Chapel Base Language, By Example

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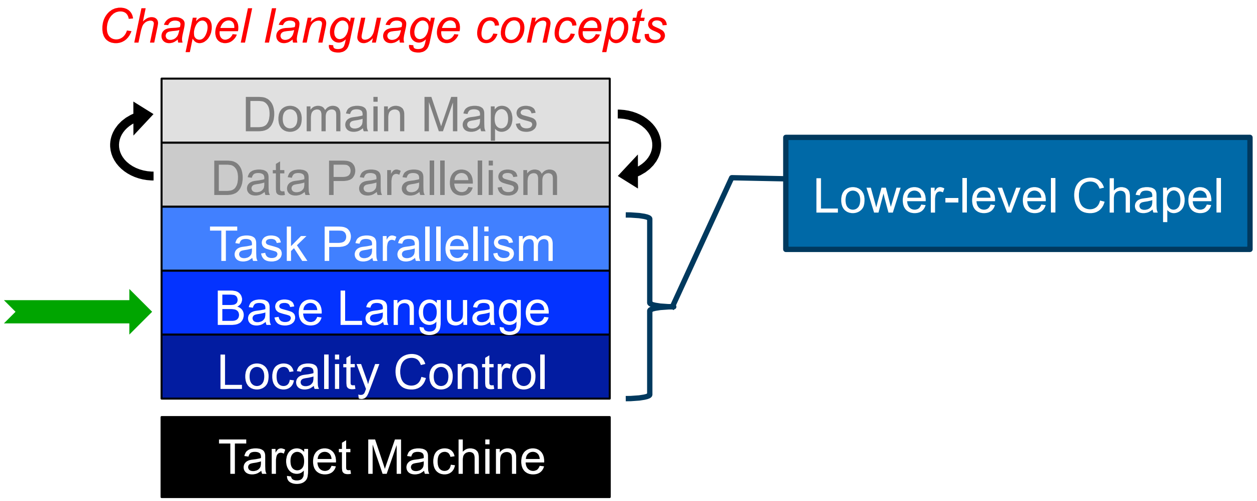
Lower-Level Features



Chapel language concepts

Domain Maps

Data Parallelism

Task Parallelism

Base Language

Locality Control

Target Machine

Lower-level Chapel

"Hello World" in Chapel: Two Versions

- Fast prototyping

```
writeln(“Hello, world!”);
```

- “Production-grade”

```
module Hello {


  proc main() {
    writeln(“Hello, world!”);
  }
}
```

"Hello World" in Chapel: Two Versions

- Fast prototyping

```
writeln(“Hello, world!”);
```

- “Production-grade” (configurable)

```
module Hello {
  config const audience = “world”;

  proc main() {
    writeln(“Hello, ”, audience, “!”);
  }
}
```

Static Type Inference

```
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
```

Configs

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

Configs

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

```
% chpl myProgram.chpl -sintSize=64 -selementType=real
% a.out --start=2 --epsilon=0.00001
```

"Hello World" in Chapel: Two Versions

- Fast prototyping

```
writeln(“Hello, world!”);
```

- “Production-grade” (configurable)

```
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

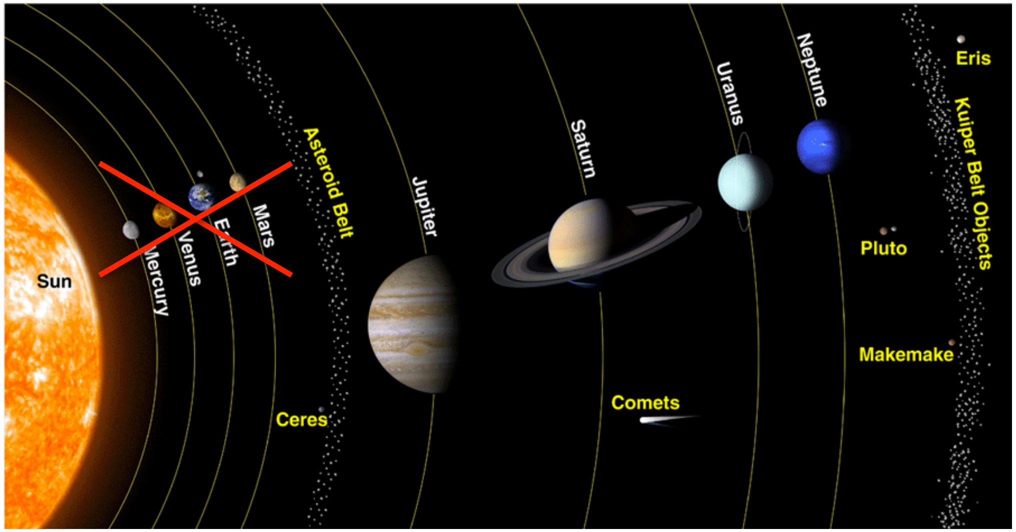


Image source: http://spaceplace.nasa.gov/review/ice-dwarf/solar-system-lrg.png

5-body in Chapel: Declarations

```
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**

```
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

```
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

```
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

```
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

```
array-type:
  [ domain-expr ] elt-type
array-value:
  [elt1, elt2, elt3, … eltn]
```

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

- ## Examples

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

Much more on arrays in data parallelism section later…

5-body in Chapel: the Bodies

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

       /* jupiter */
       new body(pos = ( 4.84143144246472090e+00,
                       -1.16032004402742839e+00,
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               mass =   9.54791938424326609e-04 * solarMass),

       /* saturn */
       new body(…),

       /* uranus */
       new body(…),

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

5-body in Chapel: main()

```
…

proc main() {
  initSun();

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

…
```

Ranges, by example

```
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();
}
```

```
1 2 3 4 5 6 7 8 9 10
1 2 3
1 3 5 7 9
10 8 6 4 2
1 3 5
1 3
0 1 2 3 4 … n-1
```

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:**

```
for-loop:
  for [index-expr in] iteratable-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**

```
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
```

5-body in Chapel: main()

```
…

proc main() {
  initSun();

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

…
```

5-body in Chapel: advance()

```
 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

```
proc area(radius: real): real {
  return 3.14 * radius**2;
}

writeln(area(2.0));   // 12.56
```

```
proc area(radius) {
  return 3.14 * radius**2;
}
```

Argument and return types can be omitted

- Example of argument default values, naming

```
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)
```

5-body in Chapel: advance()

```
 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;
}
```

5-body in Chapel: Using Iterators

```
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

```
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
```

```
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)
```

Zippered Iteration

```
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
…
```

5-body in Chapel: Using Iterators

```
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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