Language Improvements

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Outline

- Core Language Improvements
- Improvements to Intents
- Improvements for Generics
- Other Language Improvements
Core Language Improvements
Core Language Improvements

- Method Forwarding
- Void Fields
- ‘Require’ Improvements
- Module Deinit
Method Forwarding
Forwarding: Background

- As with other languages with classes...

  ... Chapel has had two ways of reusing methods:
  1. reuse by inheritance
  2. reuse by composition

- Inheritance is not always appropriate
  - it affects how the inherited object can be used
    - e.g. can cast to the parent class
    - inheritance creates an “is a” relationship
  - class authors may not wish to support inheritance
    - challenging to create a good API that expects inheritance
  - see also "composition over inheritance" principle / design pattern

- Chapel doesn't support some inheritance patterns:
  - multiple inheritance
  - record inheritance
Forwarding: Motivation

- Suppose we have MyCircle and it wraps MyCircleImpl
  - MyCircle is a record we intend to provide to users
  - MyCircleImpl is a class that implements the methods

```plaintext
class MyCircleImpl {
  var radius: real;

  proc area() {
    return pi*radius*radius;
  }

  proc circumference() {
    return 2.0*pi*radius;
  }
}

record MyCircle {
  var impl: MyCircleImpl;

  // forwarding methods
  proc area() {
    return impl.area();
  }

  proc circumference() {
    return impl.circumference();
  }
}
```

- Such record wrapper patterns are common in Chapel
  - Writing such forwarding methods can be cumbersome
    - especially for generic wrapper types such as 'Owned' and 'Shared'
Forwarding: This Effort

- Add a 'forwarding' feature for field declarations
  - Supports auto-forwarding of unresolved methods to that field
  - Previous example can now be written as:

```plaintext
class MyCircleImpl {
    var radius: real;

    proc area() {
        return pi*radius*radius;
    }

    proc circumference() {
        return 2.0*pi*radius;
    }
}

record MyCircle {
    forwarding var impl: MyCircleImpl;
    // above declaration requests forwarding

    // compiler creates area() method
    // to call impl.area()

    // compiler creates circumference() method
    // to call impl.circumference()
}
```
Forwarding: This Effort

- Add a 'forwarding' feature for field declarations
  - Note that methods handled by the original object are not forwarded:

```plaintext
class MyCircleImpl {
    var radius: real;

    proc area() {
        return pi*radius*radius;
    }
    proc circumference() {
        return 2.0*pi*radius;
    }
    proc whoAmI() {
        writeln("class");
    }
}

record MyCircle {
    forwarding var impl: MyCircleImpl;
    // above declaration requests forwarding
    // compiler creates area() method
    // to call impl.area()
    // compiler creates circumference() method
    // to call impl.circumference()
    proc whoAmI() {
        writeln("record");
    }
}
```
Forwarding: More Details

● 'forwarding' declarations…
   …indicate where to forward otherwise unresolved method calls
   …can be used multiple times inside a class or record declaration

● Two styles of use:
   ● as a field declaration prefix:
     ```
     forwarding var myField;
     ```
   ● as a standalone member declaration that refers to a field:
     ```
     var myField;
     forwarding myField;
     ```

● Filter forwarded methods with 'only' and 'except' lists
   ● similar to ‘only’ and ‘except’ on module ‘use’ statements
     ```
     forwarding impl only area;
     forwarding impl except circumference;
     ```
   ● currently only supported for the standalone declaration form
Forwarding: Impact and Next Steps

Impact:
- Easier to write composition patterns
- Enables support for generic types like 'Owned' and 'Shared'

Next Steps:
- Gain more experience with forwarding
  - Apply to record-wrapper patterns in internal/standard modules
  - e.g., sync/single variables currently manually forward ~12 methods
- Document in the language specification
- Consider improvements to the feature
  - allow 'only' and 'except' in the field declaration form
  - is there a way to forward initializers?
  - can it simplify current instances of iterator forwarding?
First Class Void Variables and Fields
Void Variables: Background

- The Chapel compiler does not use a preprocessor
  - No easy way to conditionally declare variables or fields
  - An equivalent to the following C code would be useful in Chapel

```c
#ifdef DEBUG
    const char* debugVar = "debug message";
#endif

...  
#ifdef DEBUG
    printf("%s\n", debugVar);
#endif
```
Void Variables: This Effort

- Added ‘void’ as a first-class type
- Variables and fields can have type ‘void’
- ‘void’ vars can be used in any context expecting ‘void’
  - … passing to generic functions that avoid using them inappropriately
  - … assigning to other ‘void’ vars
- A ‘void’ var used in a context requiring a value is an error
  - Such uses can be protected by param conditionals
- Compiler removes all ‘void’ vars after reporting any errors
Void Variables: Removing unused fields

- **Declarations can conditionally remove fields**
  - If ‘debug’ is ‘true’, then ’dbgMsg’ is a string available during execution
  - If ‘debug’ is ‘false’ then ‘dbgMsg’ is removed by the compiler

```plaintext
param debug = false;
record R {
  var i: int, r: real;
  var dbgMsg: if debug then string else void;
}

var myR = new R(1, 2.3);

if debug then
  myR.dbgMsg = “debugging!”;

writeln(myR);
```
Void Variables: Impact

- Removing unused fields reduces the size of types
  - e.g., a range’s ‘stride’ field is not needed if the range is not ‘stridable’
  - declaring it ‘void’ for such cases reduces storage requirements
  - reduced type sizes lead to lower memory footprint and overhead

  ![Graph 1](chart1.png)

  ![Graph 2](chart2.png)

- also used to optimize rectangular arrays for non-NUMA locale models
Void Variables: Status and Next Steps

Status:
- ‘void’ is allowed as a first class type in most circumstances
- ‘void’ variables and fields are removed by the compiler
- ranges and rectangular arrays use ‘void’ fields to reduce overhead
- a ‘void’ example/primer demonstrating use cases is available

Next Steps:
- Differentiate functions/iterators that don’t return vs. return ‘void’
  - Function with no return is currently treated as returning a single ‘void’ value
- Define and implement more complex types involving ‘void’
  - Arrays with ‘void’ elements
  - Tuples with some/all ‘void’ elements
- Finalize a name for the ‘void’ value
  - Currently using ‘_void’ which doesn’t seem ideal
‘require’ improvements
‘require’: Background and This Effort

Background:
● ‘require’ permits external file dependencies to be expressed in source
  ● for example:
    require "foo.h", "foo.c";
    require "bar.h", "-lbar";
● traditionally, such requirements…
  …could only be expressed as string literals
  …have been processed whenever they’re encountered in parsed code

This Effort:
● relaxes these constraints:
  ● permits requirements to be expressed as ‘param’ string expressions
  ● only processes ‘require’ statements in resolved code
‘require’: Impact and Next Steps

**Impact:**

- requirements can now be expressed more powerfully:

```c
config param lib = "foo",  // permit different libraries to be specified
default = false;           // link in debugging library?
require lib+".h", lib+".c"; // construct names using param expressions
if debug then
    require "-ldebug";       // only link libdebug in if ‘debug’ is true
...
module MultiThreaded {
    // the following requirements only apply if this sub-module is ‘use’d
    require lib+"_mt.h", "-l"+lib+"_mt";
    ...
}
```

- used by FFTW and BLAS modules to select between implementations

**Next Steps:** look for other packages that can benefit from this
Module deinit() functions
Module deinit: Background

- Module initialization is defined by top-level statements
- Global variables are implicitly destroyed at program exit

```fortran
module ModuleExample {
    var globalRecord: MyRecord;
    var globalArray: [1..3] real;
    writeln("done module init!");
    ......
    deallocate globalArray
    globalRecord.deinit()
}
```

- `run at program start-up`
- `run at program tear-down, implicitly`
Module deinit: Background

● Consider a global class instance:

```chapel
module ClassExample {
  var globalClass = new MyClass();
  writeln("done module init");
  ......

  delete globalClass
  writeln("deleted globalClass")
}
```

● How can the user delete ‘globalClass’ at the end?
  ● recall that deleting class instances is user responsibility
  ● Chapel has lacked a convenient way to do that
  ● … or to specify other program cleanup actions
Module deinit: This Effort

- **Allow user-defined module deinitialization functions**
  - defined as `proc deinit() {...}` at module level

```plaintext
module ClassExample {
  var globalClass = new MyClass();
  writeln("done module init");
  
  .......

  proc deinit() {
    delete globalClass;
    writeln("deleted globalClass!");
  }
}
```

`user-defined module deinit() !`
Module deinit: This Effort

- Clarified + fixed deinitialization order of global variables
  - happens after user deinit, if present; in reverse declaration order

```plaintext
module ModuleExample {
  var globalRecord: MyRecord;
  var globalArray: [1..3] real;
  var globalClass = new MyClass();
  writeln("done module init");
  ......
  proc deinit() {
    delete globalClass;
    writeln("deleted globalClass!");
  }
  deallocate globalArray
  globalRecord.deinit()
}
```

Module deinit: This Effort

- Clarified + fixed deinitialization order of modules
  - reverse order of module initialization

```fortran
module Main {
  use Helper; ......

  proc deinit() { ... }
  deinitialize/deallocate Main globals implicitly
}
```

```fortran
module Helper {
  ......

  proc deinit() { ... }
  deinitialize/deallocate Helper globals implicitly
}
```

- to see module deinitialization order, compile with
  `-s printModuleDeinitOrder`
Module deinit: Impact and Next Steps

Impact:
- No longer need to wrap module cleanup code in a global record
  - supported simplifications to the MPI module
    - contributed by Nikhil Padmanabhan

Next Steps:
- Apply to other packages
  - e.g. FFTW, FFTW_MT
- Consider adding an optional module init() routine
- Gather user feedback
Improvements to Intents
Improvements to Intents

- ‘const’ and ‘const-ref’ as ‘this’ intents
- Default intent for ‘this’ on records
- Return intent overload improvements
- Tuple changes
'const' and 'const ref' as 'this' intents
'const' and 'const ref' as 'this' intents

**Background:** ‘this’ intents control method receiver arguments
- the method receiver is called 'this' inside the method
- the 'this' intent controls the implicit formal argument for ‘this’:
  ```chapel
  proc ref int.increment() {
    this += 1; // 'this' is mutable because of 'ref' intent above
  }
  
  var x = 1; x.increment();
  ```
- Chapel has only allowed a subset of intents here:
  ```chapel
  param type ref
  ```

**This Effort:** Support 'const' and 'const ref' as 'this' intents

```chapel
proc const ref int.square() { return this*this; }
proc const int.cube() { return this*this*this; }
```

**Impact:** 'this' intent now supports more cases

**Next Steps:** Support 'const in' and 'in' as 'this' intents
Default intent for 'this' on records
Default ‘this’ intent: Background

● ‘this’ intents select a method receiver’s argument intent

● Default intent used if ‘this’ intent is not explicitly specified
  ● default intent based on the receiver’s type, as with normal arguments

● Default ‘this’ intent for records was inconsistent
  ● specified as 'const ref' but implemented as 'ref'

● Resulted in several bugs / odd behaviors
  ● methods modifying 'this' could be called on a 'const' record

```cpp
record R {  
  var x: int;  
  proc R.reset() {  
    this.x = 1;  
  }
}
const cR: R;  
// should be an error but was permitted
```

● method calls on elements of arrays of records used the 'ref' overload
  ● led to problems similar to those described in the “array default intent” slides
Default ‘this’ intent: This Effort

● **Changed the default 'this' intent for records**
  ● to 'ref' if 'this' is modified in the method body
  ● to 'const ref' if not

● **Rationale:**
  ● programmer should be able to omit 'ref' intent as a convenience
  ● 'const' should not be required to avoid surprising behaviors
  ● compatible with existing Chapel programs

● **For example:**

```chapel
record R { var x: int; }
proc R.reset() { this.x = 1; }
proc R.getX() { return this.x; }

cR: R; vR: R;
cr.reset(); // error
vR.reset(); // OK
vR.getX(); // OK
cr.getX(); // error
```

Default 'this' intent: Impact and Next Steps

Impact:
- Enabled other improvements
  - significant improvements to const-checking
  - fewer surprises with return intent overloads

Next Steps:
- Consider allowing records to select this behavior for all arguments
  - not just implicit 'this' arguments
- and/or: permit records to select between a number of default intents
Return Intent Overload Improvements
Return Intent Overloads: Background

- Return intent overloads support context-dependent calls:
  - 'ref' return version is used when call is modified/modifiable
    - typically by passing to a 'ref' formal argument, as with LHS of '='
  - value or 'const ref' return version is used in other cases

```plaintext
var x = 1;
proc accessX() ref {  // "setter" version
    return x;
}
proc accessX() {  // "getter" version
    return 0;
}
accessX() = 3;  // uses the "setter" version
writeln(x);  // prints 3
var tmp = accessX();  // uses the "getter" version
writeln(tmp);  // prints 0
```
Return Intent Overloads: Problem

- We noticed surprising behavior related to locale queries
- 'ref' version was always selected if the locale was queried:

```c
const ParentDom = {0..10};
var SparseDom: sparse subdomain(ParentDom);
var A: [SparseDom] int;
writeln(A[0].locale.id);
// error: halt reached - attempting to assign a 'zero' value in a sparse array: (0)
```

- Behavior stems from an implementation workaround
  - workaround enabled locale queries for arrays of primitive types
  - but, fragile and problematic:
    - didn't handle querying the locale of element passed to fn by 'const ref'
    - inhibited const-checking when querying the locale of a 'const' array element
Return Intent Overloads: This Effort

- Make return intent overloads handle 'const ref' vs value
  - 'ref' return version is used as before, when call is modified/modifiable
  - 'const ref' return version is used if passed to 'const ref' formal
    - e.g., when the locale is queried in previous example
  - value return version used otherwise

- All 3 return intent overloads can now be provided:
  
  ```
  var x = 1;
  proc accessX() ref { // "setter" version
    return x;
  }
  proc accessX () const ref { // "getter" const reference version
    return x;
  }
  proc accessX () { // "getter" value version
    return 0;
  }
  ```
Return Intent Overloads: Status and Next Steps

Status:
- Language change is implemented and specification updated
- Problematic workaround is removed
- Array implementation now uses all 3 return intent overloads
- Motivating example behaves correctly

Next Steps:
- Fix bug with ambiguity in return intent overloads
  - should generate an ambiguity error
  - … but return intent overload currently disabled in this case
- Allow return intent overloads without 'ref' version
  - Currently 'ref' version is required to do return intent overloading
  - 'const ref' and value return overloads are useful on their own
Tuple Changes
Details of tuple behavior have never been well-defined
- a known gap in the language specification
- CHIP-6 proposed one strategy, but was never finalized or acted upon
- things have worked “well enough” for this not to receive more attention

Array memory fixes ran afoul of issues with tuples

For example:

```plaintext
proc f( tupleArg ) {
    return tupleArg;
}

var A, B: [1..n] int;
f( (A, B) );
```

- are A and B passed by value or by reference into f?
- does returning tupleArg return the contained arrays by value or by ref?
Tuples: This Effort

- Reworked the tuple implementation to support array fixes
  - guiding principle: 1-element tuples behave similarly to plain elements
  - implementation is now more direct and straightforward

- Updated CHIP 6 to reflect current tuple semantics

- Returning to the example:

```plaintext
proc f( tupleArg ) {
  return tupleArg;
}

var A, B: [1..n] int;

f( (A, B) );
```

- are A and B passed by value or by reference into f?
  - by reference, because arrays pass by 'ref' / 'const ref' by default

- does returning tupleArg return the contained arrays by value or by ref?
  - by value, because arrays return by value by default
This example behaves differently in 1.14 and 1.15:

```plaintext
config const n = 2;
record BigRecord {
    var A: [1..n] int; // defines a record containing an array field
}
var global: BigRecord; global.A = 1;
test( (global, global) ); // how does created tuple capture the record?
    // 1.14: by value, 1.15: by const reference
proc setGlobal() {
    global.A = 9;
}
proc test( tup ) {
    setGlobal(); // does this affect tup(1)?
    writeln(tup);
}
// 1.14 prints ((A = 1 1), (A = 1 1))
// 1.15 prints ((A = 9 9), (A = 9 9))
```
Tuples: Next Steps

- Improve const-checking for tuple arguments
- Update language specification with tuple semantics
Improvements for Generics
Generics

- Where-clause improvements
- Type aliases for generic classes
- Secondary methods on instantiated types
Where-clause Improvements
Where-clause: Background

● "Where-clauses" constrain function candidate choices

```haskell
proc foo(x) where x.type == int { writeln("int"); }  
proc foo(x) where x.type == real { writeln("real"); }  
foo(3); // resolves to the “int” version
```

```haskell
proc arrayOp(A: [ ]) where A.rank == 1 { /* optimized 1D case */ }  
proc arrayOp(A: [ ]) { /* general case */ }
```

● Useful for…

…specializing/constraining functions based on types

…providing optimized functions
Support where-clauses on non-generic functions

Background: Where-clauses were restricted to generic functions
- didn’t see a use-case for non-generic functions originally
- assumed they would only compute on aspects of function signature (if function is non-generic, there’d be nothing to compute)
- have since recognized value for non-generic functions
  e.g. selecting function implementation based on a config param

```plaintext
config param layout = rowMajor;
proc matrixOp(...) where layout == rowMajor { /* row-major impl */ }
proc matrixOp(...) where layout == colMajor { /* column-major impl */ }
```

This Effort: Support where-clauses on non-generic functions

Status: Generality of where-clauses has been improved
Evaluate where-clauses on matching functions

**Background:** Historically, where-clauses were always evaluated
- even on functions that didn’t have matching signatures
- could lead to confusing error messages

```plaintext
proc foo(param x: int) where (x % 2) == 0 { writeln("even"); }
proc foo(param x: int) where (x % 2) == 1 { writeln("odd"); }
proc foo(param x: real) { writeln("real"); }
foo(2.2); // used to generate an error about “%” not being defined on real
```

**This Effort:** Evaluate where-clauses only for valid arg signatures

**Status:** Usability and stability of where-clauses has improved
- no known bugs remaining, no future work planned
Type Aliases for Generic Classes
Type Aliases for Generic Classes

**Background:** Type aliases worked for concrete types only

- a type alias introduces another name for a type
- previously these worked with concrete types, as in:
  ```
  type myint = int;
  ```
- but they did not work for generic types, as in:
  ```
  type RandomStream = PCGRandomStream;
  ```

**This Effort:** Adjust implementation to allow generic type aliases

```
  type RandomStream = PCGRandomStream;
```

**Next Steps:**

- Fix problems with aliases of instantiated types, as in:
  ```
  type RandomIntegerStream = RandomStream(eltType=int);
  ```
- Adjust Random standard module to use type alias for RandomStream
Secondary Methods on Instantiated Types
Secondary Methods on Instantiated Types

**Background:** Chapel has *open methods*
- methods can be added to existing types
- but, adding a method to an instantiated generic type required ‘where’:
  ```chapel
  proc Owned.frobnify() where this.type == Owned(MyClass) { ... }
  ```
- even though the non-method case is straightforward:
  ```chapel
  proc frobnify(arg: Owned(MyClass)) { ... }
  ```

**This Effort:** Allow parenthesized secondary method declarations
- enables a simpler expression of the above example:
  ```chapel
  proc (Owned(MyClass)).frobnify() { ... }
  ```
- parens required to disambiguate generic class’s args from formal args

**Impact:** Removes a restriction on method receivers vs other args
- where-clause approach no longer required
- simpler syntax is now available
Other Language Improvements
Other Language Improvements

- Added min() and max() param overloads
- Support for casts between c_void_ptr and class objects
- Enabled ’param’s and ‘config param’s without initializers
  
  ```
  config param x : int;
  ```

- First-class functions no longer capture outer variables
  - Removed as part of separate effort
  - First-class functions support needs redesign/revisiting anyways
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