Library Improvements

Chapel Team, Cray Inc.
Chapel version 1.15
April 6, 2017
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Outline

● **New Modules**
  ● Date and Time
  ● Owned and Shared
  ● Futures
  ● Linear Algebra

● **Module Improvements**
  ● BLAS Improvements
  ● FFTW Improvements
  ● MPI Improvements
  ● Other Library Improvements
New Modules
Date and Time
Date and Time Module: Background

- Desirable to work with dates and times from Chapel
  - Including generating, manipulating and comparing them

- No such functionality previously existed in Chapel
Date and Time Module: This Effort

- Implement a Date/Time module to handle the details
- Largely inspired by the Python datetime module

Types to represent…
- …Times (record time)
- …Dates (record date)
- …Combined Dates and Times (record datetime)
- …Amounts of time (record timedelta)
- Abstract base class for time zones (class TZInfo)

Operators to combine and compare in useful ways e.g.

\[
\begin{align*}
\text{datetime} + \text{timedelta} & \Rightarrow \text{datetime} \\
\text{date} - \text{date} & \Rightarrow \text{timedelta} \\
\text{timedelta} / \text{int} & \Rightarrow \text{timedelta} \\
\text{datetime} \geq \text{datetime} & \Rightarrow \text{bool}
\end{align*}
\]
Date and Time Module: Other Useful Methods

- **Constructor/Factory Methods**
  - `[date|datetime].today()`  // the current date
  - `[date|datetime].fromtimestamp(timestamp)`  // the date for 'timestamp'
  - `[date|datetime].fromordinal(ord)`  // 'ord' days after 12-31-0000
  - `datetime.now()`  // the current date and time
  - `datetime.combine(date, time)`  // combine the date and time

- **Formatting Methods**
  - `[time|date|datetime].isoformat()`  // create string
  - `[time|date|datetime].strftime(formatStr)`  // create string
  - `datetime.strptime(dateStr, formatStr)`  // read from string

- **General Methods**
  - `[date|datetime].toordinal()`  // number of days since 12-31-0000
  - `[time|date|datetime].replace()`  // Create a new value with fields replaced
  - `[date|datetime].weekday()`  // Day of the week for date
  - `[date|datetime].isocalendar()`  // (ISO year, ISO week #, ISO day of week)
Date and Time Module: Status and Next Steps

Status:
● Available in new DateTime standard module
● Allows users to store dates and times
● Manipulate, compare, and query information about them
● Includes basic support for including time zones
  ● Time zone definitions not included
  ● Can write 'TZInfo' subclasses to implement time zones as needed

Next Steps:
● Further review of interface and naming taking user input into account
### Chapel doesn't have garbage collection (GC)
- Users have to explicitly 'delete' class instances
- Traditional GC is unlikely to be appropriate for Chapel

### How does GC compare?

<table>
<thead>
<tr>
<th>Garbage Collection</th>
<th>'delete'</th>
</tr>
</thead>
<tbody>
<tr>
<td>+ simpler programming</td>
<td>– more chances for programmer error</td>
</tr>
<tr>
<td>+ eliminates memory leaks</td>
<td>– failure to delete results in leaks</td>
</tr>
<tr>
<td>+ eliminates common error cases</td>
<td>– may double delete, use-after-free</td>
</tr>
<tr>
<td>– implementation challenges due to distributed memory &amp; parallelism</td>
<td>+ simpler implementation</td>
</tr>
<tr>
<td>– performance challenges</td>
<td>+ predictable, scalable performance</td>
</tr>
<tr>
<td>– stop-the-world interrupts program</td>
<td></td>
</tr>
<tr>
<td>– concurrent collectors add overhead</td>
<td></td>
</tr>
<tr>
<td>– scalability may prove difficult</td>
<td></td>
</tr>
</tbody>
</table>
Owned and Shared: Background

● **Rust and C++ auto-pointers use a different strategy**
  ● user manages *ownership*; implementation takes care of deleting
  ● Rust includes compile-time checking to ensure safety properties
    ● in particular, compiler proves no use-after-free

● **A related approach seems better for Chapel**
  ● better usability than requiring 'delete'
  ● better performance than traditional GC

● **Some Chapel types already use a similar approach**
  ● involves *wrapper records*…
Owned and Shared: Wrapper Records

- Wrapper records enable class memory management
  - a class implements a particular data type
  - a record stores an instance of the class
  - the record controls copy and assignment behavior
    - copies can point to the same class instance, or
    - copies can allocate separate class instances, or ...
  - the record's deinit() method handles deleting the class instance

- This pattern is used with many built-in types
  - e.g., domains, arrays, distributions, strings

- Wrapper records rely on the implementation of records
  - correct record initialization, copy, and destruction are key
Historically, records had memory management issues

Fixing those has enabled progress in related areas:
- addressing leaks in record-wrapped types
- implementing more types as records

Recent progress in design and implementation:
- design: CHIP 13 "When Do Record and Array Copies Occur"
- implementation: graph below shows improvement in record tests
Owned and Shared: This Effort

● Create general-purpose wrapper records
  ● building upon progress with records

● Two initial patterns:
  ● Owned: uses a single-owner pattern to manage lifetime
    ● deletes contained class instance when it goes out of scope
    ● assignment and copy initialization are destructive ownership transfers
  ● Shared: uses reference-counting to manage lifetime
    ● contained class instance deleted when all Shared copies destroyed
    ● assignment and copy initialization share ownership

● Interested in feedback on this initial effort
Owned and Shared: Usage

● Create Owned or Shared types with a class instance:
  ```javascript
  var myOwned = new Owned(new MyClass());
  var myShared = new Shared(new MyClass());
  ```

● Empty an Owned or Shared and delete if appropriate
  ```javascript
  myOwned.clear(); // may delete instance; leaves the record storing nil
  ```

● Set the instance managed by an Owned or Shared
  ```javascript
  myShared.retain(new MyClass()); // may delete previous instance
  ```

● Borrow a pointer to the instance
  ```javascript
  var instance:MyClass = myOwned.borrow();
  // instance (the result of the borrow) is only valid while:
  // 1) the Owned/Shared record contains that instance
  // 2) the Owned/Shared record is in scope
  ```

● Call a method on the class
  ```javascript
  myShared.myClassMethod(); // forwards to borrow().myClassMethod()
  ```
Owned and Shared: Usage of Shared

● Starting with a Shared record managing a class instance:

```javascript
var myShared = new Shared(new MyClass());
```

● Share ownership with assignment or copy-initialization:

```javascript
var otherShared = myShared;
// now otherShared and myShared point to the same instance
// the instance will be deleted when all copies of the Shared go out of scope
// both assignment and copy-initialization share ownership
```
Owned and Shared: Usage of Owned

● Starting with Owned records managing class instances:

```javascript
var myOwned = new Owned(new MyClass());
var anotherOwned = new Owned(new MyClass());
```

● Destructively transfer ownership:

```javascript
var otherOwned = anotherOwned;
// anotherOwned now stores nil
// both assignment and copy-initialization transfer ownership
```

● Stop managing an instance and return it:

```javascript
var instance = myOwned.release();
// myOwned now stores nil and is no longer responsible for deleting;
// calling code must arrange to delete instance to prevent a memory leak
delete instance;
```
Owned and Shared: Safety Properties

● Are memory leaks still possible?
  ● yes, un-managed class instances can be created and used
  ● also, a class instance can be managed for only part of its lifetime
    ● un-managed before it is provided to Owned / Shared
    ● un-managed after Owned.release()

● Is use-after-free possible?
  ● yes, but in the future it might be detected at compile-time
  ● one use-after-free is possible in this way:
    ● result of 'borrow' is stored in a global variable
    ● Owned / Shared record goes out of scope and deletes the instance
    ● the borrowed pointer is dereferenced
  ● another possible use-after-free:
    ● a class instance is created and stored in a global variable
    ● Owned record initialized with it and is destroyed, deleting the instance
    ● the global variable is dereferenced
Owned and Shared: nil Safety

- Can an Owned / Shared record store nil?
  - currently, yes
    - like a variable of class type

- What happens with nil dereferences of class variables?
  - philosophy: only erroneous programs can have nil dereferences
  - run-time checks for nil dereferences are available
  - these are disabled with --fast, --no-checks, or --no-nil-checks

- Should Owned / Shared include more checking?
  - e.g. compiler proves that nil Owned / Shared is never dereferenced
  - e.g. always-on checks for nil in 'borrow', 'retain', or 'release'
  - current answer: no
    - it would be a big break from existing class behavior and philosophy
    - preventing nil class instances has big impact on the language design
    - ... e.g. must array elements be explicitly initialized on array creation?
Owned and Shared: Convenience

- Can Owned(T) or Shared(T) pass to an arg:T formal?
  - currently, no
  - we are considering allowing it with user-defined coercions

- Can Owned(Child) coerce into Owned(Parent) … assuming ‘class Child : Parent’?
  - currently, no
  - we are considering allowing it with user-defined coercions

- Can a method on T be called directly on an Owned(T)?
  - currently, yes
  - uses the new 'forwarding' feature
Owned and Shared: Current Surprises

- **Forwarding, but not coercing generally, can be surprising:**
  ```
  var a = new Owned(new C());
  var b = new Owned(new C());
  a.matches(b);
  ```

  ```
  class C {
    proc matches(other) {
      return this == other;  // error - this: C but other: Owned(C)
    }
  }
  ```

- **could be addressed with support for coercion from Owned(T) to T**

- **L-value checking is surprising for Owned:**
  ```
  var myOwned: Owned(C);
  myOwned = new Owned(new C(1));  // error: illegal lvalue in assignment
  ```

- **happens because Owned assignment is destructive (modifies RHS)**
- **could be addressed by relaxing l-value rules for Owned or generally**
Owned and Shared: Impact, Status, Next Steps

Impact:
● Easier to manage memory for class instances

Status:
● Owned, Shared are in package modules OwnedObject, SharedObject
● Interface is not yet final

Next Steps:
● Gain experience using Owned and Shared
● Address surprising l-value errors
● Decide if we want to implement compile-time use-after-free checks
  ● may require significant language changes
  ● see Borrow Checker in Rust and DIP 1000 in D
● Decide if we want to support coercions
  ● from Owned(T) to T
  ● from Owned(Child) to Owned(Parent)
  ● if so, start by implementing user-defined coercions
Futures
Futures: Background

● **Futures are a frequently requested feature**
  ● Futures for Chapel have been explored as far back as 2013

● **A Future…**
  …computes a function call in the background
  …is linked to a task to compute a value
  …can be stored in a variable
  …can be waited upon to return the value

● **Advantages over Chapel tasks and 'sync' / 'single' vars:**
  ● programs using only immutable future variables are deadlock-free
  ● runtime can know which task will unblock another
  ● simpler way to write the pattern of tasks that produce a value
Futures: This Effort and Next Steps

This Effort: Added Futures package module

- Contributed by Nick Park

```plaintext
use Futures;
proc calculate(n) { ... }
const future = async(calculate, 10); // starts calculate(10) in a task
// do other useful work...
compute(future.get()); // waits for task, passes result to compute()
```

Next Steps: Consider incorporating Futures into the language

- e.g., 'begin' expressions could generate Futures
- consider deprecating 'single' in favor of Futures
Linear Algebra
Linear algebra is core to a large number of applications

- Machine learning, quantum chemistry, computational physics, etc.

Chapel's linear algebra support in 1.14 included:

- LAPACK module
  - Chapel interface to standard LAPACK library
- BLAS module
  - Chapel interface to standard BLAS library
- LinearAlgebraJAMA
  - Written natively in Chapel
  - Limited routine coverage
LinearAlgebra: This Effort

- Design and implement a Chapel linear algebra library

- Current design choices
  - Implement in terms of BLAS for performant computations
    - Will also utilize LAPACK in future versions
  - Use Chapel arrays as matrices and vectors
    - Allows interoperability between LinearAlgebra matrices and other modules
  - Matrix and vector initializers create arrays with 0-based domains
  - Make additional array methods available through the module
    - For example:

```chapel
proc _array.T { return transpose(this); }
```
LinearAlgebra: Features

- **Matrix / Vector convenience initializers**
  
  ```
  var v = Vector(4);  // vector
  var m = Matrix(3, 4);  // matrix
  var i = eye(10, 10)  // identity matrix
  ```

- **Matrix structure functions**
  
  ```
  isDiag(A: [])
  isHermitian(A: [])
  isSymmetric(A: [])
  ...
  ```

- **Matrix/vector operations**
  
  ```
  dot(A, B)  // for combinations of scalars/vectors/matrices
  ```
Example 1: Rotate a vector with respect to Z-axis:

```plaintext
use LinearAlgebra;

var v1 = Vector(1, 0, 0, eltType=real);
const theta = pi;

var Rz = Matrix([cos(theta), -sin(theta), 0.0],
                 [sin(theta), cos(theta), 0.0],
                 [0.0, 0.0, 1.0],
                 eltType=real);

var v2 = dot(Rz, v1);
```
Example 2: Demonstrates initializers, dot, and transpose

```javascript
use LinearAlgebra;
use Random;

var rs = new RandomStream(real);

var M1 = Matrix(1000, 1000),
     M2 = eye(1000, 1000);
rs.fillRandom(M1);

// M1.T == transpose(M1)
var M3 = dot(M1.T, M2);
```
LinearAlgebra: Status & Next Steps

**Status:** LinearAlgebra prototype available in Chapel 1.15
- Prototype-related caveats noted in documentation

**Next Steps:** Improve LinearAlgebra module
- More features
  - Aiming for feature-coverage similar to Matlab and NumPy
- Support LAPACK routines
- Further review of design tradeoffs, taking user input into account
- Sparse array support
- Distributed array support
- More efficient native algorithms
  - e.g. transpose
Module Improvements
BLAS Improvements
BLAS Improvements: Background

- The BLAS module is made up of two components:
  - **C_BLAS**: Low-level extern API
    - Submodule in BLAS
    - C-type arguments
      
      ```c
      extern proc cblas_dgemm(...TransA: c_int, M: c_int, N: c_int, ...
      A:[] c_double, ...)
      ```

  - **BLAS**: High-level API
    - Generic across all matrix element types: real(32|64), complex(64|128)
    - Arguments with obvious defaults are made optional
      
      ```c
      ```

- BLAS 3 (matrix-matrix) routines supported in Chapel 1.14
BLAS Improvements: This Effort and Impact

This Effort: Added BLAS 1 & 2 support, improved interface

- BLAS 1: scalar-vector
- BLAS 2: vector-vector
  - With the exception of sparse formats: packed and banded arrays
- Dropped ldA argument from high-level interface
  - Inferred from array meta-data

Impact: BLAS module closer to completion

- Nearly full BLAS routine coverage
BLAS Improvements: Next Steps

● 100% BLAS routine coverage
  ● Support packed and banded arrays in BLAS 2

● Explore distributed and GPU BLAS support
  ● PBLAS
  ● CuBLAS, clBLAS

● Consider Distributing a BLAS implementation with Chapel
  ● Provide out-of-the-box high performance linear algebra
  ● Optionally downloaded and built as part of Chapel installation
  ● BLAS can be painful for users to build depending on system
FFTW Improvements
(contributed by Nikhil Padmanabhan)
FFTW Improvements

**Background:** FFTW module hard-coded 'require' statements
- In FFTW.chpl:
  ```
  require "fftw3.h", "-lfftw3";
  ```
- This did not support FFTW from Intel's Math Kernel Libraries (MKL)
  - MKL requires additional headers and different `-l` flags

**This Effort:** Added support for MKL implementations:
- Support MKL implementation based on 'config param':
  ```
  chpl -s isFFTW_MKL=true fftwProgram.chpl
  ```
- Use new ‘require’ capabilities to conditionally require MKL headers
- Remove `-l` flags from 'require' statements

**Impact:** FFTW module is more flexible

**Next Steps:** Propagate this approach to other libraries
- BLAS and LAPACK
- Use 'config param' to distinguish FFTW from FFTW_MT
MPI Improvements
MPI Improvements

**Background:** MPI module supports MPI calls within Chapel
- Still a work-in-progress module
- 'spmd' flag required to specify SPMD ranks for mpirun launcher
  - Complicated testing setup for MPI SPMD mode

**This Effort:** Improved launcher support
- mpirun launcher given default value: '--spmd=1'
- Fixed a bug revealed by testing

**Status:** MPI module now tested nightly
- Run linux64 SPMD tests nightly for '--spmd=1' and '--spmd=4'

**Next Steps:** Improve supported configurations and features
- Support gasnet+aries, ugni, qthreads
- Add MPI-2 and MPI-3 routines
Other Library Improvements

- RandomStream argument improvements for initializer
- ‘barrier’ changed from class to record
- conjg() now preserves type
- ‘List’ now cleans up its memory
  - contributed by Sagar Khatri
- MatrixMarket naming and bug fix improvements
- removed deprecated 'Sort' and 'Search' functions
- removed deprecated 'BigInt' class in favor of 'bigint' value
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