CloudCity: A Live Environment for the Management of Cloud Infrastructures

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Abstract: Cloud computing has emerged as the *de facto* approach for providing services over the Internet. Although having increased popularity, challenges arise in the management of such environments, especially when the cloud service providers are constantly evolving their services and technology stack in order to maintain position in a demanding market. This usually leads to a combination of different services, each one managed individually, not providing a big picture of the architecture. In essence, the end state will be too many resources under management in an overwhelming heterogeneous environment. An infrastructure that has considerable growth will not be able to avoid its increasing complexity. Thus, this papers introduces *liveness* as an attempt to increase the feedback-loop to the developer in the management of cloud architectures. This aims to ease the process of developing and integrating cloud-based systems, by giving the possibility to understand the system and manage it in an interactive and immersive experience, thus perceiving how the infrastructure *reacts to change*. This approach allows the real-time visualization of a cloud infrastructure composed of a set of Amazon Web Services resources, using visual city metaphors.

1 INTRODUCTION

Cloud Computing, in all its different forms, has emerged as a new paradigm for provisioning services over the Internet, in an on-demand self-service (Abbasov, 2014). Organizations can completely abstract from hardware infrastructure management and focus on the virtual architecture, eradicating concerns with resource maintenance and improving manageability (Armbrust et al., 2009).

One of the essential characteristics and advantages of the cloud is elasticity. The resources required to meet service expectations can be rapidly scaled outwards and inwards to compensate for seesaw and unpredictable business demand; creating an illusion of infinite resource power. This flexibility allows the organization to focus on the core business instead of constantly maintaining provisioned infrastructure. Consequently, most of the times, there is no exact sense of location over the provided services, except, in some cases, the ability to specify multiple higher regions which can be used to increase reliability and avoid network outages (Mell and Grance, 2011).

When services are made available in a pay-as-you-go manner to the general public, resources are monitored and metered, associating a cost depending on the type of service and usage. This deployment model is called a public cloud and associated with a Cloud Services Provider (Armbrust et al., 2009).

While these services bring increased interoperability and versatility, there is a substantial amount of complexity in building and managing consistent and reliable infrastructures, resulting in expert developers being required to implement cloud architectures (Buyya et al., 2011).

As the market becomes more demanding and evolves at lightning speed, new "as-a-service" models start to emerge (Erian, 2018; Mastelic et al., 2014). As we keep going, the result is eventually an explosion of different services, each one managed individually, which causes challenges to arise in the management of such environments. The largest challenge is to understand these complex cloud architectures and the value they bring to the business. It's not trivial to understand and manage such infrastructures (Linthicum, 2016).

To clarify this point, 451 Research headlined the fact that the cloud services provider AWS portfolio provides more than 320,000 Stock Keeping Units (SKUs), with around 53,000 of these added dur-

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ing the first two weeks of November 2017. Owen Rogers, Research Director at 451 Research reinforced (Rogers, 2017):

> Cloud buyers have access to more capabilities than ever before, but the result is greater complexity. [...] The cloud was supposed to be a simple utility like electricity, but new innovations and new pricing models, such as AWS Reserved Instances, mean the IT landscape is more complex than ever.

According to insights from RightScale's (RightScale, 2017)State of the Cloud Report, comparing the years 2016, 2017 and 2018, the number one (1) cloud challenges are the lack of resources/expertise and security in cloud management. Despite observing a decline in nearly all challenges compared with the previous year, it is interesting to note governance/control is the only challenge which has nearly stagnated in the three-year comparison.

In this work, we intend to explore how cloud management can benefit from model-driven engineering and live programming. Software visualization attempts to solve a similar problem as the one that live programming addresses - reducing programming complexity by making it easier to understand quickly what a program is doing or supposed to do (Tanimoto, 2013). By combining approaches from both areas we intend to provide a live visualization method that provides continuous feedback about a virtual cloud infrastructure.

This paper is structured as follows: the Section 2 delves into the city visual metaphor along with other core concepts of this work, Section 3 introduces different approaches for the management of cloud infrastructures, Section 4 presents an overview and architecture details of our approach, `CloudCity`, Section 5 presents the preliminary experiments carried on to validate the approach and, to conclude, Section 6 gives some final remarks and points to future work.

2 CONTEXT

2.1 Software Visualization

Software visualization refers to the visualization of information depicted and which composes software and its development process by methods for static, interactive and multi-dimensional visual representations (Diehl, 2007). Besides program source code, the target artifacts can also include requirements, architectural design, and bug reports. In this chapter we investigate high-level abstractions or proper support that could be transposed to the cloud environment, to enhance the management experience.

Kapec in (Kapec, 2010)Visualizing software artifacts using hypergraphs developed a hypergraph-based software visualization system. Relations can be transposed to source-code as function calls or class inheritance with visible links between edges and store information about developers and tasks. Since heterogeneous programming environments are a common practice (diverse language specifications) contributing to software complexity, the hypergraph combined with visual data mining hides the actual implementation but captures the call relation.

Lanza and Ducasse (Lanza and Ducasse, 2003; Lanza, 2004) present a software visualization technique enriched with metrics information. Polymetric views intend to help understand the structure and detect problems in the initial phases of a reverse engineering process. The actual visualization requires a layout, a set of metrics and a set of entities. A layout considers the selected entities, relationships and areas of interest into how they should be sorted and displayed (e.g., a tree layout is better suited for the display of an inheritance hierarchy than a circle layout). The metrics, extracted from the source code entities, heavily influence the resulting visualization, being good means to control the state of a software system during development (Lanza and Ducasse, 2003). To enhance the view, certain parts or entities of the system are selected for visualization.

Wettel et al. (Wettel et al., 2011) conceptualize a metaphor-based approach for visualization adopting the urban domain as the central metaphor. Starting on the influence of civil architecture on software engineering, a city and a software system have many similarities. Both are conceived during a planning phase, in which requirements are a central piece; built incrementally and require a ceaseless maintenance.

In this city metaphor, city elements (e.g., buildings and districts) are mapped to software system components (classes and packages respectively). Moreover, to complement the visualization, physical properties of the urban artifacts (e.g., color and dimensions) also reflect attributes of the software components.

The concept was implemented in CodeCity by Wettel et al. (Wettel et al., 2011) (Fig. 1) followed by an empirical evaluation in a series of experimental runs spanned over six months of time. The main results concluded that, for the program comprehension and design quality assessment, the city metaphor enabled the creation of efficient software visualizations. The city metaphor has also been explored recently by other researchers in CityVR - an implementation of

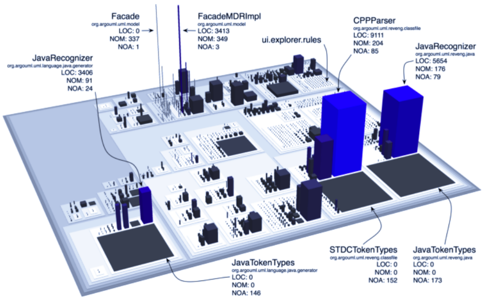


Figure 1: A real representation of the code city of ArgoUML (Wettel et al., 2011).

the city metaphor using virtual reality in an immersive 3D environment medium to boost developer engagement in software comprehension tasks (Merino et al., 2017); ExplorViz - a VR approach following the 3D city metaphor (Fittkau et al., 2015); VR City - a modification of the city metaphor in virtual reality environment, with a different layout technique that provides a higher level of detail and positioning oriented to the coupling between classes (Vincur et al., 2017); SwiftCity - metaphor applied to Swift projects (Nunes et al., 2017).

2.2 Live Programming

Programming is a strenuous task since most of the work happens in a programmer's mind while thinking about how code executes, how to write it and update it (McDirmid, 2013; Sean McDirmid, 2017). To find the cause of errors, one should resort to debugging to get feedback about how the code behaves (McDirmid, 2013). This step causes a break in the mental simulation and the editing flow.

Live programming challenges this problem by unifying the gap between code editing and debugging (Sean McDirmid, 2017), re- executing the program and providing a continuous feedback while editing (McDirmid, 2013). It is not a panacea for programming environments, but potentially very important for some. The ability to inspect and modify is taken for granted in most IDEs, adding liveness is an enhancement (Tanimoto, 2013).

Ideally, this concept is often made analogous to a water hose: moving a stream of water in an ever-evolving aim until the target is hit (Mcdirmid, 2016; Sean McDirmid, 2017). Small changes to the program should lead to small changes in the output. However, this idea is difficult to realize since the code is not directly related to program output, there is always a mental effort to produce relevant changes.

Challenges in this concept point out to how feedback can be considered harmful. Receiving continuous results with change can be potentially distracting in some cases and cause the programmer to write in a certain order to ”keep it live”. For live programming to succeed, it must enhance programming without restricting what the programmer can do, either beginner or expert (Mcdirmid, 2016).

Other criticism (as cited in (McDirmid, 2013)) highlights the fact that the steps in between execution are the most important part of programming. Therefore, by using live programming, a programmer would be hiding the critical flow of execution. This argument can remit to the concern of merely focus on updating the program output with successive code changes. However, the focus of live is not solving a ”right or wrong” programming model, where even without applying this concept the same problem remains. Nevertheless, from a debugging perspective, live programming can address this concern combining editing and debugging in time where updated debug results are readily visible while editing (McDirmid, 2013). With this approach, the focus returns back to the program flow and how changes affect certain parts of execution.

For the purpose of managing cloud infrastructures our aim is to receive continuous feedback on *how architectural* (instead of code) *changes affect the whole system*.

2.3 Cloud Management

Provisioning is defined as obtaining services from the cloud, such as spawning computers or virtual hosts and tailoring its software and configurations (Buyya et al., 2011). It should not be confused with deployment, which does not necessarily imply provisioning. Deployment is the process of getting a new application, or version, onto a prepared server (Sayers, 2017).

From the disconnection between the traditionally considered development and operations activity, DevOps surges as a software engineering culture that aims to unify software development (oriented to change) and software operation (oriented to stability) (Amazon Web Services, 2017b; Edwards, 2010). The benefits of this model include:

- **Rapid Delivery.** Quickly respond to customer needs and move a change into production (Amazon Web Services, 2017b; Edwards, 2010).
- **Reliability.** Ensure the quality of application updates and infrastructure changes through testing in practices such as continuous integration and continuous delivery (Amazon Web Services, 2017b; Edwards, 2010).

- **Scale.** Automation and consistency help changing systems efficiently and with reduced risk (Amazon Web Services, 2017b).
- **Collaboration.** Developers and operation engineers share responsibilities and combine workflows (Amazon Web Services, 2017b).

For startups, the responsibilities are broadly guided towards supporting development, followed by build, continuous integration, and fast delivery (building an effective pipeline of releases). Expanding companies focus more on configuration management, testing, and production (Kerzazi and Adams, 2016).

2.3.1 Configuration Management

In a broader context, configuration management (CM) is an important part of provisioning, which is designed to methodically handle changes to a system in order to maintain its integrity over time. Software configuration management is often referenced in a software engineering context, Pressman and Maxim (Pressman and Maxim, 2015) define it as:

> *A set of activities designed to manage change by identifying the work products that are likely to change, establishing relationships among them, defining mechanisms for managing different versions of these work products, controlling the changes imposed, and auditing and reporting on the changes made.*

Automation is the heart of server configuration management. It's common to refer to configuration management tools as Automation Tools or IT Automation Tools (Heidi, 2016).

2.3.2 Infrastructure Orchestration

On the other hand, orchestration tools define a different purpose, they are designed to enforce a workflow order to a set of automated tasks, such as the provisioning of those resources. Both categories are not mutually exclusive since some orchestration tools can extend to configuration and vice-versa (Brikman, 2016).

Automation and orchestration are becoming critical concepts to the effective management of large-scale cloud architectures allowing developers to cope with unstable business need (Tosatto et al., 2015). In this section, we intend to explore the most valuable solutions to manage virtual machines, physical machines, and containers.

3 RELATED WORK

Derived from the lack of resources/expertise and ability to manage different cloud services, there has been a growing interest in methods to support infrastructure provisioning, orchestration and configuration management.

CloudFormation is an aws-based orchestration tool to describe and provision infrastructure as code (Amazon Web Services, 2017a). It features the following aspects:

- **Modeling.** The ability to model, in a single file, the entire infrastructure, standardize all components.
- **Automation.** Infrastructure can be destroyed and re-built in "one-click", without custom scripts, and with roll-backs if errors are detected.
- **Version Control.** Source files can be authored and reviewed before deploying into production.

Source files can be formatted in two different languages: JSON or YAML and previously converted into a graphical display which can help to analyze relations between templates (Amazon Web Services, 2017a).

Terraform is another orchestration tool for building, changing and versioning infrastructure for existing service providers as well as custom in-house solutions. Similarly to the previous competitor, resources are defined as code, reflecting a blueprint of the architecture which allows it to be versioned and shared (HashiCorp, 2017). The key features are:

- **Execution Plans.** Before infrastructure deployment, an execution plan synthesizes what terraform will apply.
- **Resource Graph.** The creation of non-dependent resources can be parallelized, building infrastructure as efficient as possible.
- **Change Automation.** Complex changes can be applied to multiple services in incremental steps with minimal human interaction.

Terraform differs from the previous competitor for being cloud agnostic and enabling the combination of multiple cloud service providers with a unified syntax (HashiCorp, 2017). Configuration files follow a declarative style where resources to be provisioned are declared according to their desired end state.

Sandobalin et al., in his work presented a solution to help the management of Infrastructure-as-Code (IaC), through a domain specific language (Sandobalin et al., 2017). ARGON is a modeling tool for specifying the final state of the infrastructure and provisioning of cloud resources. The tool aims to focus mainly on automation: automatic generation of

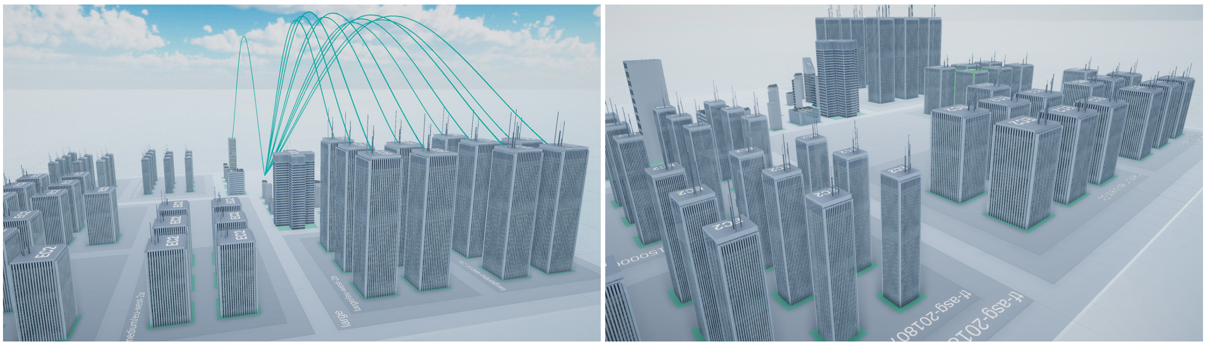


Figure 2: CloudCity's main environment containing an small size example architecture, displaying a subset of the relations.

infrastructure provisioning scripts. One of the advantages of this approach is the abstraction from the complexity of working with different cloud providers, resulting in a platform-independent metamodel and preventing vendor lock-in.

Mastelic et al., in his work takes advantage of model-driven development for building and managing arbitrary cloud services in a cloud-agnostic manner (Mastelic et al., 2014). Through the CoPS metamodel, cloud services are described using three sequential models: (a) Service, that defines services requirements; (b) Product, that defines the arrangement of the service; and (c) Component, that defines the configuration of each component of the service.

4 CLOUDCITY

The 3D visualization method we propose for managing cloud infrastructures is a city metaphor. By definition, the cloud is not a physical entity, and cannot, by nature, be purely synthesized into a straightforward visually understandable mapping. Instead, it can be transposed into other dimensions, such as code or models, in order to ease its management. Representing the cloud as a city intends to enable users to gradually become familiar with the represented architecture, due to the relationship with many similarities between the two domains.

4.1 Overview

CloudCity is a live cloud management environment which embodies the city metaphor. We opted for exploring this metaphor since it is has been picked and validated by the software engineering scientific community as one with good empirical results in what regards software visualization (see subsection 2.1). The main concept is to allow the design and analysis of cloud compositions through an intuitive mapping between city metaphors and cloud resources. Each building contains a set of properties reflected from the cloud, which can be inspected or modified through simple interaction. Relations are depicted as curved lines between two elements which can be filtered and detailed on-demand. The main difference from other model-driven approaches is that this environment doesn't reflect a static infrastructure mapping, but instead a live infrastructure which shows the real-time state of each component. A metaphor that we introduce as, *the live city*.

4.2 Architecture

The definition of CloudCity follows the model-driven engineering principles. Fig. 3 describes, in a high-level, a representation of the system architecture. The tool is composed of three core packages:

- **Cloud Service Providers API.** Provides a connection to a specific cloud service provider. For our proof of concept we picked Amazon Web Services among the existent options.
- **Importer.** Periodically pools the provider and detects changes in the infrastructure state, forwarding actions to update specific resources. In the future this could be improved by using a publish-subscribe solution.
- **Resources.** To define resources and groups, we implemented the composite pattern. A group of resources can either contain a resource or another resource group. If it contains another group, the same applies recursively downwards the tree structure.

Notwithstanding the fact that the proof of concept presented in this work currently only recognizes a unique service provider; to mitigate the complexity of working with different cloud service providers and to open the possibility of implementing their support in future work, we prepared our architecture to support different providers. For that reason, it was divided into two different decoupled layers:

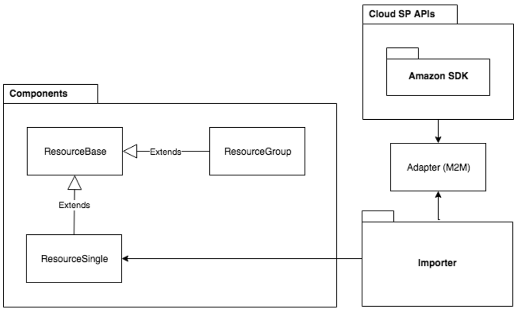


Figure 3: CloudCity's architecture described by a package diagram.

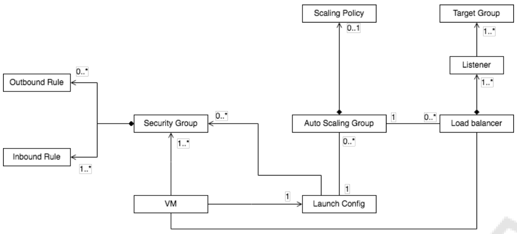


Figure 4: Infrastructure metamodel (inspired by the abstract syntax presented in (Sandobalin et al., 2017)).

1. **Platform Independent Model.** Illustrated in Fig. 4, this model is independent of any specific provider.
2. **Platform Specific Model.** This model is coupled with a specific provider and can be obtained with a model to model transformation.

The proof of concept was implemented using a multipurpose three-dimensional engine, Unity. This technology decision was derived from being an engine with extensive documentation and community support, thus accelerating the implementation. Opening room for new features to be studied and provide support for Virtual/Augmented Reality (an interesting perspective also studied in other approaches using the City Metaphor, as in (Merino et al., 2017; Vincur et al., 2017)).

4.3 Resource Mapping

One of the advantages of creating a visual map for the cloud is that there is a finite set of resources, with predictable properties. Therefore, it allows us to create an *alphabet* with models for each of the instances we want to represent, rather than defining new metrics.

However, since cloud service providers must be constantly adapting to maintain their position in a demanding market (Serrano et al., 2015), the result is an increase in their service portfolio. As a proof of concept, we prepared the environment to accept eight popular services:

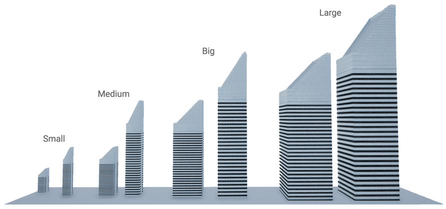


Figure 5: CloudCity's reference building dimensions sorted in ascending order.

1. **Security Group:** Security Groups act as a virtual firewall to control instances inbound and outbound. Each group contains a set of rules which controls the port range where traffic is allowed. The metric chosen for the building height varies according to the port range the security group covers. Since the security group is a very common instance in a cloud architecture (an instance can have from one up to five different groups), the building dimensions correspond to the small building type.
2. **Virtual Machine:** VMs provide scalable compute capacity in the cloud. Each instance contains a size, from a wide selection of instance types that define the hardware specifications. The metric for the building dimensions varies according to this attribute (visually represented on Fig. 6).
3. **Load Balancer:** Load balancers are responsible for distributing traffic across multiple targets, achieving multi-tenancy and resource pooling. One can have multiple listeners, to receive incoming connections and distribute them, according to a rule (a specific host or path), to multiple groups of targets. The metric chosen for the building height varies depending on the number of total rules the load balancer takes into consideration when forwarding connections. Moreover, since load balancing is a central component between the point of entry and the targets, we consider it as part of the big buildings category.
4. **Listener:** The listener, related to load balancing, is a process that checks for incoming requests on a specific port and forwards them to a target group. The metric chosen for the building height varies in consonance with the number of rules it takes consideration when forwarding a connection to a specific group of targets. As for the building type, since this component is a subset of the load balancer, we chose to consider it as part of the medium buildings category.
5. **Target Group:** A target group routes incoming listener requests to one or more registered targets. The metric chosen for the building height varies depending on the number of instances registered

in it. As for the building type, since this component can also be considered a subset of the load balancer, it falls in the medium buildings category.

6. **Launch Configuration:** A launch configuration is a parental reference of machine specifications for a VM to be mirrored from. It is useful for when the auto scaling group is expanding and needs a source from where instances will be replicated. The building type chosen for this component depends on the instance type attribute (as in Table 1).
7. **Scaling Policy:** Policies define how the scaling group increases or decreases the size, and according to which metric. The metric chosen for the building height varies depending on the scaling adjustment. As for the building type, since this component can be considered a subset of the auto scaling group, it falls in the medium buildings category.
8. **Auto Scaling Group:** In contrast with the previous resources, an auto-scaling group is not represented by a building. Instead, since it is a group with multiple VMs and scales dynamically, we represent it as a plane with sufficient area to support the different availability zones and specific VM (visually represented on Fig. 6).

Table 1: The building categories that correspond to specific instance types.

Instance Type	Building Type
Nano	small
Micro/Small	medium
large - 8xlarge	big
8xlarge - 32xlarge	large

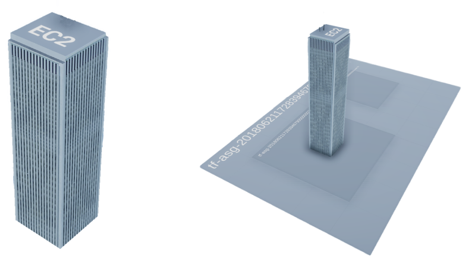


Figure 6: Visual notation for a virtual machine by itself (left), and as part of an auto-scaling group (right).

4.4 Layout

To provide a proper environment for live managing cloud infrastructures, we need a mechanism to lay out and update components as the architecture is expanded and modified. In sum, the requirements are:

- Support for laying out all the imported components of the infrastructure, with different dimensions, in an ordered manner;
- Do not waste much of the cities' real-estate (Wettel et al., 2011);
- Support for grouping components according to a class.

Our first approach was to think of the components and relations as a graph. The force-directed graph layout is one of the most popular graph layout techniques, it consists in applying spring-like forces to the edges, attempting to achieve an aesthetically-pleasing layout. However, the drawbacks of this technique are: (a) intensive computation (naive approach), worst case running time is proportional to the square of the number of nodes, and (b) diverges from the standard city metaphor - losing resemblance to a known environment.

Another approach is the Tree-Map technique which divides the existing space into rectangular blocks according to an attribute of the respective object. However, this method does not take into account the dimensions and proportions of the buildings (Wettel et al., 2011).

After all, the technique we chose for layering the elements is CodeCity's rectangle packing algorithm proposed by Wettel et al. (Wettel et al., 2011). It starts with an empty rectangular space, large enough to host a set of exposed components. Each step of the algorithm consists in layering the elements at the best free space from a list of potential candidates. In case the element does not cover the full space, we recursively split the surplus in two different cuts available to host new components, as depicted in Fig. 7.

4.5 Updates & Interaction

This section intends to address the most important question in the implementation of this concept: *how* to deal with infrastructural updates. The core idea to our suggested approach would be a publish-subscribe pattern that receives messages every time a change happens in the environment. However, since the specific cloud provider we are working with doesn't provide the means to integrate this style, we are forced to periodically poll it and manually detect the differences.

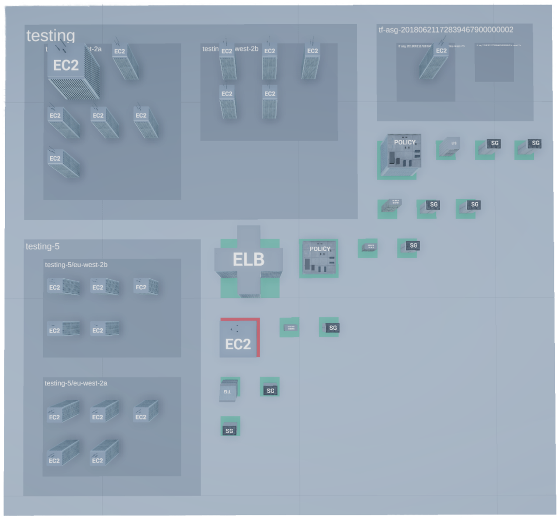


Figure 7: An example of the rectangle packing layout for a considerable size infrastructure, composed of: three auto scaling groups containing multiple size instances and two scaling policies; a stopped test instance; one load balancer and several security groups.

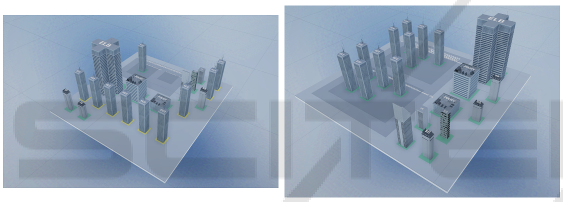


Figure 8: An illustration of an infrastructural update when an auto-scaling group increases it's desired capacity. The number of instances changed from 1 to 10. For that reason, nine new servers were spawned (Figure on the left) and then attached inside the scaling group (Figure on the right).

Having considered a method to detect the change, the next step is to refresh the infrastructure. The most naive approach would be to destroy the whole infrastructure and rebuilt it. But, for efficiency reasons, we decided not to destroy any element except if it has been terminated. Instead, every time the layout needs to re-position elements, only the affected ones will change position, as depicted in Fig. 8.

All things considered, to avoid abrupt changes in the layout, we prepared all components to change their position *slowly* (speed of 1 unit per second) to increase the response feedback (sliding in between positions).

Relations are mapped into arcs beginning at one instance or group and ending in another. Both resources and their relations may contain a state depending on their nature which can also be inspected by clicking them, and filtered when a specific component is selected.

5 EXPERIMENTS AND RESULTS

In order to illustrate our approach, we conceived two different phases, one being the construction of a cloud infrastructure and another being the analysis of an existing, which is not the implemented in the first phase.

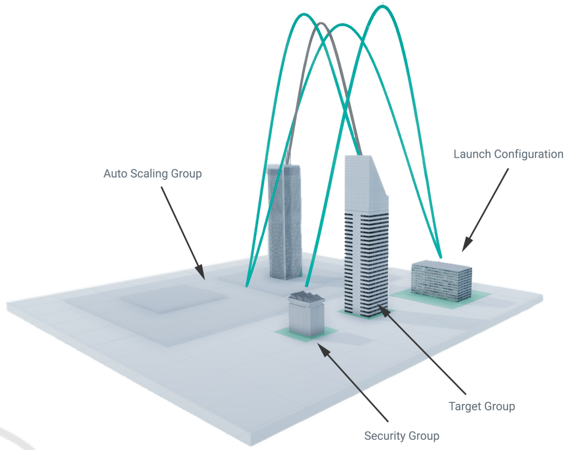
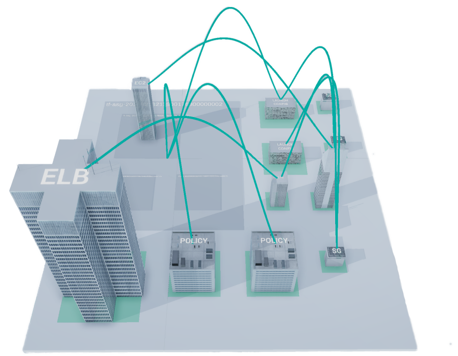


Figure 9: An illustration of the resulting CloudCity model for the first phase experiment.

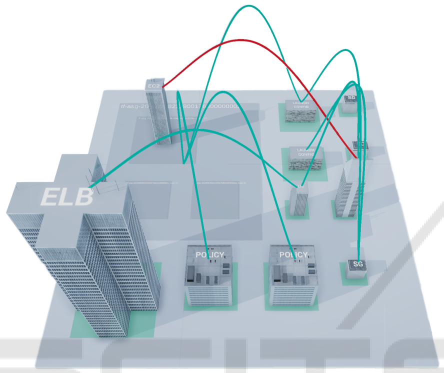
In the construction phase, we designed a typical web-hosting reference architecture (excluding storage) composed of four resources: (a) an auto-scaling group with a minimum size of two instances; (b) a launch configuration for each new instance to be spawned inside the scaling group; (c) a security group; and (d) a target group to route incoming requests to the targets in the scaling group. The resulting model is depicted in Fig. 9.

As for the second phase, analysis, it consisted in inspecting an existing infrastructure. In order to create some independence between the two phases, we prepared a different infrastructure using *Terraform* containing: (a) an auto-scaling group in two zones connected to the respective launch configuration; (b) two scaling policies; (c) a load balancer with the respective listener, target group and security group; and (d) a web server.

The rationale for this assignment is to simulate the occurrence of an unhealthy target, a common event in a cloud environment. In most cases, the cause is derived from a failed/overloaded instance or security group misconfiguration. For that purpose, we misconfigured a security group (firewall) on purpose in one of the registered targets and disallow any traffic coming from the target group. In consequence, the target group will not be able to send health check requests, and consider the instance unhealthy. The goal is to locate that specific instance and analyze its cause, targeting liveness level three: informative, significant



(a) The resulting model of the second phase of the experiment according to Terraform's configuration plan.



(b) The resulting model immediately after the misconfiguration of a security group, for the purpose of identifying the resulting infrastructural changes, in specific, a unhealthy instance.

Figure 10: Resulting visualizations of the experiments. The connections between components (buildings) are representing connections and the floor gives information about the group/context where the different components are placed. If everything is operating normally both the connections and floor colors are in green, otherwise the connections and/or floor colors of each component turn red.

and responsive. Both the occurrences can be confirmed in Fig. 10a and Fig. 10b.

6 CONCLUSIONS AND FUTURE WORK

In this paper, we started by analyzing the challenges and evolution in the management of cloud environments, specifically, it is important to notice: (a) the cloud service providers are constantly evolving their services in order to maintain position in a demanding market (b) this causes unavoidable increasing complexity when too many resources are under management in an overwhelming disheveled environment.

From the perspective of cloud management, the main result is the contribution with an integrated development environment; to analyze, architect and configure cloud compositions with a higher level of abstraction. Enabling architects to focus their interests in specific areas, and track the changes as the infrastructure evolves and the complexity increases.

Our approach combines the strengths of existing approaches, techniques and tools by introducing liveness to cloud management and providing a complete feedback loop which can help developers understand how the infrastructure reacts to change, working towards a Live Software Development (Aguiar et al., 2019) approach for cloud management.

We believe the approach represents a considerable improvement over current practices. When referring to managing cloud infrastructures, the focus is specifically cloud architecture configuration tasks.

Many issues were addressed by this work but it has also uncovered other interesting areas and subjects for further research based on this work, them being: (a) provide a modifiable layout technique - a user's ability to manually modify the position of a specific component; (b) explore other levels of liveness and (c) investigate different metaphors.

Furthermore, all the experiments carried on were made to evaluate the *sanity* and viability of the approach. We consider that in the future several controlled experiments must be carried on to assert the usefulness of the work here presented.

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