



DS-210: PROGRAMMING FOR DATA SCIENCE

LECTURE 23

1. MEMORY MANAGEMENT IN VECTORS

2. HASH MAPS





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LAST TIME: VECTORS `Vec<T>`

- Dynamic-length array/list
- Allowed operations:
 - access item at specific location
 - `push`: add something to the end
 - `pop`: remove an element from the end
- Python: `list`
- C++: `vector<T>`
- Java: `ArrayList<T>` / `Vector<T>`





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HOW TO IMPLEMENT THIS EFFICIENTLY?





SELECT IMPLEMENTATION DETAILS

CHALLENGES

- Size changes: allocate on the heap?
- What to do if a new element added?
 - Allocate a larger array and copy everything?
 - Linked list?





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SOLUTION

- Allocate more space than needed!
- When out of space:
 - Increase storage size by, say, 100%
 - Copy everything





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UNDER THE HOOD

Variable of type `Vec<T>` contains:

- pointer to allocated memory
- size: the current number of items
- capacity: how many items could currently fit

Important: $\text{size} \leq \text{capacity}$





EXAMPLE

Method `capacity()` reports current storage size

```
In [2]: // print out the current size and capacity
fn info<T>(vector:&Vec<T>) {
    println!("size = {}, capacity = {}",vector.len(),vector.capacity());
}
```



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    println!("size = {}, capacity = {}",vector.len(),vector.capacity());
}
```

```
In [3]: let mut v = Vec::new();
let mut capacity = v.capacity();
info(&v);
for i in 1..=1000 {
    v.push(i);
    if v.capacity() != capacity {
        capacity = v.capacity();
        info(&v);
    }
};
```

```
size = 0, capacity = 0
size = 1, capacity = 4
size = 5, capacity = 8
size = 9, capacity = 16
size = 17, capacity = 32
size = 33, capacity = 64
size = 65, capacity = 128
size = 129, capacity = 256
size = 257, capacity = 512
size = 513, capacity = 1024
```





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size = 513, capacity = 1024
```

```
In [4]: info(&v);
while let Some(_) = v.pop() {}
info(&v);
```

```
size = 1000, capacity = 1024
size = 0, capacity = 1024
```





EXAMPLE (CONTINUED)

```
In [5]: // shrinking the size manually
info(&v);

for i in 1..13 {
    v.push(i);
}

info(&v);

v.shrink_to_fit();

info(&v);
// note: size and capacity not guaranteed
//      to be the same
```

```
size = 0, capacity = 1024
size = 13, capacity = 1024
size = 13, capacity = 13
```





EXAMPLE (CONTINUED)

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In [5]: // shrinking the size manually
info(&v);

for i in 1..=13 {
    v.push(i);
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info(&v);

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// note: size and capacity not guaranteed
//       to be the same
```

```
size = 0, capacity = 1024
size = 13, capacity = 1024
size = 13, capacity = 13
```

```
In [6]: // creating vector with specific capacity
let mut v2 : Vec<i32> = Vec::with_capacity(1234);
info(&v2);

// avoids reallocation if you know how many items
// to expect
```

```
size = 0, capacity = 1234
```





SKETCH OF ANALYSIS: AMORTIZATION

- Inserting an element not constant time, $O(1)$





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HOWEVER

- **Assumption:** allocating memory size t takes $O(t)$ or $O(1)$ time
- **Slow operations:** $O(\text{current_size})$ time
- **Fast operations:** $O(1)$ time
- Slow operation every $\Omega(\text{current_size})$ fast operations





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SHRINKING?

- Can be implemented this way too
- Example: shrink by 50% if less than 25% used
- Most implementations don't shrink automatically



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COLLECTION `HashMap<K, V>`

Goal: a mapping from elements of `K` to elements of `V`

- elements of `K` called *keys*
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```
In [7]: // creating a hash map and inserting pair

use std::collections::HashMap;

// number of wins in a local Conterstrike league
let mut wins = HashMap::<String,u16>::new();

wins.insert(String::from("Boston University"),24);
wins.insert(String::from("Harvard"),22);
wins.insert(String::from("Boston College"),20);
wins.insert(String::from("Northeastern"),32);
```





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Extracting a reference: returns `Option<&V>`

```
In [8]: wins.get("Boston University")
```

```
Out[8]: Some(24)
```





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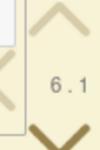
Extracting a reference: returns `Option<&V>`

```
In [8]: wins.get("Boston University")
```

```
Out[8]: Some(24)
```

```
In [9]: wins.get("MIT")
```

```
Out[9]: None
```





Insert if not present:

```
In [10]: wins.entry(String::from("MIT")).or_insert(10);  
wins.get("MIT")
```

```
Out[10]: Some(10)
```





Insert if not present:

```
In [10]: wins.entry(String::from("MIT")).or_insert(10);  
wins.get("MIT")
```

```
Out[10]: Some(10)
```

Updating:

```
In [11]: { // block to limit how long the reference lasts  
          let entry = wins.entry(String::from("Boston University")).or_insert(10);  
          *entry = 50;  
        }  
wins.insert(String::from("Boston University"),24);  
wins.get("Boston University")
```

```
Out[11]: Some(24)
```





ITERATING

```
In [12]: for (k,v) in &wins {  
         println!("{}",k,v);  
       };
```

```
MIT: 10  
Harvard: 22  
Boston College: 20  
Northeastern: 32  
Boston University: 24
```





ITERATING

```
In [12]: for (k,v) in &wins {  
        println!("{}",k,v);  
    };
```

```
MIT: 10  
Harvard: 22  
Boston College: 20  
Northeastern: 32  
Boston University: 24
```

```
In [13]: for (k,v) in &mut wins {  
        *v += 1;  
    };  
  
    for (k,v) in &wins {  
        println!("{}",k,v);  
    };
```

```
MIT: 11  
Harvard: 23  
Boston College: 21  
Northeastern: 33  
Boston University: 25
```





NEXT TIME

- How do hash tables work?
- Typical graph representations

