# Chapel: Heat Transfer (+ X10/Fortress)

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CSEP 524
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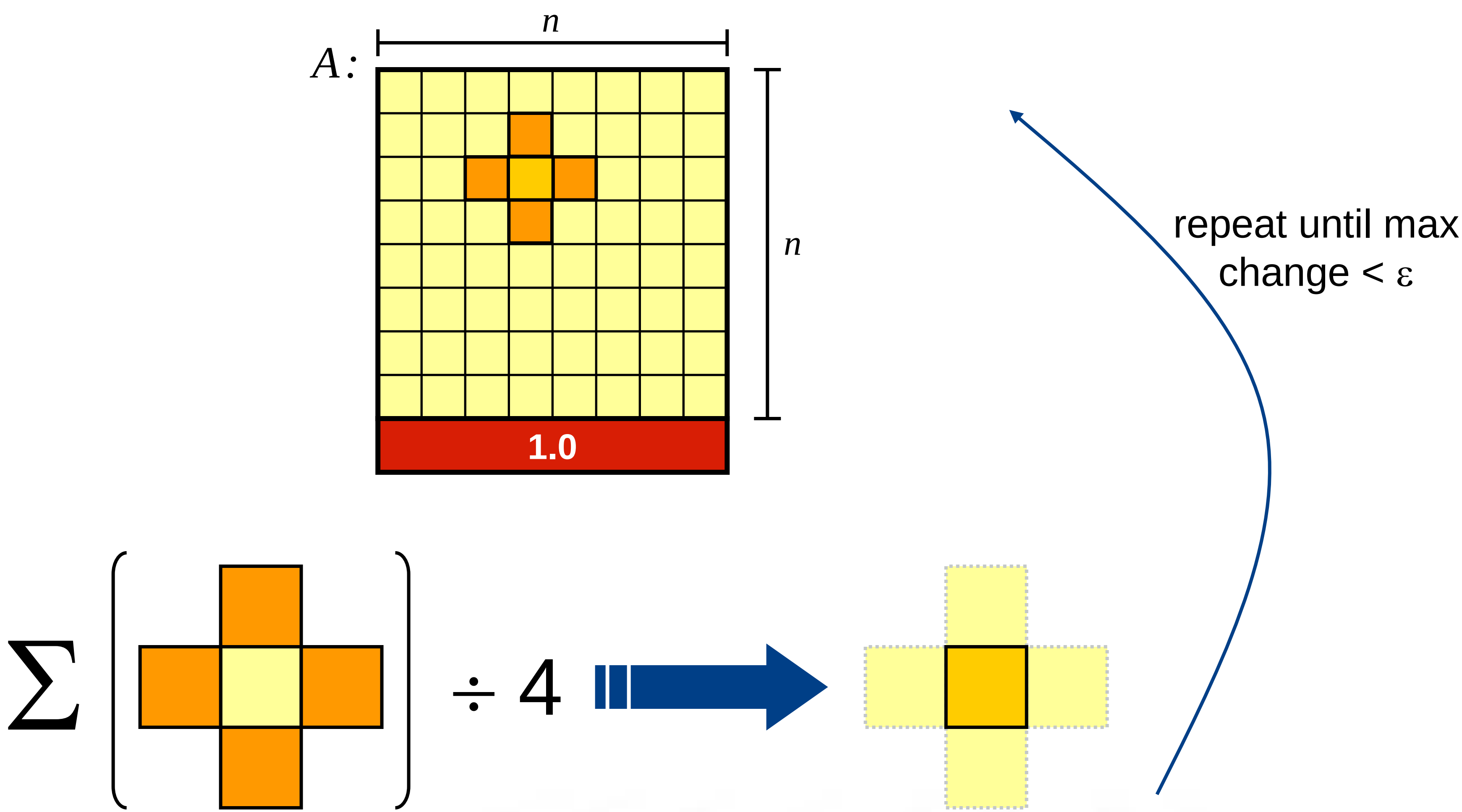
# Heat Transfer in Pictures



# Heat Transfer in Chapel

```
config const n = 6,
             epsilon = 1.0e-5;

const BigD: domain(2) = [0..n+1, 0..n+1],
         D: subdomain(BigD) = [1..n, 1..n],
   LastRow: subdomain(BigD) = D.exterior(1,0);

var A, Temp : [BigD] real;

A[LastRow] = 1.0;

do {
  [(i,j) in D] Temp(i,j) = (A(i-1,j) + A(i+1,j)
                          + A(i,j-1) + A(i,j+1)) / 4;

  const delta = max reduce abs(A[D] - Temp[D]);
  A[D] = Temp[D];
} while (delta > epsilon);

writeln(A);
```

# Heat Transfer in Chapel

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   LastRow: subdomain(BigD) = D.exterior(1,0);

var A, Temp : [BigD] real;

A[Las

do {
  [(i


  con
  A[D
} whi

writeln(A);
```

**Declare program parameters**

**const** ⇒ can't change values after initialization

**config** ⇒ can be set on executable command-line

```
prompt> jacobi --n=10000 --epsilon=0.0001
```

note that no types are given; inferred from initializer

- **n** ⇒ **integer** (current default, 32 bits)
- **epsilon** ⇒ **floating-point** (current default, 64 bits)

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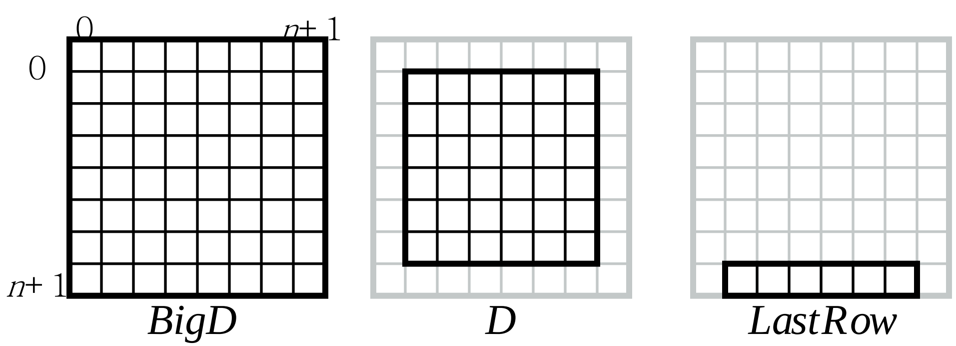
         D: subdomain(BigD) = [1..n, 1..n],
   LastRow: subdomain(BigD) = D.exterior(1,0);
```

**<u>Declare domains (first class index sets)</u>**

**domain(2)** ⇒ 2D arithmetic domain, indices are integer 2-tuples

**subdomain(*P*)** ⇒ a domain of the same type as *P* whose indices are guaranteed to be a subset of *P*'s




**exterior** ⇒ one of several built-in domain generators

# Heat Transfer in Chapel

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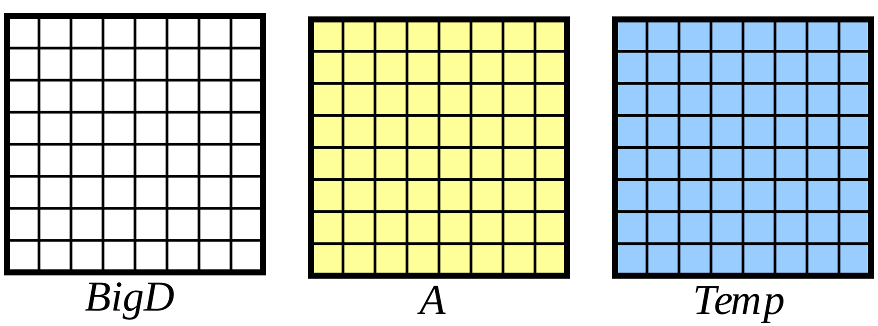
           D: subdomain(BigD) = [1..n, 1..n],
     LastRow: subdomain(BigD) = D.exterior(1,0);

var A, Temp : [BigD] real;
```

**Declare arrays**

**var** ⇒ can be modified throughout its lifetime
**: *T*** ⇒ declares variable to be of type *T*
**: *[D] T*** ⇒ array of size *D* with elements of type *T*
***(no initializer)*** ⇒ values initialized to default value (0.0 for reals)




4;

# Heat Transfer in Chapel

```
config const n = 6,
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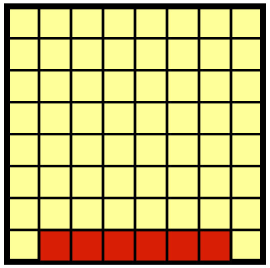
            D: subdomain(BigD) = [1..n, 1..n],
      LastRow: subdomain(BigD) = D.exterior(1,0);

var A, Temp : [BigD] real;

A[LastRow] = 1.0;
```

**Set Explicit Boundary Condition**

indexing by domain ⇒ slicing mechanism
array expressions ⇒ parallel evaluation



*A*

# Heat Transfer in Chapel

**Compute 5-point stencil**

**[(*i,j*) in *D*]** ⇒ parallel forall expression over *D*’s indices, binding them to new variables *i* and *j*

***Note:*** since (*i,j*) ∈ *D* and *D* ⊆ *BigD* and *Temp*: [*BigD*]
⇒ no bounds check required for *Temp(i,j)*
with compiler analysis, same can be proven for A’s accesses


```
    [(i,j) in D] Temp(i,j) = (A(i-1,j) + A(i+1,j)
                            + A(i,j-1) + A(i,j+1)) / 4;

    const delta = max reduce abs(A[D] - Temp[D]);
    A[D] = Temp[D];
  } while (delta > epsilon);

  writeln(A);
```

# Heat Transfer in Chapel

```
config const n = 6,
             epsilon = 1.0e-5;

const BigD: domain(2) = [0..n+1, 0..n+1],
```

**Compute maximum change**

***op* reduce** ⇒ collapse aggregate expression to scalar using *op*

***Promotion:*** *abs()* and – are scalar operators, automatically promoted to work with array operands

```
do {
  [(i,j) in D] Temp(i,j) = (A(i-1,j) + A(i+1,j)
                          + A(i,j-1) + A(i,j+1)) / 4;

  const delta = max reduce abs(A[D] - Temp[D]);
  A[D] = Temp[D];
} while (delta > epsilon);

writeln(A);
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# Heat Transfer in Chapel

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config const n = 6,
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const BigD: domain(2) = [0..n+1, 0..n+1],
           D: subdomain(BigD) = [1..n, 1..n],
     LastRow: subdomain(BigD) = D.exterior(1,0);

var

A[La

do {
  [(i,j) in D] Temp(i,j) = (A(i-1,j) + A(i+1,j)
                          + A(i,j-1) + A(i,j+1)) / 4;

  const delta = max reduce abs(A[D] - Temp[D]);
  A[D] = Temp[D];
} while (delta > epsilon);

writeln(A);
```

**Copy data back & Repeat until done**

uses slicing and whole array assignment
standard *do…while* loop construct

# Heat Transfer in Chapel

```
config const n = 6,
             epsilon = 1.0e-5;

const BigD: domain(2) = [0..n+1, 0..n+1],
         D: subdomain(BigD) = [1..n, 1..n],
   LastRow: subdomain(BigD) = D.exterior(1,0);

var A, Temp : [BigD] real;

A[LastRow] = 1.0;

do {
  [(                                          j)
                                              1)) / 4;

  const delta = max reduce abs(A[D] - Temp[D]);
  A[D] = Temp[D];
} while (delta > epsilon);

writeln(A);
```

**<u>Write array to console</u>**

If written to a file, parallel I/O would be used

# Heat Transfer in Chapel

```
config const n = 6,
             epsilon = 1.0e-5;

const BigD: domain(2) = [0..n+1, 0..n+1] dmapped Block,
         D: subdomain(BigD) = [1..n, 1..n],
   LastRow: subdomain(BigD) = D.exterior(1,0);

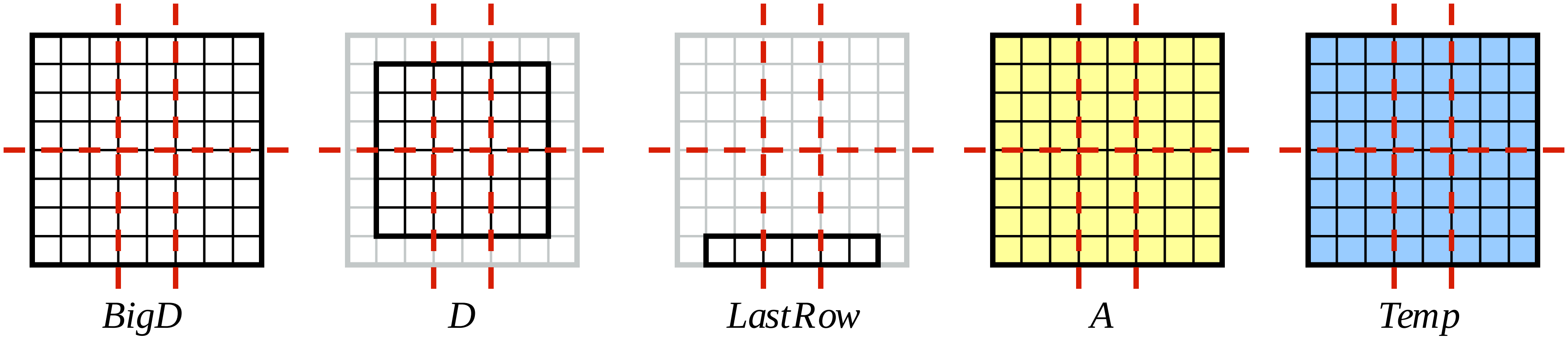
var A, Temp : [BigD] real;
```

With this change, same code runs in a distributed manner

Domain distribution maps indices to *locales*

⇒ decomposition of arrays & default location of iterations over locales

Subdomains inherit parent domain's distribution



# Heat Transfer in Chapel

```
config const n = 6,
             epsilon = 1.0e-5;

const BigD: domain(2) = [0..n+1, 0..n+1] dmapped Block,
         D: subdomain(BigD) = [1..n, 1..n],
   LastRow: subdomain(BigD) = D.exterior(1,0);

var A, Temp : [BigD] real;

A[LastRow] = 1.0;

do {
  [(i,j) in D] Temp(i,j) = (A(i-1,j) + A(i+1,j)
                          + A(i,j-1) + A(i,j+1)) / 4;

  const delta = max reduce abs(A[D] - Temp[D]);
  A[D] = Temp[D];
} while (delta > epsilon);

writeln(A);
```

# Heat Transfer in Chapel (Variations)

# Heat Transfer in Chapel (double buffered version)

```
config const n = 6,
             epsilon = 1.0e-5;

const BigD: domain(2) = [0..n+1, 0..n+1] dmapped Block,
         D: subdomain(BigD) = [1..n, 1..n],
   LastRow: subdomain(BigD) = D.exterior(1,0);

var A : [1..2] [BigD] real;

A[..][LastRow] = 1.0;

var src = 1, dst = 2;

do {
  [(i,j) in D] A(dst)(i,j) = (A(src)(i-1,j) + A(src)(i+1,j)
                            + A(src)(i,j-1) + A(src)(i,j+1)) / 4;

  const delta = max reduce abs(A[src] - A[dst]);
  src <=> dst;
} while (delta > epsilon);

writeln(A);
```

# Heat Transfer in Chapel (ZPL style)

```
config const n = 6,
             epsilon = 1.0e-5;

const BigD: domain(2) = [0..n+1, 0..n+1] dmapped Block,
         D: subdomain(BigD) = [1..n, 1..n],
   LastRow: subdomain(BigD) = D.exterior(1,0);

const north = (-1,0), south = (1,0), east = (0,1), west = (0,-1);

var A, Temp : [BigD] real;

A[LastRow] = 1.0;

do {
  [ind in D] Temp(ind) = (A(ind + north) + A(ind + south)
                        + A(ind + east)  + A(ind + west)) / 4;

  const delta = max reduce abs(A[D] - Temp[D]);
  A[D] = Temp[D];
} while (delta > epsilon);

writeln(A);
```

# Heat Transfer in Chapel (array of offsets version)

```
config const n = 6,
             epsilon = 1.0e-5;

const BigD: domain(2) = [0..n+1, 0..n+1] dmapped Block,
         D: subdomain(BigD) = [1..n, 1..n],
   LastRow: subdomain(BigD) = D.exterior(1,0);

param offset : [1..4] (int, int) = ((-1,0), (1,0), (0,1), (0,-1));

var A, Temp : [BigD] real;

A[LastRow] = 1.0;

do {
  [ind in D] Temp(ind) = (+ reduce [off in offset] A(ind + off))
                        / offset.numElements;

  const delta = max reduce abs(A[D] - Temp[D]);
  A[D] = Temp[D];
} while (delta > epsilon);

writeln(A);
```

# Heat Transfer in Chapel (sparse offsets version)

```
config const n = 6,
             epsilon = 1.0e-5;

const BigD: domain(2) = [0..n+1, 0..n+1] dmapped Block,
         D: subdomain(BigD) = [1..n, 1..n],
   LastRow: subdomain(BigD) = D.exterior(1,0);

param stencilSpace: domain(2) = [-1..1, -1..1],
      offSet: sparse subdomain(stencilSpace)
             = ((-1,0), (1,0), (0,1), (0,-1));
var A, Temp : [BigD] real;

A[LastRow] = 1.0;

do {
  [ind in D] Temp(ind) = (+ reduce [off in offSet] A(ind + off))
                         / offSet.numIndices;

  const delta = max reduce abs(A[D] - Temp[D]);
  A[D] = Temp[D];
} while (delta > epsilon);

writeln(A);
```

# The Other HPCS Languages

# X10 in a Nutshell

- Heavily influenced by Java, Scala
  - emphasis on type safety, OOP design, small core language
  - also ZPL: support for global-view domains and arrays
- Similar concepts to what you've heard about today in Chapel
  - yet a fairly different syntax and design aesthetic
- Main differences from Chapel
- For more information:
  - http://x10-lang.org/
  - http://sf.net/projects/x10
  - http://dist.codehaus.org/
  - http://dist.codehaus.org/x10/documentation/presentations/UWMay2010.pdf

# X10: Similarities to Chapel

- PGAS memory model
  - plus, language concepts for referring to realms of locality
- more dynamic ("post-SPMD") execution model
  - one logical task executes main()
  - any task can create additional tasks--local or remote
- global-view data structures
  - ability to declare and access distributed arrays holistically rather than piecemeal
- *many* similar concepts, often with different names/semantics
  - tasks vs. tasks
  - places vs. locales
  - 'at' vs. 'on'
  - 'ateach' vs' 'coforall' + 'on'
  - 'async' vs. 'begin'
  - 'finish' vs. 'sync'
  - …

# X10: Differences from Chapel

- X10:
  - takes a purer object-oriented approach
    - for example, arrays have reference rather than value semantics

      ```
      A = B; // alias or copy if A and B are arrays?
      ```
    - based on Java/Scala rather than *ab initio*
      - reflects IBM's customer base relative to Cray's
  - a bit more minimalist and purer
    - e.g., less likely to add abstractions to the language if expressible using objects
  - semantics distinguish between local and remote more strongly
    - e.g., communication is more visible in the code
    - e.g., some operations are not legal on remote objects
    - reflect differing choices on orthogonality vs. performance/safety
  - has a stronger story for exceptions

# Heat Transfer in X10

```
class HeatTransfer_v2 {
  const BigD = Dist.makeBlock([0..n+1, 0..n+1], 0);
  const D = BigD | ([1..n, 1..n] as Region);
  const LR = [0..0, 1..n] as Region;
  const A = DistArray.make[double](BigD,(p:Point)=>{ LR.contains(p) ? 1 : 0 });
  const Temp = DistArray.make[double](BigD);
  static def stencil_1((x,y):Point(2)) {
    return ((at(A.dist(x-1,y)) A(x-1,y)) +
            (at(A.dist(x+1,y)) A(x+1,y)) +
             A(x,y-1) + A(x,y+1)) / 4;
  }
  def run() {
    val D_Base = Dist.makeUnique(D.places());
    var delta:double = 1.0;
    do {
      finish ateach (z in D_Base)
      for (p:Point(2) in D | here)
      Temp(p) = stencil_1(p);
      delta = A.lift(Temp, D.region, (x:double,y:double)
            =>Math.abs(x-y)).reduce(Math.max.(Double,Double), 0);
      finish ateach (p in D) A(p) = Temp(p);
    } while (delta > epsilon);
  }
```

# Heat Transfer in Chapel

```
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                          + A(i,j-1) + A(i,j+1)) / 4;

  const delta = max reduce abs(A[D] - Temp[D]);
  A[D] = Temp[D];
} while (delta > epsilon);

writeln(A);
```

# Fortress in a Nutshell

- The most blue-sky, clean-slate of the HPCS languages
- **Goal:** define language semantics in libraries, not compiler:
  - data structures and types (including scalars types?)
  - operators, typecasts
  - operator precedence
  - in short, as much as possible to support future changes, languages
- Other themes:
  - implicitly parallel -- most things are parallel by default
  - supports mathematical notation, symbols, operators
  - functional semantics
  - hierarchical representation of target architecture's structure
  - units of measurement in the type system (meters, seconds, miles, …)
- For more information:
  - http://research.sun.com/projects/plrg/
  - http://projectfortress.sun.com/Projects/Community/