Apptainer Without Setuid

Dave Dykstra
Scientific Computing Division
Fermi National Accelerator Laboratory
Batavia, IL
https://orcid.org/0000-0003-2653-9015

Abstract—Apptainer (formerly known as Singularity) since its beginning implemented many of its container features with the assistance of a setuid-root program. It still supports that mode, but as of version 1.1.0 it no longer uses setuid by default. This is feasible because it now can mount squash filesystems, mount ext2/3/4 filesystems, and use overlays using unprivileged user namespaces and FUSE. It also now enables unprivileged users to build containers, even without requiring system administrators to configure /etc/subuid and /etc/subgid unlike other “rootless” container systems. As a result, all the unprivileged functions can be used nested inside of another container, even if the container runtime prevents any elevated privileges.

I. INTRODUCTION

Apptainer [1] (formerly known as Singularity [2]) was designed to provide a container platform that was easy to use by scientific applications on High Performance Computing (HPC) systems. Unlike other container platforms such as Docker [3] and Podman [4], it did not attempt to support all operating system functions. These differences explain why many of its design choices were different than other container platforms. It needed to support older operating systems which didn’t yet have many of the newer container-specific features of more recent Linux kernels. It needed to support containers with large numbers of small files, which when stored on an HPC’s high speed filesystem can put heavy loads on the filesystem’s metadata server. For those reasons and others, it was implemented based on using setuid-root functionality to run in namespaces and to mount image files that combined all the small files together into a single file. That moved the metadata operations to compute nodes, offloading the filesystem metadata server and resulting in improving performance with the container system compared to not using one. This was a large factor in its adoption by many users.

However, using setuid-root is always a security risk, and Apptainer has supported some common use cases without setuid-root for a long time. More recently Linux kernel support for unprivileged container operations has drastically improved. Apptainer version 1.1.0 takes advantage of enough of that new kernel support that it has been made non setuid-root by default.

II. NON-SETUID VS SETUID

Apptainer still optionally supports a setuid-root mode. That can be installed by either installing the pre-built apptainer-suid package in addition to the apptainer package, or by compiling with the −with-suid option.

Using the default non setuid-root mode has these advantages over using the setuid-root mode:

1. Setuid-root programs are notoriously difficult to make fully secure. Apptainer keeps the setuid portions to a minimum and has passed a careful review, but still it is a risk.

2. Linux kernel developers believe that it is inherently unsafe to allow unprivileged users to modify an underlying filesystem at will while kernel code is actively accessing the filesystem [5]. Kernel filesystem drivers do not and cannot protect against all kinds of modifications to that data which it has not itself written, and that fact could potentially be used to attack the kernel. Apptainer mounts images using the kernel PR_NO_NEW_PRIVS feature which prevents the most obvious modifications for obtaining elevated privileges (by setting setuid or setcap bits), and there are not currently any publicly known kernel attacks for this, but this is a significant risk.

3. Non-setuid Apptainer can run nested inside another Apptainer or inside any other container runtime that disallows elevating privileges.

However, there are also some disadvantages of the non setuid-root mode:

1. Mounting from unprivileged user namespaces makes use of FUSE filesystems, which run extra processes in user space. This has lower performance than kernel filesystems, but it is believed to not be a very significant overhead for most HPC workflows. Metadata operations are still moved to the node running the container, so it retains that big advantage over having many files directly on networked filesystems.

2. Encryption is not yet supported. In setuid-root mode, Apptainer uses kernel LUKS2 mounts to run encrypted containers without decrypting their content to disk. An unprivileged FUSE filesystem will hopefully be able to perform this operation in a future release.

3. Some little-used security and network options of Apptainer that give users elevated privileges through configuration are only available in setuid-root mode.

4. Apptainer configuration options that restrict the use of containers are not enforceable, because if unprivileged user namespaces are available then
people could compile their own copy from source and set their own configuration options.

Since the Linux kernel is subject to a much greater amount of scrutiny than the Apptainer setuid software, there have been a greater number of announced vulnerabilities that are exploitable through kernel namespace code than have been announced for Apptainer and its predecessor. Security experts generally argue that it is better to have the scrutiny than to have “security by obscurity”, but urgently responding to those vulnerabilities causes additional administrator effort and can cause disruption to operations. For this reason, the Apptainer project recommends disabling network namespaces where possible, because almost all the kernel vulnerabilities over the last few years that have been exploitable via user namespaces have also required network namespaces. Apptainer does not usually use network namespaces, although other popular container systems do.

III. UNPRIVILEGED FUSE MOUNTS

The primary kernel feature that non setuid-root Apptainer 1.1.0 depends on is unprivileged user namespaces. That has been available for a relatively long time, but more recently it was updated to support mounting FUSE filesystems completely unprivileged as well, even without the support of the setuid-root fusermount assist program. This support was even backported to Red Hat Enterprise Linux (RHEL) 7, which many HPC systems use, so it is reasonable for Apptainer to now expect that the capability is available. That functionality is now used to mount squash filesystems, ext2/3/4 filesystems, and to do overlayfs (when the kernel support for unprivileged overlayfs is not available).

A. Squash filesystems

Apptainer supports Singularity Image Format (SIF) container image files. It supports multiple partitions each with their own format, but the primary partition containing the image files is in squashfs format as supported by the Linux kernel. When running without setuid-root, Apptainer 1.1.0 mounts that partition using squashfuse which supports the squashfs format using FUSE. Squashfuse fortunately includes an option (although it is undocumented) to start at an offset into a file instead of its beginning, so it can be told where the partition starts in the SIF file.

B. Ext2/3/4 filesystems

The original Singularity container images were ext2/3/4 formatted filesystem images. Those are still supported, and the format is also still supported for overlay images both as separate files and as overlay partitions in SIF files. Apptainer 1.1.0 mounts those when running without setuid-root using fuse2fs which is a standard component of the e2fsprogs package. Unfortunately, it does not include an option to start at an offset into a file, so an additional LD_PRELOAD small library was written to support running as a partition in a SIF file.

Also unfortunately, the e2fsprogs package on RHEL 7 was too old to include fuse2fs, so it was installed as a separate fuse2fs package in the Extra Packages for Enterprise Linux (EPEL) yum repository for RHEL 7. It is already in a separate fuse2fs subpackage on all supported Debian-based systems.

C. Overlays

For the most common cases, Apptainer does not use any overlay system because by default image files are all in one layer and it can add bind mount points when needed by use of its lightweight (and as far as the author knows, unique) underlay feature. That feature makes use of scratch space for the root filesystem and bind mount points, and it bind mounts in all files from the original container image that are not overridden by other bind mounts.

Apptainer images are also readily by default, so it does not usually allow any other additions. It does however have an option to allow writability, and for that it uses overlayfs. The most recent Linux kernels include supporting overlayfs directly from unprivileged user namespaces. It’s not available on all operating systems that are actively used (for example it is not in RHEL7) plus it has restrictions on the types of filesystems it allows, so when it is not usable Apptainer 1.1.0 makes use of fuse-overlayfs.

IV. UNPRIVILEGED CONTAINER BUILDS

Building containers as unprivileged users is an especially challenging problem because that usually involves installing additional packages. That requires at least the appearance of running as root. Apptainer has for quite a while supported building containers with the --fakeroot option which made use of the same “rootless” container feature used by Podman, which makes use of an elevated-privilege program (or two) to map user and group ids for each user based on mappings that are set up in /etc/subuid and /etc/subgid. That feature has not been enabled on most systems that use Singularity or Apptainer because it requires system administrator setup and extra work to ensure that the mappings stay consistent across clusters.

In Apptainer 1.1.0, when an unprivileged user invokes the build command it assumes the --fakeroot option. It also extends the --fakeroot option to have additional modes that are easier to administer. Those modes are used both for building and for writable overlays. These are the ways that --fakeroot works depending on the conditions:

1. If the host is set up to map the current user via /etc/subuid and /etc/subgid mapping files, Apptainer will use that method first. This is the most complete emulation, also known as “rootless” mode, but it requires administrator setup. It also requires some elevated privilege assistance on the host, which means that it will not be able to run nested inside another container that disallows elevating privileges, as Apptainer does. Those elevated privileges on the host come from either a setuid-root install of Apptainer or via the host newuidmap and newgidmap commands.

2. Otherwise if unprivileged user namespaces are available, Apptainer will map only the root user id to the original unprivileged user. This method is sometimes called a “root-mapped user namespace”. Since this method is not as complete an emulation as
“rootless mode”, an info message showing it is happening is displayed.

3. If the “fakeroot” command is available on the host, Apptainer will use it in addition to a root-mapped user namespace. This command uses an LD_PRELOAD library to fake root privileges on file manipulation, telling programs that operations that would succeed as root have succeeded even though they really haven’t. This is useful for avoiding errors when building containers or when adding packages to a writable container, because many package installations attempt to do additional setup that only works as root. When the fakeroot command is used, an info message is displayed showing that. The combination of a root-mapped user namespace with the fakeroot command allows most package installations to work, but the fakeroot command is bound in from the host so if the host libc library is of a very different vintage than the corresponding container library the fakeroot command can fail. If that situation happens the user can try to run apptainer under the unshare -r command which is essentially the same thing as running in a root-mapped user namespace; in that case Apptainer will not try to run the fakeroot command even if it is in the user’s PATH. The idea to use the fakeroot command came from Charliecloud [6].

4. If user namespaces are not available but Apptainer has been installed with setuid-root and also the “fakeroot” command is available, then the fakeroot command will be run by itself. This allows some package installations to succeed but others will still fail; it is not as complete an emulation because the root-mapped user namespace causes the kernel to allow bypassing restrictions on files that are actually owned by the original user on the host, things that the fakeroot command cannot do by itself.

V. CONCLUSIONS

From a user point of view, a default Apptainer 1.1.0 installation works with almost all of the features that they were accustomed to with previous versions, plus it enables them to build containers without needing root privileges. From a system administrator’s point of view, the security risks are reduced and there is no need for the extra effort of setting up /etc/subuid and /etc/subgid files.

ACKNOWLEDGMENTS

This builds on the work of many others, including the original author, Gregory Kurtzer. Much advice was provided by long time developers Cedric Clerget and Ian Kaneshiro. The author’s work was performed using the resources of the Fermi National Accelerator Laboratory (Fermilab), a U.S. Department of Energy, Office of Science, HEP User Facility. Fermilab is managed by Fermi Research Alliance, LLC (FRA), acting under Contract No. DE-AC02-07CH11359.

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