Charliecloud

Unprivileged Containers for HPC

Michael Jennings (@*mej0*) ***mej@lanl.gov***
Reid Priedhorsky *reidpr@lanl.gov*
Tim Randles *trandles@lanl.gov*

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Los Alamos National Laboratory

- Established in 1943 as “Site Y” of the Manhattan Project to create atomic bomb
- Mission: To solve National Security challenges through Scientific Excellence
- Part of the NNSA “Tri-Lab” partnership with Lawrence Livermore and Sandia Labs
- We perform a wide variety of classified and open scientific research and development.
- Funded primarily by the Department of Energy, we also do extensive work for/with the Departments of Defense and Homeland Security, the Intelligence Community, et al.
- Our strategy reflects US government priorities including nuclear security, intelligence, defense, emergency response, nonproliferation, counterterrorism, and more.
- We help to ensure the safety, security, and effectiveness of the US nuclear stockpile.
- Since 1992, the United States no longer performs full-scale testing of nuclear weapons. This has necessitated continuous, ongoing leadership in large-scale simulation capabilities realized through investment in high-performance computing.

LANL HPC Division

- LANL’s history in high-performance computing is long and storied, dating back to the early ‘50s.
- Accomplishments include:
  - Helped IBM develop the 1st transistor-based supercomputer, Stretch
  - Our CM-5 was #1 on the inaugural Top500 List
  - The 1st vector computer, Cray-1, deployed here
  - 1st hybrid supercomputer (using IBM POWER and PlayStation Cell processors), Roadrunner, was also 1st to break the PetaFLOP/s barrier
- Led by Gary Grider, creator of Burst Buffer technology

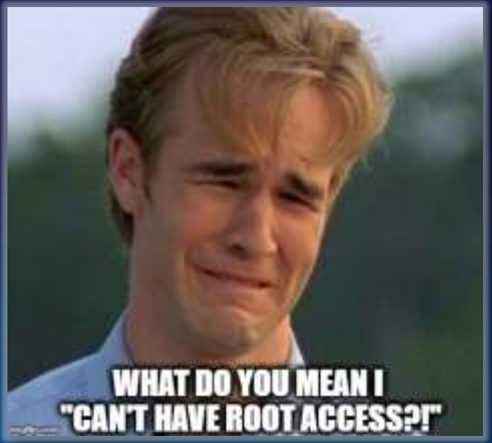
- We support over 2000 unique users across more than 100 different classified/open science projects on 20+ clusters

Serial
MANIAC
MANIAC II
IBM 701
IBM Stretch
CDC 6600
Vector
Cray-1
Cray-XMP
Cray-YMP
Massively Parallel
CM-2
CM-5
Cray T3D
Cluster
Blue Mountain
Pink
Hybrid Cluster
Roadrunner
70+ years of computing for science in the national interest

First World Problems in HPC

Problem #1: HPC clusters have narrowly focused software stacks.

- They do serial and parallel-MPI tasks well...but that's it.
- Compute node images are often in RAM/NFS & kept small.
- Managing multiple OSs, and required expertise, is rare & labor intensive.



Problem #2: We're old. And not getting any younger.

- Schools are teaching clusters, "parallel"/scalable/distributed software development...but usually "embarrassingly parallel" (e.g., map/reduce)
- All the "cool kids" are using Ubuntu (or Arch, or Alpine...), not RHEL
- Modern Machine Learning and Data Analytics toolsuites are non-trivial

Problem #3: We are finite, as is our time.

- We generally won't install extra software with low user demand.
- Unique or unusual use cases tend to be lower priority.
- The line between "innovator" and "crackpot" is often rather blurry….

The Solution: UDSS/UDI/BYOE

User-Defined Software Stacks (UDSS) allow users to supply not only their own applications/source to run on HPC systems but also the environment -- up to and including entire OS images -- in which they should run!

Advantages include portability, usability, consistency, time savings…

Potential disadvantages include missing functionality (HSN, accelerators, filesystems), performance degradation; thus, addressing these should be part of the design of any HPC-focused solution!

In rare, specific cases, certain packages may address this independently by building static binaries or otherwise coupling dependencies with executables

- Works everywhere
- No privileges required
- Requires build-time support
- May or may not be feasible
- For everyone else, our options are...

Option #1: Compile It Yourself

Advantages

- Available everywhere immediately
- Requires no privileges
- No additional privacy/security risk
- Direct access to all hardware
- No performance penalty
- Theoretically applies to any open source software library/app/stack

Disadvantages

- It’s the 21st Century; we no longer *want* to party like it’s 1999!
- Tedious and time-consuming
- Error-prone with exponential propagation of errors/time-to-fix
- Hard to update; start over each time
- No standard workflow/reproducibility
- Provides neither portability nor consistency

Nope.

Option #2: Environment Manager

Advantages

- Available for most IA32/x64 systems
- Requires no privileges
- No additional privacy/security risk
- Direct access to all hardware
- No performance penalty

Disadvantages

- Frequently still requires building from source (time/space constraints)
- Varying degrees of HPC support
- Varying degrees of reproducibility, portability, consistency, workflow
- Users/consultants bear entire burden

If You Must…

- Good options include EasyBuild, Lmod, Spack
- Also Anaconda, nixOS

"There's GOT to be a BETTER WAY!!"

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Option #3: Virtualization (VMs)

Advantages

- Ultra-flexible (any kernel/OS/arch)
- Strong-to-complete isolation
- Common use cases perform well

Disadvantages

- Performance suffers for most HPC use cases, often significantly
- Performance/isolation tradeoffs
- Infrastructure can be complex
- Direct/performant access to hardware may require privileges
- Not all “exotic” HPC hardware supported
- Entire OS must be provisioned and booted, separate hostname/IP, etc.

Should HPC become the Cloud?

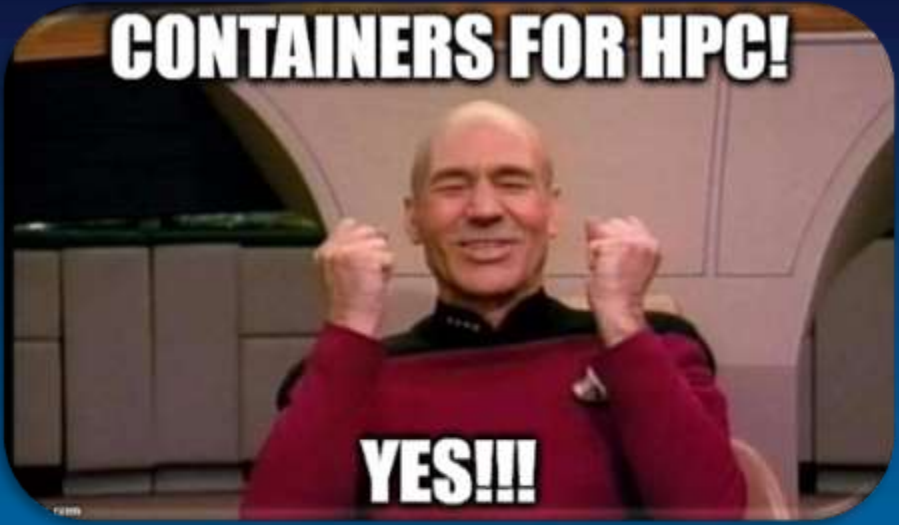
Option #4: Containers

Advantages

- Enough flexibility (only share kernel)
- Enough isolation (namespaces, etc.)
- Standard, reproducible workflow
- Bare-metal performance (or close)
- Minimal or no user/consultant burden (presumes correct solution choice)
- Extremely simple and easy-to-use (presumes correct solution choice)

Disadvantages

- Require recent Linux kernel/distro (SLES 12SP2, RHEL 7.4, Ubuntu 16.04, Linux LTS 4.4/4.9) ***or*** privilege
- Occasional growing pains due to newness (feature-complete in 2013)
- Container expertise in HPC still rare; thus, bad/misleading info & myths are ubiquitous (even in publications)!



Should HPC use containers?

So...Umm...These Container Things...Like, What Are They?

Good question! Not everyone agrees. Here's our take.

Linux Containers:

- Use one or more kernel ***namespaces*** to provide isolation for (i.e., "contain") a process (along with its child processes, if any);
- Envelope/restrict the process(es) such that escape/escalation is "impossible;" and
- Facilitate application security by providing capability constraints, integrity assurance, and content validation as required via industry-standard formats and workflows.

Namespaces, You Say?

The Linux Kernel supports 6 namespaces as of version 3.8, 7 as of 4.6.

- 6 Privileged Namespaces (require `CAP_SYS_ADMIN` to create)
  - `mount` – Private filesystem mount points, recursion/propagation controls
  - `pid` – Private view of process IDs and processes, `init` semantics
  - `uts` – Private hostname and domainname values
  - `net` – Private network resources (devices, IPs, routes, ports, etc.)
  - `ipc` – Private IPC resources (SysV IPC objects, POSIX msg queues)
  - `cgroup` – Private control group hierarchy (Linux 4.6+ only)
- 1 Unprivileged Namespace (requires no special capabilities to create)
  - `user` – Private UID and GID mappings
    - Can be combined with other namespaces, even if unprivileged
- System Call API: `unshare(2)`, `clone(2)`, `setns(2)`

Further reading: “Namespaces in Operation” (https://lwn.net/Articles/531114/)

Additional Container Elements

The Linux kernel has several additional subsystems that containers use:

- `cgroups` – Control hierarchical resource management and constraints
  - Latest kernels (4.6+) even have namespaces for this!
  - This is how modern schedulers/RMs track and control job resource utilization
- `seccomp-bpf` – Berkeley Packet Filter-based system call filtering
  - Frequently used to prevent containers from exceeding their scope
- `prctl(PR_SET_NO_NEW_PRIVS)` – Prevent privilege escalation
  - Permanent, kernel-level flag that prevents `execve()` ever granting privileges
  - Preserved across all calls to `fork()`, `clone()`, and `execve()`
- SELinux – MLS/MAC Labeling system for filesystems and applications
  - Allows admins precise control over actions, roles of applications
- AppArmor – Profile-based MAC system for limiting applications' abilities
  - Similar to SELinux but without filesystem labeling features

The Container Landscape

Full-featured Container Systems

- Support building, distribution, validation, and execution
- Provide for complete handling of containers throughout lifecycle
- Examples: Docker, CRI-O, LXC/LXD
- Most modern container engines now implement Open Container Initiative (OCI) Image and/or Runtime Spec(s)
- Building containers is still a per-system function. OCI does NOT “do” building!
  - `Dockerfiles` are the de facto standard; robust, capable DSL
  - CoreOS Rocket supplied `acbuild` based around traditional shell-fu
  - ProjectAtomic `buildah` does both!

Lightweight Container Systems

- Generally only provide runtime; most leverage Docker/OCI/K8s ecosystem
- Tend to require existing directory tree (i.e., flattened image) to run in
- Examples: RunC, CCon, NsJail, `unshare(1)`, `systemd-nspawn(1)`
- …and of course, Charliecloud!

Let’s Talk Security

Modern Cybersecurity requires many layers; true security isn’t merely the absence of access but rather the presence of protection!

- Prior to invocation, container security relies on a wide variety of content assurance methodologies (e.g., non-repudiation, CAS) to insure end-to-end transport safety.
- At runtime, container security relies entirely on the separation of authorities/roles within the Linux kernel (e.g., seccomp, MLS). **If the kernel fails, the container fails**.
- Lightweight container solutions have the advantage of leaving much of that to others.
- Most mindshare is in Linux kernel hardening and native unprivileged containers.

SECURITY
YOU KEEP USING THAT WORD. I DO NOT THINK IT MEANS WHAT YOU THINK IT MEANS.

All container solutions expose (formerly) privileged operations to unprivileged users, requiring us to accept a new security boundary! So, do you want:

- *one that’s new and known to be flawed?*
- *a well-understood one that still relies on setuid 0?*
- *the one that provides all relevant information to the kernel regarding separation of privilege?*

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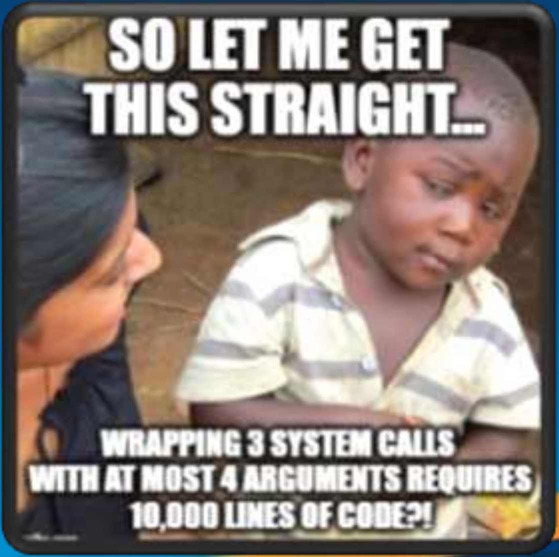
Why Charliecloud?

- Docker/Moby aren't (yet?) a good fit for HPC:
  - Performance - OverlayFS is slooooooow due to layering
  - Integrity - File removal is done by "whiting out" which causes certain subtle issues
  - Associativity - Docker containers are children of daemon, not CLI
- NERSC's Shifter offers appealing user experience but has overhead
  - User downloads container(s) from Docker Hub, submits jobs to run in them
  - Admin must set up & maintain Image Gateway
  - Relies primarily on `chroot()`; requires setuid-root
- Small/simple APIs should yield small/simple code!
  - Charliecloud weighs in at ***fewer than 1000*** LoC
  - Compare to NSJail (4,000), Shifter (19,000), Singularity (15,000), and Docker (160,000)!
- Charliecloud's security boundary <u>**is**</u> the kernel
  - Also worth watching: Moby, Rootless RunC, CRI-O


SO LET ME GET THIS STRAIGHT...
WRAPPING 3 SYSTEM CALLS WITH AT MOST 4 ARGUMENTS REQUIRES 10,000 LINES OF CODE?!

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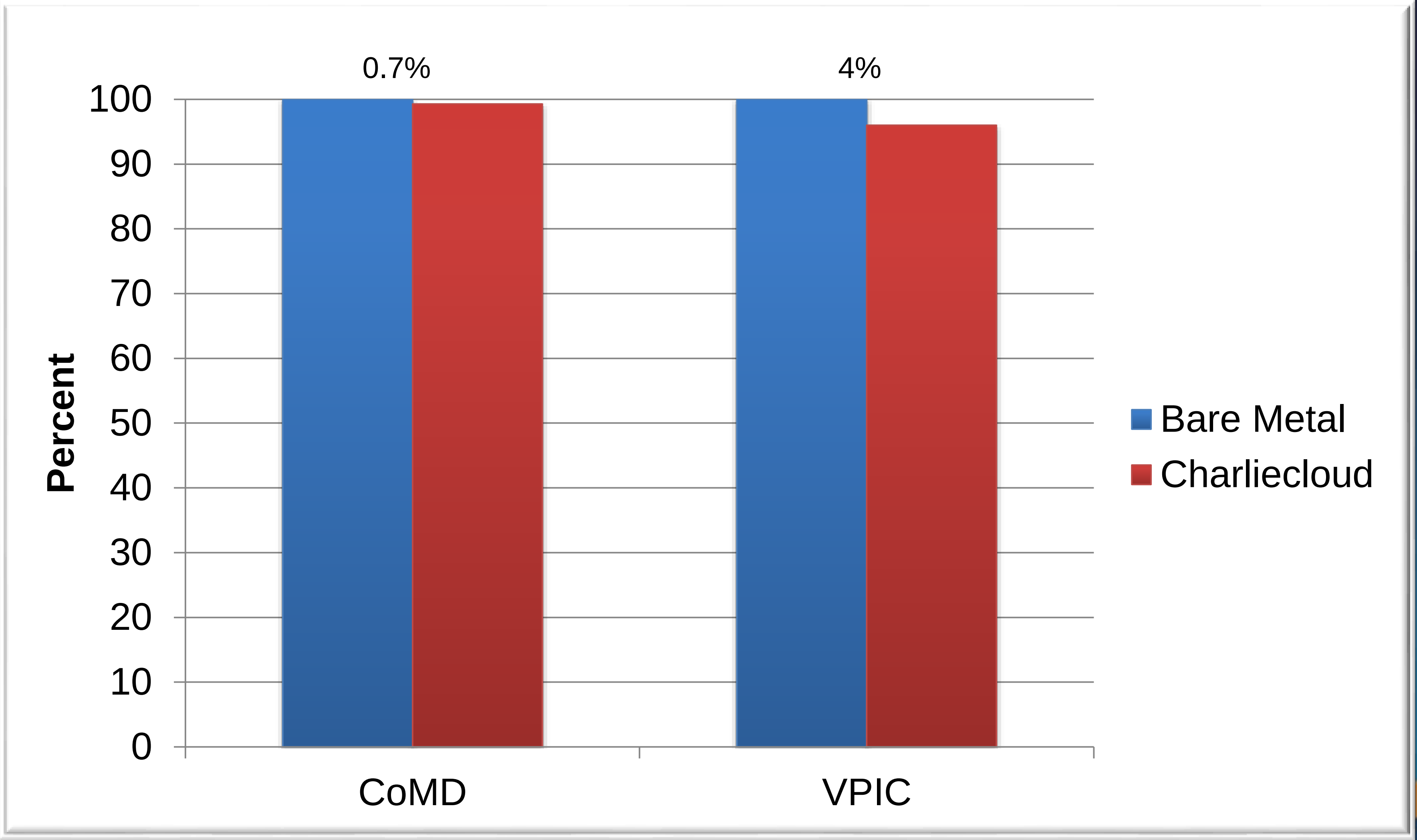
Charliecloud Demo/Walkthrough

```
$ cd ~/charliecloud/examples/serial/hello
$ ls
Dockerfile  hello.sh  README  test.bats
$ ch-build -t hello ~/charliecloud
Sending build context to Docker daemon 15.19 MB
[...]
Successfully built 30662b3f94f3
$ ch-docker2tar hello /var/tmp
57M /var/tmp/hello.tar.gz
```

```
$ ch-tar2dir /var/tmp/hello.tar.gz /var/tmp/hello
creating new image /var/tmp/hello
/var/tmp/hello unpacked ok
$ ch-run /var/tmp/hello -- cat /etc/debian_version
8.9
```

Charliecloud MPI Performance



Charliecloud Resources

- Supercomputing 2017 Paper
  by Reid Priedhorsky and Tim Randles
  - “Charliecloud: Unprivileged Containers for UDSS in HPC”
  - Los Alamos Tech Report LA-UR-17-30438
  - http://permalink.lanl.gov/object/tr?what=info:lanl-repo/lareport/LA-UR-17-30438
- ;login: Article “Linux Containers for Fun & Profit in HPC”
  by Reid Priedhorsky
  - https://www.usenix.org/publications/login/fall2017/priedhorsky
- Documentation: https://hpc.github.io/charliecloud (includes tutorials!)
- Source Code: https://github.com/hpc/charliecloud
- Mailing List: charliecloud@groups.io || https://groups.io/charliecloud
- Contact Reid (reidpr@lanl.gov), Tim (trandles@lanl.gov),
  or Michael (mej@lanl.gov, @mej0 on Twitter)

Questions/Comments?

THANK YOU!

PS: These slides, and all unclassified LANL publications, are available via LA-UR number at: http://permalink.lanl.gov/object/tr?what=info:lanl-repo/lareport/LA-UR-18-23001