

# Games@Cloud

Cloud Computing and Virtualization  
Project - 2024-25  
MEIC / METI / MECD - IST - ULisboa

## 1 Introduction

The goal of this project is to design and implement a service hosted in an elastic public cloud to give support to the execution of a set of parametrized workloads inspired in simple games. The service is meant to execute a number of computationally-intensive tasks based on games, namely: capturetheflag; fifteenpuzzle; gameoflife. You are given an already built simplified Java application (solely aimed at generating a realistic CPU load) that handles the following types of requests:

- Capture The Flag: simulates a game where agents of each team (blue and red) compete to capture their flags given a board size, agent count of each team, and how flags are spawn, and returns the final board state with paths taken;
- 15-Puzzle Solver: solves a sliding tile puzzle of given size by initially shuffling it and then rearranging the pieces into order through valid moves, and returns the solved board and the number of moves taken;
- Game of Life: simulates cellular life evolution according to Conway's Game of Life rules given a map with a cellular pattern and the number of iterations. Returns the final state of the map.

With this application, your task is to deploy it in the cloud and scale it by increasing or decreasing the number of workers according to the number and complexity of user requests. You will be using two types of cloud deployments: EC2 instances and Lambda functions. Note that while EC2 instances are cheaper per processed request, they suffer from a longer startup time. On the other hand, Lambdas are more expensive per processed request but fast to start. Therefore, you need to balance invocations between the two types of deployments to minimize request latency and cost. Measuring the complexity of requests will be done by instrumenting the application code with Javassist. Complexity is an estimate of the amount of work involved in processing the request. As you will notice, simply using processing time instead of estimating the complexity won't help since processing time quickly becomes unpredictable when multiple tasks execute at the same time and compete for possibly overcommitted resources. The project specification is accompanied by a Frequently Asked Questions document available at: <https://tinyurl.com/CNV-24-25-FAQ>.

## 2 Architecture

The Games@Cloud system should run within the Amazon Web Services ecosystem. The system (see Figure 1) will be organized in four main components:

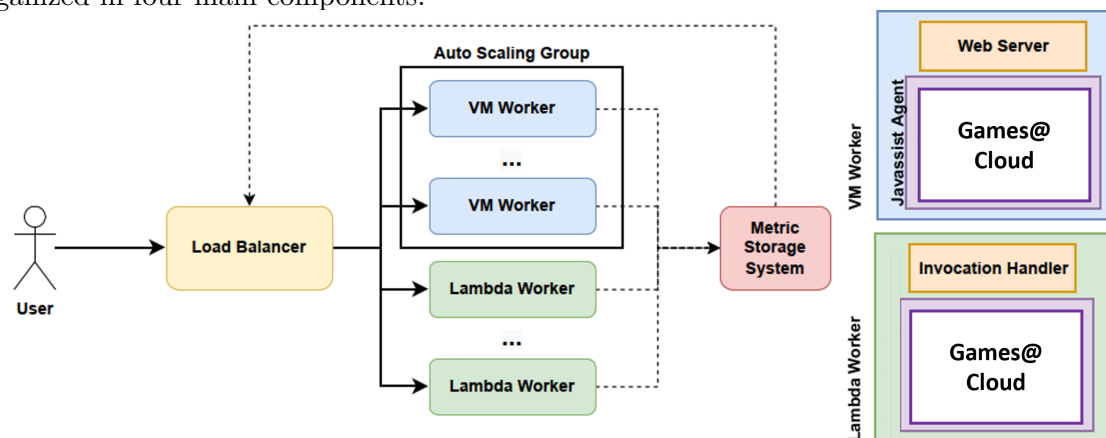


Figure 1: Architecture of Games@Cloud

- **Workers** receive web requests to perform a Games@Cloud operation. There will be a varying number of identical VMs and Lambdas running Games@Cloud operations;
- **Load Balancer (LB)** is the entry point of the system. It receives all web requests, and for each one, it selects an active VM to serve the request and forwards it to that server. In alternative, it can also trigger a Lambda function invocation;
- **Auto-Scaler (AS)** is in charge of collecting system performance metrics and, based on them, adjusting the number of active VM instances;
- **Metrics Storage System (MSS)** uses Amazon DynamoDB to store request performance metrics. These will help the LB choose the most appropriate worker.

## 2.1 Workers

Workers are responsible for executing operations. If workers fail, the LB should handle this and hide failures from users. In Games@Cloud, there are two types of workers: VM workers (EC2 instances), and FaaS workers (Lambda invocations), depicted in Figure 1. VM workers must execute Games@Cloud code instrumented with Javassist, while in FaaS workers this is optional. It is your task to use the JavassistAgent tool to instrument request handling to extract execution metrics regarding request complexity. The main difference between both types of workers is how the invocation is performed. Workers should not invoke any platform-specific interfaces to maximize portability.

**VM workers** implement a web server that receives requests directly from the LB. These requests include the input and parameters which are then passed to the application code. The result is returned to the LB and then returned to the user.

**FaaS workers** implement an invocation handler that receives Lambda invocations triggered by the LB. Similarly to VM worker requests, Lambda invocations include an input and parameters and return an output after applying the requested operation.

## 2.2 Load Balancer (LB)

The LB is the only entry point into the system. It receives requests and either selects one of the active VM workers to handle each of the requests or triggers a Lambda invocation, based on request complexity estimation. Note that in the final delivery, the LB should itself be a VM instance running a web server that uses metrics obtained in earlier requests (stored in the MSS) to decide how and where to execute (i.e. schedule) requests. You can assume that the LB instance never fails, thus no LB replication is needed here.

The LB should estimate the approximate complexity of requests based on the requests' parameters combined with data previously stored in the MSS. The LB may record and monitor which VM workers are busy and how much, how many requests there are currently executing in each VM, and how much work is left in each VM taking into account a request complexity estimate.

## 2.3 Auto Scaler (AS)

For this project, you will design an auto-scaling component that decides how many web server nodes should be active at any given moment. You should design and implement an auto-scaling strategy that provides the best balance between performance and cost. The AS should detect that the VM workers are overloaded and start new instances and, on the other hand, reduce the number of nodes when the load decreases. For simplicity, you can deploy both the AS and the LB code in the same VM (and in the same web server application).

## 2.4 Metrics Storage System (MSS)

Games@Cloud should also include a Metrics Storage System that stores metrics collected from the worker nodes regarding the cost/complexity of requests. These metrics result from running instrumented code which

collects relevant dynamic performance metrics regarding the application code executed (e.g. number of bytecode instructions or basic blocks executed, data accesses, number of function calls executed, and/or others deemed relevant). These metrics allow estimating the task complexity realistically, irrespective of variable wall-clock time delays that can be caused by frequent resource overcommit.

The final choice of the metrics extracted, instrumentation code, and structure used to store the metrics data is thus subject to analysis and decision by the students. As extracting each metric adds overhead due to the execution of the added instrumented code, students should consider the usefulness/overhead trade-offs of each and all utilized metrics. The selected storage system can be updated directly or you may resort to some intermediate transfer mechanism. For realism, you must take into account that continuously querying and exhaustively iterating this storage system is expensive and may also become a performance bottleneck for the LB.

### 3 Design and Implementation Guidelines

- Automate all cloud deployments and delete all cloud resources after each work session;
- Design and experiment with your instrumentation code locally on your or lab PCs to save resources;
- For simplicity, use `t2.micro` VM instance types and Lambdas with 512 MB of RAM.
- There are multiple possible design options for each of the components required for the project.
  - As important as the picked design is the reason for picking it, understand and explain it!

### 4 Checkpoint

Students may submit an **initial implementation** of their system by **May 30th**, 23h59 (submission instructions to be provided in the Labs Section in Fenix). This version should support running Games@Cloud on multi-threaded VM workers, with at least an AWS-configured LB and AS operating (no need for lambdas at this stage). Instrumentation gathering metrics should be working. Ideally, it should also include an initial version of your LB and AS code or pseudocode. Note that the algorithms for load balancing, auto scaling may not be fully implemented at this stage. However, it is expected that some logic is already thought out even if simplified.

The checkpoint submission bundle must include an **intermediate report** (1-page, double column) clearly describing: a) what is already developed and running in the current implementation (architecture, data structures and algorithms); b) the specification of what remains to be implemented or completed (namely pseudo-code for your final LB and AS algorithms). Students must also provide the link to a **short video** demonstrating the functionality of the submitted code against a series of tests to be provided. The report should be submitted until 23:59 on **May 31st**.

### 5 Final Submission

The final submission is to be delivered by **June 11th**, 23h59 (submission instructions to be provided in the Labs Section in Fenix). It should include a **complete implementation of the system**. In addition to the checkpoint, the project should include: i) an instrumentation tool that balances the instrumentation overhead with the precision of the extracted information; ii) an auto scaling algorithm that handles cost and performance efficiently; iii) a load balancing algorithm that minimizes cost and request latency using request complexity estimates based on previous requests.

Student groups should write a **final report** (up to 5 double column pages after the cover) describing the implemented solution, clearly explaining and justifying the algorithms, as well as any results, measurements, charts and analysis that support the design decisions and configurations. Groups are encouraged to provide information about the experiments conducted while experimenting with different design tradeoffs (e.g., charts, datasets). Students must also provide the link to a **video** demonstrating the functionality of the project against a series of tests to be provided. The report should be submitted until 23:59 on **June 12th**.