Characterizing the Performance of Analytics Workloads on the Cray XC40

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Agenda

- **Last year at CUG: Showed how to run common open source analytics frameworks on XC systems**
- **Today: How do we understand, monitor, tune performance on XC40?**
  - Focus on Apache Spark framework – more flexibility, better performace, increasing adoption relative to Hadoop
    - SyncSort Survey: 70% Spark interest vs 55% Hadoop.
- **Look at a couple use cases/techniques, plus a networking analysis**
  - Bottom-up: mining system metrics data from HiBench with `collectl`
  - Top down: application log analysis of CX matrix decompostion in Spark
  - TCP networking performance on XC
- **In the paper: additional details, plus suggested optimizations**

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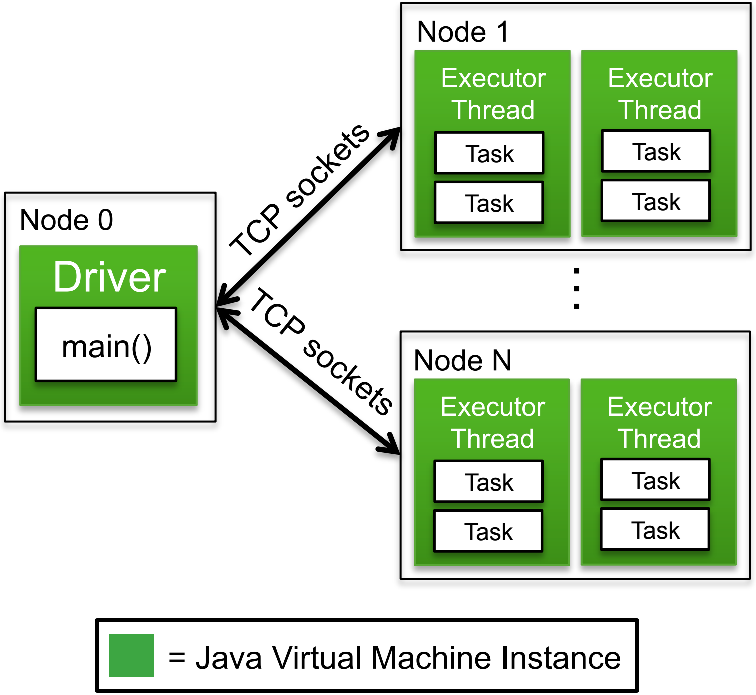
Spark Background: Execution Model

- **Driver is the "master": execute main, distribute work , collect results**
- **Executors are the "workers": execute parallel work across partitions of the data**
- **Computations lazily evaluated – nothing happens until result required at driver:**

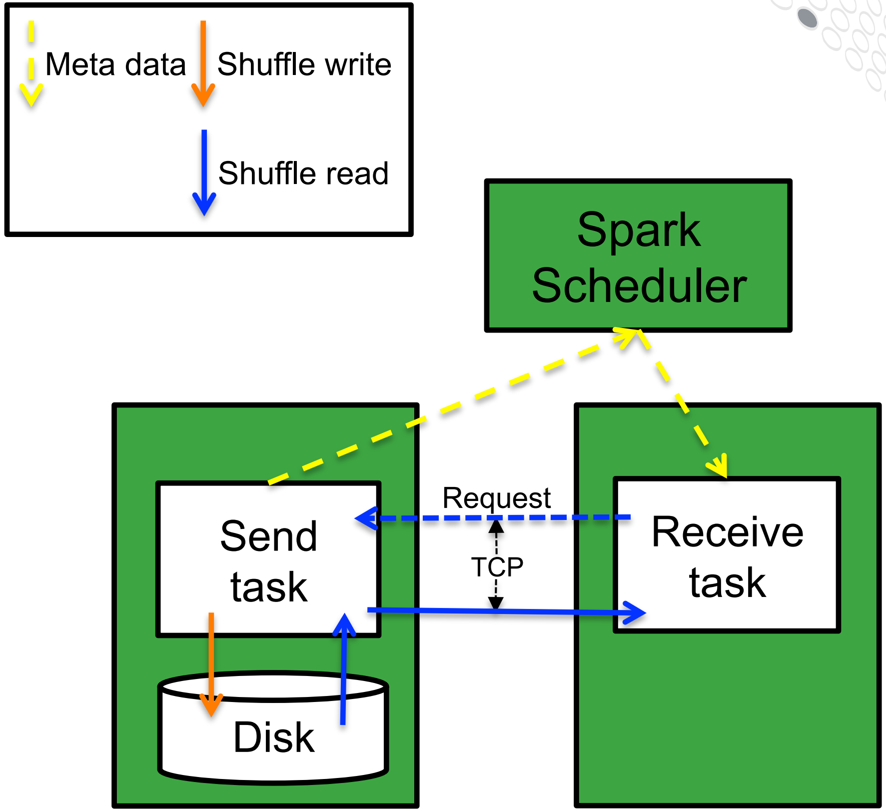
```
val lens = file.map(l => (l.length,l))
val sorted = lens.sortByKey()
sorted.collect()  // execution starts HERE
```

- **Jobs, Stages, and Tasks:**
  - Job: Computation that returns a result to driver
  - Stage: Unit of work that can be executed without communication. Jobs with internode communication requirements have multiple stages.
  - Between job stages: barrier, global all-to-all shuffle
  - Task: The computation of a stage on a single partition



Spark Background: Shuffle

- **Communication between executors implemented via *shuffles***
  - Senders send data to block managers; block managers write to disks, tell scheduler how much destined for each receiver
  - Barrier until all senders complete shuffle writes
  - Receivers request data; block managers read and send



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Shuffle on the XC40

- **Spark assumes distributed cluster, with local persistent storage on each node for shuffle files (also for spilling RDDs).**
- **Not present on XC systems. Options:**
  - Global Lustre file system: Many small files, and file opens/closes = high metadata overheads that dominate performance of shuffles.
  - DRAM-based tmpfs: Much faster, but storage limited to 50% of memory on node. Works for many workloads, but can run into memory bottlenecks.
  - Hybrid: Use both. Better performance than pure Lustre.
  - Loopback filesystems (see earlier presentation in Session 7A): Each node create a filesystem within a single Lustre file. Managed locally. Eliminates MDS overheads, coherency issues.

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Our Analysis Approaches

- **Collectl**
  - Commonly used for collecting compute node system metrics for HPC jobs
  - Used a 1 second sampling rate
    - Negligible overheads next to overheads of analytics frameworks – found to have no impact on completion time of our workloads
    - Accurate: tested by comparing aggregated Lustre metrics with input and output data set sizes, saw less than 1% variation
  - Used R+pdbMPI to analyze, plot results
- **Spark event logs**
  - Track start and end times of jobs, tasks, stages
  - Collect application level metrics for each task (GC time, serialization time, shuffle read/write, etc)
  - Can view in Spark History Server, or parse with scripts
- **TCP network performance analysis with iperf3, tcpdump**

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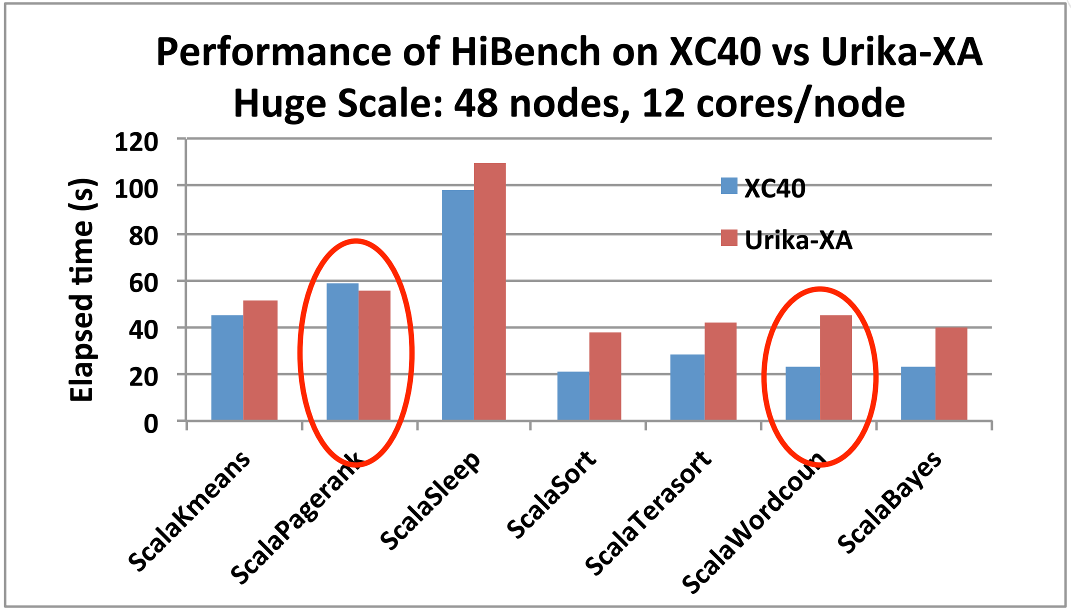
Case Study 1: HiBench Analysis

- **Intel HiBench**
  - Originally MapReduce, Spark added in version 4
  - We selected common Spark workloads without Hive dependencies
- **Compared performance with Urika XA system**
  - XA: FDR Infiniband, XC40: Aries
  - Both: 32 core Haswell nodes
  - XA: 128 GB/node, XC40: 256 GB/node (problems fit in memory on both)
- **Similar performace on Kmeans, PageRank, Sleep**
- **XC40 faster Sort, TeraSort, Wordcount, Bayes**
- **Let's examine…**



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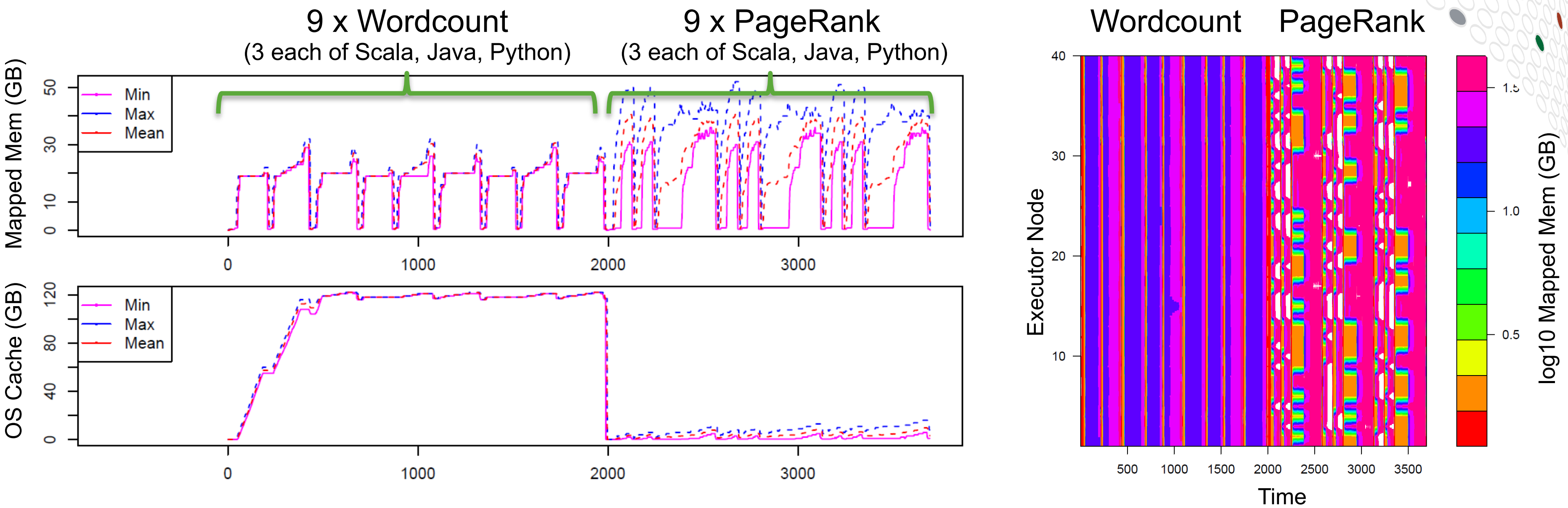
Collectl: Examining Memory Usage



- **PageRank much larger variation between executors in memory usage**
  - Points to variation in data set/# links per page
- **Wordcount much higher OS file cache usage**
  - Spark uses file system for spills and shuffle data

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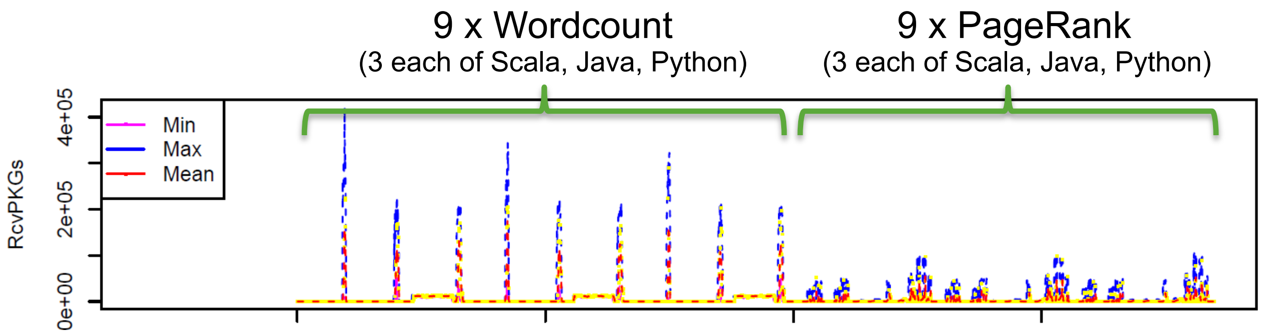
Collectl Example: Understanding Memory Usage



- **Examing TCP traffic points to reason for larger OS cache usage: Larger shuffles**
- **Variability of PageRank indicates bottleneck due to stragglers/imbalance**
- **Wordcount has larger shuffles, and much less variability, indicating potential bottleneck in data movement**
  - Takes better advantage of interconnect

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Benefits of Collectl-Based Profiling

- **Spark event log/history server can't give this level of detail**
  - Only shows static size of persisted RDDs/DataFrames
  - Only shows application memory usage (no OS)
  - Only shows total shuffle traffic per stage
  - Etc…
- **Collectl-based analysis allows you to view all system metrics, and how they change over time**

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Case Study 2: CX for MSI

- **CX matrix decomposition applied to mass spectrometry data from bioimaging (Spark implementation from NERSC and AMPLab)**
  - Analysis of 1 TB Mass Spectrometry (MSI) dataset
    - Matrix with columns for each spatial location
  - Method: dimensionality reductions via CX factorization
    - Approximately factors *m x n* matrix A into *m x k* matrix C *and k x n* matrix X, where the *k* columns of C are drawn from A. The "rank" k is typically much less than n
    - Goal is to select the *k* columns of A such that CX is as close as possible to A.
    - These columns best "explain" the data in the matrix
- **These types of matrix decomposition operations are also common in Machine Learning applications**

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Comparison Platforms

Platform	Total Cores (Haswell)	Core Frequency	Interconnect	DRAM	SSDs/ node
Amazon EC2 `r3.8xlarge`	960 (30 nodes x 32 per-node)	2.5 GHz	10 Gigabit Ethernet	256 GB	2 x 320 GB
Cray XC40	960 (30 nodes x 32 per-node)	2.3 GHz	Aries	256 GB	None
Athena early prototype	960 (40 nodes x 24 per-node)	2.5 GHx	Aries	128 GB	1 x 800 GB

Platform	Total Runtime
Amazon EC2	24.0 min
XC40 w/ tmpfs & Lustre	23.1 min
XC40 w/ tmpfs	18.1 min
Athena early prototype	15.2 min

- **Two options for XC40 scratch space: DRAM tmpfs, or tmpfs & Lustre blend**

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Performance Analysis via Event Logs

Platform	Total Runtime	Load Time	Time per iteration	Average Local Task	Average Aggregation Task	Average Network Wait
Amazon EC2	24.0 min	**92 sec**	161 sec	4.4 sec	**27.1 sec**	**21.7 sec**
Cray XC40 w/ tmpfs & Lustre	23.1 min	**139 sec**	125 sec	3.5 sec (max: 12!)	**6.8 sec**	**1.1 sec**
Cray XC40 w/ tmpfs	18.1 min	**137 sec**	94 sec	3.0 sec	**7.3 sec**	**1.5 sec**
Athena prototype	15.2 min	**53 sec**	92 sec	2.8 sec	**9.9 sec**	**2.7 sec**

- **Workload:** Load MSI dataset; 5 iterations, each with local stage (compute local sums) and aggregation stage
- **Observations:**
  - Load times faster on machines with local SSD storage
  - Aggregation stage tasks (shuffle read) much faster on Aries-based systems
  - Network wait on XC40 was lower than Athena, due to better peak TCP bandwidth
  - All tmpfs, or fast local SSDs sped up local task time (shuffle write)
  - Mixing Lustre and tmpfs adds long tail to shuffle write time distribution, creating stragglers that slow iterations

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Advantages of Log Analysis

- **Application level view**
  - What tasks are bottlenecks
  - Where applications are spending their time (e.g., garbage collection, serialization, compression, waiting at barriers, etc)
- **Tools integrated with the Spark/Hadoop/etc ecosystem**
  - WebUI
  - Visualizations that have application-level information (stages, operations, etc)
  - User familiarity

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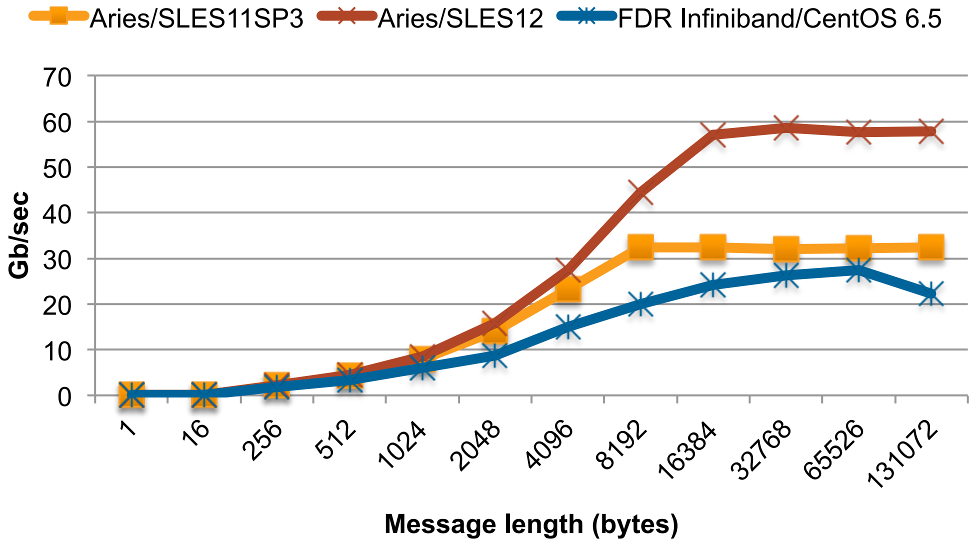
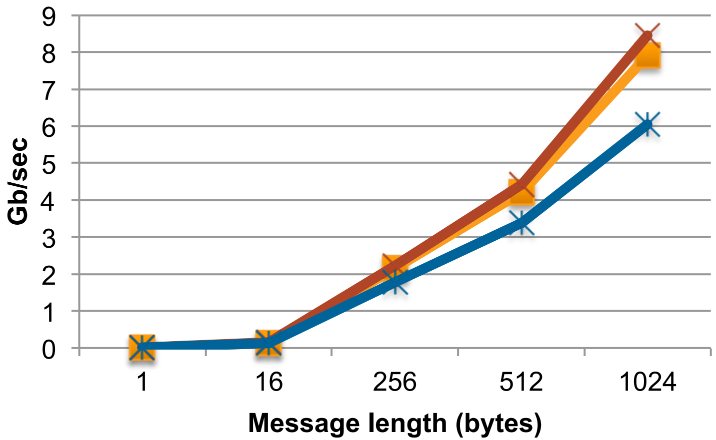
Analysis of TCP Bandwidth w/ iperf3





- **Communication in open source analytics frameworks is typically over TCP (for portability)**
- **Aries performs well, especially with new kernel. Peak performance hit at ~ 8K-16K.**

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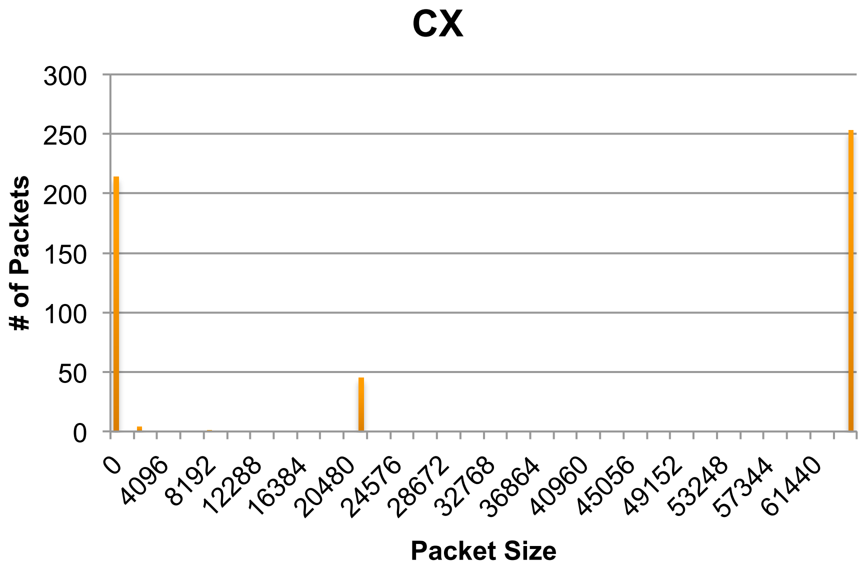
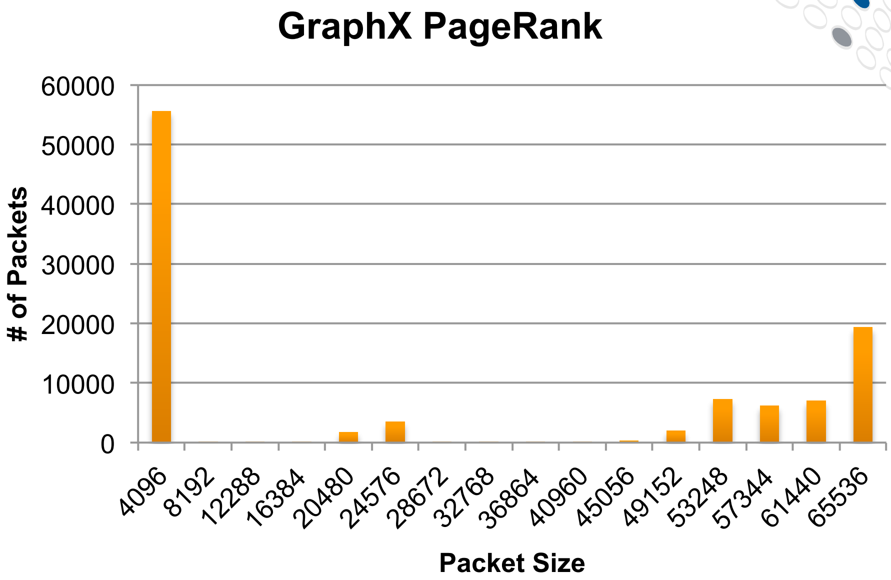
TCP Packet Size Distribution





- **Picked two shuffle senstive applications – CX and GraphX PageRank**
  - CX is more uniform (sending matrix columns) than PageRank (variable sized edge lists)
  - Both have a number of large data packets
    - CX: 58% at least 21KB
    - PageRank: 46% at least 16KB

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Summary

- **Described multiple approaches to understand analytics framework performance on XC40**
  - System metrics data from `collectl`
  - Application log analysis
  - Network performance (TCP)
- **Looked at two benchmarks**
  - HiBench suite
  - CX (NERSC implementation)
- **Paper discusses performance improvement possibilities**

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Q&A

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