Ongoing Efforts

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Context for this Slide Deck

- Typically, our release notes focus on the release contents
- This release cycle saw a number of other important efforts
  - Some of these were implementation efforts that weren’t done in time
  - Others were more forward-looking strategic or design efforts
  - Both categories seemed worth reporting on in spite of being ongoing
Outline

- **Processing Twitter @mentions Graphs in Chapel**
  - Sidebar on I/O for Twitter Processing in Chapel
- **Error Handling Approach**
- **New String Implementation**
- **Fixing Record Semantics**
- **Constructor/Destructor Refinement**
- **Interactive Programming Environment (IPE) Update**
  a.k.a. Front-End / Internal Representation Refactoring (v2)
Processing Twitter @mentions Graphs in Chapel
Processing Tweets: Motivation

Motivating Question: Is Chapel useful for Data Analytics?

- What would it look like?
- What features are we missing?
Processing Tweets: Background

**Twitter:** an online social networking service that enables users to send and read short 140-character messages called "tweets" --Wikipedia
- tweets support referencing other users via @username

**Benchmark: Label Propagation for Community Detection**
- can be considered to capture a data analytics workflow
- see CUG’15 paper: *Implementing a social-network analytics pipeline using Spark on Urika XA*
- a few implementations of this benchmark exist
  - e.g., Spark
Processing Tweets: Computation Steps

- Computation consists of these steps:
  - Read in gzip files storing JSON-encoded tweets
  - Find pairs of Twitter users that @mention each other
  - Construct a graph from such users
  - Run a label propagation algorithm on that graph
  - Output the community structure resulting from label propagation
Label Propagation Algorithm
(described in *Near linear time algorithm to detect community structures in large-scale networks*)

1. Initialize the labels at all nodes in the network.
2. Set $i = 1$.
3. Arrange the nodes in the network in a random order and set it to $X$.
4. For each $x$ in $X$, set node $x$’s label to the one that occurs most frequently among neighbors, with ties broken uniformly randomly.
5. If every node has a label that the maximum number of neighbors have, stop the algorithm. Otherwise, set $i = i + 1$ and go to step 3.
Processing Tweets: Implementation Overview

- **< 400 lines of Chapel code**
  - plus a Graph module (< 300 lines, to become a standard module)
  - plus some improvements to existing Chapel modules

- **current version is single-locale**
  - ultimately, need to support multi-locale in order to run larger data sets

- **graph representation similar to other Chapel graph codes**
  - e.g., SSCA#2
Processing Tweets: I/O

- Reading the tweets to build the graph is ~1/2 of the code
- Command line input lists files and directories to process
- `findfiles()` iterator used to enumerate files in a directory
- Reads file using `gunzip` via the new Spawn module
- **Uses new functionality for JSON I/O**
  - concept: use types and I/O that ignore irrelevant fields
  - (details in a sidebar following this section)
Processing Tweets: Algorithm in Chapel

Algorithm closely matches the pseudocode:

\[
\begin{aligned}
\text{var } i &= 0; \\
\text{var } go: \text{ atomic bool}; \\
go.\text{write}(\text{true}); \\
\text{while } \text{go.read(...) } \&\& i < \text{maxiter} \{ \\
\quad \text{go.write}(\text{false}); \\
\quad \text{// for each } x \text{ in the randomized order} \\
\quad \text{forall } \text{vid in reordered_vertices} \{ \\
\quad \quad \text{// set the label to the most frequent among neighbors} \\
\quad \quad \text{mylabel } = \text{labels[vid].read(memory_order_relaxed);} \\
\quad \quad \text{maxlabel } = \text{mostCommonLabelInNeighbors(vid);} \\
\quad \quad \text{if } \text{countNeighborsWith}(\text{vid, mylabel}) < \\
\quad \quad \quad \text{countNeighborsWith}(\text{vid, maxlabel}) \text{ then} \\
\quad \quad \quad \quad \text{go.write(\text{true}); } \text{// stop the algorithm if ...} \\
\quad \quad \text{labels[vid].write(maxlabel, memory_order_relaxed);} \\
\quad \} \\
\quad i += 1; \\
\}
\end{aligned}
\]
Processing Tweets: Caveats

The next few slides compare our Chapel version against a Spark version

Important Notes:
- Spark includes resiliency features while Chapel currently does not
- neither implementation is necessarily optimal
Processing Tweets: Productivity Comparison

**Spark**
- RDDs are immutable
  - create new RDD every iteration through algorithm
- Algorithm written in terms of mapping a fn on data
  - difficult to visit vertices in random order
  - movement of information is described as messages contributing to a new RDD
  - breaking ties randomly might require a custom operator

**Chapel**
- Chapel arrays are mutable
  - Algorithm can update labels in-place
- Algorithm written in terms of parallel loops
  - straightforward to visit vertices in random order
  - movement of information occurs through variable reads and writes
  - breaking ties randomly is an easy change

*These differences reflect Spark’s declarative nature vs. Chapel’s imperative design.*
We performed an initial performance comparison between our Chapel version and the Spark version.
- Preliminary results are promising.

However, there are several caveats:
- The results are completely apples-to-oranges:
  - Different architectures
  - Different system scales
  - Different data set sizes
  (reflects Chapel code being single-locale only, early stages of study)
- A multi-locale Chapel version will likely perform very differently
  - Multi-locale execution will be necessary for larger dataset scales

For these reasons, we’ve decided not to release results until we can perform a more rigorous study.
- Specifically, multi-locale Chapel, same data set, same architecture
Processing Tweets: Impact, Status, Next Steps

Impact:
● A positive early indication of Chapel’s applicability to data analytics

Status:
● Have a prototype data analytics benchmark
  ● reliant on pending modifications to Chapel library
● Productivity and performance are promising

Next Steps:
● Commit library modifications to master
● Create a multi-locale version
  ● primary effort: multi-locale graph data structures / domain maps
● Compare performance with other implementations, scientifically
● Describe this study in a paper to disseminate the results, get feedback
Sidebar on I/O for Twitter Processing in Chapel
Example Tweet in JSON format

- Tweets have 34 top-level fields
  - including nested structures containing much more data

```
{ "coordinates": null, "created_at": "Fri Oct 16 16:00:00 +0000 2015", "favorited": false, "truncated": false, "id_str": "28031452151", "entities": { "urls": [ { "expanded_url": null, "url": "http://chapel.cray.com", "indices": [69, 100] }, ], "hashtags": [ ], "user_mentions": [ { "name": "Cray Inc.", "id_str": "23424245", "id": 23424245, "indices": [25, 30], "screen_name": "cray" } ], "in_reply_to_user_id_str": null, "text": "Let's mention the user @cray -- here is an embedded url .......... http://chapel.cray.com", "contributors": null, "id": 28039652140, "retweet_count": null, "in_reply_to_status_id_str": null, "geo": null, "retweeted": false, "in_reply_to_user_id": null, "user": { "profile_sidebar_border_color": "C0DEED", "name": "Cray Inc.", "profile_sidebar_fill_color": "DDEEF6", "profile_image_url": "http://a3.twimg.com/profile_images/23424245/icon_normal.png", "location": "Seattle, WA", "created_at": "Fri Oct 10 23:10:00 +0000 2008", "id_str": "23502385", "follow_request_sent": false, "profile_link_color": "0084B4", "favourites_count": 1, "url": "http://cray.com", "contributors_enabled": false, "utc_offset": -25200, "id": 23548250, "profile_use_background_image": true, "listed_count": 23, "protected": false, "lang": "en", "profile_text_color": "333333", "followers_count": 1000, "time_zone": "Mountain Time (US & Canada)", "verified": false, "geo_enabled": true, "profile_background_color": "C0DEED", "notifications": false, "description": "Cray Inc", "friends_count": 71, "profile_background_image_url": "http://s.twimg.com/a/2349257201/images/themes/theme1/bg.png", "statuses_count": 302, "screen_name": "gnip", "following": false, "show_all_inline_media": false }, "in_reply_to_screen_name": null, "source": "web", "place": null, "in_reply_to_status_id": null }
```
Reading JSON Tweets

// define Chapel records whose fields reflect only
// the portions of the JSON data we care about

record TweetUser {  
    var id: int;
}
record TweetEntities {  
    var user_mentions: list(TweetUser);
}
record User {  
    var id: int;
}
record Tweet {  
    var id: int,  
    user: User,  
    entities: TweetEntities;
}

proc process_json(...) {  
    var tweet: Tweet;

    while true {  
        // “%~jt” format string:  
        // j: JSON format  
        // t: any record  
        // ~: skip other fields  
        got = logfile.readf("%~jt",  
                          tweet,  
                          error=err);
        if got && !err then  
            handle_tweet(tweet);
        if err == EFORMAT then ...;
        if err == EEOF then break;
    }
}
Open Issue: How to Read Arrays from JSON

Current approach:

```plaintext
record TweetEntities {
  var user_mentions: list(TweetUser);
}
```

Desired approach:

```plaintext
record TweetEntities {
  var user_mentions: [1..0] TweetUser;

  // not possible to know array’s length in advance; determined by file contents
  // would like a way to read this record that resizes the array appropriately…
}
```
Should Reading an Array Resize it?

● **Should we resize arrays on reads?**
  ● File formats like JSON’s variable-length arrays encode their sizes

**Pros:**
  ● makes reading arrays trivial for such file formats
  ● having the default record I/O function do this would simplify user burden

**Cons:**
  ● array resize on reads may be confusing / inconsistent
  ● traditionally, Chapel cannot resize arrays with shared domains
    ● suggests only supporting this feature for arrays with unique domains
  ● not all file formats support self-descriptive array sizes

**Challenges:**
  ● how to support benefits without causing undue surprise?
  ● under what conditions should array reads resize vs. not?
  ● how to minimize user burden?
Error Handling Approach
Error Handling: Background

- Chapel currently lacks a general strategy for errors

- Standard library uses two primary approaches at present:
  - calls to \texttt{halt()}
  - optional output arguments (\texttt{out error: syserr})
    - if argument provided, assumed user will handle; else call \texttt{halt()}

- Each of these approaches has serious drawbacks:
  - halting the program is not appropriate in library code
  - current output argument approach…
    ...only returns error codes
    ...doesn’t permit users to easily add new error codes or state

- A more general strategy is desired, supporting
  - the ability to write bulletproof code
    - ideally, in a way that supports propagation of errors, like exceptions
  - the ability to get useful messages when errors are not handled
Error Handling: This Effort

- Designing a new approach for error handling

- We considered:
  - using generalized error objects instead of error codes
  - returning tuples encoding (result, error)
  - returning error objects via optional out arguments
  - exceptions along the lines of C++
  - an exception-like approach (inspired by Swift)
    - our current leading candidate
Error Handling: Swift Error Handling Model

- Functions that can raise an error are declared with `throws`
  ```swift
  func canThrowErrors() throws { ... }
  func cannotThrowErrors() { ... }
  ```

- Calls that throw must be decorated with `try` or `try!`
  - makes the control flow possibilities clear without inspecting the callee
  - `try` propagates the error to an enclosing `do/catch` block or out of a throwing function
  - `try!` halts if an error occurred

- Programs can respond to errors with `do/catch` statements
  ```swift
  do {
    try canThrowErrors()
    try! canThrowErrors()  // will halt on failure
  } catch {
    writeln("The first call failed!")
  }
  ```
Error Handling: Expected Additions for Chapel

- Throwing errors from iterators
- Ability to catch errors generated in runtime layers:
  - Communication
  - Memory allocation
  - Task creation
  - Not mandatory to check for these
  - Try blocks are one option here
    ```chapel
    try {
    var A: [1..n] int; // array allocation could fail
    begin ...; // task launch could fail
    remoteB[i] = A[i] + A[i+1]; // communication could fail
    }
    ```

- Task joins propagate errors to parent tasks
  - Occurs at end the of `sync/coforall/cobegin` blocks
Error Handling: Advantages of This Model

- Represents a middle ground
  - arguably acceptable to devotees of both exceptions and error codes

- Easier to implement than stack-unwinding
  - re-uses the existing return mechanisms

- Fits well with existing task parallelism
Error Handling: Next Steps

- **Create a detailed proposal**
  - Description of a Swift-like model in Chapel
  - Solicit feedback from the community

- **Investigate expected additions to the Swift model**

- **Start implementing**
  - Some parts will require larger changes
    - Handling errors from the runtime
    - Task joins propagating errors to the parent task
New String Implementation
Strings: Setting

Background:
- We have been working on re-implementing strings as a Chapel record
  - To remove special-case string-specific code from the compiler
  - To plug existing memory leaks for strings
  - To serve as a proxy for other interesting value types users might write
- Early drafts indicated problems with our implementation of records
  - Given how broadly strings are used, they serve as an acid test for records
  - Currently working on addressing these on the string-as-rec branch

This Effort:
- Define a record-based string type
- Convert string literals to type string (were previously c_string)
- Support a modern set of library routines
- Add support for unicode strings
Strings: Define a record-based string type

- String record currently looks like:
  ```go
  record string {
    var len: int = 0;
    var size: int = 0;
    var buff: c_ptr(uint(8)) = nil;
    var owned: bool = true;
  }
  ```

- Implemented in the modules, used in the compiler
  - Compiler hooks onto this type early in compilation
  - Alternative implementations could be swapped in easily

- Lets us remove many special cases in the compiler
  - `string` is handled (almost) like any other record
Strings: Convert string literals to type `string`

- **String literals have been implemented as type `c_string`**
  - Implicit coercions to `string` needed to be inserted in many cases
    - Caused a new `string` to be created over and over for the same literal
      ```c
      var x = "Hello, World";  // implicit coercion from `c_string` to `string`
      ```
  - `c_string` provides `param` functionality
    - `param` records are a long ways off…
Strings: Convert string literals to type `string`

- **Added support for `param string`**
  - Specific to `string`, not generalized for all records
  - Supports the same operations as `c_string`

- **Made string literals type `string`**
  - `string` literals are constructed at the beginning of time
    - Locale private globals
  - Implicit coercions go away
  - `c_string` literals can be written using different syntax:
    ```
    var x = c"Hello, World";
    ```
Strings: Add new library routines

- `this` (substring)
- `startsWith`
- `endsWith`
- `find`
- `count`
- `rfind`
- `replace`
- `join`
- `strip`
- `partition`
- `isUpper`
- `isLower`

These all work for single-locale
- Multi-locale support forthcoming
  - Blocked by general record issues

- `isSpace`
- `isAlpha`
- `isDigit`
- `isAlnum`
- `isPrintable`
- `isTitle`
- `toLower`
- `toUpper`
- `toTitle`
- `capitalize`
- `+, *, ==, !=, <=, ...`
Strings: Next steps

- Get all of these changes onto master
  - Requires the record fixes to be completed

- Add a proper Unicode string type
  - Should be used for any operations on text

- Rename the current record to bytes (or ...?)
  - A sequence of `uint(8)`s with string-like operations
  - `bytes` is not intended for working with general text
  - Rather, for use in places like:
    - Networking
    - Filesystem operations
Fixing Record Semantics
Strings and Records: Background

The Problem: Record implementation found to have gaps

- Records of plain-old data work reasonably well…
- More interesting record types have significant problems
  - Constructor/destructor/assign not called in all cases that it should be
- Possible outcomes:
  - Uninitialized state
  - Memory leaks
  - Errors in multi-locale programs

The Approach: Extended memory management algorithms

- Flow-control algorithms to track ownership of objects
  - Ensure constructor/destructor/assignment invoked correctly
- Consistent handling for records and ref-counted types
  - e.g. domain maps, domains, arrays
- Had hoped to complete this work by 1.12 but failed to do so
- Work being pursued on string-as-rec branch
Strings and Records: This Effort and Status

Status:

● Regression count:
  ● of 5500 existing tests, 22 failures for single-locale, 64 for multi-locale

● Developed 132 new stress tests for records
  ● Single-locale: 9 fail on string-as-rec, while 30 fail on master

● Performance challenges:
  ● 15% of performance tests more than 10% slower on string-as-rec
  ● A few tests more than 100% slower
  ● Believe these to be symptomatic of the current implementation
    ● not of inherent overhead in doing Chapel’s records correctly

● Significant problems for arrays
  ● Additional calls to increment ref-counts for arrays ⇒ a performance issue
  ● Failure to decrement ref-counts ⇒ a memory leak issue
  ● Root cause of these problems likely to be linked to performance issues
  ● Arrays have been special-cased in ways that wriggle around record issues
    ● string-as-rec cleanup entangled with these special cases
Strings and Records: Next Steps

● **Tolerate inconsistencies between arrays and records**
  ● but long-term goal is to unify the underlying implementation

● **Close the gap between string-as-rec and master**
  ● string-as-rec has accumulated a lot of changes
    ● some changes are independent of records/arrays
  ● highlight material differences that contribute to…
    …improved behavior for records and strings
    …degraded behavior for ref-counted objects e.g. arrays
    …some differences may do both at the same time
  ● isolate safe changes that enhance strings and records
    ● Migrate them to master

● **Identify remaining errors on each branch**
  ● string-as-rec and master have differing errors
  ● focus on removing errors from master
Constructor/Destructor Refinement
Constructors/Destructors: Background

**Background:**

- Chapel’s OOP features have traditionally been naïve in terms of...
  - constructors and destructors
  - initialization vs. assignment
  - user-defined default values, parallel initialization, ...
- Need to get this right for correct resource management
  - memory, file descriptors, ...
Constructors/Destructors: This Effort

Goals:
- improve design of constructors, destructors, assignment operators
- clarify when they are invoked

Approach:
- design features within a sub-team; then review with team & community
- using C++ and D as primary reference points

Topics:
- syntax and semantics of constructors for records, classes
- integration with noinit and default values
- postblit-based copy construction, inspired by D language
- serialize-/deserialize-based copying into tasks and/or on-statements
- semantics of returning records and arrays
- avoiding copies in argument passing and returning
- specifying when the compiler can make bit-wise copies of records
Constructors/Destructors: Work In Progress

Status:
● sub-team reaching consensus
● work-in-progress described by draft CHIPs:
  ● CHIP 4: Constructor Syntax and Semantics
  ● CHIP 5: Implement Object Copying Using a “Postblit” Method

Next Steps:
● finish proposed design
● get consensus on approach from broader team
● complete implementation
Interactive Programming Environment (IPE) Update
a.k.a. Front-End / Internal Representation Refactoring (v2)
IPE/v2: Background

- IPE integration hampered by current compiler arch. / IR
  - Many passes implemented as program-wide transformations
    - Inconsistent with statement-by-statement interpretation
  - IR is lowered aggressively and early → loss of high-level information
  - IR is not fully typed until deep in the pipeline
  - IR carries baggage from sprint of HPCS-era development
    - Nodes overloaded in meaning, esp. CallExpr, BlockStmt, FnSymbol
    - Casual mutation of public member variables
    - Fragile assumptions embedded into code
    - Difficult to reason about state of IR across passes

- Meanwhile, other compiler efforts suffer from same
  - Simplicity of adding new features e.g. “Concepts”
  - Ability to write new optimizations/transformations
    - e.g., array optimizations want high-level information lost in lowering
  - Desire for better error messages and diagnostics
  - Module documentation
IPE/v2: This Effort

● **Integrated support for both IPE and compiler**
  ● Clean interface between front-end and back-ends
  ● Unification of param resolution and interpreter

● **Deliver a high-level, fully-typed IR**
  ● Represent Chapel’s source-level semantics more naturally
  ● Consistent semantic checking
  ● Include clear references to source text

● **Overhaul type / function resolution**
  ● Statement-oriented rather than whole-program
    ● Respect relaxed ordering of declarations w.r.t. their uses
    ● Respect potential for mutual cross-module dependencies
  ● Be lazy where practical
    ● Prefer to avoid expanding unreachable types/functions/generics
IPE/v2: A Shared Future for compiler and IPE

Parse
- Literals, Identifiers, Comments, Punctuation
- Untyped expressions and statements
- File names and line numbers

Resolve
- Lexical scopes explicit
- Typed literals, variables, fields, expressions
- Implied function calls selected

Optimize
- Scalar optimizations
- Loop optimizations
- Communication optimizations

CodeGen
- Invoke platform compiler

Source-level typed IR

Typed IR

Low Level IR

Eval typed expressions

Print value

Eval

Print

Param Eval

Streamline

Compiler

Interpreter
IPE/v2: Status

- **Initially an effort to refactor resolution**
  - Perform resolution immediately after parsing
    - Avoid relying on normalization
  - Extended early work for IPE
  - Limited progress

- **Expanded effort to include refactoring of parser**
  - Premature lowering of IR is an undesirable complication
  - Began to extend the set of IR nodes
  - Revised lexer to be “pure” and capture additional tokens
  - Modified scanner to begin to generate new IR nodes

- **Expanded investigation to contemplate a possible “v2”**
  - Should a new front-end be a step to a new back-end?
  - How to balance incremental integration vs. clean-sheet?
IPE/v2: Next Steps

- Develop an end-to-end prototype for compilation
  - Support same subset of Chapel as for IPE
  - No optimizations
  - Define extended integration path

- Confirm ability to support IPE for same language subset

- Expand to support
  - records and classes
  - iterators
  - generics
  - multi-tasking
  - multi-locale programs

- Main Challenge: How much effort to place here how soon?
  - For long-term health of Chapel, v2 seems essential
  - For short-term adoption, need to continue making obvious progress
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