Intuitionistic fuzzy load balancing in cloud computing

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Abstract: An attempt to apply the intuitionistic fuzzy sets (IFS) paradigm to construct an efficient load balancing scheme in cloud computing environment is presented. Two approaches of IFS usage are shown. One is based on a direct substitution of a classical fuzzy logic by an intuitionistic fuzzy logic, illustrated on an already proposed model of load balancing. The second approach deals with the application of the modal notions from IFS – necessity and possibility, which are proposed to be associated to the needed load and available resources respectively. Then the target of the balance scheme is to equalize both.

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AMS Classification: 03E72.

1   Introduction

Cloud computing is emerging as a new paradigm of large scale distributed computing. It becomes a leading strategy in for the future computing environment organization, though there are many existing issues like load balancing, virtual machines (VM) migrating, server consolidation etc. Central of these issues is the issue of load balancing. This is a mechanism to distribute the dynamic workload evenly to all the nodes in the whole cloud to achieve a high user satisfaction and resource utilization ration, [5, 7]. It prevents bottlenecks of the system, as a result of a load disbalance. In case of fail, load balancing also boosts the failed service continuation. Finally load balancing insures the efficient distribution of computing infrastructure, providing fair infrastructure as a service (IAAS) to the customer.

Load balancing is a process of reassigning the total load to the individual nodes of the computing environment, thus facilitating the network and resources and improving the system performance. The important sides of this process are estimation and comparison of the load, stability and performance of the system, internodes traffic optimization, etc.

To construct load balancing mechanism many technics and strategies are used, namely static or dynamic as strategies and over 15 different technics [7]. Among them the technics, based on the Fuzzy logic, are considered as the most advanced and effective in comparison with the others [4, 8, 10]

2   Intuitionistic fuzzy load balancing approaches

In conventional load balancing schemes, the values of workload are fixed, which leads to destabilisation of the system, due to the fact that task relocation is done frequently around the workload threshold.

In contrast, the load balancing based on fuzzy logic approach resolves this problem.

On the other hand, even using fuzzy logic, the load balancing scheme is not capable to manage system resources any time, because the load data from resources are exchanged in discrete intervals, not continuously to avoid the traffic problems. In that sense, certain indeterminacy takes place in the process of the load estimation, which might be modelled by the help of IFS.

In the present work, an attempt to apply the extention of the fuzzy sets formalism – the intuitionistic fuzzy sets (IFS) to model the load balancing algorithm. Following [1], IFS are determined in following way. Let us have a fixed universe E. Let A be a subset of E. Let us construct the set:

$$A^* = \{ \langle x, \mu_A(x), \nu_A(x) \mid x \in E \rangle \}$$

where $0 \le \mu_A(x) + \nu_A(x) \le 1$. We will call the set A^* intuitionistic fuzzy set (IFS).

Functions $\mu_A : E \to [0;1]$ and $\nu_A : E \to [0;1]$ represent degree of membership (validity, etc.) and non-membership (non-validity, etc.). Also defined is function $\pi_A : E \to [0;1]$ through $\pi(x) = 1 - \mu(x) - \nu(x)$, corresponding to the degree of uncertainty (indeterminacy, etc.)

Obviously, for every ordinary fuzzy set A: $\pi_A(x) = 0$ for each $x \in E$ and these sets have the form $\{ \langle x, \mu_A(x), 1 - \mu_A(x) \mid x \in E \rangle \}$.

We will use the advantages of IFS in terms of non-validity and indeterminacy to provide more "soft and precise" balancing of the load in the cloud computing environment.
Two ways of IFS application in load balancing are discussed:

3   Direct substitution of fuzzy logic algorithm
in the existing load balancing schemes by IFS algorithm

This approach will be illustrated on the load balancing scheme, proposed in [9]. The load balancing there is defined as a function of two parameters, considered as linguistic variables: *assigned load*, and *processor speed*.

Then the function of load balancing (considered also as linguistic) is presented in a rule-based structure, where the rules are in IF-THEN form:

1. **IF** (processor_speed is Low_speed) **AND** (assigned_load is Least)
   THEN (balanced_load is Medium)

2. **IF** (processor_speed is Low_speed) **AND** (assigned_load is Medium)
   THEN (balanced_load is Low)

3. **IF** (processor_speed is Low_speed) **AND** (assigned_load is High)
   THEN (balanced_load is High)

…

12. **IF** (processor_speed is Very_high) **AND** (assigned_load is High)
    THEN (balanced_load is Medium)

Then in order to fuzzify the data, representing the processor_speed, assigned_load and balanced_load, the corresponding membership functions are constructed (Figures 1, 2 and 3 – plotted with solid line).

The membership functions of assigned_load and balanced_load have 3 values: low, medium and high, while the membership function of processor_speed varies within four values: low, medium, high and very high.

The inference machine of low-high (min-max) type is used to evaluate the rules.

Finally, a defuzzification method is applied to generate the non-fuzzy control output, which represents the balanced workload, adapted to the current load conditions and computing resources.

Now, we will construct the IFS algorithm to substitute the above-described in the following way.

In the defined load balancing function, we will represent the linguistic variables processor_speed, assigned_load and balanced_load with intuitionistic fuzzy variables. This means that additionally to the membership functions μ, a non-membership function v has to be added (plotted on Figures 1, 2 and 3 – plotted with doted lines).
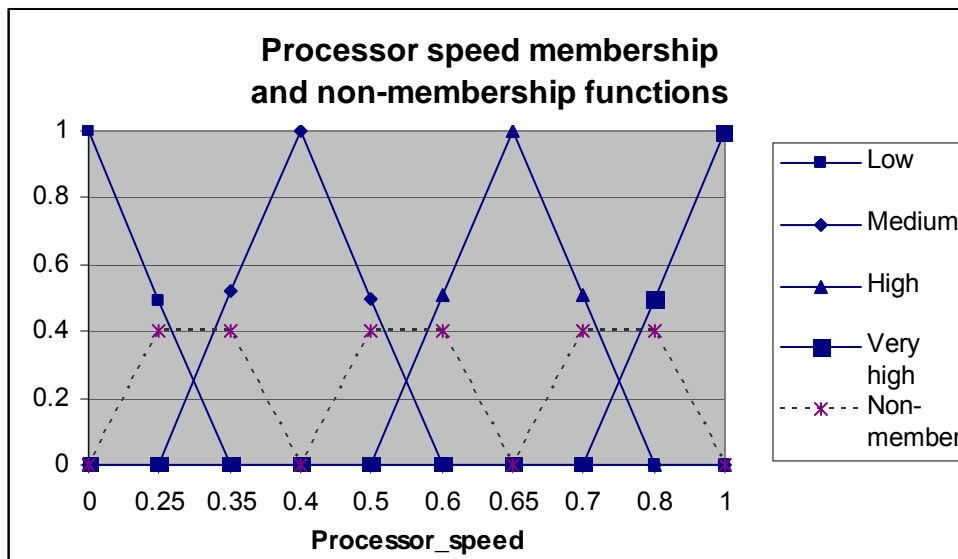

Figure 1: Processor speed membership and non-membership functions
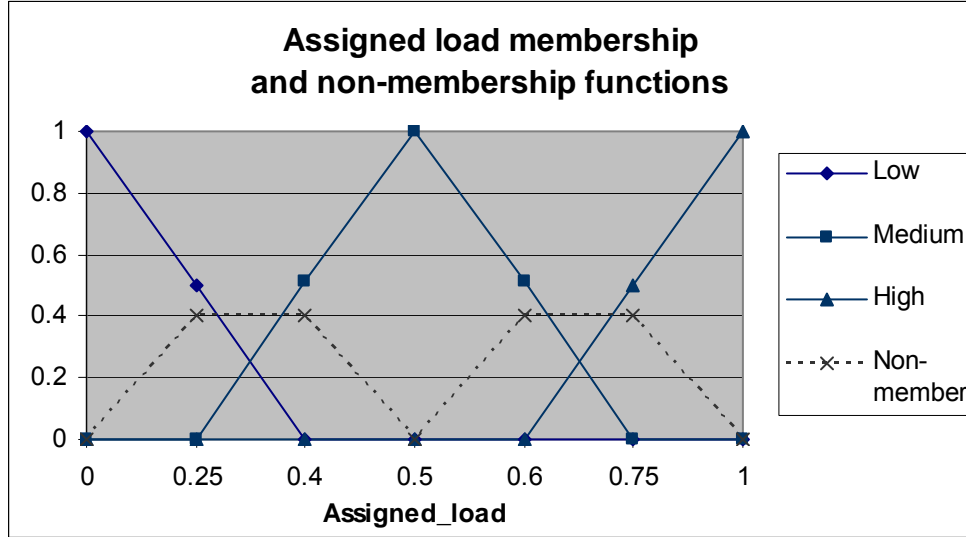
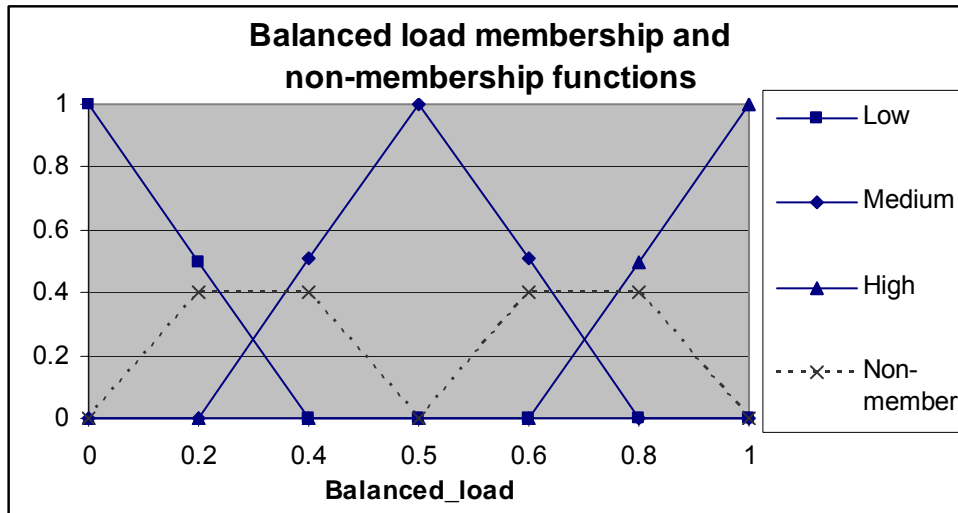Figure 2: Assigned load membership and non-membership functions

Figure 3: Balanced load membership and non-membership functions

The non-membership functions are constructed is such a way to increase the uncertainty when the linguistic parameters (load, speed etc.) are close to the well defined status like low, medium, etc. This is considered as a main contribution of IFS approach helping to achieve a more "soft" and correct load balancing in comparison with classical fuzzy and moreover with non-fuzzy approaches.

Further, the rule base should be modified, as follows:

IF (processor_speed is Low_speed (μP, $v P$))
  AND
  (assigned_load is Least (μL, $v L$))
THEN (balanced_load is Medium (μB, $v B$))

etc.

The generalized rule base, as proposed in [6], will be:

> **Rule 1:   IF** x is (A1; P1) **AND** y is (B1; Q1) ….. **THEN** z is (C1; R1)
>
> **Rule 2:   IF** x is (A2; P2) **AND** y is (B2; Q2) ….. **THEN** z is (C2; R2)
>
> . .
>
> **Rule n: IF** x is (An; Pn) **AND** y is (Bn; Qn) ….. **THEN** z is (Cn; Rn)

where:
- x, y and z are intuitionistic fuzzy variables;
- A1, A2, …, An and B1, B2,…, Bn are conditions membership functions;
- C1, C2, …, Cn are conclusions membership functions;
- P1, P2, …, Pn and Q1, Q2, …, Qn are conditions non membership functions;
- R1, R2, …, Rn are conclusions non membership functions.

The inference procedure starts with an evaluation of the left parts of the rules in the following way. The current values of the membership function μ and non-membership function v of each variable are compared with the threshold values – Ai, Pi, and Bi, Qi, respectively, as follows:

> **FOR EACH** x
>   **IF** m > Ai **OR** (m = Ai **AND** n < Pi)
>   **THEN** x = 1
>   **ELSE** x=0

and

> **FOR EACH** y
>   **IF** m > Bi **OR** (m = Bi **AND** n < Qi)
>   **THEN** y = 1
>   **ELSE** y = 0

To obtain the conclusion, the conjunction of the evaluated left parts of the rules should be equal to 1, which means that the conclusion z is activated with the corresponding membership and non-membership thresholds Ci and Ri.

Finally, the resulting values of thresholds should be calculated by taking the maximum of membership thresholds and the minimum of the non-membership thresholds on the conclusions of all activated rules.

For the de-i-fuzzification an optimistic (maximum of a membership function value) or pessimistic (maximum of a non-membership value) algorithm can be used to obtain the control output [3].

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4   Necessity and possibility load balancing model

Another strategy of IFS application in load balancing might be based on the exploitation of the two modal notions: necessity and possibility. Following [1], these operators are defined in the following way.

For every IFS A, the necessity operator is:

$$\square A = \{\langle x, \mu_A(x), 1 - \mu_A(x) \mid x \in E \rangle\}$$

and the possibility operator is:

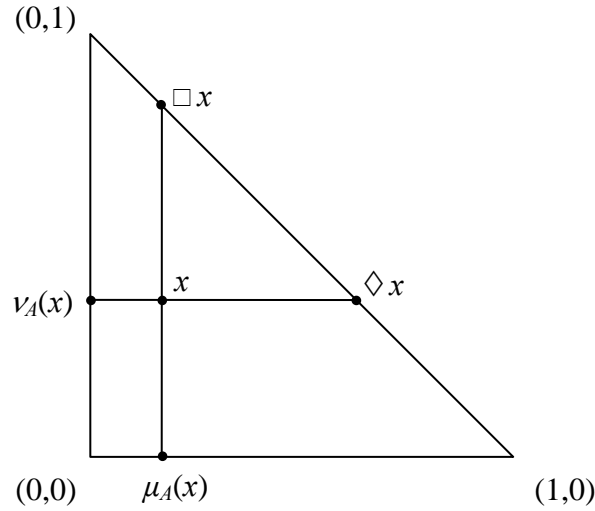$$\lozenge A = \{\langle x, 1 - \nu_A(x), \nu_A(x) \mid x \in E \rangle\}$$

Figure 4: Geometric interpretation of necessity and possibility operators

The geometrical interpretation of both operators is shown on Figure 4, where the triangle is presenting the area of the membership and non-membership functions values and both operators – a necessity and a possibility, corresponding to the intuitionistic fuzzy f(x), are plotted as well.

We will associate the required computing power, i.e. "assigned load" with the necessity, while the "balanced load" - with the possibility.

The target of the IFS controller will be to equalize the values of both operators and using same de-i-fuzzification algorithms, like in [2] to generate the aggregated output, thus managing the load balancing toward most effective operation of the computing resources.

5   Conclusions

Load balancing, based on fuzzy logic controllers needs data to generate the load weights, which to be assigned to the computing resources i.e. virtual machine. To exchange the data, the virtual machine notifies about its load periodically. The proper time interval is an important issue to be decided. A very long time interval causes inexact load balancing decision, while a short one increases the communication traffic drastically.

Applying the IFS paradigm by introducing a non-membership function for linguistic parameters fuzzification will improve the forecast of the virtual machine load, because of introducing of non-loaded and also of non-determined (intuitionistic) states in the load weight estimations. As a side effect, the communication traffic will be reduced.

The effectiveness of the modal operator based load balancing approach is still being studied.

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