USING OF INFORMATION THEORY METRICS IN SECURITY MODELING OF AUTONOMIC CLOUD COMPUTING .

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Summary

As clouds are complex, large-scale, and heterogeneous distributed systems management of their resources is a challenging task. It requires co-optimization at multiple layers (infrastructure, platform, and application) exhibiting autonomic properties. Autonomic systems exhibit the ability of self-monitoring, self-repairing, and self-optimizing by constantly sensing themselves and tuning their performance. The notions of autonomic components (ACs) and autonomic-component ensembles (ACEs) are considered in the paper. A language for coordinating ensemble components (SCEL) is used to represent specificity of security issues in autonomic computing environment.

Keywords: cloud computing. Autonomic component. Autonomic ensemble. Formal modeling. Security.

1. INTRODUCTION

As Clouds are complex, large-scale, and heterogeneous distributed systems (e.g., consisting of multiple Data Centers, each containing 1000s of servers and peta-bytes of storage capacity), management of their resources is a challenging task. They need automated and integrated intelligent strategies for provisioning of resources to offer services that are secure, reliable, and cost-efficient. However, management of large-scale and elastic Cloud infrastructure offering reliable, secure, and cost-efficient services is a challenging task [1]. It requires co-optimization at multiple layers (infrastructure, platform, and application) exhibiting autonomic properties. Effective management of services becomes fundamental in platforms that constitute the fabric of computing Clouds; and to serve this purpose, autonomic models for PaaS (Platform as a Service) software systems are essential.

Autonomic systems exhibit the ability of self-monitoring, self-repairing, and self-optimizing by constantly sensing themselves and tuning their performance. In other words, they are self-managing, i.e. capable of continuously self-monitoring and selecting appropriate operations. To capture the relevant features and challenges, the 'Interlink WG on software intensive systems and new computing paradigms' [2] has proposed to use the term ensembles.

The notions of autonomic components (ACs) and autonomic-component ensembles (ACEs) [3,4] have been put forward as a means to structure a system into well understood, independent and distributed building blocks that interact in specified ways. ACs are entities with dedicated knowledge units and resources that can cooperate while playing different roles. Awareness is made possible by providing ACs with information about their own state and behavior that can be stored in their knowledge repositories. These repositories also enable ACs to store and retrieve information about their working environment, and to use it for redirecting and adapting their behavior. Each AC is equipped with an interface, consisting of a collection of attributes, such as provided functionalities, spatial coordinates, group memberships, trust level, response time, etc.

Attributes are used by the ACs to dynamically organize themselves into ACEs. Individual ACs not only can single out communication partners by using their identities, but they can also select partners by exploiting the attributes in the interfaces of the individual ACs. Predicates over such attributes are used to specify the targets of communication actions, thus providing a sort of attribute-based communication. In this way, the formation rule of ACEs is endogenous to ACs: members of an ensemble are connected by the interdependency relations defined through predicates. An ACE is

therefore not a rigid fixed network but rather a highly dynamic structure where ACs' linkages are dynamically established.

The proposed abstractions are the basis of SCEL (Software Component Ensemble Language), a kernel language for programming autonomic computing systems.

The syntax of SCEL is presented in Table 1. The basic category of the syntax is that relative to PROCESSES that are used to build up COMPONENTS that in turn are used to define SYSTEMS. PROCESSES specify the flow of the ACTIONS that can be performed. ACTIONS can have a TARGET to characterize the other components that are involved in that action.

$$S ::= C \mid S_1 \parallel S_2 \mid (\nu n)S \quad \text{Systems}$$
$$C ::= \mathcal{I}[\mathcal{K}, \Pi, P] \quad \text{Components}$$
$$P ::= \mathbf{nil} \mid a.P \mid P_1 + P_2 \mid P_1[P_2] \mid X \mid A(\bar{p}) \quad \text{Processes}$$
$$a ::= \mathbf{get}(T)@c \mid \mathbf{qry}(T)@c \mid \mathbf{put}(t)@c \mid \mathbf{fresh}(n) \mid \mathbf{new}(\mathcal{I}, \mathcal{K}, \Pi, P) \quad \text{Actions}$$
$$c ::= n \mid x \mid \mathsf{self} \mid \mathsf{P} \mid \mathcal{I}.\mathsf{p} \quad \text{Targets}$$

Table 1. SCEL syntax

PROCESSES are the active computational units. Each process is built up from the inert process nil via action prefixing (a.P), nondeterministic choice (P1+P2), controlled composition (P1[P2]), process variable (X), and parameterized process invocation (A($\bar{p}$)). The construct P1[P2] abstracts the various forms of parallel composition commonly used in process calculi. Process variables can support higher-order communication, namely the capability to exchange (the code of) a process, and possibly execute it, by first adding an item containing the process to a knowledge repository and then retrieving/withdrawing this item while binding the process to a process variable. We assume that A ranges over a set of parameterized process identifiers that are used in recursive process definitions. We also assume that each process identifier A has a single definition of the form A($\bar{f}$) $\triangleq$ P where all free variables in P are contained in f and all occurrences of process identifiers in P are within the scope of an action prefixing. $\bar{p}$ and $\bar{f}$ denote lists of actual and formal parameters, respectively.

Processes can perform five different kinds of ACTIONS. Actions **get**(T)@c, **qry**(T)@c and **put**(t)@c are used to manage shared knowledge repositories by with drawing/retrieving/adding information items from/to the knowledge repository c. These actions exploit templates T as patterns to select knowledge items t in the repositories. They rely heavily on the used knowledge repository and are implemented by invoking the handling operations it provides. Action **fresh** (n) introduces a scope restriction for the name n so that this name is ensured to be different from any other name previously used. Action **new** $\mathcal{I}[\mathcal{K}, \Pi, P]$ creates a new component $(\mathcal{I}, \mathcal{K}, \Pi, P)$. An autonomic component $(\mathcal{I}, \mathcal{K}, \Pi, P)$is graphically depicted in Figure 1:

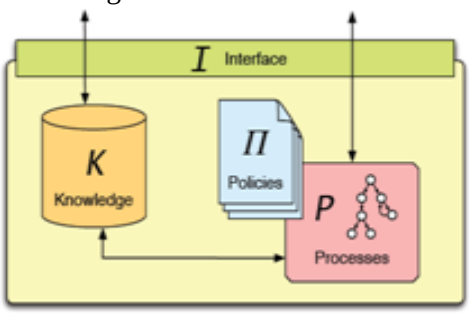

Fig.1 SCEL components

- An interface $\mathcal{I}$ publishing and making available structural and behavioral information about the component itself in the form of attributes. Among them, attribute id is mandatory and is bound to the name of the component. Notably, component names are not required to be unique; this would allow us to easily model replicated service components.
- A knowledge repository $\mathcal{K}$ managing both application data and awareness data, together with the specific handling mechanism. The knowledge repository of a component stores also the whole information provided by its interface, which therefore can be dynamically manipulated by means of the operations provided by the knowledge repositories' handling mechanisms
- A set of policies Π regulating the interaction between the different internal parts of the component and the interaction of the component with the others.
- A process P together with a set of process definitions that can be dynamically activated. Some of the processes in P perform local computation, while others may coordinate processes interaction with the knowledge repository and deal with theissues related to adaptation

Finally, SYSTEMS aggregate COMPONENTS through the composition operator $-\ ||\ -$ The operational and system semantics of SCEL is described in detail in [4].

Access control is a fundamental mechanism for restricting what operations users can perform on protected resources. Many models of access control have been defined in the literature. One of them is the Policy Based Access Control model [5]. In this model, a request to access a protected resource is evaluated with respect to one or more policies that define which requests are authorized. An authorization decision is based on attribute values required to allow access to a resource according to policies stored in system's components. Component attributes are here used to describe the entities that must be considered for authorization purposes. On this basis the SACPL (SCEL Access Control Policy Language), a simple, yet expressive, language for defining access control policies and access requests, is considered [4].

Policies are hierarchically structured as trees. A *policy* is either an atomic policy or a pair of simpler policies combined through one of the decision combining operators **p-o** (*permit override*) and **d-o** (*deny override*). An *atomic policy* is a pair made of a decision and a target. The target defines the set of *access requests* to which the policy applies. The *decision*, i.e. permit or deny, is the effect returned when the policy is 'applicable', namely the access request belongs to the target. Otherwise, i.e. when a request does not belong to the policy's target, the policy is 'not-applicable', which in this simplified setting has the same effect as deny. A *target* is either an atomic target or a pair of simpler targets combined using the standard logic operators and and or. An *atomic target* is a triple denoting the application of a matching function to values from the request and the policy, like e.g. *greater-than(subject.skill; threshold – object.*dependability*).* Finally, *Expressions* are built from values and attributes through various operators. SACPL requests, ranged over by ρ, are functions mapping *names* to *elements* and are written as collections of pairs of the form (*name*; *element*). A request's element can be a knowledge item, a component's interface, the type of an action, etc. In its turn, an interface provides a set of attributes characterizing the corresponding component, which can be either the subject or the object of the request. A typical example of request is as follows:

$$\rho = \{(\mathsf{subject}, \mathcal{I}), (\mathsf{item}, t), (\mathsf{action}, \mathbf{get}), (\mathsf{object}, \mathcal{J})\}$$

Here, the subject identified by the interface $\mathcal{I}$ requires the authorization to withdraw the item *t* from component $\mathcal{J}$. For example, the request's subject is obtained by calling ρ (subject), which returns $\mathcal{I}$

Autonomic computingis widely used in spatial-temporal data analysis for online prediction of dengue fever outbreaks[1],the science cloud [6], real time collection and dissemination of personal

health data (ECG: electrocardiograms) to patients and health-care professionals [7], etc. Cloud computing in these different areas can be thought of as a collection of desktops, servers, notebooks or virtual machines running the Cloud Platform (CP). Each (virtual) machine is running one instance of the Cloud Platform called Cloud Platform instance (CPi).Each CPi is considered to be a service component. Multiple CPs communicate over the Internet (IP ptotocol), thus forming a cloud and within this cloud one or more service component ensembles (Figure 2):

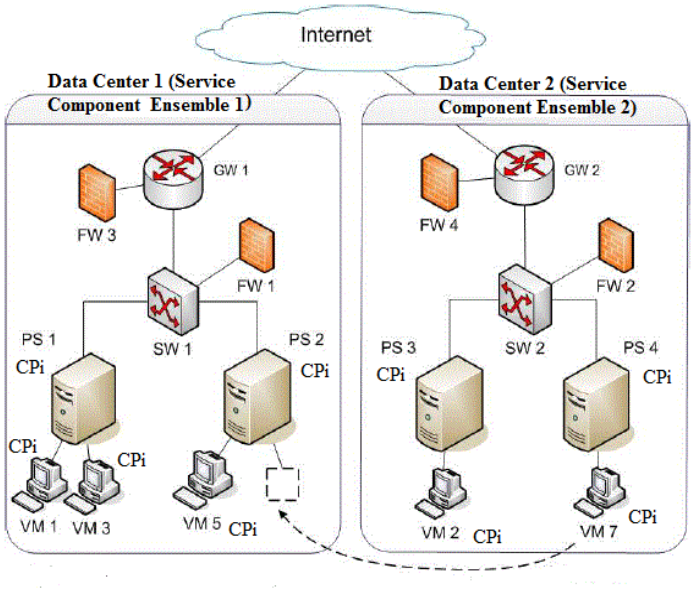

Fig.2. Cloud Platform

Each CPi has knowledge. The knowledge consist of what the CPi knows about itself (properties set by developers), about its infrastructure (CPU load, available memory), and about other CPis (acquired through the network). Since there is no *global coordinator*, each CPi must build its own world view and act upon the knowledge available. The CPi may acquire knowledge about its infrastructure using an *infrastructure sensing plug-in*, which provides information about static values such as processor speed, available memory, available disk space, number of cores etc. and dynamic values such as currently used memory, disk space, CPU load, characteristics of current traffic flowing through the CPi,etc).

Each CPi has also a connectivity component which enables it to talk to other CPis over the network. The protocol followed by these communications must enable CPis to find one another and establish links, for example by manually entering a network address or by a discovery mechanism. Furthermore, CPis must be able to query others for knowledge and distribute their own. Finally, the protocol must support exchange of data and applications.

Each CPi is considered to be autonomic in the sense that it may join and leave the cloud at will. The cloud is thus a dynamic cloud and works *without a central coordinator* in a peer-to-peer manner.

2. STATEMENT OF THE PROBLEM

The following scenario is considered. A singleton application currently runs on one of the VMs at Data Center 2 (VM7 in Service Component Ensemble 2. This application runs alone on its node and,since the application is a singleton, no additional instances can be spawned. During the sessionthe application experiences consistently high CPU load. This increase may be caused either by legitimate traffic overload or by coordinated attacks (DDOS) launched against the PaaS provider. The latter might be wrongly assumed to be legitimate requests and resources would be scaled up to handle them. This

would result in an increase in the cost of running the application (because provider will be charged by these extra resources) as well as a waste of energy. Hence, it is necessary to distinguish between these two cases, the earlier this distinction is made, the higher is the degree of protection of the application from failure and poor performance.To provide this protection, the following security measures are suggested. The traffic flows through the node (CPi) has to be analyzed using Kolmogorov complexity metrics (see later in the text). During the session the constant monitoring of the metric (by the special probe implemented in the separate module), along with measure of CPU load, is being executed.

If the simultaneous increase of these two metrics is registered at least in 3 successive time units, the conclusion about the real treat of the DDOS attack must be drawn. As a result, the application has to migrate from the CPi where it was running to another CPi (which may belong to the same ensemble or other ensemble). A new CPi must be found according to some requirements: complexity level and CPU load must be rather low, integrated hardware index (which includes such indicators as processor speed, available memory, available disk space, number of cores, etc) must correspond to the application resource requirements (they are published in the interface of the CPi where the application is running). If the required CPi is found, the application has to migrate there as soon as possible and stop its running on the "old" CPi.

We assume that, other than *id*, the interfaces provide the attributes "KLDiv", "CPULoad" and "Hardware" stores a context information, updated by the underlying infrastructure (usually, from the firewalls, gateways or special probes) and are `sensed' by the managed element.

The CPi where the application is running is the SCEL component: $\mathcal{I}[\mathcal{K}, \Pi, AM[ME]]$
The autonomic manager AM is defined as follows:AM $P \triangleq_{KLDivMonitor}[P_{CPULoad}]$
$\mathbf{P}_{KLDivMonitorr} \triangleq$ **qry**("*KLDivLevel*", "high") @ self.
get("*KLDivHigh*", false) @self.
put(("*KLDivHigh*", true) @self.
qru("*KLDivLevel*","low")@self.
get("*KLDivHigh*",true)@self.
put("*KLDivHigh*",false)@self.$P_{KLDivMonitor}$
$\mathbf{P}_{CPULoad} \triangleq$ **qry**("*CPUloadLevel*","low")@ self. **get**("*CPULow*", false) @self.
put(("*CPULow*", true) @self. **qru**("*CPUloadLevel*","high")@self.
get("*CPULow*",true)@self.
put("*CPULow*",false)@self. $P_{CPULoad}$
$\mathbf{P}_{MigrateCP} \triangleq$ **qry**("*required_functionality_id*", ?X)@ self. /* retrieving from the knowledge repository the process implementing a required functionality id and bounding it to a process variable X */
get("*required_functionality_id_args*", ?y,?z) @self.
qry("*CPiId*", ?c) @Ω. /* searching an item *c* among components belonging to the ensemble identified by predicate Ω */
fresh(n). /* fresh name *n* is used for coordination purposes */
put("*required_functionality_id_params*",n,y,z)@c /* storing actual parameters of theprocess to be executed in the found component c : moving from VM7 to MV5 on fig.2 */
get("*required_functionality_id*", "*terminated*",n) @self. /* removing the process from the knowledge repository of 'old' CPi */
get("required_functionality_id", X) @self.nil
/* eliminating the process in 'old' CPi */

Here the predicate Ω is determined as follows:
$\Omega(\mathcal{I})=(\mathcal{I}.KLDiv\text{Level}=\text{"low"}) \wedge (\mathcal{I}.\text{PULoad} <75) \wedge (\mathcal{I}.\text{ardware}>=5))$

and is used for *group-oriented communication* in the action **qry**("*CPiId*", ?c) @Ω. This predicate defines the ensemble of components which publish in their interfaces attributes "*KLDiv*Level", "CPULoad" and" Hardware"along with relevant values. We assume that these attributes are provided by the interface of each component and obtain dynamically updated values from corresponding probes (sensors) as a result of constant monitoring (sensing) of the computing environment.

We assume also that the attribute "*KLDiv*Level" (*Kullback-Leibler divergence*) gives an indication in the range [0:m] , *m*-some positive real number (see explanation below in the text) of data flow through the ensemble, the attribute "CPULoad" – in the range [0:100], the attribute "Hardware" – in the range [0:10]. In this context the meaning of the predicate Ω is as follows: find a component CPi (or components) where the "ComplexityLevel" is low (i.e. less than 0.8), "CPULoad" is less than 75 and integrated hardware index "Hardware" is more than 5.

The process P_s executed by the managed element ME is:

P$_s$ ≜ **get** ("*required_functionality_id_params*",?id, ?y, ?z)@self.
get("*load*", ?l) @self.
get("*hardware*", ?h) @self.
put("*load*", (l+5))@self.
put("*hardware*", (h-10))@self.
P$_s$ [X(id, y, z)] /* the new process (additionally to the already running process **P**$_s$), having actual parameters id, y, z,starts */

The policy Π in force at the component results from the composition, by means of the **p-o** (*permit override*) and **d-o** (*deny override*) operators, of the following policies:

⟨deny; target:{} ⟩‘ deny all *
⟨permit ; target:{equal(subject: id; n) and *permit local **qry***
equal(object: id; n) and
equal(action; **qry**) and
equal(subject: *KLDiv*Level; *level*) and
less-or-equal-than(CPULoad; *treshold*) } ⟩
⟨permit ; target:{equal(subject: id; n) and * permit remote **qry** *
equal(object: id; m) and
equal(action; qry) and
equal(subject: *KLDiv*Level; *level*) and
less-or-equal-than(CPULoad; *treshold*) } ⟩
⟨ permit;target:{equal(subject:id;n)and * always permit local **put** *
equal(object: id; n) and
equal(action; **put**)} ⟩
⟨permit;target:{equal(subject:id;n) and *always permit remote **put***
equal(object: id; m) and
equal(action; **put**) } ⟩
⟨deny;target:{equal(subject: id; n) and *always deny remote **get** *
equal(object: id; m) and
equal(action; **get**) } ⟩

3. DETECTION OF DDOS ATTACK USING KULLBACK-LEIBLER DIVERGENCE METRIC

Information theory based metrics enable sophisticated anomaly detections directly with the whole traffic that are difficult to provide with simpler metrics, like aggregated traffic workload, number of packets or single host traffic. The Kullback-Leibler divergence equation [8] is:

$$D_{KL}(P||Q) = \sum_i P(i) log \frac{P(i)}{Q(i)}$$

where the index *i* in front of the right part of the equation stands to denote: $\sum_i$.

A low D_{KL} value means a high similarity in the two probability distributions, on the other hand, high divergence values correspond to low similarity. Port and address IP distributions are highly correlated in network traffic. For this reason we only considered source and destination IP. Network flows are aggregated into time blocks of a fixed size (1 minute by default). Let f^t be the number of flows that cross themonitored network in a time block. Let f_i^t be the number of flows that have IP_i assource (or destination) address. We associate p_i to the packet distribution over a time block *t* and q_i to the packet distribution of the previous time block $t-1$:

$$p_i = \frac{f_i^t}{f^t}, q_i = \frac{f_i^{t-1}}{f^{t-1}}$$

The Kullback-Leibler divergence is computed as follows:

$$D_{KL}(t||t+1) = \sum_i \frac{f_i^t}{f^t} \log \frac{\frac{f_i^t}{f^t}}{\frac{f_i^{t-1}}{f^{t-1}}} = \sum_i \frac{f_i^t}{f^t} \log \frac{f_i^t f^{t-1}}{f^t f_i^{t-1}}$$

So if the D_{KL} during 2 succesive time moments is near to ***zero***, it means that patterns of IP addresses (source or destination) in packets are the same or very close. It can be considered as DDoS (or DoS) attacks (depending on combination of source od destination addresses patterns)

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ინფორმაციული თეორიის მეტრიკების გამოყენება ავტონომიური ღრუბლოვანი გამოთვლების უსაფრთხოების მოდელირებაში

ირაკლი როდონაია, მედხატ მუსა, ვახტანგ როდონაია
შავი ზღვის საერთაშორისო უნივერსიტეტი

რეზიუმე

განიხილება ღრუბლოვანი გამოთვლების (cloud computing) სისტემები, როგორც რთული, ფართომასშტაბიანი და არაერთგვაროვანი განაწილებული სისტემები. მათი მართვა საკმაოდ რთული ამოცანაა და მოითხოვს ერთობლივ ოპტიმიზაციას მრავალ დონეზე (ინფრასტრუქტურის, პლატფორმის, და გამოყენებითი ნაწილის) და ამჟღავნებს მკაცრად ავტონომიურ თვისებებს. ავტონომიური სისტემები ხასიათდება თვით-მონიტორინგის, თვით-გამოსწორების, და თვით-ოპტიმიზაციის უნარებით საკუთარი კომპონენტების მუდმივი სენსორული დაკვირვების მეშვეობით. ნაშრომში განხილულია ავტონომიური კომპონენტების, ავტონომიური ანსამბლის და ავტონომიური ანსამბლების კოორდინაციის ენა SCEL

ИСПОЛЬЗОВАНИЕ МЕТРИК ТЕОРИИ ИНФОРМАЦИИ В МОДЕЛИРОВАНИИ БЕЗОПАСНОСТИ ДЛЯ АВТОНОМНЫХ ОБЛАЧНЫХ ВЫЧИСЛЕНИЙ

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Резюме

Так как облачные (cloud) вычисления выполняются в сложных, широкомасштабных, неоднородных распределенных системах, управление ими представляет собой весьма трудную задачу. Требуется совместная оптимизация на многих (инфраструктурном, платформенном, и прикладном) уровнях, при этом проявляется их строго автономный характер. Автономные системы характеризуются само-мониторингом, само-восстановлением (исправлением), и само-оптимизацией, происходящим за счет постоянного сенсорного контроля собственных компонентов. В статье рассматриваются специфика автономных компонентов,автономных ансамблей, а также язык координации автономных ансамблей SCEL.