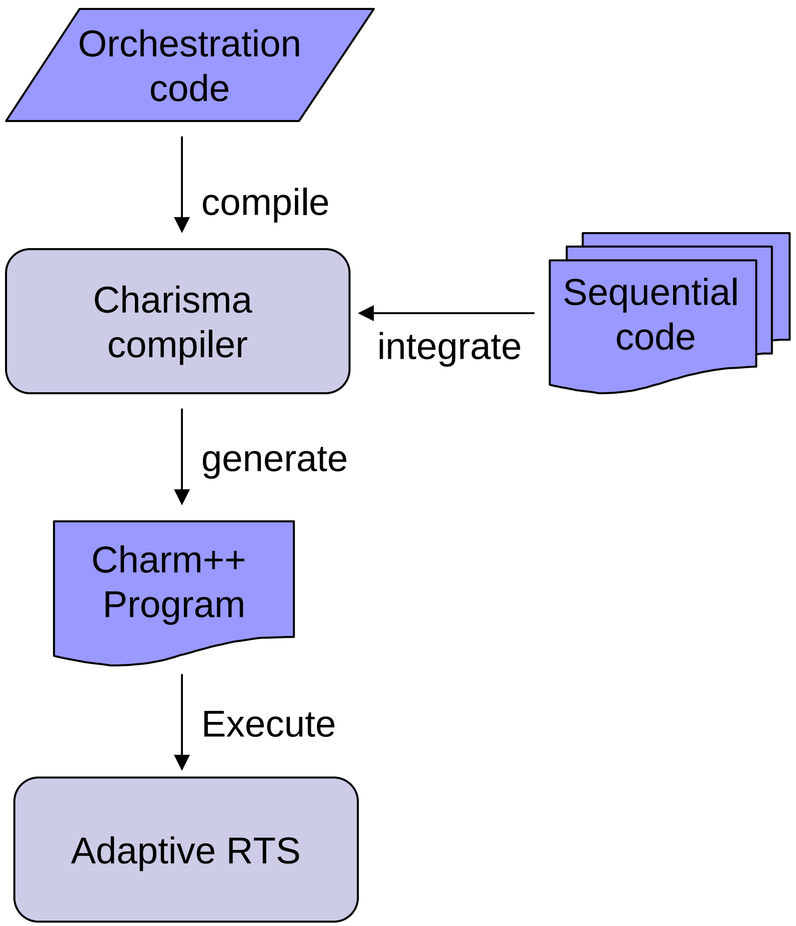
Language Overview

- Orchestration code
  - Describes global control flow
  - Macro dataflow approach
- Separate sequential code
  - Defines local components and methods
  - Standard C/C++ code
- Translated into Charm++ code
  - Taking advantage of ARTS benefits
    - Adaptive overlap, automatic load balancing, etc.



Object Arrays

- Collection of objects indexed by a general mechanism
- Array declaration and instantiation

```
class Cell : ChareArray2D;
class CellPair : ChareArray4D;

obj cells :  Cell[N,M];
obj cellpairs :  CellPair[N,M,N,M];
```

- Invoking method on an object

```
myMain.foo();
cells[0,0].foo();
```

foreach Statement

- Invokes a method across all elements in an array

```
foreach i in myWorkers
    myWorkers[i].doWork(1,100);
end-foreach
```

```
foreach x,y in cells
    cells[x,y].integrate();
end-foreach
```

- Nested foreach statement is meaningless

Input and Output of A Method

- Input and output of a Charisma method

```
foreach i in workers
    (q[i]) <- workers[i].foo(p[i+1]);
end-foreach
```

  - Method `workers::foo` *produces* the value q, and *consumes* value p
  - Multiple or none *inports* and *outports*

```
(q[i]) <- workers[i].foo(p[i-1],p[i],p[i+1]);
```

  - Produced value must have same index as object's "`i`"

    Consumed value with an index in the form of "`i±c`"

Parameter Space

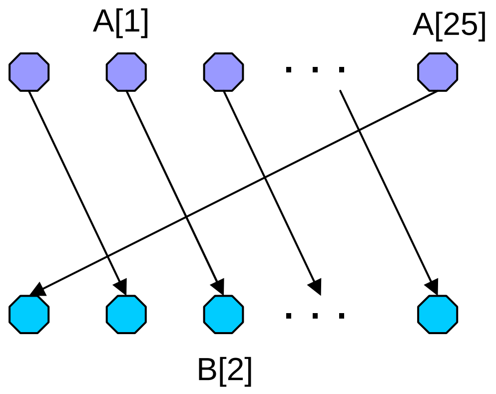
- Variables used in inports/outports constitute the "parameter space"
  - Declared and used in orchestration code
  - Type be intrinsic types, user-defined data type or arrays

```
param error : double;
param atoms : AtomBucket;
param celldata : double [CELLSIZE];
```

Program Order

- Program order is used to determine data dependence
  - An *inport* consumes the value produced by the most closely preceding statement with *outport* on the same variable
  - No implicit barrier between foreach statements
- Control transfer determined by data availability

```
foreach i in A
    (p[i]) <- A[i].foo();
end-foreach
foreach i in B
    B[i].bar(p[i-1]);
end-foreach
```



Loop Statement

- Data dependence in loops (for and while)
  - First inports in loop body connect with
    - Last outports before loop (for first iteration), and
    - Last outports in the loop body (for following iterations)
  - At the last iteration, the last unconsumed outport values will be consumed by code following the loop

```
(q[..]) <- ...
for iter = 1 to MAX_ITER
   foreach i in A
     (p[i]) <- A[i].foo(q[i+1]);
   end-foreach
   foreach i in A
     (q[i]) <- A[i].bar(p[i-1]);
   end-foreach
end-for
...(q[..]);
```

iter = 1

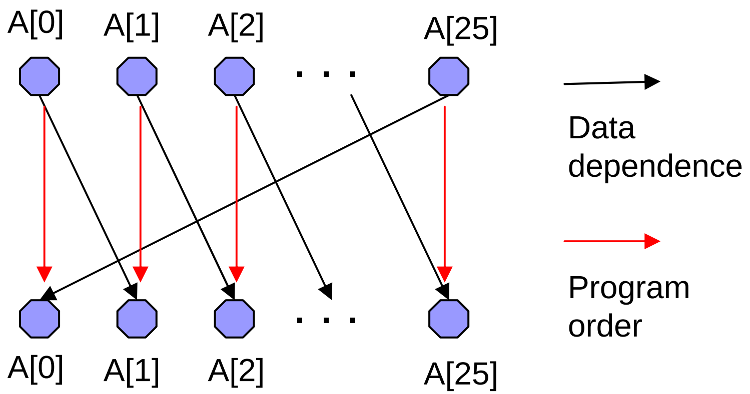
iter = 2, 3, …

iter = MAX_ITER

Program Determinacy

- Deterministic execution
  - For any individual object, Charisma methods are always executed in the program order

- Enforcing determinacy
  - State counter in object for executing methods in program order
  - Iteration epoch control
    - Avoid sending value to next iteration prematurely
    - Impose barrier where necessary



Sequential Methods

- Consumed values passed in as ordinary parameters
- Produced values indicated by keyword “outport”
- Producing with “produce” and “reduce” keywords

```
(q[i]) <- workers[i].foo(p[i+1]);
```

```
WorkerClass::foo(double p, outport q){
  ... = p;
  double local_q = ...;
  produce(q,local_q);
  ...
}
```

Communication Patterns

- Charisma is capable of expressing various communication patterns
  - Point-to-point
  - Reduction
  - Multicast
  - Gather
  - Scatter
  - All-to-all operation

Communication Patterns (1)

- Point-to-point communication

```
foreach i in A
    (p[i]) <- A[i].f(...);
end-foreach
foreach i in B
    (...) <- B[i].g(p[i]);
end-foreach
```

- Sequential code: producing a scalar

```
AClass::f(..., outport p){
    produce(p, local_p);
}
```

- Sequential code: producing an data array

```
AClass::f(..., outport p){
    produce(p, local_p_arr, arr_size);
}
```

Communication Patterns (2)

- Reduction: indicated by a “+” sign before the published value

```
foreach i,j in A
    (+err) <- A[i,j].bar(...);
end-foreach
Main.test(err);
```

- Sequential code: reduction operator

```
AClass::bar(..., outport err){
    reduce(error, local_err, CHARISMA_SUM);
}
```

Charisma++ example (Simple)

Jacobi 1D

```
begin
  forall i in J
    <lb[i],rb[i]> := J[i].init();
  end-forall
  while (e > threshold)
    forall i in J
      <+e, lb[i], rb[i]> :=  J[i].compute(rb[i-1],lb[i+1]);
    end-forall
  end-while
end
```

Mol. Dynamics with Spatial Decomposition

```
 foreach i,j,k in cells
               <atoms[i,j,k]>:= cells[i,j,k].produceAtoms();
 end-foreach
for iter := 0 to MAX_ITER
   foreach i1,j1,k1,i2,j2,k2 in cellpairs
       <+forces[i1,j1,k1]> :=
            cellpairs[i1,j1,k1,i2,j2,k2].computeCoulombForces(
                                                    atoms[i1,j1,k1],atoms[i2,j2,k2]);
   end-foreach

   foreach … for bonded forces.. Uses atoms and add to forces

   foreach i,j,k in cells
            <atoms[i,j,k]> :=  cells[i,j,k].integrate(forces[i,j,k]);
   end-foreach
end-for
```

Communication Patterns (3)

- Multicast: single produced value → multiple consuming objects

```
foreach i in A
    (points[i]) <- A[i].f(...);
end-foreach
foreach i,j in B
    (...) <- B[i,j].g(points[i]);
end-foreach
```

- Sequential code

```
 AClass::f(..., outport points){
   Point local_points;
   local_points = ...;
    produce(points, local_points);
}
```

Communication Patterns (4)

- Scatter: a collection of produced values → chunked up → multiple consuming objects

```
foreach i in A
    (points[i,*]) <- A[i].f(...);
end-foreach
foreach i,j in B
    (...) <- B[i,j].g(points[i,j]);
end-foreach
```

- Sequential code: local value at producing side has an additional dimension

```
AClass::f(..., outport points){
  Point local_points[N];
  local_points = ...;
    produce(points, local_points);
}
```

Communication Patterns (5)

- Gather: multiple producing object → concatenated
  → single consuming objects

```
foreach i,j in A
    (points[i,j]) <- A[i,j].f(...);
end-foreach
foreach j in B
    (...) <- B[j].g(points[*,j]);
end-foreach
```

- Sequential code: consumed parameter has an additional dimension

```
BClass::g(Point *point[N]){
  ...
}
```

Communication Patterns (6)

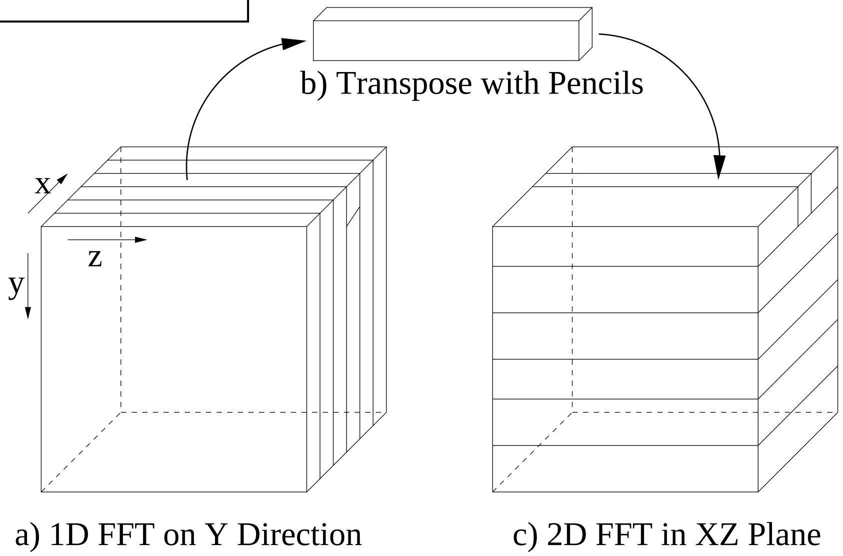
- Permutation operation: scatter + gather

```
foreach i in A
    (points[i,*]) <- A[i].f(...);
end-foreach
foreach j in B
    (...) <- B[j].g(points[*,j]);
end-foreach
```

- All-to-all operation, data transpose operation
  - 3D FFT

Parallel 3D FFT

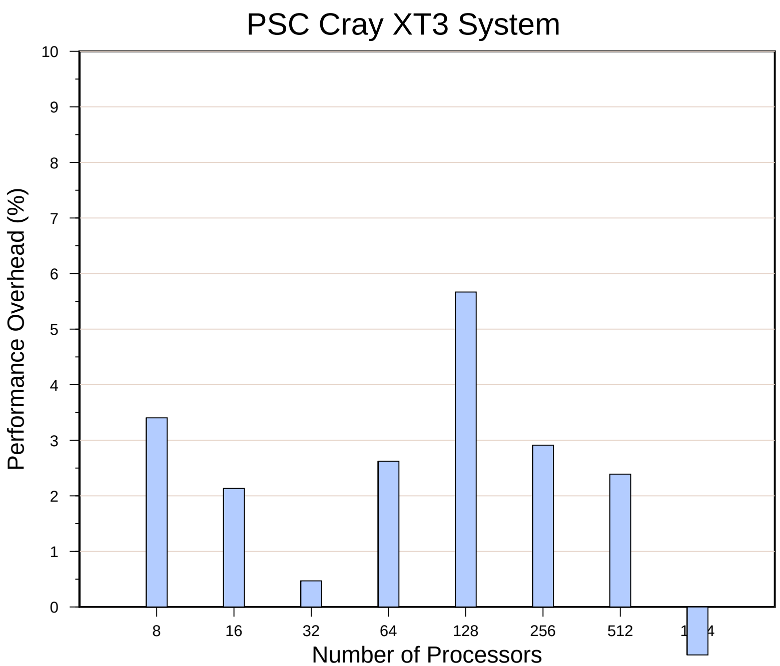
```
foreach x in planes1
 (pencils[x,*]) <- planes1[x].fft1d();
end-foreach
foreach y in planes2
 planes2[y].fft2d(pencils[*,y]);
end-foreach
```



Charisma Evaluation

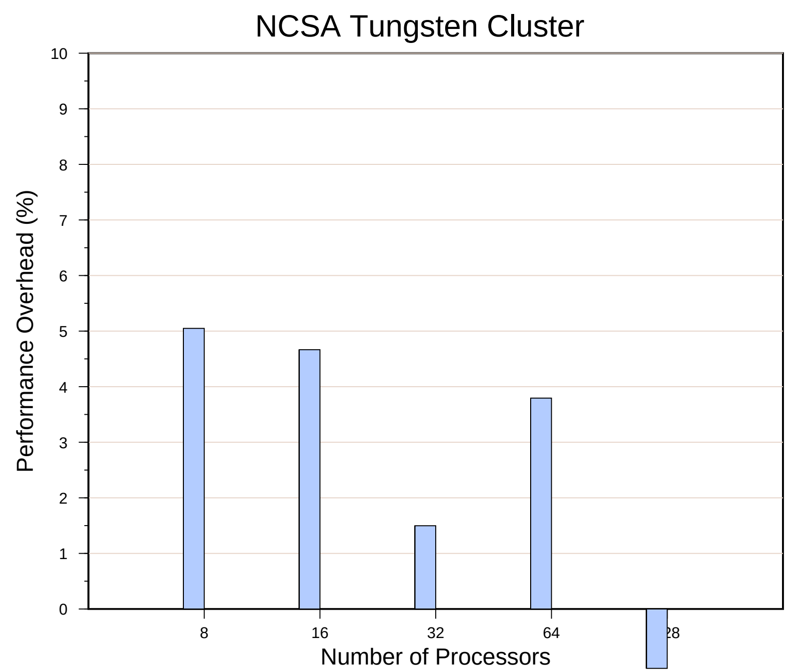
- Performance
  - ARTS benefits
- Productivity
  - SLOC
  - Development time
- Application development experiences
  - LeanCP
  - Topology optimization

Performance and SLOC



2D Jacobi

(Size: 16384^2 on 4096 objects)



3D FFT

(Size: 512^3 on 256 objects)

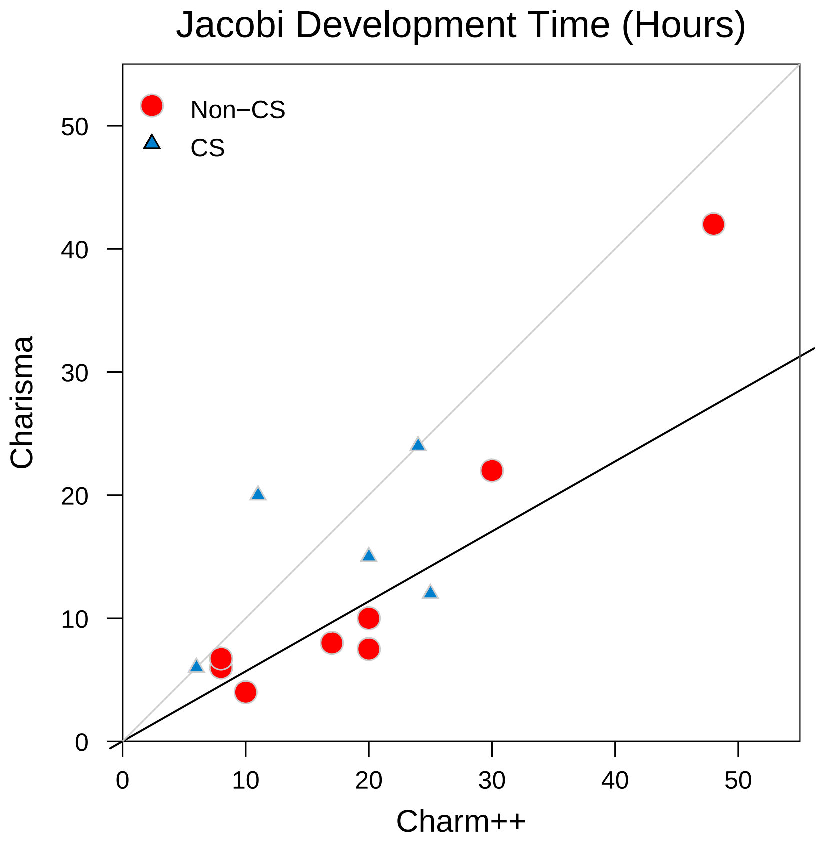
Performance and SLOC (2)

	Charisma	Charm++	Reduction
Baseline	253	354	28%
Load Balancing	273	383	29%
Visualization	307	407	24%
Both	327	436	25%

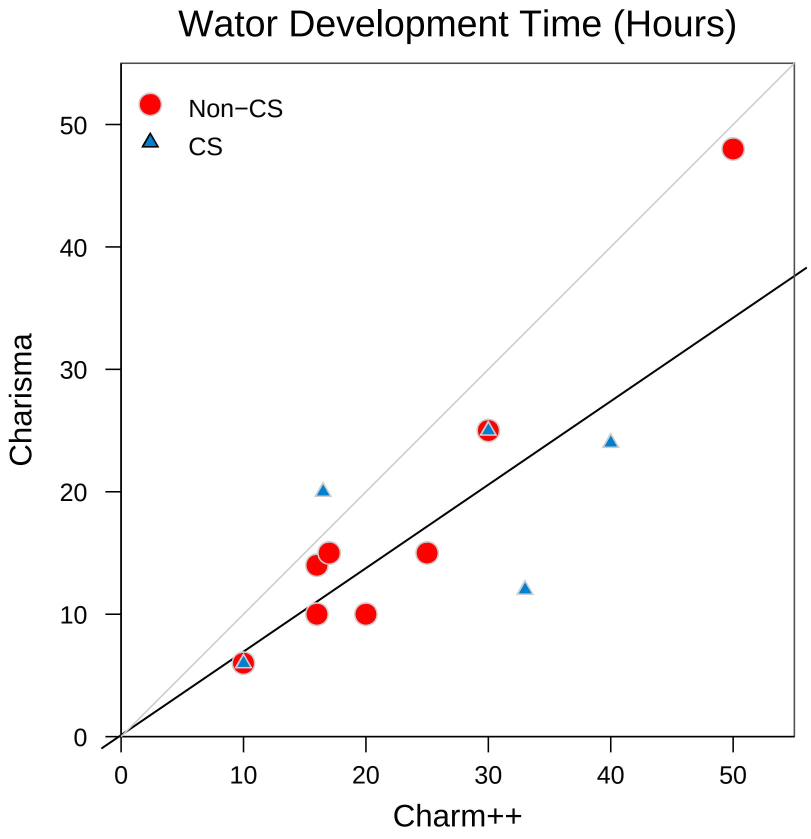
SLOC Comparison of Wator Code

Screen Capture of
Realtime Visualization of Wator

Development Time Reduction



2D Jacobi



Wator