Language Improvements

Chapel versions 1.21 / 1.22
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Chapel 2.0

Chapel 2.0: An upcoming release in which we...

...commit to not breaking core language features

...switch to semantic versioning

• Our primary goal for this release cycle was to produce a candidate for Chapel 2.0
  • approached the effort with a list of features to address, major and minor
  • successfully addressed the vast majority of them

• Due to this focus, this release’s notes are even more language-centric than usual
Chapel 1.21 vs. 1.22

• One key Chapel 2.0 focus area related to changing from 1- to 0-based indexing
• Not surprisingly, this can involve significant changes for some Chapel codes
• For this reason, we did two back-to-back releases a week apart:
  Chapel 1.21: our typical semi-annual release, with improvements of all kinds
  Chapel 1.22: Chapel 1.21, but with changes related to 0-based indexing
Outline

- Online RST / HTML Spec
- Module / Namespace Changes
- Initialization and Deinitialization
- String and Bytes Improvements
- Class Improvements
- 0- vs. 1-based Indexing
- Index-Neutral Features
- Other Changes for Chapel 2.0
Online
RST / HTML
Language Specification
Online Spec: Background

• Since 2006, the Chapel language specification has been a LaTeX / PDF doc
  • PDF originally seemed like the ideal format for an authoritative document

• Over time it had become less attractive:
  • Editing LaTeX feels fairly heavyweight today
  • PDF was not well-integrated with newer online docs:
    • Couldn’t search both at the same time
    • Couldn’t link into the spec from outside it
    • e.g., difficult to refer a user to a specific section
    • Challenging to maintain links from the spec to the online docs
Online Spec: This Effort, Impact

This Effort:

• Converted spec to RST, the same format as our other docs
• Integrated into online documentation page

Impact:

• Searching the online docs now finds entries in the spec
• Spec formatting matches the rest of the documentation
Online Spec: Next Steps

• Review online spec for formatting issues / improvements
• Review spec content for Chapel 2.0 readiness
Module / Namespace Improvements
Chapel has historically been a bit slack about namespaces

- Design and implementation were focused on modest-scale codes
- For larger-scale / more disciplined programming, approach was weak
Modules / Namespaces: This Effort

• Improving modules / namespaces was a major theme for Chapel 1.21
  • Private ‘use’ by default
  • Available-by-default symbols
  • Renaming ‘use’d modules
  • ‘import’ statements
  • Relative ‘use’ and ‘import’ statements
  • Submodules in different files
  • Implicit module warnings
  • Parent module visibility
Private ‘use’ by default
Private ‘use’: Background

• Traditionally, ‘use’ statements have been ‘public’ (transitive) by default

```cpp
module M1 {
    use BigInteger;  // traditionally interpreted as ‘public use’

    ...
}

module M2 {
    use M1;          // using ‘M1’ gives ‘M2’ access to ‘BigInteger.*’ as well

    var b: bigint;   // therefore, this was OK
}
```

• As a result, modules tended to unintentionally “leak” symbol names
Private ‘use’: This Effort

• Changed ‘use’ to be ‘private’ by default in user modules and standard modules

```cpp
module M1 {
    use BigInteger;  // now interpreted as ‘private use’

    ...
}

module M2 {
    use M1;  // using ‘M1’ no longer gives ‘M2’ access to ‘BigInteger.*’

    var b: bigint;  // error: ‘bigint’ undeclared
}
```
Private ‘use’: Impact

• Namespaces are more contained by default
• Codes that were relying on ‘use’ being public by default must be updated
  • by switching to ‘public use’ if the symbols had intentionally been exposed:

```javascript
module M1 {
    public use BigInteger;
}
```
  • by adding additional ‘use’ (or ‘import’) statements to client code otherwise:

```javascript
module M2 {
    use M1, BigInteger;
    var b: bigint;
}
```
Private ‘use’: Next Steps

• Update ‘use’ within internal modules to be ‘private’ as well
  • Doing so was non-trivial and didn’t make it into this release
  • However, current behavior should not affect user code (see next topic)
  • Nonetheless, making this change will…
    …improve the organization of internal modules
    …simplify the compiler slightly
Available-by-Default Symbols
Default Symbols: Background

• Chapel has traditionally made many symbols available by default
  • Some by design
    
    writeln("hello, world!");
    
    var infile = open("data.dat").reader(iokind.native);
  
  • Some due to historical lack of ‘private use’ feature
    
    const myint = infile.read(c_int);  // ‘c_int’ shouldn’t be available, but is
Default Symbols: This Effort (IO module)

- Reduced the number of symbols that are available by default
  - Default IO symbols reduced to just ‘write’, ‘writeln’, and ‘writef’
    ```csharp
    writeln("hello, world!");  // OK, writeln() available by default
    ```
  - Others now require ‘use IO;’
    ```csharp
    use IO;  // ‘use IO’ now required for more involved IO like this:
    var infile = open("data.dat").reader(iokind.native);
    ```
- **Rationale:** keep simple cases simple, more involved cases explicit
Default Symbols: This Effort (unintended modules)

• Reduced the number of symbols that are available by default
  • In internal modules, explicitly added ‘private’ to ‘use’s of standard modules

    module String {
      private use SysCTypes;  // ‘private’ added in this release
      ...
    }

    module DefaultSparse {
      private use RangeChunk;  // ‘private’ added in this release
      ...
    }

  • Previously, these caused the modules’ symbols to be available unintentionally
Default Symbols: Impact

• Fewer symbols are made available to user programs by default
• Explicit ‘use’ required for code that had relied on such default-available symbols
  • e.g., ‘use IO’ for programs doing non-trivial IO
  • e.g., ‘use SysCTypes;’ for programs that had previously relied on the auto-use

```c
use IO; // explicit ‘use’ now required for nontrivial IO
use SysCTypes; // explicit ‘use’ now required to access SysCTypes.*
var infile = open("data.dat").reader(iokind.native);
const myint = infile.read(c_int);
```
Default Symbols: Next Steps

• Continue reviewing the set of symbols made available by default
• Continue improving ‘use’ statements within internal modules
  • untangle web of ‘use’s between internal modules
Renaming Used Modules
Rename-in-use: Background, This Effort

**Background:**

- Prior to this effort, could only rename submodules via ‘use’ of its parent
  
  ```
  use OuterMod only InnerMod as Foo;  // Renames ‘InnerMod’ to ‘Foo’
  ```

- Couldn’t rename top-level modules at all

**This Effort:**

- Added support for renaming a module when it’s used
  
  ```
  use OuterMod as Bar;  // Now supported!
  ```
Rename-in-use: Impact, Next Steps

Impact:

• Can now rename every module
• No longer stuck typing long module names for qualified access

Next Steps:

• Implement ability to ‘use’ module and disable qualified access ([issue #15457](#15457))

```plaintext
use Mod as _;
writeln(Mod.x); // Wouldn’t work, not enabled by this ‘use’
writeln(x); // Would still work, enabled by this ‘use’
```
Import Statements
Import Statements: Background

• ‘use’ statements enable access to a module’s symbols from another module
  
  use MyModule;

• But ‘use’ statements have been imprecise
  • Default behavior brought every visible symbol into scope
  • However, could limit the symbols brought in with ‘except’ and ‘only’ lists
  • Design focused on “programming in the small” scenarios

• Users desired a feature for more precise access of module symbols
  • One better suited for maintaining large-scale software
  • Ideally, without breaking current code
Import Statements: This Effort

• We designed and implemented the ‘import’ statement as an alternative
  • Simplest form enables qualified access to the symbols in a module:

    ```
    import MyModule;
    writeln(MyModule.sym1);  // Enabled by the ‘import’
    writeln(sym1);            // Not enabled, won’t work
    ```

• This was previously only achievable with “empty” use statements, e.g.

    ```
    use MyModule only;
    use MyModule except *;
    ```

    (as part of this effort, we replaced such ‘use’s in libraries with ‘import’)

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Import Statements: Accessing Module Contents

• Can also enable unqualified access to a single symbol within a module:

```plaintext
import MyModule.sym1;
writeln(sym1); // Enabled by the ‘import’
writeln(MyModule.sym1); // Not enabled by the ‘import’
```

• Or multiple symbols within a module:

```plaintext
import MyModule.{sym1, sym2, sym3};
```

• Neither of these options was available previously
  • ‘use’ statements always enabled qualified access in addition to unqualified
Import Statements: Renaming

• Modules that are imported can be renamed:

```plaintext
import MyModule as Foo;
writeln(Foo.sym1); // Enabled by the ‘import’
writeln(sym1);    // Not enabled by the ‘import’
writeln(MyModule.sym1); // Not enabled by the ‘import’
```

• As can symbols that are imported for unqualified access:

```plaintext
import MyModule.sym1 as x; // or:
import MyModule.{sym1 as x, sym2 as y};
```
Import Statements: Nested Modules

• Nested modules must be named using their parent modules…

```plaintext
module OuterMod {
  import InnerMod;    // error: looks for top-level module ‘InnerMod’
  import OuterMod.InnerMod; // OK: names module starting from top-level
  writeln(InnerMod1.sym1);
  module InnerMod { var sym1 = …; }
}
```

• Or after being made available by another ‘import’ or ‘use’

```plaintext
use OuterMod;       // makes ‘OuterMod’s symbols available
import InnerMod;    // ‘InnerMod’ visible due to ‘use OuterMod’
```

• Or using a keyword-based relative path (see next section)
Import Statements: Public / Private

• ‘import’ statements can be declared ‘public’ or ‘private’
  • Default is ‘private’
    • as with ‘use’, reduces unintentional leaking of names
  • ‘public’ means symbols brought in are *re-exported*

```plaintext
module Mod {
    public import OtherMod;
}
module ThirdMod {
    import Mod.OtherMod;  // ‘OtherMod’ acts like a submodule of ‘Mod’
}
```
Import Statements: Impact

• The ‘import’ statement supports module access in a more precise manner
  • Its default behavior minimally extends the scope

• It also enables new functionality:
  • Can re-export symbols
  • Can bring symbols in for unqualified access without enabling qualified access

• The ‘use’ statement is still available
Import Statements: Next Steps

• Extend ‘import’ to support multiple expressions in a single statement
  
  ```
  import Mod1.{a, b}, Mod2.{x, y}; // Should this be allowed?
  ```
  
  • See issue #14971 and #15583

• Allow ‘import’ statements to refer to private symbols in parent modules
  
  • See issue #15308

• Enable re-exporting for ‘use’ statements
  
  • See issue #15282
Relative ‘use’ and ‘import’ statements
Relative Use: Background, This Effort

Background:
• ‘use’ statements could specify any module in scope
• When multiple modules share a name, could lead to confusion or errors

This Effort:
• Allowed ‘this’ and ‘super’ to specify path from current module

```javascript
use this.Submodule;  // Uses module defined within current module
use super.SiblingModule;  // Uses module defined in parent module
```
• Supported for ‘import’ statements as well:

```javascript
import this.Submodule;
import super.SiblingModule;
```
Relative Use: Impact, Next Steps

Impact:

• Origin of relatively used modules is much more obvious to the reader
• This style of ‘use’ makes code more robust to later changes
  • If dependency defines another module with same name, won’t conflict
• Simplest way to ‘import’ local submodules
  • Otherwise, must specify a path from a top-level module

Next Steps:

• Fix bug where ‘import’ can’t reference parent module’s symbols via ‘super’
  ```python
  import super.nonModSym; // Possible with full path to parent instead
  ```
• See issue #15309
Submodules in Different Files
Submodules: Background

- Nested modules always had to be defined within the text of a parent module
  - This resulted in some large source files
  - It also discouraged deep or wide module hierarchies

- Python has a strategy for specifying submodules through a file hierarchy
  - It’s a bit burdensome in ways, but seemed like a good design starting point
Submodules: This Effort

- Added ‘include’ keyword to declare a module in another file as a submodule

```chpl
include module Submodule;
```

- Submodules declared this way are treated like normal submodules

- File with submodule must be in a subdirectory with the parent module’s name
  - the module names must match their base filenames

```
M.chpl
M
  Submodule.chpl
```

- Defines a module M
- We look for M’s ‘include’d modules in this directory
- Can be included as a submodule of M
Submodules: Public vs. Private

- Included submodules can be declared ‘public’ or ‘private’
  - When ‘public’, makes Submodule available to modules that ‘use’ this module
  - When ‘private’, Submodule is unavailable to modules that ‘use’ this module
    
    ```
    include private module Submodule;
    ```

- Default is ‘public’, as with typical module declarations
Submodules: Public vs. Private

• Modules declared ‘public’ in their file can be included either publicly or privately

M.chpl
```
include private module Submodule;
```

M/Submodule.chpl
```
[public] module Submodule { ... }
```

Submodule is private to M

• Modules declared ‘private’ in their file cannot be included publicly

M.chpl
```
include public module Submodule;
```

M/Submodule.chpl
```
private module Submodule { ... }
```

Submodule was declared private, can’t be changed here
Submodules: Next Steps

• Finalize design
  • Relax current naming conventions?
  • Permit submodules to live in other places?

• Lean on implementation more
  • We believe it is correct, but need more experience with it
Implicit Module
Warnings
Implicit Module Warnings

**Background:**

- File-scope statements (other than ‘module’ decls) generate an implicit module
  - Any module declarations in the same file become submodules
  - E.g. for a file ‘Foo.chpl’:

    ```chapel
    var b: int; // This line causes the creation of a module ‘Foo’
    module TopLevel { ... } // This is a submodule of ‘Foo’ now!
    ```

- It can be difficult to notice when and why this happens

**This Effort:**

- Improved warning for cases that can lead to this confusion
  - Mixtures of file-scope module declarations and other code in one file
Parent Module
Visibility
Parent Module Visibility: Background

• Traditionally, child modules have been able to refer to their parents’ contents:

```plaintext
module Parent {
    var p = 33;

    module Child {
        writeln(p);          // rationale: ‘p’ is lexically visible, so I can name it
        writeln(Parent.p);   // same for ‘Parent’
    }
}
```
Parent Module Visibility: This Effort

• Reconsidered this rule due to the new ability to store submodules in distinct files:
  • Parent.chpl:
    ```chpl
    module Parent {
      include module Child;
    }
    ```
  • Parent/Child.chpl:
    ```chpl
    module Child {
      writeln(p); // problem: What the heck is ‘p’?
      writeln(Parent.p); // Or ‘Parent’?
    }
    ```
Parent Module Visibility: This Effort

- Decided that sub-modules must 'use' or 'import' their ancestors to refer to them
  - Parent.chpl:
    ```chpl
    module Parent {
        include module Child;
    }
    ```
  - Parent/Child.chpl:
    ```chpl
    module Child {
        import Parent; import Parent.p;
        writeln(p);
        writeln(Parent.p);
    }
    ```
Parent Module Visibility: This Effort

• Decided that sub-modules must ‘use’ or ‘import’ their ancestors to refer to them
  • (even when in a single file, for consistency)

```plaintext
module Parent {
    module Child {
        import Parent;
        import Parent.p;

        writeln(p);
        writeln(Parent.p);
    }
}
```
Parent Module Visibility: Status, Impact, Next Steps

**Status:**
- Updated modules and tests to reflect these rules

**Impact:**
- Generally resulted in cleaner code
- Analogous to requiring top-level modules to import/use one another
  - introduced in Chapel 1.20
- Can reduce compile-time when sub-modules don’t have need of ancestors

**Next Steps:**
- Get more experience with this change
Initialization and Deinitialization
Initialization & Deinitialization

• Variable initialization and deinitialization are Chapel language concepts
• Records can supply 'init', 'init=', and 'deinit' methods to be called by compiler

• This section discusses improvements in this area:
  • **Split initialization** is now supported and improves 'out' intent
  • **Copy elision** covers more cases and improves 'in' intent
  • **Deinitialization points** for temporary variables are improved

• The goal is to address known issues and allow language stabilization in this area
Split Initialization
Split Initialization: Background

• Split initialization is a feature requested by users
  • in response to challenges combining error handling and non-nilable classes
• The idea is to declare a variable in one statement and initialize it in another, e.g.:
  ```plaintext
  var x;
  x = 1;
  ```
• Historically such code would be a compilation error
  ```plaintext
  error: Variable 'x' is not initialized and has no type
  ```
• With split initialization, the second statement 'x = 1' is initializing 'x'
Split Initialization: This Effort

• Added support for split initialization to the language

• Split initialization applies to variables declared with no initialization expression

• Compiler searches forward from variable declarations for applicable assignments
  • could be assignment or a variable passed to an 'out' intent formal argument

• If no applicable assignment is found
  • default initialize the variable if possible
  • otherwise, issue a compiler error
Split Initialization: Approach

• The compiler looks forward from a declaration to find applicable assignments

```javascript
var x;

// ... compiler searches the statements that follow for applicable assignments
```

• Searches forward for applicable assignments within:
  • block declarations `{ }`
  • 'try' and 'try!' blocks
  • conditionals

• An applicable assignment is the first mention of the variable that sets it
  • can be an assignment statement like 'x = 1'
  • can be a function call passing to an 'out' intent formal
Split Initialization: Example 1

```javascript
record R { ... }
var a: R;
{
    a = new R(); // split initialization
}

var b: R;
writeln(b);
b = createR(); // not split init (not first mention), so 'b' is default init'd above
```
Split Initialization: Conditionals

• Split initializations within conditionals allow for multiple applicable assignments
  • both branches of the conditional must initialize the variable, or
  • one branch initializes the variable and the other returns or throws
• If a conditional initializes multiple variables, order must match on both branches
var c: R;
if option {
    c = new R();  // split initialization
} else {
    c = new R(1);  // split initialization
}

var d: R;
if option {
    d = new R();  // not split initialization, d is default-initialized above
}
Split Initialization: Example 3

```javascript
var e: R;
if option {
    e = new R();  // split initialization
} else {
    return;
}

var f: R;
try {
    f = createR();  // split initialization
}
```
Split Initialization: Status

- The now compiler supports split initialization for all major local symbol types:
  - 'var', 'const', 'type', 'ref', 'const ref'

- Split initialization for module-level variables is also supported
  - except for 'config' variables
Split Initialization: Impact on 'out' intent

• Used split initialization to improve the handling of the 'out' intent

```plaintext
var x: R;
setArg(x);  // split init of 'x'
proc setArg(out argument: R) {
    argument = g();  // split init of 'argument'
}
```

• As a result, the above example contains 0 copies or assignments
  • in earlier releases it would perform 2 assignments
Copy Elision
Copy Elision: Background

- *Copy elision* is a language feature to avoid copy initialization in certain cases.
- A form of *copy elision* already existed in 1.20 for nested call expressions:

```plaintext
record R { ... }
proc makeRecord() {
    return new R();
}
var a = globalRecord;    // copy initialization
var x = makeRecord();   // move initialization, not copy initialization
```
Copy Elision: This Effort

• Extended *copy elision* to cover more cases
• In particular, elide the copy when the source of the copy initialization is:
  • a local non-reference variable that is not mentioned again

• Once a copy is elided, the source variable becomes dead
• Compile-time analysis provides compiler errors for many erroneous cases
Copy Elision: Approach

- Like split initialization, the analysis searches forward from variable declarations.
- Searches for copy initializations that are the last mention of the source variable:
  - within block declarations { }, conditionals, try blocks, and try! blocks
  - but not within loops, on-statements
Copy Elision: Example 1

```haskell
proc elideCopy() {
    var x = makeRecord();
    var y = x;    // copy elided because 'x' is not used again
}

proc noElideCopy() {
    var x = makeRecord();
    var y = x;    // copy is not elided because 'x' is used again
    writeln(x);   // 'x' used here
}
```
Copy Elision: Example 2

```plaintext
proc elideCopyBothConditional() {
  var x = makeRecord();
  var y;  // split initialization below
  if option {
    y = x;
  } else {
    y = x;
  }

  // copy is elided because 'x' is not used after the copy
  // (in either branch of the conditional or after it)
}
```
Copy Elision: Example 3

```plaintext
proc copyElisionError() {
    var x = makeRecord();
    ref refX = x;
    var y = x;  // copy elided because 'x' is not used again
    writeln(refX);  // use of dead variable - error reported by compiler
}
```
Copy Elision: Impact on 'in' intent

• Historically, passing an 'in' intent argument to another function caused a copy:

```proc
f(in a) { ... }
```

```prog
g(in b) {
    f(b); // always copied here
}
```

• Now, copy elision applies to such cases to remove the copy
  • because the argument 'b' is not mentioned again after passing it to 'f'
Deinitialization Points
Deinit Points: Background

• Historically, used a simple rule to decide when to deinitialize a local variable
  • deinitialized at end of enclosing block
  • in reverse declaration order
• Led to confusing behavior for the following example:

```javascript
{
    var f = IO.opentmp();
    var A = [1,2], B = [0,0];
    f.writer().write(A); // data buffered in temporary channel
                          // until it is flushed when deinitialized at end of block
    f.reader().read(B);  // reads 0s because buffer not yet written
}
```
Deinit Points: This Effort

- Revisited rule for when to deinitialize a local variable to avoid this issue
  - also to be more similar to other languages
- Local user variables always deinitialized at the end of their containing blocks
- Temporaries for nested call expressions have new behavior
  - Deinitialized at end of block when contained in an initialization expression
  
  ```javascript
  var x = f(g());  // temporary storing g() deinitialized at end of block
  ```
  - Deinitialized at end of statement otherwise

  ```javascript
  f(g());  // temporary storing g() deinitialized at end of this statement
  ```
• With split init, initialization order can differ from declaration order
  • Adjusted deinitialization order of locals to be reverse initialization order

```javascript
{  
  var a;
  var b;
  // declaration order: a, b

  b = makeRecord();
  a = makeRecord();
  // initialization order: b, a

  } // deinitialization order: a, b
```
Deinit Points: Impact

• I/O example behavior is less surprising

```javascript
{ 
  var f = IO.opentmp();
  var A = [1,2], B = [0,0];
  f.writer().write(A); // data buffered in temporary channel
  // which is deinited and flushed at end of statement

  f.reader().read(B); // reads 1, 2 as expected
}
```
Init / Deinit
Summary
Initialization & Deinitialization: Status, Next Steps

Status:

• Split init, copy elision, and deinit point are implemented and documented
  • These features address known issues and user requests
  • Language rules in this area are expected to be stable from this point

Next Steps:

• Fix array initialization and copy initialization to no longer always default-init
• Fix deinitialization order for split-initialized module-scope variables
String and Bytes Improvements
String and Bytes: Background

• Chapel 1.20 took some steps towards having UTF-8 strings
  • Adjustments to the 'string' type to support Unicode data
    • Codepoint-based indexing, iteration, and length measurement
    • Can still opt-in to byte-based methods

• 'bytes' type was added to store arbitrary bytes and support string operations
  • Does not have to store Unicode data
  • Potentially better performance on ASCII text
String and Bytes: This Effort

• Require Chapel strings to store valid Unicode data

• 'bytes' improvements
  • Add missing features for 'bytes'
  • Adjust standard/package modules to support 'bytes' where applicable

• Stabilize 'string' and 'bytes' interfaces
String Validation
String Validation: Unicode Validation

• Strings are required to store UTF-8 encoded data
  • String literals are validated at compile-time
    ```javascript
    var s = "Invalid byte: \xff";  // compiler error: "Invalid string literal"
    ```
  • Dynamically created strings (e.g., through I/O) are validated at runtime
    ```javascript
    var s: string;
    readerChannel.readString(s);  // throws SystemError if not a valid string
    ```
  • Strings created with factory functions are also validated at runtime
    • Unless you are creating from another string, which is assumed to be valid

• These rules do not apply to 'bytes'

0xFF cannot appear in a UTF-8 sequence
String Validation: Non-UTF-8 Filenames

- POSIX standard does not limit filenames to UTF-8
  - Many operating systems do (e.g. SLES, MacOS, Cray)
  - Some do not (e.g. Ubuntu, Windows)

- How can filenames be handled where we enforce UTF-8 strings?
  - Option 1: Use 'bytes'
    - Less convenient; no implicit conversion between 'string' and 'bytes'
  - Option 2: Escape non-UTF-8 sequences and store them in 'string'
    - Not a breaking change, interface stays the same
String Validation: Escaped Strings

• Similar to Python's "surrogate escapes"
  • Prepend '0xDC' to individual bytes of illegal sequences
  • Encode this 2-byte codepoint in UTF-8 and store in the string

• '\createStringWithNewBuffer' now provides this functionality:
  
  ```chapel
  var s = createStringWithNewBuffer(c"\xff", // not UTF-8
                                  policy=decodePolicy.escape);
  ```

• 'FileSystem', 'Path' and 'IO' modules are adjusted to use this strategy
  • Provides portability using Chapel strings across different systems
String Validation: 'string.encode()' 

• 1.20 provided 'bytes.decode()' 
  • Only way to create a 'string' from a 'bytes'
  • Optional argument sets the behavior when data is not UTF-8 
    • 1.21 adds a new option to decode with escapes 

• 1.21 adds 'string.encode()' 
  • Without argument, it is a synonym for casting to 'bytes' from a 'string'
  • Optional argument sets the behavior when 'string' contains escapes 
    • Either reconstruct original data, or copy as-is
String Validation: 'encode'/'decode' samples

- Reconstruct escaped byte sequences
  
  ```python
  s.encode(policy=encodePolicy.unescape)  # b"\xff"
  ```

- Or, keep them as-is
  
  ```python
  s.encode(policy=encodePolicy.pass)  # UTF-8 for 0xDCFF as 'bytes'
  ```

- A 'bytes' can also be decoded with escaping
  
  ```python
  b.decode(policy=decodePolicy.escape);
  ```
Bytes

Improvements
Bytes Improvements: General Features

• 1.21 completes the 'bytes' features that were missing in 1.20
  • 'param' bytes can be defined and used the same way as 'param' strings
  • 'bytes' values can be compared using '<', '>', '<=', '>='
  • 1-byte 'bytes' can be converted to 'uint(8)' using 'bytes.toByte()'
  • 'bytes' can be used as associative domain indices
  • 'bytes.format()' can be used to create a new bytes
    
    "Name: %s ID: %i\n".format(name, id)  // returns a new 'bytes'
  • 'bytes.this()' accepts 'byteIndex' to support generic programming with strings
  • 'bytes' can be cast to enum
Bytes Improvements: Regular Expressions

- Added support for 'bytes'-based regular expressions

```javascript
var re = compile(b"[[:alnum:]]+@[[:alpha:]]+\\.edu");
var line: bytes;
while readChan.readline(line) {
    const m = line.match(re);
    if m then
        writeln(line[m]); // prints emails ending in "edu"
}
```

would fail if 'string' was used and the file wasn't UTF-8
Bytes Improvements: Regular Expressions

- 'regexp' is now generic and can be based on 'string' or 'bytes'
  - As of 1.21, 'regexp' defaults to 'regexp(string)'
    - Provides backward-compatibility
    - Generates a deprecation warning

- In the next releases 'regexp' will not default to 'regexp(string)'
  - Type must be used explicitly if a fully instantiated type is meant
Bytes Improvements: Other Libraries

• I/O expanded to support 'bytes'
  • 'channel.readline()' now accepts 'bytes' arguments
  • 'channel.readbytes()' was added similar to 'channel.readstring()'

• ZMQ module now supports 'bytes' messages

```python
import ZMQ;
var myMsg = b"Some \xff arbitrary \xff data";
ZMQ.send(myMsg);
var theirReply = ZMQ.recv(bytes);
```

• e.g., Arkouda messages between client and server now use 'bytes'
Interface
Stabilization for
Strings & Bytes
String / Bytes Interfaces: Indexing Updates

• Indexing and iterating over 'bytes'
  • 'bytes.this()' and 'bytes.these()' now return/yield 'uint(8)' instead of 'bytes'
    
    ```
    writeln(b"Chapel"[0]); // prints "67" not "C"
    ```

• New methods and iterators for generic programming with 'string' and 'bytes'
  • 'item()' and 'items()' on 'string' and 'bytes' return the same types

    ```
    writeln(b"Chapel".item(0)); // prints "C"
    writeln("Chapel".item(0));  // prints "C"
    ```

• For 'string' they are just synonyms for 'this' and 'these'
### String / Bytes Interfaces: Indexing Summary

<table>
<thead>
<tr>
<th>proc / iter name</th>
<th>return or yield type</th>
<th>this / these</th>
<th>byte / bytes</th>
<th>item / items</th>
<th>codepoint / codepoints</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>string</td>
<td>uint(8)</td>
<td>string</td>
<td>int(32)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>bytes</td>
<td>uint(8)</td>
<td>bytes</td>
<td>N/A</td>
</tr>
</tbody>
</table>

- **Return or Yield Type**
  - **this / these**
    - `string`
    - `uint(8)`
  - **byte / bytes**
    - `uint(8)`
    - `uint(8)`
  - **item / items**
    - `string`
    - `bytes`
  - **codepoint / codepoints**
    - `int(32)`
    - N/A

- **Note**: `this == item, these == items` for string

- **Added in 1.21**: `this == item, these == items` for string

- **Was 'bytes' in 1.20**
String / Bytes Interfaces: Stabilization

• Argument name adjustments
  • Some arguments were named 's' in both 'string' and 'bytes' interfaces
    • They are renamed to 'x' to be more type-neutral
    • e.g. factory functions, 'join()' 
  • "policy" arguments are renamed to 'policy' instead of 'errors'
    • 'errors' was inherited from Python's similar interface, but it is misleading
    • e.g. 'bytes.decode()' and newly-added 'string.encode()'

• 'string' vs 'bytes' comparisons are deprecated
• 'string' initializers that were deprecated in 1.20 are removed
String / Bytes Summary
String and Bytes: Impact and Next Steps

**Impact:**

- 'string' can only store valid UTF8-encoded data
- 'bytes' is more versatile and can be used instead of strings in many places
- More consistent and type-neutral interface in 'string' and 'bytes'

**Next Steps:**

- Performance analysis and improvements
- Reduce uses of 'c_string'
- Ensure that environment is set for using UTF-8 during program startup
Class Improvements
Class Improvements: Background

• Classes have gone through major changes in recent releases:
  • managed classes introduced in Chapel 1.18, improved in 1.19–1.20
  • nilable classes introduced in Chapel 1.20
• Have continued to have some rough edges that needed sanding down
Class Improvements: This Effort

- Managed Class Improvements
- Better Checking for Non-nilable Types
- Collection x Type Compatibility Study
- The ‘!’ Operator
- Prototype Modules and Nilability
- Accessing Type and Param Fields on Nilable Class Types
Managed class improvements
Managed Classes: Background, This Effort

**Background:** Previously, compiler parsed the following cases the same:

```
new owned X(); // typical usage
new owned(X);  // creating an owned to manage an unmanaged instance
new owned X;   // should have been an error
```

**This Effort:**

- Adjusted the parser to differentiate cases and made 'new owned X' an error:
  ```
  new owned X;  // now an error
  ```
- Deprecated 'new owned(X)' and added a clearer alternative:
  ```
  new owned(X);  // now deprecated
  owned.create(X); // clearer replacement
  ```
Managed Classes: Status, Impact

**Status:** 'owned.create' and 'shared.create' are implemented and documented
- both accept unmanaged class instances
- both accept nilable or expiring owned
- 'shared.create' accepts shared class instances

**Impact:**
- 'new owned X' is now an error as expected
- Clearer way to express creating an owned/shared with an unmanaged
Better Checking for Non-Nilable Types
Non-Nilable: Background, This Effort

**Background:** Non-nilable class types had incomplete checking in 1.20
- There were type checking problems for:
  - default initialization of arrays of non-nilable
  - resizing arrays of non-nilable
  - associative arrays of non-nilable
  - ownership transfer from non-nilable

**This Effort:** Address these problems with compile-time and run-time checking
Non-Nilable: Rectangular Arrays

• Now check for missing rectangular array initialization

  ```
  var A: [1..1] borrowed C;  // oops! non-nilable element not initialized
  // now compilation error
  ```

• Now check for invalid resize of non-nilable rectangular array

  ```
  var D = {1..1};
  var B: [D] owned C = [new C(),];
  D = {1..2};  // oops! new non-nilable element B[2] not initialized
  // now a runtime error
  ```
Non-Nilable: Associative Arrays

• Now check for associative arrays of non-nilable

  ```
  var D: domain(int) = {1, 2};
  var A: [D] borrowed C = myClass.borrow();  // now compilation error
  ```

• Error is currently necessary because:
  • Adding a new key to D would cause A to try and default-initialize a value
  • But, non-nilable classes have no default value
  • The error applies to any associative array of non-nilable
  • Hope to relax this check in the future
  • Sparse arrays should have a similar check (and do on master, but not 1.22)
Non-Nilable: This Effort

• Added compile-time checks for use of dead non-nilable owned

  ```
  var x = new owned C();
  var y = x;  // ownership transfer copy initialization which leaves 'x' dead
  writeln(x);  // oops! use of dead value 'x'
  error: mention of non-nilable variable after ownership is transferred out of it
  ```

• If 'x' is not mentioned again, the ownership transfer copy is elided and it works:

  ```
  var x = new owned C();
  var y = x;  // elided copy because x is not mentioned again
  writeln(y);
  ```

• See also section on copy elision
Non-Nilable: Impact, Status, Next Steps

**Impact:** Addressed several missing checks in the type system
  • Programs cannot continue to rely on incorrect behavior

**Status:** Many known type system problems with non-nilable are addressed

**Next Steps:**
  • Explore extending support for arrays of non-nilable to include:
    • associative arrays
    • sparse arrays
    • resizable rectangular arrays
Collection x Type Compatibility Study
Collections x Types: Background

**Background:**

- Many interacting features have been introduced in recent releases
  - Managed classes introduced in Chapel 1.18
  - Nilability introduced in Chapel 1.20
  - Lists, maps, and sets introduced in Chapel 1.20
- The combination of all collection-type interactions had not been fully tested
- Users reported several compatibility issues between types and collections
Collections x Types: This Effort

This Effort:

- Wrote tests for matrix of combinations between collections and types
  - Goal is to understand what works, what does not, and why not
  - Note that this effort took place just prior to the release
- Improved error messages for cases that are not expected to work
- Investigated fixes for failing cases
Collections x Types: Testing Procedure

• Wrote minimal API tests for each collection and tested with many types
  • This is intended to catch obvious issues, not all edge cases
• To reduce the matrix size, tuples of shared class represents all tuple cases
  • Future work could investigate tuples of all types
## Collections x Types: Status on 1.22

<table>
<thead>
<tr>
<th></th>
<th>list</th>
<th>map</th>
<th>set</th>
<th>fixed array</th>
<th>resized array</th>
<th>assoc array</th>
<th>sparse</th>
<th>tuple</th>
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</thead>
<tbody>
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<td>✓</td>
</tr>
<tr>
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<td>✓</td>
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<td>✗</td>
<td>✗</td>
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</tr>
<tr>
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**Key**
- Working
- Not yet working
- Not expected to work
### Collections x Types: Status (non-nilable tuples)

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</tr>
</tbody>
</table>

**Key**
- Working
- Not yet working
- Not expected to work

These cases fail due to a default initialization bug for tuples.
## Collections x Types: Status (Lists)

<table>
<thead>
<tr>
<th>Key</th>
<th>Working</th>
<th>Not yet working</th>
<th>Not expected to work</th>
</tr>
</thead>
<tbody>
<tr>
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<td>✗</td>
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<td>tuple</td>
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</tr>
</tbody>
</table>

- **Owned t**: ✔️
- **Shared t**: ✔️
- **Borrowed t**: ✗
- **Unmanaged t**: ✔️
- **(shared t, shared t)**: ✗
- **Owned t?**: ✔️
- **Shared t?**: ✔️
- **Borrowed t?**: ✗
- **Unmanaged t?**: ✔️
- **(shared t?, shared t?)**: ✔️
- **Record**: ✔️

- **Borrowed cases require some lifetime checking fixes**
  - Now fixed on master (1.23 pre-release)
  - Error messages are clean in 1.21

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### Collections x Types: Status (Maps)

<table>
<thead>
<tr>
<th></th>
<th>list</th>
<th>map</th>
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<th>resized array</th>
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</thead>
<tbody>
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<td>•</td>
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<td></td>
</tr>
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</tbody>
</table>

**Key**
- Working
- Not yet working
- Not expected to work

- Borrowed cases require lifetime constraints to work
- Error messages are clean in 1.21
### Collections x Types: Status (Map of owned t)

<table>
<thead>
<tr>
<th></th>
<th>list</th>
<th>map</th>
<th>set</th>
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**Key**
- Working
- Not yet working
- Not expected to work

- Non-nilable owned types not currently expected to work
- Challenges related to ownership and nilable
- Error messages are clean in 1.21
- May be supported in future releases
# Collections x Types: Status (Sets of owned)

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- **Owned types not expected to work**:  
  - No way to test membership b/c set takes ownership  
  - Error messages are clean in 1.21  
  - Could potentially support these with restricted API
## Collections x Types: Status (Sets)

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**Key**
- Working
- Not yet working
- Not expected to work

- Remaining failures due to issues w/ default assoc.
- Most stem from default hashes not supporting classes
- Most issues are now fixed on master
### Collections x Types: Status (fixed-size arrays)

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**Key**
- Working
- Not yet working
- 🔄 Not expected to work

- Non-nilable classes supported for init’d fixed-size arrays
- No default value required if not resized
### Collections x Types: Status (other arrays)

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**Key**
- Working
- Not yet working
- Not expected to work

- Other array types not expected to support non-nilable
  - Resizing domains requires default values
  - Most cases give reasonable errors in Chapel 1.21
## Collections x Types: Status on 1.22

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### Key
- **Working**
- **Not yet working**
- • **Not expected to work**
## Collections x Types: Status on master

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### Key
- **Working**
- Not yet working
- ✨ Not expected to work
Collections x Types: Next Steps

**Impact:**
- Collection and class type interactions are better understood
- Most combinations that are not expected to work have good error messages
- Several failing cases have been fixed on master since 1.22

**Next Steps:**
- Fix remaining failing cases
- Improve documentation on what types are supported
- Extend testing to more cases
  - Associative domains (similar to ‘set’)
  - Tuples of class types other than ‘(shared *, shared *)’
The '!' Operator
'!' Operator: Background

• '!' is a postfix operator that converts class values to the non-nilable variant
  • Halts when applied to 'nil' values if runtime checks are enabled
    • Checks are disabled by --no-nil-checks / --no-checks / --fast

```plaintext
var x: owned C?;  // x.type == owned C?
var y = x!;        // y.type == borrowed C, halts if checks are enabled
```

• Open question whether these checks should always be enabled
  • Ideally want checks always on, but has performance implications
'!' Operator: This Effort

• Explored performance implications of '!' always checking for 'nil'
  • Overhead was significant, 2x slowdown for PRK-Stencil and NAS-FT

• Added limited compiler optimization for '!' checks within conditionals
  • Ineffective for impacted applications, significant effort required to improve

• Manually optimized distributions
  • Used internal feature to force-unwrap nilables
"!" Operator: Status

- Identified two patterns where "!" is used in performance sensitive code
  - Code that needs a conditional guard where subsequent uses are non-nil
  - Code where implementation context guarantees non-nil

- With current language definition, always-on checks are too expensive
  - Believe this can be resolved with optional chaining and force-unwrapping
'!' Operator: Optional Chaining Background

- Conditional guard is required, but subsequent uses are non-nil

```prolog
proc BlockArr.dsiAccess(idx) ref {
    if myLocArr != nil && myLocArr!.contains(idx) then
        return myLocArr!.dsiAccess(idx);
    return nonLocalAccess(idx);
}
```

- Repeated '!' uses after nil check impacts readably
  - And would hurt performance if '!' always had a nil check
'!' Operator: Optional Chaining Next Steps

- Want some sort of optional chaining like Swift

```swift
if myLocArr != nil && myLocArr!.contains(idx) then
    return myLocArr!.dsiAccess(idx);

=>

if let arr = myLocArr? && arr.contains(idx) then
    return arr.dsiAccess(idx);
```
'!' Operator: Force-Unwrap Nilable

• Code where implementation context guarantees non-nil

```c
proc BlockArr.dsiLocalAccess(idx) ref {
    return myLocArr!.dsiAccess(idx);
}
```

• A runtime check introduces unacceptable overhead
  • Want a mechanism to force-unwrap a nilable with no runtime overhead
    • Believe this is sufficiently rare that it does not warrant syntax

```c
return forceToNonNilable(myLocArr).dsiAccess(idx);
```
'!' Operator: Next Steps

- Mitigate '!' check overheads
  - Add support for optional chaining
  - Add ability to force unwrap a nilable with no runtime check
- Enable always-on '!' runtime checks
Prototype Modules and Nilability
Prototype Modules and Nilability

**Background:** In 1.20, prototype modules changed nilable class behavior

```javascript
var x: owned C? = ...;
x.method(); // allowed in a prototype module but not production module
// compiler automatically replaced 'x' with 'x!'
```

• This difference led to confusion

**This Effort:** Removed this difference for prototype modules

• Now the above code needs to be written

```javascript
x!.method();
```

**Impact:** Easier to move code between prototype and non-prototype modules

• Now the only difference is the requirement to handle errors
Accessing Type and Param Fields on Nilable Class Types
Type Methods on Nilable: Background

• Previously required '!*' to use a type/param field on a nilable type:

```cpp
class C {
    param p;
}

type t = owned C(1)?;

t.p; // produced internal error

t!.p; // worked
```
Type Methods on Nilable: This Effort, Impact

This Effort: Adjusted compiler to no longer require '!' in this case:

```cpp
class C {
    param p;
}

type t = owned C(1) ?;
t.p; // now works
```

- Also, deprecated '!' on types in favor of more explicit casts
  - since behavior of '!' is not obvious when applied to types

  ```cpp
t!.p; // compilation warning: ! on types is now deprecated
  ```

Impact: Easier to write generic code using nilable types
0- vs. 1-based Indexing
0-based Indexing: History Lesson, Part I

• Whether a language uses 0- or 1-based indexing is a question w/ no good answer
  • each approach has its benefits and proponents
• From its original design, Chapel strived to be index-neutral
  • e.g., ranges and rectangular domains require low and high bounds
    \[ \text{const } r = 1..10; \quad \text{var } A: [0..#n] \text{ real}; \]
• However, we were unsuccessful at making Chapel completely index-neutral:
  • e.g., tuples, anonymous arrays, and string indexing from the outset:
    \[ \text{var } A = [1.2, 3.4]; \quad \text{var } t = (1.2, 3.4); \quad \text{var } "brad"[1]... \]
    // what does A[1] refer to?
    // what does t(1) refer to?
    // which letter does this refer to?
• since then, bytes and lists have been introduced and have similar issues
0-based Indexing: History Lesson, Part II

- At the time of its design, Chapel was primarily focused on users of...
  - **C/C++**: 0-based
  - **Fortran**: 1-based
  - **Java**: 0-based
  - **Matlab**: 1-based
- This made the decision seem like a coin-toss, so we went with 1-based indexing
  - **Rationale**: most people count from 1, and we were striving for productivity
0-based Indexing: Background

• However, Chapel users also complained of seeming inconsistencies:
  • most notably, certain built-in arrays chose to count from 0:
    • Locales (rationale: HPC programmers count nodes from 0)
    • args to main() (rationale: argv[0] typically refers to executable name)
  • since these are arrays, they are arguably free to choose their low bound
    • yet, being built-in, they have been a source of confusion for users
• Meanwhile, most notable recent languages have used 0-based indexing:
  • Python, Rust, Swift, Go, …
• And, most early Chapel adopters have come from C/C++ or Python backgrounds
  • notably, despite being 1-based, Chapel has not attracted many Fortran users
0-based Indexing: This Effort

• We polled Chapel users about switching to 0-based indexing
  • Most said they would prefer it, if we were designing the language from scratch
  • Most were not terribly concerned about updating their existing Chapel code
  • Most expressed concern about the expected impact to other users

• We then decided to gauge the impact on our own code base:
  • internal, standard, package modules (~150 files, ~150,000 lines)
  • Chapel tests: (~12,000 source files, ~125,000 lines)
  • mason: (19 source files, ~6,000 lines)

• Also gauged the impact on:
  • CrayAl (19 files, ~3800 lines)
  • Arkouda (~39 files, ~12,000 lines)
0-based Indexing: This Effort

• Based on all this input, we decided to make the switch
  • given the push for Chapel 2.0, seemed like a “now or never” decision
  • though it would be impactful and annoying, decided it was worthwhile
• Given the impact, we decided to constrain it to its own release
  • Thus, Chapel 1.21 is our normal semi-annual release
  • Chapel 1.22 is essentially 1.21 with 0-based indexing
• This permits users to incrementally upgrade to 0-based indexing
0-based Indexing: What changed?

• Primary cases that switched to 0-based indexing:
  
  • tuples
    
    ```
    var t = (1.2, 3.4);  // t(1) was 1.2; it's now 3.4, and t(0) is 1.2
    ```
  
  • strings, bytes
    
    ```
    "chapel"[1]...  // was “c”; it’s now “h”, and …[0] is “c”
    ```
  
  • arrays whose size is not defined by a range, domain, or array
    
    ```
    var A = [1.2, 3.4];  // A[1] was 1.2; it’s now 3.4, and A[0] is 1.2
    var B = myIter();    // B was defined over domain {1..}; it’s now over {0..}
    ```
  
  • lists
    
    ```
    var l: list(int) = ...;  // l(1) was the first element in the list; it’s now the
                              // second, and l(0) is the first
    ```
0-based Indexing: What changed?

• Secondary cases that switched to 0-based indexing:

  • varargs:

    ```plaintext
    proc foo(arg...) { writeln(arg(1)); } // ‘arg’ now counts from 0
    foo(1.2, 3.4); // used to print 1.2; it now prints 3.4 since varargs are tuples
    ```

  • tuple-oriented methods:

    ```plaintext
    const D = {1..3, 1..5};
    writeln(D.dim(1)); // used to print 1..3; it now prints 1..5 and .dim(0) prints 1..3
    ```

  • search-oriented methods:

    ```plaintext
    "chapel".find("z")... // used to return 0; it now returns -1
    ```

  • field numbering:

    ```plaintext
    myRecord.getField(1) // used to return the first field; it now returns the second
    ```
0-based Indexing: What changed?

- Secondary cases that switched to 0-based indexing:
  - random streams:
    ```javascript
    myRandomStream.getNth(i) // used to count from 1; it now counts from 0
    ```

- Other cases to be wary of:
  - untyped captures of ‘split()’ calls
    ```javascript
    var substrs = myString.split(); // capture an inferred-size array of strings
    ...substrs(1)... // this used to refer to the 1st substring; it now refers to the 2nd
    ```
0-based Indexing: What’s didn’t change?

• Arrays whose size is not defined by a range, domain, or array
  
  ```chapel
  var C = [i in -1..1] foo(i); // C's domain is still inferred to be {-1..1}…
  var D = 2*C; // …as is D’s
  ```

• Source file line numbers are still 1-based
  
  • **rationale:** because text editors are
    
  ```chapel
  vard answer = 42; // test.chpl:1: syntax error: near 'answer'
  ```
0-based Indexing: Impact

• Code changes required in the Chapel repository were approximately as follows:

<table>
<thead>
<tr>
<th></th>
<th>Files modified</th>
<th>Lines of code modified</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tuple-related changes</td>
<td>~860 (7%)</td>
<td>~7300 (2.5%)</td>
</tr>
<tr>
<td>String/Bytes-related</td>
<td>~125 (1%)</td>
<td>~650 (0.2%)</td>
</tr>
<tr>
<td>Arrays</td>
<td>~125 (1%)</td>
<td>~570 (0.2%)</td>
</tr>
<tr>
<td>Lists</td>
<td>~40 (0.3%)</td>
<td>~156 (0.05%)</td>
</tr>
</tbody>
</table>

• Though lots of code needed to be updated, most changes were straightforward
  • bounds-checking at compile-time and execution-time caught most cases
  • automated testing helped find and fix others
  • only a minimal number of cases were truly tricky or laborious to track down
0-based Indexing: Next Steps

• Help users update their code and adjust to 0-based indexing
  • tips available online: https://chapel-lang.org/docs/1.22/language/evolution.html
• Update additional cases that ought to be:
  • ‘Sort’ module’s keyPart() interface should probably use 0-based indexing
  • Check for any other interfaces that should be updated
Index-Neutral Features
Index-Neutral: Background

• Chapel has always had features supporting index-neutral programming:
  
  • ‘.domain’ queries:
    
    ```chapel
def public proc foo(A: []) {
        forall i in A.domain do ...
    }
    ```

  • de-tupling:
    
    ```chapel
    var (x,y,z) = myTuple;
    foo(myTuple);
    def public proc foo((x, y, z)) { ... }
    ```
Index-Neutral: This Effort

• Updating files from 1- to 0-based indexing motivated new index-neutral features:
  • ‘.indices’ queries on arrays, tuples, strings, bytes, lists,
    was:  for i in 1..myCollection.size do ...
    now:  for i in 0..#myCollection.size do ...
    better: for i in myCollection.indices do ...

• loops over heterogeneous tuples
  was:  for param i in 1..myCollection.size do ...myTup(i)...
  now:  for param i in 0..myCollection.size-1 do ...myTup(i)...
  better: for t in myTup do ...t...
Index-Neutral: This Effort

• Updating files from 1- to 0-based indexing motivated new index-neutral features:
  
  • open-interval ranges:
    
    was: for i in cursor..myCollection.size do ...
    
    now: for i in cursor..myCollection.size-1 do ...
    
    better: for i in cursor..<myCollection.size do ...
    
  • `.first’ / `.last’ queries on enums:
    
    enum color {red, green, blue};
    
    was/now: for c in color.red..color.blue do ...
    
    better: for c in color.first..color.last do ...
Index-Neutrality: Next Steps

• Continue looking for ways to support index-neutral programming in Chapel
  • inferred-size arrays:
    ```chapel
    var A: [1..] = myIter(); // assert 1-based indices, but not size nor eltType
    ```
  
  • array destructuring:
    ```chapel
    var [a, b, c, ...] = MyArray;
    var (a, b, c, ...) = MyArray;
    ```
Other Changes for Chapel 2.0
Chapel 2.0: Other Changes to Scalar Types

- Made ‘<<’ well-defined for signed integers
- Made bad enum casts throw
- Changed the locale type to have value semantics
- Updated the atomic compareExchange API to match C/C++
Chapel 2.0: Other Changes to Aggregate Types

- Documented tuple semantics in language specification
- Required records to support ‘init=’ and ‘=’ or neither
- Added support for creating non-copyable records
- Added a default ‘<’ operator for records
- Fixed ability to use methods/fields of private types via instances
- Made ‘C’ a subtype of ‘C?’
- Made assignment overloads for classes illegal
- Started enforcing ‘override’ keywords for compile-time (type/param) methods
- Made Error classes store strings and preserve line numbers
Chapel 2.0: Other Changes to Interfaces

• Made ‘readThis’/‘writeThis’ throw
• Deprecated synonyms for ‘.size’ (‘.length’, ‘.numIndices’, ‘.numElements’)
Chapel 2.0: Deprecated Features

• C++-style names for deinitializers

\[ \text{proc } \sim C() \ldots \Rightarrow \text{proc } \text{deinit}() \ldots \]

• ‘enumerated’ as a type class in favor of ‘enum’

\[ \text{proc } \text{foo}(e: \text{enumerated}) \Rightarrow \text{proc } \text{foo}(e: \text{enum}) \]

• support for spaces within type queries

\[ \text{proc } \text{foo}(x: ?t) \ldots \Rightarrow \text{proc } \text{foo}(x: ?t) \]
Chapel 2.0: New –warn-unstable warnings

• Expected to evolve further as they receive more attention:
  • first-class functions
  • unions
• Features known to be buggy / ill-defined:
  • arrays with negative strides
• Future uncertain:
  • identifiers beginning with ‘chpl_’ or ‘_’
  • ‘new borrowed C()’
  • enums with duplicate integer values and semi-concrete enums
  • let statements
Chapel 2.0: Outstanding Issues

- Constrained generics (see Ongoing Efforts deck)
- Point-of-instantiation definition
- Impact of GPU support
Chapel 2.0: Features expected to evolve

- Parallel iterators
- User-defined domain map interface
- User-defined reduction / scan interface
- Array initialization (from default initialization + assignment to copy initialization)
  - affects arrays-of-records, though beneficially
- Skyline arrays
- Zippered iterations involving sparse / associative domains and arrays
  
  ```chapel```
  ```
  forall (i,j) in (mySparseArr, myDenseArr) do ...
  ```
  ```
  ```

- Capturing iterators in type-inferred variables
  ```chapel```
  ```
  var A = myIter();
  ```
  ```
  ```
For More Information

For a more complete list of library-related changes in the 1.21 and 1.22 releases, 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 / Unstable / Removed Language Features
- Standard Library Modules
- Error Messages / Semantic Checks
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