Ongoing Efforts

Chapel Team, Cray Inc.
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Context for these Slides

- Our release notes largely report on work appearing in 1.13
- However, several other efforts are worth describing as well
  - Important features that are being designed
  - Work that was not complete in time for 1.13
- This deck reports on some of those efforts
Outline

- Construction/Initialization
- Error Handling
- Debian Packaging of Chapel
- numa Locale Model
- Chapel Package Manager
- Twitter Workflow
- Parallel Research Kernels
- Other Notable Ongoing Efforts
Construction/Initialization
Construction/Initialization: Background

- Chapel’s OOP features have 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
    - Some internal types handled unusual memory cases with workarounds
    - Ideal implementation would accommodate these types and more
  - Reasonable handling of const and ref fields
Construction/Initialization: This Effort

● Refinement of constructor/initializer story for Chapel
  ● What does the method look like?
    ● How it works, interaction w/ inheritance, syntax
    ● When is it invoked?

● Goal: principled, broad coverage of likely scenarios
  ● Design influenced by Swift, D
  ● As part of principled approach, will refer to as “initializers” only
    ● Method name will reflect this:

      ```chapel
      proc Foo () {…} // old constructor, used name of type
      proc init () {…} // new initializer, uses “init” as name for every type
      ```
Construction/Initialization: Two Init Phases

- **Initializer body divided into two phases**

  **Phase 1:**
  - Whole object not yet ready for use – still initializing individual fields
  - Fields must be initialized in order
  - Can leave off fields to use field initializer value, or default for type
    - Such fields are initialized in declaration order, interspersed w/ explicit initialization
  - Explicit and implicit initialization of a field can depend on earlier fields
  - Can define and use local helper variables
  - Can’t call methods on ‘this’ instance (not fully valid until Phase 2)
  - ‘field = value’ means initialization in this phase

  **Phase 2:**
  - Object can be treated as a whole
  - Can call methods on ‘this’
  - Every field in valid initial state (some may still be modified)
  - Modifications of fields are considered assignment at this point
  - ‘field = value’ means assignment
Construction/Initialization: Two Init Phases

- **Additional notes on Phase 1/Phase 2:**
  - Cannot assign to const fields in Phase 2
    - Still under discussion
    - Plan to start strict, loosen restriction later if justified
  - If not explicitly noted, initializer body assumed to be in Phase 2
    - Results in more backwards compatibility
    - Could optimize Phase 1-compliant initializers to be treated as Phase 1
Construction/Initialization: Syntax

● Syntax of initializer
  ● Considered many proposals
  ● No clear winner, so we chose one:

    ```
    proc init () {
      ...
      // Phase 1
      super.init(); // Call to parent initializer separates Phase 1 and 2
      ...
      // Phase 2
    }
    ```

  Pros:
  ● Simple syntax
  ● Can share local variables across phases

  Cons:
  ● Potential to lose dividing line in more complex initializer body
  ● Not obvious that code behaves differently on either side of init() call
    ● e.g., assignment-as-initialization in phase 1 vs. plain-old assignment in phase 2
Construction/Initialization: Alternate Syntax

**Alternate syntax**

```java
proc init () {
    ...
    // Phase 1
    // Can call super.init() as last statement, if desired
}
 finalize {
    ...
    // Phase 2
}
```

- Finalize block can be dropped

**Pros:**
- Clear division between phases

**Cons:**
- Sharing a variable between phases is more difficult
- More naturally supports Phase 1 as the default
- Syntax equally appealing, could switch at a later time
- Implementation could easily accommodate either syntax w/ same rules
Construction/Initialization: Initializing Parents

● **Calling other initializers**
  - Calls to parent initializer are formatted as:
    ```
    super.init(...);
    ```
  - As an example, flow from child to parent initializer resembles:

    ```prolog
    proc Child.init (...) {
      writeln("Child Phase 1");
      // Can't access parent fields yet
      super.init(...);
      writeln("Child Phase 2");
    }
    ```

    which will print out
    Child Phase 1
    Parent Phase 1
    // Parent of Parent output would go here, if it existed
    Parent Phase 2
    Child Phase 2

    ```prolog
    proc Parent.init (...) {
      writeln("Parent Phase 1");
      super.init(...); // no-op, no parent
      writeln("Parent Phase 2");
      // Since child fields initialized,
      // whole object use is valid
    }
    ```
Calling other initializers

Calls to sibling initializers look like:

\[
\text{this.init}(\ldots);
\]

Motivation: support Phase 1 code re-use given that methods can’t be called

```
proc Child.init (...) {
    writeln("Orig Phase 1");
    // Can’t initialize fields
    this.init(...);
    writeln("Orig Phase 2");
}
```

which will print out

Orig Phase 1
Sibling Phase 1
// Parent output would go here, if it existed
Sibling Phase 2
Orig Phase 2

```
proc Child.init (...) {
    writeln("Sibling Phase 1");
    // Should initialize child fields
    super.init(...); // no-op, no parent
    writeln("Sibling Phase 2");
}
```
Construction/Initialization: Calling Initializers

● Calling other initializers
  ● If no super.init() or this.init(), makes implicit no-argument super.init() call
    ● At start of initializer body (because body is assumed to be Phase 2)
  ● super.init() calls are currently most applicable to classes
    ● Record inheritance story is not yet fully defined
    ● For records, or when no parent is present, super.init() call is no-op
Construction/Initialization: Compiler Initializers

- Compiler-generated initializers
  - Initializes all fields by default
    - Will use field declaration’s initializing value, if present
    - Otherwise will use default value for type
  - Not generated if any user-defined initializer present
    - In step w/ current behavior
  - Would like a way to opt back in for creation of default
    - Defining semantics for this is nonessential, future work
Related Topic: Noinit

- Constructs instance, doesn’t initialize (all of) it yet
- Especially useful for arrays and other large data structures
  - Can skip default initialization when unnecessary and costly
  - For optimization purposes:

```plaintext
var A: [1..1000] int = noinit;  // “Don’t initialize because I’m about to.”

A[1] = 14;  // Helps compilers avoid being conservative when
for i in 2..1000 {  // unable to prove the default init is unnecessary.
    A[i] = i*A[i-1];
}
```
Construction/Initialization: Noinit

**Noinit, continued**

- Invalid to use instance before initialization is finalized
  ```javascript
  var A: [1..1000] int = noinit;
  ```
- Supported by any type unless type designer opts out
  - See slide on noinit and compiler-generated initializers for details
- Previous implementation was all-or-nothing
  - All of instance initialized, or uninitialized
  - Some types have fields which must always be valid
  - E.g. arrays should always have a domain defined for space allocation
  - Led to desire for more fine-grained control on what noinit means for a type
Construction/Initialization: Noinit

● **How does noinit work in initializers?**
  ● Can use on fields in Phase 1 of initializer
    ```plaintext
    proc init (...) {
      field = noinit;
      ...
    }
    ● Phase 2 should give value to field or will need to be very careful in methods
    ● Invalid in Phase 2 (all fields already initialized)
Construction/Initialization: Noinit

- **Noinit will be implicit param argument to initializer**
  - Compiler will call initializer with extra argument “noinit = true”
  - If constructor doesn’t handle it, will cause error “noinit not defined on type”
  - Allows code sharing between init/noinit initialization, e.g.

```plaintext
proc init (param noinit=false) {
    if (noinit) {
        field = noinit;
    } else {
        field = ...;
    }

    // Rest of Phase 1 code, followed by Phase 2
}
```
Construction/Initialization: Noinit

- **Compiler-generated initializers include noinit arguments**
  - Applies noinit to all fields when set to ‘true’
  - Presence of a user-defined initializer disables this support
    - since it disables the compiler-generated initializer altogether
  - Thus, user-defined initializers must explicitly support noinit arguments
    - (when the capability is desired)
Construction/Initialization: Copies

- **Related Topic:** When are record copies added?

- **Background:**
  - Compiler today very ad hoc, “as many as are necessary”
    - Often buggy
  - Desire to document intended behavior and make compiler adhere

- **Status:** **still under discussion, promising direction**
  - Describes when added (compiler implementation)
  - Describes user’s mental model (aimed at spec/user’s guide)
  - Provides details on arrays, specifically
Construction/Initialization: Status

- **Design document available**
- **Current design is sufficient to begin implementation**
  - We are prepared to adjust in some areas as needed
    - Const field assignment
    - Alternate syntax
    - etc.
Construction/Initialization: Next Steps

● Start on Implementation

● Continue discussing some open areas
  ● Copy initializers:
    ● control behavior when compiler-created copies occur
    ● considering an approach similar to D’s postblit
    ● syntax remains an area of discussion
    ● also:
      ● Will there be a super call?
      ● Could a type define more than one copy initializer?
      ● Can you set const fields in its body?
      ● Should method calls be allowed in its body?
  
  ● Move initializers:
    ● support compiler optimization when copying dead expressions
    ● haven’t reached consensus on this topic yet
Error Handling
Error Handling: Background

● Chapel currently lacks a general strategy for errors

● Standard library uses two primary approaches at present:
  ● calls `halt()`
  ● uses optional output arguments (`out error: syserr`)
    ● if argument is provided, user must handle; otherwise call `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, not additional state
    …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, as with exceptions
  ● the ability to get useful messages when errors are not handled
Error Handling: This Effort

- Design a new approach for error handling

- **We considered:**
  - using generalized error objects instead of error codes
  - returning (result, error) tuples
  - returning error objects via optional out arguments
  - exceptions along the lines of C++
  - an exception-like approach (inspired by Swift)

- **Exception-like approach preferred:**
  - 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

- **Detailed proposal:** CHIP 8
Error Handling: Basic Model

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

- Calls that `throw` should 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
  ```plaintext
  do {
      try canThrowErrors();
      try! canThrowErrors();
  } catch {
      writeln("The first call failed.");
  }
  ```
Error Handling: Tasks

- Can capture errors on task join

```java
proc throwsError() throws { throw new Error(); }
proc doesNotThrowError() throws {}
do {
    try cobegin {
        try throwsError();
        try doesNotThrowError();
        try throwsError();
    } catch errors : Errors {
        for e in errors {
            writeln(e);
        }
    }
}
```

2 tasks throw error
2 elements in errors
writeln() invoked twice
Error Handling: Iterators

- Errors can be raised in iterators too
- Such errors end serial iteration

```c
iter glob(pattern: string): string {
    ...
    if (err != 0 && err != GLOB_NOMATCH) then
        throw new Error("unhandled error in glob()");
}

do {
    try for x in glob() {
        writeln(x);
    }
} catch e: Error {
    writeln("Error in glob: ", e);
}
```

invoke catch block when iterator throws
Error Handling: Status, Next Steps

Status:

- Group consensus on general direction in CHIP 8
- Some questions remain:
  - can try or try! apply to a region of code?
  - when is try required?
    - strict rules → more checking: try required for all calls that can throw
    - relaxed rules → easier-to-read code: try, throw assumed by default
  - what compile-time flags or knobs should control behavior?
    - e.g. a flag / scope could control halting or ignoring errors in relaxed mode
  - how to handle runtime errors (e.g. out of memory)?

Next Steps:

- Resolve open design questions
- Start implementation
Debian Packaging of Chapel
Packaging: Background

- Chapel is currently available via:
  - Building from source
  - Homebrew package for OS X
  - Cray RPM for Cray systems

Download ZIP
Packaging: This Effort

● Debian package for Chapel
  ● Removed these third-party libraries/stubs from the package:
    ● GASNet, fltk, libhdfs3, massivethreads, LLVM
  ● Building with the following as a dependency:
    ● GMP
  ● Package will include these third-party libraries:
    ● hwloc, jemalloc, qthreads, re2, utf8-decoder
    ● desirable for good single-locale performance

● Package characteristics:
  ● single-locale only
  ● will support good performance due to jemalloc, qthreads, hwloc
  ● will support regular expressions and GMP
Packaging: Status

- Packaging setup scripts and debian files available at:
  - [https://github.com/chapel-lang/chapel-packaging](https://github.com/chapel-lang/chapel-packaging)
  - Scripts build package from release tarball and debian files

- At the time of writing,
  - 1.13 Debian package is drafted
  - Nearly ready for review, followed by merge into ‘Debian/sid’
    - Review process can span weeks, depending on complexity of package
Packaging: Next Steps

● Submit pull request for our package into ‘Debian/sid’
  ● After merging, the following will happen automatically:
    ● Chapel will deploy with Debian 9 (2017)
    ● Ubuntu and other downstream distributions will pull Chapel package

● Backport Chapel package for Debian 8
  ● So that Chapel is available on current release of Debian

● Expand packaging to other large distributions
  ● (or find community developers who are interested in doing so)
  ● e.g.,
    ● Arch Linux
    ● Fedora, RHEL, CentOS
    ● Suse, OpenSUSE
numa Locale Model
numa Locale Model: Background

- ‘numa’ locale model doesn’t produce desired performance
  - Gets data placement right only inadvertently
    - when inter-loop task placement is similar with respect to data locality
    - when new variables occupy already-placed memory
  - When similarly “lucky”, ‘flat’ beats ‘numa’ due to less overhead:

  ![Global STREAM Performance (GB/s)](chart)

- Want ‘numa’ to outperform ‘flat’ on any NUMA-friendly app
  - With a few caveats: e.g., big enough to amortize overheads
numa Locale Model: This Effort

- **Add numa-awareness to DefaultRectangular arrays**
  - Distribute array data predictably across NUMA domains
  - Matching how DefaultRectangular domain already distributes tasks

```plaintext
forall ... do <something> ;

coforall ... on ... { // across numa sublocales
  coforall ... on ... { // across PUs within subloc
    for ... do <appropriate subset of something>
  }
}
```

- Arrays were *single-ddata*: 1 data block per node
- Now may be *multi-ddata*: 1 data block per sub-locale

- **Goals:**
  - Principled NUMA-oriented performance, not dependent on “luck”
  - No loss of performance when multi-ddata isn’t used
numa Locale Model: a Work-in-Progress

- Enabled when > 1 sublocale/node, for “big enough” arrays
  - 10**6 elements during development, but subject to tuning later

- Implementation has been slower than desired
  - Complicated coding environment
    - DefaultRectangularArr is the heart of the array implementation
  - Lots of optimization tweaks
    - RADopt (Remote Access Data – caches network-remote array metadata)
    - bulk transfer optimization
    - bulk I/O
  - Interactions with iterator implementation
  - Need to limit overheads, maintain performance
    - can’t hurt single-ddata array performance
numa Locale Model: Status and Next Steps

Status:
- Optimizations disabled: RADopt, bulk transfer, bulk I/O
- Was fully functional before taking a step back to focus on performance
- Performance still doesn’t quite match that of flat

Next Steps:
- Bring performance up
- Enable optimizations currently turned off
- Start on related memory management work:
  - numa-awareness in runtime memory layer(s)
  - on Cray X* systems, integrate with use of hugepages
Chapel Package Manager
Package Manager: Background

● **Current approach:**
  ● modules are stored in our repository
  ● modules are released with Chapel

● **This approach will fail as the community grows**
  ● Developers must sign a CLA
  ● Code must be under a compatible license
  ● The core team needs to review each module
  ● Modules are gated for release alongside the compiler

● **And, a better model could help grow the community faster**
  ● Simplify sharing of code
  ● Reduce barriers to doing so
CHIP 9 proposes a package manager called *mason*

- *mason* is a command-line tool for building Chapel programs
- *mason.toml* is a file storing module metadata for an application/library
  - specifies dependencies which can be downloaded during a build
- proposes using *Nix* to manage C dependencies
- proposes writing mason primarily in Chapel
Package Manager: Status and Next Steps

**Impact:**
- Would improve ability to use community-contributed Chapel code
- Would simplify sharing Chapel code within the community

**Status:**
- Initial proposal created

**Next Steps:**
- Develop proposal further
- Solicit feedback from the community
- Start implementation
Twitter Workflow
Twitter Workflow

● **Background:** Studying Twitter Workflow Analysis as a benchmark in data analytics against Spark

● **Since the 1.12 report:**
  ● Committed benchmark to test suite
  ● Completed and merged supporting library changes

● **Impact:**
  ● Chapel now supports:
    ● JSON support for List
    ● Skipping unknown fields when reading JSON records/classes
    ● Generating random permutations

● **Next Steps:**
  ● Re-prioritize this effort
  ● Apples-to-Apples benchmarks between Chapel and Spark
  ● Study and understand the performance delta between them
Parallel Research Kernels
Parallel Research Kernels: Background

**About Parallel Research Kernels (PRK):**
- Kernel computations developed to investigate parallel performance
  - Motifs common in parallel applications
  - Not intended as benchmarks
- 10 small easy-to-port kernels
- 14 submitted implementations and counting...
  - Including serial C, OpenMP, MPI, SHMEM, UPC, etc.
- Good opportunity to explore Chapel’s strengths and weaknesses
  - Particularly in multi-locale performance and scalability
- Will allow comparisons between Chapel and other parallel approaches
Parallel Research Kernels: This Effort

● Chose 3 most popular kernels:
  Stencil:
  ● Apply stencil operation to 2D square input matrix writing to output matrix
  ● Input matrix is updated each iteration to add communication per iteration
  ● We have primarily focused on stencil performance to date

Synch:
  ● Point-to-point synchronization (p2p_synch)
  ● Running stencil operation across matrix with different iterations running simultaneously across locales.

Transpose:
  ● Transpose square matrix A into matrix B
  ● Parallelize matrix across columns and perform transpose
Parallel Research Kernels: Stencil - Single Locale

- Chapel scaling & performance are competitive with C / OpenMP
  - Cray XC, 1 locale, Chapel: qthreads-gnu
  - 3 iterations, 32000x32000 stencil matrix, untiled, star stencil operation

![Single Locale Scalability (strong)](image)

- Rate (MFlops/s)
- Cores

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Parallel Research Kernels: Stencil - Multi Locale

- Chapel not currently competitive with C / OpenMP + MPI (not shown)
  - not surprising given minimal effort put into stencils so far (see MiniMD slides)
  - Cray XC, 24 cores / locale, Chapel: ugni-qthreads-gnu
  - 3 iterations, 32000x32000 stencil matrix, untiled, star stencil operation

**Multi Locale Scalability (strong)**

![Graph showing scalability](chart.png)

- Default-Chapel
- OpenMP+MPI
- Block-Chapel
- Fluff-Chapel

**Rate (MFlops/s)**

- 4.4X
- 2.8X
Parallel Research Kernels: Stencil - Scalability

- Implementations differ for single- vs. multi-locale
  - Single-locale: uses Default Distribution
  - Multi-locale: uses Block Distribution or Stencil Distribution

- For single locale (24 cores):
  - Default-Chapel achieves 138.8% performance of OpenMP+MPI
  - Block-Chapel achieves 22.5% performance of OpenMP+MPI
  - Fluff-Chapel achieves 6.1% performance of OpenMP+MPI

- Positive outlook:
  - Block-Chapel is a naïve implementation of the Stencil algorithm
  - There’s no reason Fluff-Chapel should underperform Block-Chapel
    - It essentially is Block with support for ghost cells (“fluff”)
    - Suggests additional problems with Stencil Distribution
      - or improvements to BlockDist not reflected in StencilDist?
  - Scalability should dramatically improve as Stencil Distribution improves
    - due to opportunity for communication optimizations
Parallel Research Kernels: Stencil - Performance

- Exploration of more elegant solutions
  - Many expressions in Stencil can be expressed with idiomatic Chapel
    - Some of these idiomatic expressions were found to perform poorly
    - As Chapel matures, these performance deltas should decrease

- Some of the performant-to-elegant differences:

```
// Incrementing input

// Performant: explicit
forall (i,j) in Dom {
  input[i, j] += 1.0;
}

// Elegant-1: promoted +=
input += 1.0;
```
Parallel Research Kernels: Stencil - Performance

// Writing stencil operation results to output

// Performant: write to local temp variable, then write to output once
for ii in -R..R do
    for jj in -R..R do
        tmpout += weight[R1+ii][R1+jj] * input[i+ii, j+jj];
    output[i, j] += tmpout;

// Elegant-2: write directly to output each inner iteration
for ii in -R..R do
    for jj in -R..R do
        output[i, j] += weight[R1+ii][R1+jj] * input[i+ii, j+jj];

![Bar chart showing performance comparison between Performant and Elegant-2.]
Parallel Research Kernels: Stencil - Performance

- **Weight matrix representation**
  - Tightly looped over for innermost computation
  - Tuple of tuples representation performs better currently
  - 2D Array representation is slower
    - Tuples map to static C arrays, Chapel arrays to heap-allocation + metadata

---

// Data structure of weight matrix

// Performant: tuple of tuples
var weight: Wsize*(Wsize*(dtype));

// Elegant-3: 2D array
var weight: [weightDom] dtype;
Parallel Research Kernels: Next Steps

● **Stencil**
  ● Prioritize improving Stencil Distribution (Fluff-Chapel)
    ● Strive to reduce gap relative to OpenMP+MPI
    ● Reduce performance delta between performant/elegant expressions

● **Other PRKs**
  ● Investigate Transpose and Synch at the same level of detail as Stencil
  ● Investigate additional kernels as time and interest permit

● **Merge PRK implementation into ParRes/Kernels**
  ● Intel team has expressed interest in studying Chapel performance in their framework
Other Notable Ongoing Efforts
Other Notable Ongoing Efforts

- Users Guide (covered in documentation deck)
- Support for KNL HBM (covered in portability deck)
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