Base Language
Safe Harbor Statement

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naïve n-body computation in Chapel
n-body in Chapel (where n == 5)

- A serial computation
- From the Computer Language Benchmarks Game
  - Chapel implementation in release under examples/benchmarks/shootout/nbody.chpl
- 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

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

config const numsteps = 10000;

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

...
5-body in Chapel: Declarations

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

config const numsteps = 10000;

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

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

config const numsteps = 10000;

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

...
5-body in Chapel: Declarations

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

config const numsteps = 10000;

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

...
params intSize = 32;
type elementType = real(32);
const epsilon = 0.01:elementType;
var start = 1:int(intSize);
```
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
```
5-body in Chapel: Declarations

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

config const numsteps = 10000;

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

Record declaration
Records and Classes

- Chapel’s 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 circle(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 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
class circle {
    var radius: real;
    proc area() {
        return pi*radius**2;
    }
}

var c1, c2: circle;
c1 = new circle(radius=1.0);
c2 = c1; // aliases c1’s circle
c1.radius = 5.0;
writeln(c2.radius); // 5.0
delete c1; // users delete classes
```
Classes vs. Records

**Classes**
- heap-allocated
  - Pointers to fields
  - Require ‘delete’
- 'ref' semantics
  - crucial when object identity matters
- support dynamic dispatch
- support inheritance
- similar to Java classes

**Records**
- allocated in-place
  - Fields in contiguous memory
  - Memory managed
- 'value' semantics
  - compiler may introduce copies
- no dynamic dispatch
- no inheritance
- similar to C++ structs (sans pointers)
const pi = 3.141592653589793,
solarMass = 4 * pi**2,
daysPerYear = 365.24;

config const numsteps = 10000;

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

...
Tuples

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

● **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

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

config const numsteps = 10000;

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(...)
    ]
```
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),
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                            7.69901118419740425e-03 * daysPerYear,
                            -6.90460016972063023e-05 * daysPerYear),
                       mass = 9.54791938426609e-04 * solarMass),
    
      /* saturn */
      new body(...),
    
      /* uranus */
      new body(...),
    
      /* neptune */
      new body(...)
    ]
```

Create a record object
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(...)
]
```

Tuple values
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**

```
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,    // A stores 0, 0, 0
     B = [5, 3, 9],   // B stores 5, 3, 9
     C: [1..m, 1..n] real,  // 2D m by n array of reals
     D: [1..m][1..n] real; // array of arrays of reals
```

*Much more on arrays in data parallelism section later...*
var bodies =
    [ /* sun */
        new body(mass = solarMass),
    /* jupiter */
        new body(pos = ( 4.84143144246472090e+00,
            -1.16032004402742839e+00,
            -1.0362204471123109e-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(...) ]
5-body in Chapel: main()

... 

proc main() {
  initSun();

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

...
5-body in Chapel: main()

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

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

...
5-body in Chapel: main()

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

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

Procedure Call
5-body in Chapel: main()

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

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

Formatted I/O
*not covered here*
5-body in Chapel: main()

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

    writeln("%9.9r\n", energy());
    for 1..numsteps do
        advance(0.01);
        writeln("%9.9r\n", energy());
}
```

Range Value
Range Values

● **Syntax**

\[
\text{range-expr: } [\text{low}] \ldots [\text{high}]
\]

● **Semantics**

- Regular sequence of integers
  - \(\text{low} \leq \text{high}: \text{low}, \text{low}+1, \text{low}+2, \ldots, \text{high}\)
  - \(\text{low} > \text{high}:\) degenerate (an empty range)
  - \(\text{low} \text{ or } \text{high} \) unspecified: unbounded in that direction

● **Examples**

1..6  // 1, 2, 3, 4, 5, 6
6..1  // empty
3..   // 3, 4, 5, 6, 7, ...
Range Operators

```plaintext
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(i, " ");
        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
5-body in Chapel: main()

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

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

Serial for loop
For Loops

- **Syntax:**

```latex
define syntax:
\begin{verbatim}
\text{for-loop:}
\text{for [index-expr in] iterable-expr} \{ \text{stmt-list} \}
\end{verbatim}
```

- **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**

```javascript
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()

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

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

- **Procedure Definition**
- **Procedure Call**
- **Range Value**
- **Formatted I/O**
  *not covered here*
- **Serial for loop**
```chapel
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;
}"
```
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: 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

```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)
```
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;
        ...
    } 
    ...
} 
...
Additional Base Language Notes / Material
proc advance(dt) {
    for (i,j) in triangle(numbodies) {
        ref bi = bodies[i],
            bj = bodies[j];

        const dpos = bi.pos - bj.pos,
            mag = dt / sqrt(sumOfSquares(dpos))**3;

        bi.v -= dpos * bj.mass * mag;
        bj.v += dpos * bi.mass * mag;
    }

    for b in bodies do
        b.pos += dt * b.v;
}
Reference Declarations

● Syntax:

\[
\text{ref-decl:} \\
\text{ref \ ident = expr;}
\]

● Meaning:

● Causes ‘ident’ to refer to variable specified by ‘expr’
● Subsequent reads/writes of ‘ident’ refer to that variable
● Not a pointer: no way to reference something else with ‘ident’
● Similar to a C++ reference

● Examples

\begin{verbatim}
var A: [1..3] string = [" DO", " RE", " MI"]; 
ref a2 = A[2]; 
a2 = " YO"; 
for i in 1..3 { write(A[i]); } // DO YO MI
\end{verbatim}
## Primitive Types

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
<th>Default Value</th>
<th>Currently-Supported Bit Widths</th>
<th>Default Bit Width</th>
</tr>
</thead>
<tbody>
<tr>
<td>bool</td>
<td>logical value</td>
<td>false</td>
<td>8, 16, 32, 64</td>
<td>impl. dep.</td>
</tr>
<tr>
<td>int</td>
<td>signed integer</td>
<td>0</td>
<td>8, 16, 32, 64</td>
<td>64</td>
</tr>
<tr>
<td>uint</td>
<td>unsigned integer</td>
<td>0</td>
<td>8, 16, 32, 64</td>
<td>64</td>
</tr>
<tr>
<td>real</td>
<td>real floating point</td>
<td>0.0</td>
<td>32, 64</td>
<td>64</td>
</tr>
<tr>
<td>imag</td>
<td>imaginary floating point</td>
<td>0.0i</td>
<td>32, 64</td>
<td>64</td>
</tr>
<tr>
<td>complex</td>
<td>complex floating points</td>
<td>0.0 + 0.0i</td>
<td>64, 128</td>
<td>128</td>
</tr>
<tr>
<td>string</td>
<td>character string</td>
<td>&quot;&quot;</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>

### Syntax

```
primitive-type: type-name [( bit-width )]
```

### Examples

```
int(16) // 16-bit int
real(32) // 32-bit real
uint // 64-bit uint
```
Enum Types

- A lot like enum types in C:
  ```c
  enum color {red, green, blue};  // can also be assigned values
  ```
- But can also be printed!
  ```c
  var myColor = color.red;
  writeln(myColor);               // prints ‘red’
  ```
- And support built-in iterators and queries:
  ```c
  for c in color do ...
  ...
color.size...
  ```

- By default, must be fully-qualified to avoid conflicts:
  ```c
  var myColor = red;              // error by default
  ```
- But, may be ‘use’d like modules to avoid qualifying
  ```c
  use color;                      // can use standard filters, renaming, etc.
  var myColor = red;              // OK!
  ```
Type Aliases and Casts

● Basic Syntax

```
type-alias-declaration:
  type identifier = type-expr;
```
```
cast-expr:
  expr : type-expr
```

● Semantics

- type aliases are simply symbolic names for types
- casts are supported between any primitive types

● Examples

```
type elementType = complex(64);
```
```
5:int(8)  // store value as int(8) rather than int
"54":int  // convert string to an int
249:elementType  // convert int to complex(64)
# Basic Operators and Precedence

<table>
<thead>
<tr>
<th>Operator</th>
<th>Description</th>
<th>Associativity</th>
<th>Overloadable</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>:</code></td>
<td>cast</td>
<td>left</td>
<td>no</td>
</tr>
<tr>
<td><code>**</code></td>
<td>exponentiation</td>
<td>right</td>
<td>yes</td>
</tr>
<tr>
<td><code>! ~</code></td>
<td>logical and bitwise negation</td>
<td>right</td>
<td>yes</td>
</tr>
<tr>
<td><code>* / %</code></td>
<td>multiplication, division and modulus</td>
<td>left</td>
<td>yes</td>
</tr>
<tr>
<td><code>unary + -</code></td>
<td>positive identity and negation</td>
<td>right</td>
<td>yes</td>
</tr>
<tr>
<td><code>+ -</code></td>
<td>addition and subtraction</td>
<td>left</td>
<td>yes</td>
</tr>
<tr>
<td><code>&lt;&lt; &gt;&gt;</code></td>
<td>shift left and shift right</td>
<td>left</td>
<td>yes</td>
</tr>
<tr>
<td><code>&lt;= &gt;= &lt; &gt;</code></td>
<td>ordered comparison</td>
<td>left</td>
<td>yes</td>
</tr>
<tr>
<td><code>== !=</code></td>
<td>equality comparison</td>
<td>left</td>
<td>yes</td>
</tr>
<tr>
<td><code>&amp;</code></td>
<td>bitwise/logical and</td>
<td>left</td>
<td>yes</td>
</tr>
<tr>
<td><code>^</code></td>
<td>bitwise/logical xor</td>
<td>left</td>
<td>yes</td>
</tr>
<tr>
<td>`</td>
<td>`</td>
<td>bitwise/logical or</td>
<td>left</td>
</tr>
<tr>
<td><code>&amp;&amp;</code></td>
<td>short-circuiting logical and</td>
<td>left</td>
<td>via isTrue</td>
</tr>
<tr>
<td>`</td>
<td></td>
<td>`</td>
<td>short-circuiting logical or</td>
</tr>
</tbody>
</table>
Control Flow: Braces vs. Keywords

Control flow statements specify bodies using curly brackets (compound statements)

- **Conditional statements**
  
  ```
  if cond { computeA(); } else { computeB(); }
  ```

- **While loops**
  ```
  while cond { 
    compute();
  }
  ```

- **Select statements**
  ```
  select key {
    when value1 { compute1(); } 
    when value2 { compute2(); } 
    otherwise { compute3(); }
  }
  ```

- **For loops**
  ```
  for indices in iterable-expr {
    compute();
  }
  ```

Control Flow: Braces vs. Keywords

They also support keyword-based forms for single-statement cases

- Conditional statements

  ```
  if cond then computeA(); else computeB();
  ```

- While loops

  ```
  while cond do compute();
  ```

- For loops

  ```
  for indices in iterable-expr do compute();
  ```

- Select statements

  ```
  select key {
    when value1 do compute1();
    when value2 do compute2();
    otherwise do compute3();
  }
  ```
Control Flow: Braces vs. Keywords

Of course, since compound statements are single statements, the two forms can be mixed...

- **Conditional statements**
  ```plaintext
  if cond then { computeA(); } else { computeB(); }
  ```

- **While loops**
  ```plaintext
  while cond do
      compute();
  ```

- **Select statements**
  ```plaintext
  select key {
      when value1 do { compute1(); }
      when value2 do { compute2(); }
      otherwise do { compute3(); }
  }
  ```

- **For loops**
  ```plaintext
  for indices in iterable-expr do
      compute();
  ```
Procedures and iterator features

- pass by keyword (argument name)
  
  ```
  proc foo(name, age) { ... }
  foo(age=32, name="Tim");
  ```

- default argument values
  
  ```
  proc foo(name, age=18) { ... }
  foo(name="Tim");
  ```

- formal type queries
  
  ```
  proc foo(x: ?t, y: [?D] t) { ... }
  proc bar(x: int(?w)) { ... }
  ```

- overloading
  - including where clauses to filter overloads
    ```
    proc foo(x: int(?w), y: int(?w2)) where w = 2*w2 { ... }
    proc foo(x: int(?w), y: int(?w2)) { ... }
    proc foo(x, y) { ... }
    ```
Methods

- **Methods are like procedures with an implicit**
  - Chapel supports both *primary methods*:
    ```
    class circle {
      proc area() { return pi*radius**2; }
    }
    ```
  - and *secondary methods*:
    ```
    proc circle.circumference() {
      return 2*pi*radius;
    }
    ```
    ```
    var myCircle = new circle(radius=1.0);
    writeln((myCircle.area(), myCircle.circumference()));
    ```
  - Moreover, secondary methods can be defined for any type:
    ```
    proc int.square() {
      return this**2;
    }
    ```
    ```
    writeln(5.square()); // prints 25
    ```
Paren-less procedures

Procedures without arguments don’t need parenthesis

```
proc circle.diameter {
    return 2*radius;
}
 writeln(cl.radius, " ", cl.diameter);
```

Support time/space tradeoffs without code changes

- Store value with variable/field?
- Or compute on-the-fly with paren-less procedure/method?
  - Like fields, such methods don’t dispatch dynamically
Function Calls vs. Array Accesses

- Chapel doesn’t distinguish between call and array access
  - An “array access” is simply a call to a special method named “this()”
    ```chapel
    class circle {
      proc this(x: int, y: real) {
        // do whatever we want here…
      }
    }
    myCircle[2, 4.2]; // calls circle.this()
    ```
  - Related: parens/square brackets can be used for either case:
    ```chapel
    A[i,j] or A(i,j)  // these are both accesses to array A
    foo() or foo[]   // these are both function calls to foo()
    ```
- By convention, we tend to use [] for arrays and () for function calls
  - but Fortran programmers may be happy to get to use () for arrays…?
- Like paren-less methods, view this as another time-space tradeoff
  - can implement something as a function or as an array
  - since Chapel’s arrays are quite rich, access is not necessarily O(1) anyway
Default object iterators

- Objects can support default iterators

```java
class circle {
  iter these() {
    // yield whatever we want…
  }
}

for items in myCircle do ... // invokes circle.these()
```

- Similar to the ‘this()’ default accessor
- Overloads can support parallel or parallel zippered iteration
  - (true for any iterator)
Generic procedures can be defined using type and param arguments:

```plaintext
proc foo(type t, x: t) { ... }
proc bar(param bitWidth, x: int(bitWidth)) { ... }
```

Or by simply omitting an argument type (or type part):

```plaintext
proc goo(x, y) { ... }
proc sort(A: []) { ... }
```

Generic procedures are instantiated for each unique argument signature:

```plaintext
foo(int, 3);  // creates foo(x:int)
foo(string, "hi");  // creates foo(x:string)
goo(4, 2.2);  // creates goo(x:int, y:real)
```
Generic Objects

Generic objects can be defined using type and param fields:

```plaintext
record Table { param size: int; var data: size*int; }
record Matrix { type eltType; ... }
```

Or by simply eliding a field type (or type part):

```plaintext
class Triple { var x, y, z; }
```

Generic objects are instantiated for each unique type signature:

```plaintext
// instantiates Table, storing data as a 10-tuple
var myT: Table(10);
// instantiates Triple as x:int, y:int, z:real
var my3: Triple(int, int, real) = new Triple(1, 2, 3.0);
```
Modules

• Syntax

```chapel
module-def:
    module identifier { code }

module-use:
    use module-identifier;
```

• Semantics

• all Chapel code is stored in modules
• use-ing a module makes its symbols visible in that scope
• module-level statements are executed at program startup
  • typically used to initialize the module
• for convenience, a file containing code outside of a module declaration creates a module with the file’s name
Use Statement: Import Control

- **Use statements support import control**
  - ‘except’ keyword prevents unqualified access to symbols in list
    ```
    use M except bar;  // All of M’s symbols other than bar can be named directly
    ```
  - ‘only’ keyword limits unqualified access to symbols in list
    ```
    use M only foo;  // Only M’s foo can be named directly
    ```
  - Permits user to avoid importing unnecessary symbols
    - Including symbols which cause conflicts

```python
module myMod {
    var bar = true;
    
    proc myFunc() {
        use M only foo;
        foo();
        var a = bar;  // Now finds myMod.bar, rather than M.bar
    }
}

module M {
    var bar = 13;
    proc foo() { ... }
}
```
Use Statement: Symbol Renaming

- Use’d symbols can also be renamed:
  
  ```
  use M only bar as barM;
  ```

- Allows users to avoid...
  
  ...naming conflicts between multiple used modules
  
  ...shadowing outer variables with same name
  
  ...while still making that symbol available for access

```csharp
module myMod {
  var bar = true;

  proc myFunc() {
    use M only foo, bar as barM;
    foo();
    var a = bar; // Still finds myMod.bar, rather than M.bar
    var b = barM; // refers to M.bar
  }
}
```

```csharp
module M {
  var bar = 13;
  proc foo() { ... }
}
```
Modules: Public/Private Declarations

● All module-level symbols are public by default
  ```
  proc foo() { ... }  // public, since not decorated
  ```

● module-level symbols can be declared public/private:
  ```
  private var bar = ...;
  public proc baz() { ... }
  ```

● Can be used in declarations of:
  ● Modules
  ● Vars, consts, and params
    ● including configs
  ● Procedures and iterators

● Future work: extend to other symbols
  ● particularly types / object members
Program Entry Point: main()

- **Semantics**
  - Chapel programs start by:
    - initializing all modules
    - executing main(), if it exists

```chapel
M1.chpl:
use M2;
writeln("Initializing M1");
proc main() { writeln("Running M1"); }
```

```chapel
M2.chpl:
module M2 {
    writeln("Initializing M2");
}
```

```
% chpl M1.chpl M2.chpl
% ./a.out
Initializing M2
Initializing M1
Running M1
```
Argument and Return Intents

● **Arguments can optionally be given intents**
  ● (blank): varies with type; follows principle of least surprise
    ● most types: `const`
    ● arrays, sync/single vars, atomics: passed by reference
  ● `in`: copies actual into formal; permits changes
  ● `out`: copies formal into actual at procedure return
  ● `inout`: does both of the above
  ● `ref`: pass by reference
  ● `const [ref | in]`: disallows modification of the formal
  ● `param/type`: formal must be a param/type (evaluated at compile-time)

● **Return types can also have intents**
  ● (blank)/`const`: cannot be modified (without assigning to a variable)
  ● `ref`: permits modification back at the callsite
  ● `type`: returns a type (evaluated at compile-time)
  ● `param`: returns a param value (evaluated at compile-time)
Other Base Language Features not covered here

- Interoperability with external code
- **Compile-time features for meta-programming**
  - type/param procedures
  - folded conditionals
  - unrolled for loops
  - user-defined compile-time warnings and errors
- **Type select statements, argument type queries**
- Unions
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