DE LA RECHERCHE À L'INDUSTRIE

VMs and containers for a Slurm-based development cluster

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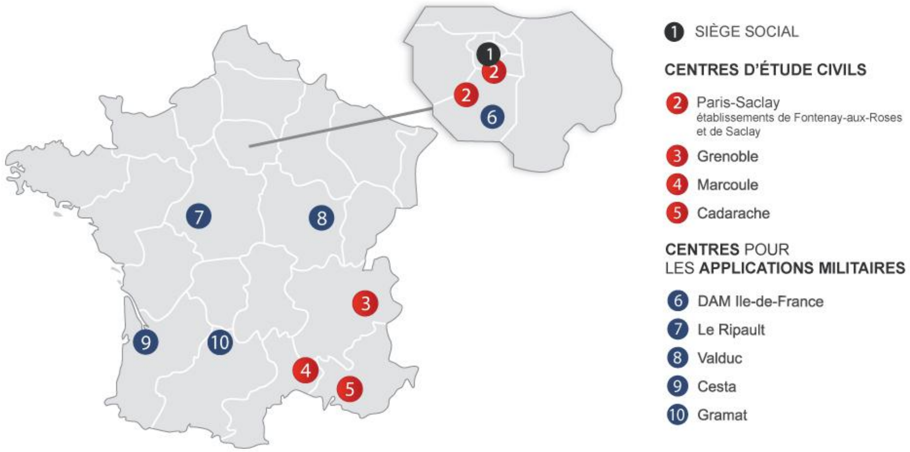
About CEA

CEA: The French Alternative Energies and Atomic Energy Commission

- **9 research centers in France**
- **Many areas of research including:**
  - Low carbon energies,
  - Information and healthcare technologies
  - Defence and security
  - Fundamental research in the physical sciences and life sciences
- **Large HPC infrastructures**
  - 2 production compute centers



CEA Compute Centers

TGCC: Très Grand Centre de Calcul du CEA

- **Hosts two main projects**
- **CCRT**
    - Shared computing center for French industrial and research partners
    - Cobalt supercomputer (installed in 2016)
        - 1422 Intel Broadwell nodes (2x14 cores, 128GB), Infiniband EDR
        - 252 Intel Skylake nodes (2x20 cores, 192GB), Infiniband EDR

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TOTAL
Valeo

TGCC: Très Grand Centre de Calcul du CEA

- **Hosts two main projects**
- **GENCI (Grand Equipement National pour le Calcul Intensif)**
  - Part of the European PRACE project (Partnership for Advanced Computing in Europe)
  - Available for french academia, industries, and european PRACE members
  - Irène Joliot-Curie supercomputer (installed in 2017)
    - 1656 Skylake nodes (2x24 cores, 192GB), Infiniband EDR: 6,9 PF/s peak)
    - 828 KNL nodes (68 cores, 96GB), Bull eXascale Interconnect: 2,5 PF/s peak)
    - A 12 PF/s peak AMD Rome partition is currently being installed

TERA: CEA Defense computing center

- **Part of the simulation project for French nuclear deterrence**
- **Tera-1000 supercomputer (installed in 2016)**
    - 2192 Haswell nodes (32 cores, 128GB), Infiniband FDR: 2,6 PF/s peak
    - 8256 KNL nodes (68 cores, 192GB), Bull eXascale Interconnect: 23,4 PF/s peak

OCRE: A pre-production compute center for R&D

- **A testbed for new hardware**
  - From both user and sysadmin perspective
  - Many node partitions spanning a large number of technologies
- **Computing resources for HPC R&D**
  - Collaborations around new / experimental hardware
  - Development and evaluation of scientific applications and system tools
    - In a representative HPC cluster environment
- **A pre-production environment**
  - Staging for new features before deployment on production centers
    - Obtain feedback from users
  - Slurm-based cluser
  - Overall setup as close as possible to production clusters

Flexible compute clusters

HPC clusters must become more flexible

- **A trend in all our clusters**
  - More and more varied scientific communities
  - New software and frameworks not designed with HPC clusters in mind
  - Users must be able to easily deploy all kinds of software
- **Applies especially for a cluster serving developers**
  - Evaluate or develop software for all levels of the stack
    - Including system or kernel level software
  - Run continous integration tests in various environments
  - Reproduce bugs in specific setups
- **VMs and containers can help achieving that flexibility**

Private Cloud On A Compute Cluster

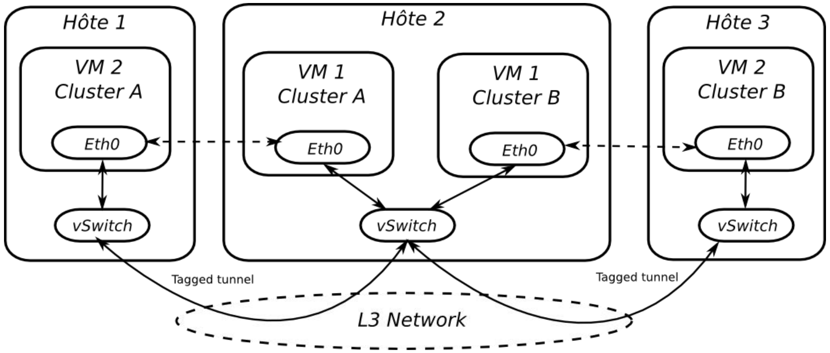
- **Bring “private cloud” features to a HPC cluster**
  - Deploy VMs and containers
  - Set up virtual networks
- **HPC oriented features**
  - Low overhead virtualization (NUMA awareness, Infiniband virtualization…)
  - Interfacing containers and HPC runtimes
- **Use the existing cluster infrastructure**
  - Slurm resource management, usual job allocation sematics
    - Number of tasks, cores and/or memory per task
    - A task can also be a VM
  - All nodes can be used for both regular jobs and hosting VMs
    - Usual scheduling, priorities, job management, accounting…
  - Images are stored in the shared parallel filesystem
    - Directories as image repositories
    - Directly accessible from compute nodes

Launching a virtual cluster

- **Example:**
  - pcocc alloc –c 8 image1:32,image2:512
  - Allocates 32 VM of one type and 512 VM of another type, each with 8 cores
- **Details:**
  - A slurm job is created to allocate the resources
    - A spank plugin setups virtualization resources during prolog
    - Virtual networks for the cluster are setup according to the VMs configurations
  - Qemu is launched as a user task
  - VM instances are created with ephemeral drives
    - Copy-on-Write using the repository image as reference
  - CPU and memory are configured according to the task allocation
    - NUMA topology is setup to match the host allocation
    - Each vCPU is bound to one of the allocated cores
    - Near native compute performance (2% overhead for HPL at 2116 cores)
  - Cancelling the job destroys VMs and cleans up nodes

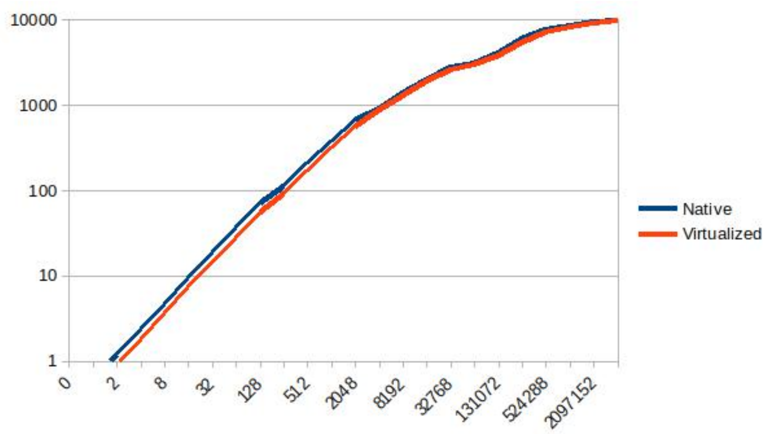
Virtual Ethernet networks

- **Create an isolated virtual Ethernet switch per virtual cluster**
  - Virtual Ethernet interfaces are attached to VMs belonging to the network
- **Implemented with Open vSwitch and the VXLAN overlay network**
  - Encapsulate Ethernet packets in UDP packets
- **Optional L3 services**
  - Automatically assigns IP to VMs
  - Provides DHCP/DNS services
  - NAT-based routing to the host cluster network
  - Reverse NAT to VM ports (SSH access)
- **Not performance optimized but good enough for most use-cases**
  - 5-10 Gbit/s between two remote VMs on our hardware



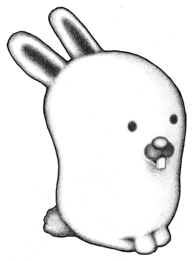
Virtual Infiniband networks

- **Create an isolated Infiniband partition per virtual cluster**
  - Makes use of Infiniband SR-IOV
    - Multiplex a physical device into multiple virtual functions (VFs)
  - VFIO is used to isolate the device from the host
    - Applies an IOMMU
  - OpenSM is reconfigured dynamically to restrict VFs to a specific partition
    - Equivalent to a VLAN
  - Infiniband VFs are attached to VMs belonging to the network
- **Near native performance**



Virtual clusters

Mounting host filesystems in VMs



- **Exported by Qemu with the 9P protocol**
  - Filesystem is accessed with privileges of the job owner
  - Fairly slow for metadata and small accesses

- **A more efficient replacement is being developped by RedHat**
  - Virtio-fs
  - Used in the Kata containers project

Docker VM allocation

- **Similar to the docker-machine tool**
  - Leverage the VM allocation support of pcocc
- **Setup a Docker environment with a single command**
  - pcocc docker alloc
    - Allocate a VM running a docker daemon
      - Hosts filesystems are available
    - Setup environment variables to redirect Docker API calls to the VM
    - Use the docker CLI as if the daemon was running locally
- **Support for Docker-based workflows**
    - Build containers with Dockerfiles
    - Use tools like docker-compose

Run unprivileged containers

- **Restriction: keep the same user id within the container**
  - Similar to other HPC-oriented container runtimes
  - pcocc run -I ctr-image [cmd]
  - Works with OCI images
    - Extracts the image once on first use
    - A cache is used for next runs
- **Namespaces**
  - Based on the bubblewrap tool
    - Used in Flatpak, a package management tool using container features
  - Uses unprivileged user namespaces if enabled
  - Can run as a setuid binary otherwise

Containers

Interface containers with host software/hardware

- **Ideally, containers should be self-contained and deployable everywhere**
- **Unfortunately, some HPC features require tight integration to the host**
  - High performance interconnect libraries
  - MPI libraries / launchers and related tuning
  - GPU runtime (CUDA)
- **Ability to define modules which inject files and/or environment variables**
  - Specified when running a container with the -M flag
  - Restricted to “sufficiently compatible” containers (glibc ...)
- **Example modules**
  - Nvidia module
    - Provides access to the host Nvidia runtime
  - OpenMPI modules
    - Injects recommended OpenMPI libraries and configurations
  - WI4MPI module
    - MPI wrapper interface
    - Translates e.g, from an IntelMPI linked application to an OpenMPI library

Planned improvements

- **Add virtual network support for containers**
  - A slurm plugin sets up a “pod” during prolog for each allocation
    - Network namespace with requested network interfaces
    - Ability to select other namespaces to unshare from the parent namespace
  - Runs user tasks using these namespaces
    - User processes setup their own mount namespaces as today

- **Allowing multiple uids in containers**
  - User namespaces with subuid/subgid
    - Maps to dedicated uid ranges on the parent namespace
  - Integration to our compute centers must be evaluated
    - Allocations of UID ranges with LDAP based accounts
    - Possible impacts on filesystems, accounting, node management etc
  - Support for full system containers, building images…

Example use cases

Large scale reproducers / debugging

- **Example: reproducers for Lustre issues**
  - Instanciate Lustre servers and client VMs
  - Reproduce issues which only happens at large scale and crash the Lustre servers
    - Issue with > 100 client nodes required to reproduce the problem
  - See Dominique Martinet presentation at Lustre Admins and Devs Workshop 2016

Example use cases

Development or evaluation of system level software

- **Easy to deploy test-beds**
  - No need for special privileges
- **Several internships every year**
  - Examples:
    - Large scale configuration deployment with Puppet
    - Development and evaluation of a diskless node management solution
    - Design of an elasticsearch based solution to process HPC logs
- **Teaching for ENSIIE engineering school**
  - HPC oriented system administration classes
  - Leverage Slurm cluster for the labs

Example use cases

Jenkins-based continous integration environment

- **Provide users with their own Jenkins instance**
  - Set up and managed by our team with the Lurch tool
  - Per-user or per-group
- **Jenkins worker accesses the HPC cluster**
  - Runs as the Jenkins instance owner and is able to submit SLURM jobs
  - Sets up custom execution environments thanks to pcocc
- **Quickly run large test suites using many parallel nodes**
  - Ex: rebuild our HPC oriented Linux distribution
- **Perform validation on representative hardware**
  - Large number of cores
  - Infiniband interconnect

Thank you !

Questions ?

Crédits photos: Jatin Sindhu, Peacock plumage