Productive Programming in Chapel: A Computation-Driven Introduction

Short Introduction to Locality

Michael Ferguson and Lydia Duncan
Cray Inc,

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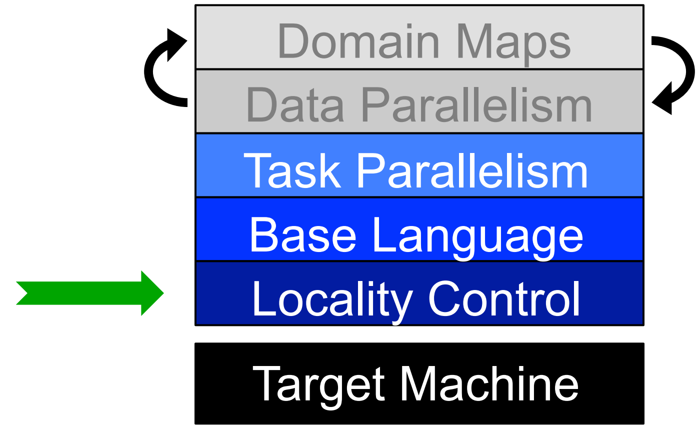
Outline

- ✓ Motivation
- ✓ Chapel Background and Themes
- ✓ Learning the Base Language with n-body
- ✓ Short Introduction to Task Par
- ✓ Hands-On 1: Hello World
- ➤ **Short Introduction to Locality**
- Data Parallelism with Jacobi
- Hands-On 2: Mandelbrot
- Project Status, Next Steps

Theme 4: Control over Locality/Affinity



The Locale Type

Definition:

- Abstract unit of target architecture
- Supports reasoning about locality
  - defines “here vs. there” / “local vs. remote”
- Capable of running tasks and storing variables
  - i.e., has processors and memory

Typically: A compute node (multicore processor or SMP)

Getting started with locales

- Specify # of locales when running Chapel programs

```
% a.out --numLocales=8
```

```
% a.out -nl 8
```

- Chapel provides built-in locale variables

```
config const numLocales: int = …;
const Locales: [0..#numLocales] locale = …;
```

Locales

L0	L1	L2	L3	L4	L5	L6	L7

- User's `main()` begins executing on locale #0

Locale Operations

- Locale methods support queries about the target system:

```
proc locale.physicalMemory(…) { … }
proc locale.numCores { … }
proc locale.id { … }
proc locale.name { … }
```

- *On-clauses* support placement of computations:

```
writeln("on locale 0");

on Locales[1] do
  writeln("now on locale 1");

writeln("on locale 0 again");
```

```
on A[i,j] do
  bigComputation(A);

on node.left do
  search(node.left);
```

Parallelism and Locality: Orthogonal in Chapel

- This is a **parallel**, but local program:

```
begin writeln("Hello world!");
writeln("Goodbye!");
```

- This is a **distributed**, but serial program:

```
writeln("Hello from locale 0!");
on Locales[1] do writeln("Hello from locale 1!");
writeln("Goodbye from locale 0!");
```

- This is a **distributed** and **parallel** program:

```
begin on Locales[1] do writeln("Hello from locale 1!");
on Locales[2] do begin writeln("Hello from locale 2!");
writeln("Goodbye from locale 0!");
```

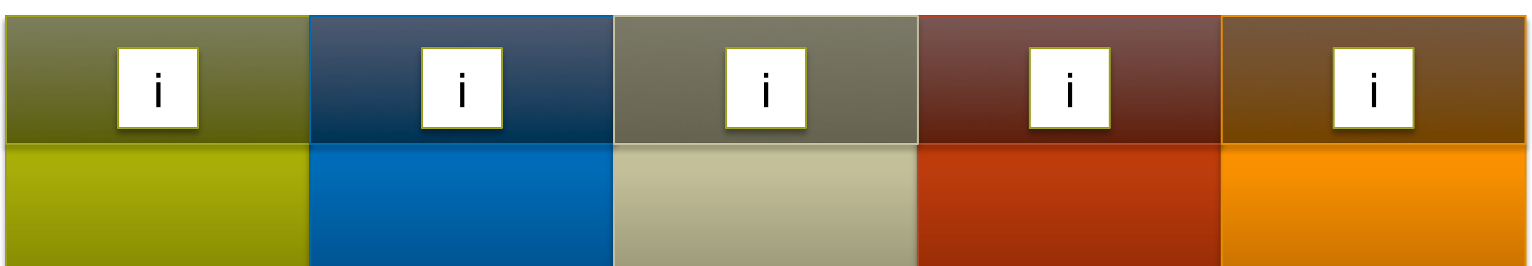
Partitioned Global Address Space (PGAS) Languages

(Or perhaps: partitioned global namespace languages)

- **abstract concept:**
  - support a shared namespace on distributed memory
    - permit parallel tasks to access remote variables by naming them
  - establish a strong sense of ownership
    - every variable has a well-defined location
    - local variables are cheaper to access than remote ones
- **traditional PGAS languages have been SPMD in nature**
  - best-known examples: Co-Array Fortran, UPC

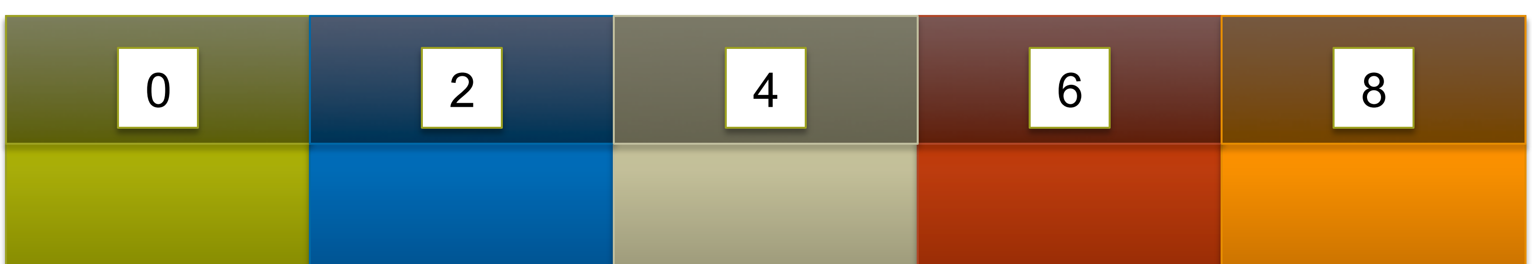
SPMD PGAS Languages (using a pseudo-language, not Chapel)

```
proc main() {
  var i(*): int;          // declare a shared variable i
```



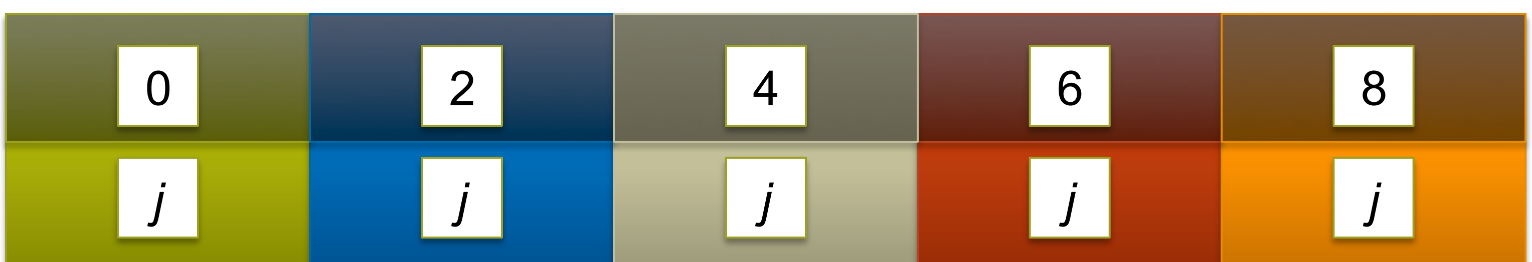
SPMD PGAS Languages (using a pseudo-language, not Chapel)

```
proc main() {
  var i(*): int;          // declare a shared variable i
  i = 2*this_image();     // each image initializes its copy
```



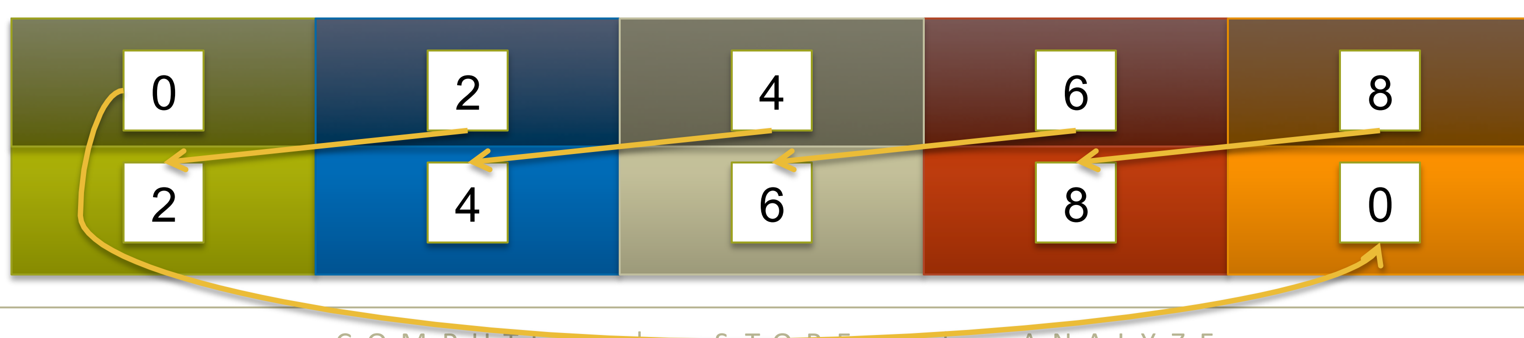
SPMD PGAS Languages (using a pseudo-language, not Chapel)

```
proc main() {
  var i(*): int;          // declare a shared variable i
  i = 2*this_image();     // each image initializes its copy
  var j: int;             // declare a private variable j
```



SPMD PGAS Languages (using a pseudo-language, not Chapel)

```
proc main() {
  var i(*): int;          // declare a shared variable i
  i = 2*this_image();     // each image initializes its copy
  var j: int;             // declare a private variable j
  j = i( (this_image()+1) % num_images() );
    // ^^ access our neighbor's copy of i
    // communication implemented by compiler + runtime

    // How did we know our neighbor had an i?
    // Because it's SPMD – we're all running the same
    // program.  (Simple, but restrictive)
```

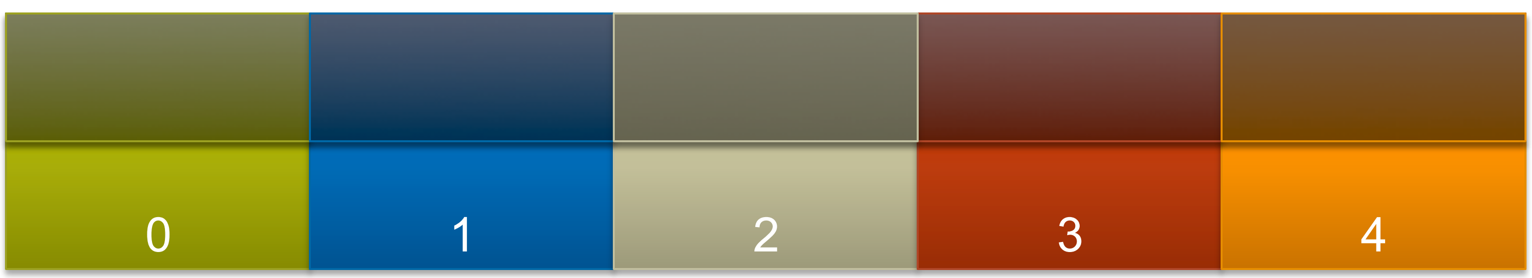


Chapel and PGAS

- **PGAS: Partitioned Global Address Space**
  - support a shared namespace on distributed memory
  - but allow reasoning about locality
- **Chapel is PGAS, but unlike most, it's not inherently SPMD**

  ⇒ never think about "the other copies of the program"

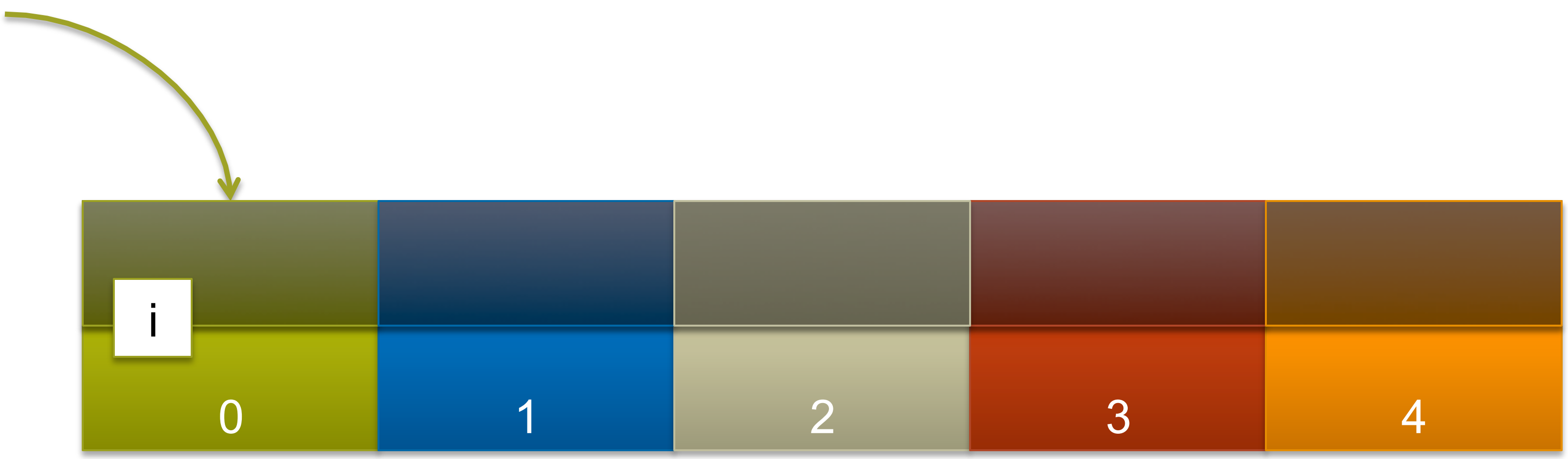
  ⇒ "global name/address space" comes from lexical scoping
  - as in traditional languages, each declaration yields one variable
  - variables are stored on the locale where the task declaring it is executing



Locales (think: "compute nodes")

Chapel: Scoping and Locality

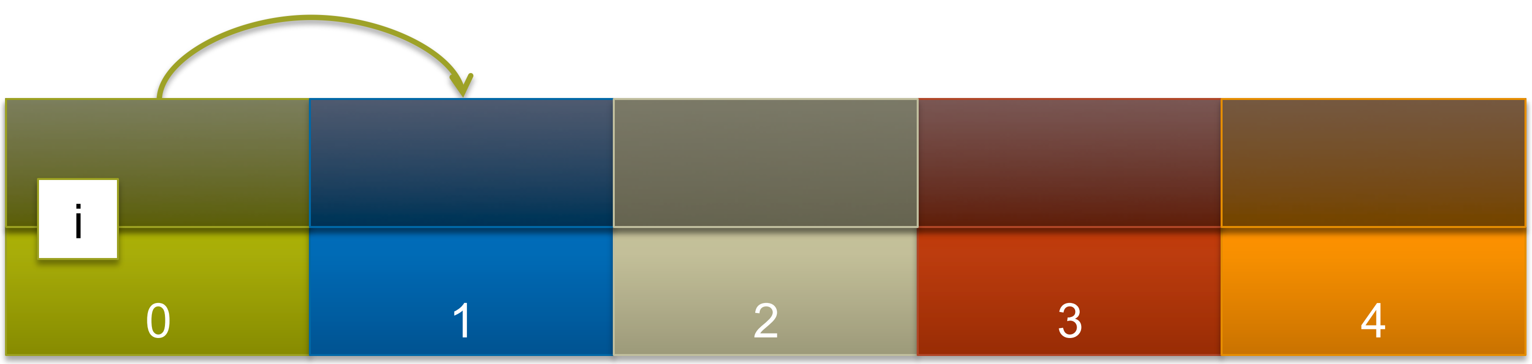
```
var i: int;
```



Locales (think: "compute nodes")

Chapel: Scoping and Locality

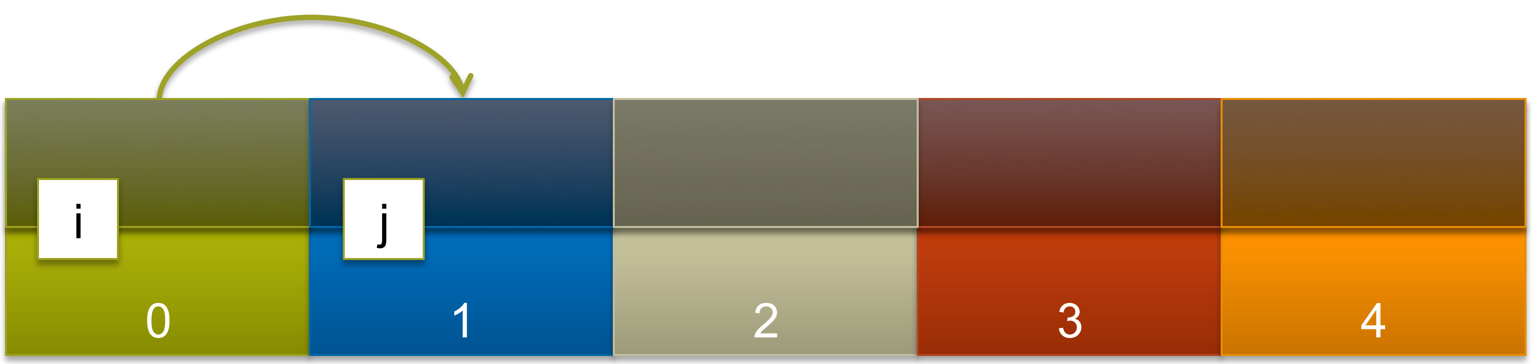
```
var i: int;
on Locales[1] {
```



Locales (think: “compute nodes”)

Chapel: Scoping and Locality

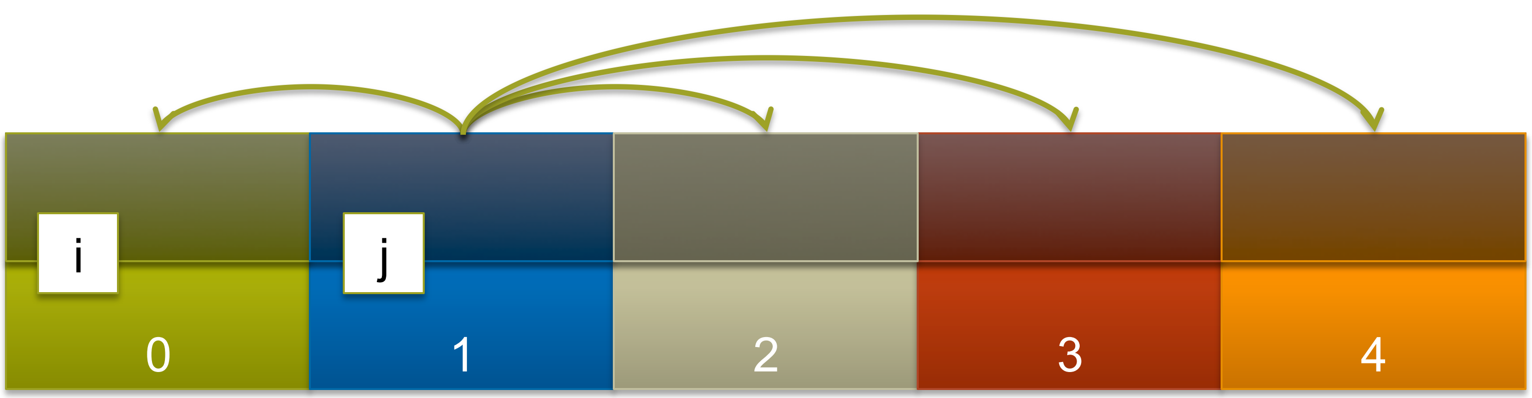
```
var i: int;
on Locales[1] {
  var j: int;
```



Locales (think: "compute nodes")

Chapel: Scoping and Locality

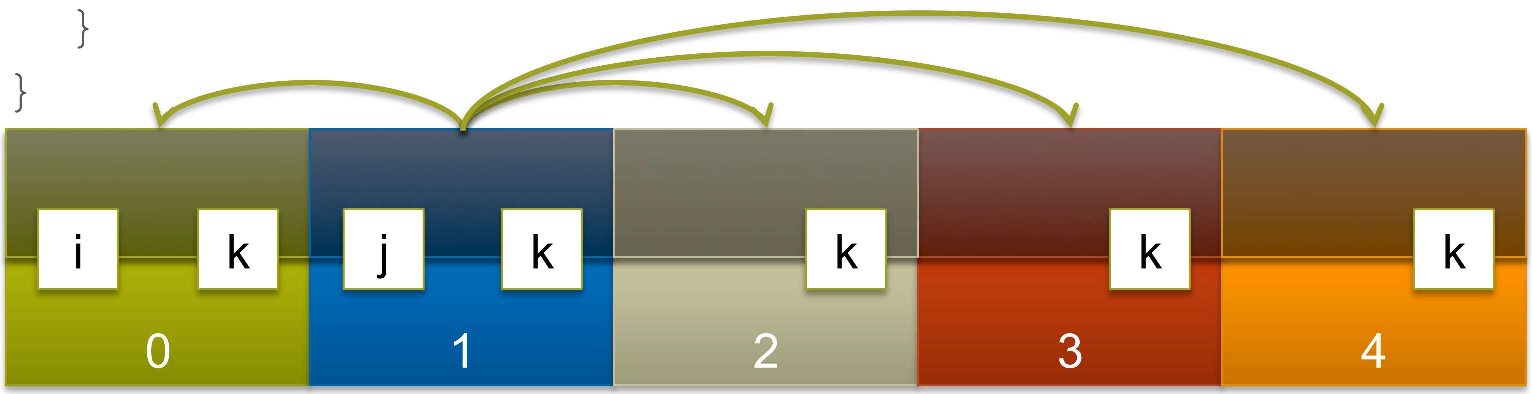
```
var i: int;
on Locales[1] {
  var j: int;
  coforall loc in Locales {
    on loc {
```



Locales (think: “compute nodes”)

Chapel: Scoping and Locality

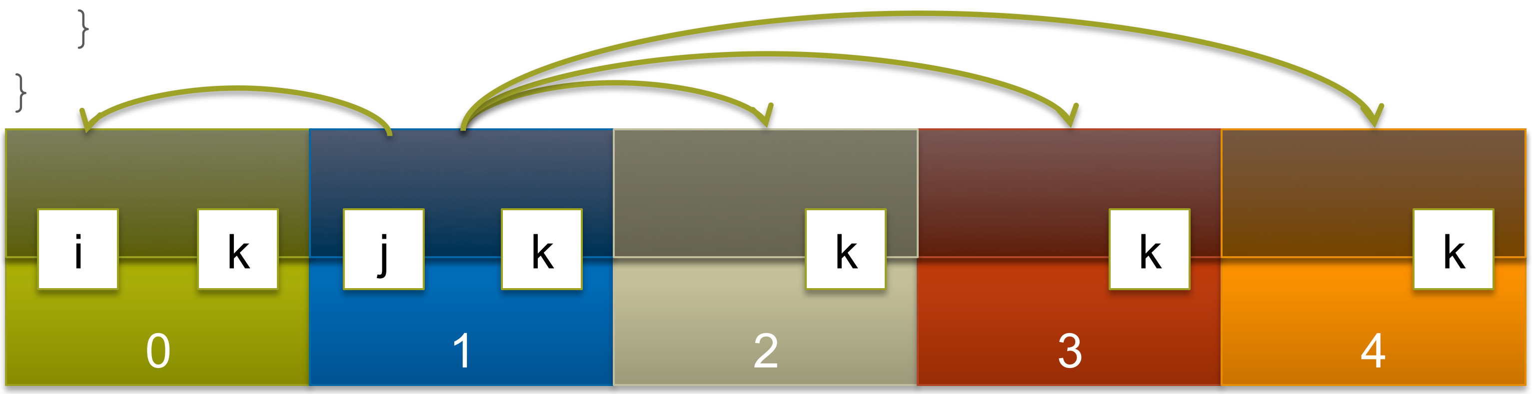
```
var i: int;
on Locales[1] {
  var j: int;
  coforall loc in Locales {
    on loc {
      var k: int;
      // within this scope, i, j, and k can be referenced;
      // the implementation manages the communication for i and j
    }
  }
}
```



Locales (think: "compute nodes")

Chapel: Scoping and Locality

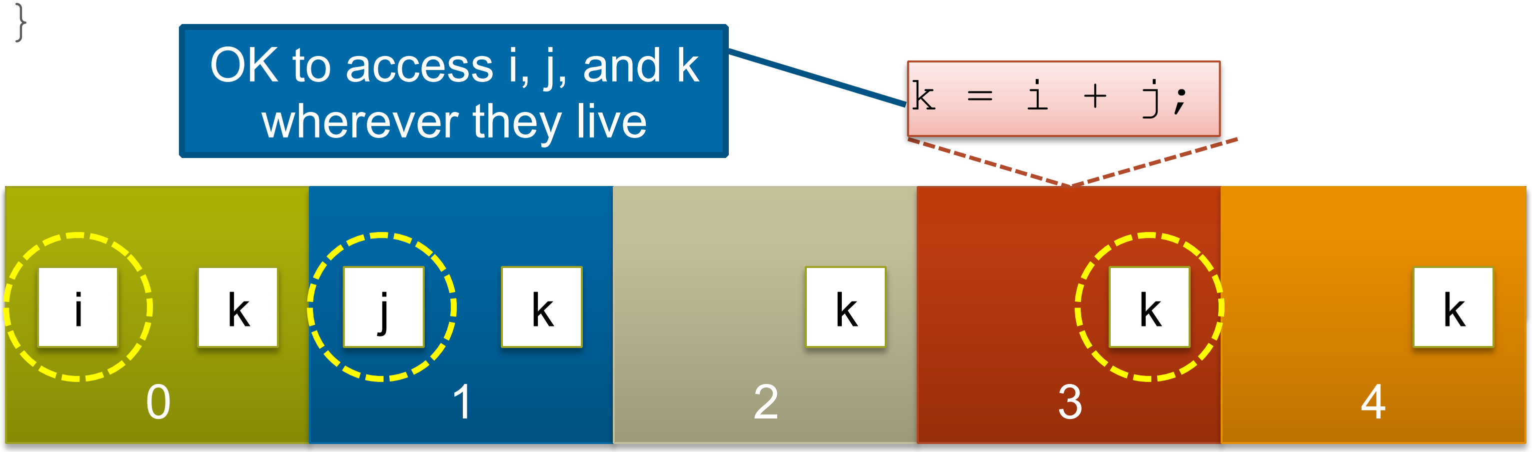
```
var i: int;
on Locales[1] {
  var j: int;
  coforall loc in Locales {
    on loc {
      var k: int;
      // within this scope, i, j, and k can be referenced;
      // the implementation manages the communication for i and j
      k = i + j;
    }
  }
}
```



Locales (think: "compute nodes")

Chapel: Scoping and Locality

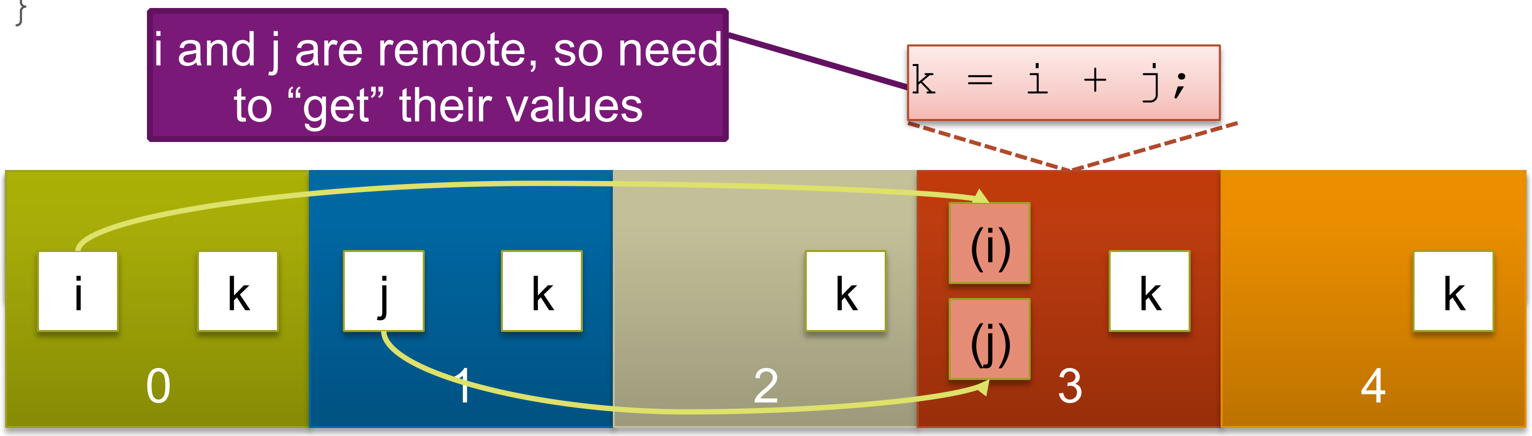
```
var i: int;
on Locales[1] {
  var j: int;
  coforall loc in Locales {
    on loc {
      var k: int;
      k = i + j;
    }
  }
}
```



Images / Threads / Locales / Places / etc. (think: "compute nodes")

Chapel: Scoping and Locality

```
var i: int;
on Locales[1] {
  var j: int;
  coforall loc in Locales {
    on loc {
      var k: int;
      k = i + j;
    }
  }
}
```



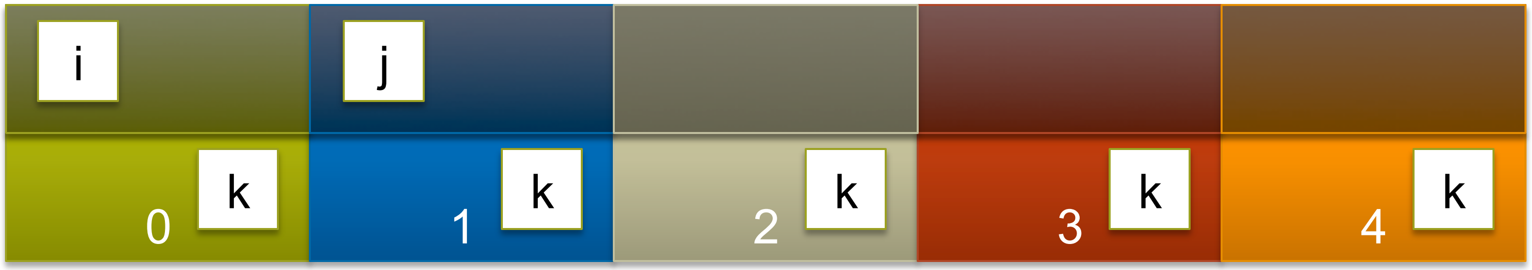
Images / Threads / Locales / Places / etc. (think: "compute nodes")

Chapel and PGAS: Public vs. Private

How public a variable is depends only on scoping

- who can see it?
- who actually bothers to refer to it non-locally?

```
var i: int;
on Locales[1] {
  var j: int;
  coforall loc in Locales {
    on loc {
      var k = i + j;
    }
  }
}
```



Locales (think: "compute nodes")

Querying a Variable's Locale

- **Syntax**

```
locale-query-expr:
  expr . locale
```

- **Semantics**
  - Returns the locale on which *expr* is stored
- **Example**

```
var i: int;
on Locales[1] {
  var j: int;
  writeln((i.locale.id, j.locale.id));  // outputs (0,1)
}
```

Here

- **Built-in locale variable**

```
const here: locale;
```

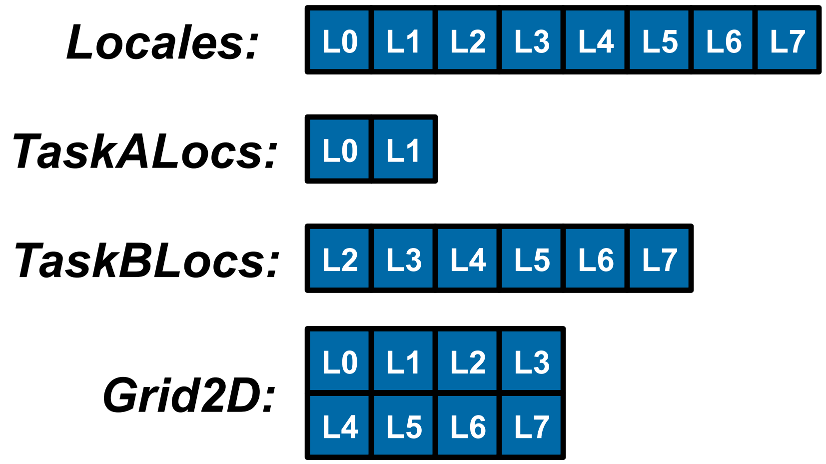
- **Semantics**
  - Refers to the locale on which the task is executing
- **Example**

```
writeln(here.id);      // outputs 0
on Locales[1] do
  writeln(here.id);    // outputs 1

on myC do
  if (here == Locales[0]) then …
```

Rearranging Locales

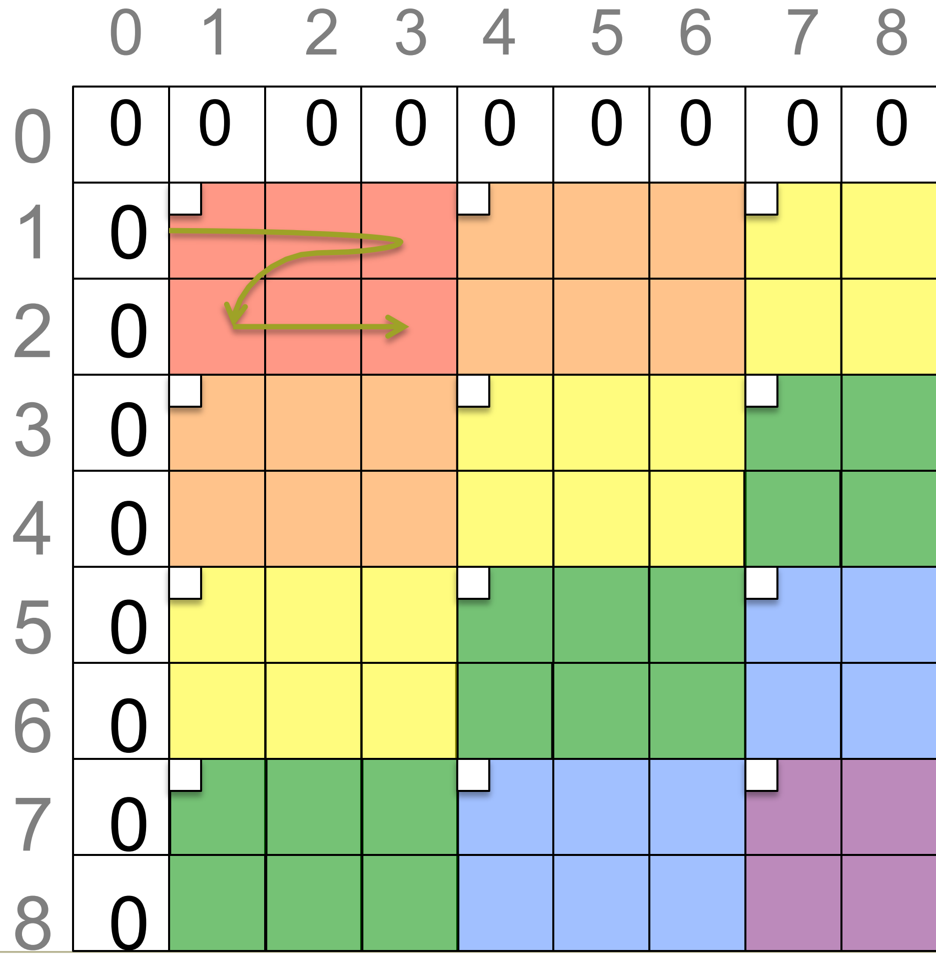
Create locale views with standard array operations:

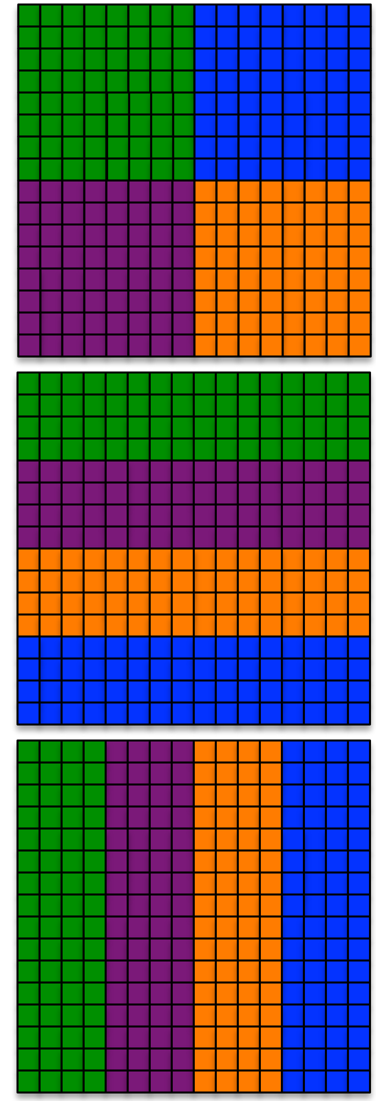
```
var TaskALocs = Locales[0..1];
var TaskBLocs = Locales[2..];

var Grid2D = reshape(Locales, {1..2, 1..4});
```



Distributed Smith-Waterman

Now, what about distributed memory?

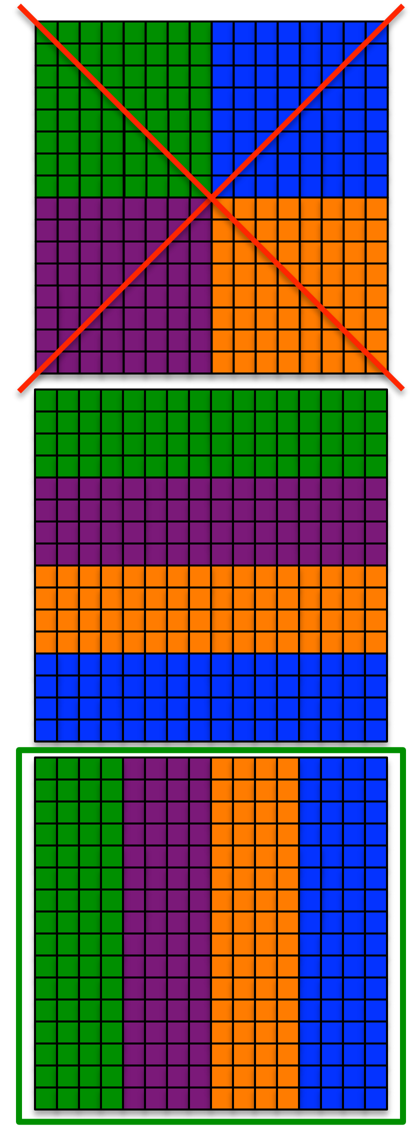




Distributed Smith-Waterman

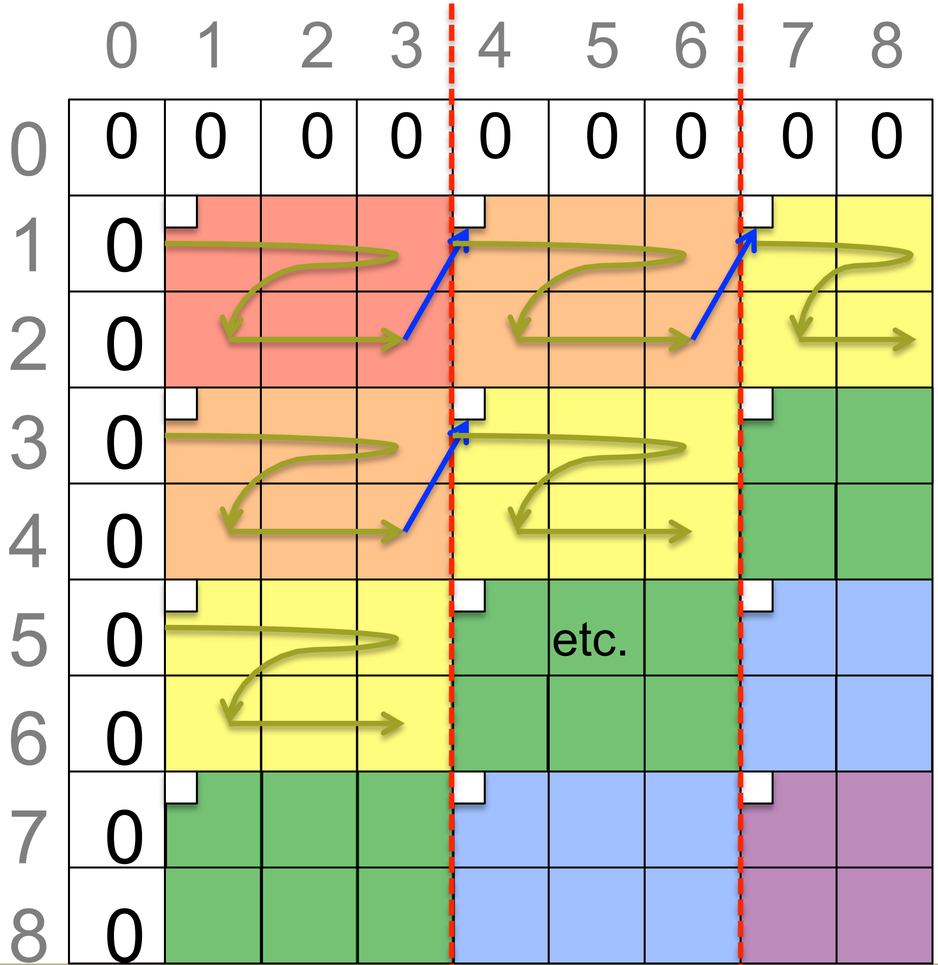
Now, what about distributed memory?

	0	1	2	3	4	5	6	7	8
0	0	0	0	0	0	0	0	0	0
1	0								
2	0								
3	0								
4	0								
5	0								
6	0								
7	0								
8	0								

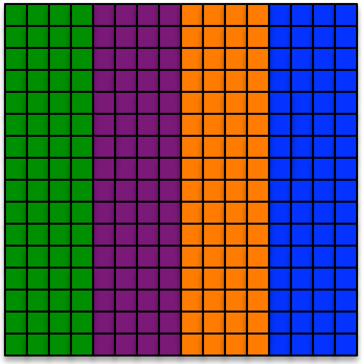


Distributed Smith-Waterman

Now, what about distributed memory?



Advantages:
- Good cache behavior: Nice fat blocks of data touchable in memory order
- Pipeline parallelism: Good utilization once pipeline is filled



Distributed Smith-Waterman

Distributed Chunked Data-Driven Task-Parallel Approach:

Reshape the 1D Locales array into a 2D column

Block-distribute the data space across the column of locales

Compute each chunk on the locale that owns its initial element

```
const Hspace = {0..n, 0..n};
const LocaleGrid = Locales.reshape({0..#numLocales, 0..0});
const DistHSpace = Hspace dmapped Block(Hspace, LocaleGrid);
var H: [DistHSpace] int;

proc computeH(H: [] int) {
  const ProbSpace = H.domain.translate(1,1);
  const StrProbSpace = ProbSpace by (rowsPerChunk, colsPerChunk);
  var NeighborsDone: [StrProbSpace] atomic int;
…
  proc computeHHelp(x,y) {
    on H[x,y] {
      for (i,j) in ProbSpace[x..#rowsPerChunk, y..#colsPerChunk] do
        H[i,j] = f(H[i-1,j-1], H[i-1,j], H[i,j-1]);
    const eastReady =  NeighborsDone[x,            y+colsPerChunk].fetchAdd(1);
    …etc…
    if (eastReady == 2)  then begin computeHHelp(x,          y+colsPerChunk);
    …etc…
} } }
```

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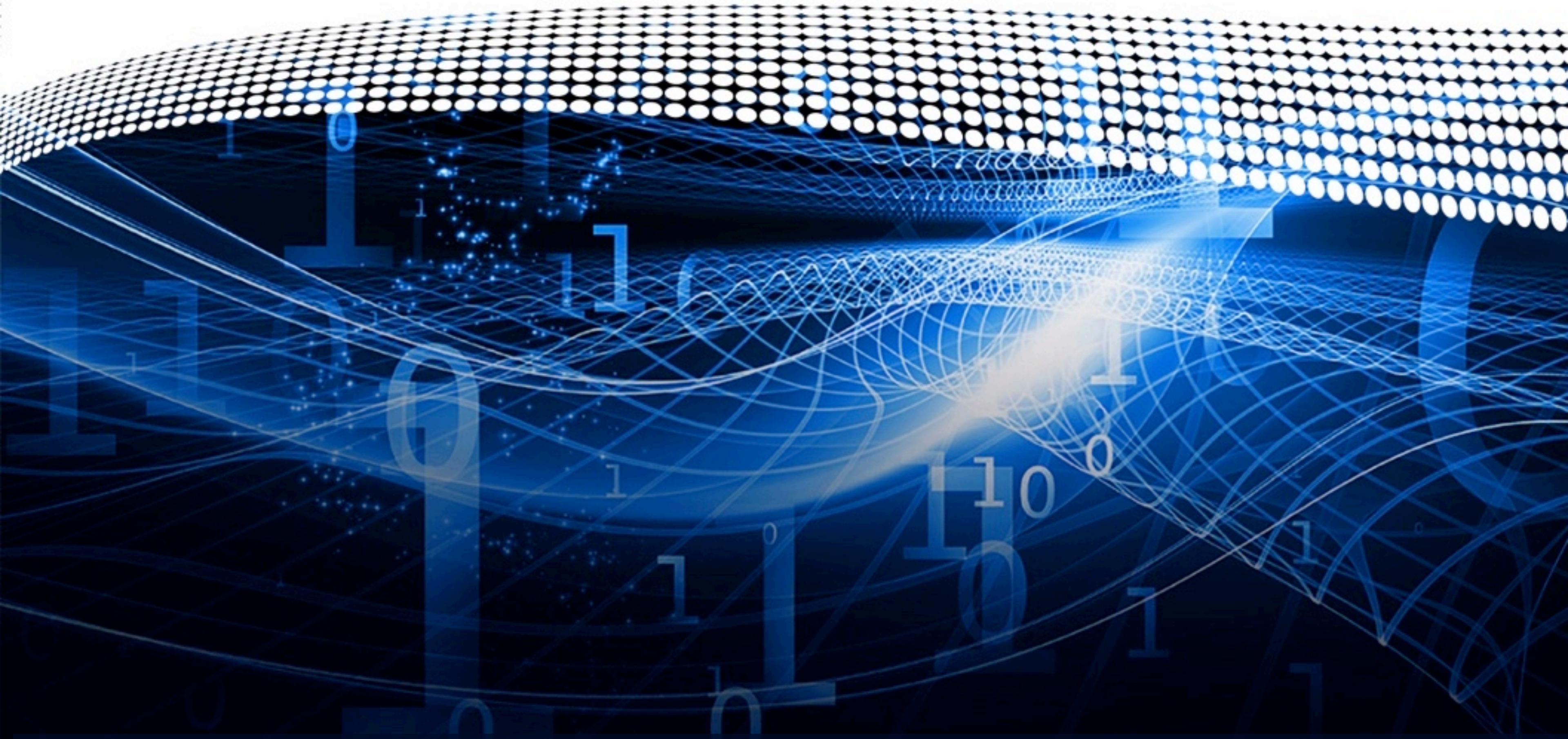

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