Introduction to Charliecloud

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Charliecloud Team (Current)

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Krishna Chilleri
Agenda

01 What are containers?

02 What is Charliecloud?

03 Fully unprivileged build
What are containers?
Users need different software

Standard HPC software stacks have a specific purpose:
- Specifically: MPI-based physics simulations

What if your thing is different?
- non-MPI simulations
- Artificial intelligence
- Spicy software dependencies

Admins will install software for you
- **IF** there is enough demand
- Unusual software needs go unmet
User-defined software stacks

BYOS (bring your own software)

- Lets users install software of their own choice
- ... up to and including a complete Linux distribution
- ... and run it on compute resources they don’t own

But, possible problems include ...

- Missing functionality
  - high speed network, accelerators, filesystems
- Performance
  - many opportunities for overhead
- Security problems
  - multiple root exploits
- Excessive complexity
  - See Spack
A container is **not**

- a lightweight virtual machine
  - or something you boot
- a container image
  - filesystem tree
- something that requires a specific tool
- the container runtime itself
  - ex. Docker

A container is

- a process
  - with its own view of kernel resources
  - or perhaps a group of processes sharing that view

An **image** is: said filesystem tree

*In whatever form it takes*
Containers are just processes!

Containers are mostly for abstraction/encapsulation.

- Moving between containers is explicitly supported.
- `setns(2)`, `/proc`, etc.

Privileged/setuid containers need more to be safe.

- SELinux/AppArmor, `seccomp-bpf`, etc.
- (this is hard! Lots of CVEs)

Unprivileged containers get kernel safety measures

- Lots of smart people’s time has gone into this
- You already trust the Linux kernel to keep unprivileged processes secure. Keep doing that.
Container Ingredients

01 Linux namespaces
- **Mount**: filesystem tree and mounts
- **PID**: process IDs
- **UTS**: host name
- **Network**: all other network stuff
- **IPC**: System V and POSIX
- **User**: UID/GID/capabilities

02 cgroups: limit resource consumption per process

03 `prctl(PR_SET_NO_NEW_PRIVS)`

04 `seccomp(2)`

05 SELinux, AppArmor, etc.
### Charliecloud privilege taxonomy

<table>
<thead>
<tr>
<th>type</th>
<th>namespace</th>
<th>setup</th>
<th>IDs in container</th>
<th>examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>mount</td>
<td>privileged</td>
<td>shares UID and GID with host</td>
<td>Docker, Singularity, Podman</td>
<td></td>
</tr>
<tr>
<td>mount + privileged user</td>
<td>privileged</td>
<td>arbitrary UIDs and GIDs separate from host</td>
<td>Singularity, Podman (rootless)</td>
<td></td>
</tr>
<tr>
<td>mount + unprivileged user</td>
<td>unprivileged</td>
<td>only 1 UID and 1 GID in container</td>
<td>Charliecloud</td>
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</table>

Priedhorsky, Canon, Randies, Younge. SC21. [https://dx.doi.org/10.1145/3458817.3476187](https://dx.doi.org/10.1145/3458817.3476187)
Reproducibility

Distros have been working on bit-identical software builds for years and *(plot twist)* it’s still not done

- e.g., timestamps get embedded everywhere

Prescriptive builds do help.

- e.g., Dockerfile ⇒ standard

But unsolved challenges remain

- FROM centos:7 ⇒ maybe different tomorrow
- FROM centos:9f38484 ⇒ maybe gone tomorrow
What is Charliecloud?
Charliecloud Philosophy

1) transparent; not opaque

- Treat containers as regular files
- Examine/debug containers with standard UNIX tools
- Things should be explicit
Charliecloud Philosophy

2) simple; not complex

- Everything is a user process
- Implement the right features; Minimize dependencies
- Use mount and user namespaces only
- Embrace UNIX: make each program do one thing well
Charliecloud Philosophy

3) trust the kernel

Don’t maintain a security boundary

Stay unprivileged

Avoid responsibility
Charliecloud Components

- **ch-run(1)**: C: container runtime
- **ch-image(1)**: Python: Docker interpreter a.k.a “builder”; push/pull/etc.
- **“glue”**: POSIX sh: helper scripts for image conversions & foreign builder wrapping
Performance impact: probably zero

SysBench

HPCG

Torrez, Randles, Priedhorsky / CANOPIE Workshop @ SC, 2019
03 Fully Unprivileged Builds
Basic Pitch

- Users want more flexibility
- Containers need root to build
- Build on generic x86 VMs
- Low-privilege containers?

| Containers                  | HPC policy mismatch
|-----------------------------|----------------------
| HPC hardware mismatch       | Build directly on HPC

**The Key:** Linux user namespaces
- New taxonomy of container privilege
- Fully-unprivileged Charliecloud

- Better workflow now & future is bright
Container image workflow

1. **laptop/workstation**
   - **build** ➔ **test** ➔ **run**

2. **CI/CD virtual machine**
   - **build** ➔ **test** ➔ **run**

3. **supercomputer**
   - **run**

- **Old 1**
  - **root ⇒ easy**
  - **generic x86-64**
  - **uninformative**

- **Old 2**
  - **specific arch**, **unprivileged**

- **Solution?**
  - **low privilege?**
# Charliecloud privilege taxonomy

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<td>mount</td>
<td>privileged</td>
<td>shares UID and GID with host</td>
<td>Docker, Singularity, Podman</td>
</tr>
<tr>
<td>II</td>
<td>mount + privileged user</td>
<td>privileged</td>
<td>arbitrary UIDs and GIDs separate from host</td>
<td>Singularity, Podman (rootless)</td>
</tr>
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<td></td>
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<td>unprivileged</td>
<td>only 1 UID and 1 GID in container</td>
<td>Charliecloud</td>
</tr>
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Only **Type III containers** are fully unprivileged throughout the container lifetime.

Priedhorsky, Canon, Randies, Younge. SC21. [https://dx.doi.org/10.1145/3458817.3476187](https://dx.doi.org/10.1145/3458817.3476187)
### Build options

<table>
<thead>
<tr>
<th>type</th>
<th>namespace</th>
<th>setup</th>
<th>IDs in container</th>
<th>approach</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>mount</td>
<td>privileged</td>
<td>shares UID and GID with host</td>
<td>sandboxed build system</td>
</tr>
<tr>
<td>II</td>
<td>mount +</td>
<td>privileged</td>
<td>arbitrary UIDs and GIDs separate from host</td>
<td>privileged helper tools; careful configuration</td>
</tr>
<tr>
<td></td>
<td>privileged user</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>III</td>
<td>mount +</td>
<td>unprivileged</td>
<td>only 1 UID and 1 GID in container</td>
<td>fakeroot(1) wrapper</td>
</tr>
<tr>
<td></td>
<td>unprivileged user</td>
<td></td>
<td></td>
<td></td>
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Charliecloud Components

- **ch-run(1)**: C: container runtime
- **ch-image(1)**: Python: Docker interpreter a.k.a. "builder"; push/pull/etc.
- **"glue"**: POSIX sh: helper scripts for image conversions & foreign builder wrapping

*Type III*
## Type II vs. Type III build

<table>
<thead>
<tr>
<th>type</th>
<th>Unprivileged?</th>
<th>File Ownership</th>
<th>ID Management on Host</th>
<th>Works with Network FS</th>
<th>No Root Emulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>II</td>
<td>mostly</td>
<td>preserved</td>
<td>security boundary</td>
<td>no</td>
<td>yes</td>
</tr>
<tr>
<td>III</td>
<td>fully</td>
<td>flattened</td>
<td>only 1 UID and 1 GID in container</td>
<td>yes</td>
<td>no</td>
</tr>
</tbody>
</table>
New Root Emulation Mode: seccomp

- Why do we need this?
  - We need to tell programs that we have real root privileges even though we are running as a normal user

- Uses the kernel’s seccomp(2) system call filtering to intercept certain privileged system calls, do absolutely nothing, and return success to the program
New Root Emulation Mode: `seccomp`

- **Advantages:**
  - Simpler
  - Faster
  - Completely agnostic to libc
  - Mostly agnostic to distribution

- **Disadvantages:**
  - Lacks consistency

- **Our previous root emulation mode, fakeroot, has already been adopted by SingularityCE and Apptainer.**
Charliecloud User Group

- If you want to join our low traffic mailing list for more information: https://groups.io/g/charliecloud

- Charliecloud User Group Meetings: First Tuesday of the month, 10 am - 11 am MDT; virtual

- Full tutorial: https://hpc.github.io/charliecloud/tutorial.html
04
Interactive Demo
Pre-Demo Notes

- User namespaces are enabled on the compute nodes and not the front-end nodes at this time.
- Access to internet resources is allowed on the front-end nodes and not the compute nodes.

**Suggestion:** have 2 tabs open, one with access to a front-end node and one with access to a compute node.
Introduction to Charliecloud

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LA-UR 24-24388
Thanks

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