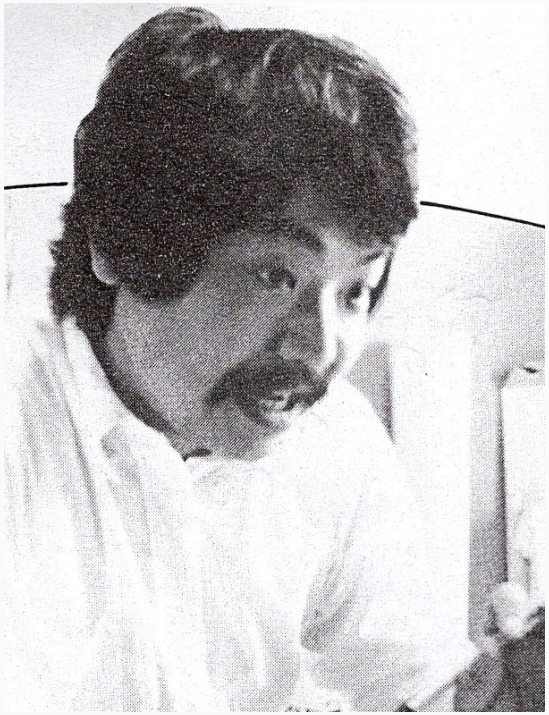
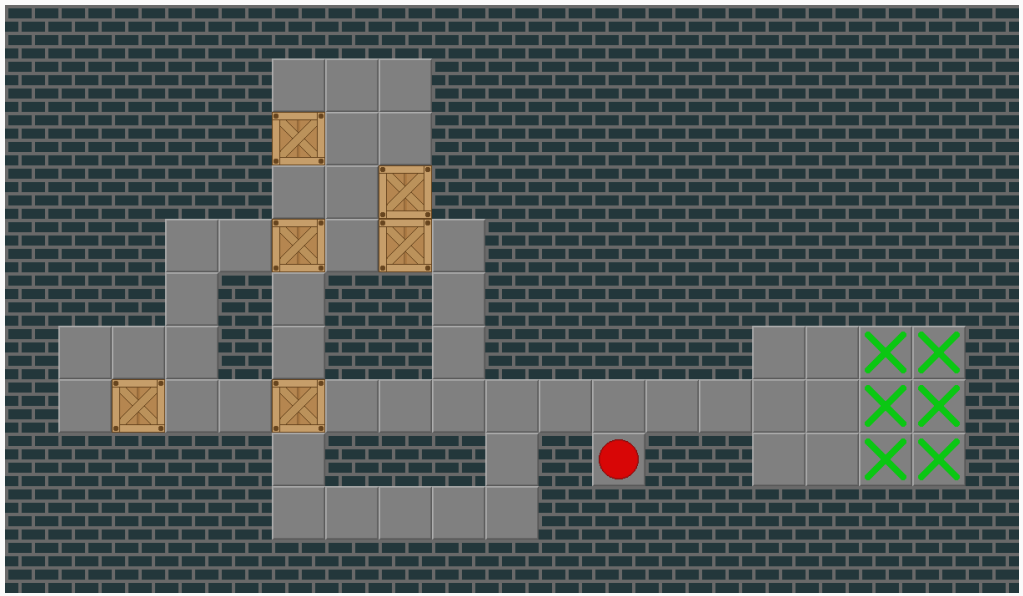
Résolution de niveaux du Sokoban

Le jeu du Sokoban



https://shmuplations.com/wp-content/uploads/2022/03/thinkingrabbit04.jpg

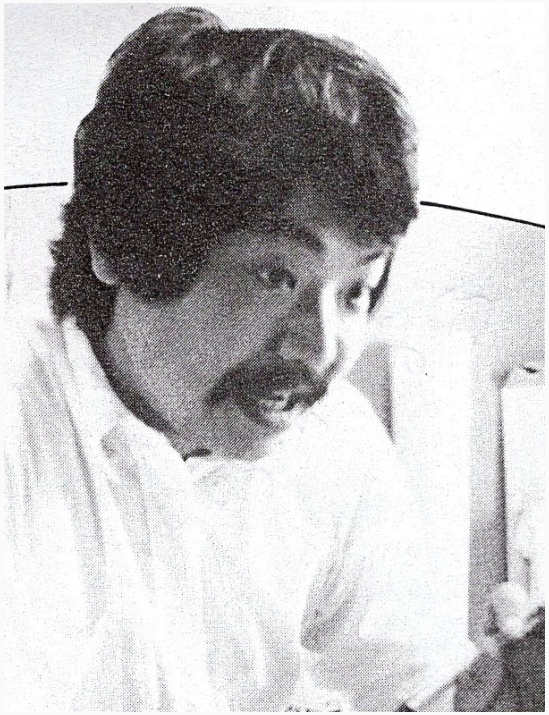
Hiroyuki Imabayashi



XSokoban 1

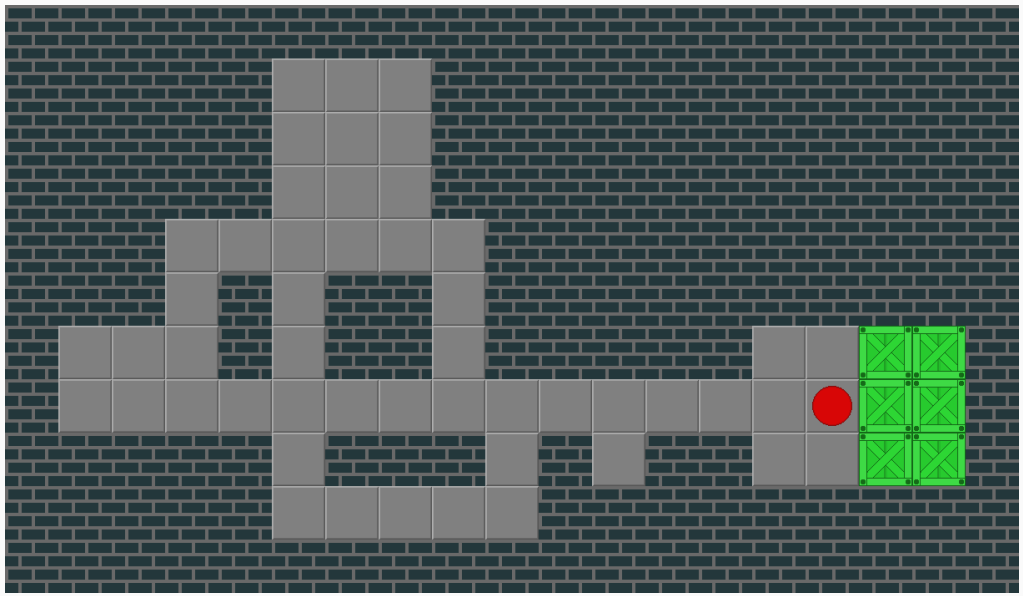
Problème **PSPACE-complet**

Le jeu du Sokoban



https://shmuplations.com/wp-content/uploads/2022/03/thinkingrabbit04.jpg

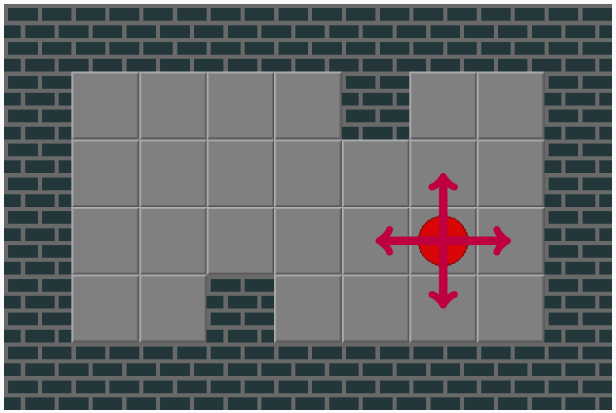
Hiroyuki Imabayashi

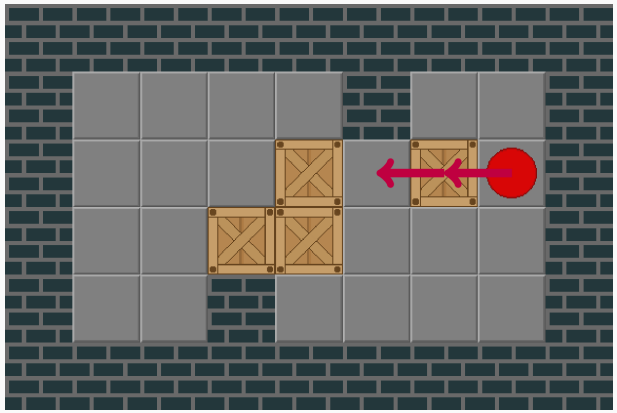


XSokoban 1 résolu

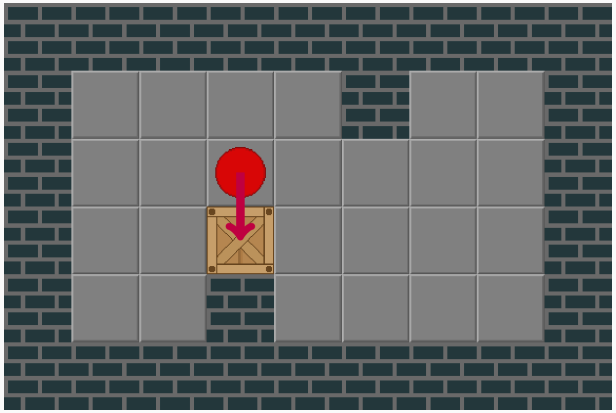
Problème **PSPACE-complet**

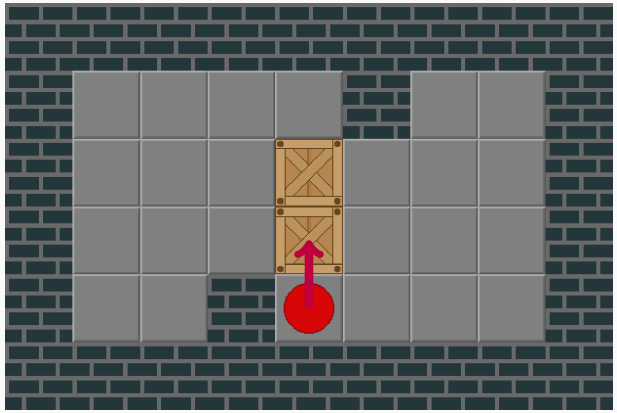
Règles





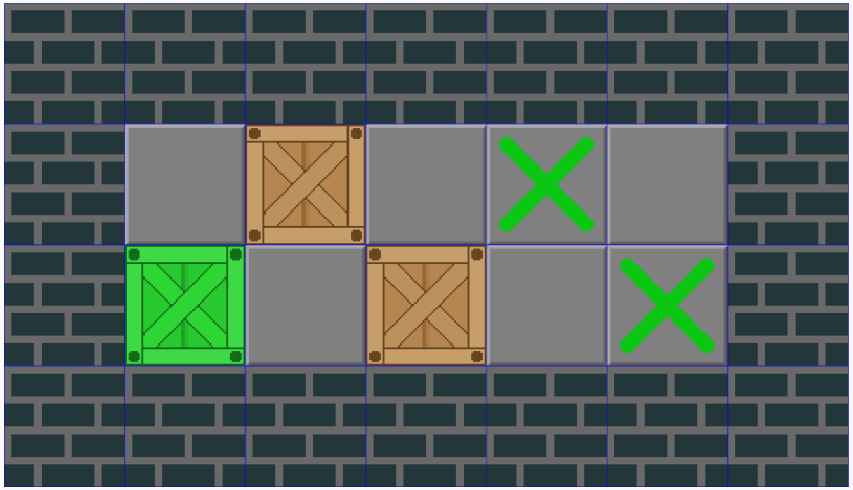
Déplacements autorisés

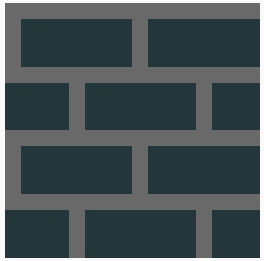




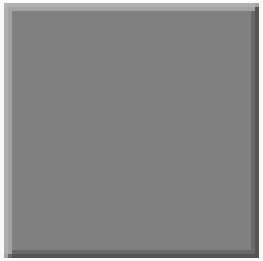
Déplacements interdits

Tuiles

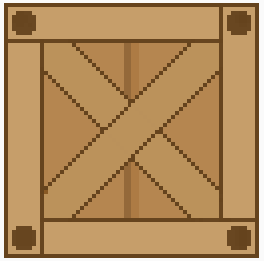




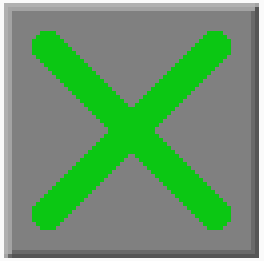
Mur



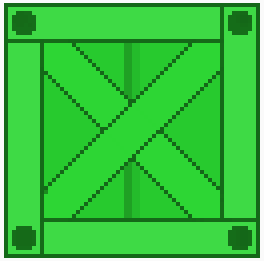
Sol



Caisse



Cible



Caisse sur une cible

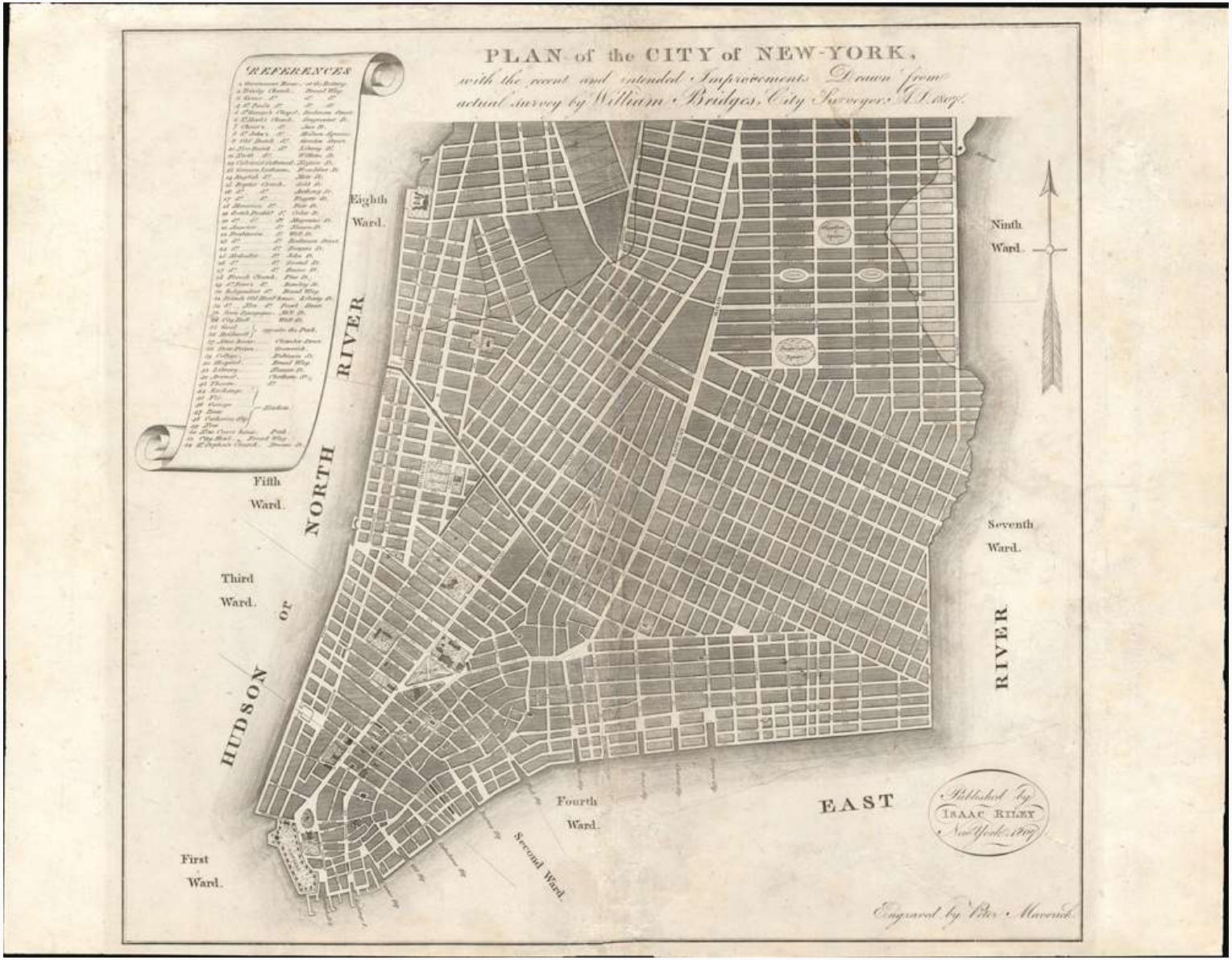
Quelles stratégies adopter pour trouver une solution le plus rapidement possible à un niveau de Sokoban ?

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

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`

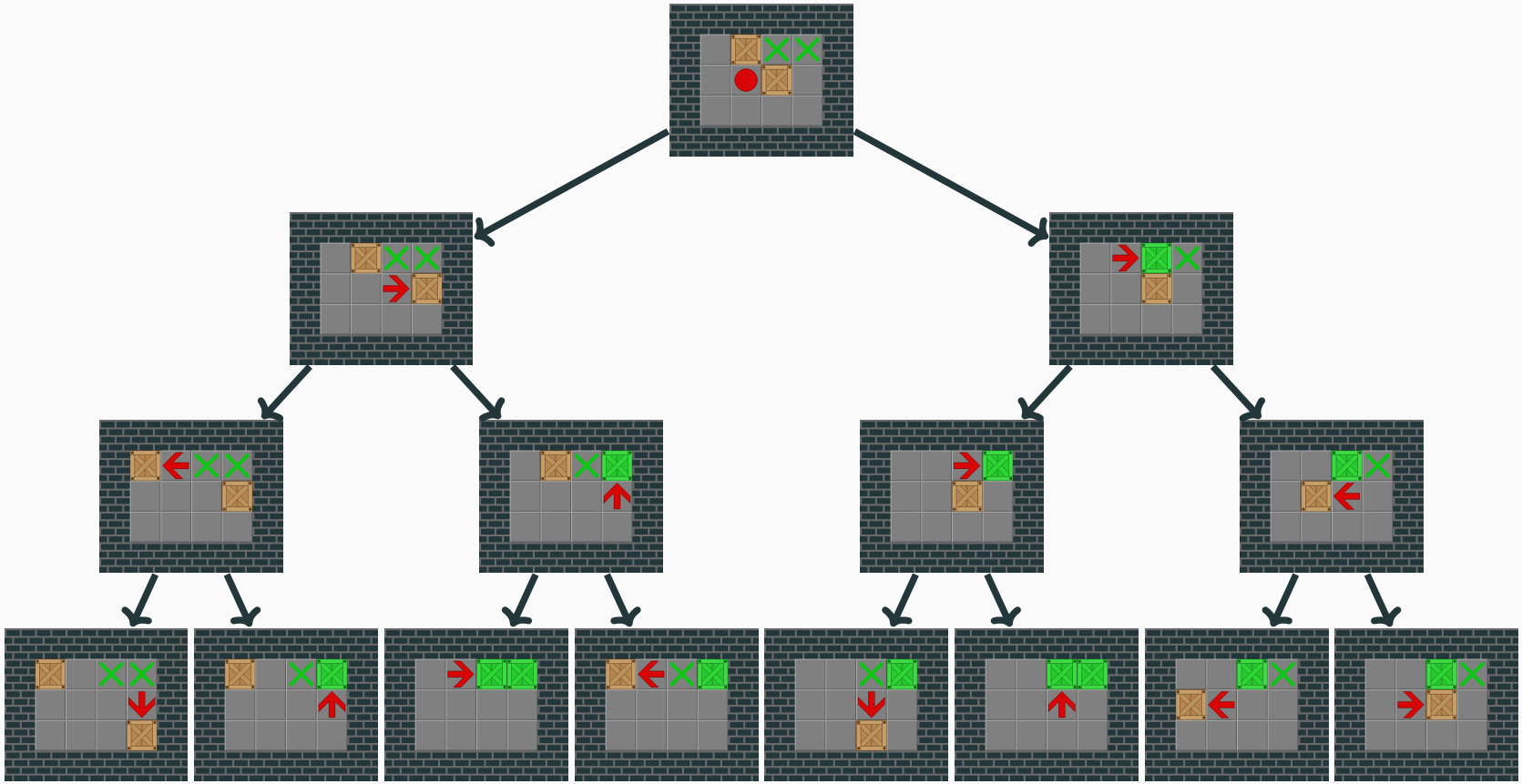
Lien avec le thème de l'année



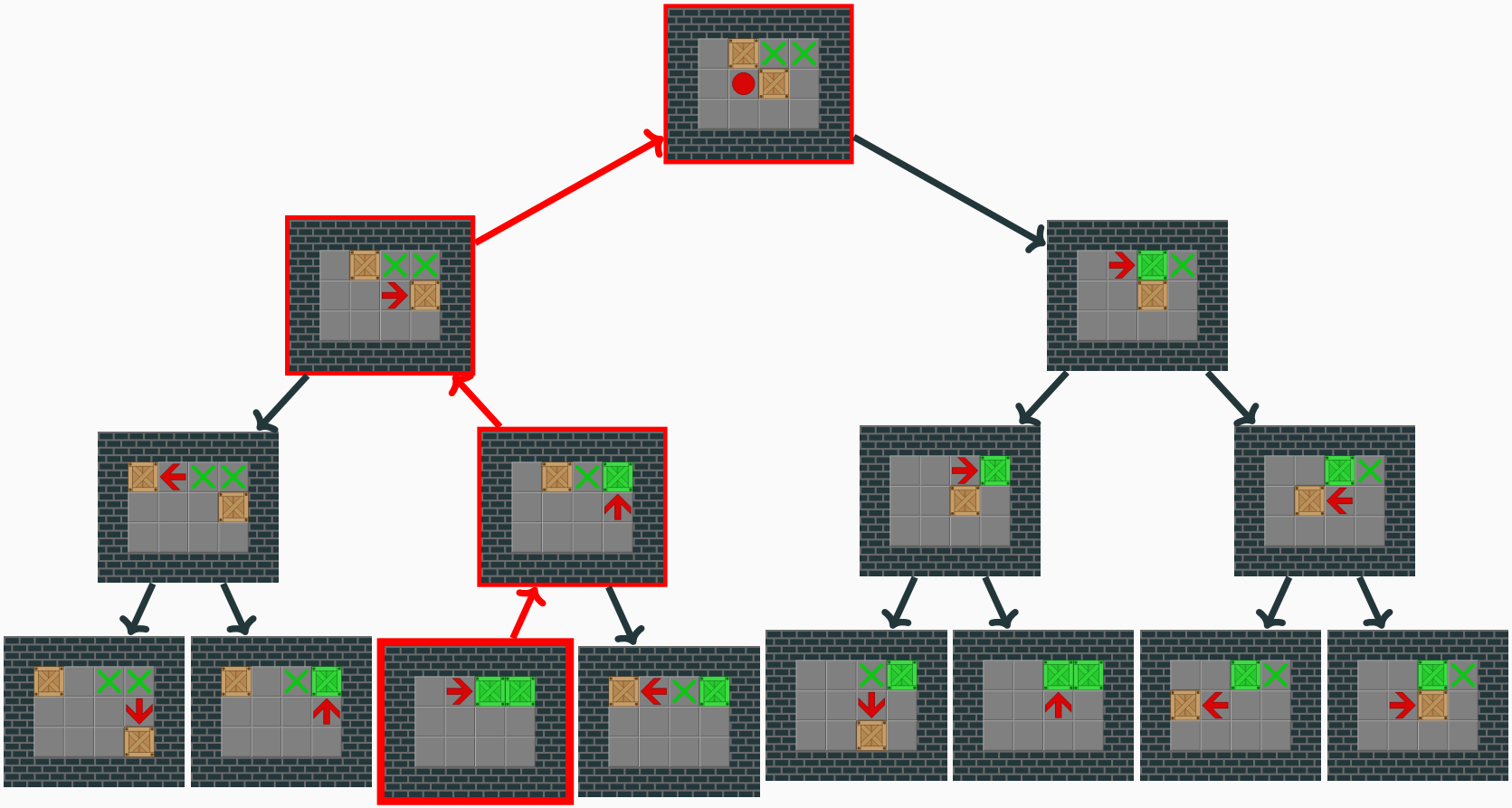
Source : https://www.geographicus.com/mm5/graphics/00000001/L/NewYork-bridgesmaverick-1807.jpg

Principe de résolution

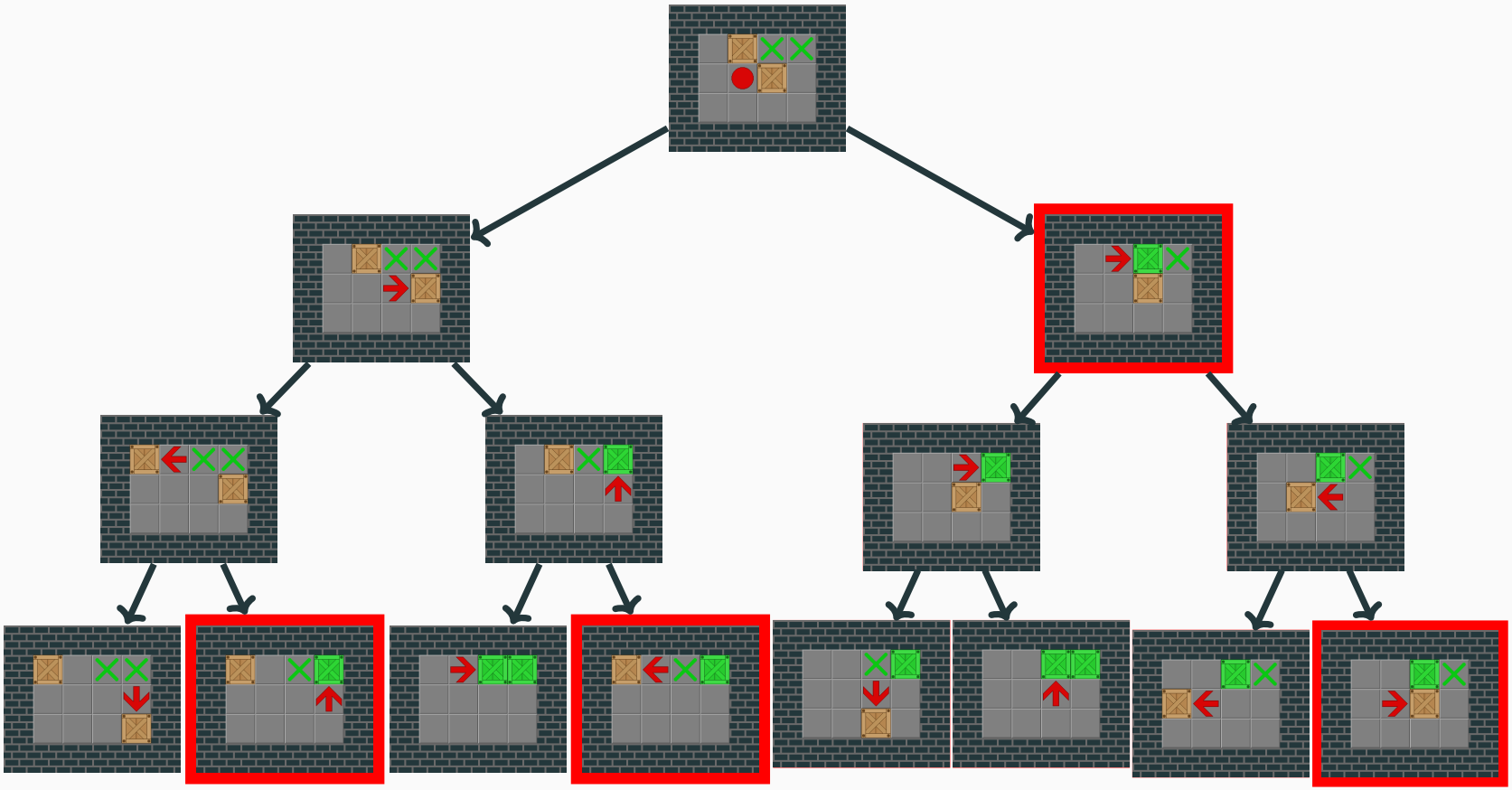
Arbre des états



Arbre des états



Arbre des états



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

Initialisation : un couple de valeurs aléatoires pour chaque case

$$T = \begin{array}{c} \begin{array}{cc} \text{caisse} & \text{joueur} \end{array} \\ \begin{pmatrix} 6357 & 1024 \\ -1378 & 42 \\ \vdots & \vdots \\ 93268 & -278 \end{pmatrix} \end{array} \begin{array}{c} \text{case} \\ 0 \\ 1 \\ \vdots \\ wh - 1 \end{array}$$

Propriétés du **XOR** :

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

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** : $c_i \to c_i', p \to p'$

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

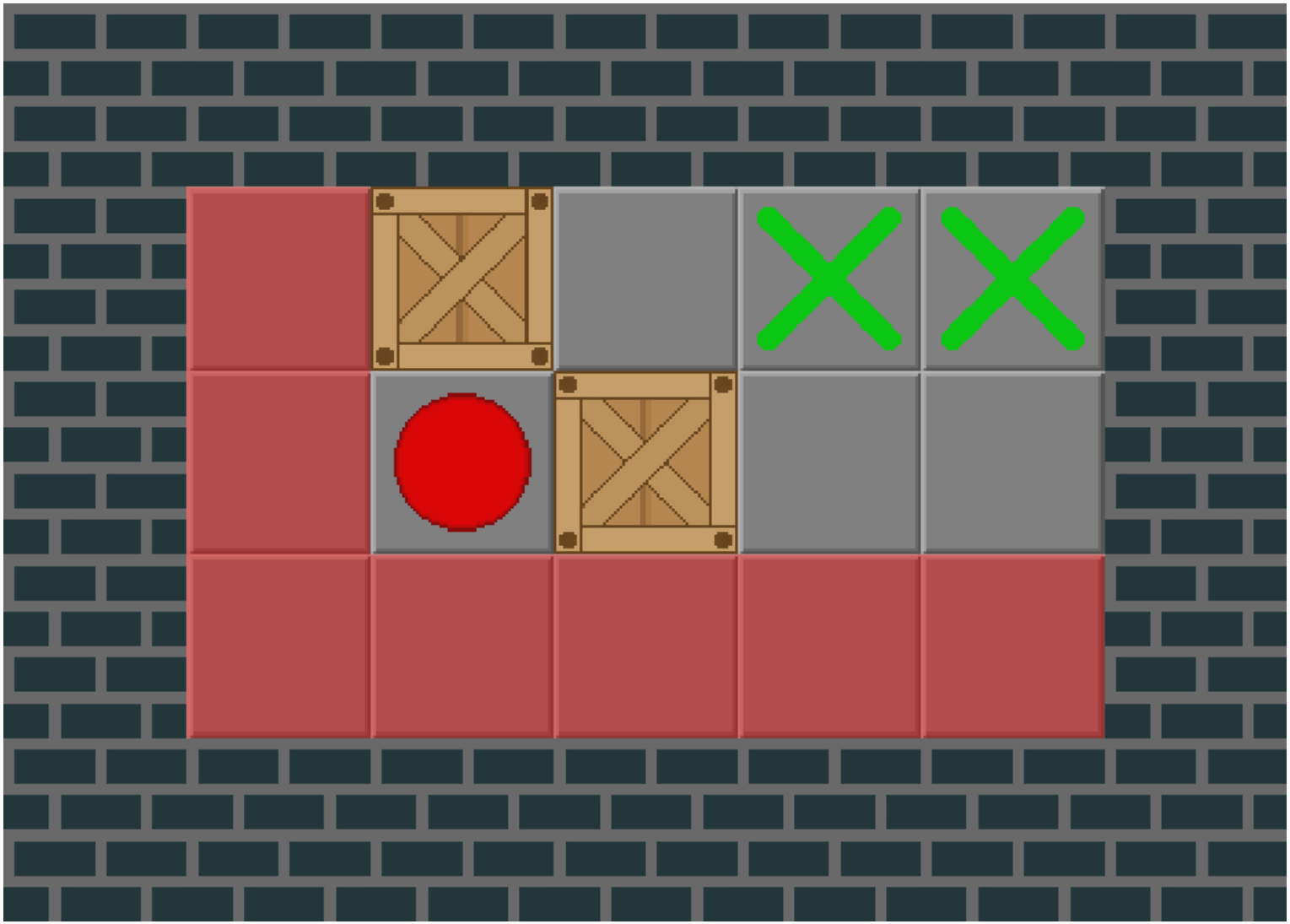
$$\boxed{\text{en } \mathcal{O}(1)}$$

Réduction de l'espace de recherche

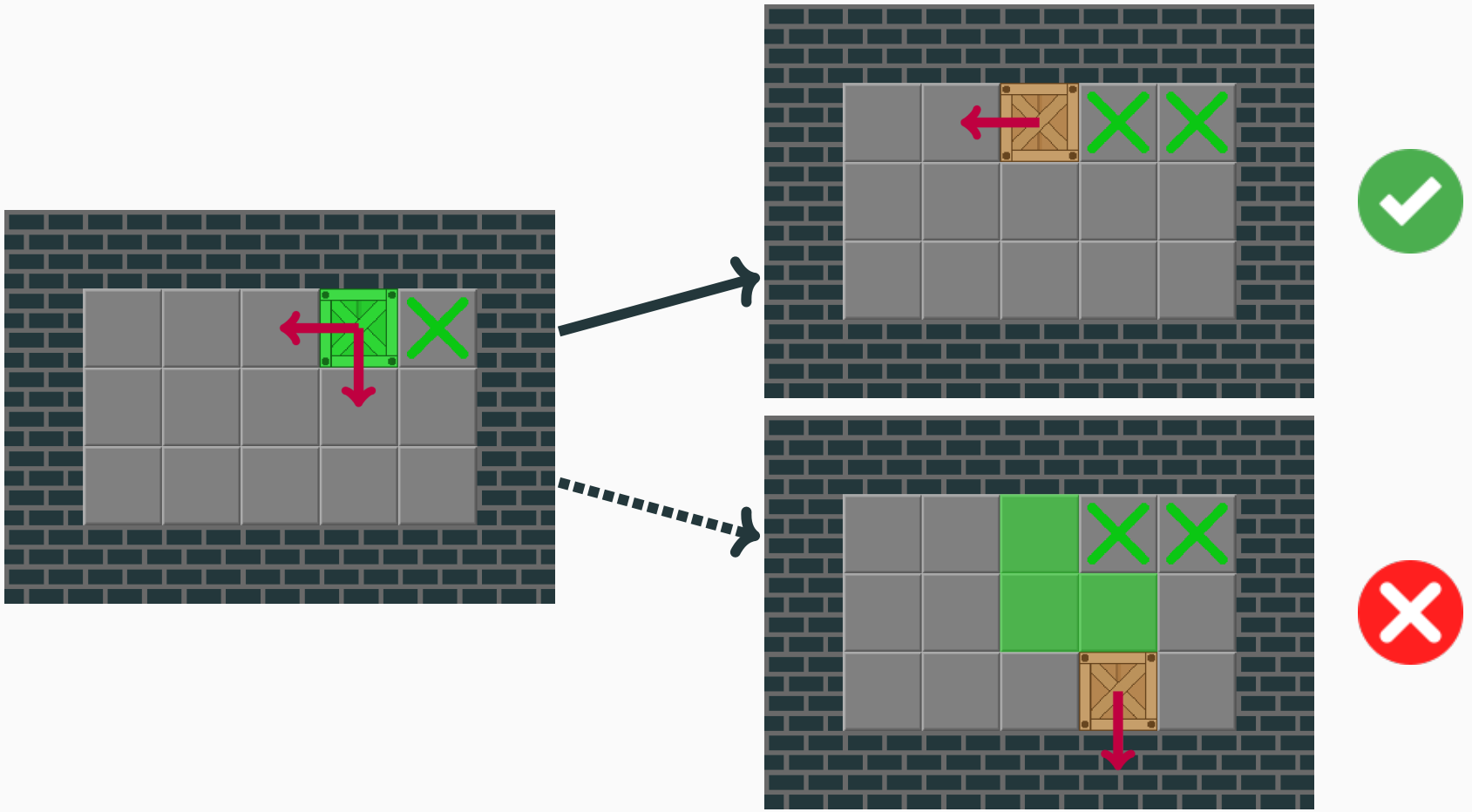
Réduction de l'espace de recherche

Analyse statique

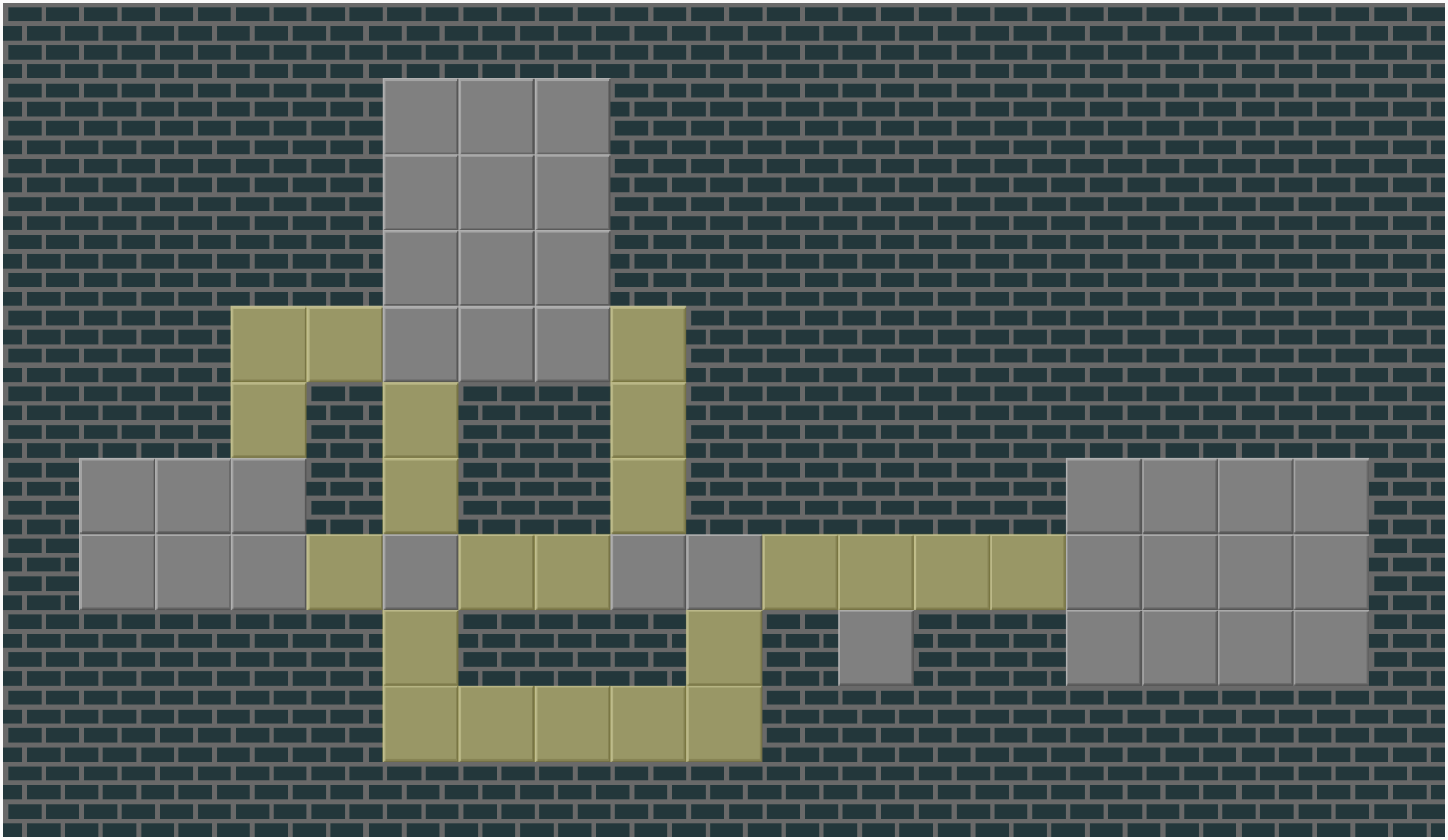
Détection des positions mortes *(dead positions)*



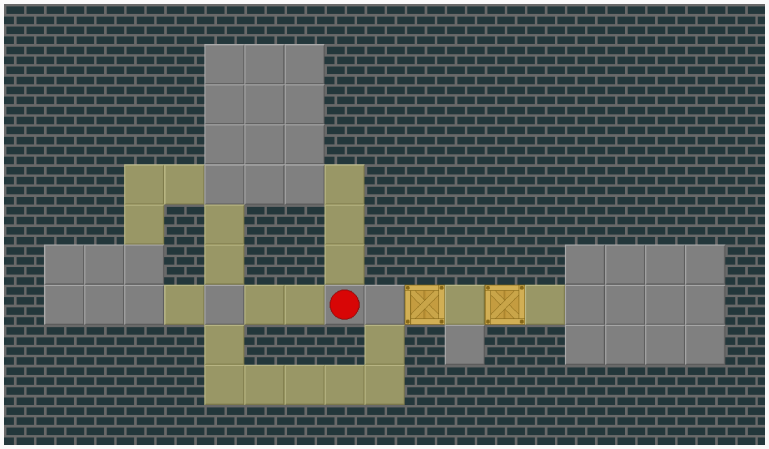
Détection des positions mortes *(dead positions)*



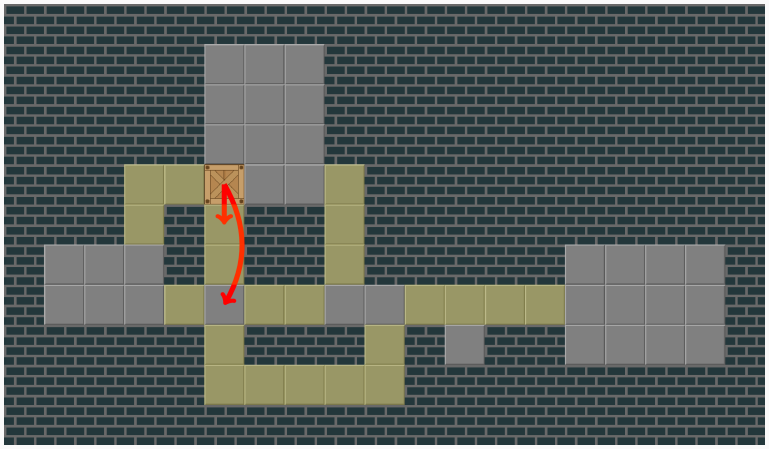
Tunnels



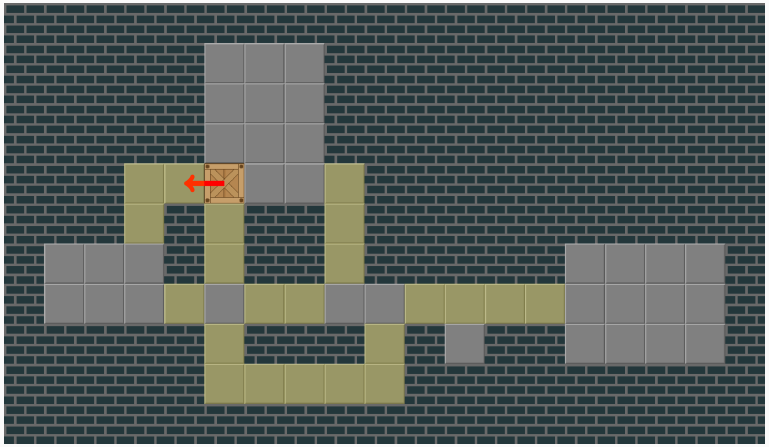
Tunnels



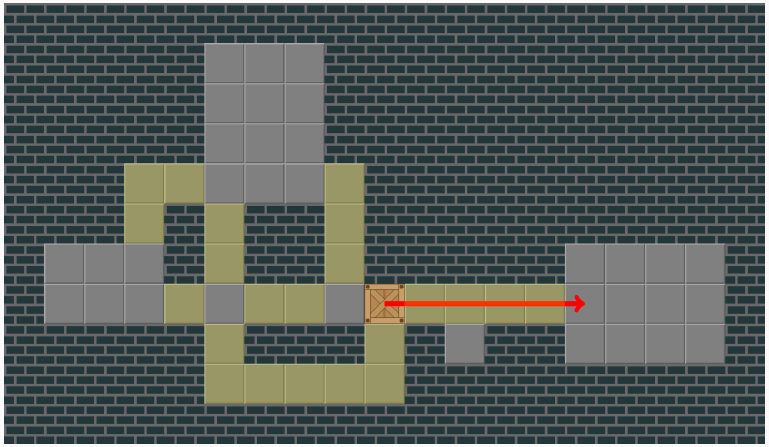
Au plus une caisse



Deux états fils



Coin $\Rightarrow$ un état fils

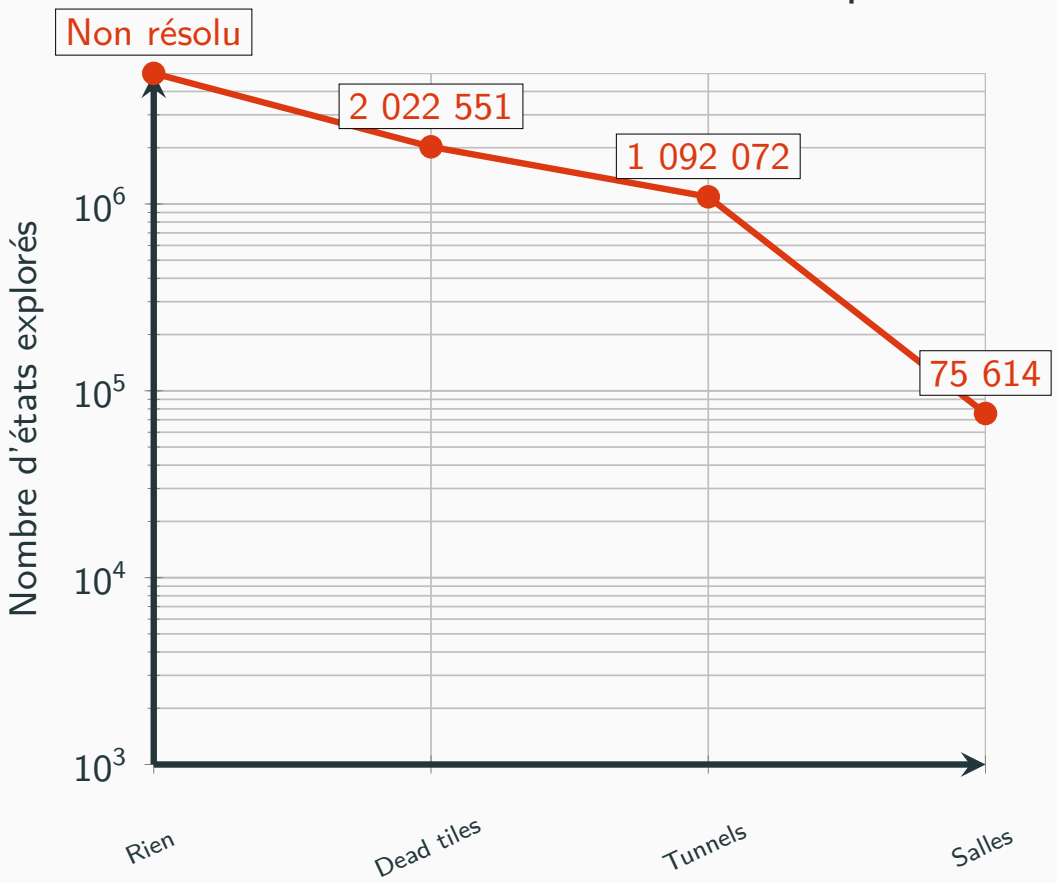


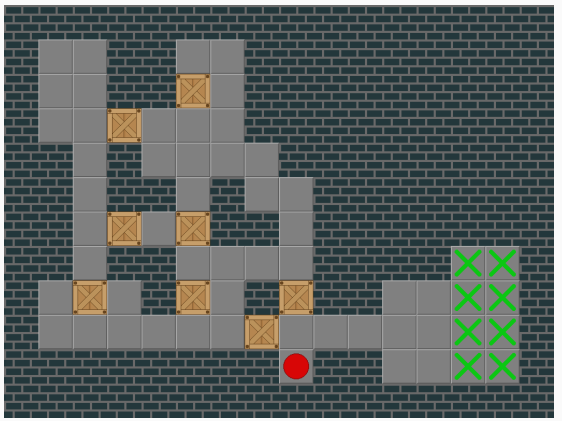
Tunnel *oneway*

Résultats intermédiaires

Niveaux résolus dans *XSokoban* : **1 / 90 (+ 1)**

Niveau 24 du pack *Boxxle* :

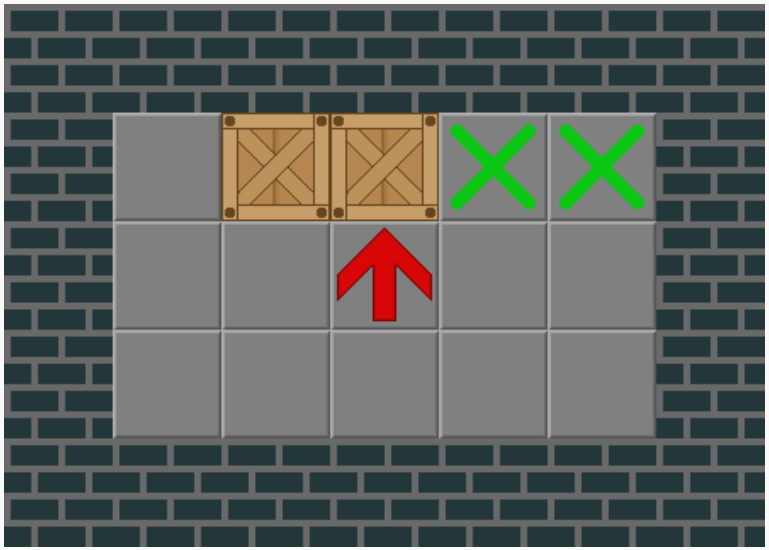


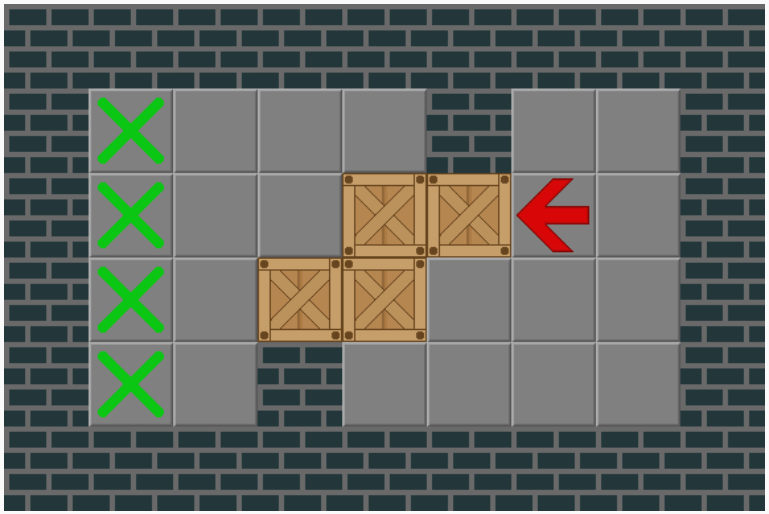


Réduction de l'espace de recherche

Analyse dynamique

Détection de *freeze deadlocks*

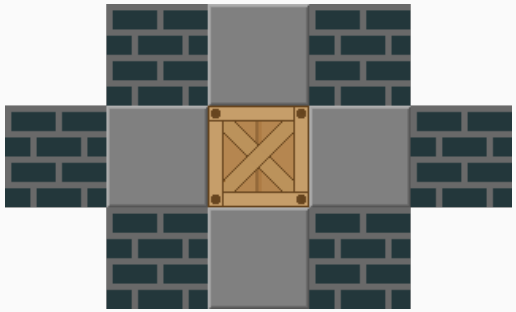




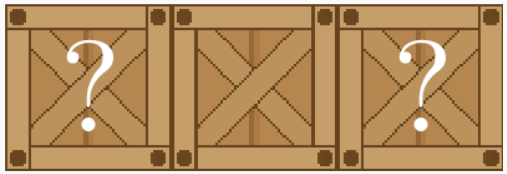
Deux *freeze deadlocks*

Détection de *freeze deadlocks*

(a) *Règle n°1*



(b) *Règle n°2*

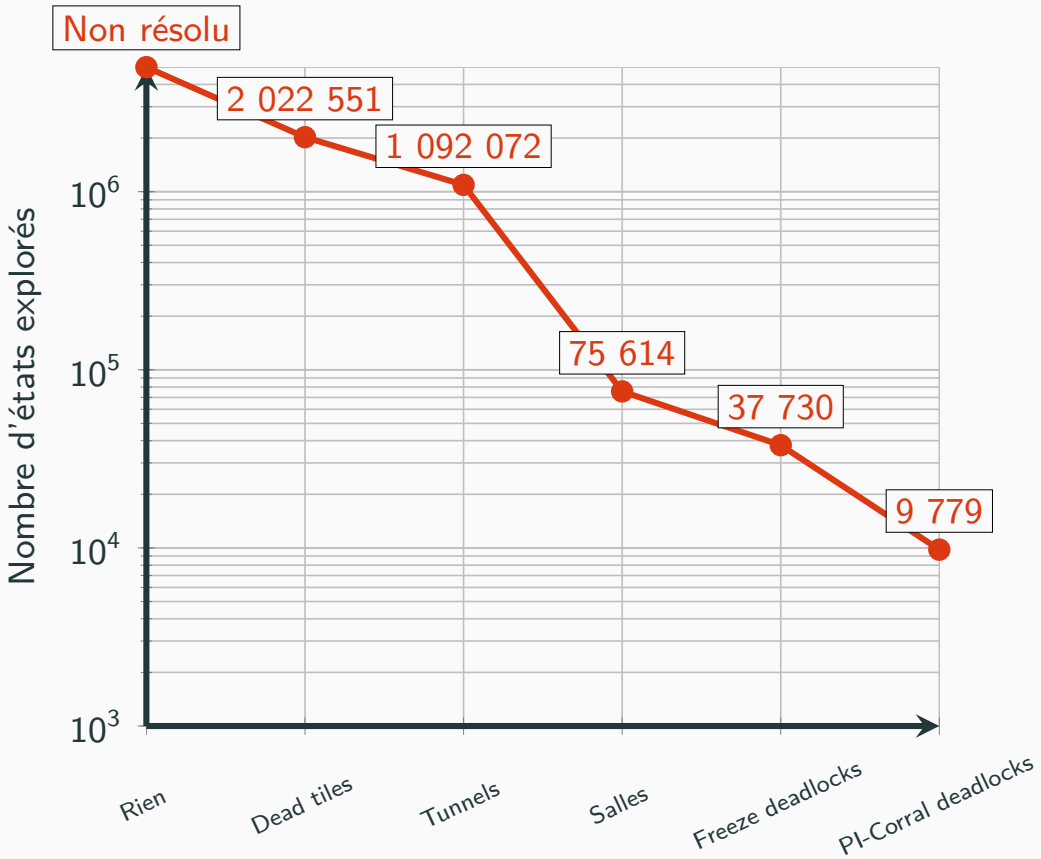


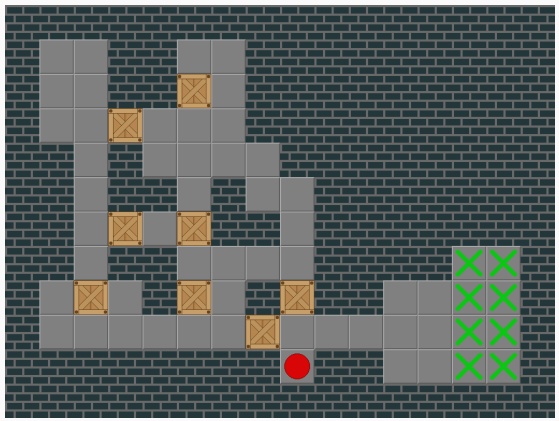
(c) *Règle n°3*

Résultats intermédiaires

Niveaux résolus dans *XSokoban* : **6 / 90 (+ 1 + 4)**

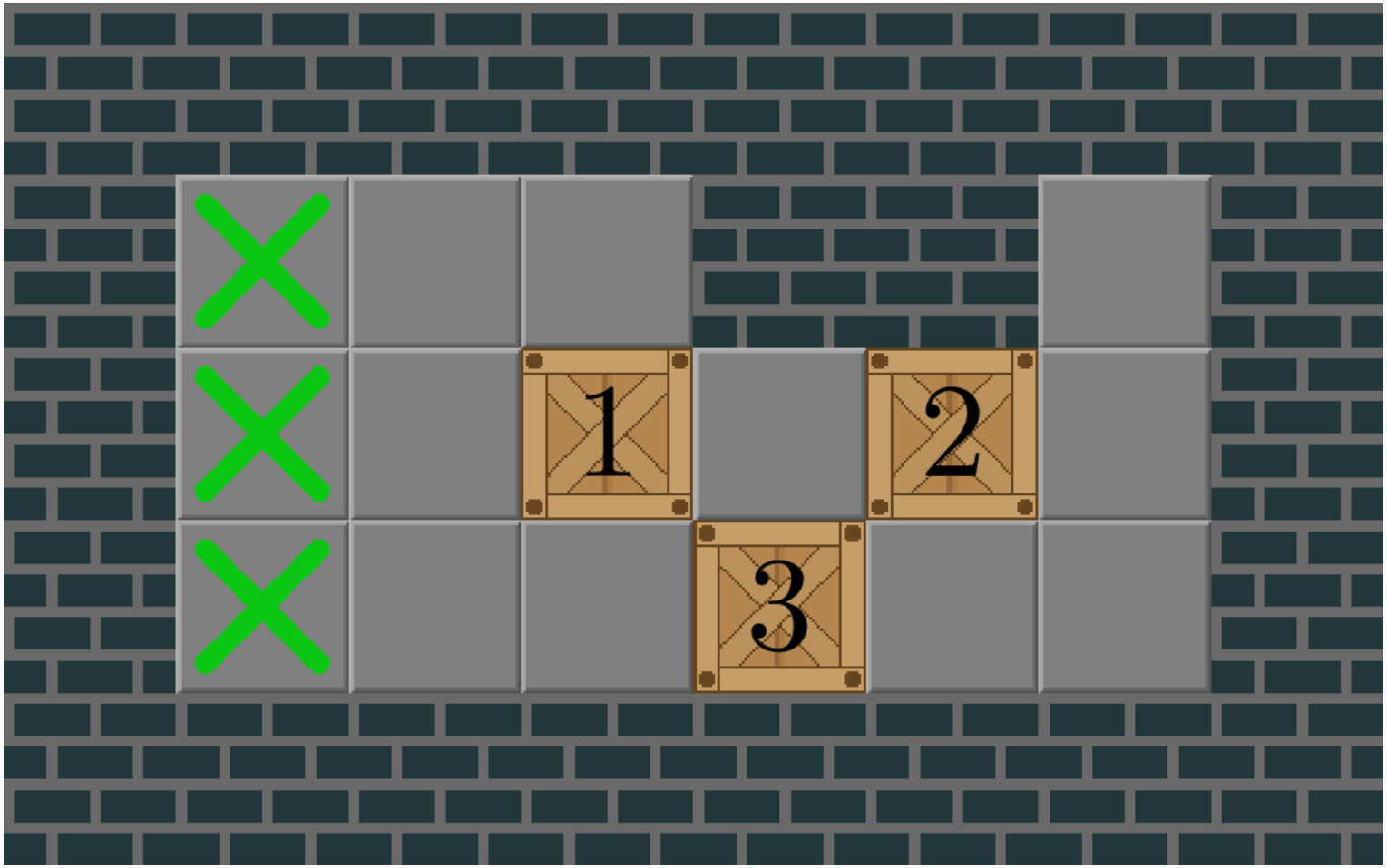
Niveau 24 du pack *Boxxle* :



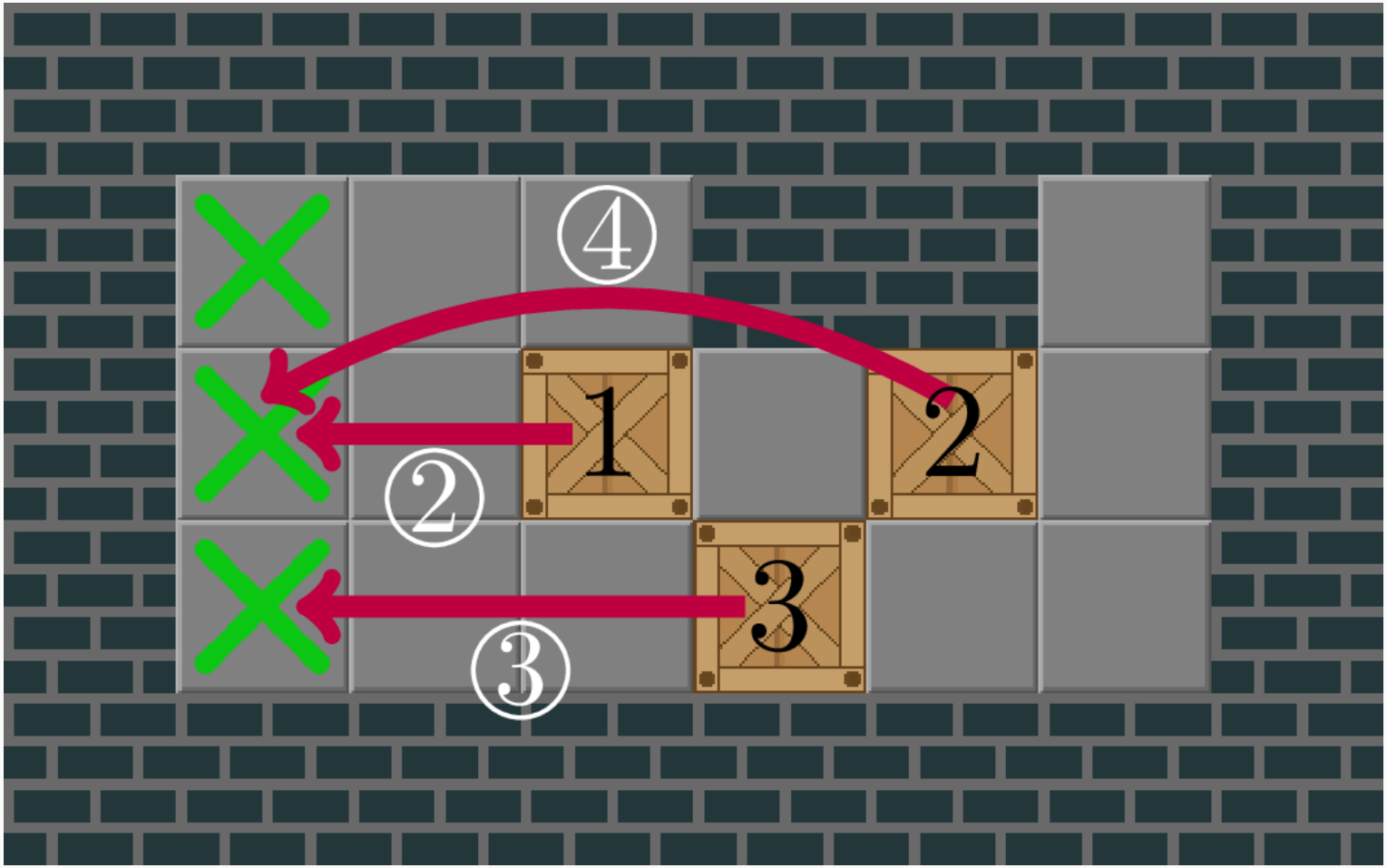


Recherche dirigée par une heuristique

Heuristique simple *(Simple Lower Bound)*

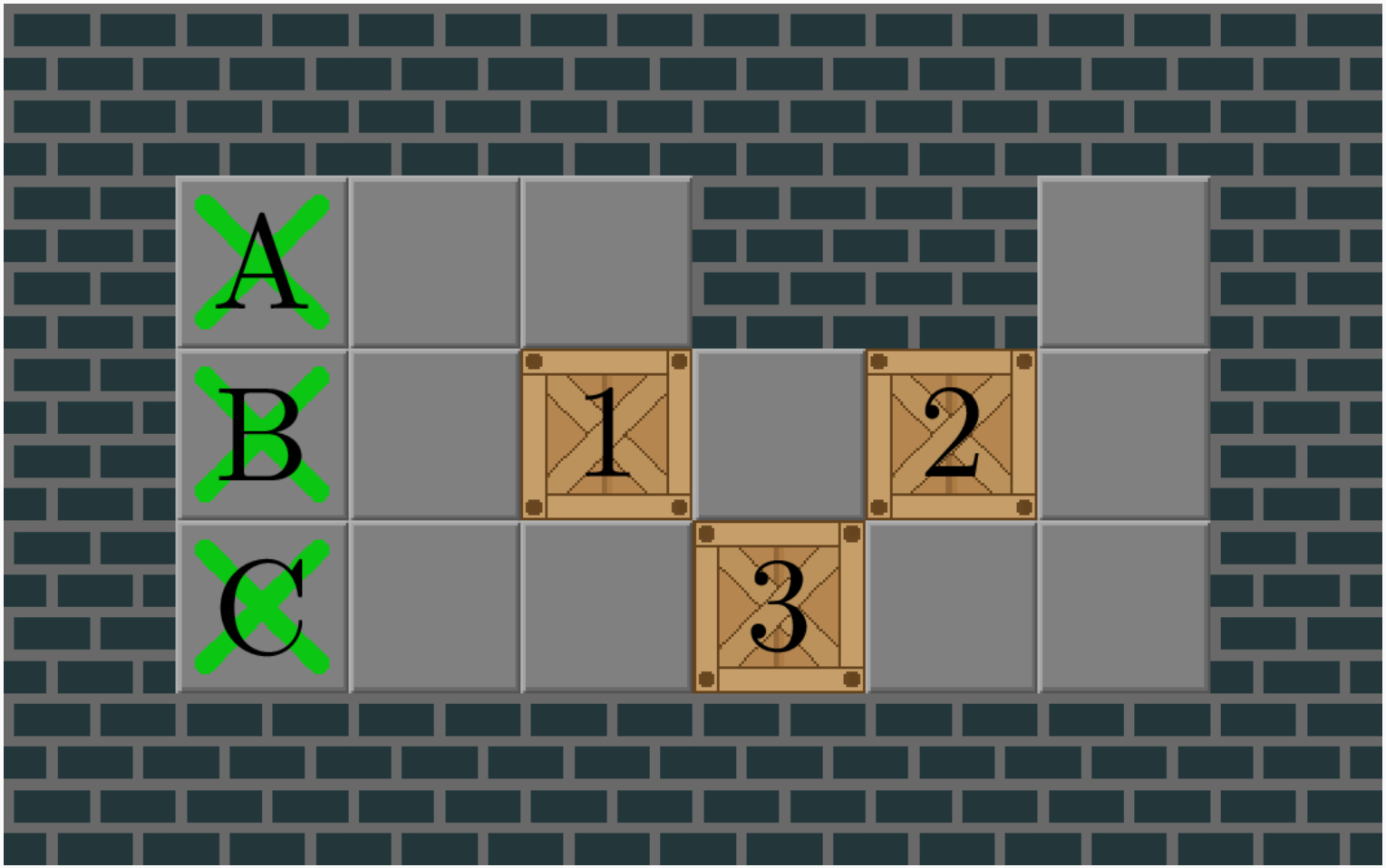


Heuristique simple *(Simple Lower Bound)*

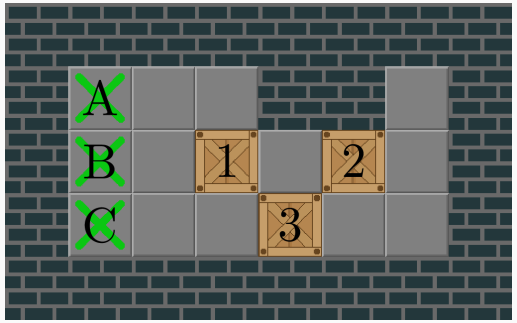


$$\boxed{2 + 4 + 3 = \mathbf{9}}$$

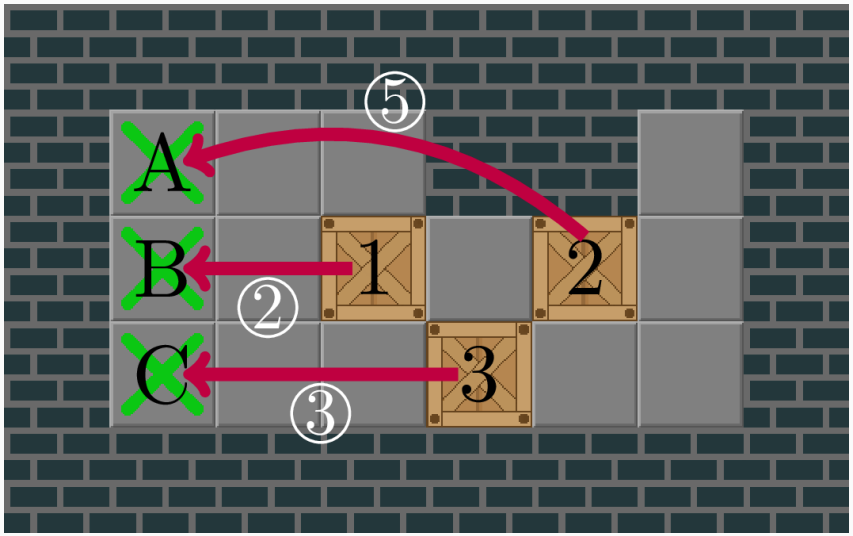
Heuristique gloutonne *(Greedy Lower Bound)*



Heuristique gloutonne *(Greedy Lower Bound)*



Caisse → Cible	Distance
1 → 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

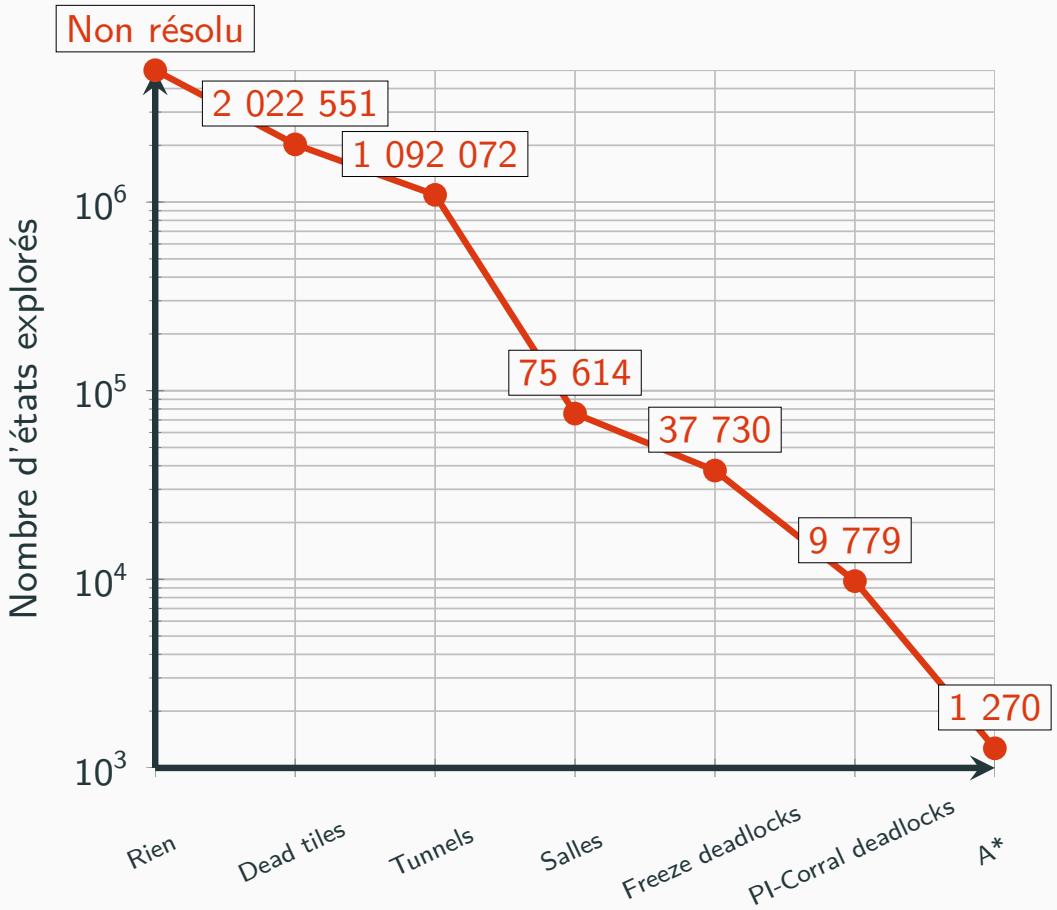


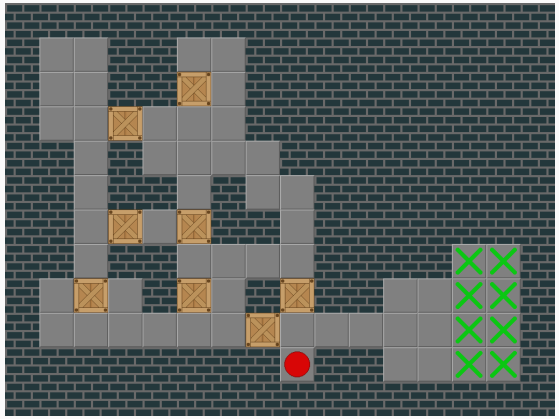
$$2 + 3 + 5 = \mathbf{10}$$

Résultats intermédiaires

Niveaux résolus dans *XSokoban* : **15 / 90 (+ 5 + 4)**

Niveau 24 du pack *Boxxle* :

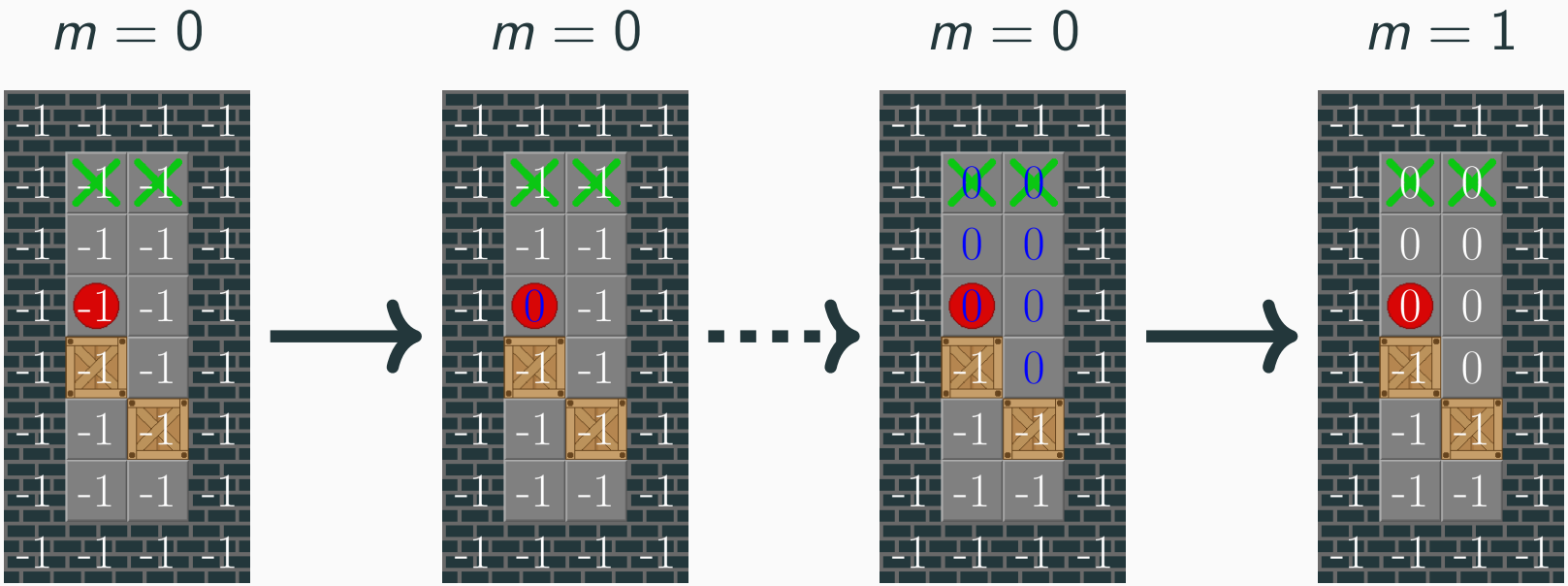




Optimisations

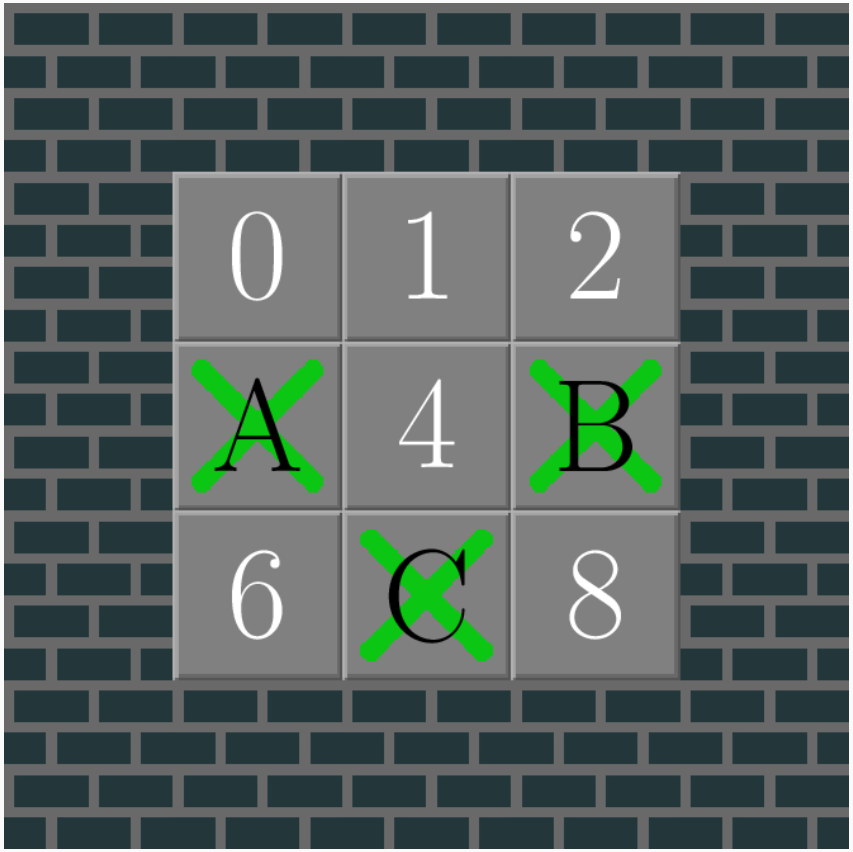
Parcours de graphes : démarquer tous les nœuds en $\mathcal{O}(1)$

nœud marqué *ssi valeur* $= m$



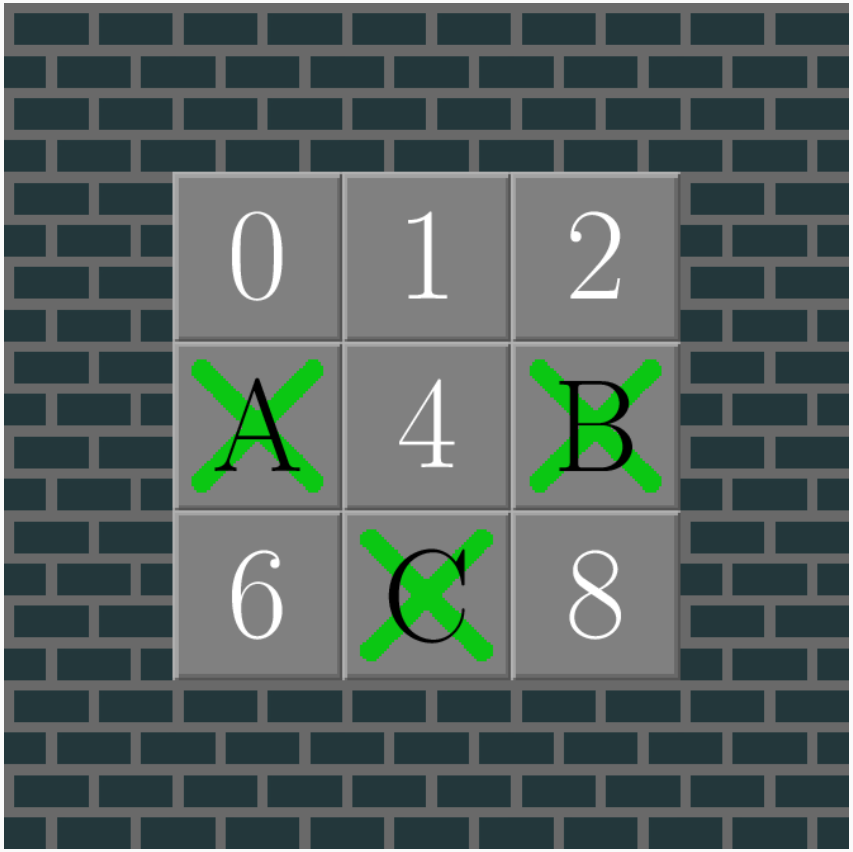
Précalcul des distances caisses-cibles

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



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/)

Conclusion

- $\approx$ 6000 lignes de code (solveur uniquement)
- Implémentation difficile (ressources disponibles plutôt théoriques)
- Première réalisation d'un solveur automatique
- Première expérience de programmation à plusieurs

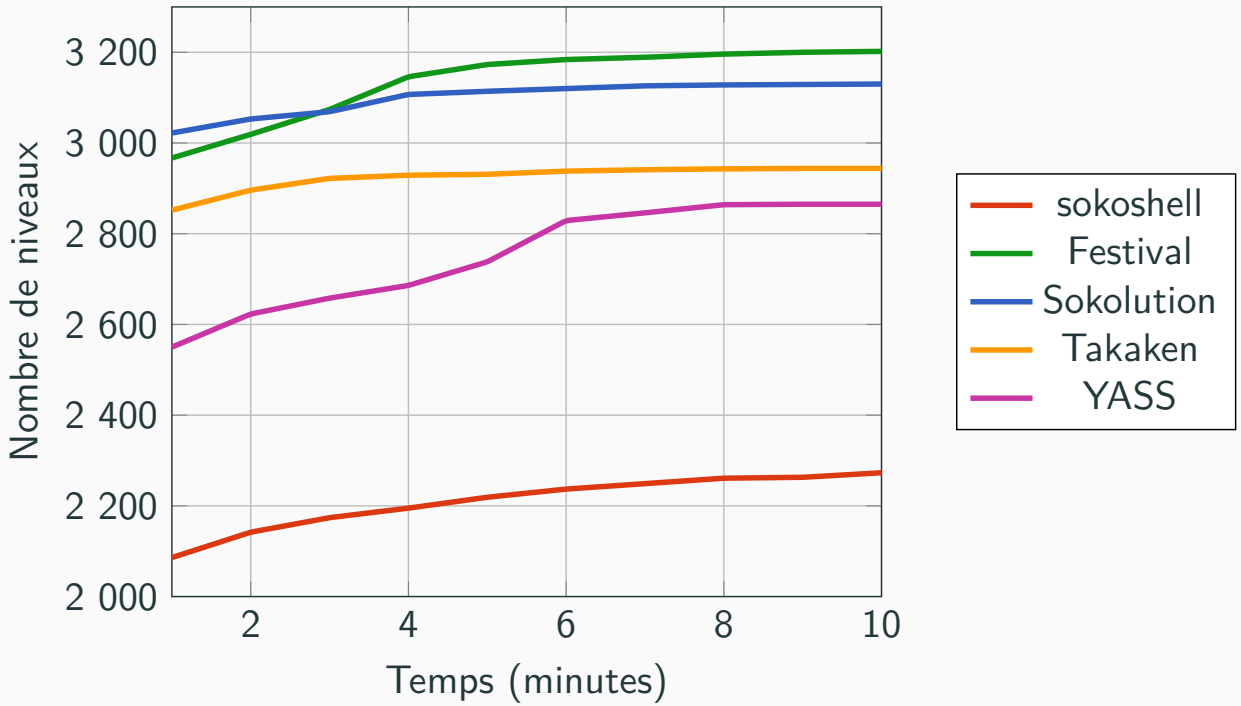
Annexe

Statistiques

Temps moyen passé par niveaux

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

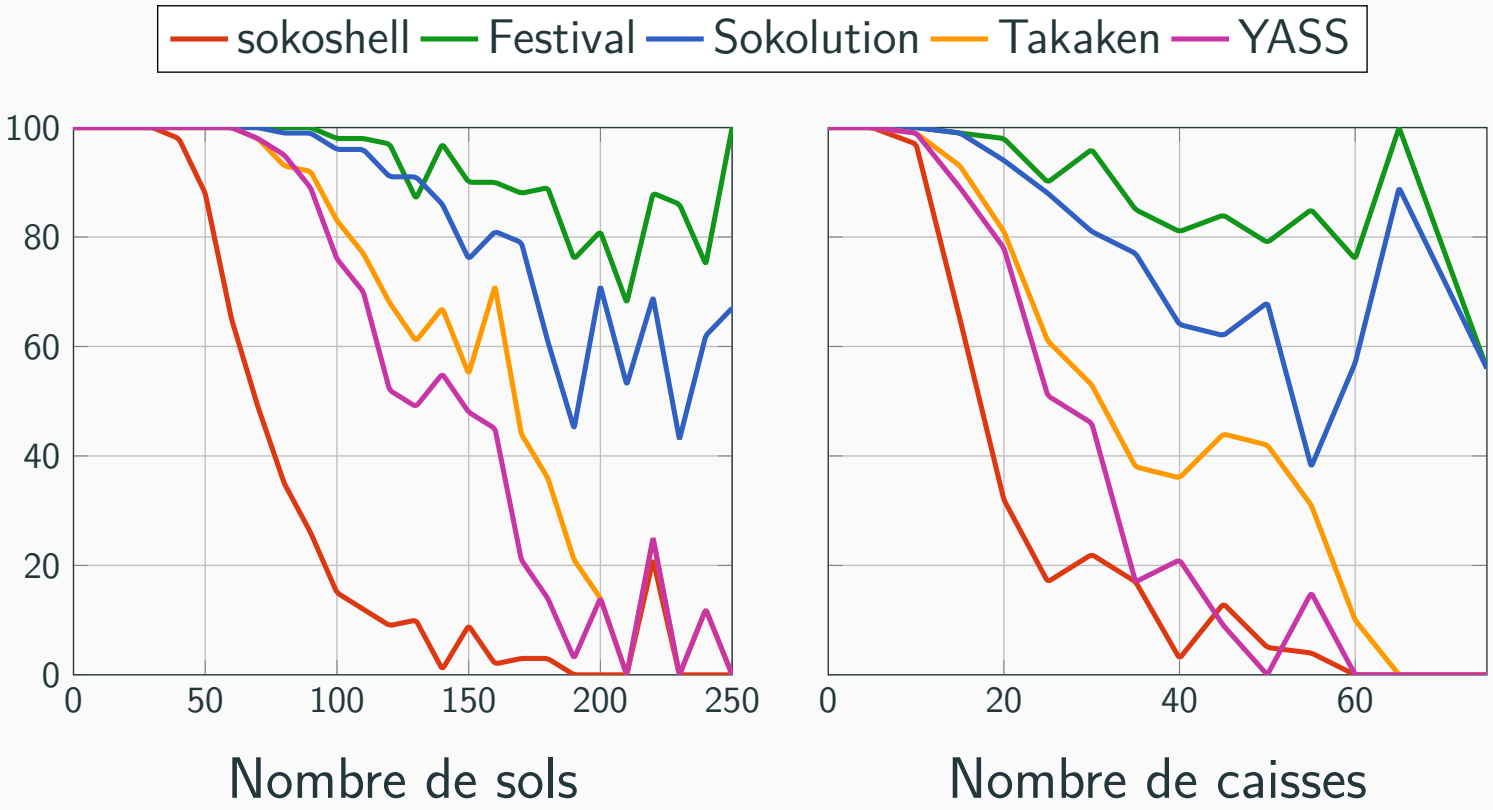
Nombre de niveaux résolus (cumulés) en fonction du temps



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

Statistiques

Pourcentage de niveaux résolus selon la composition des niveaux



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

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.

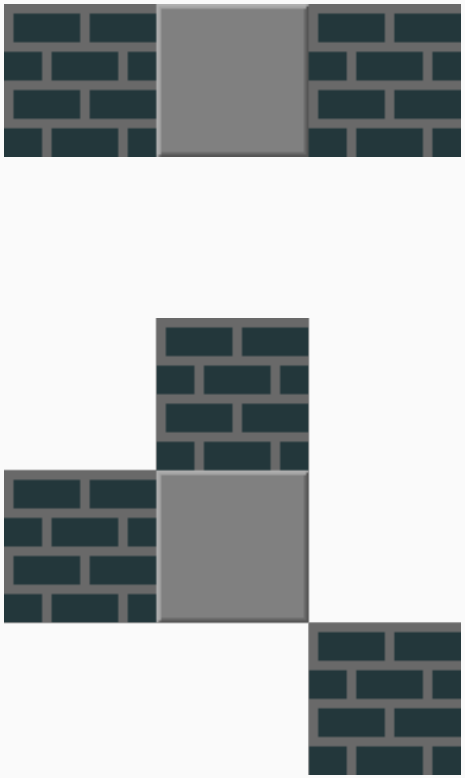
Statique	
Dead tiles	$\mathcal{O}((wh)^2)$
Détection des tunnels	$\mathcal{O}((wh)^2)$
Propriété *oneway* des tunnels	$\mathcal{O}(twh)$
Détection des salles	$\mathcal{O}((wh)^2)$
Packing order	$\mathcal{O}(rcwh)$
Précalcul des distances cibles-caisses	$\mathcal{O}(wh(Cwh + C \log C))$

Tableau des complexités - Dynamique

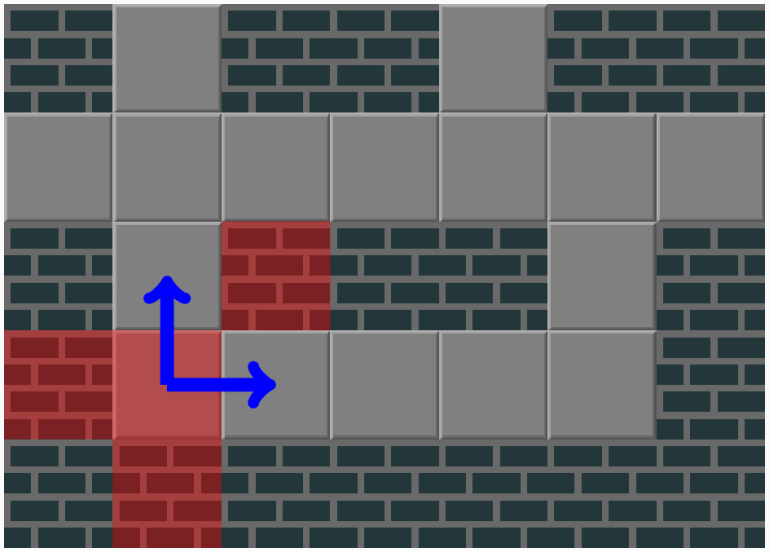
c nombre de caisses, C nombre de cibles, w longueur et h largeur du niveau, t nombre de tunnels, r nombre de salles, N nombre d'états dans la liste des états à explorer.

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)	$\mathcal{O}(c + (wh)^2 + \log N)$

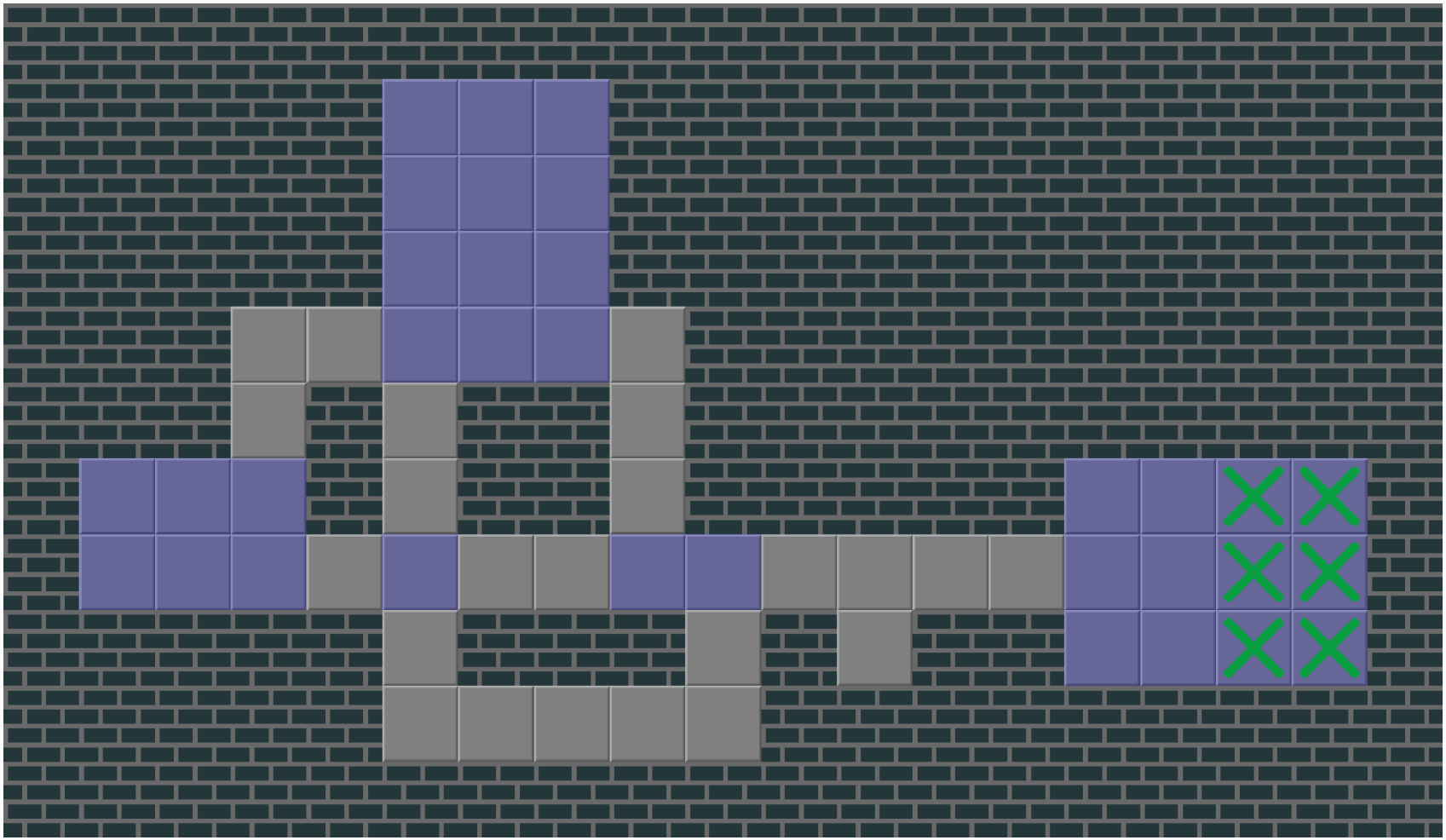
Détection de tunnels



Composition d'un tunnel



Salles et ordre de rangement *(packing order)*



Salles et ordre de rangement *(packing order)*

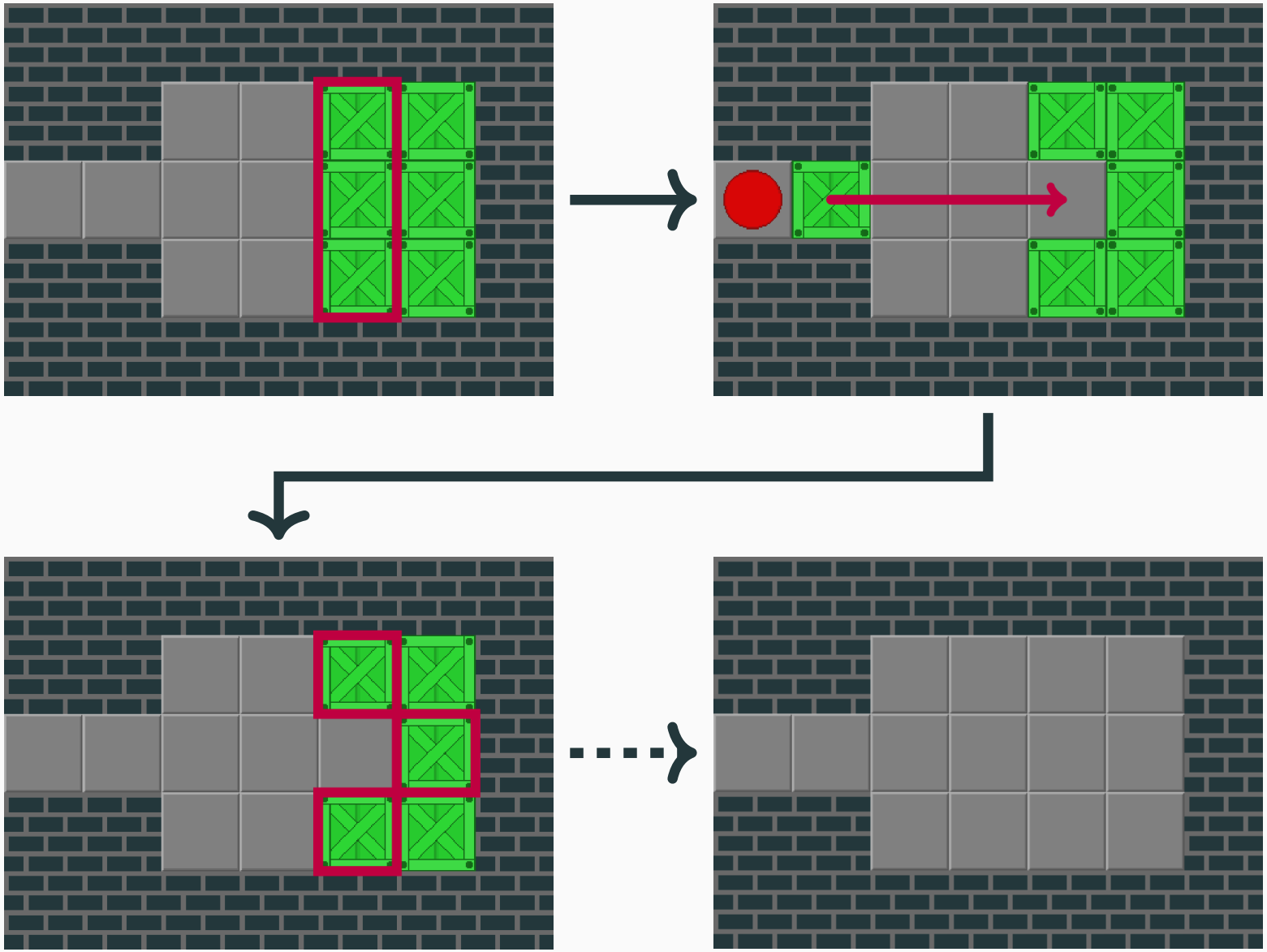
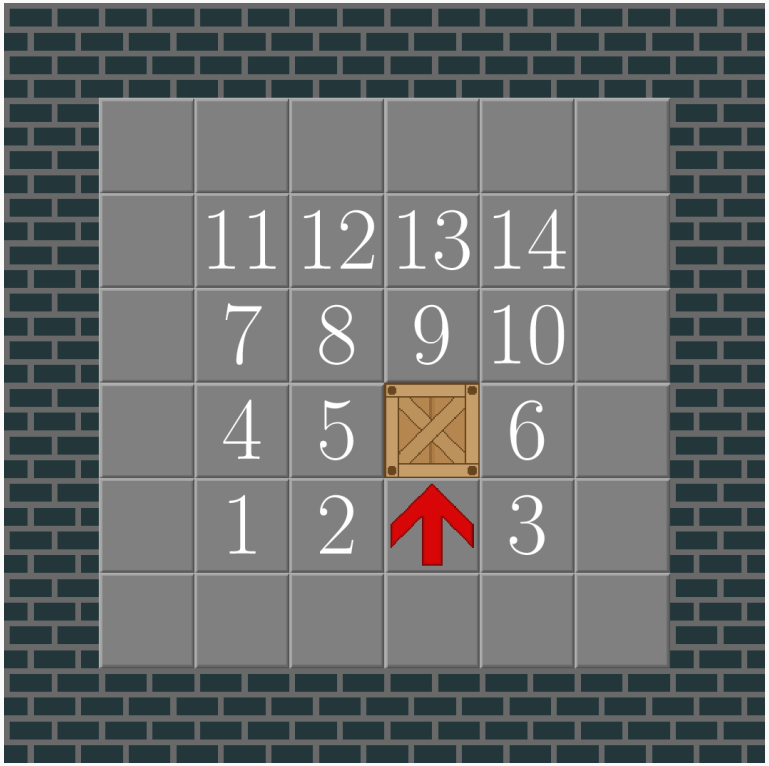


Table de *deadlocks*



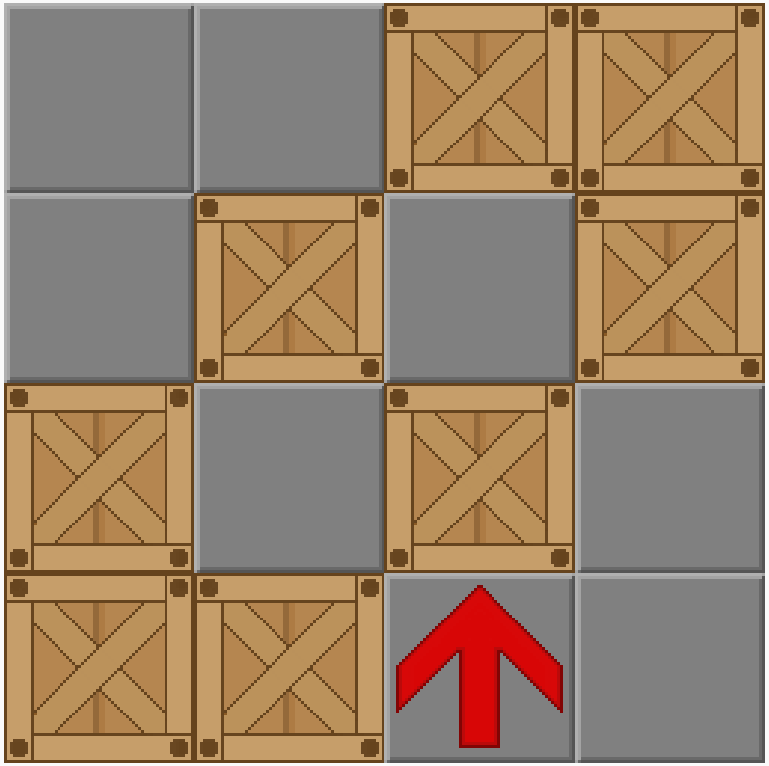
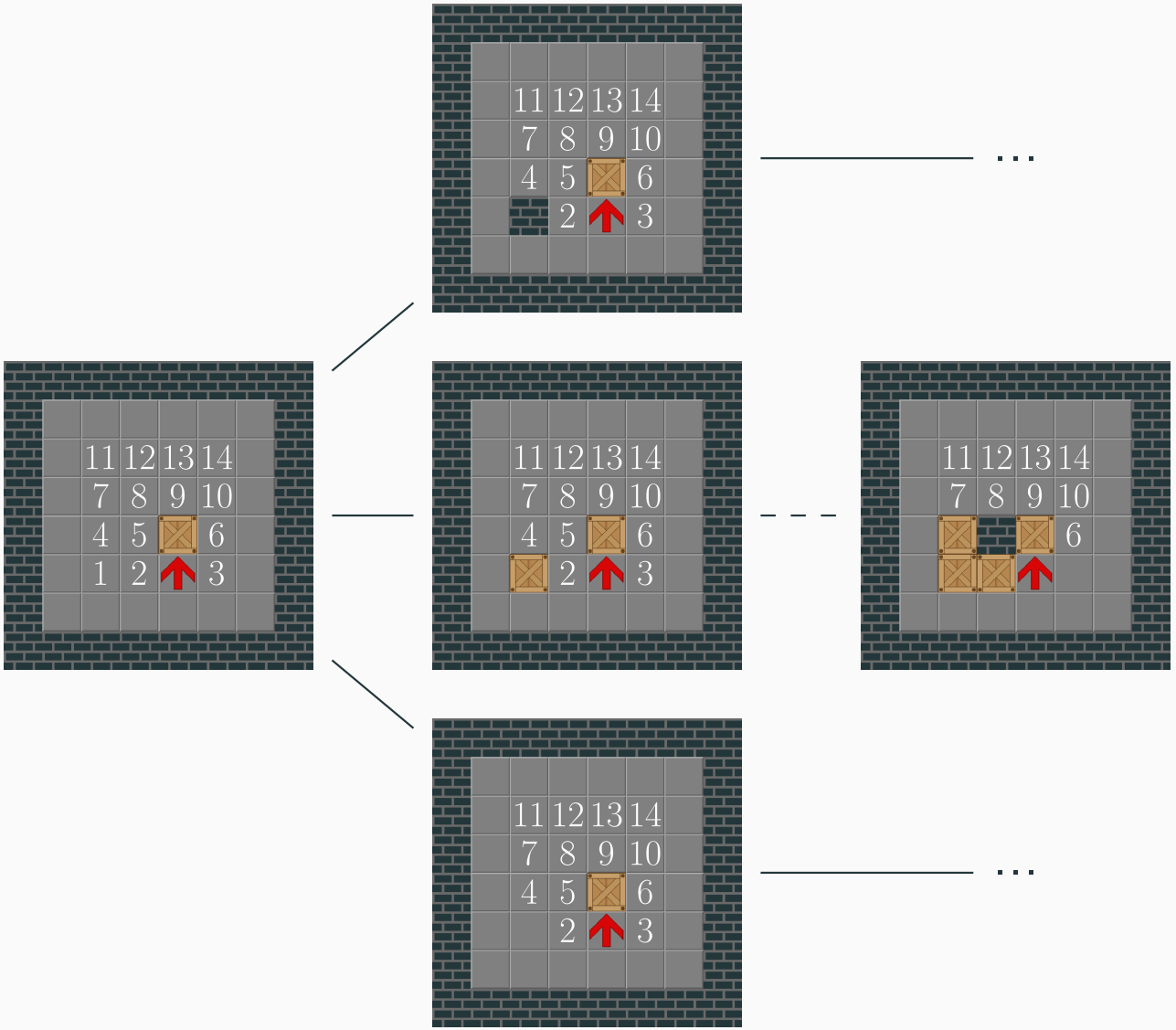
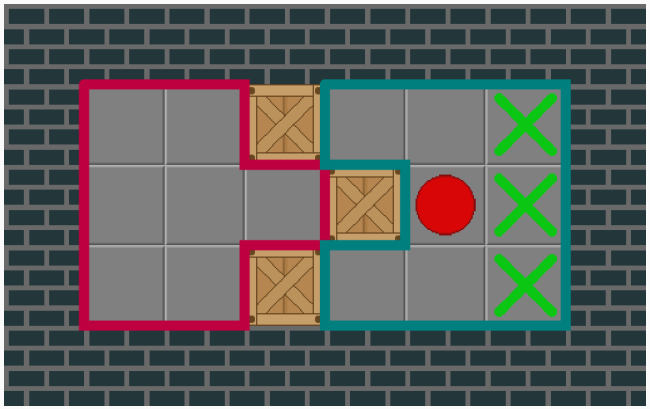


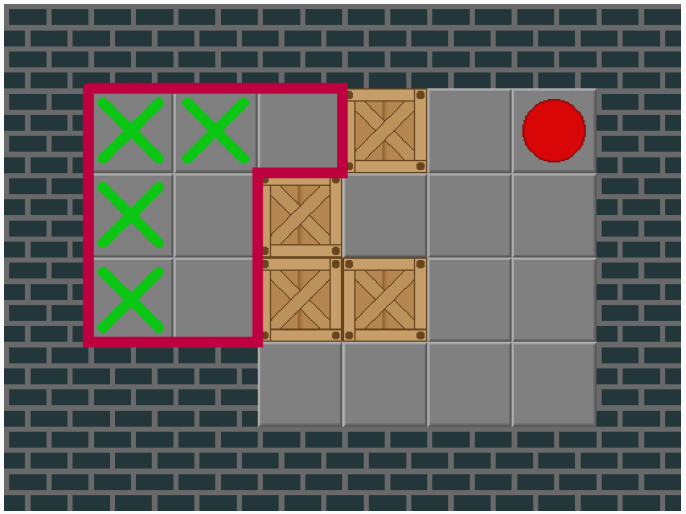
Table de *deadlocks*



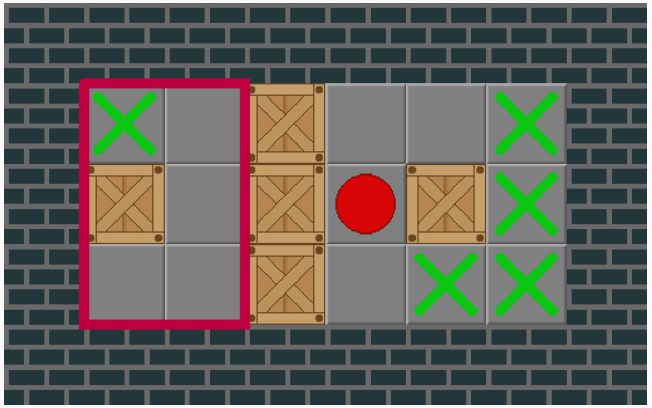
PI Corral pruning



(a) *Corral*

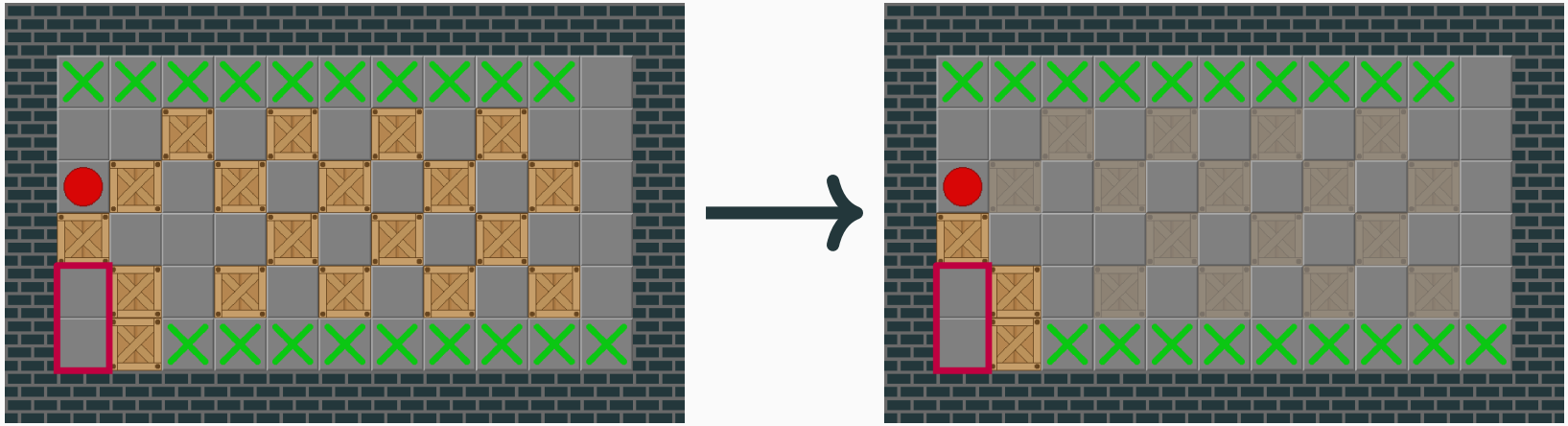


(b) *I Corral*



(c) *PI Corral*

PI Corral pruning

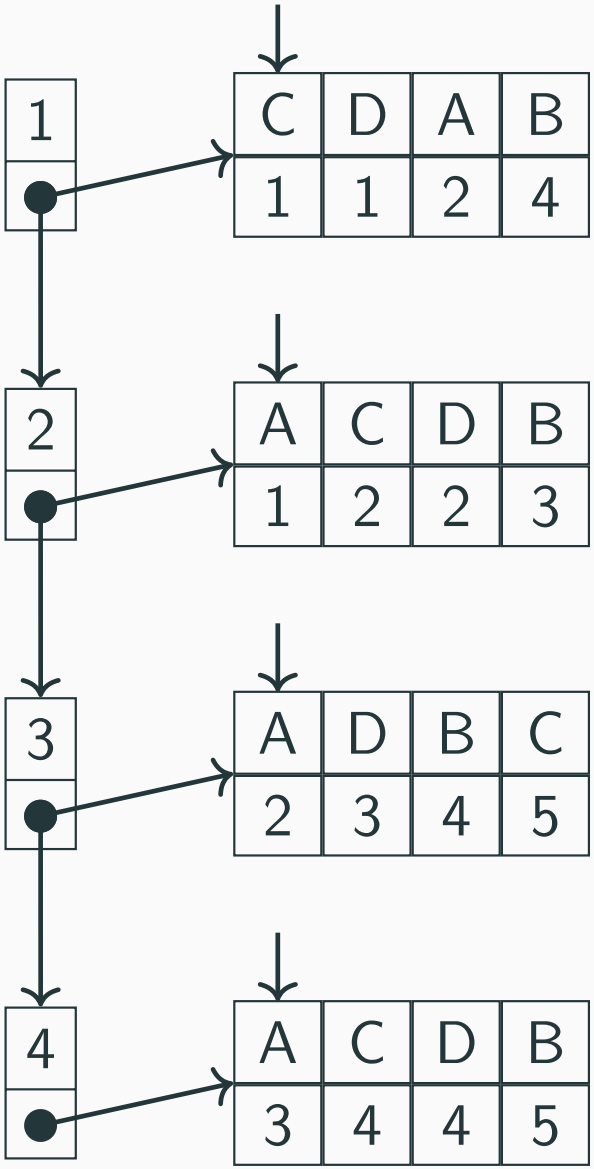


Situation complexe

Inutile de considérer
les caisses grisées

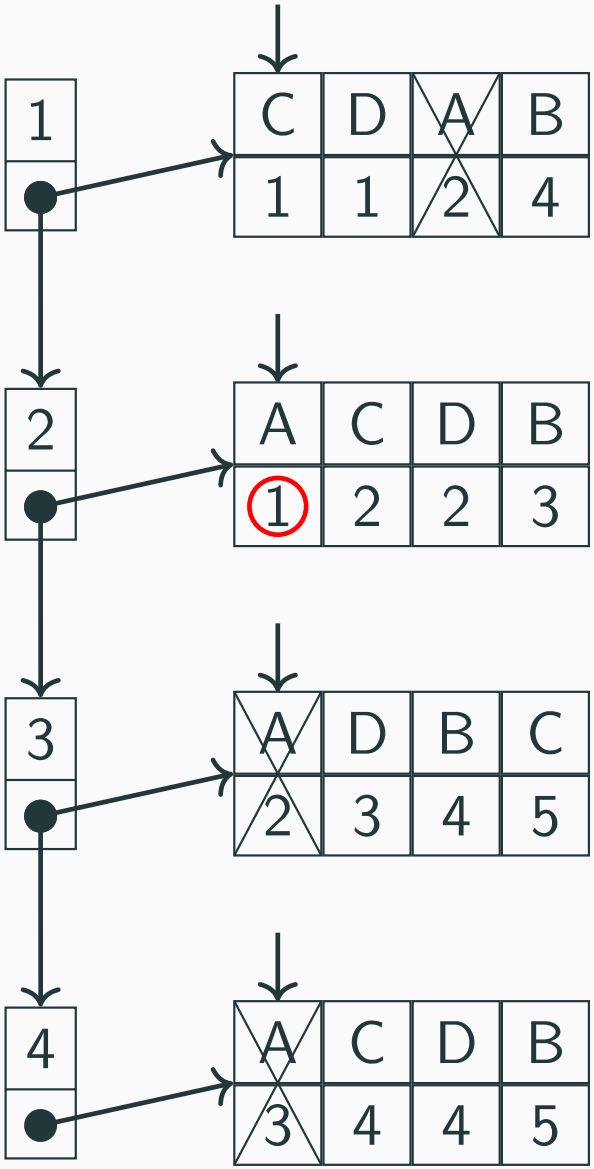
Brian Damgaard : émonde l'arbre de recherche d'au moins **20%** !

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



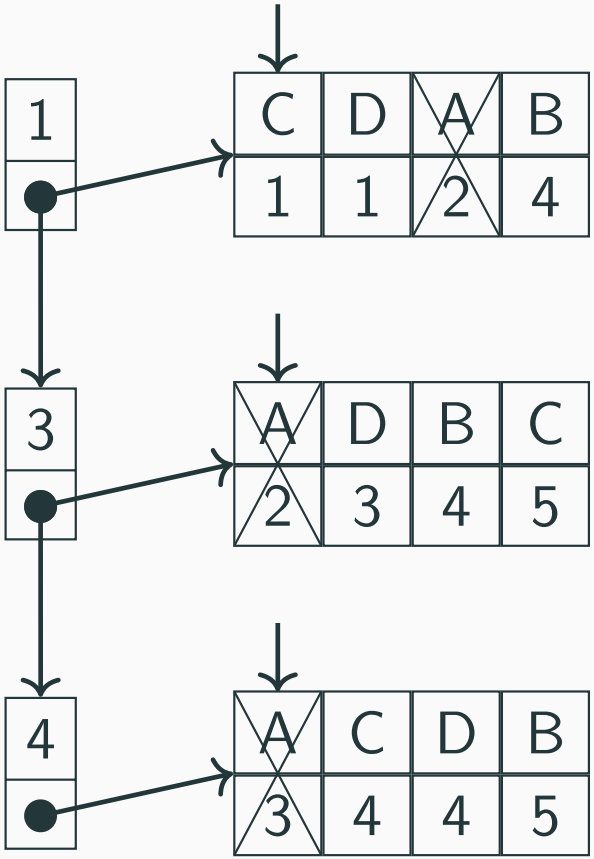
$h =$

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



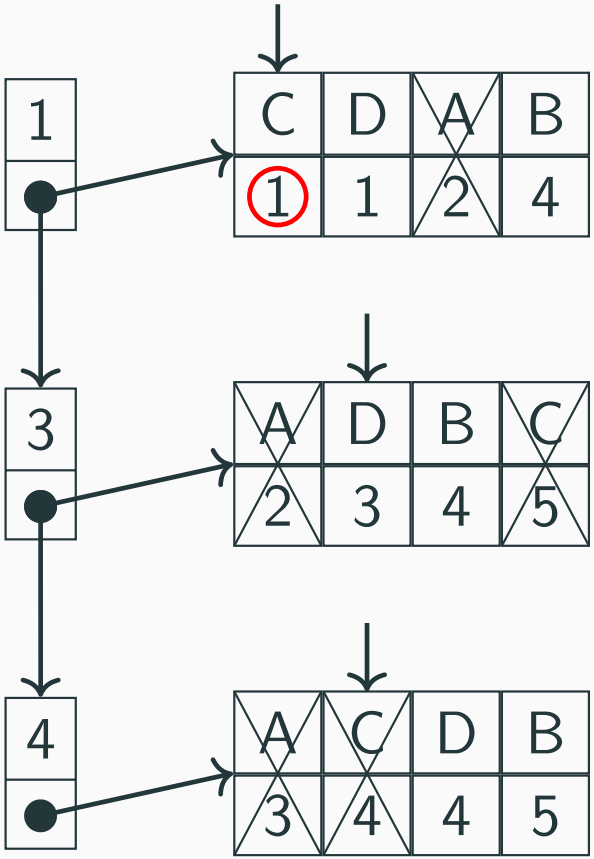
$$h = 1 +$$

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



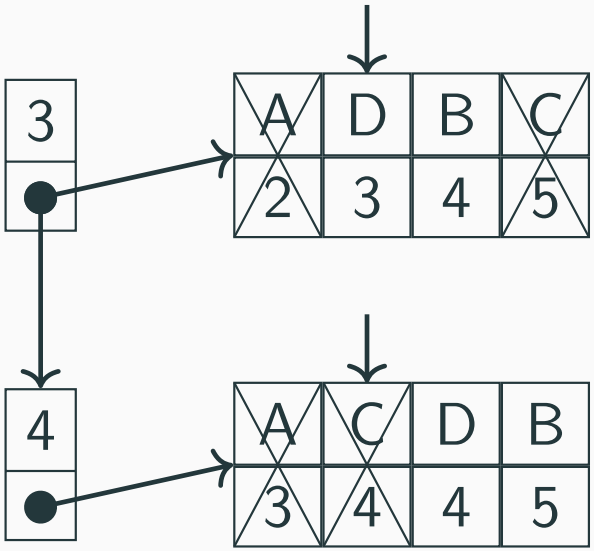
$$h = 1 +$$

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



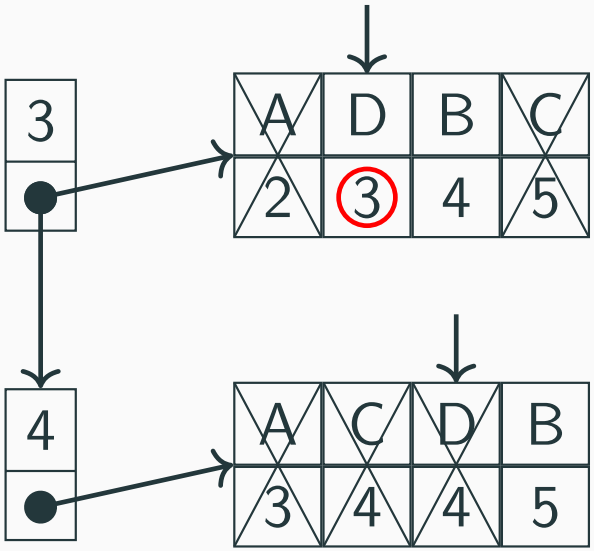
$$h = 1 + 1 +$$

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



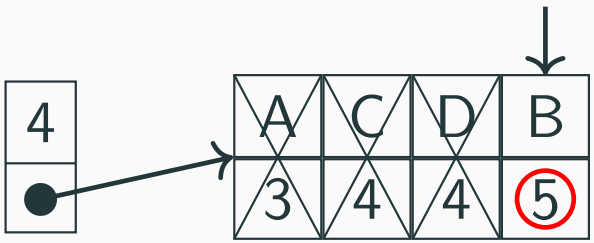
$$h = 1 + 1 +$$

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



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

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



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

Vers FESS

- FESS : algorithme utilisé par Festival, meilleur solveur.
- Ordre de priorité :
  - maximiser le nombre de caisses rangées.
  - minimiser le nombre de *corral*.
  - minimiser l'heuristique précédente.