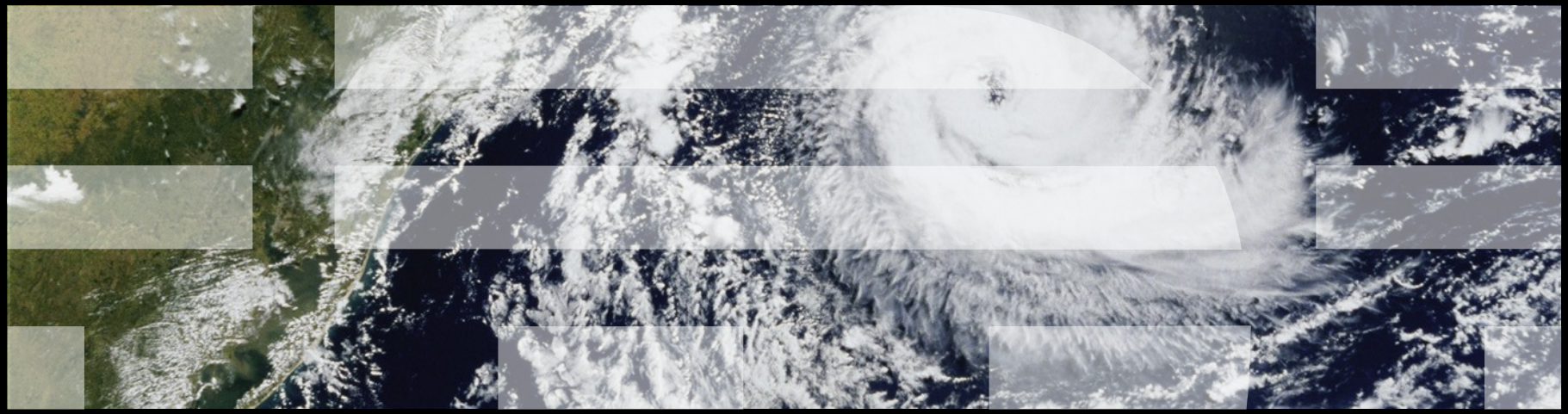
Paul E. McKenney, IBM Distinguished Engineer, Linux Technology Center

June 8, 2012

Retrofitted Parallelism Considered Grossly Sub-Optimal

HotPar '12: 4th USENIX Workshop on Hot Topics in Parallelism



HotPar'12: Retrofitted Parallelism Considered Grossly Suboptimal

Labirinto do Outeiro do Cribo, A Armenteira, Meis, Pontevedra, Galicia, Spain. Possibly dating from as early as the Bronze Age (though rock carvings are notoriously difficult to date with certainty). *10 October 2006, Froaringus*

But Now We Use Computers To Solve Mazes

Goals

Goals (Why Was I Messing With Mazes???)

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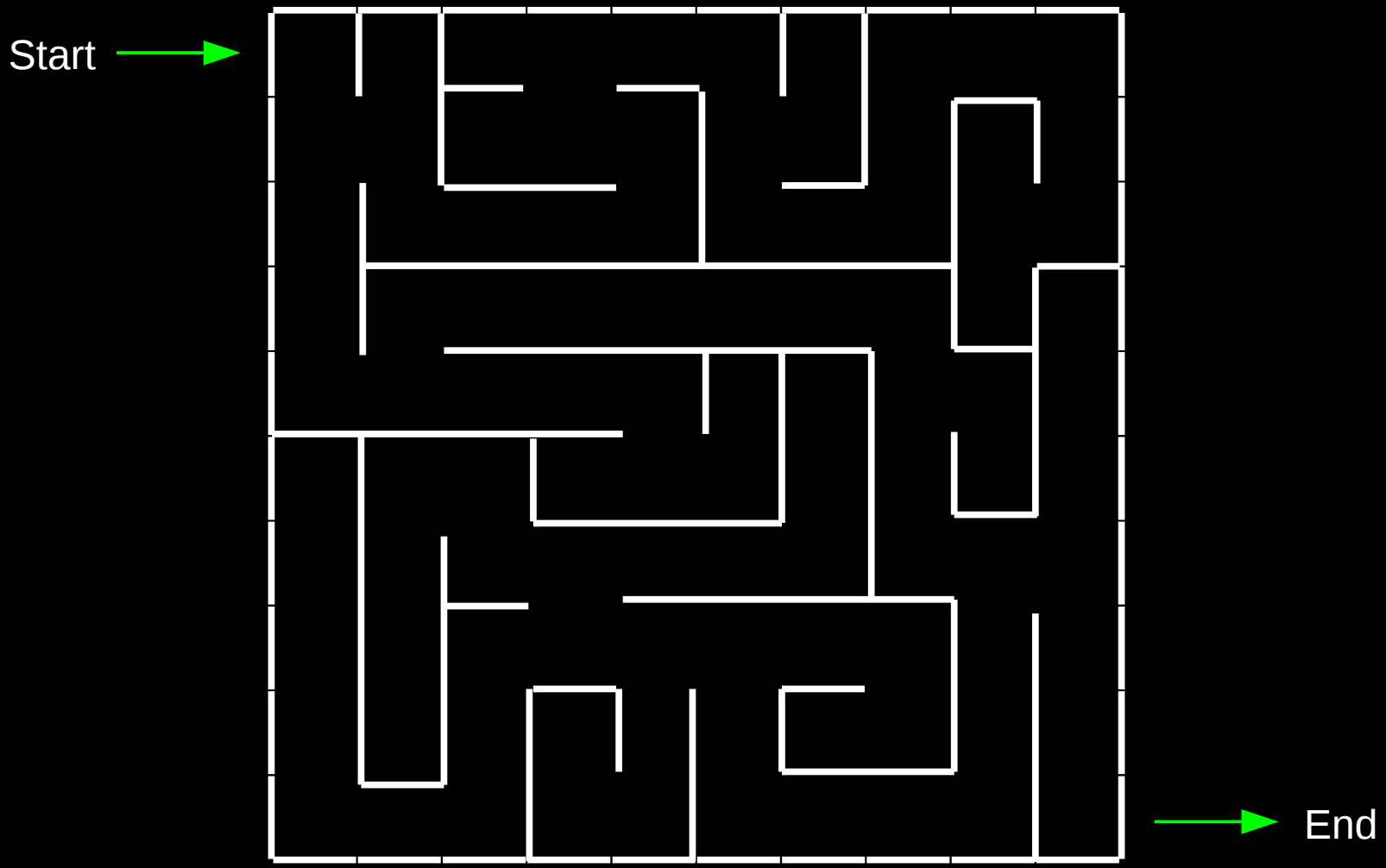
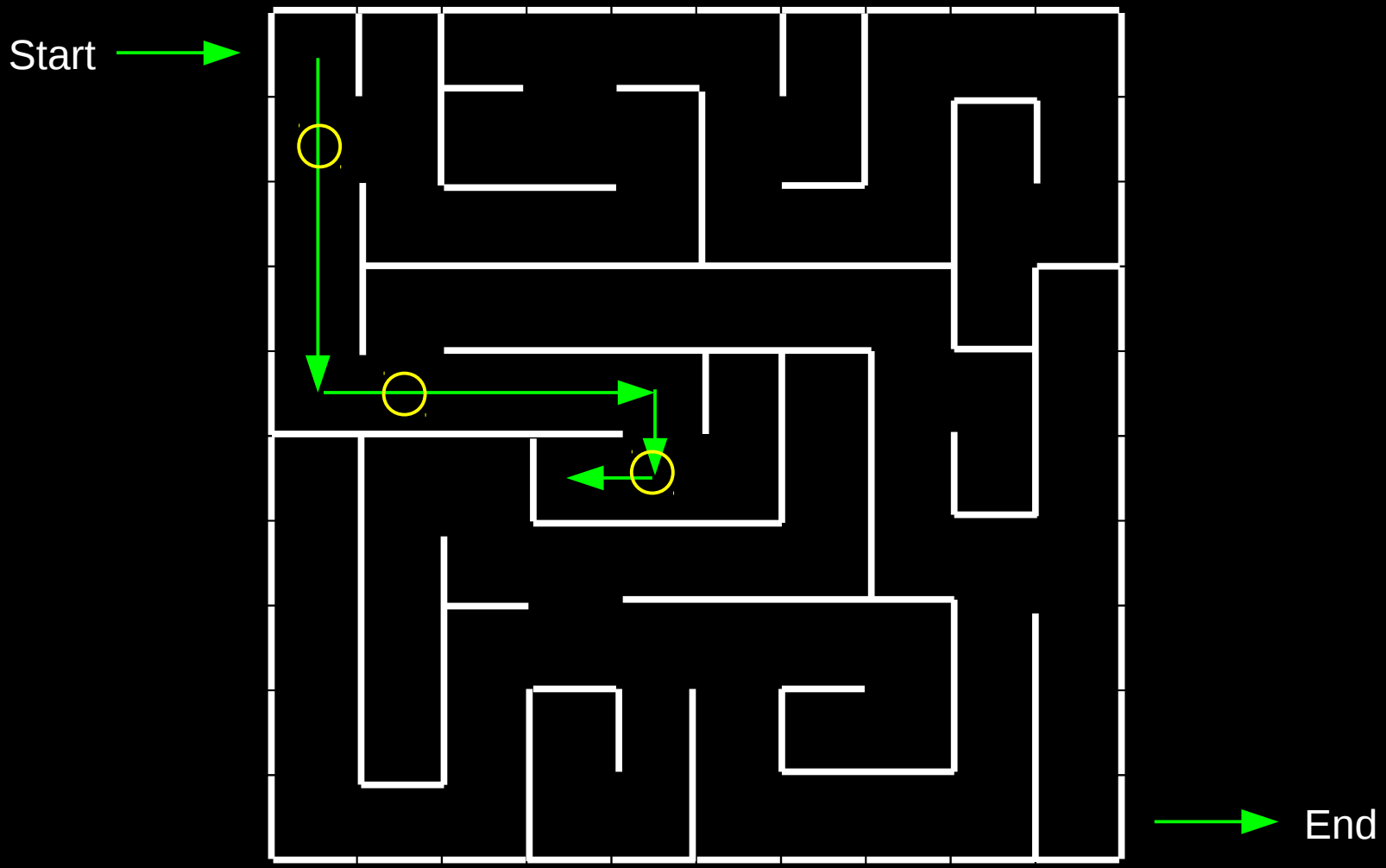
- An example of near-perfect partitioning for “Is Parallel Programming Hard, And If So, What Can You Do About It?”
- Use case for RCU-protected union-find data structure

But First, A Sequential Maze Solver

Sequential Maze Solving (SEQ)



Sequential Maze Solving



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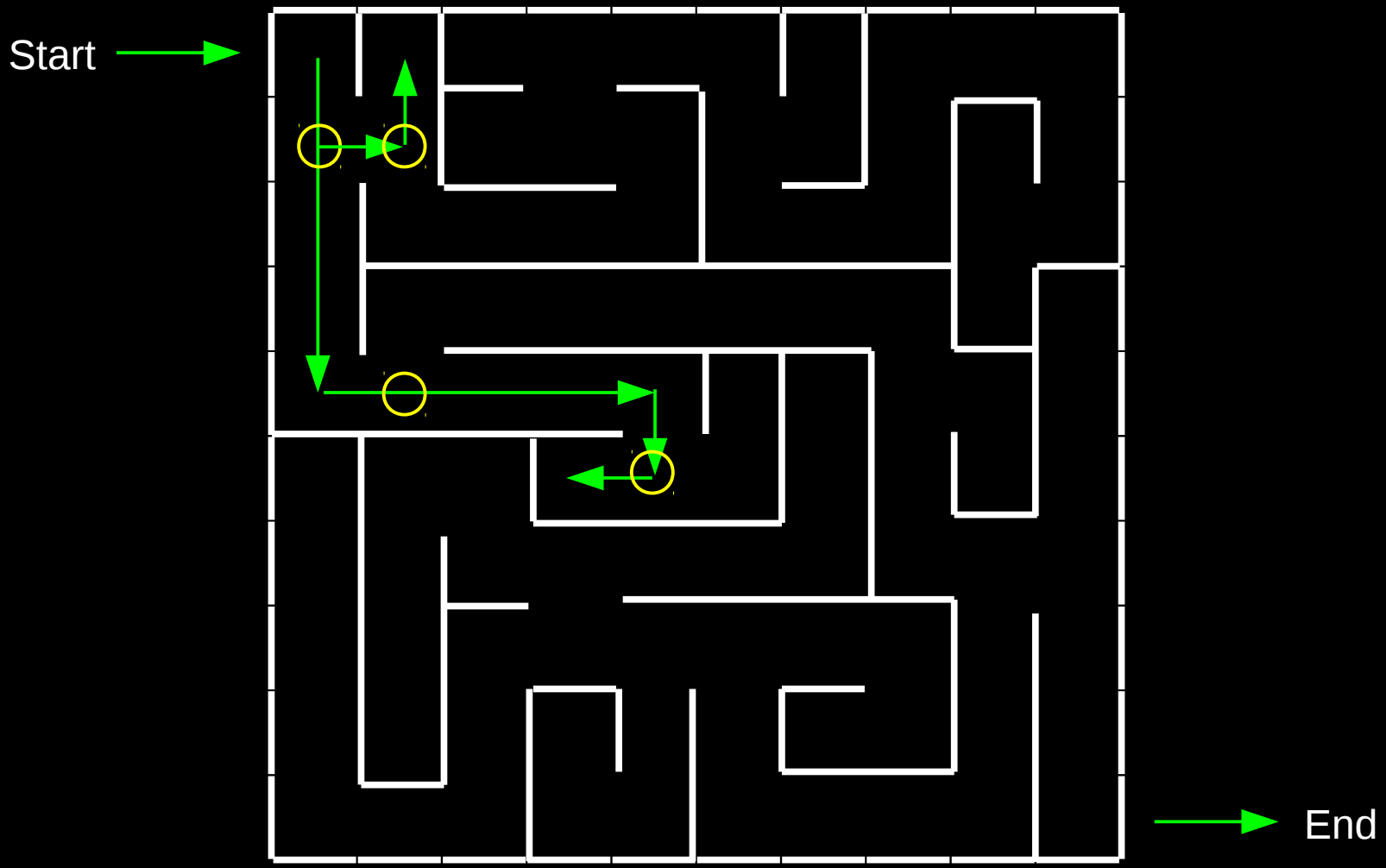

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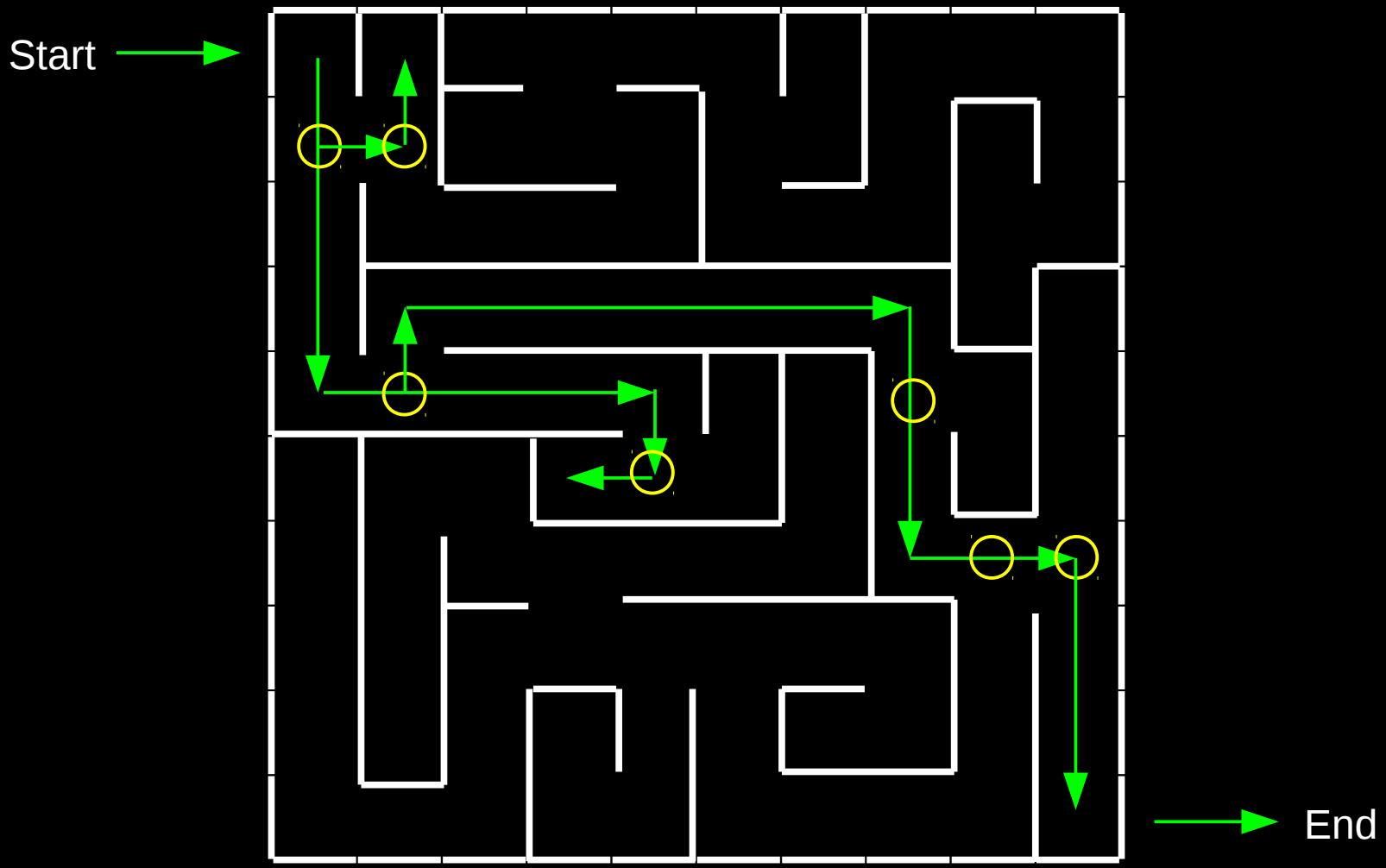
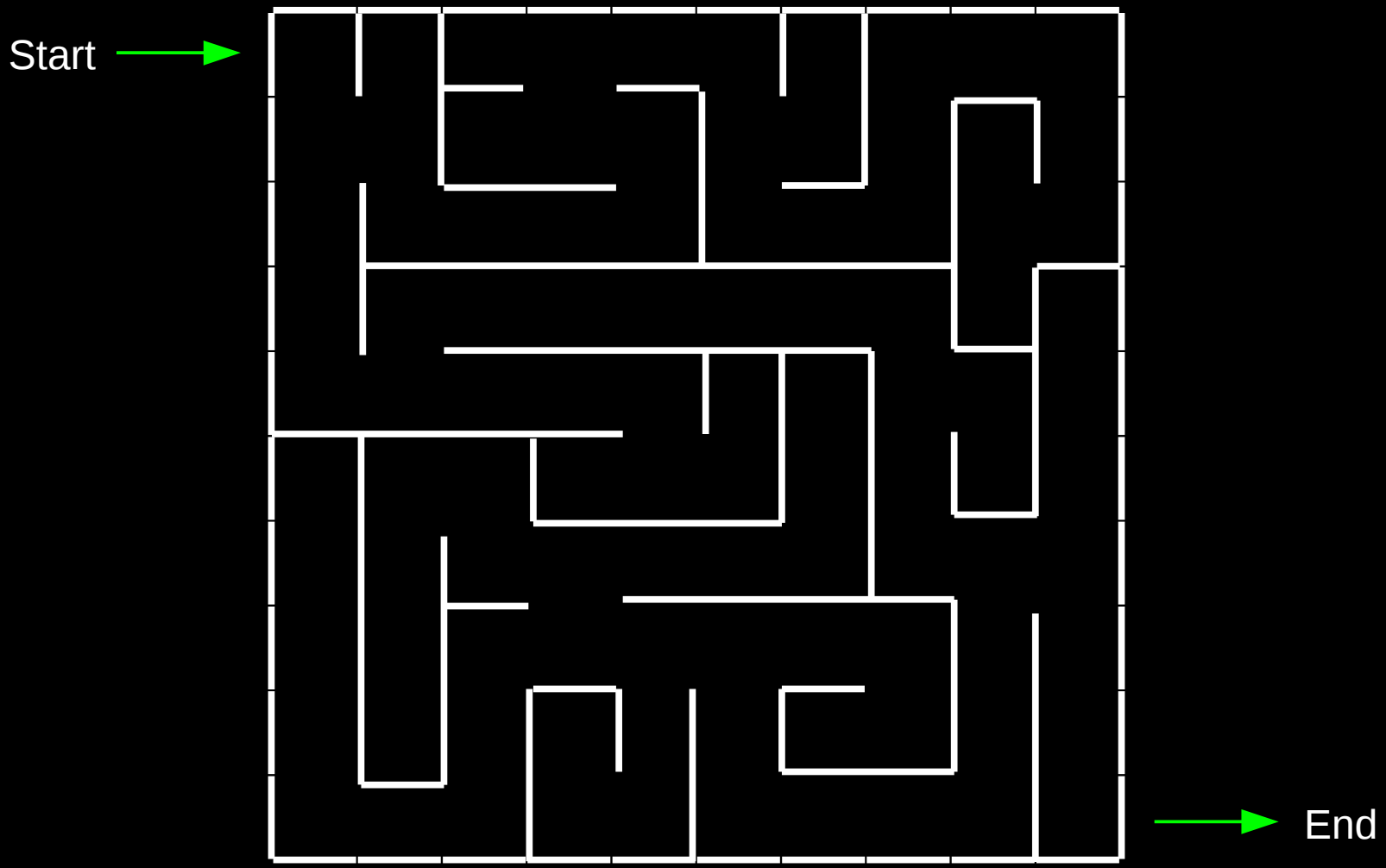
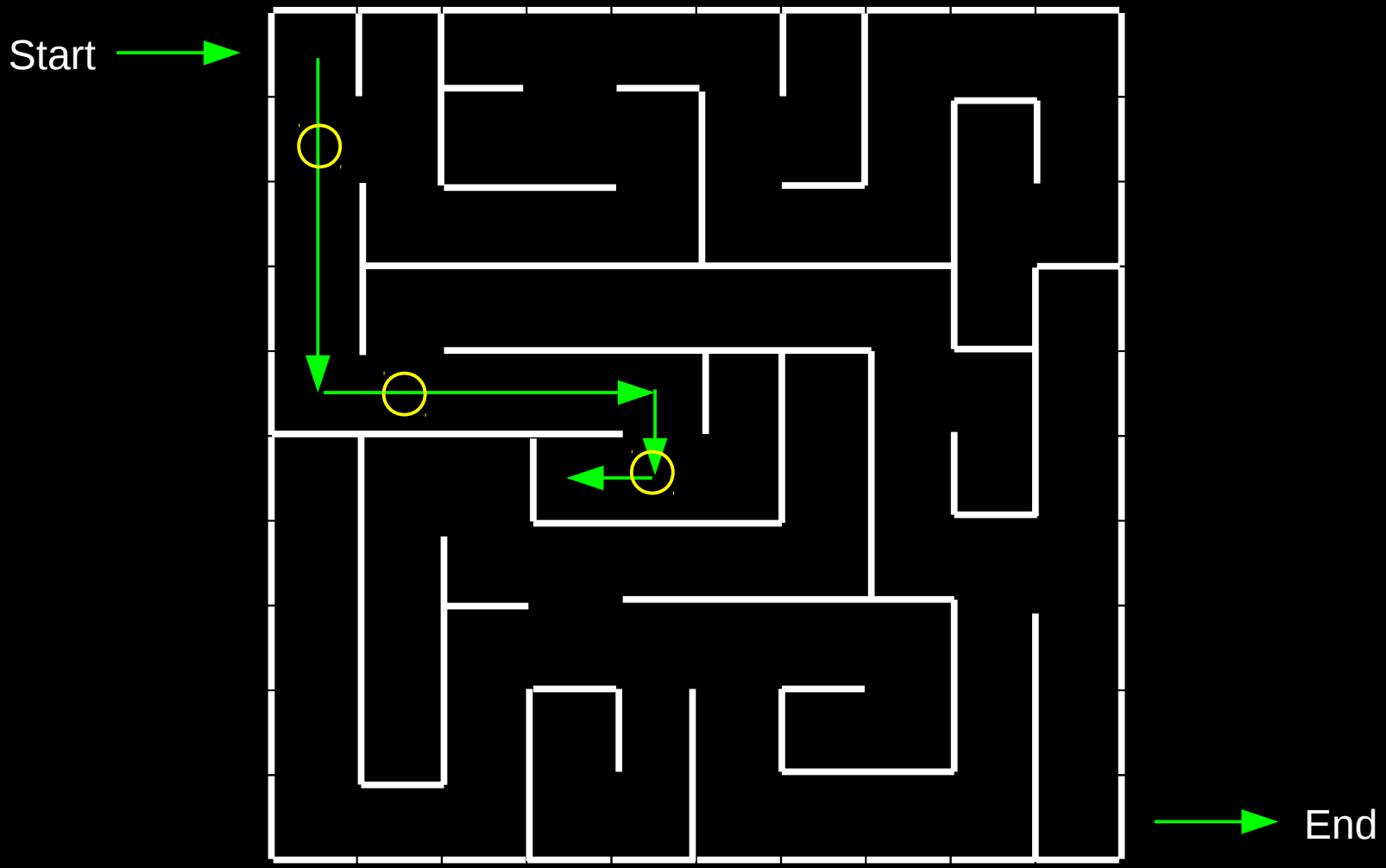


Parallel Maze Solving: Work-Queue Approach

Parallel Work Queue (PWQ)



Parallel Work Queue



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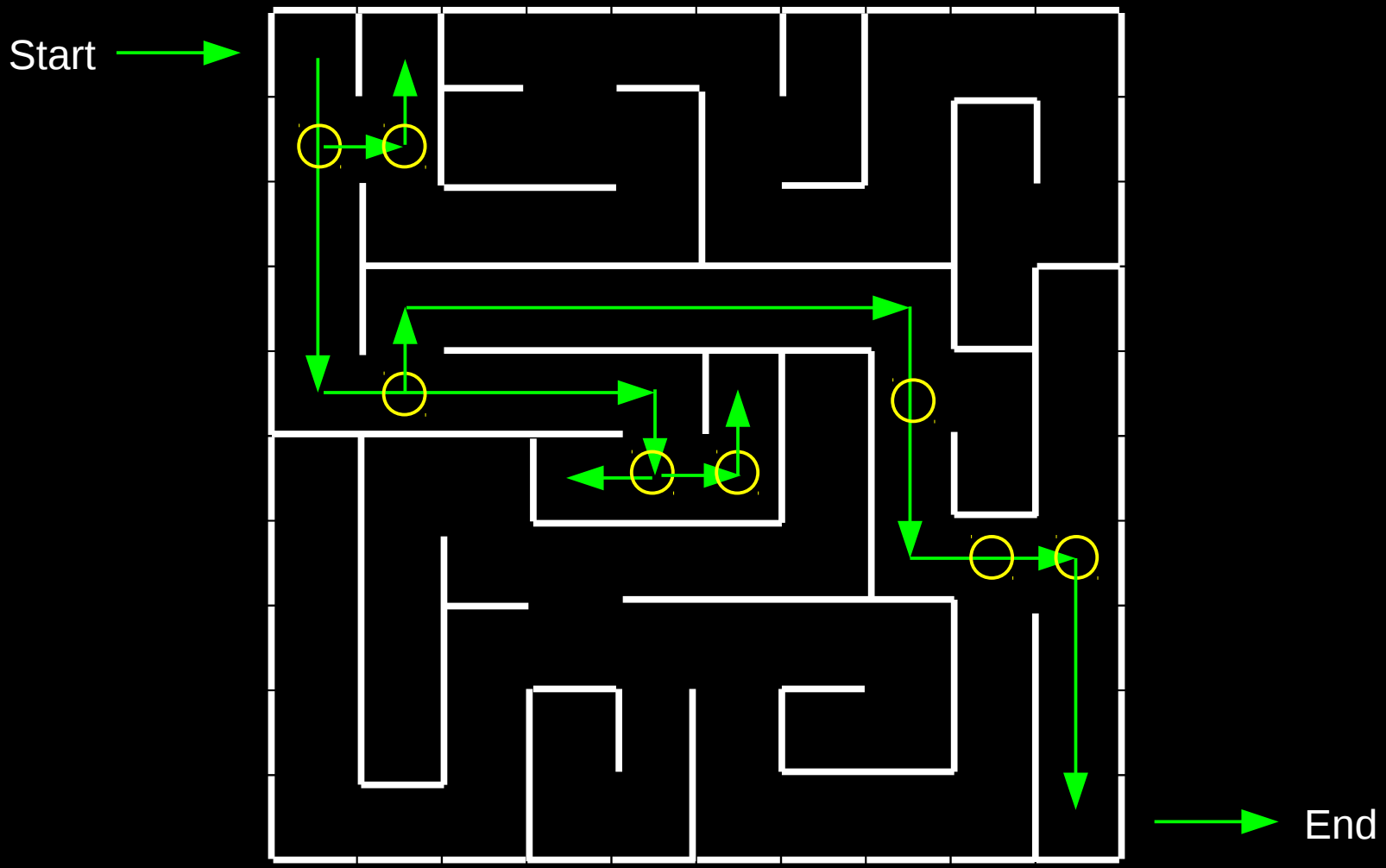
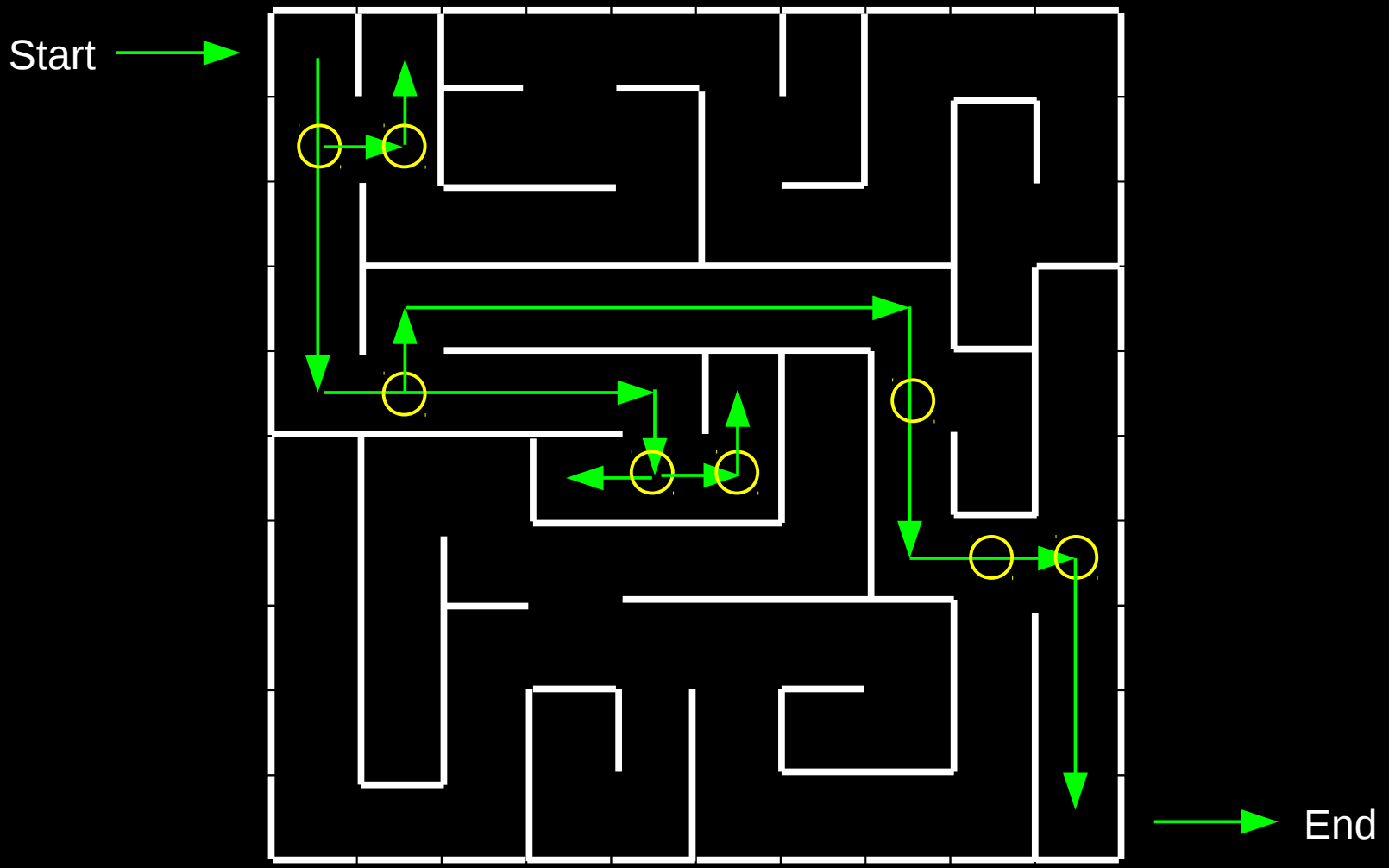


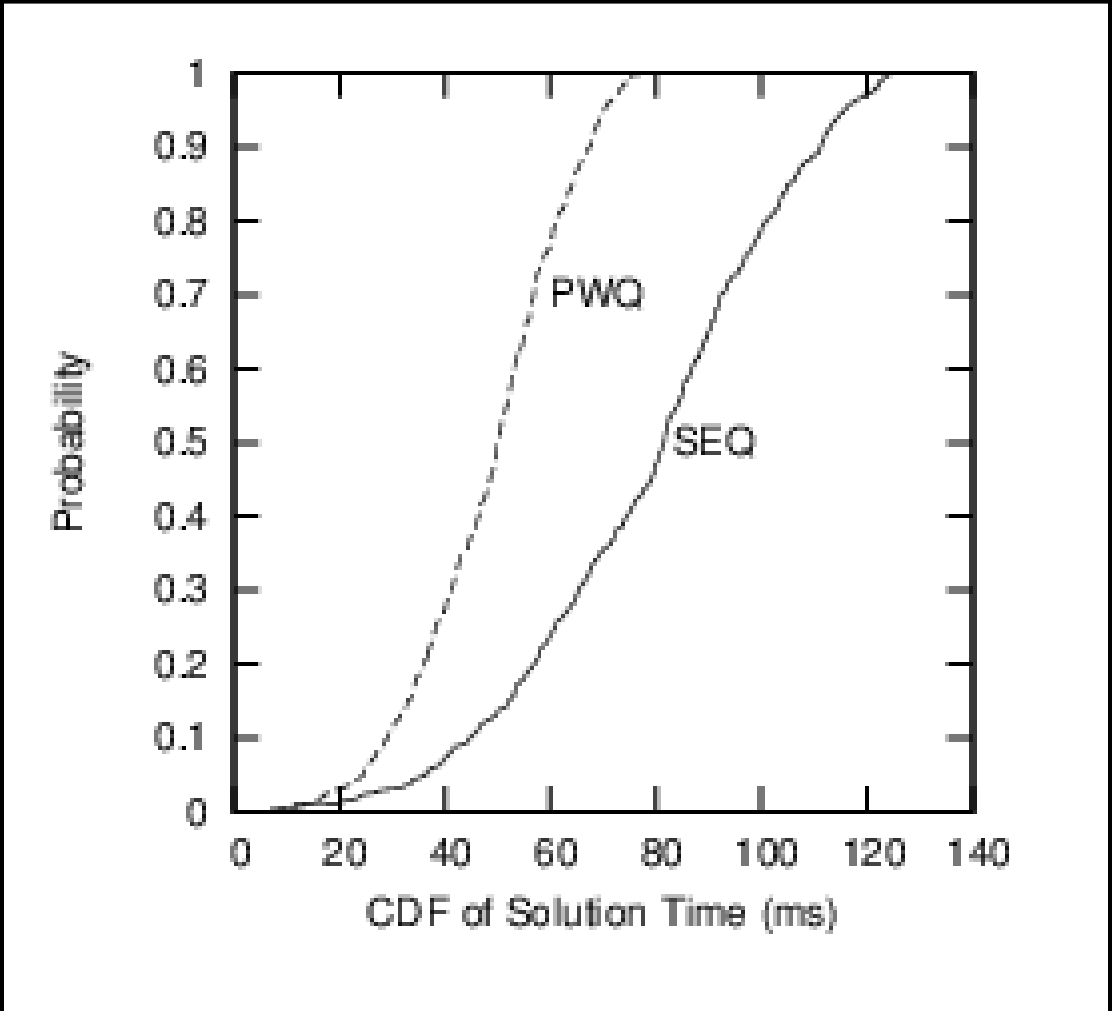
Parallel Work Queue: Saved An Iteration!!!



But can you see the weak point?

Performance Comparison: PWQ vs. SEQ

Performance Comparison: PWQ vs. SEQ (Two Threads)



Everything I Need to Know, I Learned in Kindergarten

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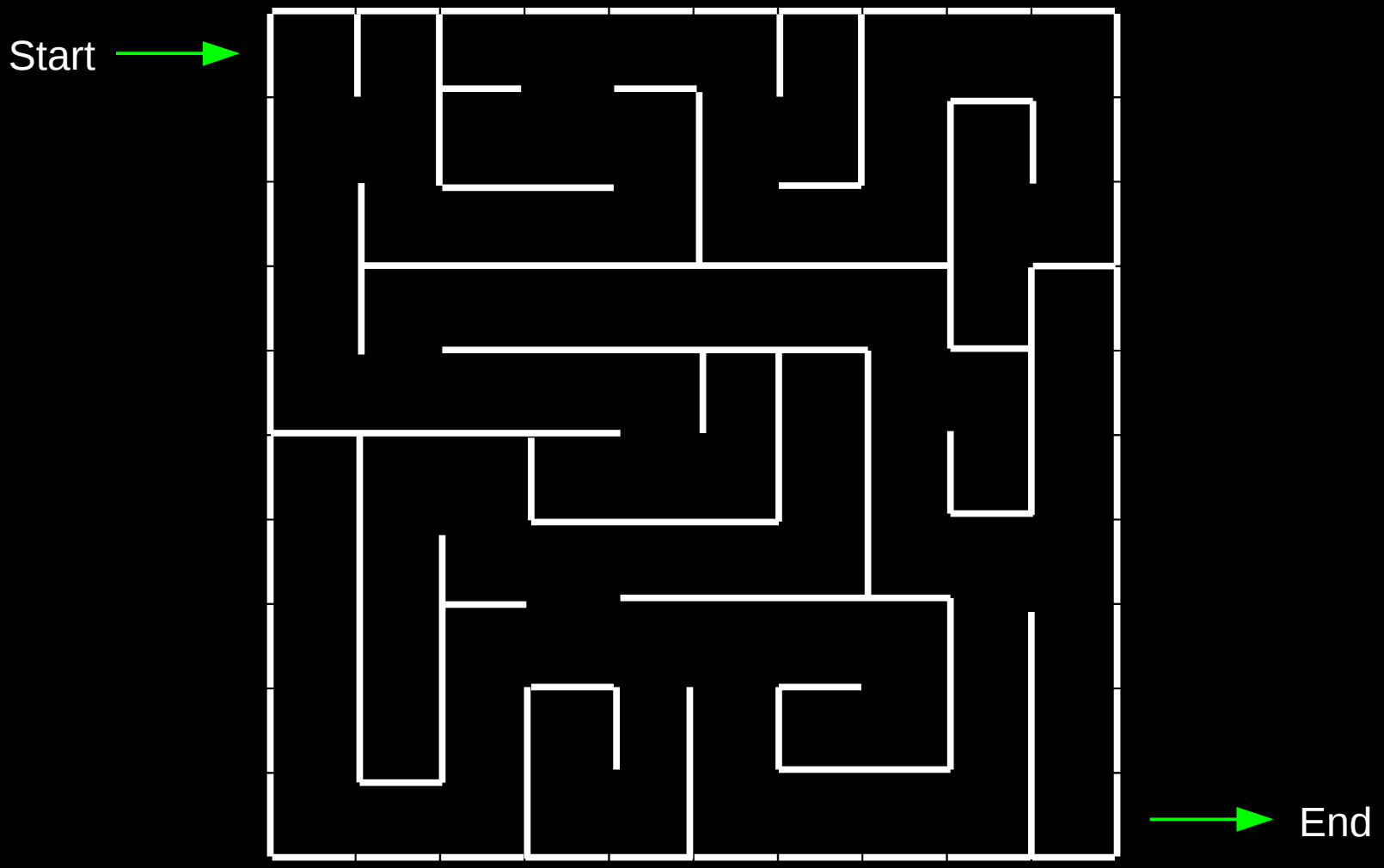
- In this case, when solving a maze, start at both ends!!!

Partitioned Parallel Solution (PART)



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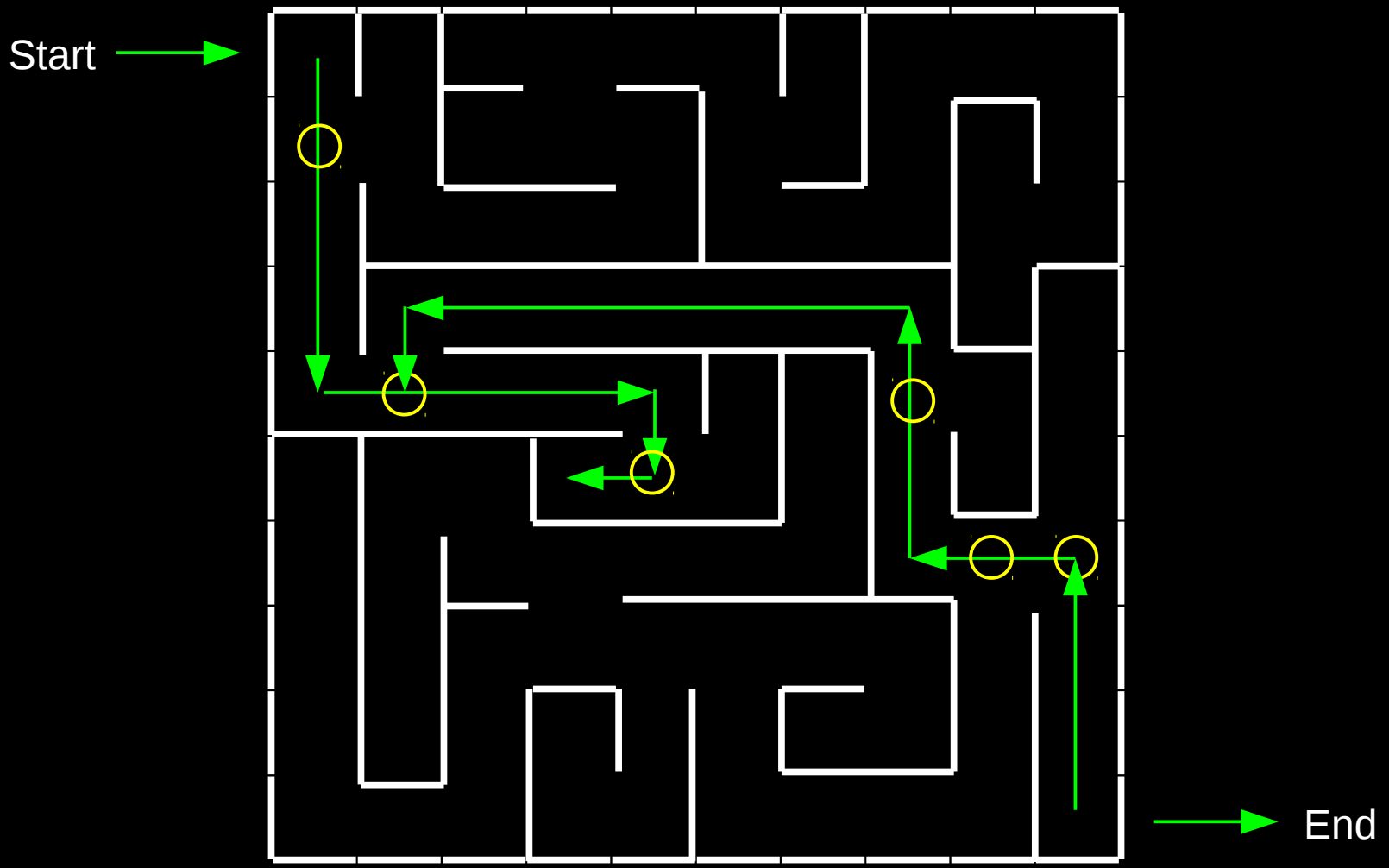
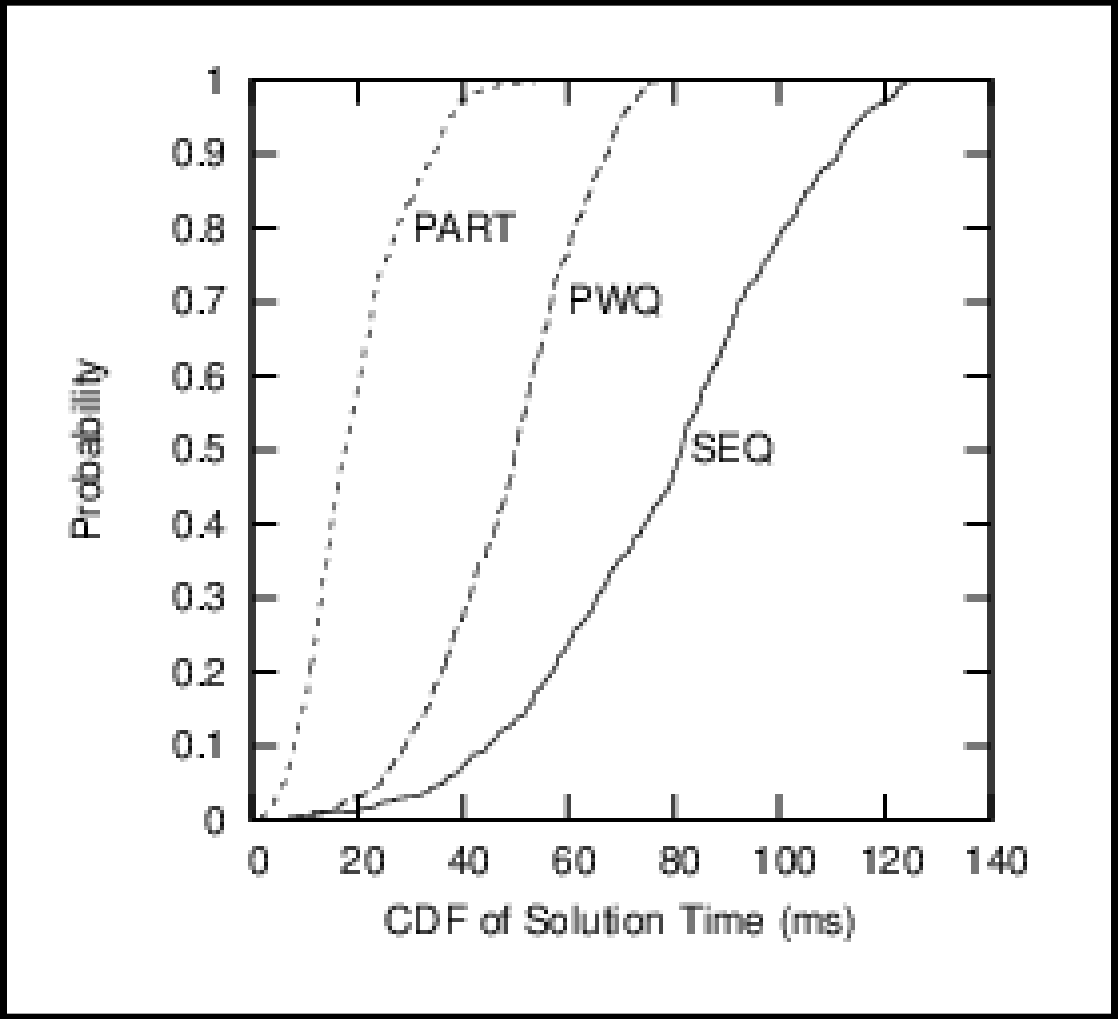


Performance Comparison: SEQ vs. PWQ vs. PART

Performance Comparison: SEQ vs. PWQ vs. PART: Two Threads



Lots of overlap – are these really different???

Performance Comparison: SEQ vs. PWQ vs. PART

- The CDFs assume independence
- This is not true: data is highly correlated
  - Test script generates a maze, then runs all solvers on that same maze
  - CDFs lose the relationship between those solutions

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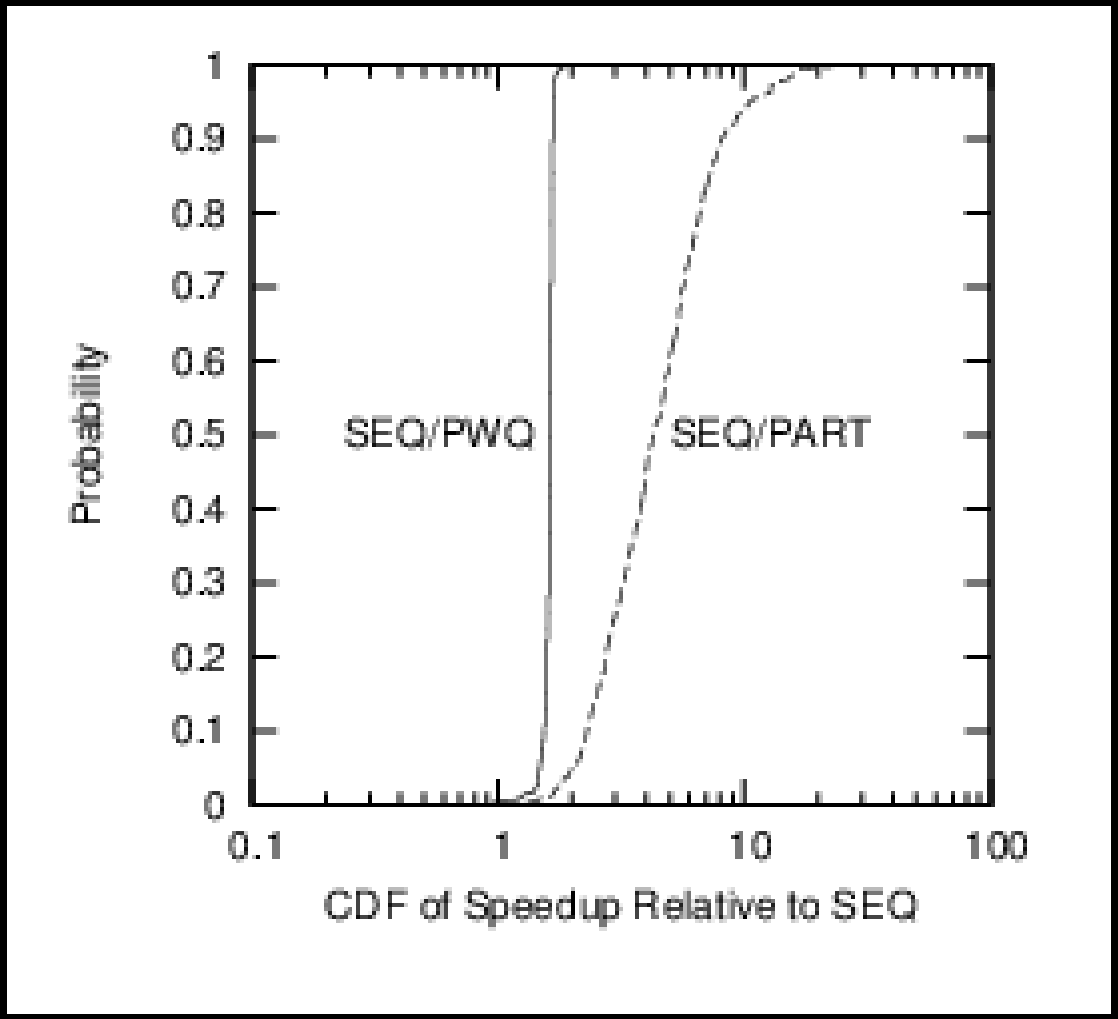
  - Test script generates a maze, then runs all solvers on that same maze
  - CDFs lose the relationship between those solutions
- Preserve this relationship by taking CDF of ratios
  - SEQ/PWQ and SEQ/PART

Performance Comparison: SEQ/PWQ vs. PWQ/PART: Two Threads



Anything odd about this graph?

What is Going on Here???

- Median speedup of 4x on only two threads!!!
- Individual data points show speedups of up to ***40x***!!!
- This is not merely embarrassingly parallel
  - **Embarrassingly parallel:** Adding threads does not significantly increase the aggregate amount of work, resulting in linear scaling

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  - **Humiliatingly parallel:** Adding threads significantly *decreases* the aggregate amount of work, resulting in superlinear scaling
- Yeah, yeah, it is great to have a definition, but how is this happening???

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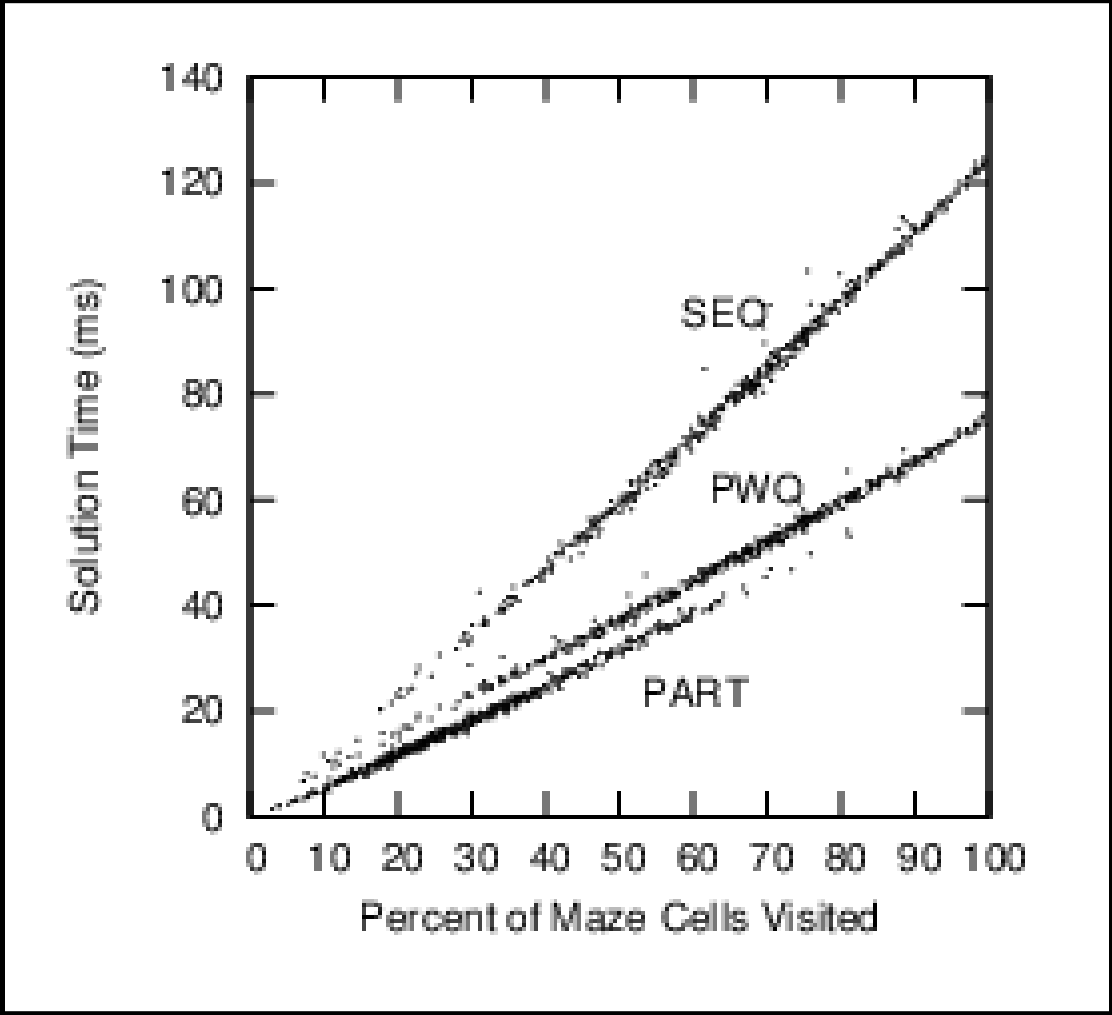
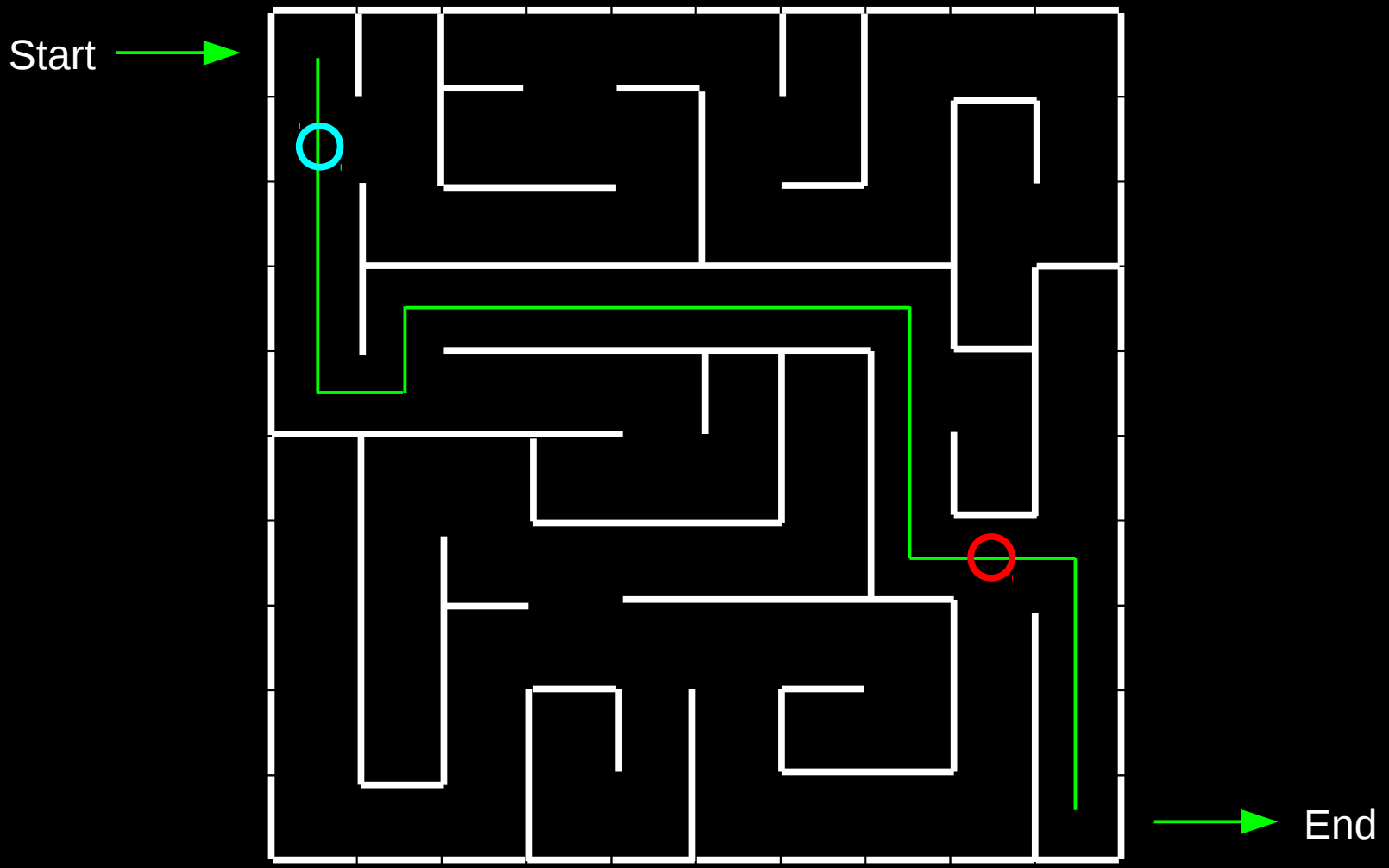
  - But PART sometimes visited fewer than 2%!!!

Visit Fraction vs. Solution Time Correlation



But correlation is not causation, nor is it “why”...

Partitioned Parallel Solution



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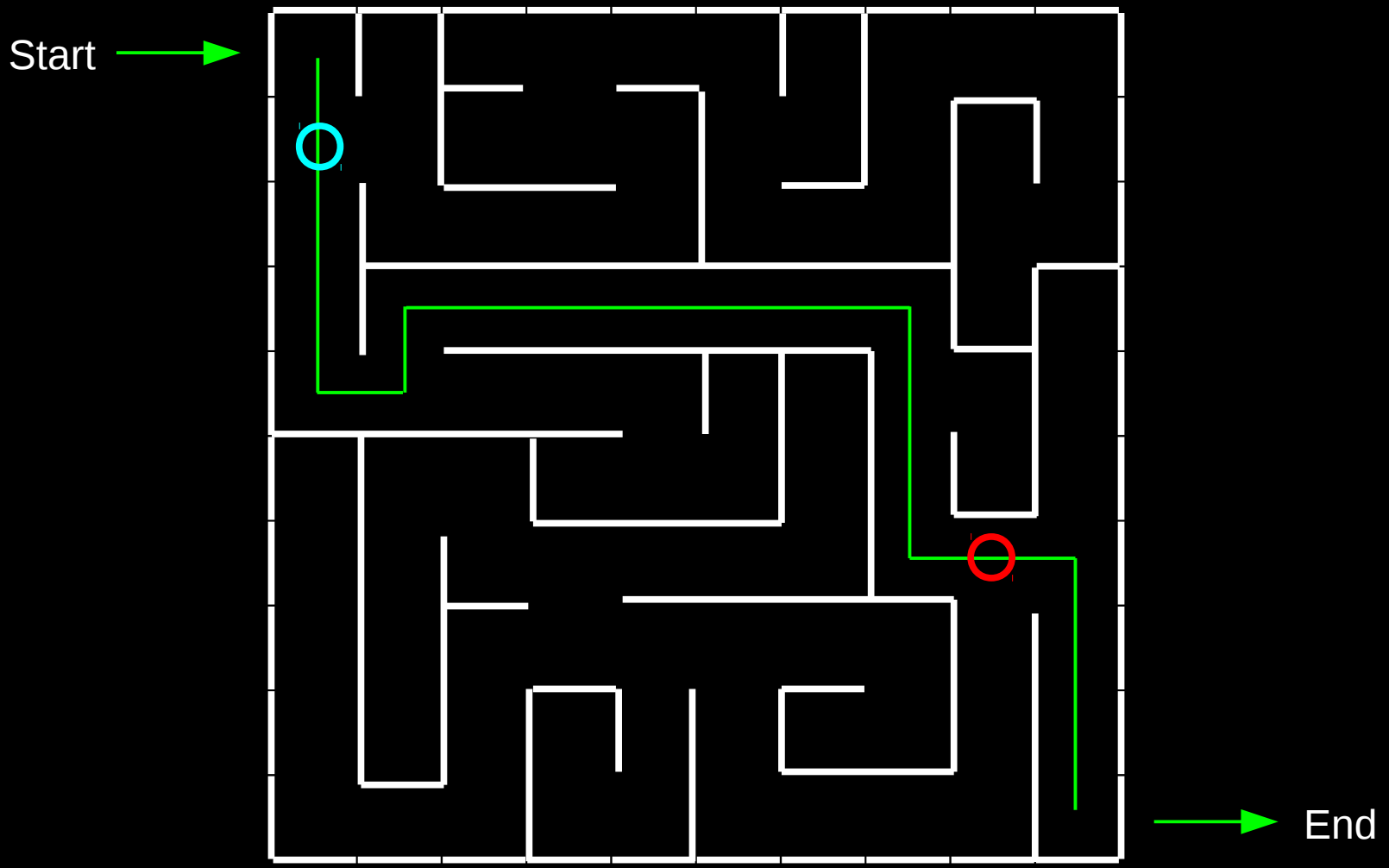
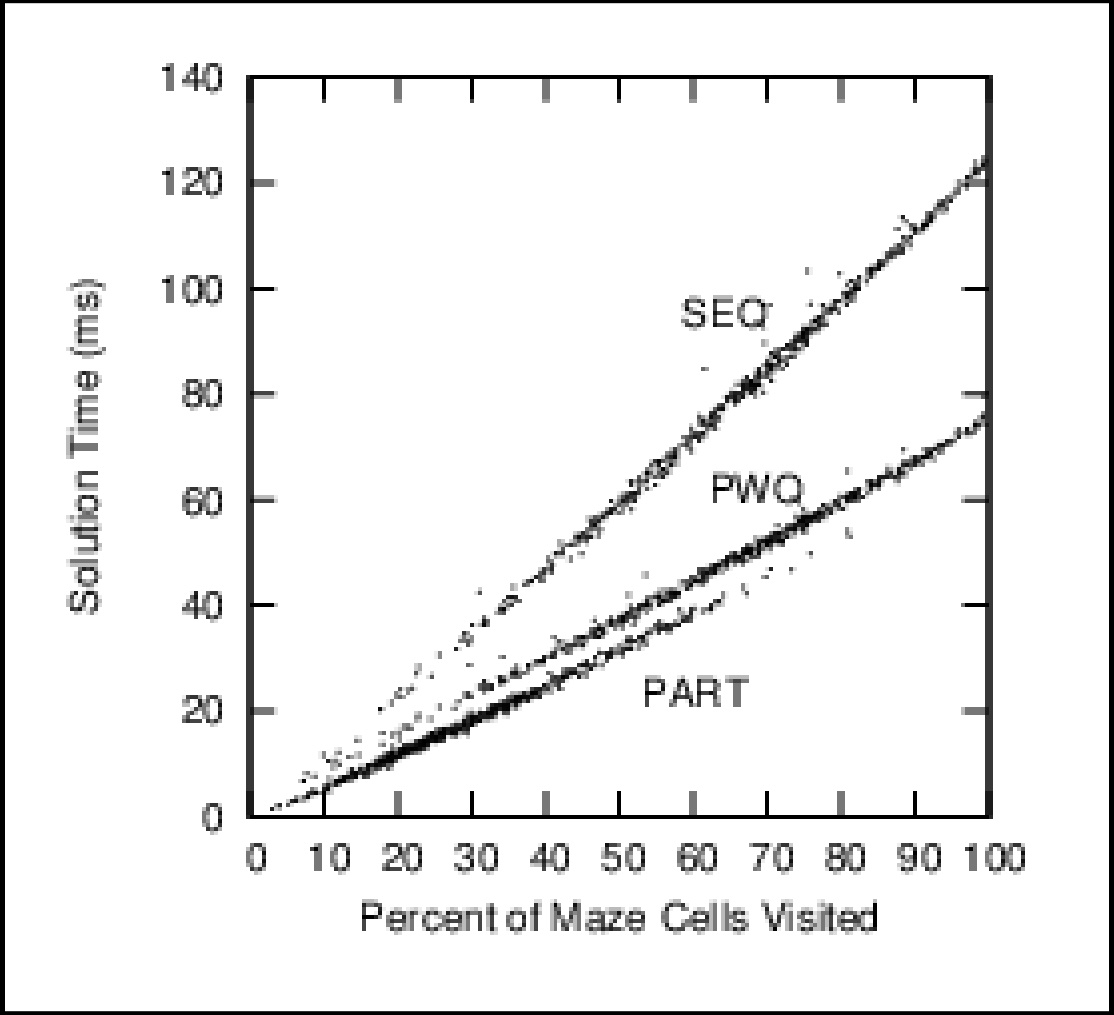
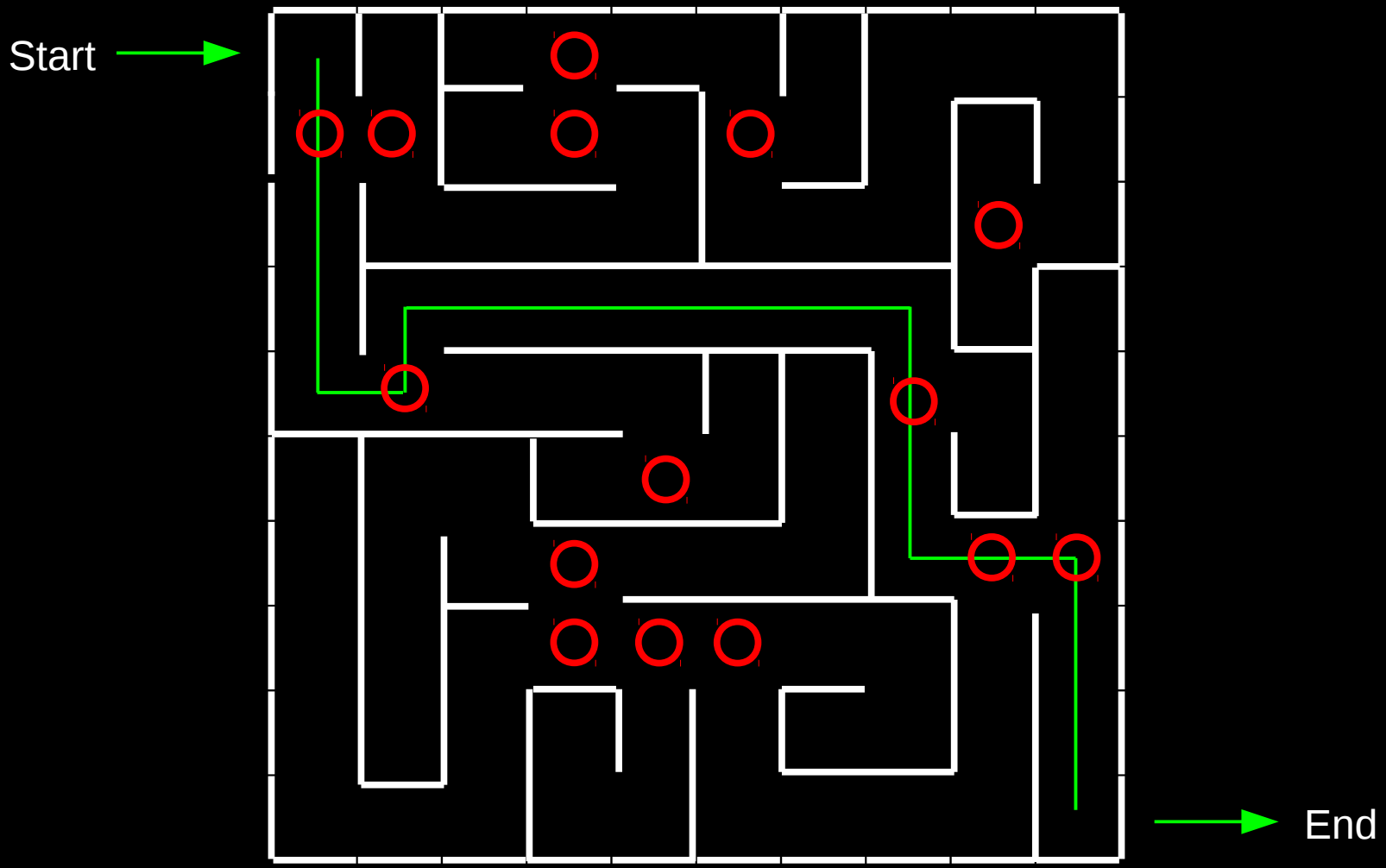


The threads get in each others' way!

But Why The Separation Between PWQ and PART?



PWQ Has Many Potential Contention Points: Contention is Expensive



Does PART Always Achieve Humiliating Parallelism?

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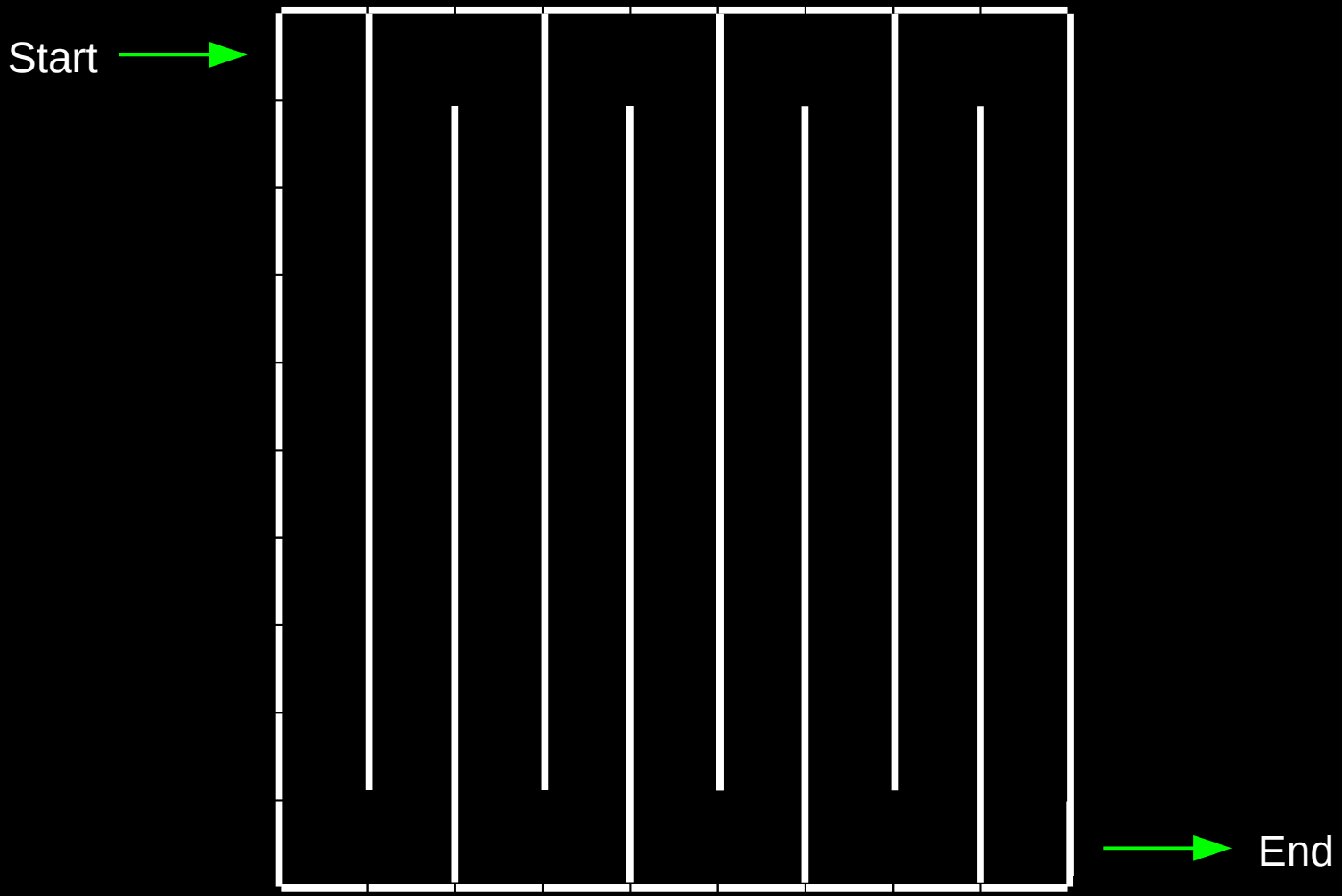

Partitioning is a Powerful Parallelization Tool

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But Let's Not Forget Sequential Optimizations!!!

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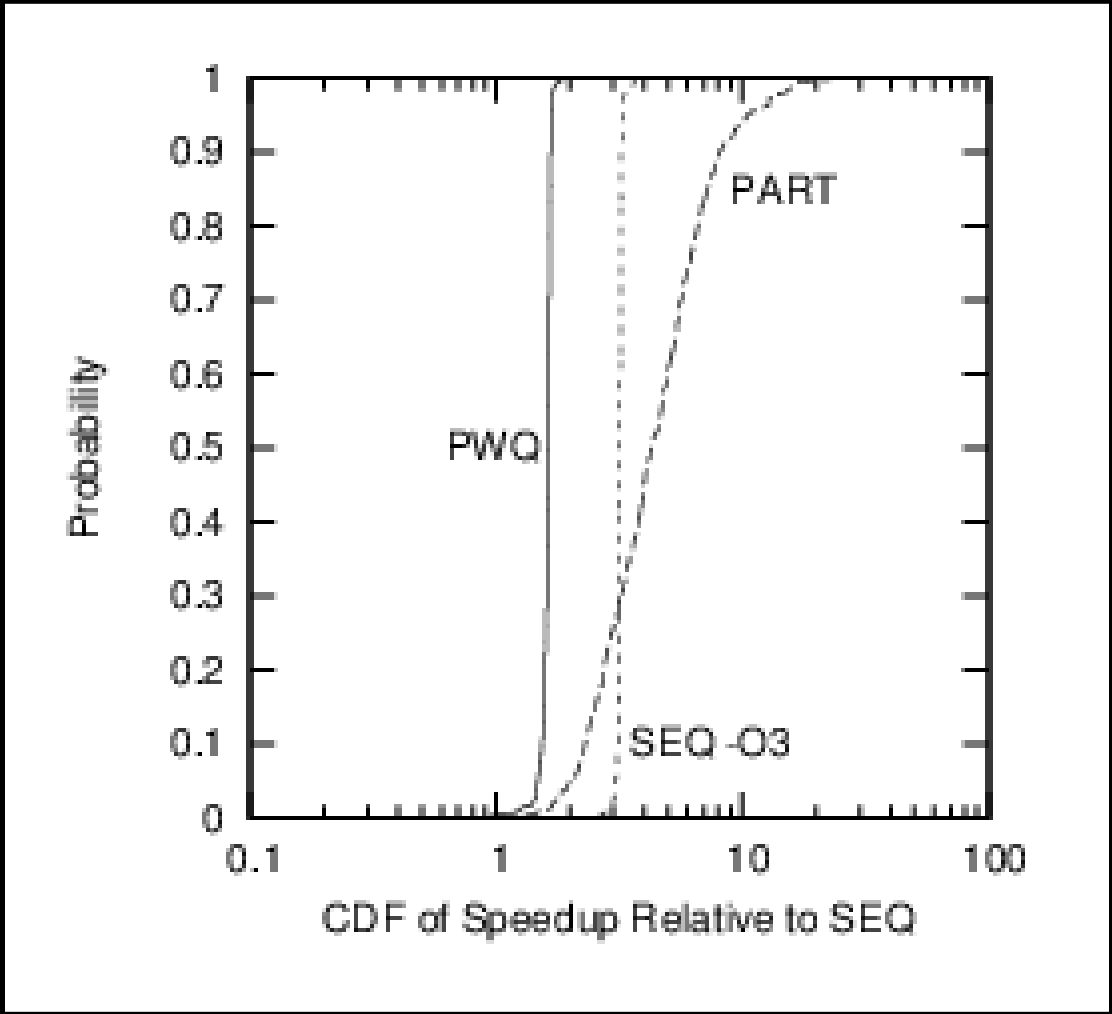

-O3 much better than PWQ, almost as good as PART!

Compiler Optimizations Beat PWQ!!!

- Yes, PART is even better, but if all you need is a 2x improvement (rather than optimality), compiler optimization is an extremely attractive option
- These results indicate that parallel-programming research making use of high-level/overhead languages is vulnerable to invalidation given improvements in optimization

And The Threads Will Get In Each Other's Way Even If They Are Running on One CPU... (Coroutines!!!)

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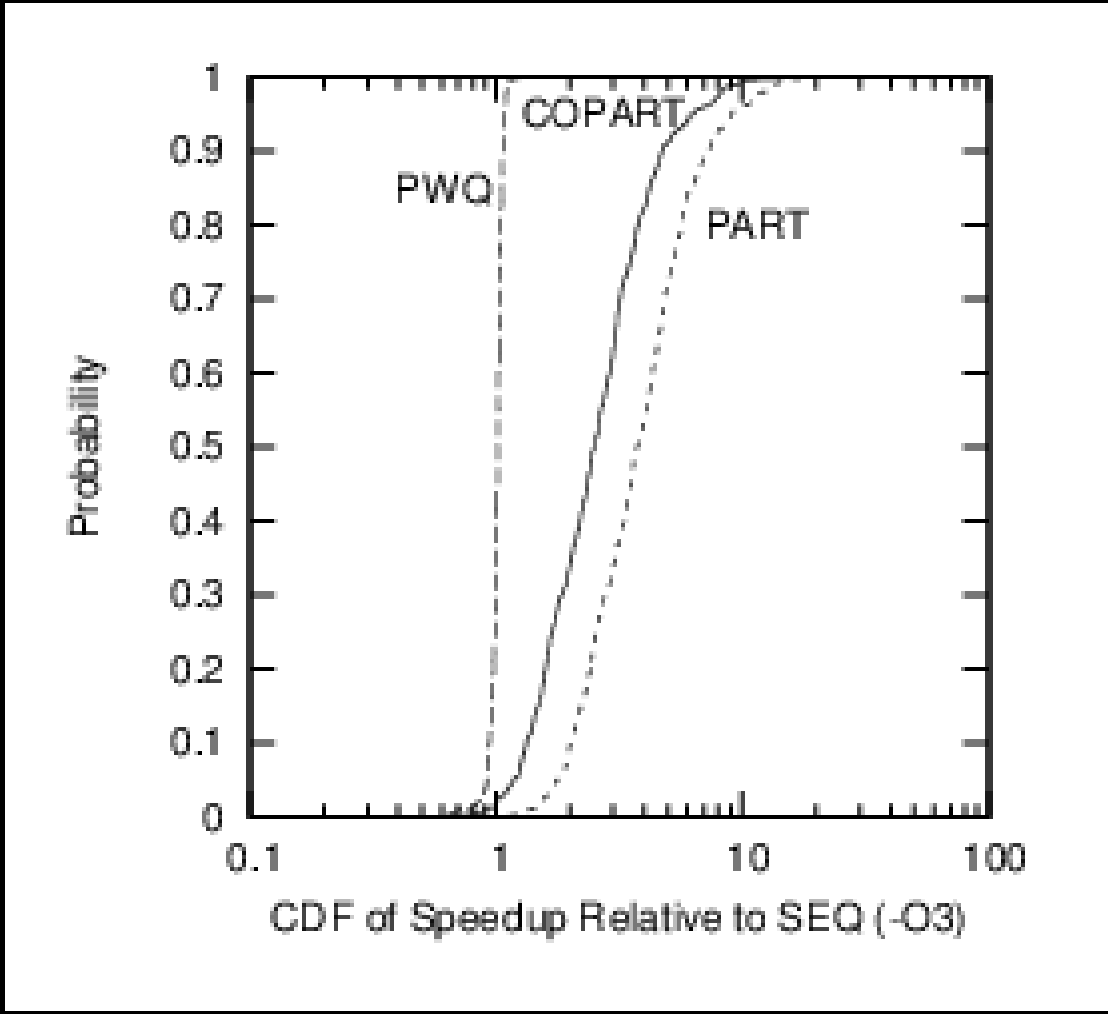
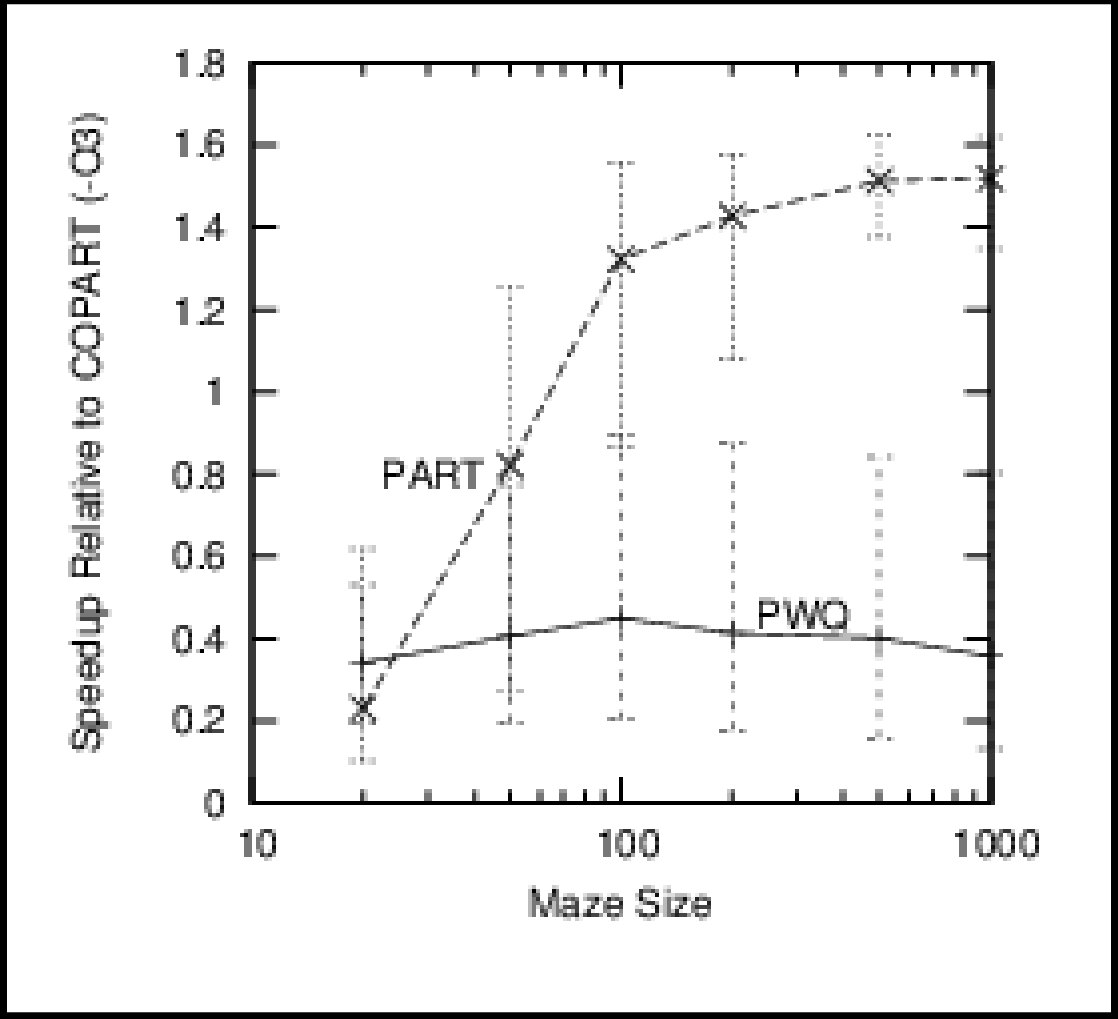
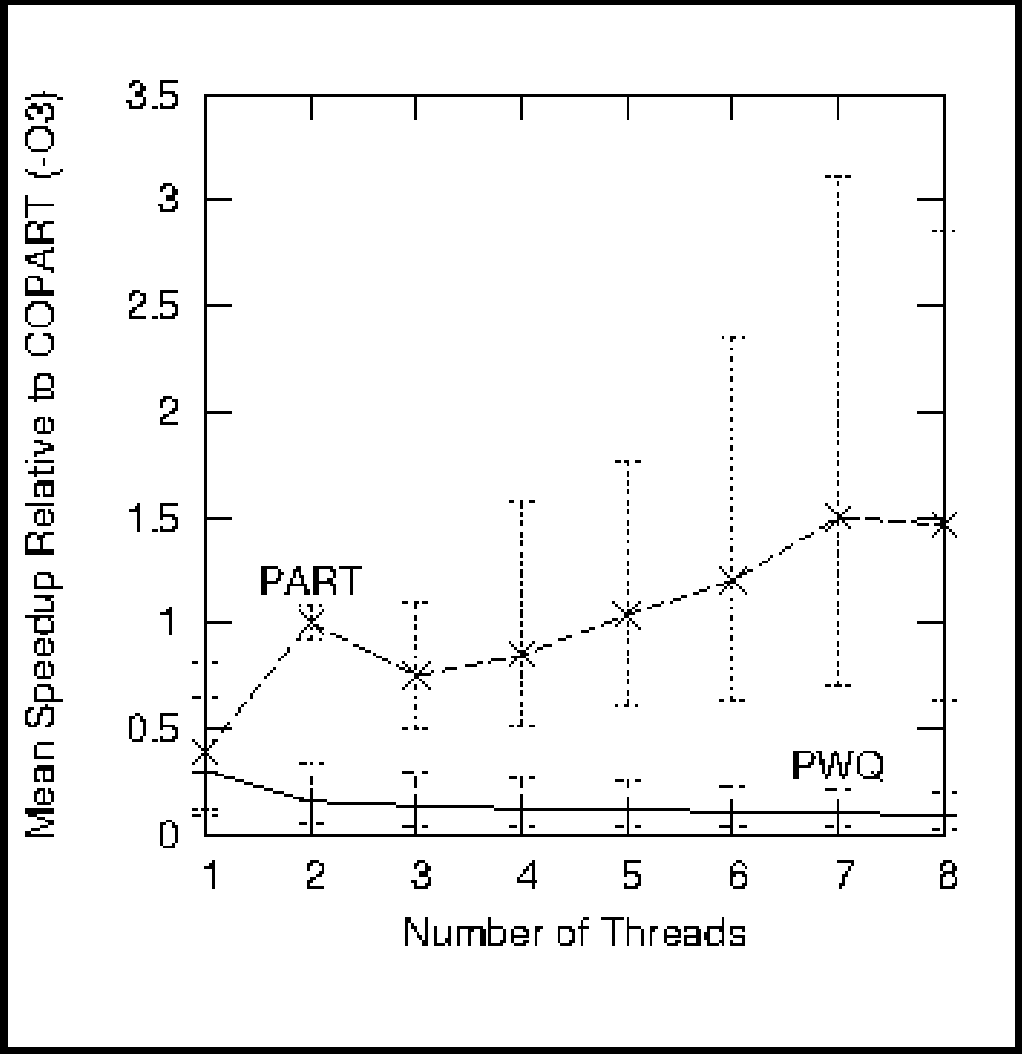


Effect Of Maze Size



Back to merely modest speedups!

Effect Of Increasing Numbers of Threads



Larger, older, less tightly integrated HW: Smaller speedups

Summary and Conclusions

How Did I Do Against My Goals?

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- ~~An example of near-perfect partitioning for "Is Parallel Programming Hard, And If So, What Can You Do About It"~~
  - Not so good!
  - From modestly scalable to humiliatingly parallel and back again
- ~~Use case for RCU-protected union-find data structure~~
  - Not so good!
  - No need for RCU in this problem

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- On the other hand, this problem turned out to be interesting in its own unexpected way!
  - And a nice change of pace from Linux kernel's RCU implementation

Open Questions

- Can other human-maze-solver techniques be applied?
  - Follow walls to exclude portions of maze
  - Choosing internal starting points based on traversal
- Do these results apply to unsolvable or cyclic mazes?
- Do other problems exhibit humiliating parallelism?
- Does humiliating parallelism always lead to a more-efficient sequential solution?
- How much current parallel-programming research can stand up to improved optimization?

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  - Follow walls to exclude portions of maze
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- Do these results apply to unsolvable or cyclic mazes?
- Do other problems exhibit humiliating parallelism?
- Does humiliating parallelism always lead to a more-efficient sequential solution? (No, it does not.)
- How much current parallel-programming research can stand up to improved optimization?

Conjecture

- Conjecture (Due to Jon Walpole):
  - Thinking from a parallel perspective leads to a much more efficient search strategy.
  - It is not the parallelism of the implementation that is important, but rather the parallelism of the strategy.

Parting Words of Advice

- Apply parallelism as a first-class optimization technique
  - Apply at as high a level as possible, to full application
  - Often simplifies solution
  - Usually reduces synchronization overhead, thereby improving both performance and scalability
- In contrast, retrofitted parallelism is likely to be grossly suboptimal
  - Especially when applied as a low-level after-the-fact optimization
  - Might be OK in some situations, but we can do much better

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Questions?