FAULT DETECTION AND GROUP MEMBERSHIP IN HPC DATA SERVICES

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STATE OF THE ART IN HPC DATA MANAGEMENT

- Apps generally use high-level I/O libraries to transform workloads into a form suitable for storing on a PFS
  - Much work invested to optimize I/O performance for specific workloads/architectures
- However, today's increasingly data-intensive apps are ill-served by PFS designs that have remained mostly stagnant for decades
  - POSIX-compliance
  - Inflexible designs that cannot efficiently leverage hierarchical storage models and emerging storage technologies (e.g., non-volatile)
  - Poor fault detection/recovery

Figure courtesy of P. Carns
A PROGRESSIVE APPROACH TO HPC DATA MANAGEMENT

- Instead of a 'one-size-fits-all' PFS, provide specialized services tailored for applications' specific data management requirements
  - Approach based on composable, re-usable, and lightweight **microservices** for data management
    - Services could be generic, supporting classical HPC data management techniques (checkpoint-restart, in-situ)
    - Or, app-specific services to handle workloads that have traditionally been problematic

![Diagram](image-url)

Figure courtesy of P. Carns
THE MOCHI PROJECT

- **Vision:** Enable rapid development/deployment of efficient HPC data management services based on the microservice model we have described
  - Develop re-usable building block microservices that form the foundation of many distinct HPC data services
    - Key-val stores, distributed object stores, pub-sub systems
  - Adapt generic microservices to satisfy application needs (e.g., scale, consistency model) and to efficiently utilize available system resources (storage hierarchies, burst buffers)
  - Present a coherent data management API that supports an application's native data model while abstracting low-level service details

The Mochi project is a collaboration between ANL, The HDF Group, LANL, & CMU
http://www.mcs.anl.gov/research/projects/mochi/
MOCHI: ENABLING TECHNOLOGY
COMMUNICATION: MERCURY
A high-performance RPC framework for HPC systems

- Mercury is an RPC system for use in the development of high performance system services.
  - Portable across systems and network technologies
  - Efficient bulk data movement to complement control messages
  - Provides simplifications for service implementers:
    - Remote procedure calls
    - RDMA abstraction (or emulation)
    - Protocol encoding
    - Clearly defined progress/event model

- No client/server role restrictions
- No global fault domain (MPI_COMM_WORLD)

Developed by The HDF Group & ANL.
https://mercury-hpc.github.io/
CONCURRENCY: ARGOBOTS
A lightweight threading/tasking framework

- User-level threading: lightweight context switching among many concurrent threads
- Use multiple cores and control delegation of work to those cores
- Key features for data services:
  - Lets us track state of many concurrent operations with simple service code paths and low OS resource consumption
  - Custom schedulers (i.e., to implement priorities, or limit CPU usage)
  - Primitives that facilitate linkage to external resources

http://argobots.org/
FAULT DETECTION AND GROUP MEMBERSHIP AS A MICROSERVICE
SSG

Scalable Service Groups

- A generic group membership service developed as part of the Mochi project
- Allows for organizing sets of Mercury endpoints into logical, fault-tolerant process groups
  - These groups provide basis for deploying and referencing distributed services
- Key functionality:
  - Bootstrapping process groups
    • Available now: MPI communicator and config file based bootstrapping routines
    • Future work: PMIx bootstrapping for production systems
  - Maintaining collective group membership state as members dynamically join/leave
    • At minimum, state includes the membership view, a mapping of group member IDs → Mercury address information
  - Detecting and notifying users of group member faults

https://xgitlab.cels.anl.gov/sds/ssg
SSG API

- Group bootstrapped by collectively calling ssg_group_create at all members
  - Returns opaque ID that uniquely references group, and that internally encodes address info on at least one group member
- Processes can dynamically add/remove themselves from the group using ssg_group_join & ssg_group_leave
- Non-group member processes can access the group view using ssg_group_attach
  - Attachment is envisioned for group "clients" -- i.e., processes that do not want to become proper group members
- Simple group accessor routines like ssg_get_group_self_id and ssg_get_group_size provide details on a caller's local group view, while ssg_get_addr can be called to map a group member's ID to its Mercury address
EXAMPLE SERVICES DEPENDENT ON SSG

- Group communication abstractions
  - Build overlay networks over SSG groups for efficient collective RPCs
  - Useful for common data reduction or broadcast operations

- Pub-sub
  - SSG groups reference publisher groups that subscribers can attach to

- Service registry
  - Apps query a known server address to get a list of services (i.e., SSG groups) currently available (think DNS)
SSG FAULT DETECTION & GROUP UPDATES

- SSG includes an implementation of SWIM, a protocol for detecting faults and managing group membership
  - Faults detected by periodically probing random group members for liveness, rather than heartbeats
  - Protocol includes a suspicion mechanism to avoid marking unresponsive members as dead until some timeout has elapsed
  - Membership updates disseminated using a gossip protocol piggybacking on the protocol's ping messages

SWIM PROTOCOL EVALUATION

- Observations:
  - Failure detection times are mostly constant, irrespective of group size
  - Update dissemination completes in $O(\log(n))$ time, with $n =$ group size
  - Network load scales linearly with subgroup size, accuracy scales exponentially
  - Accuracy can be preserved even in cases of extreme message loss

AUGMENTING SWIM

- SWIM uses gossip internally for collectively maintaining the group view -- but could we expose it for maintaining any generic group state?
  - E.g., in a pub-sub service, a publisher group needs to maintain a consistent view of subscribers to push topic updates to
  - Increases communication efficiency, as app-specific group state can just be piggybacked on SWIM's internal messages

- What if an application needs a strongly-consistent view of group membership (i.e., ordering of membership updates is important)?
  - Designate subset of group members to run a RAFT cluster to reach consensus on ordering of group state changes
  - The RAFT cluster can then lazily propagate state changes out to regular group members using SWIM's gossip protocol

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