Barcelona Supercomputing Center
Centro Nacional de Supercomputación

EXCELENCIA SEVERO OCHOA

Parallel Programming

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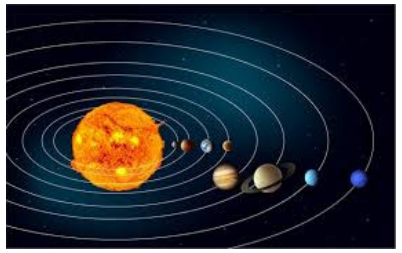
BSC & UPC

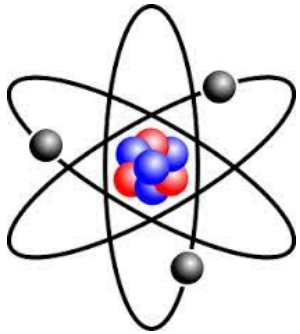
Barcelona, Jujy 1st 2019

What am I doing here ?

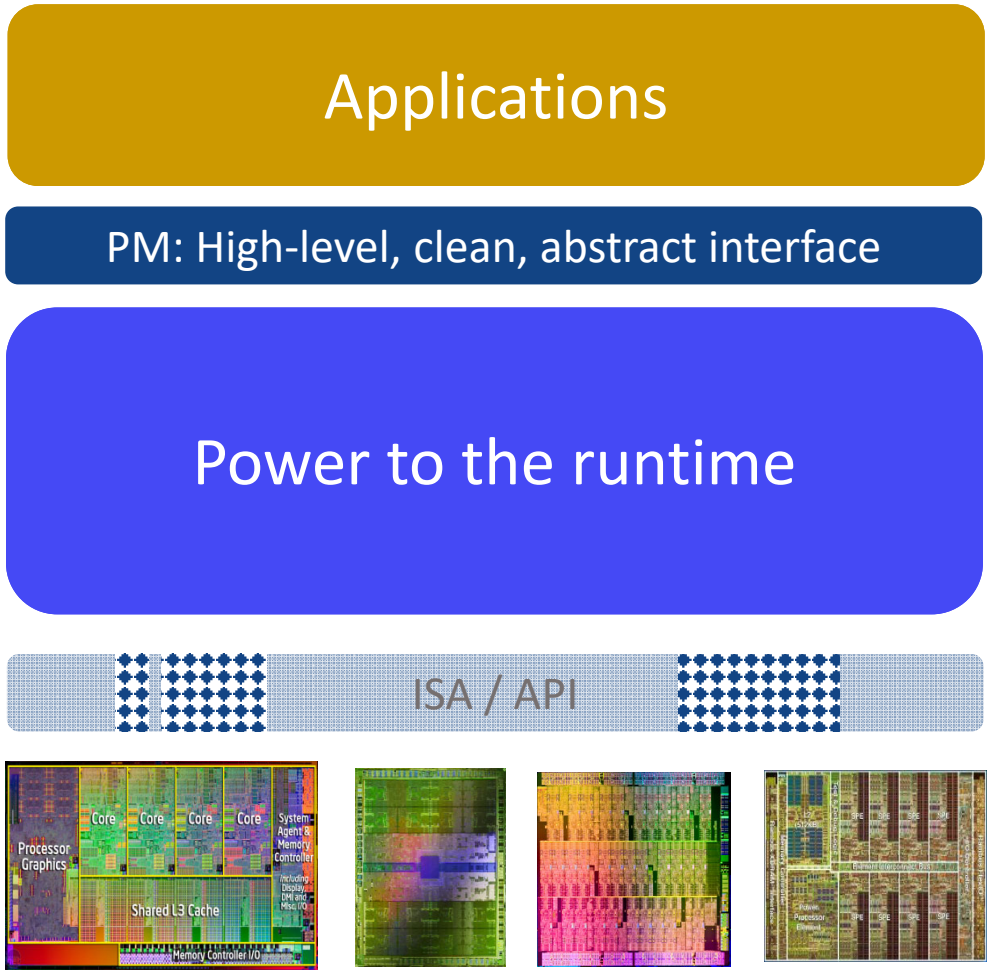
“As below, so above”

- Leverage computer architecture background …
- … in higher levels of the system stack
- Looking for further insight





The Programming model osmotic membrane

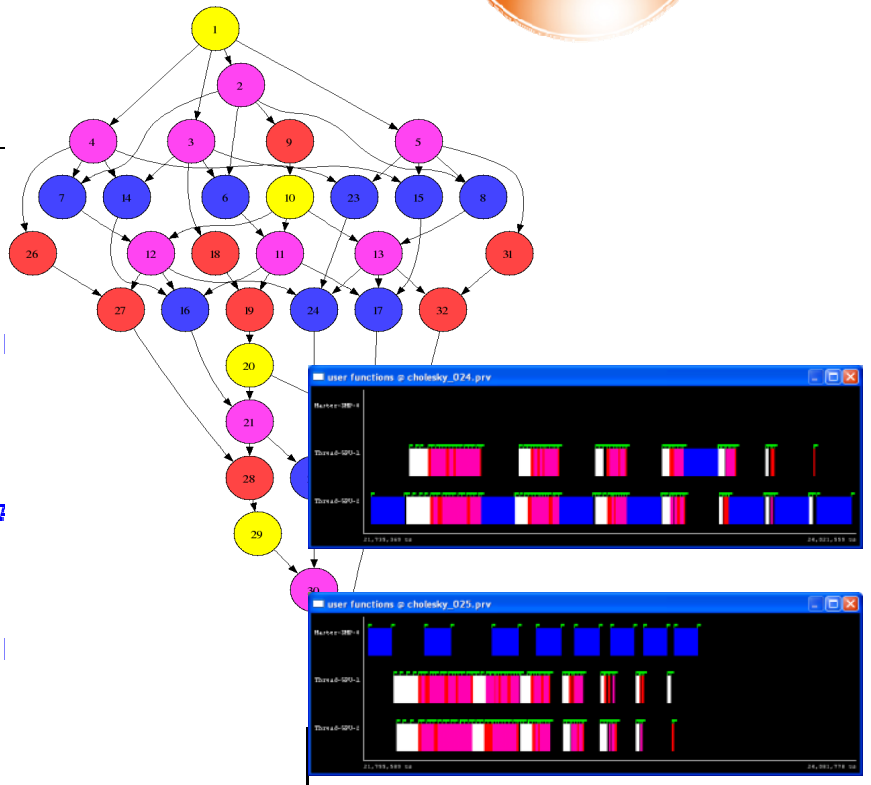


What is the right degree of porosity ?

Integrate concurrency and data

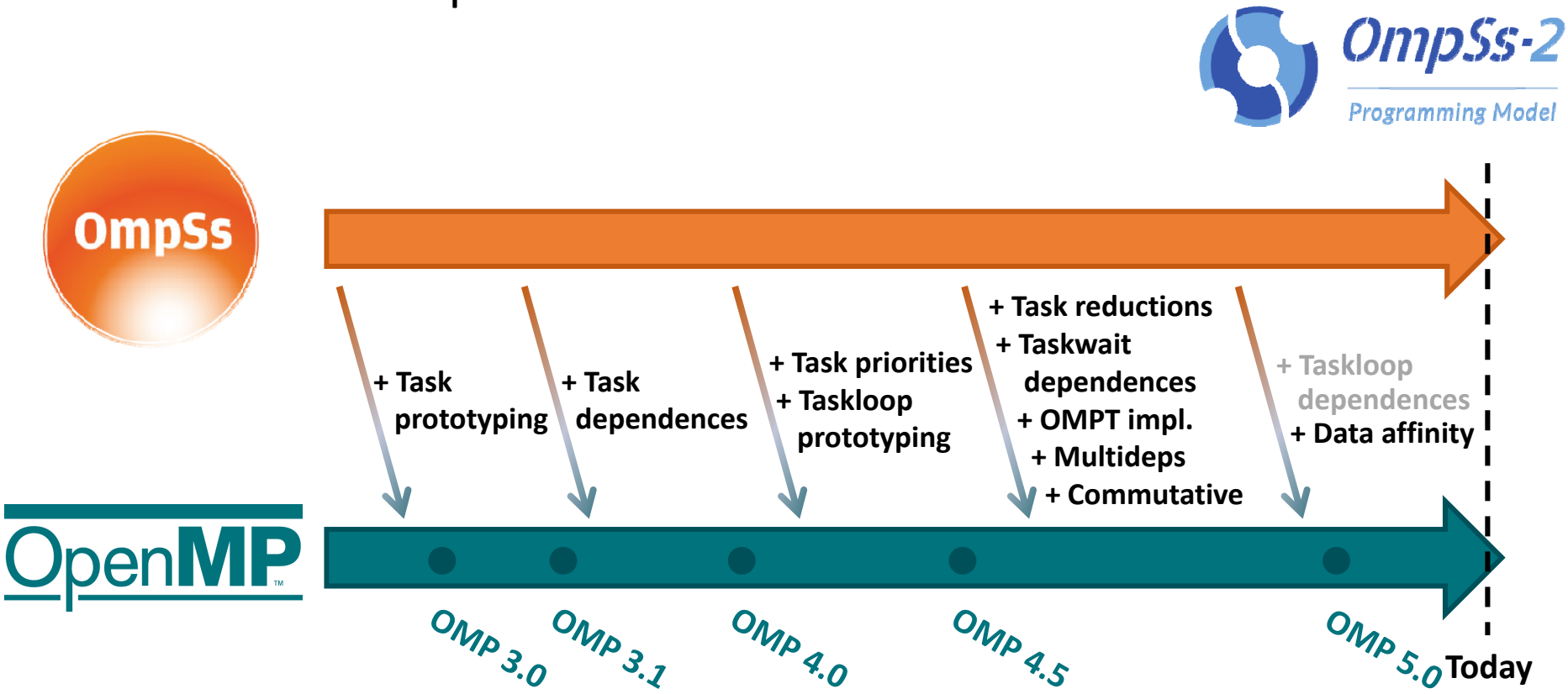
- Single mechanism
  - Concurrency:
    - Dependences built from data accesses
    - Lookahead: About instantiating work
  - Locality & data management
    - From data accesses


```
void Cholesky(int NT, float *A[NT][NT] ) {
   for (int k=0; k<NT; k++) {
      #pragma omp task inout ([TS][TS](A[k][k]))
      spotrf (A[k][k], TS) ;
      for (int i=k+1; i<NT; i++) {
        #pragma omp task in([TS][TS](A[k][k])) inout ([TS]
        strsm (A[k][k], A[k][i], TS);
      }
      for (int i=k+1; i<NT; i++) {
        for (j=k+1; j<i; j++) {
          #pragma omp task in([TS][TS](A[k][i]), [TS][TS](
                           inout ([TS][TS](*A[j][i]))
          sgemm( A[k][i], A[k][j], A[j][i], TS);
        }
        #pragma omp task in ([TS][TS](A[k][i])) inout([TS]
        ssyrk (A[k][i], A[i][i], TS);
      }
   }
}
```



OmpSs

- A forerunner for OpenMP



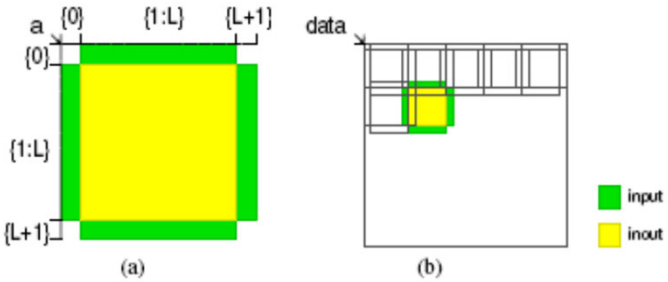
Important topics/practices

- Regions
- Nesting
- Taskloops + dependences
- Hints
- Taskify communications: MPI Interoperability
- Malleability
- Homogenize Heterogeneity
- Hierarchical “acceleration”
- Memory management & Locality

Are these topics relevant at ISA level?
Can some of these things be leveraged ?
Are they already there?

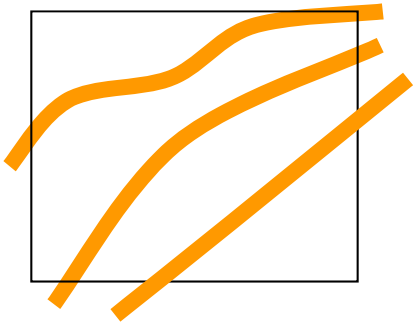
Regions

- Precise nD subarray accesses
  - “Complex” analysis but …
- Enabler for …
  - Recursion
  - Flexible nesting
  - Taskloop dependences
  - Data management
    - locality
    - layout



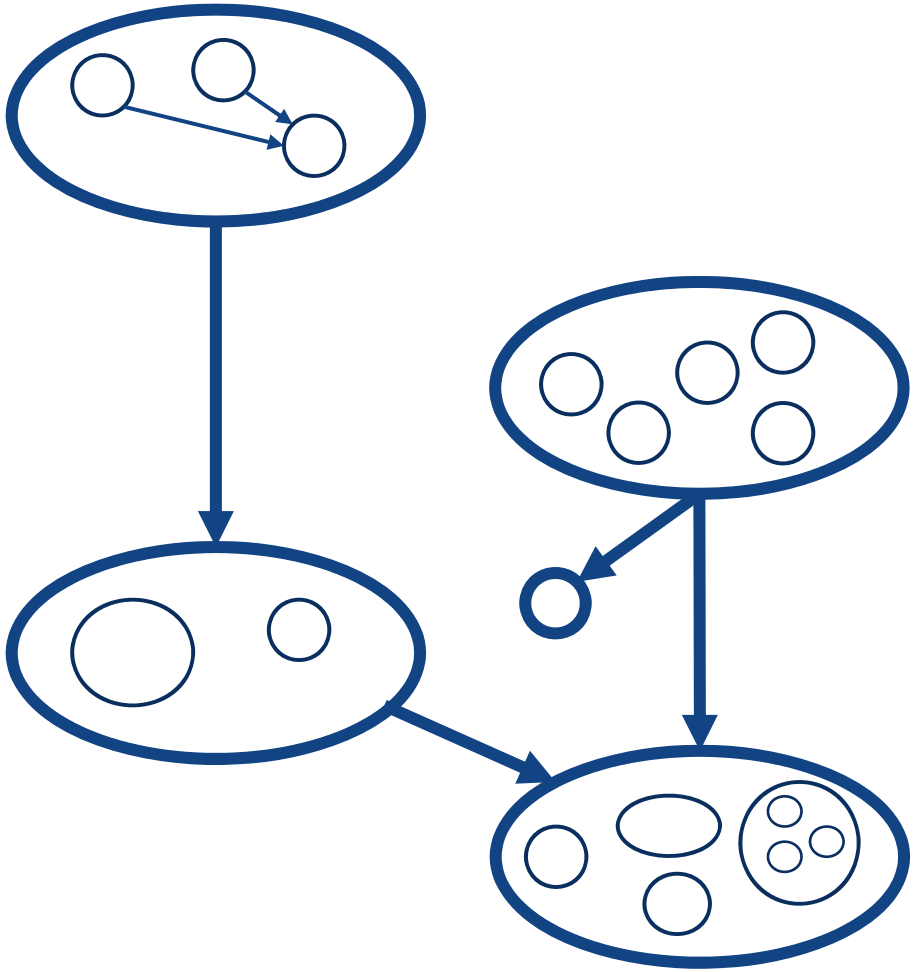

```
void gs (float A[(NB+2)*BS][(NB+2)*BS])
{
  int it,i,j;

  for (it=0; it<NITERS; it++)
    for (i=0; i<N-2; i+=BS)
      for (j=0; j<N-2; j+=BS)
        gs_tile(&A[i][j]);
}
```

```
#pragma omp task \
  in(A[0][1;BS], A[BS+1][1;BS], \
       A[1;BS][0], A[1:BS][BS+1]) \
  inout(A[1;BS][1;BS])
void gs_tile (float A[N][N])
{
  for (int i=1; i <= BS; i++)
    for (int j=1; j <= BS; j++)
      A[i][j] = 0.2*(A[i][j] + A[i-1][j] +
                A[i+1][j] + A[i][j-1] +
                A[i][j+1]);
}
```



Nesting

- Top down
  - Every level contributes
- Flattening dependence graph
  - Increase concurrency
  - Take out runtime overhead from critical path
- Granularity control
  - final clauses, runtime



J. M. Perez, et all, "Improving the Integration of Task Nesting and Dependencies in OpenMP" IDPS 2017

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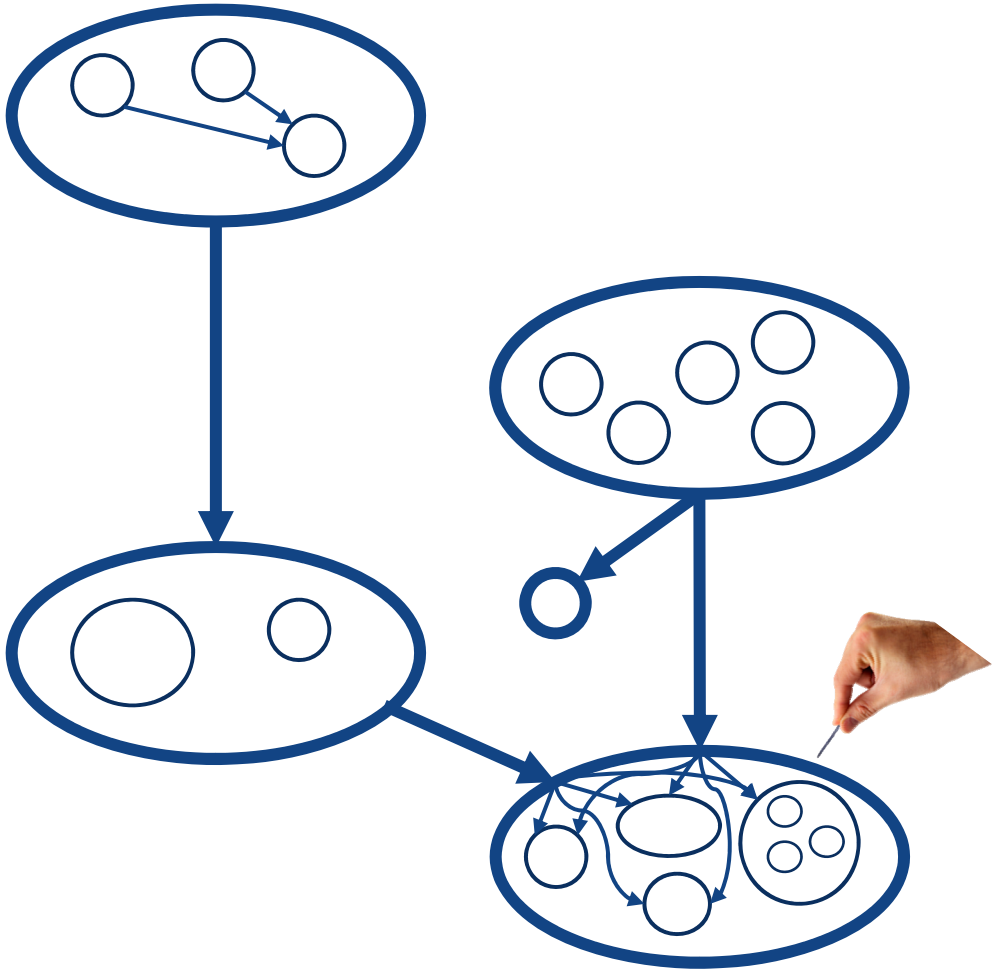

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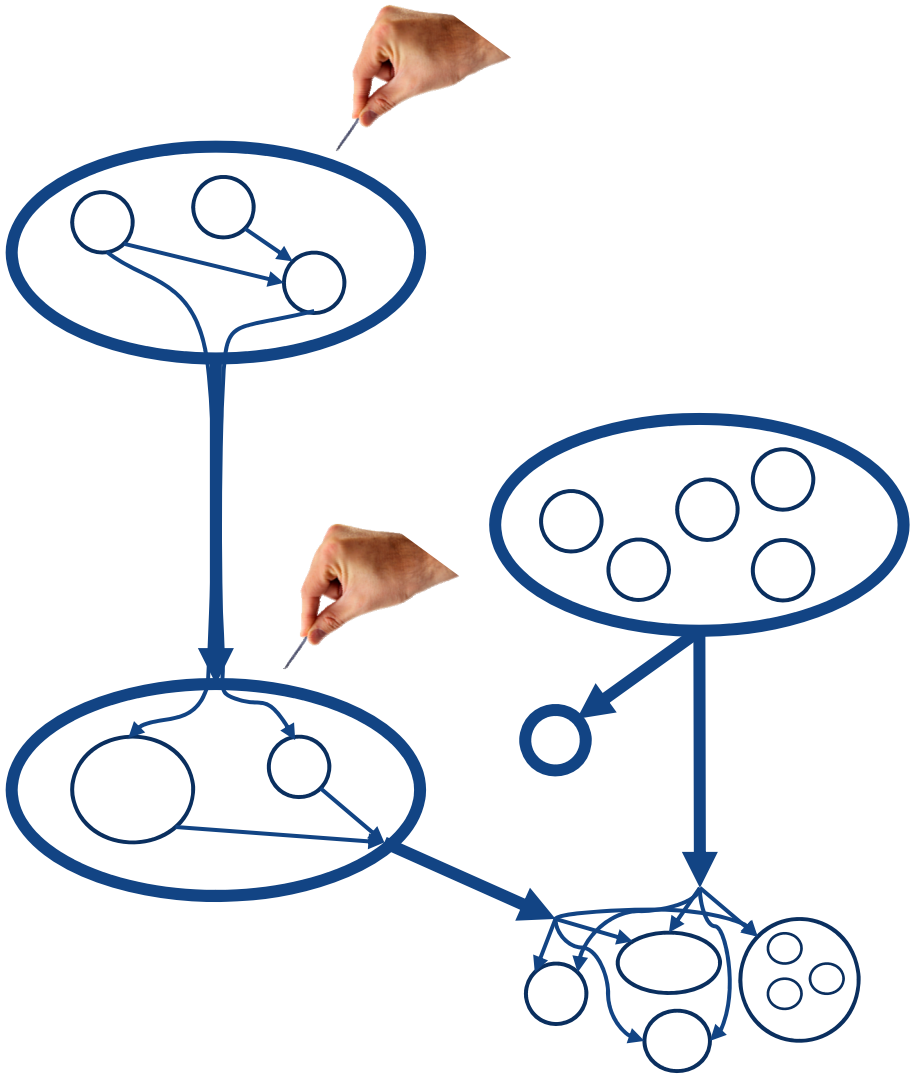

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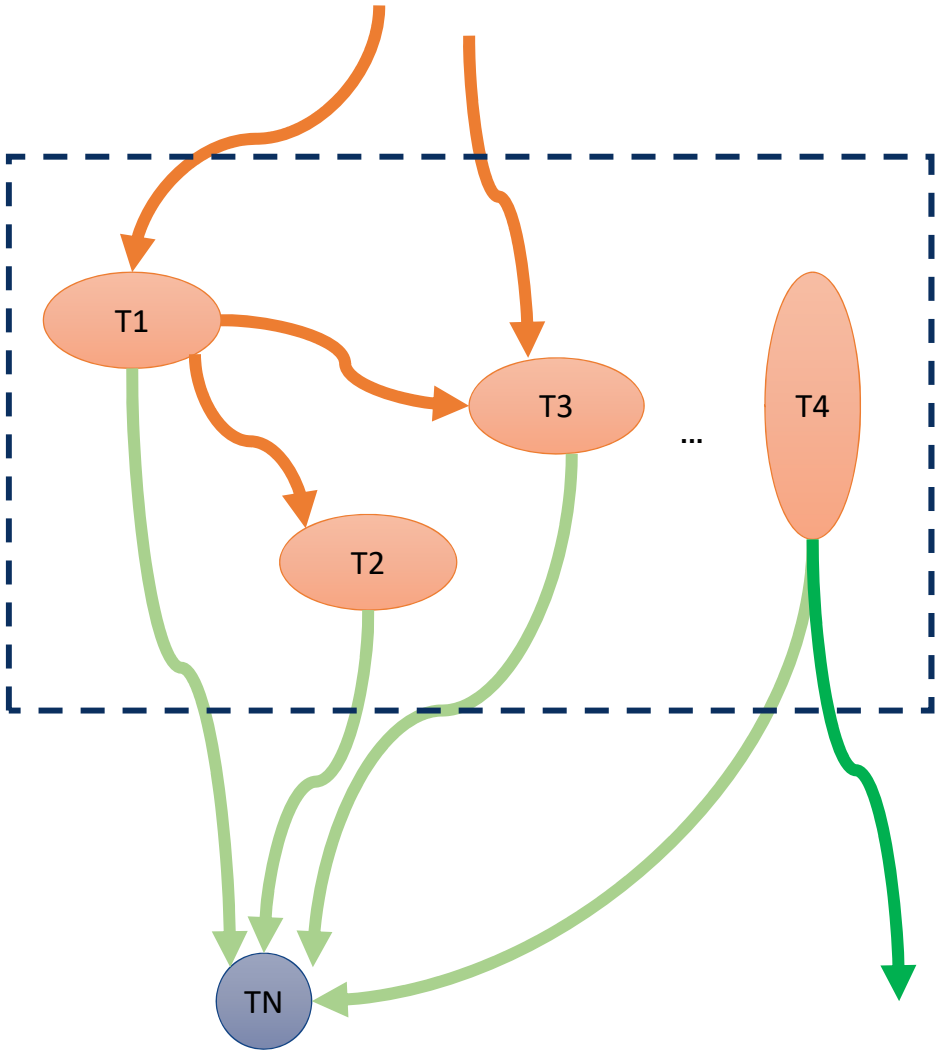
Taskloops & dependences

- Dependences
  - Intra loop
  - Inter loops
- Dynamic granularities
  - Guided
  - Runtime
- Combination
  - Enabled by regions support

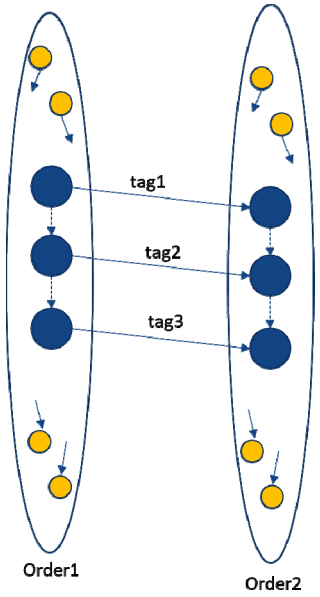


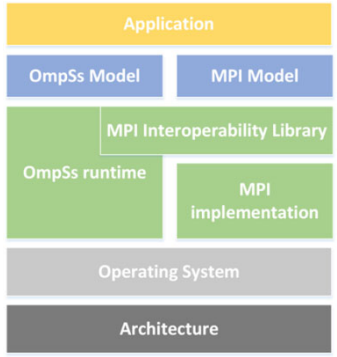
Taskifying MPI calls

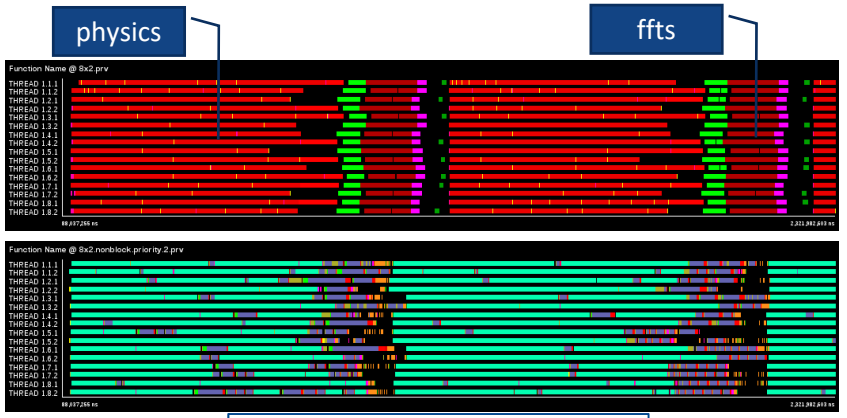
- MPI: a “fairly sequential” model

- Taskifuying MPI calls
  - Opportunities
    - Overlap/out of order execution
    - Provide laxity for communications
    - Migrate/aggregate load balance issues
  - Risk to introduce deadlocks

- TAMPI
  - Virtualize “communication resource”







IFS weather code kernel. ECMWF

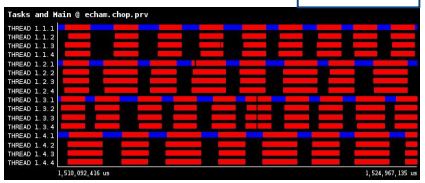
V. Marjanovic et al, “Overlapping Communication and Computation by using a Hybrid MPI/SMPSs Approach” ICS 2010

K. Sala et al, "Extending TAMPI to support asynch MPI primitives”. OpenMPCon18

Exploiting malleability

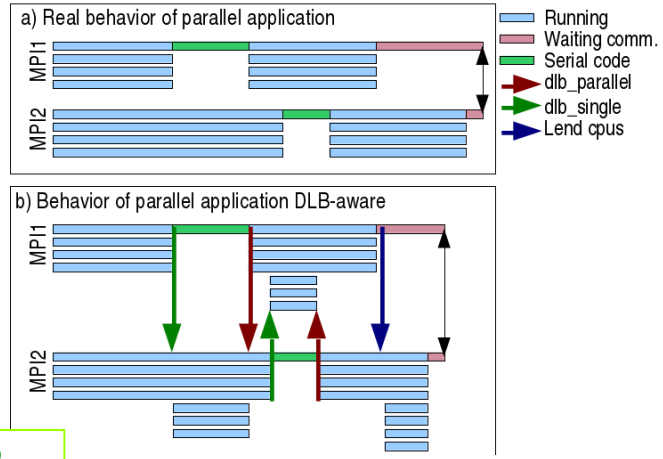
- Malleability
  - ~~Omp_get_thread_num~~, ~~Thread private~~, ~~large parallels~~ ….
- Dynamic Load Balance & Resource management
  - Intra/inter process/application
- Library (DLB)
  - Runtime interception (MPIP, OMPT, …)
  - API to hint resource demands
  - Core reallocation policy
- Opportunity to fight Amdalh's law
  - Productive / Easy !!!
    - Hybridize only imbalanced regions
    - Nx1

ECHAM



dynamic load balancing

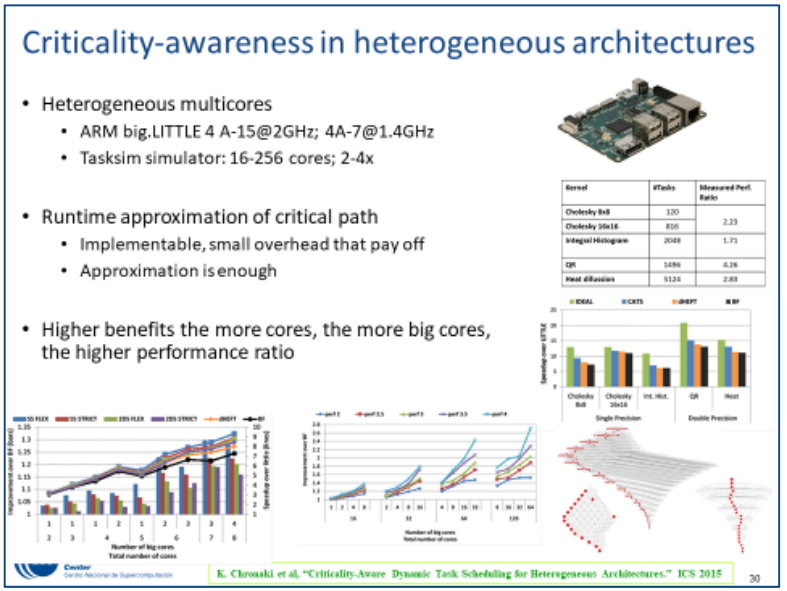
https://pm.bsc.es/dlb

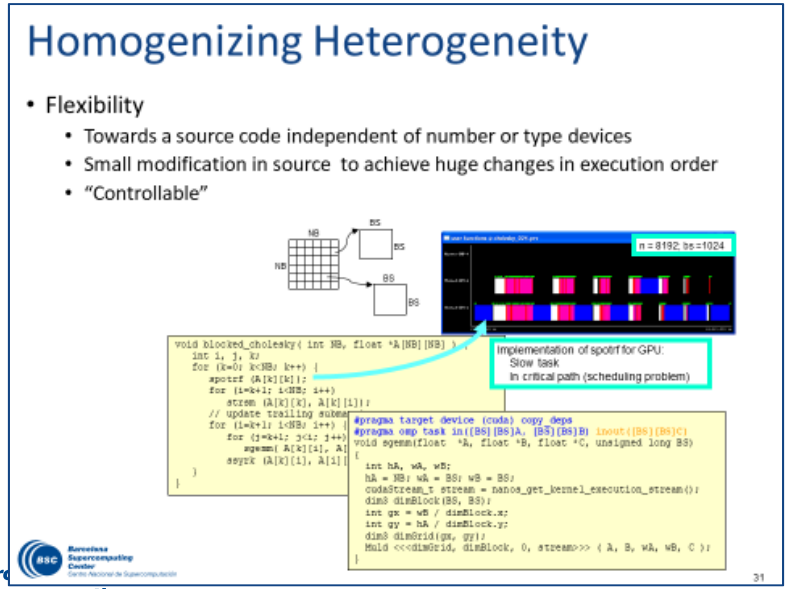


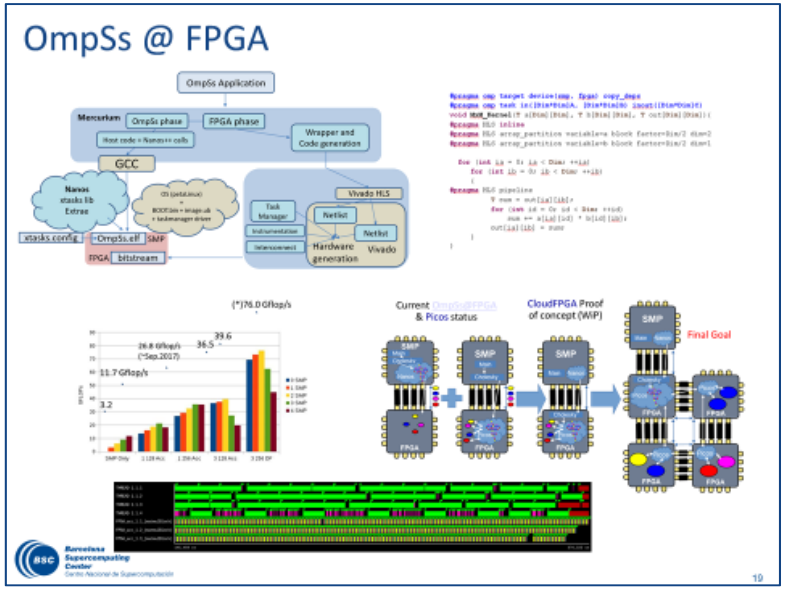
"LeWI: A Runtime Balancing Algorithm for Nested Parallelism". M.Garcia et al. ICPP09
"Hints to improve automatic load balancing with LeWI for hybrid applications" JPDC2014

Homogenizing Heterogeneity

- Performance heterogeneity
- ISA heterogeneity
- Several non coherent address spaces



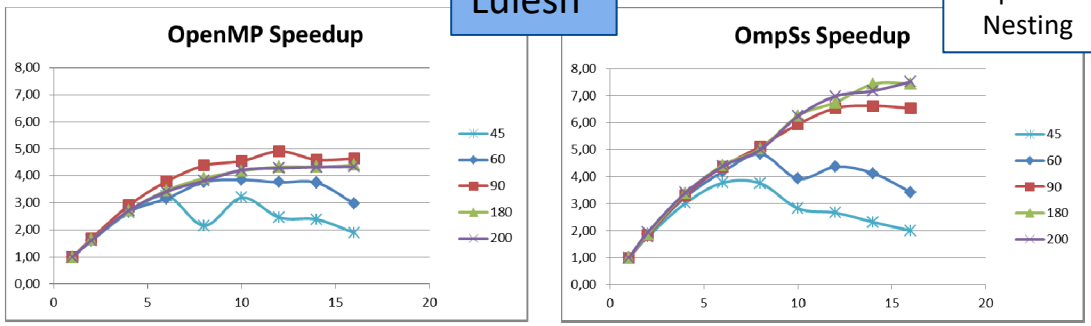




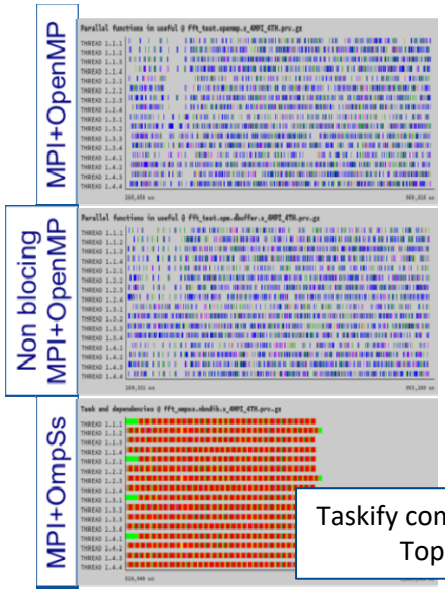
On the OmpSs road

Lulesh

Top down
Nesting



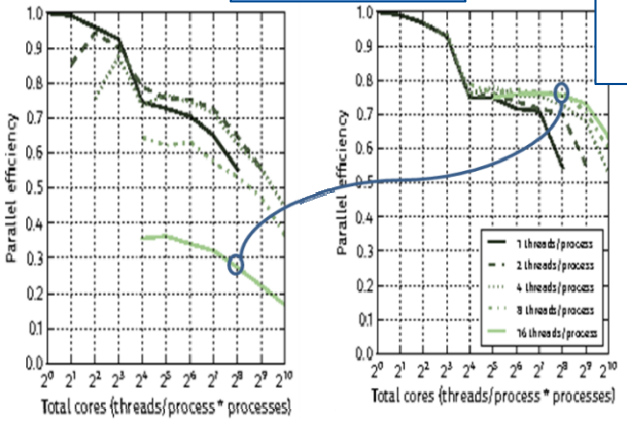
FFTlib (QE miniapp)



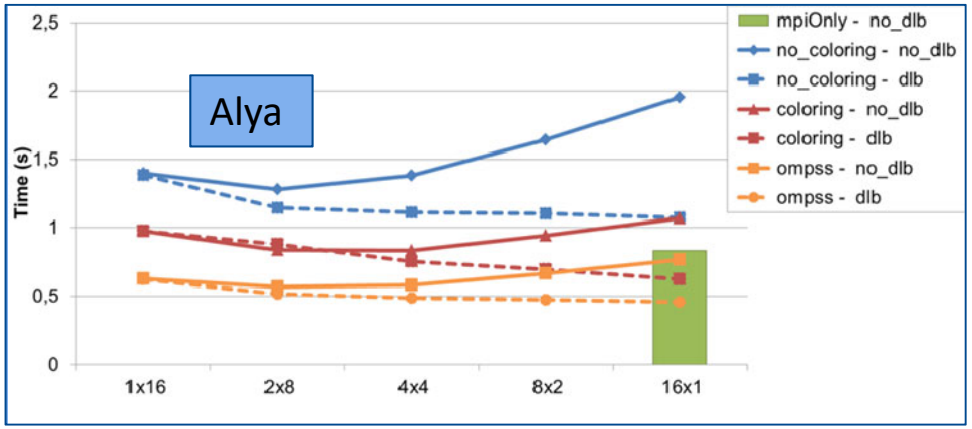
Taskify communications
Top down

NT-CHEM

Taskify
communications
Top down



Alya



Dynamic Load Balance (DLB)
Commutative - multideps

DMRG structure

- Density Matrix Renormalization Group app in condensed matter physics (ORNL)

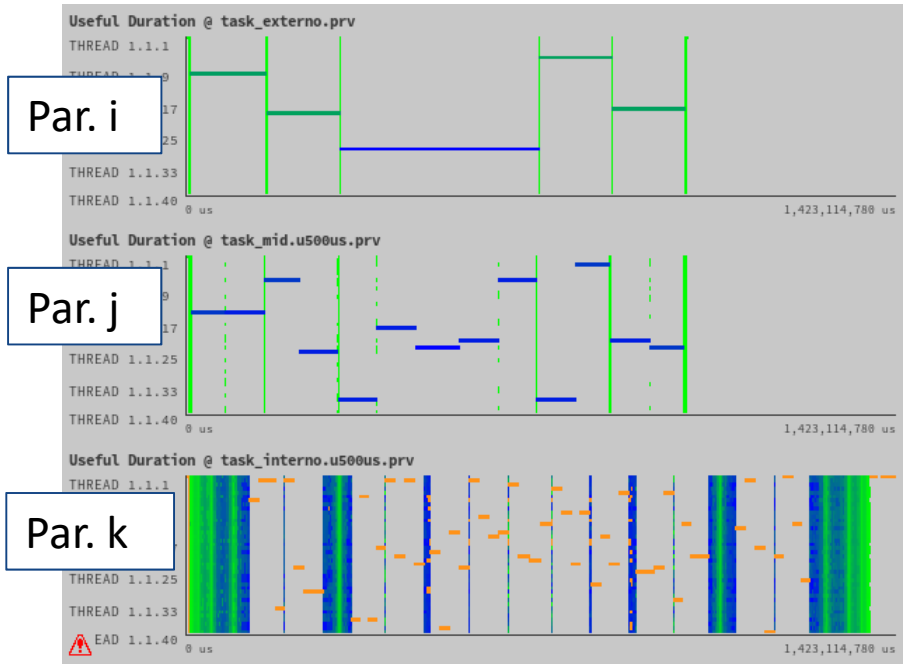
- Skeleton
  - 3 nested loop
  - Reduction on large array
  - Huge variability of op cost

- Real miniapp
  - Different sizes of Y entries

```
T Y[N];

for (i)
  for (j)
    for (k)
      Y[i] += M[k] op X[j]
```

OpenMP parallelizations

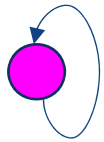
- OpenMP parallelizations
  - Reduction
    - Based on full array privatization
    - Using reduction clauses
  - Nested parallels
    - Worksharings / Tasks
    - Synchronization at end of parallels exposes cost of load imbalances at all levels
    - Overheads at fine levels
    - Issues activation of multiple levels
      - Core partition
      - Levels of Privatization



Taskification

- Serialize reductions
  - Multiple dependence chains

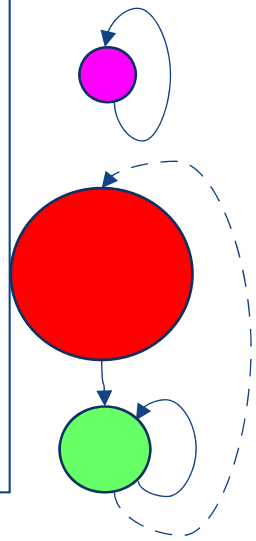
```
T Y[N];


for (i)
  for (j)
    for (k)

              Y[i] +=M[k] op X[j]
```



Taskification

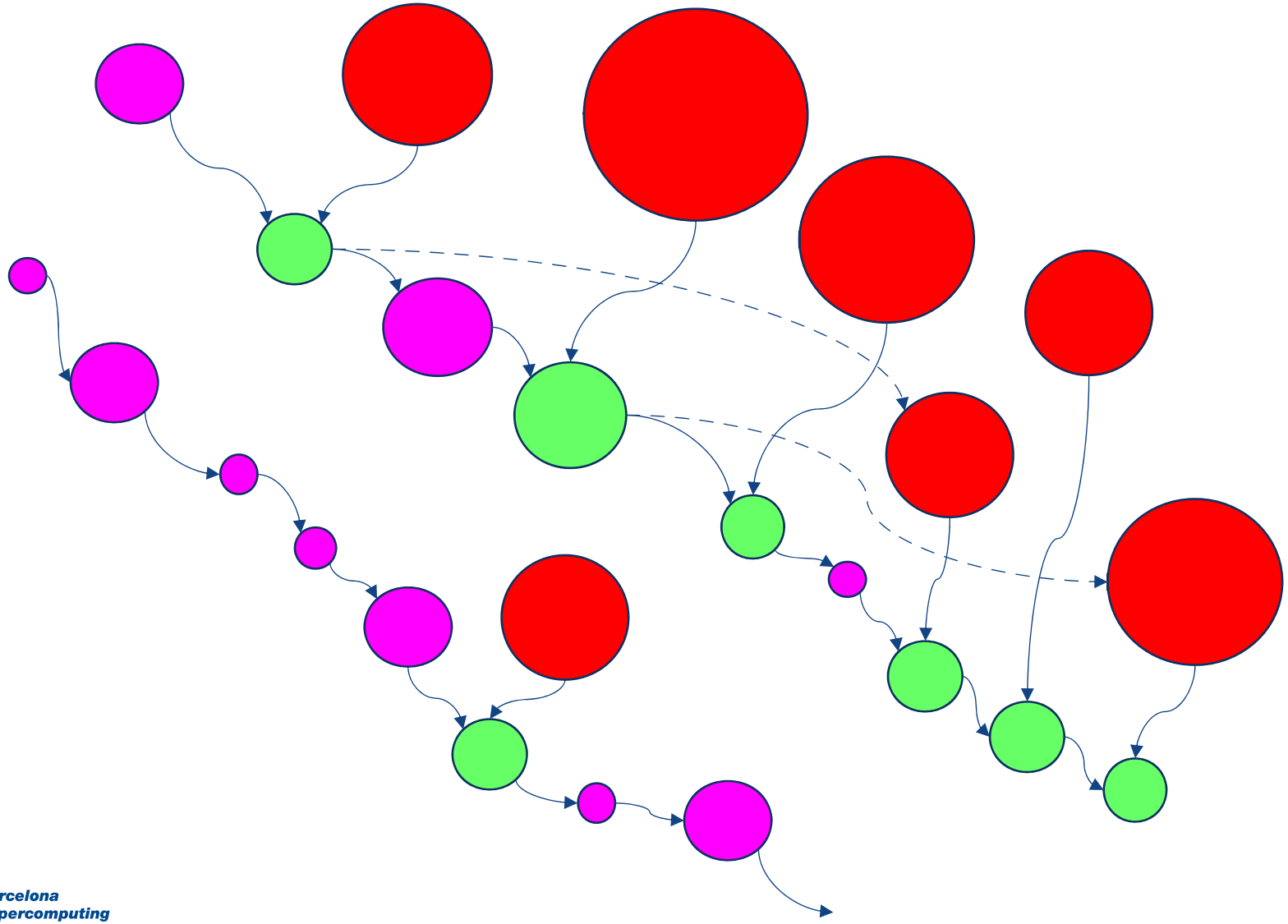
- Serialize reductions
  - Multiple dependence chains
- Split operations
  - Compute & reduce
  - Persist intermediate result
    - Global array of tmps
    - Used in a circular way
    - Enforce antidependence

```
T Y[N];
T tmp[Npriv];

for (i)
  for (j)
    for (k)
      if (small)
            Y[i] +=M[k] op X[j]

       else

            tmp[next]=M[k] op X[j]


            Y[i] += tmp[next];
```



- Reduce overhead → do not split small operation
  - Compute directly on target operand
  - Avoid task instantiation and dependence overhead
  - Avoid memory allocation, initialization & reduction to target operand

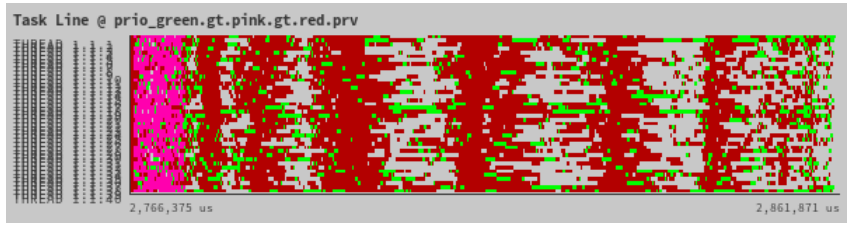
Resulting dependence chains

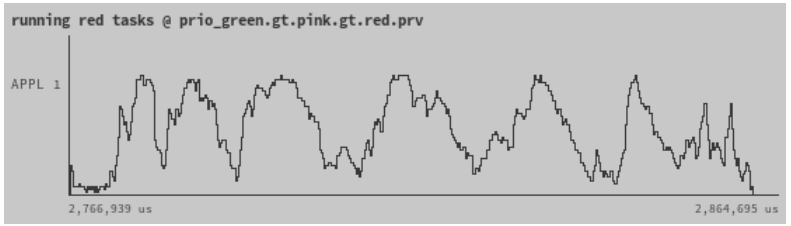


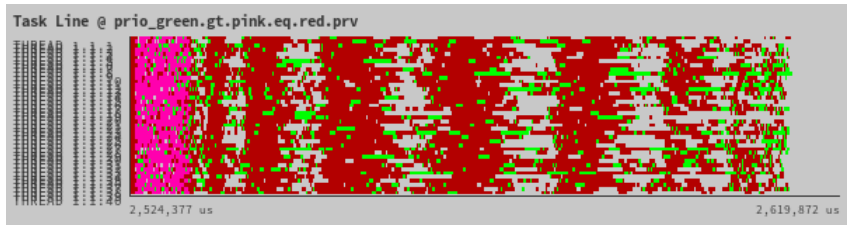
Performance ?

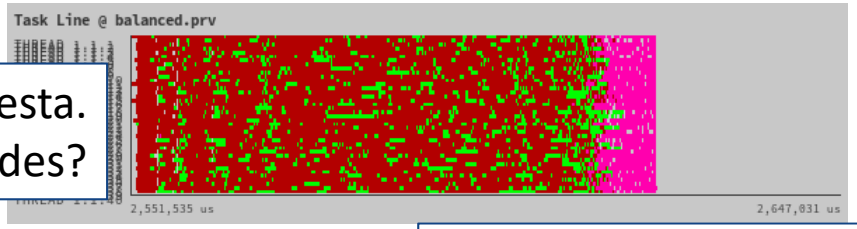
- Causes of pulsation of red tasks?
  - Instantiation order and granularity
  - Graph dependencies
- Improvements
  - Priorities
  - Anti-dependence distances
  - Nesting

Aqui tendria que poner la correspondiente sin prioridades









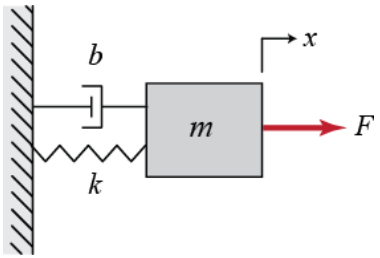
No tengo claro que era esta. Que prioridades?

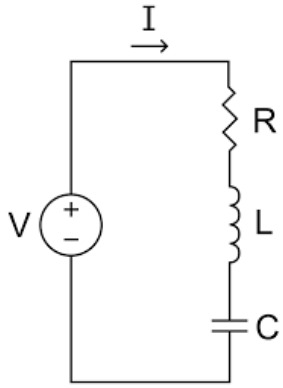
Aqui tendria que poner correspondiente con nes

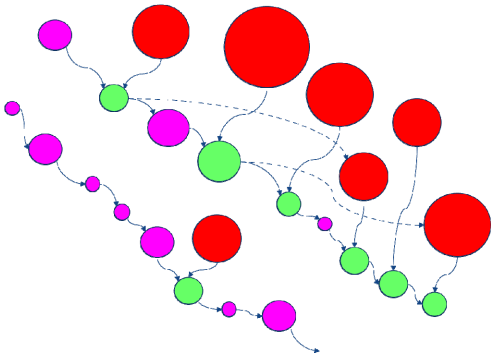
Do these effects happen also at ISA level?

Can similar techniques be used to improve performance?

Question on graph scheduling dynamics







F= $m\ddot{x} - b\dot{x} - kx$

$\omega_0 = \sqrt{k/m}$

$x(t) = Ae^{-\gamma t}\cos(wt - \varphi)$

$F(t) = F_0\cos(wt) \rightarrow x(t) = A\cos(wt)$

Effective k, m, b ?

Excitation ? Graph generation ?

Resources ?

Thanks to Yale

"There is no limit to what you can achieve provided you do not care who takes the credit"

I first heard it from Yale

Thanks !

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Centro Nacional de Supercomputación

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Thanks