Library Improvements

Chapel Team, Cray Inc.

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Outline

- **New Modules**
  - Date and Time
  - Owned and Shared
  - Futures
  - LinearAlgebra
- **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**

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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.**

```
datetime + timedelta ⇒ datetime
date - date ⇒ timedelta
timedelta / int ⇒ timedelta
datetime >= datetime ⇒ bool
```

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' sublcasses to implement time zones as needed

Next Steps:

- Further review of interface and naming taking user input into account

Owned and Shared

Owned and Shared: Background

- **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?**

Garbage Collection	'delete'
+ simpler programming + eliminates memory leaks + eliminates common error cases	– more chances for programmer error – failure to delete results in leaks – may double delete, use-after-free
– implementation challenges due to distributed memory & parallelism	+ simpler implementation
– performance challenges – stop-the-world interrupts program – concurrent collectors add overhead – scalability may prove difficult	+ predictable, scalable performance

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

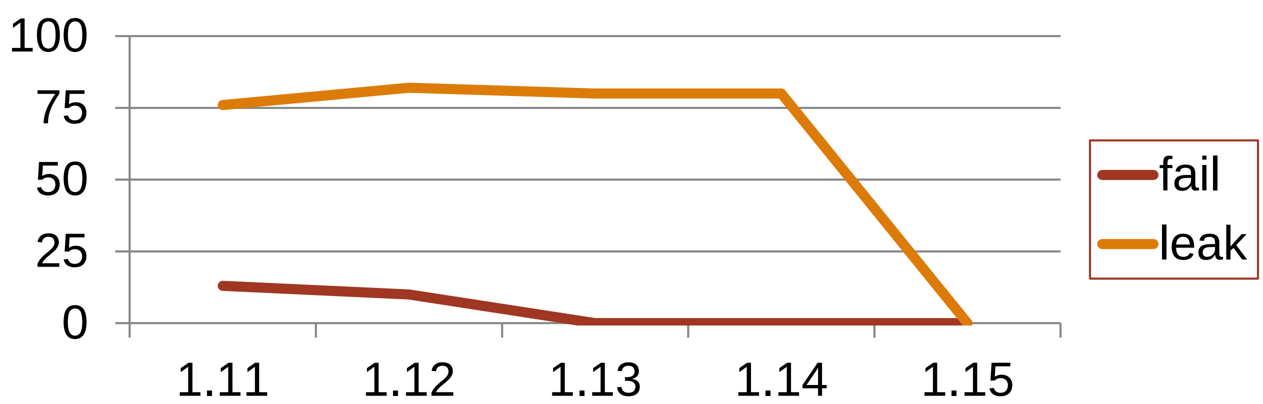
- **Wrapper records enable class memory management**
  - a class implements a particular data type
  - a record stores an instance of the class
  - the record controls copy and assignment behavior
    - copies can point to the same class instance, or
    - copies can allocate separate class instances, 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

Owned and Shared: Record Progress

- **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:**

```
var myOwned  = new Owned(new MyClass());
var myShared = new Shared(new MyClass());
```

- **Empty an Owned or Shared and delete if appropriate**

```
myOwned.clear();  // may delete instance; leaves the record storing nil
```

- **Set the instance managed by an Owned or Shared**

```
myShared.retain(new MyClass());  // may delete previous instance
```

- ***Borrow* a pointer to the instance**

```
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**

```
myShared.myClassMethod();  // forwards to borrow().myClassMethod()
```

Owned and Shared: Usage of Shared

- Starting with a Shared record managing a class instance:

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

- Share ownership with assignment or copy-initialization:

```
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:**

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

- **Destructively transfer ownership:**

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

- **Stop managing an instance and return it:**

```
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

```
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

LinearAlgebra

LinearAlgebra: Background

- **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:

```
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
```

LinearAlgebra: Impact

Example 1: Rotate a vector with respect to Z-axis:

```
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);
```

LinearAlgebra: Impact

Example 2: Demonstrates initializers, dot, and transpose

```
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

```
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

```
proc gemm(A: [?Adom] ?t, … opA = Op.N, …)
```

- **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

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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