Resource Scheduling Algorithm in Distributed Problem-Oriented Environments

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Outline

1. Introduction
   - Purpose of the work
   - Clustering algorithms
   - Requirements for a job model
2. POS algorithm
   - Mathematical job model
   - Problem-oriented scheduling (POS) algorithm
   - Example
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Purpose

Development of a resource scheduling algorithm in problem-oriented distributed computing environments

Clustering algorithms

1. Kim and Browne’s linear clustering algorithm (KB/L)
2. Sarkar’s algorithm
3. Dominant sequence clustering algorithm (DSC)

Requirements for a job model

- Representing a workflow in the form of a marked-up weighted directed acyclic graph (DAG)
- Clustering vertices
- Scaling individual tasks in a workflow
- Specifying the number of processor cores for computational nodes
- Describing known and new algorithms for clustering

Directed graph

A directed graph is called a quadruple

$$G = \langle V, E, init, fin \rangle,$$

where

V is a vertices set;

E is an edges set;

$init: E \to V$ is a function which determines *an initial vertex* of an edge;

$fin: E \to V$ is a function which determines a *final vertex* of an edge.

Weighting function and layout function of a graph

Let us take directed graph $G = \langle V, E, init, fin \rangle$.

- *Weighting function* $\delta(e)$ of edge e determines the amount of transmitted data from a task associated with vertex $init(e)$ to a task associated with vertex $fin(e)$.
- *A layout* of graph G is function $\gamma : V \to \mathbb{N}^2$.

Job graph

A job graph is called a marked-up weighted directed acyclic graph,

$$G = \langle V, E, init, fin, \delta, \gamma \rangle,$$

where

V is a set of vertices which correspond to tasks,

E is a set of edges which correspond to data flows.

Example: a job graph

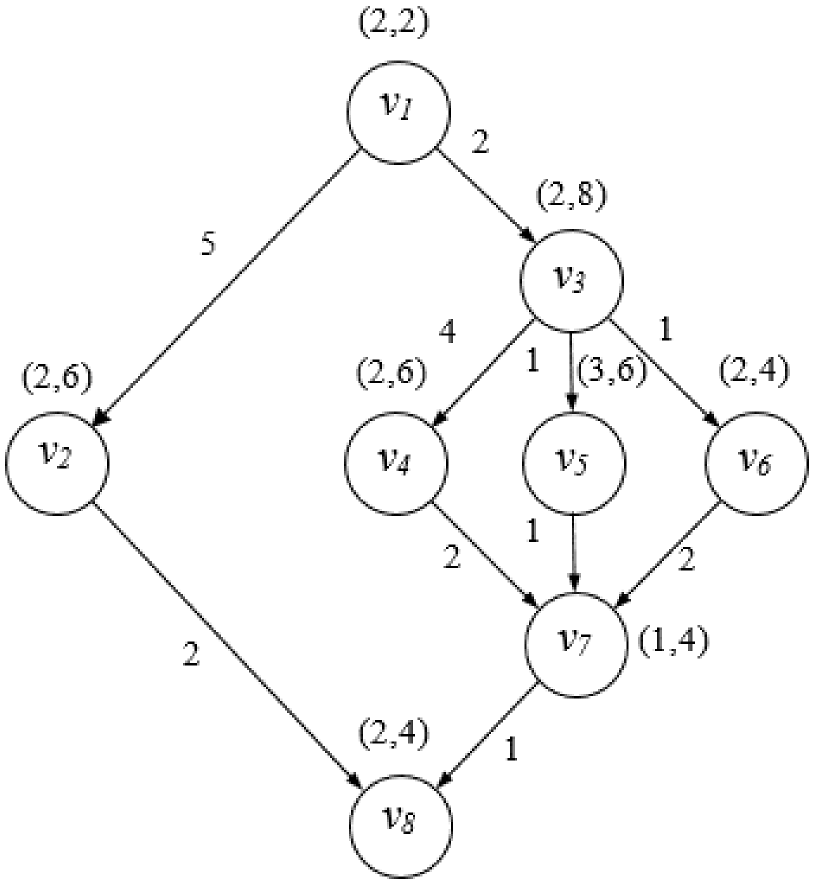
The layout function,

$$\gamma(v) = (m_v, t_v),$$

where

m_v is the maximum number of processor cores on which task v has *a nearly-linear* speedup;

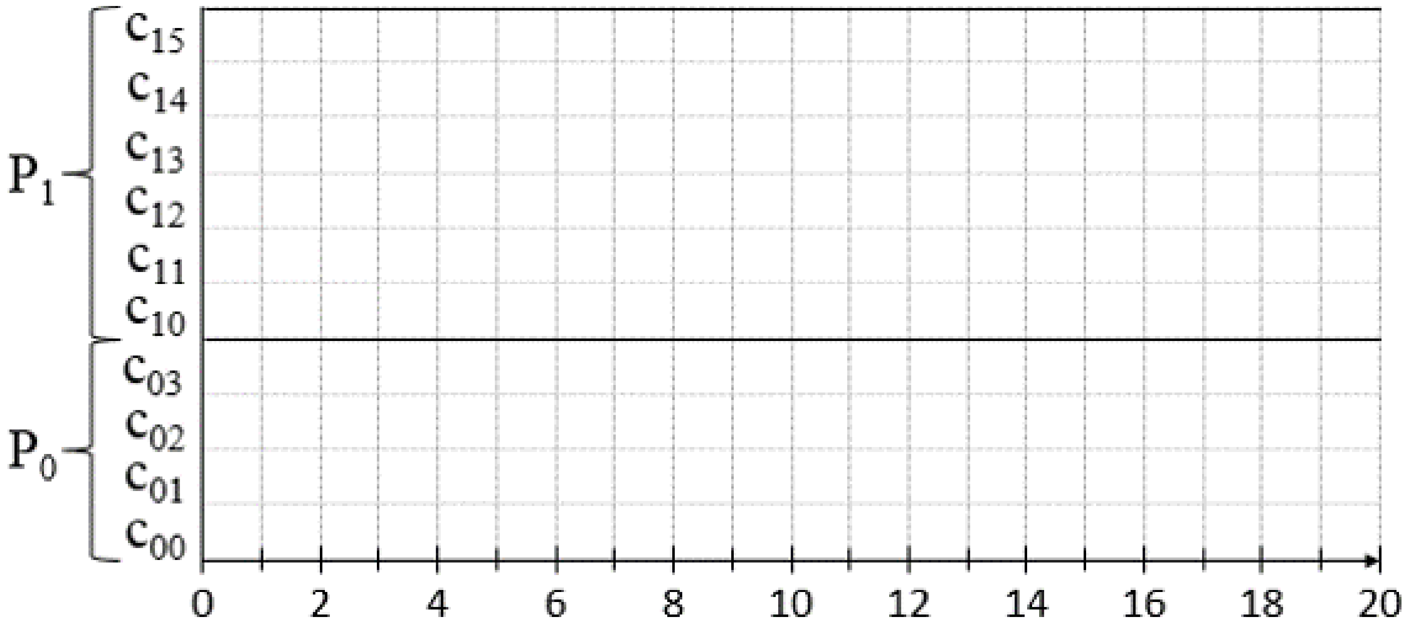
t_v is the execution time of task v on a single core.



Computer system

- *Compute node P* is an ordered set of processor cores $\{c_0, \dots, c_{q-1}\}$.
- *A computer system* is an ordered set of compute nodes,

$$\mathfrak{P} = \{P_0, \dots, P_{k-1}\}.$$



Clustering function

- *Clustering* is called single-valued transformation of vertices set V of job graph G on a set of computational nodes $\mathfrak{P}$.

$$\omega: V \to \mathfrak{P}$$

- *Cluster* W_i is a set of all vertices that are displayed on computational node $P_i \in \mathfrak{P}$.
- Example:
$W_0 = \{v_1, v_2, v_8\}$ and
$W_1 = \{v_3, v_4, v_5, v_6, v_7\}$.

Vertex v	$\omega(v)$
v_1	P_0
v_2	P_0
v_3	P_1
v_4	P_1
v_5	P_1
v_6	P_1
v_7	P_1
v_8	P_0

Example: a clustered graph

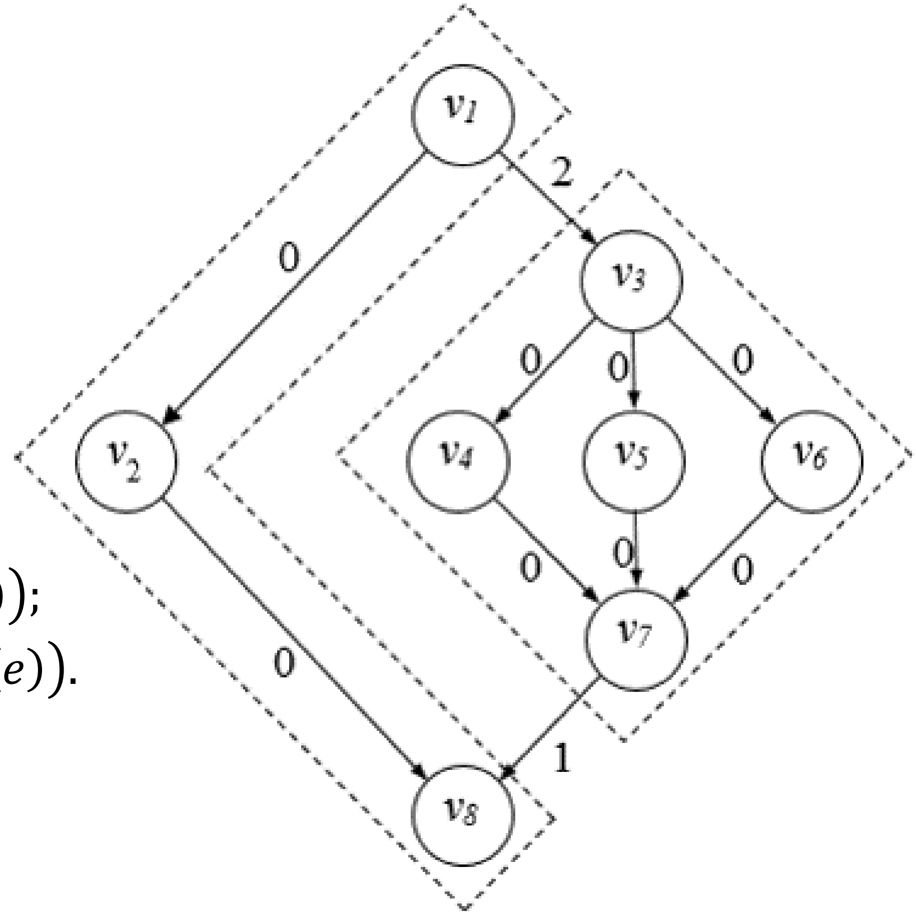
- Clusters:

$W_0 = \{v_1, v_2, v_8\}$ and
$W_1 = \{v_3, v_4, v_5, v_6, v_7\}$.

- *A communication cost* is the time of data transmission along edge $e \in E$.

- A communication cost function,

$$\sigma(e) = \begin{cases} 0, if\ \omega(init(e)) = \omega(fin(e)); \\ \delta(e), if\ \omega(init(e)) \neq \omega(fin(e)). \end{cases}$$



Schedule

A schedule is called single-valued transformation,

$$\xi: V \to \mathbb{Z}_{\geq 0} \times \mathbb{N},$$

which maps casual vertex $v \in V$ on a pair of numbers,

$$\xi(v) = (\tau_v, j_v),$$

where τ_v determines the launch time of task v; j_v is a number of processor cores allocated to task v.

Vertex v	$\xi(v) = (\tau_v, j_v)$	
	Launch time $\boldsymbol{\tau_v}$	Number of cores $\boldsymbol{j_v}$
v_1	0	2
v_2	1	2
v_3	3	2
v_4	7	2
v_5	7	2
v_6	7	2
v_7	10	1
v_8	15	2

Communication cost

Communication cost $\chi(v, j_v)$ of task v on j_v-th processor cores is determined by the following formula:

$$\chi(v, j_v) = \begin{cases} t_v / j_v, \text{if } 1 \le j \le m_v; \\ t_v / m_v, \text{if } m_v < j_v. \end{cases}$$

Vertex v	$\chi(v, j_v)$
v_1	1
v_2	3
v_3	4
v_4	3
v_5	3
v_6	2
v_7	4
v_8	2

Scheduled graph

- Clustered graph G with specified schedule ξ is called *a scheduled graph*.

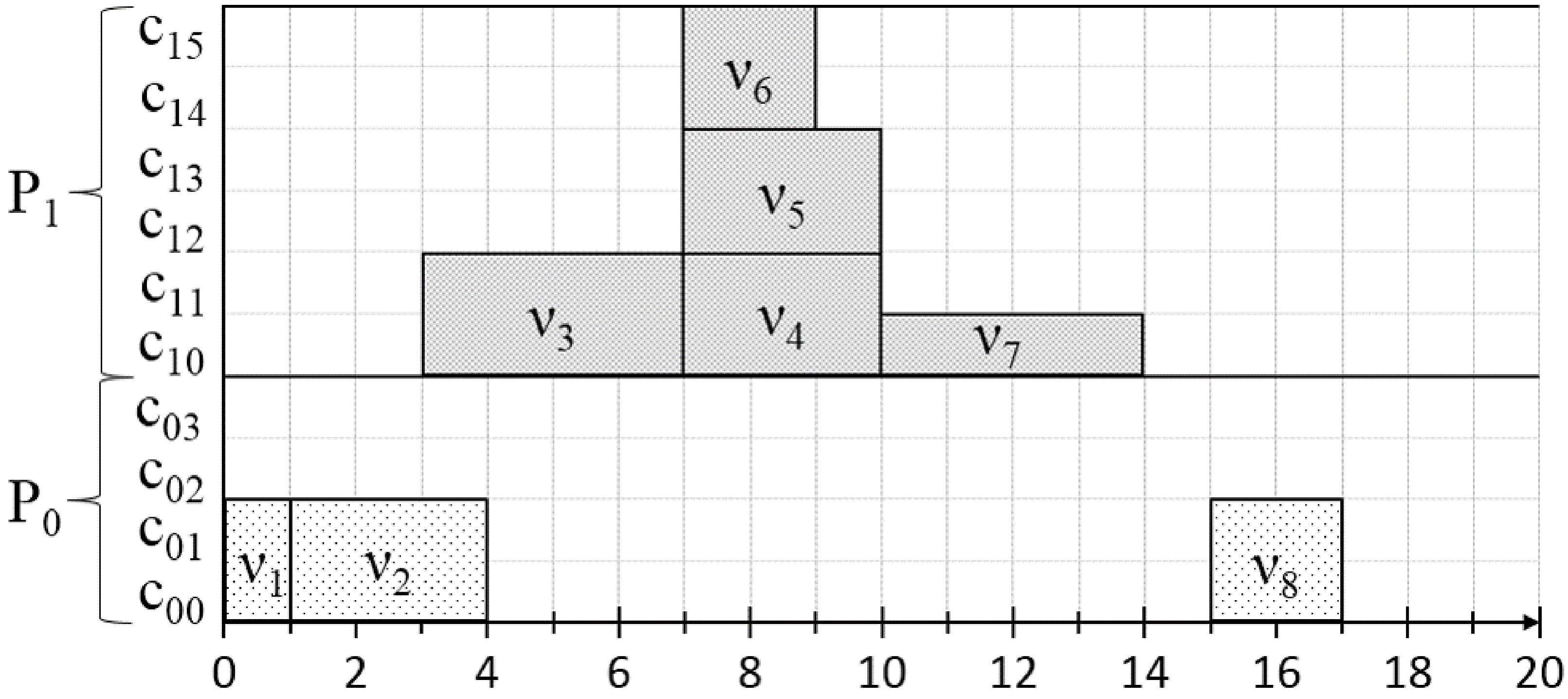
Critical path

- Let us take a simple path, $y = (e_1, e_2, \dots, e_n)$, in scheduled graph G. Path cost $u(y)$ has the following value:

$$u(y) = \chi\left(fin(e_n), j_{fin(e_n)}\right) + \sum_{i=1}^{n}\left(\chi\left(init(e_i), j_{init(e_i)}\right) + \max\left(\sigma(e_i), \tau_{fin(e_i)} - s_{init(e_i)}\right)\right)$$

- Y is a set of all simple paths in scheduled graph G. A simple path, $\bar{y} \in$ Y, is called a critical path, if it has a maximum value.

Gantt chart



The critical path equals 17.

Problem-oriented scheduling (POS) algorithm

1. Constructing an initial configuration of a graph,
   $G_0 = \langle V, E, init, fin, \delta, \gamma, \omega_0, \xi_0 \rangle$.
2. $i \coloneqq 0$.
3. Changing over from configuration
   $G_i = \langle V, E, init, fin, \delta, \gamma, \omega_i, \xi_i \rangle$ to configuration
   $G_{i+1} = \langle V, E, init, fin, \delta, \gamma, \omega_{i+1}, \xi_{i+1} \rangle$,
   such as
   (simultaneously marking up the considered edges).
4. If there remain some unconsidered edges, then
   4.1. $i \coloneqq i + 1$;
   4.2. transfer to step 3.
5. Stop.

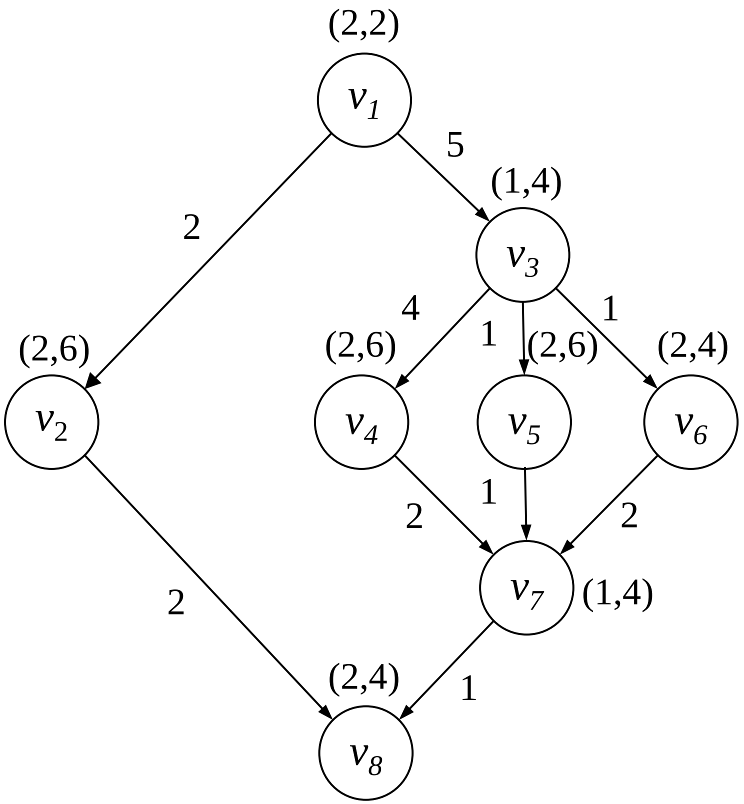
Example: a POS algorithm

A job graph,
$G = \langle V, E, init, fin, \delta, \gamma \rangle$

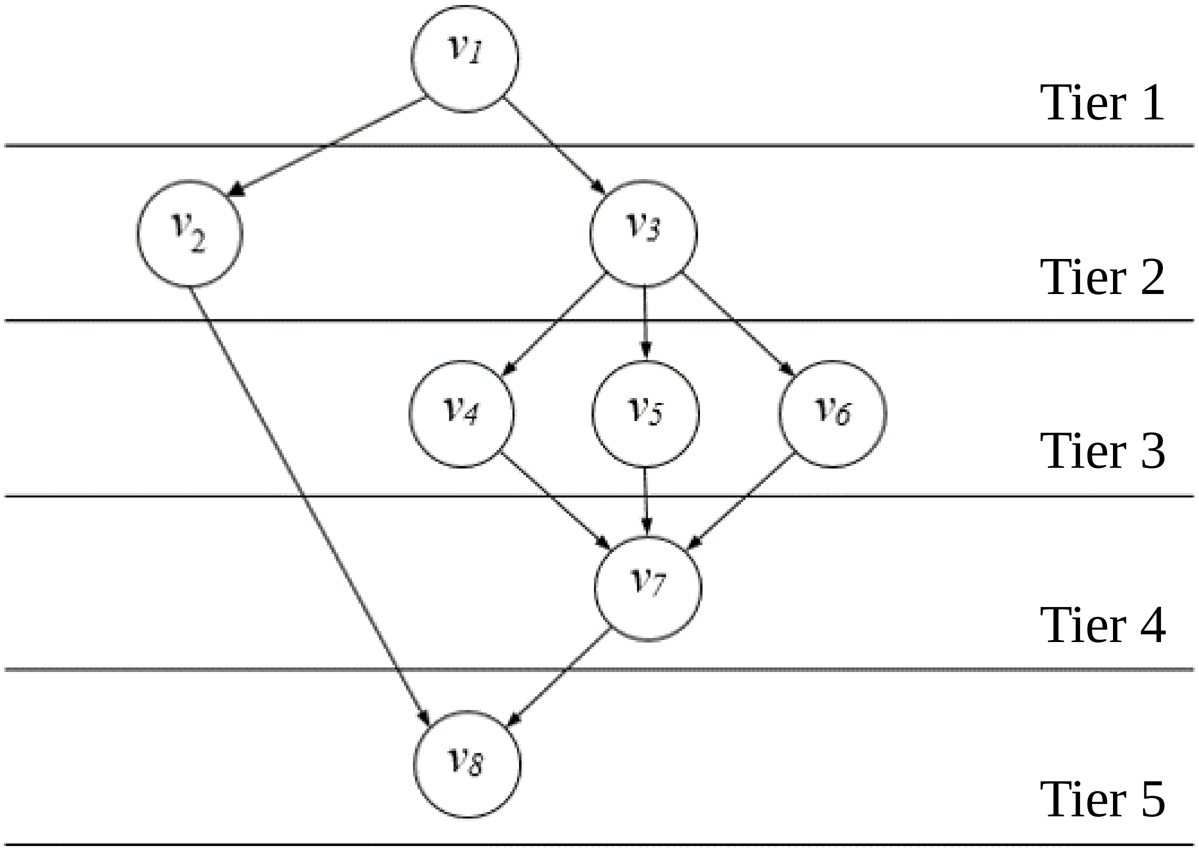
A computer system,
$\mathfrak{P} = \{P_0, P_1, \ldots, P_7\}$,

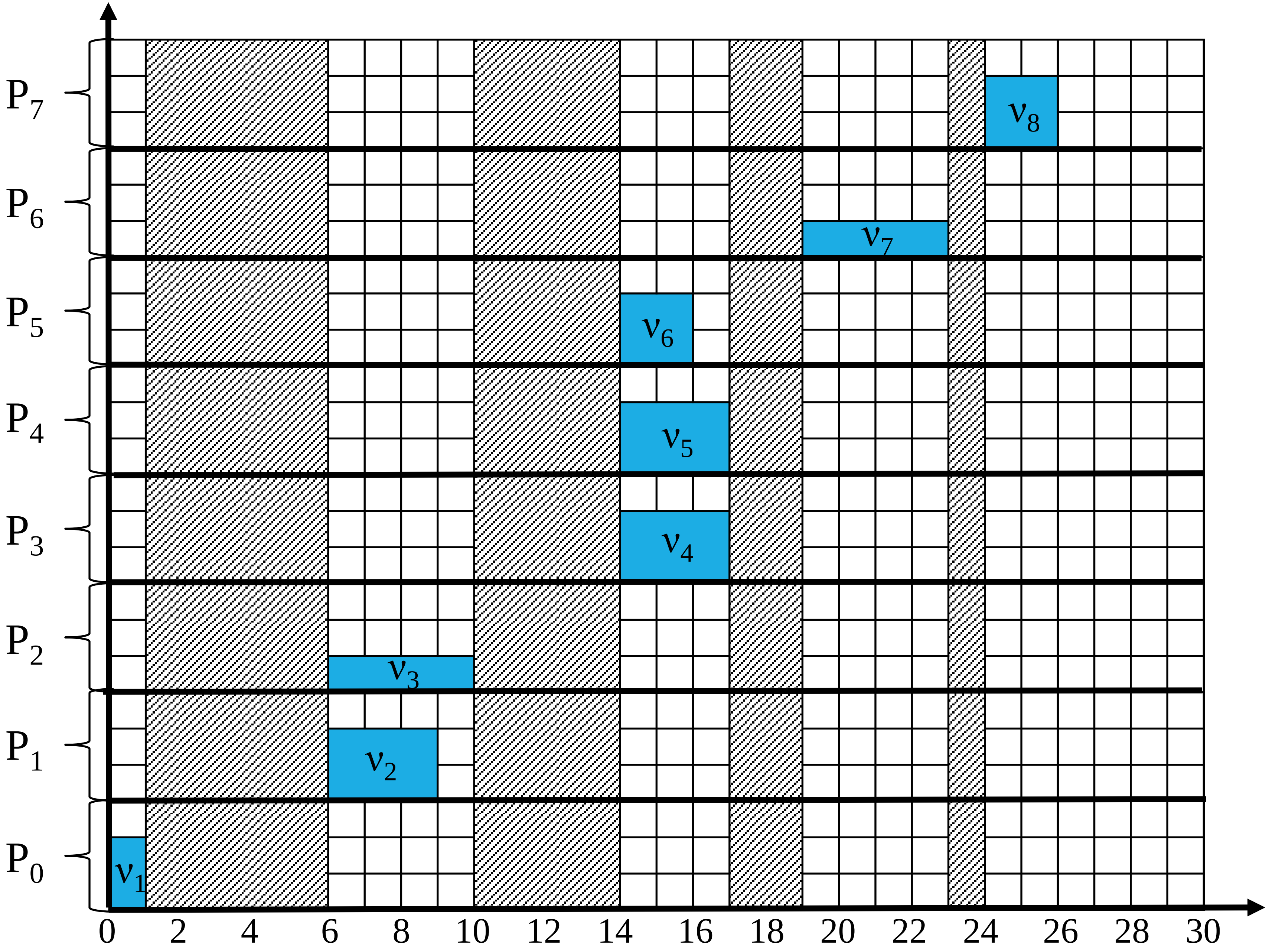
where
$P_0 = \{c_{00}, c_{01}, c_{02}, c_{03}\}$,
$P_1 = \{c_{10}, c_{11}, c_{12}, c_{13}\}$,

…



Canonical tiered-and-parallel form of a graph





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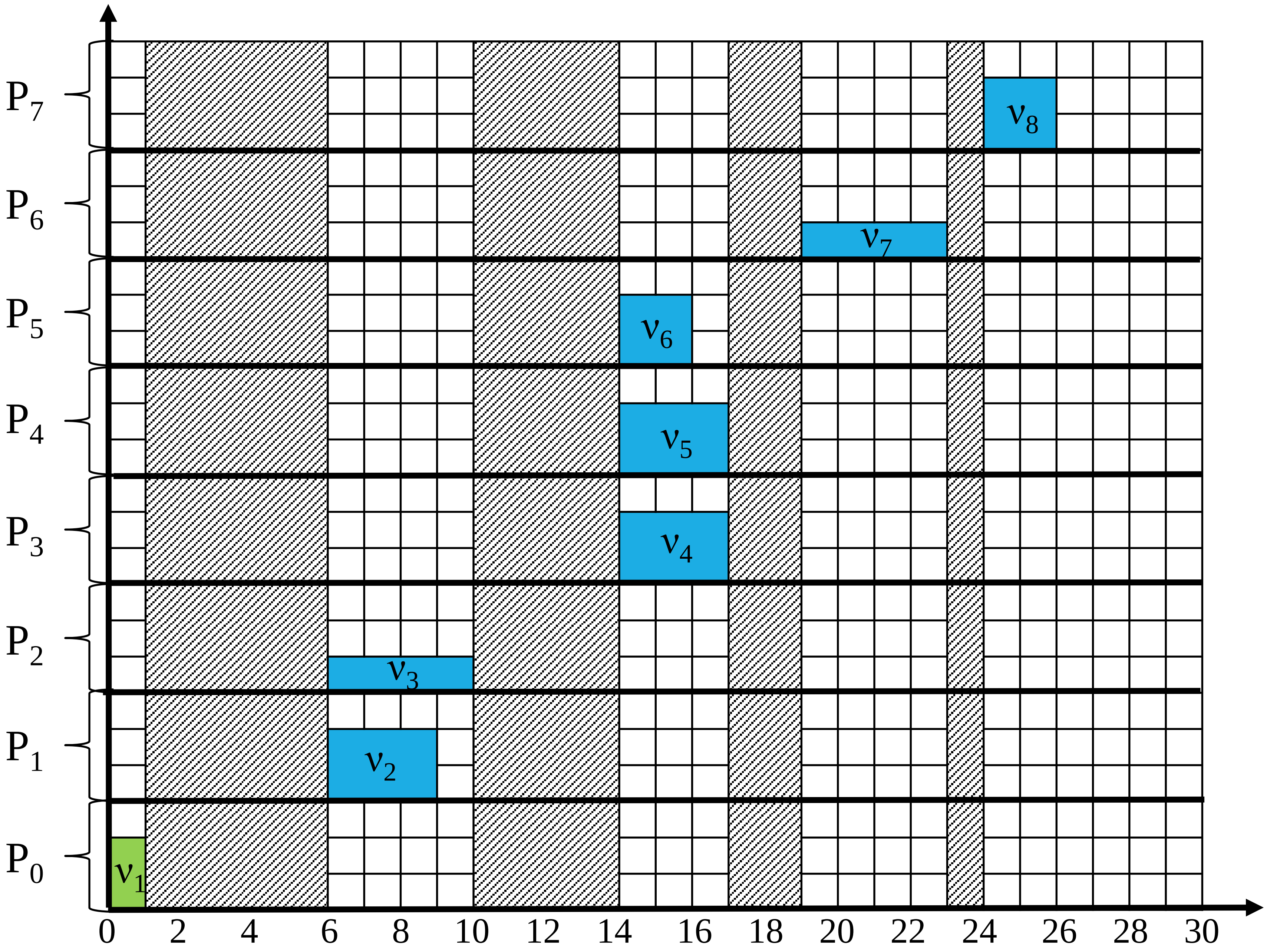

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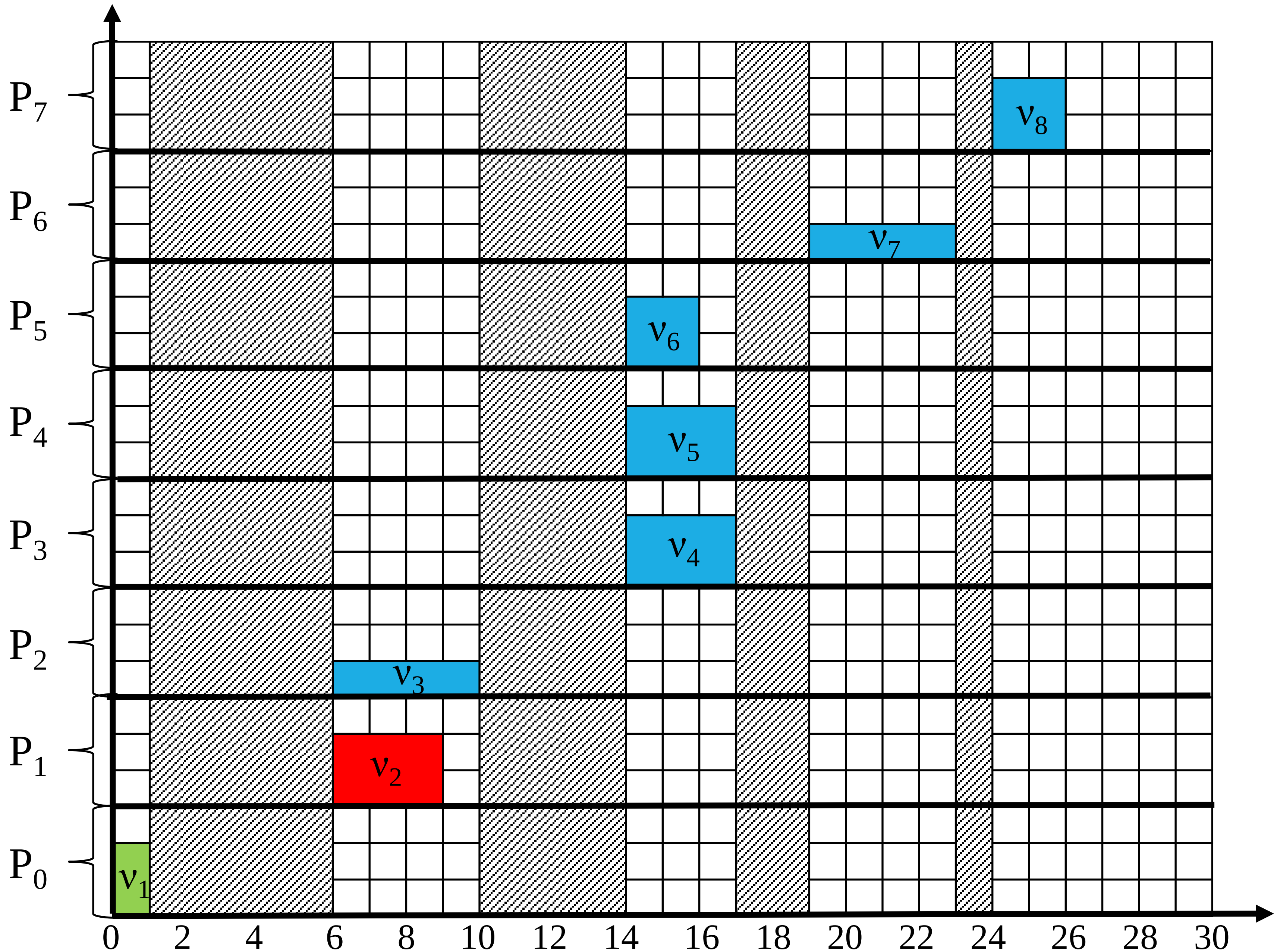

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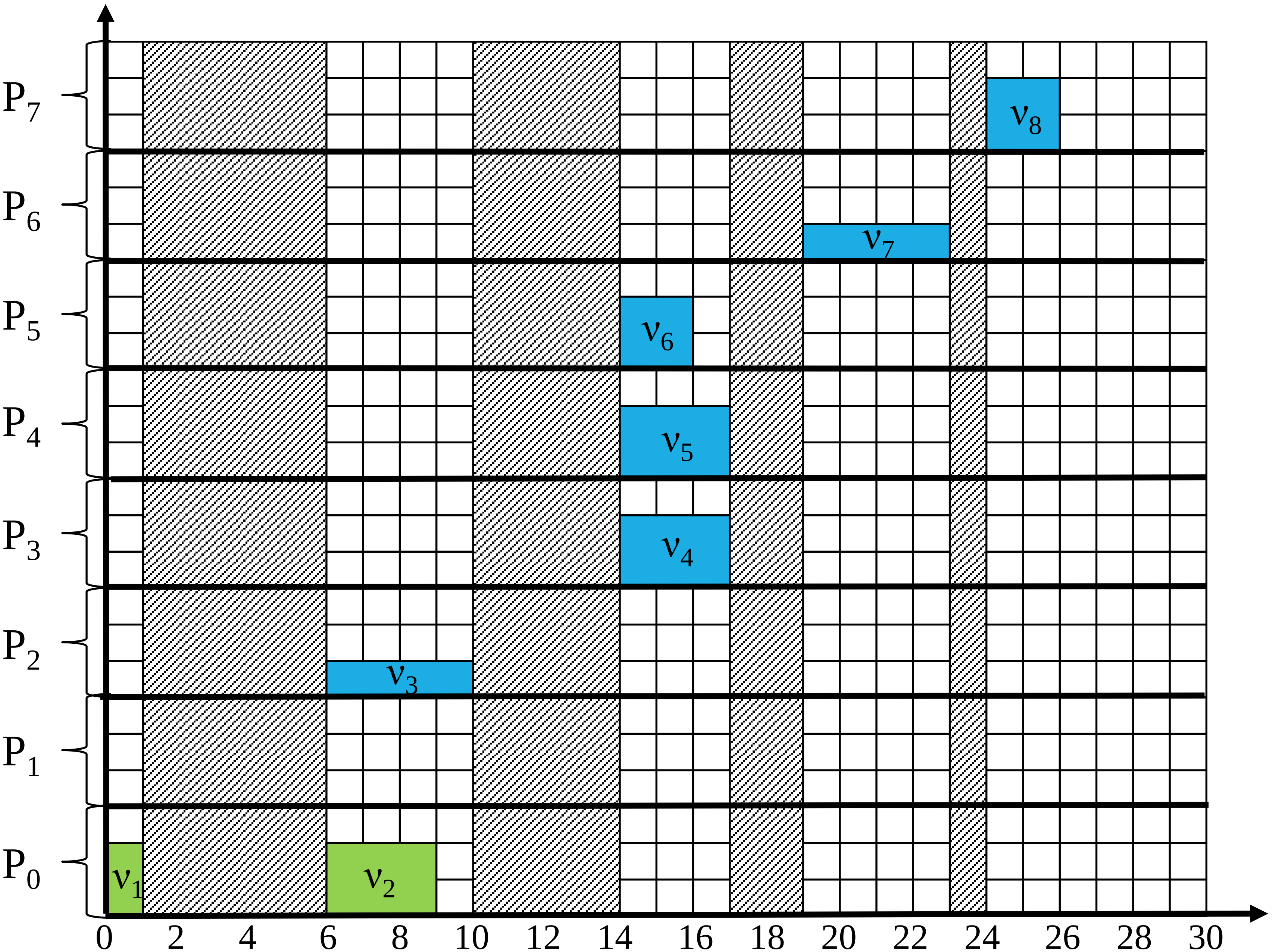
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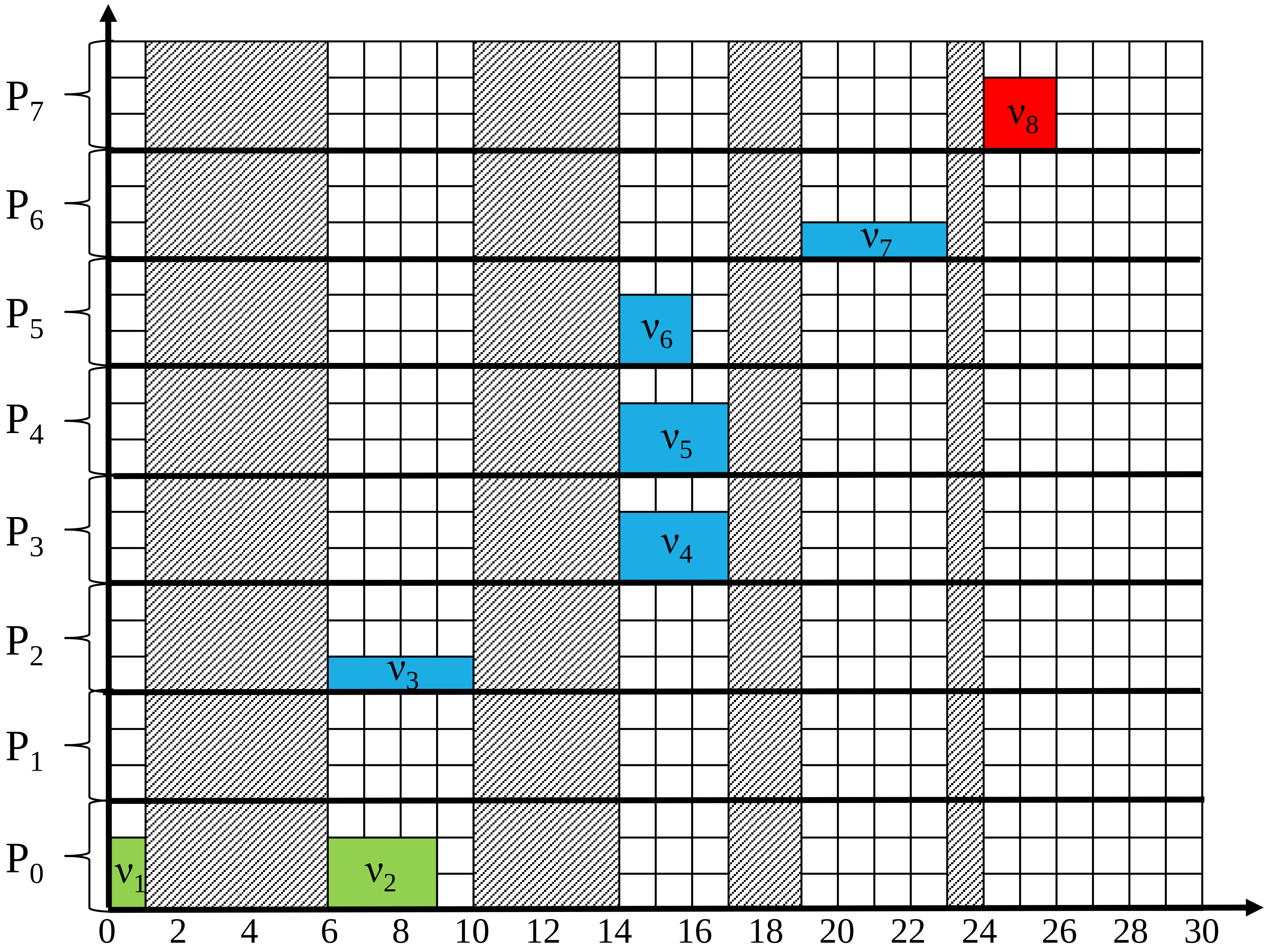
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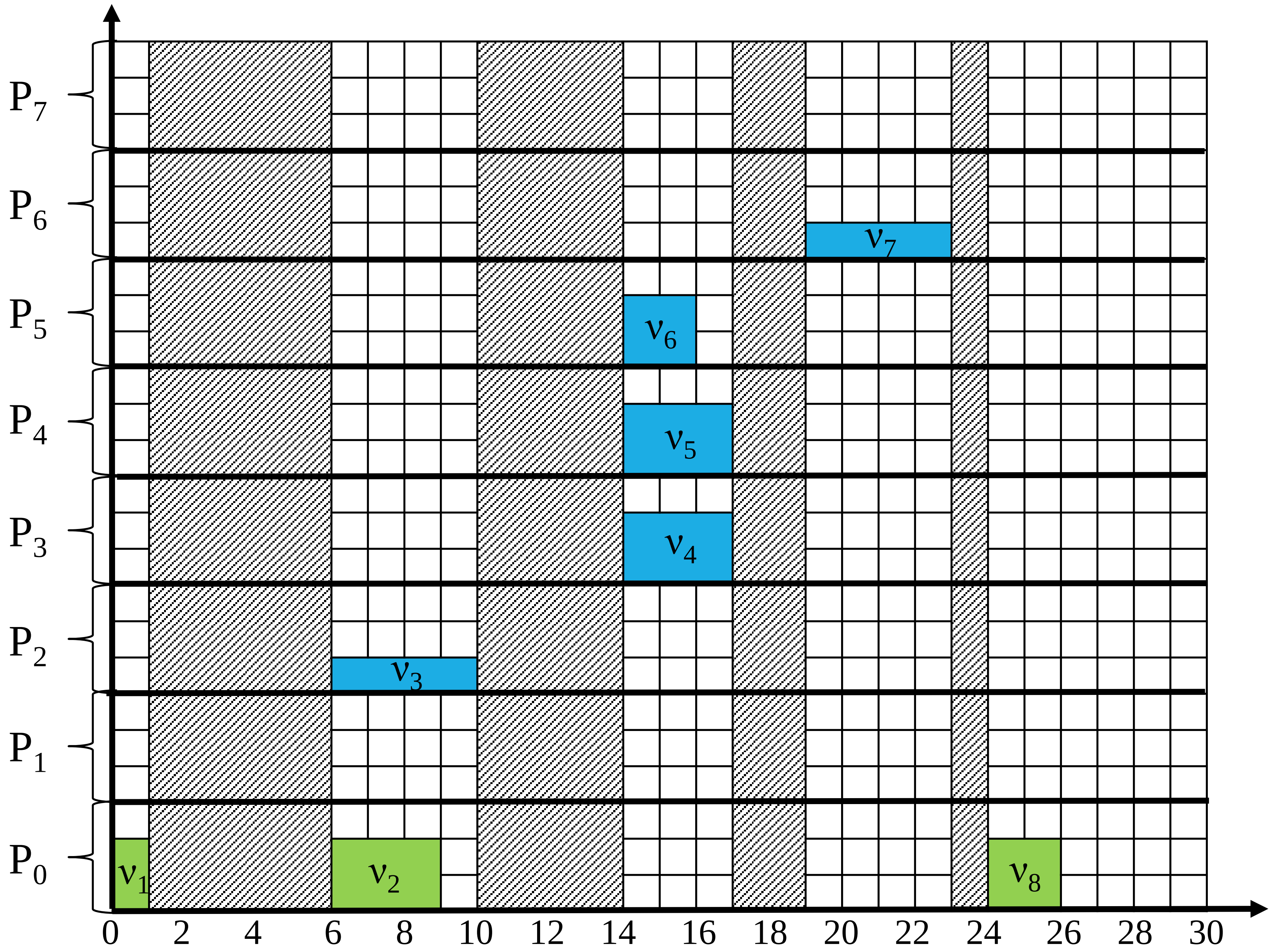
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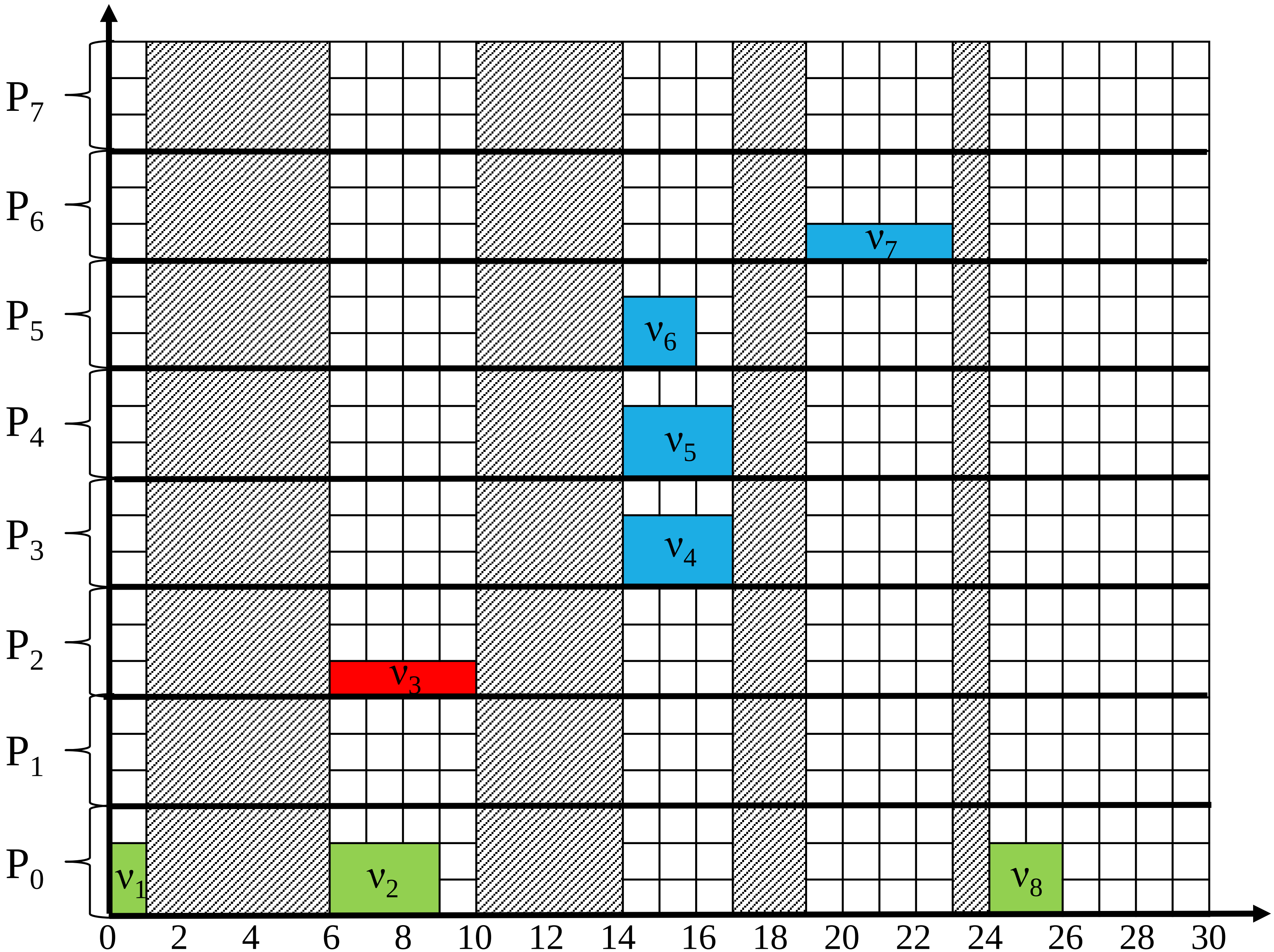

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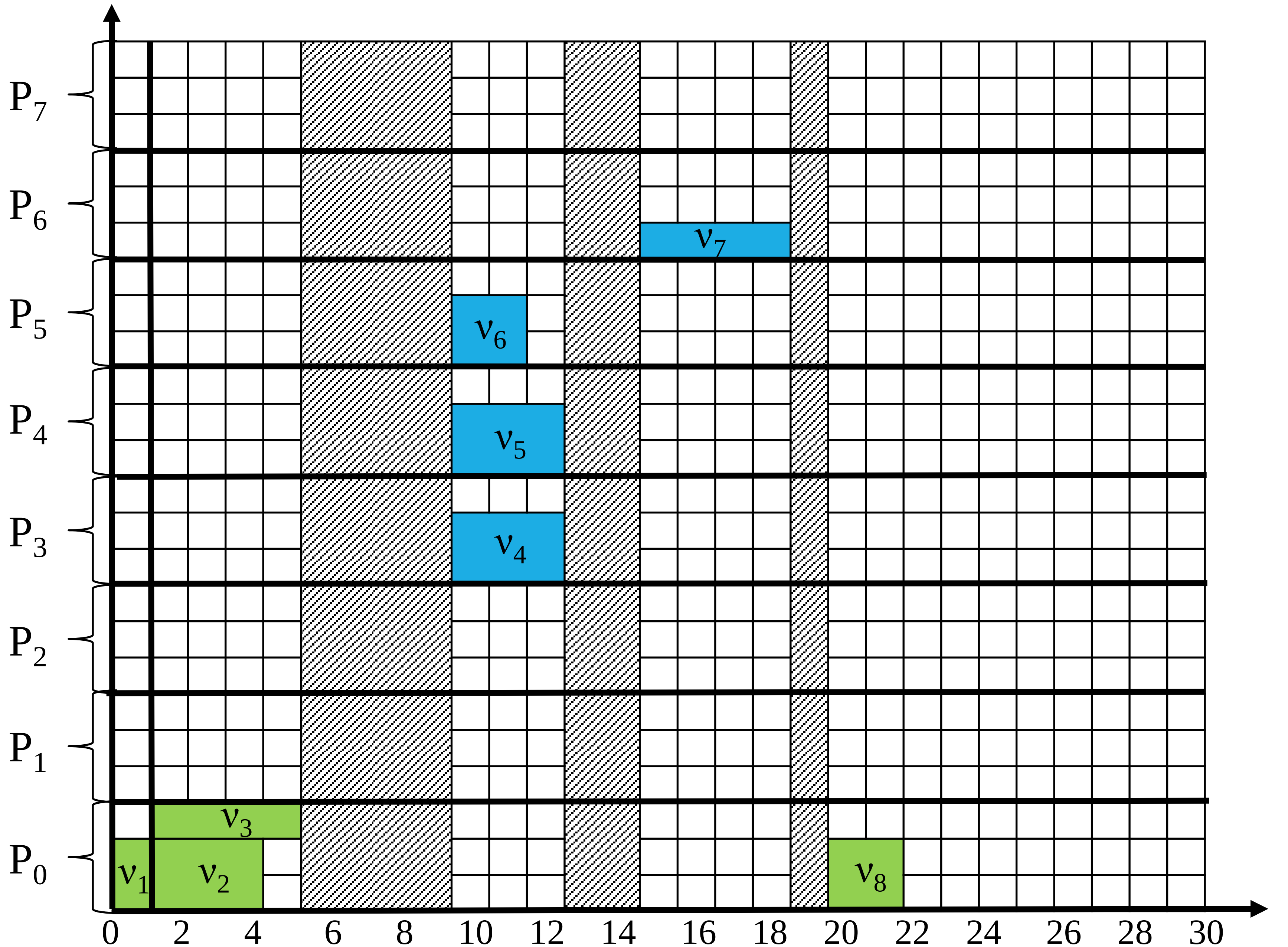

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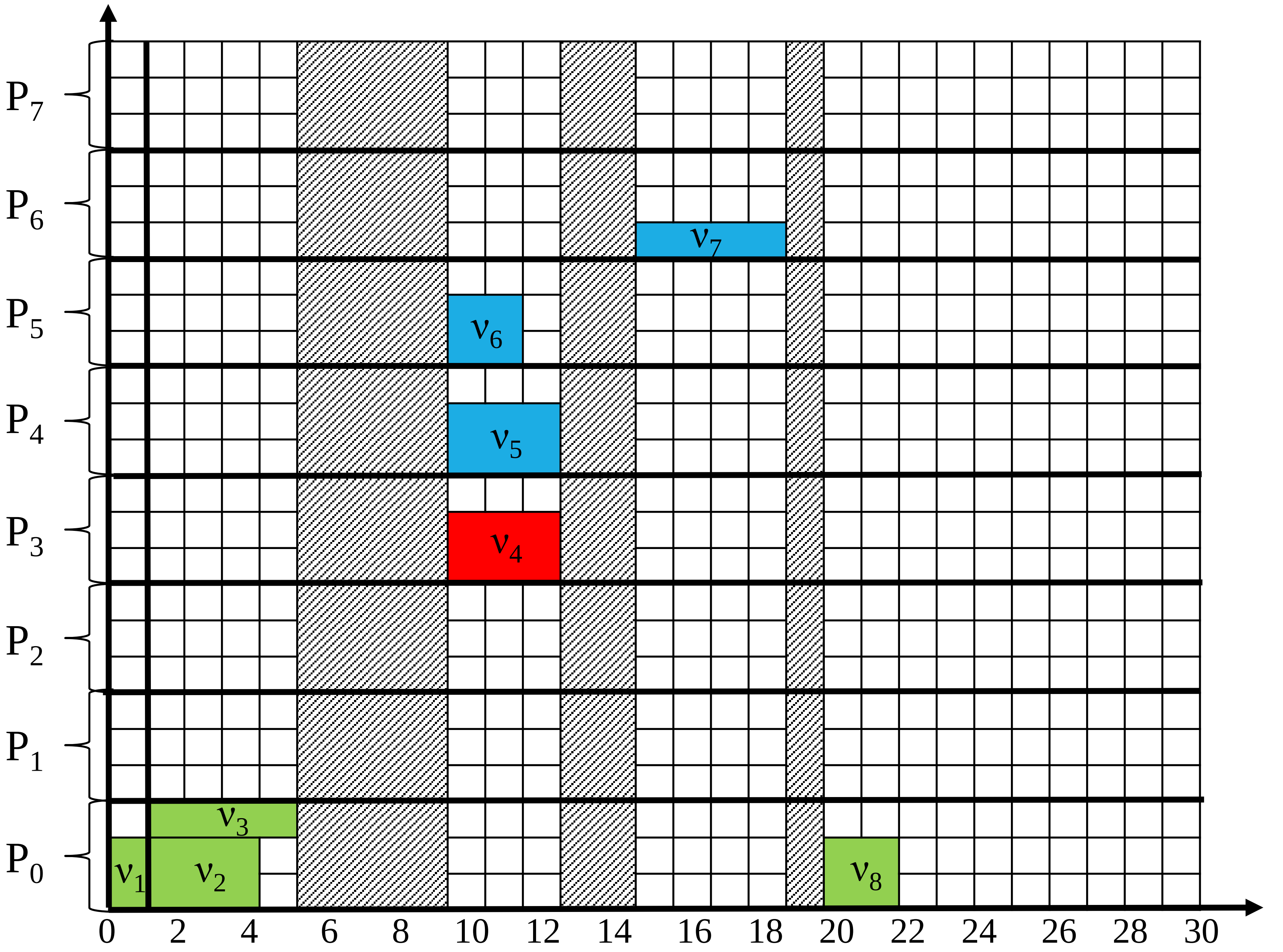

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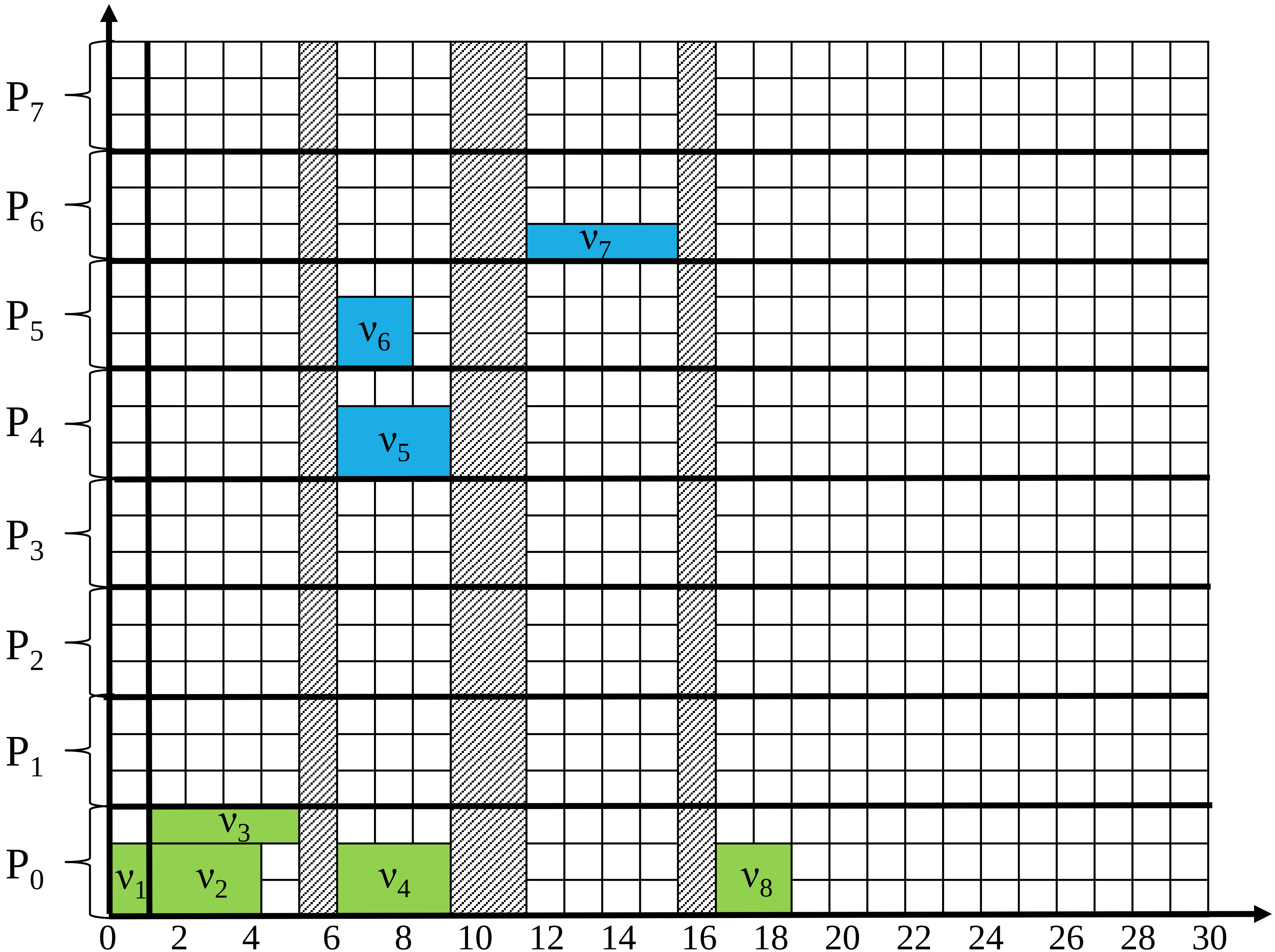

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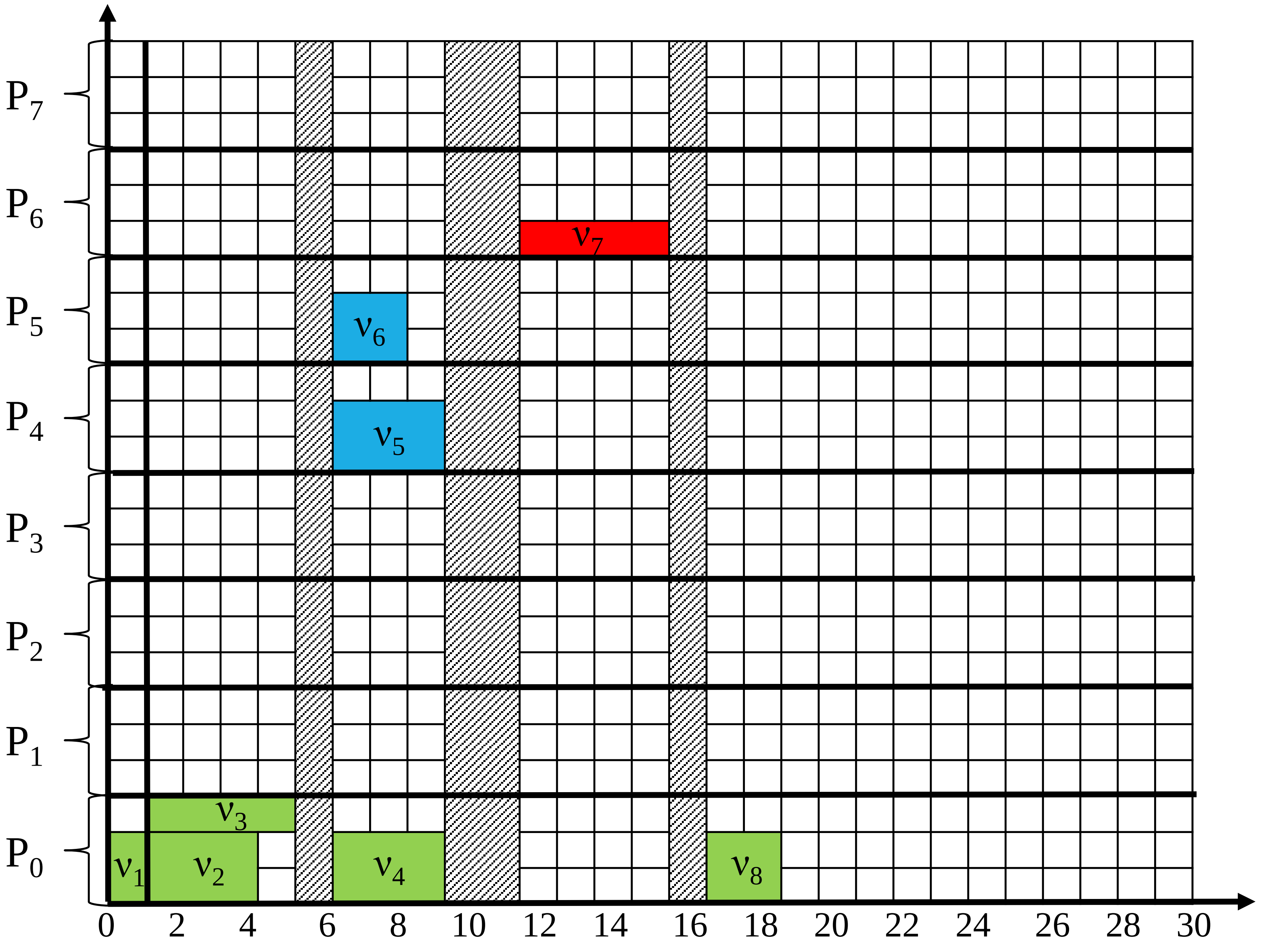

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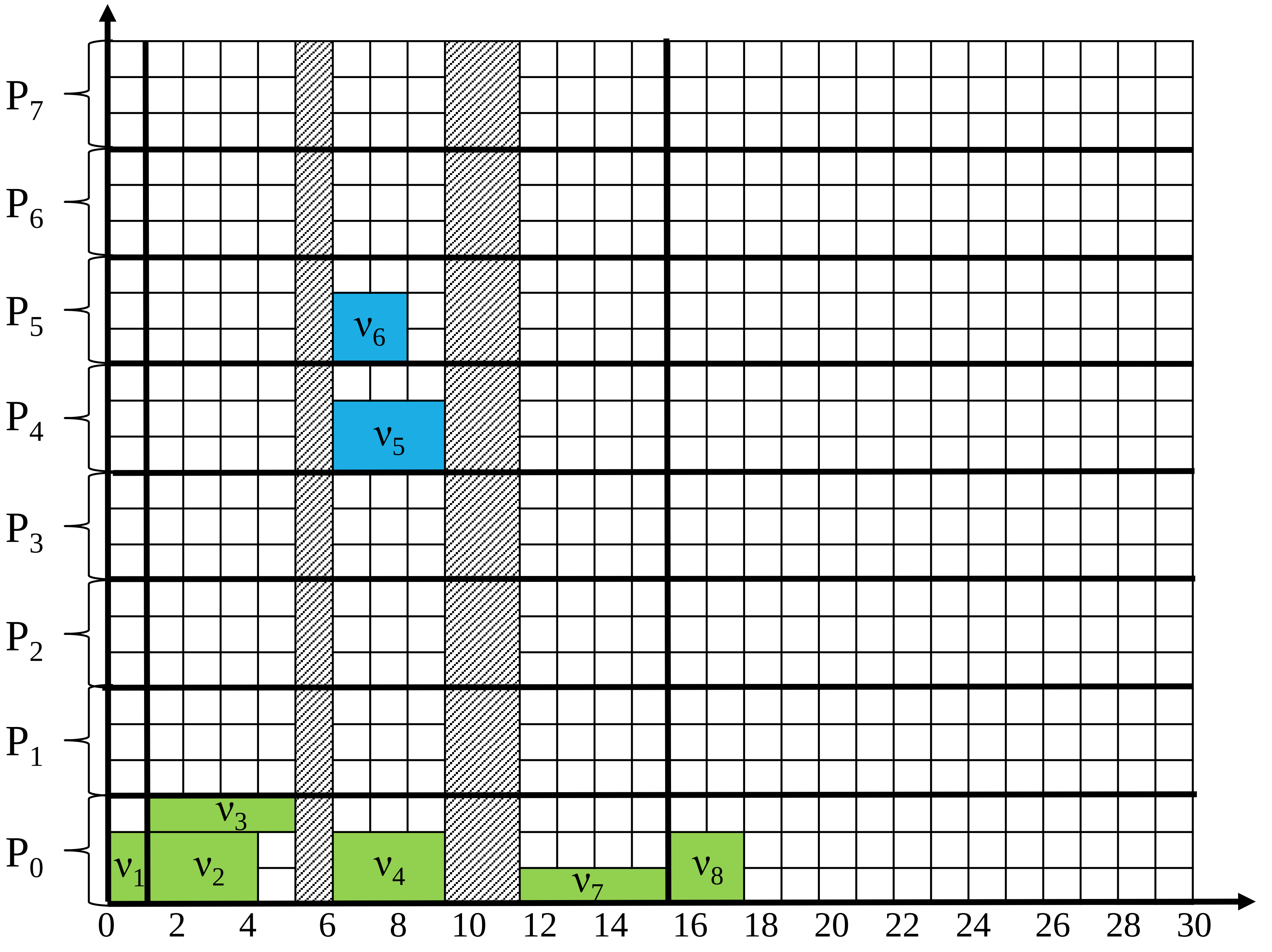

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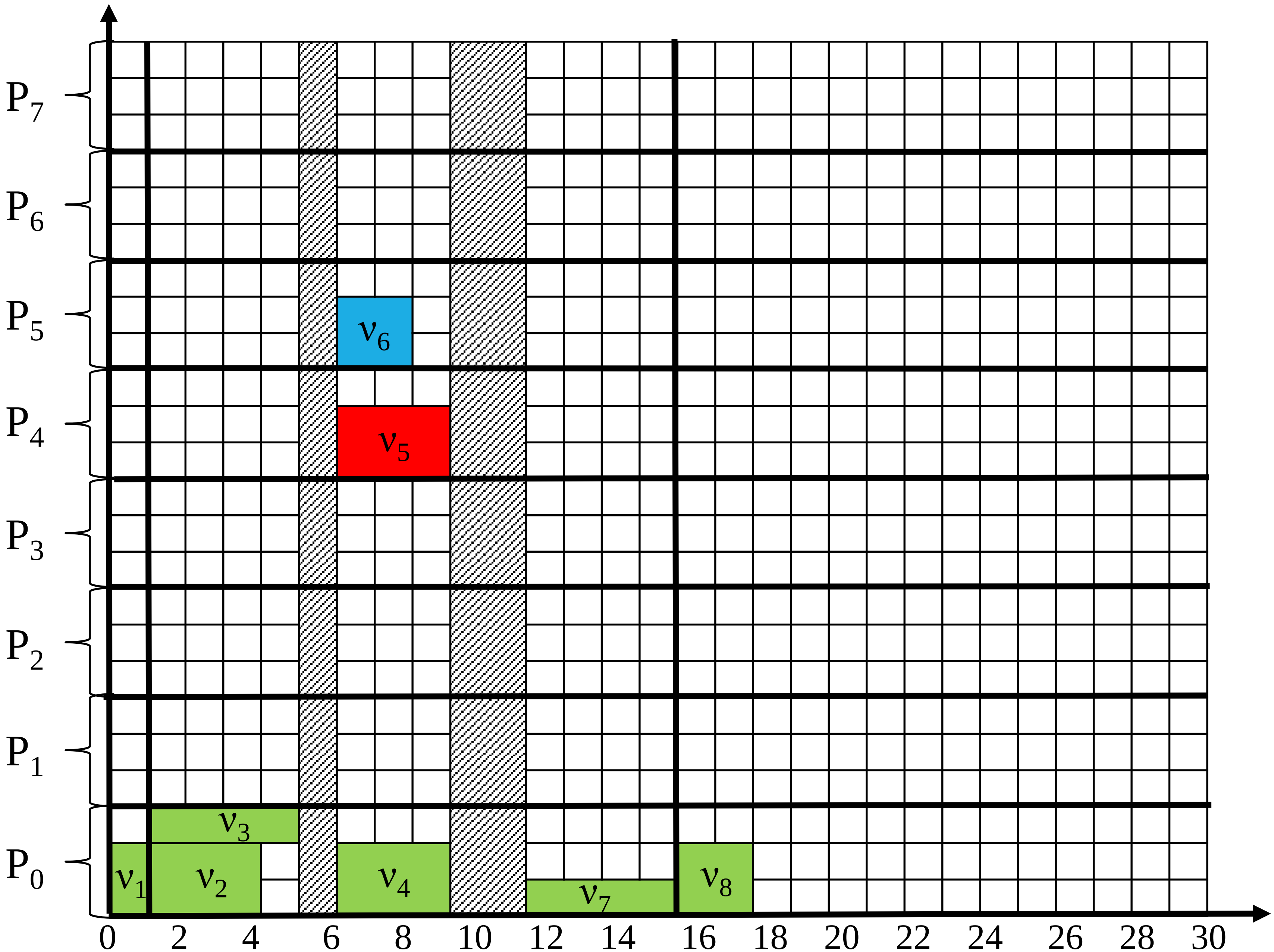

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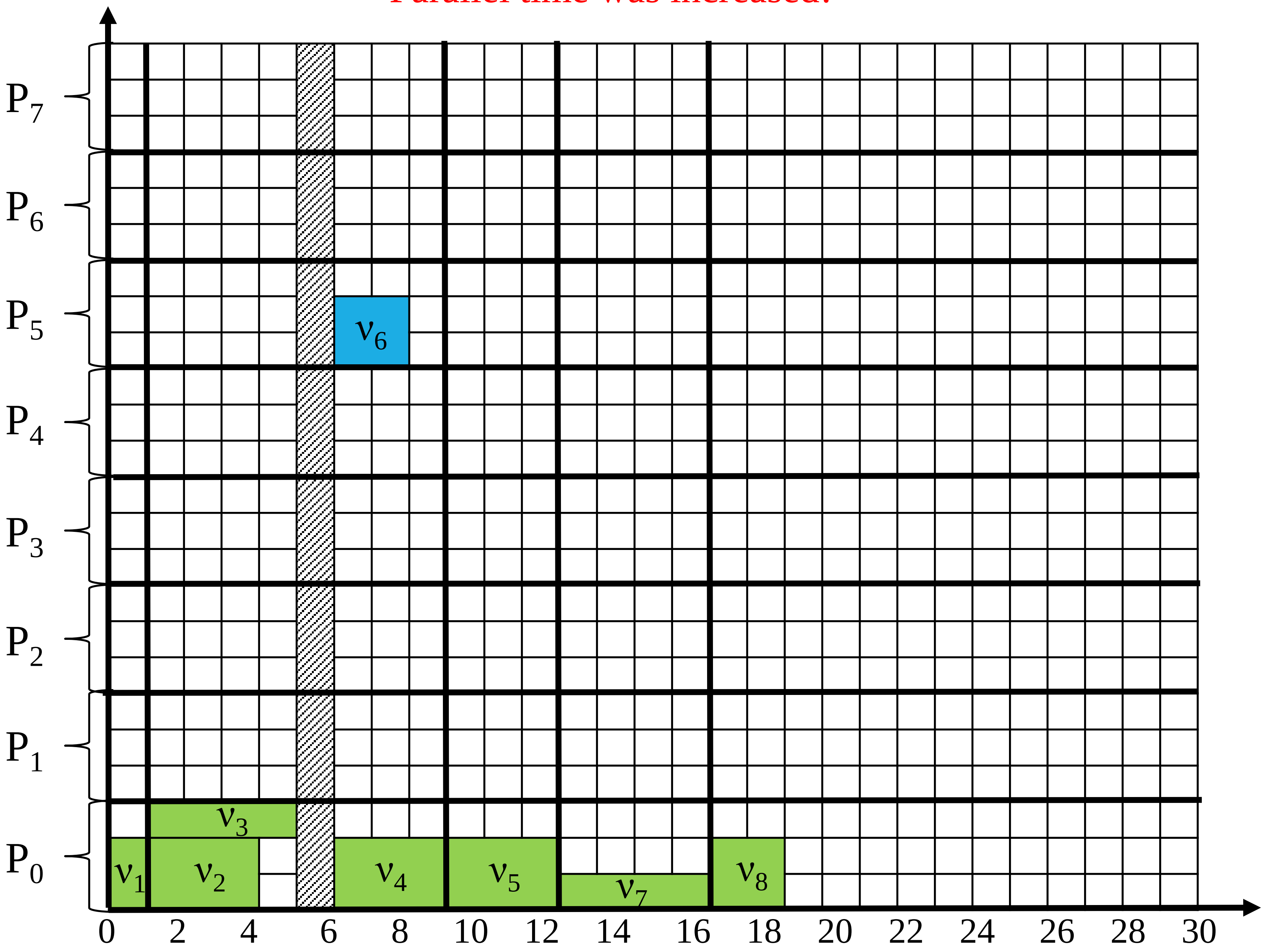
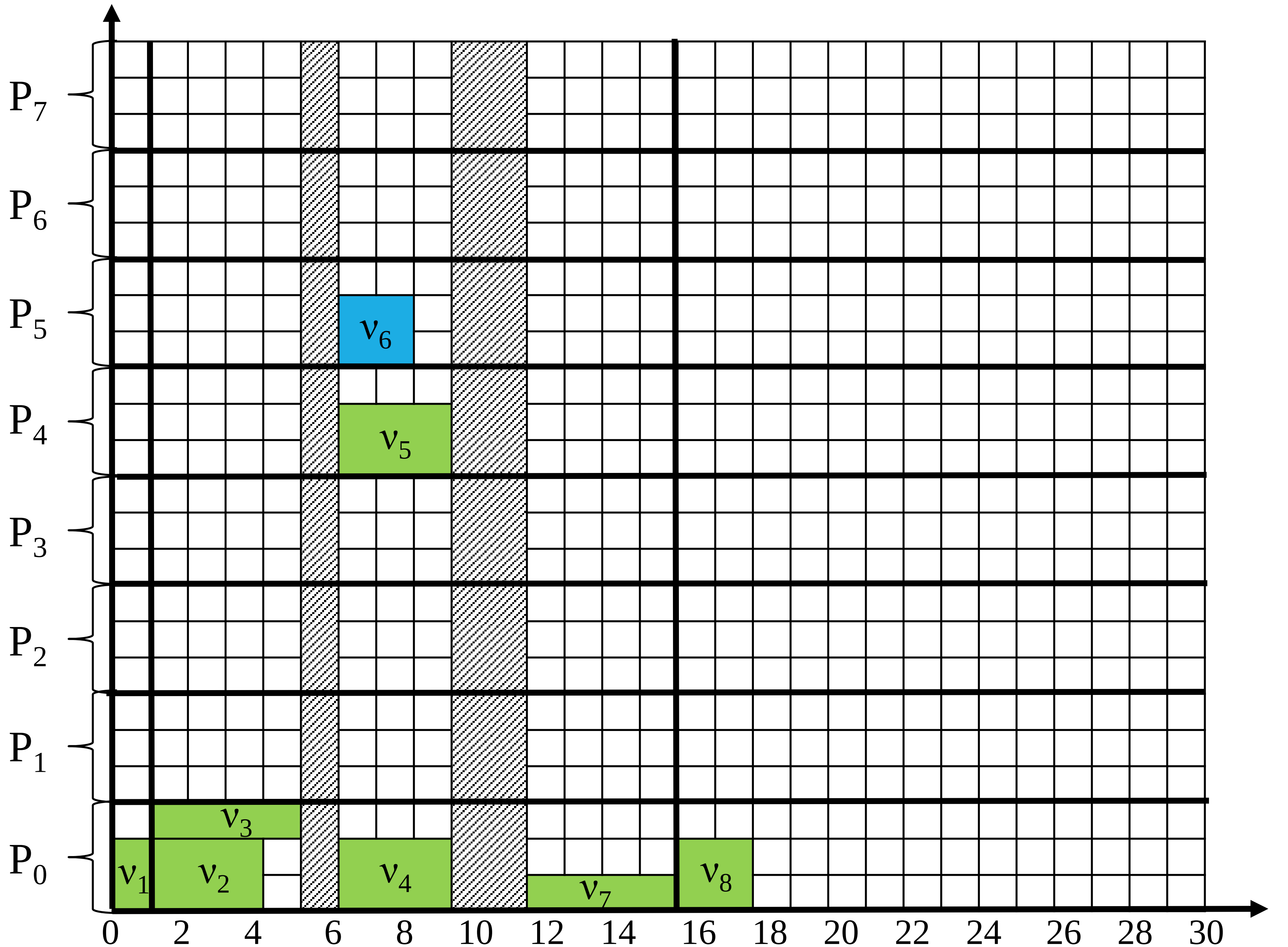
Parallel time was increased!





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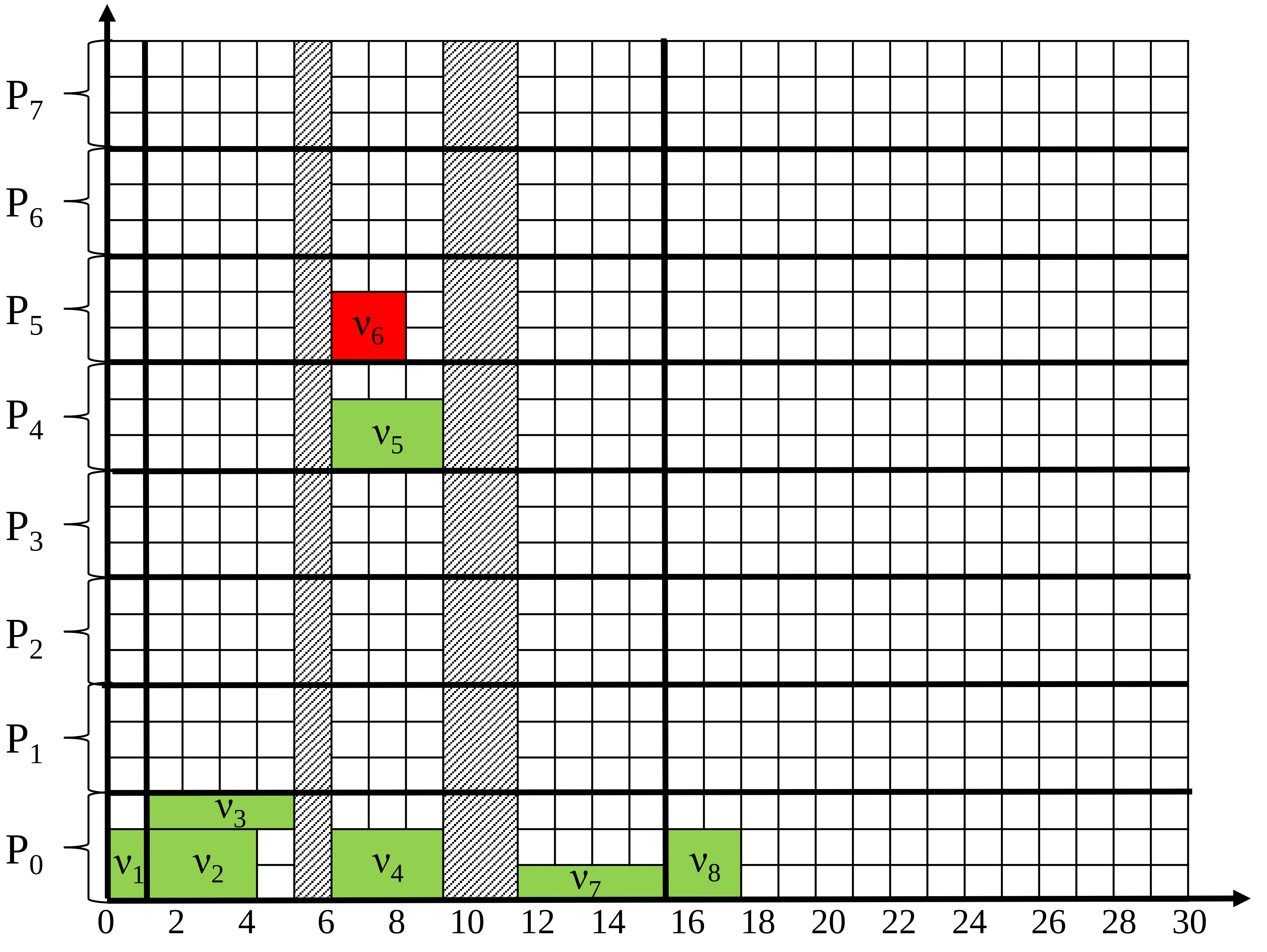

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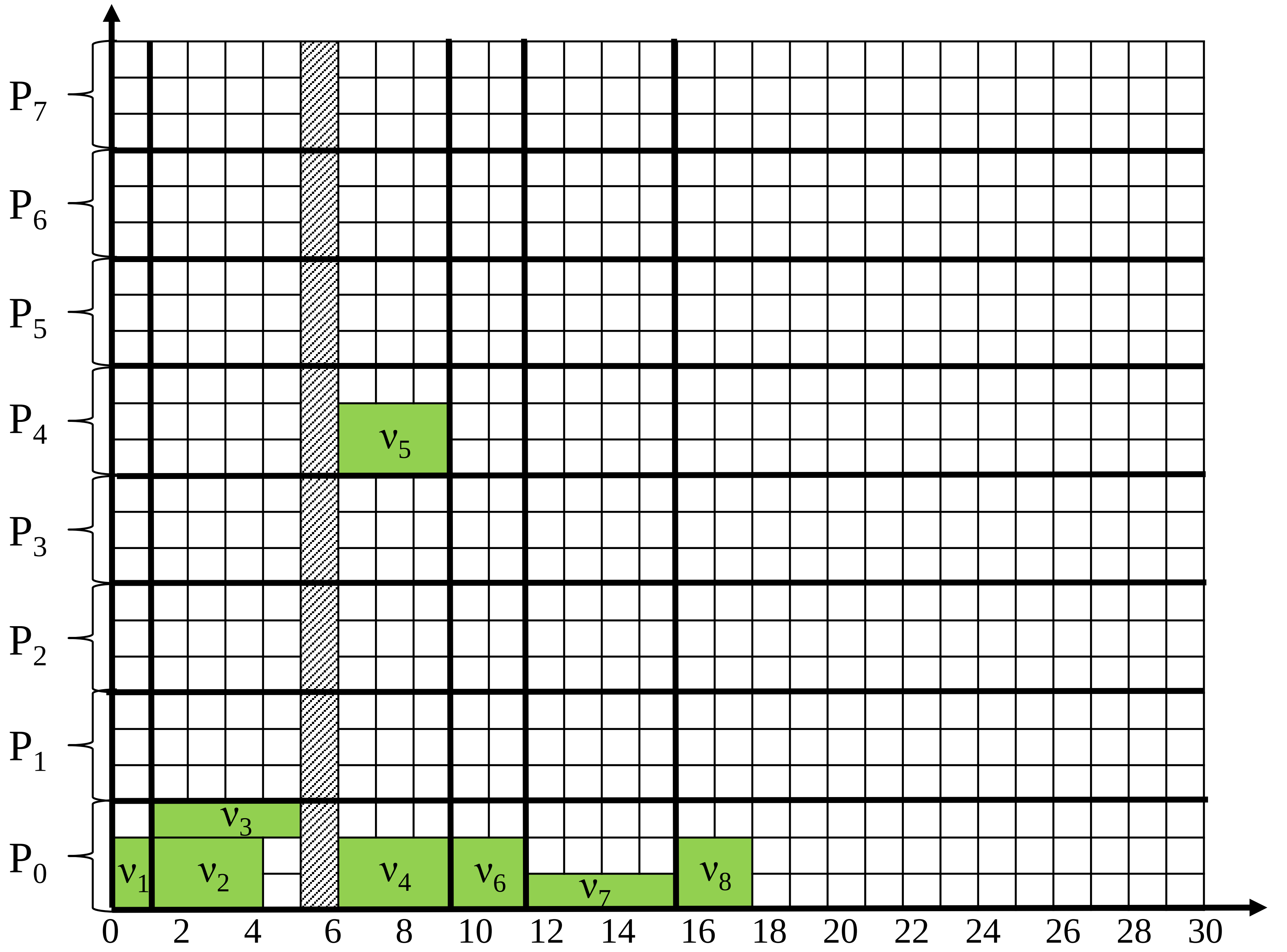
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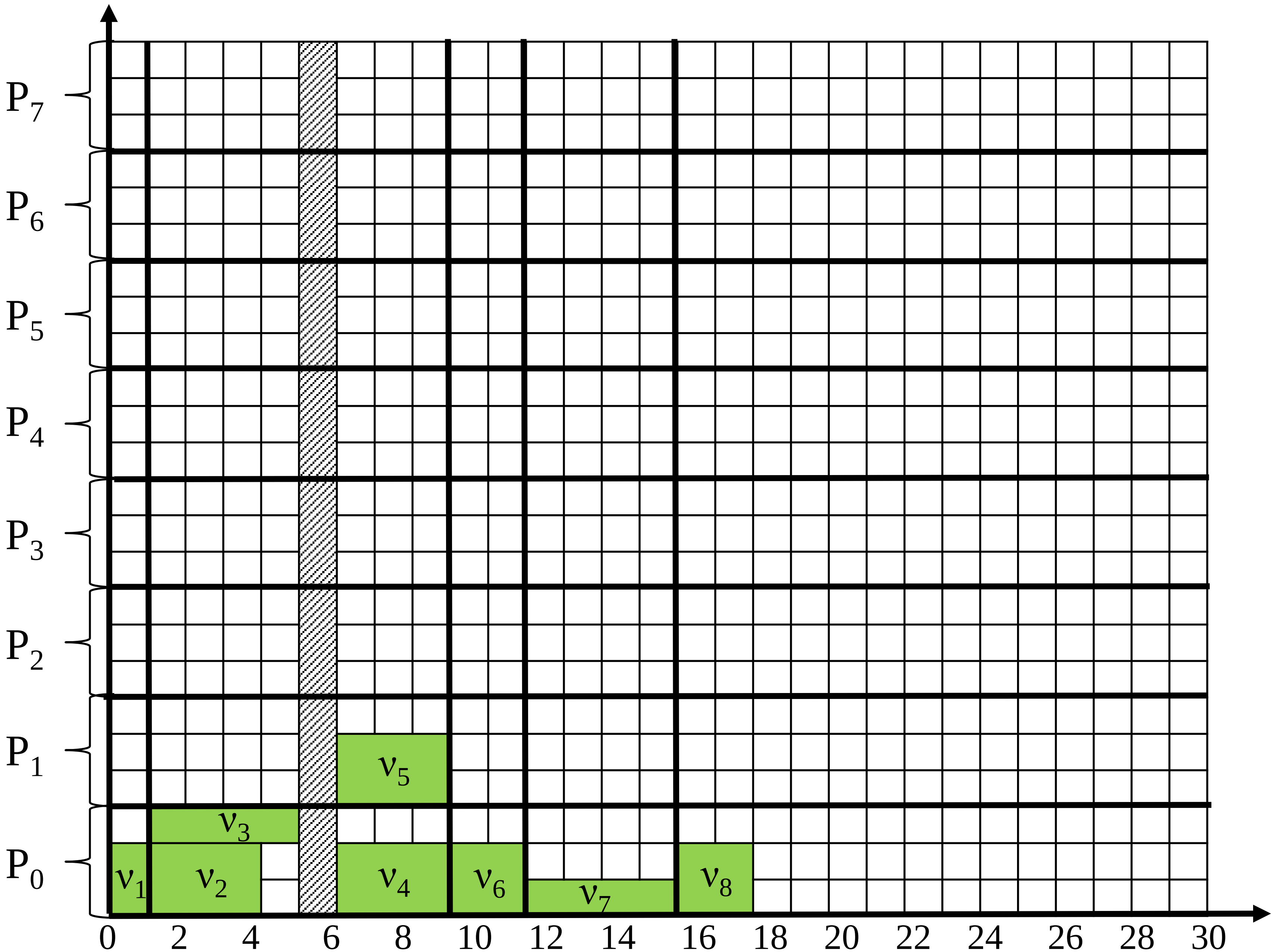
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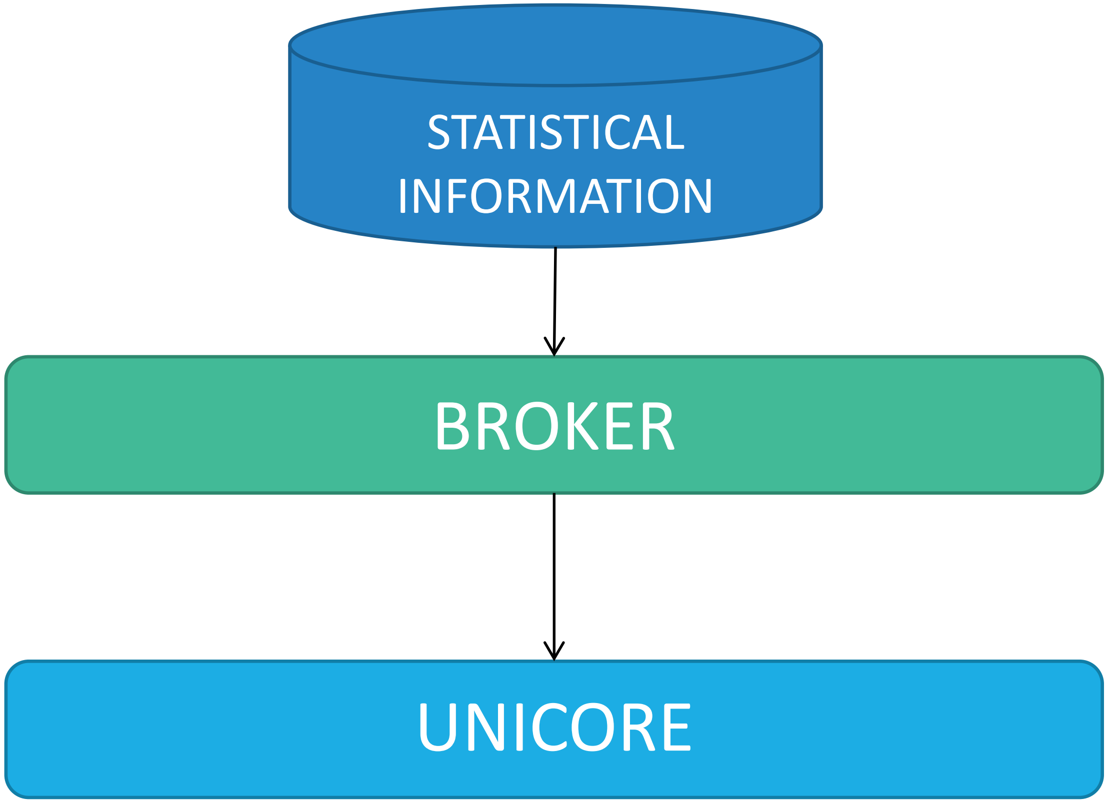
Integration with UNICORE



Conclusion

The following features have been developed:

- a mathematical job model for the description of known and new algorithms for clustering
- a resource scheduling algorithm for problem-oriented distributed computing environments