Curs 12

Programare Paralela si Distribuita

Strategii de Partitionare/Descompunere

Sabloane de proiectare

Partitionarea

- Problema partitionarii are ın vedere impartirea problemei de programare ın componente care se pot executa concurent.
- Aceasta nu implica o divizare directa a programului ıntr-un numar de componente egal cu numarul de procesoare disponibile.

- Cele mai importante scopuri ale partitionarii sunt legate de:
  - scalabilitate,
  - abilitatea de a ascunde intarzierea(latency) datorata retelei sau accesului la memorie si
  - realizarea unei granularitati cat mai mari.

- Sunt de preferat partitionarile care furnizeza mai multe componente decat procesoare, astfel ıncat sa se permita ascunderea ıntarzierii.

- Un task va fi blocat, sau va astepta, pana cand mesajul care contine informatia dorita va ajunge;

- Daca exista si alte componente program disponibile, procesorul poate continua calculul => multiprogramare => executiei concurente..

Strategii de partitionare

- Exista doua strategii principale de partitionare:
  - descompunerea domeniului de date si
  - descompunerea functionala.

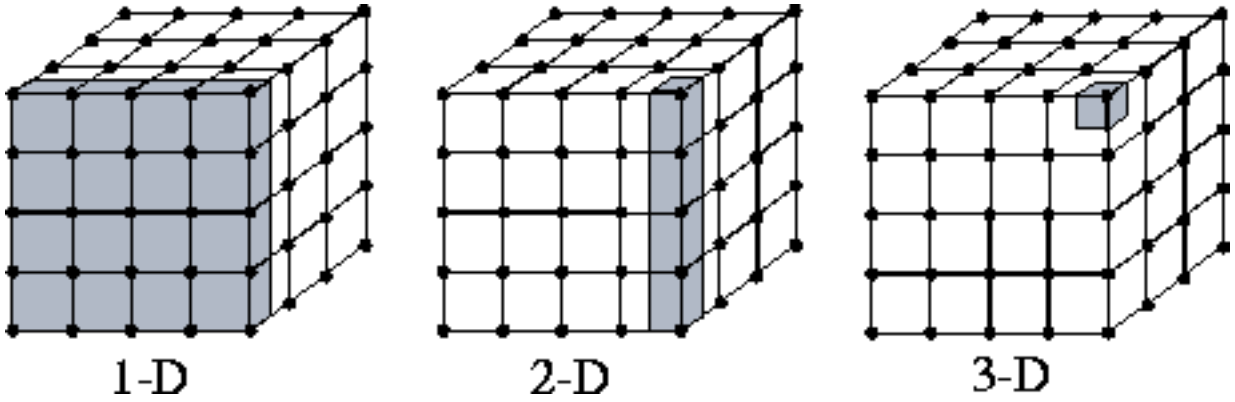
- In functie de acestea putem considera aplicatii paralele bazate pe:
  - descompunerea domeniului de date – paralelism de date, si
  - aplicatii paralele bazate pe descompunerea functionala.

- Cele doua tehnici pot fi folosite insa si impreuna:
  - de exemplu se incepe cu o descompunere functionala si dupa identificarea pricipalelor functii se poate folosi descompunerea domeniului de date pentru fiecare in parte.

Descompunerea domeniului de date

- Este aplicabila atunci cand domeniul datelor este mare si regulat.
- Ideea centrala este de a divide domeniul de date, reprezentat de principalele structuri de date, ın componente care pot fi manipulate independent.
- Apoi se partitioneaza operatiile, de regula prin asocierea calculelor cu datele asupra carora se efectueaza.
- Astfel, se obtine un numar de activitati de calcul, definite de un numar de date si de operatii.
  - Este posibil ca o operatie sa solicite date de la mai multe activitati. In acest caz, sunt necesare comunicatii.

Exemplificare



Descompunerea domeniului de date

- Sunt posibile diferite variante, in functie de structurile de date avute in vedere.

- Datele care se partitioneaza sunt in general datele de intrare, dar pot fi considerate deasemenea si datele de iesire sau intermediare.
  - Trebuie avute in vedere in special structurile de date de dimensiuni mari sau cele care sunt accesate in mod frecvent.

- Faze diferite ale calculului pot impune partitionari diferite ale aceleiasi structuri de date
  - =>redistribuiri ale datelor.
  - in acest caz trebuie avute in vedere de asemenea si costurile necesare redistribuirii datelor.

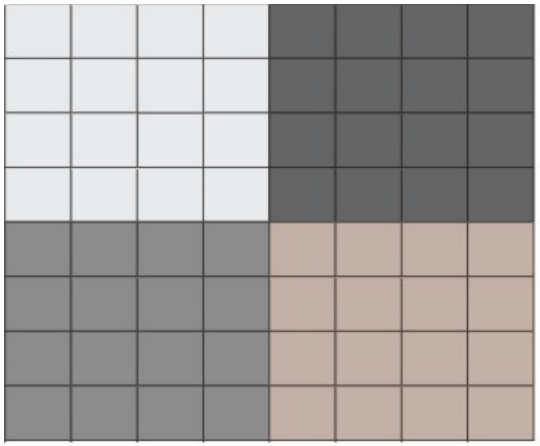
Distributii de date

- Partitionarea datelor conduce la anumite distributii ale datelor per procese si de aici implicit si per procesoare.
- Exista mai multe tehnici de partitionare a datelor, care pot fi exprimate si formal prin functii definite pe multimea indicilor datelor de intrare cu valori in multimea indicilor de procese.

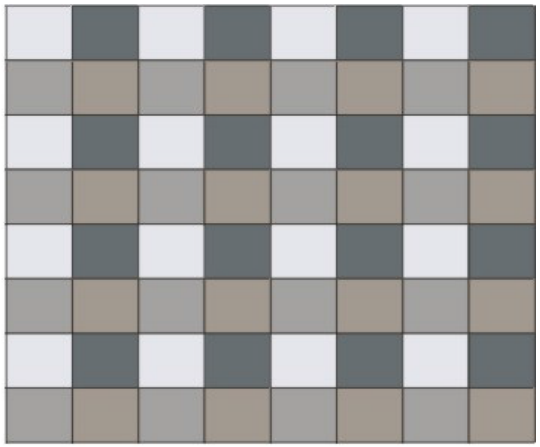
- Cele mai folosite tehnici de partitionare sunt prin “taiere” si prin “incretire” care corespund distributiilor liniara si ciclica.

Distributii de date

- De exemplu, pentru o matrice A de dimeniune 8×8, partitionarea sa in p = 4 parti:
  - prin tehnica taierii (distr. liniara) conduce la partitionarea aratata de Figura (a), iar
  - prin tehnica incretirii (distr. ciclica) conduce la partitionarea aratata de Figura (b).

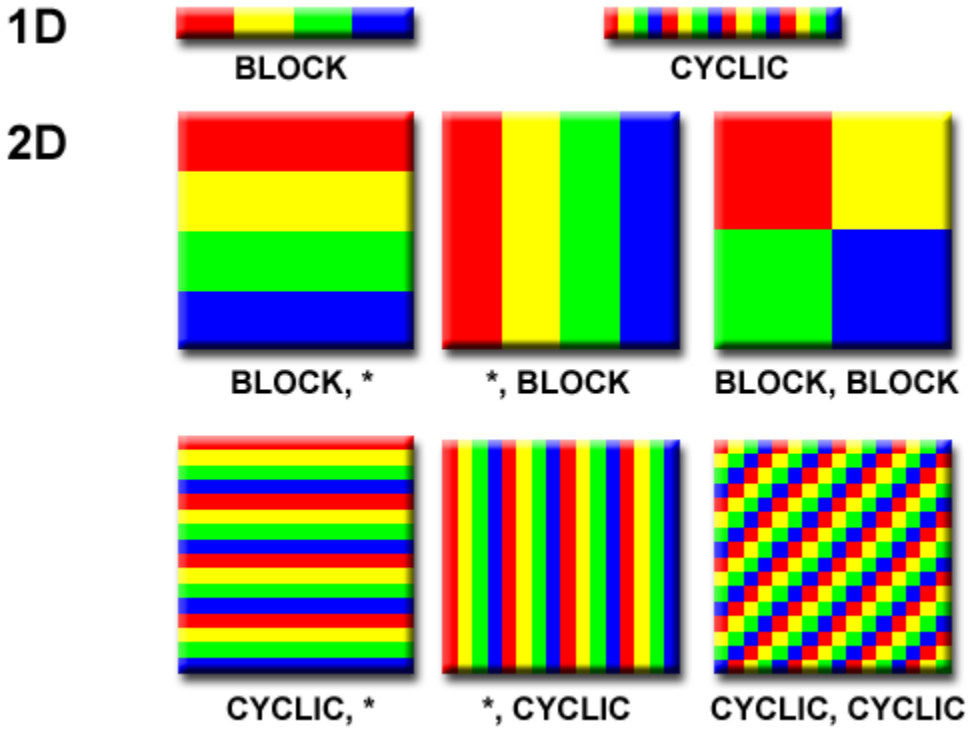


(a) Taiere (distributie bloc)



(b) Incretire (distributie grid)

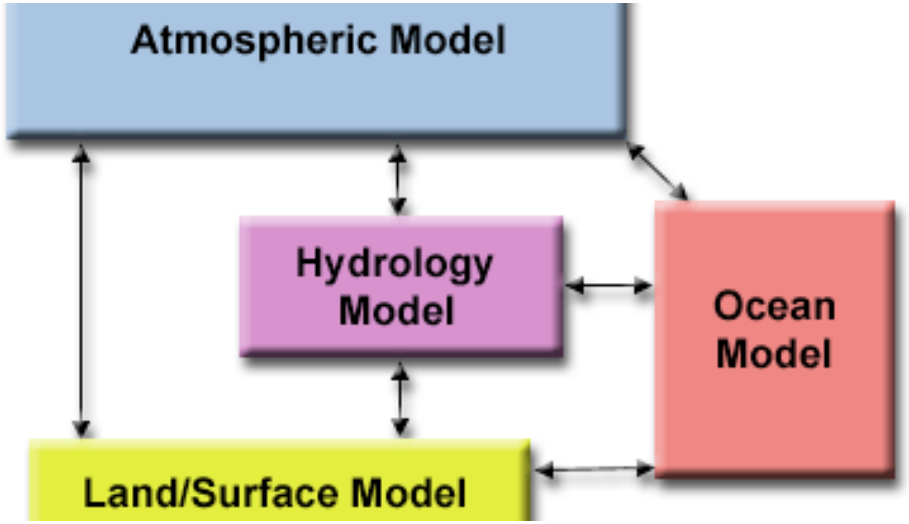
Variante


1D
BLOCK
CYCLIC
2D
BLOCK, *
*, BLOCK
BLOCK, BLOCK
CYCLIC, *
*, CYCLIC
CYCLIC, CYCLIC

Descompunerea functionala

- Descopunerea functionala este o tehnica de partitionare folosita atunci cand aspectul dominant al problemei este functia, sau algoritmul, mai degraba decat operatiile asupra datelor.
- Obiectivul este descompunerea calculelor ın activitati de calcul cat mai fine.
- Dupa crearea acestora se examineaza cerintele asupra datelor.
- Focalizarea asupra calculelor poate revela uneori o anumita structura a problemei, de unde oportunitati de optimizare, care nu sunt evidente numai din studiul datelor.
- In plus, ea are un rol important ca si tehnica de structurare a programelor.
- Aceasta varianta de descompunere nu conduce in general la o granulatie fina a sarcinilor de calcul, care se executa in paralel.

Exemplificare



Cerinte pentru partitionare

- Task-urile obtinute sunt de dimensiuni comparabile.

- Scalabilitatea poate fi obtinuta.
  - Aceasta inseamna ca numarul de sarcini de calcul sunt definite in functie de dimensiunea problemei;
  - deci cresterea dimensiunii datelor implica cresterea numarului de sarcini de lucru.

- Intazierile pot fi reduse prin multitasking.

- Granularitatea aplicatiei este suficient de mare astfel incat sa poata fi implementata cu succes pe diferite arhitecturi.

SABLOANE DE PROIECTARE

… in general proiectarea se bazeaza pe…

- Descompunere functionala
- Descompunere domeniului de date
- Fluxul de date

Observatie:

In literature exista mai multe clasificari de sabloane de proiectare paralela dar sunt cateva sabloane de baza care se regasesc in majoritatea referintelor.

Sabloane de baza

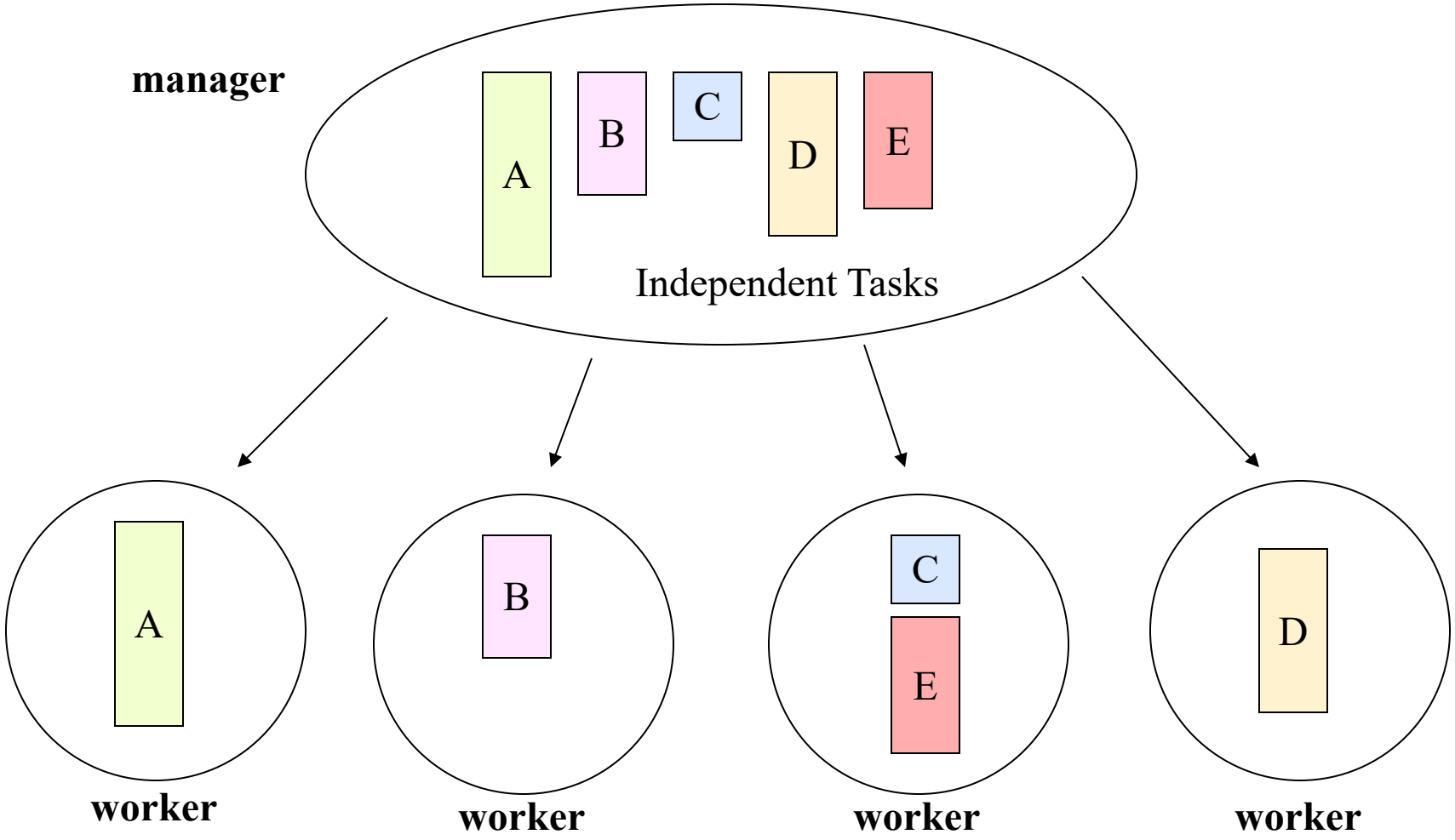
Parallel Programming Patterns
Eun-Gyu Kim
2004

- Embarassingly Parallel – e.g. suma de vectori
  - /Master-Slave
- Replicable
- Repository
- Divide&Conquer
- Pipeline
- Recursive Data
- Geometric Decomposition
- IrregularMesh

Variante pentru sabloane bazate pe descompunerea datelor sau a taskurilor

- Decomposition
  - geometrica ... -> caracter static
  - recursiva
  - exploratorie ... -> caracter dinamic
  - speculativa

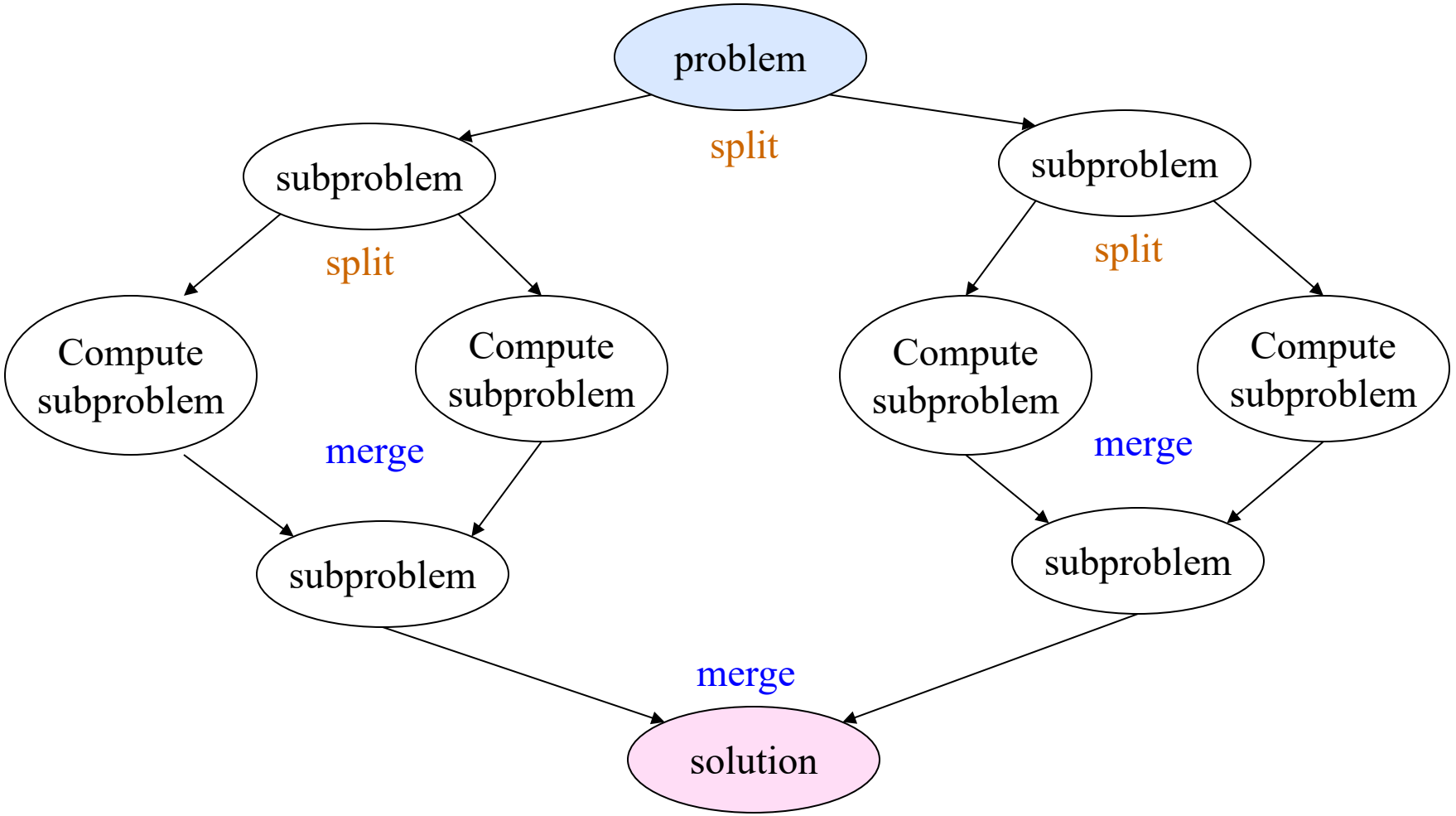
Master-slave (master-worker)



Descompunere Recursiva

- In general pentru probleme care se pot rezolva prin **divide & impera**

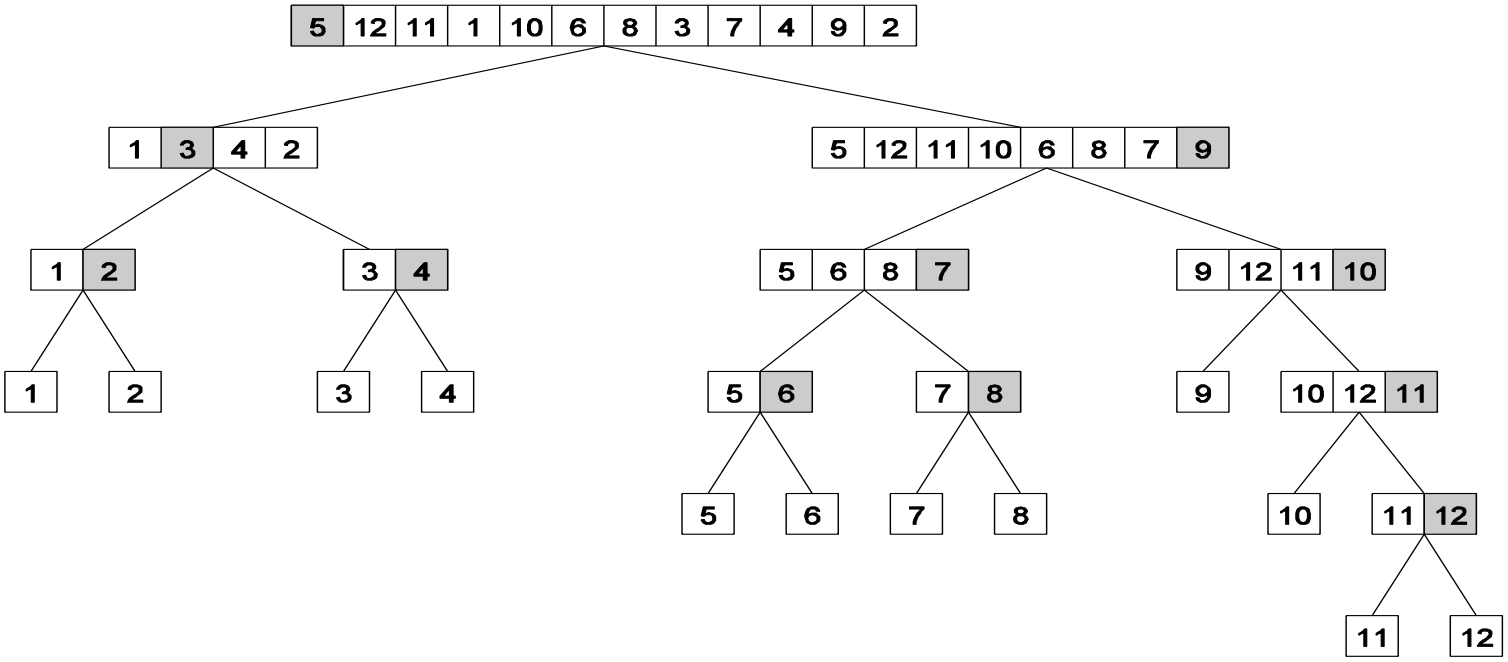
Divide & Conquer



* Nivelurile de descompunere trebuie sa fie ajustate corespunzator.

Recursive Decomposition: Exemplul 1

Quicksort.



Fiecare sublista reprezinta un task.

Recursive Decomposition: Exemplul 2

Cautarea minimului:

```
1. procedure SERIAL_MIN (A, n)
2. begin
3. min = A[0];
4. for i := 1 to n − 1 do
5.                 if (A[i] < min) min := A[i];
6. endfor;
7. return min;
8. end SERIAL_MIN
```

Recursive Decomposition

Rescriere

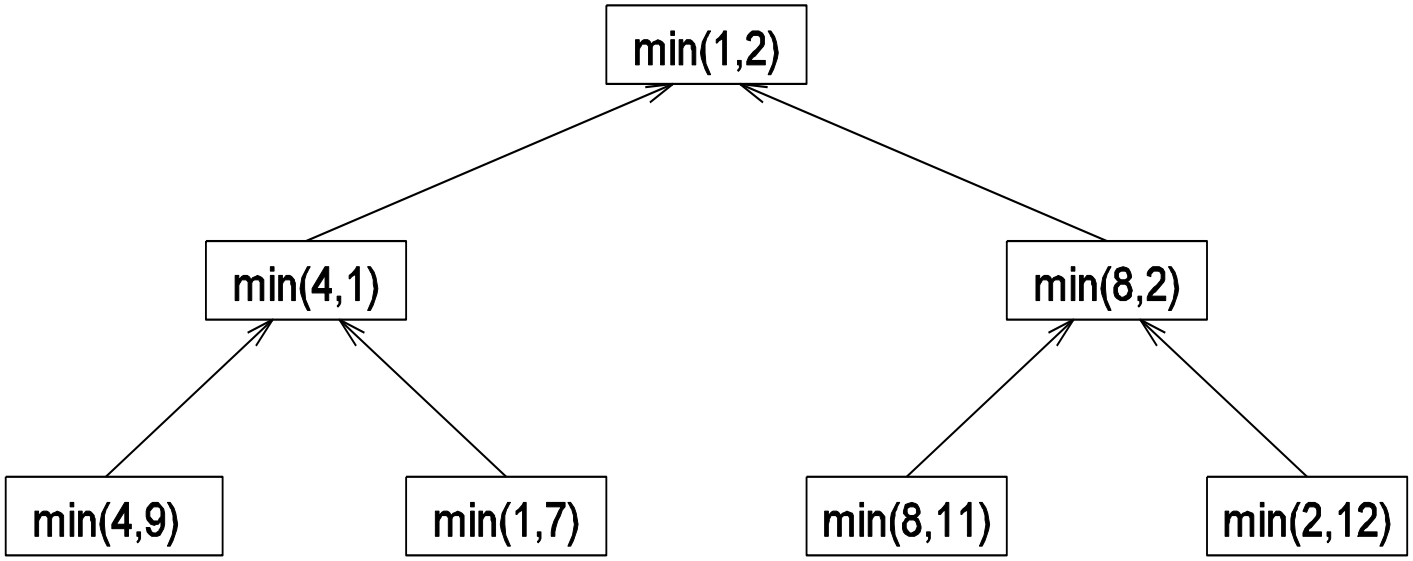
```
1. procedure RECURSIVE_MIN (A, n)
2. begin
3. if ( n = 1 ) then
4.     min := A [0]  ;
5. else
6.     lmin := RECURSIVE_MIN ( A, n/2 );
7.     rmin := RECURSIVE_MIN (  &(A[n/2]), n - n/2 );
8.     if (lmin  < rmin) then
9.                 min := lmin;
10.    else
11.                min := rmin;
12.    endelse;
13. endelse;
14. return min;
15. end RECURSIVE_MIN
```

se pot executa in paralel

Recursive Decomposition

{4, 9, 1, 7, 8, 11, 2, 12}.

- task dependency graph

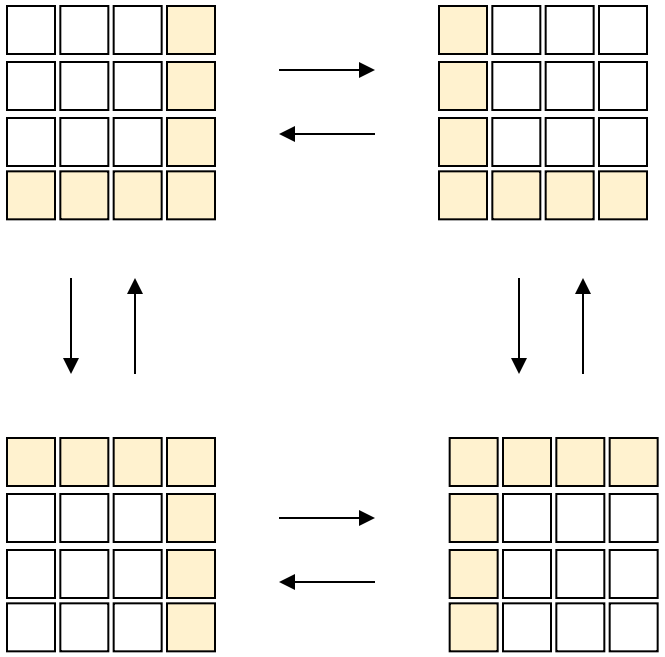


Data Decomposition (geometric)

- Identificarea datelor implicate in calcul.
- Partitionarea datelor pe taskuri.
  - Diferite modalitati care implica impact important pt performanta.

Geometric

Exista dependente dar comunicarea se face intr-un mod predictibil (geometric) -> vecini.



Neighbor-To-Neighbor communication

Output Data Decomposition: Exemplu

inmultire de matrice
n x ***n*** matricele ***A*** x ***B*** =***C***.

$$\begin{pmatrix} A_{1,1} & A_{1,2} \\ A_{2,1} & A_{2,2} \end{pmatrix} \cdot \begin{pmatrix} B_{1,1} & B_{1,2} \\ B_{2,1} & B_{2,2} \end{pmatrix} \rightarrow \begin{pmatrix} C_{1,1} & C_{1,2} \\ C_{2,1} & C_{2,2} \end{pmatrix}$$

Task 1: $C_{1,1} = A_{1,1}B_{1,1} + A_{1,2}B_{2,1}$

Task 2: $C_{1,2} = A_{1,1}B_{1,2} + A_{1,2}B_{2,2}$

Task 3: $C_{2,1} = A_{2,1}B_{1,1} + A_{2,2}B_{2,1}$

Task 4: $C_{2,2} = A_{2,1}B_{1,2} + A_{2,2}B_{2,2}$

Output Data Decomposition: Exemplu

- nu exista doar o descompunere unica – variante!

Decomposition I	**Decomposition II**
Task 1: $C_{1,1} = A_{1,1} B_{1,1}$	Task 1: $C_{1,1} = A_{1,1} B_{1,1}$
Task 2: $C_{1,1} = C_{1,1} + A_{1,2} B_{2,1}$	Task 2: $C_{1,1} = C_{1,1} + A_{1,2} B_{2,1}$
Task 3: $C_{1,2} = A_{1,1} B_{1,2}$	Task 3: $C_{1,2} = A_{1,2} B_{2,2}$
Task 4: $C_{1,2} = C_{1,2} + A_{1,2} B_{2,2}$	Task 4: $C_{1,2} = C_{1,2} + A_{1,1} B_{1,2}$
Task 5: $C_{2,1} = A_{2,1} B_{1,1}$	Task 5: $C_{2,1} = A_{2,2} B_{2,1}$
Task 6: $C_{2,1} = C_{2,1} + A_{2,2} B_{2,1}$	Task 6: $C_{2,1} = C_{2,1} + A_{2,1} B_{1,1}$
Task 7: $C_{2,2} = A_{2,1} B_{1,2}$	Task 7: $C_{2,2} = A_{2,1} B_{1,2}$
Task 8: $C_{2,2} = C_{2,2} + A_{2,2} B_{2,2}$	Task 8: $C_{2,2} = C_{2,2} + A_{2,2} B_{2,2}$

Output Data Decomposition: Exemplu

Problema: numararea instantelor unor itemi intr-o baza de date de tranzactii.
Output= itemset frequencies
se partitioneaza intre taskuri.

(a) Transactions (input), itemsets (input), and frequencies (output)

Database Transactions	Itemsets	Itemset Frequency
A, B, C, E, G, H	A, B, C	1
B, D, E, F, K, L	D, E	3
A, B, F, H, L	C, F, G	0
D, E, F, H	A, E	2
F, G, H, K,	C, D	1
A, E, F, K, L	D, K	2
B, C, D, G, H, L	B, C, F	0
G, H, L	C, D, K	0
D, E, F, K, L		
F, G, H, L		

(b) Partitioning the frequencies (and itemsets) among the tasks

Database Transactions	Itemsets	Itemset Frequency
A, B, C, E, G, H	A, B, C	1
B, D, E, F, K, L	D, E	3
A, B, F, H, L	C, F, G	0
D, E, F, H	A, E	2
F, G, H, K,		
A, E, F, K, L		
B, C, D, G, H, L		
G, H, L		
D, E, F, K, L		
F, G, H, L		

task 1

Database Transactions	Itemsets	Itemset Frequency
A, B, C, E, G, H	C, D	1
B, D, E, F, K, L	D, K	2
A, B, F, H, L	B, C, F	0
D, E, F, H	C, D, K	0
F, G, H, K,		
A, E, F, K, L		
B, C, D, G, H, L		
G, H, L		
D, E, F, K, L		
F, G, H, L		

task 2

Output Data Decomposition: Exemplu

Analiza:

- Daca baza de tranzactii este replicata pe procese fiecare task se poate executa fara comunicatii.
- Daca baza de tranzactii este distribuita pe procese (memory …) atunci fiecare task calculeaza frecvente partiale care trebuie ulterior agregate.

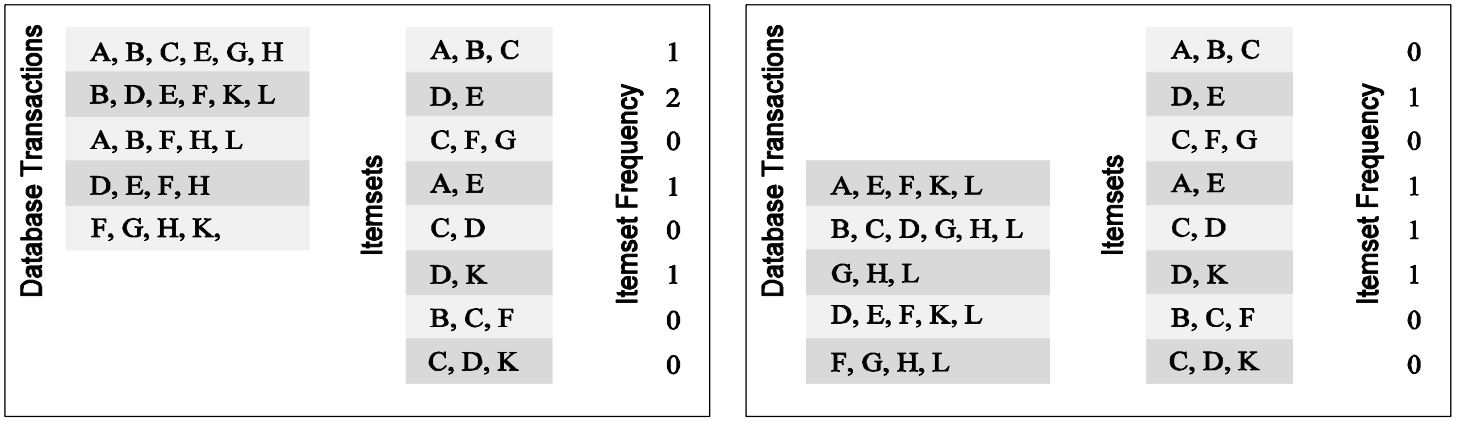
Input Data Partitioning

- Exemple: minim intr-o lista, sortare,....
- Task <=> partitie input

- Procese ulterioare pot agrega/ combina rezultatele partiale.

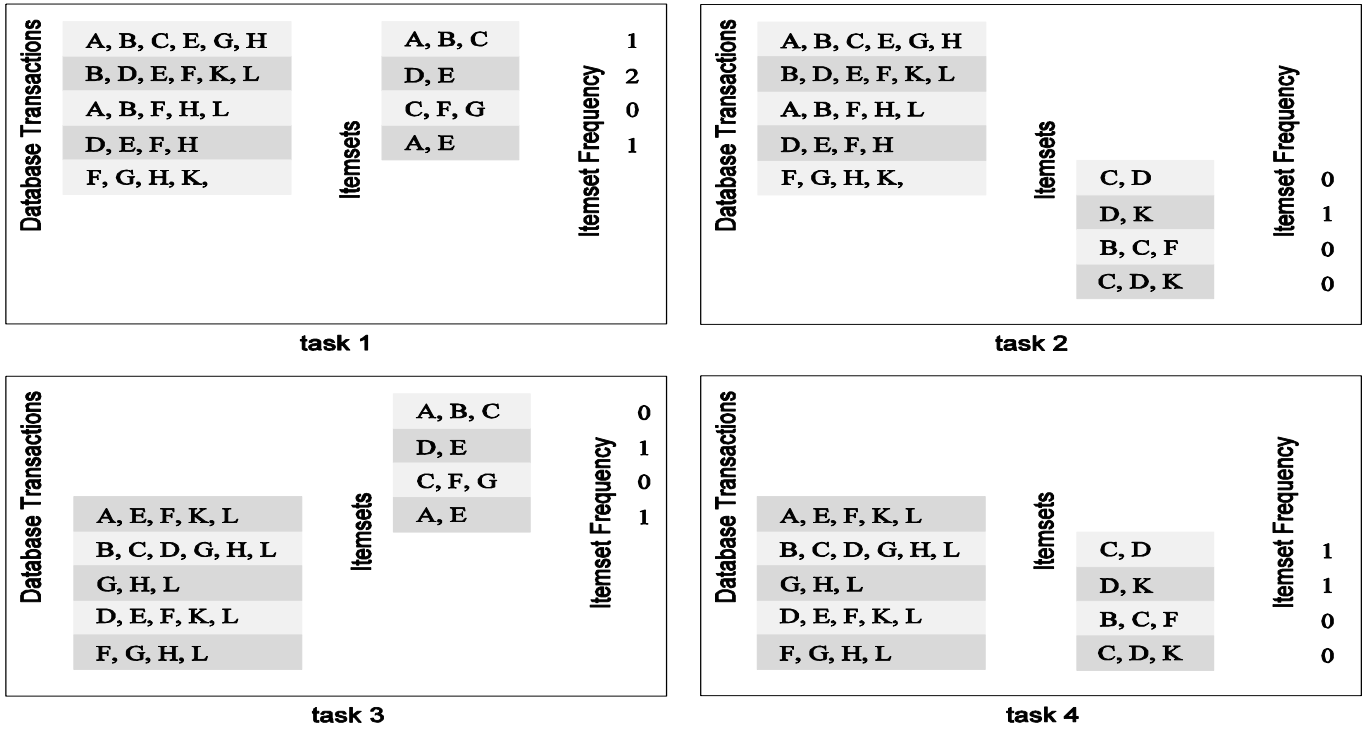
Input Data Partitioning: Exemplu

Partitioning the transactions among the tasks



Partitioning Input *and* Output Data

Partitioning both transactions and frequencies among the tasks

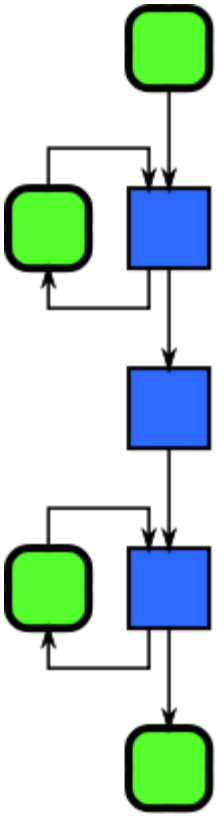


The Owner Computes Rule

- Procesul care are data asignata lui este responsabil cu calculele asociate acelei date
- Diferente:
  - input data decomposition
  - output data decomposition

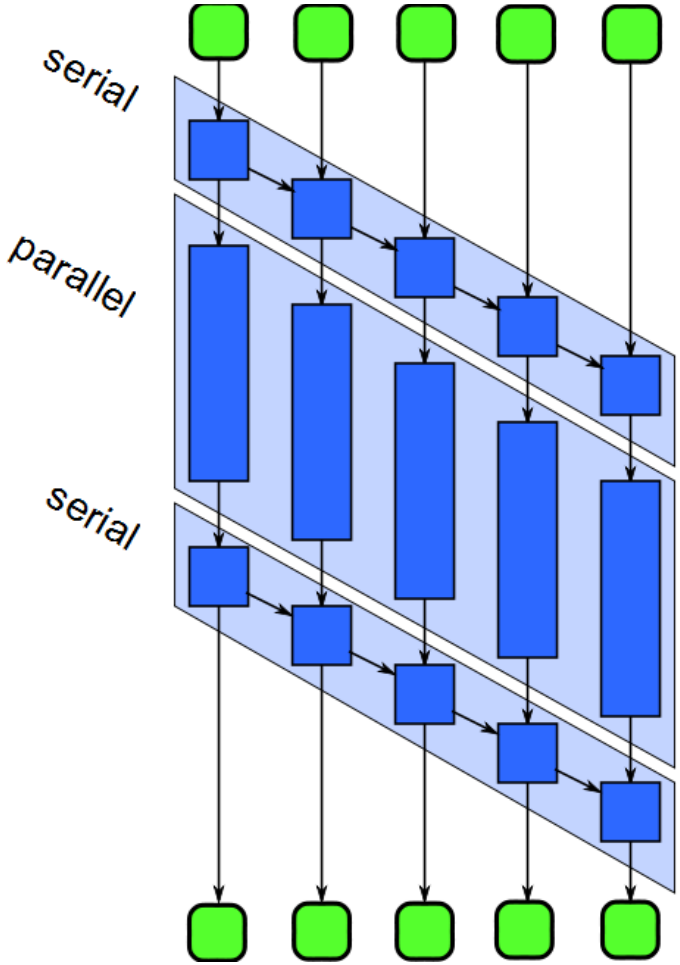
- Obs: similar sablon GRASP: Expert

Pipeline - sablon de programare paralela



- *Pipeline* – o secventa de stagii care transforma un flux de date
- Unele stagii pot sa stocheze stare
- Datele pot fi “consumate” si produse incremental.

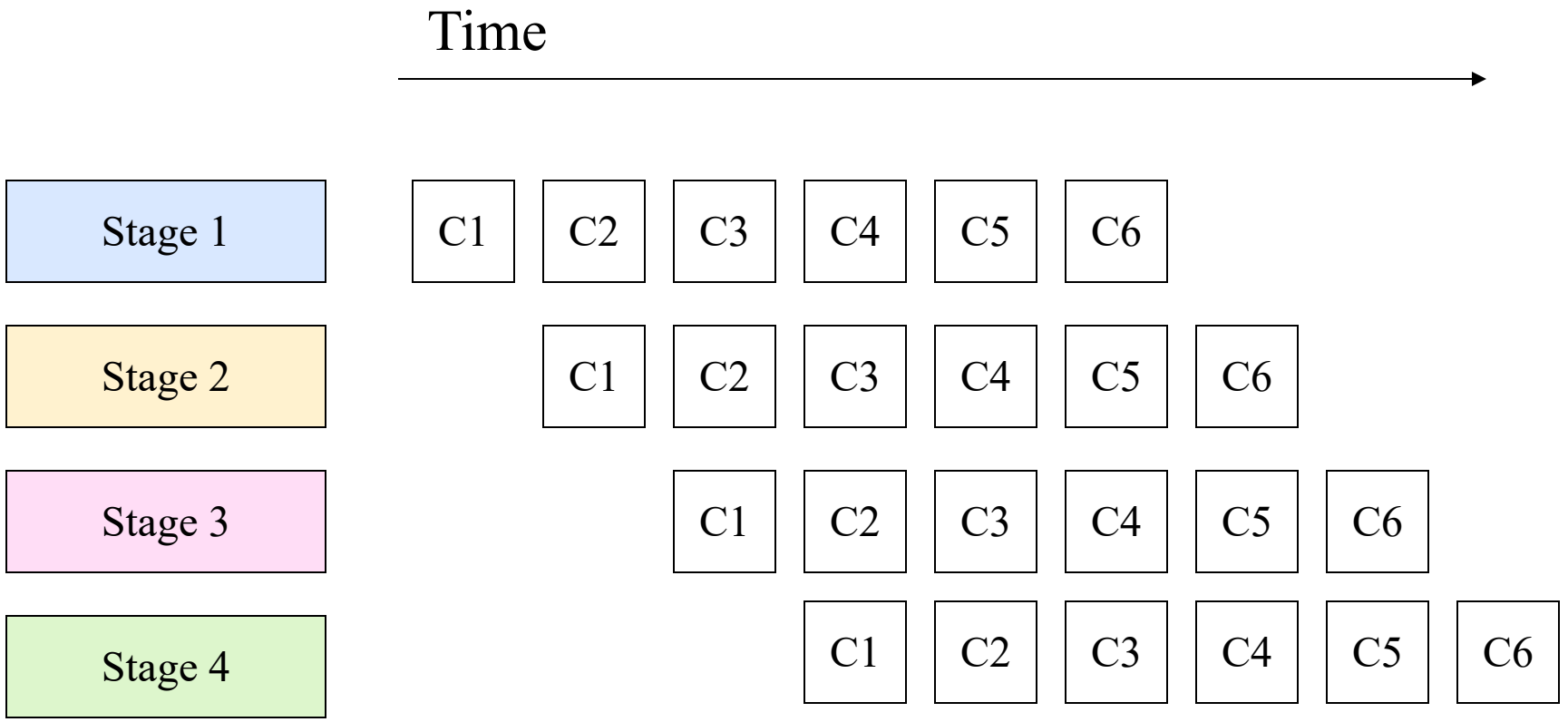
Pipeline



- Paralelizarea pipeline se face prin
  1. Executia diferitelor stagii in paralel
  2. Executia multiplelor copii ale stagiilor fara stare in paralel

Pipeline

A series of ordered but independent computation stages need to be applied on data, where each output of a computation becomes input of subsequent computation.



Sumar - descompunere

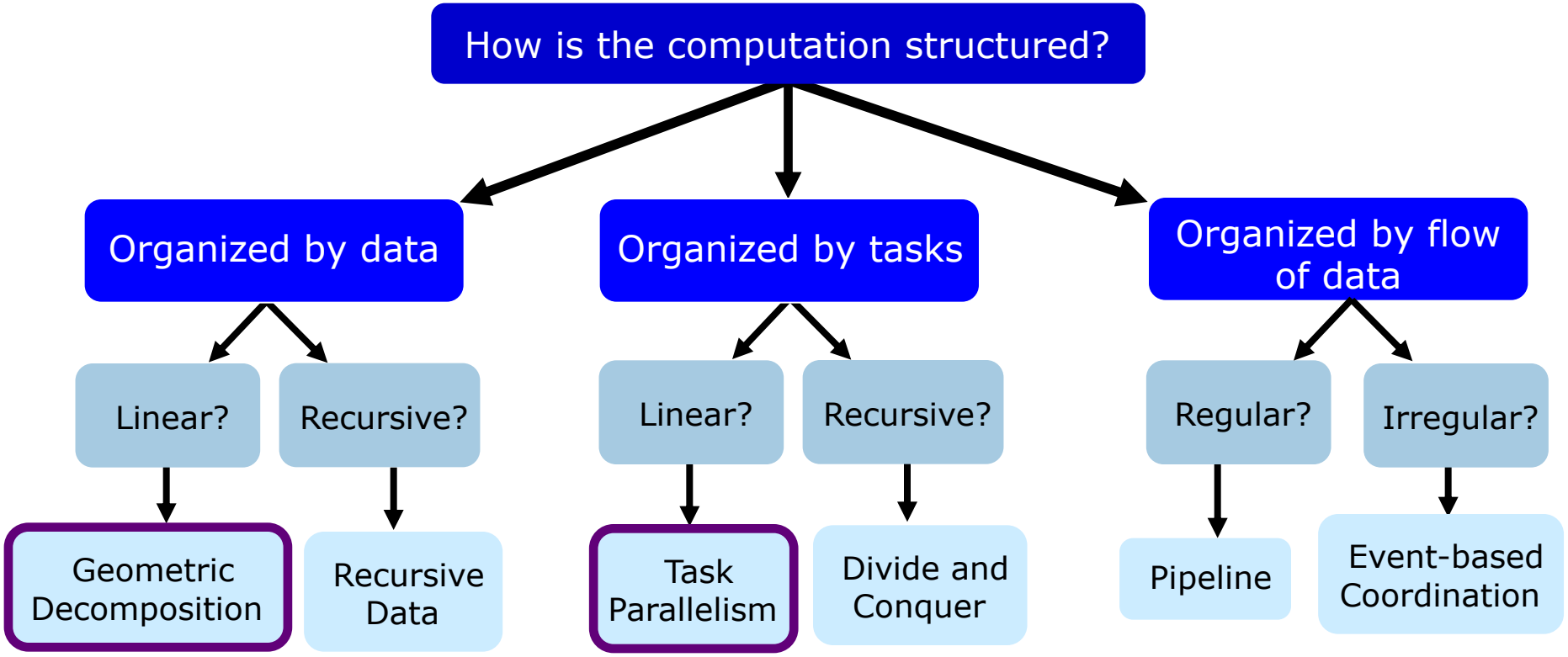
- Nu exista doar o singura reteta pentru descompunere
- Se pot aplica un set de tehnici comune pe o clasa de probleme mai vasta.

:

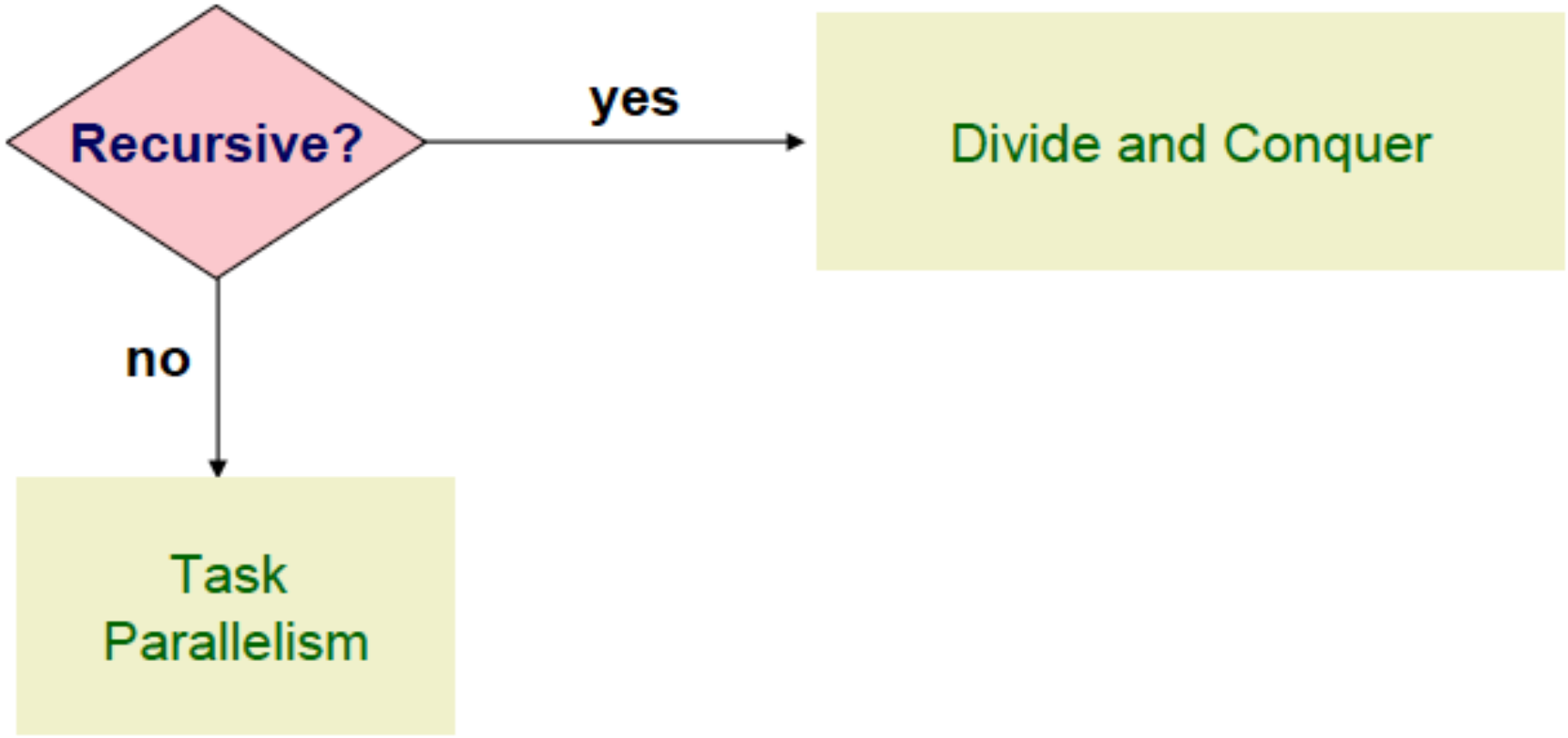
- *data decomposition (geometric decomposition)*
- *recursive decomposition*
- *exploratory decomposition*
- *speculative decomposition*

- *Pipelines… (se poate obtine prin descompunerea fluxului de date)*

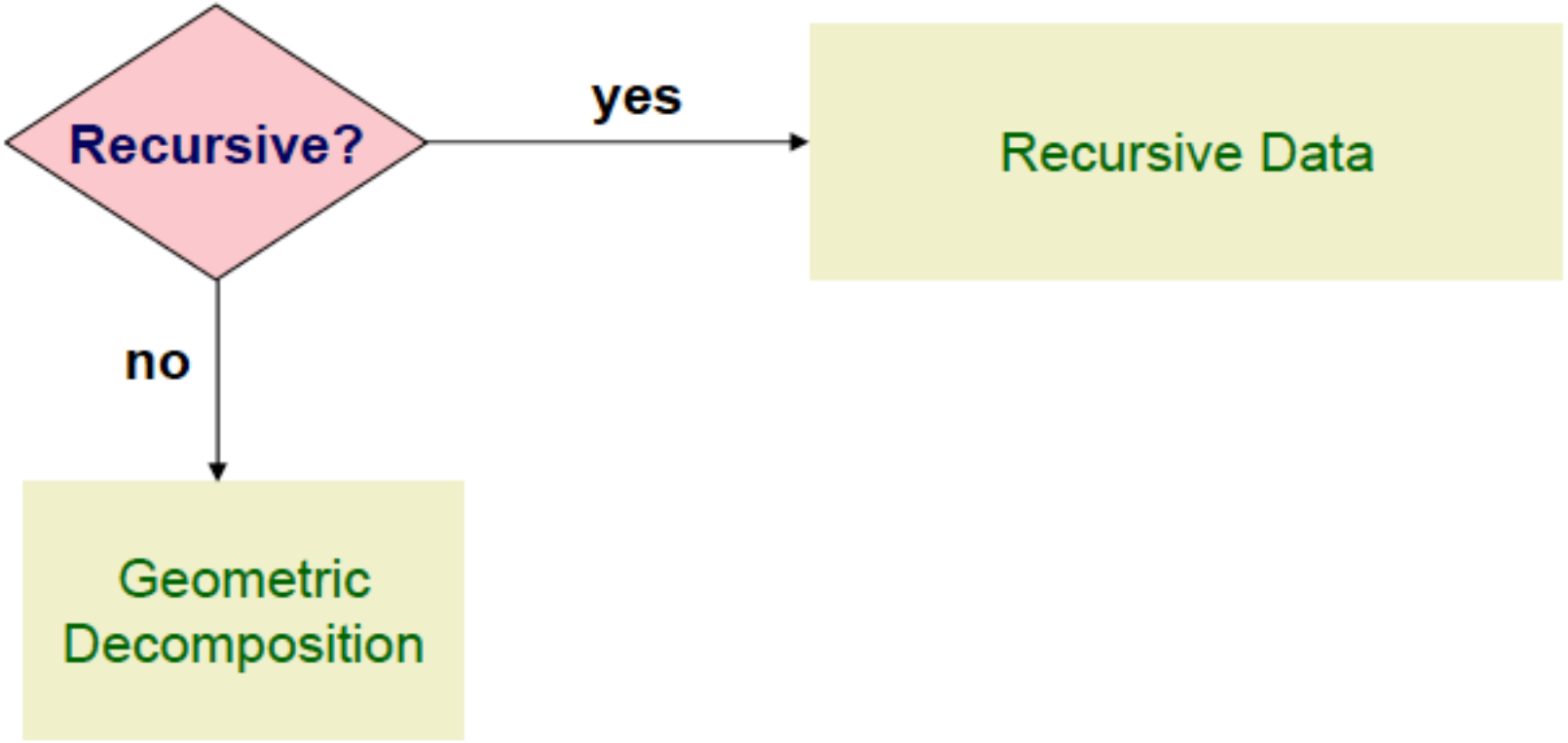
Algorithm Structure Design Space



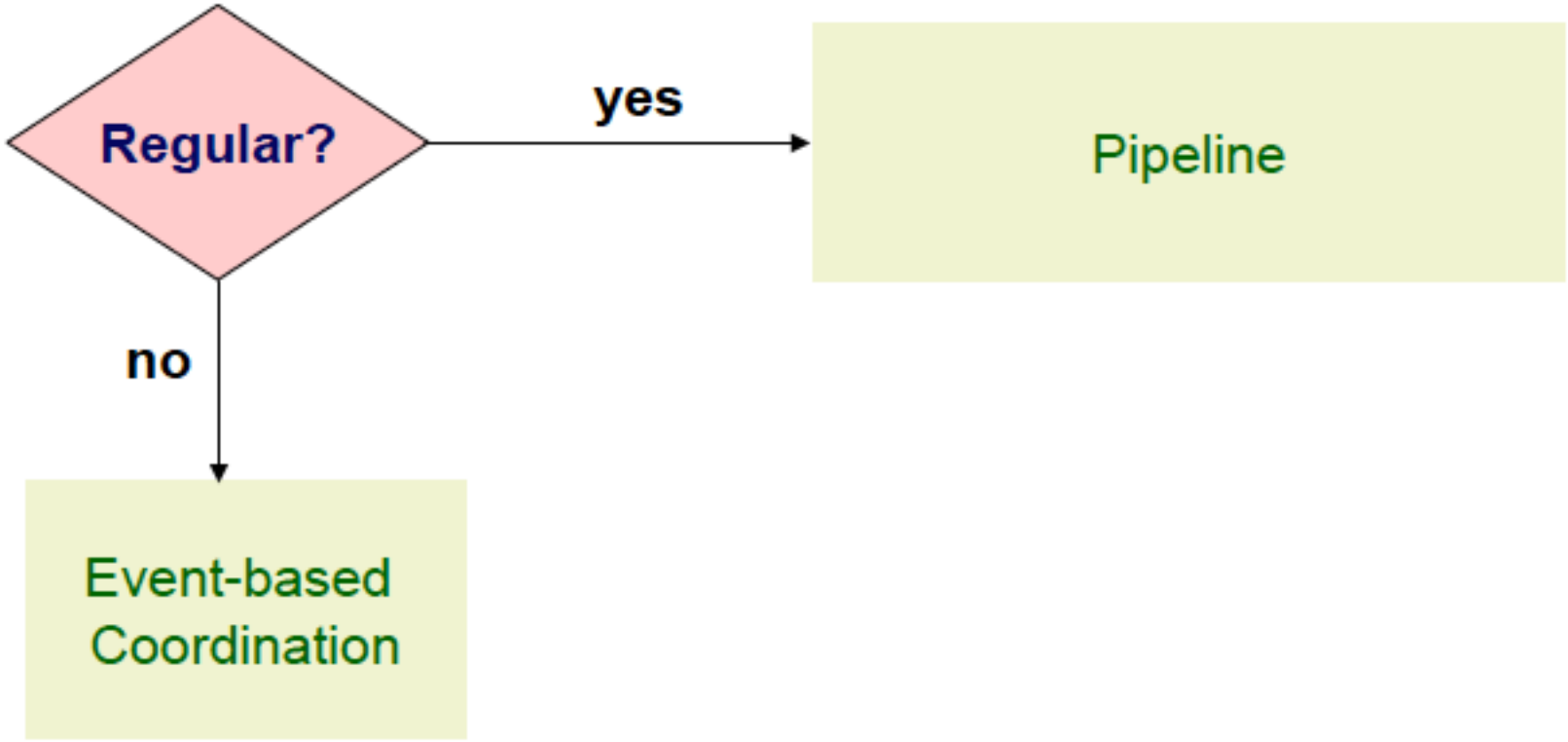
Descompunere functionala



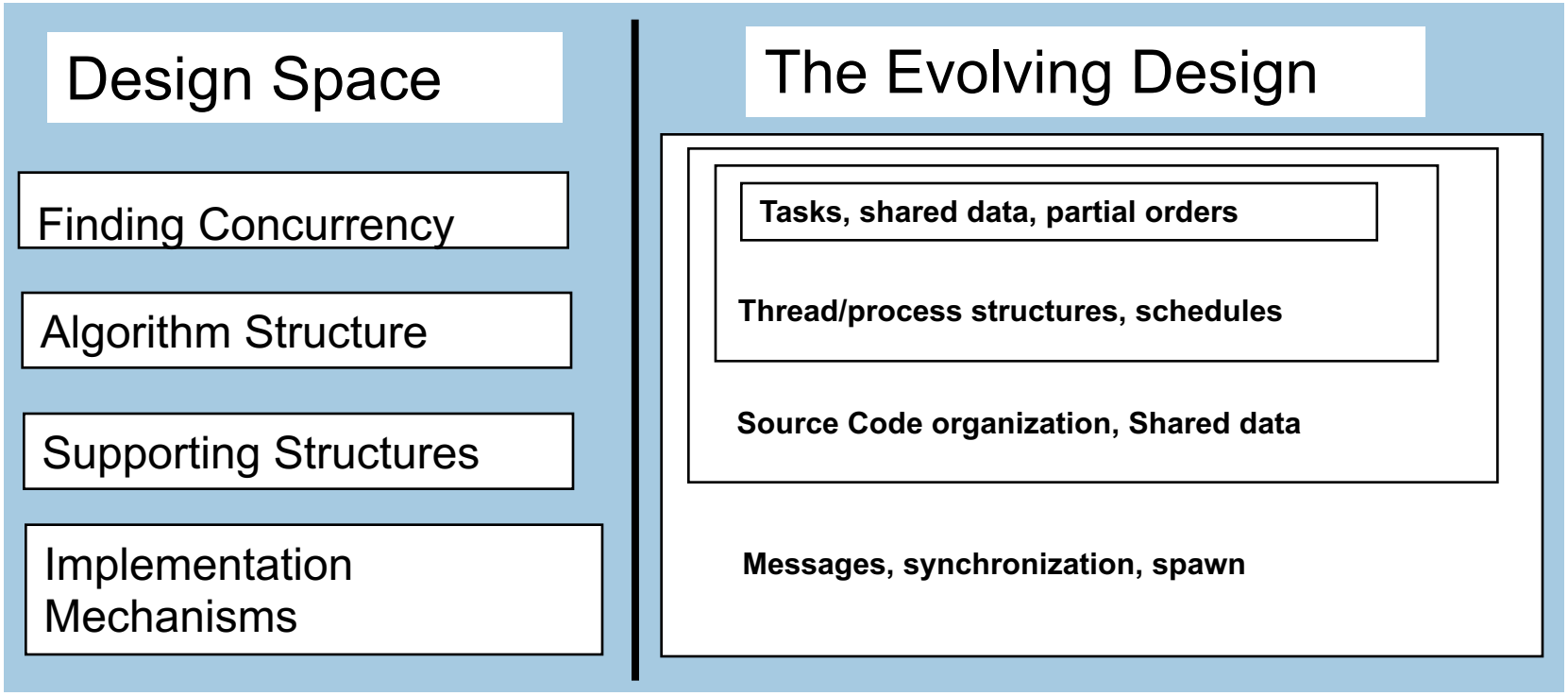
Descompunerea datelor



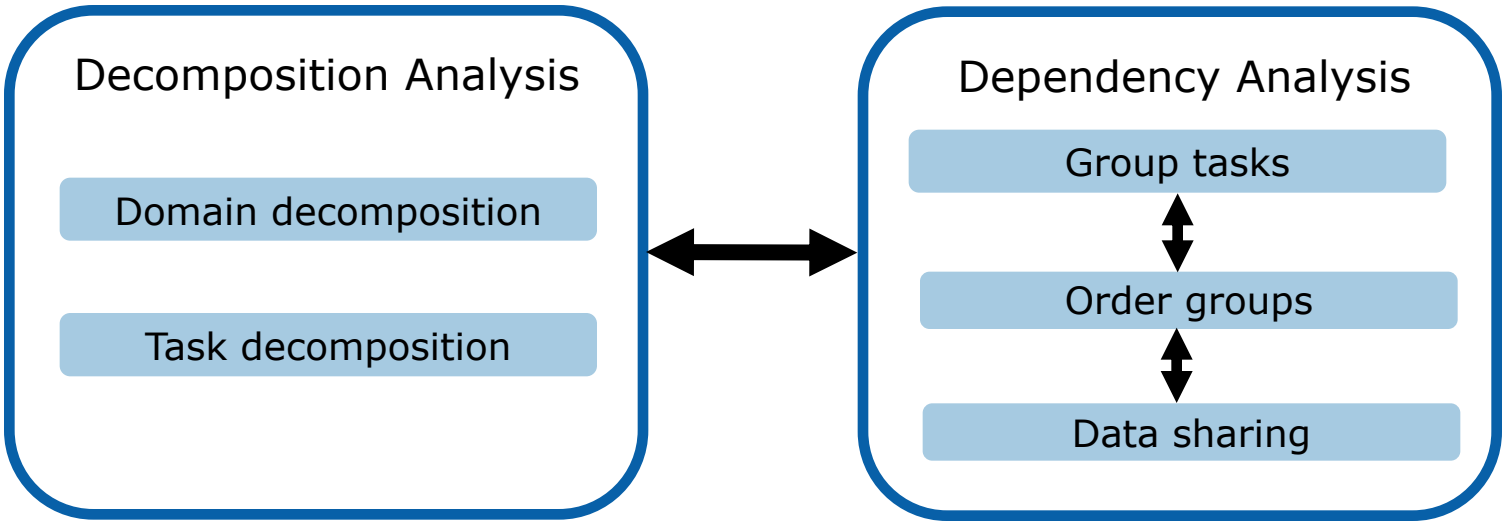
Descompunere bazata pe *Data-Flow*

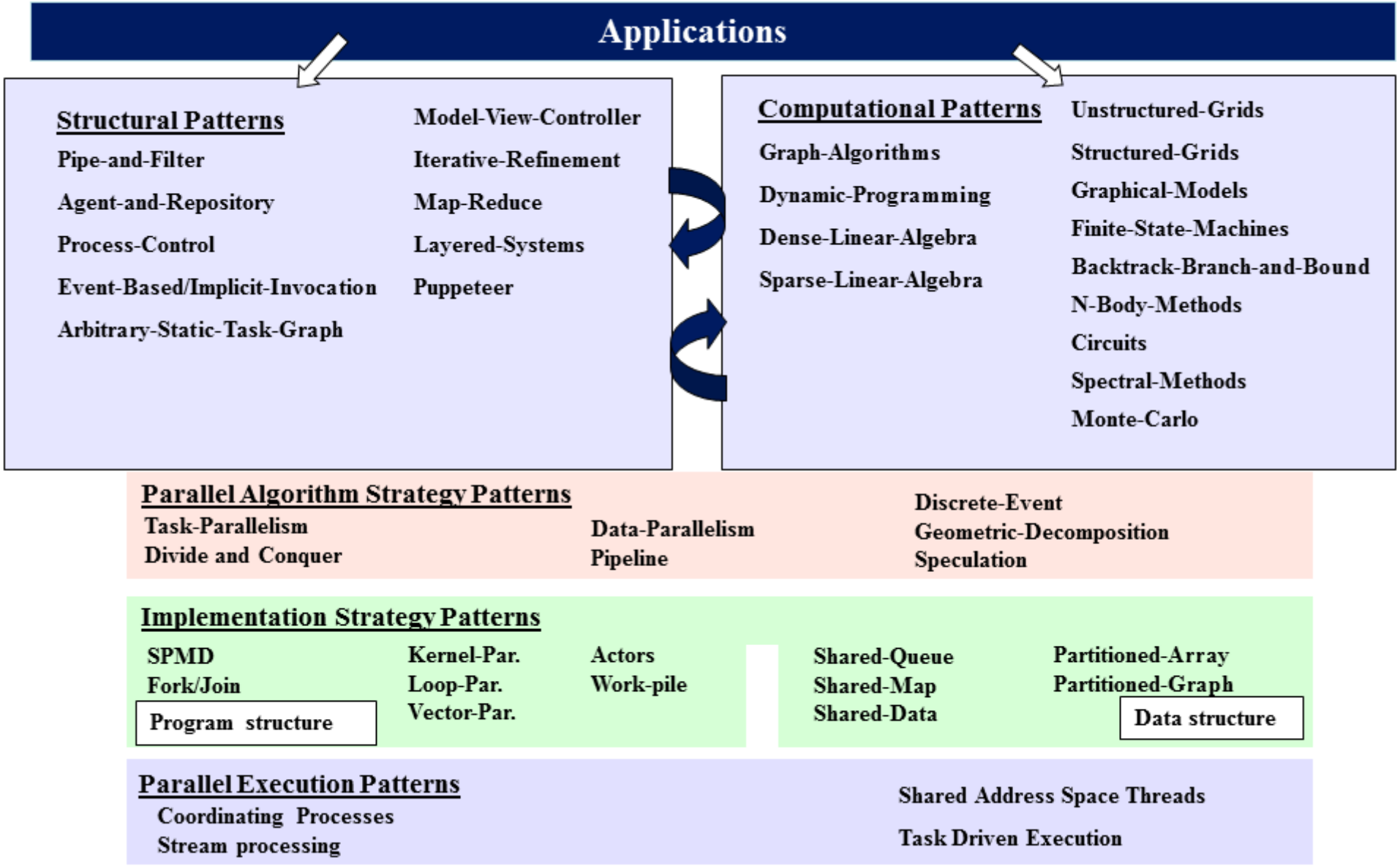


Patterns for Parallel Programming. Mattson, Sanders, and Massingill (2005).



Cautare in spatiul de proiectare concurenta




Applications
Structural Patterns
Pipe-and-Filter
Agent-and-Repository
Process-Control
Event-Based/Implicit-Invocation
Arbitrary-Static-Task-Graph
Model-View-Controller
Iterative-Refinement
Map-Reduce
Layered-Systems
Puppeteer
Computational Patterns
Graph-Algorithms
Dynamic-Programming
Dense-Linear-Algebra
Sparse-Linear-Algebra
Unstructured-Grids
Structured-Grids
Graphical-Models
Finite-State-Machines
Backtrack-Branch-and-Bound
N-Body-Methods
Circuits
Spectral-Methods
Monte-Carlo
Parallel Algorithm Strategy Patterns
Task-Parallelism
Divide and Conquer
Data-Parallelism
Pipeline
Discrete-Event
Geometric-Decomposition
Speculation
Implementation Strategy Patterns
SPMD
Fork/Join
Program structure
Kernel-Par.
Loop-Par.
Vector-Par.
Actors
Work-pile
Shared-Queue
Shared-Map
Shared-Data
Partitioned-Array
Partitioned-Graph
Data structure
Parallel Execution Patterns
Coordinating Processes
Stream processing
Shared Address Space Threads
Task Driven Execution

Referinte:

``Introduction to Parallel Computing''
Ananth Grama, Anshul Gupta, George Karypis, and Vipin Kumar
2003

Ian Foster
Designing and Building Parallel Programs, Addison Wesley, 2, Addison-Wesley Inc., Argonne National Laboratory (http://www.mcs.anl.gov/~itf/dbpp/)

Parallel Programming Patterns
Eun-Gyu Ki
2004

Patterns for Parallel Programming. Mattson, Sanders, and Massingill (2005).