Library and Array Improvements

Chapel version 1.19
March 21, 2019
Outline

- Radix Sorting
- Hashed Distribution
- Remote Subdomain Queries
- Distribution Convenience
- Filter/Map/Consume
- 'Random' Improvements
- 'LinearAlgebra' Improvements
Radix Sorting
Radix Sorting: Background

• Sort module is currently a package module
  • Because its interface is not finalized
  • Because the implementation is incomplete
    • It has lacked sorting algorithms with competitive performance
• The sort() function is called from standard modules
  • e.g., for associative domain's sorted() iterator
• The sort() function can accept a comparator
  • Is element A less than, equal to, or greater than element B?
  • Alternatively, what is the 'key' to sort by?
Radix Sorting: This Effort

- Rails Girls Summer of Code project studied radix sorting in Chapel
  - Generated several implementations
  - Led to a straw-man interface proposal
- Extended the sort() comparator API to allow keyPart() for radix sorting
- Added a parallel, in-place radix sort to the Sort module
- sort() now calls radix sort if comparators allow it
use Sort;
record MyRecord { var key: int; var value: int; } record MyKeyComparator {
     proc key(element: MyRecord) {
         return element.key; // now uses radix sorting for integral keys
     }
}
config const n = 10000;
var A: [1..n] MyRecord = [i in 1..n] new MyRecord(i, i*i);
sort(A, new MyKeyComparator());
Radix Sorting: Example

```haskell
use Sort;
record MyRecord { var key: c_string; var value: int; }
record MyKeyPartComparator { }
proc keyPart(element: MyRecord, i: int) {
    var byte = element.key[i-1]; // compute the current key byte
    // has the end been reached? Note, c_strings have a 0 terminator
    var done = if byte != 0 then 0 else -1;
    return (done, byte);
}
var A:[1..n] MyRecord = ...;
sort(A, new MyKeyPartComparator());
```
Radix Sorting: Impact

Sorting Speed of Random Integers

- **1 KiB**: 4x
- **1 MiB**: 14x
- **1 GiB**: 6x

Input Data Size

<table>
<thead>
<tr>
<th>Data Size</th>
<th>quickSort</th>
<th>msbRadixSort</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 KiB</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 MiB</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 GiB</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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Radix Sorting: Impact

Sorting Speed of Random c_strings

- **quickSort**
- **msbRadixSort**

<table>
<thead>
<tr>
<th>Input Data Size</th>
<th>1 K strings</th>
<th>1 M strings</th>
<th>128 M strings</th>
</tr>
</thead>
<tbody>
<tr>
<td>quickSort</td>
<td><img src="#" alt="Graph Data" /></td>
<td><img src="#" alt="Graph Data" /></td>
<td><img src="#" alt="Graph Data" /></td>
</tr>
<tr>
<td>msbRadixSort</td>
<td><img src="#" alt="Graph Data" /></td>
<td><img src="#" alt="Graph Data" /></td>
<td><img src="#" alt="Graph Data" /></td>
</tr>
</tbody>
</table>

- **9x** speed improvement for 1 M strings
- **10x** speed improvement for 128 M strings
Radix Sorting: Impact

- Significantly improved performance for a sparse domain benchmark:
Radix Sorting: Next Steps

- Explore ways to achieve better performance for heavily skewed data
  - Need to improve parallel load balance
- Investigate alternative parallelization strategies
  - The 'count' and 'shuffle' functions are currently serial
- Support distributed radix sorting
Hashed Distribution
HashedDist: Background

• Distributed associative arrays are important for certain applications
  • e.g. when counting or assigning unique numbers to strings in distributed data

• A prototype distribution for associative arrays was already implemented
  • Used in earlier label propagation study
  • Never promoted out of the test system
HashedDist: This Effort

• Added a new module, ‘HashedDist’, and a new distribution, ‘Hashed’
  • Based on the prototype that was in the testing system
• The ‘Hashed’ distribution:
  • Maps an associative domain and its arrays to a set of target locales
  • Maps each index to a locale based upon its value
  • Can be customized by providing a mapper
use HashedDist;

var D: domain(string) dmapped Hashed(idxType=string);

// Now D is a distributed associative domain (set) of strings. Add some elements:
D += "one"; D += "two";

var A: [D] int;

// Now A is a distributed associative array (map) from string to int
// Let's iterate over it across all Locales
forall (key, value) in zip(D, A) {
    // do something with the (key, value) pair
}
HashedDist: Impact, Next Steps

**Impact:** Distributed associative arrays and domains are now available

**Next Steps:**

- Get feedback from users of ‘HashedDist’ and improve the interface
- Improve the implementation
  - Make the domain map implementation complete
  - Support adding indices in bulk
Remote Subdomain Queries
Remote Subdomains: Background

Background:

- Chapel supports subdomain queries on distributed domains/arrays:
  ```
  const myInds = A.getLocalSubdomain();
  ```
- However, these queries have only been for the current locale ('here')
  - Thus, to query for a remote locale, on-clauses had to be used:
    ```
    var remoteInds: (A.getLocalSubdomain()).type;
    on remoteLocale do
      remoteInds = A.getLocalSubdomain();
    ```
- Yet, many distributions can compute such queries without communicating
This Effort:

- Added support for remote subdomain queries:
  
  ```plaintext
  proc <domain>.localSubdomain(loc: locale = here);
  proc <array>.localSubdomain(loc: locale = here);
  
  iter <domain>.localSubdomains(loc: locale = here);
  iter <array>.localSubdomains(loc: locale = here);
  ```

- Used an optional argument to preserve backward-compatibility
Remote Subdomains: Status, Next Steps

Status:

• Added (communication-free) implementations for most major domain maps:
  • Default / local layouts
  • Key distributions: Block, Stencil, Cyclic, Replicated, HashedDist
  • Array views

Next Steps:

• Extend to remaining domain maps: BlockCyclic, Block-Sparse, Dimensional
• Decide whether to retire the procedure forms of the queries
  • Realized that it’s broken when a locale is oversubscribed in 'targetLocales'
  • This would permit 'hasSingleLocalSubdomain()' to be retired as well
Distribution Routines: Background, This Effort

**Background:** Creating distributed domains/arrays can be repetitive

- Block domains frequently declared over same indices as `boundingBox`

  ```
  const D = {1..m, 1..n} dmapped Block(boundingBox={1..m, 1..n});
  var A: [D] real;
  ```

- Cyclic domains frequently declared with `startIdx == domain's low bound`

**This Effort:** Provide convenience routines for Block and Cyclic domains/arrays

- Simplify the common cases
Impact: The common cases for Block and Cyclic are simplified

```javascript
var BlkDom = newBlockDom({1..n, 1..m});
var CycDom = newCyclicDom({1..n, 1..m});
var BlkArr = newBlockArr({1..n, 1..m});
var CycArr = newCyclicArr({1..n, 1..m});
```

Next Steps:

- Look for common usage patterns in other distributions
- Provide similar convenience functions in those cases
- Continue to refine and improve these helper routines
Filter, Map, Consume on Iterators
Filter, Map, Consume: Background, This Effort

**Background:** Filter, Map, Consume are common patterns on stream-like data
- These operations are commonly supported in other languages, e.g. Python
- Would be useful for iterators since they yield streams of data

**This Effort:** Define methods on iterators implementing Filter, Map, and Consume

```javascript
iter iterator.map(function): function.type
iter iterator.filter(function): iterator.type
iter iterator.consume(function): void
```
Filter, Map, Consume: Status, Next Steps

Status: Functional style operations are available for iterators

• Currently requires calling 'these()' to get an iterator from an iterable object

```plaintext
var r = 1..17 by 3;
proc even(i: int) return i % 2 == 0;
for i in r.these().filter(even) do ... // 4, 10, 16
```

Next Steps:

• Add 'foldL' and 'foldR'
• Add parallel versions of these operations
• Make the functions directly available on iterable objects
Random Module Improvements
Random Module: Background, This Effort

**Background:** Random sampling was not available in ‘Random’ module

**This Effort:** Implemented choice() method for sampling from a 1D array

- Supports weighted sampling (prob) with or without replacement (replace)
- Supports returning a single value, or an N-dimensional array (size)

```plaintext
use Random;
var stream = makeRandomStream(int);
var ret = stream.choice([1,2,3], prob=[0.1, 0.3, 0.6],
                         size={1..2, 1..2}, replace=true);
```

- Improved `getNext()` in order to support 'choice':
  - Added 'getNext(resultType, min, max)' overload to PCG random stream
  - Added bounds-checking to getNext() overloads with min/max arguments
Random Module: Impact, Next Steps

**Impact:** Improved Random module
- Random sampling is now supported in the Random module
- Extended `getNext()` functionality and added bounds checking

**Next Steps:** Extend sampling functionality and provide distribution sampling
- Support sampling from an N-dimensional array
- Support sampling bigint, imaginary, and complex types
- Optimize implementation for sampling from local and distributed arrays
- Support distribution-sampling like Gaussian, Binomial, Poisson, etc.
Linear Algebra Module Improvements
LinearAlgebra Module: Background, This Effort

**Background:** LinearAlgebra module provides linear algebra routines in Chapel

**This Effort:** Made some quality of life improvements to the module

- Added checks for distributed arrays which are not yet supported
- Renamed eigvals() to eigs() since it returns eigenvalues and eigenvectors
  - Kept eigvals() for eigenvalues only
- Stopped transitively using BLAS and LAPACK with LinearAlgebra
  - Prevents a potential collision with 'BLAS.dot()'
- Removed previously deprecated features
LinearAlgebra Module: Status, Next Steps

Status:
- LinearAlgebra module is improved
  - Fewer confusing errors
  - Easier to use

Next Steps:
- Continue to improve LinearAlgebra module
  - Distributed support
  - GPU support
  - More linear algebra routines (native and BLAS/LAPACK)
For More Information

For a more complete list of library and array changes in the 1.19 release, refer to 'Standard Modules / Library', 'Package Modules' and 'Standard Domain Maps' sections in the CHANGES.md file.
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chapel_info@cray.com
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