Growth diagrams and edge local rules

GT Combinatoire, LaBRI

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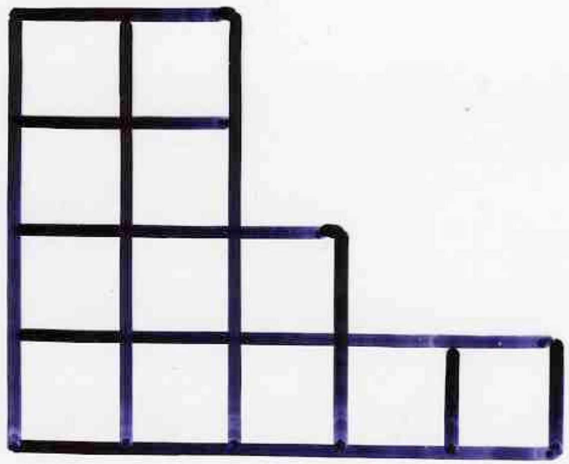
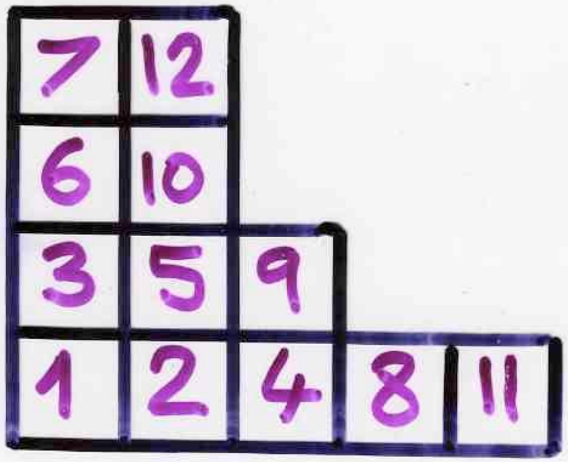
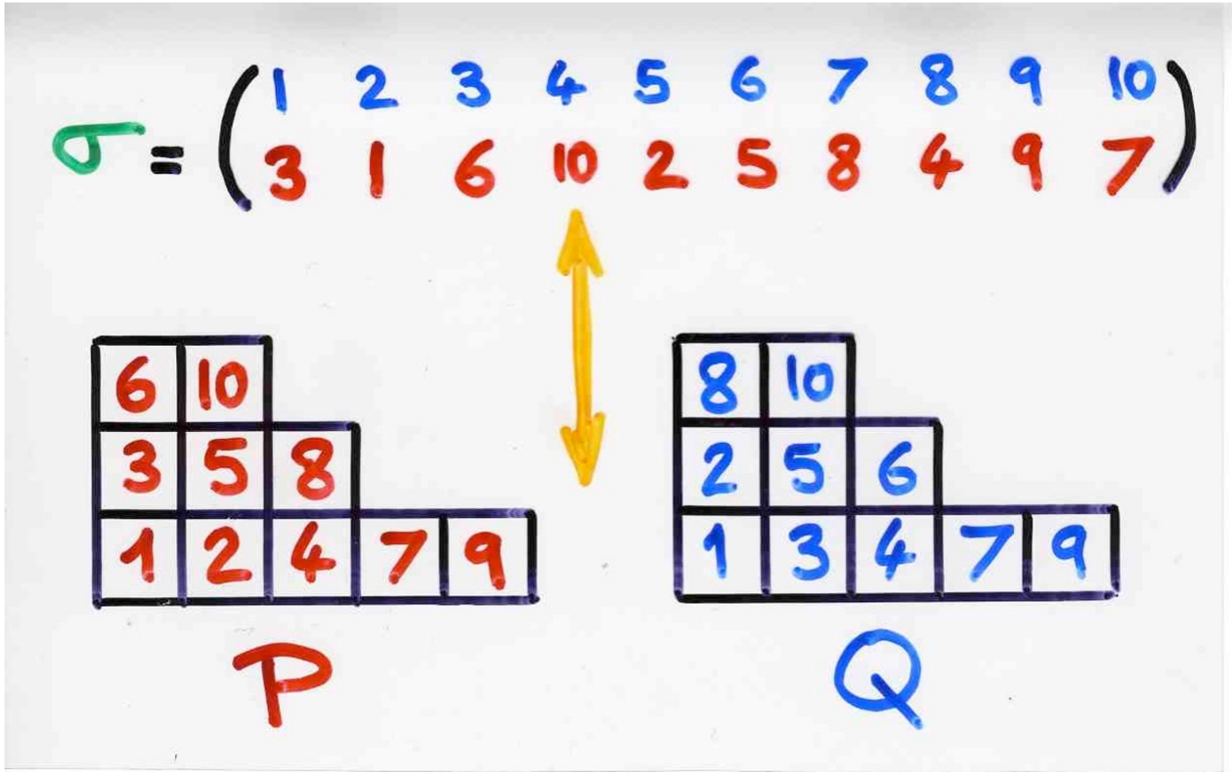
RS
The Robinson-Schensted correspondence





Young tableau

shape λ



The Robinson-Schensted correspondence between permutations and pairs of (standard) Young tableaux with the same shape

f_λ = number of Young tableaux with shape λ

$$n! = \sum_{\substack{\lambda \\ \text{partition of } n}} (f_\lambda)^2$$

“local” algorithm on a grid or “growth diagrams”

S. Fomin, 1986, 1994

C.Krattenthaler

S. V. Fomin, “Finite partially ordered sets and Young tableaux”, Soviet Math. Dokl. 19, (1978), 1510–1514.

S. V. Fomin, “Generalised Robinson-Schensted-Knuth correspondence”, Journal of Soviet Mathematics 41, (1988), 979–991. (Translation from Zapiski nauqnyh seminarov LOMI 155 (1986) 156–175; authorised translation available from the author).

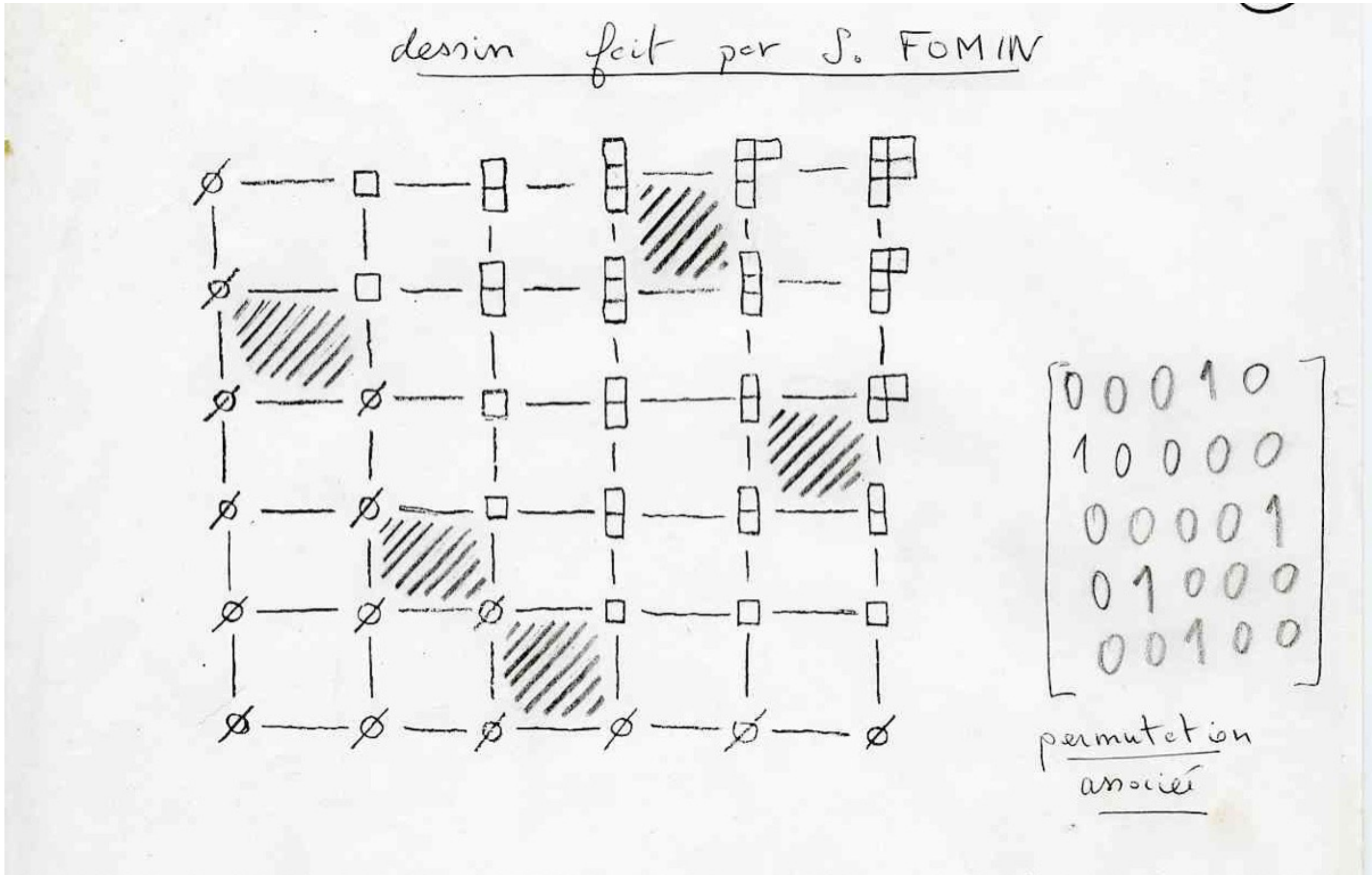
S. Fomin, Dual graphs and Schensted correspondences, Proceedings of the 4th International conference on Formal power series and Algebraic combinatorics, Montreal, (1992).

S. Fomin, Schur operators and Knuth correspondences, Institut Mittag-Leffler report No. 17, (1991/92).

S. Fomin, “Duality of graded graphs”, J. Algebr. Combinatorics 3, (1994), 357–404.

S. Fomin, “Schensted algorithms for dual graded graphs”, J. Algebr. Combinatorics 4, (1995), 5–45.

S. Fomin and C. Greene, “A Littlewood-Richardson Miscellany”, Europ. J. Combinatorics 14, (1993), 191–212.



S. Fomin, Schur operators and Knuth correspondences,

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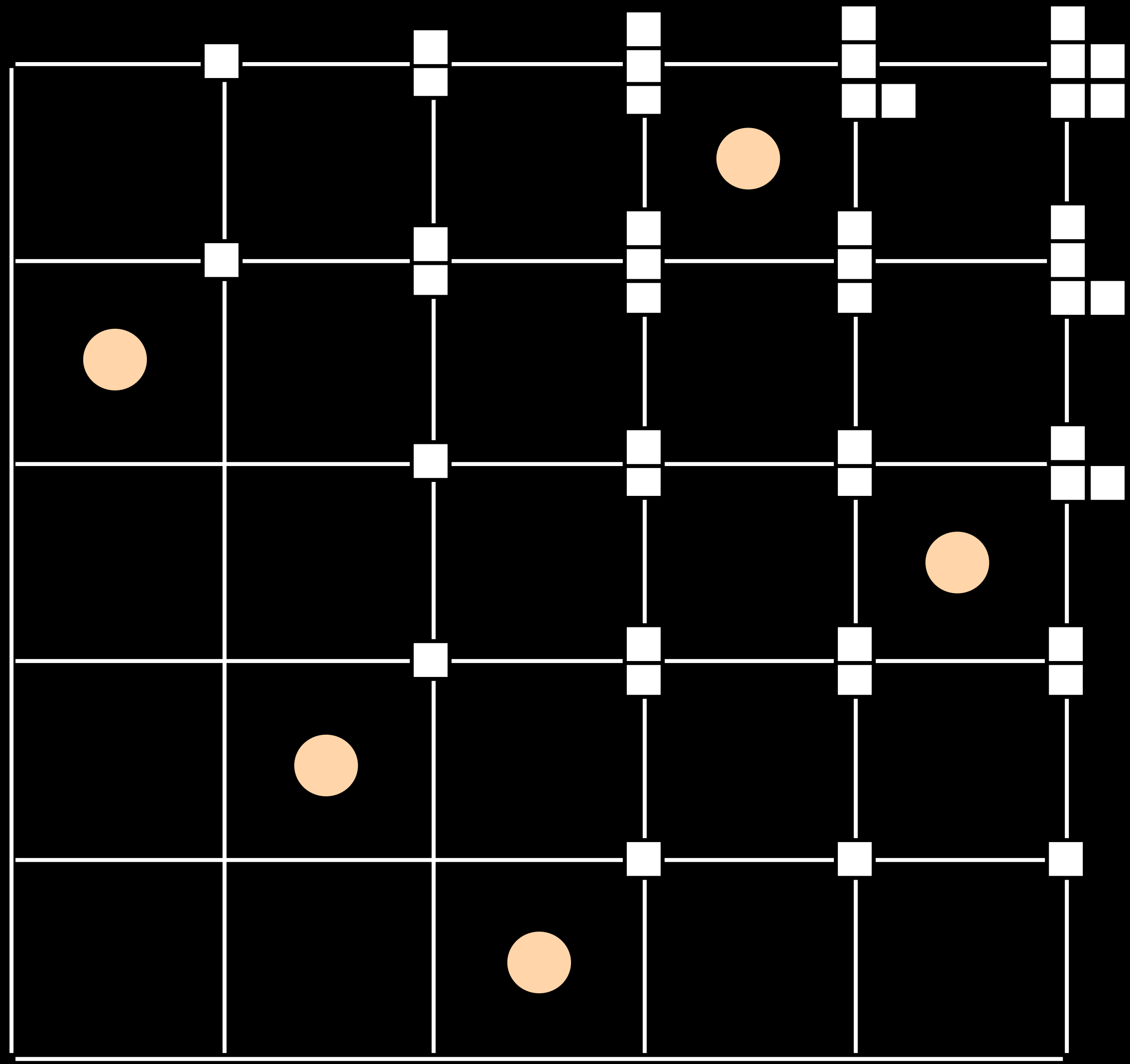
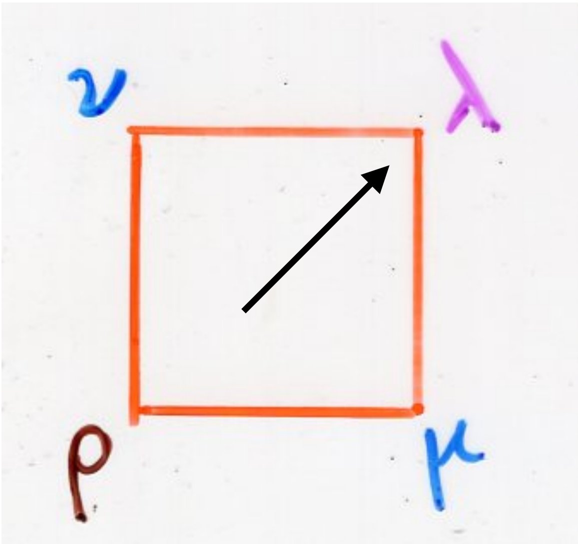


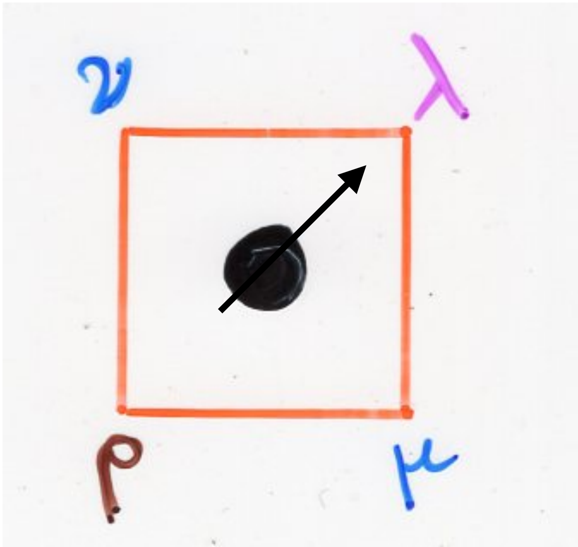
"growth diagrams"

"local rules"

"growth diagrams"

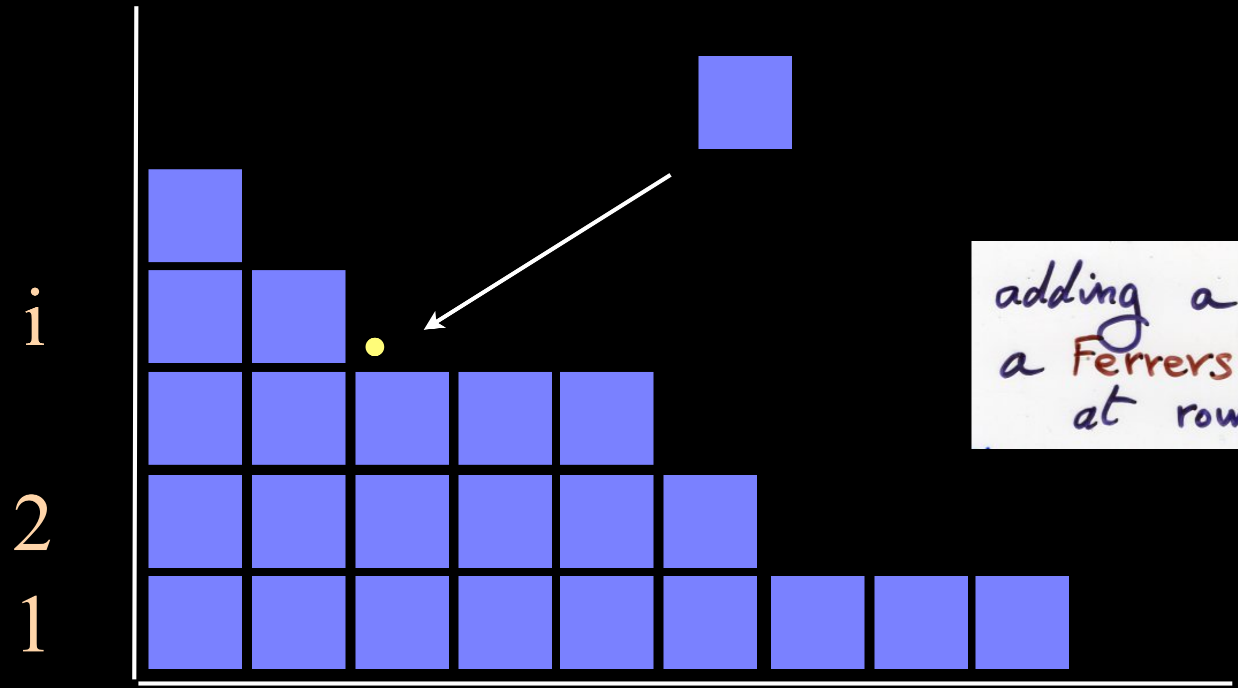
"local rules"





notations

operator U_i



adding a cell in a Ferrers diagram ρ at row i

$$U_i(\rho) = \rho + (i)$$

"local rules"

(i) $\rho = \mu = \nu$ and, then $\lambda = \rho$

(ii) $\rho = \mu \neq \nu$, then $\lambda = \nu$

(iii) $\rho = \nu \neq \mu$, then $\lambda = \mu$

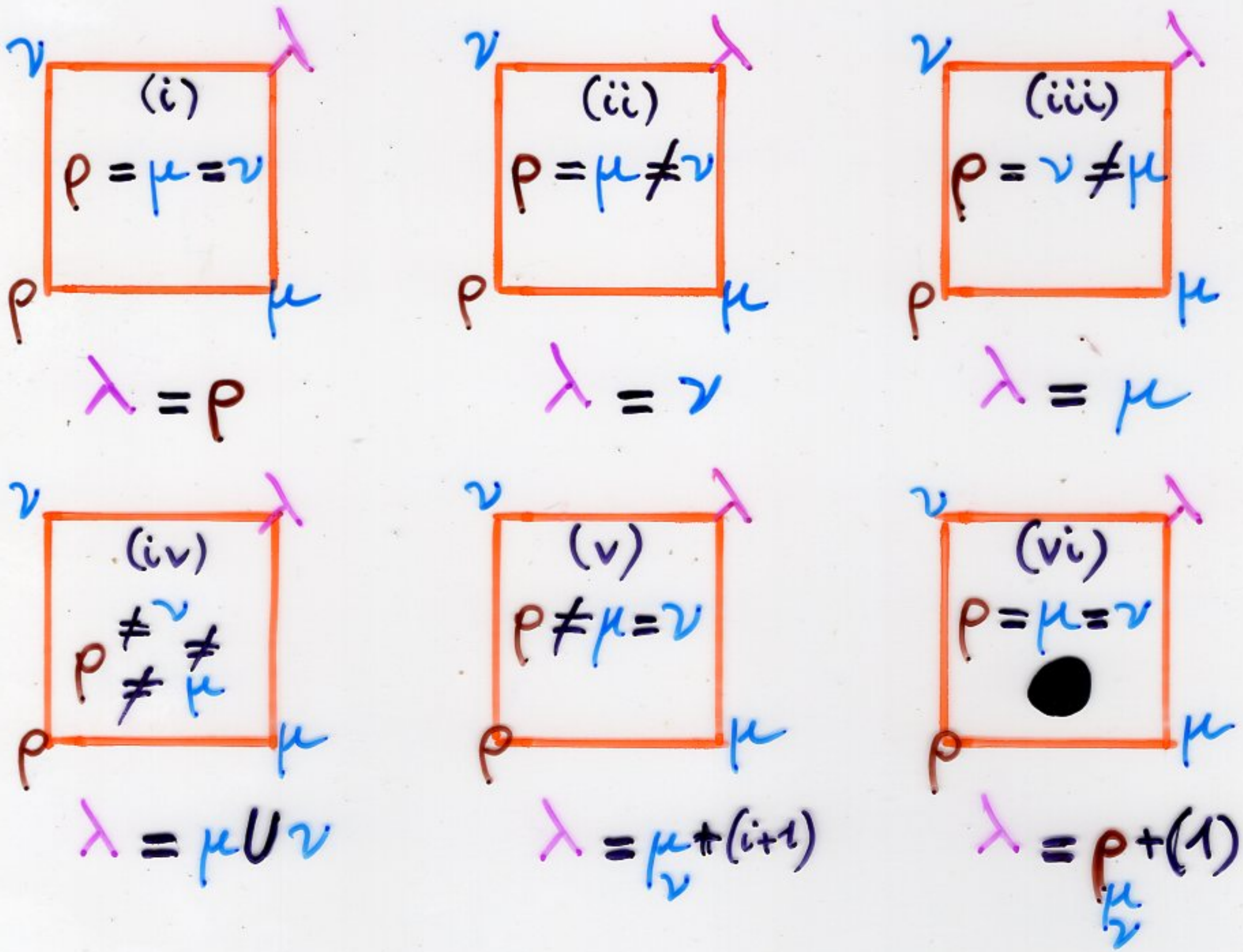
(iv) ρ, μ, ν pairwise $\neq$, then $\lambda = \mu \cup \nu$

(v) $\rho \neq \mu = \nu$, then $\lambda = \mu + (i+1)$
given that $\mu = \nu$ and ρ differ in the i-th row
[in fact $\mu = \nu = \rho + (i)$]

(vi) $\rho = \mu = \nu$ and, then $\lambda = \mu + (1)$

C.Krattentheler, (2006).

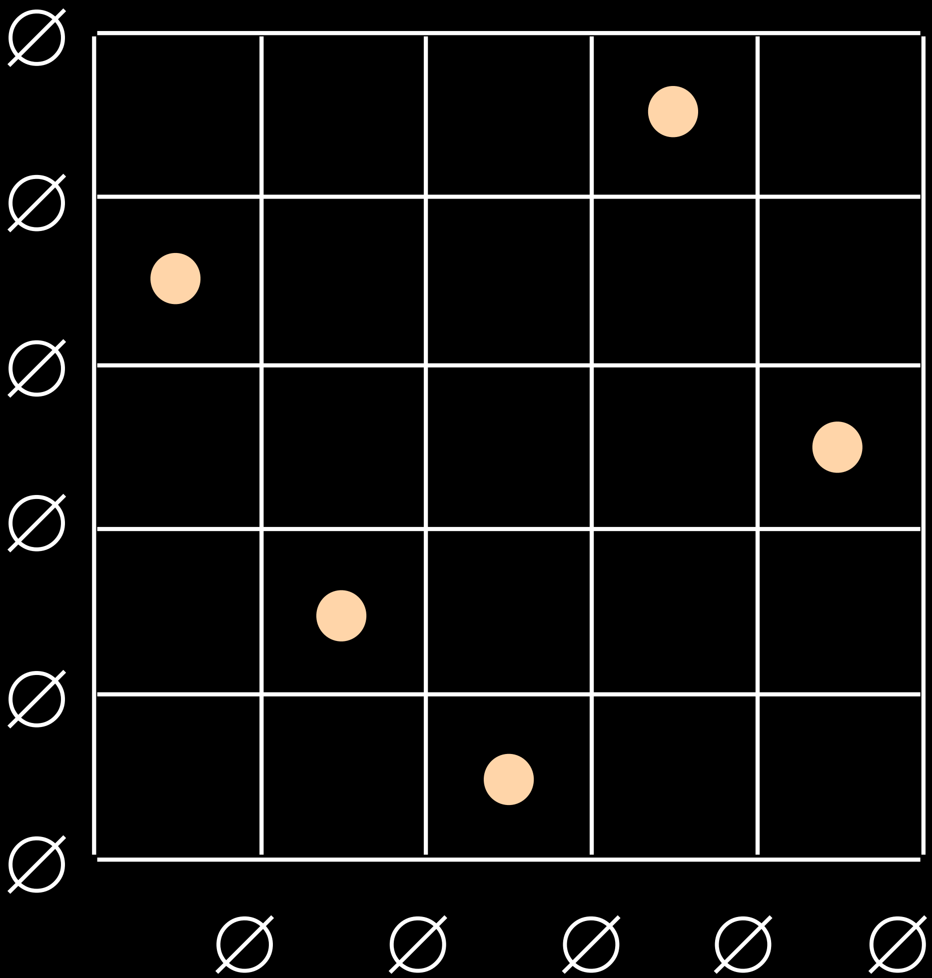
GROWTH DIAGRAMS, AND INCREASING AND DECREASING CHAINS IN FILLINGS OF FERRERS SHAPES

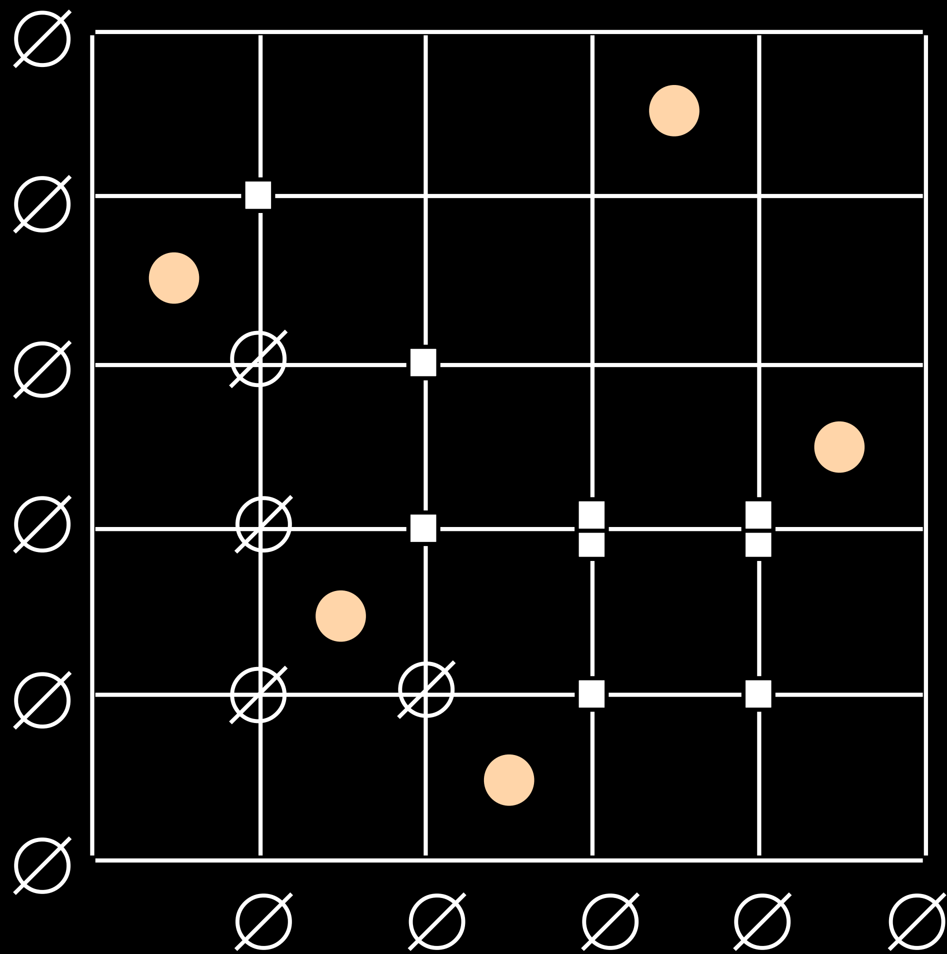


(i)
ρ = μ = ν
λ = ρ
(ii)
ρ = μ ≠ ν
λ = ν
(iii)
ρ = ν ≠ μ
λ = μ
(iv)
λ = μ ∪ ν
(v)
ρ ≠ μ = ν
λ = μ ν + (i+1)
(vi)
ρ = μ = ν
λ = ρ μ ν + (1)

initial state

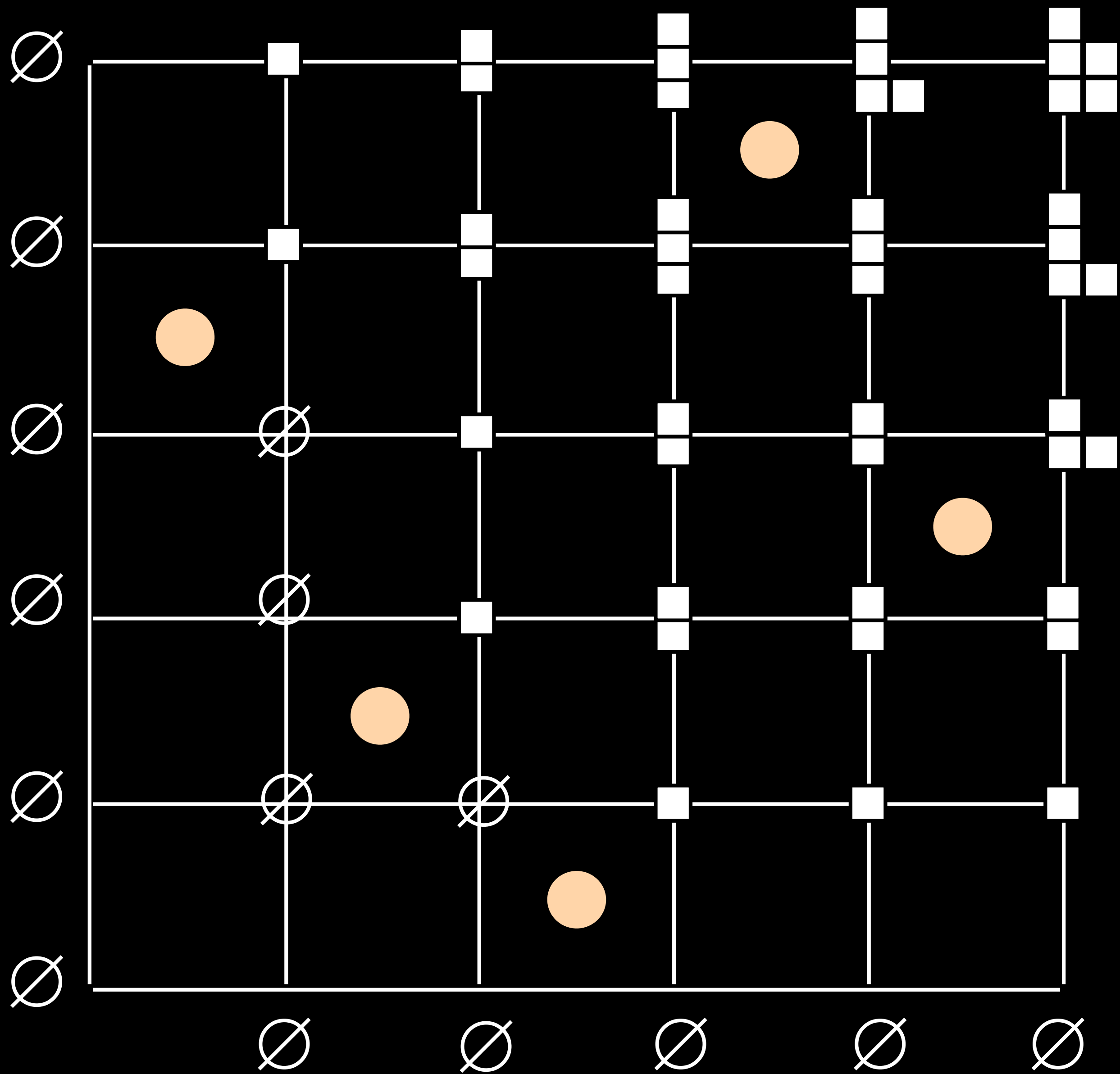
during the labeling process

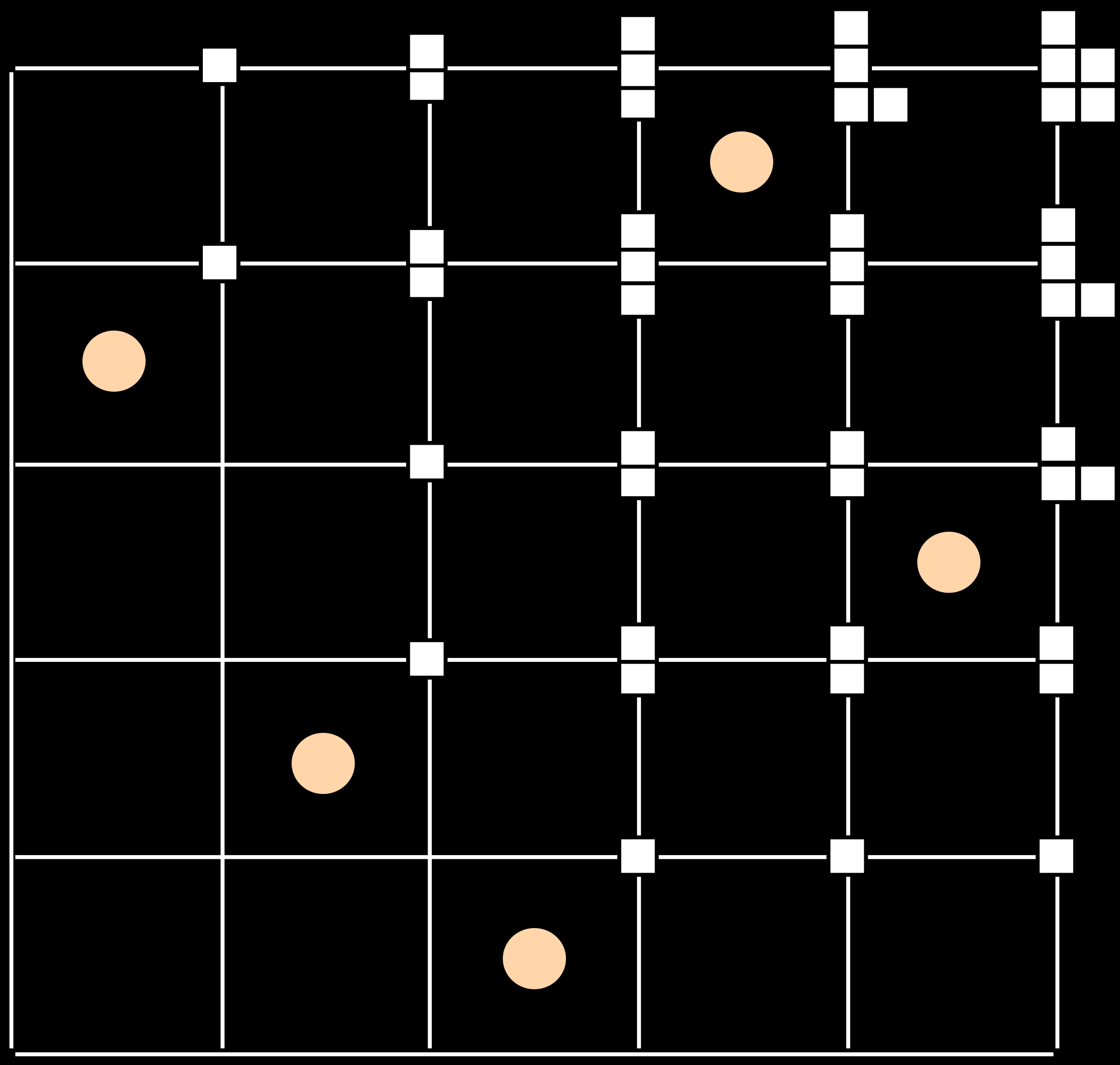


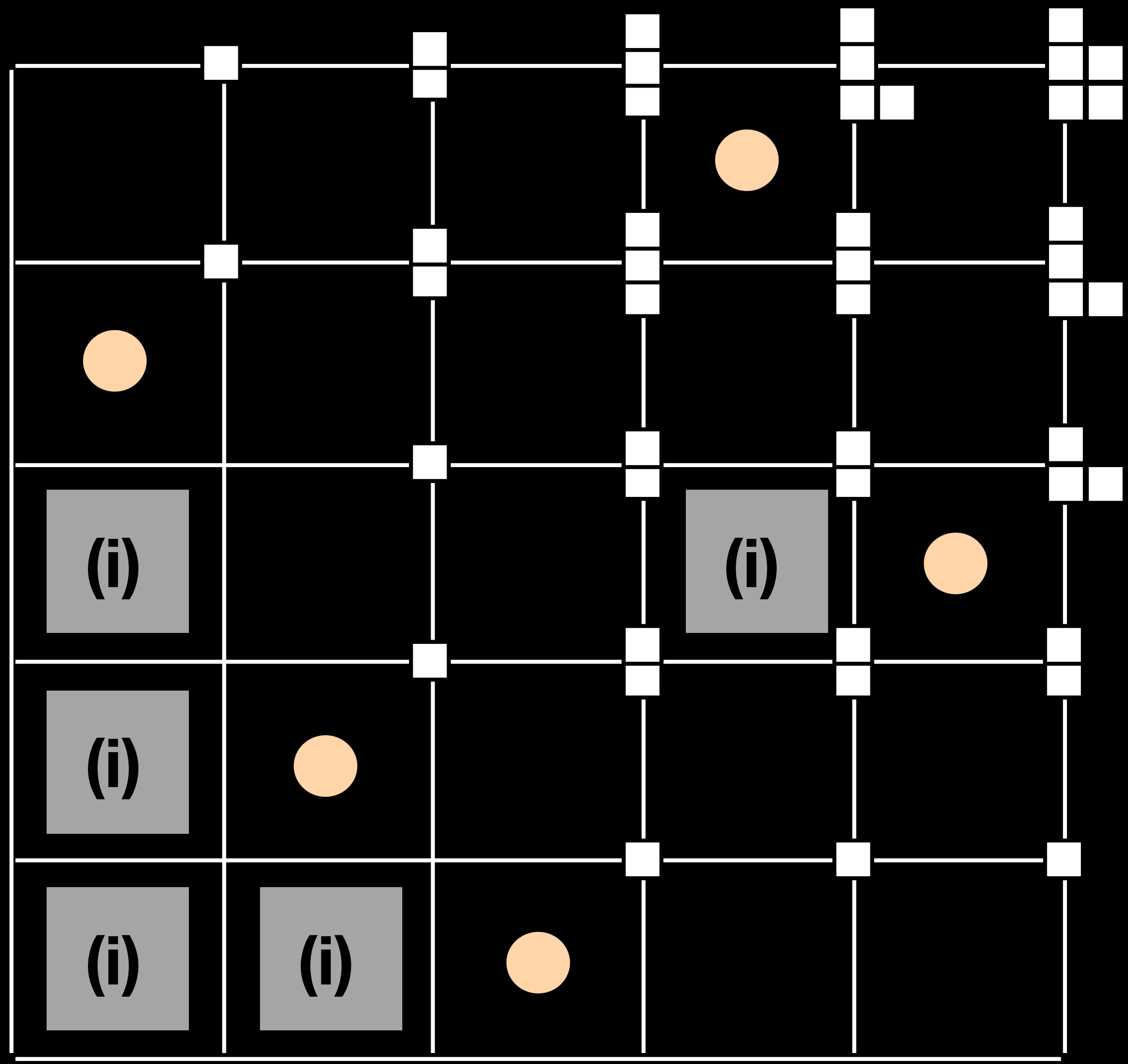


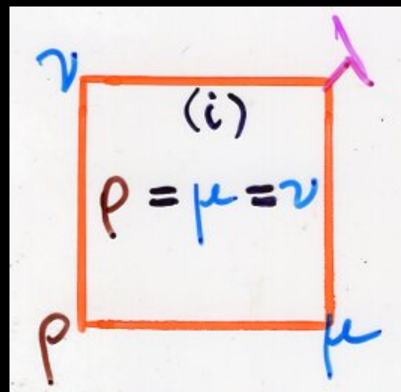
$\sigma = 4, 2, 1, 5, 3$

final state

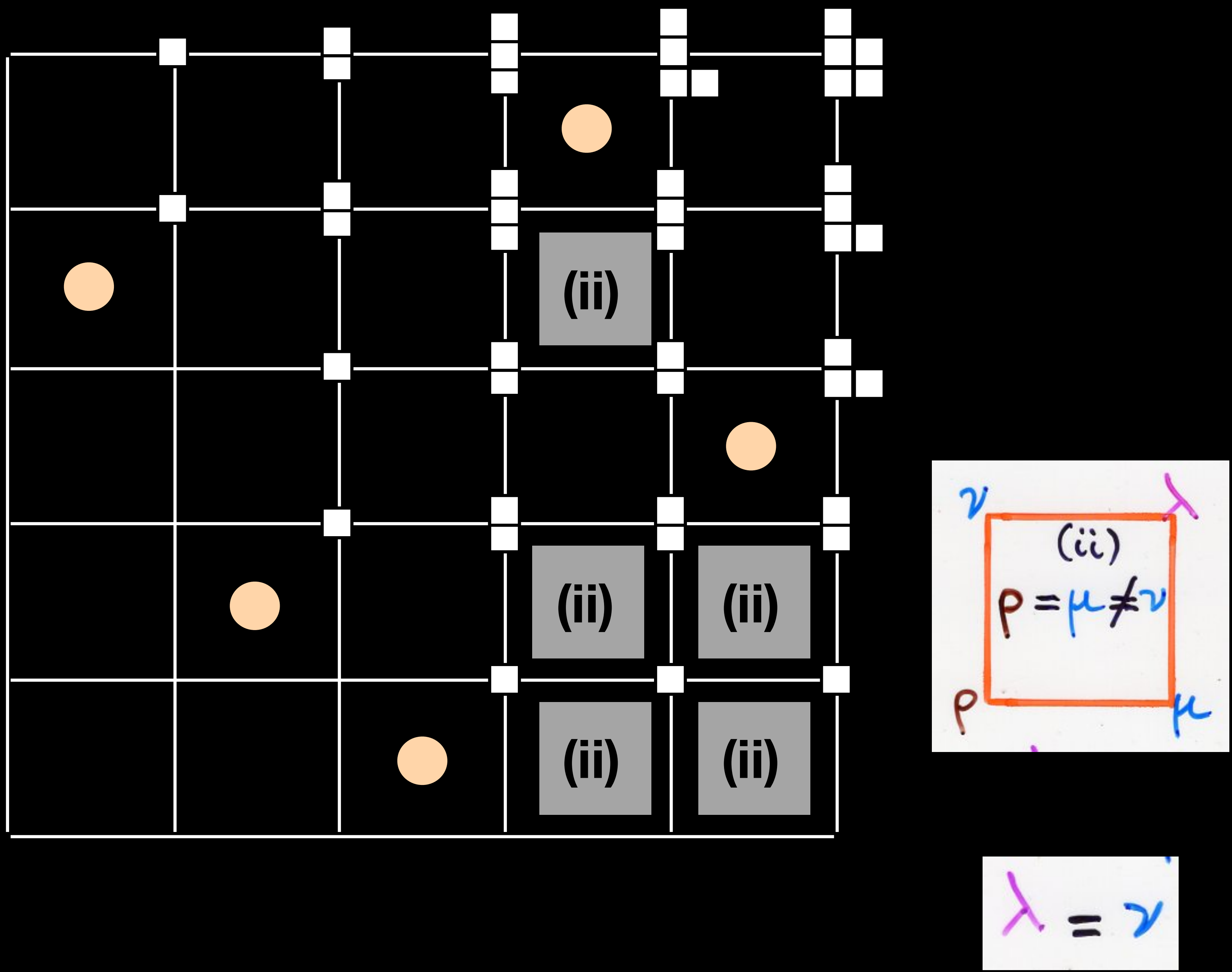


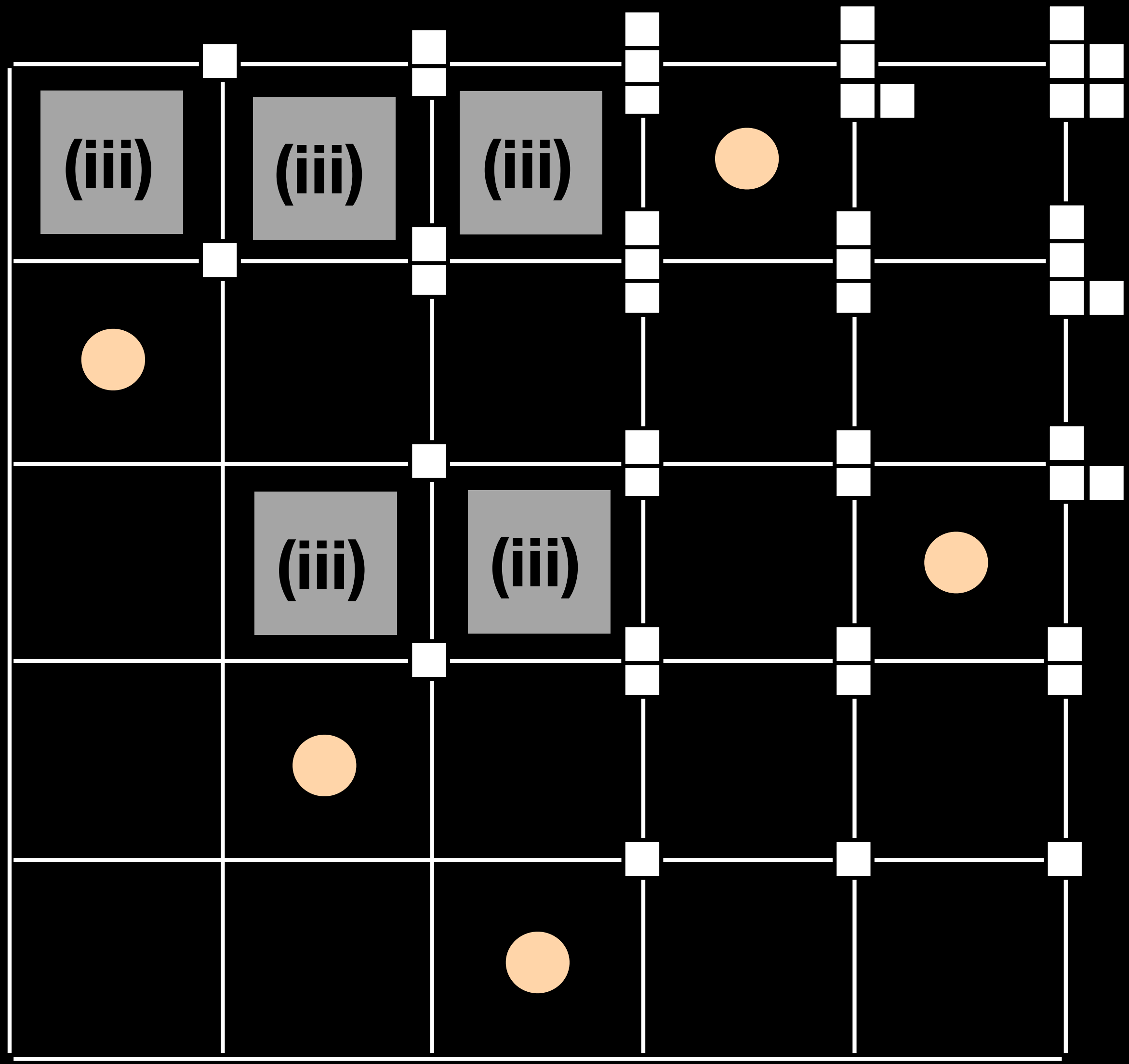


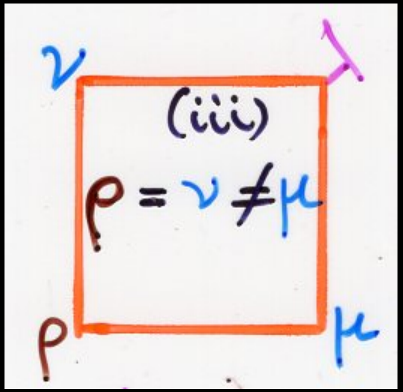




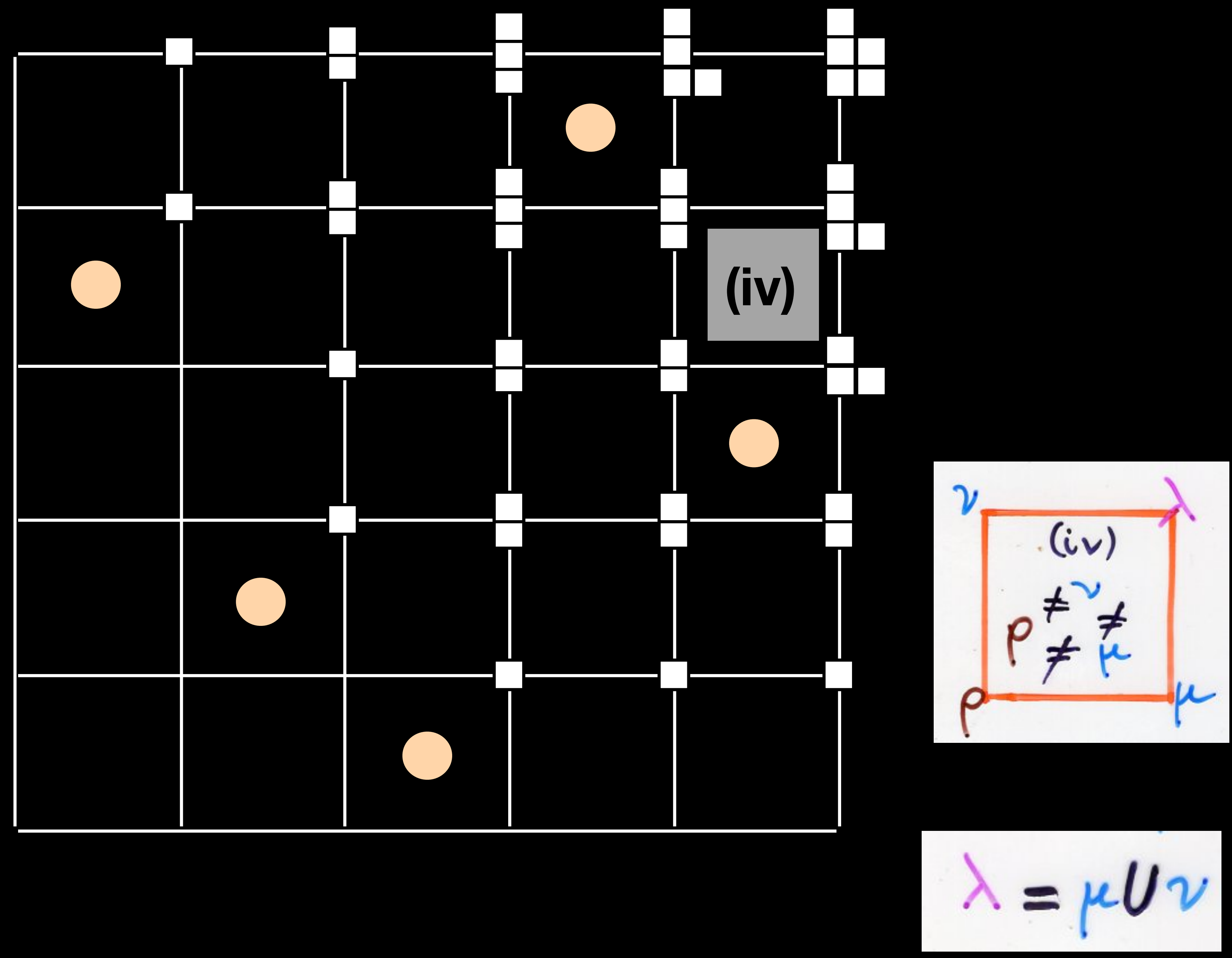
$\lambda = \rho$


(ii)
(ii)
(ii)
(ii)
(ii)
ν
λ
(ii)
$\rho = \mu \neq \nu$
ρ
μ
$\lambda = \nu$

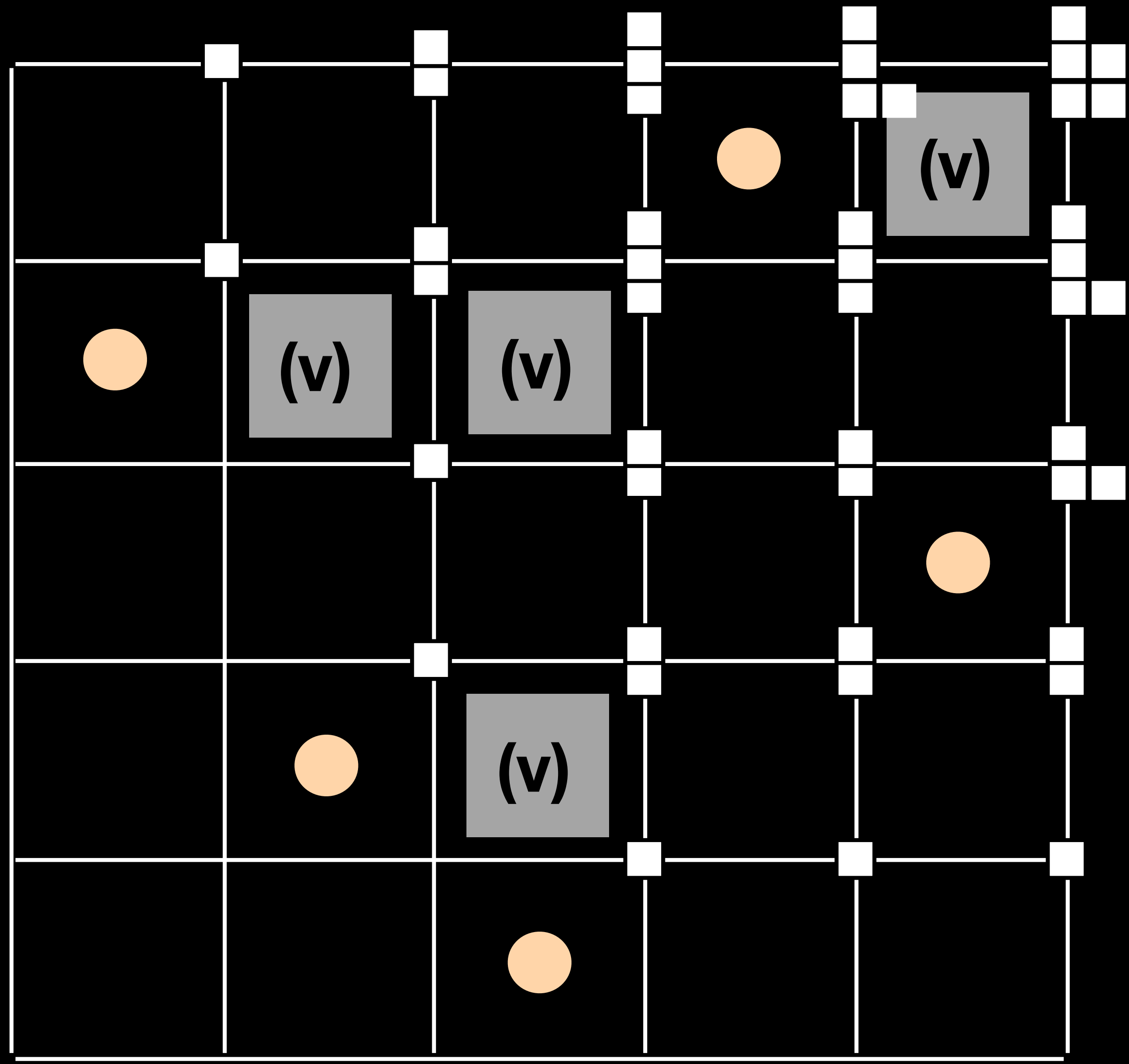


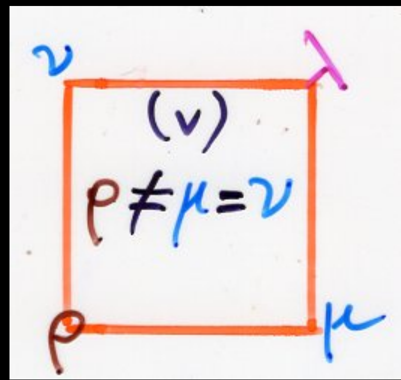


$\lambda = \mu$

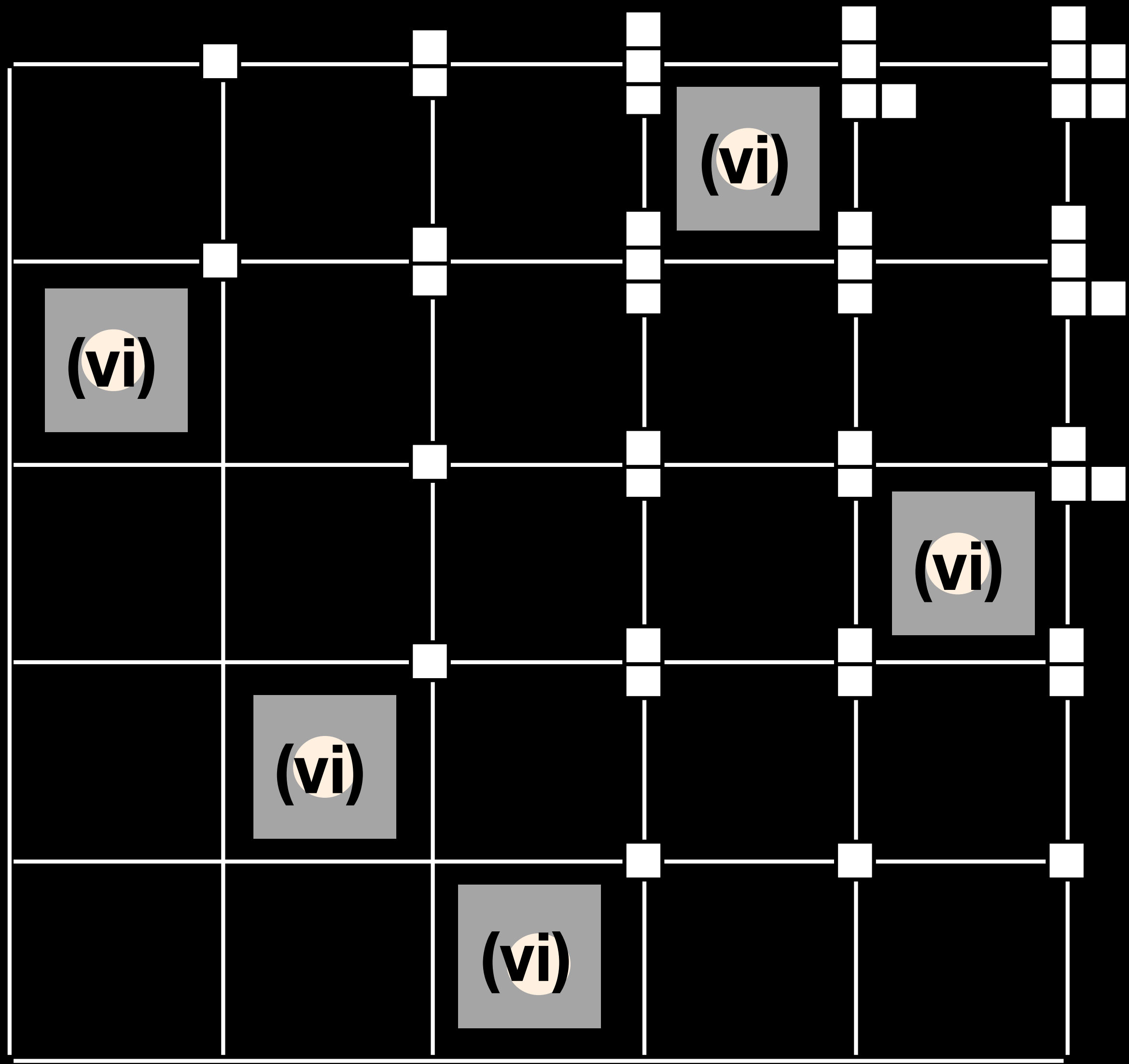


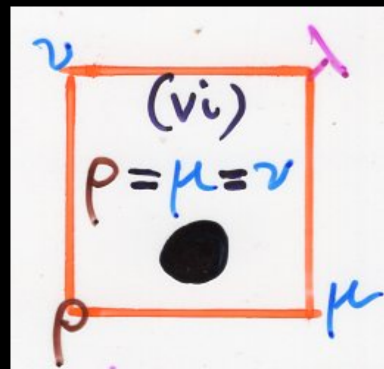
(iv)
(iv)
ν
λ
ρ
μ
ρ ≠ ν ≠ μ ≠
λ = μ ∪ ν

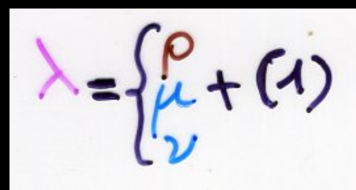


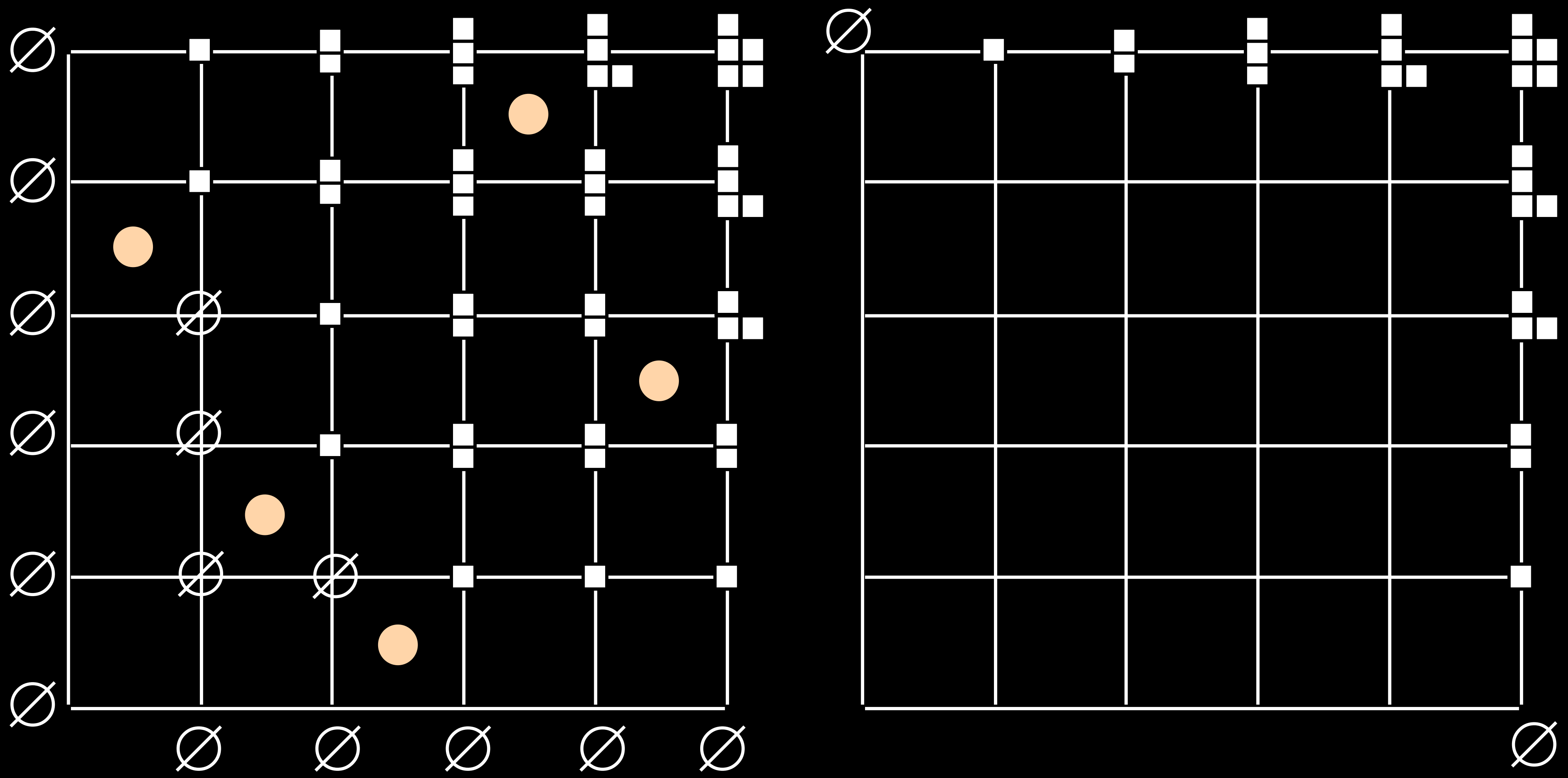


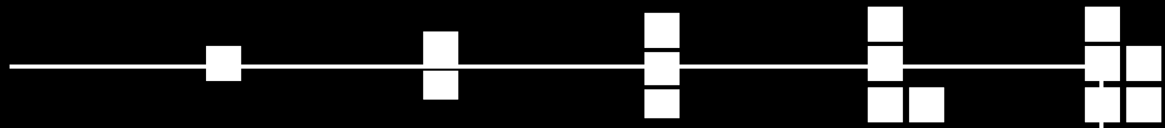
$$\lambda = \left\{ \begin{matrix} \mu \\ \nu \end{matrix} \right. + (i+1)$$


(vi)
(vi)
(vi)
(vi)
(vi)

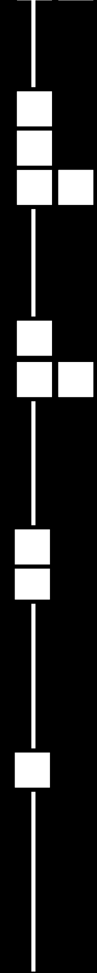

ν
λ
(vi)
ρ=μ=ν
ρ
μ

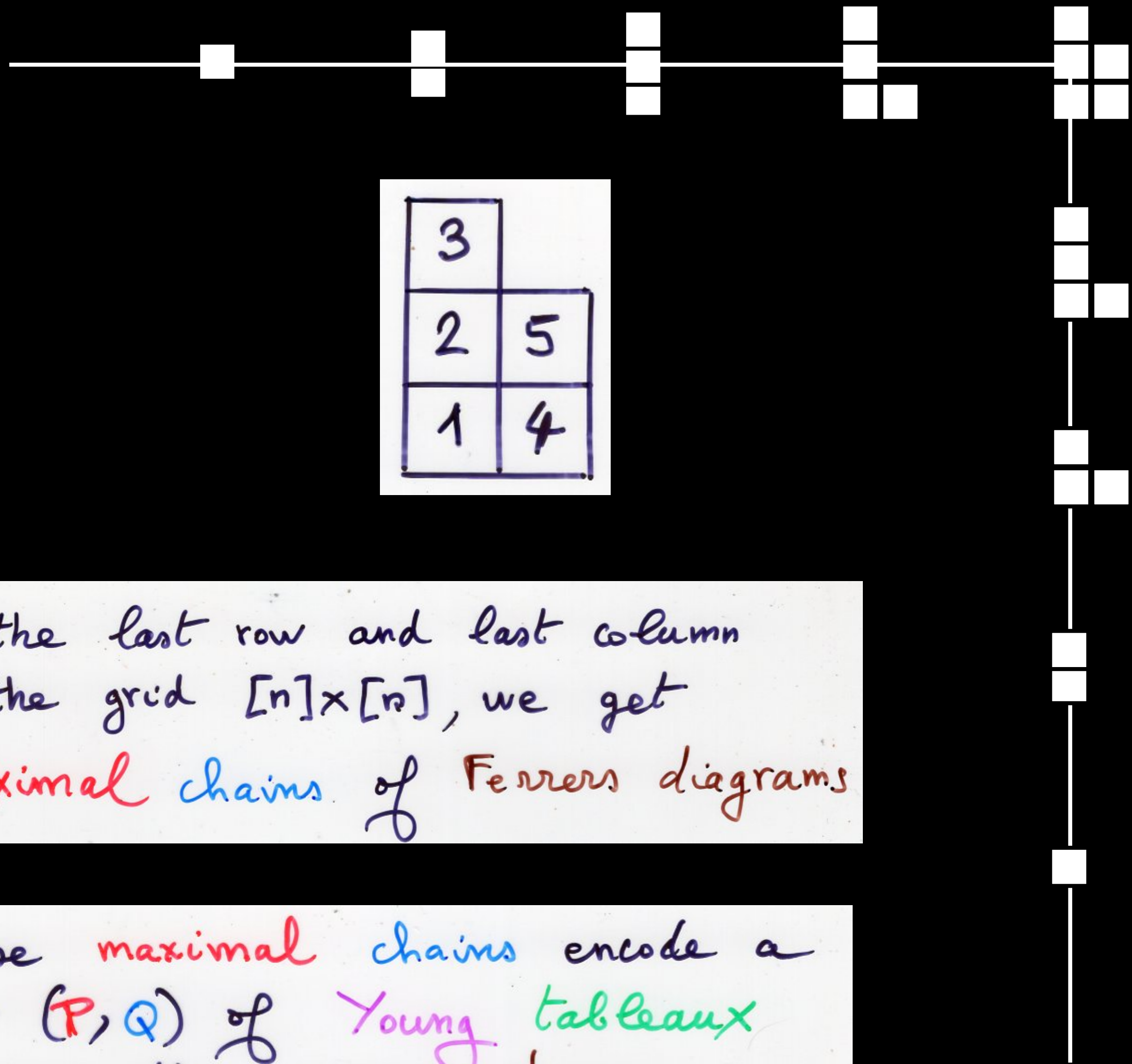

λ = {ρ μ ν + (1)





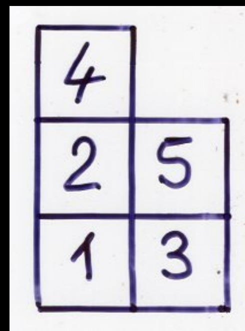
- in the last row and last column of the grid $[n]\times[n]$, we get maximal chains of Ferrers diagrams

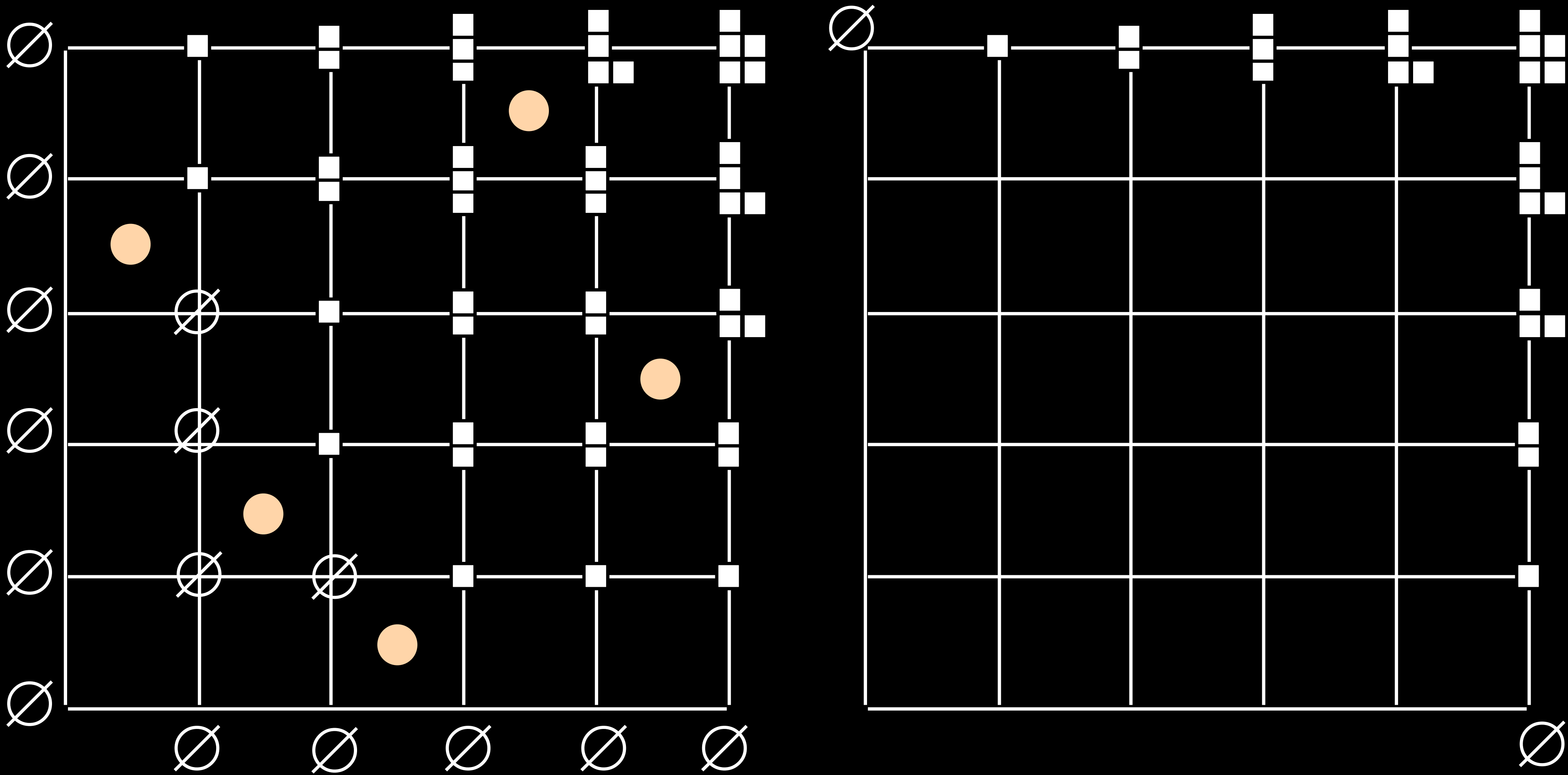




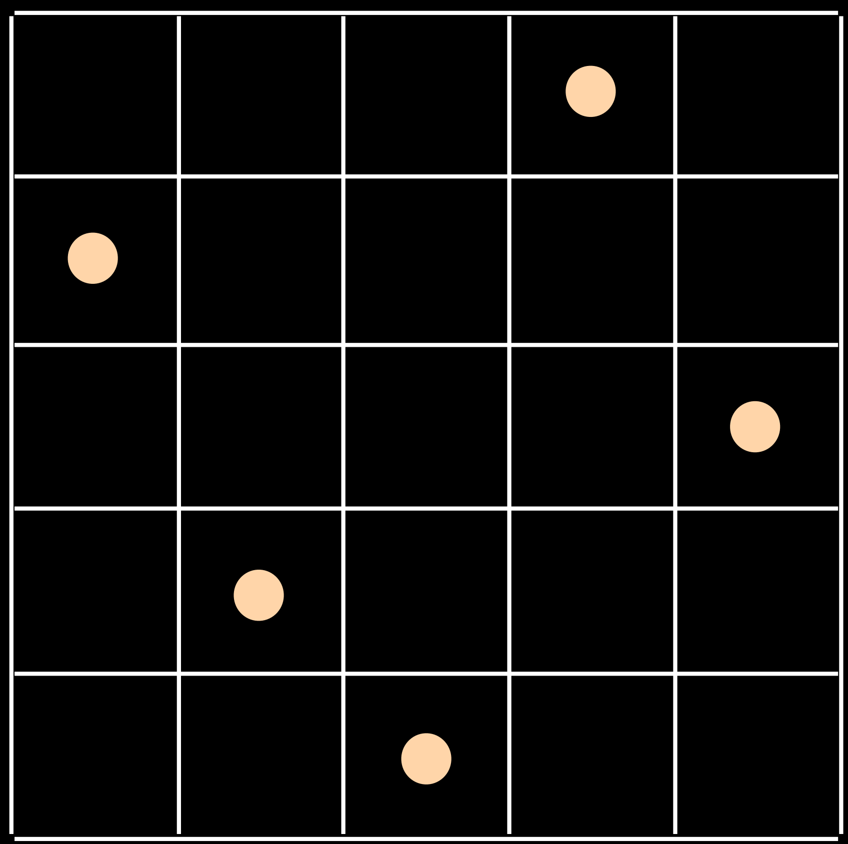
- in the last row and last column of the grid $[n] \times [n]$, we get maximal chains of Ferrers diagrams

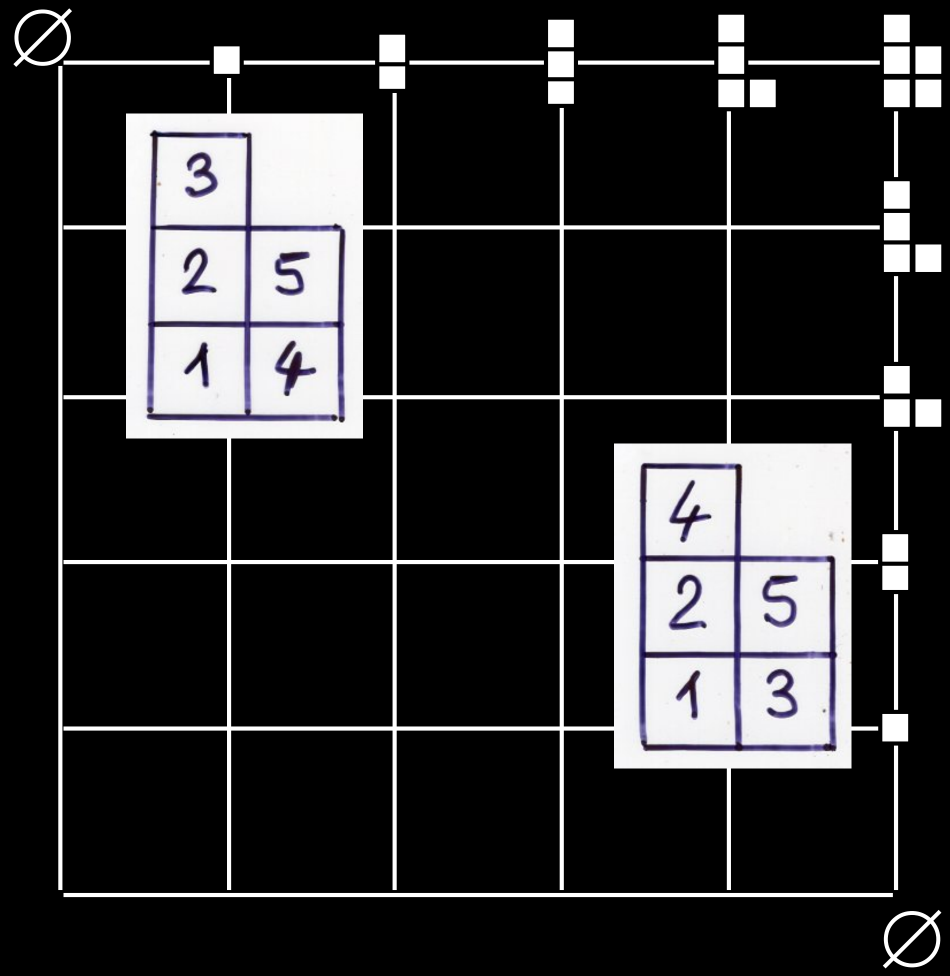
- these maximal chains encode a pair (P, Q) of Young tableaux having the same shape





- the algorithm can be reversed : from the pair (P, Q) , get back the permutation

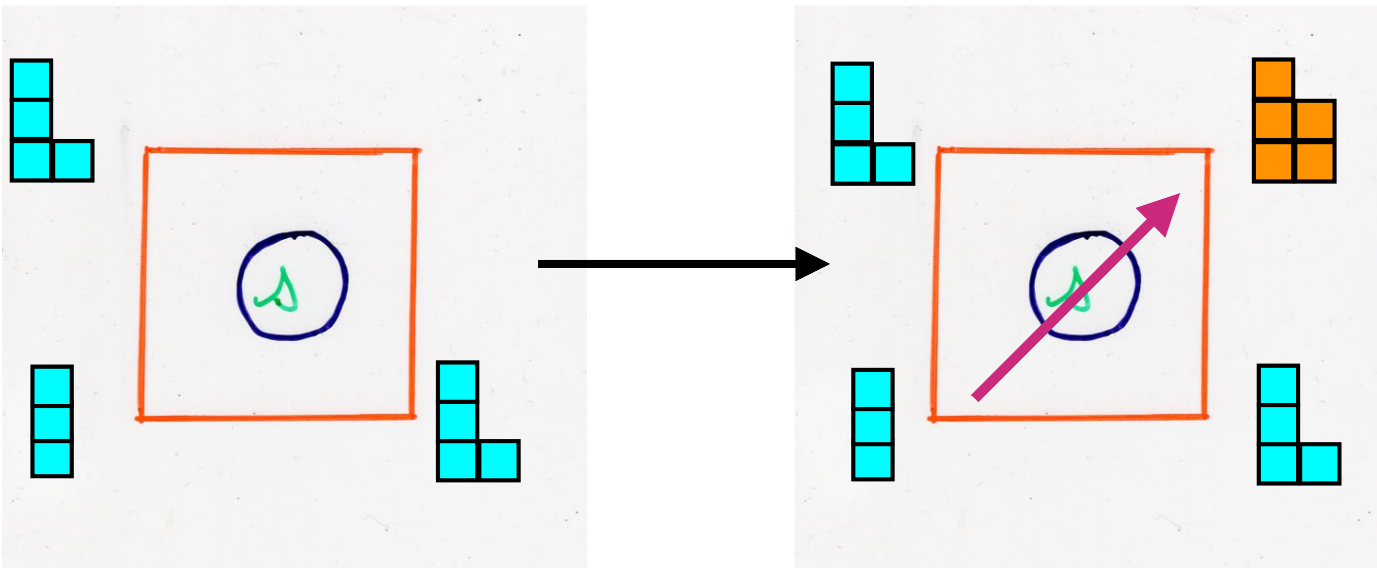




- this bijection is the same as the Robinson–Schensted correspondence

Edge Local rules

Fomin's "local rules"
"growth diagrams"



"local rules"
on the vertices

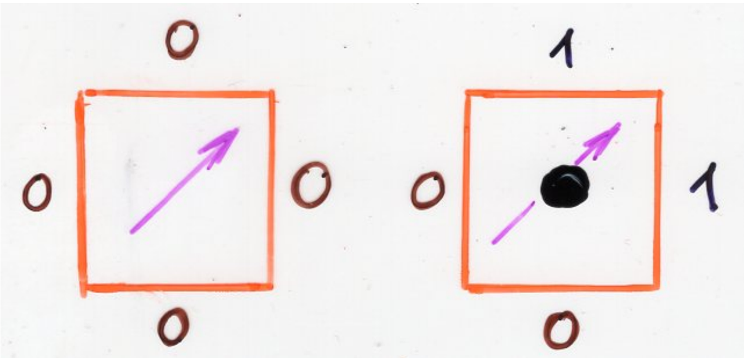
"local rules" on the edges

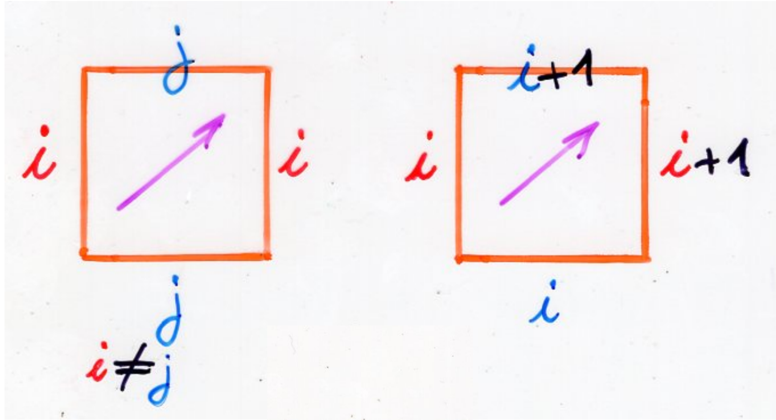
state $\{0, 1, 2, \dots\}$

state $\{0, 1, 2, \dots\}$

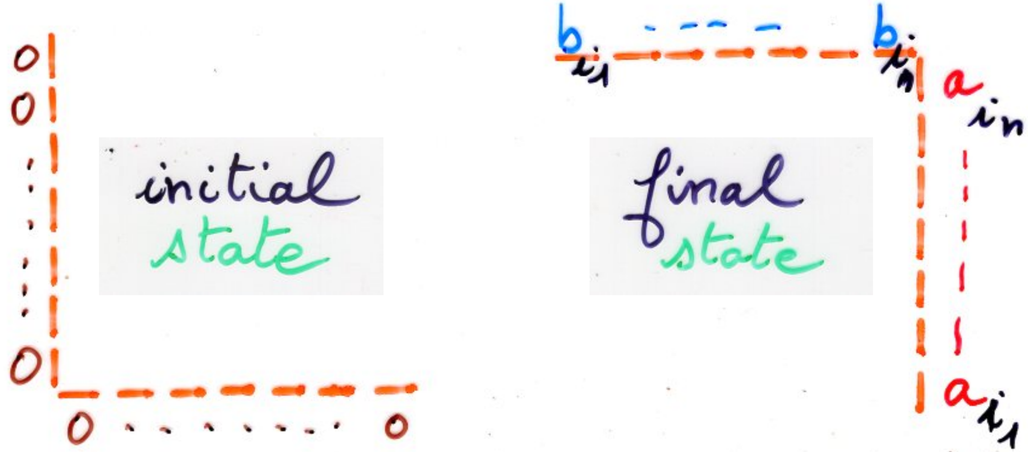
set of labels

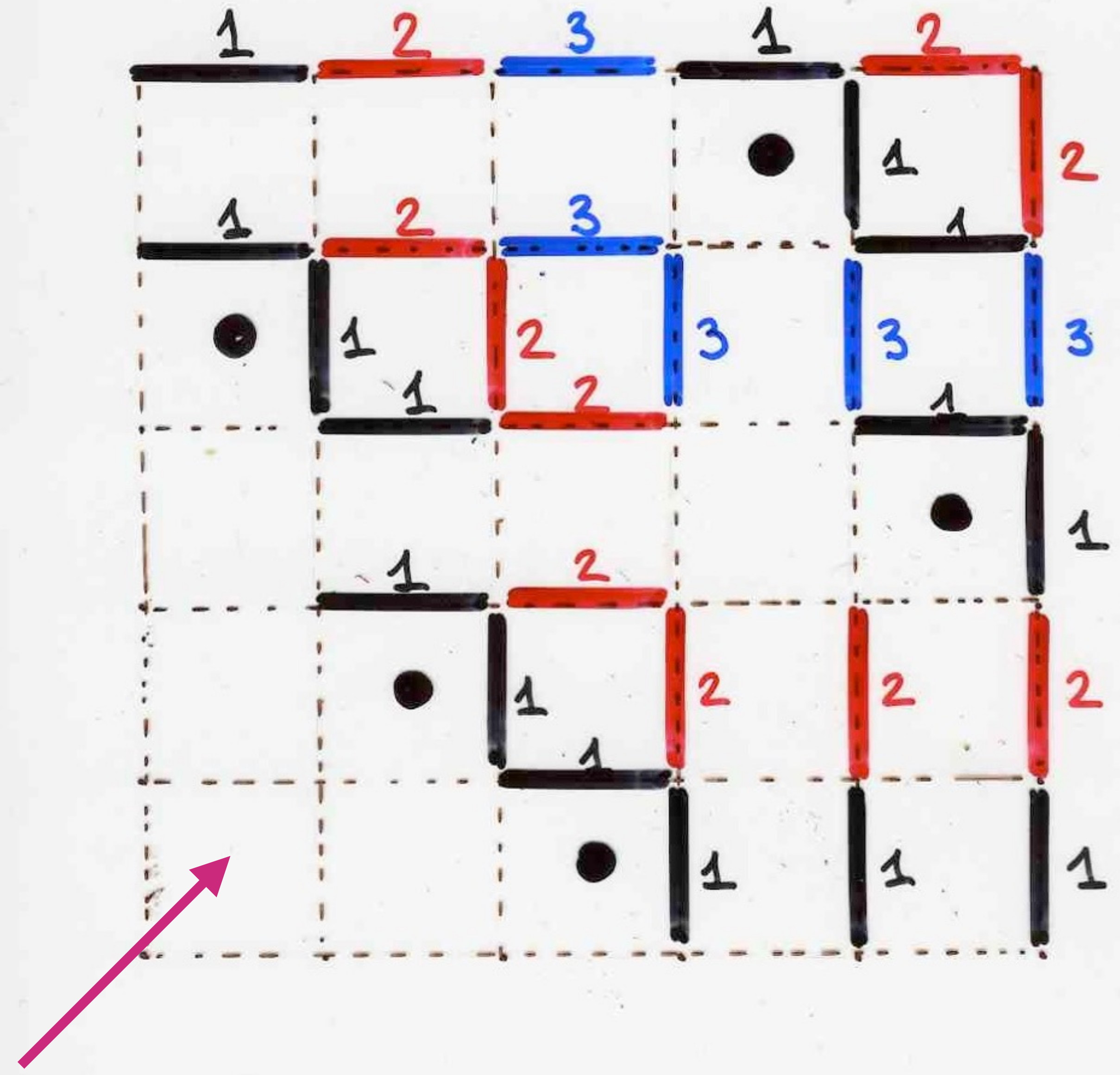
$L = \{\square, \boxdot\}$





"planar rewriting"





1
2
3
1
2

Definition Yamanouchi word w

$w \in \{1,2,\ldots\}^*$

free monoid generated by the alphabet $1,2,\ldots,$

such that:

for every factorization $w = uv$

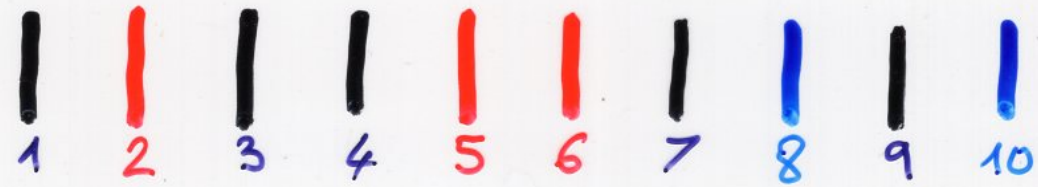
$$|u|_1 \geq |u|_2 \geq \cdots \geq |u|_i \geq \cdots$$

number of occurrences of the letter i in u

coding of a Young tableau with a Yamanouchi word

(also called lattice permutation)

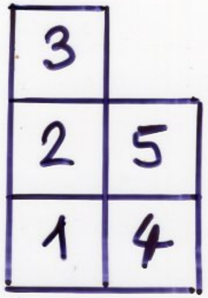
W =

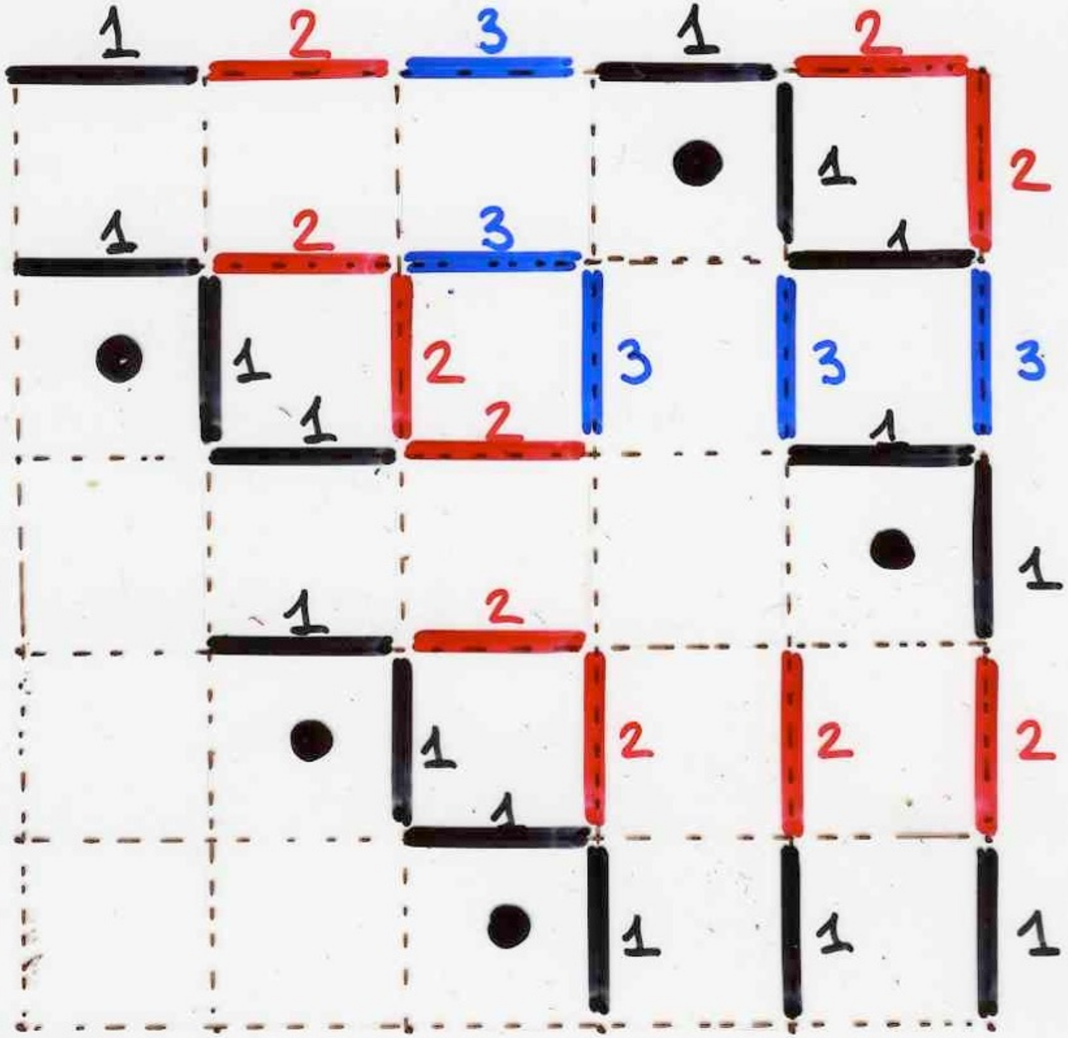


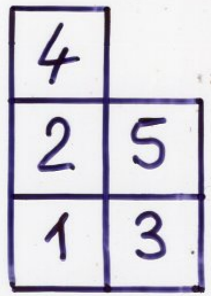
= 1 2 1 1 2 2 1 3 1 3

Q =

8	10			
2	5	6		
1	3	4	7	9

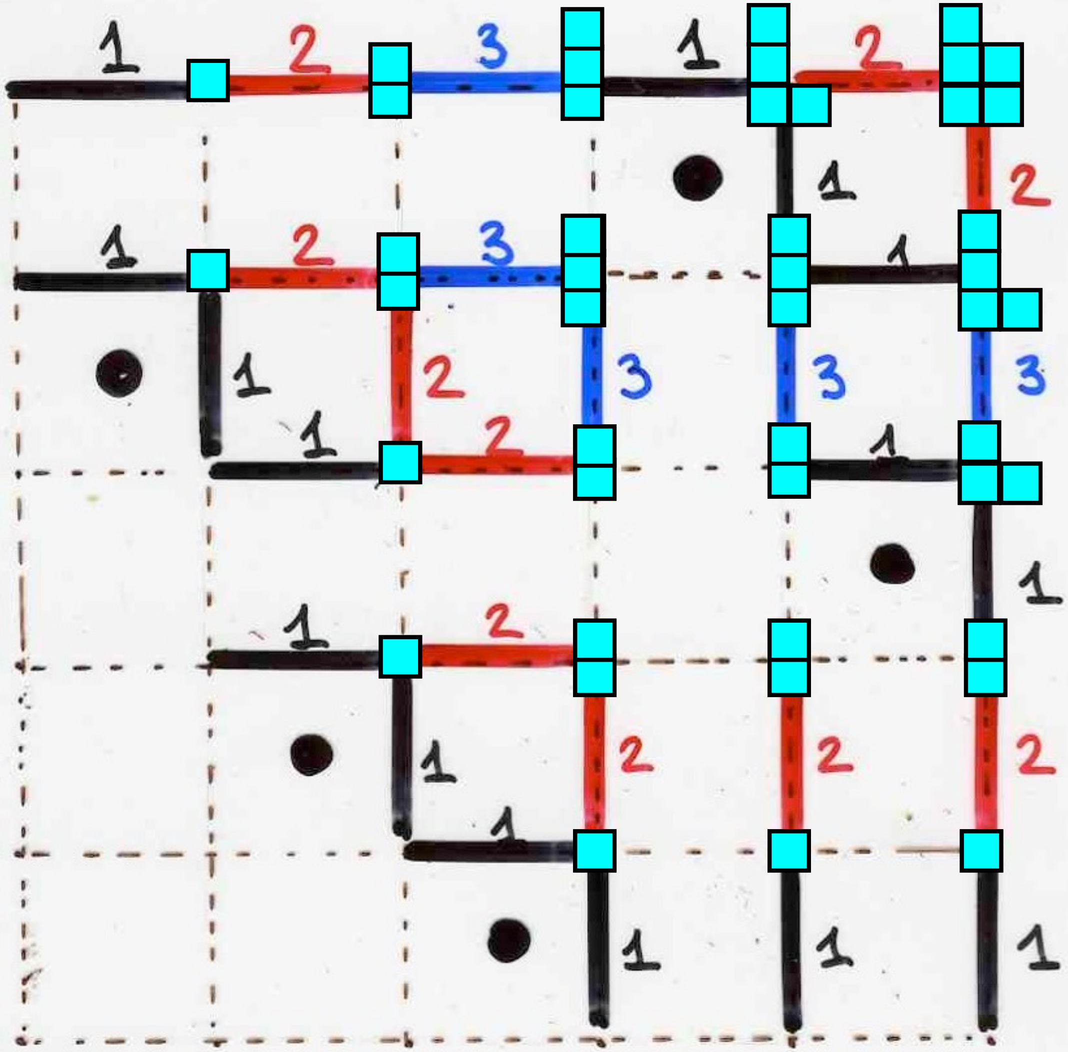

3
2 5
1 4




4
2 5
1 3

Proposition

The two processes « growth diagrams » and « edge local rules » are equivalent



1
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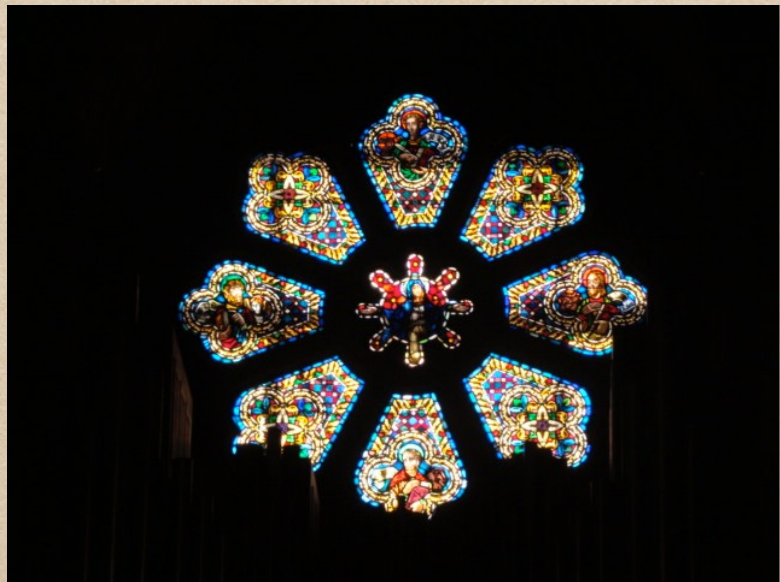
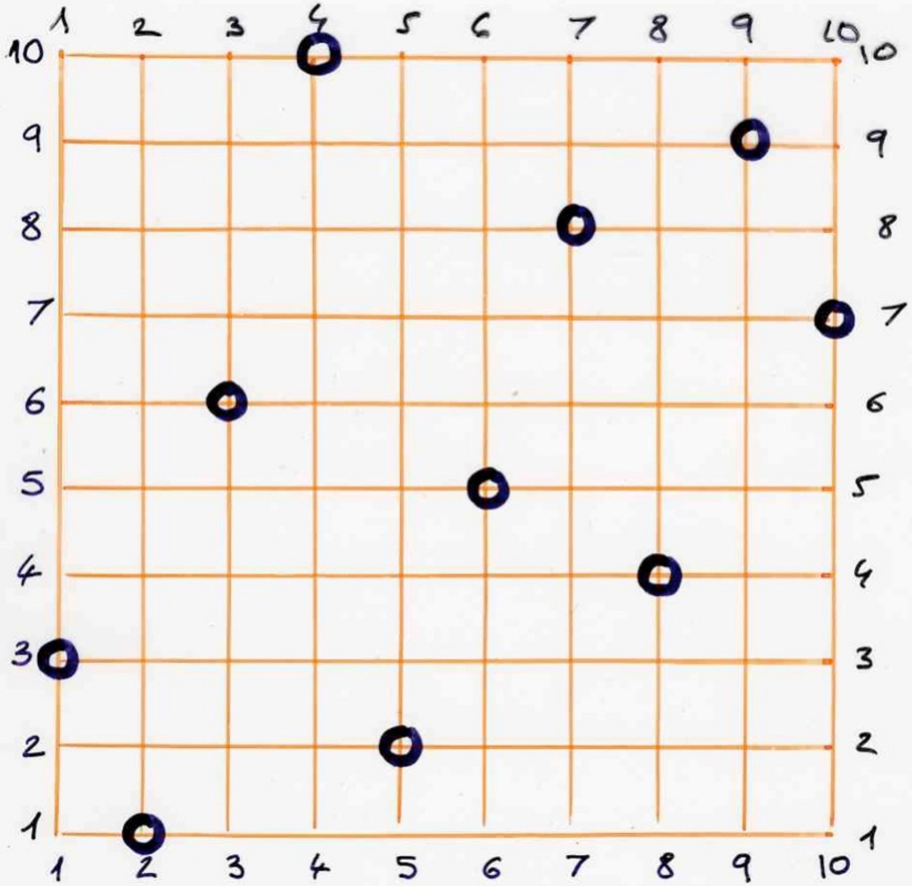
1
1
1
1

A geometric version of RSK with “light” and “shadow lines”



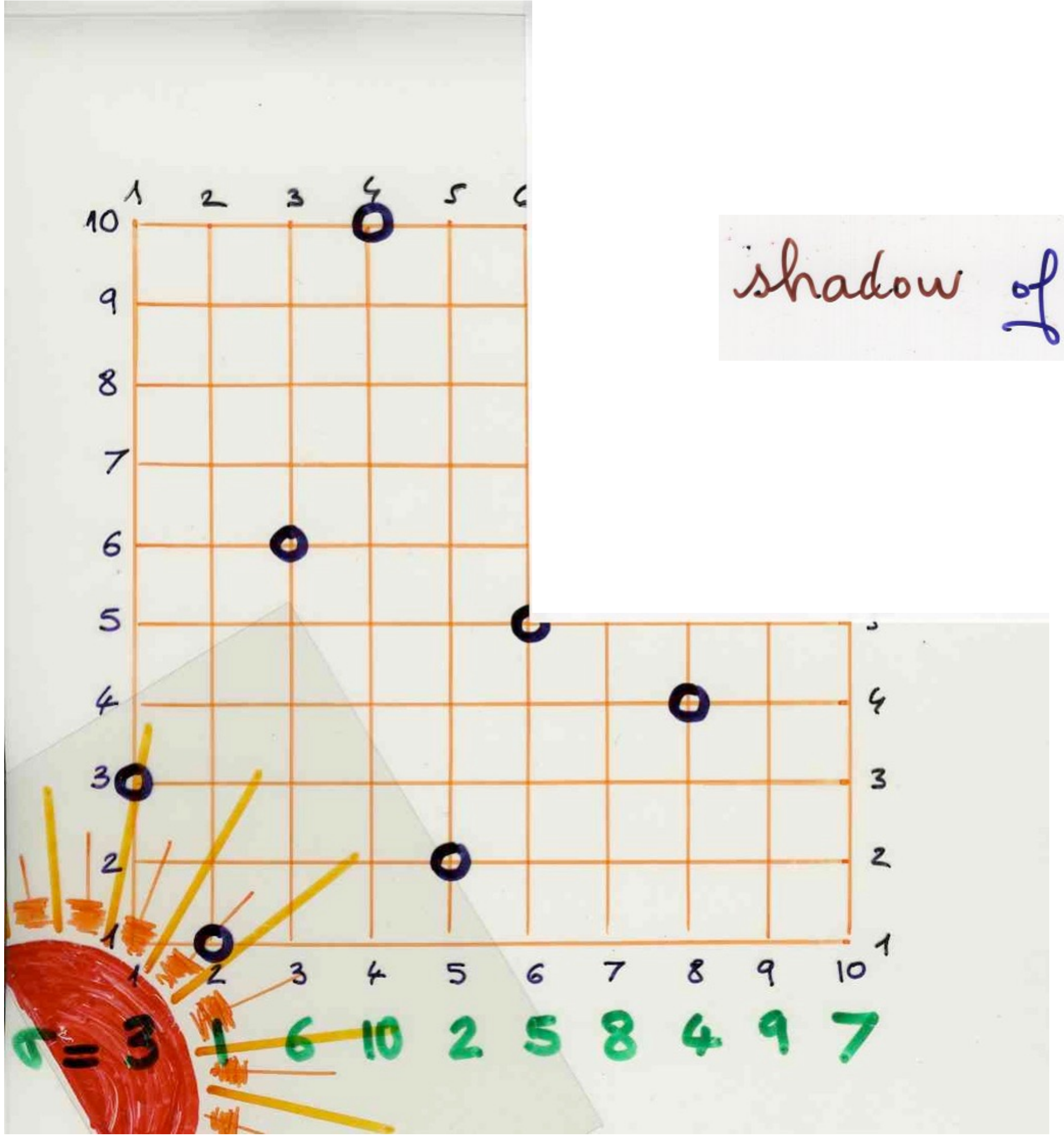
X.V. 1976

$$\{(i,\sigma(i))\}_{i=1,\dots,n} \subseteq [1,n]\times[1,n]$$



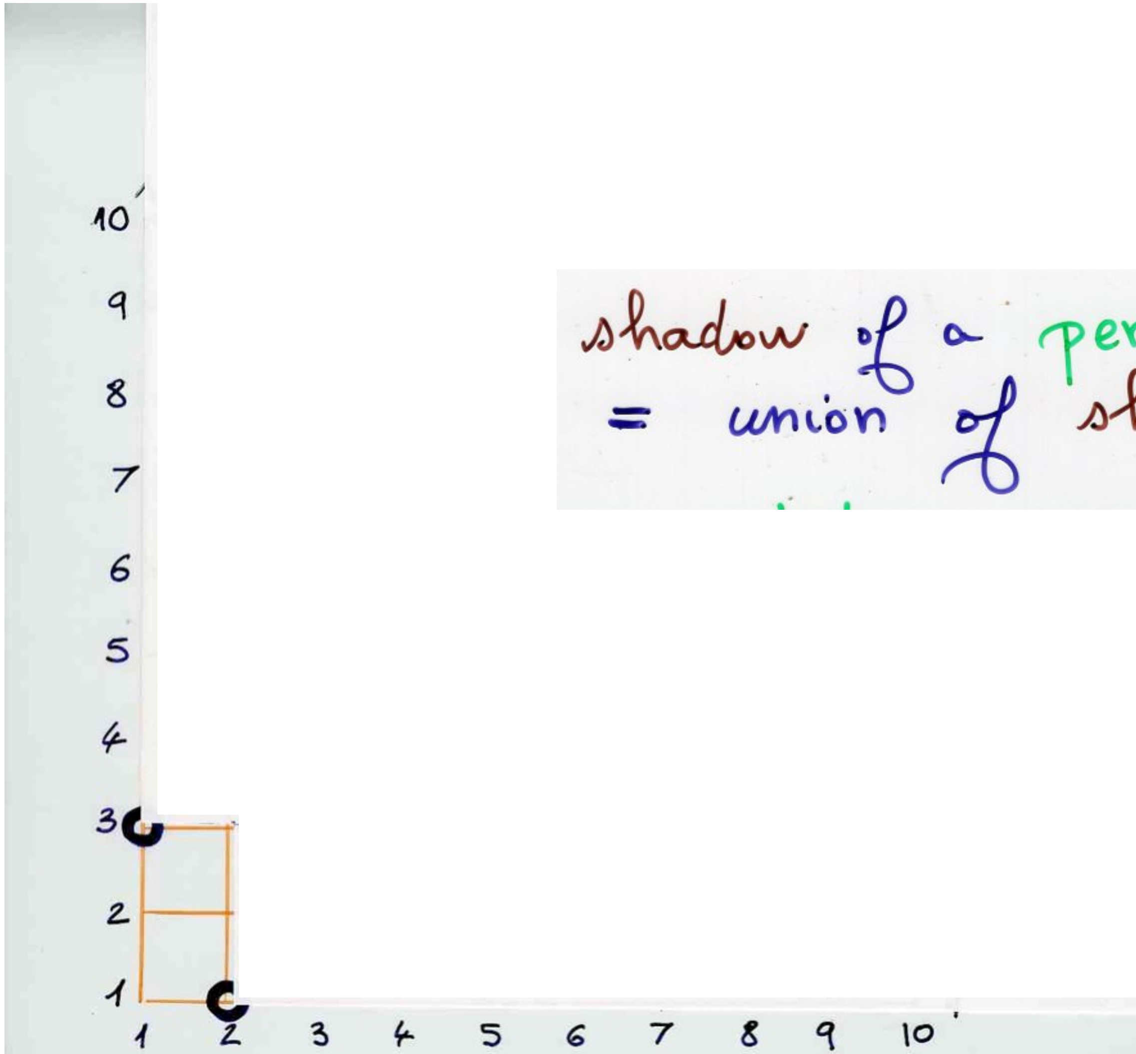
$\sigma = 3\ 1\ 6\ 10\ 2\ 5\ 8\ 4\ 9\ 7$

graph of a permutation σ

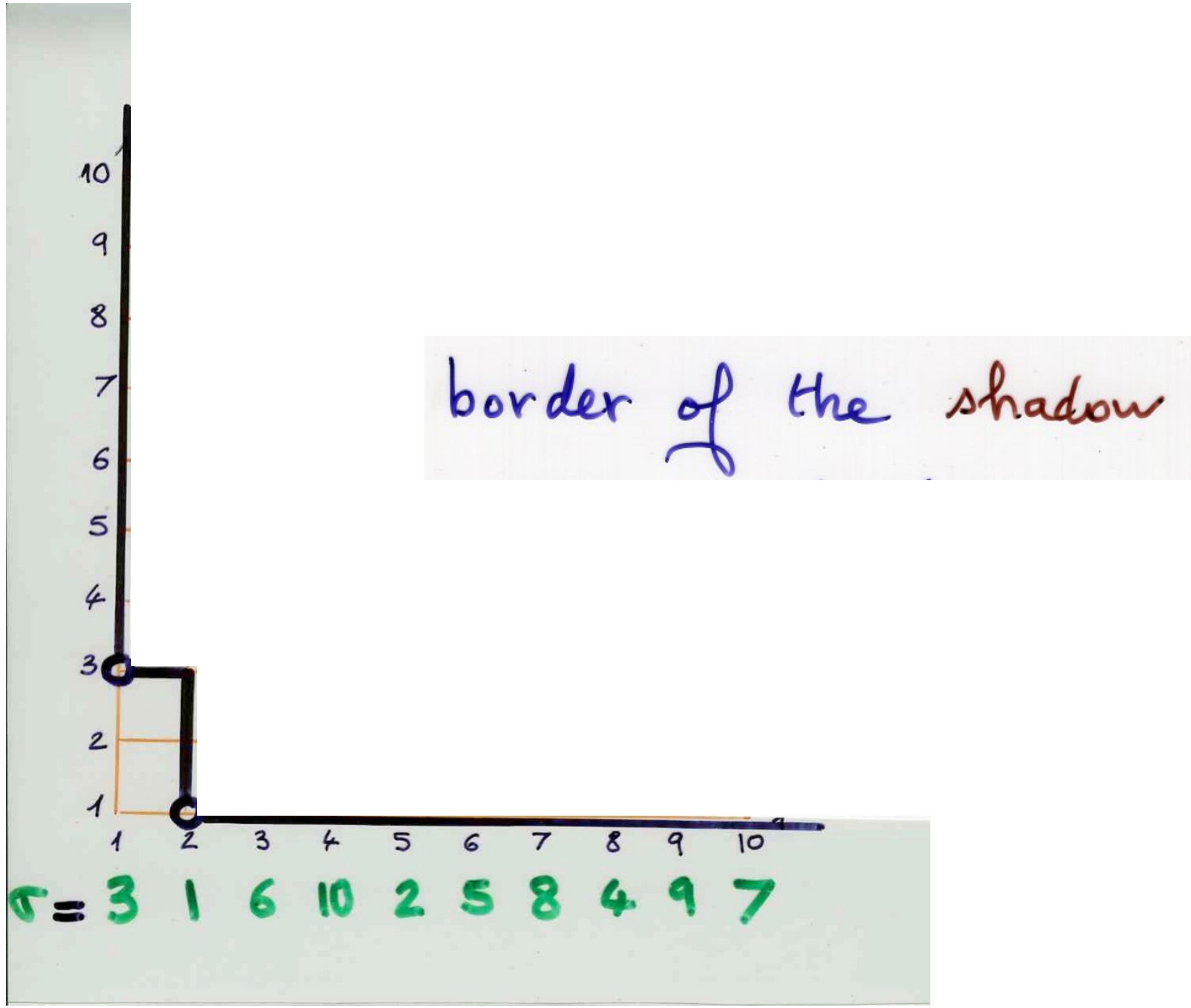


shadow of a point ●

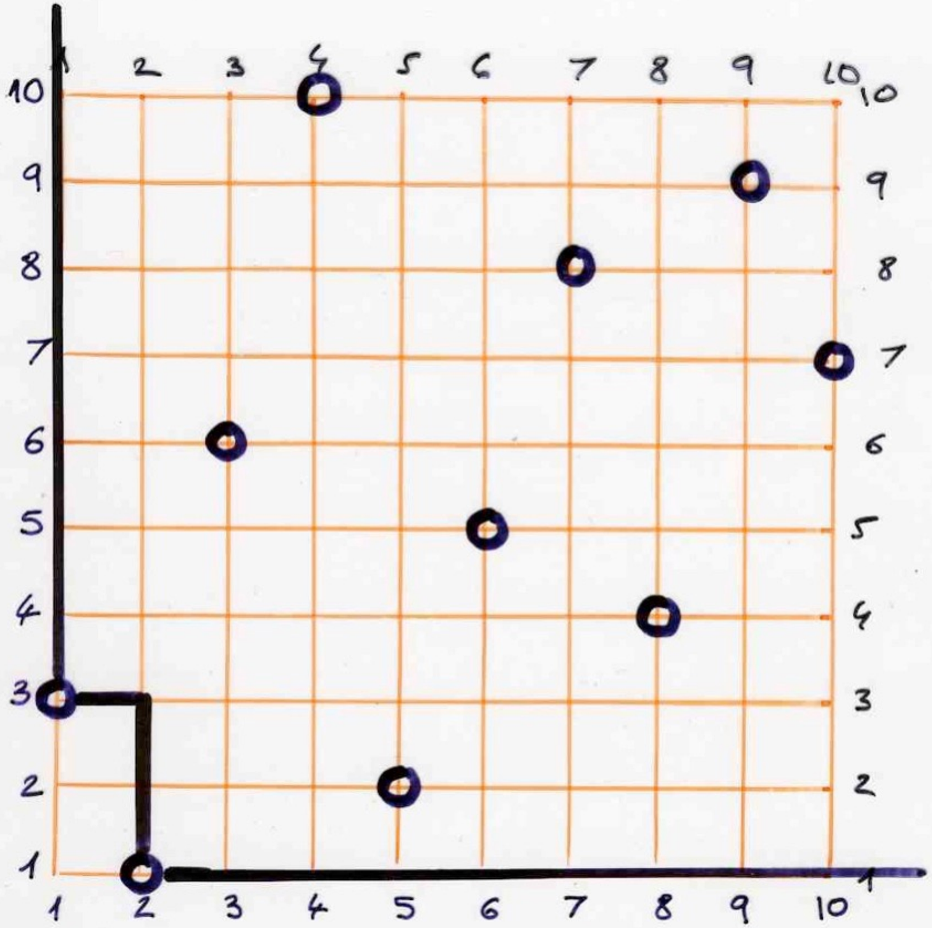
shadow of a permutation
= union of shadows



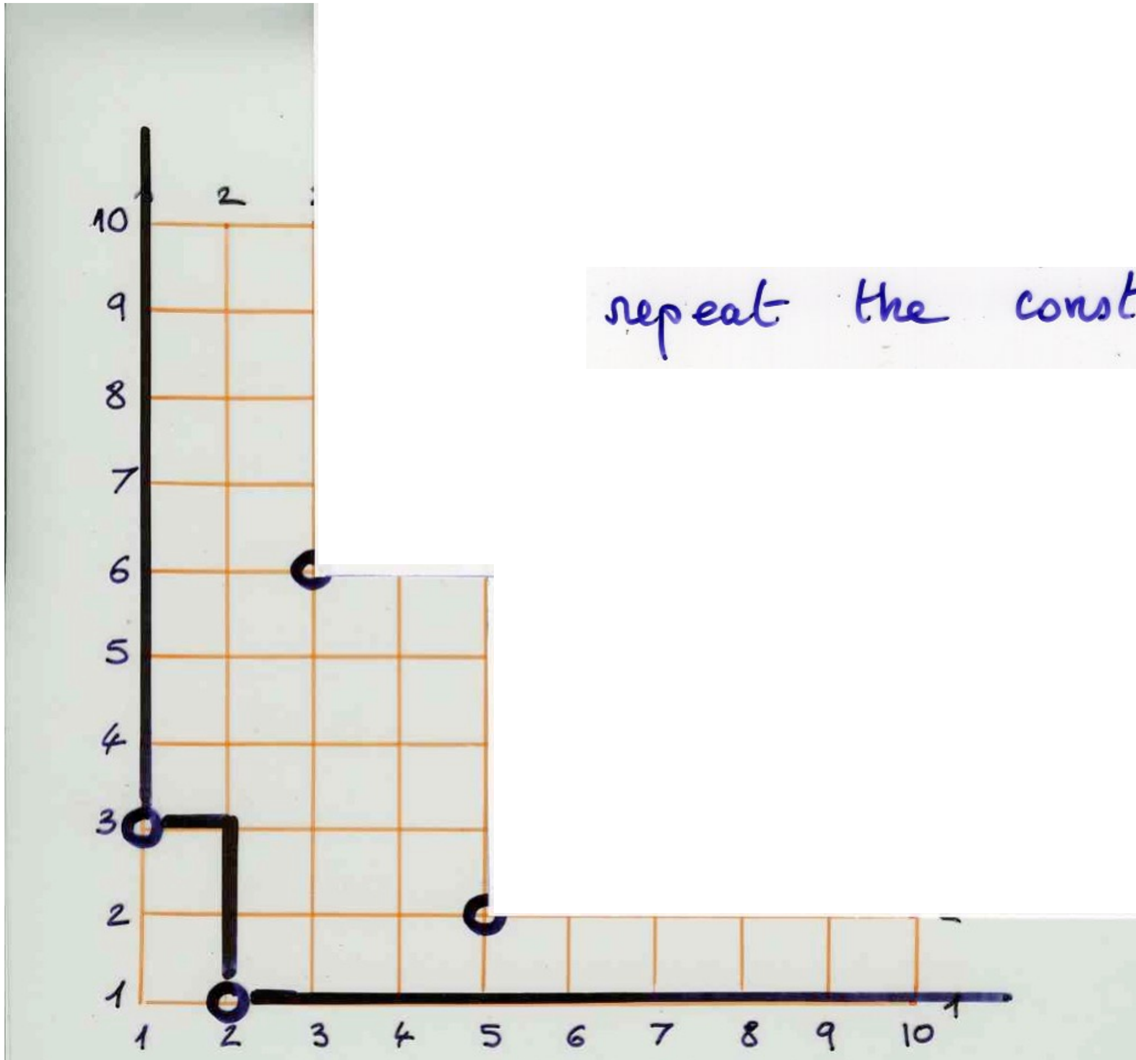
$\sigma = 3\ 1\ 6\ 10\ 2\ 5\ 8\ 4\ 9\ 7$



border of the shadow
10
9
8
7
6
5
4
3
2
1
1 2 3 4 5 6 7 8 9 10
σ = 3 1 6 10 2 5 8 4 9 7

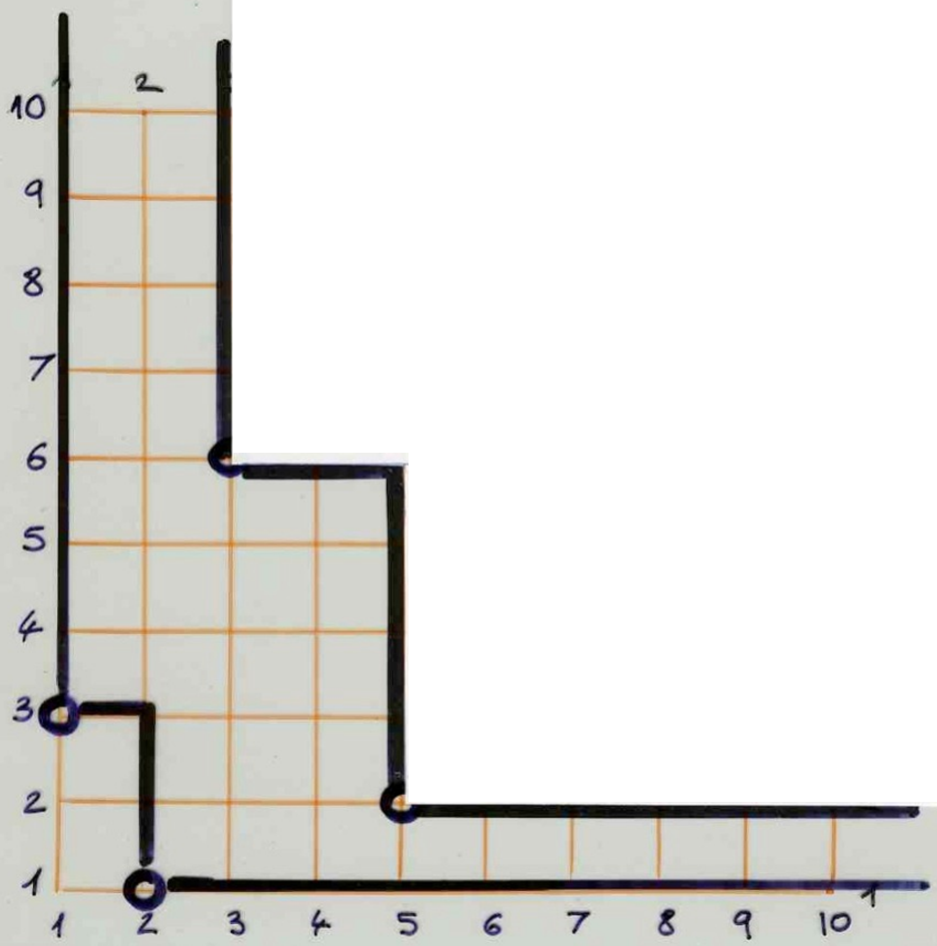


$\sigma = 3\ 1\ 6\ 10\ 2\ 5\ 8\ 4\ 9\ 7$

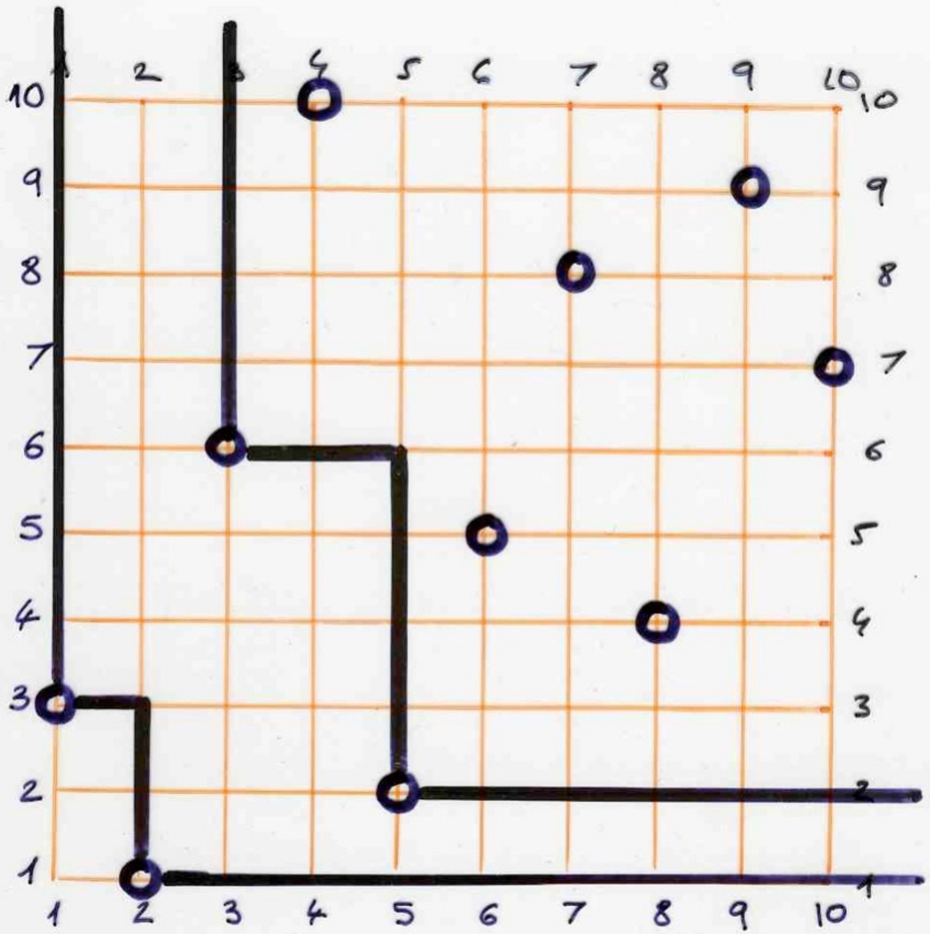


repeat the construction ...

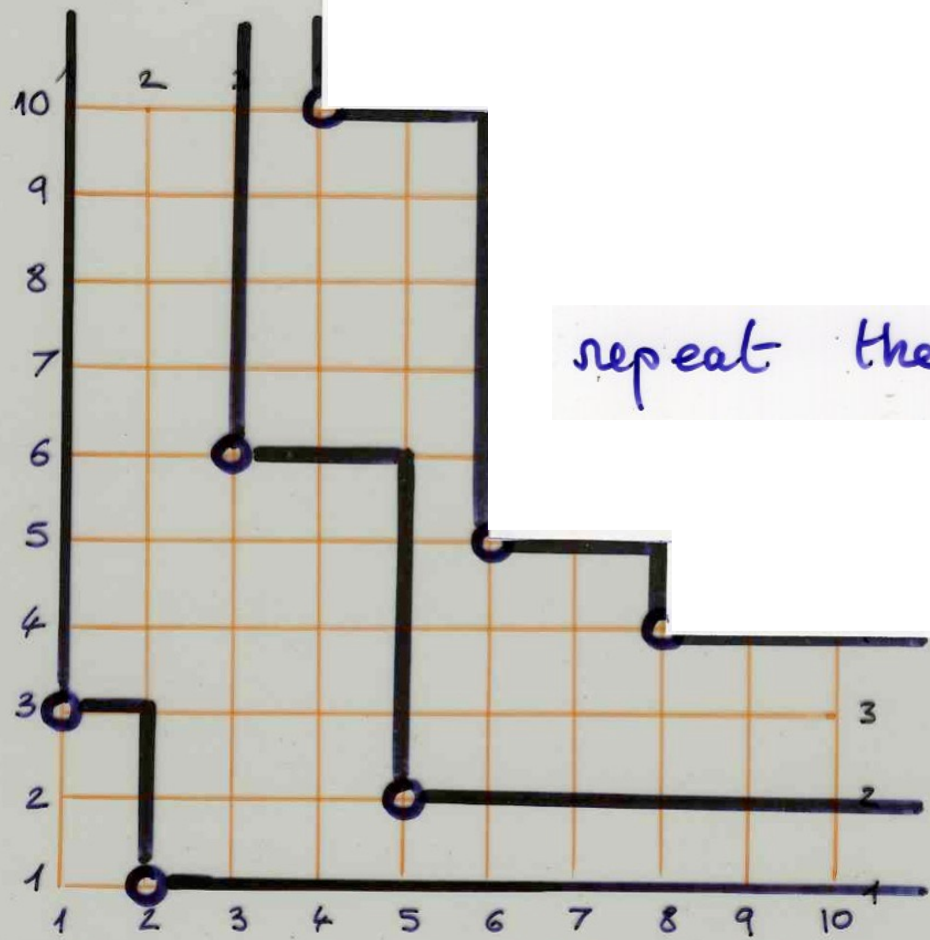
$\sigma = 3\ 1\ 6\ 10\ 2\ 5\ 8\ 4\ 9\ 7$



$\sigma = 3\ 1\ 6\ 10\ 2\ 5\ 8\ 4\ 9\ 7$

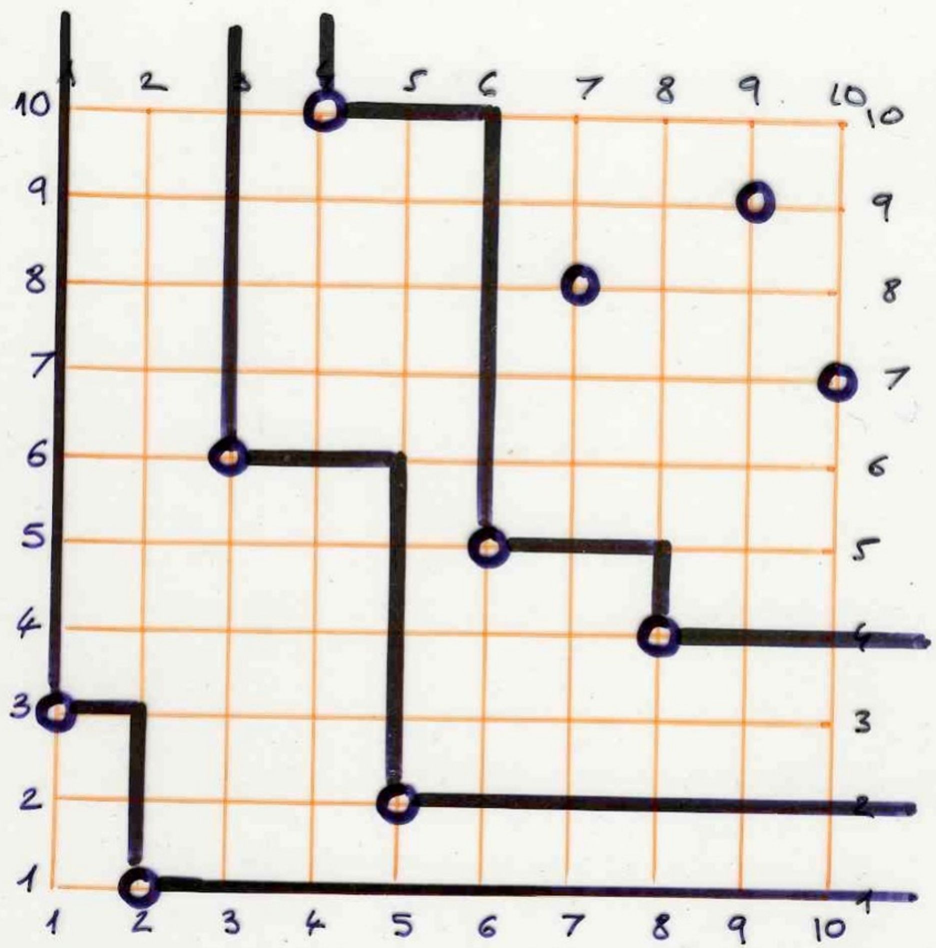


$$\sigma = 3\ 1\ 6\ 10\ 2\ 5\ 8\ 4\ 9\ 7$$

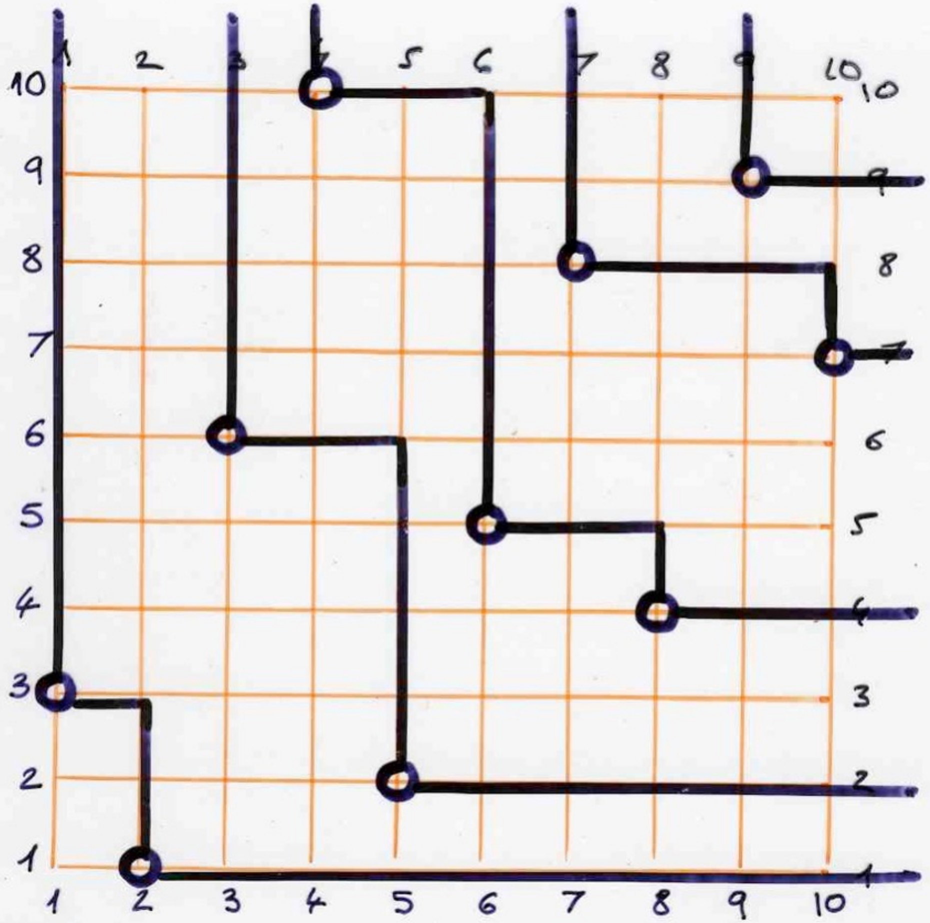


repeat the construction ...

$\sigma = 3\ 1\ 6\ 10\ 2\ 5\ 8\ 4\ 9\ 7$

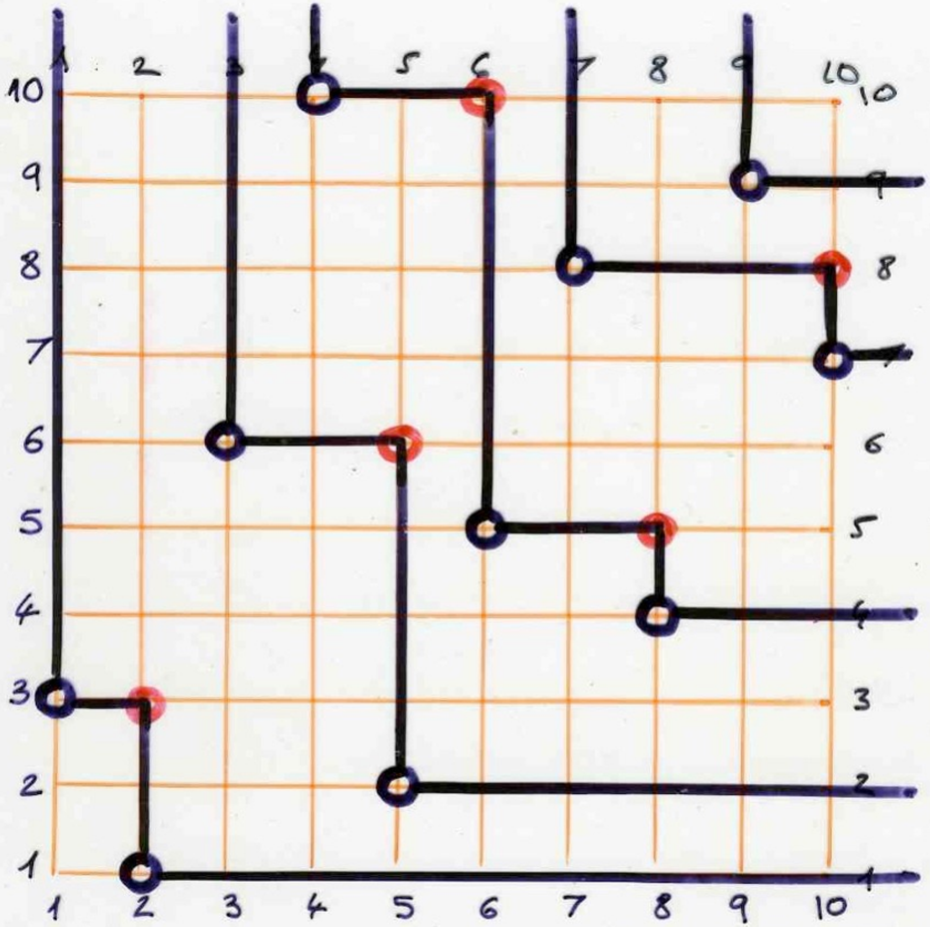


$\sigma = 3\ 1\ 6\ 10\ 2\ 5\ 8\ 4\ 9\ 7$



$\sigma = 3\ 1\ 6\ 10\ 2\ 5\ 8\ 4\ 9\ 7$

red points

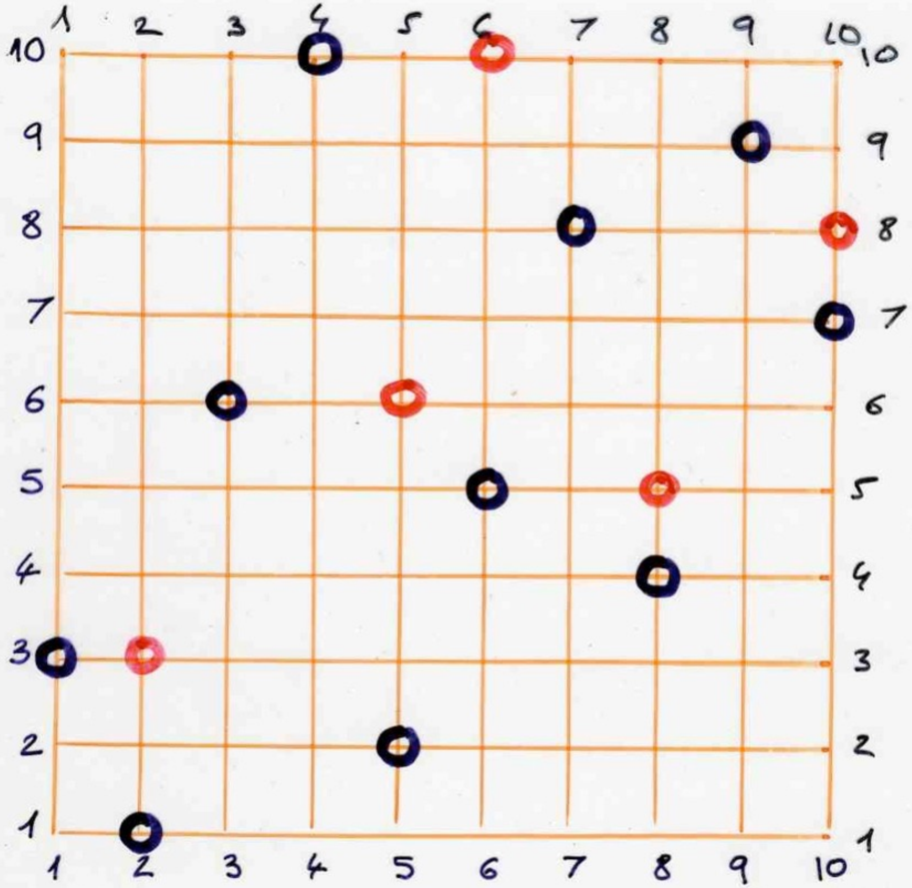


σ = 3 1 6 10 2 5 8 4 9 7

red points ●

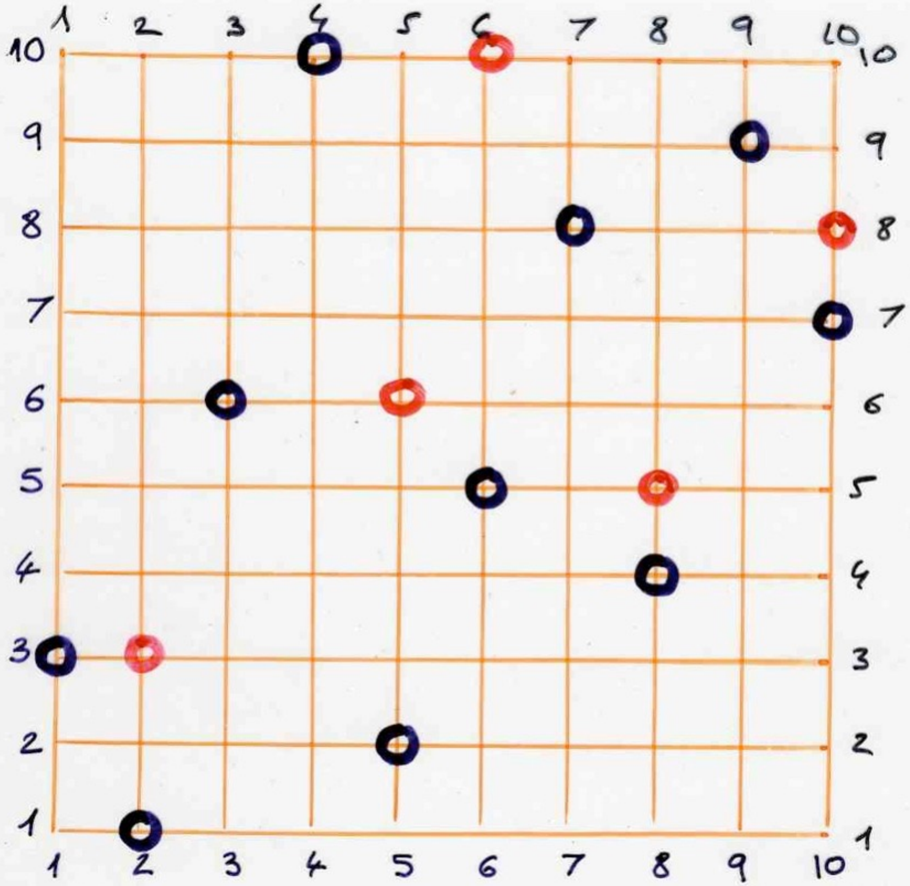
skeleton

Sq (σ)

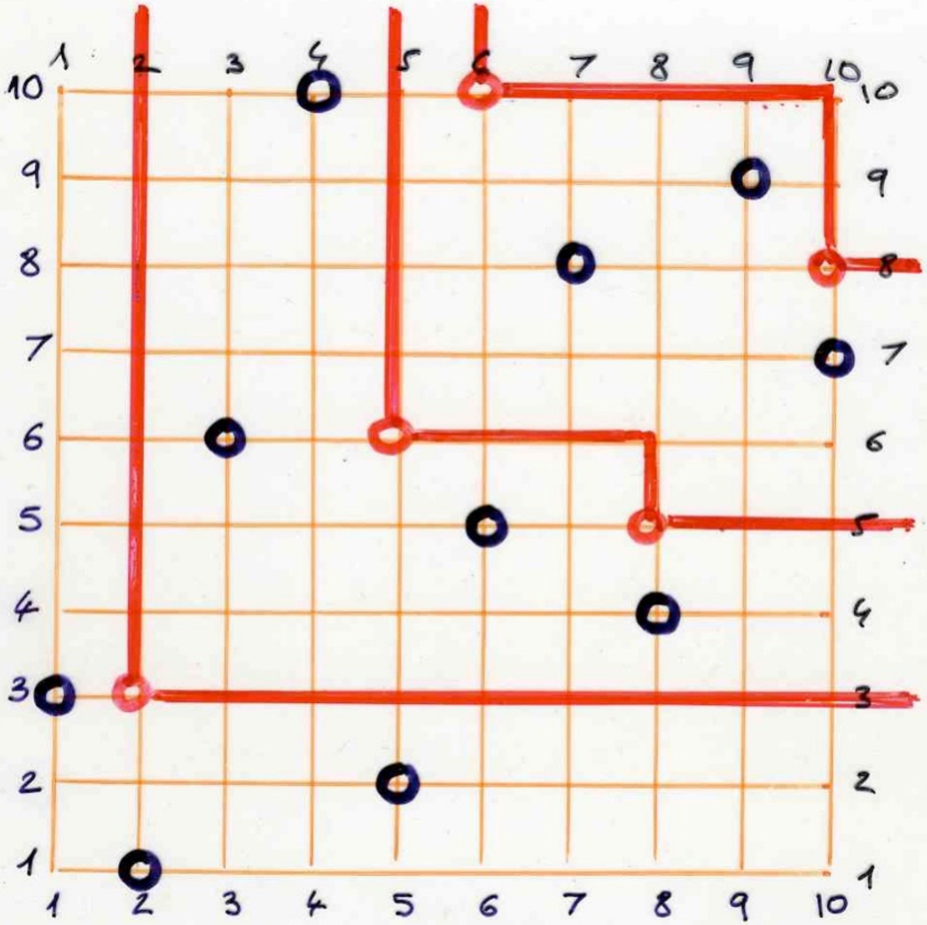


$\sigma = 3\ 1\ 6\ 10\ 2\ 5\ 8\ 4\ 9\ 7$

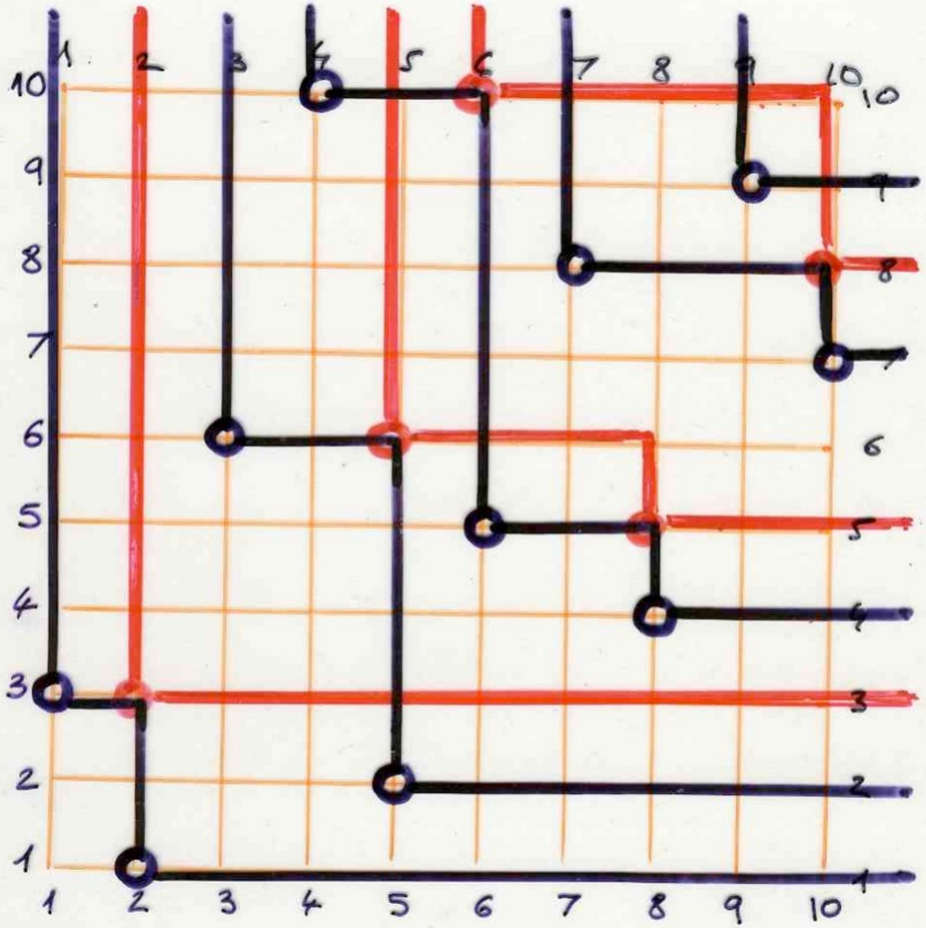
repeat with the red points
the construction of successives shadows



$\sigma = 3\ 1\ 6\ 10\ 2\ 5\ 8\ 4\ 9\ 7$

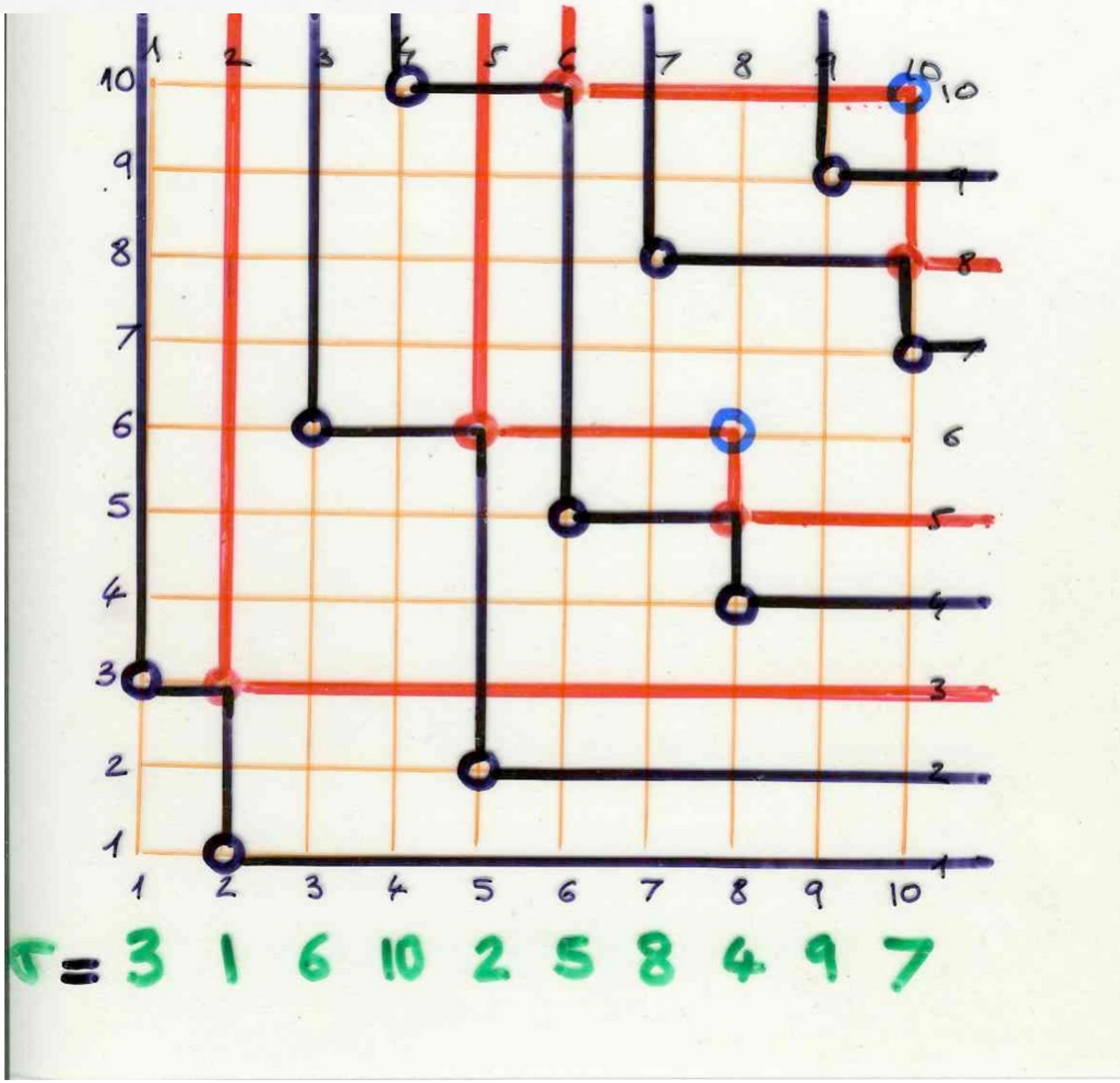


$\sigma = 3\ 1\ 6\ 10\ 2\ 5\ 8\ 4\ 9\ 7$

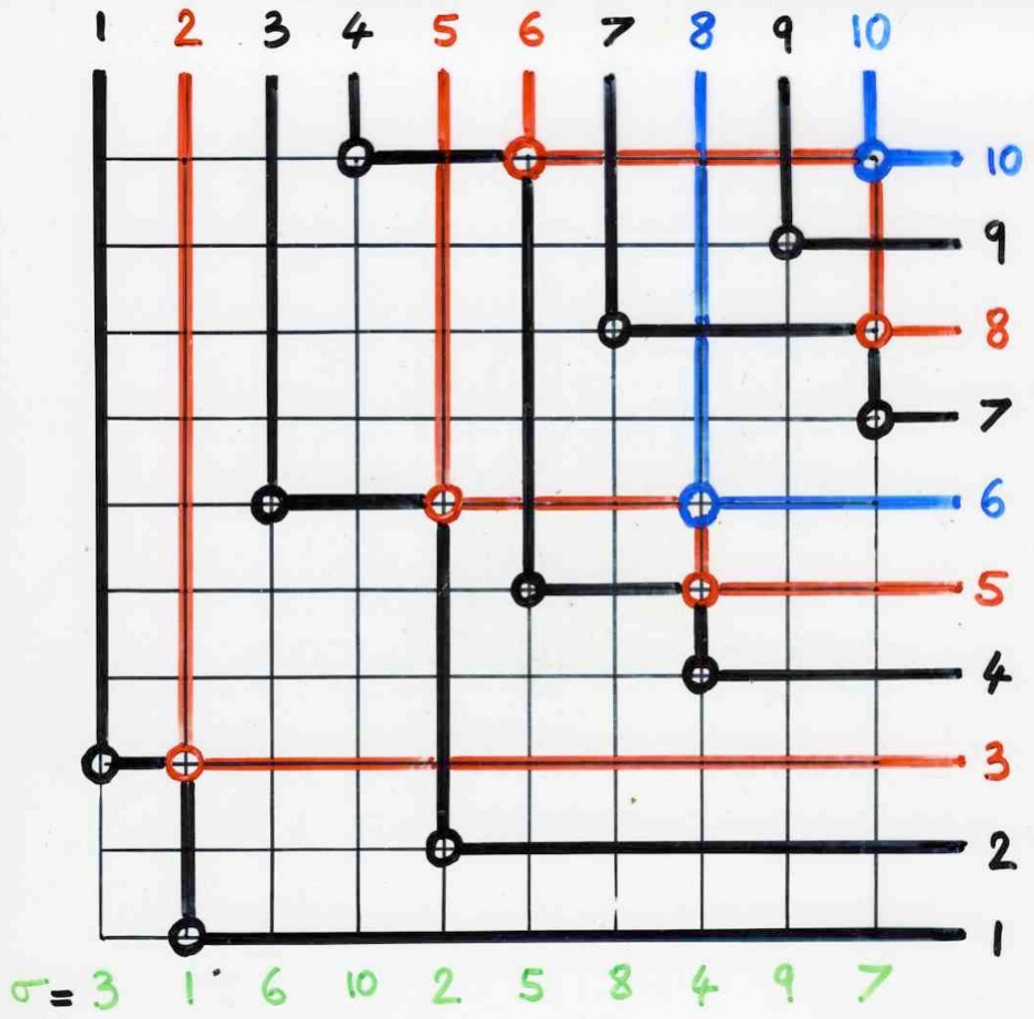


$\sigma = 3\ 1\ 6\ 10\ 2\ 5\ 8\ 4\ 9\ 7$

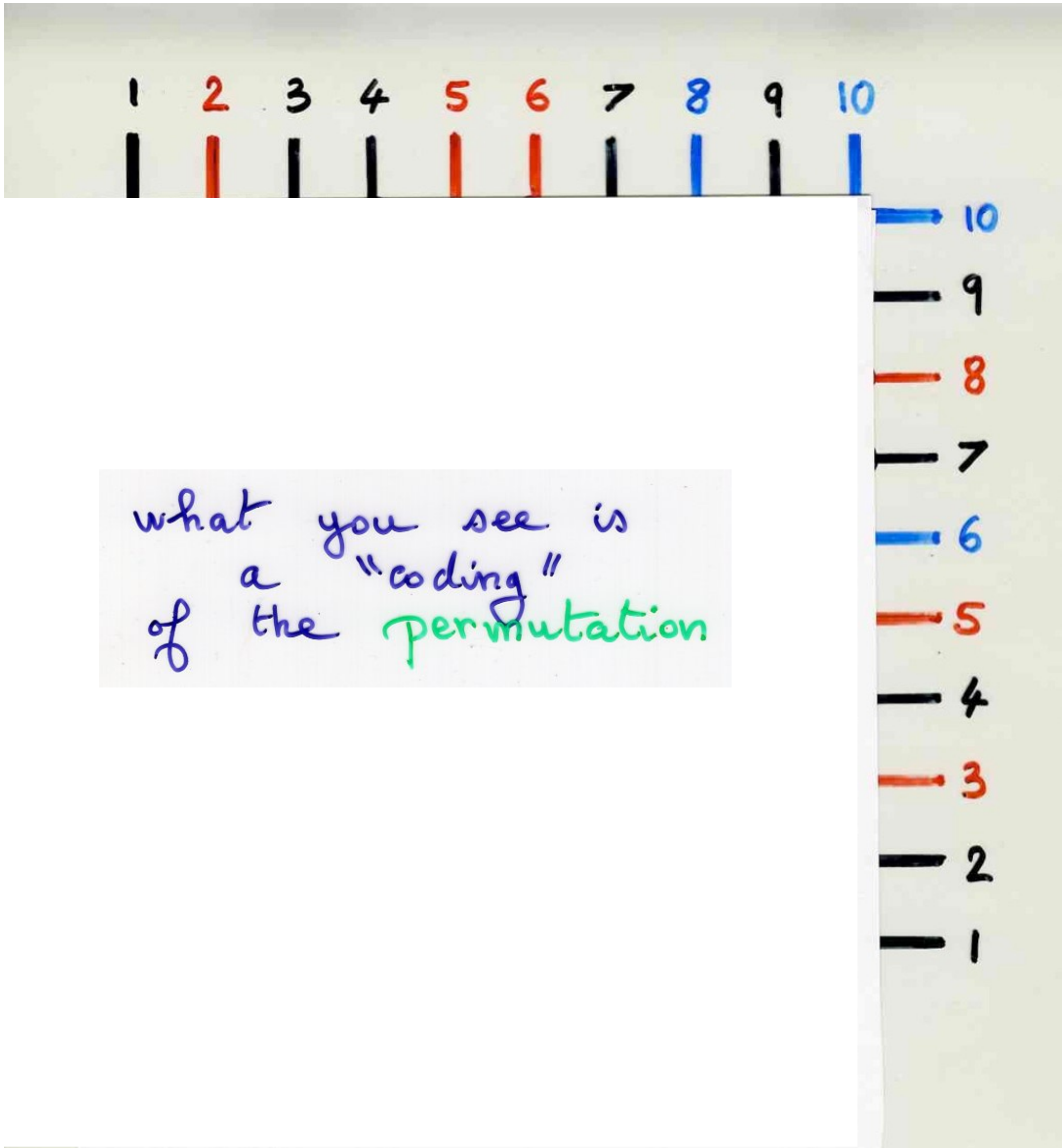
blue points



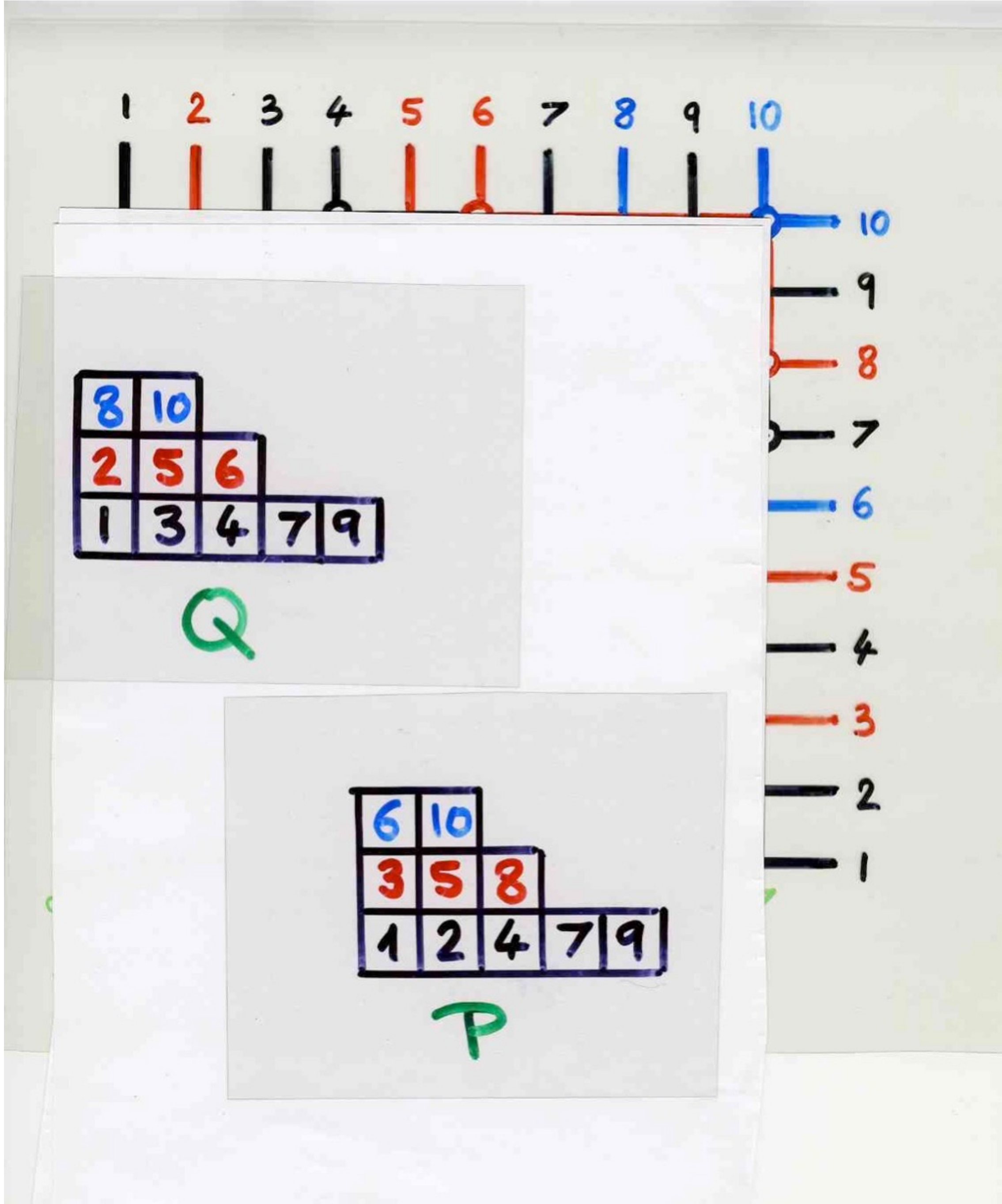
no green points



end of the construction



what you see is
a "coding"
of the permutation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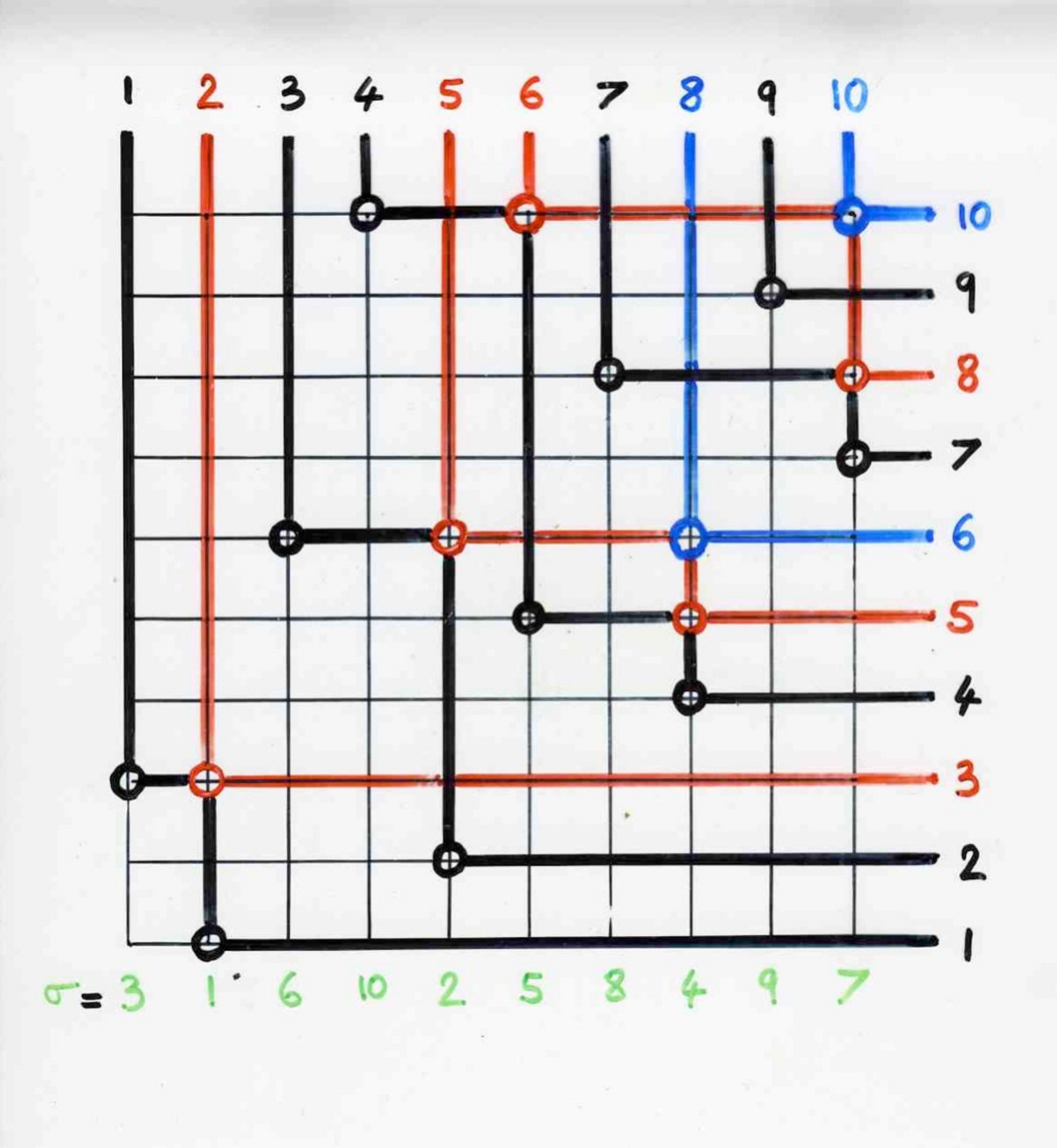
3 5 8
1 2 4 7 9
P

proof of the equivalence

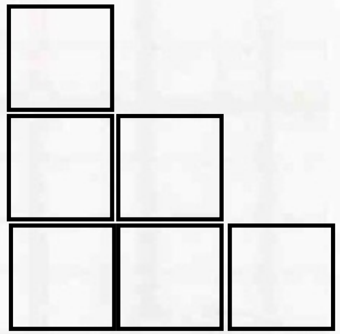
growth diagrams

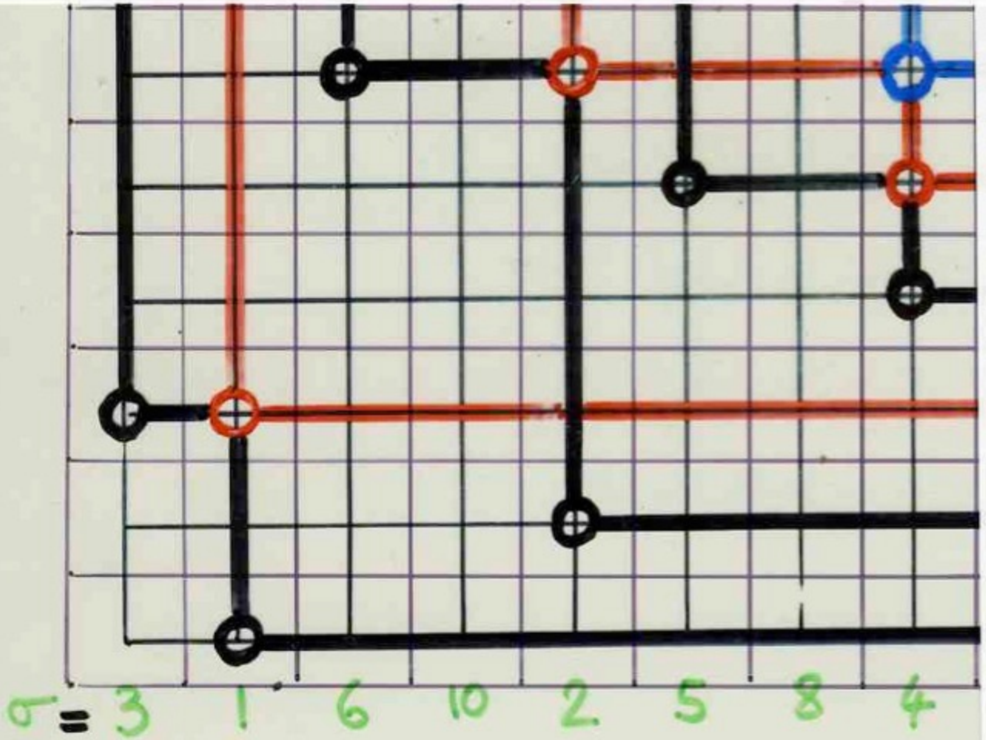
edge local rules



For any vertex of the grid translated by 1/2 we define a Ferrers diagram in the following Way

We get a tableau of Ferrers diagrams





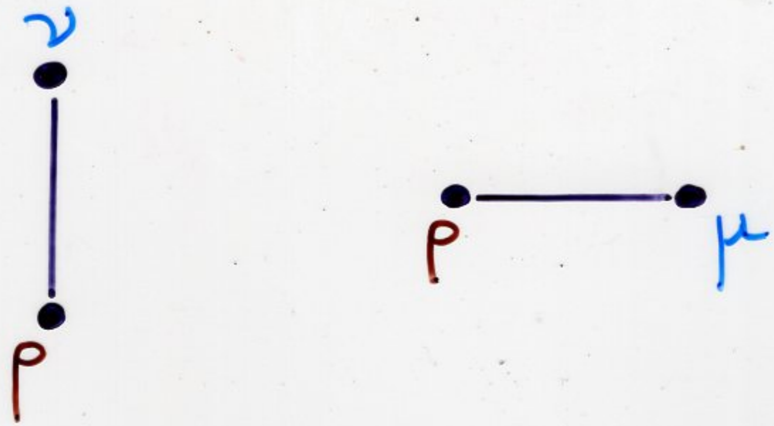
I claim that this tableau is the same as the one we get from Fomin growth diagrams

- label the first set of "shadow lines" of the permutation σ by 1
  (black lines on the figure)

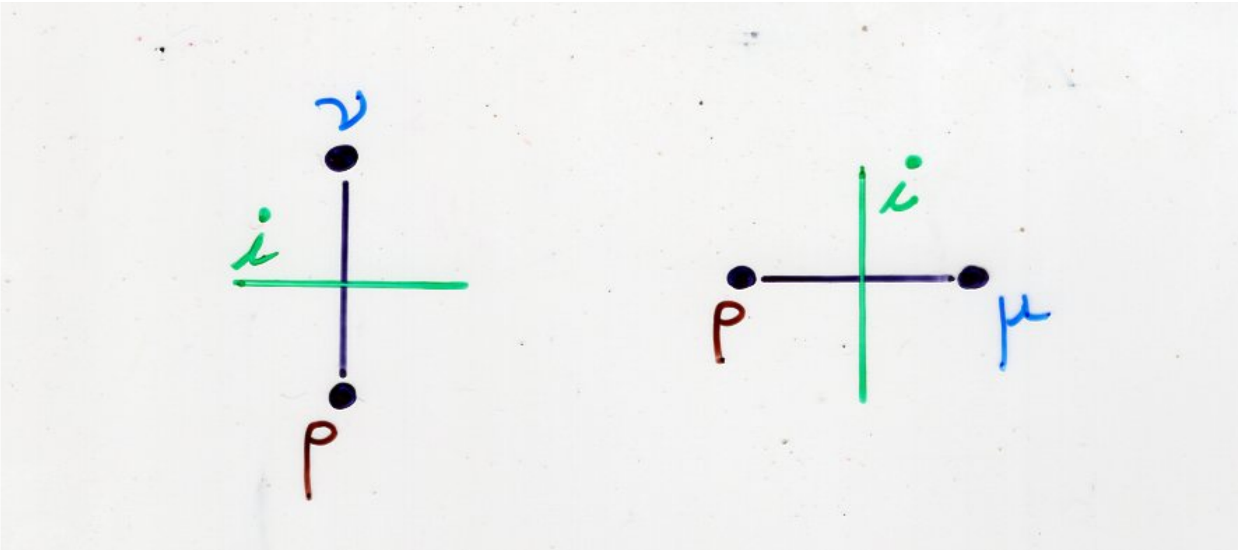
- then by 2 the second set,
  i.e. the "shadow lines" of the skeleton
  $Sq(\sigma)$
  (the red lines)

- etc., 3 the blue lines
  of $Sq(Sq(\sigma))$

- ...

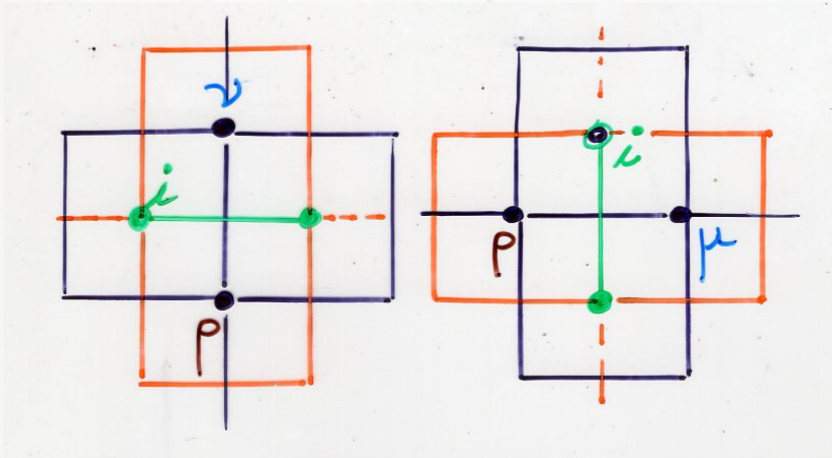


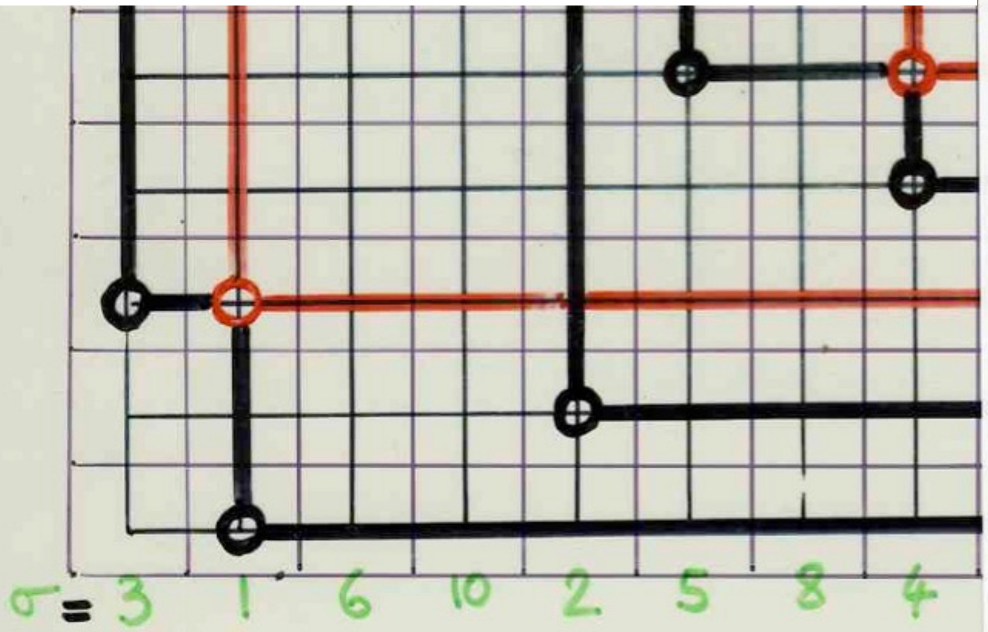
if no shadow lines are crossing, then $\mu = \nu = \rho$.

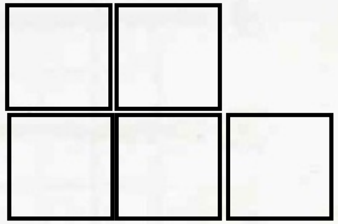


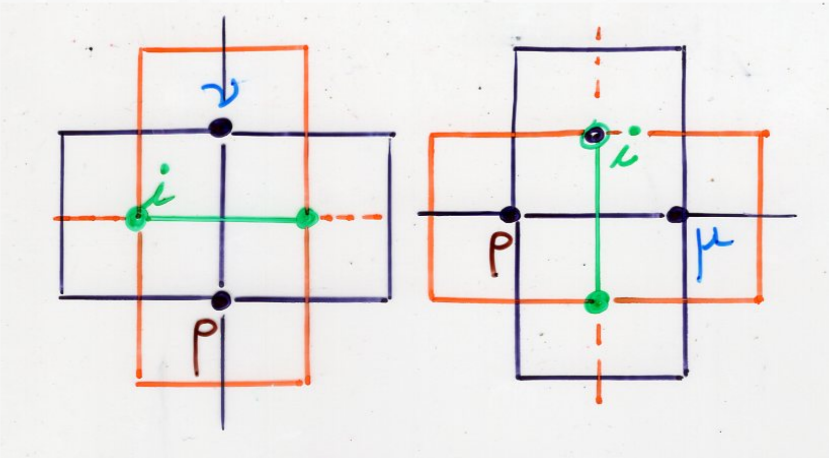
if a shadow line
with label i is crossing, then

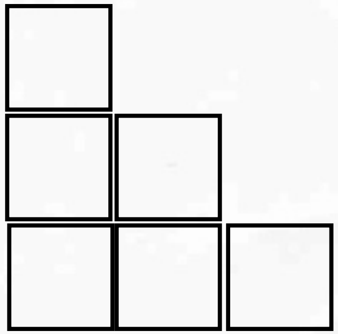
$$\begin{matrix}\mu \\ \nu\end{matrix} = \rho + (i)$$

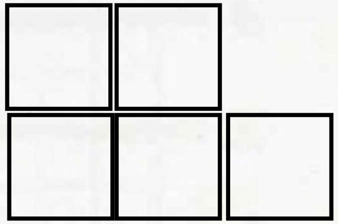

ν
i
ρ
i
ρ
μ

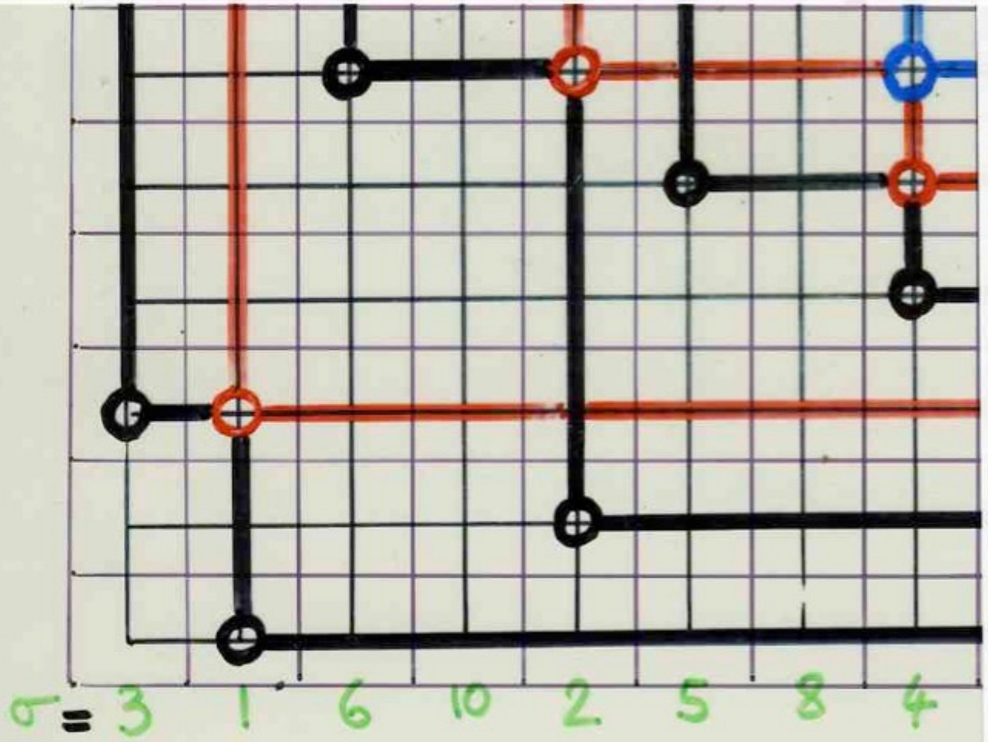

σ = 3 1 6 10 2 5 8 4



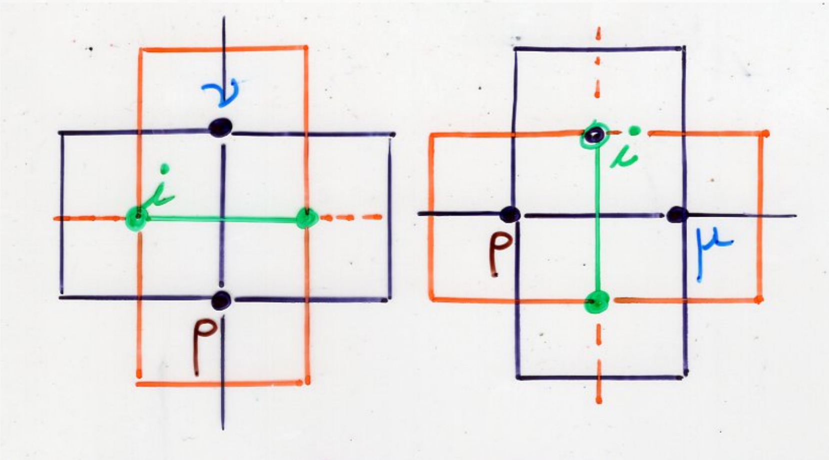


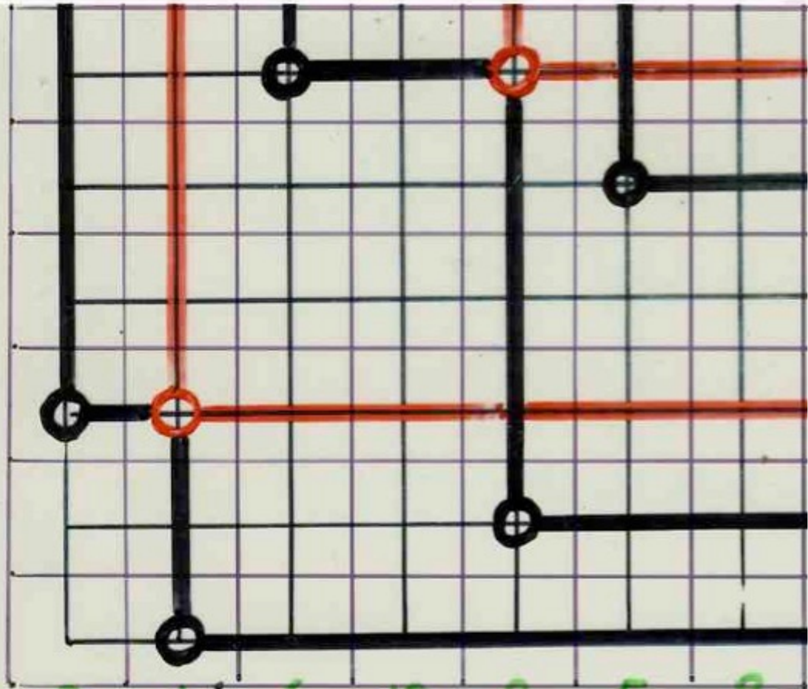




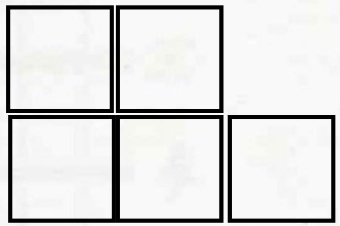


$$\mu/\nu = \rho + (i)$$

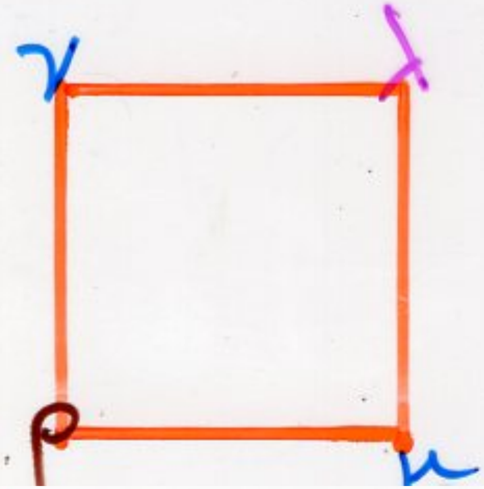




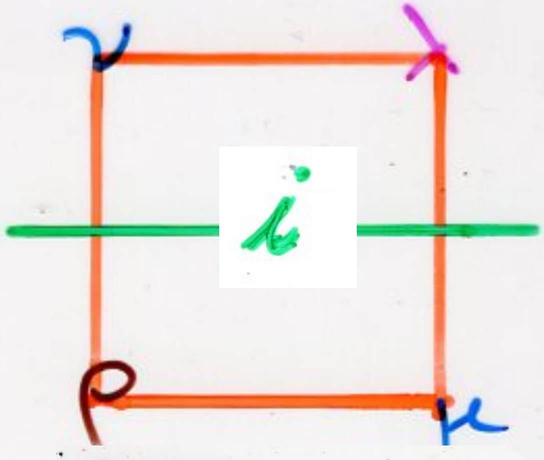
$\sigma = 3 \quad 1 \quad 6 \quad 10 \quad 2 \quad 5 \quad 8$



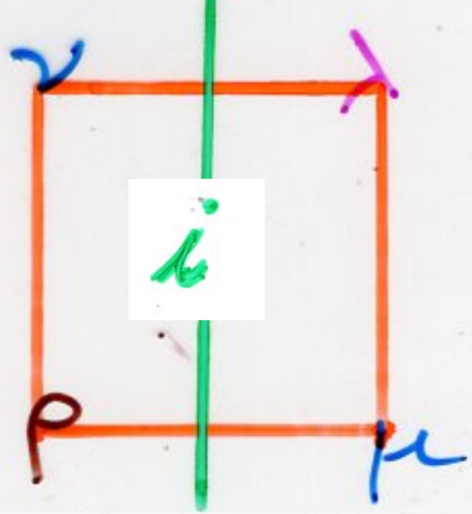
$$\substack{\mu \\ \nu} = \rho + (i)$$



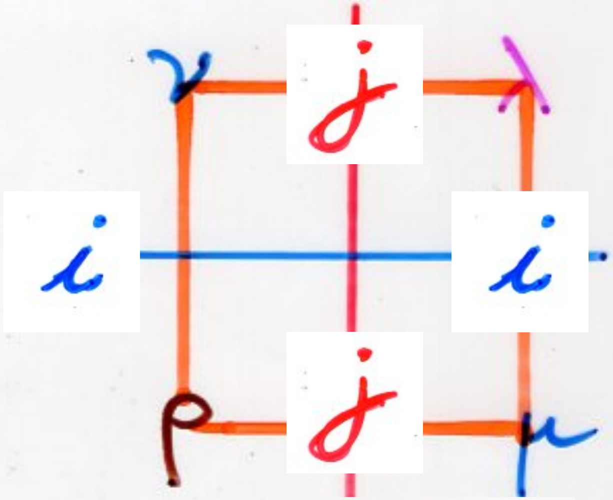
$$\lambda = \rho = \mu = \nu$$



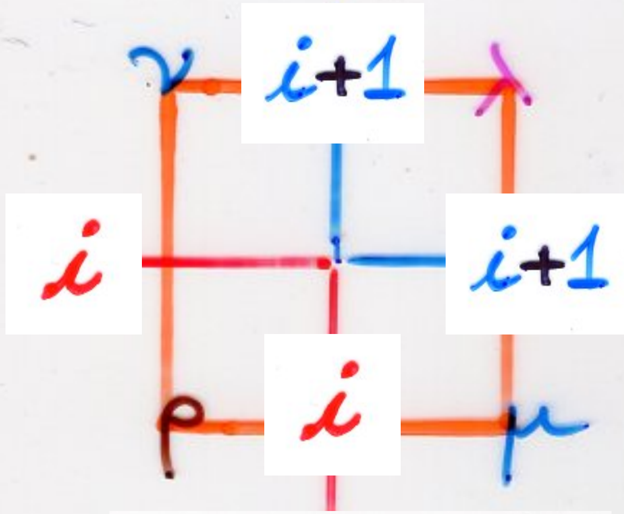
$$\rho = \mu$$
$$\lambda = \nu = \rho + (i)$$



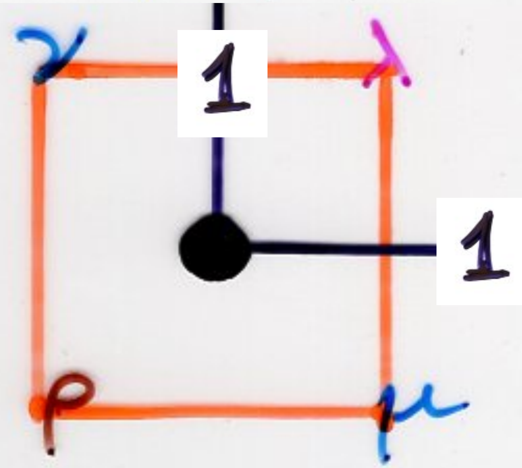
$$\rho = \nu$$
$$\lambda = \mu = \rho + (j)$$



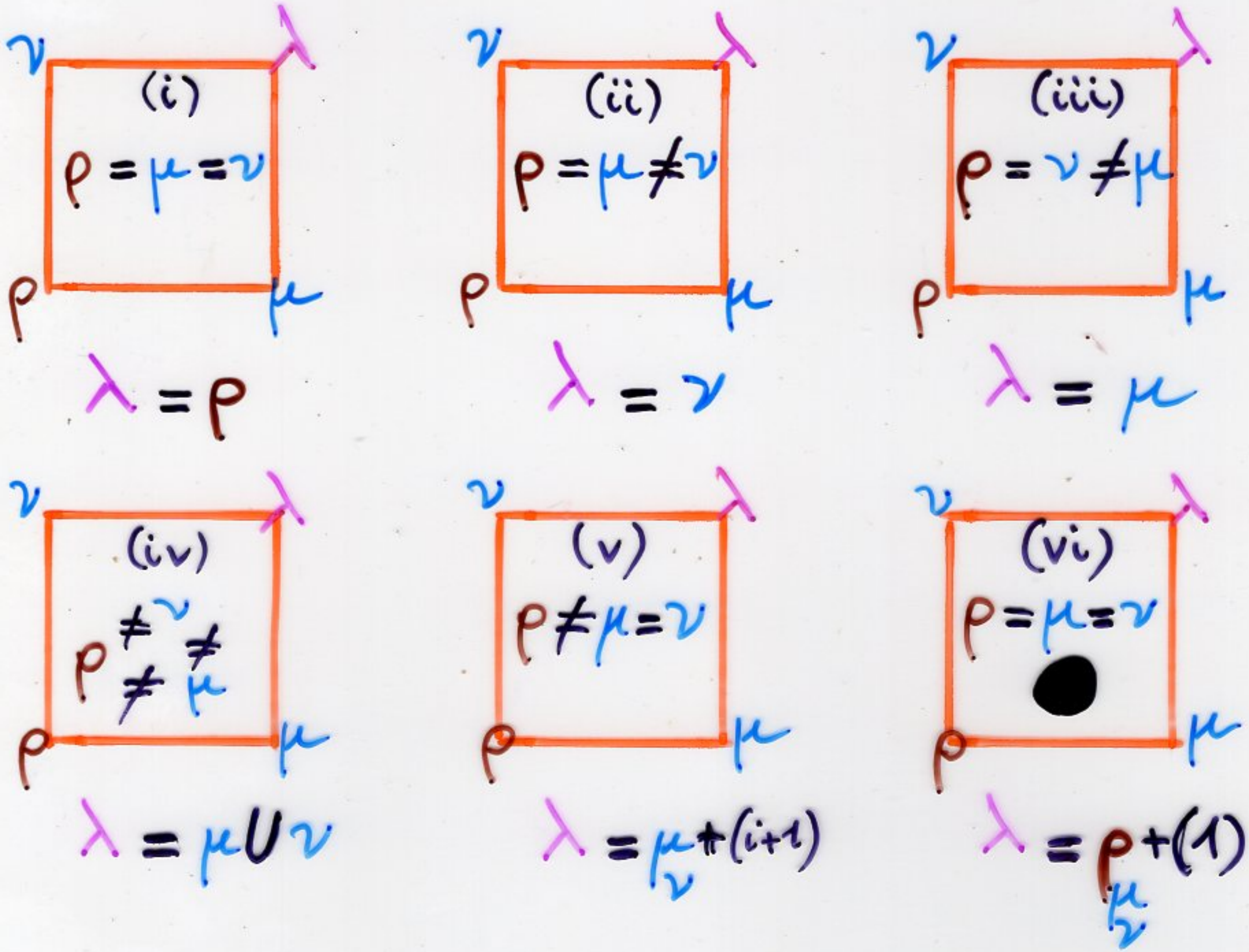
$$\nu = \rho + (i)$$
$$\mu = \rho + (j)$$
$$\lambda = \rho + (i) + (j)$$



$$\mu = \nu = \rho + (i)$$
$$\lambda = \mu + (i+1)$$



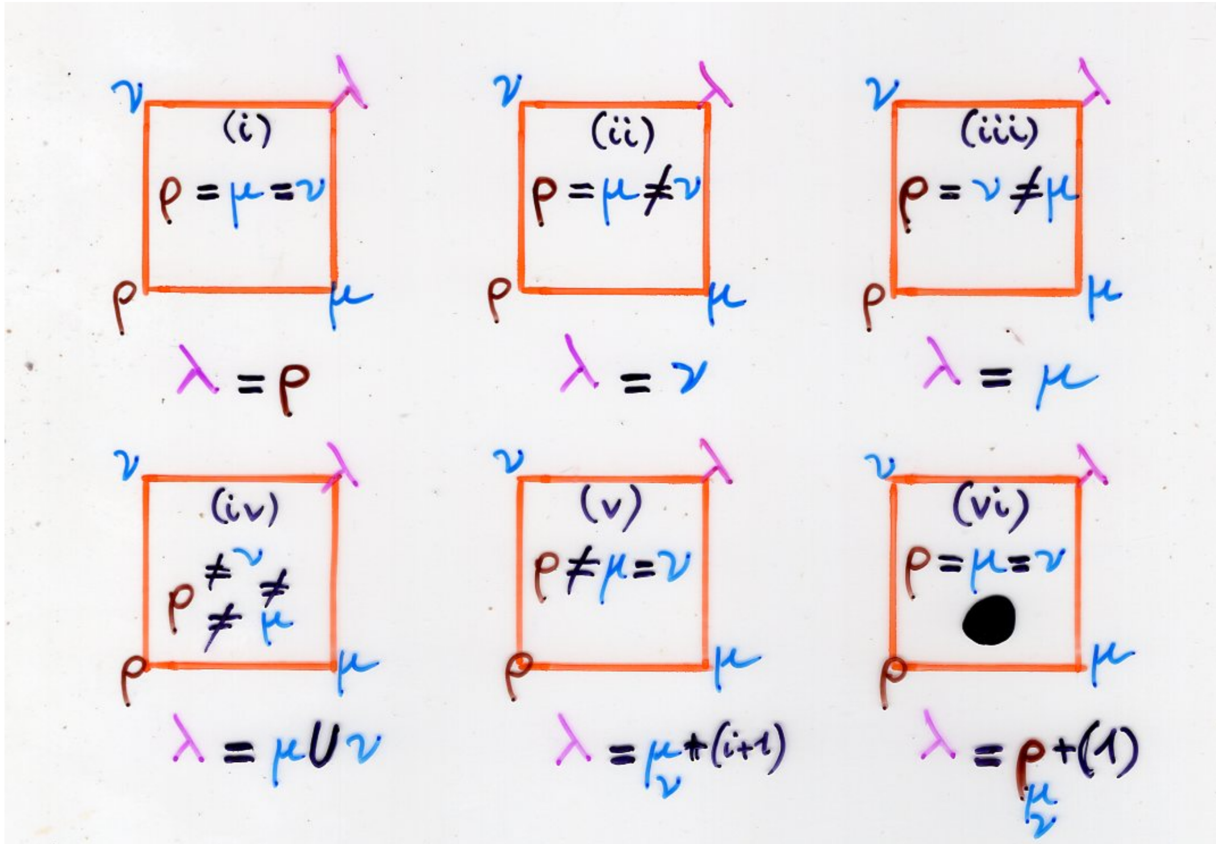
$$\lambda = \left\{\begin{matrix}\rho \\ \mu \\ \nu\end{matrix}\right. + (1)$$

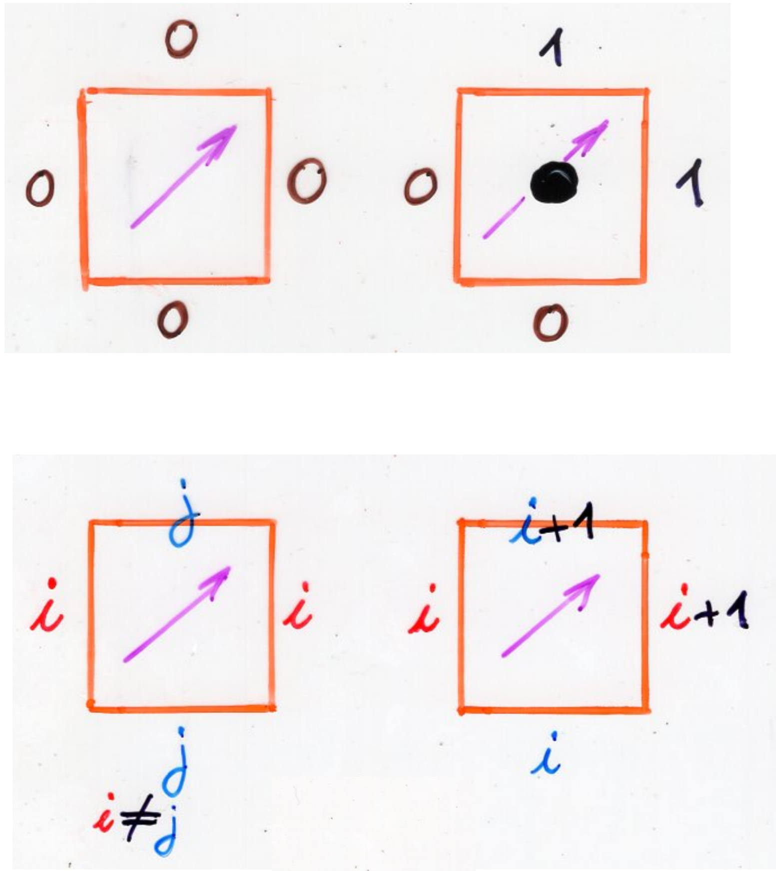


(i)
ρ = μ = ν
λ = ρ
(ii)
ρ = μ ≠ ν
λ = ν
(iii)
ρ = ν ≠ μ
λ = μ
(iv)
ρ ≠ ν ≠ μ, ρ ≠ μ
λ = μ ∪ ν
(v)
ρ ≠ μ = ν
λ = μ, ν + (i+1)
(vi)
ρ = μ = ν
λ = ρ, μ, ν + (1)

"local rules" on the vertices

"local rules" on the edges





« local rules on vertices »

Marc A. A. van Leeuwen (1996)

The Robinson-Schensted and Schützenberger algorithms, an elementary approach

C.Krattentheler, (2006).

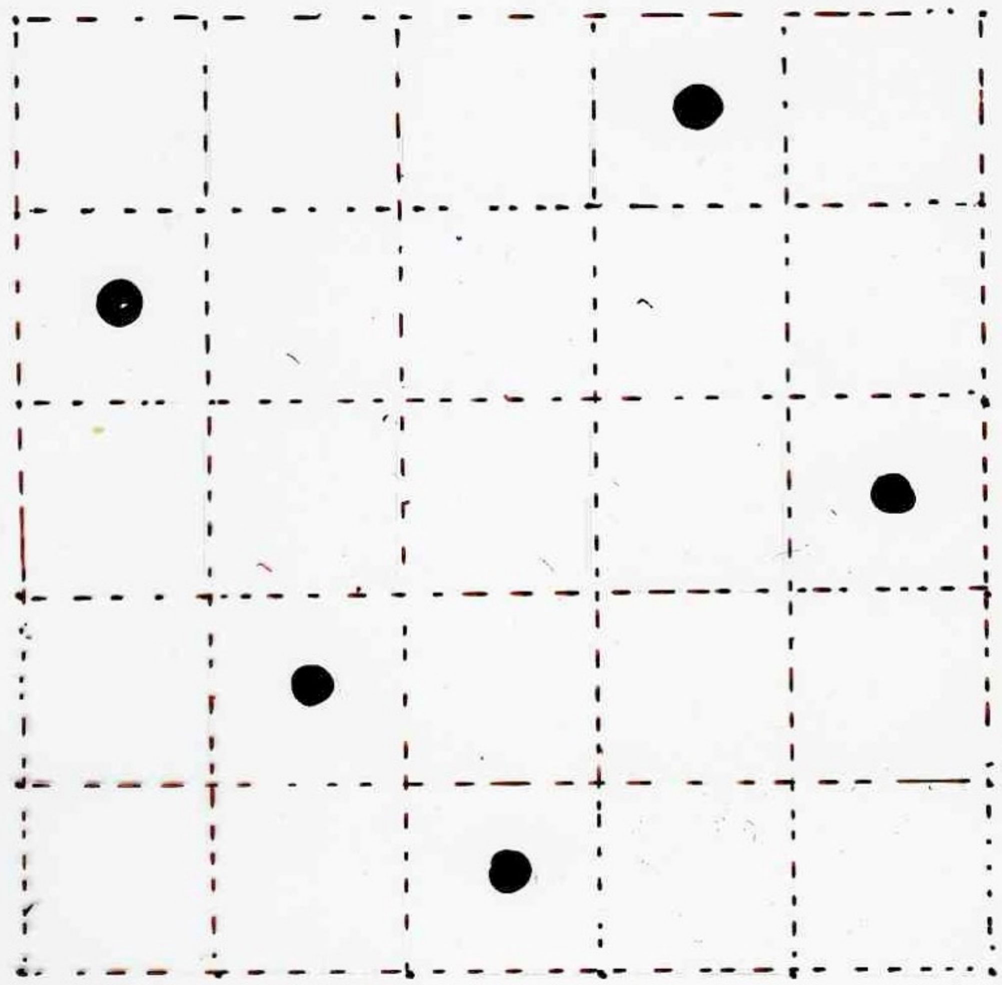
GROWTH DIAGRAMS, AND INCREASING AND DECREASING CHAINS IN FILLINGS OF FERRERS SHAPES

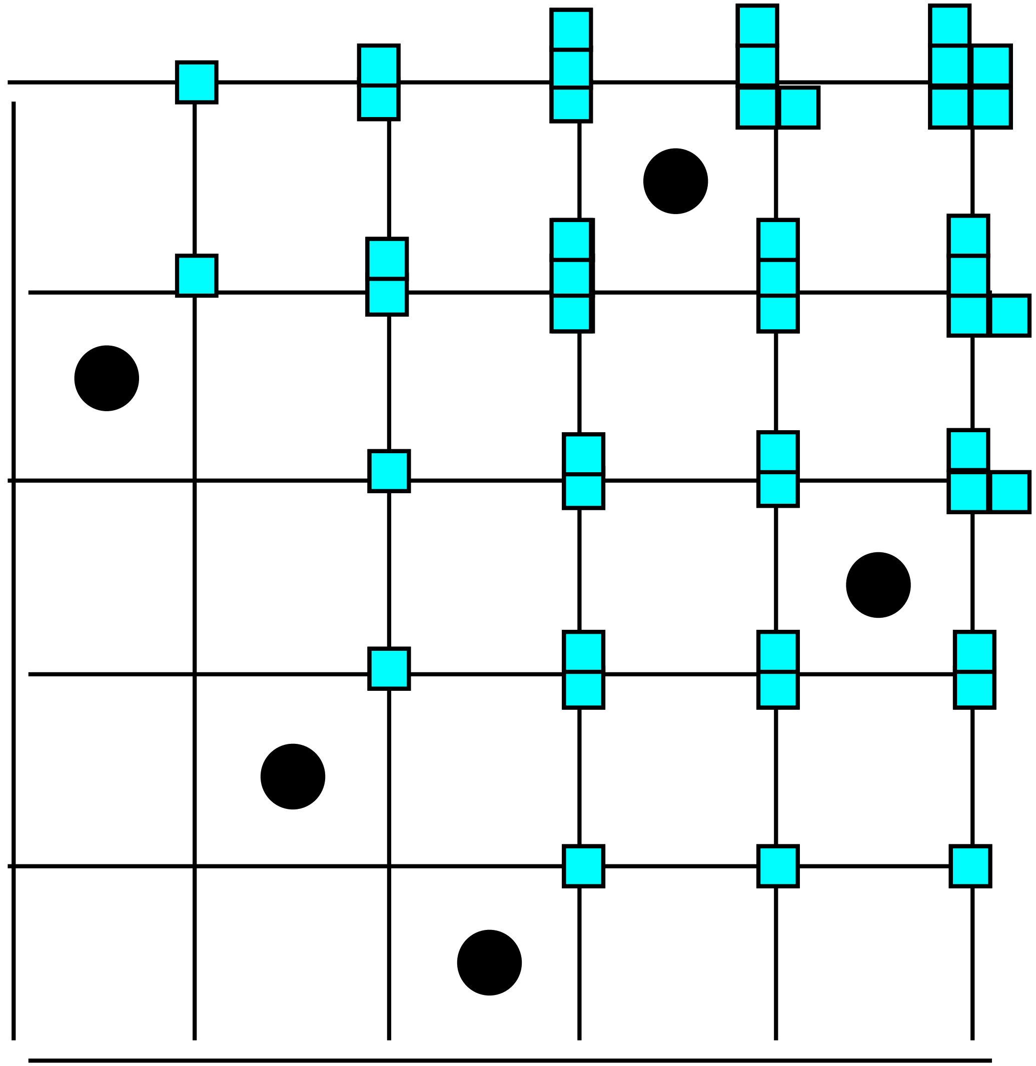
M.Rubey. (2007)

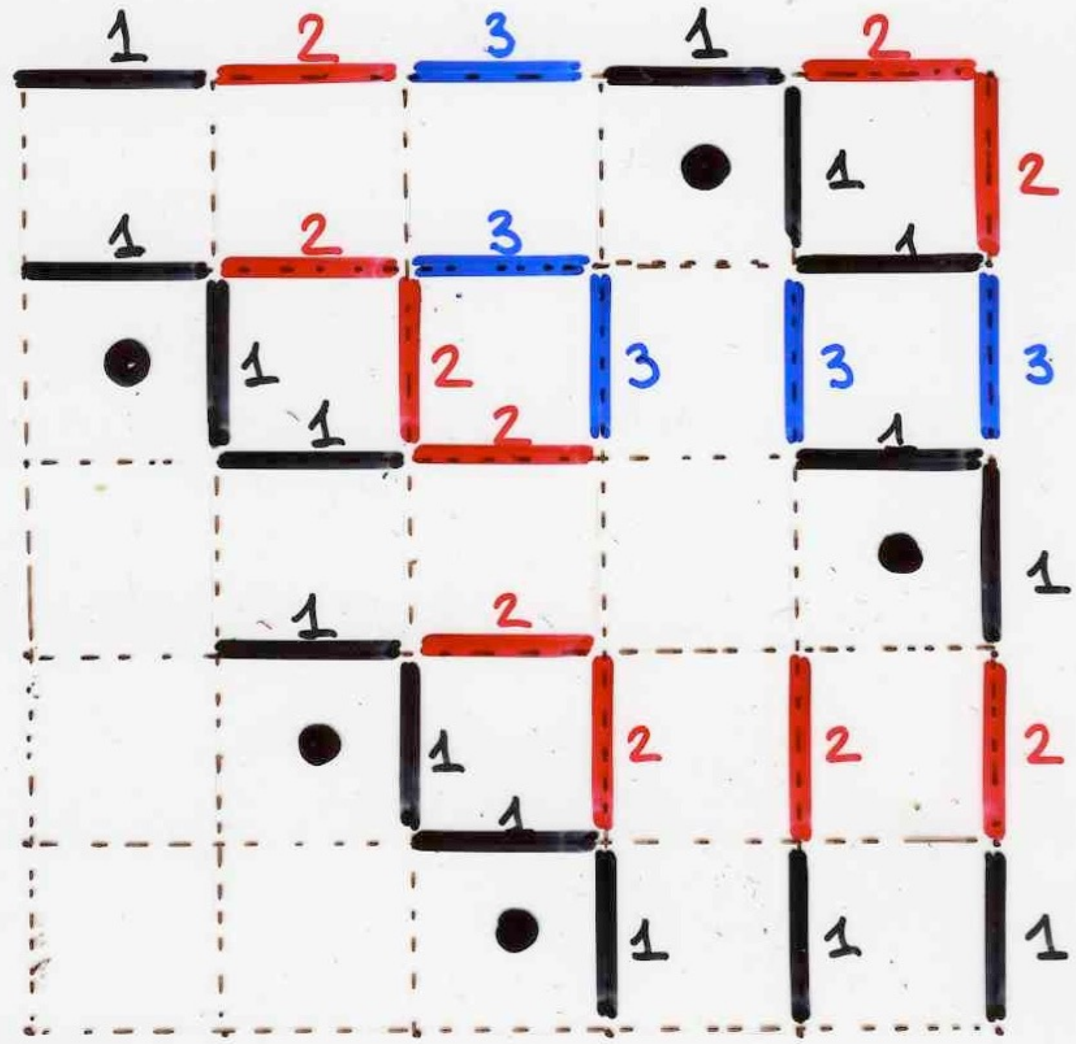
Increasing and Decreasing Sequences in Fillings of Moon Polyominoes

I claim that much attention should be given to the « local rules on edges » rather that « local rules on vertices ».

This is part of the philosophy of the « cellular ansatz »



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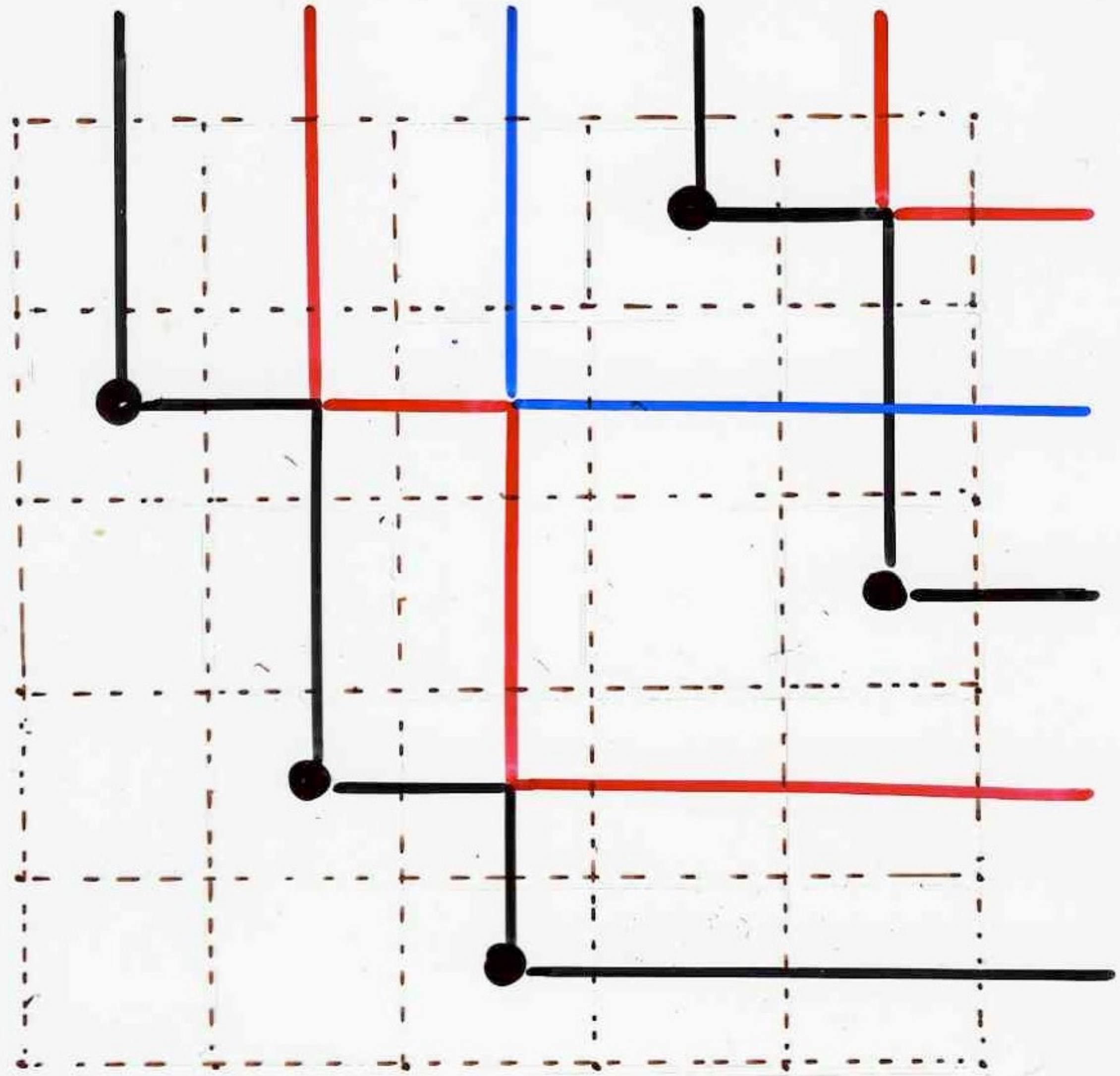

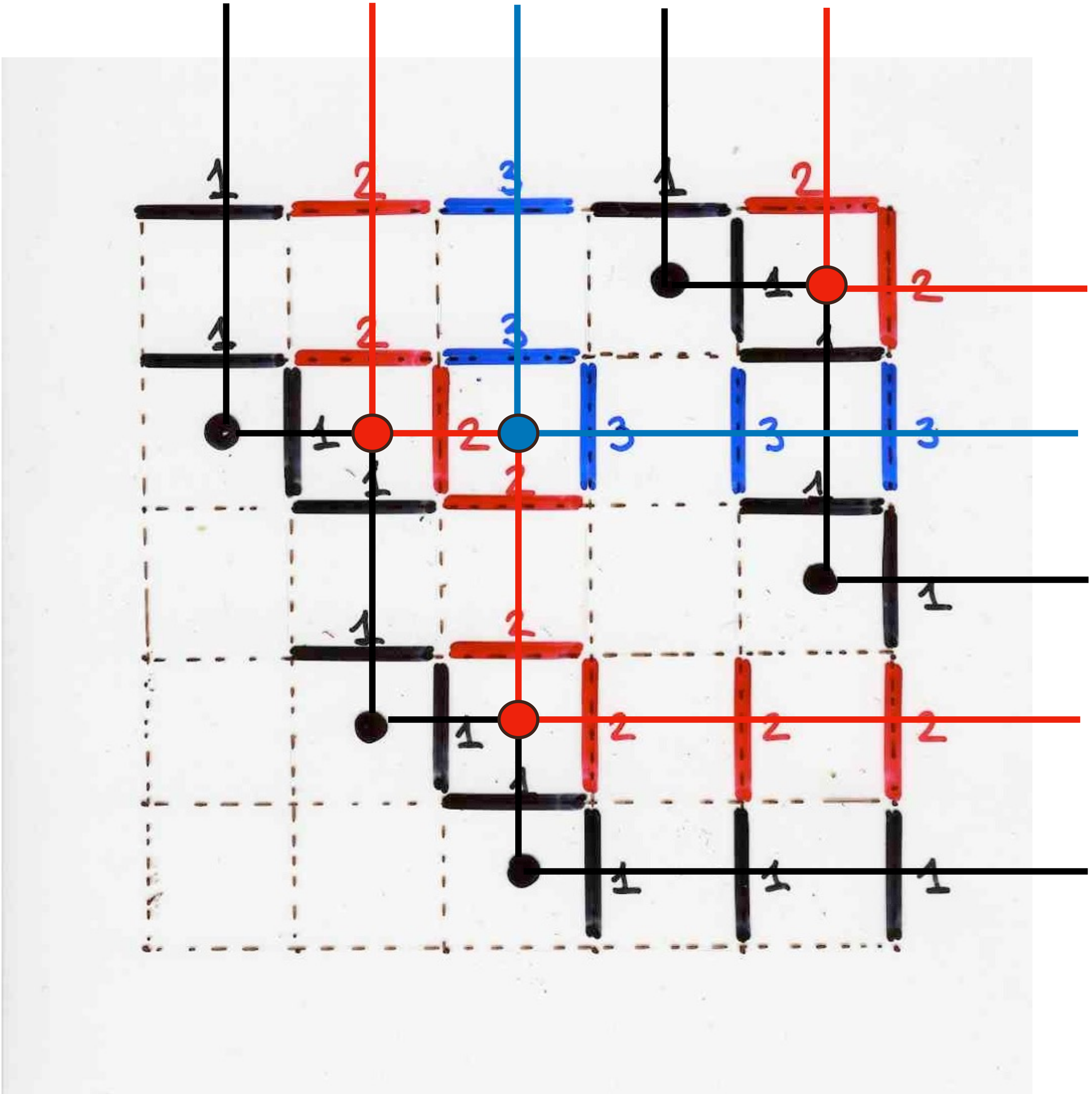

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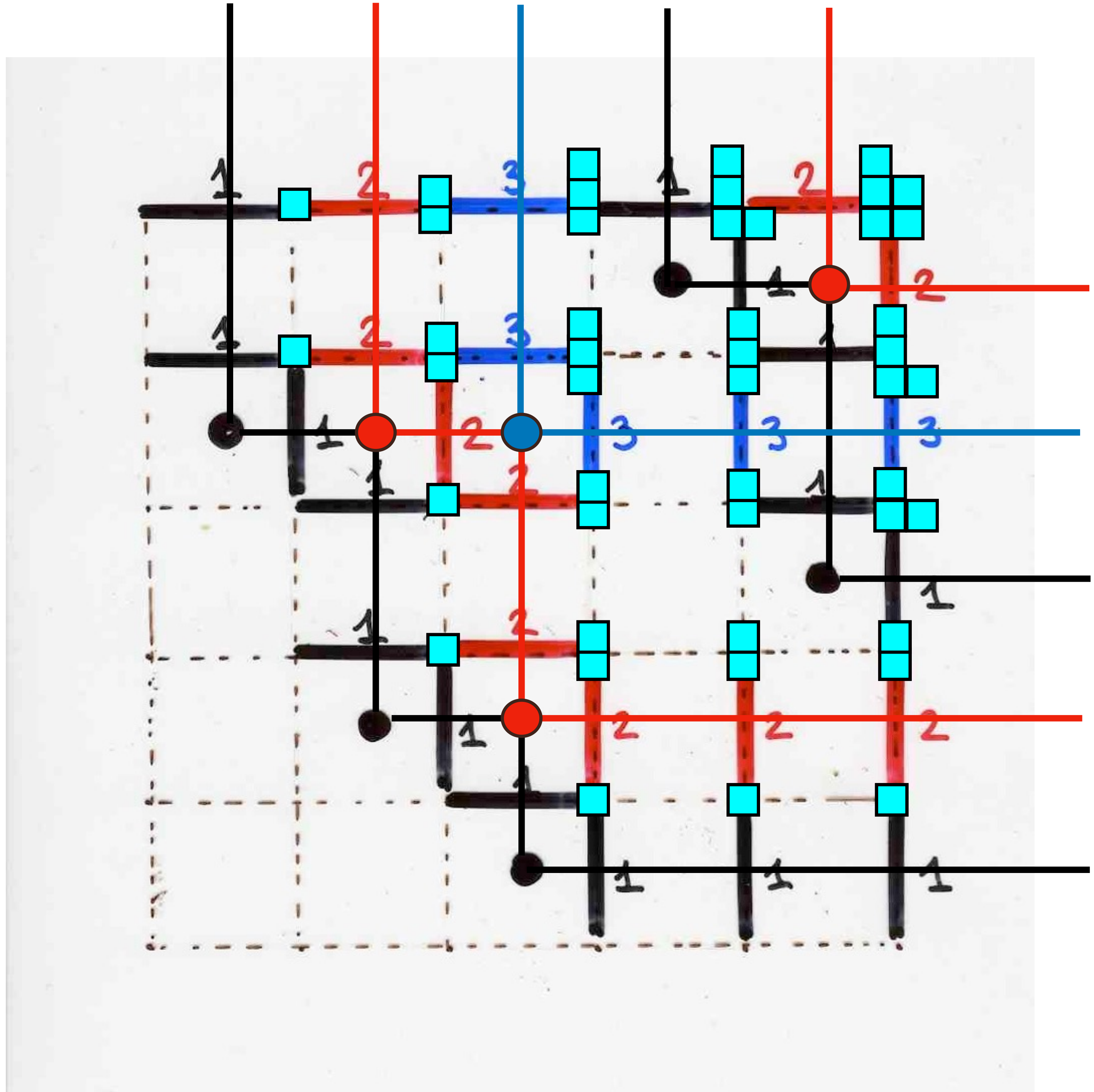

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The RSK bilateral edge local rules

bilateral
planar automaton RSK

$\mathcal{B} = \{B_i\}_{i \in \mathbb{Z} - \{0\}}$

$\mathcal{A} = \{A_j\}_{j \in \mathbb{Z} - \{0\}}$

$B_i A_j = A_j B_i$

$i \neq j$

$B_i A_i = A_{i-1} B_{i-1}$

$(i \neq 1)$

$B_1 A_1 = A_{-1} B_{-1}$

bilateral
(reverse) planar automaton RSK

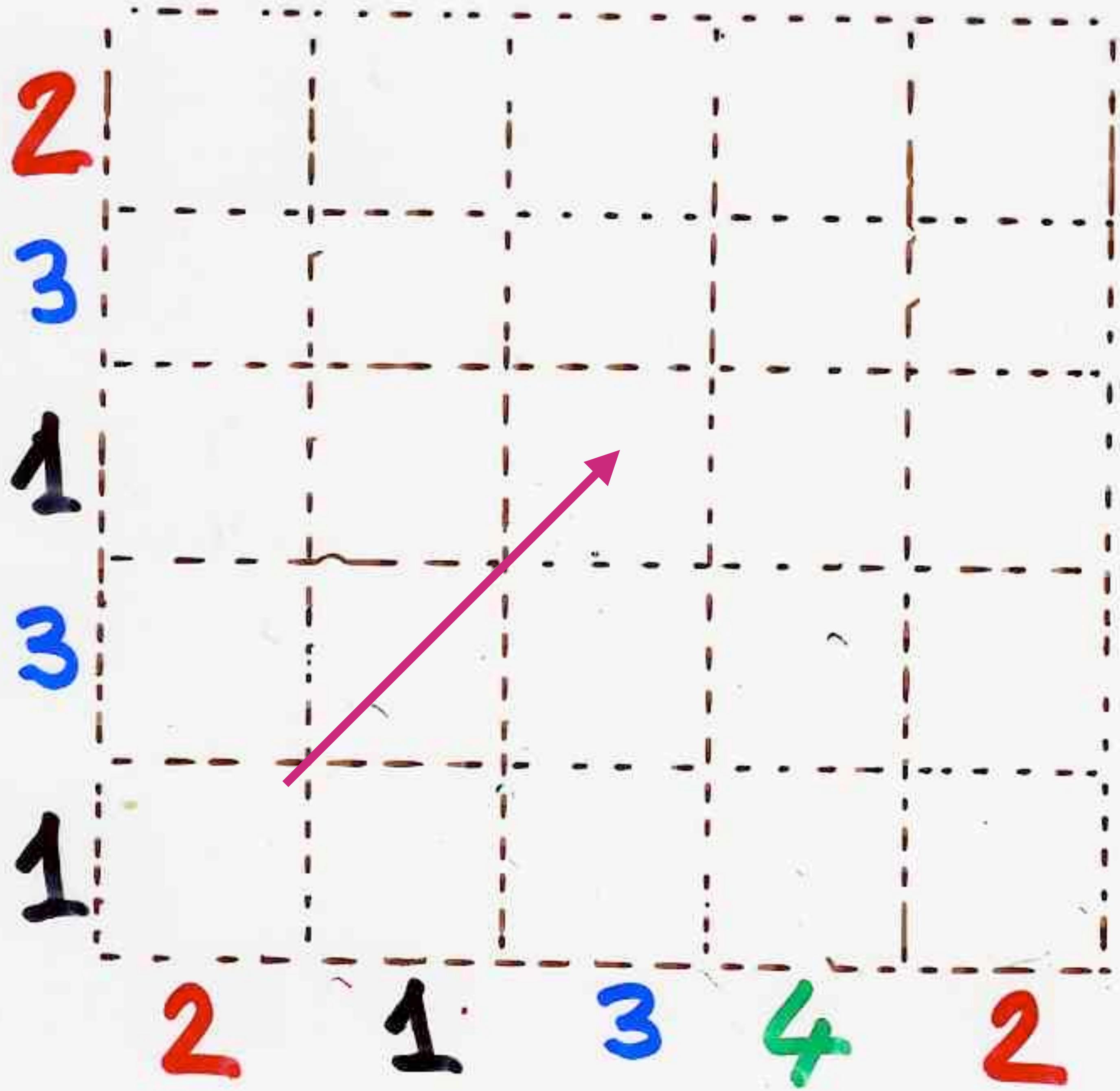
$A_j B_i = B_i A_j$

$i \neq j$

$A_i B_i = B_{i+1} A_{i+1}$

$(i \neq -1)$

$A_{-1} B_{-1} = B_1 A_1$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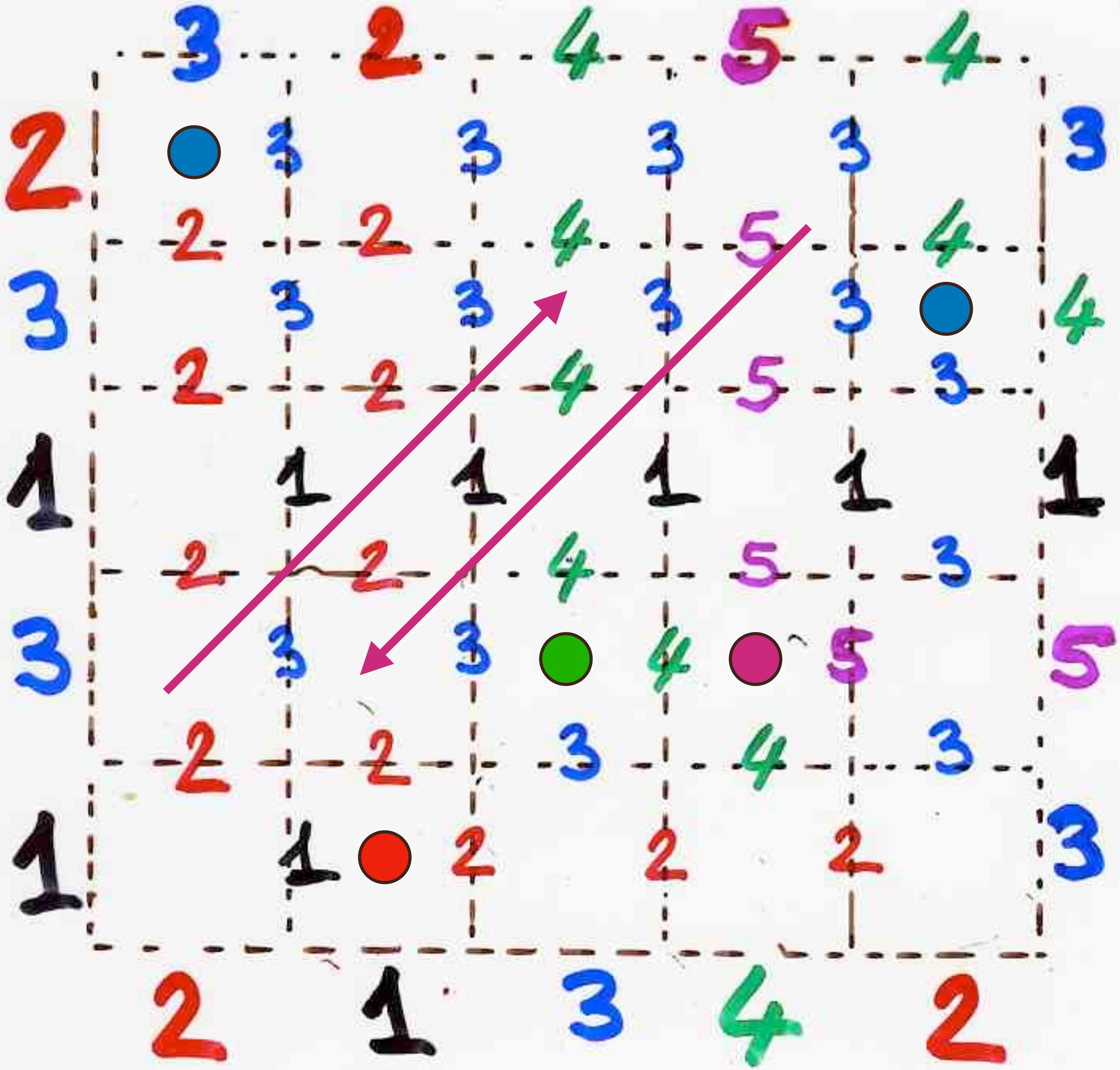

3 2 4 5 4
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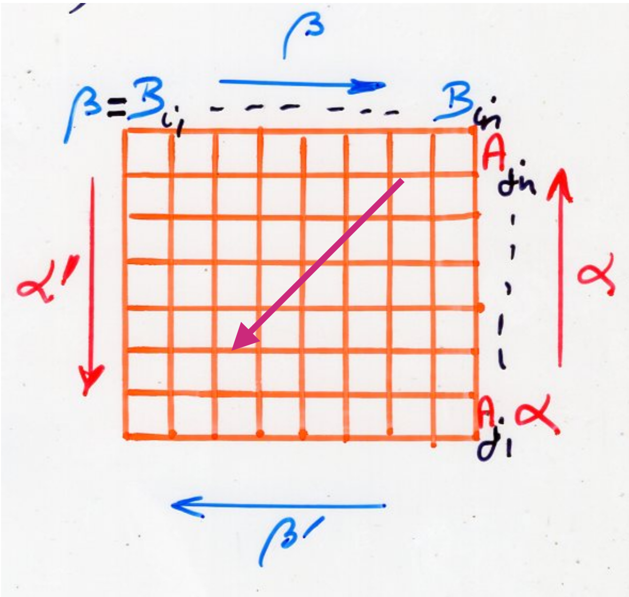
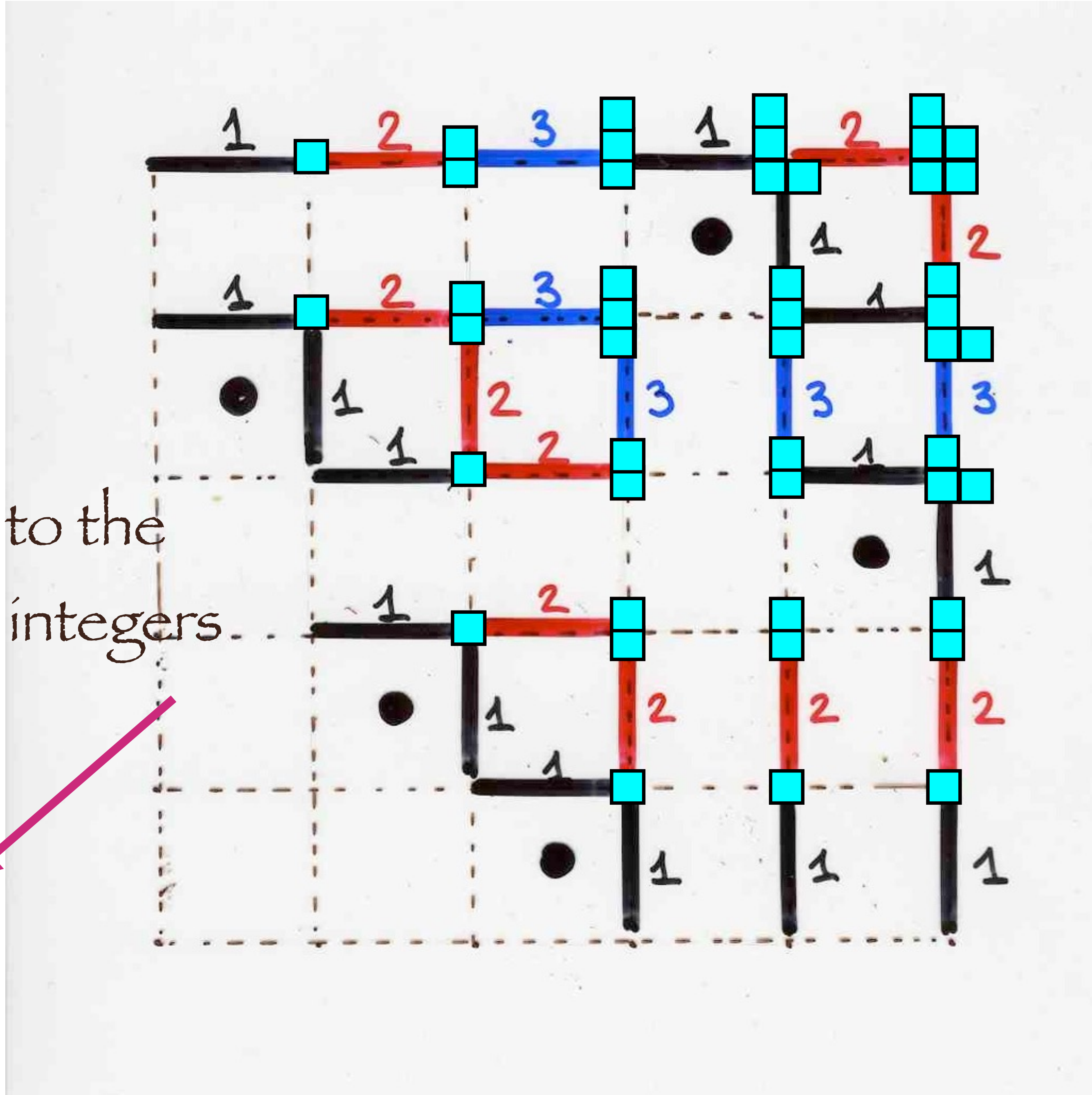
2 1 3 4 2

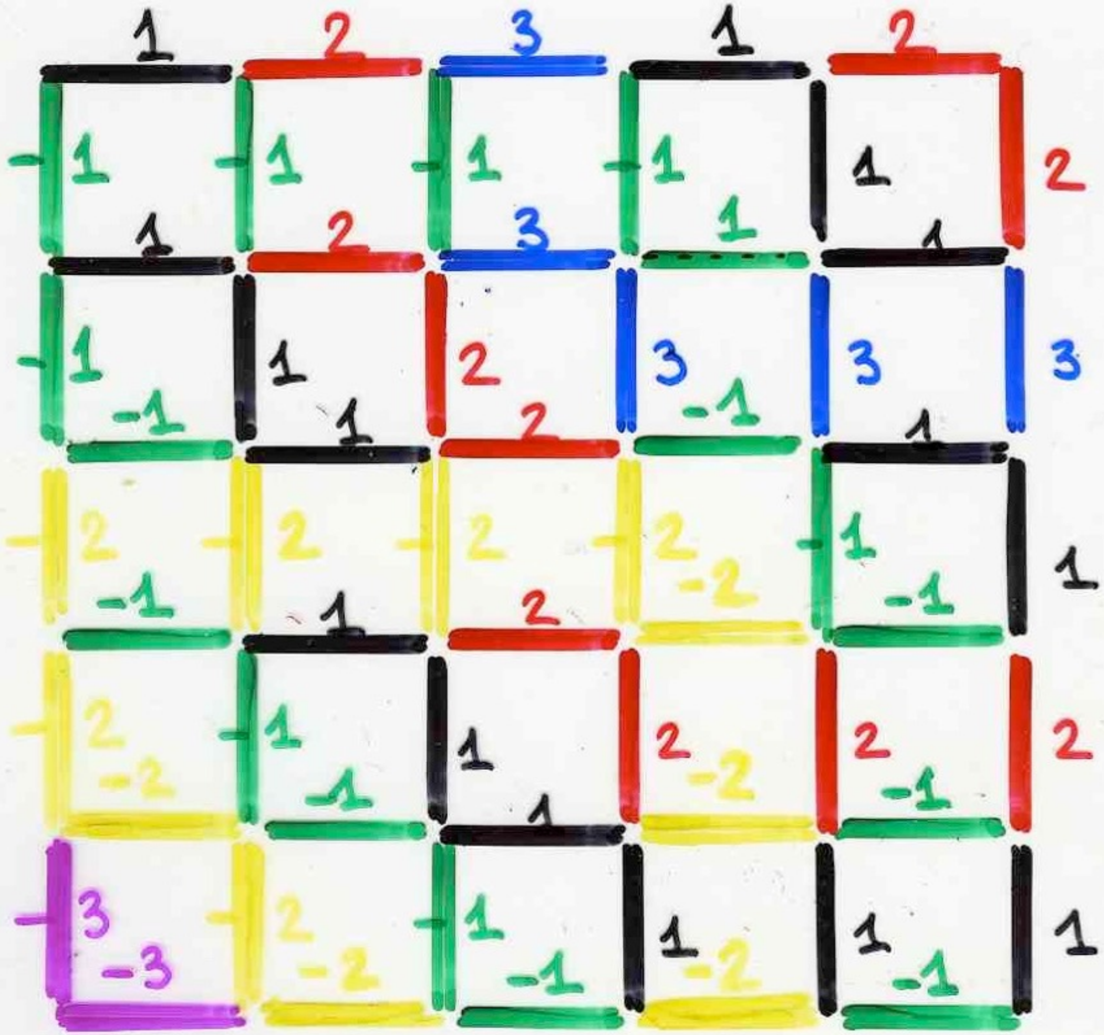
RSK product of two words

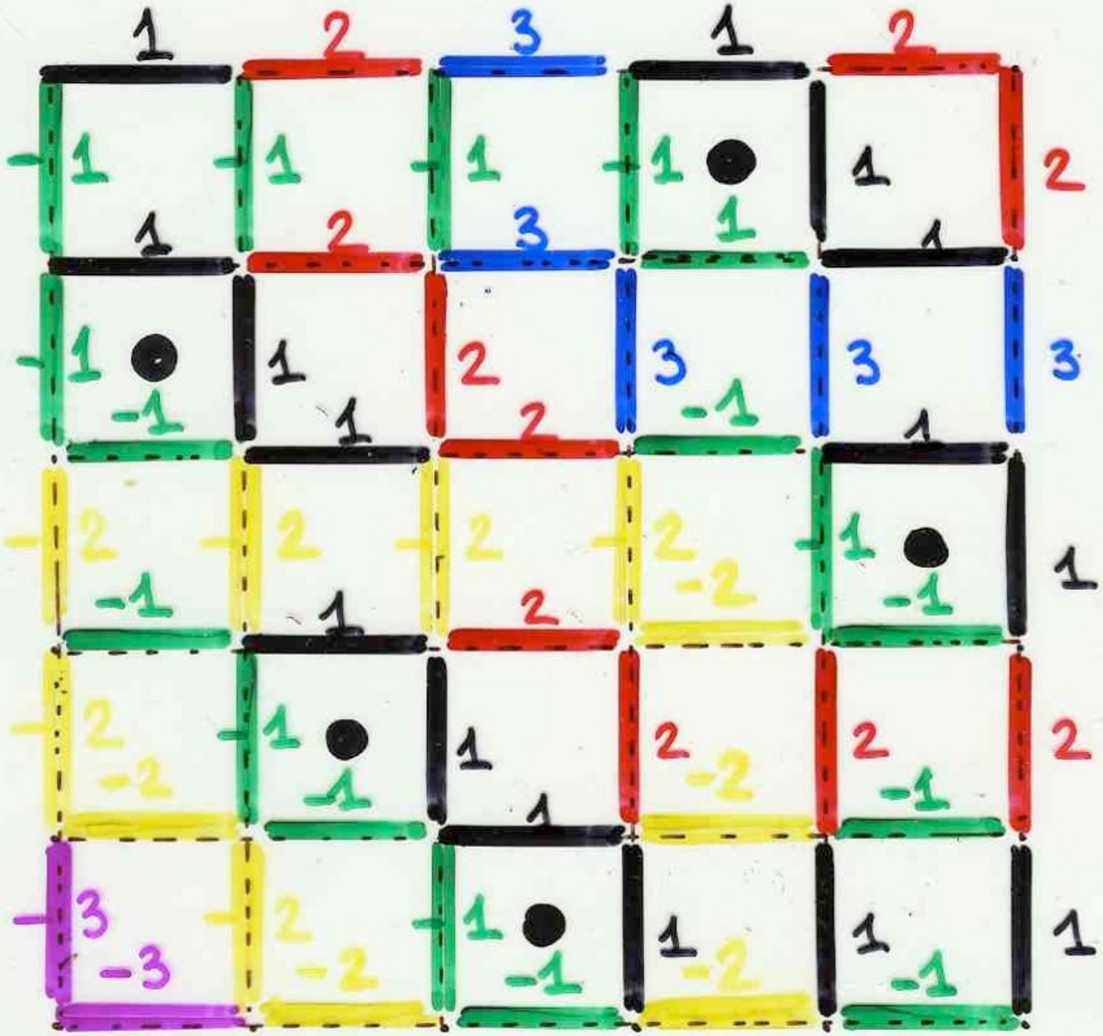
$(\beta, \alpha) \longrightarrow (\alpha', \beta')$

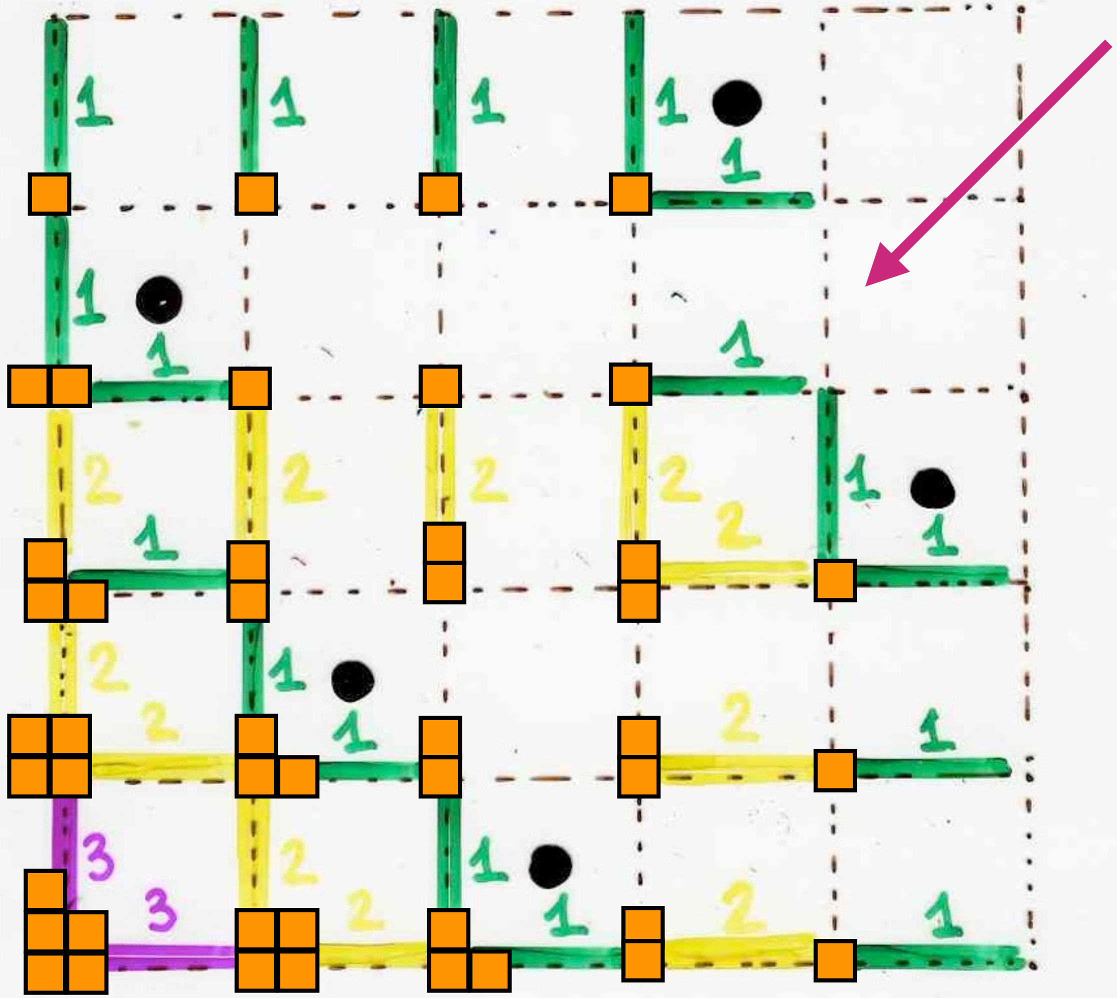


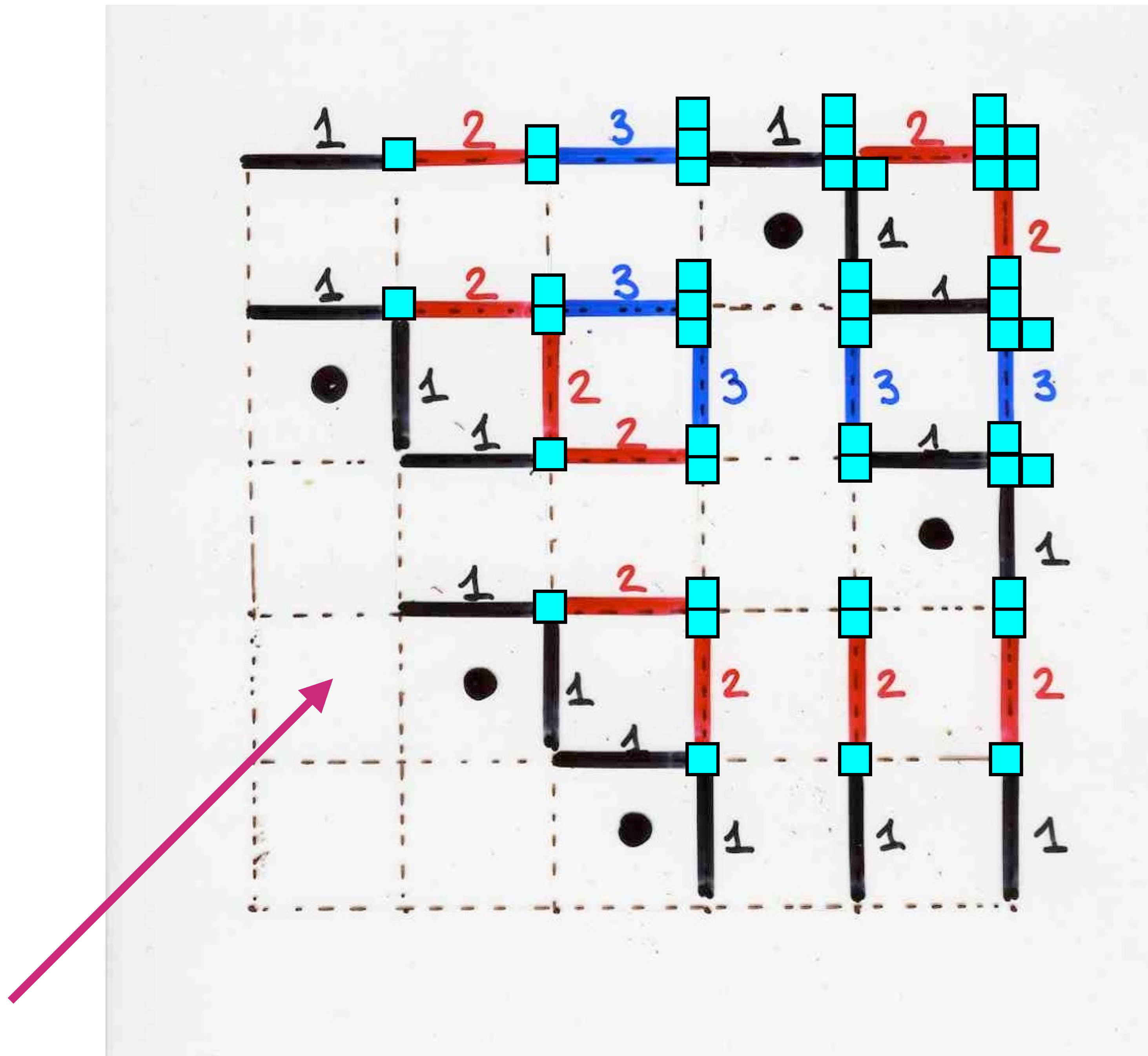
Going to the negative integers







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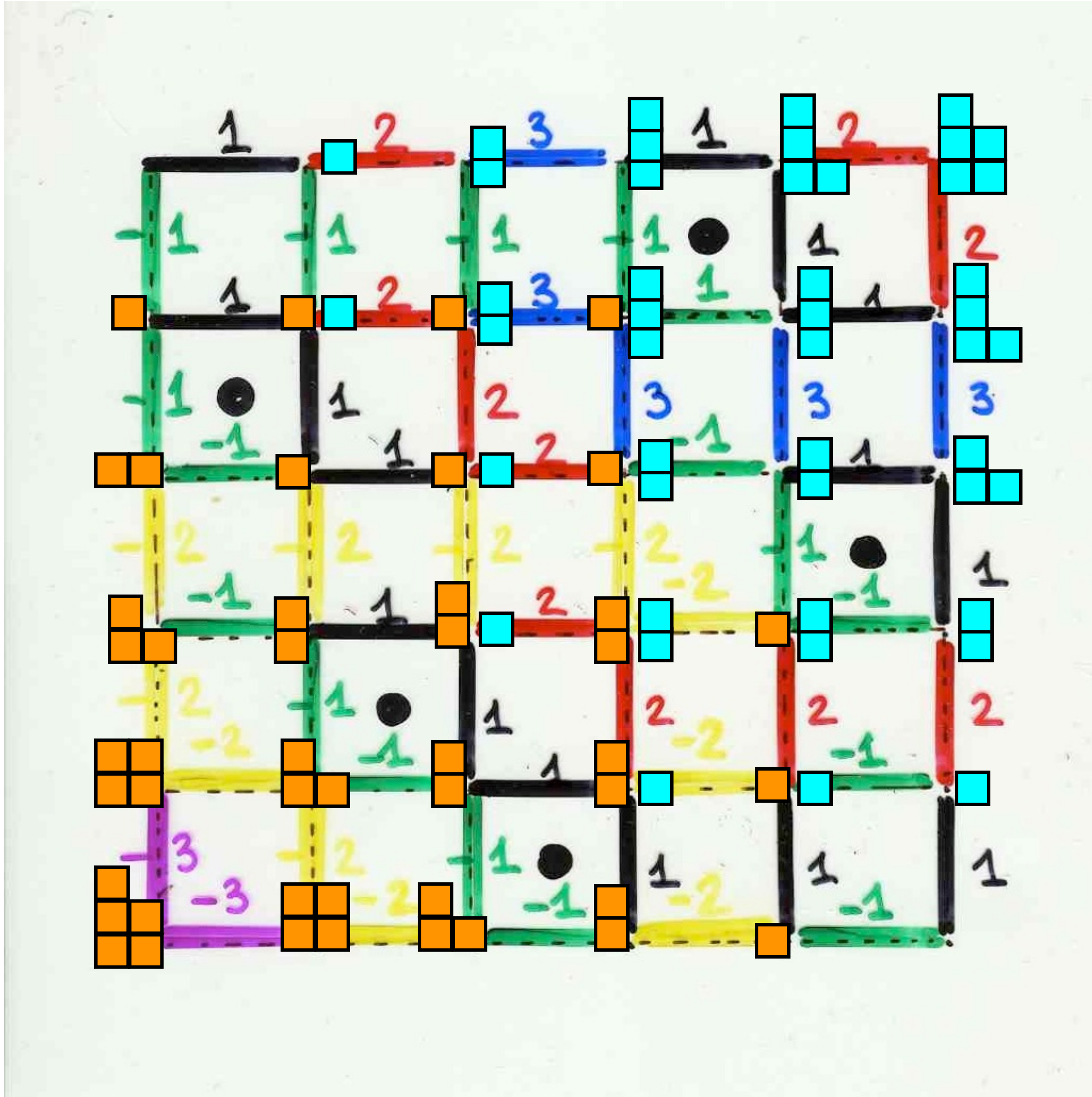
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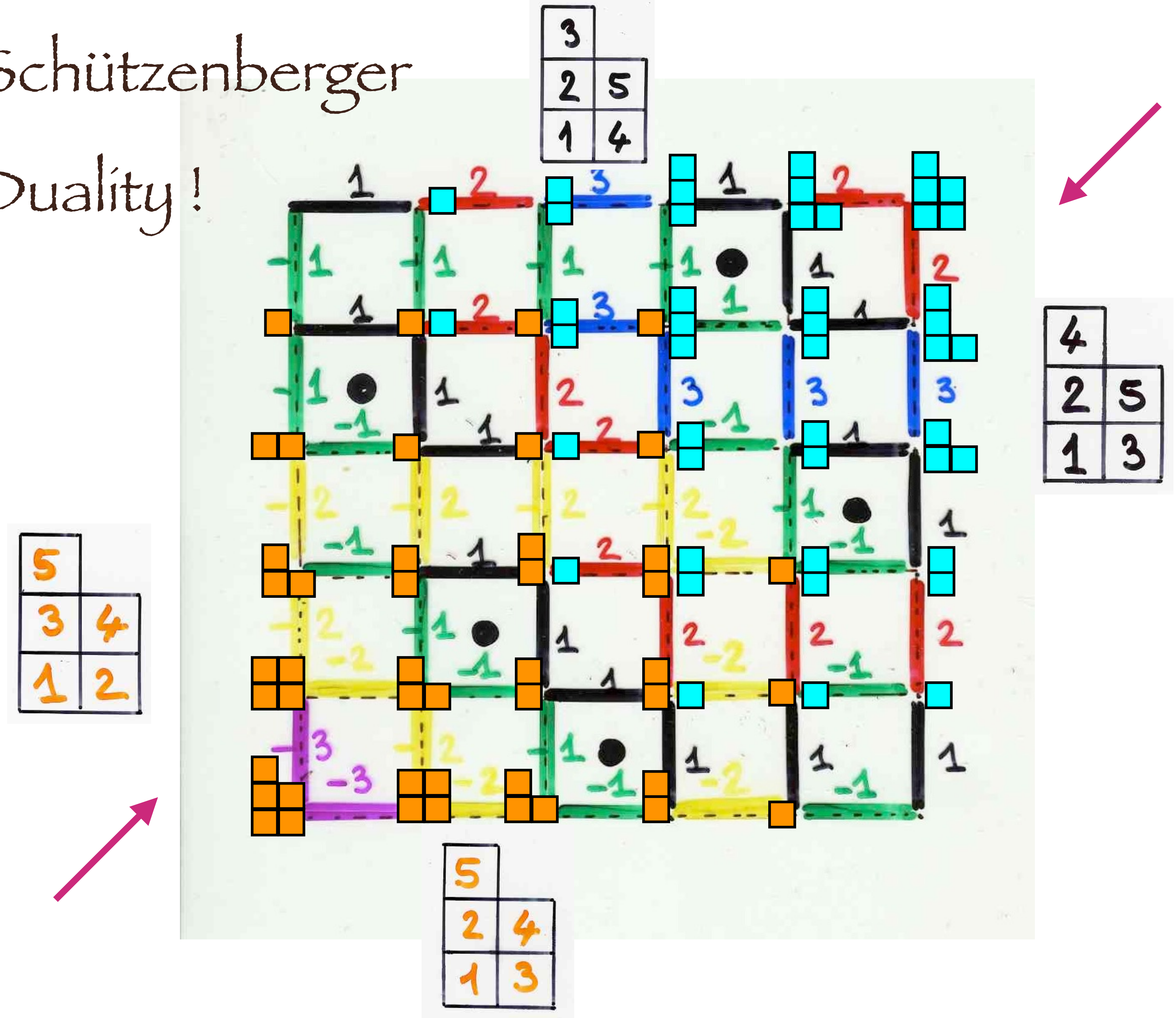
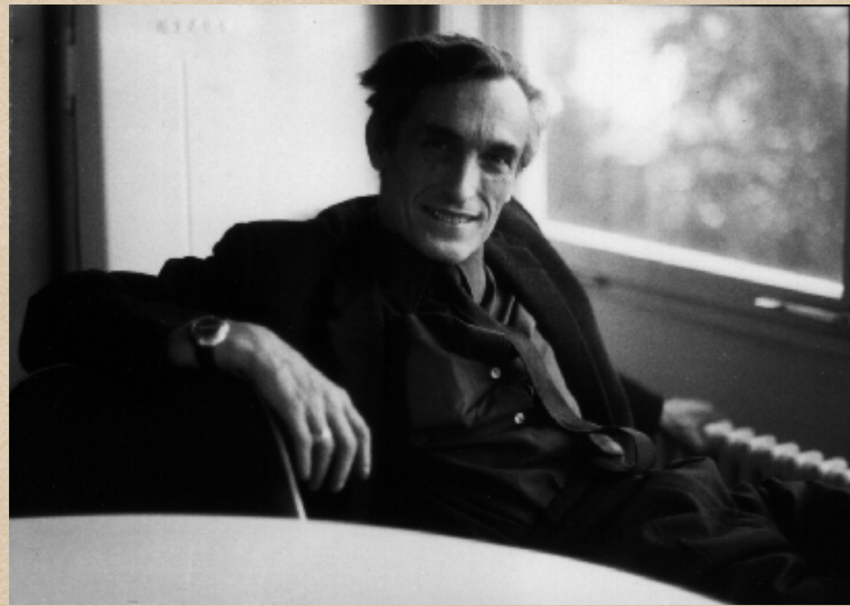
-3 -2 -1 -2 -1

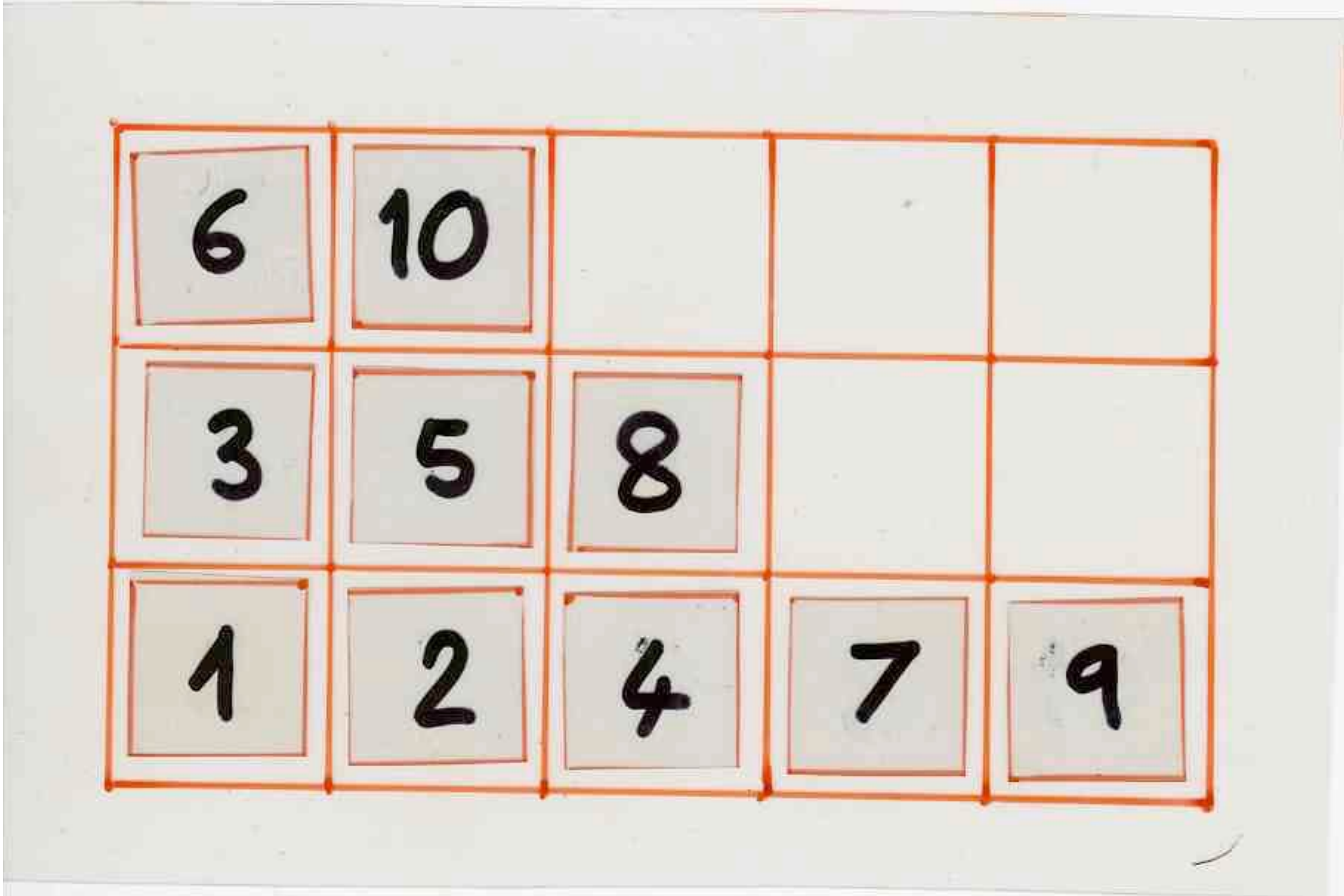
Schützenberger Duality !



dual of a Young tableau



M.P. Schützenberger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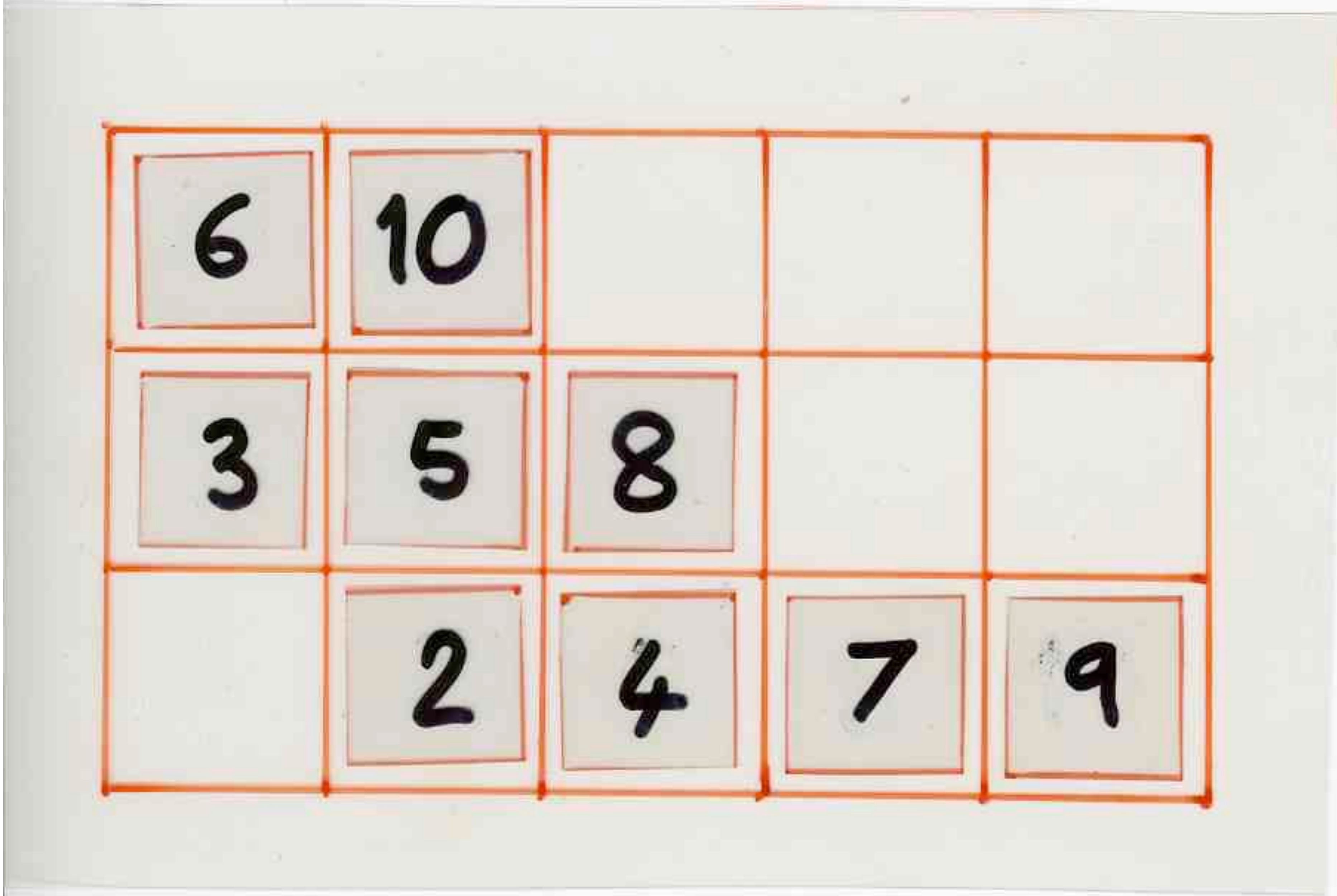
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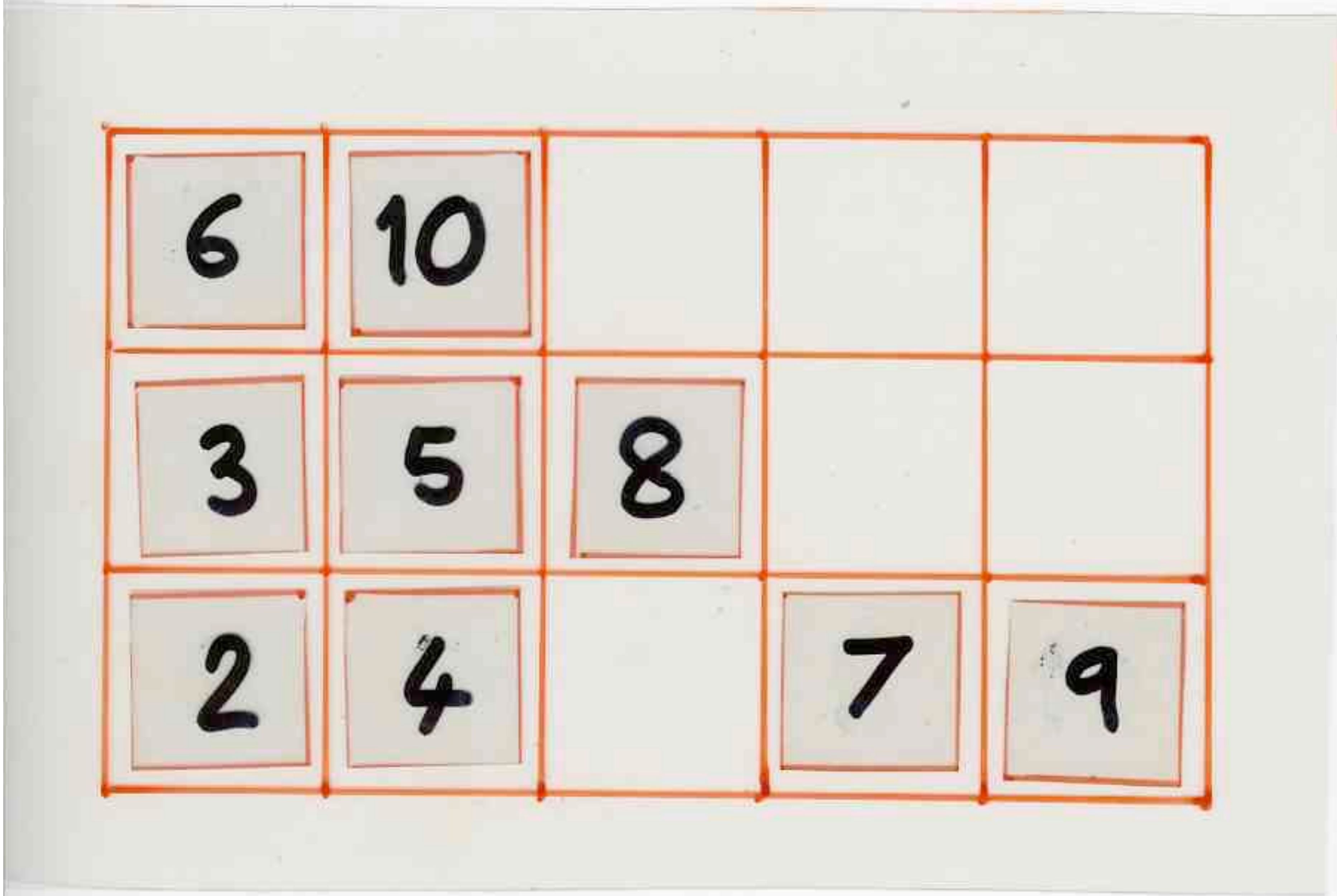
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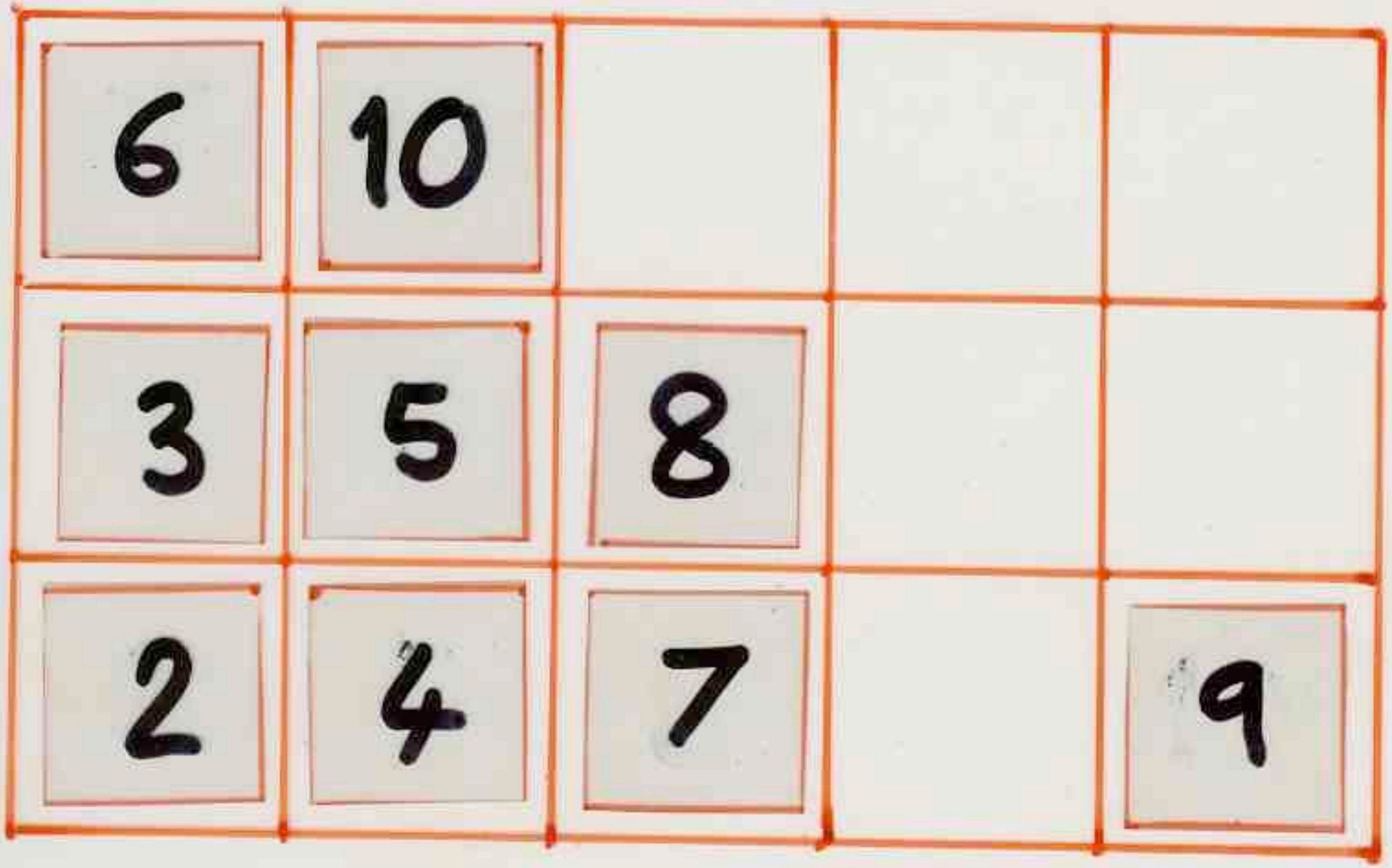
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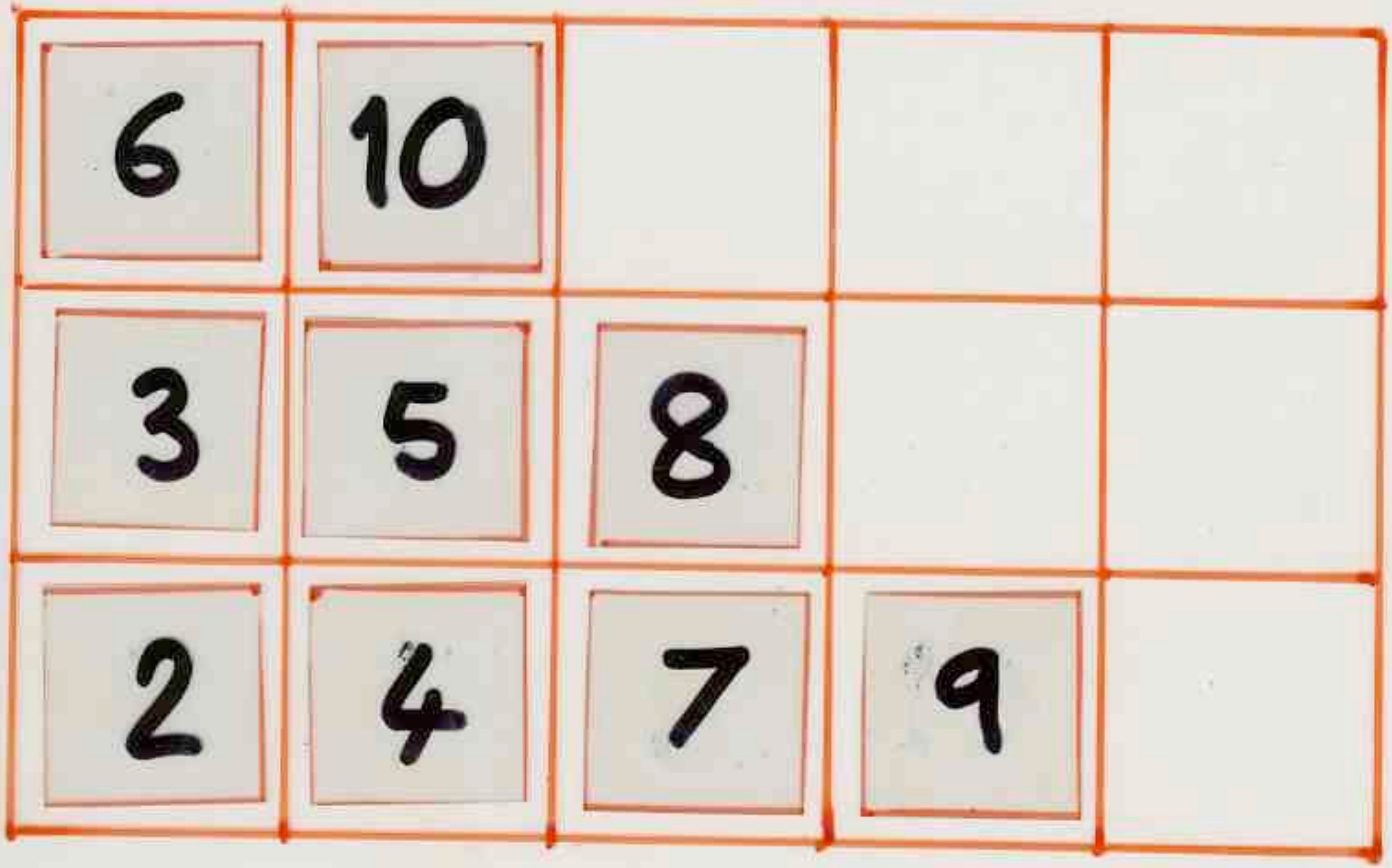
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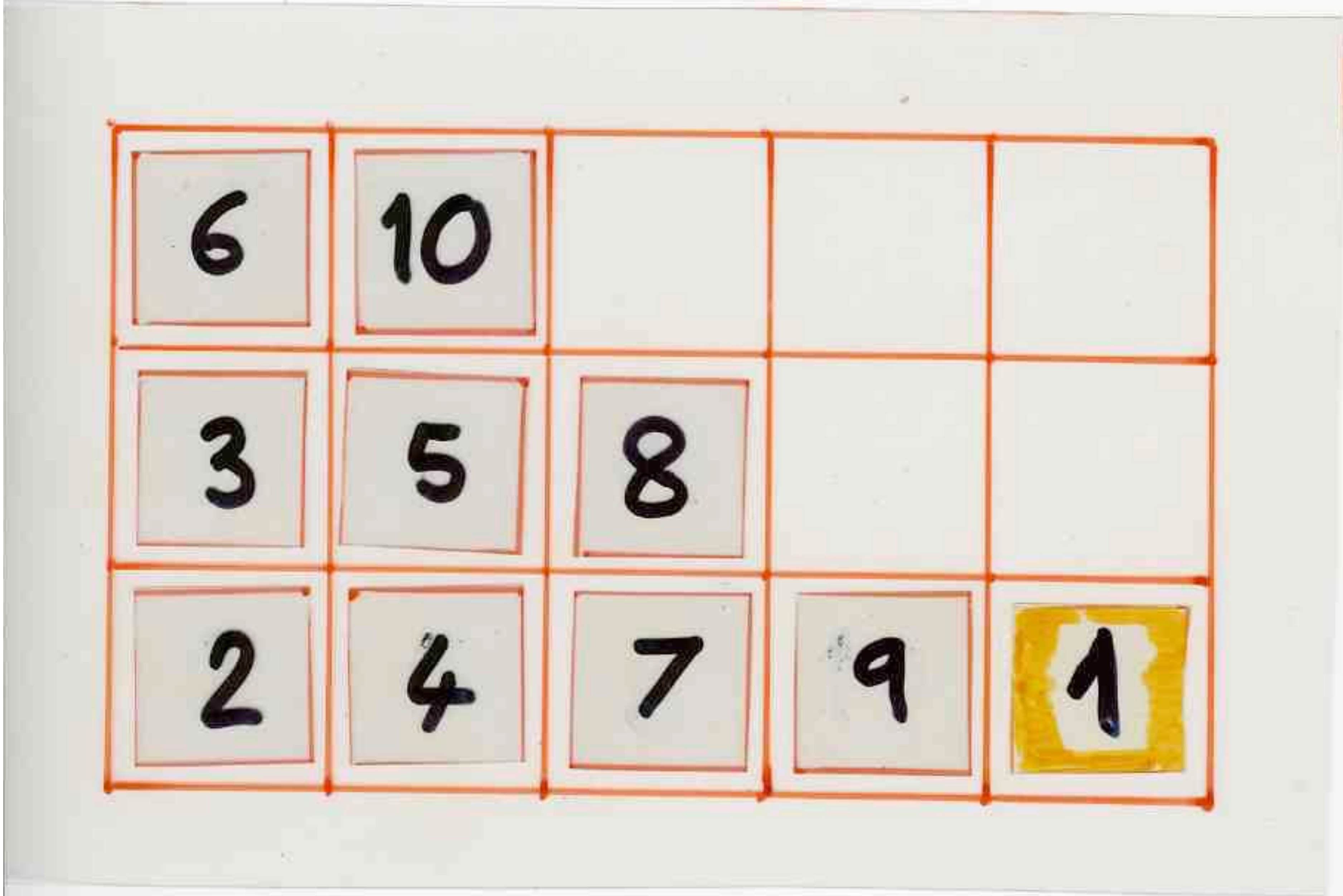
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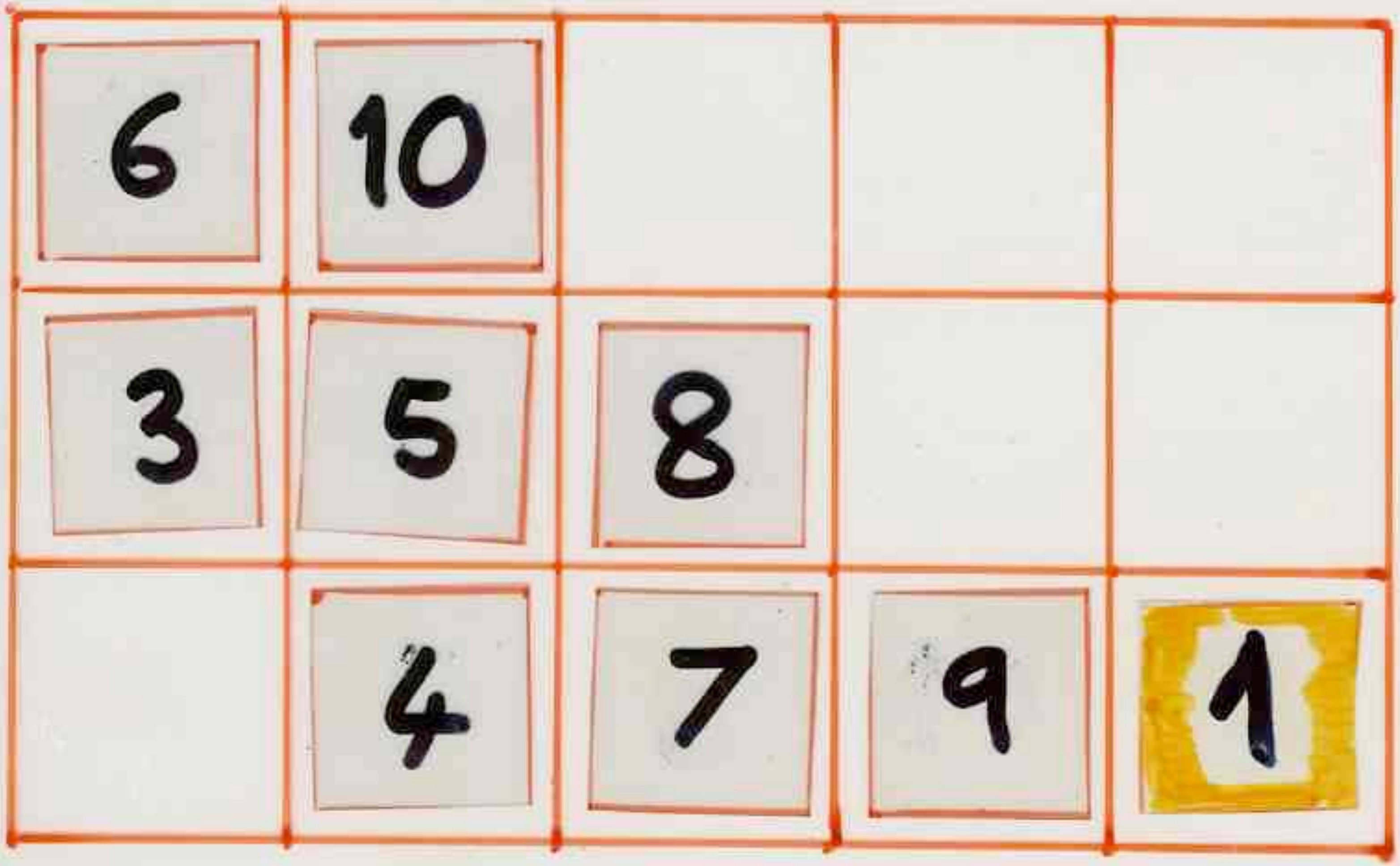
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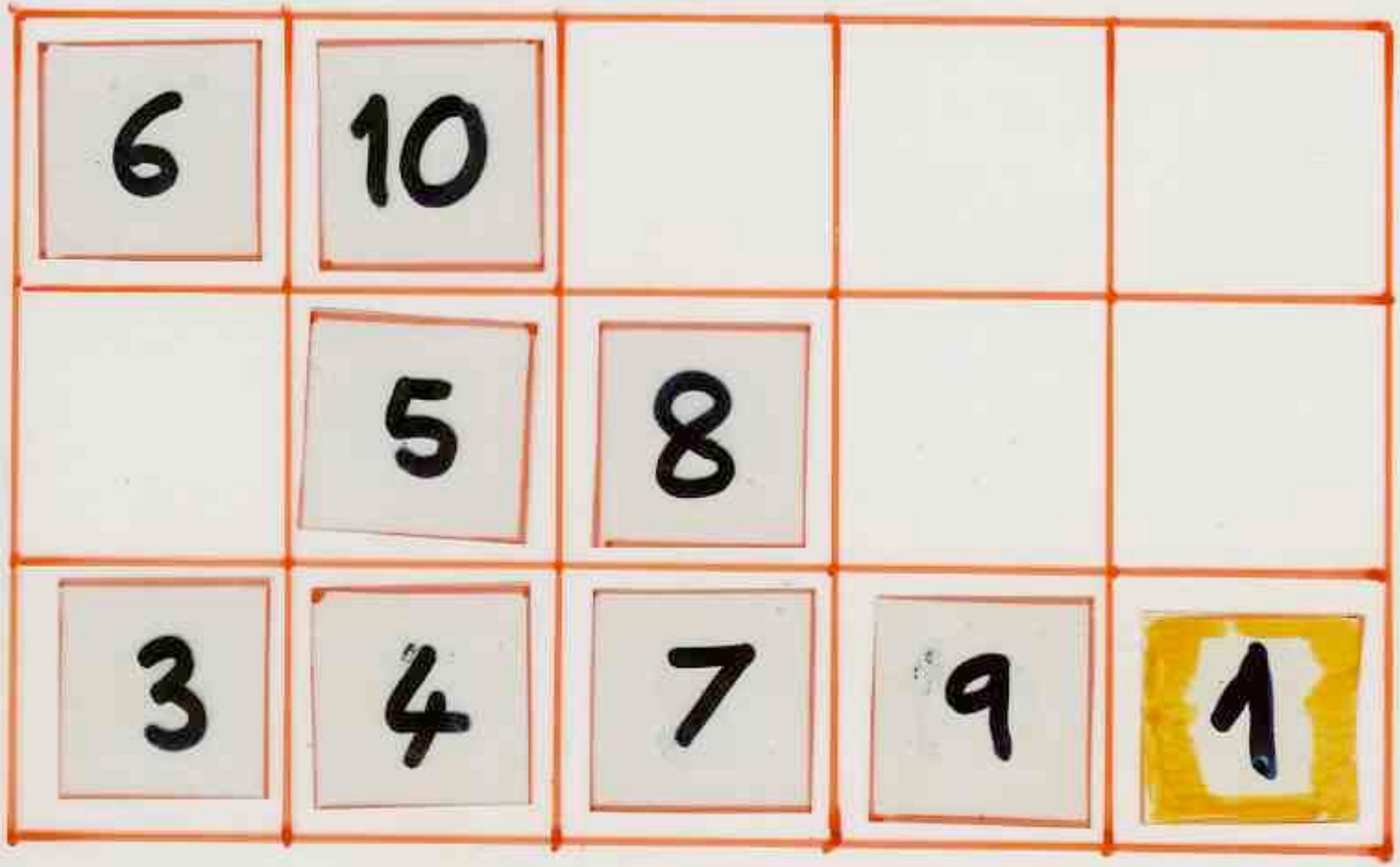
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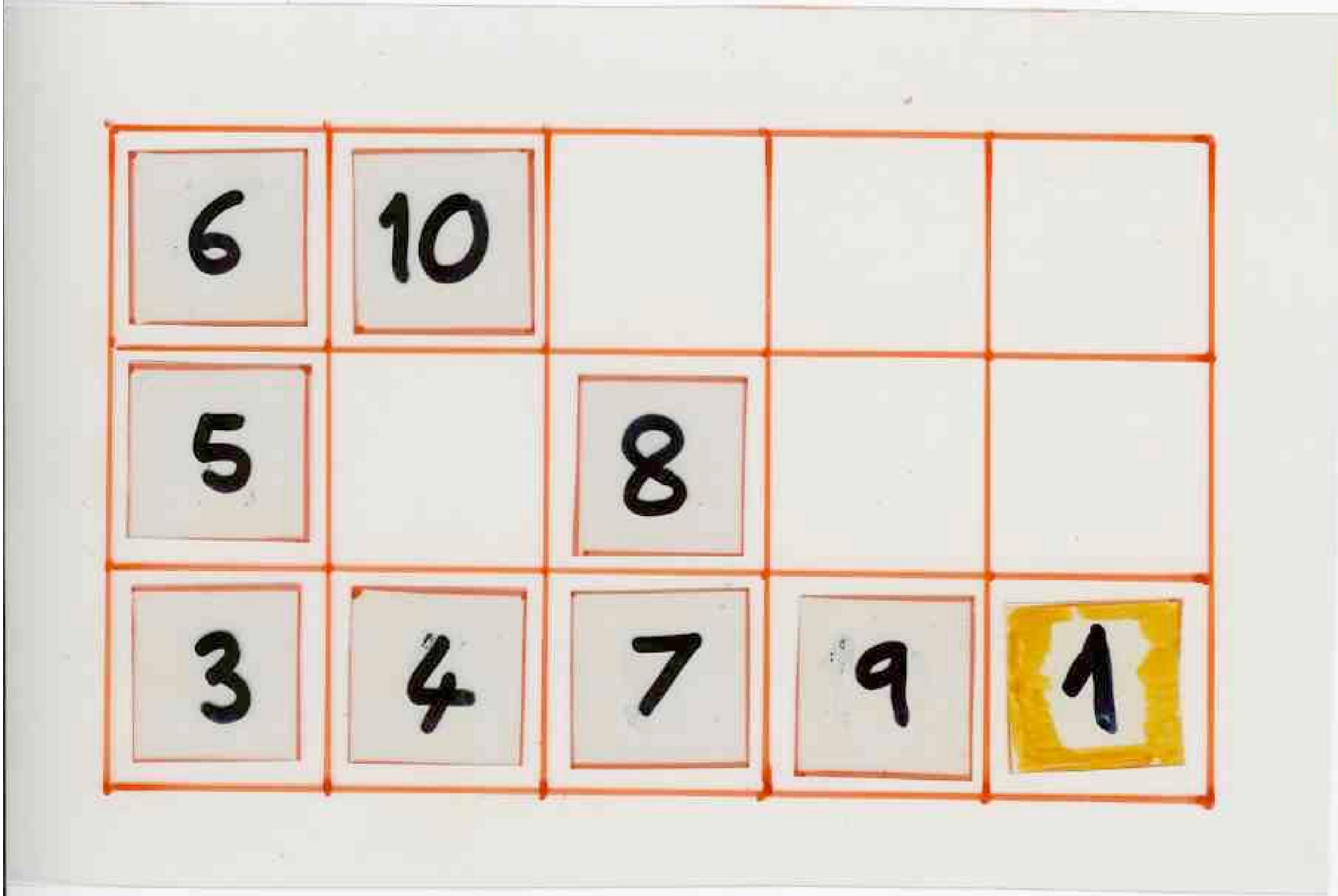
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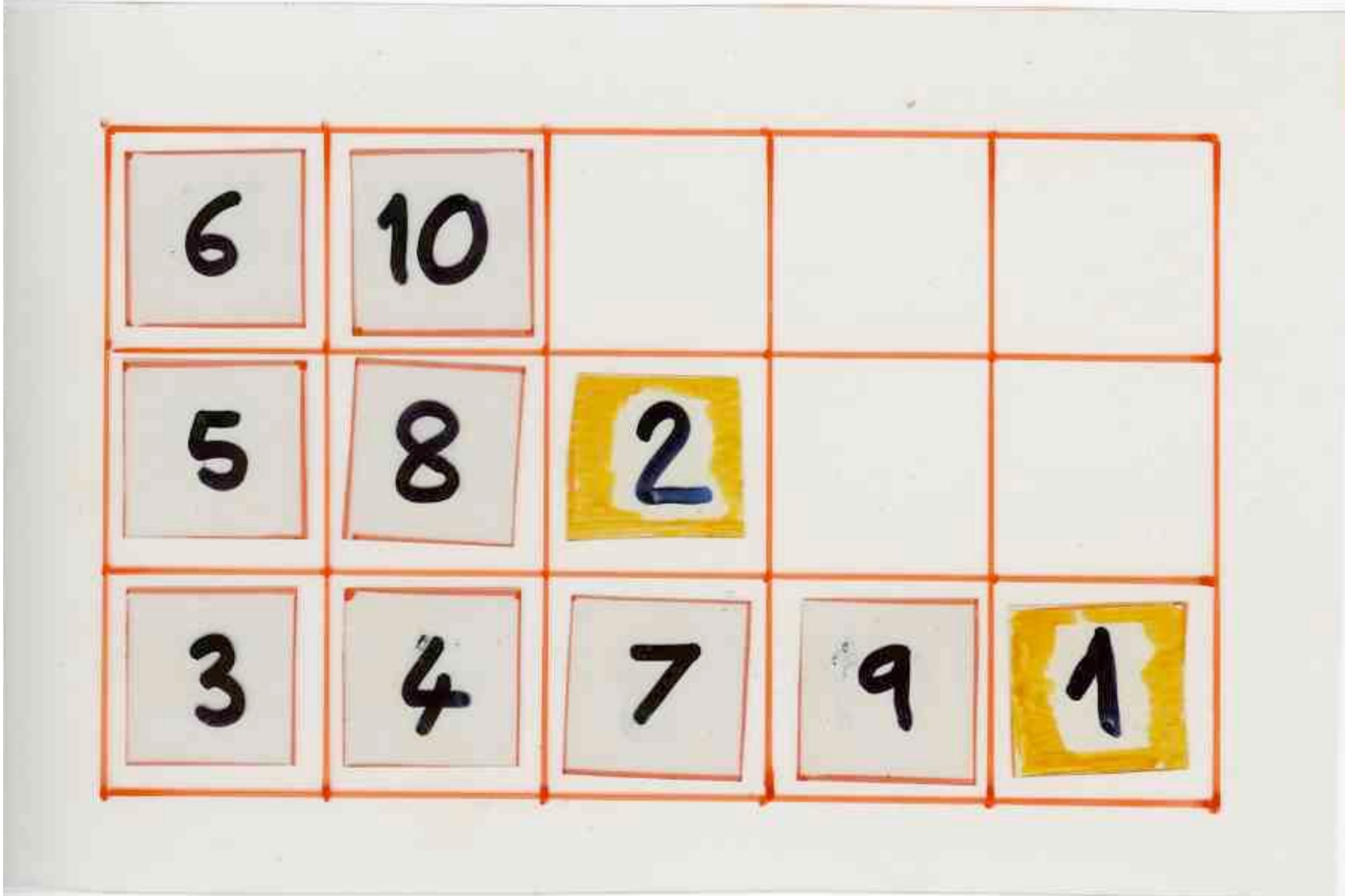
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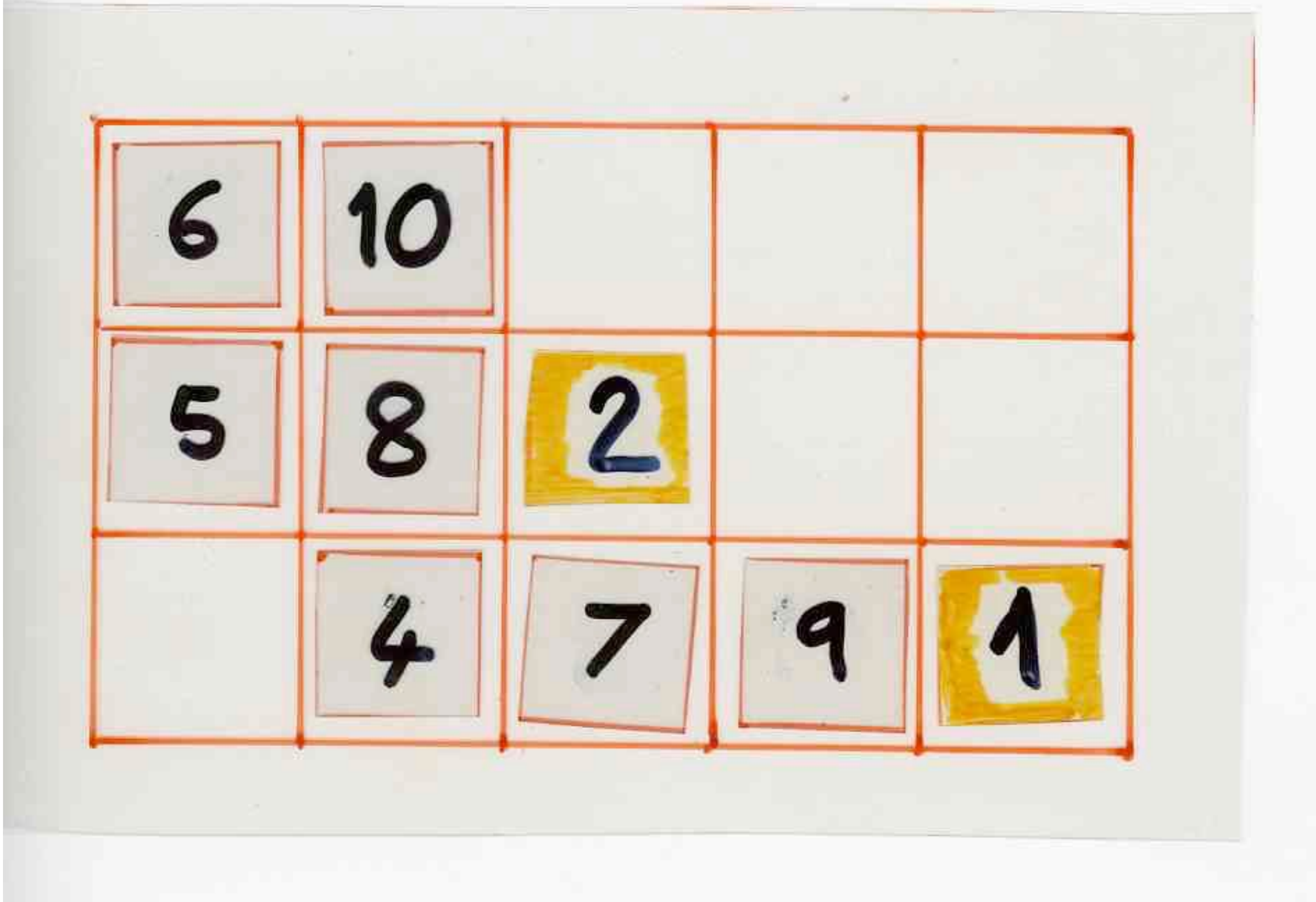
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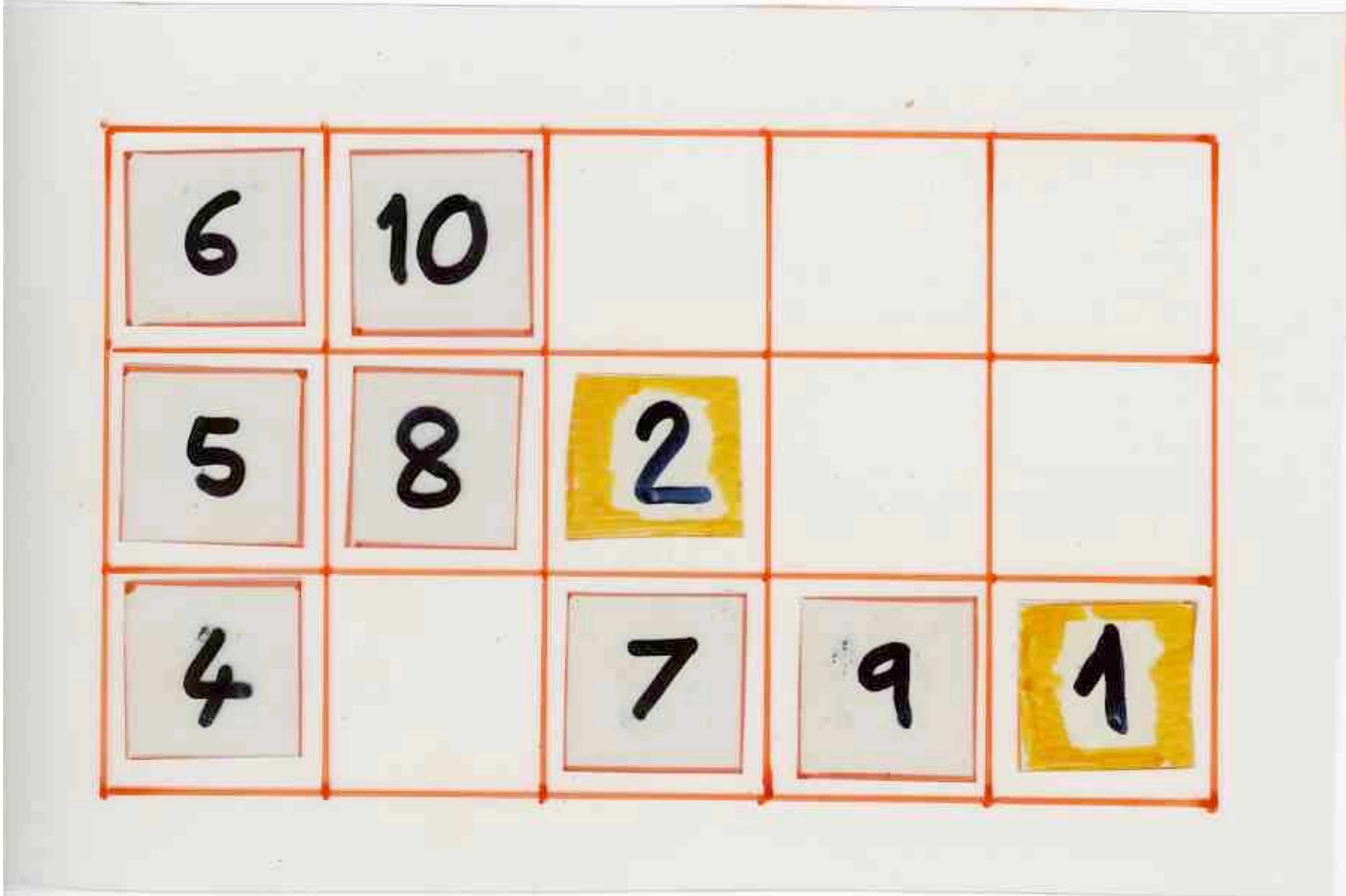
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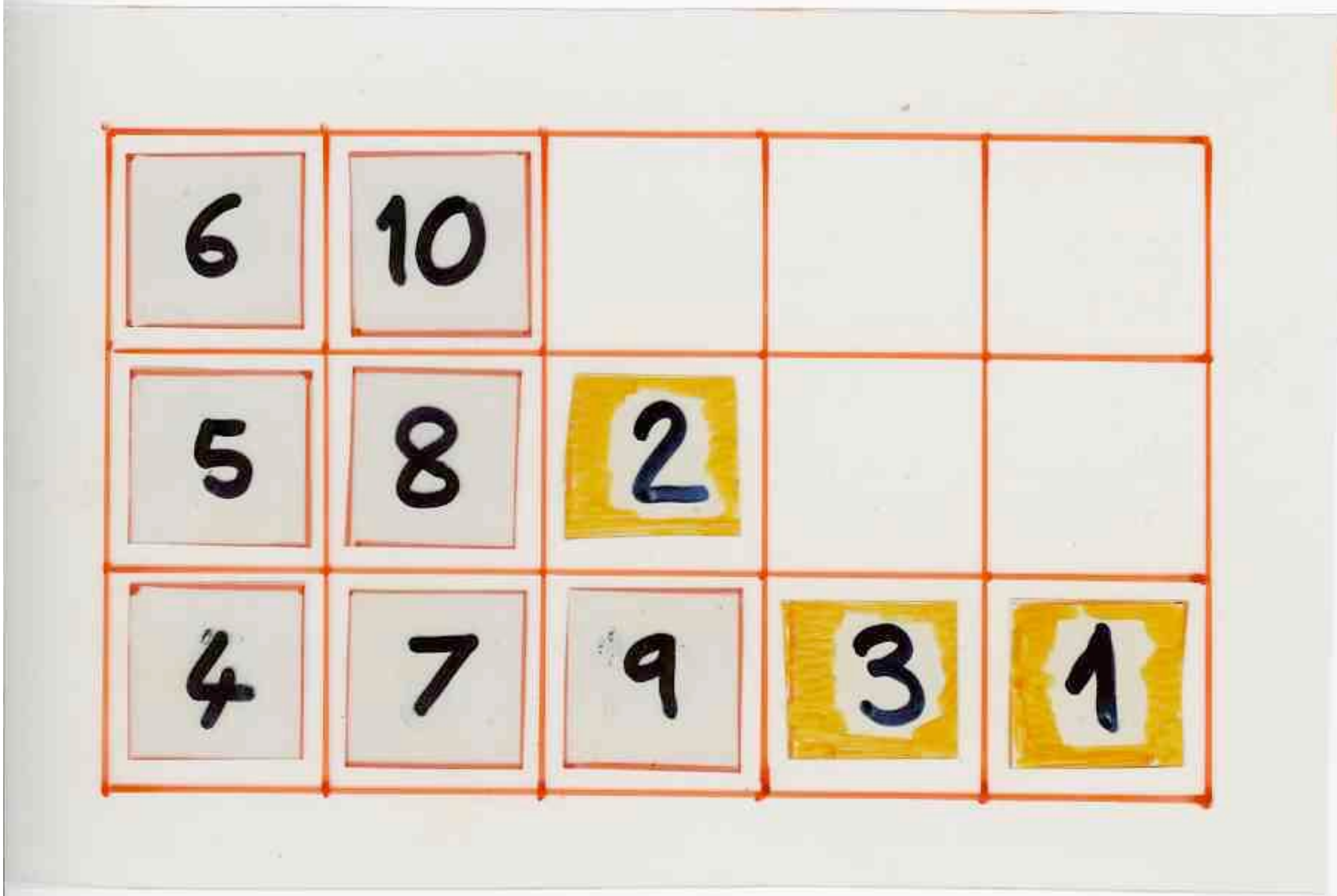
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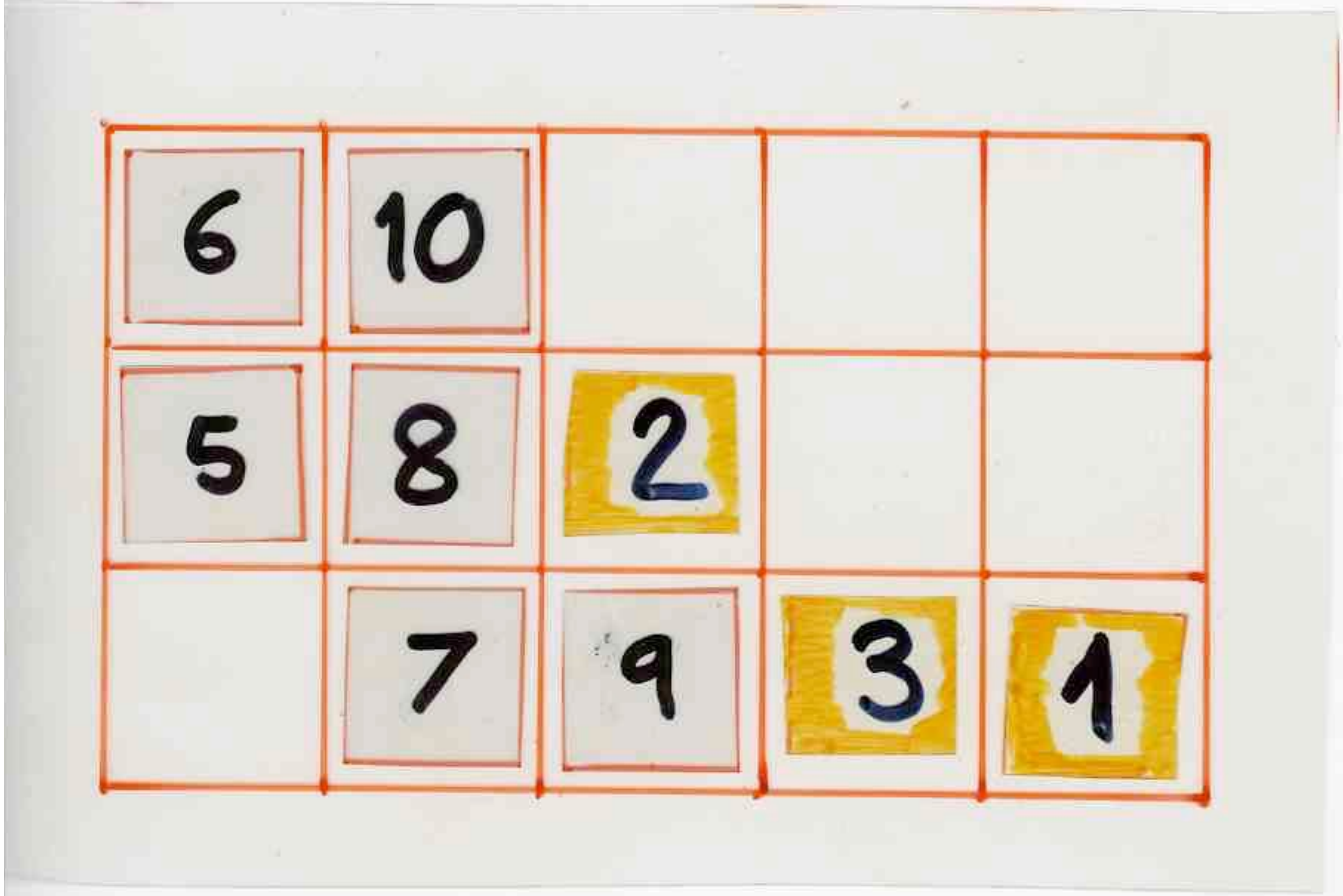
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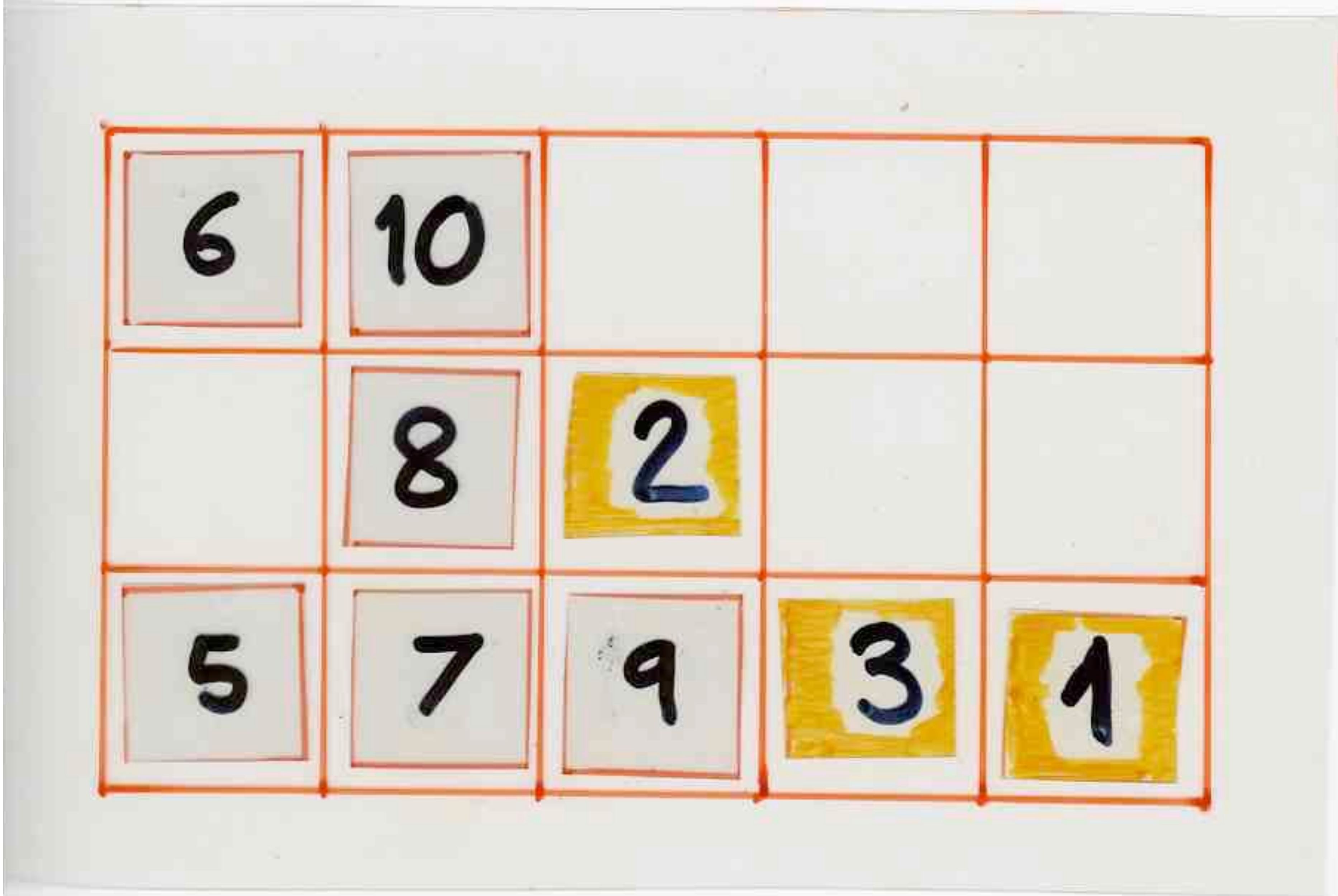
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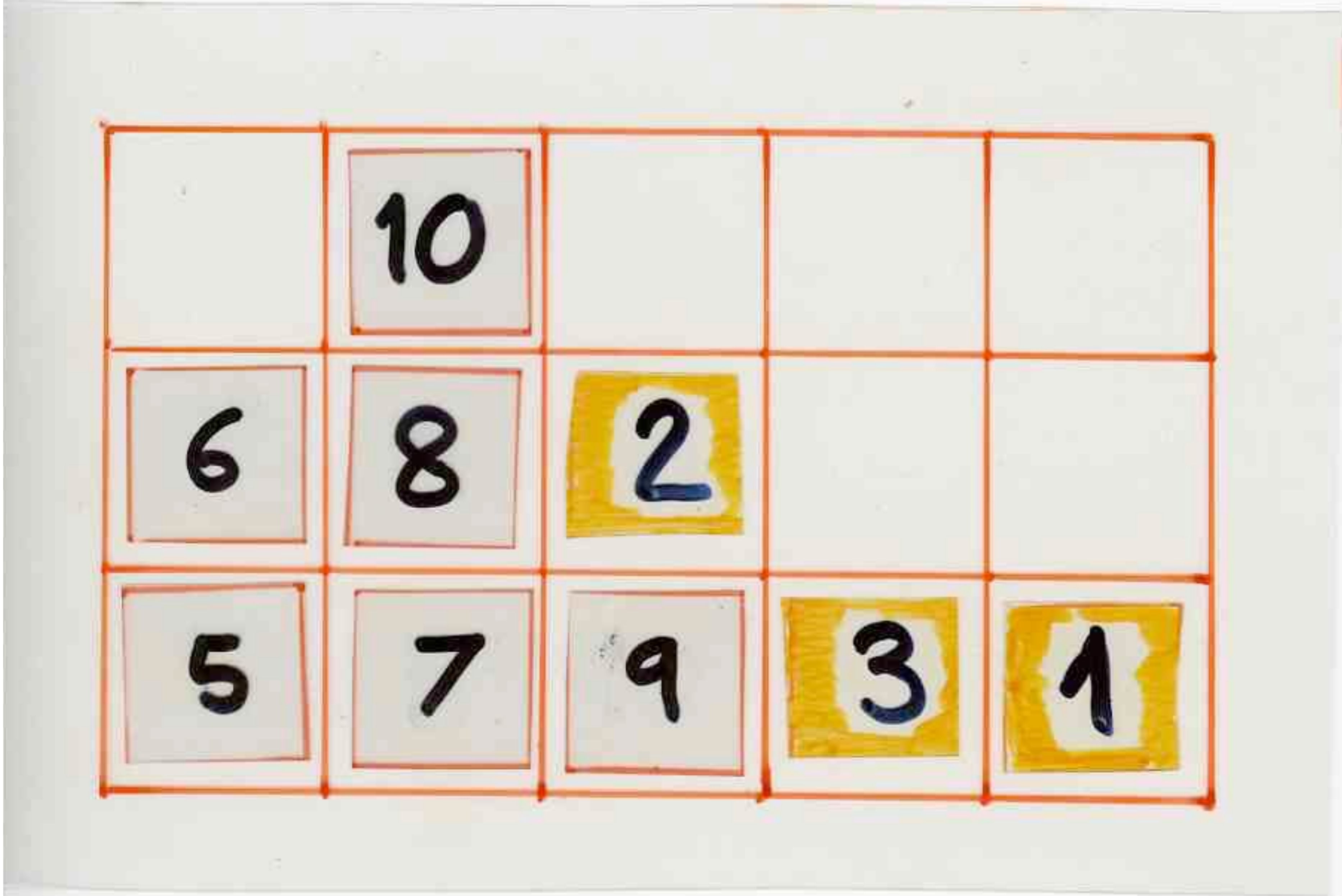
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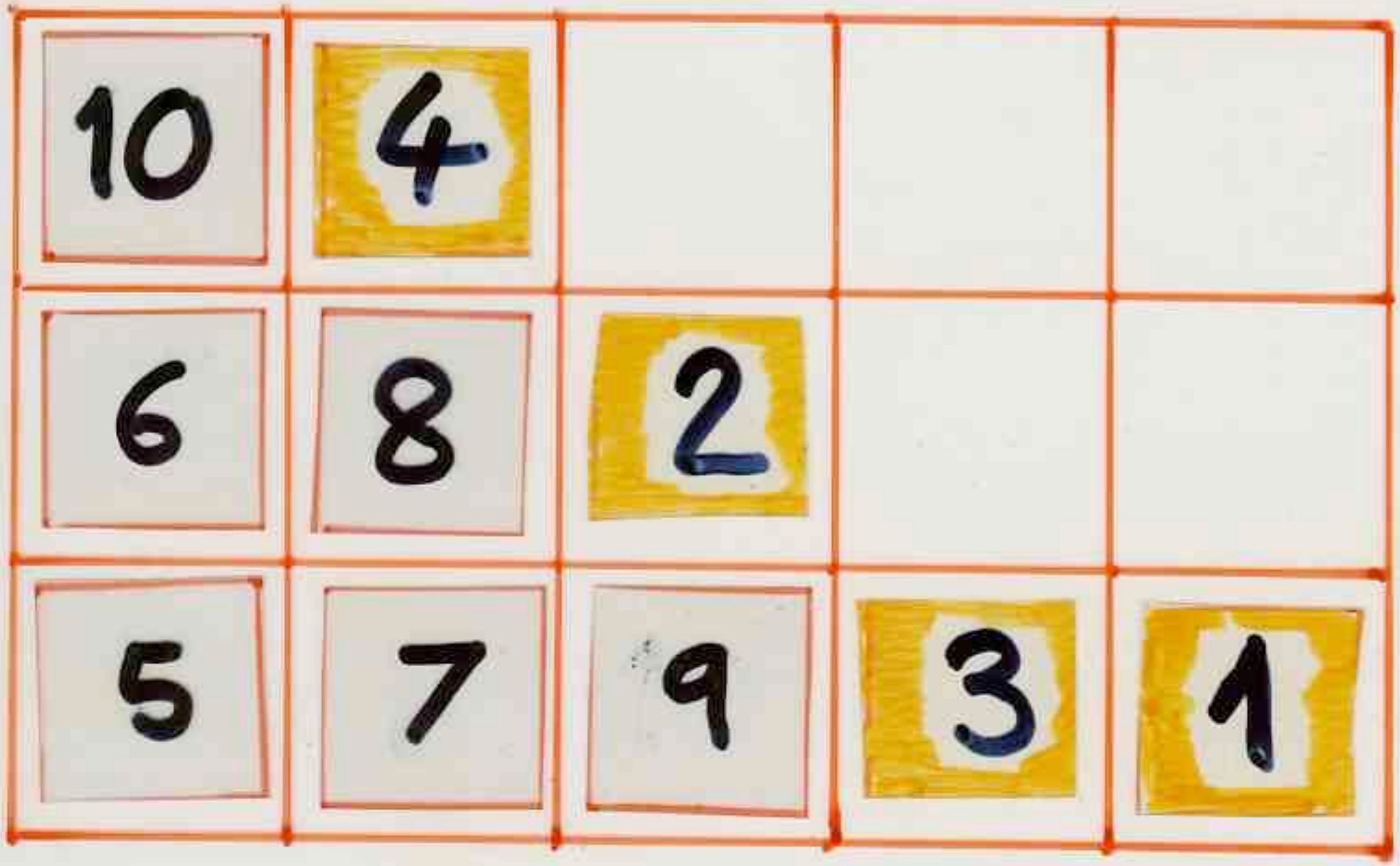
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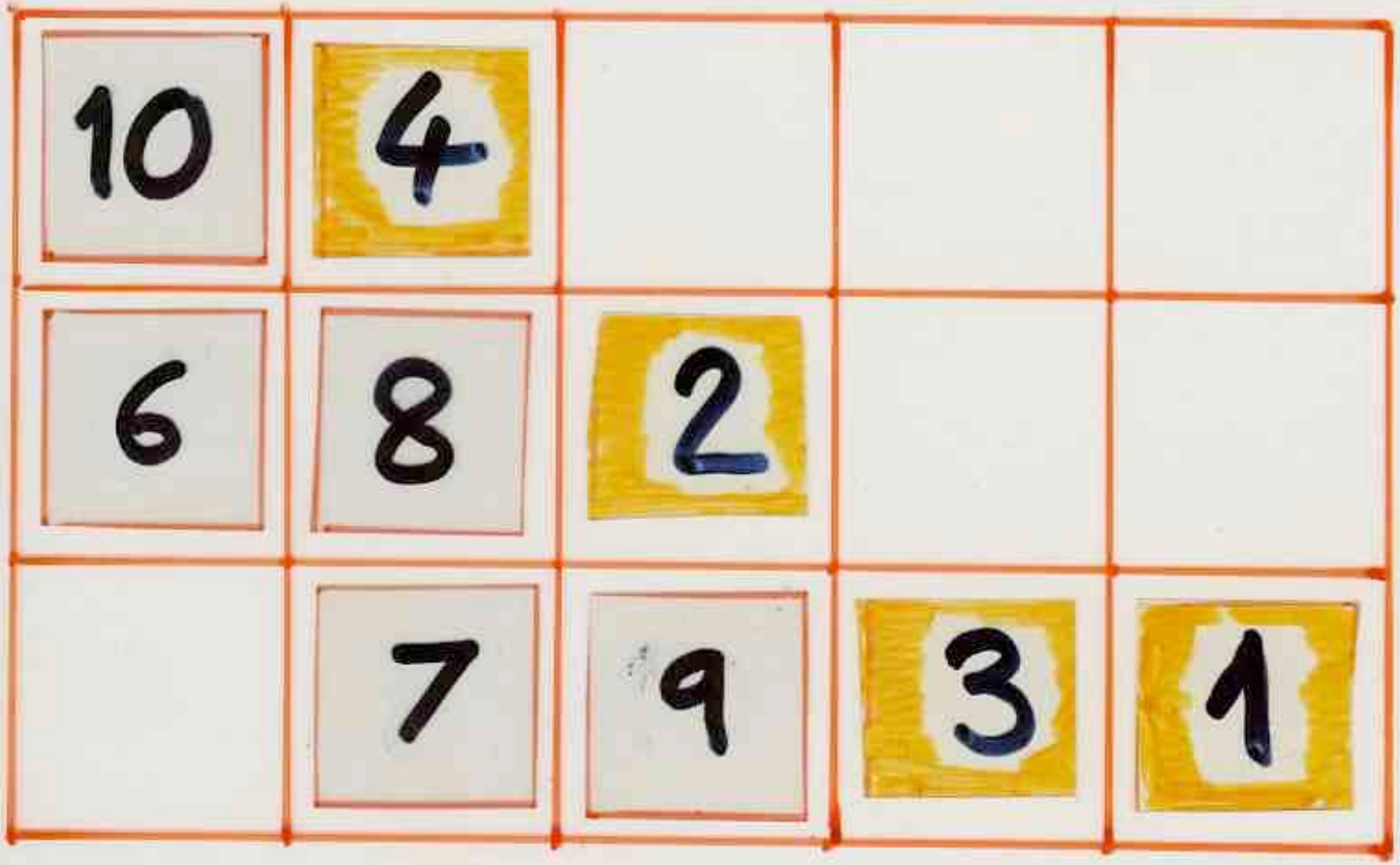
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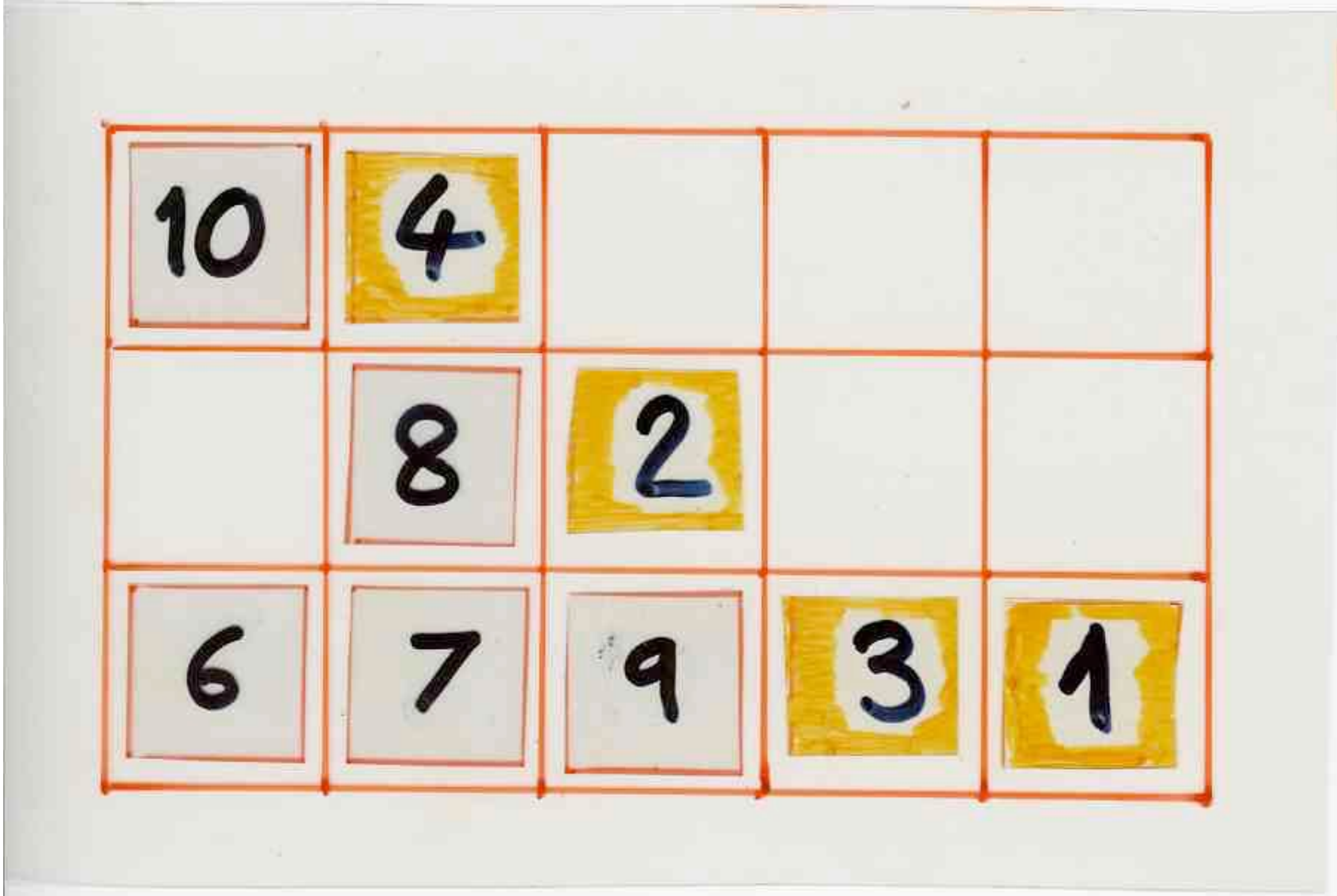
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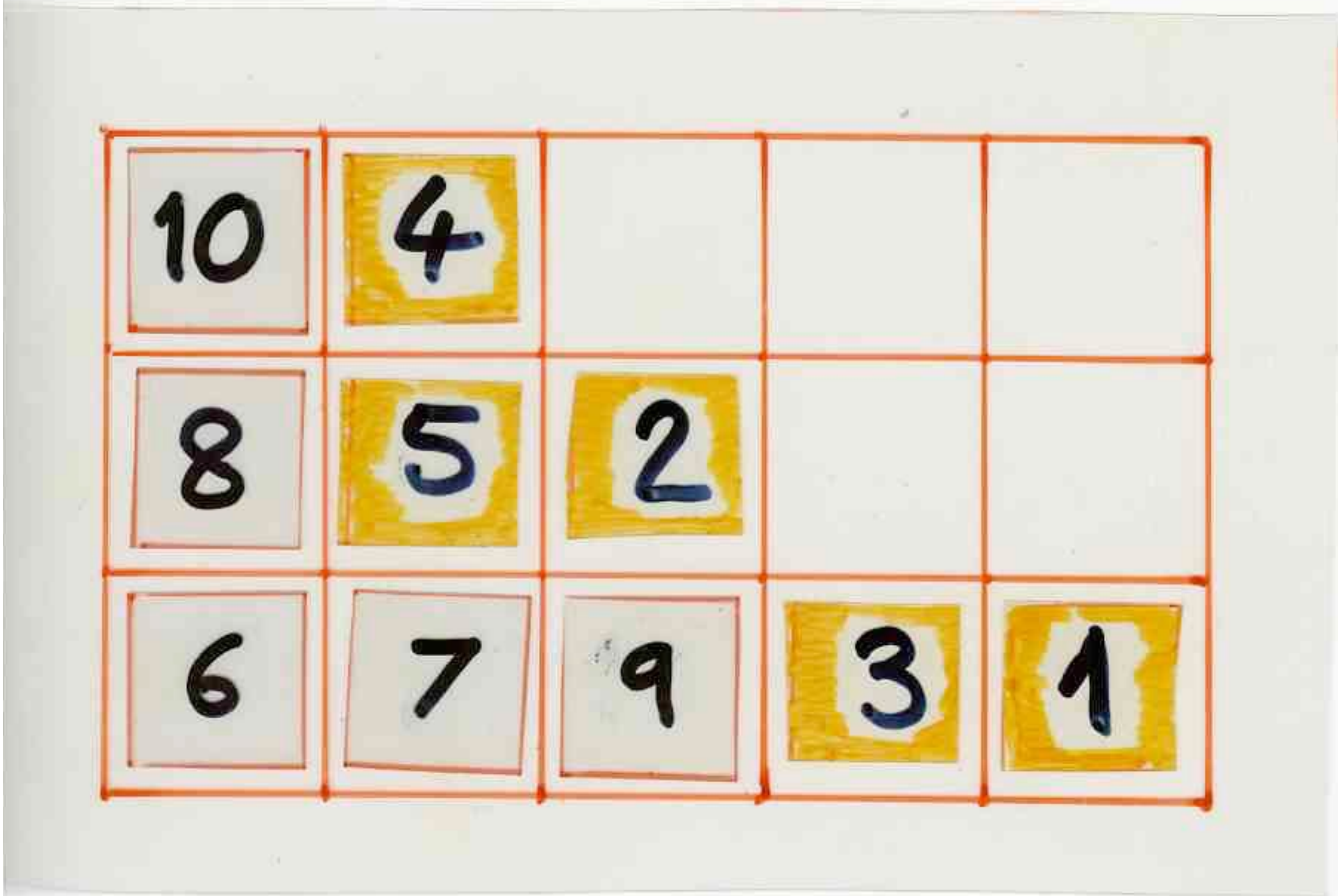
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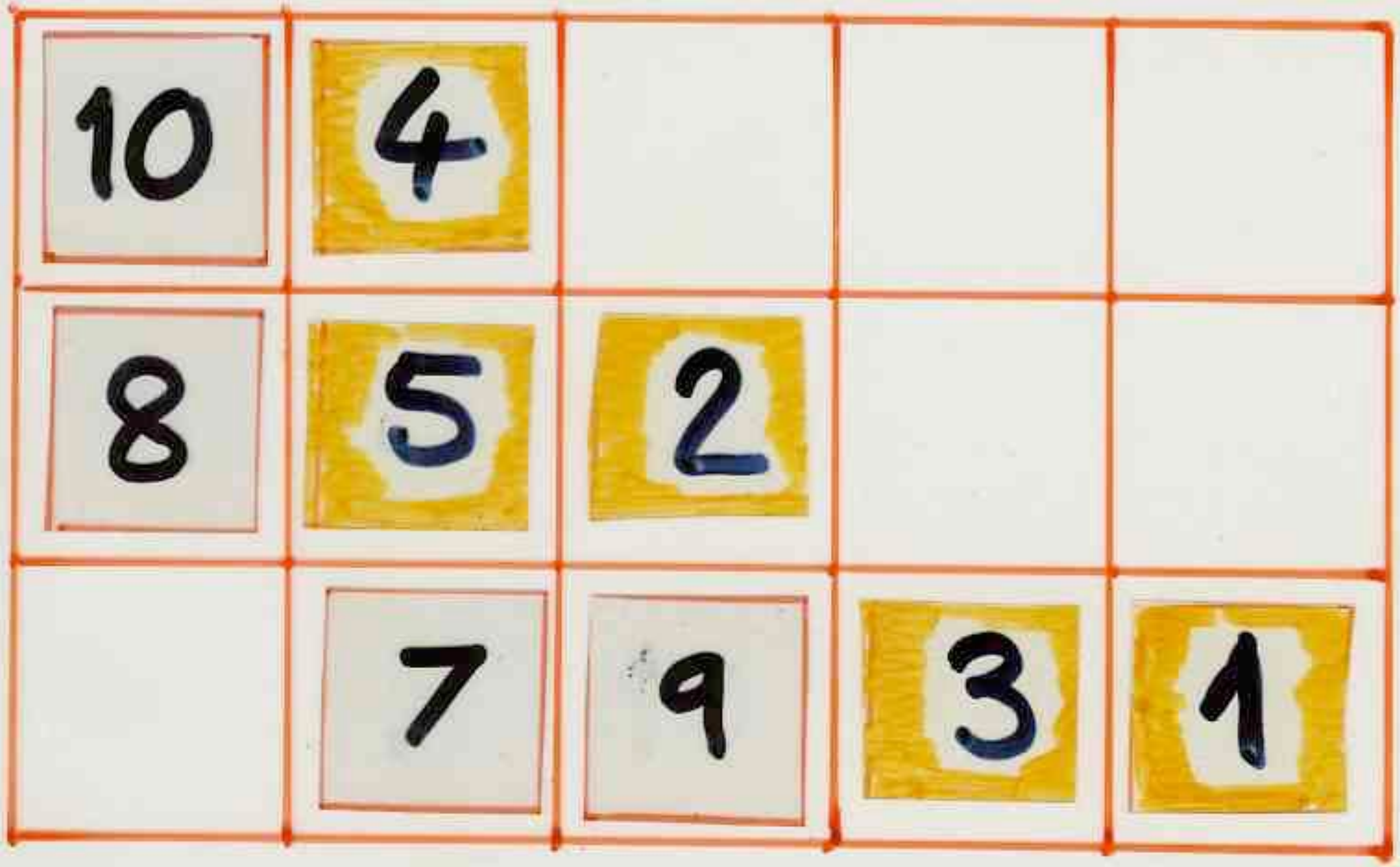
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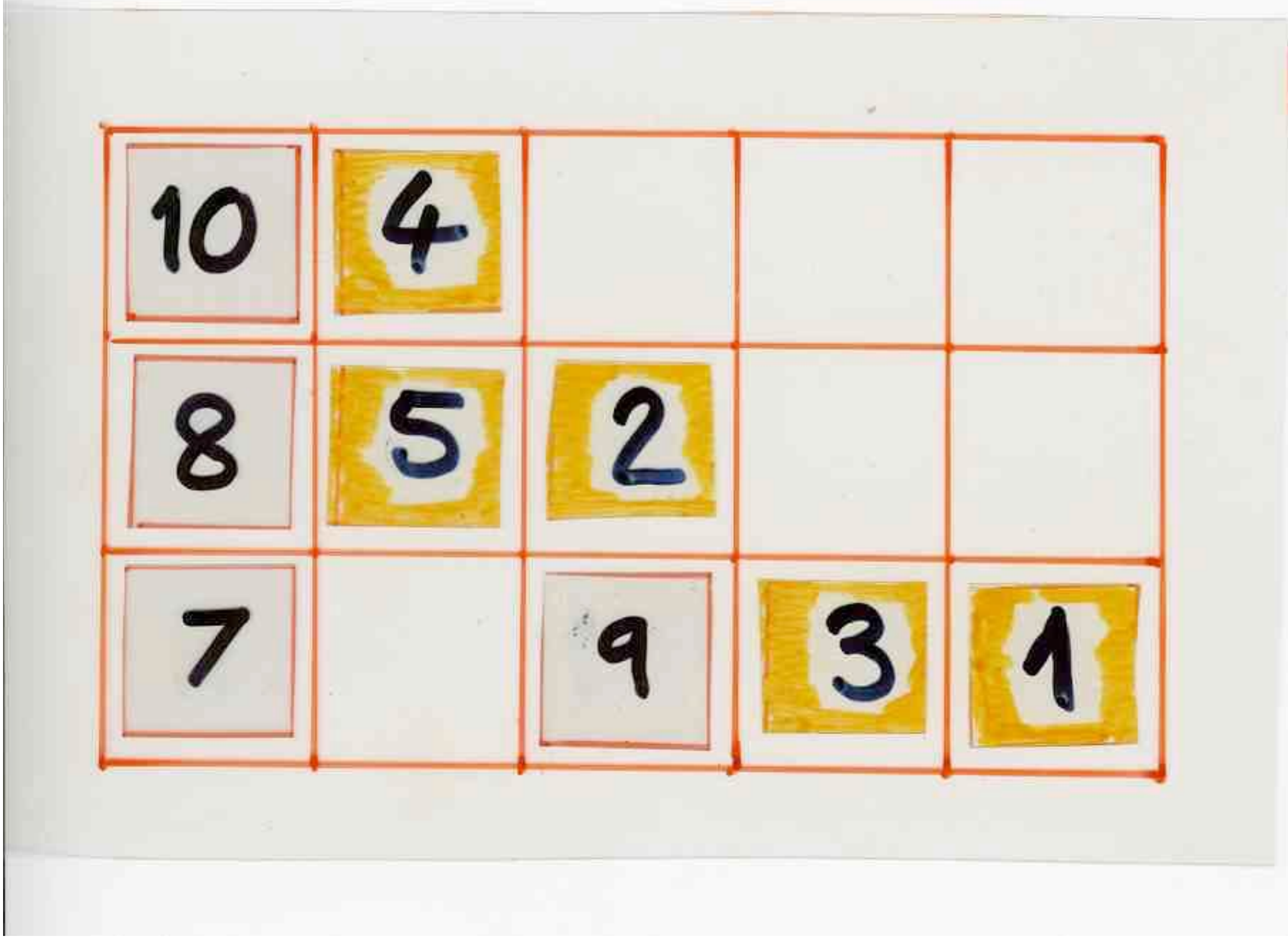
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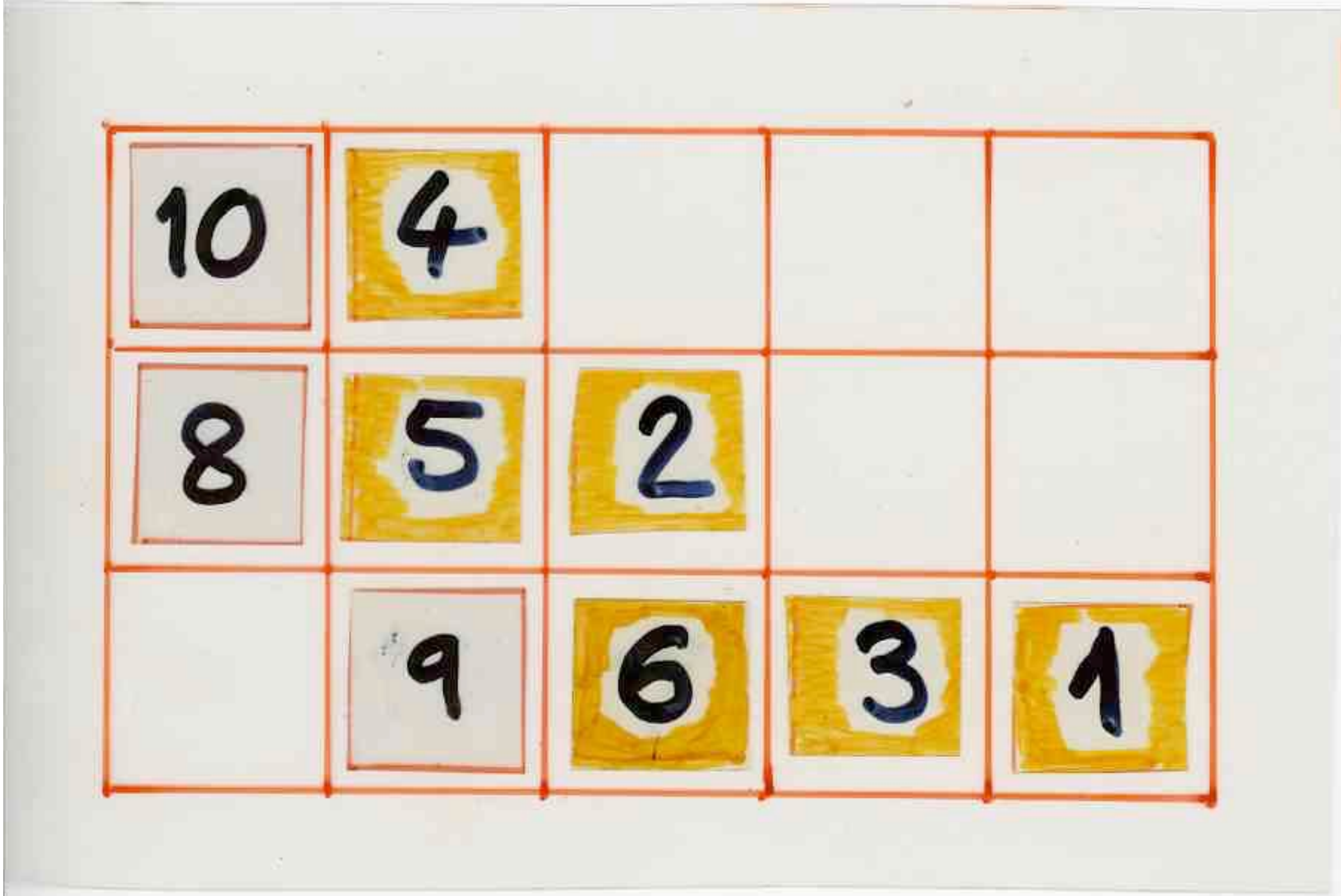
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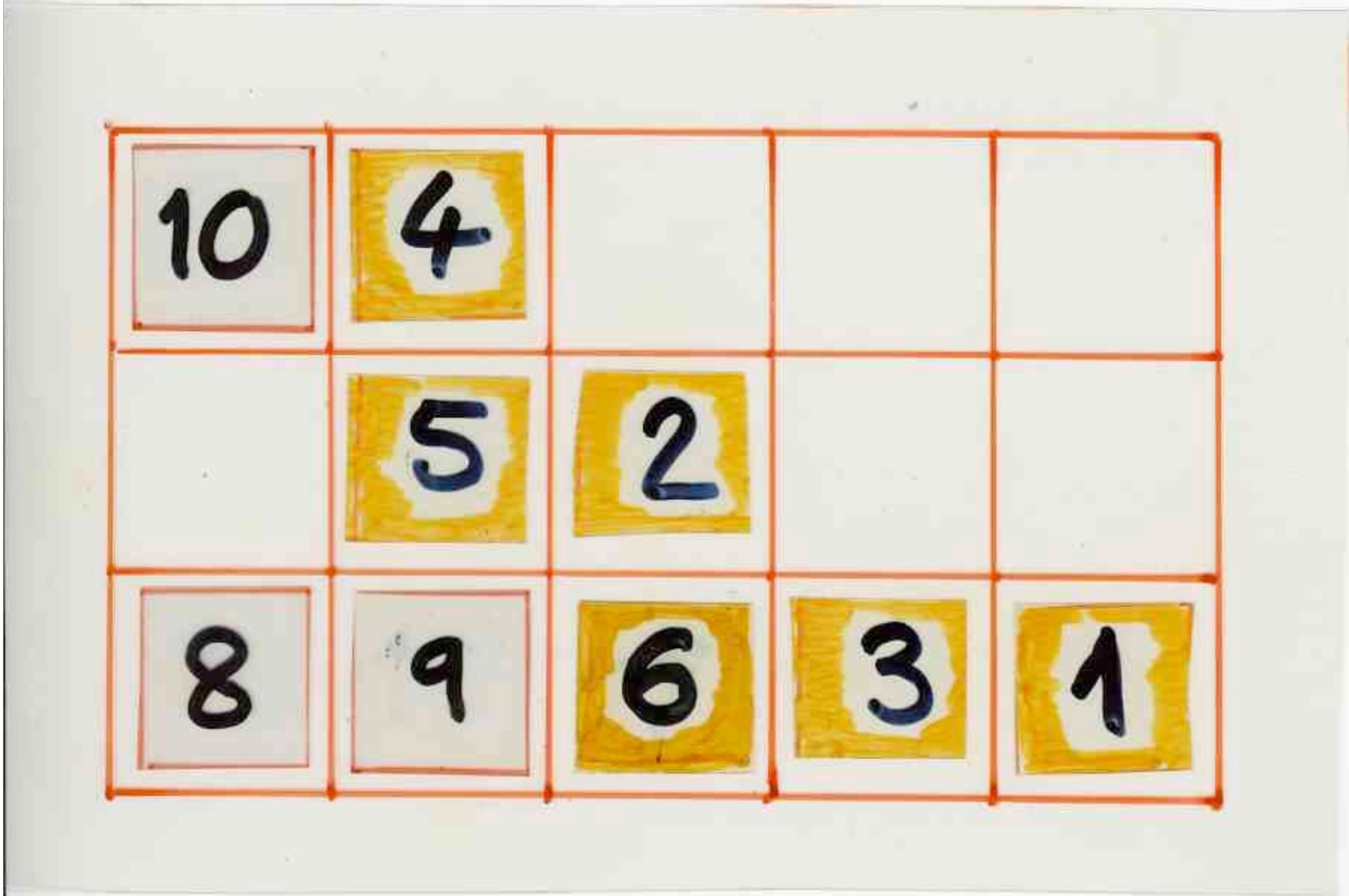
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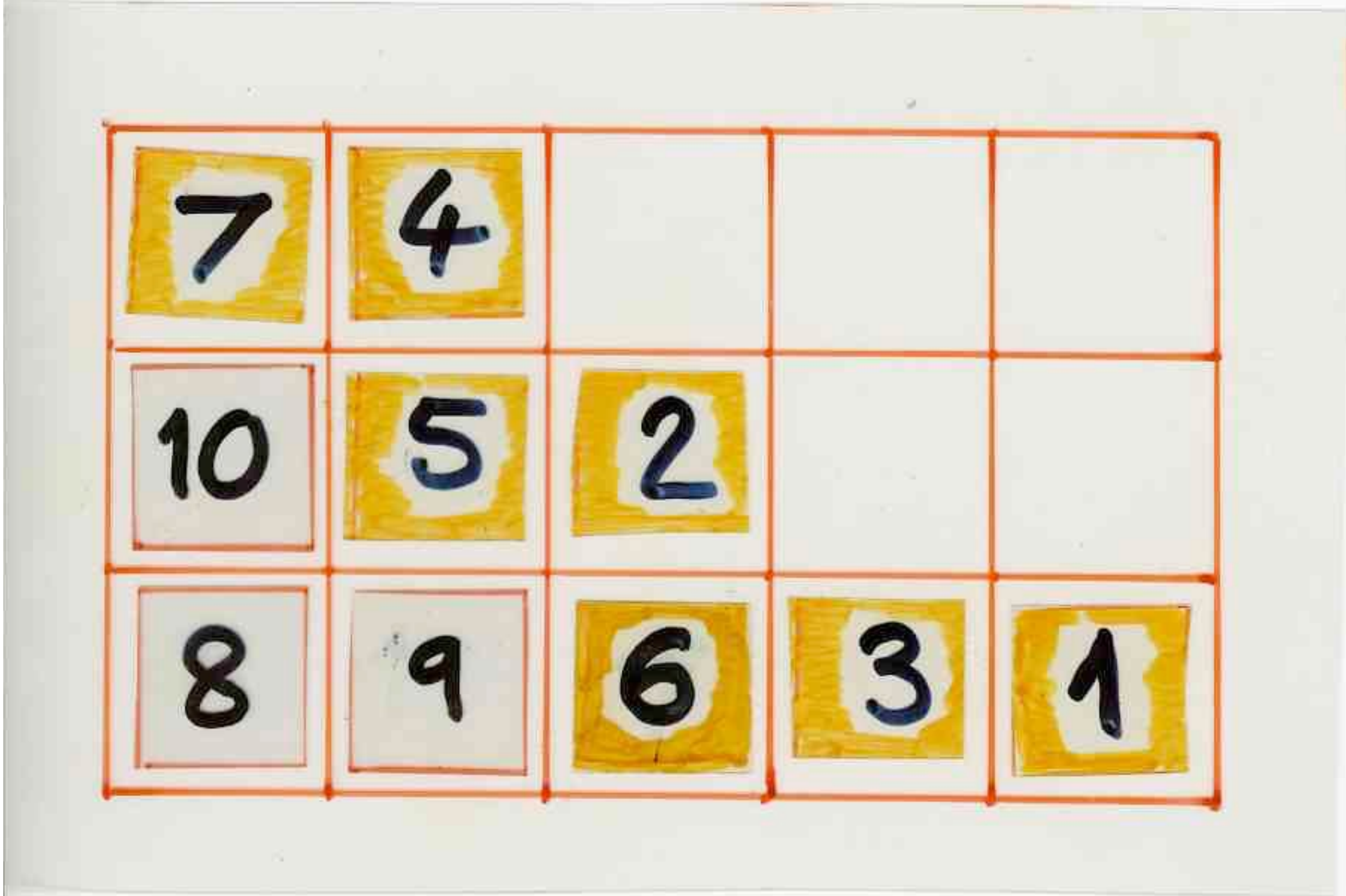
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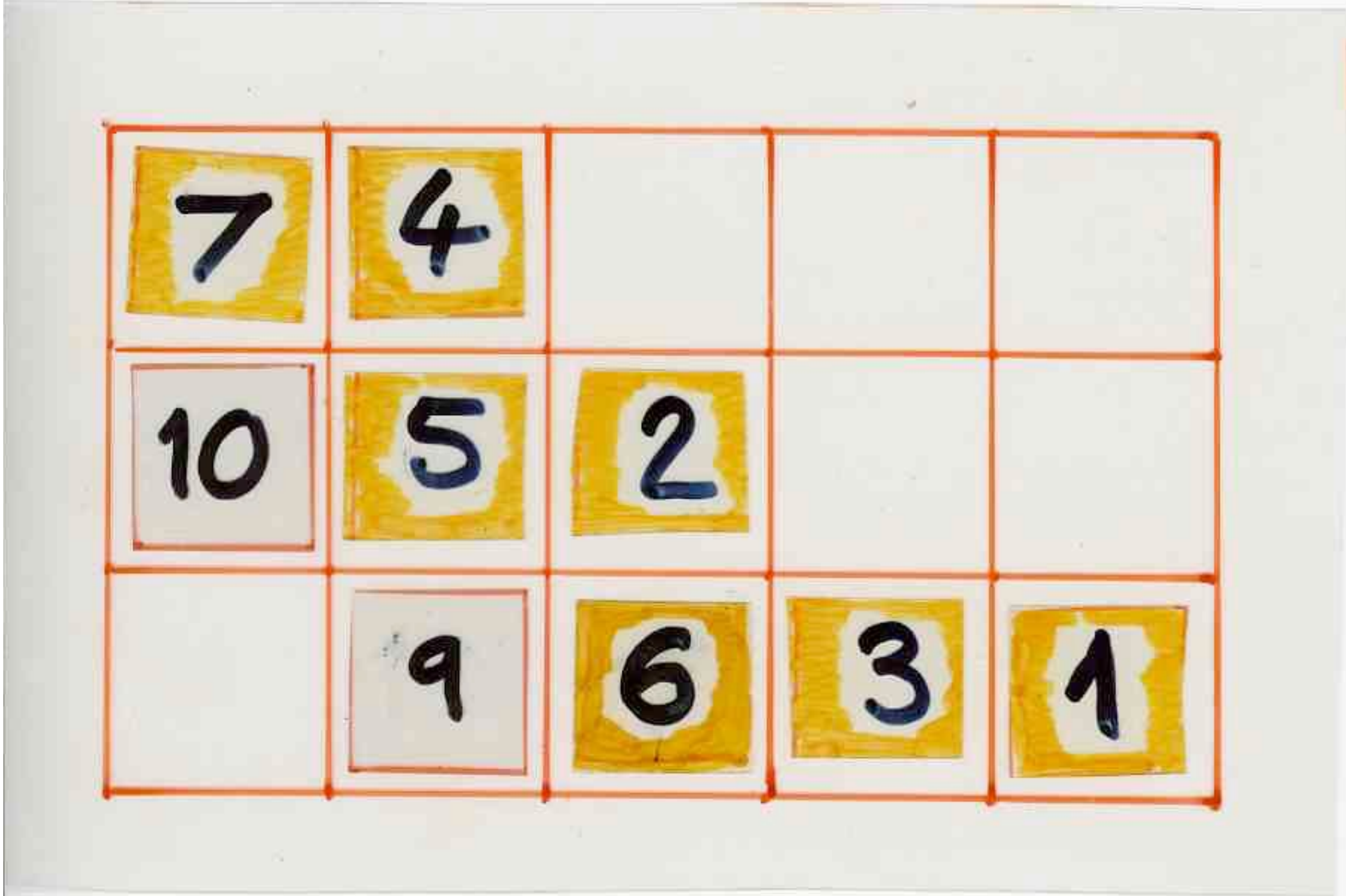
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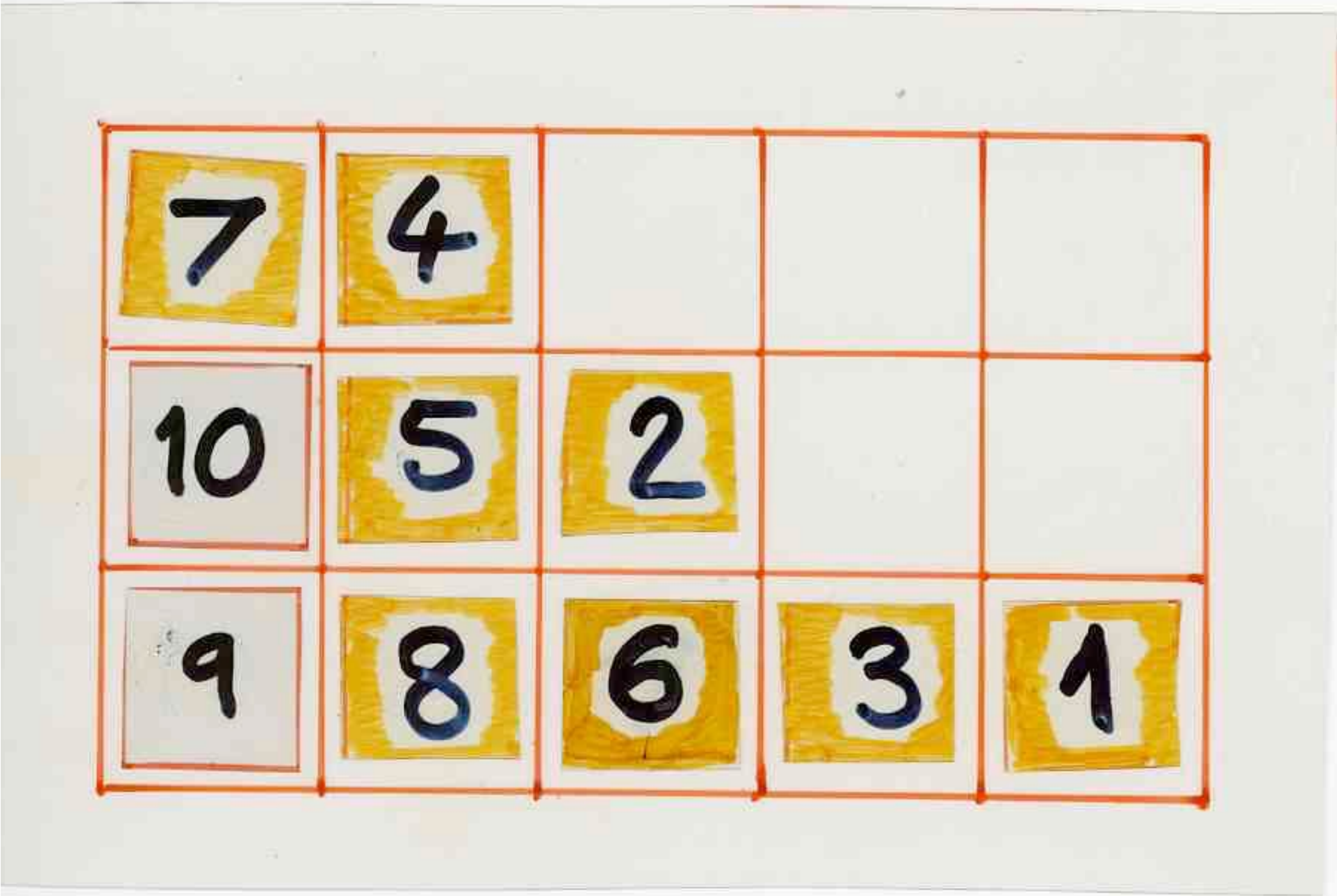
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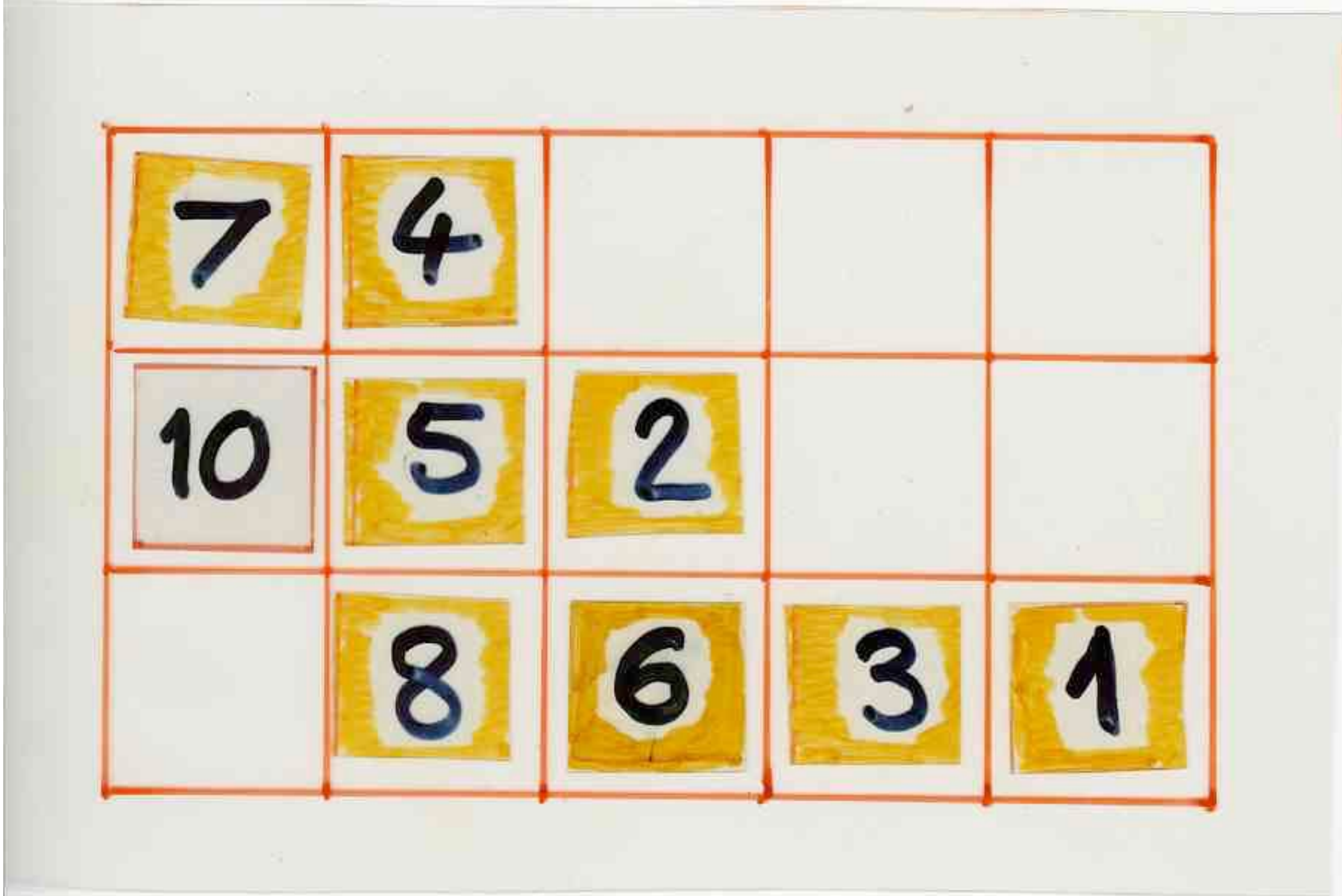
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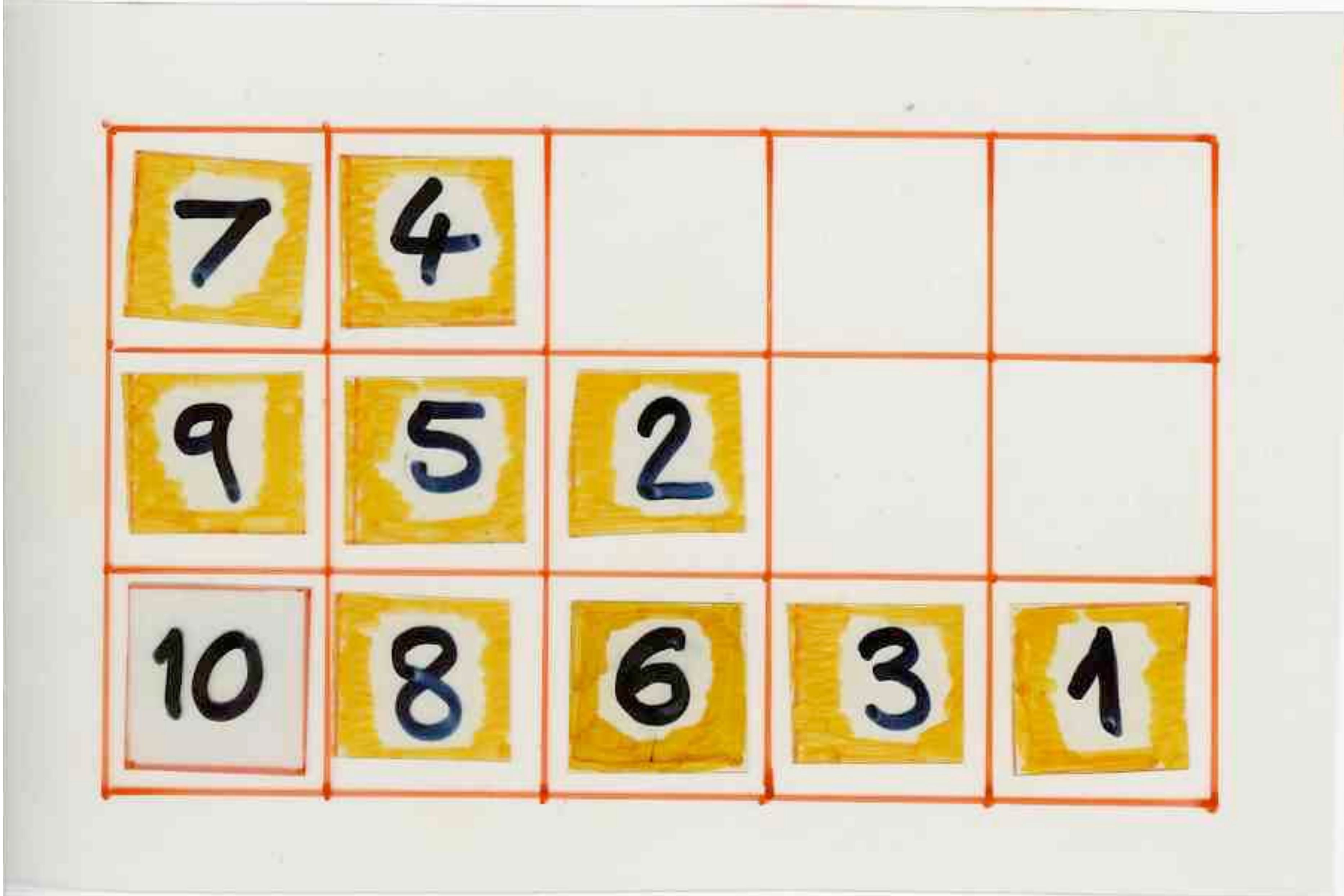
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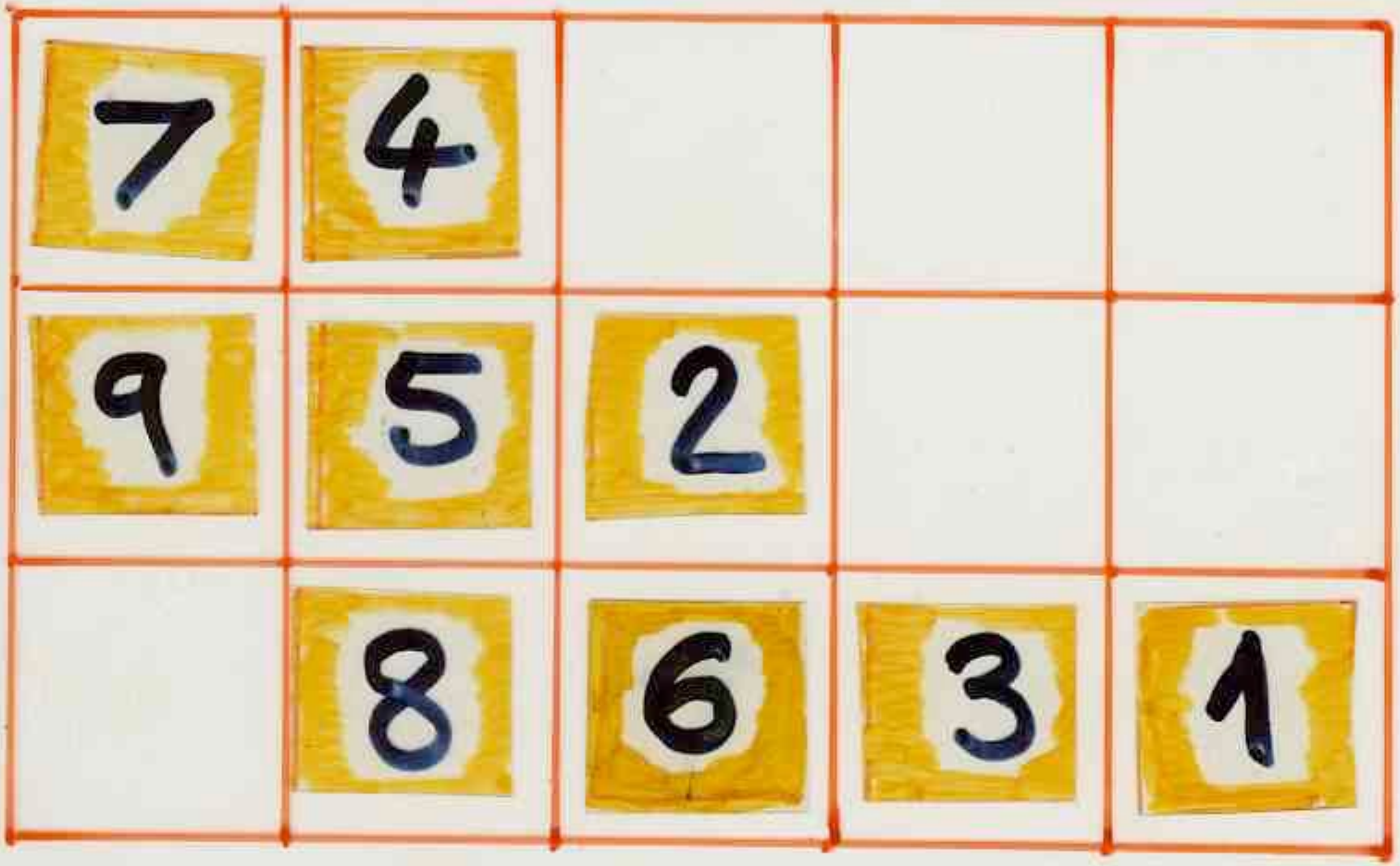
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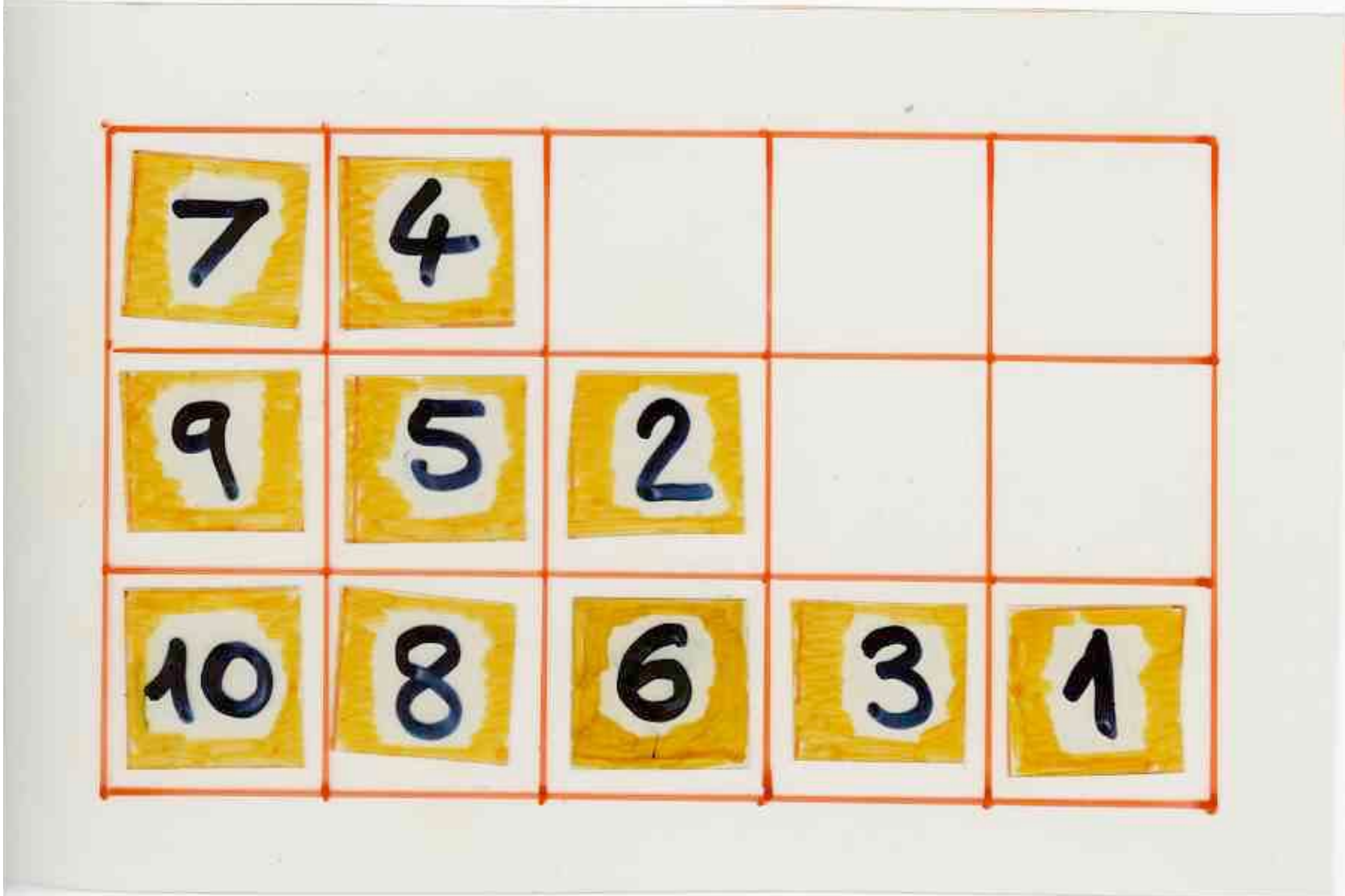
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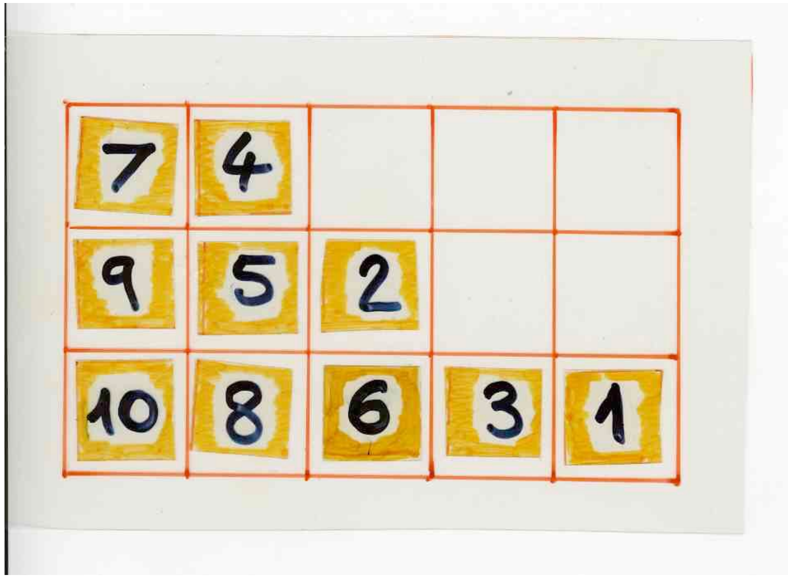


P^* =

dual

4	7			
2	6	9		
1	3	5	8	10

complement

$(i)^c = n+1-i$

P =

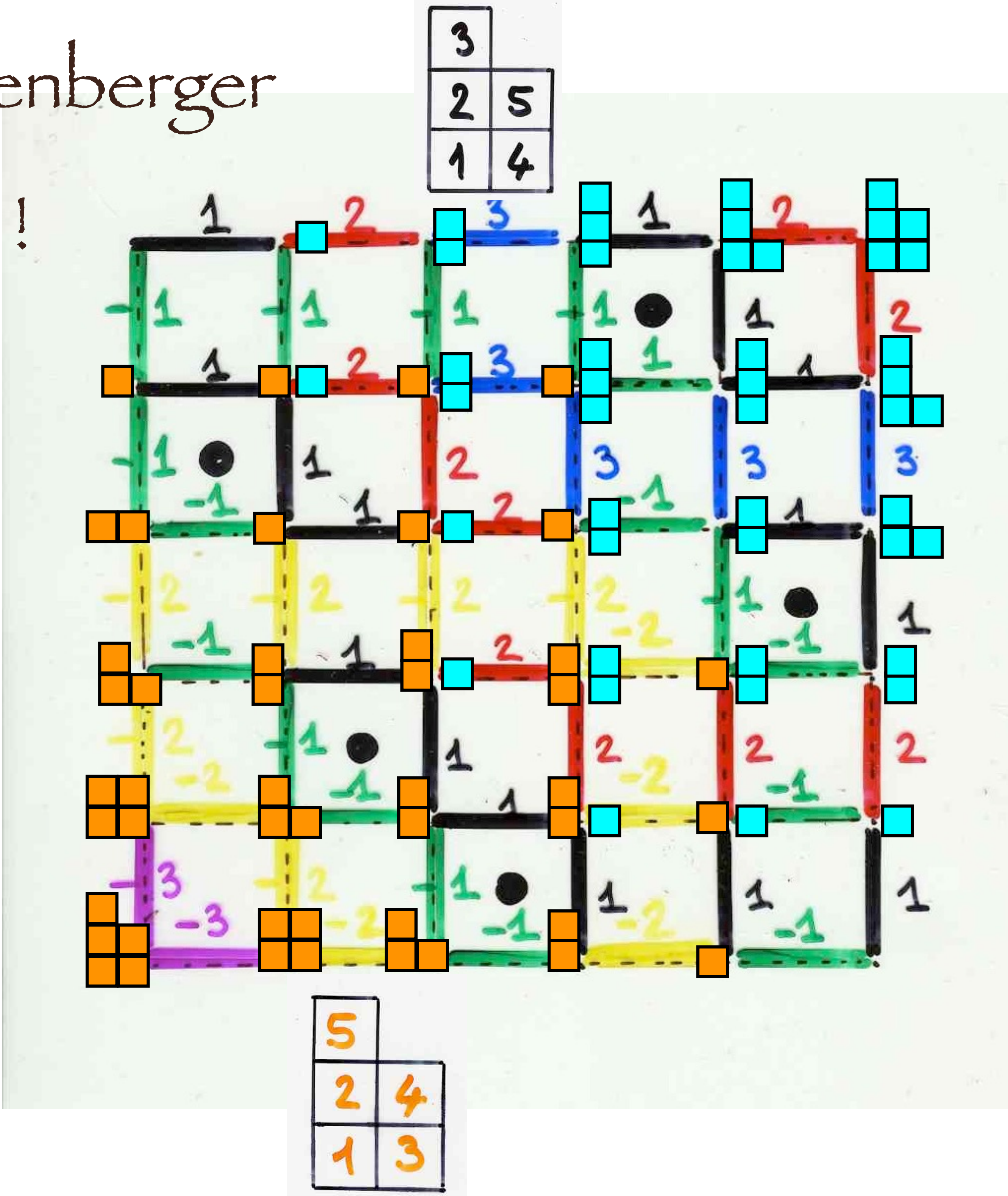
6	10			
3	5	8		
1	2	4	7	9

Schützenberger

Duality !

P^* = dual

5	
3	4
1	2



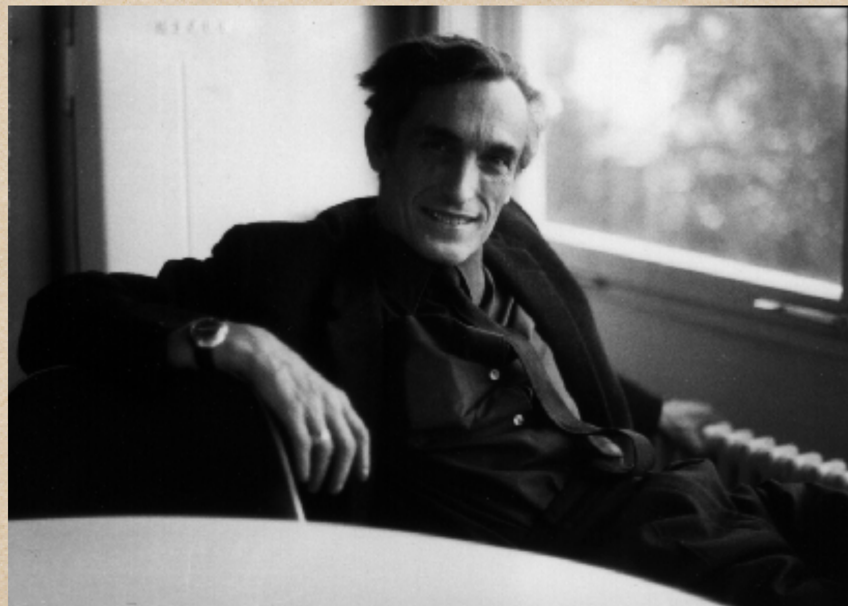
P =

4	
2	5
1	3

Jeu de taquin

M.P. Schützenberger

(1976)



$$\sigma = (3, 1, 6, 10, 2, 5, 8, 4, 9, 7)$$

$\sigma = (3, 1, 6, 10, 2, 5, 8, 4, 9, 7)$

3					
1	6	10			
		2	5	8	
				4	9
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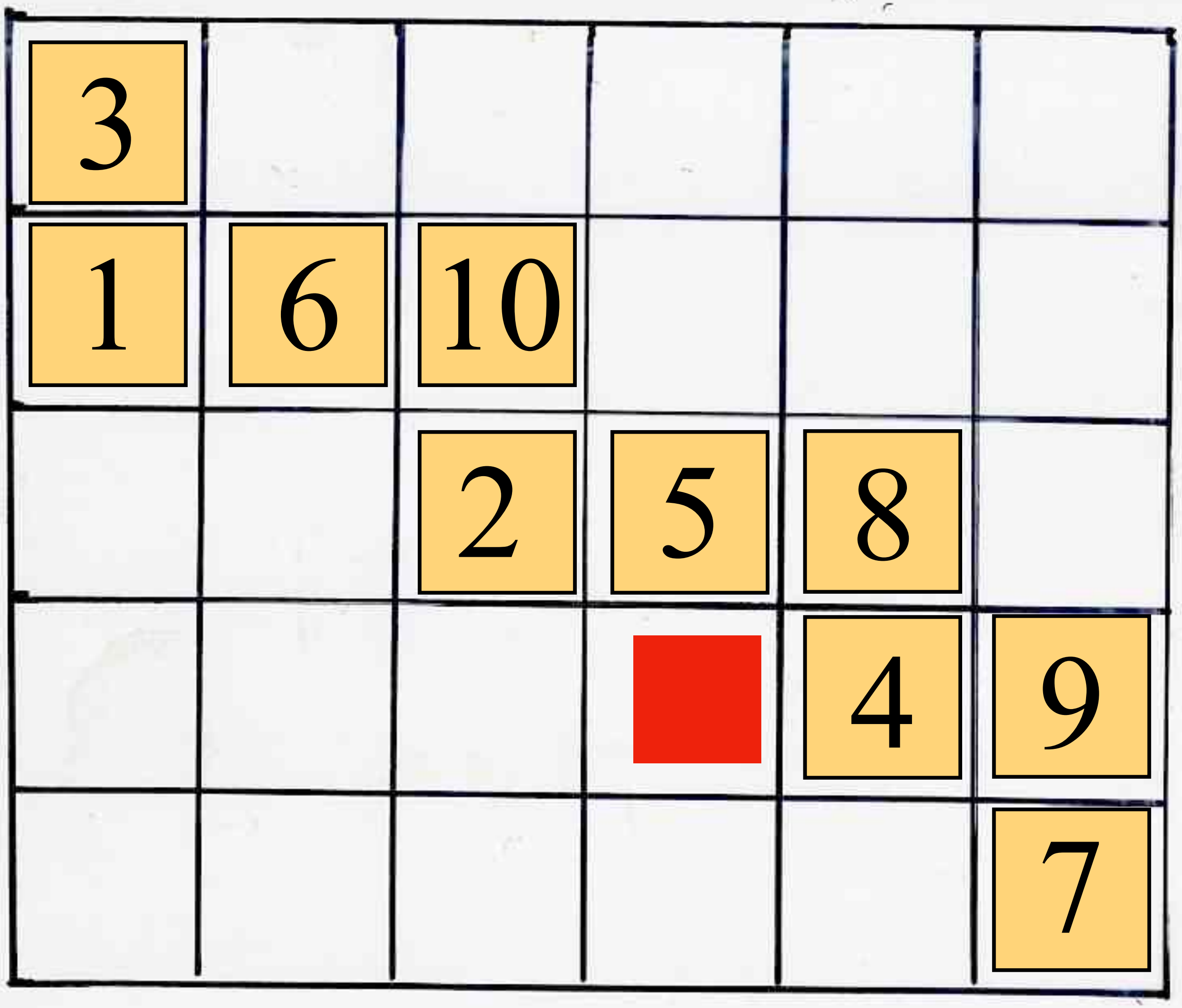
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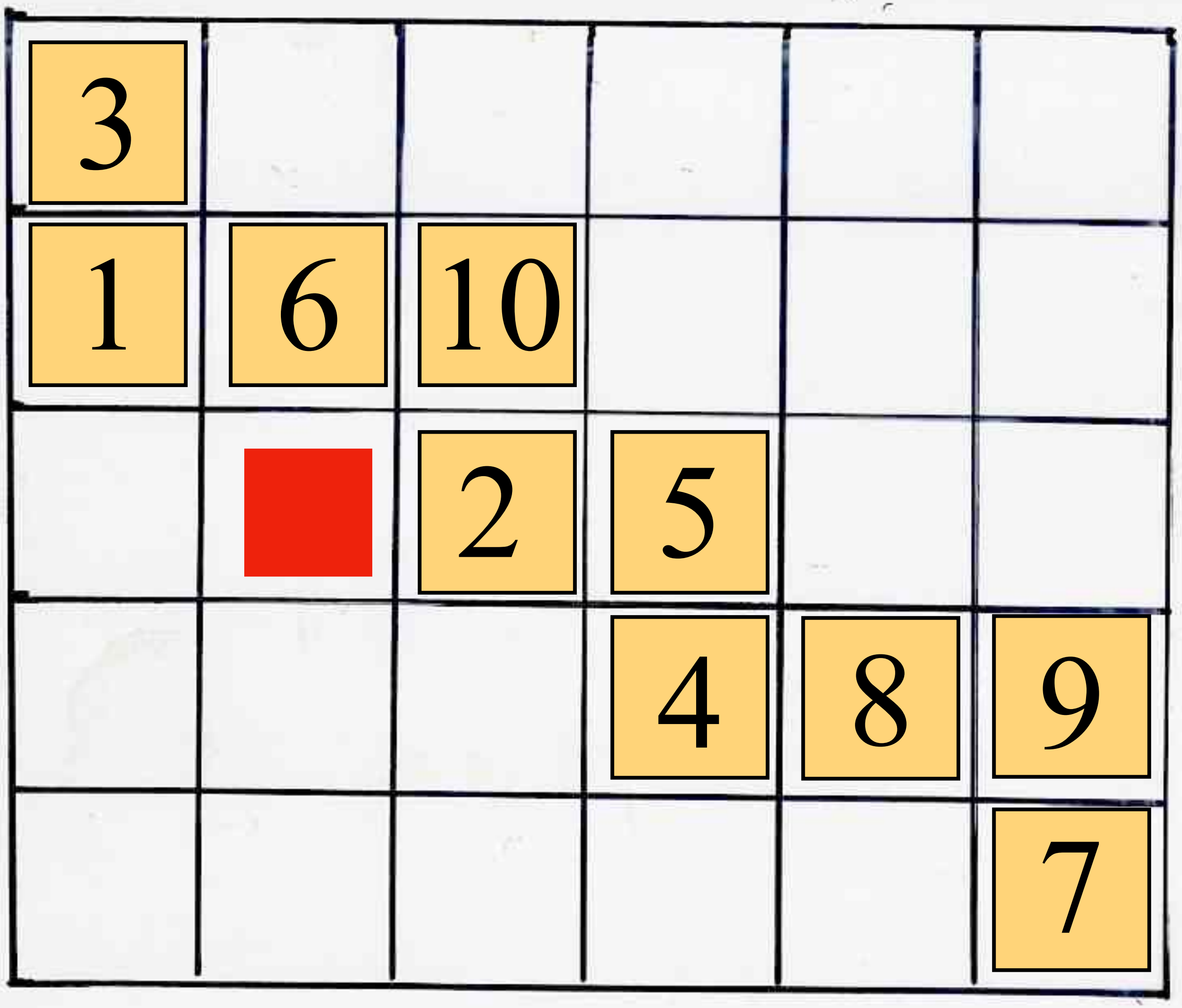
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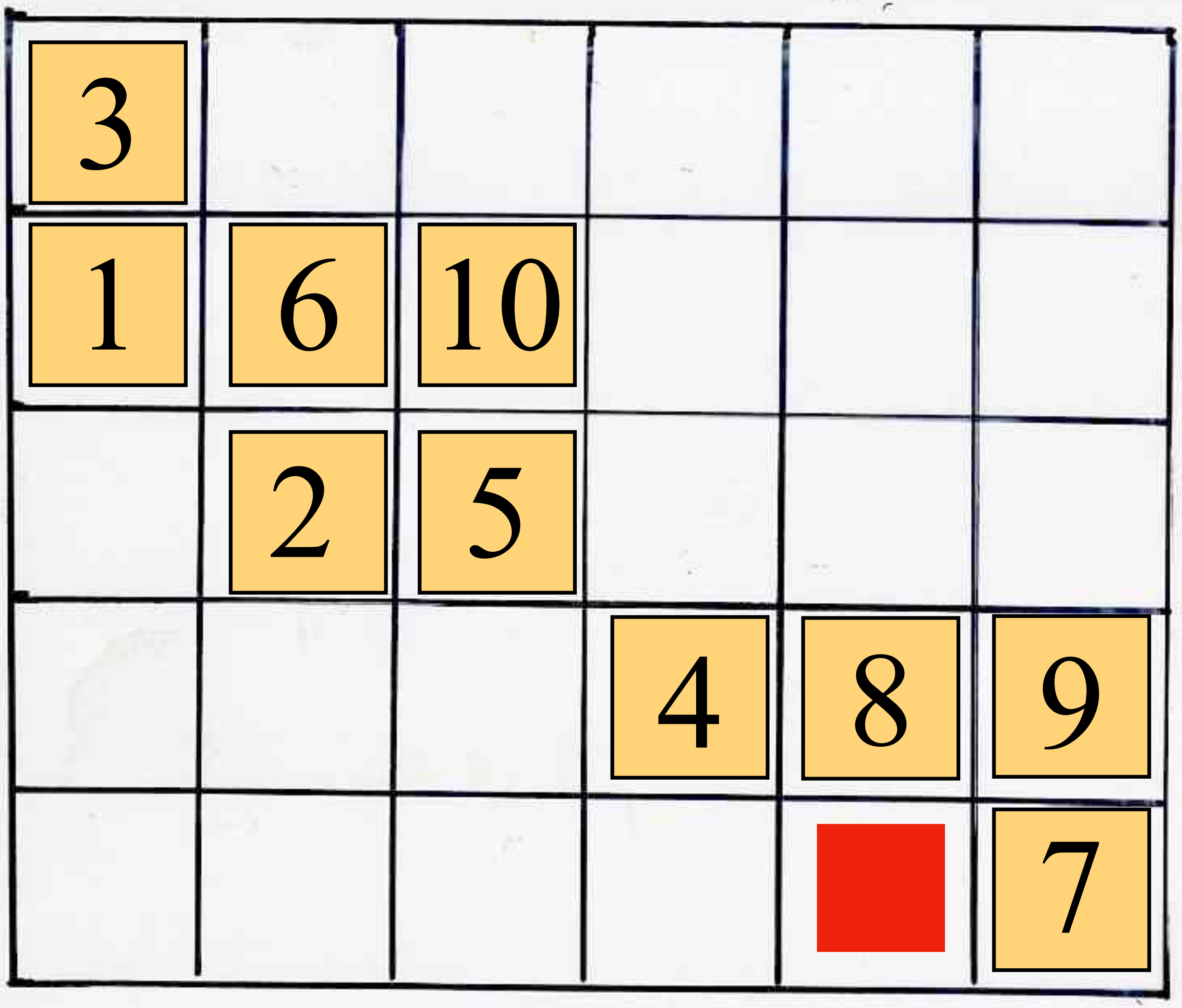
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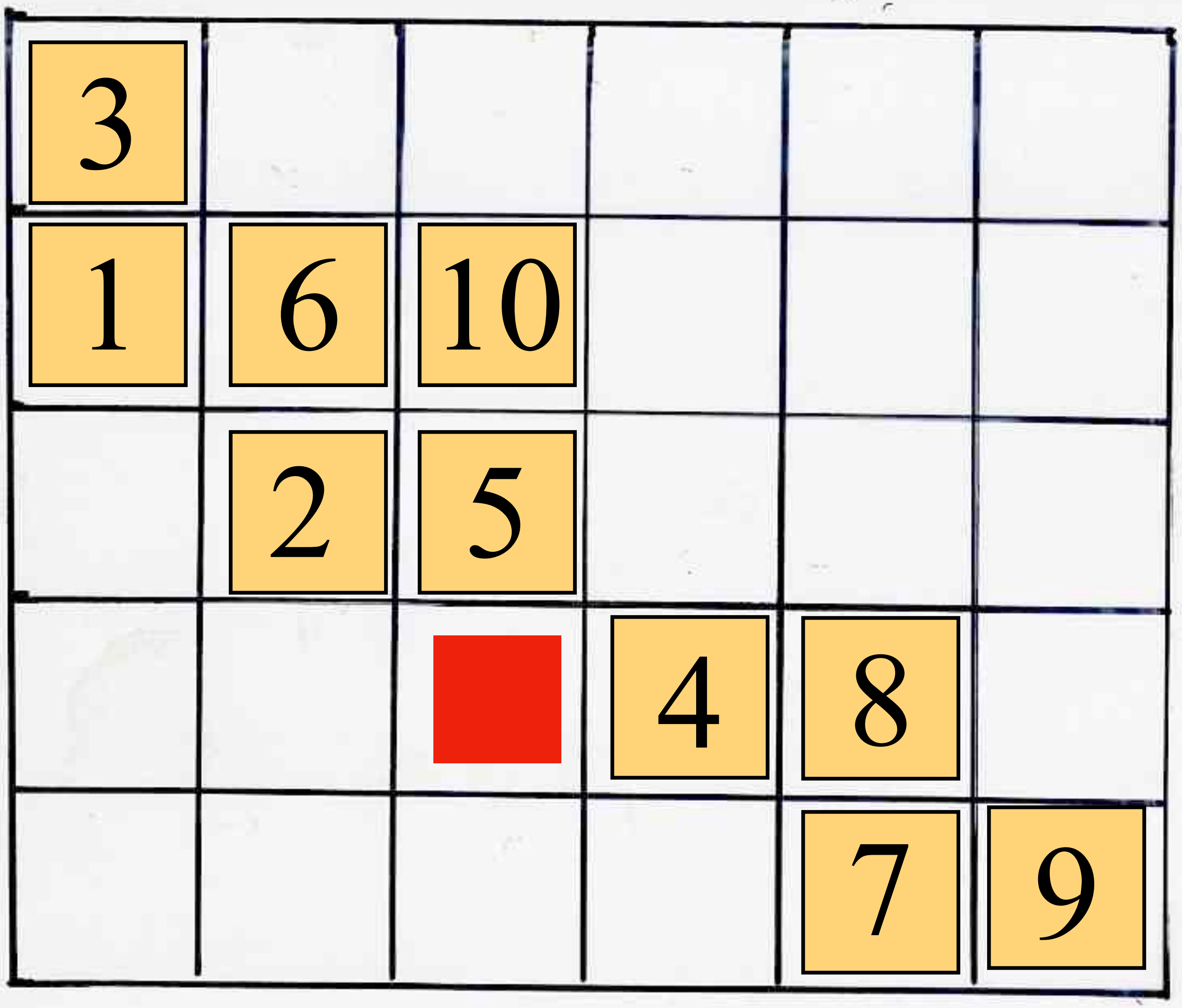
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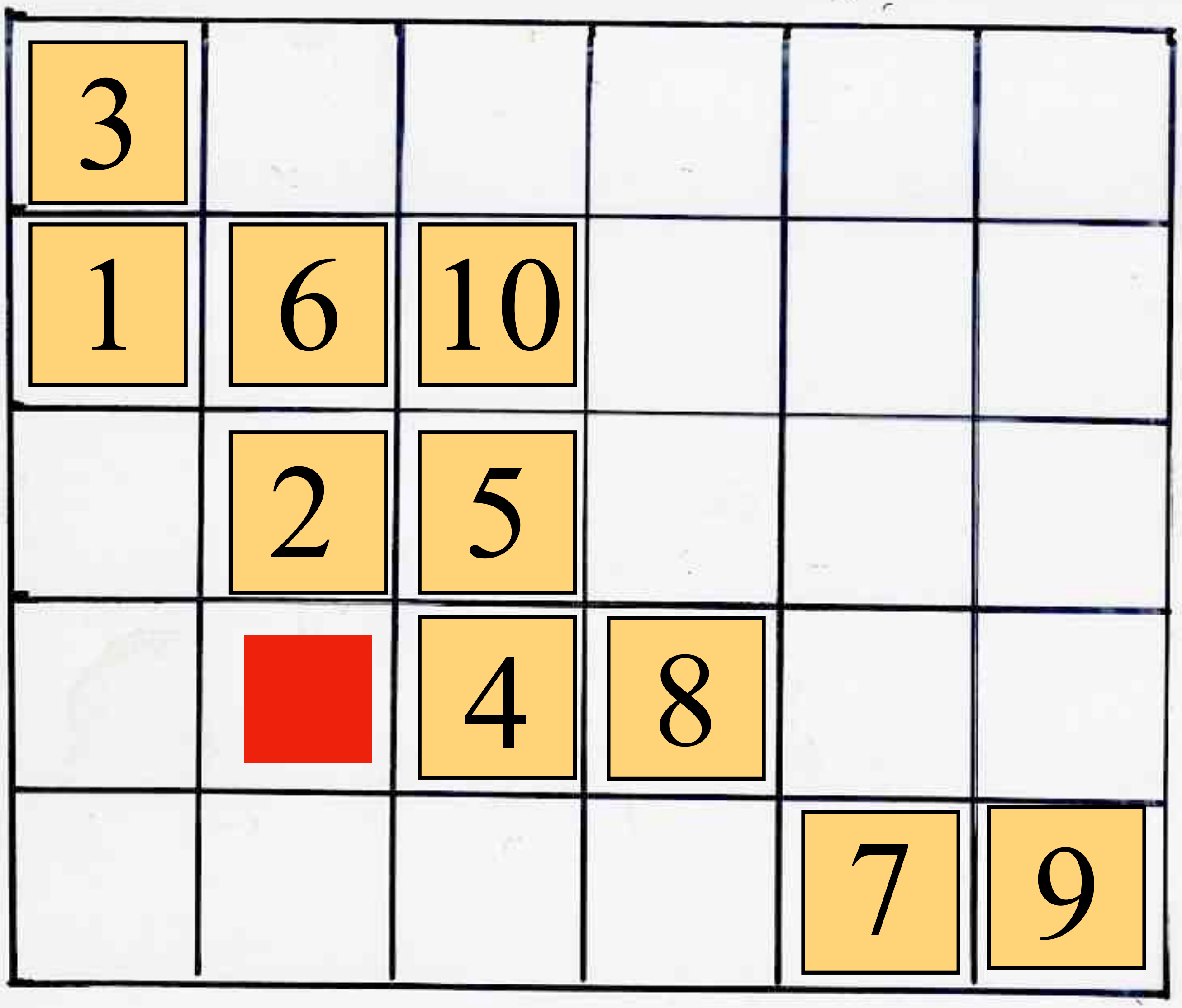
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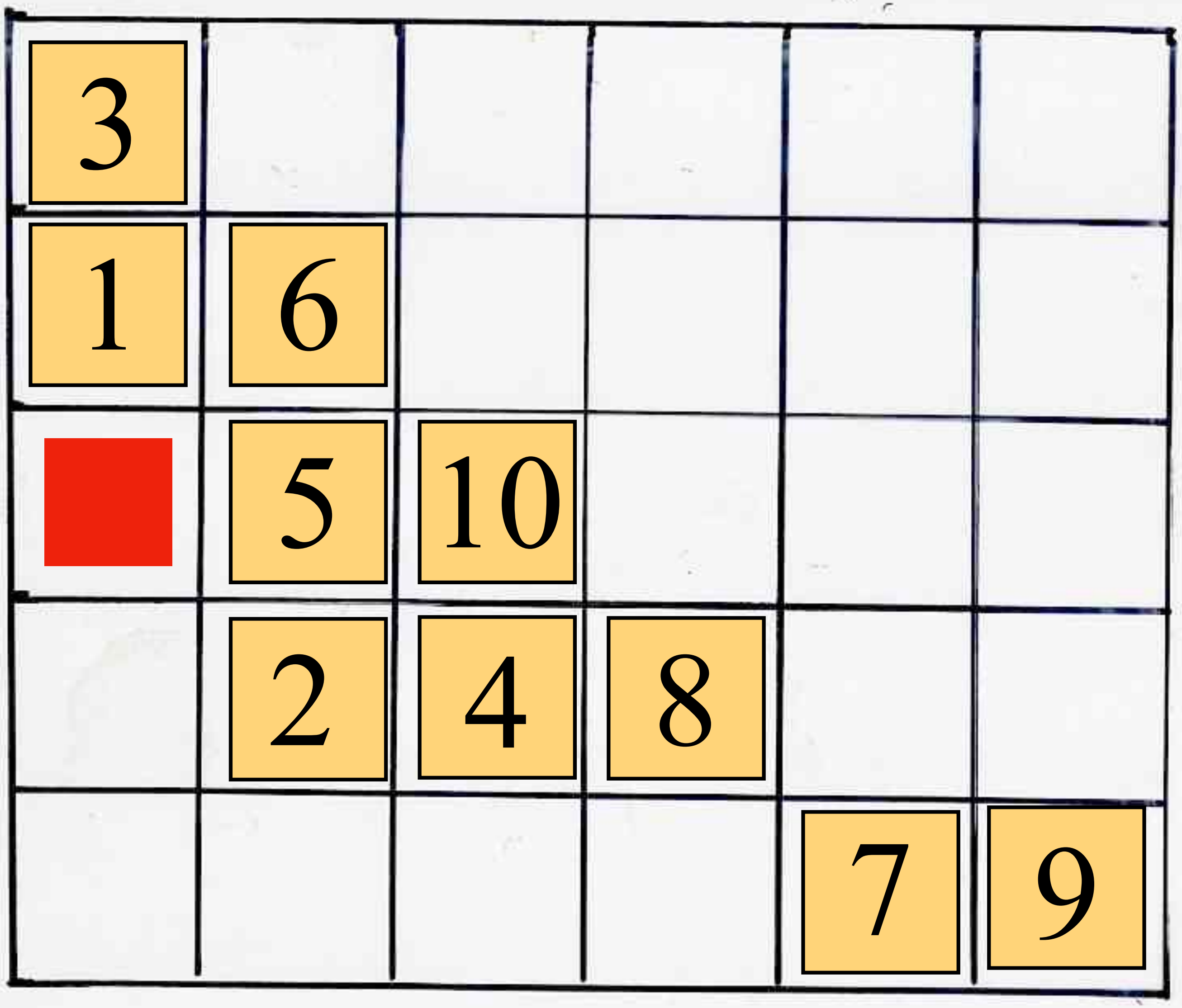
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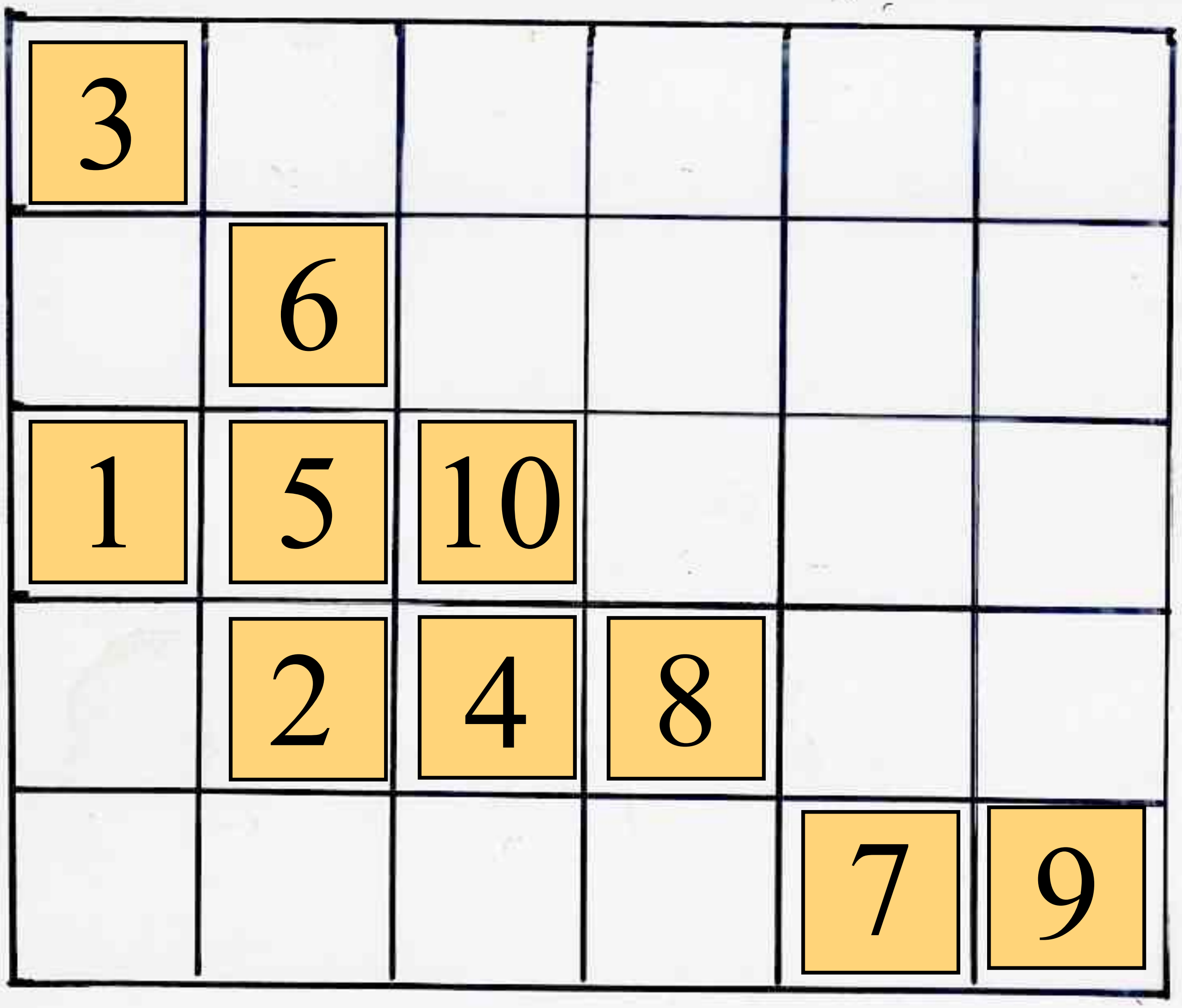
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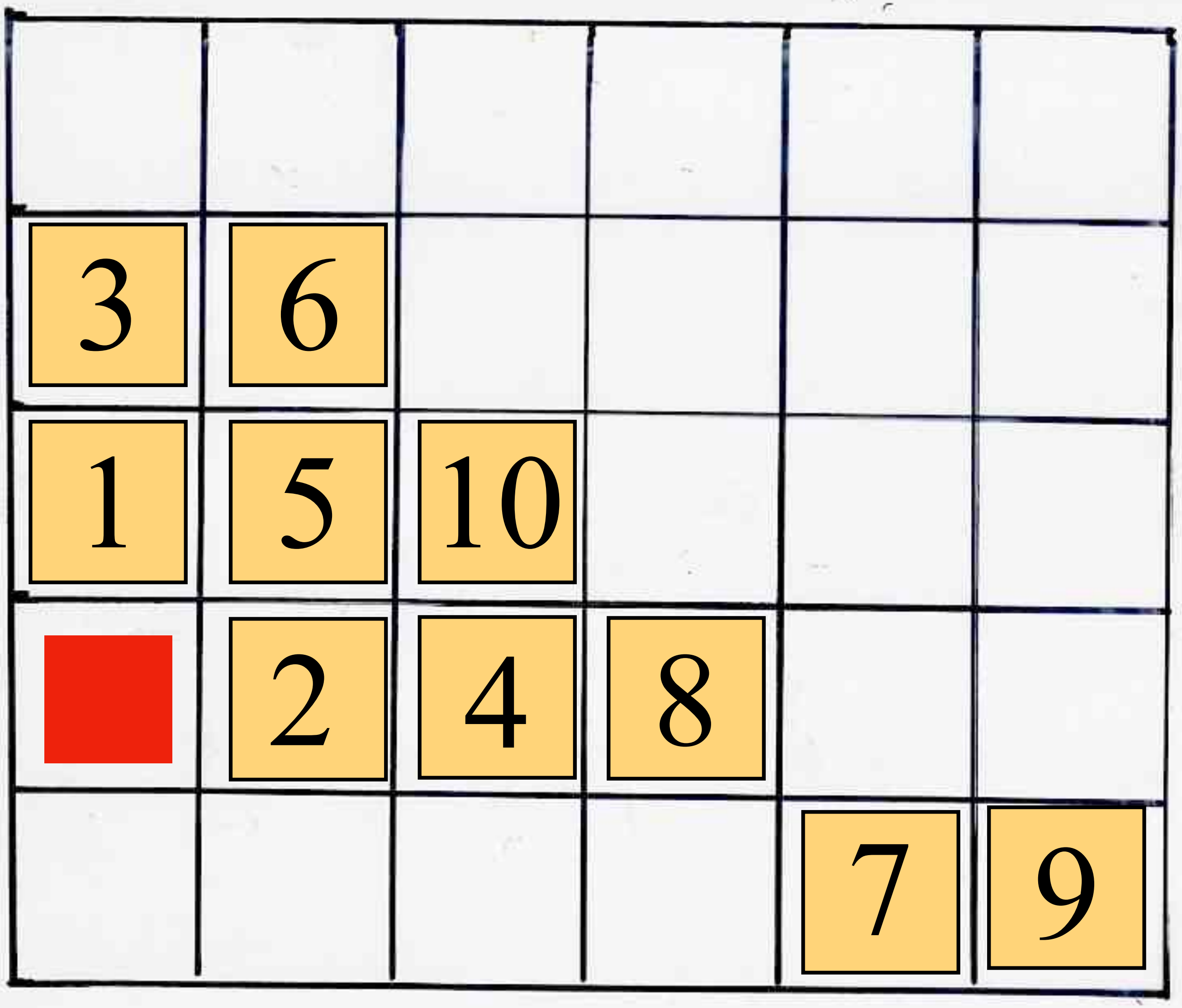
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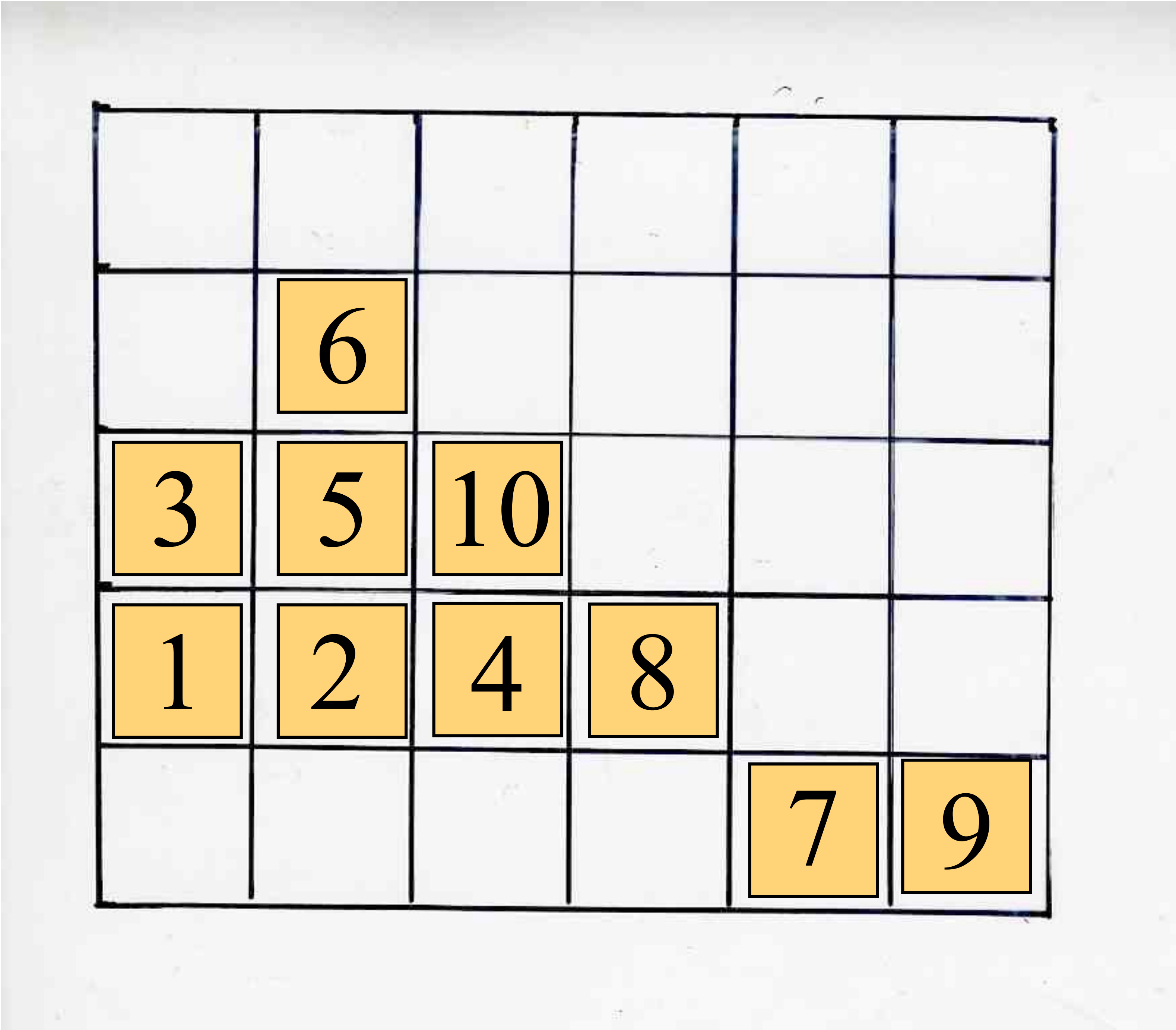
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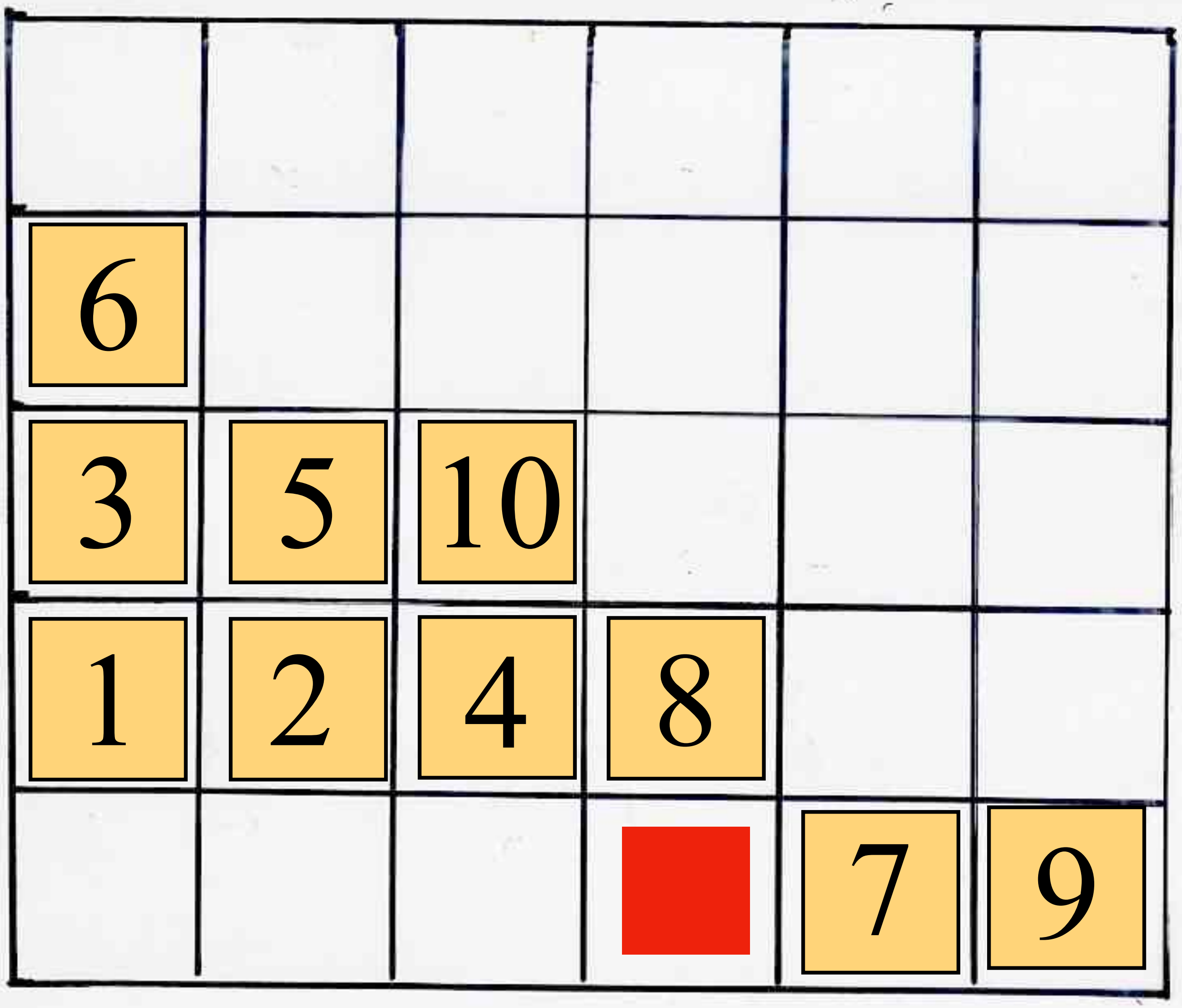
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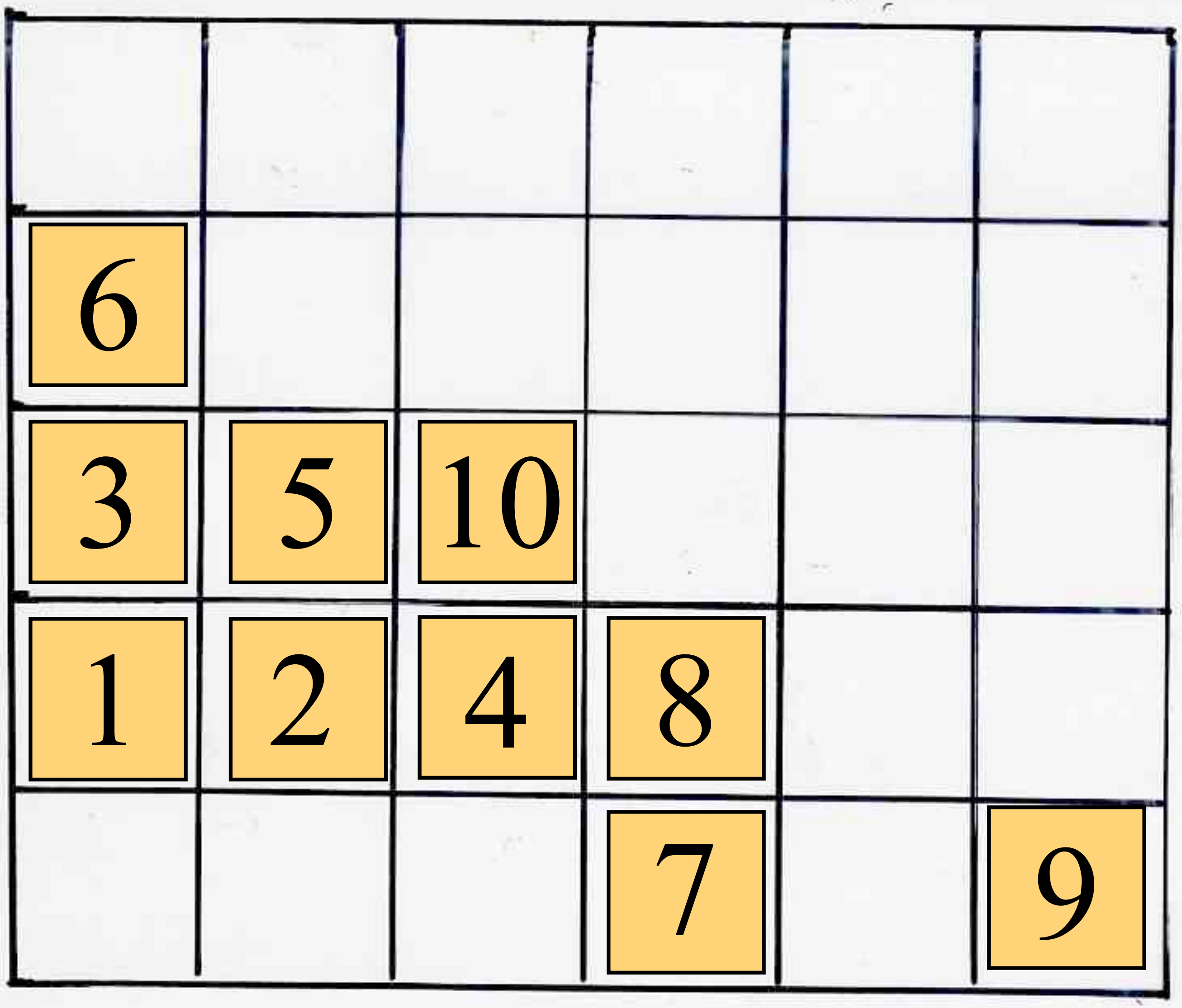
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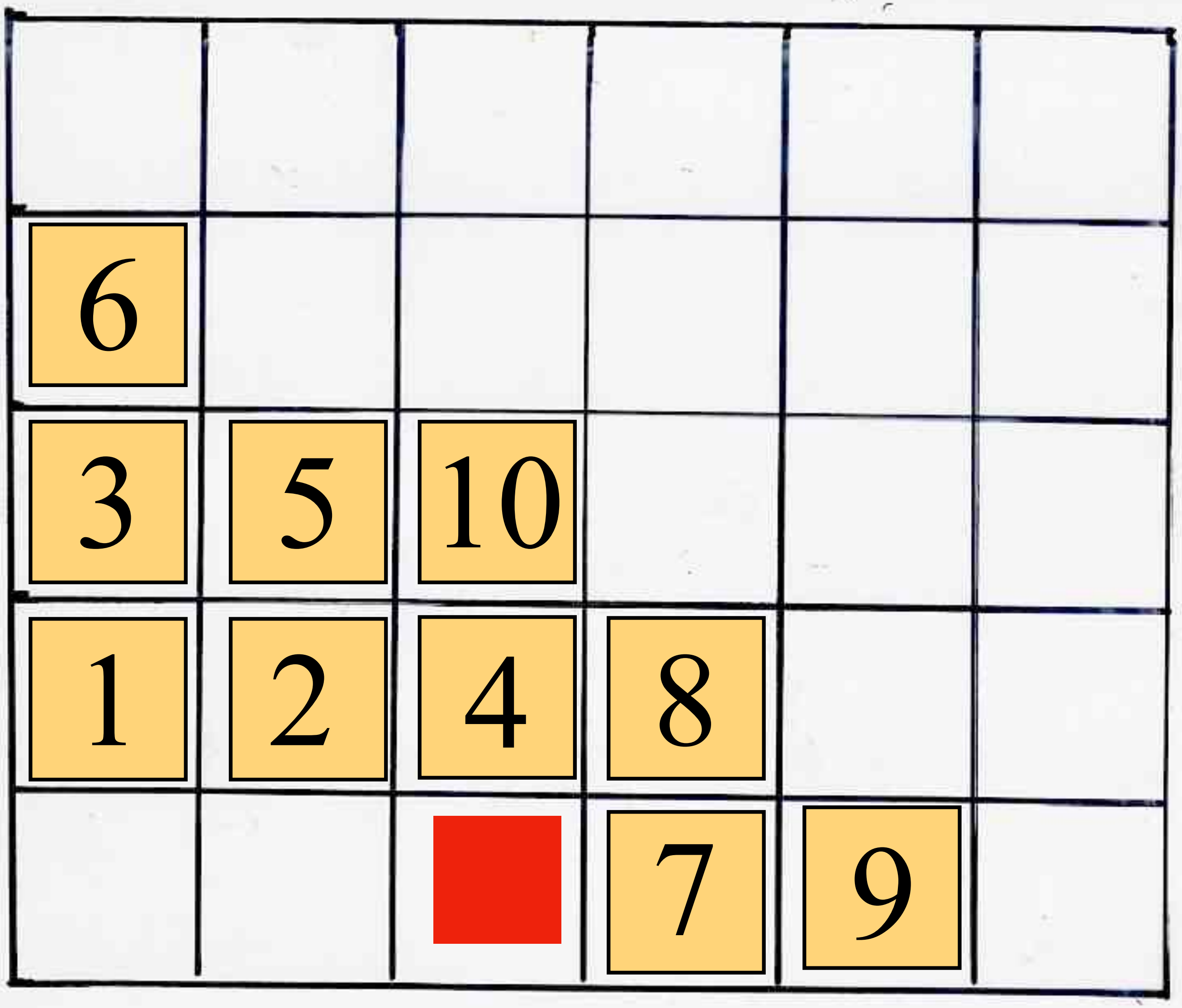
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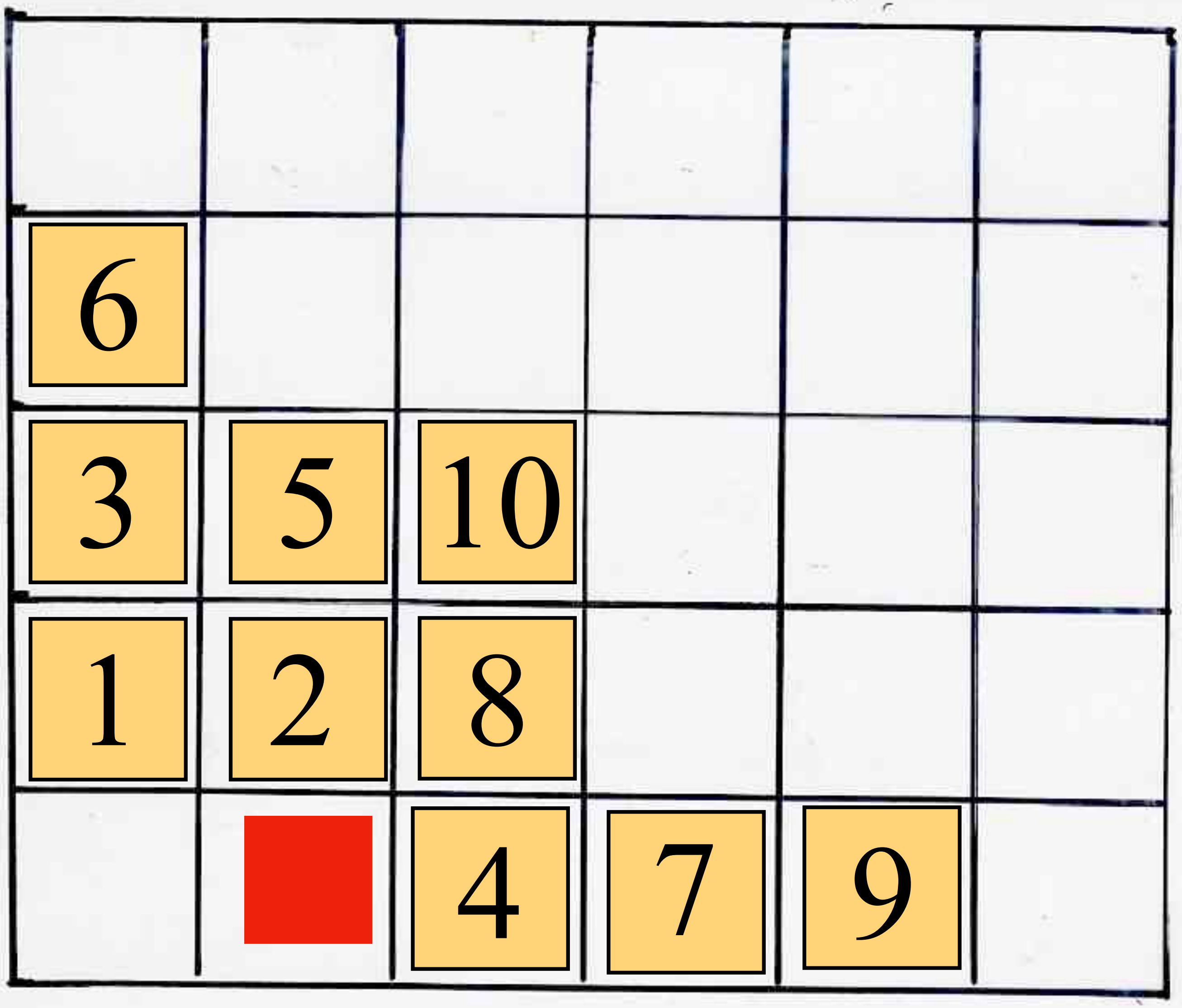
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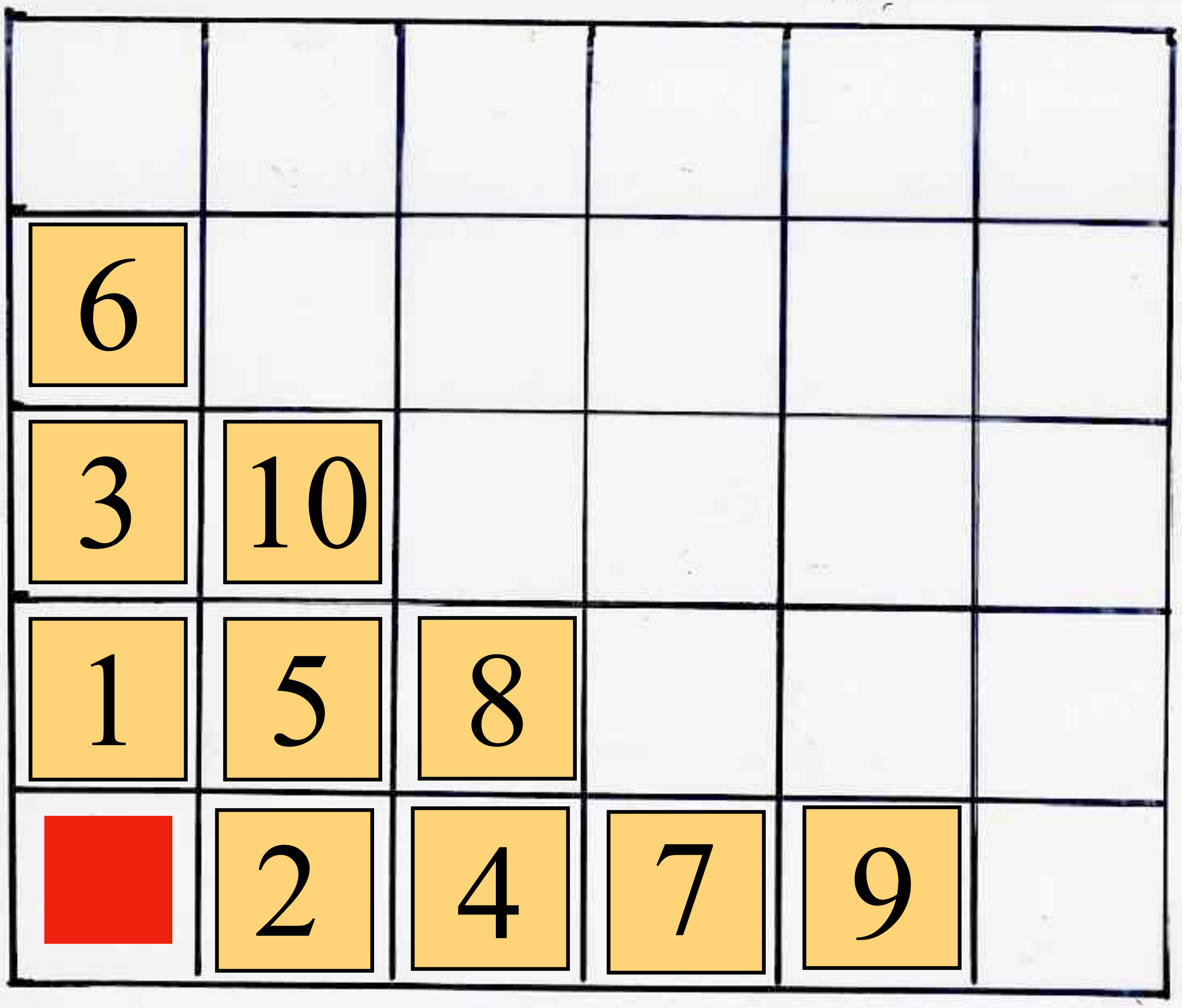
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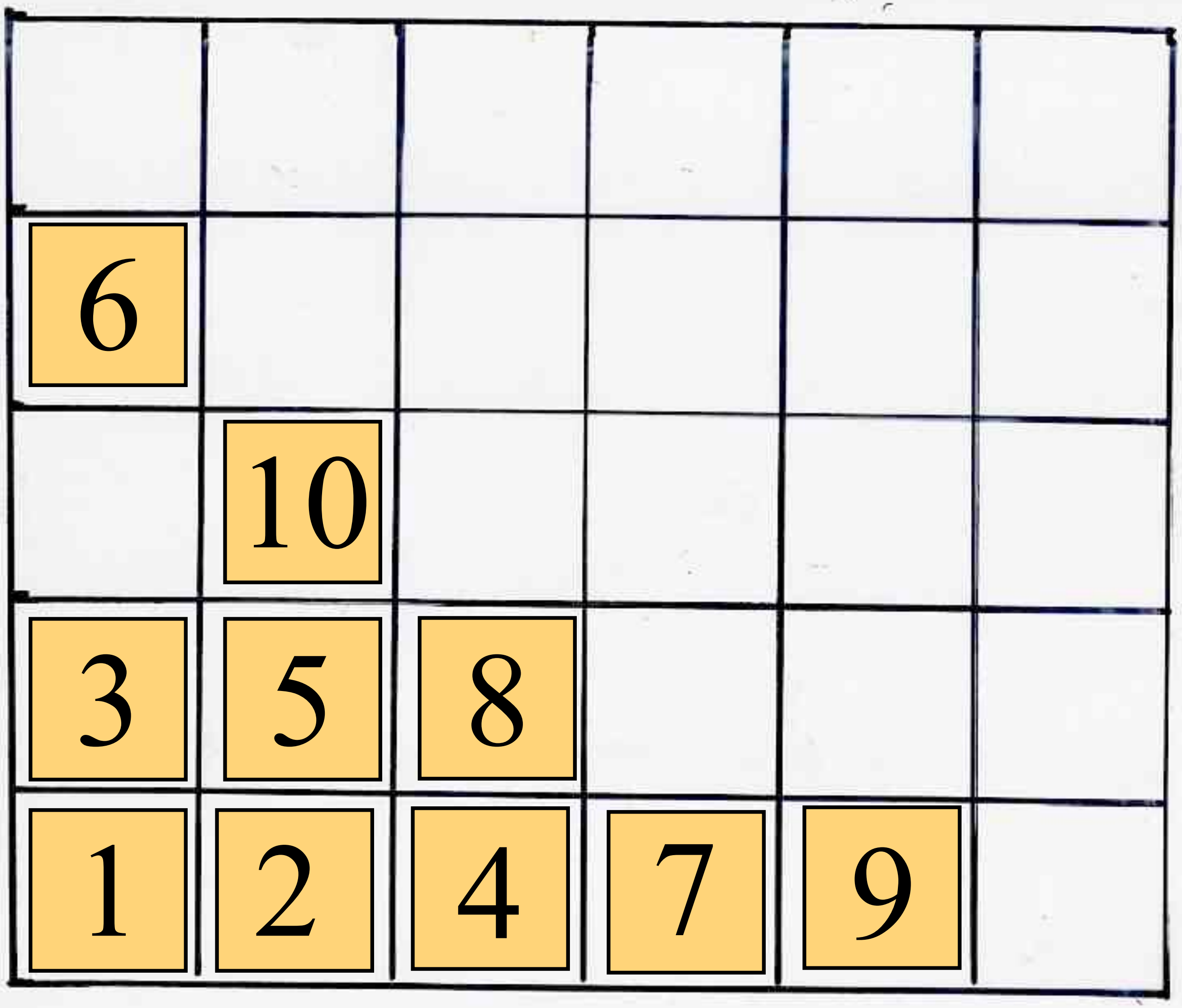
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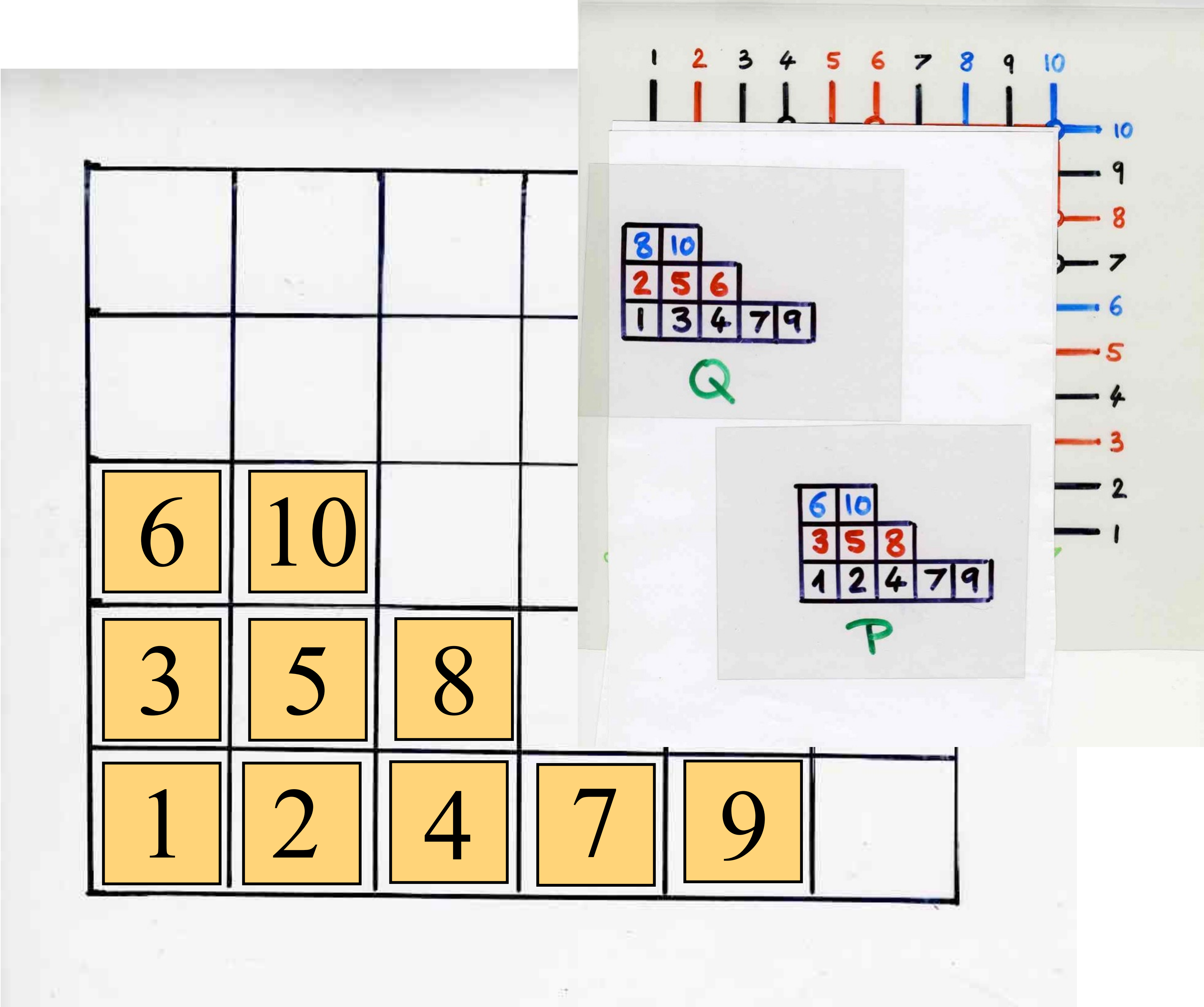
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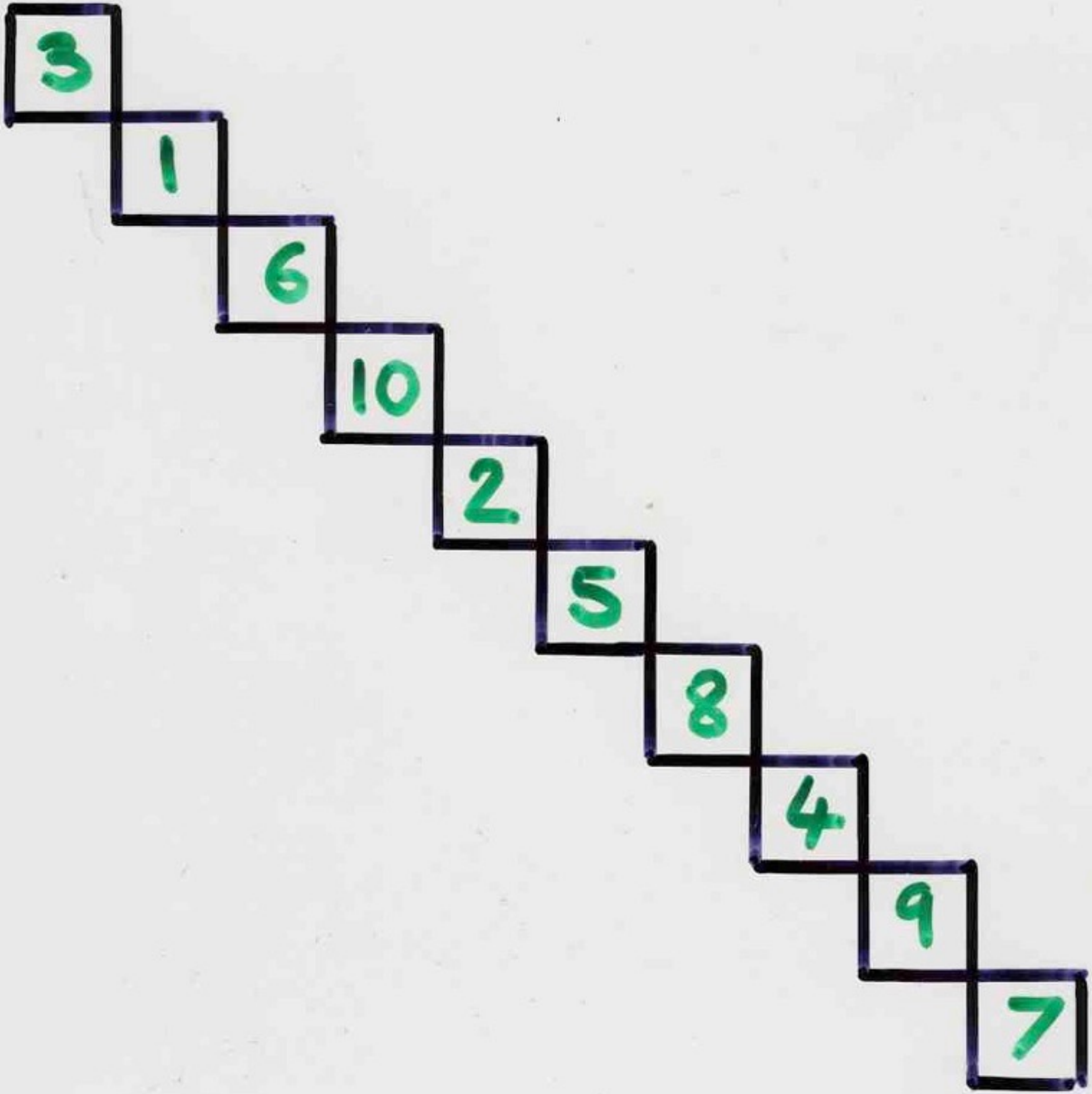
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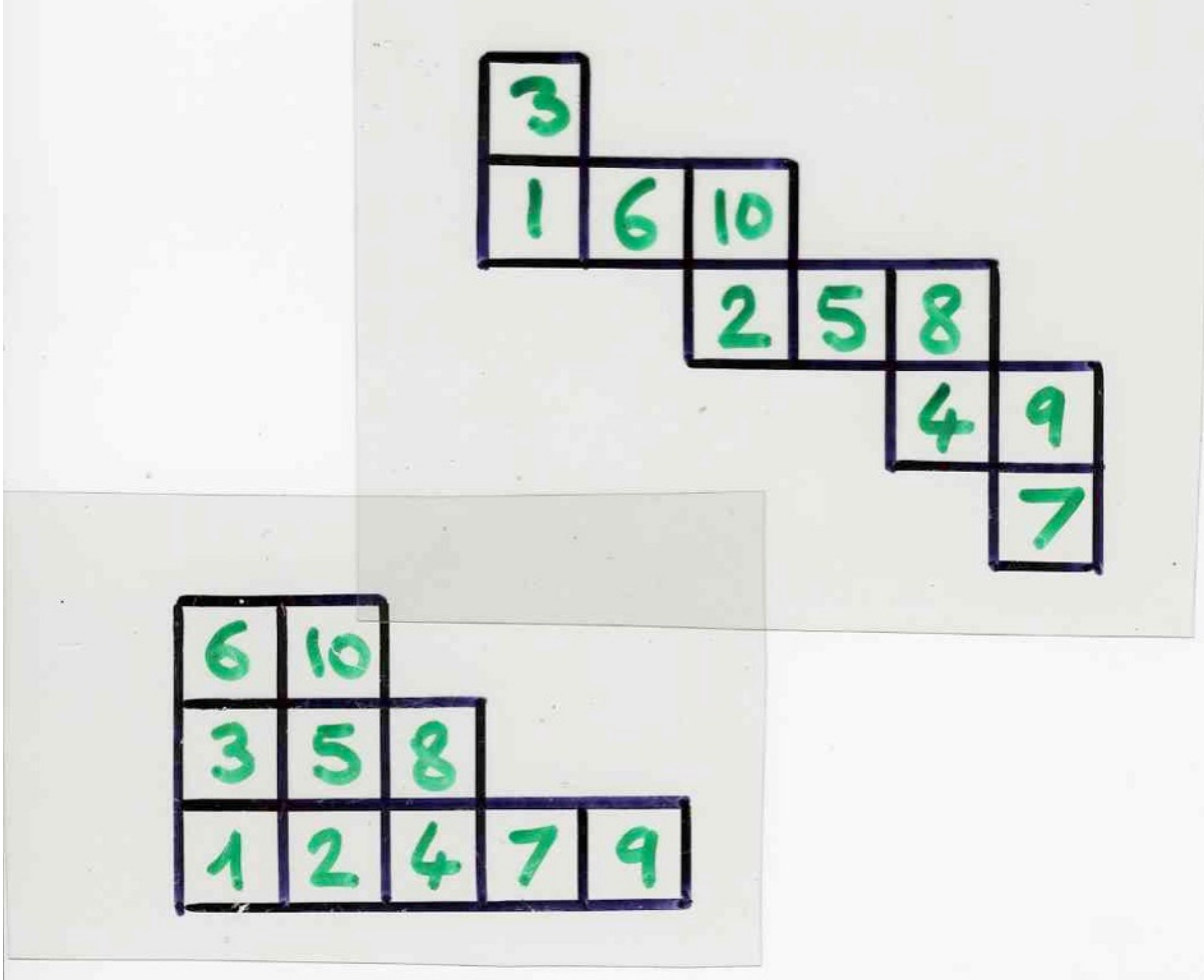
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1 6 10
2 5 8
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6 10
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1 2 4 7 9

Schur functions

and

jeu de taquin

Schur Functions

$$s_\lambda(x_1, x_2, \ldots, x_m) = \sum_{T} v(T)$$

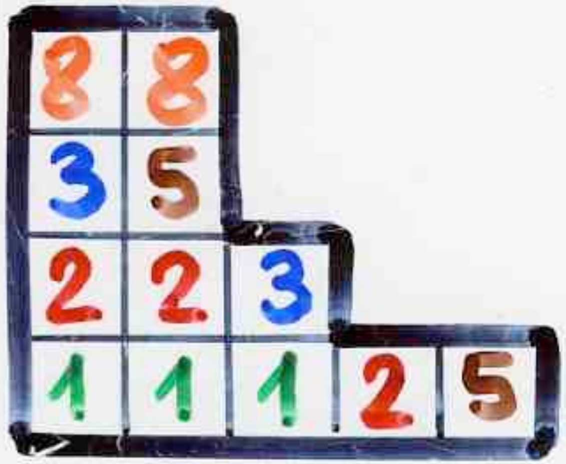
Young tableau

Jacobi (1841)
Schur (1901)

shape λ
entries $1, 2, \ldots, m$

Littlewood-Richardson (1934)

basis of **symmetric** functions

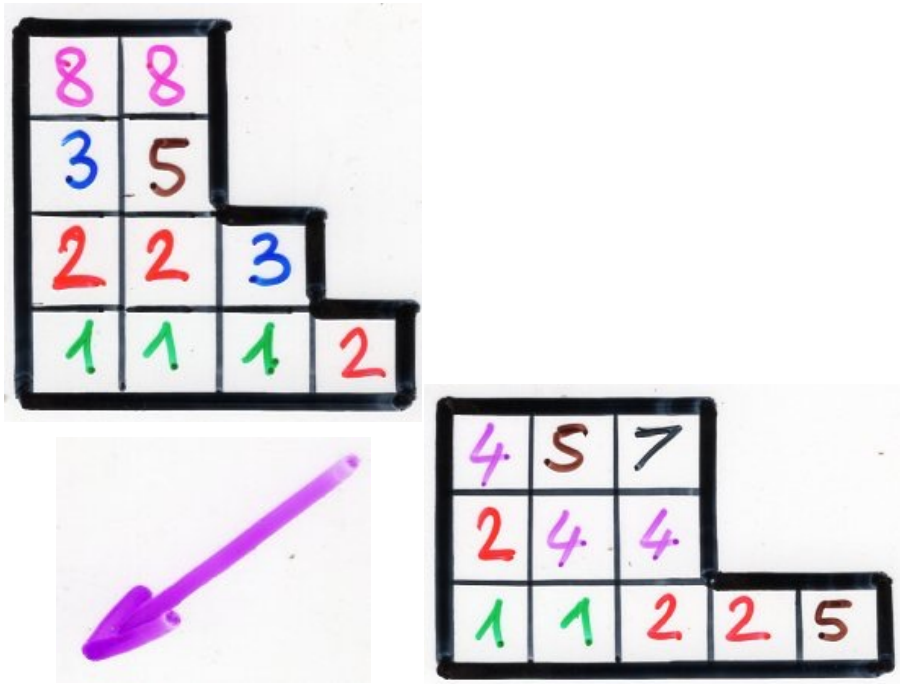


Schur functions

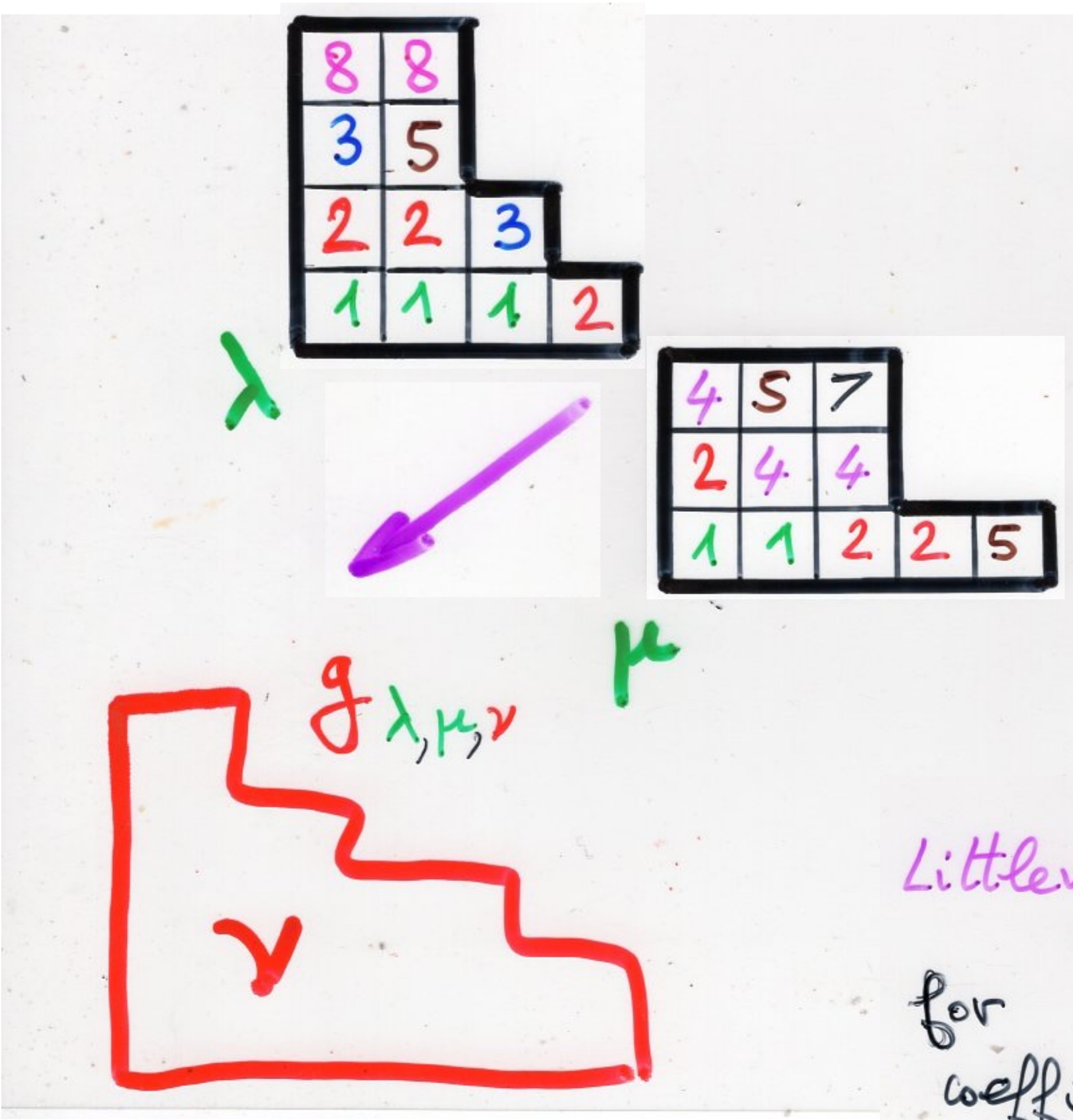
$$s_\lambda s_\mu = \sum_\nu g_{\lambda,\mu,\nu} s_\nu$$

$s_\lambda(x_1, \ldots, x_m)$

Littlewood-Richardson



Jeu de taquin



Jeu de taquin

Littlewood-Richardson rule (1934) for computing the coefficients $g_{\lambda,\mu,\nu}$

jeu de taquin in recent research work

- algebraic combinatorics

  Pechenik, Yong (2015)

  analogue of Littlewood-Richardson coefficients in the "equivariant K-theory" of the Grassmannian

Thomas, Yong (2007), cartons

3D symmetries for Littlewood-Richardson coefficients

- bijective combinatorics

  Fang (2015)

  - bijective proof of a character identity
    (Frobenius, Murnaghan-Nakayama)

  Krattenthaler (2016)

  - bijection between oscillating tableaux
    (Burrill conjecture)

- probabilistic combinatorics

  Romik, Śniady (2015)

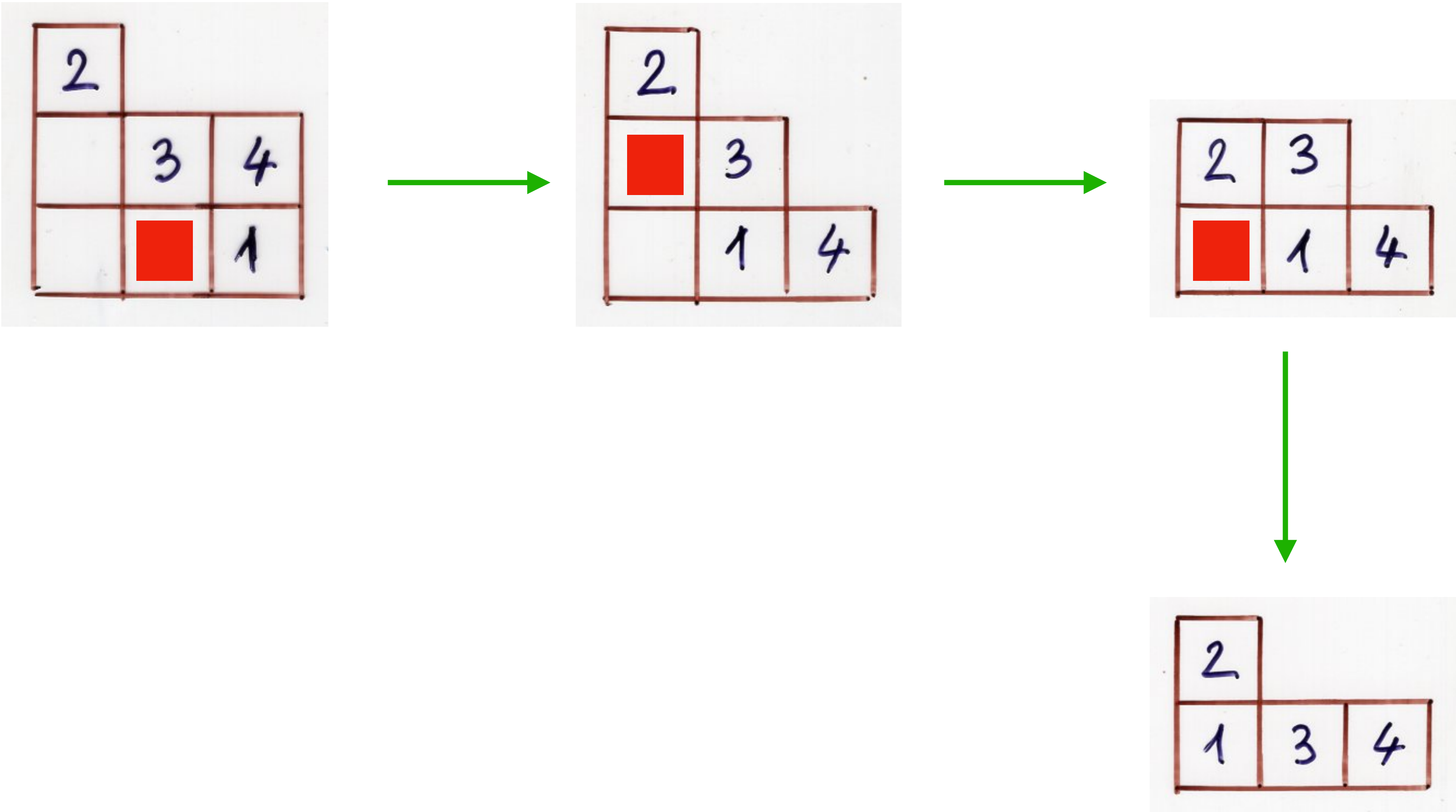
  random infinite tableaux

Jeu de taquin

with growth diagrams

S. Fomin, 1986, 1994

Сергей Владимирович Фомин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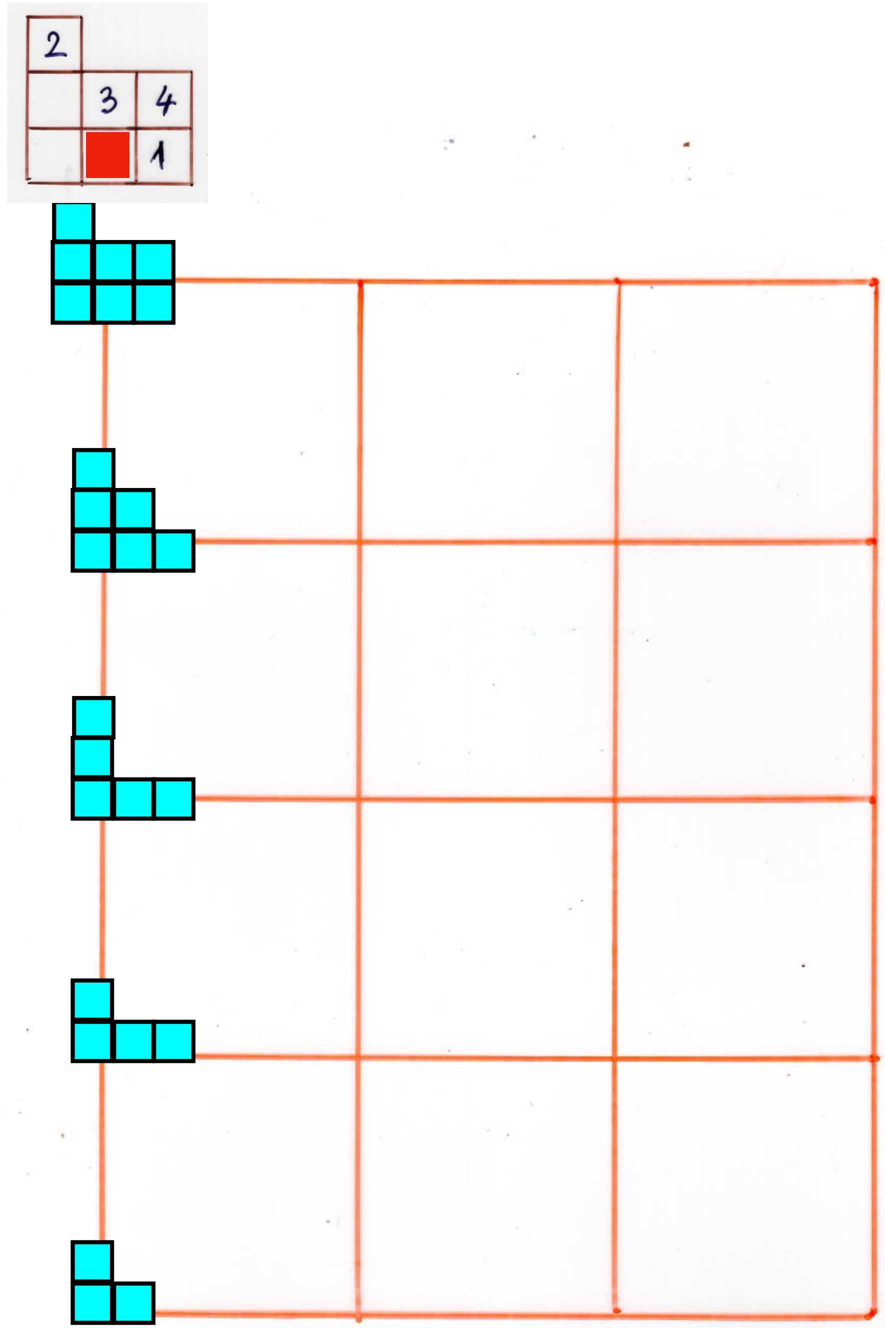
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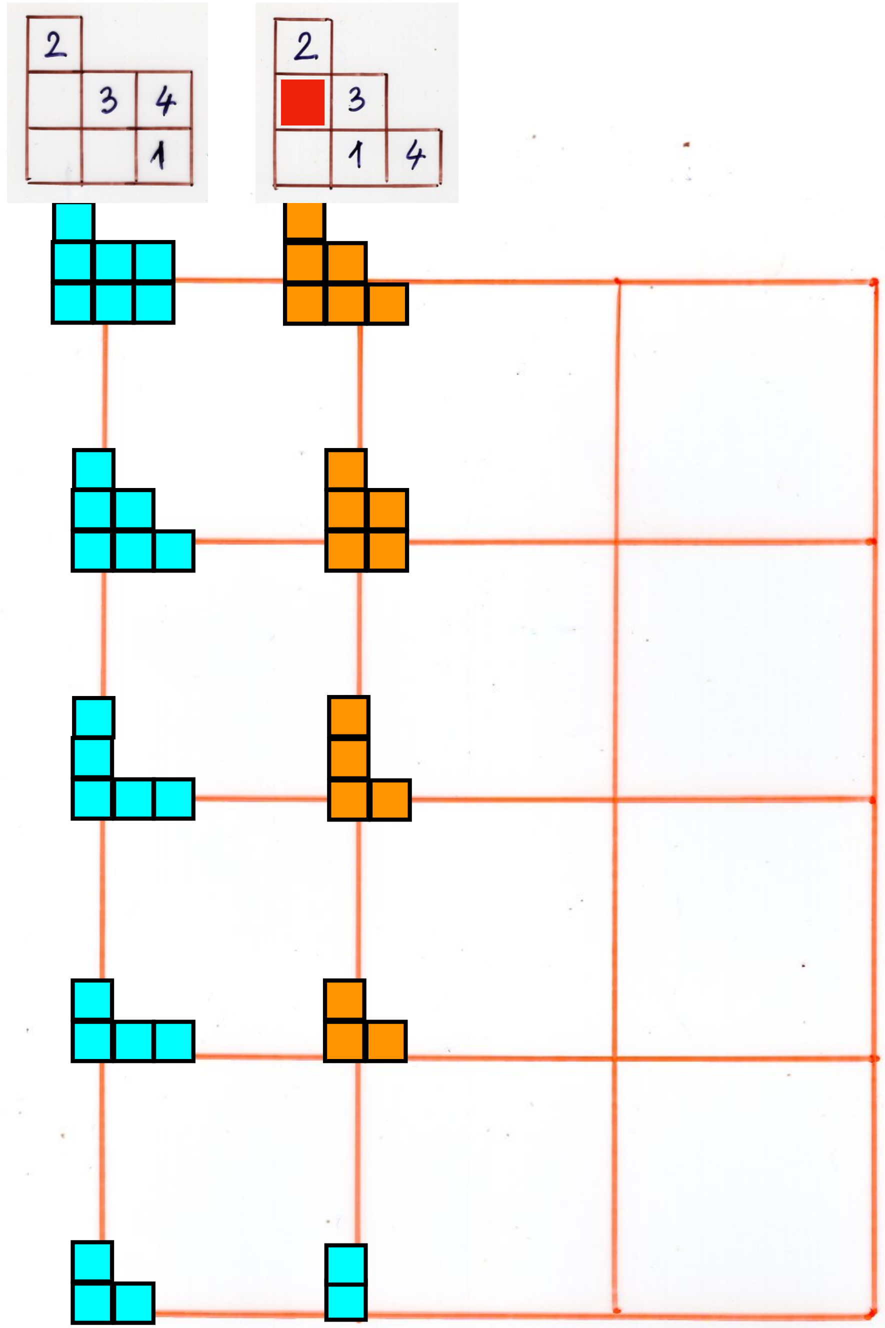
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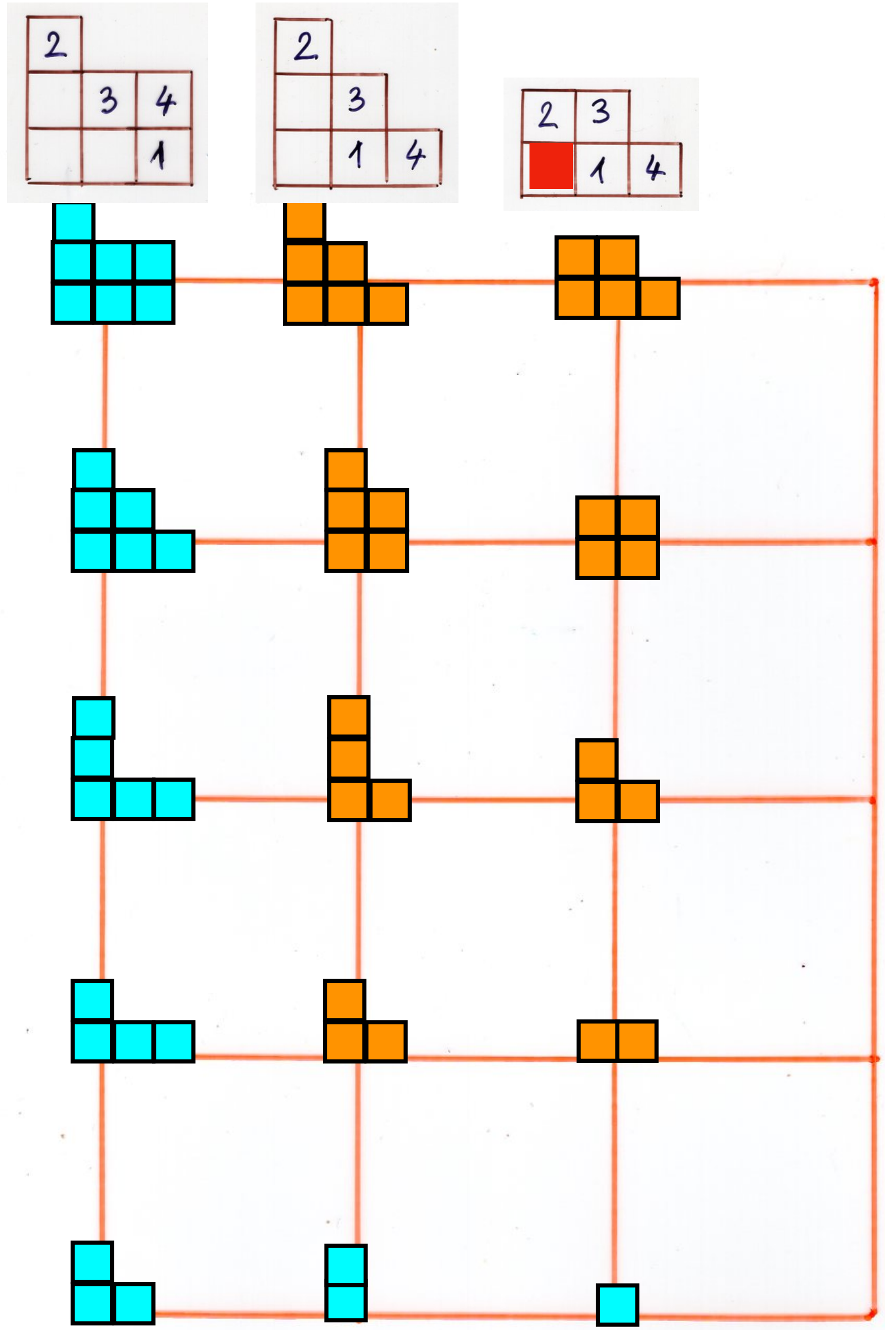
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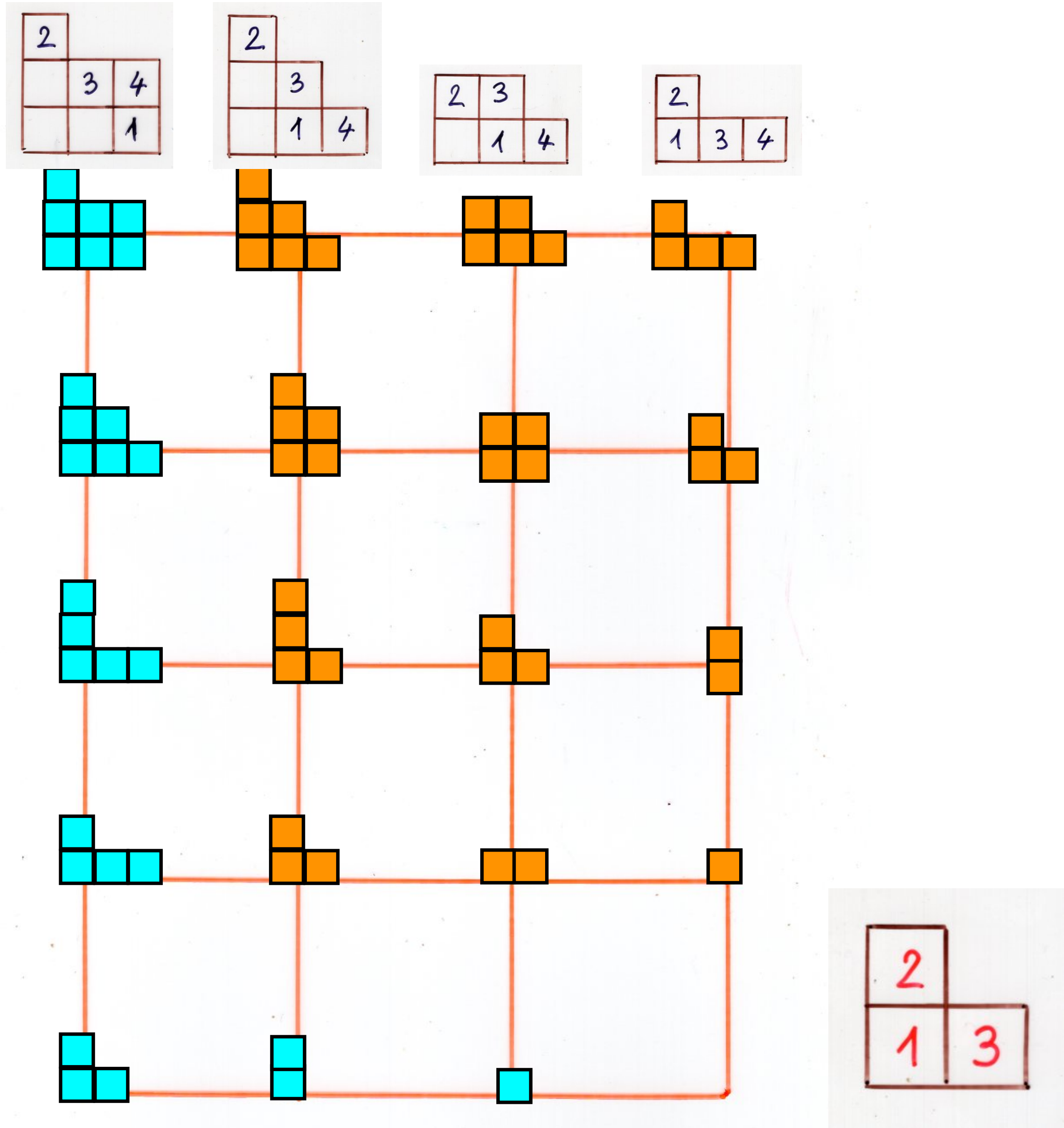
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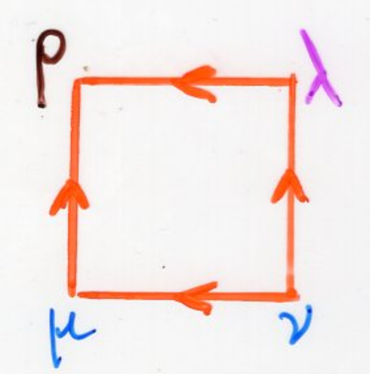
Proposition jeu de taquin local rules (Fomin)

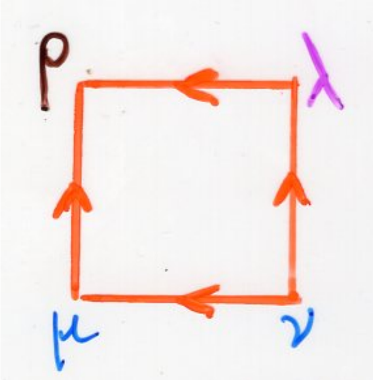


cell of the jeu de taquin growth diagram
(ρ covers μ and λ,
μ and λ cover ν)

Then λ is uniquely determined from μ, ν, ρ by the following "local rule":

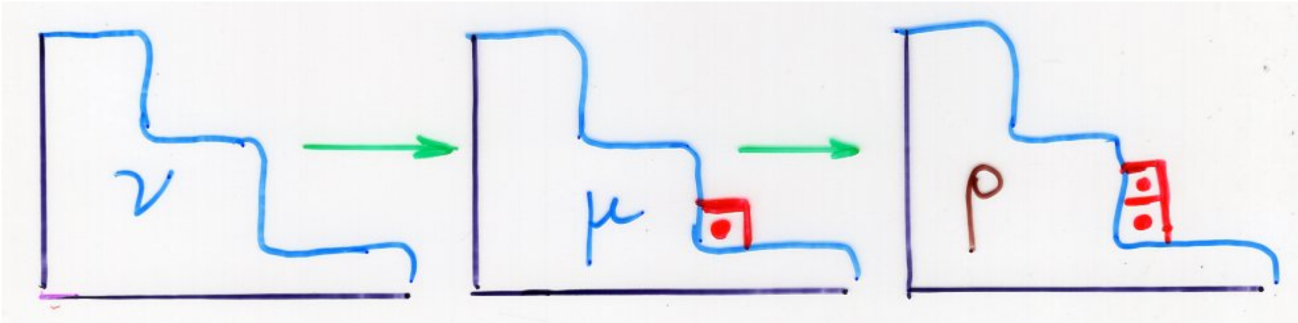
(i) • if μ is the only shape of its size that contains ν and is contained in ρ
then $\lambda = \mu$

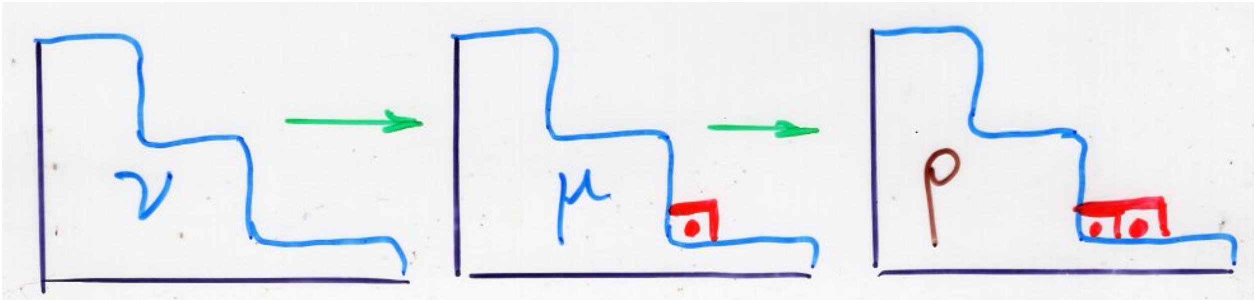
(ii) • otherwise there is a unique such shape different from μ, and
this is λ



jeu de taquin local rules

(i) • if μ is the only shape of its size that contains ν and is contained in ρ then $\lambda = \mu$

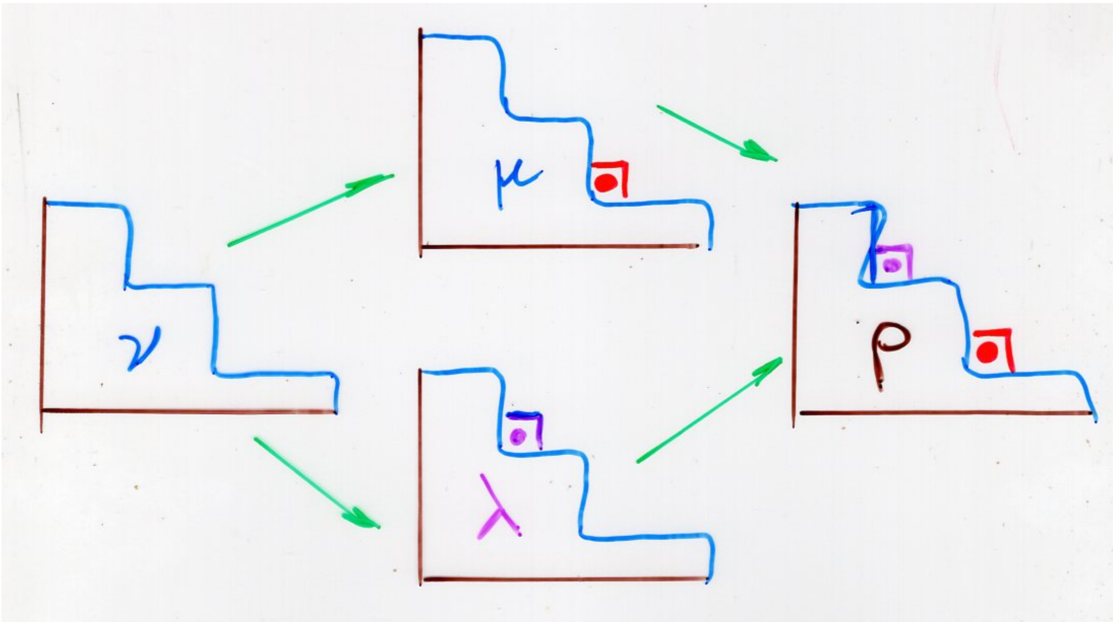


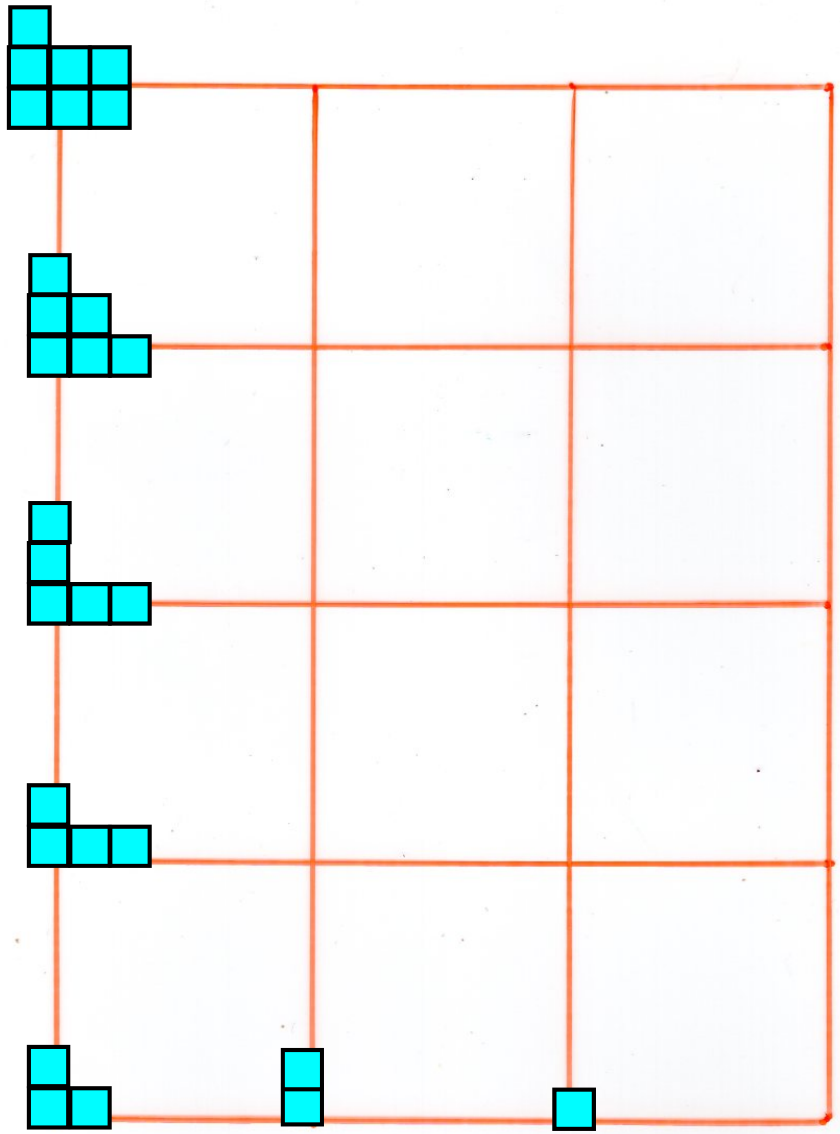


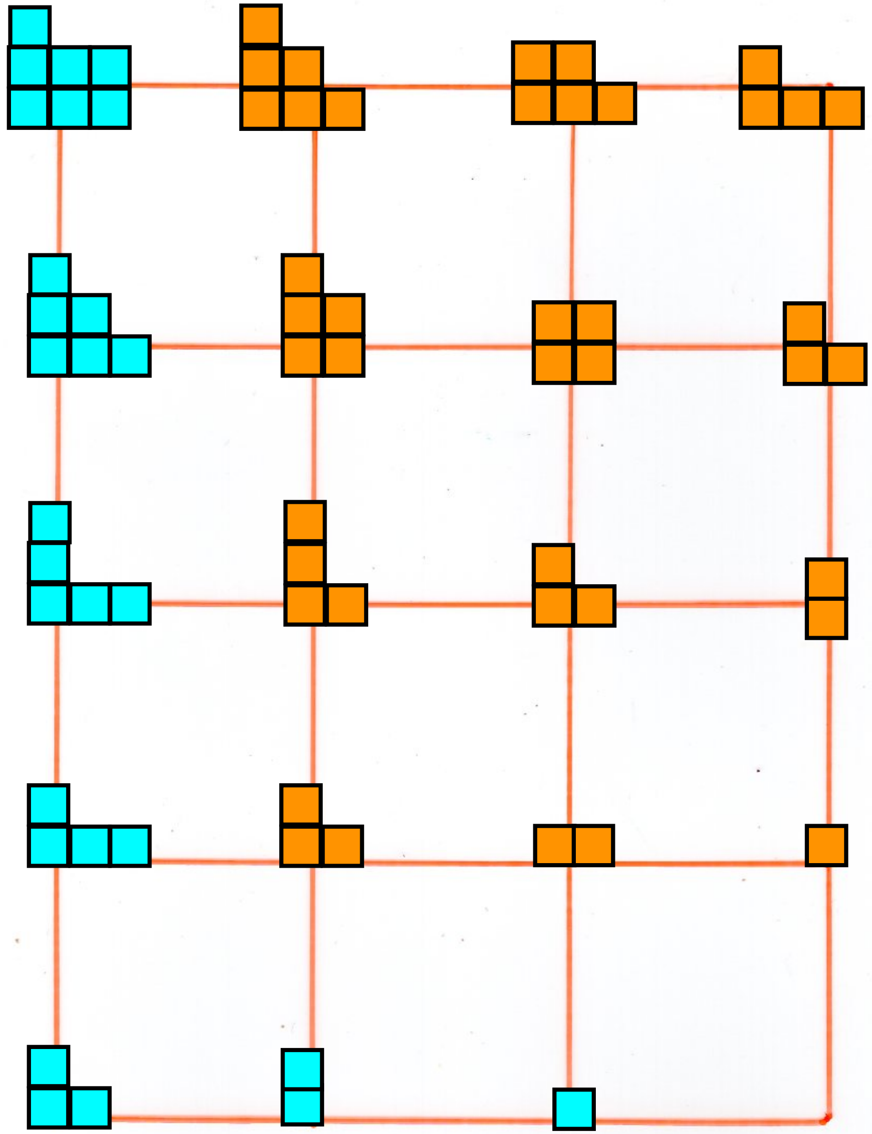
$$\begin{tikzcd} \rho & \lambda \arrow[l] \\ \mu \arrow[u] & \nu \arrow[l] \arrow[u] \end{tikzcd}$$

jeu de taquin
local rules

(ii) • otherwise there is a unique such shape different from μ, and this is λ





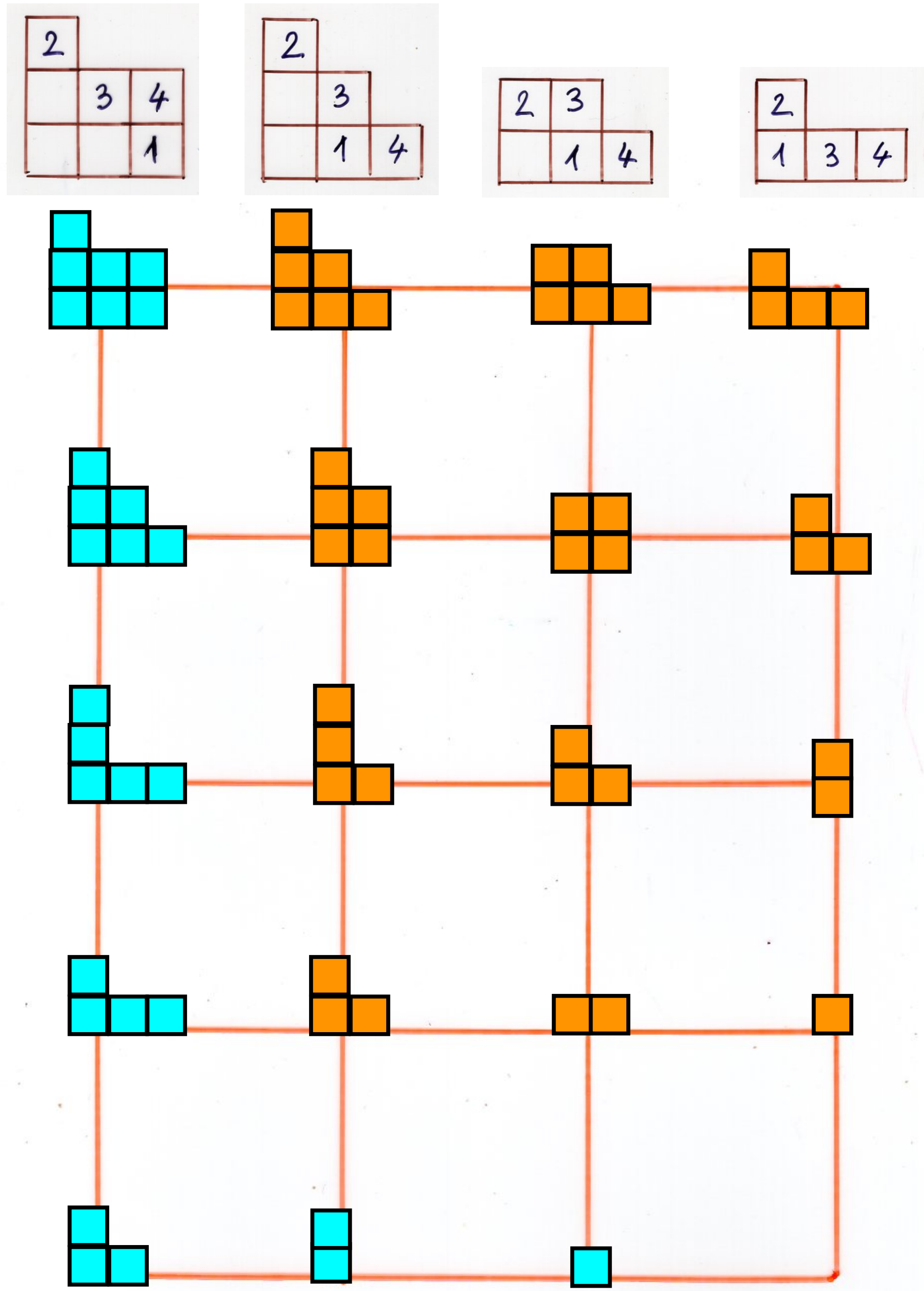


the tableau

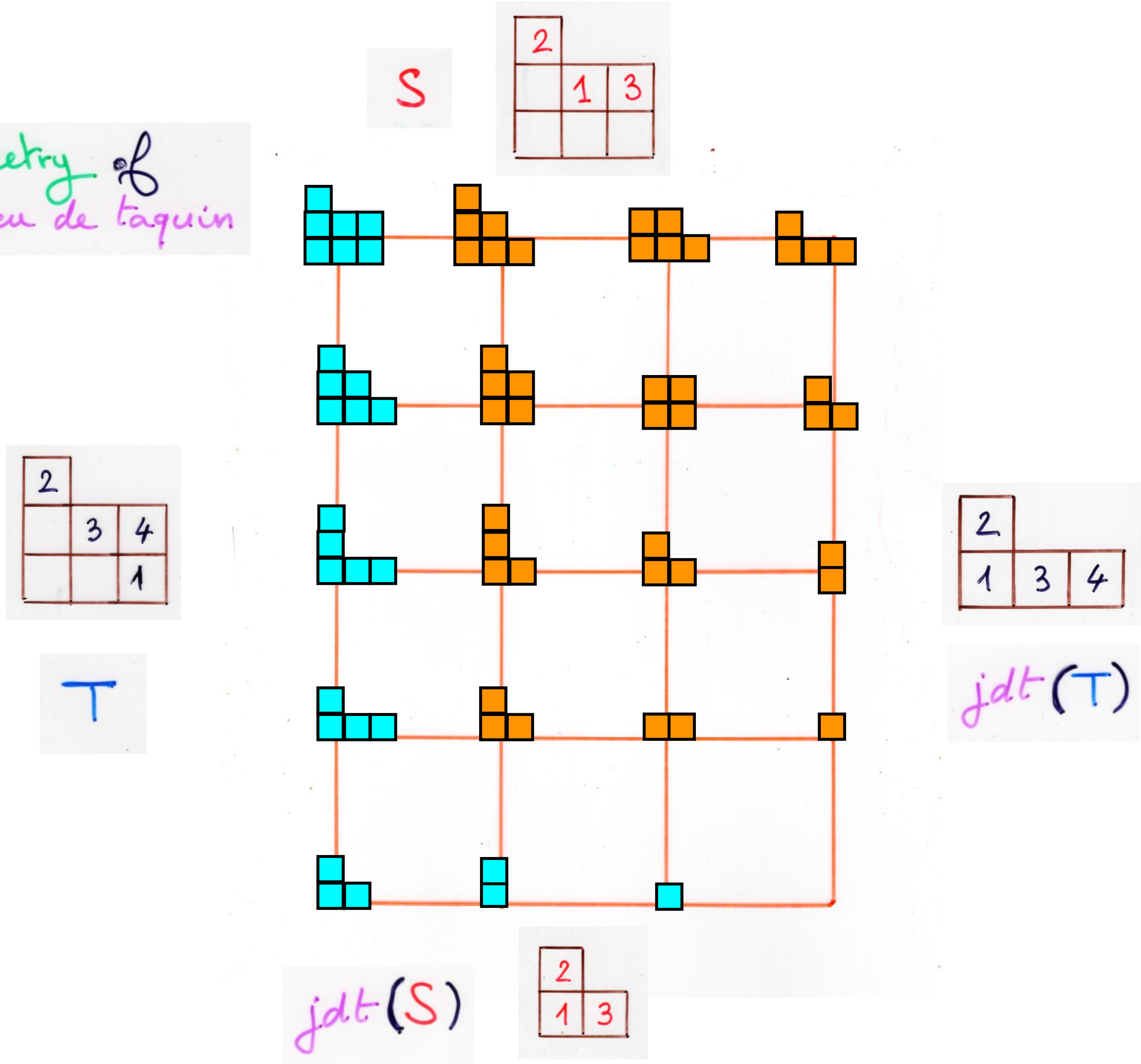
2		
1	3	4

is independant of the
choice of the tableau

2	
1	3



symmetry of the jeu de taquin

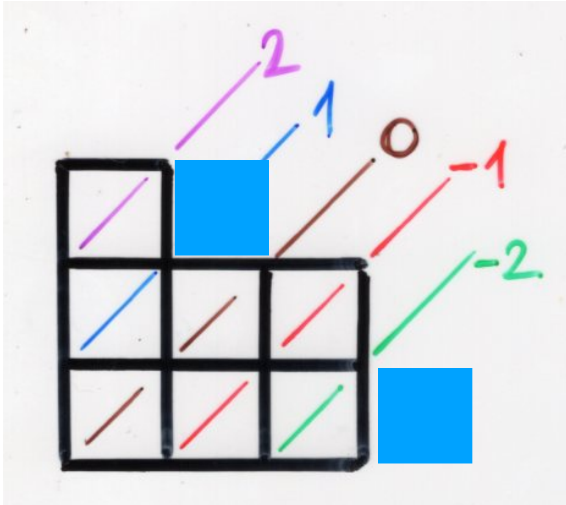


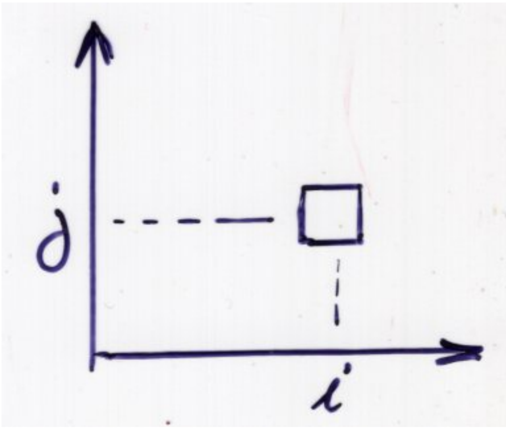
Jeu de taquin

with local rules on edges ?

diagonal operators

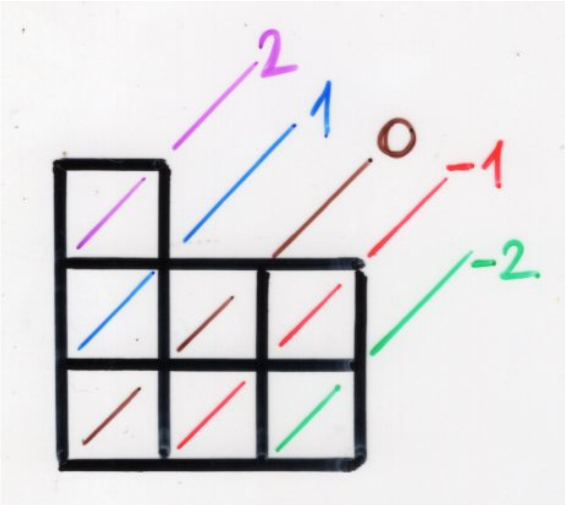
$\Delta_i \quad i \in \mathbb{Z}$





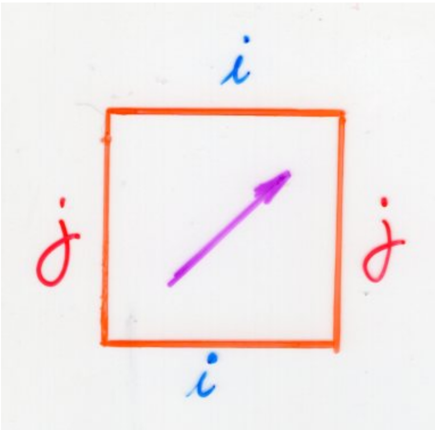
$(i, j) \longrightarrow j - i$

content

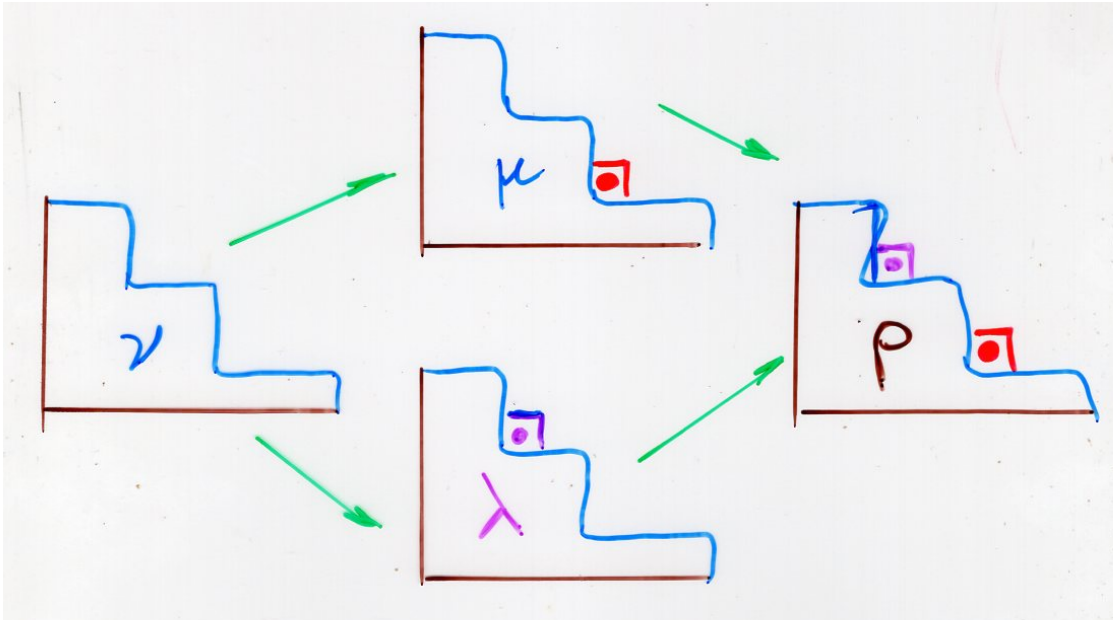


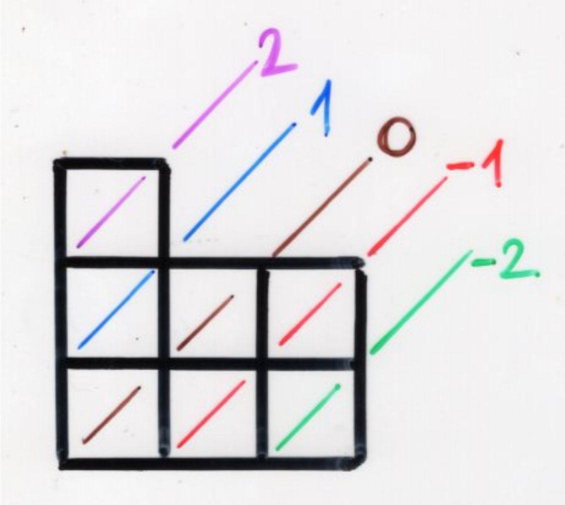
jeu de taquin

local rules on edges

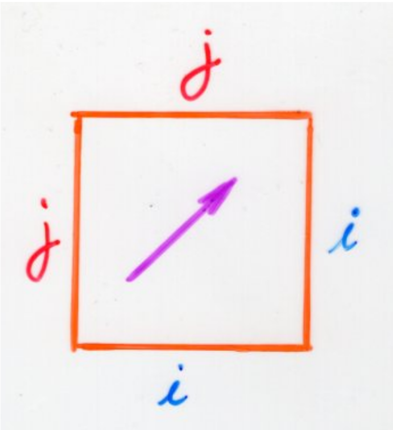


$|i-j| \geq 2$



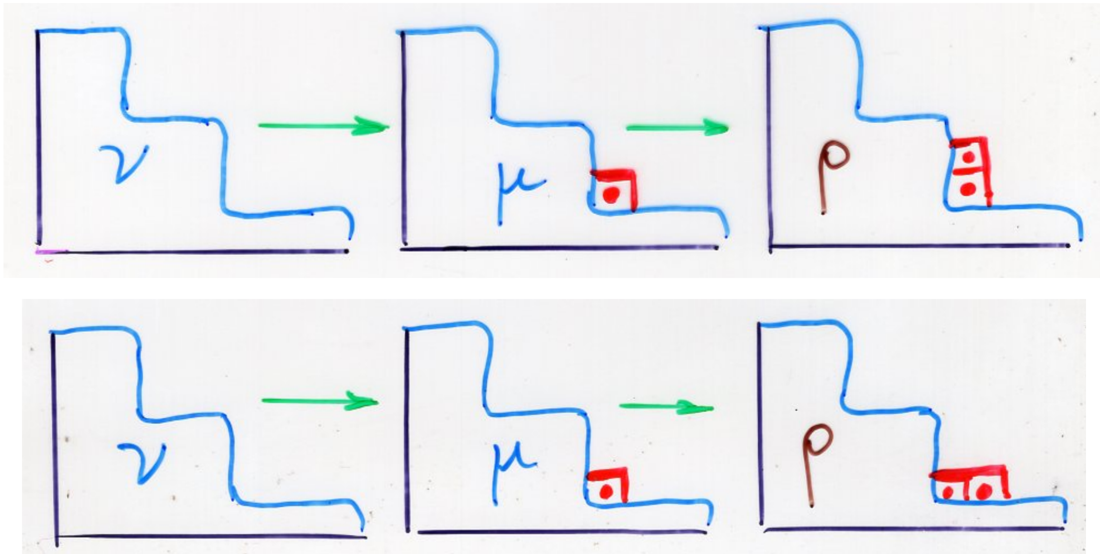


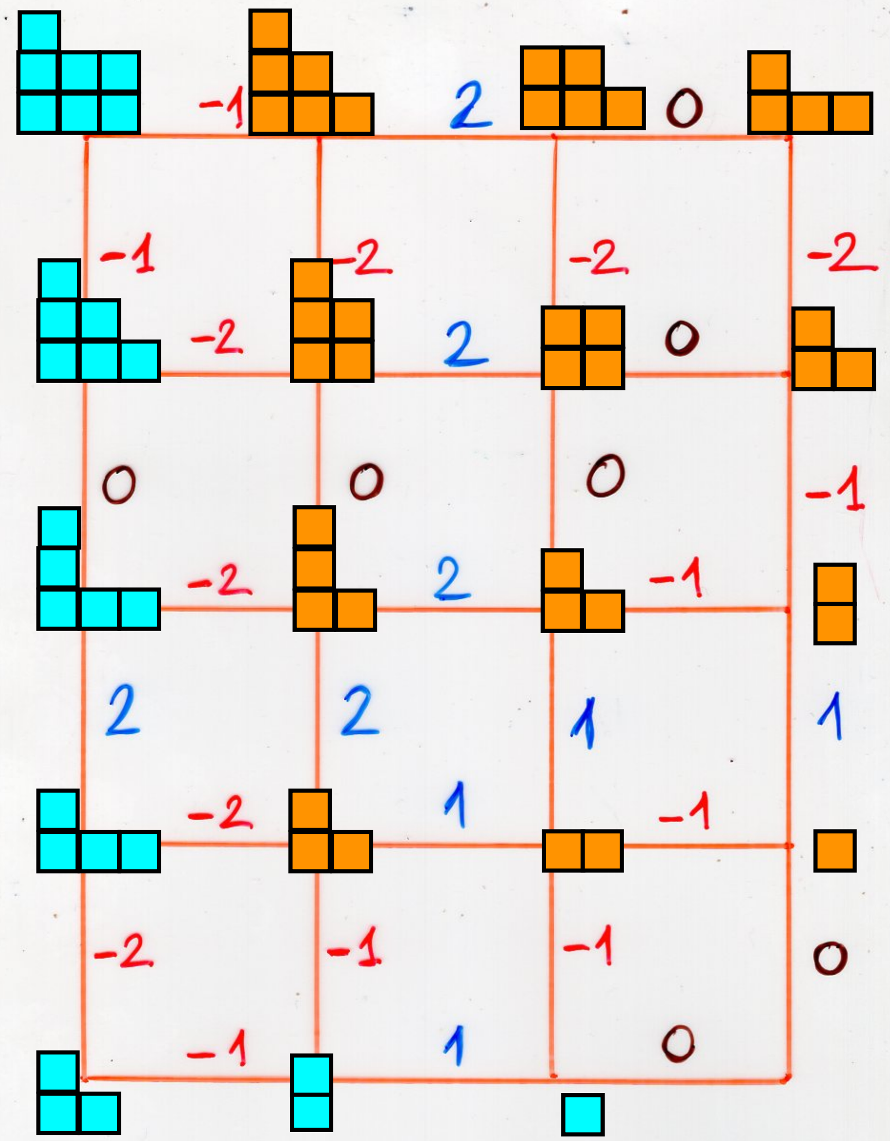
jeu de taquin
local rules on edges



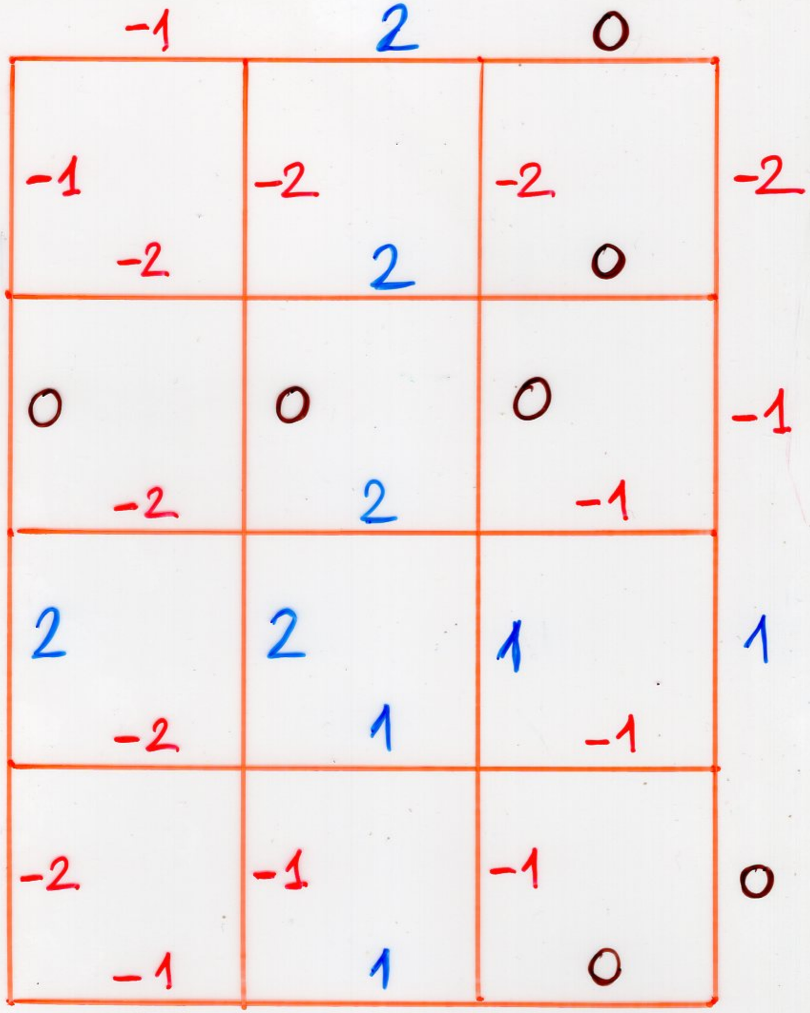
$|i - j| \leqslant 1$

or



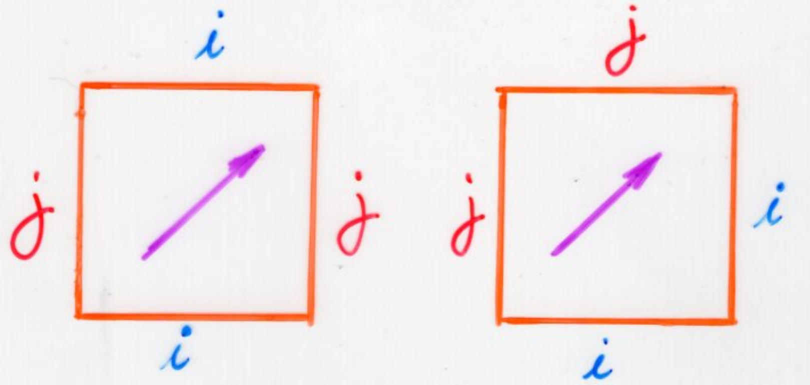


-1
2
0
-1
-2
-2
-2
-2
2
0
0
0
0
-1
-2
2
-1
2
2
1
1
-2
1
-1
-2
-1
-1
0
-1
1
0


-1 2 0
-1 -2 -2 -2
-2 2 0
0 0 0 -1
-2 2 -1
2 2 1 1
-2 1 -1
-2 -1 -1 0
-1 1 0

jeu de taquin

local rules on edges



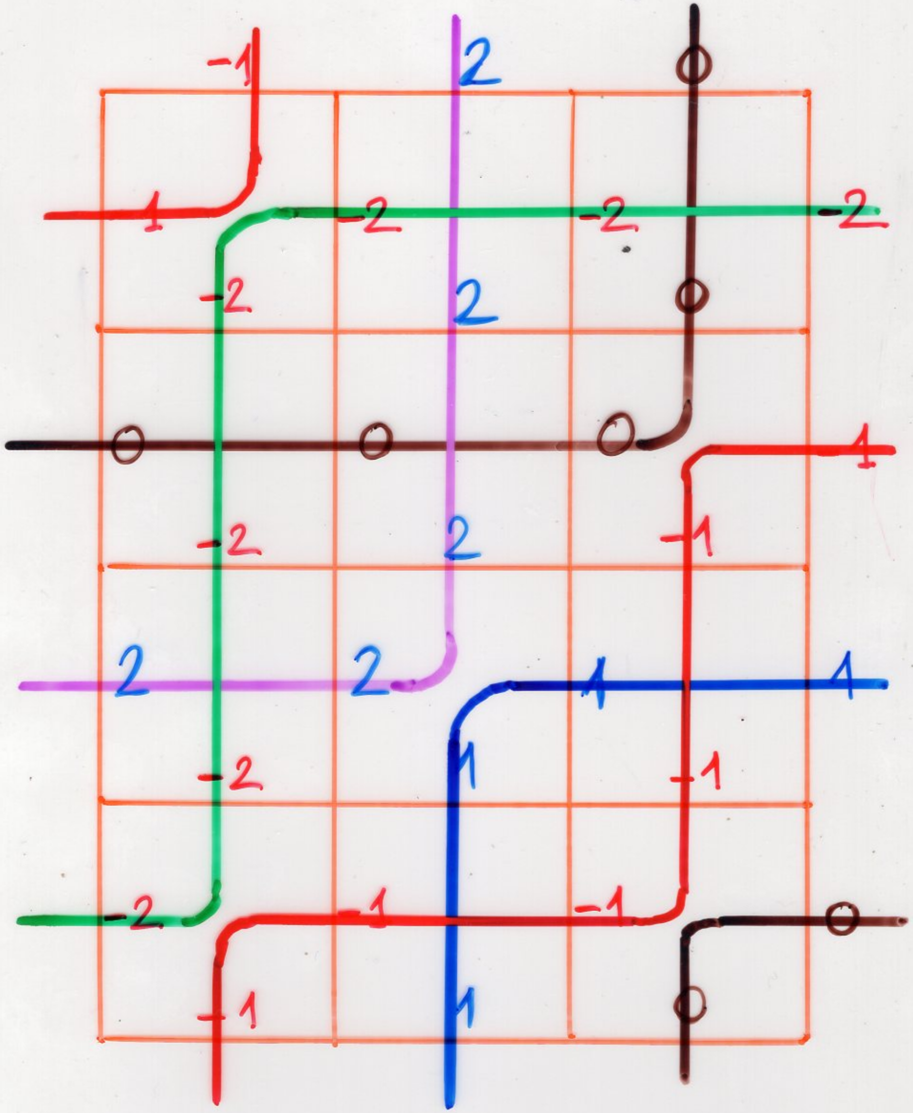
$i, j \in \mathbb{Z}$

$|i-j| \geqslant 2$ $|i-j| \leqslant 1$

in fact here $i=j$ impossible

nil-Temperley-Lieb

planar automaton



-1
2
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1
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-2
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-2
2
0
0
0
0
1
-2
2
-1
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2
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-2
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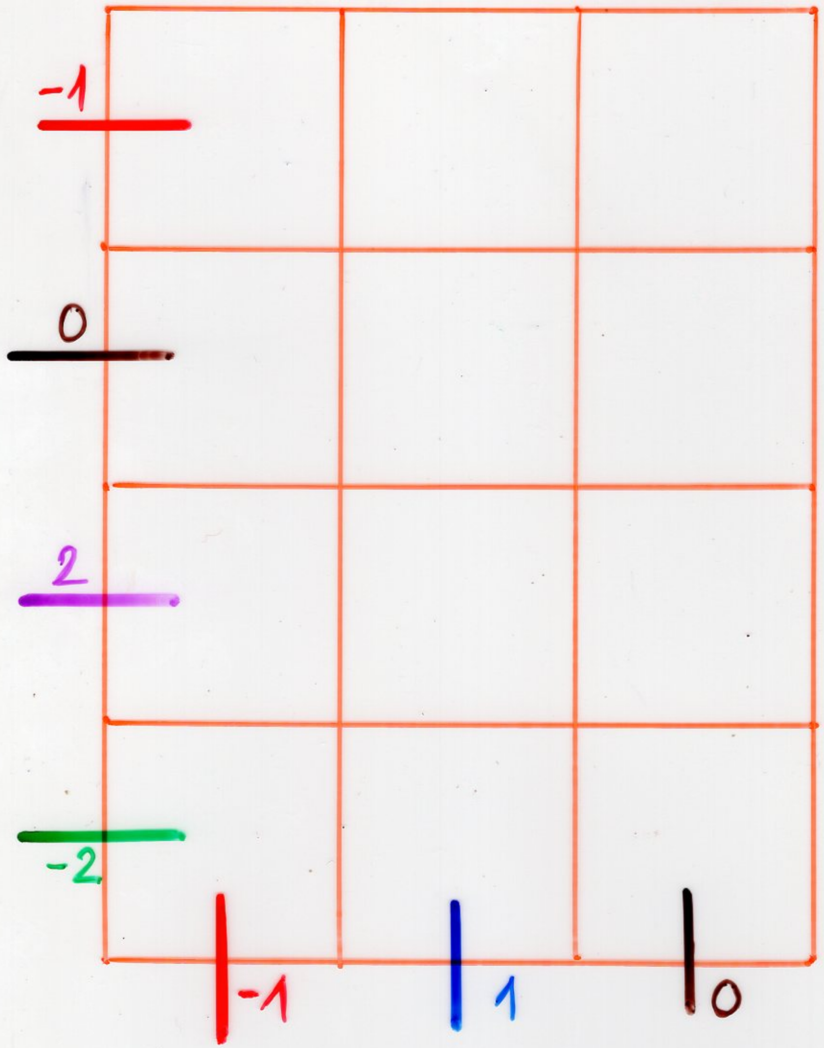
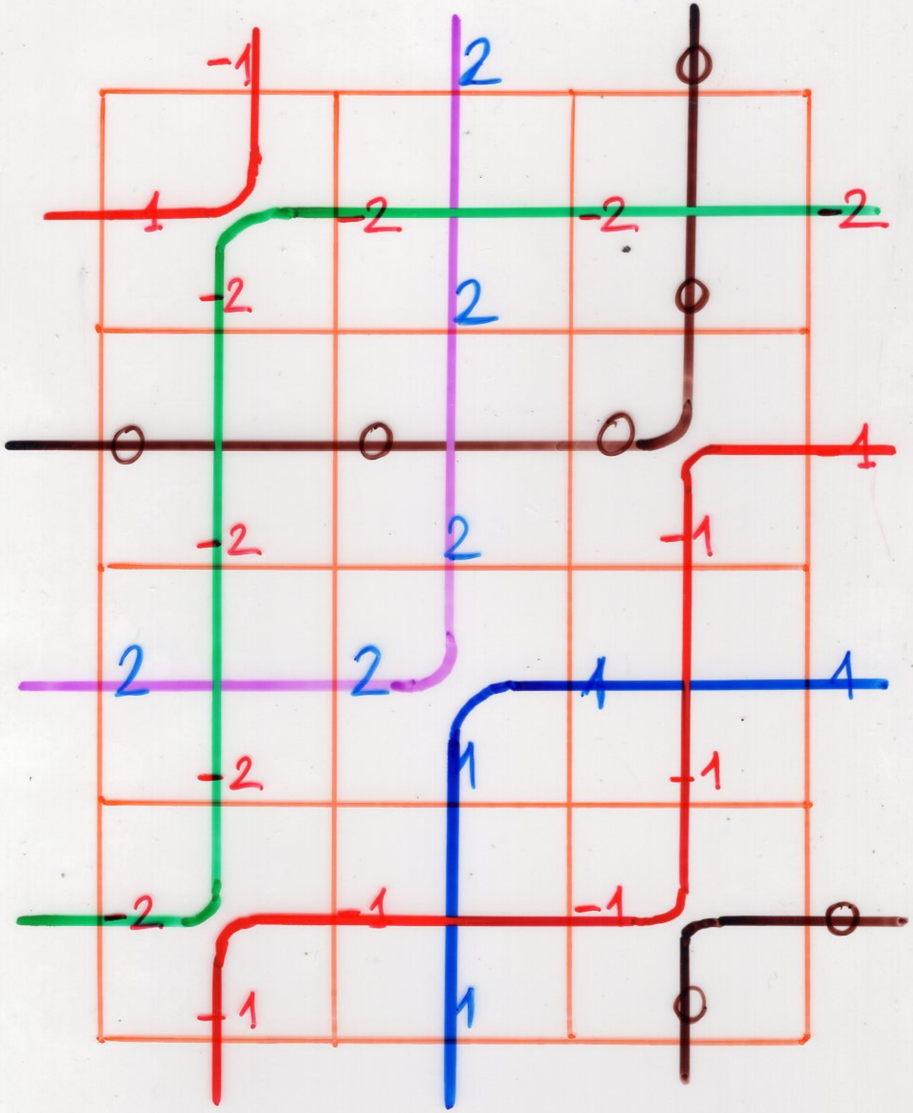
-2
-1
-1
0
1
1
0

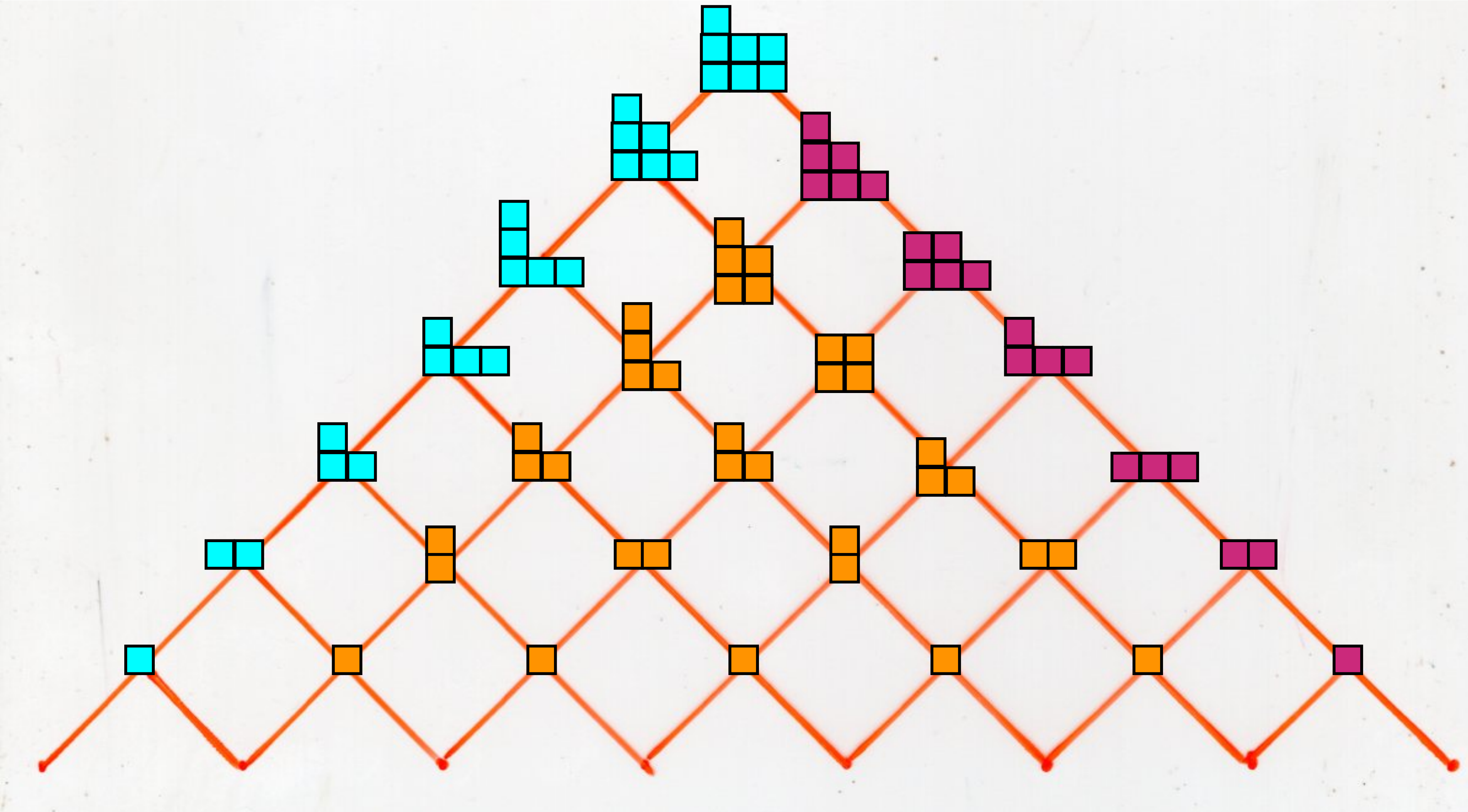


-1
0
2
-2
-1
1
0



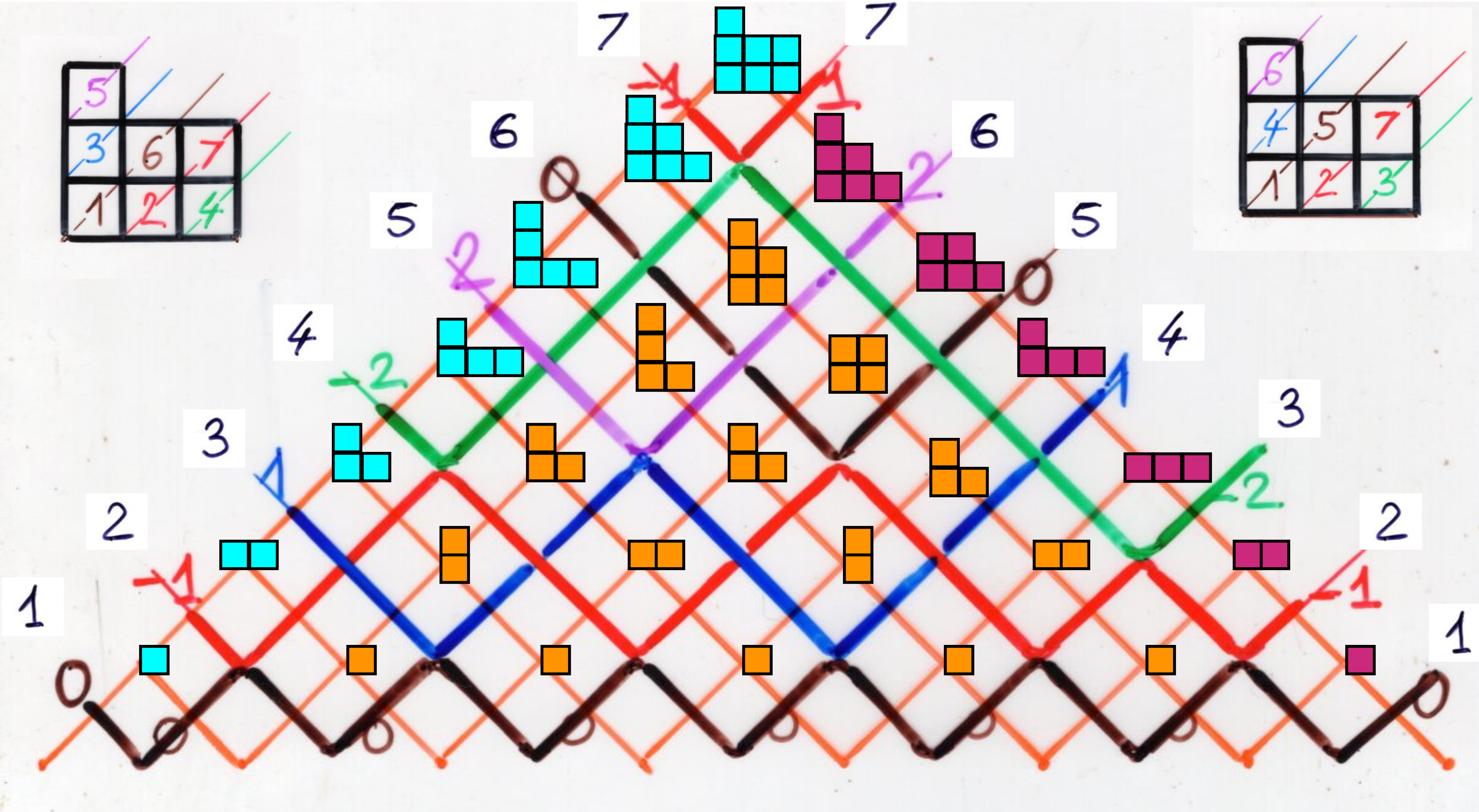
-1
2
0
1
-2
-2
-2
-2
2
0
0
0
0
1
-2
2
-1
2
2
1
1
-2
1
-1
-2
-1
-1
0
1
1
0

dual of a tableau



Schützenberger involution

dual of a tableau



Schützenberger involution

Proposition The map $T \longrightarrow T^*$ is an involution $(T^*)^* = T$

T Young tableau

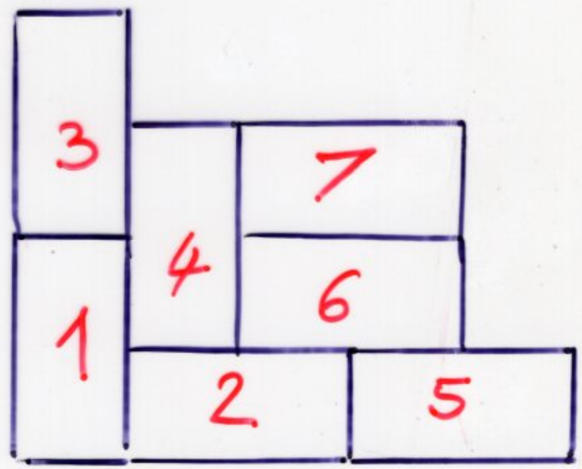
T^* dual tableau

evac (T)

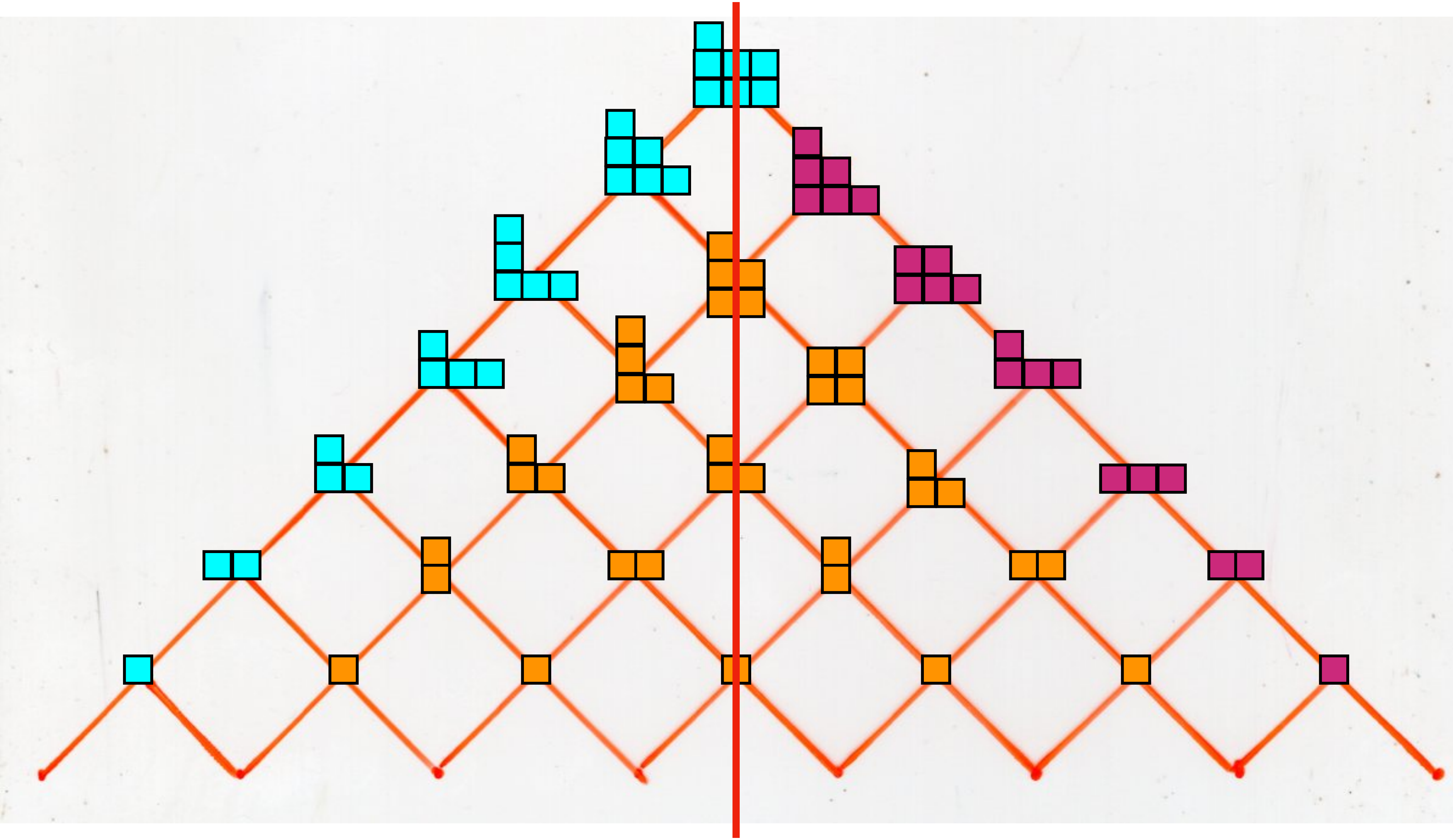
other notation

Proposition

tableaux such that $T = T^*$ are in bijection with domino tableaux



dual of a tableau



Schützenberger involution

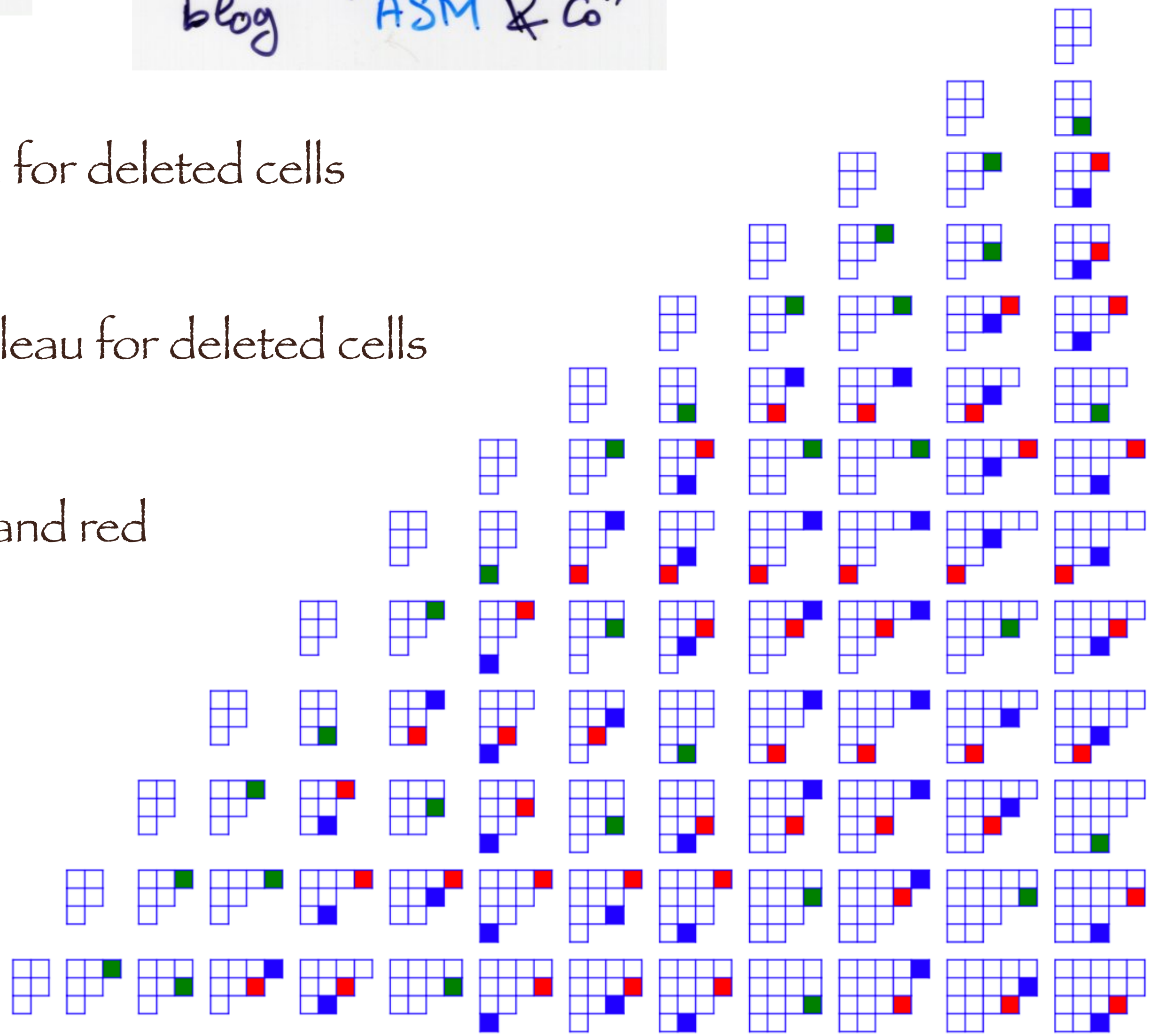
Betrema

website "Tableaux"
blog "ASM & Co"

blue cells:
in each row of the tableau for deleted cells

red cells:
in each column of the tableau for deleted cells

greene cells:
cells which are both blue and red



paper: GASCom 2018, Athens, June 2018

see the V-book:

The Art of Bijective Combinatorics

Part III. The Cellular ansatz:

bijective combinatorics and quadratic algebra

Ch1. RSK the Robinson-Schensted-Knuth correspondence

Video-book Part I, II, III

- 57 videos. (1:30 each)

- 6800 slides

- www.viennot.org

The Cellular ansatz

"The cellular ansatz"

quadratic algebra Q

$UD = DU + Id$

Q-tableaux

combinatorial objects on a 2D lattice

permutations

towers placements

representation of Q by combinatorial operators

bijections

RSK ⟷

pairs of Young tableaux

(i) first step

(ii) second step

commutations

rewriting rules

planarization

(iii) third step

"duplication"

↕

edge local rules

"The cellular ansatz"

quadratic algebra Q

Q-tableaux

combinatorial objects on a 2D lattice

representation of Q by combinatorial operators

bijections

Physics

$DE = qED + E + D$

alternative tableaux

EXF

$\longleftrightarrow$

"Laguerre histories"

permutations

orthogonal polynomials

commutations

rewriting rules

planarization

(iii) third step

"duplication" $\longleftrightarrow$ edge local rules

alternative tableaux $\longleftrightarrow$ Adela(T) = (P, Q)

The philosophy of the cellular ansatz

combinatorial representation
of the quadratic algebra

$DE = qED + E + D$

alternative
tableaux

- commutations diagrams

EXF

"Laguerre histories"

Equivalence

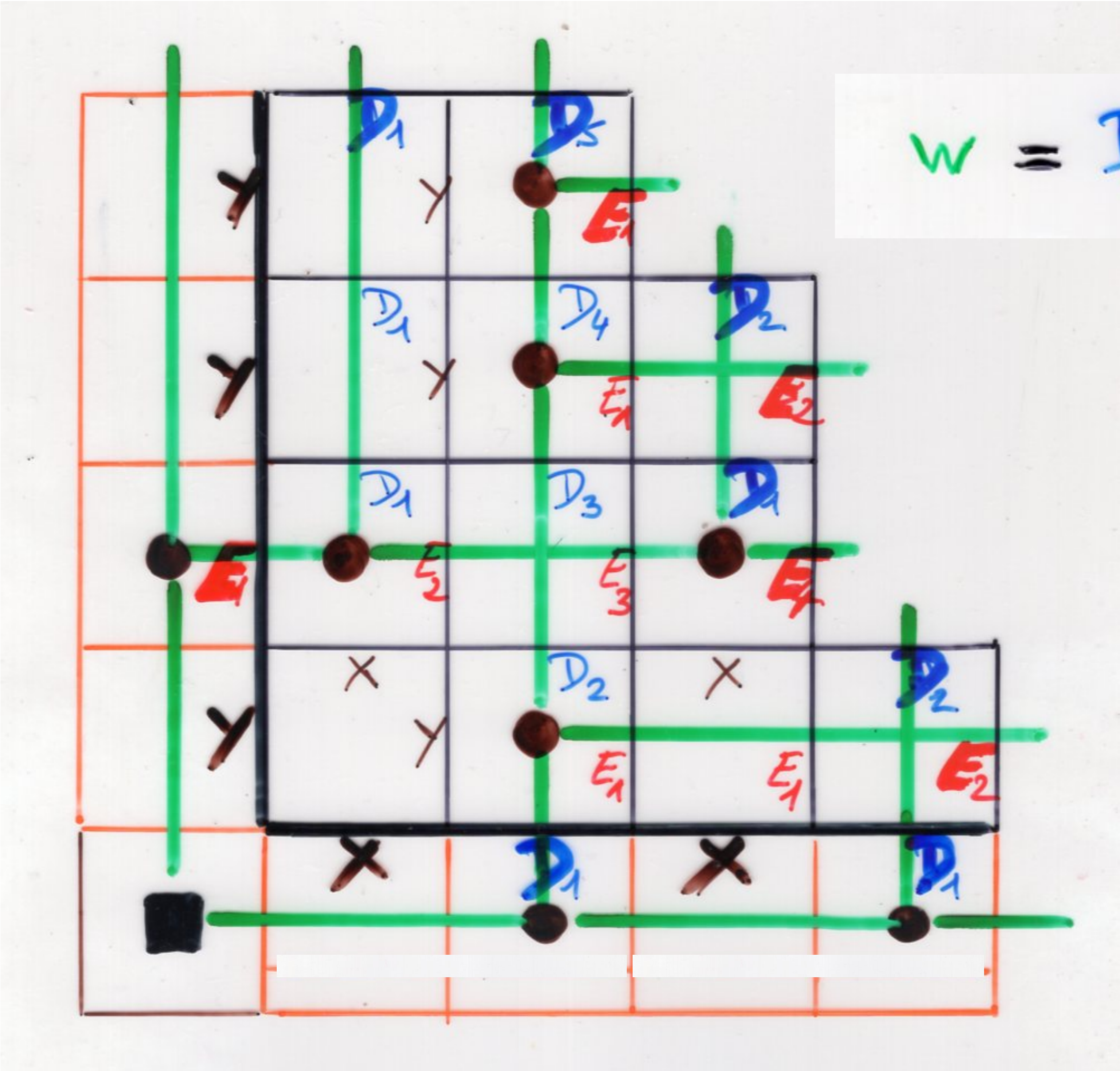
- local rules on edges

with duplication of equations
in the reverse quadratic algebra

The Tamil bijection

alternative or tree-like tableaux (size n)

some words $w \in \{D_i, E_j \,;\, i,j \geq 1\}^*$, $|w|=n$



$w = D_1\, D_5\, E_1\, D_2\, E_2\, E_4\, D_2\, E_2$

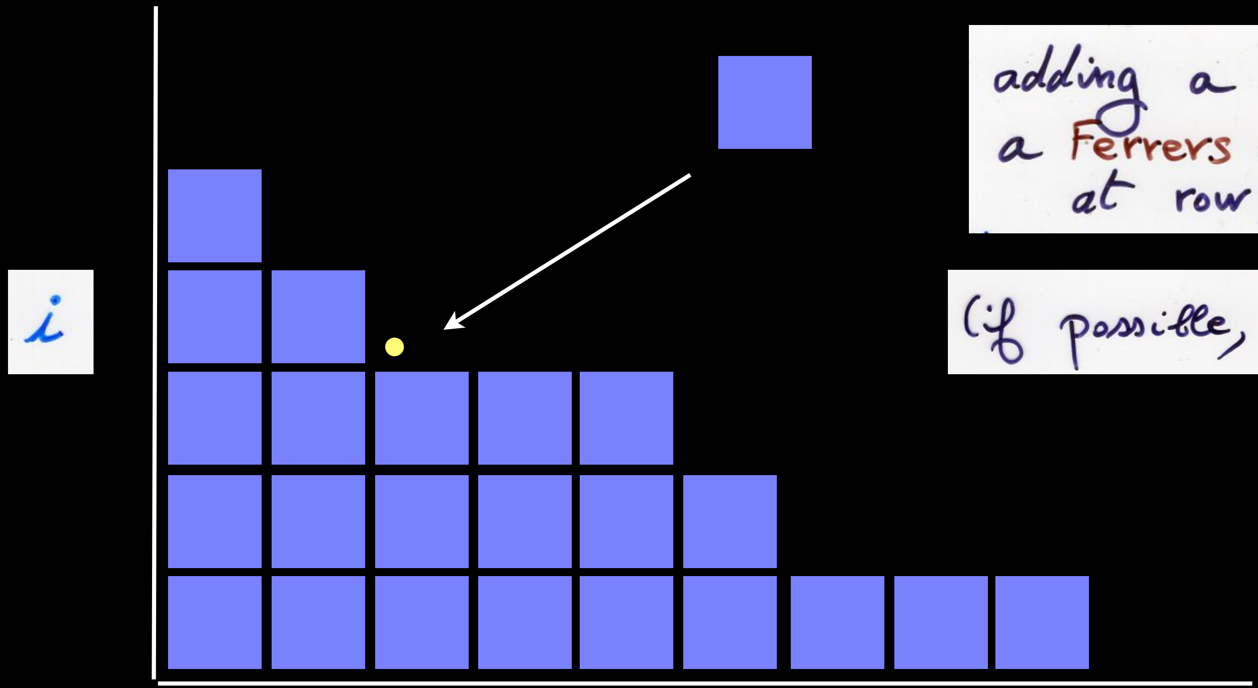
Combinatorial representation of

the algebra

$$UD = DU + Id$$

notations

operator U_i



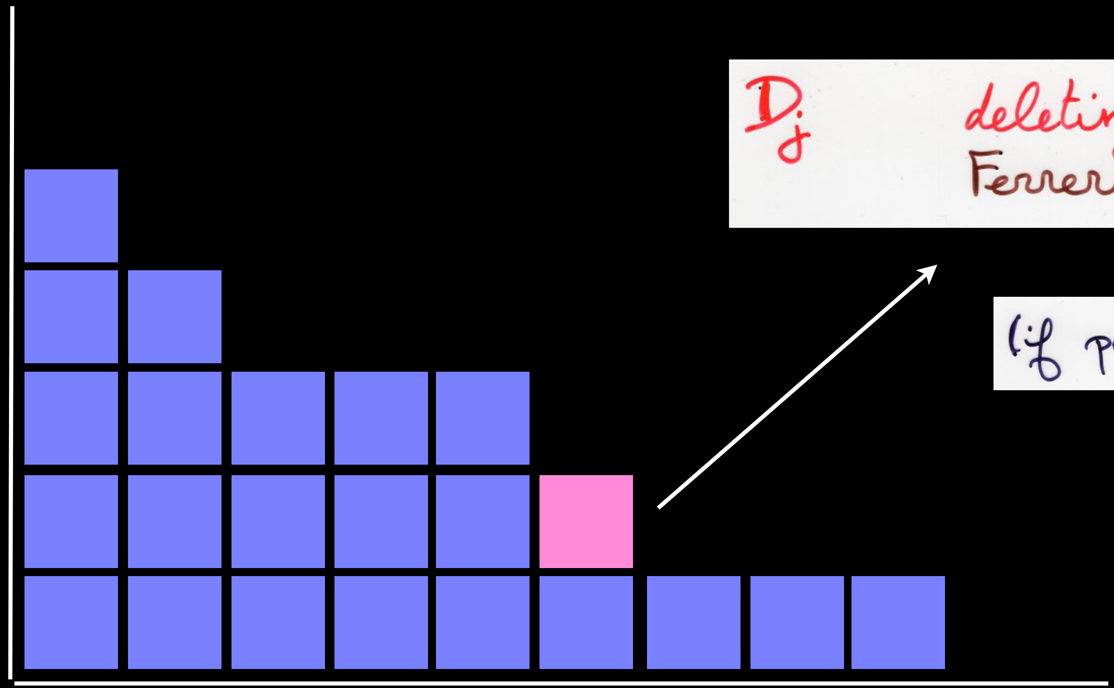
adding a cell in a Ferrers diagram ρ at row i

(if possible, else $U_i(\rho)=0$)

$$U_i(\rho) = \rho + (i)$$

$D_j(\rho) = \rho - (j)$

j

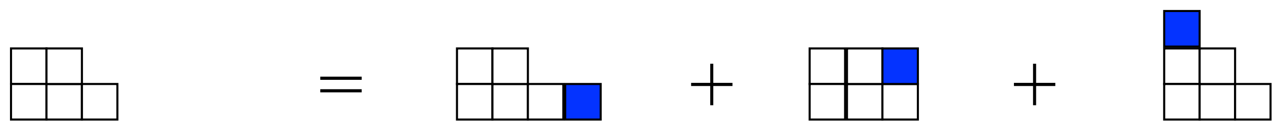


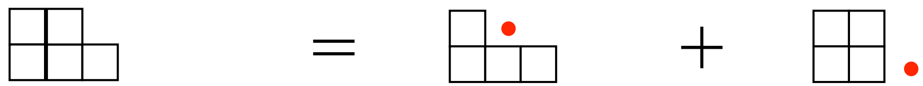
D_j deleting a cell in a Ferrers diagram ρ at row j

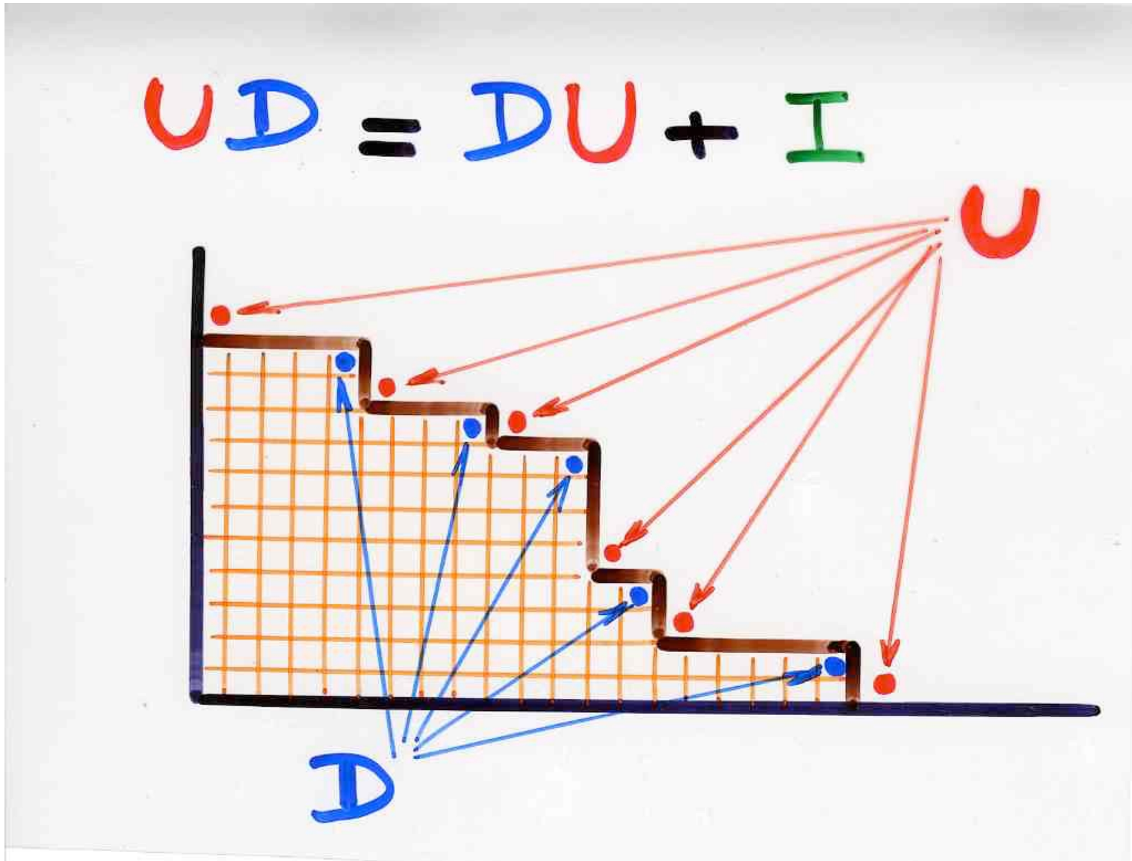
(if possible, else $D_j(\rho) = 0$)

$$U = \sum_{i \geq 1} U_i \qquad\qquad D = \sum_{i \geq 1} D_i$$

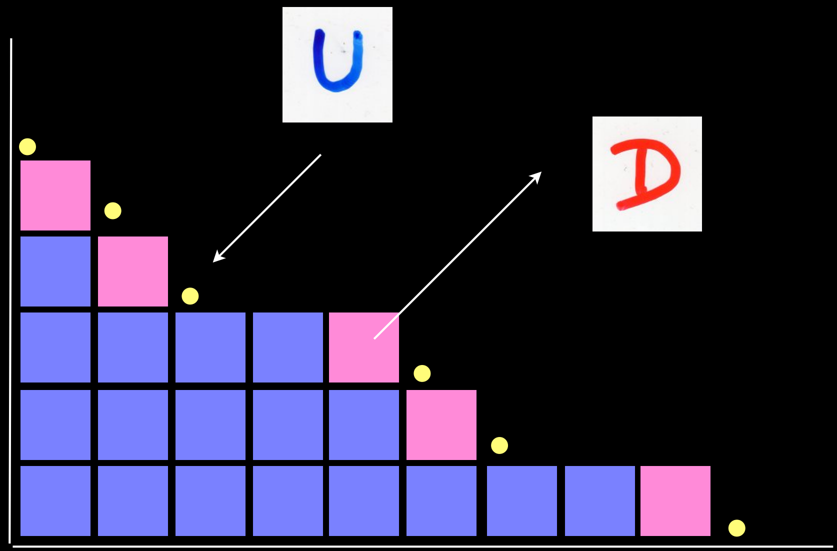
U and D are operators acting on the vector space generated by Ferrers diagrams

U 

D 

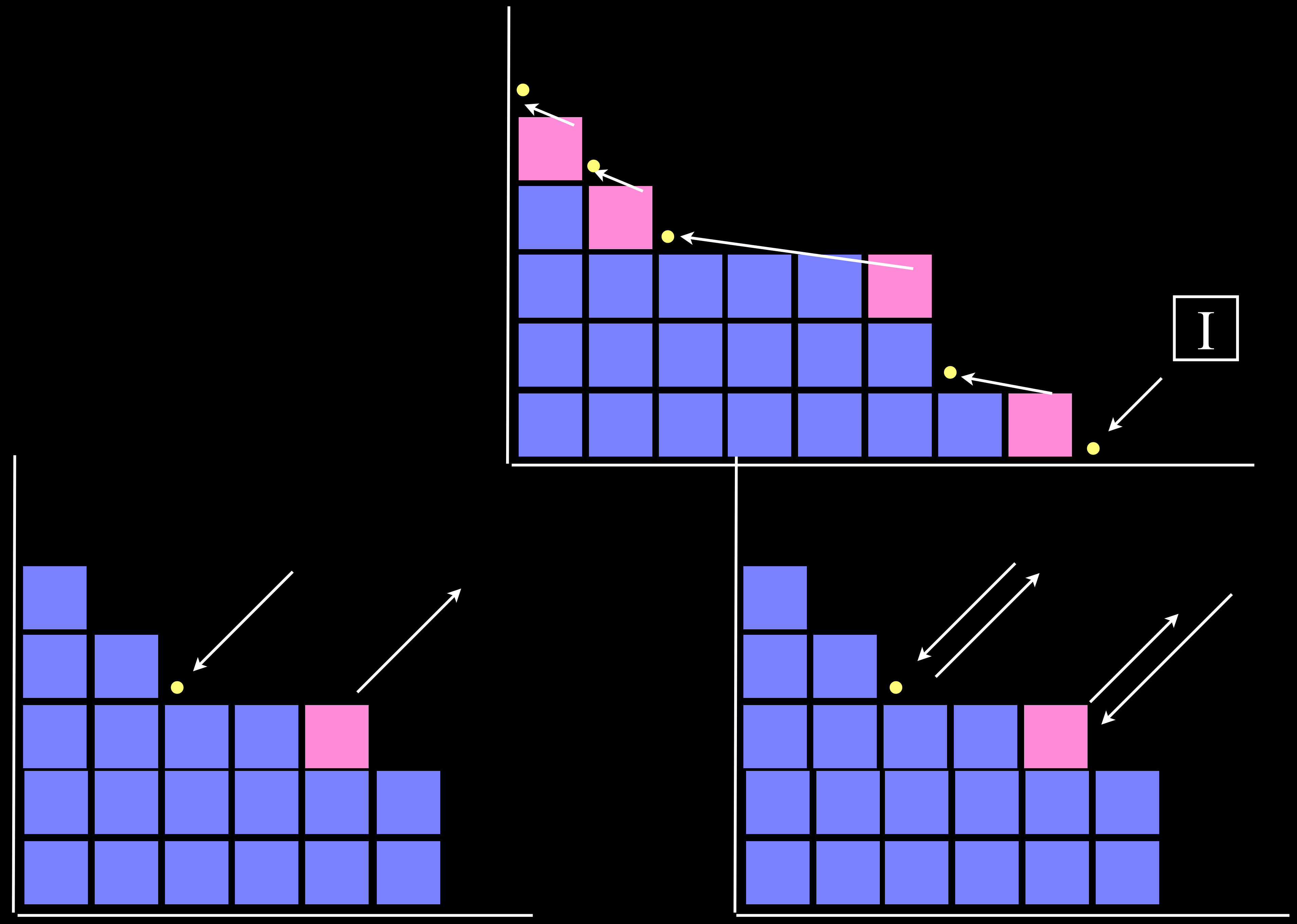

UD = DU + I
U
D

operators
U and D



Young lattice

U adding
D deleting
a cell in a Ferrers diagram


I

$$UD = DU + I_v I_h$$

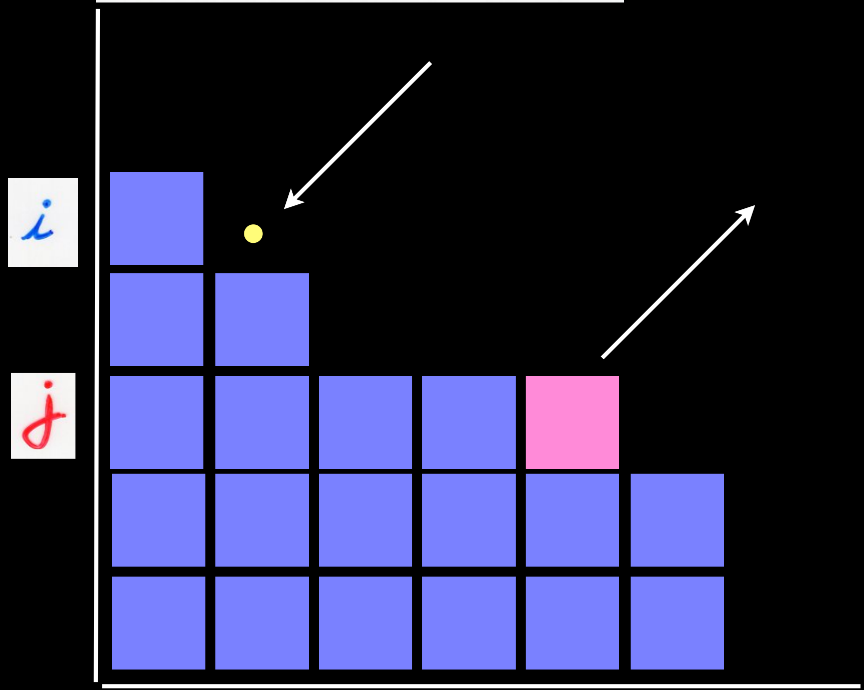
"commutation diagrams"

$$\begin{tikzcd} \nu \arrow[d, "I_v"'] & \bullet \\ \rho \arrow[r, "I_h"'] & \mu \end{tikzcd} \qquad \begin{tikzcd} (\nu, p) \arrow[d, "D"'] & \\ (\rho, m) \arrow[r, "U"'] & \mu \end{tikzcd} \quad \xleftrightarrow{\text{bijection}} \quad \begin{tikzcd} (\nu, p') \arrow[r, "U"] & (\lambda, m') \arrow[d, "D"] \\ & \mu \end{tikzcd}$$

p, m, p', m' are "positions"

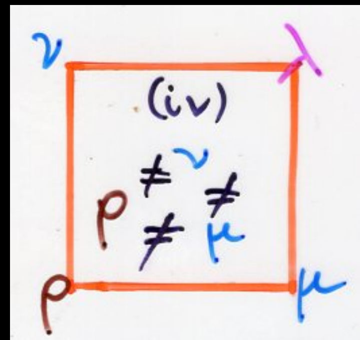
in ν, ρ, ν, λ respectively

$$\begin{tikzcd} (\nu, p) \arrow[d, "D"'] \\ (\rho, m) \arrow[r, "U"'] & \mu \end{tikzcd} \quad \longleftrightarrow \quad \begin{tikzcd} (\nu, p') \arrow[r, "U"] & (\lambda, m') \arrow[d, "D"] \\ & \mu \end{tikzcd}$$



$$p = j \qquad m = i$$

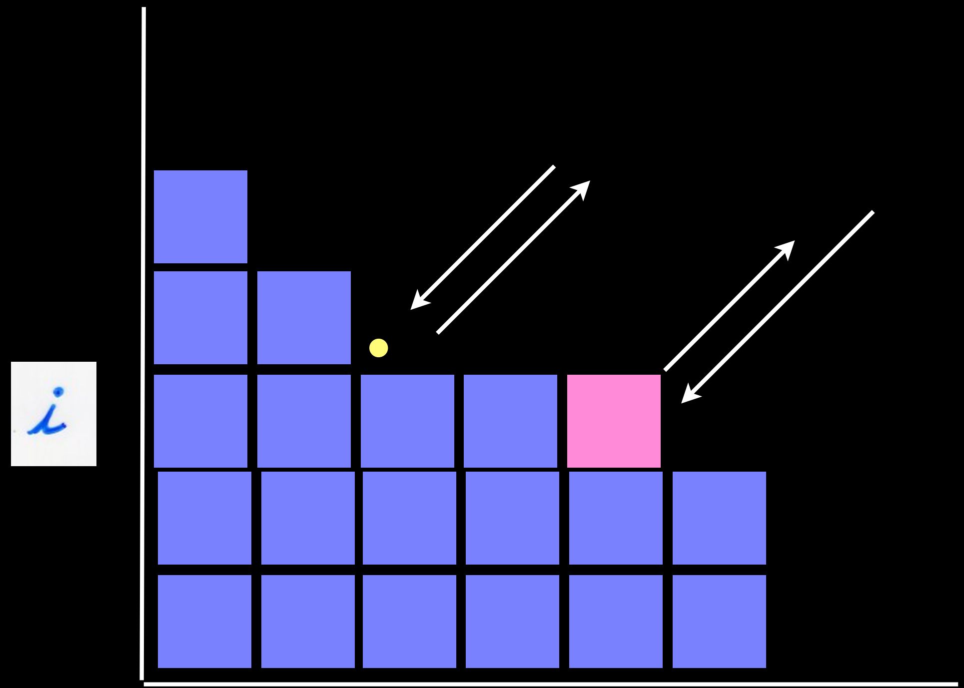
$$p' = i \qquad m' = j$$



$$\nu = \rho + (j)$$
$$\mu = \rho + (i)$$
$$\lambda = \rho + (i) + (j)$$

$$\begin{array}{ccc} (\nu, p') & \xrightarrow{U} & (\lambda, m') \\ & & \Big\downarrow D \\ & & \mu \end{array}$$

$$\begin{array}{ccc} (\nu, p) & & \\ D \Big\downarrow & & \\ (\rho, m) & \xrightarrow{U} & \mu \end{array}$$



$p = i$

$m = i$

$p' = i+1$

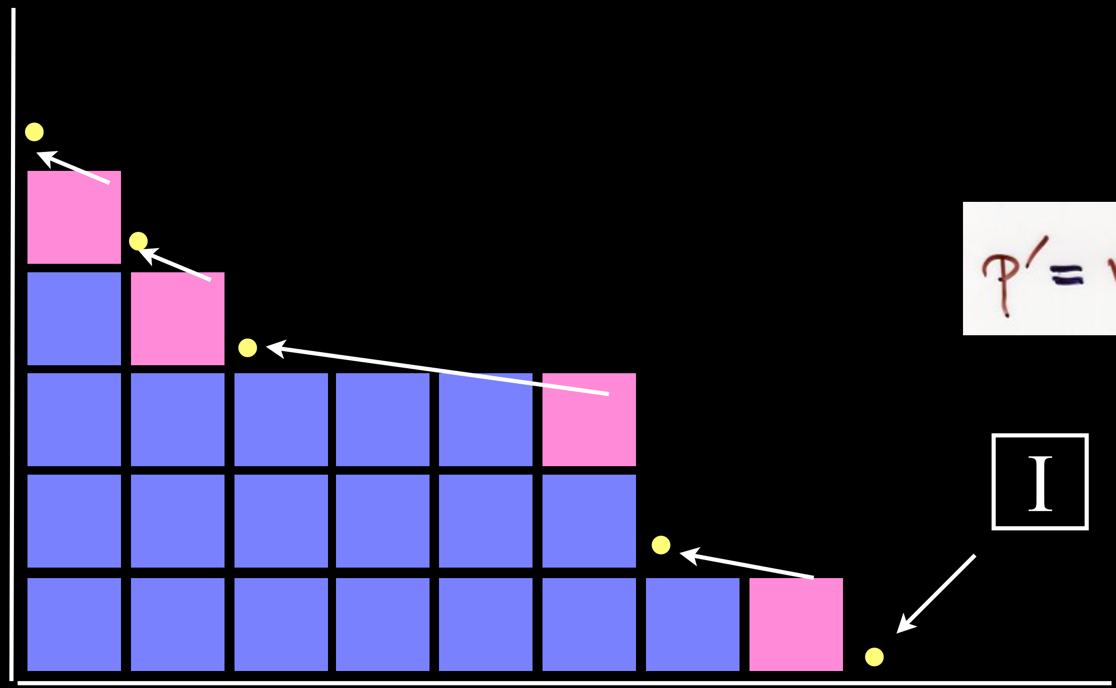
$m' = i+1$

$$\begin{tikzcd} \nu \arrow[r, dash] \arrow[d, dash] \arrow[dr, phantom, "\substack{(v) \\ \rho \neq \mu = \nu}"] & \lambda \arrow[d, dash] \\ \rho \arrow[r, dash] & \mu \end{tikzcd}$$

$\mu = \nu = \rho + (i)$

$\lambda = \mu + (i+1)$

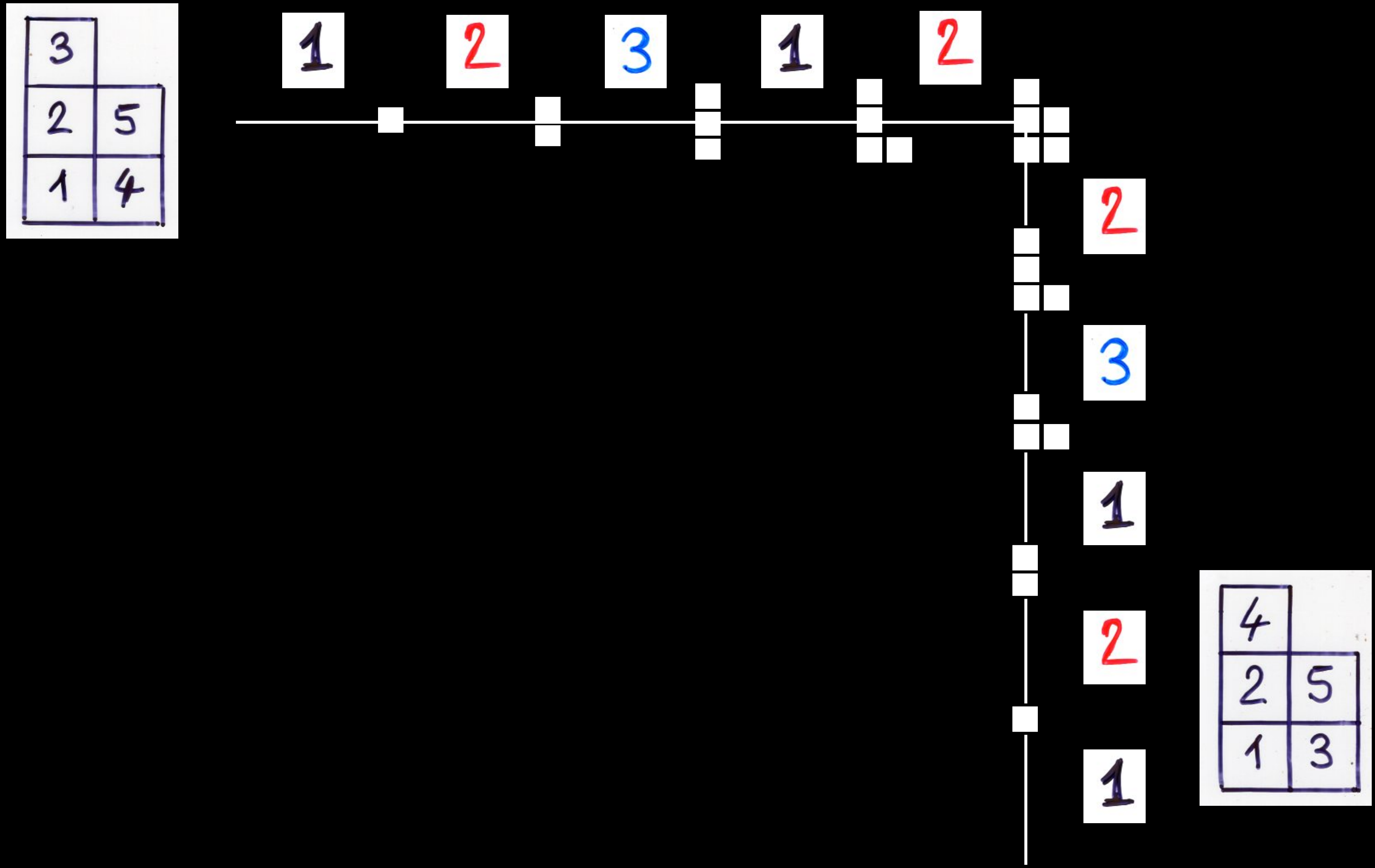
$$\begin{tikzcd} \nu \arrow[d, "I_v"'] & \\ \rho \arrow[r, "I_h"'] & \mu \end{tikzcd} \longleftrightarrow \begin{tikzcd} (\nu, p') \arrow[r, "U"] & (\lambda, m') \arrow[d, "D"] \\ & \mu \end{tikzcd}$$



$$p' = m' = 1$$

$$\begin{tikzcd} \nu \arrow[r, dash] \arrow[d, dash] \arrow[dr, phantom, "\begin{matrix}(vi)\\ \rho=\mu=\nu\end{matrix}"] & \lambda \arrow[d, dash] \\ \rho \arrow[r, dash] & \mu \end{tikzcd}$$

$$\lambda = \left\{\begin{matrix}\rho\\ \mu\\ \nu\end{matrix}\right. + (1)$$


3
2 5
1 4
1
2
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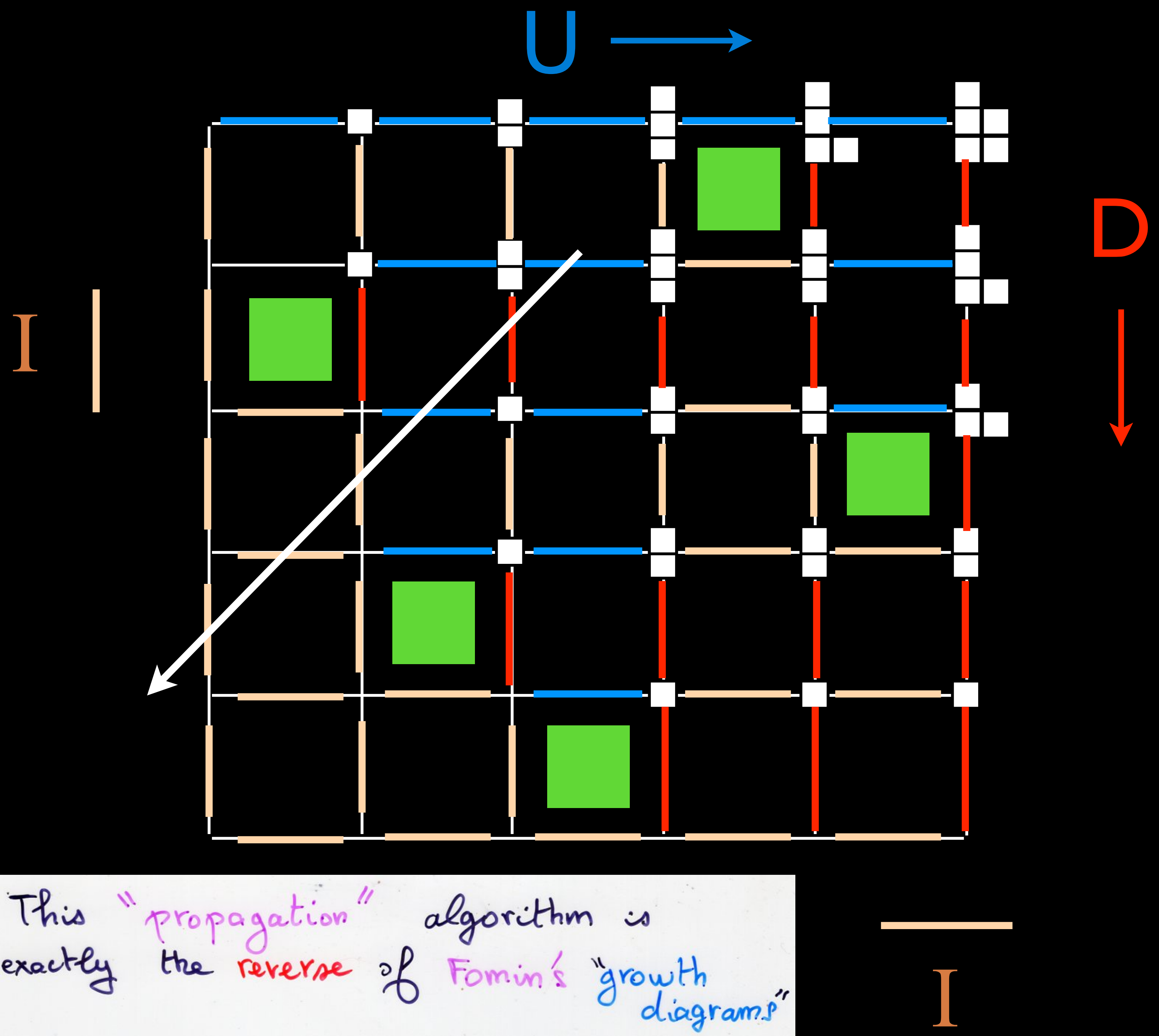
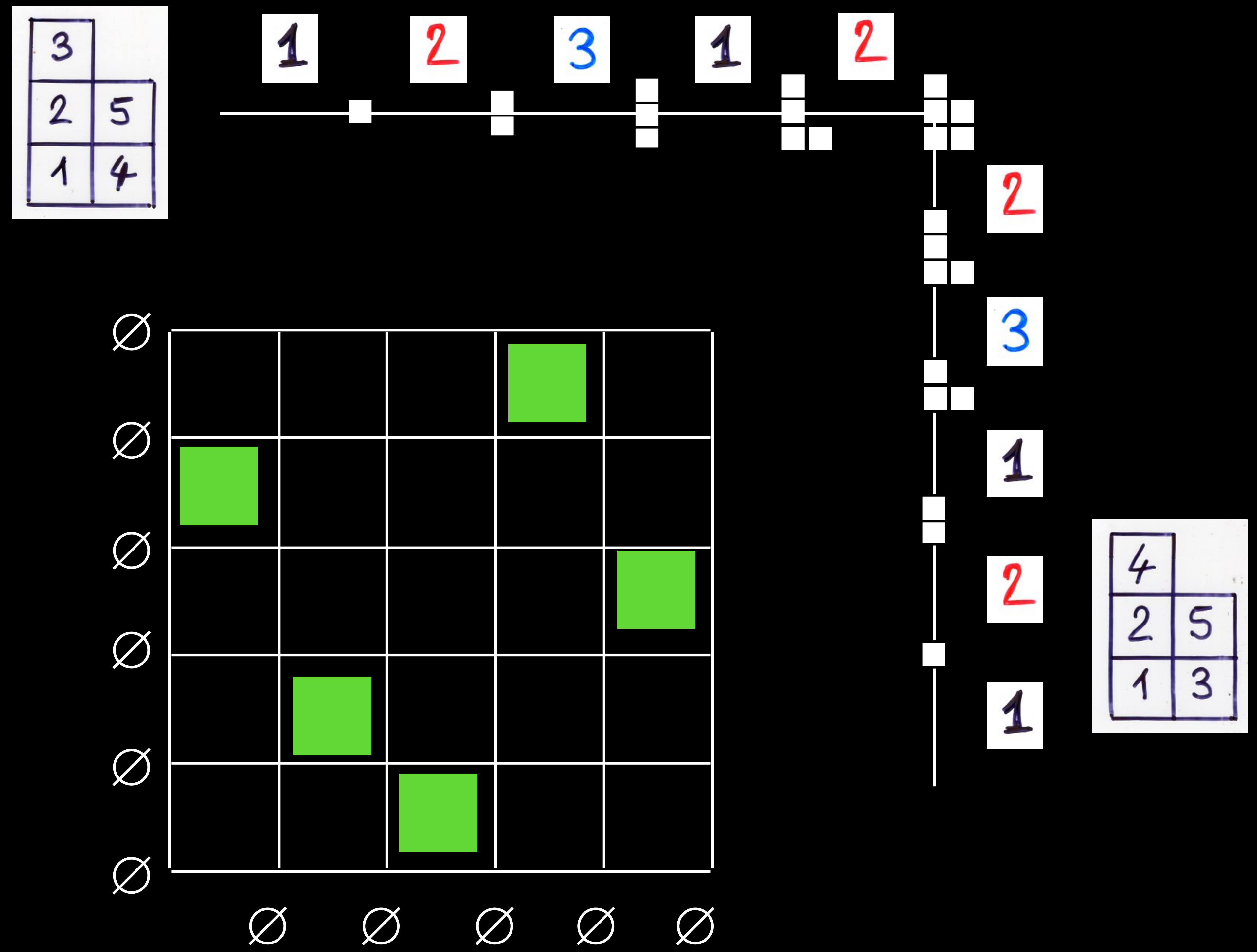
1
2
2
3
1
2
1
4
2 5
1 3

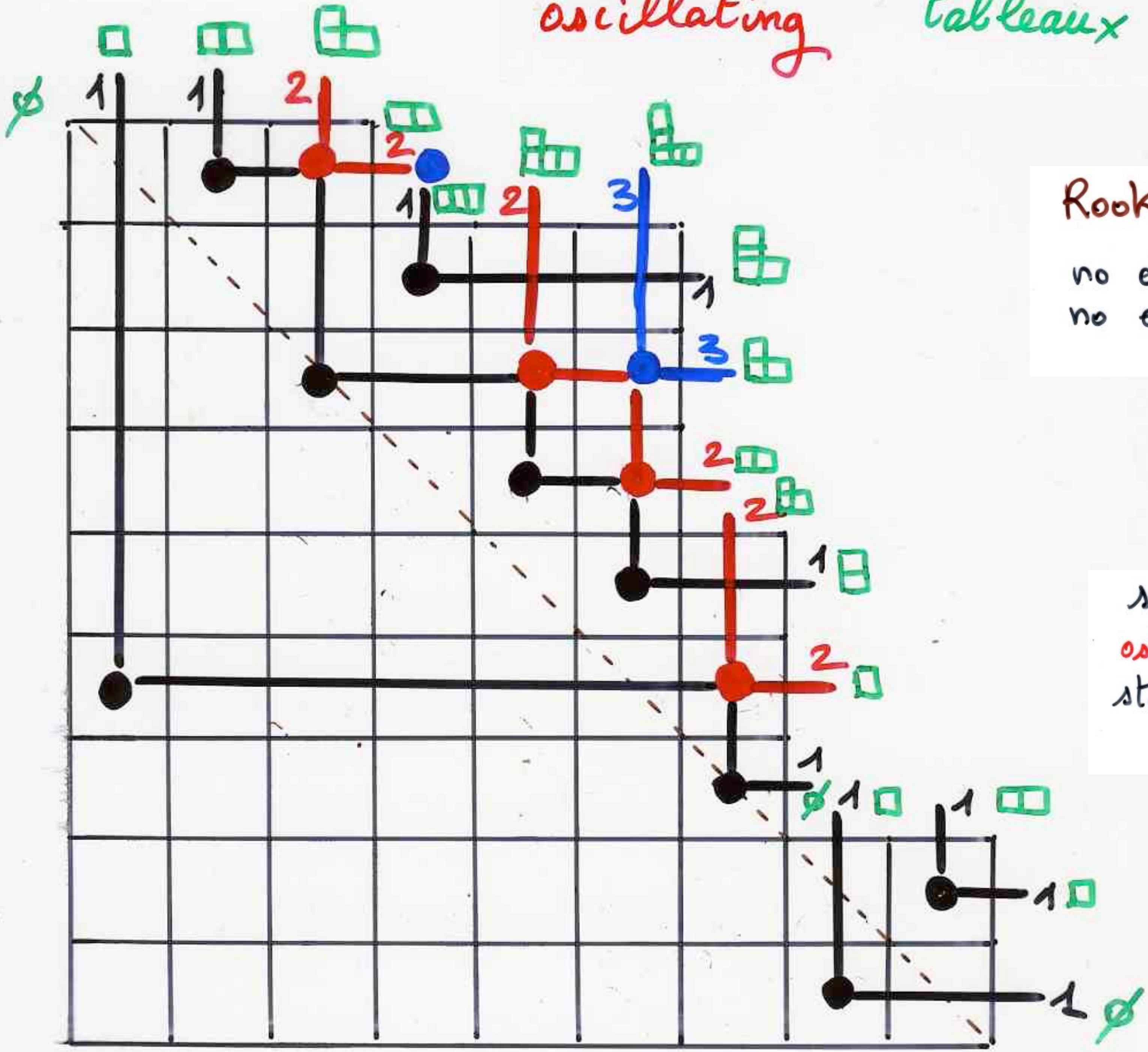


This "propagation" algorithm is exactly the reverse of Fomin's "growth diagrams"


3
2 5
1 4
1 2 3 1 2
2 3 1 2 1
4
2 5
1 3
∅ ∅ ∅ ∅ ∅ ∅
∅ ∅ ∅ ∅ ∅

extension:
rook placements

oscillating tableaux



Rook placements
with
no empty row
no empty column

$\updownarrow$

sequences of oscillating tableaux starting and ending at $\emptyset$