ULB UNIVERSITÉ LIBRE DE BRUXELLES

HIPPEROS
Predictable Real-Time, Proven Performance

SOUTENANCE THESE

Antonio Paolillo

17 octobre 2018

Agenda

1. Domaine, problème, intuition
2. Contributions et thèse
3. Directions futures

Agenda

1. **Domaine, problème, intuition**
2. Contributions et thèse
3. Directions futures


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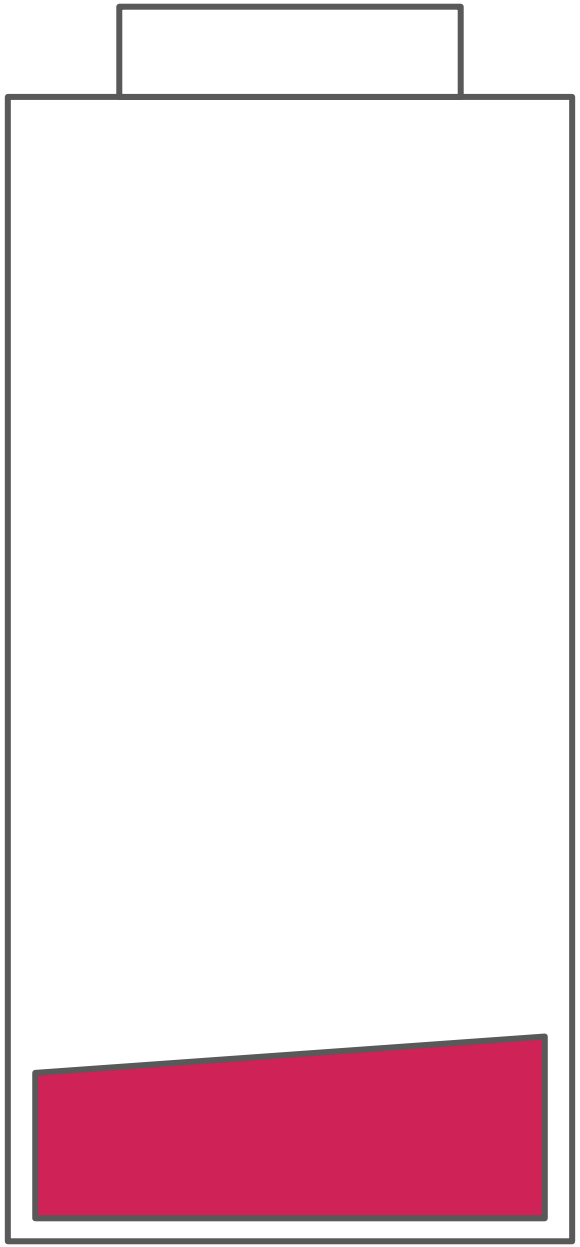


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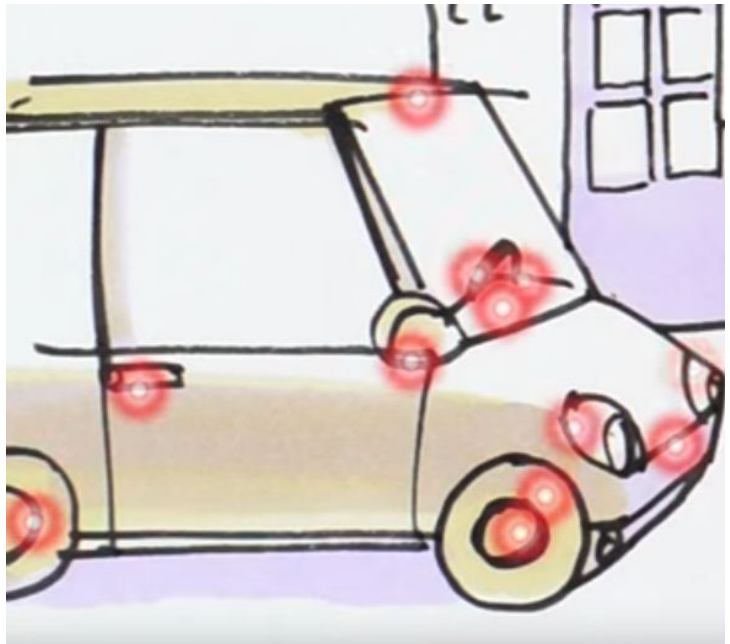


Boundary Devices
SABER LITE


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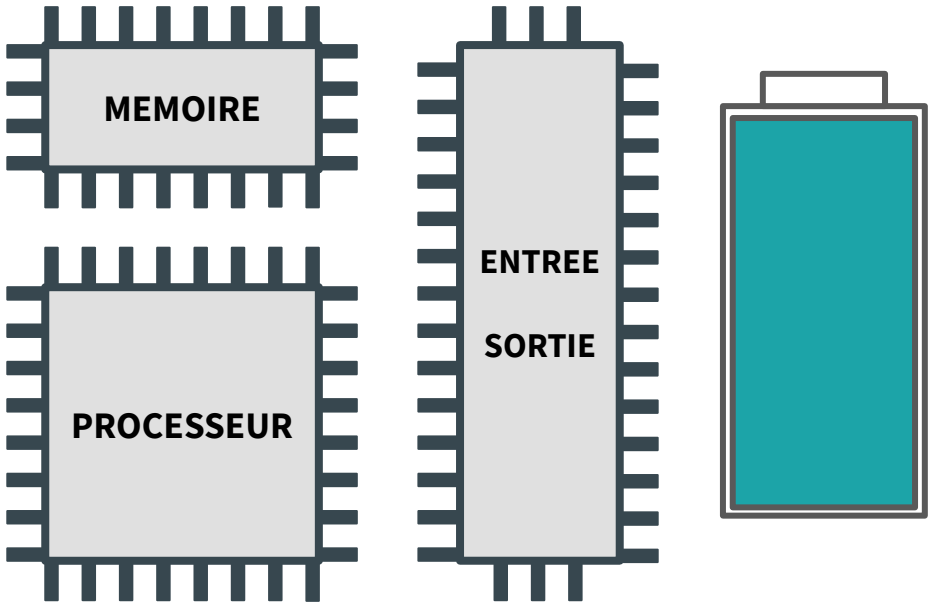
October 4
TUESDAY, 2016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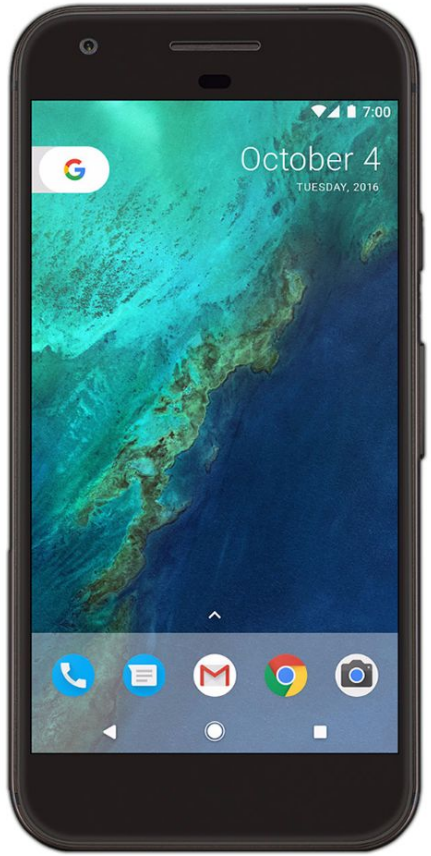
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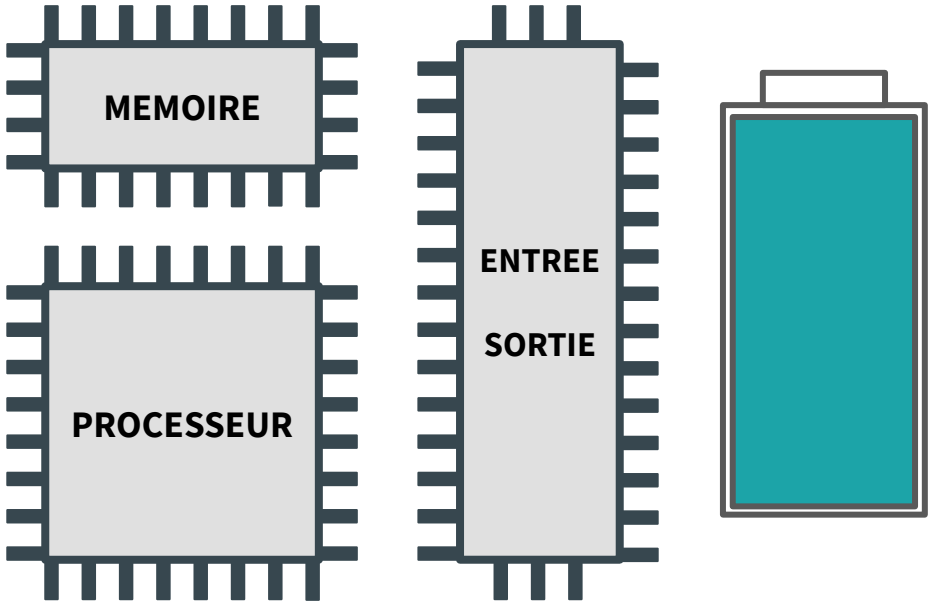
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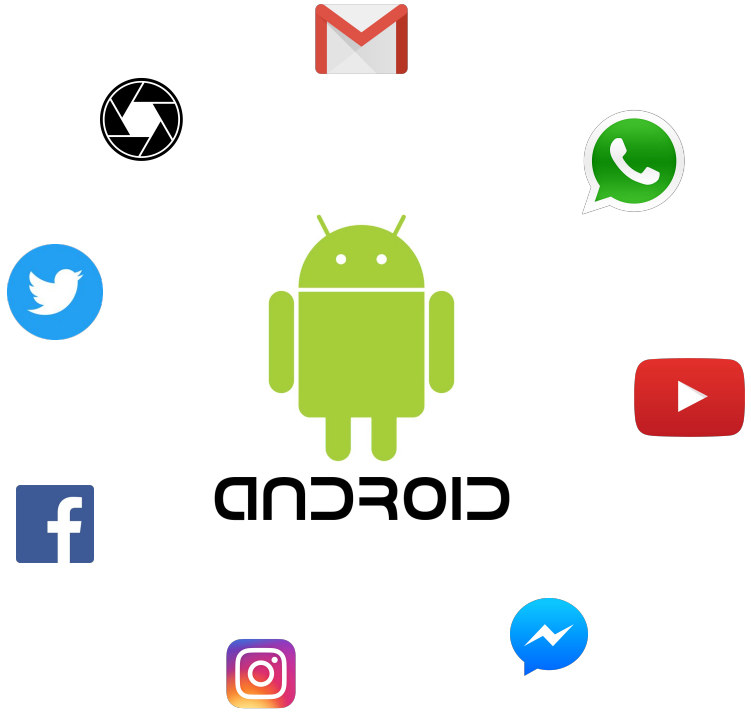
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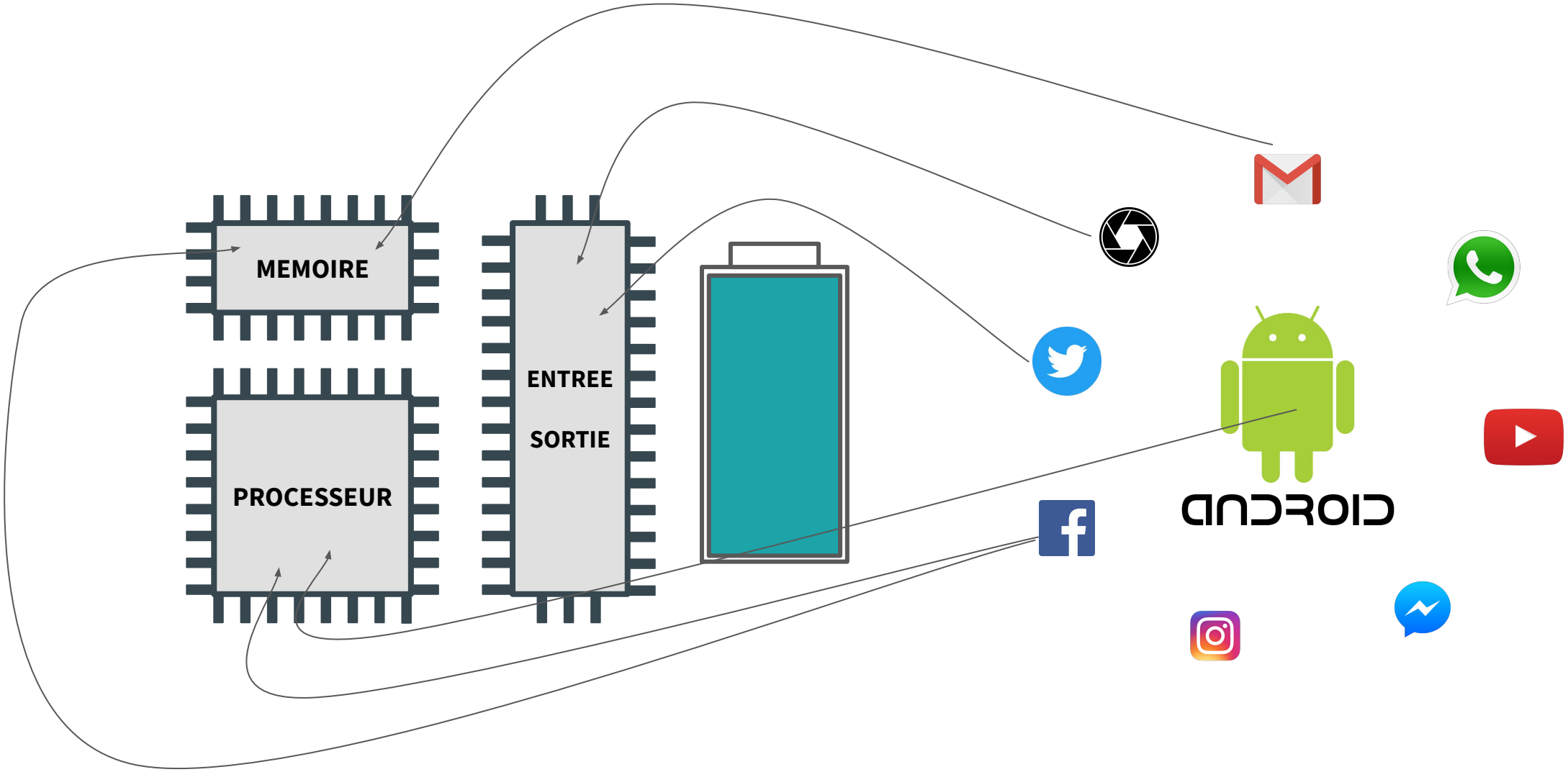
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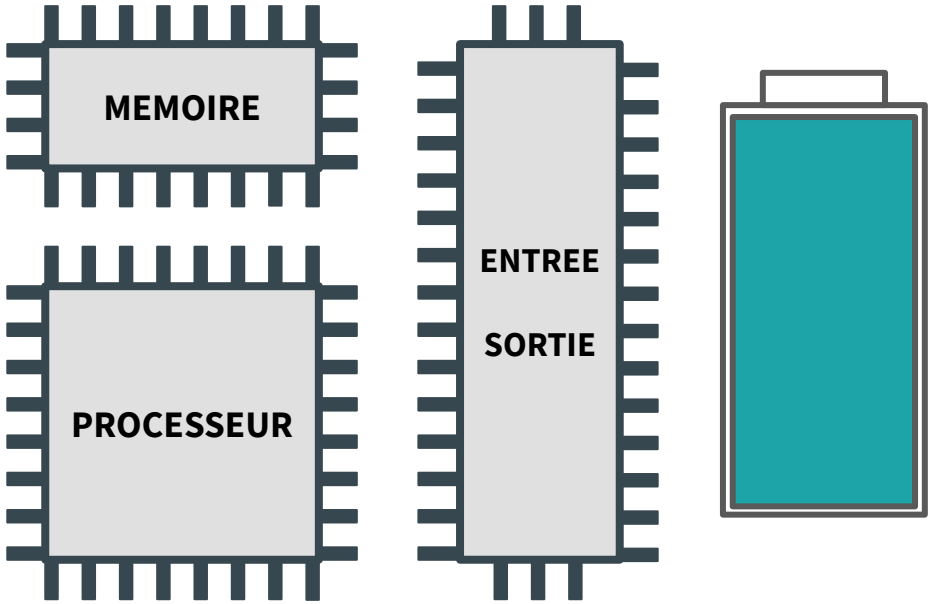
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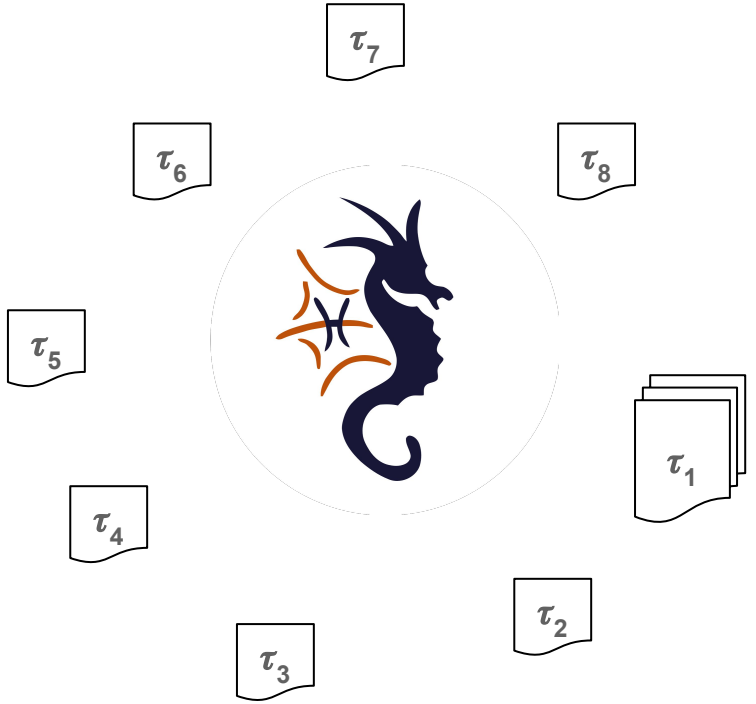
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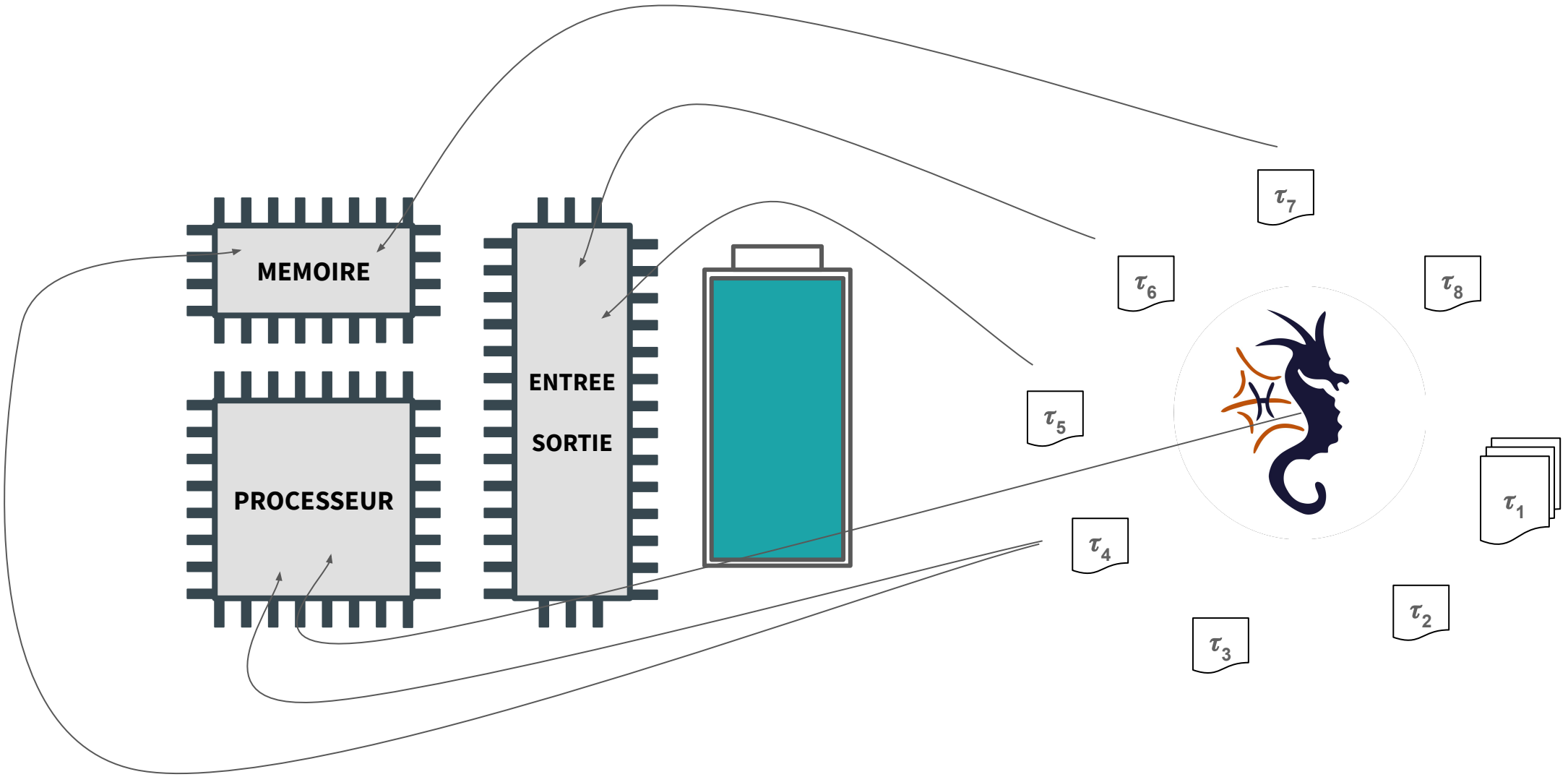
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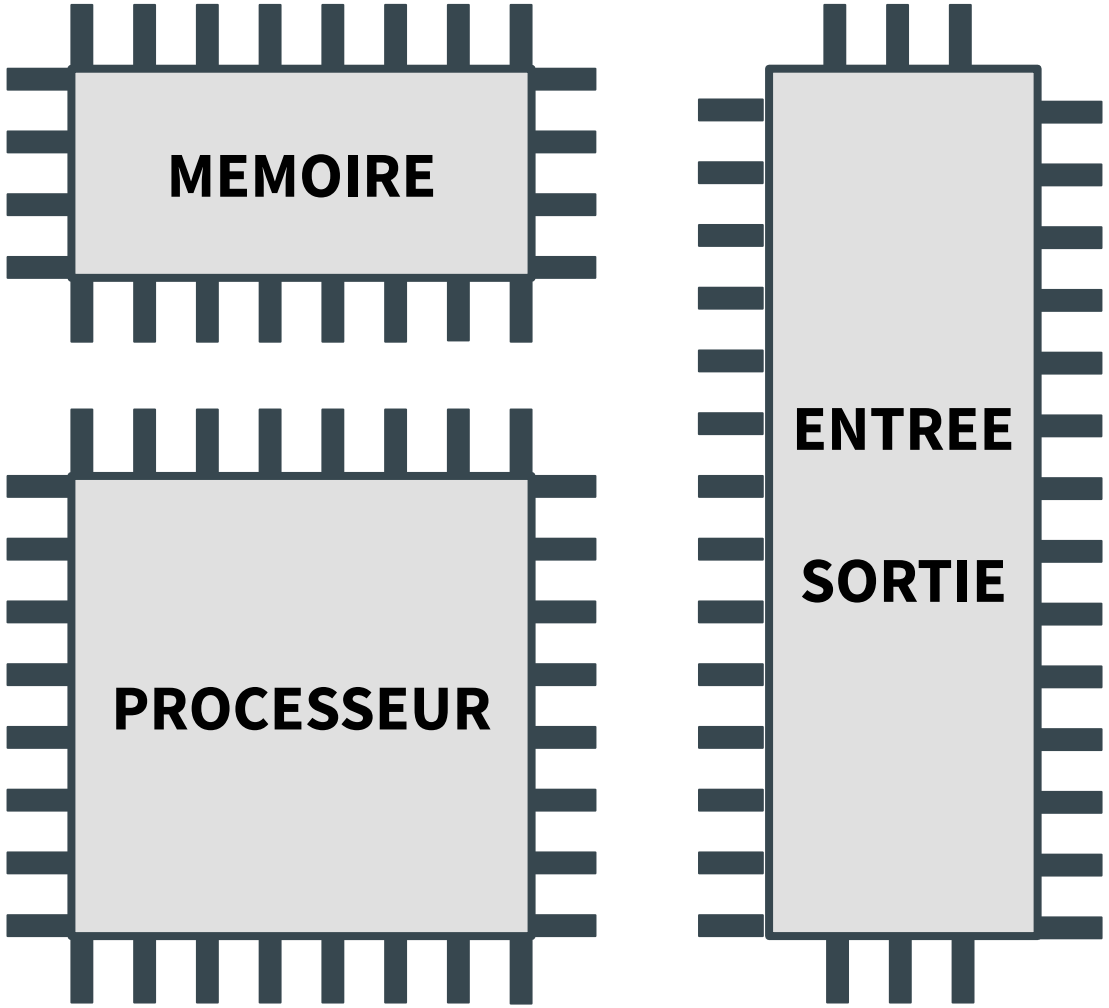
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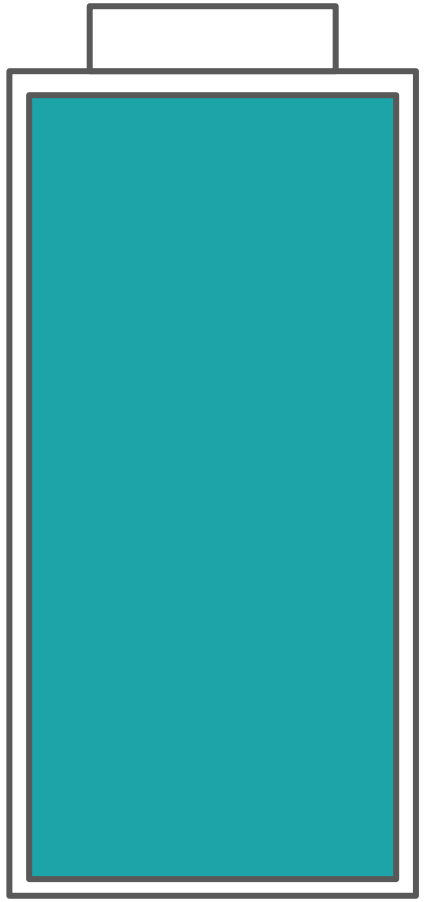

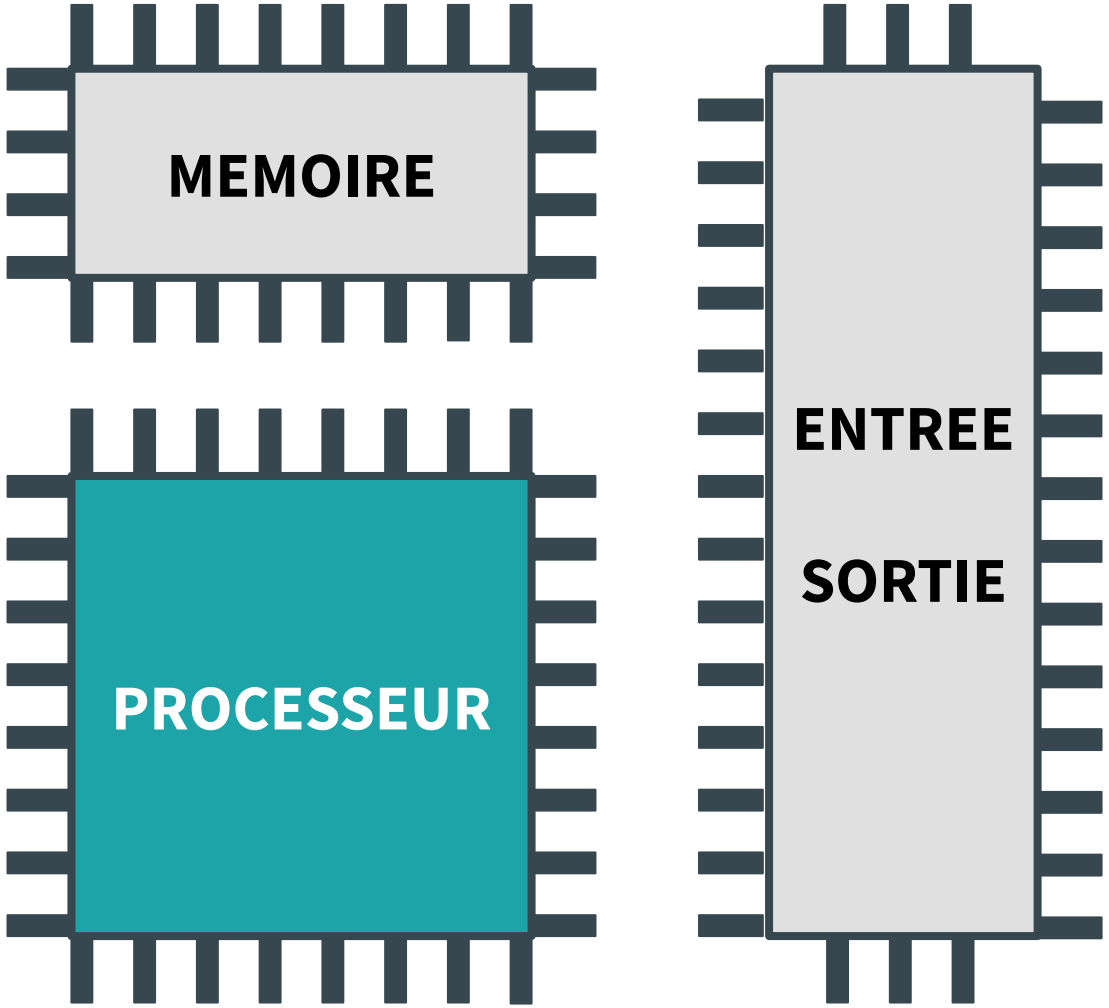
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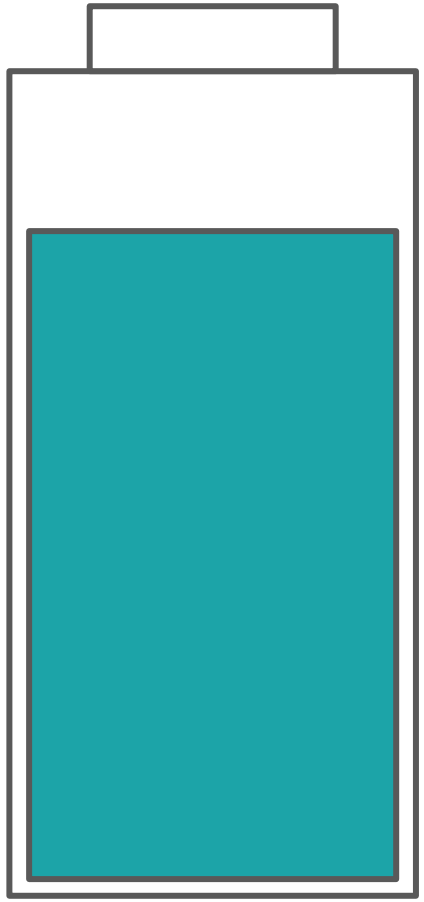

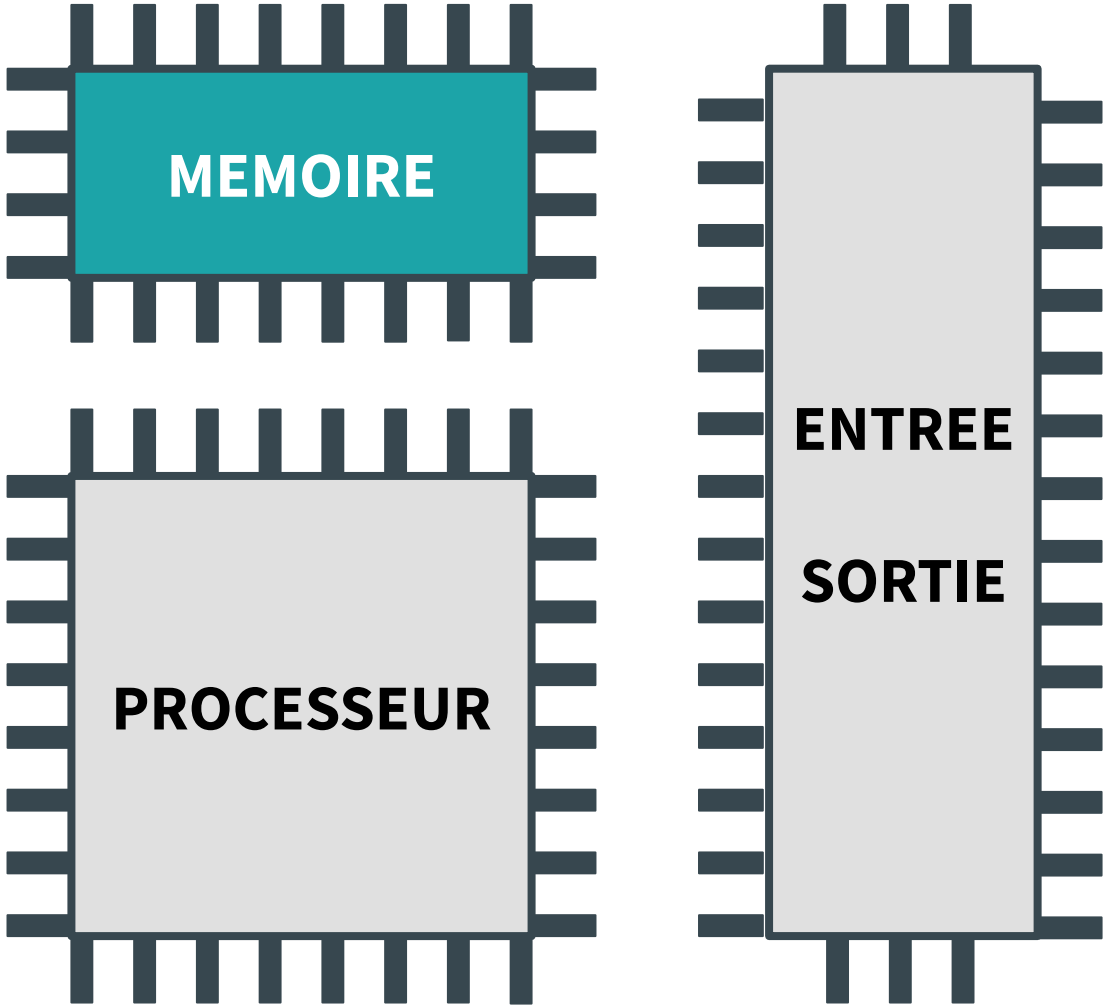
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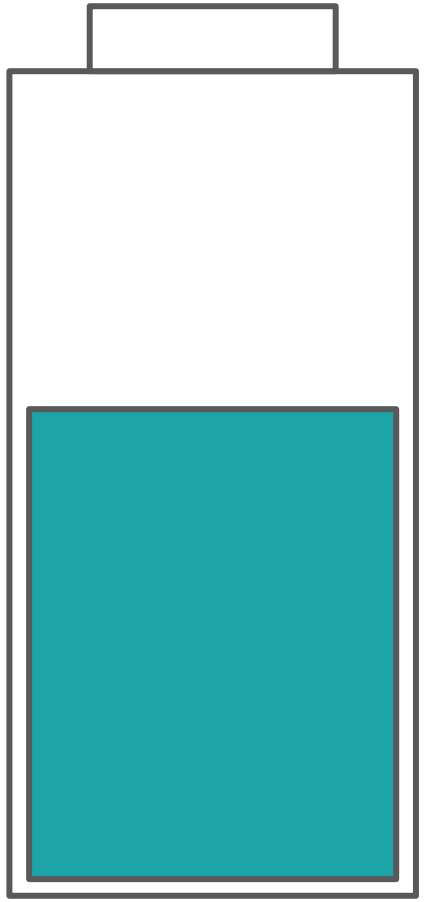

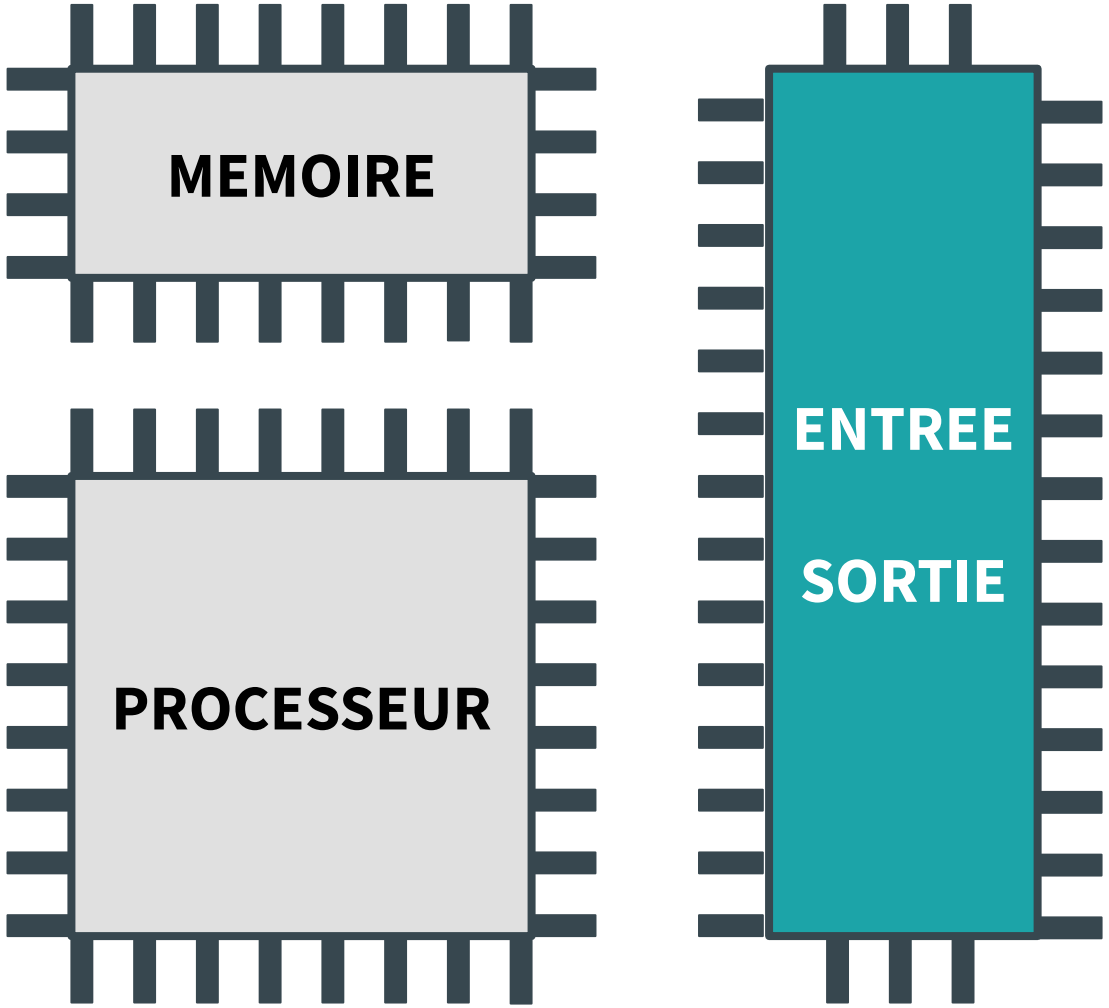
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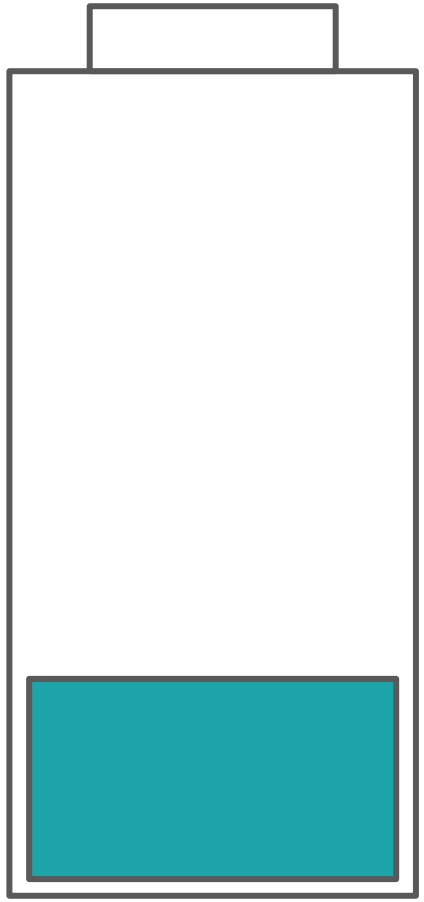

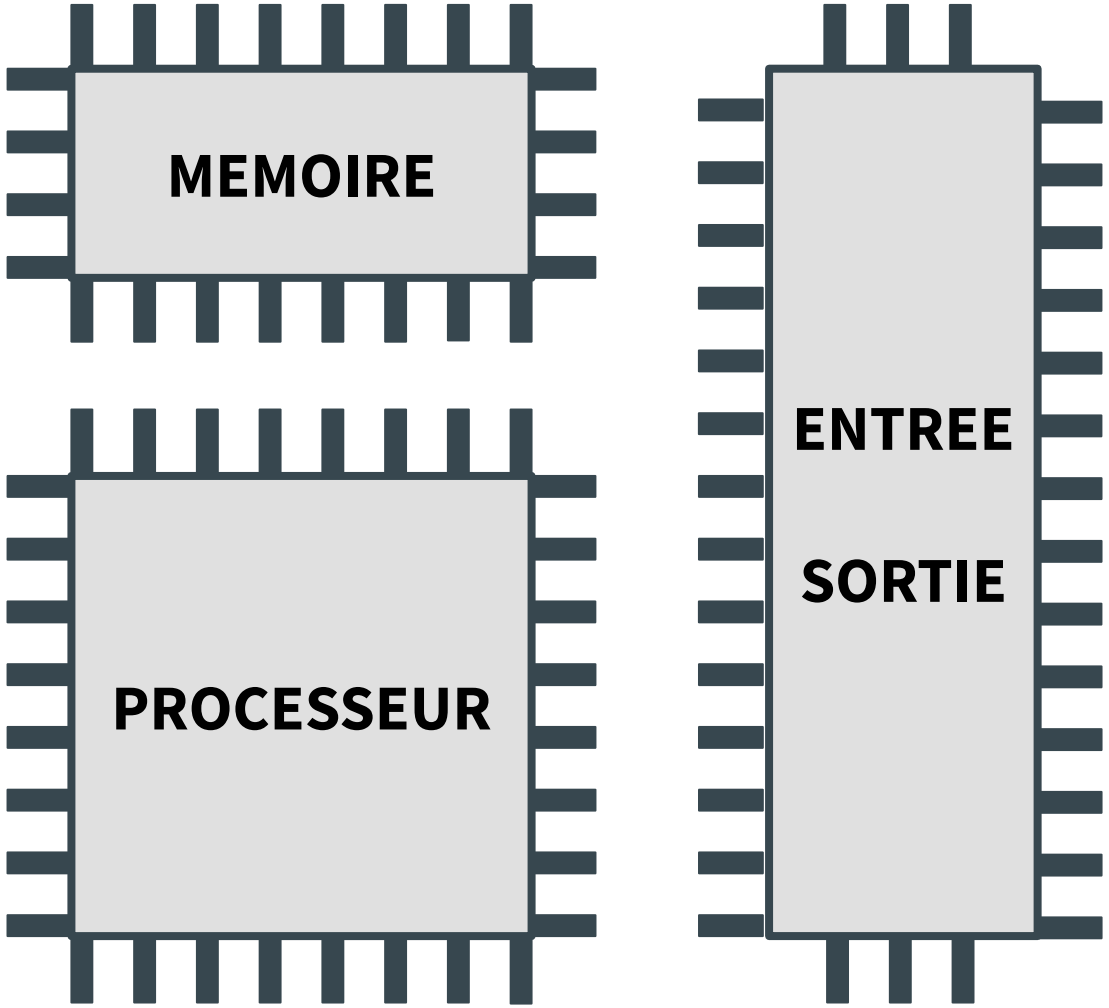
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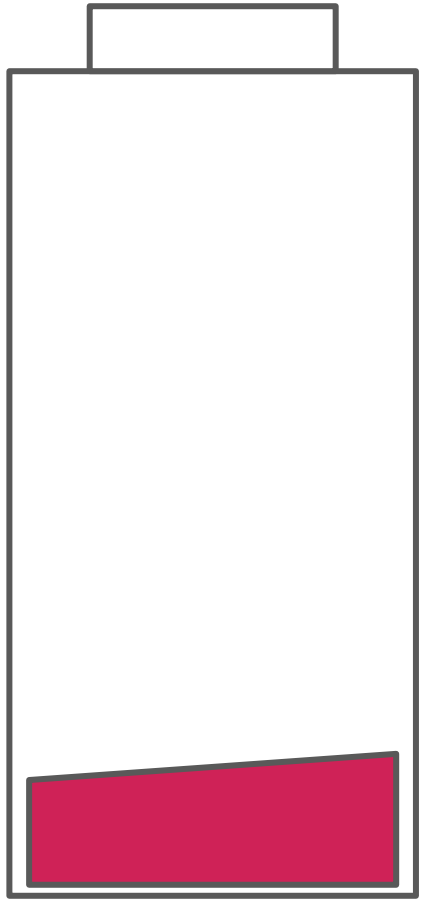

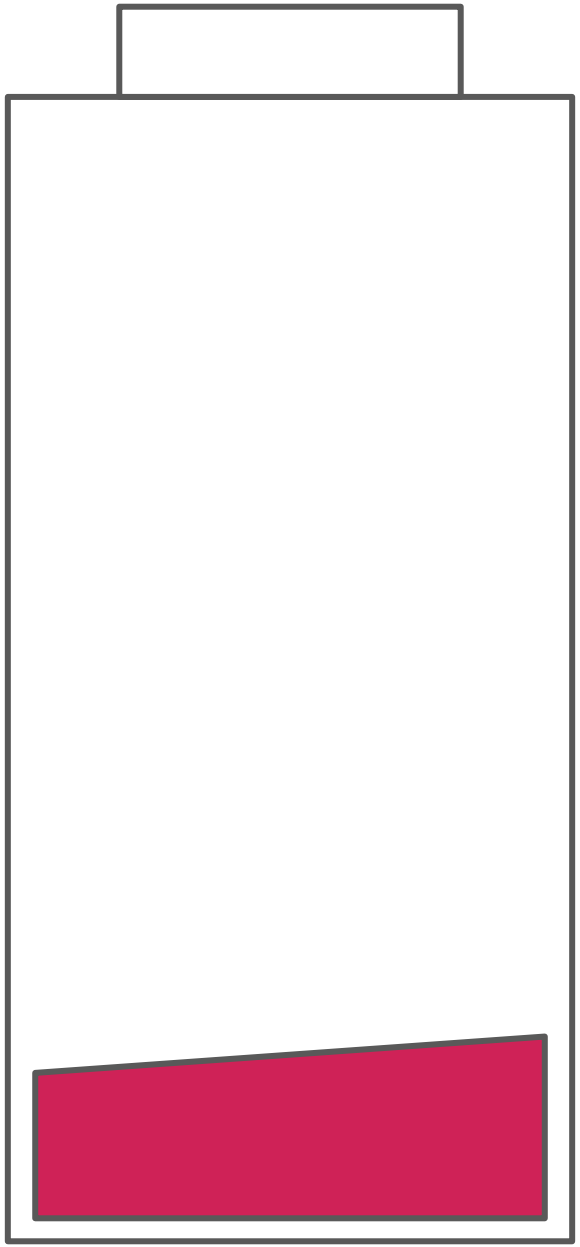

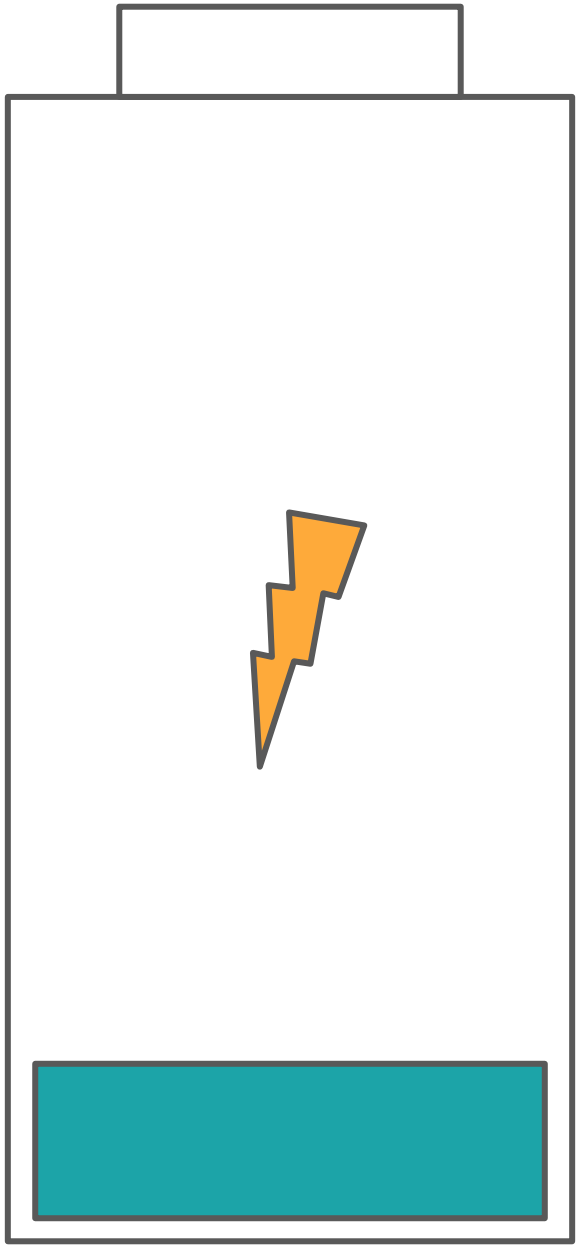

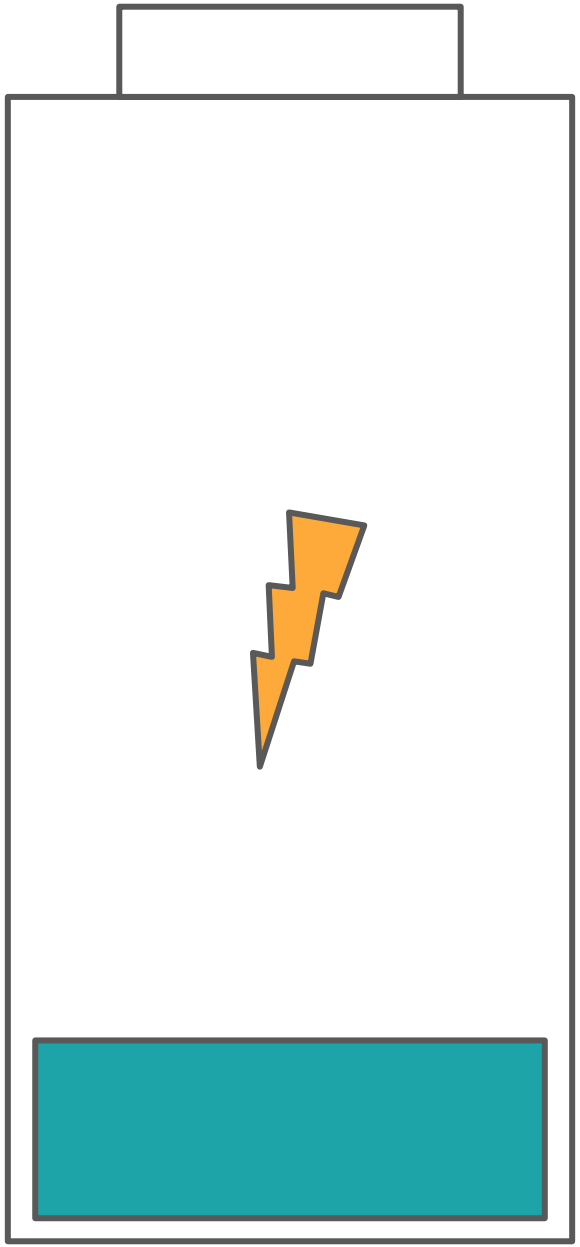

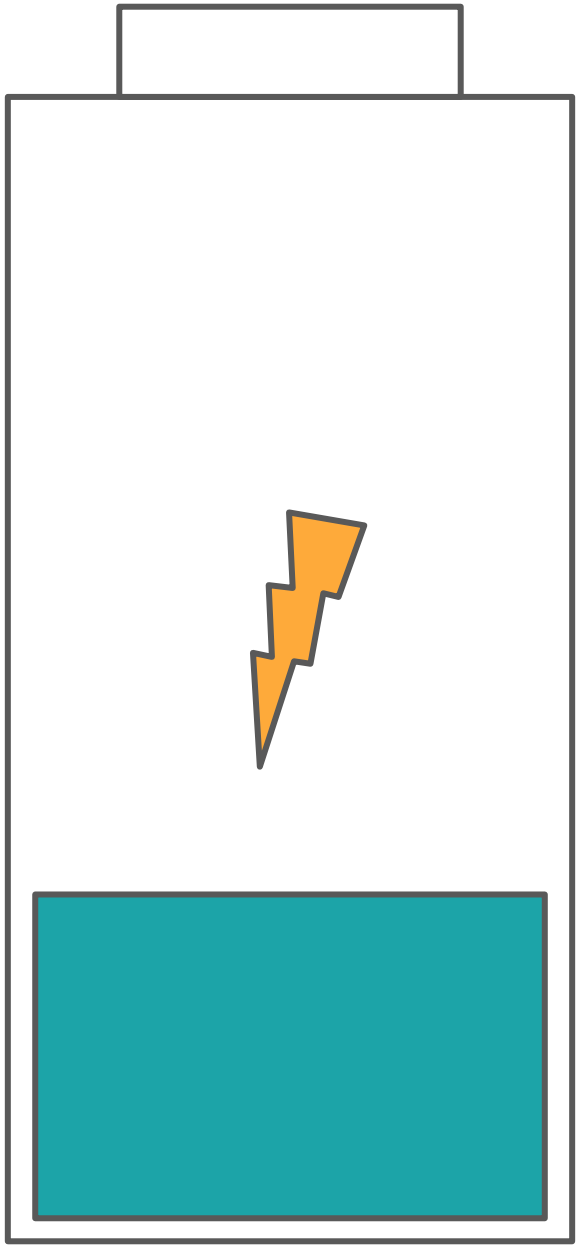

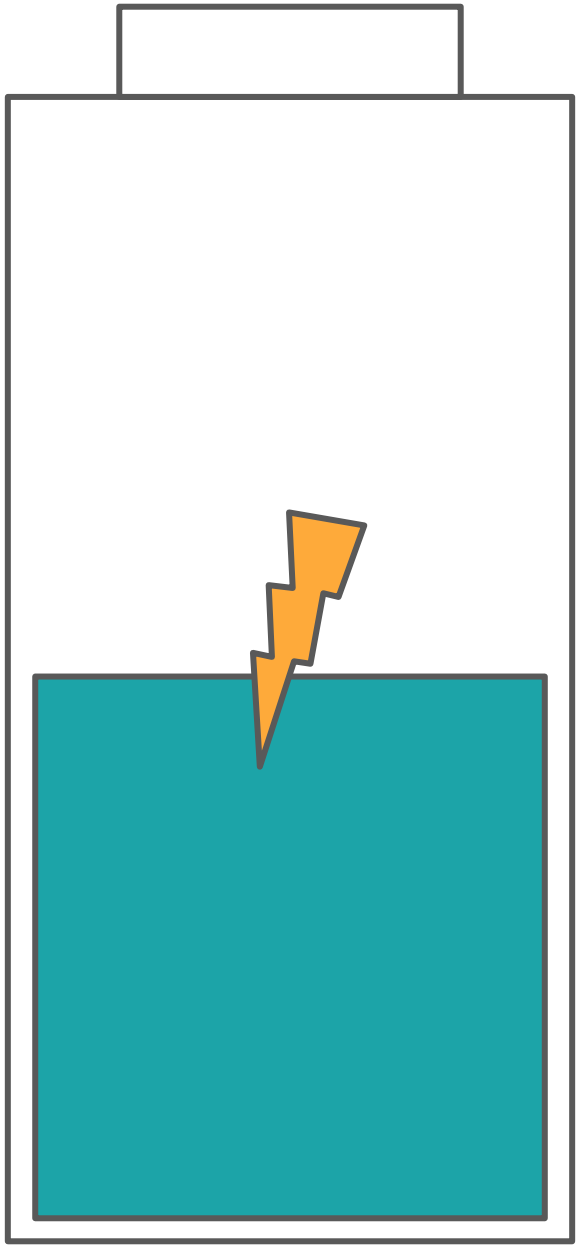

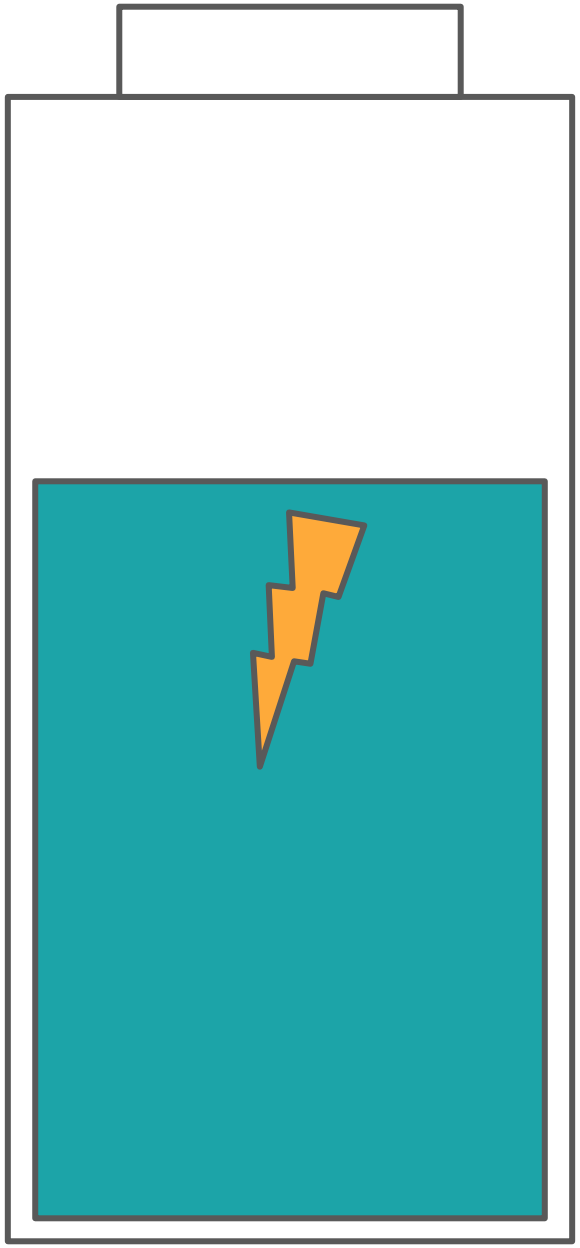

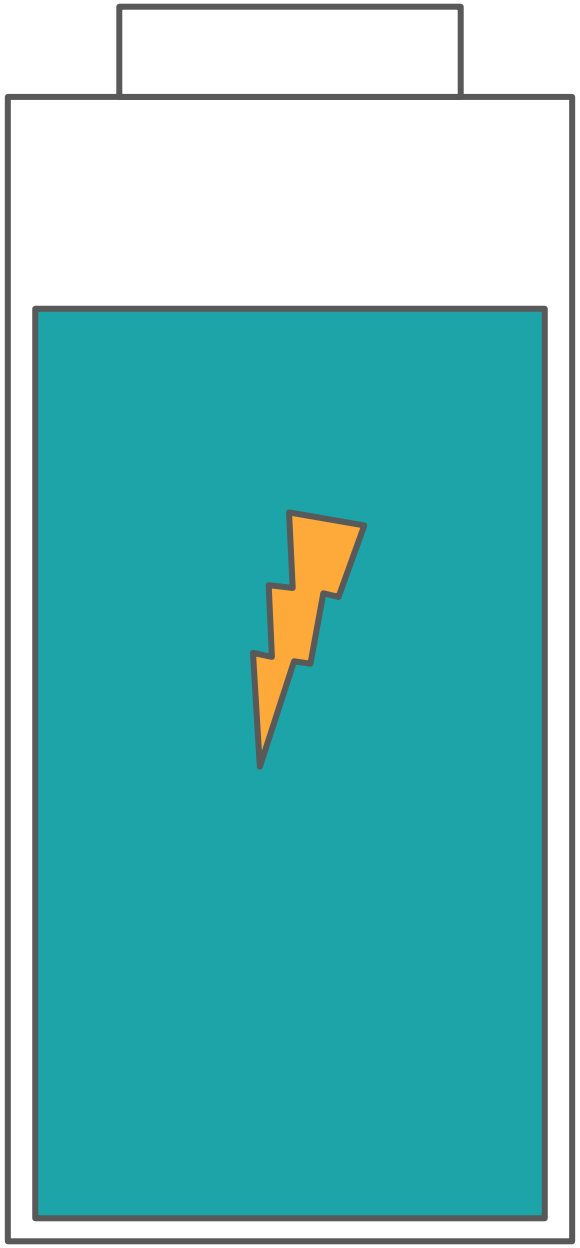

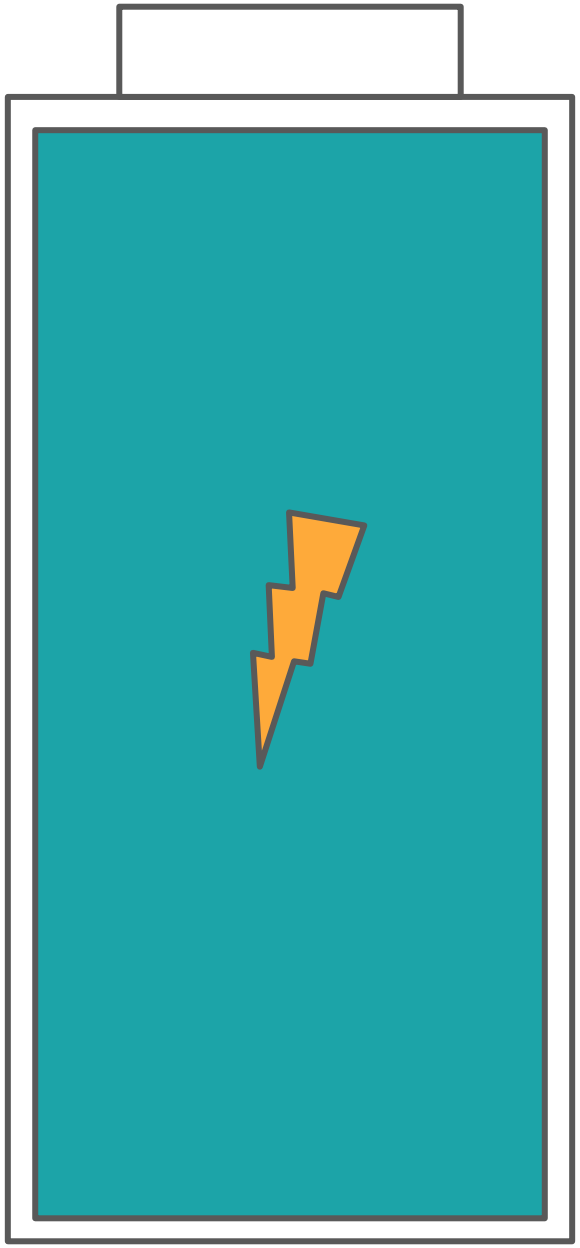

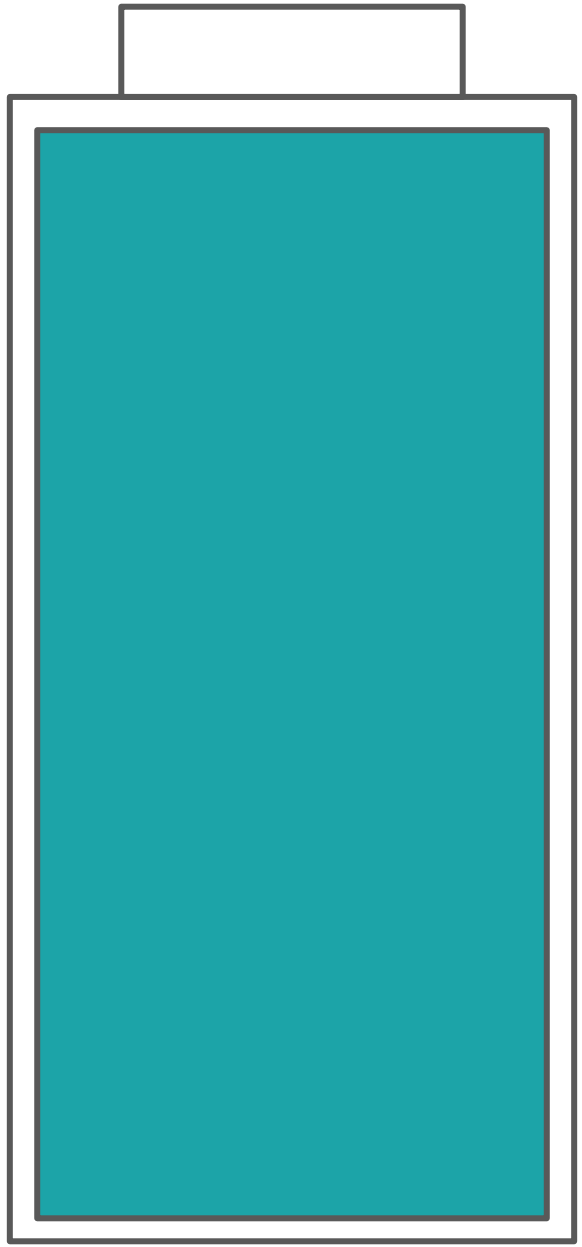

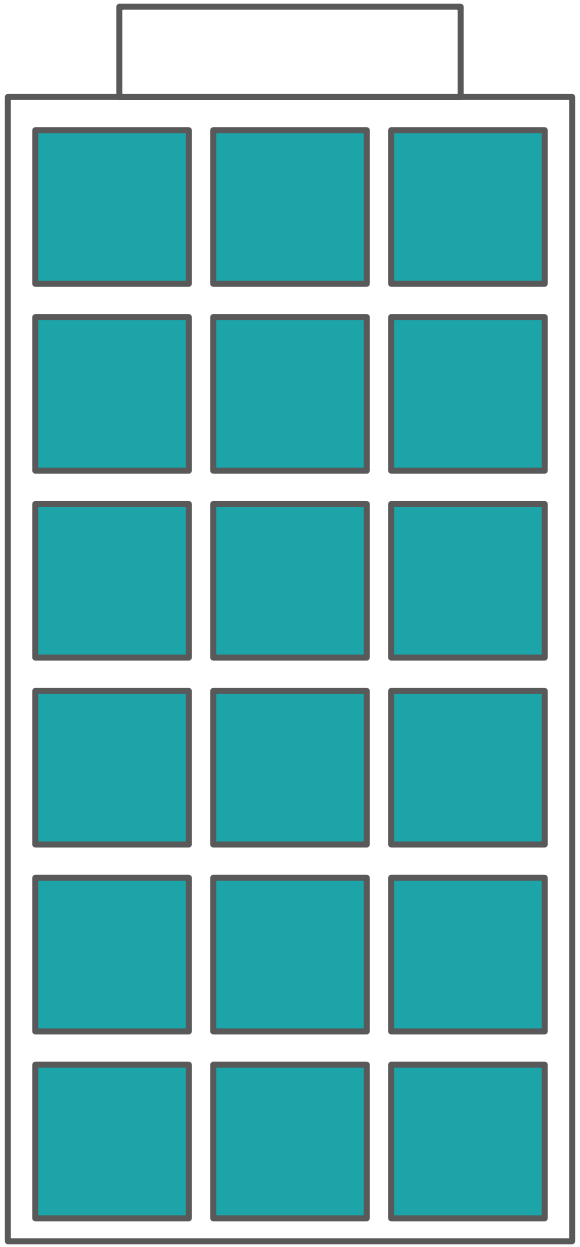

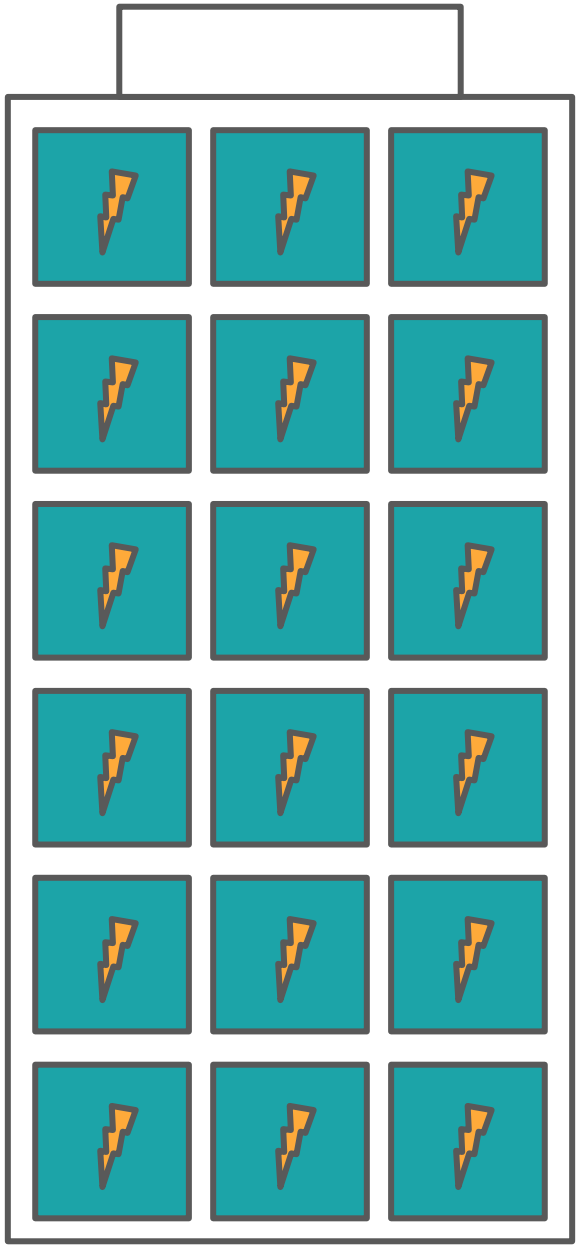

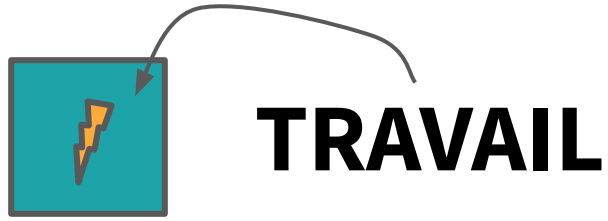
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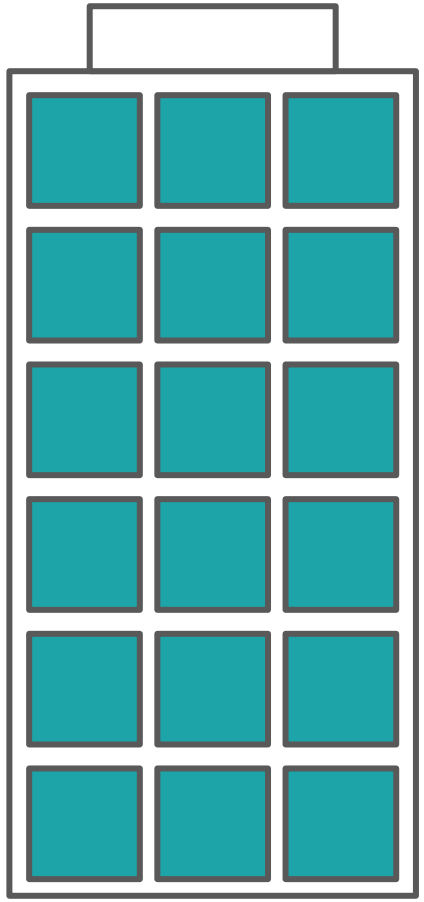

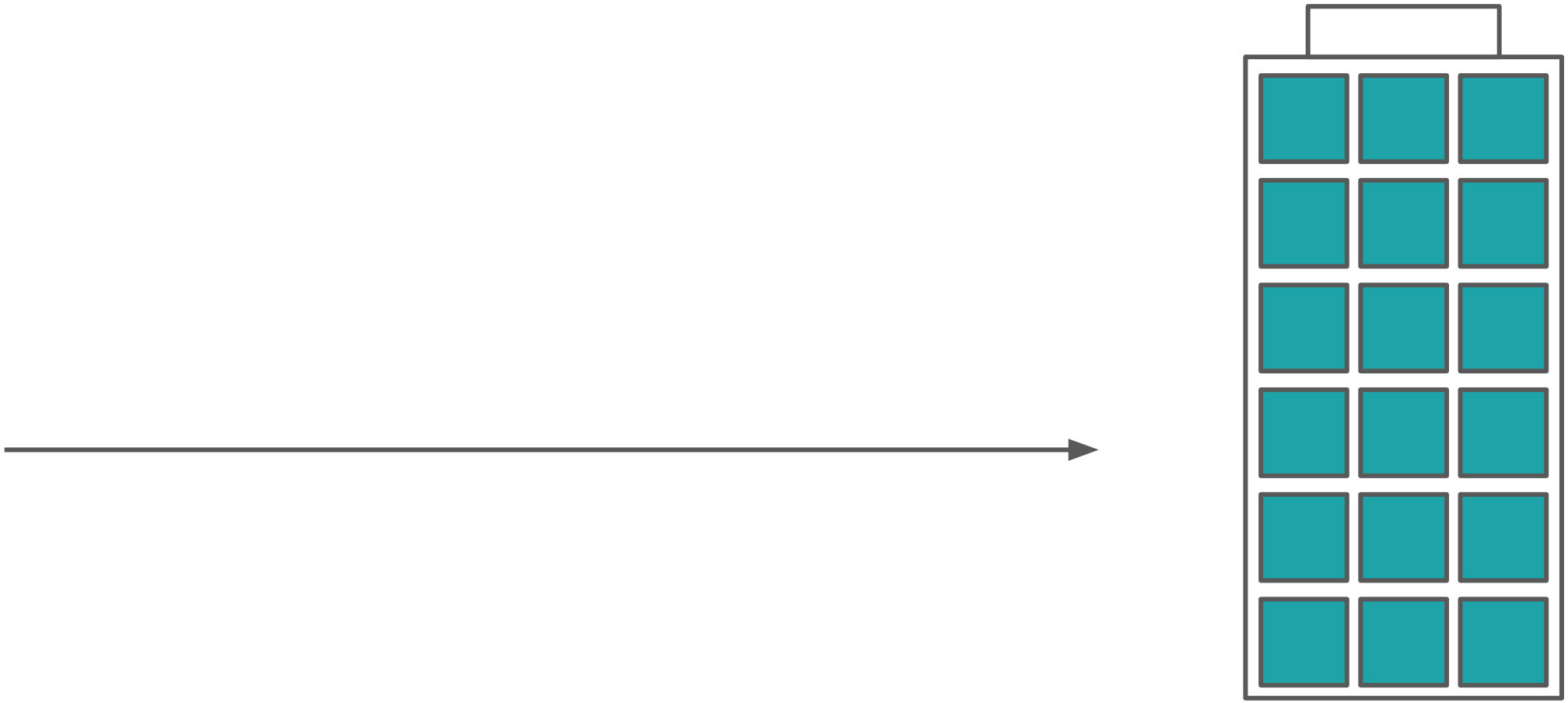

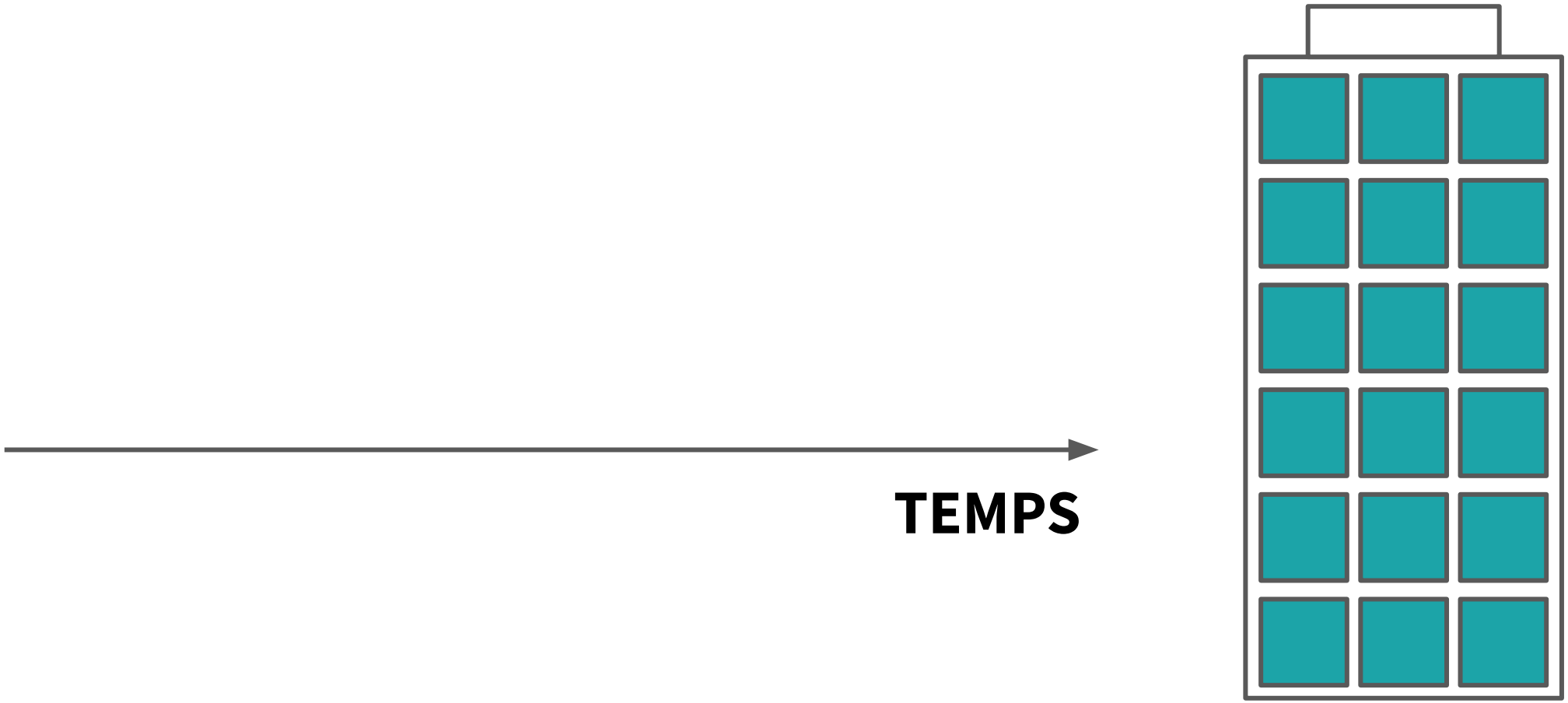
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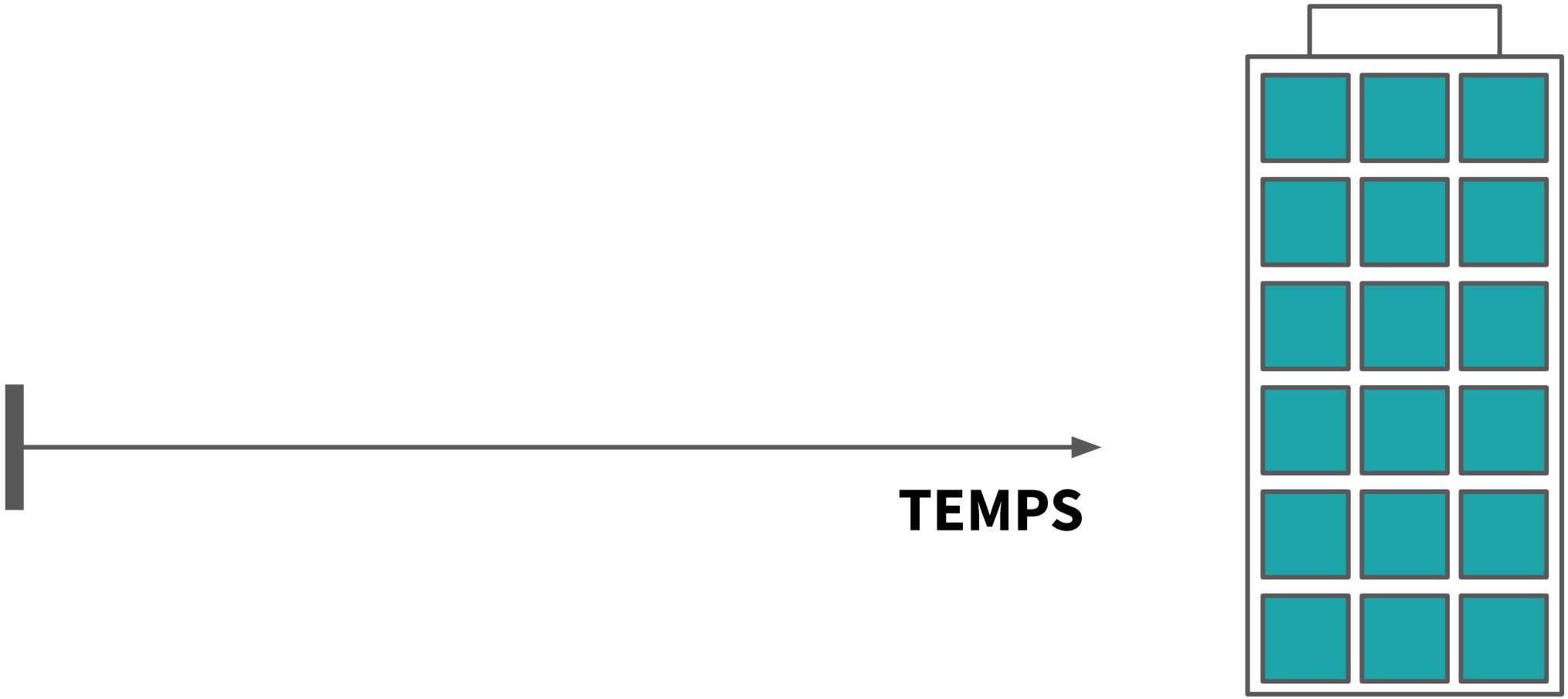
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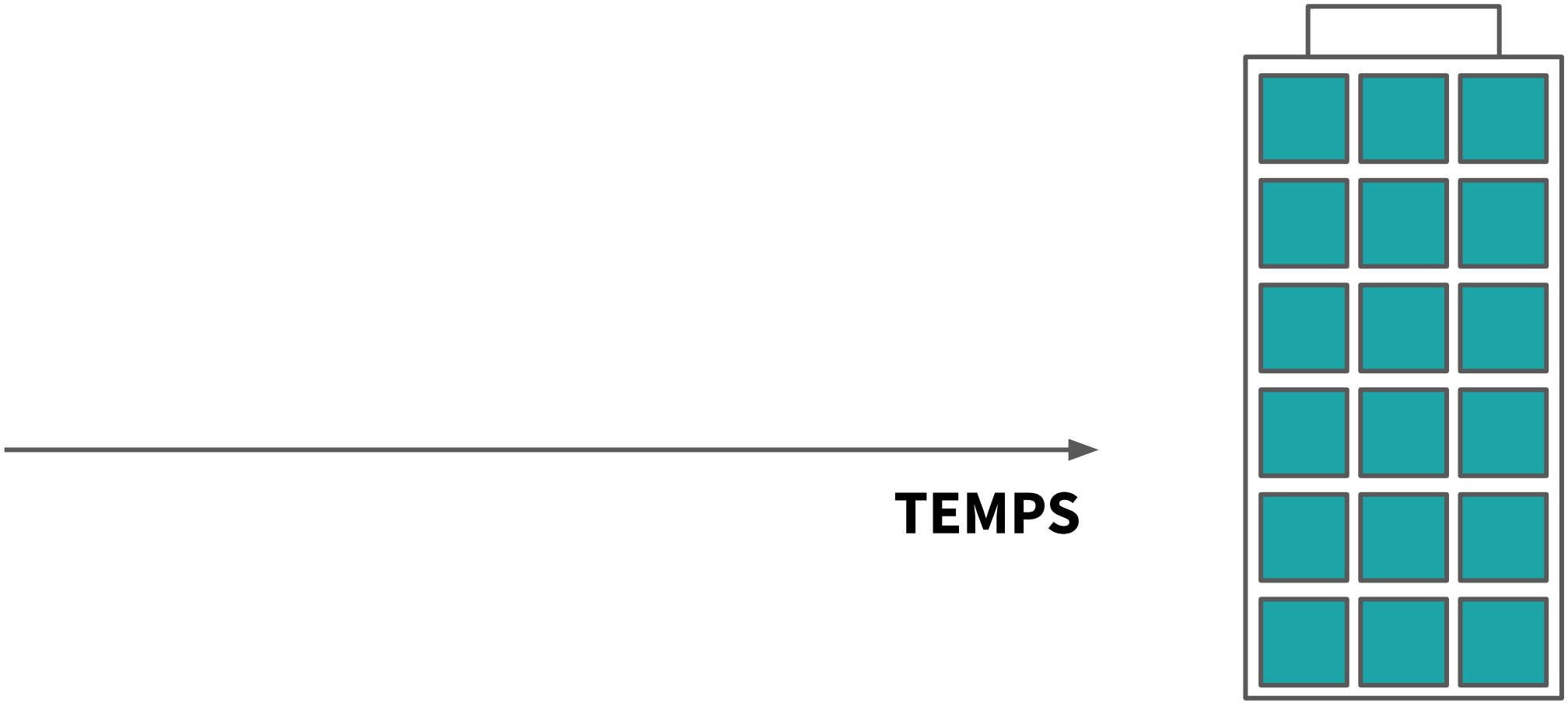
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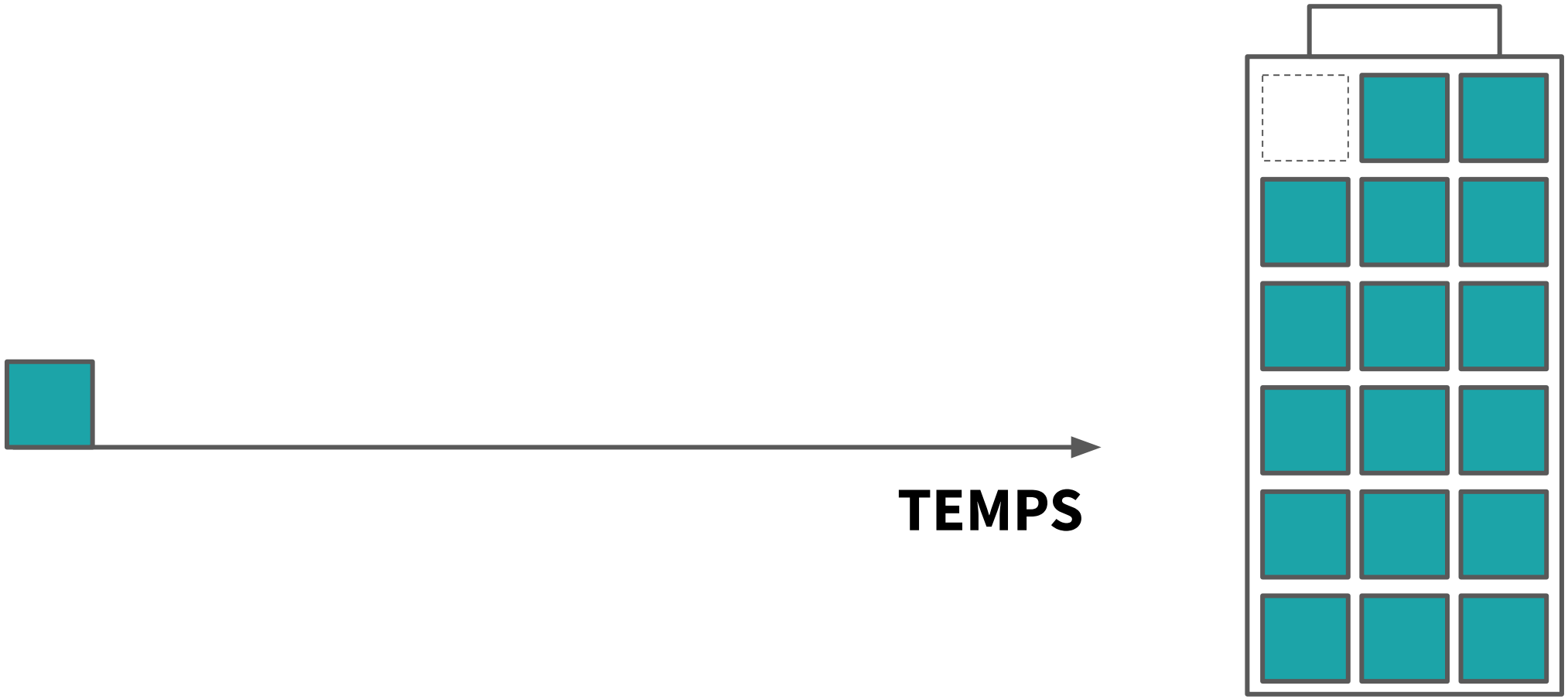
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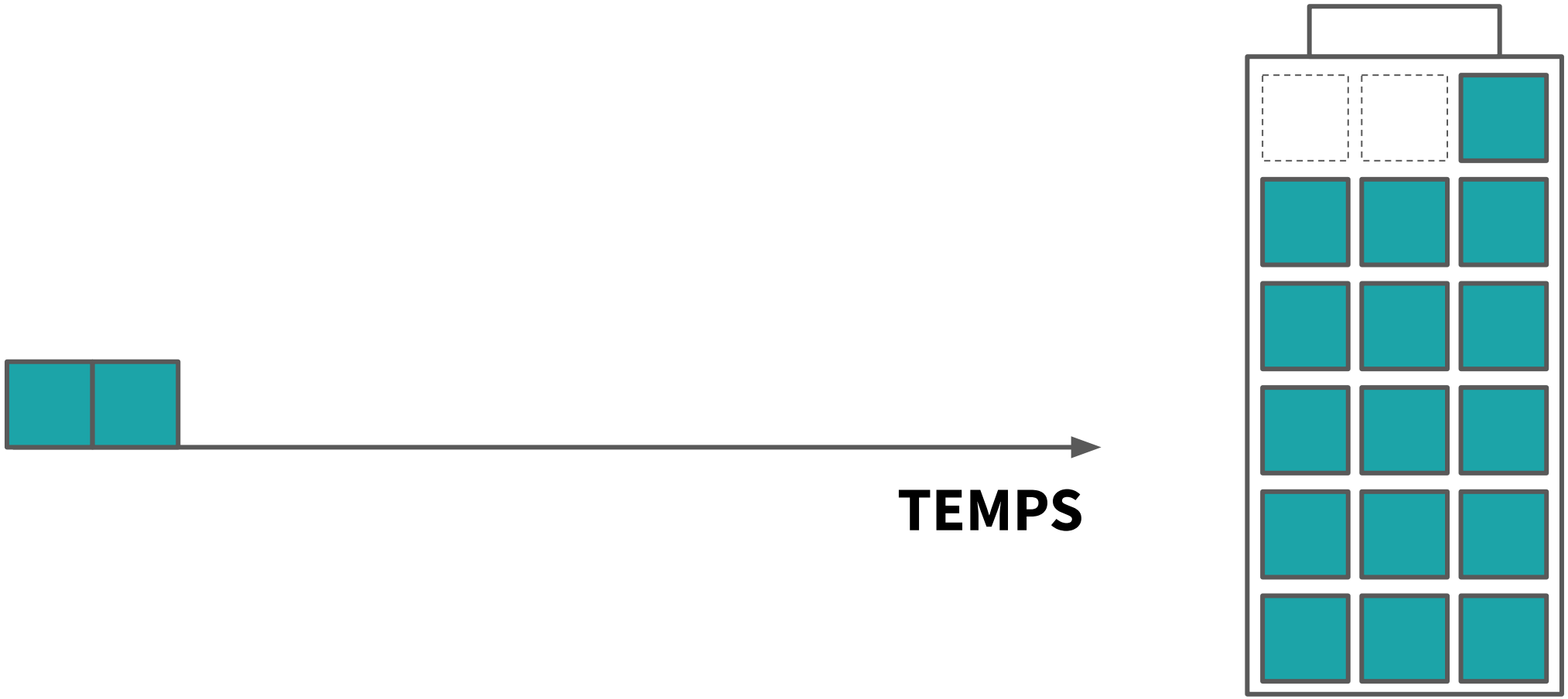
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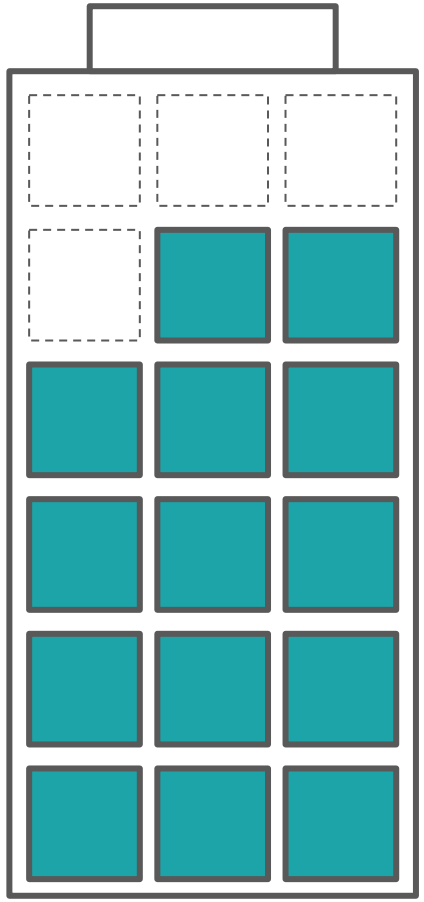

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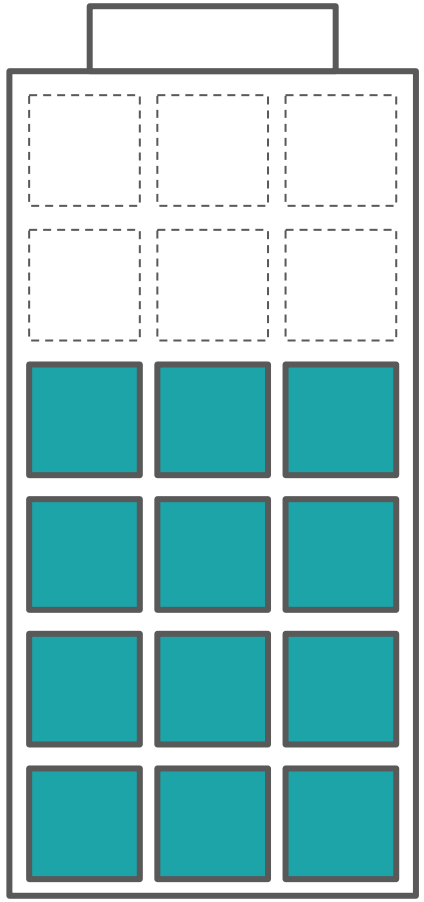

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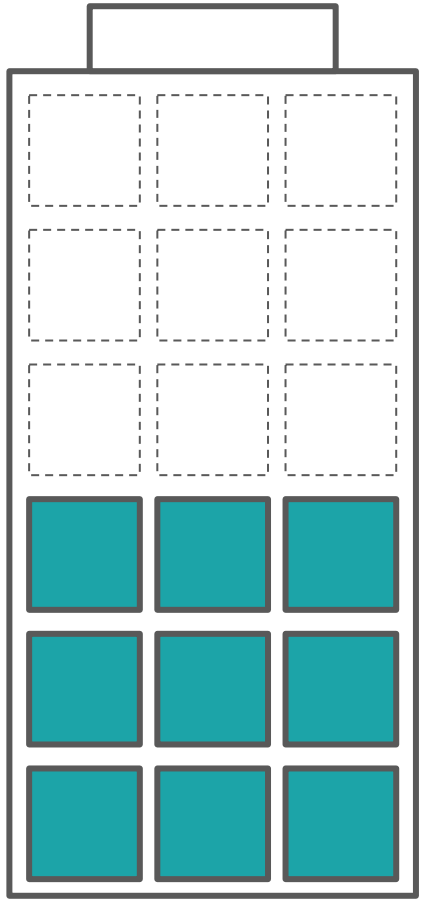

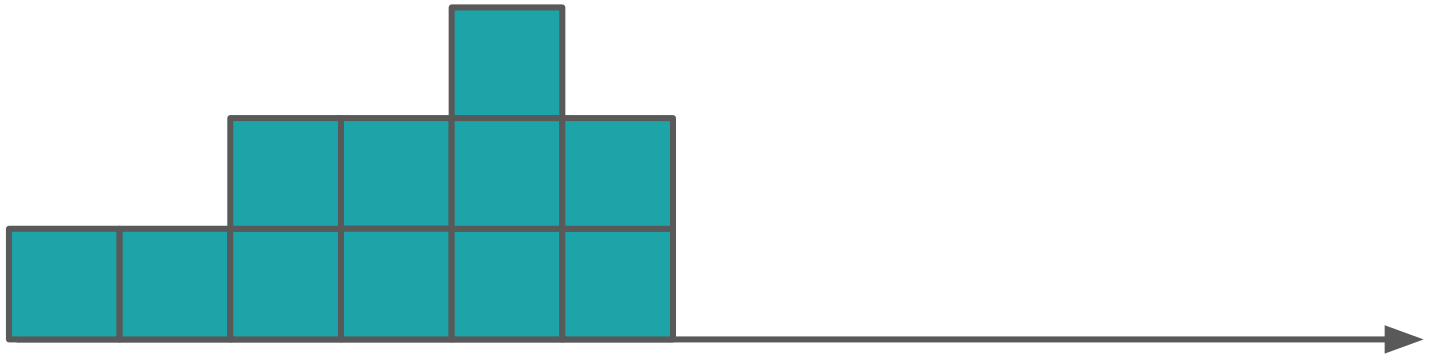

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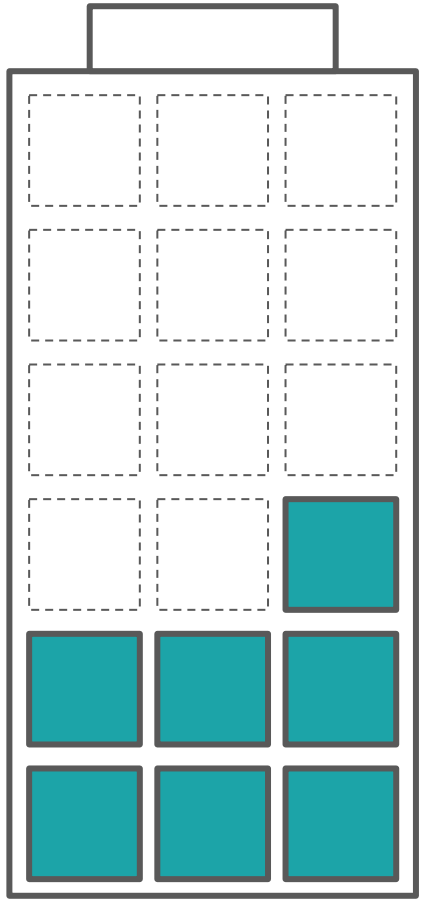

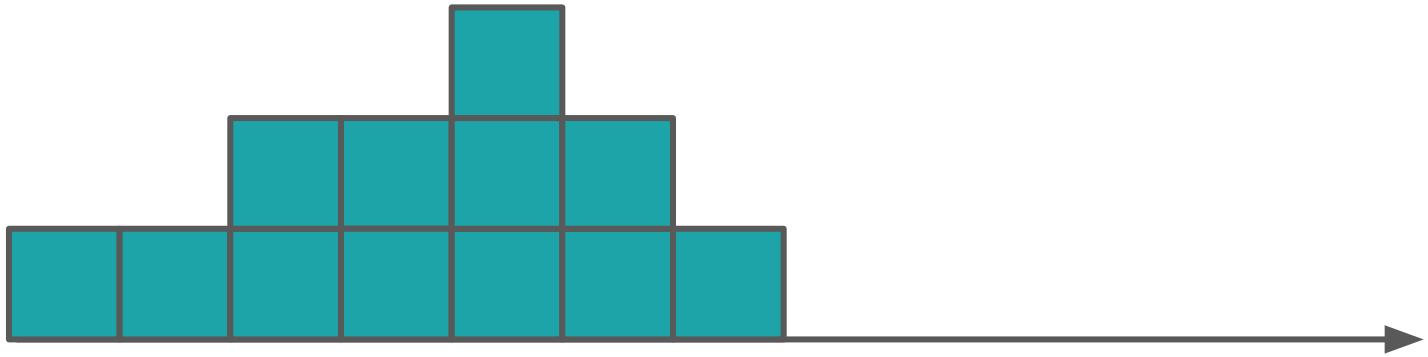

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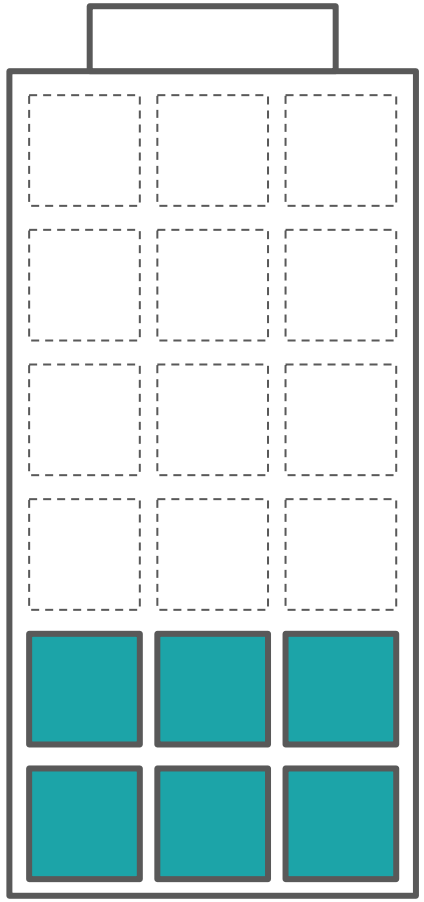

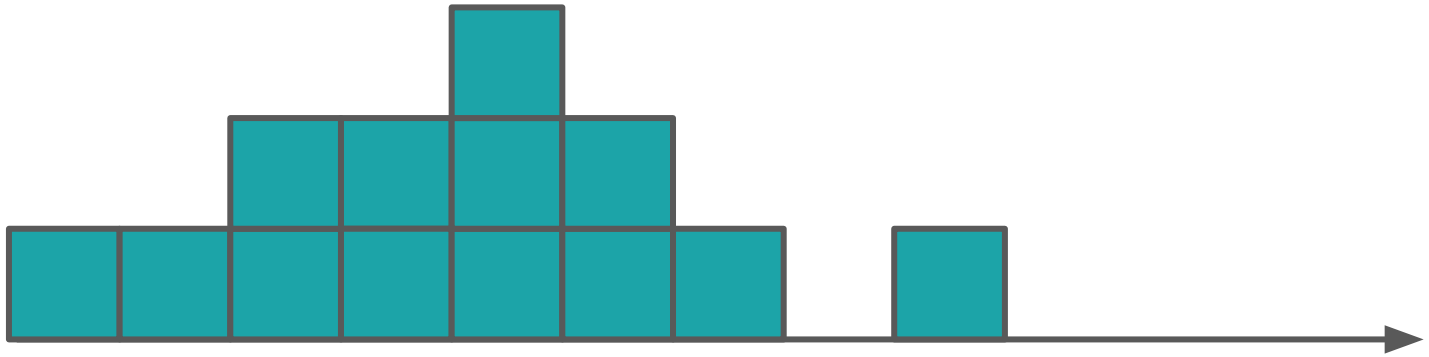

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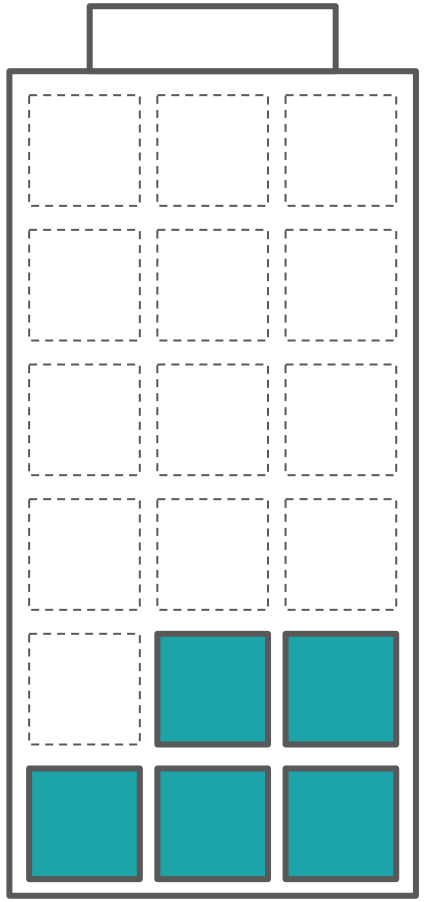

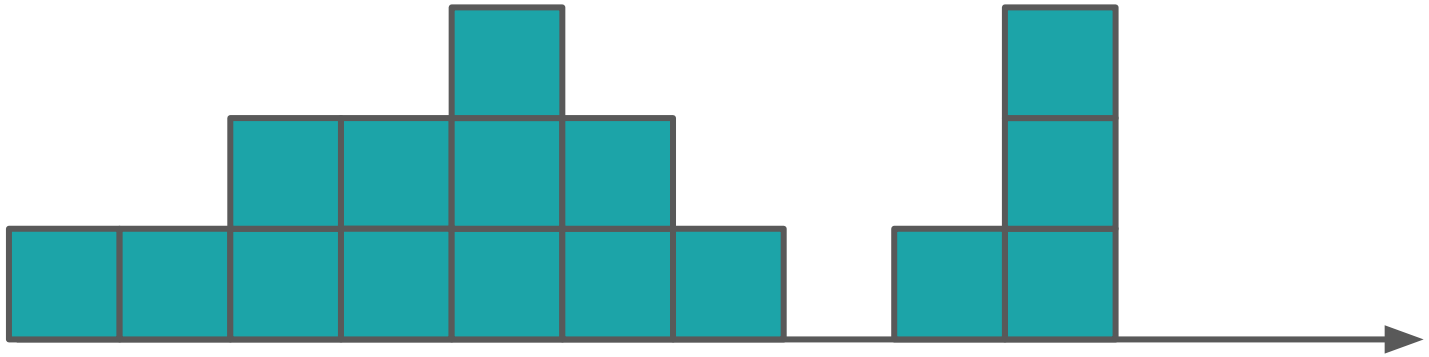

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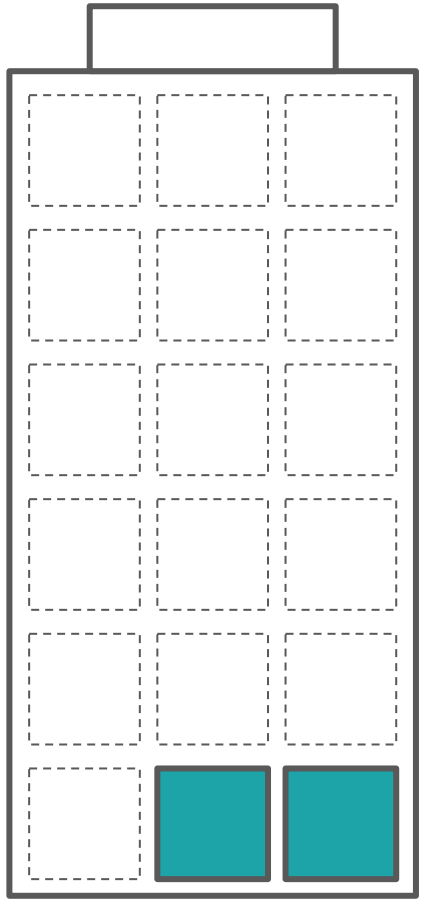

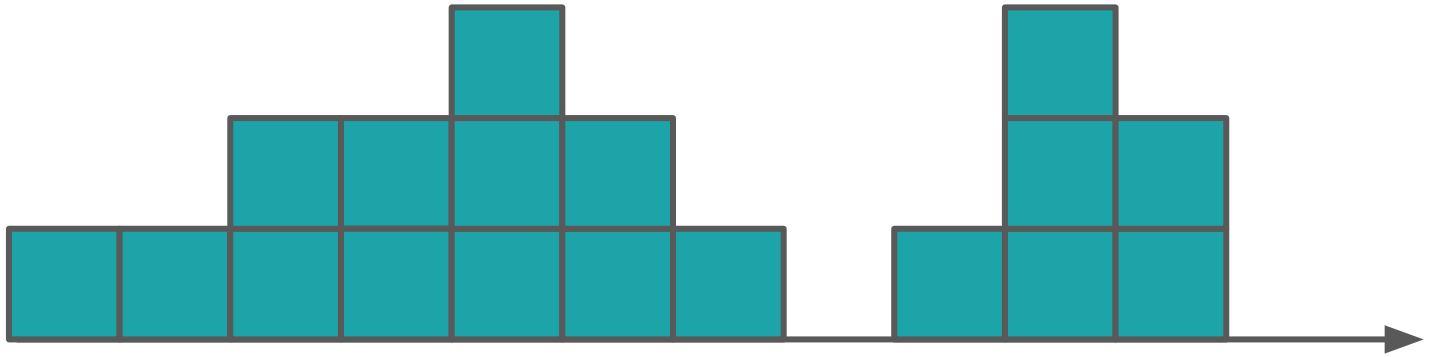

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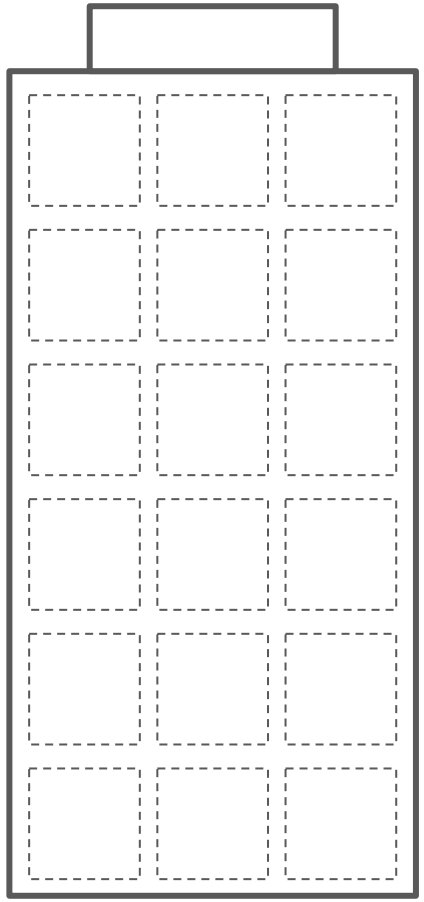

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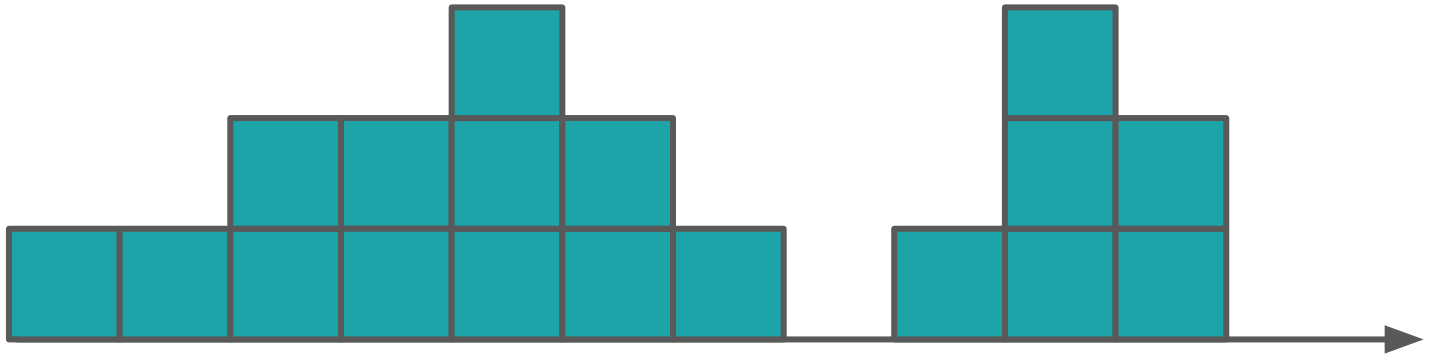
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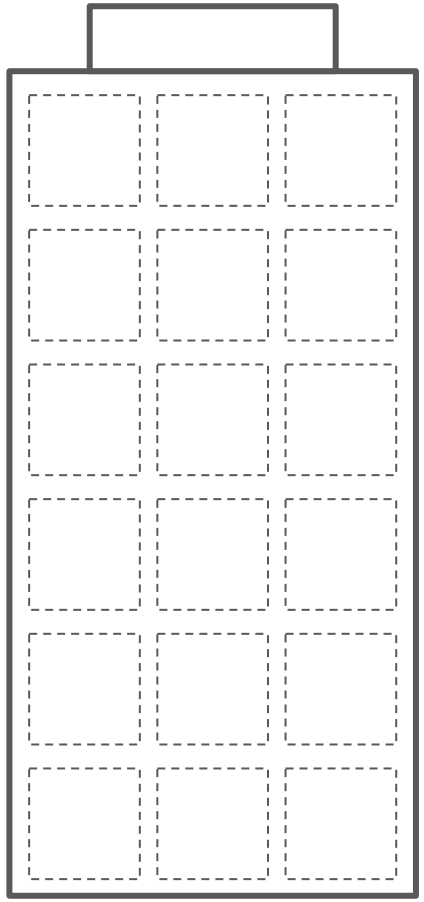

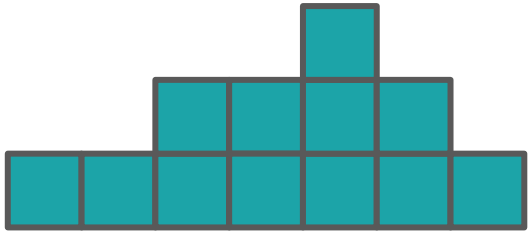

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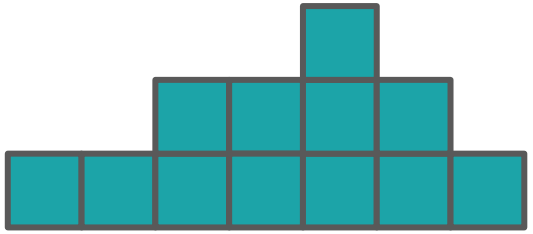

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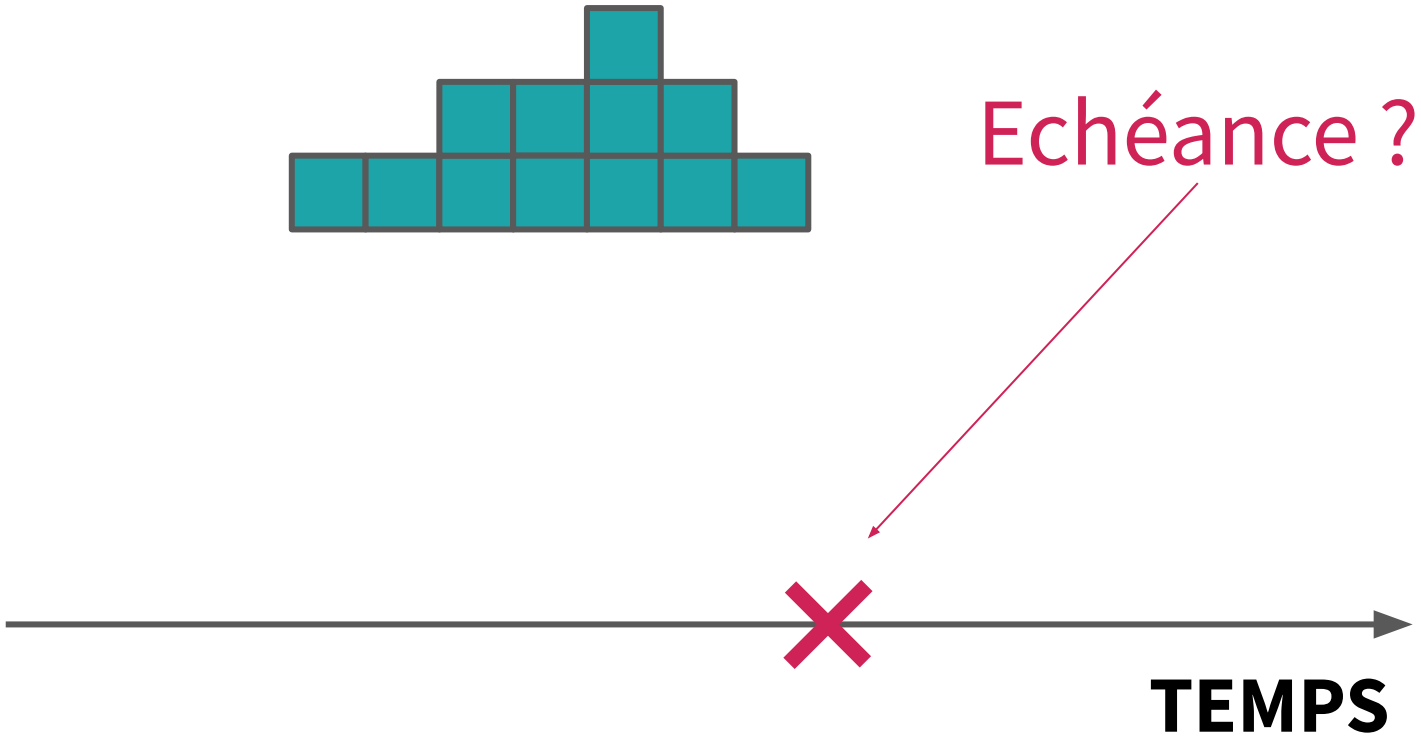
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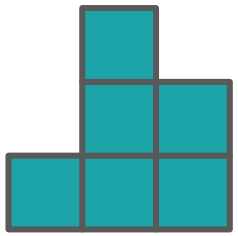
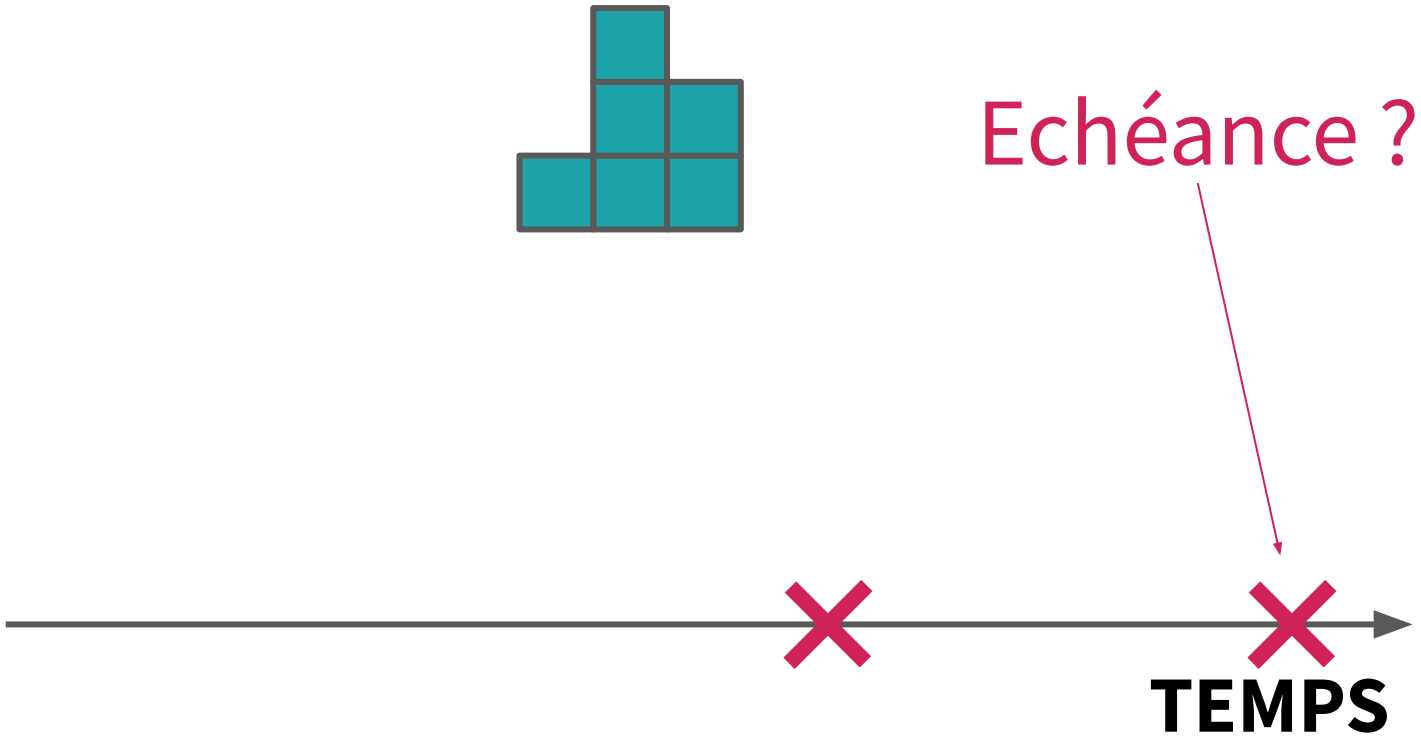
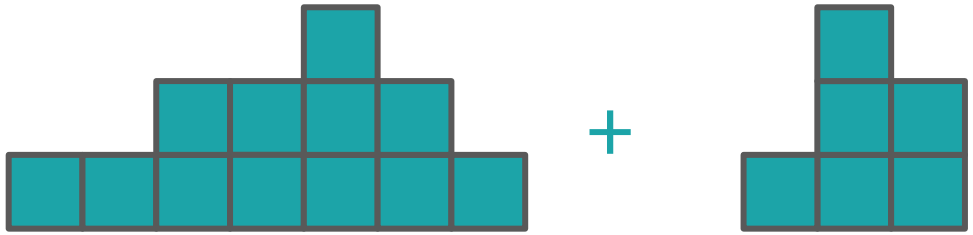


Echéance ?


Echéance ?
TEMPS


TEMPS

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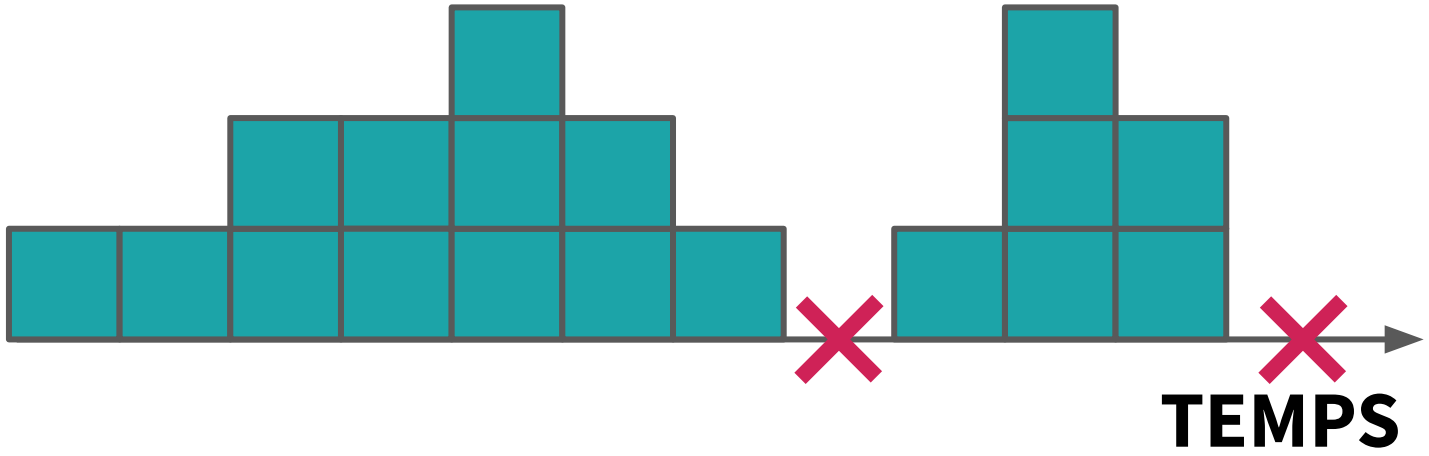
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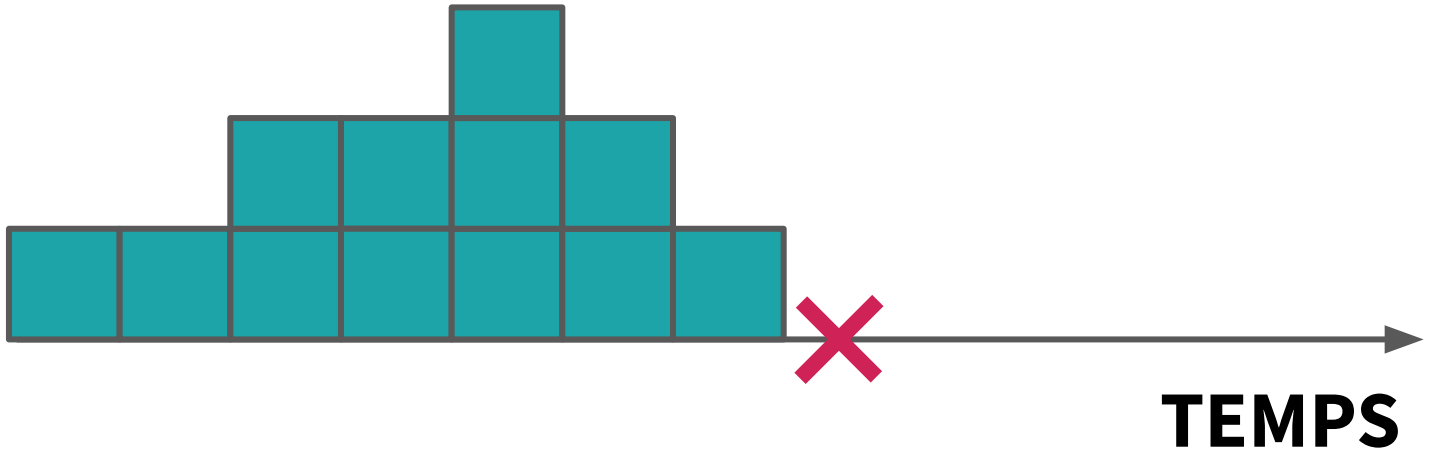
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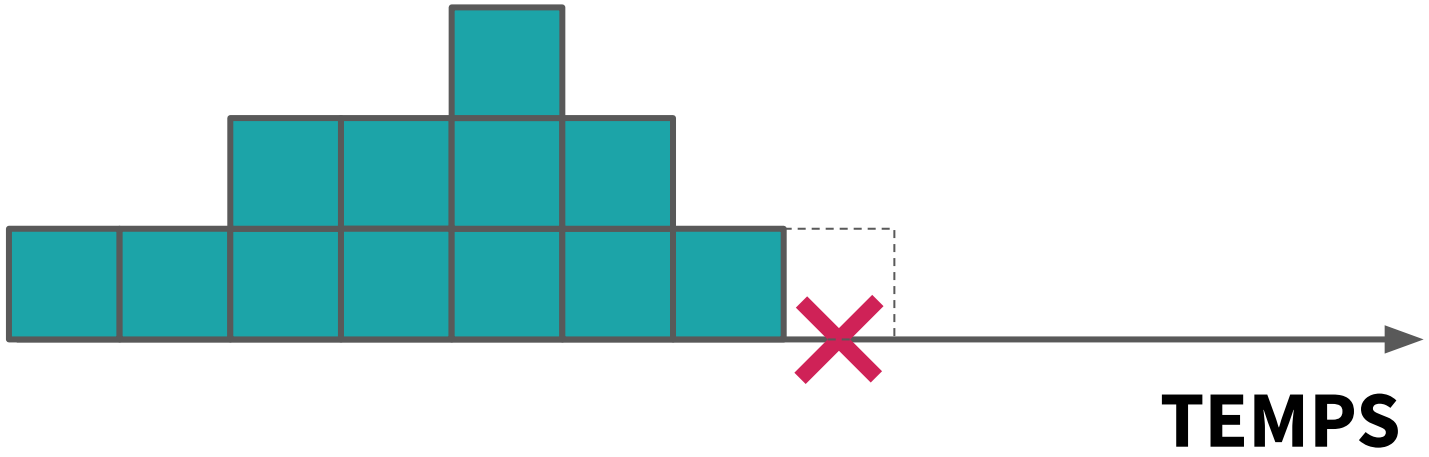
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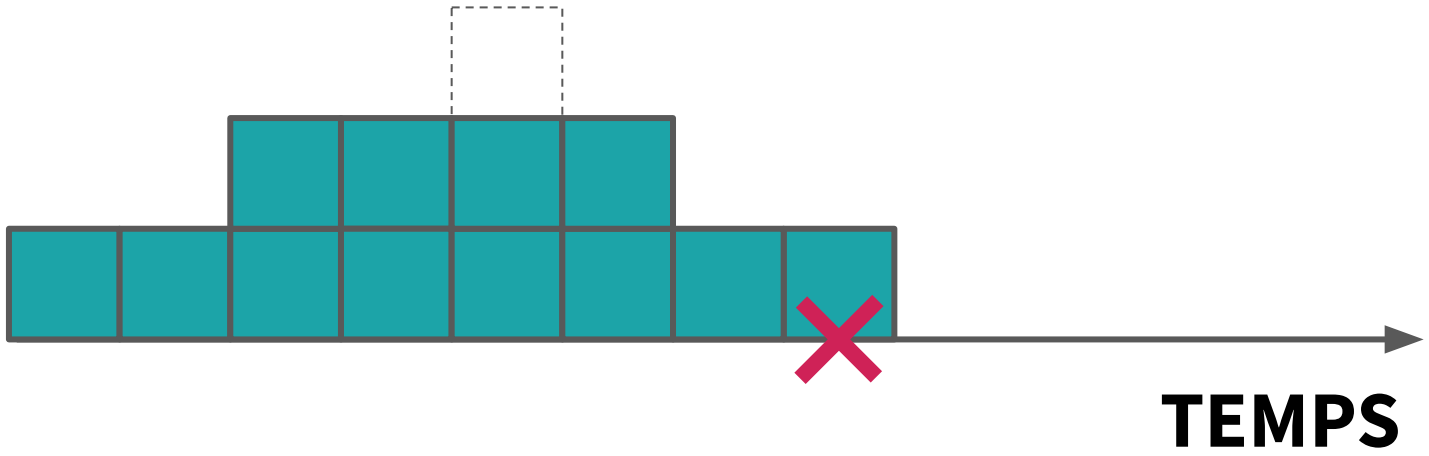
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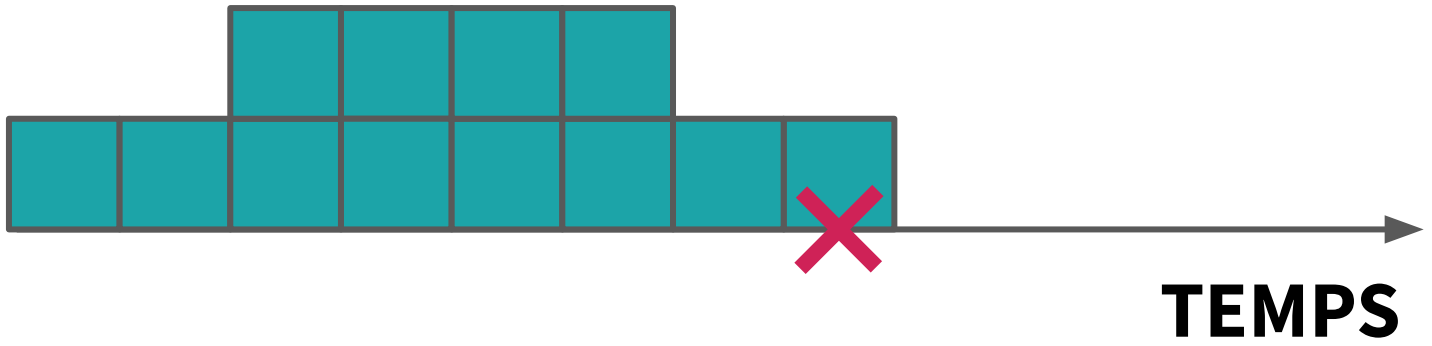
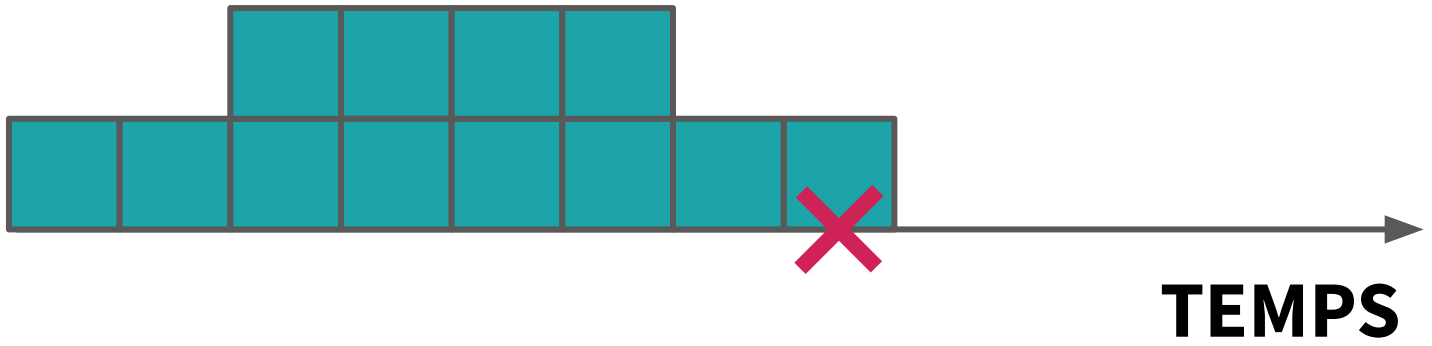
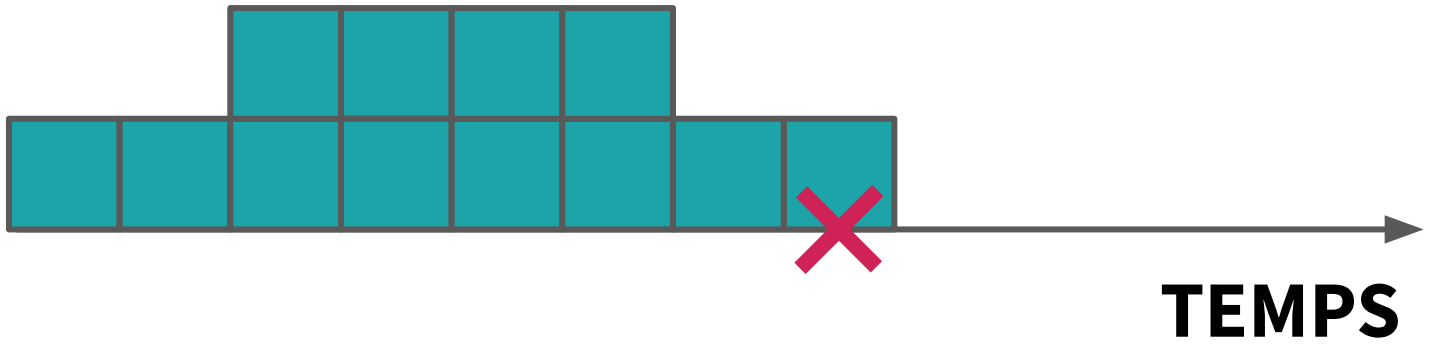
Rater une échéance !

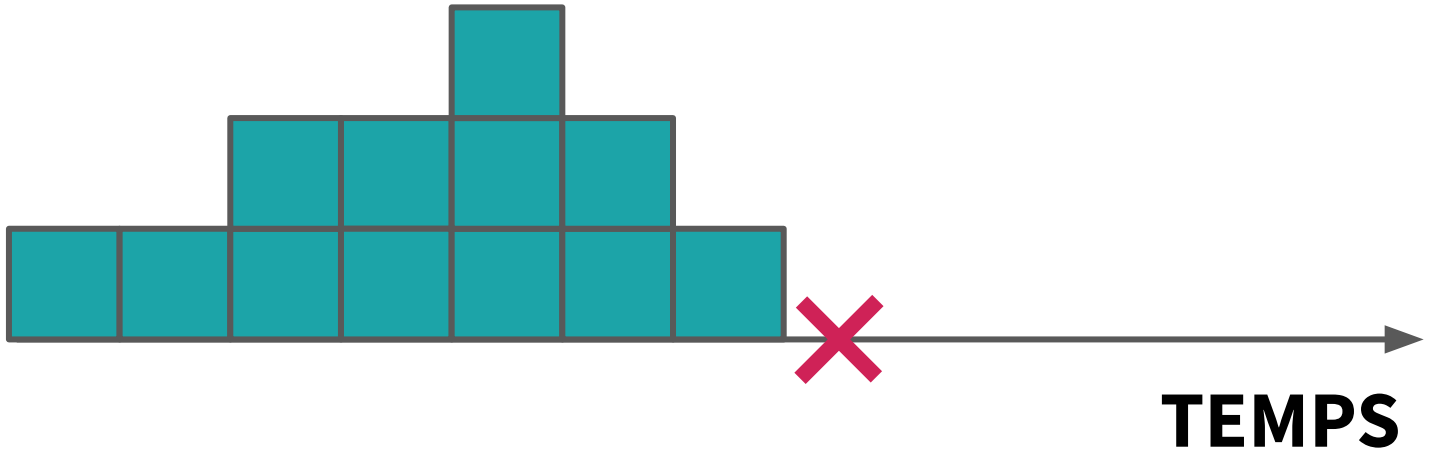


Rater une échéance ! → Conséquences dramatiques



Rater une échéance ! → Conséquences dramatiques

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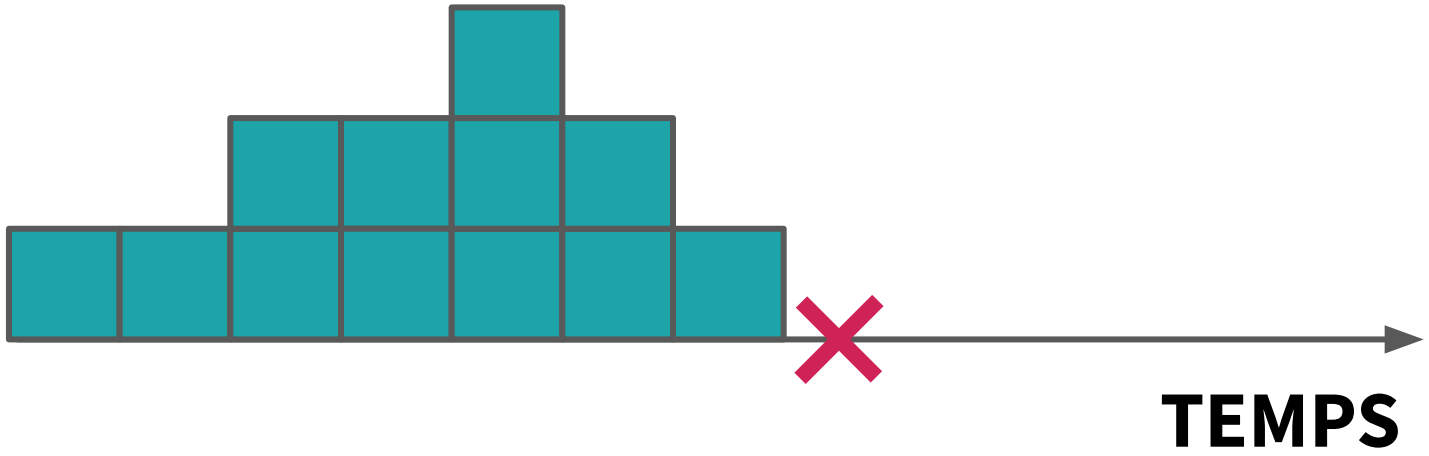
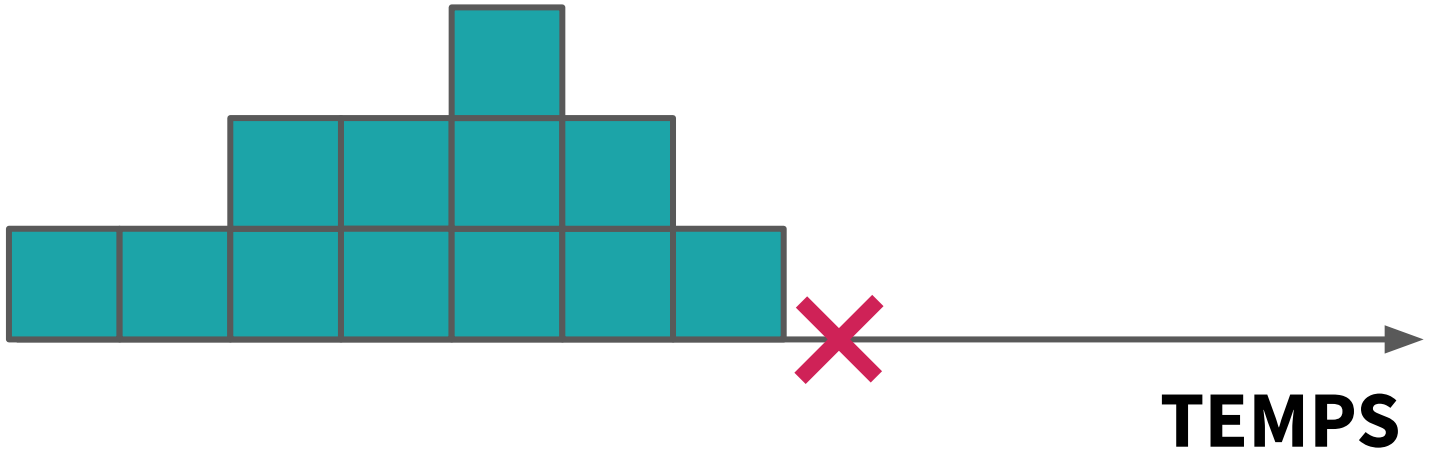
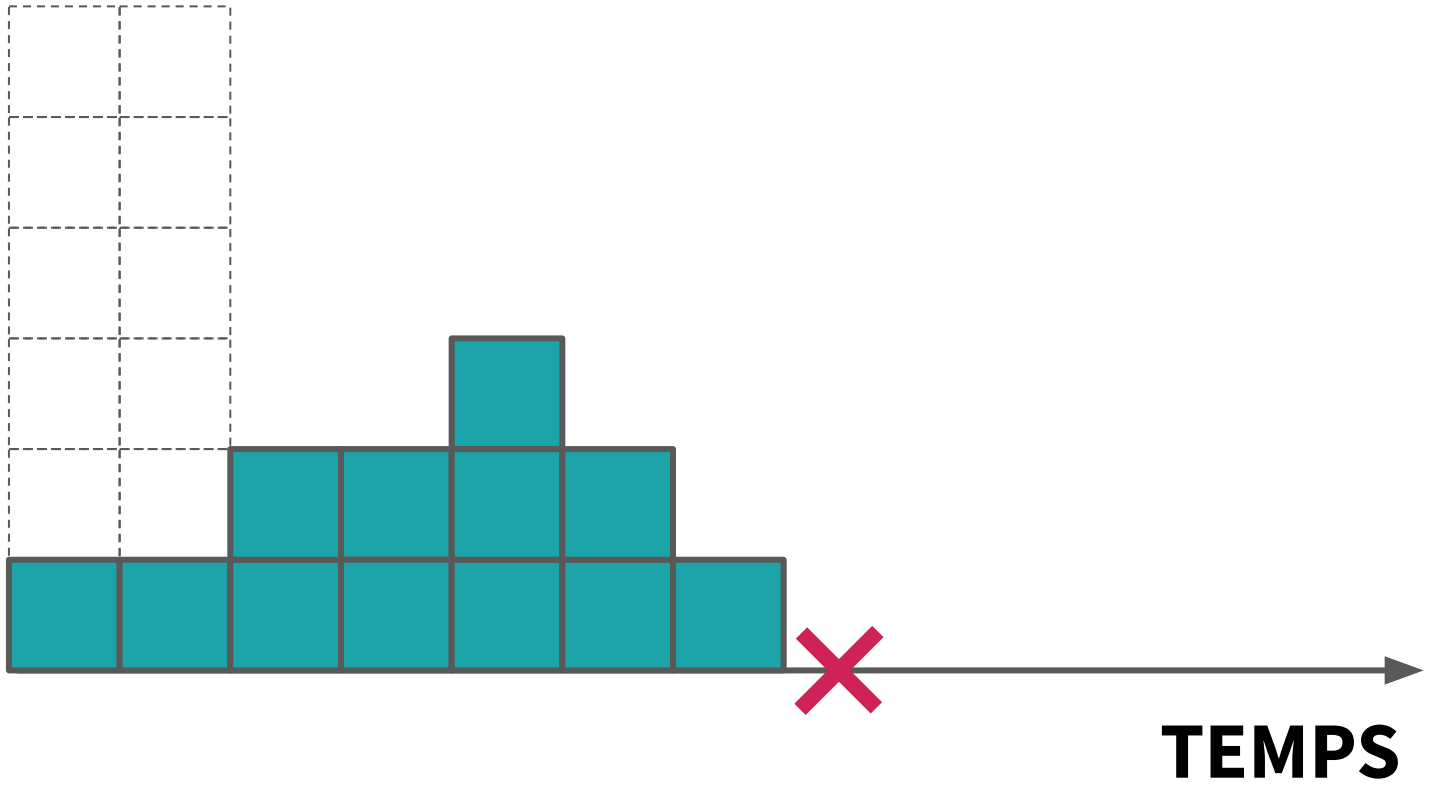
Energie dépensée avant l’échéance → tout ok.



Energie dépensée avant l’échéance → tout ok ?

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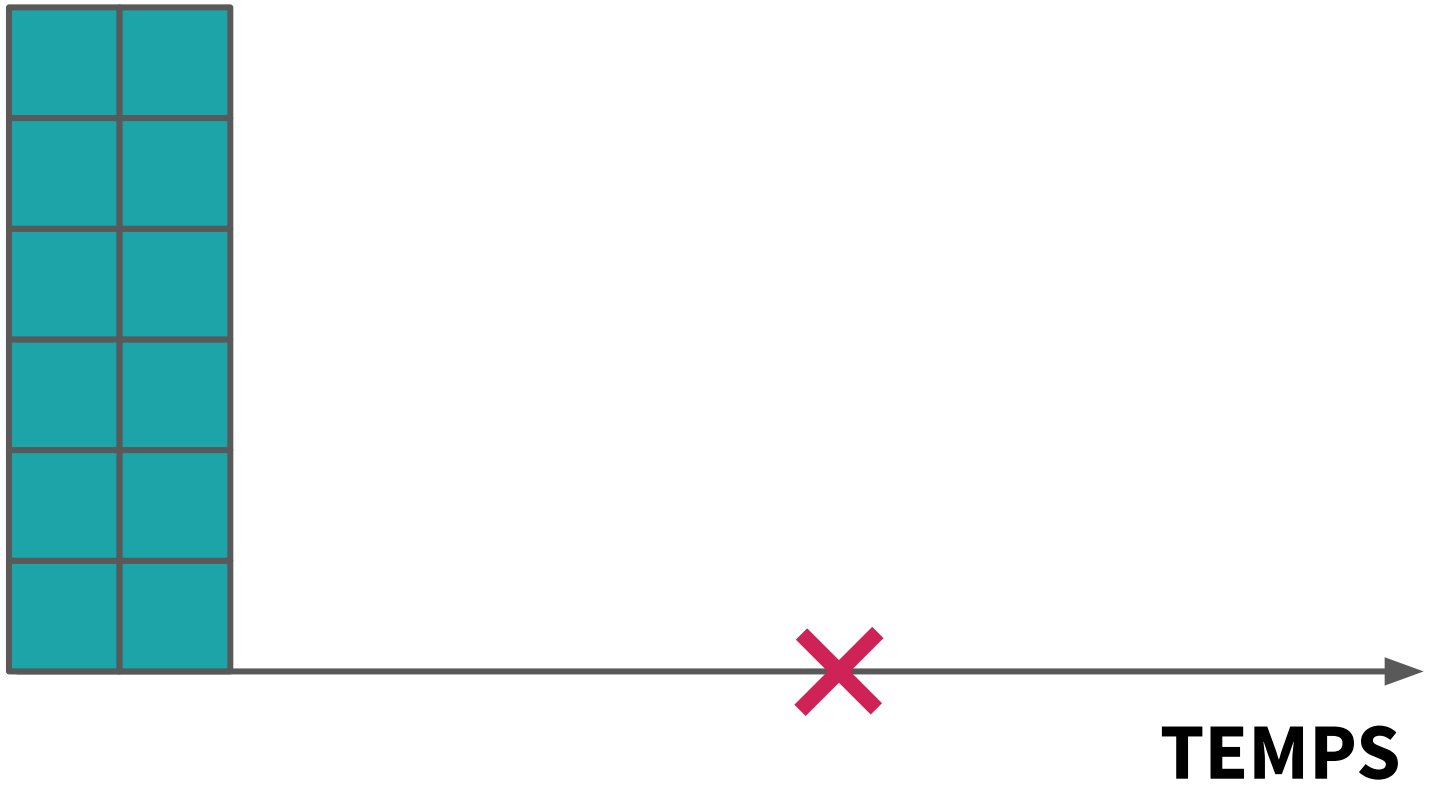
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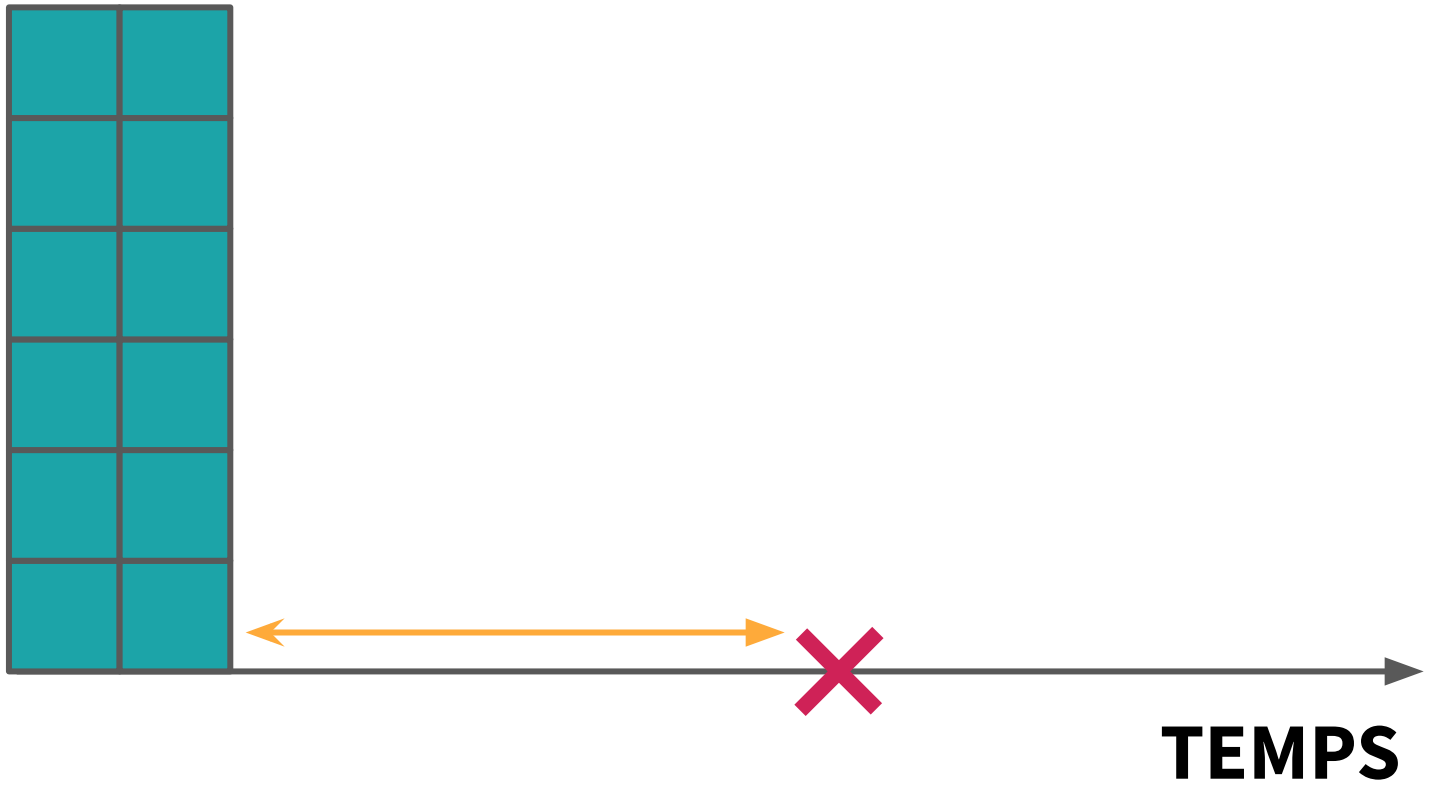
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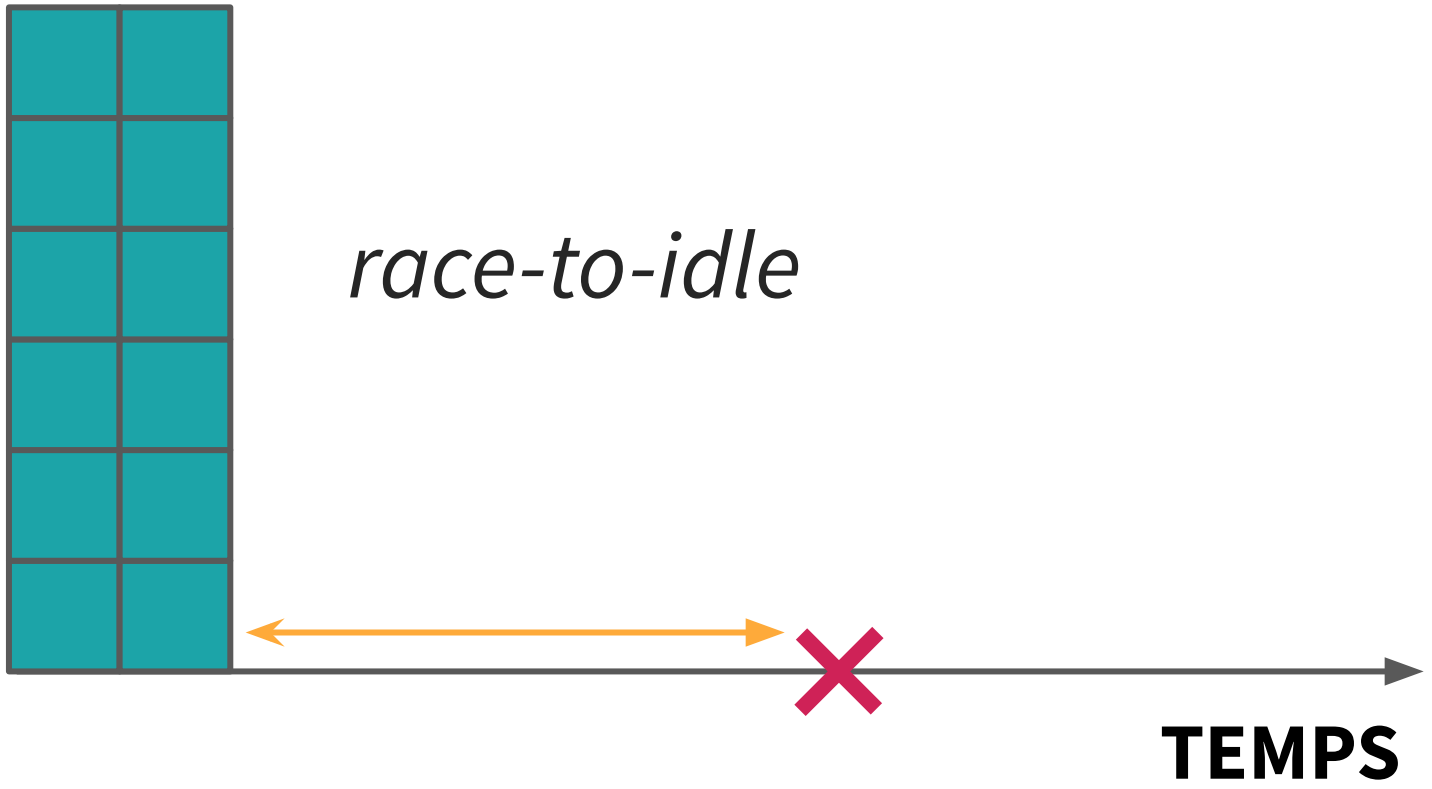
race-to-idle
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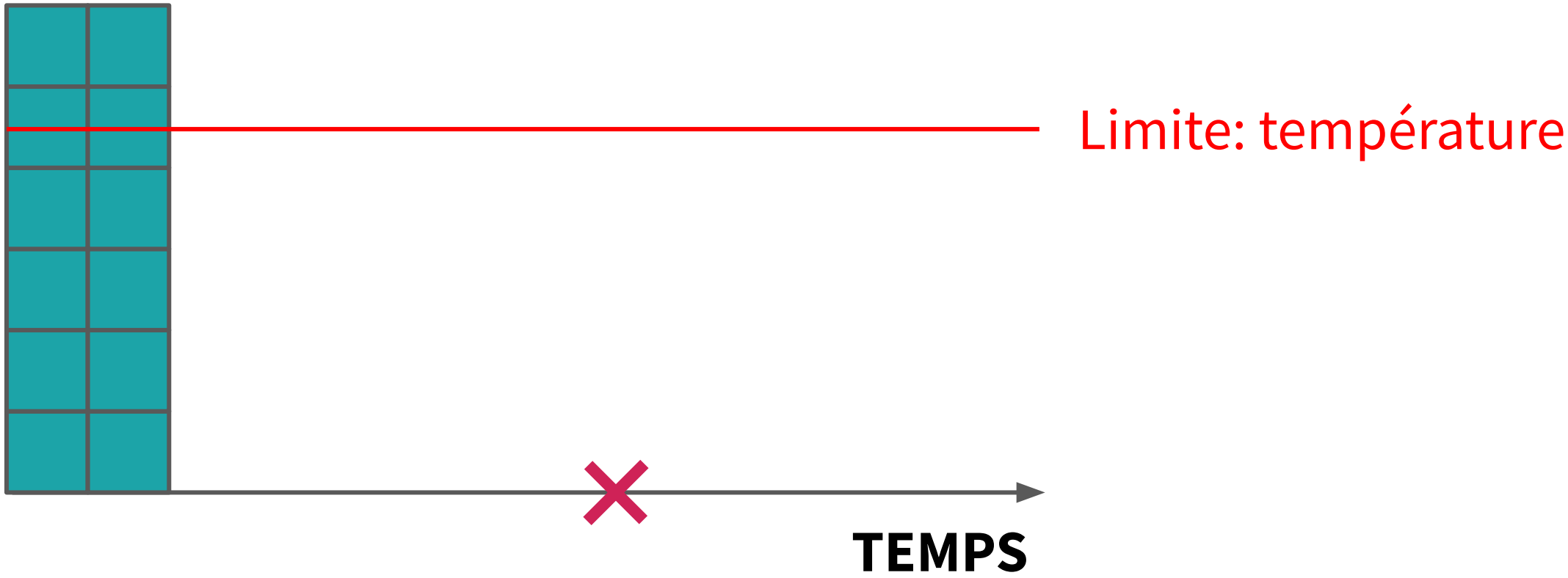
TEMPS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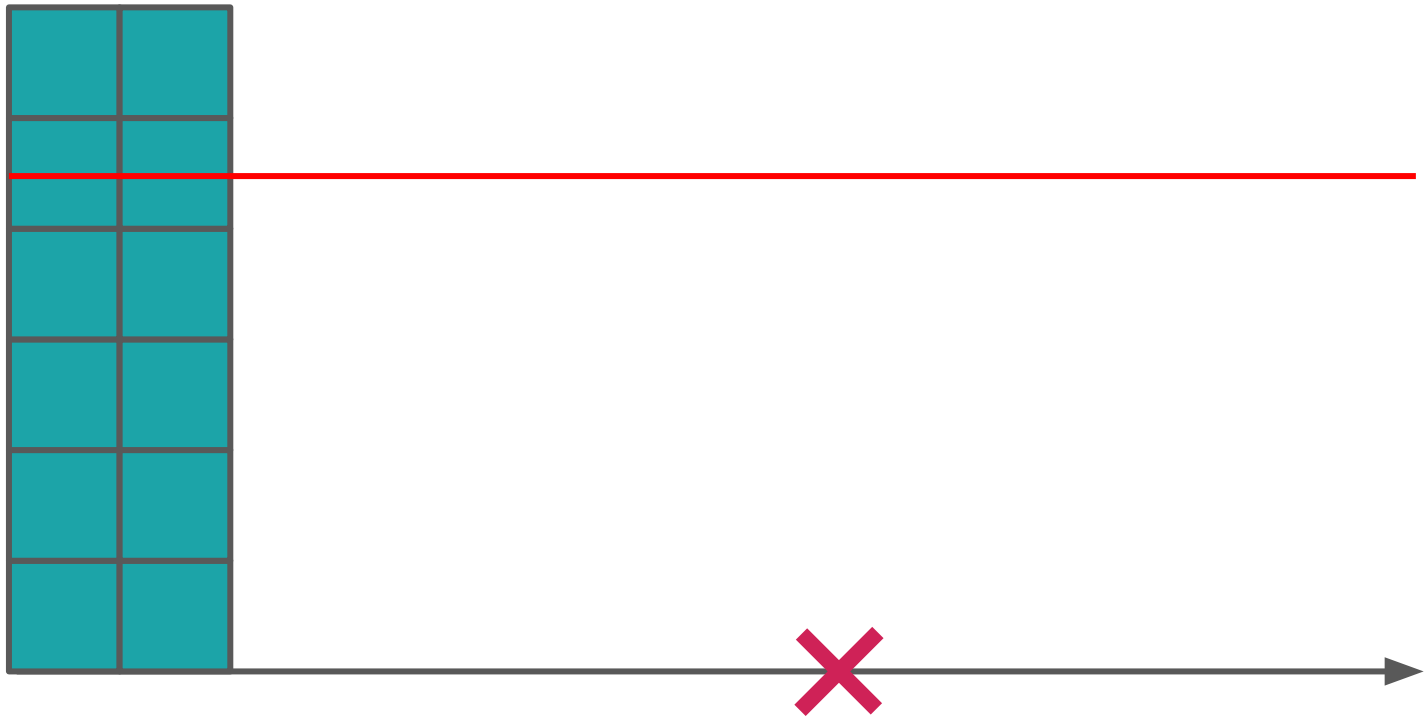
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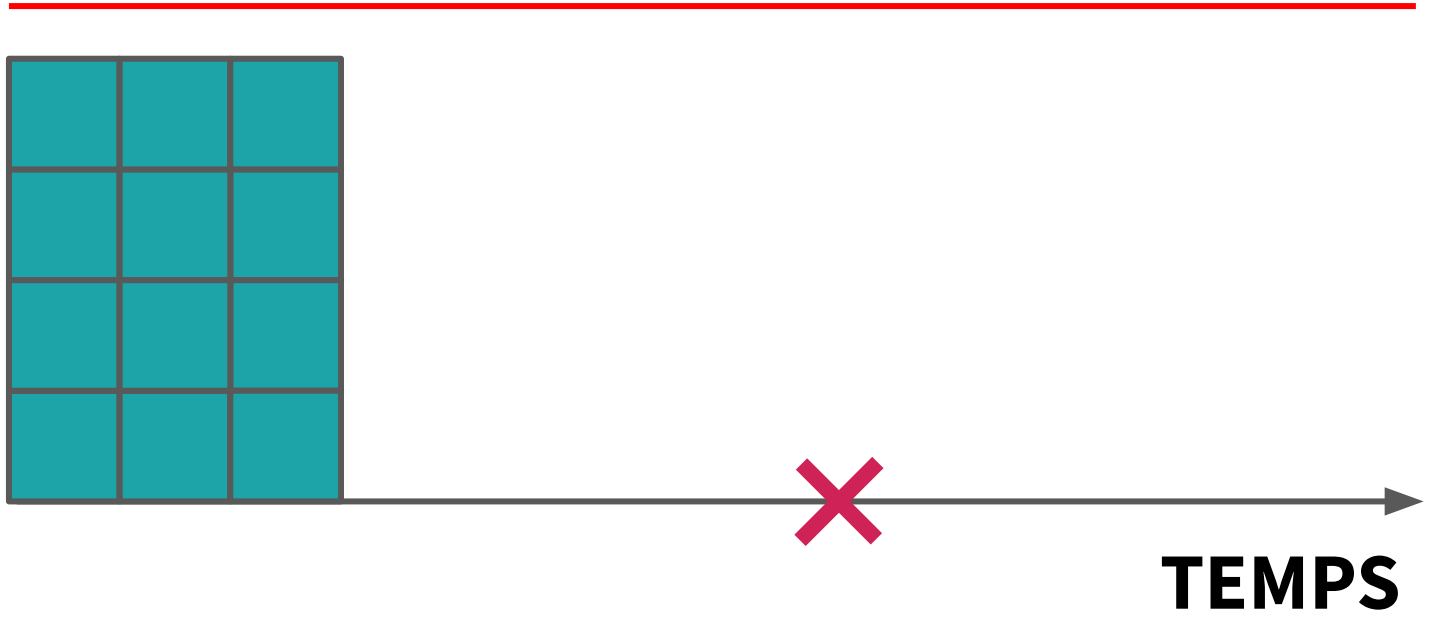
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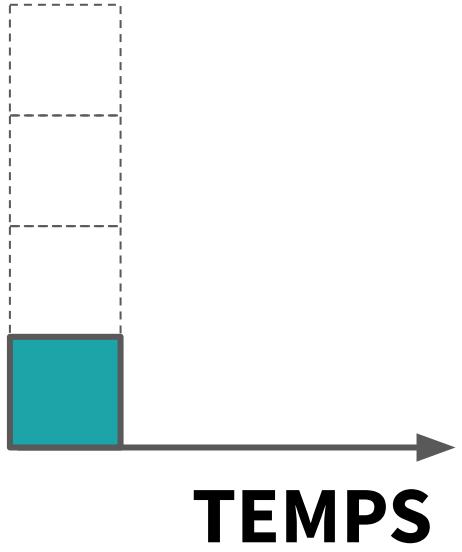
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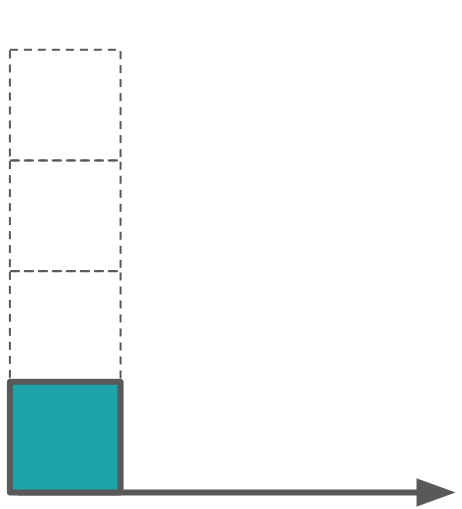

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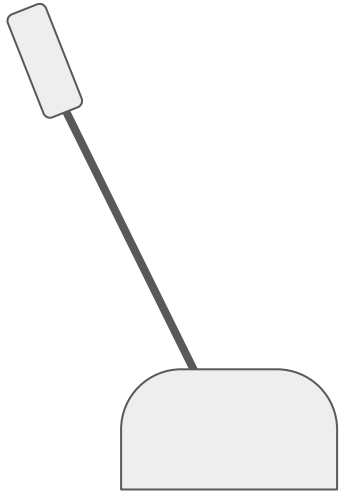

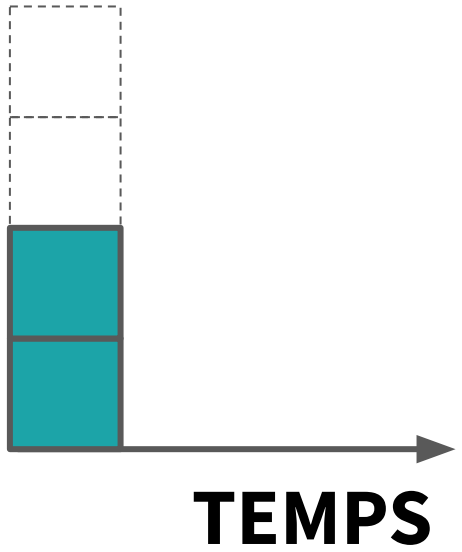
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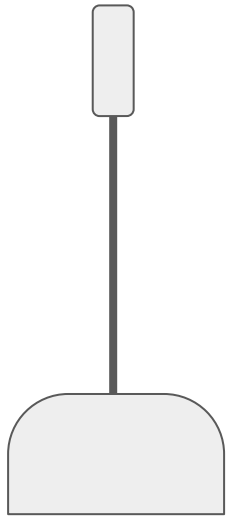

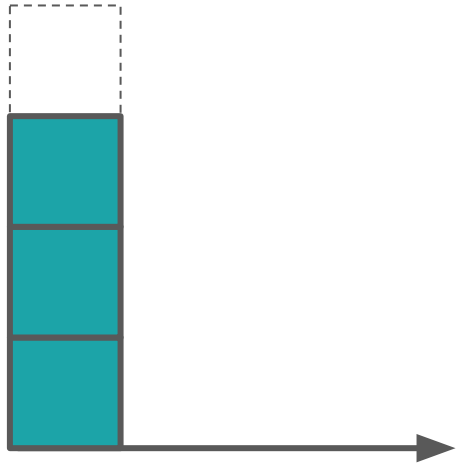

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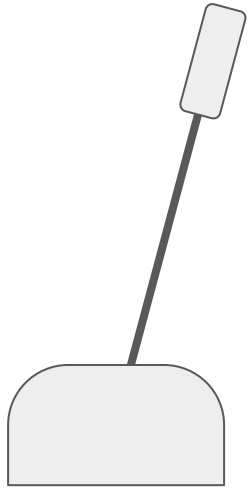

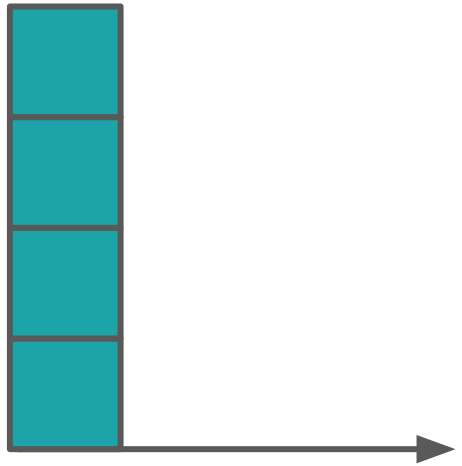

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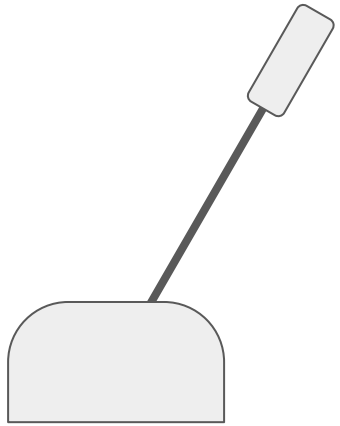

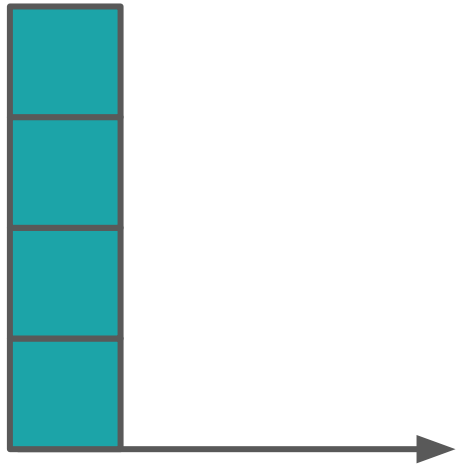

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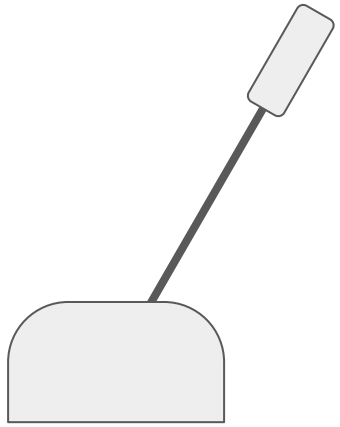
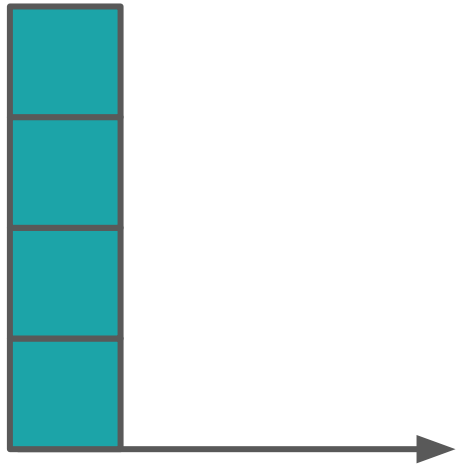


Vitesse



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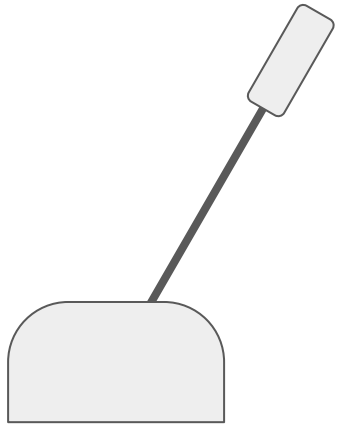
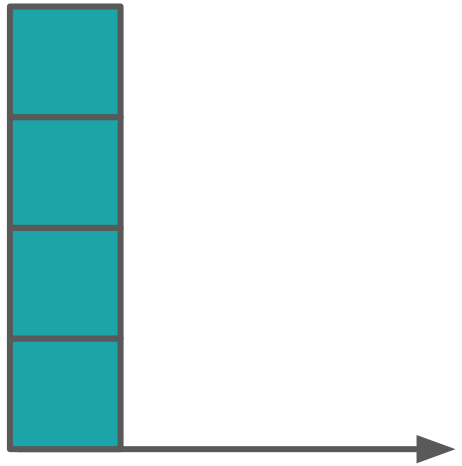


~~Vitesse~~

Fréquence



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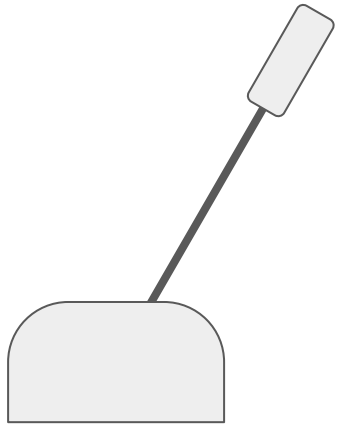
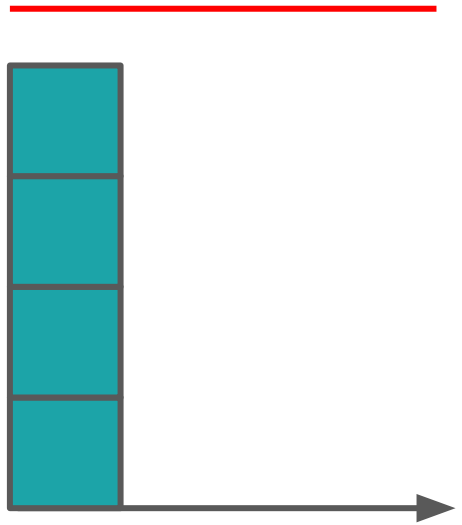
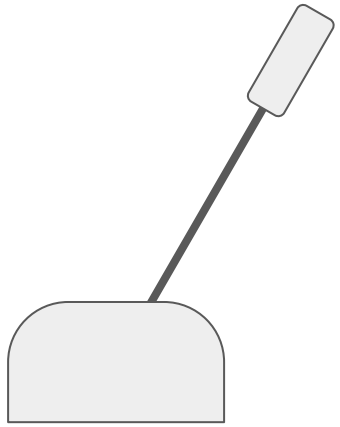


~~Vitesse~~

Fréquence
(MHz, GHz, etc.)





~~Vitesse~~

Fréquence
(MHz, GHz, etc.)

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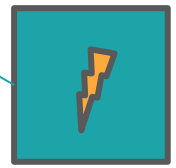
Coût



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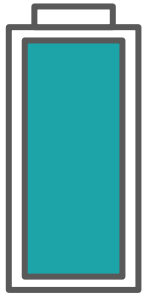

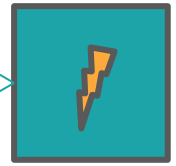

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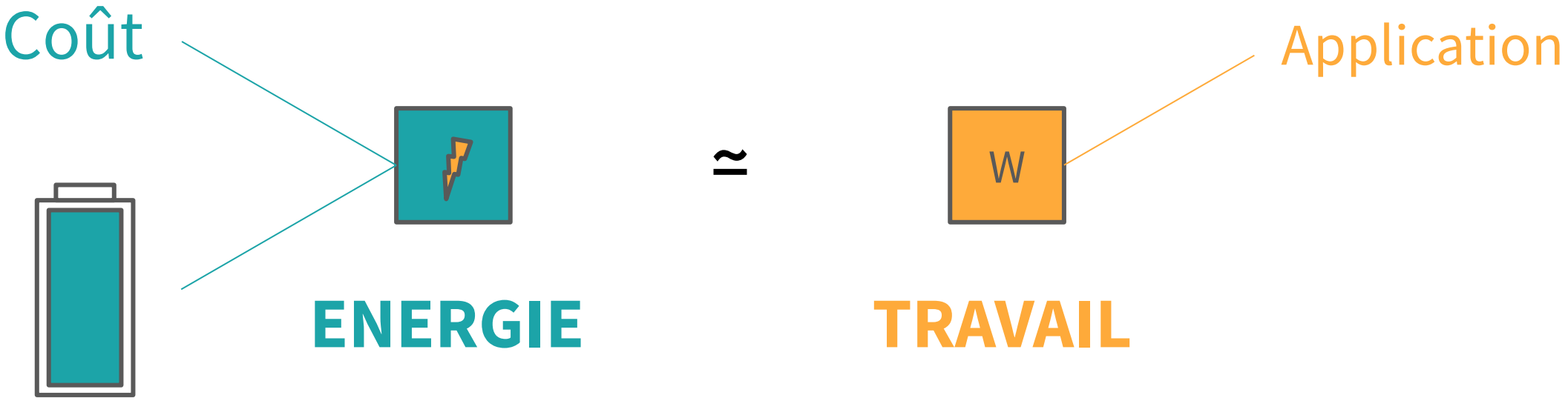
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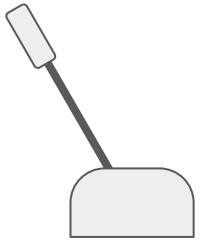

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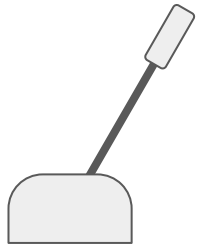

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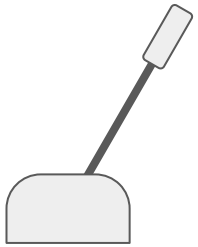

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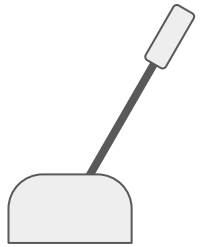

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ENERGIE **TRAVAIL**

Exemple

Objectif

Objectif

- Exécuter 10 unités de travail

Objectif

- Exécuter 10 unités de travail

Objectif

- Exécuter 10 unités de travail

- En 7 secondes

Objectif

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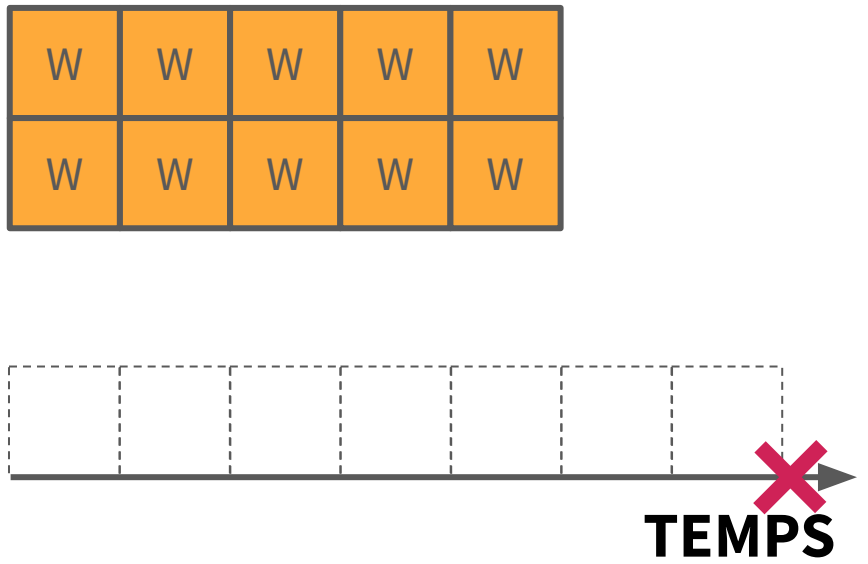
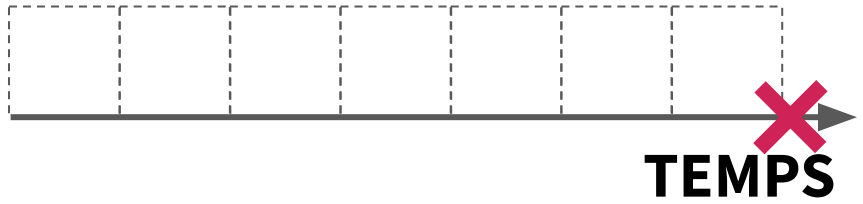


Objectif

- Exécuter 10 unités de travail

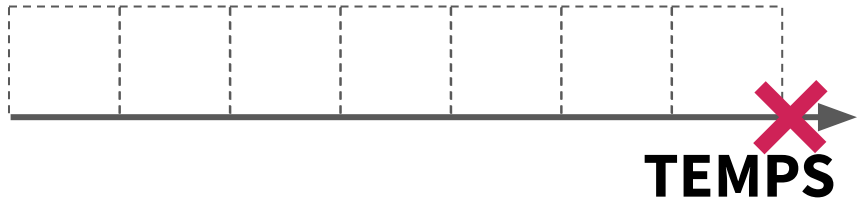
- En 7 secondes

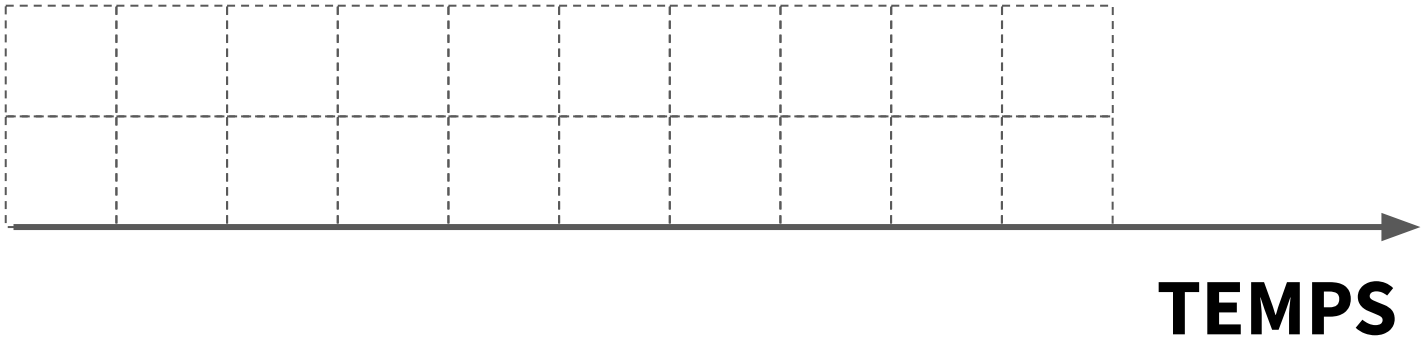


- En minimisant l’énergie consommée

Objectif

- Exécuter 10 unités de travail
- En 7 secondes
- En minimisant l’énergie consommée

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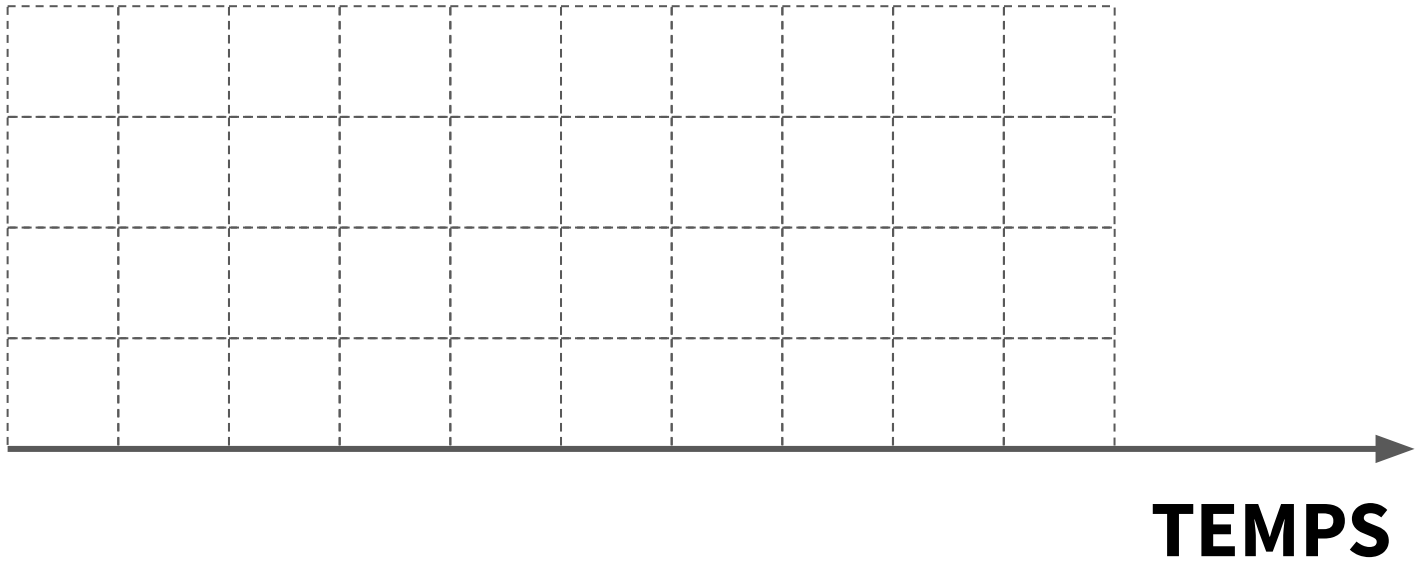
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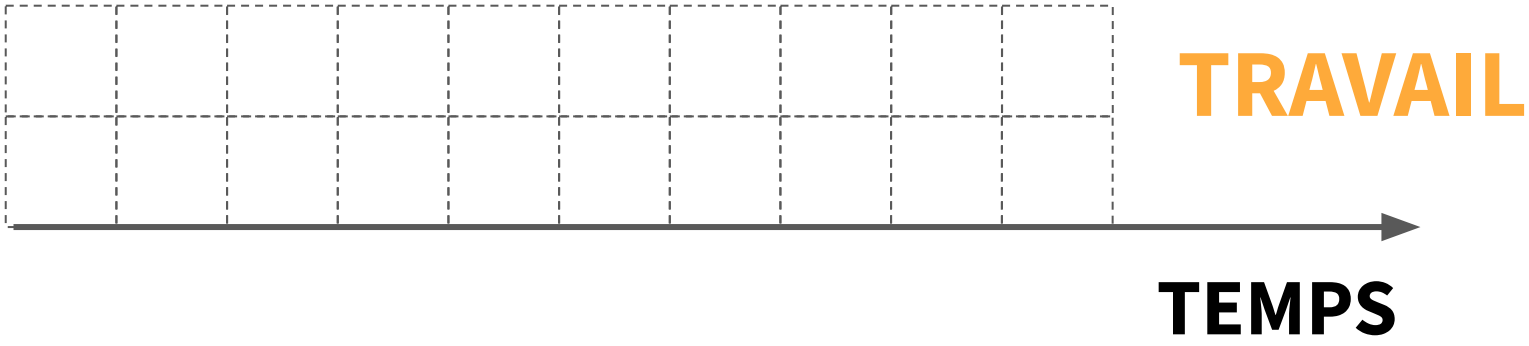
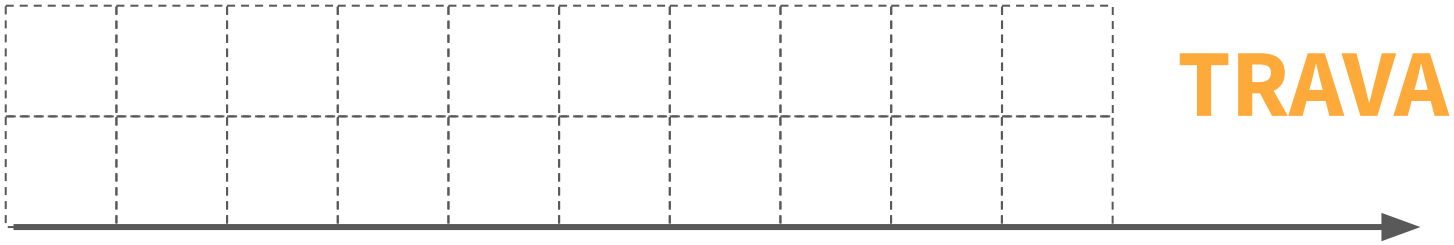

TRAVAIL
TEMPS


TEMPS



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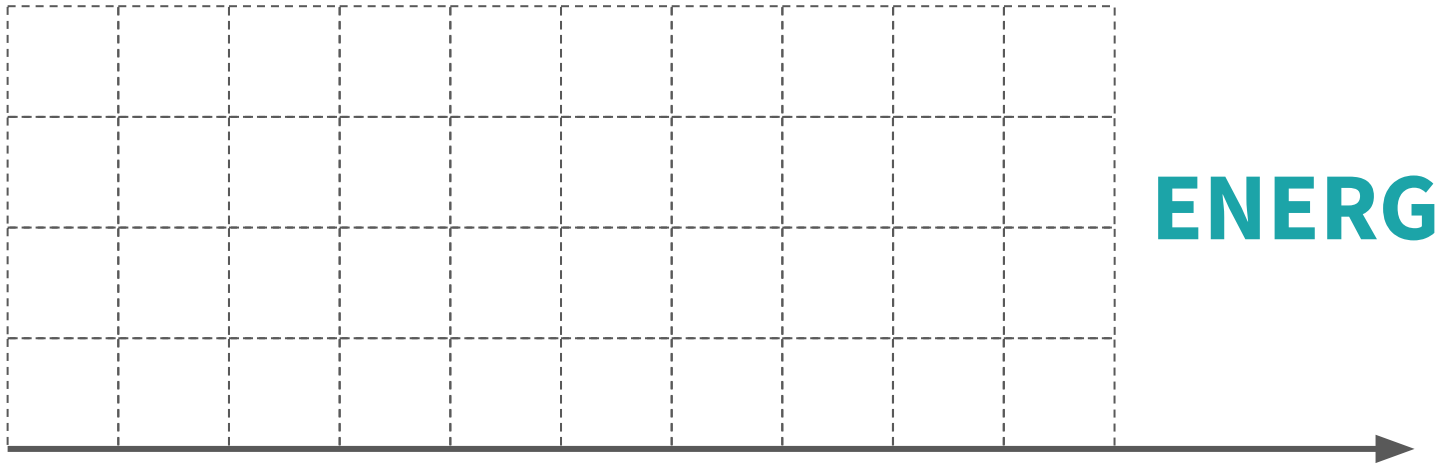

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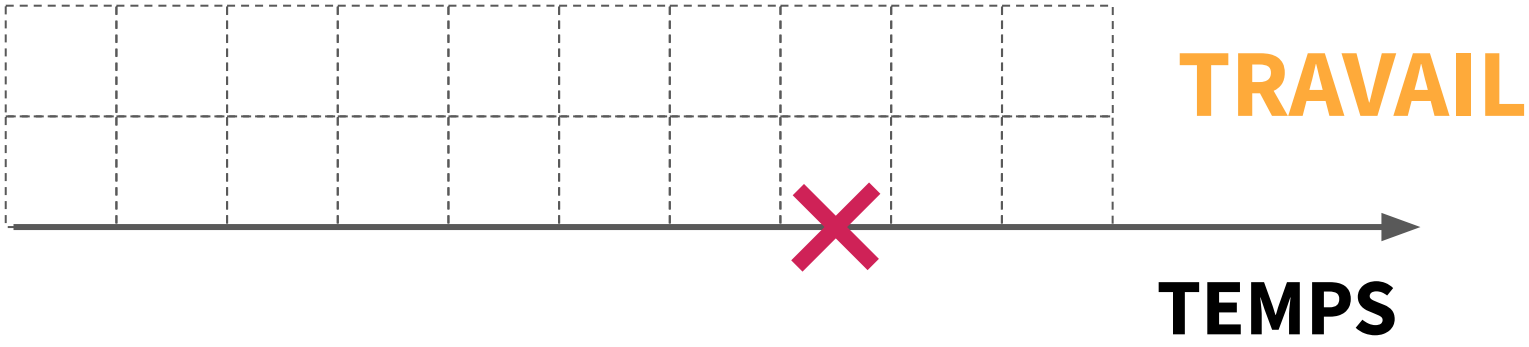
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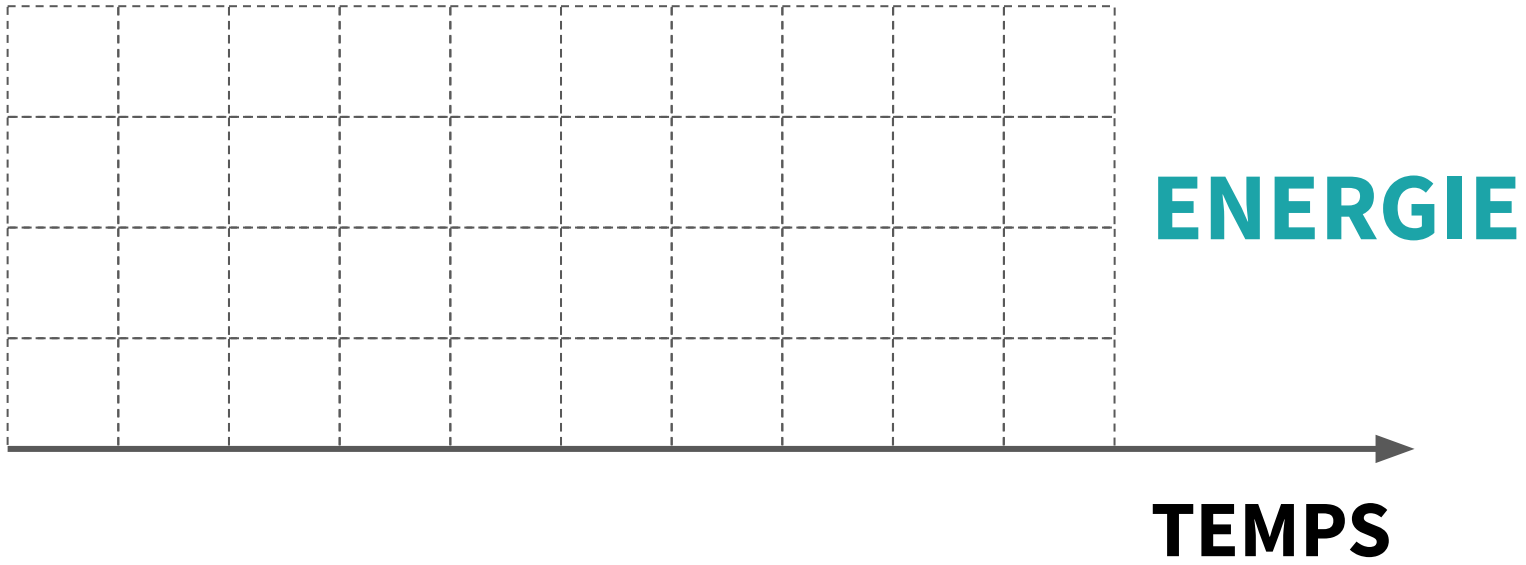
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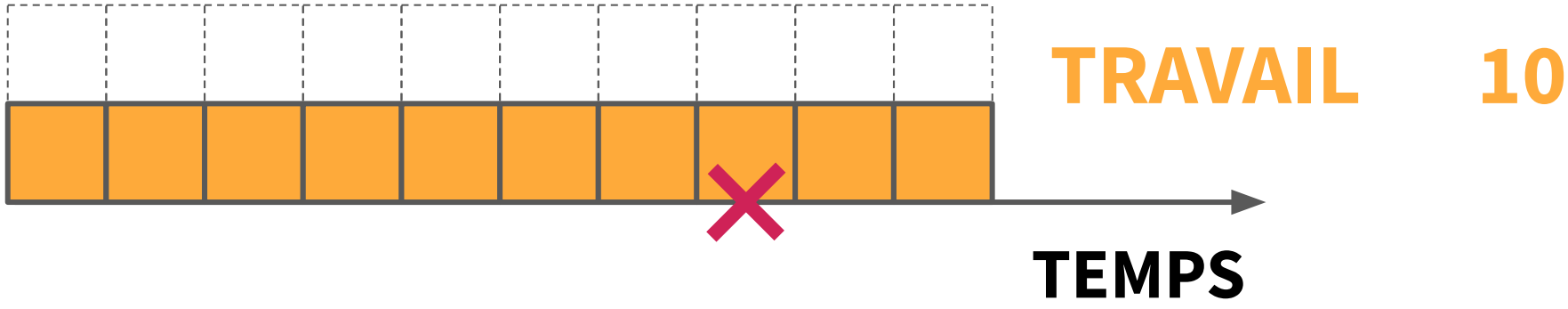
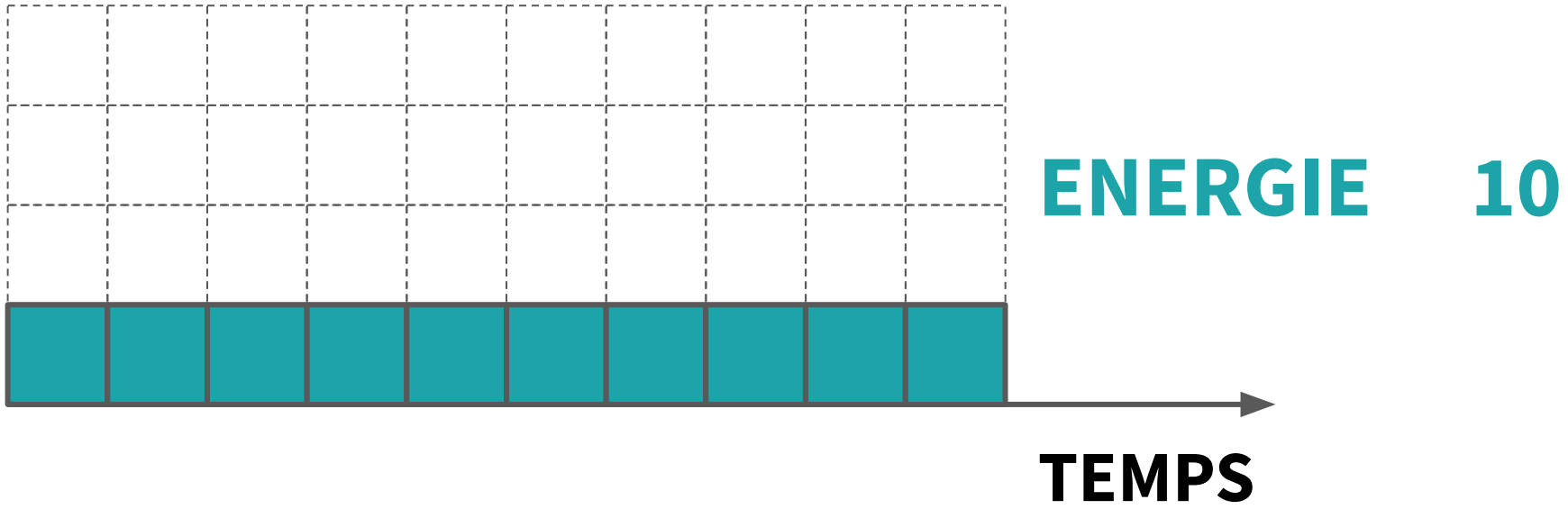
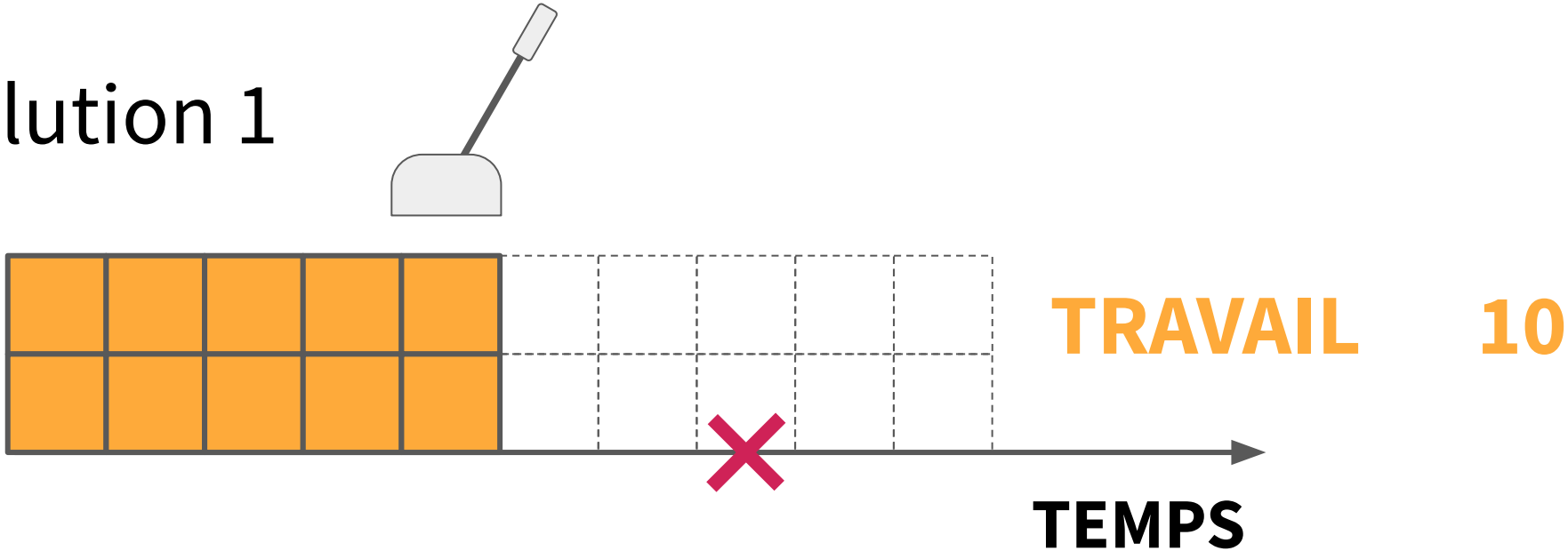
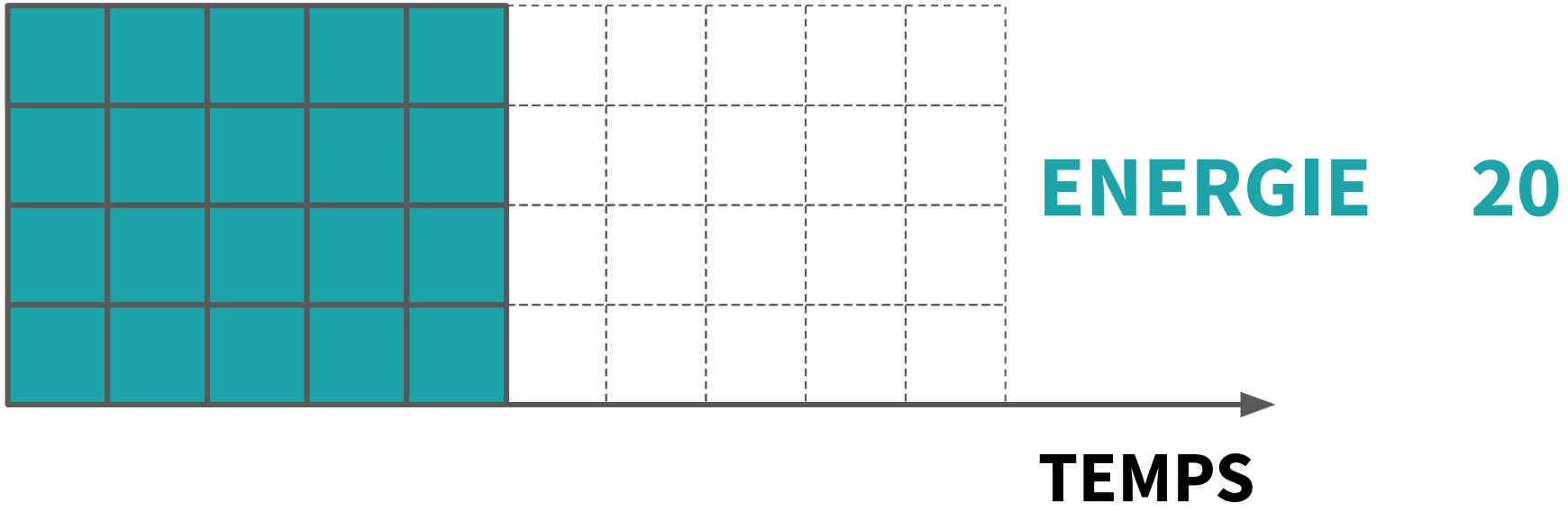
Solution 0



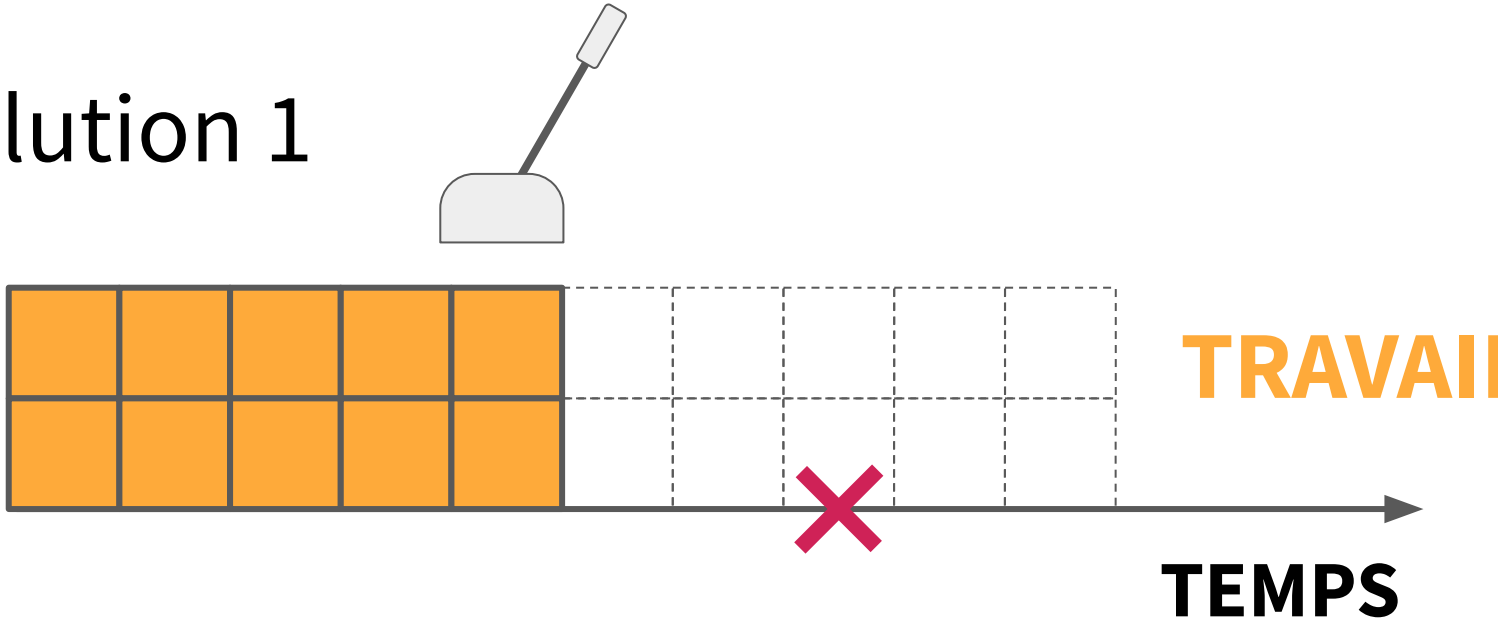


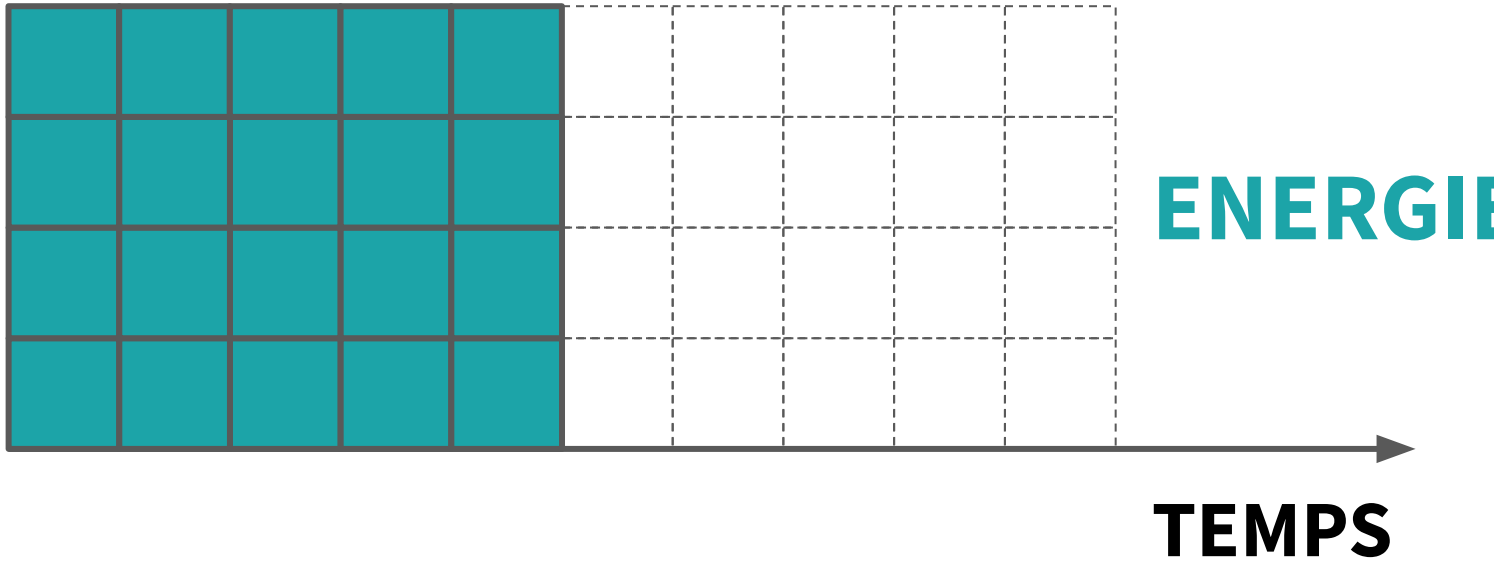
Solution 1





Solution 1





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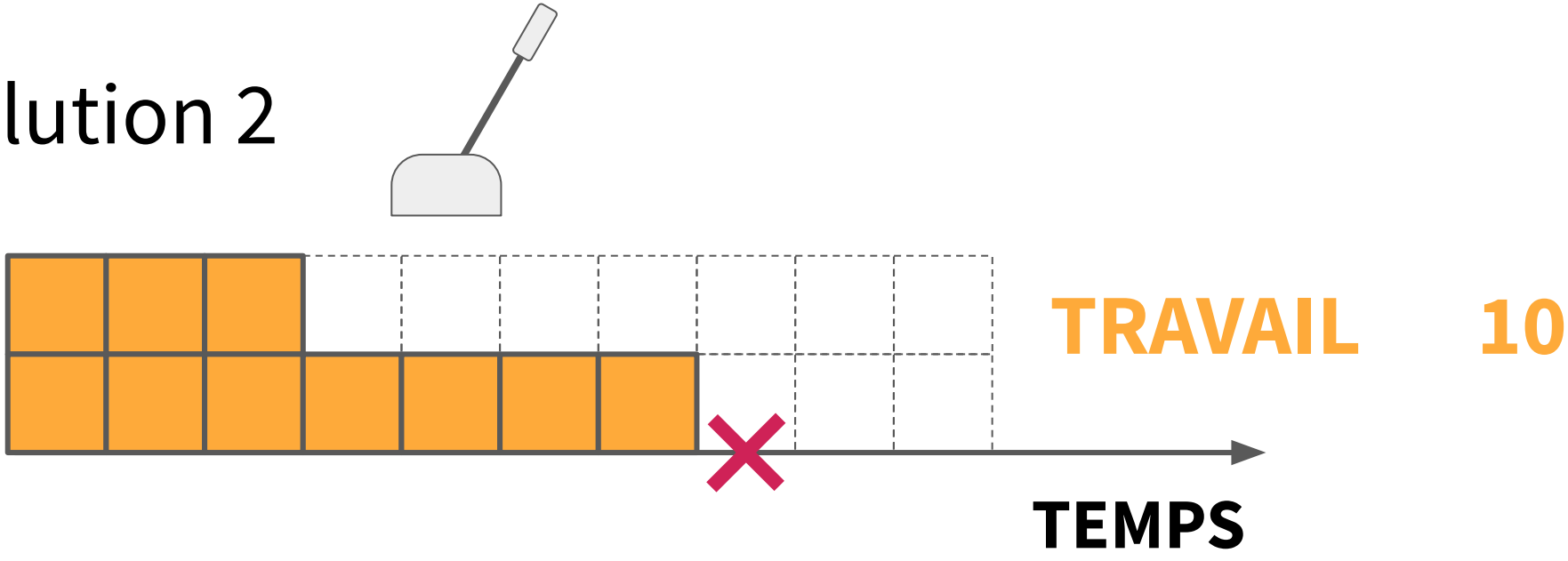

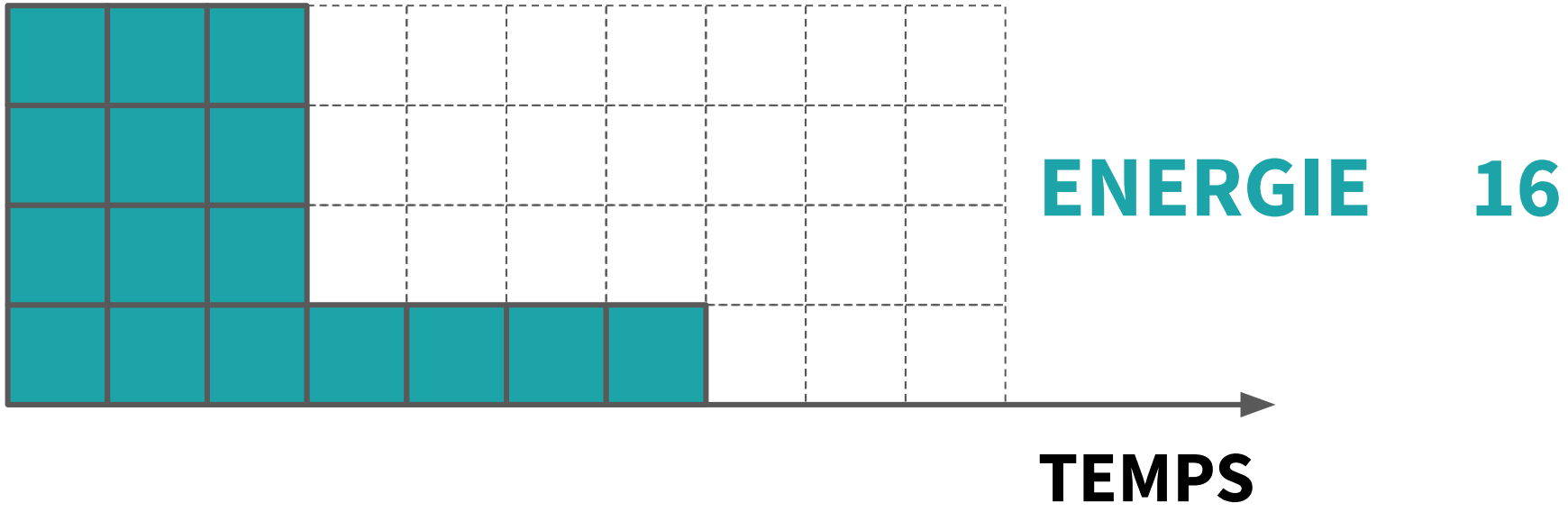

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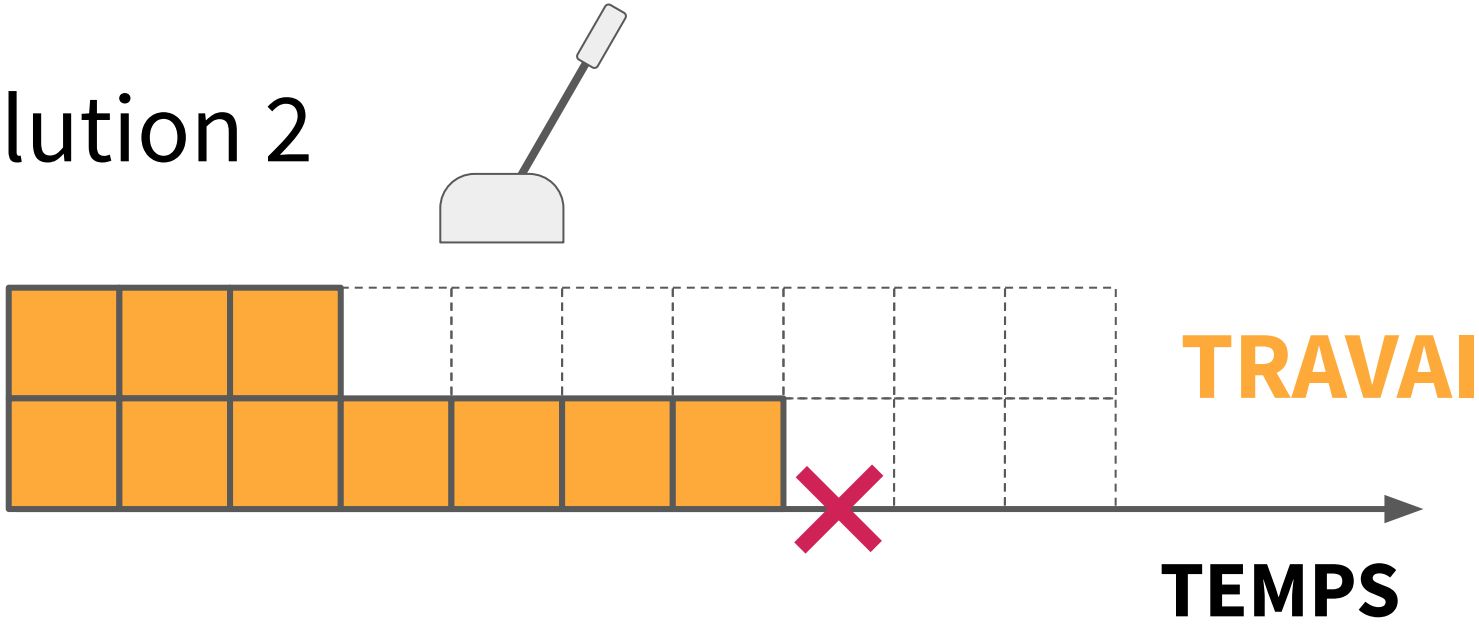
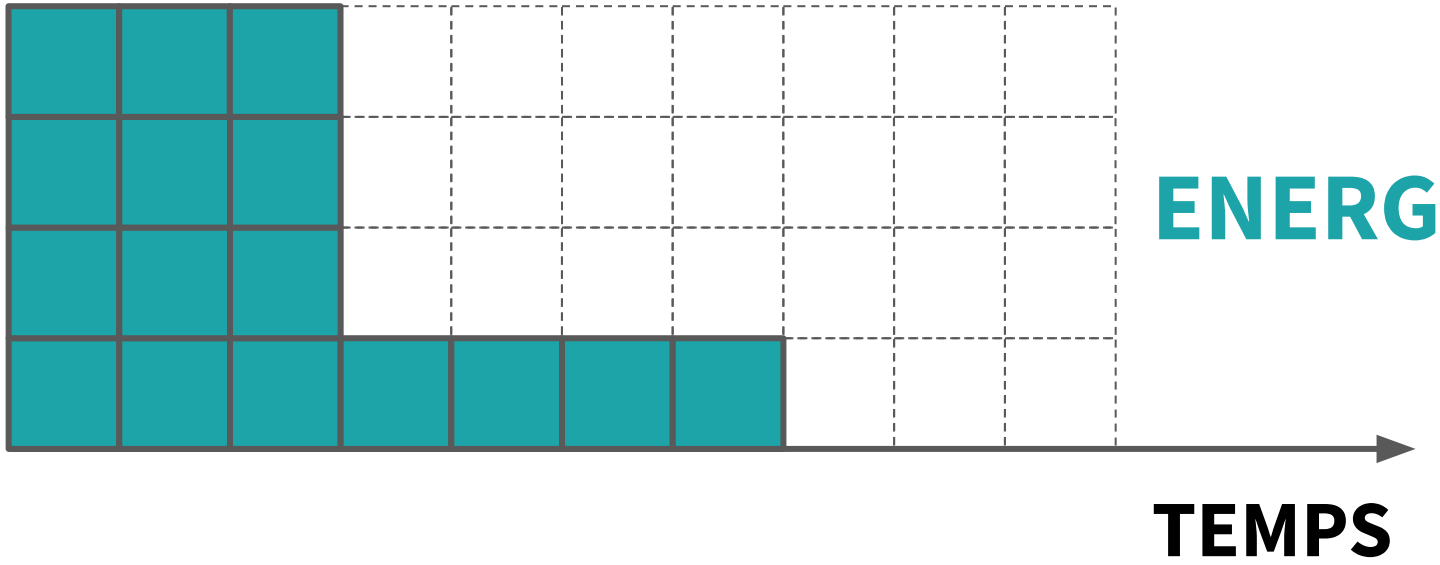
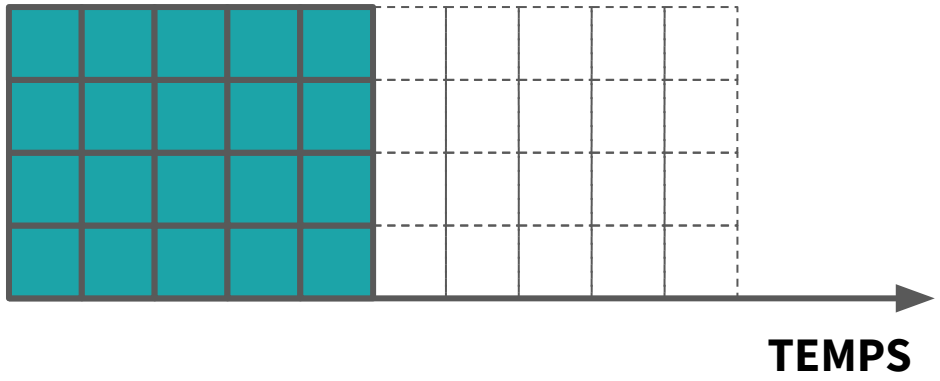




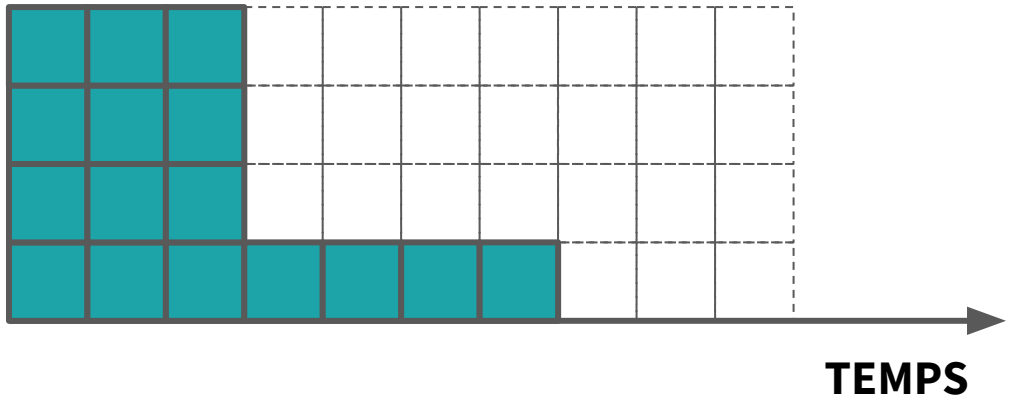
Solutions 1 et 2, facteur quadratique

1



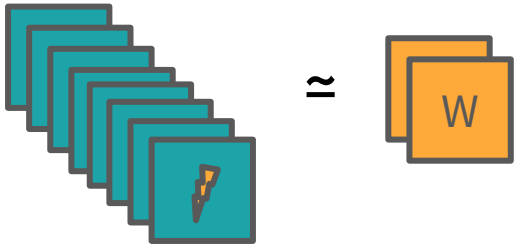
ENERGIE 20 (x2 !)

2



ENERGIE 16 (-20%)

Solutions 1 et 2, facteur cubique



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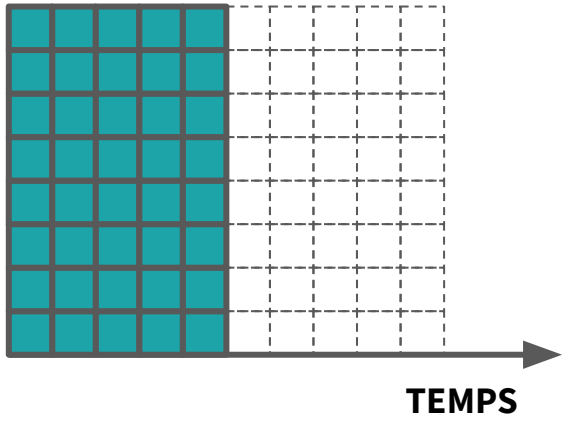
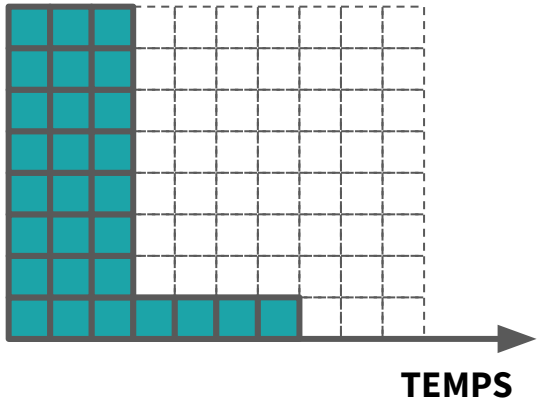
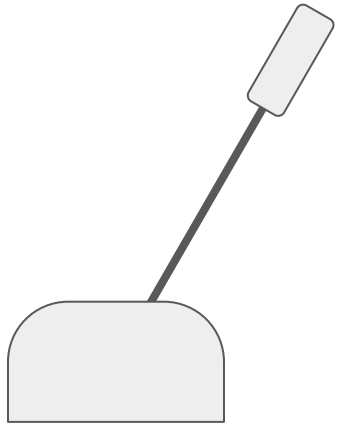


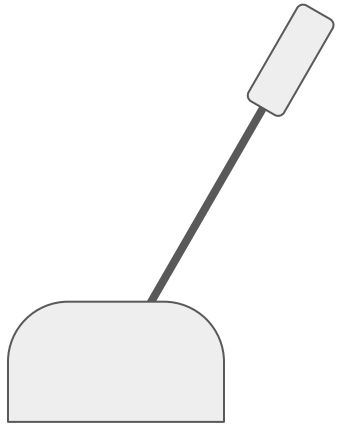
ENERGIE 40 (x4 !)

2

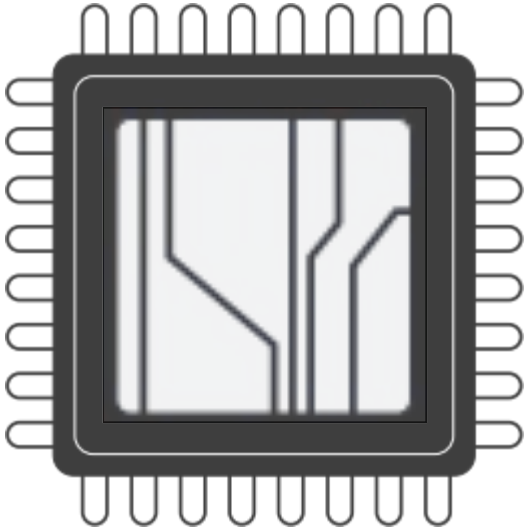


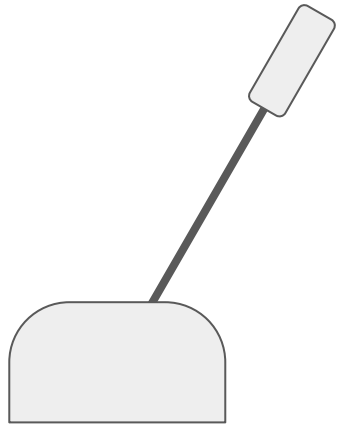
ENERGIE 28 (-30%)

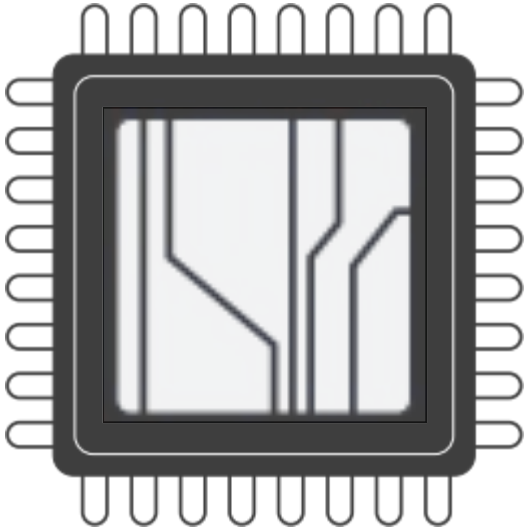





ANDROID







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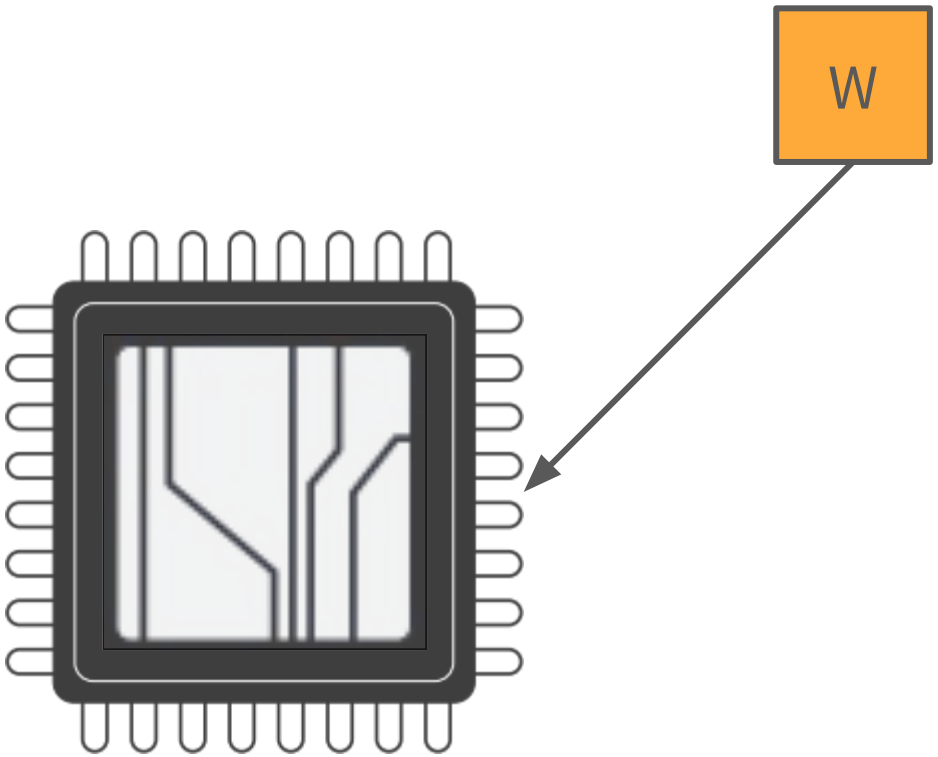
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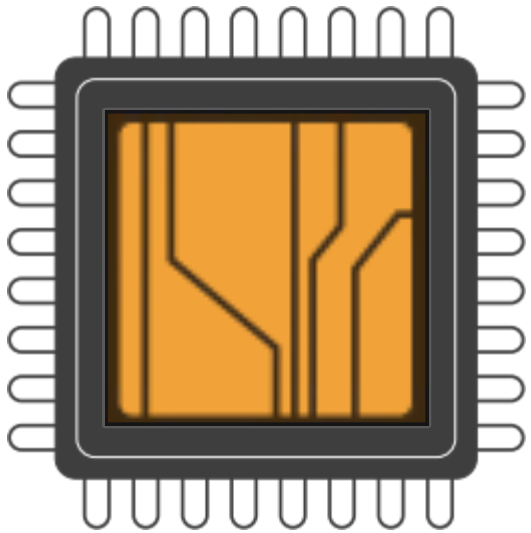

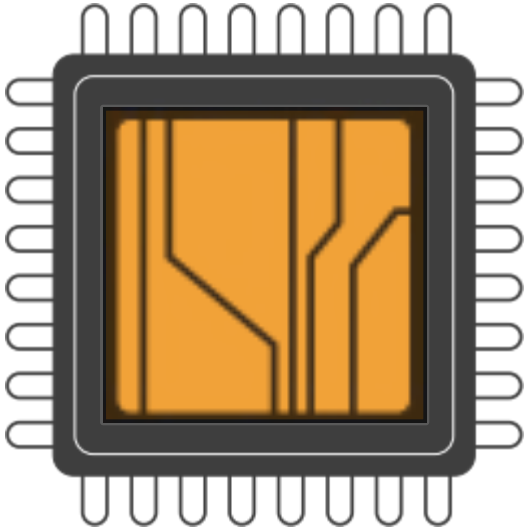

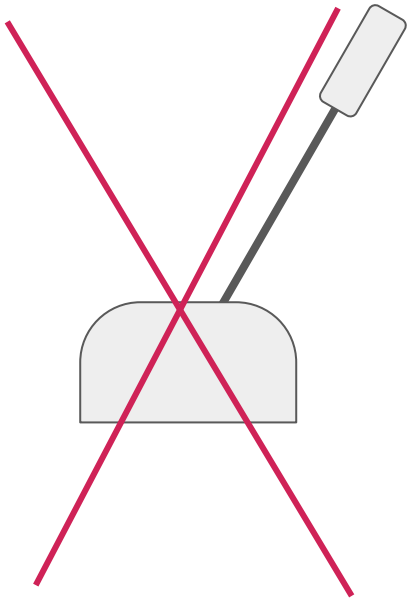

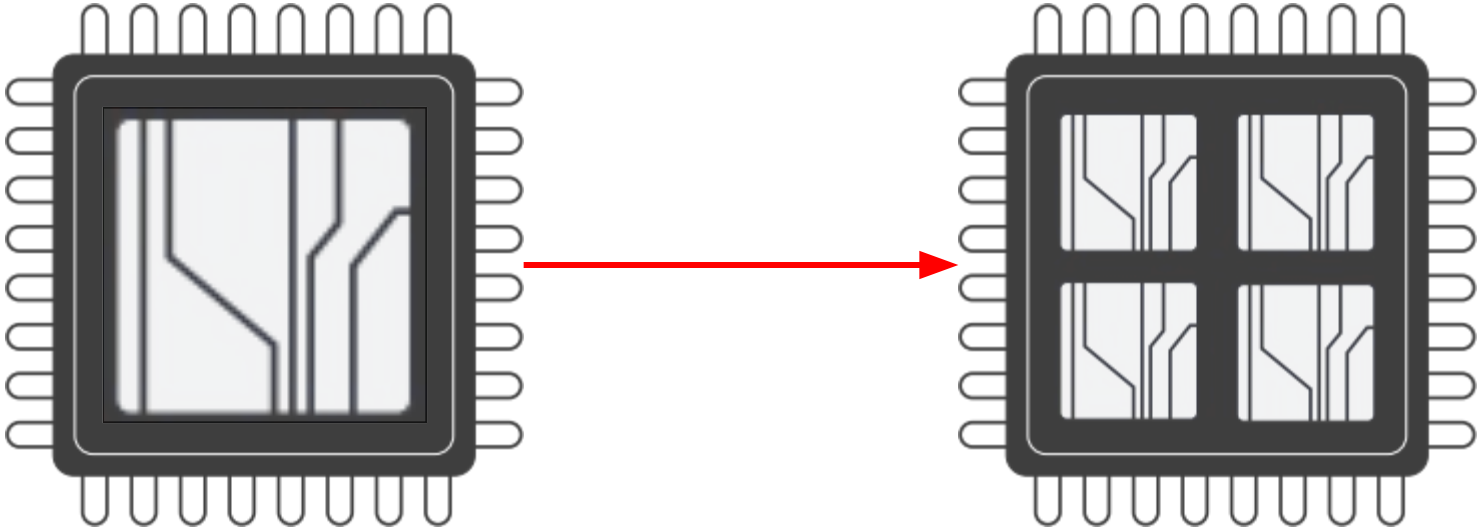

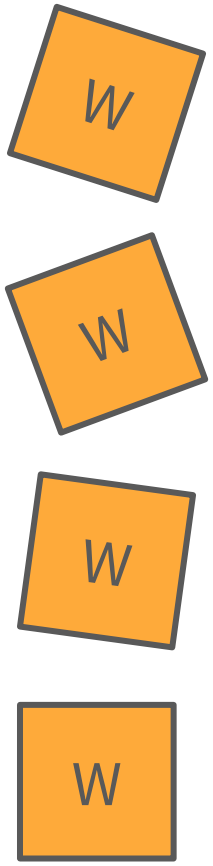
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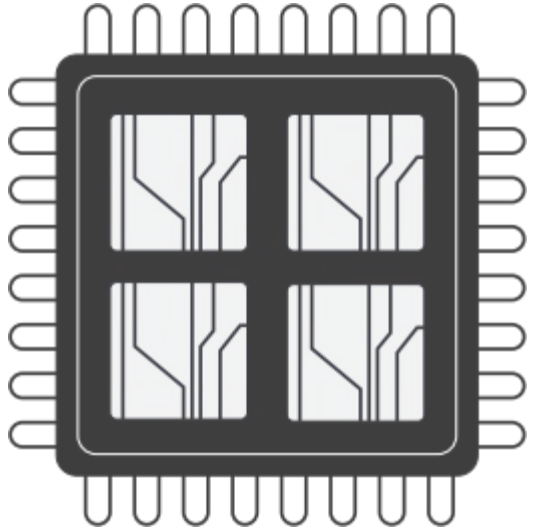

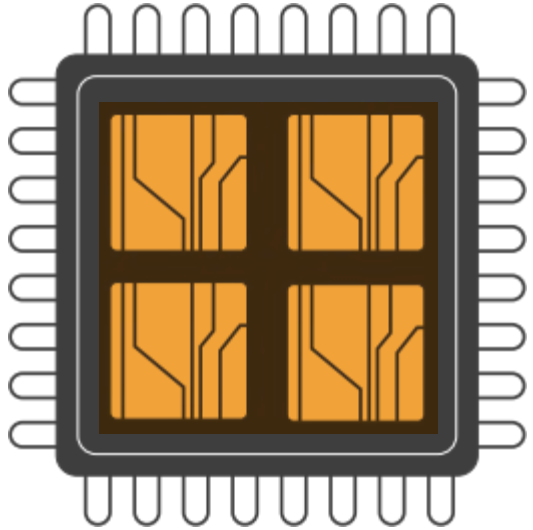

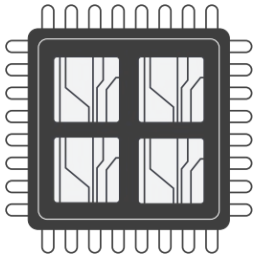

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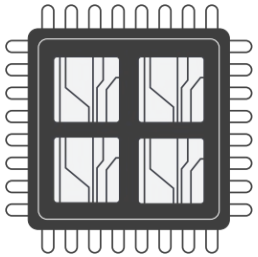
ENERGIE **TRAVAIL**



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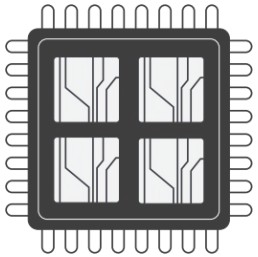
ENERGIE **TRAVAIL**



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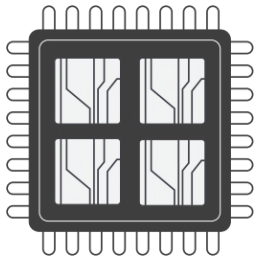
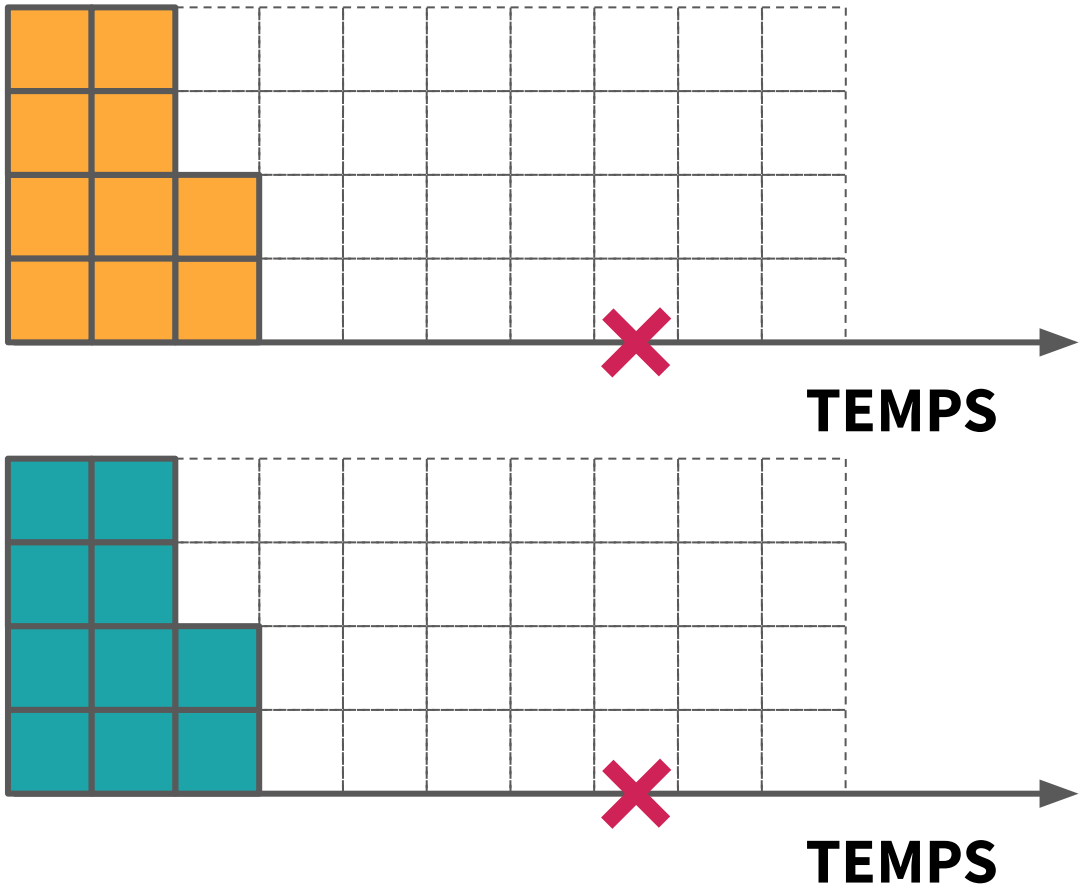
ENERGIE **TRAVAIL**

Avantages du parallélisme

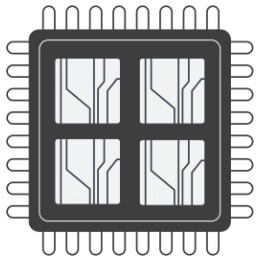




TRAVAIL 10

ENERGIE ~10

Avantages du parallélisme



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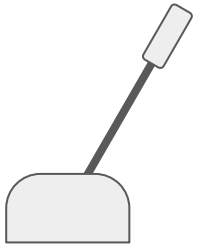
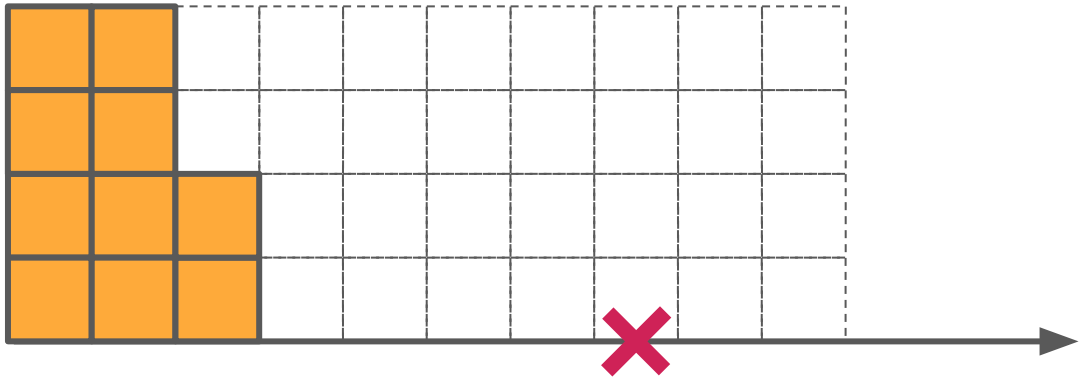
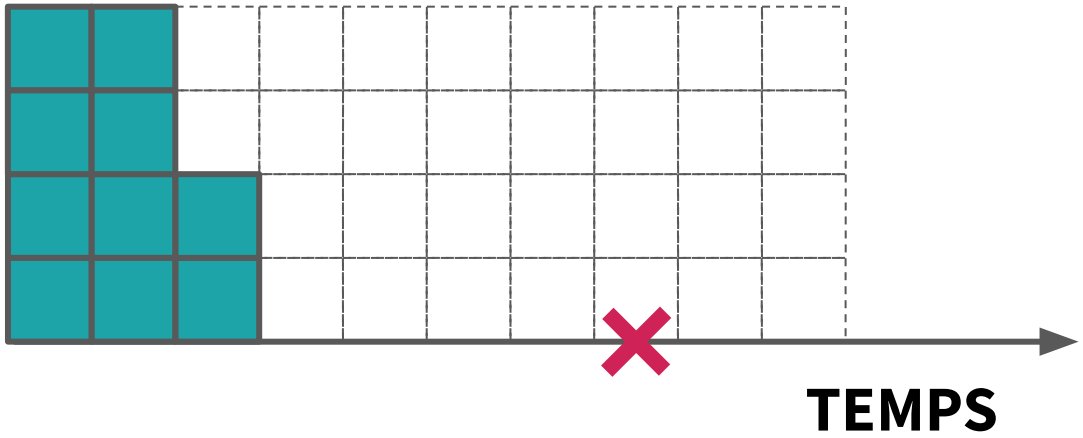


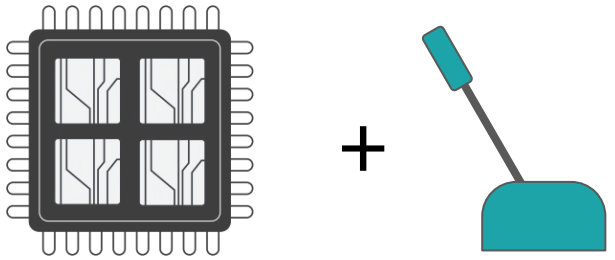


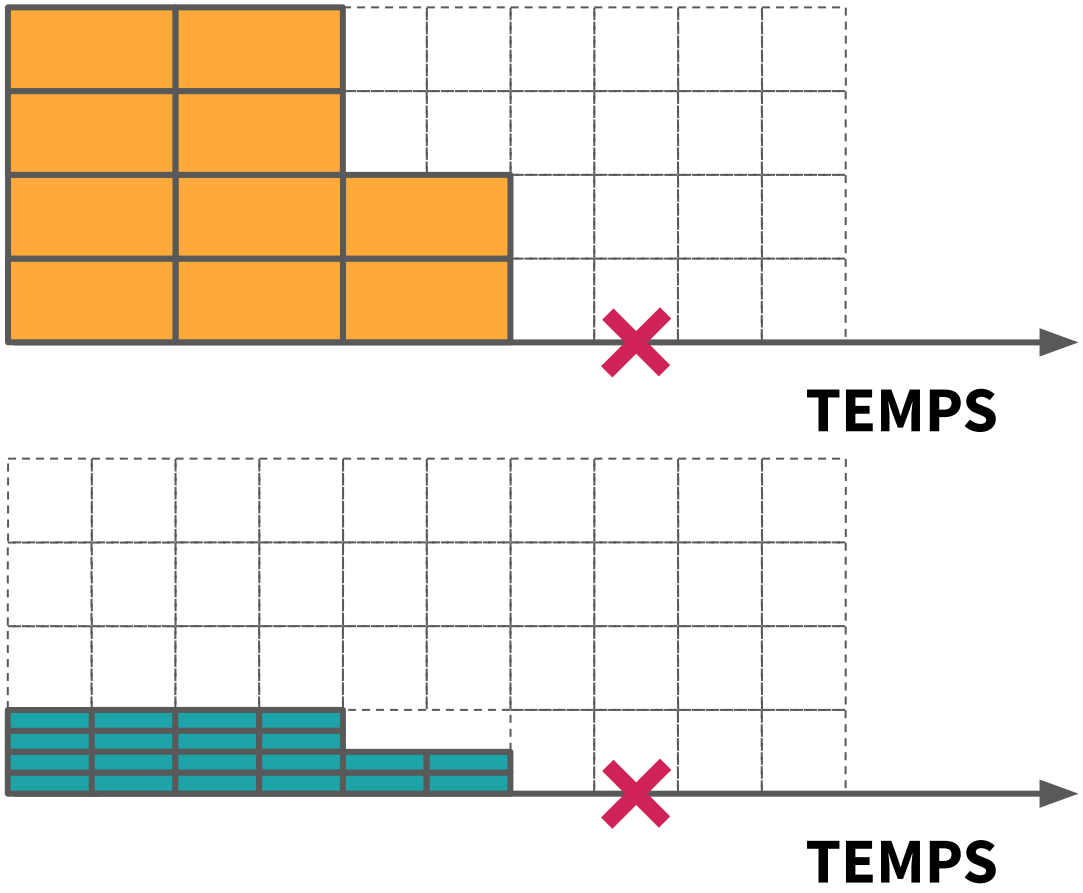
TRAVAIL 10



ENERGIE ~10

Avantages du parallélisme

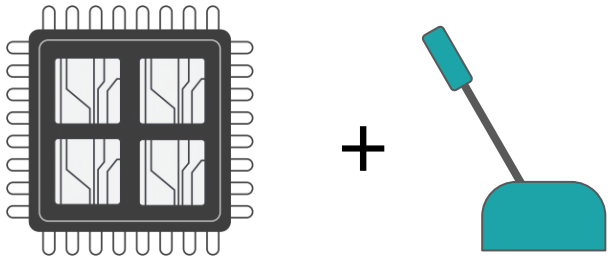


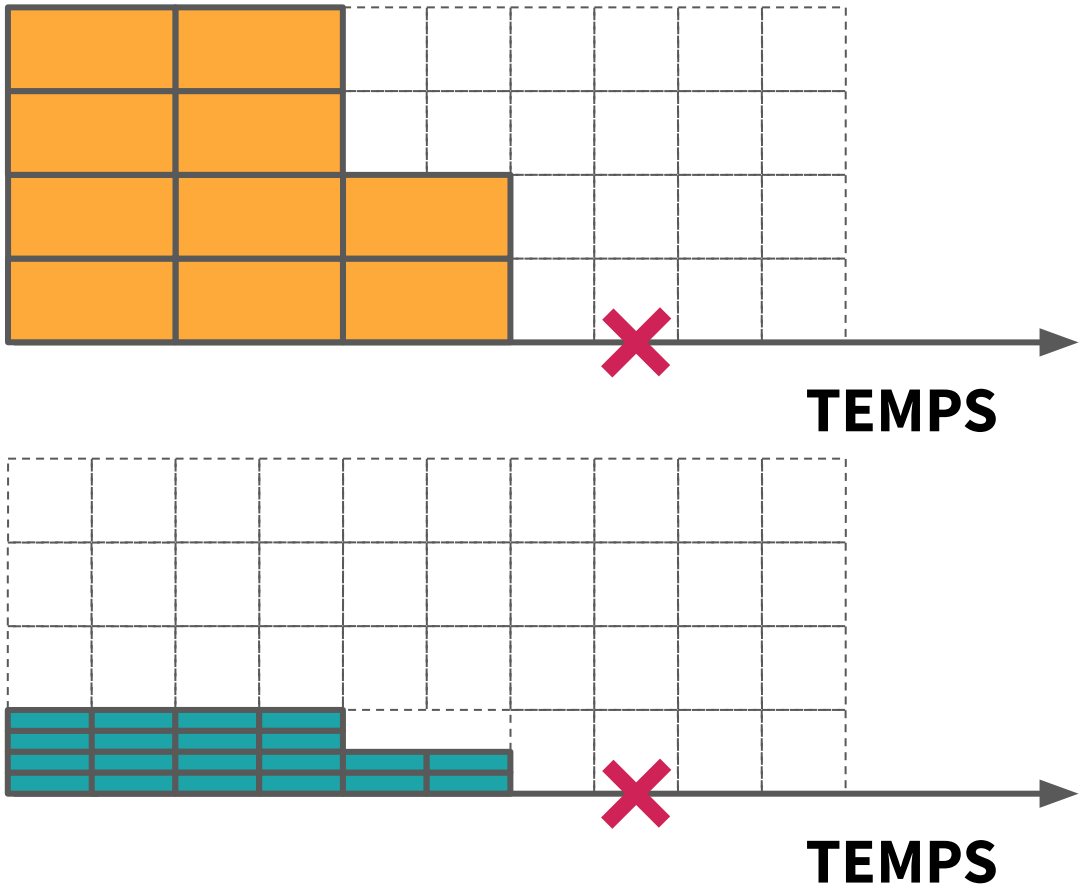


TRAVAIL 10

ENERGIE ~5

Avantages du parallélisme

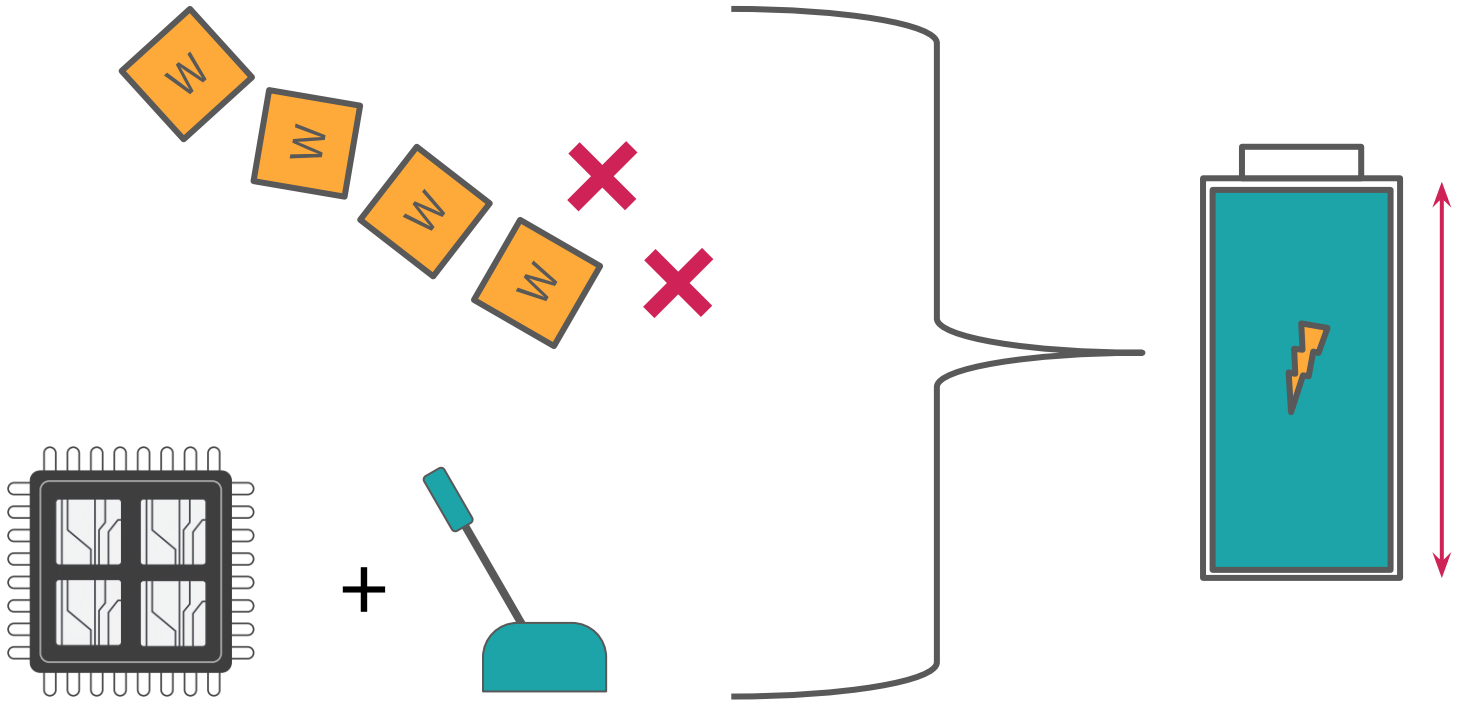


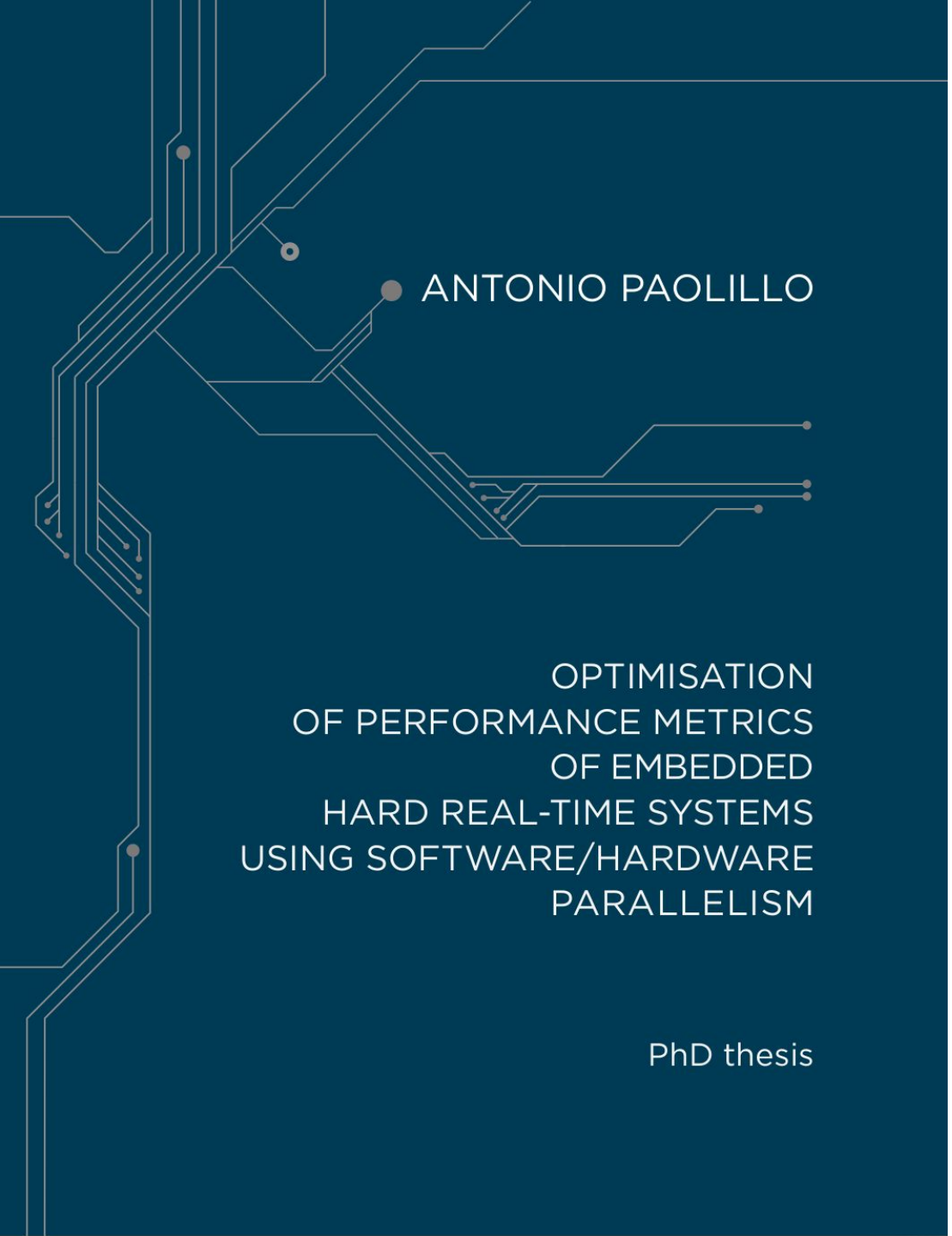


TRAVAIL 10

ENERGIE ~5 (-50%)

Le problème à résoudre




ANTONIO PAOLILLO
OPTIMISATION
OF PERFORMANCE METRICS
OF EMBEDDED
HARD REAL-TIME SYSTEMS
USING SOFTWARE/HARDWARE
PARALLELISM
PhD thesis

OPTIMISATION OF PERFORMANCE METRICS OF EMBEDDED HARD REAL-TIME SYSTEMS USING SOFTWARE/HARDWARE PARALLELISM

OPTIMISATION
OF PERFORMANCE METRICS
OF **EMBEDDED**
HARD REAL-TIME **SYSTEMS**
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PARALLELISM

OPTIMISATION
OF PERFORMANCE METRICS
OF EMBEDDED
HARD REAL-TIME SYSTEMS
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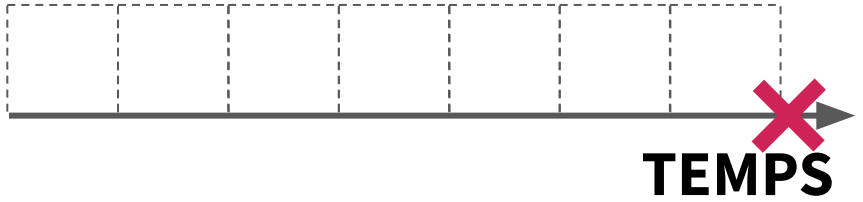
PARALLELISM



OPTIMISATION
OF **PERFORMANCE METRICS**
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HARD REAL-TIME SYSTEMS
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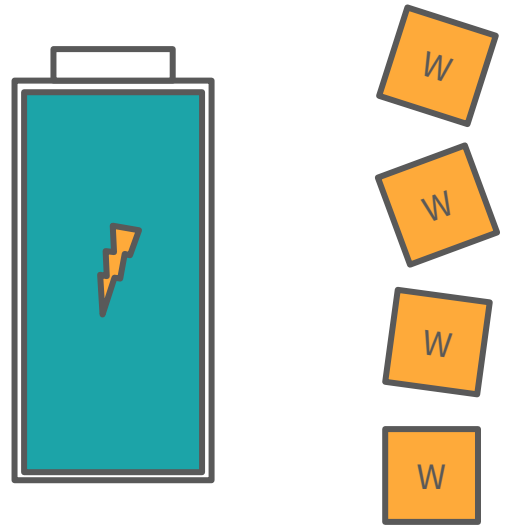
PARALLELISM



OPTIMISATION
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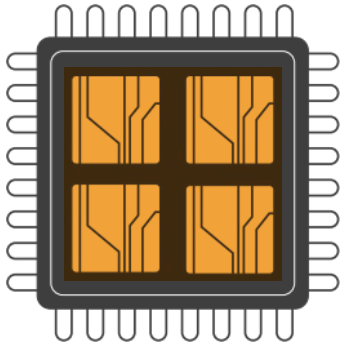
PARALLELISM



OPTIMISATION
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HARD REAL-TIME SYSTEMS
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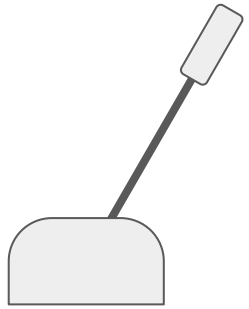
PARALLELISM



-20%

-30%

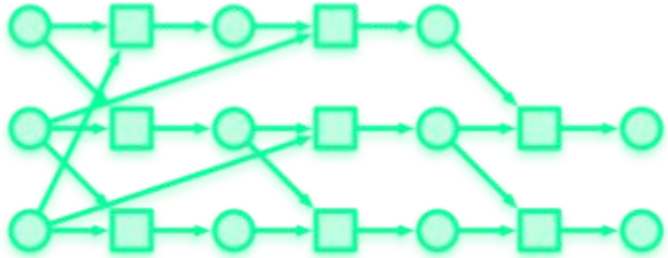
-50%

OPTIMISATION OF PERFORMANCE METRICS OF EMBEDDED HARD REAL-TIME SYSTEMS USING SOFTWARE/HARDWARE PARALLELISM

OPTIMISATION
OF PERFORMANCE METRICS
OF EMBEDDED
HARD REAL-TIME SYSTEMS
USING SOFTWARE/HARDWARE
PARALLELISM

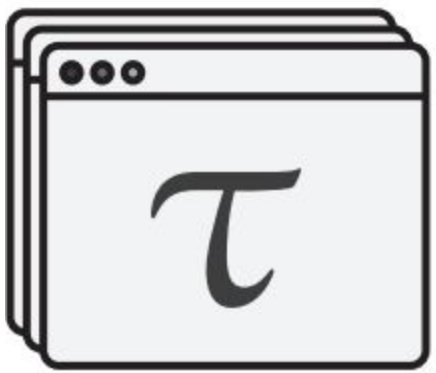
?

OPTIMISATION
OF PERFORMANCE METRICS
OF EMBEDDED
HARD REAL-TIME SYSTEMS
USING **SOFTWARE**/HARDWARE
PARALLELISM



Agenda

1. Domaine, problème, intuition
2. **Contributions et thèse**
3. Directions futures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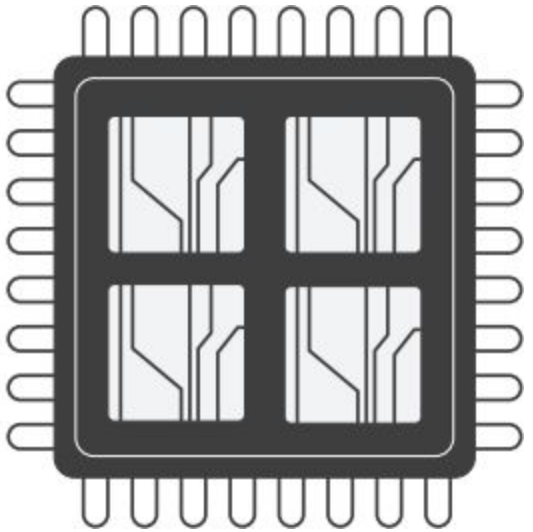

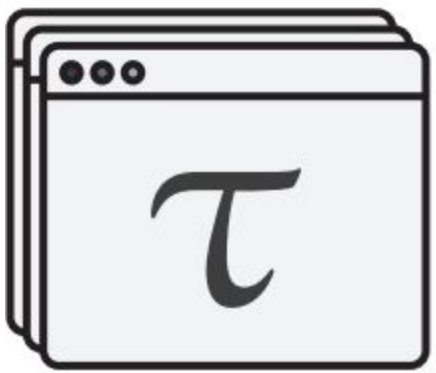
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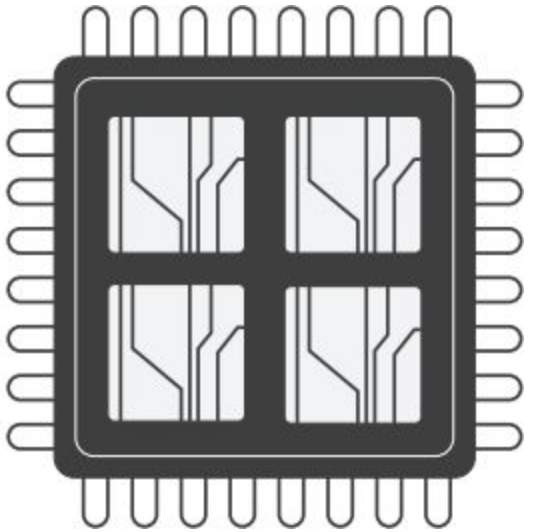

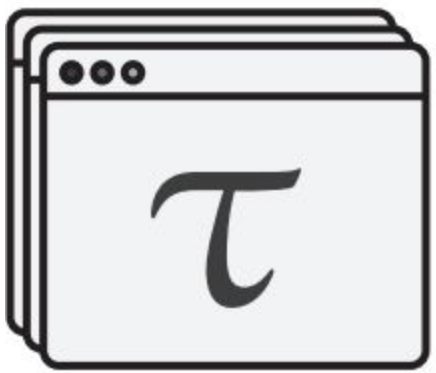
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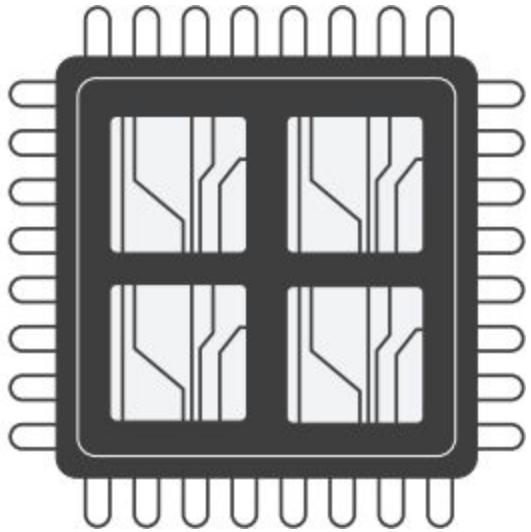

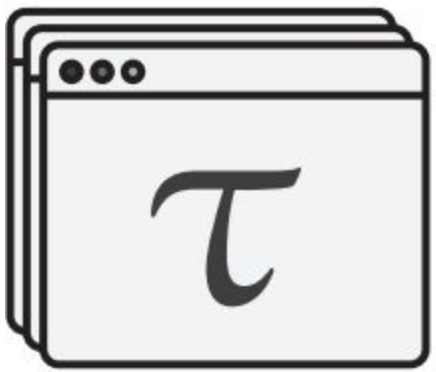
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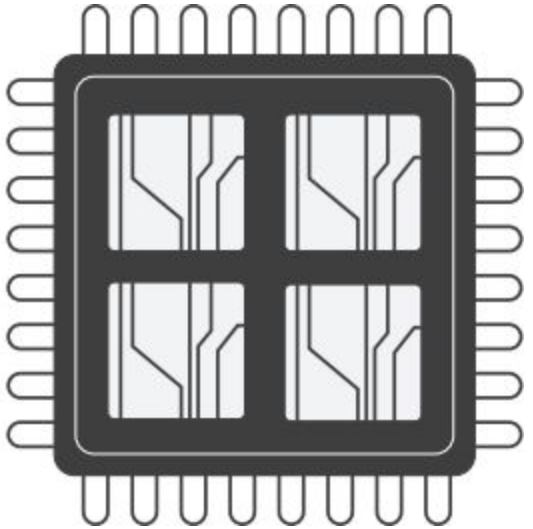

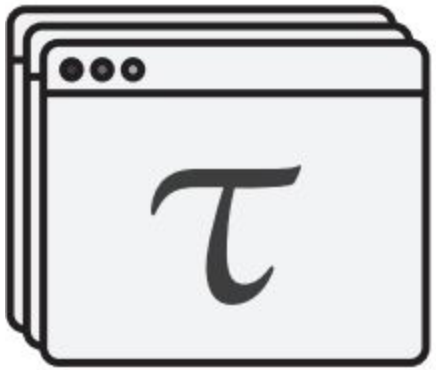
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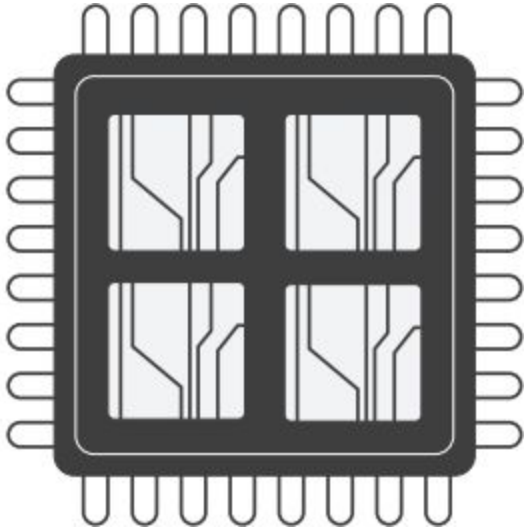

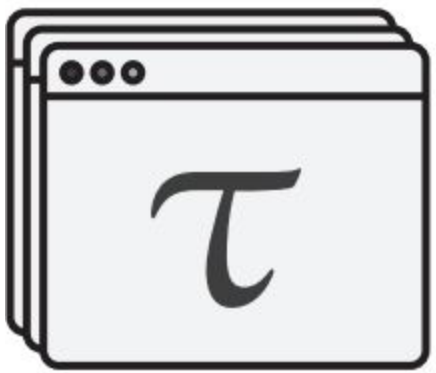
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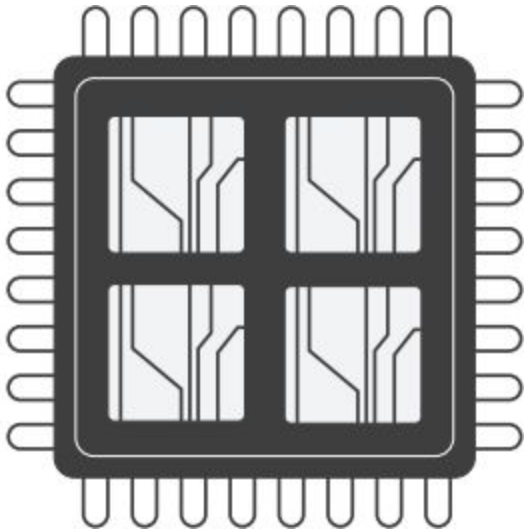

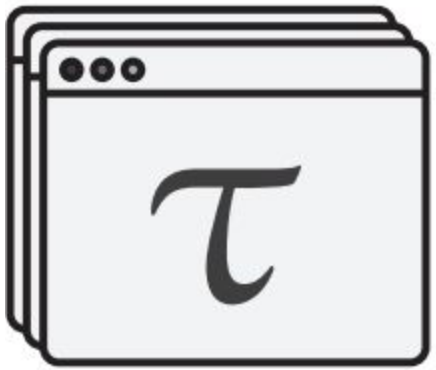
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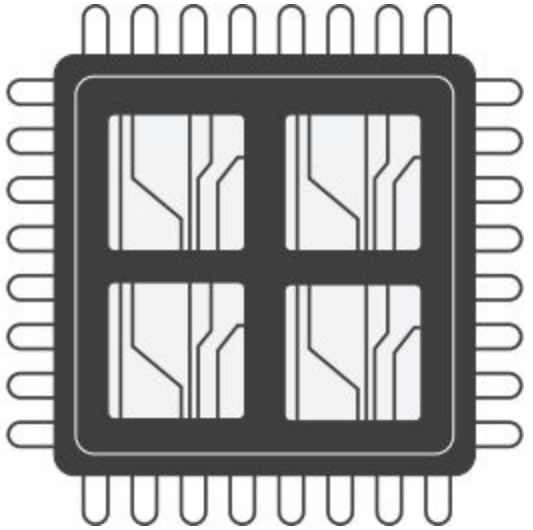

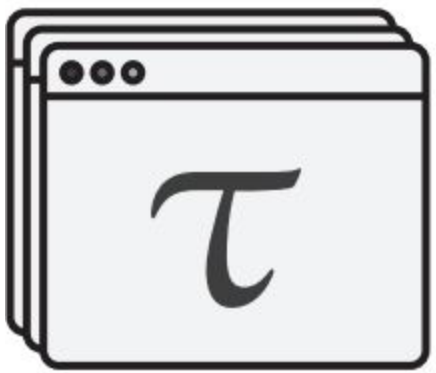
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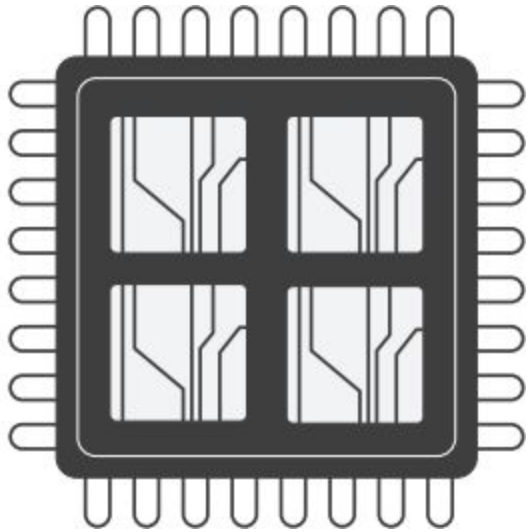

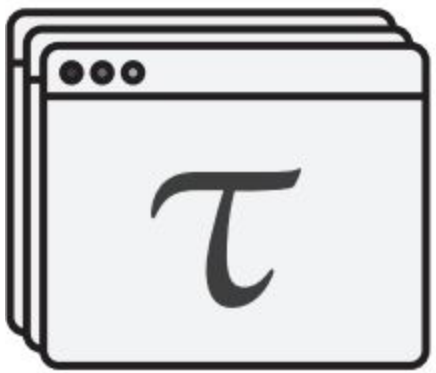
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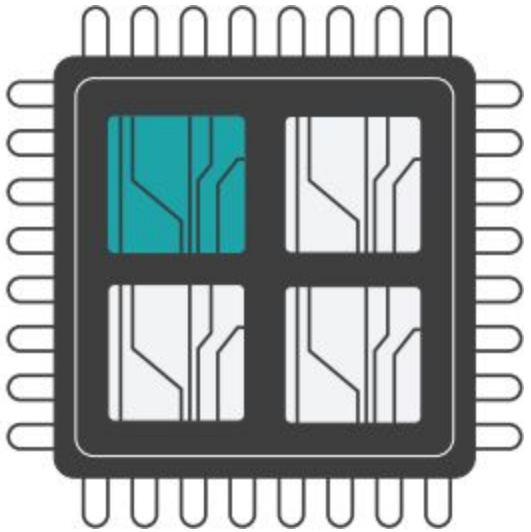

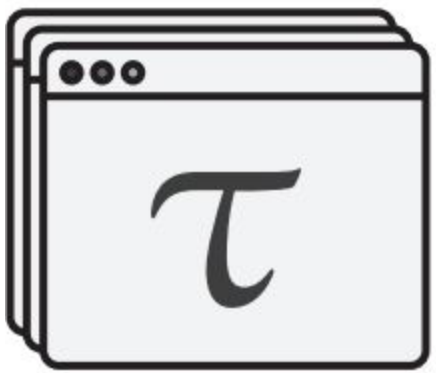
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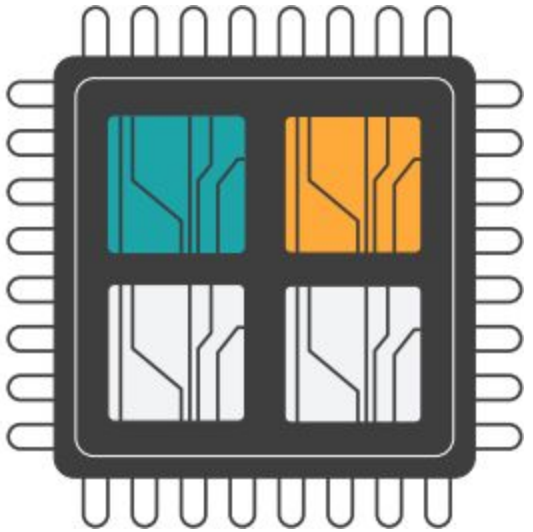

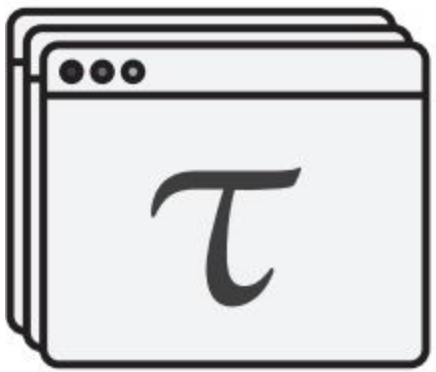
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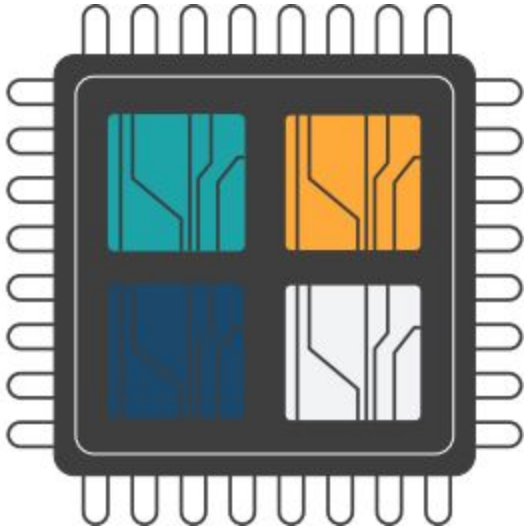

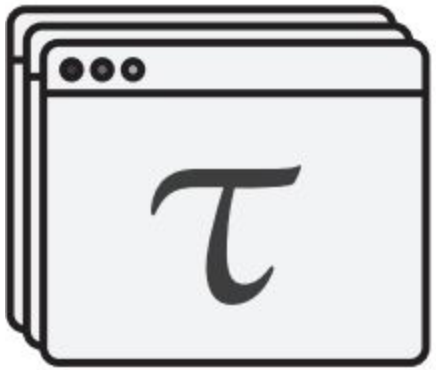
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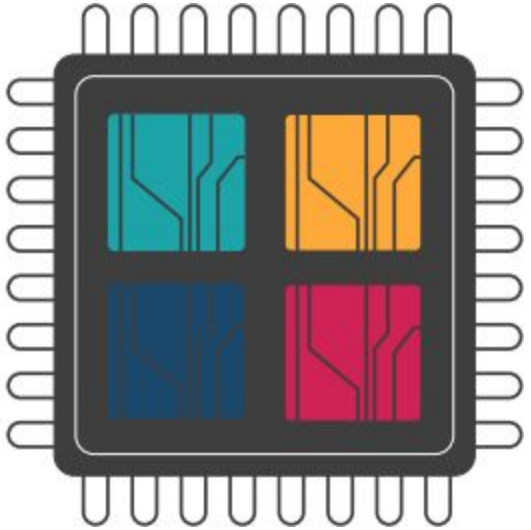

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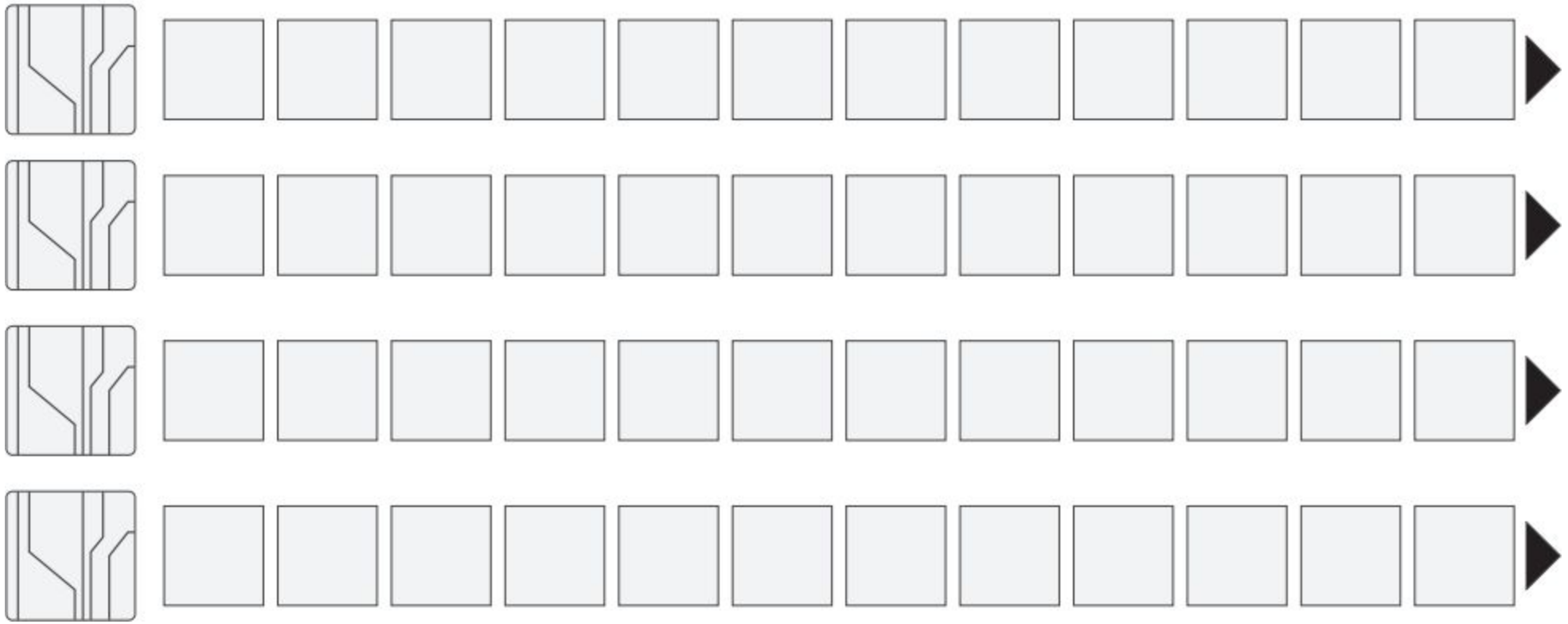

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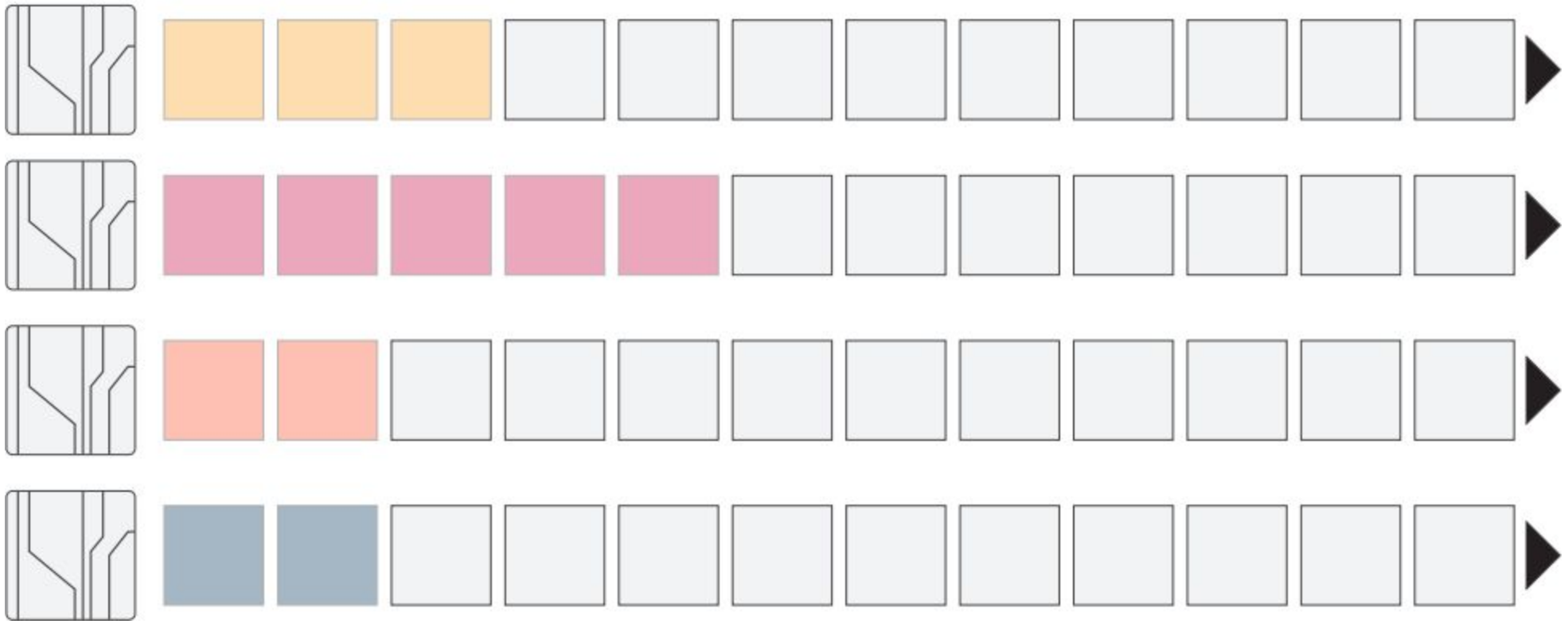

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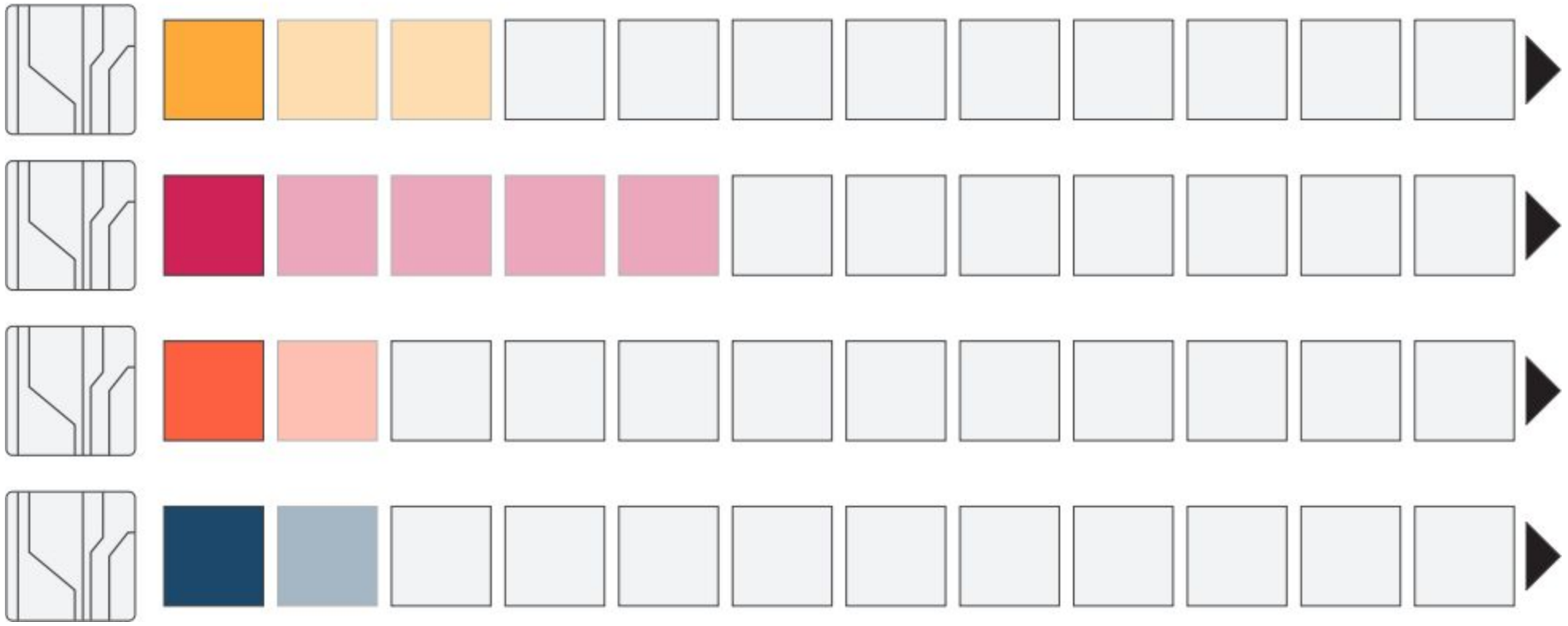

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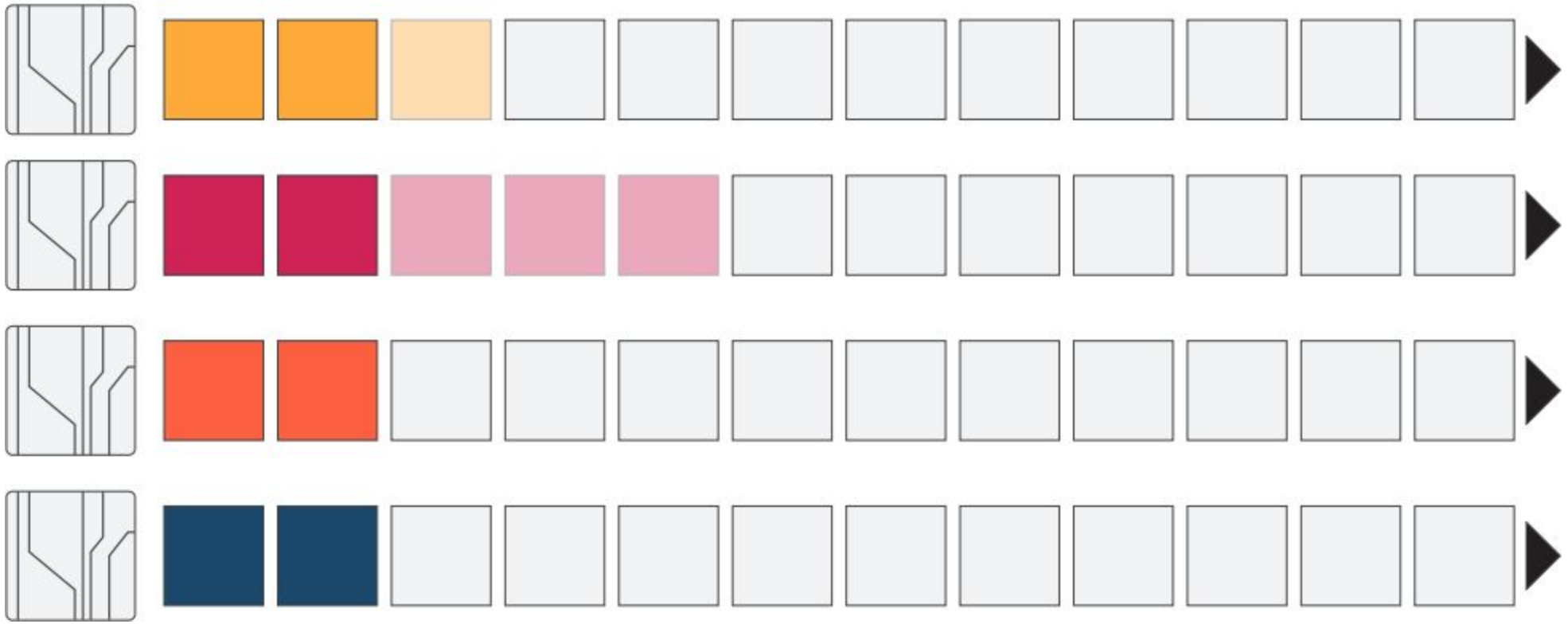

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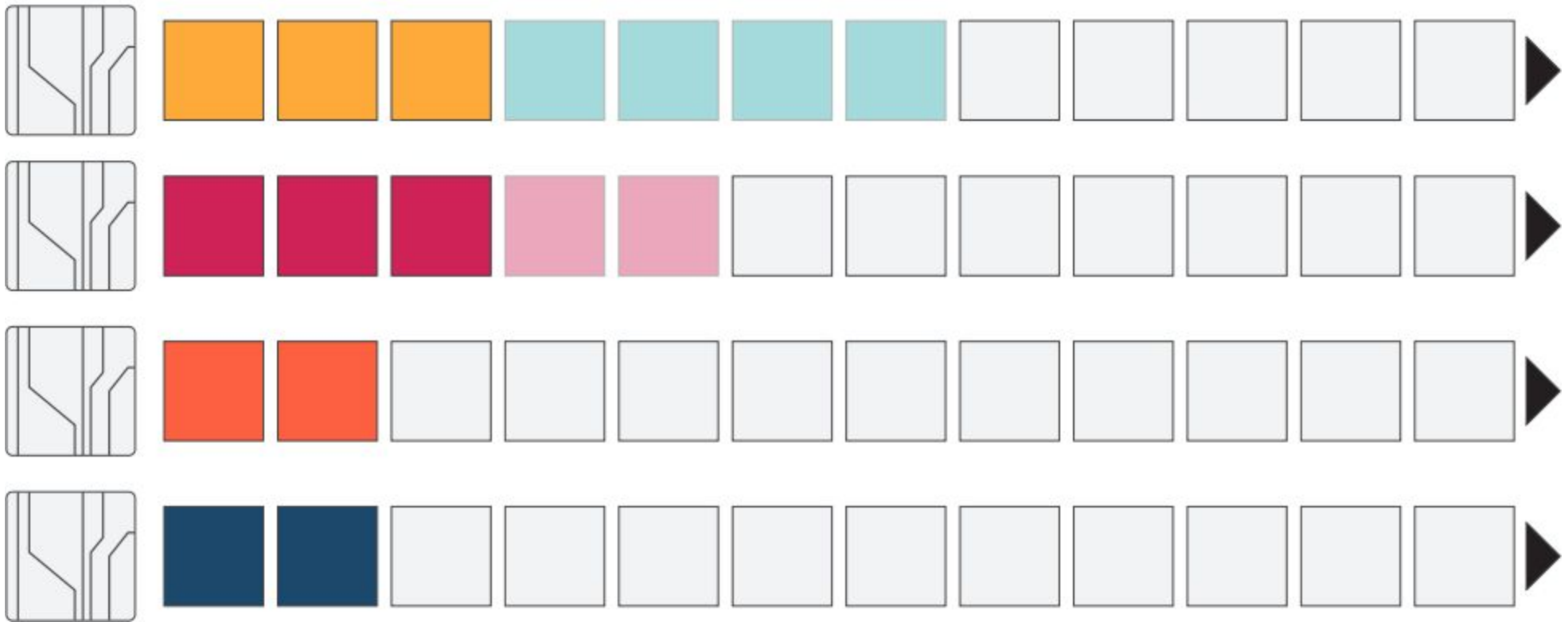

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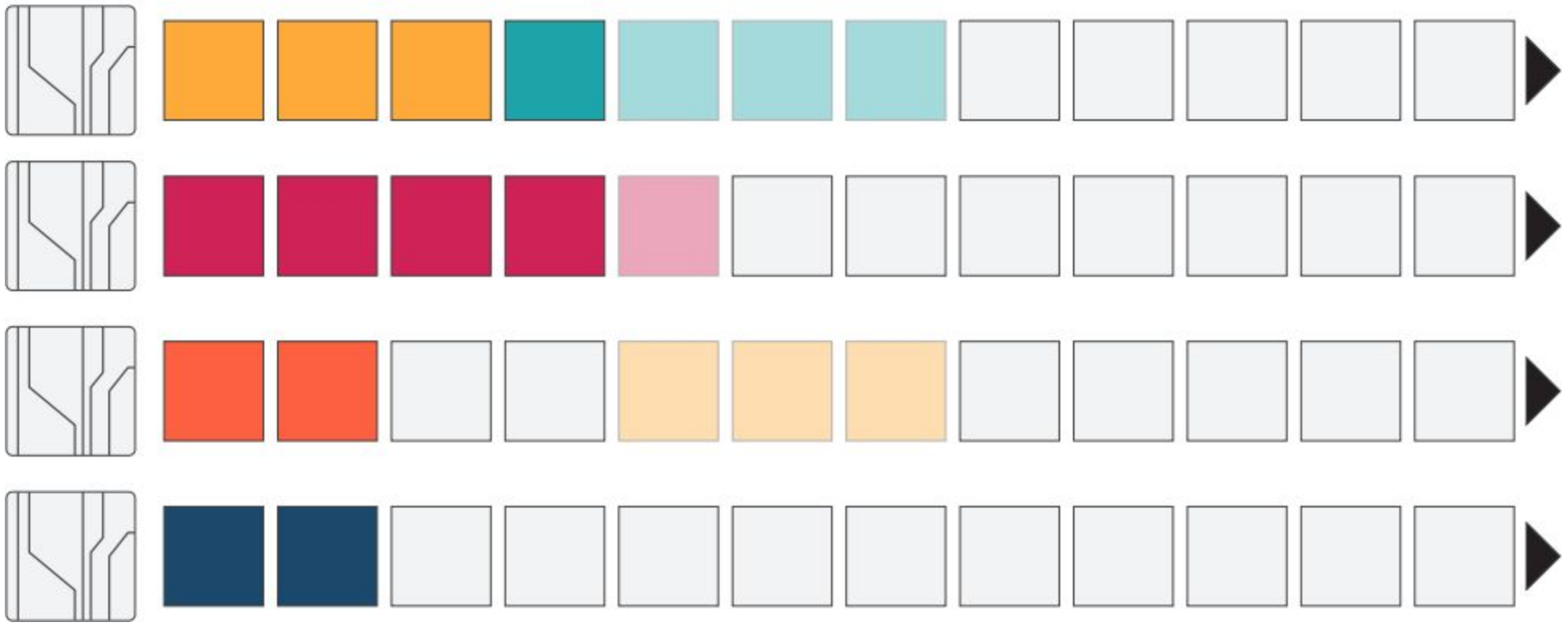

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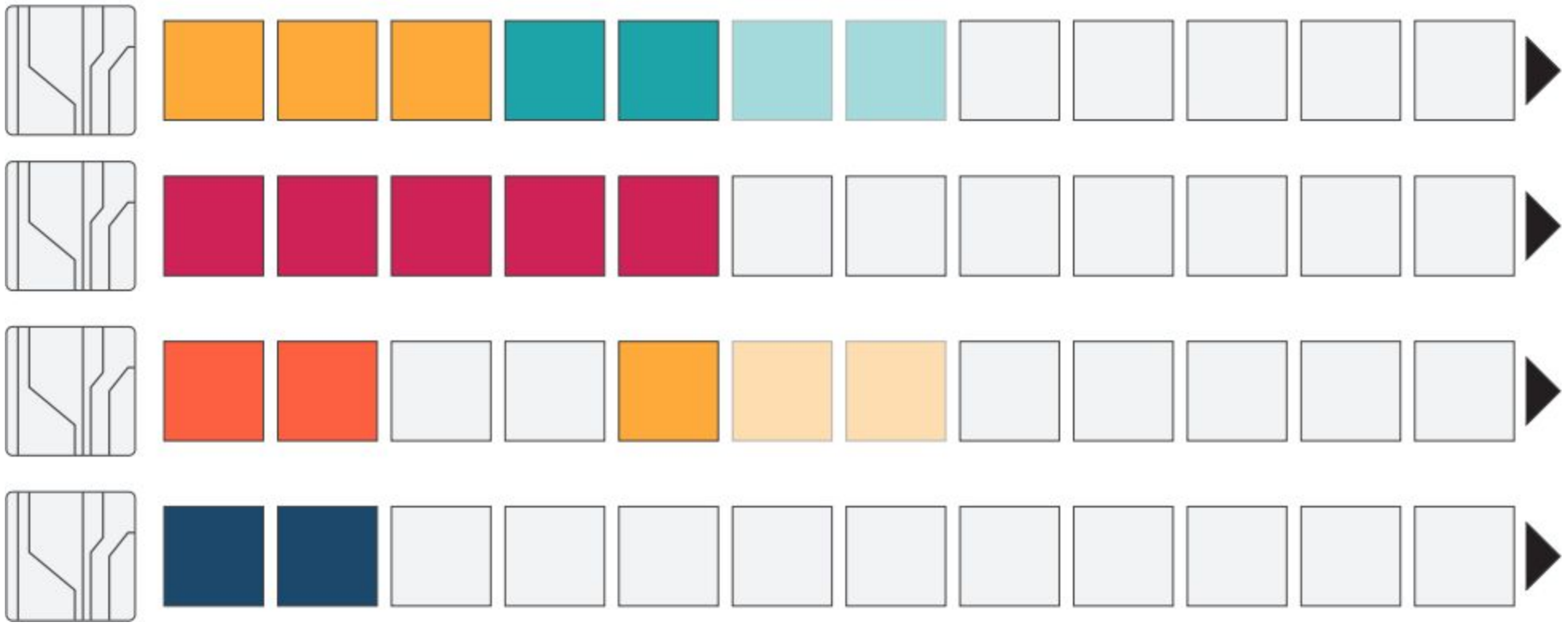

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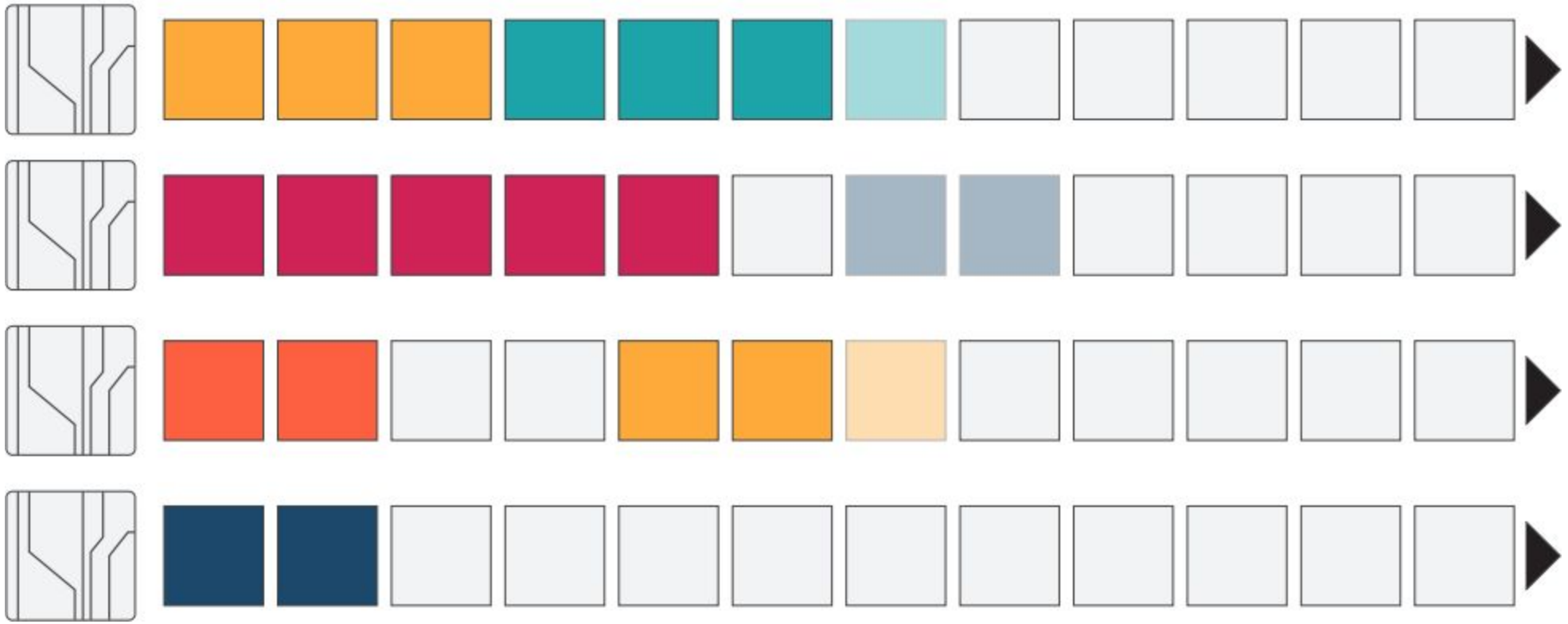

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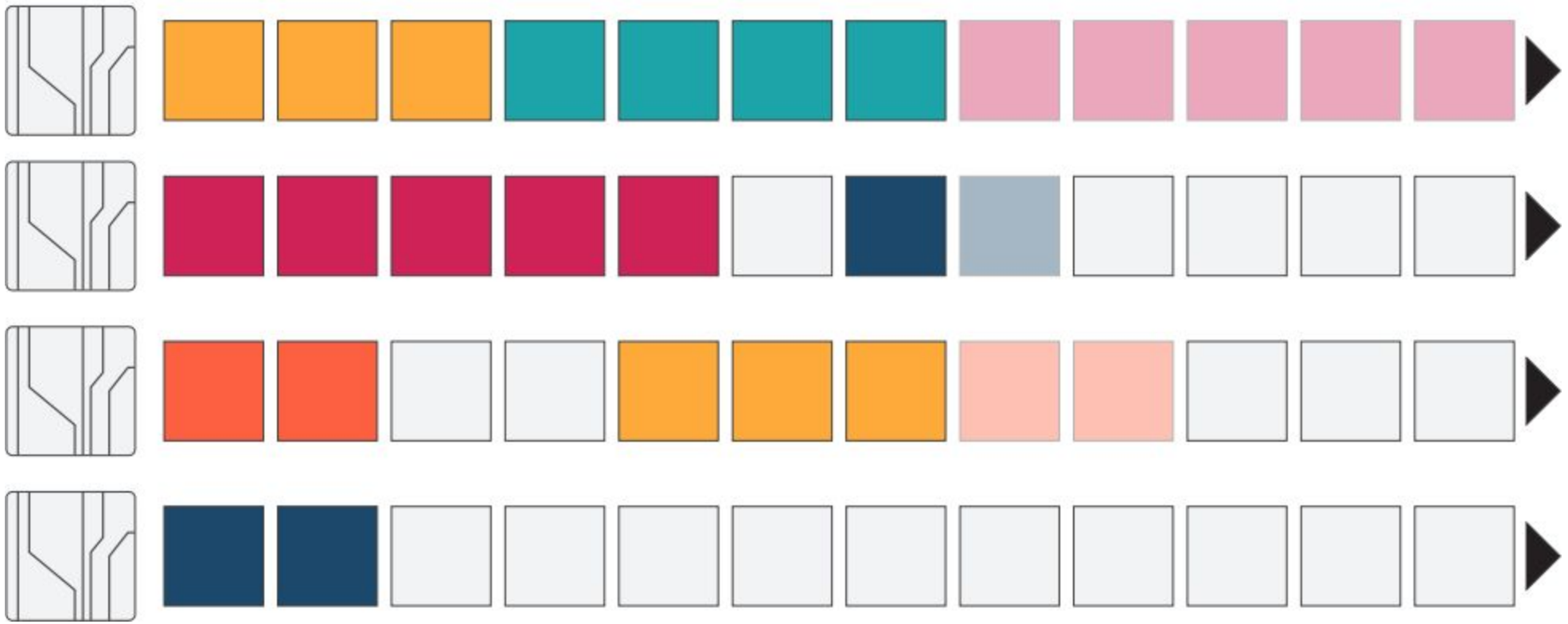

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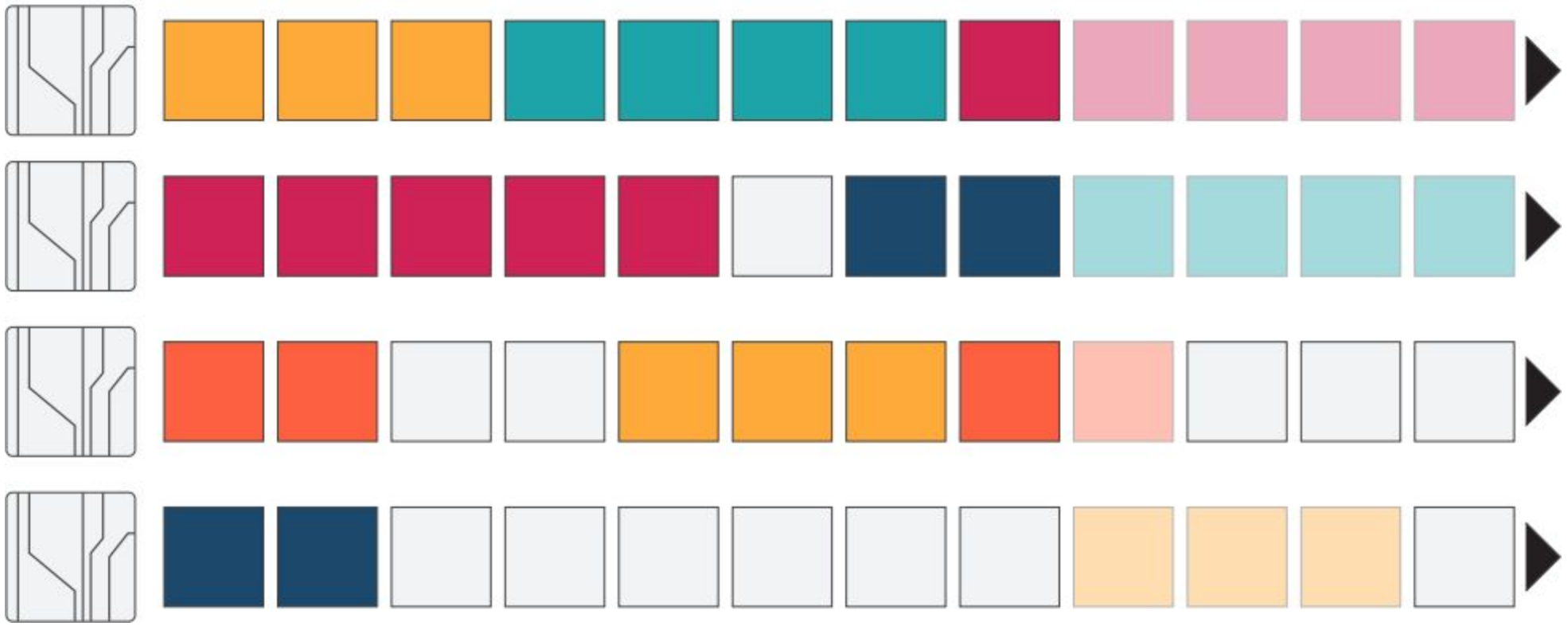

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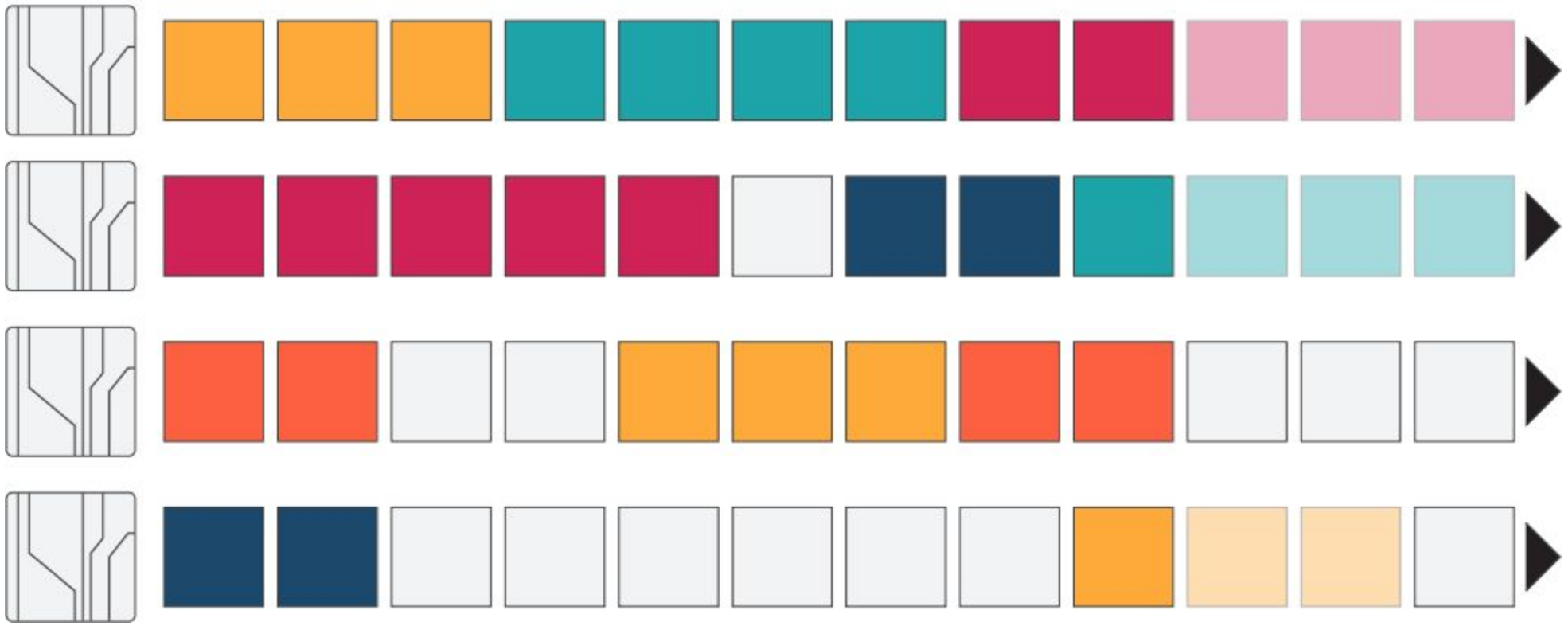

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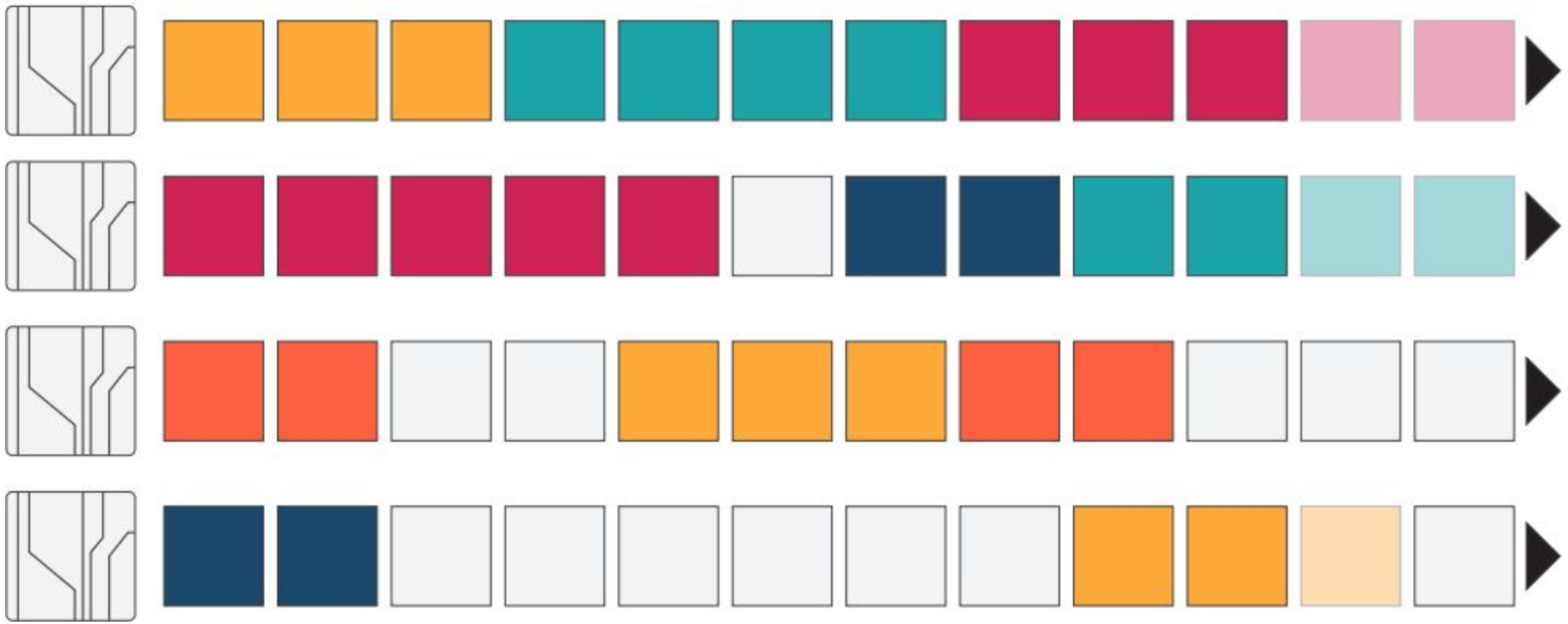

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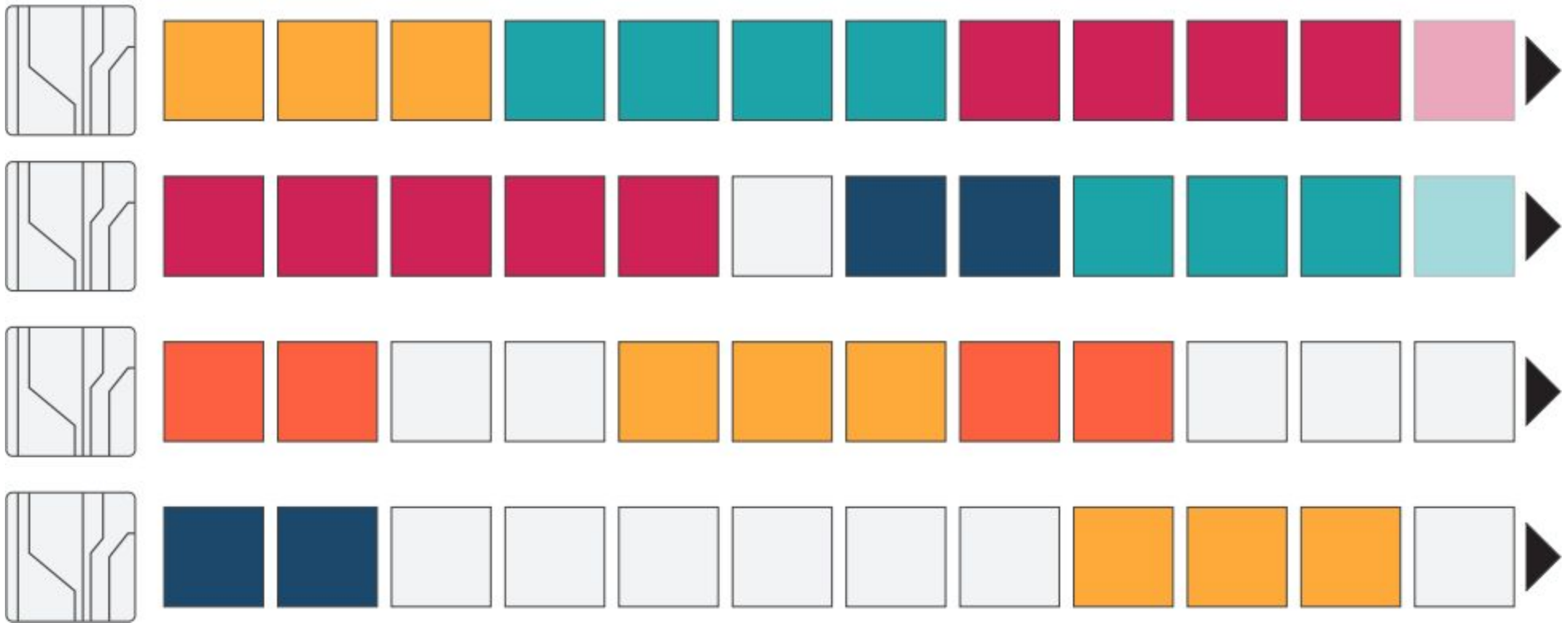

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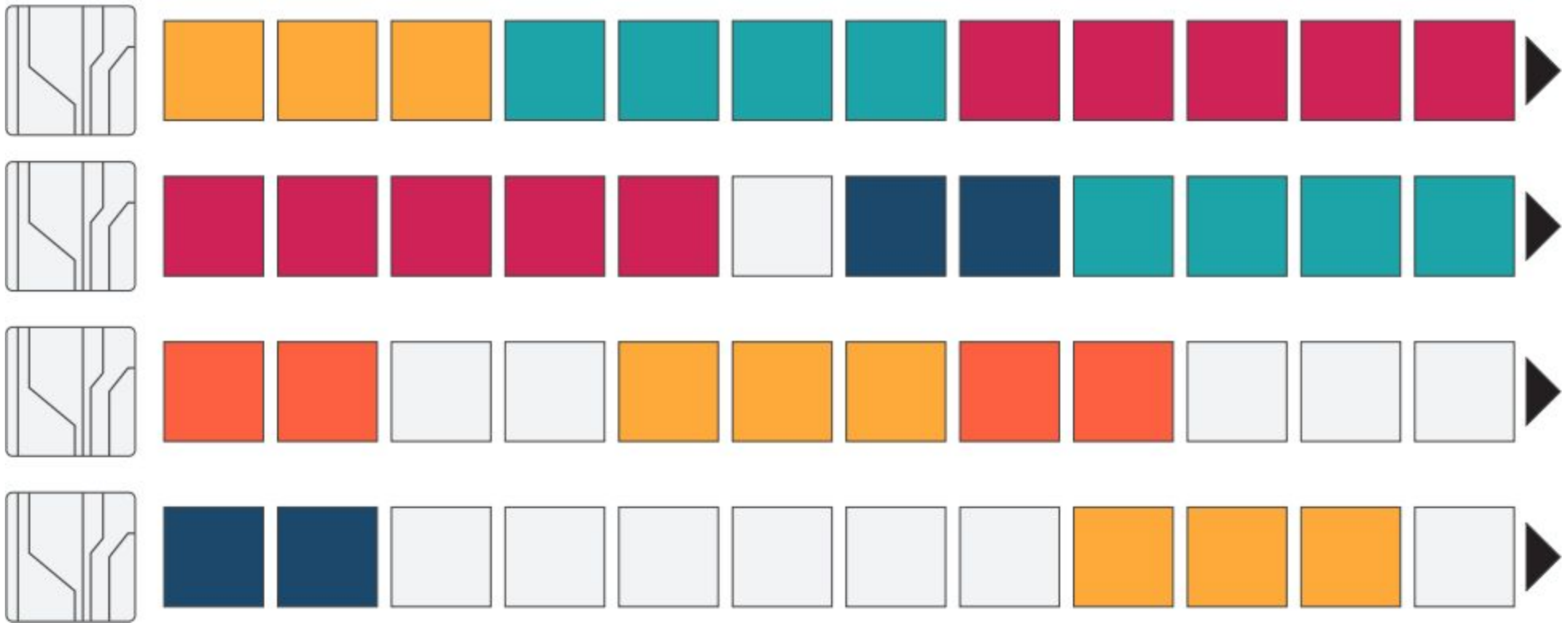

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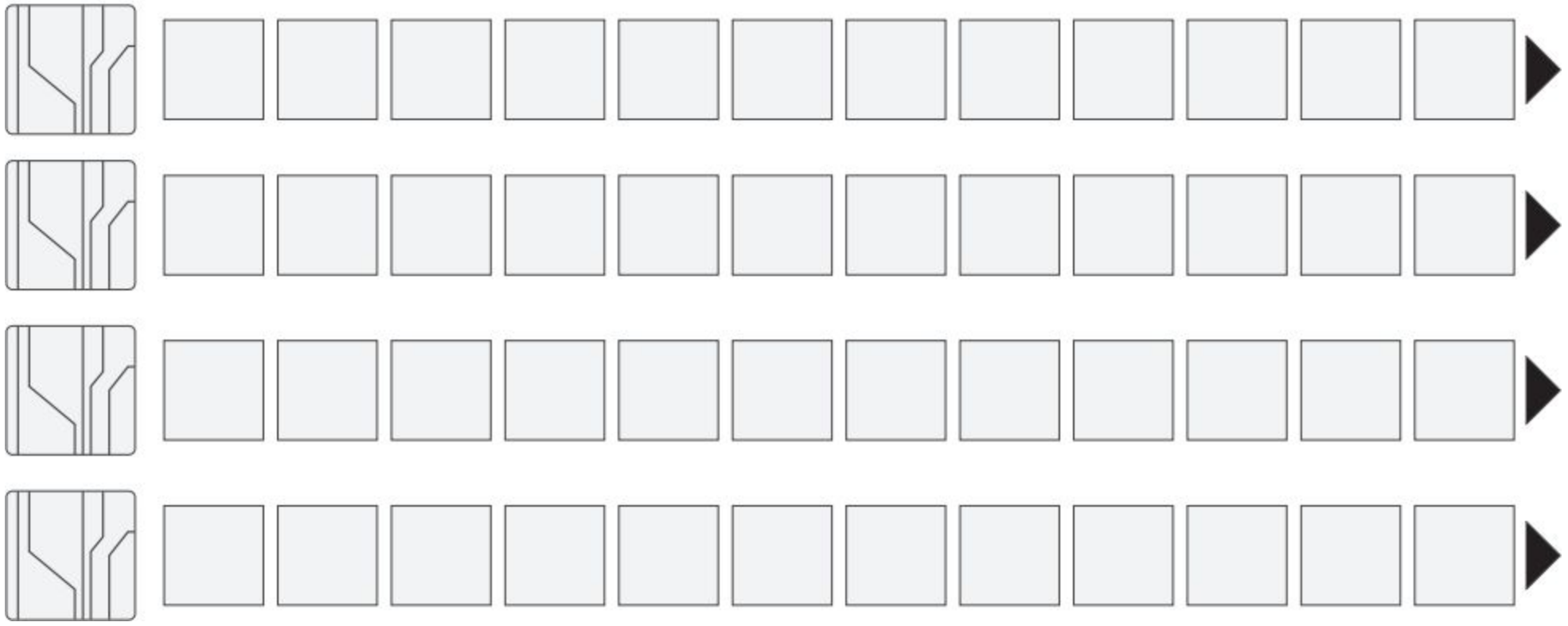
réduire l’énergie consommée

"The minimum **speed** is limited by the **sequential** job model"

- J. Anderson, S. Baruah

Ordonnancement parallèle



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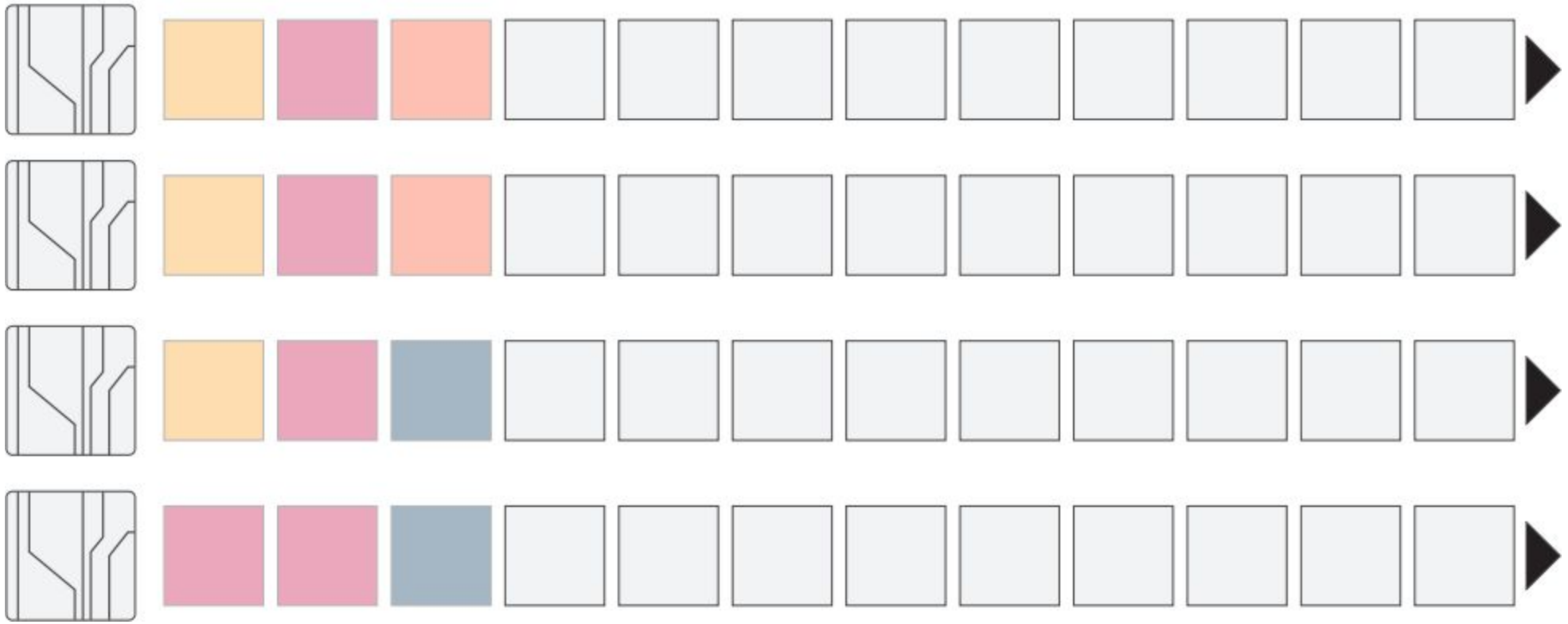

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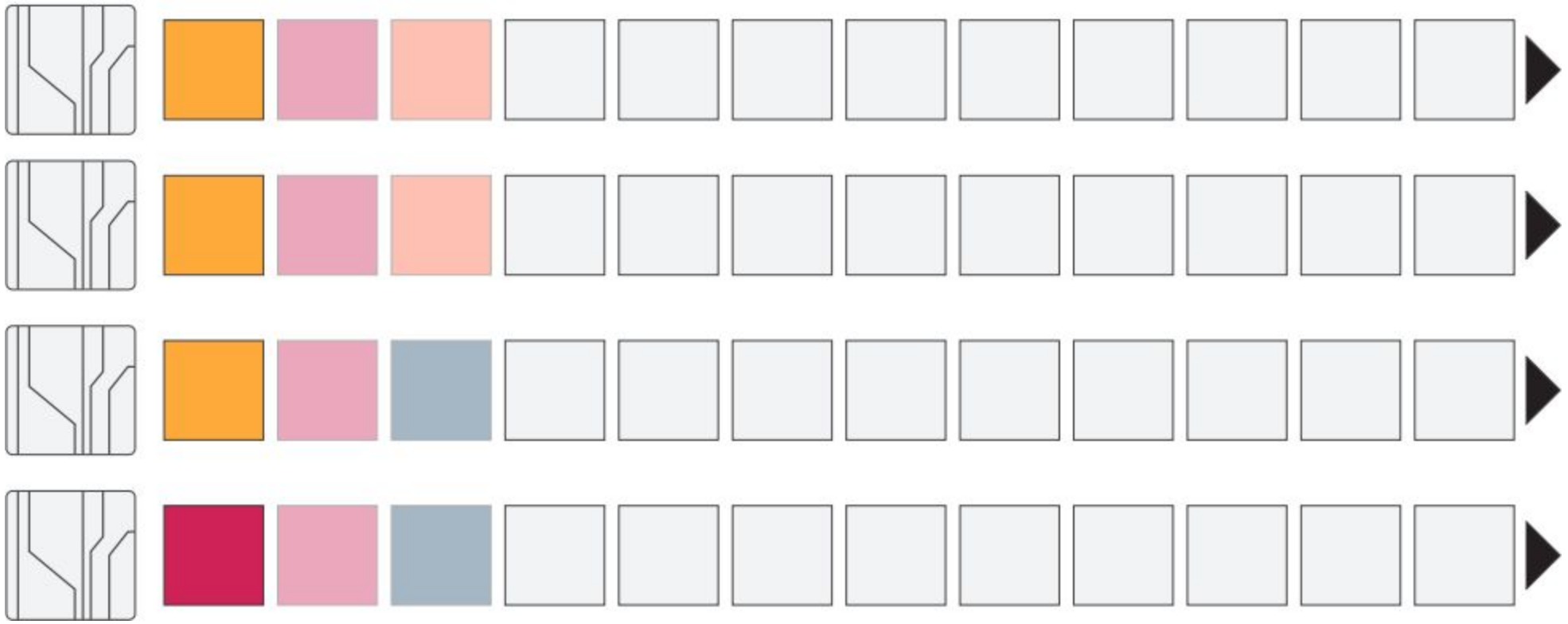

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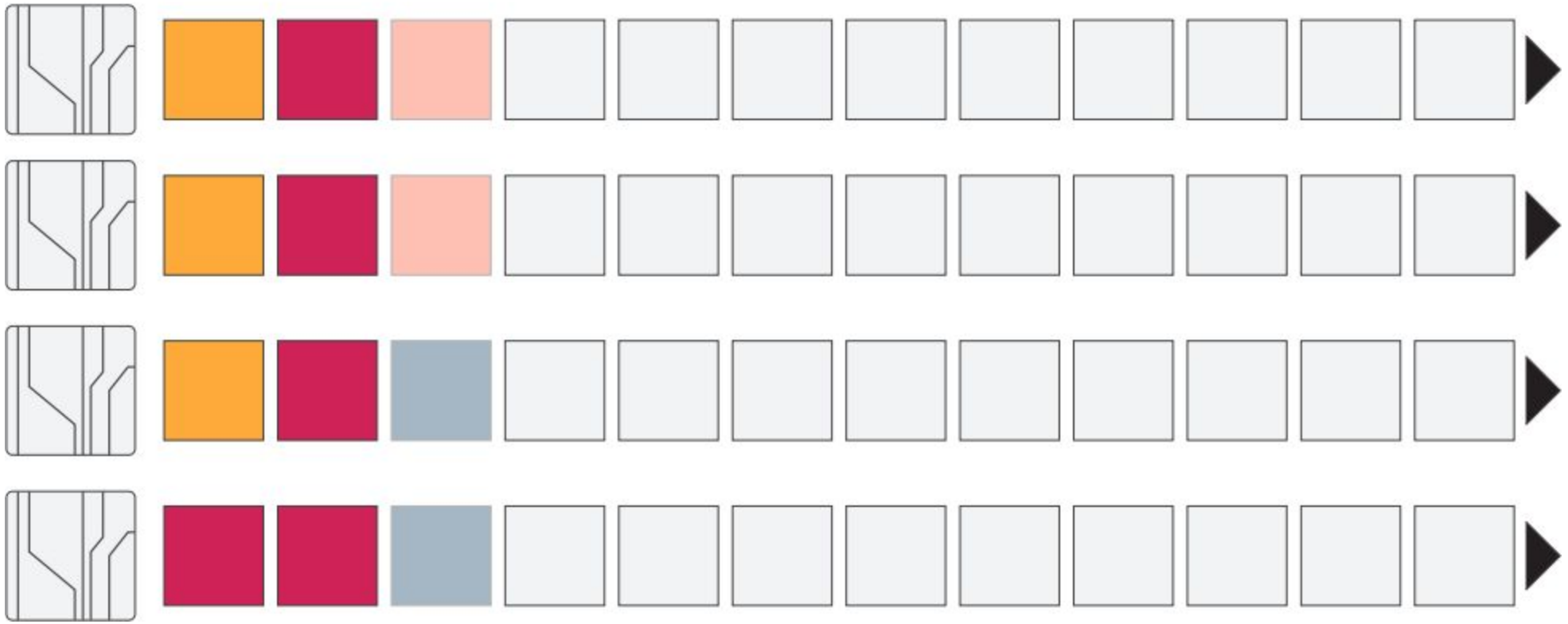

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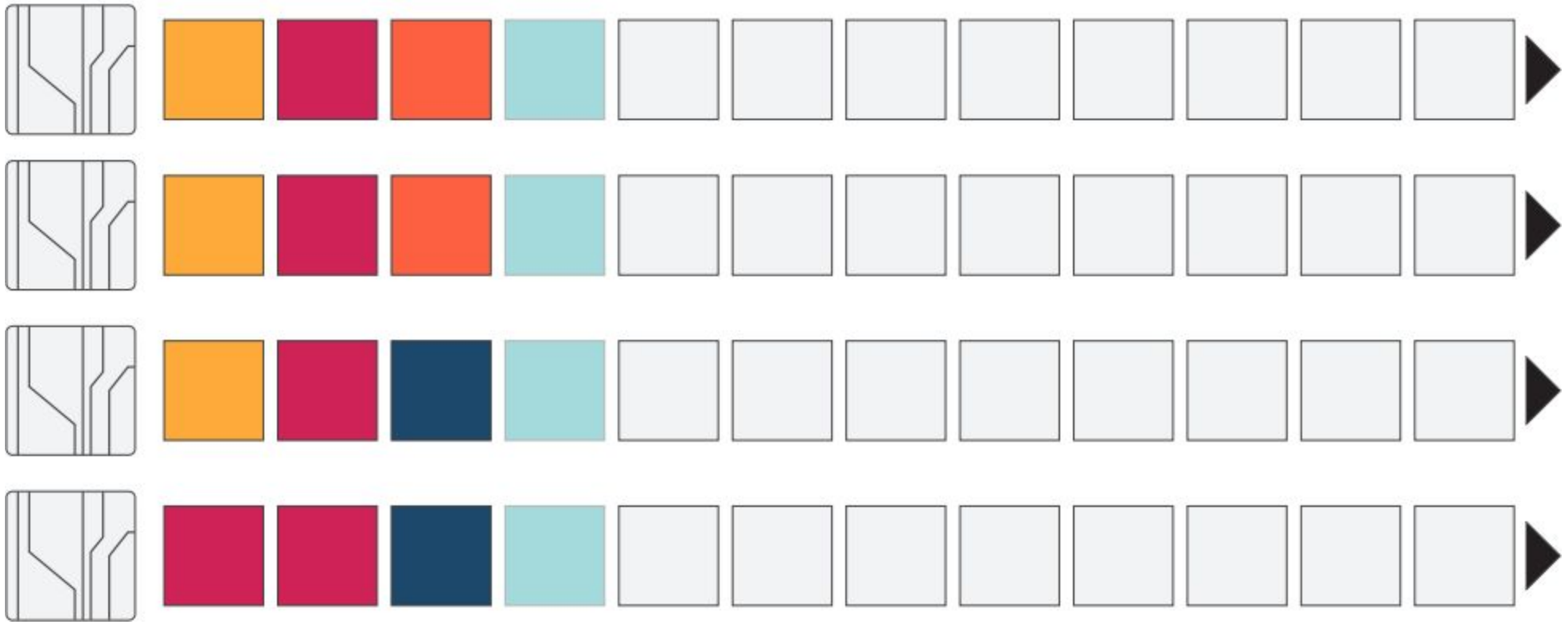

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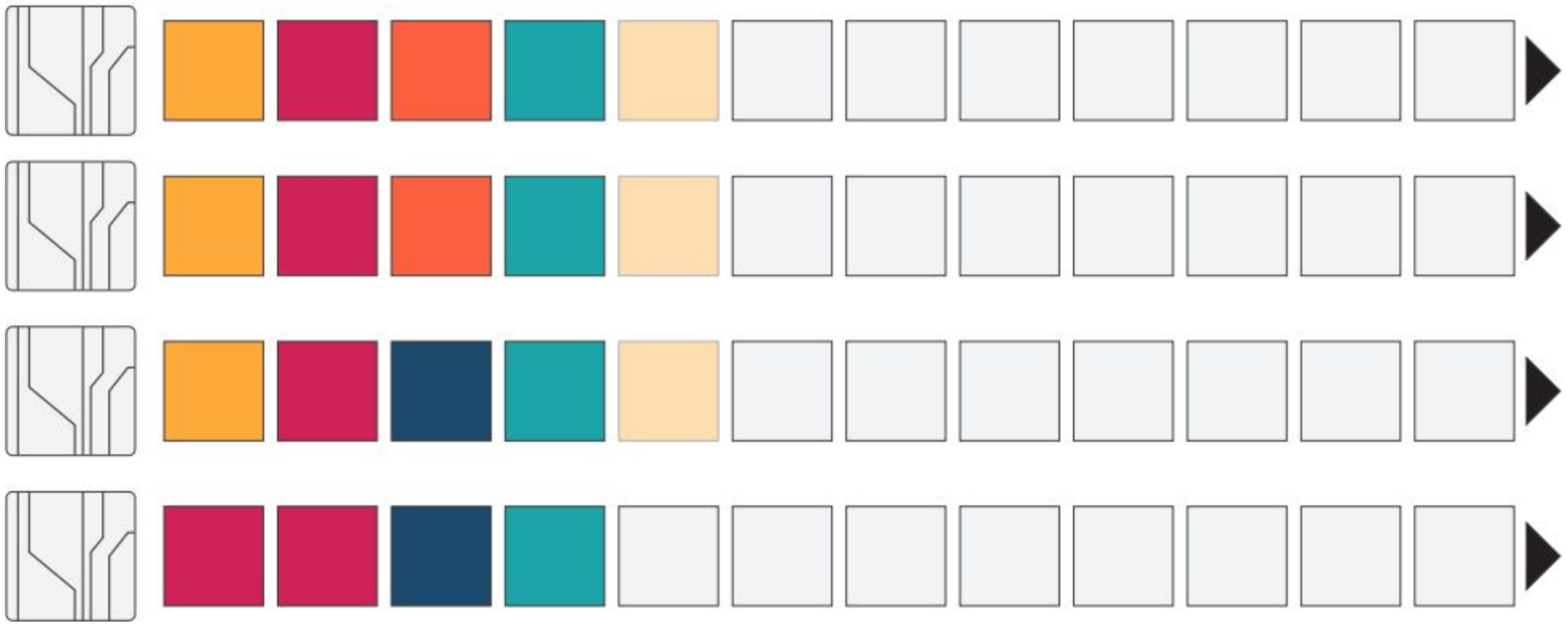

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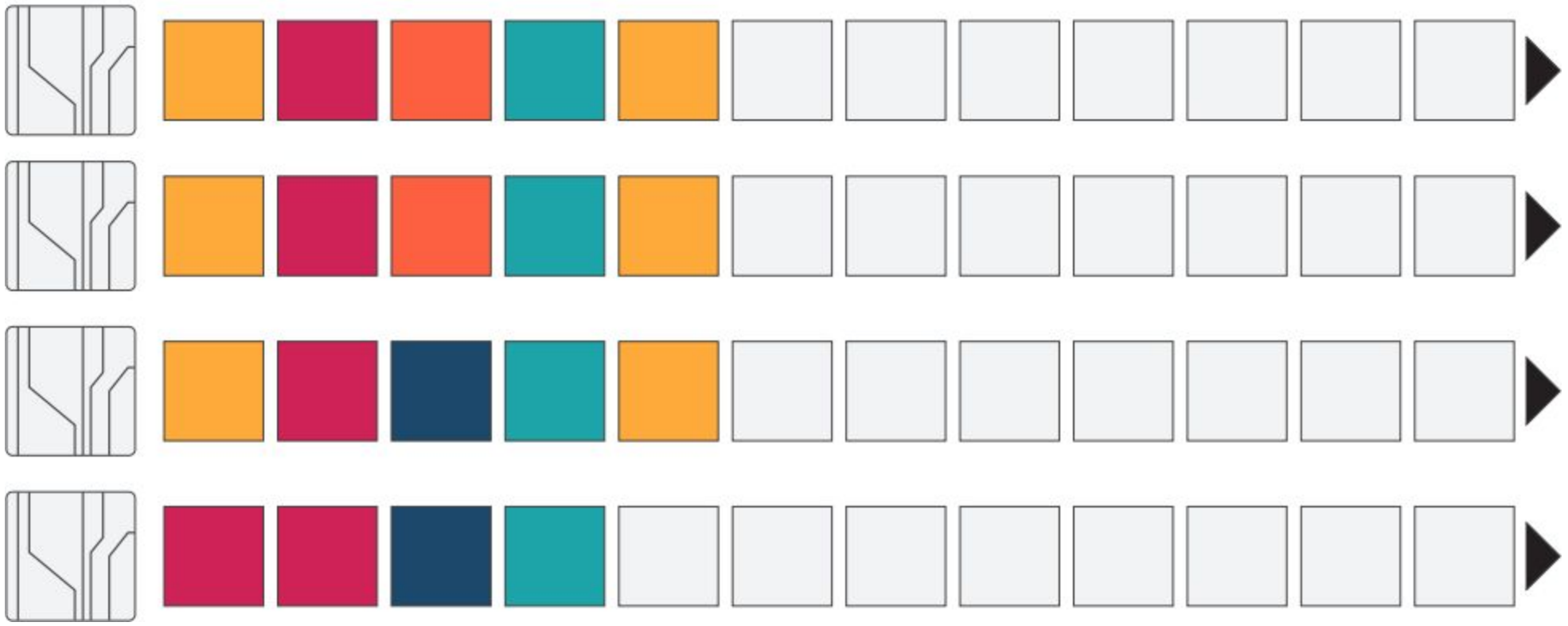

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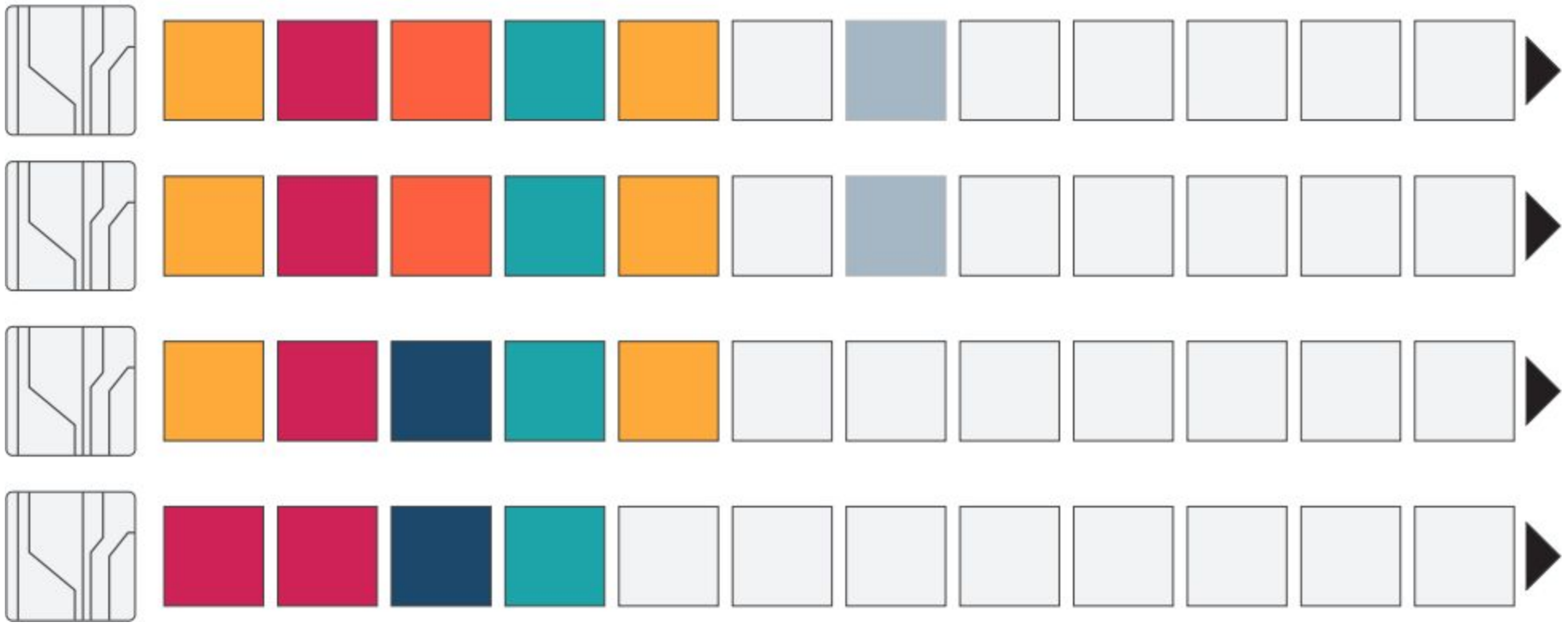

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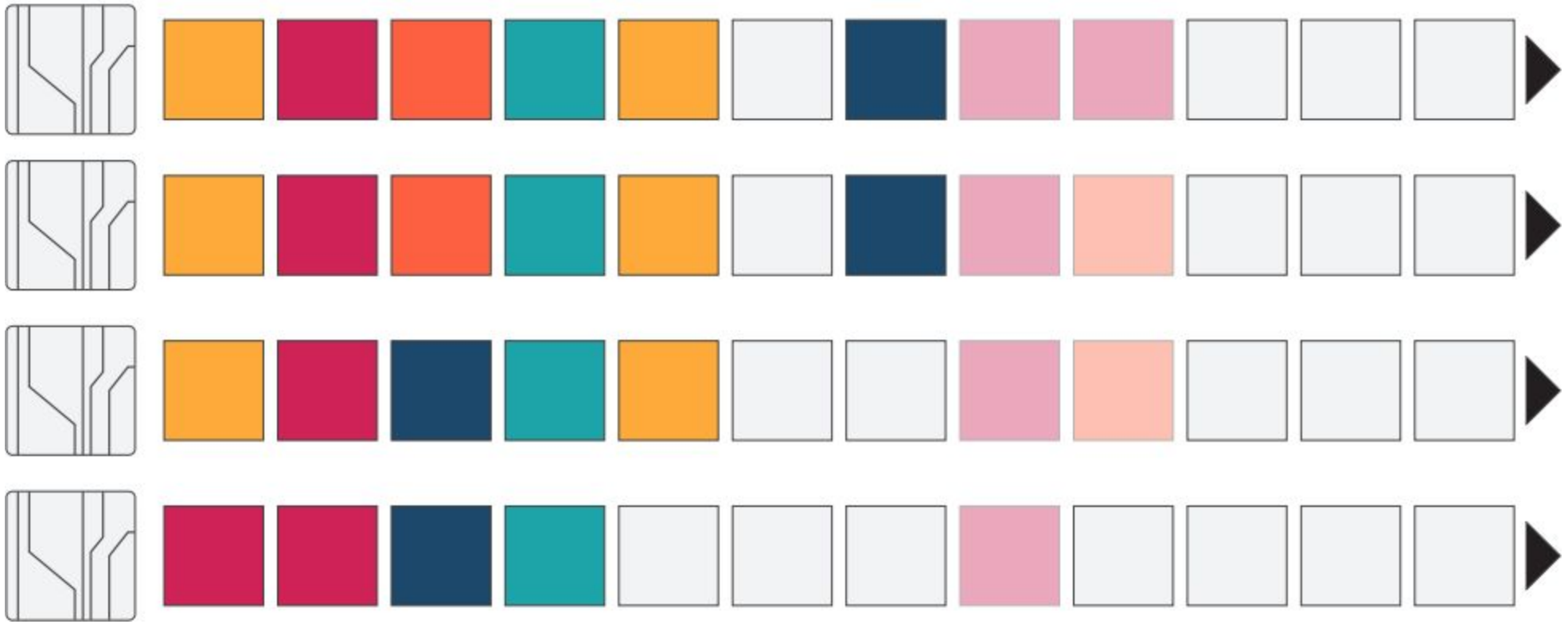

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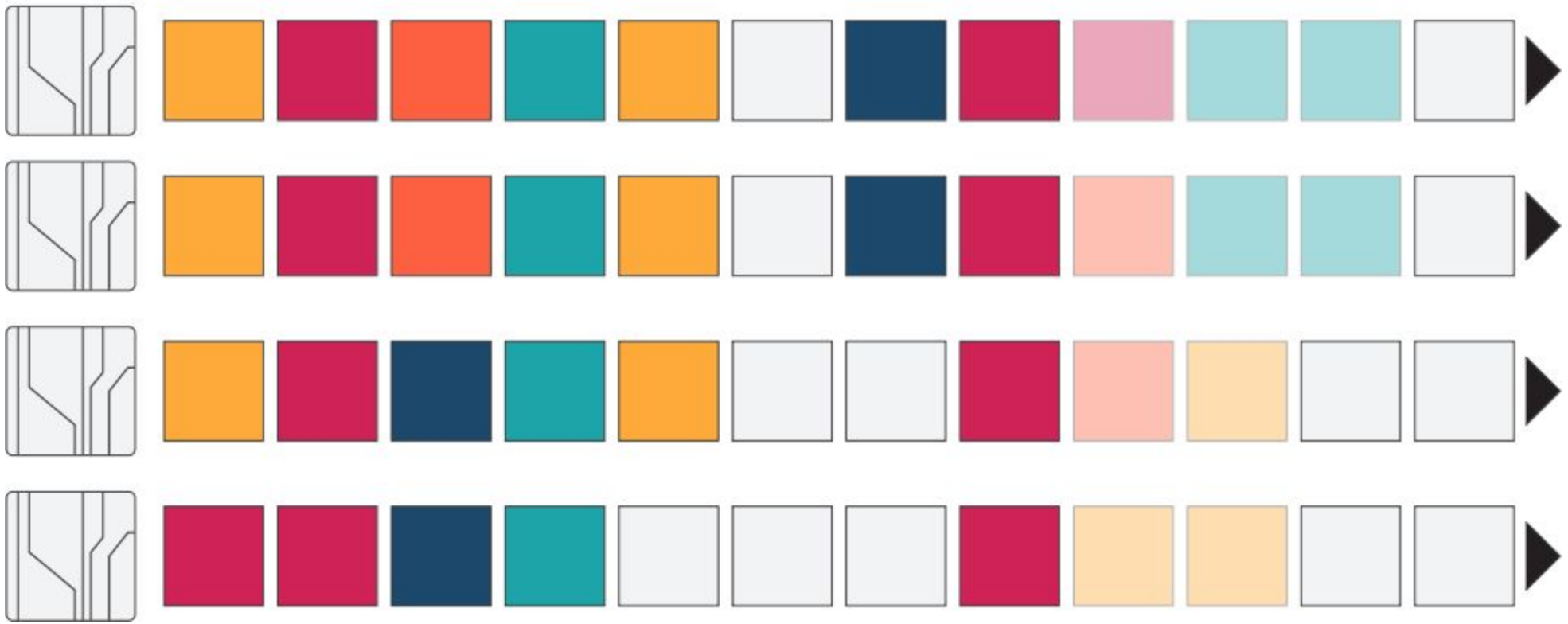

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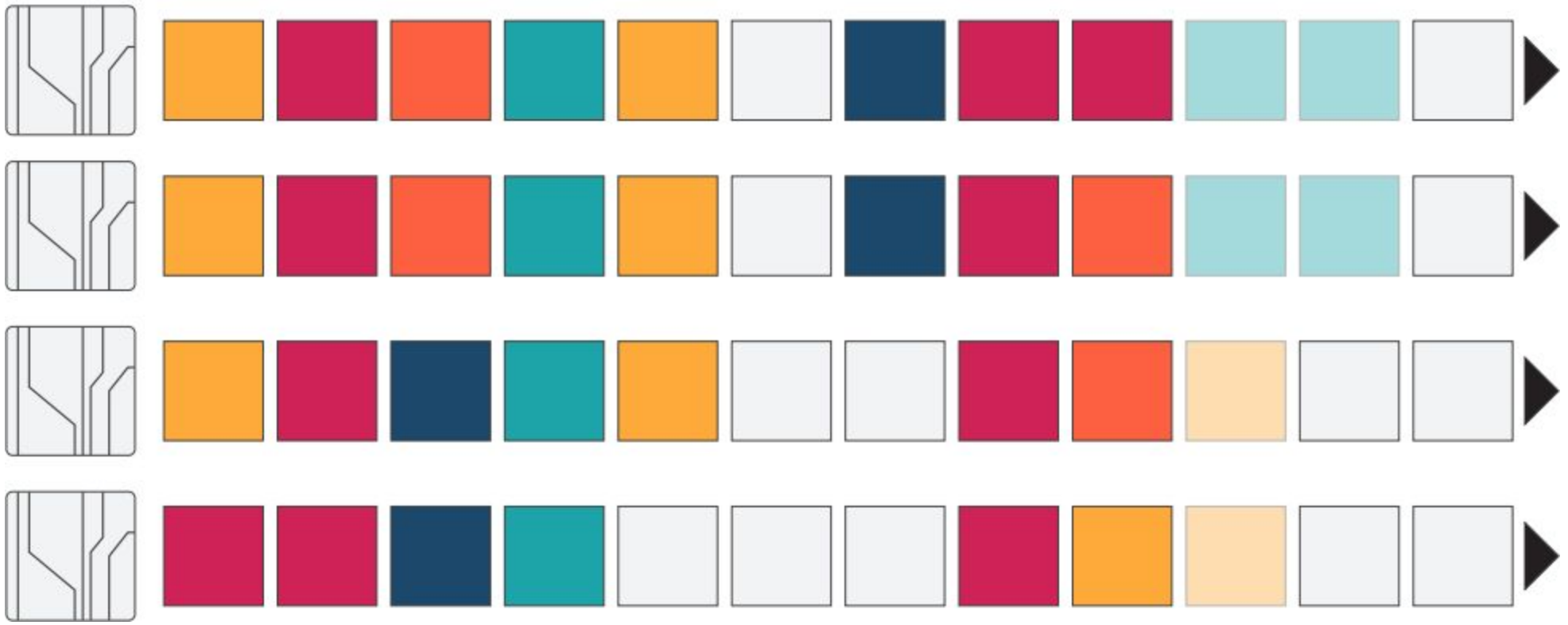

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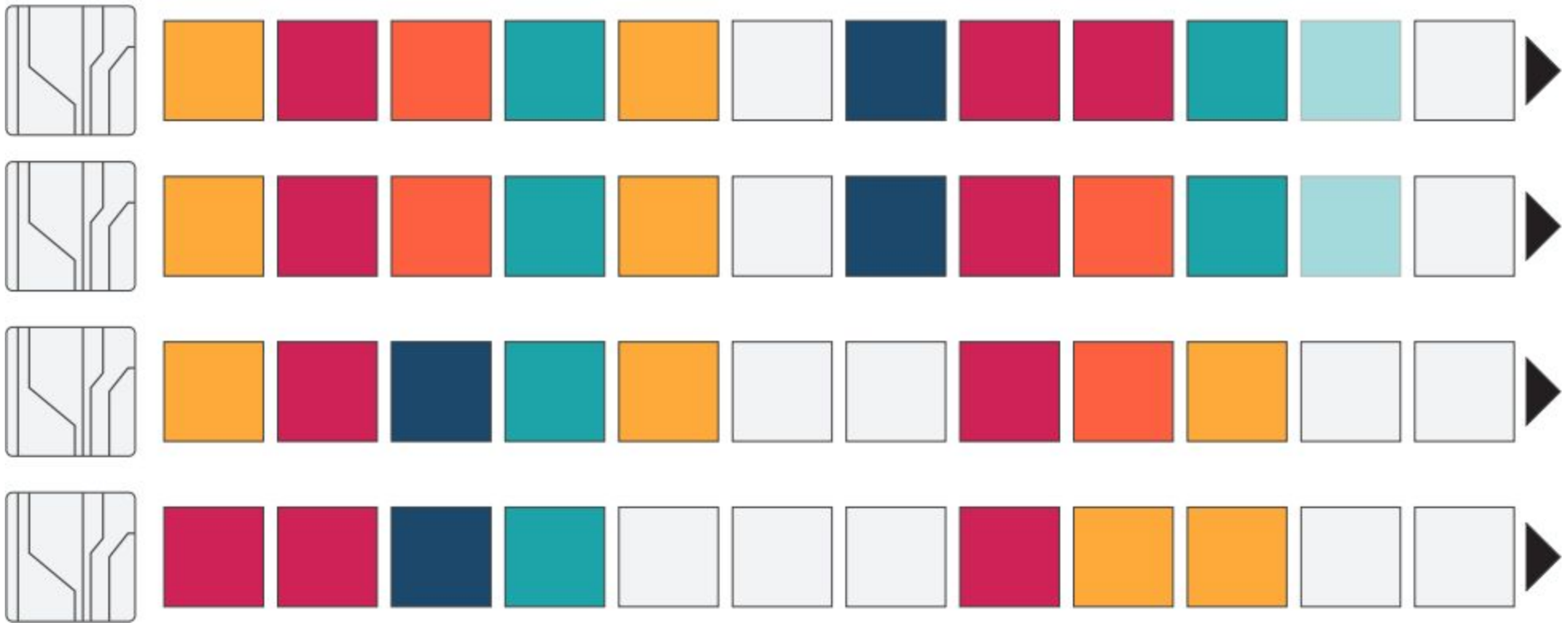

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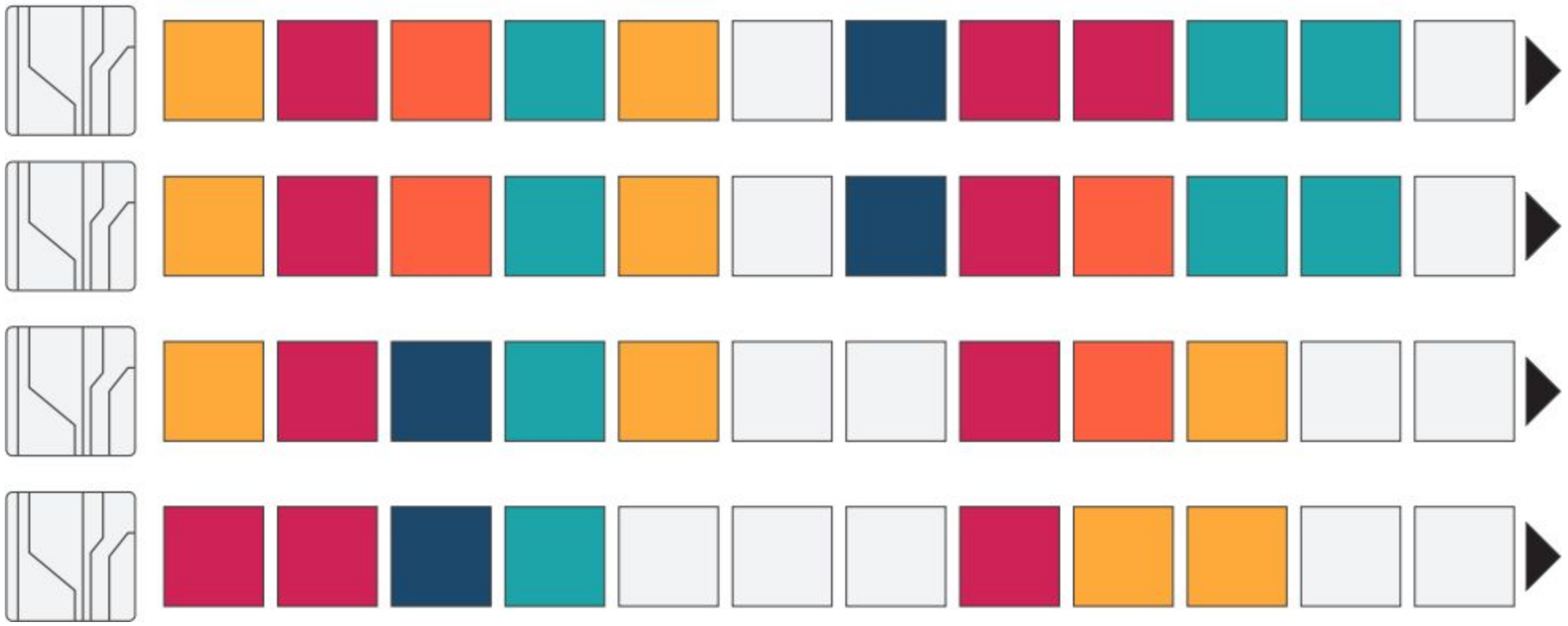

Peut-on **mieux réduire**
la consommation
en exploitant le **parallélisme** ?

Déclaration de thèse≃ solution du problème:

Déclaration de thèse≃ solution du problème:

Le parallélisme permet de
réduire l'énergie consommée tout en
garantissant **les contraintes temporelles**

Contributions choisies

- Validation théorique
- Un nouveau système d’exploitation
- Validation pratique

Contributions choisies

- **Validation théorique**
- Un nouveau système d’exploitation
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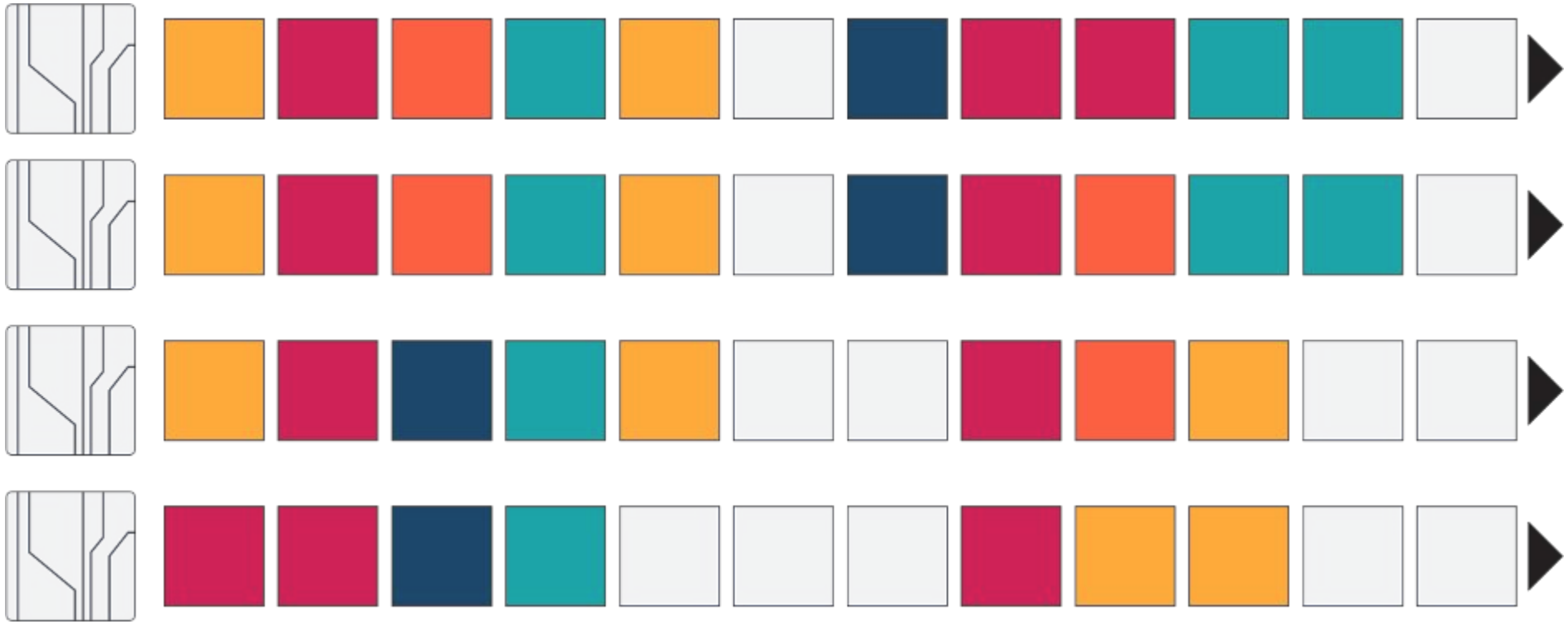
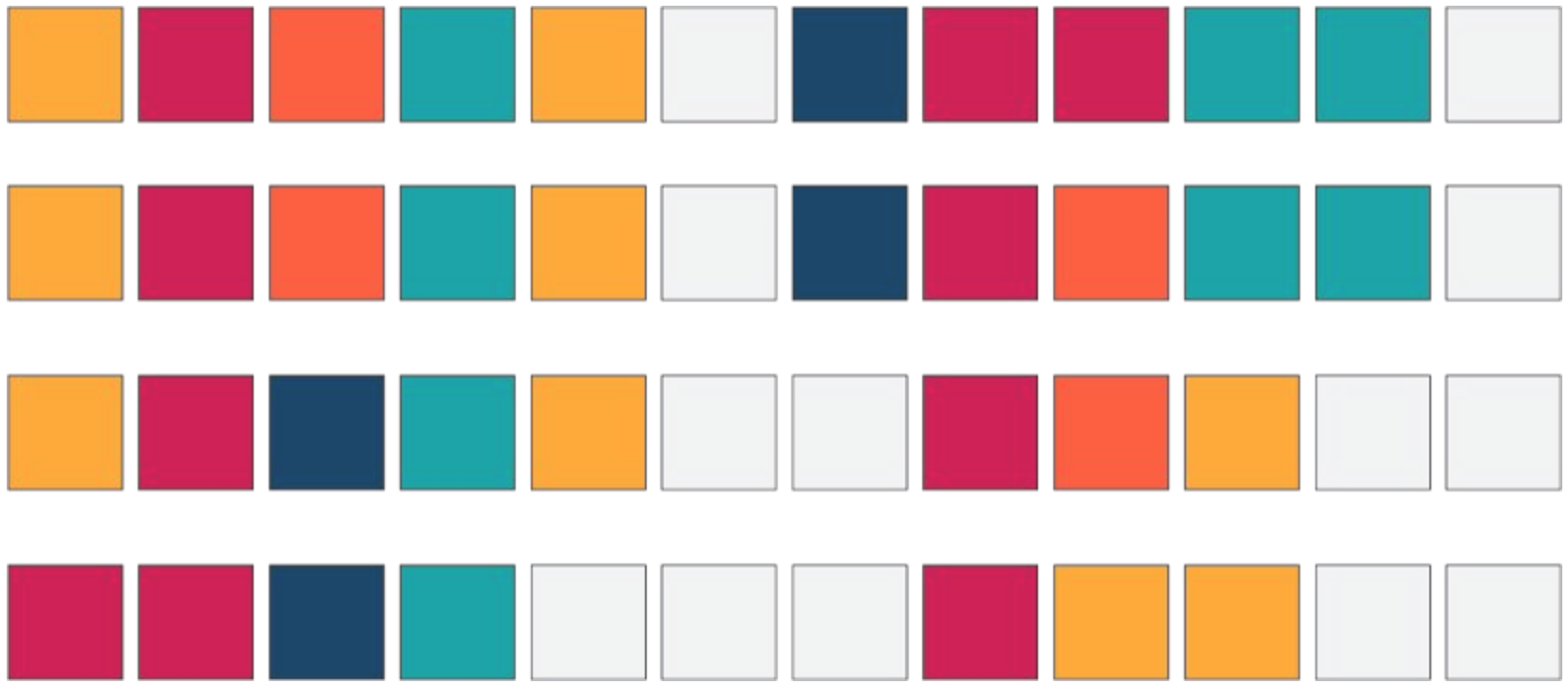
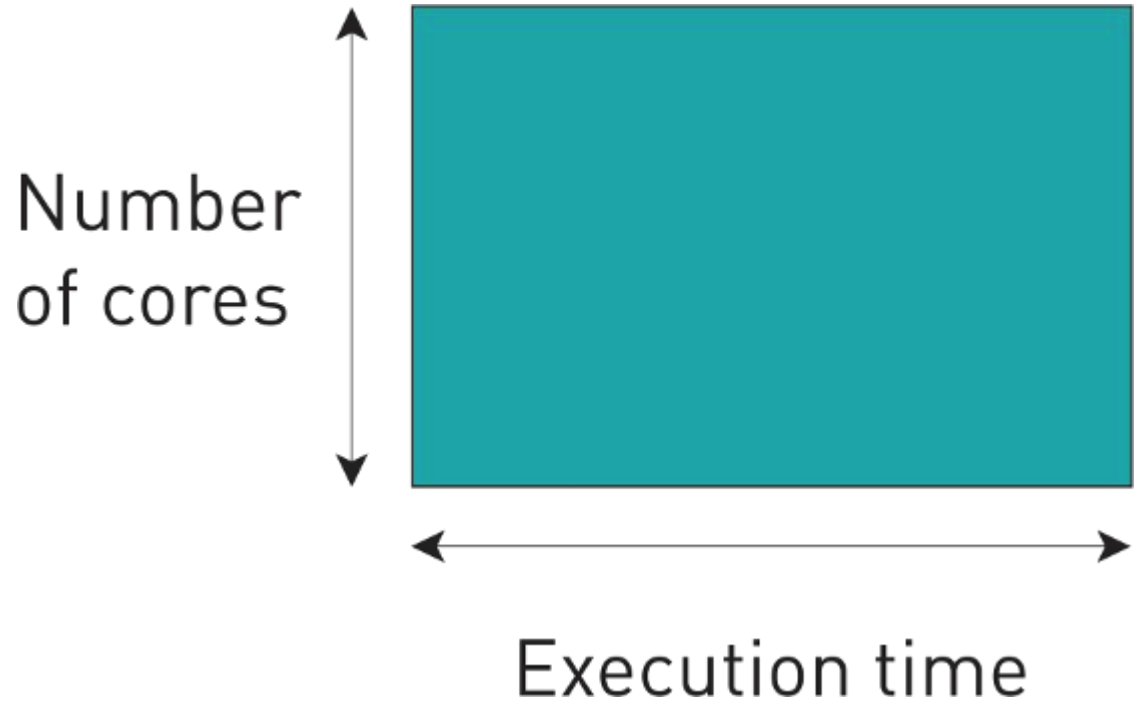
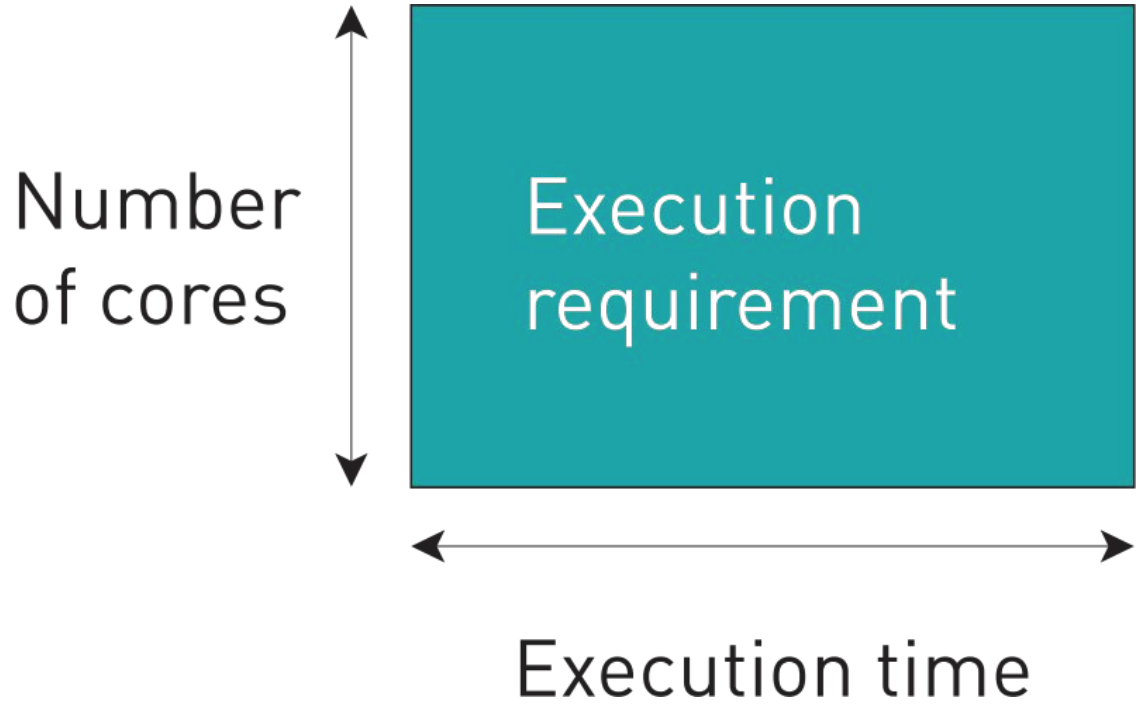




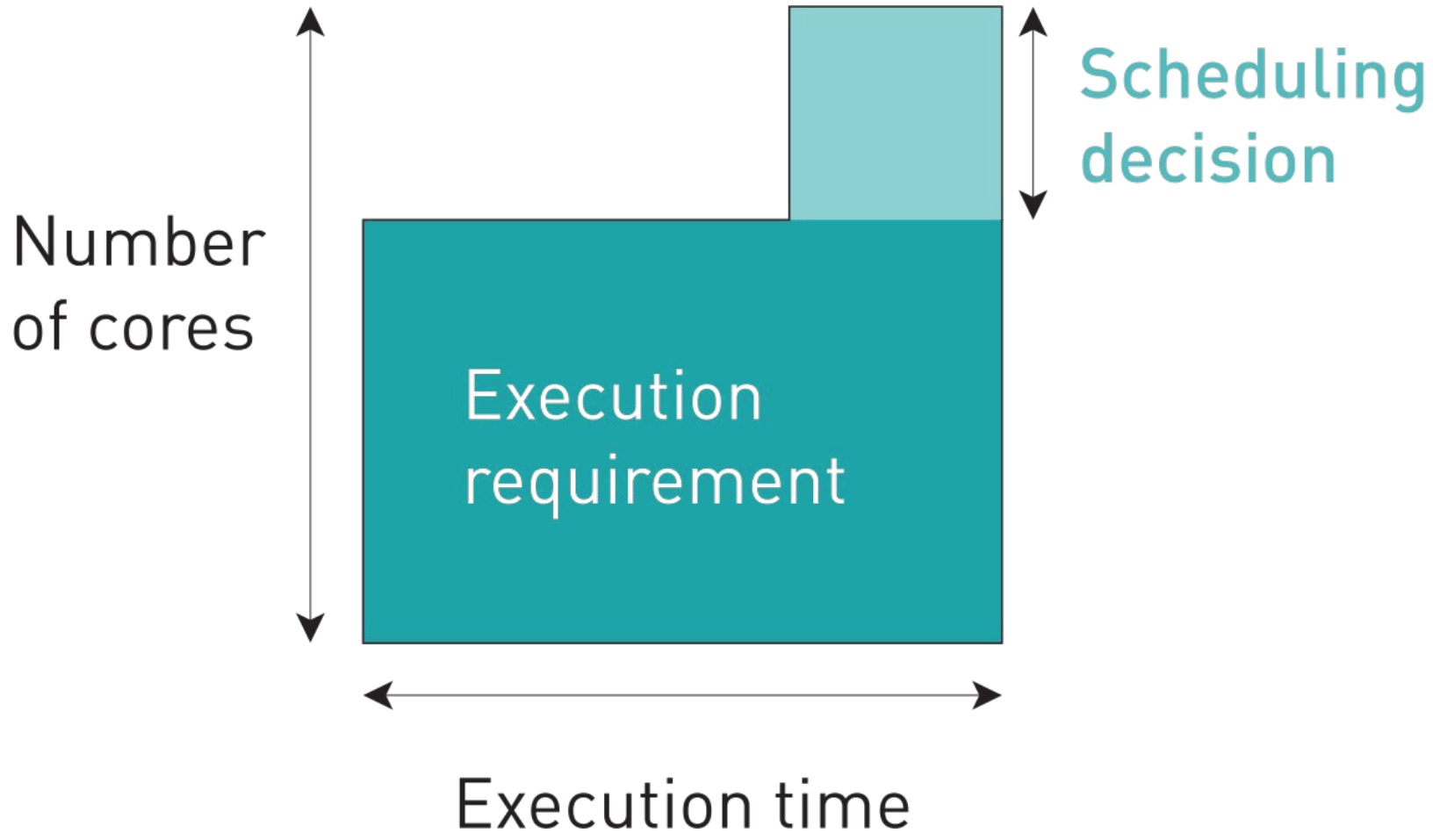
Parallel job model



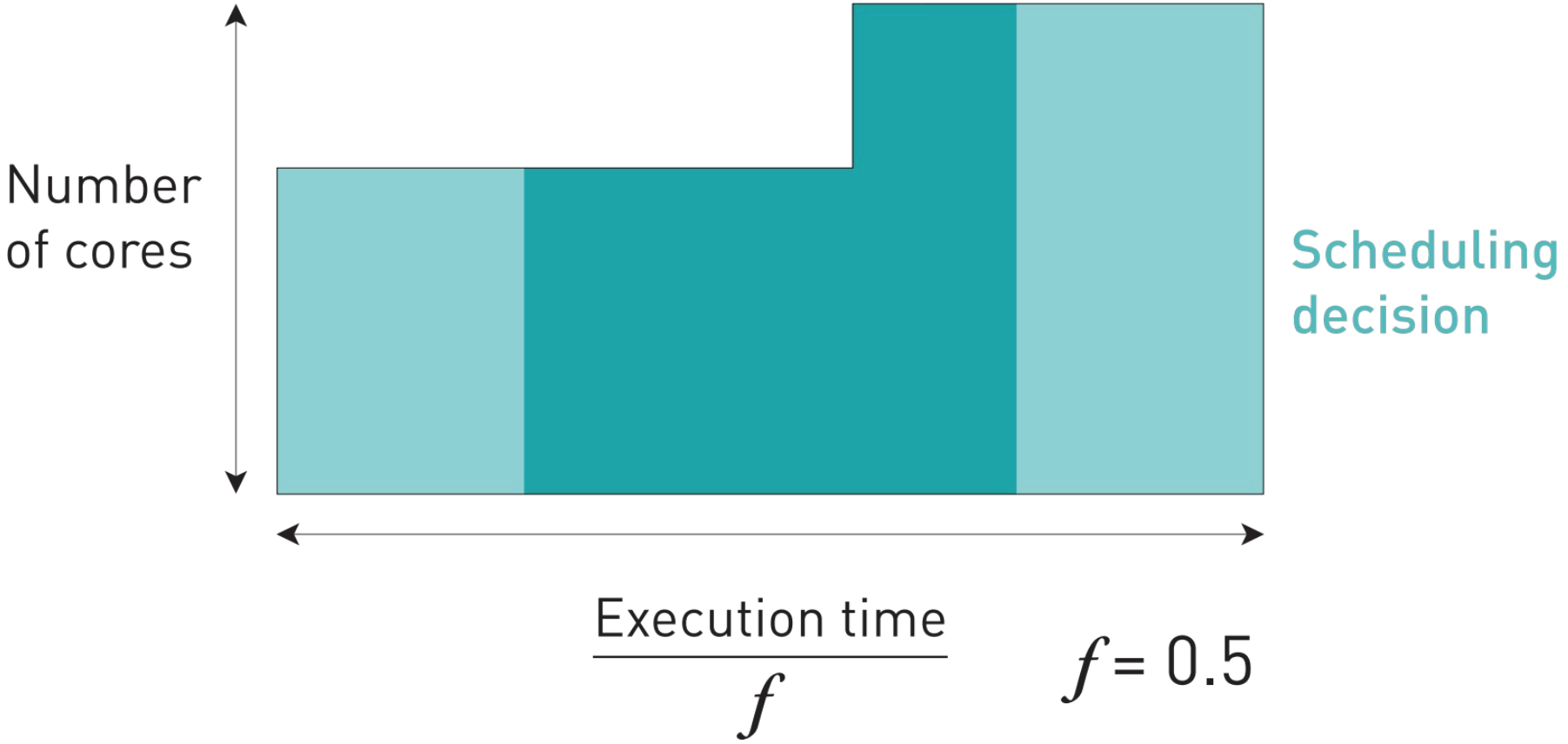
Parallel job model



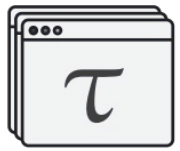
Malleable job



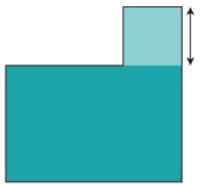
Malleable job



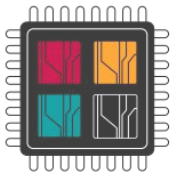
Find f and k such that $P(f, k)$ is minimized



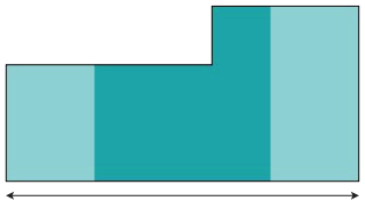
Implicit-deadline sporadic tasks



Malleable jobs



DVFS/DPM-enabled processor with m cores



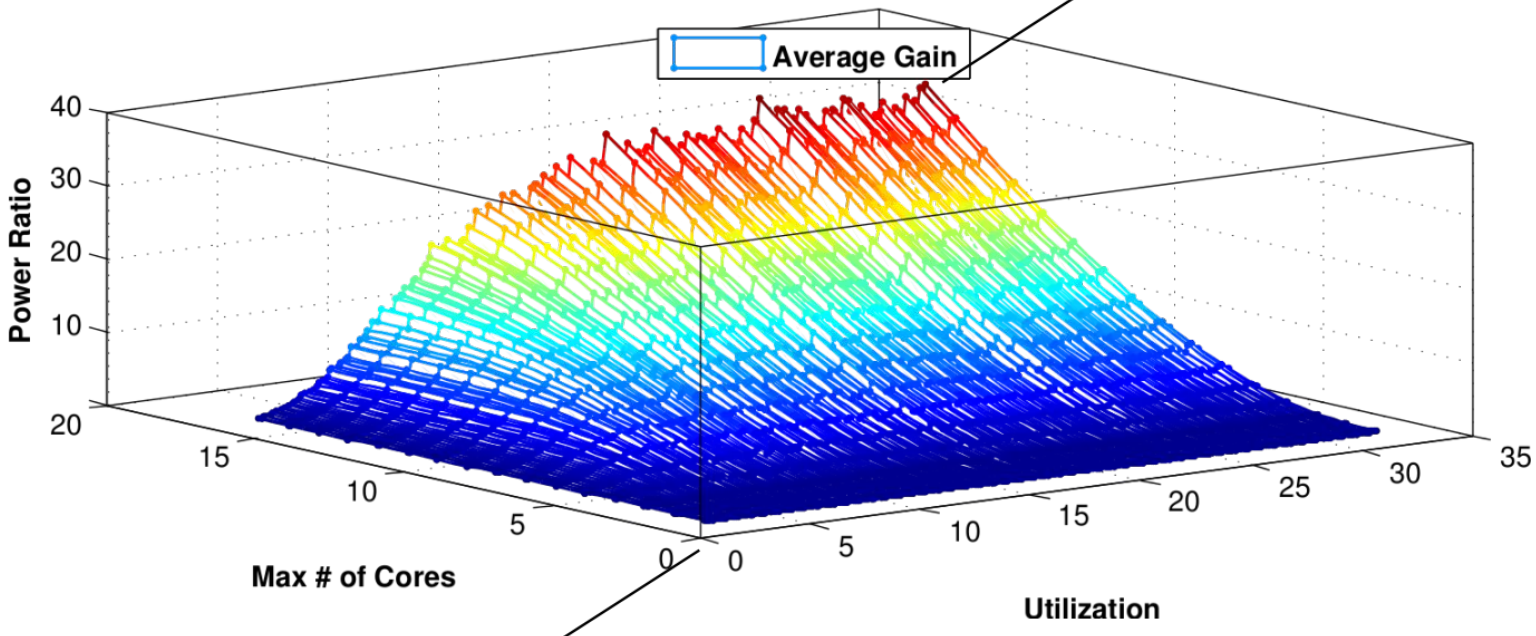
Homogeneous frequency

Canonical optimal scheduling

Results - parallelism helps

$P_{mal} << P_{seq}$

Ratio ≃ 36



$P_{mal} = P_{seq}$

Ratio = 1

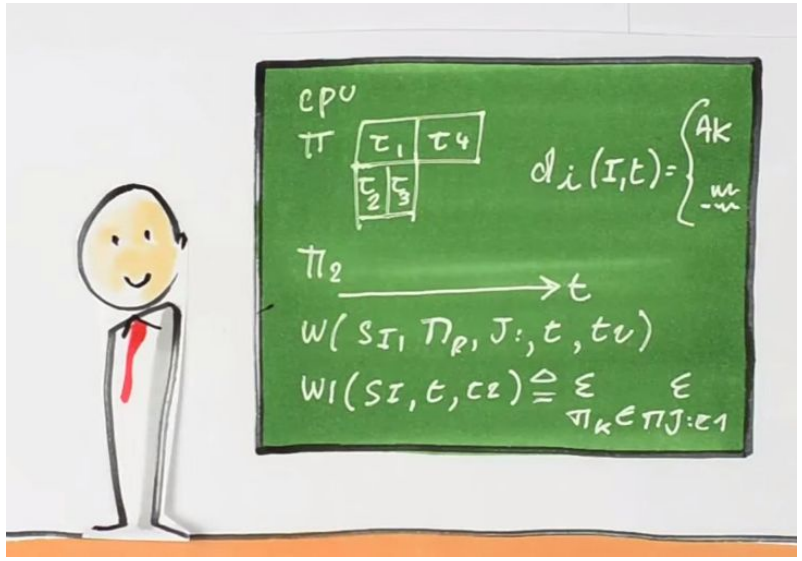
Contributions choisies

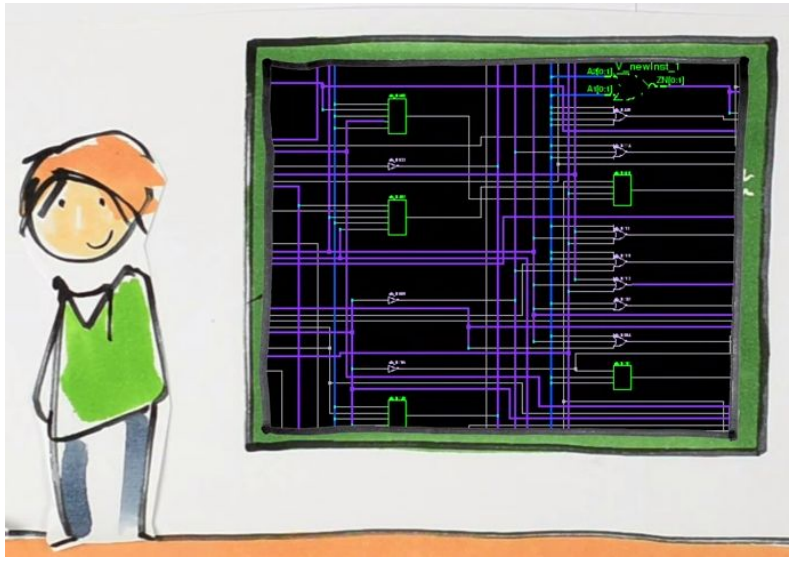
- Validation théorique
- **Un nouveau système d’exploitation**
- Validation pratique

OS pour l’embarqué en 2006

- Peu de considérations pour le multi-cœur
- Noyaux actuels ne passent pas à l’échelle [Cerqueira2014]
- Contraintes temporelles et gestion de l’alimentation non intégrés
- **Ordonnancement:** écart entre la recherche et industrie

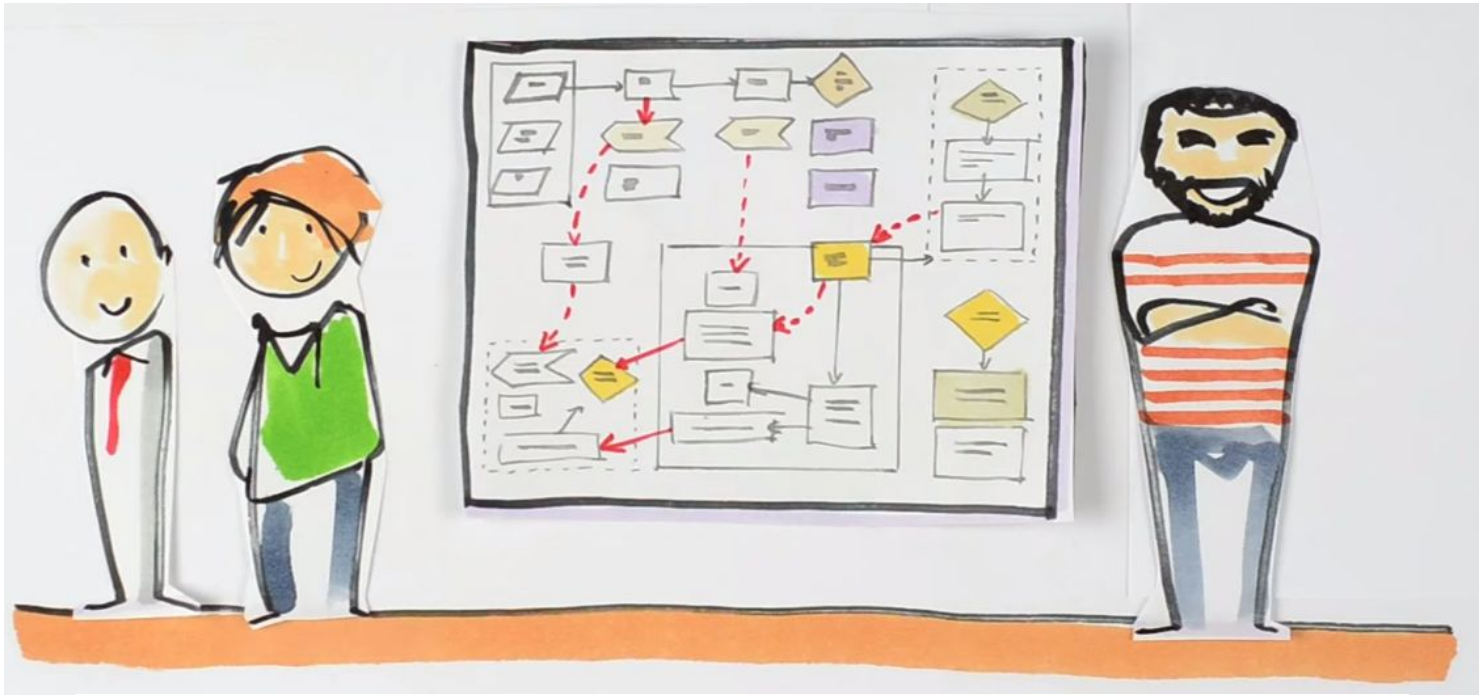
Parallel Architecture for Real-Time Systems





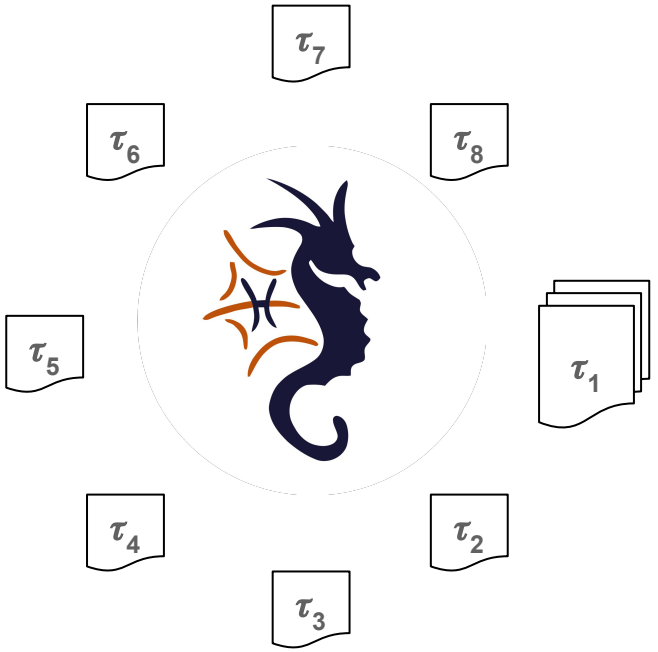
PARTS

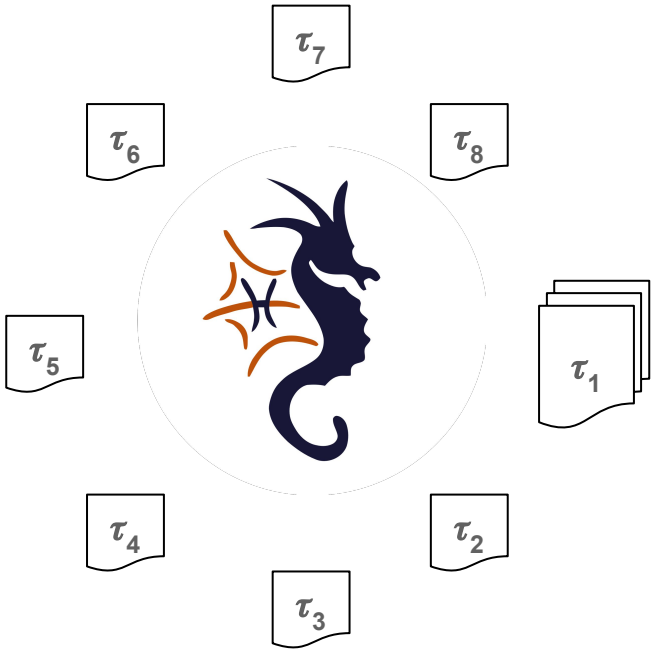
Parallel Architecture for Real-Time Systems

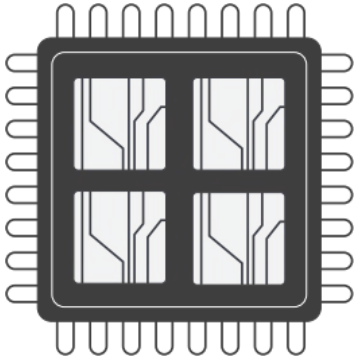


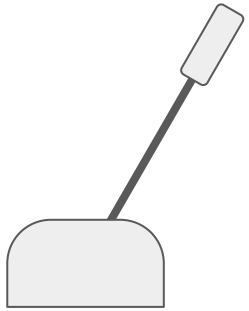
HIPPEROS®

Predictable Real-Time, Proven Performance


τ_7
τ_6
τ_8
τ_5
τ_1
τ_4
τ_2
τ_3


τ_7
τ_6
τ_8
τ_5
τ_1
τ_4
τ_2
τ_3





Contributions choisies

- Validation théorique
- Un nouveau système d’exploitation
- **Validation pratique**

Plate-forme expérimentale

Carte embarquée

Plate-forme expérimentale

Carte embarquée

Plate-forme expérimentale

OS
& bibliothèques

Carte embarquée

Plate-forme expérimentale

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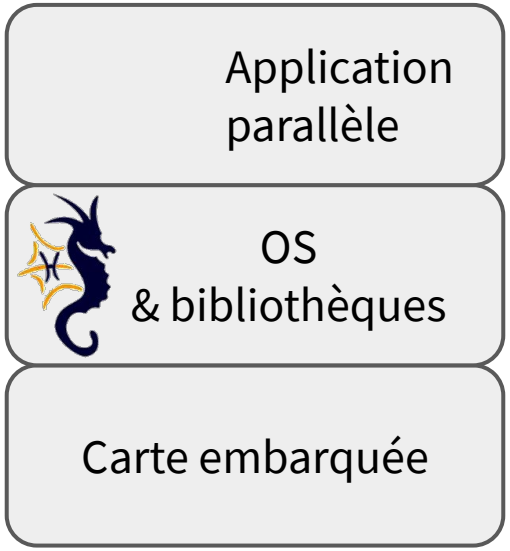
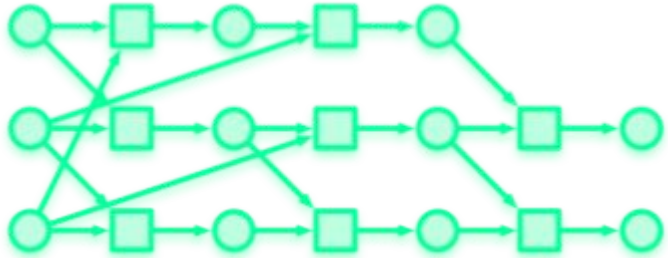
Plate-forme expérimentale



Application parallèle ?

OPTIMISATION
OF PERFORMANCE METRICS
OF EMBEDDED
HARD REAL-TIME SYSTEMS
USING **SOFTWARE**/HARDWARE
PARALLELISM



Application parallèle ?

```
1  int main()
2  {
3    const int num_steps = 1000;
4    omp_set_num_threads(4);
5
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7    {
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9      int tid = omp_get_thread_num();
10     int i_start = (tid * num_steps) / nbt;
11     int i_end = ((tid + 1) * num_steps) / nbt;
12
13     for (int i = i_start; i < i_end; ++i) {
14       /* workload executed in parallel */
15     }
16   }
17
18   return 0;
19 }
```

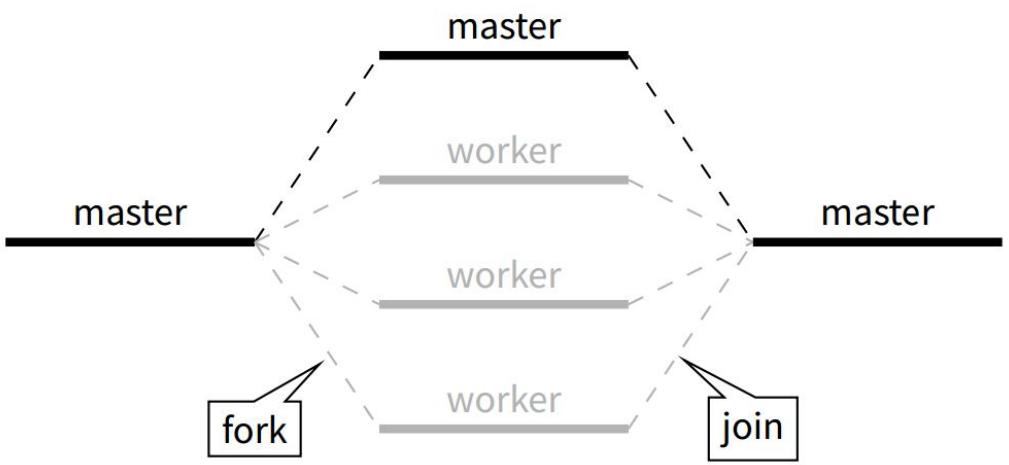


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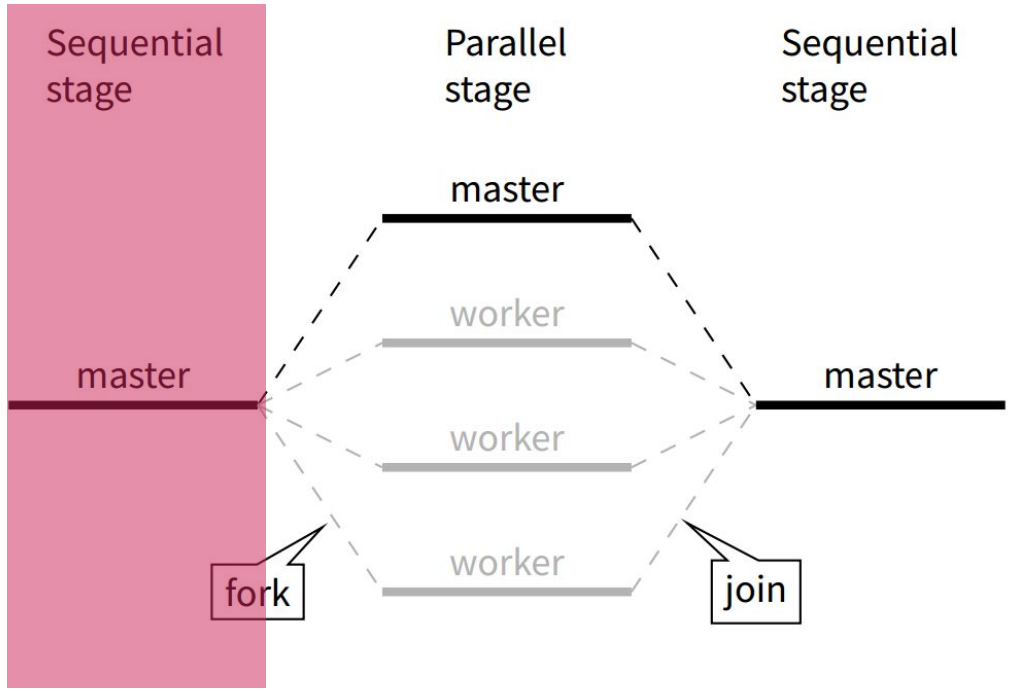


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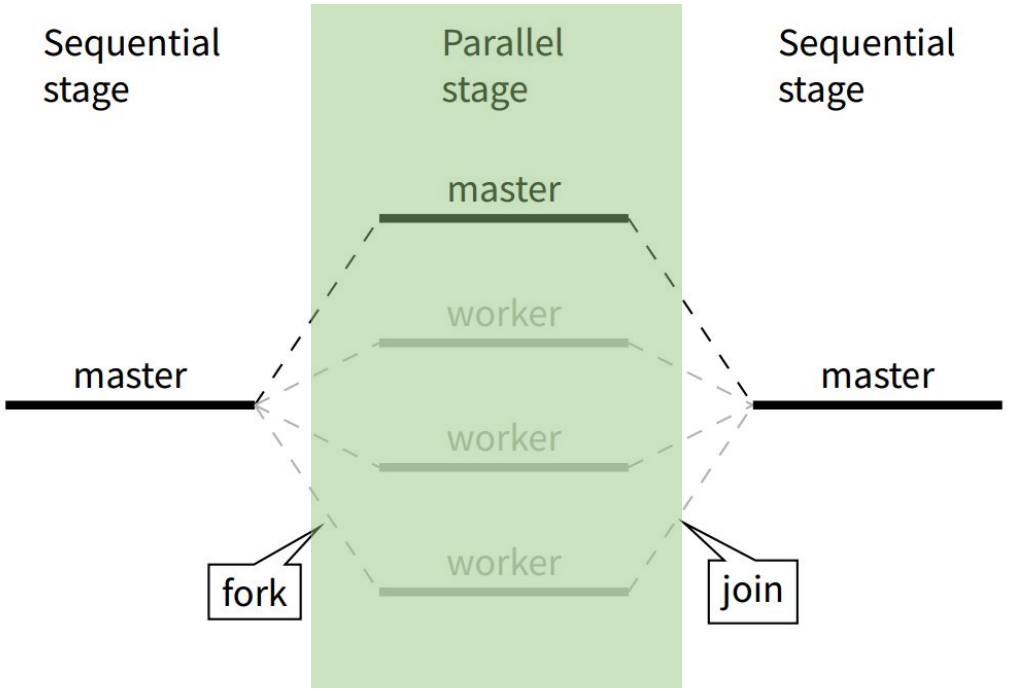


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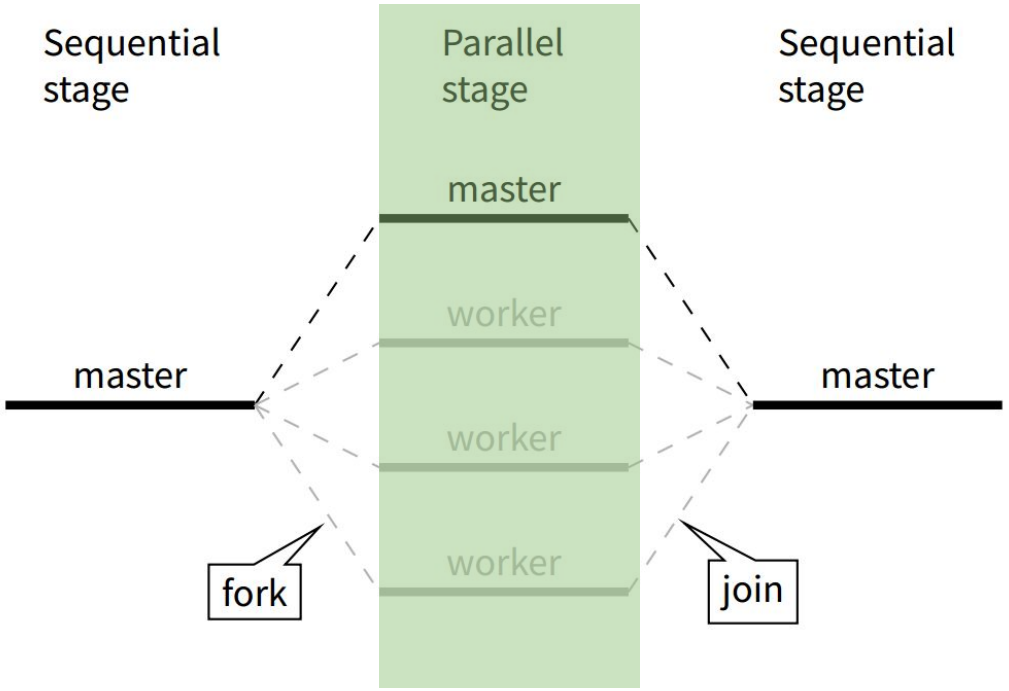


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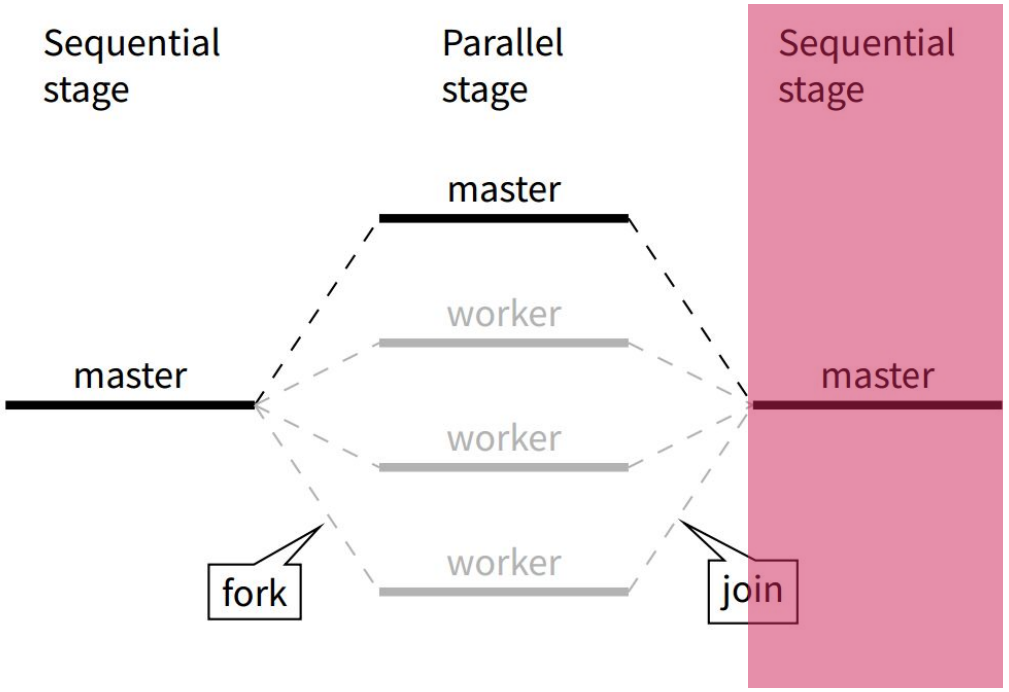


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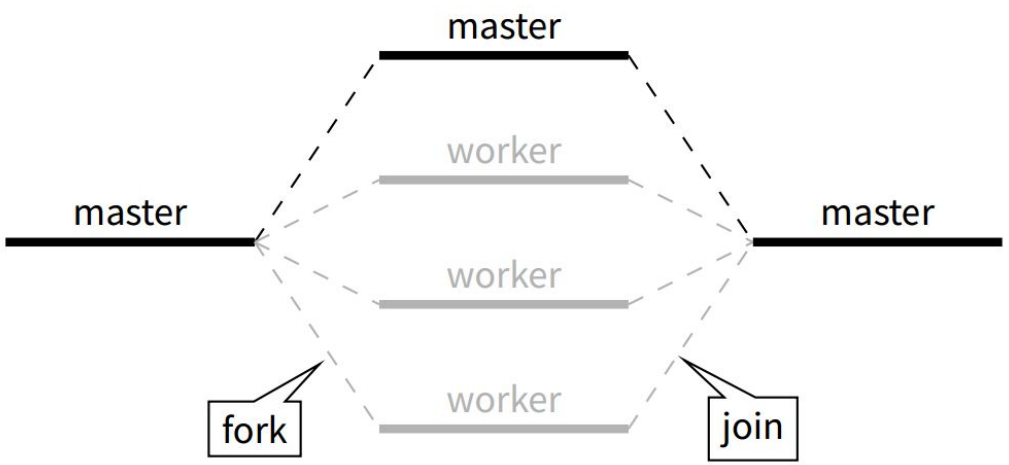


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Plate-forme expérimentale

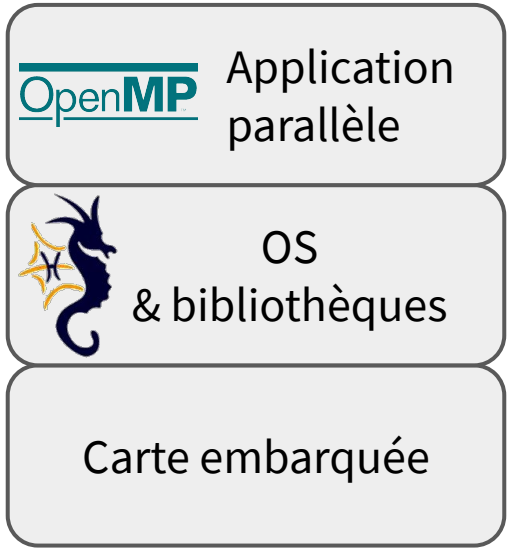
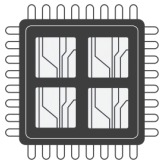
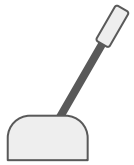
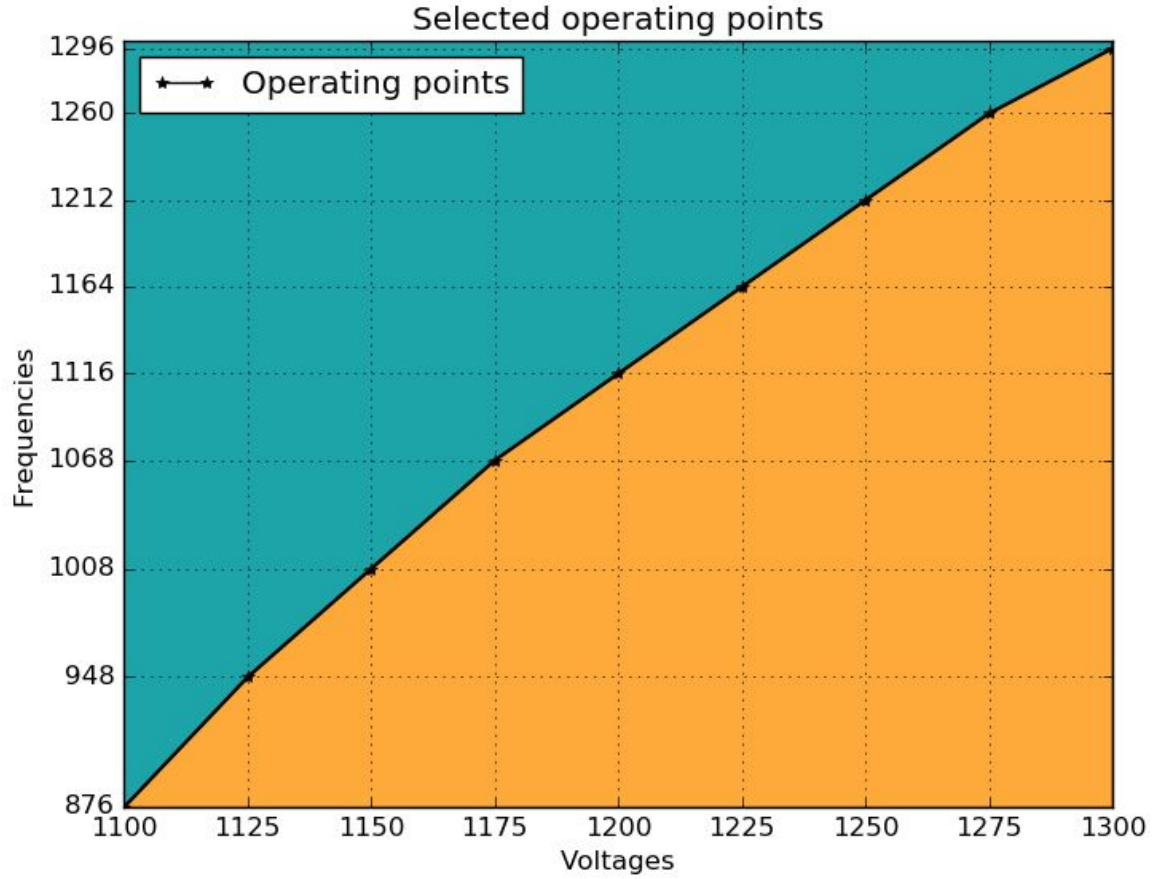


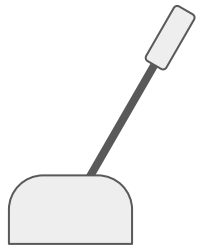
Plate-forme ciblée - i.MX6q SabreLite

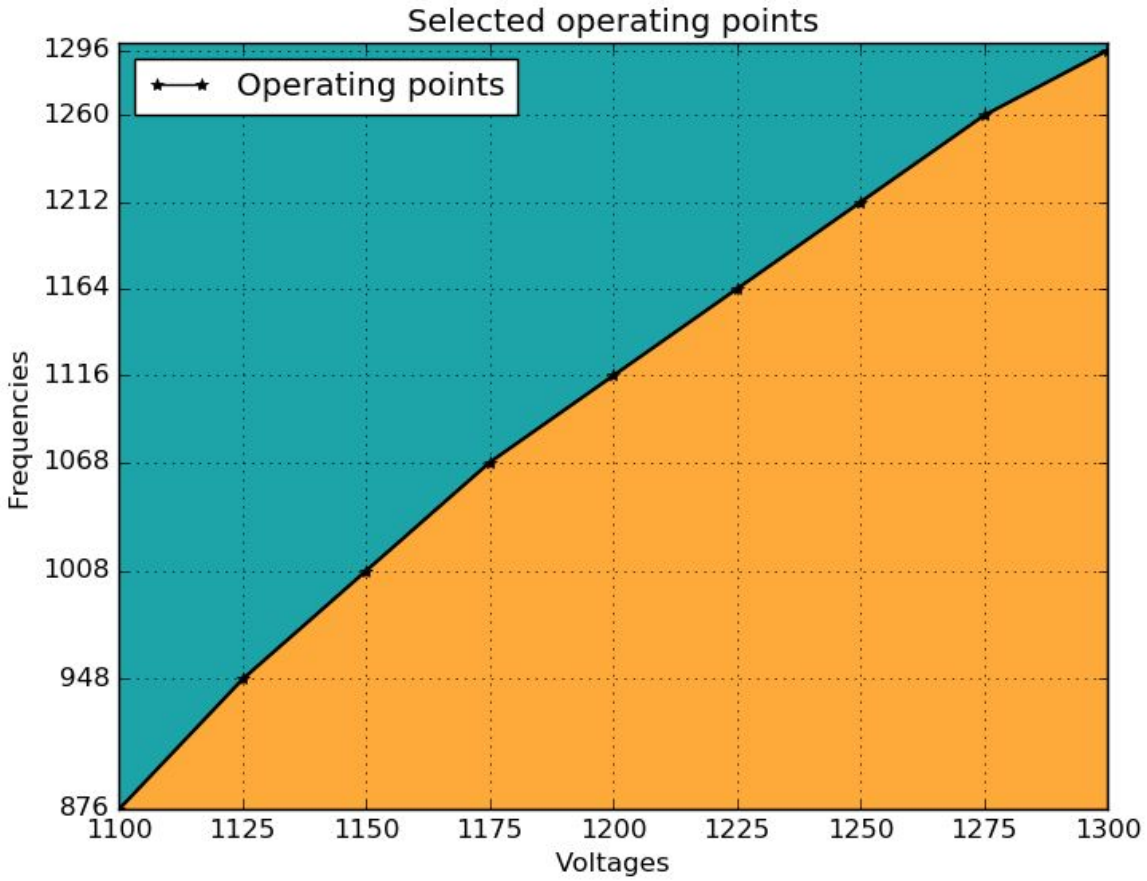
- Carte embarquée ARM Cortex A9 MP
- Supportée par HIPPEROS
- 4 cœurs 
- DVFS global *(operating points)* 

DVFS


Selected operating points
Operating points
Frequencies
1296
1260
1212
1164
1116
1068
1008
948
876
1100
1125
1150
1175
1200
1225
1250
1275
1300
Voltages

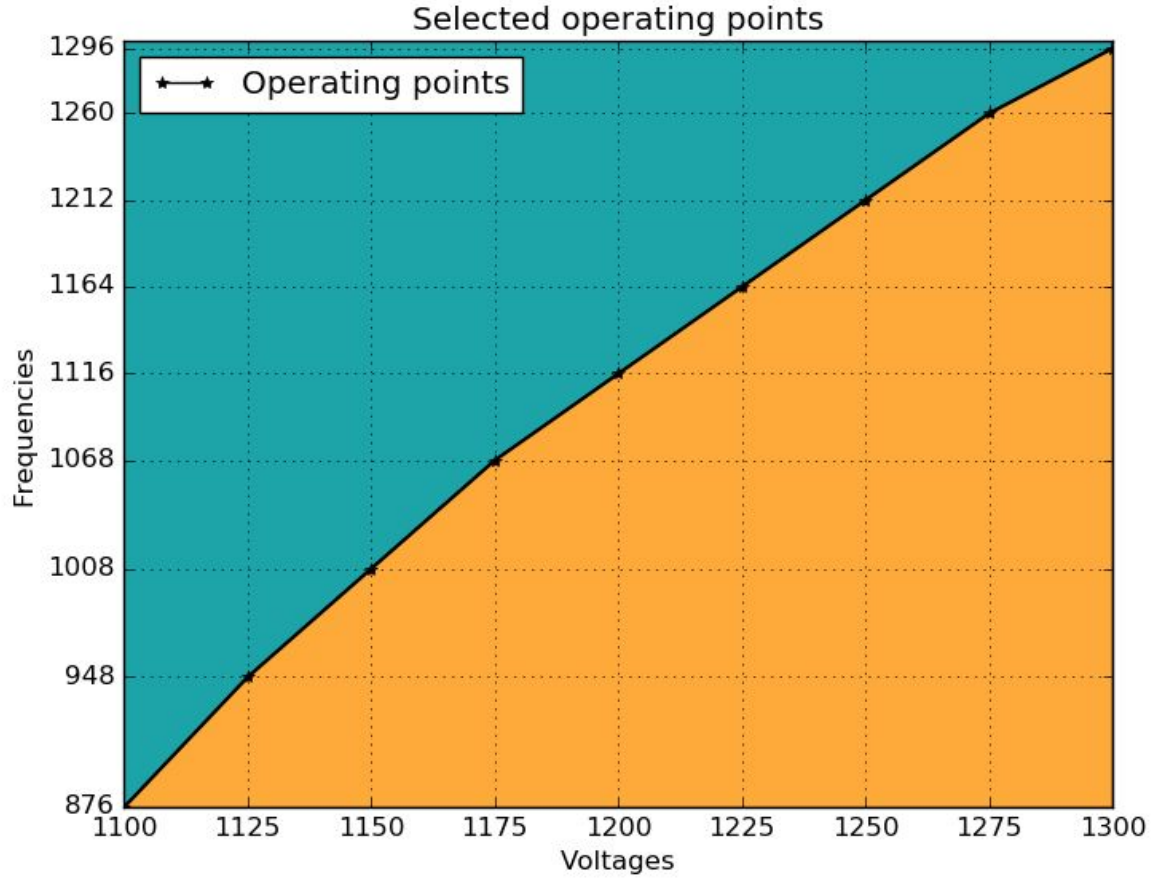
DVFS





Voltage (mV)	Frequency (MHz)
1100	876
1125	948
1150	1008
1175	1068
1200	1116
1225	1164
1250	1212
1275	1260
1300	1296

DVFS et consommation



$$P \propto V_{dd}^{2} f$$

$$V_{dd} \propto f$$

Plate-forme expérimentale

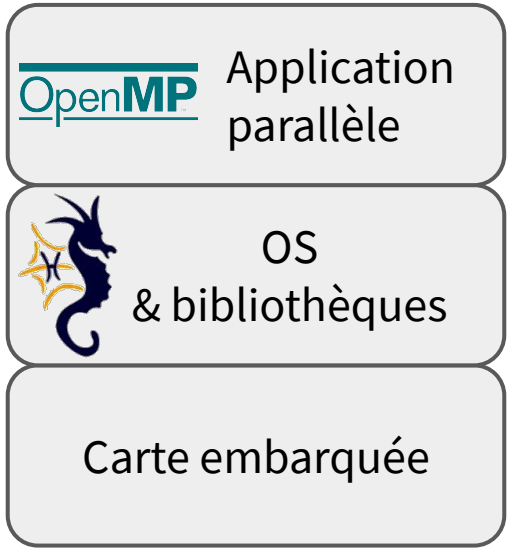


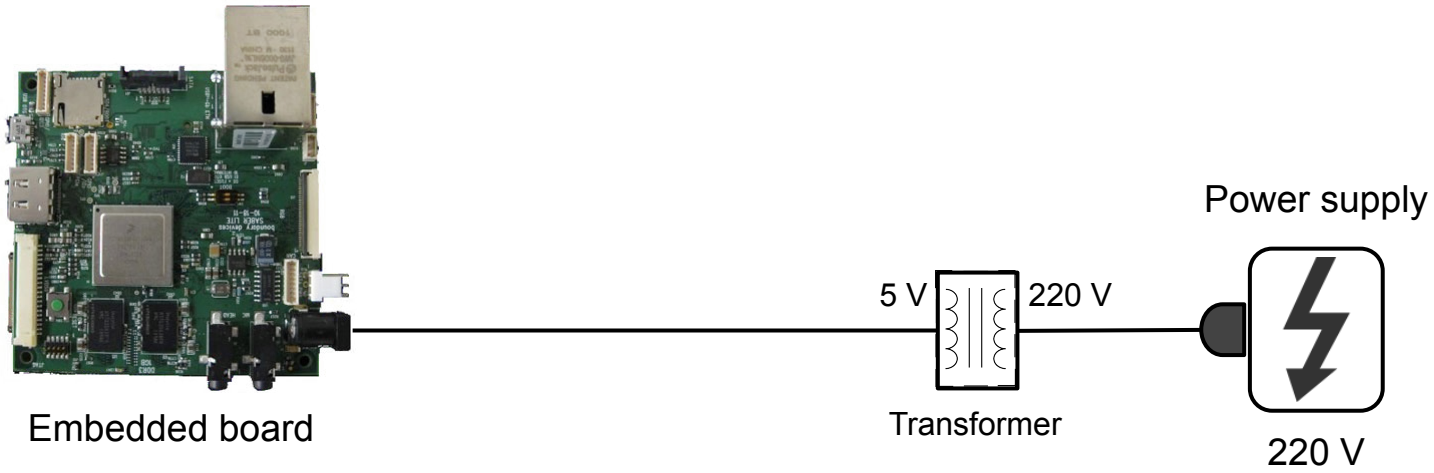
Plate-forme expérimentale

Application parallèle

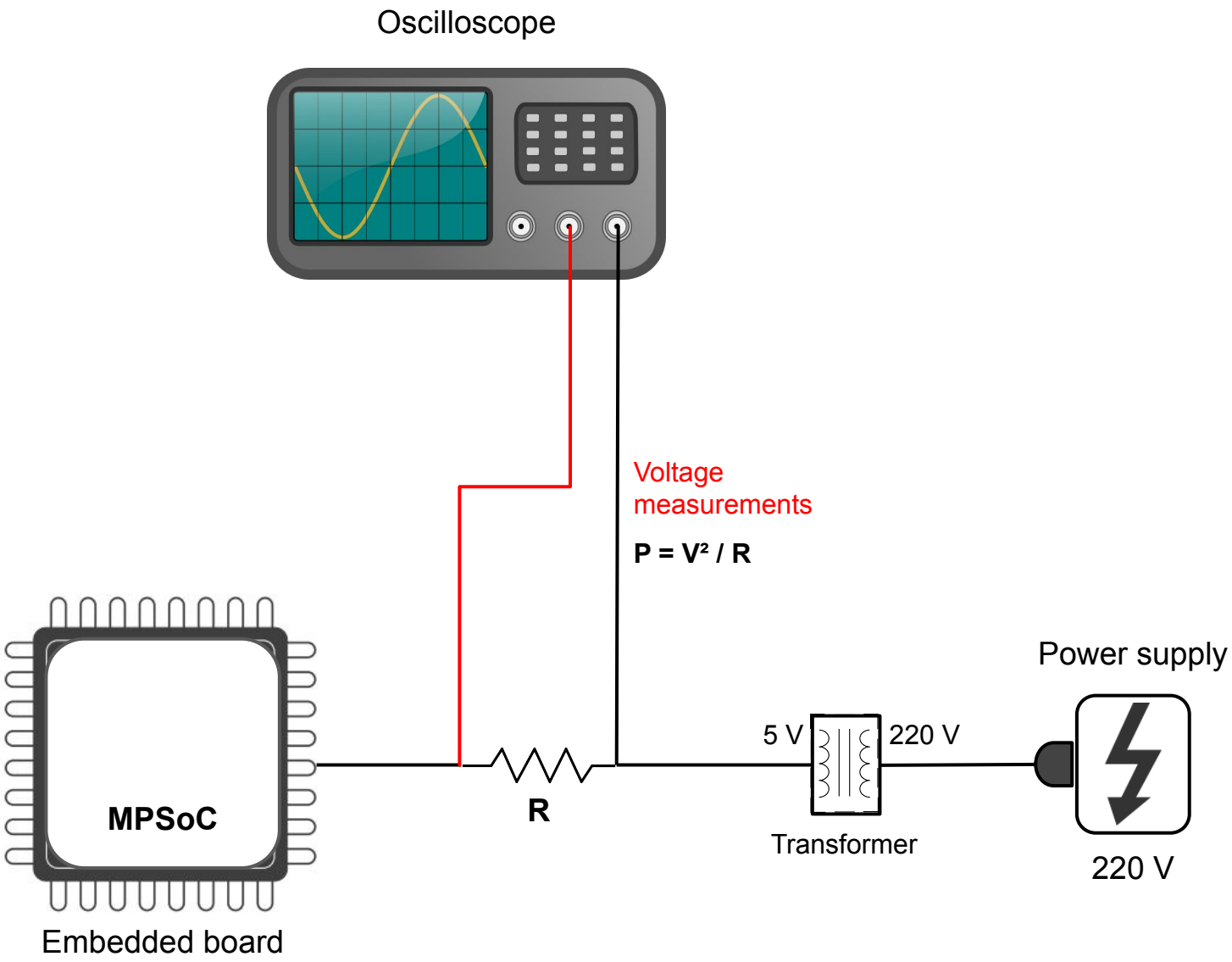
OS & bibliothèques

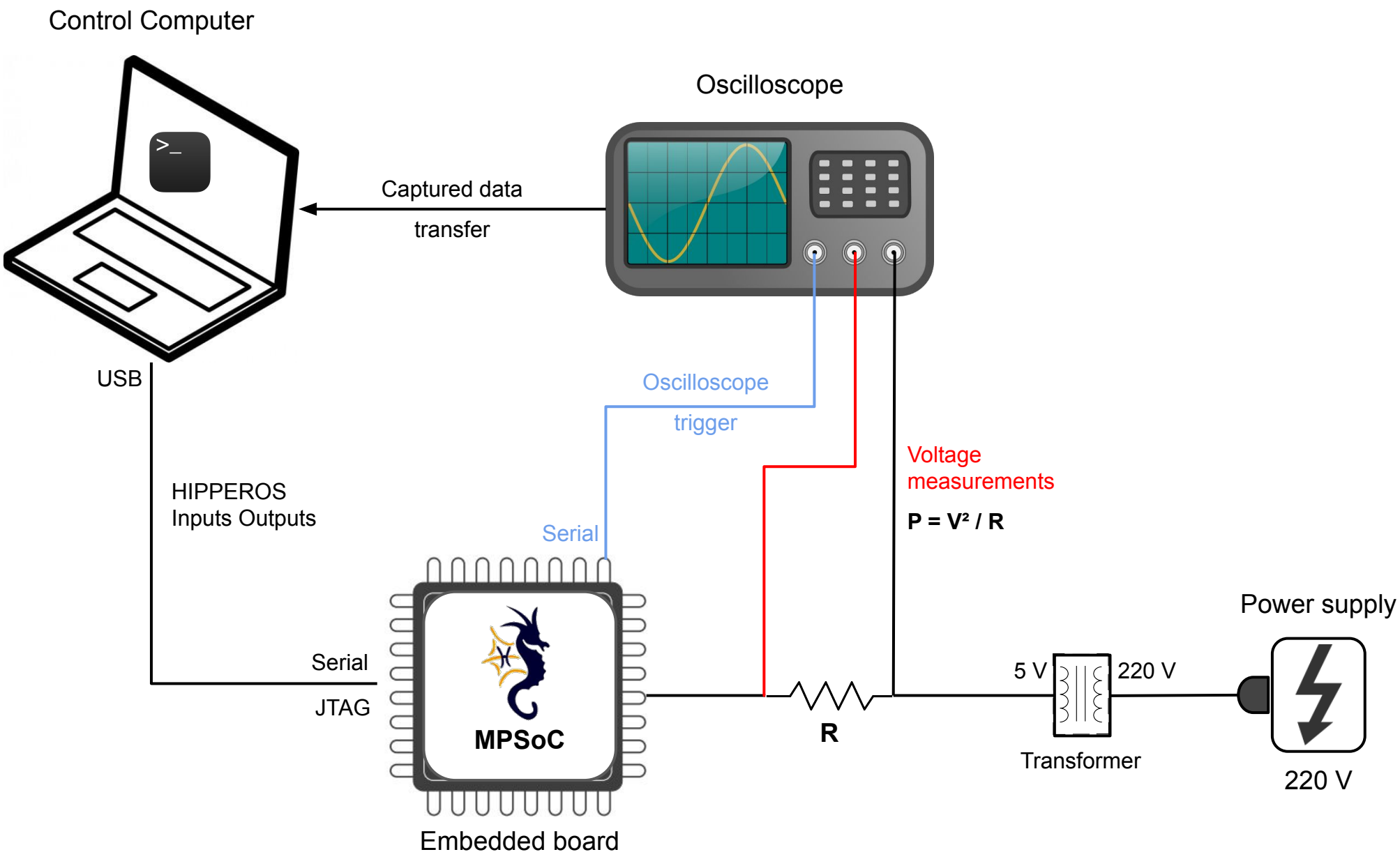
Carte embarquée

Outils de mesure


Power supply
5 V
220 V
Embedded board
Transformer
220 V


MPSoC
Embedded board
5 V
220 V
Transformer
Power supply
220 V

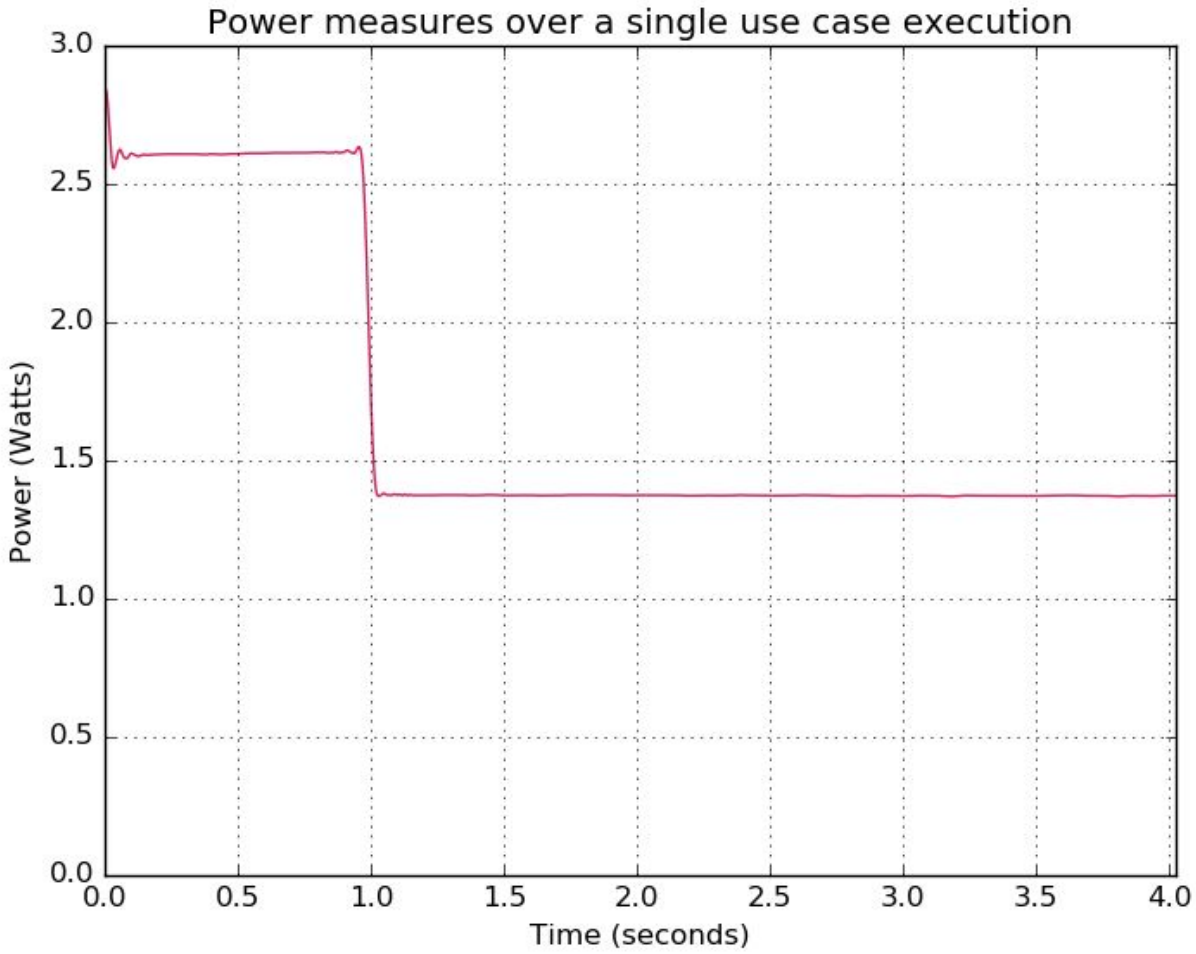

Oscilloscope
Voltage
measurements
P = V² / R
MPSoC
Embedded board
R
5 V
220 V
Transformer
Power supply
220 V


Control Computer
Oscilloscope
Captured data
transfer
USB
Oscilloscope
trigger
Voltage
measurements
P = V² / R
HIPPEROS
Inputs Outputs
Serial
Serial
JTAG
MPSoC
R
5 V
220 V
Transformer
Power supply
220 V
Embedded board

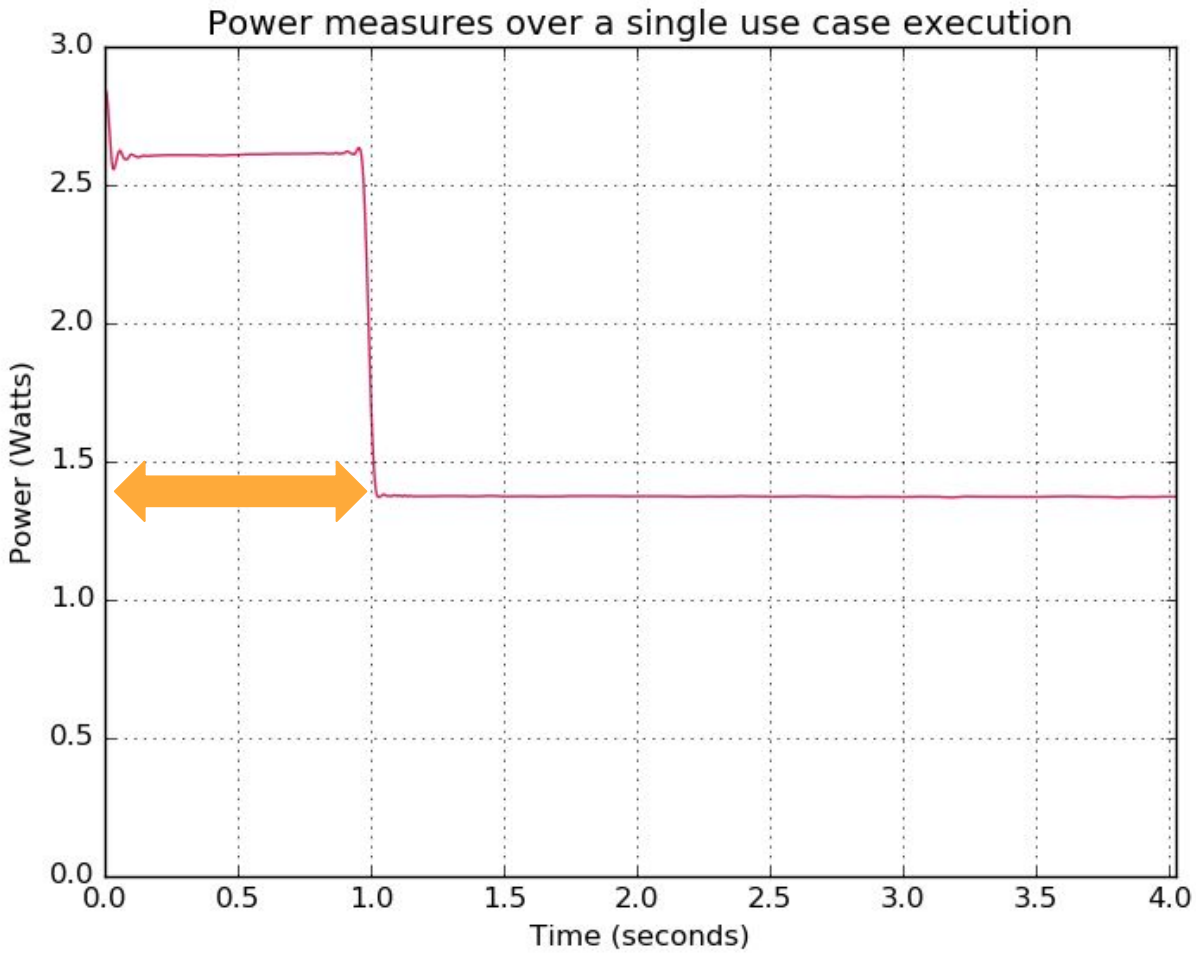

PHILIPS


Keysight Infiniium : Friday, April 08, 2016 5:22:03 AM
KEYSIGHT TECHNOLOGIES
Run
Stop
Single
50.0 Sa/s
High Res
11.0 Hz
T
2.48 V
1 1MΩ 140 mV/
444 mV
2 1MΩ 1.70 V/
-900 mV
Time Meas
Vertical Meas
Measurements
1.00 V
864 mV
724 mV
584 mV
444 mV
304 mV
164 mV
24 mV
-116 mV
-999 ms
-499 ms
1 ms
501 ms
1.00 s
1.50 s
2.00 s
2.50 s
3.00 s
3.50 s
4.00 s
H
500 ms/
1.6012800000000 s
Results

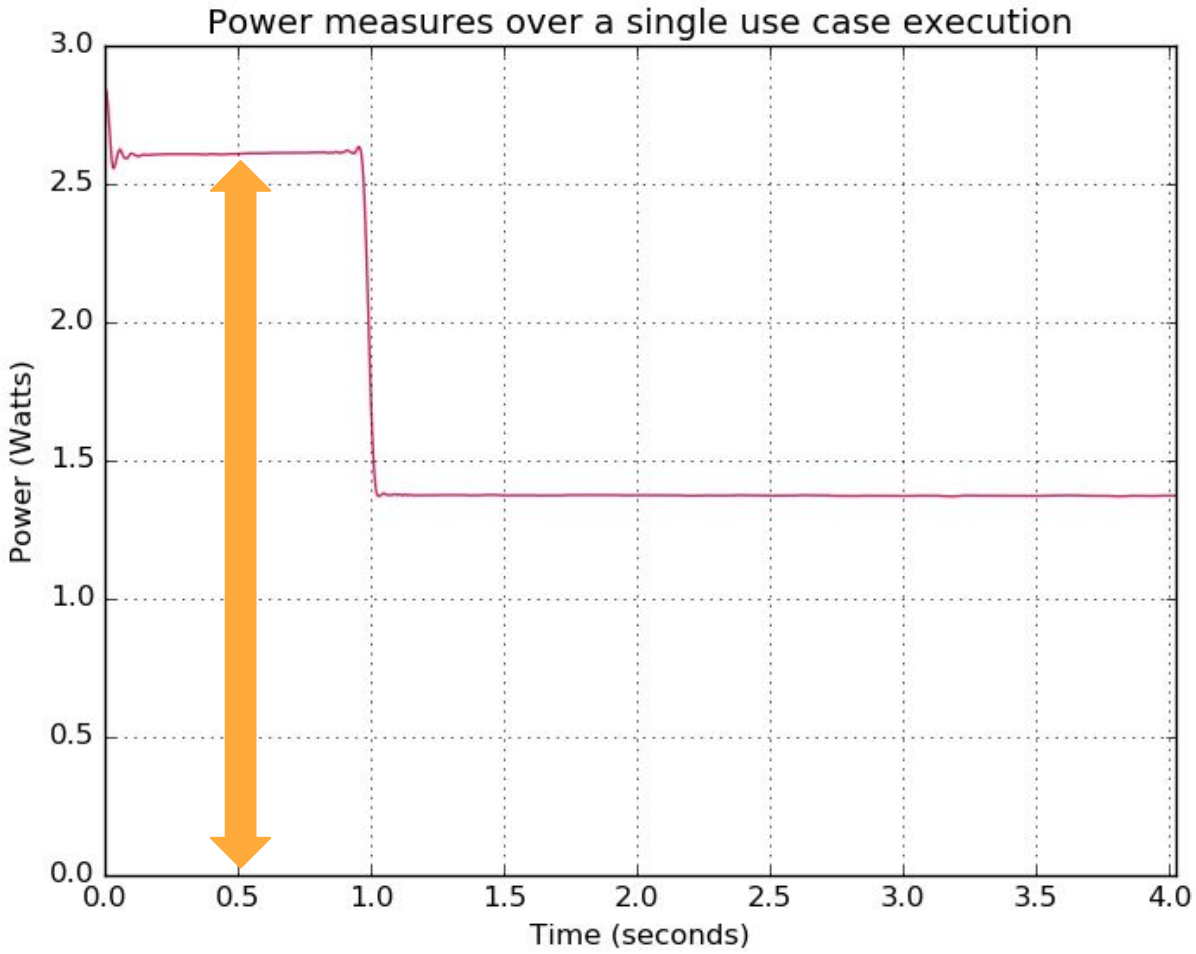
Voltage converti en puissance / temps



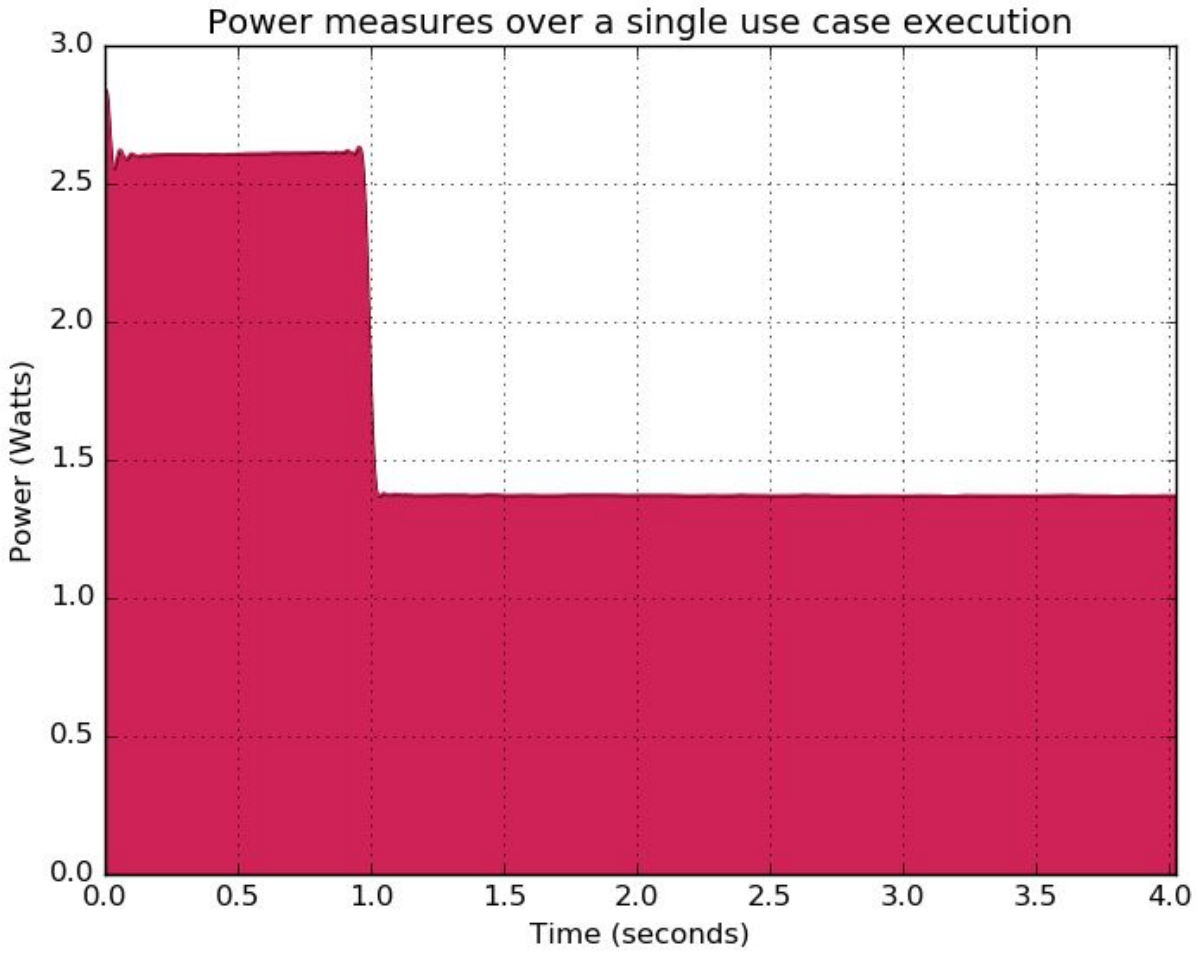
Temps d’exécution



Pic de puissance

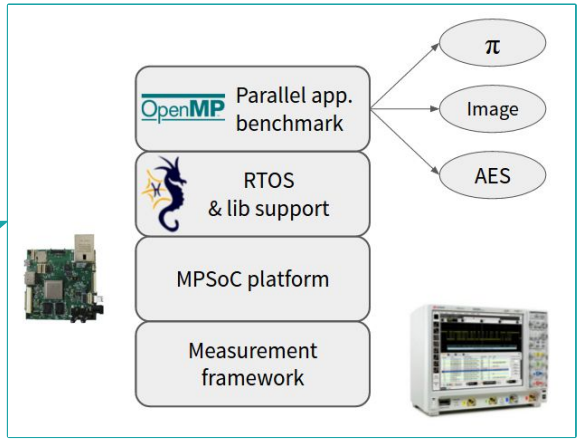


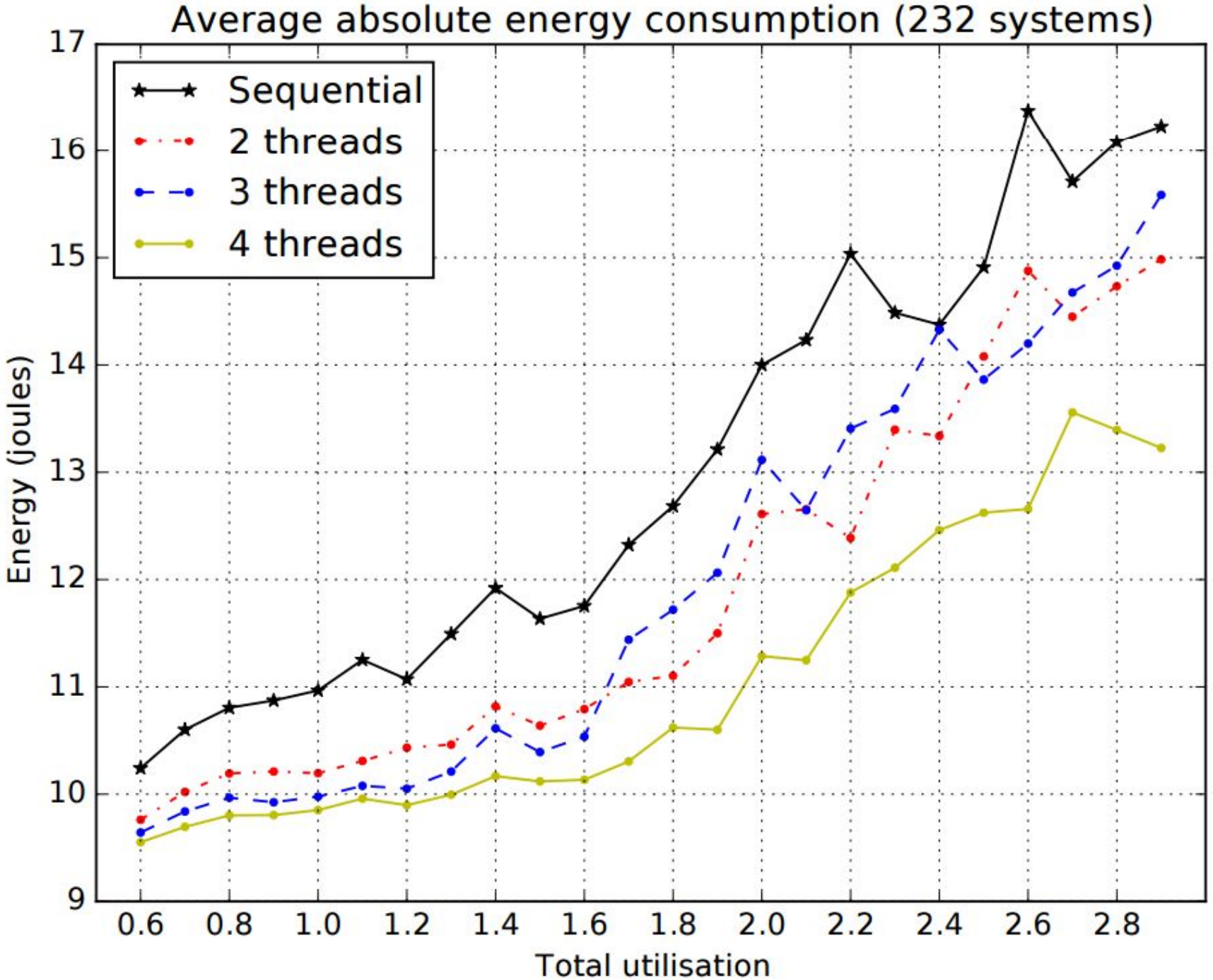
Energie consommée

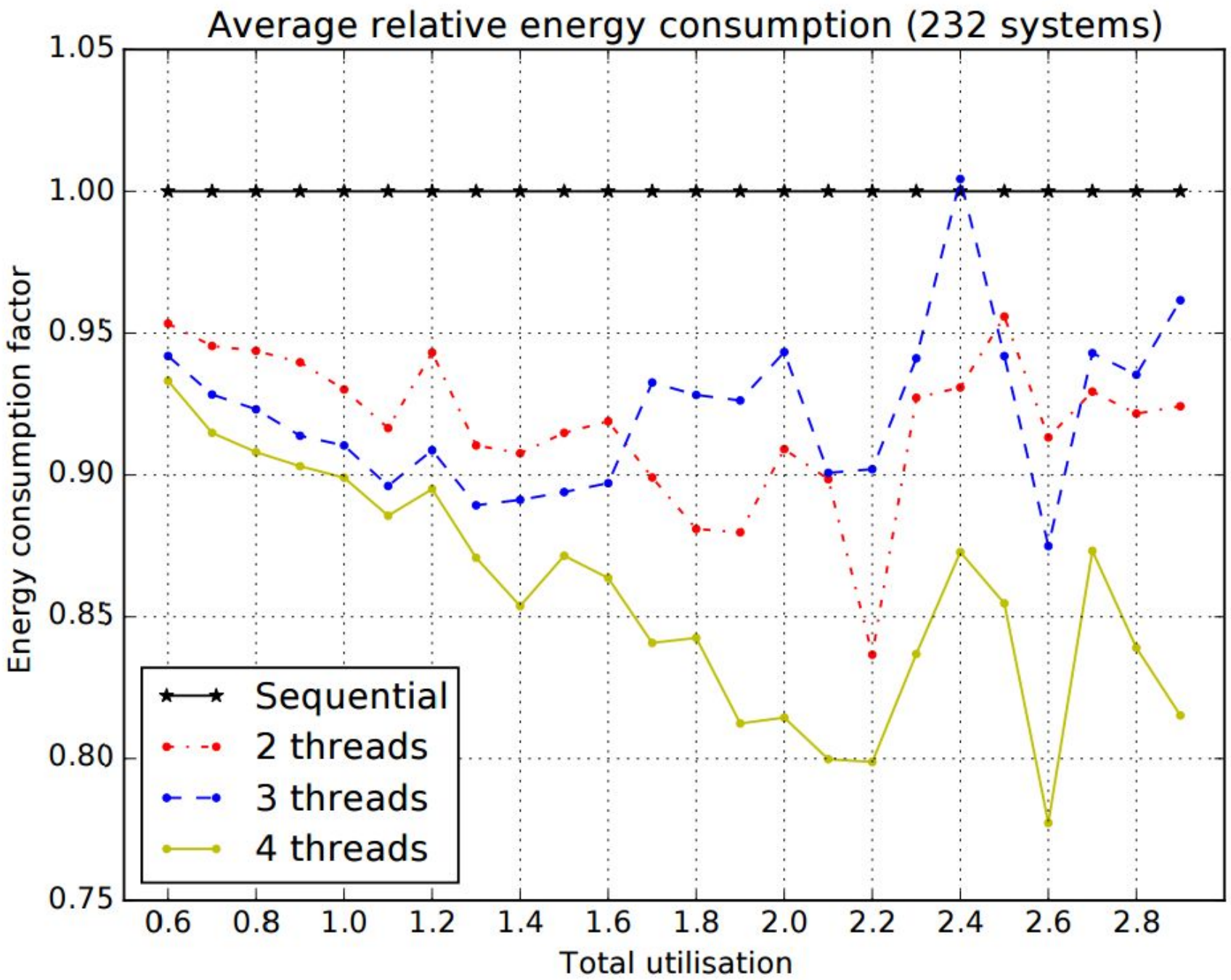


Campagne de simulations expérimentales

- Génération aléatoire de tâches applicatives à charge variable (U = 0.6 → 2.9)
- Pour différents degrés de parallélisme - **1, 2, 3, 4 threads**
- L'OS applique la gestion de l'alimentation
- On exécute les systèmes ordonnançables
- On mesure les résultats




Average absolute energy consumption (232 systems)
Sequential
2 threads
3 threads
4 threads
Energy (joules)
Total utilisation
17
16
15
14
13
12
11
10
9
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8


Average relative energy consumption (232 systems)
Energy consumption factor
1.05
1.00
0.95
0.90
0.85
0.80
0.75
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
Total utilisation
Sequential
2 threads
3 threads
4 threads

Conclusion

Le parallélisme permet de
réduire l'énergie consommée tout en
garantissant **les contraintes temporelles**

Agenda

1. Domaine, problème, intuition
2. Contributions et thèse
3. **Directions futures**

`len(`**Ph.D**`)`

=

4 ans

`len(`**Ph.D**`)`

≃

5.5 ans

`len(`**Ph.D**`)`

≃

5.5 ans

→

Vision
Haute Altitude

Conception systèmes embarqués, **aujourd'hui**

```
do {
    useful_work();
}
```

Communauté temps-réel, conception, **vision**

```
do in max 3 ms {
    useful_work();
}
```

Conception systèmes embarqués, **ma vision**

```
do in max 3 ms && in max 3 mJ {
    useful_work();
}
```

Ma vision, **directions futures**

```
do in max (3 ms,3 mJ,2°C) {
    useful_work();
}
```

Réaction du système

```
do in max (3 ms,3 mJ,2°C) {
    useful_work();
}
```

```
$ cc useful.c
```

Réaction du système

```
do in max (3 ms,3 mJ,2°C) {
    useful_work();
}
```

```
$ cc useful.c
.
```

Réaction du système

```
do in max (3 ms,3 mJ,2°C) {
    useful_work();
}
```

```
$ cc useful.c
..
```

Réaction du système

```
do in max (3 ms,3 mJ,2°C) {
    useful_work();
}
```

```
$ cc useful.c
OK (ordonnançable)
$
```

System reaction - resource requirements

```
do in max (3 ms,3 mJ,2°C) {
    useful_work();
}
```

```
$ cc useful.c
Erreur - veuillez allouer 2 cœurs à la fonction
‘useful_work’ (non ordonnançable).
$
```

Merci.

Q ?

...

• • • •

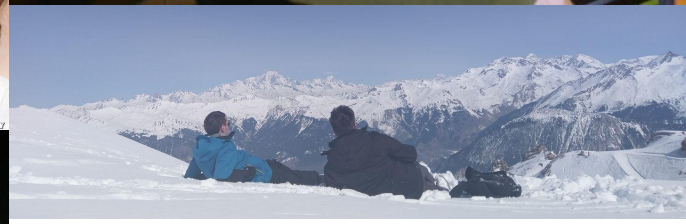
• • • • •

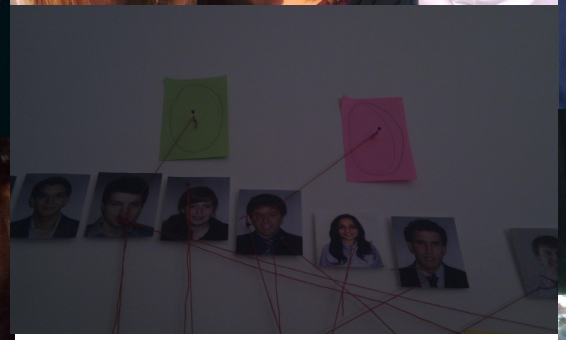
VICKINGS

FEAR THEM

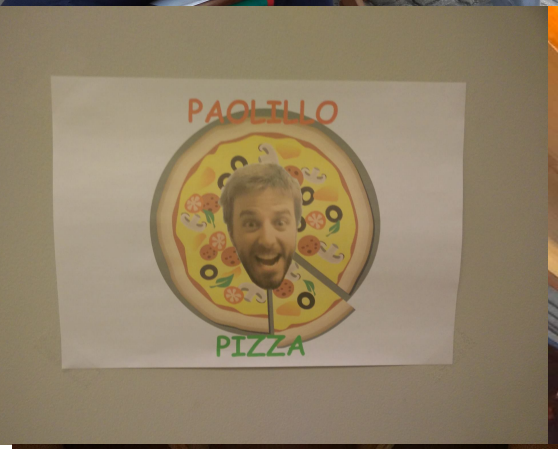

SUPREME
SINCE 1968
QUALITY
CRAFTED WITH PASSION
GOD SAVE THE 90'S


Aria & Bruno

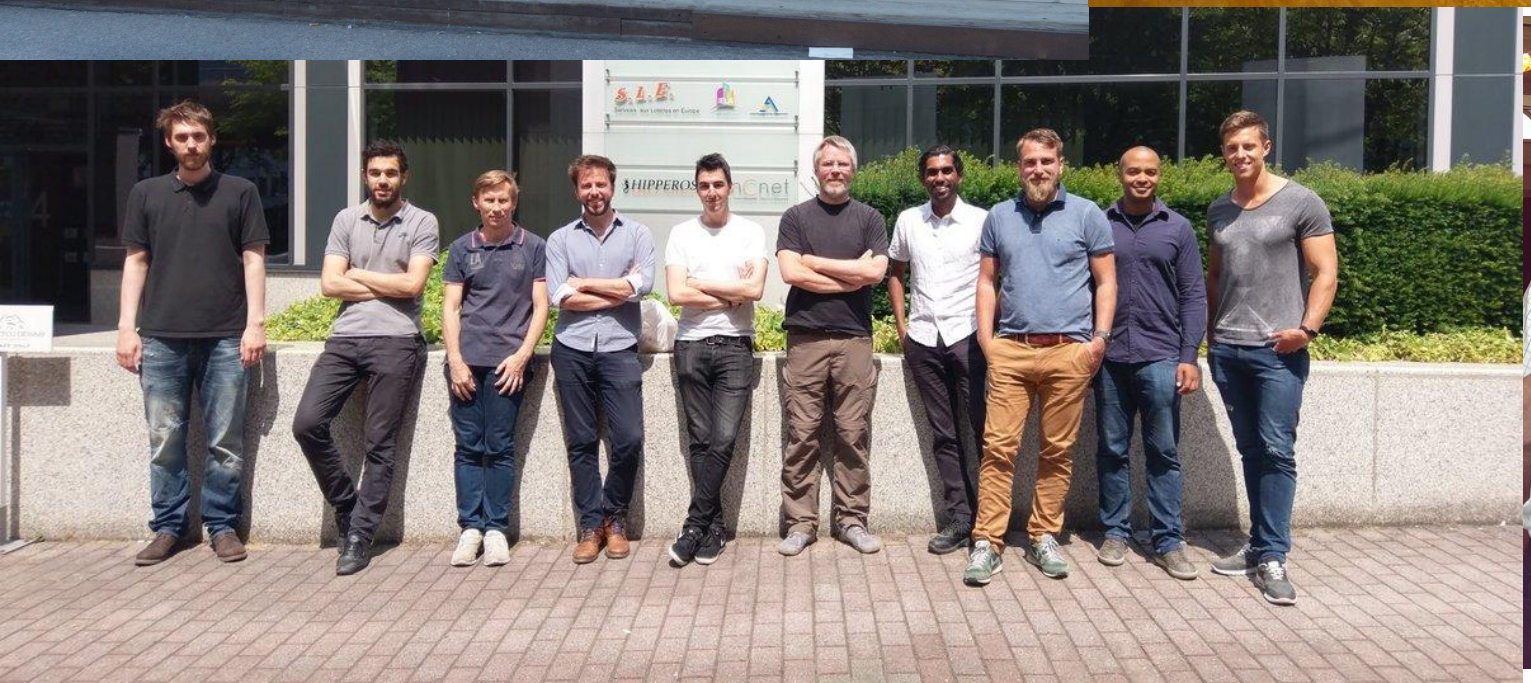


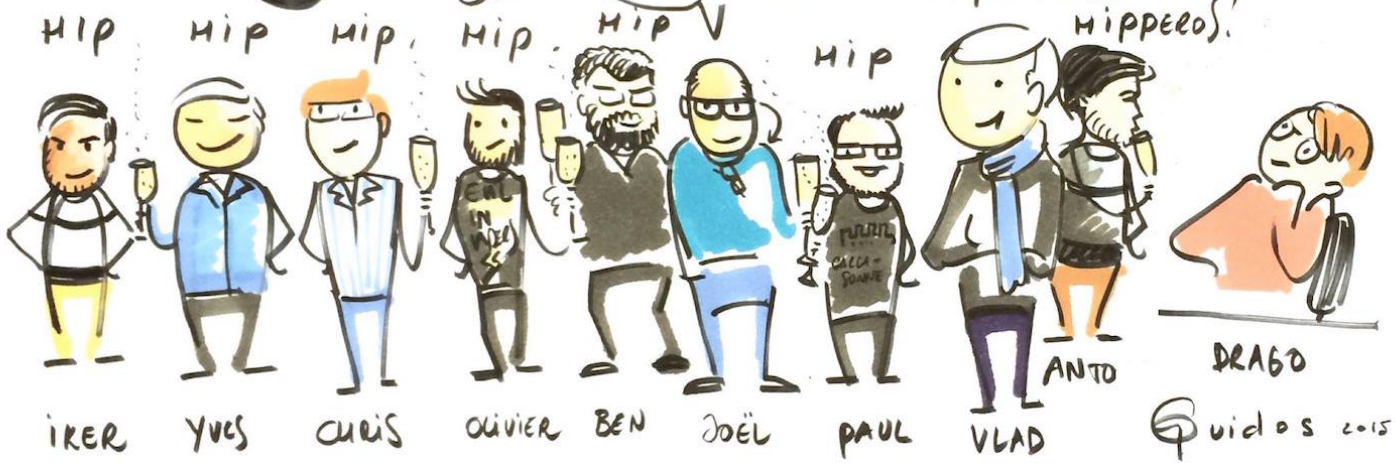



MONUMENT


PAOLILLO
PIZZA


Your Partner in
High Performance
Design

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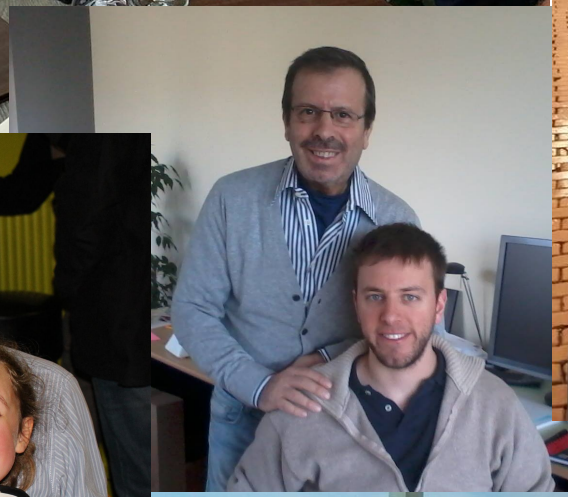


SURFING


Your journal has been updated


Merci.

Merci.


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