Array, Domain, & Domain Map Improvements

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Outline

- Block Sparse Locality Improvements
- Replicated Distribution Improvements
- Associative Array Locking Improvements
- Array View Improvements
- Compressed Sparse Row/Column Layouts (CSR/CSC)
- Optimizing Sparse bulkAdd
- Bulk Array Expansion
- Parallel Array Initialization
- Other Array, Domain, Domain Map Improvements

Block-Sparse Locality Improvements

Block-Sparse Locality: Background

Background:

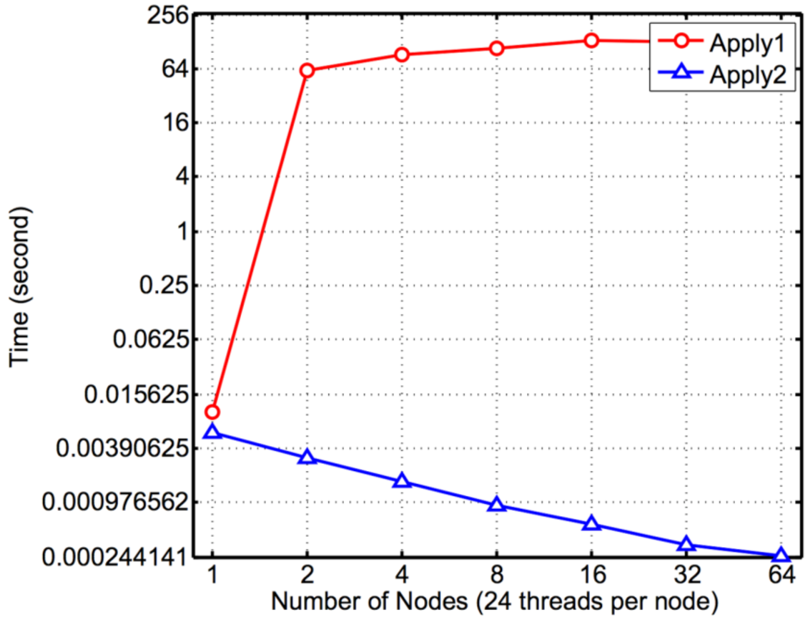
- Block-distributed sparse arrays were introduced in Chapel 1.14
- Performance was far from ideal
  - a known issue / TODO: lack of privatization
  - a significant bug, revealed in Azad and Buluç's CHIUW 2017 paper, *Towards a GraphBLAS Library in Chapel:*

preferred, high-level version:

```
forall a in spArr do
  a = unaryOp(a);
```

lower-level workaround:

```
coforall locArr in locArrs do
  on locArr do
    forall a in locArr.myElems do
      a = unaryOp(a);
```



Block-Sparse Locality: This Effort

This Effort:

- added privatization to Block-Sparse domains/arrays
  - *privatization:* localizing key descriptors to each target locale
  - contributed by Engin Kayraklioglu (GWU)
- fixed the bug revealed by CHIUW paper
  - parallel array iterator had the wrong “on-clause”, ran everything locally

```
-     coforall locA in locArr do on locArr {
+     coforall locA in locArr do on locA {
        // forward to sparse standalone iterator
        for i in locA.myElems._value.these(tag) {
          yield i;
```

  - unfortunately, not reported prior to publication, so not fixed for Chapel 1.15

Block-Sparse Locality: Impact

Impact:

- simple loops on a 1000 x 1000 matrix, 10% sparse, 4 locales

	`forall ij in SD do` `SA[ij] = …;`				`forall a in SA do` `a = …;`			
	ons	gets	puts	time (100 trials)	ons	gets	puts	time (100 trials)
1.15	3 0 0 0	0 4,227,000 3,675,000 3,675,000	0	107.44 sec	0	225,009 0 0 0	75,000 0 0 0	15.37 sec
1.16	3 0 0 0	0	0	0.162 sec	3 0 0 0	0	0	0.0193 sec

Block-Sparse Locality: Status and Next Steps

Status:

- Block-Sparse domains and arrays are now much more scalable

Next Steps:

- Further evaluation and tuning of sparse operations

Replicated Distribution Improvements

Replicated: Background

Background:

- Chapel has long supported a 'Replicated' distribution
  - concept: each target locale stores the entire domain/array (a 'replicand')
  - for example, each locale would store an *n*-ary domain/array given:

```
const D = {1..n} dmapped ReplicatedDist();
var A: [D] real;
```

- Certain aspects of its behavior have been surprising / unusual
  - e.g., the following loop traversed all elements in all replicands

```
forall a in A do …    // does O(n*numLocales) work rather than O(n)
```

  - e.g., '.size()' would return '*n*numIndices*' rather than simply '*n*'

- Other minor pain points:
  - no way to easily access another locale's replicand
  - distribution class was named 'ReplicatedDist', as was module
    - contrast with 'Block' distribution defined in 'BlockDist' module
  - target locale array had an unusual "consistency" requirement

Replicated: Consistency Improvements

This Effort: Improved naming and behavior

- Replaced 'ReplicatedDist' with 'Replicated'
- Make 'Replicated' operations refer to local data only
  - Consider the following declarations, running on two locales:

```
const D = {1..5} dmapped …;
var A: [D] real;
```

code	ReplicatedDist (1.15)	Replicated (1.16)
`for[all] i in D do…` `for[all] a in A do…`	iterated over all 10 indices / elements, generating communication	iterates over 5 indices / local elements
`D.size() / A.size()`	10	5
`writeln(D);`	{1..5} replicated over LOCALE0 LOCALE1	{1..5}
`writeln(A);`	LOCALE0: 0.0 0.0 0.0 0.0 0.0 LOCALE1: 0.0 0.0 0.0 0.0 0.0	0.0 0.0 0.0 0.0 0.0

Replicated: Other improvements

This Effort: Implemented other improvements

- "Added '.replicand()' method to access a remote locale's copy
  - e.g., could simulate old writeln(A) behavior via:

```
for loc in Locales {
  writeln(loc, ":")
  writeln(A.replicand(loc.id));
}
```

- Removed "consistency" requirement on target locale set
- Added a Replicated-specific primer, improved documentation
  - see: http://chapel.cray.com/docs/1.16/primers/replicated.html

Replicated: Status and Next Steps

Status:

- Preserved 'ReplicatedDist' for 1.16
  - maintains backwards compatibility for existing users
  - generates a deprecation warning
  - will be retired in 1.17

- "But what if I liked the old behavior?"
  - can still get it via manual rewrites:

```
coforall loc in Locales do    // implement old forall behavior
  on loc do
    forall i in D do …
```

Next Steps:

- Gain additional experience with 'Replicated' and improve it as needed

Associative Array Locking Improvements

Associative Locking: Background

Background:

- Traditionally, associative array accesses have been guarded by locks

```
proc AssocArray.access(idx) ref {
  lock$ = true;      // take lock
  ref elt = …;       // take reference to element
  lock$;             // release lock
  return elt;        // return reference
}
```

  - presumably to avoid races in the event that the array was being resized

```
cobegin {
  Age["abe"] += 1;        // update an existing person's age
  People += "billy";      // add a new person, growing the array
}
```

- However, such guards don't actually provide safety
  - the array could still be resized between the return of the ref and its use
  - the lock would need to surround the entire assignment to be effective

Associative Locking: This Effort

This Effort:

- remove locking on associative array accesses
- makes them more similar to other array types
  - e.g., rectangular arrays are also subject to such races

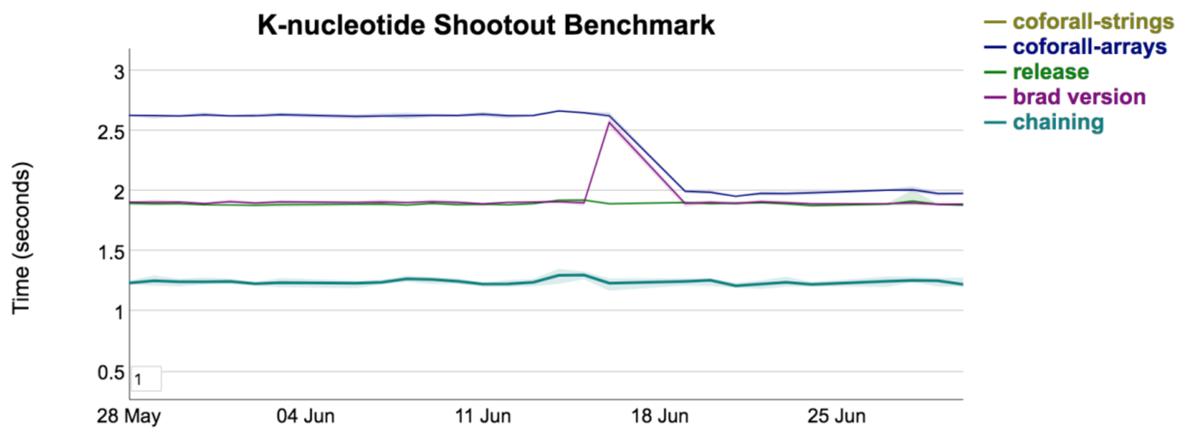
    ```
    cobegin {
      A[i,j] += 1;
      D = {1..2*m, 1..2*n};
    }
    ```

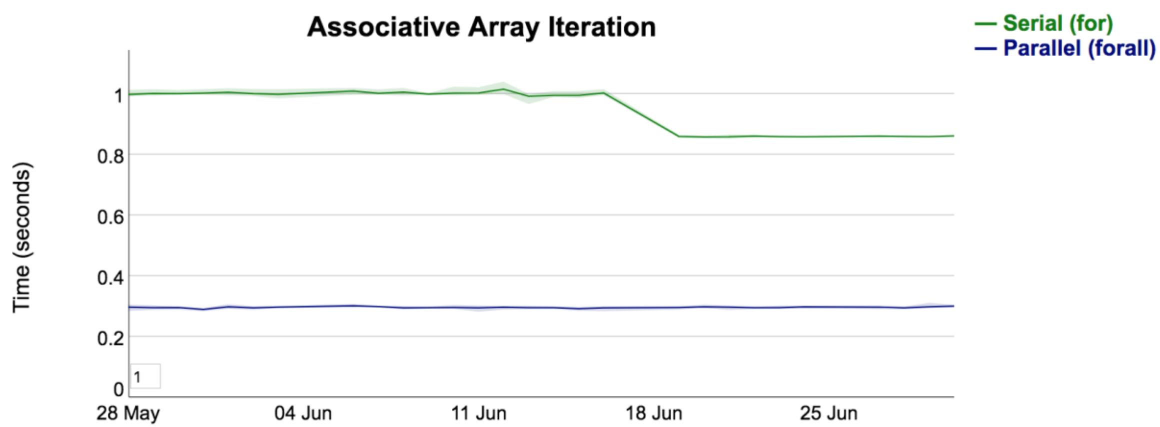
  - such cases have always been considered the user's responsibility

Associative Locking: Impact

Impact:

- improved performance for cases using associative array accesses





Associative Locking: Next Steps

Next Steps:

- Look into techniques to improve safety in such cases
  - compiler analysis?
  - (expensive) opt-in execution-time techniques?

Array View Improvements

Array Views: Background

Background:

- Chapel 1.15 introduced the concept of *array views*
  - implement array slicing, rank-change, and reindexing via indirection
  - made these operations more robust
  - simplified authoring new domain maps
- Some work was left unfinished in 1.15
  - domains/dists of reindexed distributed arrays did not preserve distribution
  - domains/dists of rank-change / reindex arrays were only stored on locale 0

```
var MyDistArr: [{1..m, 1..n} dmapped Block(…)] real;
ref ZeroBasedArr = MyDistArr.reindex({0..#m, 0..#n});
foo(ZeroBasedArr);
proc foo(X: [?D]) {
  var Y: [D] real;       // Y was not distributed as you'd think it would be
  on Locales[2] {
    const s = D.size;  // locale 2 had no local copy of D ⇒ comm. required
  }
}
```

Array Views: This Effort

This Effort:

- Fixed the aforementioned issues
  - domains and distributions of distributed array views…
    - …preserve locality
    - …are privatized

```
var MyDistArr: [{1..m, 1..n} dmapped Block(…)] real;
ref ZeroBasedArr = MyDistArr.reindex({0..#m, 0..#n});
foo(ZeroBasedArr);
proc foo(X: [?D]) {
  var Y: [D] real;      // Y is now distributed like X / MyDistArray
  on Locales[2] {
    const s = D.size; // locale 2 has a local copy of D; can compute locally
  }
}
```

Array Views: Impact and Next Steps

Impact:

- Array views of distributed arrays behave as you'd expect
- Communication requirements have been reduced in such cases

Next Steps (see 1.15 release notes for details):

- Restore ability to pass array views to default initializers
- Fix type query behavior for array views

Compressed Sparse Row/Column Layouts (CSR/CSC)

CSR/CSC

Background: Chapel has supported CSR layouts, but not CSC

- CSR (Compressed Sparse Row) supported by LayoutCSR
- CSC (Compressed Sparse Column) has not been supported
  - useful for interoperability, efficient CSR * CSC matrix multiplication, …

This Effort:

- Generalized LayoutCSR to support CSC as well:

```
// CSC specified through param-argument
var cscD: sparse subdomain(D) dmapped CS(compressRows=false);
// CSR is the default
var csrD: sparse subdomain(D) dmapped CS();
```

Status:

- Replaced LayoutCSR with LayoutCS
- Deprecated LayoutCSR (will be removed in future releases)

Next Steps: improve performance of CSR, CSC layouts

Optimizing Sparse bulkAdd

Sparse bulkAdd

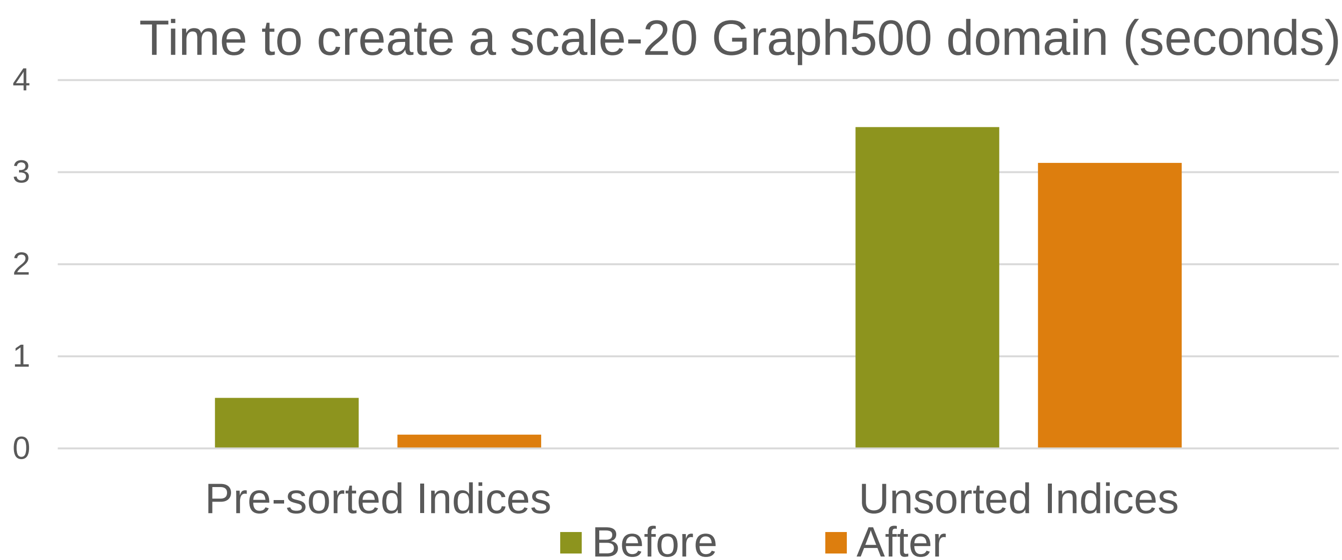
Background: Sparse domains support bulkAdd()

- Adds many new indices at once for efficiency

This Effort: Optimize bulkAdd() when domain is empty

- Contributed by Engin Kayraklioglu

Impact: Improved performance for some use cases:



Bulk Array Expansion

Bulk Array Expansion

Background: Array expansion interfaces had an issue

- Expanding arrays using array arguments resulted in promotion
- The promotion pushed new elements in an undefined order:

```
var A = [1,2,3];
A.push_back([4,5,6]); // Non-deterministic results, e.g. [1, 2, 3, 5, 6, 4]
```

This Effort: Added array overloads for extension methods

- New overloads:

```
array.push_back(arr: [])
array.push_front(arr: [])
array.insert(pos: idxType, arr: [])
```

- Optimized to grow array memory only once

Impact: Arrays can append, prepend, and insert in bulk

- The following code behaves as expected:

```
var A = [1,2,3];
A.push_back([4,5,6]); // A is now: [1,2,3,4,5,6]
```

Parallel Array Initialization

Parallel Array Initialization

Background: We initialize numerical arrays in parallel
- To get correct first-touch on NUMA systems

This Effort: Initialize POD (plain old data) arrays in parallel
- For example: records with numeric fields, tuples, etc.

Impact: No visible improvements in our performance graphs
- Significantly improved performance of a user's nbody simulation

Next steps: Extend parallel initialization to all arrays
- Including arrays-of-arrays
- Also want to permit users to override initialization strategy

Other Array, Domain, Domain Map Improvements

Other Array, Domain, Domain Map Changes

- **Added a version of reindex() that takes range arguments**
  - previously required a domain argument

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