程式各種問題與 STL 1

日月卦長

時間限制

A. Another A+B Problem

time limit per test: 1 second
memory limit per test: 1024 megabytes
input: standard input
output: standard output

A. DFS Order

time limit per test: 3 seconds
memory limit per test: 1024 megabytes
input: standard input
output: standard output

Time Limit Exceeded (TLE)

Time Limit Exceeded	2022-NCPC-Pre-B	1999ms	
Time Limit Exceeded	2022-NCPC-Pre-B	2000ms	
Time Limit Excee	W2-3	997ms	3MB
Time Limit Excee	W2-3	996ms	3MB
Time Limit Excee	W2-3	997ms	3MB
Time Limit Excee	W2-3	996ms	3MB

CPU 的速度 – 每秒鐘可以做幾次運算

產品名稱	狀態	推出日期	核心數量	最大超頻	處理器基礎頻率	快取記憶體	散熱設計功耗	處理器繪圖 ‡
Intel® Core™ i5-7300HQ 處理器 (6M 快取記憶體，最高 3.50 GHz)	Launched	Q1'17	4	3.50 GHz	2.50 GHz	6 MB	45 W	Intel® HD Graphics 630

3.5GHz ➔ 每秒最多執行 3.5×10^9 個指令

測試：你的電腦要跑多久?

```
#include <chrono>
using namespace std;
double speed(int iter_num) {
  const int block_size = 1024;
  volatile int A[block_size];
  auto begin = chrono::high_resolution_clock::now();
  while (iter_num--)
    for (int j = 0; j < block_size; ++j)
      A[j] += j;
  auto end = chrono::high_resolution_clock::now();
  chrono::duration<double> diff = end - begin;
  return diff.count();
}
```

如何計算程式的速度

大概就好(使用複雜度)

- 簡單快速
- 忽略不必要的常數

精確計算每個指令

- 非常難算

估計程式的執行時間

- 假設電腦每運行一行程式會耗費 1 個單位時間 t
  - t 的大小由 CPU 效能決定，通常是 10^{-9}~10^{-6} 之間

```
void f1() {
    int x = 99999; // 耗費 1 t
    cout << x << endl; // 耗費 1 t
}
```

總共花費 $(1+1)t = 2t$

估計程式的執行時間

- 假設電腦每運行一行程式會耗費 1 個單位時間 t
  - t 的大小由 CPU 效能決定，通常是 10^{-9}~10^{-6} 之間

```
void f2() {
    int x = 0; // 耗費 1 t
    for (int i = 0; i < 100; ++i) { // 耗費 100 t，因為重複了 100 次
        ++x; // 耗費 100 t，因為重複了 100 次
    }
    cout << x << endl; // 耗費 1 t
}
```

總共花費 $(1 + 100 + 100 + 1)t = (202)t$

更加複雜的例子

```
void f3(int n) {
    int x = 0; // 耗費 1 t
    for (int i = 0; i < n; ++i) { // 耗費 n t，因為重複了 n 次
        ++x; // 耗費 n t，因為重複了 n 次
    }
    cout << x << endl; // 耗費 1 t
}
```

總共花費 $(1 + n + n + 1)t = (2n + 2)t$

更加複雜的例子

```
int f4(int n) {
    int x = 0; // 耗費 1 t
    for (int i = 0; i < n; ++i) { // 耗費 n t
        for (int j = 0; j < n; ++j) { // 耗費 n*n t
            x += i * j; // 耗費 n*n t
        }
    }
    return x; // 耗費 1 t
}
```

總共花費 $(1 + n + n^2 + n^2 + 1)t = (2n^2 + n + 2)t$

比較

function f1	• 消耗了$2t$
function f2	• 消耗了$202t$
function f3	• 消耗了$(2n+2)t$
function f4	• 消耗了$(2n^2+n+2)t$

- 運行速度是 f1 比 f2 快
- f3、f4 則要看 n 的大小決定
- 這樣精準估計非常麻煩
  如何更加簡單的比較程式的快慢呢?

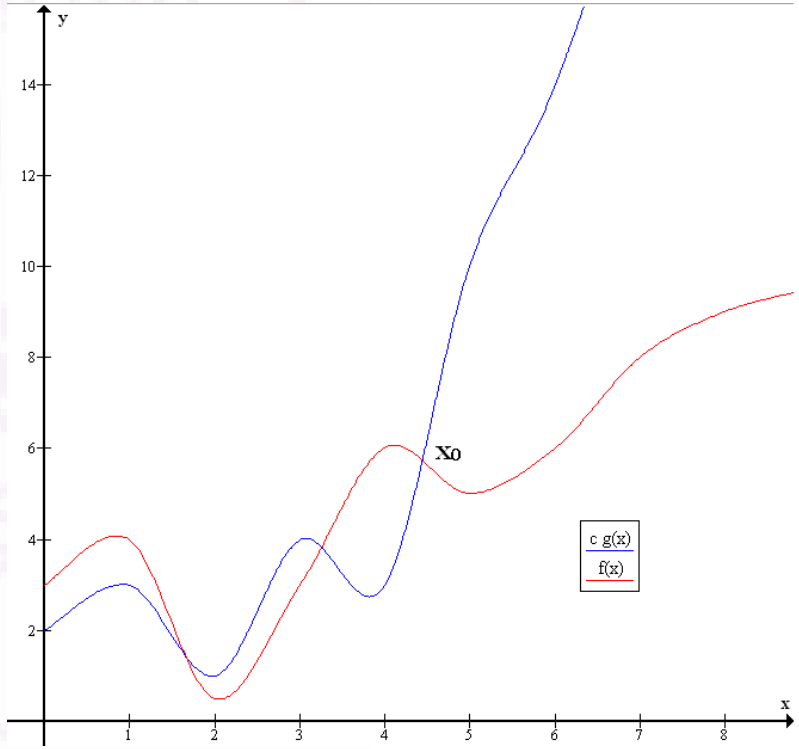
複雜度 – small o notation

- $\forall k > 0, \exists n_0, \forall n > n_0$: $|f(n)| < k \times g(n)$
- 那麼我們就可以說

$$f(x) = o\big(g(x)\big)$$

- Ex: $n^2 + n = o(n^3)$

- 回去翻 Algorithm 課本



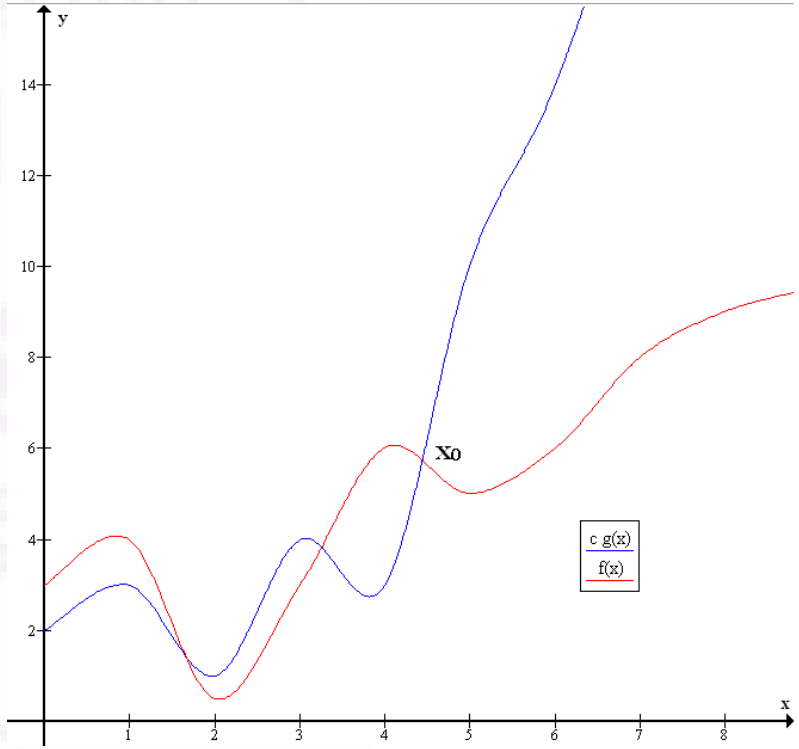
複雜度 – big O notation (最常見)

- $\exists k > 0, \exists n_0, \forall n > n_0$: $|f(n)| \leq k \times g(n)$
- 那麼我們就可以說

$$f(x) = O\big(g(x)\big)$$

- Ex: $n^2 + n = O(n^2)$

- 回去翻 Algorithm 課本



複雜度 – big Ω notation (一般不會討論)

- $\exists k > 0, \exists n_0, \forall n > n_0$: $|f(n)| \geq k \times g(n)$
- 那麼我們就可以說

$$f(x) = \Omega\big(g(x)\big)$$

- Ex: $n^2 + n = \Omega(n)$

複雜度 – big Θ notation (最嚴格)

- 若 $f(x) = O\big(g(x)\big)$ ，且 $g(x) = \Omega\big(f(x)\big)$
  則

$$f(n) = \Theta\big(g(n)\big)$$

- Ex: $n^2 + n = \Theta(n^2)$

複雜度的比較

- 若 $f(x) = O(g(x))$ ，但 $g(x) \neq O(f(x))$
  則可以說 $O(f(n)) < O(g(n))$

- $O(n^n) > O(n!) > O(3^n) > O(2^n) > O(n^4) > O(n^2) > O(n \log n)$

複雜度一些定理

1. $O\left(a_0 + a_1 n + a_2 n^2 + \cdots + a_k n^k\right) = O\left(n^k\right)$
   Ex: $O(10n^2 + 999n + 7122) = O(n^2)$

2. $O\left(f(n) + g(n)\right) = \max\{O\left(f(n)\right), O\left(g(n)\right)\}$
   Ex: $O(n^2 + 2^n) = O(2^n)$

3. $O\left(f(n) \times g(n)\right) = O\left(O\left(f(n)\right) \times O\left(g(n)\right)\right)$
   Ex: $O\left((99n^2 + n) \times (7n^3 + n^2 + 2n + 2)\right) = O(n^5)$

常數時間

- 如果某個步驟執行的基本運算次數是固定的
  我們稱其為常數時間
- 變數存取、基本變數運算 $(+-\times\div)$ 等通常會被當成常數時間

- 記為 $O(1)$

- $O(1) + O\big(f(n)\big) = O\big(f(n)\big)$
- $O(1) \times O\big(f(n)\big) = O\big(f(n)\big)$

時間複雜度計算

function f1	• 消耗了$2t = O(1)$
function f2	• 消耗了$202t = O(1)$
function f3	• 消耗了$(2n + 2)t = O(n)$
function f4	• 消耗了$(2n^2 + n + 2)t = O(n^2)$

範例 code

```
int n, g[105][105];
scanf("%d", &n);
for (int i = 0; i < n; ++i) {
  for (int j = 0; j < n; ++j) {
    scanf("%d", &g[i]);
  }
}
for (int k = 0; k < n; ++k)
  for (int i = 0; i < n; ++i)
    for (int j = 0; j < n; ++j)
      if (g[i][k] + g[k][j] < g[i][j])
        g[i][j] = g[i][k] + g[k][j];
```

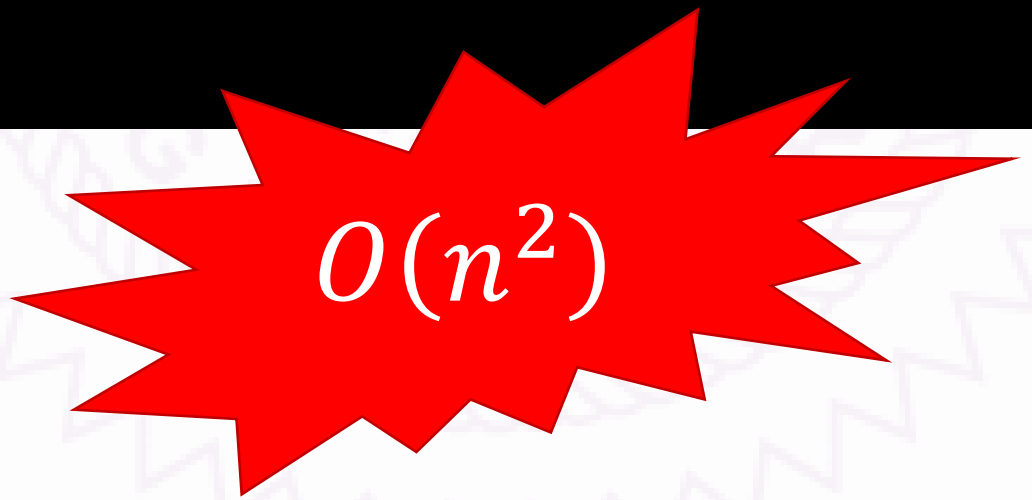
- 這個程式的會先有 $n^2 + 1$ 次的輸入
  然後有 n^3 次的運算
- 總複雜度為 $O(n^2 + 1) + O(n^3) = O(n^3)$
- 其實大部分的程式都可以直接用看的就能
  看出他的時間複雜度是多少
  非常方便

常見不會 TLE 的情況

時間複雜度	通常最大可接受的 n
$O(n!)$	10
$O(2^n)$	20
$O(n^4)$	$50\sim100$
$O(n^3)$	200
$O(n^2)$	3000
$O(n\sqrt{n})$	2×10^5
$O(n\log n)$	$2\times10^6\sim10^7$

時間複雜度與迴圈數量

```
void gnomeSort(int s[], int n) {
  for (int i = 0; i < n; ++i) {
    if (i && s[i] < s[i - 1]) {
      swap(s[i], s[i - 1]);
      i -= 2;
    }
  }
}
```



時間複雜度與遞迴

回朔演算法

- 八皇后等
- 通常難以估計
- 遇到時要靠經驗猜測是否會 TLE

分治演算法

- 列出遞迴關係式後用一些工具(例如主定理)求解

動態規劃演算法

- 未來會討論

主定理 (通常比賽時都亂猜沒人用)

設遞迴關係式 $T(n) = a \times T\left(\frac{n}{b}\right) + f(n), a \geq 1, b > 1$

情形一

- $\exists \varepsilon > 0, f(n) = O\left(n^{\log_b(a)-\varepsilon}\right)$
- 則 $T(n) = \Theta\left(n^{\log_b a}\right)$

情形二

- $\exists \varepsilon \geq 0, f(n) = \Theta\left(n^{\log_b a} \log^{\varepsilon} n\right)$
- 則 $T(n) = \Theta\left(n^{\log_b a} \log^{\varepsilon+1} n\right)$

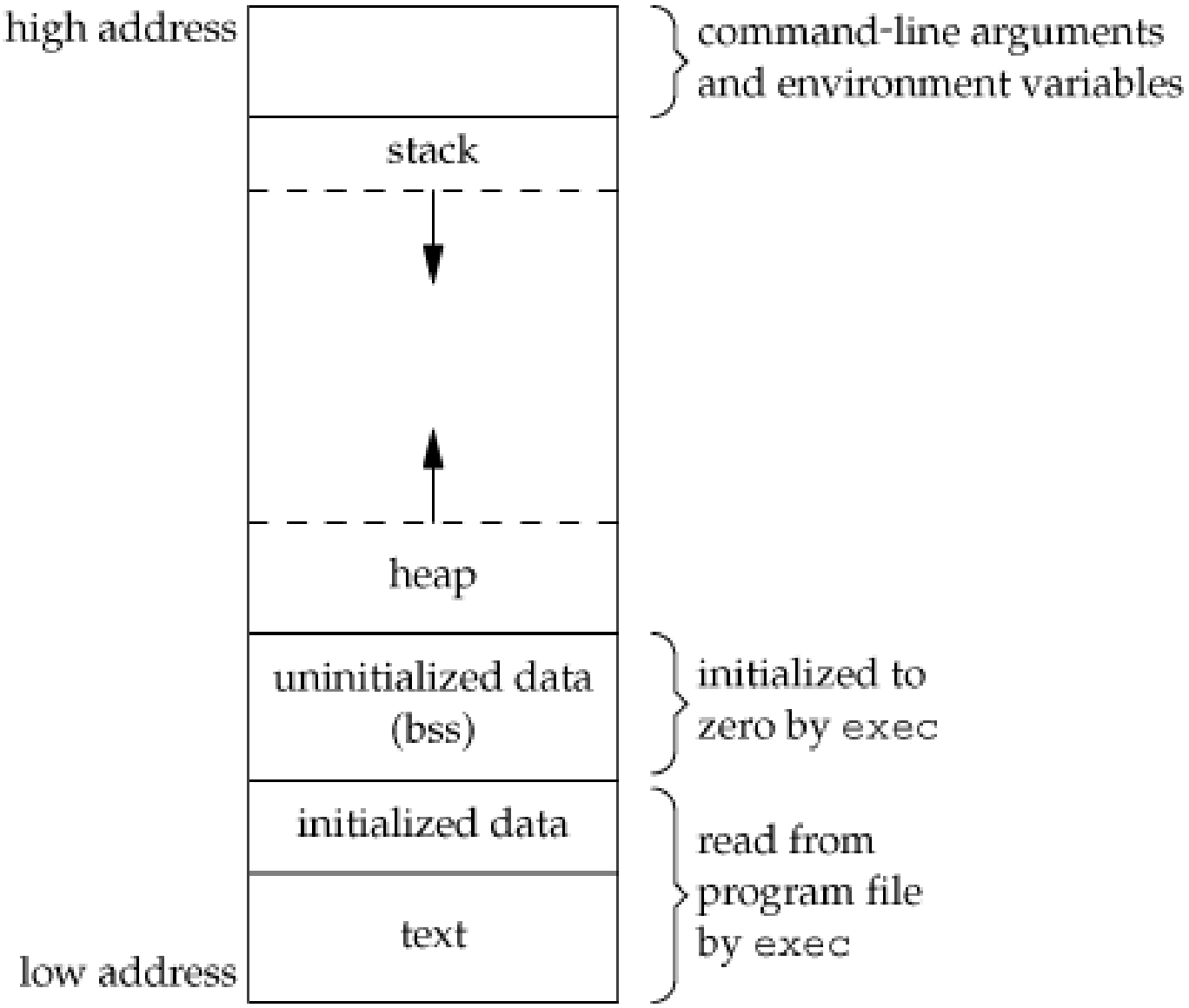
情形三

- $\exists \varepsilon > 0, f(n) = \Omega\left(n^{\log_b(a)+\varepsilon}\right)$，且 $\exists c < 1, \exists n_0, \forall n > n_0 : af\left(\frac{n}{b}\right) \leq cf(n)$
- 則 $T(n) = \Theta\left(f(n)\right)$

Runtime error (RE)

Runtime Error	bracketmatching	1ms	3MB
Runtime Error	bracketmatching	0ms	3MB
Runtime Error	bracketmatching	1ms	3MB
Runtime Error	bracketmatching	1ms	3MB
Runtime Error	bracketmatching	1ms	3MB

Stack 與 Heap


high address
command-line arguments
and environment variables
stack
heap
uninitialized data
(bss)
initialized to
zero by exec
initialized data
text
read from
program file
by exec
low address

Stack Size 測試

```
size_t block_size, bound;
void stack_size_dfs(size_t depth = 1) {
  if (depth >= bound)
    return;
  int8_t ptr[block_size]; // 若無法編譯將 block_size 改成常數
  memset(ptr, 'a', block_size);
  cout << depth << endl;
  stack_size_dfs(depth + 1);
}

void stack_size_and_runtime_error(size_t block_size, size_t bound = 1024) {
  ::block_size = block_size;
  ::bound = bound;
  stack_size_dfs();
}
```

Linux 可以直接求出 Stack size limit

```
#include <sys/resource.h>
void print_stack_limit() { // only work in Linux
  struct rlimit l;
  getrlimit(RLIMIT_STACK, &l);
  cout << "stack_size = " << l.rlim_cur << " byte" << endl;
}
```

Runtime error ➔
Time Limit Exceeded?

製造 Segmentation fault

```
void runtime_error_1() {
  // Segmentation fault
  int *ptr = nullptr;
  *(ptr + 7122) = 7122;
}
```

```
void runtime_error_2() {
  // Segmentation fault
  int *ptr = (int *)memset;
  *ptr = 7122;
}
```

製造 invalid pointer

```
void runtime_error_3() {
  // munmap_chunk(): invalid pointer
  int *ptr = (int *)memset;
  delete ptr;
}
```

```
void runtime_error_4() {
  // free(): invalid pointer
  int *ptr = new int[7122];
  ptr += 1;
  delete[] ptr;
}
```

製造 Floating point exception

```
void runtime_error_5() {
  // maybe illegal instruction
  int a = 7122, b = 0;
  cout << (a / b) << endl;
}
```

```
void runtime_error_6() {
  // floating point exception
  volatile int a = 7122, b = 0;
  cout << (a / b) << endl;
}
```

製造 Aborted

```
void runtime_error_7() {
  // call to abort.
  assert(false);
}
```

測機時間

- 測機時可以用最簡單的題目檢查
  1. Judge 執行速度
  2. Stack size limit
  3. RE 會不會被判斷成 TLE

- 打包整理過的測機模板
- https://gist.github.com/jacky860226/cbd6d9d0d4e36a48aa3487d4bf578071

STL 1

bitset, vector, deque 以及一些常用函數

STL 簡介

Container

- <array>
- <deque>
- <forward_list>
- <list>
- <map>
- <queue>
- <set>
- <stack>
- <unordered_map>
- <unordered_set>
- <vector>

Other

- <algorithm>
- <bitset>
- <complex>
- <limits>
- <string>
- <tuple>
- <utility>

STL Container

Array	Linked List	Binary Search Tree	Hash Table
• <array> • <vector> • <deque> • <queue> • <stack>	• <list> • <forward_list>	• <map> • <set>	• <unordered_map> • <unordered_set>

Template 寫給程式設計師的程式

```
template <class T> // template funtion
T func(T x) {
  return x * 2;
}

template <class T> // template class
struct ST {
  T x;
  ST(T x) : x(x) {}
};
```

```
int main() {
  double a = 0.7122;
  int b = 7122;
  cout << func(a) << ' ' << func(b) << endl;

  ST<string> s("ABC");
  cout << s.x << endl;
}
```

std::bitset 位元運算的好工具

```cpp
#include <bitset>
#include <iostream>
using namespace std;

int main() {
  bitset<100> BIT(712271227122LL);
  cout << BIT << endl;
  for (size_t i = 0; i < BIT.size() / 2; ++i)
    BIT[i] = 1;
  cout << BIT << endl;
  cout << (~BIT ^ bitset<100>("1101")) << endl;
  return 0;
}
```

std::bitset 枚舉並印出子集合

```cpp
#include <bitset>
#include <iostream>
using namespace std;

int main() {
  const int n = 4;
  for (int i = 0; i < (1 << n); ++i) {
    cout << bitset<n>(i) << endl;
  }
  return 0;
}
```

```
jacky860226(
0000
0001
0010
0011
0100
0101
0110
0111
1000
1001
1010
1011
1100
1101
1110
1111
```

當心 Runtime Error

bitset 記憶體是放在 stack 裡面的，這樣寫 dfs 內會產生新的 bitset 而有機會 stack overflow

```cpp
constexpr long long MAXN = 50001;
std::vector<int> G[MAXN];
std::bitset<MAXN> visited;
std::array<std::bitset<MAXN>, MAXN> table;
void dfs(int x) {
  if (visited[x]) return;
  table[x] = 0;
  table[x][x] = 1;
  for (auto y : G[x]) {
    dfs(y);
    table[x] |= table[y];
  }
}
```

```cpp
constexpr long long MAXN = 50001;
std::vector<int> G[MAXN];
std::bitset<MAXN> visited;
std::array<std::bitset<MAXN>, MAXN> table;
void dfs(int x) {
  if (visited[x]) return;
  table[x] = std::bitset<MAXN>(0);
  table[x][x] = 1;
  for (auto y : G[x]) {
    dfs(y);
    table[x] |= table[y];
  }
}
```

reset(): 將 bitset 所有 bit 都變成 0

```cpp
constexpr long long MAXN = 50001;
std::vector<int> G[MAXN];
std::bitset<MAXN> visited;
std::array<std::bitset<MAXN>, MAXN> table;
void dfs(int x) {
  if (visited[x]) return;
  table[x].reset();
  table[x][x] = 1;
  for (auto y : G[x]) {
    dfs(y);
    table[x] |= table[y];
  }
}
```

std::tuple 一口氣儲存一堆東西

```cpp
#include <iostream>
#include <tuple>
using namespace std;

int main() {
  tuple<int, double, char> mytuple;
  mytuple = make_tuple(10, 2.6, 'a');

  cout << get<0>(mytuple) << endl;
  cout << get<1>(mytuple) << endl;
  cout << get<2>(mytuple) << endl;
  return 0;
}
```

std::tuple 一口氣儲存一堆東西

```cpp
#include <iostream>
#include <tuple>

int main() {
  std::tuple<int, double, char> mytuple;
  mytuple = std::make_tuple(10, 2.6, 'a');

  int myint;
  char mychar;
  std::tie(myint, std::ignore, mychar) = mytuple;

  std::cout << "myint contains: " << myint << '\n';
  std::cout << "mychar contains: " << mychar << '\n';
  return 0;
}
```

(utility) std::pair 儲存兩個東西

```cpp
#include <iostream>
#include <tuple>
#include <utility>
using namespace std;

int main() {
  pair<int, double> P(1, 0.2);
  cout << P.first << ' ' << P.second << endl;

  P = make_pair('a', 2);

  int A;
  double B;
  tie(A, B) = P;
  cout << A << ' ' << B << endl;
  return 0;
}
```

C++17 Structured binding declaration

```cpp
#include <iostream>
#include <tuple>
#include <utility>
using namespace std;

int main() {
  {
    int A[2] = {1, 2};
    auto [x, y] = A;
    auto &[xr, yr] = A;
    xr = 3, yr = 4;
    cout << x << ' ' << y << endl;
    cout << A[0] << ' ' << A[1] << endl;
  }
  {
    pair<int, double> P(1, 0.2);
    auto [x, y] = P;
  }
  {
    tuple<int, double, char> T(1, 0.2, 'a');
    auto [x, y, z] = T;
  }
  return 0;
}
```

(utility) std::swap 交換兩個東西

```cpp
#include <iostream>
#include <utility>
using namespace std;

int main() {
  int x = 10, y = 20;
  swap(x, y);
  cout << x << ' ' << y << endl;

  int foo[4];
  int bar[] = {10, 20, 30, 40};
  swap(foo, bar);

  cout << "foo contains:";
  for (int i : foo) cout << ' ' << i;
  cout << '\n';
  return 0;
}
```

std::vector / std::deque 強化版陣列

#include<vector>

- 由尾部插入或是刪除資料，可以隨機存取裡面的元素
- 內部陣列大小會自動增長(可能使用倍增法)
- 移除元素時不減少記憶體花費

#include<deque>

- 由頭尾插入或是刪除資料，可以隨機存取裡面的元素
- 內部陣列大小會自動增長(可能使用倍增法)
- 移除元素時會減少記憶體花費

元素存取

	vector/deque
尾巴	back()
頭部	front()
隨機存取	[index]

數量資訊

	vector/deque
裡面是不是空的	empty()
裡面有多少東西	size()

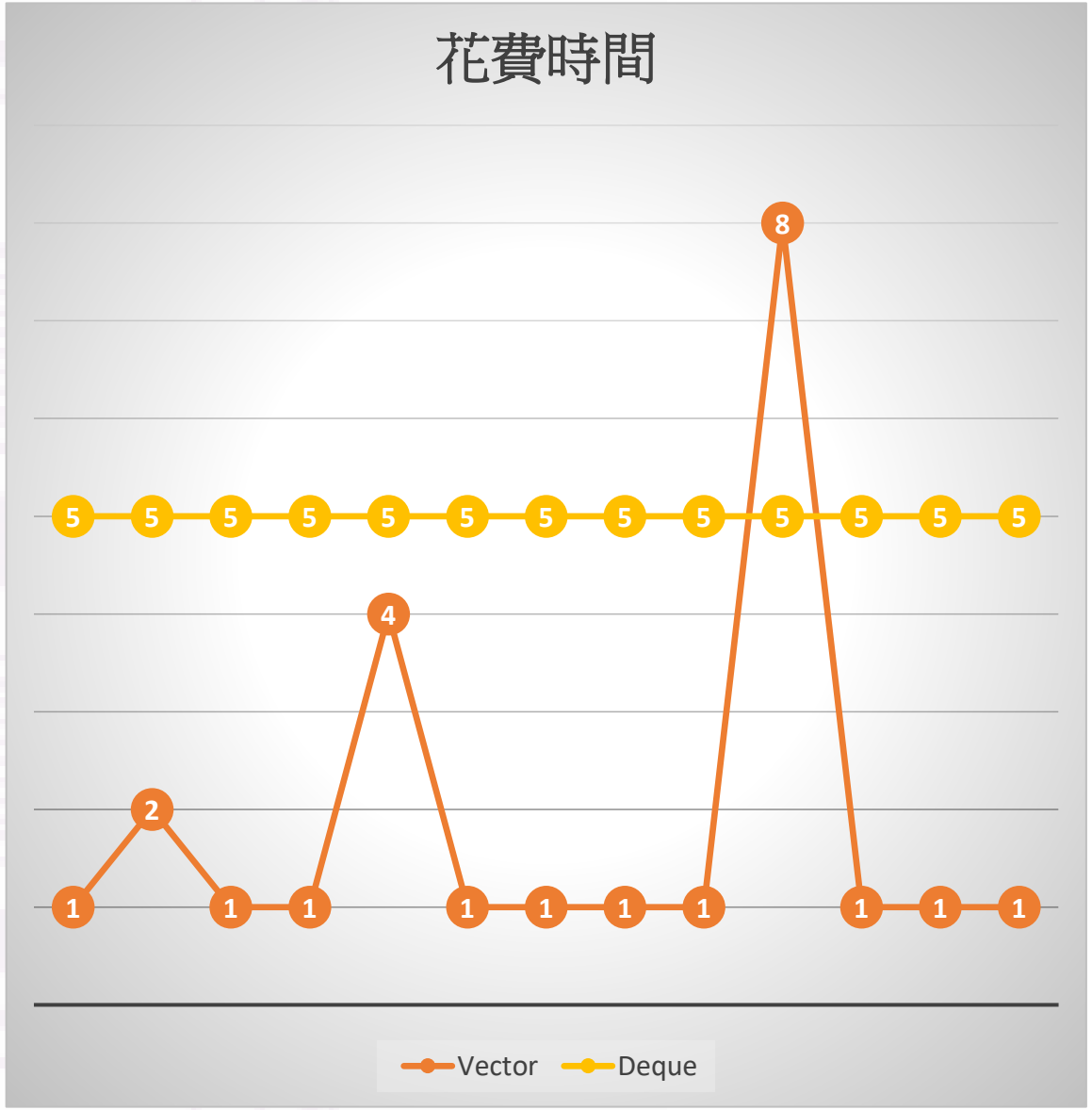
加入元素

- 在C++11以後盡可能使用emplace系列

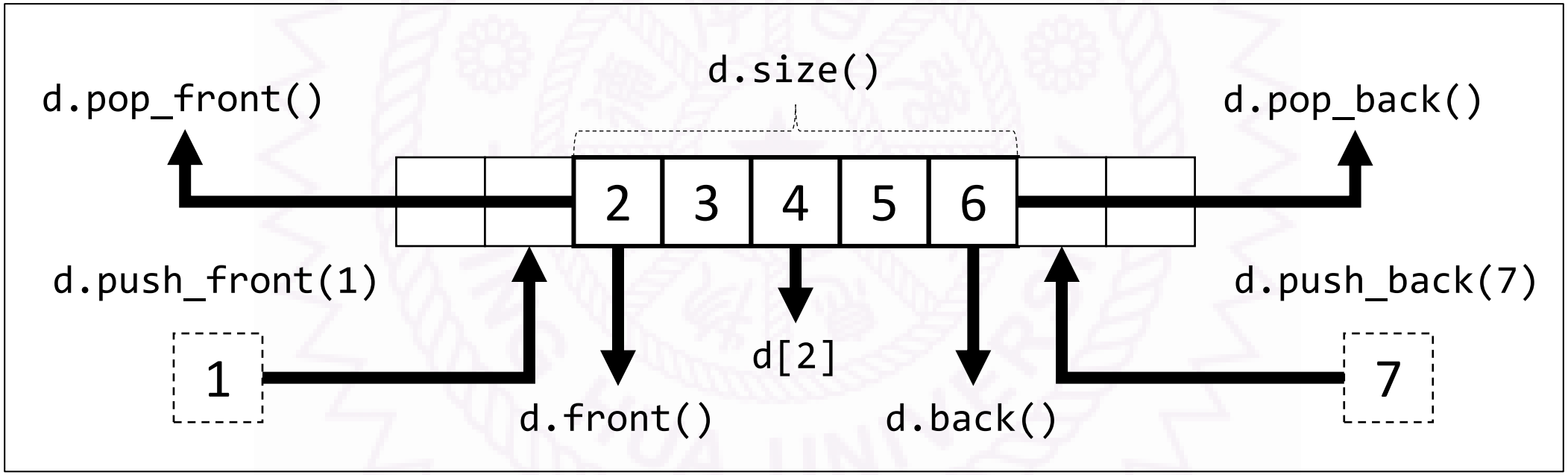
	Vector	Deque
在尾部加入	push_back(d)	push_back(d)
在尾部加入(inplace)	emplace_back(d...)	emplace_back(d...)
在尾部刪除	pop_back()	pop_back()
在頭部加入		push_front()
在頭部加入(inplace)		emplace_front(d...)
在頭部刪除		pop_front()
花費時間	均攤$O(1)$	$O(1)$

均攤複雜度

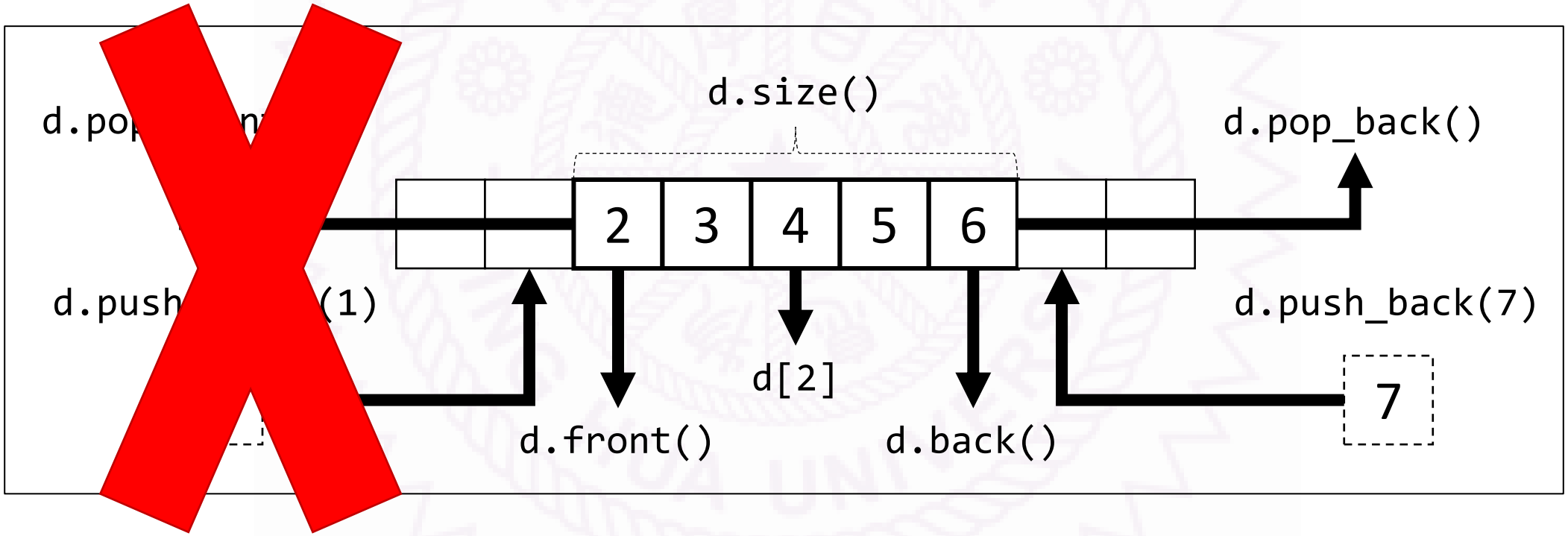
- 指經由多次操作後，整體的複雜度
  - Vector 一次操作：最快 $O(1)$，最慢 $O(n)$，但是平均來說是 $O(1)$
  - Deque 一次操作：都是 $O(1)$，但是有點慢的那種



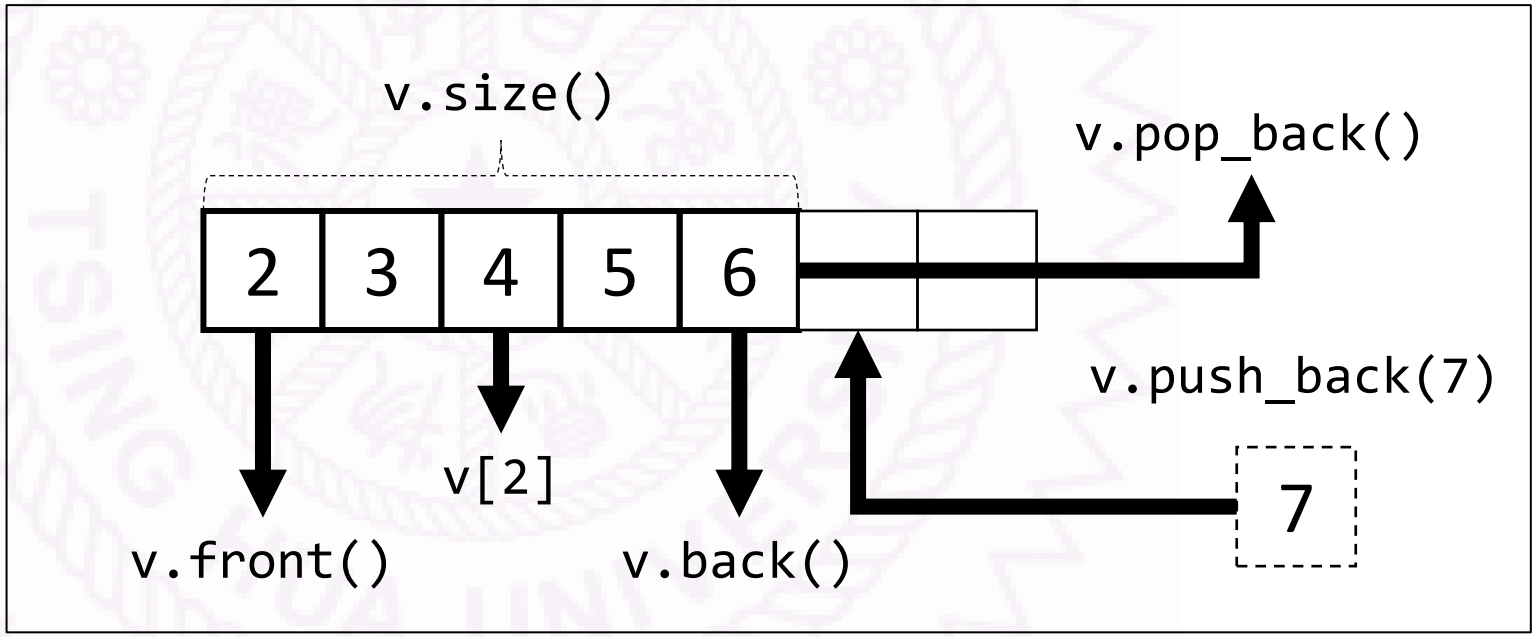
deque


d.size()
d.pop_front()
d.pop_back()
2
3
4
5
6
d.push_front(1)
d.push_back(7)
1
d[2]
7
d.front()
d.back()

vector



vector



vector 使用範例

```cpp
#include <iostream>
#include <vector>
using namespace std;

int main() {
  vector<int> V1{1, 2, 3}; // [1,2,3]
  vector<int> V2(5, 0);    // [0,0,0,0,0]
  vector<int> V3;          // []

  V1.pop_back();
  for (size_t i = 0; i < V1.size(); ++i)
    V3.emplace_back(V1[i]);
  for (size_t i = 0; i < V2.size(); ++i)
    V3.emplace_back(V2[i]);
  for (size_t i = 0; i < V3.size(); ++i)
    cout << V3[i] << '\n';
  return 0;
}
```

Terminal

```
1
2
0
0
0
0
0
```

emplace vs push

```
vector<pair<int, int>> V;
V.emplace_back(1, 2);
V.emplace_back(3, 4);
for (size_t i = 0; i < V.size(); ++i)
  cout << V[i].first << ' ' << V[i].second << '\n';
```

```
vector<pair<int, int>> V;
pair<int, int> P(1, 2);
V.push_back(P);
V.push_back(make_pair(3, 4));
for (size_t i = 0; i < V.size(); ++i)
  cout << V[i].first << ' ' << V[i].second << '\n';
```

resize、clear $O(n)$

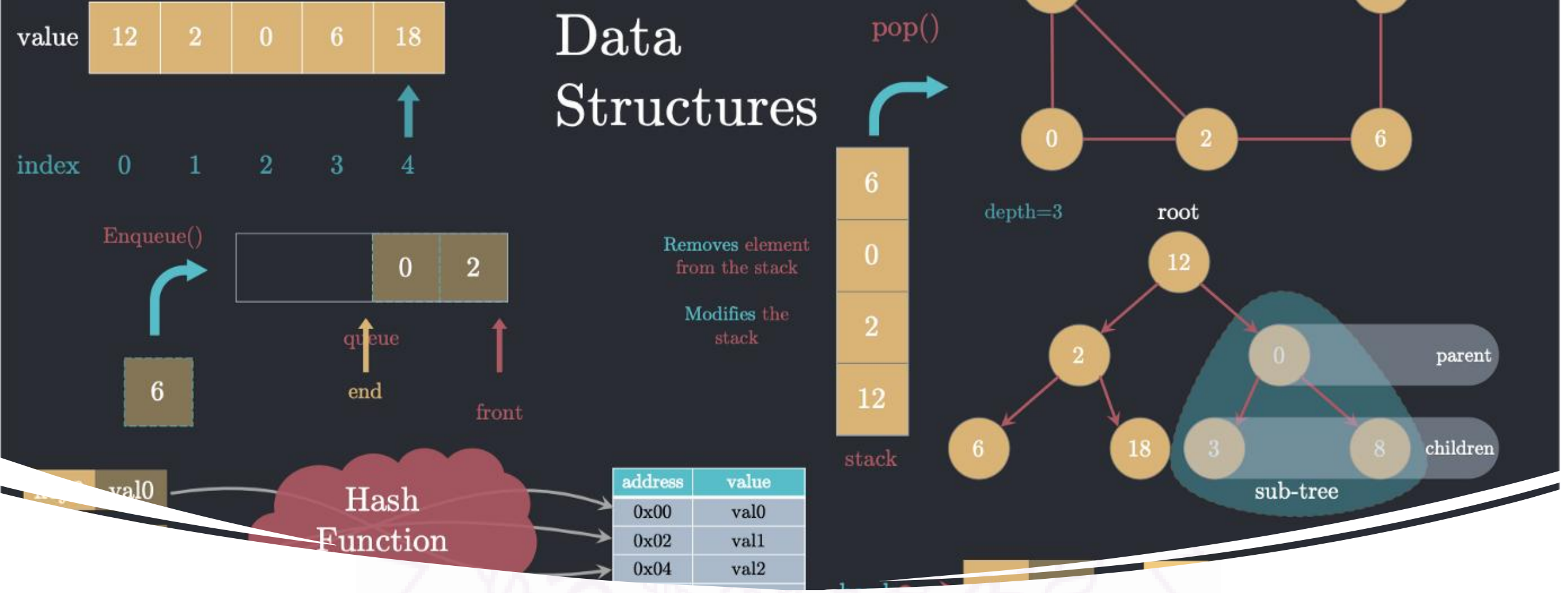
```
vector<int> V;
int n;
cin >> n;
V.resize(n);
for (int i = 0; i < n; ++i)
  cin >> V[i];
V.clear();
```

assign

```cpp
#include <iostream>
#include <vector>
using namespace std;

int main() {
  vector<int> V;
  V.assign(5, -1);
  for (size_t i = 0; i < V.size(); ++i)
    cout << V[i] << " \n"[i + 1 == V.size()];
  V.assign({1, 2, 3});
  for (size_t i = 0; i < V.size(); ++i)
    cout << V[i] << " \n"[i + 1 == V.size()];
  return 0;
}
```

Terminal

```
-1 -1 -1 -1 -1
1 2 3
```



Iterator
迭代器

- 資料結構總類繁多形狀各異
- 迭代器統一了各個資料結構**走訪**的介面

begin end $O(1)$

```cpp
int main() {
  vector<int> V{7, 1, 2, 2, 5, 3};
  for (vector<int>::iterator It = V.begin(); It != V.end(); ++It)
    cout << *It << ' ';
  cout << '\n';

  for (auto It = V.begin(); It != V.end(); ++It)
    cout << *It << ' ';
  cout << "\nsize = " << V.end() - V.begin() << endl;
  return 0;
}
```

```
jacky860226@DESKTOP-FCBV14M:/mnt/
7 1 2 2 5 3
7 1 2 2 5 3
size = 6
```

Range-based for loop

```
for (auto &x : V) {
  // ...
}
```

=

```
{
  for (auto It = V.begin(); It != V.end(); ++It) {
    auto &x = *It;
    // ...
  }
}
```

rbegin rend $O(1)$

```cpp
int main() {
  vector<int> V{7, 1, 2, 2, 5, 3};
  for (vector<int>::reverse_iterator It = V.rbegin(); It != V.rend(); ++It)
    cout << *It << ' ';
  cout << '\n';

  for (auto It = V.rbegin(); It != V.rend(); ++It)
    cout << *It << ' ';
  cout << '\n';
  return 0;
}
```

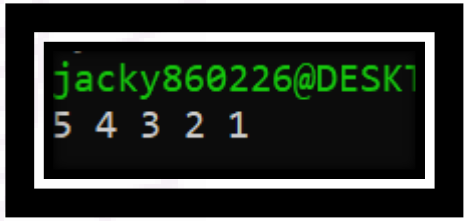
```
jacky860226@DESKTOP-FCBV14M:/mnt/
3 5 2 2 1 7
3 5 2 2 1 7
```

STL Algorithm functions

#include <algorithm>

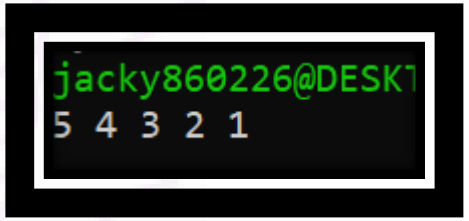
std::reverse

```cpp
#include <algorithm>
#include <iostream>
#include <vector>
using namespace std;

int main() {
  vector<int> V{1, 2, 3, 4, 5};
  reverse(V.begin(), V.end());
  for (auto x : V)
    cout << x << ' ';
  cout << '\n';
  return 0;
}
```



std::reverse

```cpp
#include <algorithm>
#include <iostream>
#include <vector>
using namespace std;

int main() {
  int V[5] = {1, 2, 3, 4, 5};
  reverse(V, V + 5);
  for (auto x : V)
    cout << x << ' ';
  cout << '\n';
  return 0;
}
```



std::reverse

```
template <class IterTy>
void reverse(IterTy first, IterTy last) {
  while ((first != last) && (first != --last)) {
    std::swap(*first, *last);
    ++first;
  }
}
```

std::fill

```cpp
#include <algorithm>
#include <iostream>
#include <vector>
using namespace std;

int main() {
  vector<int> V(5);
  fill(V.begin(), V.end(), 7122);
  for (auto x : V)
    cout << x << ' ';
  cout << '\n';
  return 0;
}
```

```
jacky860226@DESKTOP-FCBV14M:/mn
7122 7122 7122 7122 7122
```

std::fill

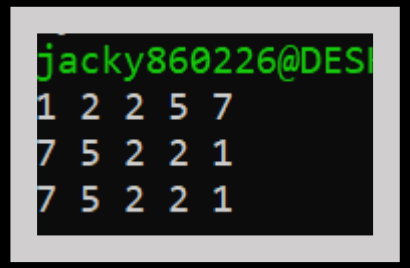
```cpp
#include <algorithm>
#include <iostream>
#include <vector>
using namespace std;

int main() {
  int V[5];
  fill(V, V + 5, 7122);
  for (auto x : V)
    cout << x << ' ';
  cout << '\n';
  return 0;
}
```

```
jacky860226@DESKTOP-FCBV14M:/mn
7122 7122 7122 7122 7122
```

std::sort

```
template <class T> void print(T &V) {
  for (auto x : V)
    cout << x << ' ';
  cout << '\n';
}
```

```
#include <algorithm>
#include <iostream>
#include <vector>
using namespace std;

int main() {
  vector<int> V{7, 1, 2, 2, 5};
  sort(V.begin(), V.end());
  print(V);
  sort(V.begin(), V.end(), [](auto a, auto b) { return a > b; });
  print(V);
  sort(V.rbegin(), V.rend());
  print(V);
  return 0;
}
```



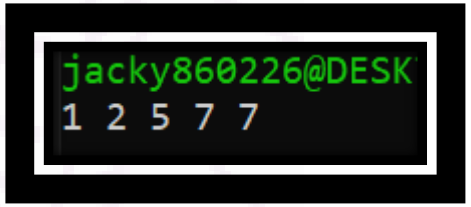
std::stable_sort

```cpp
#include <algorithm>
#include <iostream>
#include <vector>
using namespace std;

int main() {
  double V[] = {3.14, 1.41, 2.72, 4.67, 1.73, 1.32, 1.62, 2.58};
  int N = sizeof(V) / sizeof(double);
  stable_sort(V, V + N, [](int a, int b) { return a < b; });
  print(V);
  return 0;
}
```

```
jacky860226@DESKTOP-FCBV14M:/mnt/d/users,
1.41 1.73 1.32 1.62 2.72 2.58 3.14 4.67
```

std::unique

```cpp
#include <algorithm>
#include <iostream>
#include <vector>
using namespace std;

int main() {
  vector<int> V{7, 1, 2, 2, 5};
  sort(V.begin(), V.end());
  unique(V.begin(), V.end());
  print(V);
  return 0;
}
```



std::unique

```cpp
#include <algorithm>
#include <iostream>
#include <vector>
using namespace std;

int main() {
  vector<int> V{7, 1, 2, 2, 5};
  sort(V.begin(), V.end());
  auto It = unique(V.begin(), V.end());
  V.erase(It, V.end());
  print(V);
  return 0;
}
```

std::min / std::max

```cpp
#include <algorithm>
#include <iostream>
using namespace std;

int main() {
  cout << min(1, 2) << endl;
  cout << min({7, 1, 2, 2}) << endl;
  cout << max(1, 2) << endl;
  cout << max({7, 1, 2, 2}) << endl;
  return 0;
}
```

std::min / std::max 形態要一樣

```cpp
#include <algorithm>
#include <iostream>
using namespace std;

int main() {
  int a = 1;
  long long b = 2;
  cout << max(a, b); // error
  return 0;
}
```

std::min_element / std::max_element

```cpp
#include <algorithm>
#include <iostream>
#include <vector>
using namespace std;

int main() {
  vector<int> V{7, 1, 2, 2};
  auto It1 = min_element(V.begin(), V.end());
  cout << "min = " << *It1 << ", at index: " << It1 - V.begin() << endl;
  auto It2 = max_element(V.begin(), V.end());
  cout << "max = " << *It2 << ", at index: " << It2 - V.begin() << endl;
  return 0;
}
```

```
jacky860226@DESKTOP-FCBV14M:/mnt/
min = 1, at index: 1
max = 7, at index: 0
```

std::next_permutation

```cpp
#include <algorithm>
#include <iostream>
#include <vector>
using namespace std;

int main() {
  vector<int> V{7, 1, 2, 2};
  sort(V.begin(), V.end());
  do {
    print(V);
  } while (next_permutation(V.begin(), V.end()));
  return 0;
}
```

```
jacky860226@DESKTOP
1 2 2 7
1 2 7 2
1 7 2 2
2 1 2 7
2 1 7 2
2 2 1 7
2 2 7 1
2 7 1 2
2 7 2 1
7 1 2 2
7 2 1 2
7 2 2 1
```

std::prev_permutation

```cpp
#include <algorithm>
#include <iostream>
#include <vector>
using namespace std;

int main() {
  vector<int> V{7, 1, 2, 2};
  sort(V.rbegin(), V.rend());
  do {
    print(V);
  } while (prev_permutation(V.begin(), V.end()));
  return 0;
}
```