Language Improvements

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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'

```javascript
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

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

ggetField(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

ggetField(x); // compile-time error: x is nilable, passed to non-nilable

ggetField(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
  
  \[
  \begin{align*}
  &\text{C;} \quad \text{// non-nilable, generic management} \\
  &\text{C?;} \quad \text{// nilable, generic management} \\
  &\text{owned C;} \quad \text{// non-nilable owned} \\
  &\text{owned C?;} \quad \text{// nilable owned}
  \end{align*}
  \]

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

  \[
  \begin{align*}
  &\text{class C \{ var x; \}} \\
  &\text{new C(5)?} \quad \text{// equivalent to the next line} \\
  &\text{new C?(5)}
  \end{align*}
  \]
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')

<table>
<thead>
<tr>
<th>If a variable is declared as...</th>
<th>Then x! has type...</th>
</tr>
</thead>
<tbody>
<tr>
<td>var x: owned C?</td>
<td>borrowed C</td>
</tr>
<tr>
<td>var x: shared C?</td>
<td>borrowed C</td>
</tr>
<tr>
<td>var x: borrowed C?</td>
<td>borrowed C</td>
</tr>
<tr>
<td>var x: unmanaged C?</td>
<td>unmanaged C</td>
</tr>
</tbody>
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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

```plaintext
var myC: owned C = new C();
proc h(arg: borrowed class?) { ... }
```

```plaintext
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.:

```javascript
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

```java
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:

```rust
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

```javascript
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

```c
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

```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
    ```swift
    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
      ```swift
      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':
    ```swift
    var x: option(int);
    var x: int?; // perhaps this would be equivalent to the above
    ```
  - optional records, storing a record value or 'nil':
    ```swift
    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
  
```plaintext
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:
  
```plaintext
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:

```cpp
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

```plaintext
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:

```plaintext
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

```c
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':

```javascript
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

  ```java
  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:

```plaintext
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'
```
• Factory example now has clear behavior:

```plaintext
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':

```java
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:

```java
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:

    \[ f(new \ owned \ C()); \]
    \[ \text{proc } f(x) \{} \text{ } \} \quad \text{ // } x \text{ was instantiated as a borrow } \]

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

  \[ g(new \ owned \ C()); \]
  \[ \text{proc } g(y: \ owned) \{} \text{ } \} \quad \text{ // } y \text{ took over ownership from the actual arg } \]
  \[ h(new \ owned \ C()); \]
  \[ \text{proc } h(in \ z) \{} \text{ } \} \quad \text{ // } z \text{ took over ownership from the actual arg } \]

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

\[
\text{f(new owned C());}
\]

\[
\text{proc f(x) {} // x argument instantiated 'const ref x: owned C'}
\]

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

\[
\text{h(new owned C());}
\]

\[
\text{proc h(in z) {} // z takes over ownership from the actual arg}
\]

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:

```plaintext
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()'  
```
• Casts on types are available to override a management decorator
• Allows one to rewrite the examples that are now errors:

```plaintext
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.:

```pascal
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:

```cmk
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'
```
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

```c
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

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

now can update array fields

remains a 'const ref' reference to the outer 'this'
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.,
    
    ```c
    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)

```plaintext
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)'
```

```plaintext
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

```plaintext
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 '?'

```plaintext
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'

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

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

```java
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

```plaintext
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:

```plaintext
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

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

• Use 'string.numBytes' to get number of bytes
  
  ```javascript
  var len = "événement".numBytes; // len is 11
  ```

• 'byteIndex' type is now available to request byte indexing
  
  ```javascript
  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 'toUpperCase', '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

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

• 'bytes' can be created using the following literals

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

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

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

- Bytes also support formatted I/O
  ```pascal
  writef("%ht\n", b); // prints: b"xC3xA9vxC3xA9nement"
  ```

- Binary formats can be used to read/write bytes
  ```pascal
  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

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

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

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

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

```python
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’

```plaintext
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

```chapel
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

```cpp
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

```chpl
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…

```javascript
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…

```javascript
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…

```plaintext
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…

```chpl
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…

```chpl
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

```chpl
module N {
    proc foo() { ... }
}
```
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.

```plaintext
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

```plaintext
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

```plaintext
module LibA { // v1.0
  proc draw() {...}
}
module LibB {
  proc drill(x: real) {...}
}
use LibA, LibB;
draw(); drill(1);
```

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

```plaintext
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

```plaintext
module LibA {
  proc drill(x:int) {...}
  proc drill(x:imag) {...}
}
module LibB {
  proc drill(x:real) {...}
  proc drill(x:complex) {...}
}
use LibA, LibB; drill(myComplex); drill(myInt);
```

**ok:** only `drill` in LibB is applicable

**error:** functions in both overload sets are applicable
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

```c
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
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

```chapel
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);
```
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

```plaintext
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

  ```java
  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

  ```java
  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

```plaintext
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

```ruby
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
Deprecation of 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

```chapel
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.

```chapel
[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

```chapel
writeln(1 + "10");               // should this be “110” or 11?
```
- since not all types had '+' overloads, led to confusion

```chapel
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)

```chapel
[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

```chapel
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:

```chapel
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
  ```chapel
define domain(OD);
define array 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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