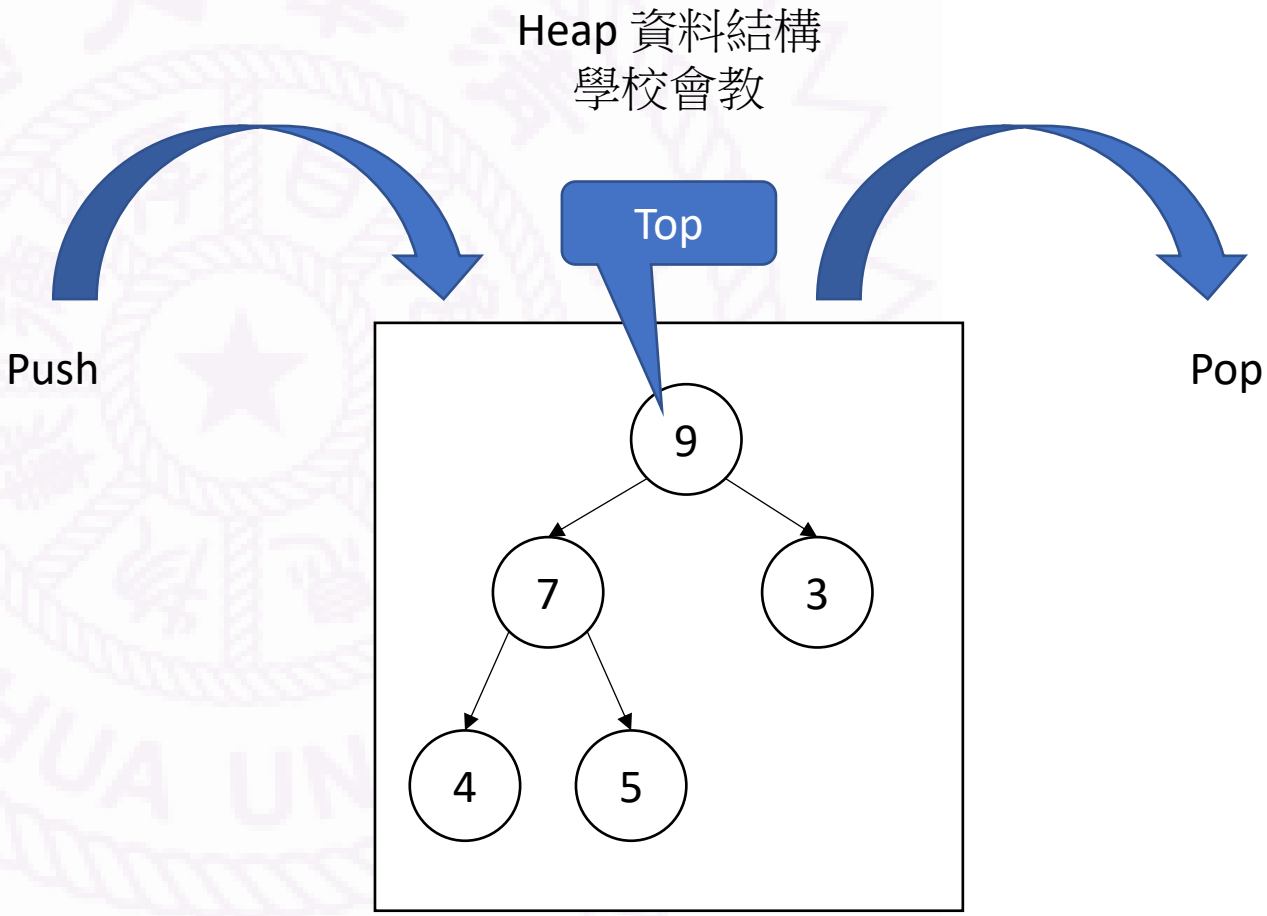
基礎資料結構應用

日月卦長

std::priority_queue

- push/ emplace(X) 加入資料
- top() 看最大的資料
- pop() 刪掉最大的資料



元素存取

最大的元素	top()	$O(1)$

插入刪除

插入元素	push(x)/emplace(x...)	$O(\log n)$
刪除最大的元素	pop()	$O(\log n)$

數量資訊

裡面是不是空的	empty()	$O(1)$
裡面有多少東西	size()	$O(1)$

Priority Queue 使用範例

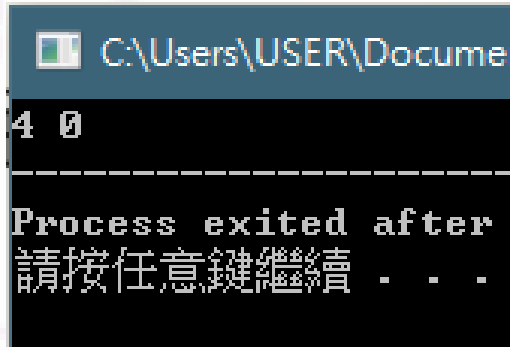
```cpp
#include <iostream>
#include <queue>
using namespace std;
int main() {
  priority_queue<int> PQ;
  PQ.emplace(1);
  PQ.emplace(3);
  PQ.emplace(2);
  while (!PQ.empty()) {
    cout << PQ.top() << '\n'; // 3 2 1
    PQ.pop();
  }
  return 0;
}
```

Example 自定義 priority_queue

- STL priority queue 是最大堆(Max heap)

```
struct CMP {
  bool operator()(int a, int b) { return a > b; }
};
int main() {
  priority_queue<int> PQ1;
  priority_queue<int, vector<int>, CMP> PQ2;
  for (int i = 0; i < 5; ++i) {
    PQ1.emplace(i);
    PQ2.emplace(i);
  }
  cout << PQ1.top() << ' ' << PQ2.top() << '\n';
  return 0;
}
```

帶有operator()的物件稱為函數物件，是一個物件，但使用行為如同函數。

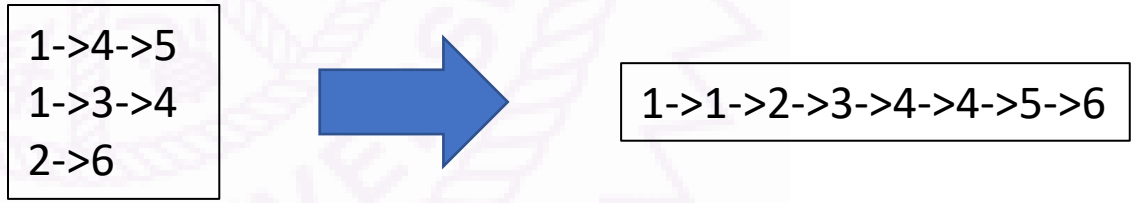


常見應用

- Heap Sort (競賽上不會用到)
- 多路合併
- 管理走訪順序 (延伸：最短路徑)
- 中位數類題
- 其他

多路合併 Merge k Sorted Lists

- https://leetcode.com/problems/merge-k-sorted-lists/
- 給你 k 個由小到大排序好的 linklist，請你將這些 linklist 合併成一個小到大排序好的 linklist 後輸出
- Example:
- lists = [[1,4,5],[1,3,4],[2,6]]
  - ans = [1,1,2,3,4,4,5,6]



輸入輸出格式

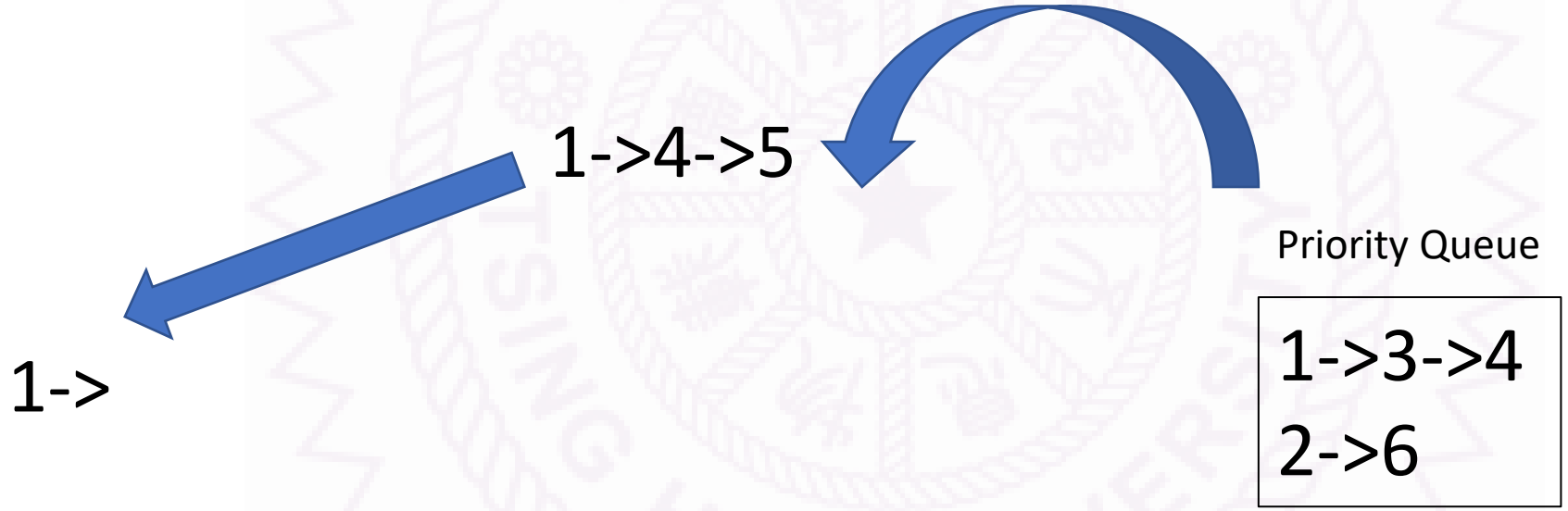
```
struct ListNode {
  int val;
  ListNode *next;
  ListNode() : val(0), next(nullptr) {}
  ListNode(int x) : val(x), next(nullptr) {}
  ListNode(int x, ListNode *next) : val(x), next(next) {}
};

ListNode* mergeKLists(vector<ListNode*>& lists);
```

模擬操作

Priority Queue

1->4->5
1->3->4
2->6

模擬操作



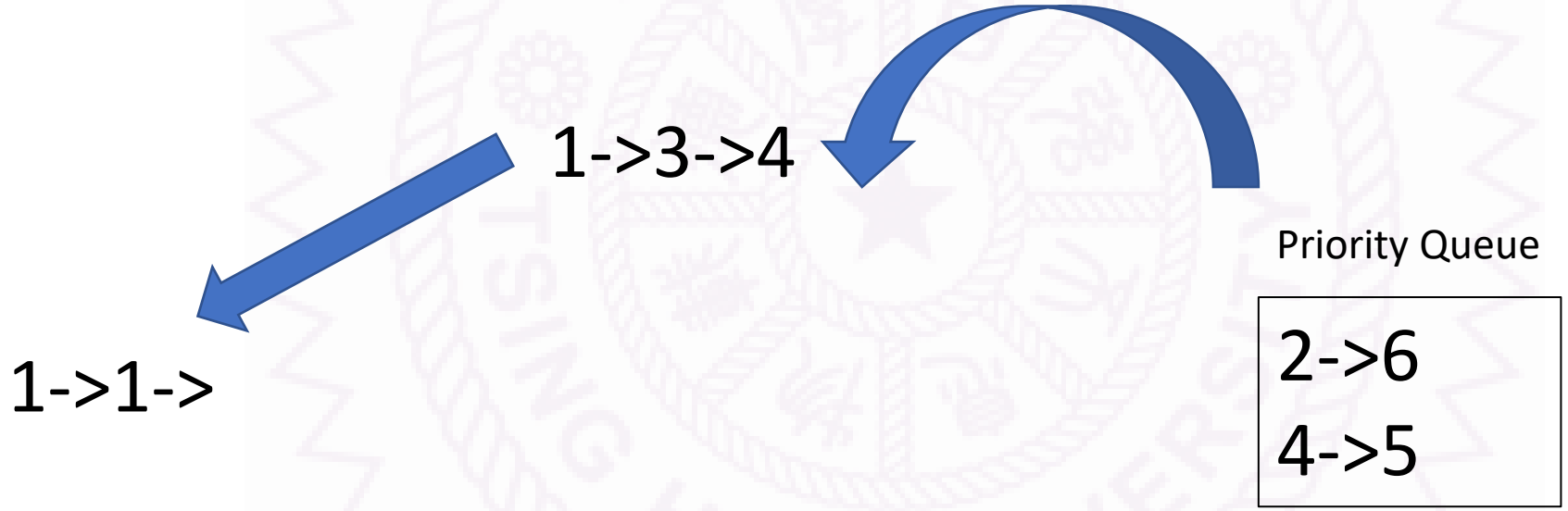
模擬操作

Priority Queue

1->3->4
2->6
4->5

1->

模擬操作



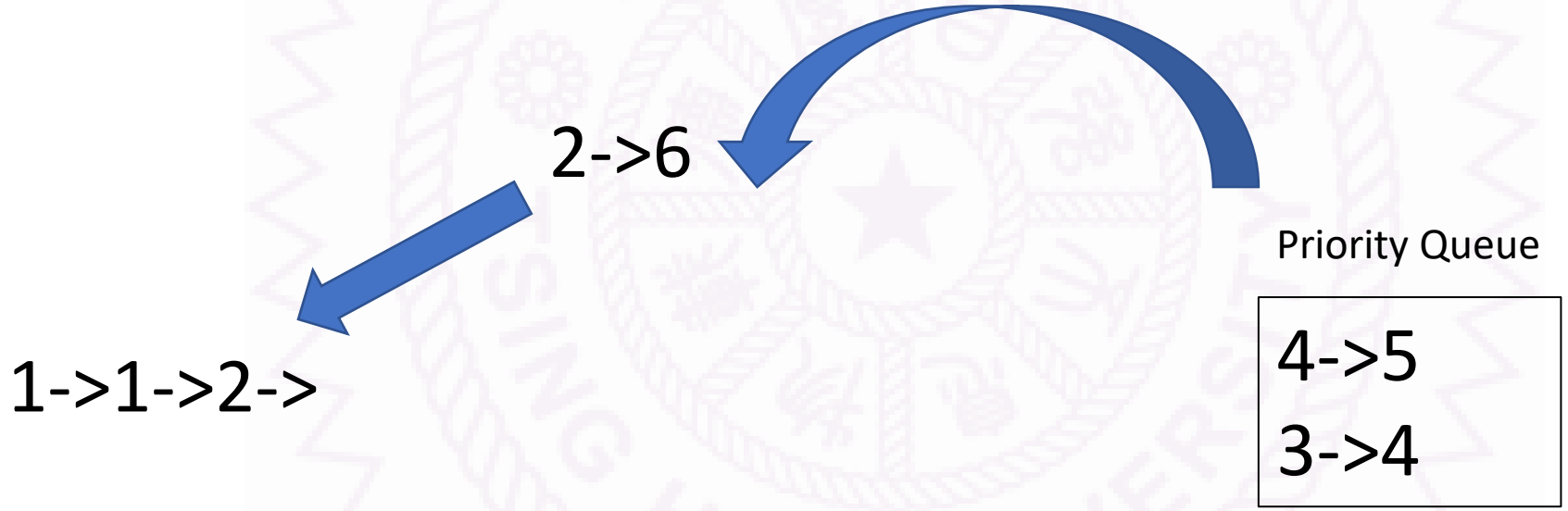
模擬操作

Priority Queue

2->6
4->5
3->4

1->1->

模擬操作



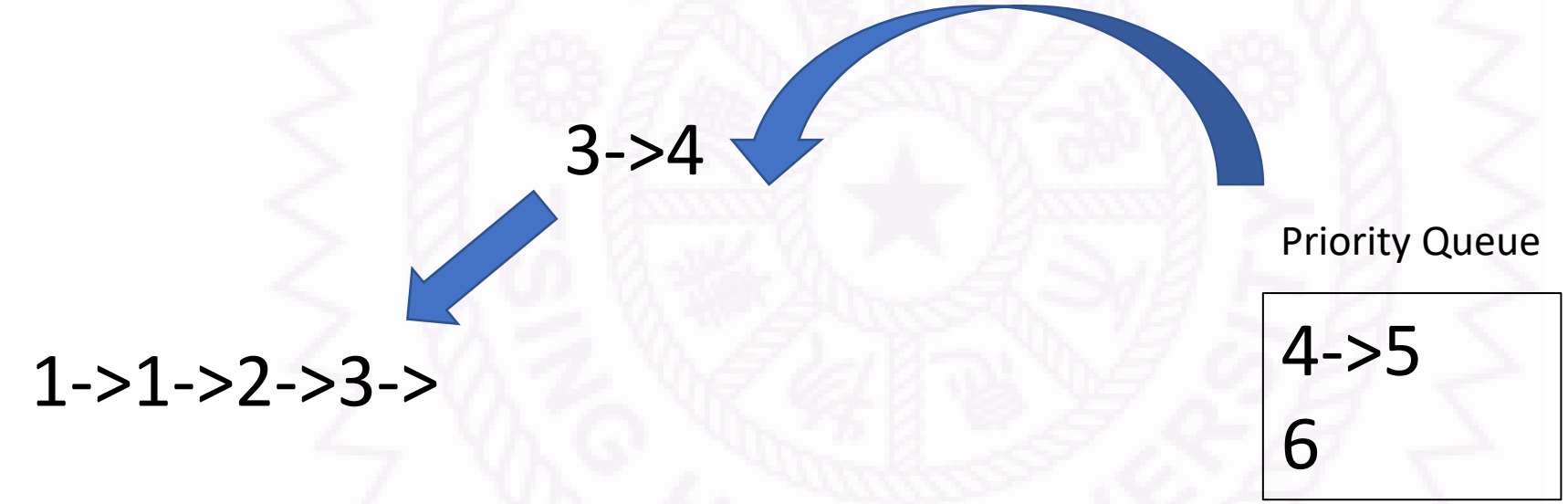
模擬操作

Priority Queue

4->5
3->4
6

1->1->2->

模擬操作



模擬操作

Priority Queue

4->5
6
4

1->1->2->3->

初始化 priority queue

```
struct CMP {
  bool operator()(ListNode *a, ListNode *b) const { return a->val > b->val; }
};
priority_queue<ListNode *, vector<ListNode *>, CMP> PQ;
void initPQ(vector<ListNode *> &lists) {
  decltype(PQ)().swap(PQ);
  for (auto nd : lists)
    if (nd) PQ.emplace(nd);
}
```

關鍵程式碼

```
ListNode *mergeKLists(vector<ListNode *> &lists) {
  initPQ(lists);
  ListNode *root = nullptr;
  ListNode **cur = &root;
  while (PQ.size()) {
    auto nd = PQ.top();
    PQ.pop();
    *cur = nd;
    cur = &nd->next;
    if (*cur) PQ.emplace(*cur);
  }
  return root;
}
```

不使用額外空間 (面試題)

```
ListNode *mergeKLists(vector<ListNode *> &lists) {
  auto iter = remove_if(lists.begin(), lists.end(), [](auto x) { return !x; });
  lists.erase(iter, lists.end());
  make_heap(lists.begin(), lists.end(), CMP());
  ListNode *root = nullptr;
  ListNode **cur = &root;
  while (lists.size()) {
    auto nd = lists.front();
    pop_heap(lists.begin(), lists.end(), CMP());
    lists.pop_back();
    *cur = nd;
    cur = &nd->next;
    if (*cur) {
      lists.emplace_back(*cur);
      push_heap(lists.begin(), lists.end(), CMP());
    }
  }
  return root;
}
```

管理走訪順序 (延伸：最短路徑)

- https://leetcode.com/problems/find-the-kth-smallest-sum-of-a-matrix-with-sorted-rows/
- 給你一個每個 row 都由小到大排的矩陣 mat，問你從每個 row 選一個數字，總和第 k 小的是多少
- Example:
- mat = [[1,3,11],[2,4,6]], k = 5
  - ans = 7
- mat = [[1,3,11],[2,4,6]], k = 9
  - ans = 17

mat	0	1	2
0	1	3	11
1	2	4	6

前五小的組合：[1,2], [1,4], [3,2], [3,4], [1,6]

觀察

- mat = [[1,10,10],[1,4,5],[2,3,6]]
- 觀察前幾小的狀態

mat	0	1	2
0	1	10	10
1	1	4	5
2	2	3	6

K = 1

- [1,1,2]

mat	0	1	2
0	1	10	10
1	1	4	5
2	2	3	6

K = 2

- [1,1,3]

mat	0	1	2
0	1	10	10
1	1	4	5
2	2	3	6

K = 3

- [1,4,2]

mat	0	1	2
0	1	10	10
1	1	4	5
2	2	3	6

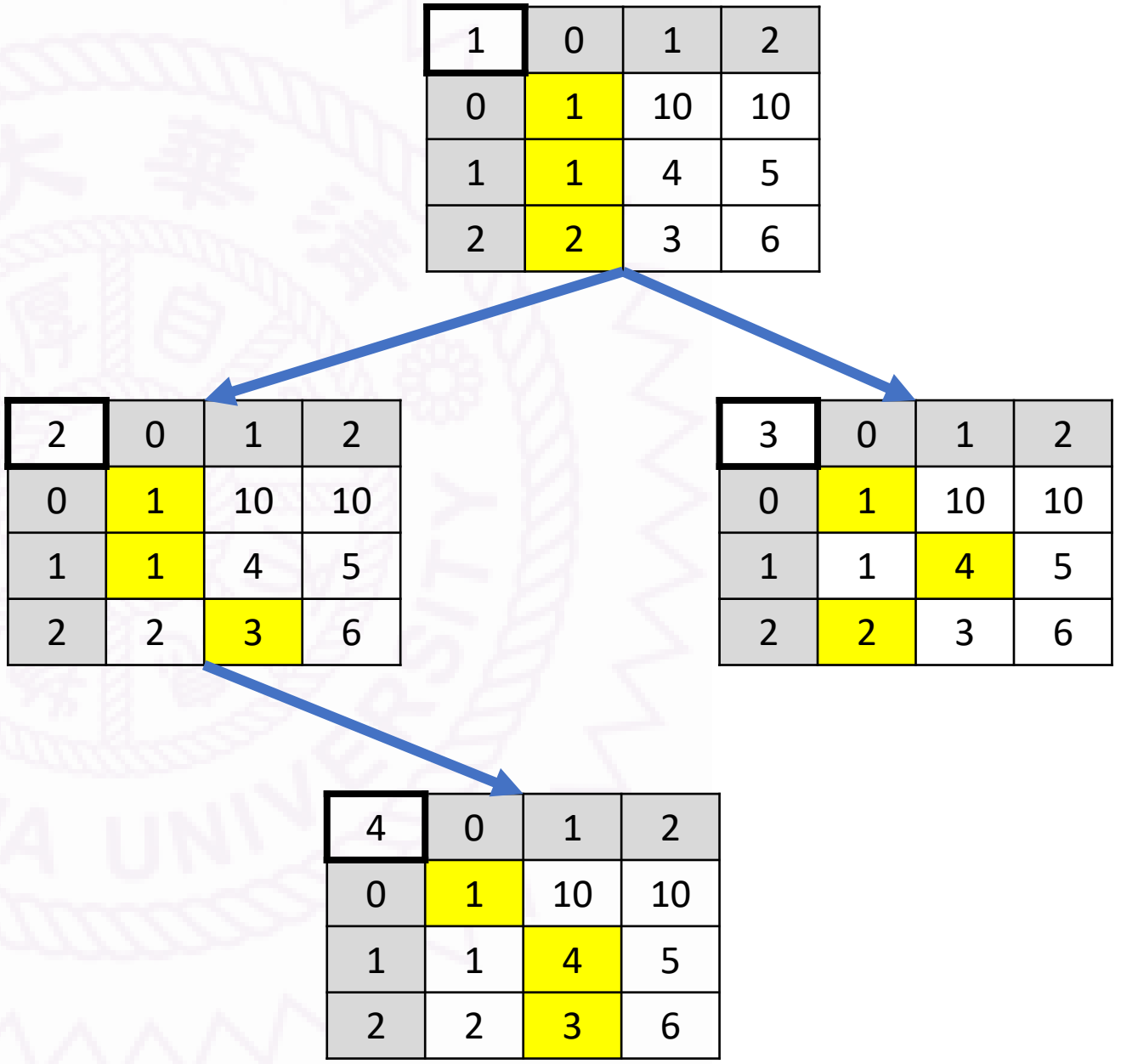
K = 4

- [1,4,3]

mat	0	1	2
0	1	10	10
1	1	4	5
2	2	3	6

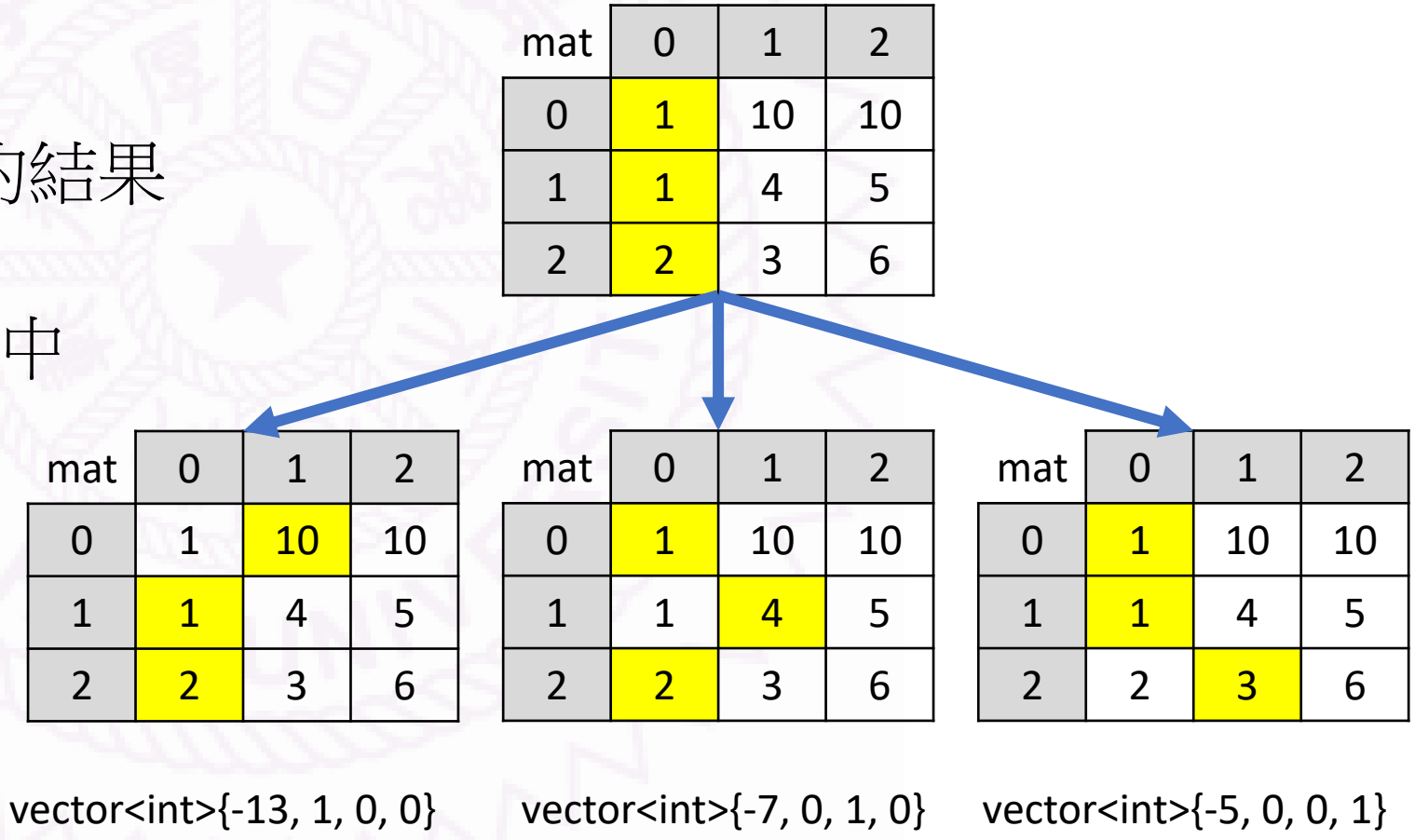
觀察

- 第 k+1 小的答案
- 是前 k 小的答案中
- 把某 row 的 index+1後得到



作法

- 用 priority queue 存資料
- 在知道第 k 小的答案後
  將每個 row 的 index+1 的結果
  存到 priority queue 中
- 下一輪從 priority queue 中
  取出第 k+1 小的答案
- 一直做下去



不同狀態有機會產生相同的結果

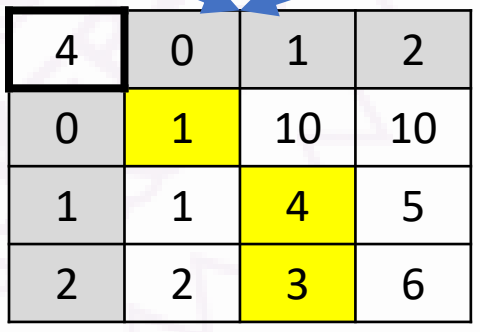
- 用 set<vector<int>>
  判斷有沒有重複計算

vector<int>{-5, 0, 1, 0}

2	0	1	2
0	1	10	10
1	1	4	5
2	2	3	6

vector<int>{-7, 0, 1, 0}

3	0	1	2
0	1	10	10
1	1	4	5
2	2	3	6



4	0	1	2
0	1	10	10
1	1	4	5
2	2	3	6

vector<int>{-8, 0, 1, 0}

程式碼

```
int kthSmallest(vector<vector<int>> &mat, int k) {
  int m = mat.size(), n = mat[0].size();
  priority_queue<vector<int>> PQ;
  vector<int> cur(m + 1, 0);
  for (auto &v: mat) cur[0] -= v[0];
  PQ.emplace(cur);
  set<vector<int>> visited{{cur}};
  for(int t = 1; t < k; ++t) {
    cur = PQ.top(), PQ.pop();
    for (int i = 1; i <= m; ++i) {
      if (cur[i] == n - 1) continue;
      auto next = cur;
      ++next[i];
      next[0] -= (mat[i - 1][next[i]] - mat[i - 1][next[i] - 1]);
      if (!visited.emplace(next).second) continue;
      PQ.emplace(move(next));
    }
  }
  return -PQ.top().at(0);
}
```

另一種二分搜的做法 (非本單元主題)

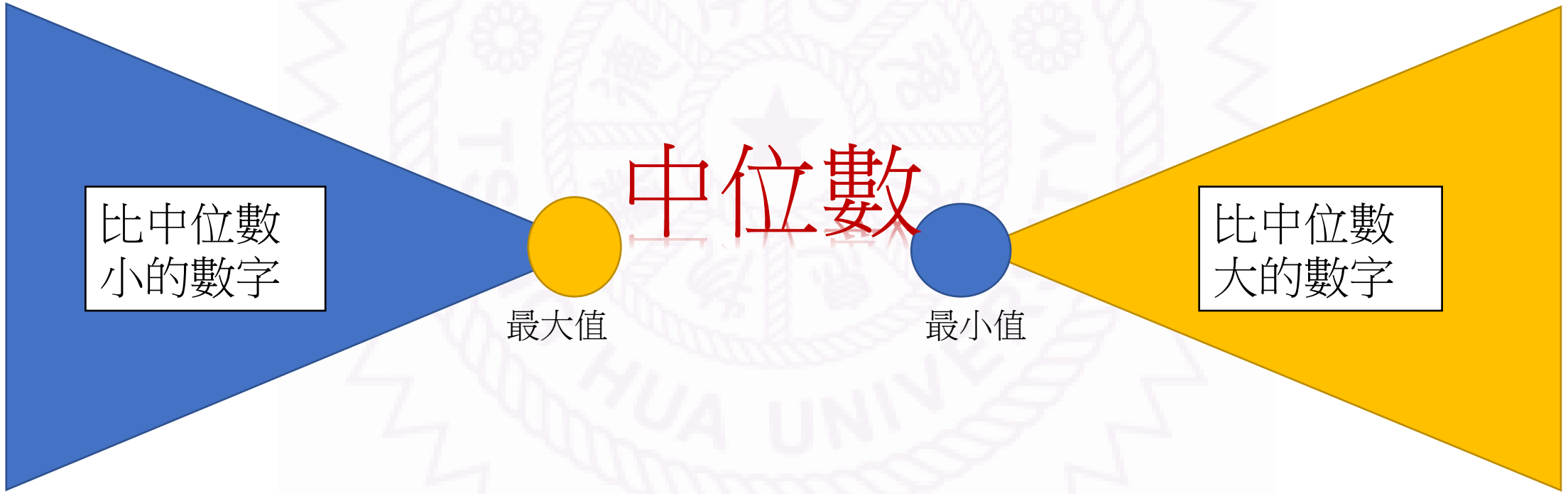
```
int n, m;
vector<vector<int>> *A;
int total, K;
bool dfs(int i, int sum, int limit) {
  if (i >= n) {
    total += sum <= limit;
    return sum <= limit;
  }
  bool ans = false;
  for (auto x : A->at(i)) {
    auto cur = dfs(i + 1, sum + x, limit);
    ans |= cur;
    if (!cur || total > K) break;
  }
  return ans;
}
```

```
int kthSmallest(
    vector<vector<int>> &mat, int k) {
  n = mat.size(), m = mat[0].size();
  int L = 0, R = 0;
  for (auto &V : mat) R += V.back();
  K = k;
  A = &mat;
  tie(ignore, R) =
  binarySearch(L, R, [&](int mid) {
    total = 0;
    dfs(0, 0, mid);
    return total < k;
  });
  return R;
}
```

中位數 (Zerojudge D713)

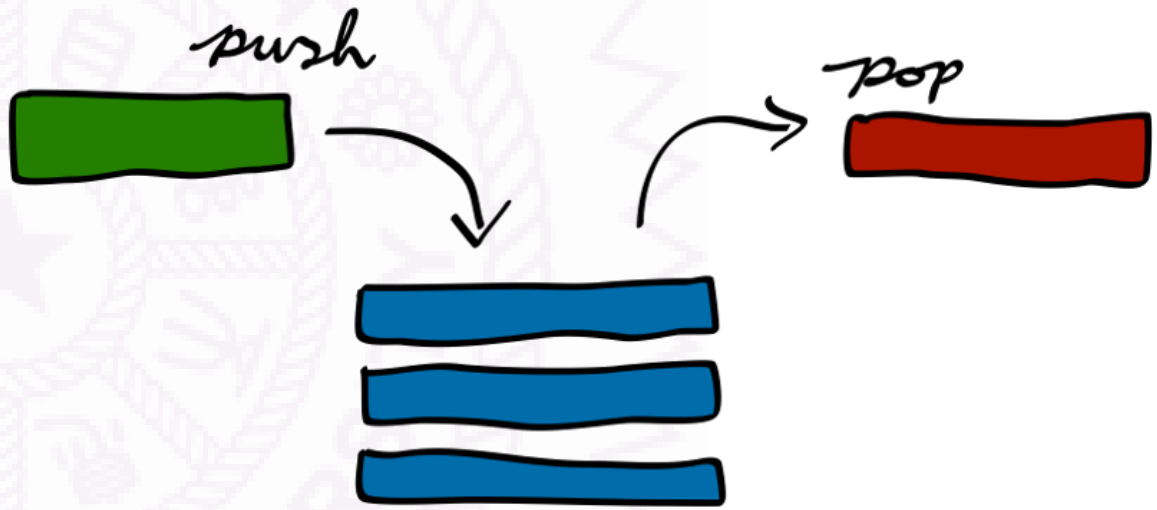
中位數	Zerojudge D713
依序讀取一個數列 $a_1, a_2, a_3, a_4, a_5 \cdots a_n$，每讀取一個數字，請回答到目前為止的中位數是多少。若有答案是小數請直接忽略到整數位。$(n < 200000)$	

中位數

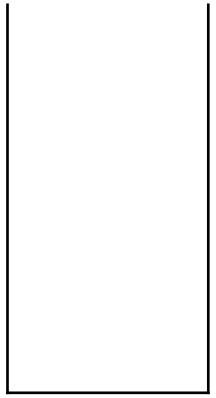


Stack

- push/emplace(X) 加入資料X
- top() 看最上面的資料
- pop() 刪掉最上面的資料
- First in last out



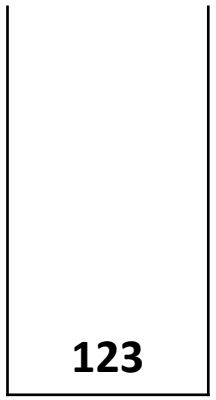
std::stack



```cpp
#include <iostream>
#include <stack>
using namespace std;
int main() {
  stack<int> STK;
  STK.emplace(123);
  STK.emplace(7122);
  STK.pop();
  STK.emplace(456);
  cout << STK.top() << '\n';
  return 0;
}
```

```cpp
#include <iostream>
#include <vector>
using namespace std;
int main() {
  vector<int> STK;
  STK.emplace_back(123);
  STK.emplace_back(7122);
  STK.pop_back();
  STK.emplace_back(456);
  cout << STK.back() << '\n';
  return 0;
}
```

std::stack

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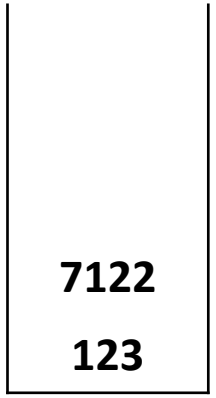
  cout << STK.back() << '\n';
  return 0;
}
```

std::stack

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using namespace std;
int main() {
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  STK.emplace(456);
  cout << STK.top() << '\n';
  return 0;
}
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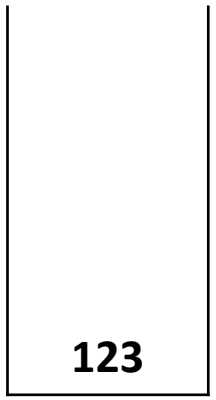
#include <vector>
using namespace std;
int main() {
  vector<int> STK;
  STK.emplace_back(123);
  STK.emplace_back(7122);
  STK.pop_back();
  STK.emplace_back(456);
  cout << STK.back() << '\n';
  return 0;
}
```

std::stack

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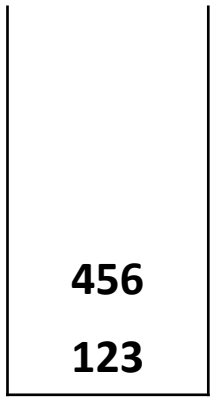
#include <stack>
using namespace std;
int main() {
  stack<int> STK;
  STK.emplace(123);
  STK.emplace(7122);
  STK.pop();
  STK.emplace(456);
  cout << STK.top() << '\n';
  return 0;
}
```

```cpp
#include <iostream>
#include <vector>
using namespace std;
int main() {
  vector<int> STK;
  STK.emplace_back(123);
  STK.emplace_back(7122);
  STK.pop_back();
  STK.emplace_back(456);
  cout << STK.back() << '\n';
  return 0;
}
```

std::stack




```cpp
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#include <stack>
using namespace std;
int main() {
  stack<int> STK;
  STK.emplace(123);
  STK.emplace(7122);
  STK.pop();
  STK.emplace(456);
  cout << STK.top() << '\n';
  return 0;
}
```

```cpp
#include <iostream>
#include <vector>
using namespace std;
int main() {
  vector<int> STK;
  STK.emplace_back(123);
  STK.emplace_back(7122);
  STK.pop_back();
  STK.emplace_back(456);
  cout << STK.back() << '\n';
  return 0;
}
```

其實是用 deque 做出來的

```
1  #include <iostream>
2  #include <vector>
3  #include <st
4  using namesp
5
6  int main() {
7    stack<int,>
8
```

```
<typename _Tp, typename _Sequence = deque < _Tp >>
stack

A standard container giving FILO behavior.
```

讓 std::stack 內部用 vector

```cpp
#include <iostream>
#include <stack>
#include <vector>
using namespace std;
int main() {
  stack<int, vector<int>> STK;
  STK.emplace(123);
  STK.emplace(7122);
  STK.pop();
  STK.emplace(456);
  cout << STK.top() << '\n';
  return 0;
}
```

元素存取

	stack
頭部	top()

數量資訊

	stack
裡面是不是空的	empty()
裡面有多少東西	size()

括號匹配問題(講義)

例題演練

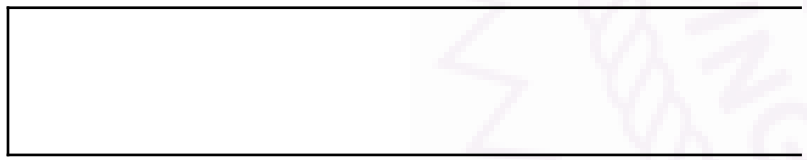
Parentheses Balance	UVa 673

今天**姆咪**正在寫程式，不過由於姆咪是 ** 很粗心的人 **，把文件中所有括號的配對都亂掉了，已知文件中的括號只有小括號 () 以及中括號 []，給出文件的括號序列，能檢查括號是否有正確配對嗎？

定義一個合法的括號配對字串如下

1. 空字串是合法的括號字串
2. 如果 A, B 是合法的括號字串，那 AB 也是合法的括號字串
3. 如果 A 是合法的括號字串，那 (A)、$[A]$ 也是合法的括號字串

example for ([])[]



([])[]

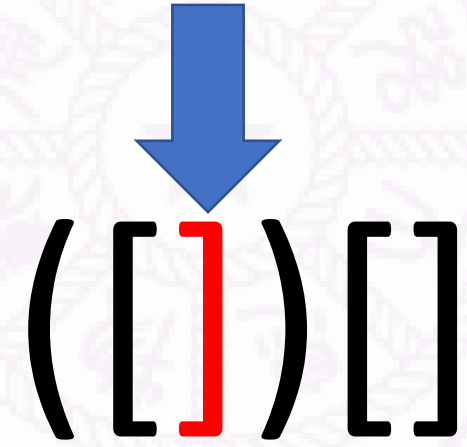
example for ([])[]

example for ([])[]

example for ([])[]

example for ([])[]

(



example for ([])[]

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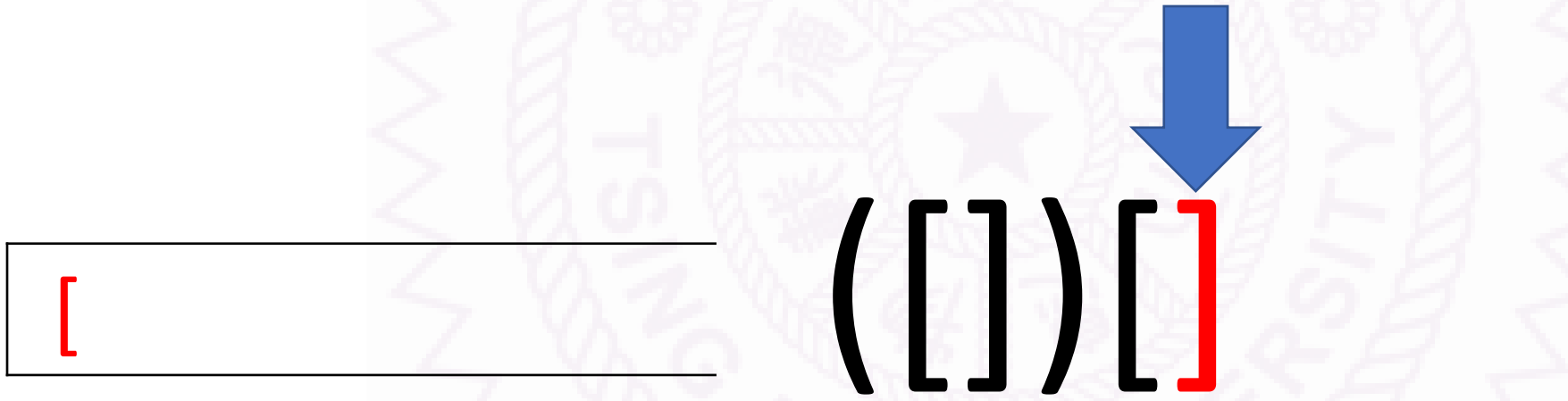
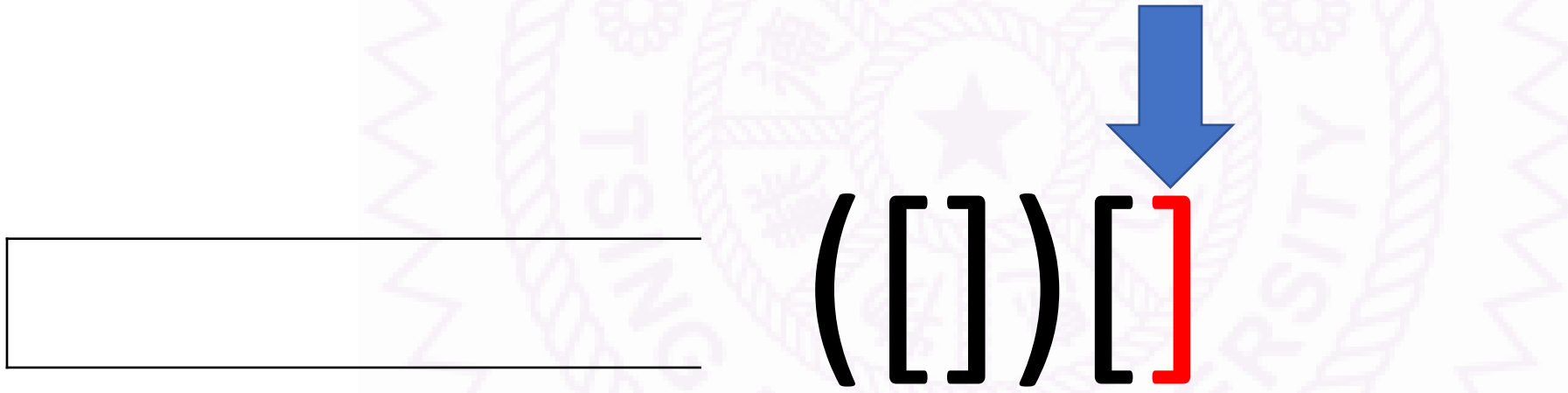


example for ([])[]



Monotonic Stack

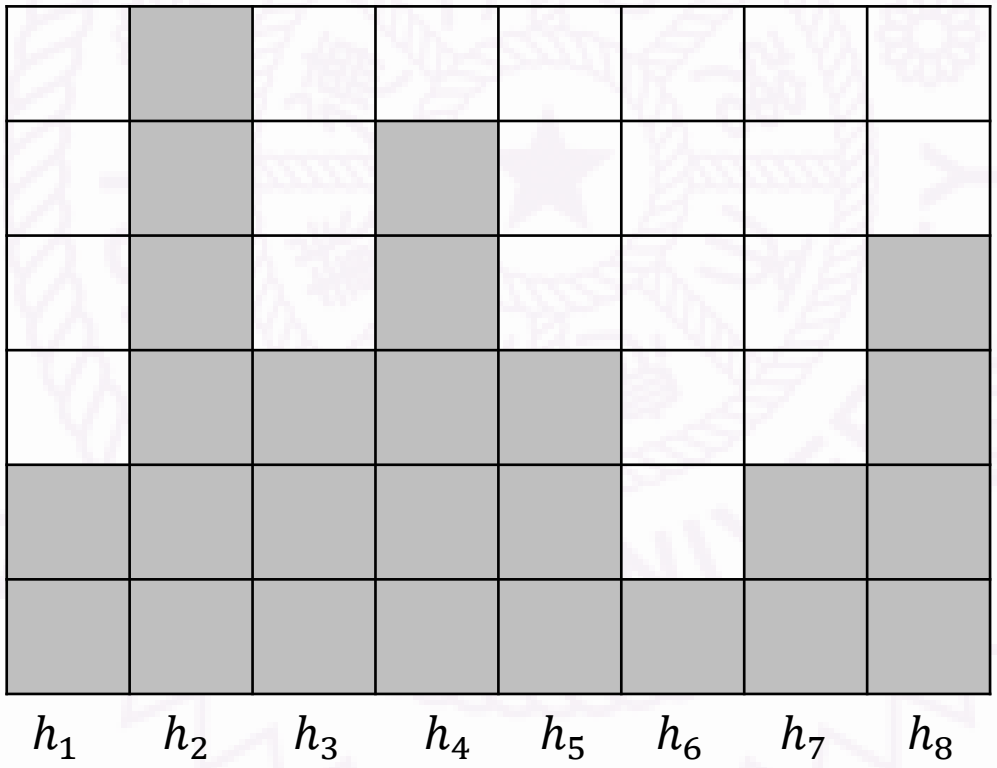
保證 stack 中的值遞增或遞減

去除永遠不可能成為答案的元素

乳牛(POJ 3250)

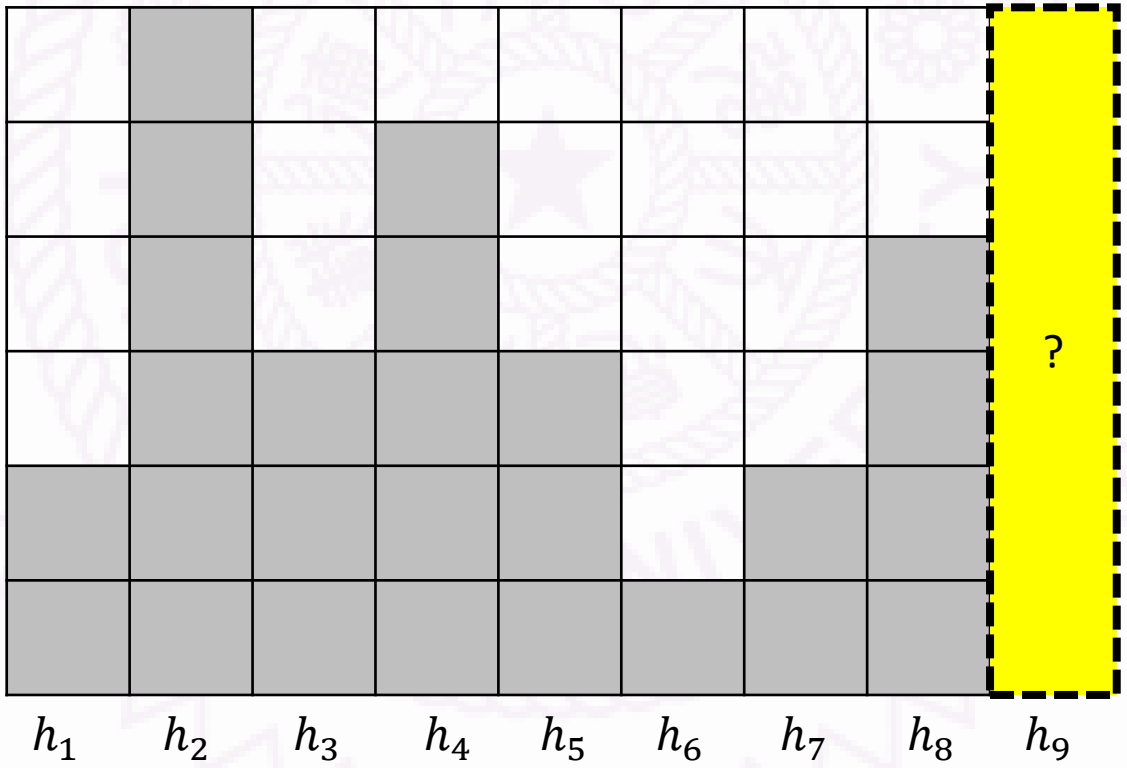
Bad Hair Day	POJ 3250
有 $n(n \leq 80000)$ 隻乳牛站在一條直線上，乳牛的身高由左而右依序為 $h_1, h_2 \cdots, h_n$，請為每一隻乳牛向左看可以看到幾隻乳牛？ 一隻乳牛可以看到左邊所有的乳牛，至到有一隻乳牛的身高大於等於該乳牛。	

考慮以下乳牛



假設有個不知道高度的 h_9

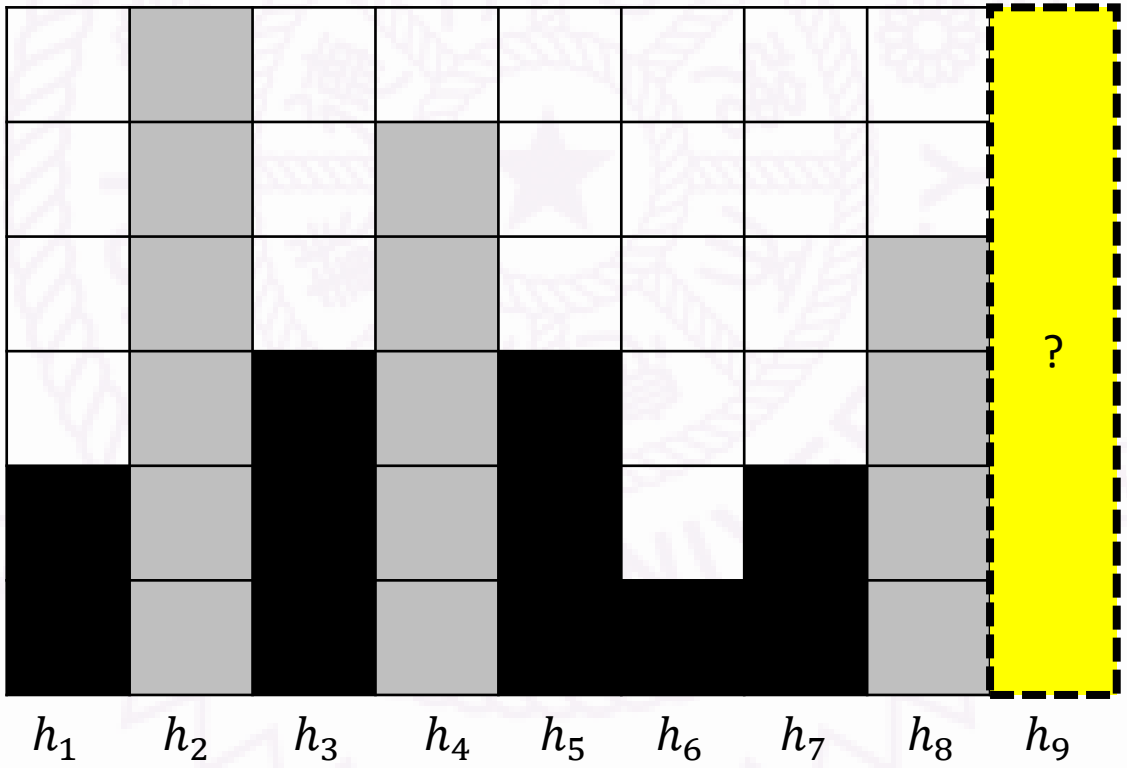
能不能將絕對不可能是 h_9 能看到最遠的乳牛刪除呢?



假設有個不知道高度的 h_9

能不能將絕對不可能是 h_9 能看到最遠的乳牛刪除呢?

無論 h_9 高度是多少
h_1, h_3, h_5, h_6, h_7 絕對不可能是 h_9 能看到最遠的乳牛

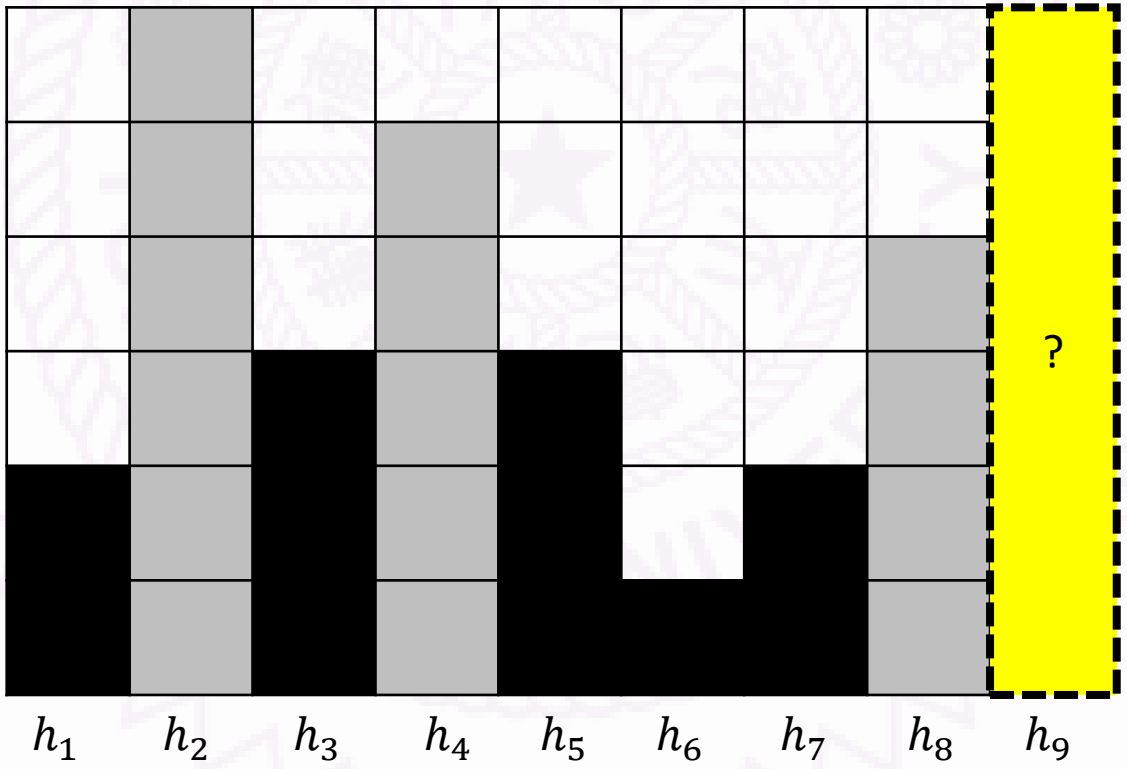


剩下的 h_2, h_4, h_8
會呈現非嚴格遞增的關係

計算 h_9 往左看能看到幾隻牛

STK | 2 | 4 | 8 |

用 stack 維護有機會被下隻牛看到的牛



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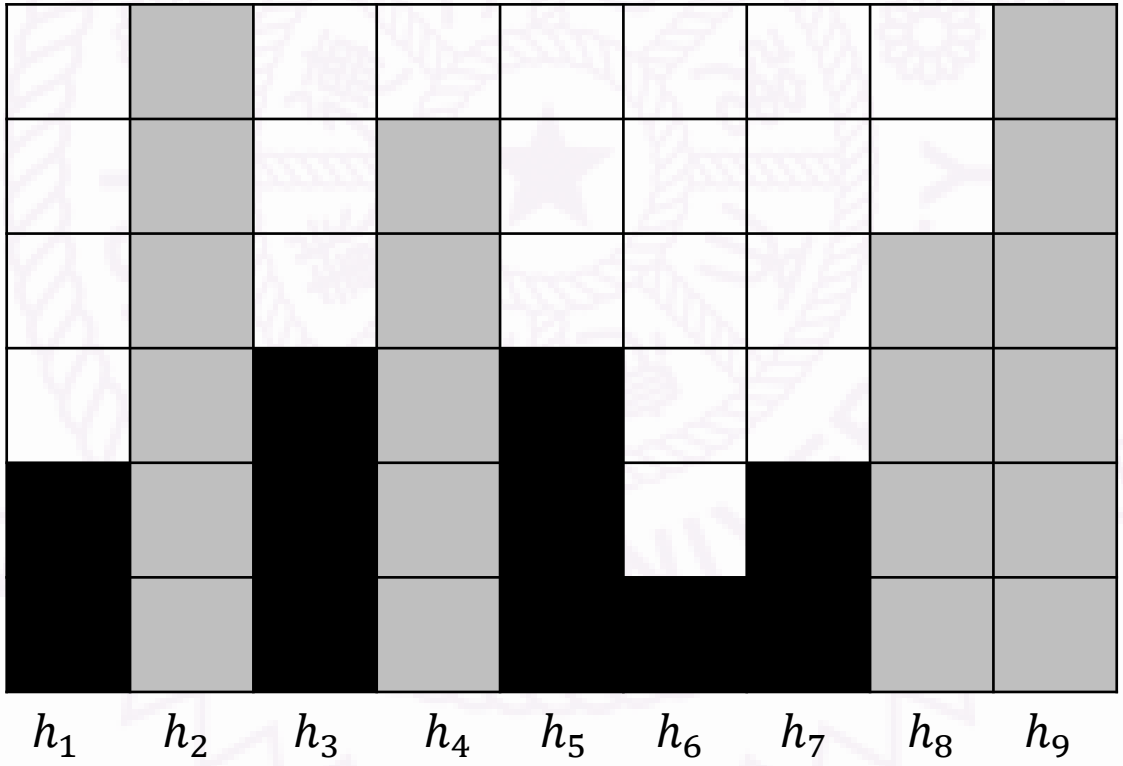
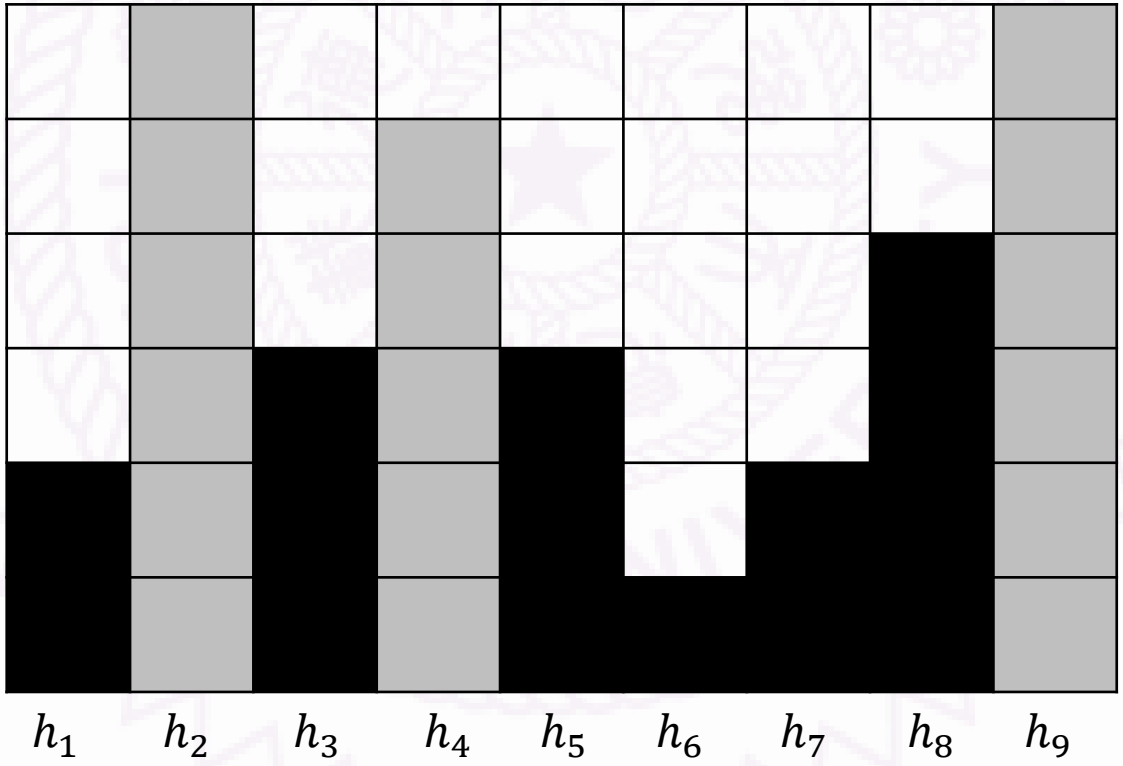


假設 $h_9 = 6$

計算 h_9 往左看能看到幾隻牛

STK | 2 | 4 |

用 stack 維護有機會被下隻牛看到的牛

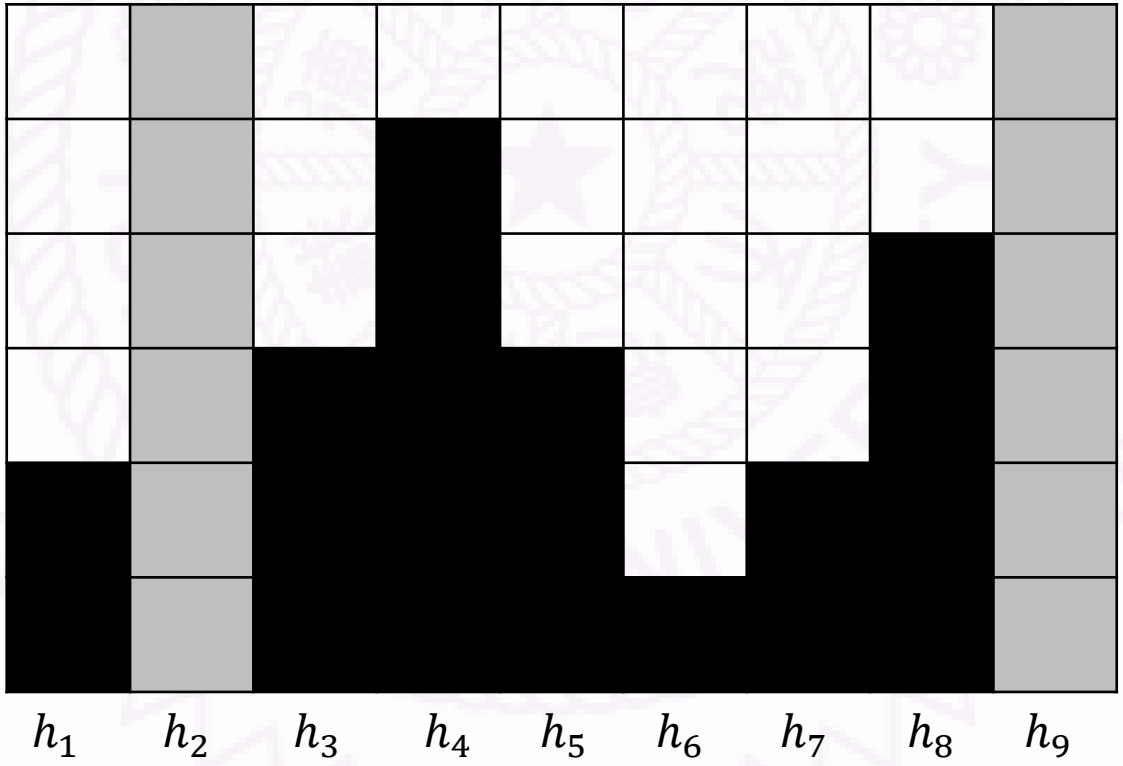


假設 $h_9 = 6$
STK 頂端是 h_8
$h_8 < h_9$ 所以 h_8 沒用了

計算 h_9 往左看能看到幾隻牛

STK | 2

用 stack 維護有機會被下隻牛看到的牛

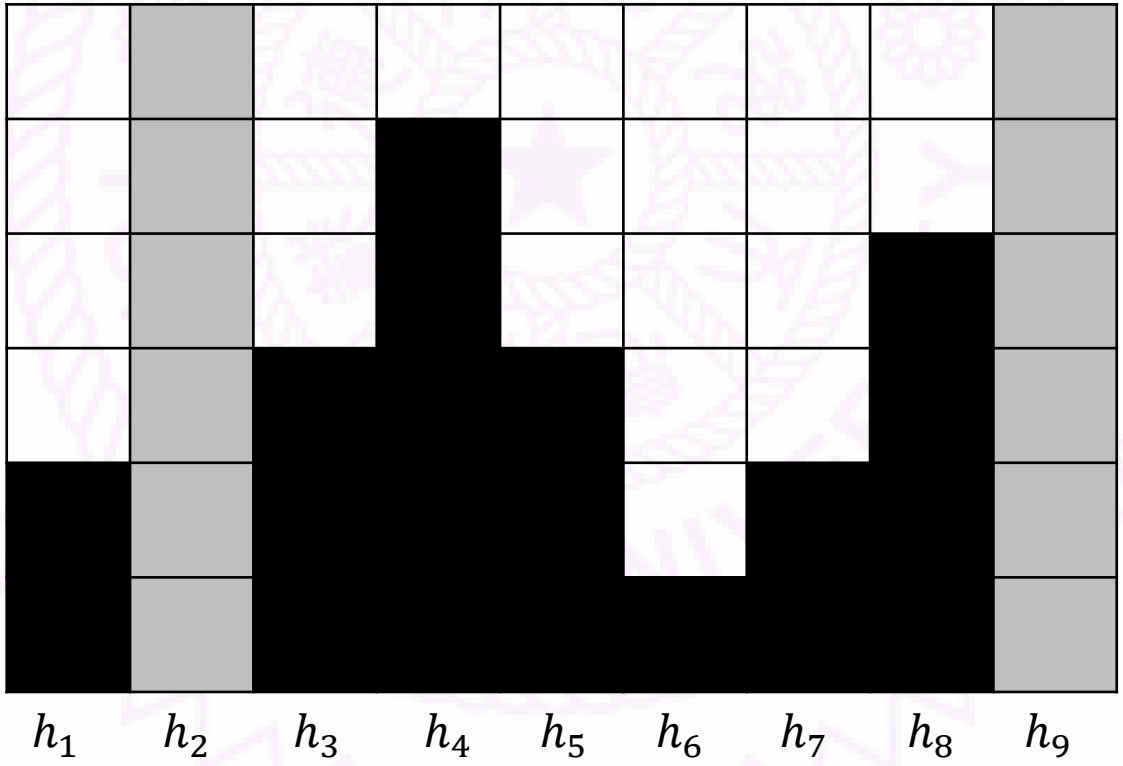


假設 h_9 =6
STK 頂端是 h_8
$h_8 < h_9$ 所以 h_8 沒用了
STK 頂端是 h_4
$h_4 < h_9$ 所以 h_4 沒用了

計算 h_9 往左看能看到幾隻牛

STK | 2 | 9 |

用 stack 維護有機會被下隻牛看到的牛



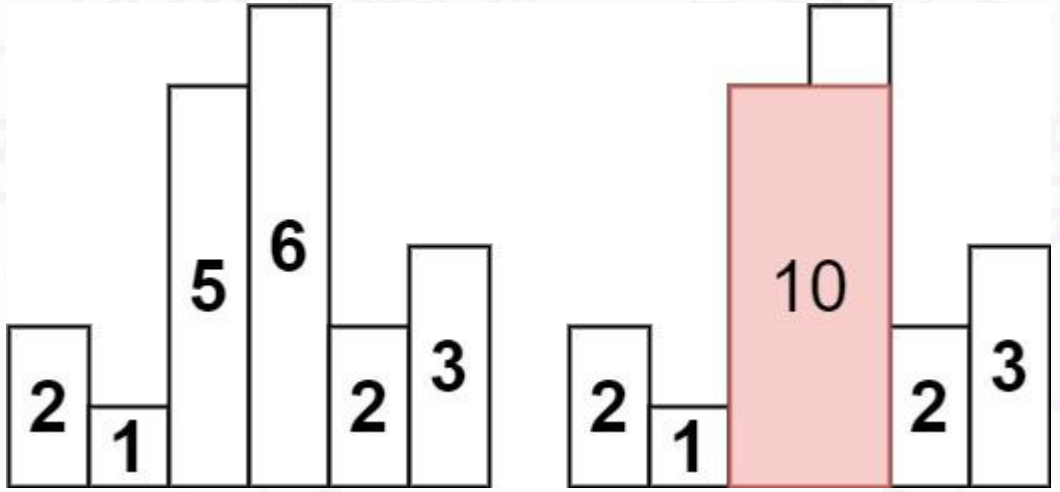
假設 $h_9 = 6$
STK 頂端是 h_8
$h_8 < h_9$ 所以 h_8 沒用了
STK 頂端是 h_4
$h_4 < h_9$ 所以 h_4 沒用了
STK 頂端是 h_2
$h_2 \not< h_9$ 所以 h_9 最遠能看到 h_2
把 h_9 放進 STK 為 h_{10} 做準備

實際程式碼有三個部分

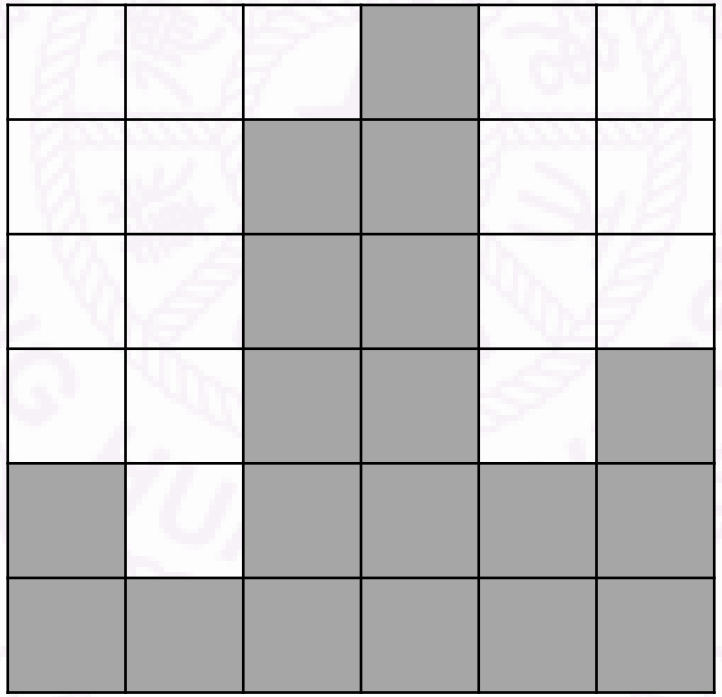

```cpp
void solve(vector<int> h) {
  stack<int> STK;
  for (size_t i = 0; i < h.size(); ++i) {
    while (STK.size() && h[STK.top()] < h[i]) STK.pop();

    if (STK.empty()) cout << i << endl;
    else cout << i - STK.top() << endl;

    STK.emplace(i);
  }
}
```

最大矩形

- https://leetcode.com/problems/largest-rectangle-in-histogram/
- 告訴你每根長條的高度，問你面積最大的矩形的面積
- heights = [2,1,5,6,2,3]



觀察所有邊界最大化的矩形



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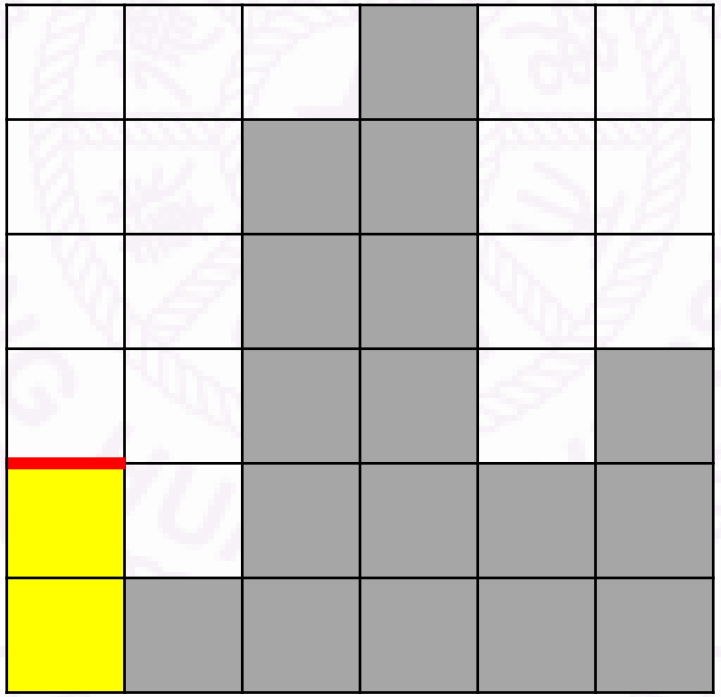

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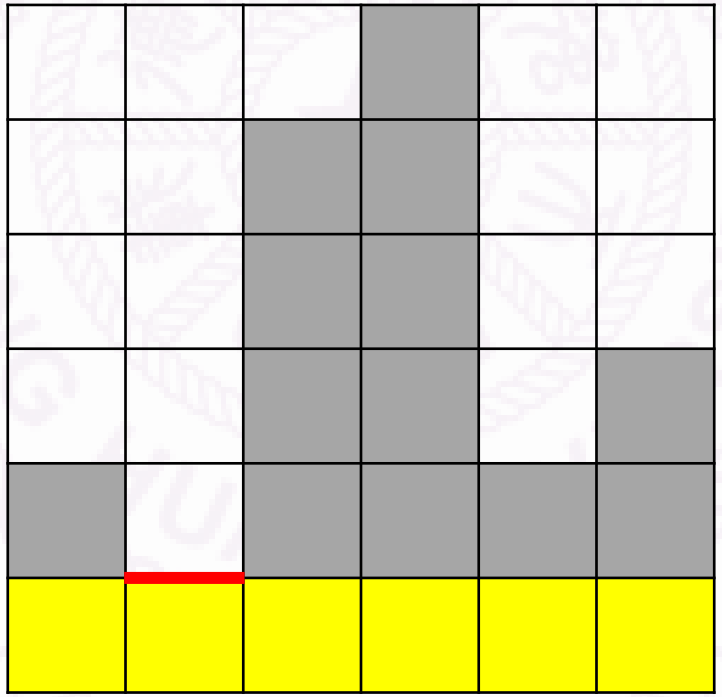

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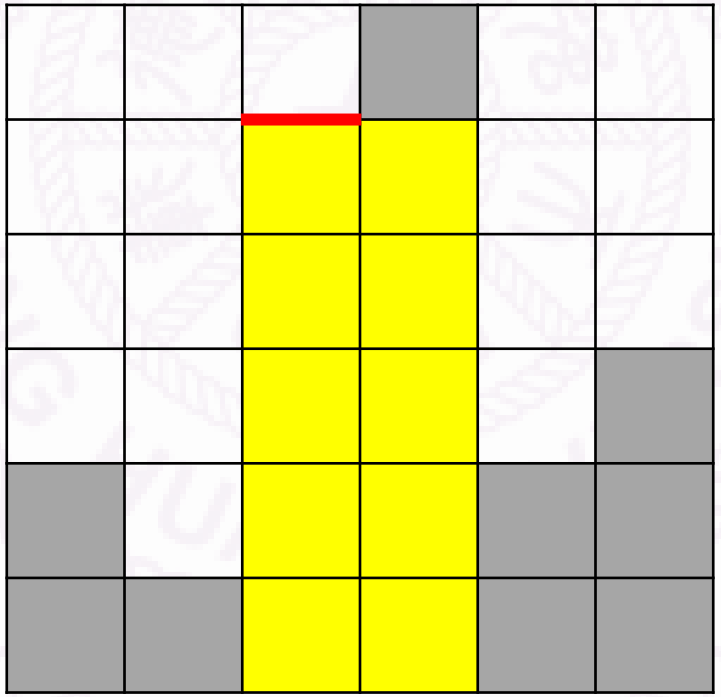

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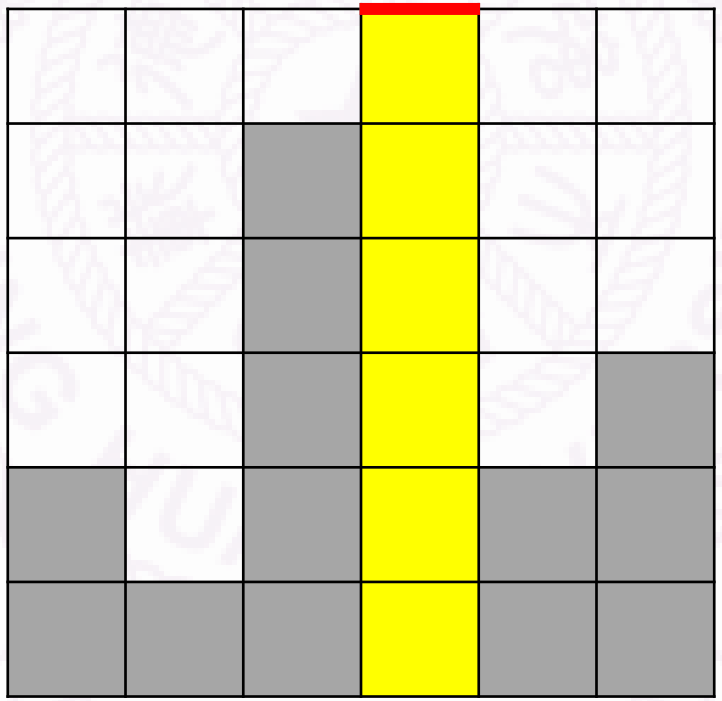

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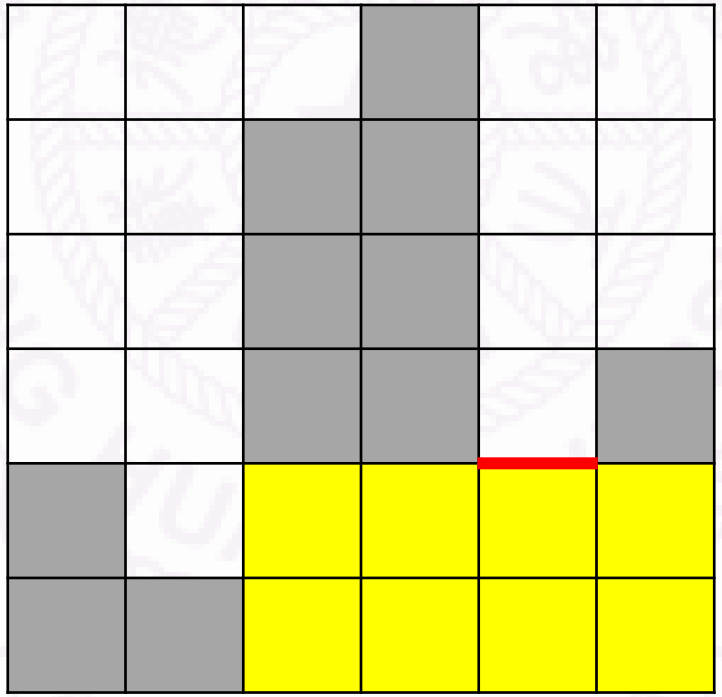

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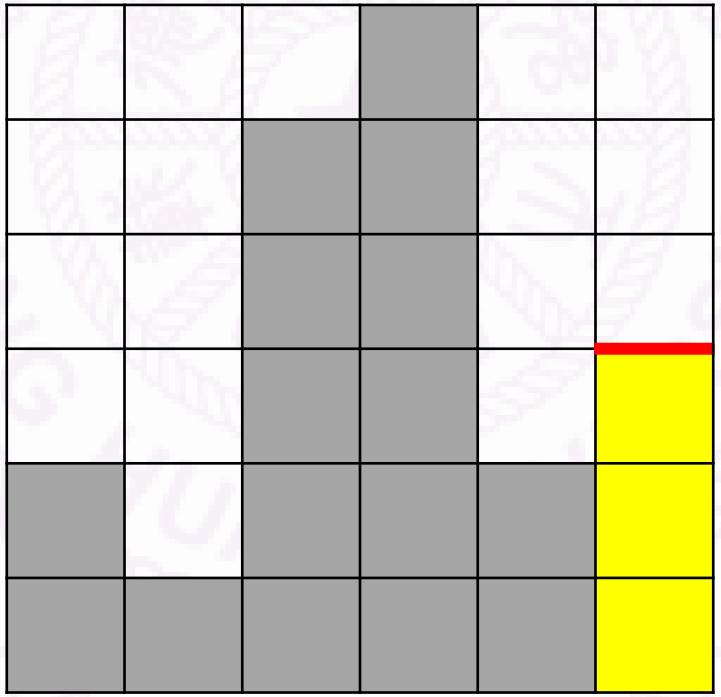
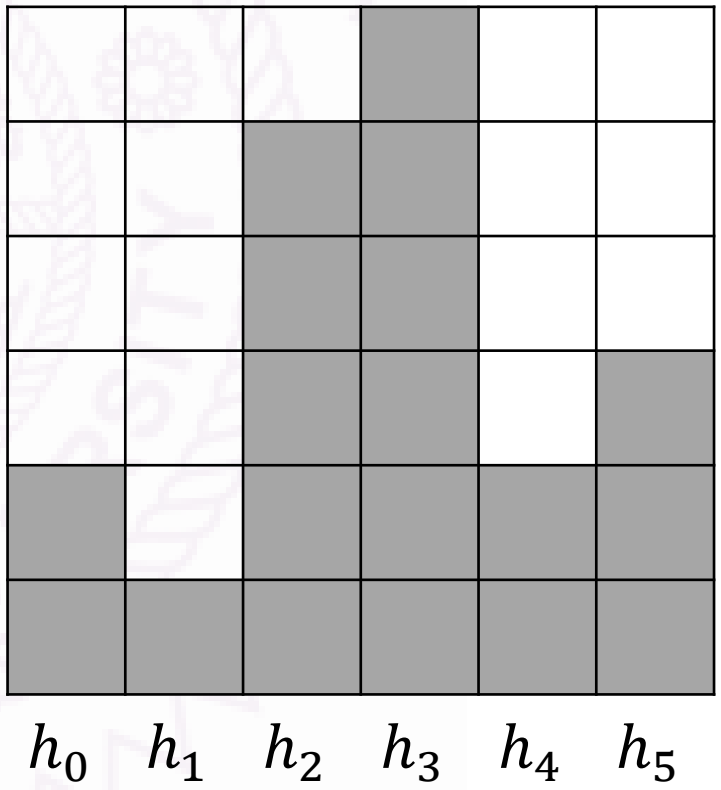


性質

邊界最大化的矩形最多只有 n 個

去除不可能成為答案的「區域」

- 由左到右依序加入長條
- 每個長條被加入時
  將左邊比他高的部分「砍掉」



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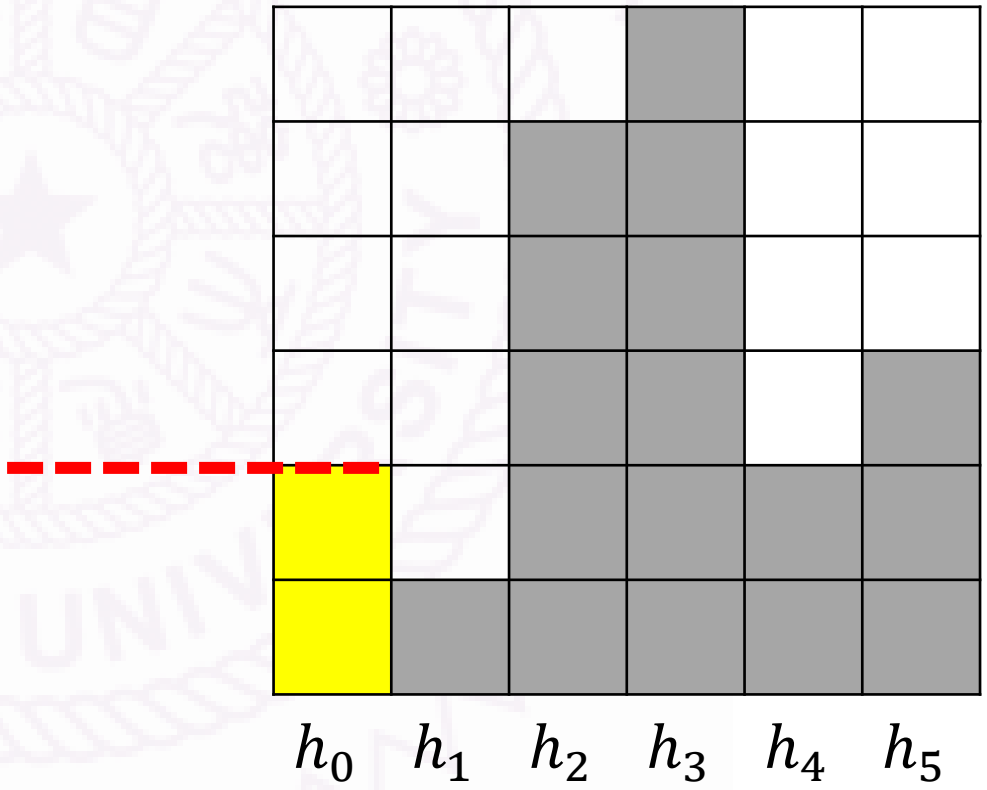

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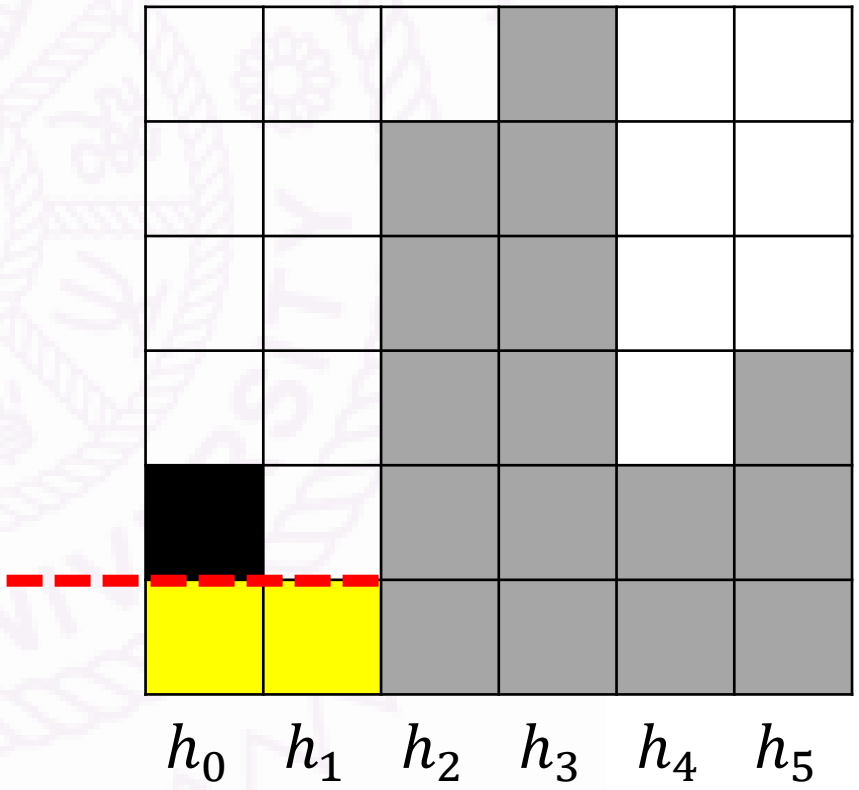

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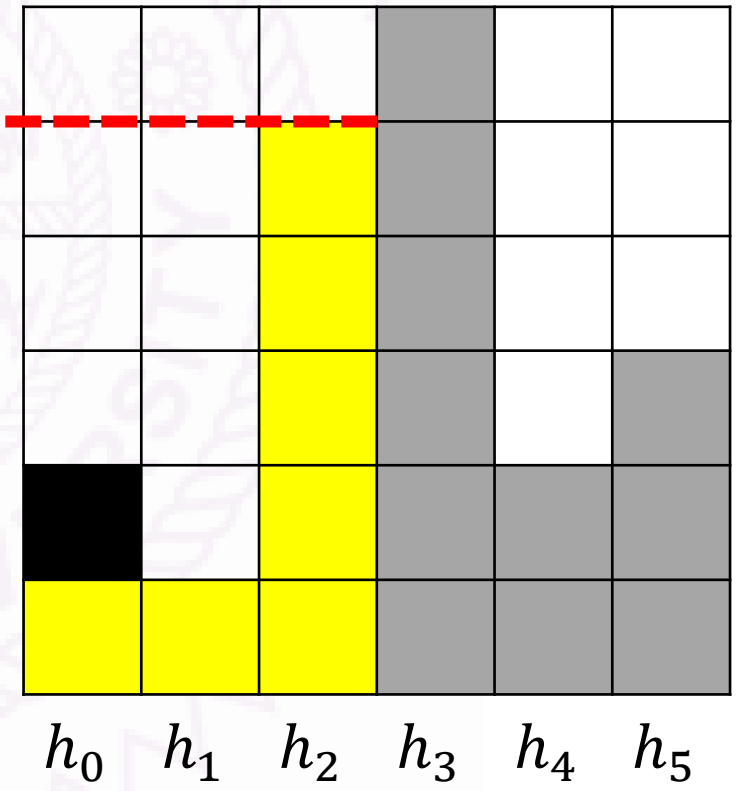

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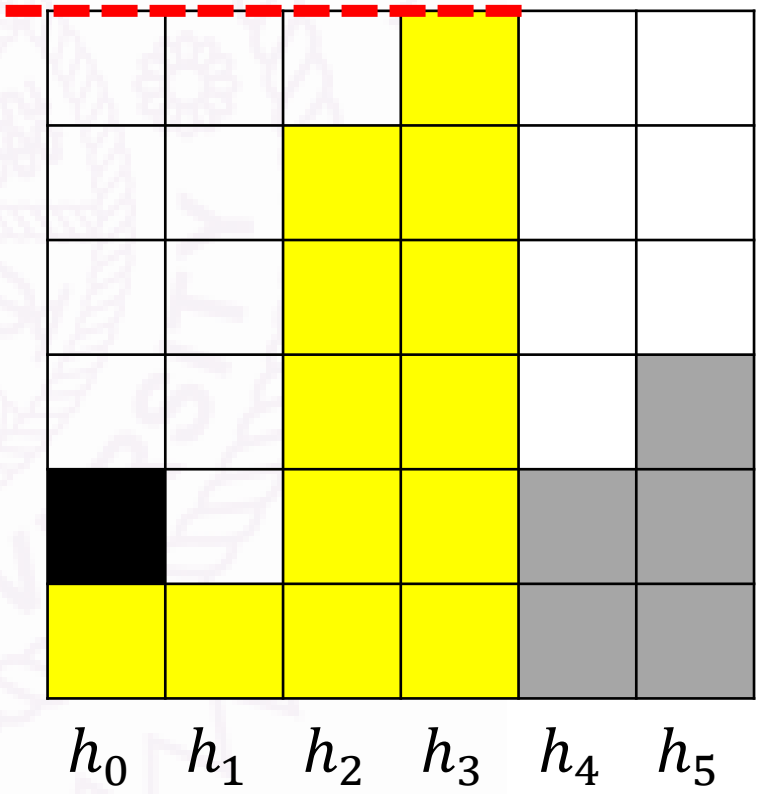

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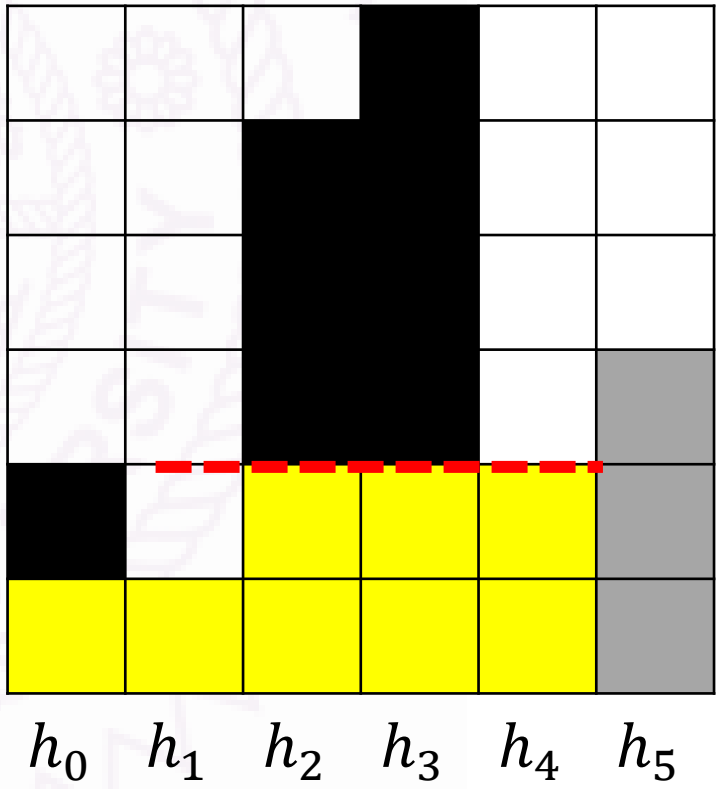

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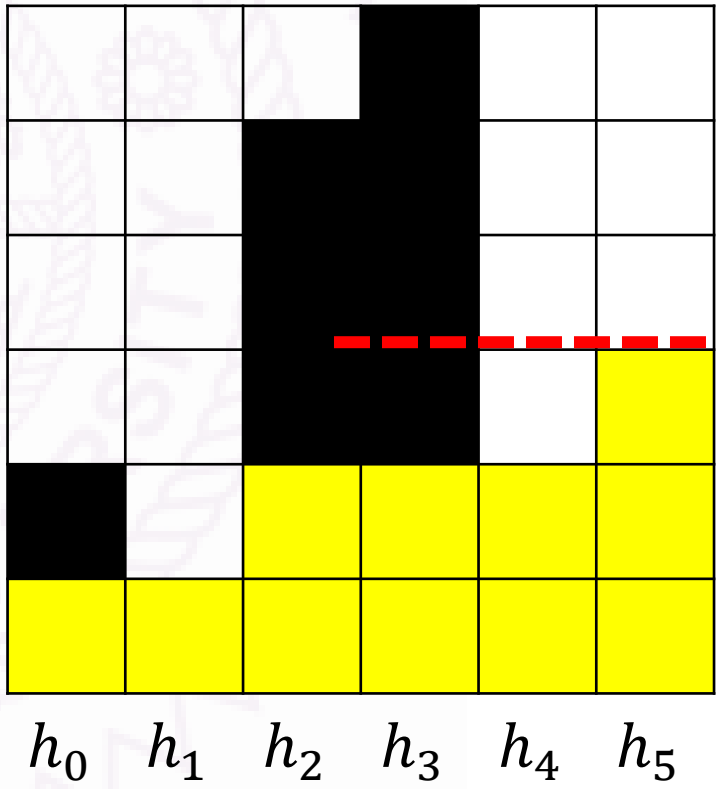

維護輪廓

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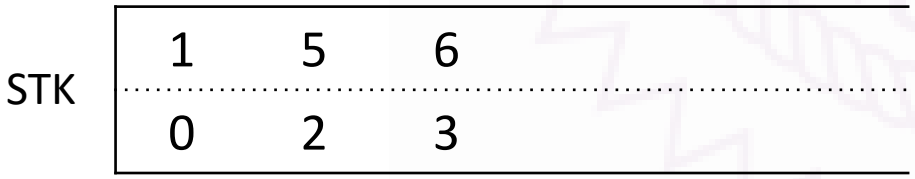

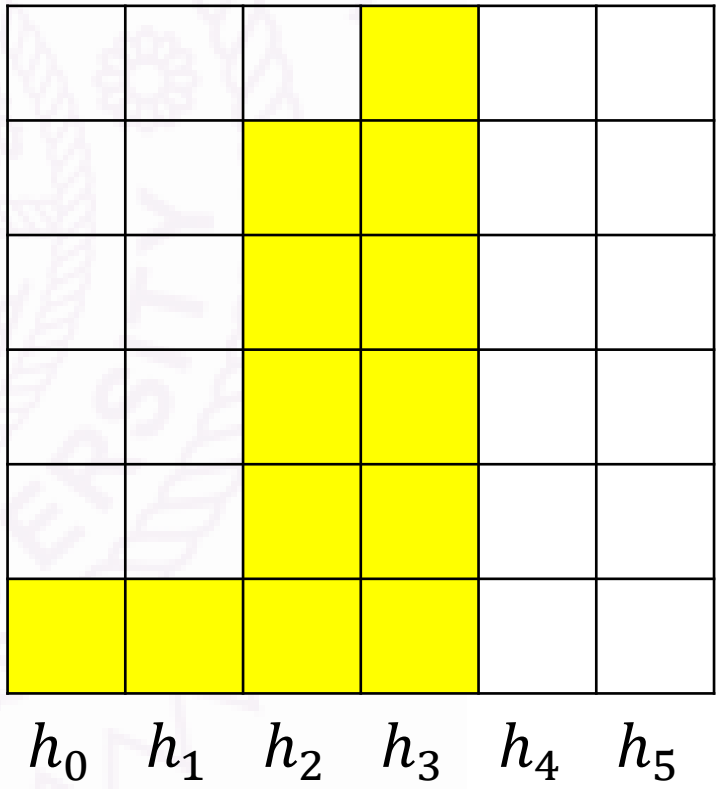

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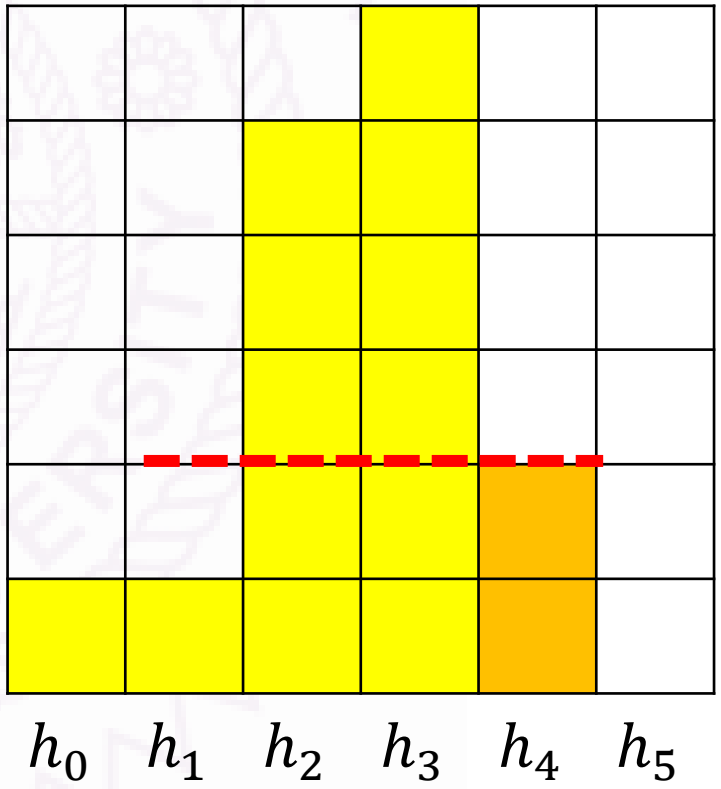
2
4

STK

1	5	6
0	2	3



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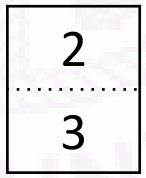
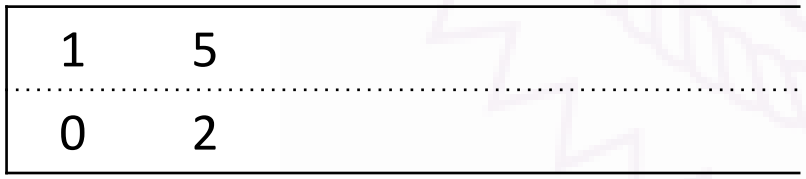
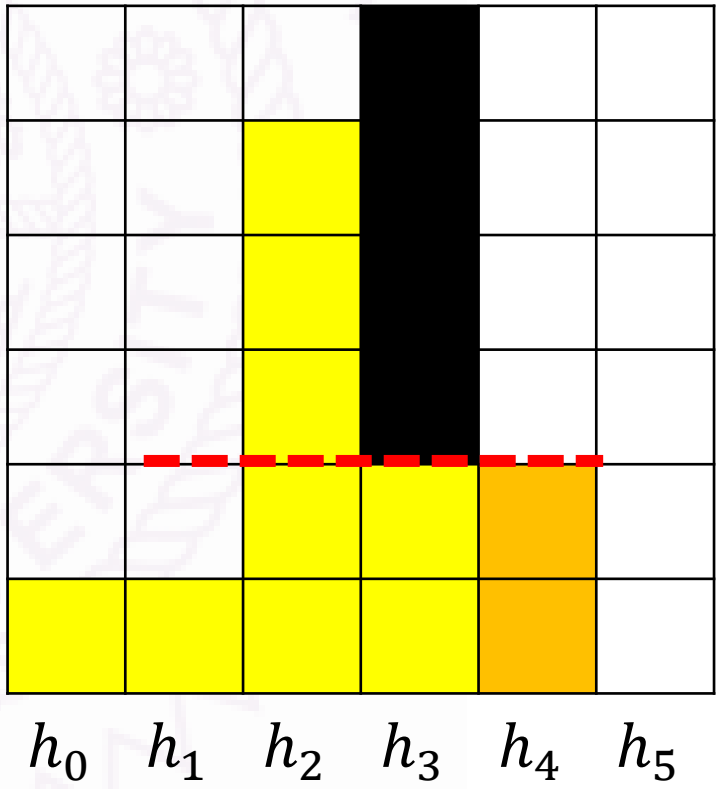


STK





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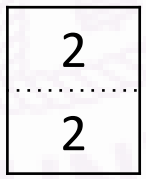
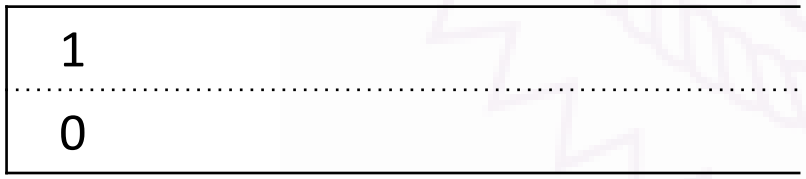
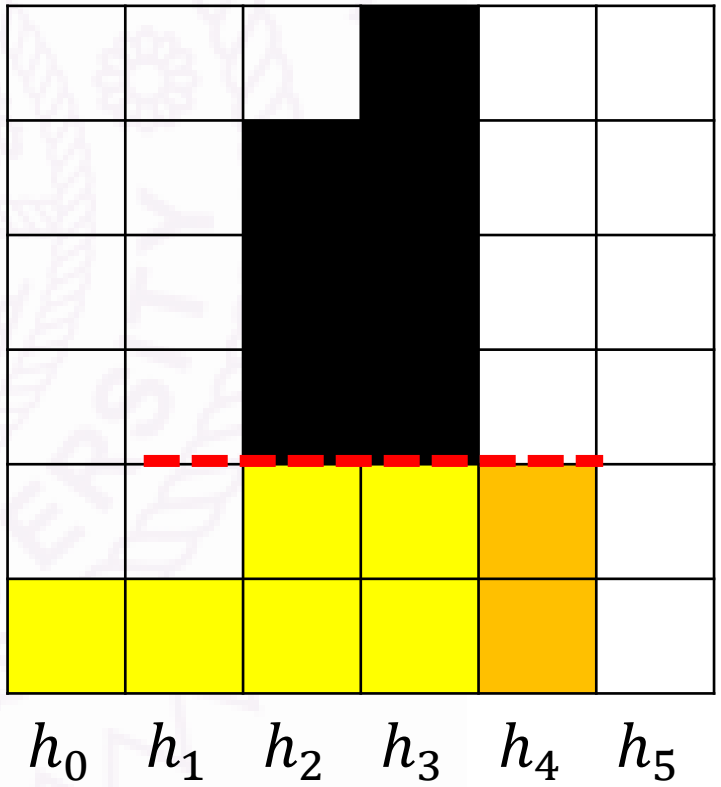


STK





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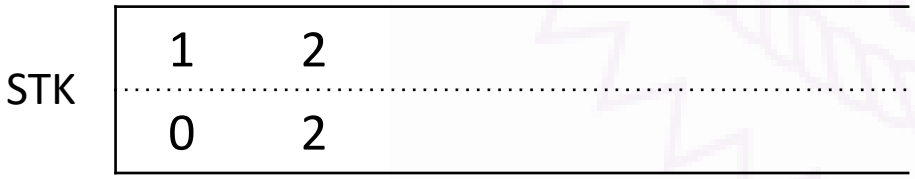
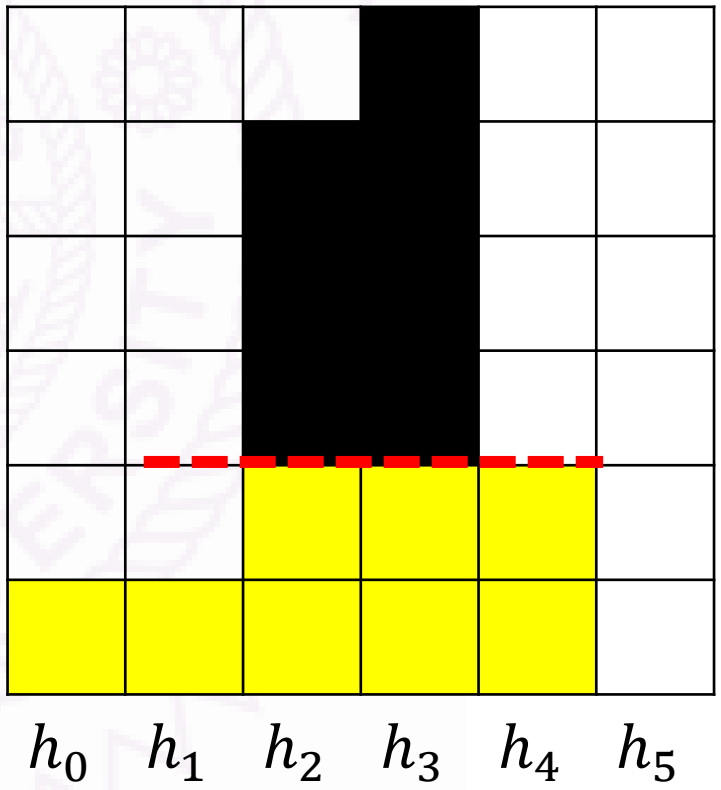
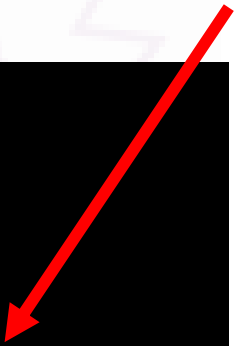




Stack $O(n)$ 維護輪廓

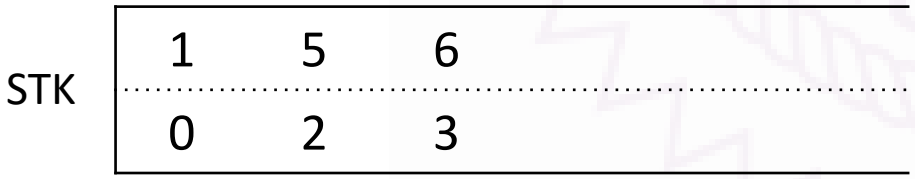
要考慮兩根一樣長的長條

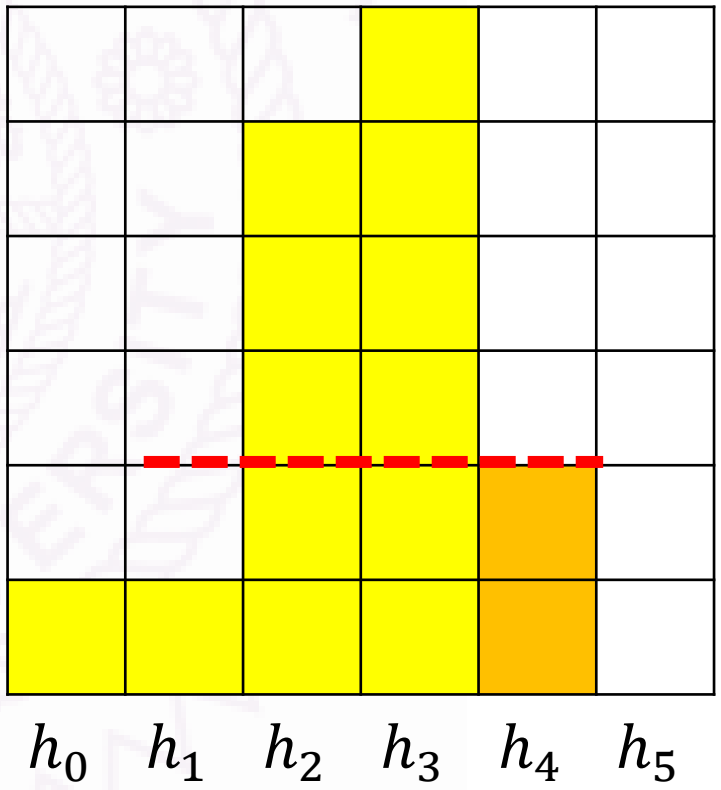


```cpp
long long maxRectangle(vector<int> h) {
  stack<pair<int, int>> STK;
  long long ans = 0;
  for (int i = 0; i < (int)h.size(); ++i) {
    int corner = i;
    while (STK.size() && STK.top().first >= h[i]) {
      corner = STK.top().second;
      STK.pop();
    }
    STK.emplace(h[i], corner);
  }
  return ans;
}
```

找出邊界最大化的矩形

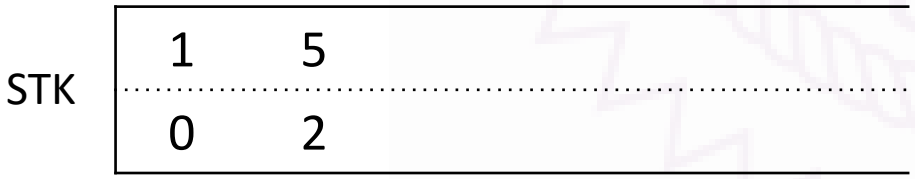
- 邊界最大化的矩形一定包含某個轉折點

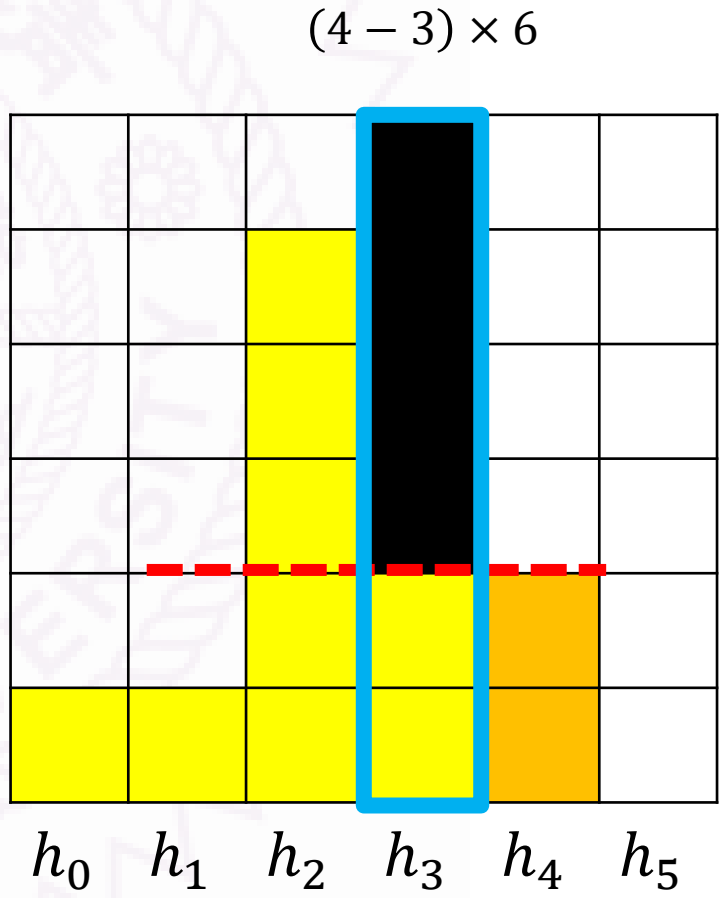




找出邊界最大化的矩形

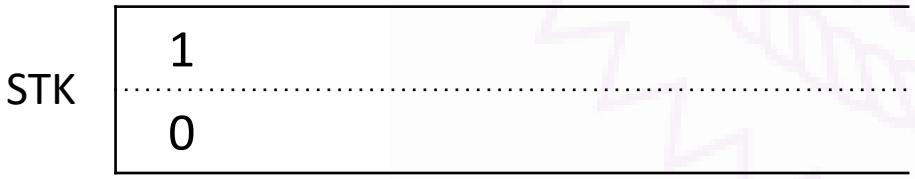
- 邊界最大化的矩形一定包含某個轉折點
- 轉折點被刪除時就能確定邊界最大化的矩形的位置

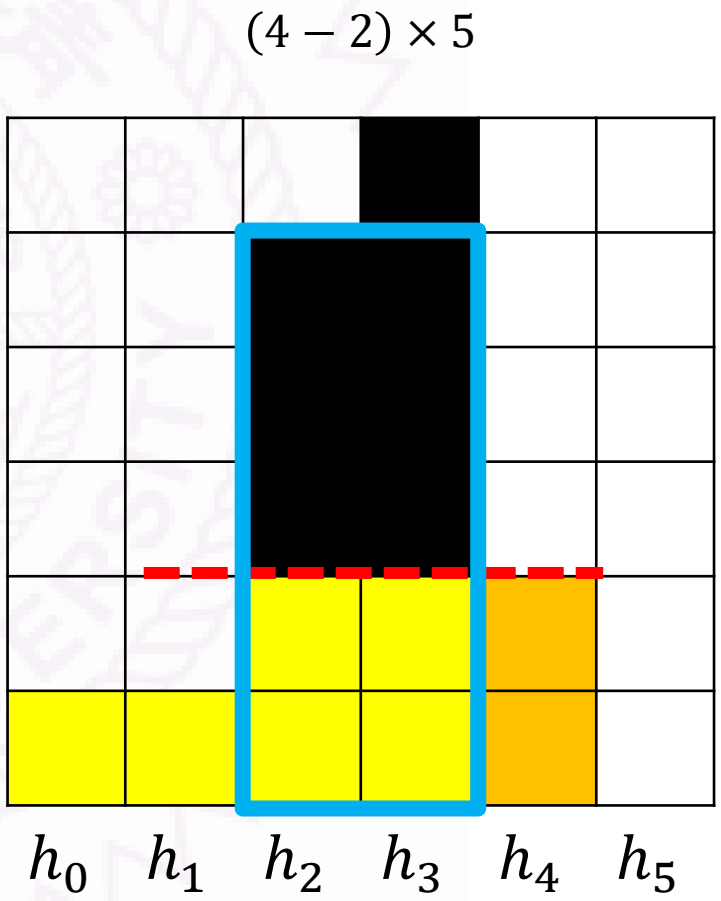




找出邊界最大化的矩形

- 邊界最大化的矩形一定包含某個轉折點
- 轉折點被刪除時就能確定邊界最大化的矩形的位置





多加兩行就能 $O(n)$ 計算答案

為了最後能刪除所有轉折點

計算當前邊界最大矩形的面積

```
long long maxRectangle(vector<int> h) {
  h.emplace_back(0);
  stack<pair<int, int>> STK;
  long long ans = 0;
  for (int i = 0; i < (int)h.size(); ++i) {
    int corner = i;
    while (STK.size() && STK.top().first >= h[i]) {
      corner = STK.top().second;
      ans = max(ans, 1LL * (i - corner) * STK.top().first);
      STK.pop();
    }
    STK.emplace(h[i], corner);
  }
  return ans;
}
```

Monotonic Queue

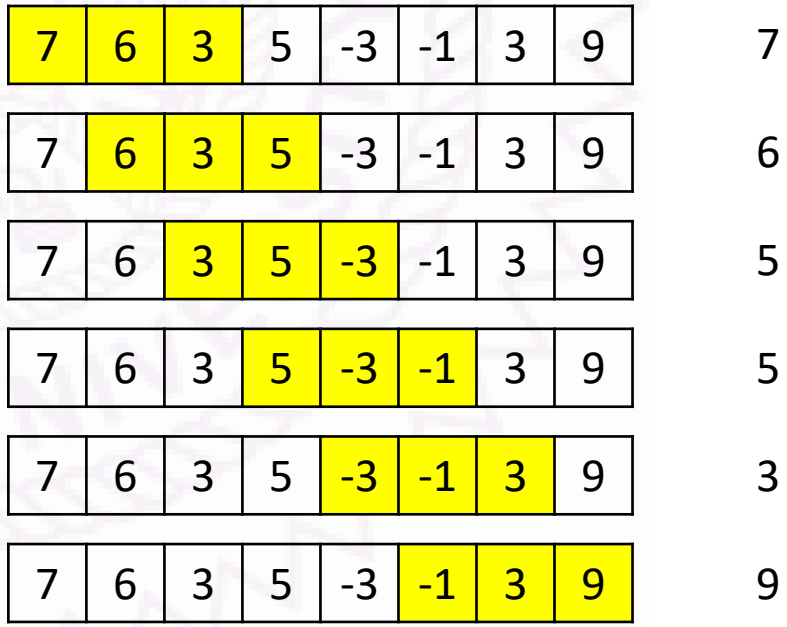
保證 deque 中的值遞增或遞減

去除永遠不可能成為答案的元素

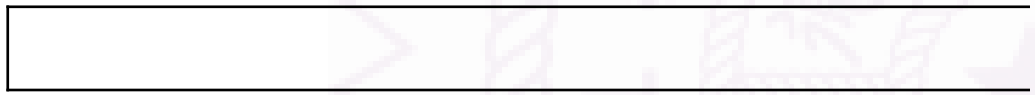
與 stack 最大的差別是可以刪掉頭部

Sliding Window

- https://leetcode.com/problems/sliding-window-maximum/
- 給你 sliding window 的大小，問你輸入陣列中每個 sliding window 的最大值
- Example
- nums = [7,6,3,5,-3,-1,3,9], k = 3
  - ans = [7,6,5,5,3,9]



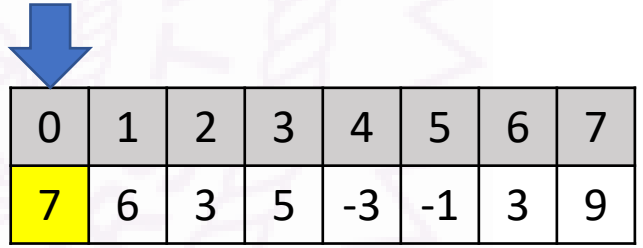
考慮使用遞減的 Monotonic Stack

STK 

0	1	2	3	4	5	6	7
7	6	3	5	-3	-1	3	9

考慮使用遞減的 Monotonic Stack

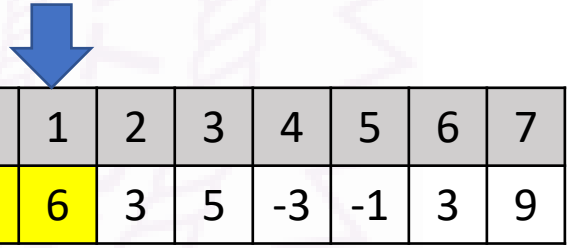
STK | 0



0	1	2	3	4	5	6	7
7	6	3	5	-3	-1	3	9

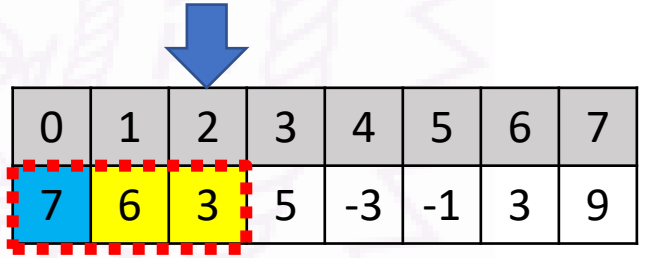
考慮使用遞減的 Monotonic Stack

STK | 0 | 1 |

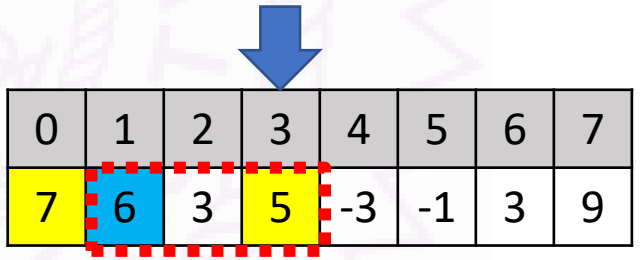


0	1	2	3	4	5	6	7
7	6	3	5	-3	-1	3	9

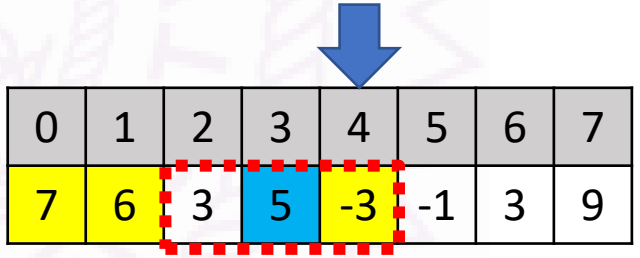
考慮使用遞減的 Monotonic Stack



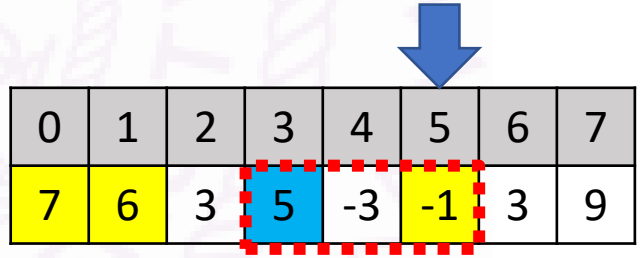
考慮使用遞減的 Monotonic Stack



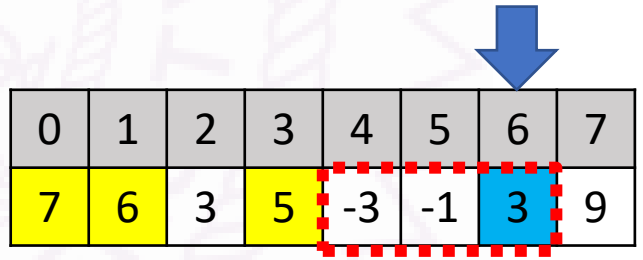
考慮使用遞減的 Monotonic Stack



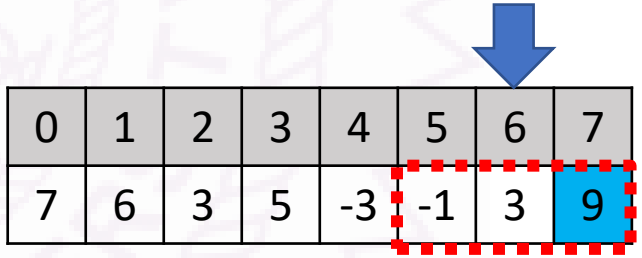
考慮使用遞減的 Monotonic Stack



考慮使用遞減的 Monotonic Stack



考慮使用遞減的 Monotonic Stack



觀察到的性質

- 每個 sliding window 的最大值一定會出現在當前 STK 中
- STK 中的 index 是由小排到大
  nums[index] 由大排到小

利用 Monotonic Stack + Binary Search

```cpp
vector<int> maxSlidingWindow(vector<int> nums, int k) {
  vector<int> STK;
  vector<int> ans;
  for (int i = 0; i < (int)nums.size(); ++i) {
    while (STK.size() && nums[STK.back()] < nums[i])
      STK.pop_back();
    STK.emplace_back(i);
    if (i >= k - 1) {
      auto [L, R] = binarySearch(0, (int)STK.size() - 1,
                                 [&](int mid) { return STK[mid] <= i - k; });
      ans.emplace_back(nums[STK[R]]);
    }
  }
  return ans;
}
```

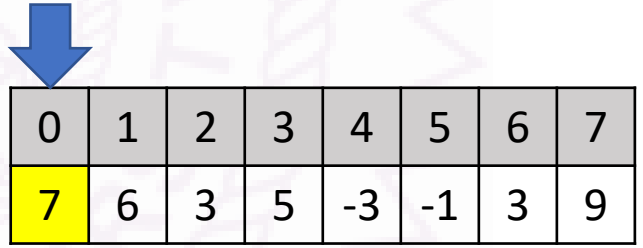
考慮用 Deque 將超出範圍的值刪掉

DQ

0	1	2	3	4	5	6	7
7	6	3	5	-3	-1	3	9

考慮用 Deque 將超出範圍的值刪掉

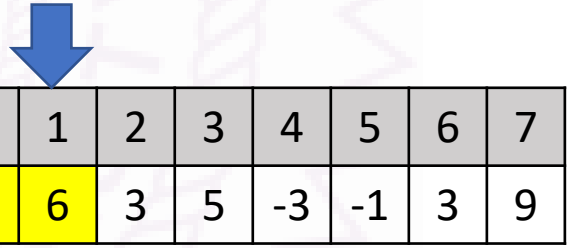
DQ 0



0	1	2	3	4	5	6	7
7	6	3	5	-3	-1	3	9

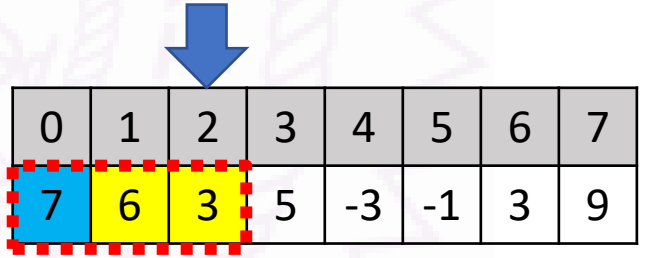
考慮用 Deque 將超出範圍的值刪掉

DQ 0 1

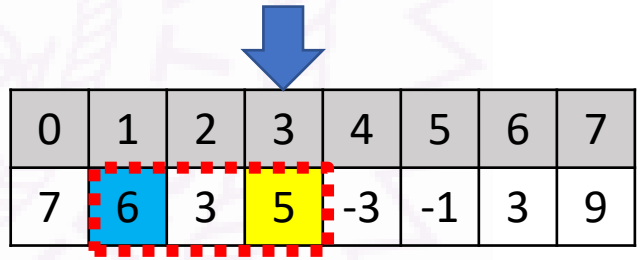


0	1	2	3	4	5	6	7
7	6	3	5	-3	-1	3	9

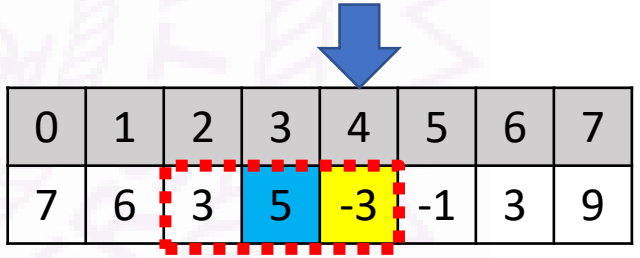
考慮用 Deque 將超出範圍的值刪掉



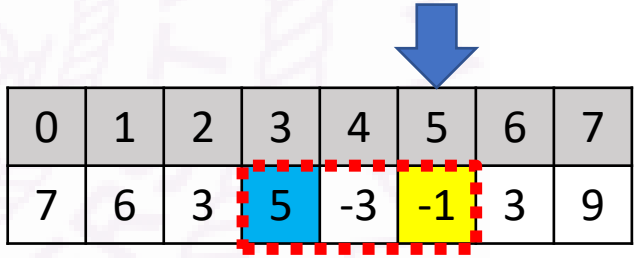
考慮用 Deque 將超出範圍的值刪掉



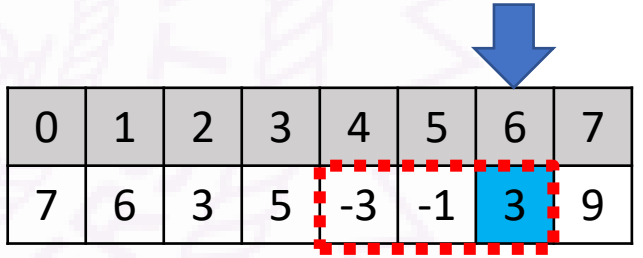
考慮用 Deque 將超出範圍的值刪掉



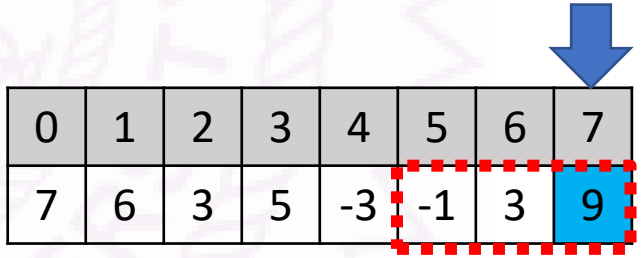
考慮用 Deque 將超出範圍的值刪掉



考慮用 Deque 將超出範圍的值刪掉



考慮用 Deque 將超出範圍的值刪掉



$O(n)$ 四個部分

根據不同題目性質
計算當前答案有能出現在
兩個刪除之間

```cpp
vector<int> maxSlidingWindow(vector<int> &nums, int k) {
  deque<int> DQ;
  vector<int> ans;
  for (int i = 0; i < (int)nums.size(); ++i) {
    while (DQ.size() && DQ.front() <= i - k)
      DQ.pop_front();

    while (DQ.size() && nums[DQ.back()] < nums[i])
      DQ.pop_back();

    DQ.emplace_back(i);

    if (i >= k - 1)
      ans.emplace_back(nums[DQ.front()]);
  }
  return ans;
}
```