Array Improvements

Chapel version 1.20
September 19, 2019
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:

```typescript
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:

```javascript
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
Creating a slice like this…

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

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

<table>
<thead>
<tr>
<th>version</th>
<th>role</th>
<th>on</th>
<th>nonblocking on</th>
<th>fast on</th>
<th>put</th>
<th>get</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.19</td>
<td>originating locale</td>
<td>4</td>
<td>numLocales-1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>typical locale</td>
<td>0-4</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>128</td>
</tr>
</tbody>
</table>
Slice Governance: Performance Impact

Creating a slice like this…

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

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

<table>
<thead>
<tr>
<th>version</th>
<th>role</th>
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<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>typical locale</td>
<td>0-4</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>128</td>
</tr>
<tr>
<td>with slice governance</td>
<td>originating locale</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>typical locale</td>
<td>0-2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

- 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

\[
\text{const } D = \{1..10, 1..10\}; \\
\text{const } \text{Diag: sparse subdomain}(D) \\
\quad = [i \text{ in } 1..10] \ (i,i); \\
\text{var } A: [D] \text{ int}; \\
A[\text{Diag}] = 1; \\
\text{writeln}(A);
\]
Lazy Slicing

Reducing slice overheads
Creating a slice like this…

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

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

<table>
<thead>
<tr>
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<th>role</th>
<th>on</th>
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<th>fast on</th>
<th>put</th>
<th>get</th>
</tr>
</thead>
<tbody>
<tr>
<td>with slice</td>
<td>originating locale</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>governance</td>
<td>typical locale</td>
<td>0-2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

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...

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

...no longer requires any communication under lazy slicing:

<table>
<thead>
<tr>
<th>version</th>
<th>role</th>
<th>on</th>
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<th>fast on</th>
<th>put</th>
<th>get</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.19</td>
<td>originating locale</td>
<td>4</td>
<td>numLocales-1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>typical locale</td>
<td>0-4</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>128</td>
</tr>
<tr>
<td>with slice governance</td>
<td>originating locale</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>typical locale</td>
<td>0-2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>with lazy slicing as well</td>
<td>originating locale</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>typical locale</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
Lazy Slicing: Impact (using slices)

Moreover, using the slice...

\[
\text{forall } a \text{ in mySlice do}
\]
\[
a += 1.0;
\]

…does not change communications relative to standard practice:

<table>
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<th>fast on</th>
<th>put</th>
<th>get</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.19</td>
<td>originating locale</td>
<td>0</td>
<td>15</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>typical locale</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>with lazy slicing</td>
<td>originating locale</td>
<td>0</td>
<td>15</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>typical locale</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

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:

```javascript
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:

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

Next Steps:

• Support unbounded index buffers
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