CODES: Using parallel discrete-event simulation to model performance and reliability of Extreme-scale and distributed data-intensive systems

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Understanding Performance and Reliability issues in HPC and distributed systems

Distributed data-intensive science infrastructure and scientific workflows
- **KBase (biosciences)**: provisioning, resource allocation, scheduling algorithms
- **High-Energy Physics**: resource allocation, cache life times, caching policies of Fermilab’s petabyte scale storage systems

Data movement and access on data-intensive science platforms

Resilience in Distributed Storage Systems
- Efficient protocols in replicated object storage systems
- Interplay of different algorithmic components (membership, I/O traffic)

Resilience in distributed data-intensive storage systems

Design space of extreme-scale HPC network and Storage Systems

Massively parallel torus, dragonfly networks.
- Key questions: configuring link bandwidth, dimensionality, buffer space, routing etc. under different workloads?
- Effect of NVRAM Burst Buffer placement on Extreme-Scale HPC Systems
CODES Simulation framework for extreme-scale HPC & Distributed Systems

- Detailed simulation of storage and network components, scientific workloads and the surrounding environment.
- Modular simulation components
  - Pluggable I/O and network workload components
  - Pluggable high-performance network models
- Incrementally develop simulation capability, validating approach and components along the way
- **Goal:** provide a simulation toolkit to the community to enable broader investigation of the design space.
Enabling CODES: parallel discrete-event simulation

- **Discrete event simulation (DES):** a computer model for a system where changes in the state of the system occur at *discrete points* in simulation time
- **Parallel DES** allows execution of simulation on a parallel platform
  - Enables much richer simulations (e.g., more events) than otherwise possible
- Rensselaer Optimistic Simulator System (ROSS) provides PDES capability for CODES
  - **Optimistically schedules events. Rollback realized via reverse computation**
  - Users provide functions for *reverse computation* – undo the effects of a particular event on the LP state
  - Logical processes (LPs) model state of the system
  - **Scalable:** can efficiently execute simulations with millions of network nodes at a flit-level fidelity

*Courtesy: Christopher D. Carothers, RPI*
CODES Pluggable Network and I/O Models

- Pluggable Network models:
  - Models are decoupled from higher levels via a consistent API
  - **Analytic** – based on LogGP
  - Flit-level simulation of **torus, dragonfly** topologies at extreme scale
  - Flit-level **fat-tree** and **SlimFly** models are being developed

- Pluggable Network and I/O workloads
  - **I/O workload component**: Allows arbitrary workload consumer components to obtain IO workloads from a diverse range of input sources including characterization tools like Darshan.
  - **Network workload component**: Allows workloads from the Design Forward* program to be replayed on pluggable network models

*http://portal.nersc.gov/project/CAL/doe-miniapps.htm

Design space of extreme-scale HPC network and Storage Systems
Example CODES Network Model Plug-in: Dragonfly

- **Hierarchical topology**: several groups connected via all-to-all links
- Used in Edison (Cray XC30) and Cori architectures
- CODES dragonfly model supports minimal, non-minimal and adaptive routing
- Shown to scale on millions of network nodes with a simulation event-rate of up to 1.33 billion events/second on IBM Blue Gene/Q
- **Key Questions**: Effect of dimensionality, network configuration and link bandwidth on performance?

Average (left) and maximum (right) latency of a 1.3M node dragonfly network model with global traffic pattern (minimal & non-minimal routing)

Million-node dragonfly simulation performance on 1 rack of Mira Blue Gene/Q

Design space of extreme-scale HPC network and Storage Systems
CODES Service Models: High-Energy Physics (HEP) Science Data Facility
CODES Service Models: High-Energy Physics (HEP) Data Facility

- Experimental/observational data processing pipeline @ Fermilab
- Work underway to develop an end-to-end simulation of Fermilab’s HEP scientific data facility
  - Validate the simulation against actual data facility logging information
  - Use realistic HEP workflows scenarios
- Research Questions:
  - How best to configure existing peta-byte scale storage systems? E.g. how to increase cache life times, trying different cache policies
  - How to quantify the value for deploying new hardware? E.g. adding more archival devices for e.g. tapes.

Fig: Initial simulation model of the Fermilab data-access facility
Example CODES Resilience Model: Distributed Object Storage Rebuild Simulation

- Some protocols of interest in a replicated object storage system:
  - Rebuild – we’ve detected a server down, how do we re-replicate data?
  - Forwarding – how do we propagate write data between servers efficiently?
- Example: rebuild (lead: Phil Carns, ANL)
- Work explores advanced placement algorithms e.g. multi-ring hash algorithm
- Design questions: Determine the effect of algorithm/configuration on rebuild? (e.g., how many rings to use?)

**Question**: How do pipelining and object placement affect rebuild performance?

![Diagram illustrating resilience in distributed data-intensive storage systems](image-url)
Example CODES Resilience Models: Group Membership with SWIM protocol

- **Storage system resilience → detection and dissemination of group membership updates**
- **Scalable Weakly-consistent Infection-style Process Group Membership Protocol [1]**
  - Developed a high-resolution model of the SWIM protocol
    - Use simulation to evaluate behavior that can’t be predicted using analytical models
    - Individual network message costs are calculated using the LogGP network model
  - **Scale:**
    - O (thousands) of file servers
    - Tolerate transient errors < 15 seconds
    - Take action (confirm failure) within 30 seconds
  - Questions:
    - How fast do membership updates propagate through the system?
    - How much network traffic are we willing/able to incur?

Summary: Work being done with CODES

- **Network models**
  - Torus
  - Dragonfly
  - Fat tree (IIT, UIUC)
  - Slim Fly (In Progress)

- **Storage models**
  - I/O protocols
  - Data placement
  - Fault Detection/ Response
  - Burst buffers

- **HPC workload models**
  - IOWA— modeling large-scale I/O workloads
  - Network --- Design Forward network trace replay

- **Workflow processing / Data management**
  - Bioinformatics: Kbase usecase, meta-genomic server model
  - High Energy Physics (HEP) : Fermilab’s peta-scale storage system (In Progress)

- ...


Modsim Workshop Questions

- **What is the major contribution of your research?**
  - High-fidelity and large-scale parallel discrete-event models of high-end computing components like HPC networks, I/O and network workloads, scientific workflows and data-intensive architecture
  - Modular components can be combined for HPC and data-intensive architectural evaluation and co-design.

- **What is the bigger picture for your research area? What are the gaps?**
  - Ability to execute high fidelity network models over 12 hr to 24 hr time-scales
  - Lack of flexible network and storage behavior descriptions
  - Reverse computation is coded by hand for CODES models.
    - Compiler efforts: LLVM (RPI)

- **What is the bigger picture for your research area? (i.e., identify synergistic projects, complementary projects in technical sense, etc)**
  - Node-level simulators such as SST (SNL), Manifold (GaTech), Booksim (Stanford)
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Repo access and SoC

- CODES developer access

- Discussion forum
  - codes-ross-users@lists.mcs.anl.gov

- 1st Summer of CODES workshop
Questions?