System Software Crash Couse

Samsung Research Russia
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Block B The Basics of C
2. Pointers, Arrays, Static/Dynamic

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Last time:

- C memory model
- Typical program structure
- Declarations & types

Today:

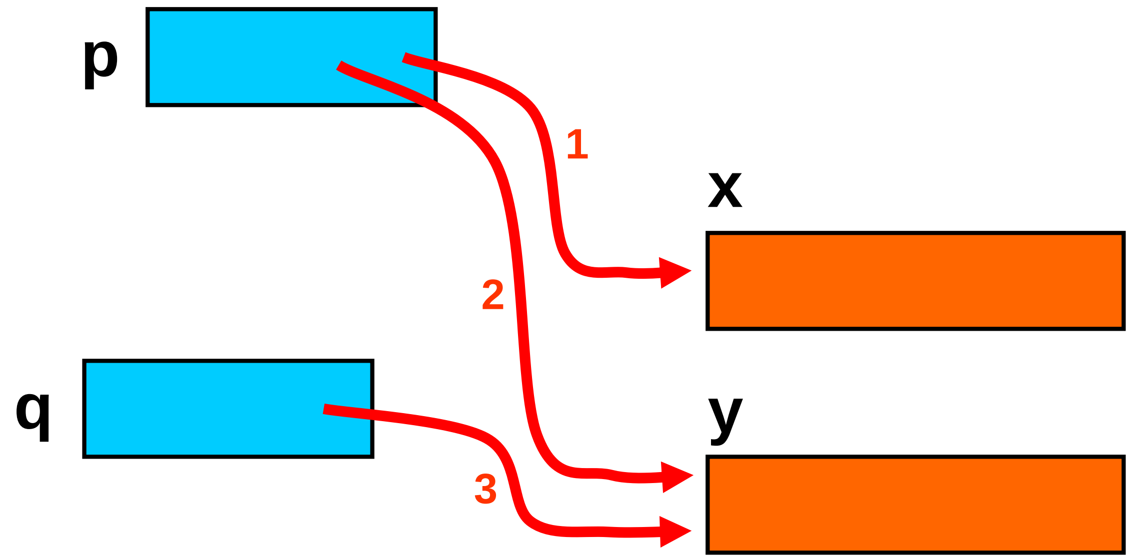
- Pointers
- Global/local & dynamic objects
- Arrays

1. The Notion of Pointer:

<u>An object</u> containing <u>an address</u> of some other object

```
int x;
int* p;
...
p = &x;   1
```

Unary "address-of" operator




```
int y;
...
p = &y;  2
```

```
int* q;
...
q = p;   3
```

Pointers

> **The task for your homework:**
> Learn the complete syntax of C declarations (esp. "declarators")

2. Pointer types

```
T* p;
```

Declaration of an object of a pointer type, where *T* denotes a type pointed

Examples:

- Pointers to (simple) variables; `int* pv;`
- Pointers to objects of struct types; `struct S* ps;`
- Pointers to arrays; `int pa[10];`
- Pointers to functions; `int (*pf)(int);`
- Pointers to pointers; `int** p;`
- Pointers to values of any type `void* p;`

3. Operators on pointers

```
&object
```

Taking address of object:
Unary prefix operator

```
int x;
int* p;
...
p = &x;
```

```
*pointer
```

Dereferencing: Getting object pointed to by the "pointer"
Unary prefix operator

```
int x;
int* p = &x;
...
*p = 777;       // x is 777
int z = *p+1;  // z is 778
```

Notice
The same token * is used for two different purposes:
a) for specifying a pointer type
b) as dereferencing operator.

Pointers

4. Operators on pointers: pointer arithmetic

Later today ☺

Pointers

5. Pointers & "Constness"

```
T* ptr1;
```

Pointer to an object of type *T*; no restrictions on access to the object pointed to by `ptr1`

```
const T* ptr2;
```

Pointer to a **constant object** of type *T*;
cannot use `ptr2` to modify object pointed to by it

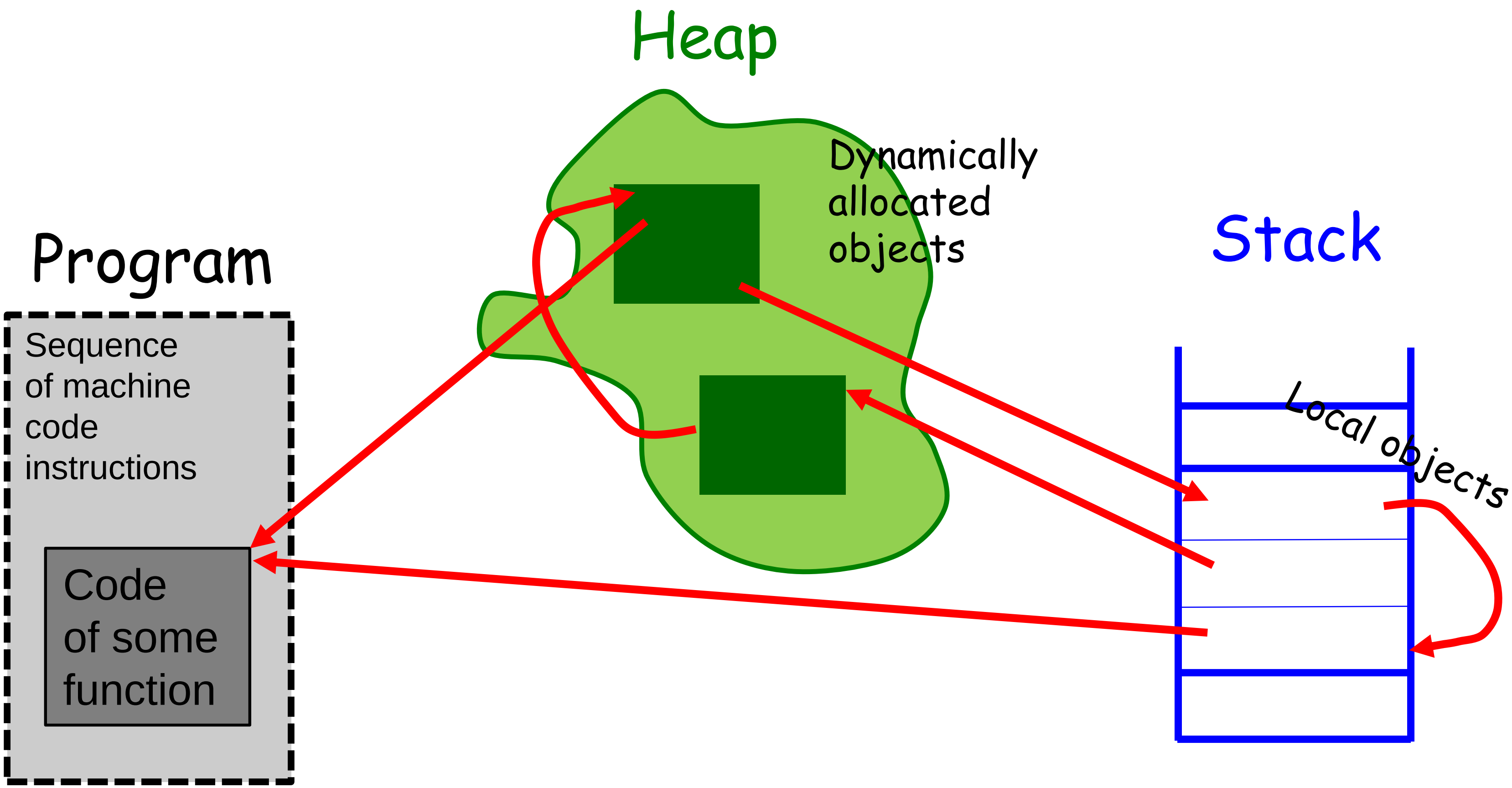
```
T*const ptr3 = &v;
```

Constant pointer to an object of type *T*; cannot modify the value of `ptr3` (it must be initialized)

```
const T*const ptr4 = &pc;
```

Constant pointer to a constant object of type *T*; cannot modify the value of `ptr4` (it must be initialized) and cannot use it to modify object pointed to by it

Pointers & The C Memory Model



Program cannot modify this memory (self-modified programs are not allowed)

The discipline of using heap is defined by program **dynamic semantics**, i.e., at runtime (while program execution)

The discipline of using stack is defined by the (static) **program structure**

Global, Local & Dynamic Objects

Global objects

Stack

Are created on program's start and exist ("live") until program is completed.
Live in the **global scope**.
Are accessible ("visible") within the translation unit they are declared in, OR within the whole program.

Local objects

Stack

Are created when a function is invoked or when the control flow enters a block, and disappear on return or on exit from the block.

Dynamic objects

Heap

Are created and destroyed on arbitrary moments while program execution, following the program logic.

Global, Local & Dynamic Objects

How global & local objects are created?
- By their declarations

How dynamic objects are created?
- Using special standard functions from the C library

Globals & locals: example

```
int x;
int* ptr;

void f(int p)
{
   int* local = &x;
   if ( p > 0 )
   {
      float m = ;
      ...
   }
}
```

x & ptr are **global objects**; they are created on the program's start and exist until its end

p & local are **local objects**; they are created when f function is invoked and disappear on return form f

m is the **local object**; it is created when the control flow enters the then-branch of **if** and disappears on return from this block

We will consider this mechanism in details on the last lecture

Dynamic Objects

How dynamic objects are created (and destroyed)?

- Using special standard functions from the C library

```
void* malloc ( int size )
{
   ...
   Allocation algorithm
   ...
}
```

```
void free ( void* ptr )
{
   ...
   Deallocation algorithm
   ...
}
```

- Specification is a bit simplified.
- The function allocates space for an object whose size (in bytes) is passed via the parameter.
- The function returns a pointer to the memory allocated.
- The pointer is "untyped" (`void*`).
- There are more allocation functions in the library.

Library Organization

Each translation unit is represented
by two source files:
- with forward declarations ("interface");
- with full declarations ("implementation").

To remind...

```
void* malloc(int size);
void free(void* ptr);
...
And many other function
headers ("prototypes")
...
```

stdlib.h

```
void* malloc(int size)
{
    ...
    Implementation
    ...
}
...
And implementations
of many other standard
functions
...
```

stdlib.c

Precompiled

Dynamic Objects

How dynamic objects are created?

- Using special standard functions from the C library

Example

```
#include <stdlib.h>

struct S { int a, b; }

void* ptr = malloc(sizeof(struct S));

struct S* s = (struct S*)ptr;

s->a = 5;
...
```

In order to use `malloc`, we should add its header

This is struct type declaration

Here, we dynamically allocate memory suitable to keep objects of type `struct S`…

…and **convert** the void pointer type to the type of pointer to `struct S`.

After that, we can use `s` to get access to elements of `struct S`.

Arrays

```
T A[size];
```

T is the type of array elements

A is the array identifier

size specifies the number of array elements; this is an expression of an integer type

In general, size should be a constant; however, in some cases, size can be omitted, or be replaced for * or be a non-constant.
Will see some cases later.

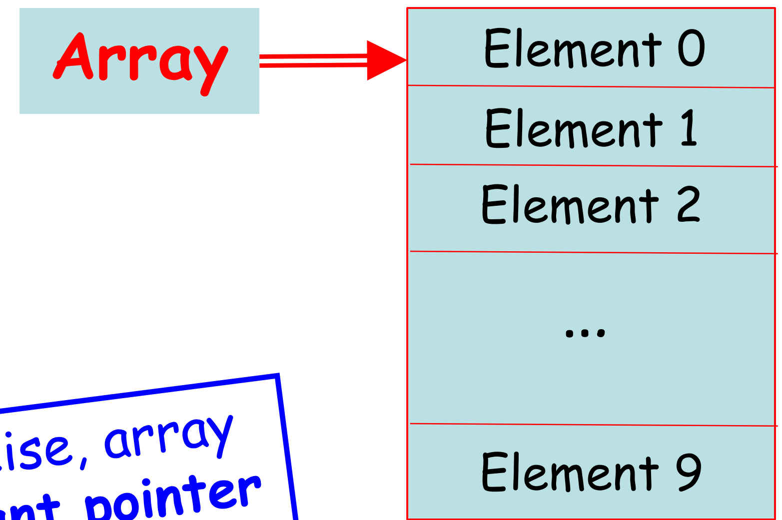
```
int Array[10];

const int x = 7;
void* Ptrs[x*2+5];

int Matrix[10][100];
```

The only operator on arrays:
- ***Getting access to an element***

```
int el5 = Array[5];

Array[7] = 7;
```

Arrays & Pointers

```
int Array[10];
```



By definition, array name is treated as a **pointer** to the first array element.

To be more precise, array name is a **constant pointer**

Therefore, these two constructs are semantically identical:

```
Array[0]
```

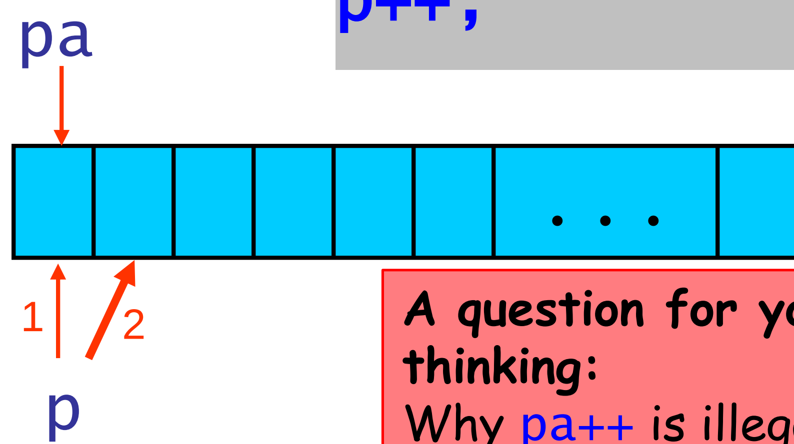
```
*Array
```

Pointers

4. Operators on pointers: pointer arithmetic

```
pointer+i
pointer-i
pointer++
pointer--
ptr1-ptr2
```

```
int pa[10];
int p = pa;        1

p++;               2
```

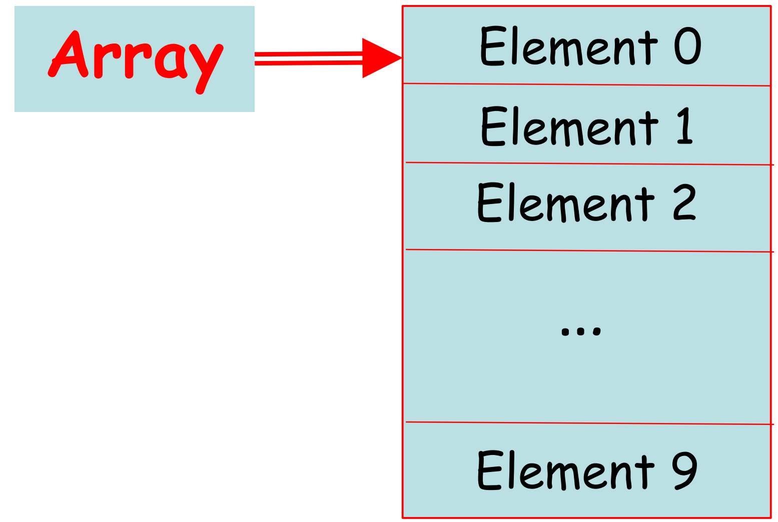


A question for your home thinking:
Why pa++ is illegal?

```
T* p;
p+i // the same as
    // (T*)((char*)p+sizeof(T)*i)
```

Arrays & Pointers (again)

```
int Array[10];
```



As we saw, these two constructs are semantically identical:

`Array[0]` `*Array`

Going on: these two constructs are also semantically identical:

`Array[1]` `*(Array+1)`

General form:

`Array[N]` `*(Array+N)`

Arrays & Pointers (again)

Interesting conclusion:
`Array[N]` and `*(Array+N)` are identical. But the second if the same as `*(N+Array)`, isn't it?
Therefore, `Array[N]` and `N[Array]` might be also identical? ☺

Check this at home!

C Standard:
6.5.2.1 Array subscripting
…
Semantics
2 A postfix expression followed by an expression in square brackets **[]** is a subscripted designation of an element of an array object. The definition of the subscript operator **[]** is that **E1[E2]** is identical to **(*((E1)+(E2)))**. Because of the conversion rules that apply to the binary **+** operator, if **E1** is an array object (equivalently, a pointer to the initial element of an array object) and **E2** is an integer, **E1[E2]** designates the **E2**-th element of **E1** (counting from zero).

C++ Standard:
…Therefore, despite its asymmetric appearance, subscripting is a commutative operation…

Breaking News:

Pointers are to be removed from the C++2023!!!

1 апреля

«Комитет по стандартизации языка в Джексонвиле две недели назад принял решение о том, что **указатели будут объявлены устаревшими** в C++20 и с **большой долей вероятности будут удалены** из C++23.»

https://habrahabr.ru/post/352570/

Problems with C pointers

```
T obj;
```

```
T* ptr;
```

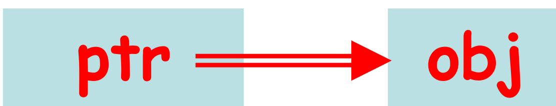
The problems with pointers come from its low-level nature…

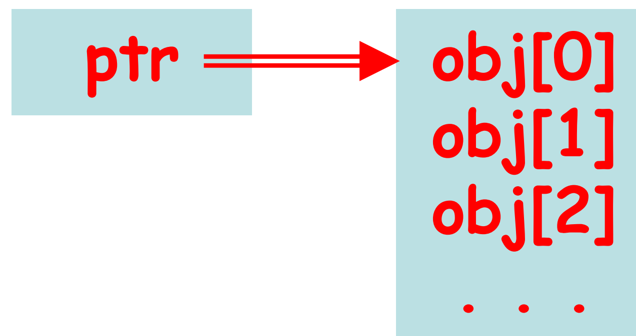
Exactly the same problems exist for ***C++* pointers** as well!!

Problems with C pointers

Scott Meyer:
6 kinds of problems with pointers

Problems 1 & 4:
A pointer can point either to a **single object**, or to an **array**. – And there's no way to distinguish betw these.






```
int x;
int A1[10];
int* A2 = &x;
int* A = cond ? A1 : A2;

int res = A[5]; // ???????
```

Problems with C pointers

Problem 2:
A declaration of a pointer tells nothing whether we must destroy the object pointed after the work is completed.

Or: does the pointer **owns the object** pointed?

```
void fun(T* ptr)
{
  // Some work with an object
  // pointed to by ptr.

  // Should we destroy the object
  // before return?
  return;
}
```

Problems with C pointers

Problem 3:
Even if we know that we should destroy the object pointed to by a pointer – in general we don't know **how to do that**!

I.e., either just to apply **delete** or use some special function for that?

```
void fun(T* ptr)
{
  // Some work with an object
  // pointed to by ptr.

  // We know that fun should destroy
  // the object before return.
  free(ptr);
  return;
}
```

…or perhaps:

```
myDealloc(ptr)
```

Problems with C pointers

Problem 5 (a consequence from problem 2): Even if we **own** the object pointed to by a pointer it's hard (or even impossible) provide **exactly one** act of destroy.

I.e., it's quite easy either to leave the object live, or to try to destroy it twice or more.

```
void lib_fun(T* ptr)
{
  // This library performs some
  // actions on the object passed
  // as parameter.

  // The function doesn't destroy
  // the object before return.
  return;
}
```

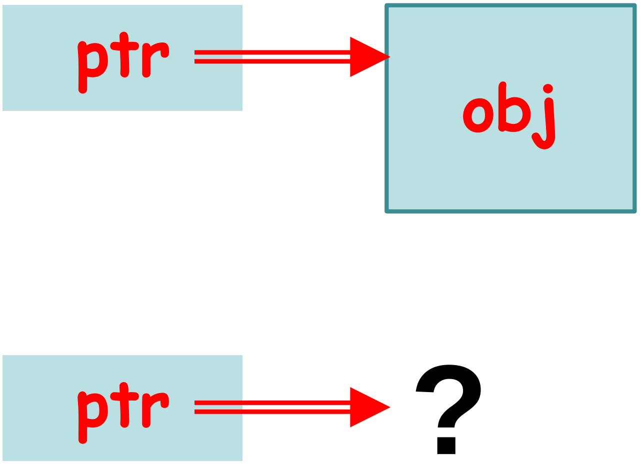
```
void user_fun()
{
  T* ptr = malloc(sizeof(T));
  // The function owns its object.

  lib_fun(ptr);
  // Should we destroy the object
  // before return, OR lib_fun has
  // already destroyed it??
  return;
}
```

Problems with C pointers

Problem 6:
There is no way to check whether a pointer actually points to a real object.

Or: to check whether the pointer is "dangling pointer".

```
T* ptr = (T*)malloc(sizeof(T));
...
if ( condition ) free(ptr);
...
// Long code…
...
// How to know whether ptr
// still points to an object?
...
```



Problems with C pointers

Problem 7 (in addition to Scott Meyers' ☺):
There is no way to ensure that an object gets destroyed when the single pointer to it disappears.

```
if ( condition )
{
   T* ptr = (T*)malloc(sizeof(T));
   ...
   // No free(ptr)
}
...
```

Here, `ptr` doesn't exist, but the object itself still does: **memory leak**