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Barcelona Supercomputing Center
Centro Nacional de Supercomputación

Tutorial OmpSs: Overlapping communication and computation

PATC course

Parallel Programming Workshop

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Tutorial OmpSs

Agenda

10:00 – 11:00	Tasking in OpenMP 3.0 and 4.0	60 min
11:00 – 11:15	Coffee break	15 min
11:15 – 12:15	Introduction to OmpSs programming model • Introduction to StarSs • OmpSs syntax • Simple examples • Development methodology and infrastructure	60 min
12:15– 12:45	Practical: heat equation example and divide-and-conquer (part I)	30 min
12:45 – 14:00	Lunch	75 min
14:00 – 15:00	Practical: heat equation example and divide-and-conquer (part I)	90 min
15:00 – 15:30	Programming using a hybrid MPI/OmpSs approach	15 min
15:30 –	Practical: heat equation example and	105 min

Agenda

- Motivation for a hybrid model
- Overlapping communication with computation
- Examples
- Dynamic Load Balancing

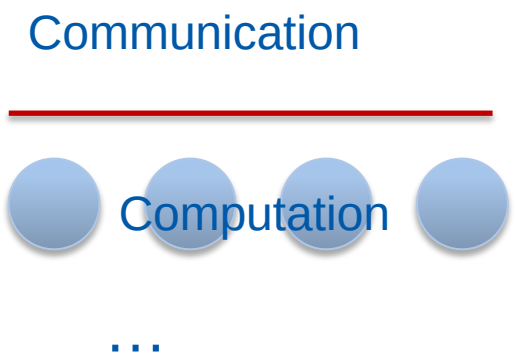
- Contact: pm-tools@bsc.es
- Source code available from http://pm.bsc.es/ompss/

MPI/StarSs hybrid programming

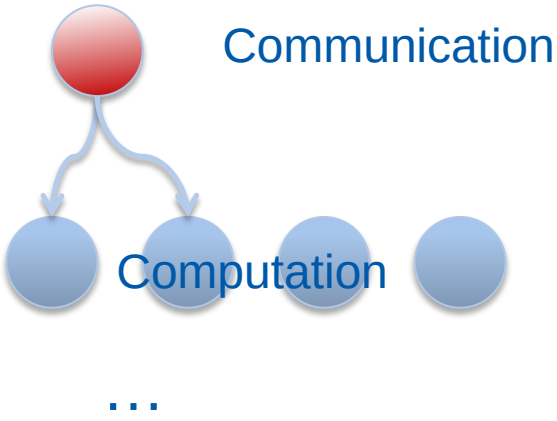
- Why hybrid?
  - MPI is here to stay.
  - A lot of HPC applications already written in MPI.
  - MPI scales well to tens/hundreds of thousands of nodes.
  - Everybody talks about MPI + X:
    - MPI exploits intra-node parallelism while X can exploit node parallelism but ...
- MPI + OmpSs
  - … propagates OmpSs features to global program behavior
  - Potential for automatic overlap of communication and computation through the inclusion of communication in the task graph

Interaction between MPI and StarSs models

- Communication can be taskified or not.
  - If not taskified:
    - Main program stalls till data to be sent and the reception buffers are available.
    - Still communication performed by main thread can overlap with previously generated tasks if they do not refer to communicated variables



  - If taskified:
    - It can be instantiated and program can proceed generating work
    - Tasks calling MPI will execute out of order with respect to any other task just honoring local dependences within the process



Taskifying communications

- Communication Tasks:
  - Single MPI communication
    - Could be done just modifying mpi.h
  - Burst of MPI communications (+ some small but potentially critical computation between them)
    - Less overhead
    - Typically the interprocess synchronization cost is paid in the first MPI call within the task

Taskifying communications

- Issues to consider
  - Possibly several concurrent MPI calls → thread safe MPI
    - Might not be available or really concurrent in some installations
  - MPI tasks waste cores if communication partner delays or long transfer times
    - Less problem as more and more cores per node become available
  - Reordering of MPI calls + blocking calls + limited number of cores → potential to introduce deadlock
    - → need to control order of communication tasks

Deadlock potential when taskifying communications

- Approaches to handle
  - Algorithmic structure may not expose loop and thus be deadlock safe
  - Enforce in order execution of communicating tasks
    - In the source code, possibly using a single sentinel specified as inout for all communication tasks
    - Specialized logical device (implemented in SMPSs, not in OmpSs)

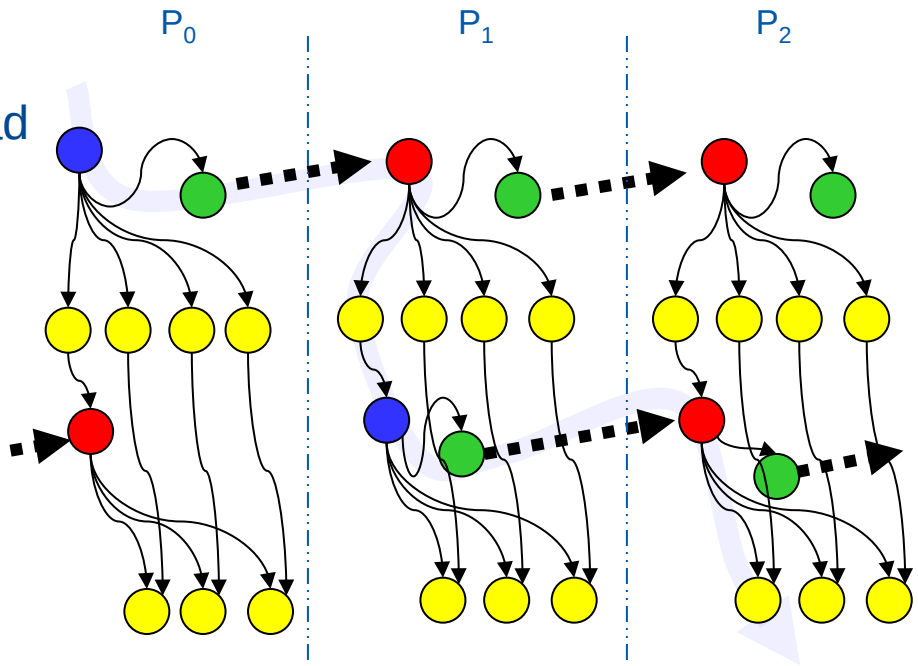
      #target device (COMM_THREAD)

      - Modification in runtime scheduler to execute tasks allocated to it in instantiation order
    - Serialization of communication can have an impact on performance
  - Virtualize communication resource. Allow infinite communication tasks
    - Integrated implementation of MPI interface in the OmpSs runtime
    - Implement blocking MPI calls by issuing nonblocking MPI calls blocking the task in NANOS and reactivate then when communication completes

Hybrid MPI/StarSs

- Overlap communication/computation
- Extend asynchronous data-flow execution to outer level
- Linpack example: Automatic lookahead

```
…
for (k=0; k<N; k++) {
   if (mine) {
      Factor_panel(A[k]);
      send (A[k])
   } else {
      receive (A[k]);
      if (necessary) resend (A[k]);
   }
   for (j=k+1; j<N; j++)
      update (A[k], A[j]);
…
```



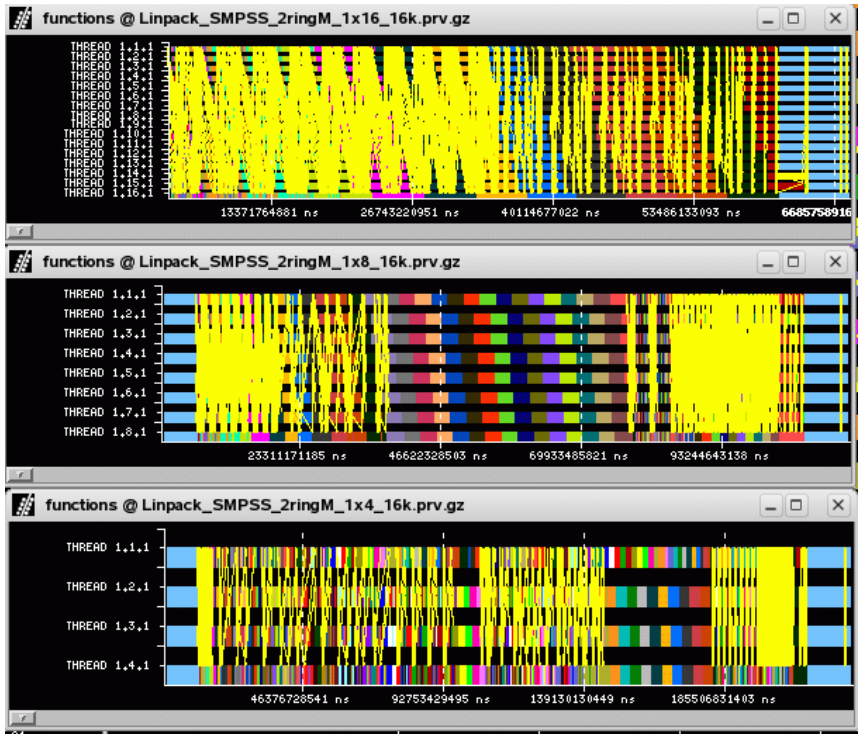

```
#pragma omp task inout([SIZE] A)
void Factor_panel(float *A);
#pragma omp task in([SIZE]A) inout([SIZE]B)
void update(float *A, float *B);
```

```
#pragma omp task in([SIZE]A)
void send(float *A);
#pragma omp task out([SIZE]A)
void receive(float *A);
#pragma omp task in([SIZE]A)
void resend(float *A);
```


V. Marjanovic, et al, "Overlapping Communication and Computation by using a Hybrid MPI/SMPSs Approach" ICS 2010

Hybrid MPI/OmpSs

- Overlap communication/computation
- Extend asynchronous data-flow execution to outer level
- Linpack example: Automatic lookahead




```
…
for (k=0; k<N; k++) {
   if (mine) {
      Factor_panel(A[k]);
      send (A[k])
   } else {
      receive (A[k]);
      if (necessary) resend (A[k]);
   }
   for (j=k+1; j<N; j++)
      update (A[k], A[j]);
…
```

```
#pragma omp task inout([SIZE]A)
void Factor_panel(float *A);
#pragma omp task in([SIZE]A) inout([SIZE]B)
void update(float *A, float *B);
```

```
#pragma omp task in([SIZE]A)
void send(float *A);
#pragma omp task out([SIZE]A)
void receive(float *A);
#pragma omp task in([SIZE]A)
void resend(float *A);
```

MxM @ MPI

```
// m: matriz size; n: local row/columns

double A[n][m], B[m][n], C[m][n], *a, *rbuf;

orig_rbuf = rbuf = (double (*)[m])malloc(m*n*sizeof(double));
if (nodes >1) { up=me<nodes-1 ? me+1:0; down=me>0 ? me-1:nodes-1;}
else { up = down = MPI_PROC_NULL; }

a=A;
i = n*me;  // first C block (different for each process)

for( it=0; it<nodes; it++ ) {

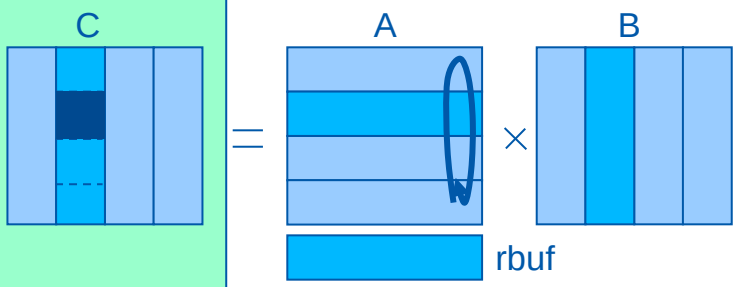
   mxm( m, n, a, B, (double (*)[n])&C[i][0]);

   callSendRecv(m, n, a, down, rbuf, up);

   //next C block circular
   i = (i+n)%m;
   //swap pointers
   ptmp=a; a=rbuf; rbuf=ptmp;

}


free (orig_rbuf);
```




```
void mxm ( int m, int n, double *a, double *b, double *c ) {
   double alpha=1.0, beta=1.0;
   int i, j;
   char tr = 't';
   dgemm(&tr, &tr, &m, &n, &n, &alpha, a, &m, b, &n, &beta, c, &n);
}
```

```
void callSendRecv(int m, int n,
                  double (*a)[m], int down,
                  double (*rbuf)[m], int up)
{
   int tag = 1000;
   int size = m*n;
   MPI_Status stats;

   MPI_Sendrecv( a, size, MPI_DOUBLE, down, tag,
                 rbuf, size, MPI_DOUBLE, up, tag,
                 MPI_COMM_WORLD, &stats);
}
```

MxM @ MPI + OmpSs: MPI calls not taskified

```
// m: matriz size; n: local row/columns

double A[n][m], B[m][n], C[m][n], *a, *rbuf;

orig_rbuf = rbuf = (double (*)[m])malloc(m*n*sizeof(double));
if (nodes >1) { up=me<nodes-1 ? me+1:0; down=me>0 ? me-1:nodes-1;}
else { up = down = MPI_PROC_NULL; }

a=A;
i = n*me;  // first C block (different for each process)

for( it=0; it<nodes; it++ ) {

   mxm( m, n, a, B, (double (*)[n])&C[i][0]);

   callSendRecv(m, n, a, down, rbuf, up);

   //next C block circular
   i = (i+n)%m;
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   ptmp=a; a=rbuf; rbuf=ptmp;

}


free (orig_rbuf);
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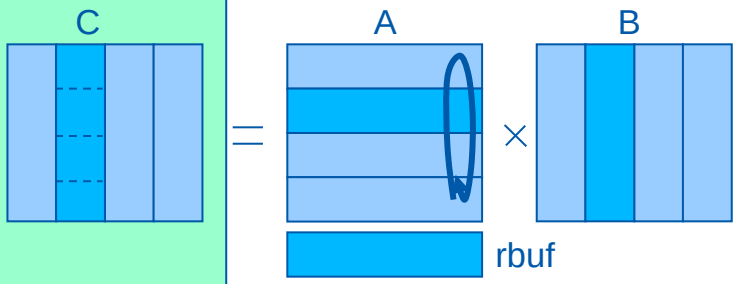


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void mxm ( int m, int n, double *a, double *b, double *c ) {
   double alpha=1.0, beta=1.0;
   int i, j, l=1;
   char tr = 't';
   for (i=0; i<n; i++) {
      #pragma omp task
      dgemm(&tr, &tr, &m, &n, &l, &alpha, a, &m, b, &n, &beta, c, &n);
      c+=n;
      a+=m;
      b+=n;
   }
   #pragma omp taskwait
}
```

```
void callSendRecv(int m, int n,
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   int tag = 1000;
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   MPI_Status stats;

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}
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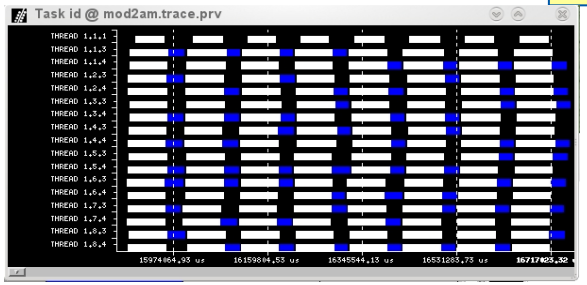

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else { up = down = MPI_PROC_NULL; }

a=A;
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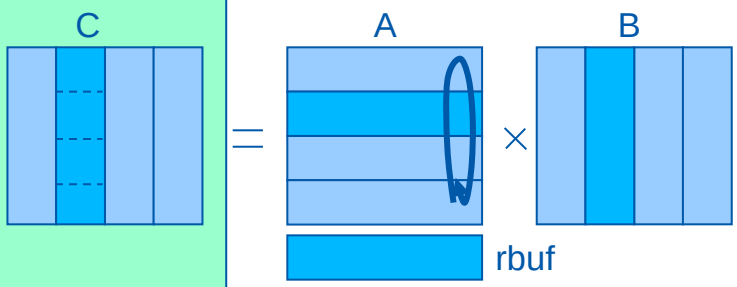
for( it=0; it<nodes; it++ ) {

   mxm( m, n, a, B, (double (*)[n])&C[i][0]);

   callSendRecv(m, n, a, down, rbuf, up);

   //next C block circular
   i = (i+n)%m;
   //swap pointers
   ptmp=a; a=rbuf; rbuf=ptmp;
   #pragma omp taskwait
}


free (orig_rbuf);
```

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   char tr = 't';
   for (i=0; i<n; i++) {
      #pragma omp task
      dgemm(&tr, &tr, &m, &n, &l, &alpha, a, &m, b, &n, &beta, c, &n);
      c+=n;
      a+=m;
      b+=n;
   }

}
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```
void callSendRecv(int m, int n,
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   MPI_Status stats;

   MPI_Sendrecv( a, size, MPI_DOUBLE, down, tag,
                 rbuf, size, MPI_DOUBLE, up, tag,
                 MPI_COMM_WORLD, &stats);
}
```

- Overlap computation in tasks and communication in master

MxM @ MPI + OmpSs: MPI calls taskified

```
// m: matriz size; n: local row/columns

double A[n][m], B[m][n], C[m][n], *a, *rbuf;

orig_rbuf = rbuf = (double (*)[m])malloc(m*n*sizeof(double));
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else { up = down = MPI_PROC_NULL; }

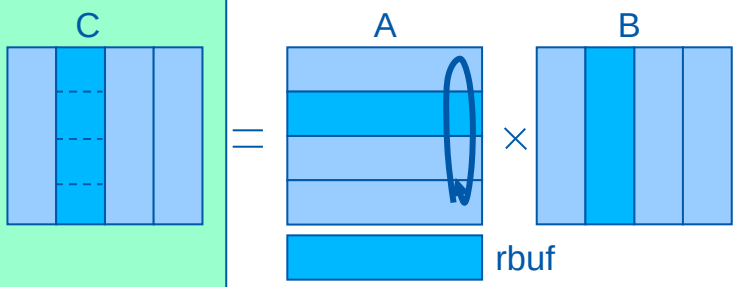
a=A;
i = n*me;  // first C block (different for each process)

for( it=0; it<nodes; it++ ) {

   mxm( m, n, a, B, (double (*)[n])&C[i][0]);
   #pragma omp task in([n][m]a) out([n][m]rbuf)
   callSendRecv(m, n, a, down, rbuf, up);

   //next C block circular
   i = (i+n)%m;
   //swap pointers
   ptmp=a; a=rbuf; rbuf=ptmp;
   #pragma omp taskwait
}


free (orig_rbuf);
```

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   double alpha=1.0, beta=1.0;
   int i, j, l=1;
   char tr = 't';
   for (i=0; i<n; i++) {
      #pragma omp task
      dgemm(&tr, &tr, &m, &n, &l, &alpha, a, &m, b, &n, &beta, c, &n);
      c+=n;
      a+=m;
      b+=n;
   }

}
```

```
void callSendRecv(int m, int n,
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                  double (*rbuf)[m], int up)
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   int size = m*n;
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   MPI_Sendrecv( a, size, MPI_DOUBLE, down, tag,
                 rbuf, size, MPI_DOUBLE, up, tag,
                 MPI_COMM_WORLD, &stats);
}
```

- Overlap computation in tasks and communication in task

MxM @ MPI + OmpSs: MPI calls taskified

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// m: matriz size; n: local row/columns

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if (nodes >1) { up=me<nodes-1 ? me+1:0; down=me>0 ? me-1:nodes-1;}
else { up = down = MPI_PROC_NULL; }

a=A;
i = n*me;  // first C block (different for each process)

for( it=0; it<nodes; it++ ) {
   #pragma omp task in( [n][m]a, B ) inout ( C[i;n][0;n] )
   mxm( m, n, a, B, (double (*)[n])&C[i][0]);
   #pragma omp task in([n][m]a) out([n][m]rbuf)
   callSendRecv(m, n, a, down, rbuf, up);

   //next C block circular
   i = (i+n)%m;
   //swap pointers
   ptmp=a; a=rbuf; rbuf=ptmp;
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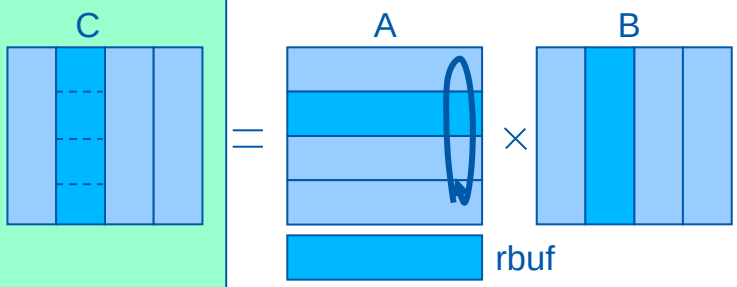
}


free (orig_rbuf);
```

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   char tr = 't';
   for (i=0; i<n; i++) {
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      dgemm(&tr, &tr, &m, &n, &l, &alpha, a, &m, b, &n, &beta, c, &n);
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}
```

- Nested. Overlap between computation and communication in tasks

MxM @ MPI + OmpSs: MPI calls taskified

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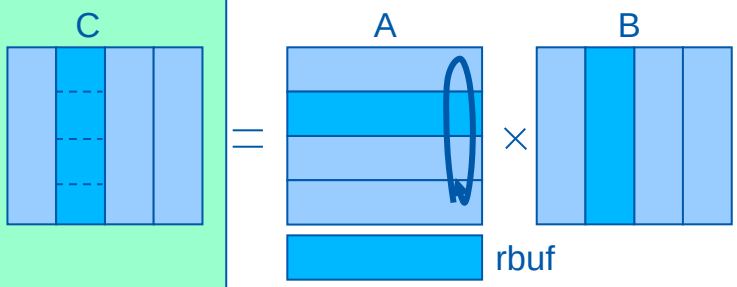
for( it=0; it<nodes; it++ ) {
   #pragma omp task in( [n][m]a, B ) inout ( C[i;n][0;n] )
   mxm( m, n, a, B, (double (*)[n])&C[i][0]);
   #pragma omp task in([n][m]a) out([n][m]rbuf)
   callSendRecv(m, n, a, down, rbuf, up);

   //next C block circular
   i = (i+n)%m;
   //swap pointers
   ptmp=a; a=rbuf; rbuf=ptmp;

}
#pragma omp taskwait

free (orig_rbuf);
```

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   char tr = 't';
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      dgemm(&tr, &tr, &m, &n, &l, &alpha, a, &m, b, &n, &beta, c, &n);
      c+=n;
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      b+=n;
   }
   #pragma omp taskwait
}
```

```
void callSendRecv(int m, int n,
                  double (*a)[m], int down,
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{
   int tag = 1000;
   int size = m*n;
   MPI_Status stats;

   MPI_Sendrecv( a, size, MPI_DOUBLE, down, tag,
                 rbuf, size, MPI_DOUBLE, up, tag,
                 MPI_COMM_WORLD, &stats);
}
```

- Can start computation of next block of C as soon as communication terminates

MxM @ MPI + OmpSs: MPI calls taskified

```
// m: matriz size; n: local row/columns

double A[n][m], B[m][n], C[m][n], *a, *rbuf;

orig_rbuf = rbuf = (double (*)[m])malloc(m*n*sizeof(double));
if (nodes >1) { up=me<nodes-1 ? me+1:0; down=me>0 ? me-1:nodes-1;}
else { up = down = MPI_PROC_NULL; }

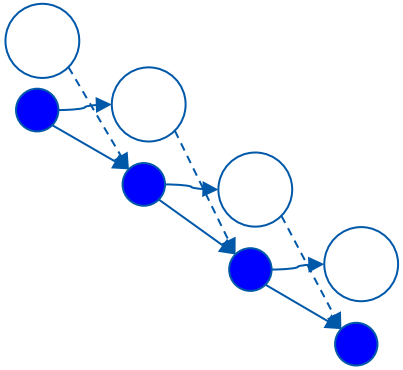
a=A;
i = n*me;  // first C block (different for each process)

for( it=0; it<nodes; it++ ) {
   #pragma omp task in( [n][m]a, B ) inout ( C[i;n][0;n] ) label (white)
   mxm( m, n, a, B, (double (*)[n])&C[i][0]);
   #pragma omp task in([n][m]a) out([n][m]rbuf) label (blue)
   callSendRecv(m, n, a, down, rbuf, up);

   //next C block circular
   i = (i+n)%m;
   //swap pointers
   ptmp=a; a=rbuf; rbuf=ptmp;

}
#pragma omp taskwait

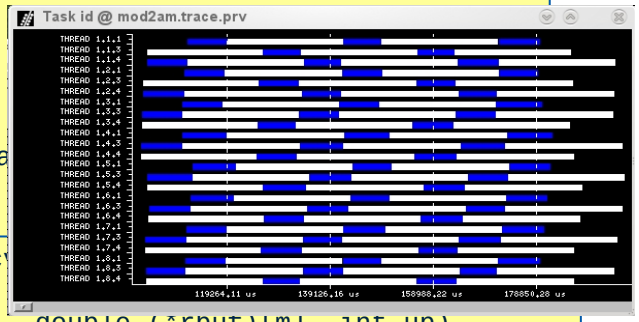
free (orig_rbuf);
```



```
void mxm ( int m, int n, double *a, double *b, double *c ) {
   double alpha=1.0, beta=1.0;
   int i, j, l=1;
   char tr = 't';
   for (i=0; i<n; i++) {

      dgemm(&tr, &tr, &m, &n, &l, &alpha, a
      c+=n;
      a+=m;
      b+=n;
   }

}
```



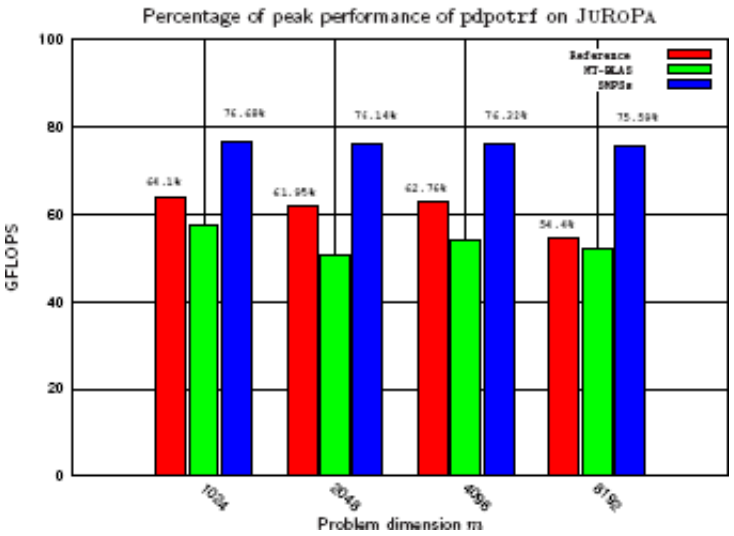

```
void callSendRecv
                                  double (*rbuf)[m], int up)
{
   int tag = 1000;
   int size = m*n;
   MPI_Status stats;

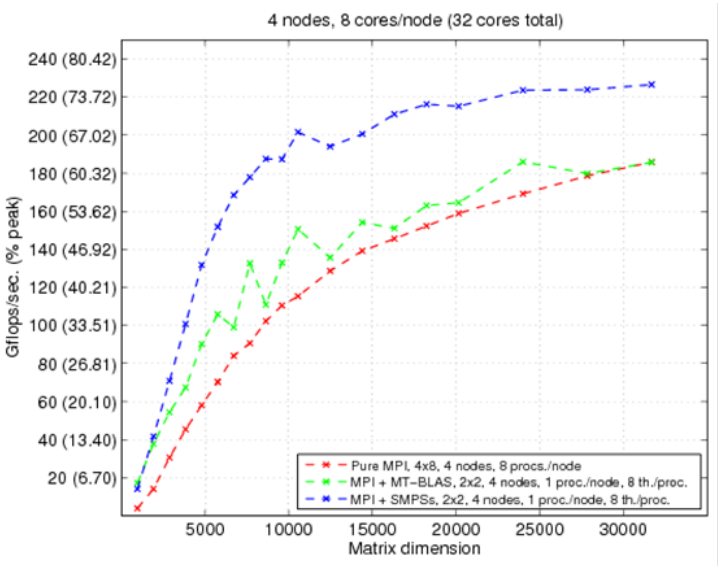
   MPI_Sendrecv( a, size, MPI_DOUBLE, down, tag,
                 rbuf, size, MPI_DOUBLE, up, tag,
                 MPI_COMM_WORLD, &stats);
}
```

- Can obtain parallelism even without parallelizing the computation

Scalapack

- Cholesky factorization
  - Example of the issues in porting legacy code
  - Demonstration that it is feasible
  - Synchronization tasks to emulate array sections behavior
    - Overhead more than compensated by flexibility
  - The importance of scheduling
    - ~ 10% difference in global performance
  - Some difficulties with legacy codes
    - Structure of sequential code
    - Memory allocation



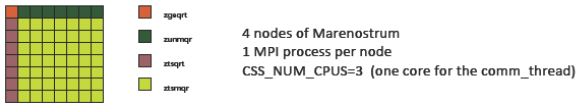


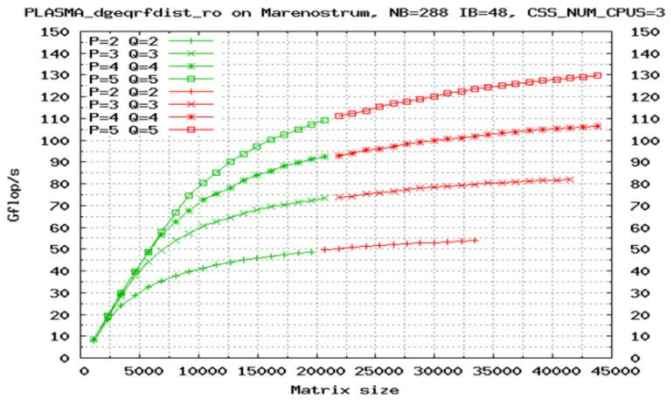
PLASMA

- UniMAN
- Dense linear algebra for multicore (QR and LU)
- Scheduling of computations and communications
  - Impact of serialization in communication thread
- Potential to integrate libraries and application parallelism

```
#pragma css task input(M, N, IB, LDA, LDT) inout(A[LDA*N]) output(T[IB*LDT])
  output(TAU[LDA], WORK[LDA*IB]) highpriority
int  CORE_zgeqrt(int M, int N, int IB,
                 PLASMA_Complex64_t *A, int LDA,
                 PLASMA_Complex64_t *T, int LDT,
                 PLASMA_Complex64_t *TAU, PLASMA_Complex64_t *WORK);

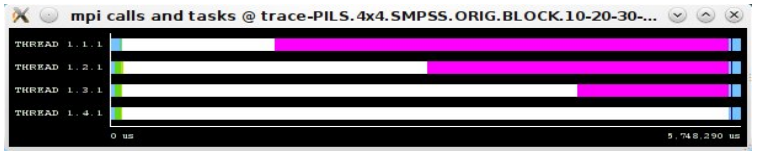
#pragma css task input(side, trans, M, N, K, IB, LDV, LDT, LDC, LDWORK)
  input(V[LDV*LDV], T[IB*LDT]) inout(C[LDC*N]) output(WORK[LDWORK*IB])
int CORE_zunmqr( int side, int trans,
                 int M, int N, int K, int IB,
                 PLASMA_Complex64_t *V, int LDV,
                 PLASMA_Complex64_t *T, int LDT,
                 PLASMA_Complex64_t *C, int LDC,
                 PLAS
```



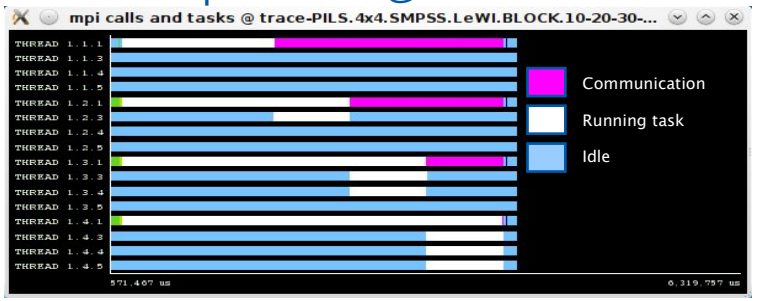


Dynamic Load Balancing: LeWI

- Automatically achieved by the runtime
  - Load balance within node
  - Fine grain
  - Complementary to user level load balance
  - **Leverage OmpSs malleability**
- LeWI: Lend core When Idle
  - User level Run time Library (DLB) coordinating processes within node
  - Lend cores to other processes in the node when entering blocking MPI calls
  - Retrieve when leaving blocking MPI
  - Fighting the Linux kernel: Explicit pinning of threads to cores



4 MPI processes @ 4 cores node

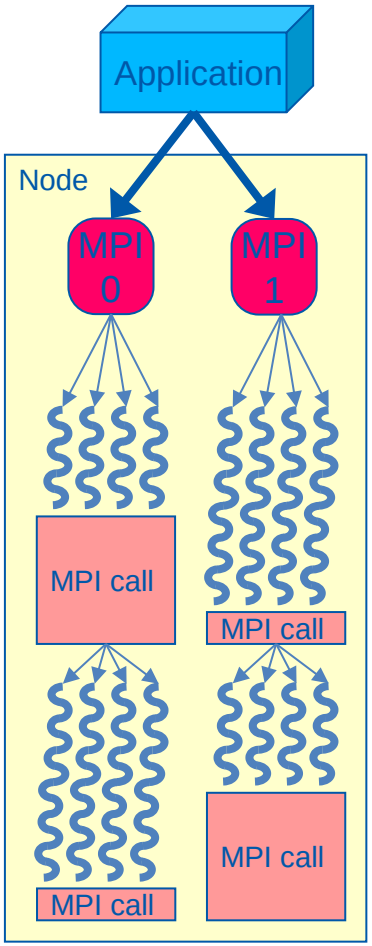


"LeWI: A Runtime Balancing Algorithm for Nested Parallelism". M.Garcia et al. ICPP09

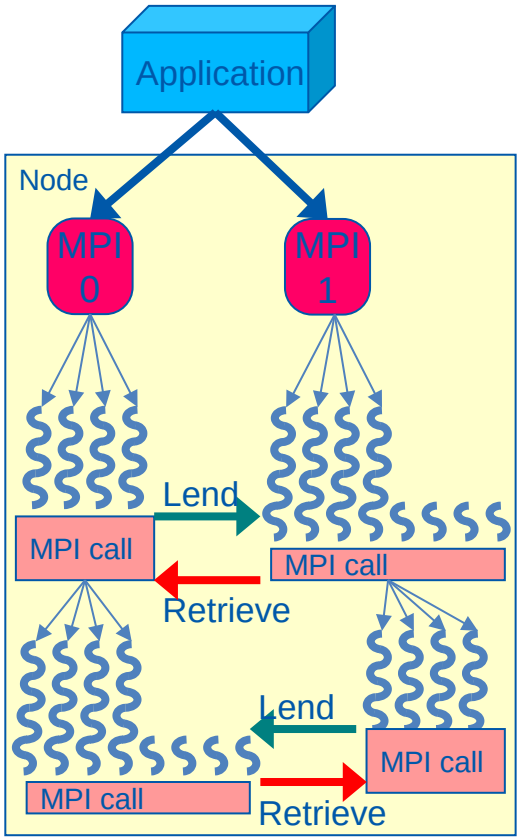
LeWI Load Balancing

- **LeWI**: Lend When Idle
  - An MPI process lends its cpus when inside a blocking MPI call.
  - Another MPI process in the same node can use the lended cpus to run with more threads.
  - When the MPI call is finished the MPI process retrieves it's cpus
- Can handle irregular imbalance
- Its performance depends on the malleability of the second level of parallelism...

- Unbalanced application

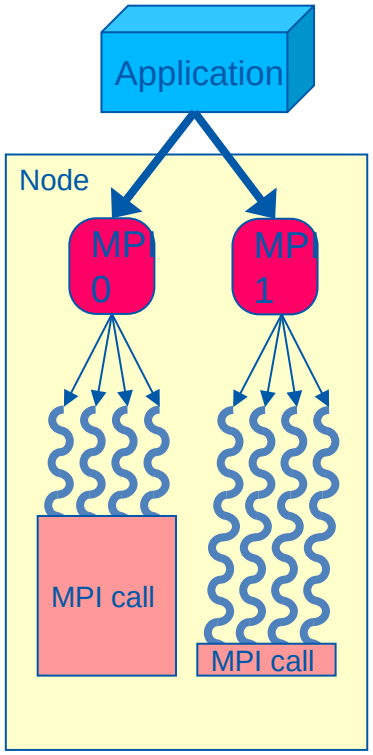


- Execution with DLB

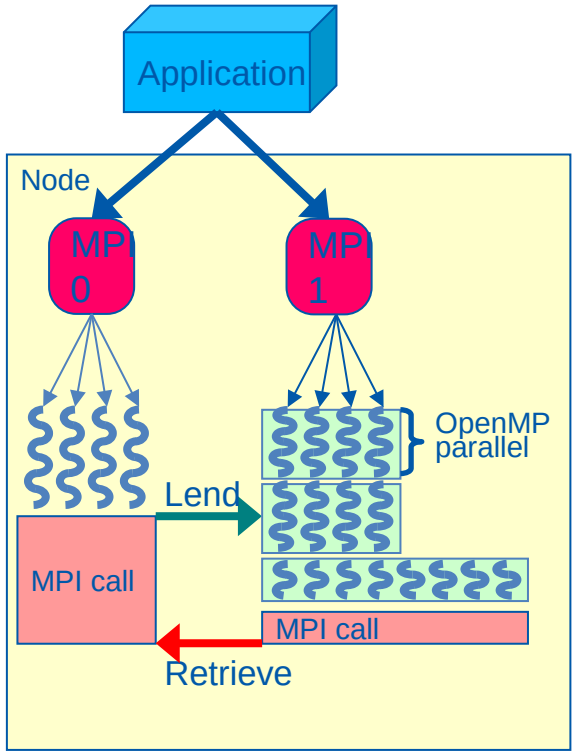


LeWI - Malleability

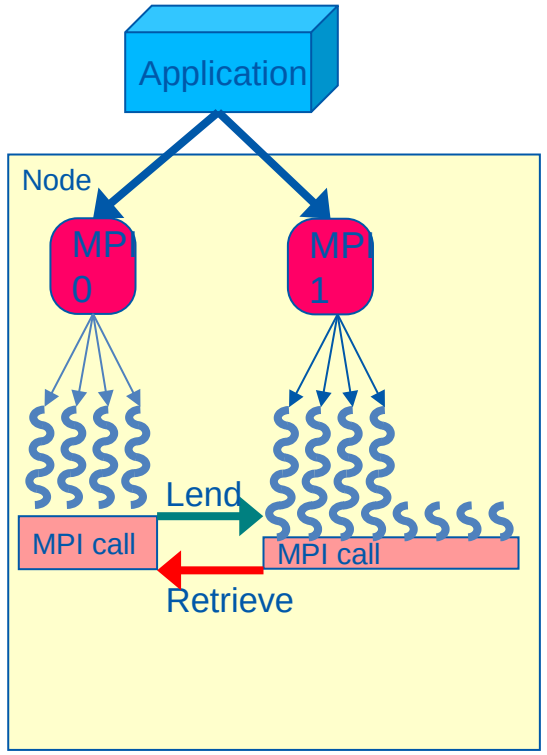
- Unbalanced application



- Execution with DLB MPI+OpenMP



- Execution with DLB MPI+OmpSs



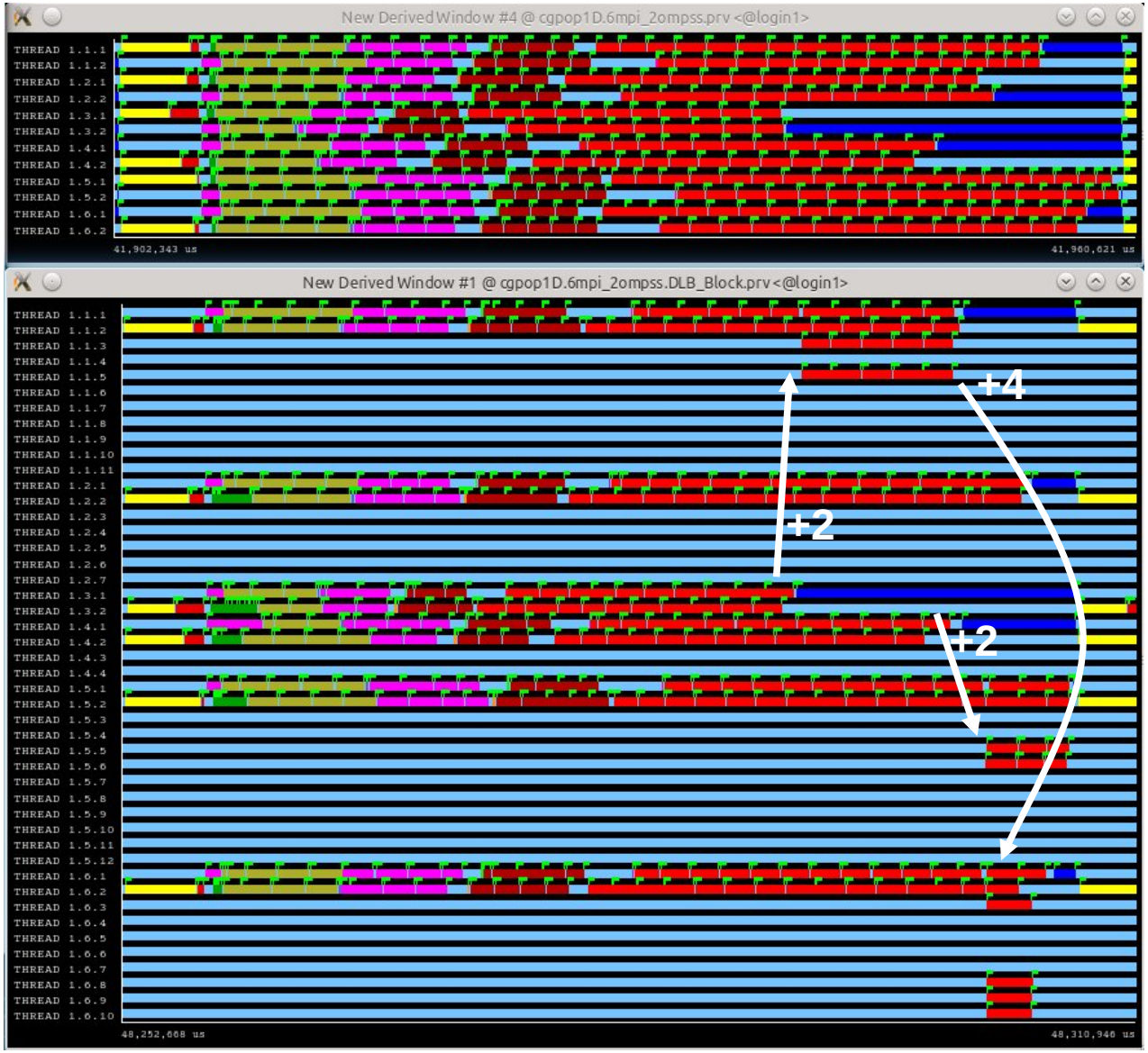
DLB in action

Original

- 6 MPIs
- 2 threads x MPI

DLB

- 6 MPIs
- Initial 2 threads x MPI
- Up to 12 threads x MPI
- 12 threads active at most



Idle

Barrier

Tasks

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Centro Nacional de Supercomputación

Thank you!

For further information please contact
rosa.m.badia@bsc.es

Problems taskifying communications

- Problems:
  - Possibly several concurrent MPI calls
    - Need to use thread safe MPI
  - Reordering of MPI calls + limited number of cores → potential source of deadlocks
    - Need to control order of communication tasks
    - Use of sentinels if necessary
  - MPI task waste cores (busy waiting if communication partner delays or long transfer times)
    - An issue today, may be not with many core nodes.