**FLASH CACHES**
- Widely used to improve storage system performance
- High random read performance (>10K IOPS, <100us)
- Slow overwrites: copy-forward, flash erasures (3.8ms for 2MB)

**RECENT ADVANCES**
- Buffering small blocks (KB) to write large containers (MB)
- Leverage internal parallelism in flash architecture
- Write/evict flash cache in container granularities
- Reduce excess copy-forward from Flash Translation Layer (FTL)

**DIVERGENT CONTAINER PROBLEM**
- Blocks in containers have different access patterns
- Access pattern variability increases with container size and cache size
- User overwrites in container structure causes invalidation
- Invalidation has bimodal pattern of fully alive and fully invalidated containers, with some mixed containers

**PANNIER DESIGN**
- **Access Pattern Variability**
  - Assign container survival time to gather stable access pattern
  - Decay block access count, copy popular blocks to new containers
- **Overwrite/Invalidation**
  - Track dead blocks with invalidation bit map
  - Reset survival time for containers as a function of live blocks
- **Ensure Flash Lifespan**
  - Assign erasure target for Pannier to ensure lifespan
  - Throttle Insertion and Reinsertion for Erasures (TIRE), to keep popular blocks in the cache

**EVALUATION**
- Blocks in containers have different access patterns
- Access pattern variability increases with container size and cache size
- User overwrites in container structure causes invalidation
- Invalidation has bimodal pattern of fully alive and fully invalidated containers, with some mixed containers

**PANNIER ARCHITECTURE**
1. **Admission control**: decide to cache or not
2. **Packing**: which container to put blocks in
3. **Write to flash**: store container to flash
4. **Read**: read from flash
5. **Update**: update the In-RAM cache status structure

**CONCLUSION**
- Pannier is designed to address the new problem of divergent containers
- Pannier has better performance (hit ratio and response time) than vanilla container caching, and is competitive with advanced per-block caching algorithms that have higher erasures
- Pannier with TIRE ensures flash lifespan while maximizing performance

**EPBPD in Pannier with TIRE**
- In-RAM Cache
- In-Flash
- MQ
- LRU+
- Pannier

**PANNIER ARCHITECTURE**
- Block index: key -> loc.
- Block insertion
- Admission control
- Packing
- Write to flash
- Read
- Update