Scalable, Automated Characterization of Parallel Application Communication Behavior

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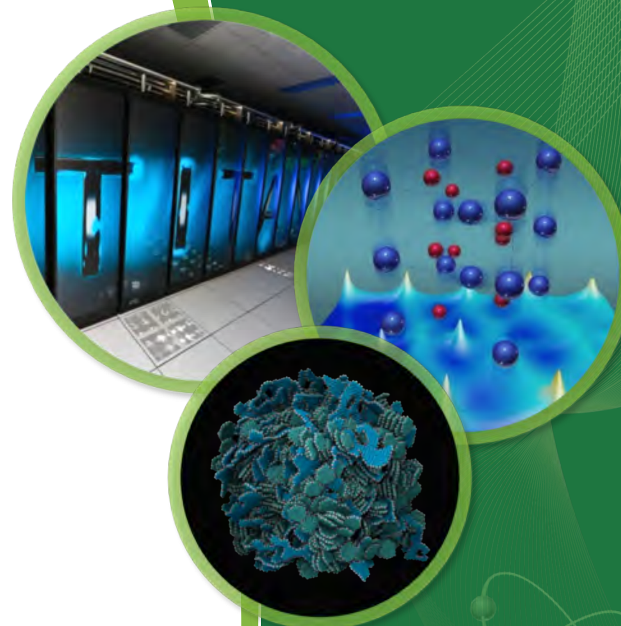
12th Scalable Tools Workshop



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- Often given unfamiliar application and asked to:
  - Describe how it works
  - Improve performance/scalability
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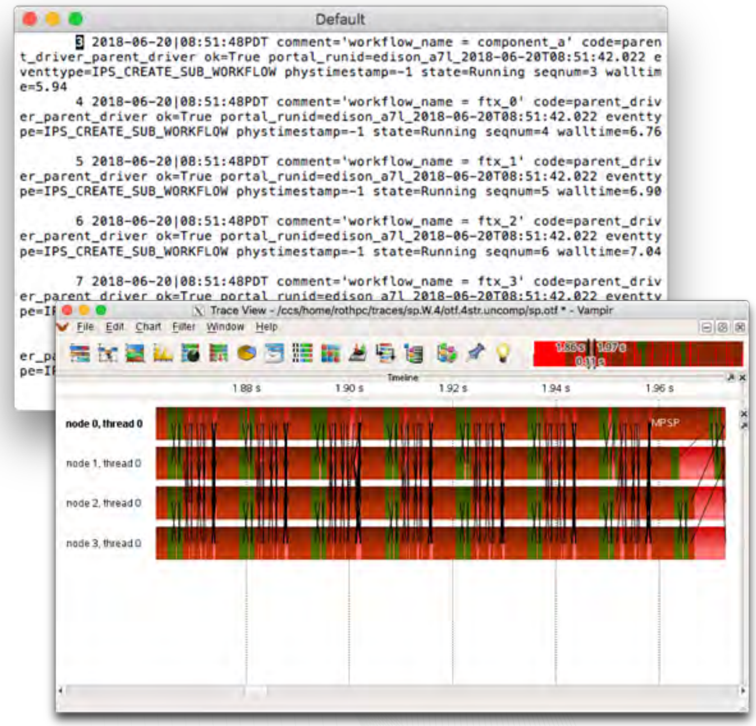

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Motivation

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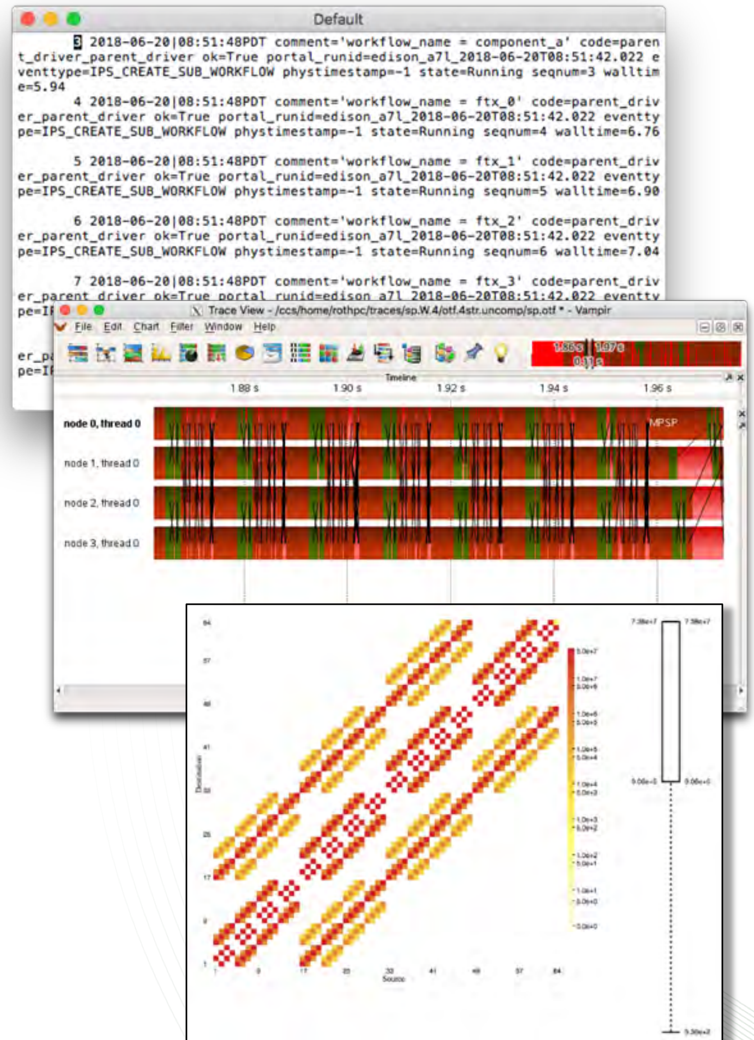
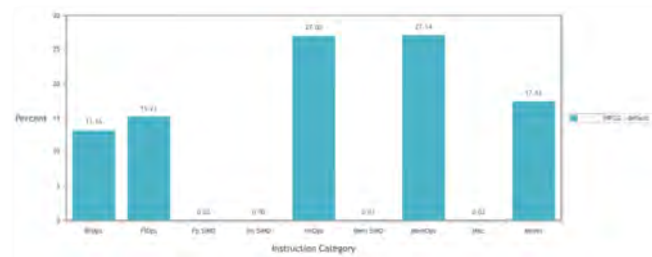
- Helps to have high-level view of how processes communicate
- Event traces and timeline visualizations → too much detail
- Communication matrix visualization → hard to interpret



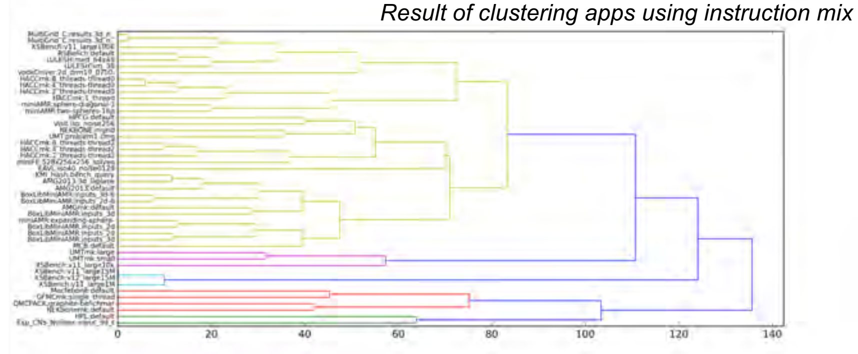
Background: Oxbow

- Characterize application demands independent of performance
  - System design
  - Representativeness of proxy apps
- Characterization on several axes:
  - Computation (instruction mix)
  - Memory access (reuse distance)
  - *Communication (topology, volume)*
- Online database for results with web portal including analytics support
- Project is dormant

Instruction Mix, HPCG, 64 processes



Result of clustering apps using instruction mix



AChax: Automated Communication Pattern Characterization

- Goal: capture communication pattern recognition expertise in an automated tool
- Given data describing application communication behavior, recognize communication pattern(s) and scale(s) that best account for observed data
- Express recognized patterns as parameterized expression

$$
\begin{aligned}
C_{LAMMPS} = {} & 13354 \cdot Broadcast(root:0)+ \\
& 700 \cdot Reduce(root:0)+ \\
& 19318888 \cdot 3DNearestNeighbor(\\
& \quad dims:(4,4,6), \\
& \quad periodic:True)
\end{aligned}
$$

Inspiration I: Paradyn's Performance Consultant

- **Automated search** through a **space** to find "point" that best explains observed performance
- **Hypothesize, test,** and **refine**
- Record results in a **search tree**

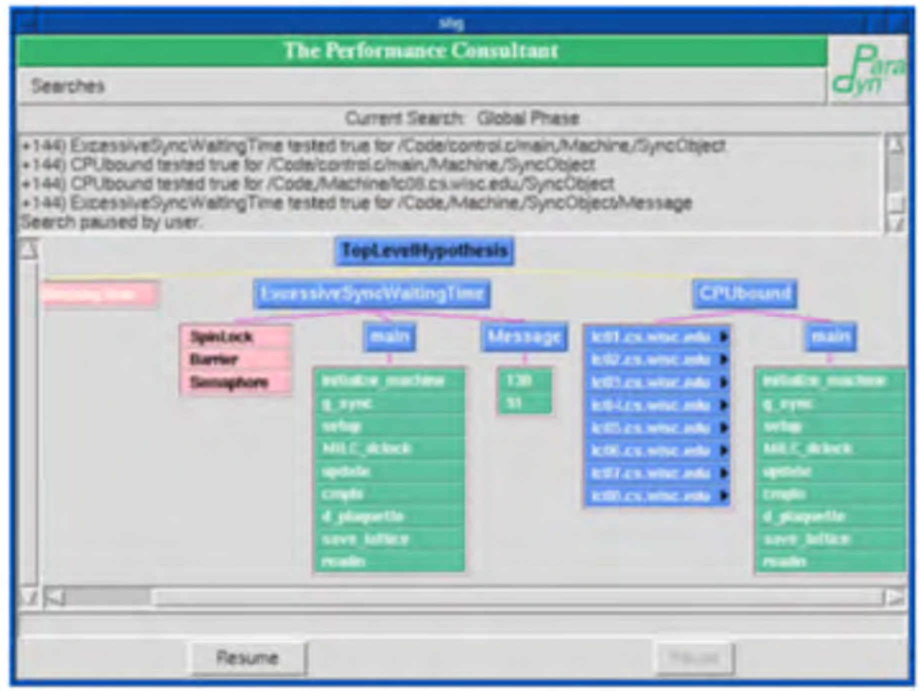
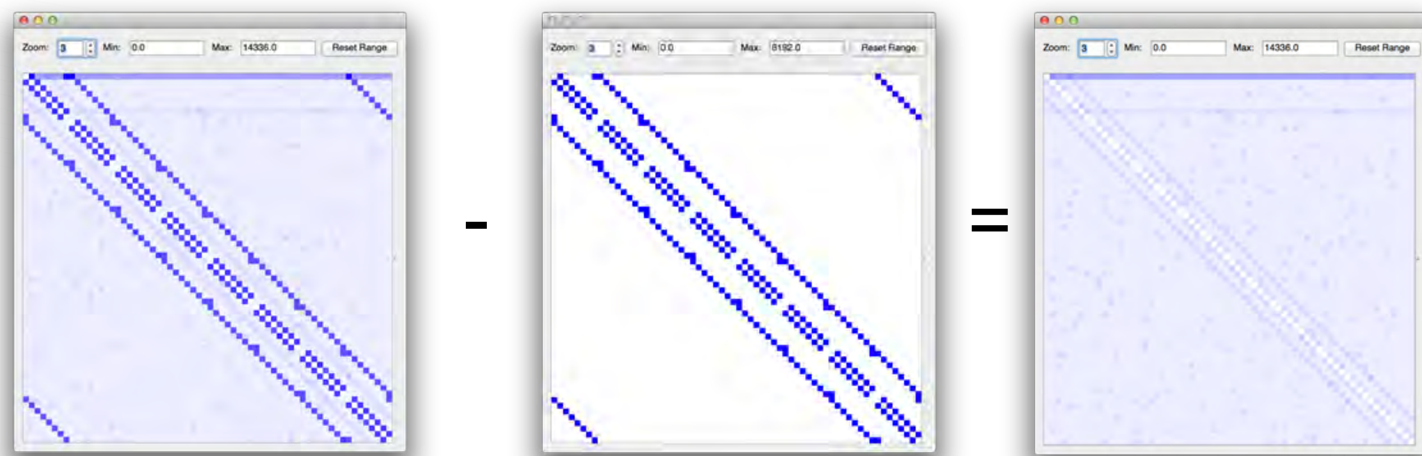


Figure 1.2 A Search History Graph display.

Inspiration II: Sky Subtraction

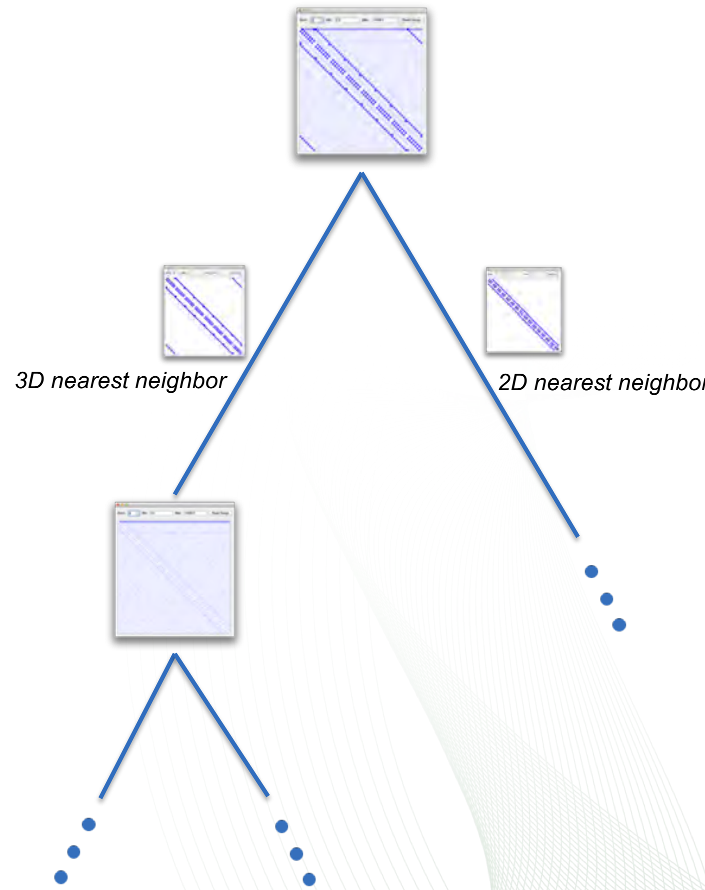
- Given an image of the sky, remove the known to make it easier to recognize the unknown



*Recognizing and removing the contribution of a 2D nearest neighbor pattern in a synthetic communication matrix. This represents **one step** in a search-based approach.*

Search Overview

- Associate application's communication matrix with root node
- At root node, for each pattern in **pattern library**
  - Attempt to recognize pattern in node's matrix
  - If recognized, subtract scaled pattern from node's matrix to get child matrix
  - Add child node with new matrix and edge to **search result tree**
  - Recursively apply search starting at child node

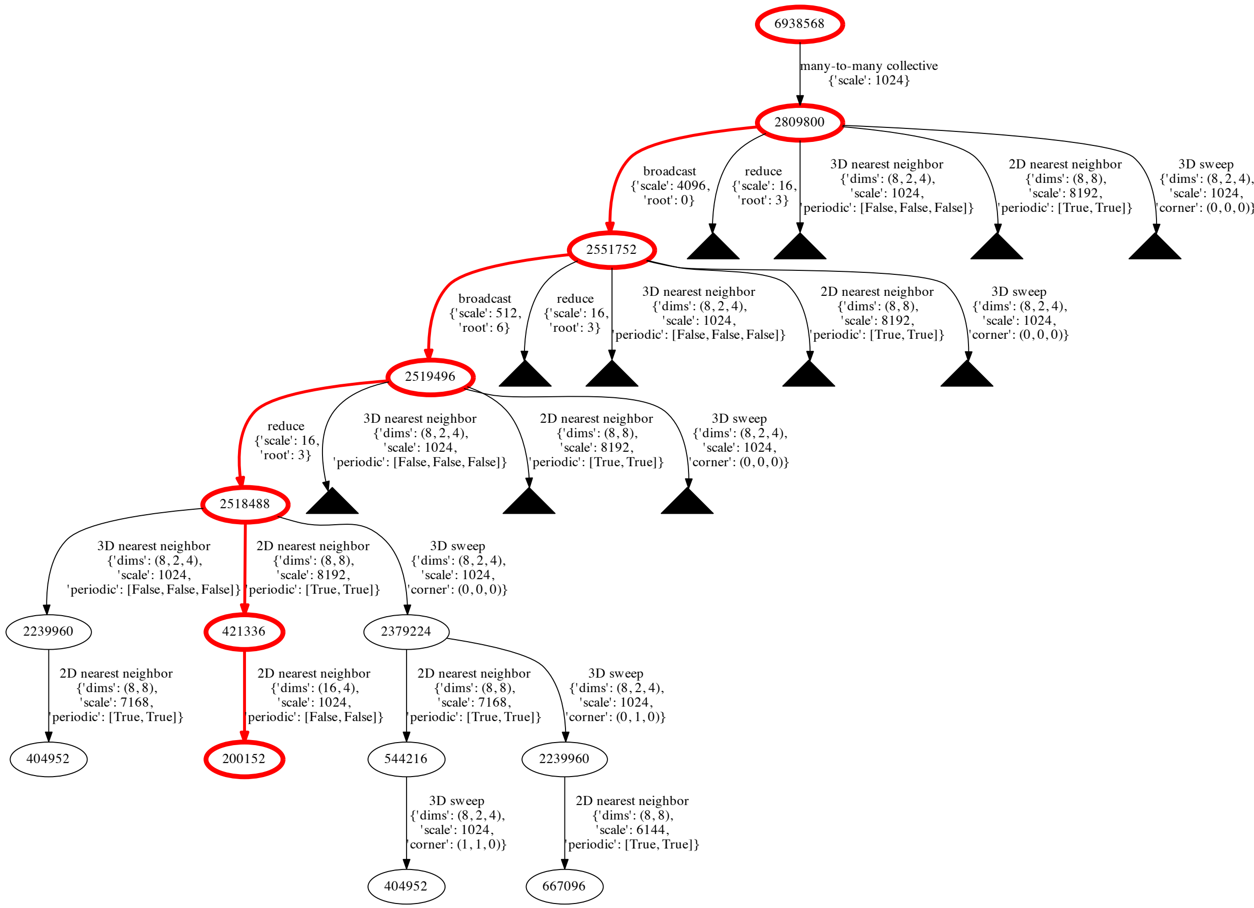


Pattern Recognition

- Library of scale-independent pattern generators and recognizers
- When attempting to recognize a pattern in a matrix
  - Determines number of processes
  - Determines dimension sizes for multidimensional patterns
  - Determines **scale** of the pattern
  - Determines root process for rooted collectives
  - Detects origin corner for wavefront patterns
- Heuristics for lightweight checks when possible

Search Result

- **Residual**: total communication volume in a communication matrix
- When search finishes, path between root and leaf with smallest residual indicates patterns that best explain original communication matrix

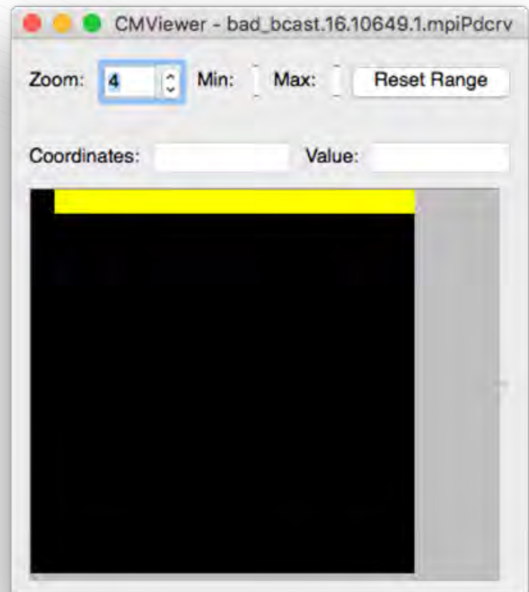


Three Problems

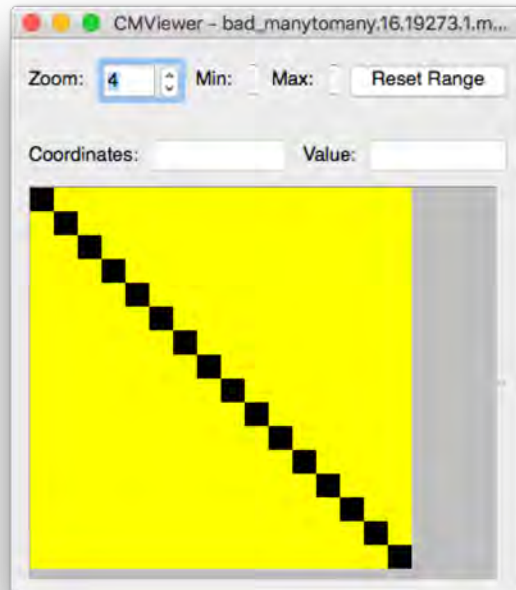
- Ambiguity in pattern recognition
- Greedy recognition approach can be too greedy
- Inefficient implementation

Problem 1: Pattern Recognition Ambiguity

- Representing communication data using traditional communication matrix leads to ambiguity, especially with collectives



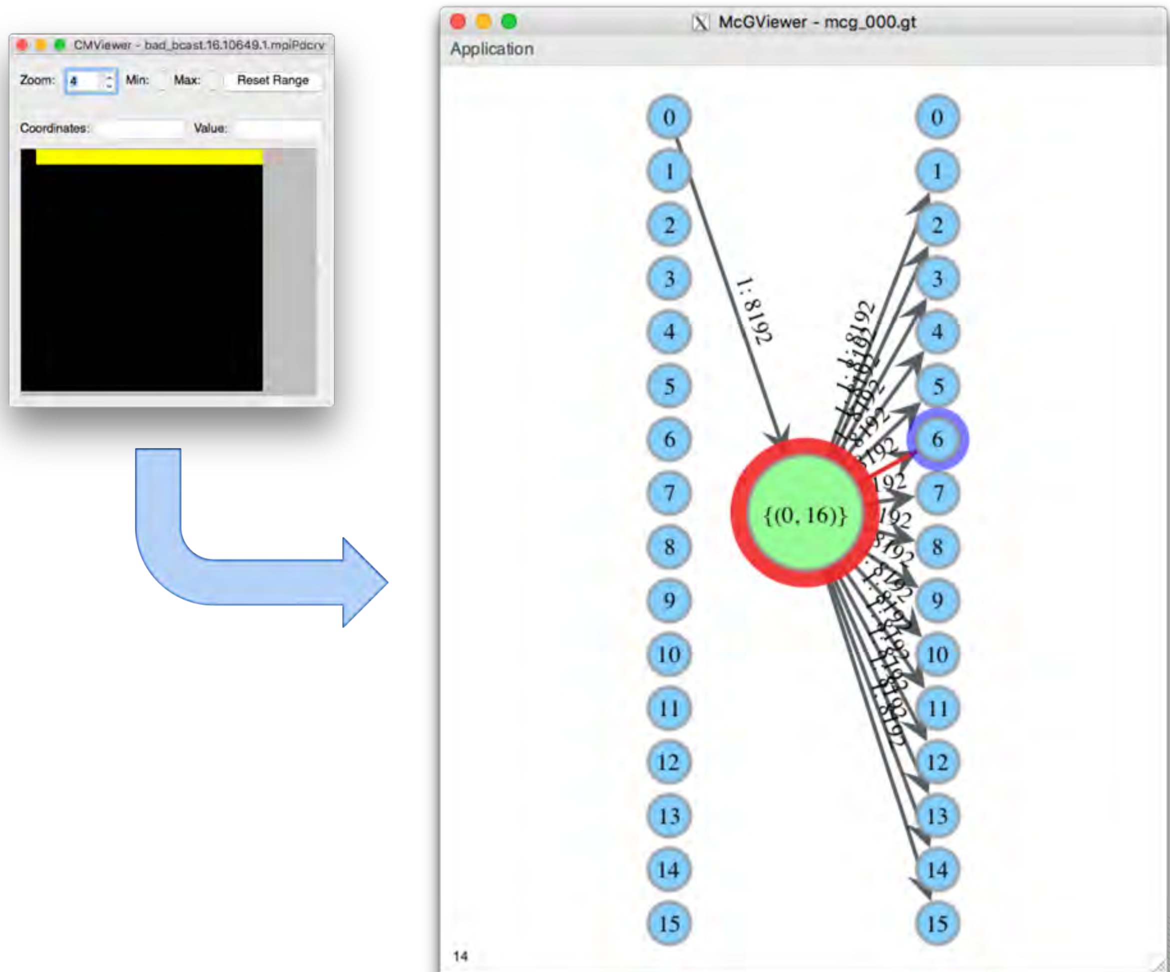
Broadcast or multiple point-to-point?



Worst case

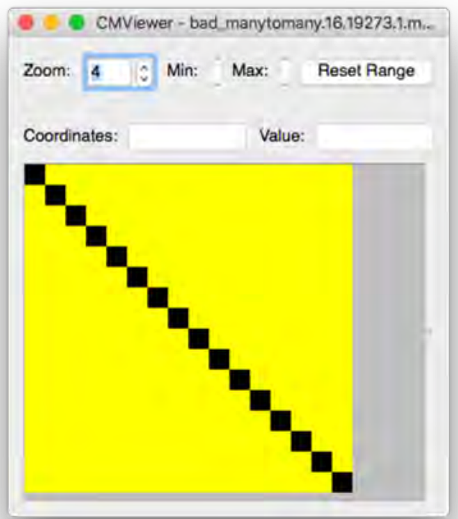
Augmented Communication Graphs (ACGs)

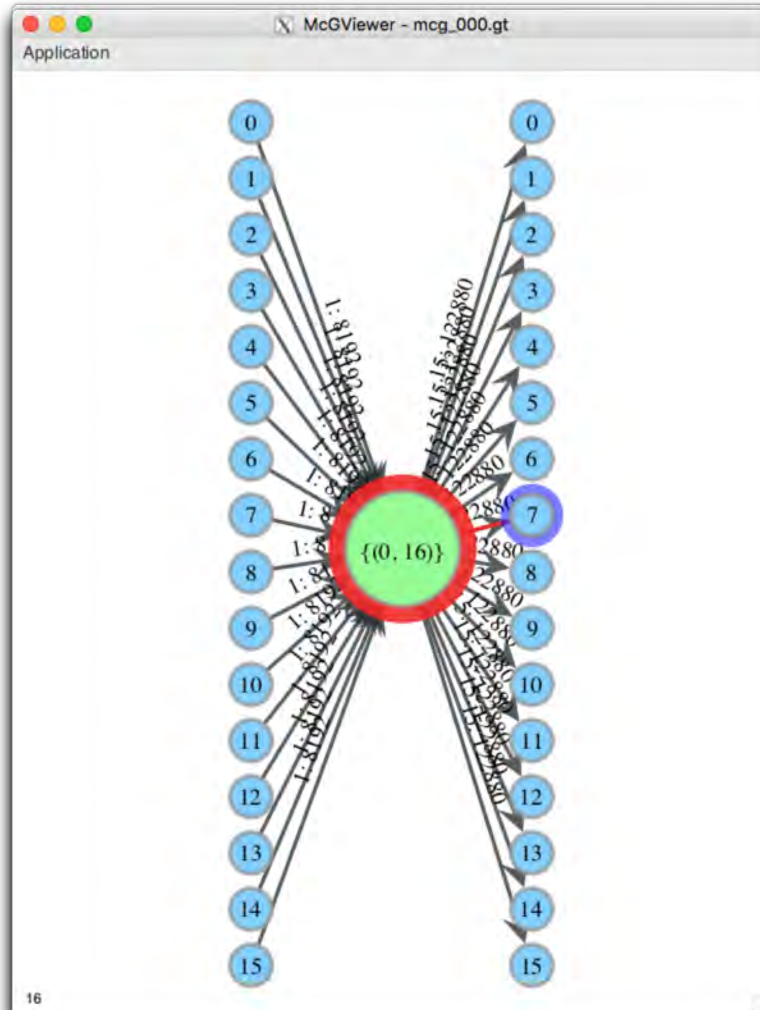
- Instead of traditional communication **matrix,** represent communication data as a graph
- Vertices for processes
  - Separate sender/receiver roles
- Edges denote communication occurred
  - Labeled with operation count and message volume
- To make it easier to discern collective operations, augment the graph with vertices representing communicators



And That Worst Case?

- As presented so far, better but not ideal
- May need to label communicator vertices with collective operation or operation type

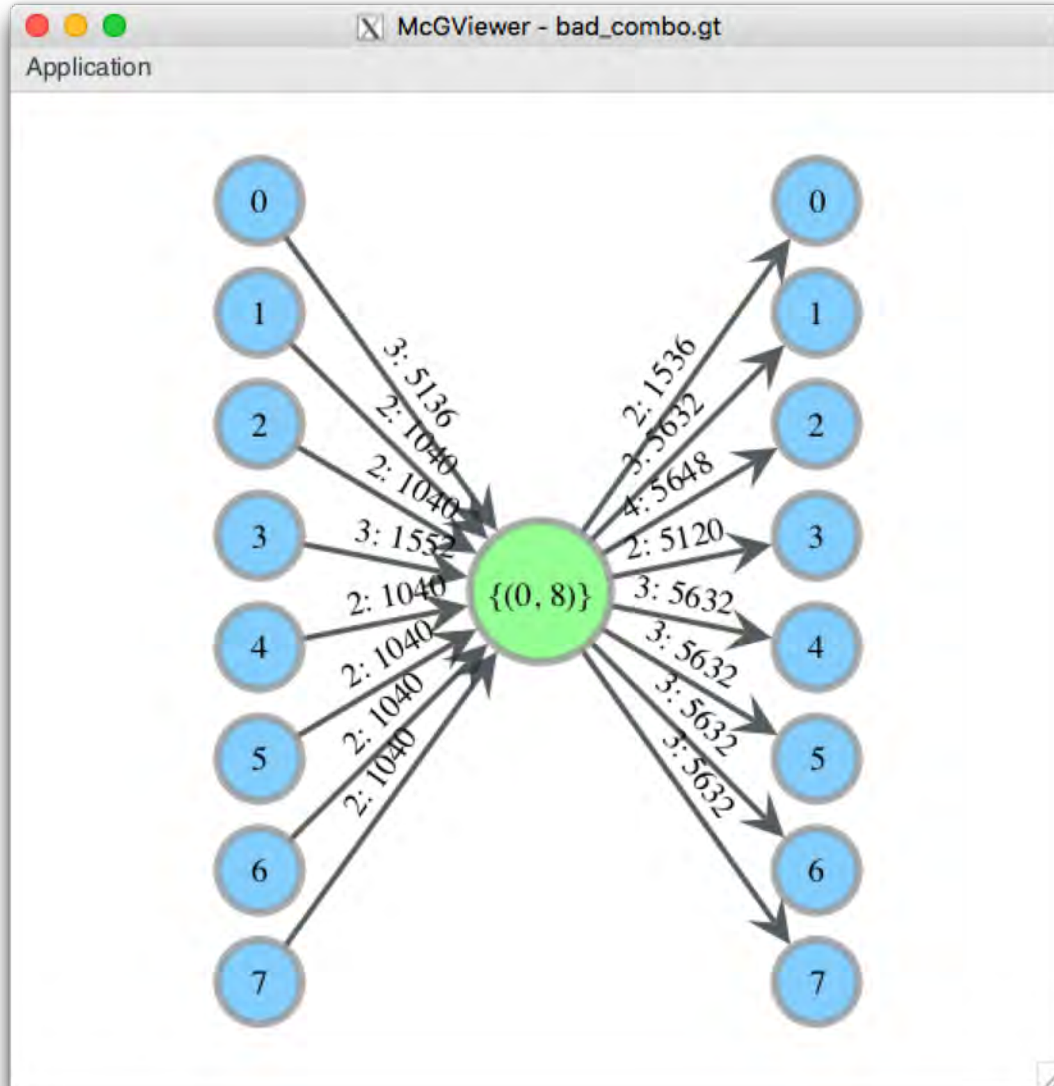




Problem 2: Too Greedy

- When recognizing a pattern, AChax recognizes as much data as possible for that pattern
- Can cause automated search to fail to recognize some pattern combinations

– broadcast: {’scale’: 4096, ’root’: 0}
– broadcast: {’scale’: 512, ’root’: 3}
– reduce: {’scale’: 16, ’root’: 2}
– many-to-many: {’scale’: 1024}

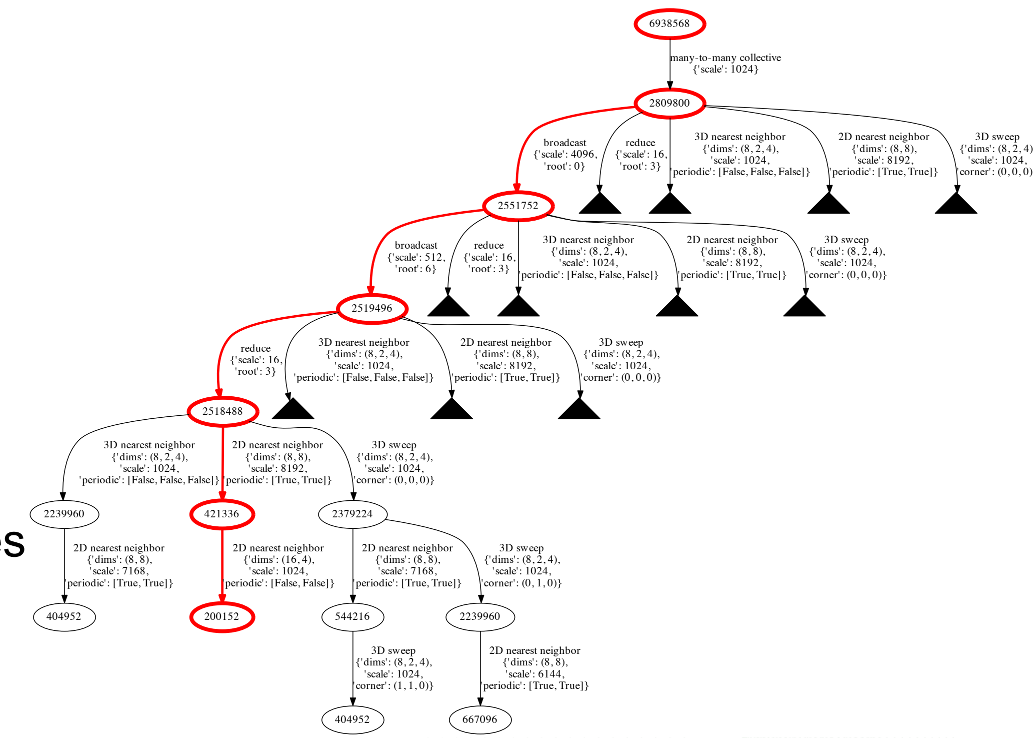


Non-Greedy Pattern Recognition

- If pattern recognized, check if removing pattern with maximum scale will result in invalid ACG
- If so, find smaller scale(s) and refine search at each
- Problem: if pattern recognized at maximum scale *S*, can be recognized for every integer scale between 0 and *S*
  - *Search space explosion*
- Instead, find “interesting” scale values
- Heuristic based on communication count differences on ACG edges
  - *Current implementation may still refine at large number of scales*

Problem 3: Inefficient Search

- Original AChax implementation susceptible to doing lots of redundant work
- E.g., pattern combination from original AChax paper
  - Search results tree has 506 nodes
  - 180 leaves ("best" for given search refinement)
  - Only ***3*** distinct residual values in leaves
- Instead, prune search when root→node path is permutation of another root→node path

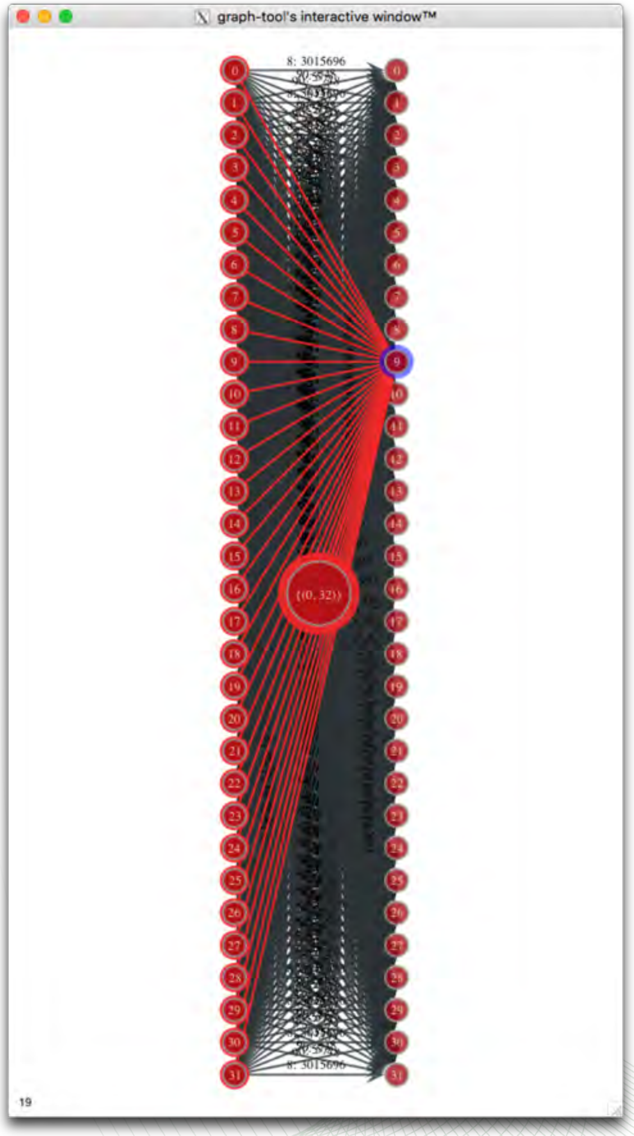


Implementation

- Original AChax tool
  - Python, using NumPy and SciPy for matrix ops and I/O
  - MatrixMarket format for communication matrix files
- AChaxG – ACG-based tool
  - Still Python
  - Graph-tool module for I/O, analysis, and visualization of ACGs
  - VERY slow ⇒ recently back to MatrixMarket representation of ACG
- Simple ACG viewer
  - Interactive, highlights edges to/from selected nodes
- Grabber: MPI communications data capture library
  - C++ with Boost and Todd Gamblin's MPI wrapper generator

Case Study: Xolotl

- Plasma surface interactions model
  - C++, MPI, PETSc
- Ran on OLCF Eos Cray XC30
  - 1D problem, 2048 grid points
  - 32 processes, 5 time steps
- AChaxG recognized broadcast, reduce, and 1D nearest neighbor patterns – didn't account for much
- Interactive visualization exposed point-to-point collectives (eventually found within PETSc)



Lots Left to Do

- Handle patterns whose communication volume depends on specific sender/receiver pair
  - Statistical distributions instead of constant scales?
- Handle sub-communicators and tightly-coupled MPMD apps
  - Two-stage pattern recognition (identify subcommunicators then original search)?
- Handle apps that re-number ranks
- Explore alternative approaches
  - Optical pattern recognition with machine learning
  - Matrix optimization problem using traditional solver techniques
- Improve recognition performance (parallelization)
- Scalable graph viewer

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Summary

- Developing automated communication pattern recognition to support debugging, optimization, system choice, system design
- Recently augmented automated communication pattern recognition approach to use:
  - Communication graphs augmented with information about collectives
  - Aggressive search space pruning
- Exploring alternatives: using statistical distributions, machine learning, optical pattern recognition, parallelization
- Publications
  - P.C. Roth, J.S. Meredith, J.S. Vetter, “Automated Characterization of Parallel Application Communication Patterns,” HPDC’15
  - P.C. Roth, “Improved Accuracy for Automated Communication Pattern Characterization Using Communication Graphs and Aggressive Search Space Pruning,” ESPT’17. Published as LNCS 11027 (to appear)

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