine and executes JavaScript code outside a web browser, which was designed to build scalable network applications. [↑](#footnote-ref-22)
22. Postman is an API platform for building and using APIs [↑](#footnote-ref-23)
23. MongoDB is an open-source cross-platform document-oriented database program. [↑](#footnote-ref-24)
24. Atlas is the database cluster for MongoDB [↑](#footnote-ref-25)