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Abstract: Several works have shown that the time to boot one virtual machine (VM) can last up to a few minutes in high consolidated cloud scenarios. This time is critical as VM boot duration defines how an application can react w.r.t. demands' fluctuations (horizontal elasticity). To limit as much as possible the time to boot a VM, we design the *YOLO* mechanism (*You Only Load Once*). *YOLO* optimizes the number of I/O operations generated during a VM boot process by relying on the *boot image* abstraction, a subset of the VM image (VMI) that contains data blocks necessary to complete the boot operation. Whenever a VM is booted, *YOLO* intercepts all read accesses and serves them directly from the boot image, which has been locally stored on fast access storage devices (*e.g.*, memory, SSD, etc.). Creating boot images for 900+ VMIs from Google Cloud shows that only 40 GB is needed to store all the mandatory data. Experiments show that *YOLO* can speed up VM boot duration 2-13 times under different resources contention with a negligible overhead on the I/O path. Finally, we underline that although *YOLO* has been validated with a KVM environment, it does not require any modification on the hypervisor, the guest kernel nor the VM image (VMI) structure and can be used for several kinds of VMIs (in this study, Linux and Windows VMIs have been tested)

Key-words: Virtual Machine, Boot Time, virtualization, boot image, prefetching

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YOLO: Accélération du temps de démarrage de la machine virtuelle en réduisant les opérations d'I/O

Résumé : Plusieurs travaux ont montré que le temps de démarrage d'une machine virtuelle (VM) peut s'étale sur plusieurs minutes dans des scénarios fortement consolidés. Ce délai est critique car la durée de démarrage d'une VM définit la réactivité d'une application en fonction des fluctuations de charge (élasticité horizontale). Pour limiter au maximum le temps de démarrage d'une VM, nous avons conçu le mécanisme YOLO (You Only Load Once). YOLO optimise le nombre d'opérations "disque" générées pendant le processus de démarrage. Pour ce faire, il s'appuie sur une nouvelle abstraction intitulée "image de démarrage" et correspondant à un sous-ensemble des données de l'image de la VM. Chaque fois qu'une machine virtuelle est démarrée, YOLO intercepte l'ensemble des accès en lecture afin de les satisfaire directement à partir de l'image de démarrage, qui a été stockée préalablement sur des périphériques de stockage à accès rapide (par exemple, mémoire, SSD, etc.). La création d'image de démarrage pour les 900 types des VMs proposées sur l'infrastructure Cloud de Google représente seulement 40 Go, ce qui est une quantité de données qui peut tout à fait être stockée sur chacun des noeuds de calculs. Les expériences réalisées montrent que YOLO permet accélérer la durée de démarrage d'un facteur allant de 2 à 13 selon les différents scénarios de consolidation. Nous soulignons que bien que YOLO ait été validé avec un environnement KVM, il ne nécessite aucune modificatfion sur l'hyperviseur, le noyau invité ou la structure d'image de la VM et peut donc être utilisé pour plusieurs types d'images (dans cette étude, nous testons des images Linux et Windows).

Mots-clés : Machine virtuelle, temsp de démarrage, virtualisation, image de démarrage, pré-chargement

YOLO: Speeding up VM Boot Time by reducing I/O operations

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Several works have shown that the time to boot one virtual machine (VM) can last up to a few minutes in high consolidated cloud scenarios. This time is critical as VM boot duration defines how an application can react w.r.t. demands' fluctuations (horizontal elasticity). To limit as much as possible the time to boot a VM, we design the *YOLO* mechanism (*You Only Load Once*). *YOLO* optimizes the number of I/O operations generated during a VM boot process by relying on the *boot image* abstraction, a subset of the VM image (VMI) that contains data blocks necessary to complete the boot operation. Whenever a VM is booted, *YOLO* intercepts all read accesses and serves them directly from the boot image, which has been locally stored on fast access storage devices (*e.g.*, memory, SSD, etc.). Creating boot images for 900+ VMIs from Google Cloud shows that only 40 GB is needed to store all the mandatory data. Experiments show that *YOLO* can speed up VM boot duration 2-13 times under different resources contention with a negligible overhead on the I/O path. Finally, we underline that although *YOLO* has been validated with a KVM environment, it does not require any modification on the hypervisor, the guest kernel nor the VM image (VMI) structure and can be used for several kinds of VMIs (in this study, Linux and Windows VMIs have been tested).

I. Introduction

The promise of elasticity of cloud computing brings the benefits for clients of adding and removing new VMs in a manner of seconds. However, in reality, users may have to wait several minutes to get a new VM in public IaaS clouds such as Amazon EC2, Microsoft Azure or RackSpace [1]. Such long startup duration has a strong negative impact on services deployed in a cloud system. For instance, when an application (*e.g.*, a web service) faces peak demands, it is important to provision additional VMs as fast as possible to prevent loss of revenue for this service. Therefore, the startup time of VMs plays an essential role in provisioning resources in a cloud infrastructure.

The startup time of VMs can be divided into two major parts: (i) the time to transfer the VMI from the repository to the selected compute node and (ii) the time to perform the VM boot process. While a lot of efforts focused on mitigating the penalty of the VMI transferring time either by using deduplication, caching and chunking techniques or by avoiding it thanks to remote attached volume approaches [2], [3], [4], [5], only a few works addressed the boot duration challenge. To the best of our knowledge, the solutions that investigated the boot time issue proposed to use either cloning techniques [6], [7] or suspend/resume capabilities of VMs [8], [9], [10]. The former relies on live VMs available on each compute node so that it is possible to spawn new identical VMs without performing the VM boot process. The latter consists in saving the entire state of each possible VM and resuming it when necessary (each time a VM is requested, the new VM is created from the master snapshot). Once the new VM is available, both approaches may use hot-plug mechanisms to reconfigure the VM physical characteristics according to the users' expectations (in terms of number CPU, RAM size, network …). Although these two solutions enable speeding up the boot duration, they have major drawbacks. The cloning technique requires to allocate dedicated resources for each live VM, which limits the number of master copy that can be executed on each node. The suspend/resume approach eliminates this issue but requires a large amount of storage space on each compute node to save a copy of the snapshot of each VM that might be instantiated according to the existing VMIs. Besides, these two approaches have not been designed with high-consolidated scenarios in mind. In other words, the process to launch a VM on the compute note (boot, cloning or resuming) performs I/O and CPU operations that impact the performance. Such an issue has been investigated for traditional boot approaches in recent studies [11], [12] where the authors show that the duration of VM boot process is highly variable depending on the effective system load and the number of simultaneous provisioning requests the compute node should satisfy.

To deal with each of the aforementioned limitation (mitigate resource wasting as well as resource competition on each compute node), we designed the *YOLO* mechanism (*You Only Load Once*). *YOLO* speeds up the boot process by manipulating mandatory data to boot a VM as less as possible. At coarse-grained, *YOLO* has been built on the observation that only a small portion of a VMI is required to boot a VM [3], [10], [13]. Hence, for each VMI, we construct a *boot image*, *i.e.*, a subset of the VMI that contains the mandatory data needed for booting a VM, and store it on a fast access storage device (memory, SSD, etc.) on each compute node. When a VM boot process starts, *YOLO* transparently loads the corresponding boot image into the memory and serve all I/O requests directly. The way *YOLO* loads the boot image is more efficient than the normal behaviour as discussed later in the document. Moreover, the boot image that has been loaded can be reused to boot additional VMs as long as the data stays into the memory. By mitigating the I/O operations that are mandatory to boot a VM, *YOLO* can reduce the VM boot duration 2-13 times according to the system load conditions. In terms of storage requirements, the size of a boot image is in the average of $50\,\mathrm{MB}$ and $350\,\mathrm{MB}$ for respectively Linux and Windows VMI. Unlike the suspend/resume approach, it is noteworthy that this size is constant and does not increase according to physical parameters of the VM. As an example, we need $40\,\mathrm{GB}$ to store all boot images for the 900+ VMI from the Google Cloud platform (3% of the total size).

The rest of this paper is organised as follows. Section II gives some background elements regarding the boot operation. Section III summarises preliminary studies that led us to propose *YOLO*. Section IV describes our solution and implementation. Section V presents our experimental protocol and discusses the results we obtained. Section VI deals with related works. Finally, Section VII concludes the article and highlights future works.

II. Background

In this section, we first describe the VM boot process so that readers can understand clearly the different steps of the boot operation. Second, we discuss the two types of VM disk that can be used in a QEMU/KVM-based environment, the default Linux hypervisor. Because a VM boot process implies I/O operations, understanding the difference in terms of the amount of manipulated data between these two strategies is important.

A. VM Boot Process

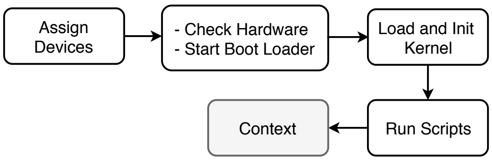
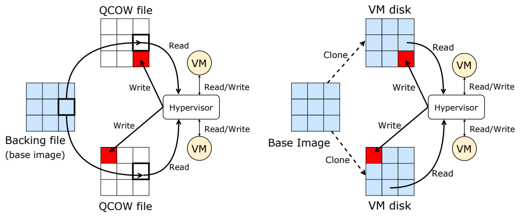


Fig. 1: Virtual Machine boot process

Figure 1 illustrates the different stages of a VM boot process. First, the hypervisor is invoked to create the virtual abstraction of the machine. That is, assigning resources (*e.g.*, CPU, memory, disks, etc.) to the VM. After that a standard boot process happens: first, the BIOS of the VM checks all the devices and tests the system, then it loads the boot loader into memory and gives it the control. Boot loader (GRUB, LILO, etc.) is responsible for loading the kernel. Finally, the kernel invokes the `init` script that starts major services such as SSH. The last step, *i.e.*, contextualisation of the VM, is made through the invocation of dedicated scripts defined according to the user's requirements.

To load the kernel into the memory and to start/configure different system services, a VM not only performs CPU operations, it also generates a significant number of small read and write I/O operations that compete with the other co-located workloads/VMs and that should be considered in the optimisation process.

B. VM Disk Types



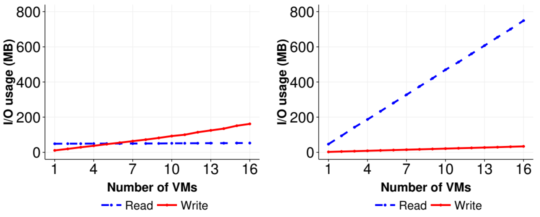
(a) shared image (b) no shared image

Fig. 2: Two types of VM disk

QEMU offers two strategies to create a VM disk image from the VMI (*a.k.a.* the VM base image). Figure 2 illustrates these two strategies. For the sake of simplicity, we call them *shared image* and *no shared image* strategies. In the *shared image* strategy, the VM disk is built on top of two images: the backing and the QCOW (QEMU Copy-On-Write) files [14]. The backing file is the base image that can be shared between several VMs while the QCOW is related to a single VM and contains write operations that has been previously performed. When a VM performs read requests, the hypervisor first tries to retrieve the requested data from the QCOW and if not it forwards the access to the backing file. In the *no shared image* strategy, the VM disk image is cloned fully from the base image and all read/writes operations executed from the VM will be performed on this standalone disk.

C. Amount of manipulated data

To identify the amount of data that is manipulated during VM boot operations in both VM disk strategies, we performed a first experiment that consisted in booting up to 16 VMs simultaneously on the same compute node. We used QEMU/KVM (QEMU-2.1.2) as the hypervisor, VMs are created from the 1.2 GB Debian image (Debian 7, Linux-3.2) with *writethrough* cache mode (at the opposite of the *writeback*, each write operation is directly propagated to the VM disk image [15]).

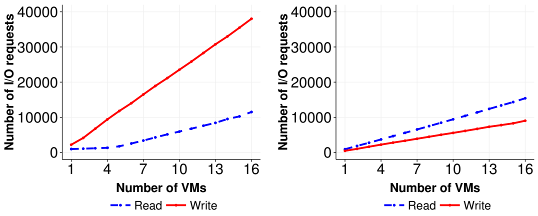


(a) *shared image* disk (b) *no shared image* disk

Fig. 3: The amount of manipulated data during boot operations (reads/writes)

Figure 3 reveals the amount of read/write data when booting up to 16 VMs at the same time.

Although the VMs have been created from a VMI of 1.2 GB, booting 1 VM only needs to read around 50 MB from kernel files in both cases of *shared image* and *no shared image*. In addition to confirming previous studies regarding the small amount of mandatory data w.r.t. the size of the VMI, this experiment shows that booting simultaneously several instances of the same VM leads to different amount of manipulated data according to the disk strategy used to create the VM disk(s). When the VMs share the same backing file (Figure 3a), the different boot process benefit from the cache and the total amount of read data stays approximately around 50 MB whatever the number of VMs started (the mandatory data has to be loaded only once and stays into the cache for later accesses). When the VMs rely on different VM disks (Figure 3b), the amount of read data grows linearly since each VM has to load 50 MB data for its own boot process. Regarding write accesses, both curves follow the same increasing trend. However, the amount of manipulated data differs: the *shared image* strategy writes 10 MB data when booting one VM and 160 MB for booting 16 VMs while the *no shared image* strategy slightly rises from 2 MB to 32 MB. The reason why the *shared image* strategy writes 5 times more data is due to the *"copy-on-write"* mechanism: when a VM writes less than cluster size of the QCOW file (generally 64 kB), the missing blocks should be read from the backing file, modified with the new data and written into that QCOW file [16]. To summarise, whatever the disk strategy, this experiment shows us that the number of I/O operations that are performed during boot operations are significant (as depicted in Figure 4) and should be mitigated as much as possible in order to prevent possible interference with other co-located workloads/vms. Loading mandatory data into the memory before starting the boot process may be an interesting approach to serve read requests faster. In the following section, we investigate how such a strategy can be achieved.



(a) *shared image* disk (b) *no shared image* disk

Fig. 4: The number of I/O requests during boot operations (reads/writes)

III. Preliminary Studies

In this section, we give additional elements regarding how we can reduce the impact of the I/O accesses during the boot operation. These preliminary studies led us to the *YOLO* proposal.

A. Prefetching initrd and kernel files

In the kernel stage of a normal Linux boot process, *initrd* [17] is used as a small file system located on RAM disk to run user space programs before the actual root file system is mounted. Because *Libvirt* [18] offers the possibility to boot a VM from specific kernel and *initrd* files, a simple way of speeding up the VM boot operation could be to load these files into the page cache beforehand. Such a strategy looks interesting because most VMIs differ only in the set of installed software. That is, we can use the same kernel and initrd files to serve many VMs that have different VMIs but the same kernel. However, diving into details, we observed that a large part of the I/O operations come after the initrd phase. That is after the kernel has mounted the real file system into the VM disk and has called the */etc/init* and other scripts on this real file system to start the services .

To summarise, the initrd and kernel files only represent a small part of the I/O accesses and another approach is needed.

B. Prefetching mandatory data

Leveraging the *shared-image* disk experiment, we observed that it is possible to mitigate the number of I/O operations by using the cache so that read operations are served from memory rather than from the storage device as long as the page cache is not evicted. To identify which part of a VMI is needed during a VM boot process, we booted one VM on a dedicated compute node with an empty page cache. To determine which pages of the VMI were resident into the cache after the boot operation, we used the Linux *mincore* function [19]. From that information, we extracted the list of logical block addresses of the VMI that a VM accesses during a boot process.

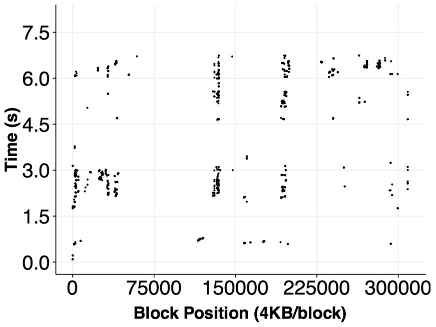
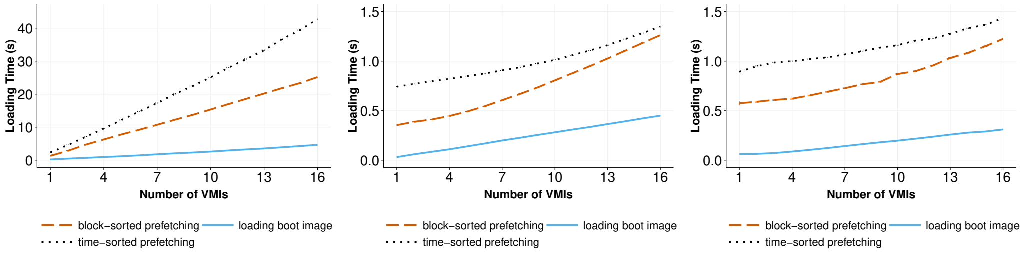


Fig. 5: Read accesses during a VM boot process. Each dot corresponds to an access at a certain period of the boot process and a certain offset.

In addition to the accesses list, we collected additional information thanks to the Linux `blktrace`. This tool allowed us to capture this exact read access pattern according to the time as depicted by Figure 5.

These results are important. First they confirm that there is a large amount of read accesses



(a) Local volume (HDD)

(b) Local volume (SSD)

(c) Remote attached volume (CEPH)

Fig. 6: Prefetching time comparison

and second that there is an alternation between I/O and CPU intensive phases. Leveraging these results, we investigated the most efficient approach to prefetch the mandatory data into the memory. There are two possibilities either by time or offset order. The time order corresponds to the same order a VM reads data during its boot process. This strategy is not optimal because of the small size of the I/O operations and the large number of random accesses. With the offset order, we sort and merge the accesses by the logical block addresses so that we can have a sequential reading of the VM image. This strategy is more efficient. However, the number of accesses is still significant. The best solution would be to extract the mandatory data from each VMI and store it into a single file in the time order. Thanks to this *boot image*, it would be possible to read the file in a contiguous manner, benefit from the kernel prefetching strategy and thus put mandatory data into the memory in the most efficient manner.

To effectively measure the benefit of the different strategies, we developed an ad-hoc script, which uses the *vmtouch* [20] command, to fetch the content of all the mandatory blocks according to the expected order. Figure 6 shows the comparison between the three policies on different storage devices emulating respectively locally stored (HDD and SSD) and remote-attached (CEPH [21]) VMIs. We underline that we did not measure the boot time duration but only the time to prefetch the mandatory data while increasing the number of manipulated VMIs (the more VMIs we have to access the more I/O contention we should expect). Hardware and configuration details are discussed in Section V-A. Results confirm that retrieving the data through the two first prefetching strategies leads to worse performance in comparison the *boot image* approach.

To conclude, it would be interesting to create for each VMI its associated boot image and link it to the VM image disk structure in a similar manner of the share image disk strategy (see Section II-B). By this way, the boot process should be modified at the hypervisor level in order to leverage the boot image during the boot process instead of using the VM image disk. However, in addition to requiring modifications at the hypervisor level and the VMI format, this solution has an important shortcoming related to the page cache space that can be claimed by the host OS whenever the memory is needed. In other words, while we expect the mandatory data would be available in the cache, VMs can face corner cases where they have to read the data once again. Consequently, it is not a practical solution especially in an I/O-intensive environment where the page cache of the host OS would be used intensively. Another approach, less dependent from the kernel and the hypervisor should be designed.

IV. YOLO Design and Implementation

To leverage the boot image abstraction as well as limiting the cache effect, we designed *YOLO* as a new method to serve the mandatory boot data for a VM effectively. In this section, we give an overview of our proposal and its implementation. First, we explain how boot images are created. Second, we introduce how *yolofs*, our custom file system, intercepts I/O requests to speed up the VM boot process.

A. *Boot Image*

In this section we present how we implement the boot image abstraction and we give a few details regarding the storage requirements by analysing the Google Cloud platform as an example with a relevant number of VM images.

1) Creating Boot Image: To create boot images, we capture all read requests generated when we boot completely a VM. Each read request has: (i) a *file_descriptor* with *file_path* and *file_name*, (ii) an *offset* which is the beginning logical address to read from, and (iii) a *length* that is the total length of the data to read. For each read request, we calculate the list of all *block_id* to be read by using the *offset* and *length* information and we record the *block_id* along with the data of that block. A boot image contains a dictionary of key-value pairs in which the key is the pair (*file_name*, *block_id*) and the value is the content of that block. Therefore, with every read request on the VMI, we can use the pair (*file_name*, *block_id*) to retrieve the data of that block. In a cloud system, we create these boot images for all available VMIs and store them on each compute node. To avoid generating I/O contention with other operations when accessing these boot images, we store them on dedicated devices for *yolofs*, which is either local storage devices, remote attached volumes, or even memory.

TABLE I: The statistics of 900+ Google Cloud VMIs and their boot images. We group the VMIs into image families and calculate the boot images for each image family.

Image	No. of images	Size of images	Size of all boot images	Reducing rate
CentOS	156	223 GB	6.3 GB	97.2 %
Debian	180	216 GB	4.7 GB	97.8 %
Ubuntu	236	272 GB	16 GB	94.1 %
CoreOS	221	173 GB	1.2 GB	99.3 %
RHEL	167	302 GB	7 GB	97.7 %
Windows	15	191 GB	5.2 GB	97.3 %
Total	983	1.34 TB	40.4 GB	97.4 %

2) Storage Requirement: The space needed to store boot images for the 900+ VMIs available from Google Cloud is 1.34 TB. Then, for each VMI, we built a boot image using the method described in Section IV-A1. In Table I, we can see how the size reduction rate goes from 94% to 99%. Instead of storing all these VM images (1.34 TB) locally on the physical machines to speed up the VM boot process, we only need to create and store 40 GB of boot images, which is less than 3% of the original size of all VMIs.

B. yolofs

1) Read/Write Data Flow: We developed *yolofs* using FUSE (**F**ilesystem in **User** space) to serve all the read requests executed by VMs during the boot process via the *boot images*. FUSE allows to create a custom file system in userspace without changing the kernel of the host OS. Furthermore, recent analysis [22], [23] confirmed that the performance overhead when using FUSE against read requests is acceptable. However, other solutions are also possible if the performance will become an issue, for example using library interposition.

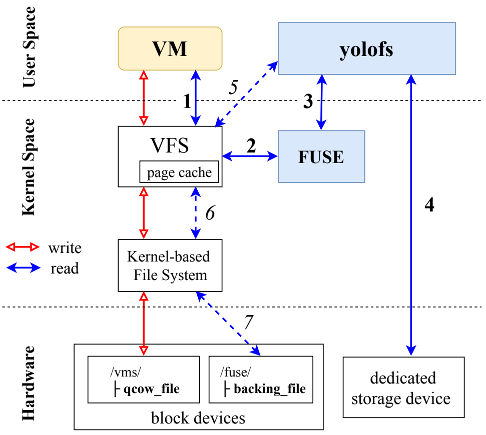


Fig. 7: yolofs read/write data flow

In Figure 7, we illustrate the workflow of *yolofs* along with the read/write data flow for a VM created with a *shared image* disk. We start *yolofs* in a compute node before starting any VM operations. When a VM issues I/O reads on its backing file which is linked to our mounted *yolofs* file system, the VFS routes the operation to the FUSE's kernel module, and *yolofs* will process it (*i.e.*, Step 1, 2, 3 of the read flow). *yolofs* then returns the data directly from the boot image which already was in the *yolofs*' memory (Step 4). If not, *yolofs* would load that boot image from its dedicated storage device (where it stores all the boot images of this cloud system) to the memory. Whenever the VM wants to access data that is not available in the boot image, *yolofs* utilises the kernel-based file system to read the data from the disk (Step 5, 6, and 7 of the read flow). All I/O writes generated from the VM go directly to the QCOW file of that VM and they are not handled by *yolofs* (the write flow in Figure 7).

Algorithm 1: VM Boot time speedup with yolofs

```
   input : boot image $B$, I/O request $R$
   output: data $D$
 1 if $R$ is a write request then
 2     forward to a kernel-based file system to handle $R$
 3 end
 4 else
 5     $offset, length, file\_descriptor \leftarrow R$
 6     $block\_begin \leftarrow \frac{offset}{BLOCK\_SIZE}$
 7     $block\_end \leftarrow \frac{offset+length}{BLOCK\_SIZE}$
 8     $D \leftarrow empty\ list$
 9     if boot image $B$ not loaded then
10         load boot image $B$ from dedicated storage device into yolofs' memory
11     end
12     for $block\_id \leftarrow block\_begin$ to $block\_end$ do
13         if $block\_id$ in boot image $B$ then
14             $D \leftarrow D + B.get(block\_id, file\_descriptor)$
15         end
16         else
17             $D \leftarrow D + ((block\_id, file\_descriptor)$ from a kernel-based file system$)$
18         end
19     end
20     return $D$
21 end
```

2) Implementation: We implemented *yolofs* to handle the VMs' I/O requests as shown in Algorithm 1. *yolofs* runs as a daemon waiting to handle I/O requests sent to the FUSE mount point. Write requests do not go through *yolofs*, the kernel-based file system is used to write this data to the hardware disk (Line 1 of *Algorithm 1*). Otherwise, with every read request, we first extract the *file_descriptor*, *offset*, and *length* of the request (line 5). We calculate the begin *block_id* and the end *block_id* given the system *BLOCK_SIZE* (Line 6 and 7). *yolofs* takes the corresponding boot image B from the local repository and loads it into the memory if needed (Line 9). Next, we iterate over all *block_id* belong to the range [*block_begin, block_end*], with each *block_id* we check the corresponding boot image for the data of that block and return it (Line 12, 13, and 14). After the VM is booted, if the VM needs to read a block which is not in the boot image, that block is read from the kernel-based file system as described in line 17.

YOLO works using any storage backend and is transparent to the VMs, the hypervisor and the kernel of the host/guest OS as well. This allows *YOLO* to be deployed on a wide range of existing systems.

V. Evaluation

In this section we discuss the experiments performed on top of Grid'5000 [24]. The code of *YOLO* as well as the set of scripts we used to conduct the experiments are available on public git repositories [1]. We underline that all experiments have been made in a software defined manner so that it is possible to reproduce them on other testbeds (with slight adaptations in order to remove the dependency to Grid'5000). We have three sets of experiments. The first set is aimed to evaluate how *YOLO* behaves compared to the traditional boot process when the VM images disks are either locally stored (HDD and SSD) or remotely attached through a CEPH system [21]. The second set investigates the impact of collocated memory and I/O intensive workloads on the boot process. Finally, we measured the overheads of using the *yolofs* during the execution of the VM with the third set of experiments.

A. Experimental Conditions

Experiments have been performed on top of the Grid'5000 Nantes cluster. Each physical node has

[1] Due to the double blind review, the link towards repositories will be given later on

2 Intel Xeon E5-2660 CPUs (8 physical cores each) running at 2.2 GHz; 64 GB of memory, a 10 Gbit Ethernet network card and one of two kinds of storage devices: (i) HDD with 10 000 rpm Seagate Savvio 200 GB (150 MB/s throughput) and (ii) SSD with Toshiba PX02SS 186 GB (346 MB/s throughput). Regarding CEPH, we used CEPH version 10.2.5 deployed through 5 nodes (1 master and 4 data nodes, using HDD). When needed, CEPH has been used to deliver the remote-attached VM image disks to different VMs (each "compute" node mounted the remote block devices with *ext4* format). Regarding the VMs' configuration, we used the Qemu/KVM hypervisor (Qemu-2.1.2 and Linux-3.2) with *virtio* [25] enabled (network and disk device drivers). VMs have been created with one vCPU and 1 GB of memory and a *share image* disk using QCOW2 format with the *writethrough* cache mode. During each experiment, each VM has been assigned to a single core to avoid CPU contention and prevent non-controlled side effects. The I/O scheduler of VMs and the physical node is CFQ.

Regarding the VM boot time, we assumed that a VM is ready to be used when it is possible to log into it using SSH. This information can be retrieved by reading the system log, and it is measured in milliseconds. To avoid side effect due to the starting of other applications, SSH has been configured as the first service to be started.

Finally, we underline that all experiments have been repeated at least ten times to get statistically significant results.

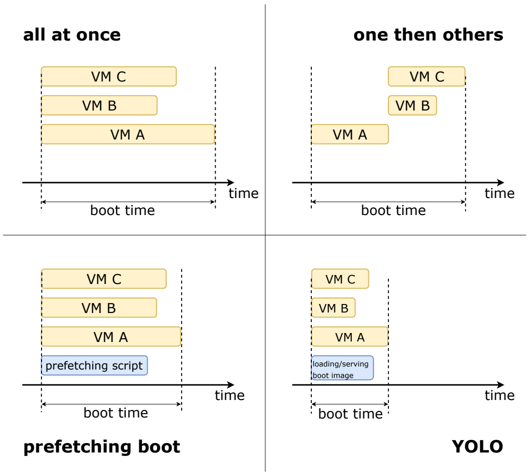


Fig. 8: Four investigated boot policies. Each block represents the time it takes to finish. *Prefetching boot* performs prefetching in a parallel fashion to leverage gaps during the booting process of a VMs for faster loading. *YOLO* loads and serves boot images whenever VMs need to access the mandatory data.

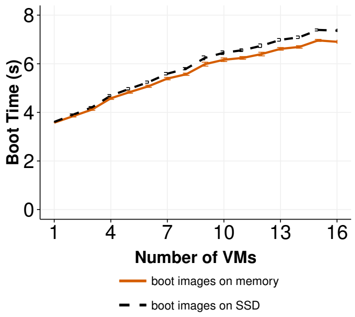
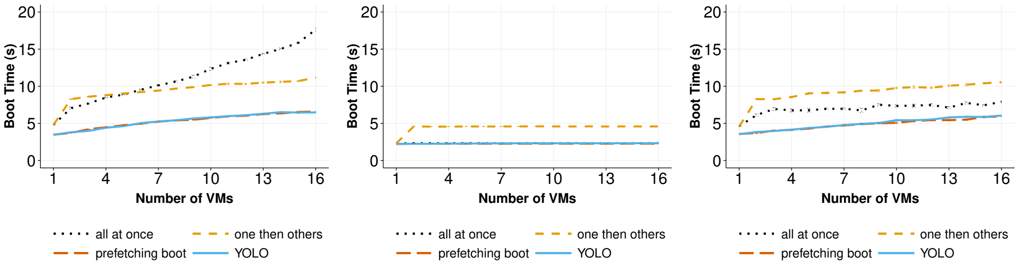


Fig. 9: Overhead of serving boot's I/O requests directly from the memory *vs.* a dedicated SSD

B. Boot Time analysis

For the first set of experiments, we investigated the time to boot up to 16 VMs in parallel. Our goal was to observe multiple VM deployment scenarios from the boot operation viewpoint. We considered four boot policies as depicted in Figure 8:

- *all at once*: all VMs are booted at the same time (the time we report is the the maximum boot time among all VMs)
- *one then others*: the first VM is started. Once the boot operation is completed, the rest of VMs are booted simultaneously. The goal is to evaluate the impact of the cache we observed during the preliminary study on the boot time (see Section III). The boot time is calculated as the time to boot the first VM plus the time to boot all remaining ones.
- *Prefetching boot*: We used the *prefetching script* we developed for the preliminary studies (see Section III) to fetch the mandatory data from the VMI in the offset order. As depicted the prefetching script and the boot process of VMs are invoked simultaneously. Figure 5 illustrates that there are several time gaps in reading data during the boot pro-



(a) HDD (b) SSD (c) CEPH

Fig. 10: Time to boot multiple VMs, which share the same VMI (cold environment: there is no other VMs that are running on the compute node)

cess, especially, at the beginning of the boot process and around the fourth second. These non I/O intensive periods, in particular the first one, enables us to start the prefetching script and the boot process of a new VM at the same time. If they were not, the duration needed for the prefetching operation would be almost similar than booting a VM, making this strategy similar to the previous one.

- *YOLO*: All VMs have been started at the same time, and when VM need to access mandatory data, *YOLO* will serve them. We underline that boot images have been preloaded into the *YOLO* memory before starting VMs. This way enabled us to emulate a non volatile device. While we agree that there might be a short overhead to copy from the non volatile device to the *YOLO* memory, we believe that doing so is acceptable as (i) the amount of manipulated boot images in our experiments is less than $800\,\mathrm{MB}$ (16*$50\,\mathrm{MB}$) and (ii) the overhead to load simultaneously 16 boot images from a dedicated SSD is negligible as discussed in the preliminary studies and confirmed in Figure 9.

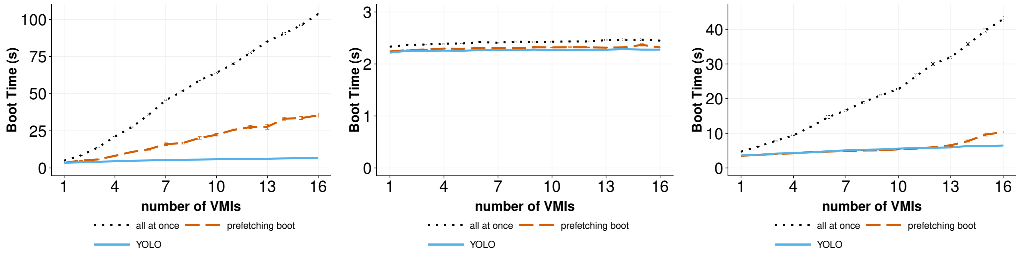
Finally, we remind that the disk strategy is the shared one (see Section II).

1) VMs deployment with the same VMI: Figure 10 shows the time to boot up to 16 VMs leveraging the same VMI (*i.e.*, the same backing file).

On HDD (Figure 10a), the *all at once* boot policy has the longest boot duration because VMs perform read and write I/O operations at the same time for their boot processes. This behavior leads to I/O contentions: the more VMs started simultaneously, the less I/O throughput can be allocated to each VM. When we use the *one then others* policy, we can see better performance in comparison to the previous policy. As already explained, this is due to the cache that has been populated during the boot of the first VM. The boot time raises slightly with the number of VMs (from 2 to 16) due to the I/O writes. Regarding the *Prefetching boot* and *YOLO* strategies, they greatly speed up the VM boot time compared to other two boot policies because the VMs always get benefit from the cache for reading mandatory data. It is noteworthy that the performance gap between both strategies is not perceptible in this scenario. This is due to (i) the number of I/O requests that is not significant and (ii) that there is not cache eviction (all VMs are using the same VMI).

On SSD (Figure 10b), the boot time of several VMs is mostly constant for all boot policies. The I/O contention generated during the boot process on SSD becomes negligible because the I/O throughput of the SSD is higher than HDD. The I/O requests executed by the VMs can be handled quickly. Therefore, *all at once*, *prefetching boot* and *YOLO* relatively show the same boot duration. The duration of *one then others* boot policy is longer because we accumulated the boot time of the first VM.

Using CEPH (Figure 10c), *prefetching boot* and *YOLO* still have the best performance. The boot duration with *one then others*, *prefetching boot* and *YOLO* policy, which are mostly affected by I/O writes contention, follows the same trends when running on HDD. However, on CEPH, *all at once* are faster than *one then others*, because the



(a) HDD (b) SSD (c) CEPH

Fig. 11: Time to boot multiple VMs, which have different VMIs (cold environment: there is no other VMs that are running on the compute node)

bottleneck on CEPH is not on I/O disk anymore (all I/O operations go through the 10 Gbit network interface and are served by CEPH).

2) VMs deployment with distinct VMIs: We performed the same experiment as the previous one, but each VM had its own VMI (*i.e.*, backing file). In this particular case, there was no interest to evaluate the *one then others* because there was no possible gain from the cache. Therefore, we only compared the results of the three other boot policies. Figure 11 depicts the results.

On HDD (Figure 11a), the boot time using *YOLO* increases slightly while *all at once* and *prefetching boot* rise sharply. For example, to boot 16 VMs, *prefetching boot* and *all at once* needs 38 s and 107 s, respectively, compared to only 7.2 s by using *YOLO*. The performance for the *prefetching boot* strategy is strongly impacted due to the fact that the script has been invoked several times simultaneously (generating a lot of competitions and a large number of seek operations on the HDD). While *YOLO* would have also suffered from this issue (we remind that the boot images have been preloaded into the memory before booting VMs), the impact would be less important because *YOLO* reads boot images in a contiguous manner. The *all at once* boot policy also suffered I/O contentions from random reads generated by multiple VMs simultaneously as in case of *prefetching boot*. However, the performance is even worse because of : (i) the I/O virtualization overhead and (ii) the I/O access pattern that cannot benefit from the read-ahead strategy of the host OS.

On SSD (Figure 11b), it takes less than *3* seconds to boot VMs in three cases of boot policies. This behaviour is again explained by the SSD capability.

On CEPH (Figure 11c), *YOLO* and *prefetching boot* rise slightly while *all at once* increases in a linear way. However, it is noteworthy to mention that *prefetching boot* is constant when the number of VMs is less than 13, and then it slightly increases. The reason for this trend is due the number requests sent through the network : when we boot more than 13 VMs at the same time, the traffic is high enough to cause a network bottleneck.

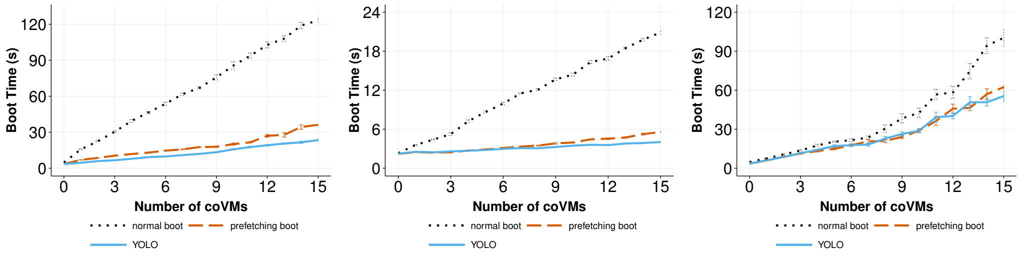
3) Summary: When simultaneously booting several VMs in a cold environment, *YOLO* does not improve the boot time on SSD in both cases with or without sharing VMIs. Because SSD has high I/O throughput, the I/O contention generated by VMs from the boot process is negligible. On HDD and CEPH, *YOLO* speeds up the VM boot time up to 13 times and 6 times respectively when VMs do not have the same VMI and 2 times when VMs are sharing the same backing file.

C. Booting one VM under high consolidation ratio

The second set of experiments is aimed to understand the effect of booting a VM in a high-consolidated environment. We defined two kinds of VMs :

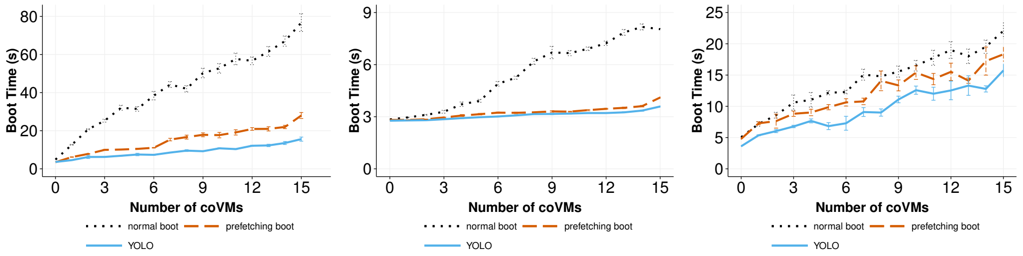
- *eVM* (*experimenting* VM), which is used to measure the boot time;
- *coVM* (*collocated* VM), which is collocated on the same compute node to run competitive workloads.

We used the command *Stress* [26] to generate the I/O and memory workloads. We measured



(a) HDD (b) SSD (c) CEPH

Fig. 12: Boot time of 1 VM (with *shared image* disk, *write through* cache mode) under I/O contention environment



(a) HDD (b) SSD (c) CEPH

Fig. 13: Boot time of 1 VM (with *shared image* disk, *write through* cache mode) under memory usage contention environment

the boot time of the eVM while the multiple coVMs run their workloads (generating I/O and memory interferences). First, we started n *coVMs* where $n \in [0, 15]$, and then we start one *eVM* to measure its boot duration. Each *coVM* utilises a separate physical core to avoid CPU contention with the *eVM* while running the *Stress* benchmark. The I/O (and respectively) memory capacity is gradually used up when we increase the number of *coVMs*. Finally, there is no difference between *all at once* and *one then others* boot policy because we measure the boot time of only one VM. Hence, we simply started the *eVM* with the *normal* boot process.

1) Booting one VM under I/O contention: Figure 12 shows the boot time of one VM on the three storage devices under an I/O-intensive scenario. *YOLO* delivers significant improvements in all cases. On HDD, booting only one VM lasts up to 2 minutes by using the *normal* boot policy. Obviously, *prefetching boot* and *YOLO* speed up boot duration much more than the *normal* one because the data is loaded into the cache in a more efficient way. However, the performance, which was almost similar for *YOLO* and the *prefetching boot* when manipulating one VMI (see Figure 10a), is now clearly different and in favour of *YOLO*.

The same trend can be found on SSD in Figure 12b where the time to boot the eVM increased from 3 to 20 seconds for the *normal* strategy, 3 to 6 seconds for the *prefetching boot*, and from 3 to 4 seconds for *YOLO*. While *YOLO* is faster than *prefetching boot* by a small amount, *YOLO* is up to 4 times faster than *all at once* policy under I/O contention of 15 coVMs. An interesting point is related to the CEPH scenario. When the *coVMs* are stressing the I/O, they generate a bottleneck on the NIC of the host OS, which impacts the performance of the write requests that are performed by the *eVM* during the boot operation. This leads to worse performance for *YOLO* and the *prefetching boot* strategies than in the HDD and SSD scenarios, ranging from 3 to 58 seconds and from 3 to 61 seconds respectively. However, it is still twice faster than the boot time of *all at once*, which is 107 seconds at 15 coVMs.

To sum up, on a physical node which already had I/O workloads, *YOLO* is the best solution to boot a new VM in a small amount of time. *YOLO* reduces the boot duration 5 times on local storage (HDD and SSD) and 2 times on remote storage (using CEPH).

2) Booting one VM under memory contention: We use this scenario to assess the influence of not having enough space to load and keep the boot images into the memory of both *prefetching boot* and *YOLO* strategies. Figure 13 gives the results we measured.

On HDD, the *normal* boot time can reach up to 4 times longer compared to the other two methods. With *prefetching boot*, the prefetched data stays in the memory to reduce the boot time until the page cache space is claimed. In this situation, the hypervisor might have to to read the prefetching data on the storage device once again. While comparing to *YOLO*, the boot data stays in *YOLO* memory space. For this reason, under memory-intensive environment, *YOLO* is almost 2 times faster than *prefetching boot* with 15 *coVMs* that stress the whole memory. On SSD, the different between *YOLO* and *prefetching boot* is small thanks to the performance of SSD. It is also true for CEPH, which has high read performance in general.

3) Summary: Using *YOLO* under I/O and memory intensive scenarios enables faster boot times in comparison to the normal boot approach. We underline that the gain should be even more important under when several VMs would be booted simultaneously under such intensive conditions. Regarding the memory impact, it would be interesting to conduct additional experiments in order to better understand the influence of the SWAP for *YOLO*. Indeed, when there is not enough memory at the host OS level, the *YOLO* daemon should be impacted by the SWAP mechanism. In such a case, it would be probably better to access boot images directly from a dedicated fast efficient storage device instead of putting the boot image into the *YOLO* memory. By such a way, it would be possible to prevent *YOLO* to suffer from SWAP operations. As we already observed in Figure 9, accessing directly a SSD device is almost similar in terms of performance than accessing the memory. Such an experiment under a memory intensive environment should be however performed to confirm this assumption.

D. yolofs *overhead*

Although booting VMs as fast as possible is the objective of our study, the performance of applications or services running inside VMs should be taken also into account. To this aim, we performed two different experiments to evaluate the I/O performance a VM can expect once it has been booted using the *YOLO* mechanism.

In the first experiment, we compared the read performance when accessing data stored in the backing file with the additional *yolofs* layer (*i.e.*, *yolofs* +ext4) and the straightforward way (*i.e.*, ext4 only). We evaluated both sequential and random access. For sequential read, we measured the time a VM needs to read sequentially a whole 2.5 GB file. For random read, we read randomly 868 MB on a 2.5 GB file. Table II presents the time we observed. The difference of read performance of a VM booted by the two methods is at worst 10%.

In the second experiment, we used *pgbench* [27] to measure PostgreSQL performance (in transactions per second). The VMI used in this experiment already contained pgbench benchmark (with PostgreSQL 9.4.17). We stored the 1.34 GB test database (with over 5 million rows of data) on a QCOW file of a VM. After booting the VM, we performed pgbench with the default TPC-B test (involving five *SELECT*, *UPDATE*, and *INSERT* commands per transaction). Table III presents the number of transactions per second when we used pgbench to access the database. The read/write accesses to the database of the VM is not handled by *yolofs* because the database is stored on the QCOW file and it is not located in the *yolofs* mount point. In other words, only I/O reads access to the files related to PostgreSQL application will go through *yolofs*. Consequently, *YOLO* has a similar performance compared to VM boot in a normal way.

To conclude, the overhead caused by FUSE in *YOLO* surfaces when a VM has to read big chunk of data on the backing file. However, in most practical cases, the backing file contains only essential application and system files that are shared with many VMs, other data of those VMs are stored on the QCOW file. This has been confirmed in a study [13], the authors showed that only a small fraction of the VMI is accessed by VMs

TABLE II: Time (second) to perform sequential and random read access on a backing file of VMs which are booted by normal boot and YOLO on three storage devices.

	HDD		**SSD**		**CEPH**	
	ext4	*yolofs* +ext4	ext4	*yolofs* +ext4	ext4	*yolofs* +ext4
Sequential Read	19.047 s	19.074 s	3.540 s	4.084 s	9.7 s	10.55 s
Random Read	13.405 s	13.553 s	6.408 s	6.692 s	11.27 s	12.25 s

TABLE III: The number of transactions per second (tps) when running *pgbench* inside a VM booted using *YOLO* and normal way on 3 types of storage devices.

	HDD	SSD	CEPH
yolofs	139	1205	145
Normal I/O path	140	1226	164

throughout its run-time. Accordingly, VMs booted by *YOLO* still maintain the same performance for running the applications or services.

VI. Related Work

Rapid VM deployment is one of the most important factors in a IaaS cloud service to provide dynamic scalability and fast provisioning. Many efforts have been made to improve the startup time of a new VM. In our discussion, we analysed the works that focus on improving the VM booting phase. As far as we known, these studies can be divided in groups by the techniques they used: cloning and resuming.

Potemkin [28] marks a parent VM memory pages as copy-on-write and shares these states to all child VMs. It can start new VM by cloning from that parent VM quickly since most memory pages are physically shared. On the contrary, Potemkin can only clone VMs within the same compute node. SnowFlock [6] and Kaleidoscope [7] are similar systems that can start stateful VMs by cloning them from a parent VM. SnowFlock utilises lazy state replication to fork child VMs which have the same state as a parent VM when started. Kaleidoscope has introduced a novel VM state replication technique that can speed up VM cloning process by identifying semantically related regions of states. Wu et al. [29] perform live cloning by resuming from the memory state file of the original VM, which is distributed to the compute nodes. The VM is then reconfigured by a daemon inside each cloned VMs that load the VM-metadata from the cloud manager. These systems clones new VMs from a live VM so that they have to keep many VMs alive for the cloning process. Another downside of the cloning technique is that the cloned VMs are the exact replica of the original VM so they have the same configuration parameters like IP or MAC address as the original's. Thus, the cloned VMs have to be reconfigured.

Several works [30], [31], [32], [8] attempt to speed up VM boot time by suspending the entire VM's state and resuming when necessary. To satisfy various VM creation requests, the resumed VMs are required to have various configurations combined with various VMIs, which leads to a storage challenge. If these pre-instantiated VMs are saved in a different compute node or an inventory cache and then they are transferred to the compute nodes when creating VMs, this may place a significant load on the network. Stripping the hardware state of VMs (includes vCPUs, memory or disk size, network interfaces, etc.) to the bare minimum VMs with only one vCPU avoids the pre-initiation of VMs with different configurations. So we have a bare minimum VM for each VMI. When a matching request arrives, this VM is resumed and its resources are hot-plugged to satisfy the request's requirements.

VMThunder+ [10] boots a VM then hibernates it to generate the persistent storage of VM memory data. When a new VM is booted, it can be quickly resumed to the running state by reading the hibernated data file. The authors use hot plug technique to re-assign the resource of VM. However, they have to keep the hibernate file in the SSD devices to accelerate the resume process. Razavi et al. [9] introduce prebaked μVMs, a solution based on lazy resuming technique to start a VM efficiently. To boot a new VM, they restore a snapshot of a booted VM with minimal resources configuration and use their hot-plugging service to add more resources for VMs based on client requirements. The authors only evaluated their solution by booting one VM with μVMs on a SSD device. However, VM boot duration is heavily impacted by the number of VM booted concurrently as well as the workloads are running on a system [12], thus, their evaluation is not enough to explore the VM boot time in different environments, especially, under high I/O contention.

VII. Conclusion

Starting a new VM in a cloud infrastructure is a long process. It depends on the time to transfer the VMI to the compute node and the time to perform the VM boot process itself. In this work, we focus on improving the duration of the VM boot process. This duration highly relies on the number of VM that boots simultaneously and the co-workloads running on the compute nodes. We discussed preliminary studies where we identified that the main factor is related to the amount of I/O requests. To mitigate as much as possible the I/O cost, we proposed *YOLO* as a new methodology to perform the read operations on the VMI during a VM boot process in an efficient manner. In our solution, we introduce the boot image abstraction which contains all the necessary data from a VMI to boot a VM. Boot images are stored on a dedicated fast efficient storage device and a dedicated FUSE-based file system is used to load them into memory and to serve boot's I/O read requests. We discussed several evaluations that show the benefit of *YOLO*. In particular, we showed that booting a VM with *YOLO* is at least 2 two times and in the best case 13 times faster than booting a VM in the normal way. While those results are promising, we should recognise that additional experiments must be performed to better understand the impact of the SWAP on *YOLO* benefits. Current experiments have been done by emulating non volatile memory devices using the same memory of other collocated workloads. It would be interesting to complete these experiments to analyse hybrid scenarios where several VMs are booted simultaneously under I/O and memory intensive environments. While using a dedicated SSD can guarantee better performance in comparison to the normal boot, understanding SWAP operations that are performed on the *YOLO* daemon is something to analyse.

Regarding ongoing and future works, we recently started several activities. First, we are investigating the interest of deduplication techniques to reduce the size of all boot images. More specifically, if several VMIs differ only in the set of installed applications and share a common underlying operating system, it would be interesting to generate only one boot image for these VMIs. This improvement should reduce the memory footprint of *YOLO* overall. Second, we are studying how it can be possible to redirect all the application's I/O requests to the Virtual Image disk directly, instead of going through *yolofs* after its boot. QEMU supports a feature to change the backing file of a running VM. Hence, it should be possible to leverage this mechanism to dismiss the FUSE mount point after the boot operation. However, this mechanism requires to restart the VM. To execute such a change in an online fashion, extensions at the hypervisor level are required. Finally, we are currently analysing whether it makes sense to complete the boot image abstraction with the data that is mandatory to start the application services. Current experiments have been done by using SSH as the end of the boot operation (in other words, we put in a boot image all the blocks that are mandatory to reach the start of SSH). The boot image creation process can be extended in order to include the data related to the boot plus the data related to the starting of the expected services. Doing so, it would enable efficient autoscaling (scale in/out techniques).

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