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Cray: The Supercomputing Company

1972: Seymour Cray founded Cray Research

2000: Tera purchased Cray Research from SGI and formed Cray Inc.
- corporate headquarters based in Seattle, WA

Technology Focus Areas:
- Computation
- Storage
- Analytics

Vision: Provide the systems and tools that our customers need to solve the world’s hardest problems.
High Performance Computing (HPC) Programming Models by Example
STREAM Triad: a trivial parallel computation

**Given:** $m$-element vectors $A$, $B$, $C$

**Compute:** $\forall i \in 1..m, A_i = B_i + \alpha \cdot C_i$

**In pictures:**

![Diagram showing the STREAM Triad computation](image)
Given: \( m \)-element vectors \( A, B, C \)

Compute: \( \forall i \in 1..m, A_i = B_i + \alpha \cdot C_i \)

In pictures, in parallel:
STREAM Triad: a trivial parallel computation

**Given:** $m$-element vectors $A$, $B$, $C$

**Compute:** $\forall i \in 1..m$, $A_i = B_i + \alpha \cdot C_i$

**In pictures, in parallel (distributed memory):**

![Diagram showing parallel computation]

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STREAM Triad: a trivial parallel computation

**Given:** $m$-element vectors $A, B, C$

**Compute:** $\forall i \in 1..m, A_i = B_i + \alpha \cdot C_i$

In pictures, in parallel (distributed memory multicore):

![Diagram](https://via.placeholder.com/150)
#include <hpcc.h>

static int VectorSize;
static double *a, *b, *c;

int HPCC_StarStream(HPCC_Params *params) {
    int myRank, commSize;
    int rv, errCount;
    MPI_Comm comm = MPI_COMM_WORLD;

    MPI_Comm_size( comm, &commSize );
    MPI_Comm_rank( comm, &myRank );

    rv = HPCC_Stream( params, 0 == myRank);
    MPI_Reduce( &rv, &errCount, 1, MPI_INT, MPI_SUM, 0, comm );

    return errCount;
}

int HPCC_Stream(HPCC_Params *params, int doIO) {
    register int j;
    double scalar;

    VectorSize = HPCC_LocalVectorSize( params, 3,
                                       sizeof(double), 0 );

    a = HPCC_XMALLOC( double, VectorSize );
    b = HPCC_XMALLOC( double, VectorSize );
    c = HPCC_XMALLOC( double, VectorSize );

    if (!a || !b || !c) {
        if (c) HPCC_free(c);
        if (b) HPCC_free(b);
        if (a) HPCC_free(a);
        if (doIO) {
            fprintf( outFile, "Failed to allocate memory
                     (%d).
                     n", VectorSize );
            fclose( outFile );
        }
        return 1;
    }

    for (j=0; j<VectorSize; j++) {
        b[j] = 2.0;
        c[j] = 0.0;
    }

    scalar = 3.0;

    for (j=0; j<VectorSize; j++)
        a[j] = b[j]+scalar*c[j];

    HPCC_free(c);
    HPCC_free(b);
    HPCC_free(a);
#include <hpcc.h>
#ifndef _OPENMP
#include <omp.h>
#endif

static int VectorSize;
static double *a, *b, *c;

int HPCC_StarStream(HPCC_Params *params) {
    int myRank, commSize;
    int rv, errCount;
    MPI_Comm comm = MPI_COMM_WORLD;

    MPI_Comm_size( comm, &commSize );
    MPI_Comm_rank( comm, &myRank );

    rv = HPCC_Stream( params, 0 == myRank);
    MPI_Reduce( &rv, &errCount, 1, MPI_INT, MPI_SUM, 0, comm );

    return errCount;
}

int HPCC_Stream(HPCC_Params *params, int doIO) {
    register int j;
    double scalar;

    VectorSize = HPCC_LocalVectorSize( params, 3, sizeof(double), 0 );

    a = HPCC_XMALLOC( double, VectorSize );
    b = HPCC_XMALLOC( double, VectorSize );
    c = HPCC_XMALLOC( double, VectorSize );

    if (!a || !b || !c) {
        if (c) HPCC_free(c);
        if (b) HPCC_free(b);
        if (a) HPCC_free(a);
        if (doIO) {
            fprintf( outFile, "Failed to allocate memory (%d).\n", VectorSize);
            fclose( outFile );
        }
        return 1;
    }

    #ifdef _OPENMP
    #pragma omp parallel for
    #endif
    for (j=0; j< VectorSize; j++) {
        b[j] = 2.0;
        c[j] = 0.0;
    }

    scalar = 3.0;

    #ifdef _OPENMP
    #pragma omp parallel for
    #endif
    for (j=0; j< VectorSize; j++)
        a[j] = b[j]+scalar*c[j];

    HPCC_free(c);
    HPCC_free(b);
    HPCC_free(a);
#define N 2000000

int main() {
    float *d_a, *d_b, *d_c;
    float scalar;

cudaMalloc((void**)&d_a, sizeof(float)*N);
cudaMalloc((void**)&d_b, sizeof(float)*N);
cudaMalloc((void**)&d_c, sizeof(float)*N);

dim3 dimBlock(128);

set_array<<<dimGrid,dimBlock>>>(d_b, .5f, N);
set_array<<<dimGrid,dimBlock>>>(d_c, .5f, N);

scalar=3.0f;
STREAM_Triad<<<dimGrid,dimBlock>>>(d_b, d_c, d_a, scalar, N);
}

__global__
void set_array(float *a, float value, int len) {
    int idx = threadIdx.x + blockIdx.x * blockDim.x;
    if (idx < len) a[idx] = value;
}

__global__
void STREAM_Triad( float *a, float *b, float *c, float scalar, int len) {
    int idx = threadIdx.x + blockIdx.x * blockDim.x;
    if (idx < len) c[idx] = a[idx]+scalar*b[idx];
}
Why so many programming models?

HPC tends to approach programming models bottom-up: Given a system and its core capabilities…
…provide features that can access the available performance.


<table>
<thead>
<tr>
<th>Type of HW Parallelism</th>
<th>Programming Model</th>
<th>Unit of Parallelism</th>
</tr>
</thead>
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<tr>
<td>Inter-node</td>
<td>MPI</td>
<td>executable</td>
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<tr>
<td>Intra-node/multicore</td>
<td>OpenMP / pthreads</td>
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<td>Instruction-level vectors/threads</td>
<td>pragmas</td>
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<td>GPU/accelerator</td>
<td>CUDA / Open[CL</td>
<td>MP</td>
</tr>
</tbody>
</table>

**benefits:** lots of control; decent generality; easy to implement

**downsides:** lots of user-managed detail; brittle to changes
Motivation for Chapel

**Q:** Can a single language be…
   - …as productive as Python?
   - …as fast as Fortran?
   - …as portable as C?
   - …as scalable as MPI?
   - …as fun as <your favorite language here>?

**A:** We believe so.
The Challenge

Q: So why don’t we have such languages already?

A: Technical challenges?

- while they exist, we don’t think this is the main issue…

A: Due to a lack of…

…long-term efforts
…resources
…community will
…co-design between developers and users
…patience

Chapel is our attempt to reverse this trend
What is Chapel?

Chapel: A productive parallel programming language
- extensible
- portable
- open-source
- a collaborative effort
- a work-in-progress

Goals:
- Support general parallel programming
  - “any parallel algorithm on any parallel hardware”
- Make parallel programming far more productive
What does “Productivity” mean to you?

Recent Graduates:
“something similar to what I used in school: Python, Matlab, Java, …”

Seasoned HPC Programmers:
“that sugary stuff that I don’t need because I was born to suffer”
“...want full control to ensure performance”

Computational Scientists:
“something that lets me express my parallel computations without having to wrestle with architecture-specific details”

Chapel Team:
“something that lets computational scientists express what they want, without taking away the control that HPC programmers need, implemented in a language as attractive as recent graduates want.”
Rewinding a few slides...

**MPI + OpenMP**

```c
#define OPENMP
#include <omp.h>
#endif

static int VectorSize;
static double *a, *b, *c;

int HPCC_StarStream(HPCC_Params *params) {
    int myRank, commSize;
    int rv, errCount;
    MPI_Comm comm = MPI_COMM_WORLD;
    MPI_Comm_size( comm, &commSize );
    MPI_Comm_rank( comm, &myRank );
    if( N % dimBlock.x != 0 )
        dimGrid.x+=1;
    MPI_Reduce( &rv, &errCount, 1, MPI_INT, MPI_SUM, 0, comm );
    return errCount;
}

__global__ void set_array(float *a, float value, int len) {
    int idx = threadIdx.x + blockIdx.x * blockDim.x;
    if (idx < len) a[idx] = value;
}

__global__ void STREAM_Triad(float *a, float *b, float *c, float scalar, int len) {
    int idx = threadIdx.x + blockIdx.x * blockDim.x;
    if (idx < len) c[idx] = a[idx] + scalar*b[idx];
}

#include <hpcc.h>
#include <omp.h>
#endif

int HPCC_StarStream(HPCC_Params *params, int doIO) {
    register int j;
    double scalar;
    VectorSize = HPCC_LocalVectorSize( params, 3, sizeof(double), 0 );
    a = HPCC_XMALLOC( double, VectorSize );
    b = HPCC_XMALLOC( double, VectorSize );
    c = HPCC_XMALLOC( double, VectorSize );
    if (!a || !b || !c) {
        if (c) HPCC_free(c);
        if (b) HPCC_free(b);
        if (a) HPCC_free(a);
        if (doIO) {
            fprintf( outFile, "Failed to allocate memory (%d).\n", VectorSize );
            fclose( outFile );
            return 1;
        }
    }
    #ifdef _OPENMP
    #pragma omp parallel for
    #endif
    for (j=0; j<VectorSize; j++) {
        b[j] = 2.0;
        c[j] = 0.0;
    }
    scalar = 3.0;
    #ifdef _OPENMP
    #pragma omp parallel for
    #endif
    for (j=0; j<VectorSize; j++)
        a[j] = b[j]+scalar*c[j];
    HPCC_free(c);
    HPCC_free(b);
    HPCC_free(a);
    return 0;
}
```

**CUDA**

```c
#include <hpcc.h>
#endif

#define N 2000000

int main() {
    float *d_a, *d_b, *d_c;
    float scalar;

cudaMalloc((void**)&d_a, sizeof(float)*N);
cudaMalloc((void**)&d_b, sizeof(float)*N);
cudaMalloc((void**)&d_c, sizeof(float)*N);

dim3 dimBlock(128);
if( N % dimBlock.x != 0 )
    dimGrid.x+=1;
set_array<<<dimGrid,dimBlock>>>(d_b, .5f, N);
set_array<<<dimGrid,dimBlock>>>(d_c, .5f, N);

scalar=3.0f;
STREAM_Triad<<<dimGrid,dimBlock>>>(d_b, d_c, d_a, scalar, N);
cudaSynchronize();
cudaFree(d_a);
cudaFree(d_b);
cudaFree(d_c);
}
```

HPC suffers from too many distinct notations for expressing parallelism and locality.
## STREAM Triad: Chapel

### Philosophy:
Good, *top-down* language design can tease system-specific implementation details away from an algorithm, permitting the compiler, runtime, applied scientist, and HPC expert to each focus on their strengths.
Outline

✓ Motivation for Chapel

➢ Survey of Chapel Concepts
  ● Chapel Project and Characterizations
  ● Chapel Resources
Chapel’s Multiresolution Philosophy

**Multiresolution Design:** Support multiple tiers of features

- higher levels for programmability, productivity
- lower levels for greater degrees of control

*Chapel language concepts*

- Domain Maps
- Data Parallelism
- Task Parallelism
- Base Language
- Locality Control
- Target Machine

- build the higher-level concepts in terms of the lower
- permit the user to intermix layers arbitrarily
Base Language

- Domain Maps
- Data Parallelism
- Task Parallelism
- Base Language
- Locality Control

Lower-level Chapel

Target Machine
Base Language Features, by example

```python
iter fib(n) {
    var current = 0,
           next = 1;

    for i in 1..n {
        yield current;
        current += next;
        current <=> next;
    }
}
```

```python
config const n = 10;
for f in fib(n) do
    writeln(f);
```

```plaintext
0
1
1
2
3
5
8
...
```
Base Language Features, by example

```
iter fib(n) {
  var current = 0,
      next = 1;

  for i in 1..n {
    yield current;
    current += next;
    current <=> next;
  }
}
```

```
config const n = 10;

for f in fib(n) do
  writeln(f);
```

CLU-style iterators
Base Language Features, by example

Configuration declarations
(to avoid command-line argument parsing)
./a.out -n=1000000

```go
iter fib(n) {
    var current = 0,
         next = 1;
    for i in 1..n {
        yield current;
        current += next;
        current <=> next;
    }
}
```

```go
config const n = 10;
for f in fib(n) do
    writeln(f);
```

```
0
1
1
2
3
5
8
...
```
```plaintext
config const n = 10;

for f in fib(n) do
    writeln(f);
```

```
iter fib(n) {
    var current = 0,
        next = 1;

    for i in 1..n {
        yield current;
        current += next;
        current <=> next;
    }
}
```
Base Language Features, by example

```plaintext
iter fib(n) {
    var current = 0,
        next = 1;

    for i in 1..n {
        yield current;
        current += next;
        current <=> next;
    }
}
```

```plaintext
config const n = 10;
for (i, f) in zip(0..#n, fib(n)) do
    writeln("fib #", i, " is ", f);
```

Zippered iteration

```
fib #0 is 0
fib #1 is 1
fib #2 is 1
fib #3 is 2
fib #4 is 3
fib #5 is 5
fib #6 is 8
...
```
Base Language Features, by example

```
iter fib(n) {
    var current = 0, next = 1;
    for i in 1..n {
        yield current;
        current += next;
        current <=> next;
    }
}
```

```
config const n = 10;
for (i, f) in zip(0..#n, fib(n)) do writeln("fib #", i, " is ", f);
```

```
fib #0 is 0
fib #1 is 1
fib #2 is 1
fib #3 is 2
fib #4 is 3
fib #5 is 5
fib #6 is 8
...```
Base Language Features, by example

```javascript
// configure const n = 10;

// iterate fib(n) {
//   var current = 0,
//       next = 1;
//   for i in 1..n {
//     yield current;
//     current += next;
//     current <=> next;
//   }
// }
```

```
config const n = 10;

for (i, f) in zip(0..#n, fib(n)) do
  writeln("fib #", i, " is ", f);
```

OF 0
fib #0 is 0
fib #1 is 1
fib #2 is 1
fib #3 is 2
fib #4 is 3
fib #5 is 5
fib #6 is 8
...
Base Language Features, by example

```
iter fib(n) {
    var current = 0,
        next = 1;

    for i in 1..n {
        yield current;
        current += next;
        current <=> next;
    }
}
```

```
config const n = 10;
for (i,f) in zip(0..#n, fib(n)) do
    writeln("fib #", i, " is ", f);

fib #0 is 0
fib #1 is 1
fib #2 is 1
fib #3 is 2
fib #4 is 3
fib #5 is 5
fib #6 is 8
...
```
Other Base Language Features

- interoperability features
- **OOP** (value- and reference-based)
- overloading, where clauses
- argument intents, default values, match-by-name
- compile-time features for meta-programming
  - e.g., compile-time functions to compute types, values; reflection
- **modules** (for namespace management)
- rank-independent programming features
- …
Task Parallelism
Task Parallelism: Begin Statements

```pascal
// create a fire-and-forget task for a statement
begin writeln(“hello world”);
writeln(“goodbye”);
```

Possible outputs:

```
hello world
goodbye
```
```
hello world
goodbye
```
Task Parallelism: Coforall Loops

// create a task per iteration
coforall t in 0..#numTasks {
    writeln(“Hello from task ”, t, “ of ”, numTasks);
} // implicit join of the numTasks tasks here

writeln(“All tasks done”);

Sample output:

Hello from task 2 of 4
Hello from task 0 of 4
Hello from task 3 of 4
Hello from task 1 of 4
All tasks done
atomic variables: support atomic operations
- e.g., compare-and-swap; atomic sum, multiply, etc.
- similar to C/C++

csync variables: store full-empty state along with value
- by default, reads/writes block until full/empty, leave in opposite state
begin producer();
consumer();

// ‘sync’ types store full/empty state along with value
var buff$: [0..#buffersize] sync real;

proc producer() {
  var i = 0;
  for ... {
    i = (i+1) % buffersize;
    buff$[i] = ...;  // writes block until empty, leave full
  }
}

proc consumer() {
  var i = 0;
  while ... {
    i = (i+1) % buffersize;
    ...buff$[i]...;  // reads block until full, leave empty
  }
}
Other Task Parallel Concepts

- **cobegins**: create tasks using compound statements
- **single variables**: like sync variables, but write-once
- **sync statements**: join unstructured tasks
- **serial statements**: conditionally squash parallelism
Locality Control
The Locale Type

Definition:

- Abstract unit of target architecture
- Supports reasoning about locality
  - defines “here vs. there” / “local vs. remote”
- Capable of running tasks and storing variables
  - i.e., has processors and memory

Typically: A compute node (multicore processor or SMP)
Getting started with locales

- Specify # of locales when running Chapel programs

  \[
  \% a.out --numLocales=8 \quad \% a.out -nl 8
  \]

- Chapel provides built-in locale variables

  \[
  \text{config const numLocales: int = ...;}
  \text{const Locales: [0..#numLocales] locale = ...;}
  \]

- \text{main()} starts execution as a task on locale #0
Locale Operations

- Locale methods support queries about the target system:
  ```plaintext
  proc locale.physicalMemory(...) { ... }
  proc locale.numCores { ... }
  proc locale.id { ... }
  proc locale.name { ... }
  ```

- **On-clauses** support placement of computations:
  ```plaintext
  writeln(“on locale 0”);
  on Locales[1] do
    writeln(“now on locale 1”);
  writeln(“on locale 0 again”);
  on A[i,j] do
    bigComputation(A);
  on node.left do
    search(node.left);
  ```
Parallelism and Locality: Orthogonal in Chapel

- This is a **parallel**, but local program:
  
  ```chapel
  coforall i in 1..msgs do
  writeln("Hello from task ", i);
  ```

- This is a **distributed**, but serial program:
  
  ```chapel
  writeln("Hello from locale 0!");
  on Locales[1] do writeln("Hello from locale 1!");
  on Locales[2] do writeln("Hello from locale 2!");
  ```

- This is a **distributed parallel** program:
  
  ```chapel
  coforall i in 1..msgs do
  on Locales[i%numLocales] do
  writeln("Hello from task ", i,
  " running on locale ", here.id);
  ```
Chapel: Scoping and Locality

```chapel
var i: int;
```

Locales (think: “compute nodes”)
Chapel: Scoping and Locality

```chapel
var i: int;
on Locales[1] {
    i
}
```

Locales (think: “compute nodes”)
Chapel: Scoping and Locality

```chapel
var i: int;
on Locales[1] {
  var j: int;
}
```

**Locales** (think: “compute nodes”)
Chapel: Scoping and Locality

```chapel
var i: int;
on Locales[1] {
  var j: int;
  coforall loc in Locales {
    on loc {
```

Locales (think: “compute nodes”)
Chapel: Scoping and Locality

```chapel
var i: int;
on Locales[1] {
    var j: int;
    coforall loc in Locales {
        on loc {
            var k: int;
            ...
        }
    }
}
```

Locales (think: “compute nodes”)
Chapel: Scoping and Locality

```chapel
var i: int;
on Locales[1] {  
    var j: int;
    coforall loc in Locales {  
        on loc {  
            var k: int;
            k = 2*i + j;
        }
    }
}
```

Locales (think: “compute nodes”)
Chapel: Scoping and Locality

```chapel
cvar i: int;
on Locales[1] {
  cvar j: int;
  coforall loc in Locales {
    on loc {
      cvar k: int;
      k = 2*i + j;
    }
  }
}
```

Here, `i` and `j` are remote, so the compiler + runtime will transfer their values.

Locales (think: “compute nodes”)

$k = 2 \times i + j$;
Chapel: Locality queries

```chapel
var i: int;
on Locales[1] {
    var j: int;
    coforall loc in Locales {
        on loc {
            var k: int;

            ...here...  // query the locale on which this task is running
            ...j.locale...  // query the locale on which j is stored
        }
    }
}
```

![Diagram showing the mapping of variables to locales](Locales_diagram)
Data Parallelism
Data Parallelism By Example: STREAM Triad

```plaintext
const ProblemSpace = {1..m};

var A, B, C: [ProblemSpace] real;

forall (a,b,c) in zip(A,B,C) do
  a = b + alpha*c;
```

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Data Parallelism By Example: STREAM Triad

\[
\text{const ProblemSpace} = \{1..m\};
\]

\[
\text{var A, B, C: [ProblemSpace] real;}
\]

\[
A = B + \alpha \cdot C; \quad \text{// equivalent to the zippered forall}
\]
Other Data Parallel Features

- **Rich Domain/Array Types:**
  - multidimensional
  - strided
  - sparse
  - associative

- **Slicing:** Refer to subarrays using ranges/domains
  - A[2..n-1, lo..#b] ...
  - A[ElementsOfInterest] ...

- **Promotion:** Call scalar functions with array arguments
  - pow(A, B)...
  - // equivalent to: forall (a,b) in zip(A,B) do pow(a,b)

- **Reductions/Scans:** Apply operations across collections
  - + reduce A ...
  - myReduceOp reduce A ...
Domain Maps

- Higher-level Chapel
- Target Machine
- Locality Control
- Base Language
- Task Parallelism
- Data Parallelism
- Domain Maps

Copyright 2014 Cray Inc.
const ProblemSpace = {1..m};

var A, B, C: [ProblemSpace] real;

A = B + alpha * C;

No domain map specified ⇒ use default layout
- current locale owns all domain indices and array values
- computation will execute using local processors only
STREAM Triad: Chapel (multilocale, cyclic)

\[
\text{const ProblemSpace} = \{1..m\} \\
\text{dmapped Cyclic(startIdx=1)}; \\
\text{var A, B, C: [ProblemSpace]} \text{ real;} \\
A = B + \alpha \cdot \text{C};
\]
STREAM Triad: Chapel (multilocale, blocked)

```chapel
const ProblemSpace = {1..m}
    dmapped Block(boundingBox={1..m});

var A, B, C: [ProblemSpace] real;

A = B + alpha * C;
```
**STREAM Triad: Chapel**

```c
#include <hpcc.h>
#ifdef _OPENMP
#include <omp.h>
#endif
static int VectorSize;
static double *a, *b, *c;
int HPCC_StarStream(HPCC_Params *params) {
    int myRank, commSize;
    int rv, errCount;
    MPI_Comm comm = MPI_COMM_WORLD;
    MPI_Comm_size( comm, &commSize );
    MPI_Comm_rank( comm, &myRank );
    rv = HPCC_Stream( params, 0 == myRank);
    MPI_Reduce( &rv, &errCount, 1, MPI_INT, MPI_SUM, 0, comm );
    return errCount;
}
int HPCC_Stream(HPCC_Params *params, int doIO) {
    register int j;
    double scalar;
    VectorSize = HPCC_LocalVectorSize( params, 3, sizeof(double), 0 );
    a = HPCC_XMALLOC( double, VectorSize );
    b = HPCC_XMALLOC( double, VectorSize);
    c = HPCC_XMALLOC( double, VectorSize);
    if (!a || !b || !c) {
        if (c) HPCC_free(c);
        if (b) HPCC_free(b);
        if (a) HPCC_free(a);
        if (doIO) {
            fprintf( outFile, "Failed to allocate memory (%d).\n", VectorSize );
            fclose( outFile );
        }
        return 1;
    }
    #ifdef _OPENMP
    #pragma omp parallel for
    #endif
    for (j=0; j<VectorSize; j++) {
        b[j] = 2.0;
        c[j] = 0.0;
    }
    scalar = 3.0;
    #ifdef _OPENMP
    #pragma omp parallel for
    #endif
    for (j=0; j<VectorSize; j++)
        a[j] = b[j] + scalar * c[j];
    HPCC_free(c);
    HPCC_free(b);
    HPCC_free(a);
    return 0;
}
```

**Philosophy:**
Good, *top-down* language design can tease system-specific implementation details away from an algorithm, permitting the compiler, runtime, applied scientist, and HPC expert to each focus on their strengths.

**Chapel**

```
config const m = 1000,
    alpha = 3.0;

const ProblemSpace = {1..m} dmapped ...;

var A, B, C: [ProblemSpace] real;

B = 2.0;
C = 3.0;
A = B + alpha * C;
```
Chapel is Extensible

Advanced users can create their own…
  …domain maps (array layouts and distributions)…
  …parallel loop schedules…
  …models of the target architecture…

…as Chapel code, without modifying the compiler.

Why? To create a future-proof language.

This has been our main R&D challenge: How to create a language that does not lock these policies into the implementation without sacrificing performance?
Language Summary

Parallel programmers deserve better programming models

Higher-level programming models can help insulate algorithms from parallel implementation details
  ● yet, without necessarily abdicating control
  ● Chapel does this via its multiresolution design

We believe Chapel can greatly improve productivity
  …for current and emerging parallel architectures
  …for HPC users as well as mainstream uses of parallelism
Outline

✓ Motivation for Chapel
✓ Survey of Chapel Concepts
➢ Chapel Project and Characterizations
● Chapel Resources
Chapel is Portable

- Chapel is designed to be hardware-independent

- The current release requires:
  - a C/C++ compiler
  - a *NIX environment (Linux, OS X, BSD, Cygwin, …)
  - POSIX threads
  - RDMA, MPI, or UDP (for distributed memory execution)

- Chapel can run on…
  - laptops and workstations
  - commodity clusters
  - the cloud
  - HPC systems from Cray and other vendors
  - modern processors like Intel Xeon Phi, GPUs*, etc.

  * = academic work only; not yet supported in the official release
Chapel is Open-Source

● Chapel’s development is hosted at GitHub
  ● https://github.com/chapel-lang

● Chapel is licensed as Apache v2.0 software

● Instructions for download + install are online
  ● see http://chapel.cray.com/download.html to get started
14 full-time employees + 2 summer interns + 1 visiting professor
(one of each started after this photo was taken)
Chapel is a Collaborative Effort

(and several others…)

http://chapel.cray.com/collaborations.html
Chapel is a Work-in-Progress

- Currently being picked up by early adopters
  - over two releases, 3000+ downloads per year
  - Users who try it generally like what they see
A notable early adopter

Chapel in the (Cosmological) Wild

Nikhil Padmanabhan, Yale University Professor, Physics & Astronomy

1:00 – 2:00

Abstract: This talk aims to present my personal experiences using Chapel in my research. My research interests are in observational cosmology; more specifically, I use large surveys of galaxies to constrain the evolution of the Universe and to probe the physics underlying that evolution. Operationally, this involves measuring a number of spatial statistics of the distribution of galaxies, both on actual observations, but also on large numbers of simulated universes.

I’ll start by presenting a whirlwind introduction to cosmology, the problems that keep me up at night and our approaches to solving these. I’ll then discuss what attracted me to Chapel — the ability to prototype algorithms quickly and the promised ease and flexibility of writing parallel programs. I’ll then present a worked example of Chapel being used in a real-world application, discussing some of these aspects as well highlighting its interoperability with existing libraries, as well as some of the challenges. I’ll conclude with what it would take for me to switch over to using Chapel all of the time.
Chapel is a Work-in-Progress

- Currently being picked up by early adopters
  - Last two releases got ~3500 downloads total in a year
  - Users who try it generally like what they see

- Most current features are functional and working well
  - Some areas need improvements, e.g., error-handling, constructors

- Performance varies, but is continually improving
  - Shared memory performance is typically competitive with C+OpenMP
  - Distributed memory performance tends to be more hit-and-miss

- We are actively working to address these lacks
Outline

✓ Motivation for Chapel
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Chapel Websites

Project page: http://chapel.cray.com
- overview, papers, presentations, language spec, ...

GitHub: https://github.com/chapel-lang
- download Chapel; browse source repository; contribute code

Facebook: https://www.facebook.com/ChapelLanguage

Twitter: https://twitter.com/ChapelLanguage
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)
Chapel Blog Articles

- a short-and-sweet introduction to Chapel

**Chapel Springs into a Summer of Code**, Cray Blog, April 2016.
- coverage of recent events

**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
Chapel Mailing Lists

low-traffic / read-only:
  chapel-announce@lists.sourceforge.net: announcements about Chapel community lists:
  chapel-users@lists.sourceforge.net: user-oriented discussion list
  chapel-developers@lists.sourceforge.net: developer discussions
  chapel-education@lists.sourceforge.net: educator discussions
  chapel-bugs@lists.sourceforge.net: public bug forum

(subscribe at SourceForge: http://sourceforge.net/p/chapel/mailman/)

To mail the Cray team:
  chapel_info@cray.com: contact the team at Cray
  chapel_bugs@cray.com: for reporting non-public bugs

or use IRC (#chapel on chat.freenode.net) or StackOverflow
Current Events: Computer Language Benchmark Game
Chapel was recently added to the game:

As of Oct 17th:

- **for performance:**
  - 1 top entries: pidigits
  - 2 top-5 entries: meteor, thread-ring
  - 2 top-10 entries: fannkuch-redux, chameneos-redux
  - 3 top-20 entries: n-body, spectral-norm, binary-trees

- **for code compactness:**
  - 2 top entries: n-body, thread-ring
  - 2 top-5 entries: spectral-norm, pidigits
  - 4 top-20 entries: mandelbrot, regex-dna, chameneos-redux, meteor

---

**The Computer Language Benchmarks Game**

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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Computer Language Benchmarks Game

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  - 4 top-20 entries: `mandelbrot`, `regex-dna`, `chameneos-redux`, `meteor`

We want easy answers, but easy answers are often incomplete or wrong. You and I know, there's more we should understand:

<table>
<thead>
<tr>
<th>stories</th>
<th>details</th>
<th>fast?</th>
<th>conclusions</th>
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{ for researchers }
Chapel: Productive Parallel Programming at Scale

Questions?