Language Improvements

Chapel Team, Cray Inc.
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Outline

- **Initializers**
  - Improvements to the Proposal
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  - Other Changes of Note
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- **Numeric Coercion Improvements**
- **Early Exits from ‘forall’**
- """Uninterpreted String Literals"""
- **Other Language Improvements**
Initializers
Initializer: Background and Summary of Work

Background:
- Have been developing initializers to replace constructors
  - Provide significantly more control over classes and records
  - Extensive progress made over last few releases
- As of Chapel 1.16…
  - Not all features implemented
  - Some open questions remained
  - Some behavior was not ideal

This Effort:
- Revisited the proposal, based on experience using initializers
- Improved support for compiler-generated initializers
Initializers: Outline

- **Improvements to the Proposal**
- **Compiler-Generated Initializers**
- **Other Changes of Note**
  - Copy Initializers
  - Operations on Initialized Fields
  - Select Bug Fixes
- **Overall Status and Next Steps**
Improvements to the Proposal
Initializers: Old Proposal

- Given a class hierarchy:
  - Classes A through D form a hierarchy: D:C:B:A

- Each class implements one or more 'init()' methods

- Body of 'init()' was divided into two phases

- In phase 1, object was uninitialized memory
  - Couldn’t do much with it other than initialize its fields

- In phase 2, object was a D (for any initializer)
  - Could do anything with it
class D : C {
    var x: int;
    var y = 2.3;
    var z: real;

    proc init(x: int) {
        var tmp = foo(x);
        this.x = x;
        // this.y = 2.3;
        this.z = tmp;

        super.init();

        this.foo();
        bar(this);
    }
}
Old Proposal: Phase 1, things you couldn’t do

class D : C {
    var x: int;
    var y = 2.3;
    var z: real;

    proc init(x: int) {
        var tmp = foo(x);
        this.x = x;
        // this.y = 2.3;
        this.z = tmp;
        super.init();
        this.foo();
        bar(this);
    }
}

Couldn’t call methods or refer to parent fields. *Rationale*: parent fields are not initialized yet.

*super.init(…) invokes the parent initializer.*
Old Proposal: Phase 2, things you could do

```plaintext
class D : C {
    var x: int;
    var y = 2.3;
    var z: real;

    proc init(x: int) {
        var tmp = foo(x);
        this.x = x;
        // this.y = 2.3;
        this.z = tmp;
        super.init();
        this.foo();
        bar(this);
    }
}
```

Entire object is initialized once super.init() returns

Full dynamic method dispatch

Can pass ‘this’ to other functions
class AbstractArr {
    param rank: int;
    proc init(param rank: int) {
        this.rank = rank;
        super.init();
    }
}

class RectangularArr : AbstractArr {
    var bounds: rank*int;

    proc init(bounds...) {
        // problem: can't set or use 'bounds' field
        // because 'rank' is not yet established
        this.bounds = bounds;
        super.init(bounds.size)
    }
}
Old Proposal: Other design Qs to revisit

● Phase 1 or phase 2 by default if no 'super.init()'?
  ● Originally chose phase 2 as default
  ● Needed to call 'super.init()' to initialize const/param/type fields

● 'super.init()' as phase 1 vs. 2 separator
  ● Records don’t inherit, so don’t have a 'super'
    ● Yet still required its use in order to specify phase 1 actions

● Modest interest in old-style 'initialize()' methods
  ● A hook called after constructor
  ● Convenient way to leverage compiler-generated constructor

New proposal also helps with each of these issues.
New Proposal: Overview

● Parent fields initialized before child fields
  ● Can now use parent fields to initialize child fields
    ```
    var bounds : rank*int;  // OK!
    ```

● Can call methods on parent type in 'init()'
  ● Current type's methods can be called…
    … after a 'this.complete()' call or
    … after a 'this.init()' call

● Introduces 'postinit()' as replacement for 'initialize()'
New Proposal: init() overview

- 'super.init()' called at start rather than end of phase 1

```
class D : C {
    var x: int;
    var y = 2.3;
    var z: real;

    proc init(x: int) {
        super.init();
        this.x = x;
        // this.y = 2.3;
        this.z = tmp;
        this.foo();
        bar(this);
    }
}
```

- `super.init(...)` invokes the parent initializer and permits child field initialization to start

- Initialize fields, in order. Can refer to parent class fields since they’re initialized.

- Omitted fields implicitly initialized.
New Proposal: init() details

- **Details:**
  - If super.init(...) is omitted, compiler inserts 0-arg super.init() call at top

  ```
  proc init(x: int) {
      this.x = x;
      this.z = tmp;
      this.foo();
      bar(this);
  }
  ```

  Compiler inserts super.init() call here

  - Records no longer support super.init()
    - They don’t need to since it’s not used as a separator anymore
    - Consistent with not supporting record inheritance
New Proposal: init() overview

```java
class D : C {
    var x: int;
    var y = 2.3;
    var z: real;

    proc init(x: int) {
        super.init();
        this.x = x;
        // this.y = 2.3;
        this.z = tmp;
        this.foo();
        bar(this);
    }
}
```

- Can call methods, but will only dispatch as type 'C'
- Can pass ‘this’ to other functions as type 'C'
- Can start setting fields in 'D'
- Now a 'C'
New Proposal: this.complete()

- Support a way to initialize remaining fields

```java
class D : C {
    proc init(x: int) {
        this.x = x;
        this.complete();
        this.foo();
        bar(this);
    }
}
```

- Enables method calls within record init()s

  - Transitions object from a 'C' to a 'D'
  - Subsequent method calls could dispatch to a method defined on 'D' or its parents
  - Can pass 'this' to other functions; it is a 'D' object
New Proposal: this.init()

- **this.init():** Similar to use in the 1.16 release
  - Calls another ‘init()’ defined on D

```plaintext
class D : C {
    var x: int;
    var y = 2.3;
    var z: real;

    proc init(x: int) {
        this.init();  // Initializes all fields in 'D' and its parents
        this.foo();
        bar(this);    // Subsequent method calls could dispatch to a method defined on 'D' or its parents
    }
}
```

Can pass ‘this’ to other functions; it is a 'D' object
New Proposal: Summary of init()

● **Given a class hierarchy:**
  ● Classes A through D form a hierarchy: D:C:B:A

● **In D.init(), object starts as nothing (a blob of memory)**
  ● Implication: You can’t do much with it yet

● **After D’s call to super.init(), object is a C**
  ● Implication: You can do anything with it that you could do with a C
  ● Plus, you can also assign to D fields to help turn it into a D

● **Object becomes a D:**
  ● After D’s call to D.complete(), or
  ● After D’s call to this.init(), or
  ● After D.init() returns
New Proposal: postinit() overview

- **postinit(): A hook called after initialization**
  - Convenient way to leverage default initializers
  - Supports virtual dispatch into child methods at object creation time

```java
class D : C {
    var x: int;
}
class E : D {
    var e = new E();
    e.foo(); // Same as calls in postinit
    bar(e);
}
```

- Can call methods as final dynamic type: `E`
- Can pass ‘this’ to other functions; it is an ‘E’ object
New Proposal: postinit() details

**Details:**
- postinit() takes no arguments
- If postinit() is not defined for a class, compiler inserts:

  ```c
  proc postinit() {
    super.postinit();
  }
  ```

- Compiler inserts `super.postinit()` if omitted in user-written postinit()
● Parent fields initialized before child fields

D.init()
C.init()
B.init()
A.init()

<Initialize A fields>
<Initialize B fields>
<Initialize C fields>
<Initialize D fields>

● Optional 'postinit()' method called after all init() methods

D.postinit()
...
A.postinit()
<run A's postinit()>
...

<run D's postinit>
Compiler-Generated Initializers
Compiler-Generated Initializers: Background

- Last release added support for compiler-generated `init()`
  - Behavior similar to compiler-generated constructors
  - Off by default, enabled via developer flag
    - Only applied to classes in user-defined modules
    - Never applied to types with explicit initializers
Compiler-Generated Initializers: This Effort

- Initial support for records in user-defined modules

- Added pragma to apply to individual types
  - To support converting module types with inheritance
  - Will not be needed once enabled by default

- Improved error checking for intermixed hierarchies
  - Inheritance hierarchies with constructors cannot generate ‘init’

```c
class A {
    proc A (...) {
        // explicit constructor
    }
}
```

```c
pragma “use default init”

class B : A {...}
```

// error: asks for compiler-generated initializer
// but inherits from type with explicit constructor
Compiler-Generated Initializers: Status

● **Many bugs fixed, others remain:**
  ● Some expressions cannot be used as default values for fields yet
    ● E.g., parallel loops, conditional expressions
  ● Nested types, when either type is generic, cannot be used
  ● Fields that are arrays of syncs can cause deadlocks
  ● Internal compiler errors

● **Once these bugs are resolved, can generate by default**
  ● And deprecate constructors
Initializers: Other Changes of Note
Initializers: Copy Initializers

- **Generic 1-arg init() now recognized as potential copy init()**
  - Compiler warns user of this subtlety for related compilation errors
  - Can avoid warnings with explicit type or a where clause
    ```
    record Foo {
        ...
        proc init(x: Foo) { ... } // Actual copy init
    }
    ```
  - May evolve this design further to make copy initializers clearer

- **Compiler now generates copy initializer if no match found**
  - Open Question: When user defines copy init or assignment, should compiler attempt to define the other based on it? Should it warn?
Initializers: This Effort

- Support more operations on initialized fields
  - Can reassign field once initialized
    ```
    this.x = 5;
    this.x *= 2;  // Now allowed in 1.17
    ```
  - Can pass a field as an argument to a function
    ```
    this.y = "hello";
    writeln(this.y);
    ```
  - Still an error to initialize fields out of order
    ```
    this.secondField = 5;
    this.firstField = 10;  // Error!
    ```
Initializers: This Effort

- **Other bug fixes**
  - Enabled support for promotion over types with initializers
  - 'new D(...)' only calls 'D.init(...)'
    - Won’t dispatch to parent class initializer with similar argument list
    - Avoids hiding compiler-generated initializer when parent has explicit ‘init()’
  - Allow fields to infer their type when default value is a ‘new’ expression
    
    ```javascript
    var myField = new D();
    ```
  - Many others (see [CHANGES.md](#) file for details)
Initializers: Overall Status and Next Steps
Initializers: Status

- Most library/internal modules converted to initializers
  - Exceptions:
    - Arrays, domains, distributions: issue with using inherited field, now resolved
    - Owned, Shared, strings: special initCopy/autoCopy functions
    - Reductions: compiler still generates constructors by default

- Most tests converted to initializers
  - Out of ~8,500 tests...
    - 26 remain unconverted due to bugs or unimplemented features
    - 28 others will be removed once constructors are deprecated
Initializers: Next Steps

- Finish compiler-generated initializers
- Fix bugs
  - Nested types when at least one of the types is generic
  - Generic instantiation when generic fields initialized in conditional
  - ...
- Deprecate constructors
- Finalize design decisions:
  - Finalize copy initializers
  - Finalize type initializer story
  - Allow users to opt into retaining compiler’s default ‘init()’?
    - Currently squashed by user’s ‘init()’
- Support incomplete initialization when explicitly requested
  - Also known as the 'noinit' feature
Error Handling
Error Handling: Background

- Error handling helps users with exceptional cases
  - For example, handling a failure when opening a file:
    ```
    var f: file;
    try {
      f = open(f1, iomode.r); // if open() raises an error, jump to the catch block
      writeln("everything is fine");
    } catch {
      writeln("an error occurred"); // catch blocks are used to handle errors
    }
    ```
Error Handling: Background

- **Greatly improved in previous releases**
  - Supported in parallel and multi-node code
  - Fine-grained error checking modes
  - 'SystemError' hierarchy provided for common error cases

- **But as of 1.16, standard modules still halt in many cases**
  - Highly problematic for users and library writers
Error Handling: This Effort

- Exclude throwing from 'defer', 'deinit()' 
- Use error handling more in the standard library 
- Bug fixes
Exclude throwing from 'defer', 'deinit()'

● Initially considered throwing from 'defer', 'deinit()'
  ```go
  var f: file = open(...);
  defer try f.close();
  ```

● But that could prevent other 'defer', 'deinit()' from running
  ```go
  defer thisNeedsToHappen(); // will this run if f.close() throws?
  defer try f.close(); // what is the handling context of this block?
  ```

● Also, no clear way to handle such an error
Exclude throwing from 'defer', 'deinit()'

- 'defer', 'deinit()' must now handle errors internally

```go
 defer {  
     try {  
         f.close();
     } catch e { // suggested pattern: complete handling, logging
         logError(e.message());
     }
 }  
```
Use error handling in internal and library code

- Before, illegal cast operations would halt:

  ```csharp
  var s = "brad";

  var i = s: int;
  ```

  ```plaintext
  > error: Unexpected character when converting from string to int(64): 'b'
  ```
Use error handling in internal and library code

- Now it throws an 'IllegalArgumentError':

```java
var s = "brad";
try! {
    var i = s: int;
} catch e: IllegalArgumentError {
    writeln("caught cast error");
}
```

> caught cast error

- Addressed several other halts in standard library modules
Bug fixes

● Correctly enforced error handling rules in 'coforall' loops

```haskell
proc test() {
  coforall i in 1..10 {
    throwme(); // throwme() is unhandled and 'test()' does not throw
    try! { } // but this empty try! made it pass error checking
  }
  // now a compilation error as intended
}
```

● Fixed garbage memory returns from 'try'/'catch'

```haskell
proc minusOne(x: int) {
  try {
    return minusOneThrows(x);
  } catch {
    writeln("caught error"); // this branch used to return garbage memory
    // now a compilation error
  }
}
```
Error Handling: Status and Next Steps

**Status:**
- Error handling is increasingly ready for production code

**Next Steps:**
- Implement missing features
  - Throwing from 'init()'  
  - Throwing from non-inlined iterators
- Use error handling where appropriate in library modules
  - Deprecate 'out error' pattern  
  - Wherever reasonable, remove 'halt()'
- Explore lower-overhead implementations of error-handling
  - E.g., avoid conditionals for non-error cases
Argument Intent Changes
Argument Intent Changes

This Effort: Improved several kinds of argument intents
- 'in' intent for functions
- 'in' intent for tasks
- range default intent
- 'type' intent

Impact: Intents are more flexible and consistent

Status: Improvements implemented and specified

Next steps:
- adjust default initializers to use 'in' intent and avoid copies
- improve 'out' and 'inout' intents
'in' Intent: Background

- 'in' intent always created a copy
  - contrast with variable initialization

    ```
    var x = g(); // does not create a copy if g returns record by value
    ```

// before 1.17

```java
record R { var x: int }
var globalR: R;
proc f(in x) { }
f(new R(1));
f(globalR);

proc f(in x) {
    var x_tmp = copy-init x;
    deinit x_tmp;
}
var call_tmp = new R(1);
f(call_tmp);
deinit call_tmp;
f(globalR);
```

This copy is not necessary for 'f(new R(1))'
'in' Intent: This Effort

- Make 'in' intent more similar to variable initialization

```plaintext
// before 1.17
record R { var x: int }
var globalR: R;
proc f(in x) { }
f(new R(1));
f(globalR);

proc f(in x) {
    var x_tmp = copy-init x;
    deinit x_tmp;
}
var call_tmp = new R(1);
f(call_tmp);
deinit call_tmp;
f(globalR);

// after 1.17
record R { var x: int }
var globalR: R;
proc f(in x) { }
f(new R(1));
f(globalR);

proc f(ref x) {
    var x_tmp = copy-init x;
    deinit x;
}
var call_tmp = new R(1);
f(call_tmp);
var x_tmp = copy-init globalR;
f(x_tmp);
```
'in' Intent: Impact

- 'in' intent better optimized
- addresses an issue with 'Owned'

// before 1.17
record R { var x: int }
var globalR: R;
proc f(in x) { }
f(new R(1));
f(globalR);

proc f(in x) {
    var x_tmp = copy-init x;
    deinit x_tmp;
}
var call_tmp = new R(1);
f(call_tmp);
deinit call_tmp;
f(globalR);

// after 1.17
record R { var x: int }
var globalR: R;
proc f(in x) { }
f(new R(1));
f(globalR);

proc f(ref x) {
    deinit x;
}
var call_tmp = new R(1);
f(call_tmp);
var x_tmp = copy-init globalR;
f(x_tmp);
'in' Intent for Tasks

Background: 'in' task intent was handled after task launch
  ● Causing the potential for race conditions when combining:
    ● record copy initializer
    ● 'begin'
    ● 'in' task intent

This Effort: Handle 'in' task intent during task setup
  ● Resolves the potential for race condition in a case like the following:

```plaintext
record R { /* includes class fields */ }
R.init(from: R) { /* copy initialize copies class fields */ }
var r: R;
begin with (in r) {
  f(r);
}
mutable(r); // mutation races with copy from 'in' intent
```

Impact: Potential race condition addressed
Range Default Intent

**Background:** Before 1.17, range default intent was inconsistent
- for tasks, it was 'const in'
- for functions, it was 'const ref'

**This Effort:** Changed range default intent to 'const in'
- range now behaves more like 'int'

**Impact:** Range semantics simplified and more optimizable
'type' intent

**Background:** Combining 'type' intent with type specifier allowed

- e.g.
  
  ```
  proc f(type t: integral) { }
  ```

- but behavior of such code was neither specified nor consistent

**This Effort:** Specify the behavior and address bugs

- 'type' intents with type specifier:
  
  - limits the 'type' arguments that can be passed in
  - does not allow coercion

**Impact:** 'type' intent with specified type now usable
Improving Productivity of 'delete'
Productive 'delete': Background and This Effort

Background:
- Previously, 'delete' could only be applied to a single class object
- This made certain patterns verbose:
  - deleting multiple objects:
    ```plaintext
delete C1;
delete C2;
delete C3;
```
  - deleting arrays of objects:
    ```plaintext
    forall c in Arr do
    delete c;
    ```

This Effort: Improved 'delete' to support...
- comma-separated expressions
- arrays
Productive 'delete': Impact and Next Steps

Impact:
- Can now write these patterns more succinctly:
  
  - deleting multiple objects:
    ```
    delete C1;
    delete C2;
    delete C3;
    ```

  - deleting arrays of objects:
    ```
    forall c in Arr do
    delete c;
    ```

Next Steps:
- Add support for users to define types that can promote, like arrays
- ensure that this feature works for such cases
Accessing Type and Param Fields
Accessing Type and Param Fields

**Background:** classes/records can have 'type' or 'param' fields

- Such fields make the class/record generic
- They are part of the generic type’s instantiation
- But, they could not be accessed from a type variable

**This Effort:** Enable accessing such fields from a type variable

```pascal
record Element {
  param p;
  type t;
}

type MyElement = Element(1, int);
param MyElementP = MyElement.p;
type MyElementT = MyElement.t;
writeln(MyElementP, " ", MyElementT:string);
// now outputs: 1 int(64)
```

**Impact:** Type variables and arguments are more capable

- Can now call '.size' on a tuple type
Numeric Coercion Improvements
Numeric Coercions

**Background:** There are coercions between some numeric types
- But the implementation presented usability issues with 'real(32)'
- For example, each of these lines caused a compilation error:
  
```
var a: real(32) = 0.0;
var b: real(32) = 1;
var half: real(32) = 1 / (2.0:real(32));
```

**This Effort:** Improved numeric coercions
- Above 'real(32)' examples now compile and run, as does this example:
  
```
param x: int(16) = 0;
var y: int(8) = x;
```

**Impact:** Numeric types of non-default sizes are easier to use
Early Exits from 'forall'
Early Exits from 'forall'

**Background:** early exit errors were incomplete and unclear

**This Effort:** completed checking with clear error messages

```
label outer for ... {
forall ... {
  continue;       // OK: skips the current iteration of ‘forall’
  break;          // Error: cannot exit a ‘forall’ from its loop body
  return ...;     // Error: cannot exit a ‘forall’ from its loop body
  continue outer; // Error: cannot exit a ‘forall’ from its loop body
  yield ...;      // OK only within the definition of a parallel iterator
}
for ... {         // OK: exits the inner for-loop, stays in the forall-loop
  break;
  return;
  ...
```

"""Uninterpreted String Literals"""
Uninterpreted Strings: Background, This Effort

**Background**: String literals are interpreted
- e.g. "\n" translates into a newline
- Applies to both 'single' and "double" quote variants
- Literal newlines are not allowed

**This Effort**: Add triple-quoted uninterpreted string literals
- Uninterpreted – e.g. """"\n"""" is two characters
- Applies to both '"single"' and '"double"' quote variants
- Literal newlines are allowed inside them
Uninterpreted Strings: Impact, Next Steps

**Impact:** Uninterpreted multi-line strings are available

- capturing code as a string
- general purpose multiline messages

```javascript
var query = ""
SELECT
  a_column
, another_column
FROM
  {%s}
WHERE
  {%s} = {%s};"

var helpMsg = ""
Usage: ./parallelProg <options>
  --option1 : Do option1 things
  --option2 : Do option2 things
  --option3 : Do option3 things"";
```

**Next Steps:**
- Consider support for multi-line traditional strings
- Add library functions to trim leading whitespace
Other Language Improvements
Other Language Improvements

- **Arrays**
  - 'clear()' on an array of records now calls the records' deinitializers
  - Improved support for casting arrays to strings

- **Domains**
  - Associative domains may use index types containing ranges
  - 'isEmpty()' method on domains

- **Subtype queries on distributions now supported**

- **Alignment of non-stridable range is low bound**
  - Used to always be 0
Other Language Improvements

- **Forwarding**
  - Error-handling propagates through forwarded methods
  - Support for forwarding methods on arrays, domains, and distributions
  - See [documentation](#)

- **Owned and Shared**
  - ‘Owned(C)’ and ‘Shared(C)’ coerce to type ‘C’
  - ‘Owned(D)’ coerces to ‘Owned(C)’ when D is a subclass of C
  - Writing out an ‘Owned(C)’ simply prints the ‘C’ object
Other Language Improvements

● Miscellaneous
  ● Recursive parallel iterators may be invoked via 'forall' loop
  ● Improved support for enums with non-trivial init expressions
  ● Improved default argument handling
  ● Support for defining multiple config types in a single statement
  ● Enabled wide pointers to be cast to 'c_void_ptr'
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