ETH zürich

Exercise Session W13

Computer Science (CSE & CBB & Statistics) – AS 23

Overview

Today's Agenda

Follow-up
Objectives
Pointers
Exercise "Push Back"
Memory Management
Outro

n.ethz.ch/~agavranovic

1. Follow-up

Follow-up from previous exercise sessions

Follow-up from previous exercise sessions

- I messed up the Plan: The recap will be next week!

Follow-up from previous exercise sessions

- I messed up the Plan: The recap will be next week!
- Feel free to send me an email with your questions

2. Objectives

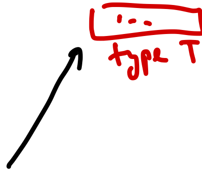
Objectives

- ☐ Understand the difference between `new` / `delete` and `new[]` / `delete[]`
- ☐ Be able to trace programs that use pointer arithmetic
- ☐ Be able to write programs that use pointer arithmetic

3. Pointers

`new` VS `new[]`

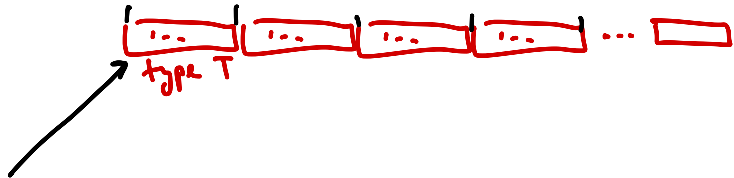
- `new T` allocates **one** space in memory for the specified type



[1]this memory will be *contiguous*, i.e. "next to each other in memory"

`new` VS `new[]`

- `new T` allocates **one** space in memory for the specified type
- `new T[n]` allocates n spaces in memory for the specified type[1]



[1] this memory will be *contiguous*, i.e. "next to each other in memory"

`new` vs `new[]`

- `new T` allocates **one** space in memory for the specified type
- `new T[n]` allocates n spaces in memory for the specified type[1]
- Both return a pointer which points to the (first) element of the range

[1] this memory will be *contiguous*, i.e. "next to each other in memory"

`new` vs `new[]`

- `new T` allocates **one** space in memory for the specified type
- `new T[n]` allocates n spaces in memory for the specified type[1]
- Both return a pointer which points to the (first) element of the range

[1] this memory will be *contiguous*, i.e. "next to each other in memory"

`new` vs `new[]`

- `new T` allocates **one** space in memory for the specified type
- `new T[n]` allocates n spaces in memory for the specified type[1]
- Both return a pointer which points to the (first) element of the range

Example

```
int my_arr[5] = {2, 3, 8, -1, 3};
```

- `my_arr` now points to the

[1] this memory will be *contiguous*, i.e. "next to each other in memory"

new VS new[]

- `new T` allocates **one** space in memory for the specified type
- `new T[n]` allocates n spaces in memory for the specified type[1]
- Both return a pointer which points to the (first) element of the range

Example

```
int my_arr[5] = {2, 3, 8, -1, 3};
```

- `my_arr` now points to the 2
- `*my_arr` returns

[1] this memory will be *contiguous*, i.e. "next to each other in memory"

`new` vs `new[]`

- `new T` allocates **one** space in memory for the specified type
- `new T[n]` allocates n spaces in memory for the specified type[1]
- Both return a pointer which points to the (first) element of the range

Example

```
int my_arr[5] = {2, 3, 8, -1, 3};
```

- `my_arr` now points to the 2
- `*my_arr` returns 2
- `my_arr[2]` returns

[1] this memory will be *contiguous*, i.e. "next to each other in memory"

`new` VS `new[]`

- `new T` allocates **one** space in memory for the specified type
- `new T[n]` allocates n spaces in memory for the specified type[1]
- Both return a pointer which points to the (first) element of the range

Example

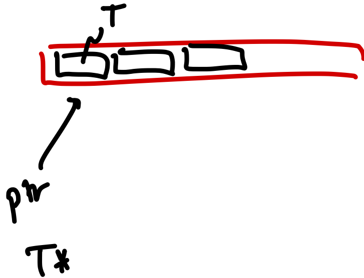
```
int my_arr[5] = {2, 3, 8, -1, 3};
```

- `my_arr` now points to the 2
- `*my_arr` returns 2
- `my_arr[2]` returns 8

[1] this memory will be *contiguous*, i.e. "next to each other in memory"

delete VS delete[]

- We remember:



`delete` VS `delete[]`

- We remember: every **`new`** needs a **`delete`**

`delete` vs `delete[]`

- We remember: every `new` needs a `delete`
- `delete[]` is the corresponding operator to `new[]`

delete VS delete[]

- We remember: every **new** needs a **delete**
- **delete[]** is the corresponding operator to **new[]**
- Be aware: We do not delete the pointer but the range of objects to which the pointer is pointing

`delete` vs `delete[]`

- We remember: every `new` needs a `delete`
- `delete[]` is the corresponding operator to `new[]`
- Be aware: We do not delete the pointer but the range of objects to which the pointer is pointing
- **Common source of bugs**
  Calling `delete` on the first element but not the entire array (with `delete[]`)

Pointer Arithmetic

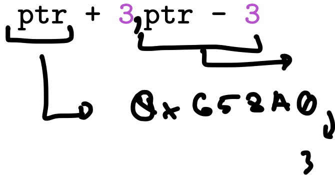
- We can do "pointer math"
- The most important instructions are:

Pointer Arithmetic

- We can do "pointer math"
- The most important instructions are:

- Temporary shifts

```
ptr + 3, ptr - 3
```



Pointer Arithmetic

- We can do "pointer math"
- The most important instructions are:

- Temporary shifts

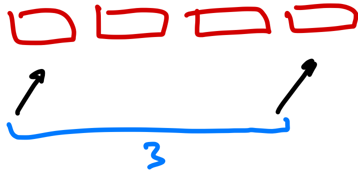
  `ptr + 3`, `ptr - 3`
- Permanent shifts

  `ptr++`, `--ptr`, `ptr += 2`

3 + 2

a += 2

Pointer Arithmetic



- We can do "pointer math"
- The most important instructions are:

- Temporary shifts
  `ptr + 3` `ptr - 3`
- Permanent shifts
  `ptr++` `--ptr` `ptr += 2`

- Determine distance between pointers
  `ptr_1 - ptr_2`

Pointer Arithmetic

*ptr gives you access to the thing ptr is pointing to

- We can do "pointer math"
- The most important instructions are:

- Temporary shifts

  `ptr + 3` `ptr - 3`
- Permanent shifts

  `ptr++` `--ptr` `ptr += 2`

- Determine distance between pointers

  `ptr_1 - ptr_2`
- Compare positions

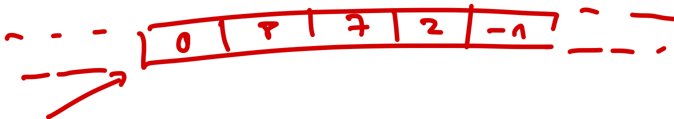
  `ptr_1 < ptr_2`

  `ptr_1 != ptr_2`

Questions?

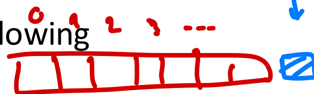
Pointer Program

```
int* a = new int[5]{0, 8, 7, 2, -1};
int* ptr = a;                           // pointer assignment
++ptr;                                  // shift to the right
int my_int = *ptr;                      // read target
ptr += 2;                               // shift by 2 elements
*ptr = 18;                              // overwrite target
int* past = a+5;
std::cout << (ptr < past) << "\n"; // compare pointers
```



Pointer Program

Find and fix at least 3 problems in the following program.




```
#include <iostream>
int main () {
    int* a = new int[7]{0, 6, 5, 3, 2, 4, 1};
    int* b = new int[7];
    int* c = b;
    // copy a into b using pointers
    for (int* p = a; p < a+7; ++p) {
        *c++ = *p;
    }
    // cross-check with random access
    for (int i = 0; i < 7; ++i) {
        if (a[i] != c[i]) {
            std::cout << "Oops, copy error...\n";
        }
    }
    return 0;
}
```

arr_ptr

arr_ptr[i]

Pointer Program

```
#include <iostream>
int main () {
    int* a = new int[7]{0, 6, 5, 3, 2,
    int* b = new int[7];
    int* c = b;
    // copy a into b using pointers
    for (int* p = a; p <= a+7; ++p) {
        *c++ = *p;
    }
    // cross-check with random access
    for (int i = 0; i <= 7; ++i) {
        if (a[i] != c[i]) {
            std::cout << "Oops, copy error...\n";
        }
    }
    return 0;
}
```

`p = a+7` is dereferenced

Solution:

Use `<` instead of `<=`

Pointer Program

```
#include <iostream>
int main () {
    int* a = new int[7]{0, 6, 5, 3, 2, 4
    int* b = new int[7];
    int* c = b;
    // copy a into b using pointers
    for (int* p = a; p <= a+7; ++p) {
        *c++ = *p;
    }
    // cross-check with random access
    for (int i = 0; i <= 7; ++i) {
        if (a[i] != c[i]) {
            std::cout << "Oops, copy error
        }
    }
    return 0;
}
```

p = a+7 is dereferenced

Solution:
Use < instead of <=

Same problem as above

Pointer Program

```
#include <iostream>
int main () {
    int* a = new int[7]{0, 6, 5, 3, 2, 4
    int* b = new int[7];
    int* c = b;
    // copy a into b using pointers
    for (int* p = a; p <= a+7; ++p) {
        *c++ = *p;

     cross-check with random access
        (int i = 0; i <= 7; ++i) {
        if (a[i] != c[i]) {
            std::cout << "Oops, copy err
        }
    }
    return 0;
}
```

`p = a+7` is dereferenced

Solution:
Use `<` instead of `<=`

`c` doesn't point to `b[0]` anymore.

Solution:
Use `b` instead of `c`

Same problem as above

Exercise – Applying Pointers

Exercise – Applying Pointers

```
// PRE: [b, e) and [o, o+(e-b)) are disjoint
//      valid ranges
void f (int* b, int* e, int* o) {
    while (b != e) {
        --e;
        *o = *e;
        ++o;
    }
}
```

Variable	Value
b	●
e	●
o	●

0	1	2	3	4	5	6
1	3	-8	1	5	-3	4

Exercise – Applying Pointers

Now determine a POST-condition for the function.

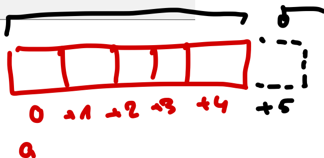
```
// PRE: [b, e) and [o, o+(e-b)) are disjoint
//      valid ranges
void f (int* b, int* e, int* o) {
    while (b != e) {
        --e;
        *o = *e;
        ++o;
    }
}
```

Exercise – Applying Pointers

```
// PRE: [b, e) and [o, o+(e-b)) are disjoint
//        valid ranges
// POST: The range [b, e) is copied in reverse
//        order into the range [o, o+(e-b))
void f (int* b, int* e, int* o) {
    while (b != e) {
        --e;
        *o = *e;
        ++o;
    }
}
```

Exercise – Valid Inputs

Exercise – Valid Inputs



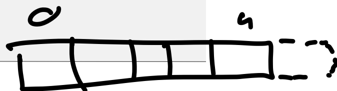
- Which of these inputs are valid?

```
int* a = new int[5];
// Initialise a.
  a)  f(a, a+5, a+5);
  b)  f(a, a+2, a+3);
  c)  f(a, a+3, a+2);
```

```
// PRE: [b, e) and [o, o+(e-b)) are disjoint
//      valid ranges
void f (int* b, int* e, int* o) {
    while (b != e) {
        --e;
        *o = *e;
        ++o;
    }
}
```

(From: Script Exercise 113)

Exercise – Valid Inputs



- Which of these inputs are valid?

```
int* a = new int[5];
// Initialise a.
  a)  f(a, a+5, a+5);
  b)  f(a, a+2, a+3);
  c)  f(a, a+3, a+2);
```

[o,o+(e-b)) is **out of bounds**

```
// PRE: [b, e) and [o, o+(e-b)) are disjoint
//      valid ranges
void f (int* b, int* e, int* o) {
    while (b != e) {
        --e;
        *o = *e;
        ++o;
    }
}
```

(From: Script Exercise 113)

Exercise – Valid Inputs

- Which of these inputs are valid?

```
int* a = new int[5];
// Initialise a.
  a)  f(a, a+5, a+5);  ✗
  b)  f(a, a+2, a+3);  ✓
  c)  f(a, a+3, a+2);
```

[o,o+(e-b))
is **out of bounds**

```
// PRE: [b, e) and [o, o+(e-b)) are disjoint
//      valid ranges
void f (int* b, int* e, int* o) {
    while (b != e) {
        --e;
        *o = *e;
        ++o;
    }
}
```

Exercise – Valid Inputs

- Which of these inputs are valid?

```
int* a = new int[5];
// Initialise a.
  a)   f(a, a+5, a+5); ✗
  b)   f(a, a+2, a+3); ✓
  c)   f(a, a+3, a+2); ✗
```

[o,o+(e-b)) is **out of bounds**

Ranges **not disjoint**

```
// PRE: [b, e) and [o, o+(e-b)) are disjoint
//      valid ranges
void f (int* b, int* e, int* o) {
    while (b != e) {
        --e;
        *o = *e;
        ++o;
    }
}
```

(From: Script Exercise 113)

Questions?

Pointer Costness

There are two kinds of constness of pointers:

```
const int* ptr = &a;
```

Pointer Costness

There are two kinds of constness of pointers:

```
const int* ptr = &a;
```

no write-access to target `a`

```
ptr = newlocation;
*ptr = 5;
```

↯ Error

Pointer Costness

There are two kinds of constness of pointers:

```
const int* ptr = &a;
```

no write-access to target `a`
i.e. we are *not* allowed to change the value of the integer `a`

Pointer Costness

There are two kinds of constness of pointers:

```
const int* ptr = &a;
```

```
int* const ptr = &a;
```

no write-access to target **a**

i.e. we are *not* allowed to change the value of the integer **a**

Pointer Costness

There are two kinds of constness of pointers:

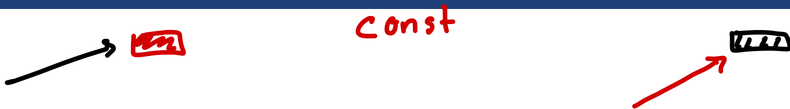
```
const int* ptr = &a;
```

no write-access to target `a`
i.e. we are *not* allowed to change the value of the integer `a`

```
int* const ptr = &a;
```

no write-access to pointer `ptr`

Pointer Costness



There are two kinds of constness of pointers:

```
const int* ptr = &a;
```

no write-access to target `a`
i.e. we are *not* allowed to change the value of the integer `a`

```
int* const ptr = &a;
```

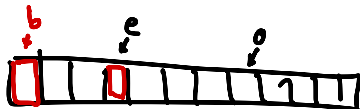
no write-access to pointer `ptr`
i.e. we are not allowed to change to where the pointer points

Exercise – `const` Correctness

Exercise – `const` Correctness

const

- Make the function `const`-correct.




```
// PRE: [b, e) and [o, o+(e-b)) are disjoint
//       valid ranges
void f (int* b, int* e, int* o) {
    while (b != e) {
        --e;
        *o = *e;
        ++o;
    }
}
```

Exercise – const Correctness

- Make the function const-correct.

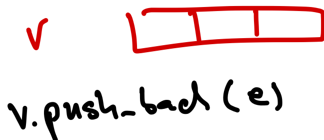
```
// PRE: [b, e) and [o, o+(e-b)) are disjoint
//       valid ranges
void f (const int* const b, const int* e, int* o) {
    while (b != e) {
        --e;
        *o = *e;
        ++o;
    }
}
```

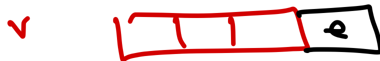
Questions?

4. Exercise "Push Back"

Exercise "Push Back"

- Open "Push Back" on **code** expert





Exercise "Push Back"

- Open "Push Back" on **code** expert
- Think about how you would approach the problem with pen and paper

Exercise "Push Back"

- Open "Push Back" on **code** expert
- Think about how you would approach the problem with pen and paper
- Implement a solution (optionally in groups)

Solution "Push Back"

```
// PRE: source_begin points to first element to be copied.
// PRE: source_ends points to element after the last element to be copied.
// PRE: destination_begin points to first element of target memory block
// PRE: #elements in target memory location >= #elements in source
// POST: copies the content of the source memory block to the destination
//      memory block.
void copy_range(const int* const source_begin,
                const int* const source_end,
                int* const destination_begin   ){

  int* dst = destination_begin;
  for (const int* src = source_begin; src != source_end; ++src) {
    *dst = *src;
    ++dst;
  }
}
```

Solution "Push Back"

```
// POST: this contains the same sequence as before with the
// new_element appended at the end.
void our_vector::push_back(int new_element){
  int* const new_elements = new int[this->count + 1];
  copy_range(this->elements, this->elements + this->count, new_elements);
  delete[] this->elements;
  new_elements[this->count] = new_element;
  this->count++;
  this->elements = new_elements;
}
```

Studenten sagen Professor mit Inserat Danke

Eine Gruppe ETH-Studenten will sich bei einem ihrer Professoren bedanken. Dafür kauft sie eine ganze 20-Minuten-Seite. Auf das ungewöhnliche Geschenk reagiert der Lehrer sichtlich gerührt.

«Wir wollten die Seite unbedingt kaufen, um uns bei einem unserer Professoren für seinen Einsatz zu bedanken», sagt Zibung. Tatsächlich schaffte es einer der Studenten, der erste von 4000 Teilnehmern zu sein, die in den ersten drei Sekunden nach Aktionsstart den Sofortkaufen-Button auf Ricardo drückten. Somit gehörte die Seite der Studentengruppe.

5. Memory Management

Find mistakes in the following code and suggest fixes:

```
1  // PRE: len is the length of the memory block that starts at array
2  void test1(int* array, int len) {
3      int* fourth = array + 3;
4      if (len > 3) {
5          std::cout << *fourth << std::endl;
6      }
7      for (int* p = array; p != array + len; ++p) {
8          std::cout << *p << std::endl;
9      }
10 }
```

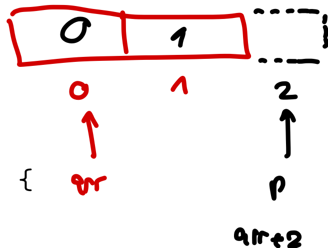
Find mistakes in the following code and suggest fixes:

```
1  // PRE: len is the length of the memory block that starts at array
2  void test1(int* array, int len) {
3      //int* fourth = array + 3;       // ERROR
4      if (len > 3) {
5          int* fourth = array + 3;    // OK
6          std::cout << *fourth << std::endl;
7      }
8      for (int* p = array; p != array + len; ++p) {
9          std::cout << *p << std::endl;
10     }
11 }
```

Even if the pointer is not dereferenced, it must point into a memory block or to the element just after its end.

Find mistakes in the following code and suggest fixes:

```
1  // PRE: len >= 2
2  int* fib(unsigned int len) {
3      int* array = new int[len];
4      array[0] = 0; array[1] = 1;
5      for (int* p = array+2; p < array + len; ++p) {
6          *p = *(p-2) + *(p-1); }
7      return array; }
8  void print(int* array, int len) {
9      for (int* p = array+2; p < array + len; ++p) {
10         std::cout << *p << " ";
11     }
12 }
13 void test2(unsigned int len) {
14     int* array = fib(len);
15     print(array, len);
16 }
```



error from before!

```
// PRE: len >= 2
int* fib(unsigned int len) {
    int* array = new int[len];
    array[0] = 0; array[1] = 1;
    for (int* p = array+2; p < array + len; ++p) {
        *p = *(p-2) + *(p-1); }
    return array; }
void print(int* array, int len) {
    for (int* p = array+2; p < array + len; ++p) {
        std::cout << *p << " ";
    }
}
void test2(unsigned int len) {
    int* array = fib(len);
    print(array, len);
}   // array is leaked; to fix add: delete[] array
```

Find mistakes in the following code and suggest fixes:

```
1  // PRE: len >= 2
2  int* fib(unsigned int len) {
3      // ...
4  }
5  void print(int* m, int len) {
6      for (int* p = m+2; p < m + len; ++p) {
7          std::cout << *p << " ";
8      }
9      delete m;
10 }
11 void test2(unsigned int len) {
12     int* array = fib(len);
13     print(array, len);
14     delete[] array;
15 }
```

```
1  // PRE: len >= 2
2  int* fib(unsigned int len) {
3      // ...
4  }
5  void print(int* m, int len) {
6      for (int* p = m+2; p < m + len; ++p) {
7          std::cout << *p << " ";
8      }
9      delete m;    // should be delete[]
10 }
11 void test2(unsigned int len) {
12     int* array = fib(len);
13     print(array, len);
14     delete[] array; // array deallocated twice
15 }
```

Questions?

6. Outro

General Questions?

Till next time!

Cheers!