Pointers

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Overview

Introduction

Talking about memory this week.

- Pointers.
- References.
- Dynamic vs. static memory allocation.
- Memory leaks.

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- Pointers.
- References.
- Dynamic vs. static memory allocation.
- Memory leaks.

- Very important subject.
  - People can get nervous about them.
  - Not actually difficult.

Introduction

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- Pointers.
- References.
- Dynamic vs. static memory allocation.
- Memory leaks.

- Very important subject.
  - People can get nervous about them.
  - Not actually difficult.
  - Calm down, have a kitten.

Pointers

C

- Variables are pieces of information stored in a computers memory.
- Don’t typically care where in the memory.
- Just care that we can use the variables.
- Pointers store memory locations.
  - Find where variables are stored.
  - Move through memory.

- In Python almost everything is a pointer.
  - So we don’t notice.

  Technically Python uses aliases not a pointers.
- In C++ pointers are explicitly stated.

Variables & Memory

C

- Variables are stored in memory.
  - Can be visualised as series of uniquely addressed boxes.

```
char myVariable = 'Q';
```

Address	Value
1242	'Q'

- OS picks an unused memory location e.g. 1242
  - This location must have enough space to store the variable.
  - Different variable types have different sizes.
  - I.e. sizeof(int) == 4 bytes, sizeof(double) == 8 bytes.
    - Need multiple 'boxes'.
- `myVariable` is our name for memory location 1242.
- In Python can get memory location info using `id(myVariable)` function.

Big variables and Memory

C

- Variables are stored in memory.
- Arrays are groups of variables called elements.
- Array elements stored sequentially in contiguous blocks of memory.
  - Large objects, i.e. arrays, class instances, floats may span multiple blocks.

Big variables and Memory

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- Array elements stored sequentially in contiguous blocks of memory.
  - Large objects, i.e. arrays, class instances, floats may span multiple blocks.

```
array<char,6> myArray = {"Hello"};
```

Address	Value
4213	'H'
4214	'e'
4215	'l'
4216	'l'
4217	'o'
4218	'\0'

Big variables and Memory

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- Variables are stored in memory.
- Arrays are groups of variables called elements.
- Array elements stored sequentially in contiguous blocks of memory.
  - Large objects, i.e. arrays, class instances, floats may span multiple blocks.

```
array<char,6> myArray = {"Hello"};
```

Address	Value
4213	'H'
4214	'e'
4215	'l'
4216	'l'
4217	'o'
4218	'\0'

```
float myVariable = 12.34;
```

Address	Value
4213	
4214	12.34
4215	
4216	
4217	
4218	

Pointer types

I

Variables are named blocks of memory.

- Pointers are variables that hold memory addresses.
- Each type of variable has an associated pointer type.
- We declare a pointer using an * after the type name.

```
typename * variableName;
int * i;
char * c;
float * f;
```

- Pointers "point to" other variables in memory.

Referencing

I

- Referencing is when we store a memory address in a pointer.
- The pointer is now 'pointing' to that memory address.
- Is achieved using the & operator.
- & means the memory address of.

```
char myVariable = 'Q';
```

Name	Address	Value
`char myVariable;`	4213	'Q'
	4214	
	4215	
	4216	

Referencing

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- Referencing is when we store a memory address in a pointer.
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- Is achieved using the & operator.
- & means the memory address of.

```c
char myVariable = 'Q';
char *myPointer = &myVariable;
```

Name	Address	Value
`char myVariable;`	4213	`'Q'`
	4214	
	4215	
	4216	

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```
char myVariable = 'Q';
char *myPointer = &myVariable;
```

Name	Address	Value
char myVariable;	4213	'Q'
	4214	
	4215	
char *myPointer;	4216	4213

Dereferencing

I

- The opposite of referencing is dereferencing.
- A pointer stores a memory address.
- Dereferencing means getting the value that is stored in that memory address.
- Is achieved using the * operator.

```
char myVariable = 'Q';
```

Name	Address	Value
`char myVariable;`	4213	'Q'
	...	
	5617	
	...	
	7584	

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```
char myVariable = 'Q';
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```

Name	Address	Value
char myVariable;	4213	'Q'
	...	
	5617	
	...	
	7584	

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- Is achieved using the * operator.

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char myVariable = 'Q';
char *myPointer = &myVariable;
```

Name	Address	Value
`char myVariable;`	4213	`'Q'`
	...	
`char *myPointer;`	5617	4213
	...	
	7584	

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- A pointer stores a memory address.
- Dereferencing means getting the value that is stored in that memory address.
- Is achieved using the * operator.

```
char myVariable = 'Q';
char *myPointer = &myVariable;
char myOther = *myPointer;
```

Name	Address	Value
char myVariable;	4213	'Q'
	...	
char *myPointer;	5617	4213
	...	
	7584	

Dereferencing

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- The opposite of referencing is dereferencing.
- A pointer stores a memory address.
- Dereferencing means getting the value that is stored in that memory address.
- Is achieved using the $*$ operator.

```
char myVariable = 'Q';
char *myPointer = &myVariable;
char myOther = *myPointer;
```

Name	Address	Value
`char myVariable;`	4213	`'Q'`
	...	
`char *myPointer;`	5617	4213
	...	
`char myOther;`	7584	`'Q'`

Dereferencing II

I

- Already seen that we can get the value of a variable via a dereferenced pointer.
- Can also set the value of a variable through a pointer.

```
char myVariable = 'Q';
char *myPointer = &myVariable;
```

Name	Address	Value
char myVariable;	4213	'Q'
	...	
char *myPointer;	5617	4213

Dereferencing II

- Already seen that we can get the value of a variable via a dereferenced pointer.
- Can also set the value of a variable through a pointer.

```
char myVariable = 'Q';
char *myPointer = &myVariable;
myVariable = 'A';
```

Name	Address	Value
char myVariable;	4213	'A'
	...	
char *myPointer;	5617	4213

Dereferencing II

I

- Already seen that we can get the value of a variable via a dereferenced pointer.
- Can also set the value of a variable through a pointer.

```
char myVariable = 'Q';
char *myPointer = &myVariable;
myVariable = 'A';
*myPointer = 'Z';
```

Name	Address	Value
`char myVariable;`	4213	'Z'
	...	
`char *myPointer;`	5617	4213

Pointer arithmetic

A

- Have seen how to change variables pointed to by a pointer.
- Pointers are also variables.
- Can change the values of pointers.
  - Can change where they are pointing.

```
array<int,4> myArray {69, 42, 99, 3};
```

Name	Addr	Value
myArray	4213	69
	4214	42
	4215	99
	4216	3
	4217	

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- Pointers are also variables.
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  - Can change where they are pointing.

```
array<int,4> myArray {69, 42, 99, 3};
int *myPointer = myArray.data();
```

Name	Addr	Value
myArray	4213	69
	4214	42
	4215	99
	4216	3
myPointer	4217	4213

Pointer arithmetic

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- Have seen how to change variables pointed to by a pointer.
- Pointers are also variables.
- Can change the values of pointers.
    - Can change where they are pointing.

```
array<int,4> myArray {69, 42, 99, 3};
int *myPointer = myArray.data();

cout << *myPointer << endl; // 69
```

Name	Addr	Value
myArray	4213	69
	4214	42
	4215	99
	4216	3
myPointer	4217	4213

Pointer arithmetic

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- Have seen how to change variables pointed to by a pointer.
- Pointers are also variables.
- Can change the values of pointers.
  - Can change where they are pointing.

```
array<int,4> myArray {69, 42, 99, 3};
int *myPointer = myArray.data();

cout << *myPointer << endl; // 69
myPointer += 1;
```

Name	Addr	Value
myArray	4213	69
	4214	42
	4215	99
	4216	3
myPointer	4217	4214

Pointer arithmetic

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- Have seen how to change variables pointed to by a pointer.
- Pointers are also variables.
- Can change the values of pointers.
  - Can change where they are pointing.
- Powerful but highly dangerous.

```
array<int,4> myArray {69, 42, 99, 3};
int *myPointer = myArray.data();

cout << *myPointer << endl; // 69
myPointer += 1;
cout << *myPointer << endl; // 42
```

Name	Addr	Value
myArray	4213	69
	4214	42
	4215	99
	4216	3
myPointer	4217	4214

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- Powerful but highly dangerous.

```
array<int,4> myArray {69, 42, 99, 3};
int *myPointer = myArray.data();

cout << *myPointer << endl; // 69
myPointer += 1;
cout << *myPointer << endl; // 42
myPointer += 2;
```

Name	Addr	Value
myArray	4213	69
	4214	42
	4215	99
	4216	3
myPointer	4217	4216

Pointer arithmetic

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- Have seen how to change variables pointed to by a pointer.
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  - Can change where they are pointing.
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```
array<int,4> myArray {69, 42, 99, 3};
int *myPointer = myArray.data();

cout << *myPointer << endl; // 69
myPointer += 1;
cout << *myPointer << endl; // 42
myPointer += 2;
cout << *myPointer << endl; // 3
```

Name	Addr	Value
myArray	4213	69
	4214	42
	4215	99
	4216	3
myPointer	4217	4216

Null pointers

I

Pointers don't have to point anywhere.

- If they don't point to anything they are called null pointers.
- Dereferencing a null pointer will cause your program to crash.
- You can set any pointer to point to null.

- Old way (still works).

```
int *myPointer = NULL;
```

- New C++11 way (use this one).

```
int *myPointer = nullptr;
```

Why use pointers/references?

C

Advantages.

- Pointers/references are small.
  - Instead of copying big data structures around just copy the pointer.
  - E.g. an array storing a picture == millions of bytes.
  - Pointer/reference to an array storing a picture == 4-8 bytes.
- Pointers are required for dynamic memory allocation (C++).
  - Required for some behaviours.

Disadvantages.

- Pointers are dangerous.
  - Buggy pointer code can crash your program/computer.

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Danger

I

Pointers let us move around the memory.

- ANYWHERE in memory.
  - Newer systems are getting more secure.
  - Segmentation fault.

```
array<int,4> myArray {69, 42, 99, 3};
int *myPtr = myArray.data();

for( int i=0; i<=myArray.size(); ++i )
{
    cout << *myPtr << endl;
    myPtr += 1;
}
```
lec_bad.cpp

Address	Value	
4213	69	← myPtr
4214	42	
4215	99	
4216	3	
4217		
4218		

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← myPtr

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    myPtr += 1;
}
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Address	Value	
4213	69	
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int *myPtr = myArray.data();

for( int i=0; i<=myArray.size(); ++i )
{
    cout << *myPtr << endl;
    myPtr += 1;
}
```

lec_bad.cpp

Address	Value
4213	69
4214	42
4215	99
4216	3 ← myPtr
4217	
4218	

Danger

I

Pointers let us move around the memory.

- ANYWHERE in memory.
  - Newer systems are getting more secure.
  - Segmentation fault.
- Reading from invalid memory is bad.
  - Writing to invalid memory can be disastrous.

```
array<int,4> myArray {69, 42, 99, 3};
int *myPtr = myArray.data();

for( int i=0; i<=myArray.size(); ++i )
{
    cout << *myPtr << endl;
    myPtr += 1;
}
```

lec_bad.cpp

Address	Value	
4213	69	
4214	42	
4215	99	
4216	3	
4217	?????	← myPtr
4218	?????	

Required for....

I

Simple function that doubles all the values given to it.

```
import sys

def some_function( values ):
    for i in range(len(values)):
        values[i] *= 2

def main():
    v = [ i for i in range(5) ]
    print(v)  # [0, 1, 2, 3, 4]

    some_function(v)
    print(v)  # [0, 2, 4, 6, 8]

if __name__ == '__main__':
    sys.exit(main())
```

lec_some_function.py

Required for.... II

Same program in C++ doesn't work.

```
void some_function( array<int,5> values )
{
    for( int i=0; i<values.size(); ++i )
        values[i] *= 2;
}

int main()
{
    array<int,5> v {0, 1, 2, 3, 4};

    for( int i : v )          // 0,1,2,3,4
        cout << i << ",";
    cout << endl;

    some_function(v);
    for( int i : v )          // 0,1,2,3,4
        cout << i << ",";
    cout << endl;
}
```

lec_some_function.cpp

The C++ program didn’t work, why?

I

The C++ program didn't work, why?

I

- In Python we passed a mutable type to the function.
  - Actually just sends an 'alias' of the original mutable structure.
  - Mutable types, e.g. lists, sets, dicts etc.
  - Changing value/s in function changes original variable/s too.
  - Aliases are similar to pointers/references.

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  - Changing value/s in function changes original variable/s too.
  - Aliases are similar to pointers/references.
- If we passed an immutable type Python would create actual copy and send that instead.
  - Immutable types, e.g. int, float, string.
  - Original would stay same regardless.

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- In Python we passed a mutable type to the function.
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  - Changing value/s in function changes original variable/s too.
  - Aliases are similar to pointers/references.
- If we passed an immutable type Python would create actual copy and send that instead.
  - Immutable types, e.g. int, float, string.
  - Original would stay same regardless.
- When C++ variable passed to a function, always creates a new variable.
  - New variable stored in a new memory location.
  - Even for vectors, arrays etc.
- Changing value/s in function doesn't change original variable/s.
- How to fix?

References

I

C++ also has references.

- Safer than pointers.
  - Less powerful.
- Declared like pointers but with & instead of *.

```
int myVariable = 42;

int &refA = myVariable;
int &refB = refA;
```

References II

I

Looking at the earlier function example.

```
int some_function( array<int,5> &values )
{
  for( int i=0; i<values.size(); ++i )
    values[i] *= 2;
}

int main()
{
  array<int,5> v {0, 1, 2, 3, 4};

  some_function(v);

  for( int i : v )      // 0,2,4,6,8
    cout << i << ",";
  cout << endl;

  return 0;
}
```

lec_ref_function.cpp

Differences to pointers.

I

- Can’t be null.
- Can’t be changed to point at different locations.
- References automatically redirects to the variable.
  - Automatic dereferencing.
- Have to be initialised on creation.
  - References point at a variable the instant they are created.

Differences to pointers.

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- References automatically redirects to the variable.
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- Have to be initialised on creation.
  - References point at a variable the instant they are created.

Use references instead of pointers whenever possible.

Dynamic memory

C

Most important feature of pointers.

- Can't always know how much memory program will need at compile time.
  - E.g. a program that reads in a file, memory required depends on size of the file.
- Have to allocate it at run time.
  - Dynamic memory allocation.
  - As opposed to Static memory allocation.
- Code gives itself more memory, has to remember to give it back when it's finished
  - Deallocation.

Dynamic memory allocation

I

```
int *myInt;
```

Name	Address	Value
int *myInt;	4213	
	4214	
	4215	
	4216	
	4217	
	4218	

Dynamic memory allocation

I

```
int *myInt;
myInt = new int;
```

Name	Address	Value
int *myInt;	4213	4215
	4214	
	4215	
	4216	
	4217	
	4218	

Dynamic memory allocation

I

```
int *myInt;
myInt = new int;
*myInt = 42;
```

Name	Address	Value
`int *myInt;`	4213	4215
	4214	
	4215	42
	4216	
	4217	
	4218	

Dynamic memory allocation

I

```
int *myInt;
myInt = new int;
*myInt = 42;
delete myInt
```

Name	Address	Value
`int *myInt;`	4213	4215
	4214	
	4215	
	4216	
	4217	
	4218	

Dynamic why?

I

Used to have to dynamically ask for more memory.

- Create a chunk of memory of the size requested.
- Return a pointer to it so know where it is.

E.g. vectors.

- C/C++ arrays can't be resized.
- But vectors are resizeable arrays.
  - How?

1. Dynamically allocate new array.
2. Copy old array contents into new array.
3. Deallocate old array.

Array allocation

I

How to dynamically allocate arrays?

- Have to use old, C-style arrays.
  - For the moment, talk again after C++17.

```
int staticArray[10]; // works
int* dynamicArray = new int[10]; // works
```

```
int size;
cout << "How big an array do you want?" << endl;
cin >> size;

int staticArray[size]; // won't compile
int* dynamicArray = new int[size]; // works
```

Dynamic memory deallocation

C

- You **MUST** remember to deallocate any dynamic memory.
- Failure to do so causes a memory leak.
  - Memory gradually gets ‘lost’.
- Every `new` needs a matching `delete`.

```
int* myVariable = new int;
int* myArray = new int[1000];

// do stuff

delete myVariable;
delete [] myArray;
```

Dynamic memory deallocation

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- You **MUST** remember to deallocate any dynamic memory.
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- Every `new` needs a matching `delete`.
- No exceptions.

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- NO EXCEPTIONS!

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int* myVariable = new int;
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```

Dynamic memory deallocation

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- NO EXCEPTIONS!

NO EXCEPTIONS

```
int* myVariable = new int;
int* myArray = new int[1000];

// do stuff

delete myVariable;
delete [] myArray;
```

Garbage collection

I

- Python does memory allocation and deallocation for you automatically.
  - Automatically allocates memory as you create variables.
  - Automatically deallocates memory that isn't in use.
  - Garbage collection.
- Can still manually deallocate Python objects.

```
variable = 42

// do stuff

del(variable)
```

C++ Garbage collection

I

C++ does not have automatic garbage collection.

- C++11 comes close.
- New features - `shared_ptr` and `unique_ptr`, `weak_ptr`.
- Special new smart pointers.
  - Automatically deallocate memory when nothing pointing at it.
  - Don't need to remember to `delete`.
  - No memory leaks!
- `shared_ptr` is 99% the same as 'normal' pointers.
  - `unique_ptr` and `weak_ptr` have extra features.

Dynamic avoidance

I

C++ is moving away developer allocated memory.

- Use vectors instead of arrays etc.
  - Handles memory allocation for you.
  - Safe, bug free.

Dynamic avoidance

I

C++ is moving away developer allocated memory.

- Use vectors instead of arrays etc.
  - Handles memory allocation for you.
  - Safe, bug free.

When you HAVE to dynamically allocate memory...

- C++11 has new features.
  - `shared_ptr` and `unique_ptr`, `weak_ptr`.
- Special new smart pointers.
  - Automatically deallocate memory when nothing pointing at it.
  - Don't need to remember to `delete`, no memory leaks!
- `shared_ptr` is 99% the same as 'normal' pointers.

shared_ptr<>

STRONGLY recommend you use `shared_ptr`.

- Whenever dynamically allocating memory.
- No memory leaks.

```
int main()
{
    shared_ptr<int> pointerA = make_shared<int>();
    *pointerA = 42;

    cout << pointerA.use_count() << endl; // 1

    shared_ptr<int> pointerB = pointerA;
    cout << pointerA.use_count() << endl; // 2

    pointerB = nullptr;
    cout << pointerA.use_count() << endl; // 1

    return 0;
}
```

Quiz

Recap

- Variables stored in memory.
- Different variables need different amounts of memory.
- Array elements stored in contiguous sequential blocks of memory.
- Pointers/references store memory addresses.
- Pointers are dangerous but necessary.
- If, at compile time, we don't know how much memory our program will need use dynamic memory allocation.
- Always deallocate memory before the program exits.

Recap

- Variables stored in memory.
- Different variables need different amounts of memory.
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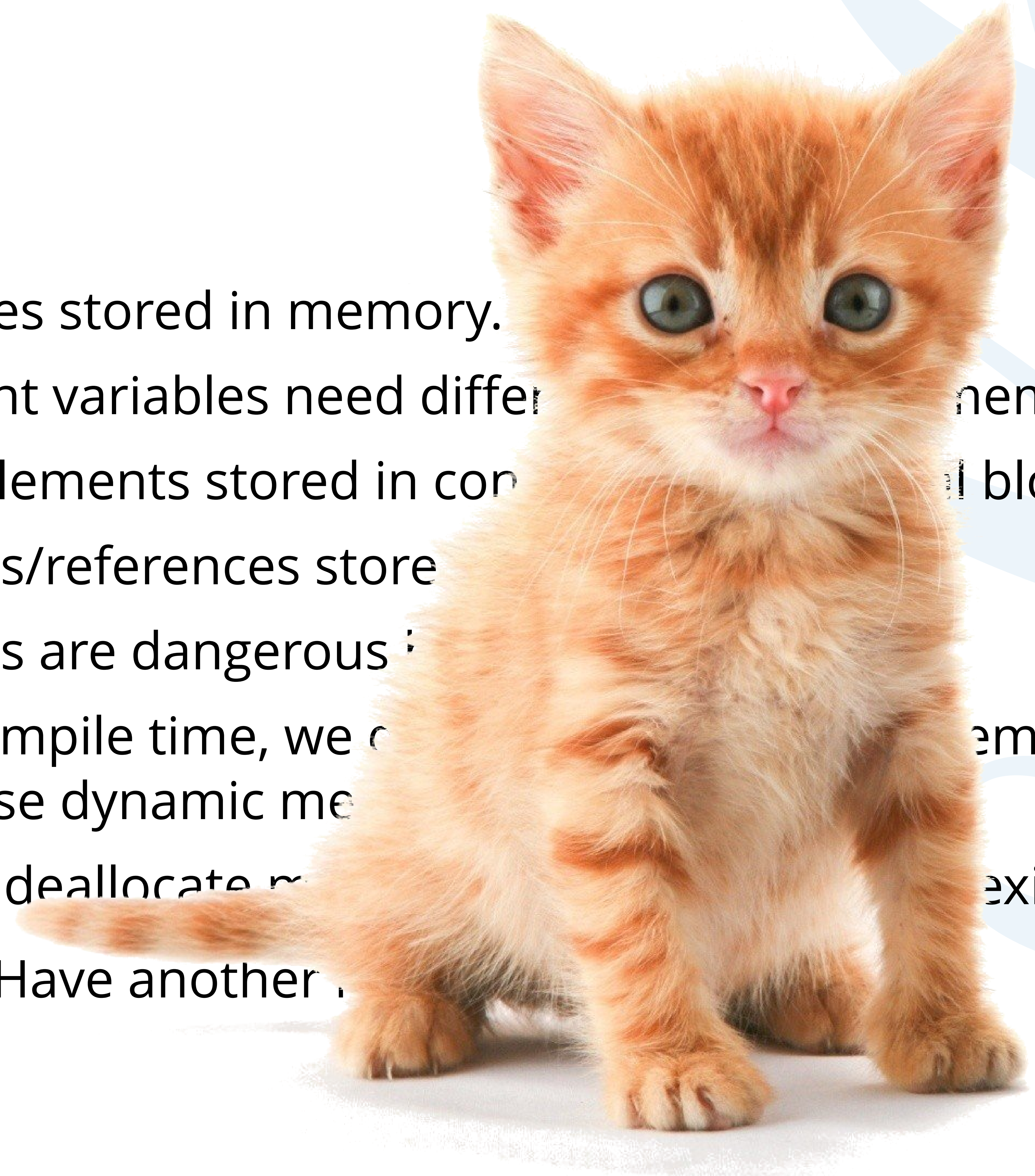
- Pointers/references store memory addresses.
- Pointers are dangerous but necessary.
- If, at compile time, we don't know how much memory our program will need use dynamic memory allocation.
- Always deallocate memory before the program exits.

Well done! Have another kitten.

Recap

- Variables stored in memory.
- Different variables need diffe… …nemory.
- Array elements stored in co… …l blocks of memory.
- Pointers/references store…
- Pointers are dangerous…
- If, at compile time, we … …emory our program will need use dynamic me…
- Always deallocate m… …exits.

Well done! Have another…



The End