Library and Array Improvements

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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

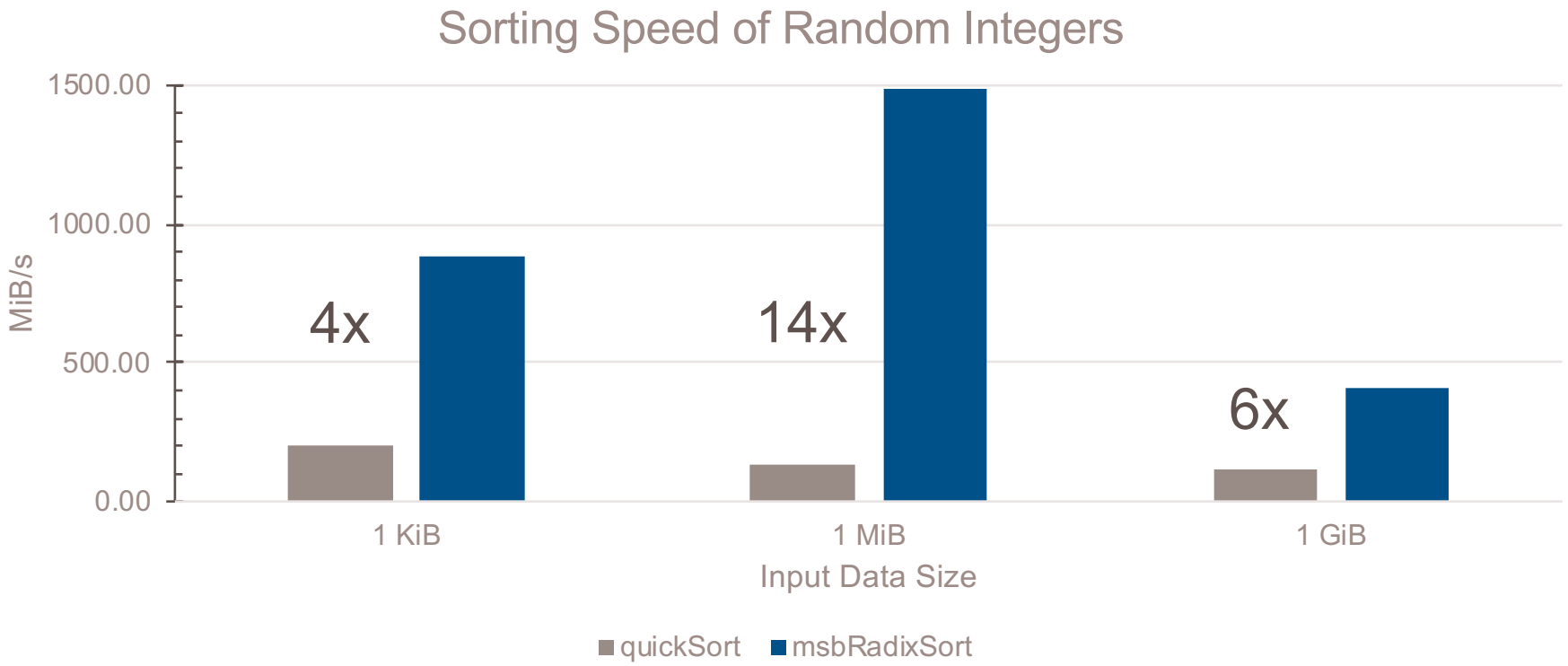
Radix Sorting: Example

```
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());
```

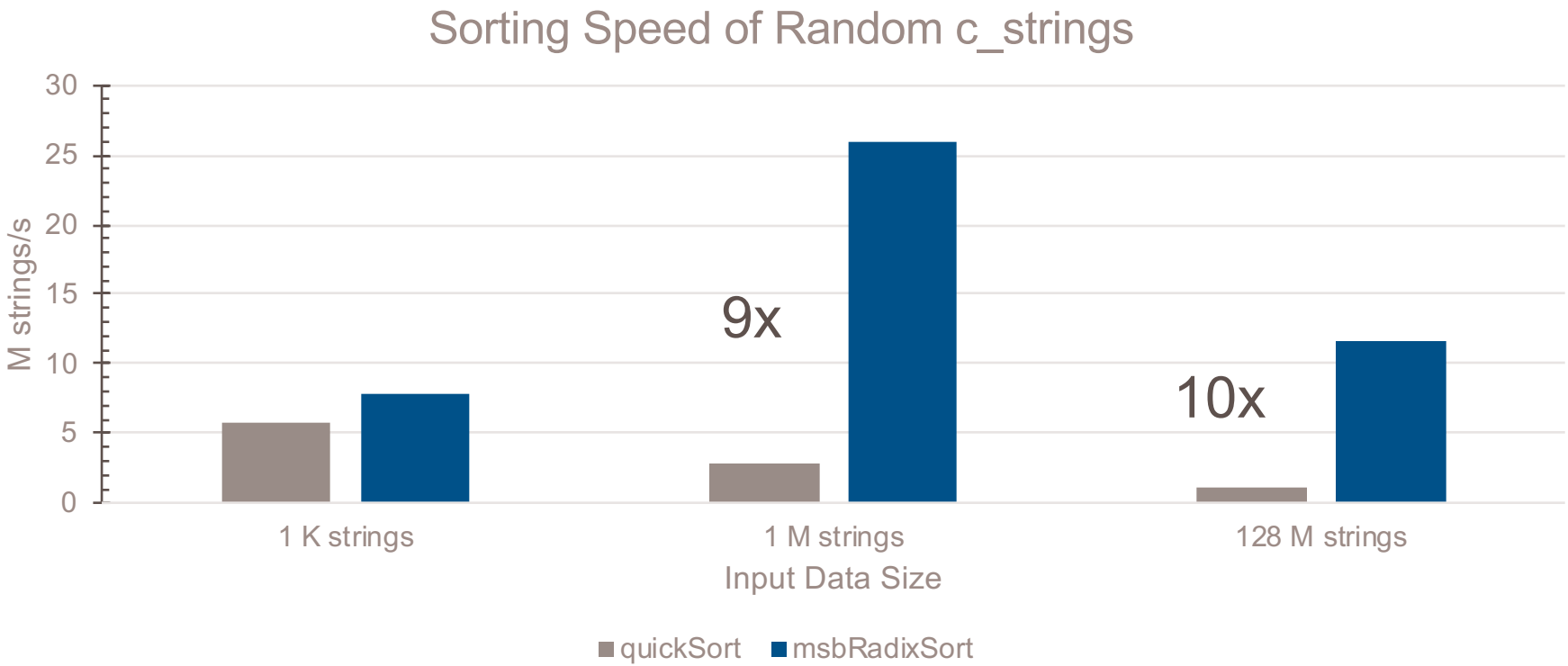

Radix Sorting: Example

```
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

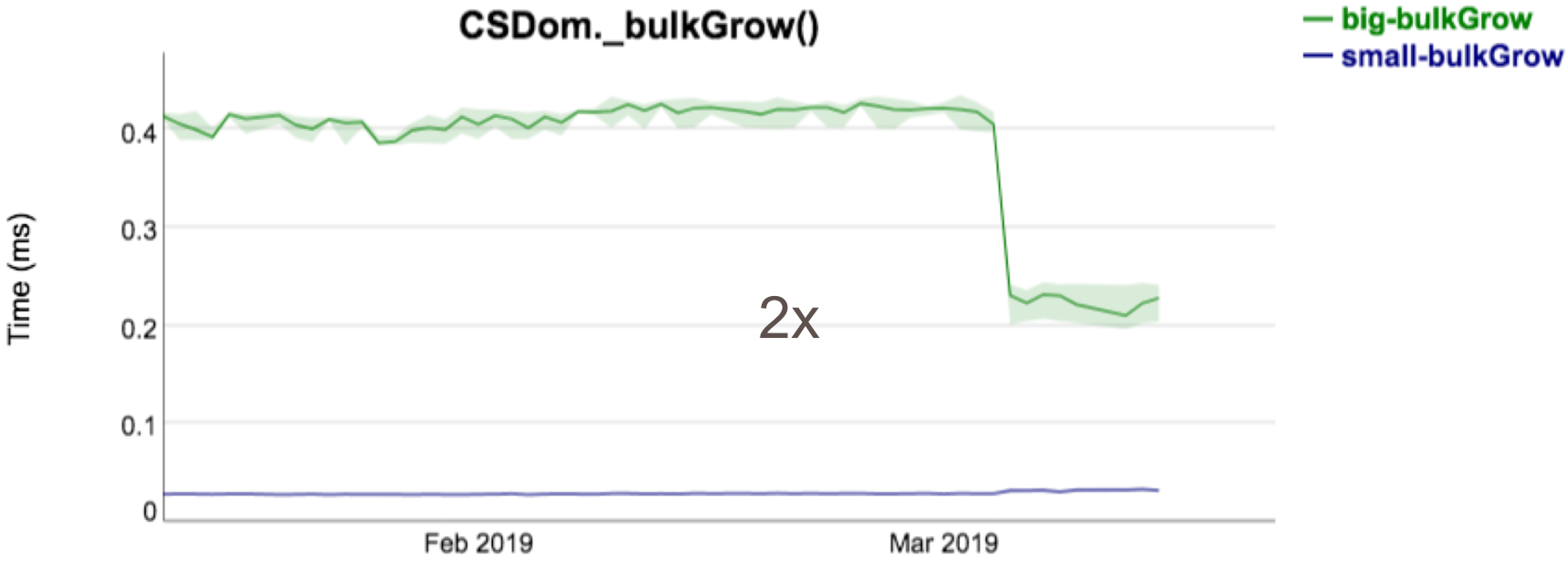


Radix Sorting: Impact



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

HashedDist: This Effort

```
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

Remote Subdomains: This Effort

This Effort:

- Added support for remote subdomain queries:

```
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 Convenience Routines

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

Distribution Routines: Impact, Next Steps

Impact: The common cases for Block and Cyclic are simplified

```
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

```
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

```
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*)

```
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.

LinearAlgebra 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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