Mapping a two-dimensional cellular automaton onto distributed memory machines

Thomas LEDUC

October 27-29, 1999

Contents

☞ subduction of oceanic crust beneath continent,

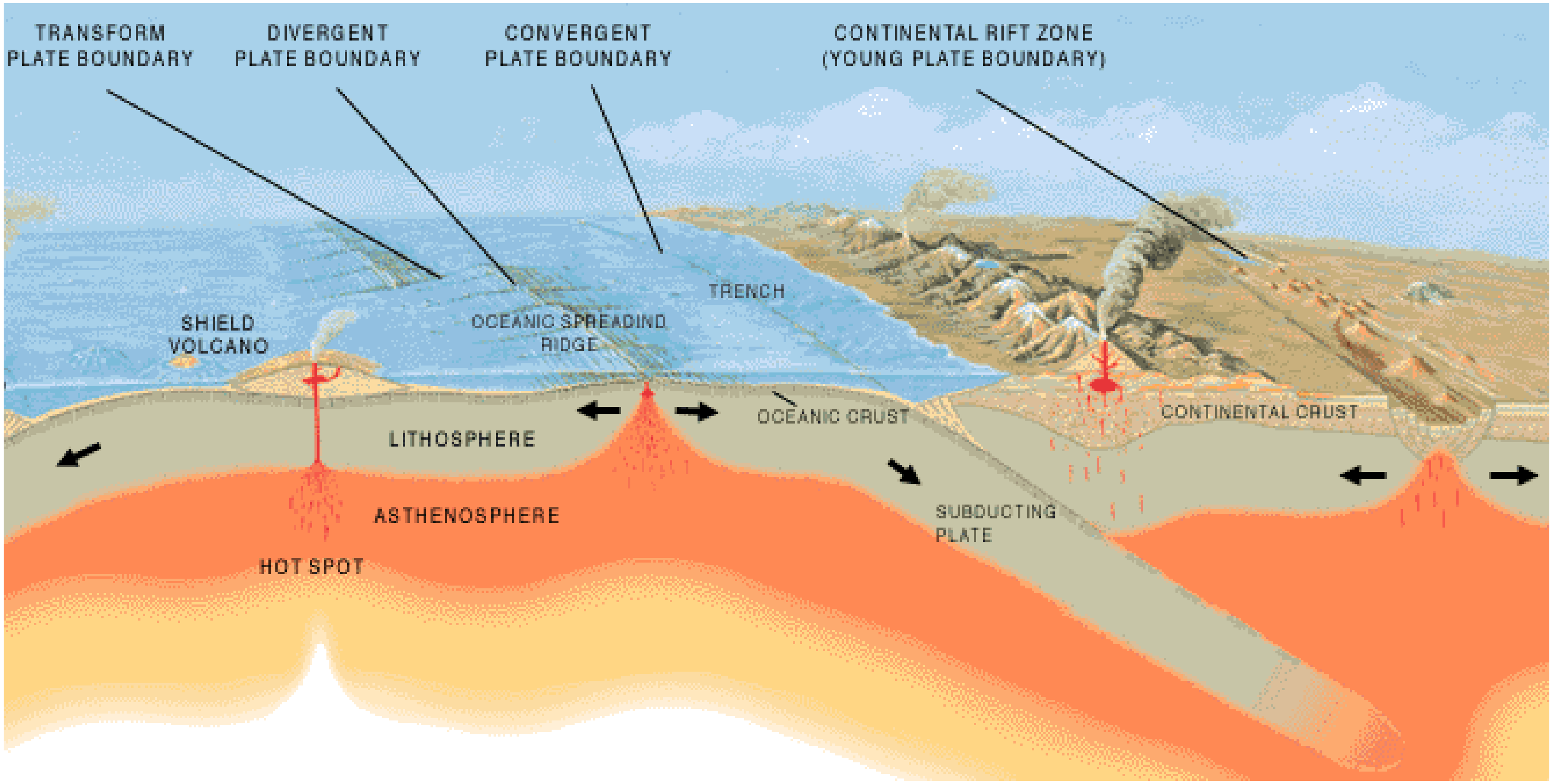
☞ CA as an alternative to differential equations in modelling physics,

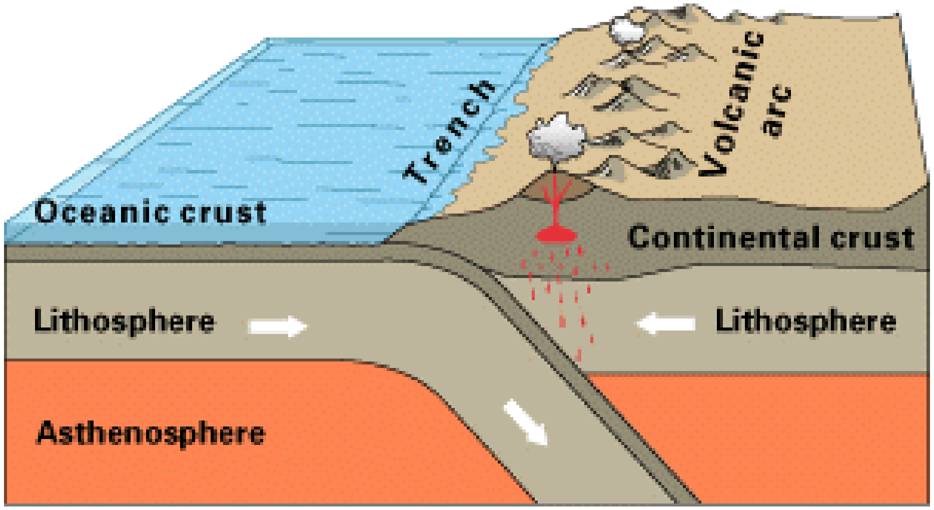
☞ models : topology, dynamics and specificities,

☞ simulations : development of new dedicated parallel softwares,

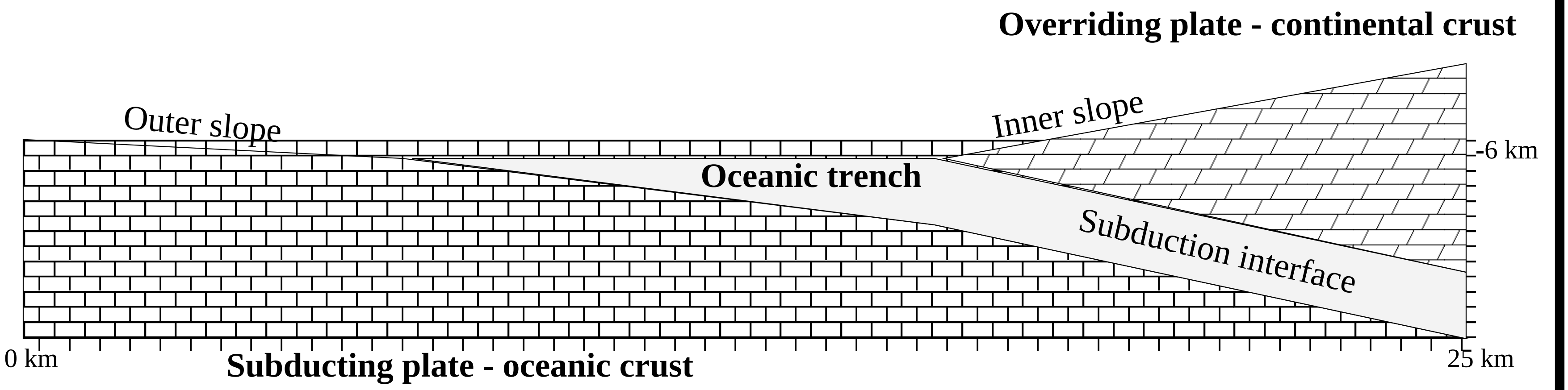
☞ results, screen-dumps and future research works. . .

Subduction of oceanic crust beneath continent





Oceanic-continental convergence



An alternative to diff. equ. in modelling physics

➥the 1D SPM :

➧dynamics of granular material (Bak, Tang and Wiesenfeld - 1980),

➧an infinite sequence of stacks (or sizes of stacks),

➧each stack holds a finite number of grains,

➧transition rule :

$$\text{let} : \mathbb{I}(n) = \begin{cases} 0 \text{ if } n < 2 \\ 1 \text{ otherwise} \end{cases}$$

➥the 2D case :

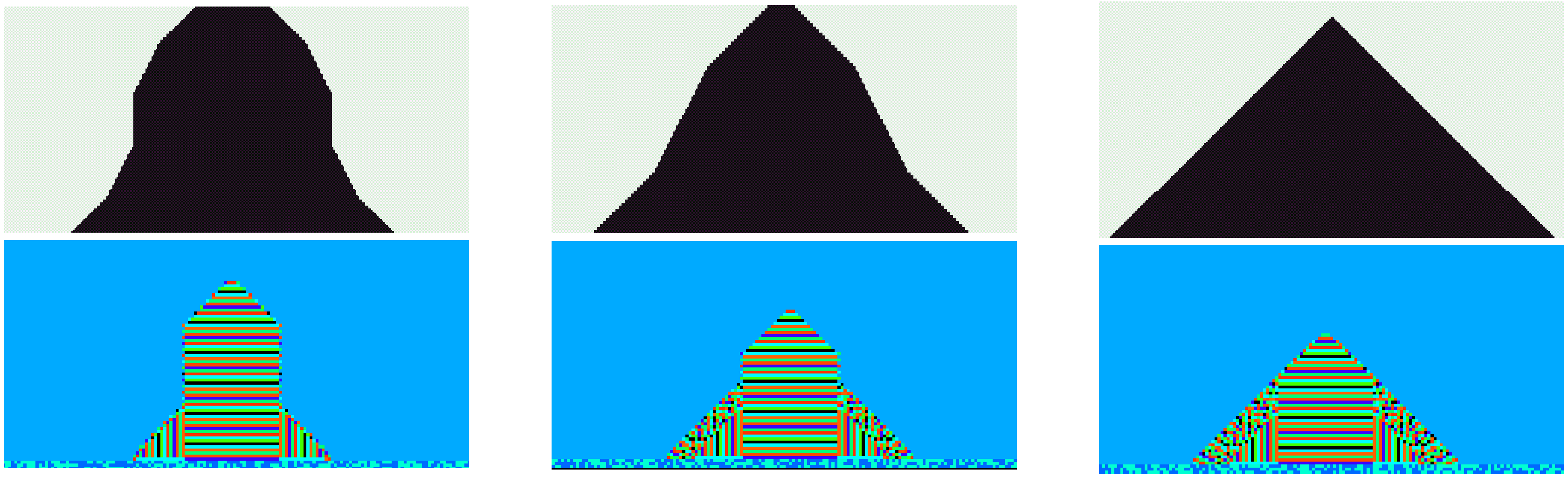
➧a two-dimensional regular lattice of cells/grains,

➧a sort of individual-based model : each grain is individualize (with their own nature/colour attributes),

➧a more complicated transition rule based on the extended Moore neighbourhood (depending on the previous states of 25 neighbouring cells),

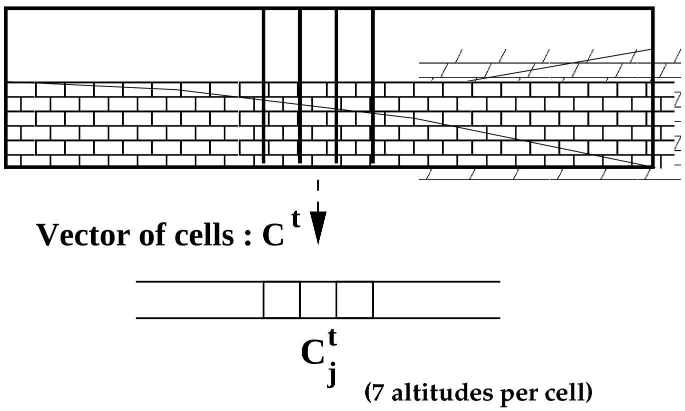
$$C_j^{t+1} = C_j^t - \mathbb{I}(C_j^t - C_{j-1}^t) - \mathbb{I}(C_j^t - C_{j+1}^t) + \mathbb{I}(C_{j-1}^t - C_j^t) + \mathbb{I}(C_{j+1}^t - C_j^t)$$

➥Screen dumps of the 1D/2D SPM simulations :



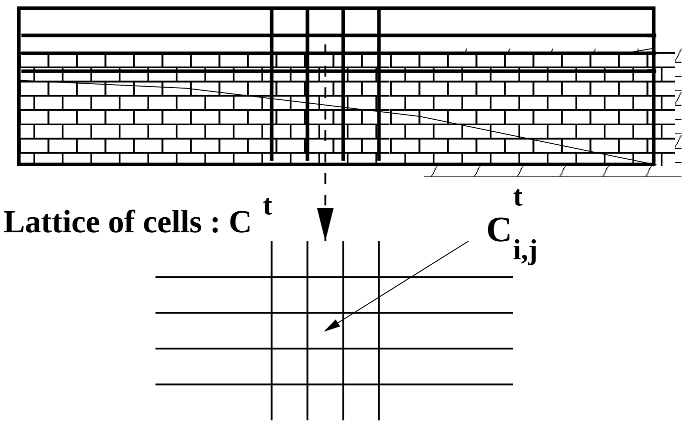
Models : topology, dynamics and specificities

One dimensional model



1D discretization of space (block decomposition)

Two dimensional model



2D discretization of space (block-block decomposition)

➥1D model :

- a finite array of 1,000 cells. Each of them represents a vertical portion of the ”universe”,
- the state of a cell is determined by a set of seven cross-section thicknesses and 2 coefficients (ageing and step) ⇒ a finite set of states,
- 2 neighbours,
- an overlap of 3 functions of transition. They represent 3 different physical phenomena, themselves, on 3 quite distinct scales of time,
- a global value (signal) : $Coeff_{Translation}$,

➥2D model :

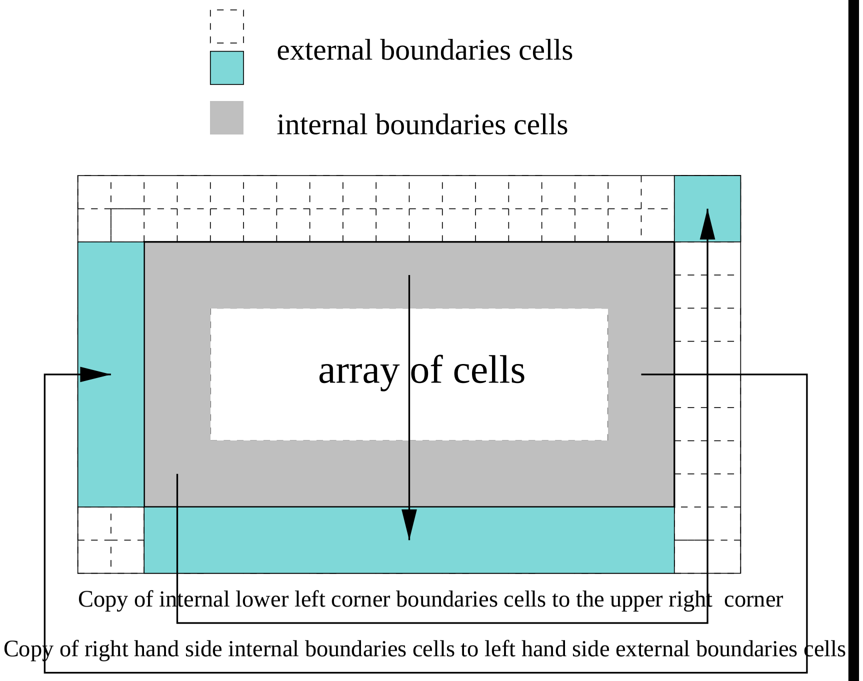
- a 2D regular lattice of 200,000 cells,
- the state of a cell is determined by a set of 6 integers (colour, nature, ageing. . .) ⇒ a finite set of states,
- 24 neighbours (the extended Moore neighbourhood),
- a mechanism of copy of inside boundaries cells marked by an invariant boundary state,

➥1D simplified algorithm

```
repeat
    CC ← C
    $C \leftarrow F_{slow}(CC, Coeff_{Tr})$
    repeat
        CC ← C
        $C \leftarrow F_{intermediate}(CC, Coeff_{Tr})$
        repeat
            CC ← C
            $C \leftarrow F_{fast}(CC)$
        until ‘‘fast condition’’
            is achieved,
    until ‘‘intermediate
        condition’’ is achieved,
    save the current image
        if necessary,
until ‘‘slow condition’’
    is achieved,
```

➥2D simplified algorithm

```
repeat
    $CC \leftarrow C$
    copy of boundaries cells
        of CC
    $C \leftarrow F(CC)$
until condition is achieved
```


external boundaries cells
internal boundaries cells
array of cells
Copy of internal lower left corner boundaries cells to the upper right corner
Copy of right hand side internal boundaries cells to left hand side external boundaries cells

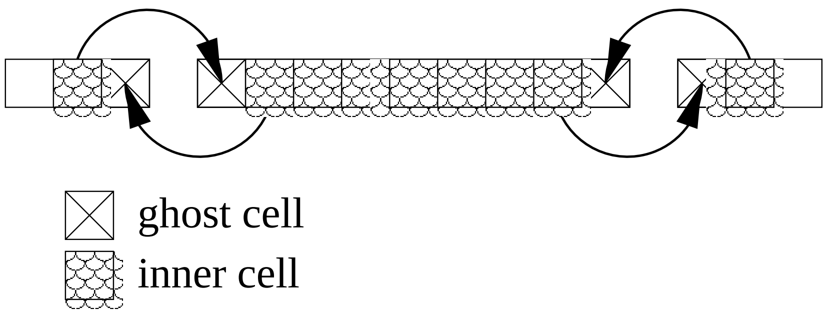
Simulations : development of new dedicated parallel soft

➥strategy :

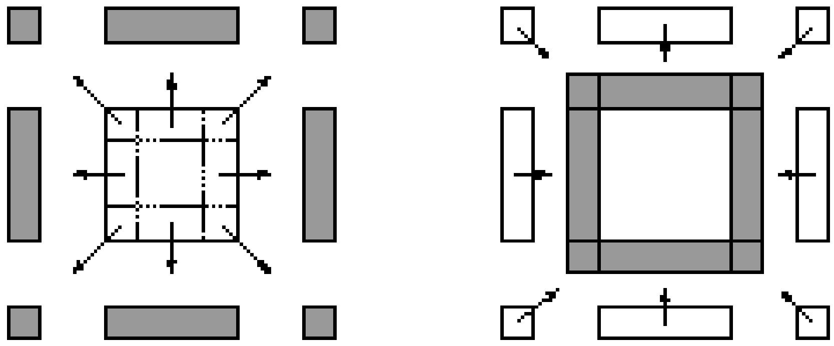
➧parallelization via domain decomposition ⇒ all the subproblems can be solve concurrently

➧all the subproblems are coupled ⇒ domain decomposition with overlapping grids on each subdomain :

1D model



2D model



➥simplified algorithm :

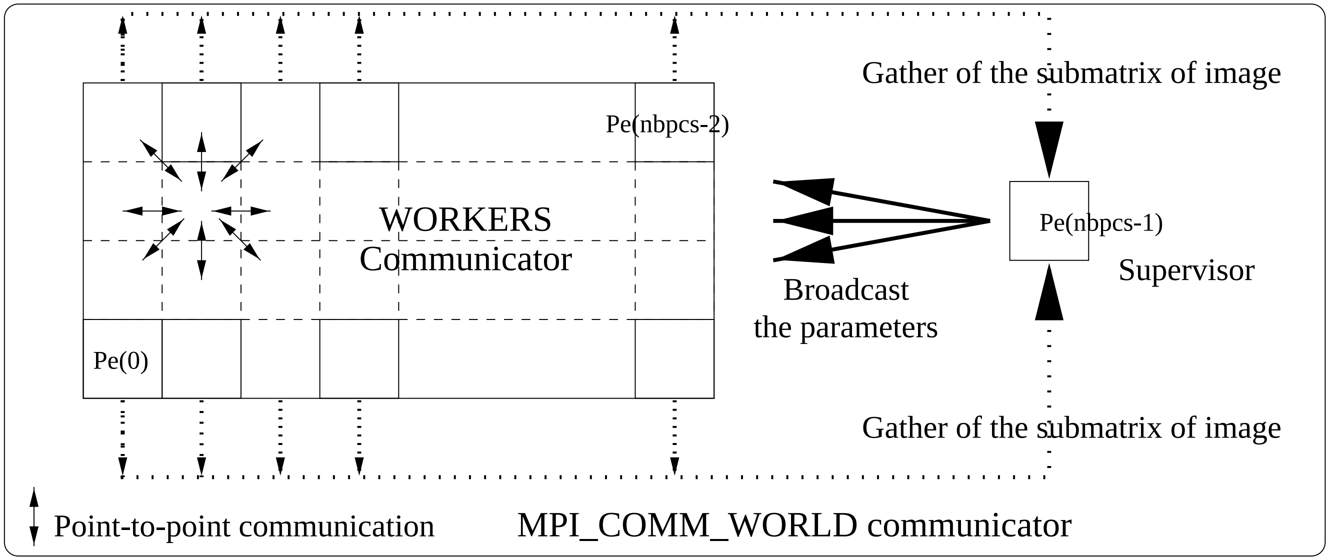
➧to improve performance : overlap communication and computation periods :

1. non-blocking send of internal boundaries cells,
2. update of pure inner cells of the current subdomain,
3. blocking receive of outer boundaries cells,
4. update of internal boundaries cells.

➥Specificities of the parallelism of the 2D simulation

➧a virtual Cartesian topology of process

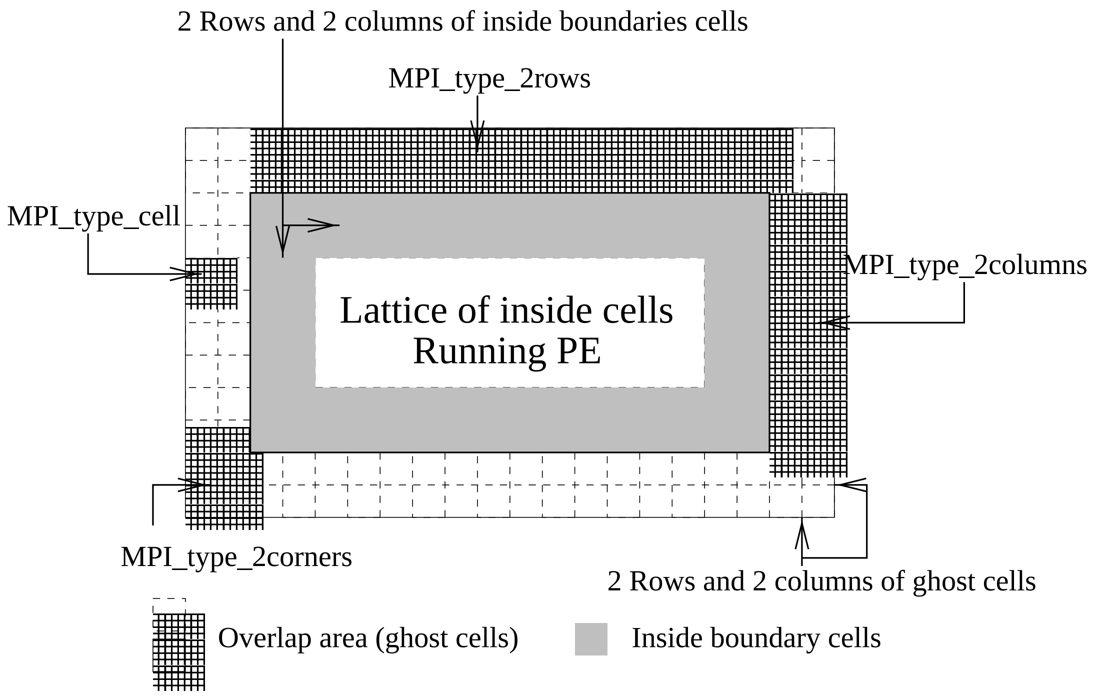
- the default MPI_COMM_WORLD has been divided into two distinct subgroups (divide up the processes ⇒ allow different groups of processes to perform independent work),
- the “workers” are mapped onto a regular logical 2D-Cartesian topology (MPI_Cart_create()),


Gather of the submatrix of image
Pe(nbpcs-2)
WORKERS
Communicator
Pe(0)
Broadcast
the parameters
Pe(nbpcs-1)
Supervisor
Gather of the submatrix of image
Point-to-point communication
MPI_COMM_WORLD communicator

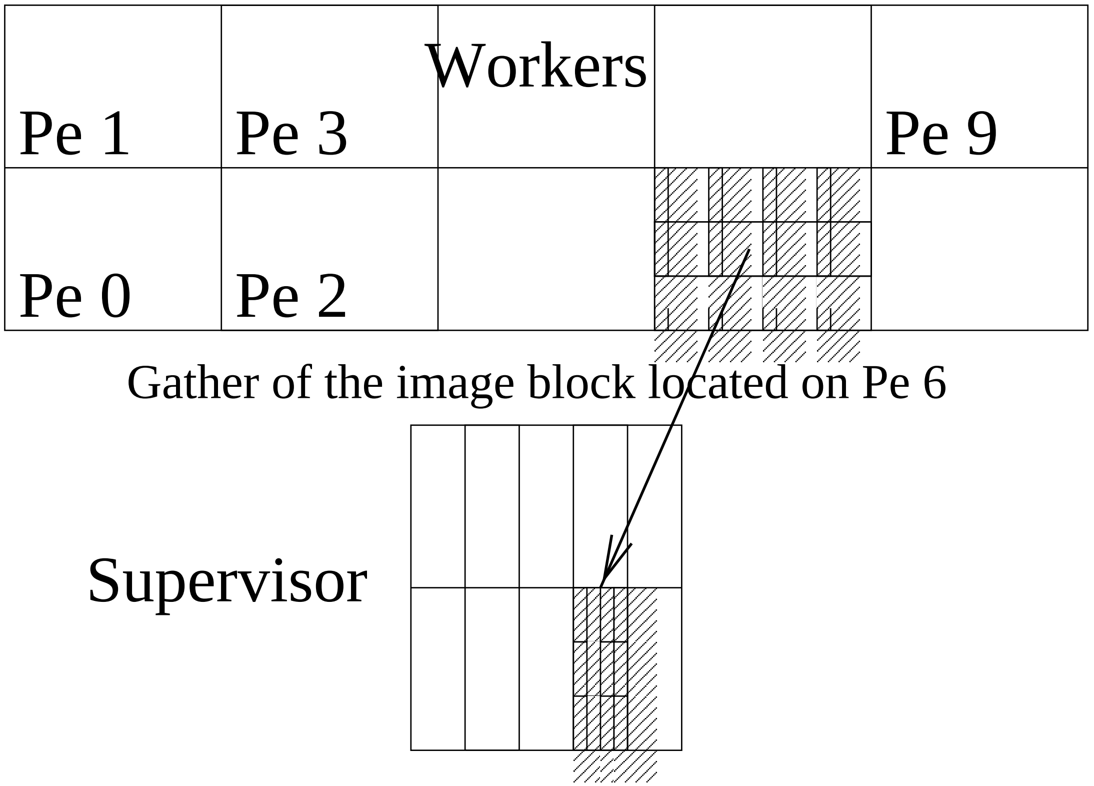
➧use of derived datatypes

MPI provides mechanisms for grouping individual data items into a single message : build new derived datatypes.

- point-to-point communications : MPI_Type_cell (MPI_Type_struct()), MPI_Type_2rows, MPI_Type_2corners and MPI_Type_2columns,



- collective communications : MPI_Type_block_image, MPI_Type_total_image,



Workers

Pe 1 Pe 3 Pe 9

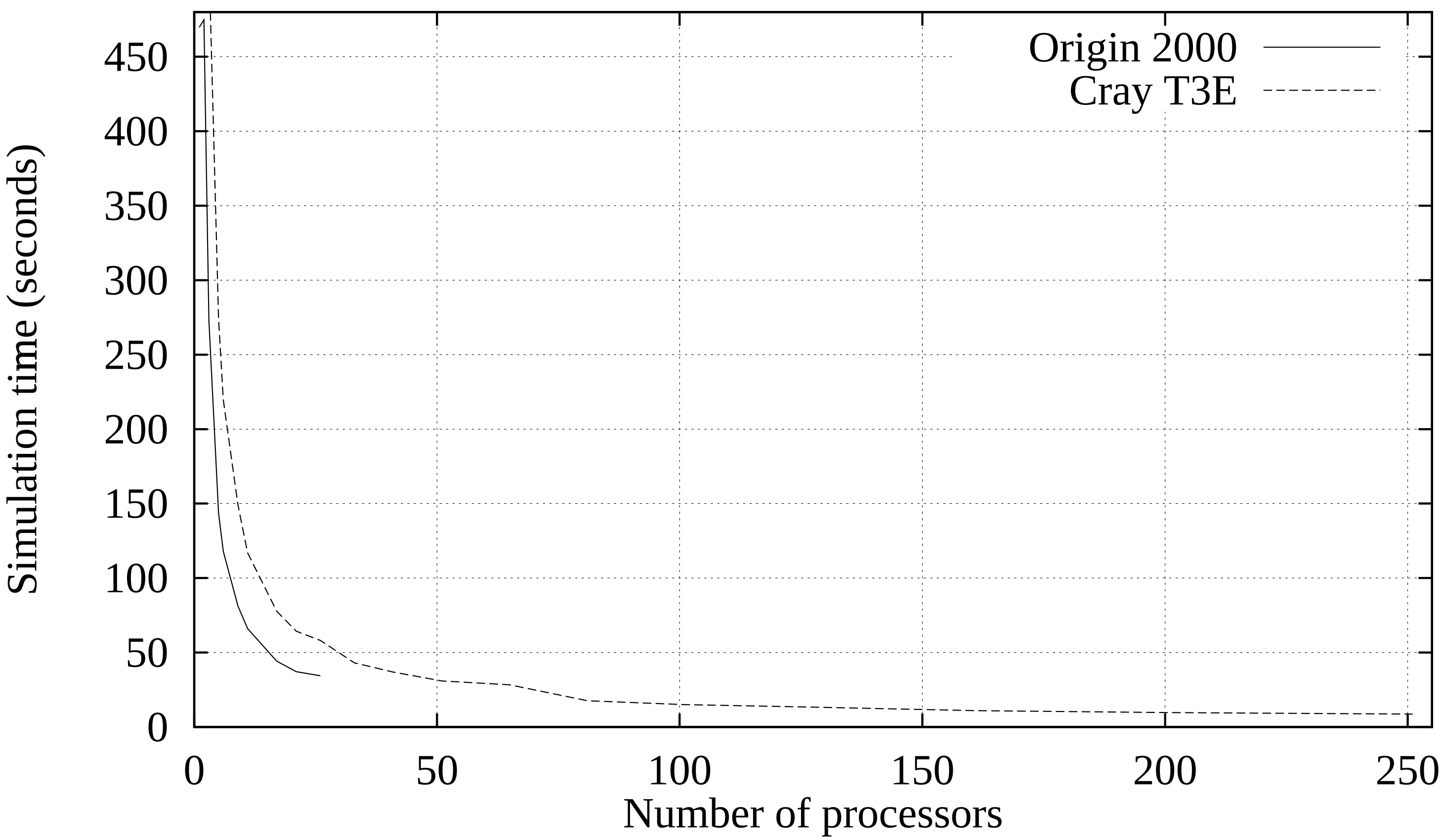
Pe 0 Pe 2

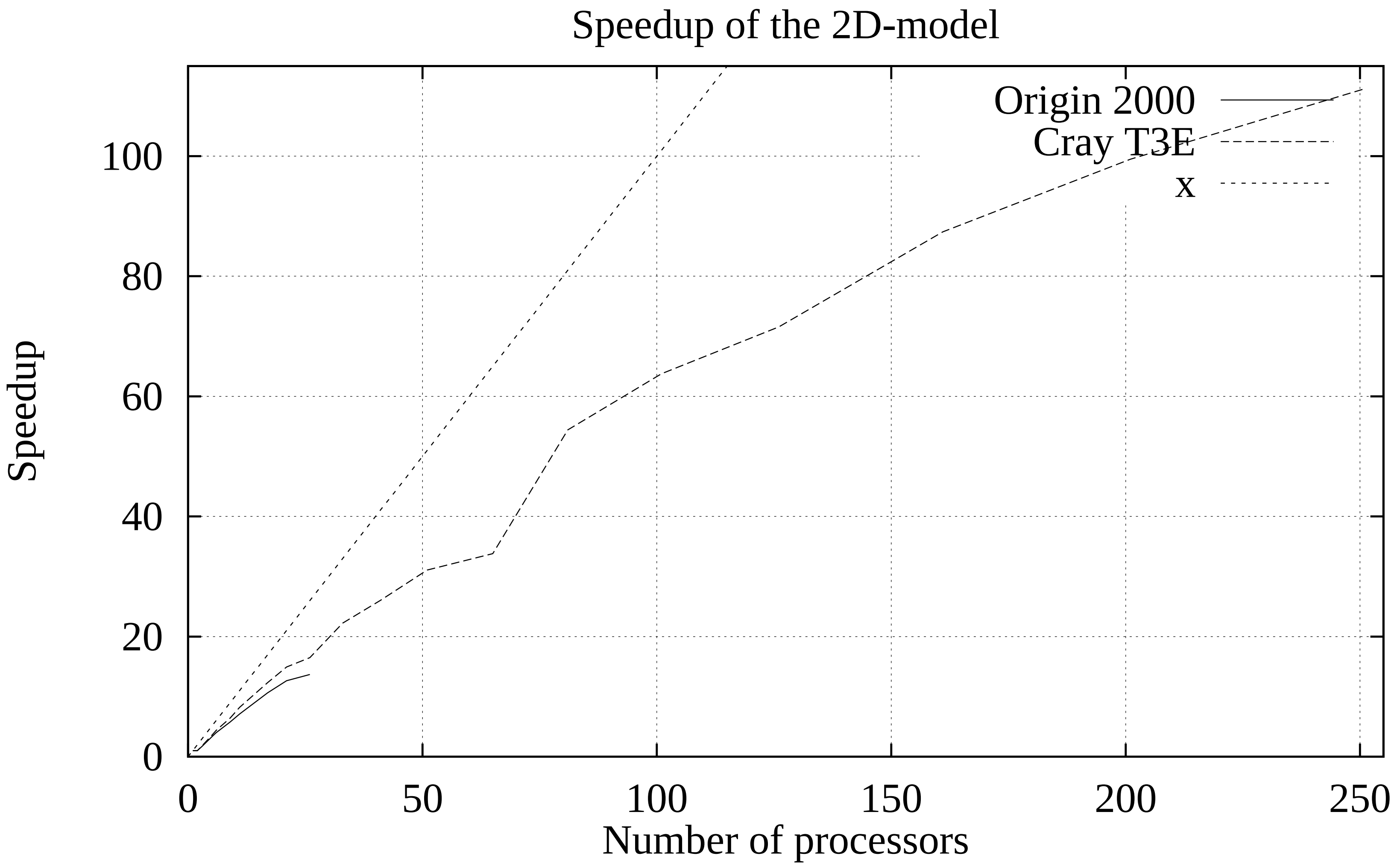
Gather of the image block located on Pe 6

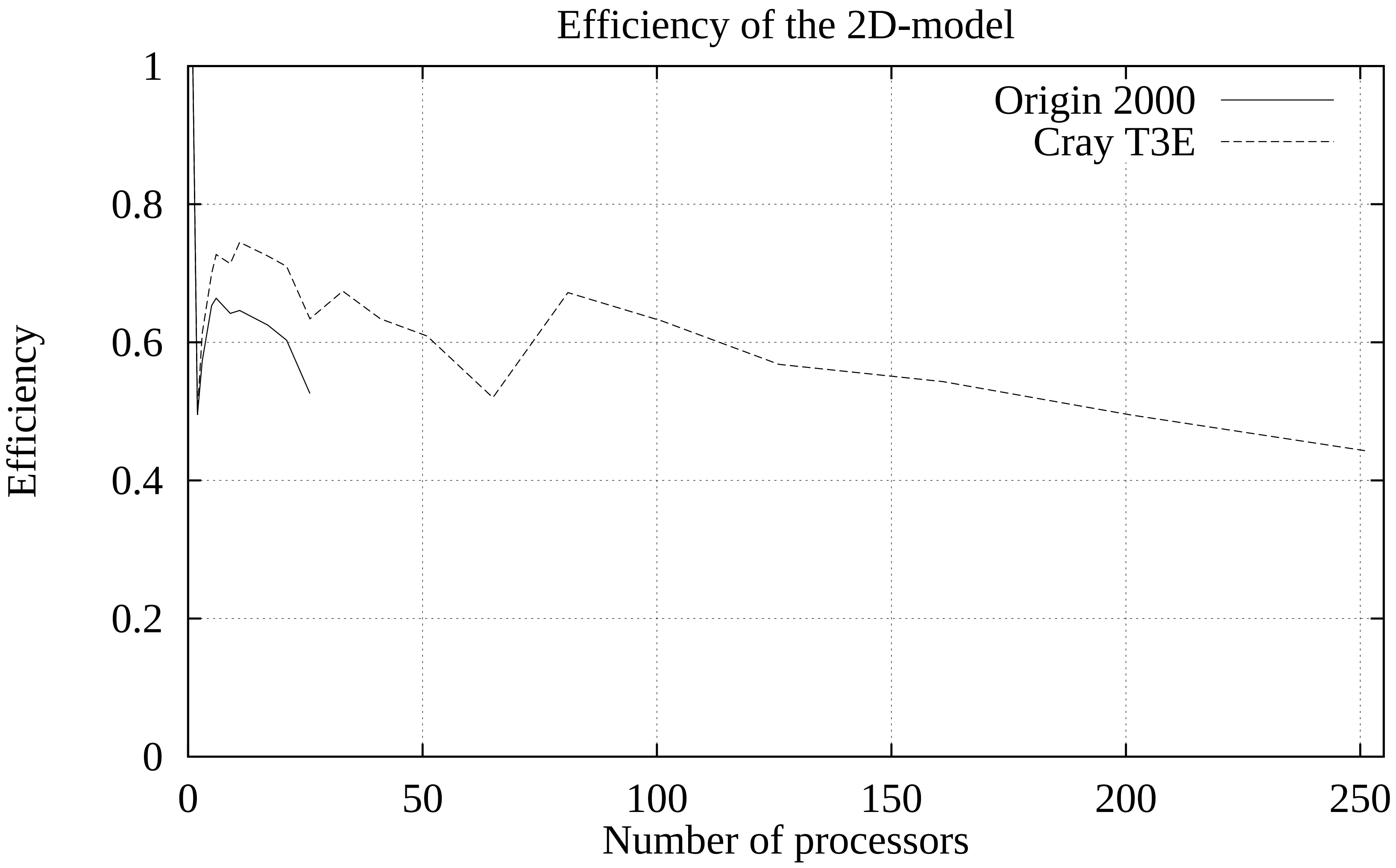
Supervisor

Results, screen-dumps

Simulation time of the 2D-model




Speedup of the 2D-model
Speedup
Number of processors
0
20
40
60
80
100
0
50
100
150
200
250
Origin 2000
Cray T3E
x

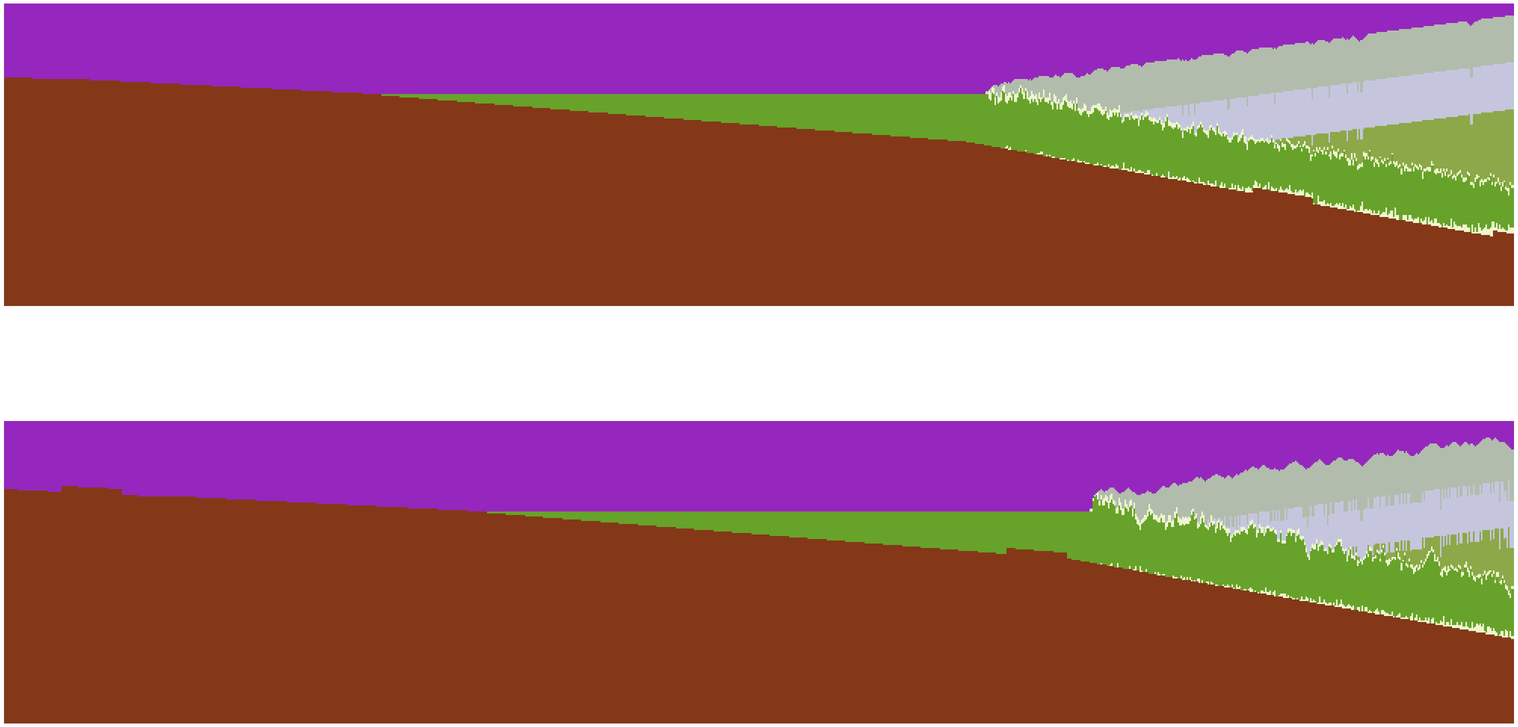

Efficiency of the 2D-model
Efficiency
Number of processors
Origin 2000
Cray T3E
0
0.2
0.4
0.6
0.8
1
0
50
100
150
200
250

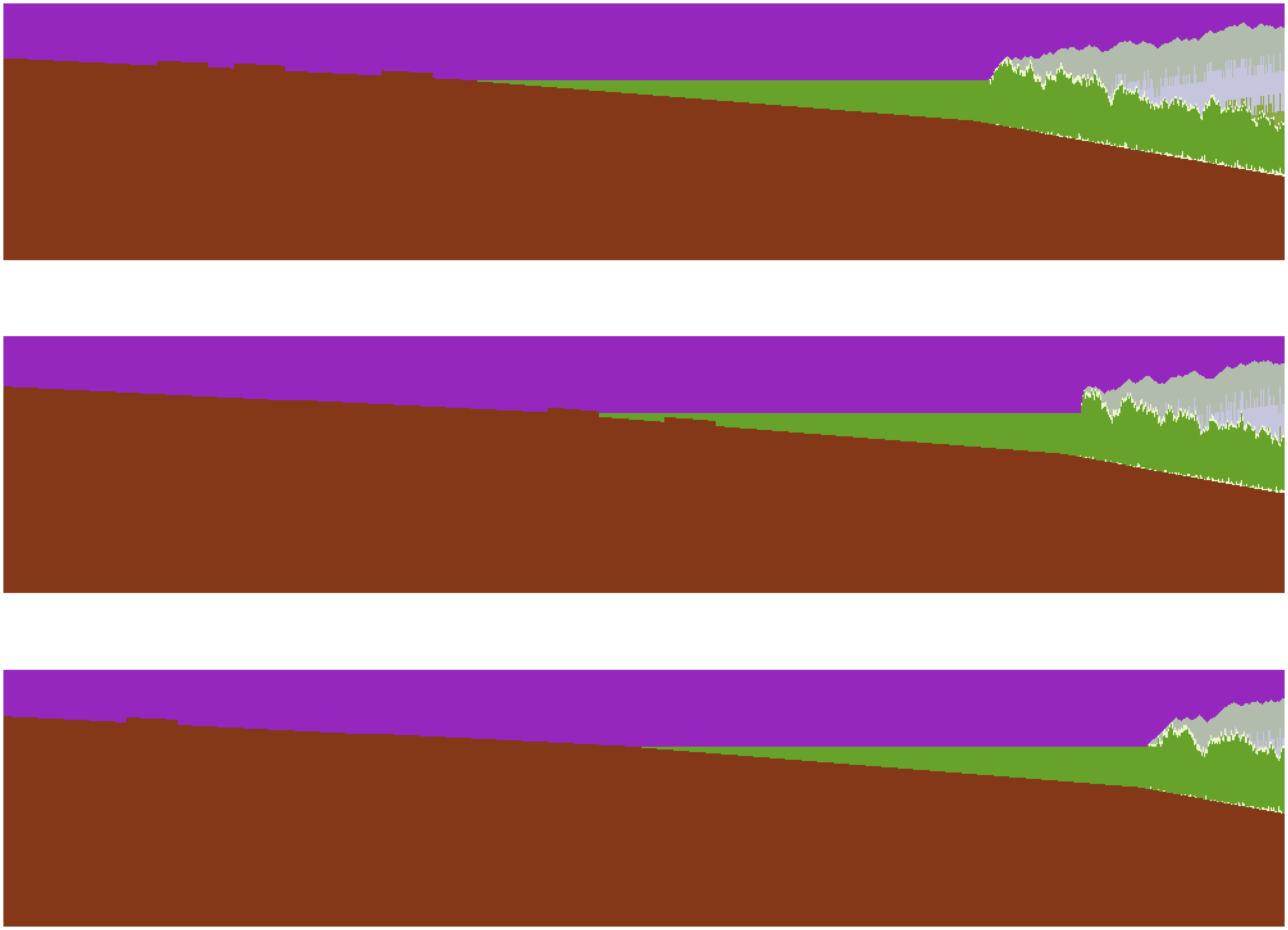
➥minimize the ratio : size of the subdomain boundaries/global size of each subdomain

nb of proc	number of processors per raw ∗ number of processors per column associed ratio (number of boundaries cells over global number of cells per subdomain)											
2	1 ∗ 2 4,23	2 ∗ 1 **2,74**										
4	1 ∗ 4 7,78	2 ∗ 2 4,61	4 ∗ 1 **3,50**									
5	1 ∗ 5 9,45	5 ∗ 1 **3,88**										
8	1 ∗ 8 14,14	2 ∗ 4 8,14	4 ∗ 2 5,36	8 ∗ 1 **5,00**								
10	1∗10 17,00	2 ∗ 5 9,81	5 ∗ 2 **5,73**	10∗1 **5,73**								
16	2 ∗ 8 14,48	4 ∗ 4 8,87	8 ∗ 2 **6,83**									
20	1∗20 28,86	2∗10 17,33	4 ∗ 5 10,52	5 ∗ 4 9,22	10∗2 **7,54**	20∗1 9,22						
25	1∗25 33,60	5 ∗ 5 **10,87**	25∗1 **10,87**									
32	4 ∗ 8 15,15	8 ∗ 4 **10,28**										

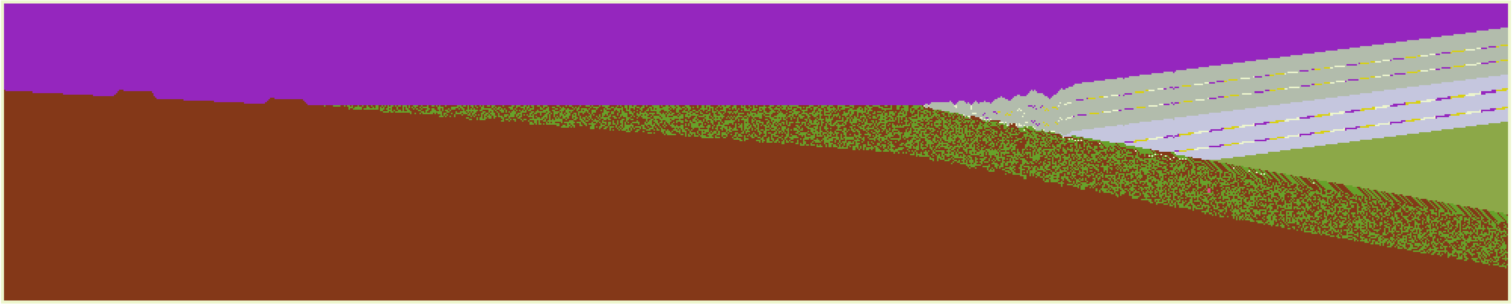
nb of proc	number of processors per raw * number of processors per column associed ratio (number of boundaries cells over global number of cells per subdomain)											
40	1*40 44,67	2*20 29,14	4*10 17,98	5 * 8 15,48	8 * 5 11,91	10*4 **10,97**	20*2 **10,97**	40*1 15,48				
50	1*50 50,20	2*25 33,86	5*10 18,30	10*5 **12,59**	25*2 **12,59**	50*1 18,30						
64	8 * 8 **16,47**											
80	2*40 44,89	4*20 29,70	8*10 19,25	10*8 17,11	20*4 **14,27**	40*2 17,11						
100	1 * 100 66,80	2*50 50,40	4*25 34,38	5*20 29,97	10 * 10 19,87	20*5 **15,82**	25*4 **15,82**	50*2 19,87	100* 1 29,97			
125	5*25 34,64	25*5 **17,36**	125* 1 34,64									
160	4*40 45,32	8*20 30,79	20*8 **20,18**	40*4 **20,18**								
200	1 * 200 80,08	2 * 100 66,93	4*50 50,79	5*40 45,53	8*25 35,40	10 * 20 31,32	20 * 10 22,84	25*8 **21,63**	40*5 **21,63**	50*4 22,84	100* 2 31,32	200* 1 45 ,53
250	5*50 50,98	10 * 25 35,90	25 * 10 **24,24**	50*5 **24,24**	125* 2 35,90	250* 1 50,98						

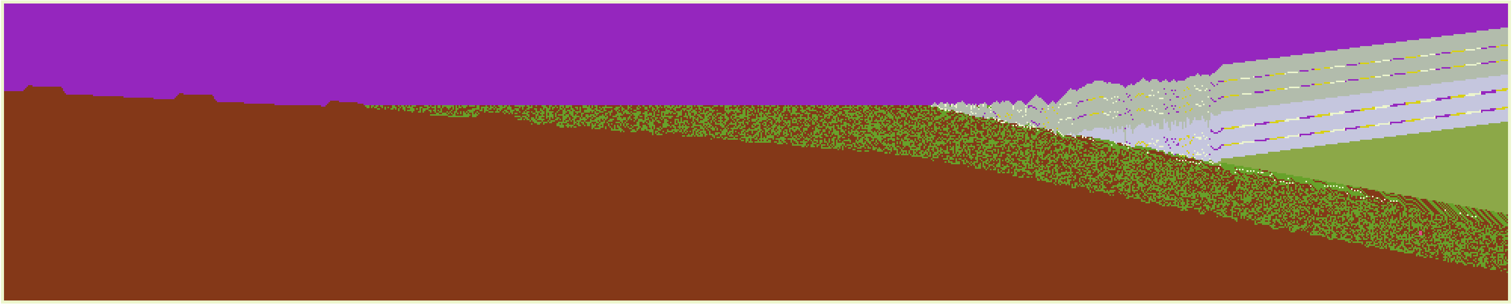
➥Screen-dumps of the 1D simulation :

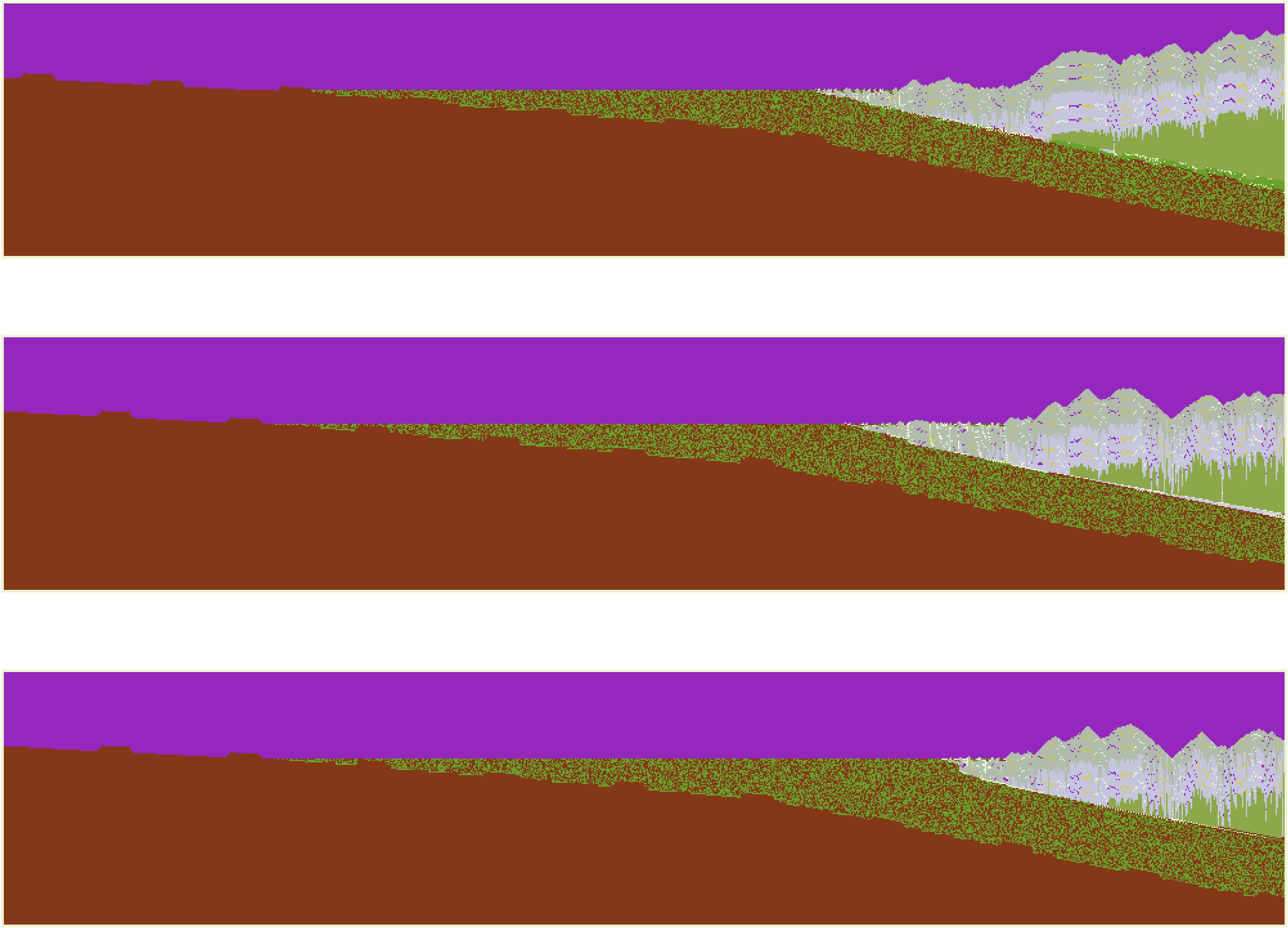




➥Screen-dumps of the 2D simulation :







Conclusion and future research works…

- ➥ concerning the models : we draw our inspiration from the 1D SPM to develop our own 1D model. In the 2D case, according to the same principle, we first implement a 2D model of avalanches. Since the multiplication of the data stored in the structure offers better visual results, we then choose to generalize this method,
- ➥ the results obtained show (for the 2D simulation at least) the very good parallelisability of the problem and show also what can be gained by using a suitable message-passing library in the field of regular domain decomposition onto parallel architecture,
- ➥ future research works could concern the development of a specialized parallel software and the study of the concentration of the deformations within the overlapping plate.