Chapel Base Language, By Example
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Lower-Level Features

Chapel language concepts

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

Lower-level Chapel

Target Machine
"Hello World" in Chapel: Two Versions

- **Fast prototyping**
  ```chapel
  writeln("Hello, world!");
  ```

- **“Production-grade”**
  ```chapel
  module Hello {

  proc main() {
    writeln("Hello, world!");
  }

  }
  ```
"Hello World" in Chapel: Two Versions

- Fast prototyping

  ```chapel
  writeln(“Hello, world!”);
  ```

- “Production-grade” (configurable)

  ```chapel
  module Hello {
    config const audience = “world”;
    
    proc main() {
      writeln(“Hello, “, audience, “!”);
    }
  }
  ```
const pi = 3.14, // pi is a real
coord = 1.2 + 3.4i, // coord is a complex...
coord2 = pi*coord, // ...as is coord2
name = "brad", // name is a string
verbose = false; // verbose is boolean

proc addem(x, y) { // addem() has generic arguments
    return x + y; // and an inferred return type
}

var sum = addem(1, pi), // sum is a real
    fullname = addem(name, "ford"); // fullname is a string

writeln((sum, fullname));

(4.14, bradford)
Variables, Constants, and Parameters

- **Basic syntax**
  
  ```
  declaration:
  var identifier [: type] [= init-expr];
  const identifier [: type] [= init-expr];
  param identifier [: type] [= init-expr];
  ```

- **Meaning**
  - **var/const**: execution-time variable/constant
  - **param**: compile-time constant
  - No **init-expr** ⇒ initial value is the type’s default
  - No **type** ⇒ type is taken from **init-expr**

- **Examples**
  ```
  const pi: real = 3.14159;
  var count: int;       // initialized to 0
  param debug = true;   // inferred to be bool
  ```
param intSize = 32;
type elementType = real(32);
const epsilon = 0.01:elementType;
var start = 1:int(intSize);
Configs

```chapl
config param intSize = 32;
config type elementType = real(32);
config const epsilon = 0.01:elementType;
config var start = 1:int(intSize);
```

```bash
% chpl myProgram.chpl -sintSize=64 -selementType=real
% a.out --start=2 --epsilon=0.00001
```
"Hello World" in Chapel: Two Versions

- Fast prototyping

```chapel
writeln("Hello, world!");
```

- "Production-grade" (configurable)

```chapel
module Hello {
    config const audience = "world";

    proc main() {
        writeln("Hello, ", audience, "!");
    }
}
```
n-body in Chapel (for n == 5)
(a sample serial computation)
n-body in Chapel (where n == 5)

- A serial computation
- From the Computer Language Benchmarks Game
- Computes the influence of 5 bodies on one another
  - The Sun, Jupiter, Saturn, Uranus, Neptune
- Executes for a user-specifiable number of timesteps

Image source: http://spaceplace.nasa.gov/review/ice-dwarf/solar-system-lrg.png
5-body in Chapel: Declarations

```chapel
config const numsteps = 10000;

const pi = 3.141592653589793,
solarMass = 4 * pi**2,
daysPerYear = 365.24;

record body {
  var pos: 3*real;
  var v: 3*real;
  var mass: real;
}

...
Records and Classes

- Chapel’s struct/object types
  - Contain variable definitions (fields)
  - Contain procedure & iterator definitions (methods)
  - Records: value-based (e.g., assignment copies fields)
  - Classes: reference-based (e.g., assignment aliases object)
  - Record : Class :: C++ struct : Java class

- Example

```plaintext
record circle {
    var radius: real;
    proc area() {
        return pi*radius**2;
    }
}

var c1, c2: circle;
c1 = new c1(radius=1.0);
c2 = c1;  // copies c1
c1.radius = 5.0;
writeln(c2.radius);  // 1.0
// records deleted by compiler
```
Records and Classes

- **Chapel’s struct/object types**
  - Contain variable definitions (fields)
  - Contain procedure & iterator definitions (methods)
  - Records: value-based (e.g., assignment copies fields)
  - Classes: reference-based (e.g., assignment aliases object)
  - Record : Class :: C++ struct : Java class

- **Example**

```
class circle {
    var radius: real;
    proc area() {
        return pi*radius**2;
    }
}
```

```
var c1, c2: circle;

c1 = new c1(radius=1.0);
c2 = c1; // aliases c1’s circle

c1.radius = 5.0;
writeln(c2.radius); // 5.0

delete c1; // users delete classes
```
Tuples

● **Use**
  ● support lightweight grouping of values
    ● e.g., passing/returning procedure arguments
    ● multidimensional array indices
    ● short vectors

● **Examples**

```chapel
var coord: (int, int, int) = (1, 2, 3);
var coordCopy: 3*int = coord;
var (i1, i2, i3) = coord;
var triple: (int, string, real) = (7, "eight", 9.0);
```
5-body in Chapel: Declarations

```chapel
config const numsteps = 10000;

const pi = 3.141592653589793,
    solarMass = 4 * pi**2,
    daysPerYear = 365.24;

record body {
    var pos: 3*real;
    var v: 3*real;
    var mass: real;
}
...
```
5-body in Chapel: the Bodies

```chapel
var bodies =
    [/* sun */
     new body(mass = solarMass),

    /* jupiter */
     new body(pos = ( 4.84143144246472090e+00, 
                    -1.16032004402742839e+00, 
                    -1.03622044471123109e-01),
     v = ( 1.66007664274403694e-03 * daysPerYear, 
          7.69901118419740425e-03 * daysPerYear, 
          -6.90460016972063023e-05 * daysPerYear),
     mass = 9.54791938424326609e-04 * solarMass),

    /* saturn */
     new body(...),

    /* uranus */
     new body(...),

    /* neptune */
     new body(...)
    ]
```
Array Types

- **Syntax**

  \[ \text{array-type:} \ [ \text{domain-expr} \ ] \ \text{elt-type} \]

  \[ \text{array-value:} \ [\text{elt1}, \text{elt2}, \text{elt3}, \ldots \text{elt}n] \]

- **Meaning:**
  - array-type: stores an element of *elt-type* for each index
  - array-value: represent the array with these values

- **Examples**

  ```
  \textbf{var} \ A: [1..3] \ \textbf{int} = [5, 3, 9], // 3-element array of ints
  B: [1..3, 1..5] \ \textbf{real}, // 2D array of reals
  C: [1..3][1..5] \ \textbf{real}; // array of arrays of reals
  ```

Much more on arrays in data parallelism section later…
5-body in Chapel: the Bodies

```chapel
var bodies =
    [/* sun */
     new body(mass = solarMass),

    /* jupiter */
     new body(pos = ( 4.8414314424647209e+00,
                    -1.16032004402742839e+00,
                    -1.03622044471123109e-01),
                  v = ( 1.66007664274403694e-03 * daysPerYear,
                        7.69901118419740425e-03 * daysPerYear,
                        -6.90460016972063023e-05 * daysPerYear),
                  mass =  9.54791938424326609e-04 * solarMass),

    /* saturn */
     new body(...),

    /* uranus */
     new body(...),

    /* neptune */
     new body(...) ]
```
... 

```chapel
proc main() {
    initSun();

    writef("%.9r\n", energy());
    for 1..numsteps do
        advance(0.01);
    writef("%.9r\n", energy());
}
```

...
Ranges, by example

```chapel
const r = 1..10;
printVals(r);
printVals(r # 3);
printVals(r by 2);
printVals(r by -2);
printVals(r by 2 # 3);
printVals(r # 3 by 2);
printVals(0.. #n);

proc printVals(r) {
    for i in r do
        write(r, " ");
        writeln();
}
```
Range Values

● **Syntax**

```
range-expr:
  [low] .. [high]
```

● **Semantics**

- Regular sequence of integers
  - `low <= high`: `low, low+1, low+2, …, high`
  - `low > high`: degenerate (an empty range)
  - `low` or `high` unspecified: unbounded in that direction

● **Examples**

```
1..6   // 1, 2, 3, 4, 5, 6
6..1   // empty
3..    // 3, 4, 5, 6, 7, …
```
For Loops

● Syntax:

```plaintext
for-loop:
    for [index-expr in] iterable-expr { stmt-list }
```

● Meaning:
  ● Executes loop body serially, once per loop iteration
  ● Declares new variables for identifiers in `index-expr`
    ● type and const-ness determined by `iteratable-expr`
    ● `iteratable-expr` could be a range, array, or iterator

● Examples

```plaintext
var A: [1..3] string = [“DO”, “RE”, “MI”];

for i in 1..3 { write(A[i]); }  // DO RE MI
for a in A { a += “LA”; } write(A);  // DOLA RELA MILA
```
... 

```chapel
class proc main() {
    initSun();

    writef("%.9r\n", energy());
    for 1..numsteps do
        advance(0.01);
        writef("%.9r\n", energy());
}
```

...
advance(0.01);
...

proc advance(dt) {
  for i in 1..numbodies {
    for j in i+1..numbodies {
      const dpos = bodies[i].pos - bodies[j].pos,
      mag = dt / sqrt(sumOfSquares(dpos))**3;
      bodies[i].v -= dpos * bodies[j].mass * mag;
      bodies[j].v += dpos * bodies[i].mass * mag;
    }
  }
}

for b in bodies do
  b.pos += dt * b.v;
}
Procedures, by example

● Example to compute the area of a circle

```plaintext
proc area(radius: real): real {
    return 3.14 * radius**2;
}
writeln(area(2.0)); // 12.56
```

● Example of argument default values, naming

```plaintext
proc writeCoord(x: real = 0.0, y: real = 0.0) {
    writeln((x,y));
}
writeCoord(2.0); // (2.0, 0.0)
writeCoord(y=2.0); // (0.0, 2.0)
writeCoord(y=2.0, 3.0); // (3.0, 2.0)
```
advance(0.01);
...

proc advance(dt) {
  for i in 1..numbodies {
    for j in i+1..numbodies {
      const dpos = bodies[i].pos - bodies[j].pos,
      mag = dt / sqrt(sumOfSquares(dpos))**3;

      bodies[i].v -= dpos * bodies[j].mass * mag;
      bodies[j].v += dpos * bodies[i].mass * mag;
    }
  }
}

for b in bodies do
  b.pos += dt * b.v;
iter triangle(n) {
   for i in 1..n do
      for j in i+1..n do
         yield (i,j);
}

proc advance(dt) {
   for (i,j) in triangle(numbodies) {
      const dpos = bodies[i].pos - bodies[j].pos,
         mag = dt / sqrt(sumOfSquares(dpos))**3;
         ...
   }
   ...
}
Iterators

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

for f in fibonacci(7) do writeln(f);
0
1
1
2
3
5
8
```

```plaintext
iter tiledRMO(D, tilesize) {
  const tile = {0..#tilesize, 0..#tilesize};
  for base in D by tilesize do
    for ij in D[tile + base] do yield ij;
}

for ij in tiledRMO({1..m, 1..n}, 2) do
  write(ij);
(1,1) (1,2) (2,1) (2,2)
(1,3) (1,4) (2,3) (2,4)
(1,5) (1,6) (2,5) (2,6)
...
(3,1) (3,2) (4,1) (4,2)
```
for (i,f) in zip(0..#n, fibonacci(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
...

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5-body in Chapel: Using Iterators

```chapel
iter triangle(n) {
    for i in 1..n do
        for j in i+1..n do
            yield (i,j);
}

proc advance(dt) {
    for (i,j) in triangle(numbodies) {
        const dpos = bodies[i].pos - bodies[j].pos,
            mag = dt / sqrt(sumOfSquares(dpos))**3;

        ...
    }

    ...
}
```

Other Base Language Features

- rank-independent programming features
- interoperability features
- compile-time features for meta-programming
  - e.g., compile-time functions to compute types, parameters
- other OOP features
- argument intents, default values, match-by-name
- overloading, where clauses
- modules (for namespace management)
- …
Questions about the Base Language?
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