The Basics of ZPL

Like sequential computation with its C programming language and von Neumann model of computation explaining the performance of programs, parallel computation needs a language calibrated to the CTA model. ZPL is the only such language.

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ZPL -- A Practical Parallel Language

- ZPL was designed from “1st principles” meaning…
  - ZPL is not an extension of existing language -- it’s new
  - Careful analysis of programming task: XYZ-levels
  - No programming “fads”: functional, OO, “miracle” solutions
  - Search for new ideas that *help* parallel programmers
  - Focus on “user needs,” e.g. scientific computation
- ZPL emphasizes
  - Performance … user’s programs run as well or better than message passing
  - Portability … it runs on any parallel computer or cluster
  - Convenience … parallel programming is tough, so ZPL is high level

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ZPL ...

Is an array language -- whole arrays are manipulated with primitive operations

- Requires new thinking strategies --
  - Forget one-operation-a-time scalar programming
  - Think of the computation globally -- make the global logic work efficiently and leave the details to the compiler
- Is parallel, but there are no parallel constructs in the language; the compiler...
  - Finds all concurrency
  - Performs all interprocessor communication
  - Implements all necessary synchronization (almost none)
  - Performs extensive parallel and scalar optimizations

A Sample of ZPL Code

```
program Jacobi;
config var n : integer = 512;
         eps : float = 0.00001;

region      R = [1..n, 1..n];
         BigR = [0..n+1,0..n+1];
direction   N = [-1, 0];  S = [ 1, 0];
            E = [ 0, 1];  W = [ 0,-1];
var      Temp : [R] float;
            A : [BigR] float;
          err : float;

procedure Jacobi();
     [R] begin
  [BigR] A := 0.0;
[S of R] A := 1.0;
          repeat
            Temp := (A@N + A@E + A@S + A@W)/4.0;
            err  := max<< abs(Temp - A);
            A    := Temp;
          until err < eps;
         end;
end;
```

ZPL is an imperative array language with the usual datatypes and operators, the familiar statement forms, and a few new concepts added

Is a mix of Pascal, C and new syntax

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          repeat
            Temp := (A@N + A@E + A@S + A@W)/4.0;
            err  := max<< abs(Temp - A);
            A    := Temp;
          until err < eps;
         end;
end;
```

New features
config vars
region
direction
prefixing [ ]
assist with the global view of computation

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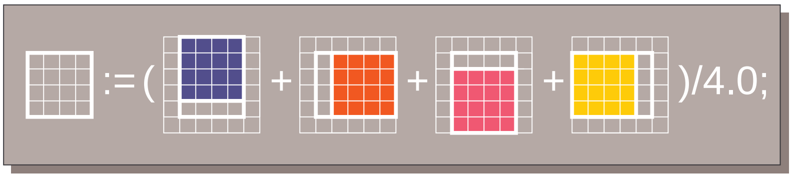
Jacobi Iteration: How does it work?

```
program Jacobi;
config var n : integer = 512;
         eps : float = 0.00001;
```




```
procedure Jacobi();
     [R] begin
  [BigR] A := 0.0;
[S of R] A := 1.0;
          repeat
            Temp := (A@N + A@E + A@S + A@W)/4.0;
            err  := max<< abs(Temp - A);
            A    := Temp;
          until err < eps;
         end;
end;
```

Think of averaging the 4 nearest neighbors as whole array operations

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Regions: A New Concept

```
program Jacobi;
config var n : integer = 512;
         eps : float = 0.00001;

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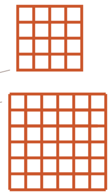
         BigR = [0..n+1,0..n+1];
direction   N = [-1, 0];  S = [ 1, 0];
            E = [ 0, 1];  W = [ 0,-1];
var      Temp : [R] float;
            A : [BigR] float;
          err : float;

procedure Jacobi();
     [R] begin
  [BigR] A := 0.0;
[S of R] A := 1.0;
          repeat
            Temp := (A@N + A@E + A@S + A@W)/4.0;
            err  := max<< abs(Temp - A);
            A    := Temp;
          until err < eps;
         end;
end;
```



Regions are index sets -- like arrays but with no data; used for declarations and execution control

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Directions: Another New Concept

```
program Jacobi;
config var n : integer = 512;
         eps : float = 0.00001;

region      R = [1..n, 1..n];
         BigR = [0..n+1,0..n+1];
direction   N = [-1, 0];  S = [ 1, 0];
            E = [ 0, 1];  W = [ 0,-1];
var      Temp : [R] float;
            A : [BigR] float;
          err : float;

procedure Jacobi();
     [R] begin
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          repeat
            Temp := (A@N + A@E + A@S + A@W)/4.0;
            err  := max<< abs(Temp - A);
            A    := Temp;
          until err < eps;
         end;
end;
```

Directions are vectors pointing in *index* space … e.g.
`S = [ 1, 0 ]`
points to row below

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Operations on Regions

```
program Jacobi;
config var n : integer = 512;
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region      R = [1..n, 1..n];
         BigR = [0..n+1,0..n+1];
direction   N = [-1, 0];  S = [ 1, 0];
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          err : float;

procedure Jacobi();
     [R] begin
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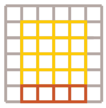
          repeat
            Temp := (A@N + A@E + A@S + A@W)/4.0;
            err  := max<< abs(Temp - A);
            A    := Temp;
          until err < eps;
         end;
end;
```



Transform regions using “prepositional” operators: of, in, at, by, etc. e.g.

[S of R]

specifies region south of R of extent given by len., i.e. single row

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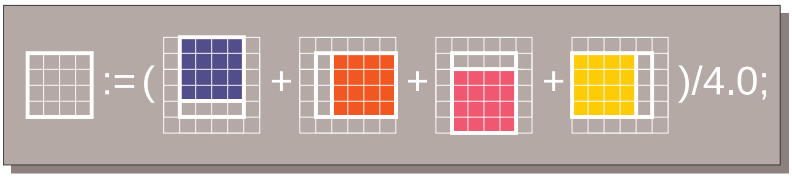
Referencing 4 Nearest Neighbors

```
program Jacobi;
config var n : integer = 512;
          eps : float = 0.00001;
```




```
procedure Jacobi();
     [R] begin
  [BigR] A := 0.0;
[S of R] A := 1.0;
          repeat
            Temp := (A@N + A@E + A@S + A@W)/4.0;
            err  := max<< abs(Temp - A);
            A    := Temp;
          until err < eps;
         end;
end;
```

@d shifts applicable region in d direction

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The “High Level” Logic Of J-Iteration

```
program Jacobi;
config var n : integer = 512;
         eps : float = 0.00001;

region      R = [1..n, 1..n];
         BigR = [0..n+1,0..n+1];
direction   N = [-1, 0];  S = [ 1, 0];
            E = [ 0, 1];  W = [ 0,-1];
var      Temp : [R] float;
            A : [BigR] float;
          err : float;

procedure Jacobi();
     [R] begin
  [BigR] A := 0.0;
[S of R] A := 1.0;
          repeat
            Temp := (A@N + A@E + A@S + A@W)/4.0;
            err  := max<< abs(Temp - A);
            A    := Temp;
          until err < eps;
         end;
end;
```

Compute new averages
Find the largest error
Update array
… until convergence

ZPL In Detail ...

ZPL has the usual stuff

- Datatypes: **`boolean`**, **`float`**, **`double`**, **`quad`**, **`complex`**, signed and unsigned integers: **`byte`**, **`ubyte`**, **`integer`**, **`uinteger`**, **`char`**, …
- Operators:
  - Unary: `+, -, !`
  - Binary: `+, -, *, /, ^, %, &, |`
  - Relational: `<, <=, =, !=, >=, >=`
  - Bit Operations: `bnot(), band(), bor(), bxor(), bsl(), bsr()`
  - Assignments: `:=, +=, -=, *=, /=, %=, &=, |=`
- Control Structures: if-then-[elsif]-else, repeat-until, while-do, for-do, exit, return, continue, halt, begin-end

ZPL Detail (continued)

- White space ignored
- All statements are terminated by semicolon (;)
- Comments are

  `--`   to the end of the line

  `/*   */`   all text within pairs including newlines
- All variables must be declared using **`var`**
- Names are case sensitive
- Programs begin with

  ```
  program <name>;
  ```

  the procedure with <name> is the entry point

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ZPL Detail (continued)

- The unary global operation reduction (**<<**) “reduces” an entire array to a single value using an associative operator: **`+<<`**, **`*<<`**, **`max<<`**, **`min<<`**, **`&<<`**, **`|<<`**
- For example, **`+<<`** is summation (Σ) and **`max<<`** is global maximum

  ```
  err := max<< abs(Temp - A);
  ```

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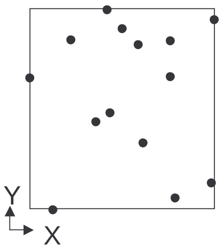
Bounding Box

- Let X,Y be 1-dimensional *n* element arrays such that (x_i, y_i) is a position in the plane
- The bounding box is the extreme coordinates in each dimension

```
[1..n] begin
        rightedge := max<< X;
        topedge := max<< Y;
        leftedge := min<< X;
        bottomedge := min<< Y;
       end
```



Alternative Data Representation

- ZPL allows programmers to define a type
- Rather than using X and Y arrays, define

```
type cartPoint = record
             x : integer; -- x coordinate
             y : integer; -- y coordinate
     end;
...
var Pts : [1..n] cartPoint; -- an array of points
             rightedge  := max<< Pts.x;
             topedge    := max<< Pts.y;
             leftedge   := min<< Pts.x;
             bottomedge := min<< Pts.y;
```

ZPL Inherits from C

- ZPL is translated into C
- Mathematical functions come from math.h
- ZPL's Input and Output follow C conventions and formatting, though the behavior on parallel machines can differ

Configuration variables (config vars) and constants are a list of command line assignable identifiers with specified defaults … config const cannot be reset

```
config const prob_size : integer = 64;
```

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Mean and Standard Deviation ...

Find μ and σ for array of Sample values

```
program Sample_Stats;
  config var n : integer = 100;
  region     V = [1..n];

procedure Sample_Stats();
  var Sample : [V] float;
     mu,sigma: float;
  [V] begin
        read(Sample);
        mu := +<<Sample/n;
        sigma := sqrt(+<<((Sample-mu)^2)/n);
        write ("Mean: ", mu,"S.D. :", sigma);
      end;
```

$$\sigma = \sqrt{\frac{\Sigma(Sample_i - \mu)^2}{n}}$$

$$\mu = \frac{\Sigma\ Sample_i}{n}$$

Basically, a direct translation into imperative form

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