Reducing False Sharing on Shared Memory Multiprocessors through Compile Time Data Transformations

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What is false sharing?

- Multiple CPUs, each with their own cache
- Different CPUs using different pieces of data should be able to run completely in parallel
- **False sharing:** The different pieces of data end up on the same cache line, so the CPUs must coordinate whenever either piece of data is changed
    - A CPU that writes to a falsely shared cache line must invalidate all other CPUs' caches
    - Other CPUs will incur cache misses when they try to read the falsely shared cache line

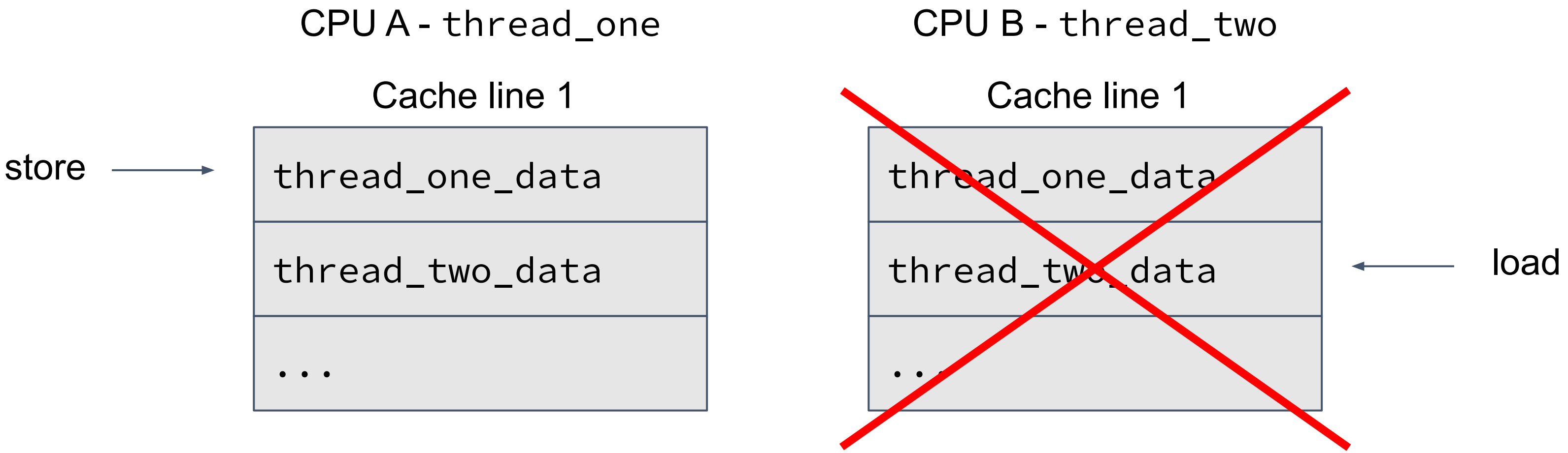
What is false sharing?

```
struct {
    int thread_one_data;
    int thread_two_data;
} shared;

void thread_one() {
    for (int i = 0; i < 1000; ++i) {
        ++shared.thread_one_data;
    }
}

void thread_two() {
    for (int i = 0; i < 1000; ++i) {
        printf("%d\n", shared.thread_two_data);
    }
}
```

What is false sharing?



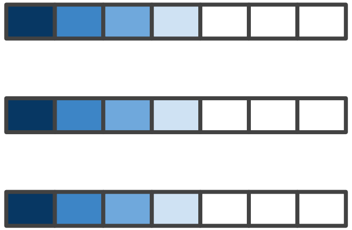
Group and Transpose

- Physically group per-process data together by changing the layout of data structures in memory
- If each processor's data is less than the cache block size, it may be padded
- May also improve spatial locality

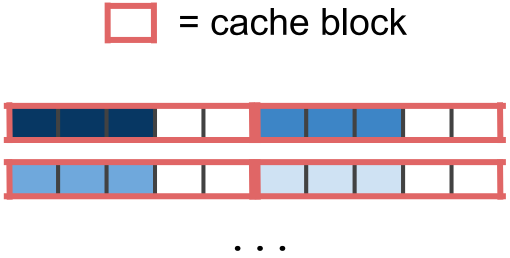
```
typeA Vect1[N]

typeB Vect2[N]

typeC Vect3[N]
```

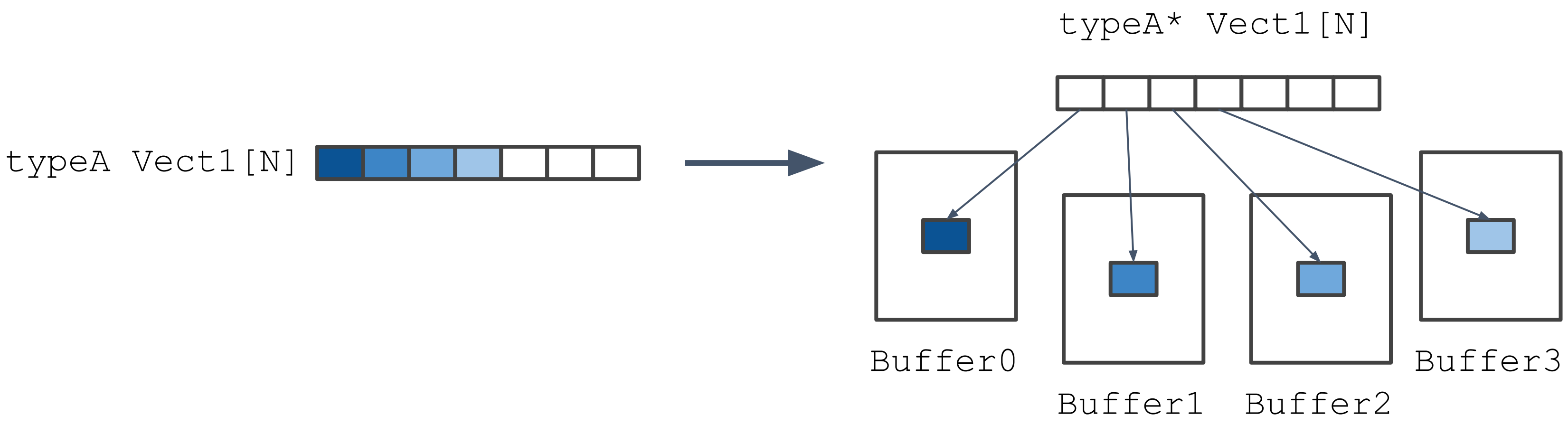


```
struct {
    typeA Vect1;
    typeB Vect2;
    typeC Vect3;
    gt_pad1 Padding;
} GTVect[N];
```



Indirection

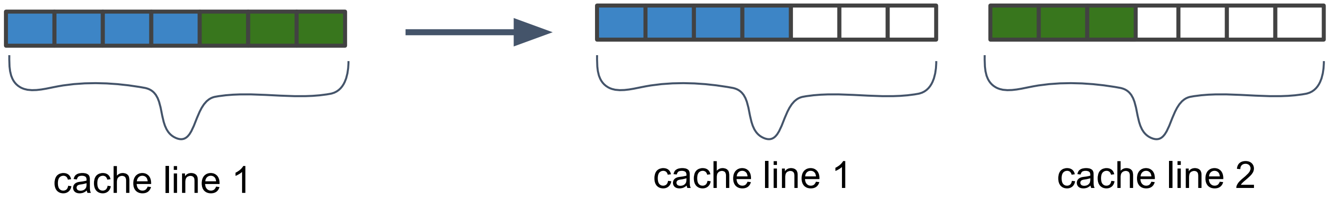
- When it's not physically possible to change the data layout, we can use indirection
  - Pointers are read-only
- Run time overhead
  - additional space for the pointers
  - additional memory access for each reference to the data



Pad and Align

- Pads and aligns scalars, array elements, and locks on cache block boundaries
- Increases data set size, so may increase conflict and capacity misses and reduce spatial locality
    - Therefore only pad data structures that lack processor locality, i.e., where the possible loss of spatial locality is insignificant relative to the savings in false sharing.

```
typeA Vect1[7]
```




```
struct {
   typeA Vect1[4];
   typeA padding[3];
   typeA Vect2[3];
} PadVect;
```

Detecting and Applying Transformations

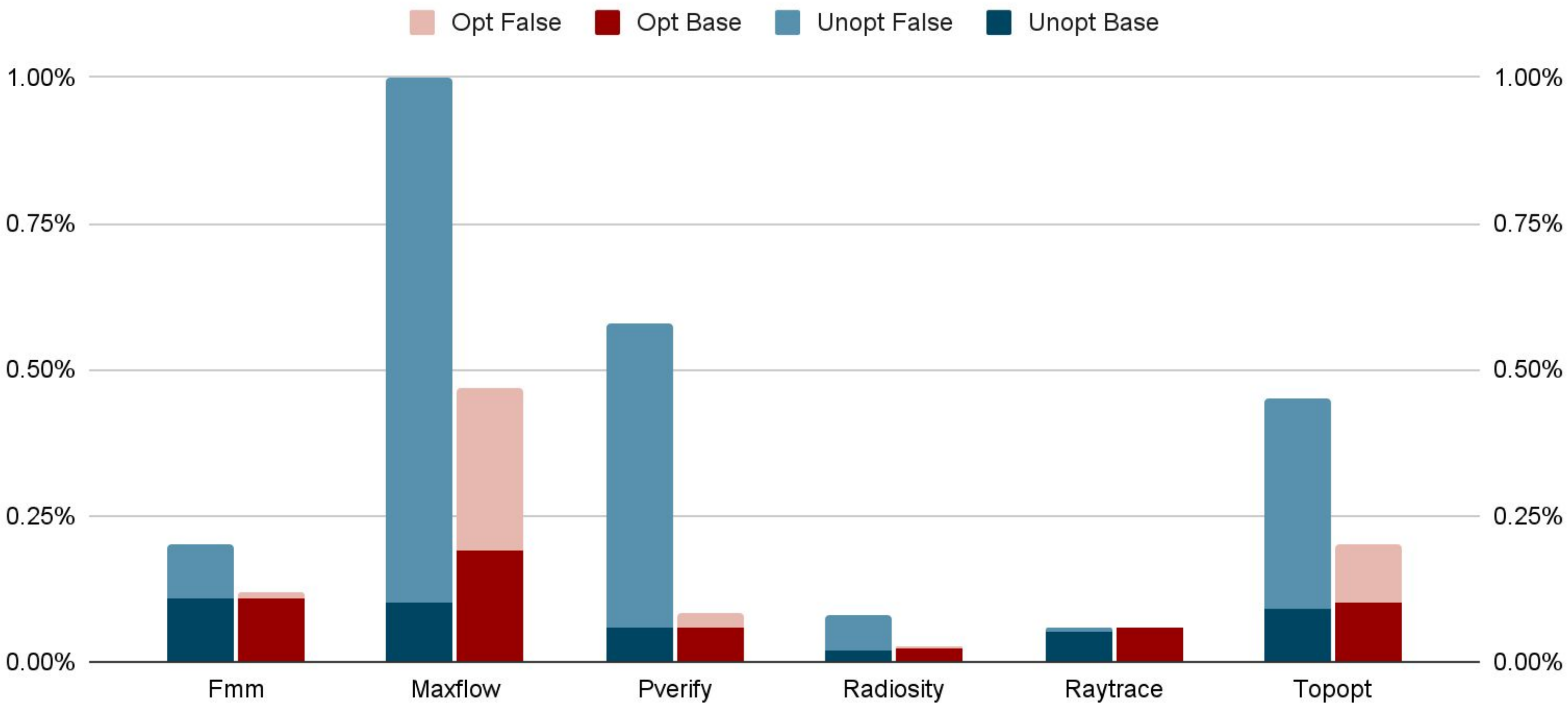
- Compile-time analysis is used to pinpoint data structures that are susceptible to false sharing. Approximate memory access pattern is computed.
    - **Stage 1**: Inter-procedural analysis of the control flow. CFG nodes annotated accordingly.
    - **Stage 2**: Non-concurrency analysis using barrier synchronization points to determine which portions of a program can execute in parallel and which cannot.
    - **Stage 3**: Summary side-effect analysis and static profiling on a per-process basis (based on the control flow determined in Stage 1) for each phase (determined in Stage 2).
- After static analysis, **heuristics** were used to determine where to mitigate false sharing
    - Compare results of the **per-process side-effect analysis** to **profiling information from simulations** that showed the number of false sharing misses per data structure.
    - Transformations **applied when reduction in false sharing exceeds any performance loss from reduced spatial locality**

Results

- Evaluated performance for multiple different programs
    - Maxflow - maximum flow in a directed graph
    - Pverify - logical verification
    - Topopt - topological optimization
    - Fmm - fast multipole method
    - Radiosity - equilibrium distribution of light
    - Raytrace - rendering of 3-dimensional scene

    - More: LocusRoute, Mp3d, Pthor, Water

Results - Comparison



Results - Performance Breakdown

Program	Total Reduction in False Sharing	Fraction of Reduction by Transformation			
		Group & Transpose	Indirection	Pad & Align	Locks
Maxflow	56.5%			**49.2%**	7.3%
Pverify	91.2%	6.4%	**81.6%**		3.1%
Topopt	79.9%	**61.3%**	18.6%		
Fmm	90.8%	**84.8%**			6.0%
Radiosity	93.5%	**85.6%**		1.0%	6.8%
Raytrace	78.3%	**70.4%**		3.3%	4.6%

Paper Pros

- Novel ideas to reduce false-sharing
- Static Analysis
- Techniques help with both performance and scalability!

Paper Cons

- Reordering members of struct may be disallowed
- Can lead to extra memory usage and less locality
- Indirection creates extra overhead
- Static analysis
  - Heuristics are unclear

Conclusion

- False sharing is a silent killer of performance in concurrent programs
- By using static analysis, Jeremiassen and Eggers identify heuristics to detect where false sharing occurs and determine how best to fix it
- If locality is not hurt too much, the Group & Transpose, Indirection, and Pad & Align transformations can be applied to reduce false sharing
- Performance is demonstrably improved on a variety of benchmarks