The Spatter Benchmark

Or: Benchmarking and Modeling Sparse Memory Accesses for Heterogeneous Systems

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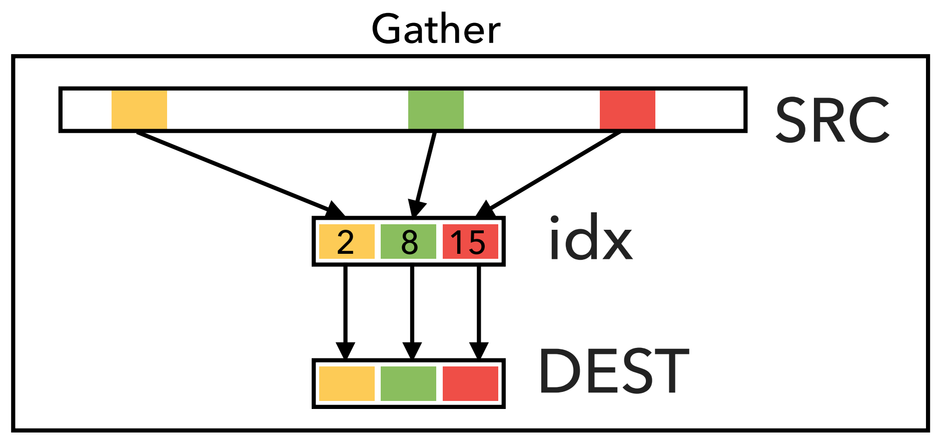
Purpose

- Dense memory access is well understood, but it is difficult to predict how a memory system will respond in irregular scenarios
    - Indirection, poor spatial and temporal locality
- Spatter allows us to view performance changes across architectures, so that we can better understand their differences
- You can't understand what you can't measure

Spatter

- Memory benchmark based on a scatter/gather kernels
  - Scatter `Y[j[:]] = X[:]`
  - Gather `Y[:]      = X[i[:]]`
  - SG `Y[j[:]] = X[i[:]]`



- Designed to model sparse data movement in applications like SuperLU and kernels like SpGEMM

- Includes effects of indirection and random or sparse access

Configuration

OpenCL

- Backend - OpenMP, OpenCL, or CUDA
- Work per thread (work item)
- CUDA (or OpenCL) block size
- Buffer sizes, cache-ability, *access stride*

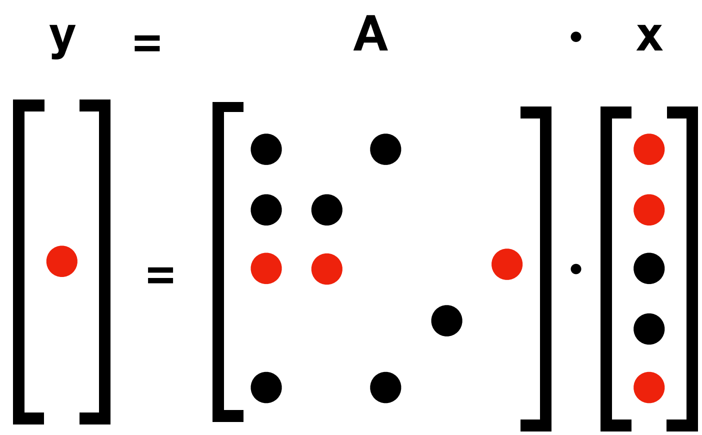
NVIDIA.
CUDA®

OpenMP®

Examples

Examples - CSR SpMV

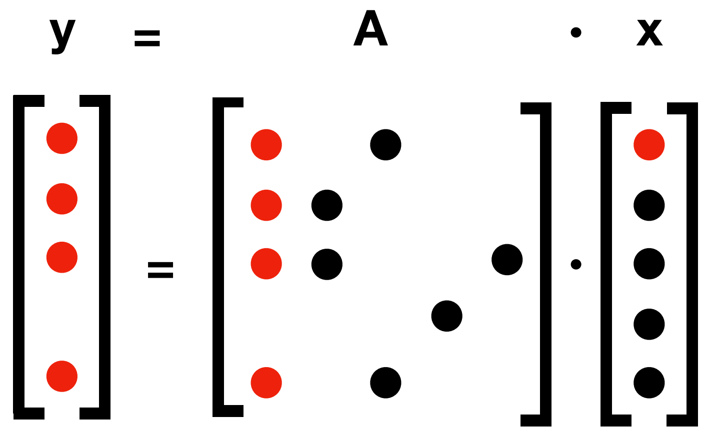
- Gather elements of x, then do a dot product with data in A.




```
for (i in range(nrows)):
    indices ← row[i] : row[i+1]
    gather(tmp, x, col[indices])
    y[i] = dot_prod(val[indices], tmp)
```

Examples - CSC SpMV

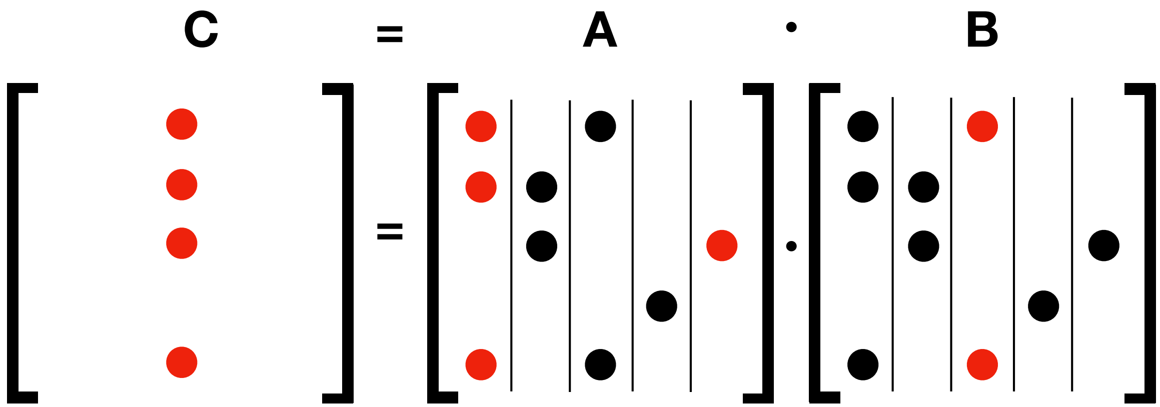
- Scale some a column of A by the value in x, then scatter-accumulate into y.

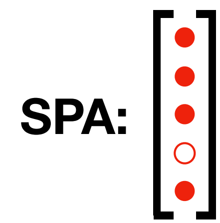



```
for (i in range(ncols)):
    indices ← col[i] : col[i+1]
    tmp ← vector_scale(val[indices], x[i])
    scatter_accum(y, row[indices], tmp)
```

Examples - SpGEMM

- Scatter-accumulate columns of A corresponding to non-zero entries in a column of B into a *dense* SPA buffer. Gather SPA into C.






```
for (j in range(ncols) :
    SPA = 0 //dense accumulation buffer
    for non-zero B(k,j) :
        scatter_accum(SPA, A(:,k)*B(k,j))
    gather(C.val, SPA)
    gather(C.row, which(SPA))
    C.col[j+1] = C.col[j] + nnz(SPA)
```

Algorithm from Buluç and Gilbert: *Parallel Sparse Matrix-Matrix Multiplication and Indexing: Implementation and Experiments*
https://doi.org/10.1137/110848244

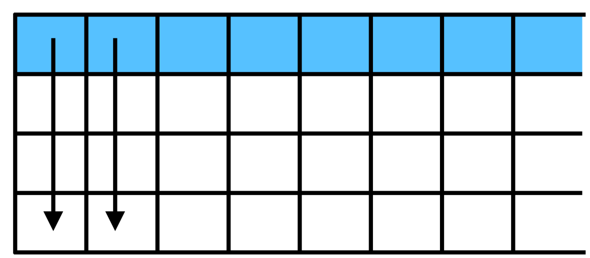
Examples - Vectorization

- Some forms of vectorization may naturally lead to Gather/Scatter operations

```
for (j in range(N)):
   for (i in range(4)):
        out[j] += data[i,j]
```

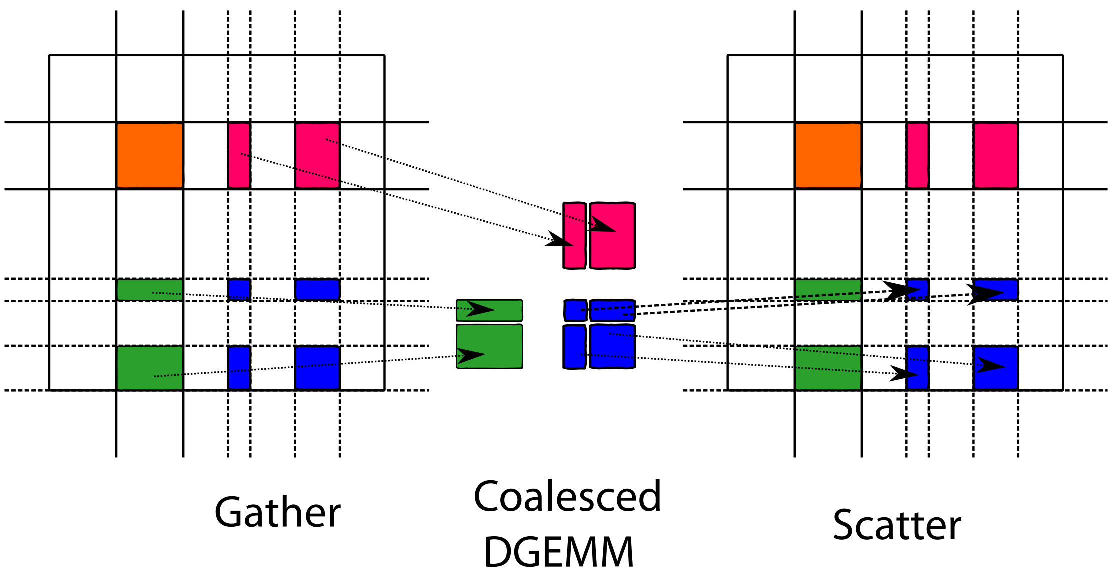
```
for (j = 0; j < N; j+=8):
    for (i in range(4)):
        gather_accum_stride(temp,j+i, 8, 4) //gather 8 elements,
                                            //gap size 4
    out[j:j+8] = temp
```

Column-Major



Example - SuperLU

- SuperLU spends a large portion its runtime on just scattering data



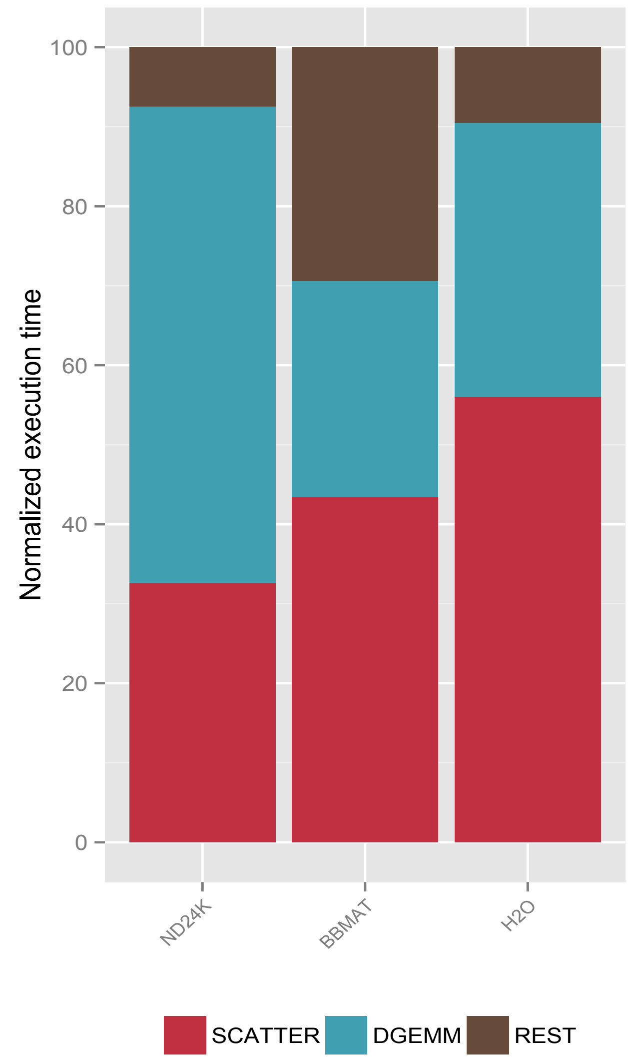


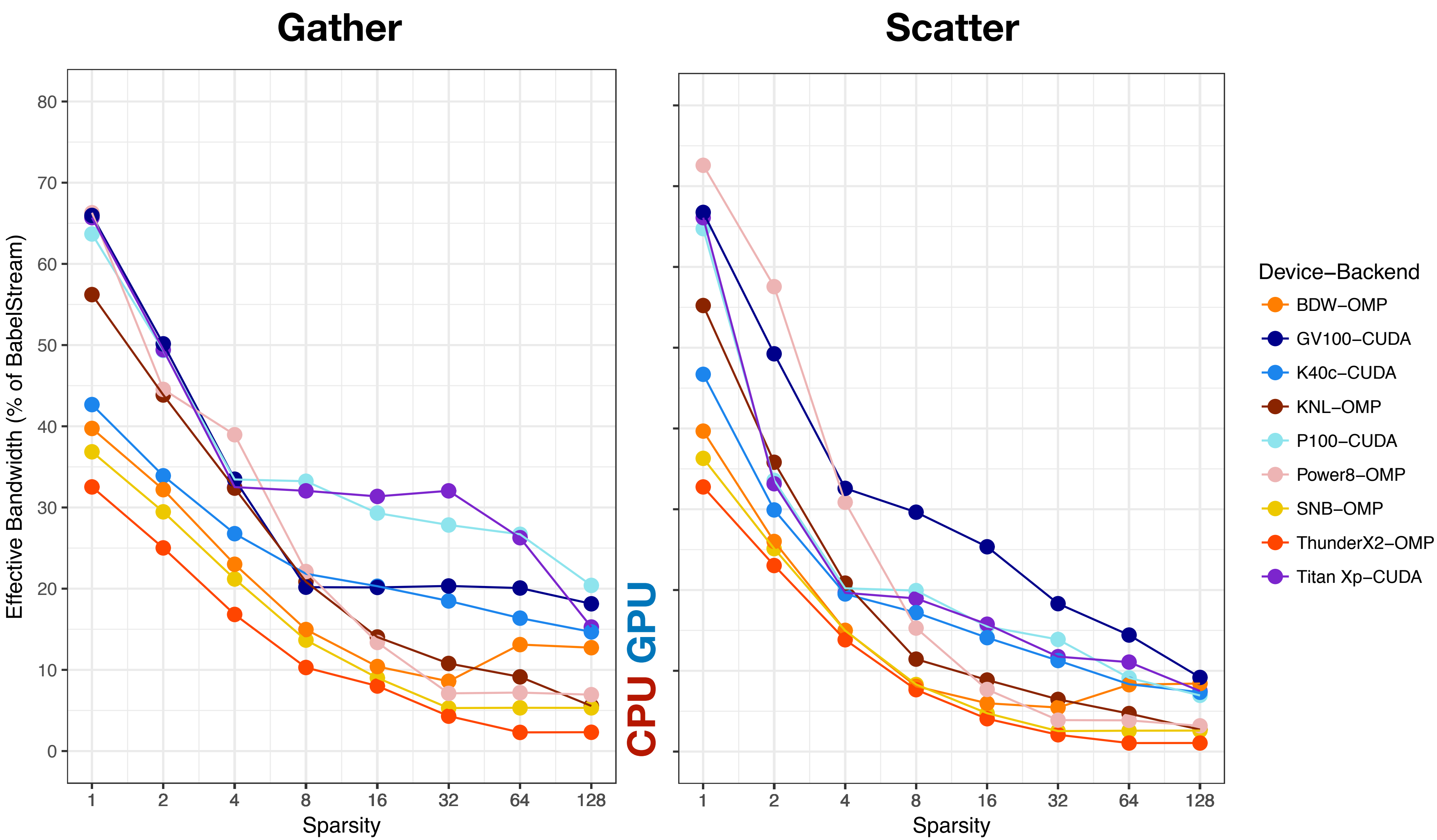
Chart credits: Piyush Sao

Benchmark Output

Performance Exploration

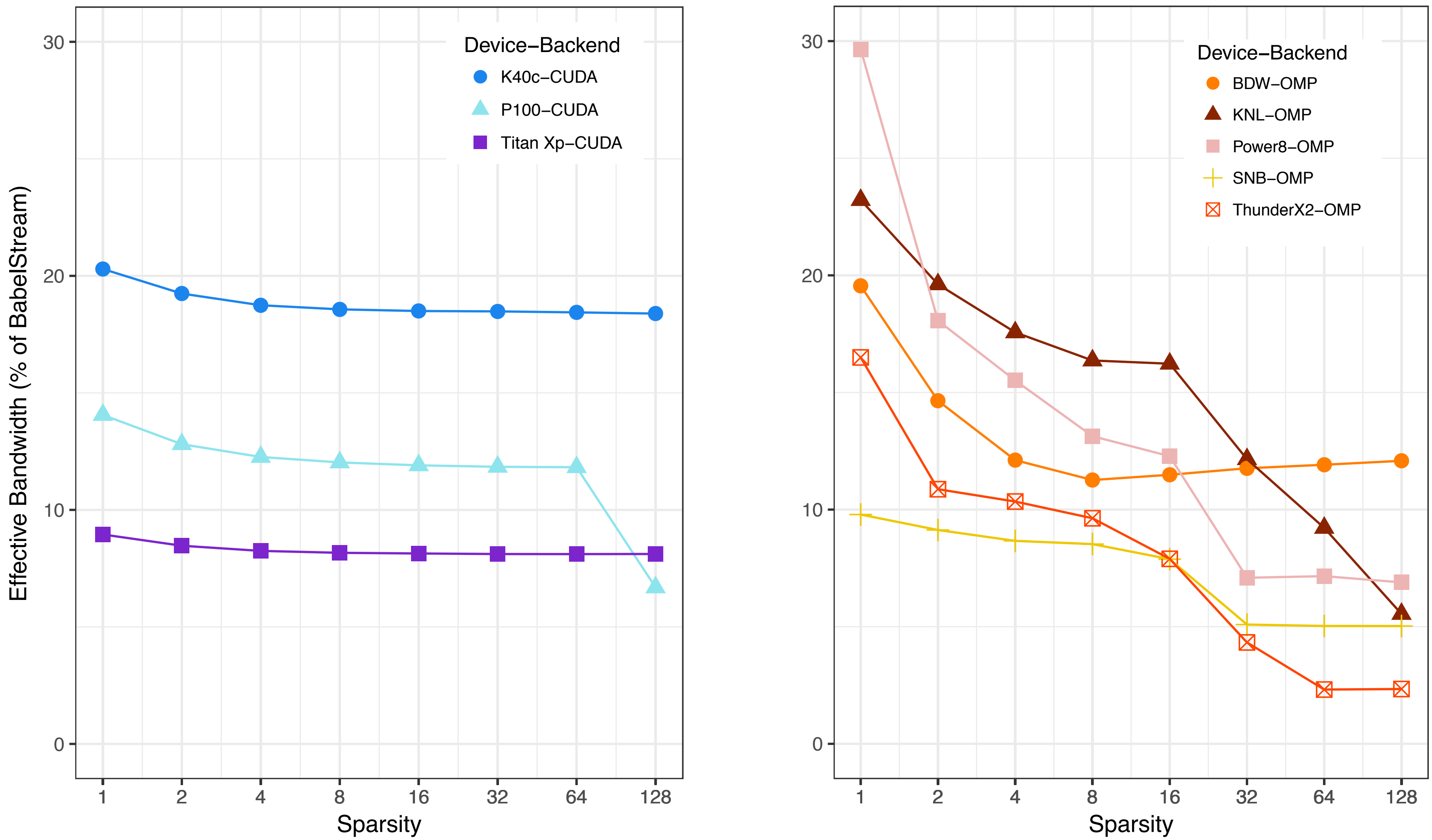
Uniform Stride

Uniform Stride Access



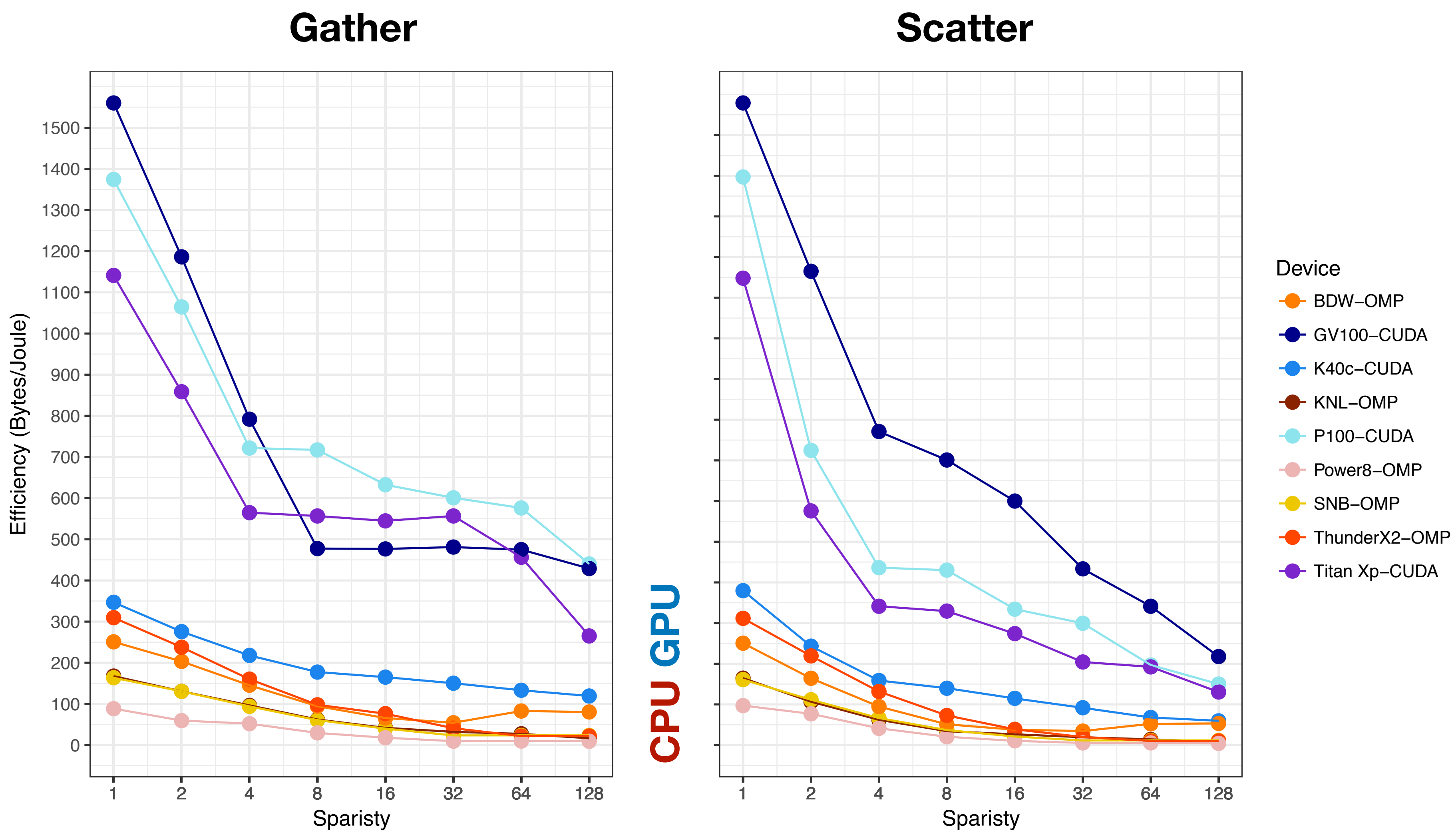
Random Access

Gather, Uniform



Energy Efficiency

Uniform Stride



What's Next?

- Partner with industry to run on upcoming systems
- Evaluation of slightly more complex synthetic traces
  - Mostly stride-1
  - Write collisions
- Gather/Scatter traces from real (DOE) mini-apps
- Measure impact of vector length (SVE and AVX) on generated code (and therefore cache performance)
- CILK backend for EMU, FPGA-specific OpenCL Backend
- More general kernels, with accumulation and a length buffer
- **Simplify to present a STREAM-like result**

More Info

- Spatter.io
  - Documentation
  - Guide to easily plot your GPU against ours
- ArXiv Pre-print
  - Spatter: A Benchmark Suite for Evaluating Sparse Access Patterns
  - https://arxiv.org/abs/1811.03743
- Code
  - https://github.com/hpcgarage/spatter

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