COLORIS: A Dynamic Cache Partitioning System Using Page Coloring

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Overview

Background

- For multicore platforms, tightly-coupled on-chip resources allow faster data sharing between processing cores, at the same time, suffering from potentially heavy resource contention

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  - severe performance degradation
  - compromised QoS

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  - unpredictable caching behaviors
  - severe performance degradation
  - compromised QoS
- Performance isolation needed for QoS-demanding systems

Page Coloring

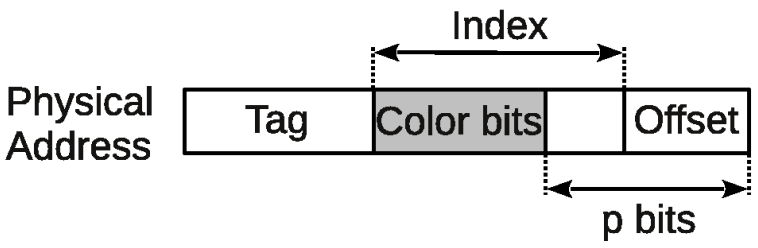


Figure: Page Color Bits

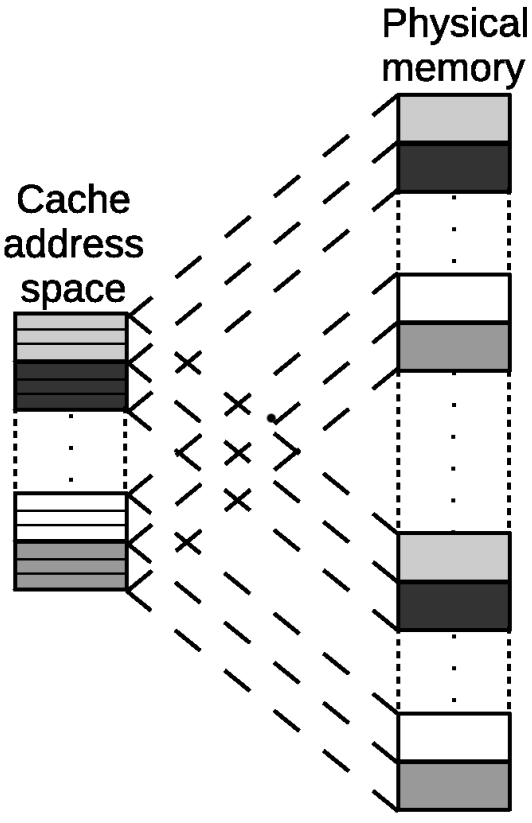
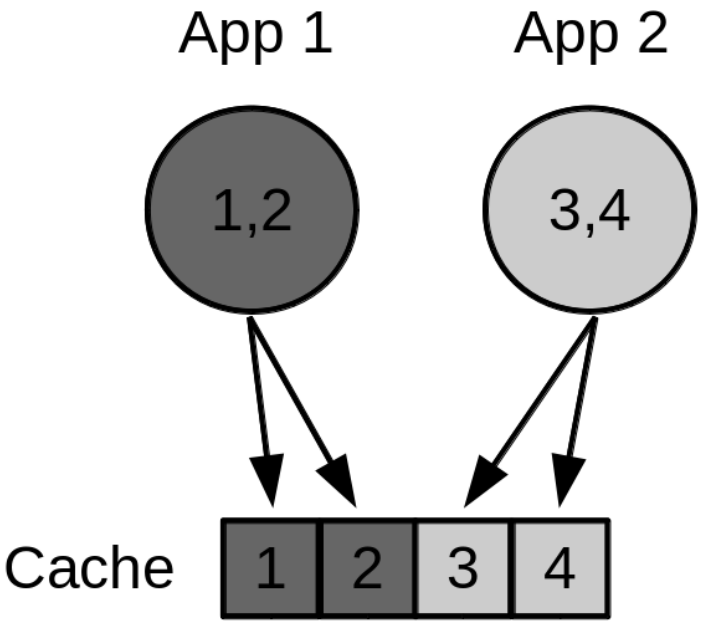


Figure: Mapping Between Memory Pages and Cache Space

Page Coloring



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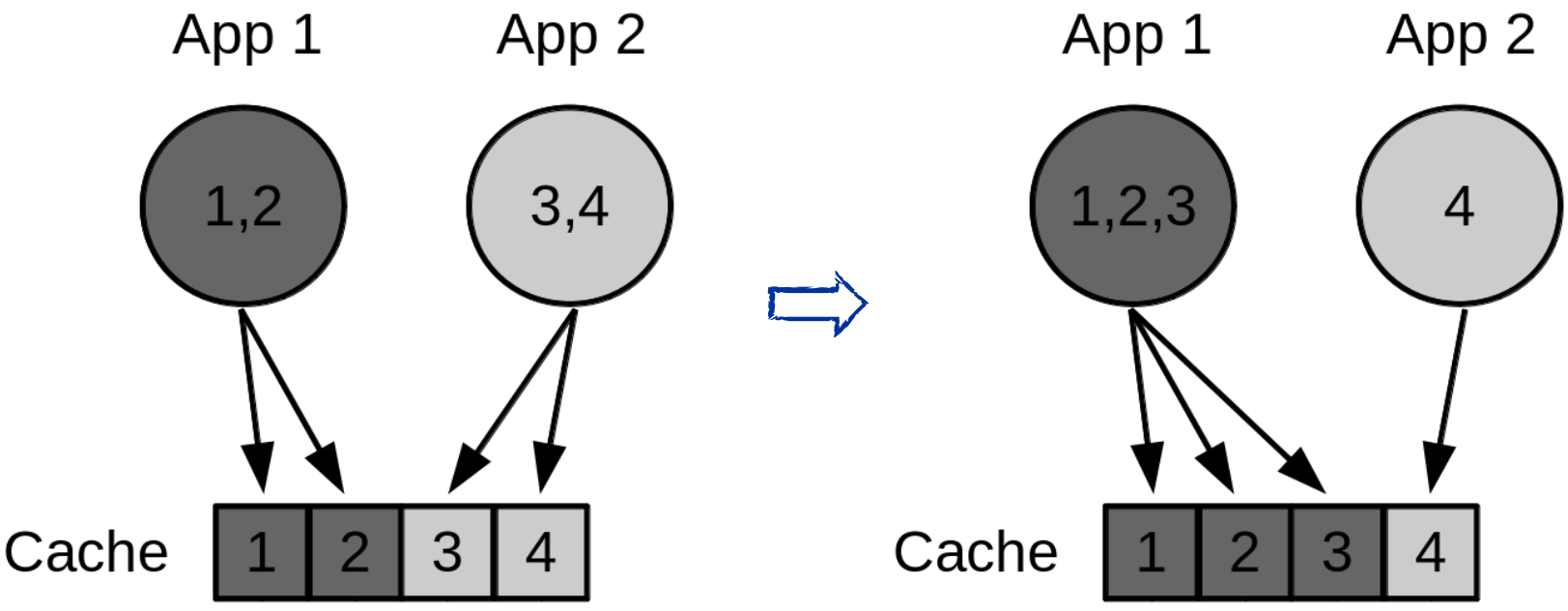

Dynamic Partitioning

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- What is the right partition size?
- How to recolor memory?
  - heavy overhead; inefficient use
- How to work with over-committed systems?

Contribution

- Our work tries to solve all problems above associated with implementing dynamic page coloring in production systems
- We proposes an efficient page recoloring framework in the Linux kernel, called COLORIS (COLOR ISolation)

Page COLOR ISolation Architecture

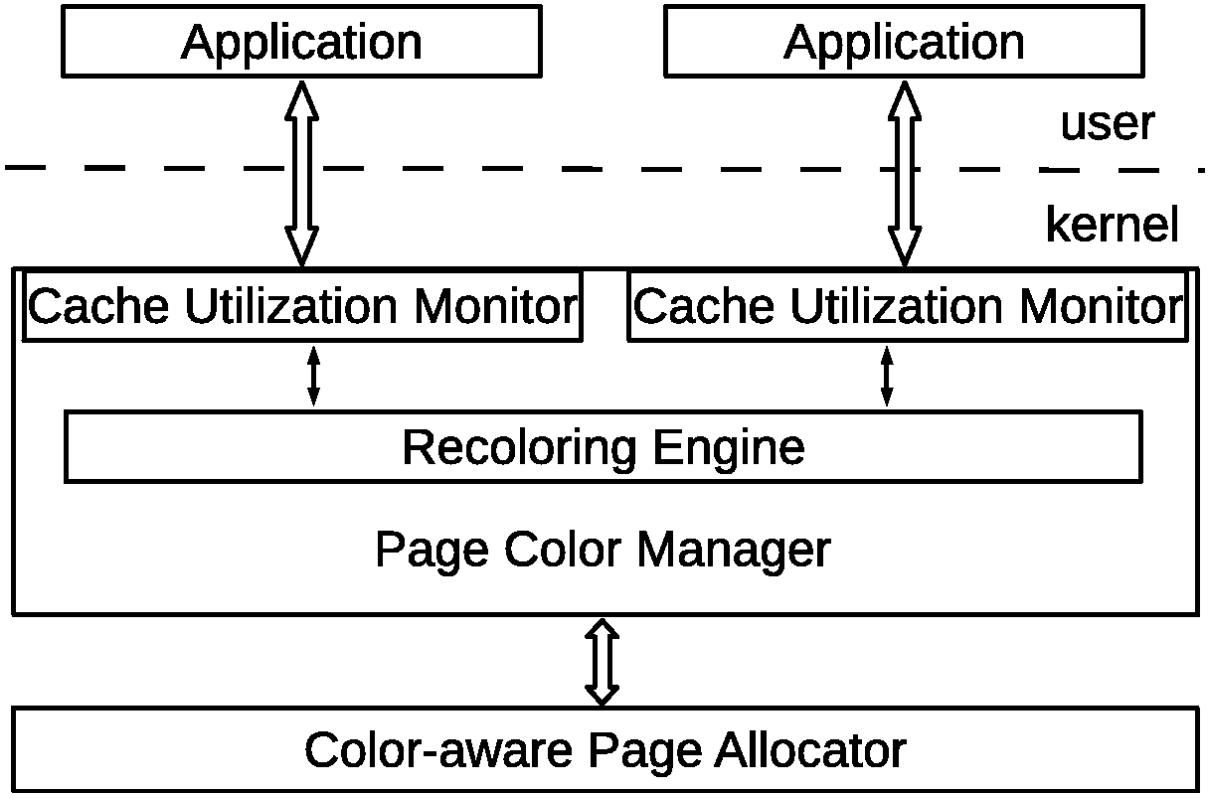


Figure: COLORIS Architecture

Color-aware Page Allocator

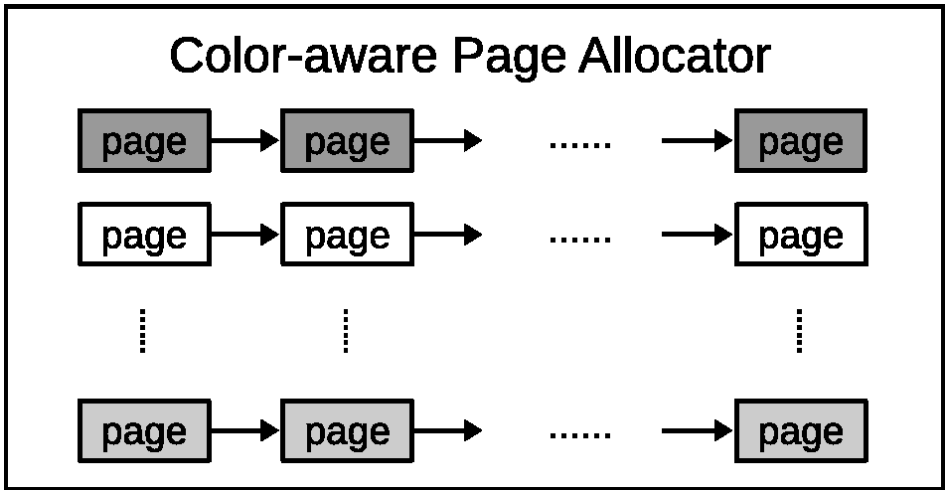
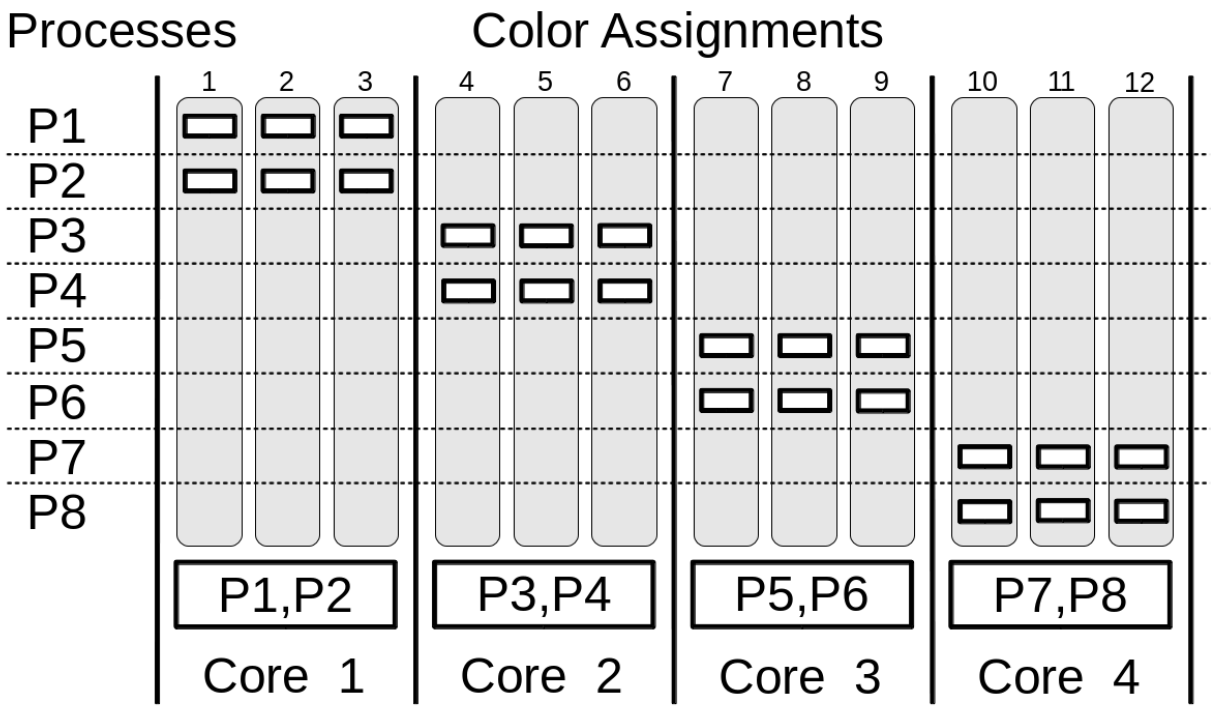


Figure: Page Allocator

Page Color Manager

- Static color assignment
  - Cache is divided into N sections of contiguous colors
  - Each cache section is statically assigned to a core
    - local core; remote core
  - Each process is assigned a section of page colors and runs on the corresponding core
    - local color; remote color

Static Color Assignment



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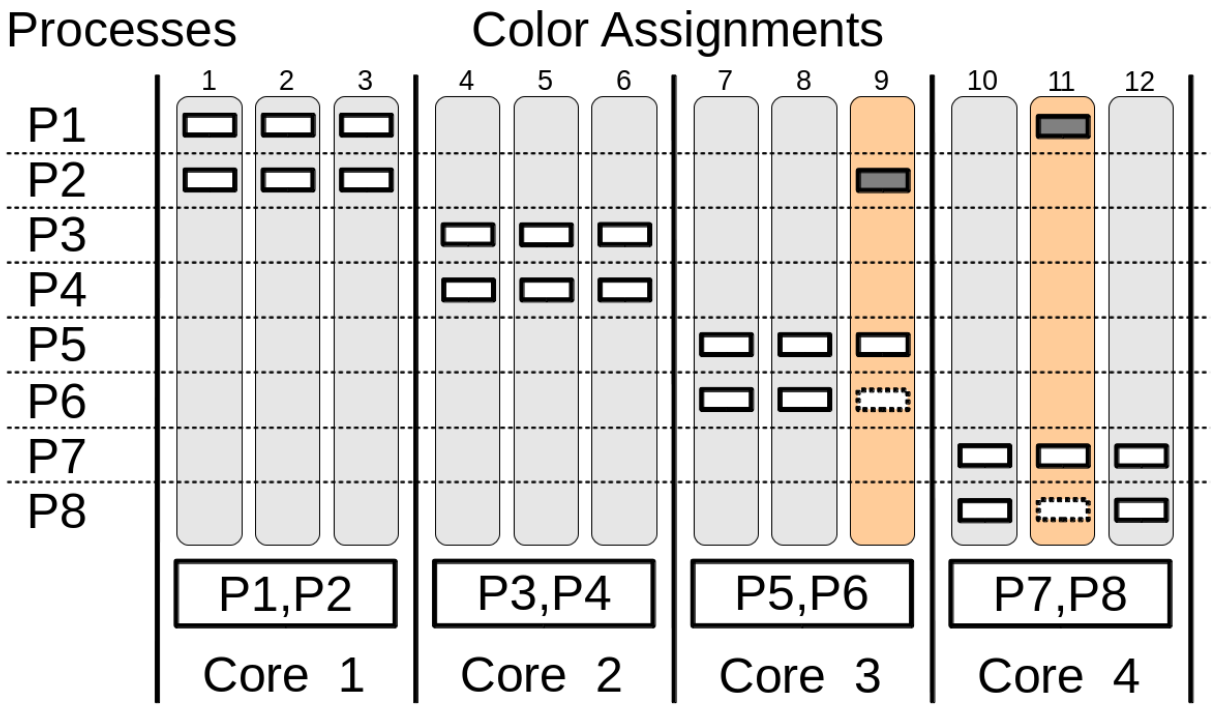
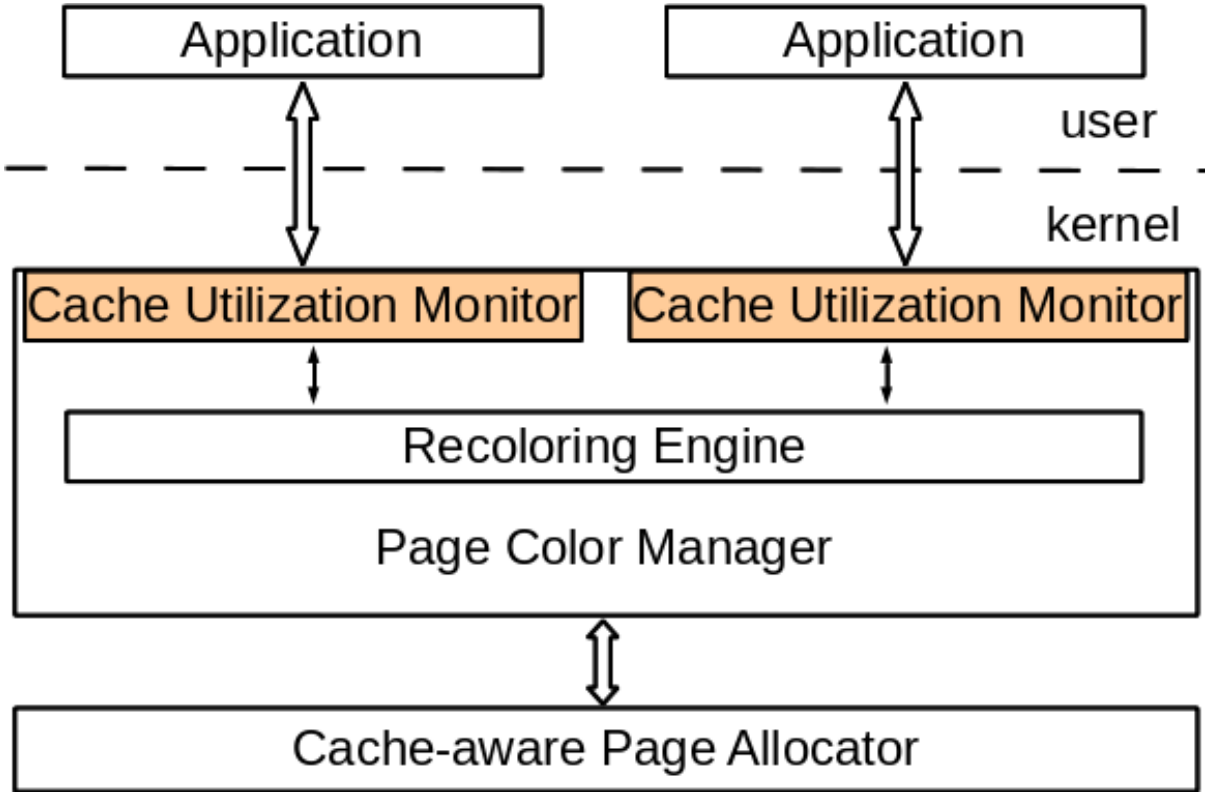


Cache Utilization Monitor



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  - $\textit{cache miss rate} = \frac{\textit{misses}}{\textit{accesses}}$
- Triggers cache re-partitioning:
  - miss rate higher than *HighThreshold*
  - miss rate lower than *LowThreshold*

Cache Re-partitioning

Color Hotness

The number of processes sharing the color

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The number of processes sharing the color

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- Remote Hotness: number of owners on remote cores
  - if color A is in the cache section statically assigned to core X, all other cores are called remote cores with respect to A

Cache Re-partitioning

```
procedure alloc_colors(num)
new ← φ
while num > 0
   if needRemote()
      new + =
         pick_coldest_remote()
   else
      new + =
         pick_coldest_local()
   num ← num − 1
return new
end procedure
```

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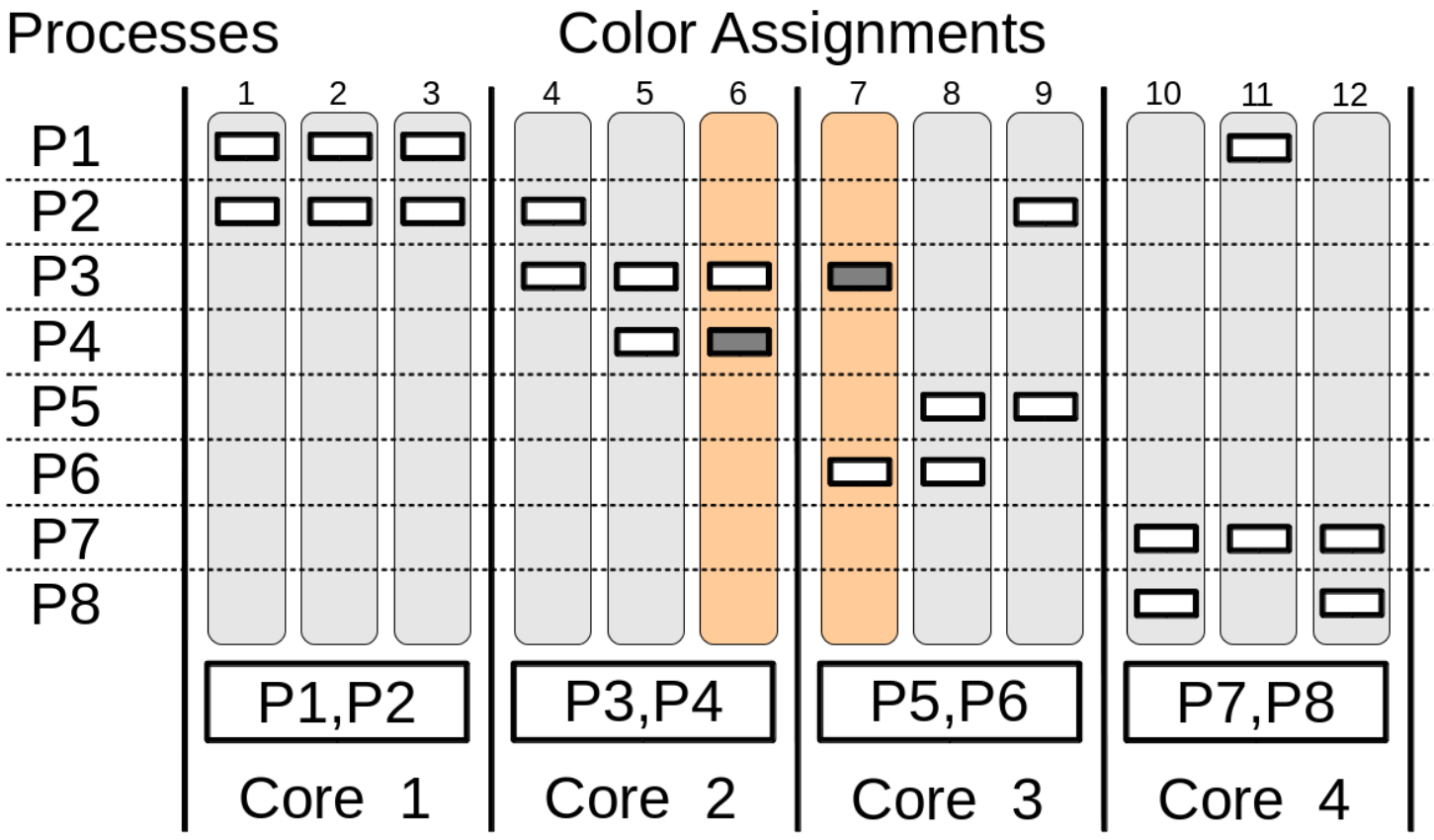
Processes
Color Assignments
1
2
3
4
5
6
7
8
9
10
11
12
P1
P2
P3
P4
P5
P6
P7
P8
P1,P2
P3,P4
P5,P6
P7,P8
Core 1
Core 2
Core 3
Core 4

Cache Re-partitioning

```
procedure pick_victims(num)
victims ← φ
while num > 0
   if hasRemote()
      victims + =
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   else
      victims + =
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   num ← num − 1
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- pick_hottest_remote: pick a color in a remote cache section, with the largest global hotness

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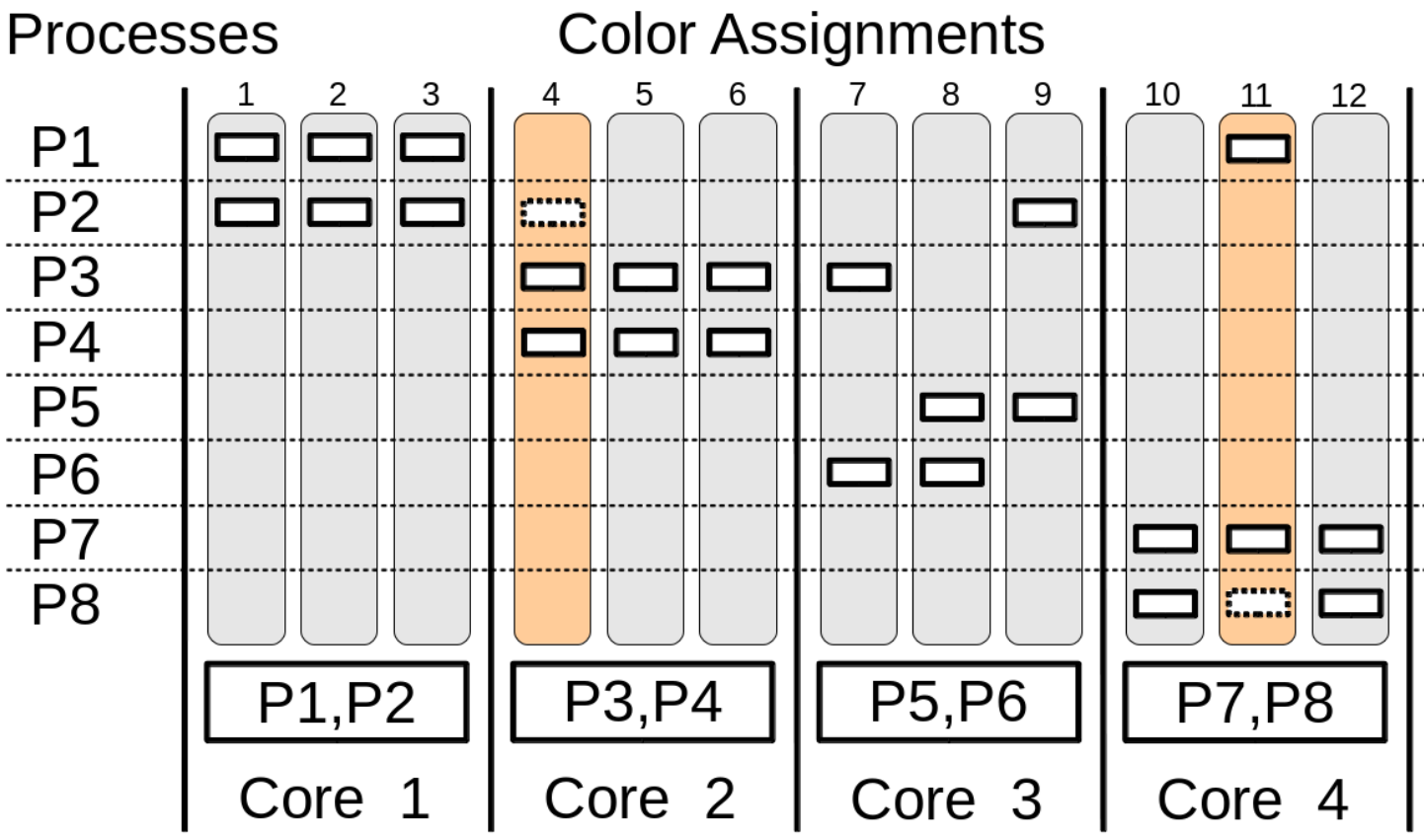
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Recoloring Engine

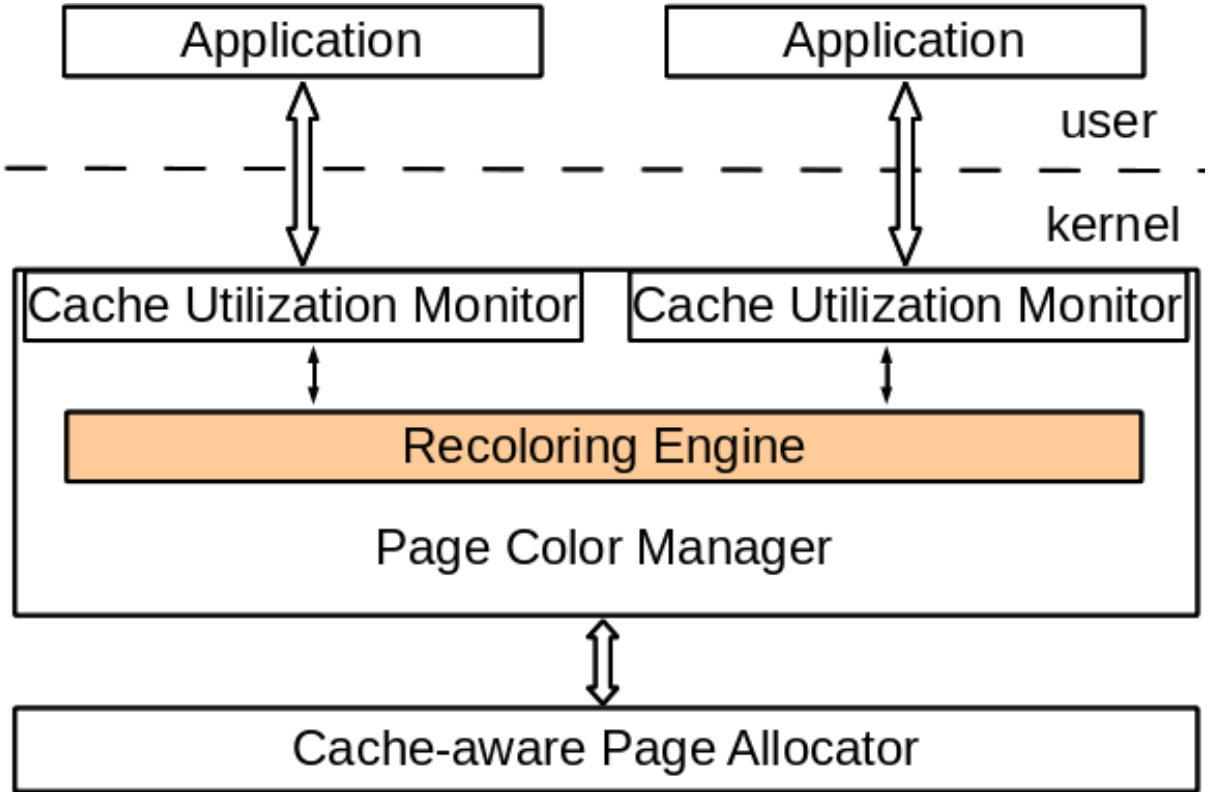

Figure: COLORIS Architecture

Recoloring Engine

- Shrinkage: lazy recoloring [Lin et al:08]
  - look for pages of specific colors that are going to be taken away and clear the present bits of their page table entries
  - an unused bit is set to indicate recoloring needed
  - allocate new pages from assigned colors in a round-robin manner

Recoloring Engine

- Expansion

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    Assuming n-way set associative cache, scan the whole page table and recolor one in every n + 1 pages of the same color

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- Expansion
  - Selective Moving:
    Assuming n-way set associative cache, scan the whole page table and recolor one in every n + 1 pages of the same color
  - Redistribution:
    - clear the access bit of every page table entry
    - after a fixed time window, scan the page table again
    - apply lazy recoloring to entries with access bits set

Evaluation

- Experiment setup

  Dell PowerEdge T410 machine with quad-core Intel Xeon E5506 2.13GHz processor, 8GB RAM, shared 4MB 16-way set-associative L3 cache

- Benchmark: SPEC CPU2006

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- Dynamic partitioning for QoS
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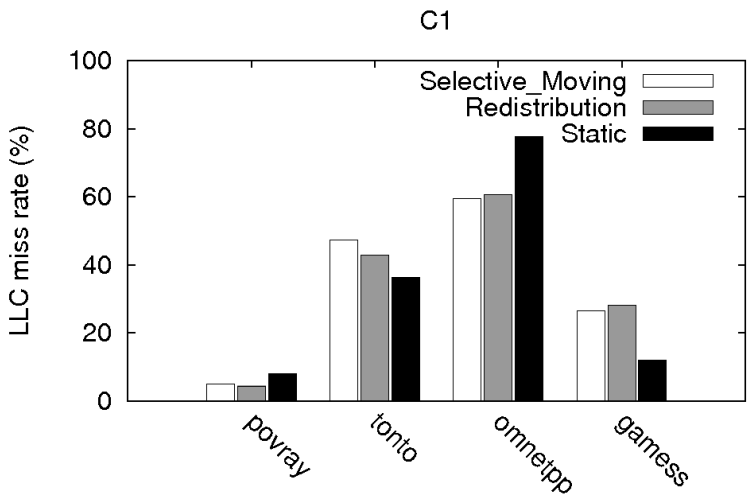
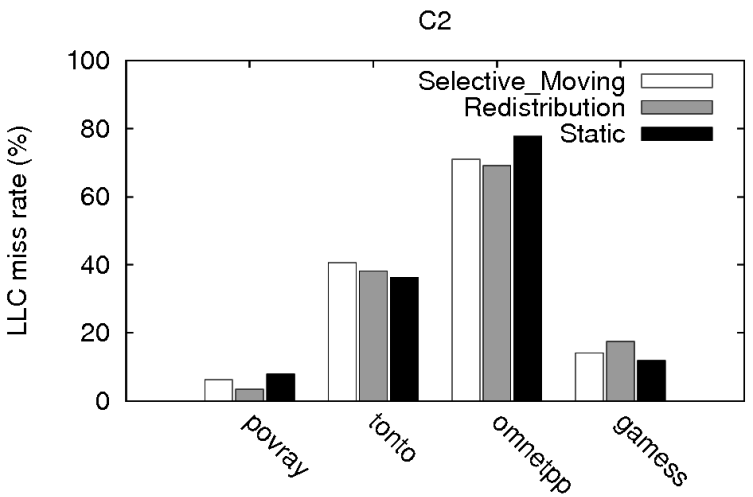
  In C1 and C2, *HighThreshold* is 65% and 75% respectively





Evaluation

- COLORIS in over-committed systems
- Eight applications run together, with each two pinned to a core

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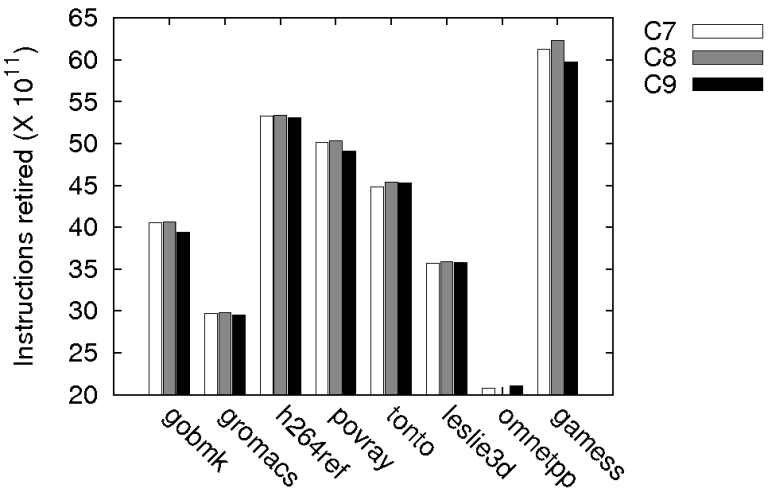
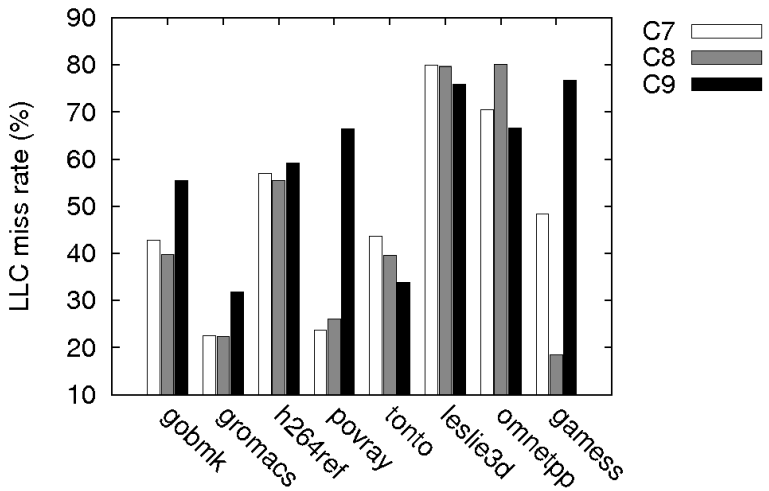
  C7: Dynamic; C8: Static; C9: None (Linux default)





Conclusion

- Designed a memory sub-system that provides static/dynamic cache partitioning capabilities
- Proposed a scheme for managing page colors, which works for over-committed systems
- Studied two page selection policies for effective page recoloring

The End

Thank you!