Optimisation du Game of Life sur GPU

De l'implémentation naïve au Bit-Packing

A5 TP Conway

NVIDIA RTX 3080 — Grille 32k $\times$ 32k

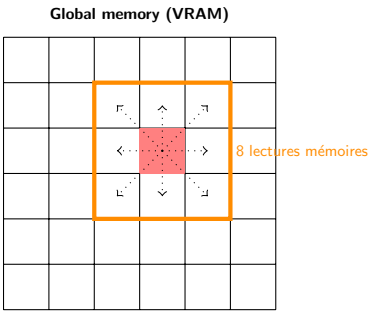
48 FPS $\rightarrow$ *416 FPS*

Version 1: noif-char (Naïve)

Taille grille: 32768×32768 octets
≈ 1 Go de RAM

FPS: 48.69
Type des données: `char` (1 octet = 1 cellule)
Pas de shared memory

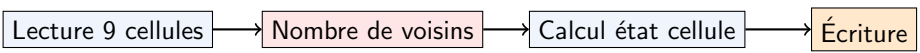
Taille bloc: 32×32 threads (calculent 32×32 cellules)



Logique “branchless” (noif)

```
// On compte les voisins vivants
int neighbors = 0;
for (int dy = -1; dy < 2; dy++) {
    for (int dx = -1; dx < 2; dx++) {
        if (x + dx >= 0 && x + dx < width && y + dy >= 0 && y + dy < height && (dy != 0 || dx !=
            0)) {
        neighbors += grid[idx + dx + dy * width];
        }
    }
}

// Calcul conditionnel sans 'if'
int alive = (neighbors == 3) | (grid[y * width + x] == 1 && neighbors == 2);
new_grid[idx] = alive;
```

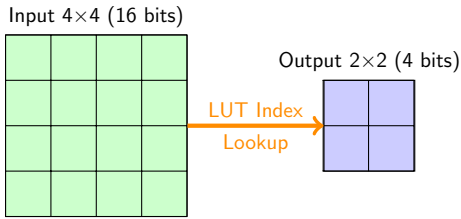


Version 2: Lookup table 4×4

Performance:

- **FPS:** 112.76 (×2.3)
- **Stratégie:** Pré-calcul (LUT)
- **Mémoire:** Utilisation de la **shared memory**

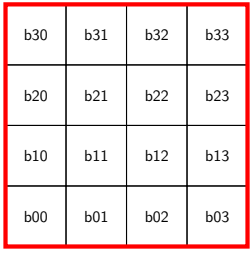
Concept: Réduire les calculs (comptage voisins) par une simple lecture tableau.




```
unsigned char host_lut[65536]
```

Construction de l'index LUT

```
// Construction de l'index 16-bits
uint16_t state_idx = 0;
#pragma unroll
for (int r = 0; r < 4; r++) {
  #pragma unroll
  for (int c = 0; c < 4; c++) {
    if (tile[tile_r + r][tile_c + c]) {
       state_idx |= (1 << (r * 4 + c));
    }
  }
}
unsigned char res = lut[state_idx];
```



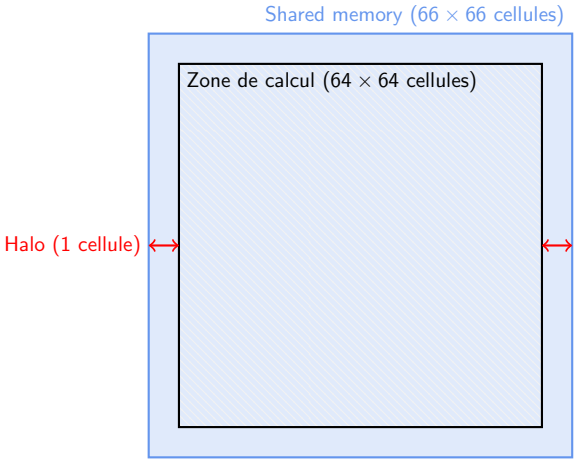
Bloc 4×4 (voisinage)

Gestion mémoire: stratégie par bloc

Un thread calcule **2×2 cellules**

Bloc 32×32 threads
Surface calculée: **64 × 64 cellules**

Shared Memory: **66 × 66 cellules**



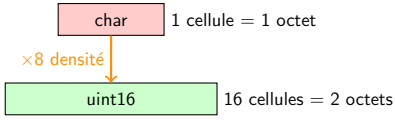
Version 3: uint16 (Bit-Packing)

Performance:

- **FPS: 416.51** ($\times$8.5 vs naïve)
- **Stratégie:** compression mémoire

Principe:

- 1 cellule = 1 bit (pas 1 octet)
- Grille 32768 $\times$ 32768 cellules
- $\frac{32768 \times 32768}{8 \text{ bits/octet}} = 128$ Mo



0	1	2	3	0	1	2	3
4	5	6	7	4	5	6	7
8	9	10	11	8	9	10	11
12	13	14	15	12	13	14	15
0	1	2	3	0	1	2	3
4	5	6	7	4	5	6	7
8	9	10	11	8	9	10	11
12	13	14	15	12	13	14	15

Architecture du kernel uint16

1 uint16 = 1 thread

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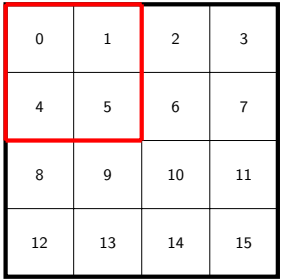
Utilisation de la LUT 4×4

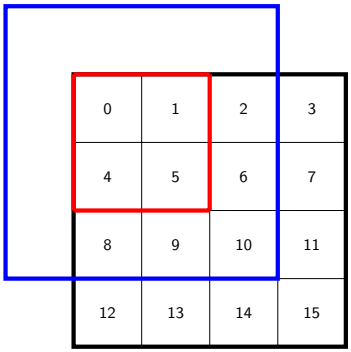


Architecture du kernel uint16

Utilisation de la LUT 4×4

Construction de l'indice 16-bits
à partir des uint16 voisins

1 uint16 = 1 thread



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Patch suivant

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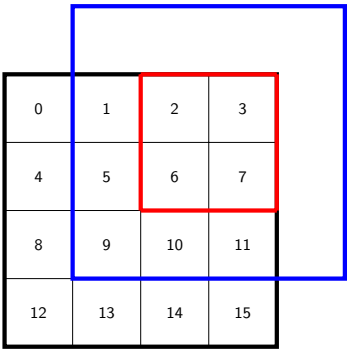

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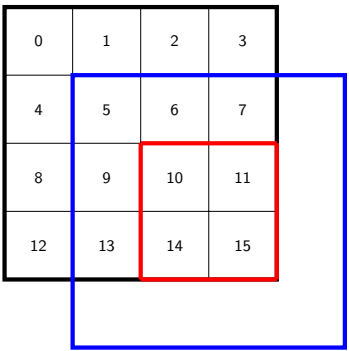

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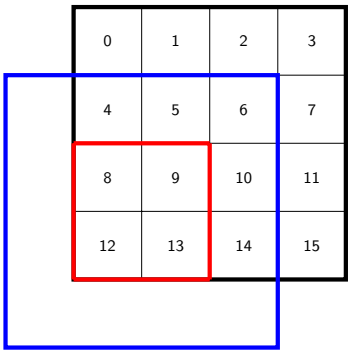

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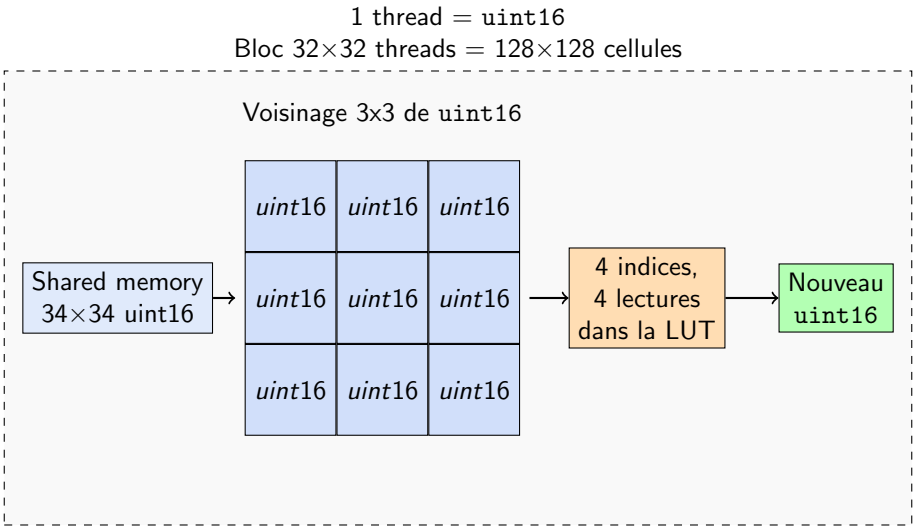


Résumé des gains de performance

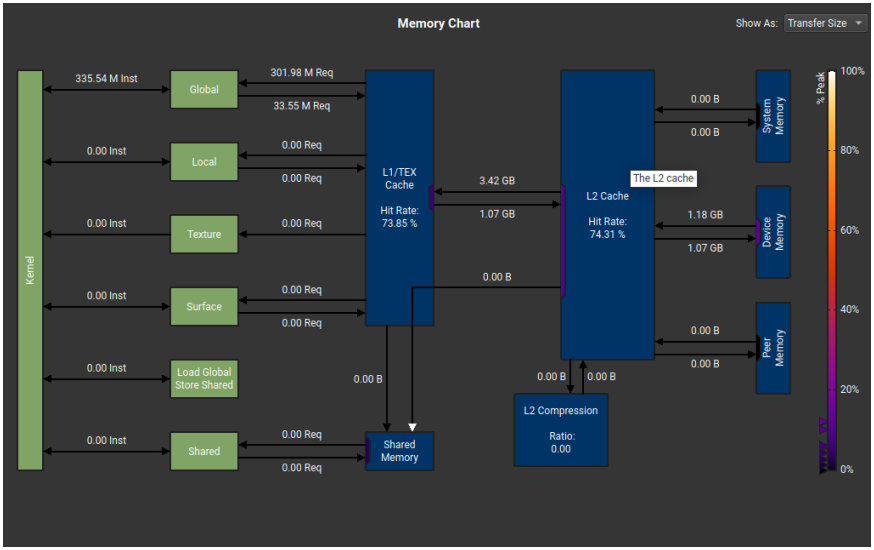
Métriques de débit et temps d'exécution

Version	**Thread/cellule**	**Durée** (ms)	**BP Mém.** (Go/s)	**BP Mém.** (%)	**FPS**
`noif-char`	1	25.21	89.42	32.72	48.81
`lookup4×4`	4	11.21	196.02	48.30	152.04
`uint16`	16	**3.03**	90.54	25.85	416.51

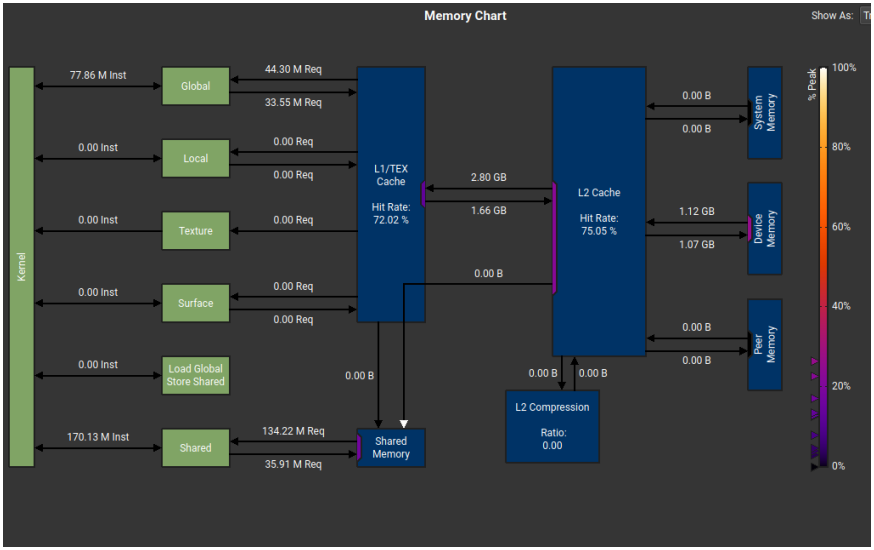
Efficacité matérielle

Version	**Hit L1/TEX** (%)	**Occupation Mém.** (%)	**SM Busy** (%)	**Calcul** (%)
`noif-char`	73.85	16.56	32.46	32.72
`lookup4×4`	72.02	31.05	46.56	48.30
`uint16`	**95.56**	20.68	39.18	37.25

Profiling: noif-char



Profiling: lookup4×4



Profiling: uint16 (division par 8 des accès mémoire)