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Distro Differences

Introduction

Linux distributions provide users with a wide array of options when choosing an operating system. Users typically anticipate that software designed for Linux should operate seamlessly across various distributions. Nonetheless, the responsibility falls on developers to ensure their applications are compatible with all the different distros. This book aims to establish a foundation that assists software engineers in creating more versatile programs. It does so by highlighting some of the key differences among Linux distributions that are significant for software development, as well as explaining how these diversities are first built into the distributions themselves.

In the Reproduction chapter, you will find guides on how you can also generate these distro differences for your own analysis.

Under the Distros section, you will find how these linux distributions are built from the ground up, which is where the divergence happens.

Under the Main Differences section, you will find some of the main differences between Linux distros, and how they may impact a software's portability.

This book hopes to be useful for all software engineers, sysadmins, and security researchers. This book, code used throughout, and results are all available on Github under the MIT License.

This document was created by *Ezri Zhu <https://ezrizhu.com>>_* as their final project for CS 497 Independent Study at the Stevens Institute of Technology, advised by Professor Michael Greenberg.

Testing Infrastructure

We can reproduce our experiments with Vagrant and Ansible. Vagrant is responsible for spinning up the VMs that we want, and Ansible is to run the experiments on these machines.

Ansible will read from the inventory file generated by Vagrant.

Currently, the Vagrant file is configured to use the libvirt provider. However, you can also use the VirtualBox provider that's provided by Vagrant by default.

First, please ensure Ansible, Vagrant, and the Vagrant Provider that you're using is installed and setup.

Second, clone the repository `git clone https://github.com/ezrizhu/cs497.git` and then delete the output directory `out` from the cloned repo.

To spin up the Vagrant environment and run the ansible playbook, simply run `sudo vagrant up`.

You can also easily modify the array of distros that you want to test on by editing the `Vagrantfile` in the repository.

Here is what it looks like.

Vagrantfile

```
config.vm.define "arch" do |arch|
  arch.vm.box = "archlinux/archlinux"
  arch.vm.provision "shell", inline: "sudo pacman --noconfirm --needed -Syy python pkg-config"
  config.vm.synced_folder '.', '/vagrant', disabled: true
end

config.vm.define "alma" do |alma|
  alma.vm.box = "generic/alma9"
  config.vm.synced_folder '.', '/vagrant', disabled: true
end

config.vm.provision "ansible", after: :all do |ansible|
  ansible.playbook = "playbook.yml"
end
```

For distros that may require some setup commands to be run, we're using the shell provisioner. The ansible provisioner will be run after that.

After Vagrant spins up all the VMs and run the shell provisioner if specified, it will run the ansible playbook.

Here's what that looks like.

playbook.yml

```
- hosts: all
  vars:
    commands:
      - cmd: uname -a
        output_dir: uname
      - cmd: ldd --version
```

```
        output_dir: ldd
      - cmd: whereis python
        output_dir: py_where
      - cmd: python --version
        output_dir: py_where
      - cmd: sudo sysctl kernel.unprivileged_userns_clone
        output_dir: userns_clone
      - cmd: unshare --map-root-user ping -c1 1.1
        output_dir: unshare_ping
      - cmd: ls -lah /sbin/init
        output_dir: init
```

You can also modify the array of tests that you want to run by editing the file.

After that is complete, the outputs of all of our experiments will be under `out/`.

When you are done running the experiments, run `vagrant destroy -f` to remove all the VMs Vagrant created.

A terminal recording of the vagrant execution is available.

Clickable Link

I also developed test scripts for some of the below differences to help extract the relevant data. They can be found under `tests/`, and will read the data from `out/` generated by the last steps.

Linux Distributions

By default, our Vagrant covers some of the popular Linux distributions.

RHEL (Red Hat Enterprise Linux) is one of the most popular Linux distribution developed by Red Hat. CentOS was one of the most common, free Linux distro until it was discontinued by Red Hat. Rocky Linux emerged to become it's community maintained successor. Fedora is also a community maintained desktop orientated rhel derivative. Oracle and Alma linux are both also rhel derivatives.

Debian is another one of the most popular Linux distributions, it is community maintained, with Ubuntu being one of the very popular corporate supported derivative.

Alpine Linux is another community maintained Linux distribution that is focused on simplicity. It uses a busybox instead of coreutils, and musl libc instead of glibc. It is very popular in container runtimes as it is very light weight.

Lastly, Arch and Gentoo are both power user focused Linux distributions that offers an incredible amount of user customization. They are both quite different as well.

`./tests/uname.sh`

Distro	OS	uname
RHEL	GNU/Linux	5.14.0-362.8.1.el9_3.x86_64 #1 SMP PREEMPT_DYNAMIC
CentOS	GNU/Linux	3.10.0-1160.105.1.el7.x86_64 #1 SMP
Rocky	GNU/Linux	5.14.0-362.13.1.el9_3.x86_64 #1 SMP PREEMPT_DYNAMIC
Fedora	GNU/Linux	6.6.8-100.fc38.x86_64 #1 SMP PREEMPT_DYNAMIC
Alma	GNU/Linux	5.14.0-362.13.1.el9_3.x86_64 #1 SMP PREEMPT_DYNAMIC
Oracle	GNU/Linux	3.10.0-1160.105.1.0.1.el7.x86_64 #1 SMP
Debian	GNU/Linux	6.1.0-17-amd64 #1 SMP PREEMPT_DYNAMIC Debian 6.1.69-1
Ubuntu	GNU/Linux	5.15.0-91-generic #101-Ubuntu SMP

Alpine	Linux	6.1.70-0-virt #1-Alpine SMP PREEMPT_DYNAMIC
Arch	GNU/Linux	6.8.8-arch1-1 #1 SMP PREEMPT_DYNAMIC
Gentoo	GNU/Linux	6.1.69-gentoo-dist #1 SMP PREEMPT_DYNAMIC

Debian

Debian is installed via debootstrap(debian) source.

A good amount of modifications to the kernel by the Debian team can be found in their linux repo

Their changes for other packages that Debian ships with can be found also in the debian gitlab. Such as procps.

Ubuntu

Ubuntu is also installed via debootstrap(ubuntu).

All of the source code for Ubuntu, as well as all the OS divergences from Debian and the mainline kernel, can be found on their git server

For example, the vm_max_map_count issue was patched in Ubuntu's procps package

Their fork of the Linux kernel can also be found here.

Alpine

Alpine's differences can be easily spotted because their build process is very simple. Their repository for packages build scripts also has the script to build the base system.

The base layouts directory.

The base layout build file.

Arch

Since Arch Linux is mostly less opinionated in terms of defaults, the only places where you can find where differences are built in on the distro levels is the installer.

Arch Linux Github Kernel Repo Installer Repo

Rocky

Rocky Linux is a community fork of CentOS after RedHat made it into stream only.

It's build process is similar to the rest of the RHEL derivatives. You can find the base package that builds the OS on their Gitlab. Which includes the default packages, sysctl.conf config, os-release file, etc...

rocky-release

Fedora

Fedora follows a similar install structure as the rest of the RHEL derivatives. You can find the fedora-release package on the fedora gitlab

Gentoo

The Gentoo base image comes from the stage3 tarball. Which is built with Catalyst using spec files.

They're all highly customizable and different. You can find the spec files in the catalyst repo

That said, if your user uses Gentoo, they are hopefully competent enough to make their own patch to your software.

Main Differences

libc

Most of the time we assume it would be fine if we are just compiling against glibc, however, in some cases, especially ones that runs your application in a alpine docker container, it may need to be compiled to musl libc.

There may also be other small tweaks that the upstream makes to glibc. i.e., Debain glibc patches Gentoo glibc patchset

`./tests/ldd.sh`

Distro	Vendor	Version	Extra
RHEL	GNU libc	2.34	
CentOS	GNU libc	2.17	
Rocky	GNU libc	2.34	
Fedora	GNU libc	2.37	
Alma	GNU libc	2.24	
Oracle	GNU libc	2.17	
Debian	Debian libc	2.36	2.36-9+deb12u3
Ubuntu	Ubuntu GLIBC	2.35	2.35-0ubuntu3.5
Alpine	musl	1.2.4	
Arch	GNU libc	2.39	
Gentoo	Gentoo glibc	2.37	2.37-r7 (patchset 10)

init

Systemd is a very common init system, however, for alpine, gentoo, and some other obscure distros, you may need to supply another form of service file. Such as a less declarative format i.e., a script.

`./tests/init.sh`

Distro	Init
RHEL	systemd
CentOS	systemd
Rocky	systemd
Fedora	systemd
Alma	systemd
Oracle	systemd
Debian	systemd
Ubuntu	systemd
Alpine	busybox
Arch	systemd
Gentoo	init

pkgconfig

`pkgconfig --list-all` lists all the pre-installed libraries.

RHEL, Rocky, and Alma all contain the same below set.

Arch and Gentoo comes with the largest sit due to the nature of compiling software on their distro, specifically Gentoo.

And most of the rest of the distros comes with very similar sets of libraries, such as openssl, udev, systemd, ncurses, panel, etc...

systemd

Systemd, being the most popular init system for Linux distros, can also be running different versions and compile flags.

	RHEL	CentOS	Rocky	Fedora	Alma	Oracle	Debian	Ubuntu	Arch
Version	252-18.el9	219	252-18.el9	253.14-1.fc38	252-18.el9	219	252.19-1~deb12u1	249.11-0ubuntu3.11	255.5-3-arch
PAM AUDIT SMACK UTMP ACL BLKID ELFUTILS KMOD XZ LZ4 LIBCRYPTSETUP	INCL	INCL	INCL	INCL	INCL	INCL	INCL	INCL	INCL
LIBFDISK PCRE2 IDN2 BZIP2 ZLIB ZSTD TPM2 P11KIT	INCL		INCL	INCL	INCL		INCL	INCL	INCL
SELINUX	INCL	INCL	INCL	INCL	INCL	INCL	INCL	INCL	EXCL
APPARMOR	EXCL	EXCL	EXCL	EXCL	EXCL	EXCL	INCL	INCL	EXCL
IMA	INCL	INCL	INCL	INCL	INCL	INCL	INCL	INCL	INCL
SECCOMP	INCL	EXCL	INCL	INCL	INCL	EXCL	INCL	INCL	INCL
GCRYPT	INCL	INCL	INCL	EXCL	INCL	INCL	INCL	INCL	INCL
GNUTLS	INCL	INCL	INCL	INCL	INCL	INCL		INCL	INCL
OPENSSL	INCL		INCL	INCL	INCL		INCL	INCL	INCL
SYSVINIT	INCL	INCL	INCL	INCL	INCL	INCL	INCL	INCL	EXCL

CURL	INCL		INCL	INCL	INCL		INCL	INCL	INCL
IDN	EXCL	INCL	EXCL	EXCL	EXCL	INCL	EXCL	EXCL	EXCL
IDN2	INCL		INCL	INCL	INCL		INCL	INCL	INCL
GNUTLS							EXCL		
FIDO2	EXCL		EXCL	INCL	EXCL		INCL	INCL	INCL
IPTC	EXCL		EXCL	EXCL	EXCL		INCL	INCL	INCL
PWQUALITY	EXCL		EXCL	INCL	EXCL		EXCL	EXCL	INCL
QRENCODE	EXCL		EXCL	INCL	EXCL		INCL	EXCL	INCL
BPF_FRAMEWORK	EXCL		EXCL	INCL	EXCL		EXCL		INCL
XKBCOMMON	INCL		INCL	INCL	INCL		EXCL	EXCL	INCL
P11KIT								EXCL	
default-hierarchy	unified		unified	unified	unified		unified	unified	unified

Environments and other shell behaviors

Your environments come from your shell. First, let's look into what your default shell is.

```
./tests/default_shell.sh
```

Distro	Default Shell
RHEL	/bin/bash
CentOS	/bin/bash

Rocky	/bin/bash
Fedora	/bin/bash
Alma	/bin/bash
Oracle	/bin/bash
Debian	/bin/bash
Ubuntu	/bin/bash
Alpine	/bin/bash
Arch	/usr/bin/bash
Gentoo	/bin/bash

It appears that they're all bash, which makes our lives easier.

To quote from the bash manpage

> When bash is invoked as an interactive login shell, or as a non-interactive shell with the --login option, it first reads and executes commands from the file /etc/profile, if that file exists. After reading that file, it looks for ~/.bash_profile, ~/.bash_login, and ~/.profile, in that order, and reads and executes commands from the first one that exists and is readable. The --noprofile option may be used when the shell is started to inhibit this behavior.

You can use your favorite diff tool to inspect the differences in all of these files from the out directory. Our test covers `.bash_profile`, `.bash_login`, `.profile` and `/etc/profile`.

First, for `/etc/profile`, RHEL, CentOS, Oracle, ALma, Fedora, and Rocky all have this following lines.

TODO

For `.bash_profile`, Alma, CentOS, Fedora, Gentoo, Oracle, RHEL, and Rocky all have lines to load `.bashrc` if it exists.

And CentOS and Oracle having a line to add `$HOME/.local/bin:$HOME/bin` to the PATH.

`.bash_login` was empty/nonexistant on all of the distros we tested against.

For `.profile`, only Ubuntu and Debian had these two files.

```
if [ "${PS1-}" ]; then
  if [ "${BASH-}" ] && [ "$BASH" != "/bin/sh" ]; then
    # The file bash.bashrc already sets the default PS1.
    # PS1='\h:\w\$ '
    if [ -f /etc/bash.bashrc ]; then
      . /etc/bash.bashrc
    fi
  else
    if [ "$(id -u)" -eq 0 ]; then
      PS1='# '
    else
      PS1='$ '
    fi
  fi
fi

if [ -d /etc/profile.d ]; then
  for i in /etc/profile.d/*.sh; do
    if [ -r $i ]; then
      . $i
    fi
  done
```

```
  unset i
fi
```

With Debian having this one extra block

```
if [ "$(id -u)" -eq 0 ]; then
  PATH="/usr/local/sbin:/usr/local/bin:/usr/sbin:/usr/bin:/sbin:/bin"
else
  PATH="/usr/local/bin:/usr/bin:/bin:/usr/local/games:/usr/games"
fi
export PATH
```

File Structures

With Linux's "everything is a file" model, developers tend to make certain assumptions about the system provided psudo-filesystems such as the root tree, procfs, and sysfs. But could those directories change?

Root FS

./tests/root.sh outputs resulting, filtered files to out/root

We are also able to confirm that boot, dev, etc, home, mnt, opt, proc, root, run, srv, sys, tmp and usr exists on all of our distros.

To generate our table, we are also running this to exclude the dir thats standard across all distros.

```
for i in *.result; do echo -n "$i -> " && cat $i | egrep -v "\.|boot|dev|etc|home|mnt|opt|proc|root|run|srv|sys|tmp|usr" | tr -d "\n" && echo ;done
```

And for the remaining directories.

	RHEL	**CentOS**	**Rocky**	**Fedora**	**Alma**	**Oracle**	**Debian**	**Ubuntu**	**Arch**	**Gentoo**	**Alpine**
afs media	X		X	X	X						
media	X	X	X	X	X	X	X	X		X	X
snap								X			
distfiles										X	

Proc FS

`./tests/procfs.sh` outputs resulting, filtered files to out/root Then, use your favorite diff tool to visually inspect the differences.

```
vim -d debian.out.result alma.out.result  alpine.out.result  arch.out.result  centos.out.result fedora.out.result
vim -d debian.out.result gentoo.out.result  oracle.out.result  rhel.out.result  rocky.out.result  ubuntu.out.result
```

	RHEL	**CentOS**	**Rocky**	**Fedora**	**Alma**	**Oracle**	**Debian**	**Ubuntu**	**Alpine**	**Gentoo**	**Arch**
bootconfig	X		X	X	X			X		X	X
dynamic_debug	X		X	X	X		X	X	X	X	X
config.gz										X	X
kcore	X	X	X	X	X	X	X	X	X	X	X
kpagecgroup	X		X	X	X		X	X	X	X	X
latency_stats				X					X		

mdstat	X	X	X	X		X		X	X	X	
pressure				X			X	X		X	X
sched_debug		X				X					
scsi	X	X	X	X		X		X	X	X	
slabinfo	X	X	X	X	X	X	X	X		X	X
thread-self	X		X	X	X		X	X	X	X	X
timer_stats		X				X					
version_signature								X			

Sys FS

Simply use your favorite diff tool to look at all the .out files at out/sysfs

```
vim -d debian.out gentoo.out oracle.out rhel.out rocky.out ubuntu.out
vim -d debian.out alma.out alpine.out arch.out centos.out fedora.out
```

We're able to see that they're all the same.

Dev FS

You can use your favorite diff tool to visually inspect the differences.

```
vim -d debian.out.result gentoo.out.result  oracle.out.result  rhel.out.result  rocky.out.result  ubuntu.out.result
vim -d debian.out.result alma.out.result  alpine.out.result  arch.out.result  centos.out.result fedora.out.result
```

We're able to see that the below are always there in the distros that we're testing against.

```
block bus console cpu_dma_latency disk fb0 fd full input kmsg kvm log mem mqueue null port ptmx pts random rtc0 shm stderr stdin stdout tty vcs urandom zero
```

Sudo Secure Path

Sudo secure path is the path that is used when a user uses sudo.

When you write an administrative tool and expects something to be only executed with root permissions, you might install something to one of the sbin directories.

One notable divergence is that on any of the RHEL derivatives, */usr/local/bin* is not included in sbin, while every other distro we tested with has it in the secure path.

`./tests/secure_path.sh`

Distro	/sbin	/bin	/usr/sbin	/usr/bin	/usr/local/sbin	/usr/local/bin	/snap/bin	/var/lib/snapd/snap/bin
RHEL	X	X	X	X				
CentOS	X	X	X	X				
Rocky	X	X	X	X				
Fedora	X	X	X	X	X	X		X
Alma	X	X	X	X				

Oracle	X	X	X	X				
Debian	X	X	X	X	X	X		
Ubuntu	X	X	X	X	X	X	X	
Alpine	X	X	X	X	X	X		
Arch	X	X	X	X	X	X		
Gentoo	X	X	X	X	X	X		

kernel config and sysctl

Kernel config, the configuration that the Linux kernel is compiled with, as well as the runtime kernel parameters(sysctl), can also vary drastically across distros.

I.e., all RHEL based distros have a lowered swappiness because they were originally built for server workloads. optimized for server workloads.

`vm.swappiness`

Distro	Swappiness
RHEL	30
CentOS	30
Rocky	30
Fedora	30
Alma	30
Oracle	30
Debian	60
Ubuntu	60
Alpine	60
Arch	60
Gentoo	60

For this divergence point, we're recording each distro's *sysctl -a* runtime params, and the */boot/config-$(uname -r)* kernel config(compiled in).

Please note that arch linux does not come with the config file, and alpine stores them under a non-standard name under */boot*, they have been manually extracted into the out directory as `alpine-kernel-config` (taken from /boot/config-virt) and `arch-kernel-config` (taken from `/proc/config.gz`)

Here, you can see the differences to the system request key, how they're written in the kernel config (capitalized), and sysctl (lowercase).

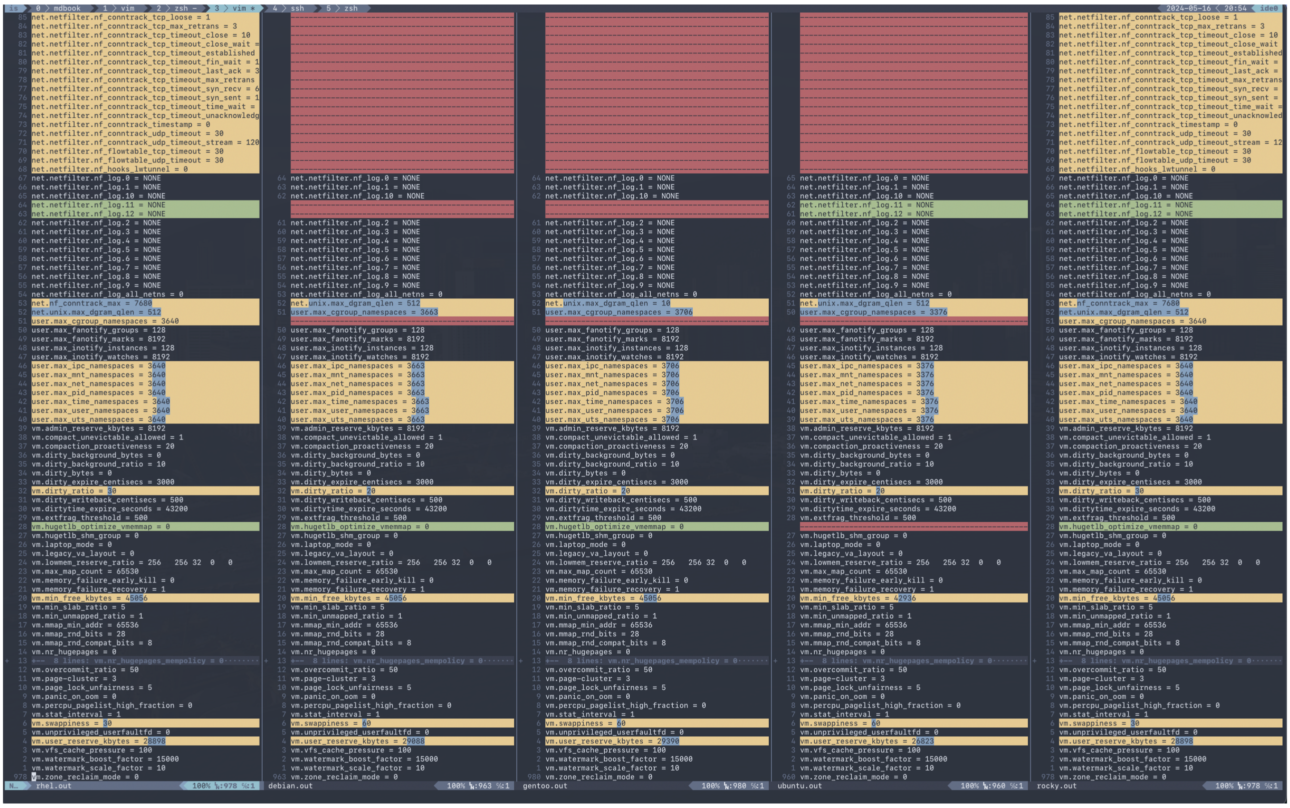
`./tests/sysrq.sh`

Distro	kernel.sysrq	CONFIG_MAGIC_SYSRQ_DEFAULT_ENABLE
RHEL	16	0x1
CentOS	16	

Rocky	16	0x1
Fedora	16	0x0
Alma	16	0x1
Oracle	16	
Debian	438	0x01b6
Ubuntu	176	0x01b6
Alpine	1	0x1
Gentoo	0	0x0
Arch	16	0x0

sysrq docs

There are a lot of other differences, such as the strictness of it's network protocols, as well as virtual memory parameters. Please also use your favorite diffing tool in the out directories for *sysctl* and *kernel_config* to explore the differences.



See also:

kernel.org kernel params docs

`man 5 proc`

> /proc/config.gz (since Linux 2.6) This file exposes the configuration options that were used to build the currently running kernel, in the same format as they would be shown in the .config file that resulted when configuring the kernel (using make xconfig, make config, or similar). The file contents are compressed; view or search them using zcat(1) and zgrep(1). As long as no changes have been made to the following file, the contents of /proc/config.gz are the same as those provided by:
>
> cat /lib/modules/$(uname -r)/build/.config
>
> /proc/config.gz is provided only if the kernel is configured with CONFIG_IKCONFIG_PROC.

From our suite of distros, only arch and gentoo comes with a config.gz in proc.

sh

When writing POSIX compliant scripts for usually systems purposes. We tend to use /bin/sh as our shabang. However, they're usually just symlinks to other shell interpreters. Most of the time it is bash with restricted shell (see man 1 bash, under Restricted Shell).

However in other times, it may be to busybox, or dash.

Distro	/bin/sh
RHEL	/bin/bash
CentOS	/bin/bash
Rocky	/bin/bash
Fedora	/bin/bash
Alma	/bin/bash
Oracle	/bin/bash
Debian	/bin/dash
Ubuntu	/bin/dash
Alpine	/bin/busybox
Arch	/bin/bash
Gentoo	/bin/bash

Notable Instances of Divergence

vm_max_map_count

This one is more recent, certain Windows games crash on Linux due to a not high enough maximum number of memory map areas a process may have. To improve Linux on Desktop's experience for many gamers, distros have begun to increase that setting by default.

Arch Announcement <https://archlinux.org/news/increasing-the-default-vmmax_map_count-value/>`__

Arch Mailing List <https://lists.archlinux.org/archives/list/arch-dev-public@lists.archlinux.org/thread/5GU7ZUFI25T2IRXIQ62YYERQKIPE3U6E/>`__

Ubuntu bug report <https://bugs.launchpad.net/ubuntu/+source/linux/+bug/2057792>`__

Ubuntu Patch <https://git.launchpad.net/ubuntu/+source/procps/commit/?h=applied/2%254.0.4-4ubuntu2&id=b4a4a046cf018a942598e55f3fbc7b5ef474f676>`__

Fedora wiki on the change <https://fedoraproject.org/wiki/Changes/IncreaseVmMaxMapCount>`__

NixOS PR

See also: kernel docs on max-mem-count

Userspace Namespaces

The security of userspace linux namespaces has always been under debate. For a while, a few distros had it disabled via a kernel patch.

```
λ ./tests/userns_clone.sh
arch.out -> kernel.unprivileged_userns_clone = 1
debian.out -> kernel.unprivileged_userns_clone = 1
ubuntu.out -> kernel.unprivileged_userns_clone = 1
```

Although now, they have now been reverted back to default allowed.

Arch Source

Debian Patch

See also

ping

Sometimes, ping will not work in an unshare namespaced environment.

```
λ ./tests/ping.sh
centos.err -> unshare: unshare failed: Invalid argument
debian.err -> ping: socktype: SOCK_RAW ping: socket: Operation not permitted
gentoo.err -> ping: socktype: SOCK_RAW ping: socket: Operation not permitted
oracle.err -> unshare: unshare failed: Invalid argument
```

However, we're able to pinpoint exactly why that happens from another experiment.

`./tests/ping2.sh` then we're mapping the output data of the sysctl option of `net.ipv4.ping_group_range` to a table below.

Distro	Min	Max
RHEL	0	2147483647
CentOS	1	0
Rocky	0	2147483647
Fedora	0	2147483647
Alma	0	2147483647
Oracle	1	0
Debian	1	0
Ubuntu	0	2147483647
Alpine	999	59999
Arch	0	2147483647
Gentoo	1	0

This gets the data from sysctl. And we're able to see that centos, debian, gentoo, and oracle all has the ping group range set to 0 and 1, which are only privileged groups. Although on Centos and oracle it fails earlier due to the unshare userspace package lacking one of the flags we're invoking.

However, on userspace in those distros you're able to ping due to the capabilities set on the ping binary, which was somehow dropped when we enter into the unshared environment.

Thanks for reading.