POINTERS

- What is a pointer?
  - The index of a book contains pointers.
  - A URL (e.g., http://turing.ubishops.ca/home/cs318) is a pointer.
  - A street address is a pointer.
  - What is then a forwarding address?

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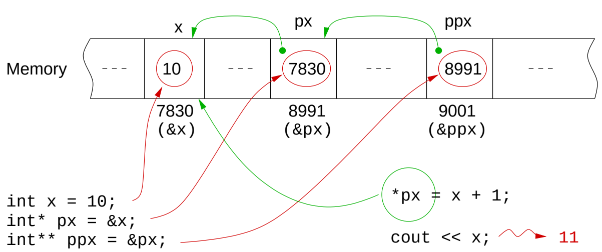
  - The index of a book contains pointers.
  - A URL (e.g., http://turing.ubishops.ca/home/csc218) is a pointer.
  - A street address is a pointer.
  - What is then a forwarding address?
    - ∗ a pointer to a pointer!
- OK, so what is a (C++) pointer?
  - Computer memory contains data which can be accessed using an address.
    - ∗ A pointer is such an address, nothing more.
  - If you want, computer memory is like an array holding data.
    - ∗ A pointer then is an index in such an array.
  - What are in fact pointers?

POINTERS (CONT'D)

- Pointers can (just as array indices) be stored in variables.
- If we have some type d, then

d `vx;`	$\rightarrow$	`vx` is a variable of type d
d`* px;`	$\rightarrow$	`px` is a (variable holding a) pointer to a variable of type d
`&vx`	$\rightarrow$	denotes the address of `vx` (i.e., a pointer, of type d`*`)
`*px`	$\rightarrow$	denotes the value from the memory location pointed at by `px`, of type d (we thus dereference `px`)



WHAT POINTERS REALLY ARE

- Since a pointer is an address, it is usually represented internally as `unsigned int`.
- Do we need a type for a pointer?
  - Why?
  - Always?

WHAT POINTERS REALLY ARE

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  - Why?
  - Always?

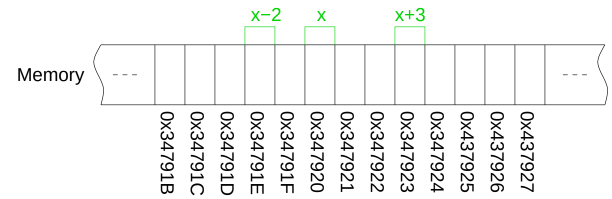
```
int x=10;
void* p = &x;
int * pi;
float* pf;
pi = (int*)p;
pf = (float*)p;
cout << "Pointer " << p << " holds the int: "<< *pi
     << " ...and the float: " << *pf << "\n";
```

- Special pointer (of type `void*`): `NULL` (really, `0`), which points to nothing.

POINTER ARITHMETIC

- The types of pointers do matter:
  1. We know what we get when we dereference a pointer
  2. We can do meaningful pointer arithmetic

```
int i=10;           long j=10;
int *x = &i;        long *y = &j;
int *x1 = x + 3;    long *y1 = y + 3;
int *x2 = x - 2;    long *y2 = y - 2;
```



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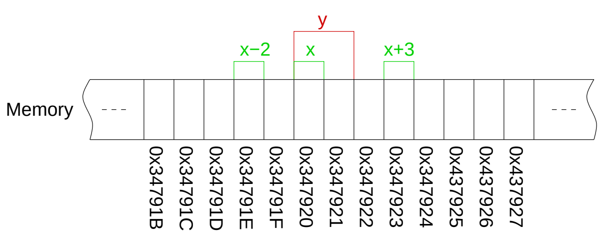

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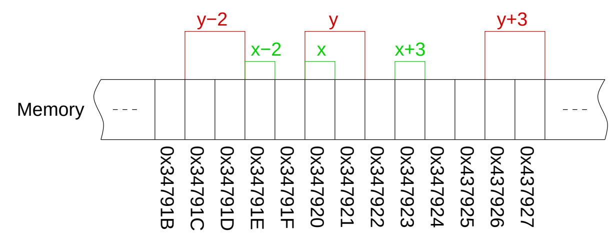
```

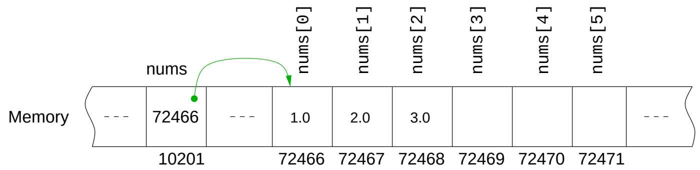


- Meaningful pointer arithmetic?!?

Arrays and pointers

- An array is just a pointer to its content:

```
float nums[6] = {1,2,3}
```



  - In addition, when you declare an array (contiguous) memory space is also reserved to hold its elements.

- What do they all mean?

```
float nums[6] = {1,2,3};        int nums[6] = {1,2,3};
float* p1 = nums;               int* p1 = nums;
float* p2 = nums + 3;           int* p2 = nums + 3;
```


Arrays versus pointers

- The following declarations mean almost the same thing:

```
int* nums;
int  numsA[20];
```

- Because we have:

```
numsA[2] = 17;    →    Good
numsP[2] = 17;    →    Disaster!
```

  - Prize for the most uninformative error message goes to "`Segmentation fault`."

- But it is perfectly good to do:

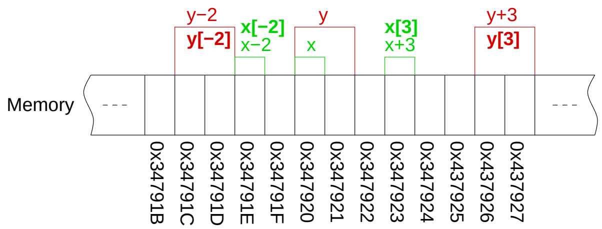
```
int numsP[] = {1,2,3};
```

- In other words, you do not have to provide the dimension for an array if you initialize it at the moment of declaration (e.g., by providing a literal array).

Array subscripts

- We access elements in an array precisely as we do it in Java:
  - `cout << x[6];` prints the seventh element of x
  - `x[5] = 20;` assigns 20 to the sixth element of x

- The subscript operator `[]` is in fact implemented usingpointer arithmetic
  - `x[5]` is a shorthand for (and thus a perfect equivalent to) &x+5.
  - the subscript operator works with any pointer, not just with arrays.
  - it does correct pointer arithmetic so that we access the intended element



Arrays, pointers, and functions

```
#include <iostream>
using namespace std;

void translate(char a) {
  if (a == 'A') a = '5'; else a = '0';
}

void translate(char* array, int size) {
  for (int i = 0; i < size; i++) {
    if (array[i] == 'A') array[i] = '5';
    else array[i] = '0';
  }
}

int main () {
  char mark = 'A'; char marks[5] = {'A','F','A','F','F'};
  translate(mark);
  translate(marks,5);
  cout << mark << "\n";
  for (int i = 0; i < 5; i++)
    cout << marks[i] << " ";
  cout << "\n";
}
```

Arrays, pointers, and functions

```
#include <iostream>
using namespace std;

void translate(char a) {   // translate, by the way, is a OVERLOADED FUNCTION
  if (a == 'A') a = '5'; else a = '0';
}

void translate(char* array, int size) {
  for (int i = 0; i < size; i++) {
    if (array[i] == 'A') array[i] = '5';
    else array[i] = '0';
  }
}

int main () {
  char mark = 'A'; char marks[5] = {'A','F','A','F','F'};
  translate(mark);
  translate(marks,5);
  cout << mark << "\n";
  for (int i = 0; i < 5; i++)
    cout << marks[i] << " ";
  cout << "\n";
}
```

```
A
5 0 5 0 0
```


Arrays, pointers, and functions (cont'd)

```
#include <iostream>
using namespace std;

int translate(char a) {  // still overloaded...
  if (a == 'A') a = '5'; else a = '0';
  return a;
}
void translate(char* array, int size) {
  for (int i = 0; i < size; i++) {
    if (array[i] == 'A') array[i] = '5';
    else array[i] = '0';
  }
}

int main () {
  char mark = 'A'; char marks[5] = {'A','F','A','F','F'};
  mark = translate(mark);
  translate(marks,5);
  cout << mark << "\n";
  for (int i = 0; i < 5; i++)
    cout << marks[i] << " ";
  cout << "\n";
}
```

```
5
5 0 5 0 0
```


Pointers and functions

- An argument can be passed in C++ to a function using:
  - Call by value: the value of the argument is passed; argument cannot be changed by the function.

    `int aFunction(int i);`
  - Call by reference: the pointer to the argument is passed to the function; argument can be changed at will by the function.

    `int aFunction(int* i);`

    Used for output arguments (messy, error prone syntax).
  - Call by constant reference: the pointer to the argument is passed to the function; but the function is not allowed to change the argument.

    `int aFunction(const int* i);`

    more useful:

    `int aFunction(const char* i);`

    Used for bulky arguments (still messy syntax).

Call by reference

foo.cc

```
void increment (int* i) {
  *i = *i + 1;
}

void increment1 (const int* i) {
 *i = *i + 1;
}

int main () {
  int n = 0;
  increment(&n);
  increment1(&n);
}
```

g++ -Wall foo.cc

```
foo.cc: In function 'void increment1(const int *)':
foo.cc:9: assignment of read-only location
```

Call by reference (cont'd)

foo.cc

```
void increment (int& i) {
  i = i + 1;
}

void increment1 (const int& i) {
 i = i + 1;
}

int main () {
  int n = 0;
  increment(n);
  increment1(n);
}
```

⟶ no more messy syntax!

g++ -Wall foo.cc

```
foo.cc: In function 'void increment1(const int &)':
foo.cc:9: assignment of read-only reference 'i'
```


Call by reference (cont'd)

foo.cc

```
#include <iostream>
using namespace std;

void increment (int& i) {
  i = i + 1;
}

int increment1 (const int& i) {
 int r = i + 1;
 return r;
}

int main () {
  int n = 0;
  increment(n);
  cout << n << "\n";
  n = increment1(n);
  cout << n << "\n";
}
```

output

```
1
2
```


Calling conventions in C++ and Java

- The following are the implicit calling conventions:

What	Java	C++
Primitive types (`int`, `float`, etc.)	value	value
Arrays	reference	value
Objects	reference	value

  - In C++ everything is passed by value unless explicitly stated otherwise. Arrays are apparently passed by reference, but only because of the array structure (pointer + content).

- In Java there is no other way to pass arguments than the implicit one.

- In C++ you can request that an argument be passed by reference by either passing a pointer to the actual argument or by saying explicitly that you want to pass the argument by reference.

C strings

- There is no special type for strings.
  - Instead, strings are simply arrays of characters.
    - ∗ Literal strings can be written surrounded by double quotes though.

    `char message[20] = "Hello.";`
  - The last character in a string is always the null byte (`'\0'`). So if you declare a string of size 20 it will hold a maximum of 19 characters.
    - ∗ C does not check for array overflow, so be careful not to go over the array size.
  - You can access individual characters just as you access elements in a normal array:

    `message[1] = 'x';`
- Strings cannot be compared using the usual comparison operators (e.g., ==) (why?).
  - Use `strcmp` instead.

Operations on strings

- You can implement your own operations on strings (just do not forget about the null byte at the end).
- Some operations are already defined for you though, including:
  - Copy a string: `strcpy` (see `man strcpy`)
  - Length of a string: `strlen` (see `man strlen`)
- Just do not forget to include the appropriate header:
  `#include <string.h>`

Structures

- An array holds a number of elements of a given type.
  - Individual elements are referred to by integer indices.
- By contrast, a structure holds elements of not necessarily the same type.
  - Individual elements are referred to by symbolic names.
  - Of course, we cannot thus loop over the members of a structure.
- For instance, a structure representing a student might contain
  - the given name and surname (strings),
  - the student number (integer),
  - the mailbox number (integer), and
  - the grade point average (floating point).

Student structure

```
struct student {
  char* name;
  char* surname;
  unsigned int number;
  unsigned short mailbox;
  float gpa;
};
```

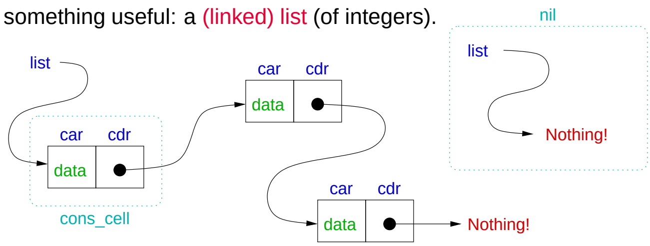

Student structure

```
struct student {
  char* name;
  char* surname;
  unsigned int number;
  unsigned short mailbox;
  float gpa;
};

int main () {
  student studs[5];
  studs[0].name = "Jane";
  studs[0].surname = "Doe";
  studs[0].number = 1234567;
  studs[1].name = "John";
  studs[1].surname = "Smith";
  studs[1].number = 7654321;
  cout << studs[1].name << " " << studs[1].surname
       << " (" << studs[1].number << ")\n";
}
```

Pointers to structures

- Let's do something useful: a (linked) list (of integers).



- Interesting operations:

Operation	Meaning
cons	adds an integer to the list
car	returns the first element of a list
cdr	returns a list without its first element
null	returns true iff the list is empty

Linked list

```
struct cons_cell {
  int car;
  cons_cell* cdr;
};
typedef cons_cell* list;   // careful, could be bad programming practice!

const list nil = 0;

int null (list cons) {
  return cons == nil;
}
list cons (int car, list cdr = nil) {
  list new_cons = new cons_cell;
  new_cons -> car = car;          // (*new_cons).car = car;
  new_cons -> cdr = cdr;          // (*new_cons).cdr = cdr;
  return new_cons;
}
int car (list cons) {
  return cons -> car;
}
list cdr (list cons) {
  return cons -> cdr;
}
```


New (and delete)

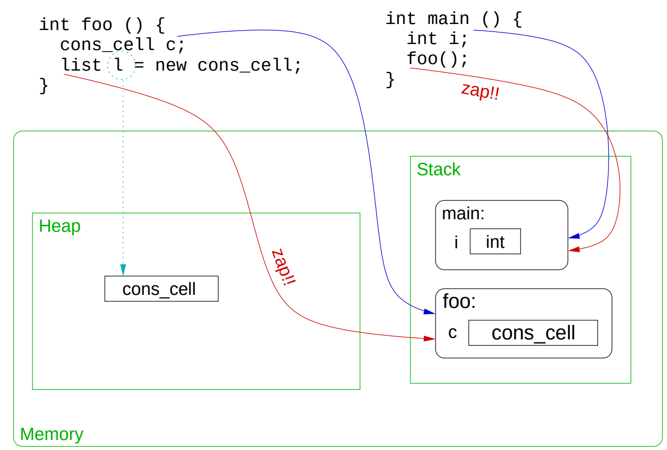
- new allocates memory for your data. The following are (somehow) equivalent:

```
char message[256];     char* pmessage;
                       pmessage = new char[256];
```

  - Exception:
    - ∗ message takes care of itself (i.e., gets deleted when it is no longer in use), whereas
    - ∗ pmessage however must be explicitly deleted when it is no longer needed:
      `delete[] pmessage;`
  - Perrils of not using new:

```
list cons (int car, list cdr = nil) {
  cons_cell new_cons;
  new_cons.car = car;                int main () {
  new_cons.cdr = cdr;                  list bad = cons(1);
  return &new_cons;                    cout << car(bad);    → Boom!
}
```


Dynamic memory management



Conclusion: ✓ foo returns l ✗ foo returns c

Using linked lists

```
list rmth (list cons, int which) {
  list place = cons;
  for (int i = 0; i < which - 1; i++) {
    if (null(place))
      break;
    place = place -> cdr;
  }
  if (! null(place) ) {
    if (null(cdr(place)))
      place -> cdr = nil;
    else
      place -> cdr = cdr(place -> cdr);
  }
  return cons;
}
```


Using linked lists (cont'd)

```
int main () {
  int elm = -1;
  list lst = nil;
  while (elm != 0) {
    cin >> elm;
    if (elm != 0)
      lst = cons(elm,lst);
  }
  lst = rmth(lst,1);
  lst = rmth(lst,10);
  cout << "List is:\n";
  list iter = lst;
  while (! null(iter) ) {
    cout << car(iter) << "\n";
    iter = cdr(iter);
  }
}
```

```
1
2
3
4
5
0
List is:
5
3
2
1
```


Memory leaks

- A good example:

```
list rmth (list cons, int which) {
  list place = cons;
  for (int i = 0; i < which - 1; i++) {
    if (null(place))
      break;
    place = place -> cdr;
  }
  if (! null(place) ) {
    if (null(cdr(place)))
      place -> cdr = nil;
    else
      place -> cdr = cdr(place -> cdr);
  }
  return cons;
}
```

- If you create something using new then you must eventually delete it using `delete`.

Say no to memory leaks

```
list rmth (list cons, int which) {
  list place = cons;
  for (int i = 0; i < which - 1; i++) {
    if (null(place))
      break;
    place = place -> cdr;
  }
  if (! null(place) ) {
    if (null(cdr(place)))
      place -> cdr = nil;
    else {
      list to_delete = cdr(place);
      place -> cdr = cdr(place -> cdr);
      delete to_delete;
    }
  }
  return cons;
}
```

Student structure, take two

- The following won't work. Why? What would happen if it would work?

```
struct student {
  char name[20];
  char surname[20];
  unsigned int number;
  unsigned short mailbox;
  float gpa;
};

int main () {
  student studs[5];
  studs[0].name = "Jane";
  studs[0].surname = "Doe";
  studs[0].number = 1234567;
  studs[1].name = "John";
  studs[1].surname = "Smith";
  studs[1].number = 7654321;
  cout << studs[1].name << " " << studs[1].surname
       << " (" << studs[1].number << ")\n";
}
```


Student structure, take two (cont'd)

- The following does work.

```
struct student {
  char name[20];
  char surname[20];
  unsigned int number;
  unsigned short mailbox;
  float gpa;
};

int main () {
  student studs[5];
  strncpy(studs[0].name,"Jane",20);
  strncpy(studs[0].surname,"Doe",20);
  studs[0].number = 1234567;
  strncpy(studs[1].name,"John",20);
  strncpy(studs[1].surname,"Smith",20);
  studs[1].number = 7654321;
  cout << studs[1].name << " " << studs[1].surname
       << " (" << studs[1].number << ")\n";
}
```


The perils of delete

- Thou shall not leak memory, but also:
- Thou shall not leave stale pointers behind.

`char* str = new char[128];`	→ allocate memory for `str`
`strcpy(str,"hello");`	→ put something in there ("hello")
`char* p = str;`	→ p points to the same thing
`delete p;`	→ "hello" is gone, `str` is a stale pointer!!

- Thou shall not dereference deleted pointers.

`strcpy(str,"hi");`	→ `str` already deleted!!

- Thou shall not delete a pointer more than once.

`delete str;`	→ `str` already deleted!!

  - You can however delete null pointers as many times as you wish!

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- Thou shall not leak memory, but also:
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`char* str = new char[128];`	→ allocate memory for `str`
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- Thou shall not dereference deleted pointers.

`strcpy(str,"hi");`	→ `str` already deleted!!

- Thou shall not delete a pointer more than once.

`delete str;`	→ `str` already deleted!!

  - You can however delete null pointers as many times as you wish!
  - So assign zero to deleted pointers whenever possible (not a panaceum)

```
struct prof {
  char* name;
  char* dept;
};
char *csc = new char[30];
strcpy (csc,"Computer Science");
prof *stefan, *dimitri, *bruda;
stefan = new prof; dimitri = new prof;
stefan->name = new char[30];
dimitri->name = new char[30];
strcpy(stefan->name,"Stefan Bruda");
strcpy(dimitri->name,"Dimitri Vouliouris");
stefan->dept = csc;
dimitri->dept = csc;
```

Exogenous data

```
// Delete dimitri
delete dimitri->name;
delete dimitri->dept;
delete dimitri;
```

OK

???

Indigenous data

```
// Copy stefan
bruda = new prof;
// (a) Shallow copying
bruda->name = stefan->name;
bruda->dept = stefan->dept;
```

// Can we delete stefan now??

```
// (b) Deep copying
bruda->name = new char[30];
bruda->dept = new char[30];
strcpy(bruda.name,stefan.name);
strcpy(bruda.dept,stefan.dept);
```

// Can we delete stefan now??