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# Studying timed aspects for cloud configuration management tools: validation and recommendations for safe execution

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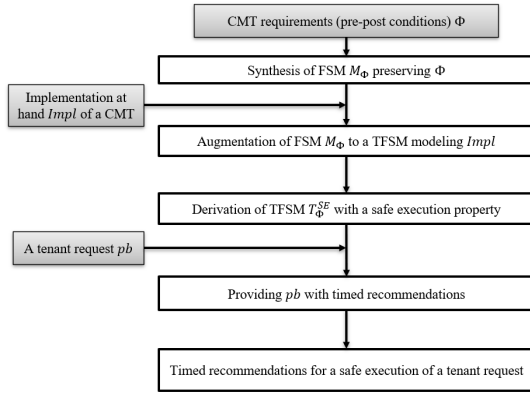


Fig. 2: CMT-VSE overview

delay  $d$  indicates the specified time needed to produce output  $o$  after input  $i$  is applied. In this case, the TFSM contains implicit concurrent procedures that can execute the next input even if the output for the previous one is still pending<sup>2</sup>.

Consider TFSM  $\mathcal{A}$  (see [3] for details) shown in Fig. 1 that describes the behavior of Ansible-2.16 (see [4]),  $pb = open, allow, send$  and its timed extensions  $pb_t^1 = (open, 44.1), (allow, 73.2), (send, 98.3)$  and  $pb_t^2 = (open, 44.1), (allow, 73.2), (send, 98.8)$  of  $pb$ . The output reaction of  $\mathcal{A}$  for  $pb_t^1$  is  $(opened, 44.6), (delivered, 98.6), (allowed, 99.0)$  where *delivered* is produced before *allowed*, i.e.,  $\varphi_{send}$  is violated. Otherwise, the output reaction of  $\mathcal{A}$  for  $pb_t^2$  is  $(opened, 44.6), (allowed, 99.0), (delivered, 99.1)$ , i.e.,  $\varphi_{send}$  is preserved. Thus, the TFSM allows to provide a timed extension for a trace of processes to guarantee that the pre-post conditions are preserved. In this paper, we introduce CMT-VSE – a framework based on TFSM theory for validation of CMTs and for providing tenant requests with timed recommendations for their safe execution.

## II. CMT-VSE FRAMEWORK

CMT-VSE takes three inputs: i) CMT requirements  $\Phi$  given as pre-post conditions that describe the expected behavior of a CMT, ii) an implementation at hand *Impl* of a CMT, and iii) a tenant request  $pb$ ; as an output, CMT-VSE returns recommended timeouts  $pb_t$  for its safe execution (see Fig. 2). In this section, we just briefly discuss the main modules of CMT-VSE, their detailed description can be found in [4].

### A. Synthesis of an FSM preserving CMT requirements

Let  $\varphi_a := C_a \Rightarrow a$  be a pre-post condition,  $I = C \cup \bar{C} \cup A$  and  $O = C^+ \cup \bar{C}^+ \cup A^+ \cup A^-$  be a set of processes and notifications of their terminations (see Section I). We say that an FSM  $\mathcal{A}$  preserves  $\varphi_a$  for an input/output trace  $\beta/\gamma$  over  $I^*/O^*$  if for every appearance of input/output pair  $a/a^+$  in  $\beta/\gamma$  the following holds: i)  $c \prec_\beta a$  for every configuration

process  $c \in C_a$ , and ii) if there exists  $\bar{c} \in \bar{C}_a$  such that  $\bar{c} \prec_\beta a$ , then  $\bar{c} \prec_\beta c \prec_\beta a$ . Consequently,  $\mathcal{A}$  preserves  $\Phi$  if  $\mathcal{A}$  preserves every  $\varphi$  of  $\Phi$  for every input/output trace.

The synthesis module of CMT-VSE takes pre-post conditions  $\Phi$  and synthesizes the transition graph of FSM  $\mathcal{M}_\Phi = (S, I, O, h_S, s_0)$  preserving  $\Phi$ . In order to do this, CMT-VSE utilizes a breadth-first search algorithm. States represent possible configurations of VMs, namely, a state is a Boolean vector  $[is_{c_1}, \dots, is_{c_m}]$  that indicates which configuration processes have been executed and have not been reverted. The initial state is  $[is_{c_1} \leftarrow false, \dots, is_{c_m} \leftarrow false]$ . CMT-VSE starts at the initial state, and at every step takes an unvisited state and builds transitions from that state in the following way: i) the next state for every positive configuration process  $c \in C$  is  $is_c \leftarrow true$  and the transition is labeled by pair  $c/c^+$ , ii) for every negative configuration process  $\bar{c} \in \bar{C}$ , it is  $is_c \leftarrow false$  and the transition is labeled by pair  $\bar{c}/c^+$ , iii) for every action process  $a \in A$  with pre-post condition  $\varphi_a := C_a \Rightarrow a$  if at the current state  $\varphi_a$  is preserved, the transition is labeled by pair  $a/a^+$ , otherwise the transition is labeled by pair  $a/a^-$ . The following theorem holds.

**Theorem II.1.** *Let  $C$  and  $A$  be sets of configuration and action processes and  $\Phi$  be a set of pre-post conditions over  $C$  and  $A$ , CMT-VSE derives FSM  $\mathcal{M}_\Phi = (S, I, O, h_S, s_0)$  preserving  $\Phi$ , where  $|S| \leq 2^{|C|}$ .*

### B. FSM augmentation with timed parameters

To augment FSM  $\mathcal{M}_\Phi$ , CMT-VSE works with the direct simulation of an implementation *Impl* at hand. Given FSM  $\mathcal{M}_\Phi$  preserving pre-post conditions  $\Phi$ , CMT-VSE extends  $\mathcal{M}_\Phi$  to TFSM  $\mathcal{T}$  using the following algorithm. At the first step, timed parameters (timed guards and delays) for every transition are estimated. Namely, let  $tran = (s, i, o, s')$  be a transition of  $\mathcal{A}$ , and a trace  $\alpha' = i_1, \dots, i_k$  bring  $\mathcal{A}$  to state  $s$ ,  $pb_\alpha$  defines a tenant request for a CMT of interest for trace  $\alpha = \alpha', i$ . CMT-VSE runs  $pb_\alpha$   $N > 0$  times to compute timed intervals  $(u, v)$  and  $(p, q)$ , where  $(u, v)$  denotes the fluctuation for the timestamp of process  $i$ , while  $(p, q)$  denotes the fluctuation for the response time for command  $i$ . We assign  $(u, v)$  as a timed guard of  $tran$ , since our purpose is to satisfy pre-post conditions; further, we assign a delay for transition  $tran$  in the following way. If  $i$  is a configuration process, then the output delay for  $tran$  is equal to the right boundary of the interval, i.e.,  $d \leftarrow q$ , otherwise  $d \leftarrow p$ .

TFSM  $\mathcal{T}$  does not necessarily preserve pre-post conditions  $\Phi$  (see Section II-C). At the second step, we derive TFSM  $\mathcal{T}_\Phi^{SE}$  by modifying timed guards  $(u, v)$  for transitions of  $\mathcal{T}$  to guarantee a *safe execution* property. The *safe execution* means that if for input trace  $pb$  FSM  $\mathcal{M}_\Phi$  preserves pre-post conditions  $\Phi$ , then there exists a timed extension  $pb_t$  of  $pb$  such that  $\mathcal{T}_\Phi^{SE}$  preserves  $\Phi$  for  $pb_t$ . In order to transform TFSM  $\mathcal{T}$  to  $\mathcal{T}_\Phi^{SE}$ , CMT-VSE extends the right boundaries of every transition labeled by a positive configuration or an action process (see details in [4]). Thus, TFSM  $\mathcal{T}_\Phi^{SE}$  which models the implementation of a CMT at hand and guarantees a safe execution property is derived.

<sup>2</sup>The number  $L$  of these procedures, if finite, is limited by the ratio of the maximal output delay of the TFSM to the minimal left boundary [3].

### C. Timed recommendations for a tenant request

Let  $\beta$  be an input trace of  $\mathcal{A}$  and  $\beta_t$  be a timed extension of  $\beta$  such that  $\beta_t/\gamma_t$  is a timed input/output trace of  $\mathcal{T}$ . The order of outputs in  $\gamma_t$  can be not the same as the order of the corresponding inputs in  $\beta$ , see for example the output reaction for  $pb_t^1$  in Section I. Therefore, even if an FSM preserves pre-post conditions for an untimed input trace, TFSM augmented with timed parameters can violate them for a timed input trace. The main purpose of this module is to provide a tenant request with the timed recommendations for its safe execution w.r.t. TFSM  $\mathcal{T}_\Phi^{SE}$ . We propose a procedure *Providing\_timed\_recommendation* that takes an untimed trace  $pb = i_1, \dots, i_k$  preserving  $\Phi$  and returns the timed extension  $pb_t = (i_1, t_1), \dots, (i_k, t_k)$  preserving  $\Phi$  w.r.t. the timed parameters of  $\mathcal{T}_\Phi^{SE}$ . To assign timestamps, the procedure works according to the following algorithm. Let  $L$  be the number of procedures of  $\mathcal{T}_\Phi^{SE}$ ,  $\varepsilon$  is chosen as  $\frac{1}{2L}$ . Since  $\mathcal{T}_\Phi^{SE}$  extends  $\mathcal{M}_\Phi$ ,  $\mathcal{T}_\Phi^{SE}$  has the sequence of transitions  $s_0 \xrightarrow{i_1, (u_1, v_1)/(o_1, d_1)} s_1 \dots s_{k-1} \xrightarrow{i_k, (u_k, v_k)/(o_k, d_k)} s_k$ . The procedure assigns  $t_1 \leftarrow u_1 + \varepsilon$  and  $t_j, j \in \{2, \dots, k\}$ , is chosen in the following way.

- 1) If  $i_j \in C$  and there exists  $\ell \in \{1, \dots, j-1\}$  such that  $i_\ell = \bar{i}_j$  and  $t_\ell + d_\ell > t_{j-1} + u_j + d_j$ , then  $t_j \leftarrow t_\ell + d_\ell - d_j + \varepsilon$ ; otherwise  $t_j \leftarrow t_{j-1} + u_j + \varepsilon^3$ .
- 2) If  $i_j \in A$  and there exists  $\ell \in \{1, \dots, j-1\}$  such that  $i_\ell \in C$  and  $t_\ell + d_\ell > t_{j-1} + u_j + d_j$ , then  $t_j \leftarrow \max(t_1 + d_1, \dots, t_{j-1} + d_{j-1}) - d_j + \varepsilon$ ; otherwise  $t_j \leftarrow t_{j-1} + u_j + \varepsilon^4$ .

**Theorem II.2.** Given  $pb = i_1, \dots, i_k$ ,  $\mathcal{M}_\Phi$  preserves  $\Phi$  for timed input trace  $pb_t = \text{Providing\_timed\_recommendation}(pb)$ .

**Corollary 1.** Given  $pb = i_1, \dots, i_k$ , the complexity of *Providing\_timed\_recommendation* is  $O(k^2)$ .

As an example we consider  $pb = open, allow, send$  and TFSM shown in Fig. 1, correspondingly. As mentioned in Section I,  $pb_t^1 = (open, 44.1), (allow, 73.2), (send, 98.3)$  does not preserve  $\varphi_{send} := (open, allow) \Rightarrow send$ . However, if we choose  $\varepsilon = 0.1$ , since  $73.2 + 25.8 < 99.1$ , we conclude that  $pb_t^2 = \text{Providing\_timed\_recommendation}(pb) = (open, 44.1), (allow, 73.2), (send, 98.8)$  preserves  $\varphi_{send}$ .

### III. EVALUATION & CONCLUSION

We have experimentally evaluated the performance of *CMT-VSE* with Ansible-2.16 and SaltStack-3006 (run for OpenStack 2023.2 [5]). The goal of our experimental evaluation is to estimate a *CMT-VSE* performance by comparing the average execution time for *naive* and *CMT-VSE*-based strategies. The former applies a next command of a tenant request only if all previous commands of the request have been already finished. The latter relies on the timeouts recommended by

<sup>3</sup>Therefore,  $t_j + d_j \geq t_\ell + d_\ell - d_j + d_j + \varepsilon > t_\ell + d_\ell$ .

<sup>4</sup>Therefore,  $t_j + d_j \geq \max(t_1 + d_1, \dots, t_{j-1} + d_{j-1}) - d_j + d_j + \varepsilon > \max(t_1 + d_1, \dots, t_{j-1} + d_{j-1})$ .

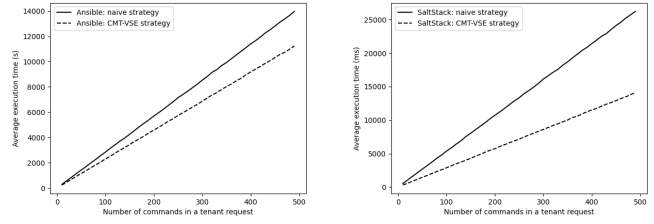


Fig. 3: Performance evaluation of *CMT-VSE*

*CMT-VSE* and thus, the next command is executed at a given timestamp suggested by the framework. Let  $\varphi := (vm2\_open, vm1\_allow\_sub2) \Rightarrow vm1\_send\_vm2$  be a pre-post condition, the derived FSM preserving  $\varphi$  can be found in [4]. We estimated the average execution time for *naive* and *CMT-VSE*-based strategies for input traces with length 10, 20,  $\dots$ , 500. The execution of the *CMT-VSE*-based strategy is on average 1.24 and 1.86 times faster for Ansible-2.16 and SaltStack-3006 than the *naive* one (see Fig. 3) [4].

One of the ways to analyze the obtained experimental results is to compare *CMT-VSE* with scheduling approaches [6], [7] for assigning proper timeouts to tenant requests. Due to potential network channel instability, there can be significant fluctuations for the delivery response time, for each task. Moreover, the scheduling problem is NP-hard [8]. In TFSM-based approach, to handle the complexity, *CMT-VSE* uses a preprocessing to estimate timed parameters, and further takes a quadratic time w.r.t. the length of the tenant request to provide recommendations. The efficiency is showcased by the experiments, even if performed for rather simple pre-post conditions when building the CMT specifications. We recall that *CMT-VSE* relies on simulating an implementation of a CMT at hand to derive timed parameters for transitions, another way to extract such parameters is based on the theoretical analysis of the devices involved; we plan to develop such an approach in the future.

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