# Optimizing Chapel for Intra-Node, Multi-Core Environments

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# Motivation: Building a better Chapel

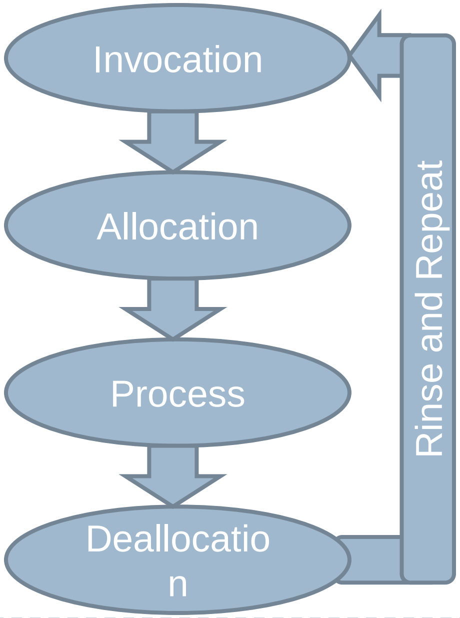
- Evaluate how well Chapel performs in practice.
  - Comparison of Chapel benchmark performance against implementations in competitive parallel frameworks.
  - Identify opportunities to improve language performance.
- Goals: Investigating techniques to
  - Improve development practices for Chapel programmers.
  - Automate solutions that could be incorporated into future versions of the Chapel compiler and runtime framework.
- We will focus on single-locale environments.

# Strategy

- Use benchmarks
  - Represent real world scientific computing applications
  - Embodies different usage of language features
- Performance tuning
  - Profile benchmarks to identify bottlenecks in performance.
  - Analyze performance gaps between parallel frameworks.
- Determine where changes are needed to close gaps.
- Generalize the lessons learned.
  - Improvement over original and competitive benchmark
  - Impact across other Chapel benchmarks

# LULESH Overview and Pitfalls

- LULESH is a 'shock hydro' parallel benchmark designed for hydrodynamics calculations.
- Large array declarations inside subroutines:
  - Translate into large heap allocation requests.
  - Write operations are performed to set all elements to zero
  - Occurs each time the function is invoked.




**Lulesh.chpl** (1695 lines)

CalcHourglassControlForElems()

```
proc CalcHourglassControlForElems(determ) {
  var dvdx, dvdy, dvdz, x8n, y8n, z8n: [Elems] 8*real;

  forall eli in Elems {
    ...
  }
  ...
}
```

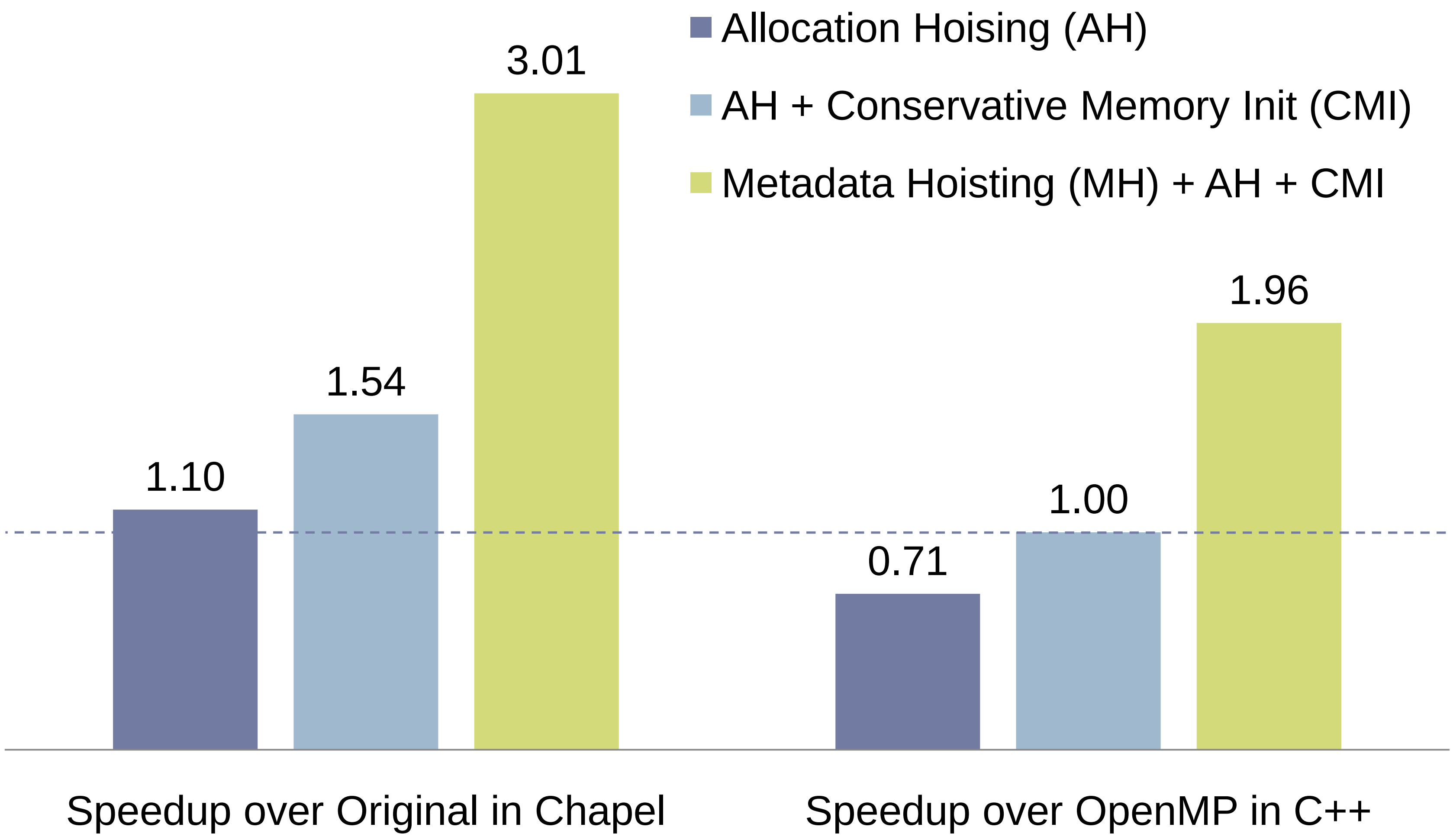
**18.8% of the wall time is spent on one line of code in the sequential part of the program.**

# LULESH Insights

- Hoisting
  - Store recurring requests of large local allocation for reuse.
  - Additionally store allocations of all compiler generated metadata structures related to each memory allocation.
- Conservative Memory Initialization
  - For each allocation, does there exist an entry in the subsequent code that is read prior to being set explicitly?
  - Static analysis: determine when to invoke calloc vs. malloc and memset for memory reuse in generated code
- Provide optional compiler support for language feature similar to static in C.
  - Avoid having to use globals.

```
proc foo() {
  persistent var a: [dom] int;
  ...
```

# LULESH Performance



# MiniMD Overview, Pitfalls, and Insights

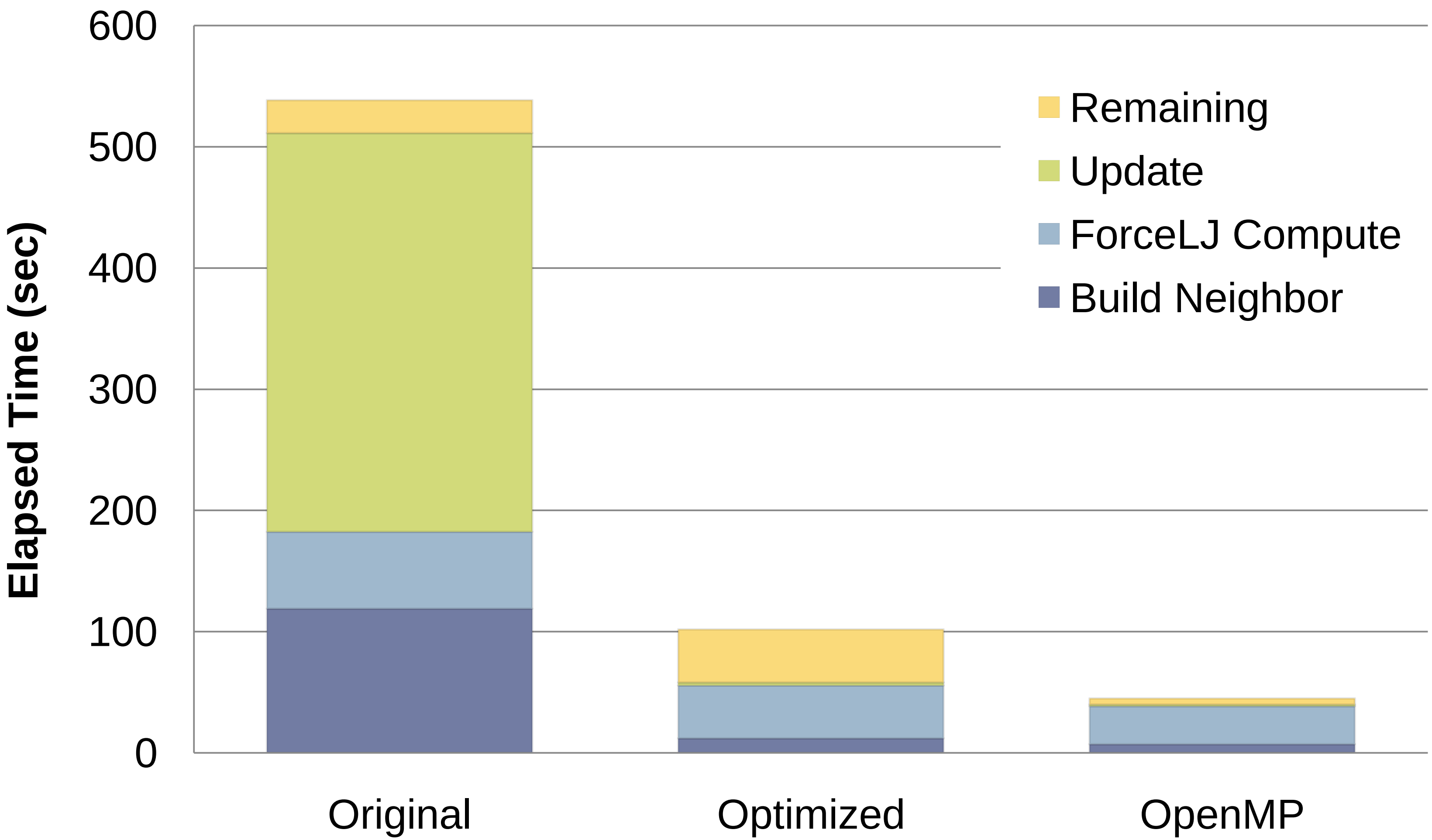
- **Mini** parallel benchmark for **M**olecular **D**ynamics
- Avoid repetitive mapping from one domain to another when iterating over nested loops.

**UpdateFluff()**

| Original | Optimized |
| --- | --- |
| `forall (P,D,S) in zip (PosOffset, Dest, Src) {`<br>`  Pos[D] = Pos[S];`<br>`  Count[D] = Count[S];`<br><br>`  // offset positions`<br>`  forall d in D do`<br>`    Pos[d][1..Count[d]] += P;` | `forall (P,D,S) in zip (PosOffset, Dest, Src) {`<br>`  forall (d, s) in zip (D,S) do {`<br>`    Pos[d] = Pos[s];`<br>`    Count[d] = Count[s];`<br>`    for i in 1..Count[d] do {`<br>`      Pos[d][i] += P;`<br>`    }` |

- Remove unnecessary autoCopy / autoDestroy calls
  - Found inside ‘coforall_fn_chpl#’ loops generated from the parallel loops of ‘Build Neighbors’ and ‘ForceLJ compute’

# MiniMD Performance



# SSCA#2 Overview and Implementations

- **S**calable **S**ynthetic **C**ompact **A**pplications #2
  - Generates weighted, directed multigraph.
  - Performs approximate betweenness centrality (BC).
- Chapel vs. OpenMP version of SSCA#2
  - Different approaches to betweennessCentrality()
  - Developed ports to achieve a more fair comparison.
- Each version of the benchmark was ported to the other framework respectively.
  - Algorithm I:  Chapel benchmark
  - Algorithm II: OpenMP benchmark

# SSCA#2 Pitfalls and Insights: Alg. I

- Algorithm I was not optimized for single-locale.
  - One task private variable (TPV) data structure per core instead of per locale.
- Managing parallel redundancies in nested loops.
- User specific thread initialization for nested loops.
  - Removing the need for task private data management could improve parallel loop performance by 12% or more.
- Selectively disable redundant memory initializations 'init_elts#' found in 'initialize#' in the generated code.
  - Shown to improve performance of other benchmarks too

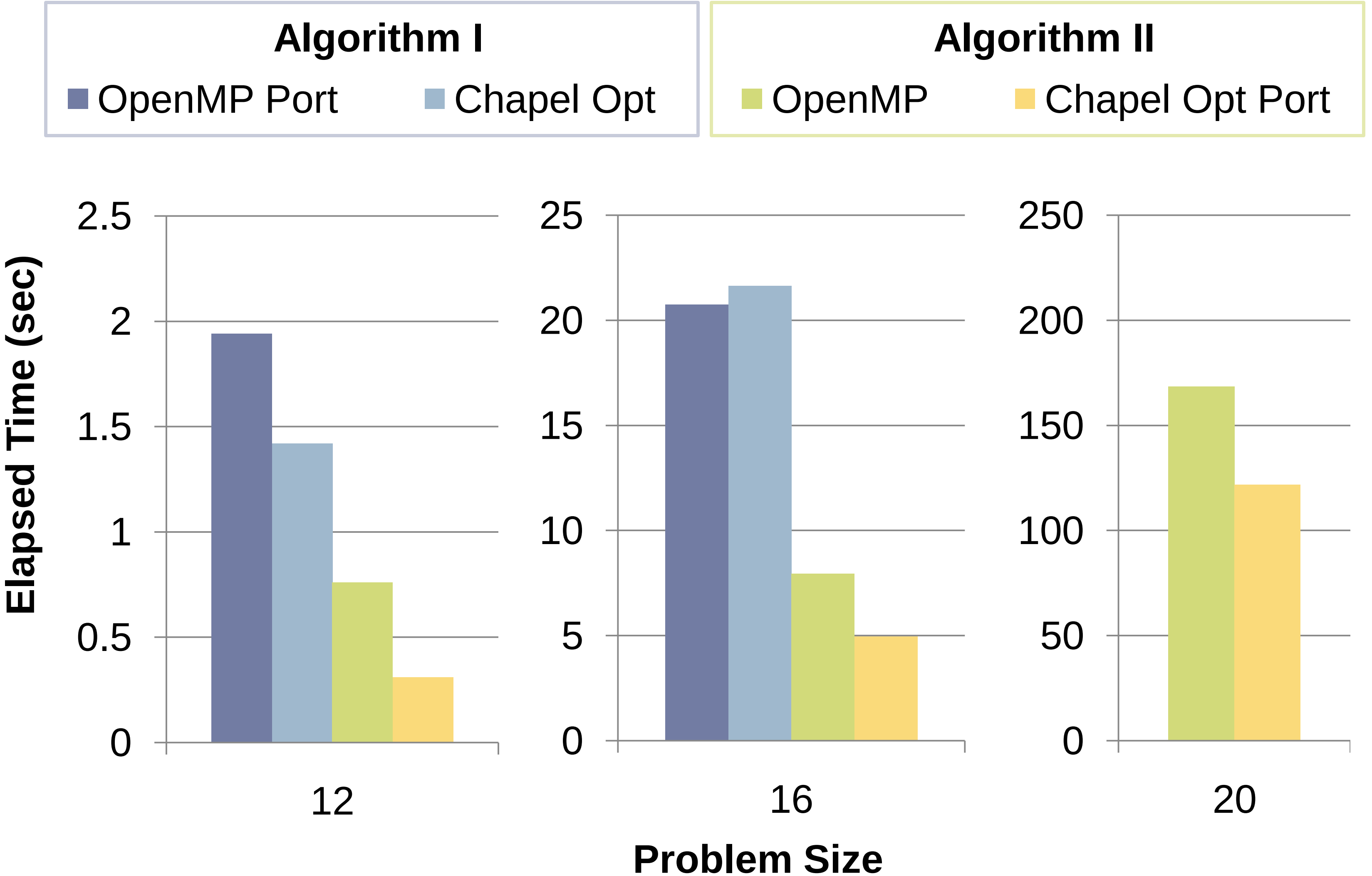
# SSCA#2 Pitfalls and Insights: Alg. II

- Initial port into Chapel performed 4.9x slower
  - Overhead of parallelization in BC: 46% of overall BC time
  - Up to 54.5% of parallel time in BC was spent on variable synchronizations (locks)
  - Fluctuating number of iterations in BC inner loops
    - Non-uniform workload distribution
- Developed a proxy to model parallelization of BC.
  - Overhead of parallel loops nested inside sequential loops
  - Compare uniform and non-uniform workload performance
  - Comparisons between parallel frameworks.

# SSCA#2 Insights: Alg. II

- BC proxy lessons learned:
  - Non-uniform workloads
    - Chapel: 4.7x slower, OpenMP: unaffected
    - Chapel performance on par with OpenMP (static,1 scheduler)
  - No usage of #pragma omp parallel: 28x slower
  - Chapel: parallelizing outer loop instead: 15% speed up
- Application towards BC in Chapel port (Alg. II)
  - Parallelize the outermost loop over starting vertices:
    - Reduces the sequential parts of BC and parallel overhead.
    - Allows for the removal of most synchronization variables.

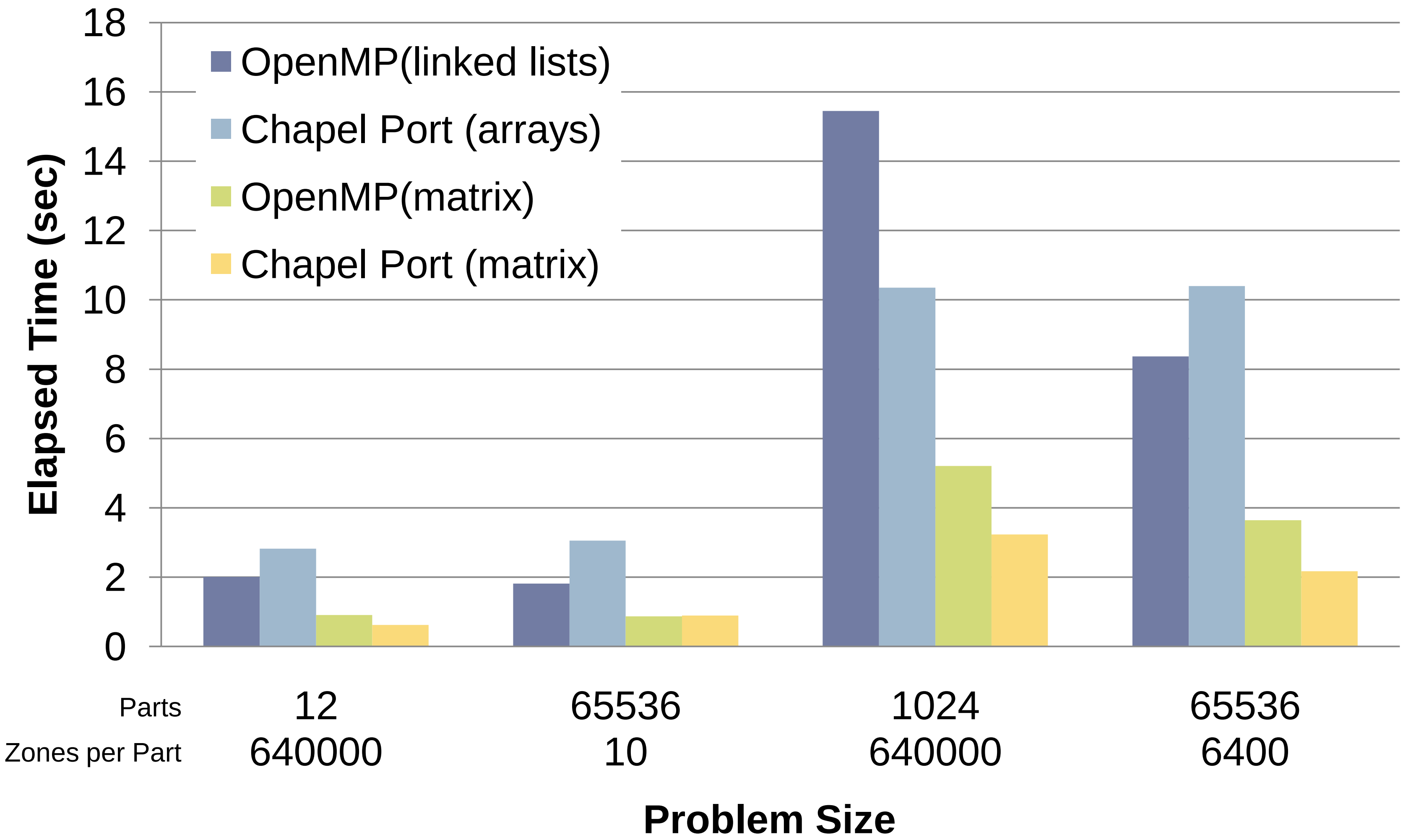
# SSCA#2 Performance



# CLOMP Overview and Pitfalls

- Coral Collaboration Benchmark Codes
- CLOMP: **C** version of **L**ivermore **OMP** benchmark
  - Skeleton benchmark for measuring the overhead of different OpenMP primitives.
  - Sequential loop test: serial
  - Parallel loop tests: static, dynamic, and manual
- Chapel benchmark
  - Ported serial and a generic version of parallel loop test.
  - Chapel does not allow for explicit thread control.
- Redundant memory initializations; Memory structure

# CLOMP Performance



# Overlap and Impact of Bottlenecks

| Degradation | LULESH | MiniMD | SSCA#2 | CLOMP |
|---|---|---|---|---|
| Reoccurring local allocations | **X** | | | |
| Thread / task private allocations | | | **X** | |
| Adaptive memory reset | x | | | |
| Redundant memory init_elts# | x | x | x | **X** |
| Redundant autoCopy / autoDestroy | x | x | | |
| Redundant parallelism | | | x | |
| Domain remapping overhead | | **X** | | |
| Application bottleneck | | | **X** | |
| Memory structure | | | | **X** |

**X:** Major impact**,** x: Minor impact

# Conclusion

Performance gain over:

| Benchmark | Original Chapel | OpenMP |
|---|---|---|
| LULESH | 3.0x | 2.0x |
| MiniMD | 5.3x | 0.4x |
| SSCA#2 (I) | 6.3x | On par |
| SSCA#2 (II) | 7.9x | 1.6x |
| CLOMP | 4.8x | 1.7x |

- Future work
  - Explore Chapel performance and develop optimization strategies for inter-node (multi-locale) environments.
    - Task delegation and memory localization over PGAS
    - Communication access patterns
    - Remote prefetch and caching
  - Automate optimizations in Chapel reference compiler.