Informatics 3.
Lecture 3: Dynamic memory handling

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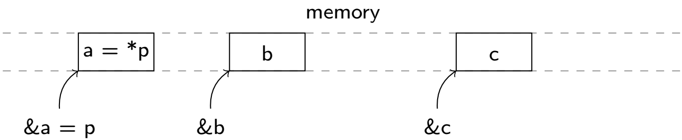
- We can directly reference parts of the memory with pointers:

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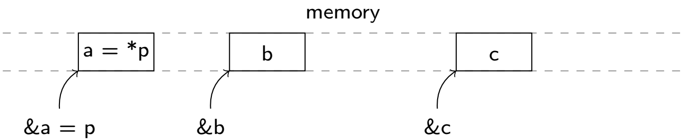


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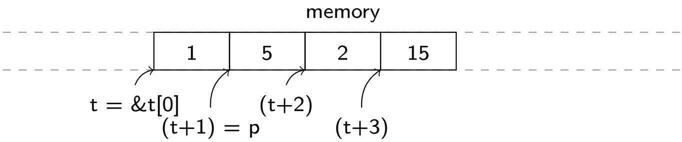
- Every pointer is an array and every array is a pointer:




```c
int t[] = {1, 5, 2, 15};
int *p = t + 1;
int x = *(t + 1); // 5
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- The above uses the C++ style output. We will no longer use **stdio.h**, **printf** or **scanf** from now on.
- There is dynamic memory handling in C as well. However it is more complicated so we'll stick to C++ from now on.

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- Those who work in a command line should use **g++** instead of **gcc**.

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- **endl** is a new line (end line).

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- A complete program showing cin and cout:

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using namespace std;
int main(void) {
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- The using namespace std line will come up later. For now let's just copy and paste it after iostream always.

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- New feature: we can define the cycle variable in **for**.

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  int t[] = {1, 2, 5};
  return t;
}
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  int *a = fv();
  for(int i = 0; i < 3; i++) {
    cout << a[i] << endl;
  }
  return 0;
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  }
  return 0;
}
```

- This leads to the `Segmentation Fault` error.
- The array **t** is destroyed once the **fv** function ends, like all other local variables.
- The true return value of the function is a copy of **t** as a pointer.

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  return 0;
}
```

- In truth, if something is dynamically allocated it can exist for as long as the program runs.

Returning an array 3

- What's the issue here?

```
int* fv() {
  int *t = new int[3];
  t[0] = 1; t[1] = 2; t[2] = 5;
  int *t_sqr = new int[3];
  for(int i = 0; i < 3; i++) {
    t_sqr[i] = t[i] * t[i];
  }
  return t_sqr;
}
```

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- If we execute the function 100 times, then it will be present in the memory 100 separate times uselessly.

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- And for dynamically allocated arrays the **delete[]** keyword:

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  int *t_sqr = new int[3];
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    t_sqr[i] = t[i] * t[i];
  }
  delete[] t;
  return t_sqr;
}
```

Freeing memory 2

- Since the function **fv** returns with a dynamically allocated array, it is the responsibility of the caller to free this array (the caller is the **main** fucntion here):

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int main(void) {
  int *a;
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- The way we should think about this is that every dynamical allocation has to have its freeing pair.

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  - We could handle arrays as pointers (though it's not that useful).
  - We can use pointers to store the pointer of the dynamically allocated memory.
  - We can directly return an array with a function.
- Now we'll use pointers to create a new data structure.

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- What we want is a similar data structure as the list in python. The following or something similar should work:

```
int x;          // auxiliary variable
list l;         // our new data type
append(l, 5) // we append 5 at the end of ;
append(l, 4) // now 4
cin >> x;
while(x != 0) { // while we do not get a 0
  append(l, x)  // add elements to l
  cin >> x;   // read the next element
}
```

Array expansion idea

First idea:

- Let's use a dynamically allocated array.
- Store the current length of it in a variable
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Issues:

- It's still limited in size. That's because **int** has a limit, a so called "int max". There would be no way to index the array past this number.
- During every expansion we'll need to do a lot of copying. At one point this will simply take too long.
- At this point we could just as well create an int array the size of "int max" and we would be in the same boat.

Minimalist array expansion implementation (just for show)

(The **x->y** command is equivalent to **(*x).y**. We'll talk about it later.)

```
struct list {
  int *a;
  int n;
  int max;
};

void append(struct list *l, int e) {
  if(l->n >= l->max) {
    int *t = new int[l->max + 100];
    for(int i = 0; i < l->n; i++) {
      t[i] = l->a[i];
    }
    delete[] l->a;
    l->a = t;
    l->max = l->max + 100;
  }
  l->a[l->n] = e;
  l->n++;
}
```

```
int main(void) {
  struct list l;
  l.a = new int[1];
  l.n = 0;
  l.max = 1;
  append(&l, 1);
  append(&l, 5);
  append(&l, -2);
  for(int i = 0; i < l.n; i++) {
    cout << l.a[i] << endl;
  }
  delete[] l.a;
  return 0;
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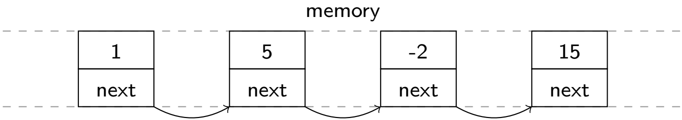

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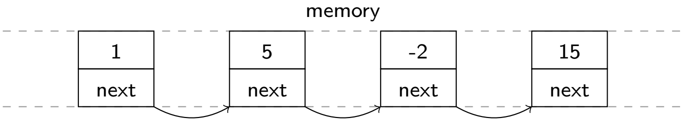

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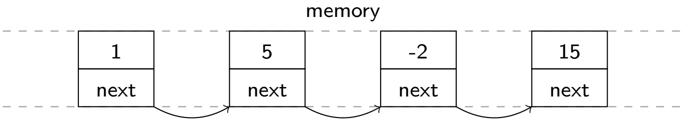

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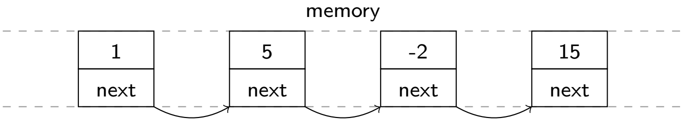

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- It stores a value **num** and the pointer to the next element in **next**.

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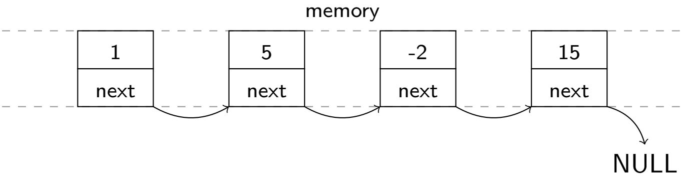

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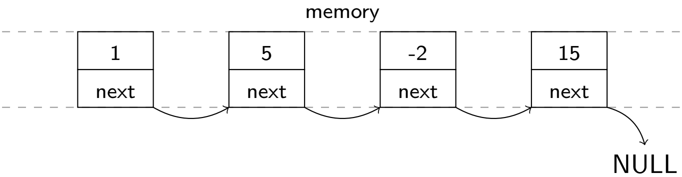
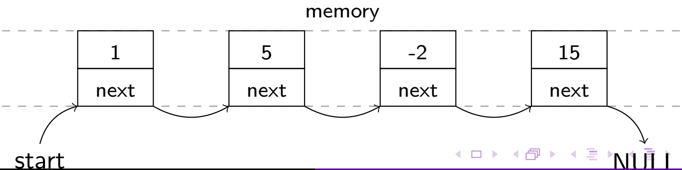


- Now we just need to store the first element's pointer in a variable and we're basically done:



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  append(start, 1);            // add the first element
  append(start, 5);            // then the second
  append(start, -2);           // and a third
  for(;;) {    // we'll have to iterate over this list someh
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- Since we'll be going step by step there wll be moments when the code contains errors. I'll let you know each time.
- Let's use the previously defined **struct list_e** type.

Implementation of linked lists

- The very first thing we need to do is to add the first element. At this point **start** is still **NULL**, since we're not storing anything yet.

```
void append(struct list_e *start, int n) {
  struct list_e *e = new struct list_e;
  (*e).num = n;
  (*e).next = NULL;
  start = e;
}
```

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  struct list_e *e = new struct list_e;
  (*e).num = n;
  (*e).next = NULL;
  start = e;
}
```

- Dynamically create the element, so that it remains after the function returns.

Implementation of linked lists

- The very first thing we need to do is to add the first element. At this point **start** is still **NULL**, since we're not storing anything yet.

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void append(struct list_e *start, int n) {
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- Dynamically create the element, so that it remains after the function returns.
- If you try this with only 1 **append** call it will still not be okay
- Since we're trying to change the **start** pointer, not its stored stuff in the memory. So we'll have to use a pointer pointer.

Implementation of linked lists

- I only changed the pointer of a pointer part:

```
void append(struct list_e **start, int n) {
  struct list_e *e = new struct list_e;
  (*e).num = n;
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}
```

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```

- This works. We can add 1 element to the list.

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}
```

- This works. We can add 1 element to the list.
- However the notation `(*x).y` would quickly become infuriating. Thankfully there's a solution. It means the same as the `x->y` expression.

Implementation of linked lists

- Only replaced with `x->y`

```
void append(struct list_e **start, int n) {
  struct list_e *e = new struct list_e;
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Implementation of linked lists

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  e->num = n;
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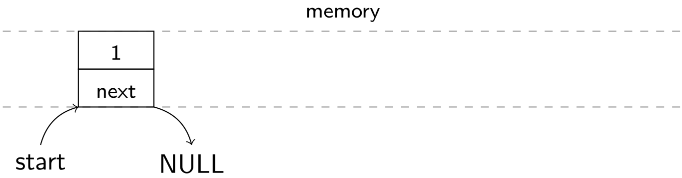
- This is how the memory looks now:



Implementation of linked lists

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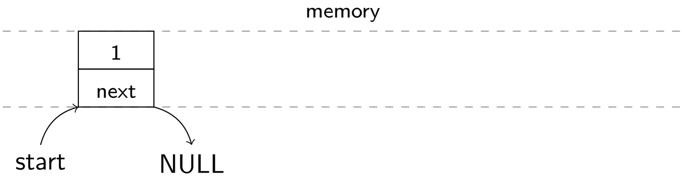

- However if we were to call **append** again (to append an element) then it wouldn't work and it's easy to see why. We would only change the first element to this new element.

Implementation of linked lists

- Let's do a condition based on whether we're appending the first element or not:

```
void append(struct list_e **start, int n) {
  struct list_e *e = new struct list_e;
  e->num = n;
  e->next = NULL;
  if (*start == NULL) {
    *start = e;
  } else {
    (*start)->next = e;
  }
}
```

Implementation of linked lists

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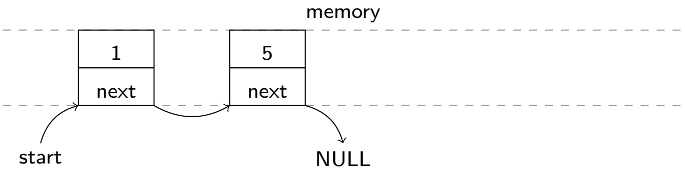

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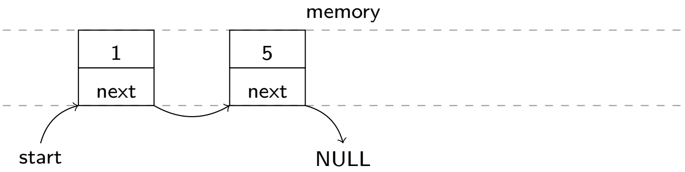

- It's easy to see again that this still isn't right. When we use **append**-et, we always change the **next** of the **start** element.

Iterating over a linked list

- Let's stop for a moment and think about how we would navigate to the last element. Since that's the element whose **next** we need to set.

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- We can borrow from C strings again. We parsed a string there until we encountered the **'\0'** terminal zero. In a linked list the equivalent would be the **NULL** pointer:

```
for(struct list_e *e = start; e != NULL; e = e->next) {
  cout << e->num << endl;
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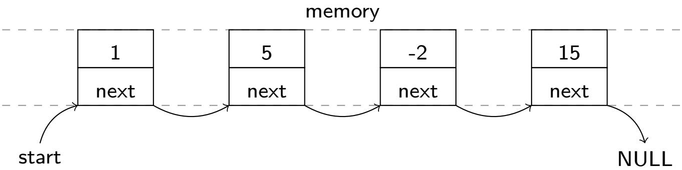
- If you think about it this is just a regular **for** loop:
  - We initialize the cycle variable (**e**) with the first element.
  - Stopping condition is almost the same as with C strings.
  - We step onto the next element.
- We can use this in the **main** function to print the linked list's elements.

Iterating over a linked list

Let's see how this iteration over the linked list would work in our (theoretical) complete implementation of a linked list.

```
for(struct list_e *e = start; e != NULL; e = e->next) {
  cout << e->num << endl;
}
```

Where we are: before the loop



Output:

Iterating over a linked list

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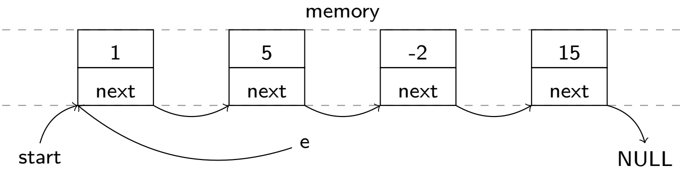
```
for(struct list_e *e = start; e != NULL; e = e->next) {
  cout << e->num << endl;
}
```

Where we are: initialization happened



Output:

Iterating over a linked list

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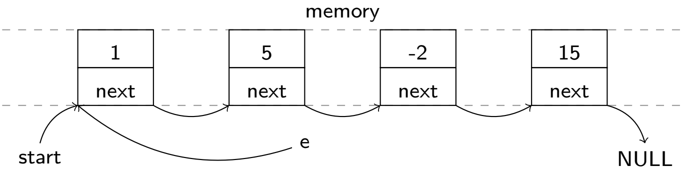
```
for(struct list_e *e = start; e != NULL; e = e->next) {
  cout << e->num << endl;
}
```

Where we are: end of the first loop



Output:
1

Iterating over a linked list

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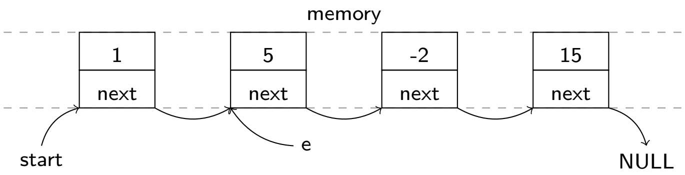
```
for(struct list_e *e = start; e != NULL; e = e->next) {
  cout << e->num << endl;
}
```

Where we are: beginning of the second loop



Output:
1

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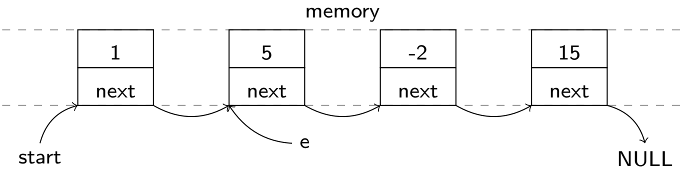
```
for(struct list_e *e = start; e != NULL; e = e->next) {
  cout << e->num << endl;
}
```

Where we are: end of the second loop



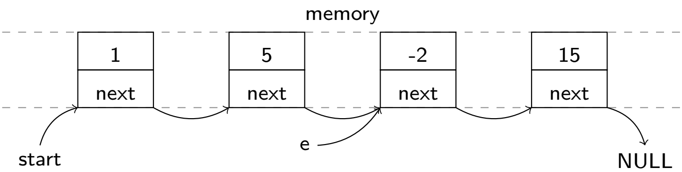
Output:
1
5

Iterating over a linked list

Let's see how this iteration over the linked list would work in our (theoretical) complete implementation of a linked list.

```
for(struct list_e *e = start; e != NULL; e = e->next) {
  cout << e->num << endl;
}
```

Where we are: end of the third loop



Output:

1

5

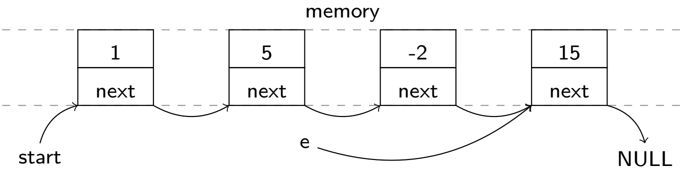
-2

Iterating over a linked list

Let's see how this iteration over the linked list would work in our (theoretical) complete implementation of a linked list.

```
for(struct list_e *e = start; e != NULL; e = e->next) {
  cout << e->num << endl;
}
```

Where we are: end of the forth loop



Output:

1
5
-2

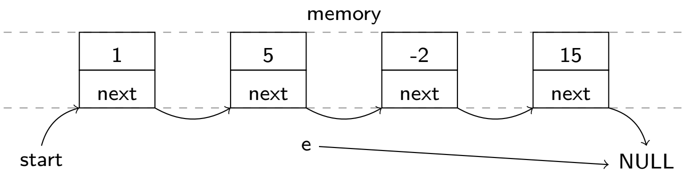
15

Iterating over a linked list

Let's see how this iteration over the linked list would work in our (theoretical) complete implementation of a linked list.

```
for(struct list_e *e = start; e != NULL; e = e->next) {
  cout << e->num << endl;
}
```

Where we are: end of the forth loop and the step also happened



Output:
1
5
-2

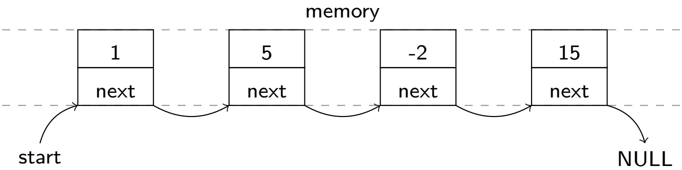
15

Iterating over a linked list

Let's see how this iteration over the linked list would work in our (theoretical) complete implementation of a linked list.

```
for(struct list_e *e = start; e != NULL; e = e->next) {
  cout << e->num << endl;
}
```

Where we are: end of the loop, the condition was false



Output:
1
5
-2

15

Implementation of linked lists

- Let's go back to the implementation and use what we learned:

```
void append(struct list_e **start, int n) {
  struct list_e *e = new struct list_e;
  e->num = n;
  e->next = NULL;
  if (*start == NULL) {
    *start = e; // most már *start kell
  } else {
    struct list_e *p = NULL;
    for(p = *start; p->next != NULL; p = p->next){}
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  }
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- The loop that we used is a bit different to the one we discussed previously.

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- Here we want to stop when we've reached the last element.

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- Here we want to stop when we've reached the last element.
- We know we're at the last element when the element's **next** is **NULL**.
- There is no command in the inner part of the loop. We only need to set the **p** pointer to the last element.
- This truly implements a dynamically expanding data structure that might even fill the whole memory.

Implementation of linked lists (complete code)

```
#include <iostream>

using namespace std;

struct list_e {
  int num;
  struct list_e *next;
};

void append(struct list_e **start, int n) {
  struct list_e *e = new struct list_e;
  e->num = n;
  e->next = NULL;
  if (*start == NULL) {
    *start = e;
  } else {
    struct list_e *p = NULL;
    for(p = *start; p->next != NULL; p = p->next){}
    p->next = e;
  }
}
```

```
int main(void) {
  struct list_e *start = NULL;
  append(&start, 1);
  append(&start, 5);
  append(&start, -2);
  append(&start, 15);
  for(struct list_e *e = start; e != NULL; e = e->next) {
    cout << e->num << endl;
  }
  return 0;
}
```

Where to now

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- It would be confusing in the long run if we used **append** and similarly named functions (we would need an append_list, append_dictionary, append_set, etc.). The solution to this will be classes.

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- We need a way to free the dynamically created linked list.
- It would be confusing in the long run if we used **append** and similarly named functions (we would need an append_list, append_dictionary, append_set, etc.). The solution to this will be **class**es.
- Another issue is that the type of the stored element is set in stone in this implementation (we only stored 1 **int**). The solution to this will be **template**s.

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- We need a way to free the dynamically created linked list.
- It would be confusing in the long run if we used **append** and similarly named functions (we would need an append_list, append_dictionary, append_set, etc.). The solution to this will be **class**es.
- Another issue is that the type of the stored element is set in stone in this implementation (we only stored 1 **int**). The solution to this will be **template**s.
- We can't store everything in one file. Once we start using more structures like this we'll need to start using more source files and **header** files.

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- Another issue is that the type of the stored element is set in stone in this implementation (we only stored 1 **int**). The solution to this will be **template**s.
- We can't store everything in one file. Once we start using more structures like this we'll need to start using more source files and **header** files.
- We can't implement everything ourselves. We'll start using already implemented data structure from libraries at some point.

Pop quiz questions

- Draw a schematic representation of a linked list in memory.
- What is the **NULL** pointer?
- Show an example of dynamically creating an array.
- What is **delete** and **delete[]** used for?