Arhitecturi Paralele
Pipeline

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Address Space Qualifiers

- __global
  - Accesibil de toate work-item-urile.
- __local
  - Accesibil doar de work-item-urile unui work-group.
- __private
  - Accesibil de un singur work-item.
- __constant

Synchronization

- void **barrier**(cl_mem_fence_flags *flags*)
- void **work_group_barrier**(cl_mem_fence_flags *flags*)
  - Toate work-item-urile unui work-group trebuie să aștepte la barieră pentru a trece mai departe.
  - Dacă bariera în if toate să intre pe aceeași ramură a if-ului.
  - Dacă bariera în for toate să facă același număr de iterații ale for-ului.

Built in Functions

- uint **get_work_dim**()
  - Cu câte dimensiuni a fost rulat kernel-ul.
- size_t **get_global_size**(uint *dimindx*)
  - Mărimea globală pentru dimensiunea dimindx.
- size_t **get_global_id**(uint *dimindx*)
  - Locația în dimensiunea dimindx.
- size_t **get_local_size**(uint *dimindx*)
  - Mărimea work-group-ului pe dimensiunea dimindx.
- size_t **get_local_id**(uint *dimindx*)
  - Locația în work-group pe dimensiunea dimindx.

Synchronization

- No mutex
- No semaphore
- Yes atomics... Tons of atomics.
  - atomic_add
  - atomic_sub
  - atomic_xchg
  - atomic_inc
  - atomic_min
  - atomic_and

OpenCL Hardware vs Software

Work Item (Thread) executes on a core

Work Group executes on an **SM**

GTX 1080 (Pascal) **Streaming Multiprocessor** (Compute Unit)

Detalii Work Group

- **Work Group**
  - Conține mai mulți work items (threads)
  - Toate work items dintr-un work group împart Shared memory (__local)
  - Barieră din kernel există doar la nivel de work group
    - **Toate** work items din work group trebuie să apeleze bariera
  - Atomicele pot funcționa la nivel de work group
  - Work items din același work group pot rula în **lock step**
- Unul (sau mai mulți – depinde de implementare) work group pe **SM**
- **MAX** un **SM** pe work group

Barieră globală

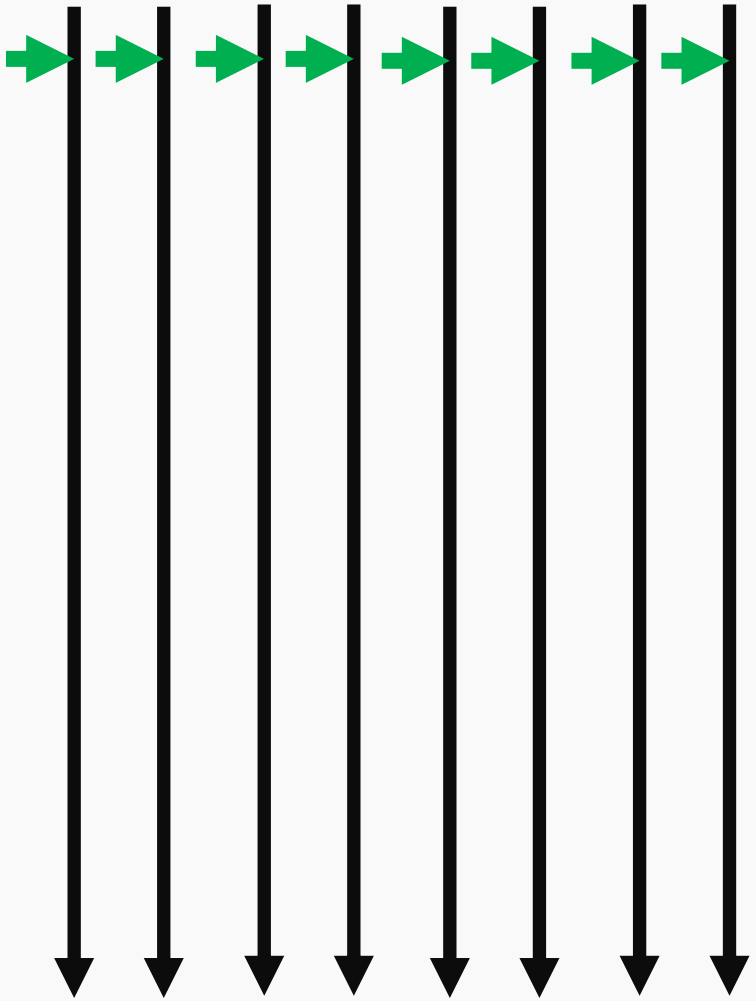
- Default toate comenzile introduse într-un queue sunt executate în ordine și se așteaptă terminarea uneia ca să înceapă alta.
- Dacă avem nevoie de barieră globală, singura metodă e să separăm codul la acea barieră și să executăm porțiunea de după barieră printr-un nou apel clEnqueueNDRangeKernel (fie că e același kernel cu alți parametri sau altul)

OpenCL Hardware vs Software

- GTX 1080
  - CUDA cores: 2560
  - Max Compute Units (raportat de OpenCL): 20
  - CUDA cores per SM: 128
  - Max Work Group Size (raportat de OpenCL): 1024
- i7-6800k
  - Cores: 6 (12 hyper-threaded)
  - Max Compute Units (raportat de OpenCL): 12
  - AVX2: operații pe vectori de 8 int
  - Max Work Group Size (raportat de OpenCL): 8192

Max Work Group Size poate să fie afectat de mărimea kernel-ului.

Execuție lock-step



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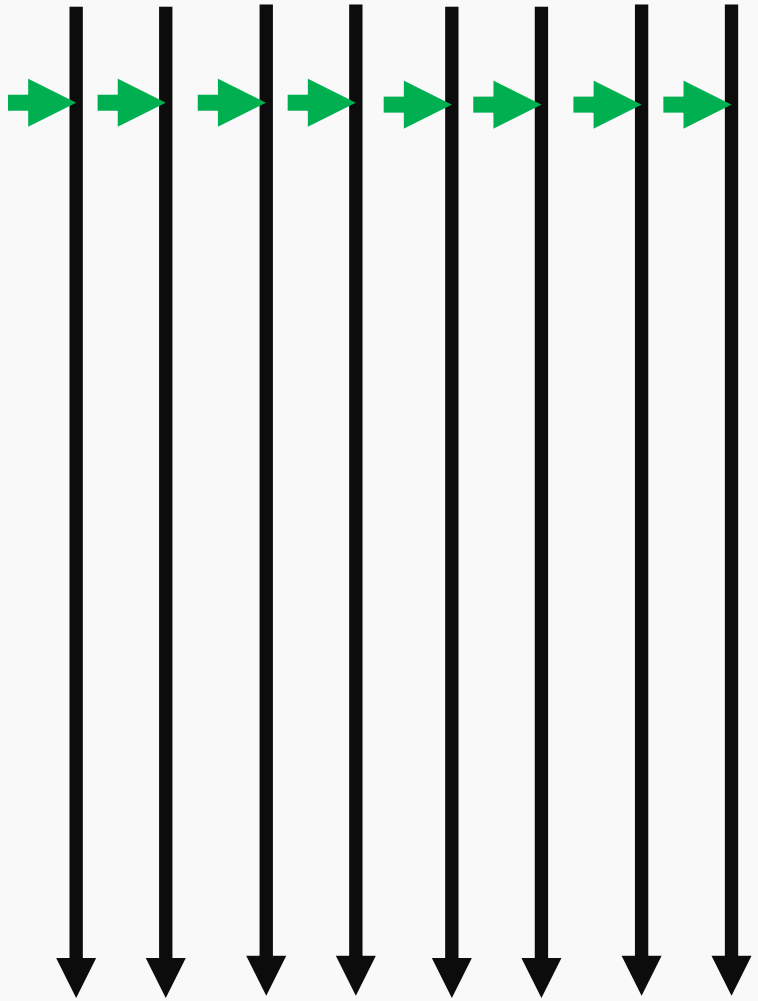

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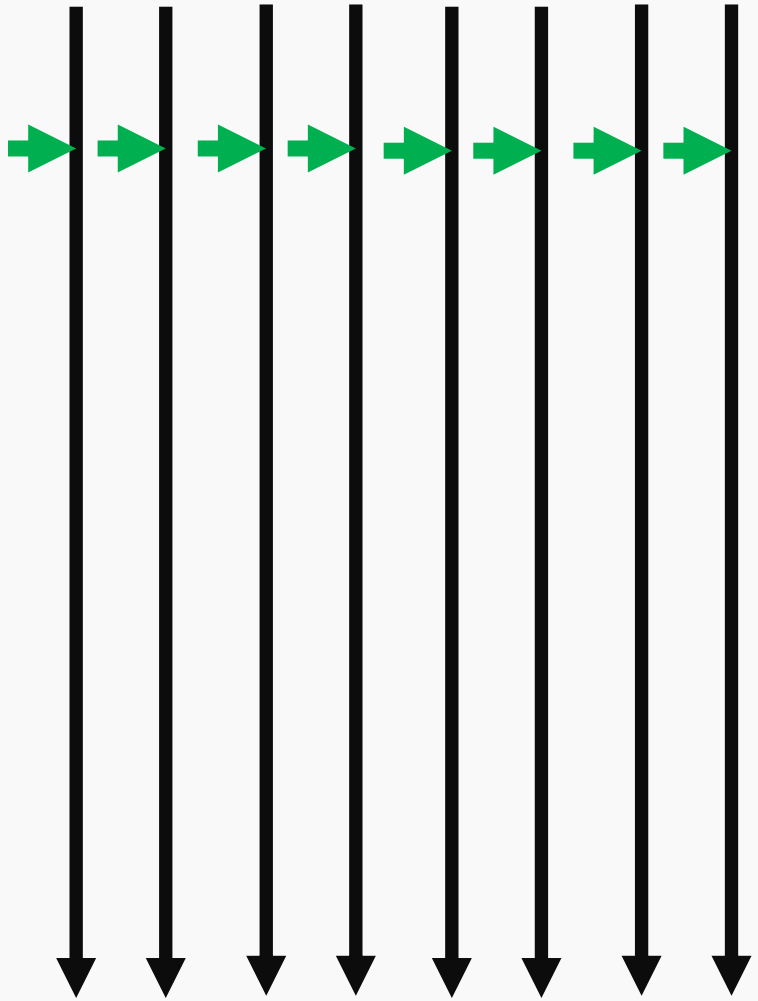

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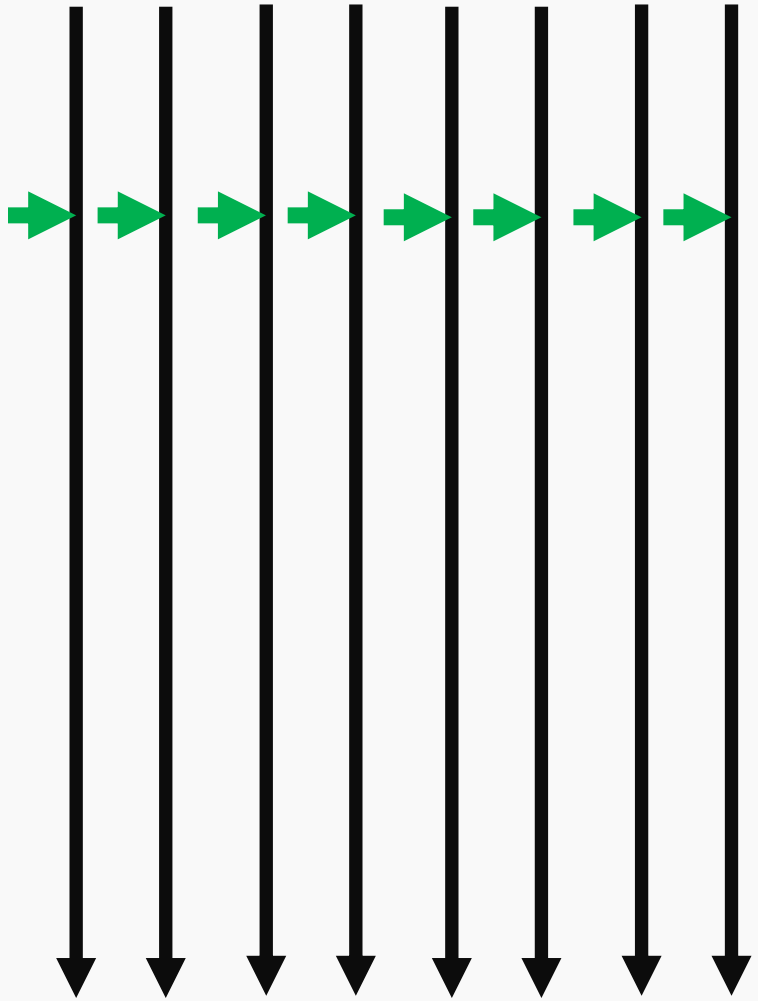
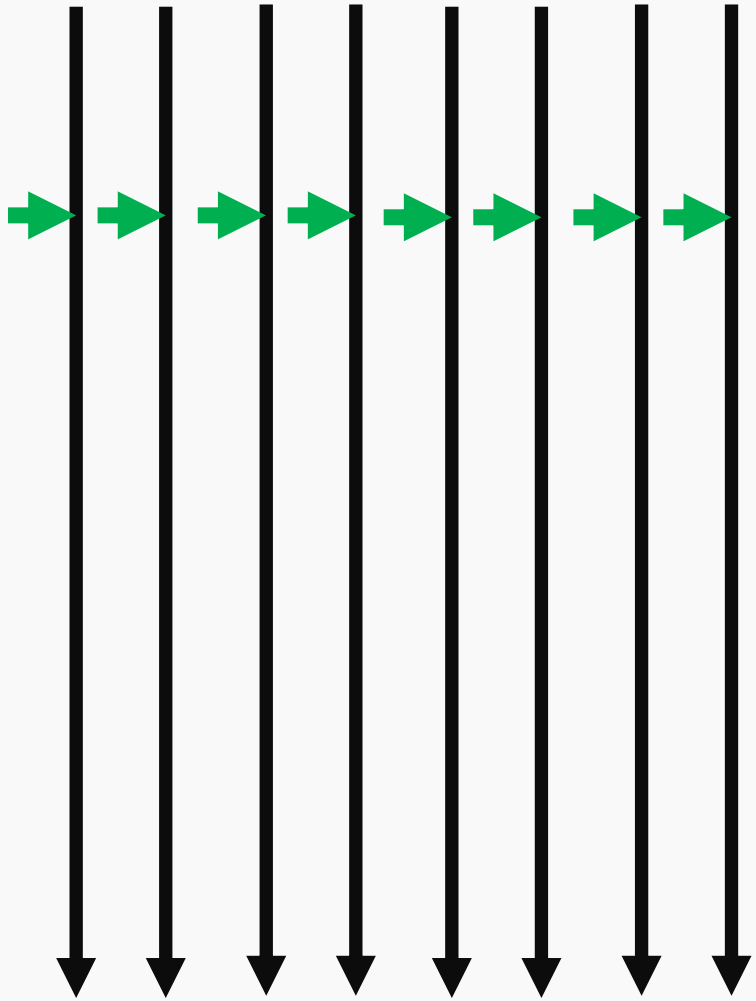


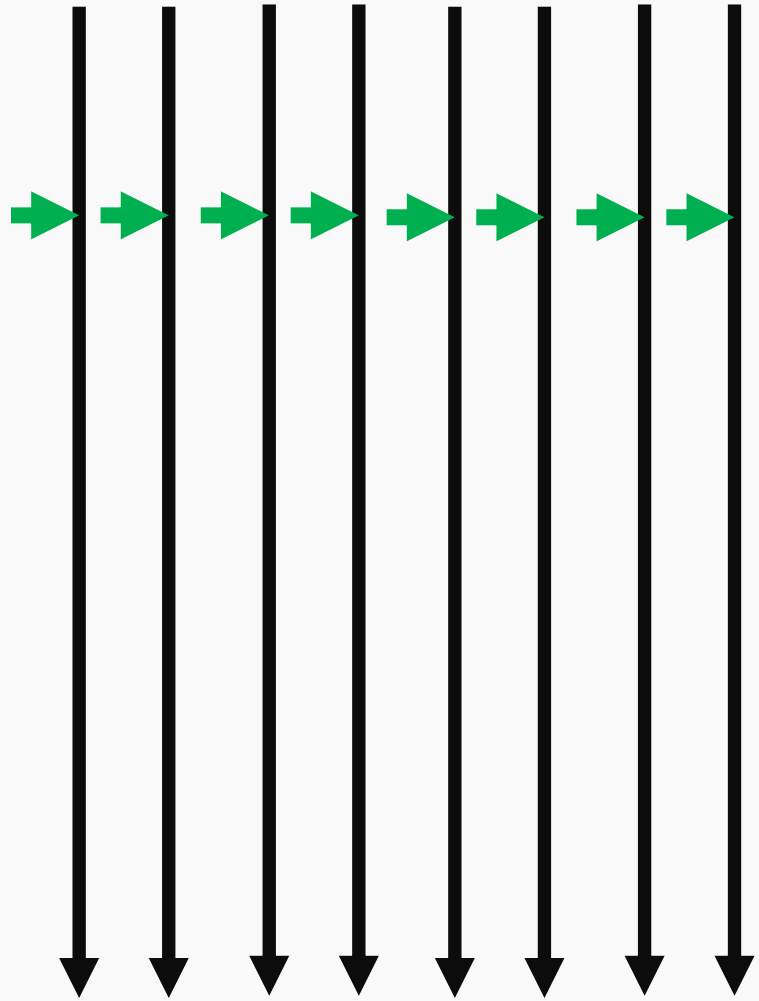
Execuție lock-step

Dar la if?



Execuție lock-step

```
if(thread_id%i==1)
        do_something();
else
        do_somethingelse();
```



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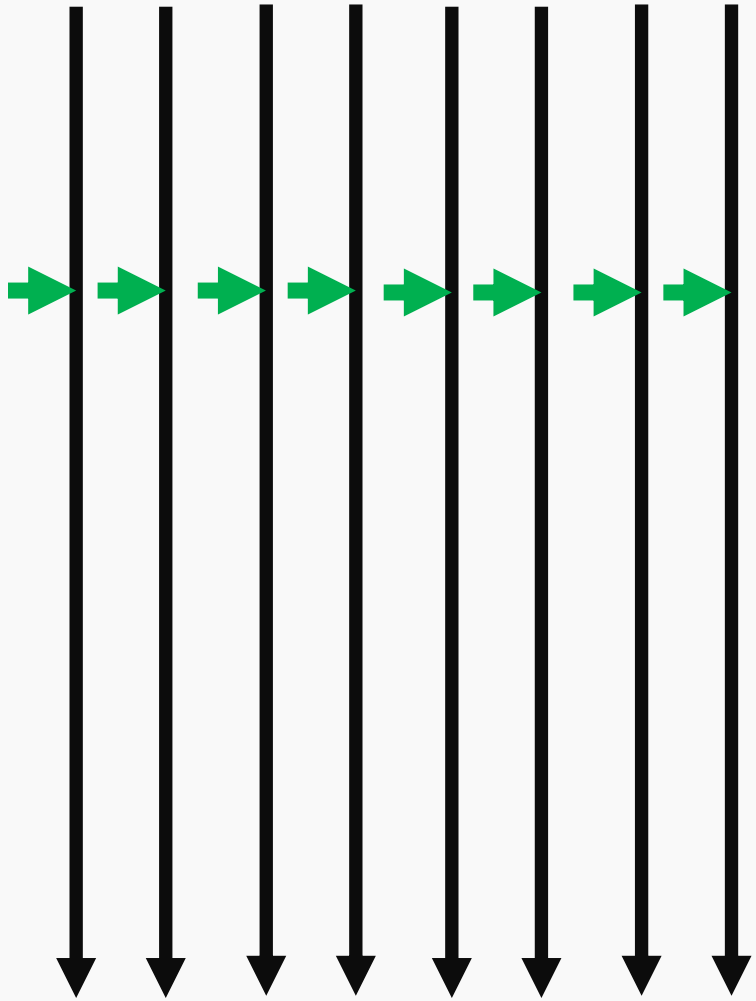

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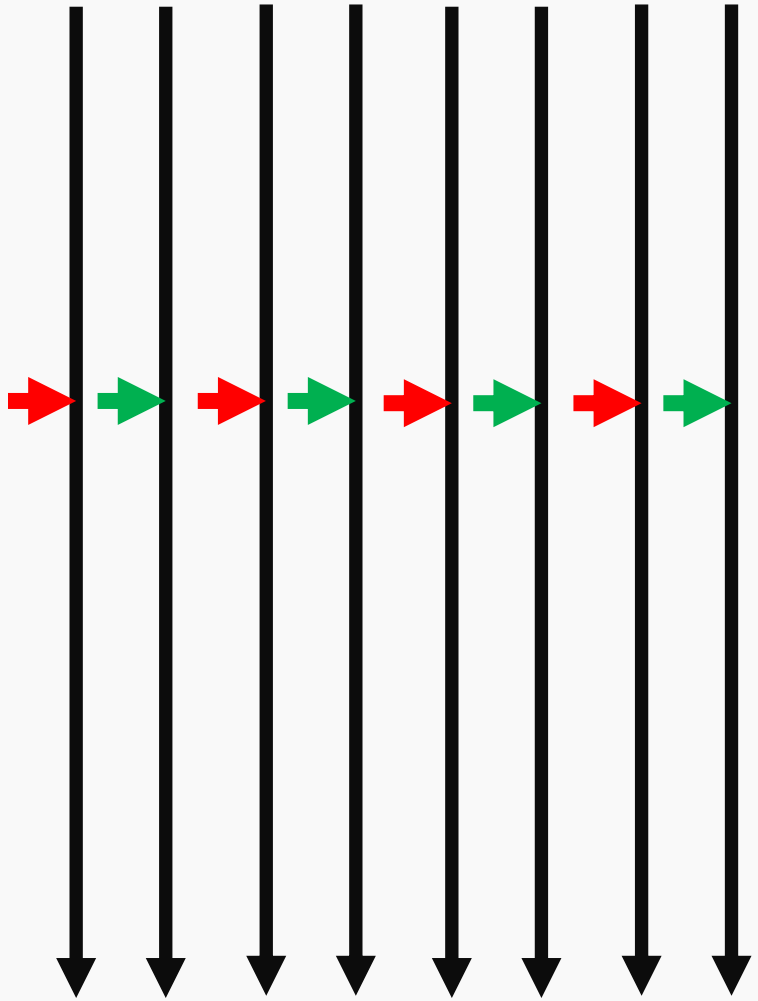

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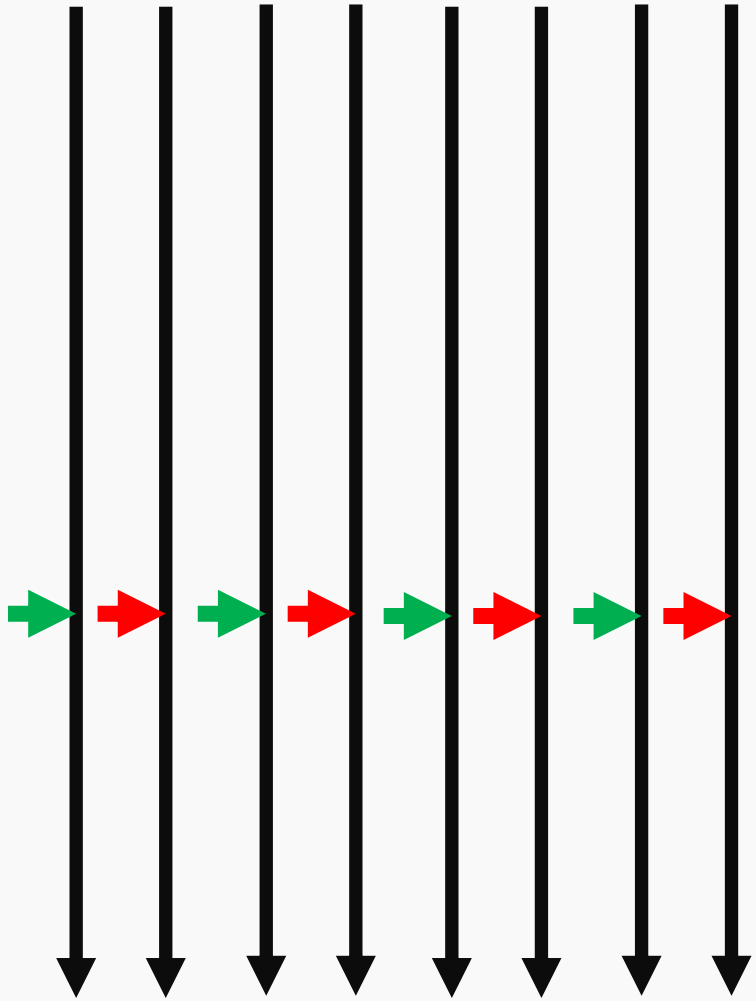

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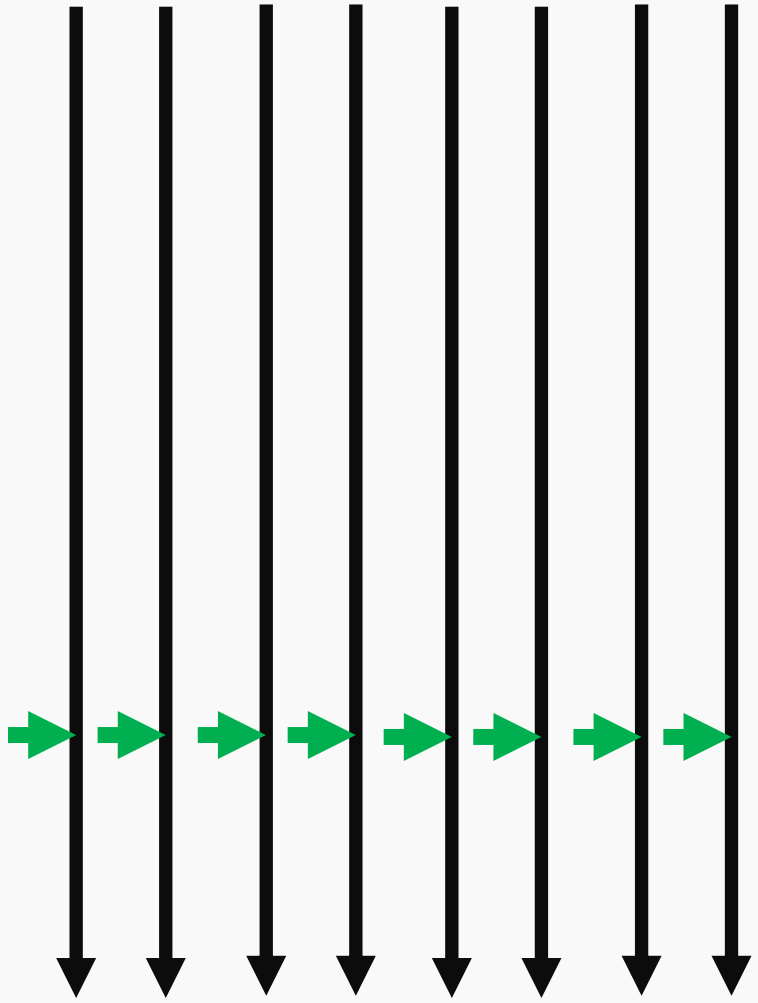
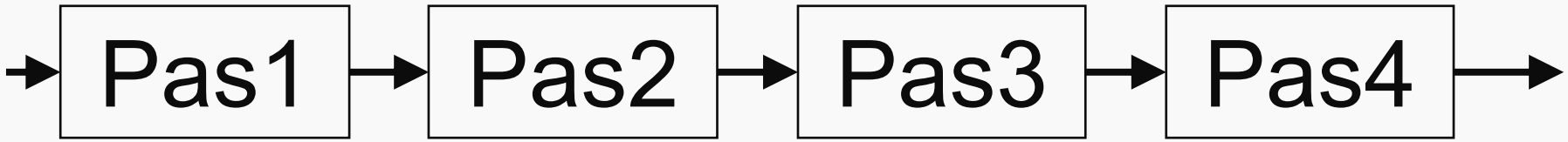


Pipeline

- Pipeline de instrucțiuni CPU
- Pipeline grafic (randare, antialiasting)
- Diferiți algoritmi

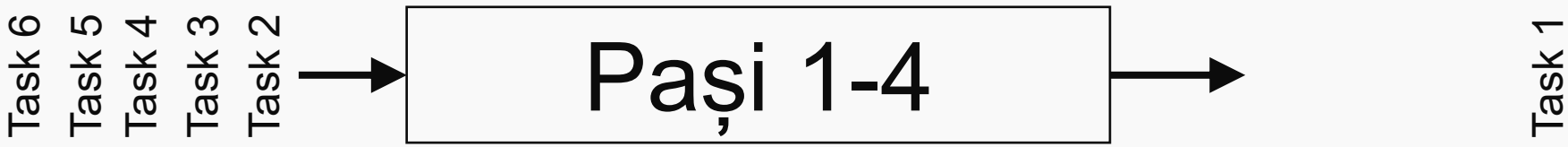


Un **pas** poate fi un:

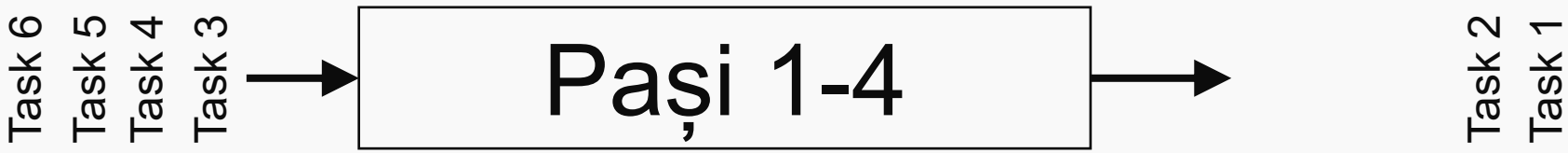
- thread
- proces
- element hardware

Fără Pipeline

Fără Pipeline



Fără Pipeline



Fără Pipeline

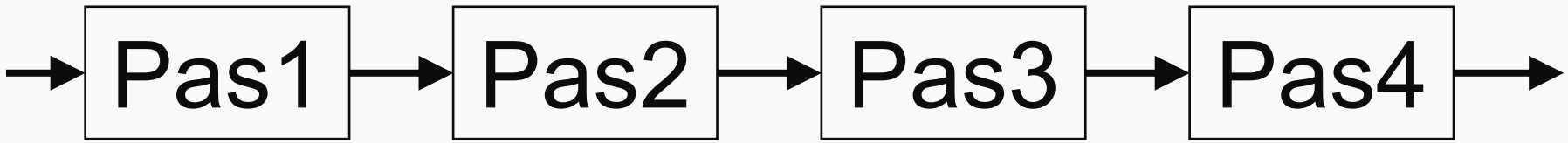
Fără Pipeline

Fără Pipeline

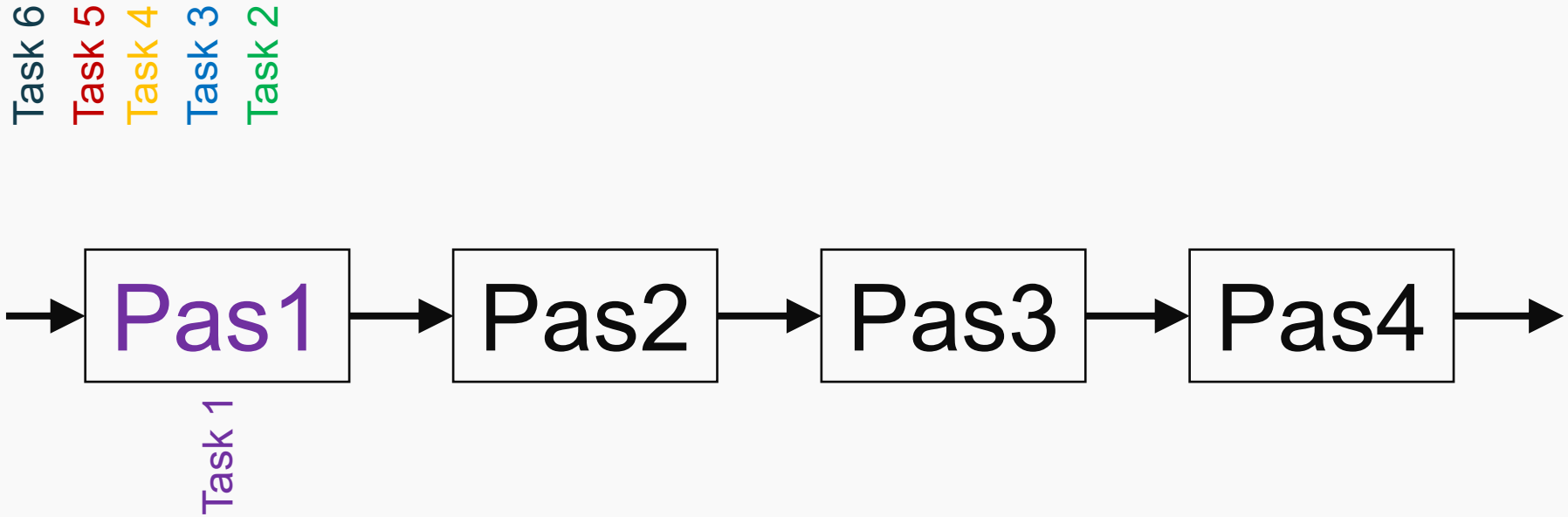
$$total\_execution\_time = task\_execution\_time * number\_of\_tasks$$

Pipeline

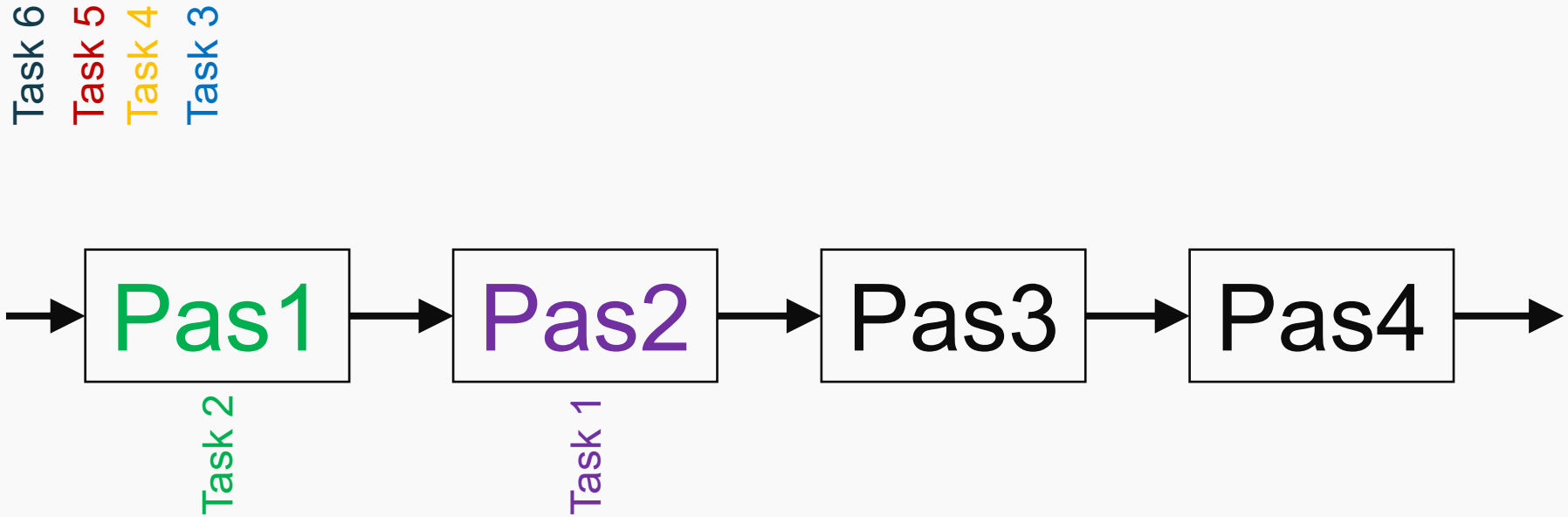
Task 6 Task 5 Task 4 Task 3 Task 2 Task 1



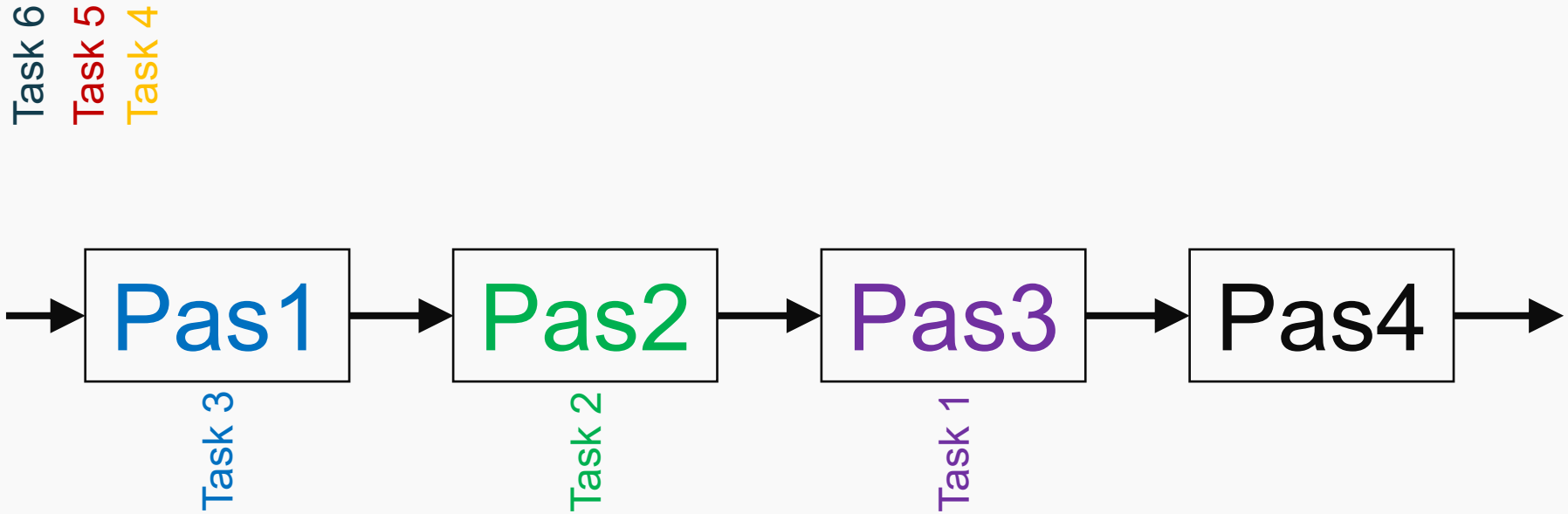
Pipeline



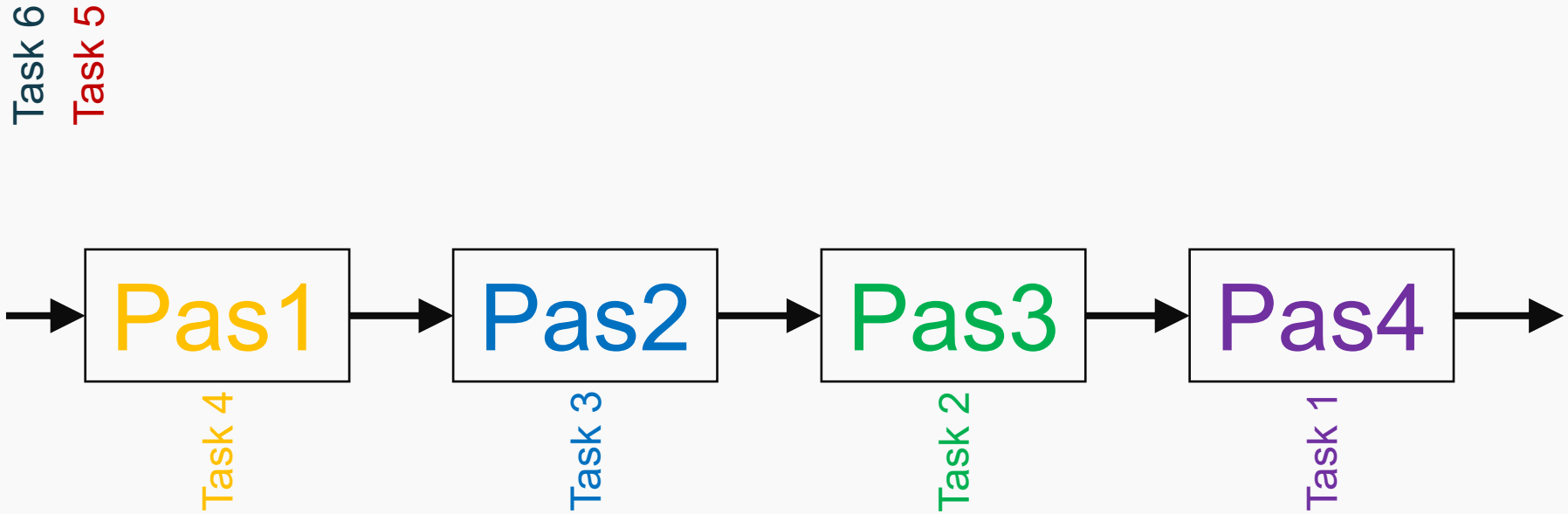
Pipeline



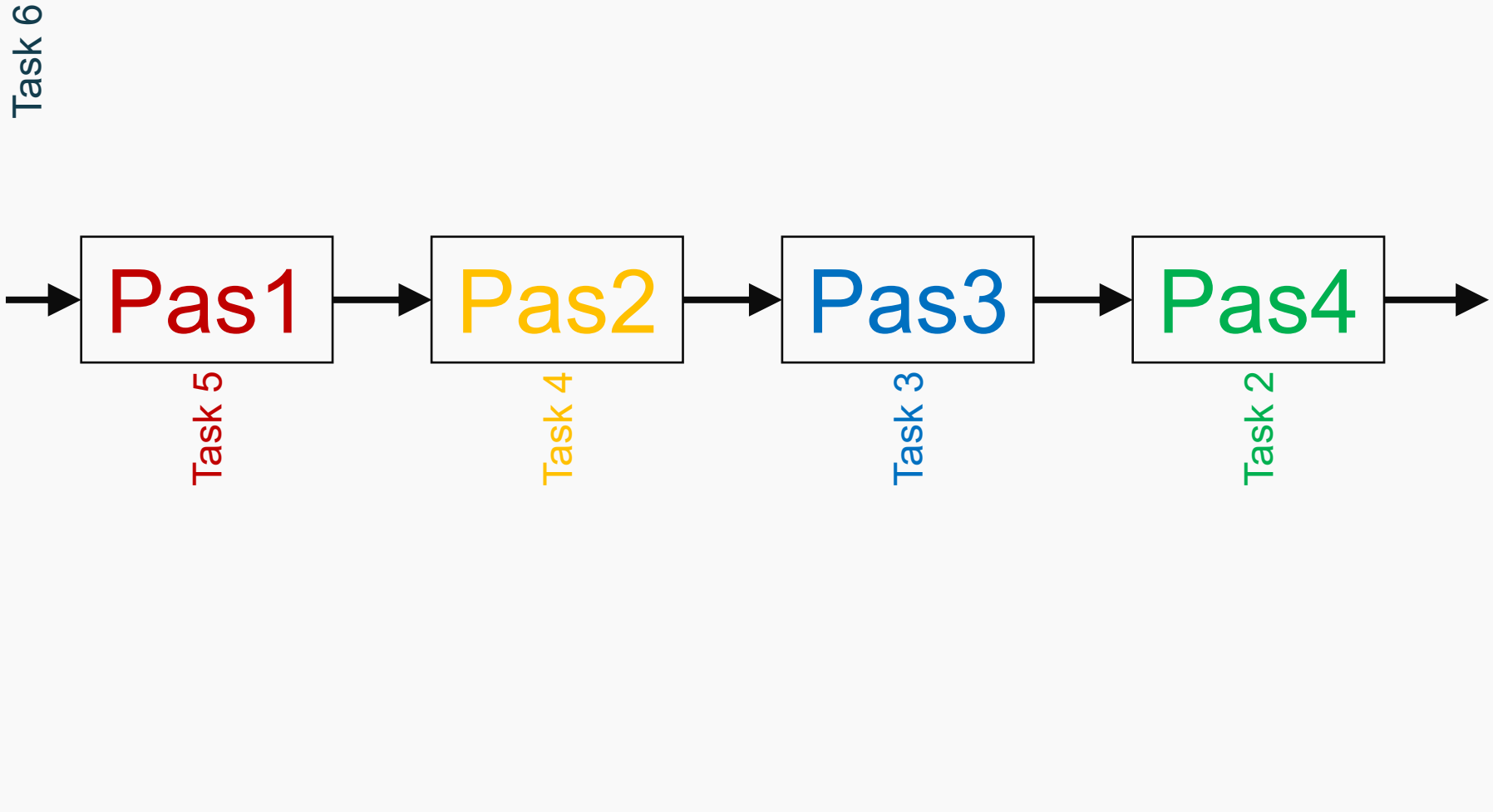
Pipeline



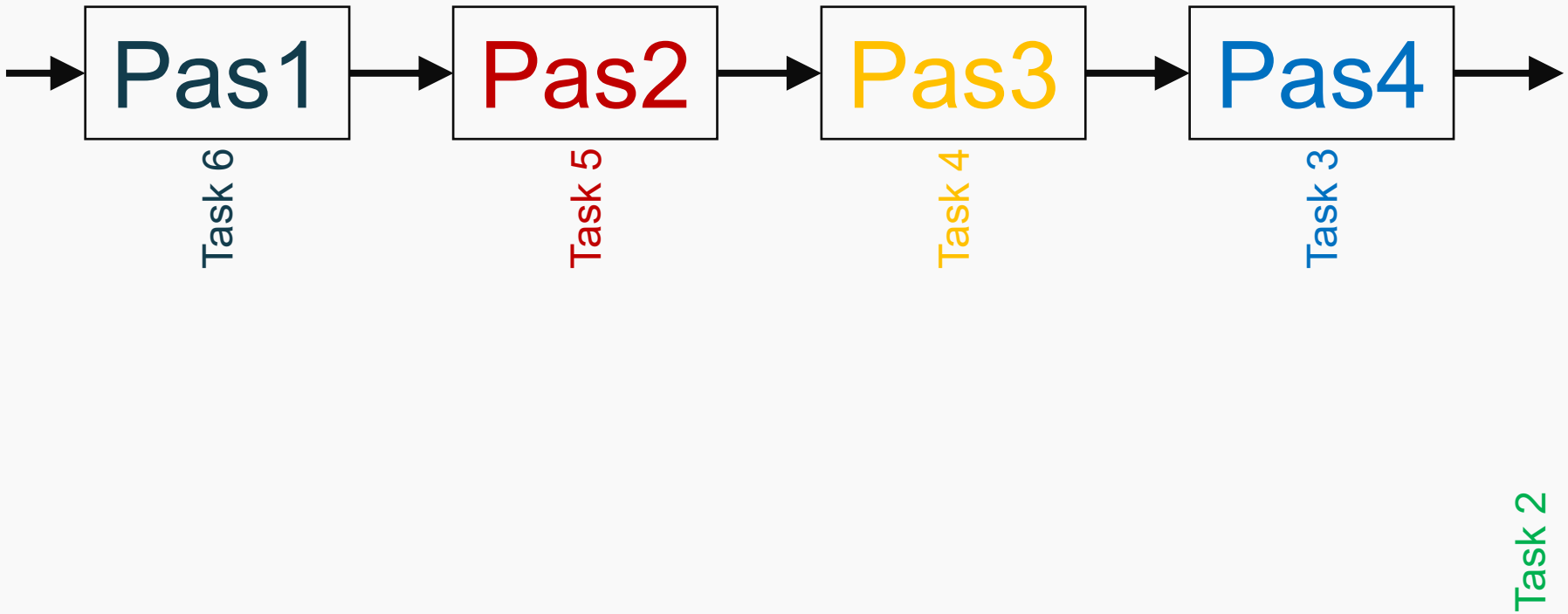
Pipeline



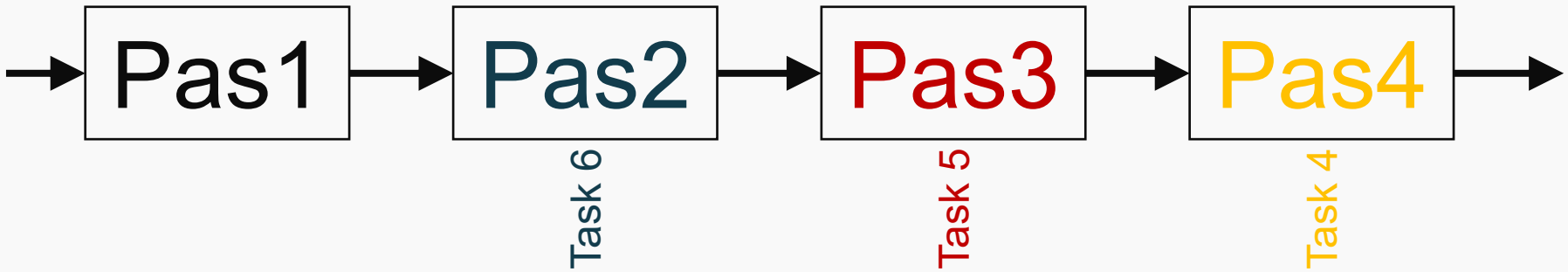
Pipeline



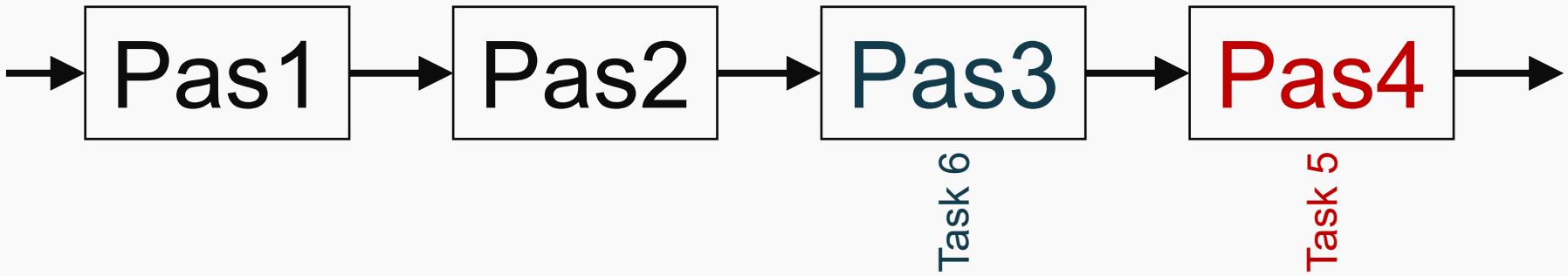
Pipeline



Pipeline

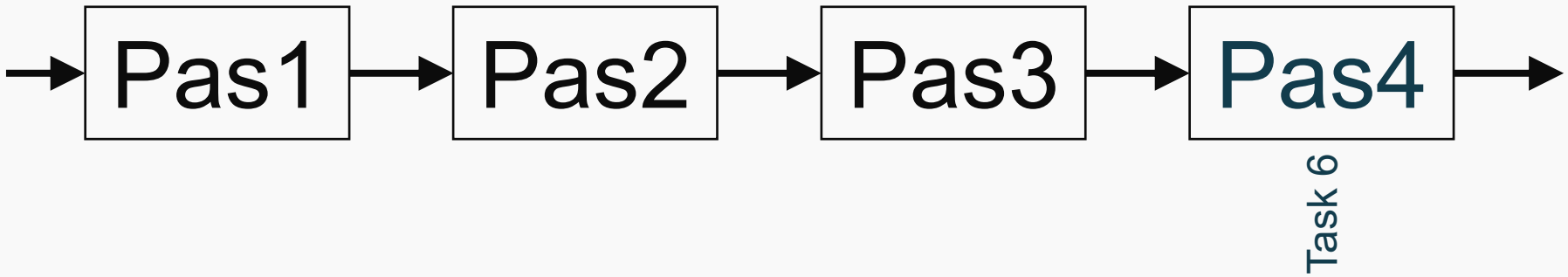


Pipeline



Pipeline

Ideal: $step\_execution\_time = \frac{task\_execution\_time}{number\_of\_steps}$

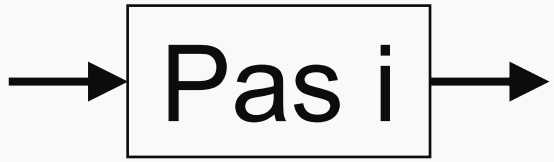


După avem mai mult decât $number\_of\_steps$ tasks timpul devine:

$total\_execution\_time = number\_of\_tasks * step\_execution\_time$

Un task se termină la fiecare “step tick”

Pipeline – ghid programare



Inițializare

for(un număr de pași) {

    primește date de la Pas(i-1)

    procesează

    trimite date la Pas(i+1)

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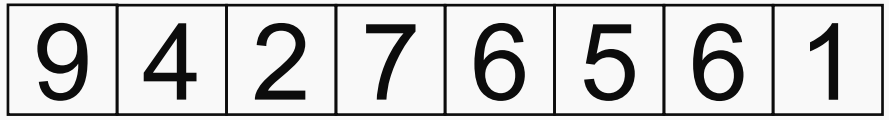
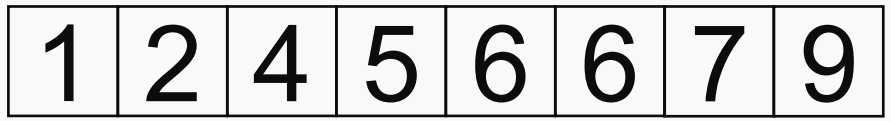
Finalizare

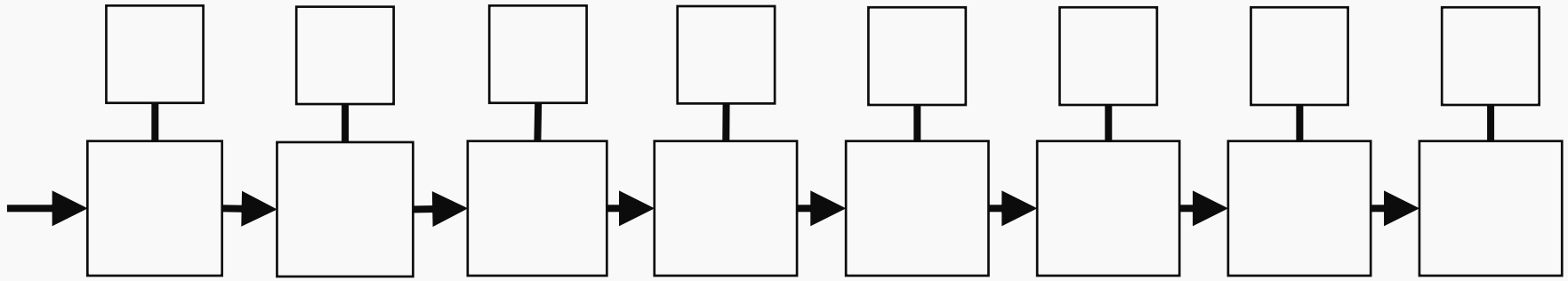
Sortare cu pipeline





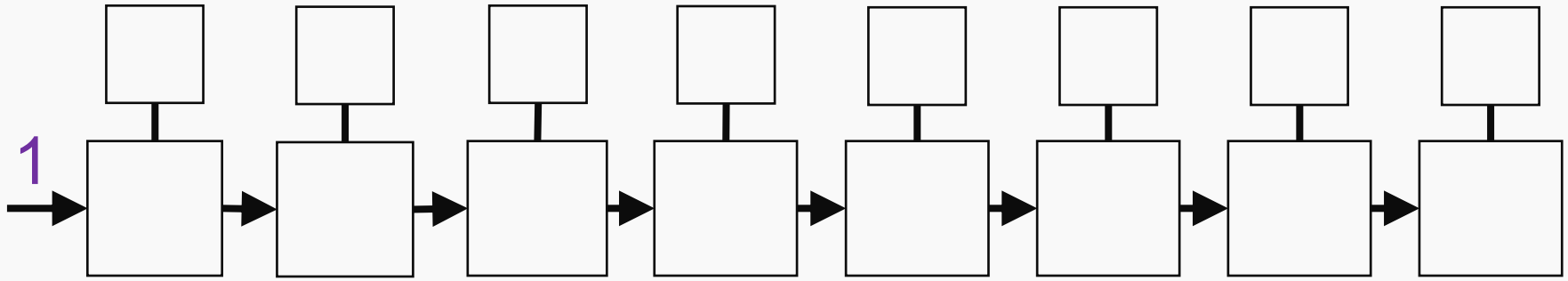
Sortare cu pipeline

9	4	2	7	6	5	6	1



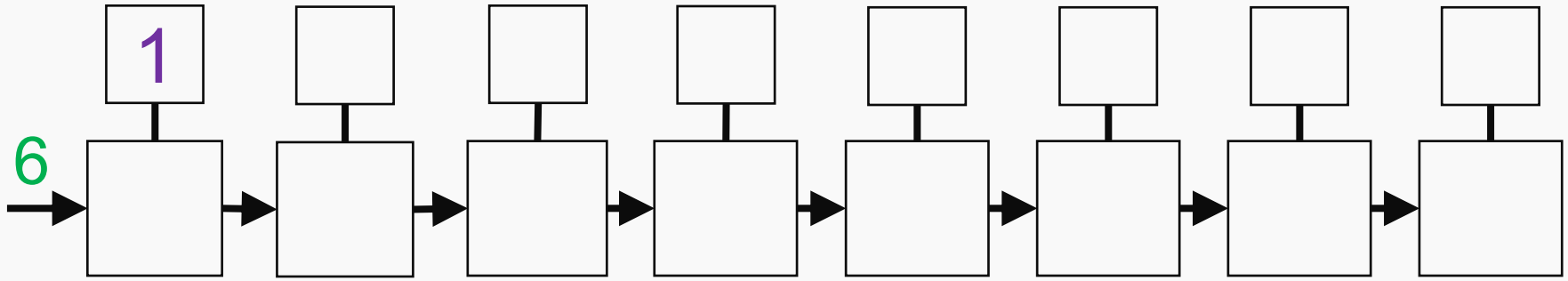
Sortare cu pipeline

9	4	2	7	6	5	6



Sorting with pipeline

9	4	2	7	6	5



Sortare cu pipeline

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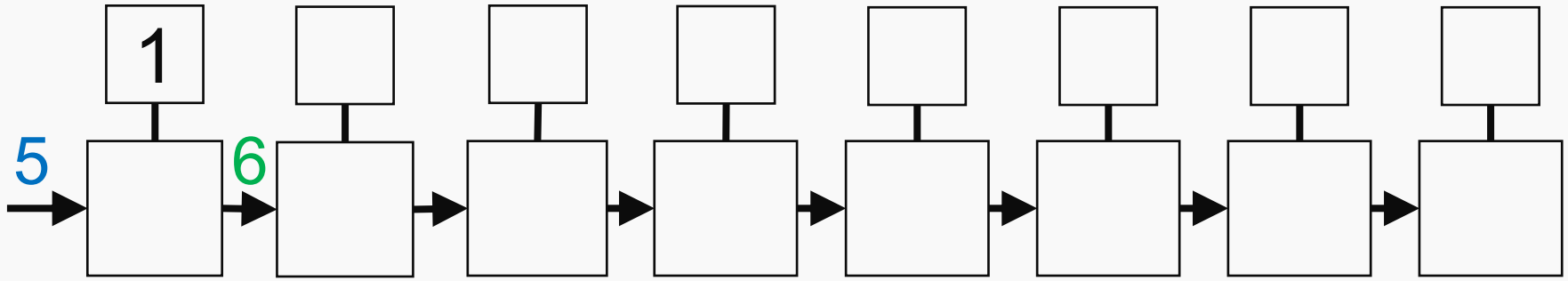

Sortare cu pipeline

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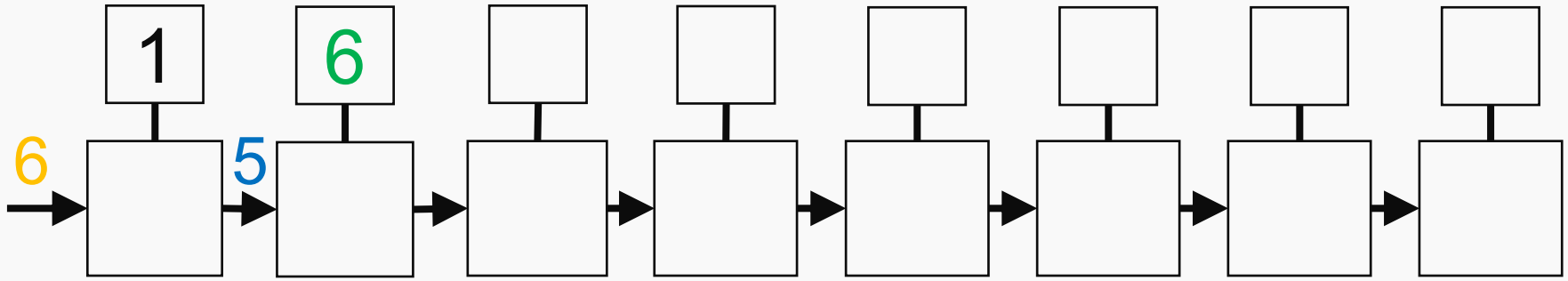

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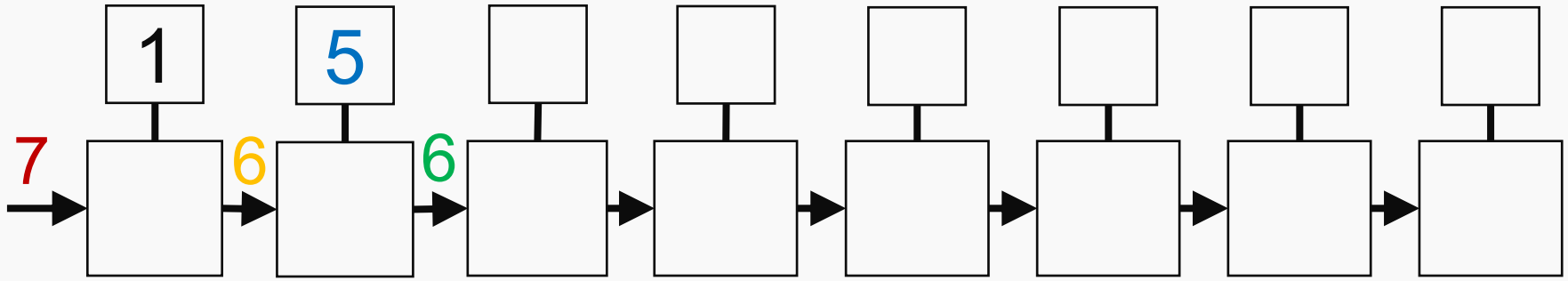

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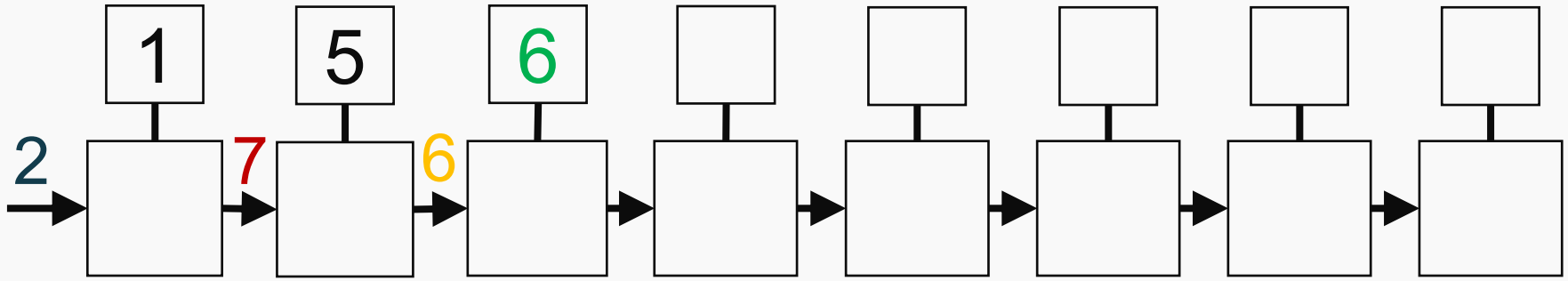
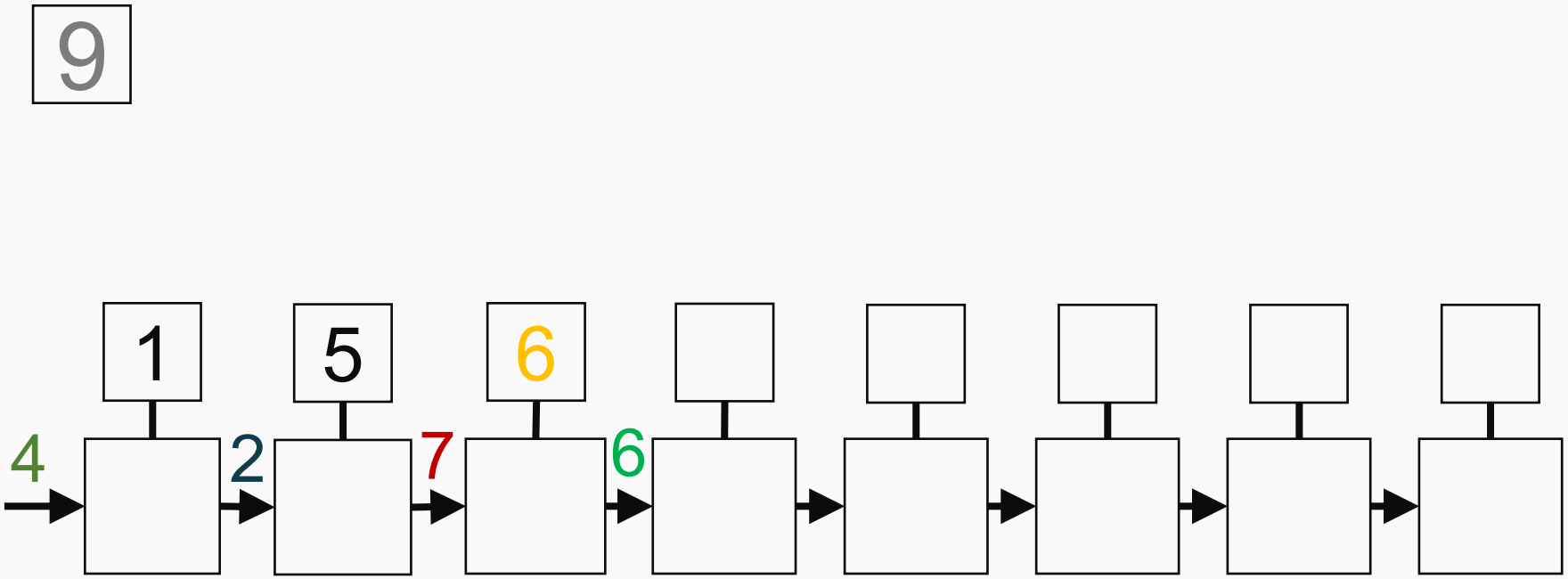
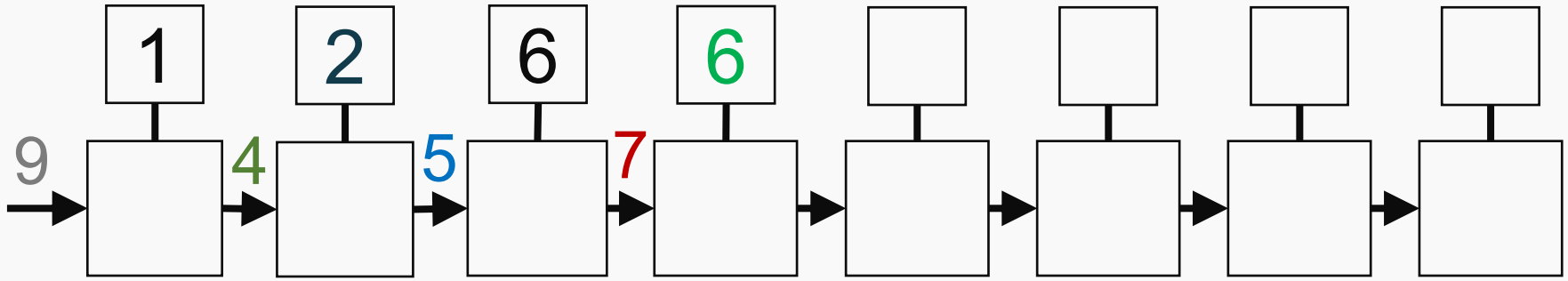


Sortare cu pipeline



Sortare cu pipeline



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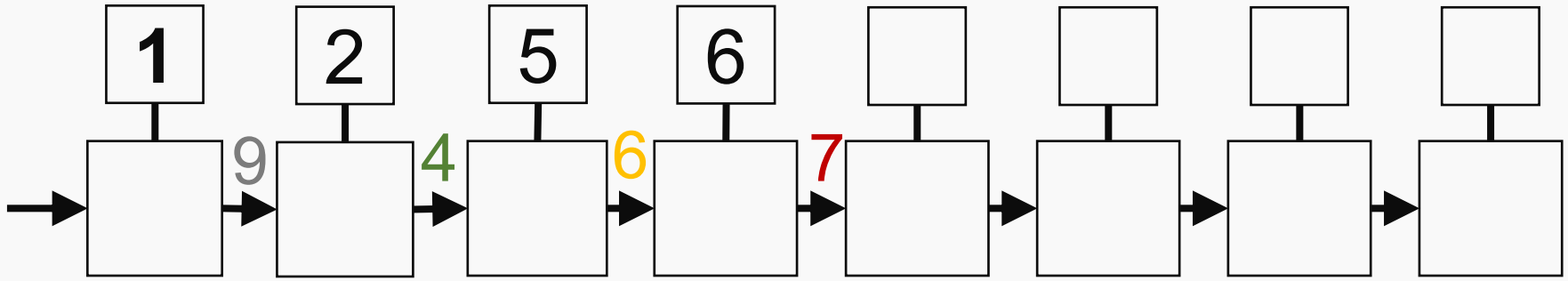

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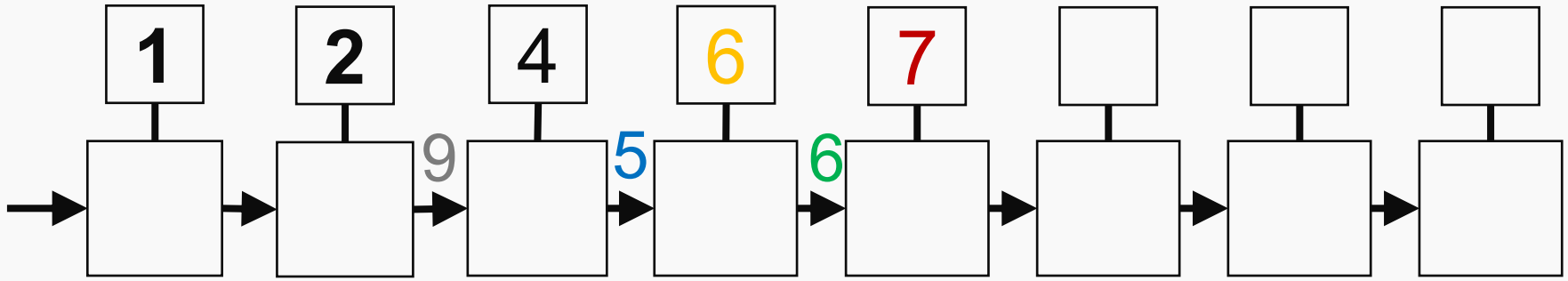

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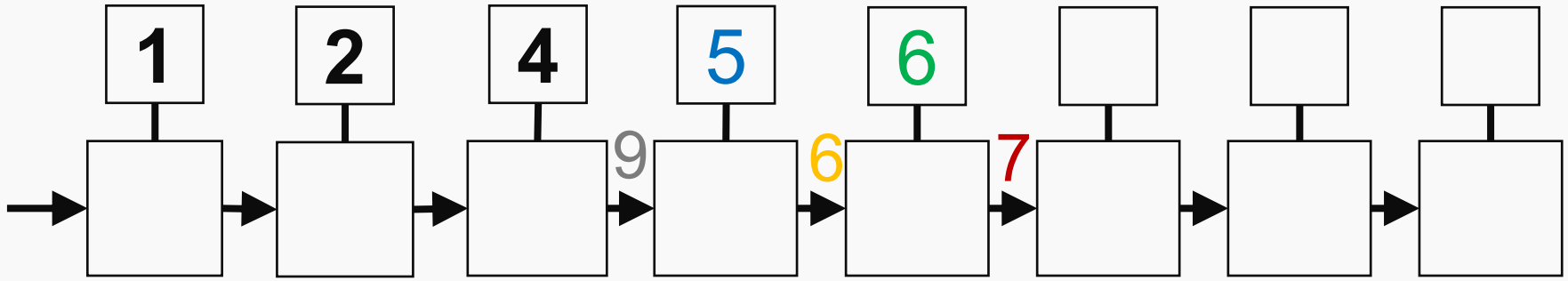

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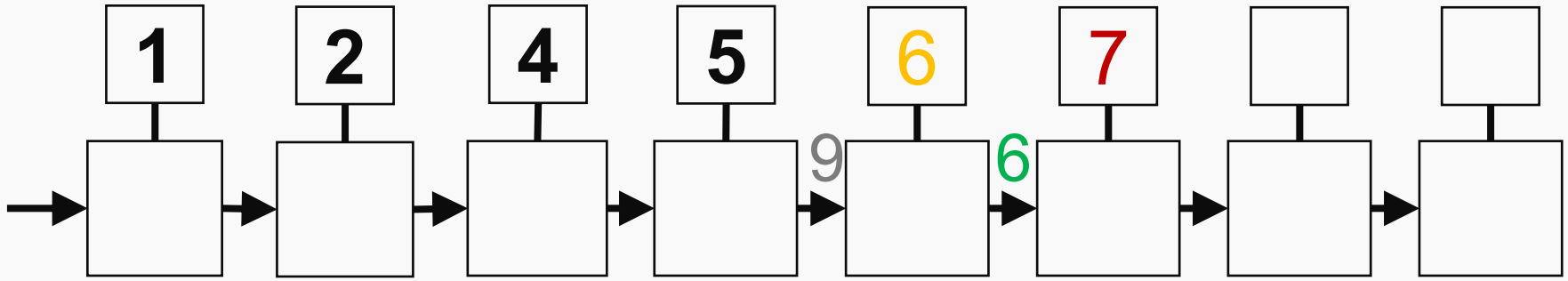

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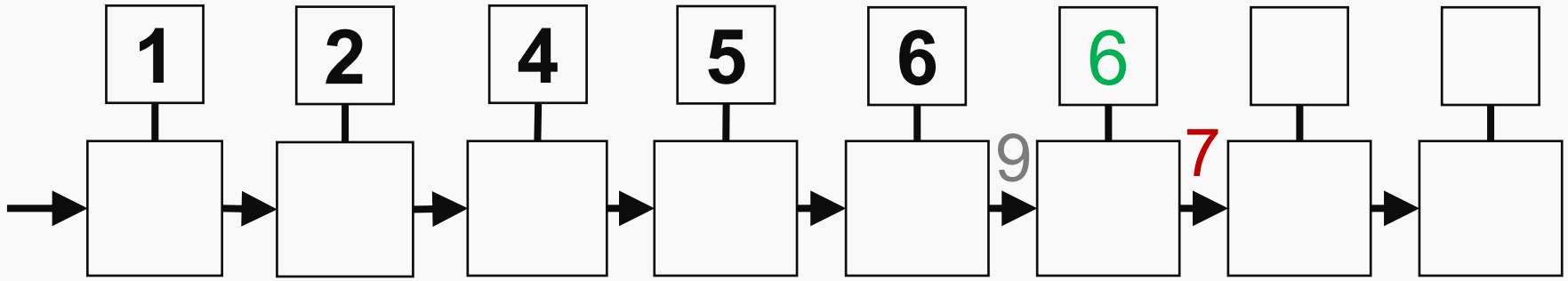
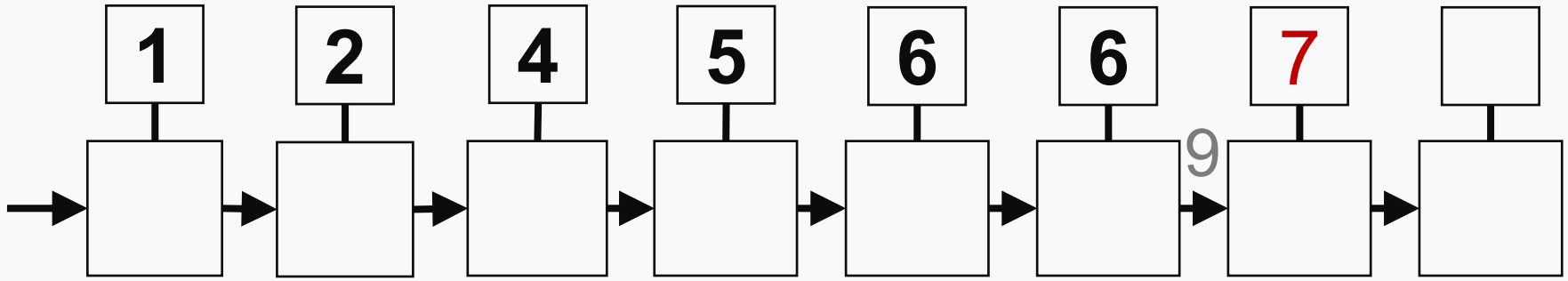


Sortare cu pipeline



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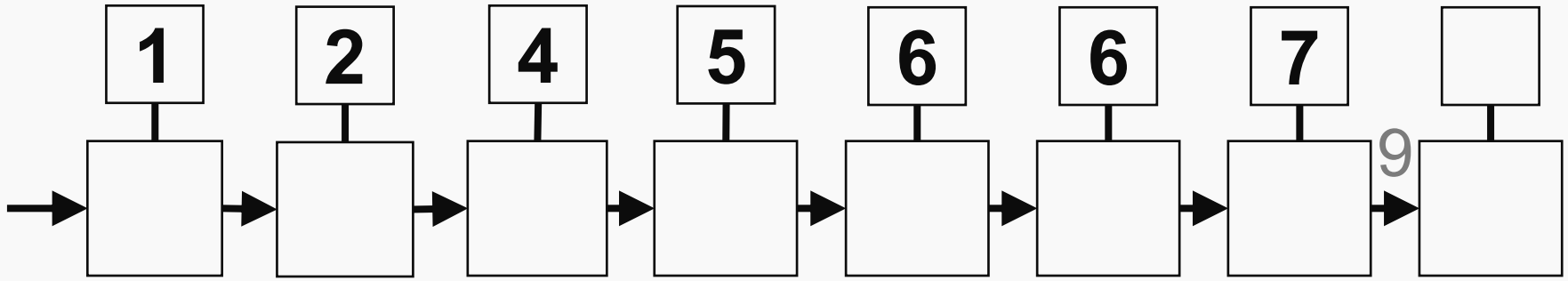

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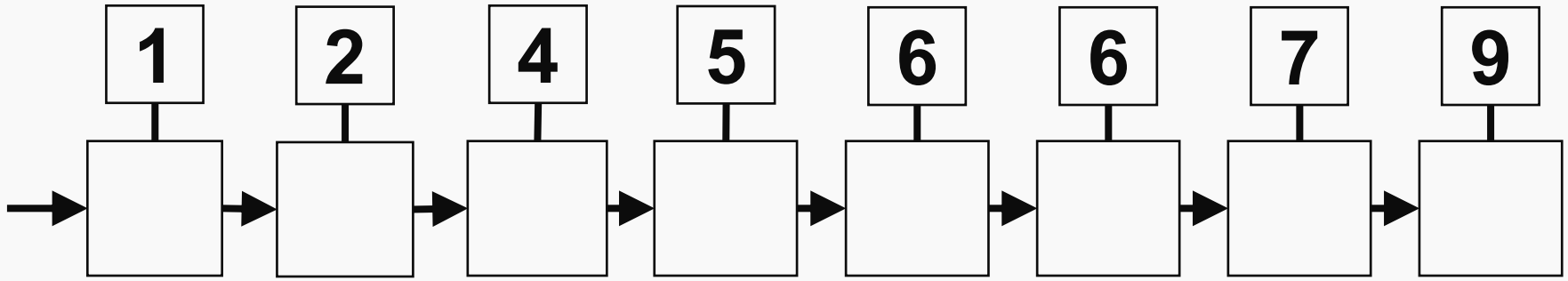


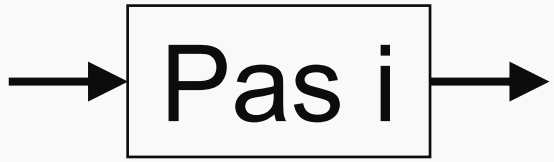
Sortare cu pipeline - complexitate

$$O(N)$$

pentru P=N

Dar comunicația e foarte lentă

Pipeline – ghid programare



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for(un număr de pași) {

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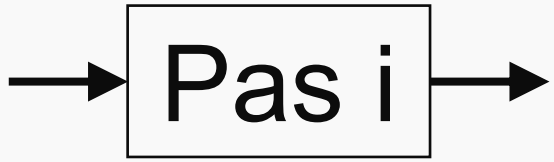
Finalizare

Sortare cu Pipeline – ghid programare



noop;

for(fiecare face cu o operație mai puțin decât pasul precedent) {

primește număr de la Pas(i-1)

ține local numărul minim între cel primit sau cel avut

trimite numărul mai mare la Pas(i+1)

}

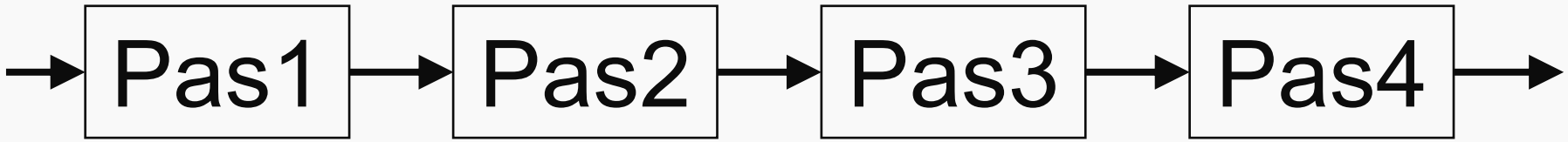
Scrie numărul la poziția i

Calcul unui polinom cu pipeline

$$P(x) = \sum_{i=0}^{n} a_i x^i = a_0 x^0 + a_1 x^1 + a_2 x^2 + \cdots + a_{n-1} x^{n-1} + a_n x^n, n \geq 0$$

Se dorește să calculăm valoarea lui P pentru diverși x.
Use case: desenarea graficului aferent polinomului.

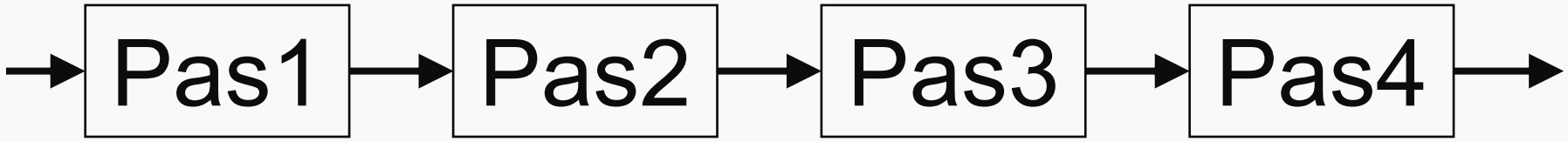
Pipeline



Calcul unui polinom cu pipeline

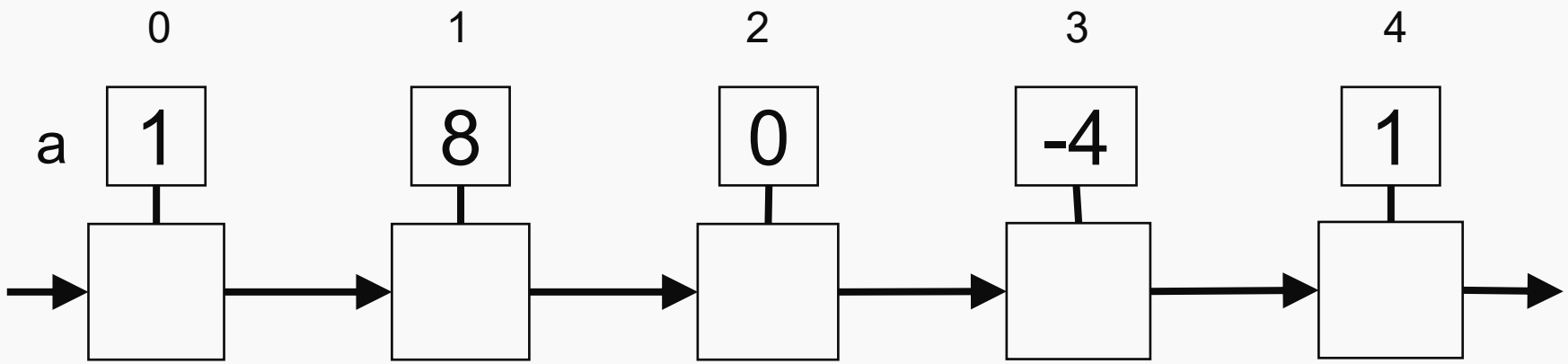
$$P(x) = 1 + 8x + (-4)x^3 + x^4$$

	0	1	2	3	4
a	1	8	0	-4	1



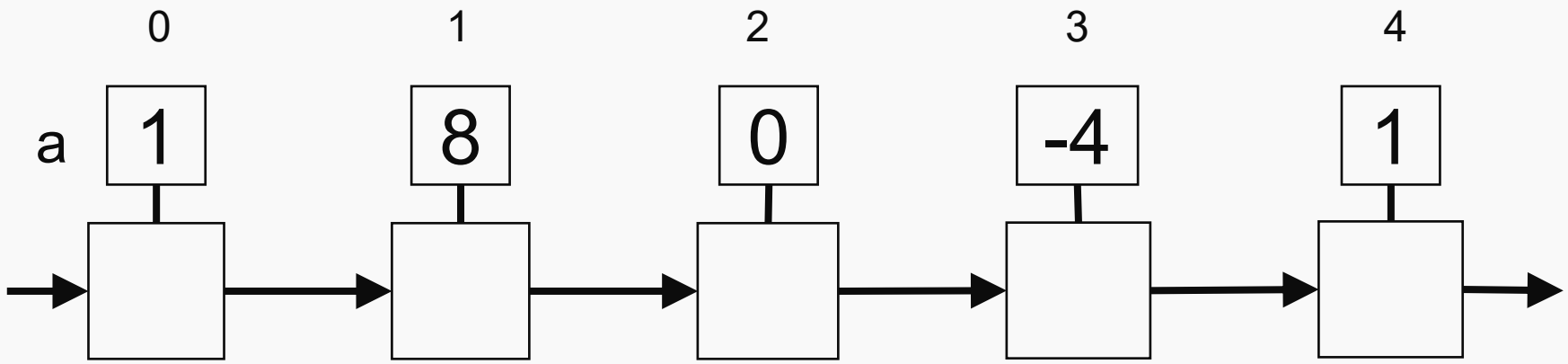
Calcul unui polinom cu pipeline

$$P(x) = 1 + 8x + (-4)x^3 + x^4$$



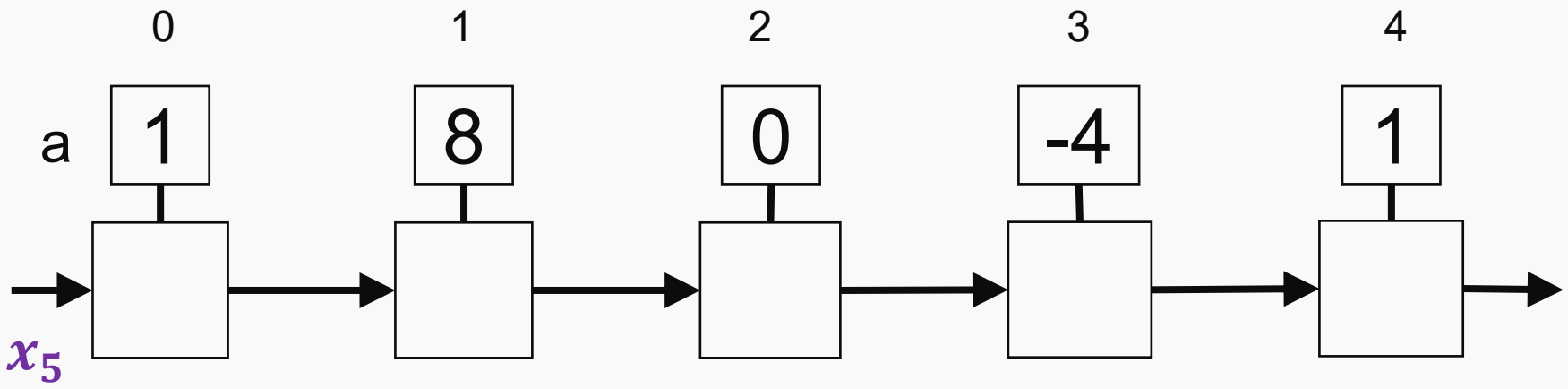
Calcul unui polinom cu pipeline

x_1 x_2 x_3 x_4 x_5

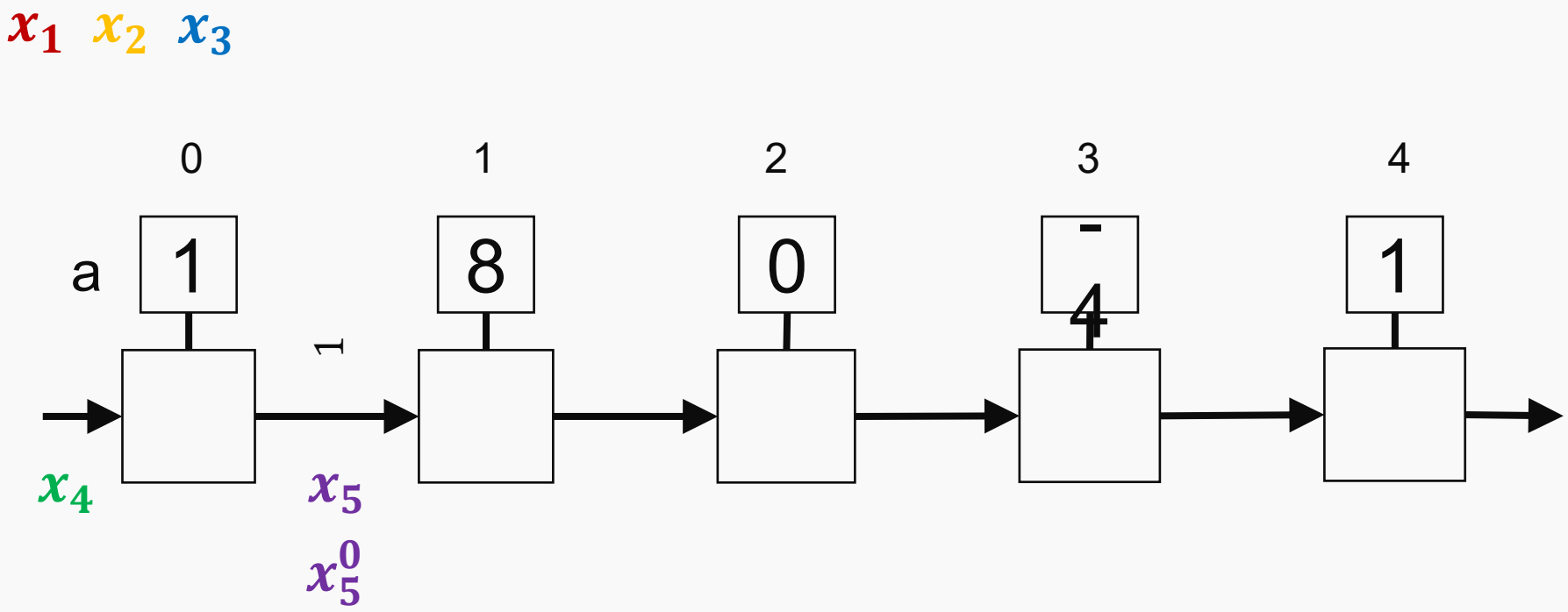


Calcul unui polinom cu pipeline

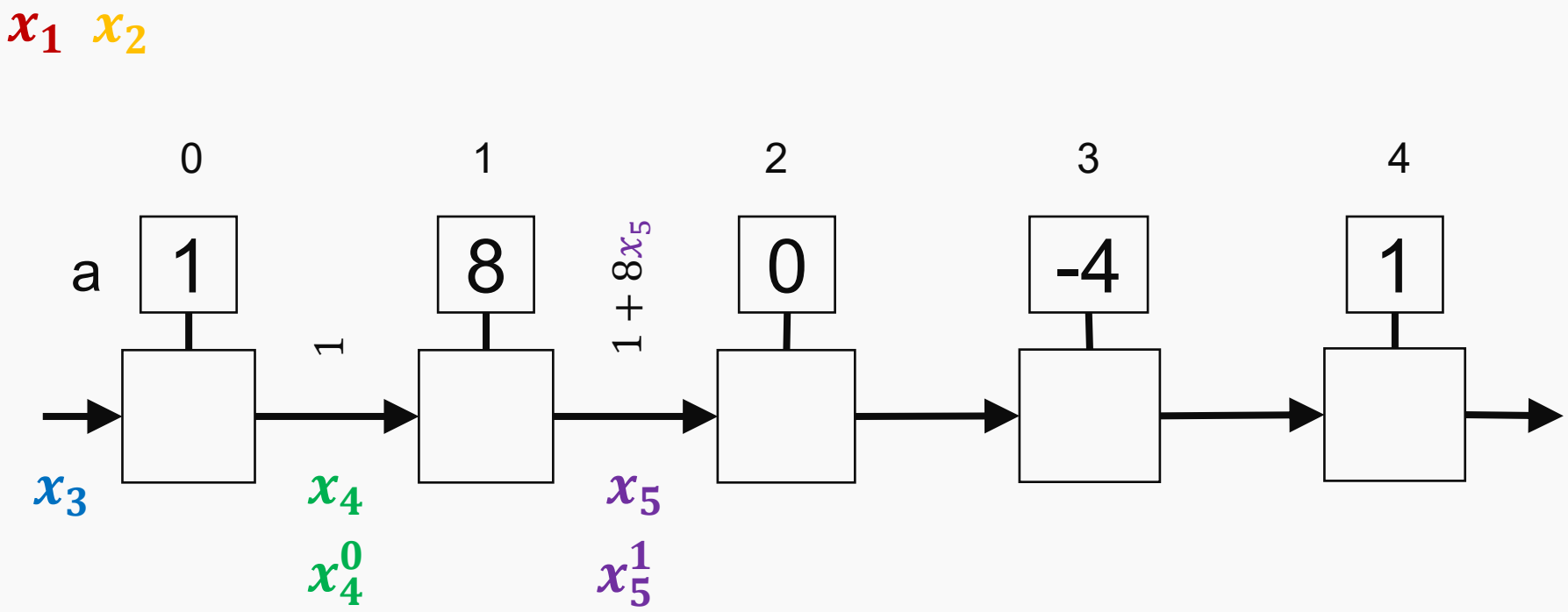
x_1 x_2 x_3 x_4



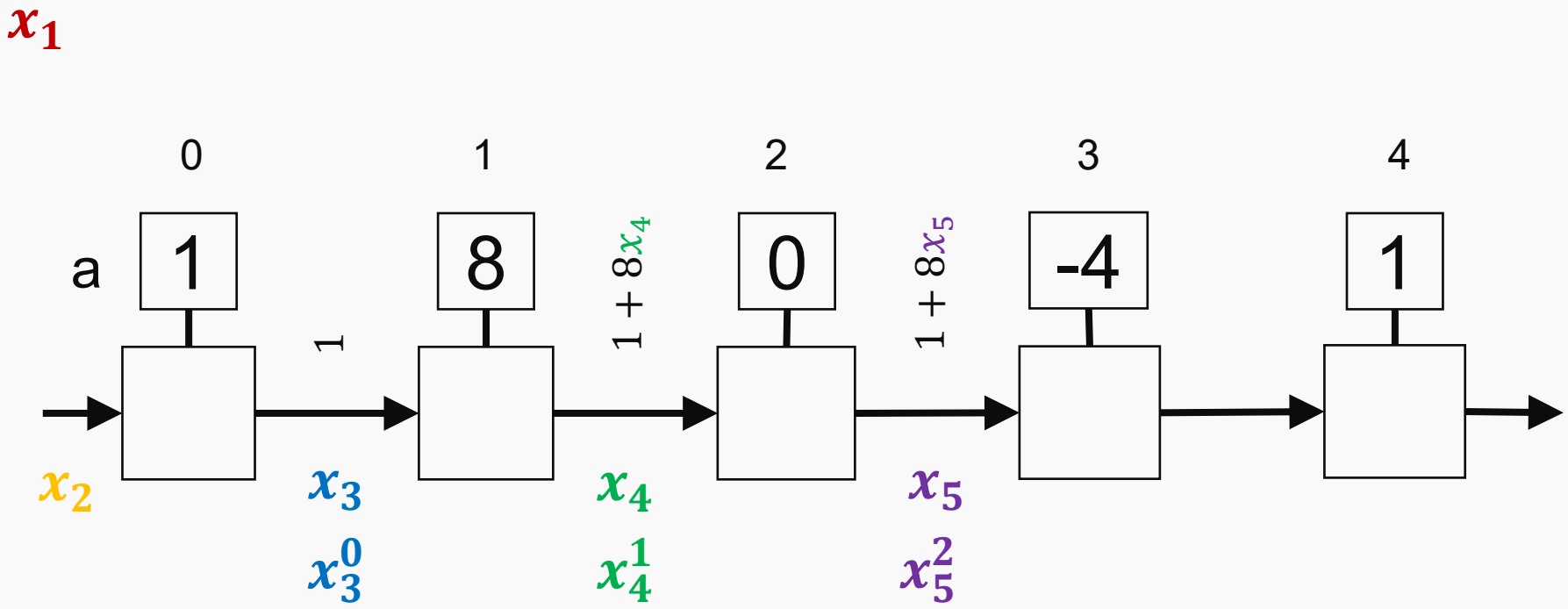
Calcul unui polinom cu pipeline



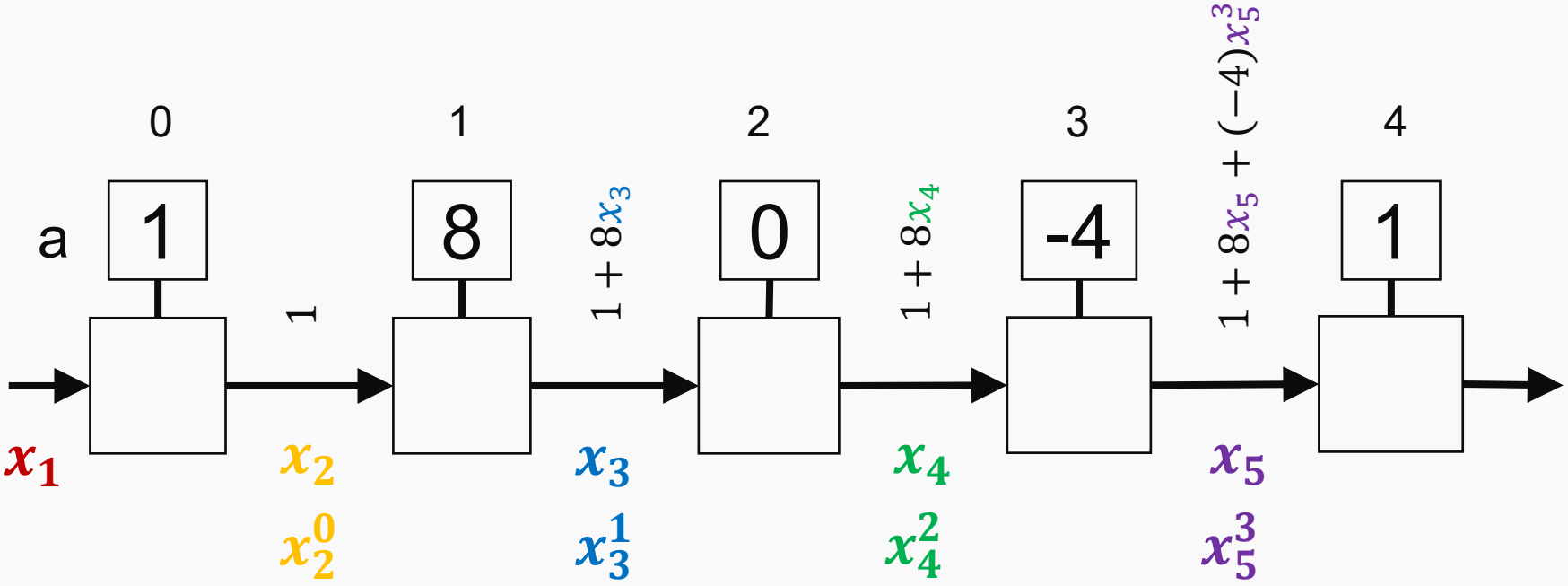
Calcul unui polinom cu pipeline



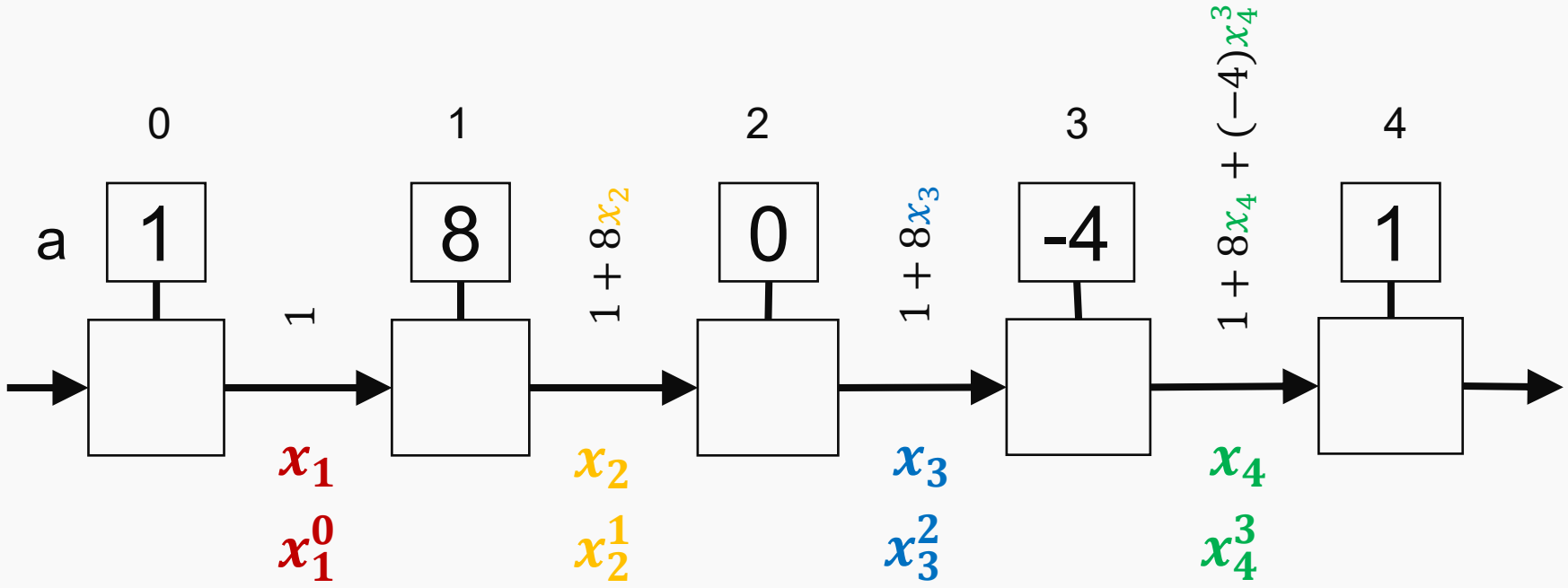
Calcul unui polinom cu pipeline



Calcul unui polinom cu pipeline

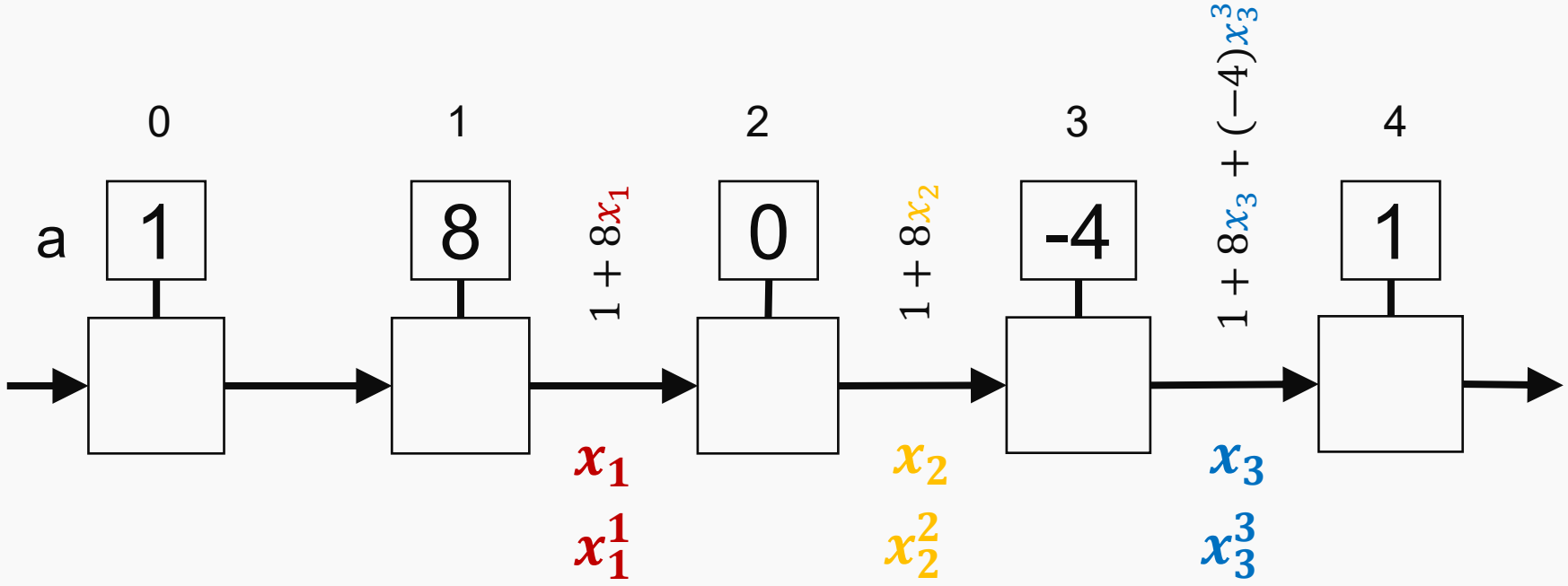


Calcul unui polinom cu pipeline



$$1+8x_5+(-4)x_5^3+x_5^4$$

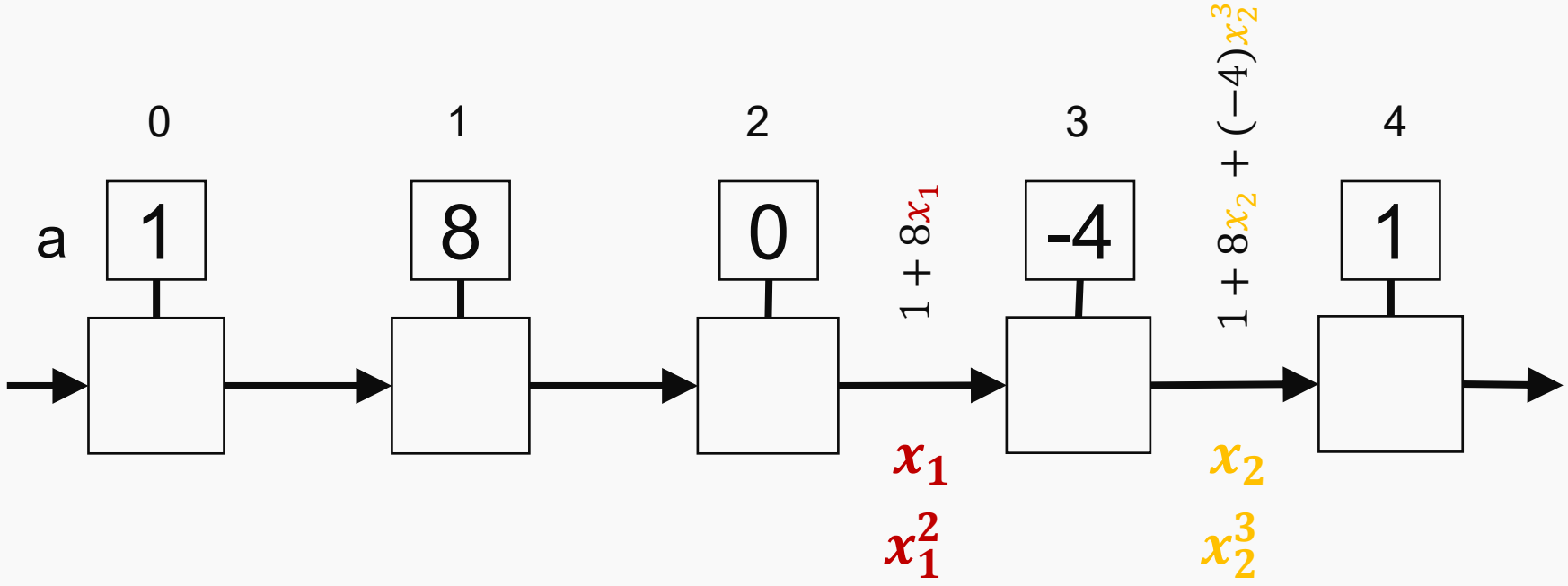
Calcul unui polinom cu pipeline



$$1+8x_4+(-4)x_4^3+x_4^4$$

$$1+8x_5+(-4)x_5^3+x_5^4$$

Calcul unui polinom cu pipeline

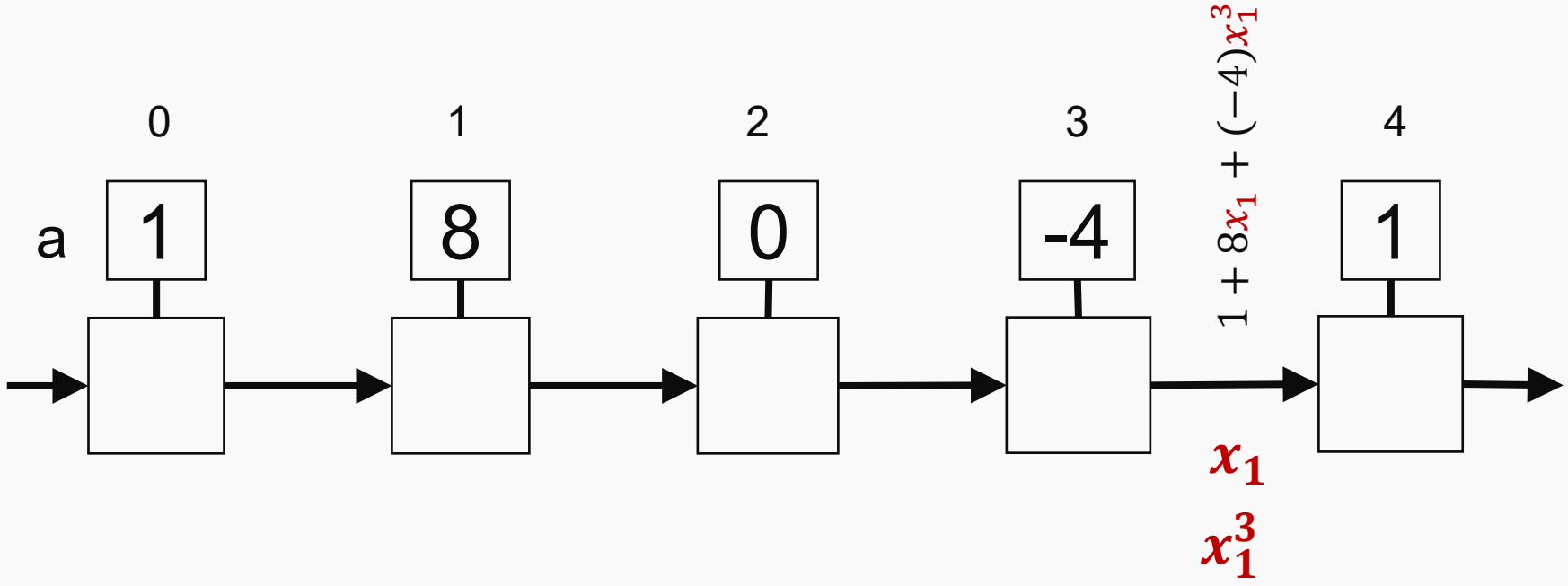


$$1+8x_3+(-4)x_3^3+x_3^4$$

$$1+8x_4+(-4)x_4^3+x_4^4$$

$$1+8x_5+(-4)x_5^3+x_5^4$$

Calcul unui polinom cu pipeline



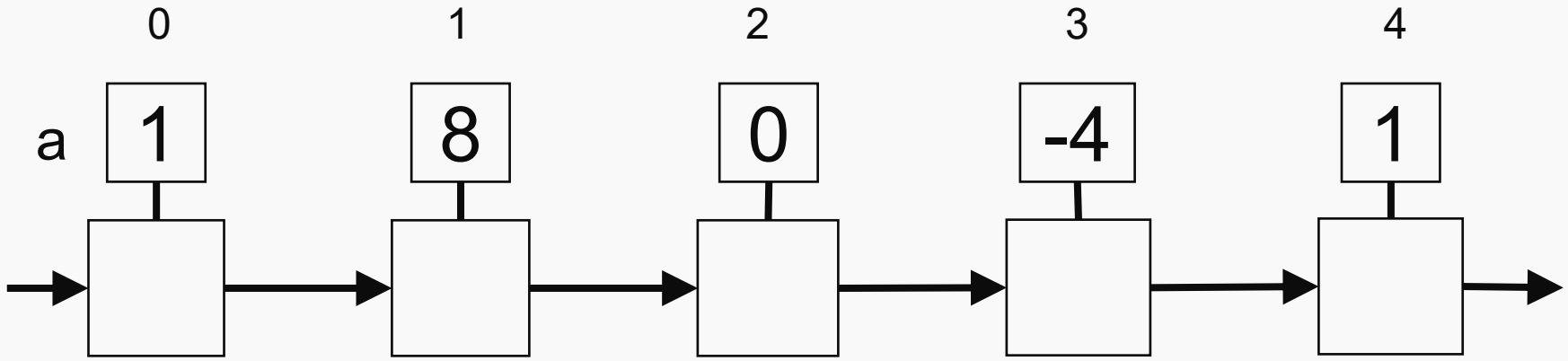
$1 + 8x_2 + (-4)x_2^3 + x_2^4$

$1 + 8x_3 + (-4)x_3^3 + x_3^4$

$1 + 8x_4 + (-4)x_4^3 + x_4^4$

$1 + 8x_5 + (-4)x_5^3 + x_5^4$

Calcul unui polinom cu pipeline



$$1 + 8x_1 + (-4)x_1^3 + x_1^4$$

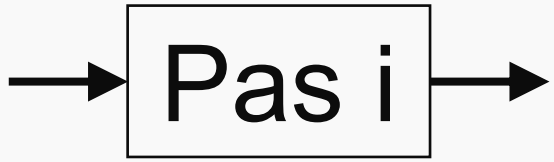
$$1 + 8x_2 + (-4)x_2^3 + x_2^4$$

$$1 + 8x_3 + (-4)x_3^3 + x_3^4$$

$$1 + 8x_4 + (-4)x_4^3 + x_4^4$$

$$1 + 8x_5 + (-4)x_5^3 + x_5^4$$

Pipeline – ghid programare



Inițializare

for(un număr de pași) {

    primește date de la Pas(i-1)

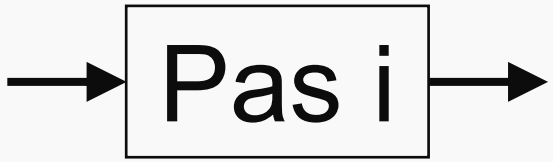
    procesează

    trimite date la Pas(i+1)

}

Finalizare

Pipeline – ghid programare



Primește coeficientul potrivit pasului

for(un număr de pași egal cu numărul de valori) {

primește de la Pas(i-1): polinom parțial calculat

valoarea originală

valoare originală ^ (i-1)

Calculează (valoarea originală ^ i) și adaugă la polinom parțial calculat produsul dintre coeficient și aceasta.

trimite spre Pas(i+1): noul polinom parțial calculat, valoarea originală și valoare originală ^ i)

}