PAIO

General, Portable I/O Optimizations With Minor Application Modifications

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1 CHALLENGES AND MOTIVATION

EXISTING I/O OPTIMIZATIONS ARE IMPLEMENTED IN SUB-OPTIMAL MANNER:

⊗ Tightly coupled optimizations
- Optimizations are single-purposed
- Require deep understanding of the system's internal operation model
- Require profound system refactoring

✓ Decouple optimizations
- Disaggregated from the system's logic
- Generally applicable and portable

⊗ Rigid interfaces
- Existing interfaces are predefined and do not consider application-level logic
- Discard information that could be used to classify and differentiate requests with different levels of granularity

✓ Information propagation
- Propagate application-level information down the I/O stack

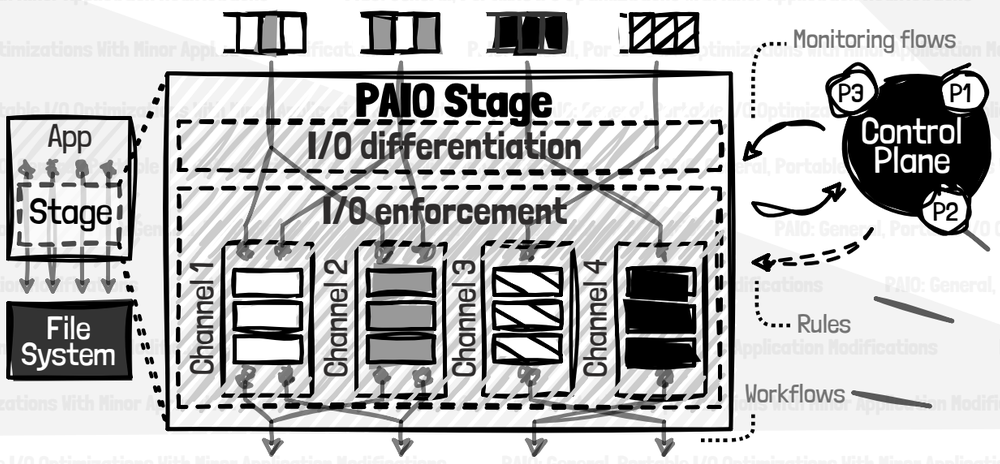
⊗ Kernel-level layers
- Impossible to extend without breaking APIs
- More restricted and error prone environment
- Ineffective under kernel-bypass stacks

✓ Actuate at user-level
- Dedicated user-level layer
- Promotes portability
- Eases information propagation

⊗ Partial visibility
- Optimizations act in isolation
- Oblivious to other systems, competing for shared resources
- Lack of coordination

✓ Global I/O control
- Operate in coordination
- Ensure holistic control of I/O workflows

2 PAIO IN A NUTSHELL



PAIO IS A USER-LEVEL FRAMEWORK THAT ENABLES BUILDING PORTABLE AND GENERALLY APPLICABLE STORAGE OPTIMIZATIONS

General applicability
- Stages are disaggregated from internal system logic, ensuring applicability across different I/O layers

Programmable building blocks
- Decoupled design that separates I/O mechanisms from policies
- Provides abstractions for building new storage optimizations

Fine-grained I/O control
- Classifies, differentiates, and enforces I/O requests with different levels of granularity

Stage coordination
- Exposes a control interface that enables the control plane to dynamically adapt stages to new policies and workloads

Low intrusiveness
- Porting I/O layers to use PAIO requires none to minor code changes

3 DIFFERENTIATION & ENFORCEMENT

Context propagation
- PAIO combines ideas from context propagation and applies them to ensure fine-grained control over I/O requests
- Context propagation enables a system to forward application-level information along its execution path

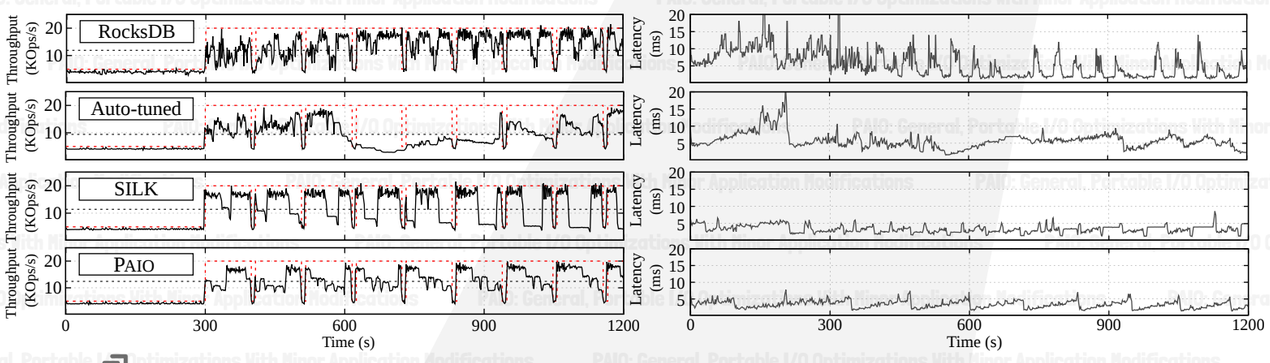
Channel and enforcement object-level I/O differentiation
- To classify requests, PAIO creates Context objects that contain the metadata that characterize a given I/O request
- Examples of such classifiers include the workflow-id, request type, size, and request context

Enforcement of I/O mechanisms over requests
- Provides building blocks for developing I/O mechanisms to be employed over I/O requests
- Noop implements a pass-through mechanism that copies the request's content to a Result object
- Dynamic Rate Limiter implements a token-bucket to control the rate and burstiness of I/O workflows

Transparent interception of I/O calls
- PAIO uses LD_PRELOAD to intercept calls to shared libraries (e.g., libc) and route them to the data plane stage
- Enables I/O layers to use PAIO without changing any line of code

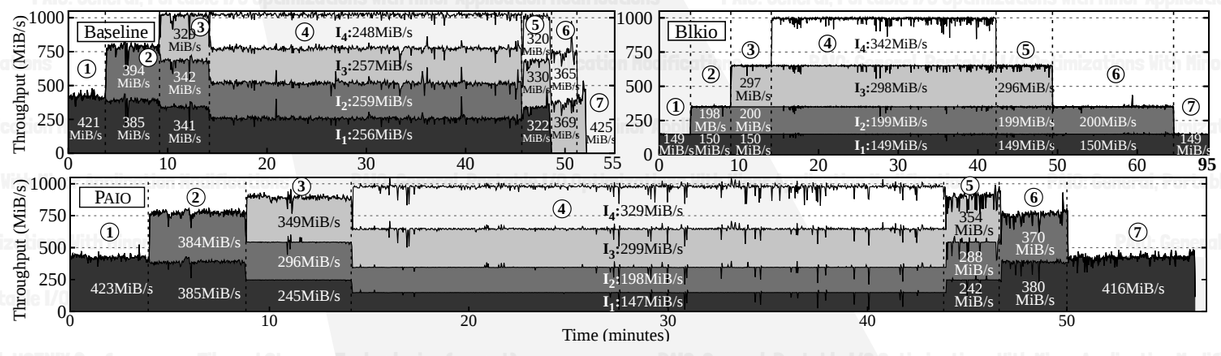
4 TAIL LATENCY CONTROL IN KVS

- We implemented a PAIO stage to prevent latency spikes in RocksDB
- The stage replicates SILK's I/O scheduler by (1) dynamically allocating bandwidth to internal operations, and (2) prioritizing flushes and low level compactions
- Integrating PAIO in RocksDB only required adding 85 LoC
- PAIO improves RocksDB's 99th percentile latency by 4x and enables similar control and performance as SILK



5 PER-APP. BANDWIDTH CONTROL

- We implemented a PAIO stage to achieve dynamic per-application bandwidth guarantees under shared-storage at the ABCI supercomputer
- Each stage controls the workflows' rate through a max-min fair share algorithm
- Integrating PAIO in TensorFlow did not required any code changes
- PAIO ensures that policies are met at all times, and whenever leftover bandwidth is available, PAIO shares it across active instances



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