Hobbes: OS and Runtime Support for Application Composition

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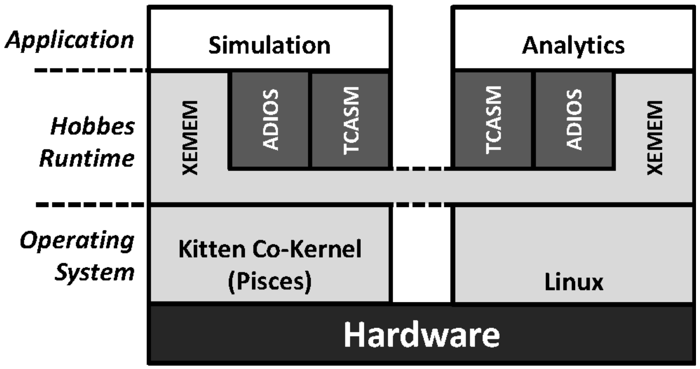
Project Goals

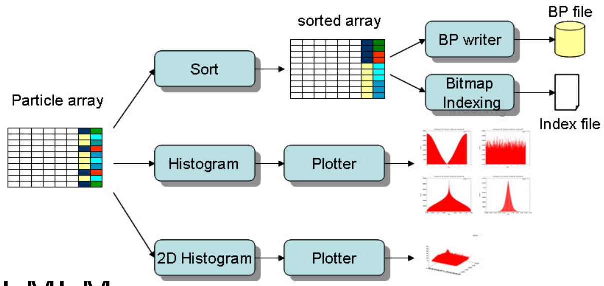
- Deliver prototype OS/R environment for R&D in extreme-scale scientific computing
- Focus on application composition as a fundamental driver
  - Develop necessary OS/R interfaces and system services required to support resource isolation and sharing
  - Support complex simulation and analysis workflows
- Provide a lightweight OS/R environment with flexibility to build custom runtimes
  - Compose applications from a collection of enclaves
- Leverage Kitten lightweight kernel and Palacios lightweight virtual machine monitor
  - Node Virtualization Layer (NVL)
  - Enable high-risk high-impact research in virtualization, energy/power, scheduling, and resilience

System-Level Support for Composition of Applications

- Problem
  - HPC applications are increasingly comprised of multiple distinct components with different requirements for OS, software stack and system resources
    - E.g., simulation+analytics, coupled multiphysics, scalable performance analysis and debugging



- Solution
  - Instantiate “enclaves” for each application **component** using high-performance virtualization technology
  - Provide OS and software stack tailored for application **component** within each enclave
  - Provide mechanisms for controlled interaction between enclaves (**components**)
    - Selective sharing of memory regions (data exchange)
    - Name service (discovery and rendezvous)

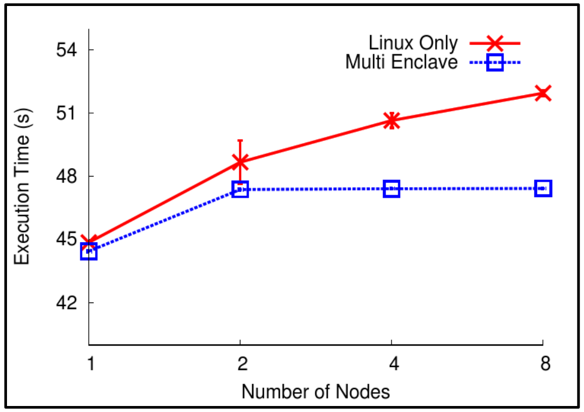


- Recent results
  - Proof-of-principle for XEMEM cross-enclave memory API
  - Use XEMEM as “transport” in ADIOS, TCASM coupling tools
  - Demonstrate composite simulation+analytics applications using XEMEM

– Impact
  - Composition can be made transparent at the application level (no changes, performance neutral)
  - Allows detailed resource management and scheduling among enclaves (other Hobbes R&D areas)

Enabling Multi-OS/R Stack Application Composition

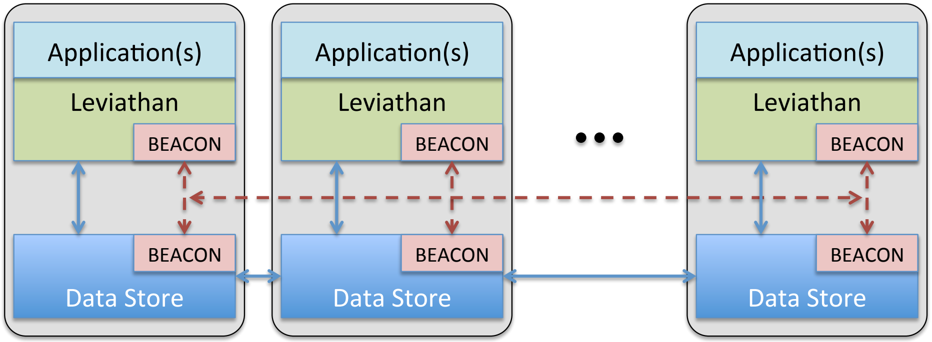
- Problem
  - HPC applications evolving to more compositional approach, overall application is a composition of coupled simulation, analysis, and tool components
  - Each component may have different OS/R requirements, no "one-size-fits-all" OS/R stack
- Solution
  - Partition node-level resources into "enclaves", run different OS/R instance in each enclave
    Pisces Co-kernel Architecture: http://www.prognosticlab.org/pisces/
  - Provide tools for creating and managing enclaves, launching applications into enclaves
    Leviathan Node Manager: http://www.prognosticlab.org/leviathan/
  - Provide mechanisms for cross-enclave application composition and synchronization
    XEMEM Shared Memory: http://www.prognosticlab.org/xemem/
- Recent results
  - Demonstrated Multi-OS/R approach provides excellent performance isolation; better than native performance possible
  - Demonstrated drop in compatibility with both commodity and Cray Linux environments
- Impact
  - Application components with differing OS/R requirements can be composed together efficiently within a compute node, minimizing off-node data movement
  - Compatible with unmodified vendor provided OS/R environments, simplifies deployment



In-situ Simulation + Analytics composition in single Linux OS vs. Multiple Enclaves

Support for extreme-scale OS/R monitoring and control

- Problem
  - Operating system/runtime (OS/R) components running throughout system must be monitored and controlled, but extreme system scale makes it difficult to do so (too much data, and/or too many "hops" to get data from one part of system to another)
- Solution
  - Integrate scalable, distributed data store with publish and subscribe service in a Global Information Bus (GIB)
  - Interface with Hobbes Leviathan node-level resource manager

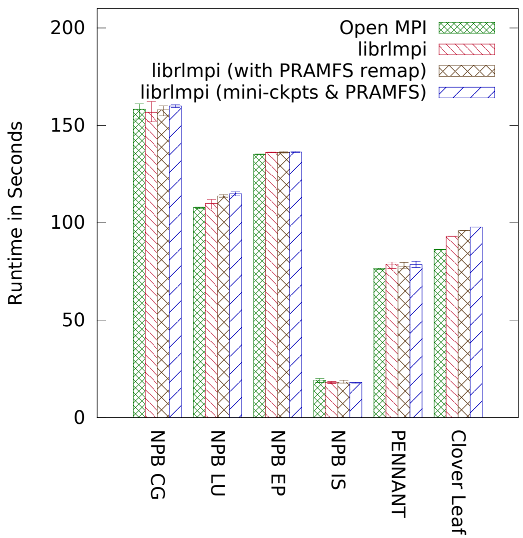


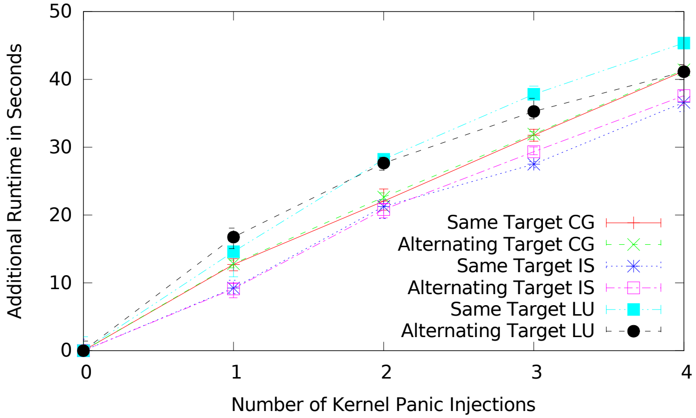
GIB data store and publish/subscribe components
Dashed lines indicate potential notifications from publishers to subscribers

– Recent progress
  - Defined important GIB use cases
    - System boot
    - Launch application
    - Respond to application failure
    - Respond to application termination
  - Designed and began pilot implementation of integration of distributed data store based on Riak open source database, BEACON publish-subscribe software from ARGO project, and Leviathan
- Impact
  - Supports monitoring and control of a large number of system software components without excessive application intrusion
  - Usable by both Hobbes and ARGO projects

mini-ckpts: Surviving OS Failures in Persistent Memory

- Problem
  - A failure of the operating system (OS) causes a failure of an otherwise healthy HPC application
- Solution
  - Execute the application in persistent memory (PRAMFS in DRAM) that is able to survive OS failures and reboots
  - Track OS state used by the application and MPI for recovery
  - Rejuvenate (warm reboot) the OS in case of a failure
  - Restore tracked OS state used by the application and MPI
  - Transparently continue to execute the application in persistent memory without loss of state/progress
- Recent results
  - Prototype implementation supports OpenMP and MPI applications with certain limitations
  - OS rejuvenation and recovery takes 3-6 seconds
  - Failure-free runtime overhead is of 3-5% for a number of key HPC workloads





- Impact
  - First solution that transparently offers OS failure tolerance without loss of state/progress
  - Transparently handling OS failures locally reduces the need for global checkpoint/restart
  - Latent OS errors that have not resulted in a failure can be cleared by rejuvinating the OS