Array Improvements

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Outline

- Array Slice Improvements
- Bulk-Transfer Improvements
- Scan Improvements
- Sparse Domain Improvements

Array Slice Improvements

Array Slices: Background

- Chapel supports array slices as a means of referring to a subset of an array:

```
… A[lo..hi] …
… A[myDomain] …
```

- However, slices have traditionally been expensive, esp. for distributed arrays…
  - communication to create a distributed domain representing the slicing indices
  - communication to create a distributed view representing the array slice
  - communication to move array elements around
    - e.g., in assignment contexts:

```
A[i..#sliceSize] = B[j..#sliceSize];
```


Array Slices: This Effort

- Reduced the overheads caused by slicing arrays
  - Changed slices to be governed by their slicing domain
  - Implemented a technique that reduces other slice-related overheads
  - Optimized data transfers between array slices using bulk-transfer
    - (see next section)
- Improved the expressiveness of array slicing:
  - Enabled sparse slicing of dense arrays
  - Reduced barriers to supporting slices of associative arrays

Governing Slices by their Domains

Slice Governance: Background

- Historically, Chapel has created a snapshot of the domain slicing an array:
  - a slice expression like this:

    … `A[Dom]` …
  - essentially becomes:

```
const tmpSliceDom = A.domain[Dom];    // intersect A's domain with Dom
… A[tmpSliceDom] …
```

- This could be very expensive:
  - if 'A' is distributed, a new distributed domain was created for 'tmpSliceDom'
  - if 'Dom' requires O(*n*) storage, a full copy of that storage was created
    - e.g., sparse or associative domains

Slice Governance: This Effort

Concept: rather than creating new domains, have slices refer to the original:

- a slice expression like this:

```
… A[Dom] …
```

- now essentially becomes:

```
ref tmp = newSliceView(A, Dom);   // represent A being sliced by Dom
… tmp …
```

Implications:

- Overheads associated with creating new domains are eliminated
- Changes slice behavior in some cases

Slice Governance: Semantic Impact

Consider the following example:

```
var D = {1..10};
ref Aslice = A[D]; // capture a reference to a slice
D = {1..20};       // change the slicing domain
writeln(Aslice);   // what should happen here?
```

Previously: since the slice used a copy of ‘D’, 10 elements were printed

Now: since it’s governed by ‘D’ itself, 20 elements are

Slice Governance: Semantic Impact

Consider the following example:

```
const DLoc = {lo..hi};
const DDist = newBlockDom({lo..hi});
var B = A[DLoc];
var C = A[DDist];
```

Previously:

- ‘B’ and ‘C’ would have been distributed arrays, each with its own domain

Now:

- ‘B’ is a new local array whose domain is ‘DLoc’
- ‘C’ is a new distributed array whose domain is ‘DDist’

Slice Governance: Semantic Impact

- The preceding examples represent changes to the language, yet powerful ones
  - Can create views of data that respond to dynamic changes:

```
ref SeattleIDs = ID[EmployeesInSeattle];
// …can modify `EmployeesInSeattle' as the program runs…
… SeattleIDs …   // this will always refer to the IDs of those employees
```

  - Can now distinguish between slice copies that should be localized vs. not:

```
const smallChunk = {lo..#4, lo..#4};
const bigChunk = newBlockDom({2..n-1, 2..n-1});
var Ablock = A[smallChunk];   // I just want a small, local 4x4 array
var AInner = A[bigChunk];     // I want to keep this array distributed
```

  - They are also more flexible and consistent with existing Chapel semantics

Slice Governance: Performance Impact

Creating a slice like this…

```
ref mySlice = myDistArray[myDistDom];
```

…results in the following communications (for 16 locales):

version	role	on	nonblocking on	fast on	put	get
1.19	originating locale	4	numLocales-1	0	0	0
	typical locale	0-4	0	1	1	128

Slice Governance: Performance Impact

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version	role	on	nonblocking on	fast on	put	get
1.19	originating locale	4	numLocales-1	0	0	0
	typical locale	0-4	0	1	1	128
with slice governance	originating locale	**2**	**0**	0	0	0
	typical locale	**0-2**	0	**0**	**0**	**0**

- Reduced communication is due to no longer creating a copy of ‘myDistDom’
- Cost of operating on the slice expression is unchanged

Slice Governance: Sparse Slicing

- This change also trivially enabled sparse slicing of dense arrays, which we've…
  - …intended to support since day one
  - …advertised in talks for years
  - …never actually supported until now

```
const D = {1..10, 1..10};
const Diag: sparse subdomain(D)
          = [i in 1..10] (i,i);
var A: [D] int;

A[Diag] = 1;
writeln(A);
```

```
1 0 0 0 0 0 0 0 0 0
0 1 0 0 0 0 0 0 0 0
0 0 1 0 0 0 0 0 0 0
0 0 0 1 0 0 0 0 0 0
0 0 0 0 1 0 0 0 0 0
0 0 0 0 0 1 0 0 0 0
0 0 0 0 0 0 1 0 0 0
0 0 0 0 0 0 0 1 0 0
0 0 0 0 0 0 0 0 1 0
0 0 0 0 0 0 0 0 0 1
```

Lazy Slicing

Reducing slice overheads

Lazy Slicing: Background

Creating a slice like this…

```
ref mySlice = myDistArray[myDistDom];
```

…still results in the following communications, involving all locales:

version	role	on	nonblocking on	fast on	put	get
with slice governance	originating locale	2	0	0	0	0
	typical locale	0-2	0	0	0	0

These remaining communications are due to “proactive slicing”:

- When slicing a distributed array, we tell every locale about the slice
- But what if most of them don’t care…?
  - e.g., the slice doesn’t even involve their sub-arrays

Lazy Slicing: This Effort

Concept: only tell locales about slices on a need-to-know basis

- As an example:

```
ref mySlice = myDistArray[myDistDom];
// only the current locale needs to know about mySlice here…
forall a in mySlice do // other locales do here, but only if they own a piece
  a += 1.0;
```

Approach:

- when creating slices, only represent them locally
- forward / serialize them across on-clauses
  - note that this is cheap for distributed domain/array slices (send IDs only)

Lazy Slicing: Impact (creating slices)

Creating a slice like this…

```
ref mySlice = myDistArray[myDistDom];
```

…no longer requires any communication under lazy slicing:

version	role	on	nonblocking on	fast on	put	get
1.19	originating locale	4	numLocales-1	0	0	0
	typical locale	0-4	0	1	1	128
with slice governance	originating locale	2	0	0	0	0
	typical locale	0-2	0	0	0	0
with lazy slicing as well	originating locale	**0**	0	0	0	0
	typical locale	**0**	0	0	0	0

Lazy Slicing: Impact (using slices)

Moreover, using the slice…

```
forall a in mySlice do
  a += 1.0;
```

…does not change communications relative to standard practice:

version	role	on	nonblocking on	fast on	put	get
1.19	originating locale	0	15	0	0	0
	typical locale	0	0	1	0	0
with lazy slicing	originating locale	0	15	0	0	0
	typical locale	0	0	1	0	0

The payloads of the “nonblocking ons” do change modestly to represent the slice

Lazy Slicing: Status, Next Steps

Status: Lazy slicing is not enabled by default on master today

- While performance improves in many cases, others exchange on's for get's
  - e.g., zippered iteration involving slices
- Users can opt-in by compiling with `-schpl_serializeSlices=true`

Next Steps:

- Enable distributed arrays and domains to generally be forwarded
- Permit tuples to be forwarded / serialized if their elements can be
  - (these are used for zippered iteration)

Array Slices: Status, Next Steps

Status: Array slices have improved in Chapel 1.20

- in terms of semantics and performance
- particularly for slices that use domains (rather than ranges)

Next Steps:

- Turn on lazy slicing by default
- Reduce overheads for slicing using ranges
  - “easier” because there’s no pre-existing domain that could change
  - challenging because it requires lazily creating a new distributed domain

Bulk-Transfer Improvements

Bulk-Transfer Improvements: Background

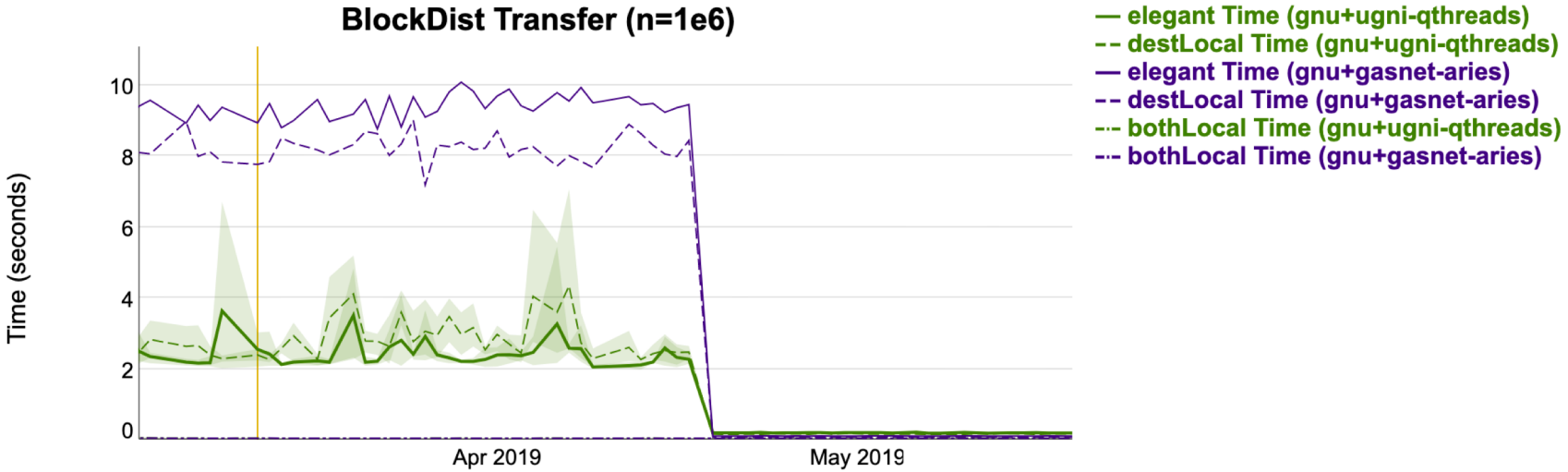
- Support for bulk-transfer of block-distributed arrays has existed since 2013
  - Contributed by external developers
- Not enabled by default due to lack of testing
- Could be enabled with config param
  - "-suseBulkTransferDist"

Bulk-Transfer Improvements: This Effort, Impact

This Effort: Enable bulk-transfer by default for BlockDist

- Simplified implementation and added tests to improve confidence
- Added config param 'disableBlockDistBulkTransfer' to disable optimization

Impact: Improved performance without requiring knowledge of special flags



Bulk-Transfer Improvements: Next Steps

- Find ways to reduce metadata communication in bulk-transfer implementation
  - e.g., caching remote array metadata
  - Optimize placement of tasks used to initiate bulk-transfers
  - on-statements and PUTs vs. GETs

- Improve performance of related array assignment features
  - e.g., reduce cost of creating an array slice

Scan Improvements

Scans: Background, This Effort

Background:

- Chapel has supported a scan (parallel prefix) operator since the outset
- Yet, historically, it has not received much attention
- 1.19 added an opt-in parallel implementation for block and local 1D arrays

This Effort:

- enabled the parallel implementation by default
- optimized the implementation for single-task runs (when the system is loaded)
- fixed a bug affecting scans of array slices (e.g., `+ scan A[lo..hi]`)
- fixed a bug affecting scan operators other than '+'

Scans: Impact, Status, Next Steps

Impact:

- The scan operator is now scalable for local and Block 1D arrays

Next Steps:

- Design and support other flavors of scan:
  - exclusive scans
  - segmented scans
  - multidimensional scans (via partial scans or wraparound)
- Parallelize scans for other expression types:
  - other array layouts and distributions
  - other shape-ful expressions (e.g., `+ scan (A:int)')

Sparse Domain Improvements

Sparse Domains: Background, This Effort

Background: Index addition to sparse domains is an expensive operation

- There is support for adding indices in bulk:

```
spsDom += arrayOfIndices;
```

- However this has some limitations:
  - Users have to manually create an array to store indices before adding
  - Distributed index addition is bottlenecked by local sort

This Effort: Added two new ways of adding indices

- Buffered index addition
- Local index addition (for distributed arrays)

Sparse Domains: Status, Next Steps

Status:

- Buffered index addition:

```
var idxBuf = spsDom.makeIndexBuffer(size=N);   // create buffer
for idx in someIndexGenerator() do
  idxBuf.add(idx); // buffer will be flushed as it gets full
idxBuf.commit();    // commit the remaining indices in the buffer
```

- Local index addition:

```
coforall l in Locales do on l do
  distSpsDom.bulkAdd(getLocalIndices(), addOn=here);
```

Next Steps:

- Support unbounded index buffers

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