Analyzing Performance and Efficiency of HPC Applications in the Cloud

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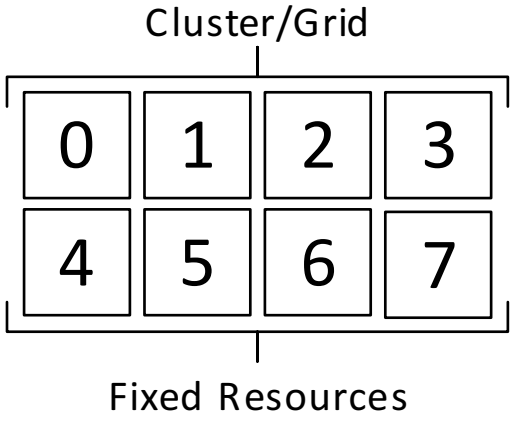
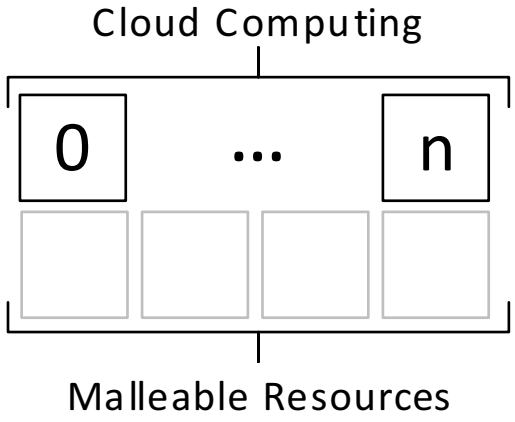
Introduction

- Traditionally, high-performance computing (HPC) applications are executed on clusters or even in grid architectures;
- These environments have a fixed number of resources;
- Recently, cloud computing appears as possibility to execute HPC applications;
- One of the main cloud characteristics is the possibility to increase or decrease the number of resources on-the-fly;





Introduction

- Traditionally, the **speedup** and **efficiency** metrics are used to measure **performance** and **efficiency** of parallel applications in scenarios where the **number of processes is the same** in the entire application execution time;
- In **elastic** environments, the **number of processes can change** at any moment and the speedup metric may not be suitable;
- Related work presents a **gap** concerning defining **decision functions** for elasticity viability in the combination of **performance** and **efficiency**;
- We propose a **redefinition** of the so-called speedup and parallel efficiency metrics for elastic HPC environments: **ES (Elastic Speedup)** and **EE (Elastic Efficiency)**.

Performance and Efficiency Models

Speedup: $S(p) = \frac{t(1)}{t(p)}$

- $t(1)$: time to execute the application with $\mathbf{1}$ process (sequential time);
- $t(p)$: time to execute the application with $\boldsymbol{p}$ processes (distributed time).

Efficiency: $E(p) = \frac{S(p)}{p}$

- $S(p)$: speedup of the execution with $\boldsymbol{p}$ processes;
- p : number of processes used in the execution.

Elastic Speedup (ES)

$$ES(n, l, u) = \frac{tne(l)}{te(n, l, u)}$$

$$where\ l \leq n \leq u$$

- n: **initial** number of processes when the application is started;
- l : the **lower** amount of processes that the environment can achieve while executing the application (defined by cloud SLA);
- u: the **upper** amount of processes that the environment can achieve while executing the application (defined by cloud SLA);
- $tne(l)$: time to execute the application with $\boldsymbol{l}$ processes without elasticity. In this execution the amount of resources is not changed in the execution time;
- $te(n, l, u)$: time to execute the application in the **cloud with elastic environment** where an SLA define the lower(l) and upper(u) amounts of resources.

Elastic Efficiency (EE)

$$EE(n,l,u) = \frac{ES(n,l,u) \times n}{Resource(n,l,u)} \qquad Resource(n,l,u) = \sum_{i=l}^{u} (i \times \frac{pte(i)}{te(n,l,u)})$$

- Function $EE(n,l,u)$ computes elastic efficiency;
- Its parameters, except $pte(i)$, are the same as the preceding function ES:
  - n: **initial** number of processes when the application is started;
  - l : the **lower** amount of processes that the environment can achieve while executing the application (defined by cloud SLA);
  - u: the **upper** amount of processes that the environment can achieve while executing the application (defined by cloud SLA);
  - $te(n,l,u)$: time to execute the application in the **cloud with elastic environment** where an SLA define the lower(l) and upper(u) amounts of resources.

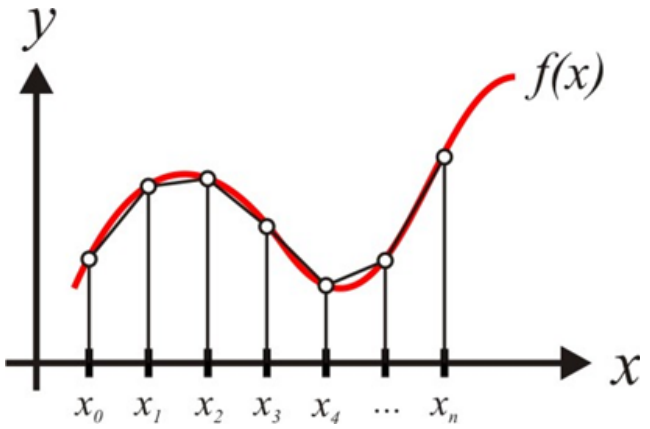
Elastic Efficiency (EE)

$$EE(n,l,u) = \frac{ES(n,l,u) \times n}{Resource(n,l,u)} \qquad Resource(n,l,u) = \sum_{i=l}^{u} (i \times \frac{pte(i)}{te(n,l,u)})$$

- Unlike equation $E(p)$, the resources here are malleable;
- To define a value that represents the **amount of resources used** in the execution, we defined the equation $Resources(n,l,u)$, where $pte(i)$ is the application's **partial** time when running over i resources;
- $Resources(n,l,u)$ captures the **amount of time** that the application was executed using $\boldsymbol{i}$ **resources**, and divide this time by the total time of execution. This value is results in a **weight** that is multiplied by i. The final result is the sum of the each possible i (from l to u) multiplied by its weight;
- EE presents parameter $\boldsymbol{n}$ in the **numerator**, which is multiplying the elastic speedup, because $ES(n,n,n)$ (**without elasticity**) is always equal to **1** and $Resources(n,n,n)$ equal to $\boldsymbol{n}$, so n in the numerator **returns** an elastic efficiency of **100%**.

Evaluation Methodology

- The application used in the tests computes the numerical integration of a function *f(x)* in a closed interval *[a; b]*;

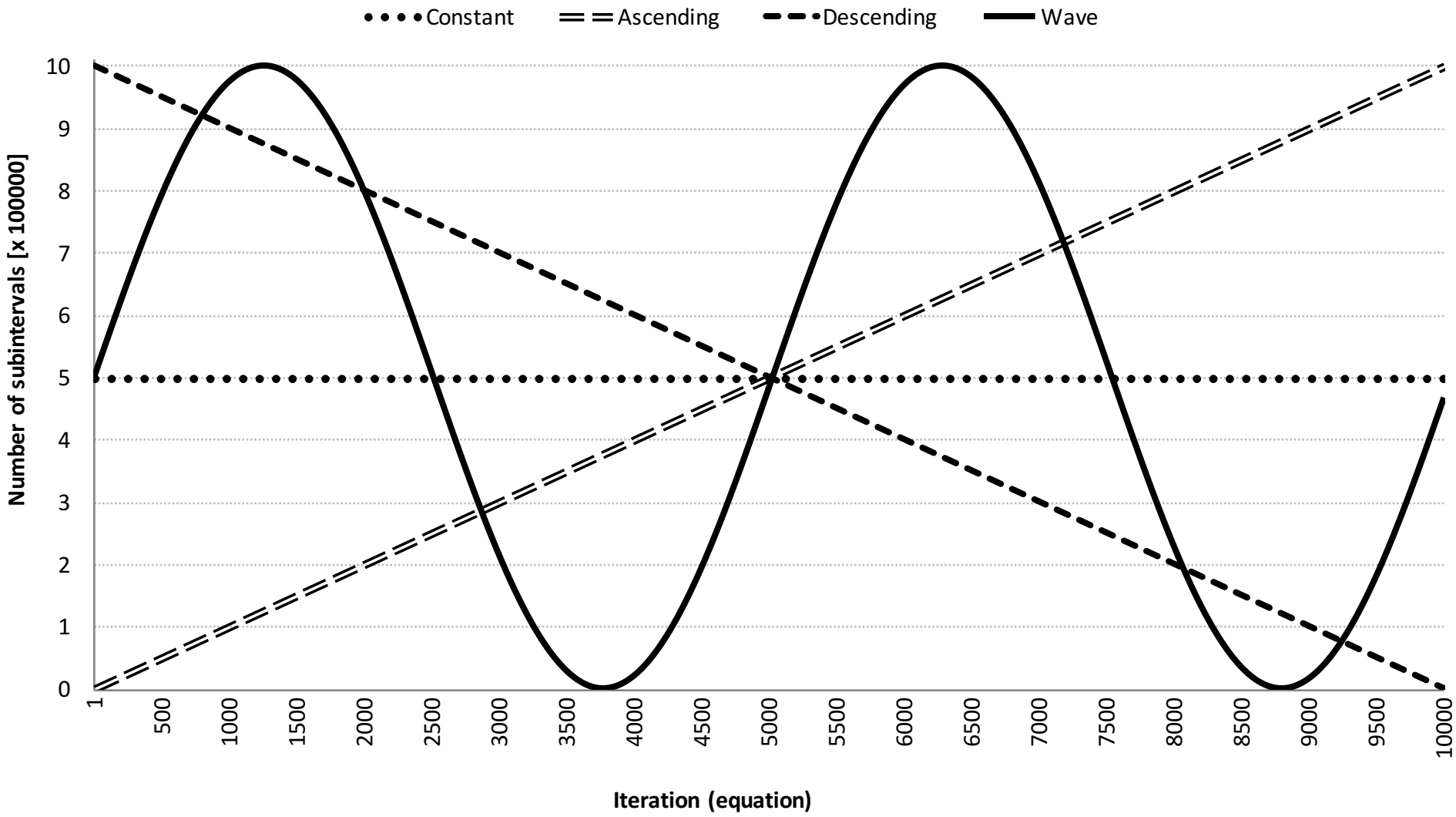


- We used the Composite Trapezoidal rule from a Newton-Cotes postulation to implement a loop-based Java application using Sockets.

- The application receive a set of equations and in each iteration distributes one equation with a different amount of subintervals between x_0 and x_n between the processes;

- To evaluate different application behavior, four patterns were modeled: Ascending, Constant, Descending and Wave.

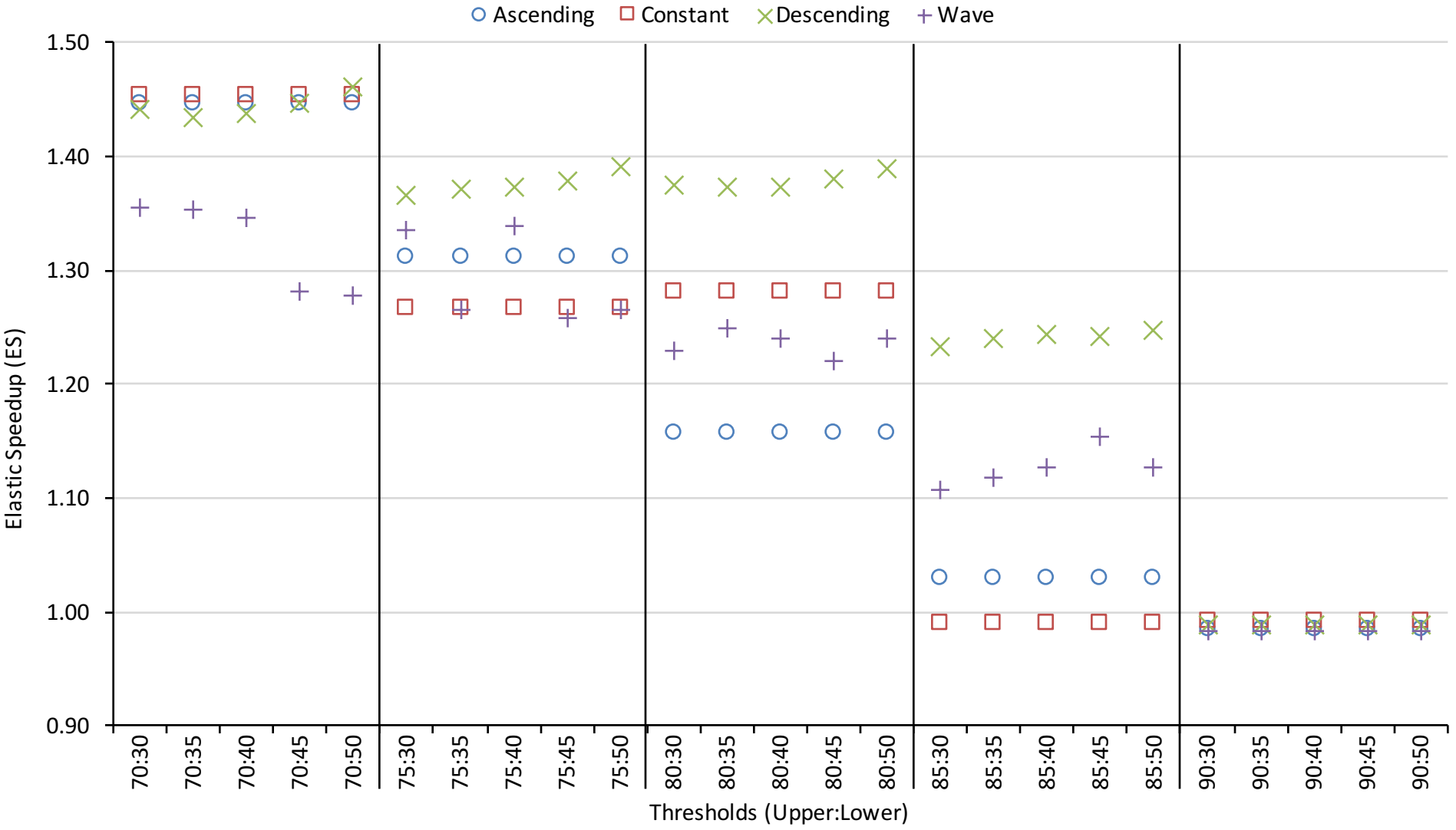
Evaluation Methodology



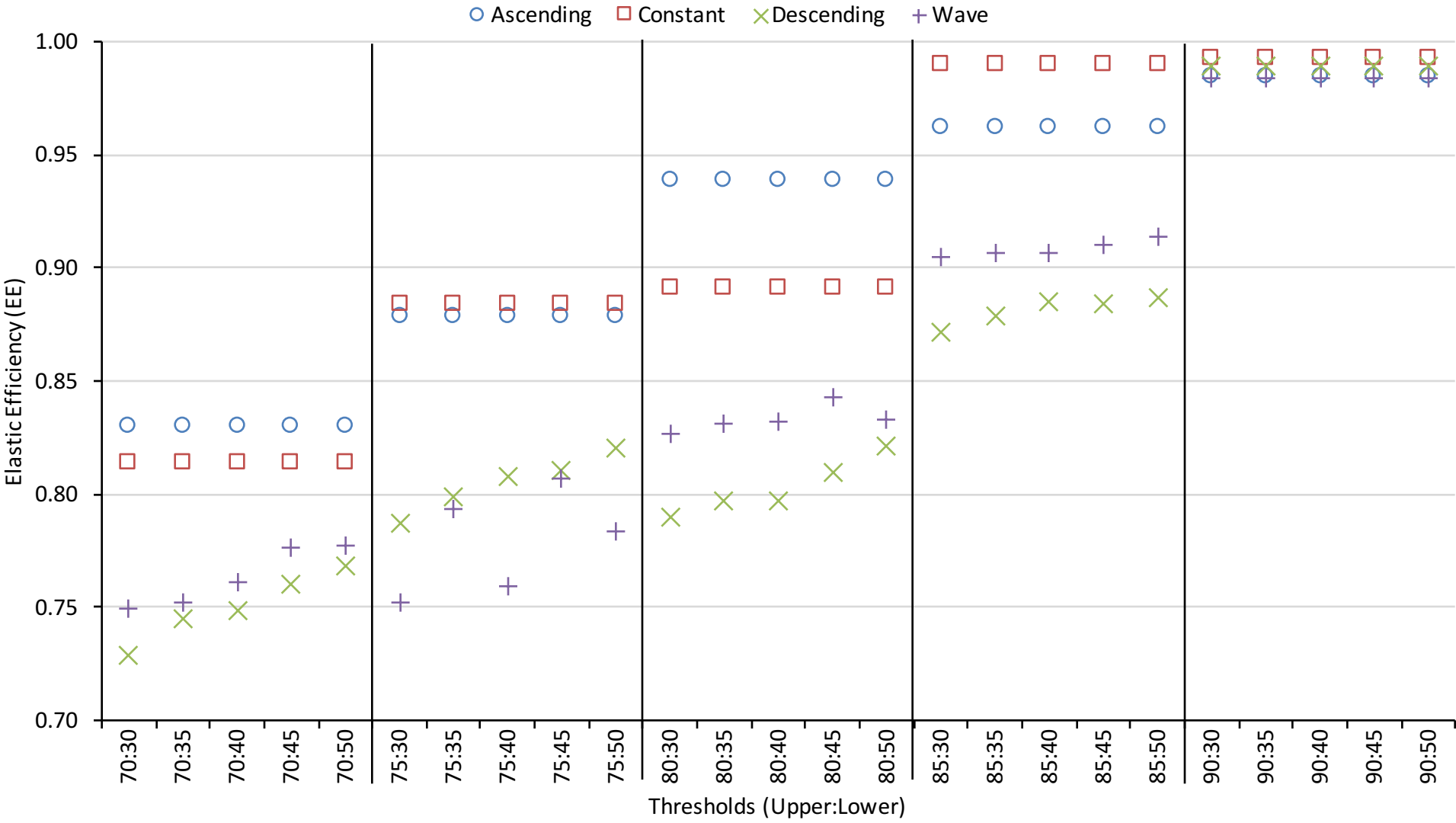
Evaluation Methodology

- The tests were executed in a private cloud environment using OpenNebula;
- We used AutoElastic to provide automatic elasticity for HPC applications. The elasticity model consists in horizontal elasticity, by virtual machine replication, based on thresholds;
- Used thresholds:
  - Lower: 30, 35, 40, 45 and 50;
  - Upper: 70, 75, 80, 85 and 90.
- Minimum of resources(*l*): 4 virtual machines;
- Maximum of resources(*u*): 10 virtual machines.

Results: Elastic Speedup (ES)



Results: Elastic Efficiency (EE)



Conclusions

- Considering the initial number of VMs and the lower and upper bounds, the work contribution explores the traditional speedup and efficiency for parallel systems, now considered in elastic infrastructures;
- Although ES provides possible gains with on-the-fly resource reorganization, EE indicates the effectiveness of resource use;
- Using a automatic elasticity based in thresholds, the variation of the upper threshold causes more significant variations on the Elastic Speedup and Elastic Efficiency;
- Different thresholds result in different resource usage impacting the application performance.

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