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GEORGETOWN UNIVERSITY

Using Computational Storage Devices: OpenMP/MPI and Charliecloud

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Introducing Computational Storage Devices (CSDs)

- Computational Storage → Near-data processing
- Runs software where data resides
- Potential performance improvement
    - Offload tasks from host

Moving On From Previous Experiments

- Originally used Spark and HadoopFS
- Collected interesting results, but this method had its issues
  - Slow
  - Limited Application
  - Too much overhead from Spark abstraction
- Solution? Rewrite our benchmarks without Spark:
  - Serial Python
  - Serial & Parallel C++ (Combinations of OpenMP & OpenMPI)

Why Serial Python?

Able to test on single core with no overhead.

Compare efficiency of different solutions.

- Implementations:
  - SparkDF & SparkSQL → Pandas (dataframes) & Numpy (matrices)
  - Natively written functions (no libraries)
  - Dataframes → Lists

Experiment Results: Running on One CSD

Function	100 MB (s)	200 MB (s)	500 MB (s)	1 GB (s)	5 GB (s)
Count Lines	5.4598 e -5	5.3644 e -5	5.4836 e -5	5.4836 e -5	N/A
Sum of Column	0.1135	0.2281	0.5687	1.2115	N/A
Mean of Column	3.5763 e -5	3.5048 e -5	3.5048 e -5	4.0054 e -5	N/A
Grammarian Matrix: AT*A	17.9477	35.6603	89.483	190.936	N/A
Normalize Column	5.3809	10.6566	25.6559	55.5248	N/A
Compute Mean	0.1138	0.2273	0.5676	1.2162	N/A
Compute Std Dev	3.6919	7.173	17.9616	38.0247	N/A
Count Digits	6.668	6.4407	16.0995	34.4509	N/A
Measure Shannon Entropy	343.624	650.1484	1699.7029	3576.3302	N/A
Total Elapsed Time	6.8031 Minutes	13.1948 Minutes	34.1343 Minutes	71.9462 Minutes	N/A

Where to Go From Python?

Python’s Shortcomings

- Running in “parallel” is less than ideal in native Python

Using Python’s Multithreading Libraries?

- Typically accelerates one machine
- C++ implementation would be more thorough

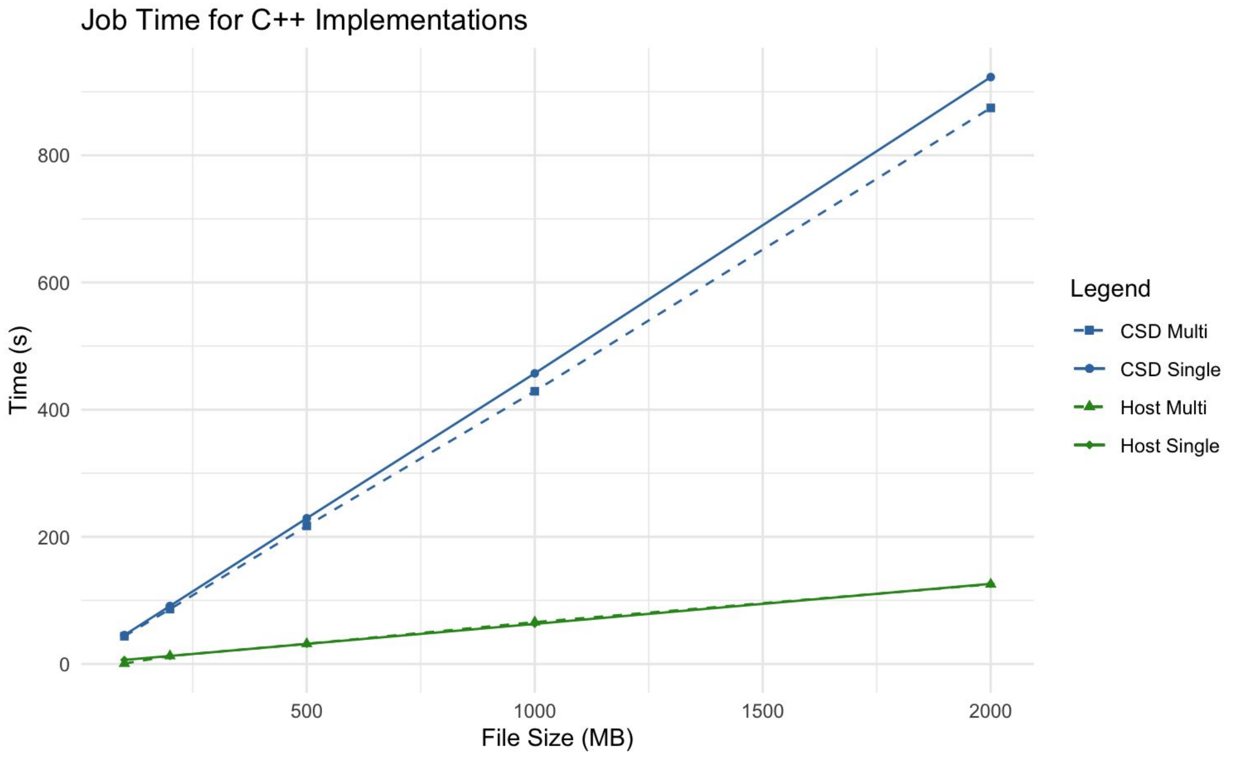
Duplicating Spark Tests in C++

- C++ is "lower level" than Pyspark or basic Python
  - Lets us get a better understanding of CSDs baseline performance
- Basic C++ Implementation is a reimplemented version of our Spark program, with a single-threaded and a multi-threaded version using OpenMP

```cpp
// get sum of normalizedVector
auto sumNormVectTimeStart = std::chrono::high_resolution_clock::now();
int normalizedVectorSum = 0;
for (int i = 0; i < normalizedVector.size(); i++)
{
    normalizedVectorSum += normalizedVector[i];
}
auto sumNormVectTimeEnd = std::chrono::high_resolution_clock::now();
std::cout << "Sum of third row normalized is: " << normalizedVectorSum << std::endl;
```

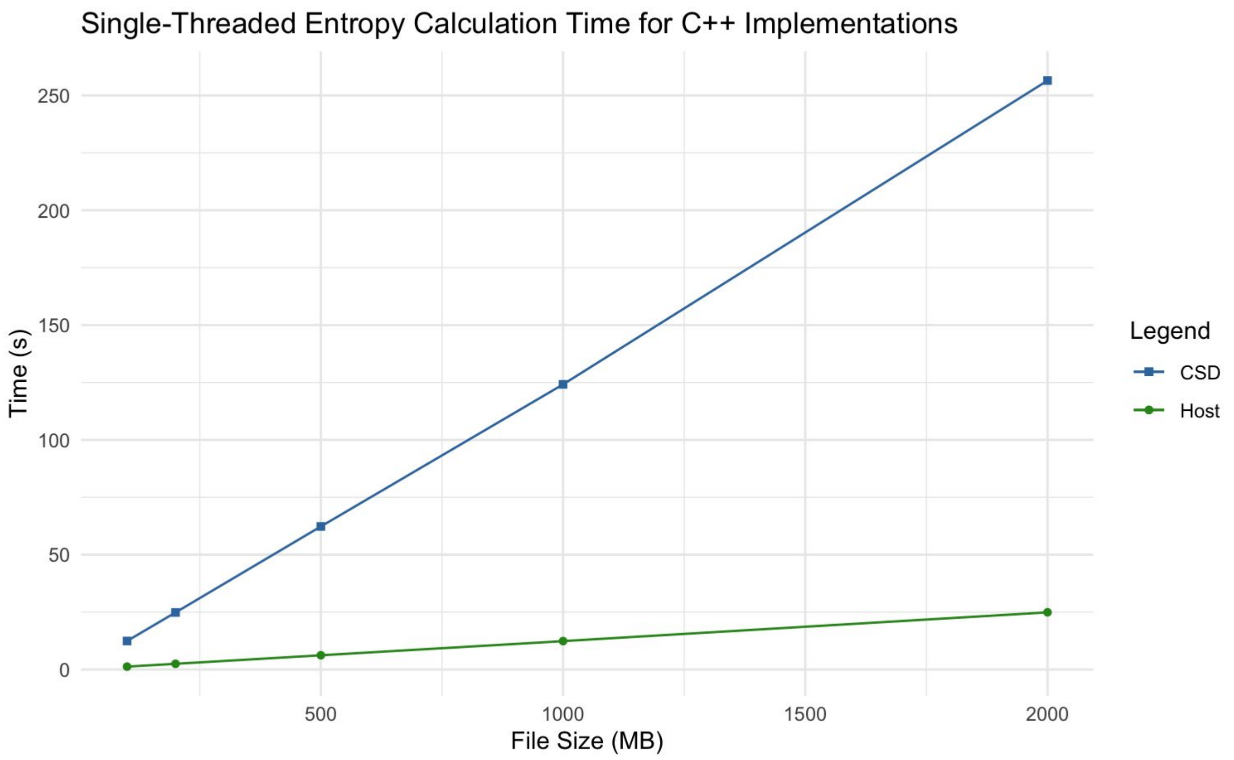
```cpp
// get sum of normalizedVector
auto sumNormVectTimeStart = std::chrono::high_resolution_clock::now();
int normalizedVectorSum = 0;
#pragma omp parallel for
for (int i = 0; i < normalizedVector.size(); i++)
{
    #pragma omp atomic update
    normalizedVectorSum += normalizedVector[i];
}
auto sumNormVectTimeEnd = std::chrono::high_resolution_clock::now();
std::cout << "Sum of third row normalized is: " << normalizedVectorSum << std::endl;
```

Results

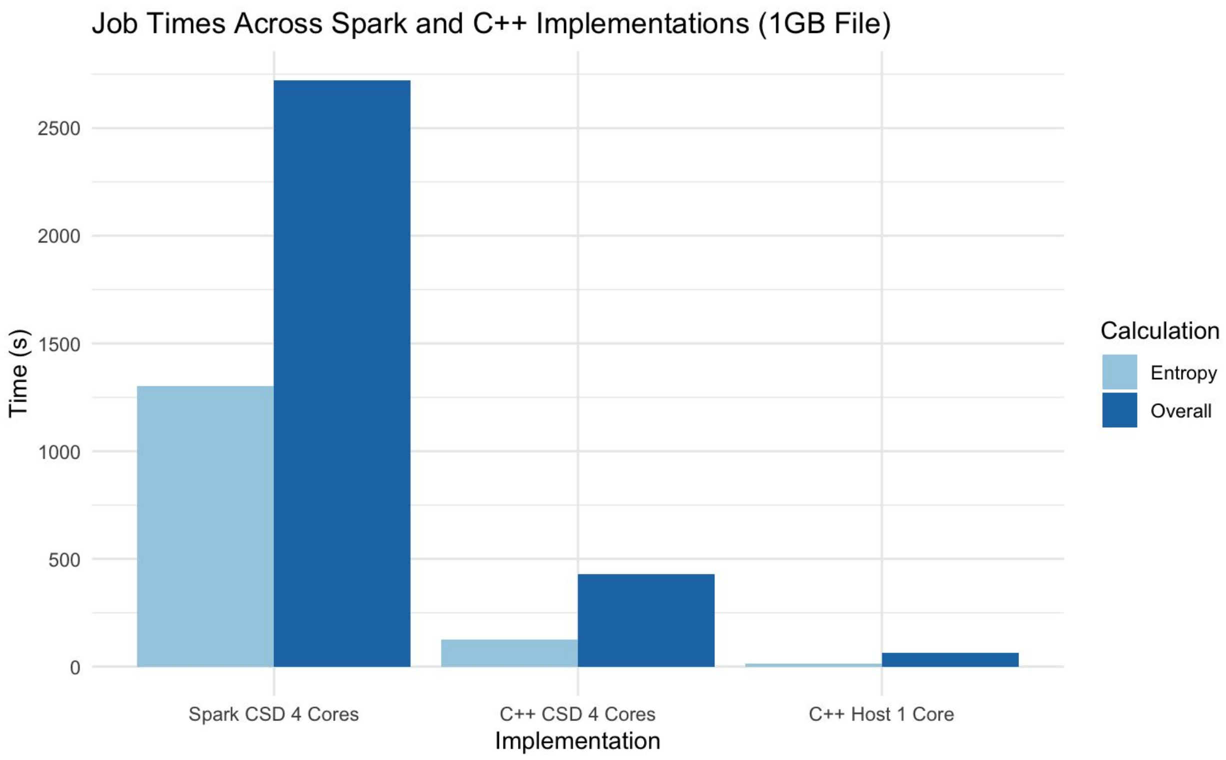


Job Time for C++ Implementations
Time (s)
0
200
400
600
800
500
1000
1500
2000
File Size (MB)
Legend
CSD Multi
CSD Single
Host Multi
Host Single

Results contd.



Results contd.



C++ Conclusions and Thoughts

- Compared to Spark and Python, C++ implementation is *a lot* faster
  - Caveat: an expert with Spark or Python would likely be able to improve the performance of those implementations
- Computational power of our CSDs seem to be much lower than the host machine
  - Using all 4 cores of a single CSD, the job takes ~6.8x longer than using just one core on the host machine.
  - Host also seems to scale better with increasing file size
- Resulting Question: When, if ever, would it make sense to use CSDs for compute rather than a much-faster host?

Host (1.5GHz) and CSDs (1GHz)

Host: 128GB RAM (8GB swap)		**CSD (x8): 5.8 GB RAM**	
Architecture:	x86_64	Architecture:	aarch64
CPU(s):	64	CPU(s):	4
Thread(s) per core:	2	Thread(s) per core:	1
Core(s) per socket:	32	Core(s) per socket:	4
Socket(s):	1	Socket(s):	1

How to Offload Selected Operations?

Disclaimer: Our test was done using host system and 1 csd node (not the full 8 supported). This analysis applies specifically to the operations used in this experiment.

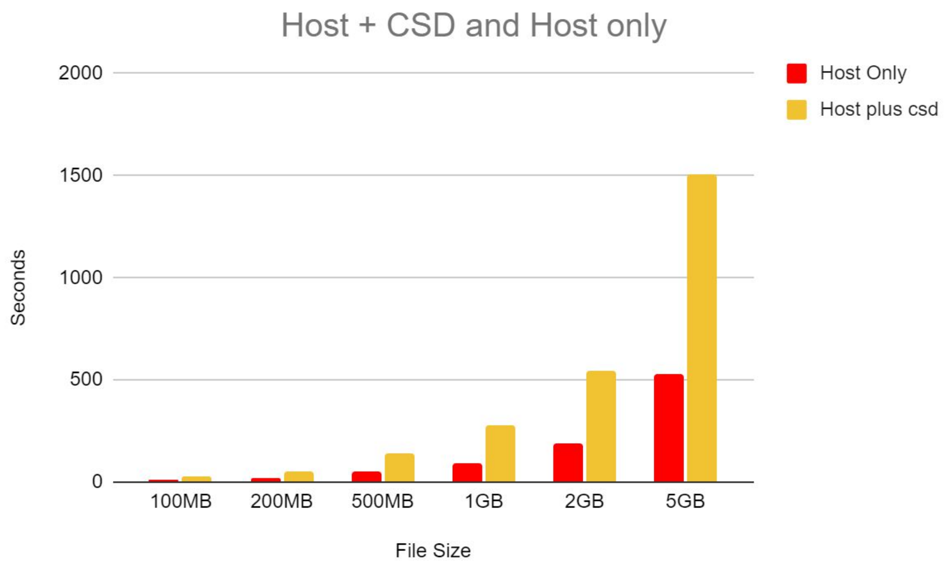
Why use MPI?

Tests: Quickest scalable operations:

- Compute mean (constant time)
- Normalized Compute sum
- Normalized Compute standard deviation
- Normalized Count frequency of digits

When does it make sense to distribute our operations to the CSD? Host and CSD reading in log file

- Tool used: stress-ng --cpu 64 --vm 1 --vm-bytes 95% (stressed RAM and core count)
- Stressed Host tested with mounted CSD storage.
- No Stress CSD tested with mounted CSD storage.



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Can message passing be used to decrease csd vector build time

Issue:

- Most expensive operations for the CSD was to read file and build vector.
- Host completes those operations in 5.86(s)(stressed) 3.91(s)(no stress)
- CSD completes those operations in 23.75(s)

Test:

- 100MB/200MB/500MB/1GB/2GB log file.
- The host reads file from CSD storage and creates vector. Host will then message pass vector to csd.
- See if there is an decrease in overall time for csd to complete its operations.
- Additional parameter for mpirun --mca btl_tcp_if_include flannel.1 (includes interface)

Offloading operations passing vector to CSD

- Tool used: stress-ng --cpu 64 --vm 1 --vm-bytes 95% (stressed RAM and core count)
- Stressed Host tested with mounted CSD storage.
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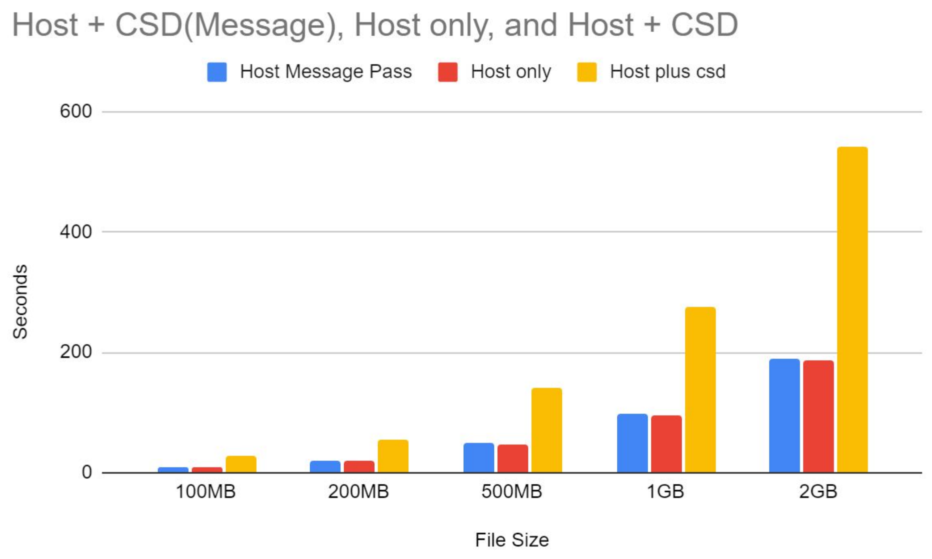

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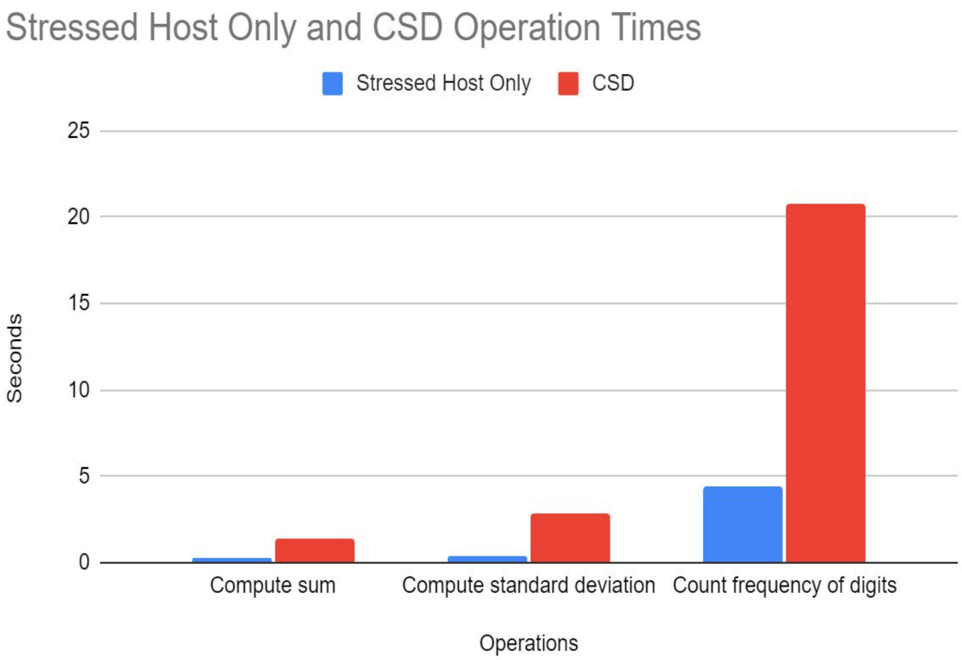
Still does not make sense on a per operation comparison



- Operation costs on a 1GB data log.
- Even after vector is in memory, the csd still executes the operation significantly slower than the stressed host test.
- Future work needs to be done with a focus on small operations. CSDs seem to be of more use in smaller operations on smaller files.

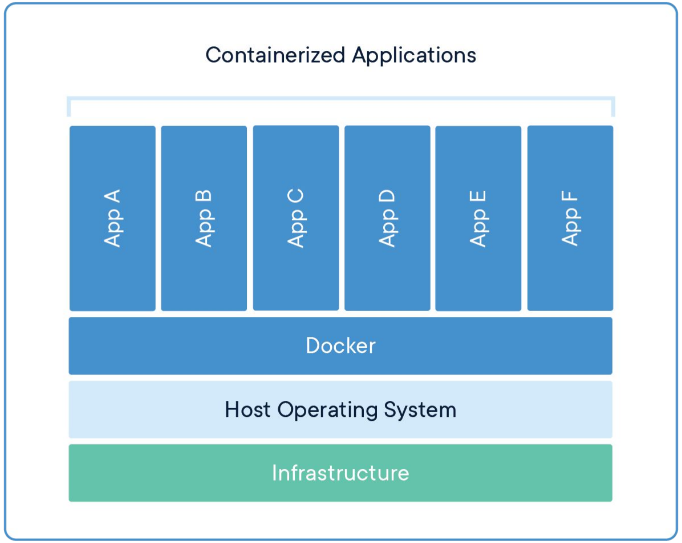
Future work for passing information

- Further investigate MPI's usage for communication.
- Need to develop a better way for host and csds to share storage.
- Create a pooled storage for CSDs, possibly ZFS.
- Data filtering (encrypt/decrypt)

CSDs with Charliecloud

About Charliecloud
Background on experiments
Analysis of results

About Charliecloud



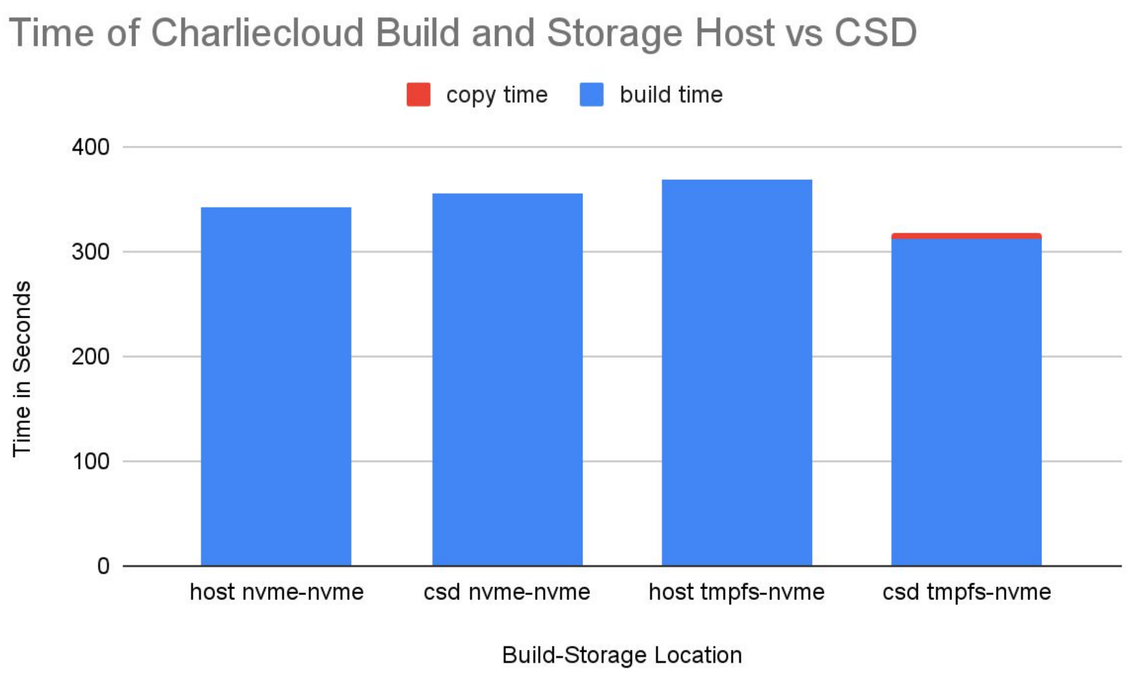
- Bring your own software stack
  - Containers
  - Container images
    - Code
    - System tools
    - Runtime
    - Settings
- Charliecloud Images
  - Few permissions
  - Minimally affect cluster resources

1st Experiments

Build Location	Storage Location
Host NVME	Host NVME
Host tmpfs	Host tmpfs
CSD NVME	CSD NVME
CSD tmpfs	CSD tmpfs

- Typical workflow: Build image on a compute node
    - (Inefficient!)
- Research Question: What is the best filesystem to store user images on in a cluster environment?
    - Compare small CSD to big host
    - Compare big host to LANL's Fog (later)

CSDs out-perform host on small image?



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2nd Experiments

Build Location	Storage Location
NVME	NVME
tmpfs	NVME
NFS	NFS
LUSTRE	LUSTRE
tmpfs	LUSTRE
tmpfs	NFS

- How does our host with NVME compare to a LANL production setup?
  - Lustre on Fog vs
  - NFS on Fog vs
  - NVME on our host

Our host

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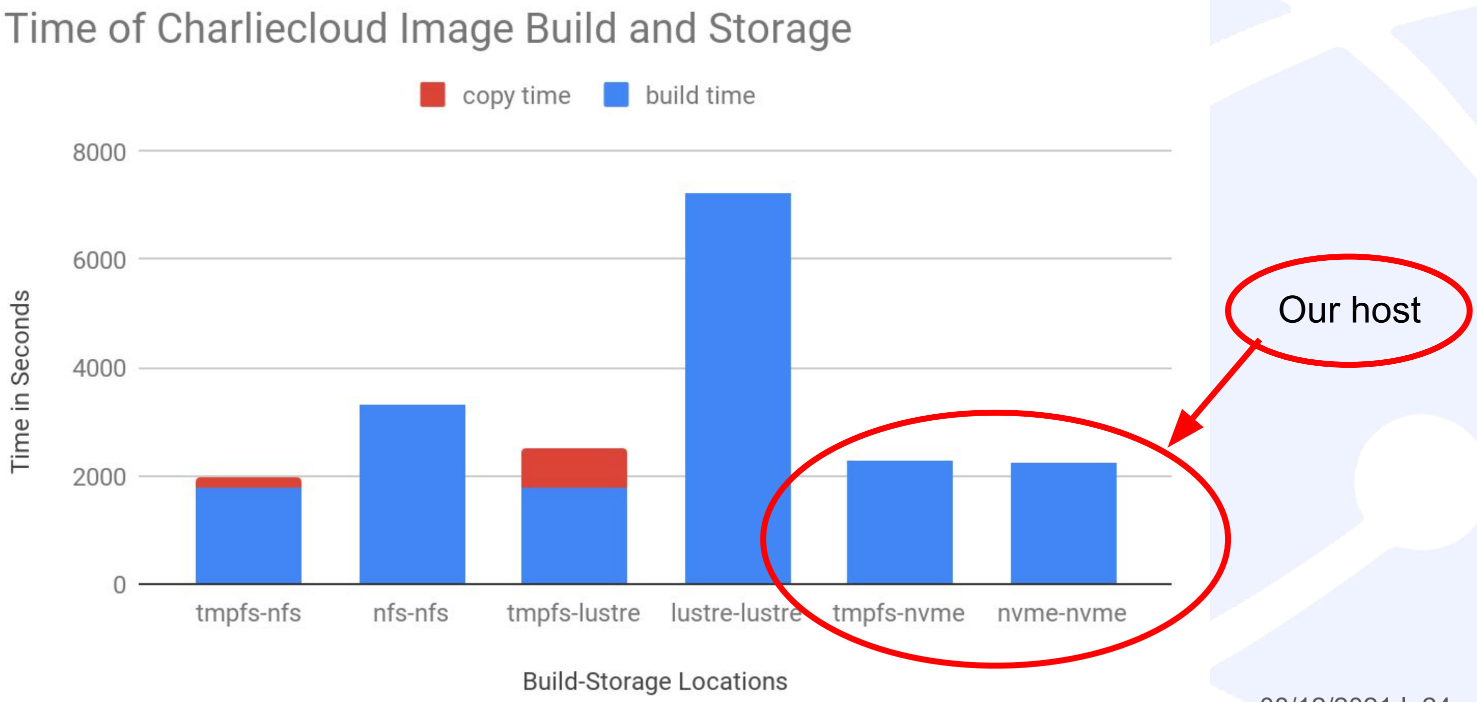
NVMe vs Other Filesystems



Conclusions and Next Steps

- Future work on variability across runs
  - Implications for scaling to larger container image builds
- Viability of CSDs for medium term storage (Stability!)
- Memory restrictions of our CSDs for building large images
- Potential use case for CSDs with Charliecloud
  - Envisioning a new user workflow

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Overall times to complete all operations per data size

Method	Spark		Python	C++			
	1 CSDs	8 CSDS	Serial on CSD	Serial on CSD	Multithread on CSD	Host stressed and CSD	Host stressed
100MB	N/A	N/A	408 s	45.47s	43.94s	36.83s	9.82s
200MB	N/A	N/A	792 s	90.61s	87.40s	72.51s	19.36s
500MB	N/A	N/A	2,048 s	229.10s	217.09s	181.97s	48.16s
1GB	2759.17s	542.44s	4,317 s	457.74s	432.54s	358.16s	94.61s
2GB	N/A	N/A	N/A	929.60s	870.97s	714.72s	187.58s