ISx in Chapel

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CHIUW @ IPDPS

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What Is The ISx Benchmark?

- **ISx: Scalable Integer Sort benchmark**
  - Modern replacement for NPB IS to address its shortcomings
  - Developed at Intel, published at PGAS 2015
  - Computation style:
    - Local SPMD-style computation with barriers
    - Punctuated by all-to-all bucket exchange pattern

- **SHMEM and MPI reference versions available on GitHub**
  - [https://github.com/ParRes/ISx](https://github.com/ParRes/ISx)

- **A good case study for Chapel**
  - A common parallel pattern for distributed memory programming
What Is The ISx Benchmark?

Generate Random Keys

Bucketize Keys

Exchange data

Local histogram & verify

Barrier
Chapel Implementation

```chapel
const BucketSpace = {0..#numBuckets};
const DistBucketSpace = BucketSpace dmapped Block(BucketSpace);

// For each bucket, create an array to receive keys
var allBucketKeys : [DistBucketSpace] [0..#recvBuffSize] int(32);

// Create globally-visible barrier
var barrier = new Barrier(numBuckets);

// Start a task for each bucket, call bucketSort
coforall loc in Locales do on loc {
    coforall tid in 0..#bucketsPerLocale {
        const taskID = (loc.id * bucketsPerLocale) + tid;
        for i in 1..numTrials {
            bucketSort(taskID, i);
        }
    }
}
```
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}
```
// Within bucketSort…

var myKeys = makeInput(taskID);

var myBucketedKeys = bucketizeLocalKeys(taskID, myKeys);

// Exchange step
for i in 0..#numBuckets {
  const transferSize, dstOffset, srcOffset = ...

  allBucketKeys[i][dstOffset..#transferSize] =
    myBucketedKeys[srcOffset..#transferSize];
}

barrier.barrier();

var keyCounts = countLocalKeys(taskID);

verify(taskID, keyCounts);
SPMD vs. Global-view

● SPMD: bucket per core
  ● Serial for-loops
  ● Example from ‘countLocalKeys’
    
    ```
    var keyCounts : [...] int;
    for i in 0..#myBucketSize do
        keyCounts[allBucketKeys[taskID][i]] += 1;
    ```

● Global view: bucket per locale
  ● Forall loops for intra-locale parallelism
  ● Atomics used to coordinate between loop iterations
    
    ```
    var keyCounts : [...] atomic int;
   forall i in 0..#myBucketSize do
        keyCounts[allBucketKeys[taskID][i]].add(1);
    ```
SPMD vs. Global-view - performance

- Global-view slower than SPMD version
  - by up to 4x!

  ![Graph showing time (seconds) vs. date from 20 Mar to 28 Mar]

  **ISx variations**

<table>
<thead>
<tr>
<th>Date</th>
<th>Time (seconds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 Mar</td>
<td>5</td>
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<tr>
<td>22 Mar</td>
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<td>24 Mar</td>
<td>5</td>
</tr>
<tr>
<td>26 Mar</td>
<td>5</td>
</tr>
<tr>
<td>28 Mar</td>
<td>5</td>
</tr>
</tbody>
</table>

  2016/03/18:
  - Bucket-based SPMD (gnu+gasnet-aries): 21.02
  - Pure SPMD (gnu+gasnet-aries): 5.62

- Likely due to atomics
  - Global-view uses atomics to coordinate between forall-loop iterations
  - SPMD uses serial for loops, no atomics
Chapel vs. SHMEM

- SPMD is faster and a more natural fit

- Initial port was much slower than SHMEM reference

- Numbers gathered with
  - ISx reference version 1.1, weakISO scaling
  - Chapel 1.13, ugni-qthreads
  - gcc 5.1.0, -O3
  - cray-shmem/7.3.3
  - Cray XC, 36 broadwell cores per node
  - 134217728 ($2^{27}$) keys per bucket
Chapel vs. SHMEM

- Initial comparison with two XC nodes: yikes!
  - Nearly 80x worse!
Chapel vs. SHMEM

● Timing output indicated some problem areas
  exchange = 355.502 (349.506..386.19)
  count keys = 56.406 (16.9024..124.789)

● Exchange step ~350s, compared to SHMEM’s 1.6s

● Counting step ~56s, compared to SHMEM’s .2s
Chapel vs. SHMEM - Bulk Transfer

● Exchange looks something like this:
  ● Slice and assign between two arrays
    allBucketKeys[i][dstOffset..#transferSize] =
    myBucketedKeys[srcOffset..#transferSize];

● We expect this to use Chapel’s bulk transfer optimization
  ● One large GET/PUT/memcpy better than element-by-element

● Investigation revealed bulk transfer not firing correctly
Solution: remove overly-conservative runtime check
- Prevented bulk transfers when slicing from the middle of an array
- Near 6x improvement!

```chapel
var A, B : [1..20] int;

// optimization works!
A[1..10] = B[1..10];

// Failed to bulk transfer!
// Fixed in 1.13 release
A[1..10] = B[5..15];
```
Chapel vs. SHMEM: Loop Hoisting

- Counting step slow (56s vs .2s)

- Solution: Manually optimize source code
  
  ```chapel
  for i in 0..#myBucketSize do
    keyCounts[allBucketKeys[taskID][i]] += 1;  // loop-invariant
  ```

  - Manually hoisting helps tremendously
  - Compiler should perform this optimization in the future

- Result: immensely better
  - ~7x improvement

- Now, let’s look at scaling…
Chapel vs. SHMEM: Scaling

- Starts out OK, then goes off the rails…
- Exchange step still too long
  - ~96s vs SHMEM’s ~8s
Chapel vs. SHMEM: Scaling

- Bulk transfer is firing, what gives?
- Reference counting is a known source of overhead
  - Especially for array/domain slicing…
  - Can be disabled with ‘–snoRefCount’
Observation: exchange is still slower than reference

Suspicion: array slicing is at fault
  - DefaultRectangular array slicing uses an on-statement
    - Ensures slices lives on same locale as actual array
    - # of ons equals numBuckets**2

Currently not a simple task to remove the on-statement
  - Other optimizations rely on the existing semantics

Idea: avoid doing a full slice for bulk transfers
  - Recognize the slice is short-lived
  - Bulk transfer really only needs the slice’s offset information
Conclusions

● Easy to write in Chapel

● Without reference counting, about 2x worse
  ● Relatively good for Chapel, today

● Future work for performance
  ● Improve reference counting
  ● Better loop hoisting
  ● Improve slicing performance
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