Ongoing Efforts

Chapel Team, Cray Inc.

Chapel version 1.13

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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:

```
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**

```
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:

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

```
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
}
```

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
```

Construction/Initialization: Forward to Sibling

- **Calling other initializers**
  - Calls to sibling initializers look like:

    ```
    this.init(…);
    ```

    - 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");
}
```

```
proc Child.init (…) {
  writeln("Sibling Phase 1");
  // Should initialize child fields
  super.init(…); // no-op, no parent
  writeln("Sibling 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
```

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

Construction/Initialization: Noinit

- **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:

```
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

```
var A: [1..1000] int = noinit;
var badAccess = A[15]; // A[15] is garbage memory right now
```

  - 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

```
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.

```
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
    https://github.com/mppf/chapel/blob/copy-semantics-chip/doc/chips/10.rst

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`**

```
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**

on failure:

invoke **`catch`** block

***halt*()** program

```
do {
    try canThrowErrors();
    try! canThrowErrors();
} catch {
    writeln("The first call failed.");
}
```

Error Handling: Tasks

- Can capture errors on task join

```
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

```
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**
  https://github.com/chapel-lang/chapel/blob/master/doc/chips/8.rst
- 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

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
  - 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

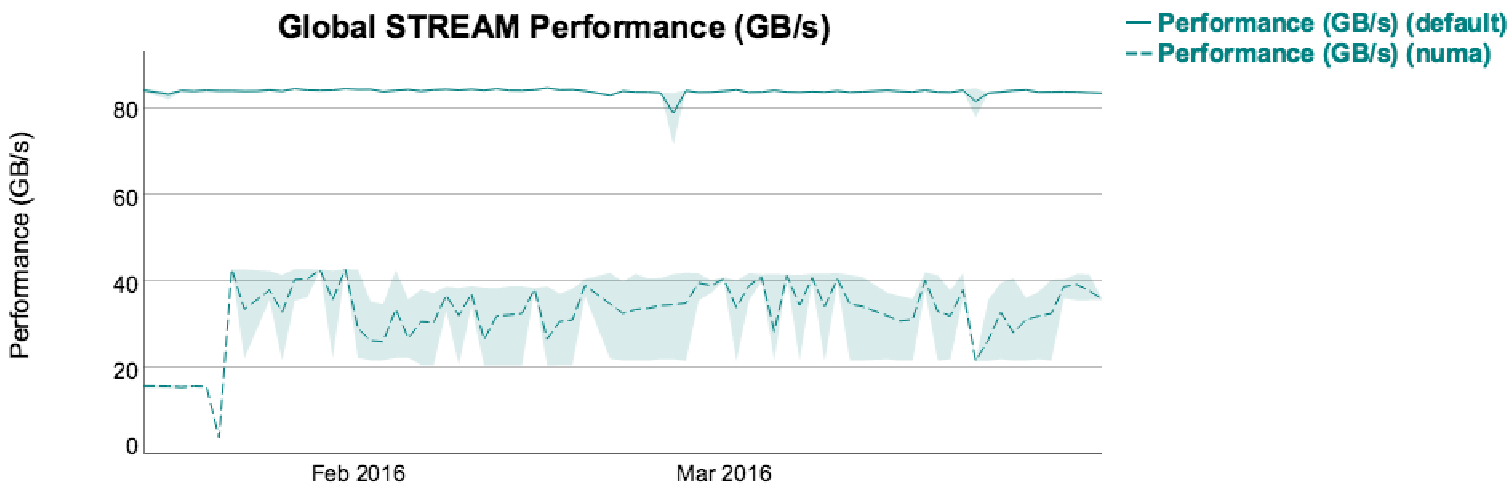
Packaging: Next Steps

- **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:



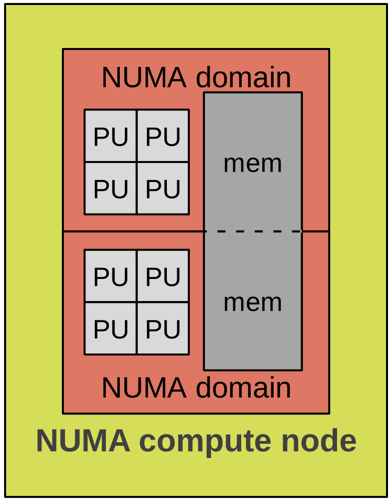
- **Want 'numa' to ourperform 'flat' on any NUMA-friendly app**
  - With a few caveats: e.g., big enough to amortize overheads

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

```
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

Package Manager: This Effort

- **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

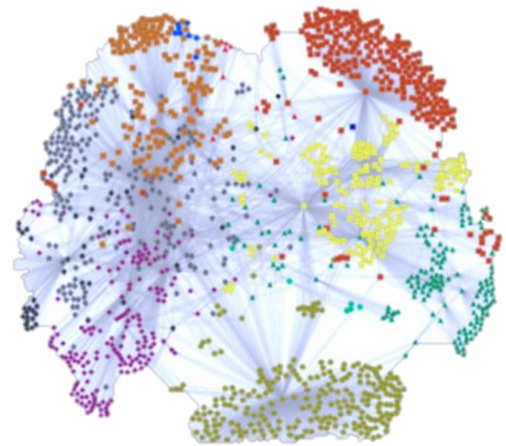
Next Steps:

- 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:

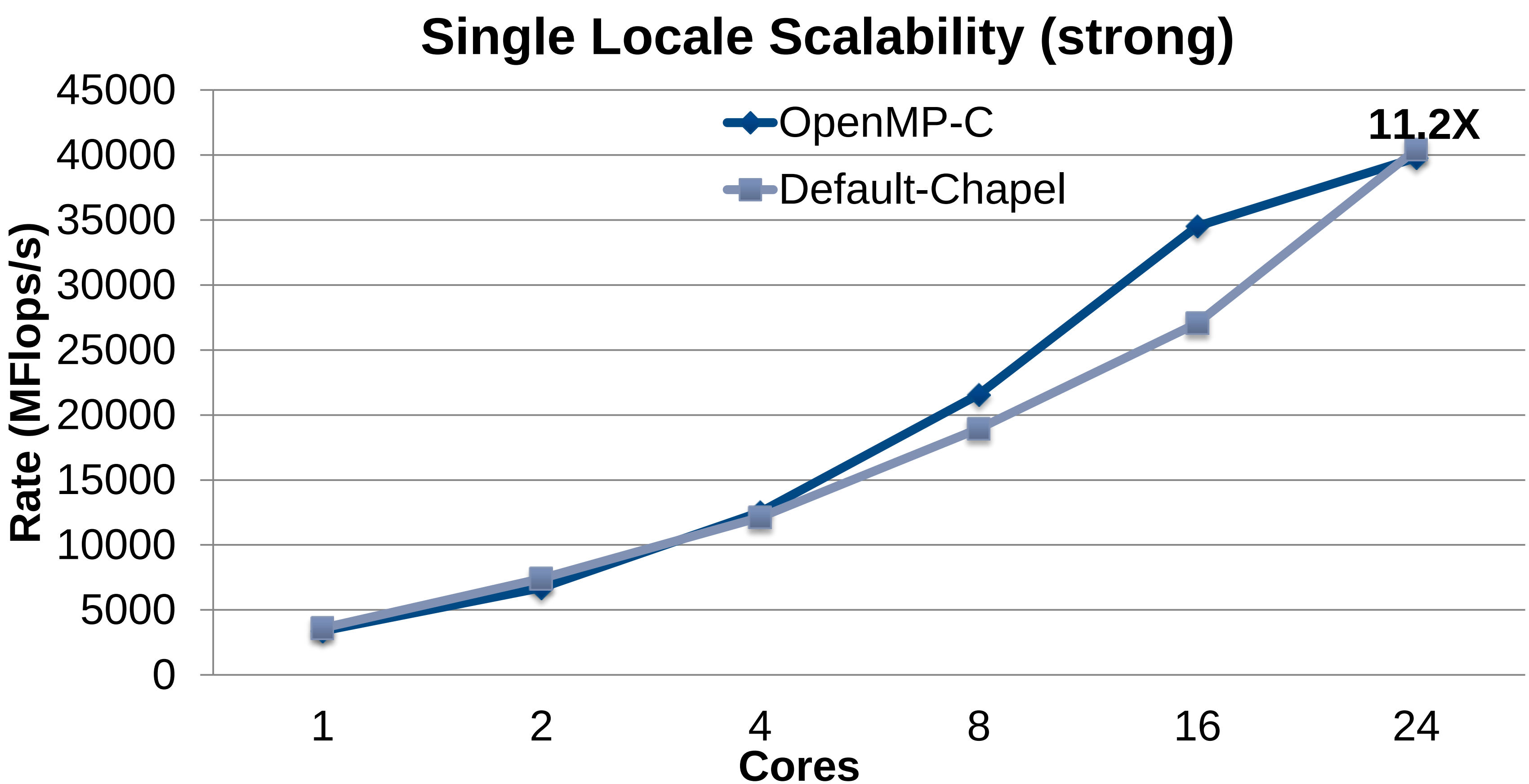
- Point-to-point synchronization (p2p_synch)
- Running stencil operation across matrix with different iterations running simultaneously across locales.

Transpose:

- Transpose square matrix A into matrix B
- Parallelize matrix across columns and perform transpose

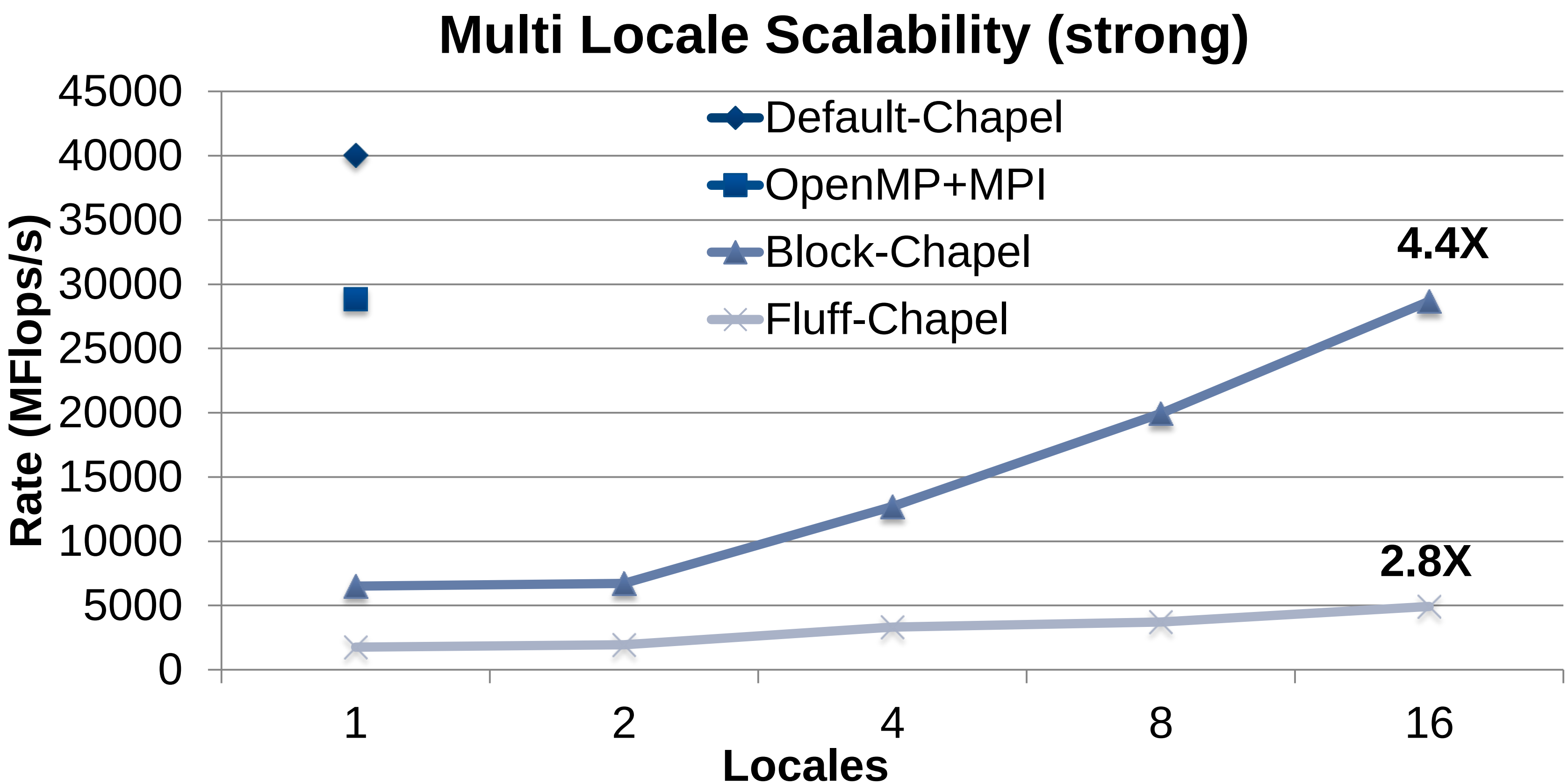
Parallel Research Kernels: Stencil - Single Locale

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



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



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

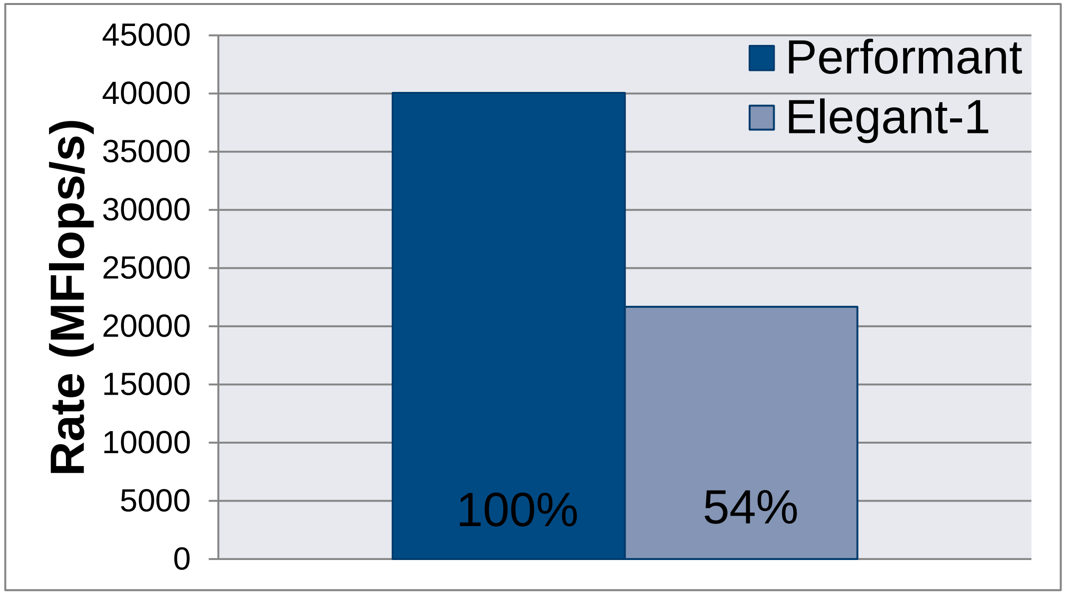
Parallel Research Kernels: Stencil - Performance

- **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;
```

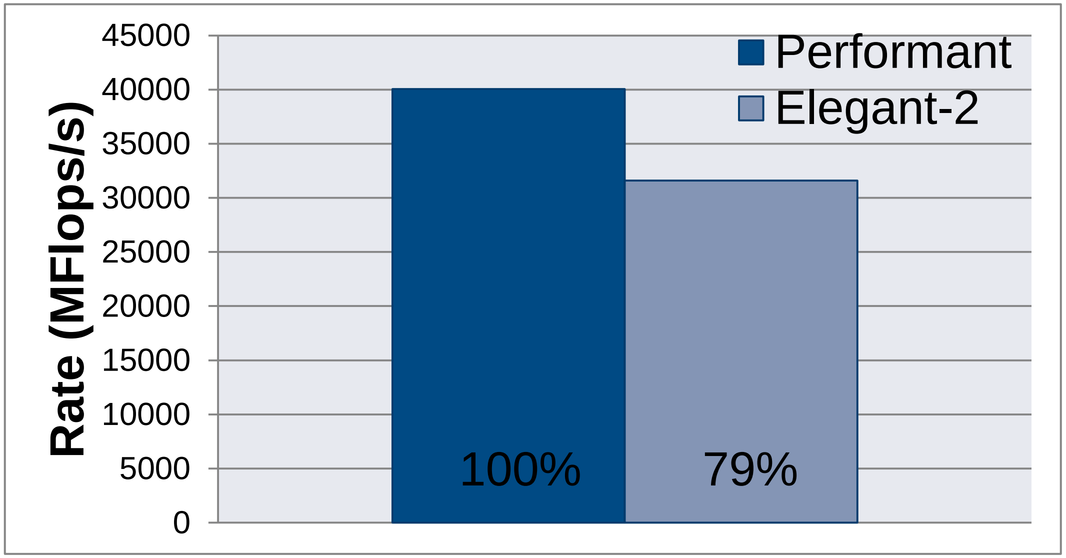


Parallel Research Kernels: Stencil - Performance

```
// 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];
```



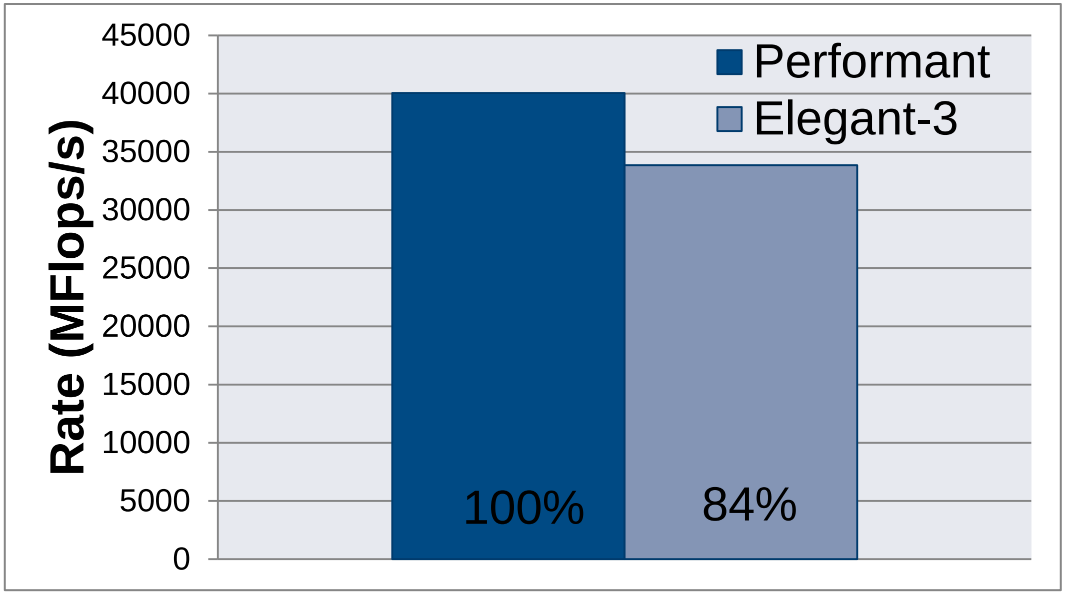
Parallel Research Kernels: Stencil - Performance

- **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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