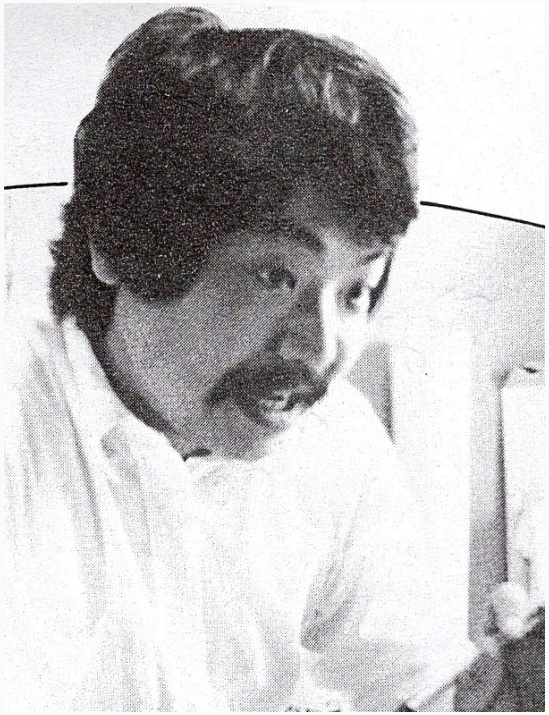
Résolution de niveaux du Sokoban

Nom Prénom

Candidat n°01234

Introduction

Le jeu du Sokoban



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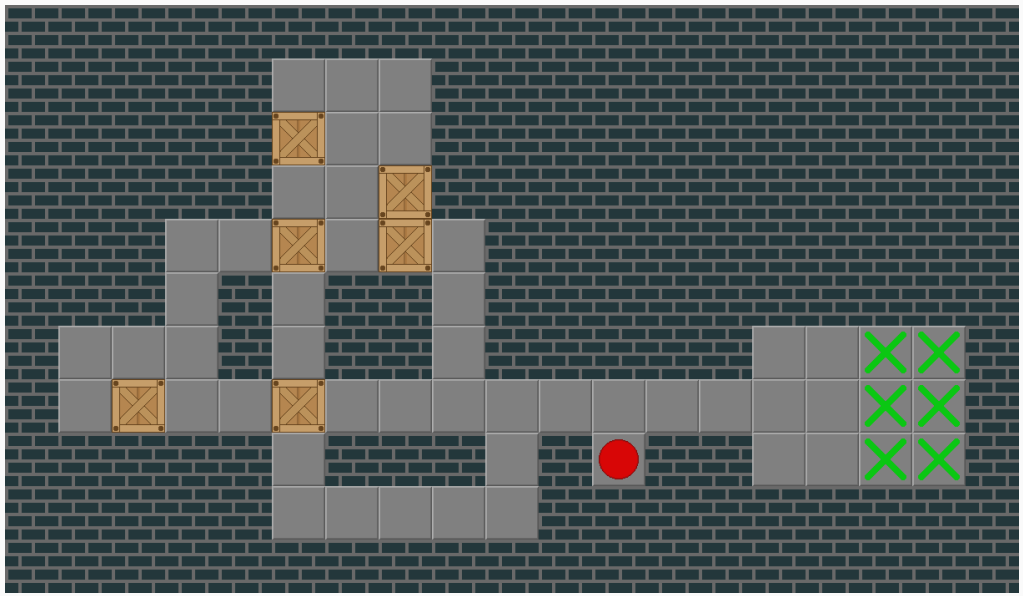
Hiroyuki Imabayashi

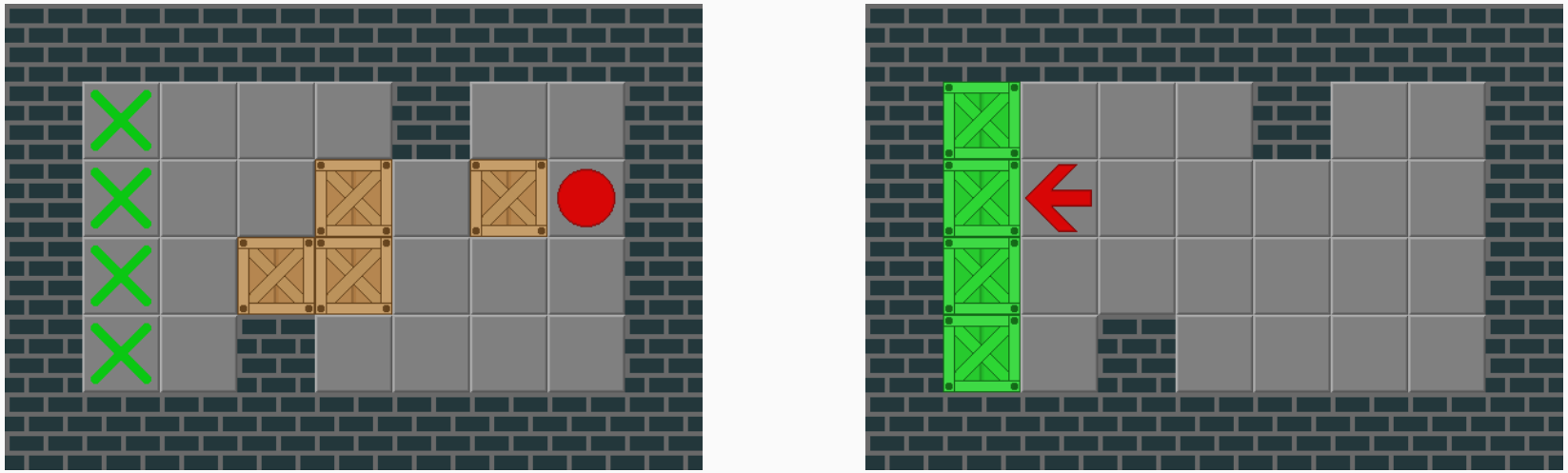


XSokoban

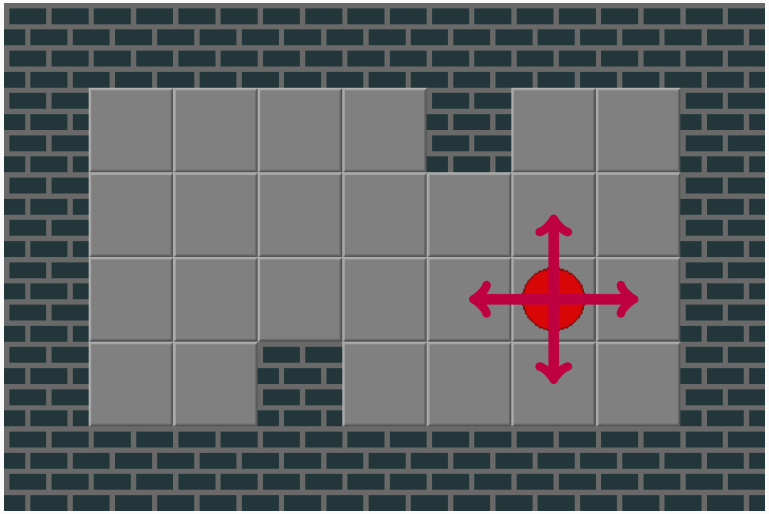
Problème **PSPACE-complet**

But du jeu

Déplacements

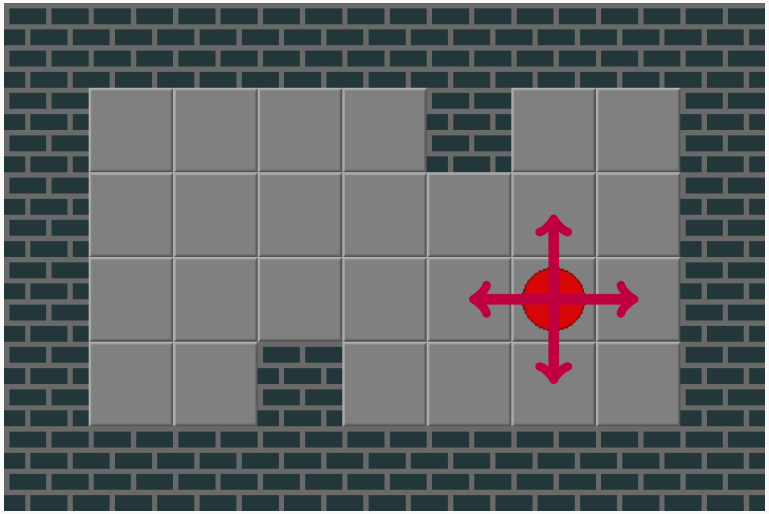


Règles

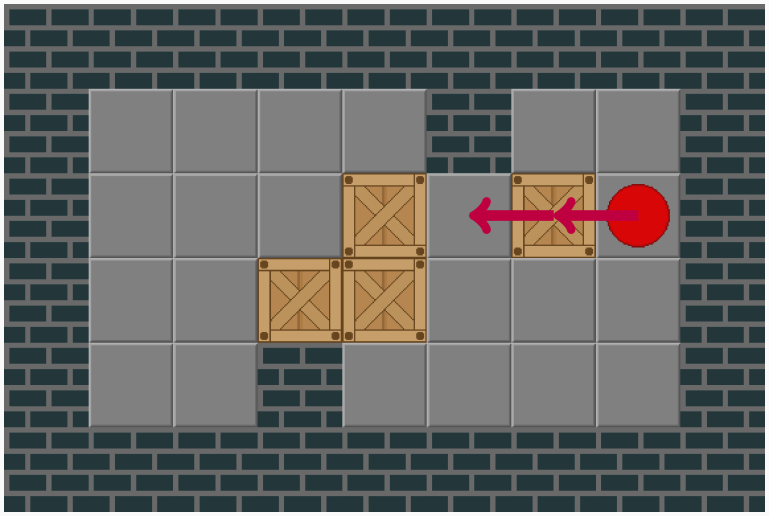


Déplacements autorisés

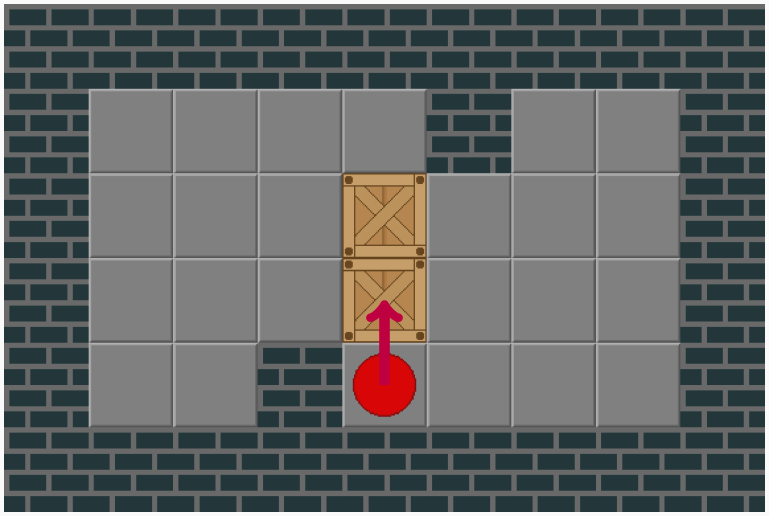
Règles

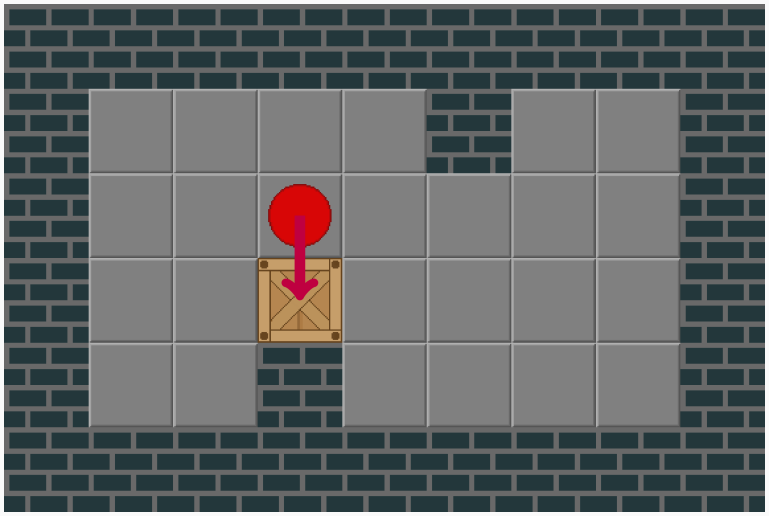


Déplacements autorisés

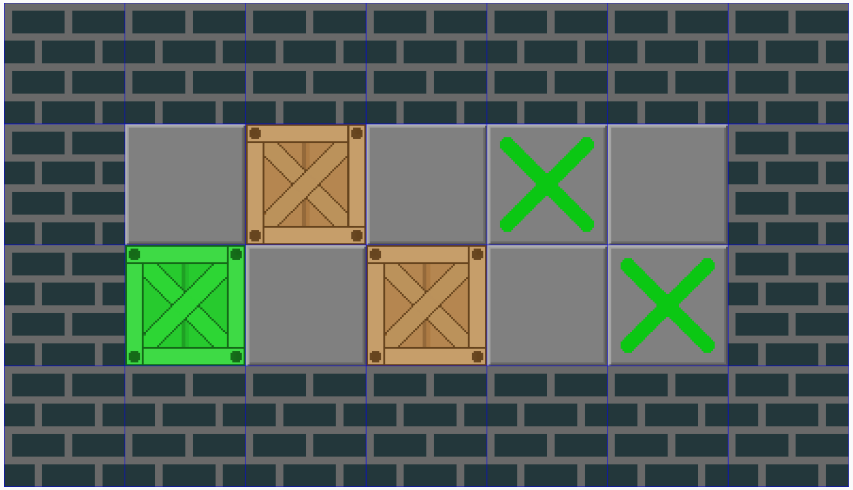


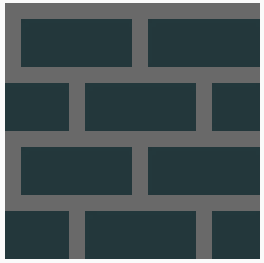
Règles



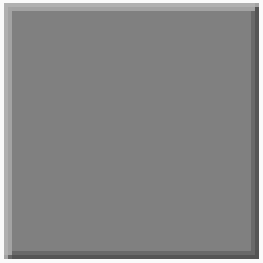


Tuiles

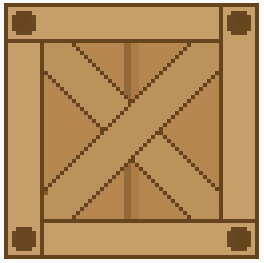




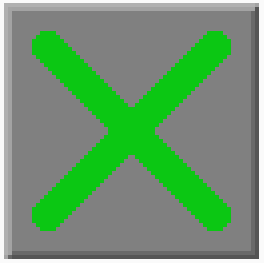
Mur



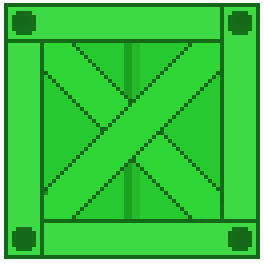
Sol



Caisse



Cible



Caisse sur une cible

Quelles stratégies adopter pour trouver une solution le plus rapidement possible à un niveau de Sokoban ?

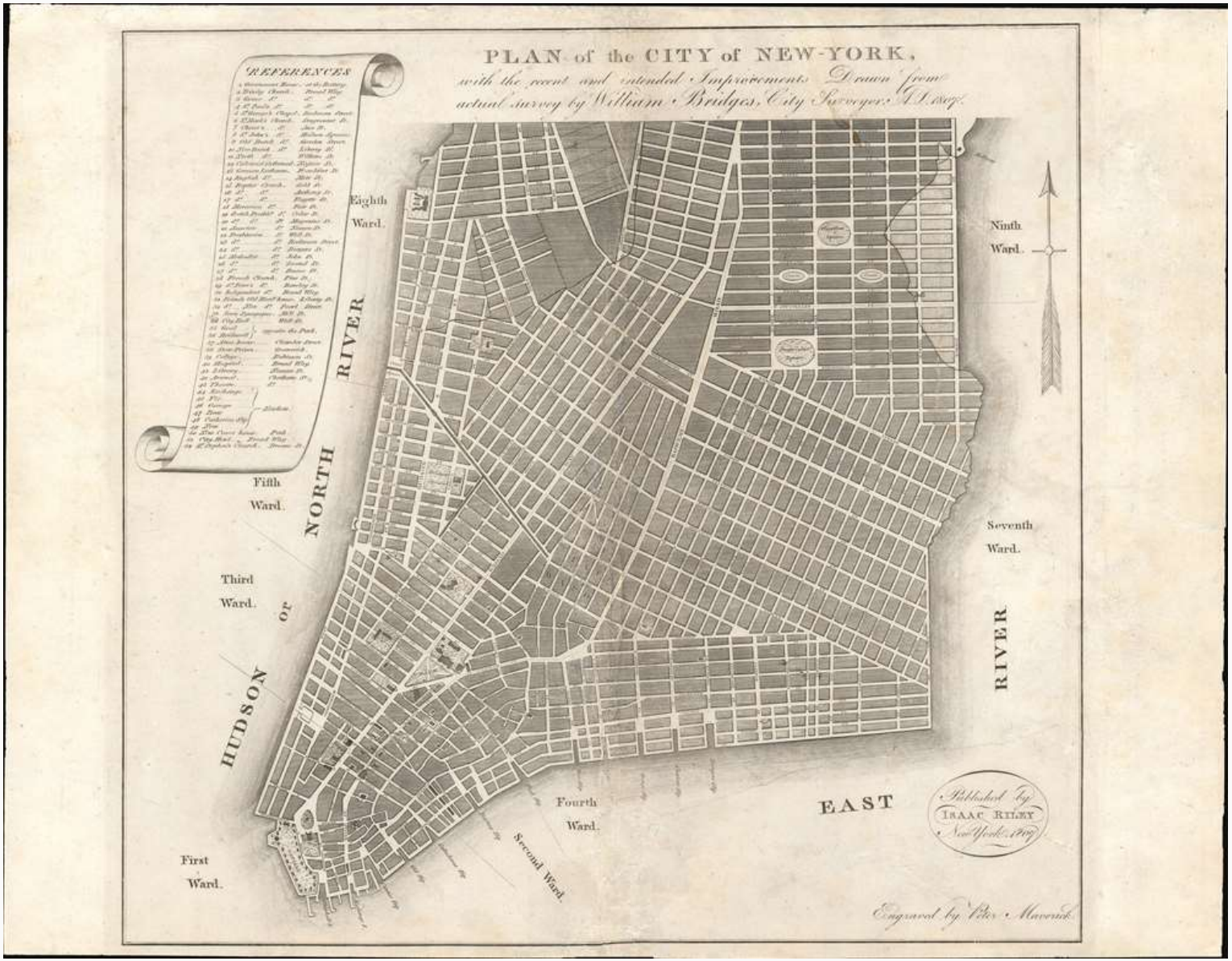
```
Welcome to sokoshell - Version 1.0
Type 'help' to show help. More help for a command with 'help command'
sokoshell>
```

Plan

Lien avec le thème de l'année

Source : *Indiana Jones et les Aventuriers de l'arche perdue* (scène de fin), Steven Spielberg, 1981
`https://pbs.twimg.com/media/EyjVShEVEAAQZjK.jpg`

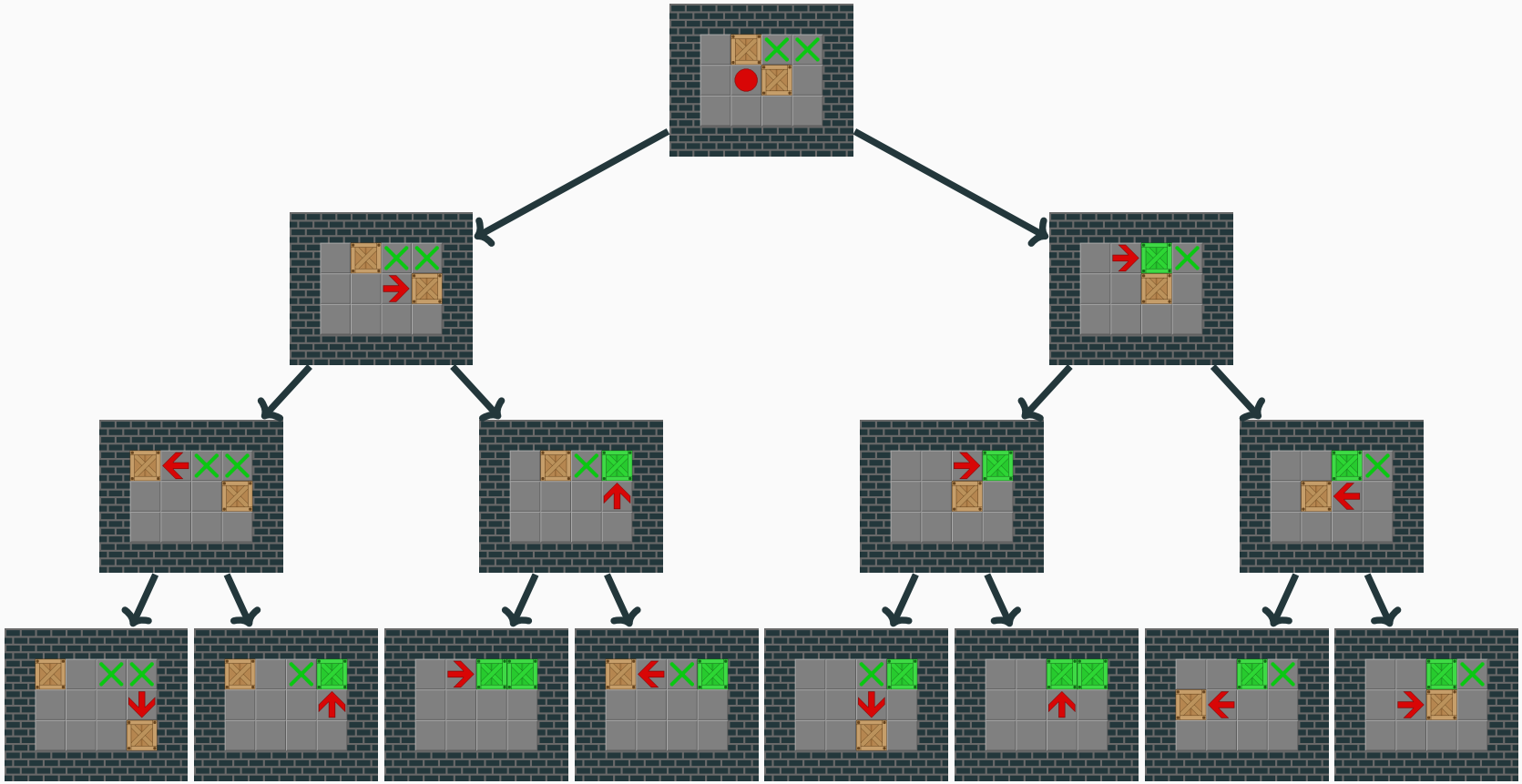
Lien avec le thème de l'année



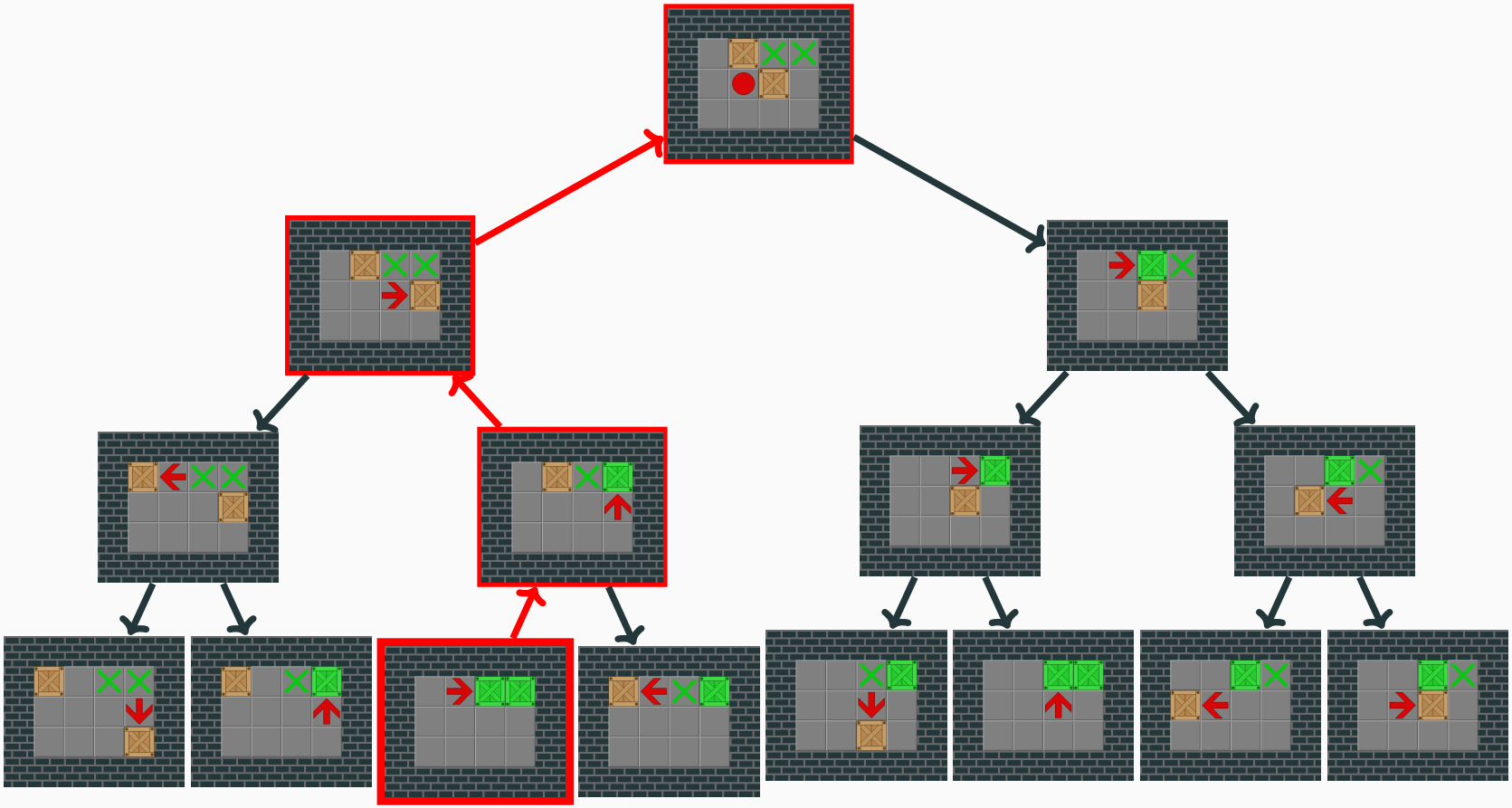
Source : https://www.geographicus.com/mm5/graphics/00000001/L/NewYork-bridgesmaverick-1807.jpg

Principe de résolution

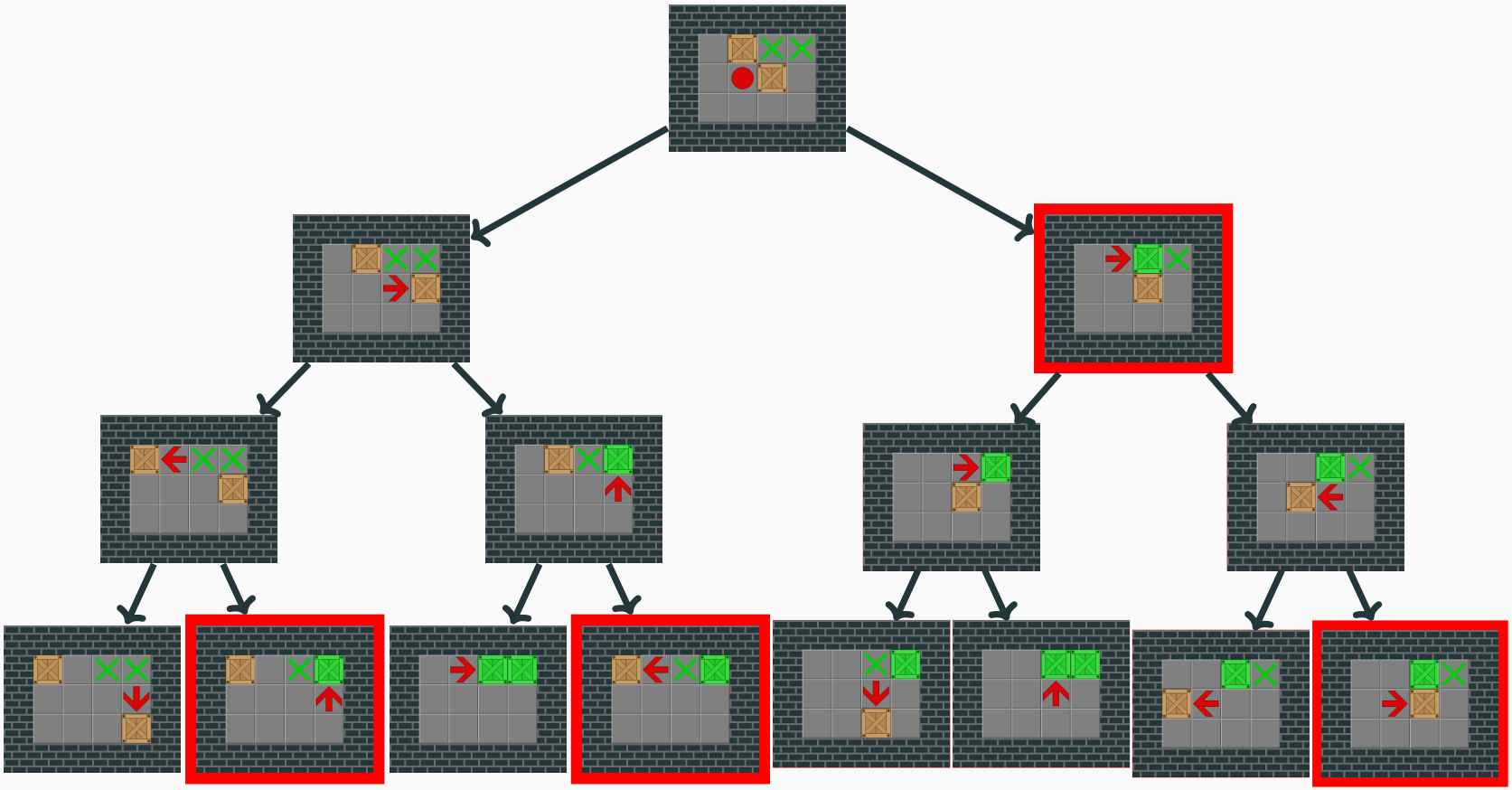
Arbre des états



Arbre des états



Arbre des états



Calcul du *hash* d'un état - Hash de Zobrist

Propriétés du **XOR** :

1. a **XOR** $a = 0$
2. **XOR** commutatif, associatif
3. **XOR** préserve l'aléatoire

Initialisation :

$$T = \begin{array}{c} \begin{array}{ccc} \text{caisse} & \text{joueur} & \text{case} \end{array} \\ \begin{pmatrix} 6357 & 01234 \\ -1378 & 42 \\ \vdots & \vdots \\ 93268 & -278 \end{pmatrix} \begin{array}{c} 0 \\ 1 \\ \vdots \\ wh-1 \end{array} \end{array}$$

Calcul du *hash* d'un état - Hash de Zobrist

- $(c_1, ..., c_n)$ n caisses et p position du joueur :

$$h = \bigoplus_{i=0}^{n} T[c_i][0] \,\textbf{XOR}\, T[p][1]$$

en $\mathcal{O}(n)$

- **Connaissant le hash de l'état parent** : $c_i \to c_i', p \to p'$

$$h' = h \,\textbf{XOR}\, T[c_i][0] \,\textbf{XOR}\, T[c_i'][0] \,\textbf{XOR}\, T[p][1] \,\textbf{XOR}\, T[p'][1]$$

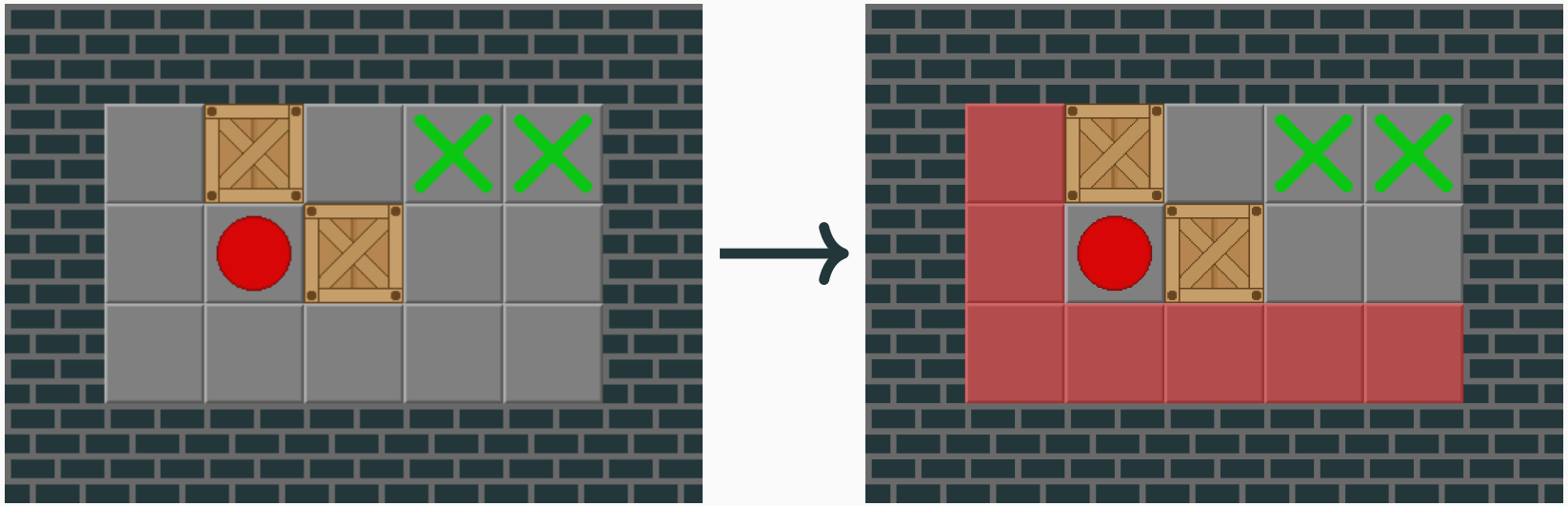
$$\boxed{\text{en } \mathcal{O}(1)}$$

Réduction de l'espace de recherche

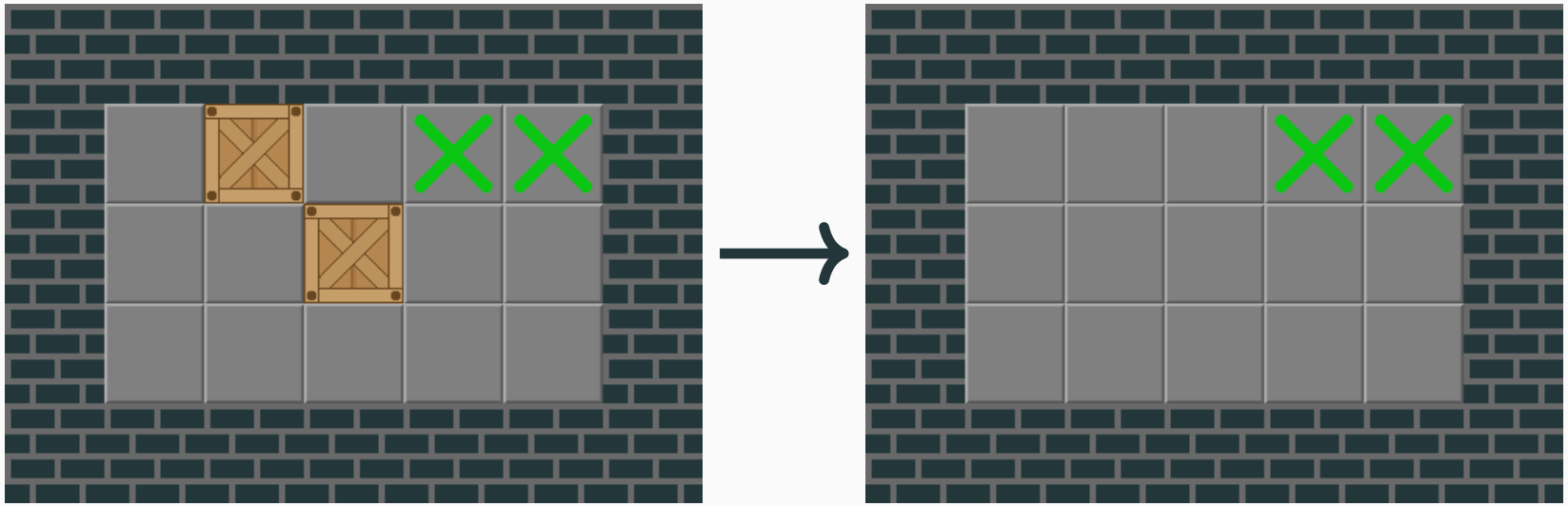
Réduction de l'espace de recherche

Analyse statique

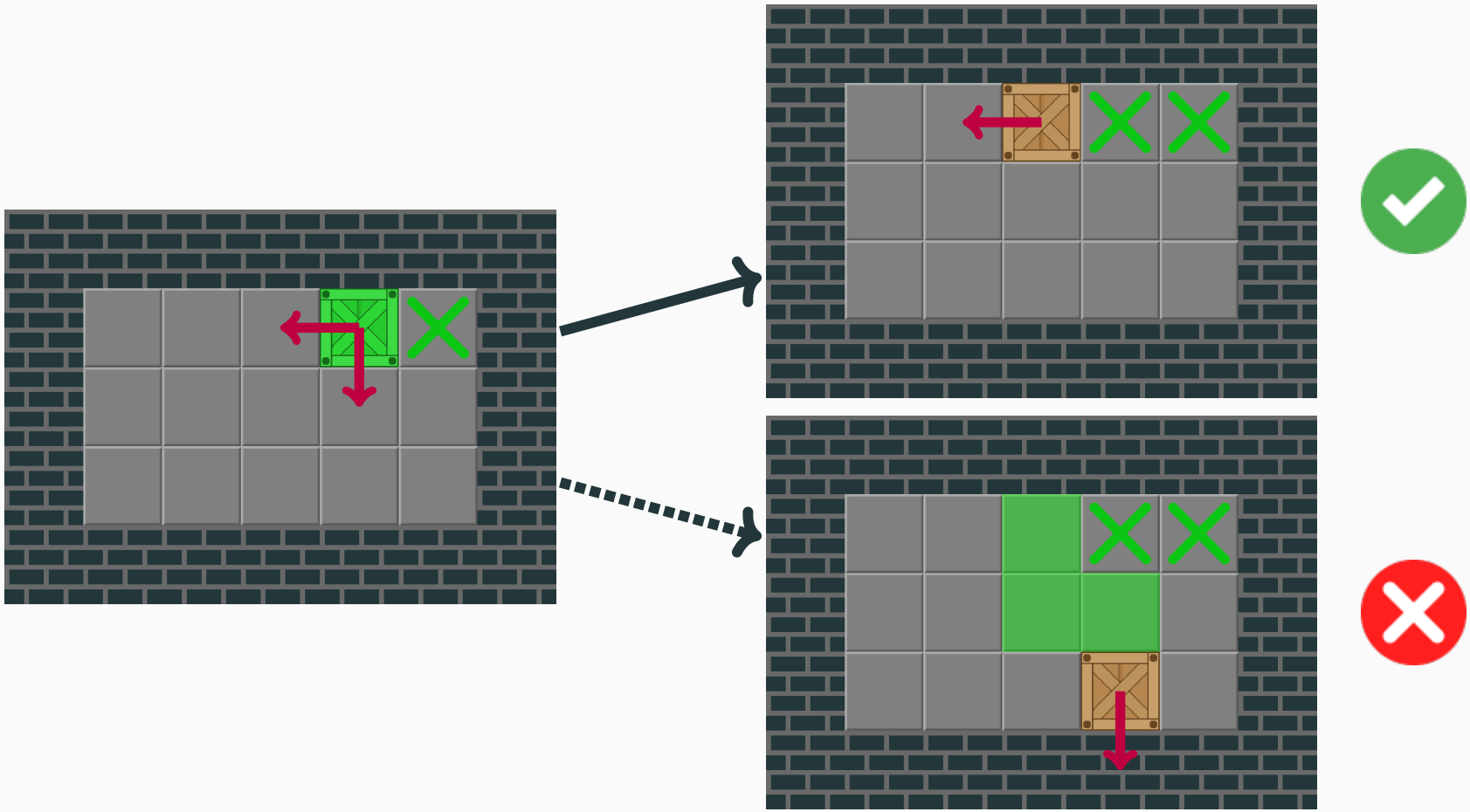
Détection des positions mortes *(dead positions)*



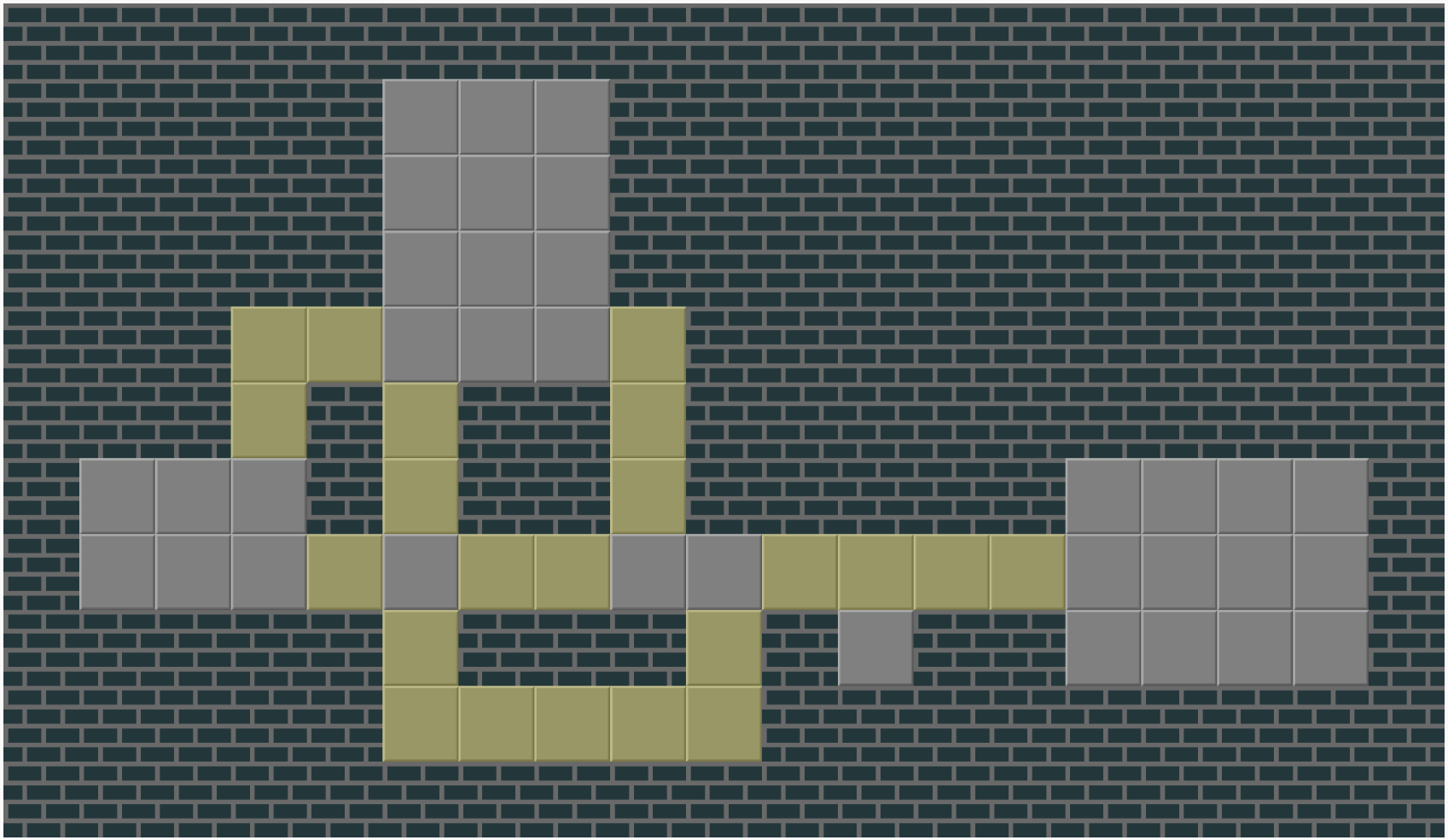
Détection des positions mortes *(dead positions)*



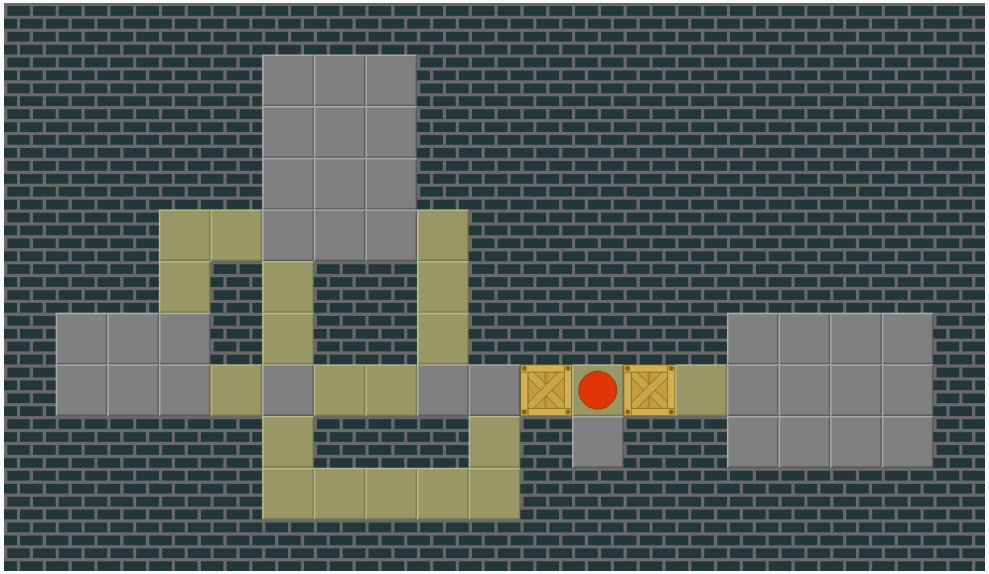
Détection des positions mortes *(dead positions)*

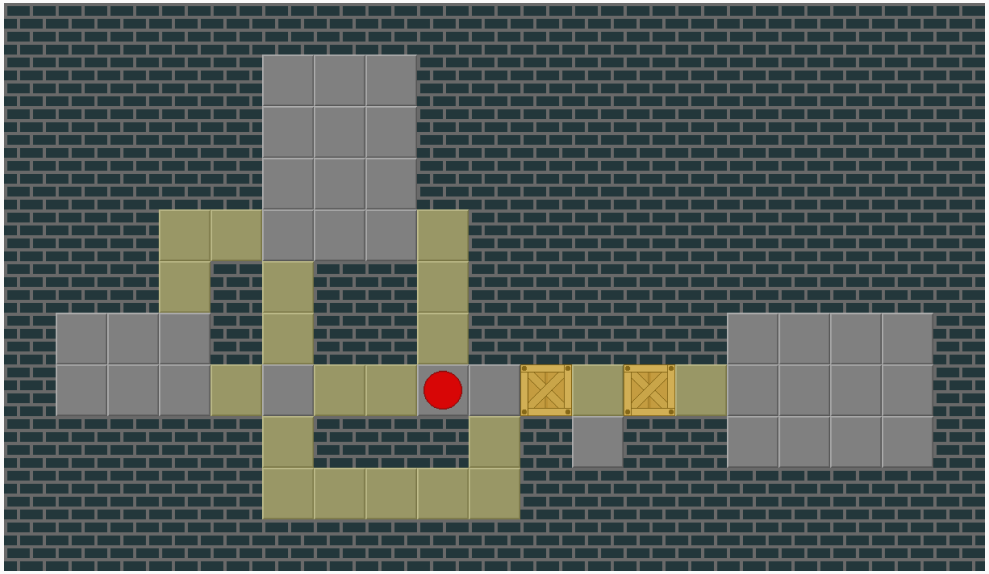


Détection de tunnels

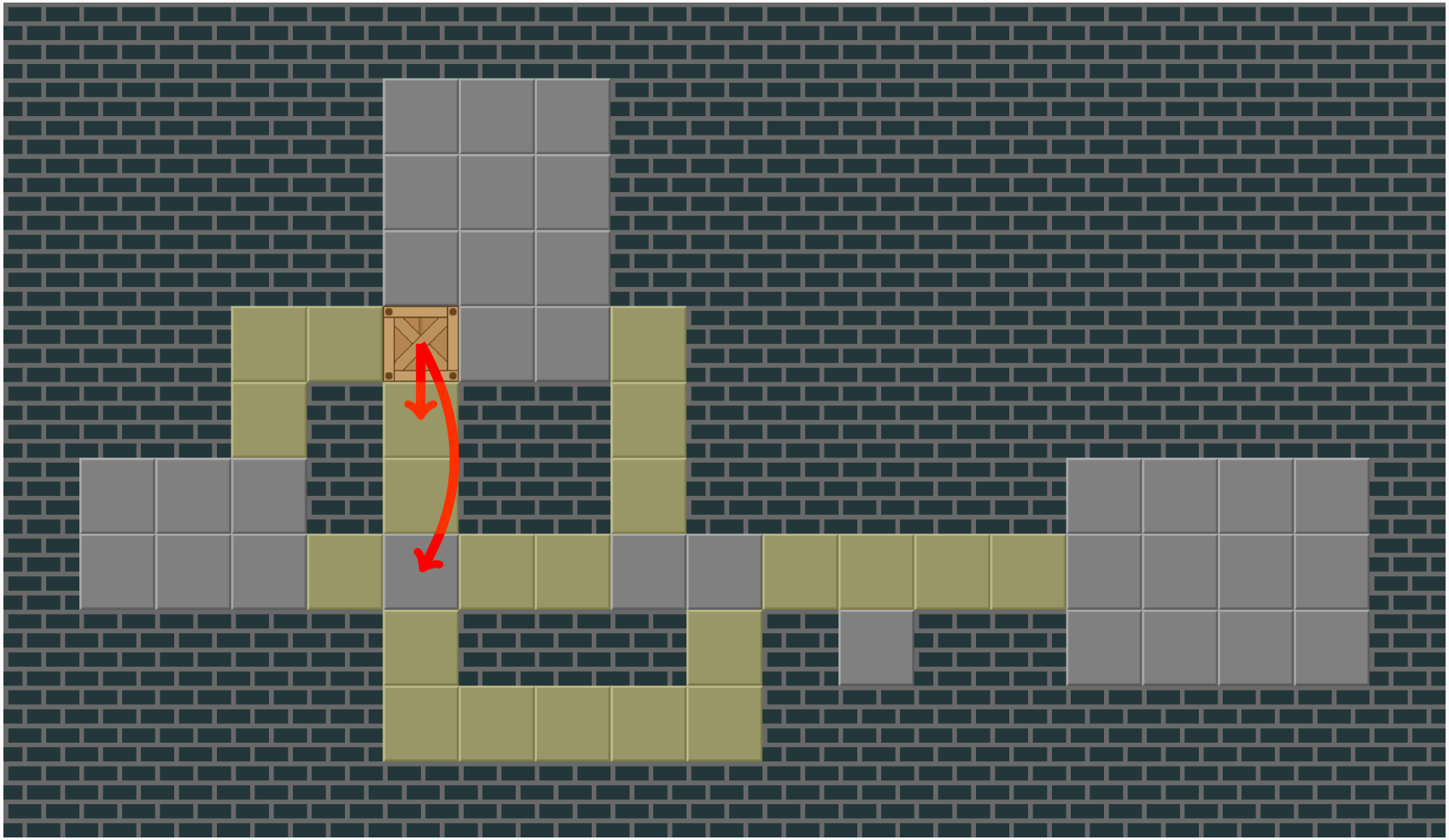


Détection de tunnels

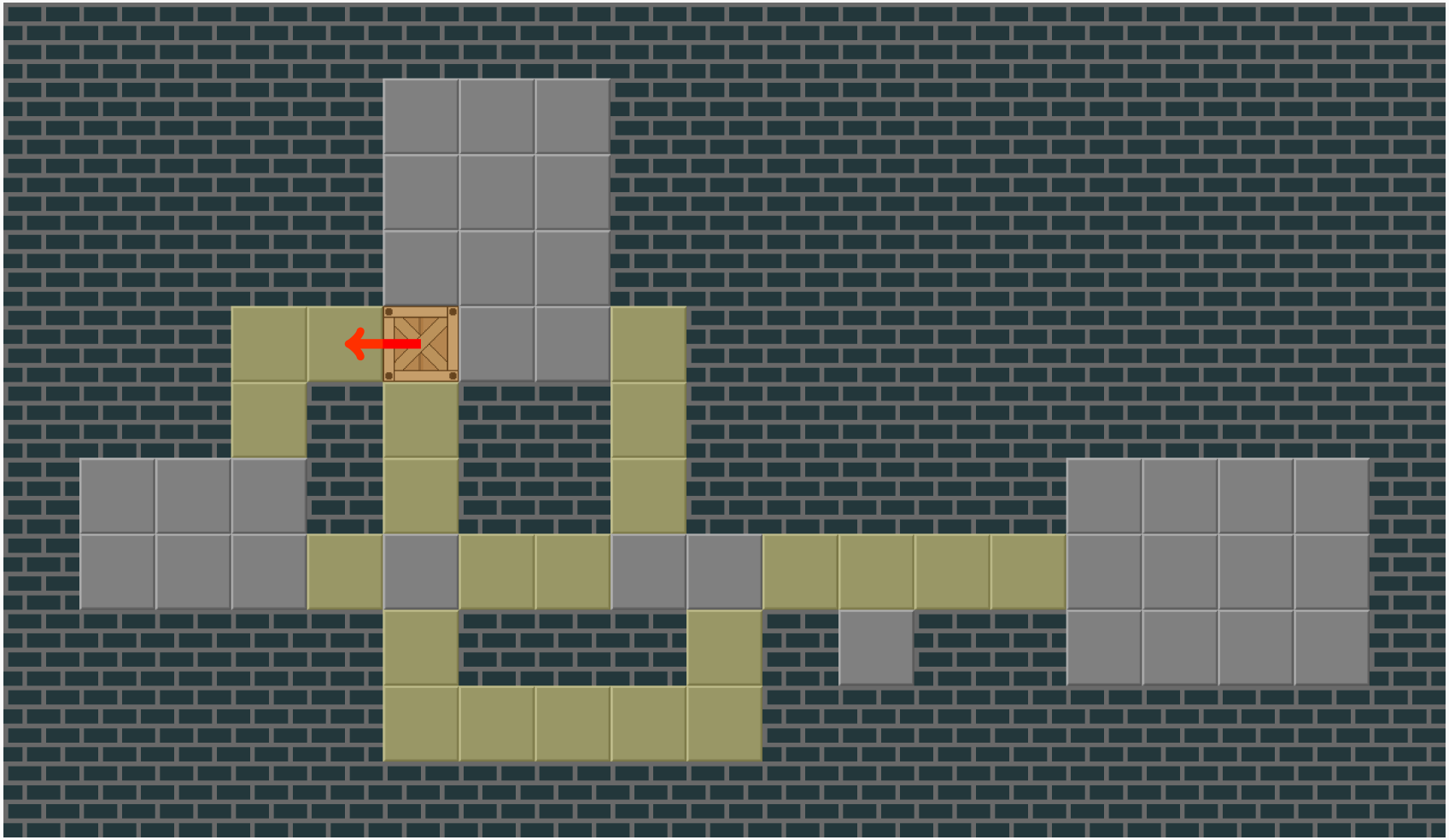




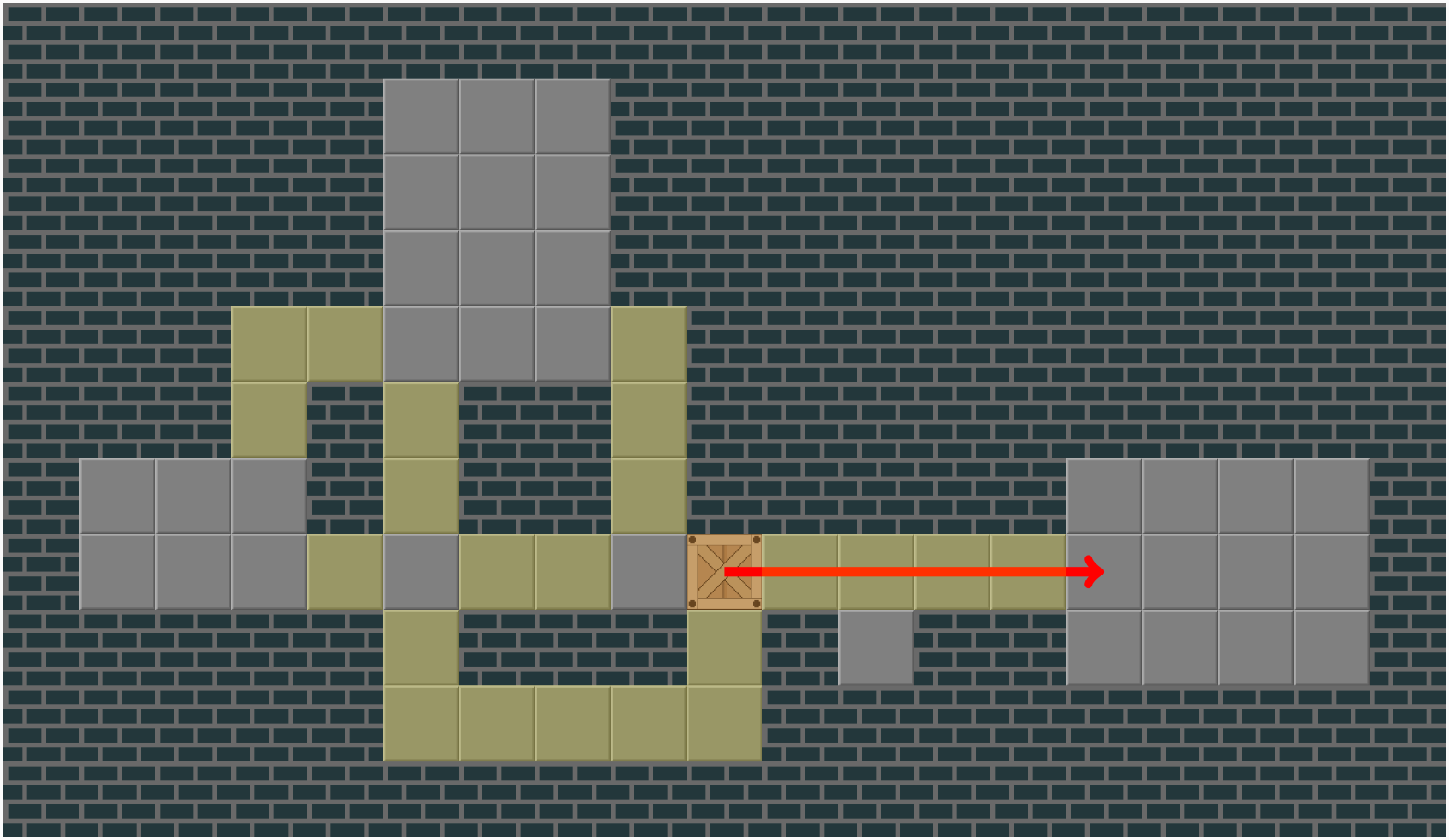
Détection de tunnels



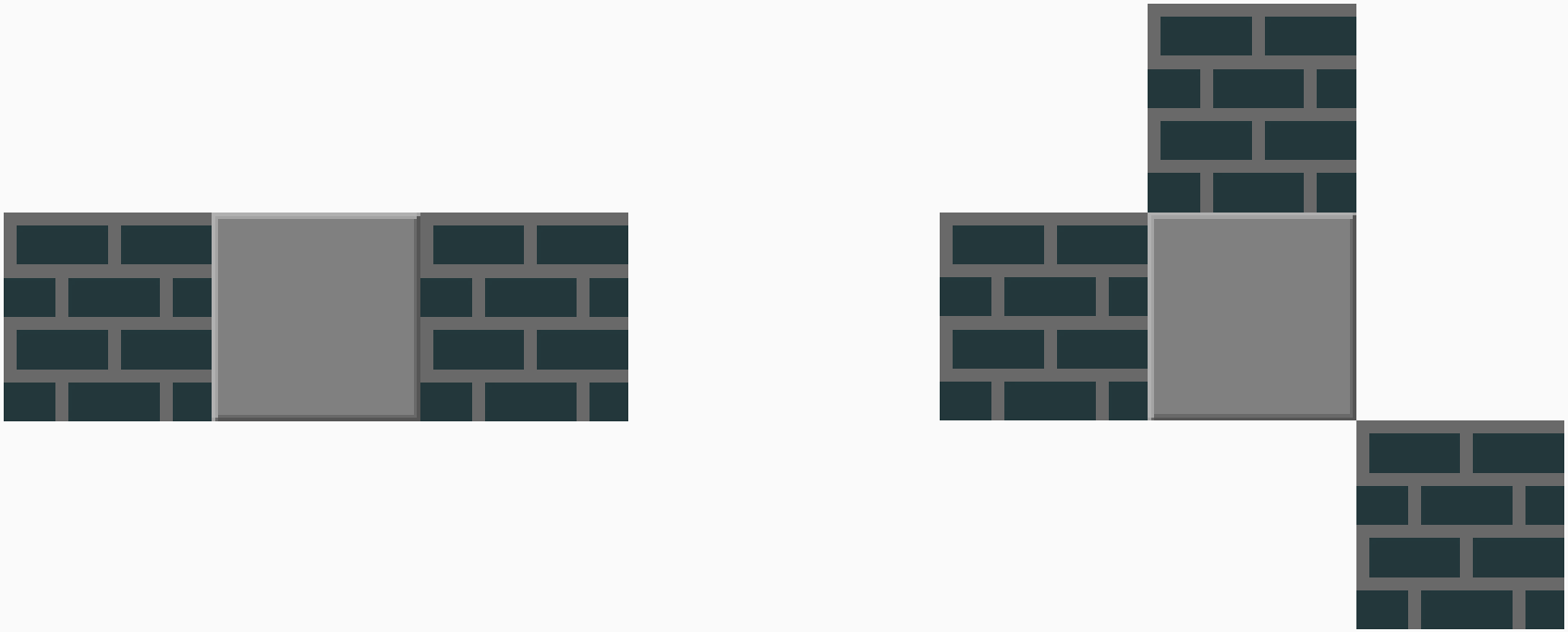
Détection de tunnels



Détection de tunnels

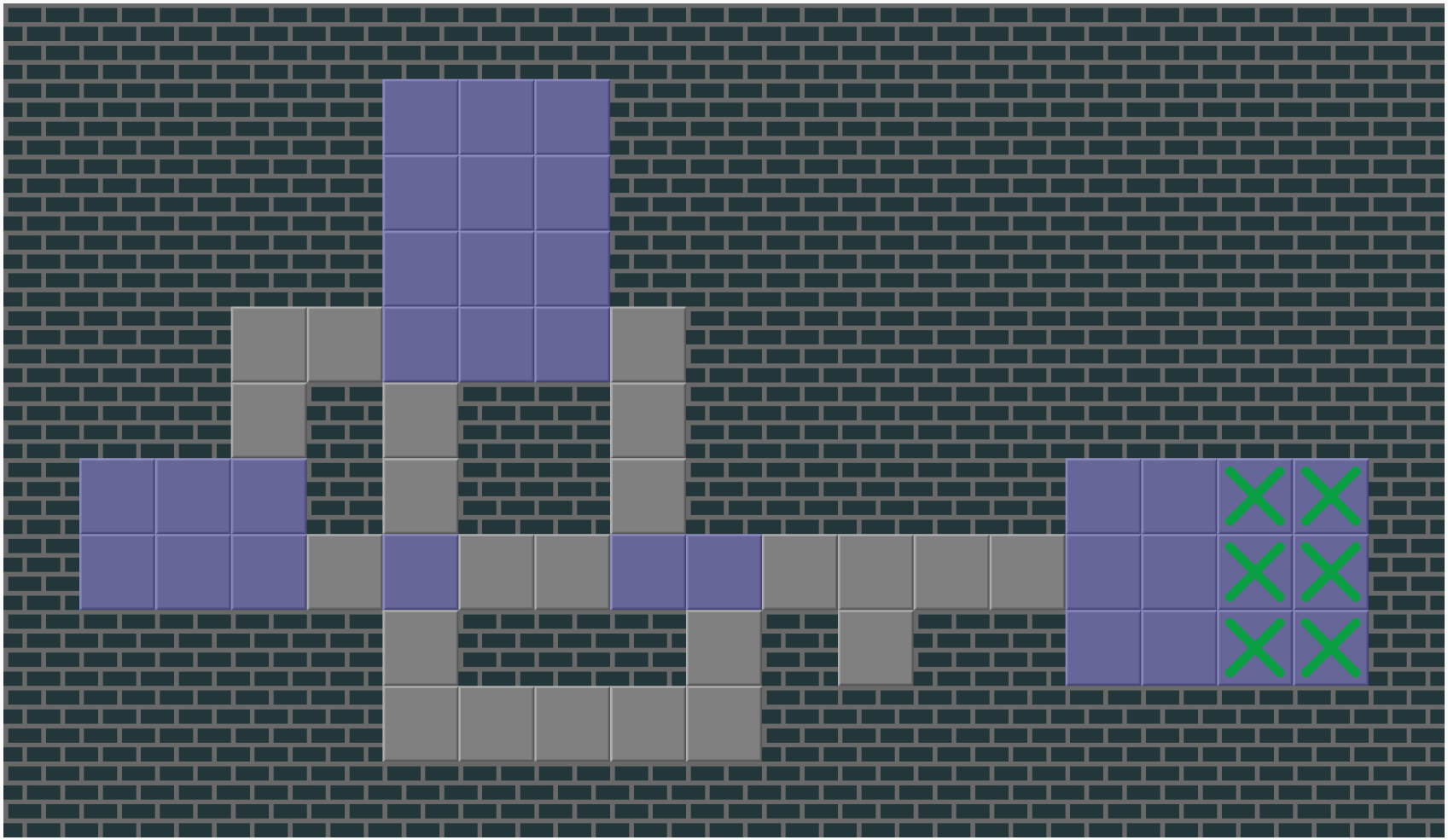


Détection de tunnels

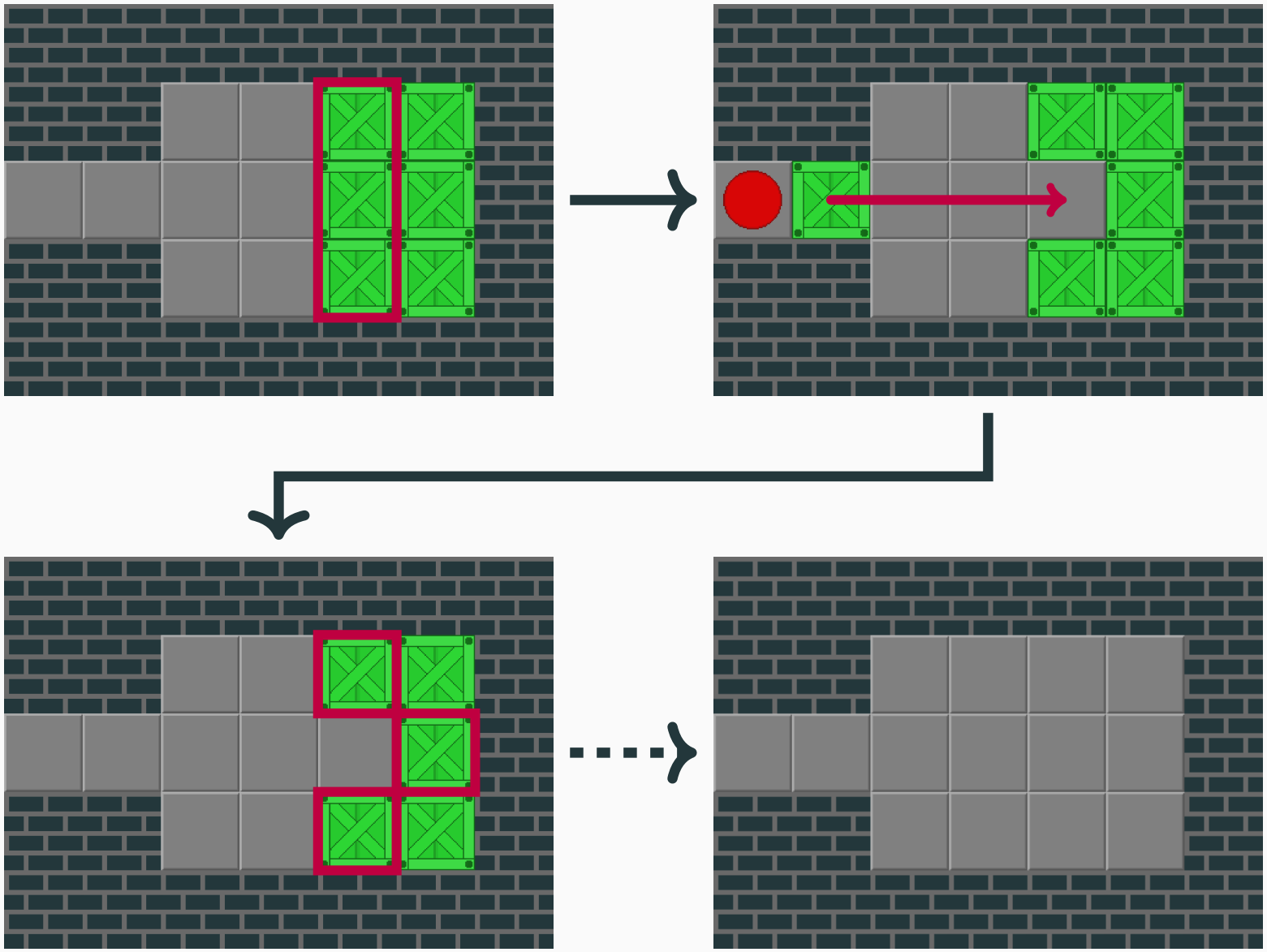


Composition d'un tunnel

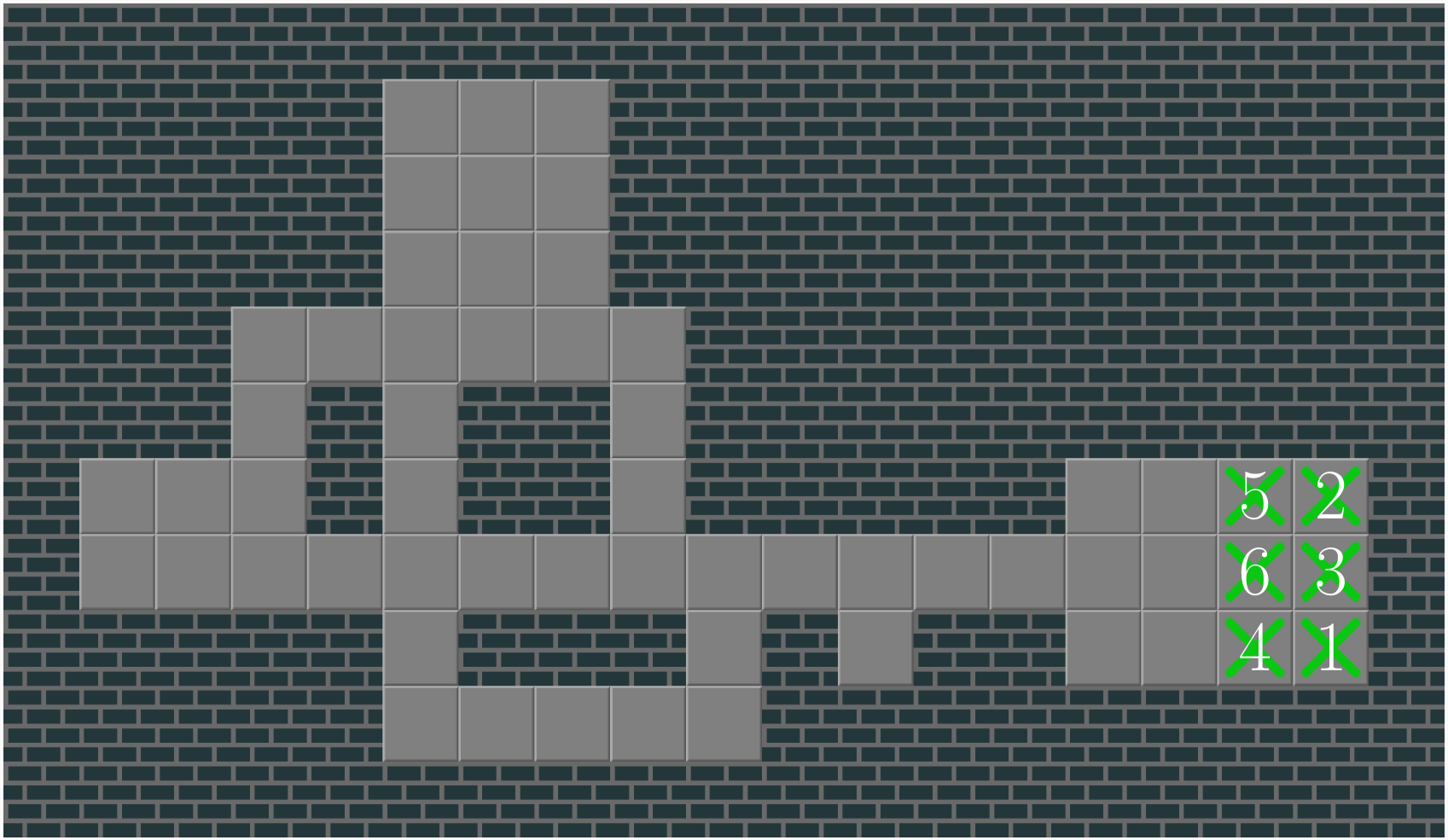
Salles et ordre de rangement *(packing order)*



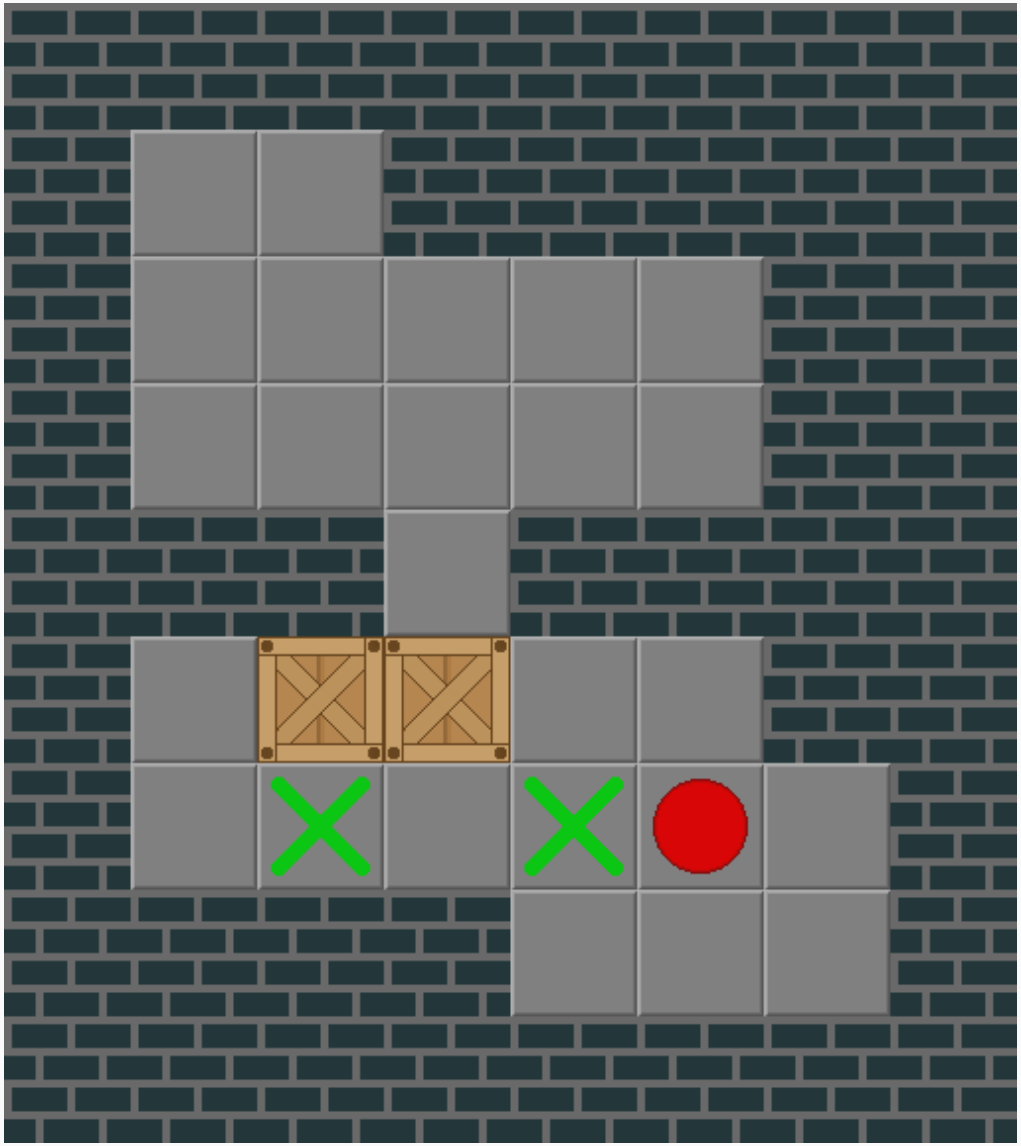
Salles et ordre de rangement *(packing order)*



Salles et ordre de rangement *(packing order)*



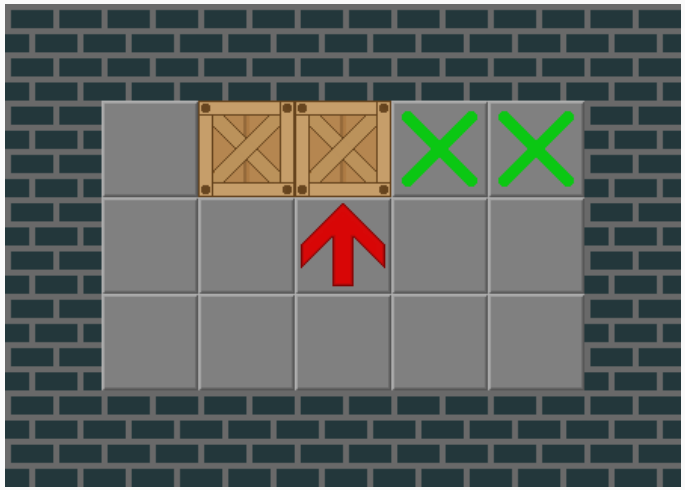
Salles et ordre de rangement *(packing order)*



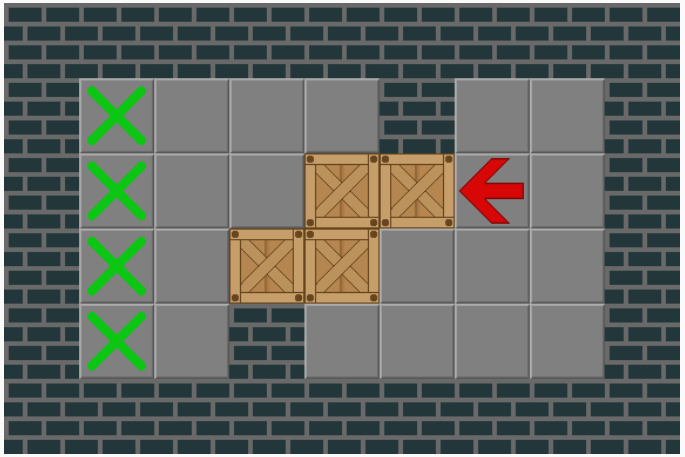
Réduction de l'espace de recherche

Analyse dynamique

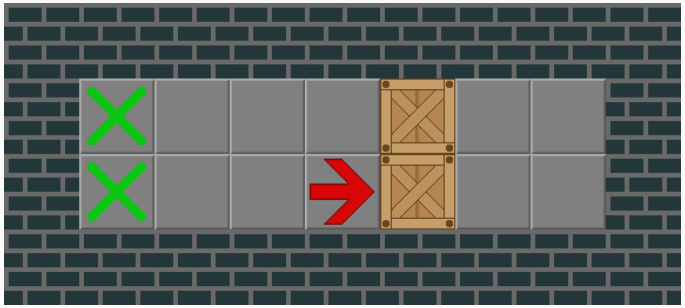
Détection d'impasses *(deadlocks)*



(a) *Freeze deadlock n°1*



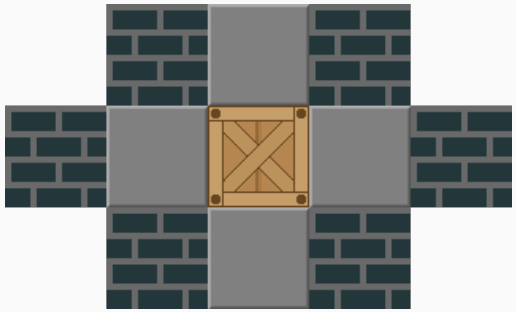
(b) *Freeze deadlock n°2*



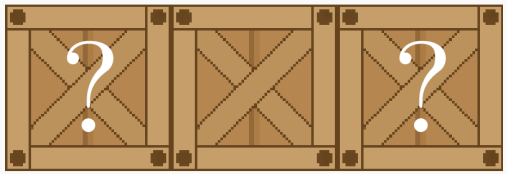
(c) *PI Corral deadlock*

Détection de *freeze deadlocks*

(a) *Règle n°1*

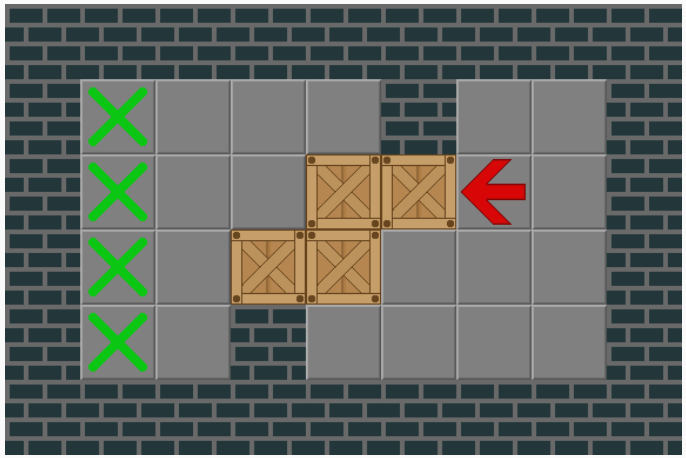


(b) *Règle n°2*

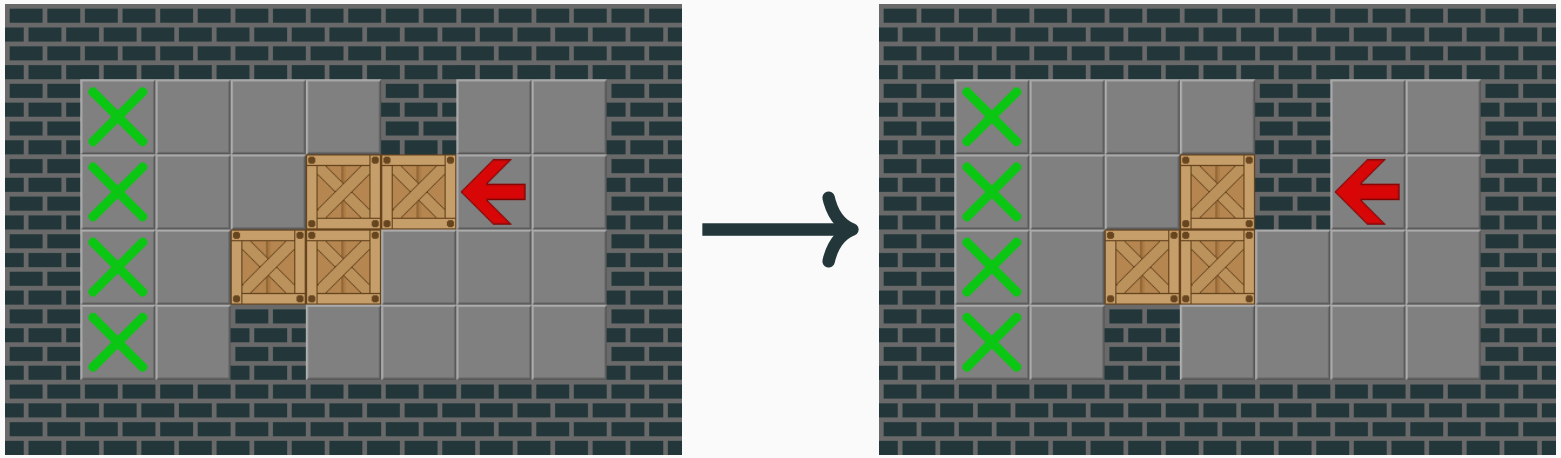


(c) *Règle n°3*

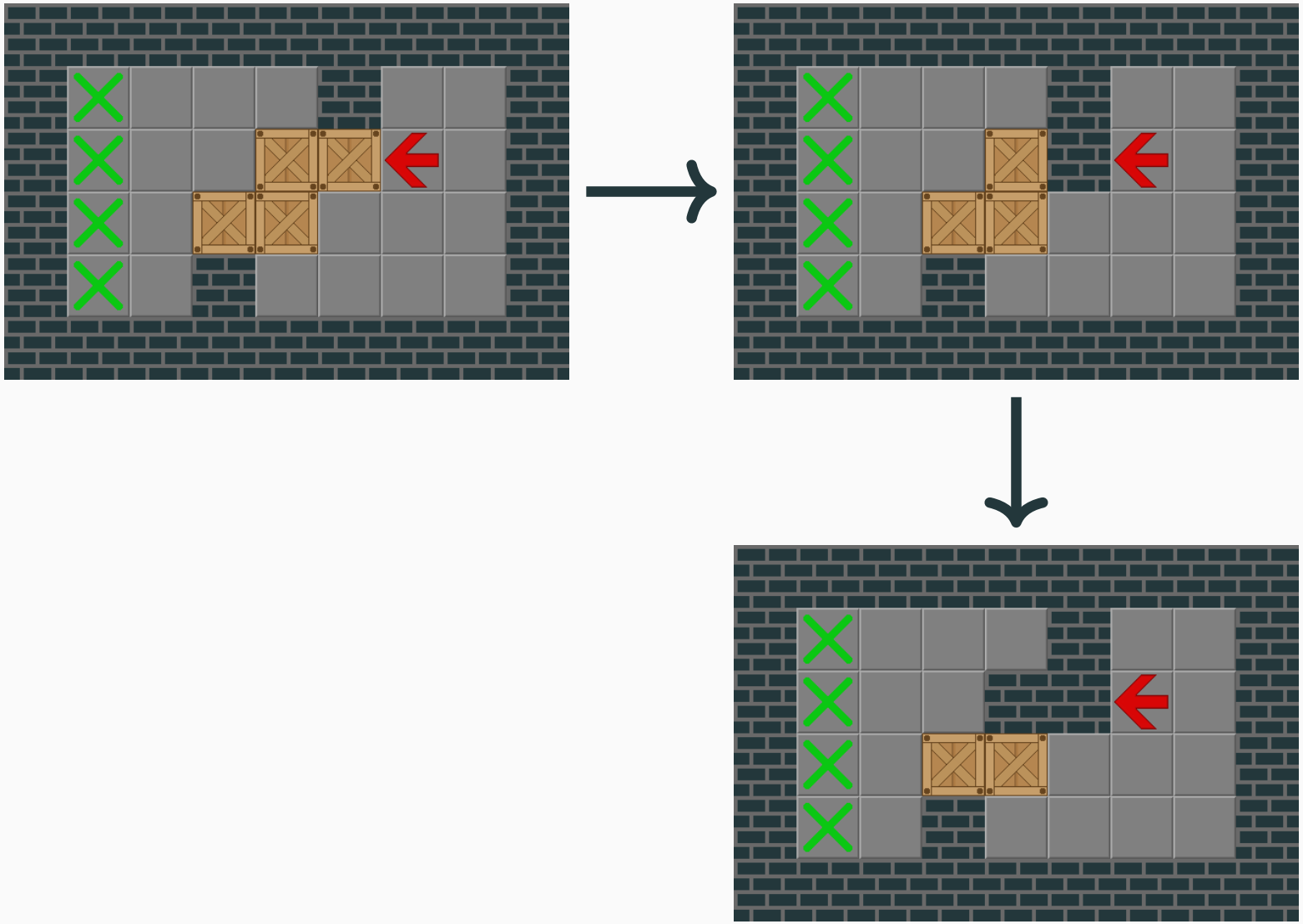
Détection de *freeze deadlocks*



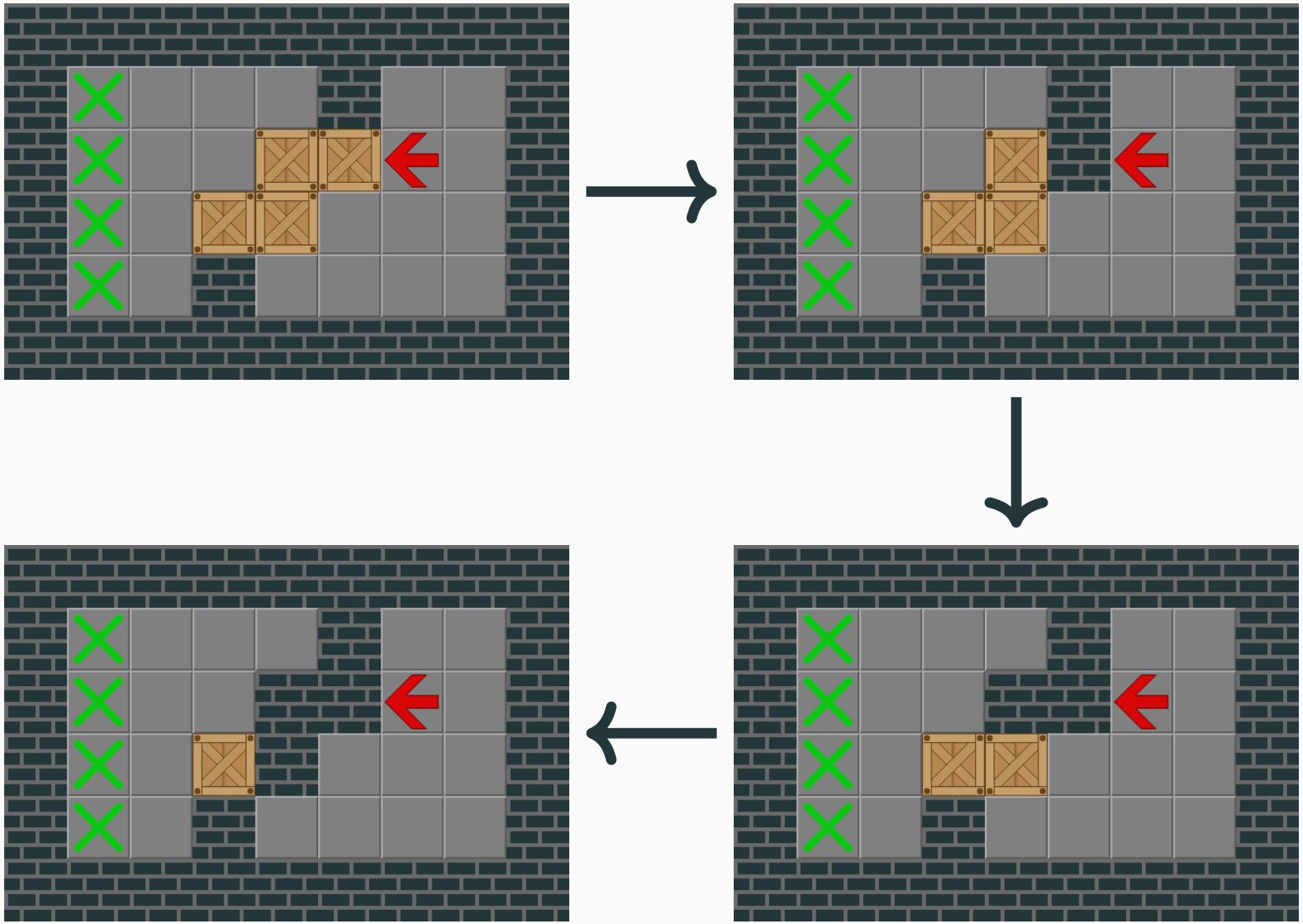
Détection de *freeze deadlocks*



Détection de *freeze deadlocks*

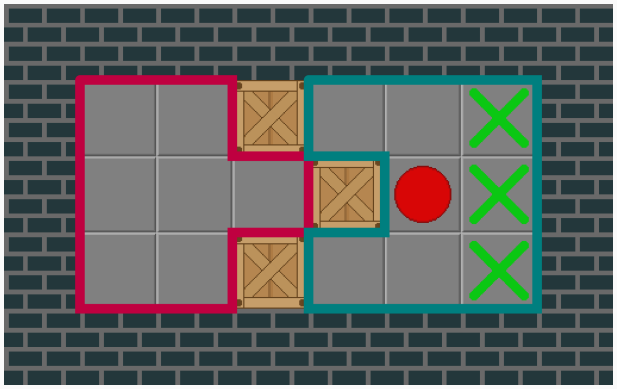


Détection de *freeze deadlocks*

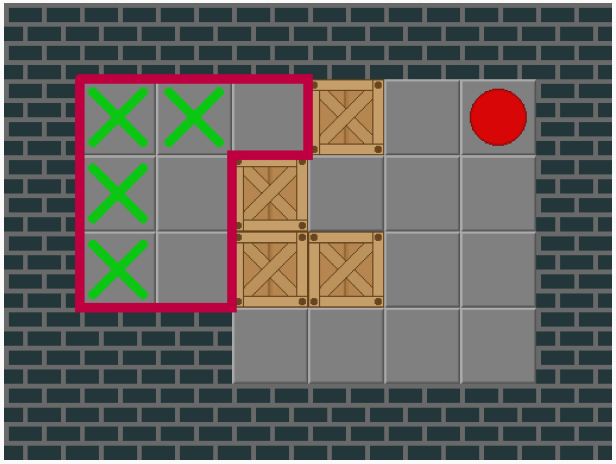


Gelée!

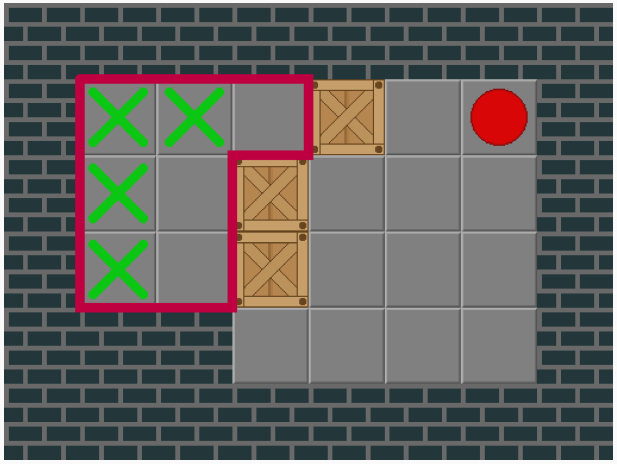
Détection de *PI Corral deadlocks*



(a) *Corral*

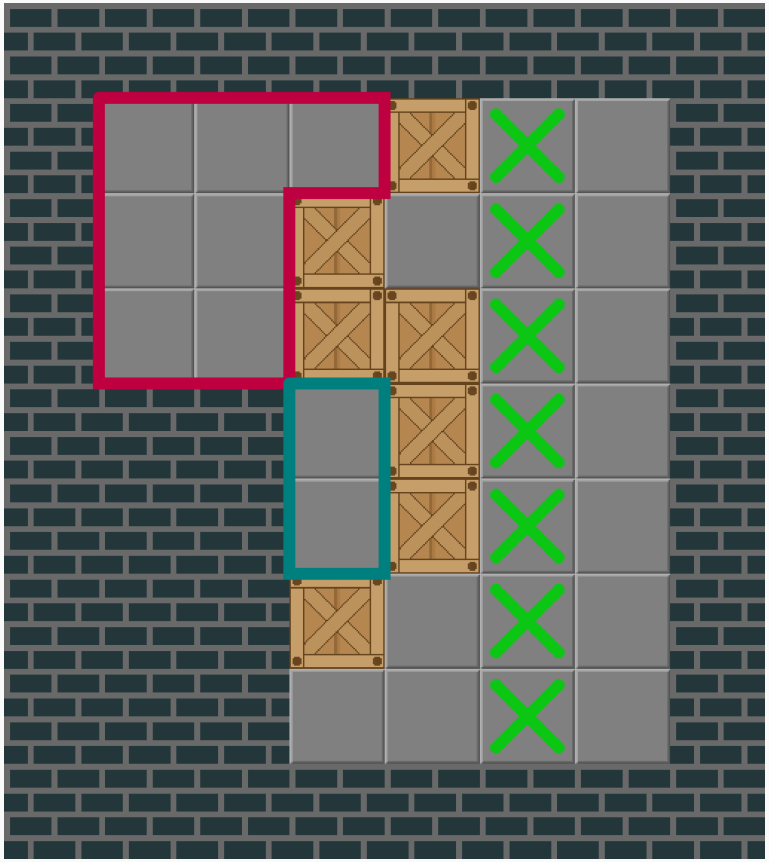


(b) *I Corral*

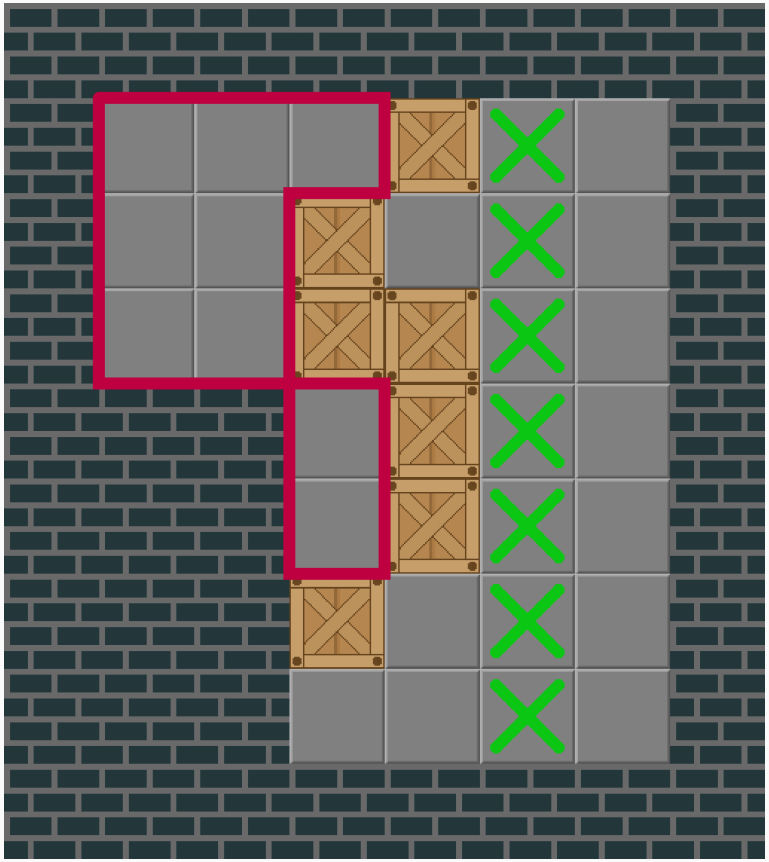


(c) *PI Corral*

Détection de *PI Corral deadlocks*



Deux *I-Corrals*

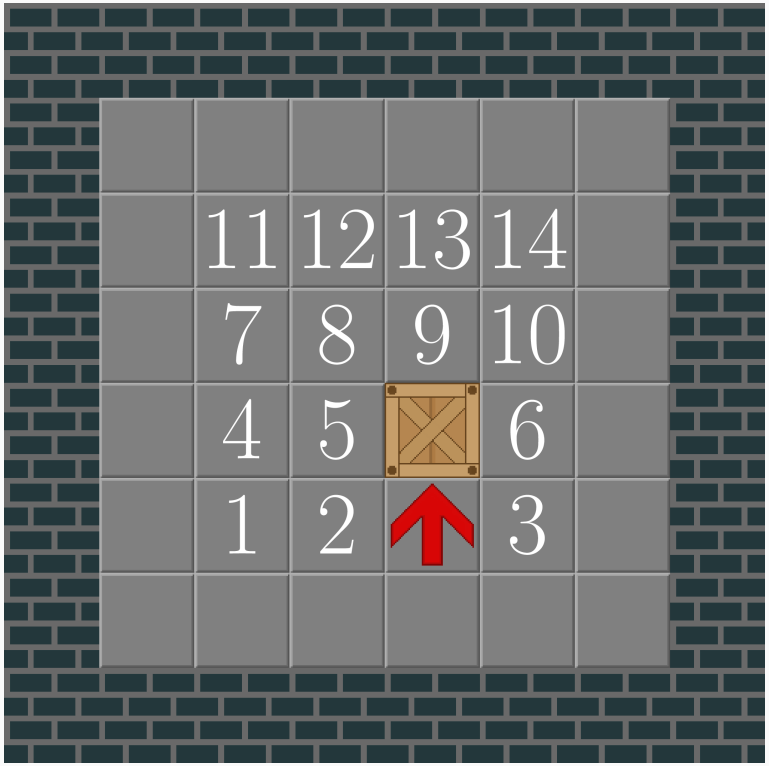


Un multi *PI-Corral*

Détection de *PI Corral deadlocks*

Brian Damgaard : émonde l'arbre de recherche d'au moins **20%** !

Table de *deadlocks*



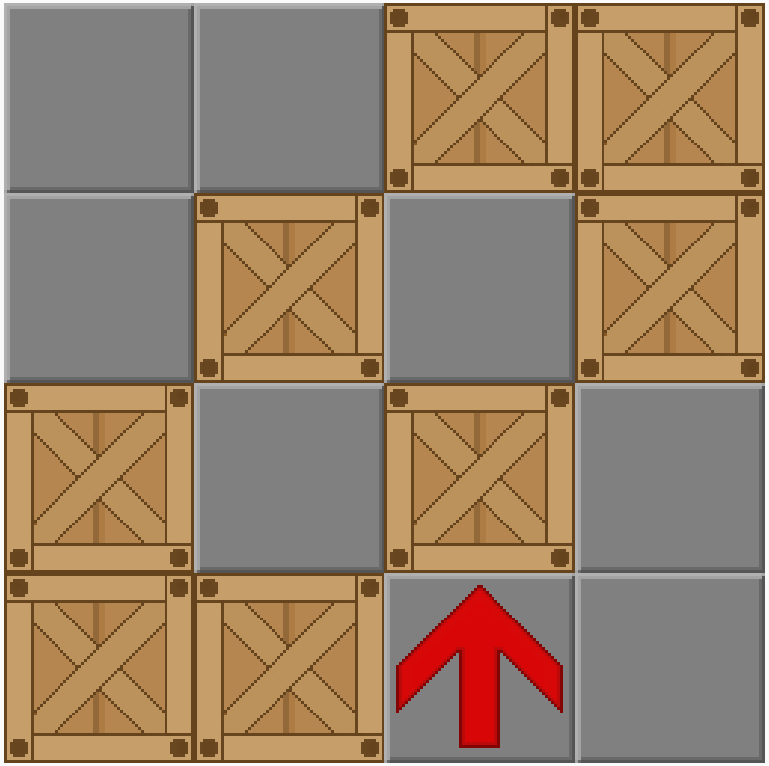
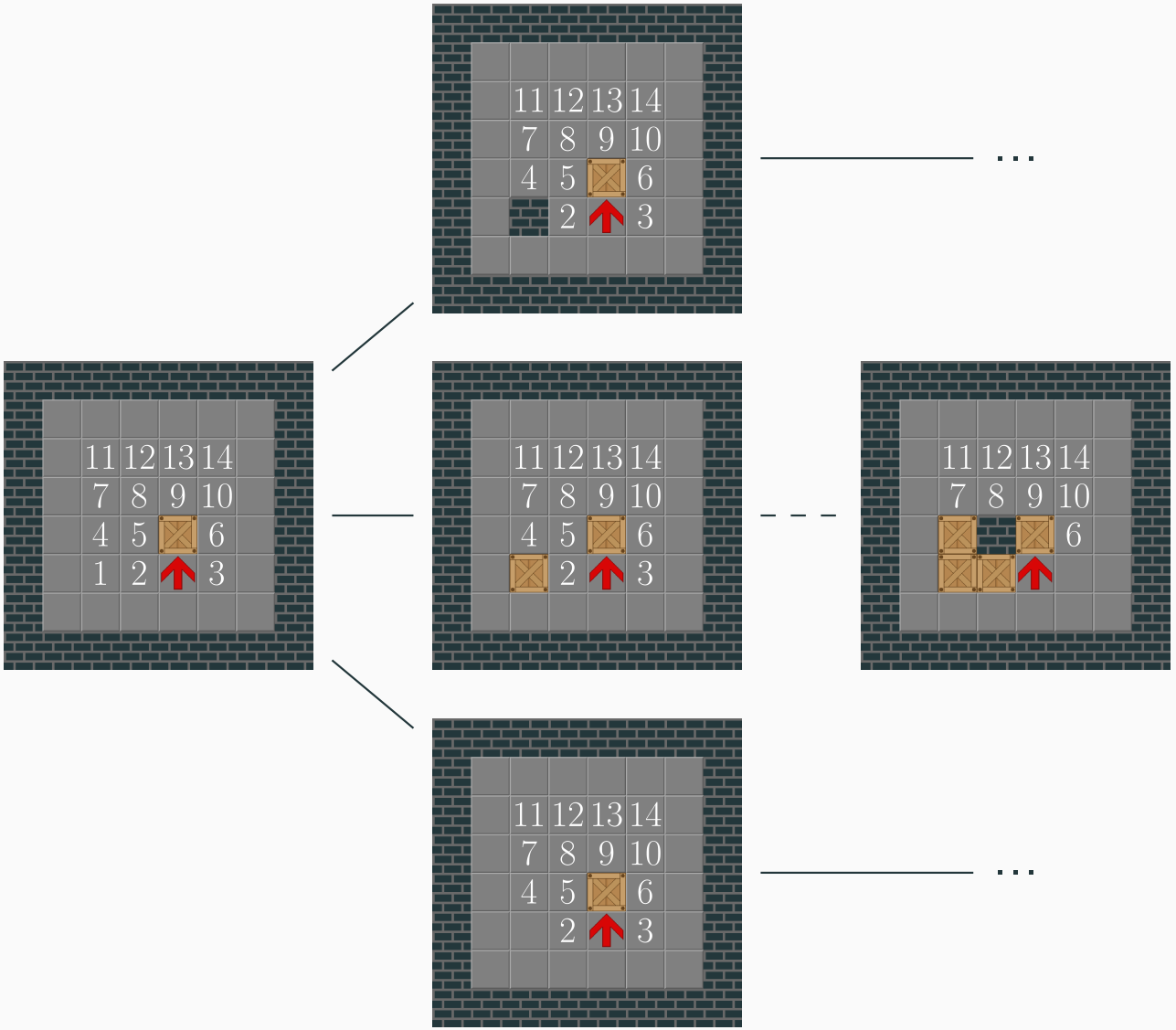
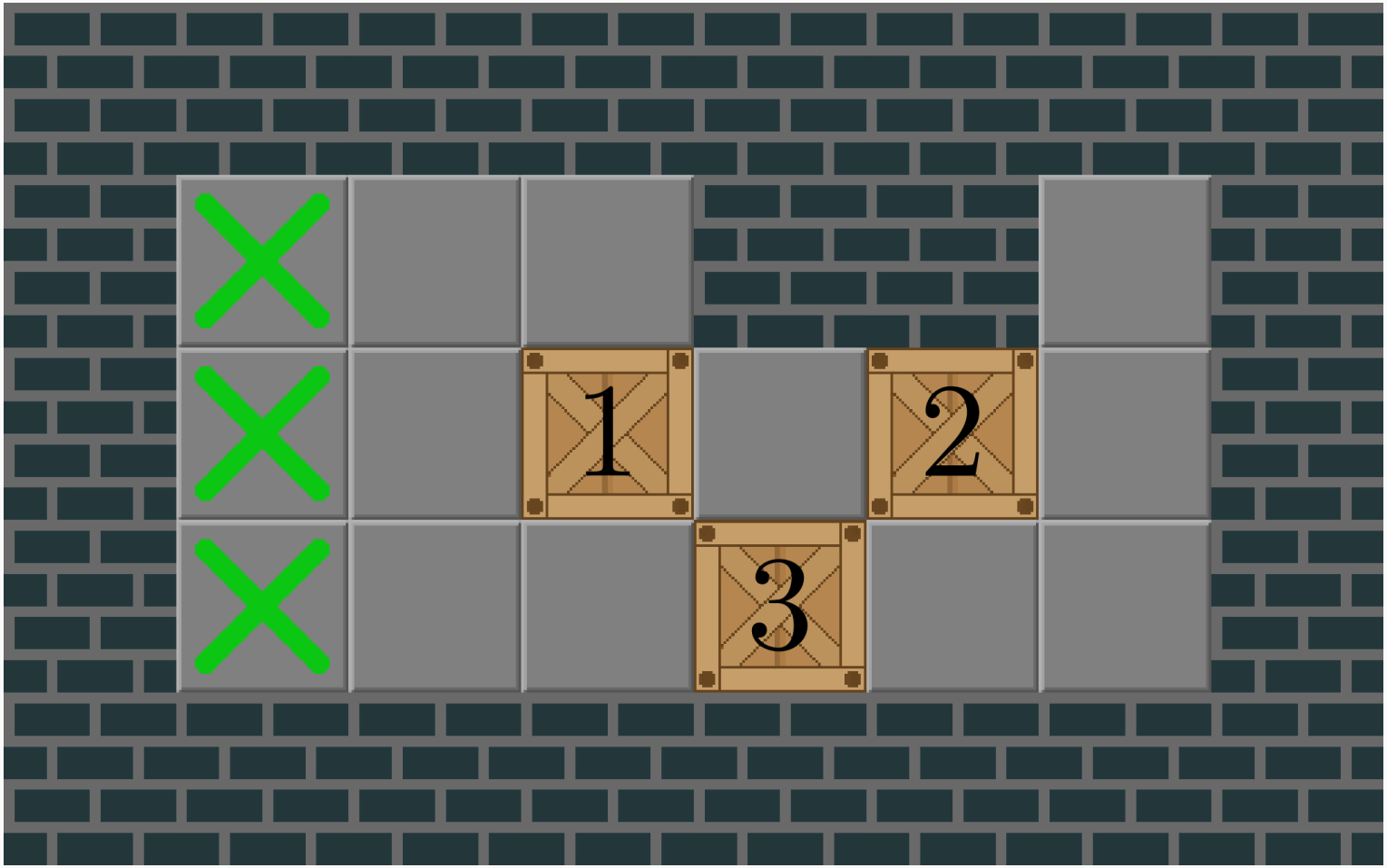


Table de *deadlocks*

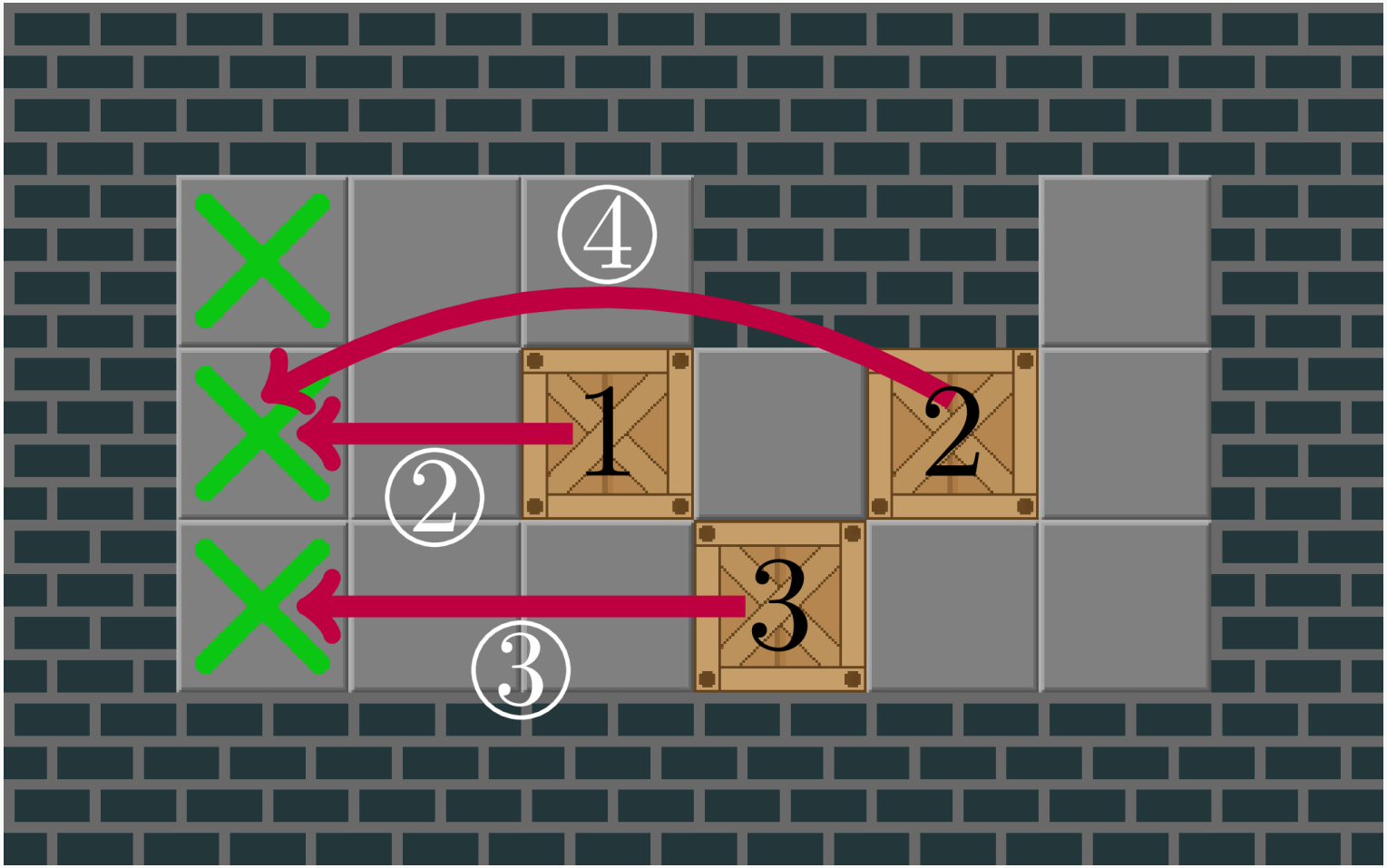


Recherche dirigée par une heuristique

Heuristique simple *(Simple Lower Bound)*

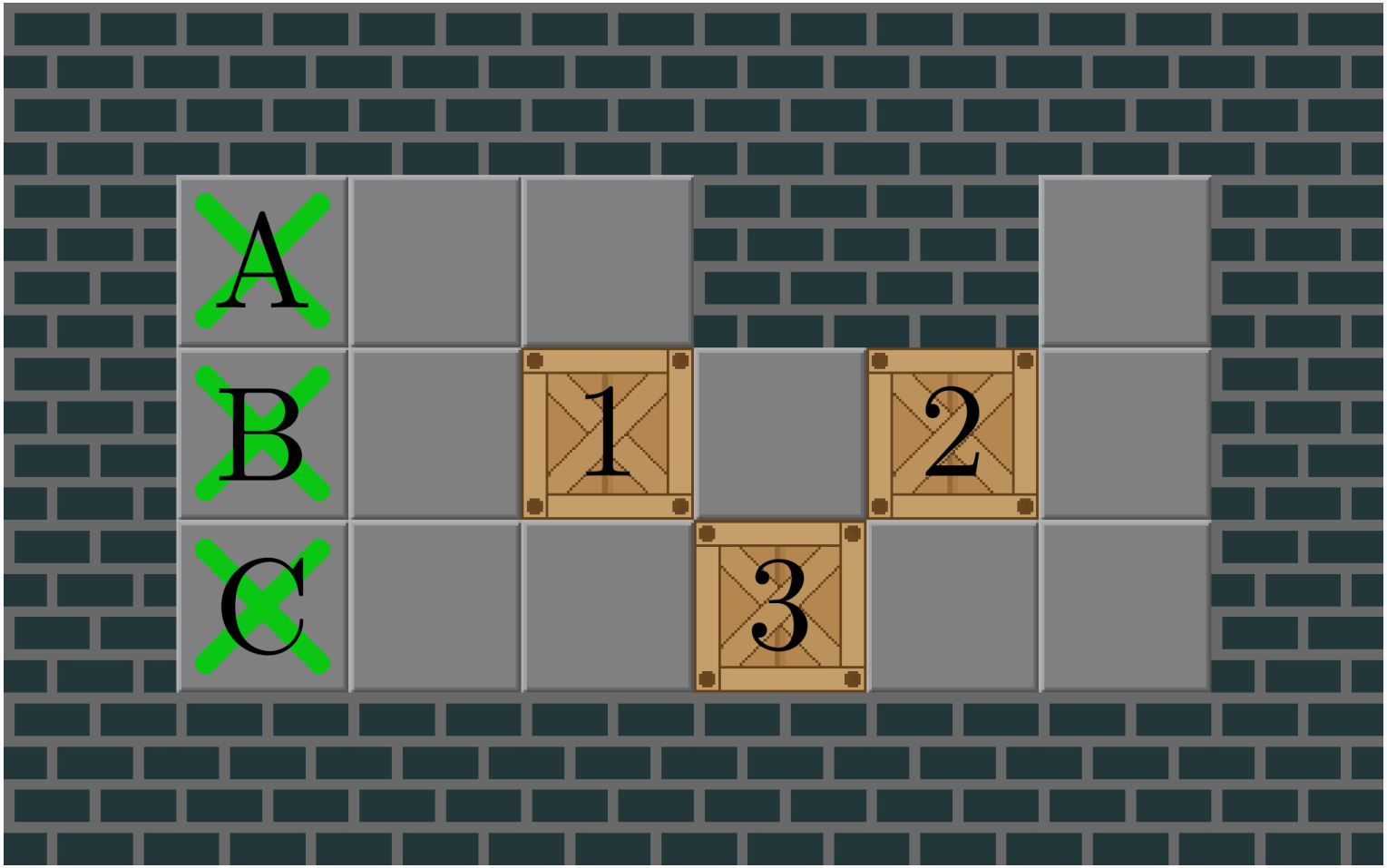


Heuristique simple *(Simple Lower Bound)*

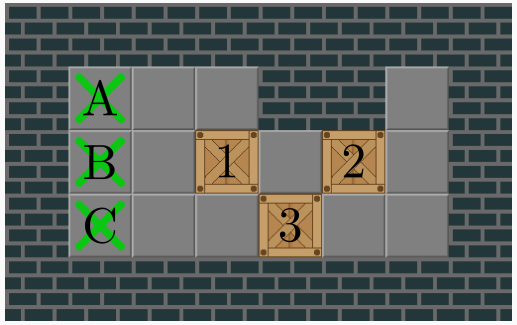


$$\boxed{2 + 4 + 3 = \mathbf{9}}$$

Heuristique gloutonne *(Greedy Lower Bound)*



Heuristique gloutonne *(Greedy Lower Bound)*

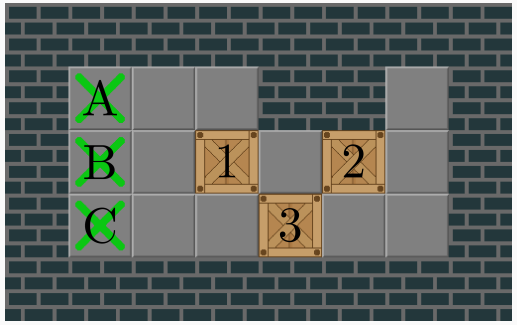


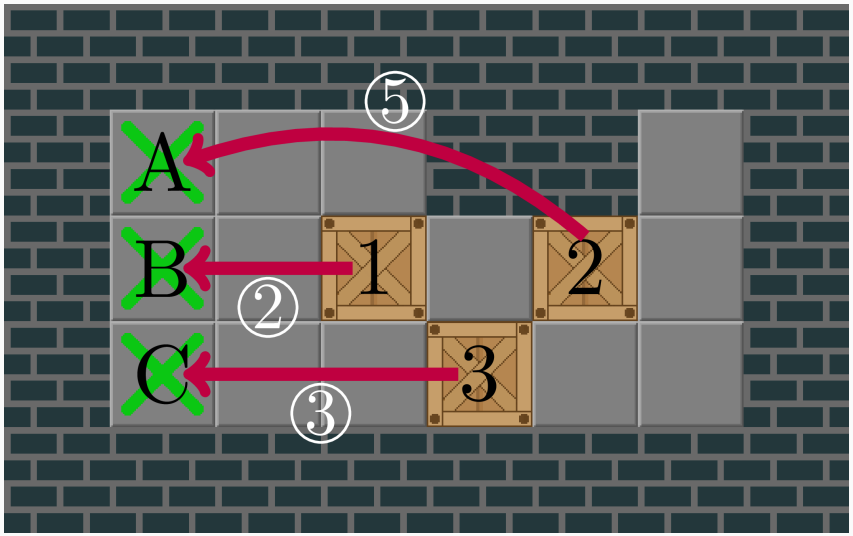
Caisse → Cible	Distance
$1 \rightarrow A$	3
$1 \rightarrow B$	2
$1 \rightarrow C$	3
$2 \rightarrow A$	4
$2 \rightarrow B$	4
$2 \rightarrow C$	5
$3 \rightarrow A$	5
$3 \rightarrow B$	4
$3 \rightarrow C$	3

Tri →

Caisse → Cible	Distance
$1 \rightarrow B$	**2**
$1 \rightarrow A$	3
$1 \rightarrow C$	3
$3 \rightarrow C$	**3**
$2 \rightarrow B$	4
$3 \rightarrow B$	4
$2 \rightarrow A$	5
$2 \rightarrow C$	5
$3 \rightarrow A$	**5**

Heuristique gloutonne *(Greedy Lower Bound)*





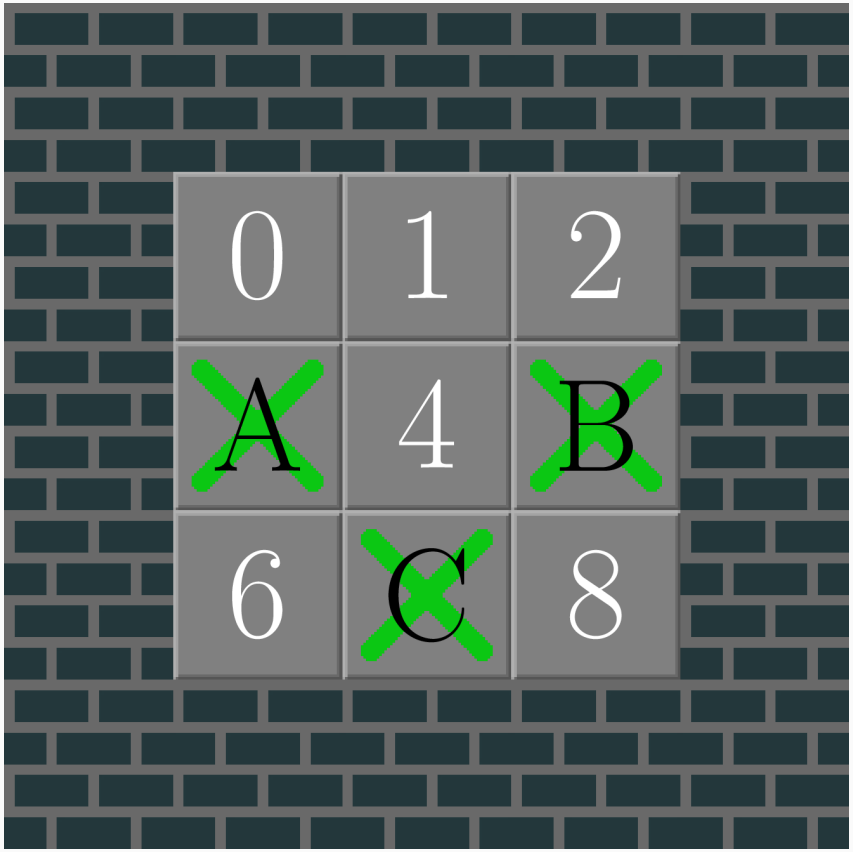
$$2 + 3 + 5 = \mathbf{10}$$

Caisse → Cible	Distance
1 → B	**2**
1 → *A*	3
1 → *C*	3
3 → C	**3**
2 → *B*	4
3 → *B*	4
2 → *A*	5
2 → *C*	5
3 → A	**5**

Optimisations

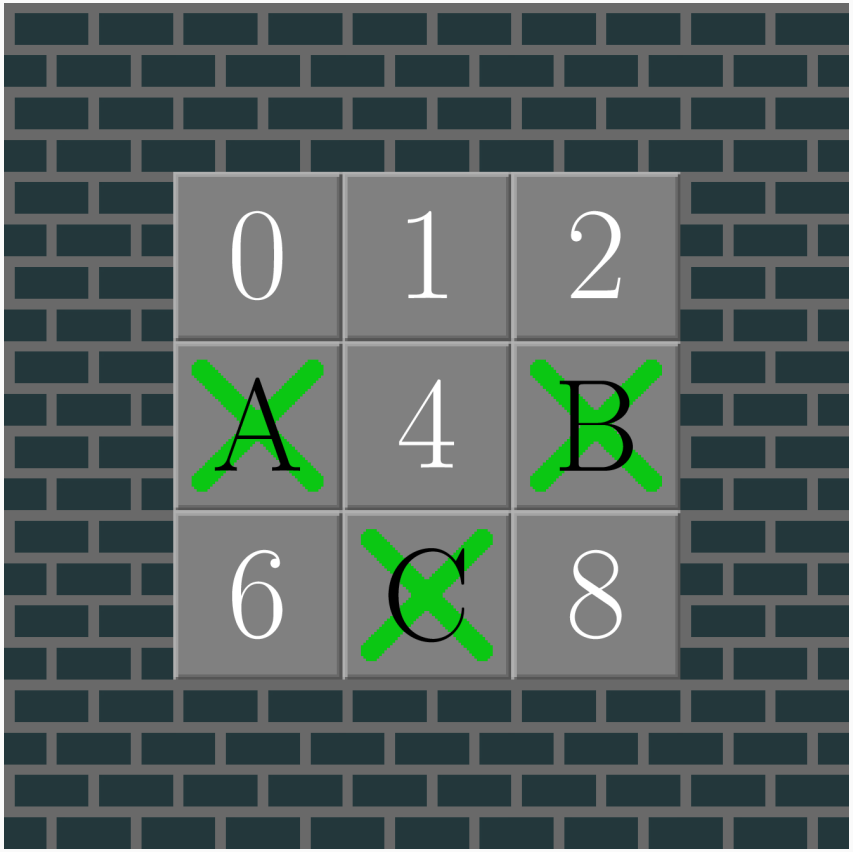
Précalcul des distances caisses-cibles

Case	Distances		
	A	B	C
0	1	3	3
1	2	2	2
2	3	1	3
3	0	2	2
4	1	1	1
5	2	0	2
6	1	3	1
7	2	2	0
8	3	1	1

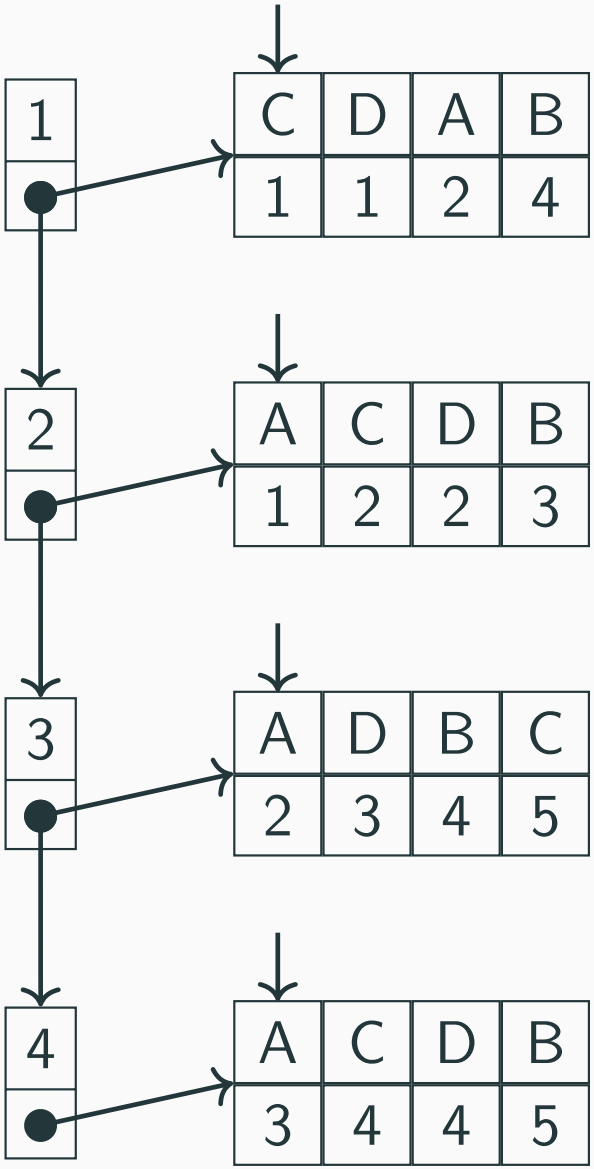


Précalcul des distances caisses-cibles

Case	Distances triées		
0	A : 1	B : 3	C : 3
1	A : 2	B : 2	C : 2
2	B : 1	A : 3	C : 3
3	A : 0	B : 2	C : 2
4	A : 1	B : 1	C : 1
5	B : 0	A : 2	C : 2
6	A : 1	C : 1	B : 3
7	C : 0	A : 2	B : 2
8	B : 1	C : 1	A : 3

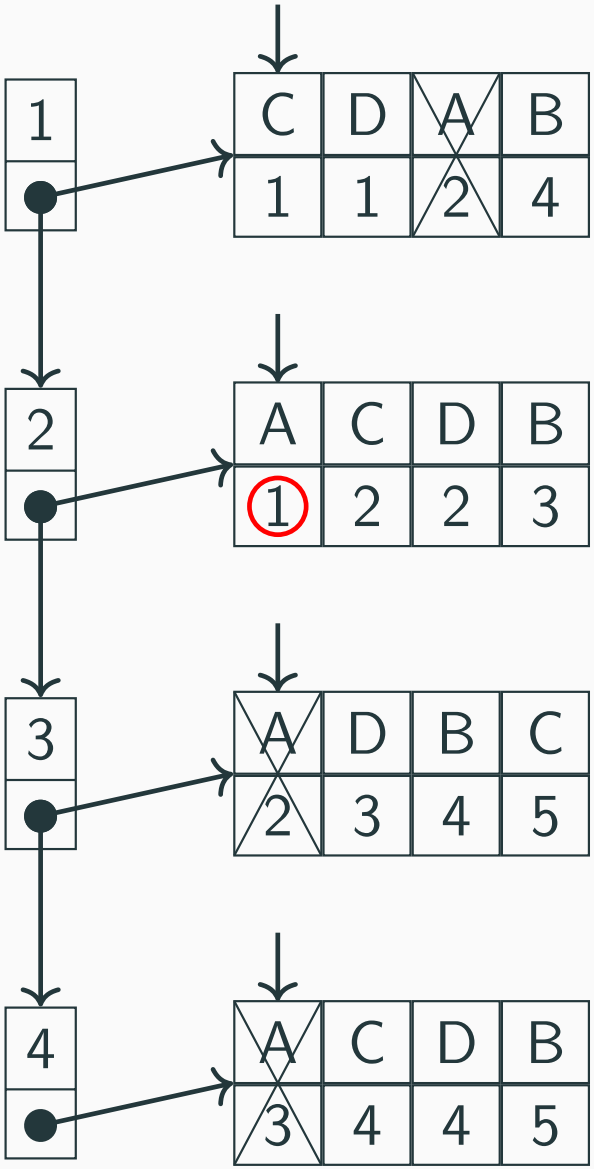


Greedy Lower Bound en $\mathcal{O}(n^2)$



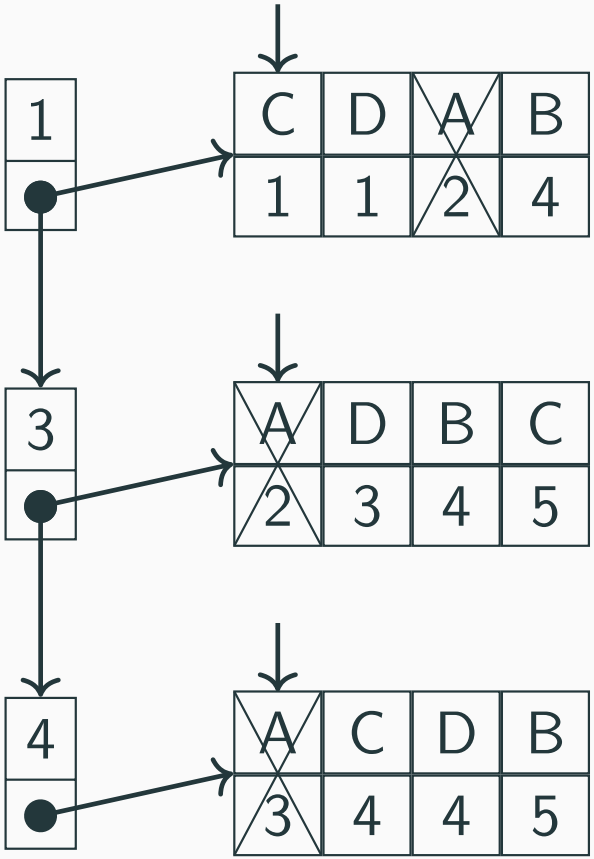
$h =$

Greedy Lower Bound en $\mathcal{O}(n^2)$



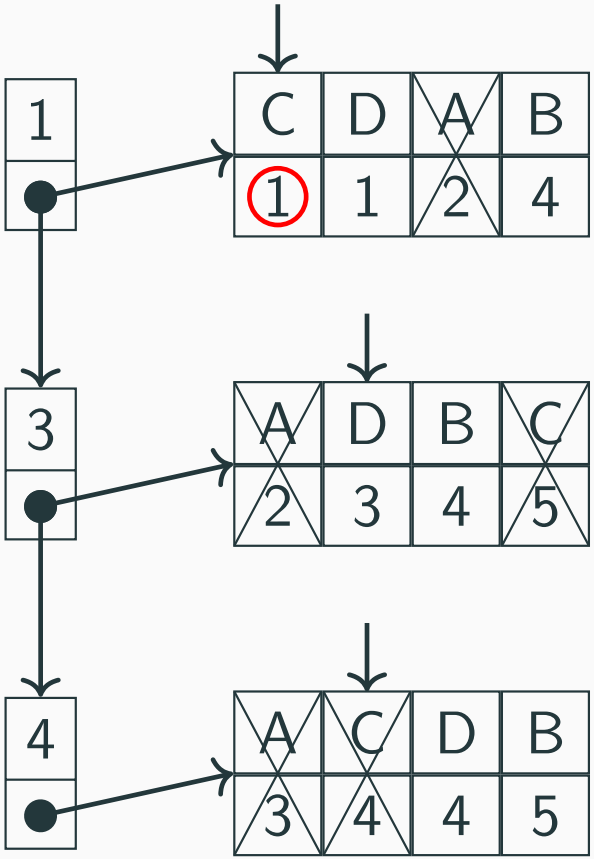
$$h = 1 +$$

Greedy Lower Bound en $\mathcal{O}(n^2)$



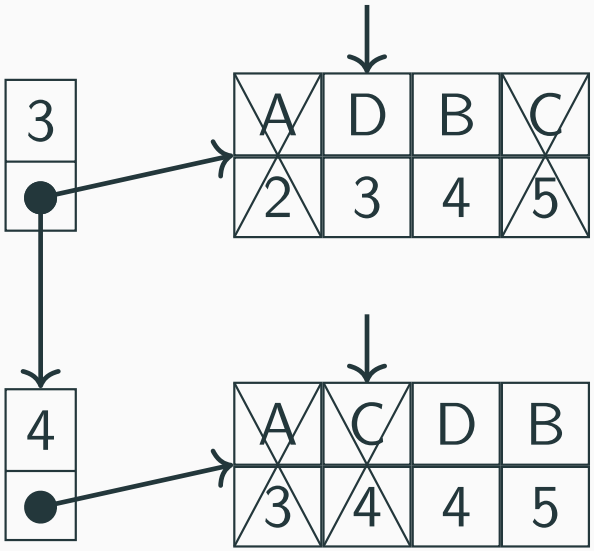
$$h = 1 +$$

Greedy Lower Bound en $\mathcal{O}(n^2)$



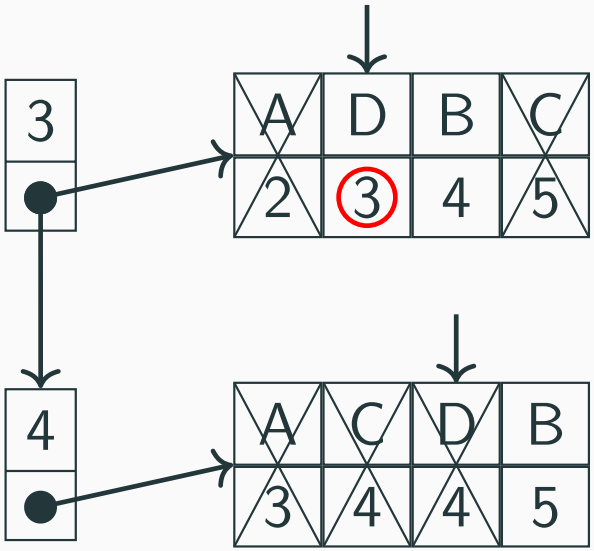
$$h = 1 + 1 +$$

Greedy Lower Bound en $\mathcal{O}(n^2)$



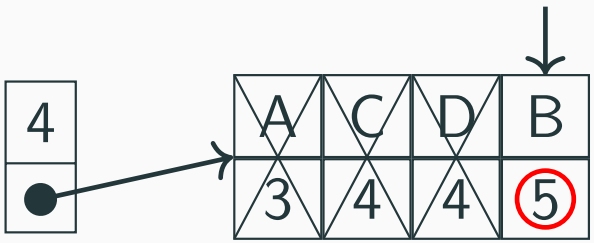
$$h = 1 + 1 +$$

Greedy Lower Bound en $\mathcal{O}(n^2)$



$$h = 1 + 1 + 3 +$$

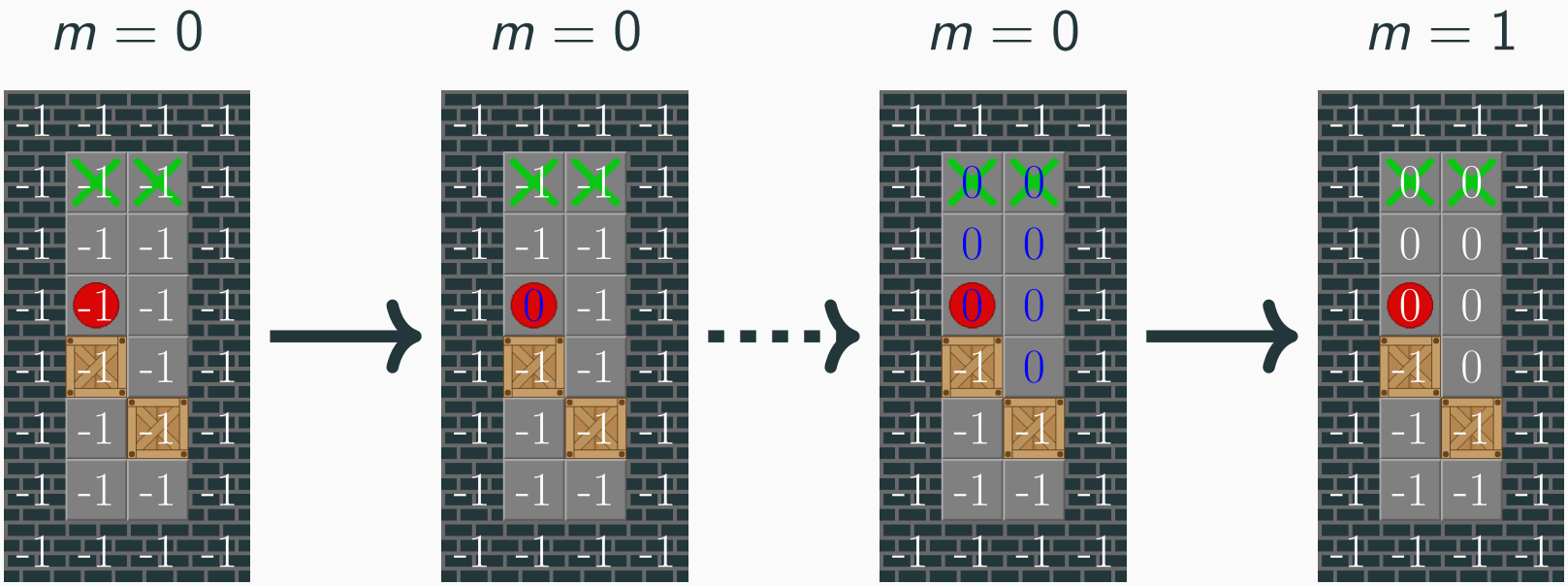
Greedy Lower Bound en $\mathcal{O}(n^2)$



$$h = 1 + 1 + 3 + 5 = 10$$

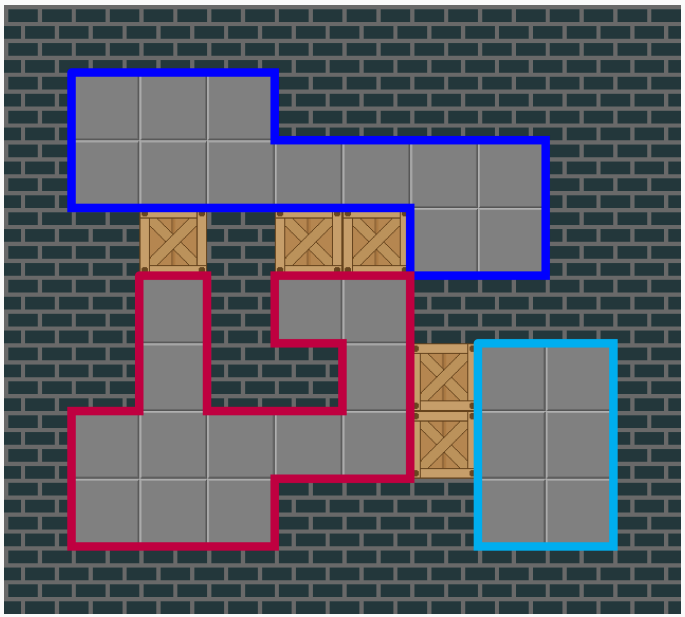
Parcours de graphes : démarquer tous les nœuds en $\mathcal{O}(1)$

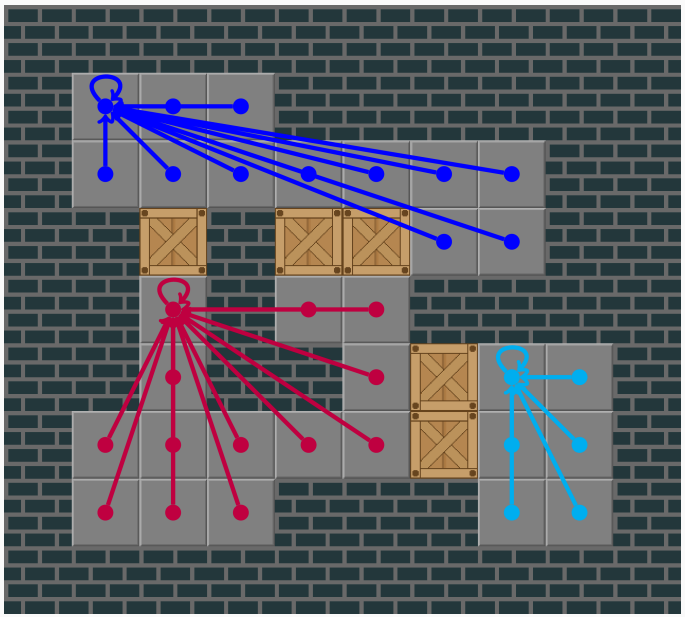
nœud marqué *ssi valeur* $= m$



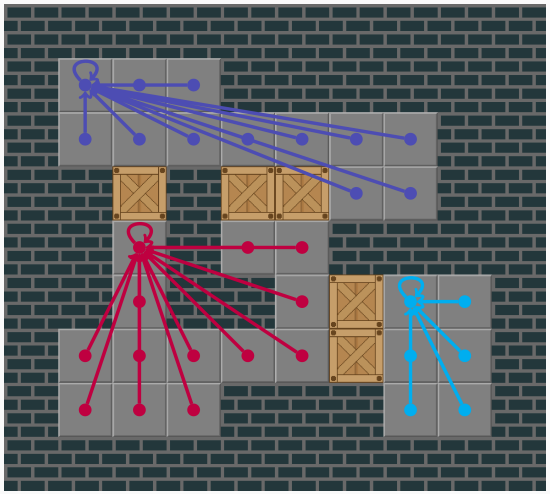
Calcul des *corrals* en $\mathcal{O}(wh)$

Utilisation de *Union-Find* : partition de $[\![0; wh - 1]\!]$.

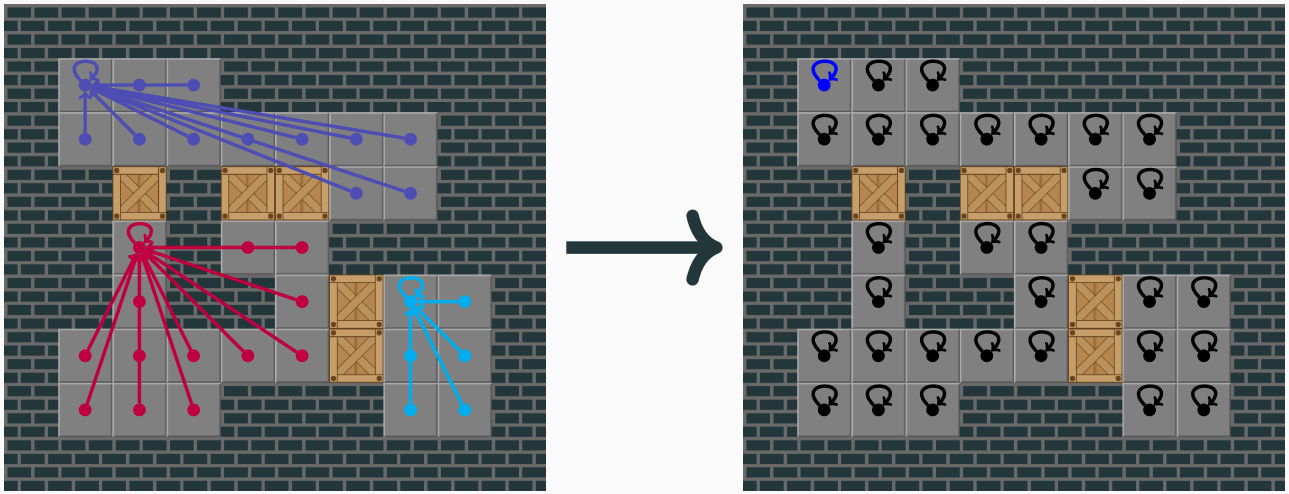




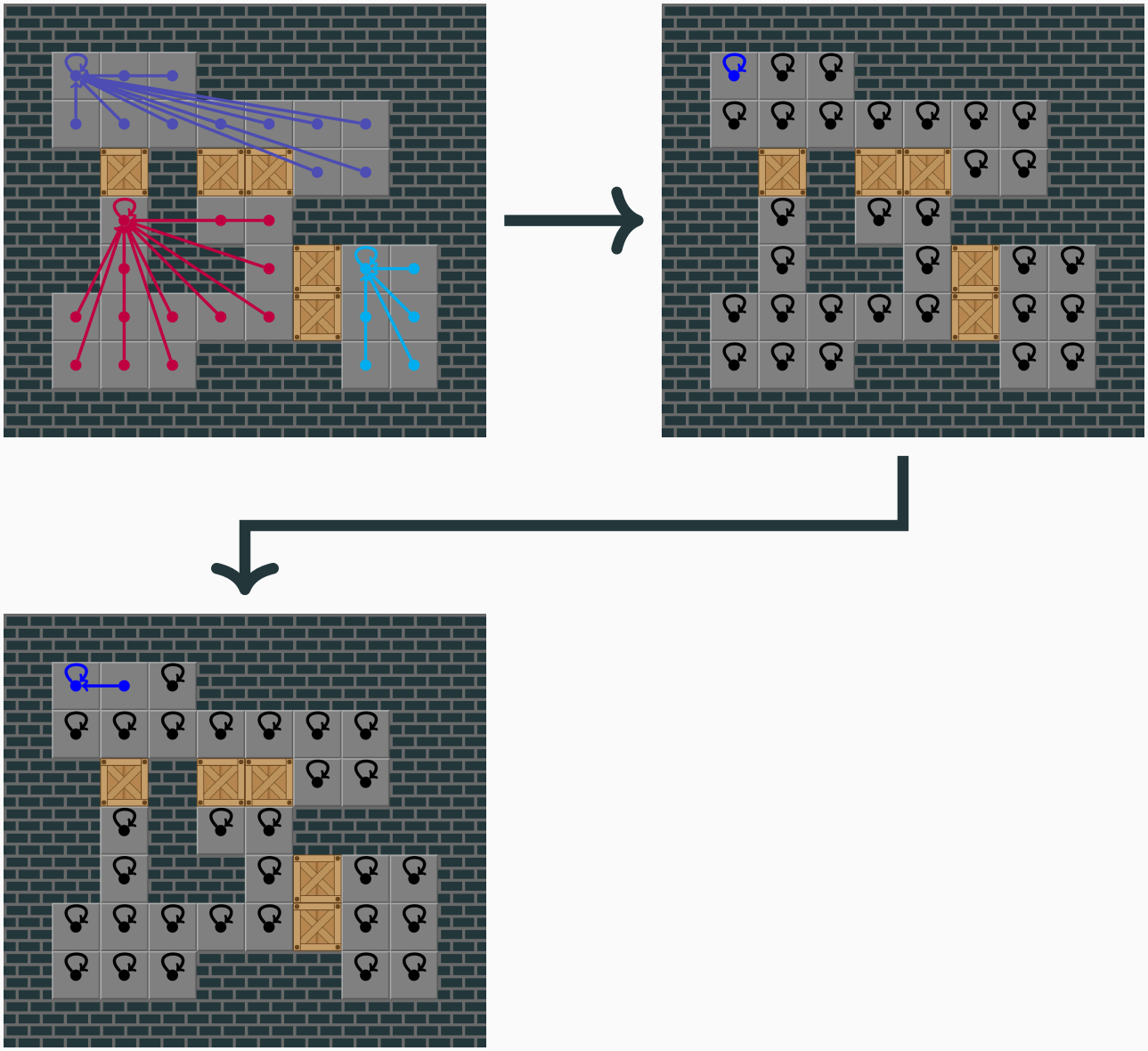
Calcul des *corrals* en $\mathcal{O}(wh)$



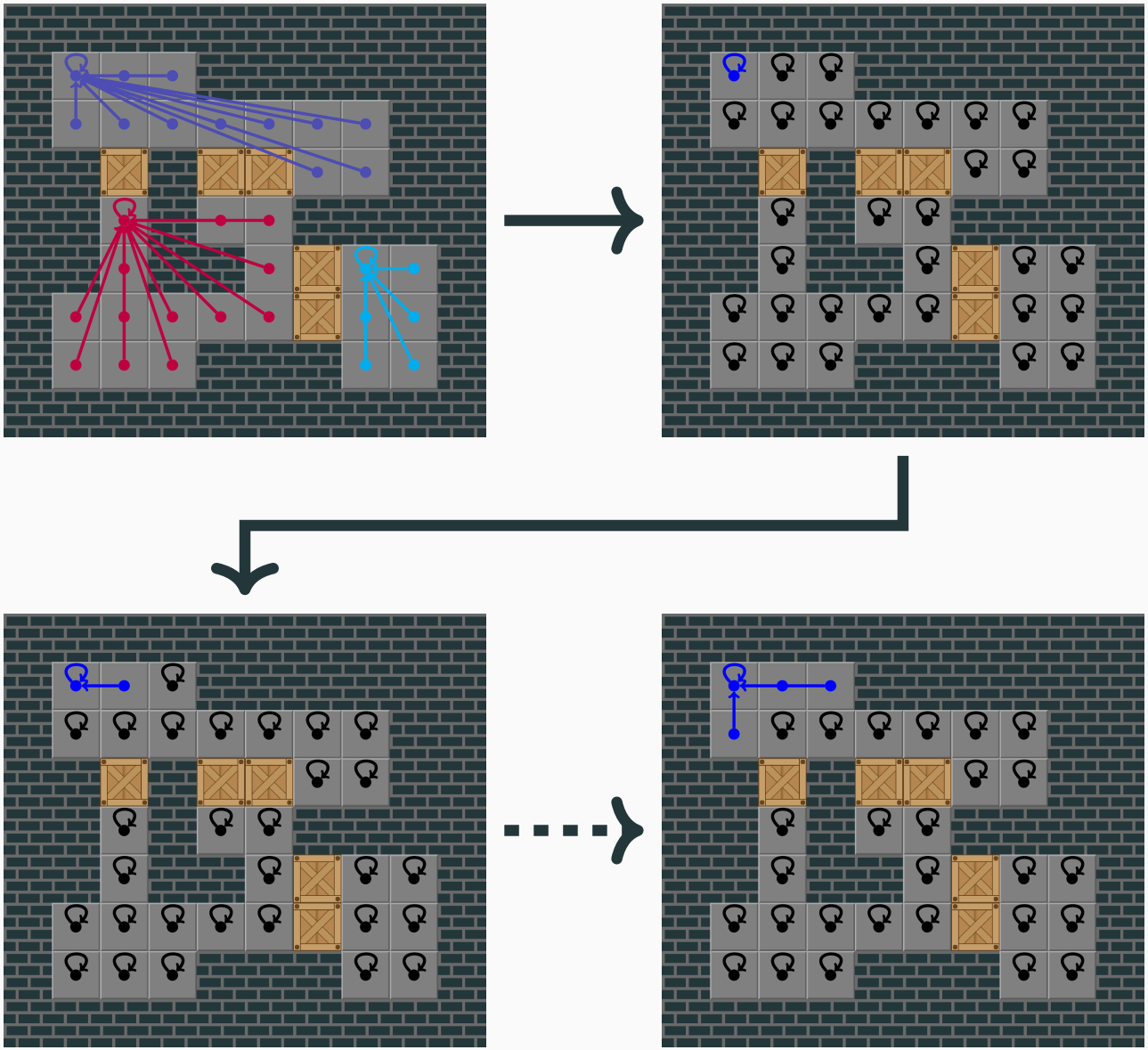
Calcul des *corrals* en $\mathcal{O}(wh)$



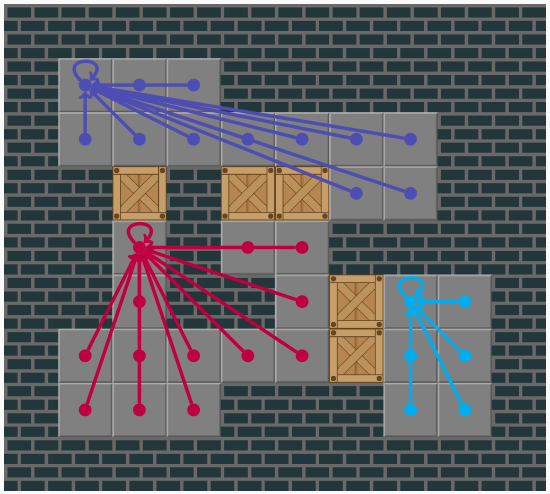
Calcul des *corrals* en $\mathcal{O}(wh)$



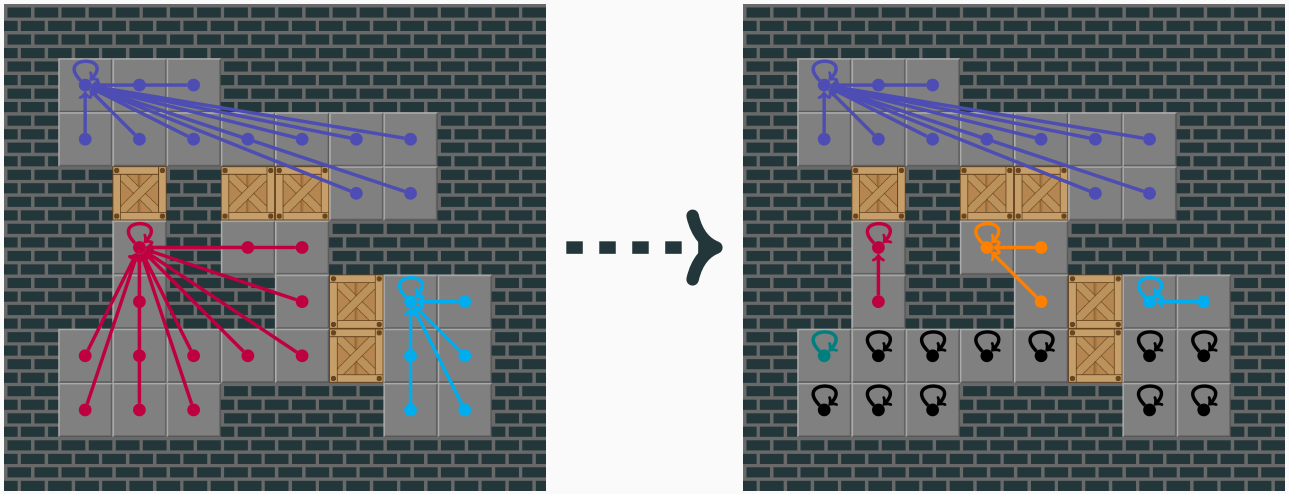
Calcul des *corrals* en $\mathcal{O}(wh)$



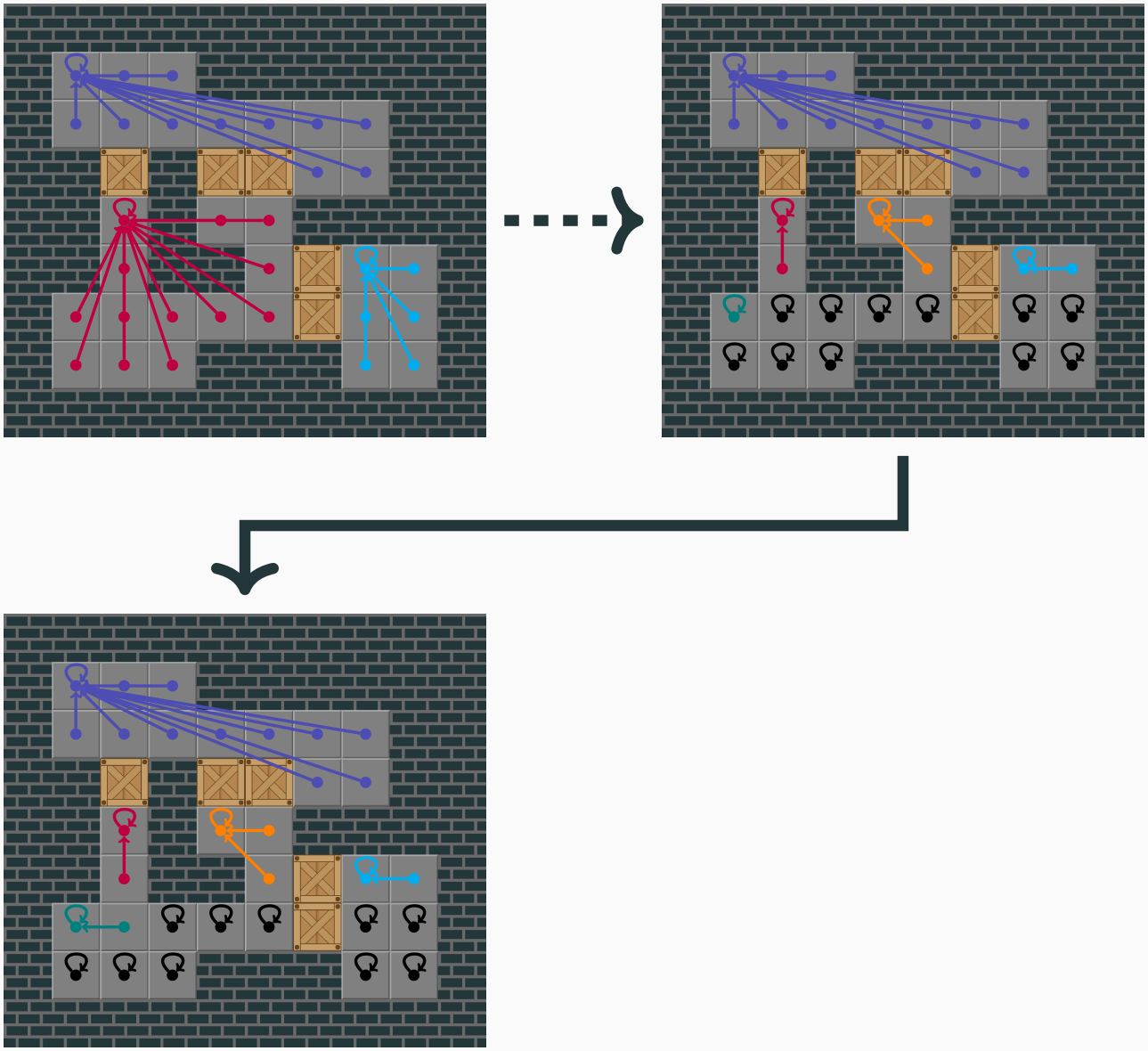
Calcul des *corrals* en $\mathcal{O}(wh)$



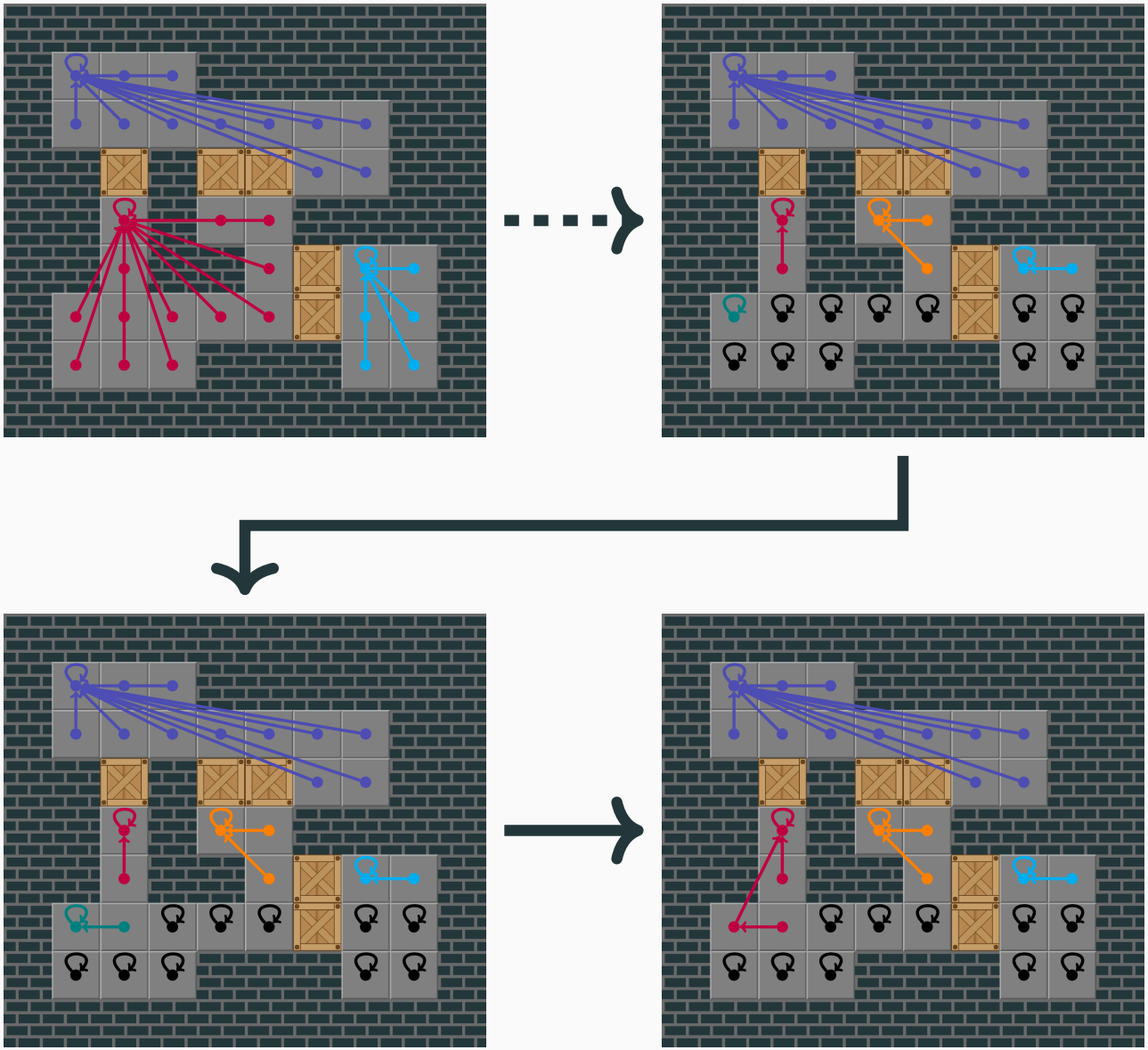
Calcul des *corrals* en $\mathcal{O}(wh)$



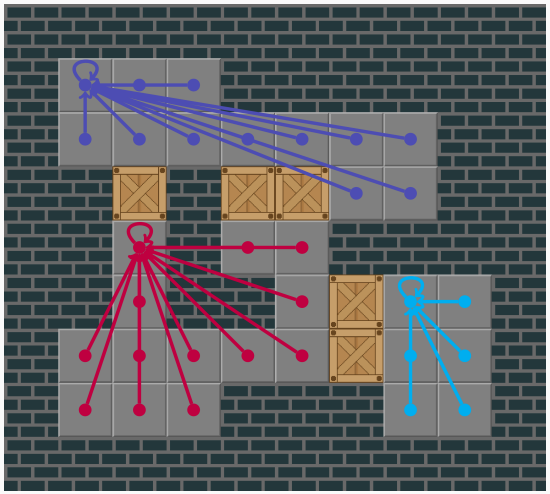
Calcul des *corrals* en $\mathcal{O}(wh)$



Calcul des *corrals* en $\mathcal{O}(wh)$



Calcul des *corrals* en $\mathcal{O}(wh)$



Résultats

Nombre de niveaux résolus

Limite de temps : 10 min. Limite de RAM : 32 Gio.

Ensemble de niveaux	XSokoban	*Large test suite*
Nombre de niveaux	90	3272
A*	**11**	**2204**
fess0	**15**	**2273**
Festival (Yaron Shoham)	90	3202
Sokolution (Florent Diedler)	90	3130
Takaken (Ken'ichiro Takahashi)	90	2944
YASS (Brian Damgaard)	89	2865

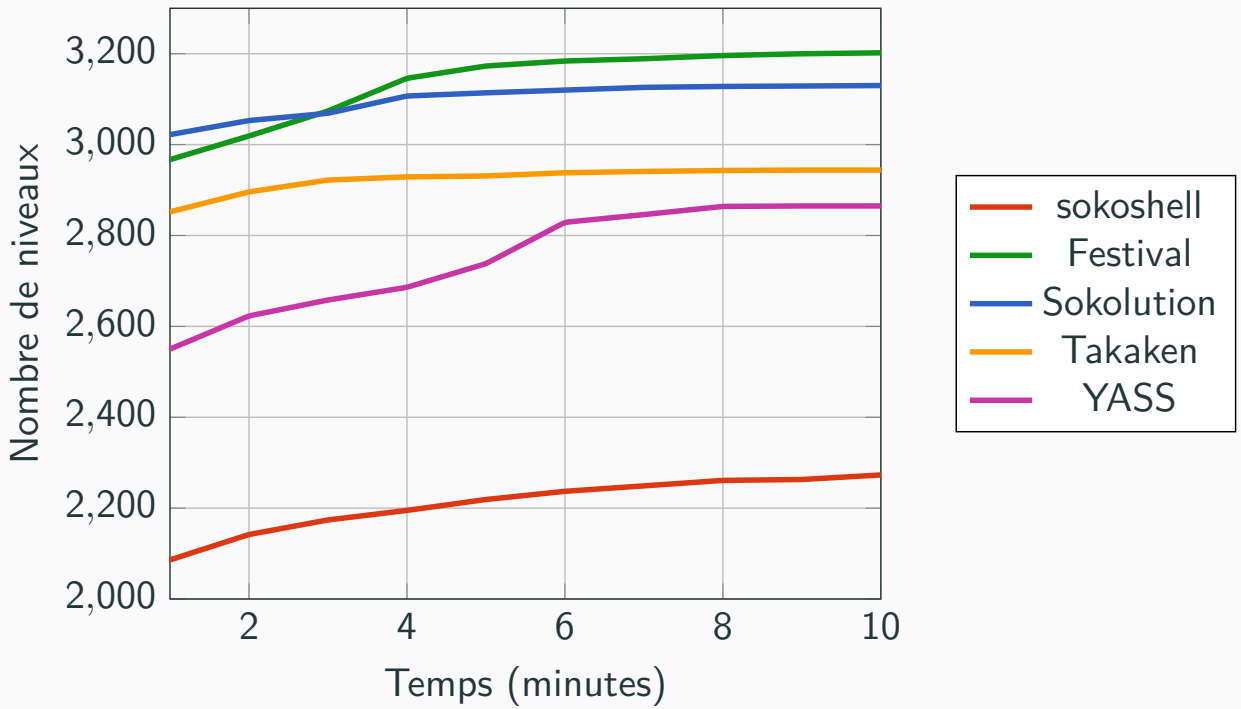
Statistiques (pour les autres solveurs) par Matthias Meger et Brian Damgaard (https://sourceforge.net/projects/sokoban-solver-statistics/)

Statistiques

Temps moyen passé par niveaux

Solveur	**A***	**fess0**	Festival	Sokolution	Takaken	YASS
Temps moyen	**3min 28s**	**3min 16s**	3s	2s	7s	24s

Nombre de niveaux résolus (cumulés) en fonction du temps



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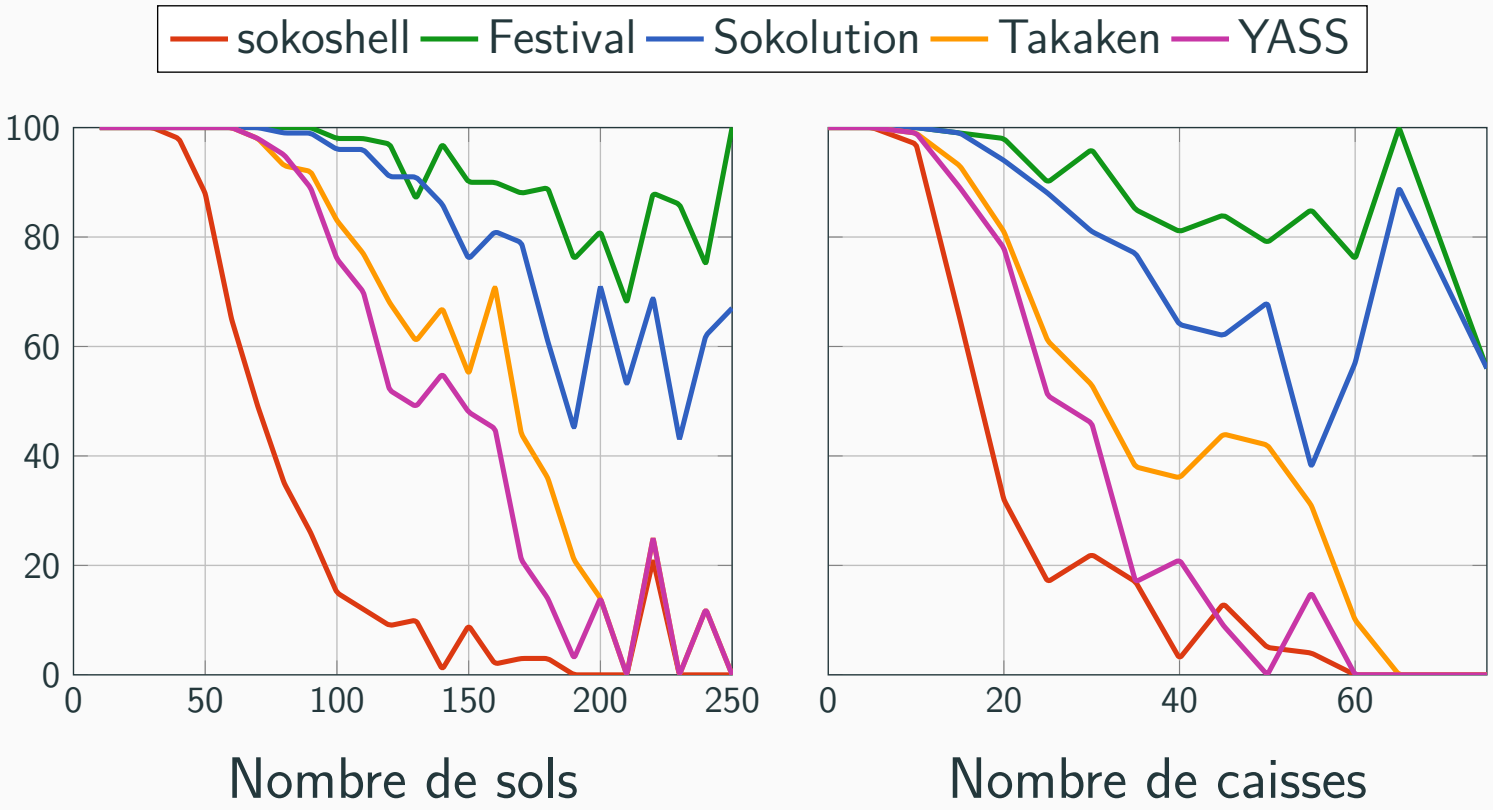
Statistiques

Pourcentage de niveaux résolus selon la composition des niveaux



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Annexe

Tableau des complexités