Kaleidoscope: Cloud Micro-Elasticity via VM State Coloring

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Current Elasticity Models: Issues

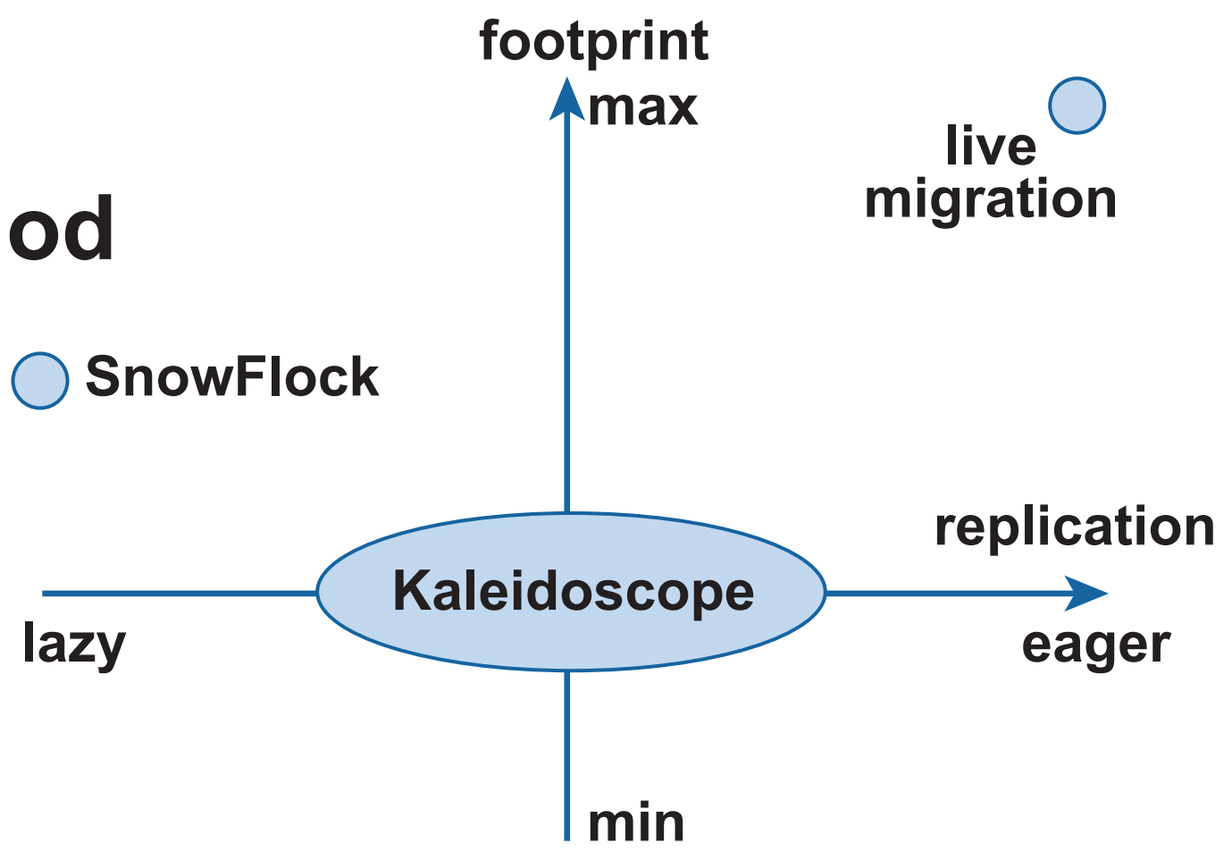
- Long instantiation times
- Coarse granularity of footprint
- Network bandwidth & latency overhead
  - Common practice: dedicated migration bandwidth!
  - Wide-range variability in instantiation times
- Fresh workers → cold state
- Number of servers with runtime > month – doubled

Kaleidoscope Vision: Cloud μ-elasticity

- Allocate resources proportionally to the working set
- Stateful replication of VMs (inherit expensive warm state)
- Color-guided state propagation
  - proactive prefetch
  - reactive (on-demand)
- Continuum between full copy and minimal/on demand copy

Kaleidoscope Design Space

- Fundamental tradeoff:
  - Instantiation time vs. warmup period
- Continuum between lazy and eager replication
- Continuum between minimal and maximal footprint



Uses of Color

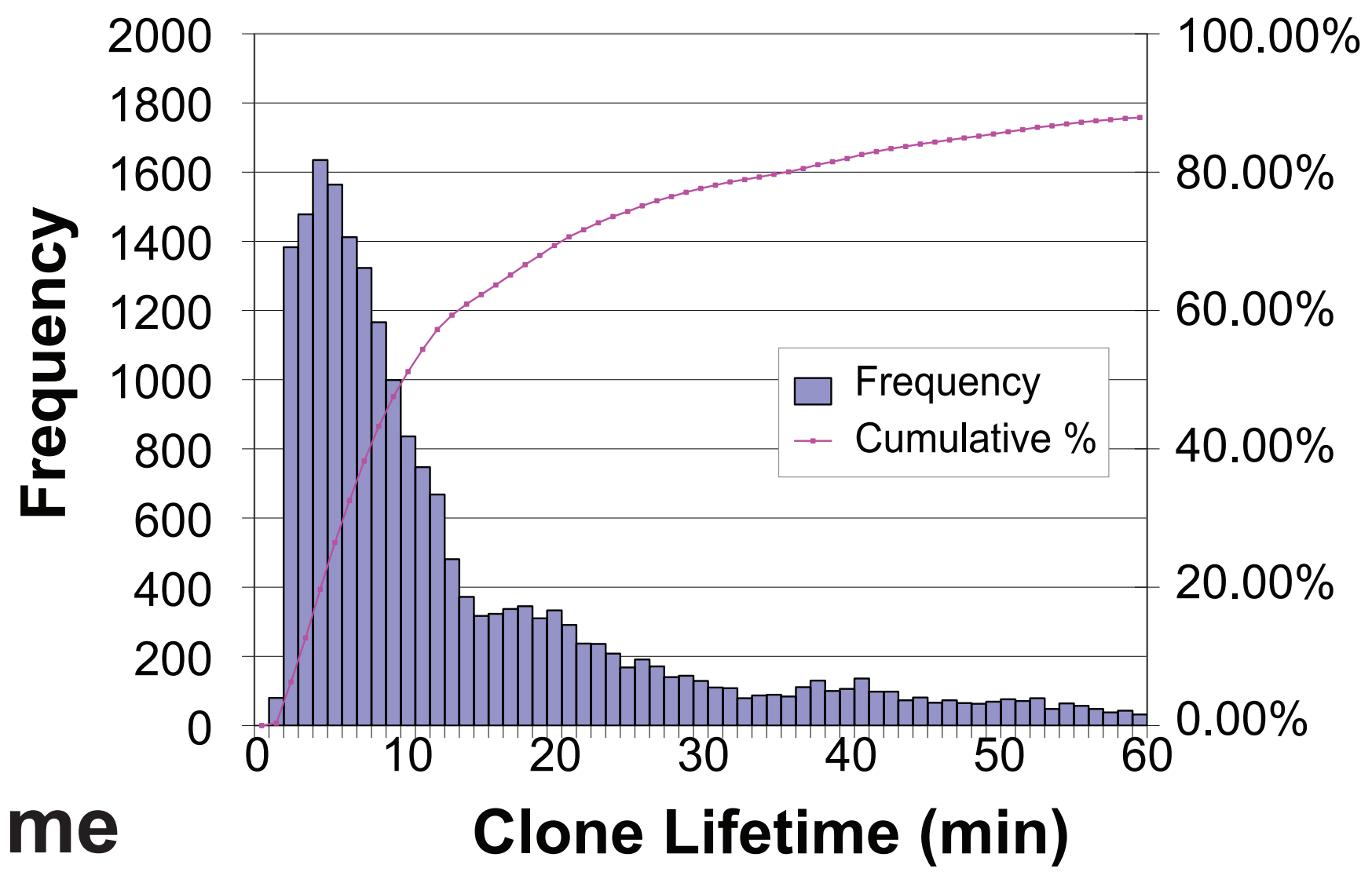
- State prefetch of consecutive pages in **color space**
  - Significant reduction in bandwidth consumption
- Per-color differentiation in the width of the prefetch window
  - *Insight*: reduced window size for executable state
  - User/kernel data windows : 3-4 times wider than executable
- Color-directed memory deduplication
  - Per-color probabilities of inter-VM page similarities
  - One-time, color guided calculation of hashes for the master memory state

Evaluation Categories

- Blocking time reduction
- Elastic footprint / resource preservation
- Scalability
- Runtime
- QoS

Motivation

- Strong need for elasticity
  - 15.3% of peak capacity – average usage
  - Wide-range short-term variability in workload
- Elastic workers – short lived
  - 85% of workers – live < 1hr
  - 10 min → mean worker lifetime

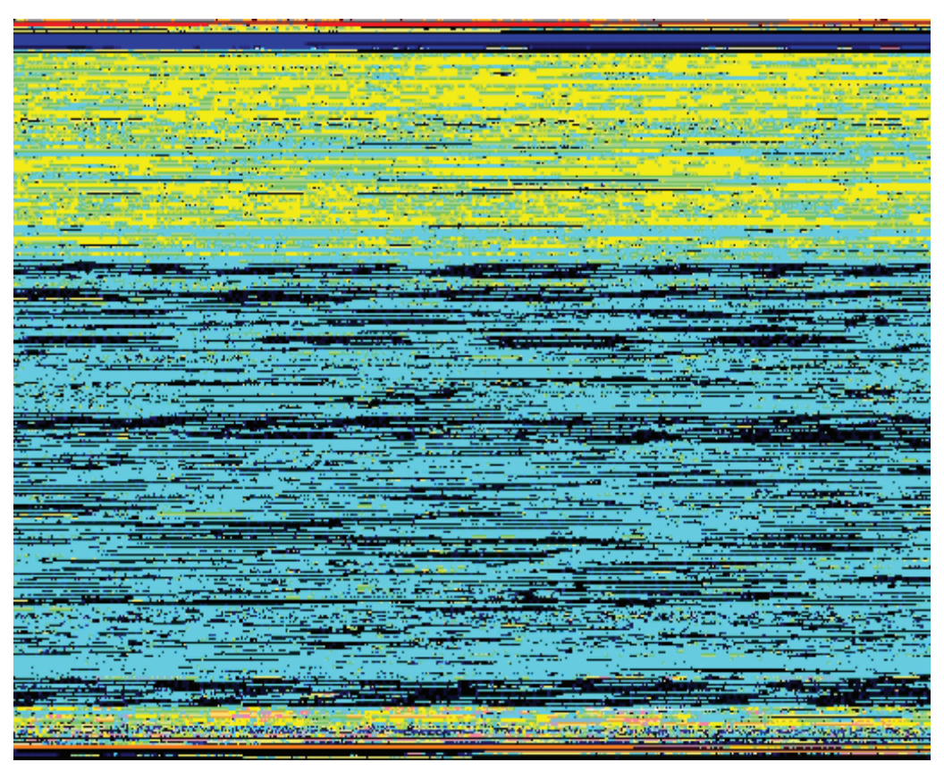


Kaleidoscope Contributions

1. VM memory state coloring
   - Semantically-aware state propagation
   - Architectural & introspective runtime memory state information
2. Time & space efficient implementation of coloring
3. Micro-elastic cloud server
   - Color-aware replication & sharing
   - Near-ideal post-clone QoS
   - Resource consumption proportional to demand
4. Real world datacenter savings

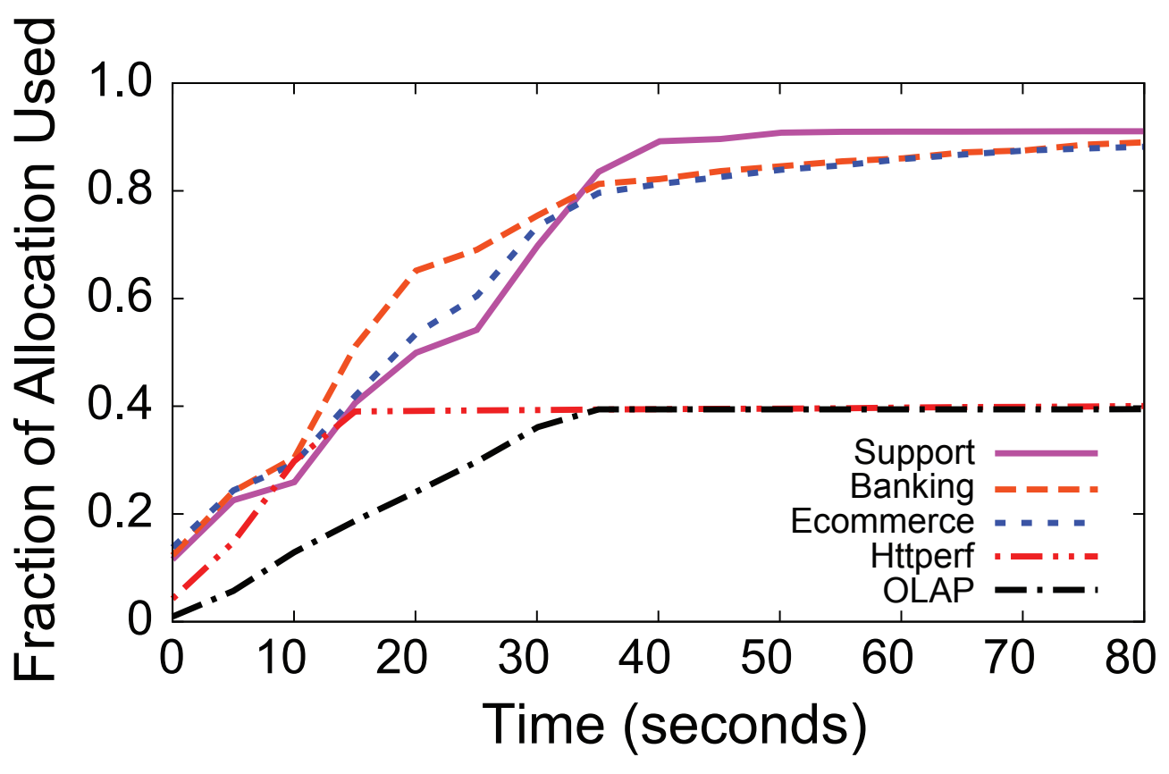
VM Memory State Coloring

- Architecture-based coloring
  - Performed on translated page table pages undergoing mandatory canonicalization at clone time
  - Extracting the NX bit (executable)
  - Identifying the kernel/user-space split
- Introspective coloring
  - Performed on a "frozen" memory image of the master
  - File cache radix trees
  - Frame page structure: used/unused physical pages



Fractional Footprint

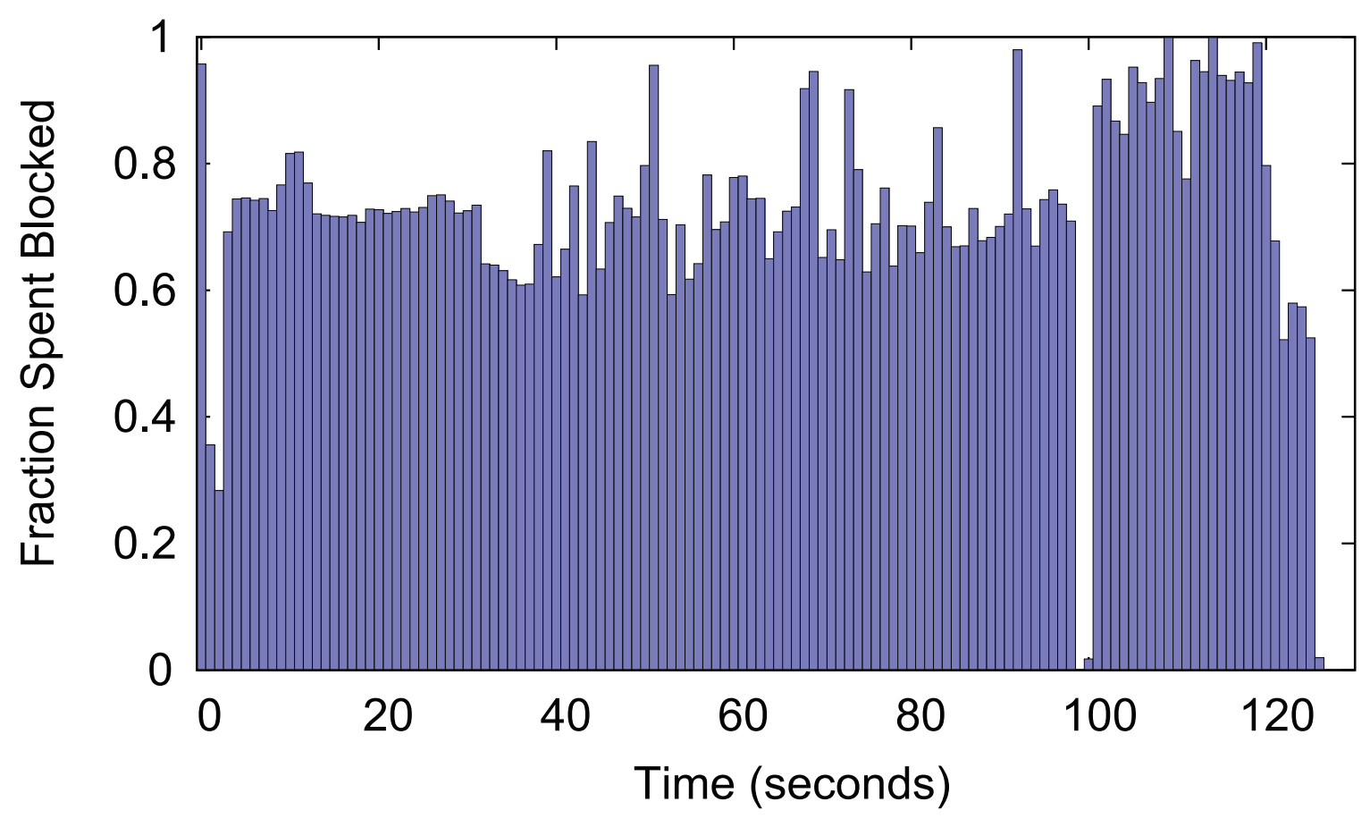
- Definition: ability to consume physical resources at sub-VM granularity, tracking effective resource demand
  - Physical host memory
  - Network bandwidth
- Description: Kaleidoscope workers allocate memory as necessary, an advantage when spikes are short lived.



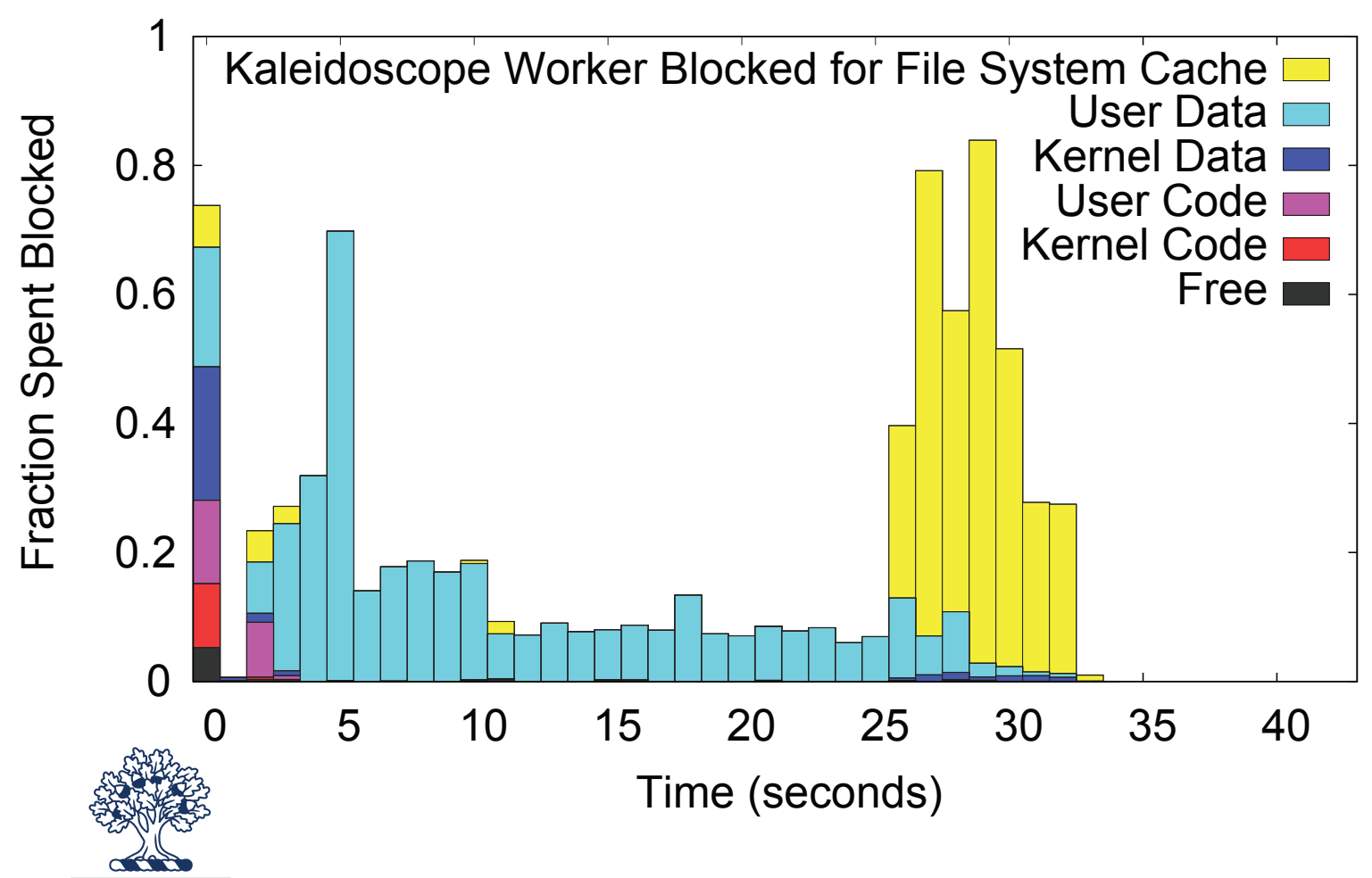
Traces in this figure include transferred state plus new allocations.

Evaluation Results

Reduction of page faults and blocking

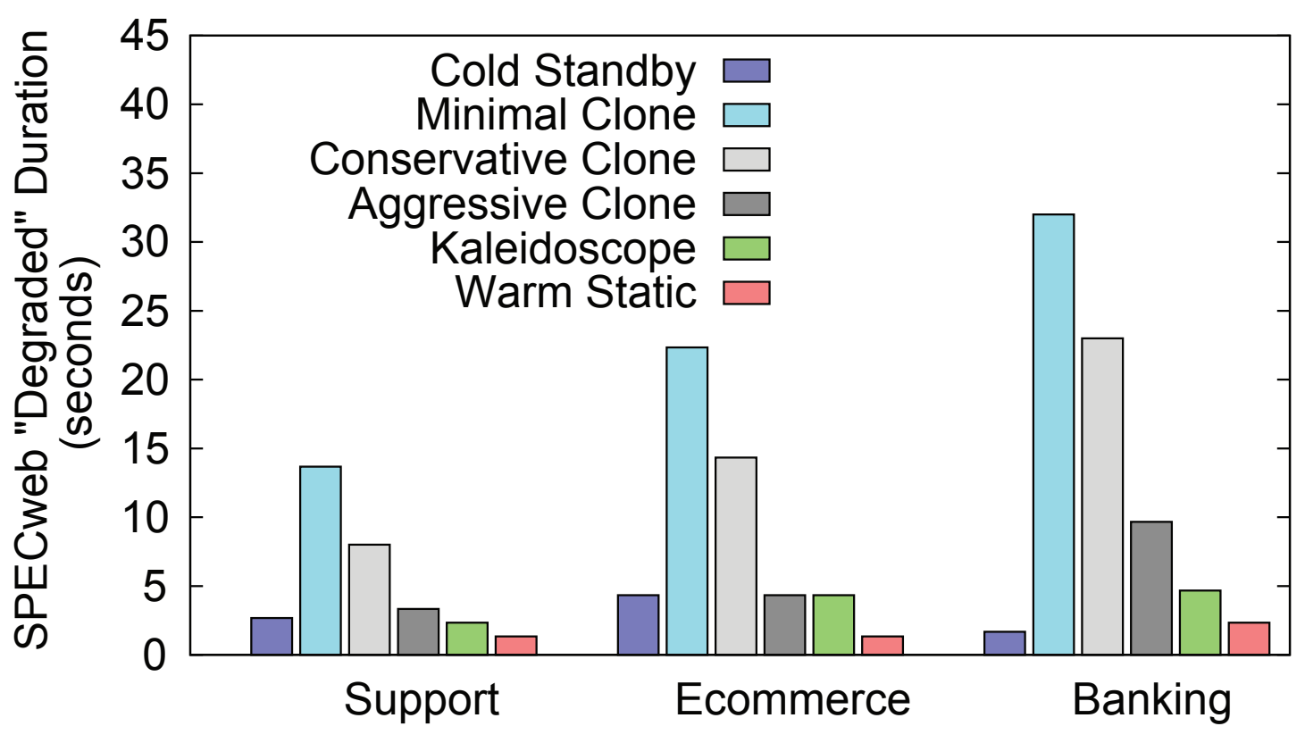


Before



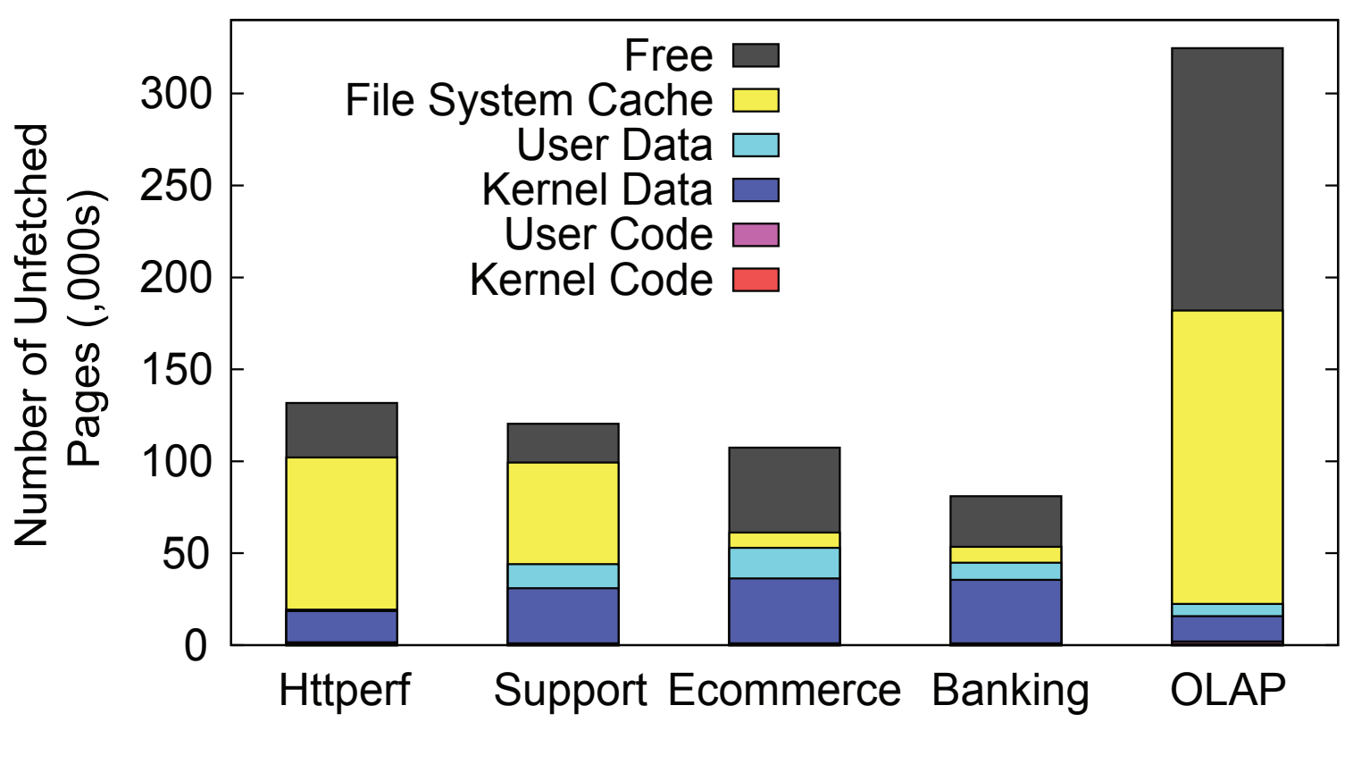
After

Near-optimal QoS



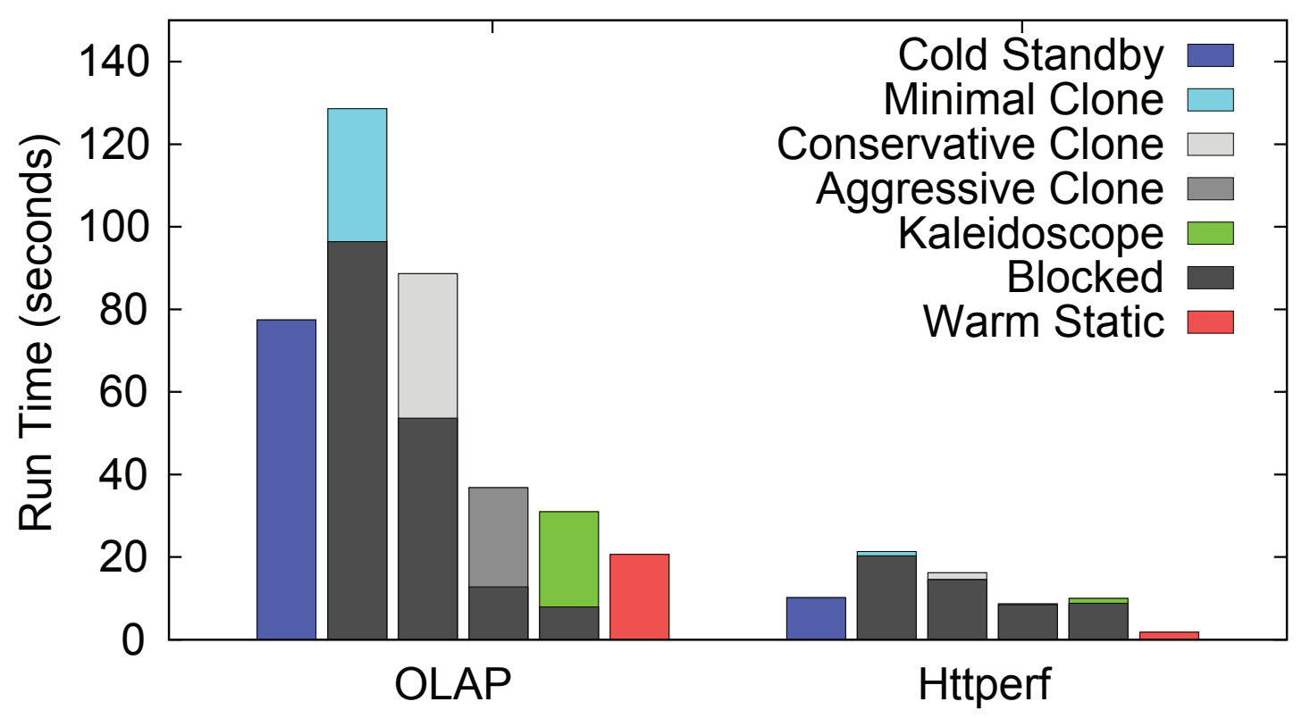
Prefetching reduces the length of time that prototypes fail to meet SPECweb's minimum acceptable QoS.

Resource preservation



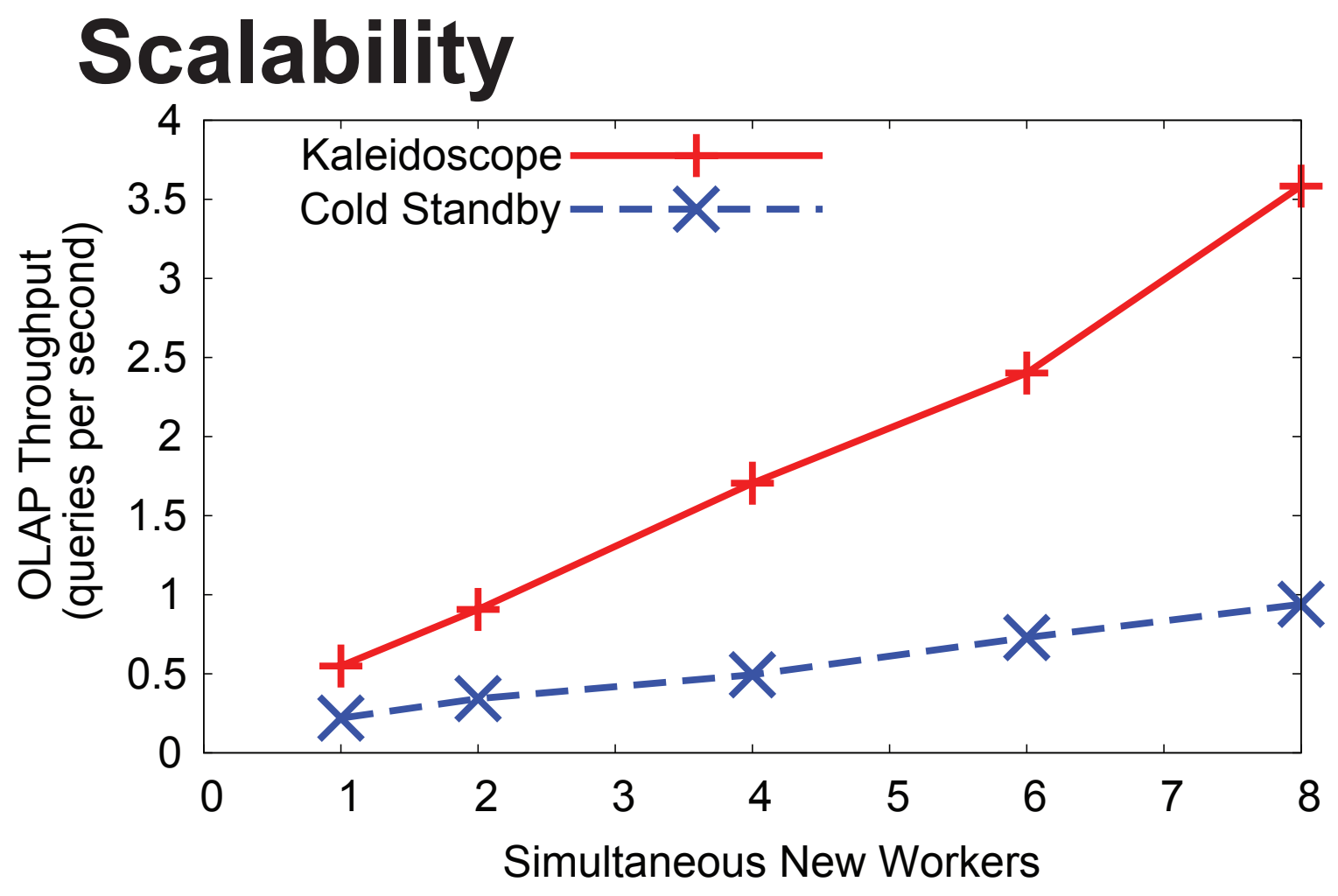
Kaleidoscope workers avoid unnecessary pages. Unfetched pages save precious bandwidth and are mostly file system cache and a free list.

Runtime



Runtime approaches near-optimal (warm static) as VCPU blocking and page faults are anticipated by colordirected prefetch and eliminated from the critical path.

Scalability



The database's OLAP throughput scales well with the number of simultaneous clones

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