Library Improvements

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@ChapelLanguage

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Outline

- New Modules
  - Collection Types
  - UnitTest
  - EpochManager
- Module Improvements
  - Sort
  - Reflection
  - LinearAlgebra

New Modules

- Collection Types
- UnitTest
- EpochManager

Collection Types

List, Map and Set

Collections: Background

- List, set, and map operations had been supported by arrays and domains

```
// Append to a "list"
var D1 = {1..0};
var A: [D1] real;
A.push_back(1.1);
```

```
// Add to a "map"
var D2: domain(string);
var B: [D2] int;
B[”hello”] = 42;
```

Collections: Background

- Using arrays as collection types had some problems
  - Required (via assertion) that the array and its domain had a 1:1 relationship
    - resulted in surprising instabilities for users once domains were shared

```
// Append to a "list"
var D1 = {1..0};
var A: [D1] real;
A.push_back(1.1);   // OK
var C = A;
A.push_back(2.2);   // error
```

```
// Add to a "map"
var D2: domain(string);
var B: [D2] int;
B[”hello”] = 42;    // OK
var D = B;
B[”bye”] = 33;      // error
```

Collections: Background

- Using arrays as collection types had some problems
  - Permitted modifying ‘const’ domains

```
// Illegally modifies D1
const D1 = {1..0};
var A: [D1] real;
A.push_back(1.1);
```

```
// Illegally modifies D2
const D2: domain(string);
var B: [D2] int;
B[”hello”] = 42;
```


Collections: This Effort

- Implemented new collection types
  - list – Replaces "vector-like" operations on arrays
  - map – Replaces "map-like" operations on arrays
  - set – Alternative to set operations on associative domains

- Deprecated list- and map-style operations on arrays
  - pop_back, push_back, pop_front, push_front
  - clear, insert, remove
  - |=, +=, ^=, &=

Collections: List

- The list type enables users to build up and iterate over a collection of elements

```
use List;
var lst: list(int);      // Declare a list
lst.extend(1..8);        // Extend with items from a range.
writeln(lst);
```

- Parallel-safe operations can be used by setting "parSafe" to true at initialization

```
var lst: list(int, parSafe=true);
coforall tid in 1..8 with (ref lst) do
    lst.append(tid);
```

Collections: List

- Intended to replace "vector-like" array methods, which are now deprecated

```
var foo: [1..0] int;
foo.push_back(4); // warning: push_back is deprecated – please use list.append
foo.clear();      // warning: clear is deprecated – please use list.clear
```

- Can now be written as:

```
use List;
var foo: list(int);
foo.append(100);
foo.clear();
```

Collections: Map

- The map type enables users to associate keys with values. It supports…
  - Assignment to any index of the key type
  - Reading from indices in the map
  - Iterators over the keys, values, or key-value pairs
  - Boolean set operators over the keys

```
// Boolean set operators
m1 |= m2;
m1 &= m2;
m1 ^= m2;
```

```
// Declarations and basic usage
use Map;
var m1 = new map(string, int);
var m2 = new map(string, int);
m1["one"] = 1;
m2["two"] = 2;
```

```
// Iterators
for k in m1 {…} // keys
for v in m1.values() {…} // values
for kv in m1.items() {…} // both
```

Collections: Map

- Intended to replace "map-like" methods on arrays, which are now deprecated

```
var D: domain(string);
var A: [D] int;
A["hello"] = 42;    // warning: growing associative domains by assigning
                    // to an array is deprecated
```

- Can now be written as:

```
var m = new map(string, int);
m["hello"] = 42;
```


Collections: Set

- Offers a lightweight alternative to domains
- Similar to both list and map, set operations can be made parallel-safe

```
use Set;
var s1: set(int, parSafe=true);
coforall i in 1..8 with (ref s1) do
  s1.add(i);
writeln(s1 ^ s1);
```

Collections: Impact, Status

Impact:

- New list, set, and map data structures added to standard modules
- Vector-like and map-like methods on arrays are deprecated

Status:

- All three types have testing coverage
- List and map are used in the Mason, UnitTest, and TOML packages

Collections: Next Steps

Next Steps:

- Collect user feedback
- Investigate the performance of list and map
- Explore potential optimizations
- Make sure parallel safety strategies are appropriate
- Consider alternative underlying implementations

UnitTest

UnitTest: Background

- Existing options for writing Chapel user code tests are problematic
  - start_test
    - Not ideal for writing unit tests
    - Not a user-facing test feature, not supported by mason
  - mason test
    - Very limited capabilities by design
    - Only uses exit code of program to determine pass/fail status

UnitTest: This Effort

- Introduced a ‘UnitTest’ package module for writing unit tests in Chapel
- Implemented as a Google Summer of Code project

Student	Mentors
Krishna Kumar Dey	Ben Albrecht, Lydia Duncan, Sam Partee

- Functions are designated as tests through their signature
  - Test functions must take a ‘borrowed Test’, throw, and return nothing:

```
proc someTest(t: borrowed Test) throws
```


UnitTest: This Effort

- ‘mason test’ acts as the test runner both inside and outside of mason packages
  - Inside mason packages, runs tests in ‘test/’ directory
  - Outside mason packages, finds tests in current directory, unless path given
- Test runner compiles and runs tests
  - This allows resuming test suite after a halt

UnitTest: Test Assertions

- The ‘Test’ type provides JUnit-style assertion methods

```
proc testFoo(t: borrowed Test) throws {
  t.assertTrue(FileSystem.isFile('foo'));
  t.assertFalse(FileSystem.isDir('foo'));

  t.assertEqual(here.id, 0);
  t.assertNotEqual(here.id, 1);

  t.assertGreaterThan(10, 1);
  t.assertLessThan(1, 10);
}
```


UnitTest: Example Usage

```
use UnitTest;

proc testUpper(test: borrowed Test) throws {
  test.assertEqual('foo'.toUpper(), 'FOO');
}
UnitTest.main();

> mason test example.chpl
-----------------------------------------------------------
Ran 1 test in 11.3092 seconds

OK (passed = 1 )
```


UnitTest: Skipping Tests

- Metadata is attached to test functions via ‘Test’ methods
  - Tests can be skipped with or without a condition:

```
proc skip(reason: string) throws
proc skipIf(condition: bool, reason: string) throws
```


UnitTest: Skipped Test Example

```
proc testFoo(t: borrowed Test) throws {
  t.skipIf(CHPL_LLVM == 'none', "This test requires LLVM");
  ...
}

proc testFoo(t: borrowed Test) throws {
  t.skip( "This is not yet expected to work");
  ...
}
```

UnitTest: Test Dependencies

- Cross-test dependencies can be specified:
  - Functions are specified as first-class functions

```
proc dependsOn(tests: argType ...?n) throws
```


UnitTest: Test Dependency Example

```
use FileSystem, UnitTest;
proc testMoveDir(t: borrowed Test) throws {
  // testMkdir must be run before testMoveDir is run
  t.dependsOn(testMkdir);
  moveDir('foo', 'bar');
  t.assertTrue(isDir('bar'));
}
proc testMkdir(t: borrowed Test) throws {
  mkdir('foo');
  t.assertTrue(isDir('foo'));
}
```


UnitTest: Multilocale Tests

- Tests can specify how many locales they require
  - Tests can list discrete numbers of locales supported:

```
proc addNumLocales(locales: int ...?n) throws
```

  - Tests can provide a range of locales supported:

```
proc maxLocales(value: int) throws
proc minLocales(value: int) throws
```

- The test runner makes multiple passes with different numbers of locales …

  ... such that each tests is run with a number of locales that it requires

- Running one test with *N* numLocales values requires wrapping it with *N* tests

UnitTest: Multilocale Test Example 1

```
proc foo(t: borrowed Test) throws {
  t.addNumLocales(4);
  // Will run with 4 locales only
}

proc bar(t: borrowed Test) throws {
  t.minLocales(8);
  t.maxLocales(16);
  // Will run with 16 locales only (defaults to max of locale bounds)
}
```


UnitTest: Multilocale Test Example 2

```
proc foo(t: borrowed Test) throws {
  t.addNumLocales(4, 8);
  // Will run with 8 locales only
}

proc bar(t: borrowed Test) throws {
  t.minLocales(8);
  t.maxLocales(16);
  // Will run with 8 locales only
}
```

UnitTest: Multilocale Test Example 3

```
proc foo() {
  // Will run with 4 and 8 locales, because called from foo4 and foo8
}
proc foo4(t: borrowed Test) throws {
  t.addNumLocales(4);
  foo();
}
proc foo8(t: borrowed Test) throws {
  t.addNumLocales(8);
  foo();
}
```

UnitTest: Status, Next Steps

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Status:

- Chapel has an official user-facing test framework
- UnitTest is available as a package module
- ‘mason test’ is the UnitTest test runner

Next Steps:

- Support test suites as modules, records, and/or classes
- Support introspective assertions, similar to pytest
  - Allows a general assert function to give useful information when failing
- Respond to user feedback

EpochManager

EpochManager: Background

- Would like Chapel to include a library of lock-free data structures:
  - After all, Chapel has an emphasis on productivity and performance
- Two missing features preventing implementation of such structures
  1. Compare-and-swap is not implemented for Chapel classes
     - Challenge: 128-bit wide pointers in multilocale configurations
  2. A general solution to the ABA problem is needed
     - Challenge: Chapel is not garbage collected
     - Challenge: Generation counters would require 256-bit compare-and-swap
     - Challenge: Hazard Pointers are not sufficiently composable

EpochManager: This Effort

This Effort: Add prototype EpochManager and related package modules

- Implemented as a Google Summer of Code project

Student	Mentors
Garvit Dewan	Louis Jenkins Michael Ferguson

- EpochManager solves the ABA problem by deferring deletion in Epochs
- AtomicObjects provides compare-and-swap on local or wide pointers
- These enabled implementation of LockFreeQueue and LockFreeStack

Next Steps:

- Migrate 128-bit CAS support to runtime
- Handle nested usage of EpochManager

Module Improvements

- Sort
- Reflection
- LinearAlgebra

Sort Improvements

Sort: Background, This Effort

Background: A parallel radix sort was added in 1.19

- Only recursive sorts were run in parallel
  - count and bucketize were serial
- Not as fast as some C++ sort implementations
- No support for distributed sorting

This Effort:

- Improve the Sort module by fixing bugs and improving performance
- Prototype more performant algorithms and distributed sorting

Sort: Implementation Improvements

- For radix sort:
  - count step is now parallel
  - now supports floating point numbers as well as 'c_string'
- Arrays with domains using ranges with 'align' can now be sorted
- isSorted() is now efficient for Block-distributed arrays

Sort: Prototype Sorts

- Developed prototype two-array radix sort and distributed sort
  - These are included as undocumented features in the Sort module
- Two-array radix sort can offer significantly better performance
  - ~5x faster than the recursive implementation
  - but using 2x the space
- Distributed radix sort is functional but has scaling problems
- Described in a CHIUW 2019 presentation

Sort: Next Steps

Next Steps: Follow up on investigations to improve Sort module

- Decide if 2x space overhead is acceptable
- Investigate in-place parallel algorithms
- Resolve performance problems with distributed sort
- Investigate other distributed sort algorithms

Reflection Improvements

Reflection: Background, This Effort

Background: There was no way to query the location of the current code

- Users desired a way to know things like file name and line number
  - e.g. for logging

This Effort: Added source location query functions to the Reflection module

```
proc getLineNumber() param : int
proc getFileName() param : string
proc getRoutineName() param : string
proc getModuleName() param : string
```


Reflection: Impact, Next Steps

Impact: Chapel programs can now query source locations

```
use Reflection;
writeln(getFileName(), ":", getLineNumber(), " ",
        getModuleName(), ".", getRoutineName());
```

Next Steps:

- Add functionality for nested routines and modules
  - 'get[Module/Routine]Name()' only return the nearest module/routine
  - Want to be able reason about the full stack in nested cases
- Enable getting location information where a routine is called

LinearAlgebra Improvements

LinearAlgebra Module: Background, This Effort

Background: Chapel's LinearAlgebra module provides linear algebra routines

This Effort: New routines and improved support for distributed and/or sparse data

- New routines for CSR and COO matrices:

```
proc isDiag(A): bool;
proc isHermitian(A): bool;
proc isSymmetric(A): bool;
```


LinearAlgebra Module: This Effort

- The following are implemented as part of Google Summer of Code

Student	Mentors
Alvis Wong	Engin Kayraklioglu, Ben Albrecht

- New routines for linear system solution:

```
proc lu(A);
proc solve(A, b);
```

- Miscellaneous routines:

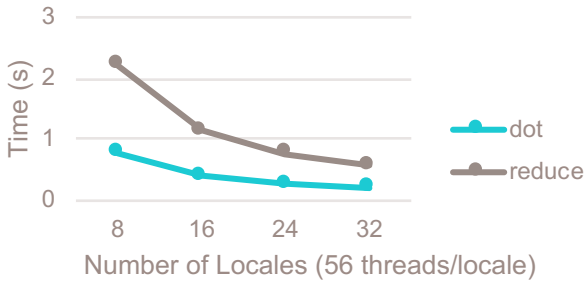
```
proc setDiag(X, offset=0, val=0);
proc det(A);
proc inv(A);
proc jacobi(A, ref x, b, tol=0.0001, maxiter=1000);
```

- More support for distributed vectors/matrices: 'plus', 'minus', faster 'dot'

LinearAlgebra Module: Impact, Next Steps

Impact:

- Support for more routines, on different types of data (sparse or distributed)
- Improved dot performance



Next Steps: Continue improvements

- More support for distributed and/or sparse data
- GPU support

For More Information

For a more complete list of library-related changes in the 1.20 release, refer to the following sections of the CHANGES.md file:

- Deprecated / Removed Library Features
- Standard Library Modules
- Package Modules
- Bug Fixes

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