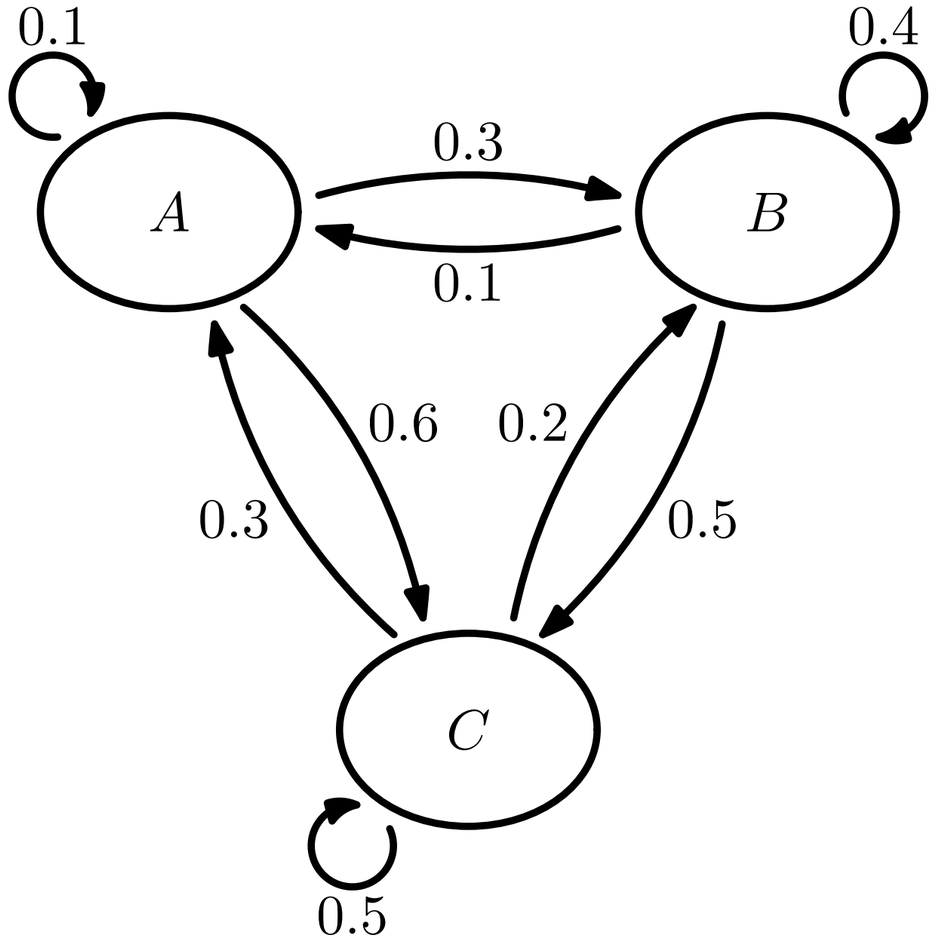
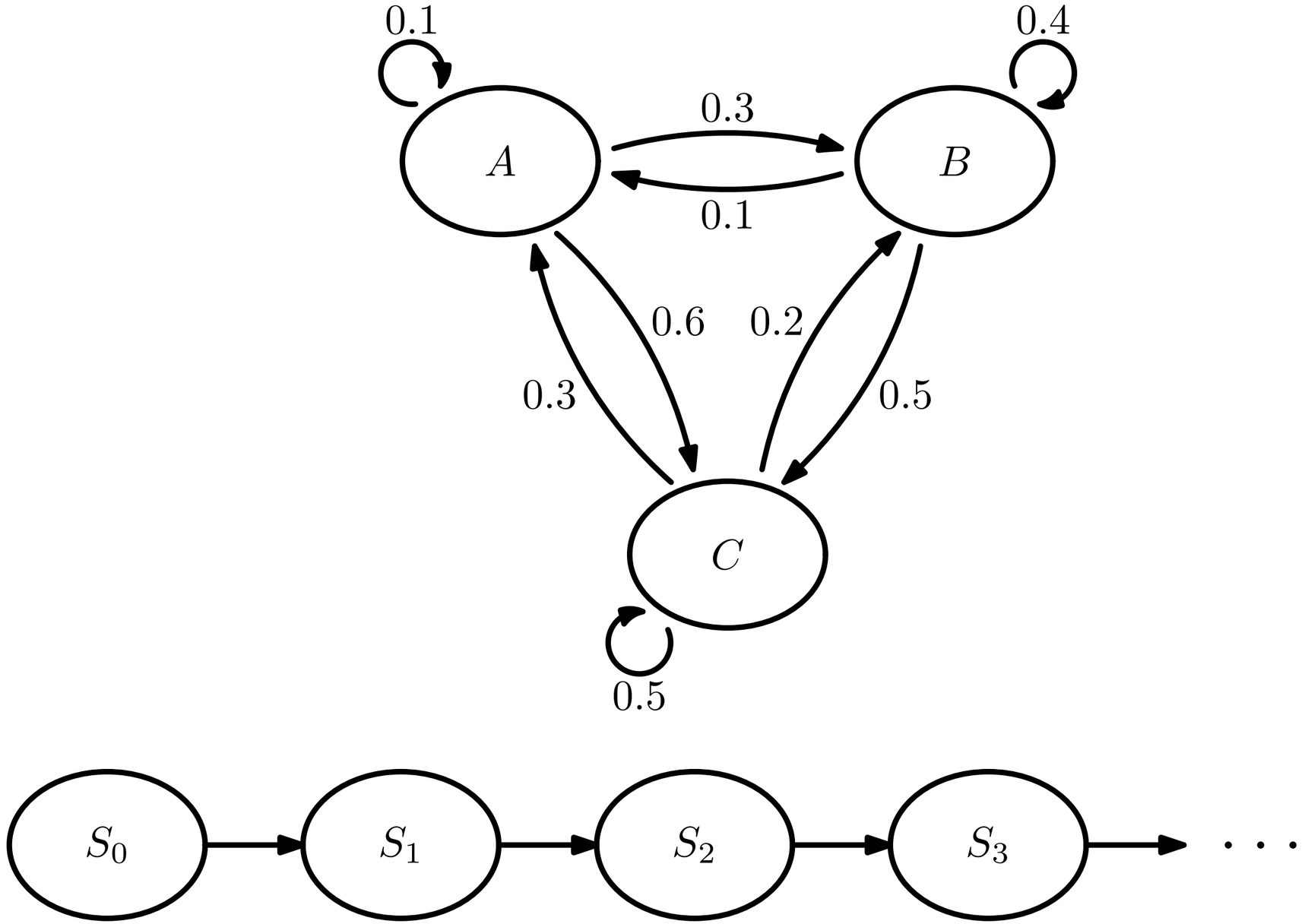
Markov chains

$$S = \{s_1, s_2, \ldots, s_n\}$$

$$S = \{s_1, s_2, \ldots, s_n\}$$

$$P(S_t|S_{t-1})$$


0.1
0.4
A
B
0.3
0.1
0.6
0.2
0.3
0.5
C
0.5

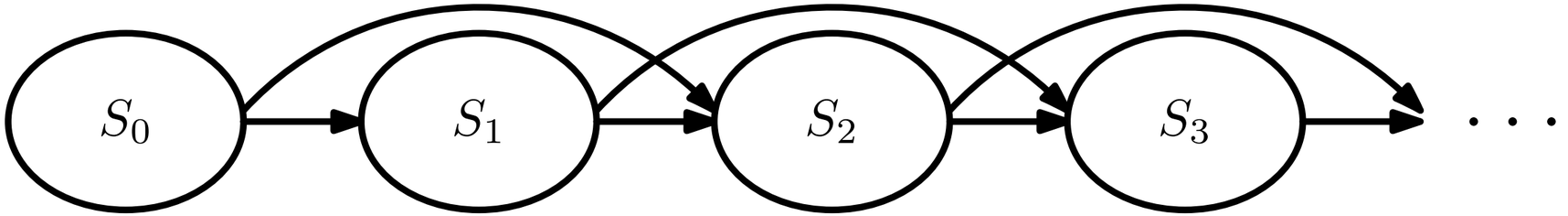

0.1
0.4
A
0.3
B
0.1
0.6
0.2
0.3
0.5
C
0.5
S_0
S_1
S_2
S_3
. . .

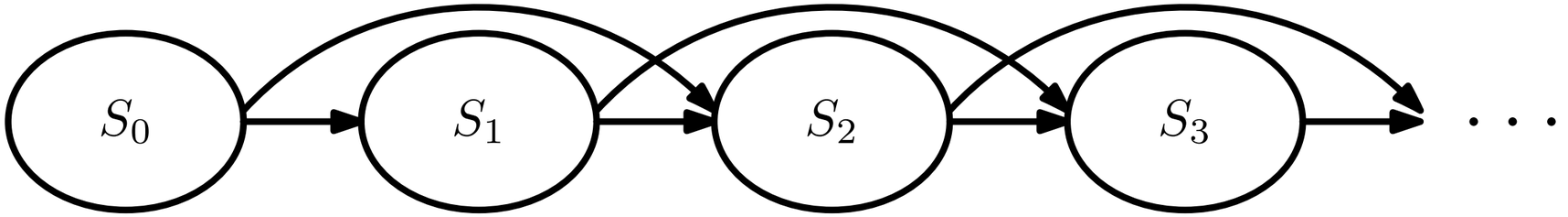
Assignment 1

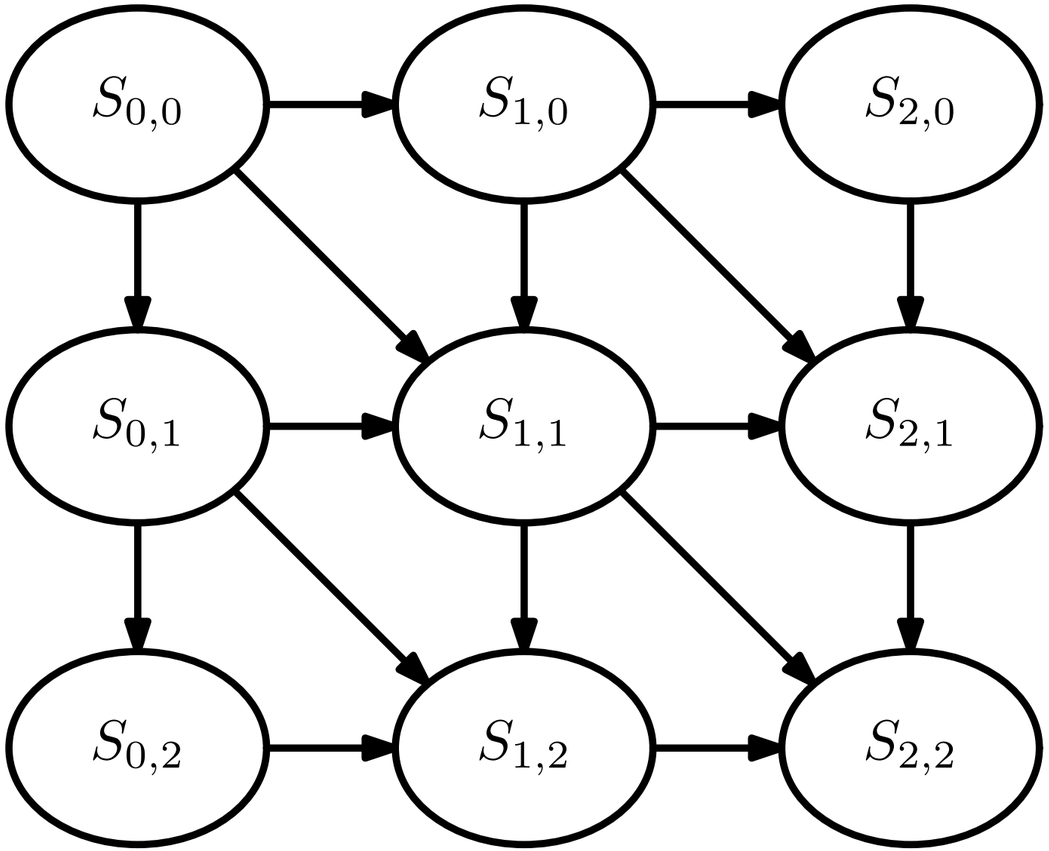
Name a (board) game that can be perfectly modelled by a Markov chain.

$$S = \{s_1, s_2, \ldots, s_n\}$$

$$P(S_t | S_{t-1} \ldots S_{t-k})$$


S_0
S_1
S_2
S_3
. . .


S_0
S_1
S_2
S_3
. . .


$S_{0,0}$
$S_{1,0}$
$S_{2,0}$
$S_{0,1}$
$S_{1,1}$
$S_{2,1}$
$S_{0,2}$
$S_{1,2}$
$S_{2,2}$

Super Mario Bros.

Generating Maps Using Markov Chains

Sam Snodgrass, Santiago Ontañón
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Philadelphia, PA, USA
sps74@drexel.edu, santi@cs.drexel.edu

A Hierarchical Approach to Generating Maps Using Markov Chains

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A Hierarchical MdMC Approach to 2D Video Game Map Generation

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Controllable Procedural Content Generation via Constrained Multi-Dimensional Markov Chain Sampling

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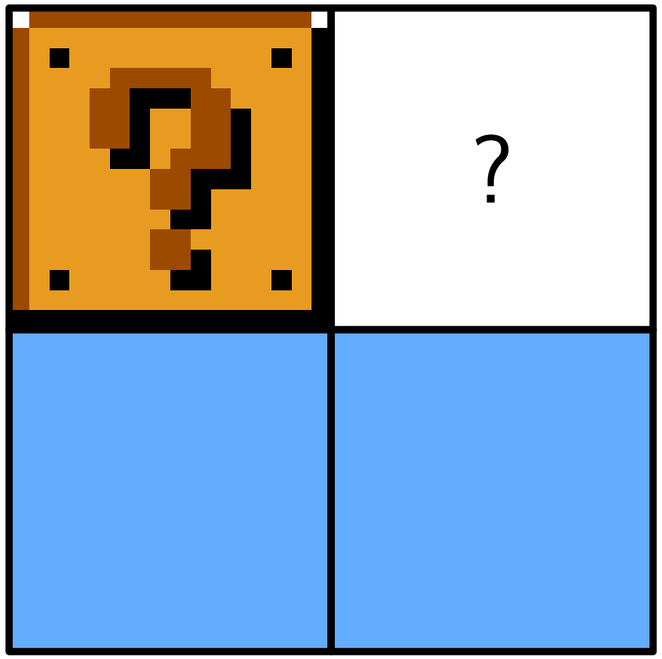
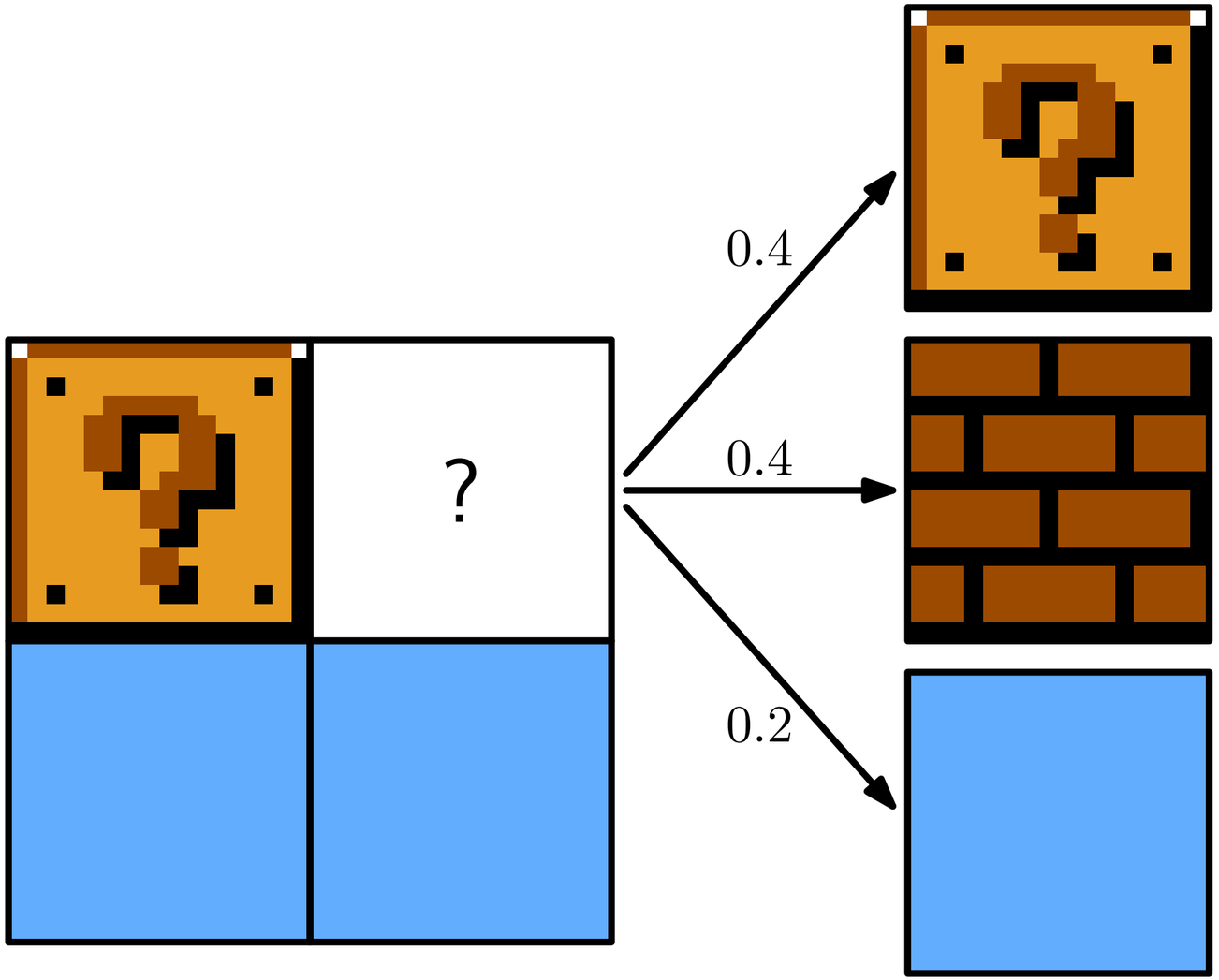
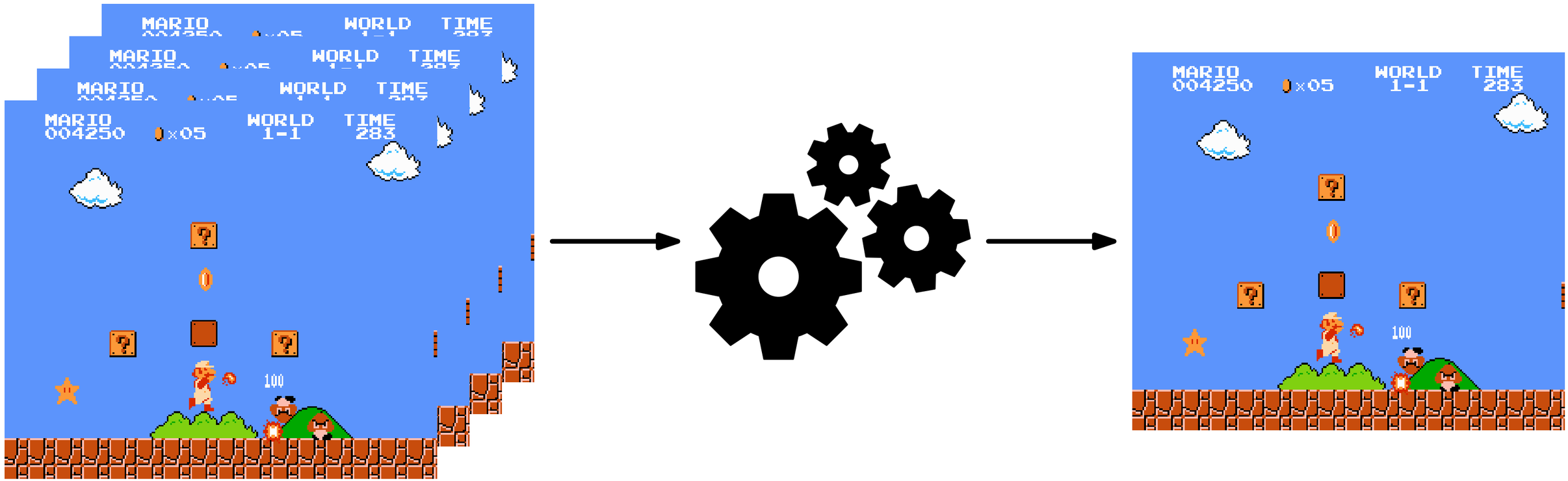
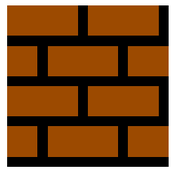
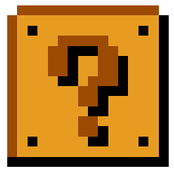
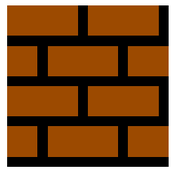
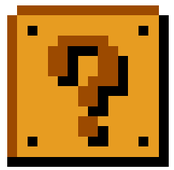
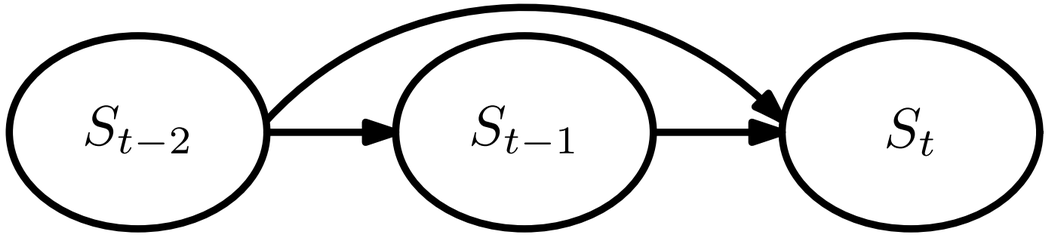


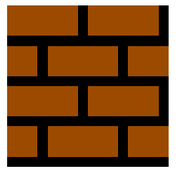
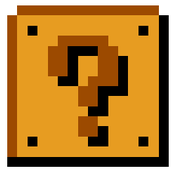

?
0.4
0.4
0.2

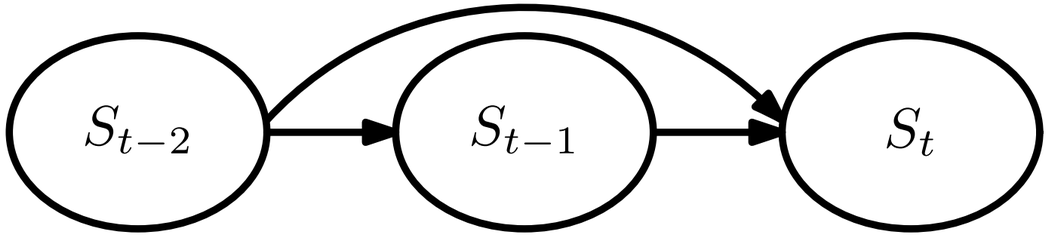

MARIO
WORLD
TIME
MARIO
004250
x05
1-1
283
100

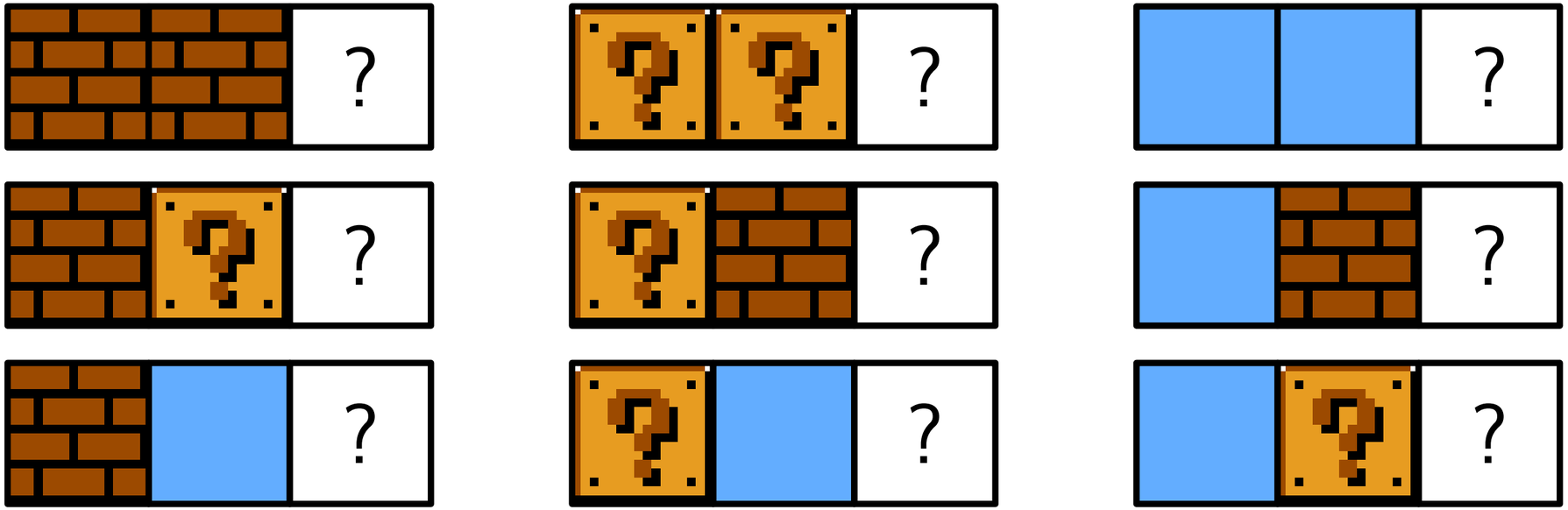
$S = \{$  ,  ,  $\}$

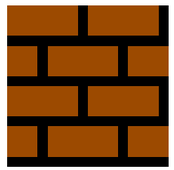
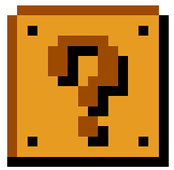
$S = \{$  ,  ,  $\}$

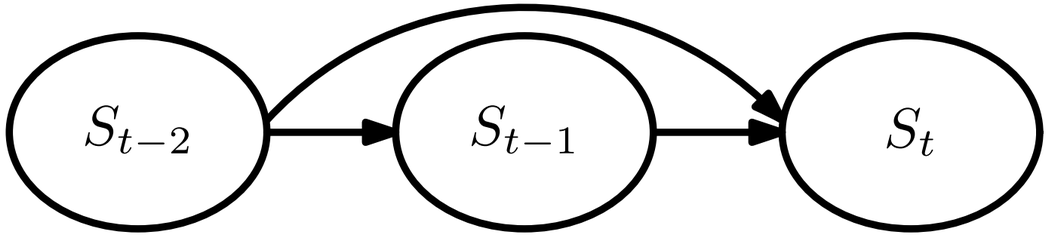


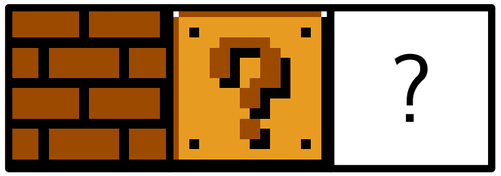
$S = \{$  ,  ,  $\}$

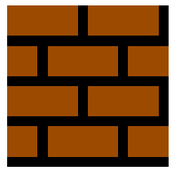
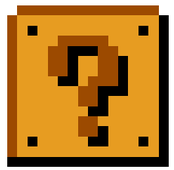


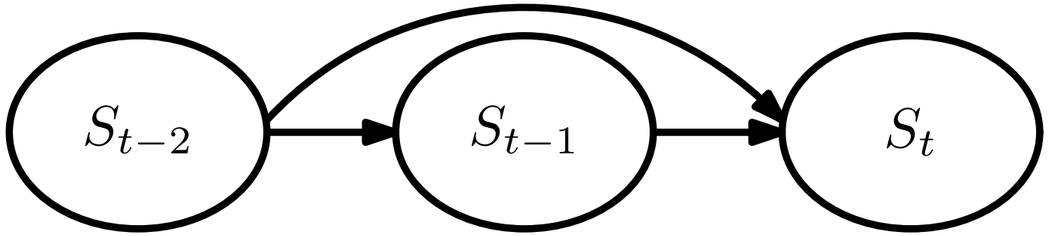


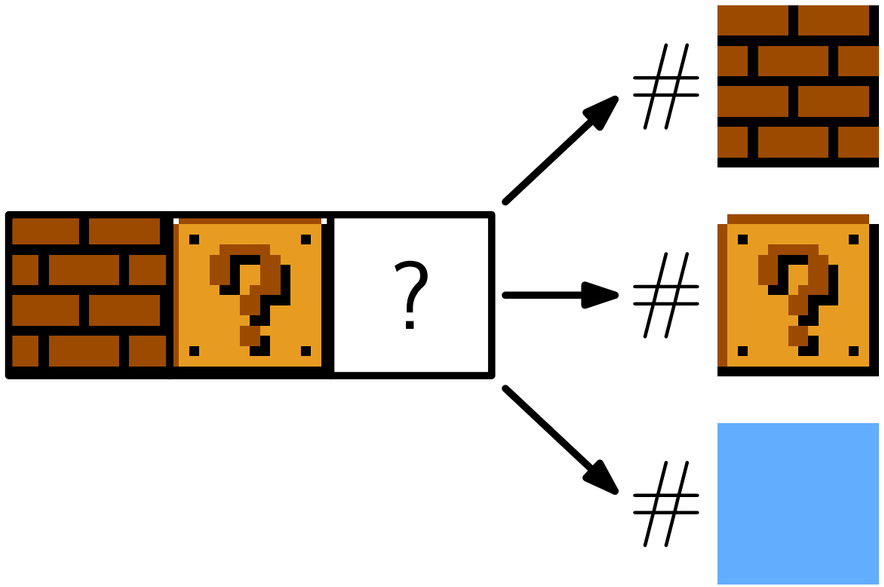
$S = \{$  ,  ,  $\}$

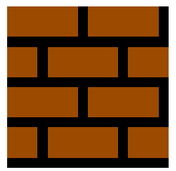
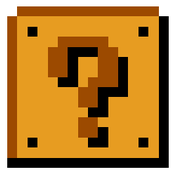


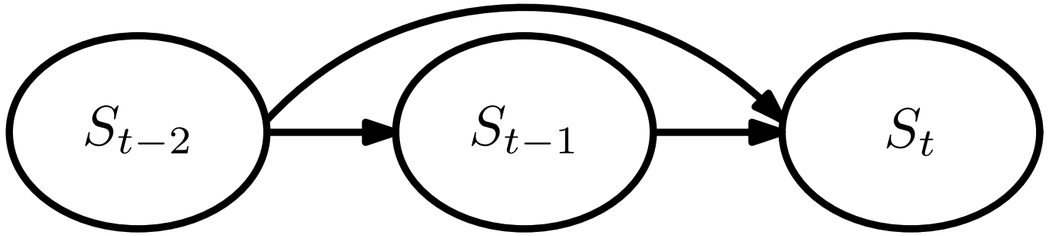


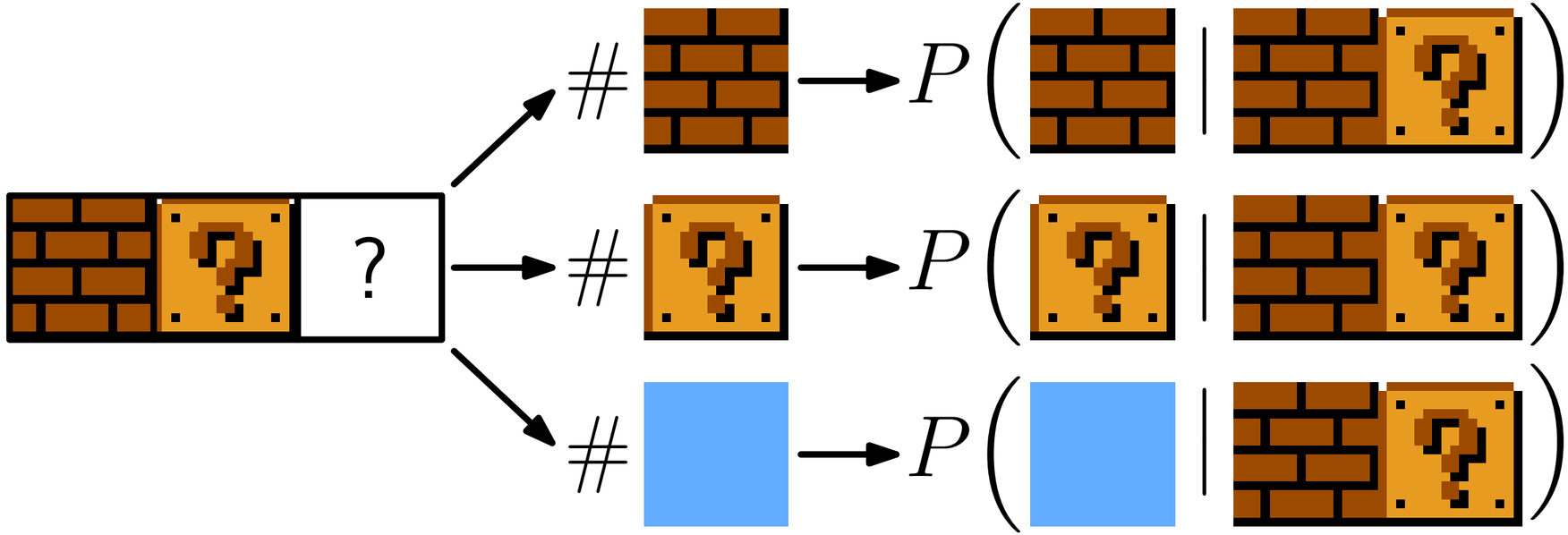
$S = \{$  ,  ,  $\}$





$S = \{$  ,  ,  $\}$


S_{t-2}
S_{t-1}
S_t

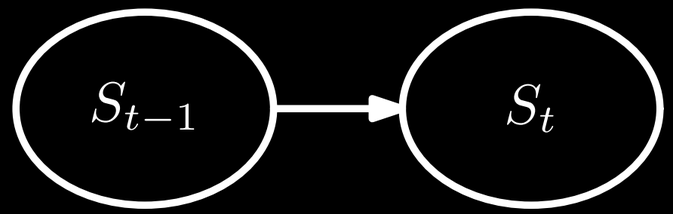

?
#
$P\left(\quad | \quad \right)$
#
$P\left(\quad | \quad \right)$
#
$P\left(\quad | \quad \right)$

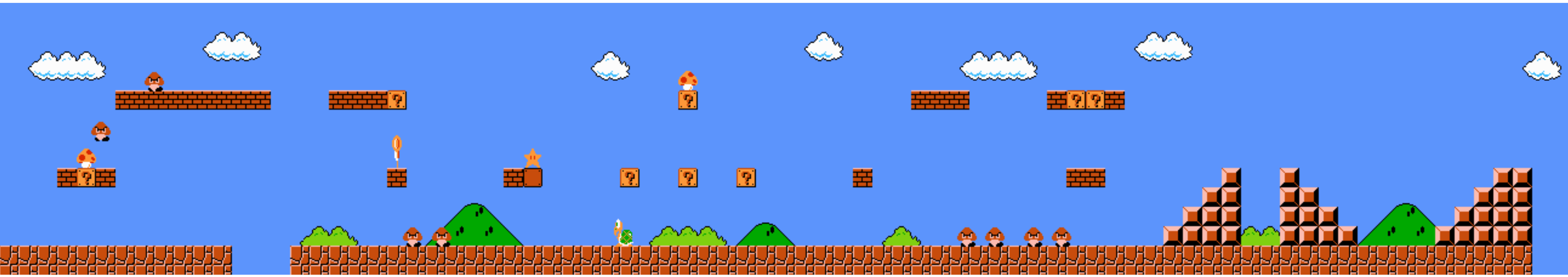
Assignment 2

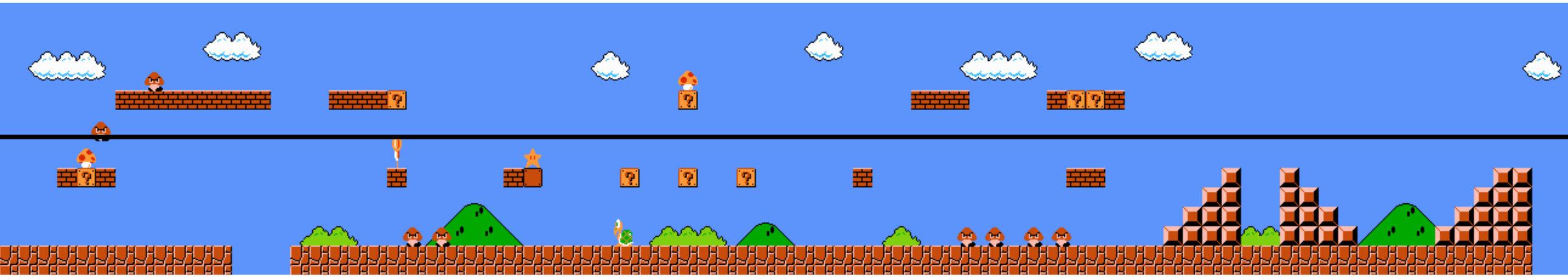
What important property can a level generated by a Markov chain not guarantee?

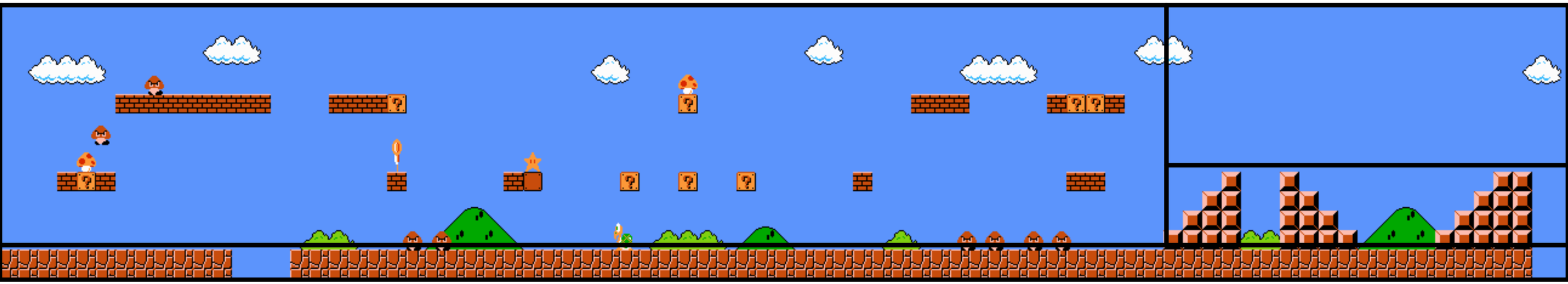
Assignment 3

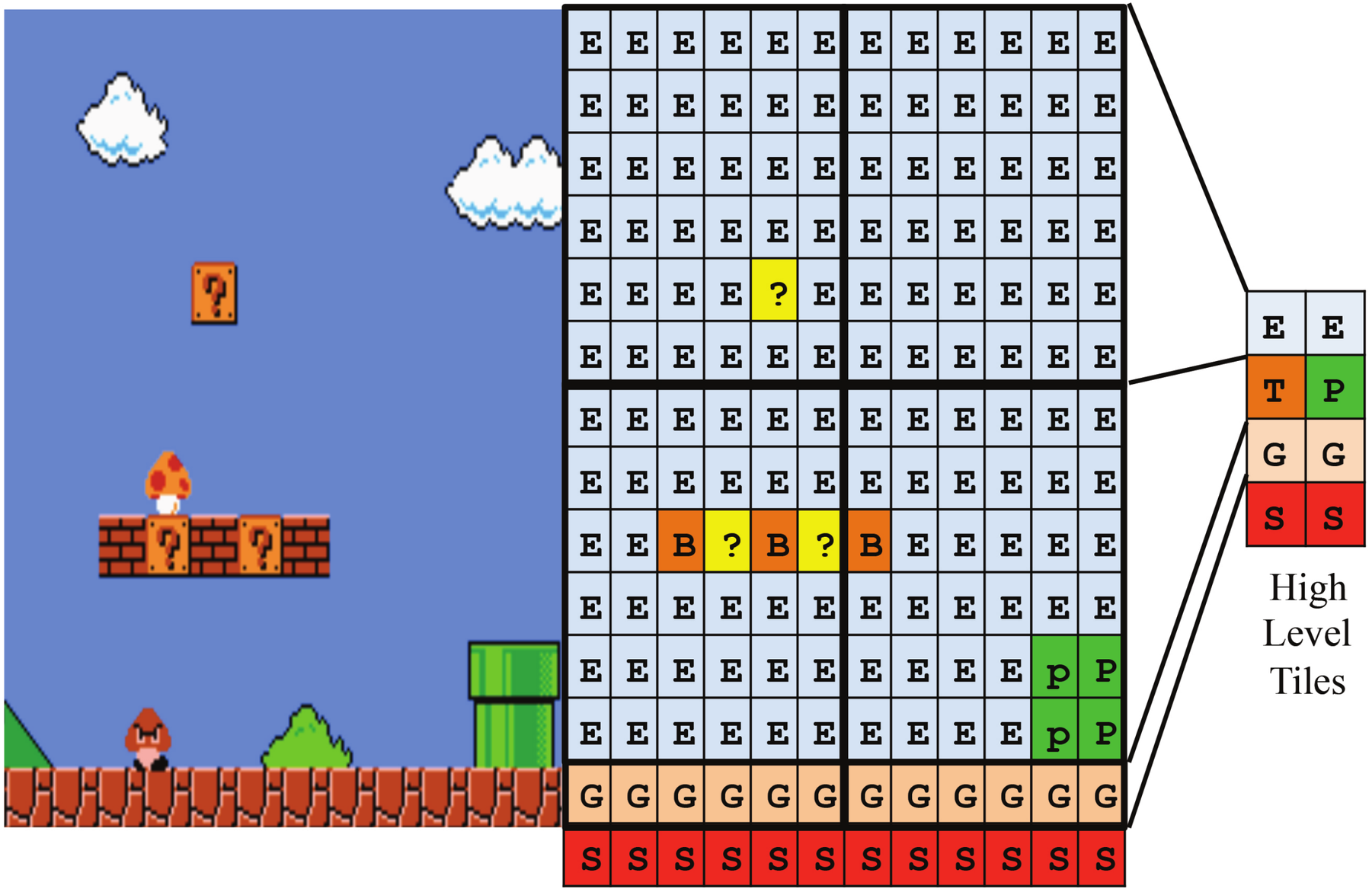
Given $S = \{a, b, c\}$, calculate the probability distribution $P(S_t|S_{t-1})$
when training a Markov chain on the example sequence $abbccbaabcba$.










E E E E E E E E E E E E
E E E E E E E E E E E E
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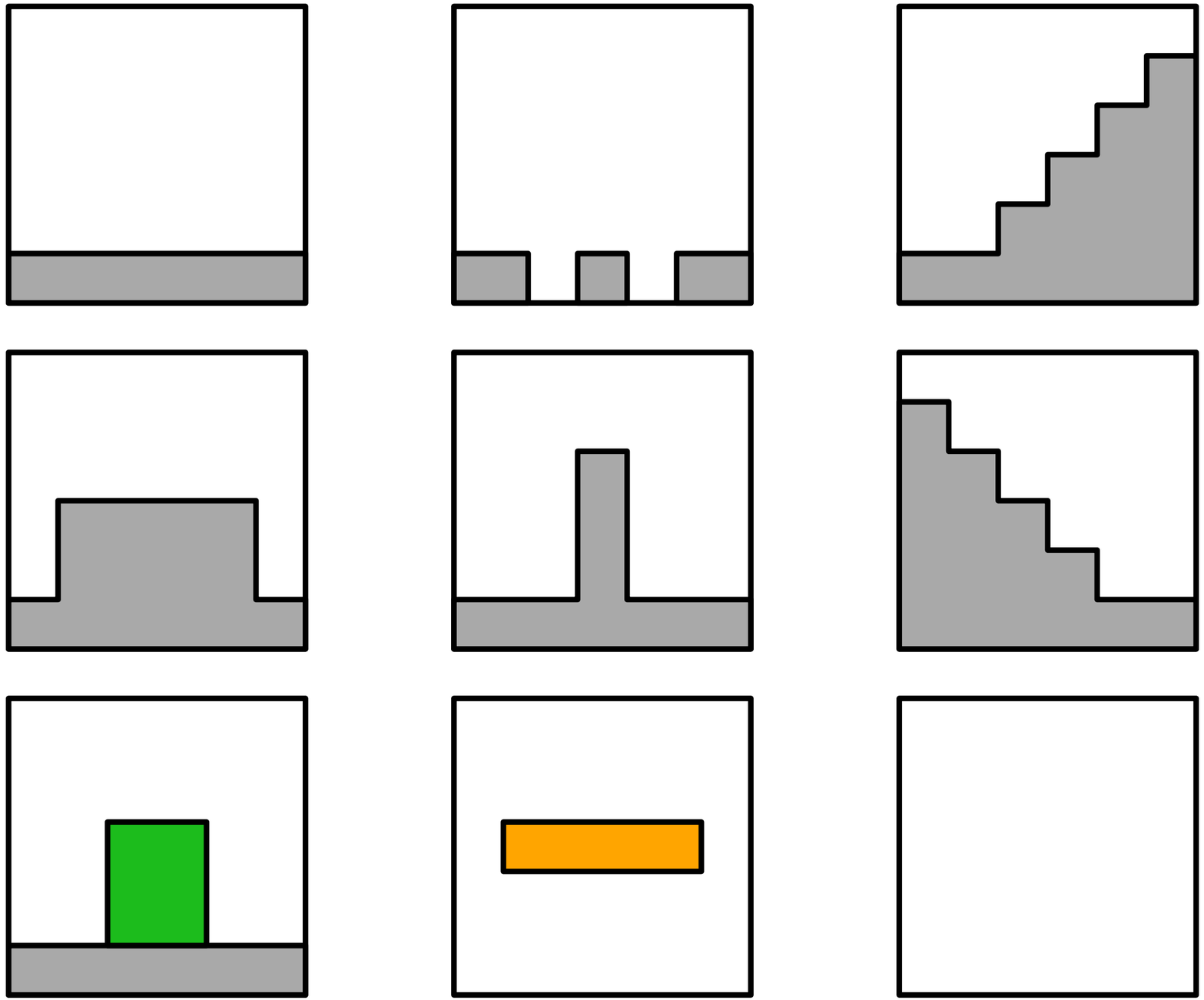
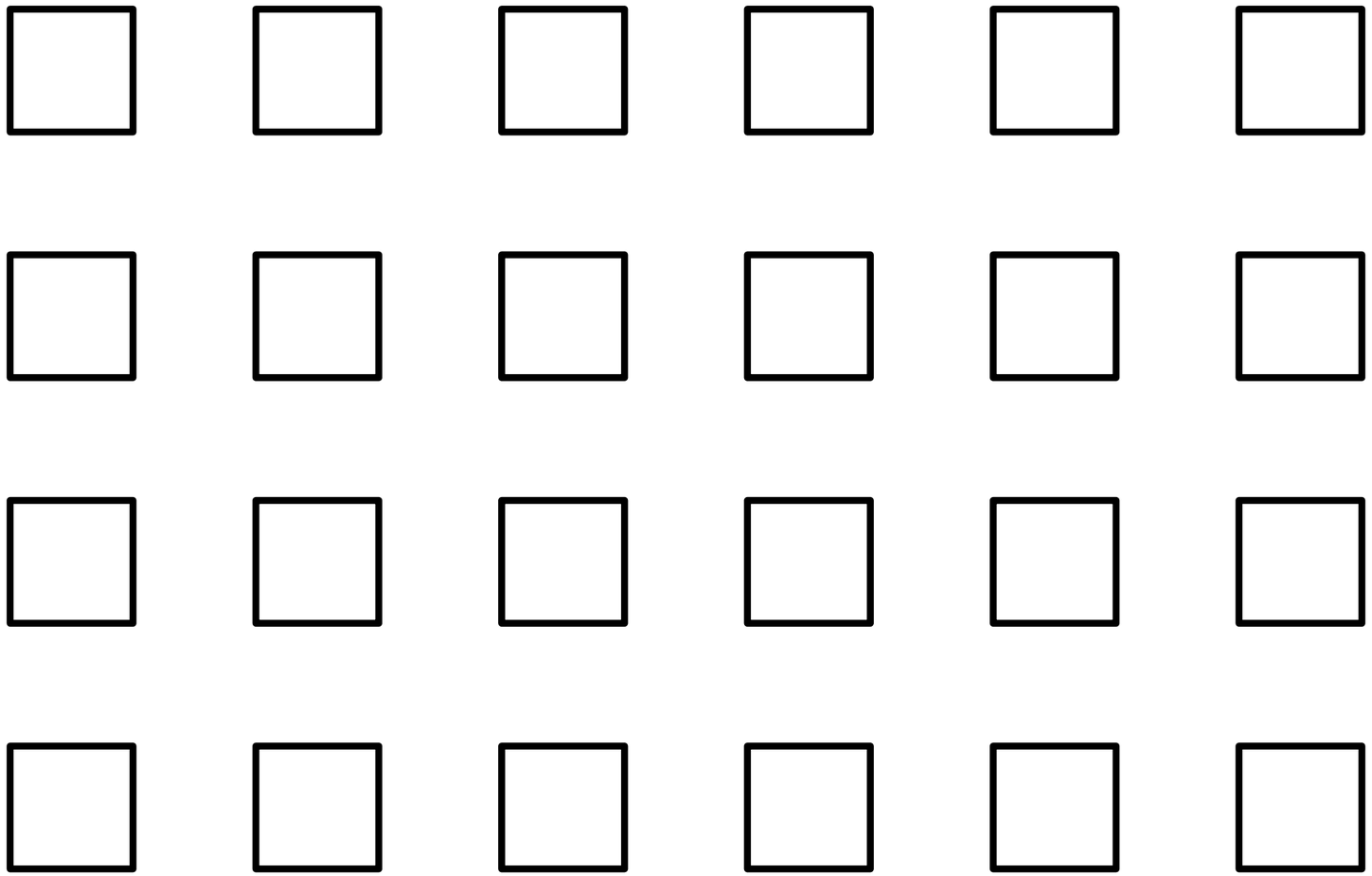
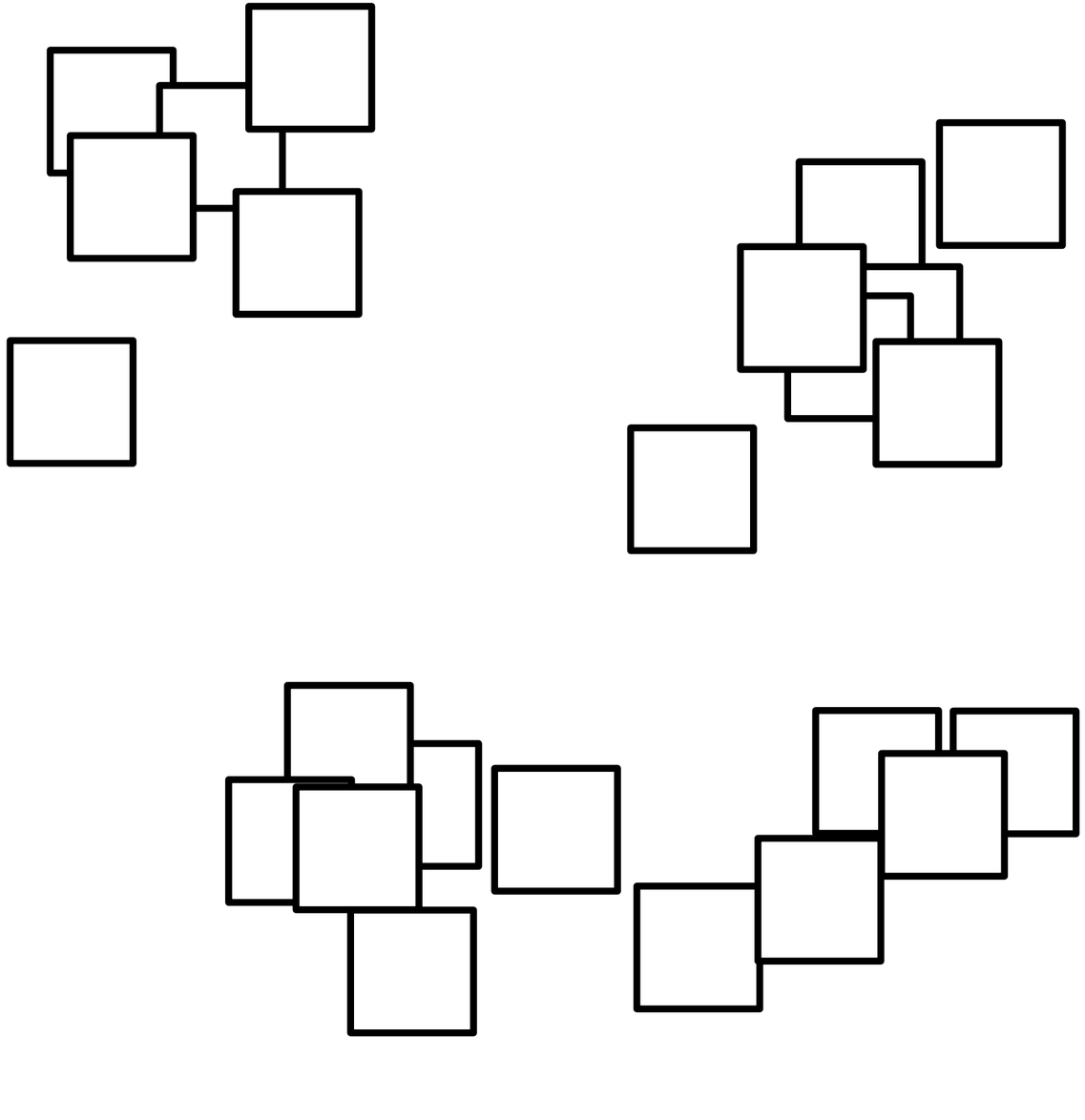
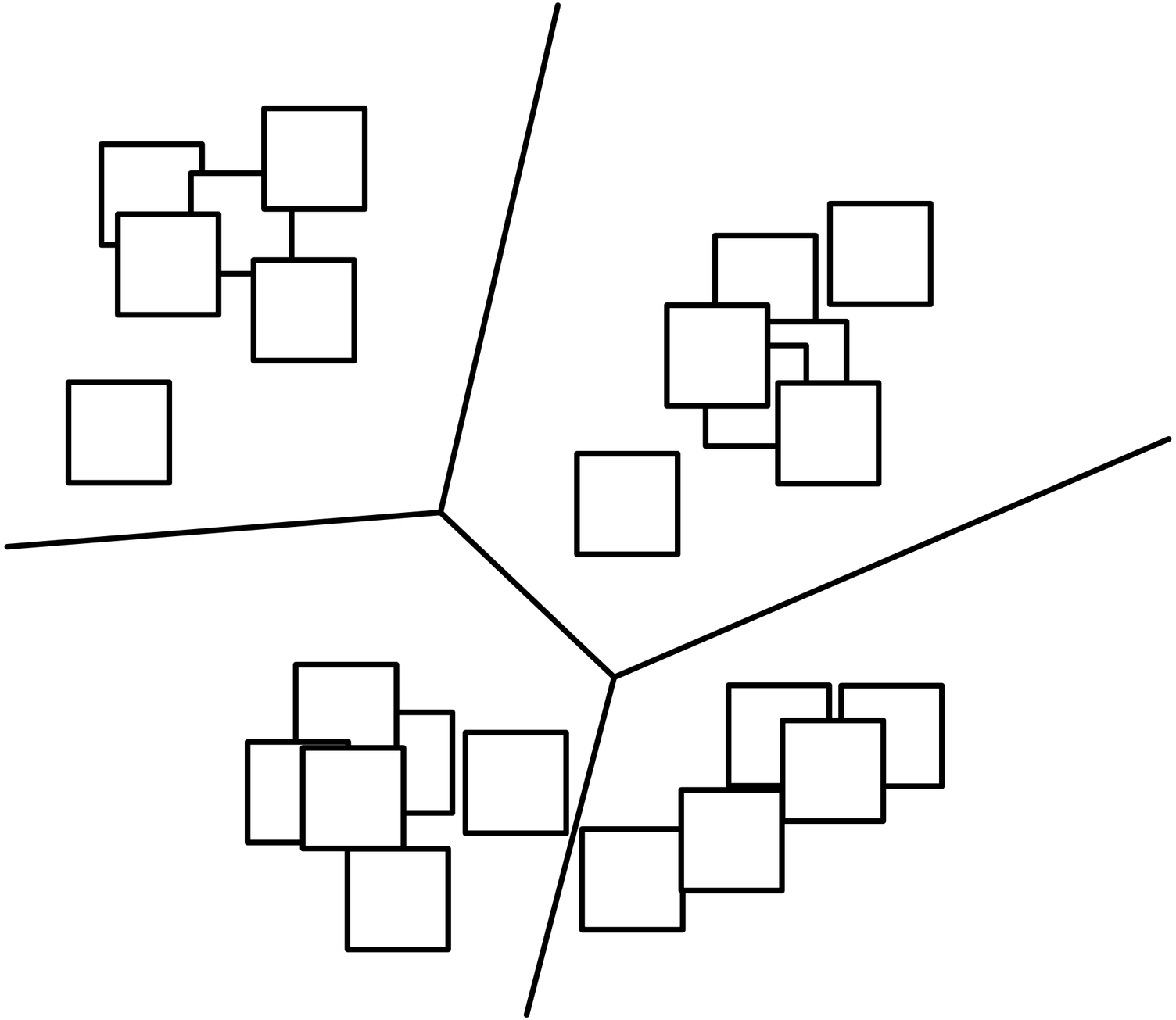
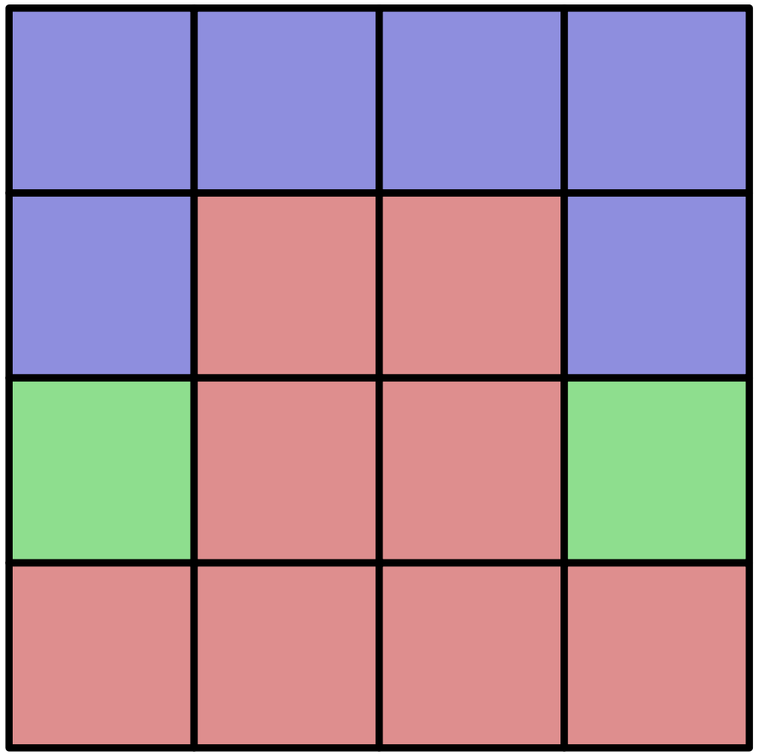
E E E E E E E E E E E E
E E E E E E E E E E E E
E E E E E E E E E E E E
E E B ? B ? B E E E E E
E E E E E E E E E E E E
E E E E E E E E E E p P
E E E E E E E E E E p P
G G G G G G G G G G G G
S S S S S S S S S S S S
E E
T P
G G
S S
High Level Tiles
Low-Level Tiles

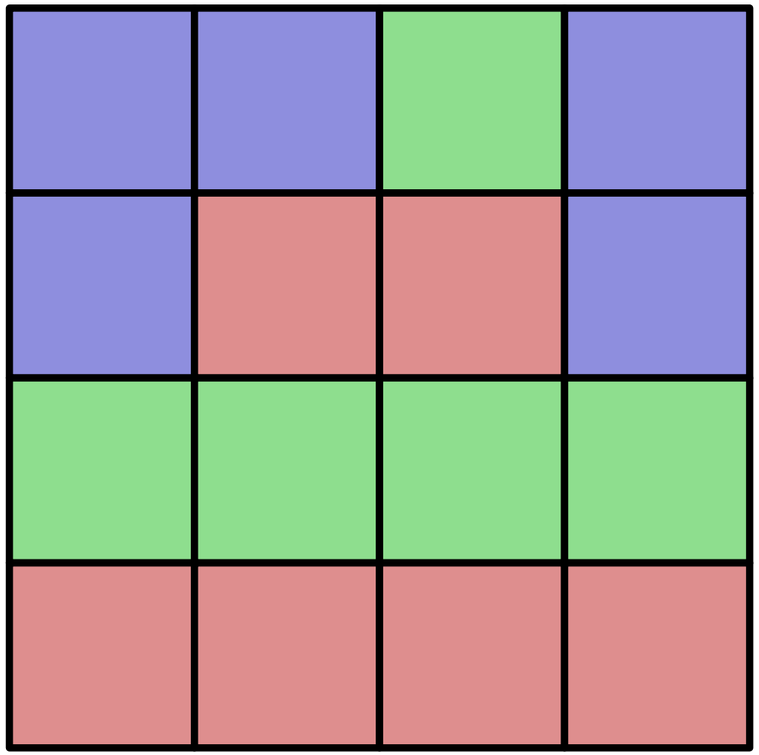


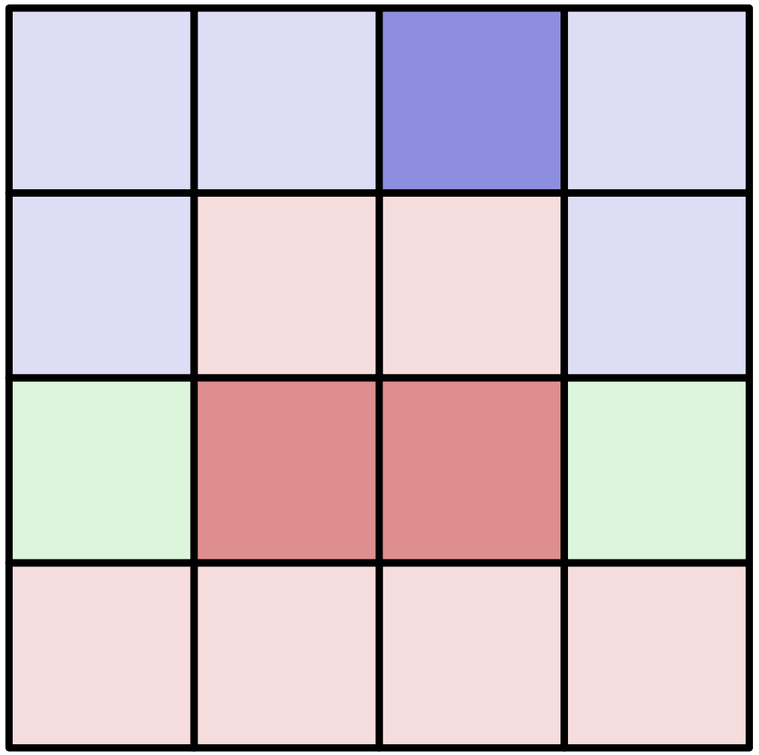


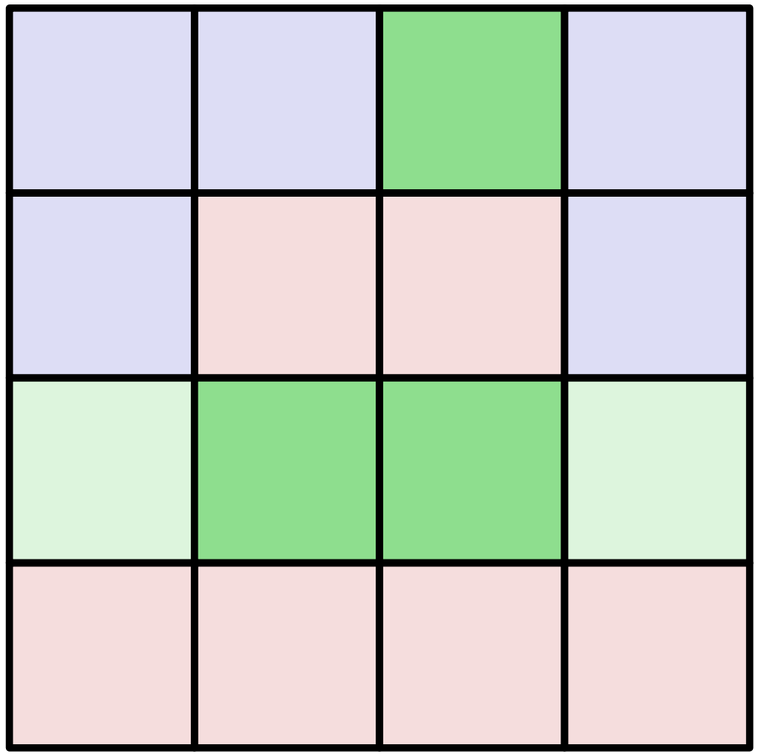


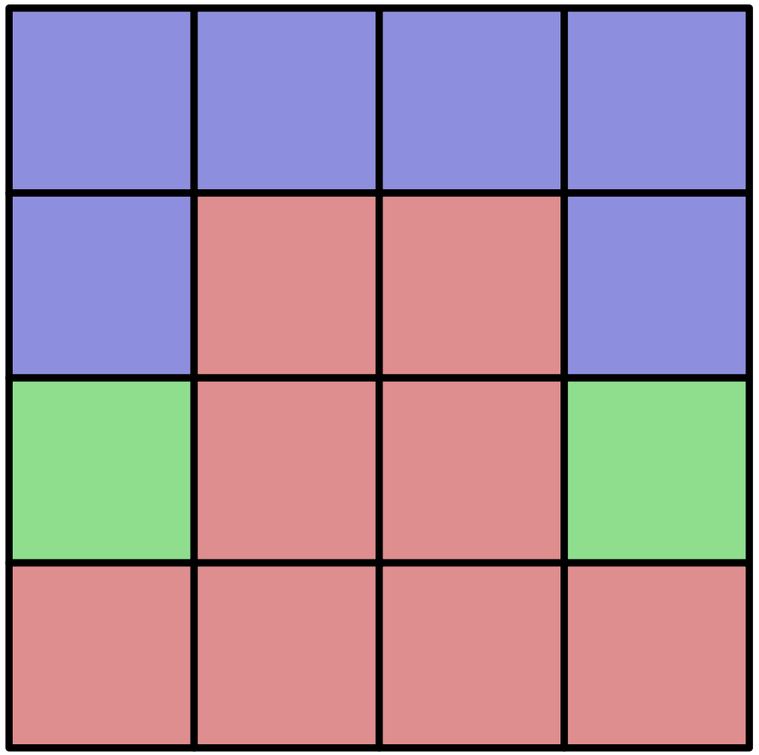


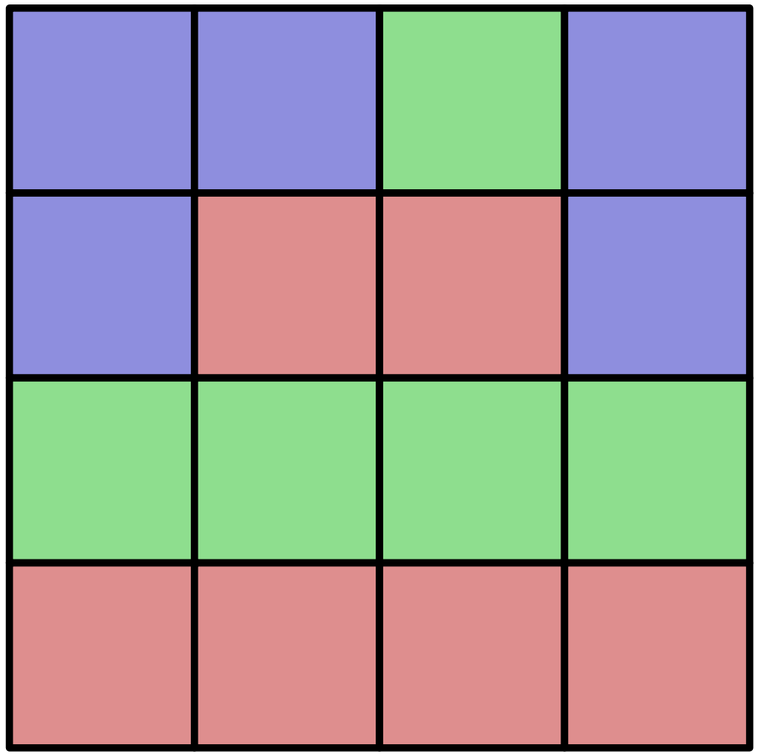




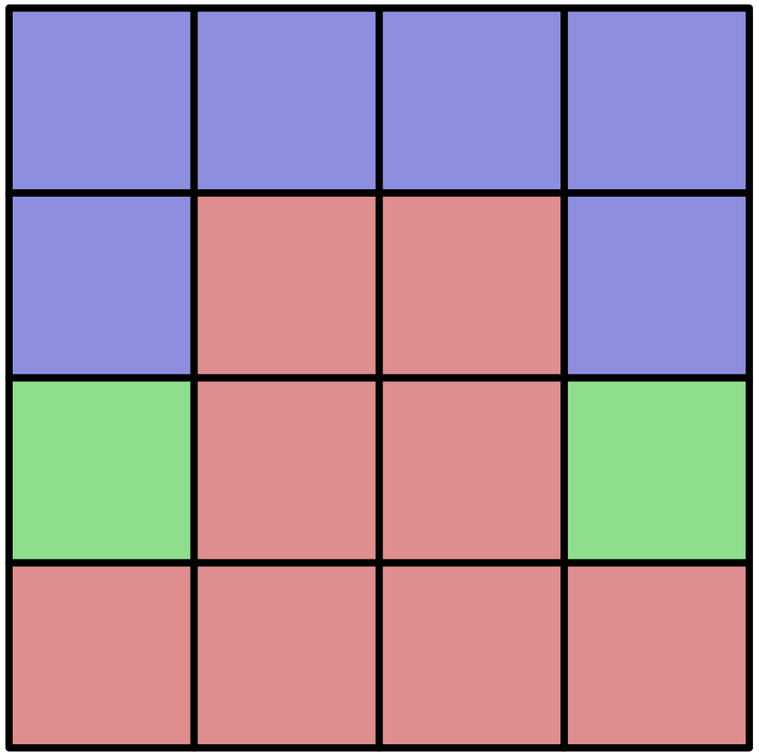




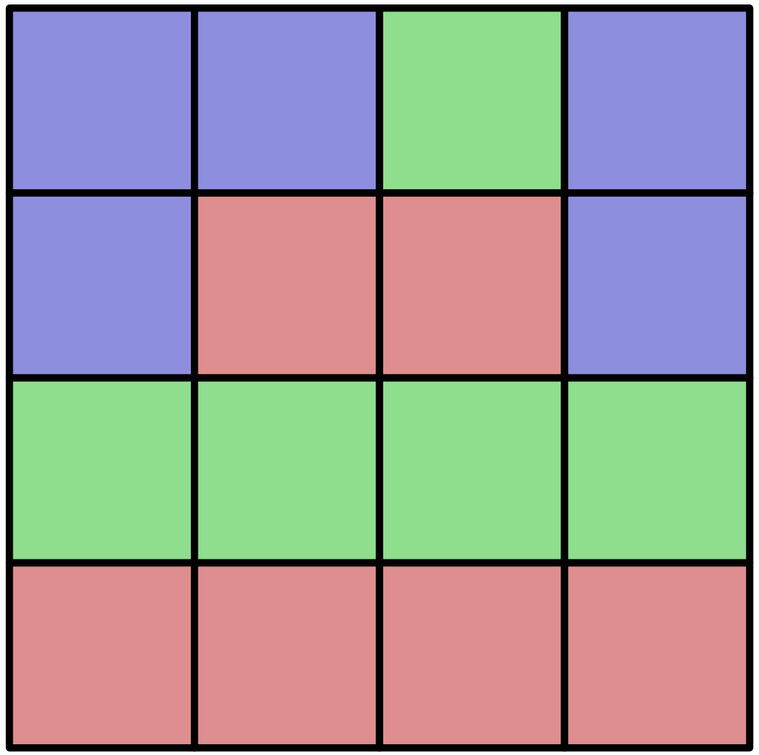




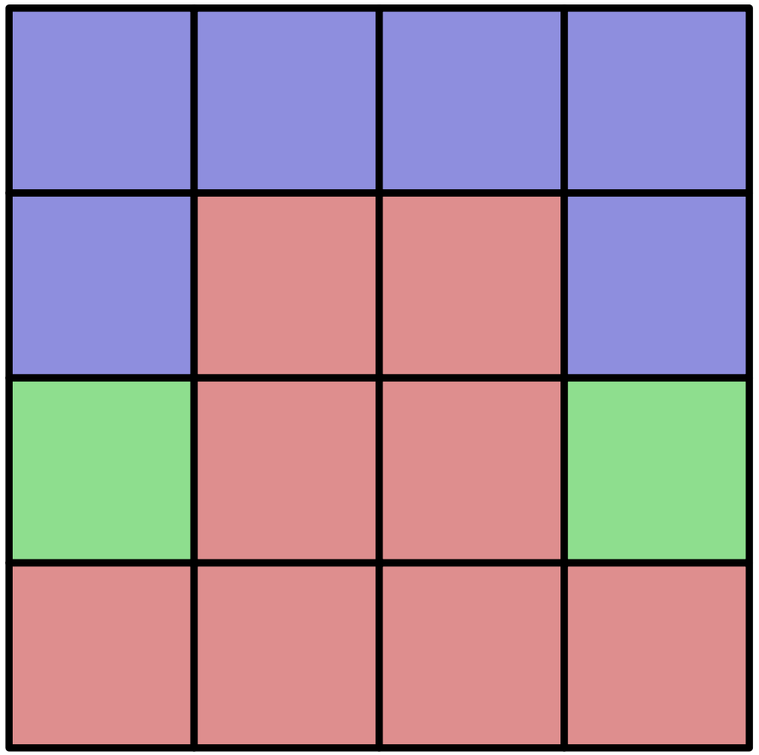
$P(S_t|S_{t-1})$



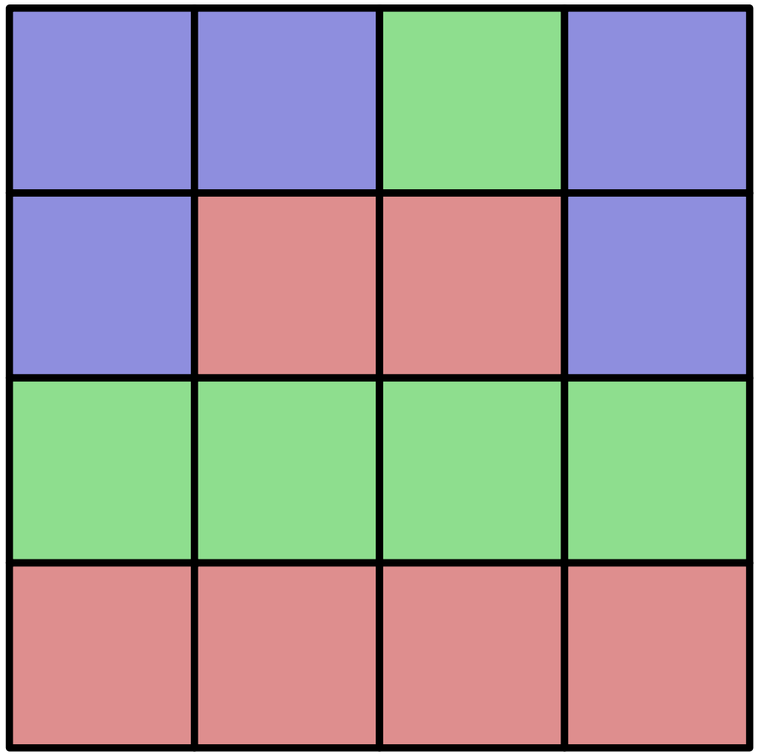
$P(S'_t|S'_{t-1})$



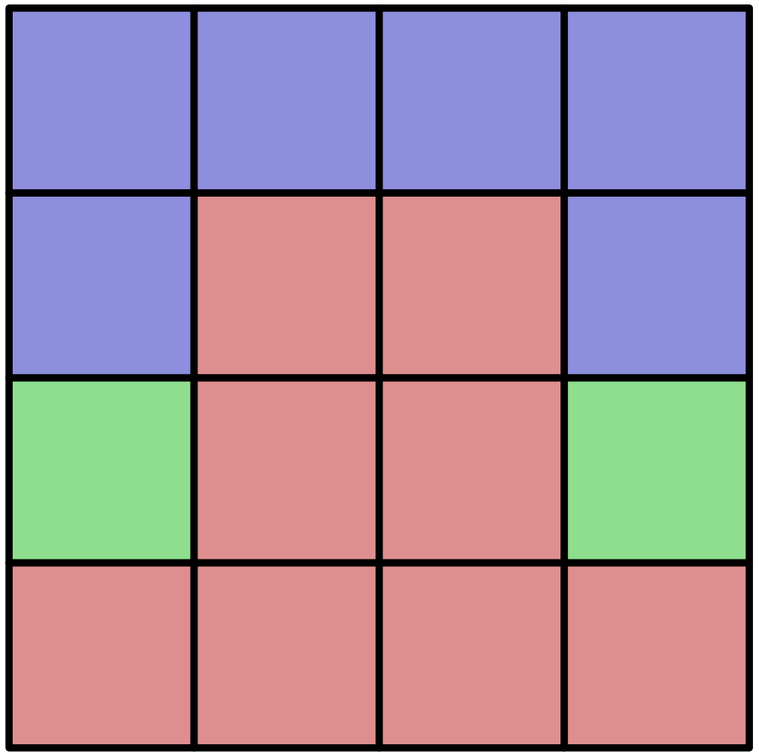
$P(S_t|S_{t-1})$

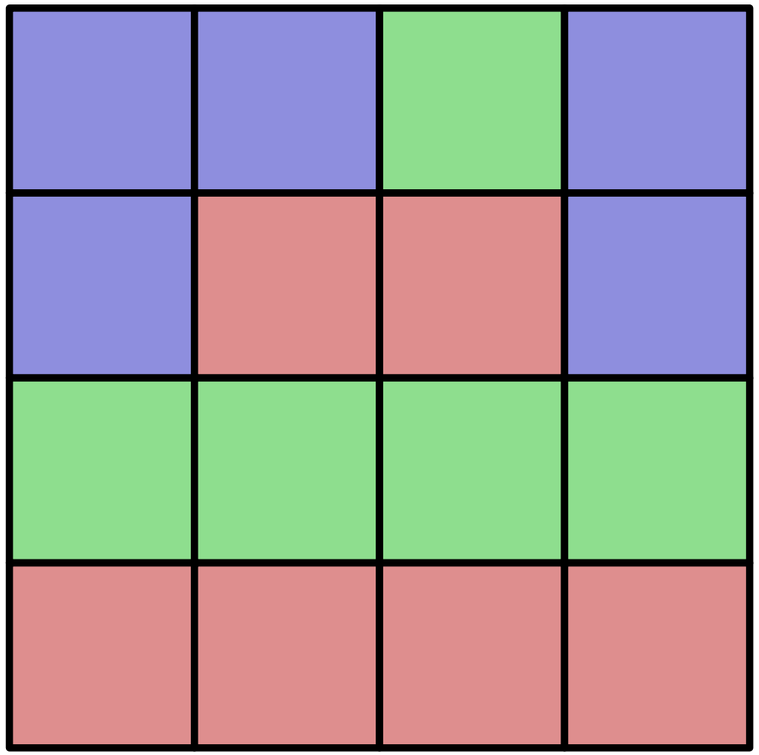


$P(S'_t|S'_{t-1})$

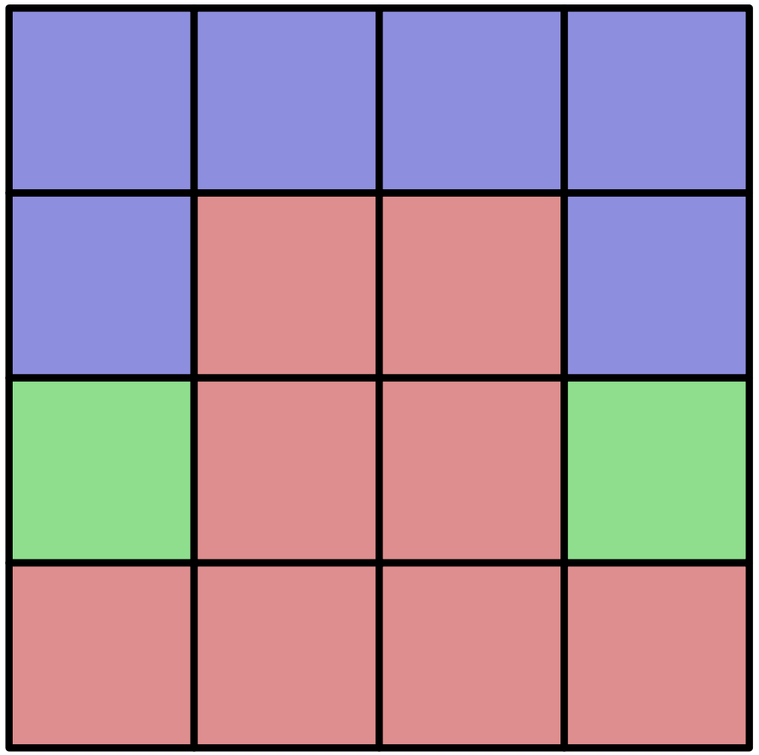


$d(P(S_t|S_{t-1}), P(S'_t|S'_{t-1}))$

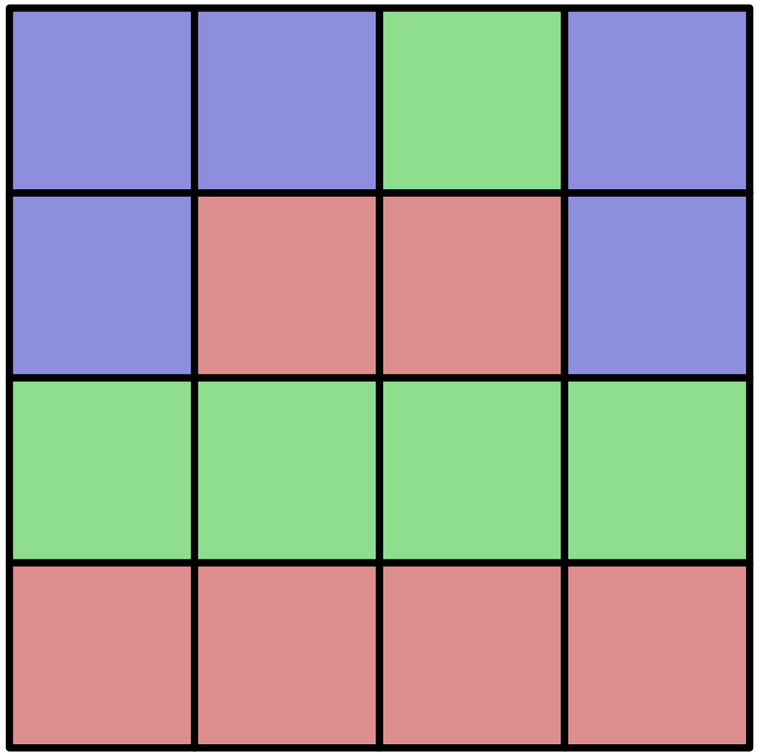




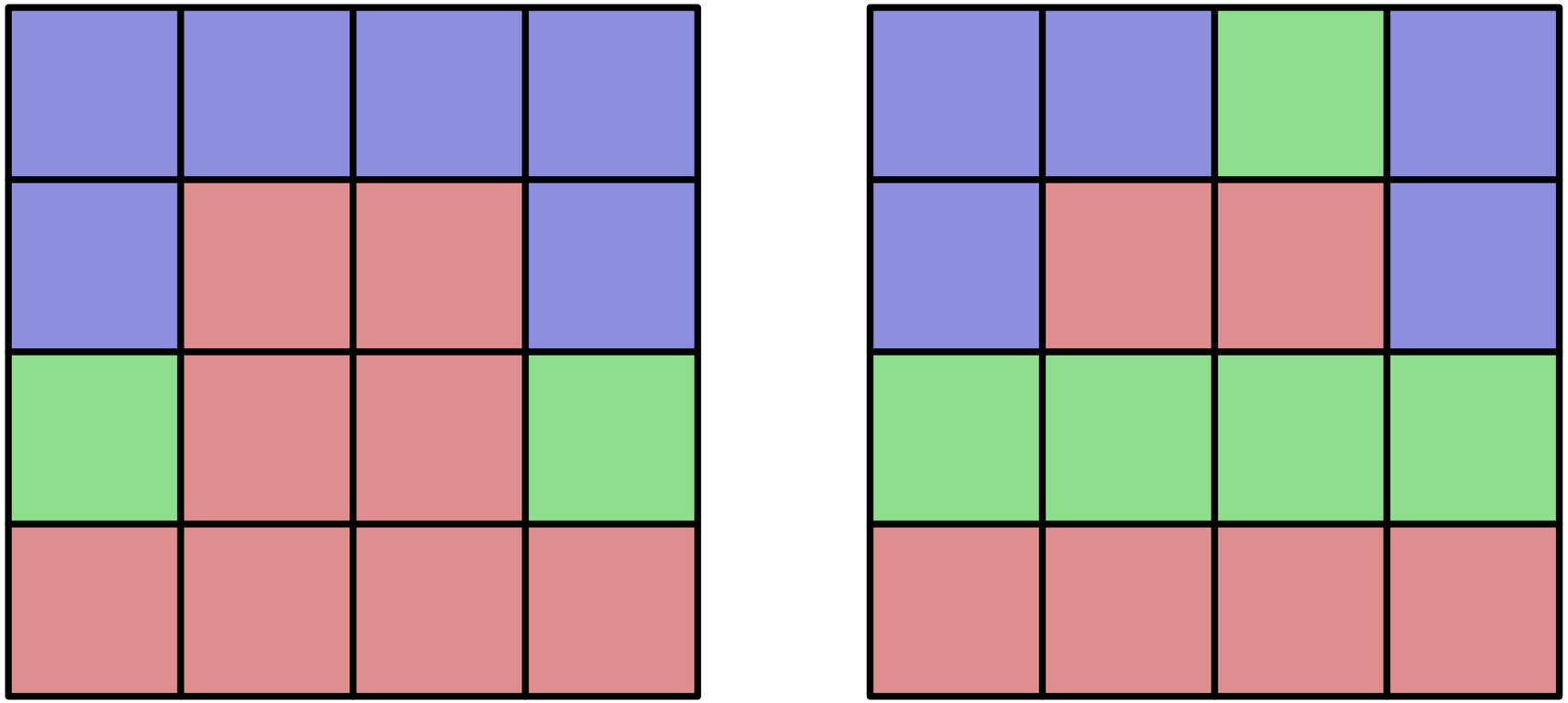
$\langle 6\square, 2\square, 8\square \rangle$



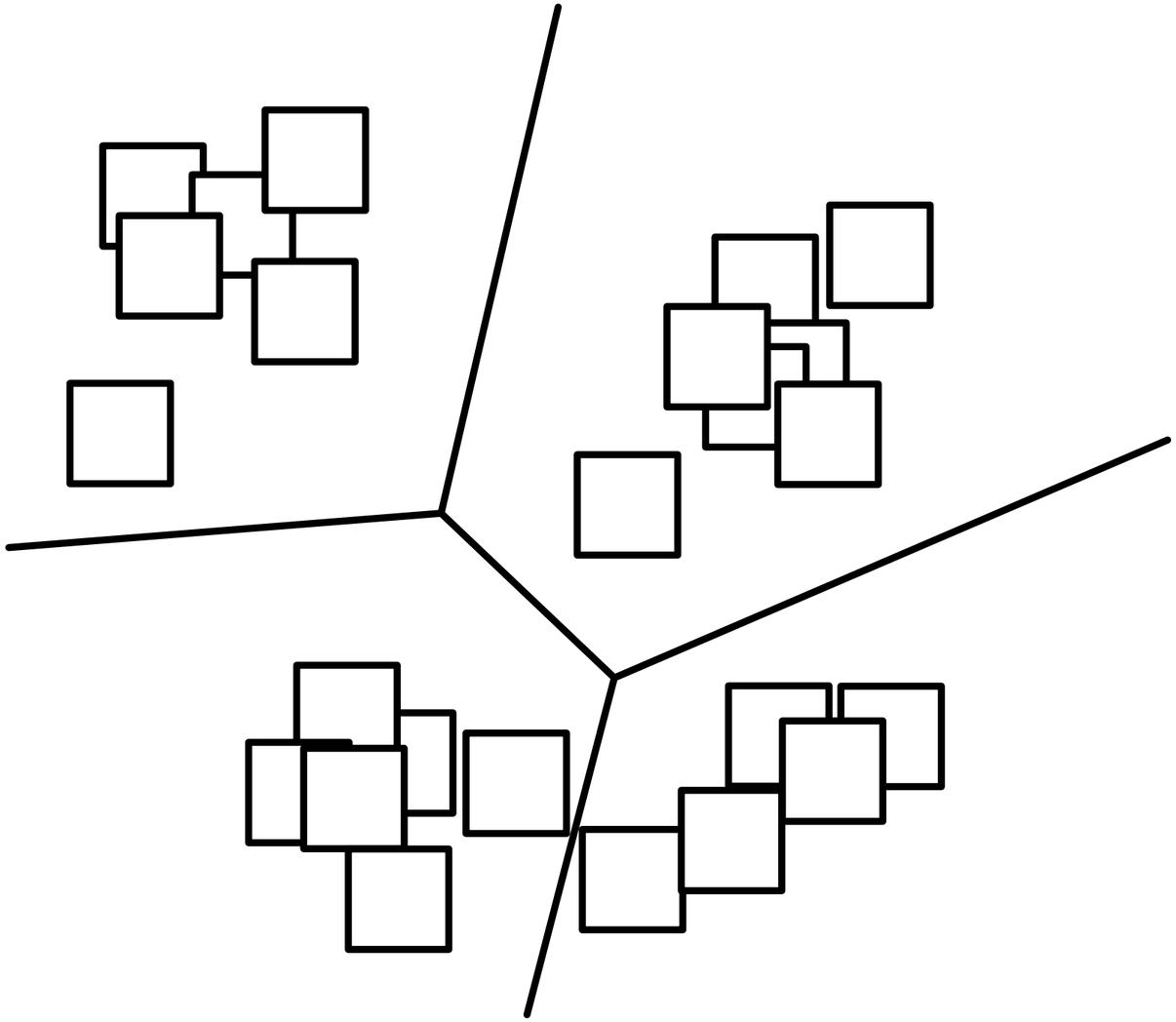
$\langle 5\square, 5\square, 6\square \rangle$

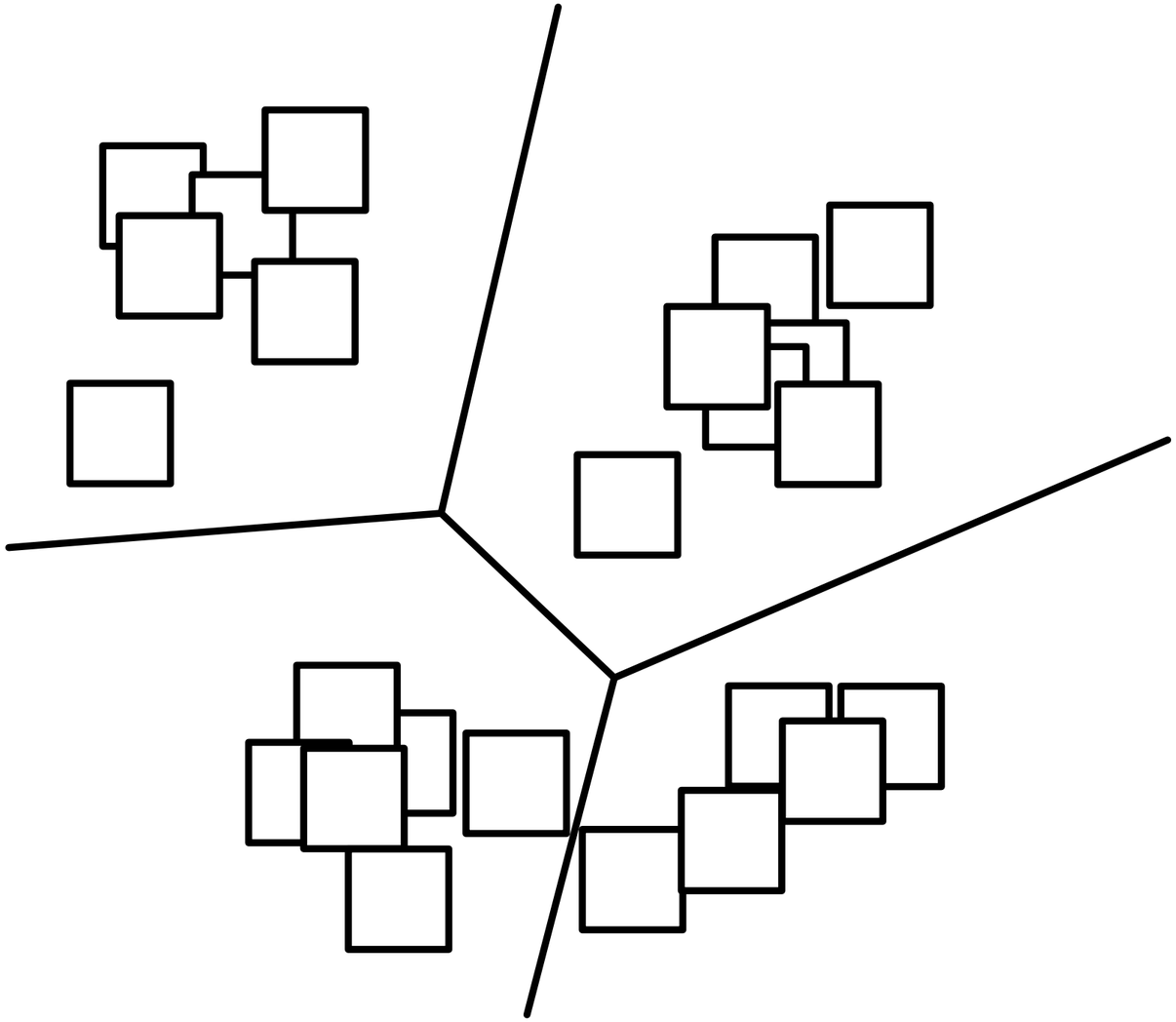


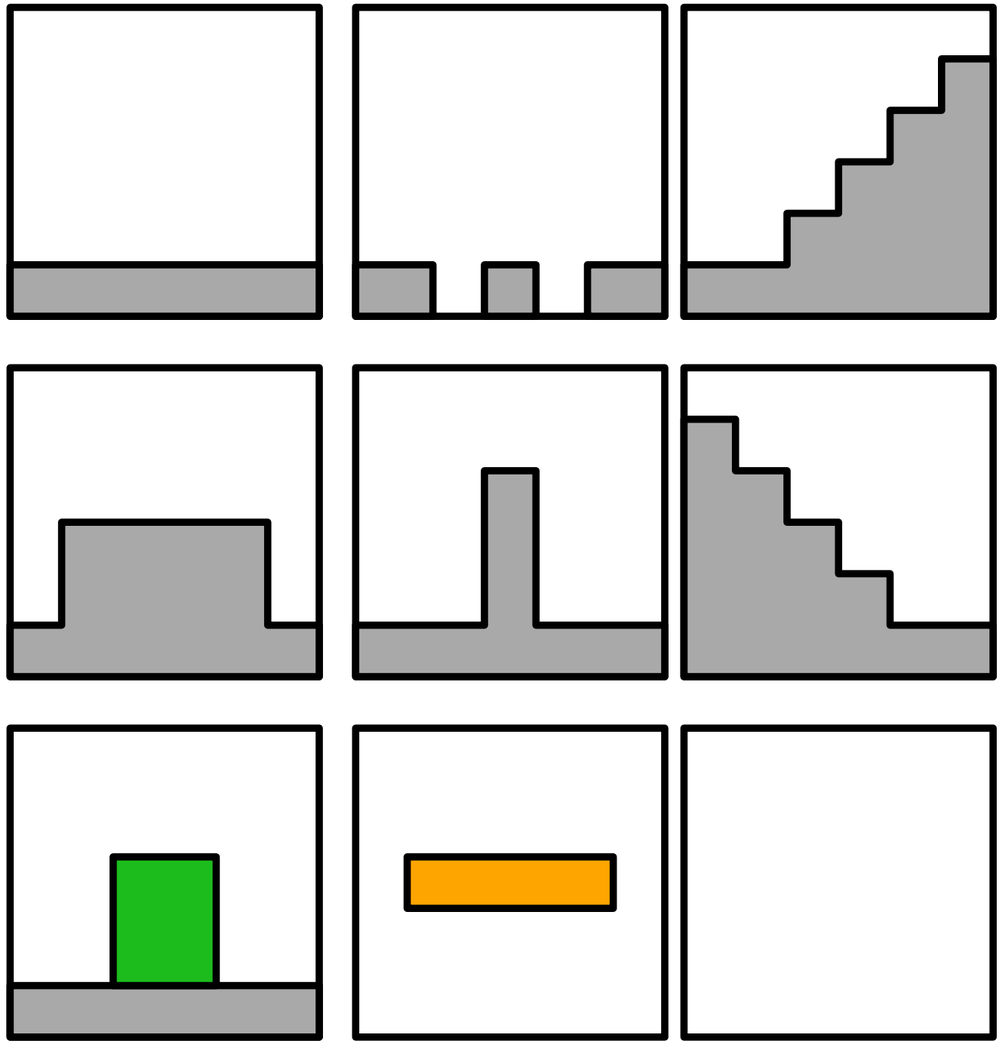
$\langle 6, 2, 8 \rangle$ $\langle 5, 5, 6 \rangle$

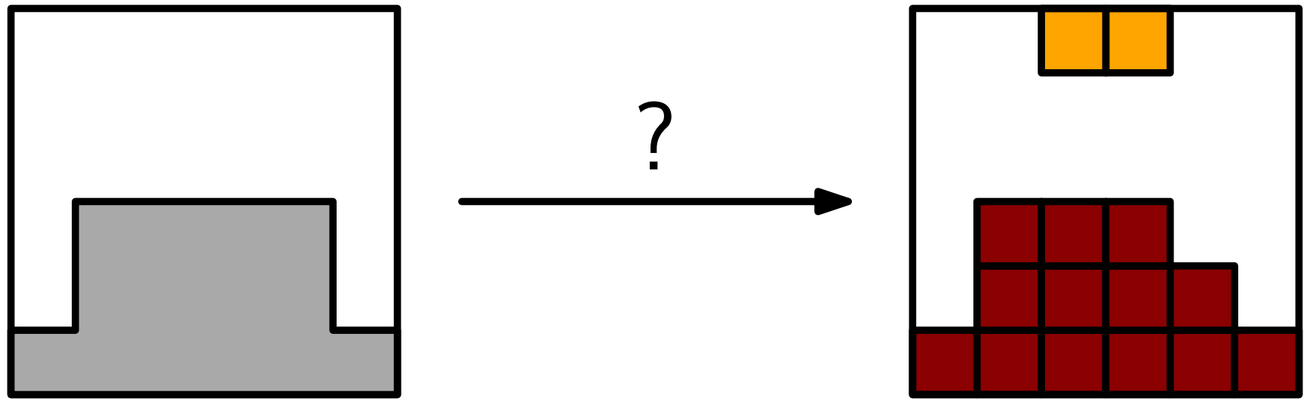


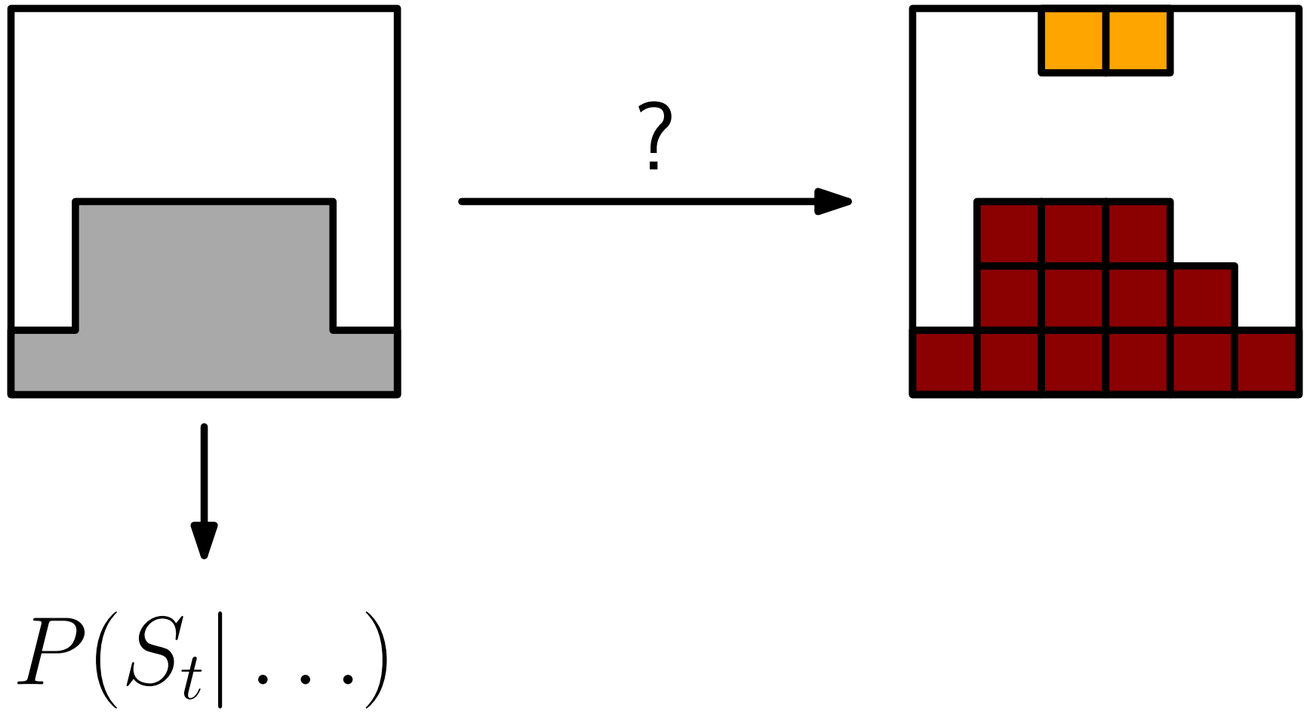
$d(\langle 6, 2, 8 \rangle, \langle 5, 5, 6 \rangle)$

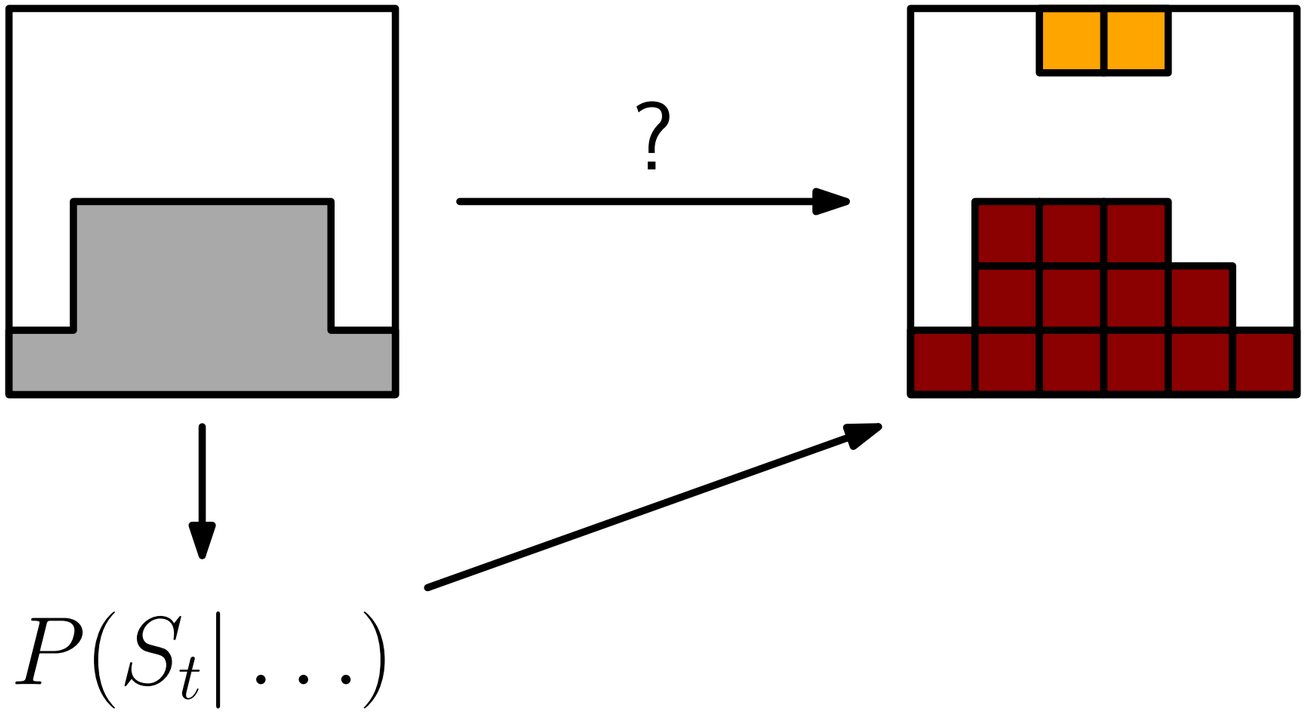


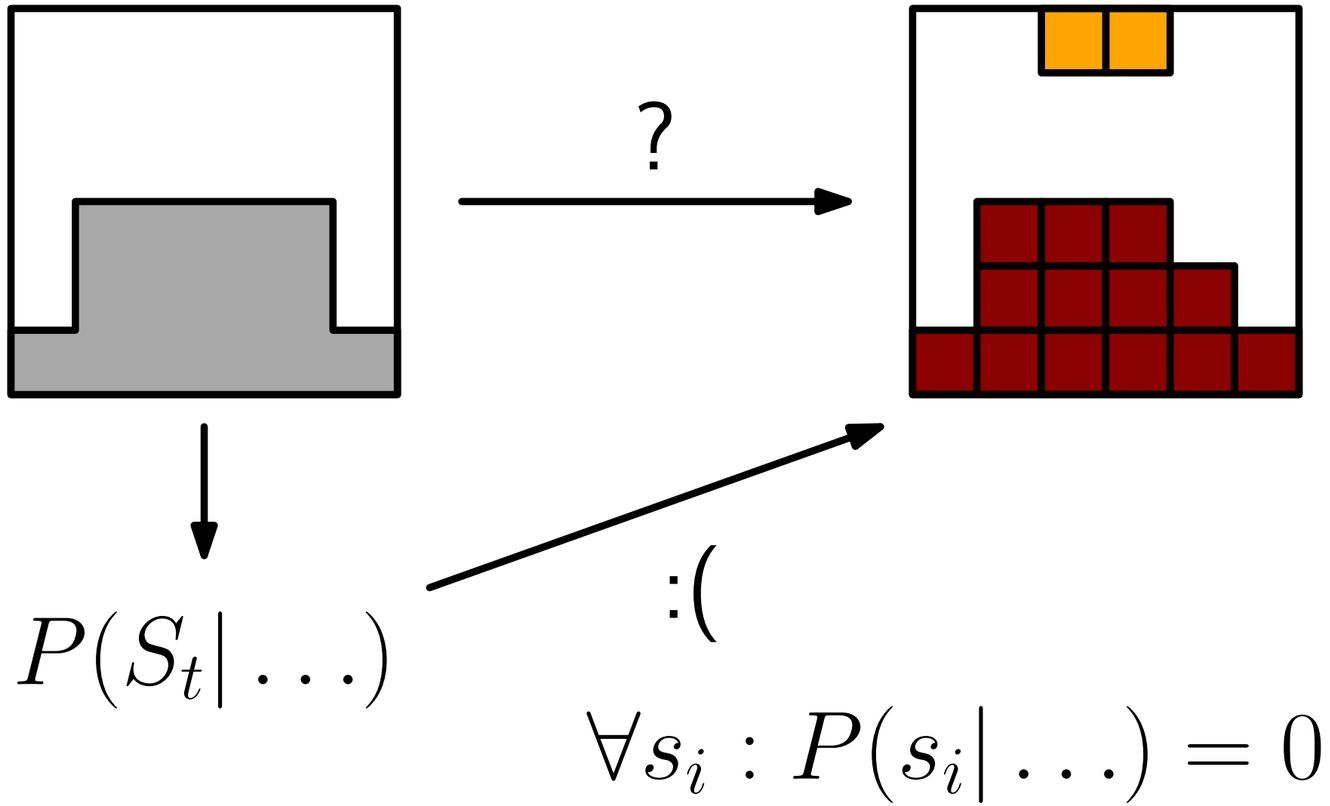


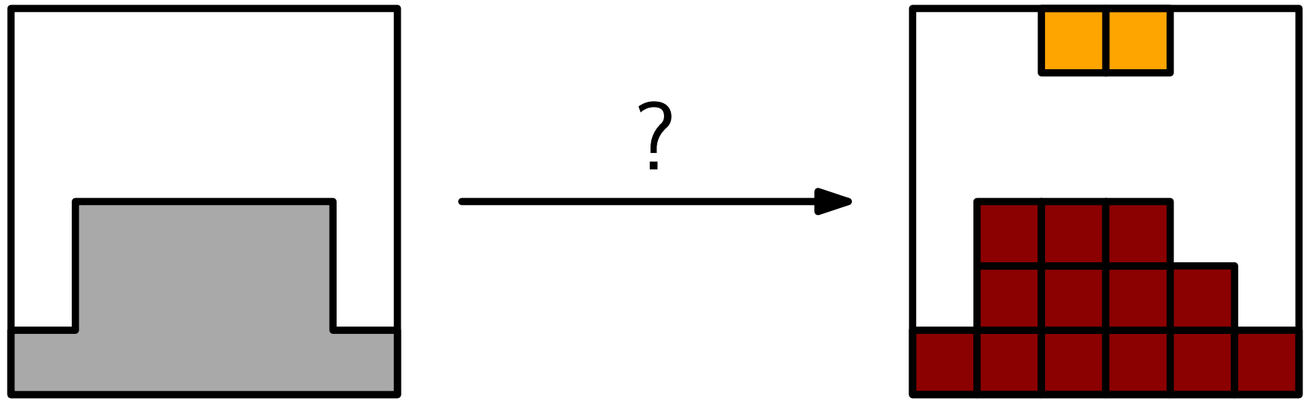





?
$P(S_t|\ldots)$


?
$P(S_t| \ldots)$

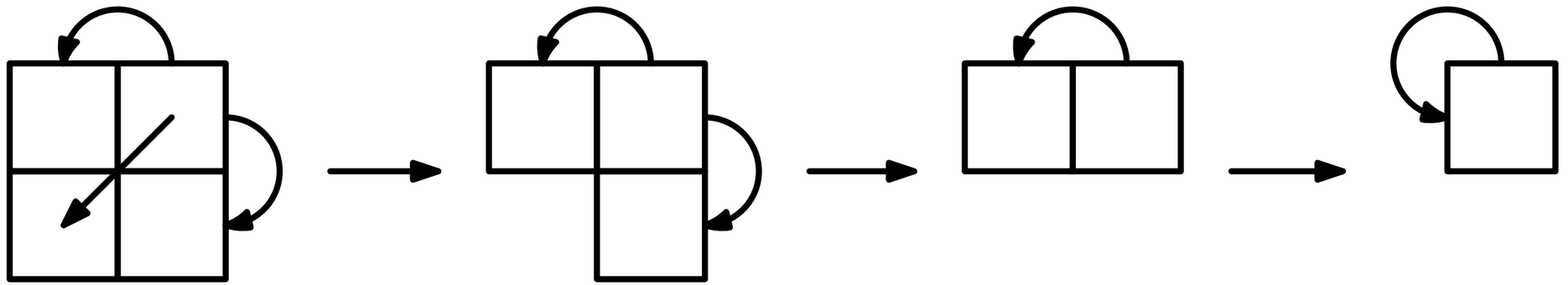

?
$P(S_t|\ldots)$
:(
$\forall s_i : P(s_i|\ldots) = 0$

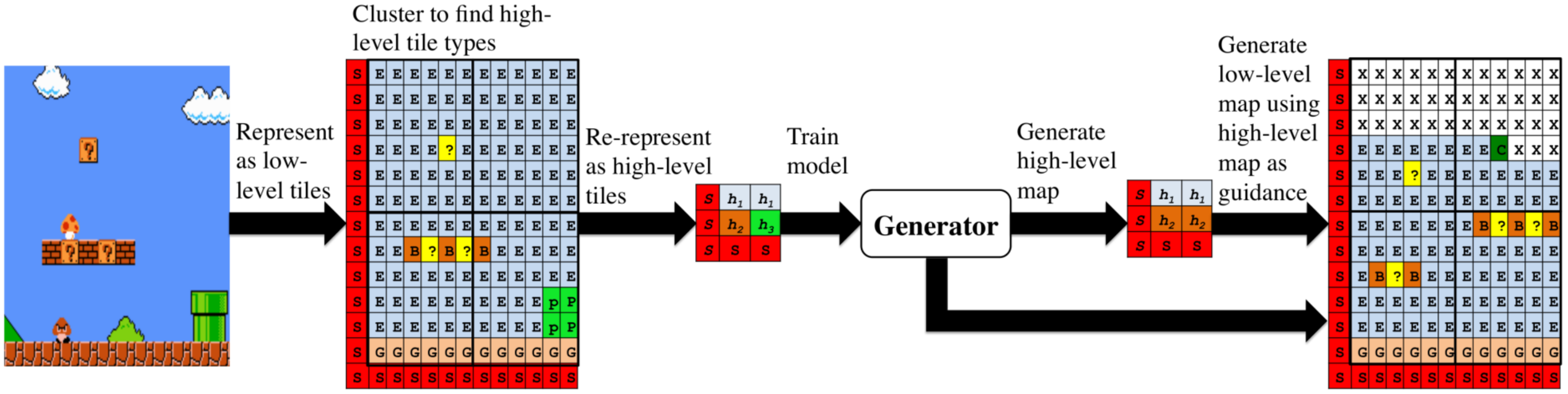


$P(S_t|\ldots)$

:(

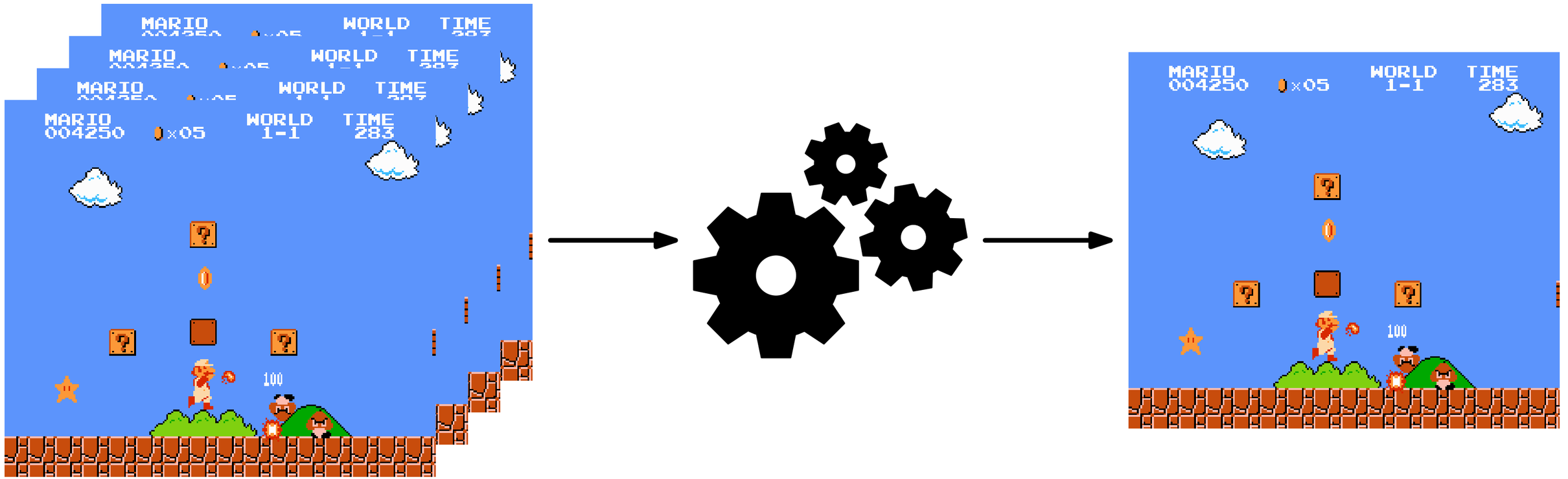
$\forall s_i : P(s_i|\ldots) = 0$

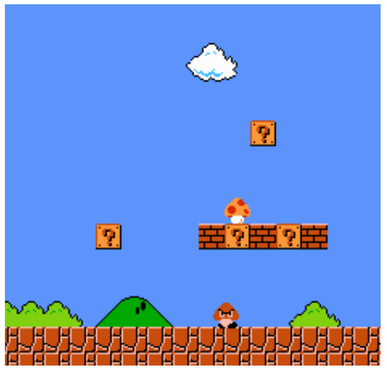



Represent as low-level tiles
Cluster to find high-level tile types
Re-represent as high-level tiles
Train model
Generator
Generate high-level map
Generate low-level map using high-level map as guidance

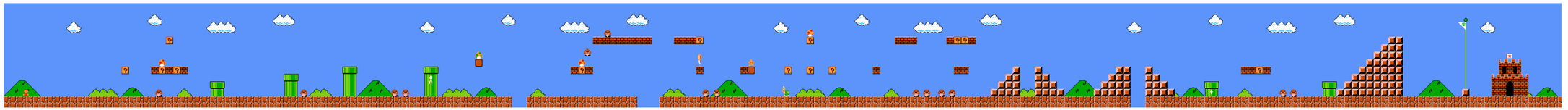
Assignment 4

Name three benefits of using a hierarchical Markov chain model over using only a single layer of Markov chains to generate levels.

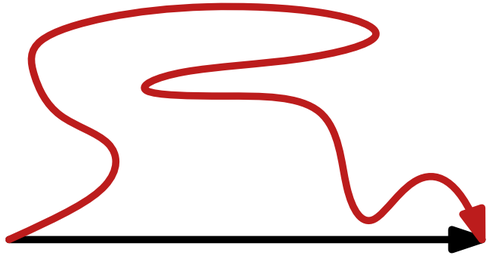

MARIO
WORLD
TIME
MARIO
004250
x05
WORLD
1-1
TIME
283
100

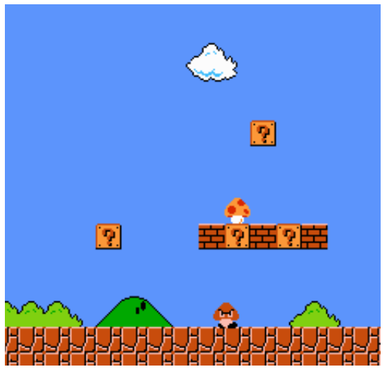


$\rightarrow \mathbb{R}_{\geq 0}$

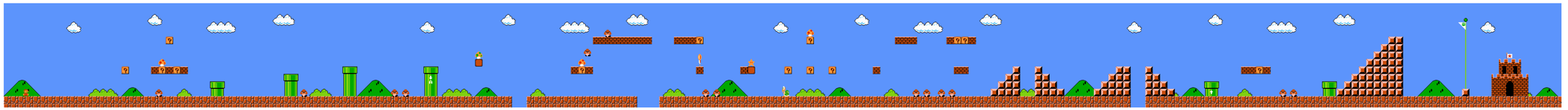


$\rightarrow \mathbb{R}_{\geq 0}$

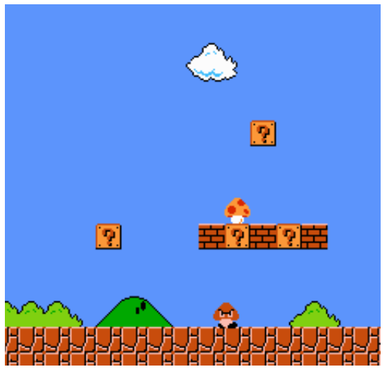




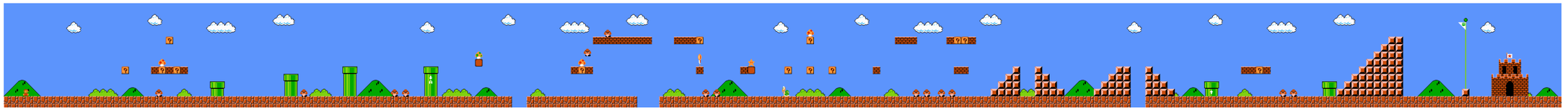
$\rightarrow \mathbb{R}_{\geq 0}$



$\rightarrow \mathbb{R}_{\geq 0}$

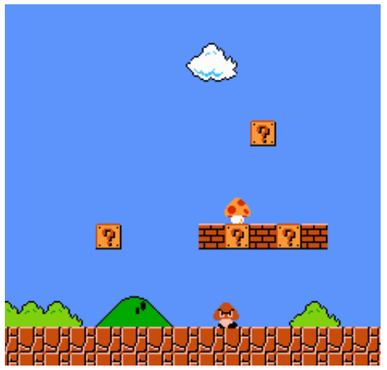


$\rightarrow \mathbb{R}_{\geq 0}$

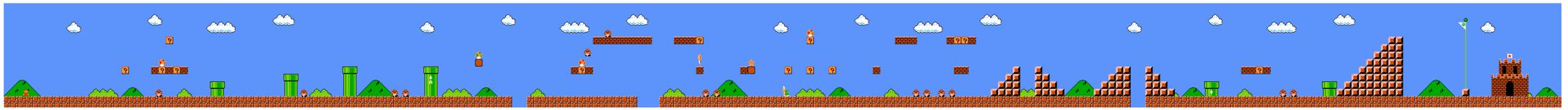


$\rightarrow \mathbb{R}_{\geq 0}$

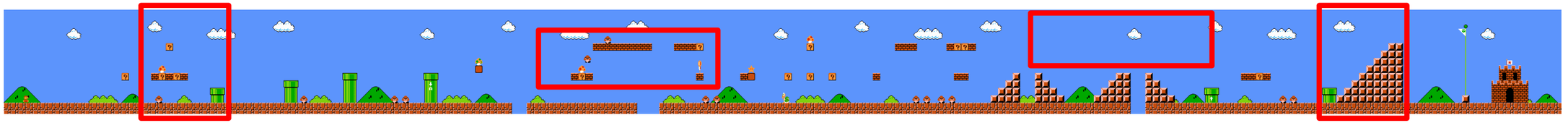
$\rightarrow \mathbb{R}_{\geq 0}$



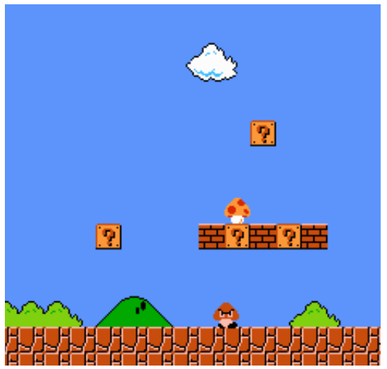
$\rightarrow \mathbb{R}_{\geq 0}$



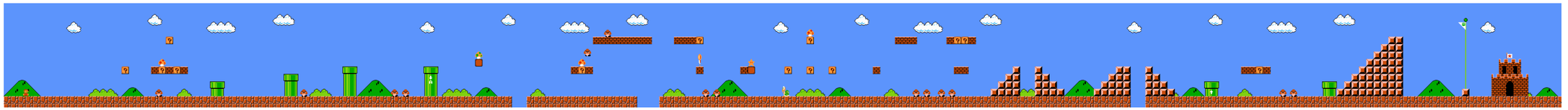
$\rightarrow \mathbb{R}_{\geq 0}$



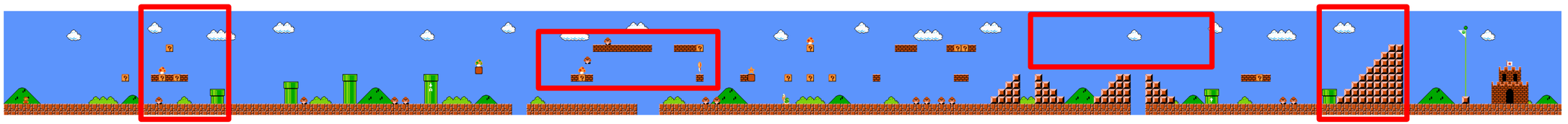
$\rightarrow \mathbb{R}_{\geq 0}$



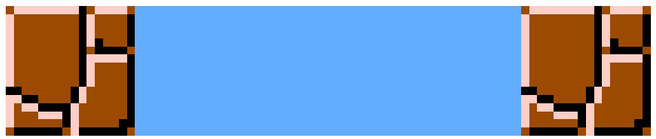
$\rightarrow \mathbb{R}_{\geq 0}$

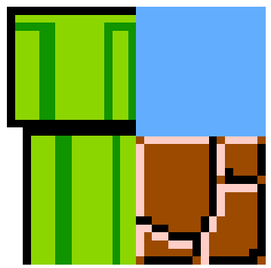


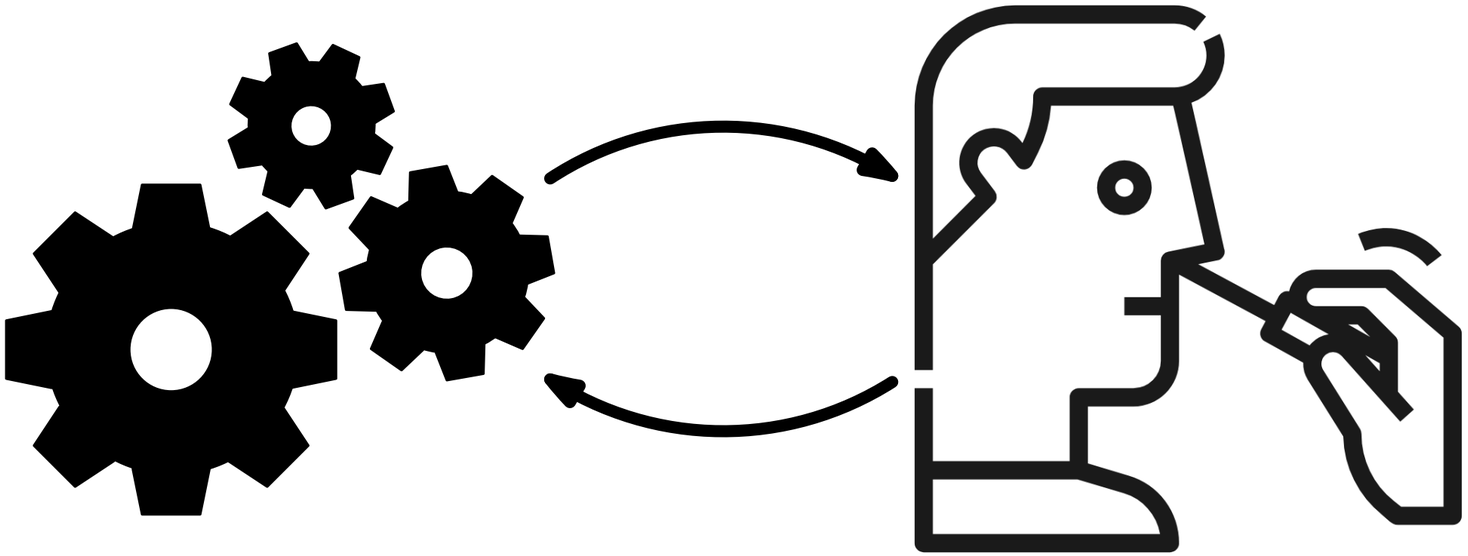
$\rightarrow \mathbb{R}_{\geq 0}$

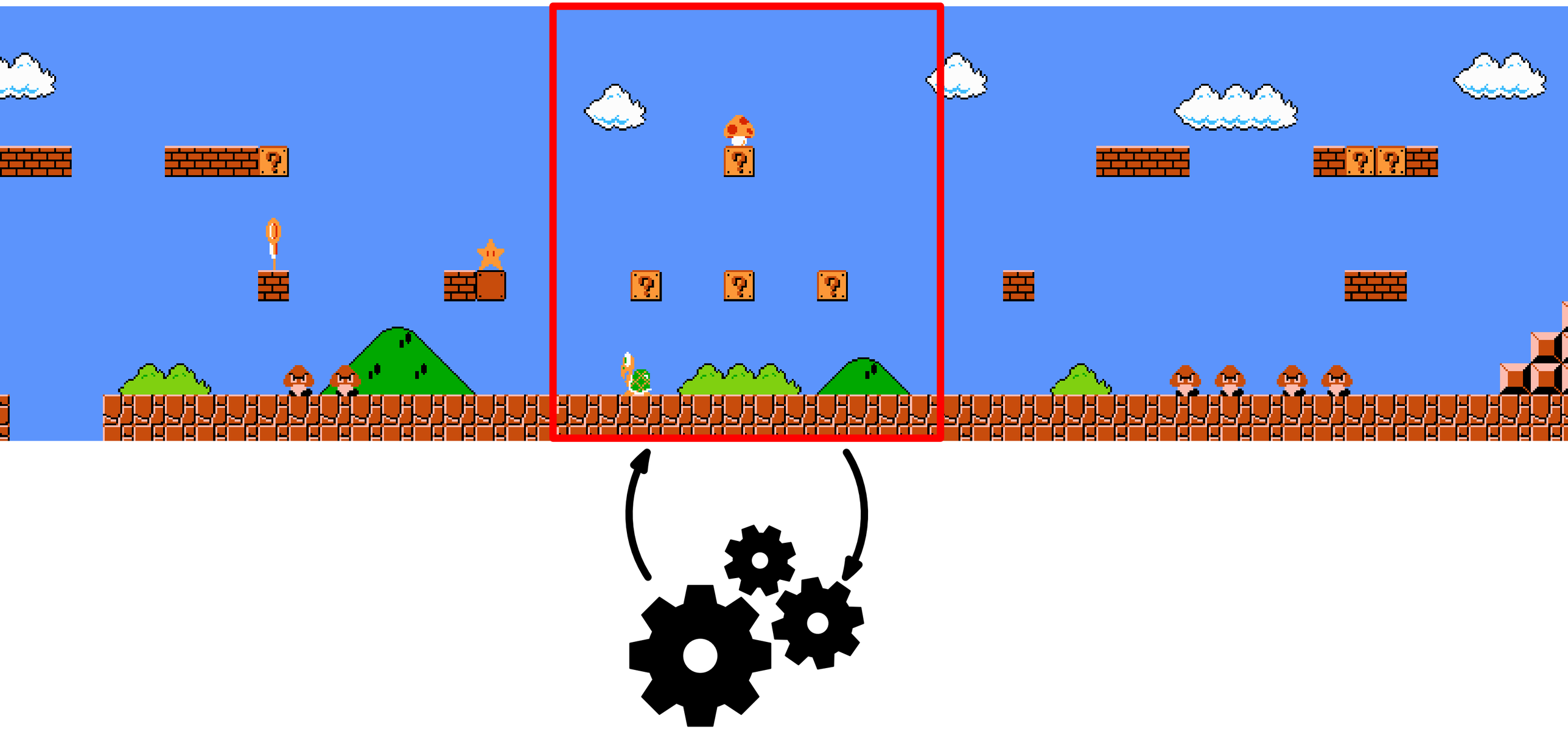


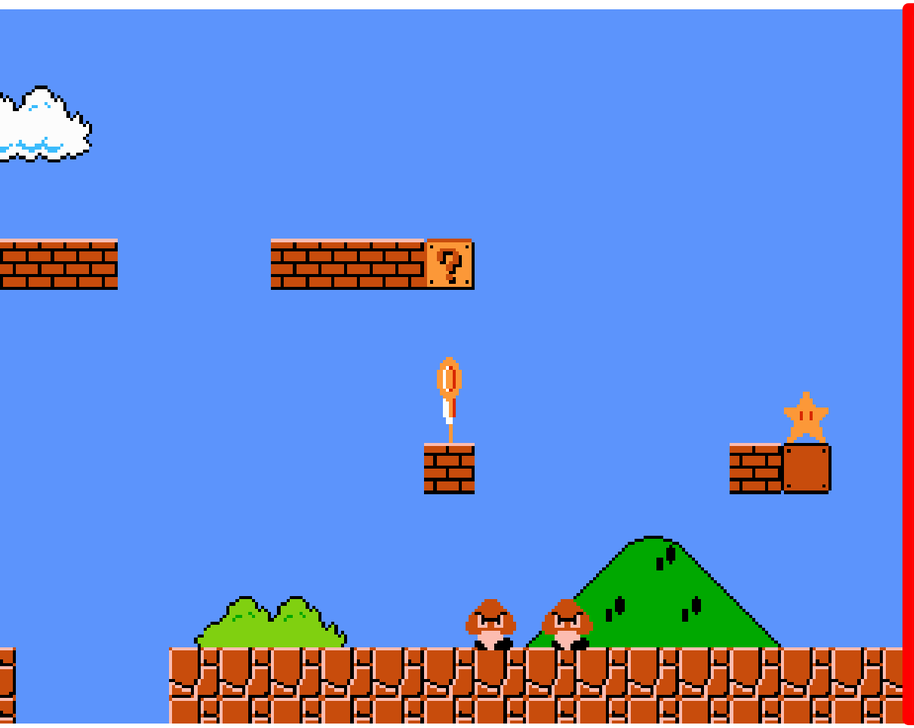
$\rightarrow \mathbb{R}_{\geq 0}$

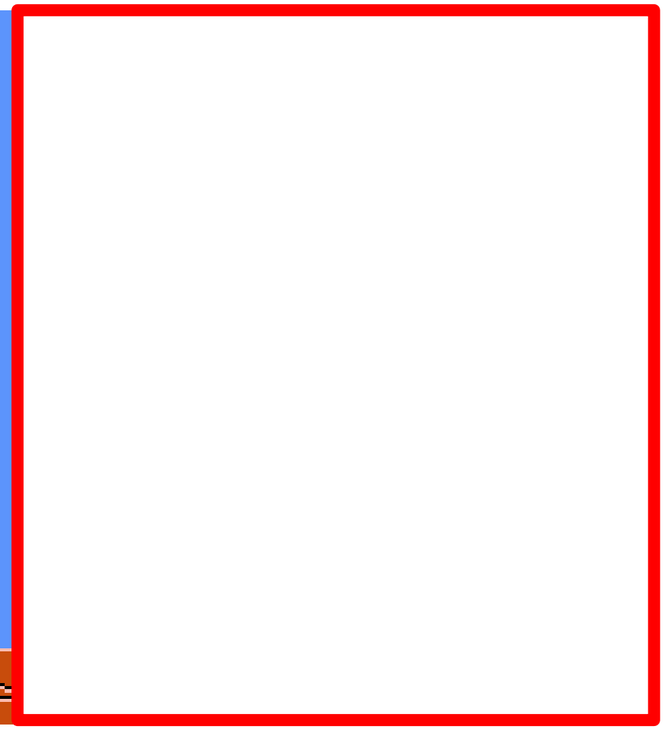


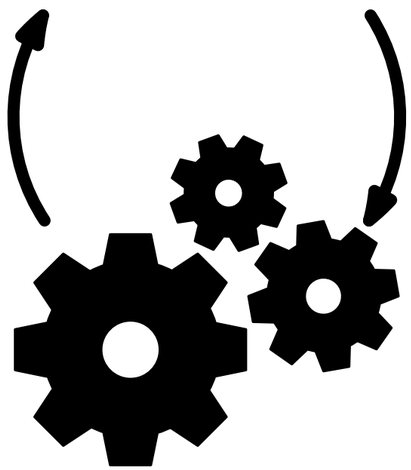












Assignment 5

Name two local and two global constraints that we might want to enforce for Mario levels.