# Parallel Consistency in Constraint Programming

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# Outline

- Introduction to Constraint Programming (CP)
- Parallelism in CP
- Our Model of Parallel Consistency
- Experimental Results
- Conclusions
- Future Work

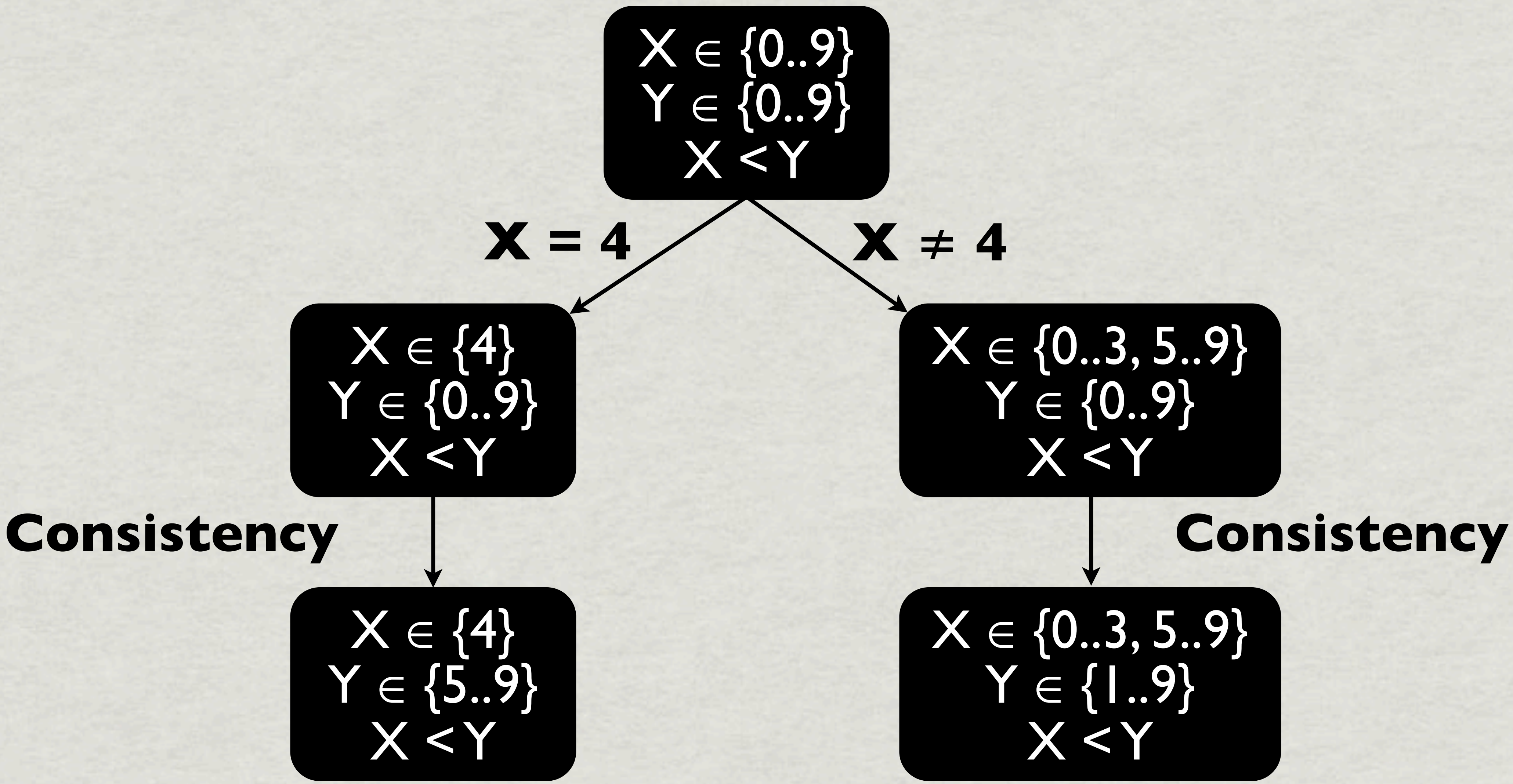
# Introduction to CP

- Similar to Integer Programming, but more natural modeling
- Constraint programming is declarative, useful for automatic parallelism
- Can be used to formulate problems such as Sudoku, Jobshop scheduling, and aircrew scheduling
- Solving is NP-complete

# Solving a CP-Problem

- Constraint problem solving = Search + Consistency
- Search is usually depth-first
- Consistency prunes values that cannot lead to a solution (pruning not complete, hence search)
- Solving is search tree exploration with very heavy nodes

# Example of CP-Solving




One branch evaluated at a time

Consistency enforced on every level of the search tree

# Questions?

## Or are the basics of CP clear to everyone?

# Parallelism in CP

- Data parallelism: Split the search tree
- Task parallelism: Split the work in the search nodes

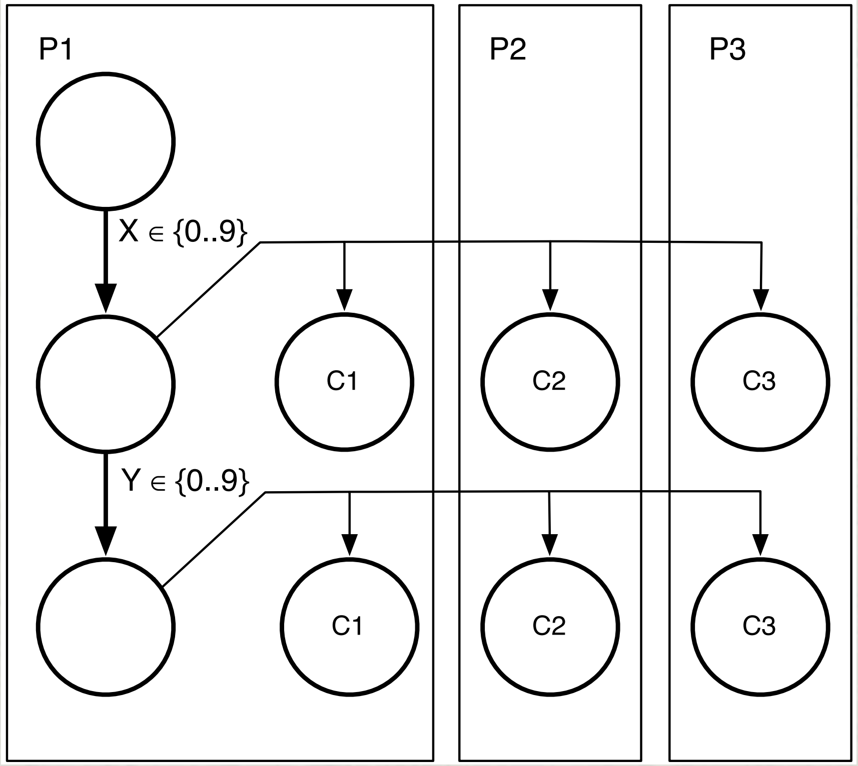
# Problems with Data Parallelism

- Problems can’t always be split efficiently - eventually the work is too small
- Communication costs
- Does not suit all problems, e.g., scheduling need customized splitting method
- Consistency often magnitudes more time-consuming than search

# Solution

- Combine data and task parallelism
  - When splitting is inefficient, use task parallelism
  - When tasks are too small, split tree instead
- First we need task parallelism, hence this work

# Our Model of Parallel Consistency

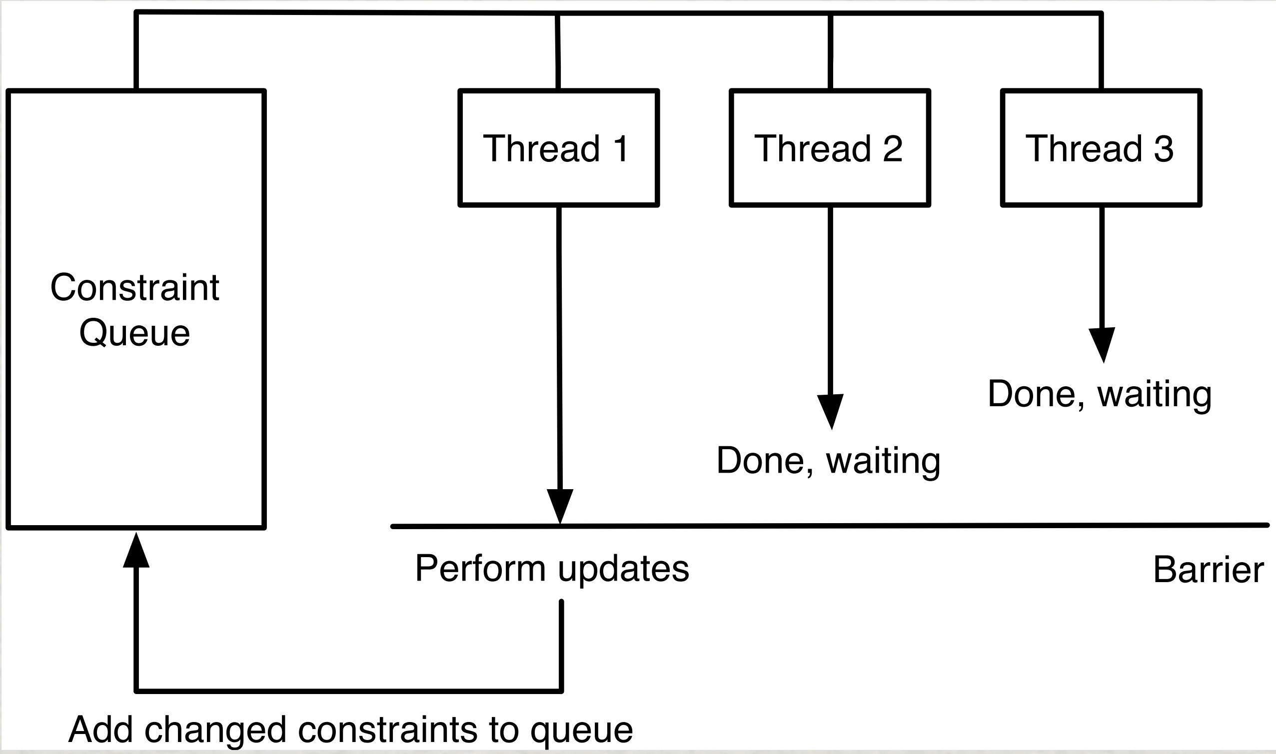



- The solver has several consistency threads (running on processors P1, P2, and P3 in the example)
- Each iteration of consistency takes data from the store held by the solver

# Variants

- Shared updates: the changes to variables are visible to the other constraints <u>before</u> the barrier
- Thread local updates: the changes are only visible after the barrier
- Thread local updates needs no extra synchronization, but slower to detect inconsistency

# Shared Updates

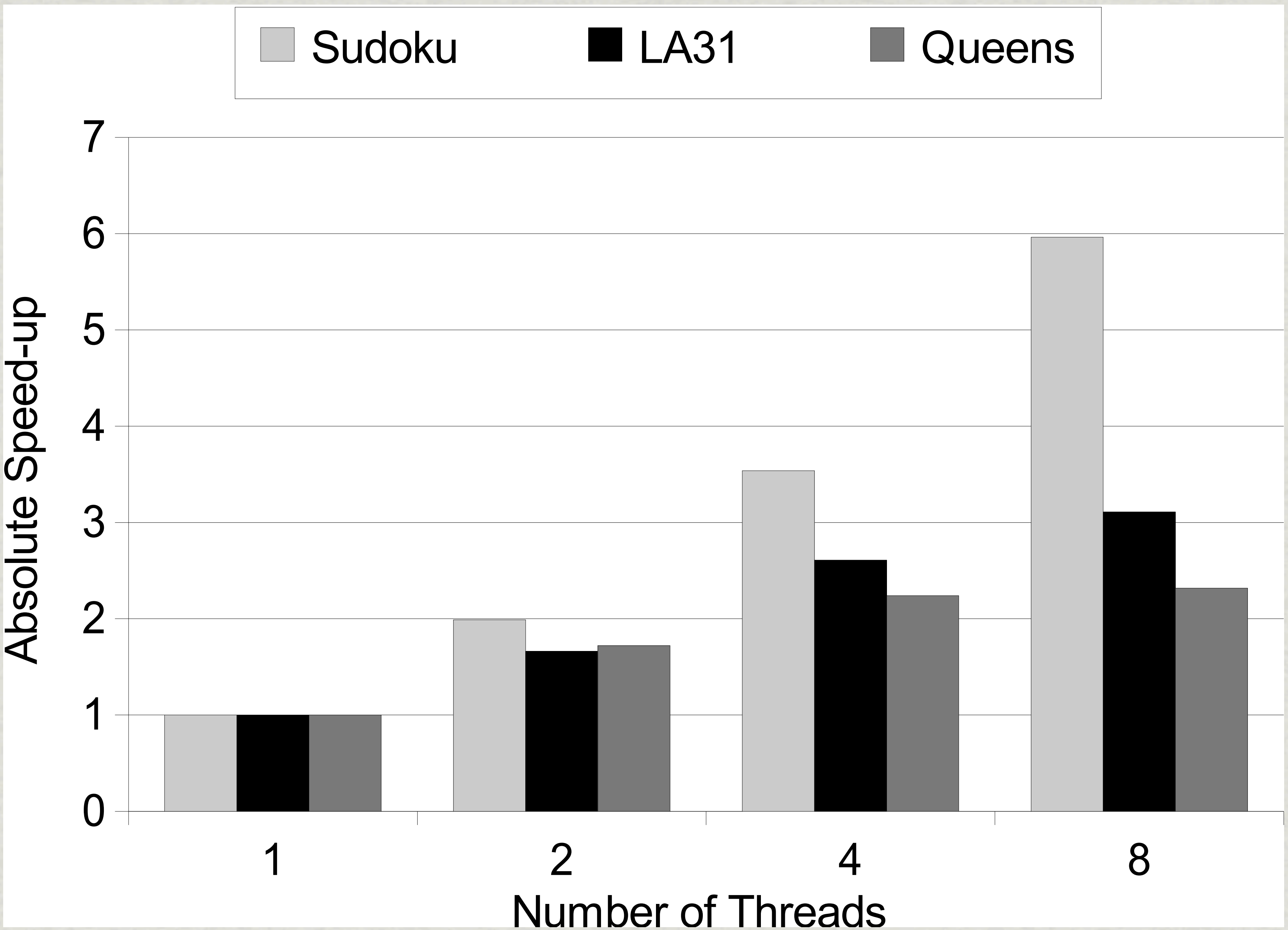



- Changes to variables are visible to other threads between constraints
- Updates are written to the store after the barrier

# Experimental Results

- n-Sudoku, n = 1024
- LA31, 30 by 10 jobshop
- n-Queens, n = 40 000
- JaCoP solver, written in Java 5
- Mac Pro with 8 cores
- Speed-up <u>before</u> search

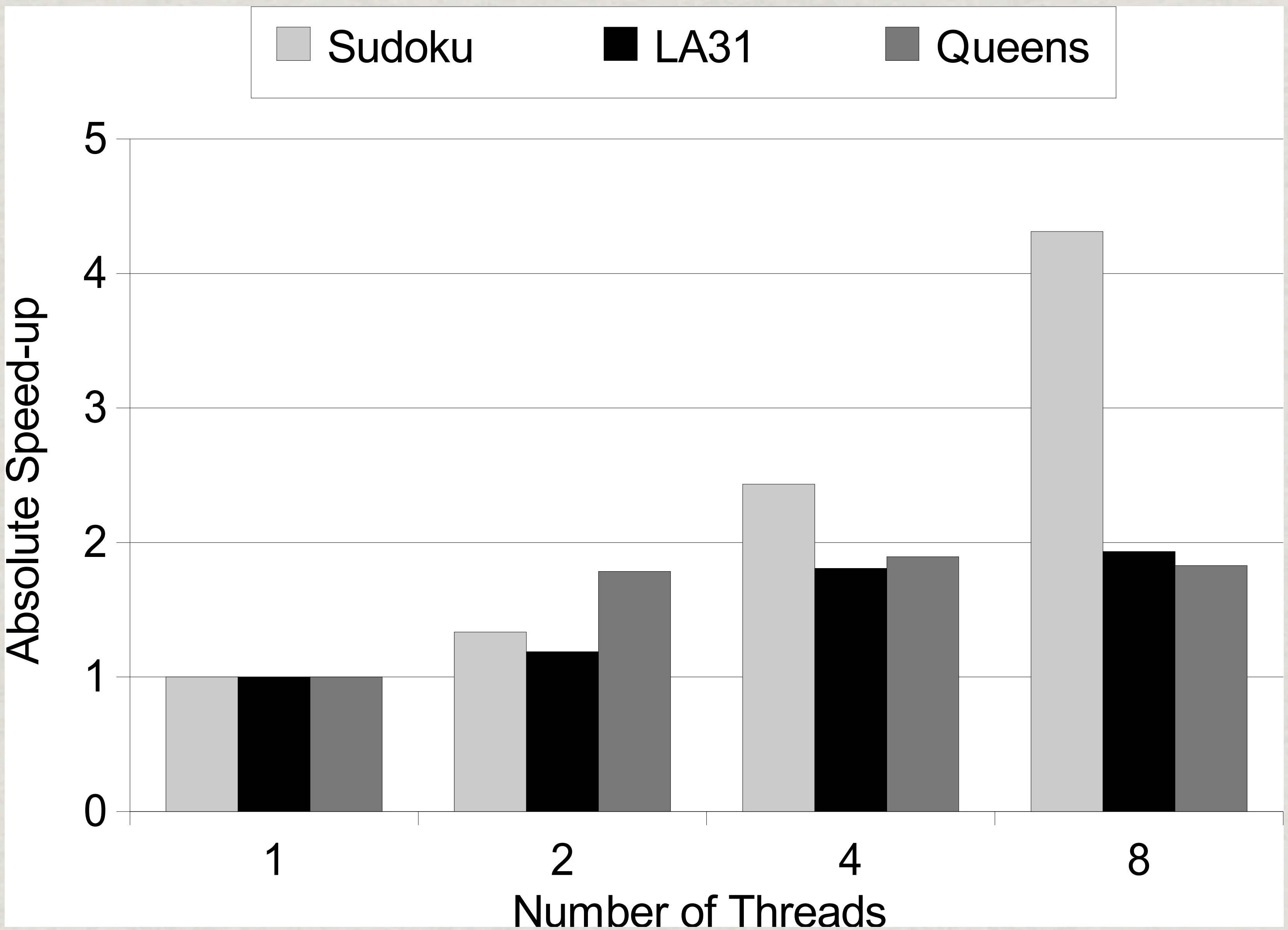
# Consistent Store



# Observations

- Sudoku is a perfect problem, performs no pruning
- LA31 - global constraints are too small
- Queens - three alldiff constraints dominates execution

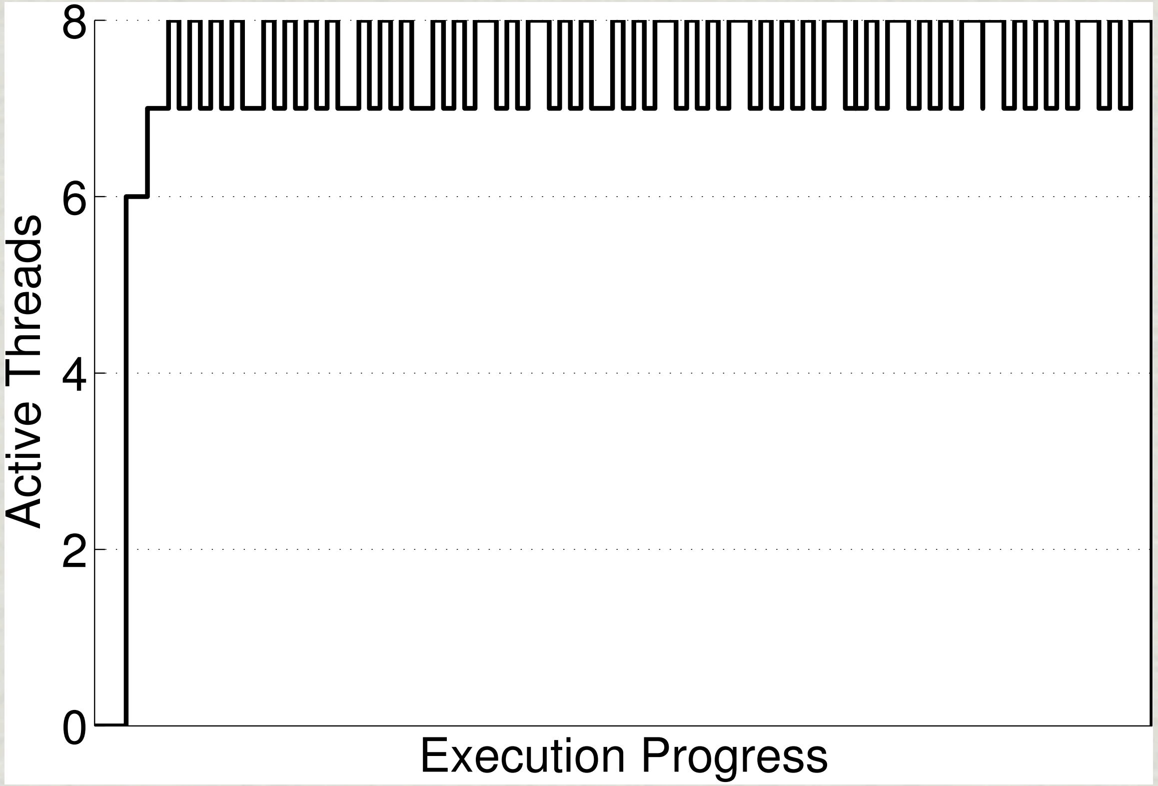
# Inconsistent Store

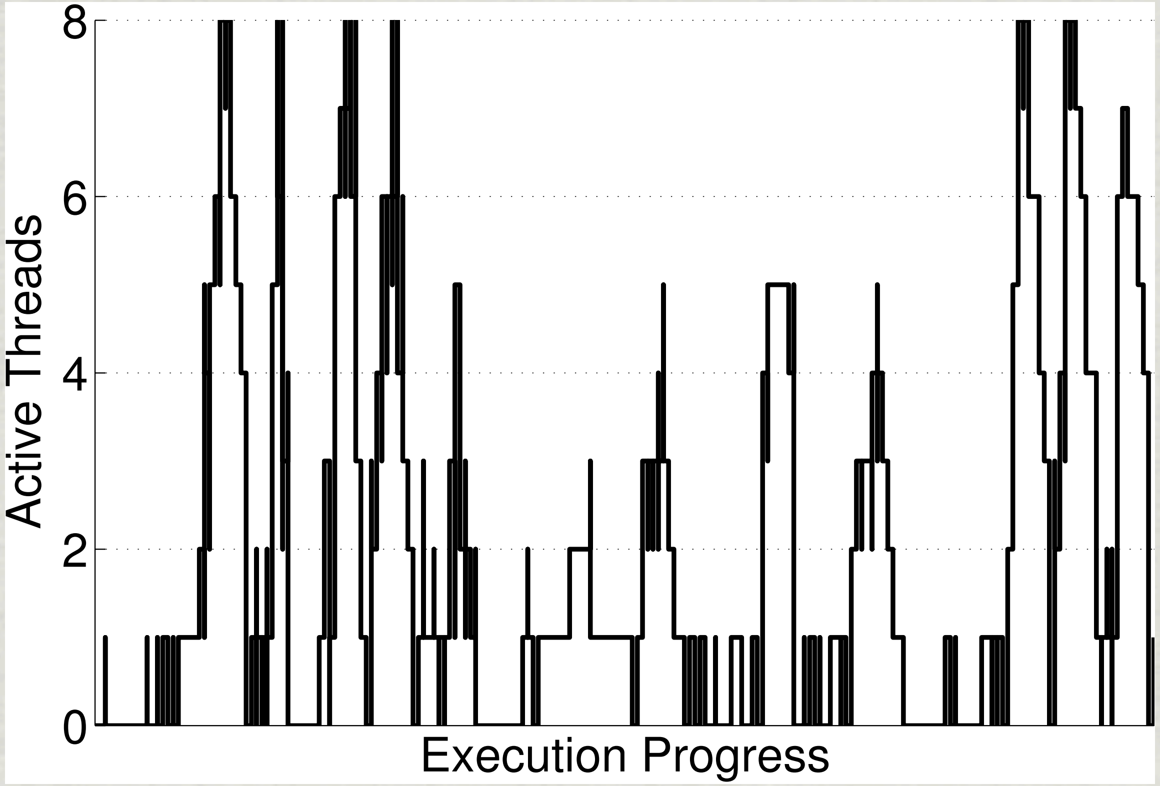


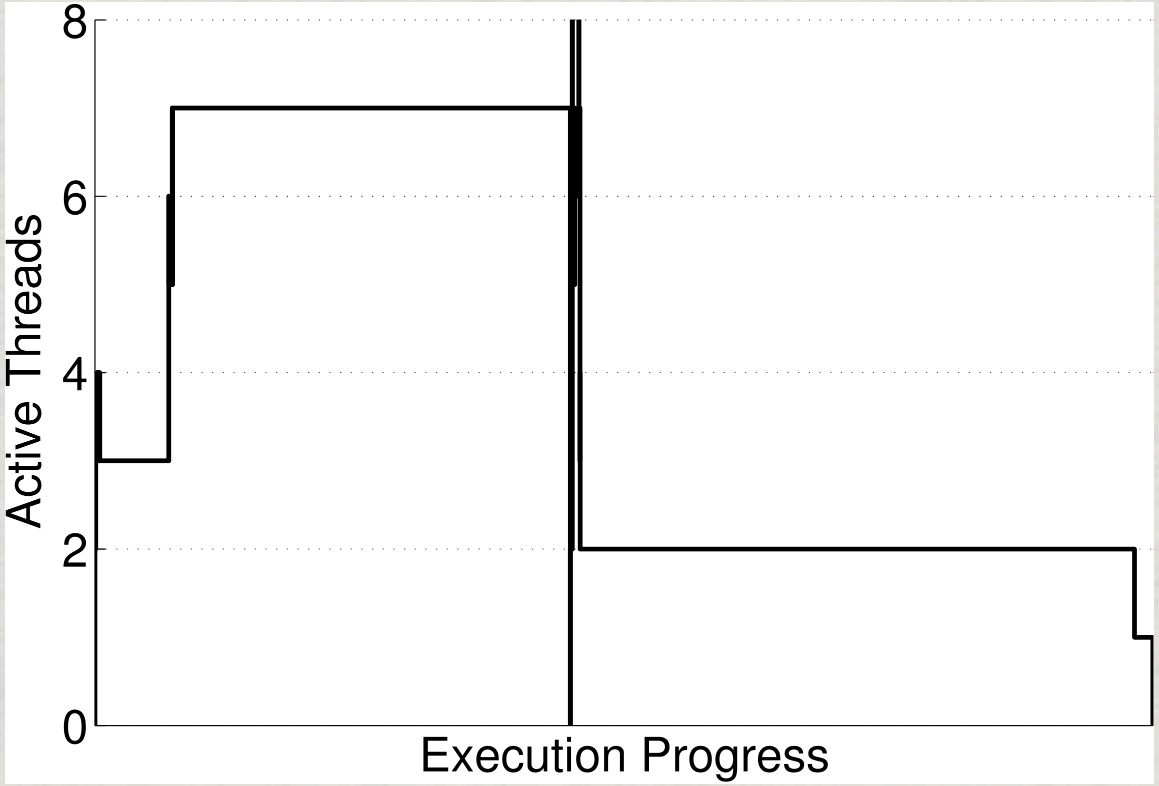
# Observations

- Many more iterations of consistency, also for Sudoku
- Speed-up drops compared to consistent store

# Processor Load




- Sudoku perfect, LA31 twelve iterations of consistency, Queens two iterations

# Conclusions

- Some problems do not scale well, they need parallel consistency algorithms
- Very hard to retain speed-up during search (due to locking and wait/notify)
- Small difference between thread local updates and shared updates
- Is probably best as an extension to data parallelism

# Future Work

- Combine data and task parallelism
- Load balancing in task parallelism
- Ideally: share updates during execution of consistency algorithms
- Long-term future of parallelism in CP: data parallelism + task parallelism + <u>parallel consistency algorithms</u>

# Thank You

## Questions?