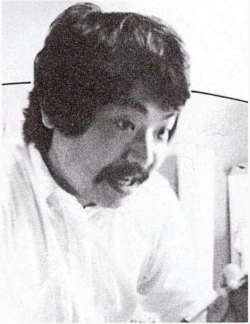
Résolution de niveaux du Sokoban

Nom Prénom

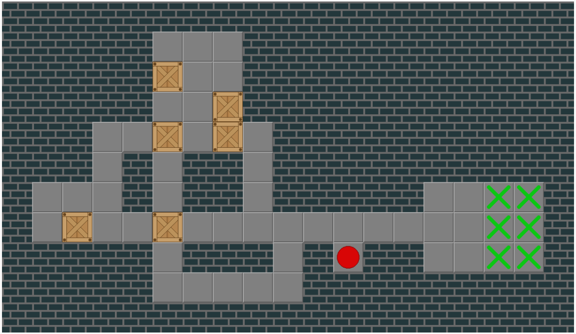
Candidat n°01234

Introduction

Le jeu du Sokoban



Hiroyuki Imabayashi

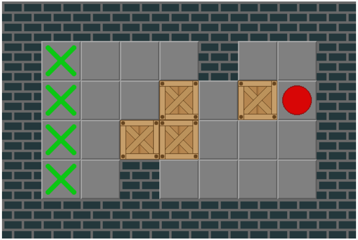


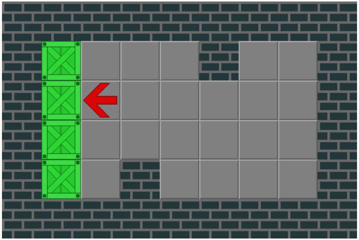
XSokoban

Problème **PSPACE-complet**

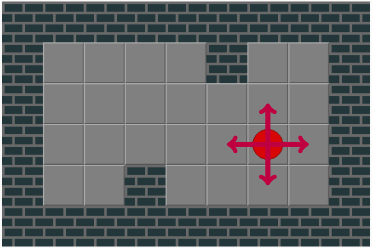
But du jeu

Déplacements



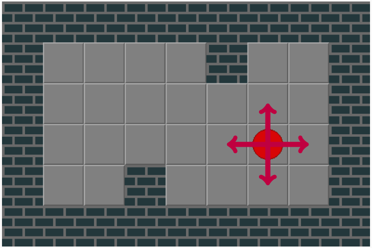


Règles

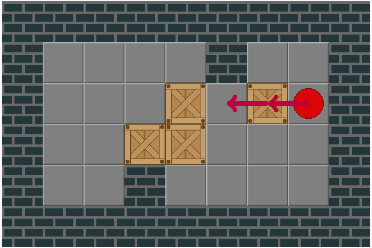


Déplacements autorisés

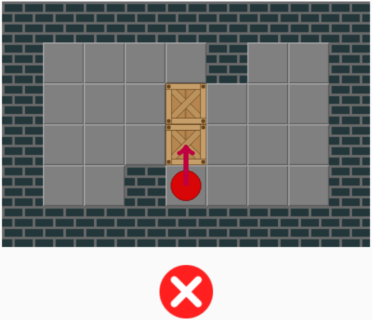
Règles

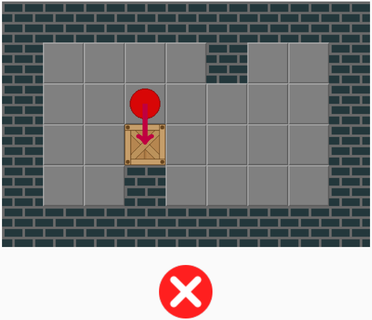


Déplacements autorisés

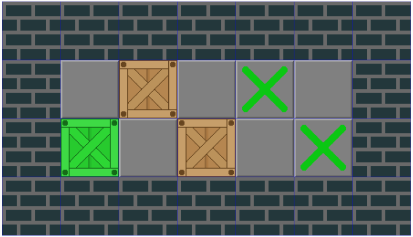


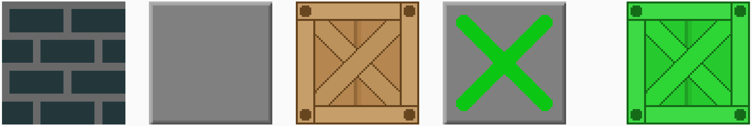
Règles





Tuiles





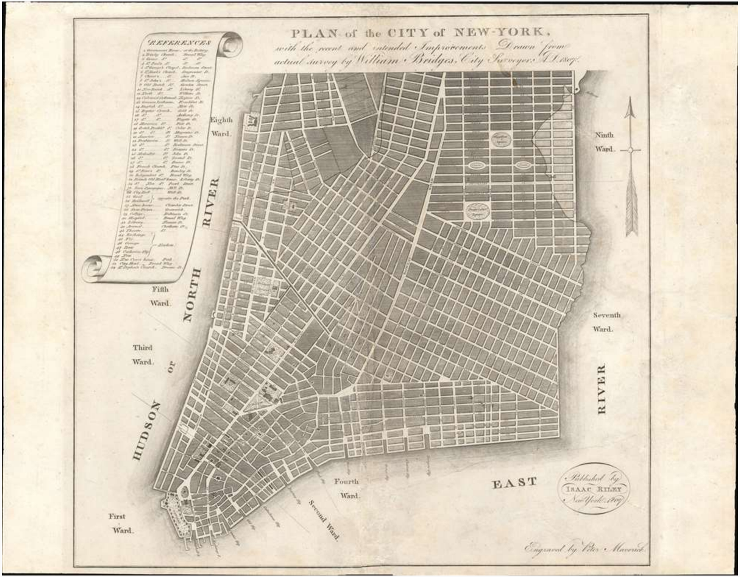
Mur | Sol | **Caisse** | Cible | **Caisse sur une cible**

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>
```

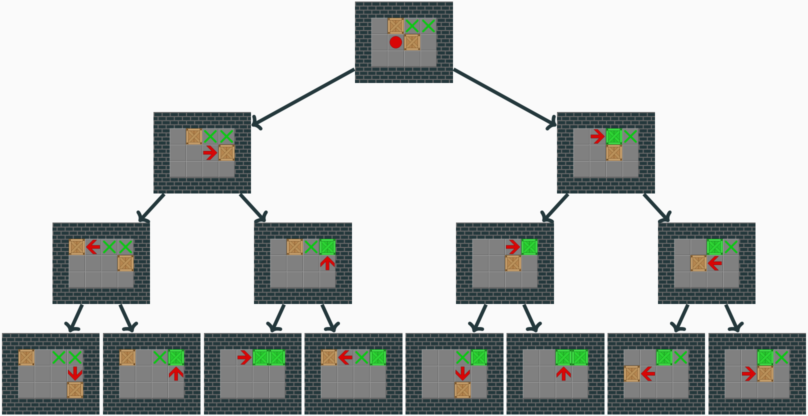
Plan

Lien avec le thème de l'année

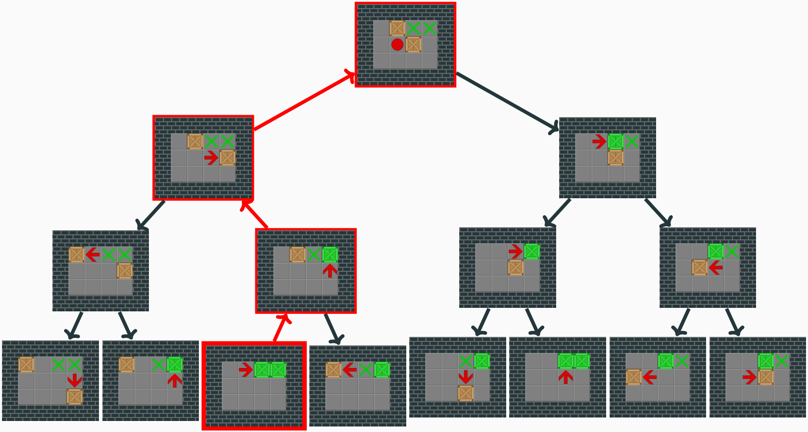

PLAN of the CITY of NEW-YORK,
with the recent and intended Improvements Drawn from
actual survey by William Bridges, City Surveyor: A.D. 1807.
REFERENCES
Eighth Ward.
Ninth Ward.
NORTH RIVER
Fifth Ward.
Third Ward.
HUDSON or
Seventh Ward.
EAST RIVER
Fourth Ward.
Second Ward.
First Ward.
Published by ISAAC RILEY New York 1807
Engraved by Peter Maverick

Principe de résolution

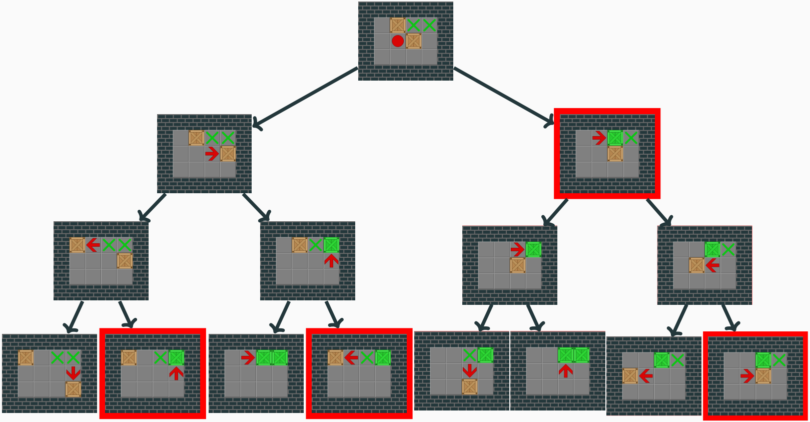
Arbre des états



Arbre des états



Arbre des états



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

Propriétés du **XOR** :

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

Initialisation :

$$T = \begin{array}{cc} \text{caisse} & \text{joueur} \\ \end{array}$$

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

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

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

$$h = \underset{i=0}{\overset{n}{\textbf{XOR}}}\, T[c_i][0]\,\textbf{XOR}\; T[p][1]$$

en $\mathcal{O}(n)$

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

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

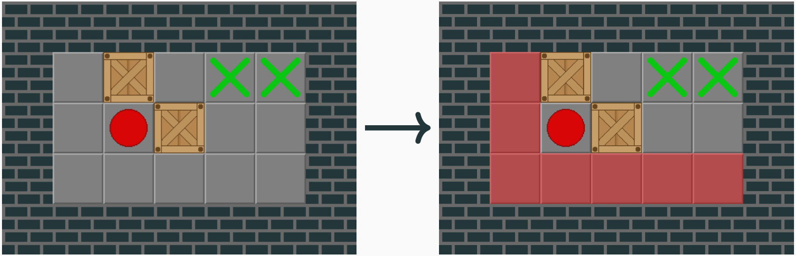
$$\boxed{\text{en } \mathcal{O}(1)}$$

Réduction de l’espace de recherche

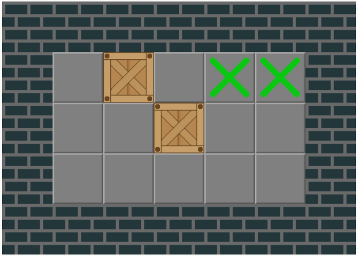
Réduction de l'espace de recherche

Analyse statique

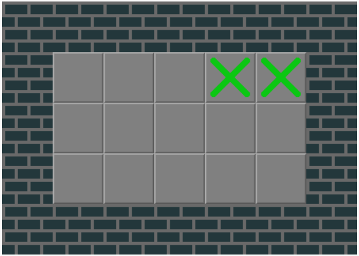
Détection des positions mortes *(dead positions)*



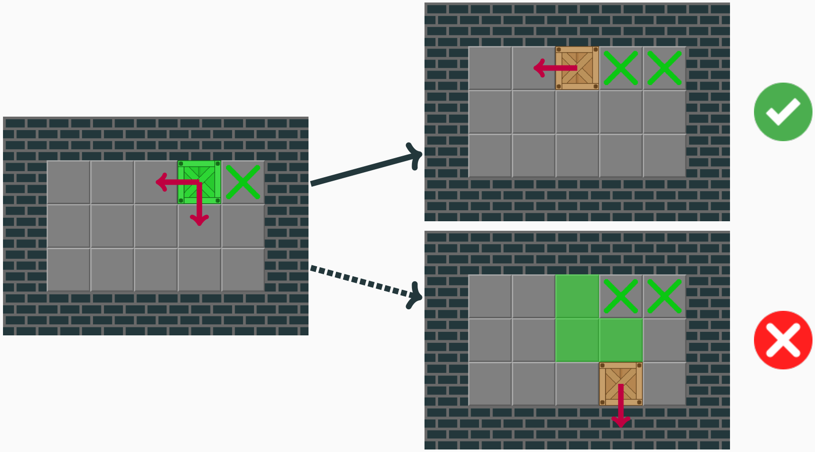
Détection des positions mortes *(dead positions)*



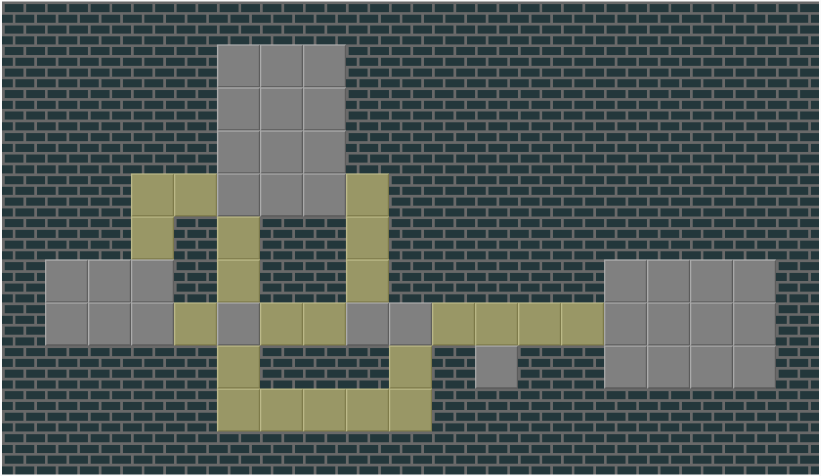
$\longrightarrow$



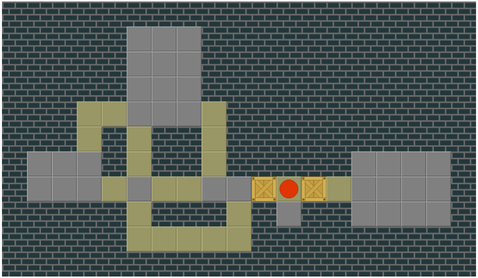
Détection des positions mortes *(dead positions)*

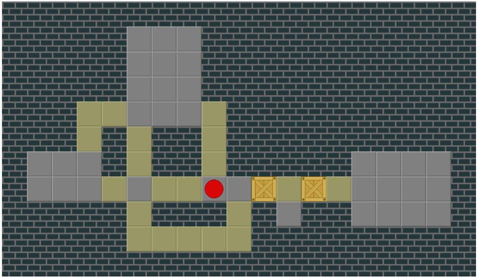


Détection de tunnels

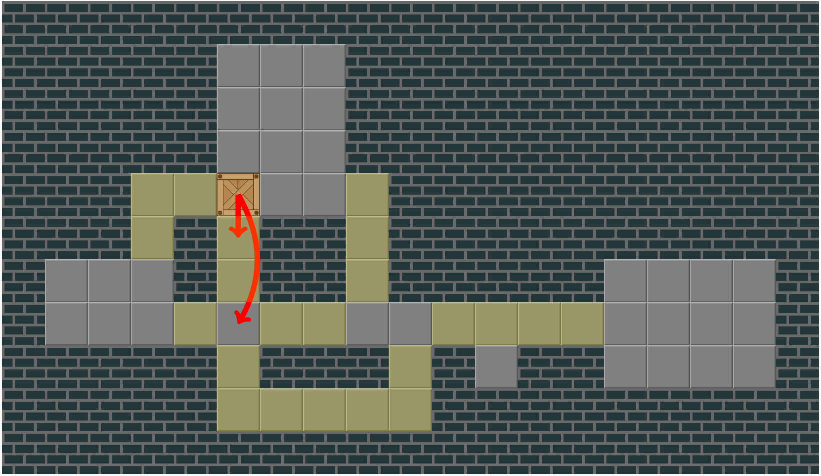


Détection de tunnels

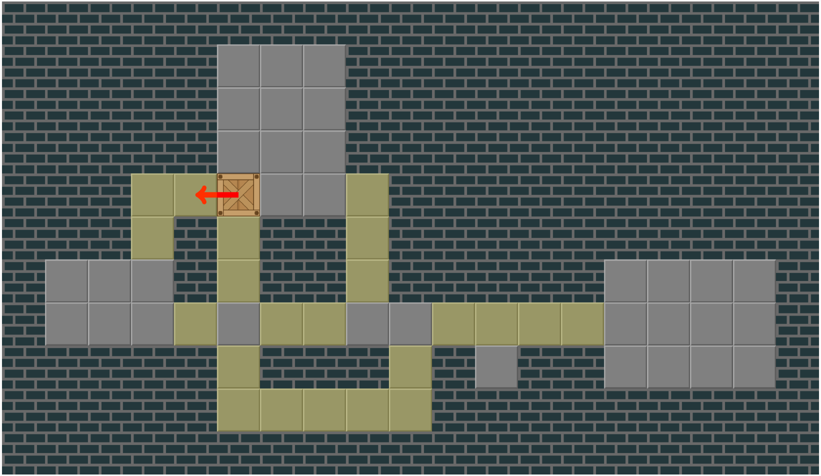




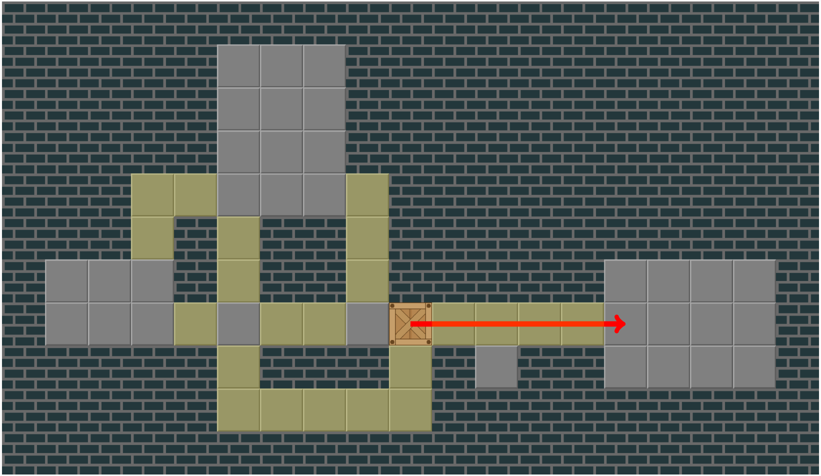
Détection de tunnels



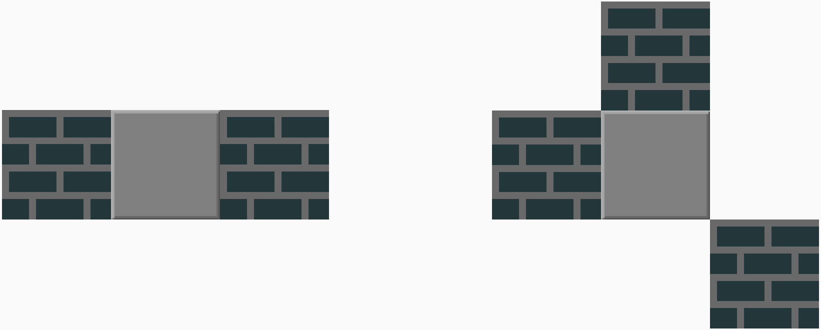
Détection de tunnels



Détection de tunnels

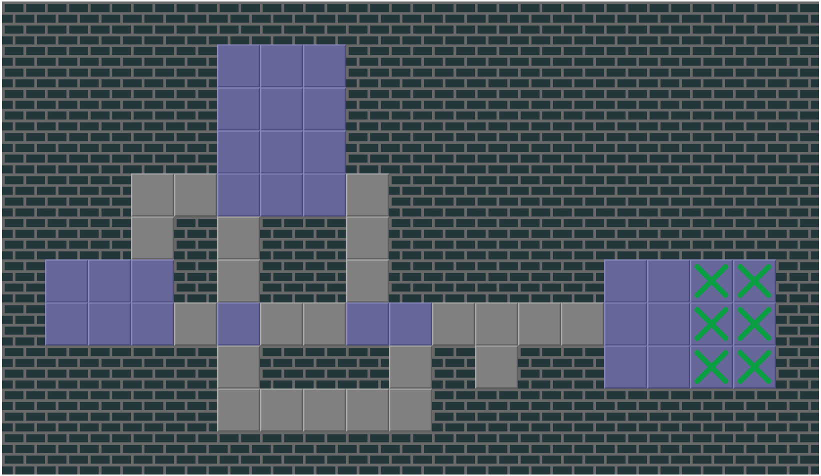


Détection de tunnels

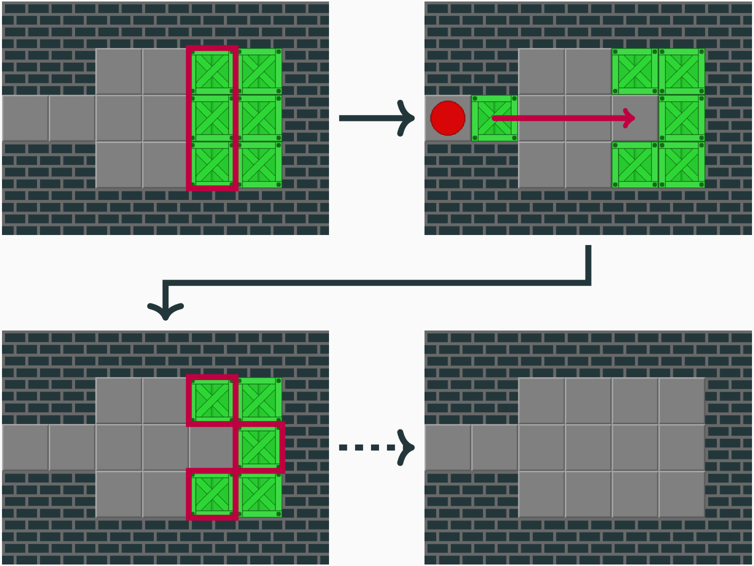


Composition d'un tunnel

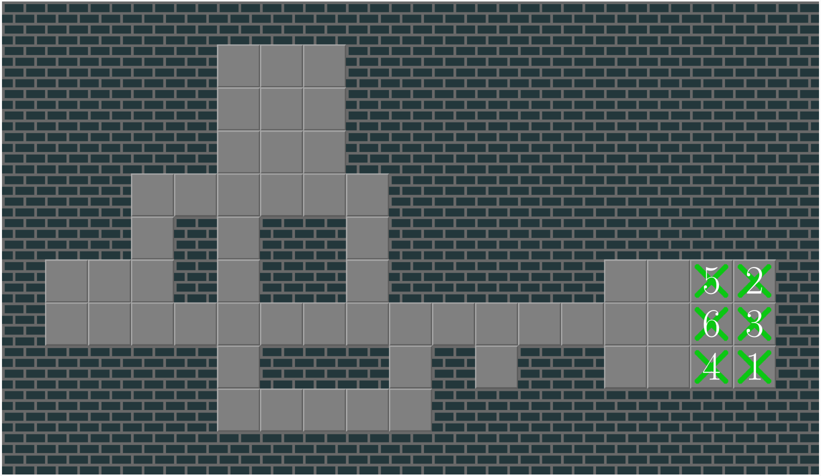
Salles et ordre de rangement *(packing order)*



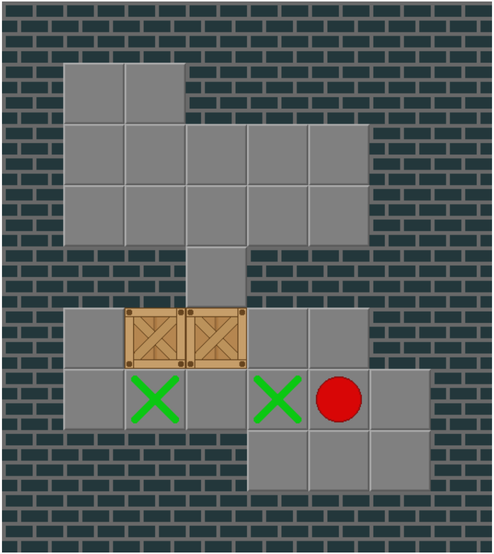
Salles et ordre de rangement *(packing order)*



Salles et ordre de rangement *(packing order)*



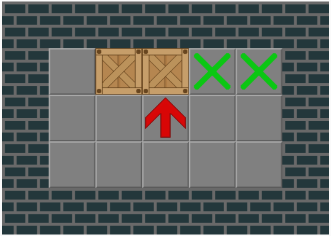
Salles et ordre de rangement *(packing order)*



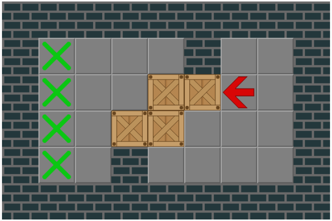
Réduction de l’espace de recherche

Analyse dynamique

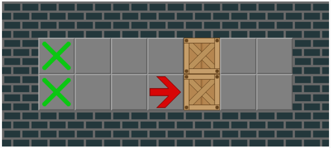
Détection d'impasses *(deadlocks)*



(a) *Freeze deadlock n°1*

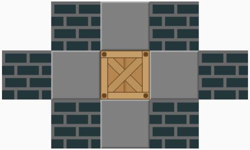


(b) *Freeze deadlock n°2*

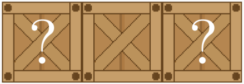


(c) *PI Corral deadlock*

(a) *Règle n°1*

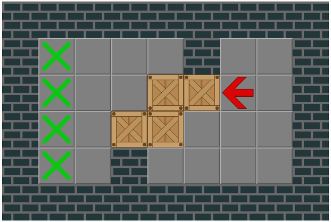


(b) *Règle n°2*

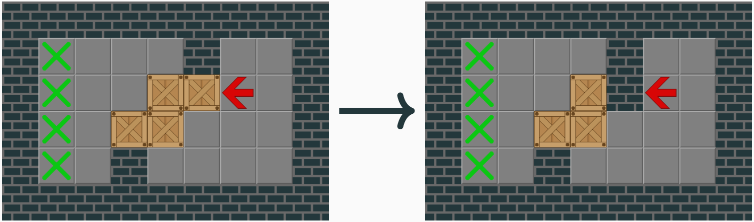


(c) *Règle n°3*

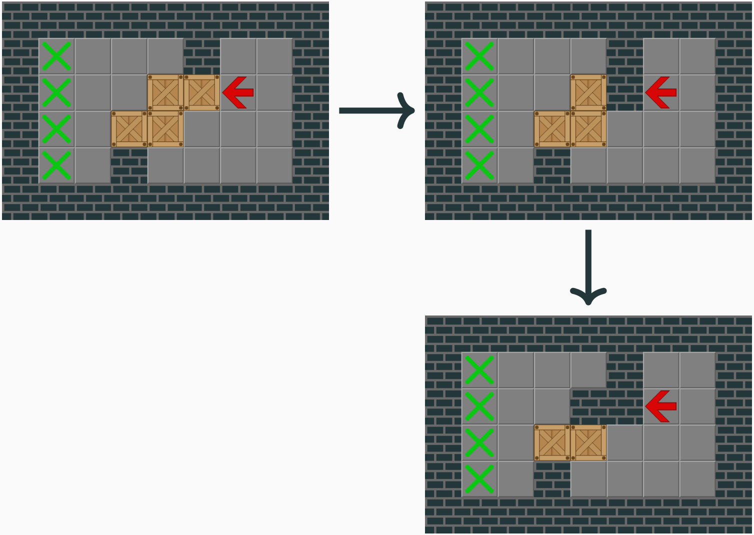
Détection de *freeze deadlocks*



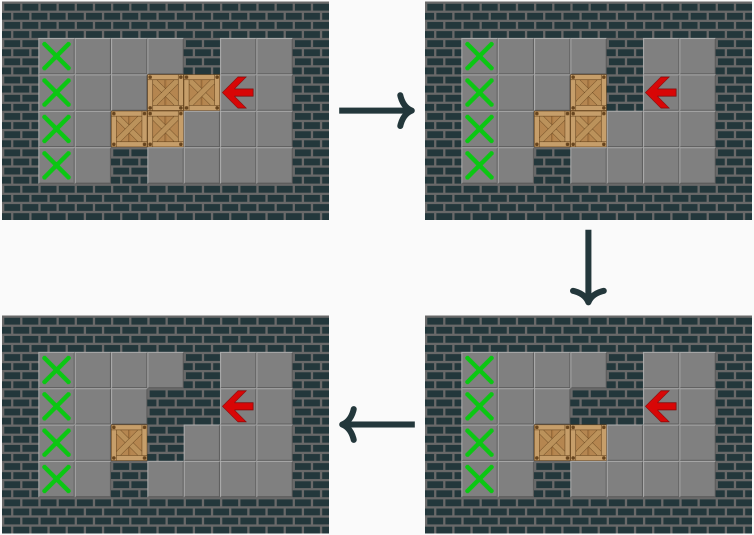
Détection de *freeze deadlocks*



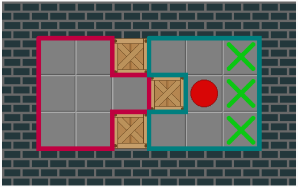
Détection de *freeze deadlocks*



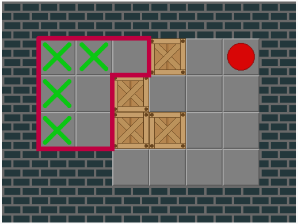
Détection de *freeze deadlocks*



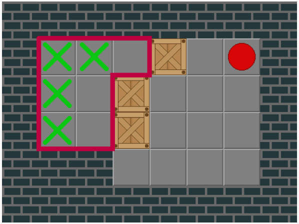
Gelée!



(a) *Corral*

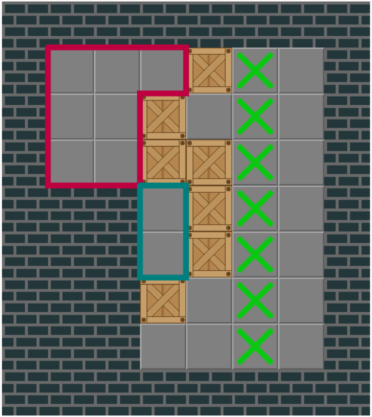


(b) *I Corral*

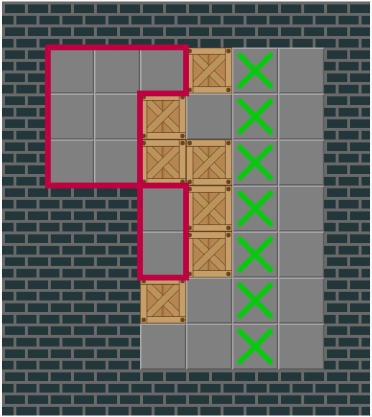


(c) *PI Corral*

Détection de *PI Corral deadlocks*



Deux *I-Corrals*

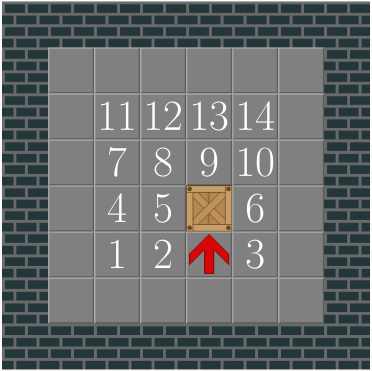


Un multi *PI-Corrals*

Détection de *PI Corral deadlocks*

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

Table de *deadlocks*



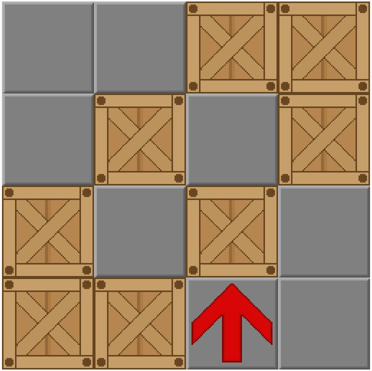
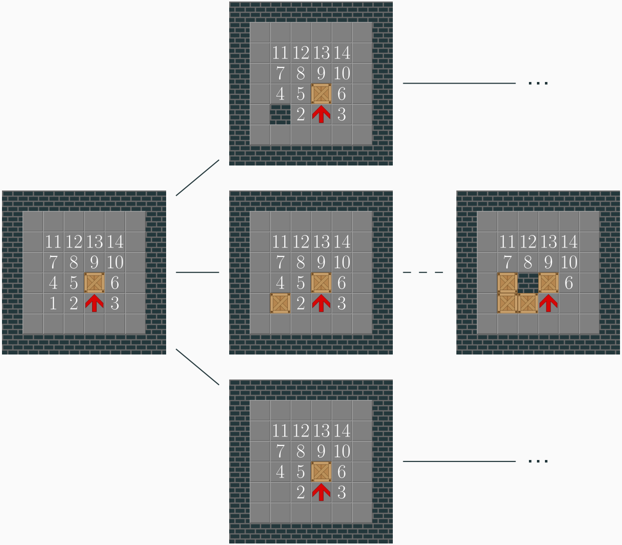
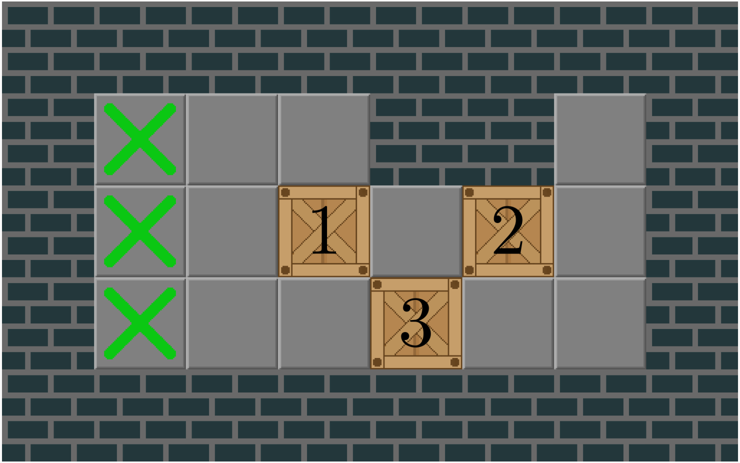


Table de *deadlocks*

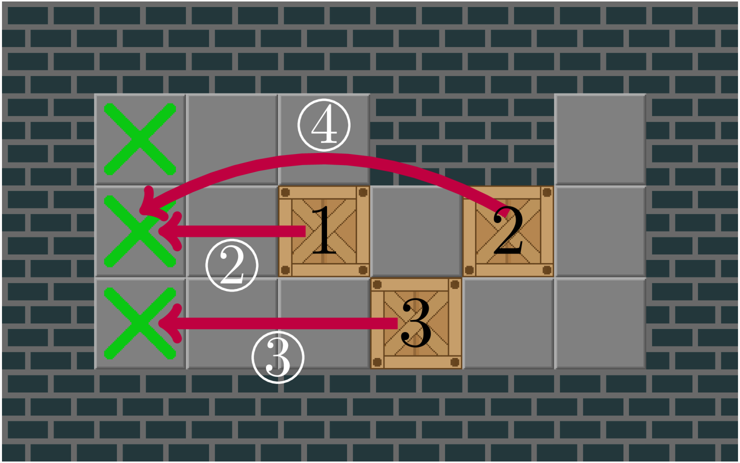


Recherche dirigée par une heuristique

Heuristique simple *(Simple Lower Bound)*

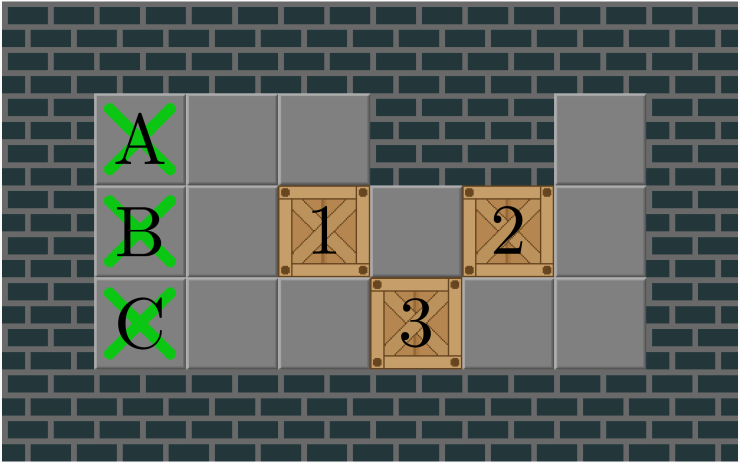


Heuristique simple *(Simple Lower Bound)*

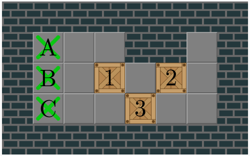


$$\boxed{2 + 4 + 3 = \mathbf{9}}$$

Heuristique gloutonne *(Greedy Lower Bound)*



Heuristique gloutonne *(Greedy Lower Bound)*

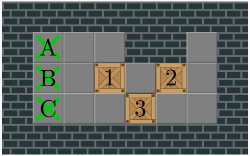


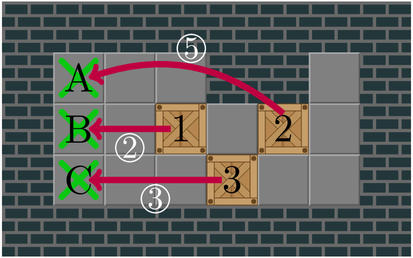
Caisse $\rightarrow$ Cible	Distance
$1 \rightarrow A$	3
$1 \rightarrow B$	2
$1 \rightarrow C$	3
$2 \rightarrow A$	4
$2 \rightarrow B$	4
$2 \rightarrow C$	5
$3 \rightarrow A$	5
$3 \rightarrow B$	4
$3 \rightarrow C$	3

Tri $\longrightarrow$

Caisse $\rightarrow$ Cible	Distance
$\mathbf{1 \rightarrow B}$	**2**
$1 \rightarrow A$	3
$1 \rightarrow C$	3
$\mathbf{3 \rightarrow C}$	**3**
$2 \rightarrow B$	4
$3 \rightarrow B$	4
$2 \rightarrow A$	5
$2 \rightarrow C$	5
$\mathbf{3 \rightarrow A}$	**5**

Heuristique gloutonne *(Greedy Lower Bound)*





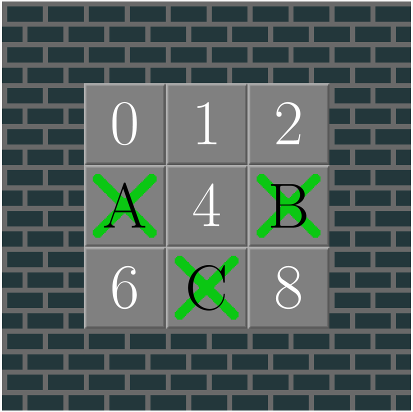
$$\boxed{2 + 3 + 5 = \mathbf{10}}$$

Caisse $\rightarrow$ 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**

Optimisations

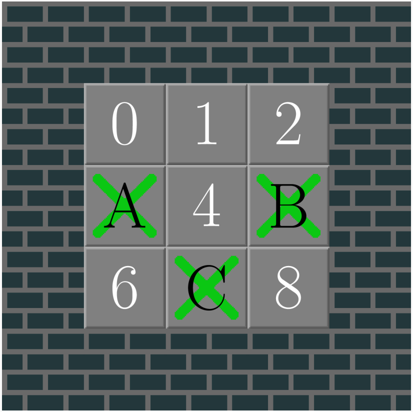
Précalcul des distances caisses-cibles

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

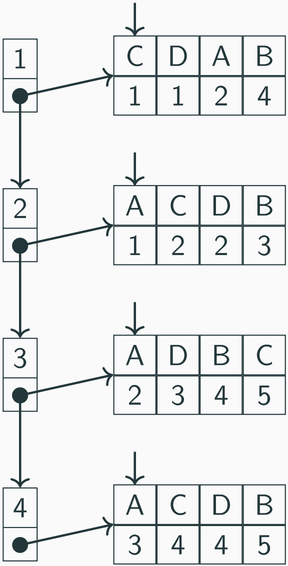


Précalcul des distances caisses-cibles

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

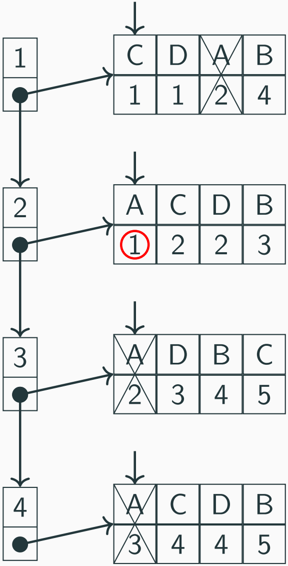


Greedy Lower Bound en $\mathcal{O}(n^2)$



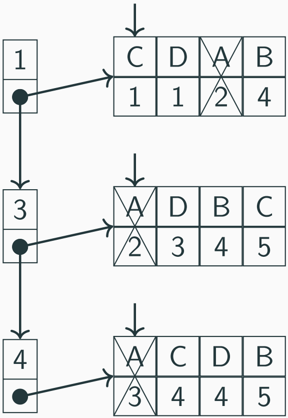
$h =$

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



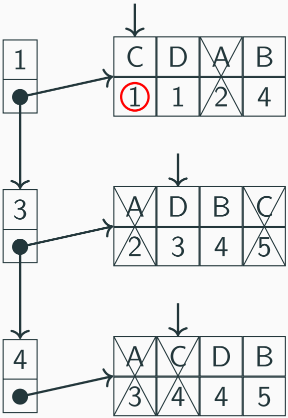
$$h = 1 +$$

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



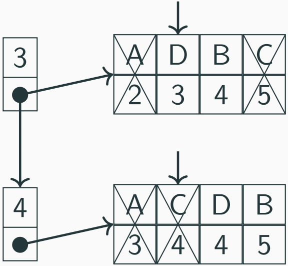
$h = 1 +$

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



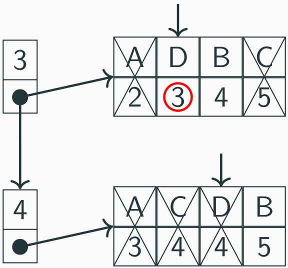
$$h = 1 + 1 +$$

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



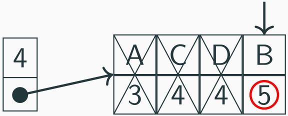
$$h = 1 + 1 +$$

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



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

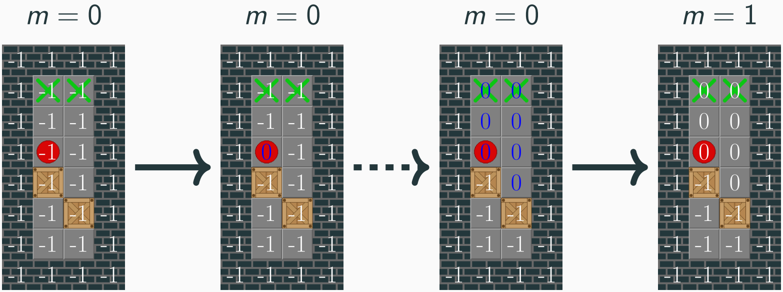
Greedy Lower Bound en $\mathcal{O}(n^2)$



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

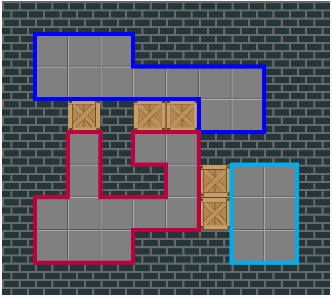
Parcours de graphes : démarquer tous les nœuds en $\mathcal{O}(1)$

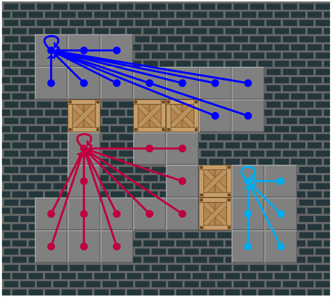
nœud marqué *ssi valeur* $= m$



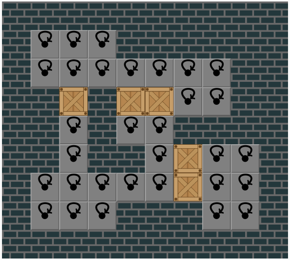
Calcul des ***corrals*** en $\mathcal{O}(wh)$

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

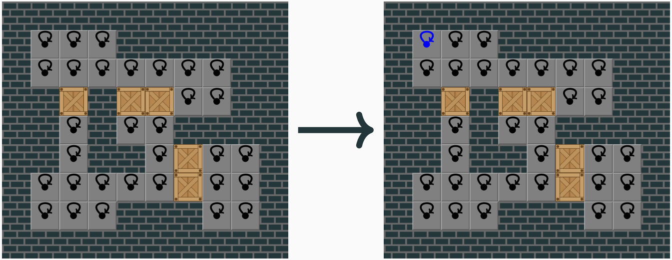




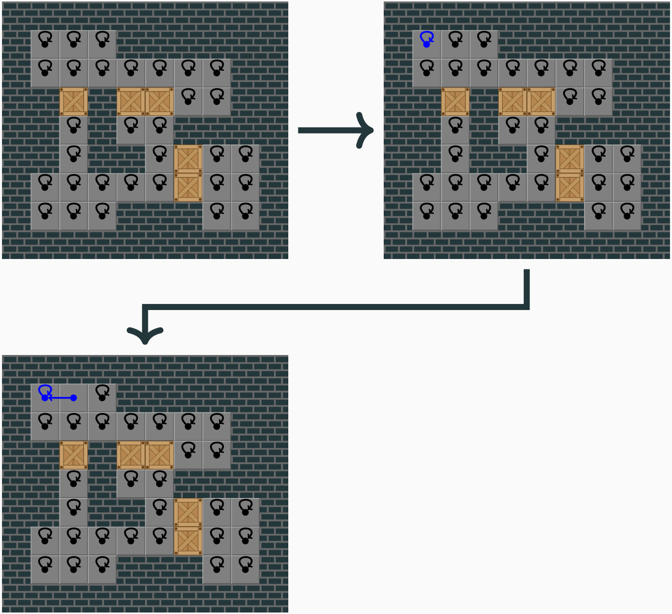
Calcul des *corrals* en $\mathcal{O}(wh)$



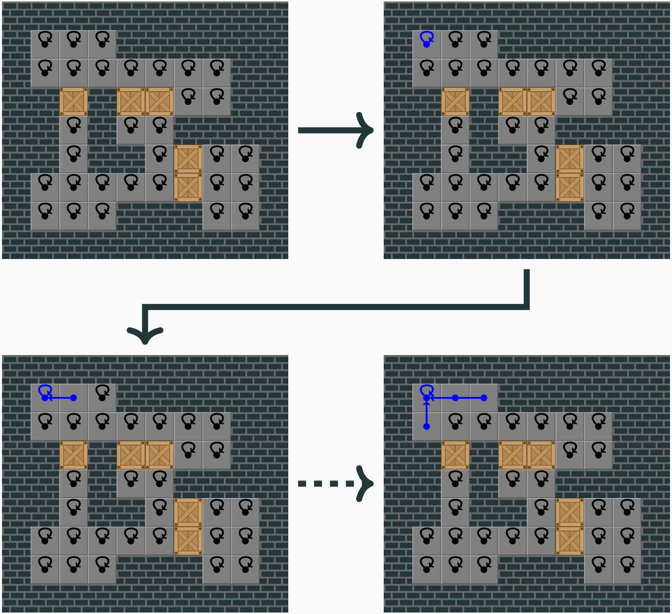
Calcul des *corrals* en $\mathcal{O}(wh)$



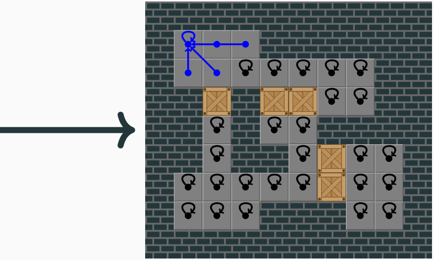
Calcul des *corrals* en $\mathcal{O}(wh)$



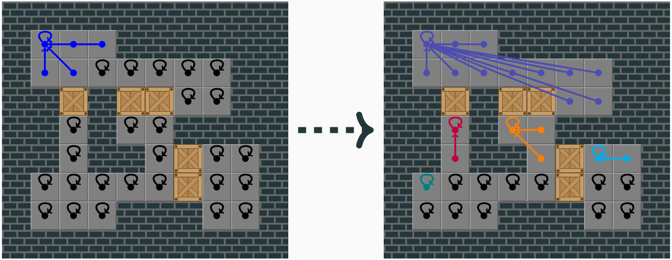
Calcul des *corrals* en $\mathcal{O}(wh)$



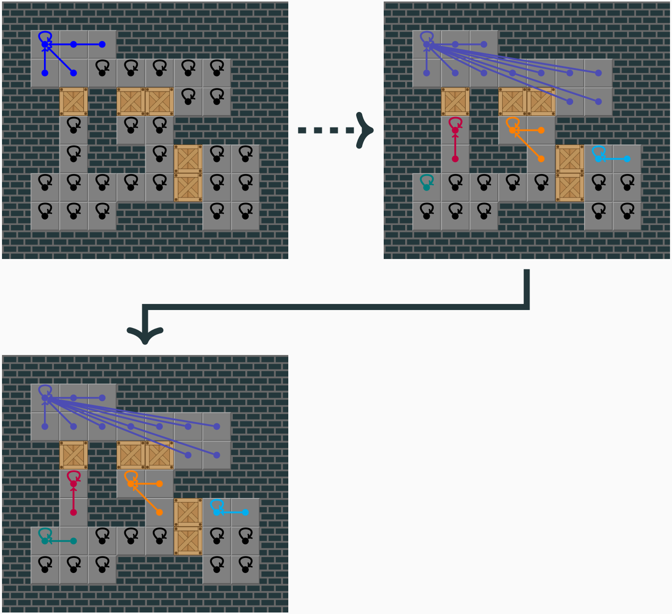
Calcul des *corrals* en $\mathcal{O}(wh)$



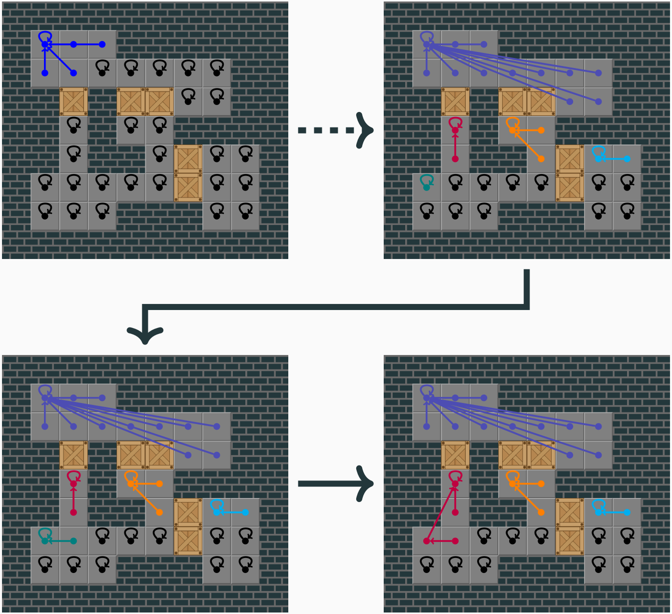
Calcul des *corrals* en $\mathcal{O}(wh)$



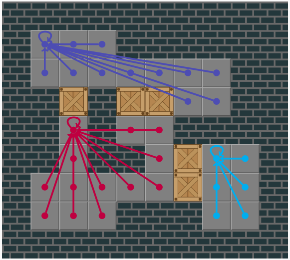
Calcul des *corrals* en $\mathcal{O}(wh)$



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

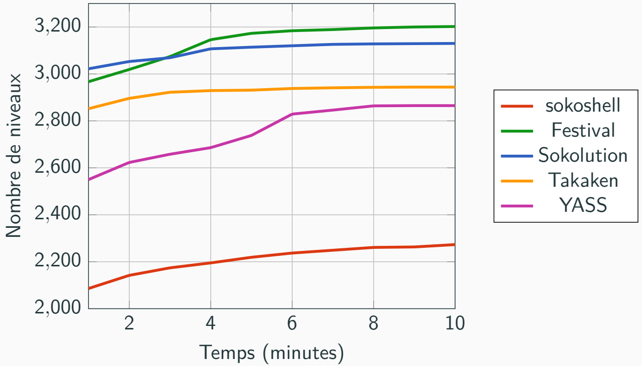
Statistiques par Matthias Meger et Brian Damgaard

Statistiques

Temps moyen passé par niveaux

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

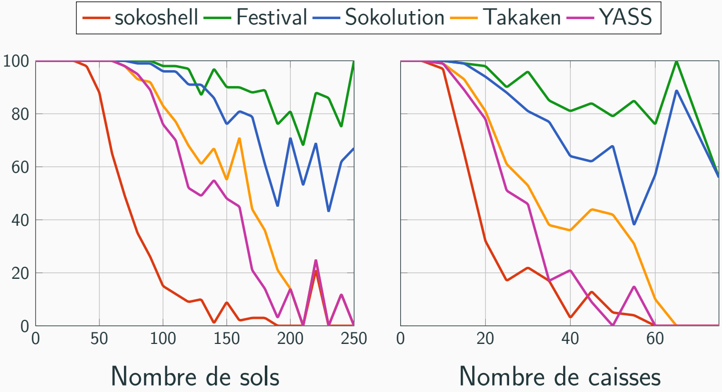
Nombre de niveaux résolus (cumulés) en fonction du temps



Statistiques par Matthias Meger et Brian Damgaard

Statistiques

Pourcentage de niveaux résolus selon la composition des niveaux



Statistiques par Matthias Meger et Brian Damgaard

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	
Dead tiles	$\mathcal{O}((wh)^2)$
Détection des tunnels	$\mathcal{O}((wh)^2)$
Propriété *oneway* des tunnels	$\mathcal{O}(twh)$
Détection des salles	$\mathcal{O}((wh)^2)$
Packing order	$\mathcal{O}(rcwh)$
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	
Freeze deadlocks	$\mathcal{O}(c)$
Détection des *corrals*	$\mathcal{O}(wh)$
PI-*corral deadlocks*	Exponentielle
Table de *deadlocks*	$\mathcal{O}(1)$
Recherche des états enfants	$\mathcal{O}(crwh)$
Ajout des états enfants (A*)	$\mathcal{O}((wh)^2 + \log N)$
Ajout des états enfants (fess0)	$\mathcal{O}(c + (wh)^2 + \log N)$