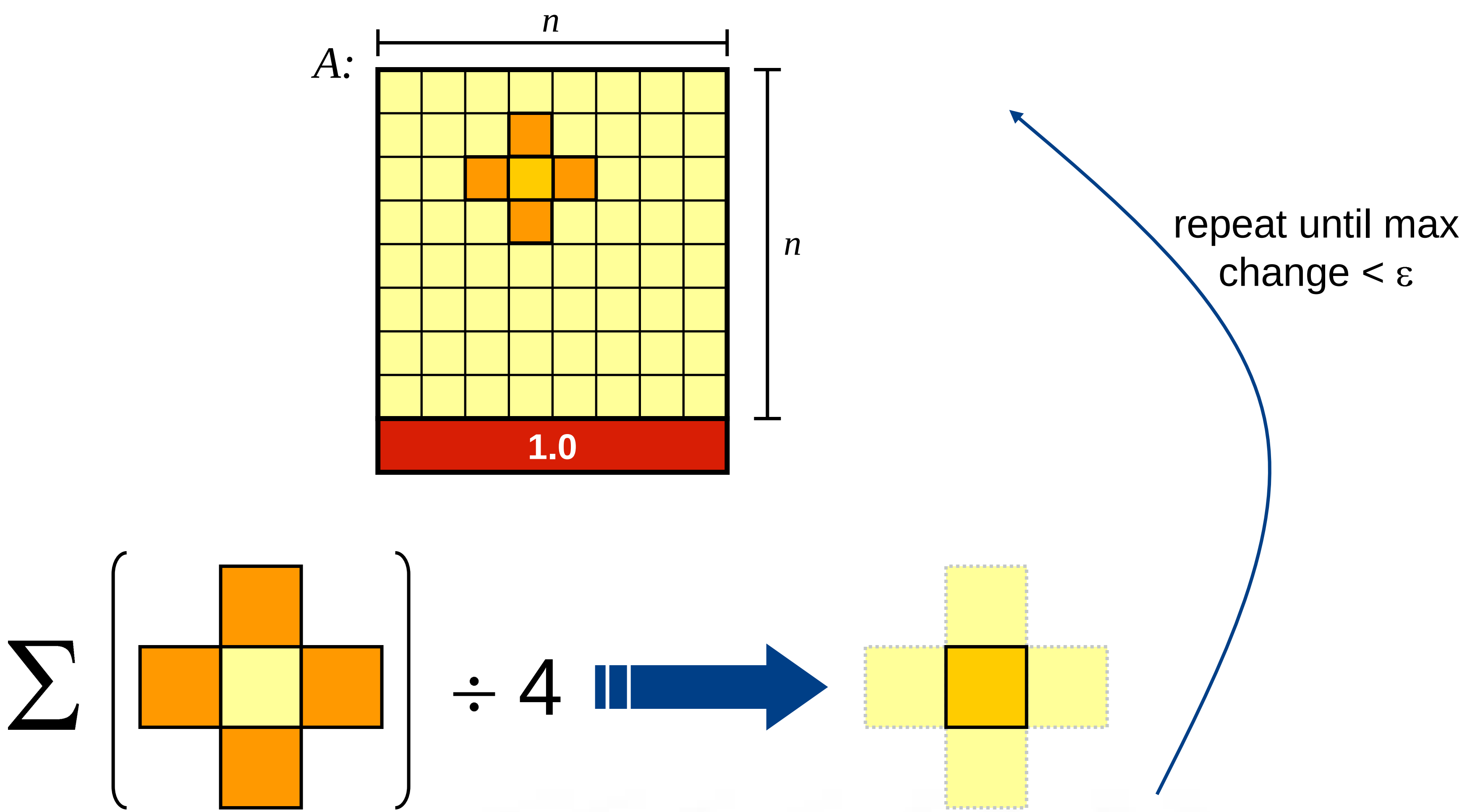
Heat Transfer in Chapel

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

```
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[Las

do {
  [(i


  con
  A[D
} whi

writeln(A);
```

<u>Declare program parameters</u>

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)

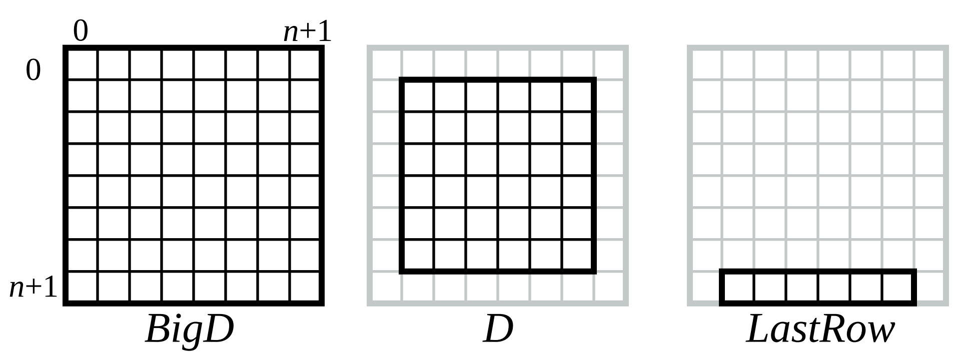
Heat Transfer in Chapel

```
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);
```

<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

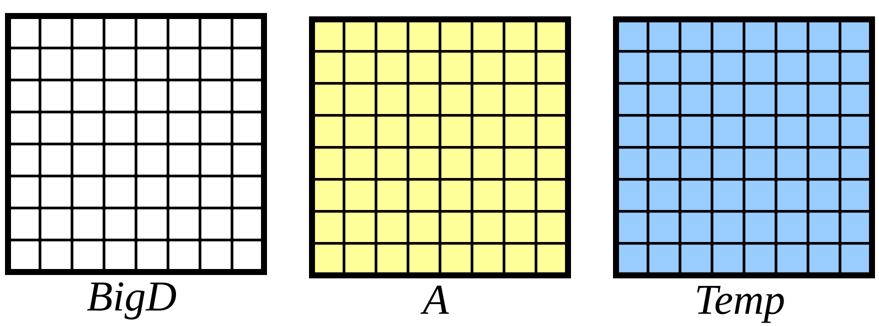
4;

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;
```

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)



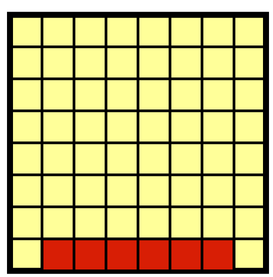
4;

Heat Transfer in Chapel

```
config const n = 6,
             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;
```

Set Explicit Boundary Condition

indexing by domain ⇒ slicing mechanism
array expressions ⇒ parallel evaluation



A

Heat Transfer in Chapel

<u>Compute 5-point stencil</u>

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

Note: since $(i,j) \in D$ and $D \subseteq BigD$ 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);
```

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[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);
```

Write array to console

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

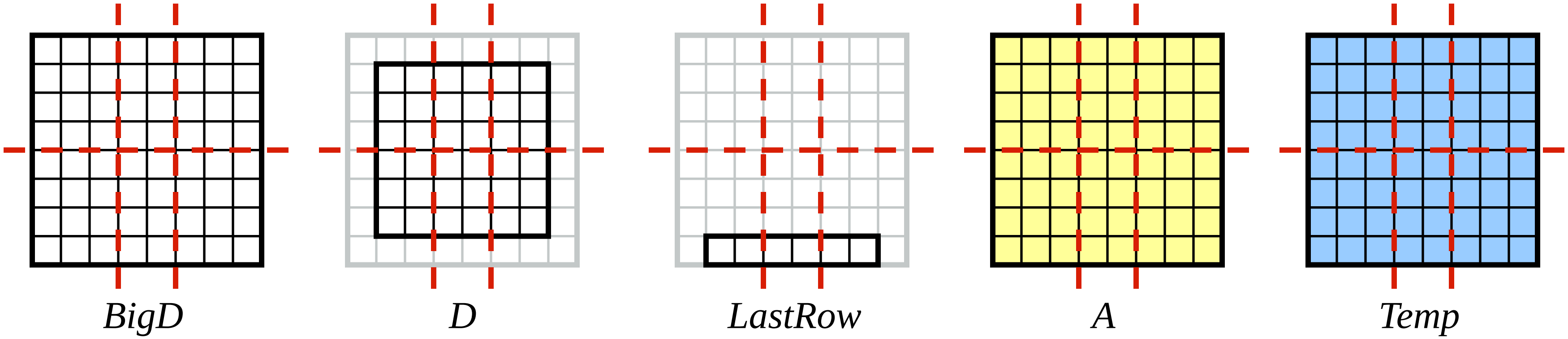
Heat Transfer in Chapel

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

const BigD: domain(2) = [0..n+1, 0..n+1] distributed 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] distributed 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
(Backup 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] distributed 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 (named direction version)

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

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

Heat Transfer in Chapel (UPC-ish version)

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

const BigD: domain(2) = [0..#N, 0..#N] distributed Block,
          D: subdomain(BigD) = D.expand(-1);

var grids : [0..1] [BigD] real;
var sg = 0, dg = 1;

do {
  [(x,y) in D] grids(dst)(x,y) = (grids(src)(x-1,y)
                                + grids(src)(x+1,y)
                                + grids(src)(x,y-1)
                                + grids(src)(x,y+1)) / 4;

  const dTmax = max reduce abs(grids(src) - grids(dst));
  src <=> dst;
} while (dTmax > epsilon);

writeln(A);
```