

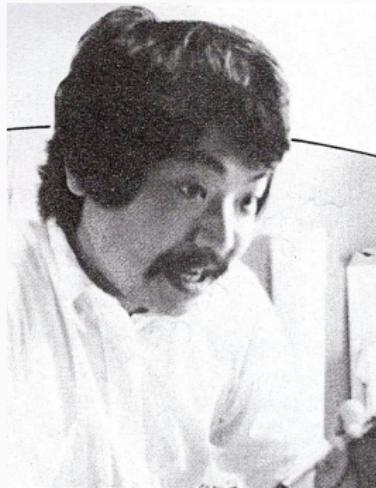
Résolution de niveaux du Sokoban

Nom Prénom

Candidat n°01234

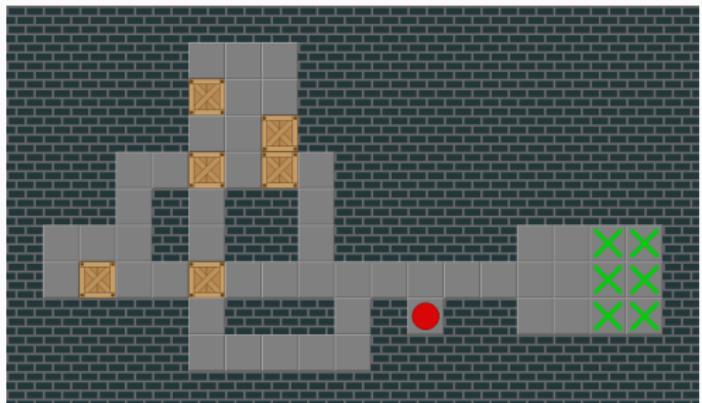
Introduction

Le jeu du Sokoban



<https://shmuulations.com/wp-content/uploads/2022/03/thinkingrabbit04.jpg>

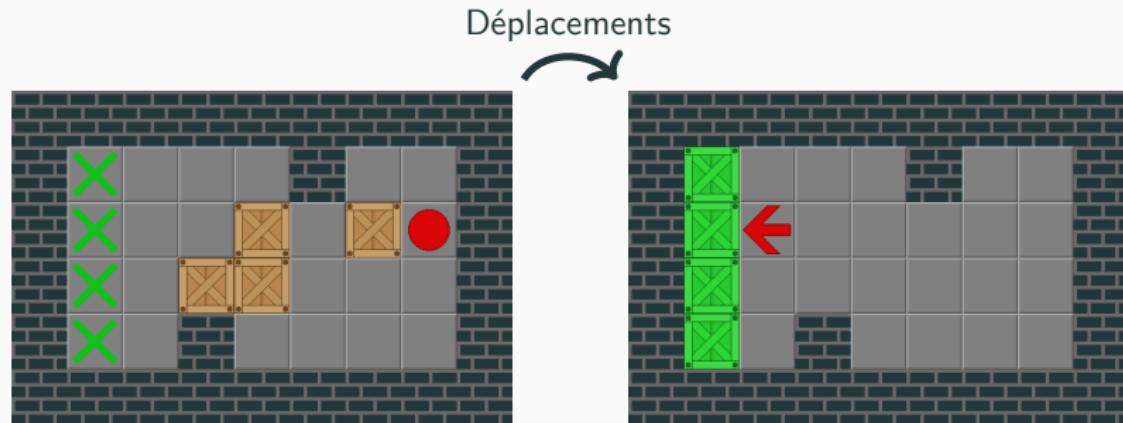
Hiroyuki Imabayashi



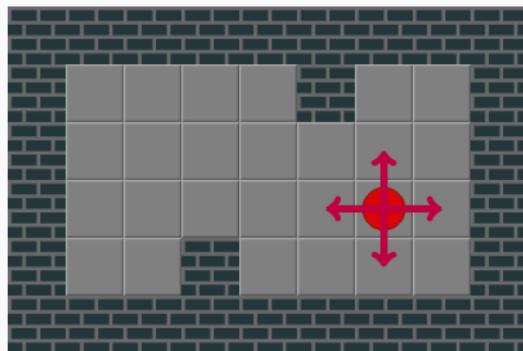
*X*Sokoban

Problème **PSPACE-complet**

But du jeu

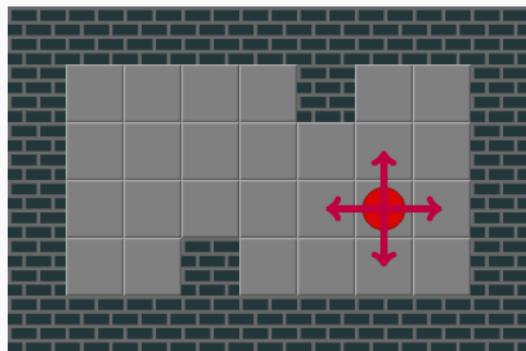


Règles

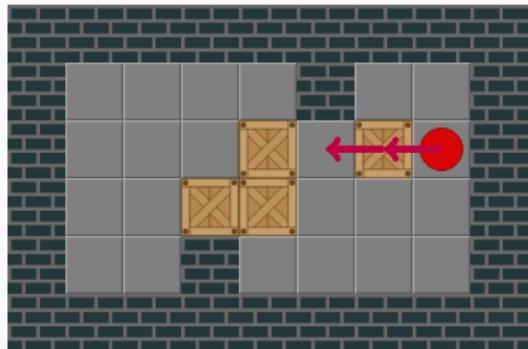


Déplacements autorisés

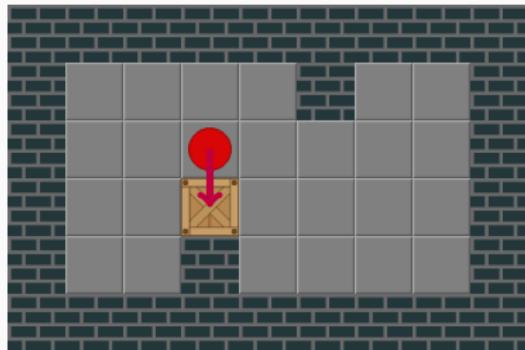
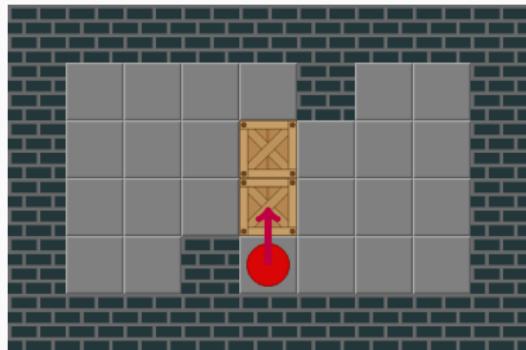
Règles



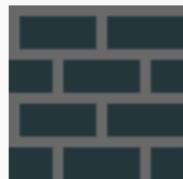
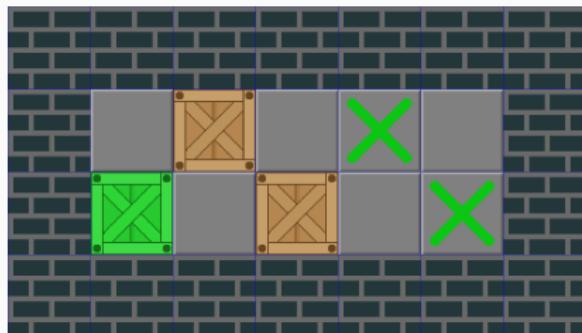
Déplacements autorisés



Règles



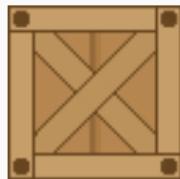
Tuiles



Mur



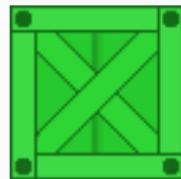
Sol



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

Introduction

Principe de résolution

Réduction de l'espace de recherche

Analyse statique

Analyse dynamique

Recherche dirigée par une heuristique

Optimisations

Résultats

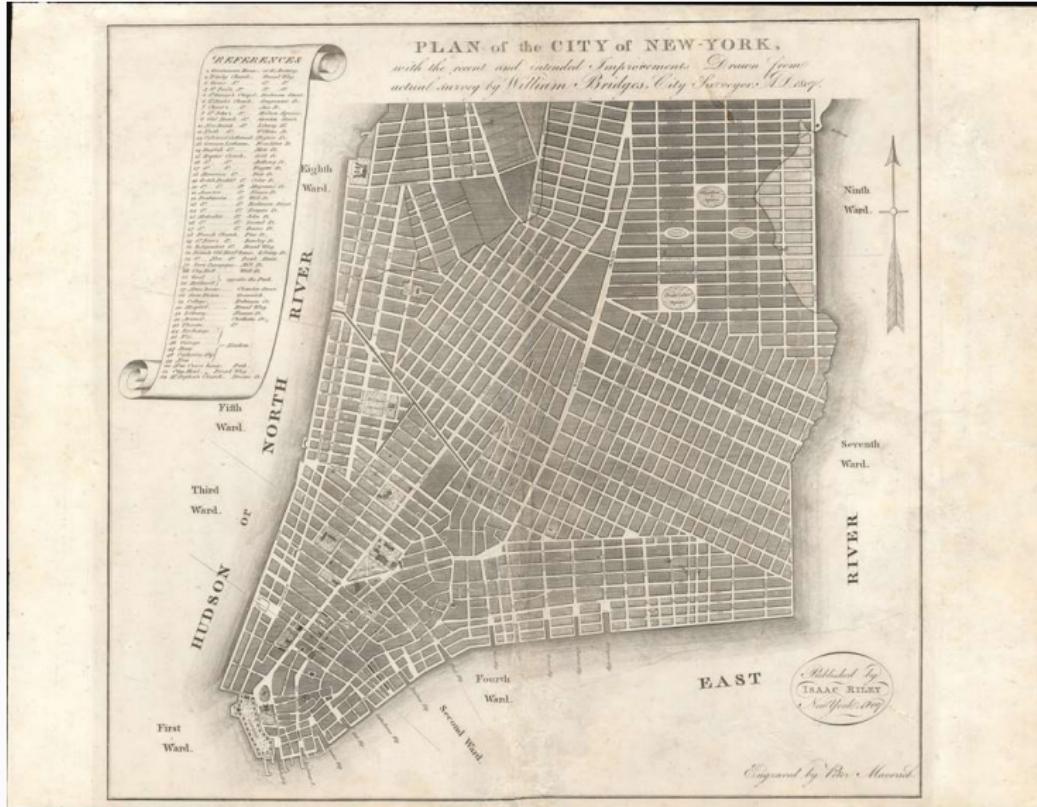
Annexe

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>

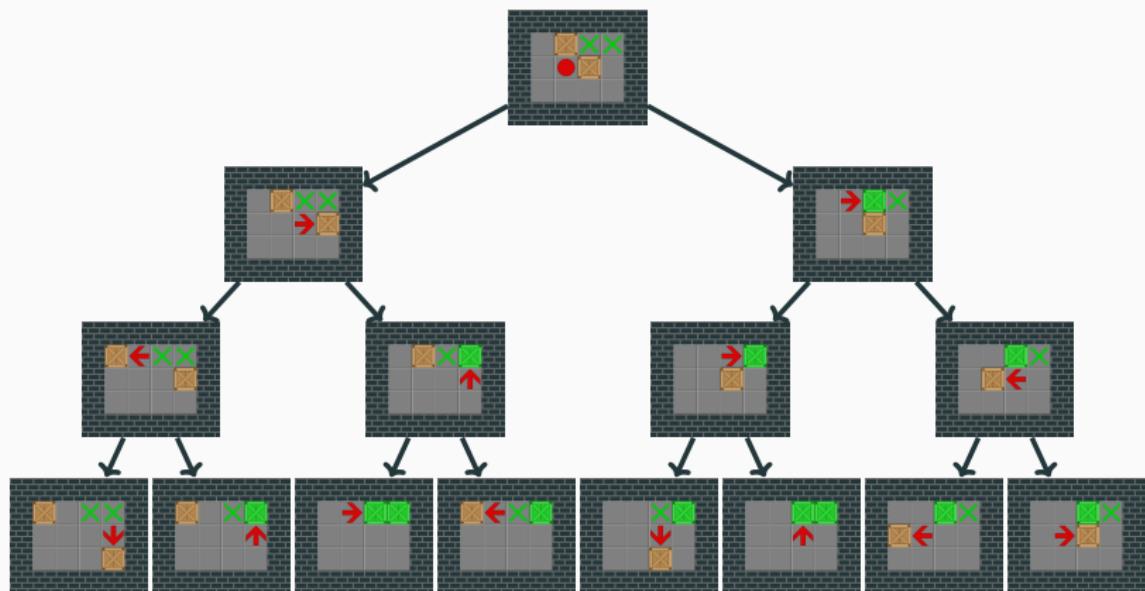
Lien avec le thème de l'année



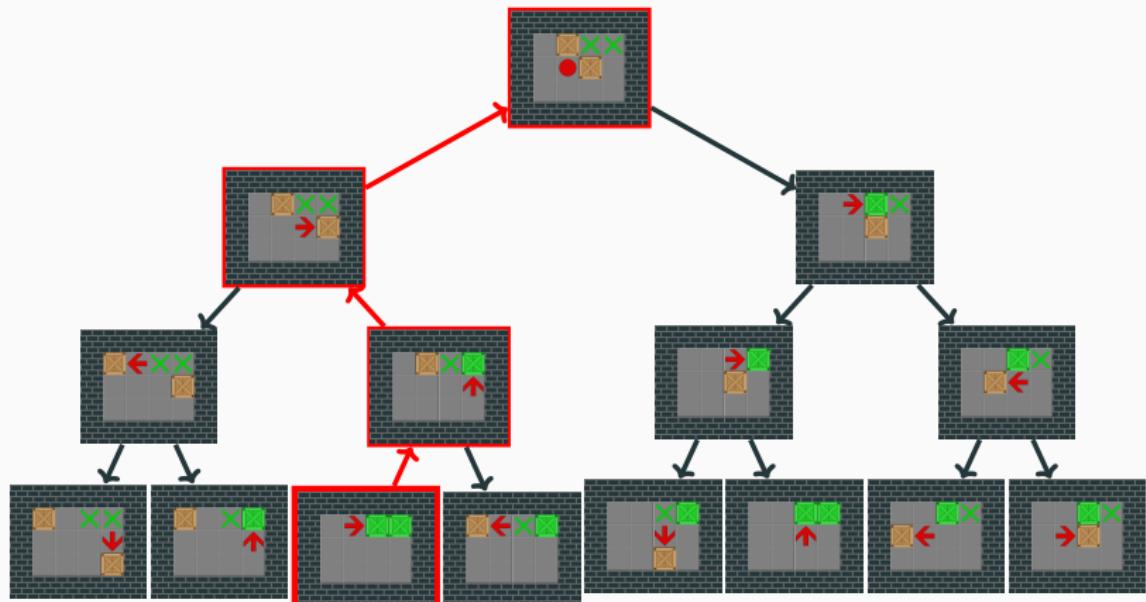
Source : <https://www.geographicus.com/mm5/graphics/00000001/L/NewYork-bridgesmaverick-1807.jpg>

Principe de résolution

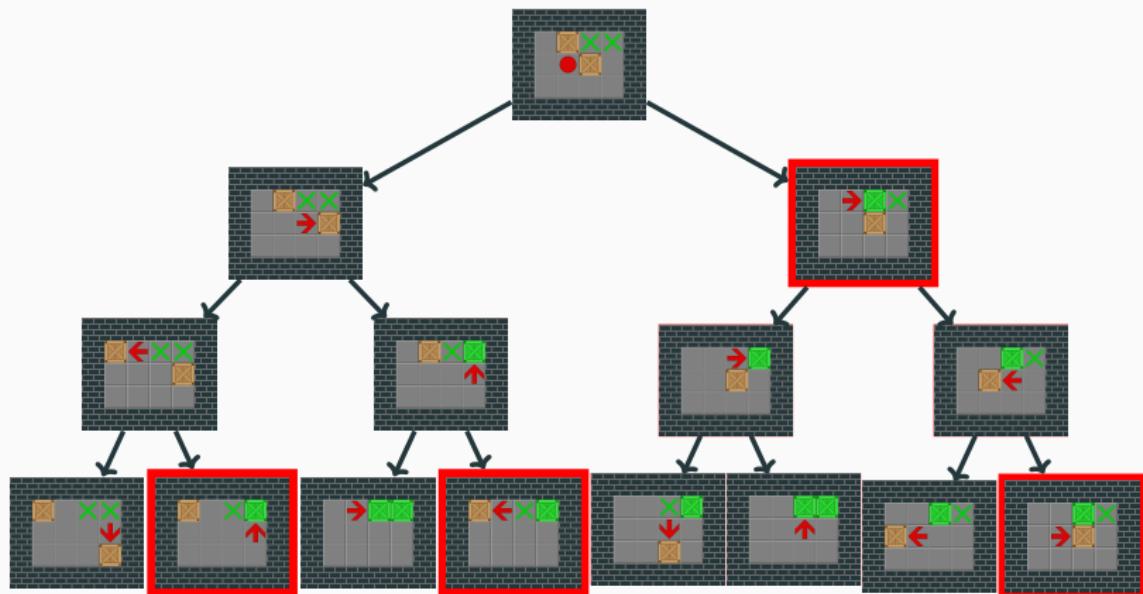
Arbre des états



Arbre des états



Arbre des états



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

Propriétés du **XOR** :

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

Initialisation :

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

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

- (c_1, \dots, c_n) n caisses et p position du joueur :

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

en $\mathcal{O}(n)$

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

$$h' = h \text{ XOR } T[c_i][0] \text{ XOR } T[c'_i][0] \text{ XOR } T[p][1] \text{ XOR } T[p'][1]$$

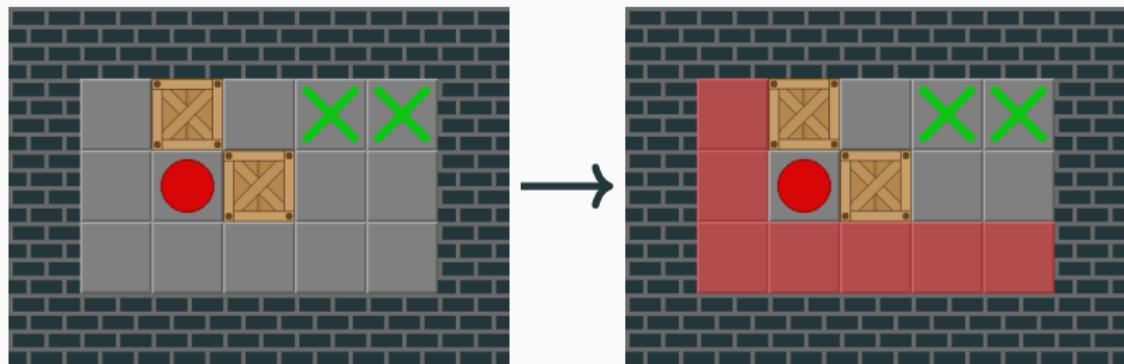
en $\mathcal{O}(1)$

Réduction de l'espace de recherche

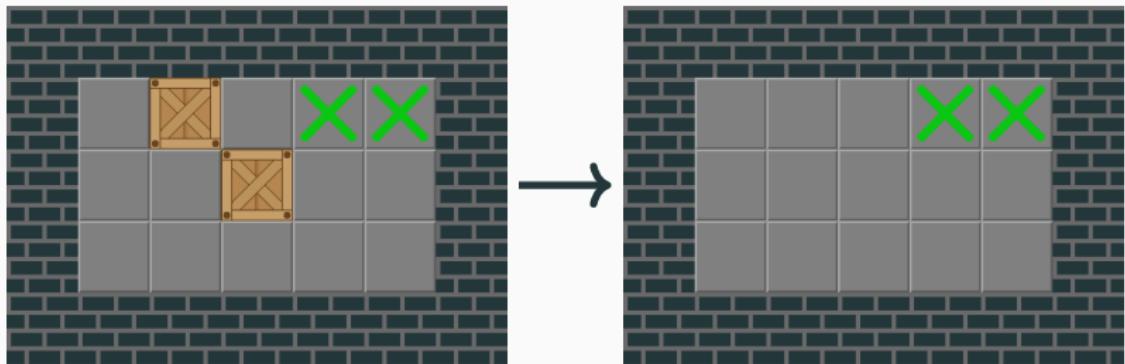
Réduction de l'espace de recherche

Analyse statique

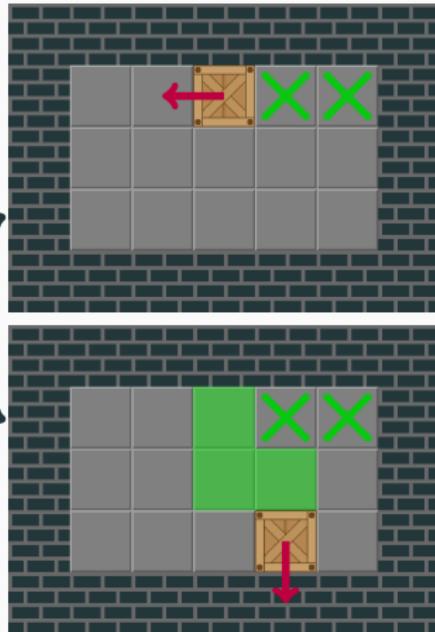
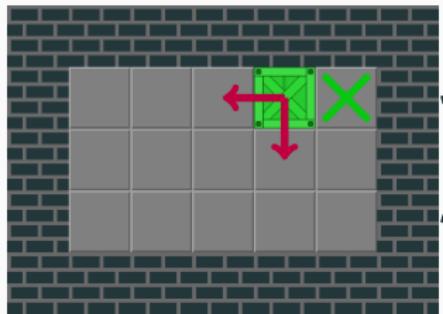
Détection des positions mortes (*dead positions*)



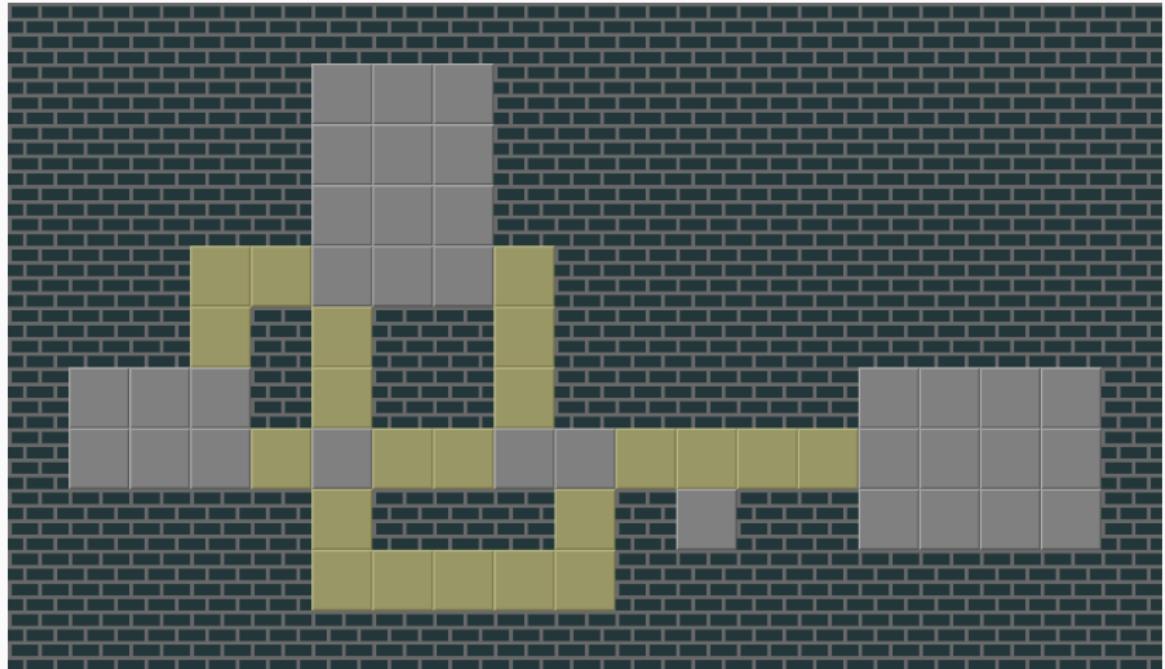
Détection des positions mortes (*dead positions*)



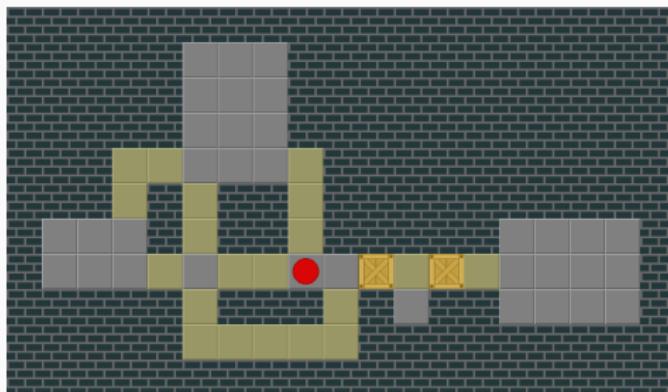
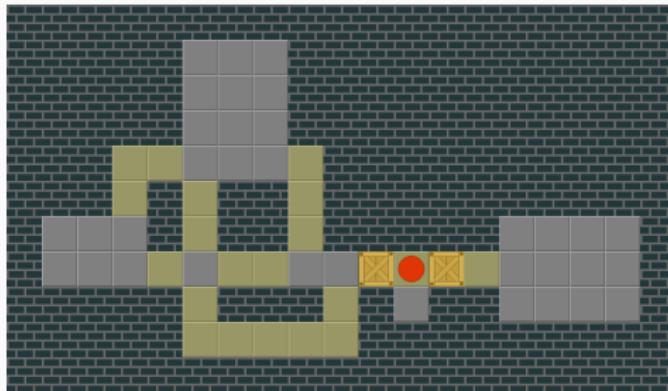
Détection des positions mortes (*dead positions*)



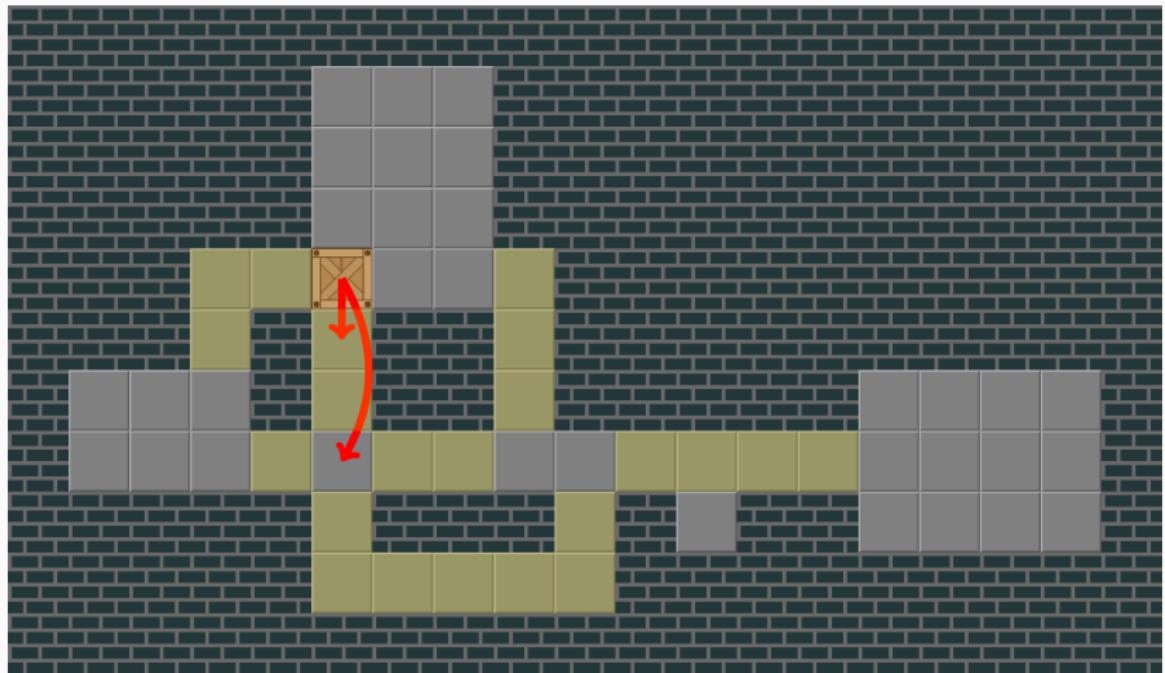
Détection de tunnels



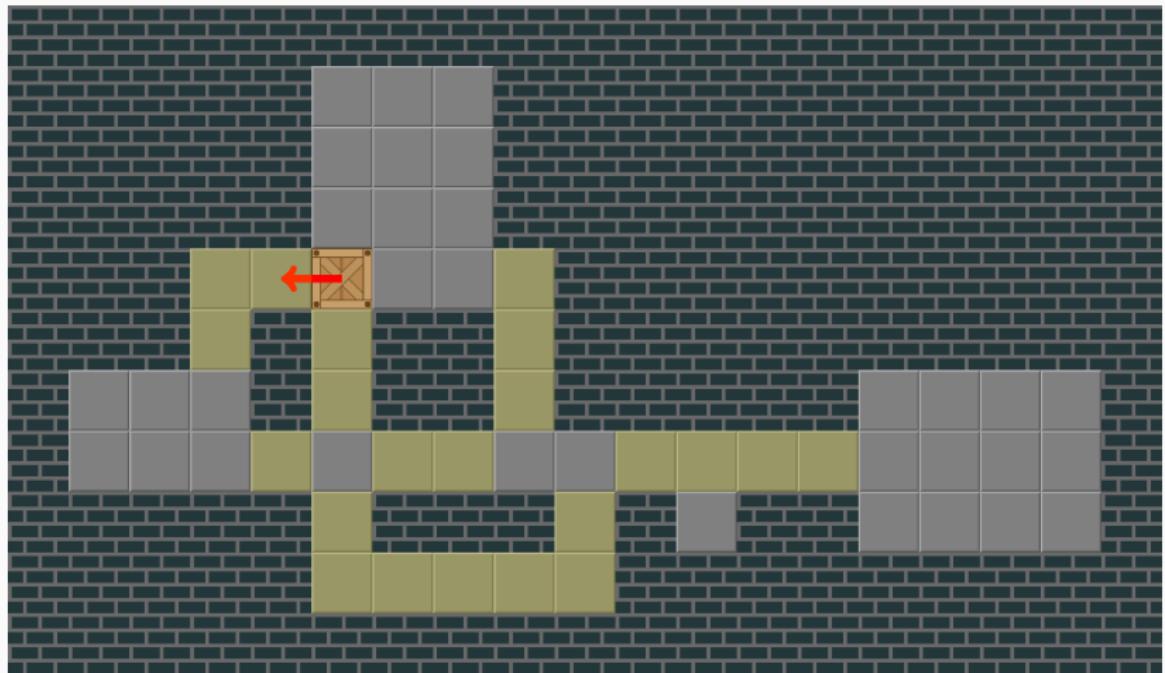
Détection de tunnels



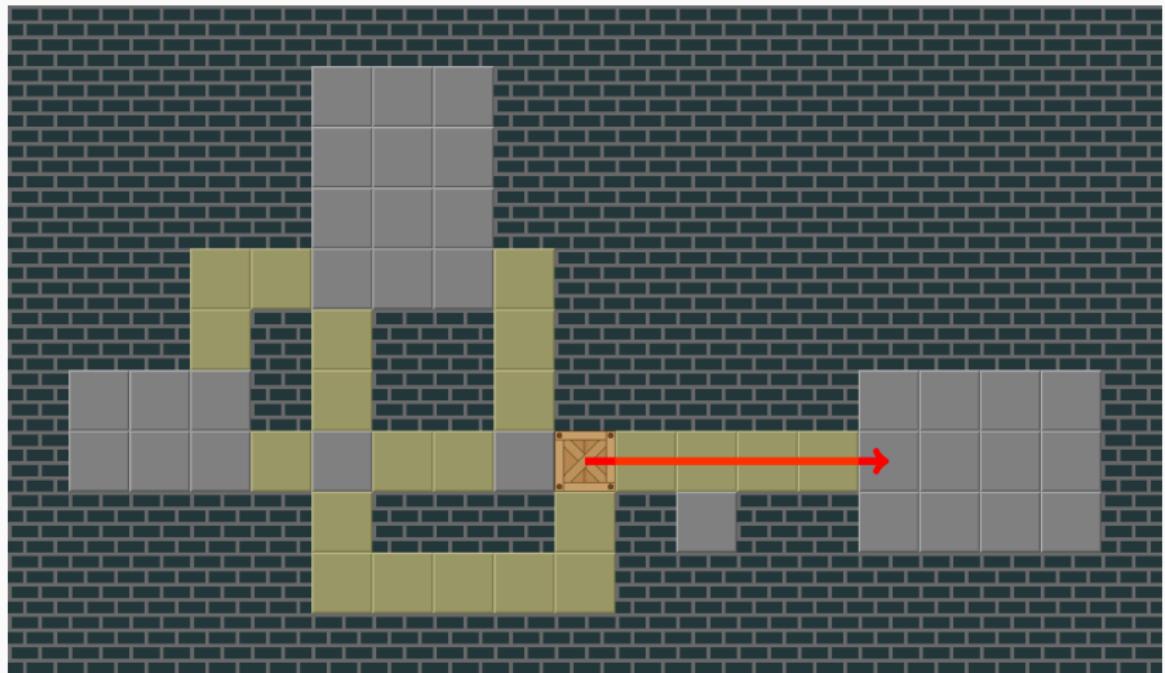
Détection de tunnels



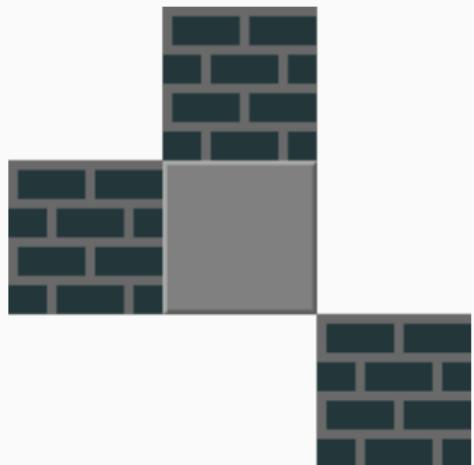
Détection de tunnels



Détection de tunnels

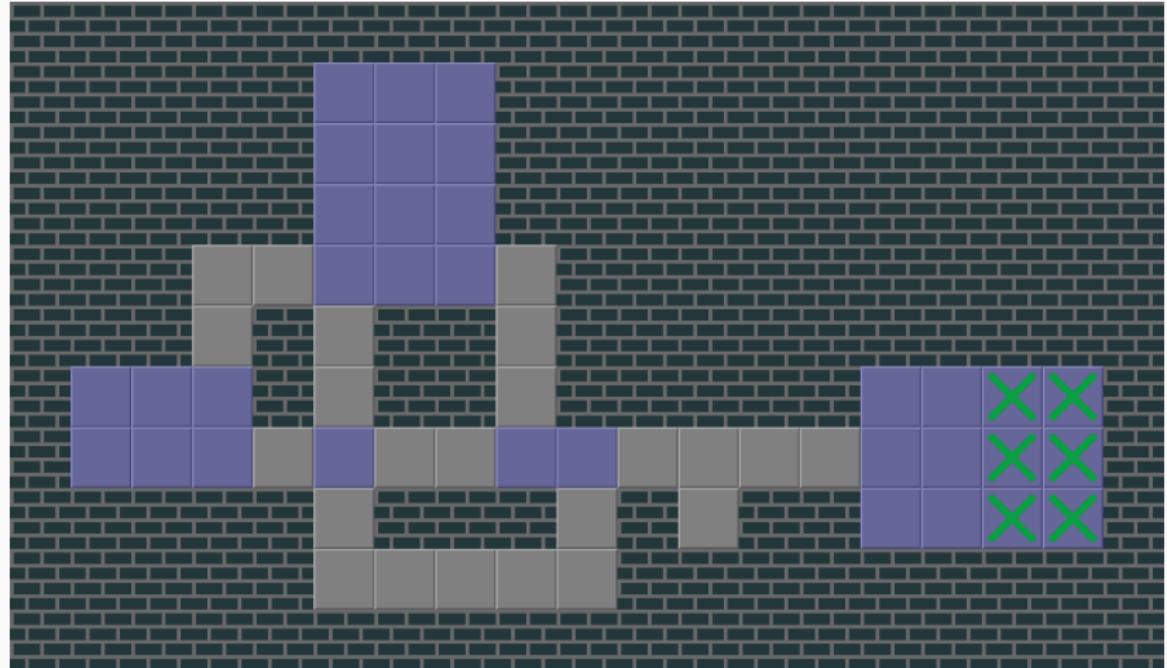


Détection de tunnels

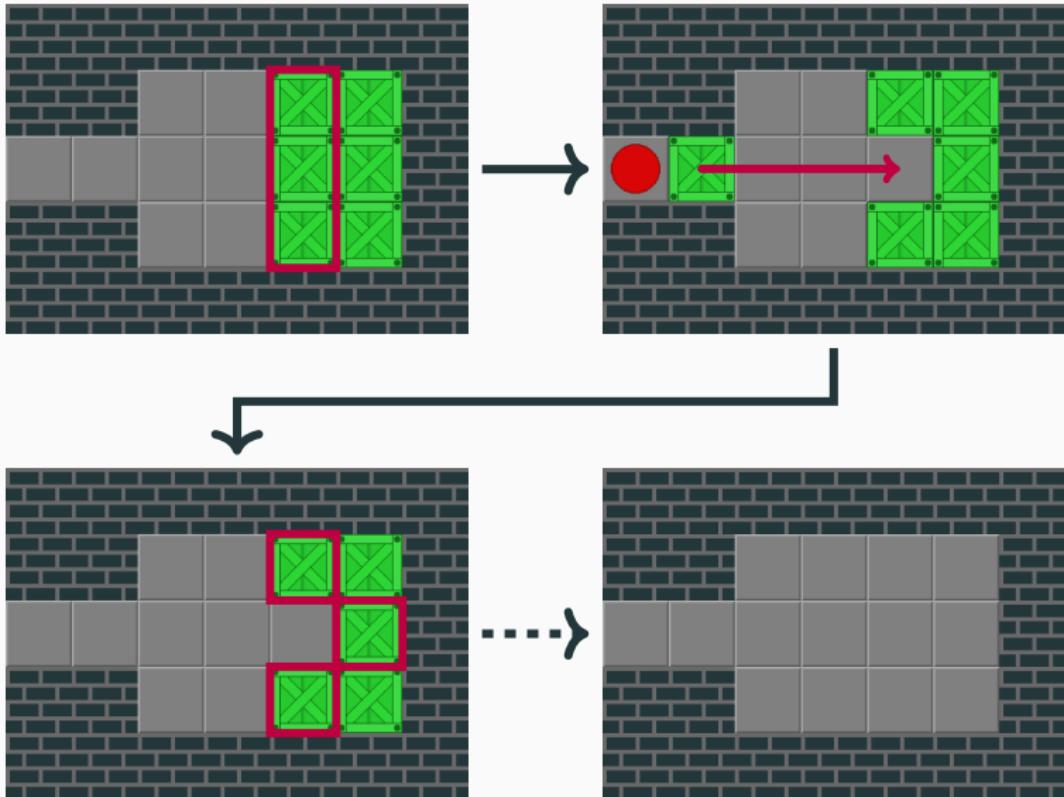


Composition d'un tunnel

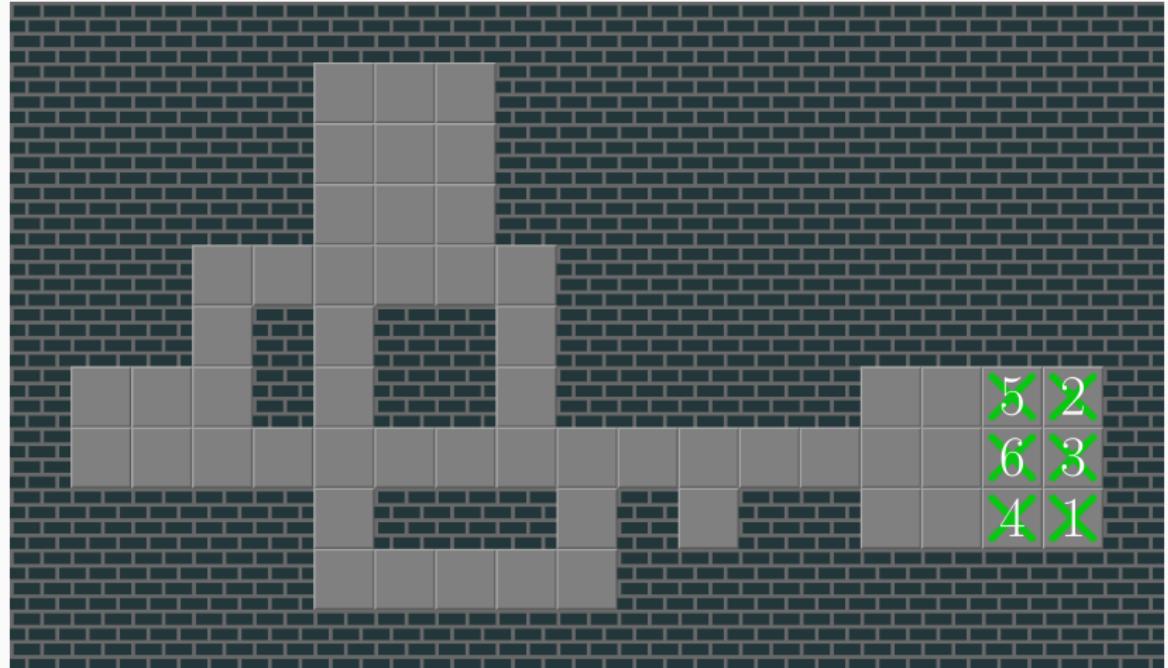
Salles et ordre de rangement (*packing order*)



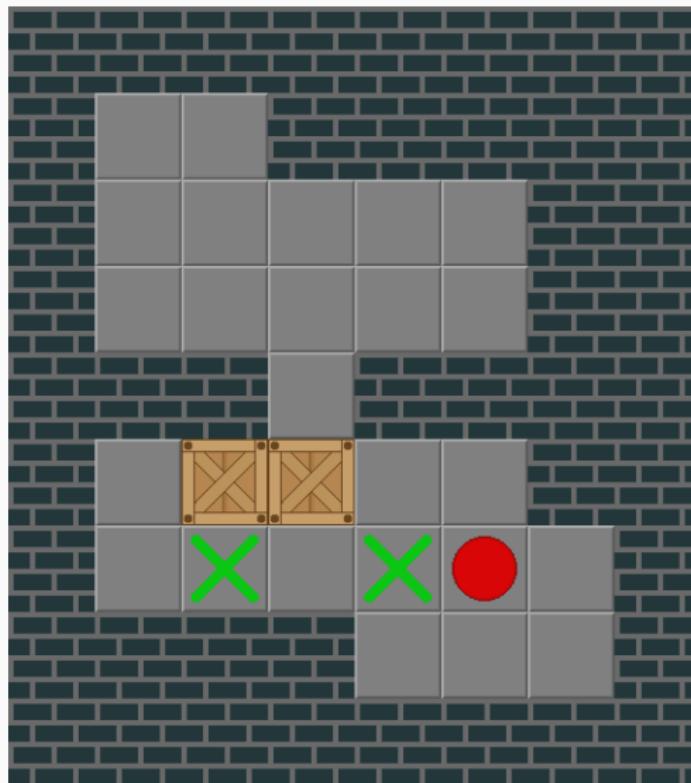
Salles et ordre de rangement (*packing order*)



Salles et ordre de rangement (*packing order*)



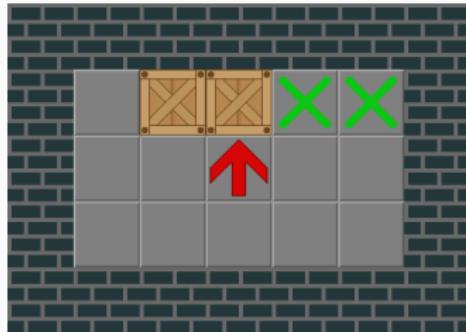
Salles et ordre de rangement (*packing order*)



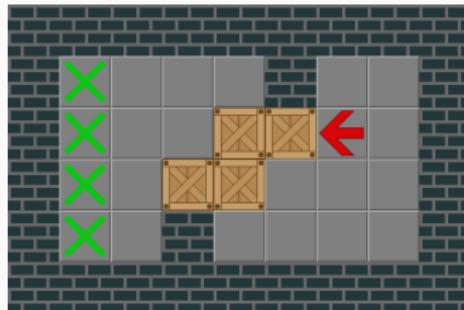
Réduction de l'espace de recherche

Analyse dynamique

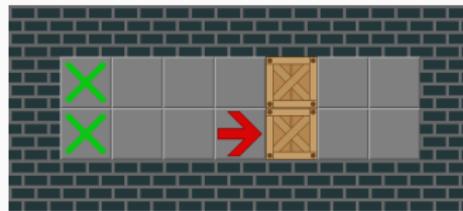
Détection d'impasses (*deadlocks*)



(a) *Freeze deadlock n°1*



(b) *Freeze deadlock n°2*

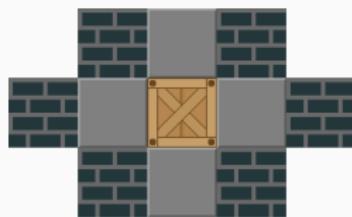


(c) *PI Corral deadlock*

Détection de *freeze deadlock*



(a) Règle n°1

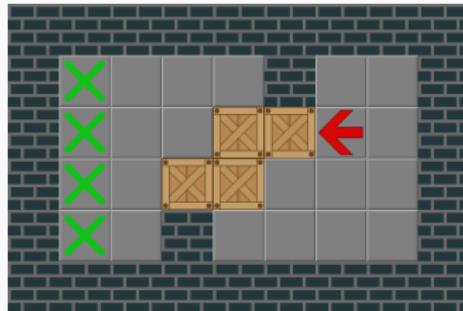


(b) Règle n°2

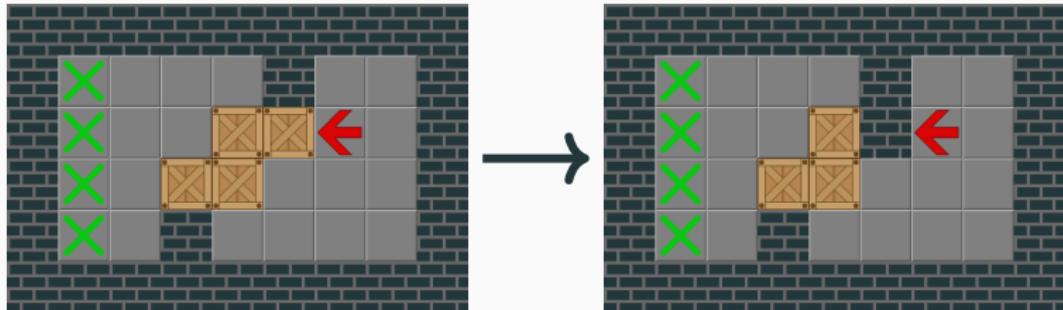


(c) Règle n°3

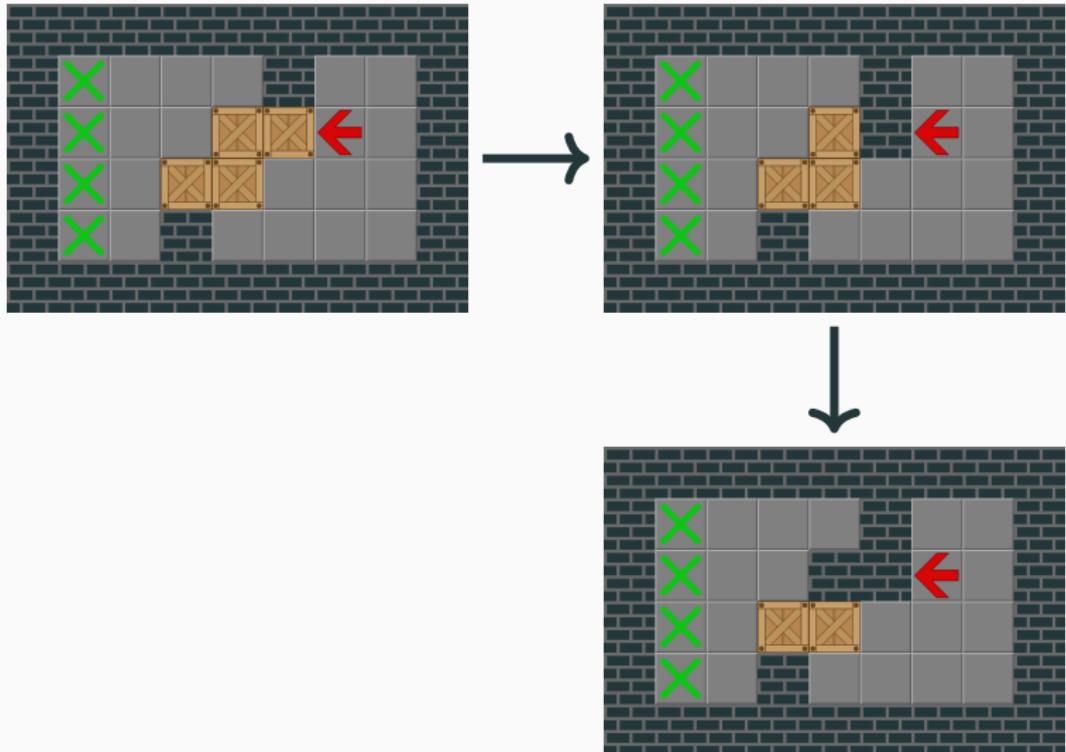
Détection de *freeze deadlocks*



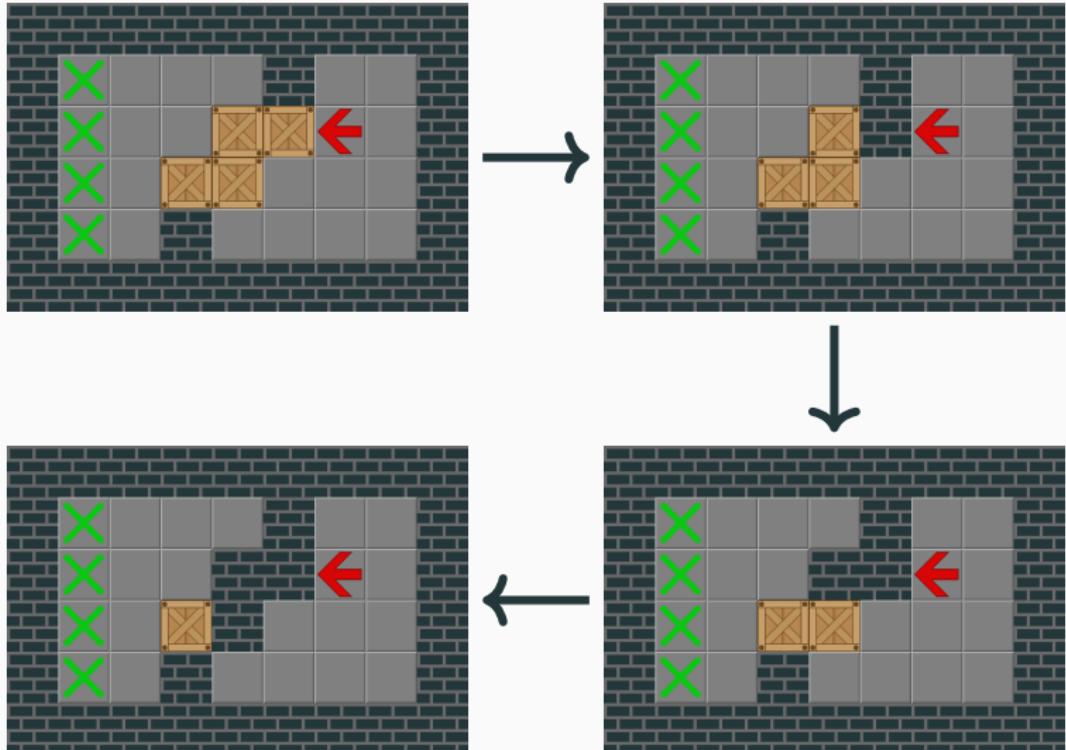
Détection de *freeze deadlocks*



Détection de *freeze deadlocks*

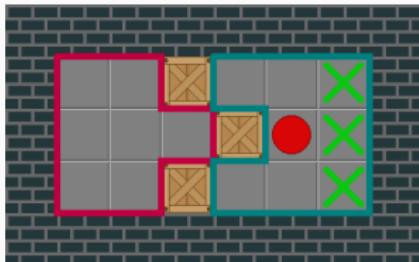


Détection de *freeze deadlocks*

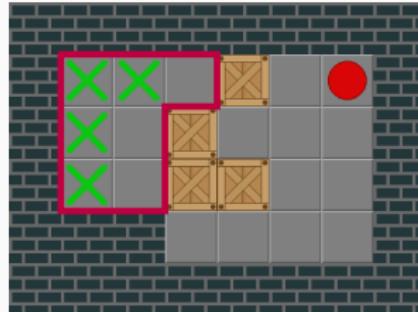


Gelée!

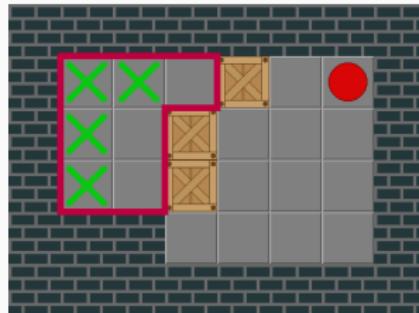
Détection de *PI Corral deadlocks*



(a) *Corral*

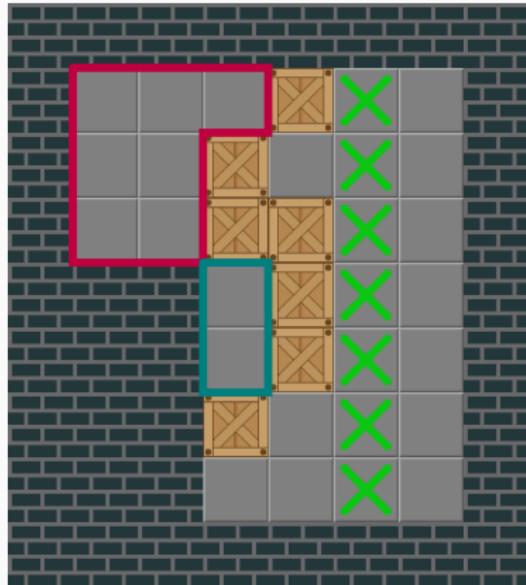


(b) *I Corral*

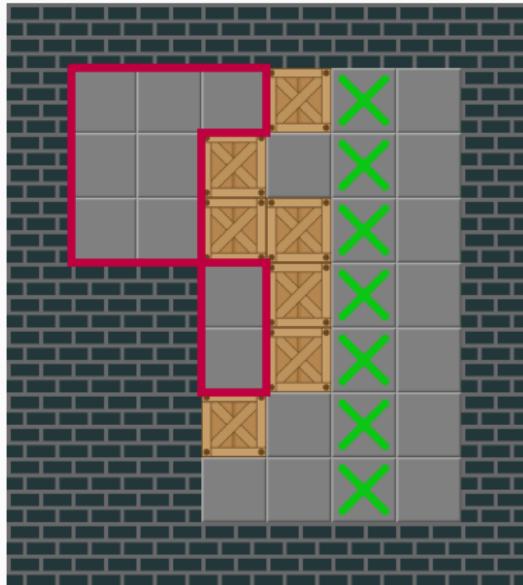


(c) *PI Corral*

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

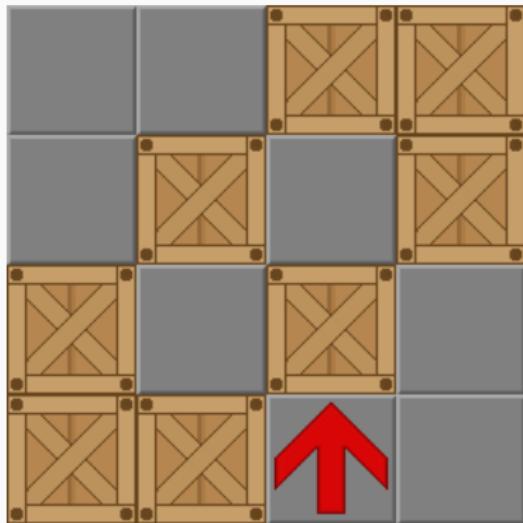
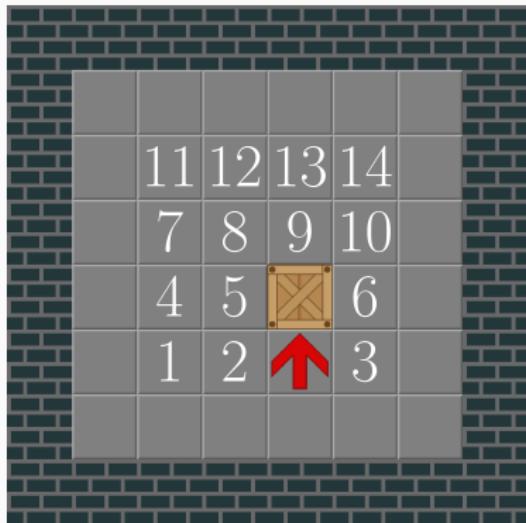
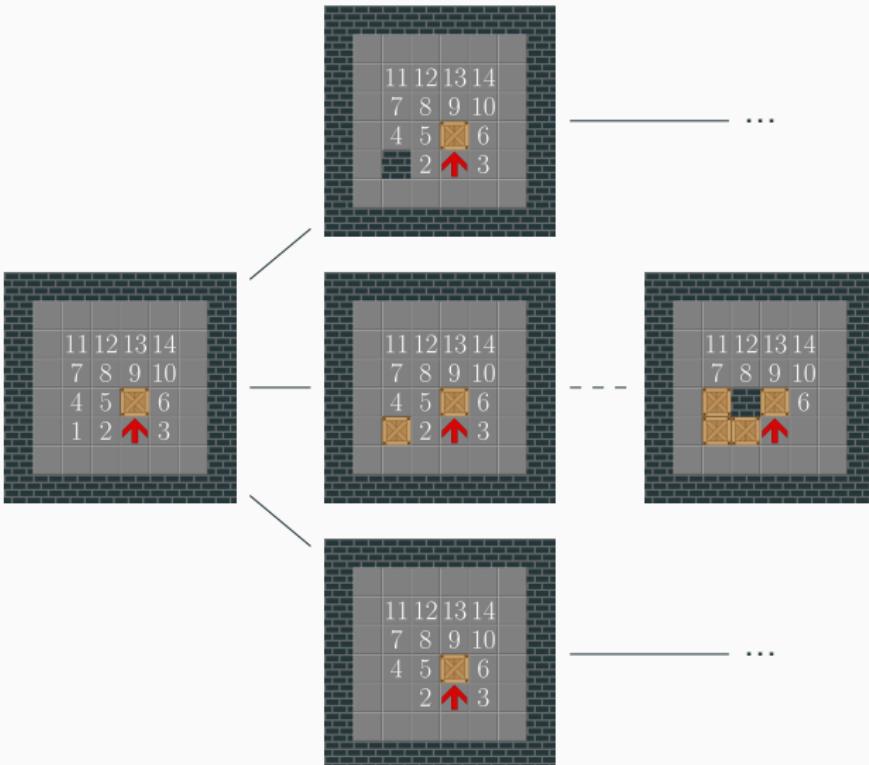
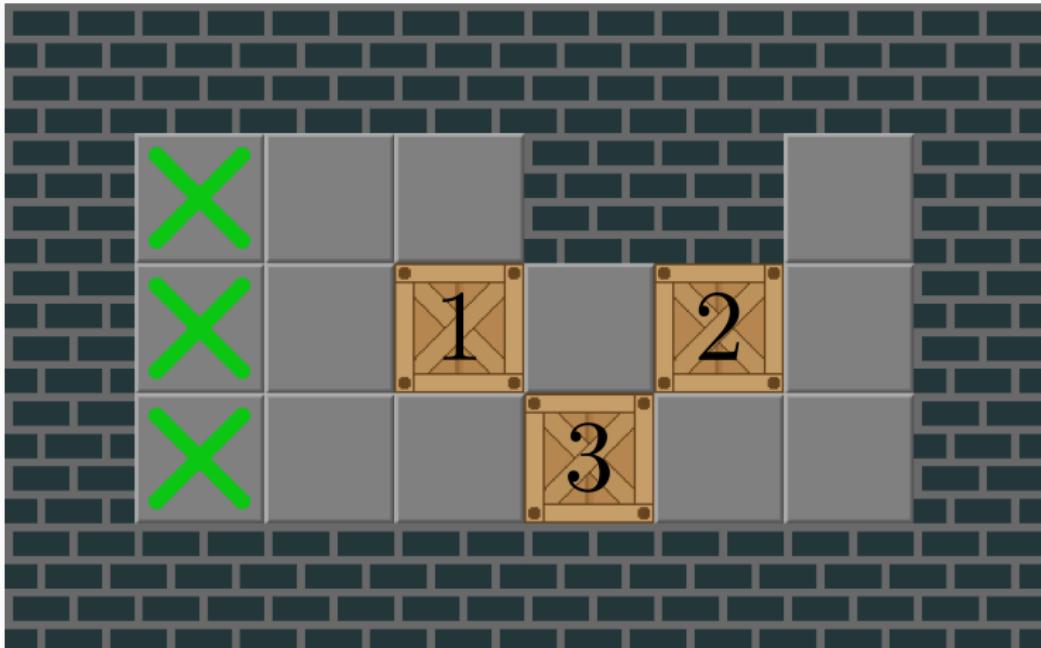


Table de deadlocks

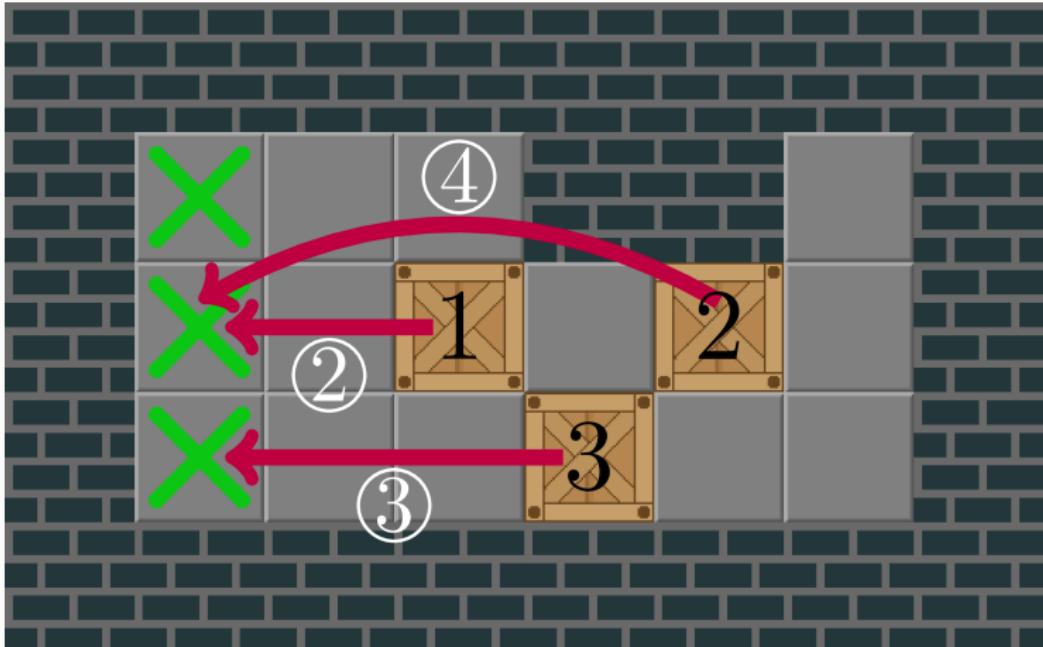


Recherche dirigée par une heuristique

Heuristique simple (*Simple Lower Bound*)

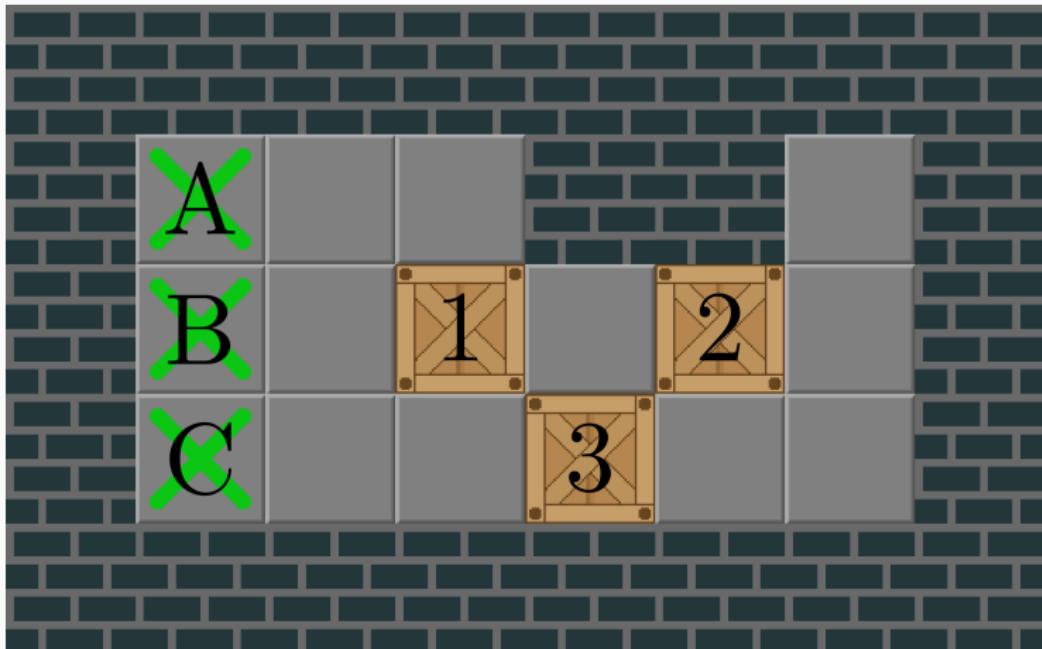


Heuristique simple (*Simple Lower Bound*)

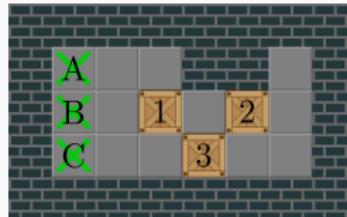


$$2 + 4 + 3 = 9$$

Heuristique gloutonne (*Greedy Lower Bound*)



Heuristique gloutonne (*Greedy Lower Bound*)

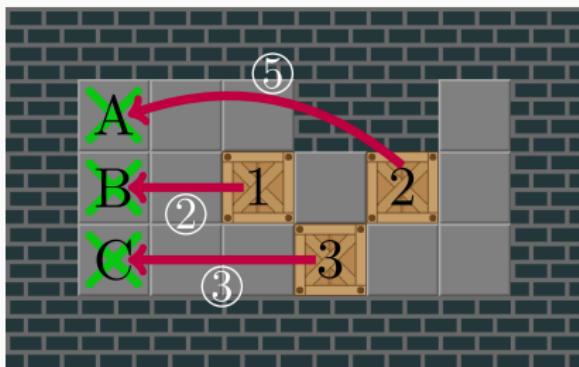
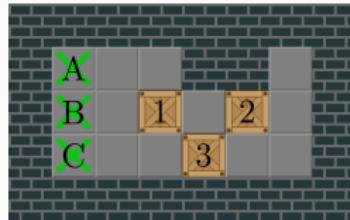


Caisse → Cible	Distance
1 → A	3
1 → B	2
1 → C	3
2 → A	4
2 → B	4
2 → C	5
3 → A	5
3 → B	4
3 → C	3

Tri

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

Heuristique gloutonne (*Greedy Lower Bound*)



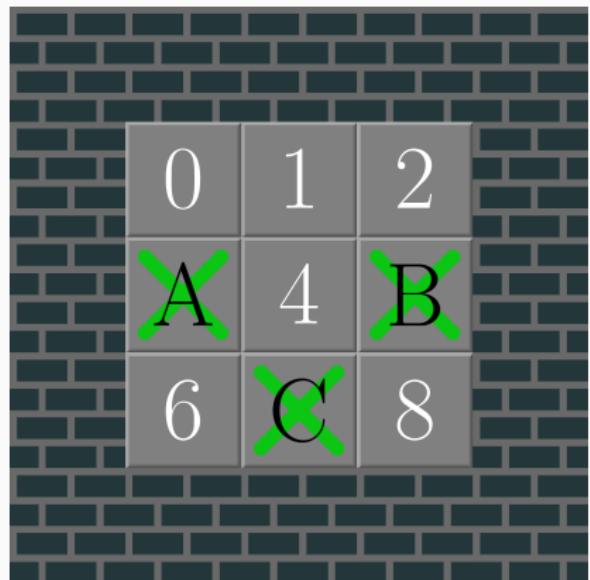
$$2 + 3 + 5 = \mathbf{10}$$

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

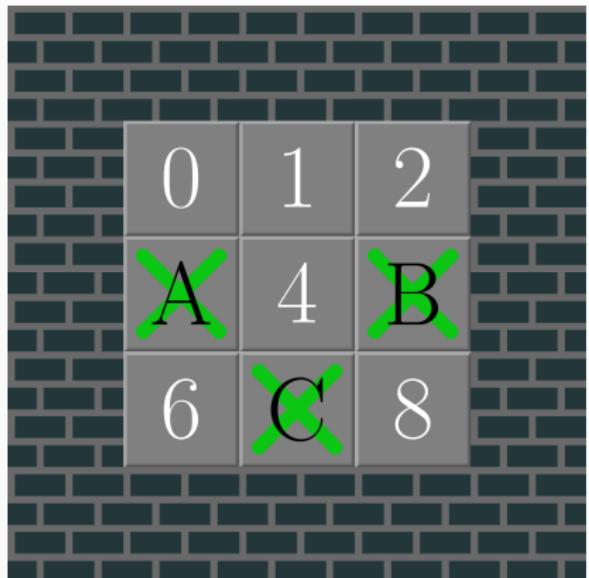
Précalcul des distances caisses-cibles

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

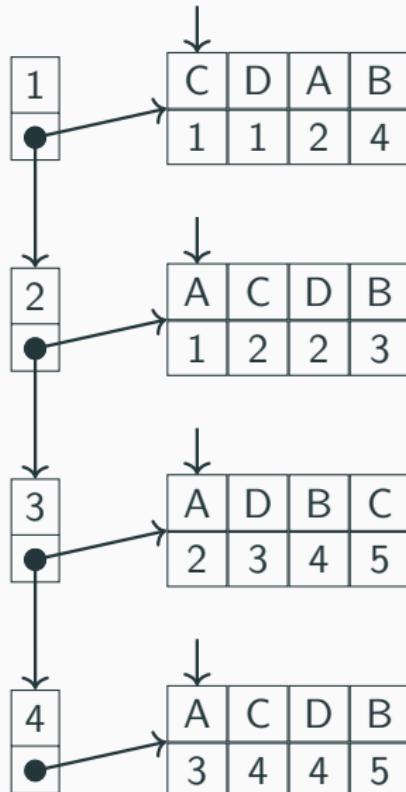


Précalcul des distances caisses-cibles

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

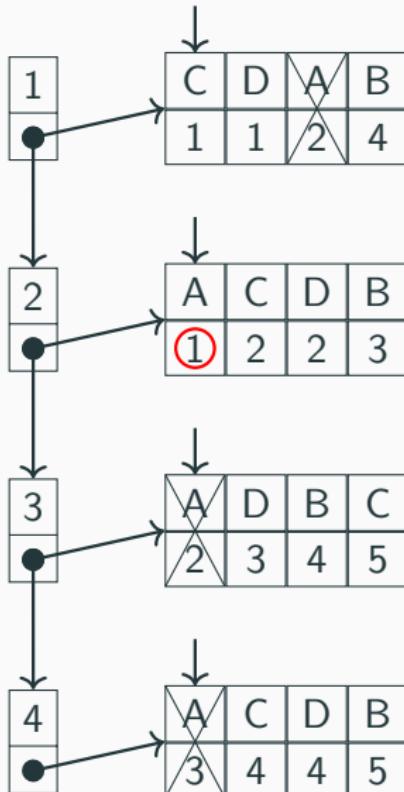


Greedy Lower Bound en $\mathcal{O}(n^2)$



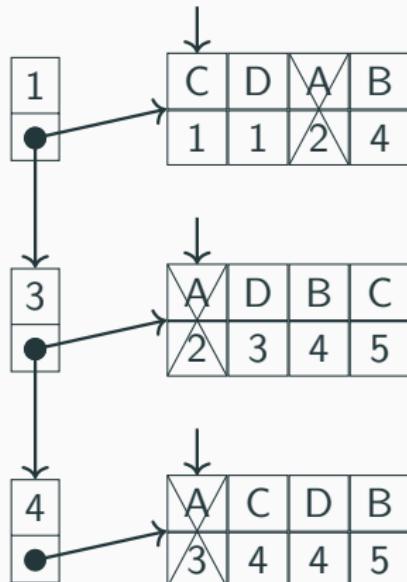
$h =$

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



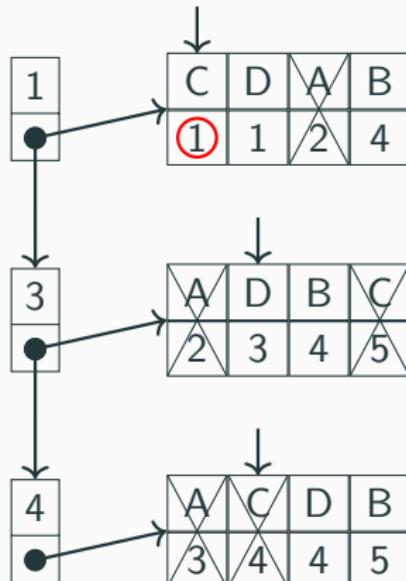
$$h = 1 +$$

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



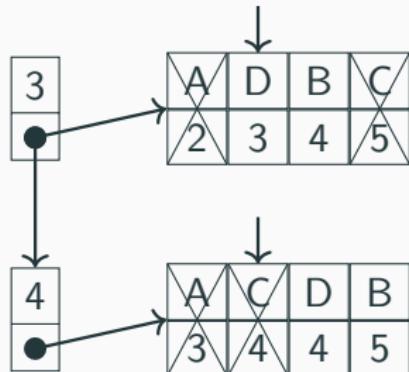
$$h = 1 +$$

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



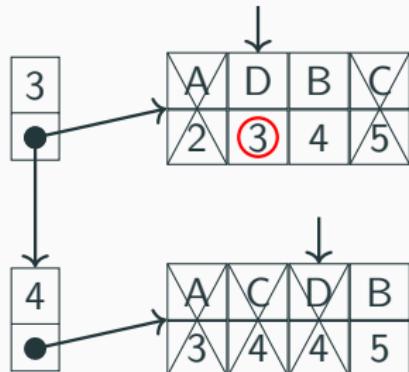
$$h = 1 + 1 +$$

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

$m = 0$

-1	-1	-1	-1	-1
-1	X	X	-1	-1
-1	-1	-1	-1	-1
-1	-1	-1	-1	-1
-1	-1	-1	-1	-1

$m = 0$

-1	-1	-1	-1	-1
-1	X	X	-1	-1
-1	-1	-1	-1	-1
-1	0	-1	-1	-1
-1	-1	-1	-1	-1

$m = 0$

-1	-1	-1	-1	-1
-1	X	X	-1	-1
-1	0	0	-1	-1
-1	0	0	-1	-1
-1	-1	-1	-1	-1

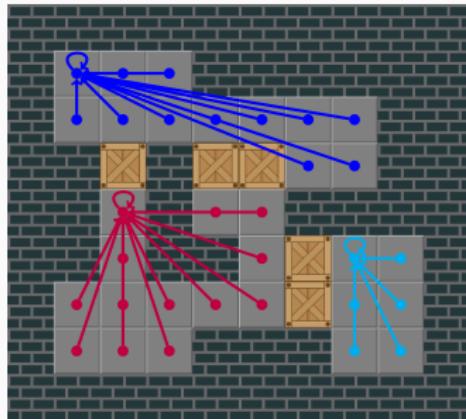
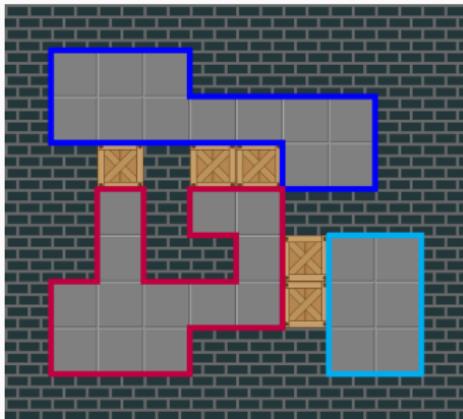
$m = 1$

-1	-1	-1	-1	-1
-1	X	X	-1	-1
-1	0	0	-1	-1
-1	0	0	-1	-1
-1	-1	-1	-1	-1



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

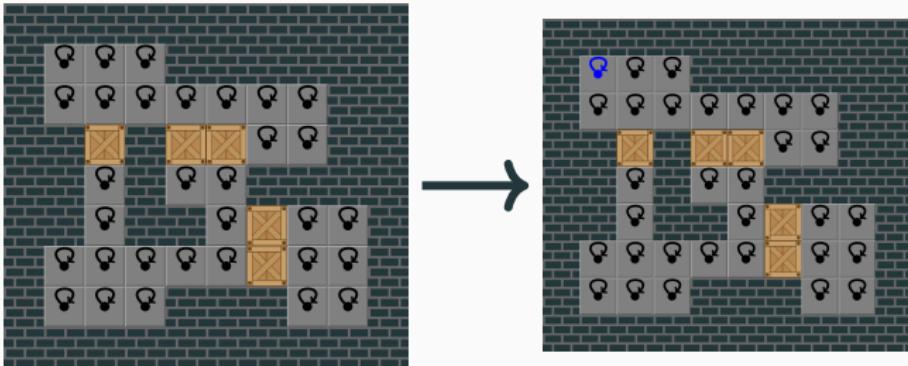
Utilisation de *Union-Find* : partition de $\llbracket 0; wh - 1 \rrbracket$.



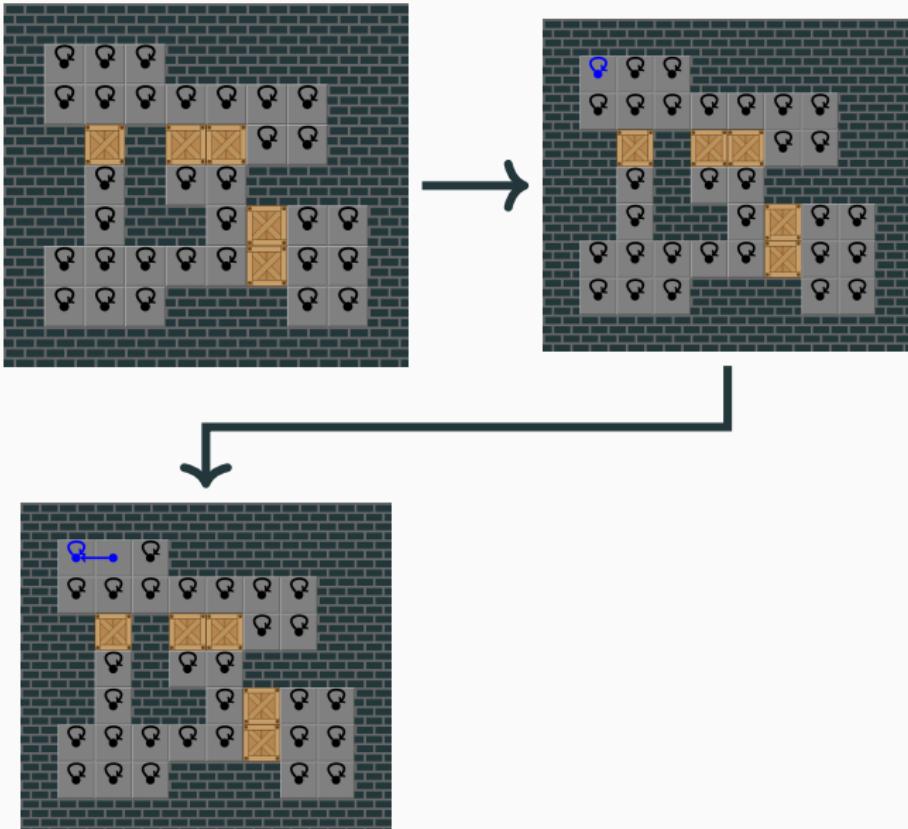
Calcul des *corrals* en $\mathcal{O}(wh)$



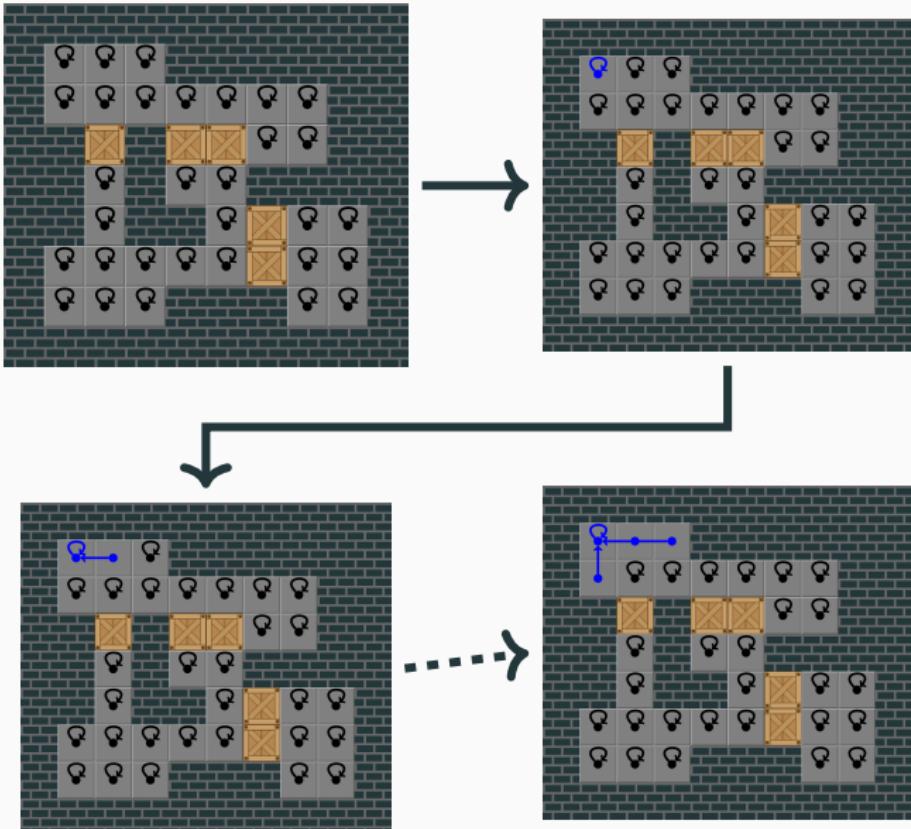
Calcul des *corrals* en $\mathcal{O}(wh)$



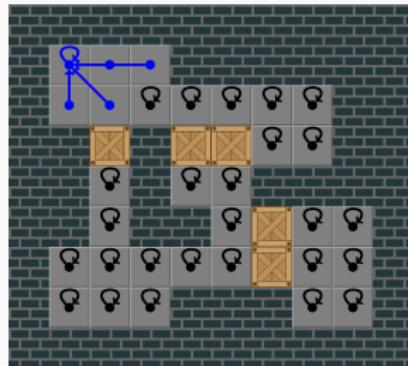
Calcul des *corrals* en $\mathcal{O}(wh)$



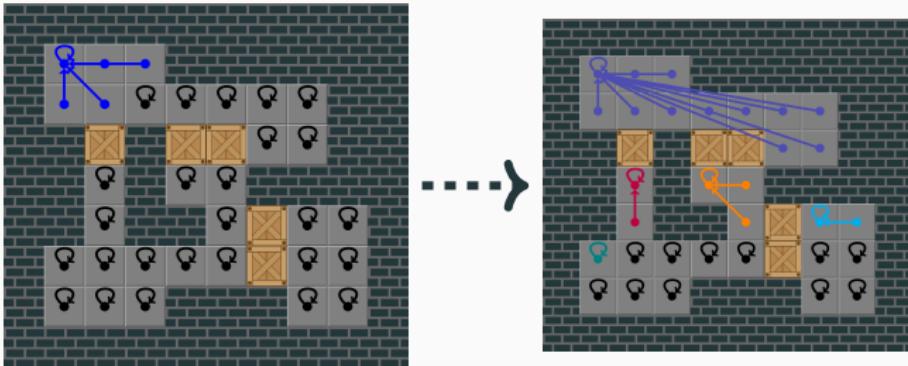
Calcul des *corrals* en $\mathcal{O}(wh)$



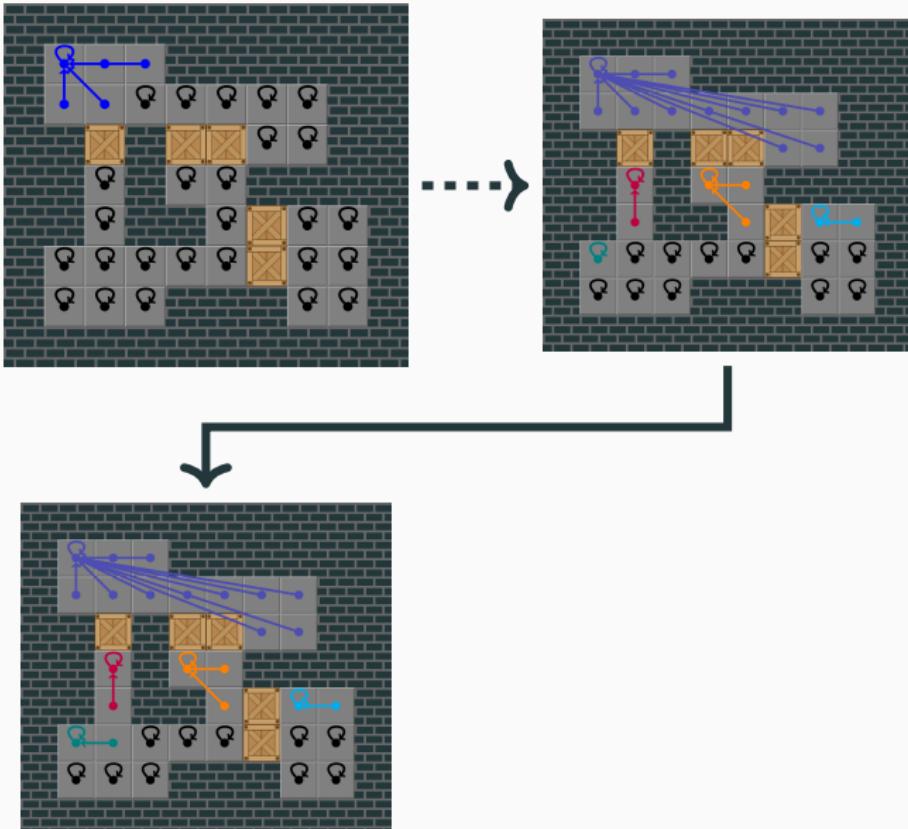
Calcul des *corrals* en $\mathcal{O}(wh)$



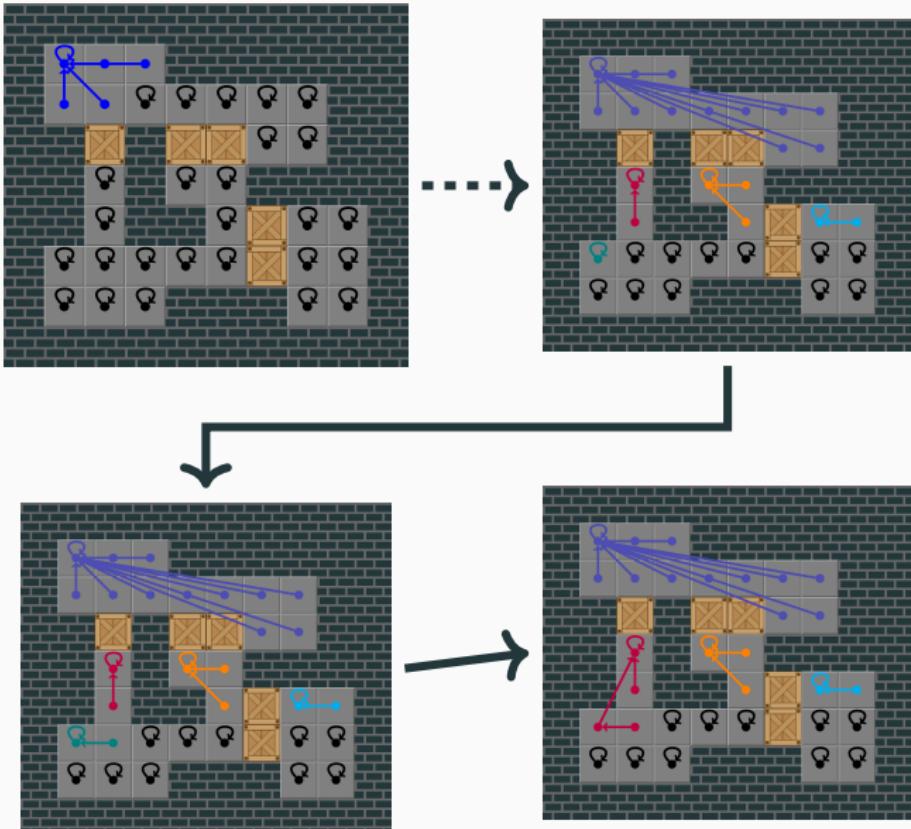
Calcul des *corrals* en $\mathcal{O}(wh)$



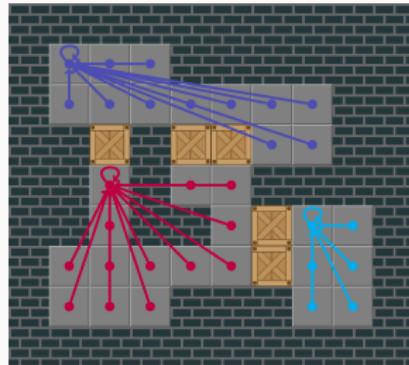
Calcul des *corrals* en $\mathcal{O}(wh)$



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.

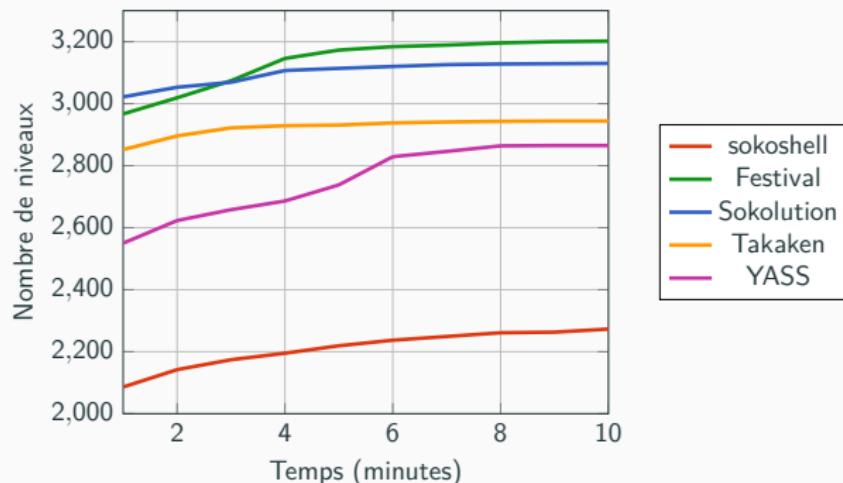
Ensemble de niveaux	XSokoban	<i>Large test suite</i>
Nombre de niveaux	90	3272
A*	11	2204
fess0	15	2273
Festival (Yaron Shoham)	90	3202
Sokolution (Florent Diedler)	90	3130
Takaken (Ken'ichiro Takahashi)	90	2944
YASS (Brian Damgaard)	89	2865

Statistiques

Temps moyen passé par niveaux

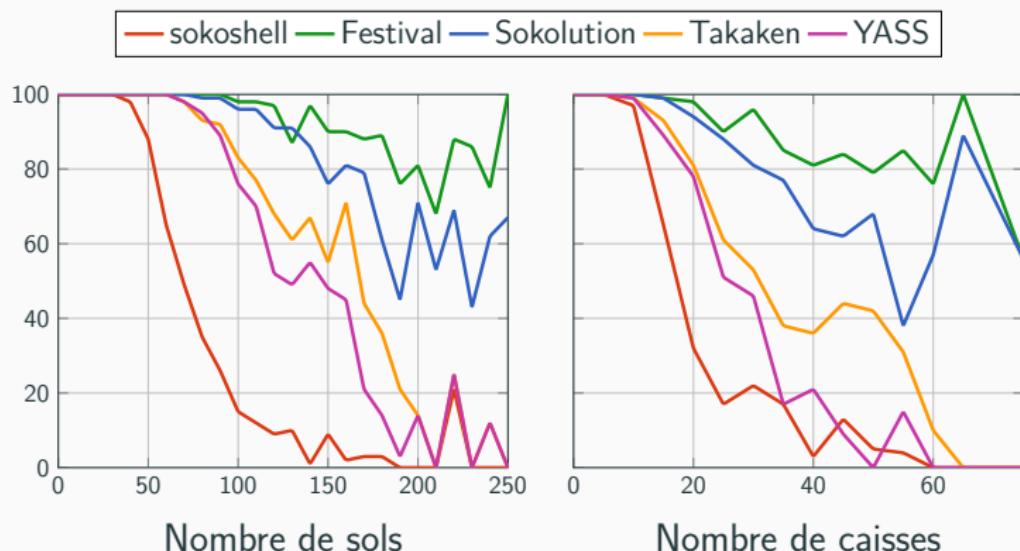
Solveur	A*	fess0	Festival	Sokolution	Takaken	YASS
Temps moyen	3min 28s	3min 16s	3s	2s	7s	24s

Nombre de niveaux résolus (cumulés) en fonction du temps



Statistiques

Pourcentage de niveaux résolus selon la composition des niveaux



Annexe

Tableau des complexités - Statique

c nombre de caisses, C nombre de cibles, w longueur et h largeur du niveau, t nombre de tunnels, r nombre de salles, N nombre d'états dans la liste des états à explorer.

Statique	
<i>Dead tiles</i>	$\mathcal{O}((wh)^2)$
Détection des tunnels	$\mathcal{O}((wh)^2)$
Propriété <i>oneway</i> des tunnels	$\mathcal{O}(twh)$
Détection des salles	$\mathcal{O}((wh)^2)$
<i>Packing order</i>	$\mathcal{O}(rcwh)$
Précalcul des distances cibles-caisses	$\mathcal{O}(wh(Cwh + C \log C))$

Tableau des complexités - Dynamique

c nombre de caisses, C nombre de cibles, w longueur et h largeur du niveau, t nombre de tunnels, r nombre de salles, N nombre d'états dans la liste des états à explorer.

Dynamique	
<i>Freeze deadlocks</i>	$\mathcal{O}(c)$
Détection des <i>corrals</i>	$\mathcal{O}(wh)$
<i>PI-corral deadlocks</i>	Exponentielle
Table de <i>deadlocks</i>	$\mathcal{O}(1)$
Recherche des états enfants	$\mathcal{O}(crwh)$
Ajout des états enfants (A*)	$\mathcal{O}((wh)^2 + \log N)$
Ajout des états enfants (fess0)	$\mathcal{O}(c + (wh)^2 + \log N)$