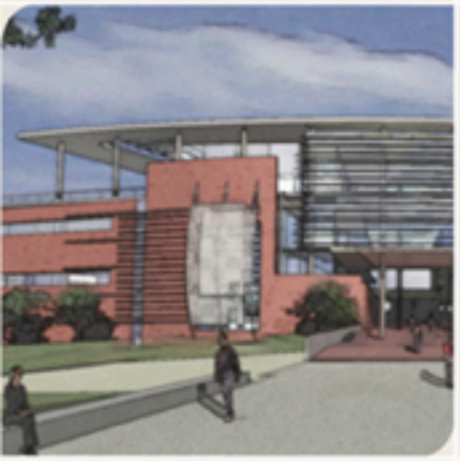

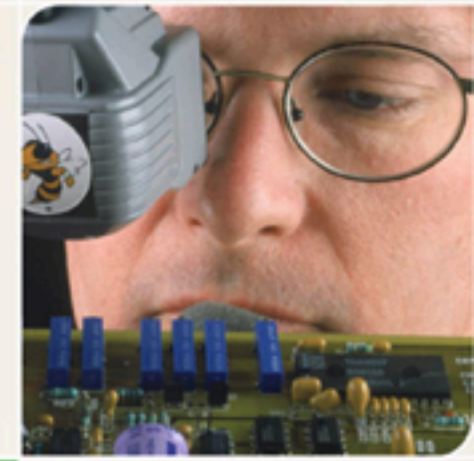

Collaborative Threads

Exposing and Leveraging Dynamic Thread State for Efficient Computation

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Outline

- Views on Parallelism
- Thread Collaboration and Semantic State
- Representation of Semantic State with the CST
- Experimental Results
  - Result reuse
  - Orienting a Computation

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Parallelism and Threads

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- Parallelism today relies on threads
  - Splitting-up of data with data-parallelism
  - Splitting-up of work with task-parallelism

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Parallelism and Threads

- Parallelism today relies on threads
  - Splitting-up of data with data-parallelism
  - Splitting-up of work with task-parallelism
- Higher-level models exist as well
  - TBB, Cilk to express task-parallelism
    - Implements the fork-join paradigm
    - Provides higher-level parallel abstractions (parallel_for, parallel_do,...)
  - CnC to express natural parallelism

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- Thread interactions is restricted to
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  - Locks, barriers and TMs for synchronization
  - Shared memory and message passing for shared data
- Threads have no knowledge of and do not communicate about:
  - their “role” in the overall computation (semantics)
  - the overall state of the computation

What is Missing?

Can we view threads differently?

Current Use of Parallelism

Current Use of Parallelism

- Current models *break-up* a computation
  - Distribution of work is done just in time at best
  - Break-up oblivious to the state of the computation
  - Only the state of data-structures (what threads read/write to them) is used (for example, the Galois model)
  - Higher-level semantic information is lost

Alternative Uses Required

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- Many HPC combinatorial optimization problems and search problems
  - Are resource bound
  - Have a performance dependency on more than how work is split-up
- Performance depends on the direction of computation, scheduling of tasks, ordering of computations, pruning of the search space, etc...
  - For example: certain orderings will lead to a faster space pruning

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  - Pick the best through competition amongst diverse ways

Alternate Views on Parallelism

- N-way parallelism leverages competition [HotPar 2009]
  - Pick the best through competition amongst diverse ways
- We propose to allow threads to **collaborate**
  - Share higher-level semantic information
  - Allows the dynamic adaptation of work and leveraging of the state of the entire computation

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What is Thread Collaboration?

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- Programmer identification of useful semantic state
- Sharing of identified state and meta-information to dynamically determine the best way to
  - optimize for computational efficiency (do no more than required)
  - orient the computation (do what is most likely to yield results)
  - utilize resources (select adapted resources)

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- If I am looking for work amongst several possibilities, which should I choose?
- Which resource is the best for my sub-problem?
- What data are other threads likely to touch?

Challenges for the Model

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- **Expression** of higher-level semantic state
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- **Expression** of higher-level semantic state
  - Flexible and easy way to express state
- **Organization** of semantic information in a useful way
  - Compact representation of shared state
  - Low-overhead storage and retrieval

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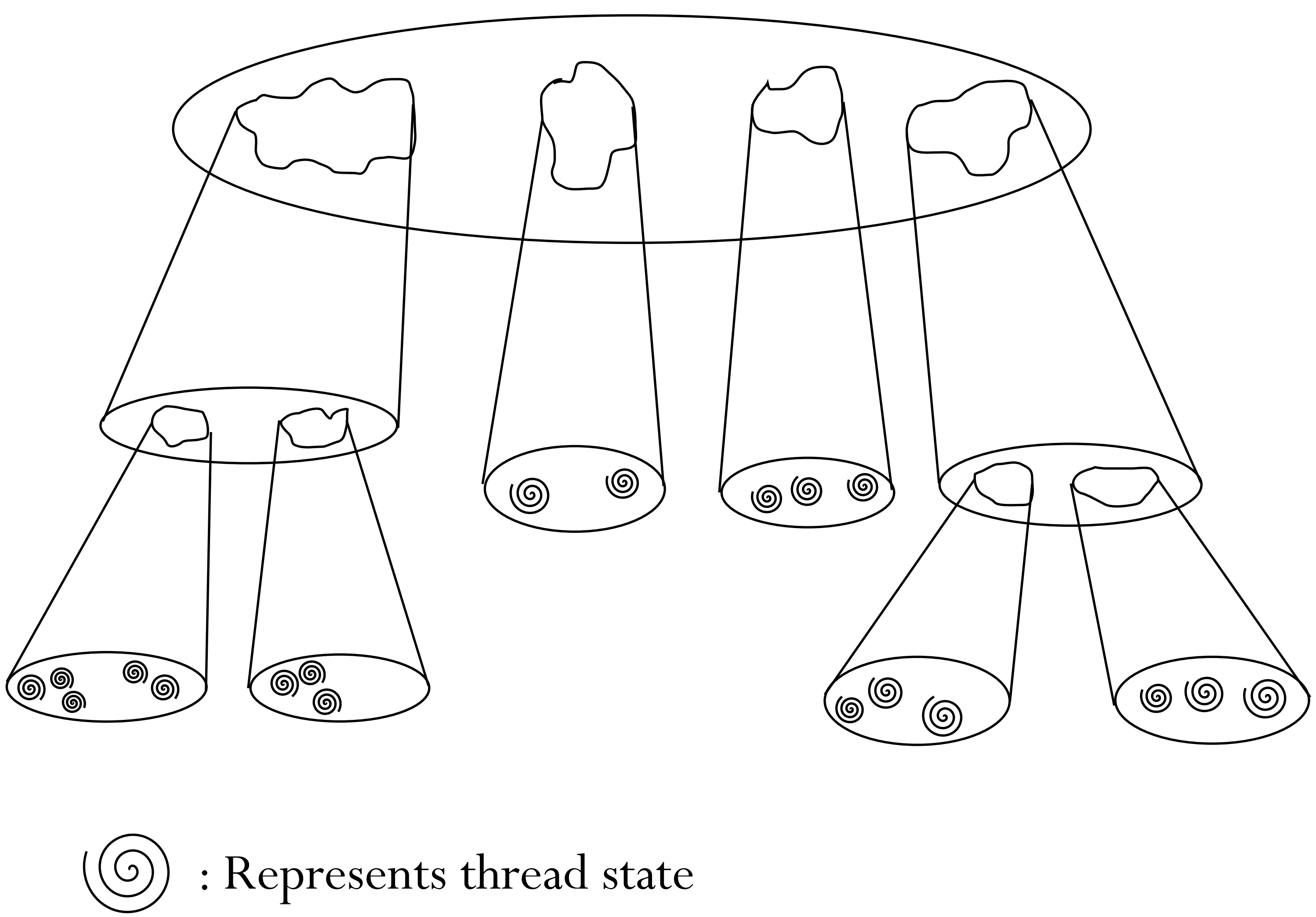
Computational State Tree (CST)

- Clusters "Similar Sub-problems" together into a tree



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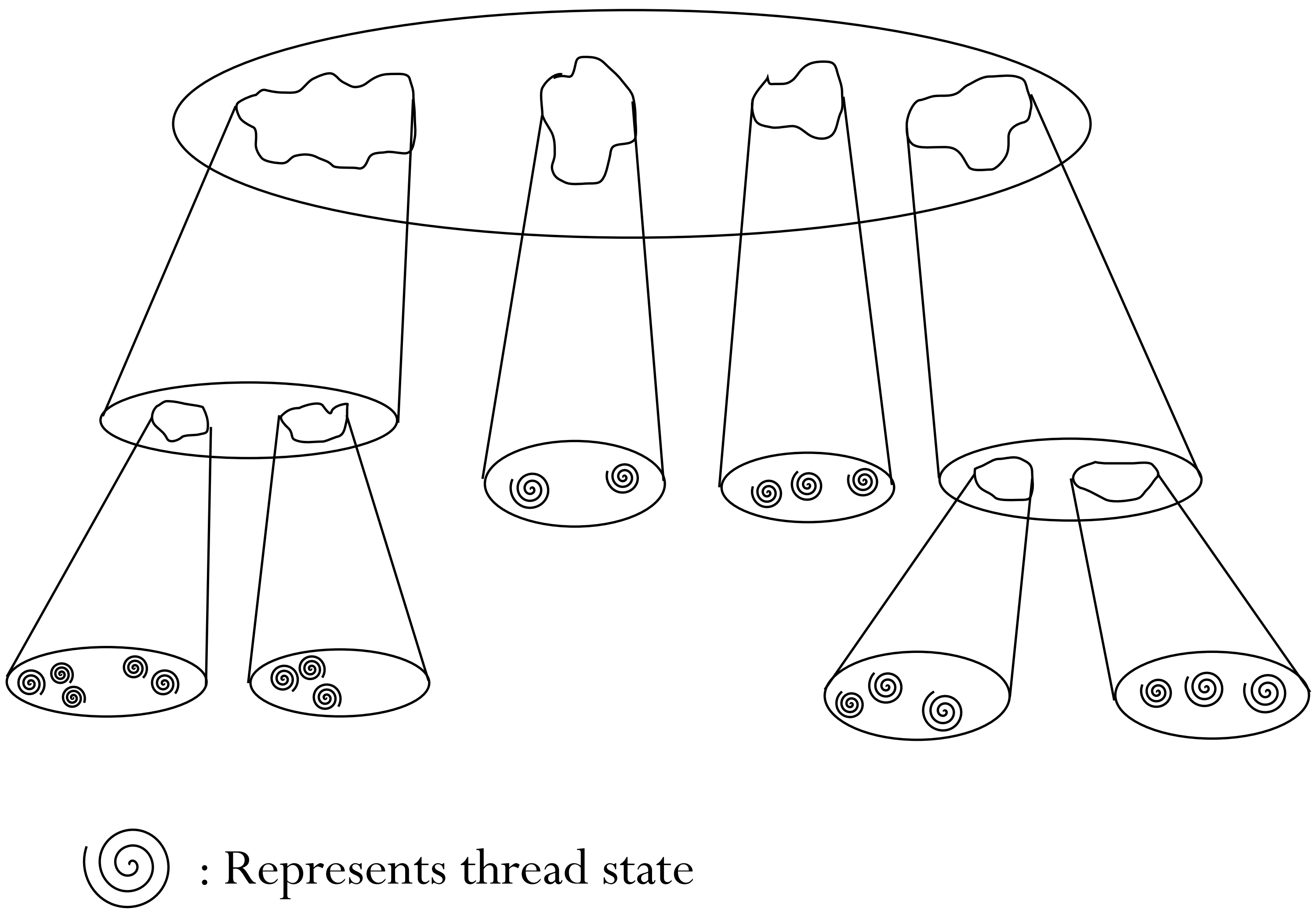

- Hierarchical
- Incremental
- Approximate

Computational State Tree (CST)

- Hierarchical
  - Logarithmic lookup time on the clusters
- Incremental
  - Incrementally build without rebuilding from scratch
- Approximate
  - Not guaranteed to form best clusters
  - Results in quick lookups but not optimal

What Can We Do With This?

- Results re-use
- Orient a computation
- Sub-problem prioritization
- Core selection

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Results Re-use

- Leverage results of “Similar sub-problems”
- Locate sub-problems which are similar
- Share partial results
- Examples
  - Sum of subsets
  - K-Means

Sum of Subsets

- Given a set of integers and 's', does any non-empty subset sum to 's'?

- Naive parallelization makes each subset computation a different task

$\{3, 4, 5, 6, 7, 8, 9\}$

$\{2, 3, 4, 5, 6, 7, 8, 9\}$

$\{3, 4, 5, 6, 9\}$

$\{3, 4, 5, 6, 7, 8, 9, 12\}$

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$\{3, 4, 5, 6, 7, 8, 9, 12\}$

- Large amount of redundancy can be exploited

Sum of Subsets

- Programmer specifies a similarity metric:
  - Here, cardinality of the symmetric difference
    - |(A-B) U (B-A)|
- Threads can share their current computation:
  - share ({1, 10, 9, 8, 3, 4}, 35);
  - share ({8, 3, 4}, 15);

Sum of Subsets

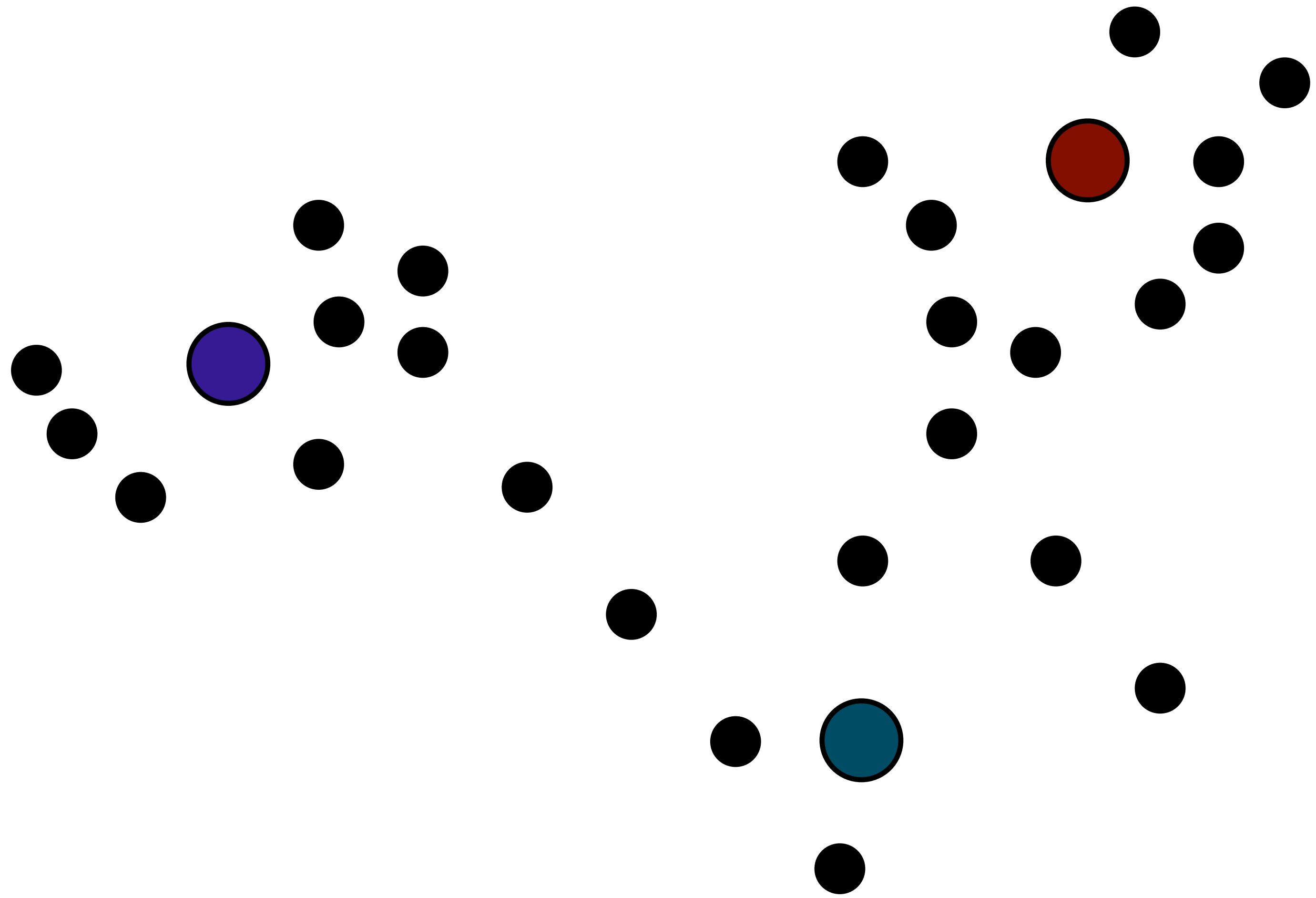
- Before computing a sum, threads can lookup the currently best available result:
  - lookup_closest({10, 9, 8, 3, 4});
- The return value varies based on scheduling
- Might need to add or subtract a few values to generate needed sum
- Automatically makes best use of previously computed values

K-Means

- Partitions ‘n’ points into ‘k’ clusters
- Choose ‘k’ random centroids
- Associate point to closest centroid
- Re-compute centroids
- Iterate

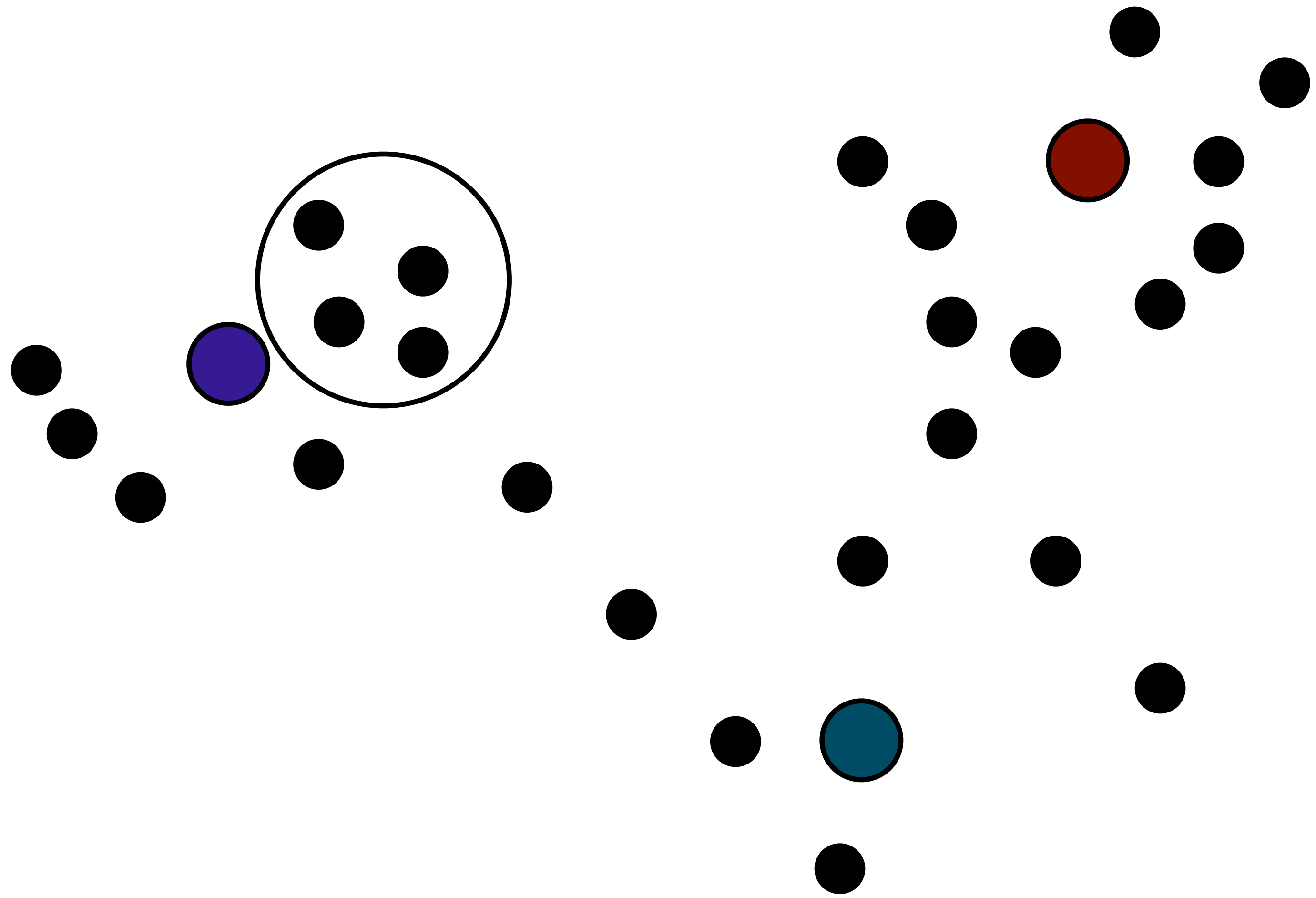
K-Means

- Each point performs 'k' computations to determine closest centroid



K-Means

- Points which are close to each other can potentially share their closest centroid



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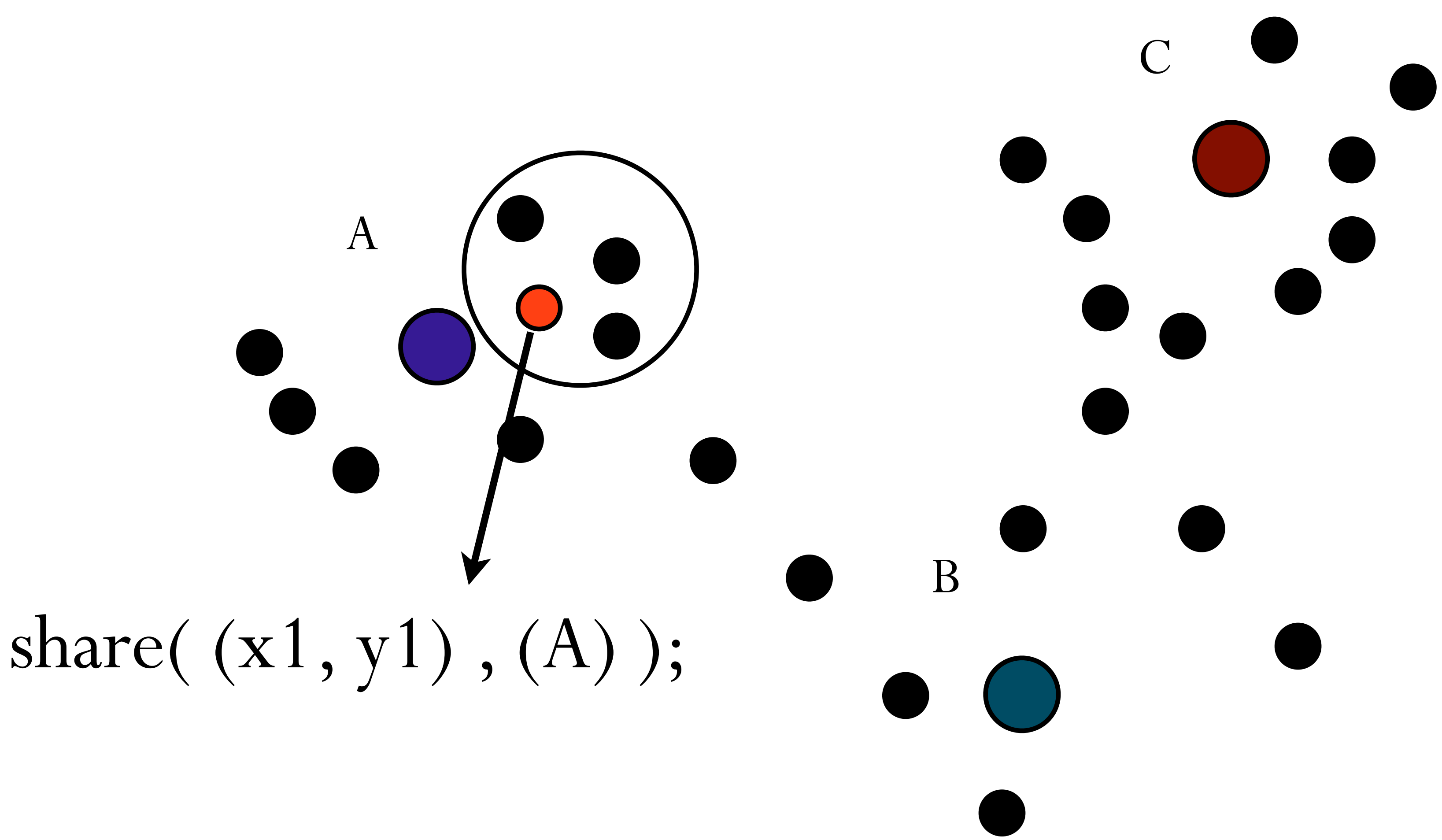

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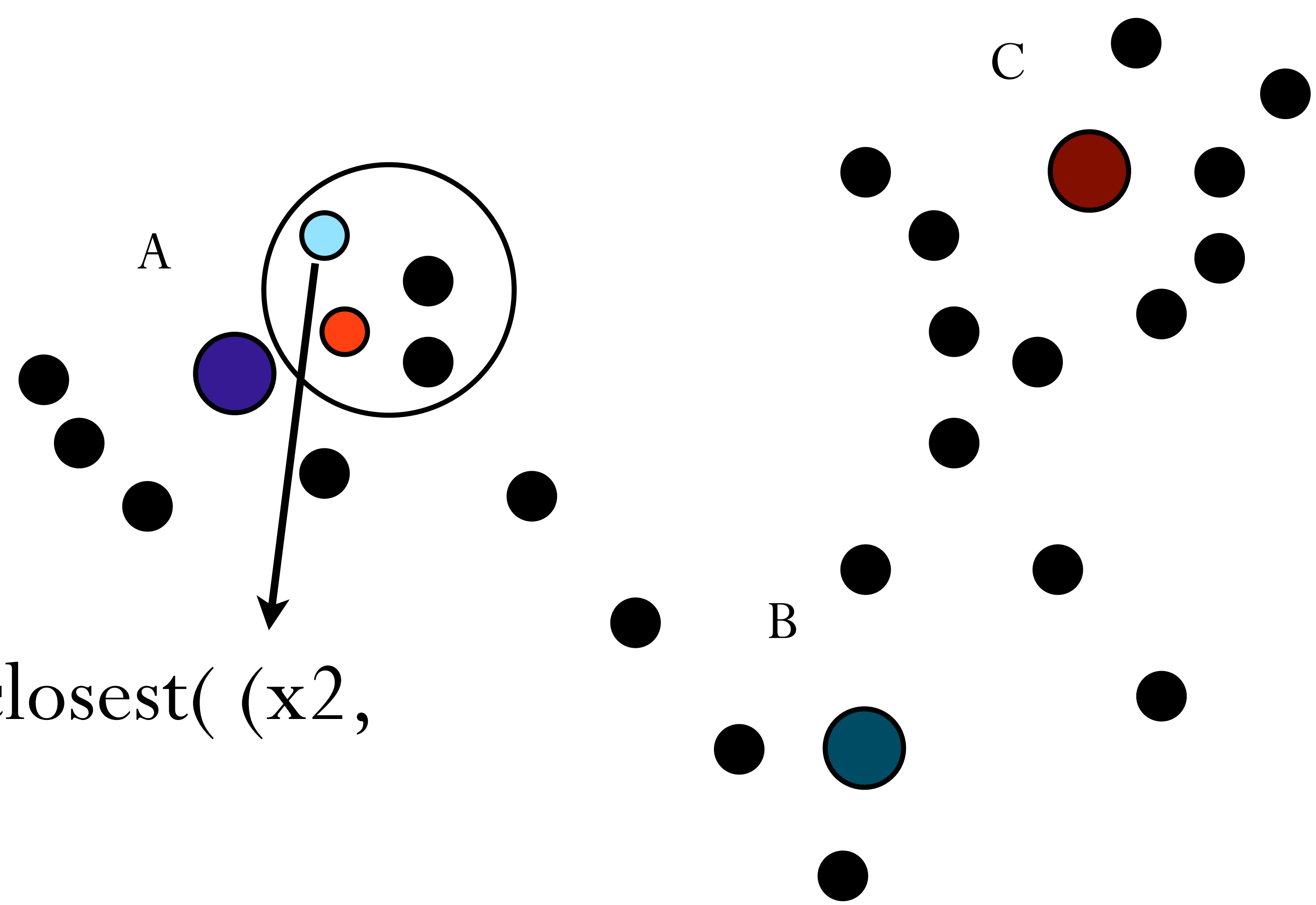

lookup_closest((x2, y2));

K-Means

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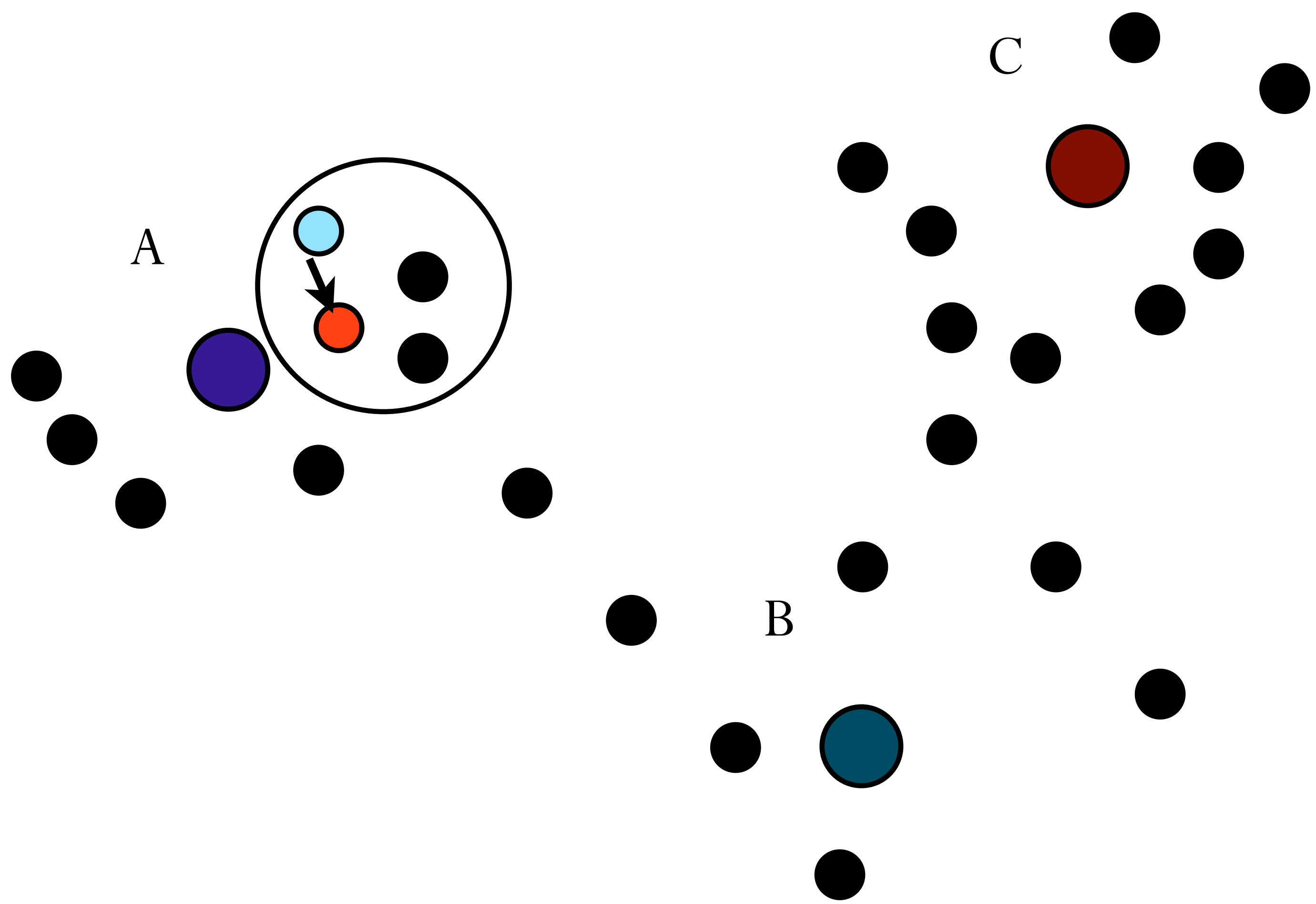
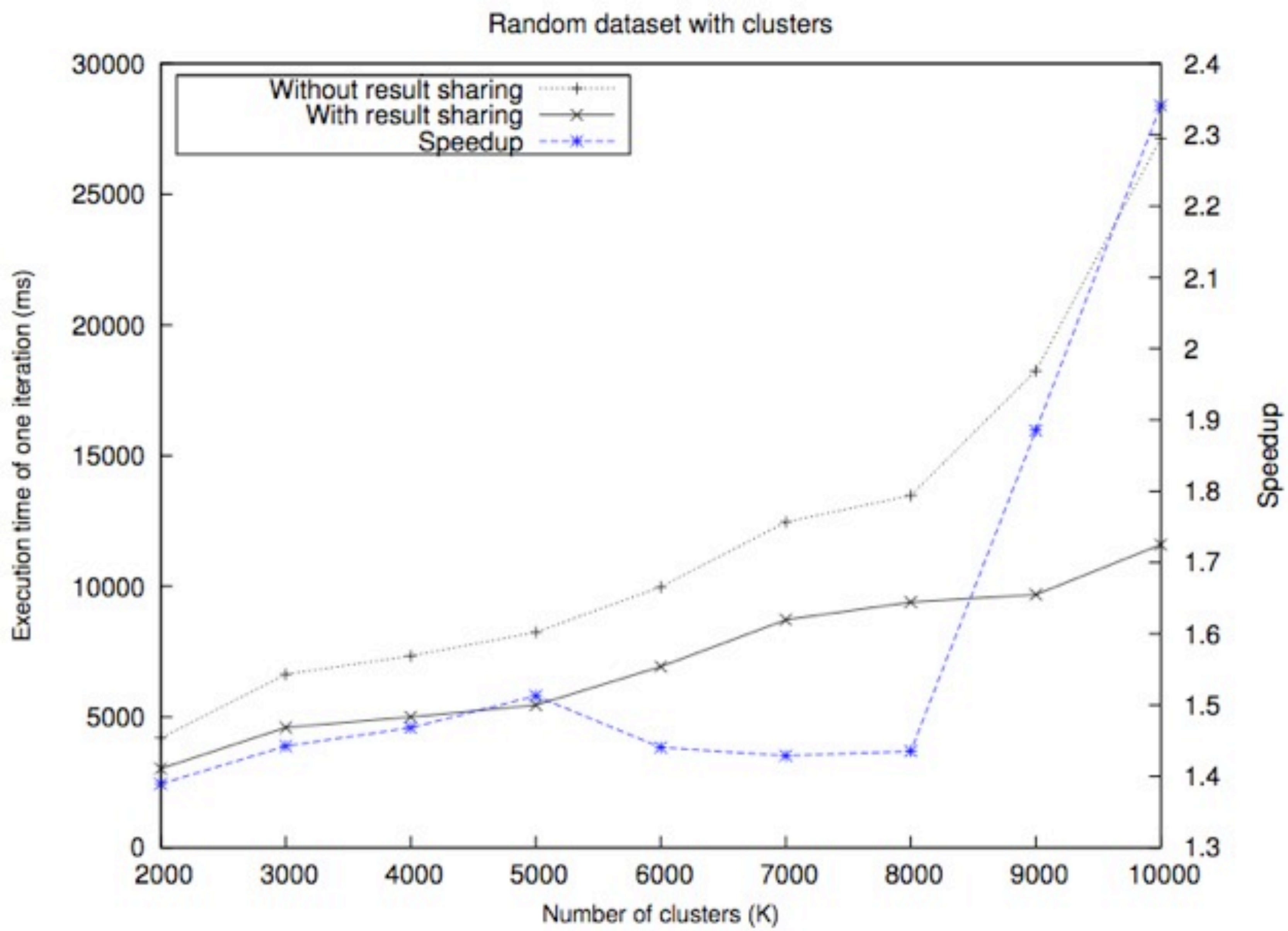


Results



- Ran more than twice as fast with collaboration turned on

Where Does the Speedup Come From?

- Computation Reduction
  - *Original*: Makes 'k' comparisons for each point
  - *Collaborative*: Single point computes, and those around it share the value (the more dense the points, the more potential for collaboration)
- More efficient computation with collaboration
- Re-wrote key sub-step in a collaborative manner

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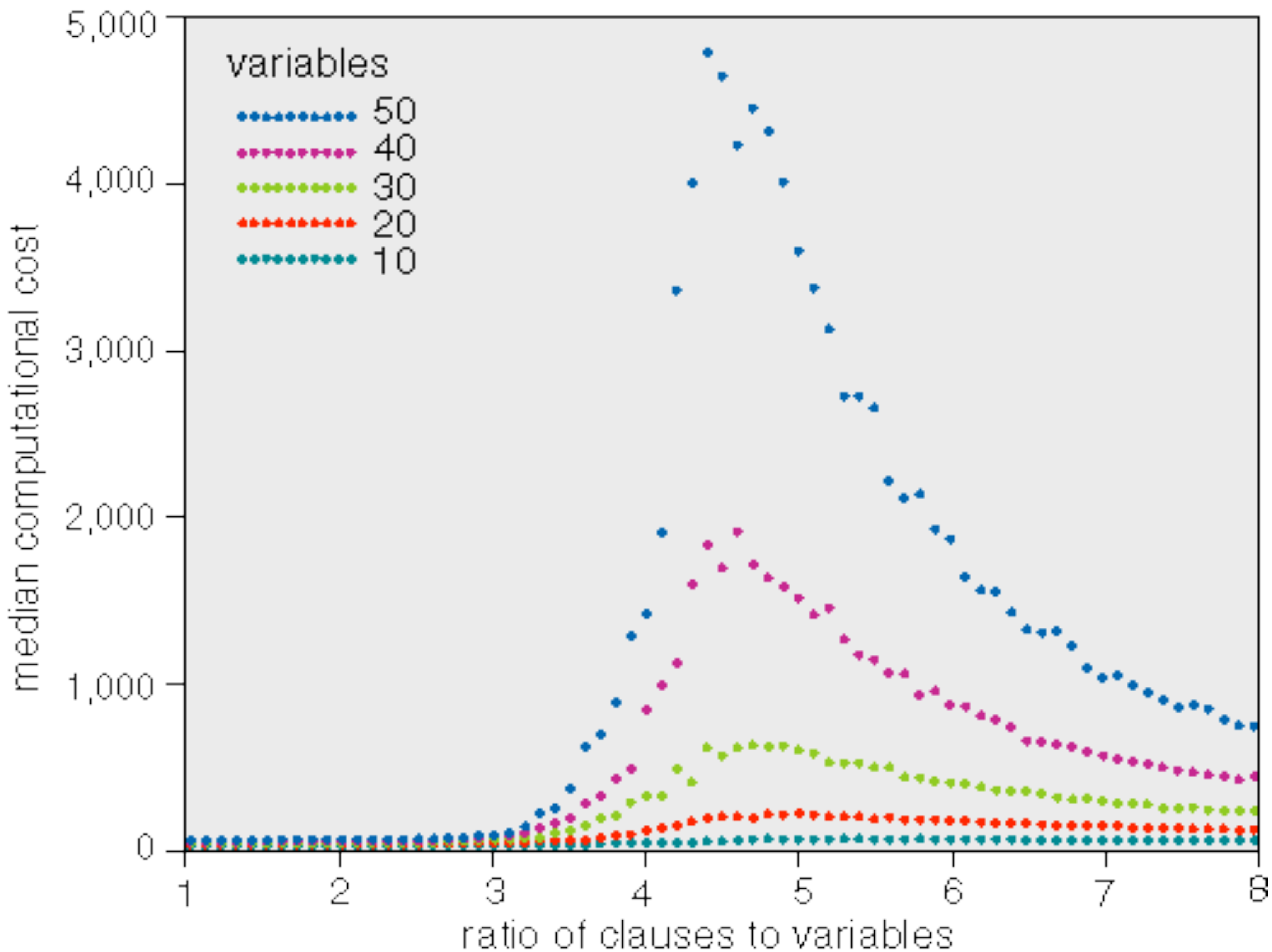
Orienting a Computation

- Computational space is large
- Some parts of this space may be more fruitful to process
- Guide threads to these parts of the space
- Example: SAT Solver, Finding maxima/minima for non-convex spaces

SAT Computational Difficulty



- k-SAT with m clauses and n variables
- $\alpha = m/n \approx 4.26$

- Satisfiable solutions are clustered in small pockets

GSat

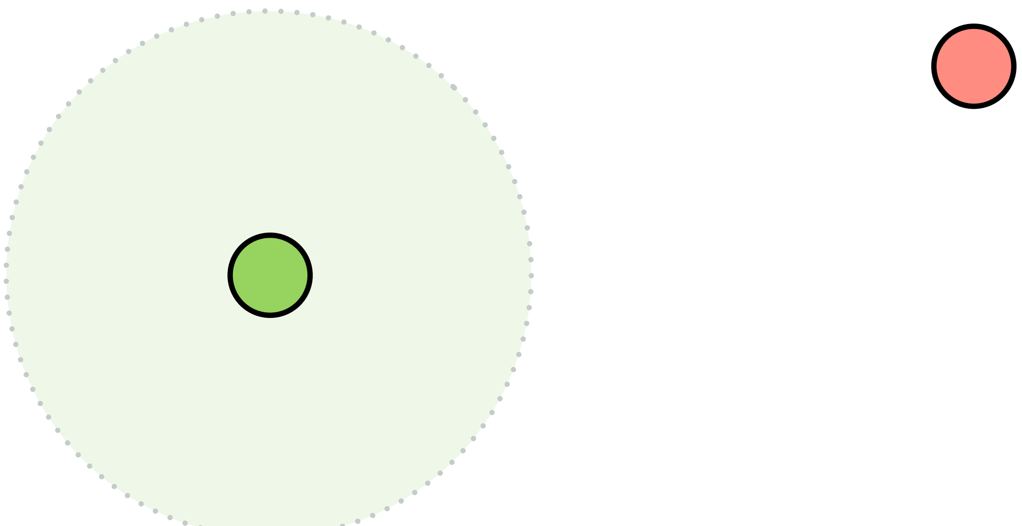
- Similar to WalkSAT
- Local Search Algorithm
- Start with Random Assignment
- Flip a variable, minimizing number of unsatisfied clauses
- Iterate till you find a solution

Orienting GSat

- Use GSat as an All-Solutions finder
- When one Satisfiable solutions is found
- Publish the location of the successful solution
- share (current_truth_assignment)
- Guide other close-by threads into these pockets

Guiding other threads

Solution space



Guiding other threads

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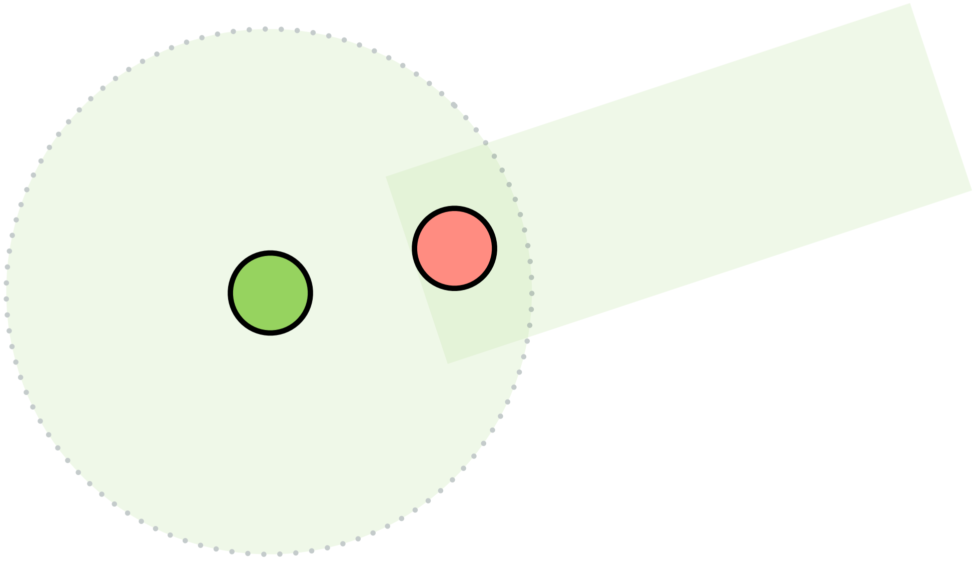

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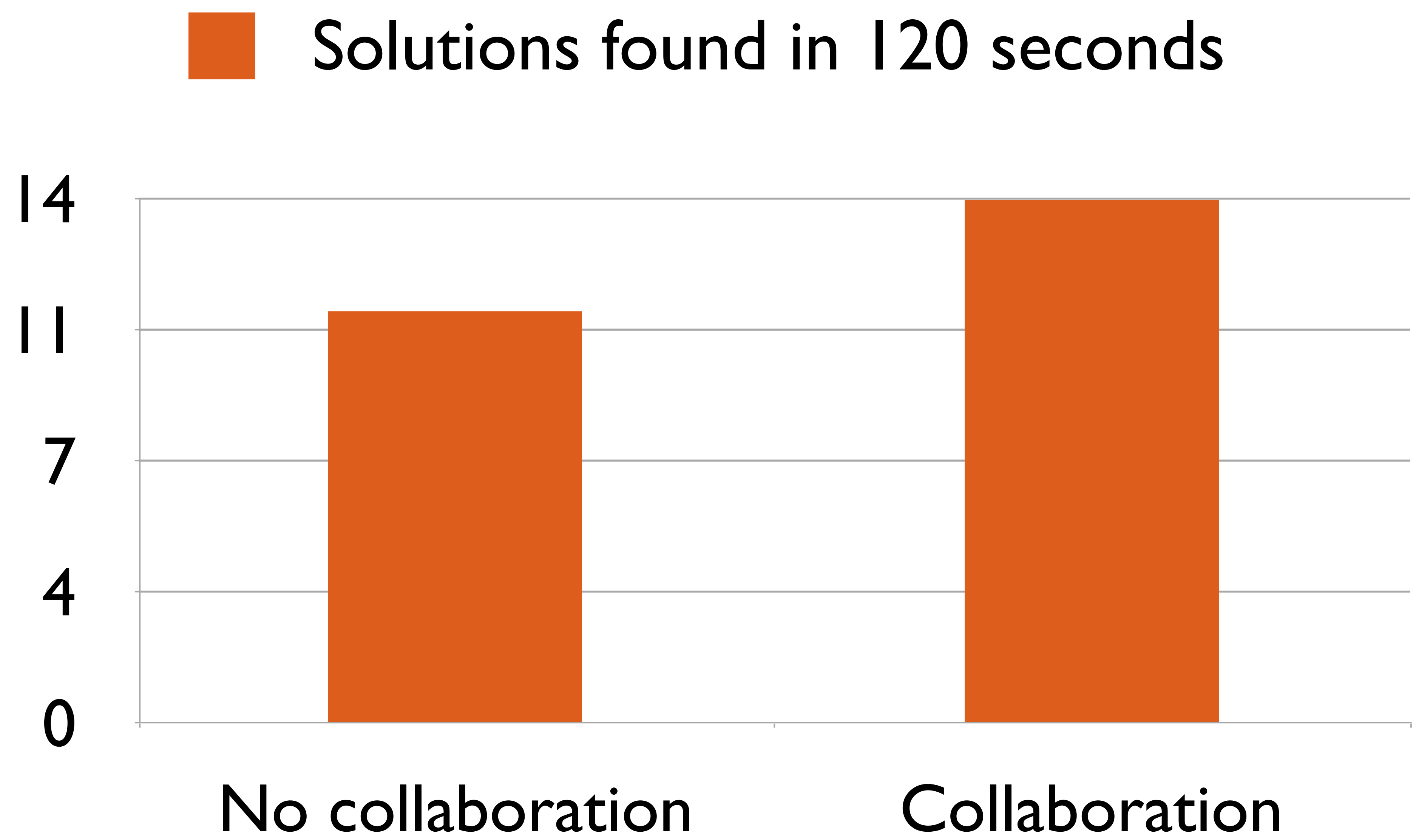

$n = 38, \alpha = m/n \approx 4.26$

Conclusion

- *For some problems, everything is parallel, but not everything is useful*
- We proposed an alternative view of parallelism
  - State exposure coupled with collaboration, facilitates a new paradigm for writing parallel algorithms
  - It provides improved computational efficiency, orientation and dynamic scheduling.
- We showed improvements for K-Means and GSat
- We are exploring more applications of the collaborative paradigms and different representations of the CST

Q & A

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