A Cleanup Algorithm for Implementing Storage Constraints in Scientific Workflow Executions

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Problem

- Data-intensive workflow
- Disk space is limited (storage constraint)
  - Machines may not have enough disk space
  - Quotas may impose caps on disk usage
  - Want to reduce or limit use of resources
- Need to remove data as workflow is running in order to free enough space to finish the workflow
- It may not be possible to execute the workflow
  - Identifying the minimum storage required is hard
  - But we can compute some bounds

Assumptions

- Storage constraint is given
- Workflow is modeled as a DAG
  - Nodes: Tasks
  - Edges: Data flow dependencies
- Input/output files for each task are known
- Size of each file is known
  - Or at least a reasonable estimate

Previous Solutions

- Manual dependencies and cleanup tasks
  - Forces a certain ordering of tasks that results in smaller footprint
  - Cleanup removes data
- Partitioning
  - Split up tasks across several sites based on available storage
  - Does not work for a single site
  - Does not work if total available storage < workflow size
  - Transfers may cause performance problems (can be minimized)
- Cleanup task algorithms
  - Add tasks to the workflow that remove data when it is not needed
  - One task for each file – Generates lots of cleanup tasks
  - Clustering – Still may cleanup tasks (1 per task)

Problems with Previous Solutions

- Typically require development of a data-aware scheduler
  - May not be feasible on some infrastructures
- Online solutions can result in deadlock
  - Backtracking required to resolve the problem
  - Particularly problematic if no solution is possible
- Cleanup approaches can hurt performance
  - Often result in too many cleanup tasks
  - Can increase workflow makespan
- Many don’t provide any guarantees about disk usage

Goals

- Provide some guarantee about storage used by workflow
  - No deadlocks (if solution found and estimates are accurate)
- No modifications to scheduler
  - Only requires DAG engine
- Minimize impact on performance
  - Few cleanup tasks
  - Reduce bottlenecks

Approach

- Storage-Constrained Cleanup Algorithm
- Adds cleanup tasks to the workflow at planning time
- Cleanup tasks added only when and where they are needed
- Makes non-cleanup tasks depend on cleanup tasks in order to ensure that space is available at each step of the workflow

Storage-Constrained Cleanup Algorithm

1. Choose a ready task to schedule

2. If space is available: run the task

3. If enough space can be cleaned up to let the task run:
   - 3.1 Create one or more cleanup tasks to remove all of the eligible files
   - 3.2 Make queued jobs depend on cleanup tasks
   - 3.3 Make cleanup tasks depend on tasks that use cleaned up files
   - 3.4 Mark task as finished, queue additional tasks

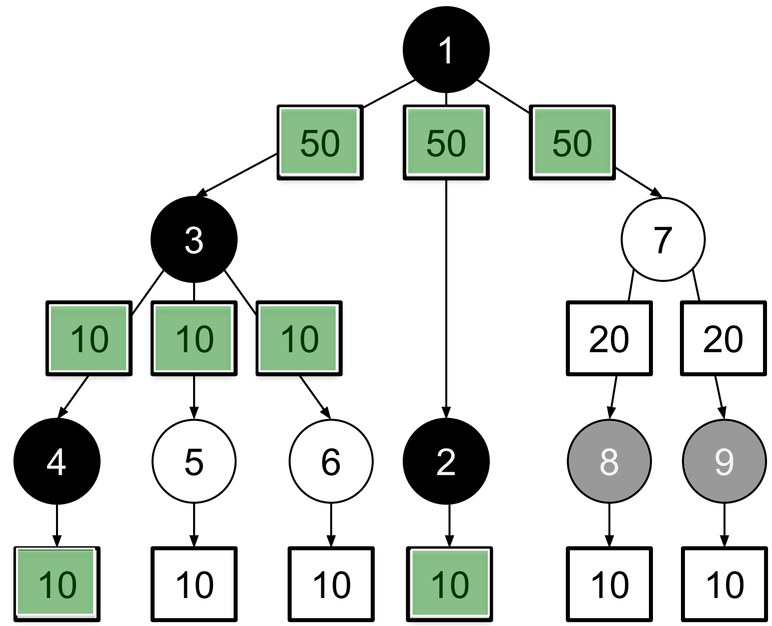
4. If no more data can be cleaned up:
   - *4.1 Report failure*

5. If more ready tasks: goto 1

6. Add leaf cleanup task, return updated DAG

Example

- **Storage limit set to 200 units**
- **Algorithm proceeds until there is insufficient disk space to run the next task**

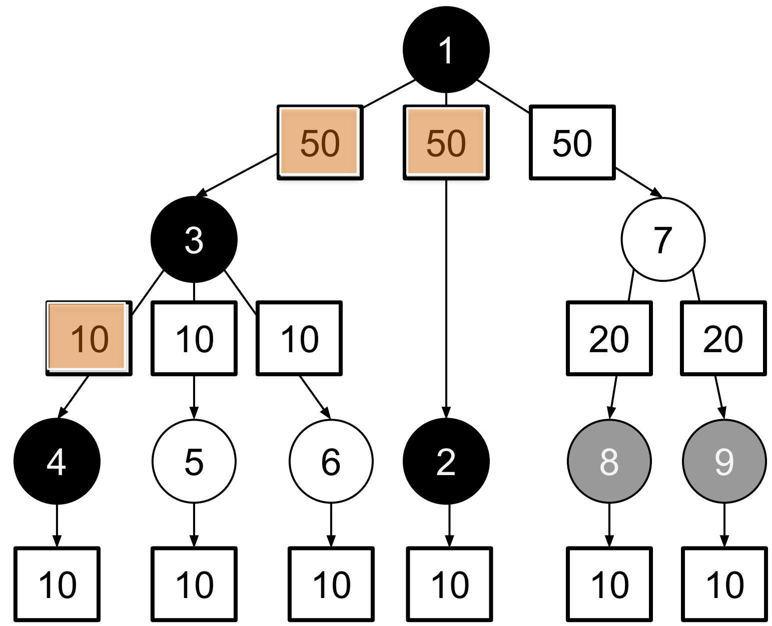


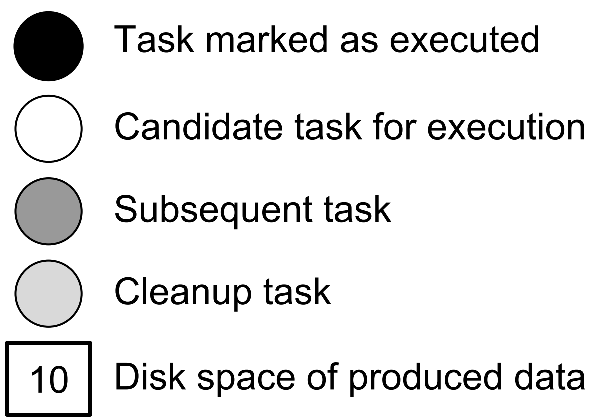
- Task marked as executed
- Candidate task for execution
- Subsequent task
- Cleanup task
- 10 Disk space of produced data

200 units are used

Example

- Storage limit set to 200 units
- Algorithm proceeds until there is insufficient disk space to run the next task

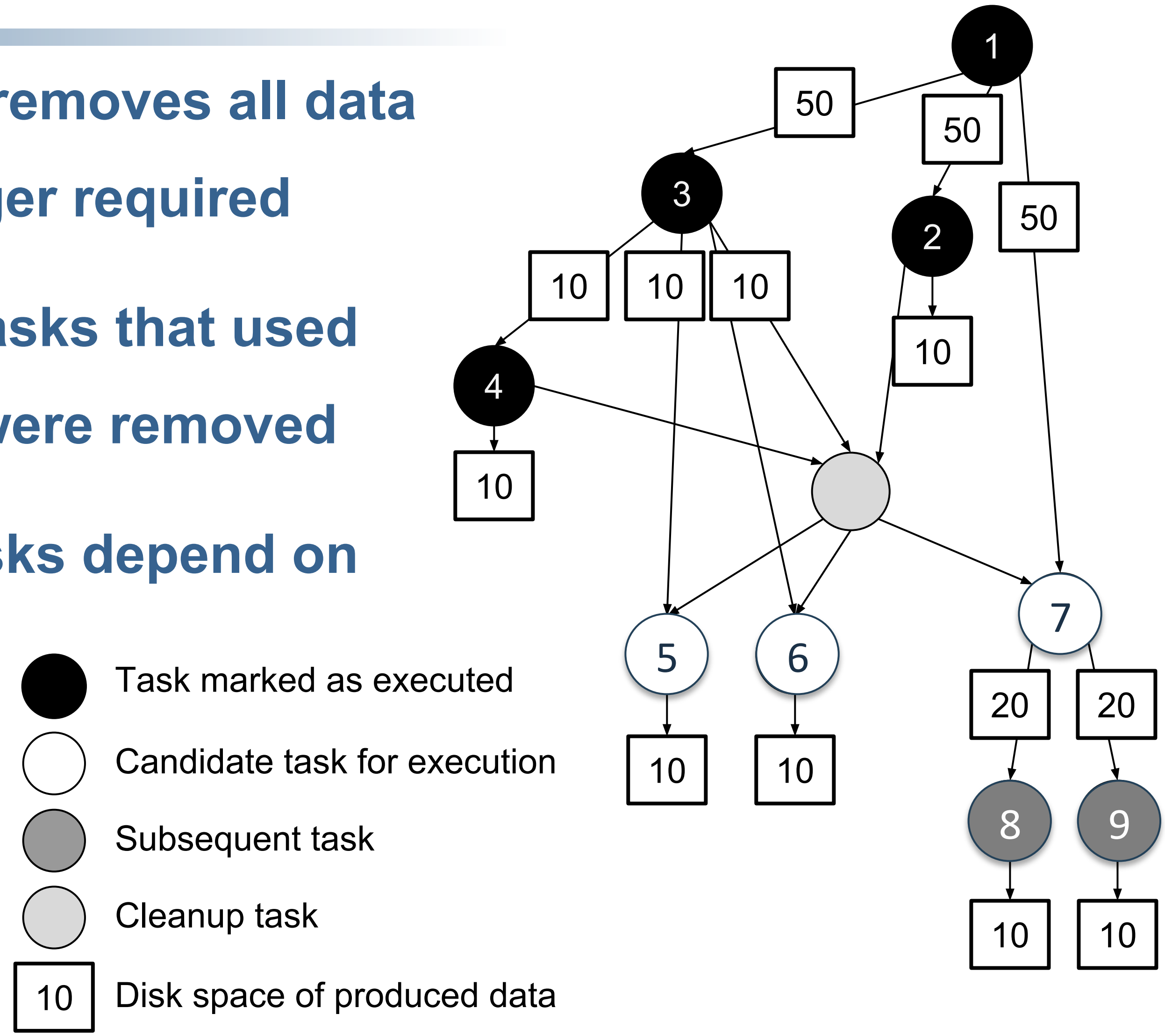




110 units can be removed

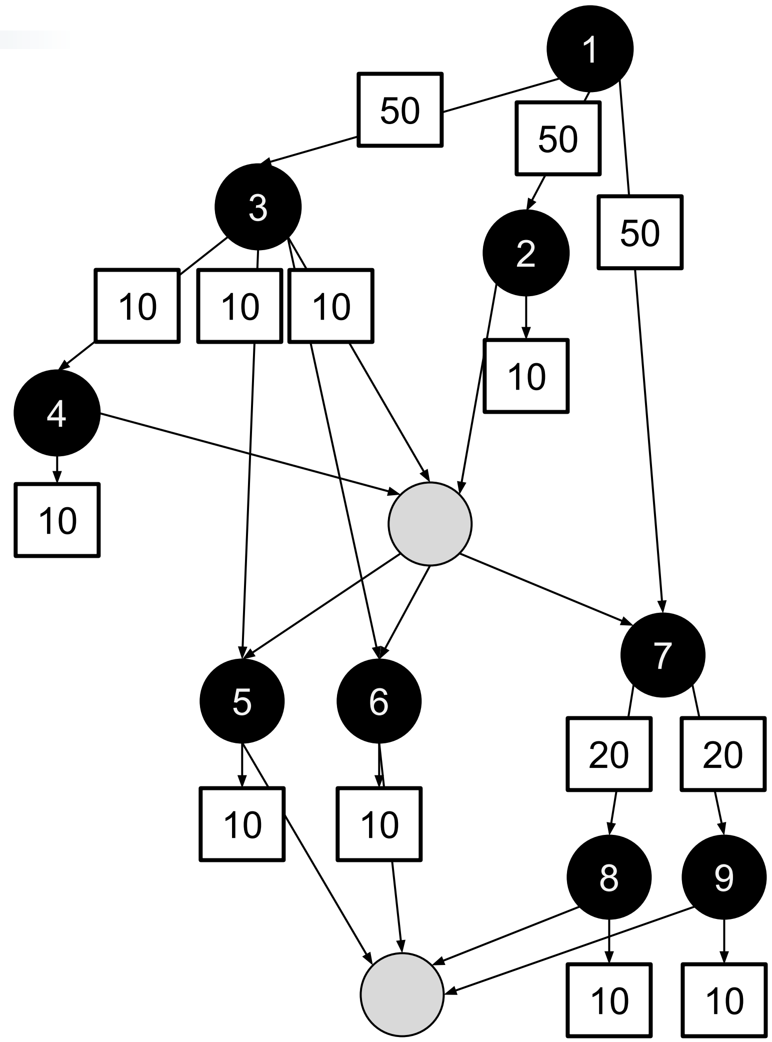
Example

- Cleanup task removes all data that is no longer required
- Depends on tasks that used the files that were removed
- All queued tasks depend on cleanup task



Example

- **A final cleanup task is inserted to ensure that all intermediate data is removed**



Task marked as executed

Candidate task for execution

Subsequent task

Cleanup task

10 Disk space of produced data

Heuristics for selecting a task (Step 1)

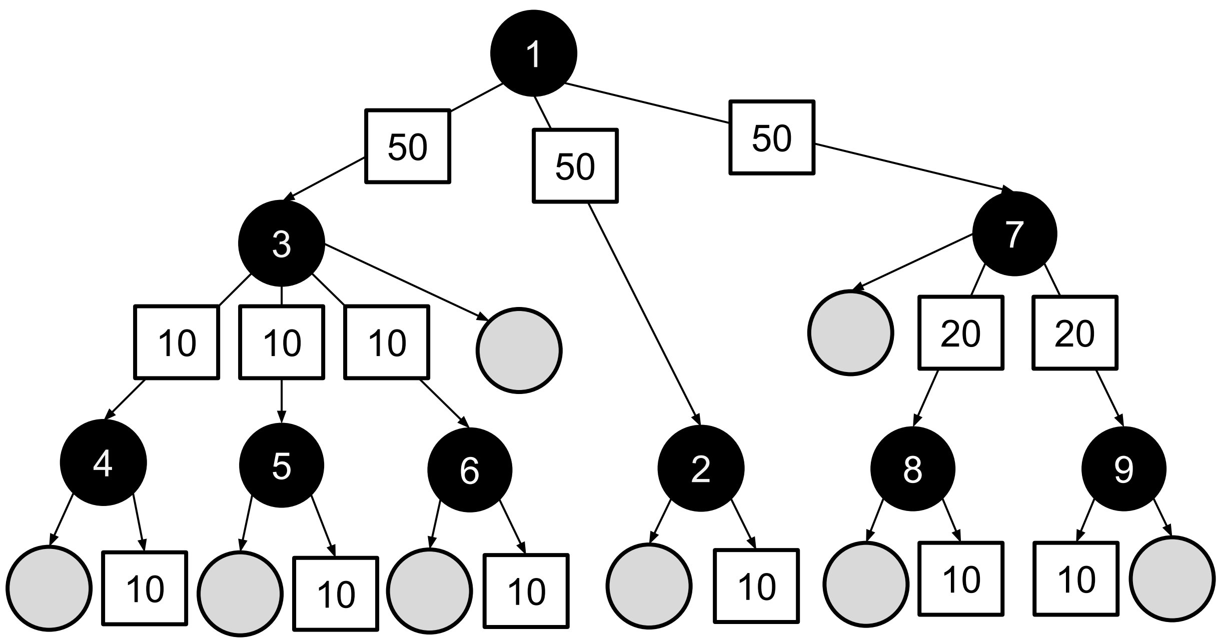
- **Max Freed**
  - Select the task that maximizes the amount of data that can be cleaned up
- **Min Required**
  - Select the task that requires the least amount of storage space (smallest output) – Make more progress before cleanup
- **Max Required**
  - Select the task that requires the largest amount of storage space (largest output) – Most difficult to accommodate
- **Balance Factor**
  - Select task with largest "balance factor" – Difference between space freed, and space required

Heuristics for creating cleanup tasks (Step 3.1)

- Single Task
  - Create one cleanup task to remove all of the files
- Queued Tasks
  - Create one cleanup task for each queued task
- Random Tasks
  - Adds a random number between 1 and the number of queued tasks
- Resources Tasks
  - Adds cleanup tasks up to the number of resources
- Note:
  - Not more than than the number of files being removed

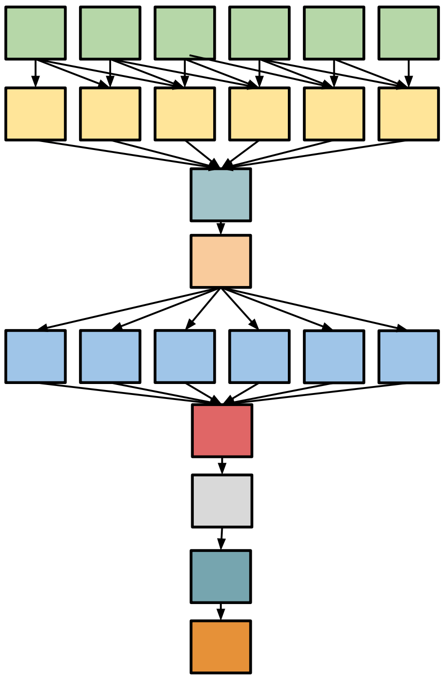
Evaluation – Alternative algorithm

- Compare proposed algorithm with algorithm by Singh, et al.
- Singh's algorithm is the default cleanup algorithm in Pegasus

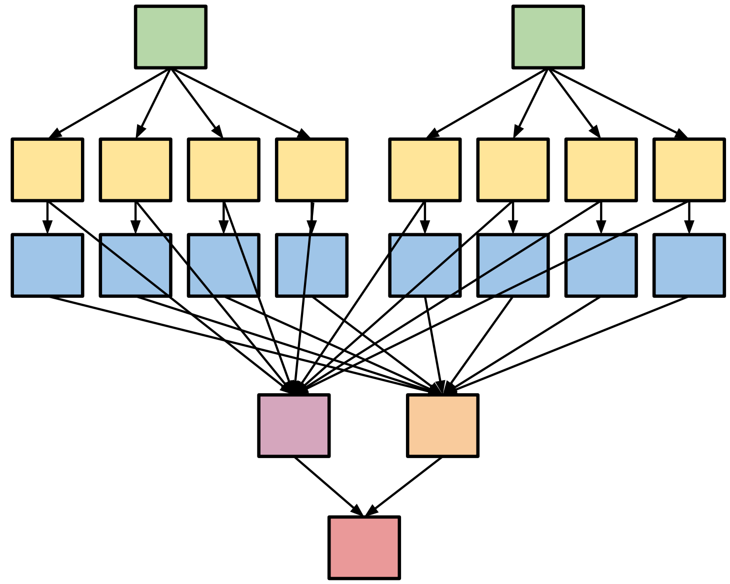


DAG generated by Singh's algorithm

Evaluation – Applications



Montage



CyberShake

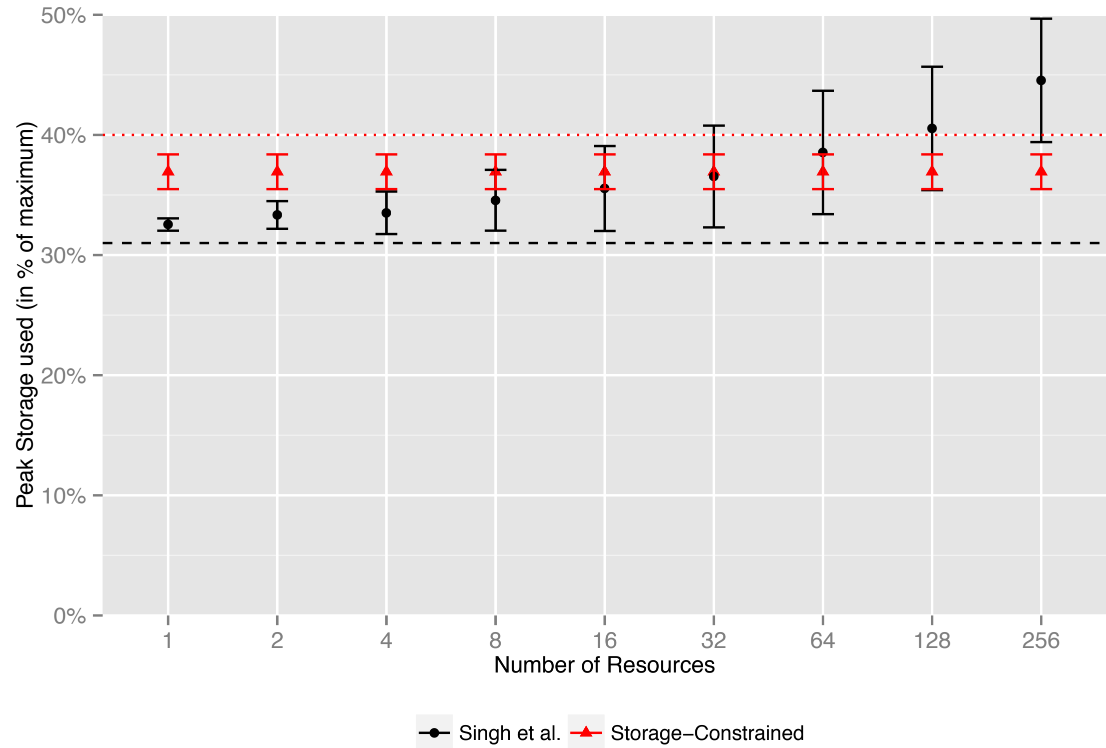
- Generated synthetic workflows based on real application
- Most experiments used workflows with 1000 tasks

Evaluation – Simulator

- Simulator based on CloudSim framework
- Parameterized with values from a previous paper on workflow overheads, and some experiments
- Priority based scheduling with randomization
- 100 simulation runs for most data points

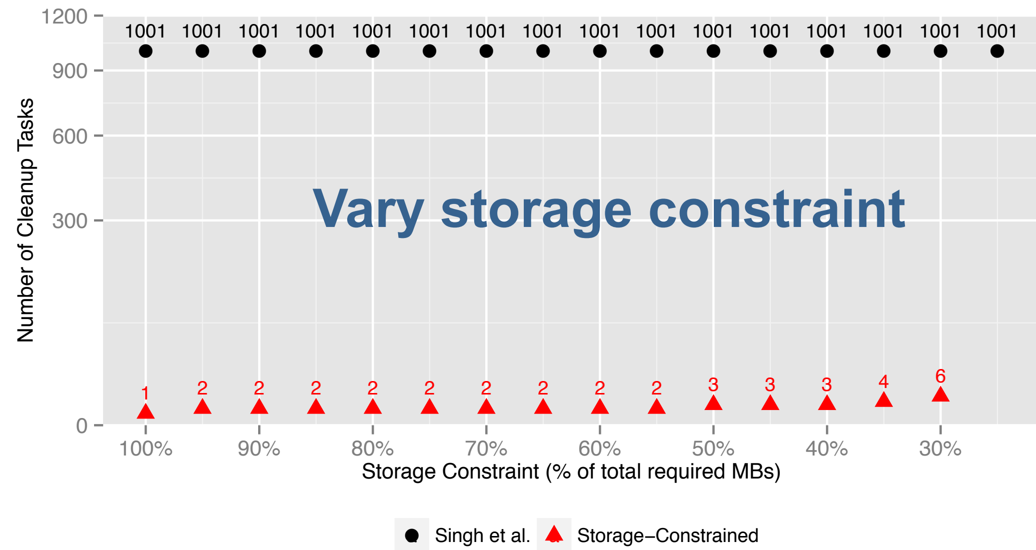
Experiment 1 – Ability to meet storage constraint

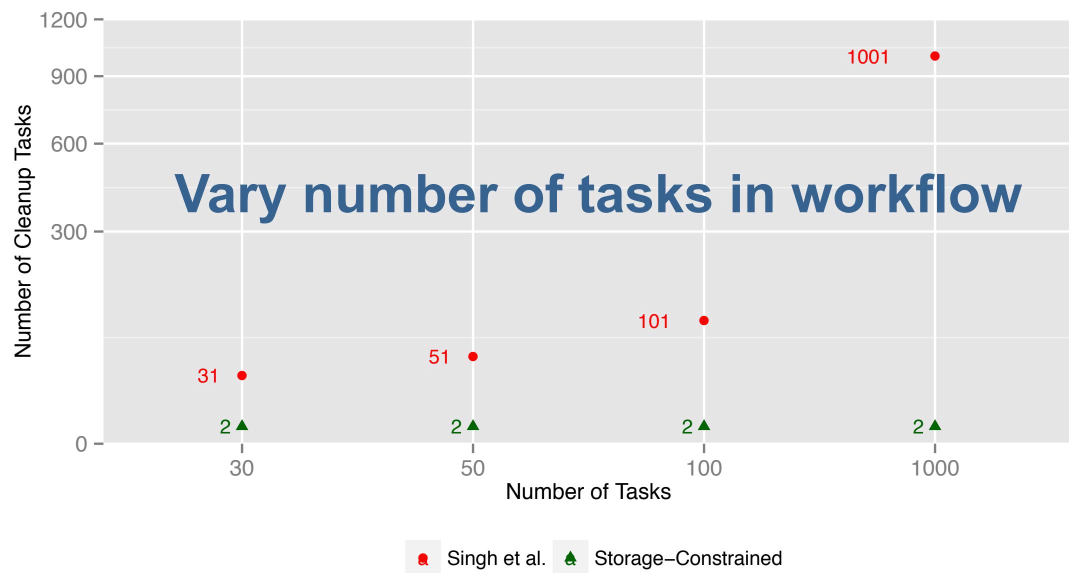
- Cleanup tasks are prioritized
- Constraint set to 40% of maximum storage
- Montage results (CS is similar)
- New algorithm doesn't exceed constraint. Existing algorithm is ok on fewer resources.



Experiment 2 – Number of cleanup tasks

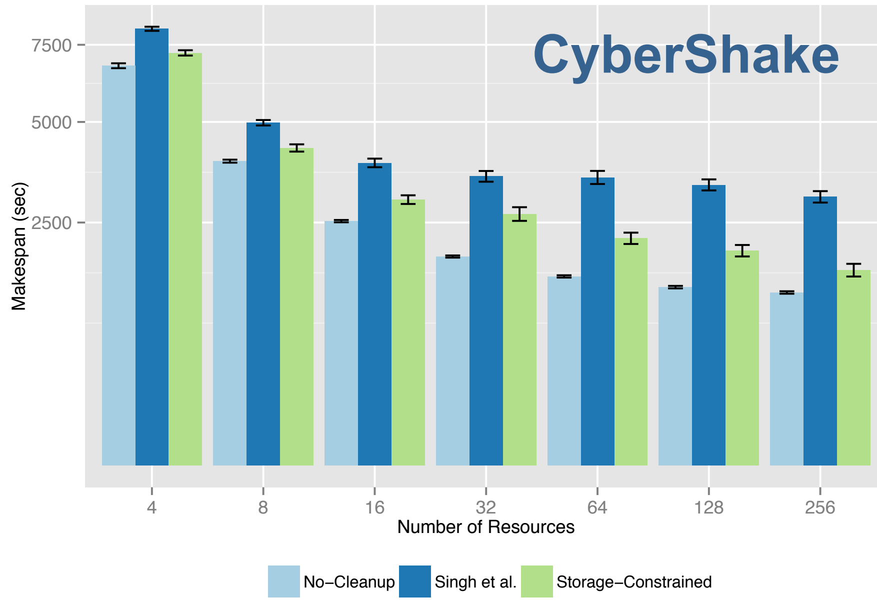
- **Compare the number of cleanup tasks generated by both algorithms**
- **CyberShake results (Montage is similar)**
- **New algorithm generated far fewer cleanup jobs**

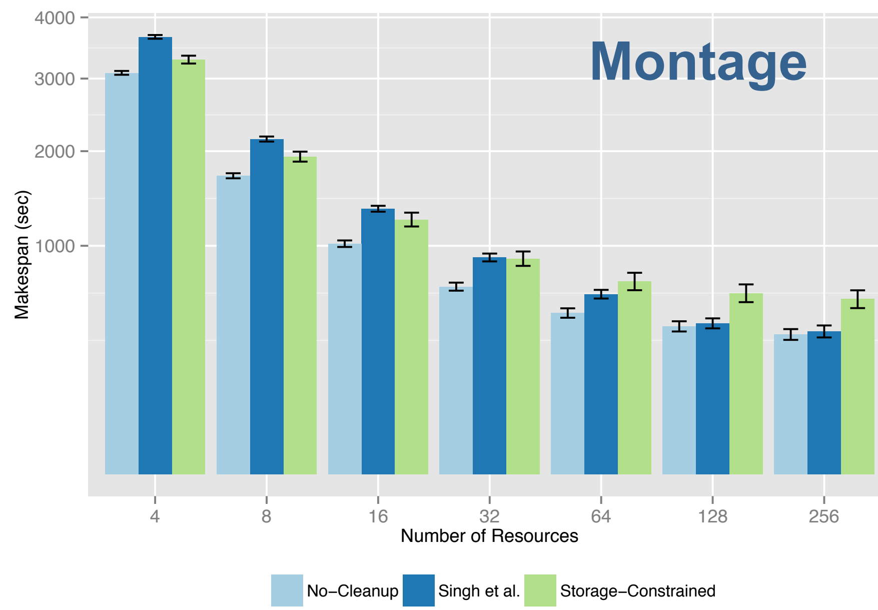




Experiment 3 – Effect of cleanup on makespan

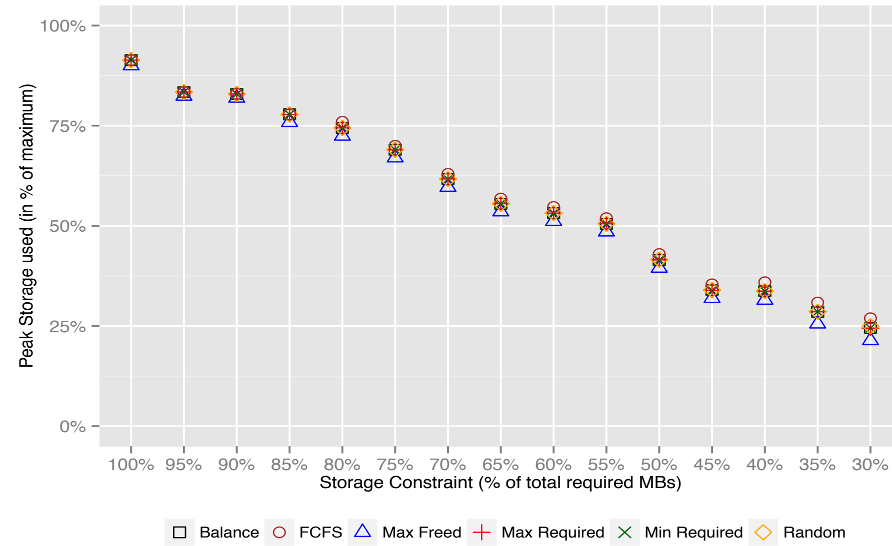
- Vary the number of resources
- Storage constraint set to 75% of total workflow size
- New algorithm is much better for CyberShake, mixed results for Montage

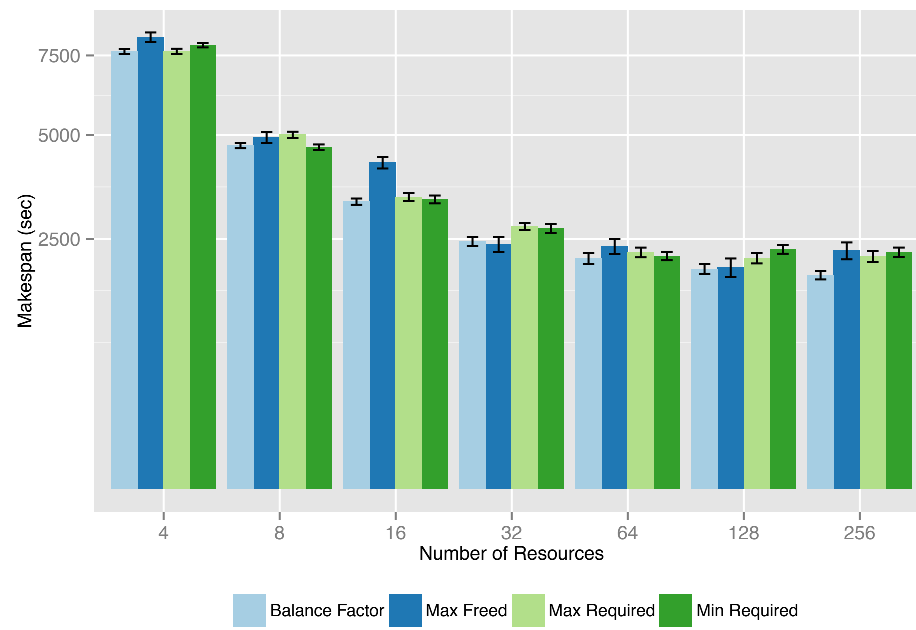




Experiment 4 – Heuristics for task selection

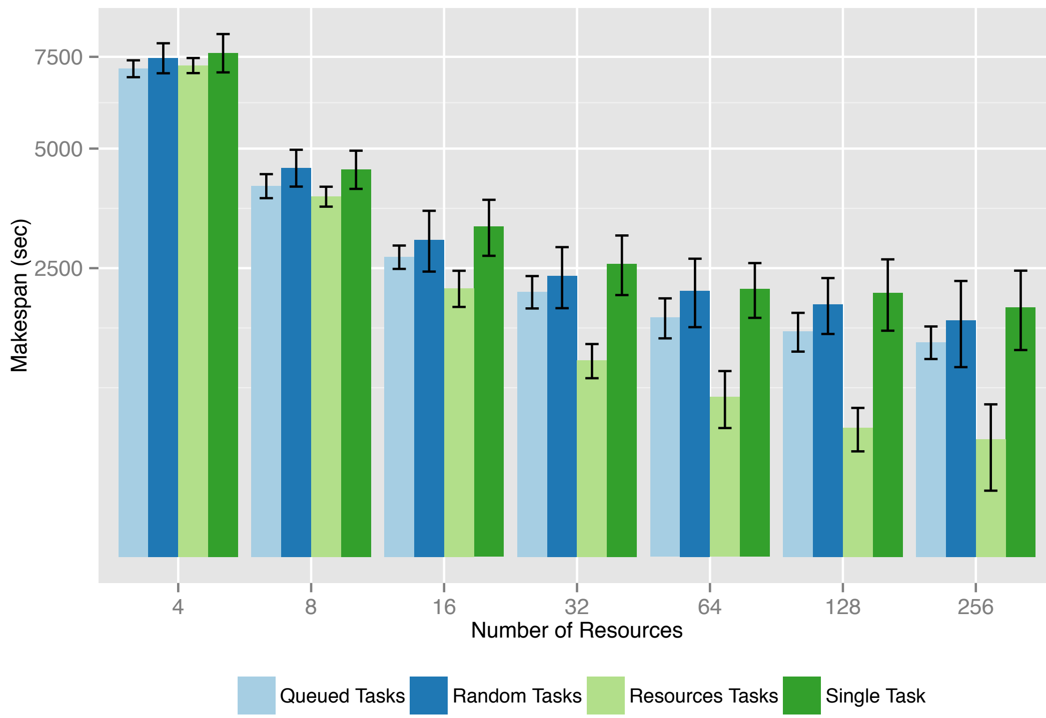
- **CyberShake results (Montage is similar)**
- **Not much effect on peak storage, but Max Freed is as you would expect**
- **For makespan, balance factor is usually better**





Experiment 5 – Heuristics for no. of cleanup tasks

- **30% storage constraint**
- **CyberShake results (Montage difference is relatively insignificant)**
- **Heuristic based on number of resources is best**



Conclusion

- Proposed a new algorithm for storage constrained workflows that:
  - Does not require a data-aware scheduler
  - Provides more guarantees about storage space used
  - Generates far fewer cleanup jobs that existing approaches
  - Often results in smaller makespan than existing cleanup approaches (depends on application)
- Future work
  - What if size estimates are wrong?
  - Handling workflows executed on multiple sites
  - Enhancements to reduce dependencies and improve parallelism