Domain Map Improvements

Chapel Team, Cray Inc.
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Outline

- Stencil Distribution
- Sparse Block Distribution
- Bulk Add for Sparse Domains
- Locality Queries for Domains and Distributions
- Associative Domain Improvements
- Other Domain Map Improvements
Stencil Distribution
StencilDist: Background

- **Block-like distribution that caches remote halo elements**
  - For a user-provided number of indices outside the domain

- **Useful because stencils access neighboring elements**

- **Initially developed during miniMD intern project**
  - Functional for miniMD, but buggy for other use cases
  - Lived under miniMD’s source tree in previous releases

- **Occasional interest from external users**
  - Typically replied with “Cool! But be aware of bugs”
  - Having to copy the distribution from miniMD’s directory was odd
StencilDist: Background

- Much better miniMD performance compared to BlockDist
  - 16 BW nodes on XC30

![miniMD - size 20](image)

- Bar chart comparing miniMD performance for BlockDist and StencilDist.
StencilDist: This Effort

- **Promoted StencilDist to $CHPL_HOME/modules/dists**
  - Makes it simple to "use" in a program

- **Improved testing**
  - Confirmed and exposed some embarrassing bugs

- **Bug fixes**
  - Slicing (used to drop cached elements)
  - Strided domains (had been completely broken)
  - Block-like view (now its own method)
    - Supports a view with no caching, easier to reason about reads/writes
StencilDist: Status and Next Steps

**Status:**
- Now a standard distribution
- No known correctness bugs

**Next Steps:**
- Improve performance
  - Look at some known locality issues
- Investigate new features
  - 6-face halo exchange vs. 27-point
  - Only cache on one side of an axis (PRK motivated)
- Possibly merge with BlockDist to create a single powerful distribution
- Move towards having compiler automatically insert communication
Sparse Block Distribution
Sparse Block: Background

- Sparse Block originally prototyped in fall 2012
- Supported distributed sparse arrays and domains
  … but prototype fell by the wayside
- Sparse Block implemented with the Block distribution
  - the data distribution is the same
  - but store sparse local domains and arrays rather than dense
Sparse Block: Example

```javascript
var Dom = {1..4, 1..8} dmapped Block( {1..4, 1..8} );

var SparseDom : sparse subdomain(Dom);
var Indices = [(1,1), (2,2), (3,1), ...]
SparseDom += Indices;
```
Sparse Block: This Effort

- Cleaned up the prototype from 2012 and get it working
  - fixed compiler bugs
  - added missing features
- Supports users of distributed sparse data structures
Sparse Block: Status and Next Steps

Status:
- Basic functionality available
  - There may be missing features – not broadly tested yet
- bulkAdd or using += in bulk is critical to performance
- Available in 1.14 release

Impact: Enables sparse / distributed graph algorithms

Next Steps:
- Build more with sparse block
- Consider other ways of declaring sparse arrays and domains
- Further optimize communication for sparse block
- Investigate related compiler optimizations
- Explore distributions other than Block (e.g., recursive bisection)
Bulk Add for Sparse Domains
Bulk Add

**Background:** Often, `+=` is used to add elements to a domain

```haskell
var DenseDomain = {1..10};
var D: sparse subdomain(DenseDomain);
D += 1; D += 2; D += 3; D += 5; D += 7;
```

- but this approach has significant performance overhead
- per-element locking, reallocating, sorting, communicating, resizing arrays

**This Effort:** sparse domains now support bulk addition

```haskell
D += [1,2,3,5,7];
// or, for more control:
D.bulkAdd([1,2,3,5,7], dataSorted=true);
```

**Impact:** Greatly reduces overhead

**Next Steps:** Support bulkAdd efficiently on all irregular domains
- Associative and Opaque
Speedup from bulkAdd, adding 100000 indices

![Graph showing speedup comparison between bulkAdd and bulkAdd sorted for different layouts and number of locales.](image)

- **Coordinate List (COO) Layout**
- **Compressed Sparse Row (CSR) Layout**

Legend:
- Green bar: bulkAdd
- Orange bar: bulkAdd sorted
Locality Queries for Domains and Distributions
Locality Queries for Domains and Distributions

**Background:** Chapel supports locality-based queries on arrays

- `A.targetLocales()` // returns the locales grid
- `A.getLocalSubdomain()` // returns the single local portion, if possible
- `A.getLocalSubdomains()` // iterates over all local portions
- `A.hasSingleLocalSubdomain()` // check if `getLocalSubdomain` can be called

- these were only supported on arrays

**This Effort:** Added these operations to domains and distributions

**Impact:** Arrays no longer required to make these queries

<table>
<thead>
<tr>
<th></th>
<th>distribution</th>
<th>domain</th>
<th>array</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>targetLocales()</code></td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td><code>getLocalSubdomain()</code></td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td><code>getLocalSubdomains()</code></td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
</tbody>
</table>
Associative Domain Improvements
Associative Domain Sizes

**Background:** Associative domains implemented via a hash table
- implemented with quadratic probing
  - uses a table of prime numbers
- these primes previously stopped at about 2 billion elements,
  - this limited the size of associative domains

**This Effort:** Improve the primes used by associative domains
- primes now go up to $2^{60}$
- primes selected to maximize usage of jemalloc allocation blocks

**Impact:** Larger associative domains are possible

**Next Steps:** Consider supporting different hash table algorithms
requestCapacity on Associative Domains

**Background:** requestCapacity existed but wasn't documented
- useful when adding many elements to an associative domain
- can be used to minimize the number of reallocations

```chapel
var D: domain(int);
D.requestCapacity(n);  // indicate n elements will be added
for i in 1..n {
    D += computeElement(i);  // D += computeElement(i);
}
```

**This Effort:** Adds documentation for requestCapacity

**Impact:** requestCapacity now available to Chapel users

**Next Steps:** Support requestCapacity on other irregular domains
Distributed Associative Domains/Arrays (WIP)

Background: Distributed associative support has been missing
- associative domains require distinct distributions
  - e.g., Block doesn't make sense for a domain(string)
- a prototype was developed in 2009 but was only partially functional
  - concept: user provides a value→locale mapper object

This Effort: Clean up distributed associative implementation

```plaintext
proc Map.indexToLocaleIndex(ind, targetLocs: [] locale): int
var D: domain(string) dmapped
   new UserMapAssoc(idxType=string, mapper=new Map());
```

Impact: Supported multi-locale label propagation study

Next Steps:
- Promote to modules/distributions
- Improve performance
Other Domain Map Improvements
Other Domain Map Improvements

- Block distributions support strided bounding box args
  - previously, bounding boxes had to be non-strided
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