Language Improvements

Chapel version 1.20

September 19, 2019

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@ChapelLanguage

Outline

- Nilable Class Types
- Class Memory Management
- Task/Forall Intents on 'this'
- Partial Instantiations
- String and Bytes Types
- Private and Public Use
- Use of Top-Level Modules
- Overload Set Checking
- Atomic Interface Stabilization
- Distinguishing 'nothing' from 'void'
- 'class' 'record' and 'enum' as Types
- Changes to 'isSubtype'
- Deprecated Language Features

Nilable Class Types

Nilable Types: Background and This Effort

Background: Nilable types were proposed but not implemented in 1.19

- 'nil' pointers are problematic
  - Tony Hoare calls them "my billion-dollar mistake"
  - 'nil' dereference errors can be difficult to debug
  - other languages are moving towards opting into storing 'nil'
- In 1.19, class instance pointers could be 'nil' and defaulted to 'nil'

```
var x: MyClass;          // stores 'nil'
var y: owned MyClass;    // stores 'nil'
```

This Effort: Implement the proposal and fill in details

Nilable Types: Design

- A class type 'C' means a non-nilable pointer to an instance
  - cannot store 'nil'
  - has no default value
  - including 'borrowed C', 'owned C', 'shared C', 'unmanaged C'
- The type 'C?' is available to opt into being possibly 'nil'
  - 'nil' is the default value
  - including 'borrowed C?', 'owned C?', 'shared C?', 'unmanaged C?'
- 'C' and 'C?' are different types
- The '!' operator unwraps a nilable value, halting if it is 'nil'
- Implicit conversions are allowed from non-nilable to nilable class types

Nilable Types: Example

```
proc getField(x: C) {     // C is a class
  return x.field;         // no check needed here since 'x: C' cannot store nil
}

getField(nil);            // compile-time error: 'getField' expects a non-nilable
var a: C;                 // compile-time error: 'a: C' has no default value
var x: C?;                // ok, use 'nil' as the default value
getField(x);              // compile-time error: x is nilable, passed to non-nilable
getField(x!);             // compiles OK; adds a nil check at runtime
```


The '?' Operator

Nilable Types: the '?' Operator

- The postfix '?' operator on a class type produces the nilable type
  - available only on class types; not on values
- '?' can be combined with a management decorator

```
C;          // non-nilable, generic management
C?;         // nilable, generic management
owned C;    // non-nilable owned
owned C?;   // nilable owned
```

- '?' can combine with 'new' and modifies the type to be created:

```
class C { var x; }
new C(5)? // equivalent to the next line
new C?(5)
```

The '!' Operator

Nilable Types: the '!' Operator

- The '!' is a postfix operator available on class types or values
- It converts the argument to the non-nilable variant
  - and, for 'owned' / 'shared', to the borrowed variant
- When applied to a type, returns the same type as '!' would on a value of that type
- It will halt if it is applied to the 'nil' value (but see 'Open Questions')

If a variable is declared as...	Then x! has type...
`var x: owned C?`	`borrowed C`
`var x: shared C?`	`borrowed C`
`var x: borrowed C?`	`borrowed C`
`var x: unmanaged C?`	`unmanaged C`

Implicit Conversions for Nilability

Nilable Types: Implicit Conversions

- A value of non-nilable type can coerce to an argument expecting nilable

```
var myC: owned C = new C();
proc f(in arg: owned C?) { ... }
f(myC); // coercion and ownership transfer (but see 'Open Questions')
```

  - Note that 'ref' / 'const ref' formals do not allow coercions:

```
proc g(const ref arg: owned C?) { ... }
g(myC); // error: cannot coerce for const ref intent
```

- In contrast, type arguments accept subtypes but do not allow coercions
  - so cannot pass the type 'C' to a 'type t: C?' argument

Nilable Types: Implicit Conversions

- In some cases, implicit conversions combine with generic instantiation

```
var myC: owned C = new C();
proc h(arg: borrowed class?) { ... }
h(myC); // h instantiates with 'borrowed C?'
        // and then 'myC' implicitly converts to 'borrowed C?'
```

- See also the section Generic Types 'class' 'record' and 'enum'

Changes to Casting

Nilable Types: Casts from c_void_ptr

- Casts from 'c_void_ptr' to 'borrowed C' were previously allowed, e.g.:

```
class C { }
var myC = new C();
var cptr: c_void_ptr; // defaults to 'nil'
cptr = myC.borrow() : c_void_ptr;
var c = cptr: borrowed C;
```

- The last line no longer sensible:
  - 'c_void_ptr' can store 'nil' but 'borrowed C' cannot

Nilable Types: Casts from c_void_ptr

- To focus the language design and implementation effort, limited cases supported

- Now 'c_void_ptr' can only be cast to an unmanaged nilable type, e.g.:

```
var c = cptr: unmanaged C?;
```

- Use more casts or '!' to go from there to the appropriate type

```
var c2 = (cptr: unmanaged C?) !;          // halts upon nil
var c3 = (cptr: unmanaged C?) : class;    // throws upon nil, see later
```


Nilable Types: Class Downcast

- Previously, downcast resulted in 'nil' if the value did not have compatible type

```
class Parent { }
class Child : Parent { }
proc f( arg: borrowed Parent ) {
  var asChild = arg: borrowed Child;
  if asChild != nil {
    // do something special for the Child type
  }
}
```

- This no longer makes sense now that 'borrowed Child' cannot store 'nil'

Nilable Types: Class Downcast

- This code can work as before if the target type of the cast is nilable:

```
class Parent { }
class Child : Parent { }
proc f( arg: borrowed Parent ) {
  var asChild = arg: borrowed Child?;
  if asChild != nil {
    // do something special for the Child type
  }
}
```

- Quite a few more cast patterns were added to work with nilable types

Nilable Types: More Class Downcasts

```
var p: borrowed Parent = ...;
p:borrowed Child    // throws if runtime type is not compatible
p:Child             // same as above; infers target management
p:Child?            // results in 'nil' if runtime type is not compatible
                    // (does not throw)

var q: borrowed Parent? = ...;
q:borrowed Child    // throws if runtime type is not compatible or q==nil
q:Child             // same as above; infers target management
q:Child?            // results in 'nil' if q==nil or runtime type is not compatible
                    // (does not throw)
```


Nilable Types: Upcasts and Nilable

```
var c: borrowed Child = ...;
c:borrowed Parent   // class upcast always succeeds (as before)
c:Parent            // same as above; infers target management
c:Child?            // always succeeds; converts to nilable type
c:class?            // always succeeds; converts to nilable type
c:Parent?           // as above but combines with class upcast
var d: borrowed Child? = ...;
d:borrowed Child    // throws if d==nil
d:class             // throws if d==nil; infers target management
d:Child             // same as above; infers target management
d:Parent            // as above but combines with class upcast
```


Nilable Types: Casting Owned and Shared

- Similar casts work with 'owned' and 'shared'
  - upcast
  - downcast
  - cast to change nilability

- For example:

```
var x: owned Child? = ...;
x:class                 // throws if d==nil; infers target management
x:Parent                // as above but combines with class upcast
```

Checking if a Type is Nilable

Nilable Types: Checking if a Type is Nilable

- To support generics with nilable types, added two functions to Types modules:
  - 'isNilableClass' returns 'true' for any class type that can store 'nil'
  - 'isNonNilableClass' returns 'true' for any class type that cannot store 'nil'
  - both work…

    …for 'owned', 'shared', 'unmanaged', and 'borrowed' variants

    …for types and for values
- New support for 'class' as a generic type enables several other patterns:

```
isSubtype(t, class?)        // equivalent to 'isNilableClass(t)'
isSubtype(t, class)         // equivalent to 'isNonNilableClass(t)'
isSubtype(t, owned class)   // returns 'true' if 't' is non-nilable 'owned'
```


Open Questions

Nilable Types: Open Questions

- Does '!' always halt when given 'nil' or can the check be omitted on '--fast' ?
- Should '!' applied to an 'unmanaged' result in the 'borrowed' type?
- Should we support features inspired by the Swift conveniences?
- Should we generalize nilable types to non-class types?
- Should it be possible to initialize a non-nilable variable in a separate statement?

Nilable Types: '!' checking and '--fast'

- Proposal for nilability changes indicated that '!' should check even with '--fast'
- However, the 1.20 compiler leaves this check out with '--fast'
- One of the two strategies needs to be adopted:
  - nil-checks for '!' are left out with '--fast'
    - consider adding another operator that always checks
  - nil-checks for '!' are always included, even with '--fast'
    - need to investigate performance impact and attempt to reduce it
- Strategy under discussion in issue #13603

Nilable Types: '!' and 'unmanaged'

- For 'owned' and 'shared', '!' results in the borrowed type by design
  - a common case with '!' is to call methods, e.g.

```
myOwnedNilable!.method();
```

  - in this situation, ownership transfer would be surprising
- For 'unmanaged' the compiler is inconsistent:

```
type t = unmanaged C?;
var x: t;
x! // unmanaged C
t! // borrowed C
```

- Should both result in 'unmanaged C' or 'borrowed C' ? Discussion in #14092

Nilable Types: Convenience Features

- We expect to add convenience features inspired by Swift

```
if let notNil = possiblyNil {
   // notNil has the non-nilable class type and cannot store 'nil'
}

// if possiblyNil is 'nil', returns 'nil', otherwise computes someMethod()
possiblyNil?.someMethod()

// supplies a default value to use when possiblyNil is 'nil'
possiblyNil ?? default
```

Nilable Types: Conditional Guard

- Should conditional guards introduce a new variable?
  - pro: each variable has a single type

```
if let notNil = possiblyNil {
    // notNil has the non-nilable class type and cannot store 'nil'
}
```

- Or should the compiler just know that the variable is not nil within the conditional?
  - pro: uses existing syntax

```
if possiblyNil {
    // compiler knows that possiblyNil is not 'nil'. Is the type of possiblyNil nilable here?
}
```

- Currently leaning towards introducing a new variable

Nilable Types: Generalizing to Non-Class Types

- Would like to generalize nilable types to a general 'option' type, e.g.
  - an optional 'int', storing an integer value or 'nil':

```
var x: option(int);
var x: int?; // perhaps this would be equivalent to the above
```

  - optional records, storing a record value or 'nil':

```
var y: option(R);
var y: R?;    // perhaps this would be equivalent to the above
```

- Swift offers a precedent for this

Nilable Types: Initializing in Separate Statement

- Currently, a variable of non-nilable type needs to be initialized when declared:

```
var x: owned C;          // error
var x: owned C = f(); // OK
```

- Should the first case be allowed if 'x' is provably not used before it is initialized?

```
var x: owned C;
...; // code not using 'x'
x = new owned C();
```

- This pattern is currently common with arrays, e.g.:

```
var B:[D] owned C;
forall i in D do B[i] = new owned C();
```

- This pattern is also common in initializers to initialize array fields

Incomplete Checking

Nilable Types: Incomplete Checking

- The type checking for nilable types is incomplete in 1.20
- We expect to resolve this in the next release

- Two cases should produce compilation errors but do not yet:
  - arrays containing elements of non-nilable types that are not initialized
  - ownership transfer from a non-nilable owned that may be used again

Nilable Types: Problem with Array Elements

- The compiler currently has incomplete nilable type checking for arrays
- Array elements can be 'nil' when the element type is non-nilable

```
var A:[1..10] borrowed C;  // allowed, even though elements store 'nil'
```

- This is a bug

- The compiler should insist such an array is initialized:

```
var A:[1..10] borrowed C = f();  // OK
```

Nilable Types: Transfer from Non-Nilable Owned

- The compiler currently allows ownership transfer from any 'owned'
  - including non-nilable 'owned'

- Ownership transfer leaves an 'owned' storing 'nil'
  - so this is a hole in the nil-checking

- For example:

```
var x: owned C = new owned C();
var y = x;    // ownership transfer; leaves 'x' nil
x.method();   // dereferences 'nil' — can we catch it at compile time?
```

Nilable Types: Transfer from Non-Nilable Owned

- Here are 3 potential directions for a solution:
  - Do nothing and rely on run-time checks
  - Make ownership transfer from non-nilable a compilation error
  - As above, but error only if the 'owned' might be used afterwards

Nilable Types: Always an Error

- What if ownership transfer from non-nilable 'owned' is a compilation error?
- Some common patterns would be difficult to express cleanly

```
proc makeC() {
  return new owned C();
}
var x = makeC();
// during compilation, it is:
temp t: owned C = makeC();
var x = t; // ownership transfer leaving 't' storing 'nil'
```

- Allowing this case would amount to allowing transfers from temporaries
  - but what is so special about temporaries?

Nilable Types: Always an Error

- Only supporting transfers from temporaries might prohibit simple examples:

```
proc f() {
  var x: owned C = makeC();
  var y = x;  // ownership transfer from x to y
}
```

- Intuitively this is OK since 'x' is non-nil everywhere it is used

- Suggests considering more general rules of when a variable is dead
  - See section in Ongoing Efforts and issue #13704

Nilable Types: Impact, Status, Next Steps

Impact: We can start to move beyond this big language change

Status: Implemented in 1.20; some bugs and open questions remain

- '--legacy-classes' flag available to mostly revert to 1.19 behavior

Next Steps:

- Fix bugs and migrate ~24 tests to the new behavior
- Address the two gaps in checking
- Address open questions

Class Memory Management Improvements

Classes: Background

- Chapel has features to enable automatic memory management of classes
  - 'owned', 'shared', 'borrowed' and 'unmanaged'
- However certain language design questions remained open
- Uncertainty remained around these topics:
  - 'new C()' and 'new borrowed C()' for a 'class C'
  - 'new T()' where 'T' is a type argument
  - behavior of untyped arguments instantiated with 'owned'/'shared'
  - type of 'this' in a type method invoked on 'owned C'

Classes: This Effort

- Address these open questions with the following language adjustments:
  - for a 'class C', 'new C()' results in an 'owned C'
  - undecorated class types have generic management
  - default intent for 'owned' and 'shared' is now 'const ref'
  - removed special rule for untyped arguments instantiated with 'owned'/'shared'
  - stacking management decorators is no longer legal
  - type methods on classes now work for any management and any nilability

'new C()'

Classes: 'new' in 1.19

- In 1.19:
  - 'C' by itself meant 'borrowed C'
  - 'new C()' was equivalent to 'new borrowed C()'
    - which is equivalent to '(new owned C()).borrow()'

- Chose this to make the following statements have the same meaning:

```
var x = new C();
var x: C = new C();
var x: borrowed C = new borrowed C();
```


Classes: Problems with 'new' in 1.19

- 'new C()' being the same as 'new borrowed C()' presented some problems:
  - some programmers found that default and syntax unintuitive and confusing
  - the following common patterns needed 'owned' or 'shared'
    - default of 'new borrowed' caused immediate deletion

```
var x = [i in 1..3] new C(i);

record R { var field = new C(); }

proc f() { return new C(); }

throw new C()
```

Classes: 'new' in 1.20

- Now 'new C()' is equivalent to 'new owned C()':
- This enables all of the following common patterns to work:

```
var x = [i in 1..3] new C(i);

record R { var field = new C(); }

proc f() { return new C(); }

throw new C()
```

- And it reduces the need for 'new borrowed'
  - so we could remove it with less impact on the language

Undecorated 'C'

Classes: Undecorated was 'borrowed' in 1.19

- In 1.19, an undecorated 'C' was equivalent to 'borrowed C':

```
var x: C; // is equivalent to:
var x: borrowed C;
```

- Motivation: 'borrowed' is more common than any other management

- However this strategy led to some problems...

Classes: Problems with undecorated is 'borrowed'

- Default of 'borrowed C' was unsatisfying in the context of field declarations

- When declaring fields, users were more likely to want an 'owned' field

```
record wrapper {
  var field: Implementation;
}
new wrapper(new owned Implementation())
// lifetime error in 1.19 — 'field' is of type 'borrowed Implementation'
```

Classes: Problems with undecorated is 'borrowed'

- Changing 'new C()' to be 'new owned C()' brought about two problems:
  - Inconsistency in type inference:

```
var x     = new C();     // type of x is inferred to be 'owned C'
var x: C = new C();      // type of x 'borrowed C'
```

  - Left the following example unclear and confusing:

```
proc factory(type t) {
  return new t();
}
factory(owned C);        // = 'new owned C()'
factory(C);              // = 'new owned C()' or 'new borrowed C()' ?
factory(borrowed C);     // = 'new owned C()' or 'new borrowed C()' ?
```

Classes: Undecorated is Generic in 1.20

- Now an un-decorated 'C' indicates generic management
  - that is, it is a generic type leaving the management unspecified

- This change addresses all 3 problems

- Field example now works as expected:

```
record wrapper { var field: Implementation; }
new wrapper(new Implementation())
// works as expected in 1.20 — 'field' is of type 'owned Implementation'
```


Classes: Undecorated is Generic in 1.20

- Type inference problems with 'new' are resolved:

```
var x     = new C();          // type of x is inferred to be 'owned C'
var x: C  = new C();          // type of x is inferred to be 'owned C'
var x: C  = new owned C();    // type of x is inferred to be 'owned C'
var y: C  = new shared C();   // type of x is inferred to be 'shared C'
```


Classes: Undecorated is Generic in 1.20

- Factory example now has clear behavior:

```
proc factory(type t) {
  return new t();
}
factory(owned C);       // = 'new owned C()'
factory(C);             // = 'new C()' = 'new owned C()'
factory(borrowed C);    // = 'new borrowed C()'
```

- Now each case behaves the same as textually substituting the type argument

Classes: Behavior not Changed

- Function signature still indicates whether ownership transfer is possible
  - now 'in' intent is the only indicator

- Methods on classes still use 'borrowed' type for 'this'
  - see next slide

Classes: Methods

- Methods on classes still use the borrow type for 'this':

```
class C {
  proc primary()    { /* this.type == borrowed C */ }
}
proc C.secondary() { /* this.type == borrowed C */ }
```

- Changing these to generic management would interfere with overriding
  - requiring significant implementation changes to virtual dispatch
  - creating more combinations of overriding and overloading
- Perhaps a parenthesized type expression should allow generic management:

```
proc (C).secondary() { /* this.type management from call site */ }
```


Passing 'owned' and 'shared' Actual Arguments

Classes: 'owned'/'shared' Actual Arguments in 1.19

- In 1.19, the default intent for 'owned' / 'shared' was 'in'
  - Ownership transfer not surprising since formal argument indicates 'owned'

```
give(new owned C());

proc give(a: owned C) {} // 'a' takes over ownership from the actual arg
```

- 'owned C' passed to 'C' formal argument does not cause ownership transfer
  - Ownership transfer in this case would be surprising
  - Call uses coercion from 'owned C' to 'borrowed C'

```
var mine = new owned C();

borrowing(mine);

proc borrowing(c: C) {}   // borrows because 'C' = 'borrowed C'
```


Classes: 'owned'/'shared' Actual Arguments in 1.20

- The default intent for 'owned' / 'shared' is now 'const ref'
  - avoids the need for a special instantiation rule (see next slide)
- 'owned' typed formal arguments need 'in' intent to transfer ownership:

```
give(new owned C());
proc give(a: owned C) {}      // 'const ref' intent -- no ownership transfer
proc give(in a: owned C) {}   // adding 'in' causes ownership transfer
```

- 'owned C' passed to 'C' argument still does not cause ownership transfer
  - formal argument instantiates as 'owned C' then uses 'const ref' intent:

```
var mine = new owned C();
borrowing(mine);
proc borrowing(c: C) {}       // instantiates to 'owned C' passed by 'const ref'
```


Classes: 'owned'/'shared' to Untyped in 1.19

- Special instantiation rule supported untyped arguments
  - Ownership transfer for such untyped arguments would be surprising
  - So, default-intent untyped formal instantiated to a borrowed type:

```
f(new owned C());
proc f(x) {}          // x was instantiated as a borrow
```

- Declaring a type or using an 'in' intent overrode this behavior

```
g(new owned C());
proc g(y: owned) {}   // y took over ownership from the actual arg
h(new owned C());
proc h(in z) {}       // z took over ownership from the actual arg
```

- Rule was hard to remember and required special handling in generic code

Classes: 'owned'/'shared' to Untyped in 1.20

- To make the language more uniform, we chose to remove the special rule
- Default intent of 'const ref' avoids ownership transfer in the untyped case:

```
f(new owned C());
proc f(x) {}        // x argument instantiated 'const ref x: owned C'
```

- Ownership transfer is still available with the 'in' intent

```
h(new owned C());
proc h(in z) {}     // z takes over ownership from the actual arg
```

- This change resolved many problems with generic code in the standard modules

Combining Management Decorators

Classes: Combining Decorators in 1.19

- In 1.19, management decorators could not be combined in one expression:

```
var x: owned unmanaged C; // error
new borrowed owned C();   // error
```

- However they could be combined in generic code
  - in which case, the outermost decorator would override the others:

```
proc f(type t) { return owned t; }
f(borrowed C); // returns 'owned C'
proc g(type t) { return new owned t(); }
g(borrowed C); // returns 'new owned C()'
```


Classes: Combining Decorators in 1.20

- Now management decorators cannot be combined in any circumstance:

```
var x: owned unmanaged C; // error
new borrowed owned C();   // error
proc f(type t)  { return owned t; }
f(borrowed C); // error: 'owned borrowed C'
proc g(type t)  { return new owned t(); }
g(borrowed C); // error: 'new owned borrowed C()'
```


Classes: Combining Decorators in 1.20

- Casts on types are available to override a management decorator
- Allows one to rewrite the examples that are now errors:

```
proc f(type t) {
  return t:owned;
}
f(borrowed C); // 'owned C'
proc g(type t) {
  type ownedT = t:owned;
  return new ownedT();
}
g(borrowed C); // 'new owned C()'
```

Type Methods

Classes: Type Methods in 1.19

- In 1.19, type methods on class C only worked on 'borrowed C'
- To fix, needed to decide upon the type of 'this' in other cases, e.g.:

```
class C {
  proc type typeMethod() {
    writeln(this:string);
  }
}
var x = new owned C();
x.type.typeMethod();      // should it output 'owned C' or 'borrowed C' ?
```

Classes: Type Methods in 1.20

- Now type methods on classes work on any management and any nilability
- The 'this' type is considered generic and instantiated with the actual type:

```
class C {
  proc type typeMethod() {
    writeln(this:string);
  }
}
var myOwned = new owned C();
myOwned.type.typeMethod();     // outputs 'owned C'
(borrowed C?).typeMethod();    // outputs 'borrowed C?'
C.typeMethod();                // outputs 'C'
```


Classes: Impact, Status, Next Steps

Impact: Language stability in this area has significantly improved

Status: Open questions are addressed and solutions are implemented

Next Steps: Gain experience with current language

- Migrate a straggling test or two to the new behavior
- Resolve the remaining open questions based on experience:
  - Should methods on classes always use 'borrowed' for 'this'?
    - Should there be a way to opt into something more generic?
  - Do we need an optimization to remove indirection for 'const ref' 'owned' ?

Task/Forall Intents on 'this'

Task/Forall Intents: Background

Fields were ignored by task/forall intents

- unintuitive for task/forall constructs in methods on a record
- because 'this' is passed by *default intent* i.e. 'const ref' into task functions

```
forall idx in … {
  this.myArrayField[idx] = 5;   // disallowed: 'this' is a 'const ref' here
  writeln(this);
}
```

Task/Forall Intents: This Effort

Treat fields of 'this' as individual variables

- passed by *default intent* into task functions
- only when 'this' is a record

```
forall idx in … {
  this.myArrayField[idx] = 5;   // ok
  writeln(this);
}
```

now can update array fields

remains a 'const ref' reference to the outer 'this'

Task/Forall Intents: Impact, Status

Impact: More intuitive operation on fields of 'this'

Status: The implementation disallows explicit intents on 'this', on fields of 'this'

- in 'with'-clauses of 'forall', 'coforall', 'cobegin', 'begin'
- to avoid potential ambiguity, e.g.,

```
forall idx in … with (in this) {
  myArrayField[idx] = 5; // treat it as an individual variable with 'ref' intent
                         // or as a field of the shadow variable for 'this' ?
}
```

- we may enable these if a compelling use case arises

Partial Instantiations

Partial Instantiations: Background

- Partial instantiations are generic types with some, but not all, fields instantiated

```
record R {
  type T;
  type U;
  ...
}
type RI = R(int); // 'U' is uninstantiated
```

- Partial instantiations are useful in initialization or in argument types

```
proc foo(r_int : R(int)) { ... } // Any 'R' provided 'T' is 'int'
var x : RI = new R(int, real); // limit type of 'x'
var y = new RI(real); // use 'RI' to avoid typing 'int' repeatedly
```


Partial Instantiations: Background

- Partial Instantiations were not supported in Chapel 1.19
  - Special support existed for argument types but was not widely available
- Many design questions remained open
  - How should users create partial instantiations?
  - How to detect partial instantiations?
  - How to handle fields with default values?
  - How do partial instantiations interact with initializers?

Partial Instantiations: This Effort

- Answered design questions
  - Chose a design with minimal impact on existing programs
- Implemented partial instantiations
  - Users can create partial instantiations
  - Users can programmatically identify partial instantiations
  - Generic types can be passed to and returned from functions
  - Partial instantiations can be used with initializers

Partial Instantiations: Simple Instantiations

- Partial instantiations are instantiated like normal generic types
  - The result is still generic and has a type constructor
  - Type constructor has arguments for uninstantiated fields in declaration order
  - Fields can be instantiated in any order (provided there are no dependencies)

```
record R { type X; type Y; param p : int; }
type A = R(int);   // A's type constructor accepts two args for 'Y' and 'p'
type B = A(p=5);   // B's type constructor accepts one arg for 'Y'
type C = B(real); // C is fully instantiated as 'R(int, real, 5)'

record S { type T; param p : T; } // 'p' depends on 'T'
type Bad = S(p=5); // compile-time error, must instantiate 'T' before 'p'
```

Partial Instantiations: Default Values

- Historically, fields with default values are instantiated in the absence of args
  - E.g., 'range' meant 'range(int, BoundedType.bounded, false)'
- In 1.20 users can pass '?' to indicate that such fields should stay uninstantiated
  - Minimizes impact on existing code
  - Similar to existing feature for formal types

```
record R { type T = int; param S = false; }
proc foo(arg : R); // accepts only 'R(int, false)'
proc foo(arg : R(?)); // accepts any 'R'
proc foo(arg : R(real, ?)); // any 'R" where 'T' is a 'real'
var r : range(?) = 1..10 by 2; // new: initialize ranges of arbitrary types
type RI = R(S=?); // new: 'S' is explicitly uninstantiated, 'T' defaults to 'int'
```

Partial Instantiations: Default Values (continued)

- In 1.20 '?' applies to **all** remaining fields with default values for convenience
  - 'range(?)' vs 'range(?, ?, ?)'
- '?' can only appear once in a type constructor call
  - Cannot be used as a positional argument
  - Must use named expressions after '?'

```
record R { type X = ...; type Y = ...; type Z = ...; }
R(?, ?, int); // compiler-error; '?' used as positional arg
R(uint, real, ?); // OK because '?' is last
R(?, Y=complex); // OK because only named expressions after '?'
R(Y=complex, ?); // Can use named expressions before '?' if desired
```

Partial Instantiations: Querying Fields

- Users have a few options for identifying partial instantiations
- Basic detection is provided by 'isGeneric'

```
record R { type T; param p : int; }
writeln(isGeneric(R(int))); // true
```

- Reflection provides 'isFieldBound'
  - Useful when field names are known

```
use Reflection;
type RI = R(int);
writeln(isFieldBound(RI, "T")); // true
```

Partial Instantiations: Querying Fields

- Alternatively users can compare fields against '?'
  - Here '?' acts as either a type or param expression when needed

```
record R { type T; param p : int; }
type RI = R(int);
writeln(RI.T == ?); // false
writeln(RI.p == ?); // true
```

Partial Instantiations: Passing/Returning Generics

- Generic types can now be passed to and returned from functions
  - For consistency with concrete and fully instantiated types

```
record R { type T; param p : int; }
// Passing and returning fully-generic types
proc getR() type return R;
proc make(type Base, type T, param p : int) return new Base(T, p);
var x = make(getR(), int, 5); // creates an 'R(int,5)'

// Passing and returning partial instantiations
proc RInt type return R(int);
proc make(type Base, param p : int) return new Base(p);
var y = make(RInt, 5); // creates an 'R(int,5)'
```

Partial Instantiations: New-Expressions

- Type aliases can be used with new-expressions
  - Compiler inserts named-expressions for each instantiated field

```
record R { type T; type U; var x : T; var y : U; }
type RIS = R(int, string);
var x = new RIS(5, "hello");
// becomes... new R(T=int, U=string, 5, "hello");
```

- In 1.20 the compiler provides similar support for partial instantiations

```
type RI = R(int);
var y = new RI(string, 5, "hello");
// becomes... new R(T=int, string, 5, "hello");
```

Partial Instantiations: init=

- 'init=' can now support initializing variables with generic type expressions:

```
record Wrapper { type T; var x : T; }
var x : Wrapper(int(8)) = 5; // creates a Wrapper(int(8)) from bound 'T'
var y : Wrapper = 10; // creates Wrapper(int(64)) inferred from '10.type'
```

- To do so, 'init=' uses 'this.type' to compare fields against '?' for the generic case

```
// a user-defined 'init=' method for the Wrapper type
proc Wrapper.init=(x : integral) {
  this.T = if this.type.T != ? then this.type.T else x.type;
  this.x = x:this.T;
}
```

Initializers and Generic Types: Next Steps

Initializers and Generic Types: Next Steps

- Gather feedback on partial instantiations
- Design and implement 'noinit'
  - Allows users to disable initialization of a variable
- Update array and domain implementation to use 'init='
- Allow type aliases to be used with new-expressions involving typeless fields
  - Can possibly leverage new partial instantiation features

String and Bytes Types

Strings and Bytes: Background and This Effort

Background:

- Chapel's string type recently switched to using UTF-8 encoding
  - Currently, POSIX environment variables need to specify a UTF-8 locale
- Several design decisions had also been made but not implemented
  - Index by codepoints by default
  - Create a string-like type to hold arbitrary binary data

This Effort:

- Complete 'string' changes to support Unicode
- Add 'string' factory functions
- Add a new 'bytes' type

String and Bytes: Unicode Support

- Indexing, iteration and length now use codepoint units by default

```
var str = "événement"; // In UTF-8; c3 a9 76 c3 a9 6e 65 6d 65 6e 74
var len = str.length; // len is 9
```

- Use 'string.numBytes' to get number of bytes

```
var len = "événement".numBytes;        // len is 11
```

- 'byteIndex' type is now available to request byte indexing

```
var s1: string = str[3]; // gets the 3rd codepoint as a string: "é"
var s2: string = str[3:byteIndex]; // gets the codepoint starting at the
                                   // 3rd byte as a string: "v"
```


String and Bytes: Factory Functions

- Previously, string initializers used flags to control ownership and copy behavior
  - For example:

```
// Create a string taking ownership of the buffer of myCPtr.
// When the string goes out of scope, the buffer will be freed.
var s = new string(cPtr, length=N, size=N+1, isowned=true,
                   needToCopy=false);
```

  - Error prone: 'isowned=false', 'needToCopy=true' leaks the buffer
- These initializers are now deprecated in favor of the following factory functions:

```
createStringWithNewBuffer(cPtr, length=N, size=N+1);    // copy and dealloc
createStringWithOwnedBuffer(cPtr, length=N, size=N+1);  // no copy but dealloc
createStringWithBorrowedBuffer(cPtr, length=N, size=N+1); // no copy, no dealloc
```

String and Bytes: New 'bytes' type

- The new 'bytes' type stores arbitrary bytes
  - It does not have to be Unicode or character data at all

```
var myBytes = b"some bytes";     // myBytes is a bytes
```

- Has similar methods to string, such as 'find', 'replace', 'join' etc.

- Also supports character-based methods, such as 'toUpper', 'isTitle' etc.
  - These operations assume ASCII encoding and ignore non-ASCII bytes

- Better performance on ASCII text, as there is no need for character decoding

String and Bytes: 'bytes' keyword and literals

- 'bytes' is now a keyword

```
var myBytes: bytes;    // default-initialized bytes
```

- 'bytes' can be created using the following literals

```
var myBytes = b"bytes\nwith quotes";
writeln(myBytes);    //prints: bytes
                                with quotes
```

- Triple quotes can be used to create multiline and/or unescaped 'bytes'

```
var myBytes = b"""raw bytes\nwith triple quotes""";
writeln(myBytes);    //prints: raw bytes\nwith triple quotes
```

- As with strings, single quotes can also be used to specify bytes literals

String and Bytes: I/O with 'bytes'

- 'bytes' type work with I/O calls:

```
var b = b"événement";
writeln(b);    // prints: événement
```

- Bytes also support formatted I/O

```
writef("%ht\n", b);    //prints: b"\xC3\xA9v\xC3\xA9nement"
```

- Binary formats can be used to read/write bytes

```
var b: bytes;
readf("%|4s", b);    // read 4 bytes into b
writef("%|4s", b);  // write 4 bytes from b
```


String and Bytes: Conversions

- A 'string' can be cast to 'bytes', because bytes can hold arbitrary data

```
var myBytes: bytes = "some string":bytes;
```

- To create a string from a bytes, it needs to be decoded

```
var myString: string = b"some bytes".decode();
```

  - Behavior for decoding errors can be specified, e.g.:

```
myBytes.decode(decodePolicy.strict);   // throw DecodeError (default)

myBytes.decode(decodePolicy.replace);  // replace invalid bytes with the
                                       // UTF-8 replacement character

myBytes.decode(decodePolicy.ignore);   // drop invalid bytes
```

- Currently only UTF-8 is supported, but we plan to add more encodings

String and Bytes: Impact

- Better support for UTF-8 strings
- New 'bytes' type holds arbitrary bytes
- Easy-to-use factory functions instead of error-prone initializers

String and Bytes: Open Questions

- How and when are errors with invalid UTF-8 sequences reported?
- How to handle POSIX filenames?
  - Filenames are not necessarily UTF-8 but often will be
- Should the I/O system support conversion between character sets?
  - e.g., to address garbles when printing UTF-8 data to a non-UTF-8 terminal
- Should Chapel source code support non-ascii identifiers? e.g.

```
var événement = 1;
```

- What should different ways to index a 'bytes' return?

```
myBytes[5]; // returns another 'bytes' today, but maybe should return uint(8)?
for b in myBytes do … ;   // yields 'bytes' but maybe should yield 'uint(8)'s?
```


String and Bytes: Next Steps

- Resolve the open questions
- Implement UTF-8 validation for strings
- Fail at program startup if environment is incompatible with UTF-8 encoding
- Retire 'c_string'
- Improve the 'bytes' implementation
  - support param 'bytes'
  - add I/O convenience functions such as 'readbytes'
  - identify and resolve any performance problems

Private and Public Use Statements

Use Statements: Background

- ‘use’ statements are transitive by default
  - Symbols made available to a module are available to its clients, too

```
module Foo { var someVar = 10; }
module Bar { use Foo; }
module Baz {
  use Bar;
  someVar = 1; // Refers to ‘Foo.someVar’ and is currently allowed
}
```

- Possible to hide symbols brought in by ‘use’ in some cases
  - By moving the ‘use’ statement inside function bodies or local scopes …

  … but doesn’t help with symbols needed in arguments/return types

Use Statements: This Effort

- Added support for declaring ‘use’ statements as ‘public’ and ‘private’
  - ‘public use’ means symbols are available to clients of the current module
  - ‘private use’ makes the symbols only visible to the scope of the ‘use’

```
module Bar { private use Foo; }
module Baz {
  use Bar;
  someVar = 1; // Can’t reference ‘someVar’ any more: Bar’s ‘use’ is private!
}
```

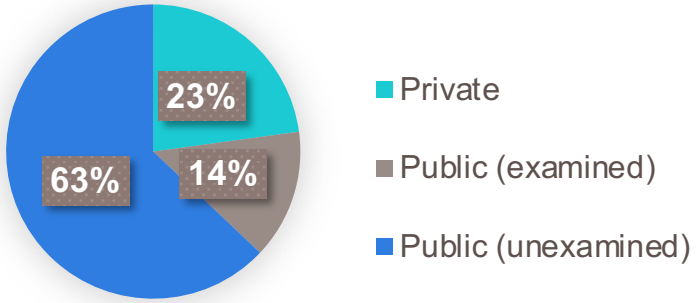
  - ‘use’ without public/private is currently the same as ‘public use’
- Applied ‘private use’ to many internal/standard/package ‘use’ statements

Use Statements: Impact

- Allows libraries to more intentionally control available symbols
  - About 25% of internal module uses no longer leak symbols (see chart)
- Addresses a problem with variables matching library symbols

```
var e = 17;
{
  use Foo;      // Foo has implicit 'use Math'
  writeln(e);   // used to refer to Math.e
}
```

Uses in Chapel Libraries Today



Use Statements: Next Steps

- Continue to convert more public uses to private where reasonable
- Consider changing default ‘use’ to mean ‘private’ for safety
- Add ‘import’ keyword
  - To allow qualified access to a module's symbols without unqualified access

```
import Foo;
writeln(Foo.someVar); // allowed by ‘import’ statement
writeln(someVar);     // not allowed by ‘import’ statement
```

- Resolve open language design questions around ‘use’/‘import’
  - See section in Ongoing Efforts

Use of Top-Level Modules

'use' of Modules: Background

- Traditionally, if a top-level module was known to 'chpl', it could be named in code

```
module M {
  N.foo();   // referring to N is OK since it's visible through lexical scoping
}

module N {
  proc foo() { … }
}
```


'use' of Modules: Background

- However, this also resulted in some surprising / inconsistent behaviors…

```
module M {
  N.foo();   // error: compiler has no notion of what `N` is
}
```


'use' of Modules: Background

- However, this also resulted in some surprising / inconsistent behaviors…

```
module M {
  N.foo();   // whether or not `N` makes sense here depends on O's contents…
  {  use O;  }
}
```

'use' of Modules: Background

- However, this also resulted in some surprising / inconsistent behaviors…

```
module M {
  N.foo();   // error: compiler still has no notion of what `N` is
  {  use O; }
}

module O {
  proc bar() { … }
}
```


'use' of Modules: Background

- However, this also resulted in some surprising / inconsistent behaviors…

```
module M {
  N.foo();   // OK: O's use of `N` adds it as a top-level module, so now it's visible
  {  use O; }
}

module O {
  use N;
  proc bar() { … }
}
```

N.chpl

```
module N {
  proc foo() { … }
}
```

'use' of Modules: Background

- However, this also resulted in some surprising / inconsistent behaviors…

```
module M {
  N.foo();   // Still OK: O's use of `N` may be private, but N is still lexically visible
  {  use O; }
}

module O {
  private use N;
  proc bar() { … }
}
```

N.chpl

```
module N {
  proc foo() { … }
}
```

'use' of Modules: This Effort

- This release adopts a new rule to avoid this instability:
  - To refer to a top-level module, a 'use' of that module must be lexically visible

```
module M {

  N.foo();   // this reference to N is no longer OK since there is no `use` of it
}

module N {
  proc foo() { … }
}
```

'use' of Modules: This Effort

- This release adopts a new rule to avoid this instability:
  - To refer to a top-level module, a 'use' of that module must be lexically visible

```
module M {
  use N;
  N.foo();    // now it's OK due to the lexically visible `use N`
}

module N {
  proc foo() { … }
}
```

'use' of Modules: Impact, Next Steps

Impact:

- Code that relies on the historical rules needs updating to add 'use's
- Code updated in this way has typically ended up being easier to understand

Next Steps:

- Should the same rule apply to submodules?
  - Ones defined in the current module?
  - Ones defined in a sibling or cousin module?
- Continue efforts to improve modules in their role as namespaces

Overload Set Checking

Overload Sets: Background

Hijacking: when a change to a library affects user code inadvertently

- with a reasonable addition of a function

```
module LibA { // v1.0
  proc draw() {…}


}
module LibB {
  proc drill(x: real) {…}
}
use LibA, LibB;
draw(); drill(1);
```

use LibA to `draw`

initially, user code invokes `LibB.drill` as desired

Overload Sets: Background

Hijacking: when a change to a library affects user code inadvertently

- with a reasonable addition of a function

```
module LibA { // v2.0
  proc draw() {…}
  proc drill(x: int) {…}
}
module LibB {
  proc drill(x: real) {…}
}
use LibA, LibB;
draw(); drill(1);
```

LibA 2.0 adds new functionality

After update to LibA 2.0, this switches to `LibA.drill` without user knowledge

Overload Sets: This Effort

Report an error upon a possibility of hijacking

- upon a function call, all applicable functions must be in the same *overload set*
- an *overload set* contains like-named functions defined in the same module

```
module LibA {
  proc drill(x:int) {…}
  proc drill(x:imag) {…}
}
```

```
module LibB {
  proc drill(x:real) {…}
  proc drill(x:complex) {…}
}
```

ok: only `drill` in LibB is applicable

error: functions in both overload sets are applicalbe

```
use LibA, LibB;  drill(myComplex);  drill(myInt);
```

Overload Sets: This Effort

Overload Sets check passes when one of the following applies:

- all applicable functions are in one overload set
- the best applicable function is in the overload set that is *more visible* than others
- for methods on classes:
  - the best function is in the same overload set as the class declaration

```
use Barriers, AllLocalesBarriers; // AllLocalesBarrier is child of Barrier
(new AllLocalesBarrier()).lock(); // would be an error without this rule
```

Compiler option '--no-overload-sets-check' turns off this check

Further details available in the online technote Checking Overload Sets

Overload Sets: Impact, Next Steps

Impact: out of >10k Chapel tests:

- potential issues were exposed in 3 tests
- multiple overload sets are intentional in 2 tests

Next Steps:

- seek user feedback: what needs adjusting?
- language support for merging overload sets?

```
use LibA, LibB;

merge-overload-sets drill;  // syntax t.b.d.

drill(4.7932);   // use LibB.drill(real)

drill(5);        // use LibA.drill(int); ok that LibB.drill is also applicable
```


Atomic Interface Stabilization

Atomics: Background and This Effort

Background: Chapel atomics were modeled after C11/C++11 atomics

- We identified several interface problems during language stabilization efforts
  - C names were used for memory orders instead of a Chapel enum
  - peek/poke operations were not ready for stabilization
  - compareExchange interface did not match C/C++

This Effort: Addressed the above problems to stabilize the atomics API

Atomics: Memory Order

Background: Previously, we used the C names for atomic memory orders

- e.g. memory_order_relaxed

This Effort: Changed memory orders to a Chapel enum

- Updated atomic operations to require param orders
  - Order must be known at compile-time to optimize; params enforce this

```
enum memoryOrder { relaxed, acquire, release, acqRel, seqCst }

proc AtomicT.add(value: T, param order:memoryOrder = memoryOrder.seqCst) ...

a.add(1);
a.add(1, memoryOrder.relaxed);
a.add(1, memoryOrder.seqCst);
```


Atomics: peek and poke

Background: peek/poke provide non-atomic read/write operations

- These can mitigate overhead when atomicity is not required
  - e.g peek/poke are 200x faster than read/write for ugni network atomics
- However, peek/poke need interface work

This Effort: Moved peek/poke to an unstable opt-in module

- Allows us to improve their API without breaking core atomic interface

```
use PeekPoke;
var T: [1..n] atomic int;
[i in 1..n] T[i].poke(i);
const sum = + reduce T.peek();
```

Atomics: compareExchange: Background

- compareExchange API did not match C/C++

  Chapel:

```
proc compareExchangeStrong(expected: T, desired: T): bool
```

  C++:

```
bool compare_exchange_strong(T& expected, T desired);
```

- In C/C++, 'expected' is passed by reference and updated on failure
  - In Chapel, it is passed by value, so not modified on failure
  - This presented a problem because symmetry with C/C++ is important

Atomics: compareExchange: This Effort

- Decided to adjust the API to match C/C++
  - Renamed compareExchange to compareAndSwap this release
  - Will add compareExchange that matches C/C++ next release
- compareAndSwap simplifies common patterns

```
while !l.compareAndSwap(false, true) { } // exchange would need tmp and assignment in loop
l.write(false);
```

- compareExchange is more efficient when 'expected' has to be updated

```
proc AtomicT.mult(v: T) {
  var oldV = this.read();
  while !this.compareExchange(oldV, oldV * v) { } // swap would need atomic load in loop
}
```


Atomics: Status and Next Steps

Status: Atomic interface has been improved

- Not expecting any further breaking changes

Next Steps: Continue to improve atomic capabilities

- Add a general mechanism to perform non-atomic updates on atomics
  - Enables optimization of HPC apps with distinct init, write, and read phases
  - May look to Rust ‘get_mut’ or C++ ‘atomic_ref’ for inspiration
- Add optimization hints for local vs. remote access
- Allow users to specify required operations (for networks with limited atomics)
- Extend atomic support to classes and records
- Implement operator overloads

Distinguishing 'nothing' from 'void'

Void/Nothing: Background

Background: Two types of 'void'

- A routine that doesn't return anything has type 'void'
  - Result cannot be assigned to a variable

```
proc f(): void { writeln("no return"); }
var a = f(); // error: illegal use of a function that doesn't return a value
```

- Giving a variable the type 'void' made the compiler remove it

```
var filename: if useFilename then string else void;
```

  - There was also a value of type 'void' that could be returned and assigned

```
proc g(): void { return _void; }
var filename = if useFilename then "myfile.txt" else g();
```


Void/Nothing: This Effort, Impact

This Effort: Break the two concepts apart into 'void' and 'nothing'

- The 'nothing' type has a single value: 'none'

```
proc f(): void { writeln("no return"); }
proc g(): nothing { return none; }
var fn: if useFilename then string else g();
```

Impact: Naturally separates two distinct concepts

- Removes ambiguity around routine returns
- Corresponds roughly to notions of “bottom” vs. “unit” type

Generic Types 'class' 'record' and 'enum'

Generic Types: Background, This Effort

Background: Generic types are sometimes useful for categories of types

- Provide a useful alternative to 'where' clauses
  - faster to compile in practice
- 'enumerated', 'integral', and 'numeric' have existed for this purpose

This Effort: Added 'class', 'record', and 'enum' generic types

```
proc a( x: class ) { }   // x accepts any non-nilable class
proc b( y: record ) { }  // y accepts any record
proc c( z: enum ) { }    // z accepts any enum
```


Generic Types: Impact, Next Steps

Impact: Easy and intuitive to express particular management or nilability

```
proc f( x: class ) { }              // any non-nilable class
proc g( x: class? ) { }             // any nilable class
proc h( x: owned)   { }             // nilable or non-nilable owned
proc i( x: borrowed class ) { }     // any non-nilable borrowed class
proc j( x: shared class? )  { }     // any nilable shared class
```

Next Steps:

- Deprecate 'enumerated' in favor of 'enum'
- Consider adding user-defined type classes

Changes to 'isSubtype'

Subtypes: Background

- 'isSubtype' has included coercions since 1.18

- However class inheritance is really different from numeric conversion:
  - passing an 'int(8)' to an 'int' formal argument creates a new value
  - passing a 'Child' class to a 'Parent' formal argument aliases the original

- Would like to support type queries to identify these cases

Subtypes: This Effort

- Split 'isSubtype' into 'isSubtype' and 'isCoercible'
  - 'isSubtype' no longer considers coercions
  - '<=' on types is still equivalent to 'isSubtype'
    - so, it no longer considers coercions
- The term 'subtype' now has a more concrete meaning:
  - an implicit conversion to a subtype refers to the original memory
  - vs. a coercion which produces a new value of the target type
- In principle, subtypes can be passed to 'const ref' arguments
  - but this is not implementable until we move to '--llvm' by default

Subtypes: Impact, Next Steps

Impact: Several language design elements are on firmer ground

- 'type' arguments allow subtyping but not coercion
- applied subtype definition to new management and nilability conversions
  - conversion to borrowed type or to a parent class type are subtyping
  - conversion from non-nilable to nilable is a coercion

Next Steps:

- Improve language documentation about the meaning of the term 'subtype'
- Consider enabling subtyping conversions for 'const ref' arguments with '--llvm'

Deprecated Language Features

Deprecated Language Features: Background

- To prepare for the Chapel 2.0 release, we're also removing problematic features
- Some notable cases in Chapel 1.20 were:
  - copy-initializers implemented with 'init'
  - string + value operations
  - assignment from ranges to n-dimensional arrays
  - opaque domains and arrays
- See "Deprecated / Removed Language Features" in CHANGES.md for others

Deprecating Copy Initializers

Deprecating Copy Init: Background, This Effort

Background: 1.19 introduced the 'init=' method for copy initialization

- Allowed users to implement either 'init' or 'init=' methods for copy initialization
  - Kept existing code working
  - Allowed users to explore 'init='

This Effort: Added deprecation warning if 'init' is resolved as the copy initializer

```
9  proc R.init(other:R) {
10   this.x = other.x;
11 }
```

```
foo.chpl:9: warning: 'init' has been deprecated as the copy-initializer, use 'init=' instead.
```


Deprecating Copy Init: Impact, Next Steps

Impact: Most programs simply require changing text from 'init' to 'init='

- Some programs used 'init' for new-expressions and copy-init
  - Needed to write a new 'init=' method

Next Step: Change the warning to an error

String + Value Operations

String + Value: Background, This Effort

Background: Chapel has traditionally supported *string* + *value* operations

- these were supported for basic scalar types: bools, ints, reals, etc.

```
[i in 1..10] writeln("hello " + i);
```

This Effort: Deprecated these '+' overloads due to possible confusion

- the '+' operator is typically only supported on identical types

```
writeln(1 + "10");          // should this be “110” or 11?
```

- since not all types had '+' overloads, led to confusion

```
writeln("hello " + 1..10); // “hello 1..10” or an array of “hello i” strings?
```

- workarounds don’t seem onerous (using casts or creating new '+' overloads)

```
[i in 1..10] writeln("hello " + i:string);
```

String + Value: Impact, Status, Next Steps

Impact:

- existing code must be rewritten to use explicit casts or user overloads
  - all existing tests and released modules have been updated

Next Steps:

- consider other non-orthogonalities and points of confusion in the language

Assignment from Ranges to n-dimensional Arrays

(for n > 1)

Array = Range: Background, This Effort, Status

Background: Chapel has long supported assignments from ranges to nD arrays

```
var A: [1..10, 1..10] int;
A = 1..100;
```

- however, this doesn't match our traditional notion of *matching shape*

This Effort: Deprecated these features now to avoid future surprises

Next Steps: Add utility iterators that can support such patterns

- for example:

```
for (a, i) in zip(flatten(A), 1..100) do a = i;
flatten(A) = 1..100;
```

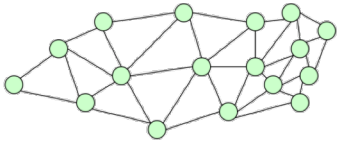

Opaque Domains and Arrays

Opaque Domains: Background, This Effort, Status

Background: Chapel has supported opaque domains / arrays since the outset

- intended to support unstructured collections as domains / arrays

```
var OD: domain(opaque);
var A: [OD] real;
```



- however, in practice, users have always relied upon different approaches
  - e.g., sparse or associative domains / arrays; class-based collections

This Effort: Deprecated these features to reduce code maintenance

- could always reintroduce in the future, if considered valuable

Status: Deprecation warnings added in 1.20; features will be removed in 1.21

For More Information

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

- Syntactic/Naming Changes
- Semantic Changes / Changes to the Chapel Language
- New Features
- Feature Improvements
- Deprecated / Removed Language Features
- Standard Library Modules
- Error Messages / Semantic Checks

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THANK YOU

QUESTIONS?


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