CP::queue

Will the circle be unbroken?

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Intro

- Queue, unlike stack, require more sophisticated technique to achieve fast performance
- We start by writing a simple class that just work (slowly)
- Then we try to improve it

Key Idea

- Just like stack, we will use the same format as vector, using dynamic array to store data
- However, we have to somehow manage how we works with front() and back() of the queue

v0.1 simple implementation of queue

- To illustrate this idea, we will use a vector as our data member
- `push(e)` is simply `v.push_back(e)`, this is fast
- `front()` is `v[0]`, `back()` is `v[v.size()-1]`, this is also fast
- `pop()` is `v.erase(v.begin())`, this is slow (always propotional to `v.size()`)
  - Unlike std::queue which has very fast pop()

```
namespace CP {
  template <typename T>
  class queue {
    protected:
      std::vector<T> v;
    public:
      //------------- capacity function -------------------
      queue() : v() {}
      //------------- capacity function -------------------
      bool empty() const                { return v.empty();}
      size_t size() const                { return v.size();}
      //----------------- access --------------------------
      const T& front() const                 { return v[0];}
      const T& back() const         { return v[v.size()-1];}
      //----------------- modifier ------------------------
      void push(const T& element)  { v.push_back(element);}
      void pop()                     { v.erase(v.begin());}

  };
}
```

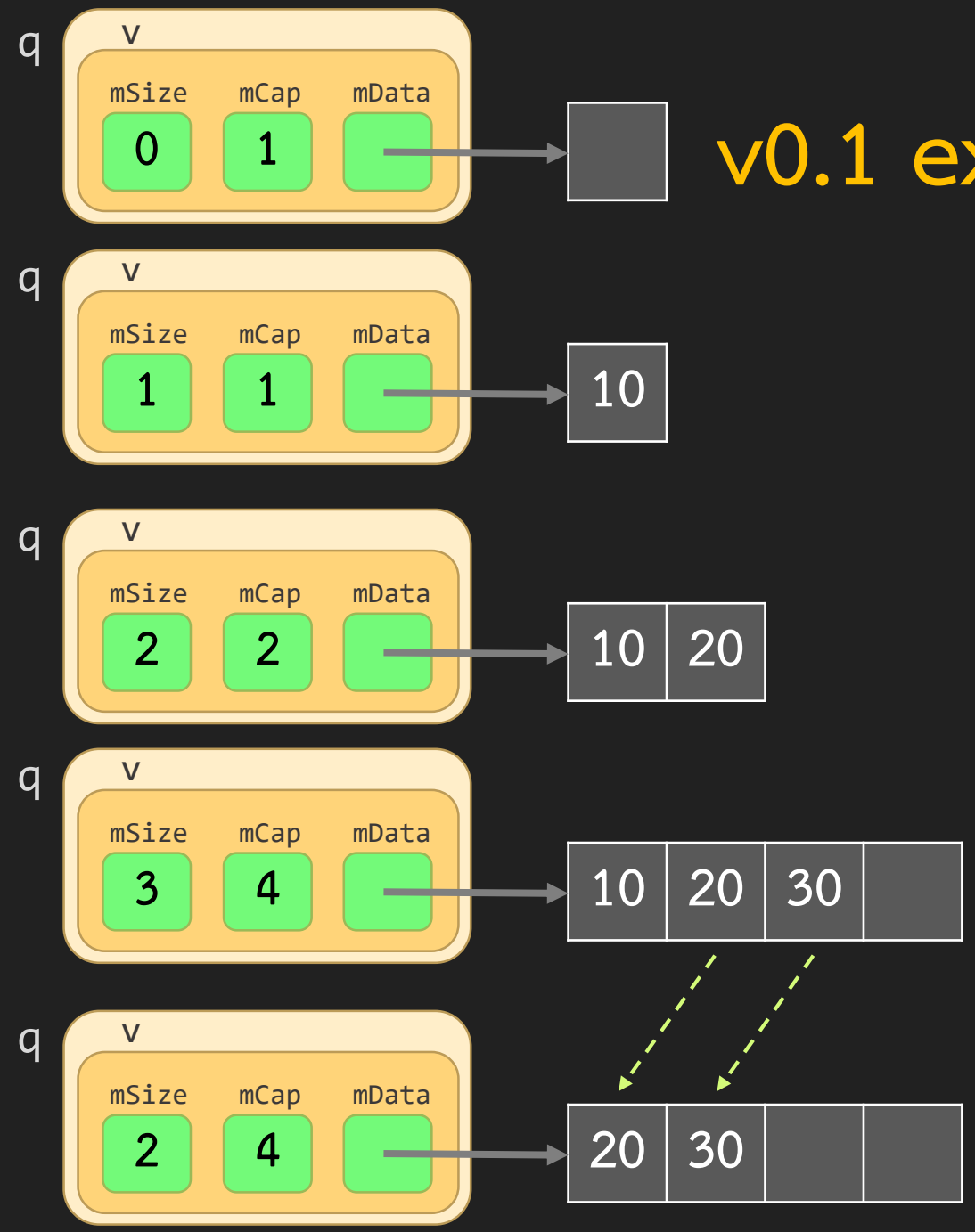
```
CP::queue<int> q;
```

```
q.push(10);
```

```
q.push(20);
```

```
q.push(30);
```

```
q.pop();
```



v0.1 example

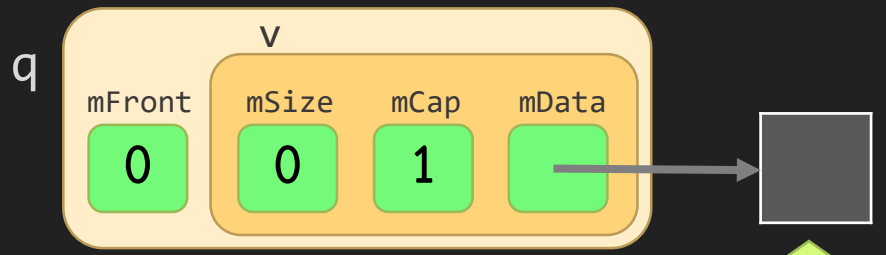
v0.2 faster queue

- Add more data member mFront, initialized as 0
- `push(e)` is simply `v.push_back(e)`, this is fast
- `front()` is `v[mFront]`, `back()` is `v[v.size()-1]`, this is also fast
- `pop()` is `mFront++`, this is fast
  - However, we don't really remove anything when pop

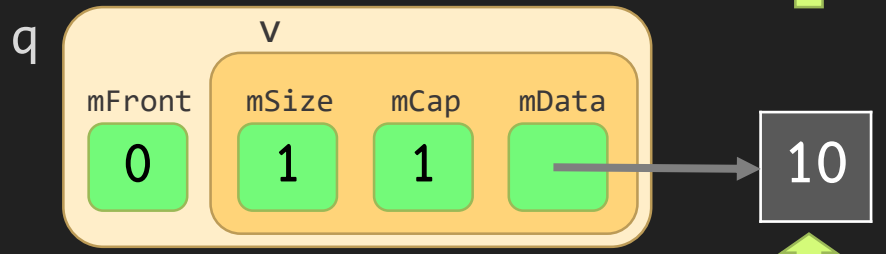
```
#include <vector>

namespace CP {
  template <typename T>
  class queue
  {
    protected:
      std::vector<T> v;
      int mFront;
    public:
      //------------- capacity function ------------------
      queue() : v(), mFront() {}
      //------------- capacity function ------------------
      bool empty() const                { return v.empty();}
      size_t size() const       { return v.size()- mFront;}
      //----------------- access -------------------------
      const T& front() const            { return v[mFront];}
      const T& back() const         { return v[v.size()-1];}
      //----------------- modifier -----------------------
      void push(const T& element)  { v.push_back(element);}
      void pop()                                 { mFront++;}
  };
}
```

v0.2 example

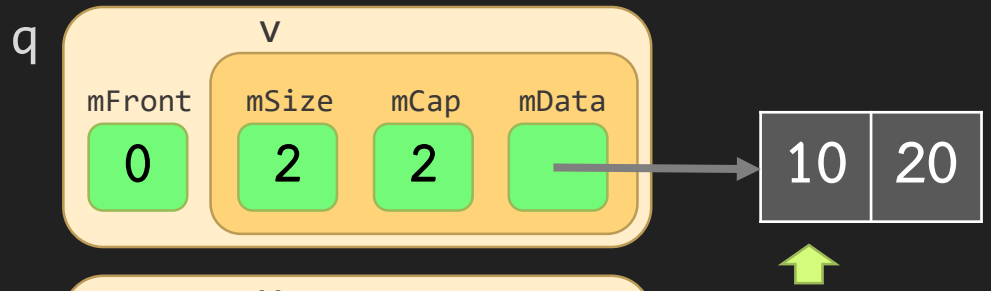
```
CP::queue<int> q;
```



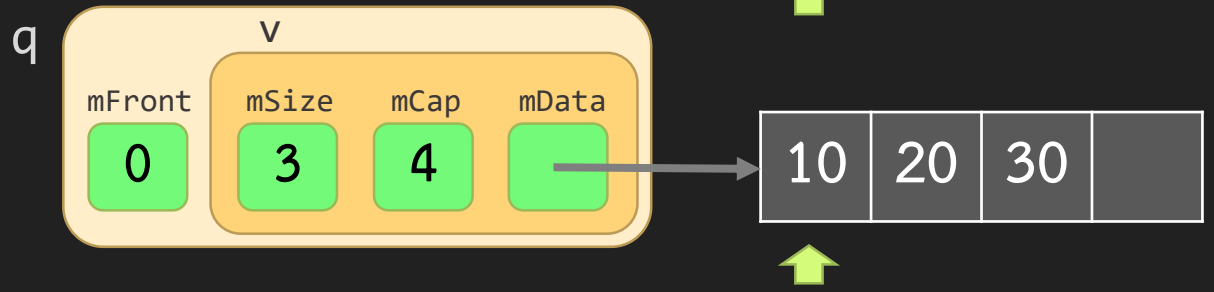

```
q.push(10);
```



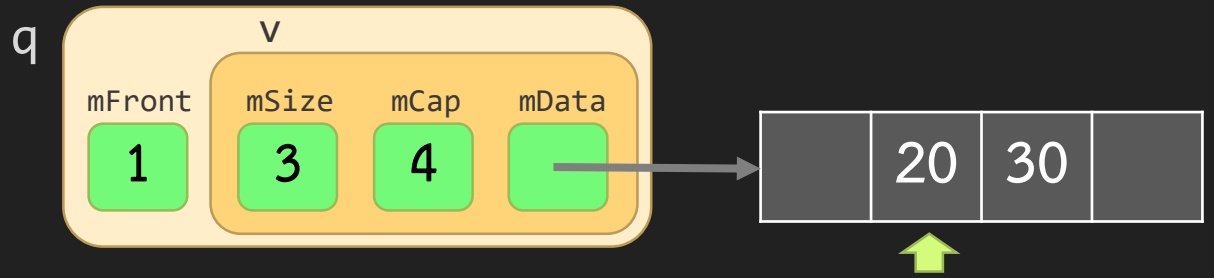

```
q.push(20);
```




```
q.push(30);
```



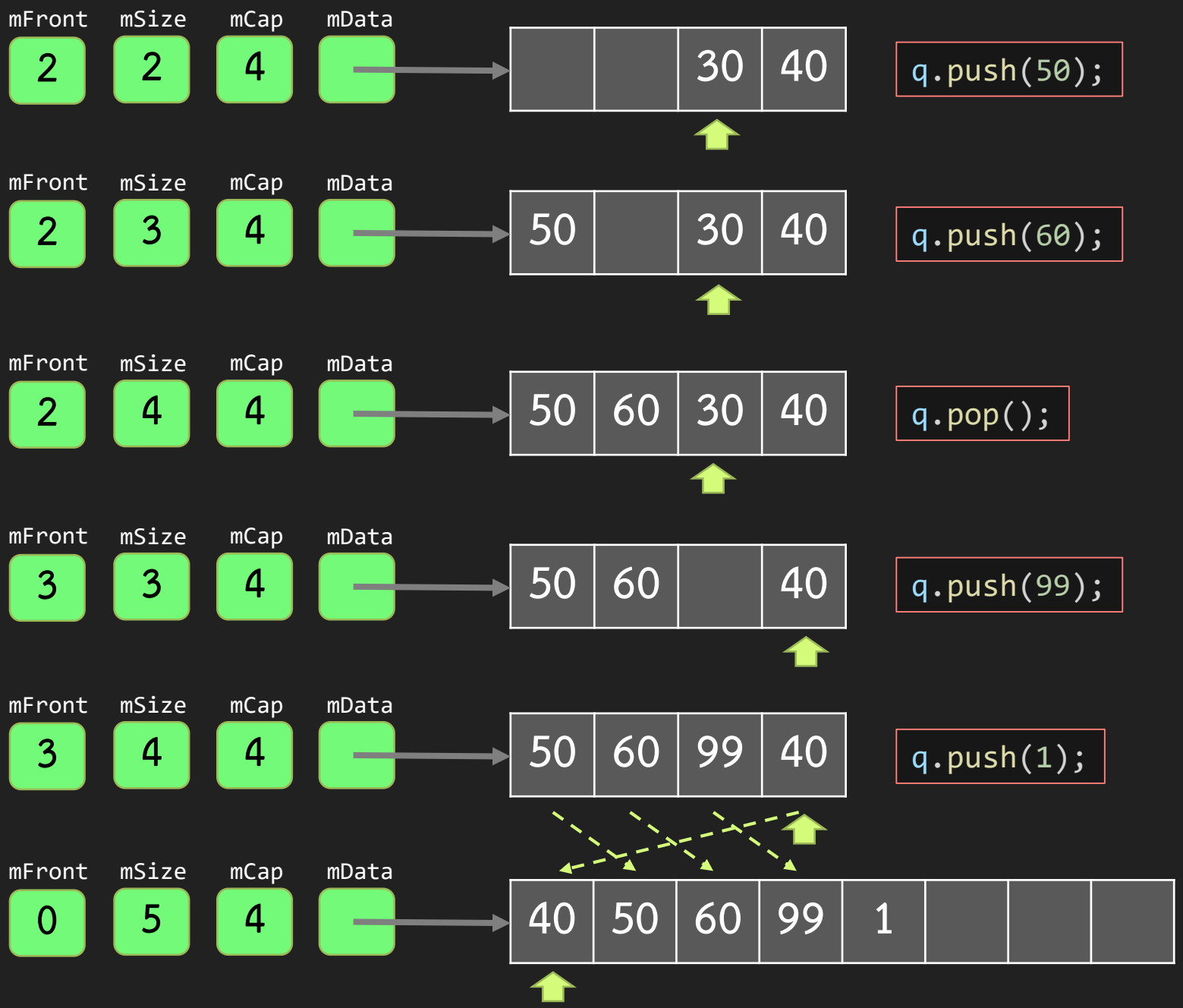

```
q.pop();
```



Problem with v0.2

- Fast but use too many space
- Queue grows according to how many time push is called
  - regardless of how many pop is called
- The data stored in the vector can be much larger than the actual data in the queue
- Does not really work in real world

```
for (int i = 0;i < 1000000;i++) {
  q.push(i);
  q.pop();
}
std::cout << q.size() << std::endl;
```

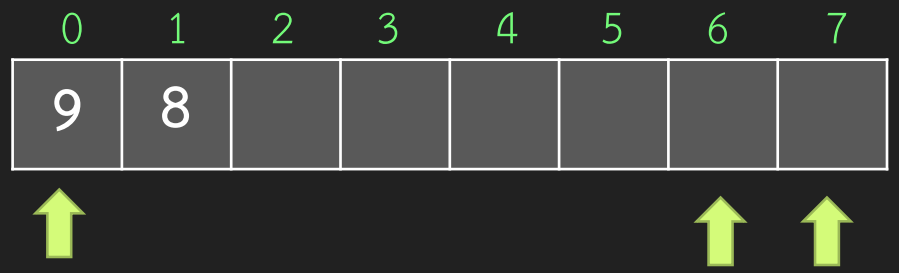


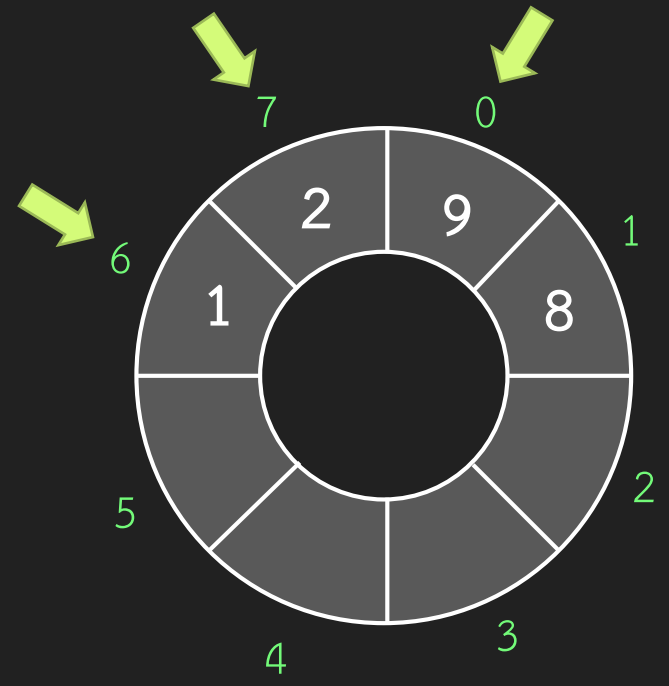
Final Idea

- We take v0.2 and reuse the area at the beginning of mData
  - Expand when necessary
  - Re-arrange when expand

Circular Queue

- We can think of mData to be circular
  - End of the last element of the mData is connected to the first element
- Consider i^{th} element
  - the next element is `(i+1) % mCap`
  - The previous element is `(i-1+mCap) % mCap`
  - Next k element is `(i+k) % mCap`





queue.h

```
namespace CP {
  template <typename T>
  class queue
  {
    protected:
      T *mData;
      size_t mCap;
      size_t mSize;
      size_t mFront;
      void expand(size_t capacity) {...}
      void ensureCapacity(size_t capacity) {...}
    public:
      //-------------- constructor --------------
      queue(const queue<T>& a) {...}
      queue() {...}
      queue<T>& operator=(queue<T> other) {...}
      ~queue() {...}
      //------------- capacity function ---------
      bool empty() const {...}
      size_t size() const {...}
      //----------------- access ----------------
      const T& front() const  {...}
      const T& back() const  {...}
      //----------------- modifier --------------
      void push(const T& element)  {...}
      void pop()  {...}
  };
}
```

Additional data member mFront

Almost the same but have to take care of mFront

Same as vector

Circular queue implementation

```
template <typename T>
class queue {
  protected:
    T *mData;  size_t mCap;  size_t mSize;   size_t mFront;
  public:
    // default constructor
    queue() : mData(new T[1]()), mCap(1),
              mSize(0), mFront(0) { }
    // copy constructor
    queue(const queue<T>& a) : mData(new T[a.mCap]()), mCap( a.mCap ),
                               mSize( a.mSize ), mFront( a.mFront ) {
      for (size_t i = 0; i < a.mCap;i++) {
        mData[i] = a.mData[i];
      }
    }
    // copy assignment operator
    queue<T>& operator=(queue<T> other) {
      using std::swap;
      swap(mSize,other.mSize);
      swap(mCap,other.mCap);
      swap(mData,other.mData);
      swap(mFront,other.mFront);
      return *this;
    }
    ~queue() {
      delete [] mData;
    }
};
```

List initialization

Need to copy entire mData (not just mSize)

Also swap mFront

same

Ctor, Dtor, copy

- Dtor is the same
- ctor also have to initialize mFront
- Copy also have to copy mFront

front(), back(), pop()

```
template <typename T>
class queue {
  protected:
    T *mData;
    size_t mCap;
    size_t mSize;
    size_t mFront;
  public:
    //----------------- access -----------------
    const T& front() const {
      return mData[mFront];
    }
    const T& back() const {
      return mData[(mFront + mSize - 1) % mCap];
    }
    //----------------- modify -----------------
    void pop() {
      mFront = (mFront + 1) % mCap;
      mSize--;
    }
};
```

- back = mFront + mSize -1
  - Also circular (by % mCap)
- pop = move mFront by 1
  - Also circular
  - Also change size

push, expand

- push add data to `(mFront+mSize) % mCap`
  - The space just after `back()`
- Expand re-pack the `mData` so that `mFront` is 0
- `ensureCapacity` is the same

```
template <typename T>
class queue {
  protected:
    T *mData;
    size_t mCap;
    size_t mSize;
    size_t mFront;
    void expand(size_t capacity) {
      T *arr = new T[capacity]();
      for (size_t i = 0;i < mSize;i++) {
        arr[i] = mData[(mFront + i) % mCap];
      }
      delete [] mData;
      mData = arr;
      mCap = capacity;
      mFront = 0;
    }
    void ensureCapacity(size_t capacity) {
      if (capacity > mCap) {
        size_t s = (capacity > 2 * mCap) ? capacity : 2 * mCap;
        expand(s);
      }
    }
  public:
    void push(const T& element) {
      ensureCapacity(mSize+1);
      mData[(mFront + mSize) % mCap] = element;
      mSize++;
    }
};
```

Analysis

- All access, modification is fast (constant time)
- Space is re-used
  - It is not shrunk when mSize reduce
  - Space is not more than double of maximum mSize during its lifetime

Exercise

- We implement circular queue by maintain mFront and use circular logic (% mCap) to calculate the position of back of the queue
  - Can we maintain mBack instead?
  - Can we maintain both mFront and mBack but not mSize?
- How about mCap, if we know mFront, mSize, mBack, can we calculate mCap?

mFront	mSize	mBack	front()	back()	size()
YES	YES	No	v[mFront]	v[(mFront + mSize - 1) % mCap]	mSize
No	YES	YES	????	v[mBack]	mSize
YES	No	YES	v[mFront]	v[mBack]	????

Now, meet deque

- Can you modify queue to include
  - push_front(), add to the front of the queue
  - pop_back(), remove from back of the queue
- All operation should still be constant time