hpcs lab
High Performance Computing System

Towards next generation parallel language framework for Petascale systems:

XcalableMP project and Experience from HPF

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Agenda

- Lesson learned from HPF
  - Think about MPI …
  - History of HPF in Japan
- XcalableMP : directive-based language eXtension for Scalable and performance-tunable Parallel Programming
  - Motivation
  - Concept and model
  - Some examples

Message Passing Model (MPI)

- Message passing model was the dominant programming model in the past.
  - …. Yes.
- Message passing is the dominant programming model today.
  - … Unfortunately, yes…
- Will OpenMP be a programming model for future system?
  - OpenMP is only for shared memory model.
- Are programmers satisfied with MPI?
  - yes…? Many programmers writes MPI.
- Is MPI enough for parallelizing scientific parallel programs?
- Application programmer's concern is to get their answers faster!!
  - Automatic parallelizing compiler is the best, but …
    many problems remain.
- Why was MPI accepted and so successful?
  - Portability and Education, and more …?

The rise and fall of High Performance Fortran in Japan
～Lessons learned from HPF ～
(by Sakagami@NIFS and Murai@NEC)

- (A similar retrospective paper was published by Prof. Ken Kennedy and Zima)

- Background of HPF (in 1992-1997, 1st draft)
  - MPI (message passing model) was (still now) an **obstacle** for programming distributed memory systems.
    - Debugging MPI code is not easy, and update/modification of MPI program forces a tough work for application people.
    - If MPI is only a solution to parallel machine, nobody wants to use parallel machines. (EP is ok, but …)
  - There was a great demand for parallel programming languages!
    - Application people want just easy parallel programming environment with reasonable (not necessarily perfect) performance.
    - OpenMP is just for shared memory systems.
    - Not practical alternative solutions. (Now, how about HPCS languages?!)

HPF history in Japan

- Japanese supercomputer venders were interested in HPF and developed HPF compiler on their systems.
- NEC has been supporting HPF for Earth Simulator System.
- Many workshops: HPF Users Group Meeting (HUG from 1996-2000), HFP intl. workshop (in Japan, 2002 and 2005)
- Japan HPF promotion consortium was organized by NEC, Hitatchi, Fujitsu …
  - HPF/JA proposal
- Still survive in Japan, supported by Japan HPF promotion consortium
- Compiler Availability
  - HPF/ES (HPF+HPF/JA+some extension for Earth Simulator)
  - HPF/SX, HPF/VPP, HPF/ES for PC clusters, fhpf (free software distributed by HPF consortium)

“Pitfalls” and Lessons learned from HPF (1)

- “Ideal” design policy of HPF
  - A user gives a small information such as data distribution and parallelism.
  - The compiler generates “good” communication and work-sharing automatically.
  - By ignoring directives, parallelized code can be considered as the original sequential code.
  - Large specifications were included to satisfy “theoretical” completeness of the language model.

- **Lesson : *“Don’t give too much expectation to users which the technology could not meet.”***
  - This “ideal” design policy had generated a great “expectation” from users! But, the reality was not …
  - Initial (reference) implementation is important to attract people.
    - No reference implementation of HPF like MPICH in MPI standard.

“Pitfalls” and Lessons learned from HPF (2)

- The base language of HPF was “immature” F90
  - A bad thing was that at the moment of HPF announced (mid 90’s), F90 was still immature.
  - Many application people had to rewrite programs in F90 in order to use HPF
    - Re-write from F77 to F90 was not easy work.
  - No C/C++

- **Lesson :“*Application people don’t want to rewrite their programs. They are very conservative*”**
  - Sometimes, they complained that “I re-wrote my program by spending a lot time, but the performance was not good!”
  - The reason why the performance of HPF was not so good was sometimes due to the immaturity of F90 implementation.

“Pitfalls” and Lessons learned from HPF (3)

- No explicit mean for performance tuning .
  - Everything depends on compiler optimization.
  - Users can specify more detail directives, but no information how much performance improvement will be obtained by additional informations
    - INDEPENDENT for parallel loop
    - PROCESSOR + DISTRIBUTE
    - ON HOME
  - The performance is too much dependent on the compiler quality, resulting in “incompatibility” due to compilers.
- **Lesson :“*Specification must be clear. Programmers want to know what happens by giving directives*”**
  - The way for tuning performance should be provided.

“Petascale” Parallel language design working group

- Objectives
  - Making a draft on “petascale” parallel language for “standard” parallel programming
  - To propose the draft to “world-wide” community as “standard”
- Members
  - Academia: M. Sato, T. Boku (compiler and system, U. Tsukuba), K. Nakajima (app. and programming, U. Tokyo), Nanri (system, Kyusyu U.), Okabe (HPF, Kyoto U.)
  - Research Lab.: Watanabe and Yokokawa (RIKEN), Sakagami (app. and HPF, NIFS), Matsuo (app., JAXA), Uehara (app., JAMSTEC/ES)
  - Industries: Iwashita and Hotta (HPF and XPFortran, Fujitsu), Murai and Seo (HPF, NEC), Anzaki and Negishi (Hitachi)
- More than 10 WG meetings have been held (Dec. 13/2007 for kick-off)
- Funding for development
  - E-science project : “Seamless and Highly-productive Parallel Programming Environment for High-performance computing” project funded by Ministry of Education, Culture, Sports, Science and Technology, JAPAN.
    - Project PI: Yutaka Ishiakwa, co-PI: Sato and Nakashima(Kyoto), PO: Prof. Oyanagi
    - Project Period: 2008/Oct to 2012/Mar (3.5 years)

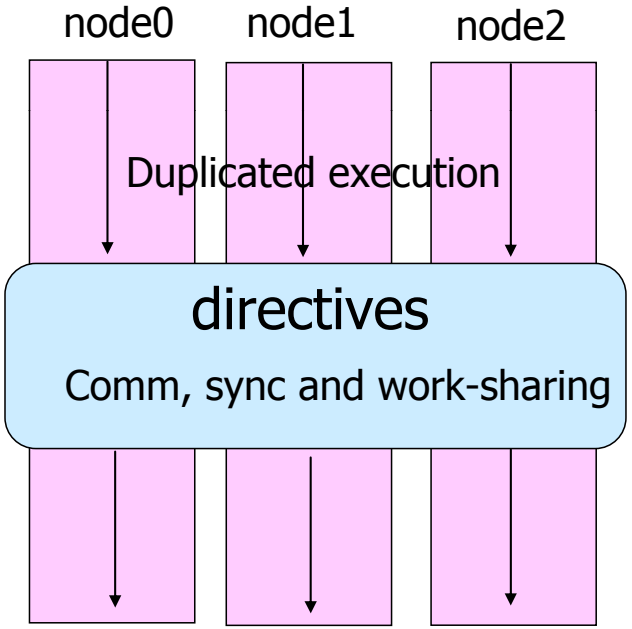
Requirements of “petascale” language

- Performance
  - The user can achieve performance “equivalent to in MPI”
  - More than MPI – one-sided communication (remote memory copy)
- Expressiveness
  - The user can express parallelism “equivalent in MPI” in easier way.
  - Task parallelism – for multi-physics
- Optimizability
  - Structured description of parallelism for analysis and optimization
  - Should have some mechanism to map to hardware network topology
- Education cost
  - For non-CS people, it should be not necessarily new, but practical

http://www.xcalablemp.org

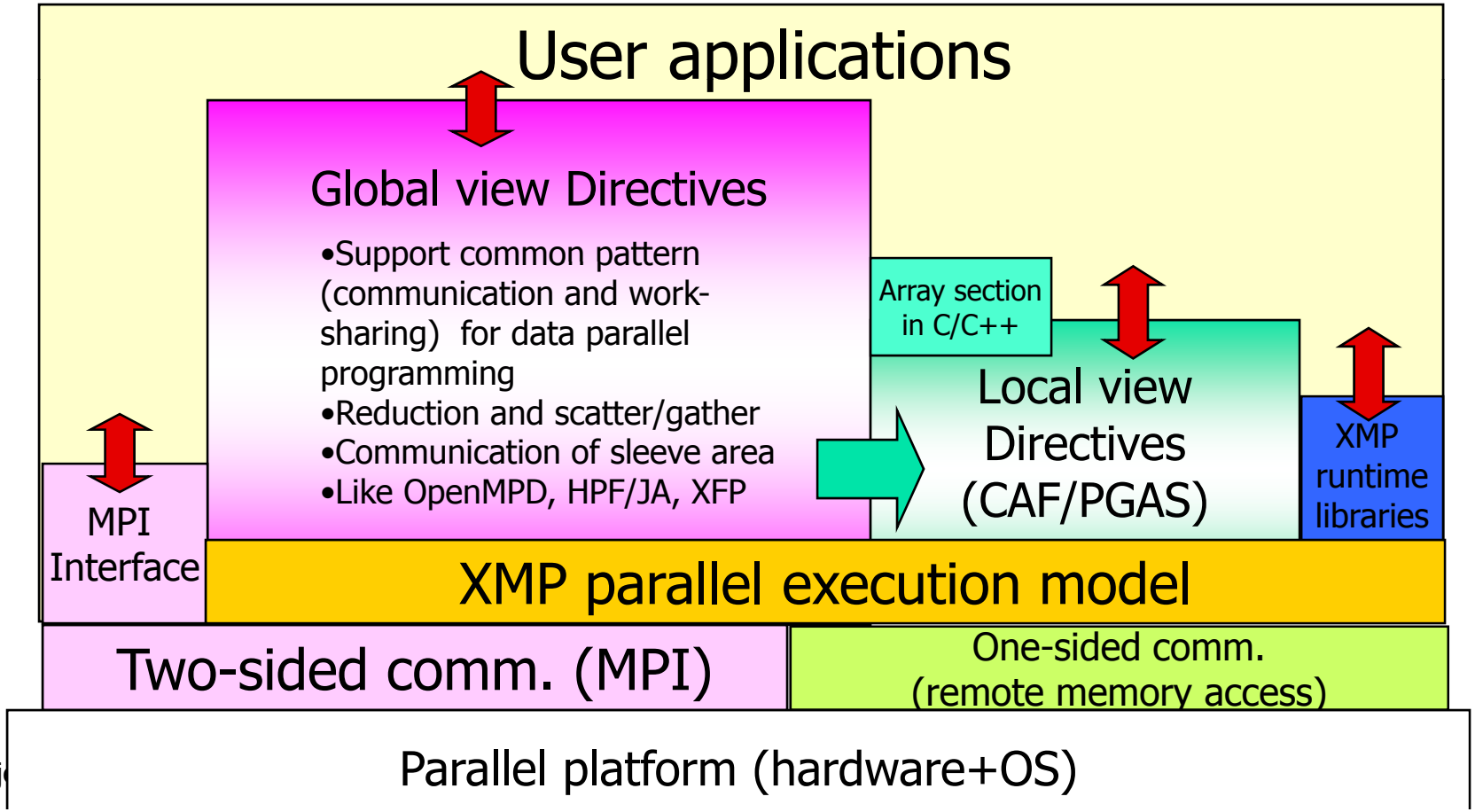
XcalableMP : directive-based language eXtension
for Scalable and performance-tunable Parallel Programming

- **Directive-based language extensions** for familiar languages F90/C/C++
  - To reduce code-rewriting and educational costs.
- **"Scalable" for Distributed Memory Programming**
  - SPMD as a basic execution model
  - A thread starts execution in each node independently (as in MPI) .
  - Duplicated execution if no directive specified.
  - MIMD for Task parallelism
- **"performance tunable" for explicit communication and synchronization.**
  - Work-sharing and communication occurs when directives are encountered
  - All actions are taken by directives for being "easy-to-understand" in performance tuning (different from HPF)



Overview of XcalableMP

- XMP supports typical parallelization based on the **data parallel paradigm** and work sharing under "**global view**“
  - An original sequential code can be parallelized with **directives**, like OpenMP.
- XMP also includes CAF-like PGAS (Partitioned Global Address Space) feature as "**local view**" programming.



Code Example

```
int array[YMAX][XMAX];

#pragma xmp nodes p(4)
#pragma xmp template t(YMAX)
#pragma xmp distribute t(block) on p
#pragma xmp align array[i][*] to t(i)

main(){
  int i, j, res;
  res = 0;

#pragma xmp loop on t(i)  reduction(+:res)
  for(i = 0; i < 10; i++)
    for(j = 0; j < 10; j++){
      array[i][j] = func(i, j);
      res += array[i][j];
    }
}
```

data distribution

add to the serial code : incremental parallelization

work sharing and data synchronization

The same code written in MPI

```
int array[YMAX][XMAX];

main(int argc, char**argv){
  int i,j,res,temp_res, dx,llimit,ulimit,size,rank;

  MPI_Init(argc, argv);
  MPI_Comm_rank(MPI_COMM_WORLD, &rank);
  MPI_Comm_size(MPI_COMM_WORLD, &size);
  dx = YMAX/size;
  llimit = rank * dx;
  if(rank != (size - 1)) ulimit = llimit + dx;
  else ulimit = YMAX;

  temp_res = 0;
  for(i = llimit; i < ulimit; i++)
    for(j = 0; j < 10; j++){
      array[i][j] = func(i, j);
      temp_res += array[i][j];
    }

  MPI_Allreduce(&temp_res, &res, 1, MPI_INT, MPI_SUM, MPI_COMM_WORLD);
  MPI_Finalize();
}
```

Nodes, templates and data/loop distributions

- Idea inherited from HPF
- Node is an abstraction of processor and memory in distributed memory environment.

#pragma xmp nodes p(32)

- Template is used as a dummy array distributed on nodes

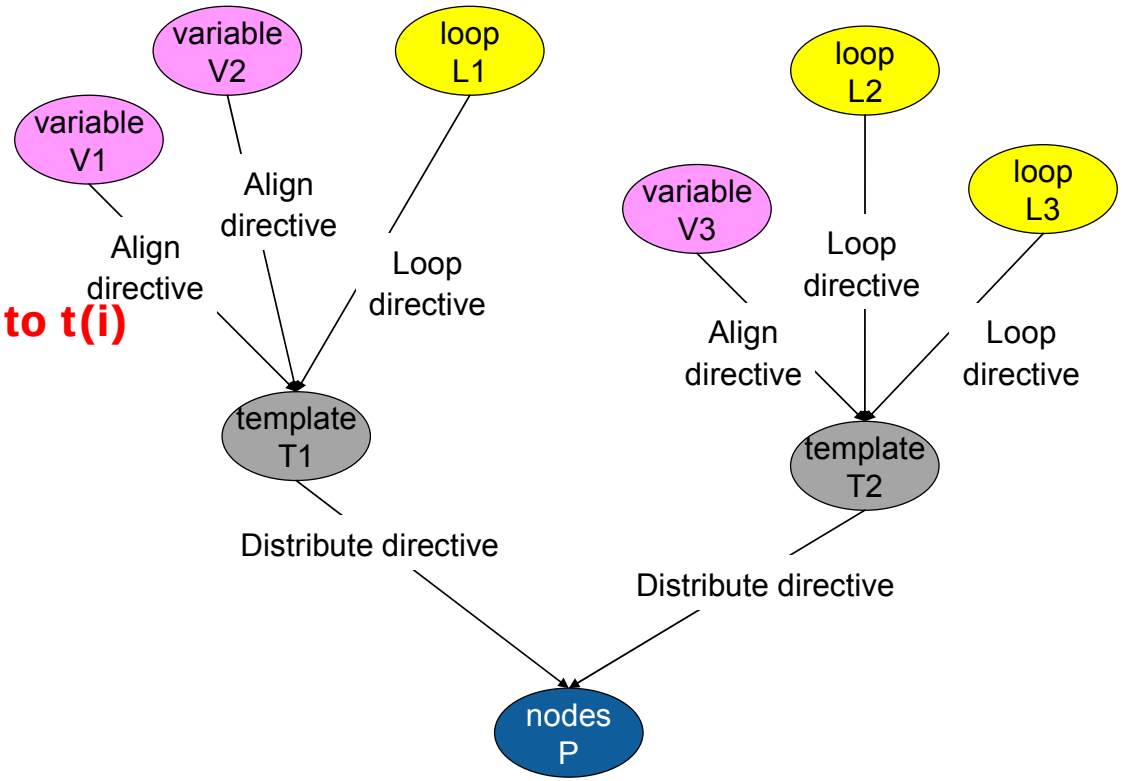
#pragma xmp template t(100)
#pragma distribute t(block) on p

- A global data is aligned to the template

#pragma xmp distribute array[i][*] to t(i)

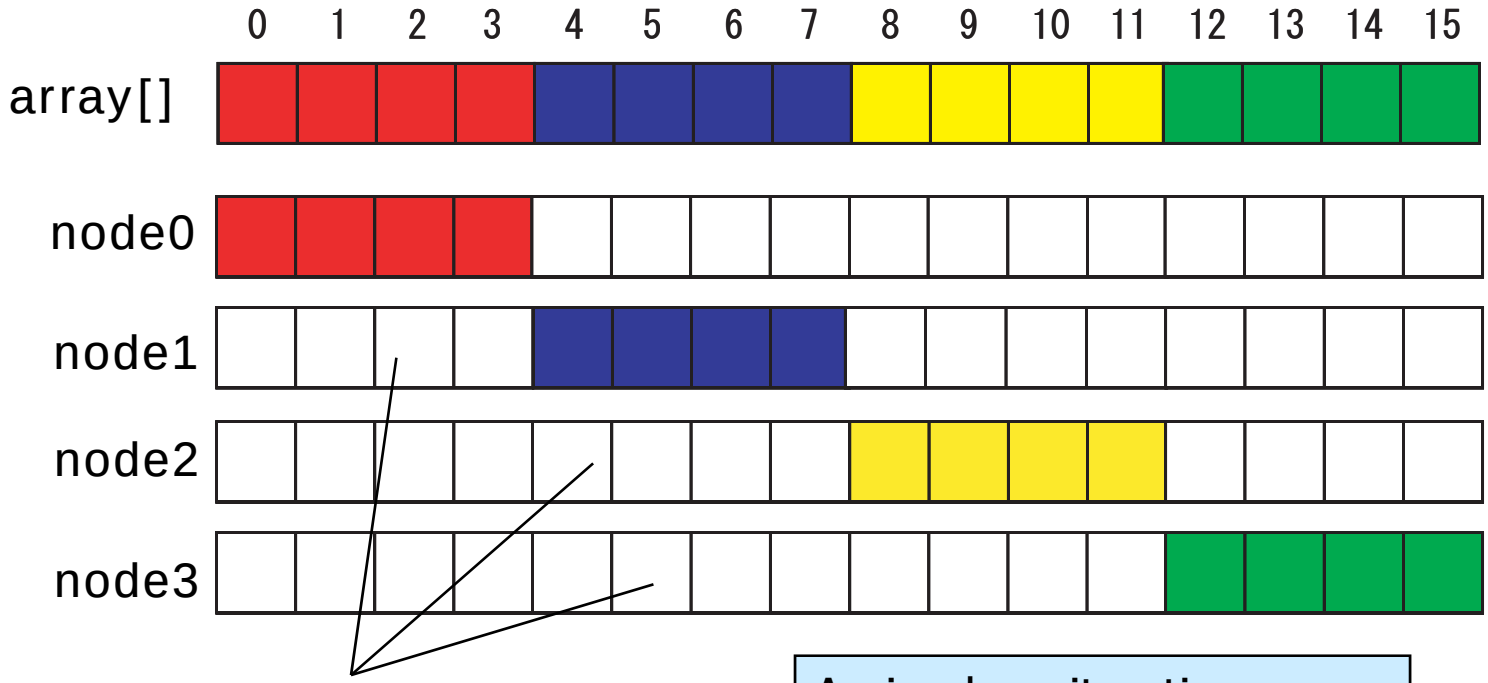
- Loop iteration must also be aligned to the template by on-clause.

#pragma xmp loop on t(i)



Array data distribution

- The following directives specify a data distribution among nodes
  - #pragma xmp nodes p(*)
  - #pragma xmp template T(0:15)
  - #pragma xmp distribute T(block) on p
  - #pragma xmp align array[i] to T(i)



Reference to assigned to other nodes may causes error!!

Assign loop iteration as to compute own regions

Communicate data between other nodes

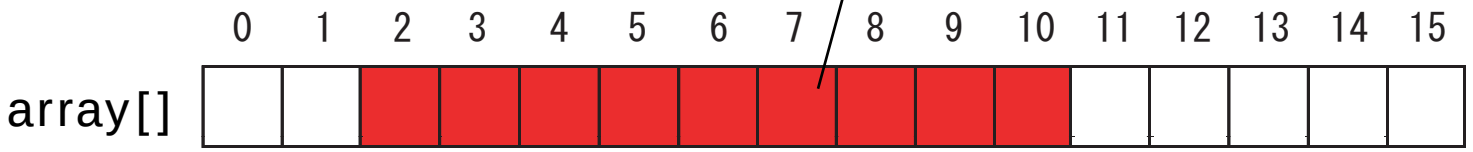
Parallel Execution of “for” loop

- Execute for loop to compute on array

```
#pragma xmp nodes p(*)
#pragma xmp template T(0:15)
#pragma xmp distributed T(block) on p
#pragma xmp align array[i] to T(i)
```

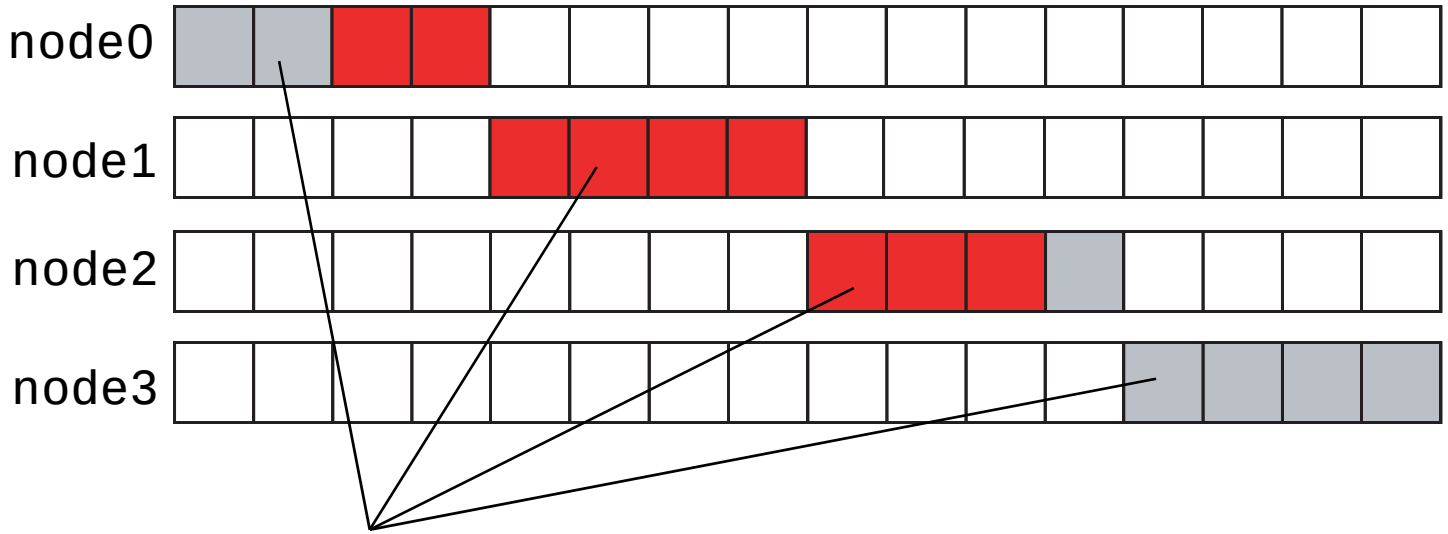
```
#pragma xmp loop on t(i)
for(i=2; i <=10; i++)
```

Data region to be computed by for loop



Execute “for” loop in parallel with affinity to array distribution by on-clause:

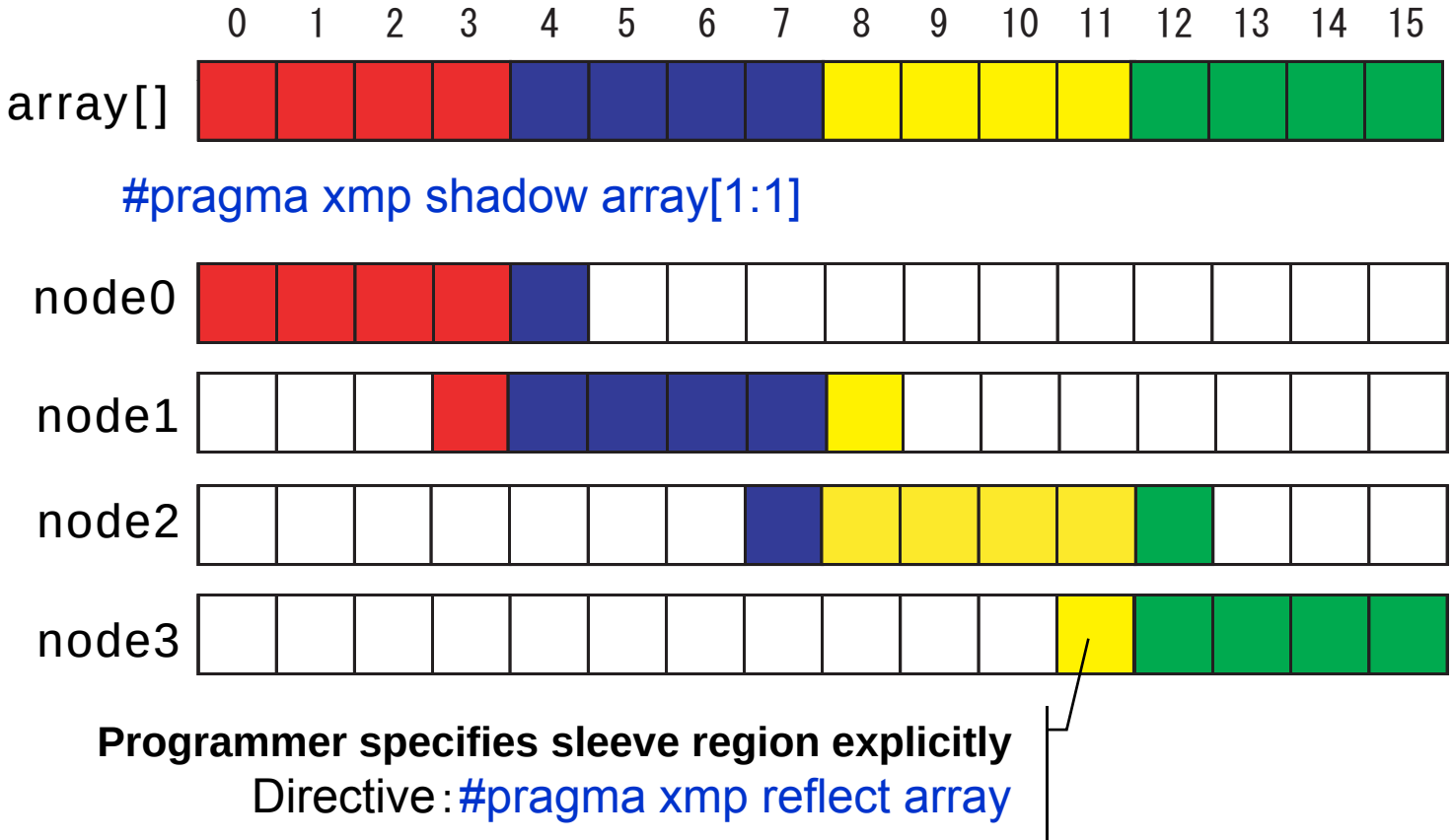
```
#pragma xmp loop on t(i)
```



Data synchronization of array (shadow)

- Exchange data only on “shadow” (sleeve) region
  - If neighbor data is required to communicate, then only sleeve area can be considered.
  - example：b[i] = array[i-1] + array[i+1]

#pragma xmp align array[i] to t(i)



XcalableMP example (Laplace, global view)

```
#pragma xmp nodes p(NPROCS)
#pragma xmp template t(1:N)
#pragma xmp distribute t(block) on p

double u[XSIZE+2][YSIZE+2],
       uu[XSIZE+2][YSIZE+2];
#pragma xmp align u[i][*] to t(i)
#pragma xmp align uu[i][*] to t(i)
#pragma xmp shadow uu[1:1][0:0]

lap_main()
{
 int x,y,k;
 double sum;
    …
```

Definition of nodes

Template to define distribution

Use “align” to specify data distribution
For data synchronization, use “shadow” directive specify sleeve area

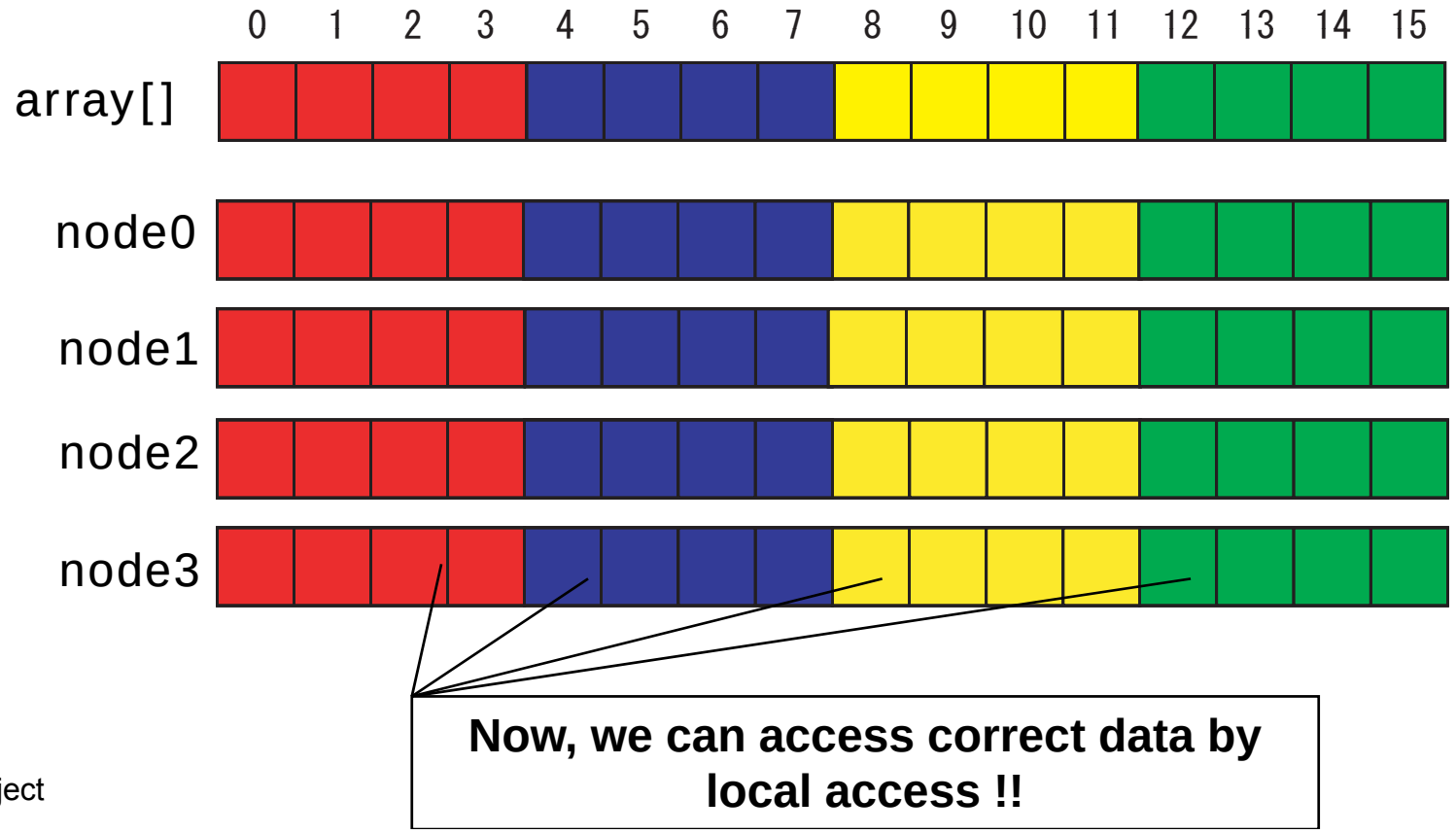
```
for(k = 0; k < NITER; k++){
        /* old <- new */
#pragma xmp loop on t(x)
        for(x = 1; x <= XSIZE; x++)
          for(y = 1; y <= YSIZE; y++)
            uu[x][y] = u[x][y];
#pragma xmp reflect uu
#pragma xmp loop on t(x)
        for(x = 1; x <= XSIZE; x++)
          for(y = 1; y <= YSIZE; y++)
            u[x][y] = (uu[x-1][y] + uu[x+1][y
                 uu[x][y-1] + uu[x][y+1])/4.0
    }
    /* check sum */
    sum = 0.0;
#pragma xmp loop on t[x] reduction(+:sum)
    for(x = 1; x <= XSIZE; x++)
        for(y = 1; y <= YSIZE; y++)
          sum += (uu[x][y]-u[x][y]);
#pragma xmp block on master
    printf("sum = %g\n",sum);
}
```

Loop partitioning
And scheduling

Data synchronization

Data synchronization of array (full shadow)

- Full shadow specifies whole data replicated in all nodes
  - #pragma xmp shadow array[*]
- reflect operation to distribute data to every nodes
  - #pragma reflect array
  - Execute communication to get data assigned to other nodes
  - Most easy way to synchronize → But, communication is expensive!



XcalableMP example (NPB CG, global view)

```
#pragma xmp nodes p(NPROCS)
#pragma xmp template t(N)
#pragma xmp distribute t(block) on p
...
#pragma xmp align [i] to t(i) :: x,z,p,q,r,w
#pragma xmp shadow [*] :: x,z,p,q,r,w
...
```

Define nodes

Define template distributed onto nodes

Align to the template for data distribution
In this case, use "full shadow"

```
/* code fragment from conj_grad in NPB CG */
sum = 0.0;
#pragma xmp loop on t(j) reduction(+:sum)
    for (j = 1; j <= lastcol-firstcol+1; j++) {
        sum = sum + r[j]*r[j];
    }
    rho = sum;
for (cgit = 1; cgit <= cgitmax; cgit++) {
#pragma xmp reflect p
#pragma xmp loop on t(j)
        for (j = 1; j <= lastrow-firstrow+1; j++) {
            sum = 0.0;
            for (k = rowstr[j]; k <= rowstr[j+1]-1; k+
                sum = sum + a[k]*p[colidx[k]];
            }
            w[j] = sum;
        }
#pragma xmp loop on t(j)
        for (j = 1; j <= lastcol-firstcol+1; j++) {
            q[j] = w[j];
        }
```

Work sharing
Loop scheduling

Data synchronization, in this case, all gather

XcalableMP Global view directives

- Execution only master node
  - #pragma xmp block on master
- Broadcast from master node
  - #pragma xmp bcast (*var*)
- Barrier/Reduction
  - #pragma xmp reduction (*op: var*)
  - #pragma xmp barrier
- Global data move directives for collective comm./get/put
- Task parallelism
  - #pragma xmp task on *node-set*

XcalableMP Local view directives

- XcalableMP also includes CAF-like PGAS (Partitioned Global Address Space) feature as "**local view**" programming.
  - The basic execution model of XcalableMP is SPMD
    - Each node executes the program independently on local data if no directive
  - We adopt Co-Array as our PGAS feature.
  - In C language, we propose array section construct.
  - Can be useful to optimize the communication
  - Support alias Global view to Local view

Array section in C

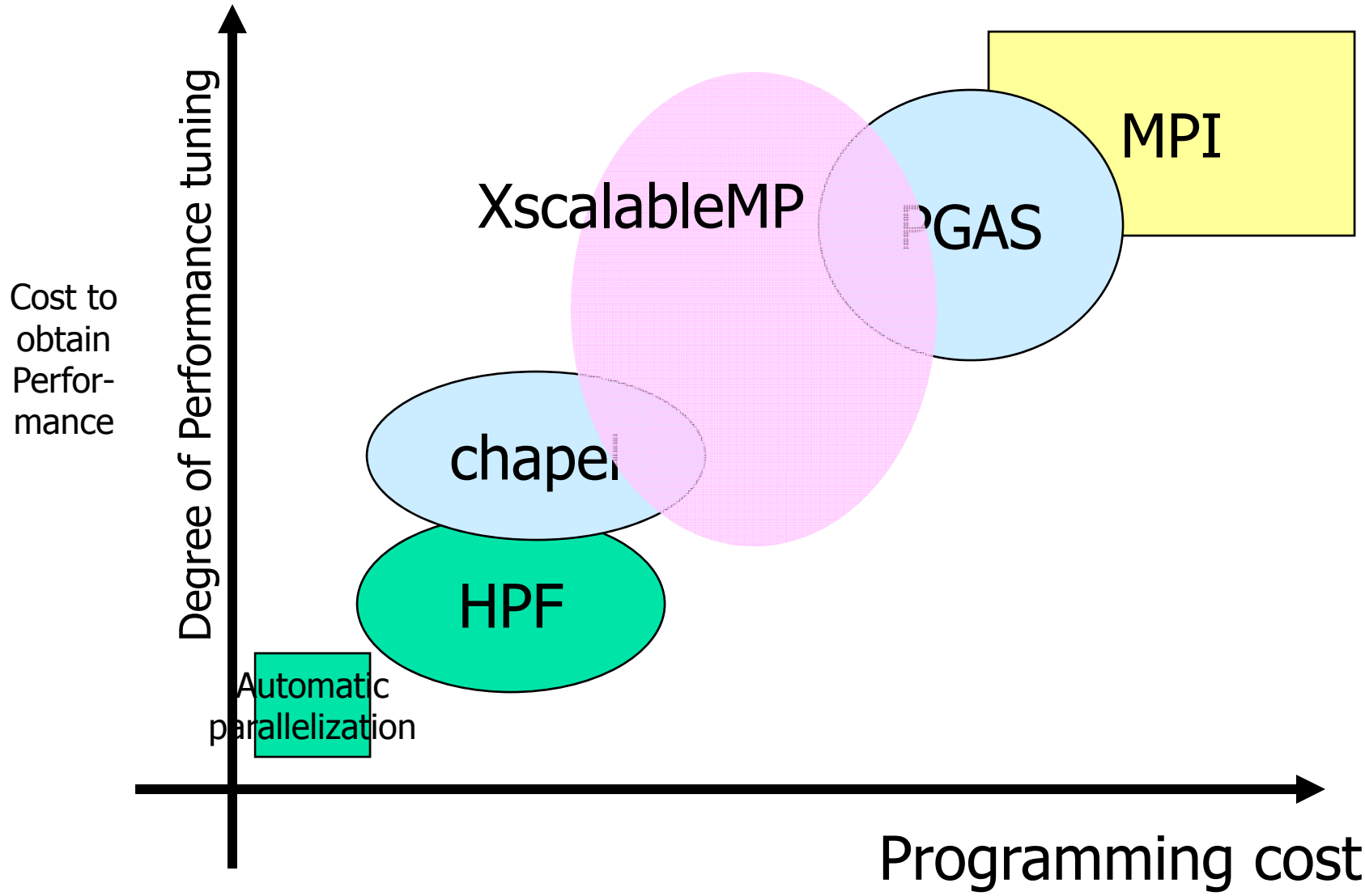
```
int A[10]:
int B[5];

A[4:9] = B[0:4];
```

```
int A[10], B[10];
#pragma xmp coarray [*]: A, B
…
A[:] = B[:]:[10];
```

- For flexibility and extensibility, the execution model allows **combining with explicit MPI coding** for more complicated and tuned parallel codes & libraries.
  - Need to interface to MPI at low level to allows the programmer to use MPI for optimization
  - It can be useful to program for large-scale parallel machine.
- For multi-core and SMP clusters, **OpenMP directives can be combined** into XcalableMP for thread programming inside each node for hybrid programming.

Position of XcalableMP



Summary

XcalableMP

http://www.xcalablemp.org

- Our objective of “language working group” is to design “standard” parallel programming language for petascale distributed memory systems
  - High productivity for distributed memory parallel programming
  - Not just for research, but collecting ideas for “standard”
  - Distributed memory programming “better than MPI” !!!
- XcalableMP project: status and schedule
  - 1Q/09 first draft of XcalableMP specification
  - 2Q/09 β release, C language version
  - 3Q/09 Fortran version (for SC09 HPC Challenge!)
  - Ask international community for review of the specification

Thank you for your attention!!!

XcalableMP is under design. Any comments and contributions will be very welcome!

Q & A?