Chapel’s New Adventures in Data Locality

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What is Chapel?

**Chapel:** A productive parallel programming language
- portable
- open-source
- a collaborative effort

**Goals:**
- Support general parallel programming at scale
- Make parallel programming far more productive
Chapel and Productivity

● Chapel strives to be...
  ...
as programmable as Python
  ...
as fast as Fortran
  ...
as scalable as MPI, SHMEM, or UPC
  ...
as portable as C
  ...
as flexible as C++
  ...
as fun as [your favorite programming language]
The Chapel Team at Cray (May 2017)

14 full-time employees + 2 summer interns
The Broader Chapel Community (a subset)

http://chapel.cray.com/collaborations.html
Typical Chapel programmers should focus on:

- **Parallelism:** What should execute simultaneously?
- **Locality:** Where should those tasks execute? their data reside?
Outline

✓ What’s Chapel?

➢ Classic Chapel Concepts for Locality (‘CCC’s)
  ● Three Recent Locality Endeavors (“New Adventures”)
  ● Wrap-up
locale: Chapel type/values representing architectural locality

- (think “compute node”)

locale
locale: Chapel type/values representing architectural locality

- (think “compute node”)
- Chapel automatically provides a 1D array of locales:

```chapel
const Locales: [0..#numLocales] locale;
```

locale #0 locale #1 locale #2 locale #3
CCC #2: on-clauses

*on-clause*: Moves the current task to the specified locale
**CCC #2: on-clauses**

**on-clause:** Moves the current task to the specified locale

```c
// programs begin execution as a single task on locale #0
config const n = computeLocalProblemSize(),
    alpha = 0.5;
```
**on-clause:** Moves the current task to the specified locale

```c
// programs begin execution as a single task on locale #0
config const n = computeLocalProblemSize(),
    alpha = 0.5;
coforall loc in Locales do  // creates a task per locale
    on loc {                   // moves the task to its locale

    }
```

locale #0
locale #1
locale #2
locale #3
on-clause: Moves the current task to the specified locale

// programs begin execution as a single task on locale #0
config const n = computeLocalProblemSize(),
    alpha = 0.5;
coforall loc in Locales do  // creates a task per locale
    on loc {
        // moves the task to its locale
        var A, B, C: [1..n] real;
        A = B + alpha * C;
    }

locale #0  locale #1  locale #2  locale #3
A | B | C | A | B | C | A | B | C | A | B | C
locale #0  locale #1  locale #2  locale #3

(conceptual view)
on-clause: Moves the current task to the specified locale

```cpp
// programs begin execution as a single task on locale #0
config const n = computeLocalProblemSize(),
    alpha = 0.5;
coforall loc in Locales do  // creates a task per locale
    on loc {  // moves the task to its locale
        var A, B, C: [1..n] real;
        A = B + alpha * C;
    }
```

(optimized view)
distribution: Maps domains ("index sets") to locales
distribution: Maps domains ("index sets") to locales

```cpp
config const n = computeGlobalProblemSize(),
alpha = 0.5;
```

![Diagram showing distribution to locales](image)
distribution: Maps *domains* ("index sets") to locales

```cpp
config const n = computeGlobalProblemSize(),
    alpha = 0.5;

use BlockDist;

const ProblemSpace = {1..n} dmapped Block(...);
```
distribution: Maps domains ("index sets") to locales

```
config const n = computeGlobalProblemSize(),
    alpha = 0.5;
use BlockDist;
const ProblemSpace = {1..n} dmapped Block(...);
var A, B, C: [ProblemSpace] real;
```
distribution: Maps domains ("index sets") to locales

```plaintext
config const n = computeGlobalProblemSize(),
    alpha = 0.5;
use BlockDist;
const ProblemSpace = {1..n} dmapped Block(...);
var A, B, C: [ProblemSpace] real;
A = B + alpha * C;
```

![Diagram showing distribution of A, B, and C to locales #0, #1, #2, #3 with alpha values and block districation]
CCC #4: User Control over Locality Policies

● In Chapel, users can…
  …write their own distributions
  “How should domains & arrays be mapped to locales and their memories?”

  …write their own parallel iterators
  “How should forall-loops be implemented? How many tasks, running where?”

  …write their own locale models
  “How should tasks, memory, communication be mapped to the system?”

● This gives users full control over key locality policies
  ● Moreover, all “built-in” Chapel features are written in this framework
Locality Adventure #1: NUMA Locale Model
The Perils of NUMA Obliviousness

- Accessing non-NUMA-local memory ⇒ performance hit
  - e.g., Stream EP on Cray XC w/ 2 NUMA domains per node:
Flat vs. Hierarchical Locales

- Traditionally, Chapel has supported a “flat” locale model
  - intra-locale decisions are managed on the user’s behalf

- But, users can also write hierarchical locale models
Adventure #1: NUMA locale model

- Created ‘numa’ locale model to describe NUMA nodes

- Also made the default domain map NUMA-aware
  - allocates local arrays using a chunk per sublocale

```plaintext
var A: [1..n] real;
```
Adventure #1: Positive Impact

Stream EP

* = ostensibly… we’ll come back to this in a few slides
Adventure #1: Negative Impact

- Array accesses like $A[i]$ now require a divide
The increased array access cost is problematic

We’d like these idioms to all perform equivalently in Chapel:

- **whole-array operations:**
  \[ A = B + \alpha \times C; \]

- **zippered iteration:**
  ```
  forall \ (a, b, c) \in \text{zip}(A, B, C) \ do \\
  a = b + \alpha \times c;
  ```

- **random access:**
  ```
  forall \ i \in \text{ProblemSpace} \ do \\
  A[i] = B[i] + \alpha \times C[i];
  ```

While there are ways to mitigate the overheads, they aren’t ideal
- still not overhead-free (in some approaches)
- too expensive to implement (in others)

So, let’s try something else…
Locality Adventure #2: **PGAS, Networks, & Locality**
I suggested that the flat locale model is NUMA-oblivious

- It is, but the default domain map actually is not
  - it distributes array indices using first-touch, heuristically

Sometimes results in good performance, but not always:
Flat Locale Model: Why does GASNet/MPI win?

- Chapel usually performs best when using ugni
  - leverages Cray network capabilities
  - matches Chapel’s PGAS features well

Q: why not here, when no communication is used?
A: PGAS-based network registration of heap at program startup
  - serves as first-touch, pinning all memory to NUMA domain 0
  - lack of communication magnifies memory-oriented bottlenecks

![Bar chart showing GB/s for Chapel 1.14 with comm = gasnet/mpi and comm = ugni]
NUMA locale model and network registration

- For ‘numa’, each sublocale registers its own local heap
  - thus, this is one approach to addressing the problem

- but, it introduces the aforementioned overheads for random access
Adventure #2: Dynamic Memory Registration

- Register array memory with network at allocation time
  - heuristically, divide array into approximately equal # of pages

- Impact: Restores performance for ugni:

![Graph showing performance comparison]

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<th>gasnet-mpi</th>
<th>ugni, static registration</th>
<th>ugni, dynamic registration</th>
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flat locale
Locality Adventure #3: Intel Xeon Phi ("KNL") HBM
Adventure #3: KNL Locale Model

KNL Locale Model: Usage and Status

- Chapel can target KNL’s MCDRAM via normal on-clauses
  - accessor methods expose memory-based sub-locales
  - methods implemented across all standard locale models for portability

```chapel
on here.highBandwidthMemory() {
    x = new myClass();    // placed in MCDRAM
    ...

on here.defaultMemory() {
    y = new myClass();    // placed in DDR
    ...
}
```

Status: Supported as of Chapel 1.15
- no performance results to report at this time
- next step: improve support for memory introspection (“if I have…”)
General Chapel Performance Snapshots
**LCALS Timings:** Chapel 1.15 vs. C [+ OpenMP]

Shared memory performance competitive with hand-coded

Serial LCALS kernels: Chapel vs. g++

Parallel LCALS kernels: Chapel vs g++ w/ OMP
HPCC RA Performance: Chapel 1.15 vs. MPI

Performance of RA (atomics)

GUP/s

Locales (x 36 cores per locale)
- ref MPI no-bucketing
- ref MPI bucketing
- 1.15 u+q
- 1.15 u+q oversubscribed

faster
ISx Timings: Chapel 1.15 vs. MPI, SHMEM

ISx weakISO Total Time

Time (seconds)

Cray XC nodes (x 36 cores per node)

faster

SHMEM

MPI

Chapel 1.15
The Computer Language Benchmarks Game (CLBG)

64-bit quad core data set
Will your toy benchmark program be faster if you write it in a different programming language? It depends how you write it!

Which programs are fast?
Which are succinct? Which are efficient?

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<tr>
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<th>Dart</th>
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{ for researchers } fast-faster-fastest stories

Chapel entry accepted Fall 2016
CLBG Language Cross-Language Summary (May 2017 standings, no Python)

- Geometric mean code size (normalized to smallest entry)
- Geometric mean execution time (normalized to fastest entry)

smaller

faster
A Closing Quote
(source: Jonathan Dursi’s CHI-UW 2017 keynote)
“My opinion as an outsider…is that Chapel is important, Chapel is mature, and Chapel is just getting started.

“If the scientific community is going to have frameworks for solving scientific problems that are actually designed for our problems, they’re going to come from a project like Chapel.

“And the thing about Chapel is that the set of all things that are ‘projects like Chapel’ is ‘Chapel.’”

—Jonathan Dursi

Chapel’s Home in the New Landscape of Scientific Frameworks (and what it can learn from the neighbours)

CHIUW 2017 keynote
Questions?
Chapel Resources
Ways to Track Chapel Remotely

Facebook: http://facebook.com/ChapelLanguage
Twitter: http://twitter.com/ChapelLanguage
Youtube: https://www.youtube.com/channel/UCHmm27bYjhknK5mU7ZzPGsQ/
e-mail: chapel-announce@lists.sourceforge.net
Suggested Reading

Chapel chapter from *Programming Models for Parallel Computing*
- a detailed overview of Chapel’s history, motivating themes, features
- published by MIT Press, November 2015
- edited by Pavan Balaji (Argonne)
- chapter is now also available [online](http://chapel.cray.com/papers.html)

Other Chapel papers/publications available at [http://chapel.cray.com/papers.html](http://chapel.cray.com/papers.html)
Suggested Short Reads (Blog Articles)

- a run-down of recent events

- a short-and-sweet introduction to Chapel

**Six Ways to Say “Hello” in Chapel** (parts 1, 2, 3), Cray Blog, Sep-Oct 2015.
- a series of articles illustrating the basics of parallelism and locality in Chapel

**Why Chapel?** (parts 1, 2, 3), Cray Blog, Jun-Oct 2014.
- a series of articles answering common questions about why we are pursuing Chapel in spite of the inherent challenges

- a series of technical opinion pieces designed to argue against standard reasons given for not developing high-level parallel languages
Where to..

Submit bug reports:
GitHub issues for chapel-lang/chapel: public bug forum
chapel_bugs@cray.com: for reporting non-public bugs

Ask User-Oriented Questions:
StackOverflow: when appropriate / other users might care
#chapel-users (irc.freenode.net): user-oriented IRC channel
chapel-users@lists.sourceforge.net: user discussions

Discuss Chapel development
chapel-developers@lists.sourceforge.net: developer discussions
#chapel-developers (irc.freenode.net): developer-oriented IRC channel

Discuss Chapel’s use in education
chapel-education@lists.sourceforge.net: educator discussions

Directly contact Chapel team at Cray: chapel_info@cray.com
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