Implementing Abstractions

Part One

Previously on CS106B…

```
class RandomBag {
public:
    void add(int value);
    int  removeRandom();

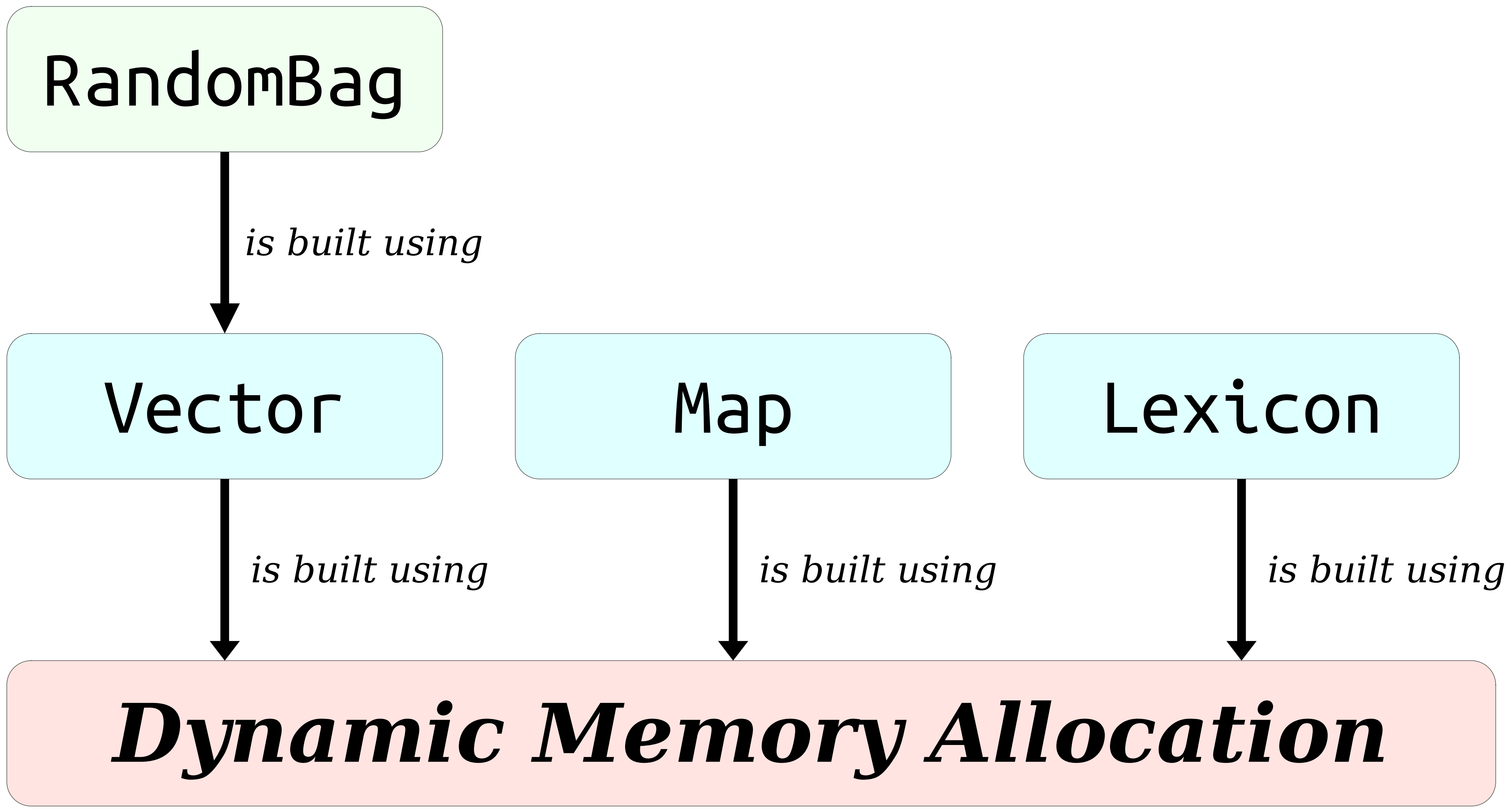
    int  size() const;
    bool isEmpty() const;

private:
    Vector<int> elems;
};
```

```
class RandomBag {
public:
    void add(int value);
    int  removeRandom();

    int  size() const;
    bool isEmpty() const;

private:
    Vector<int> elems;
};
```


RandomBag
is built using
Vector
Map
Lexicon
is built using
is built using
is built using
Dynamic Memory Allocation

Dynamic Memory Allocation

- Types like `Vector`, `Map`, `Set`, etc. that store a variable number of items need space to store those elements.
- When you use those types as a client, they just “work” and somehow figure out where to store things. You as the end user don’t see how.
- Internally, those types use a technique called ***dynamic memory allocation*** to get space where they can put their elements.
- How they do this – and how you can do this in your own code – is our next major topic.

A Change in Perspective

- ***Key Question From Before:*** How do we use the `Map`, `Vector`, etc. to model and solve complex problems?
- ***Key Question For Now:*** How can we use the simple tools afforded by C++ to build things like `Map`, `Vector`, etc.?
- The coding techniques that go into this will subjectively feel very different than what we've seen so far.
  - There will be fewer tools available to you.
  - Those tools require different mental models than what you're used to.
- And yet, by learning how to use them:
  - You'll learn more about how the computer actually works.
  - You'll see how to build complex systems out of simple parts.
  - You'll get an appreciation for just how clever the techniques that power the `Map`, `Set`, and `Vector` are.

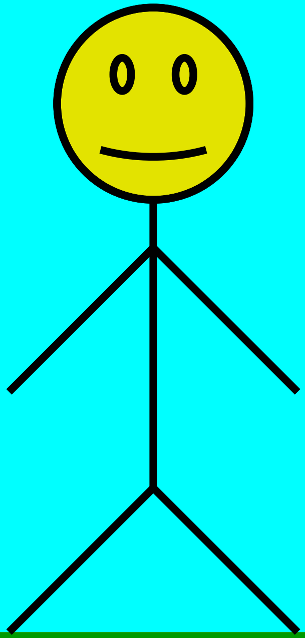
Dynamic Allocation: The Basics

```
string* ptr;
```

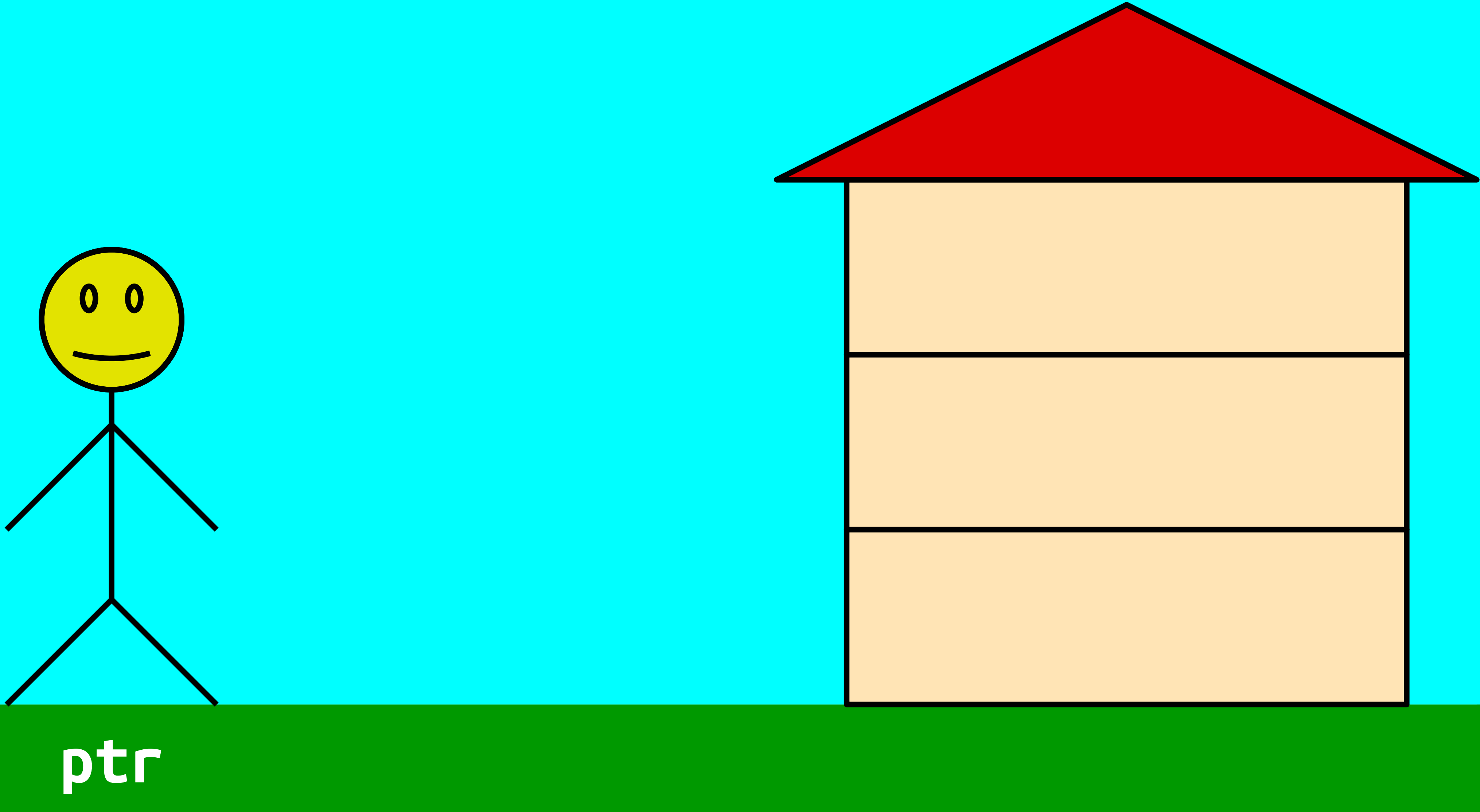
The variable `ptr` has type

`string*`

rather than `string`. We'll explain this in a moment.

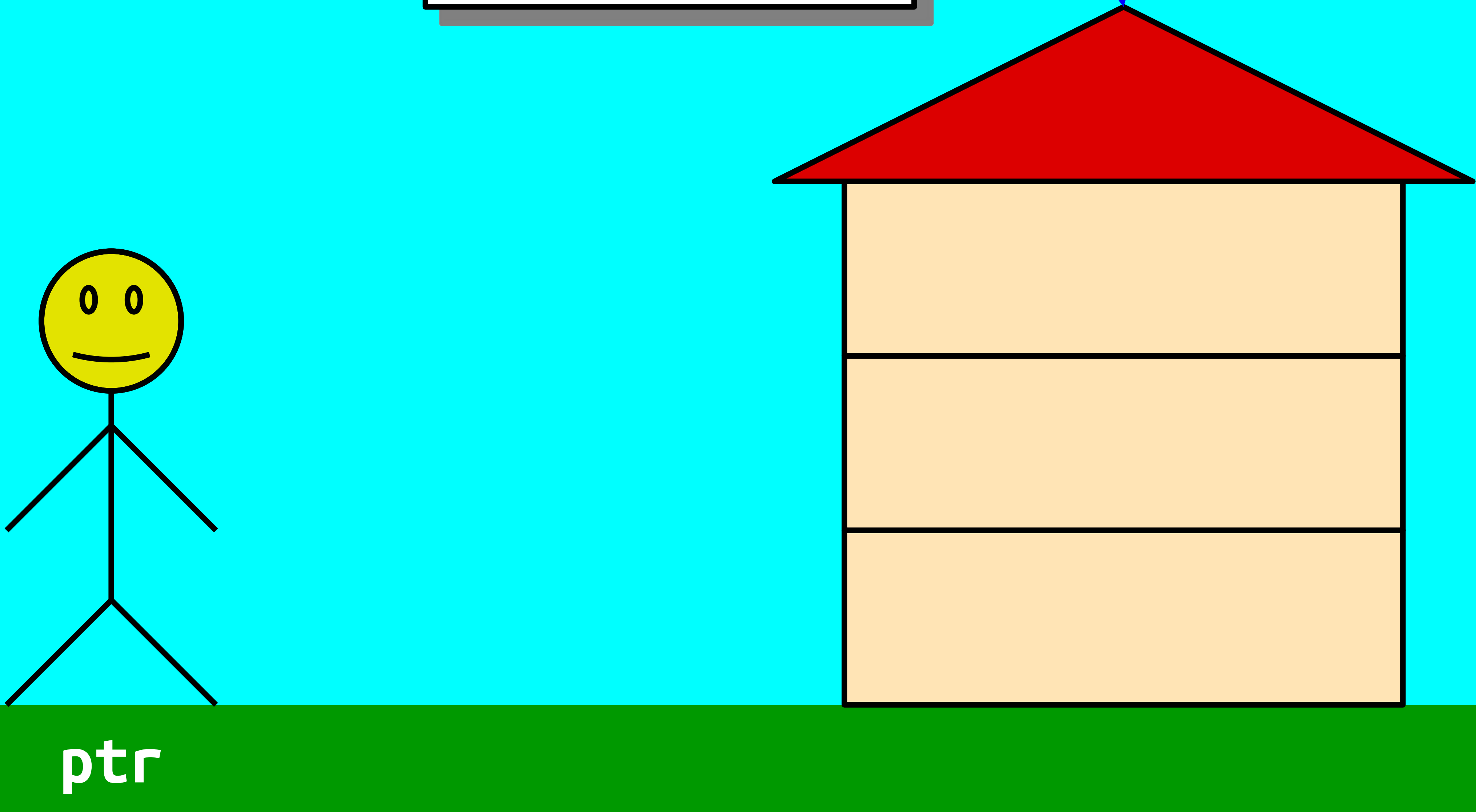


```
string* ptr;
ptr = new string[3];
```



```
string* ptr;
ptr = new string[3];
```

This is an array of three strings. I'll represent it as a three-story building.



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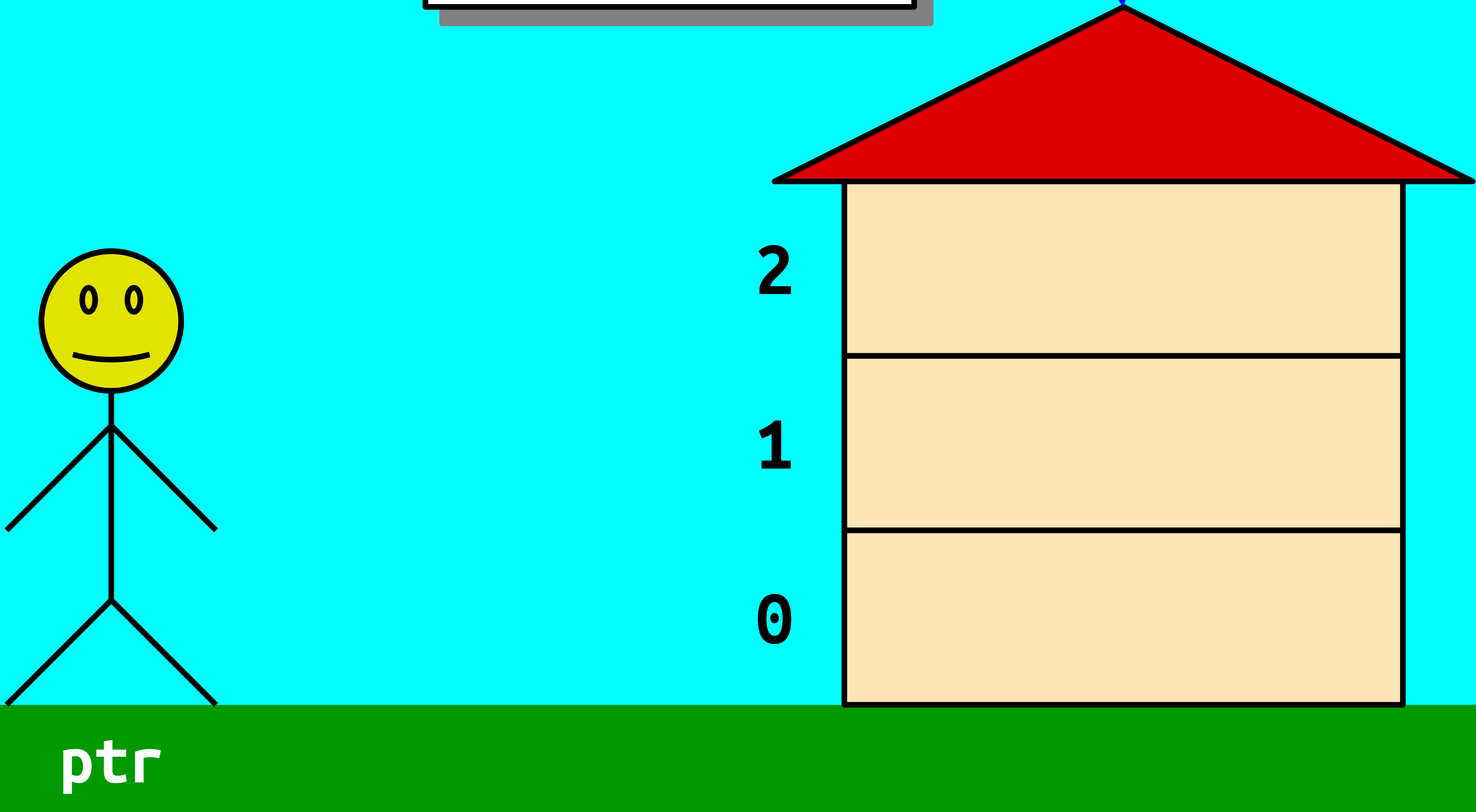
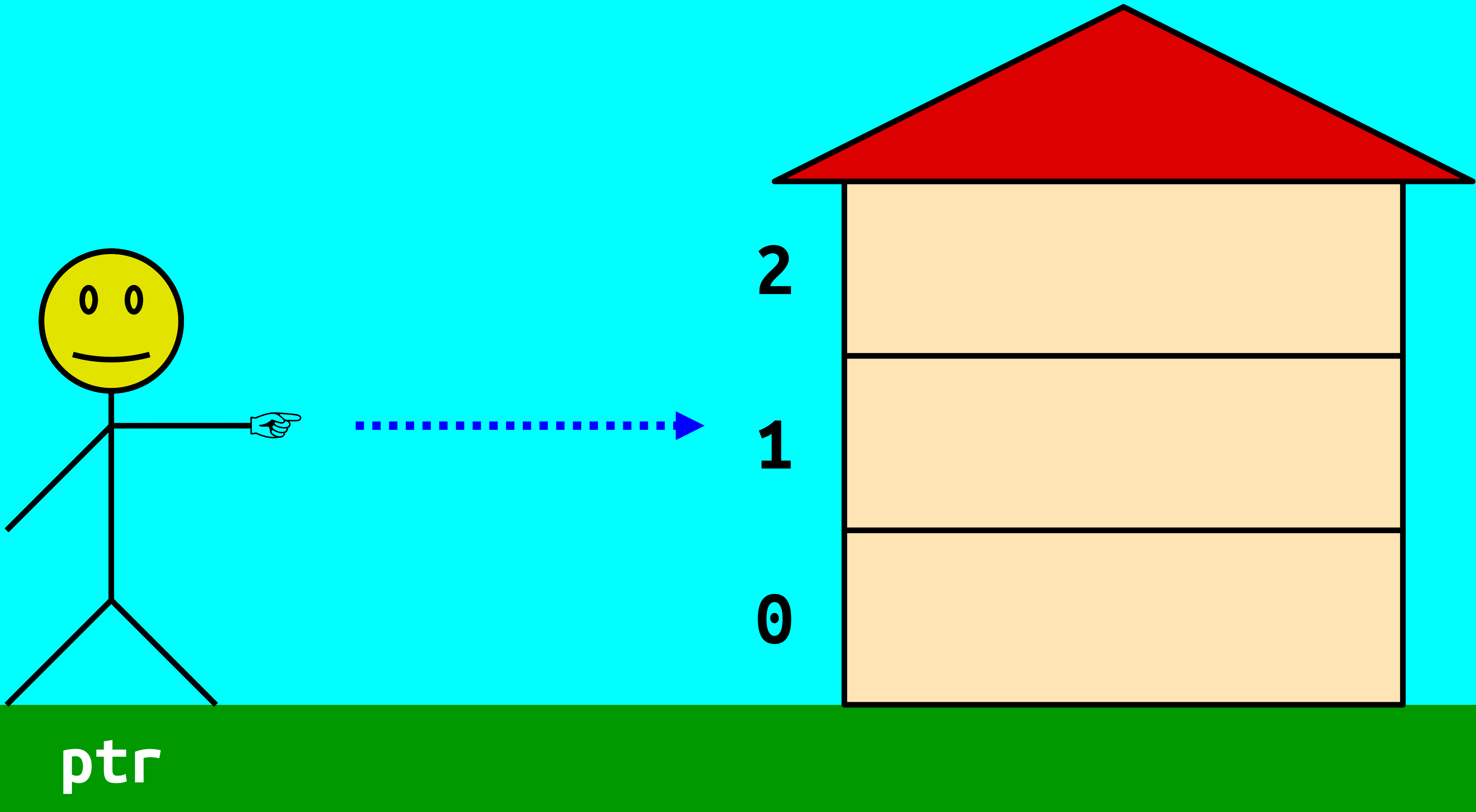


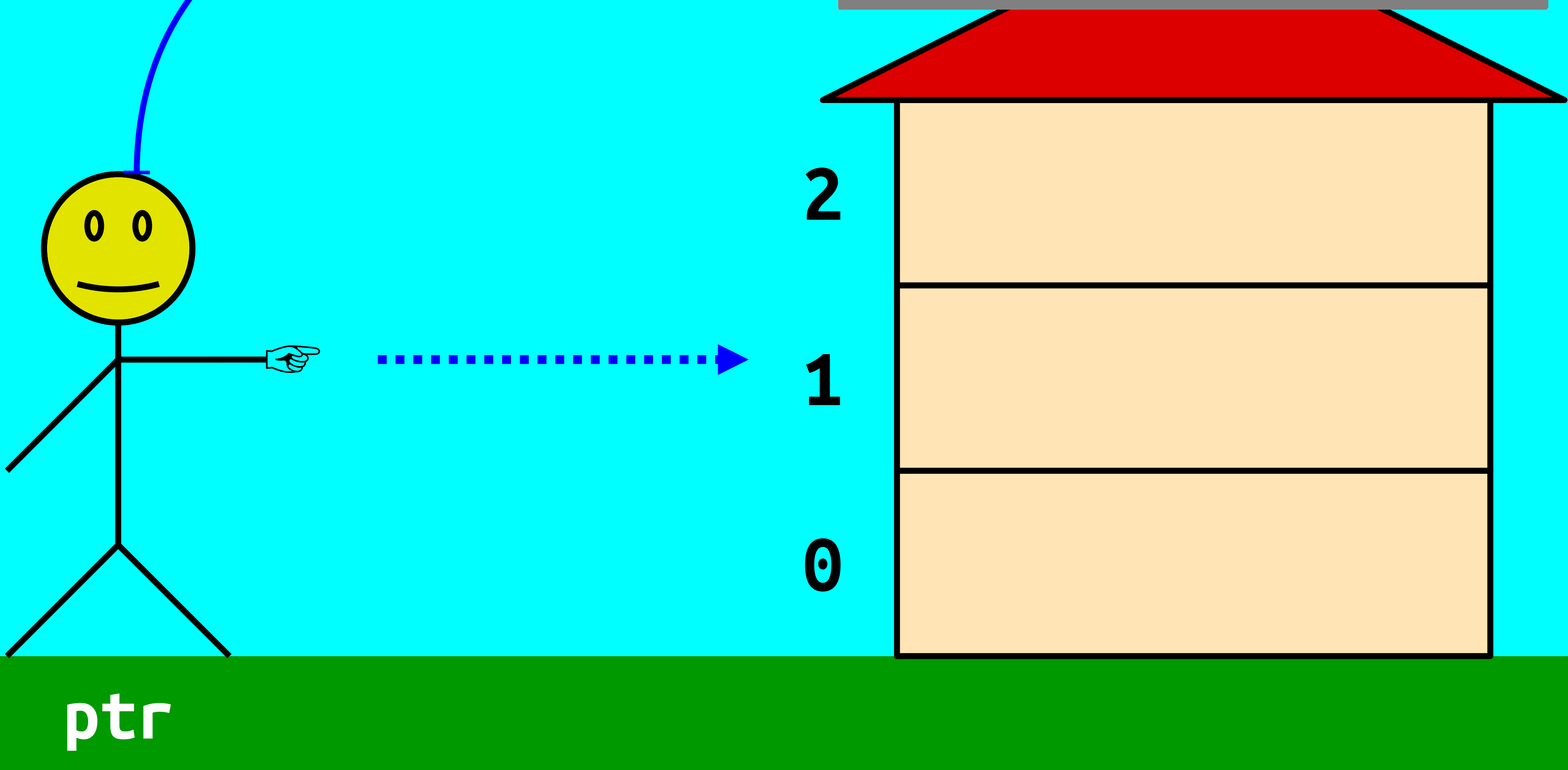
```
string* ptr;
ptr = new string[3];
```



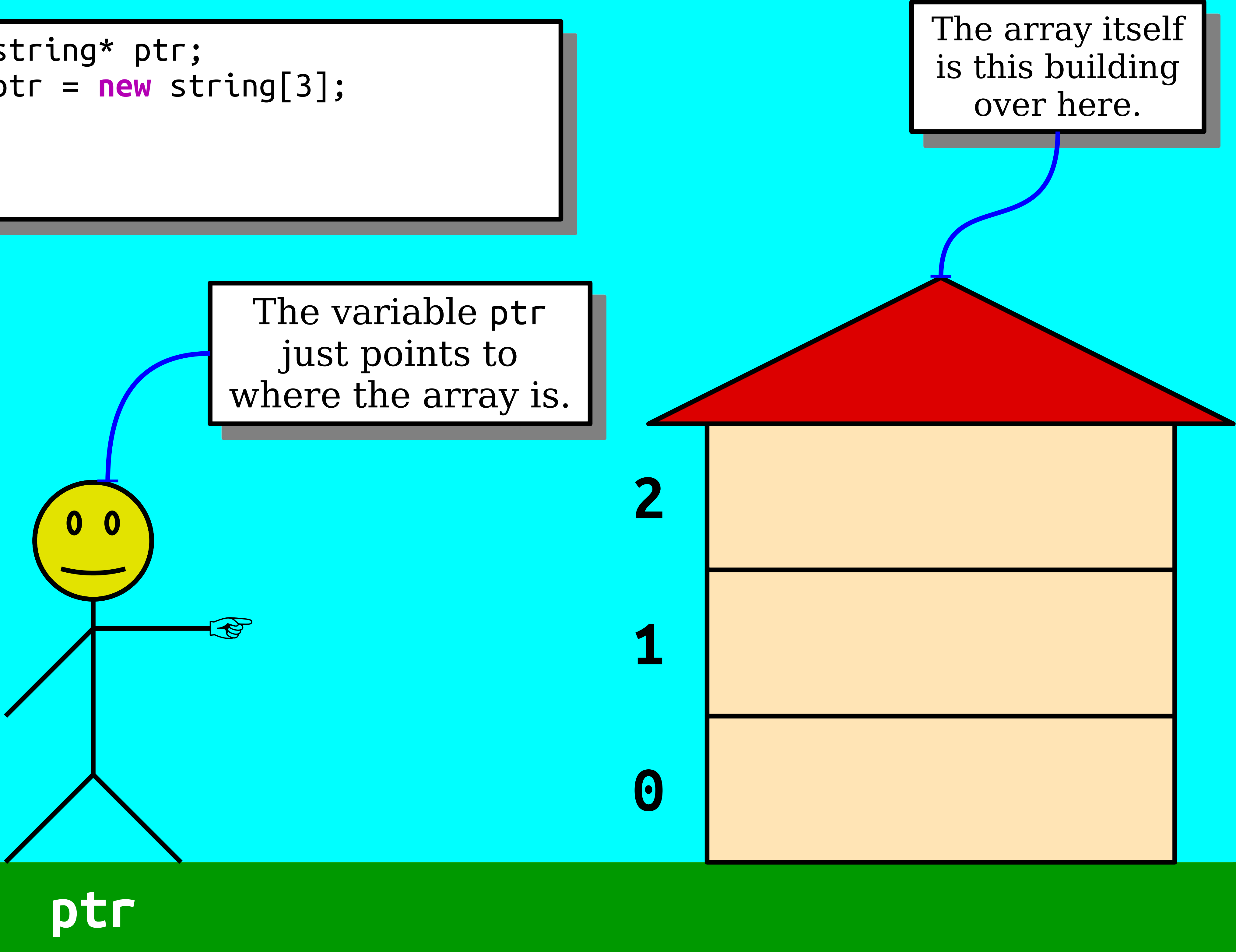
```
string* ptr;
ptr = new string[3];
```

The variable `ptr` ***points*** to an array of strings. It's therefore called a ***pointer***.

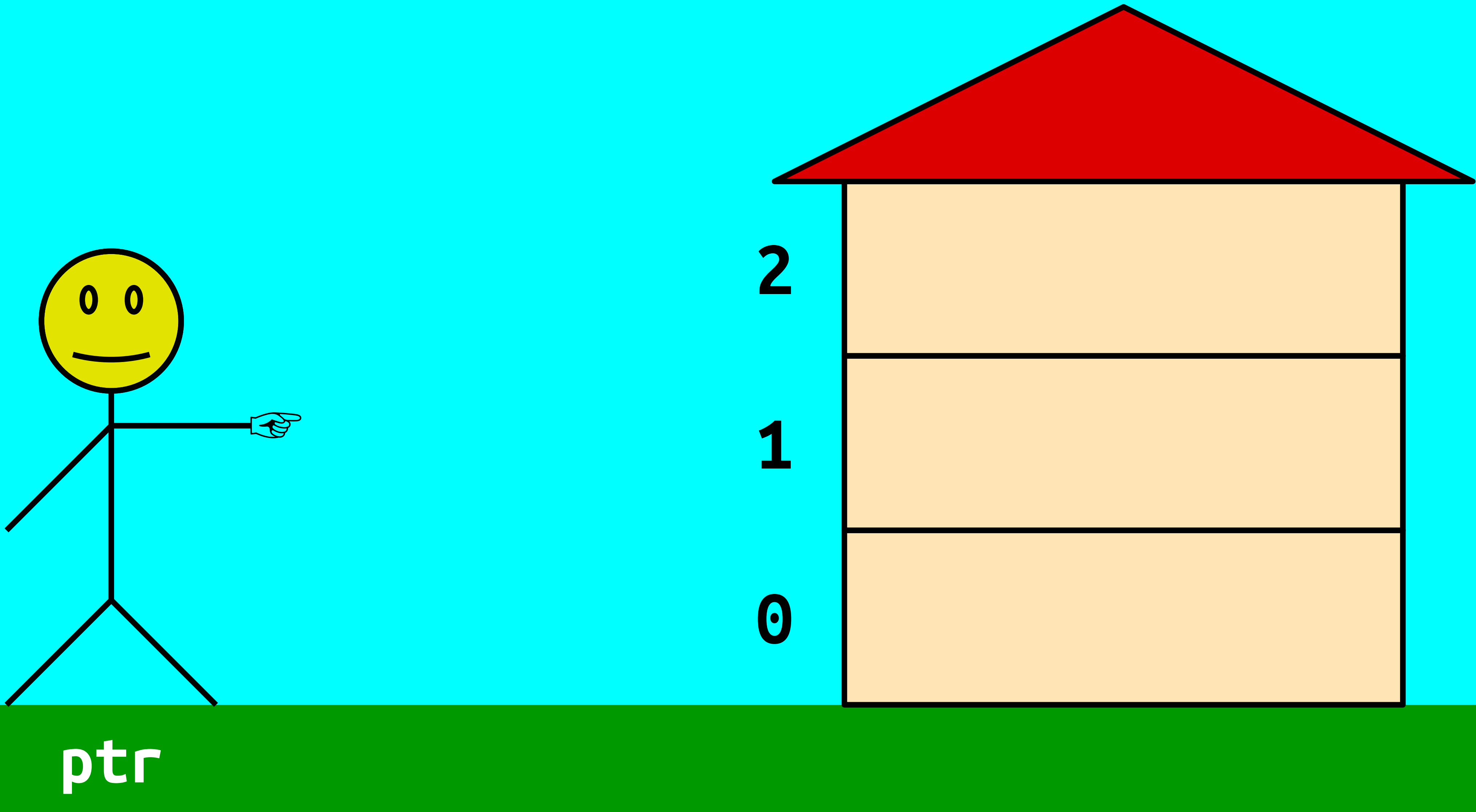
Since `ptr` points to an array of strings, we give it the type `string*`.



```
string* ptr;
ptr = new string[3];
```


The array itself is this building over here.
The variable ptr just points to where the array is.
2
1
0
ptr

```
string* ptr;
ptr = new string[3];
ptr[0] = "Coffee Shop";
```



```
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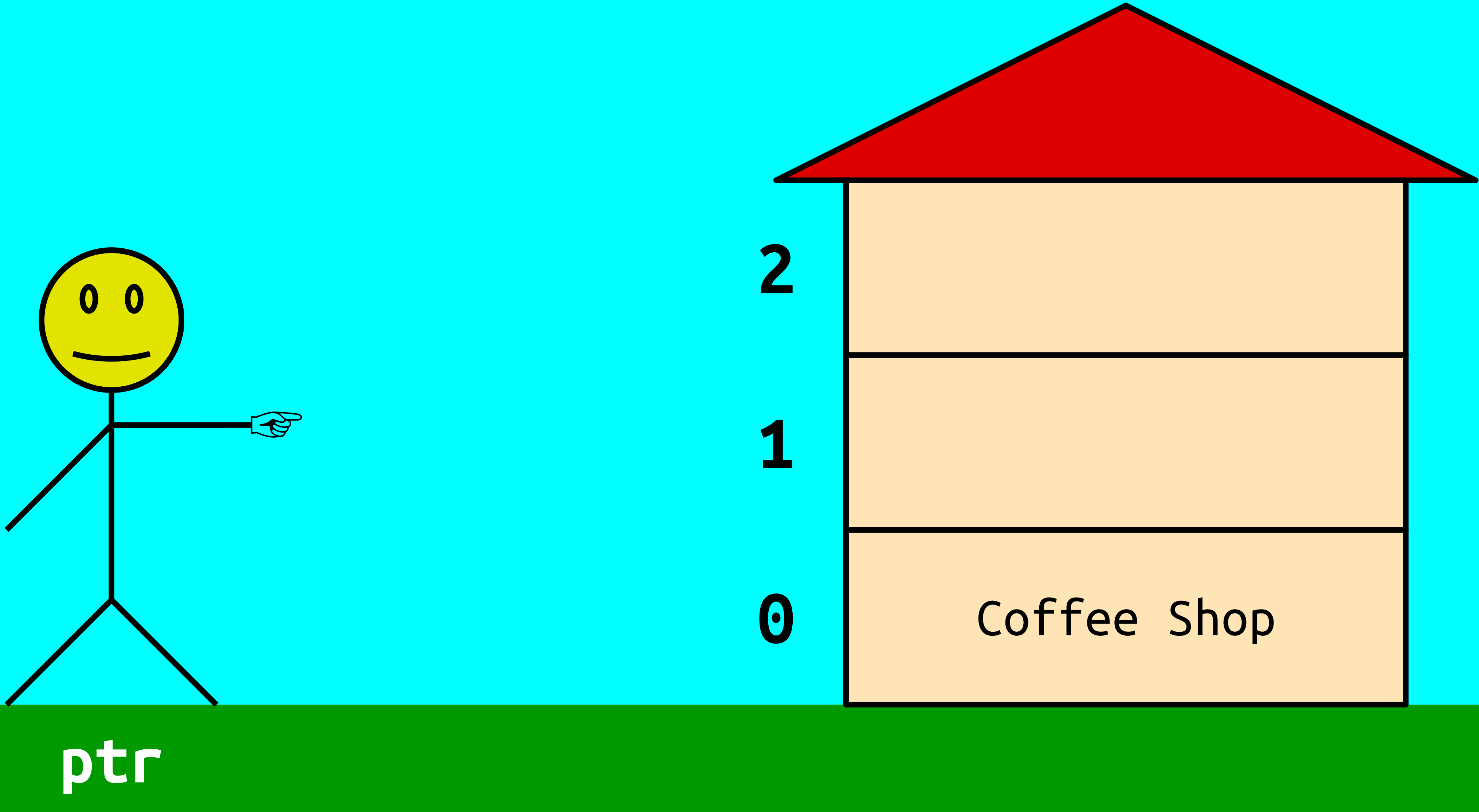
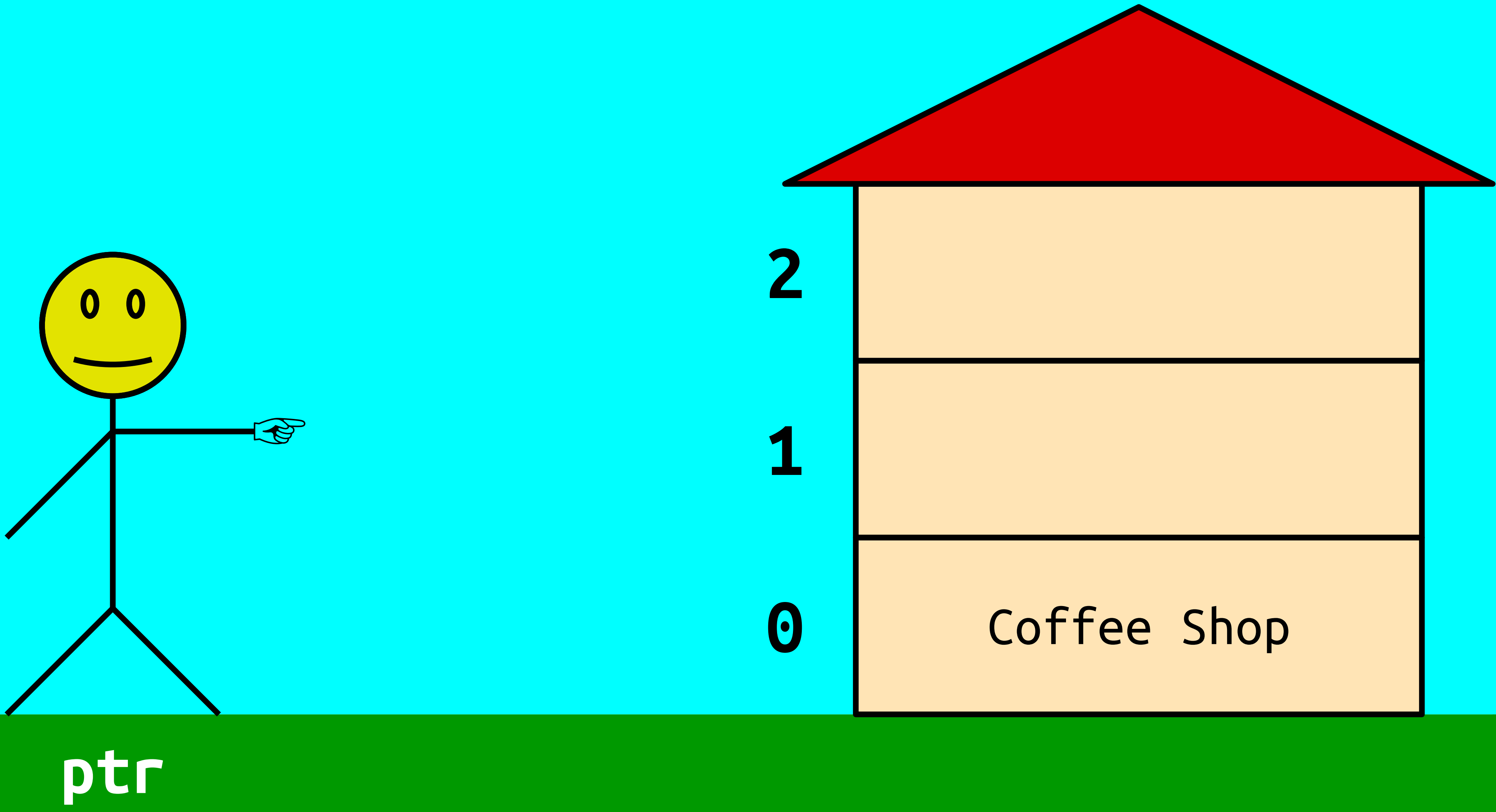
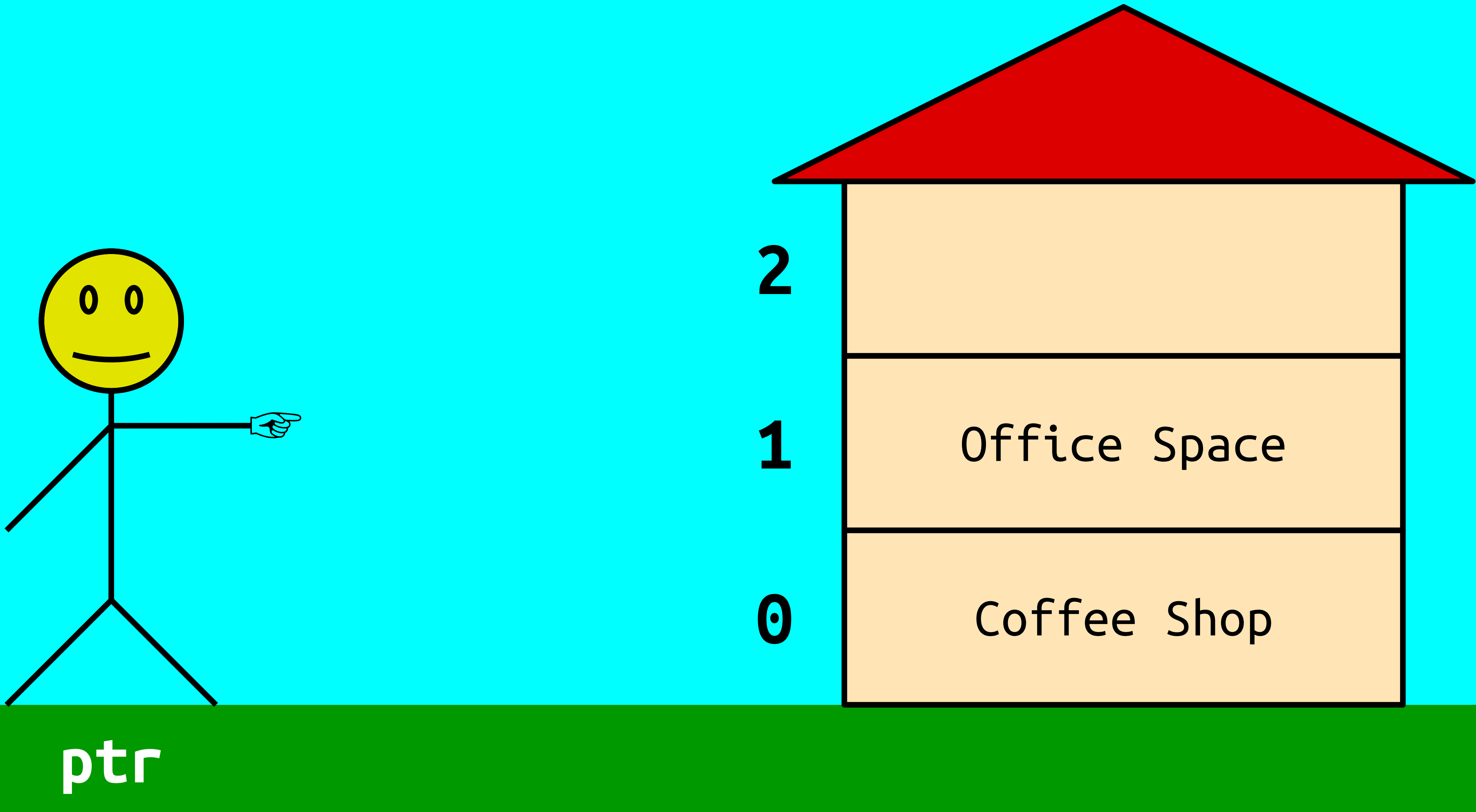
ptr = new string[3];
ptr[0] = "Coffee Shop";
```



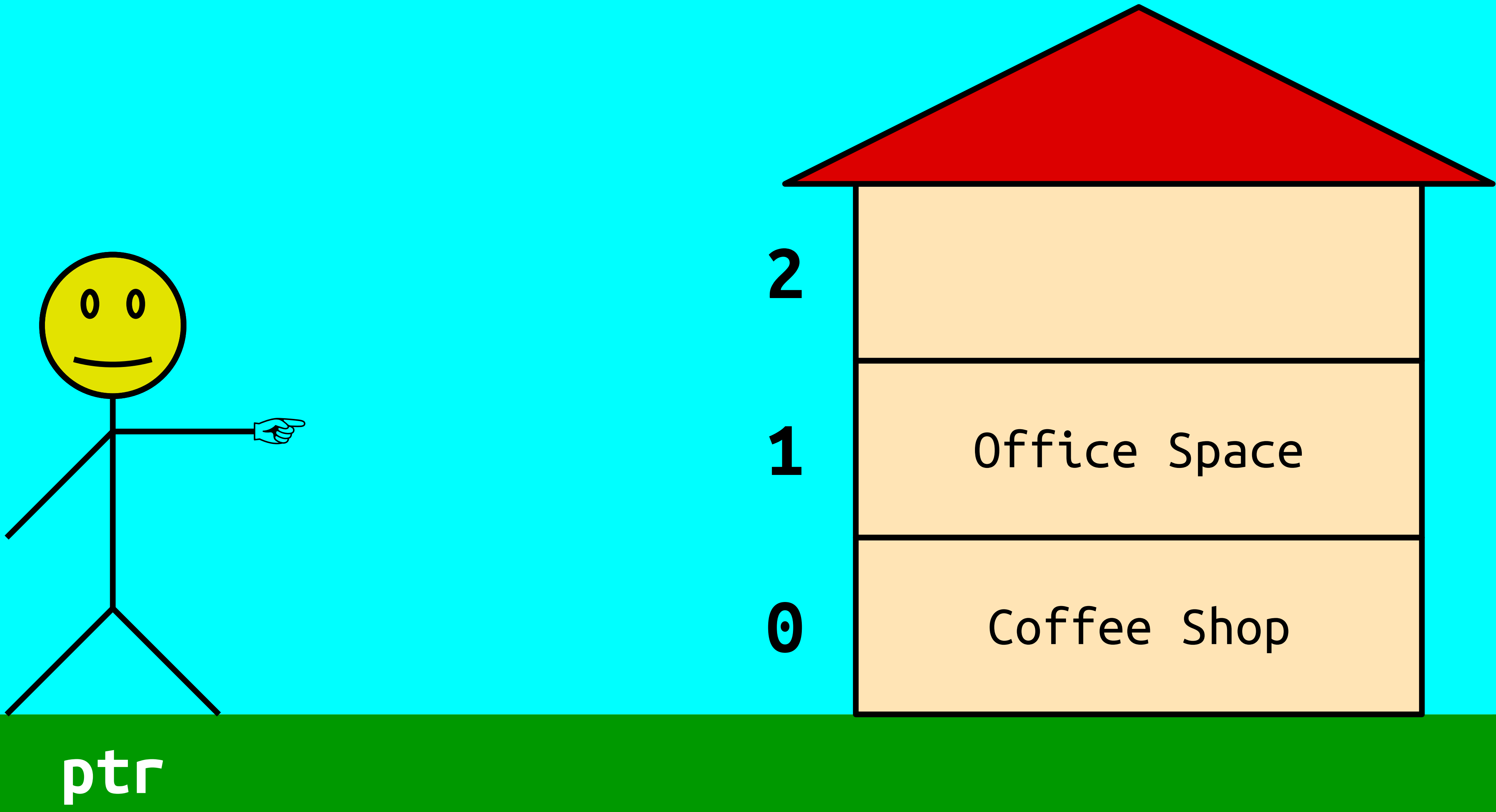
```
string* ptr;
ptr = new string[3];
ptr[0] = "Coffee Shop";
ptr[1] = "Office Space";
```



```
string* ptr;
ptr = new string[3];
ptr[0] = "Coffee Shop";
ptr[1] = "Office Space";
```



```
string* ptr;
ptr = new string[3];
ptr[0] = "Coffee Shop";
ptr[1] = "Office Space";
ptr[2] = "Residential";
```



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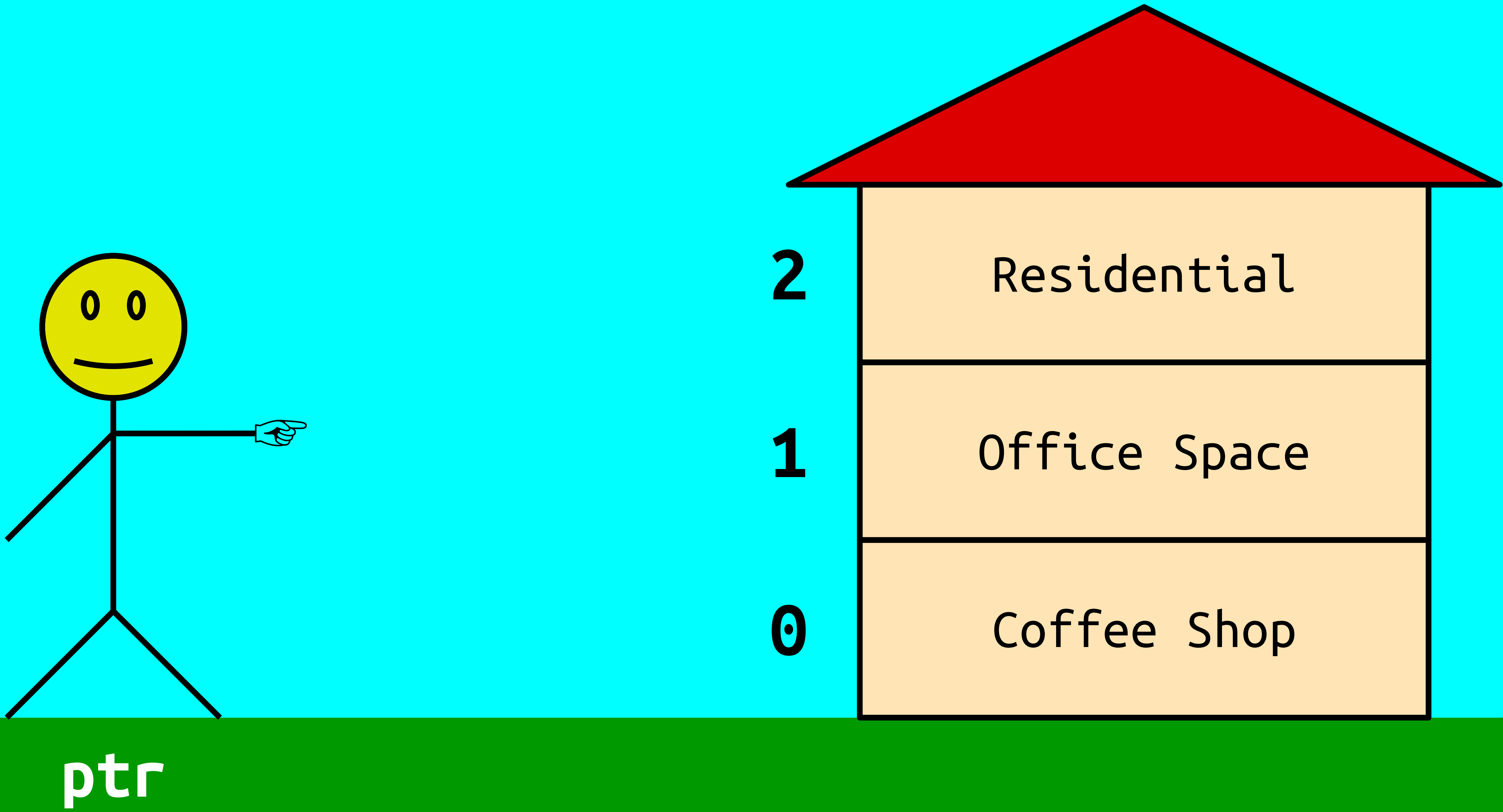
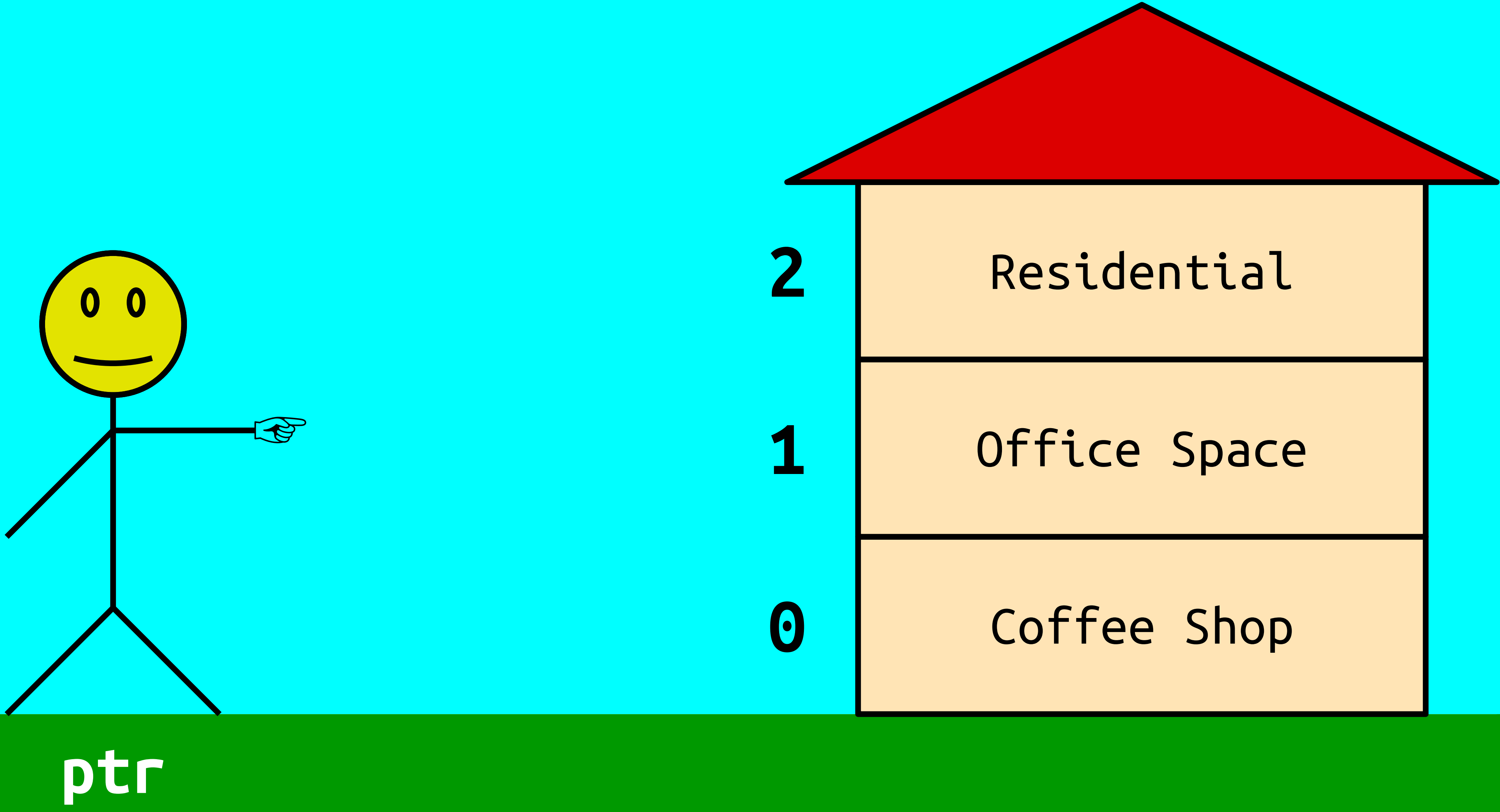
string* ptr;
ptr = new string[3];
ptr[0] = "Coffee Shop";
ptr[1] = "Office Space";
ptr[2] = "Residential";
```

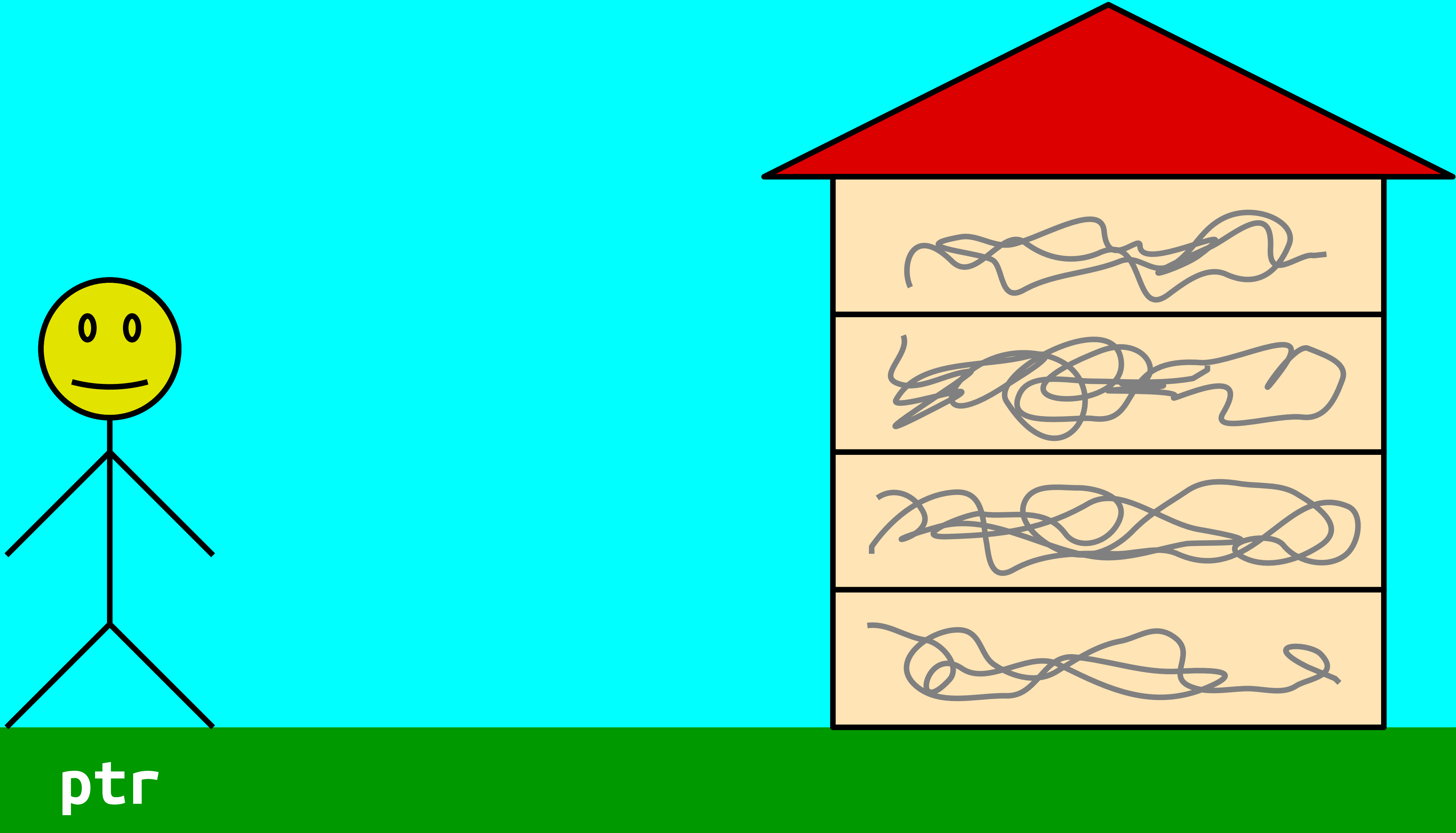


```
string* ptr;
ptr = new string[3];
ptr[0] = "Coffee Shop";
ptr[1] = "Office Space";
ptr[2] = "Residential";
```

This building will always be exactly three stories tall. You cannot add or remove floors. (“Conservation of mass.”)

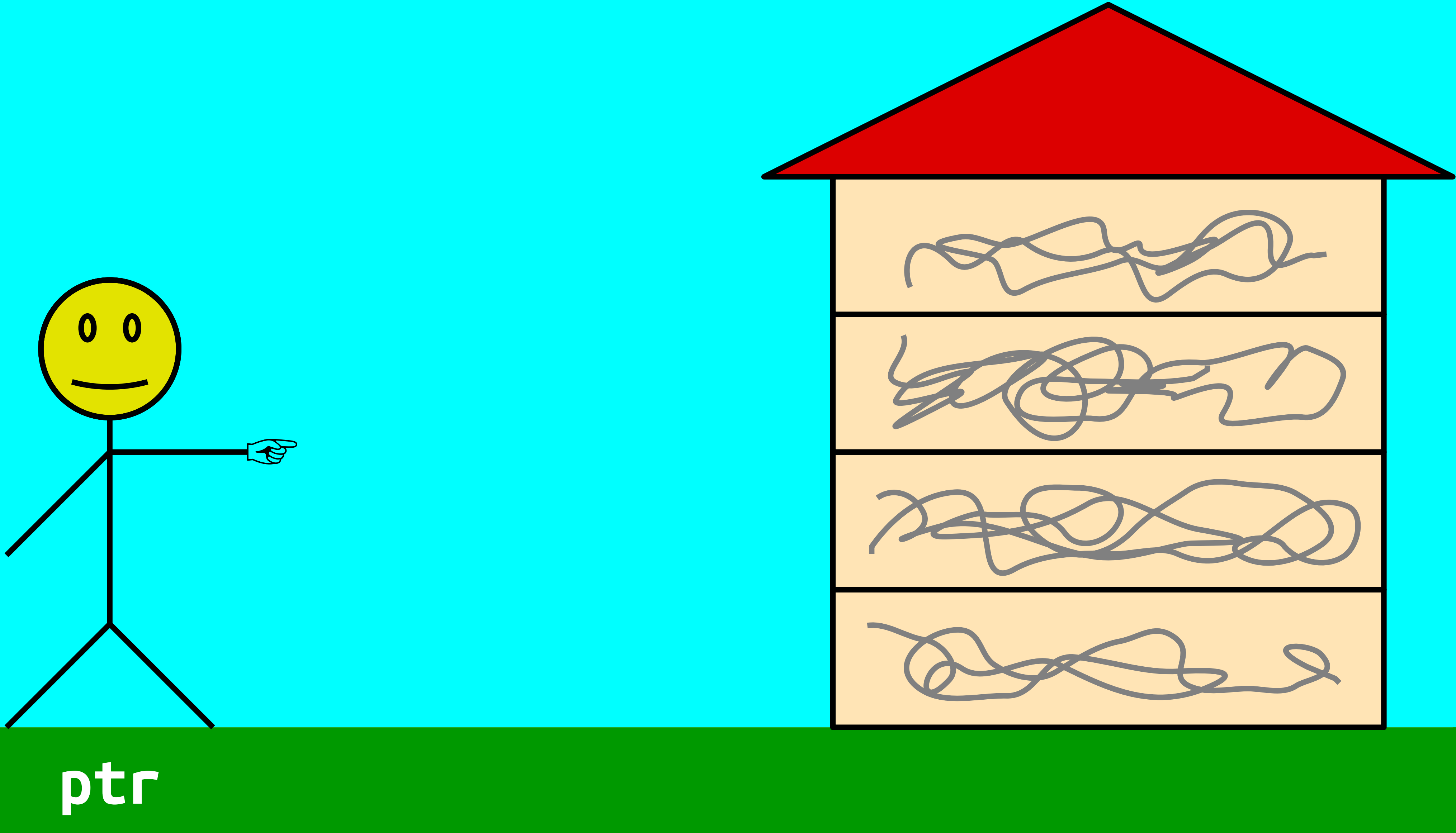


```
int* ptr = new int[4];
```



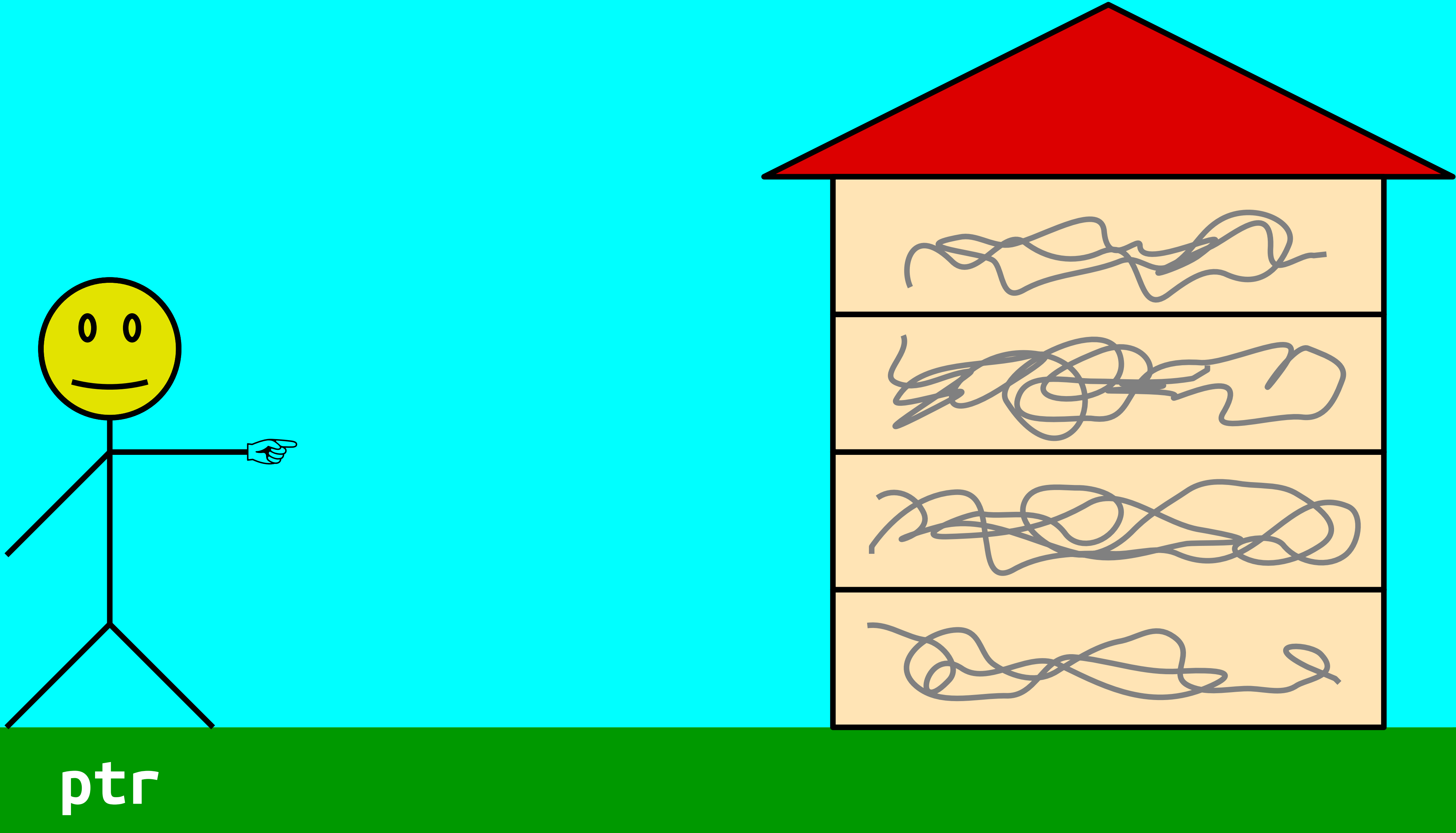
```
int* ptr = new int[4];
```

Arrays of ints, doubles, chars, or bools initially have garbage values. Other types use good defaults.



```
int* ptr = new int[4];
cout << ptr[0] << endl;
```

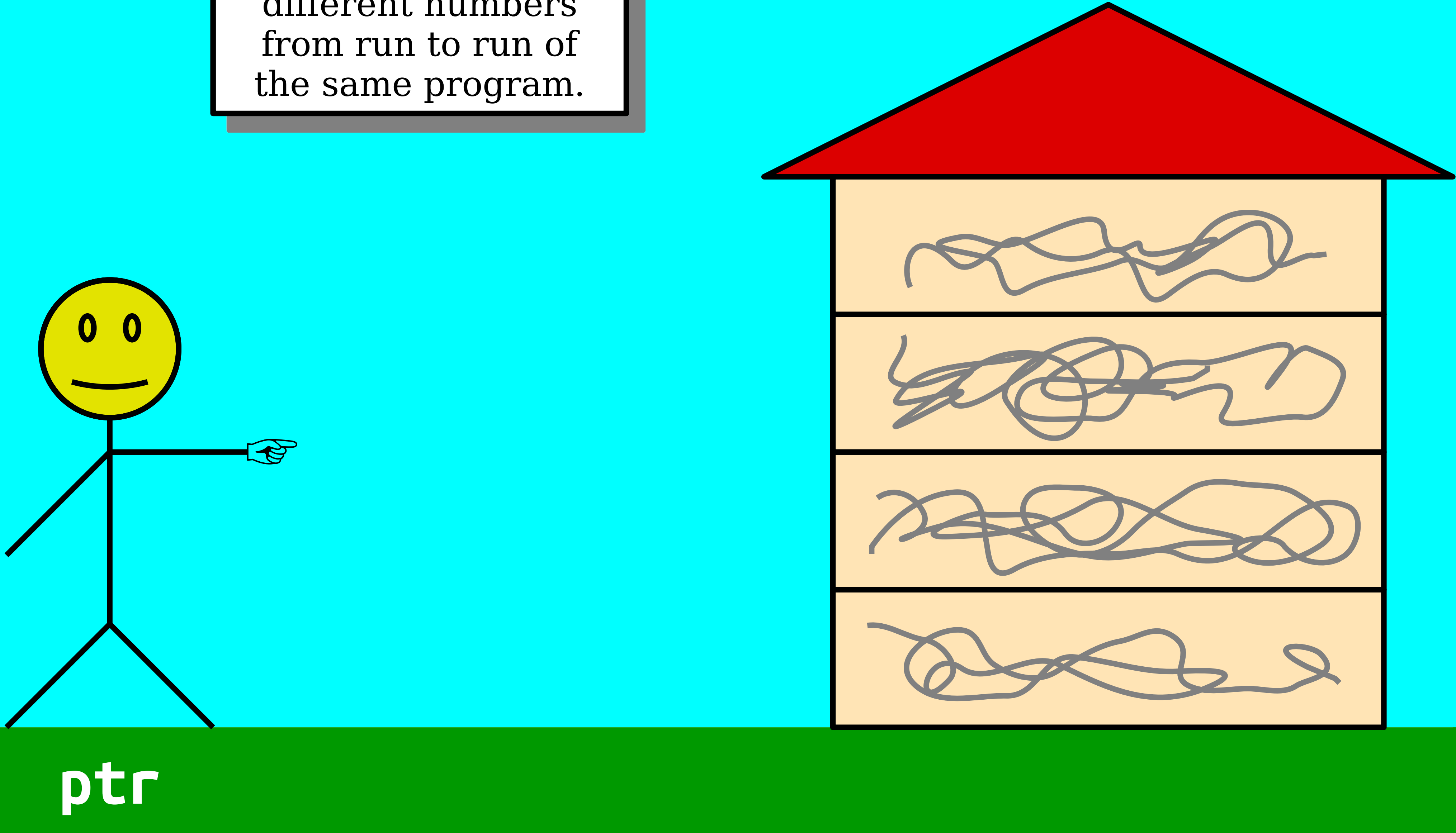
Arrays of ints, doubles, chars, or bools initially have garbage values. Other types use good defaults.



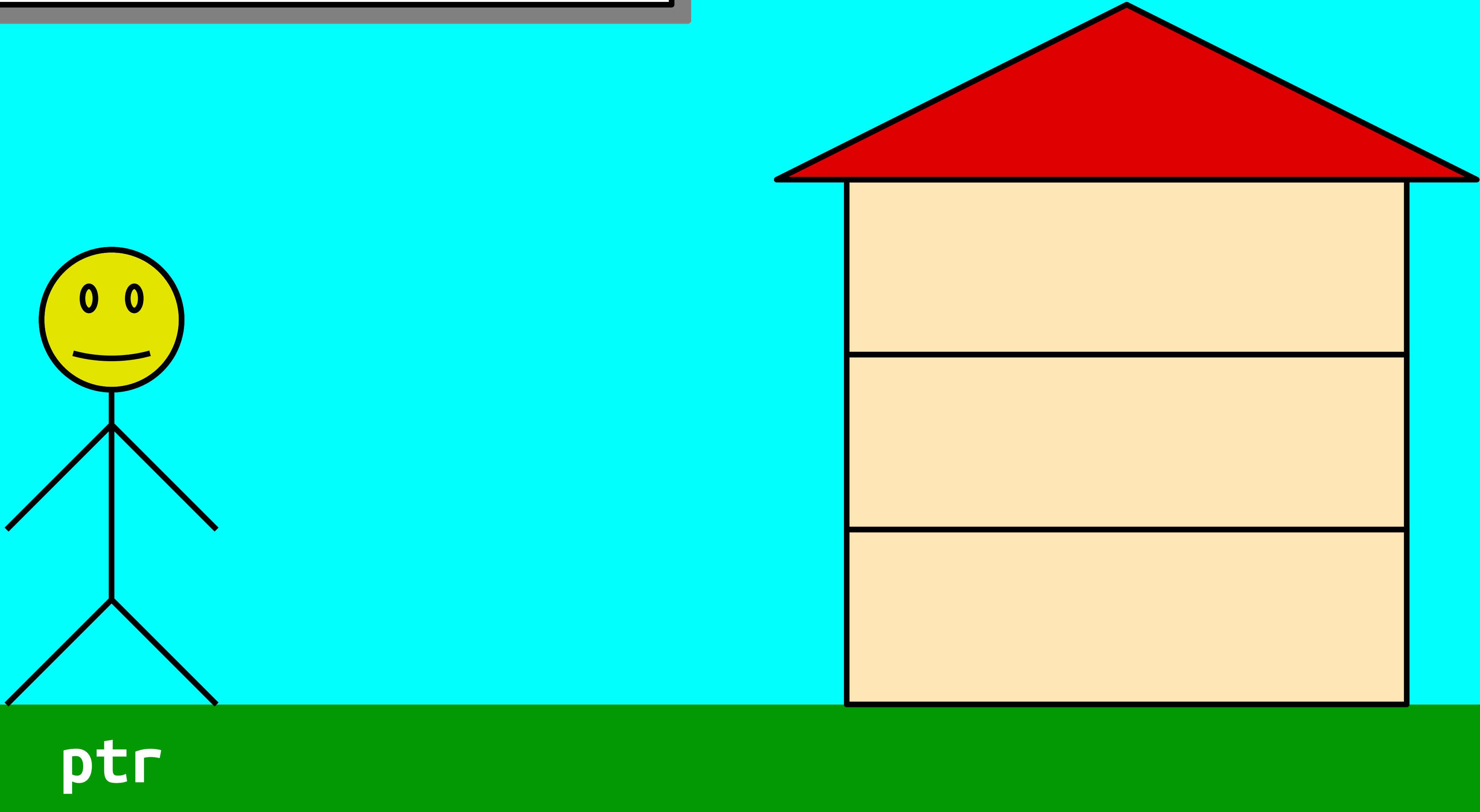
```
int* ptr = new int[4];
cout << ptr[0] << endl;
```

This might print different numbers from run to run of the same program.

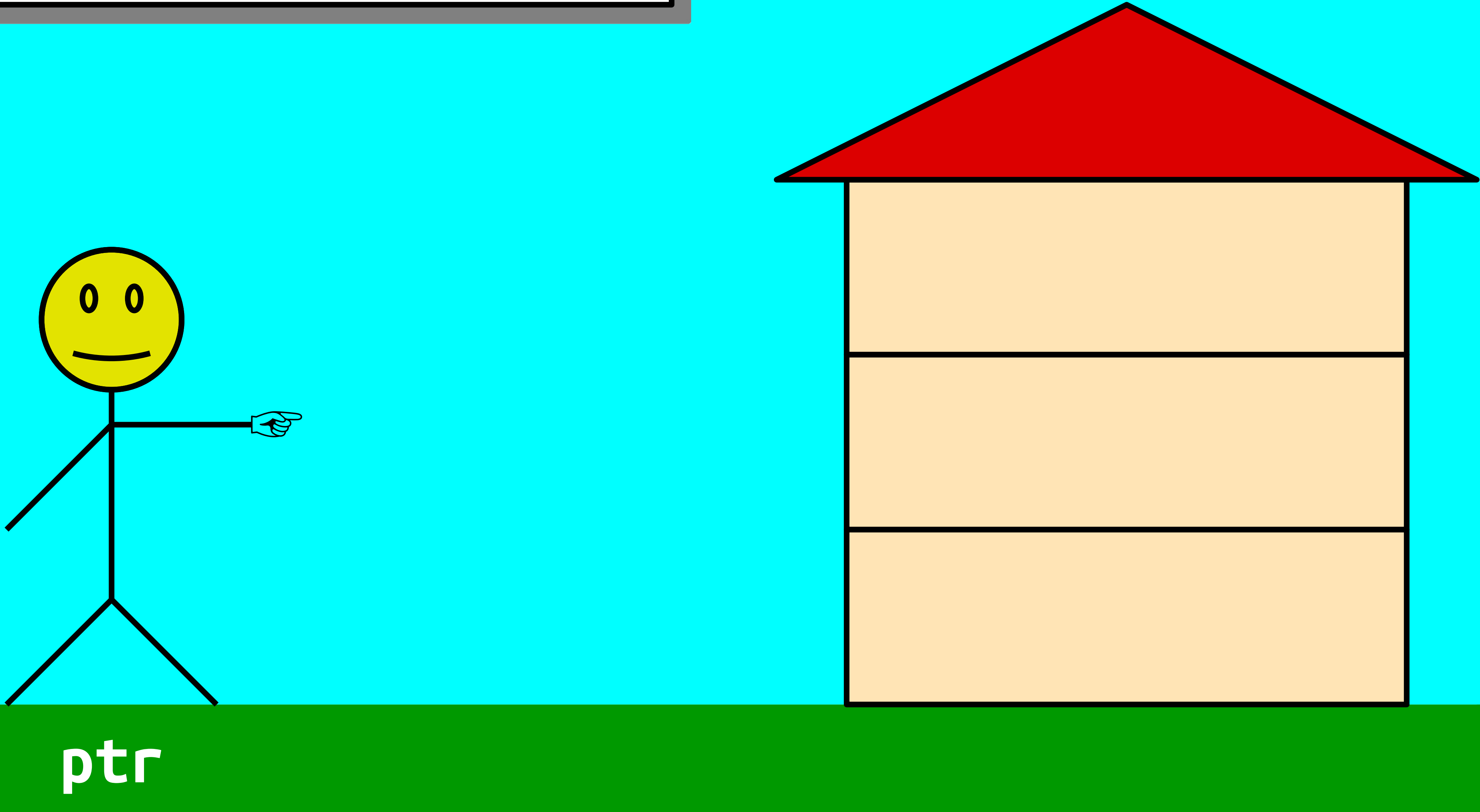
Arrays of ints, doubles, chars, or bools initially have garbage values. Other types use good defaults.



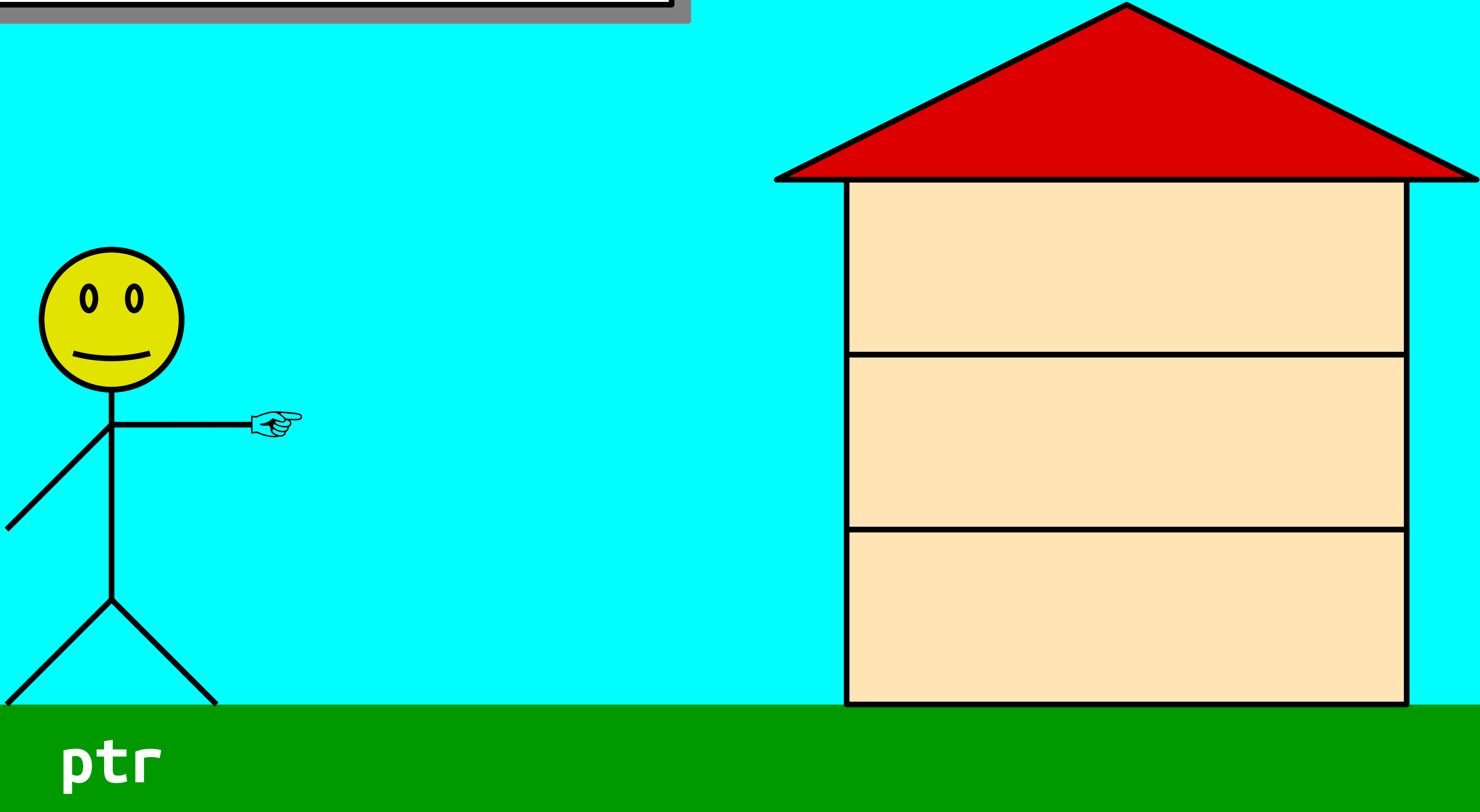
```
string* ptr = new string[3];
```



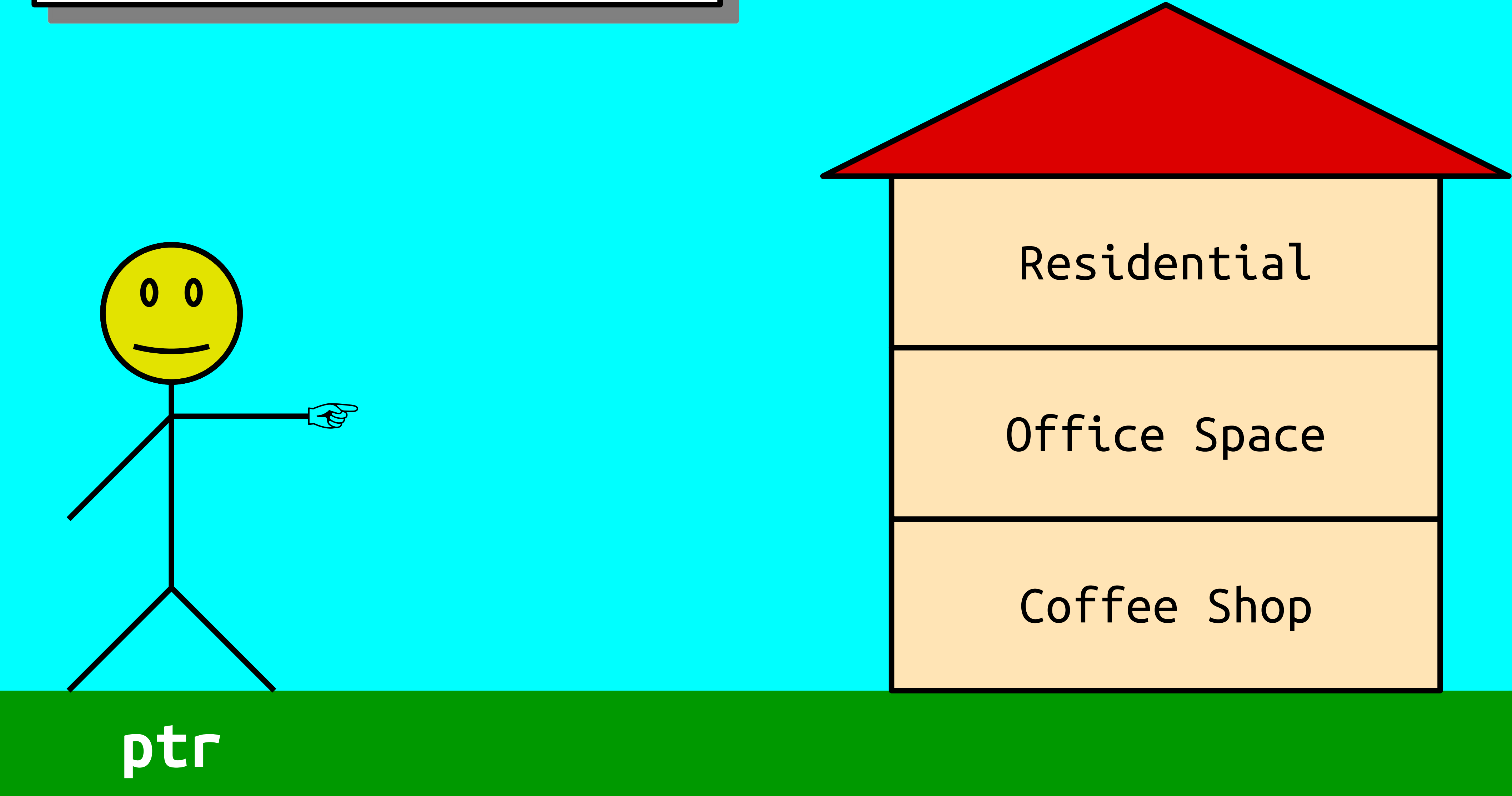
```
string* ptr = new string[3];
```



```
string* ptr = new string[3];
ptr[0] = "Coffee Shop";
ptr[1] = "Office Space";
ptr[2] = "Residential";
```



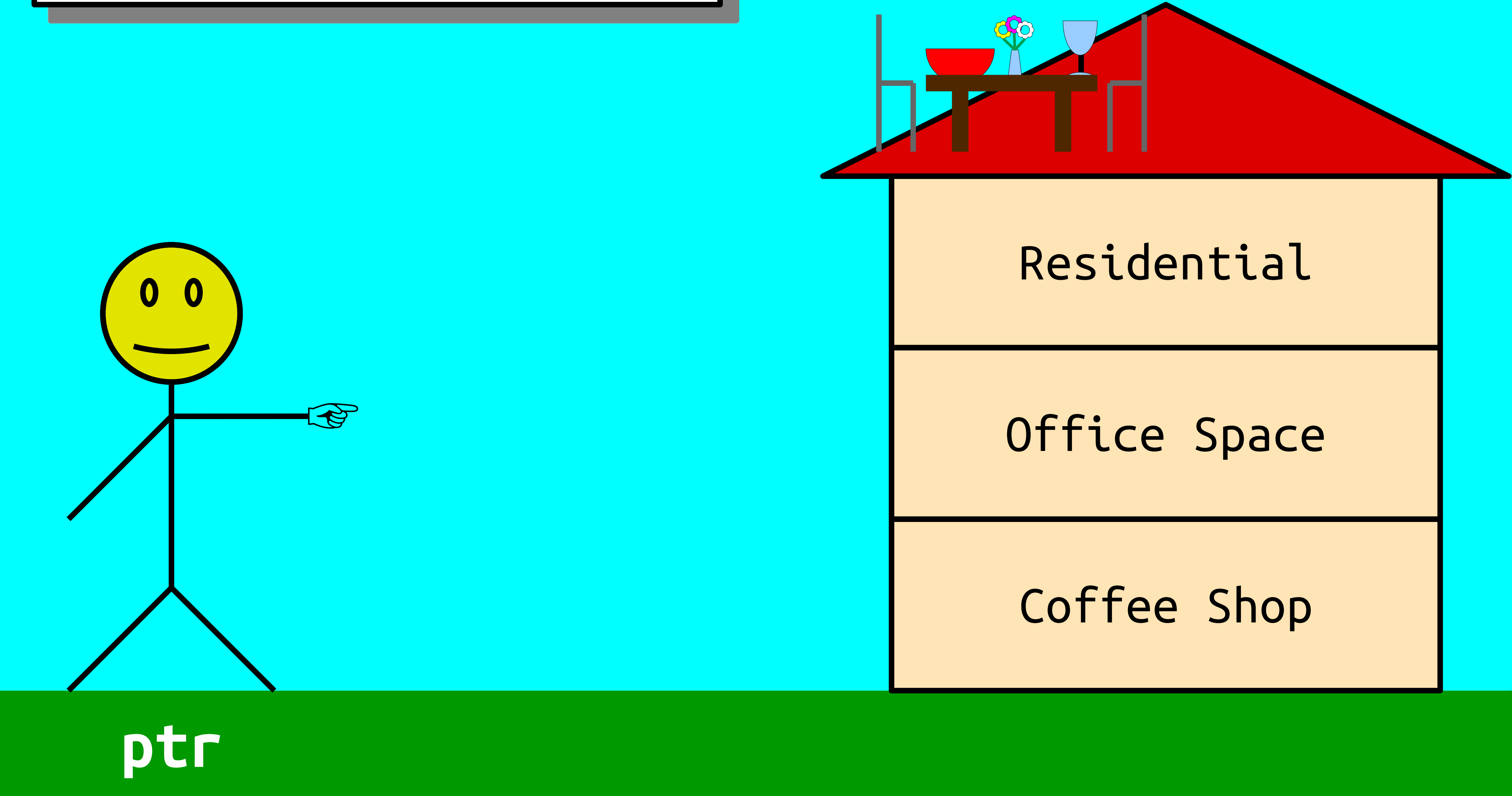
```
string* ptr = new string[3];
ptr[0] = "Coffee Shop";
ptr[1] = "Office Space";
ptr[2] = "Residential";
```



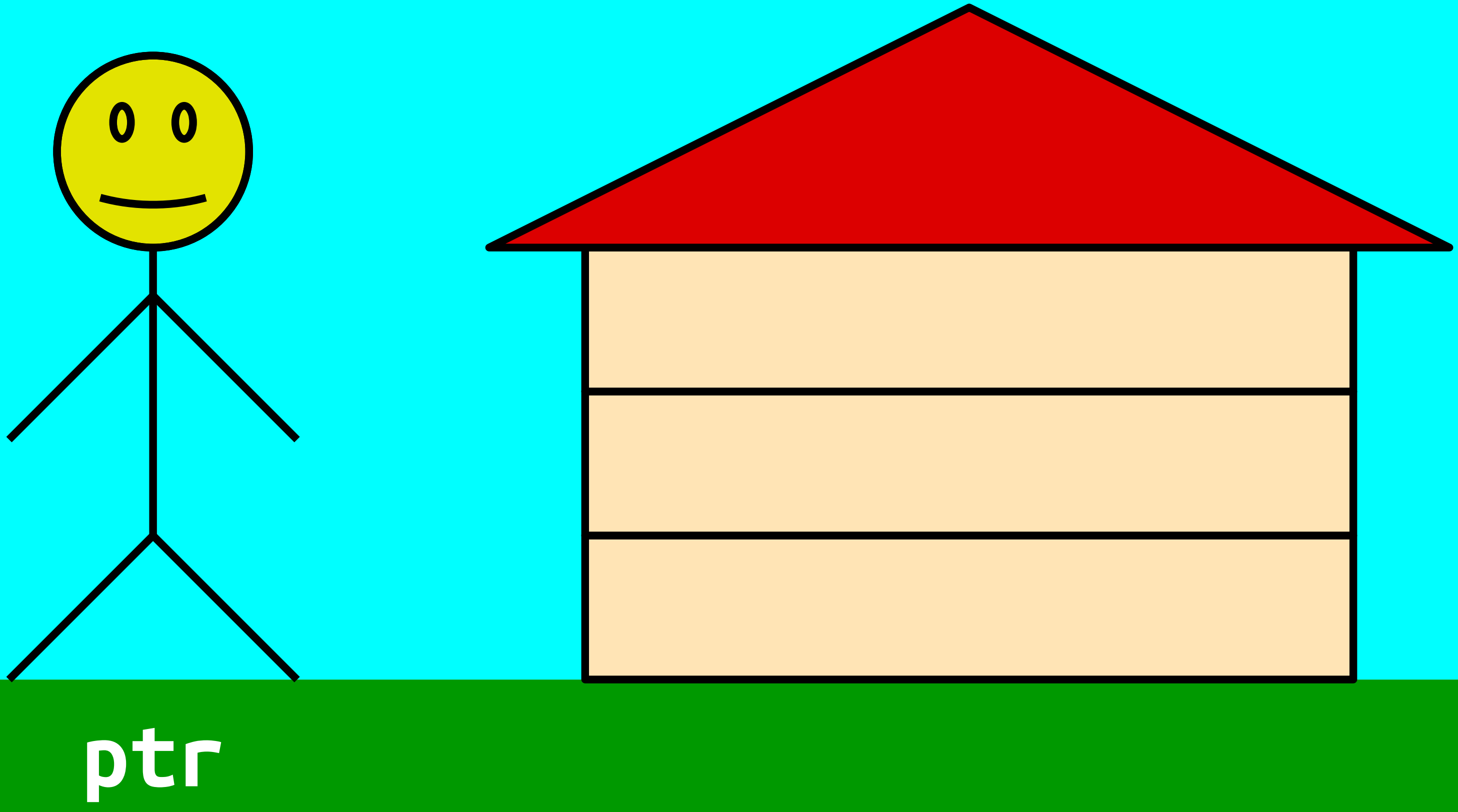
```
string* ptr = new string[3];
ptr[0] = "Coffee Shop";
ptr[1] = "Office Space";
ptr[2] = "Residential";

ptr[3] = "Restaurant"; // Uh…
```

Arrays in C++ do not do any bounds checking. Writing off the end of an array might crash, might corrupt other data, or might do nothing.



```
string* ptr = new string[3];
```



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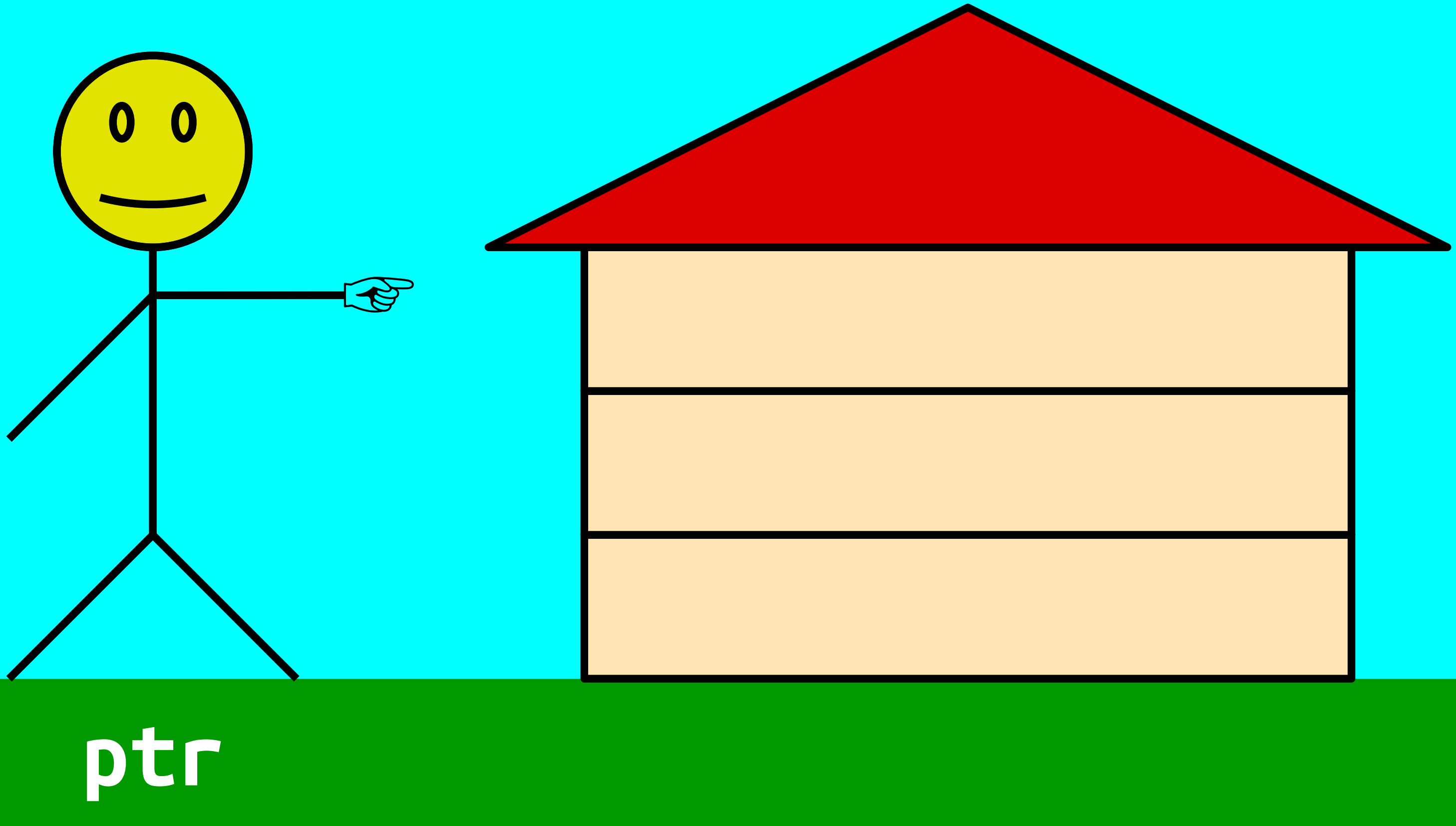
string* ptr = new string[3];
```



```
string* ptr = new string[3];
ptr[0] = "Coffee Shop";
ptr[1] = "Office Space";
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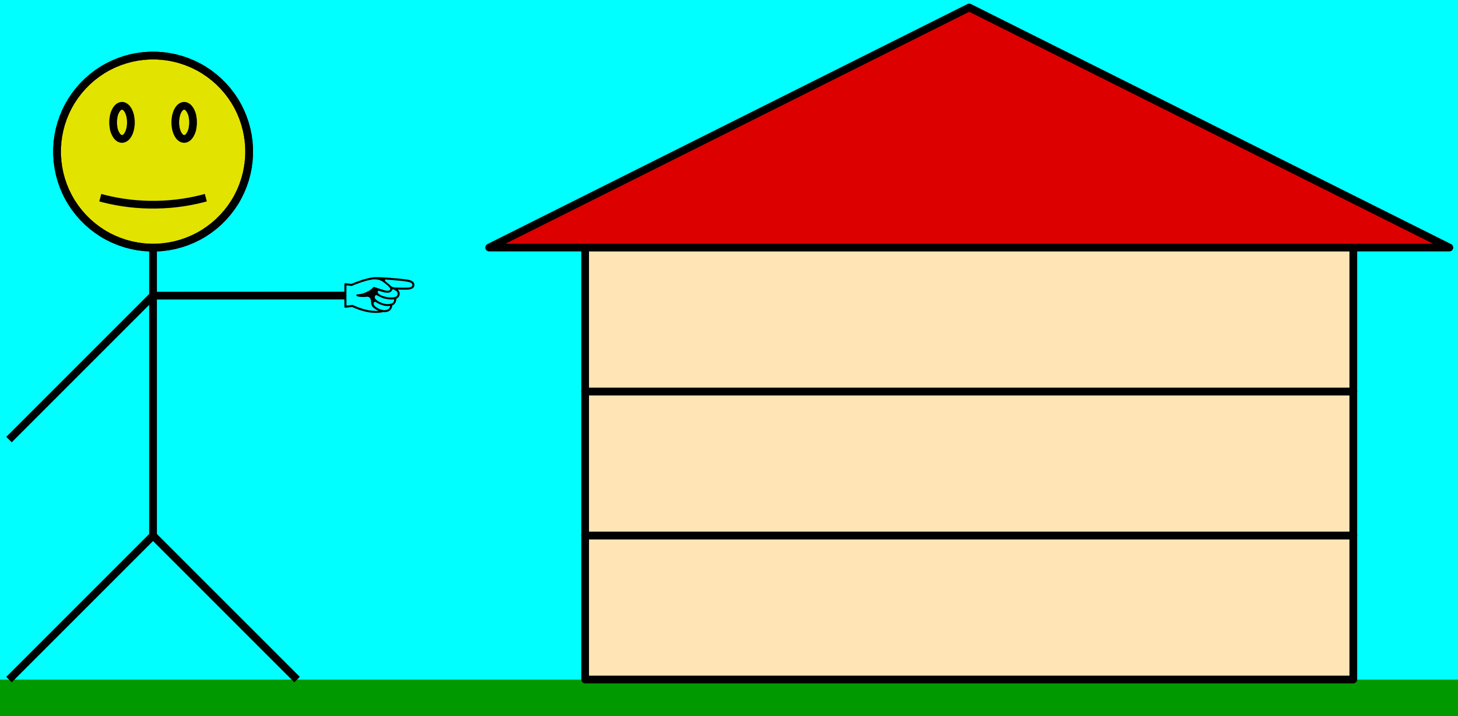
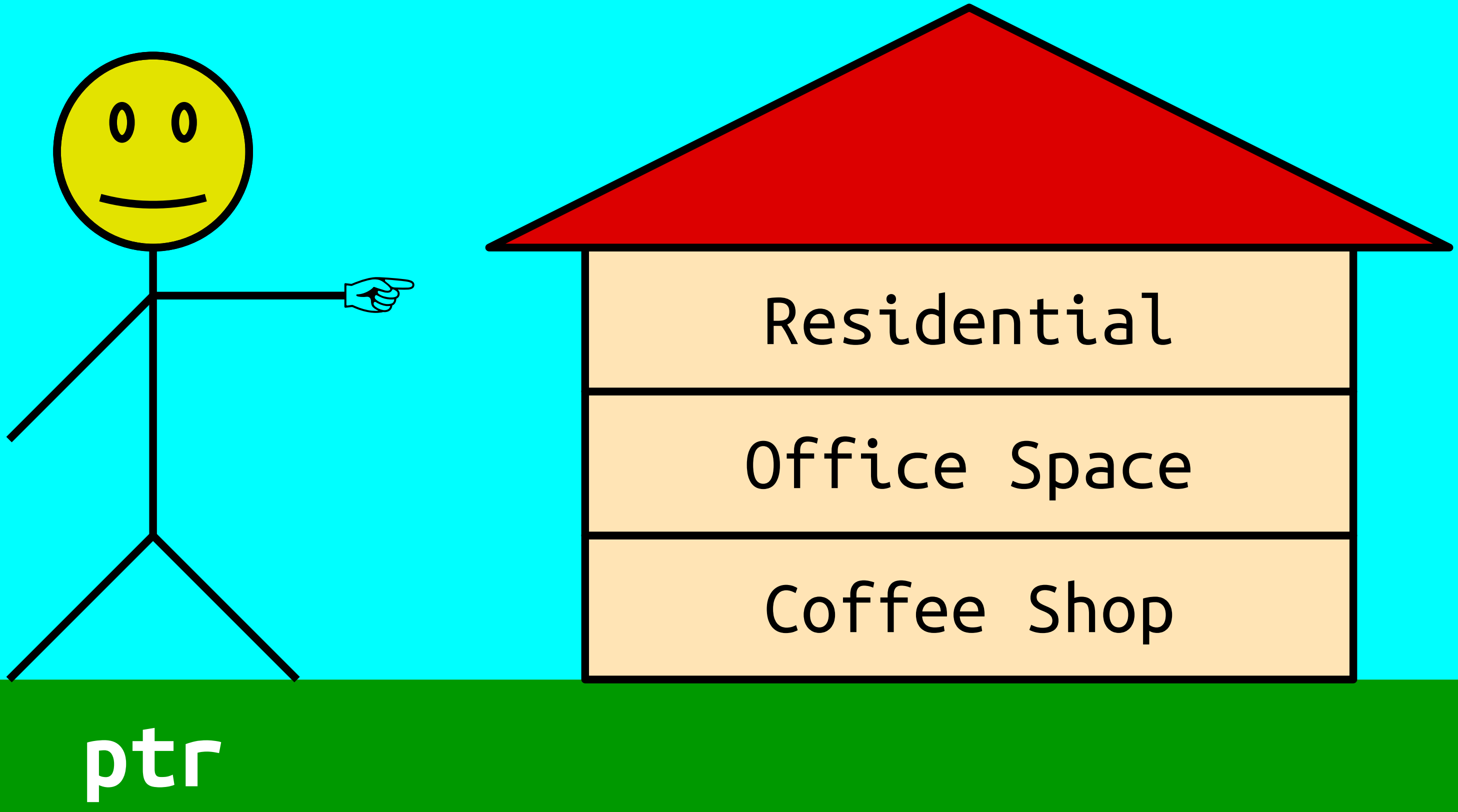
```

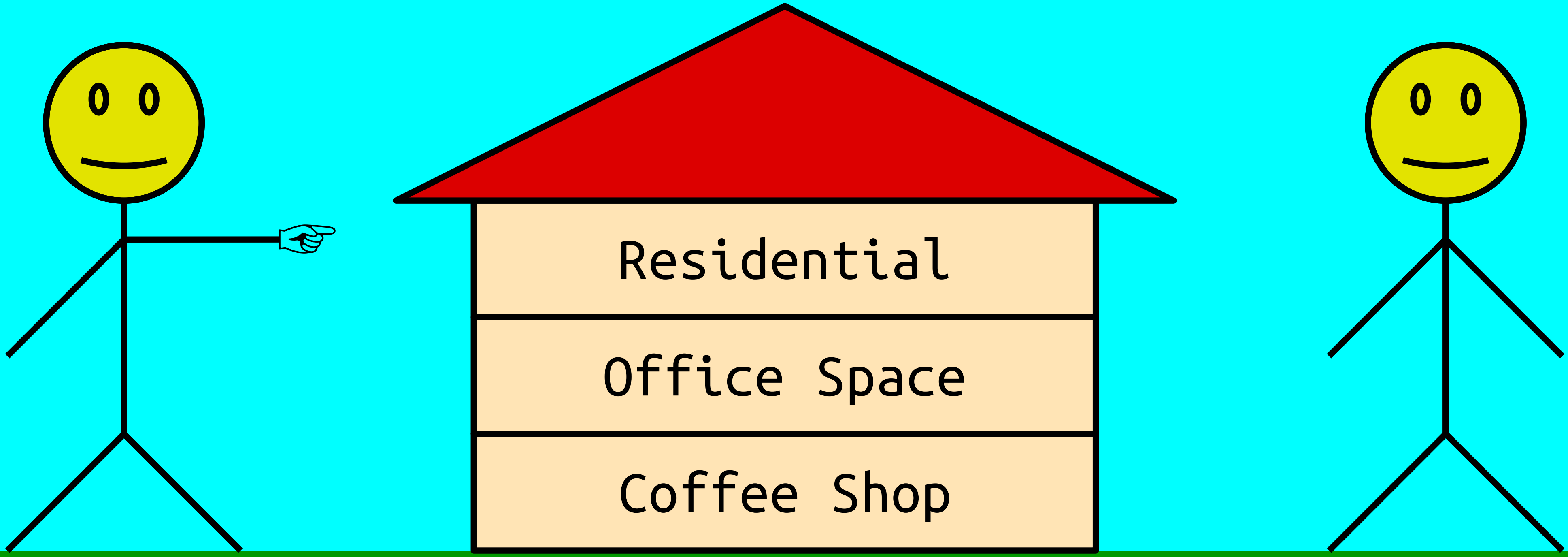


```
string* ptr = new string[3];
ptr[0] = "Coffee Shop";
ptr[1] = "Office Space";
ptr[2] = "Residential";
```



```
string* ptr = new string[3];
ptr[0] = "Coffee Shop";
ptr[1] = "Office Space";
ptr[2] = "Residential";

string* ptr2 = ptr;
```

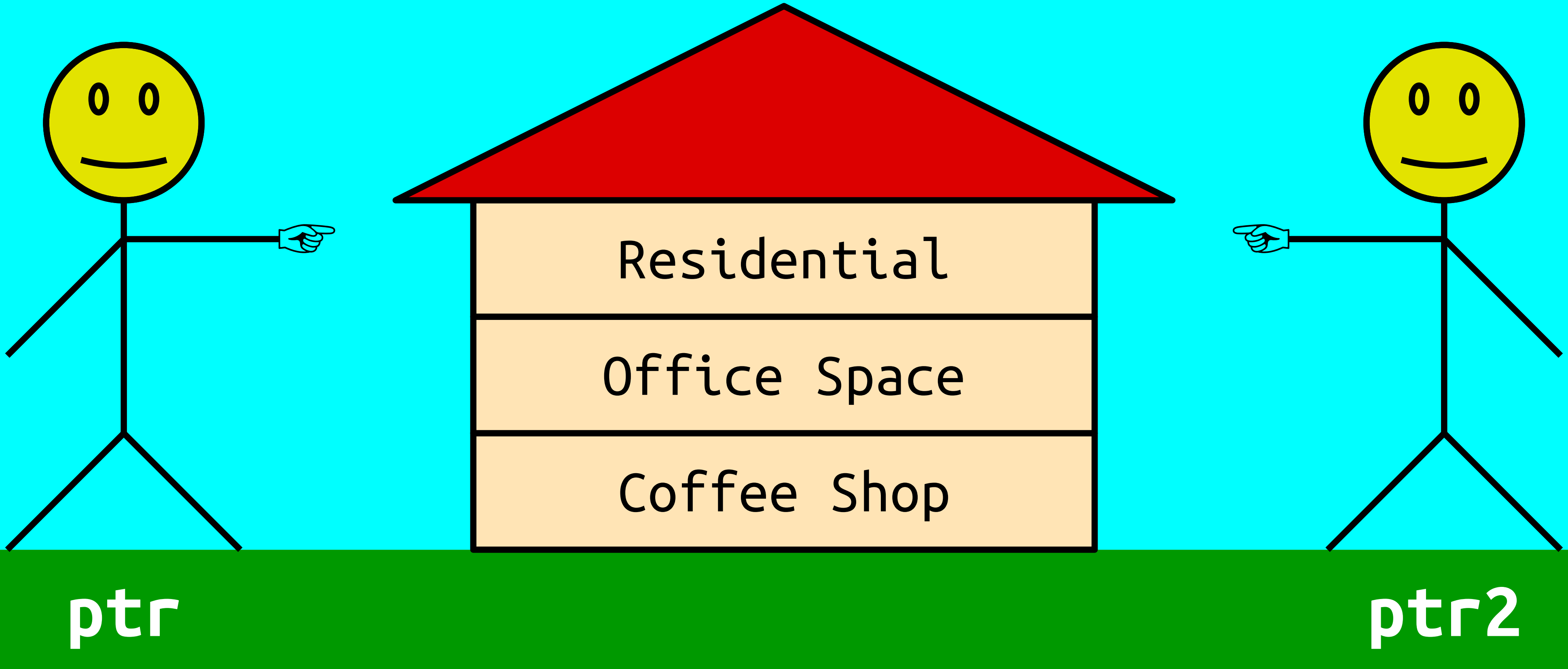


ptr **ptr2**

```
string* ptr = new string[3];
ptr[0] = "Coffee Shop";
ptr[1] = "Office Space";
ptr[2] = "Residential";

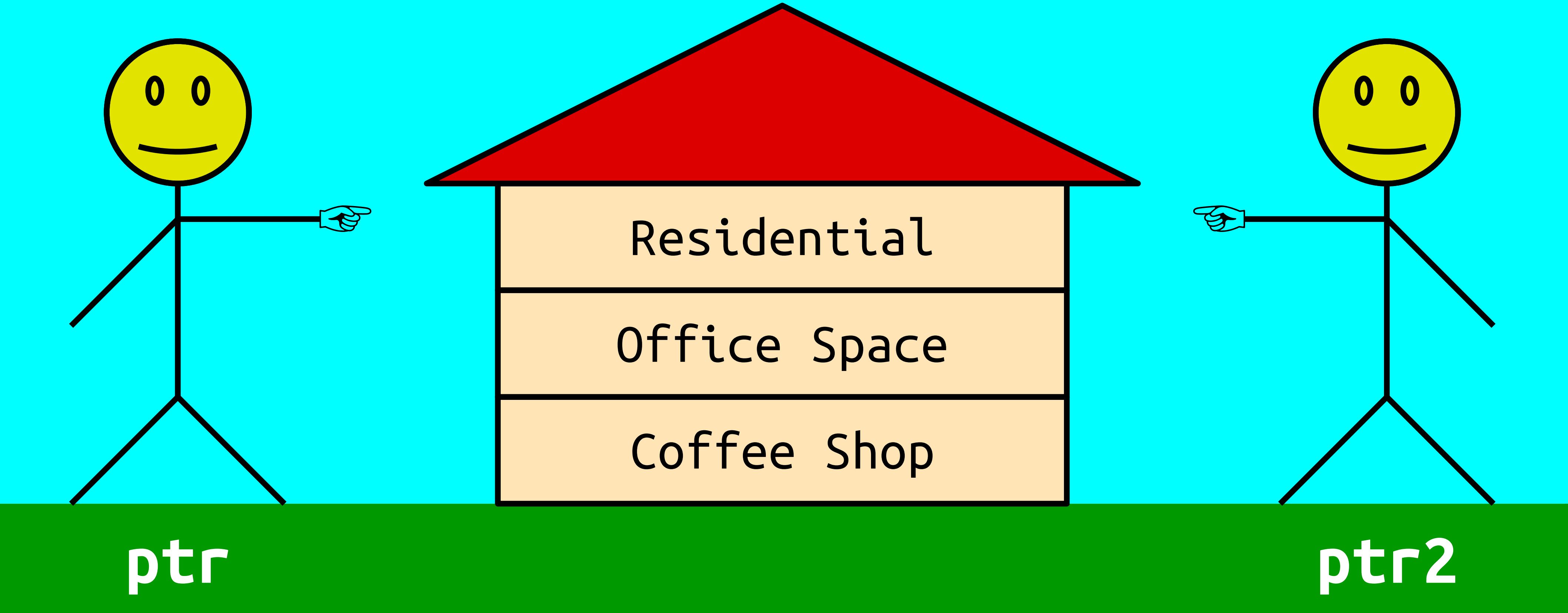
string* ptr2 = ptr;
```

Assigning one pointer to another makes them both point to the same array.



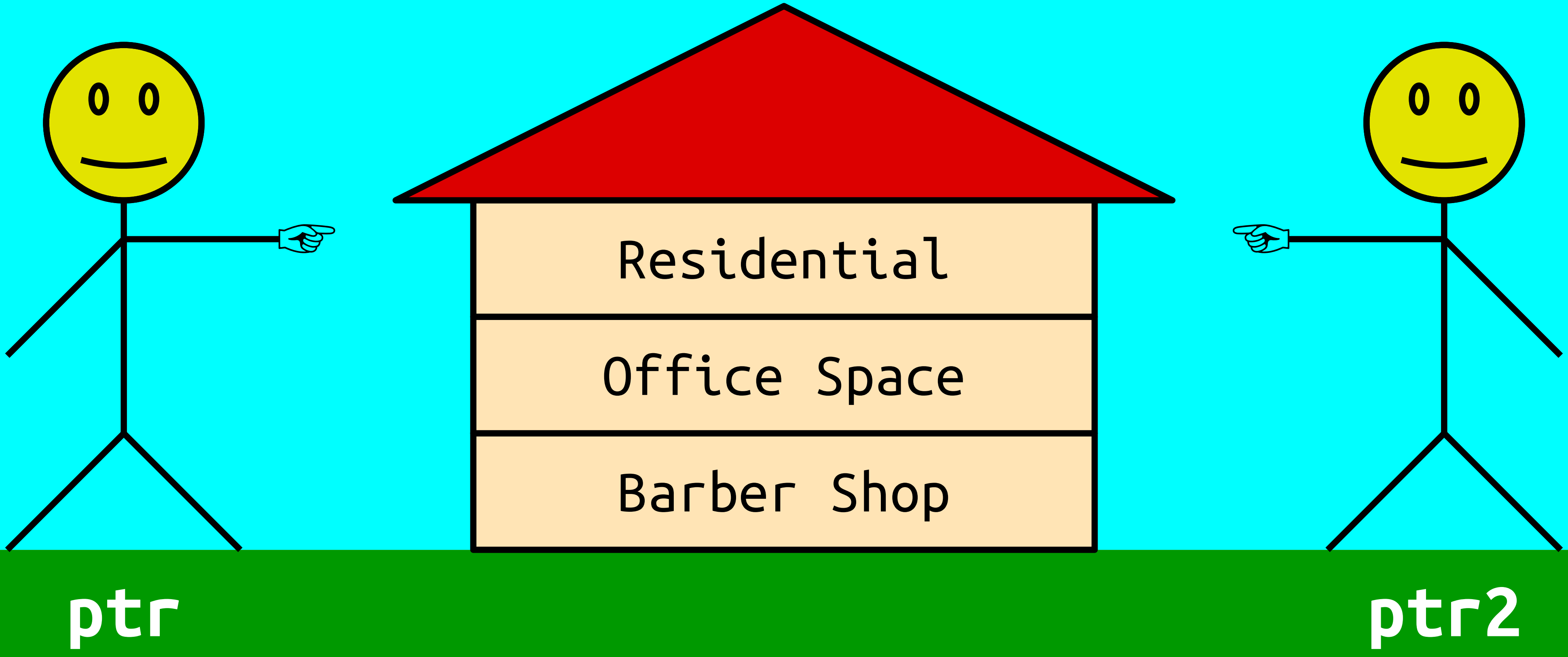
```
string* ptr = new string[3];
ptr[0] = "Coffee Shop";
ptr[1] = "Office Space";
ptr[2] = "Residential";

string* ptr2 = ptr;
ptr2[0] = "Barber Shop";
```



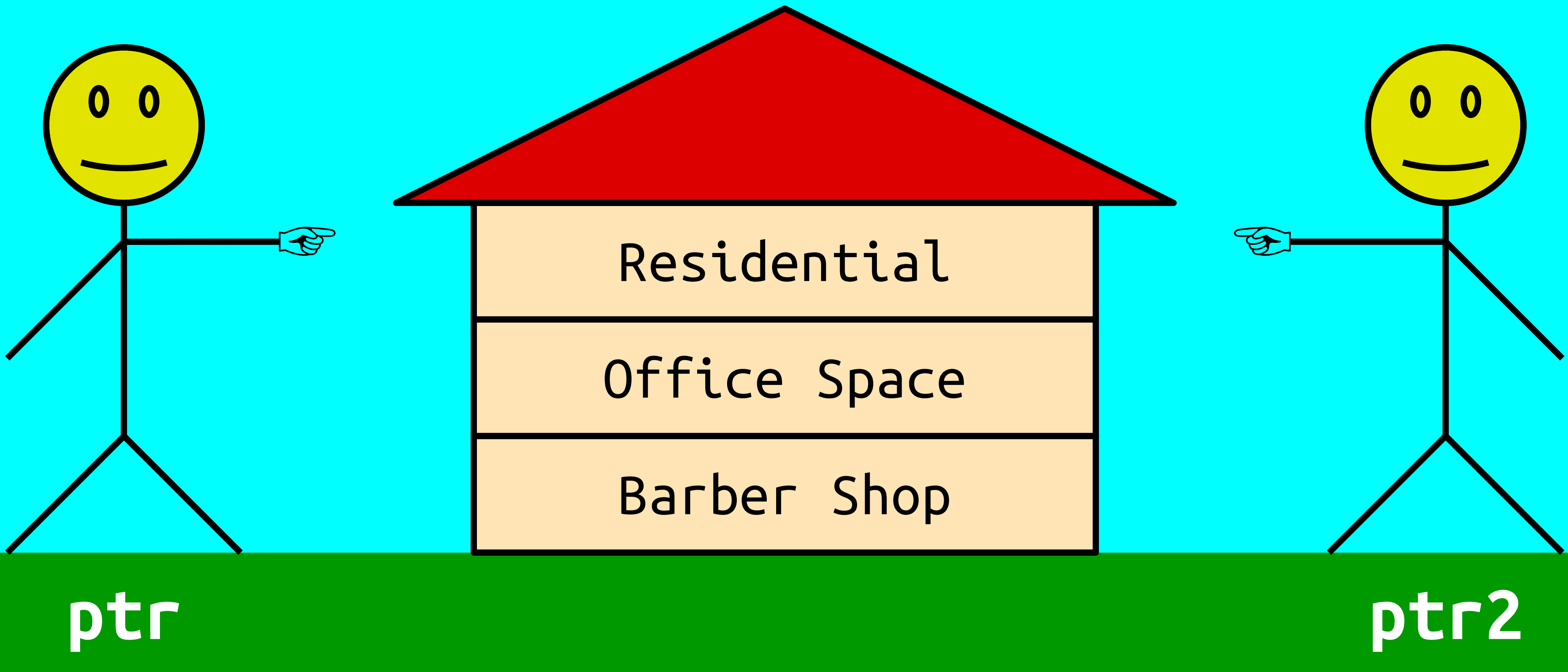
```
string* ptr = new string[3];
ptr[0] = "Coffee Shop";
ptr[1] = "Office Space";
ptr[2] = "Residential";

string* ptr2 = ptr;
ptr2[0] = "Barber Shop";
```



```
string* ptr = new string[3];
ptr[0] = "Coffee Shop";
ptr[1] = "Office Space";
ptr[2] = "Residential";

string* ptr2 = ptr;
ptr2[0] = "Barber Shop";
cout << ptr[0] << endl;
```

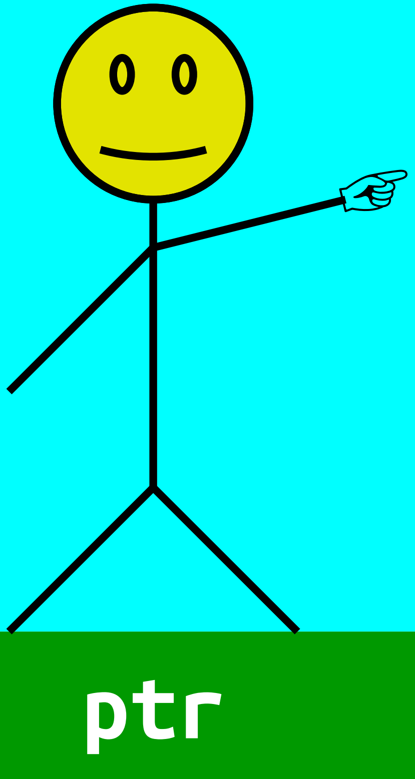


```
string* ptr;
```

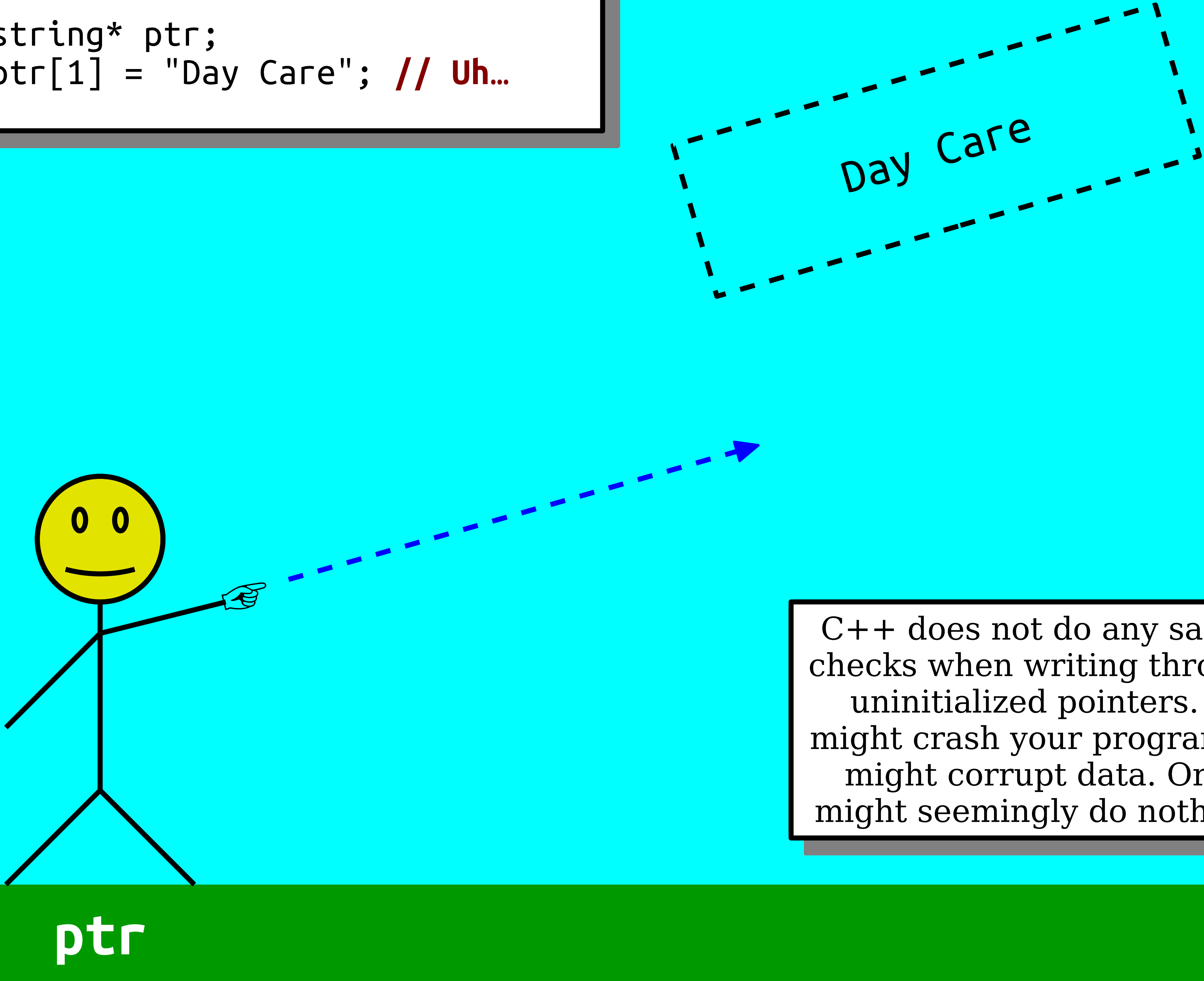
Pointers always point somewhere, even if you don't initialize them.

An ***uninitialized pointer*** (sometimes called a ***garbage pointer***) is a pointer that hasn't been assigned to point to anything.

Uninitialized pointers point somewhere, but there's no way to predict exactly where.



```
string* ptr;
ptr[1] = "Day Care"; // Uh…
```



C++ does not do any safety checks when writing through uninitialized pointers. It might crash your program. It might corrupt data. Or it might seemingly do nothing.

```
void makeAnArray() {
    string* ptr = new string[3];
}

int main() {
    for (int i = 0; i < 5; i++) {
        makeAnArray();
    }
}
```

```
void makeAnArray() {
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int main() {
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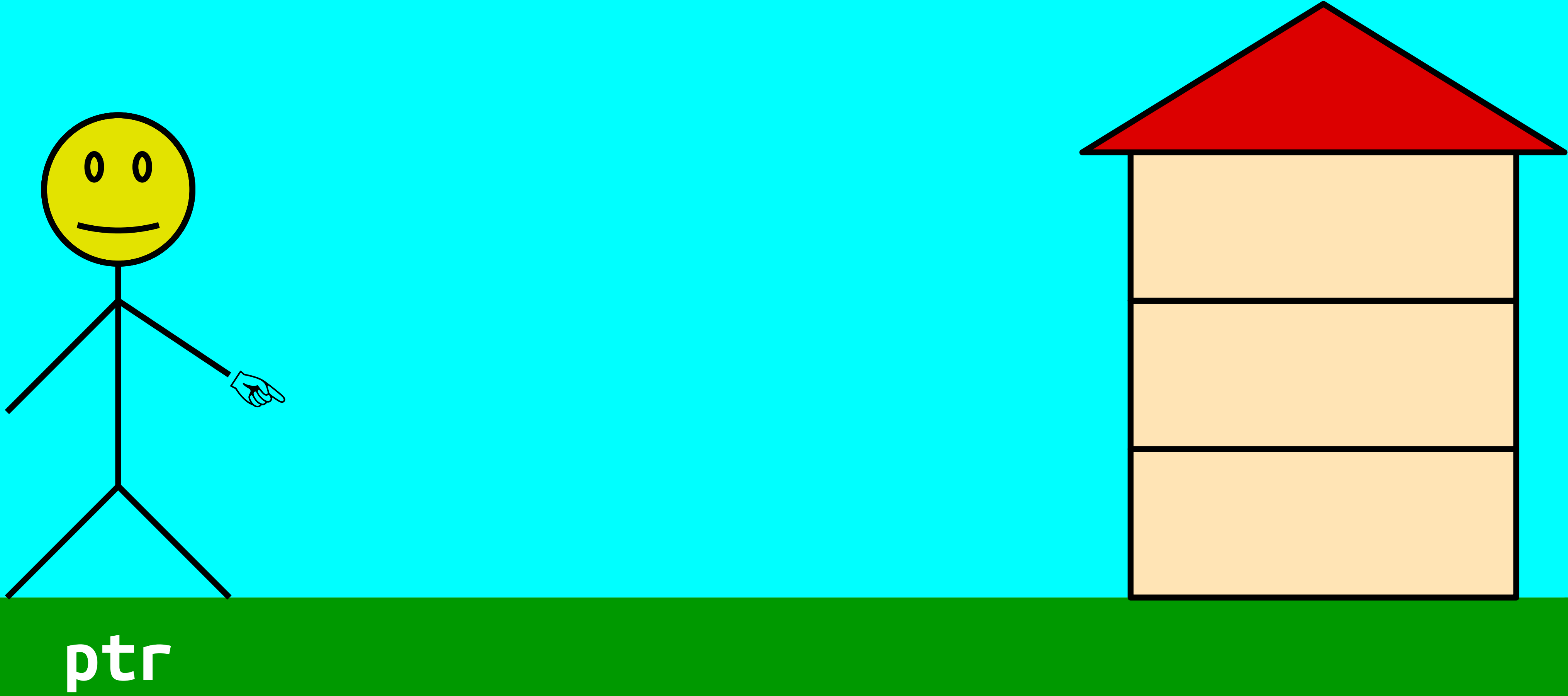

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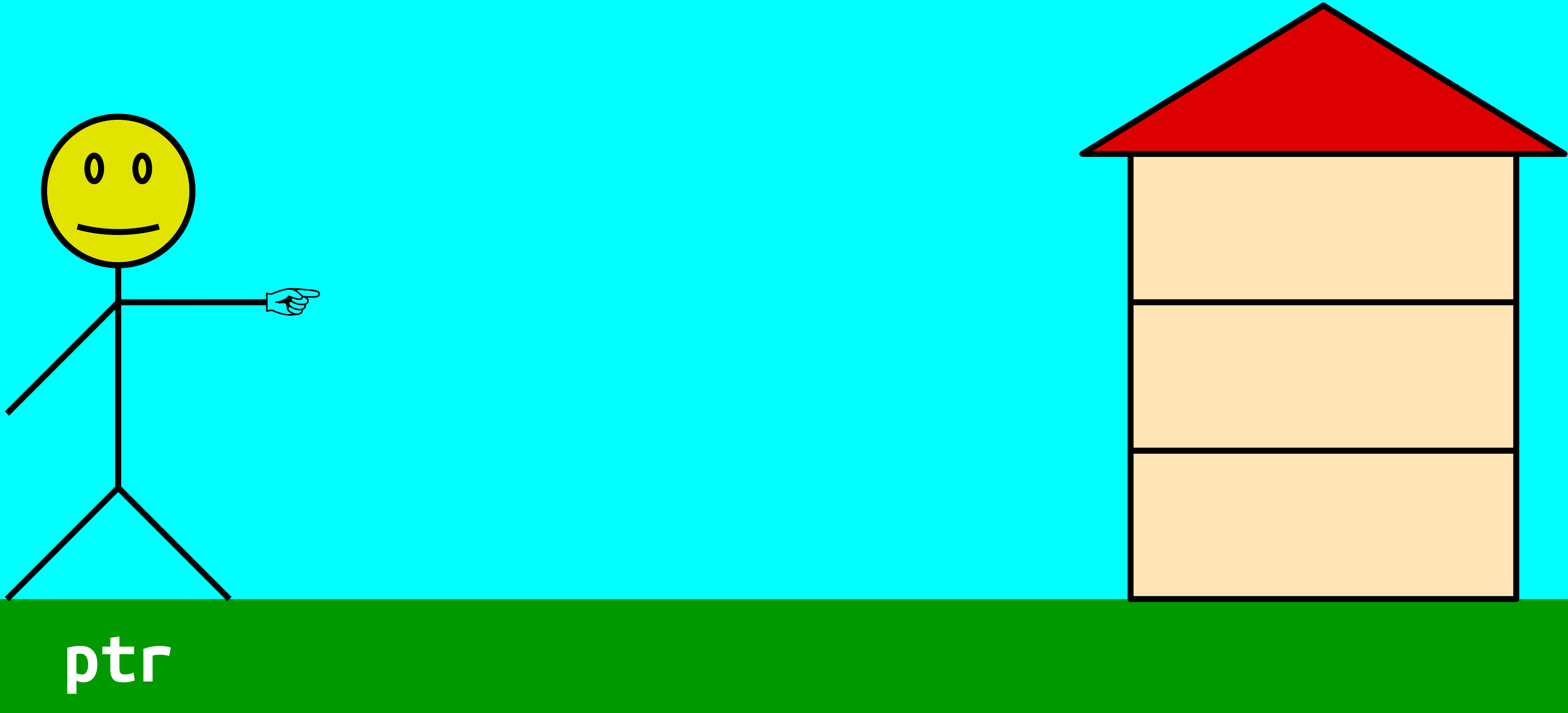

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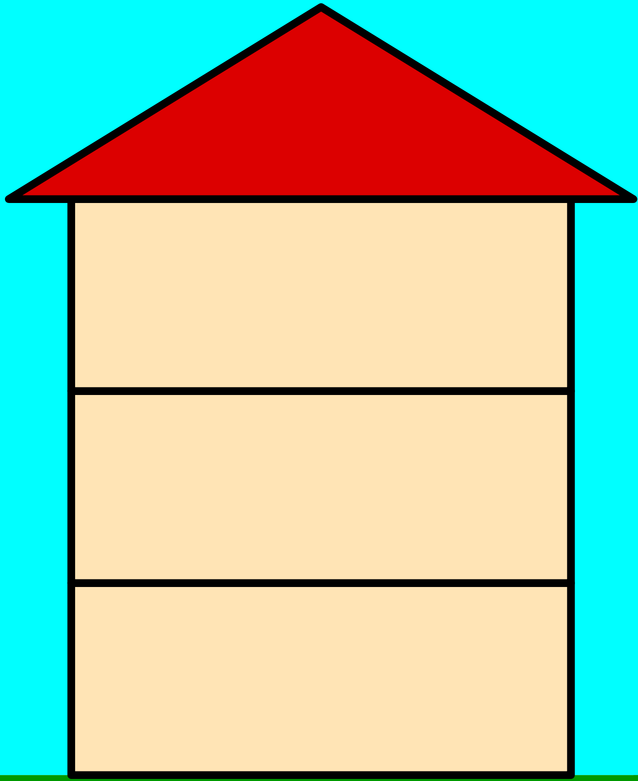
```
void makeAnArray() {
    string* ptr = new string[3];
}

int main() {
    for (int i = 0; i < 5; i++) {
        makeAnArray();
    }
}
```

The local variable `ptr` is cleaned up once the function returns – but the array itself remains!

This is different than how the container types work.

Anything created with `new[]` persists until explicitly cleaned up.



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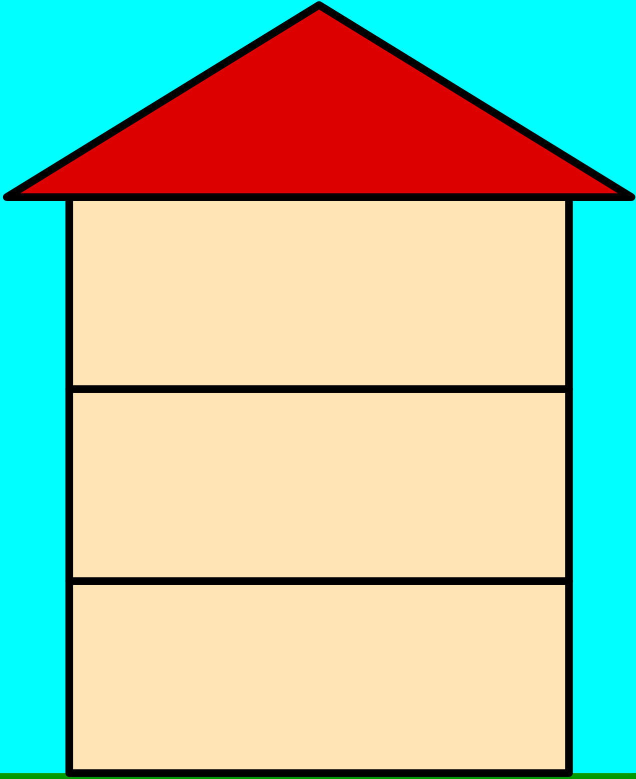
    }
}
```



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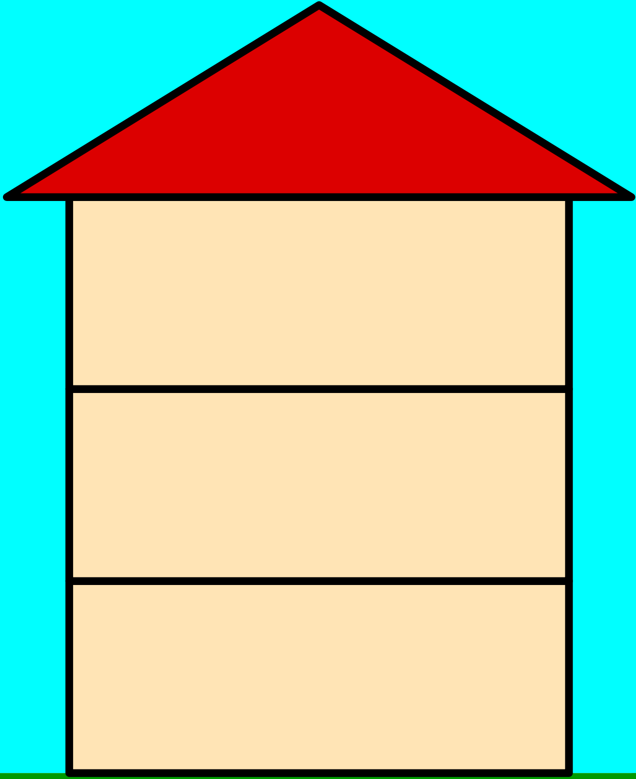

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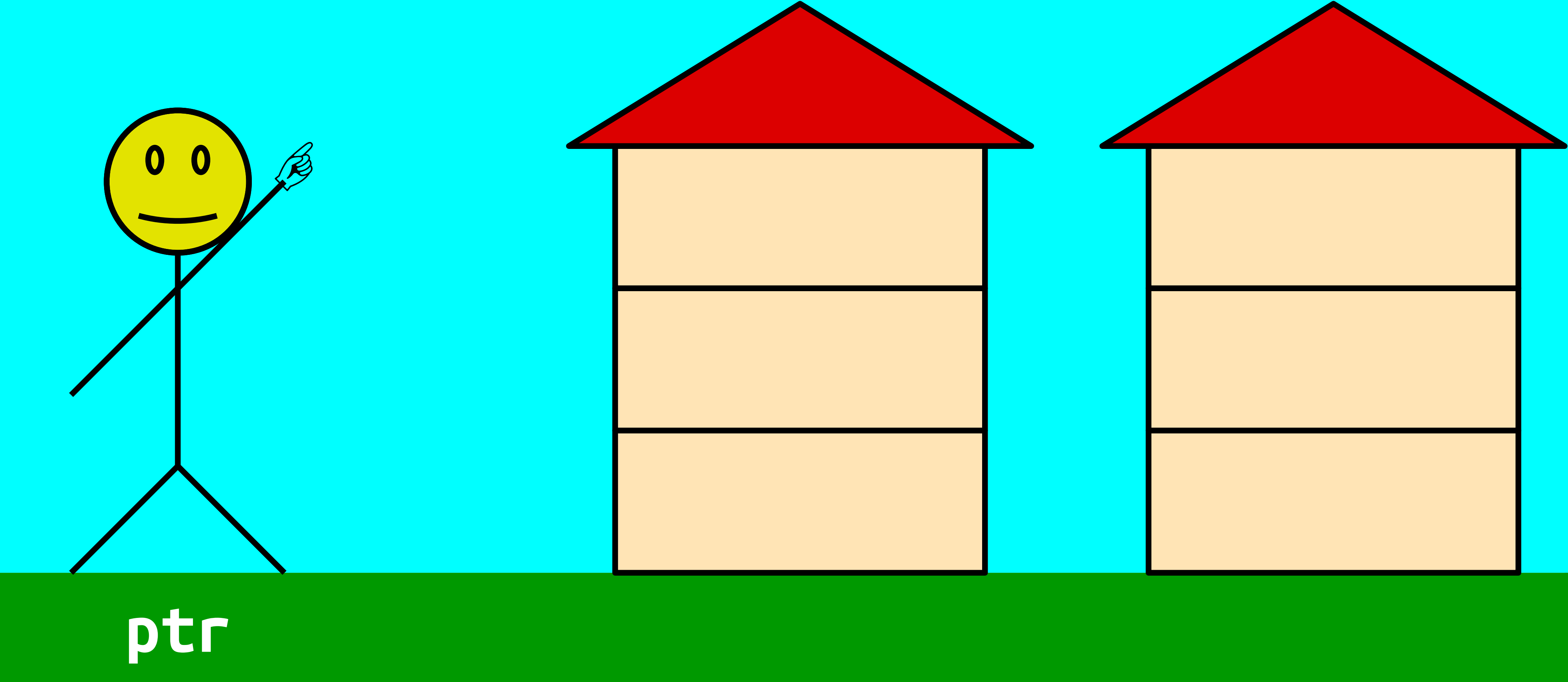

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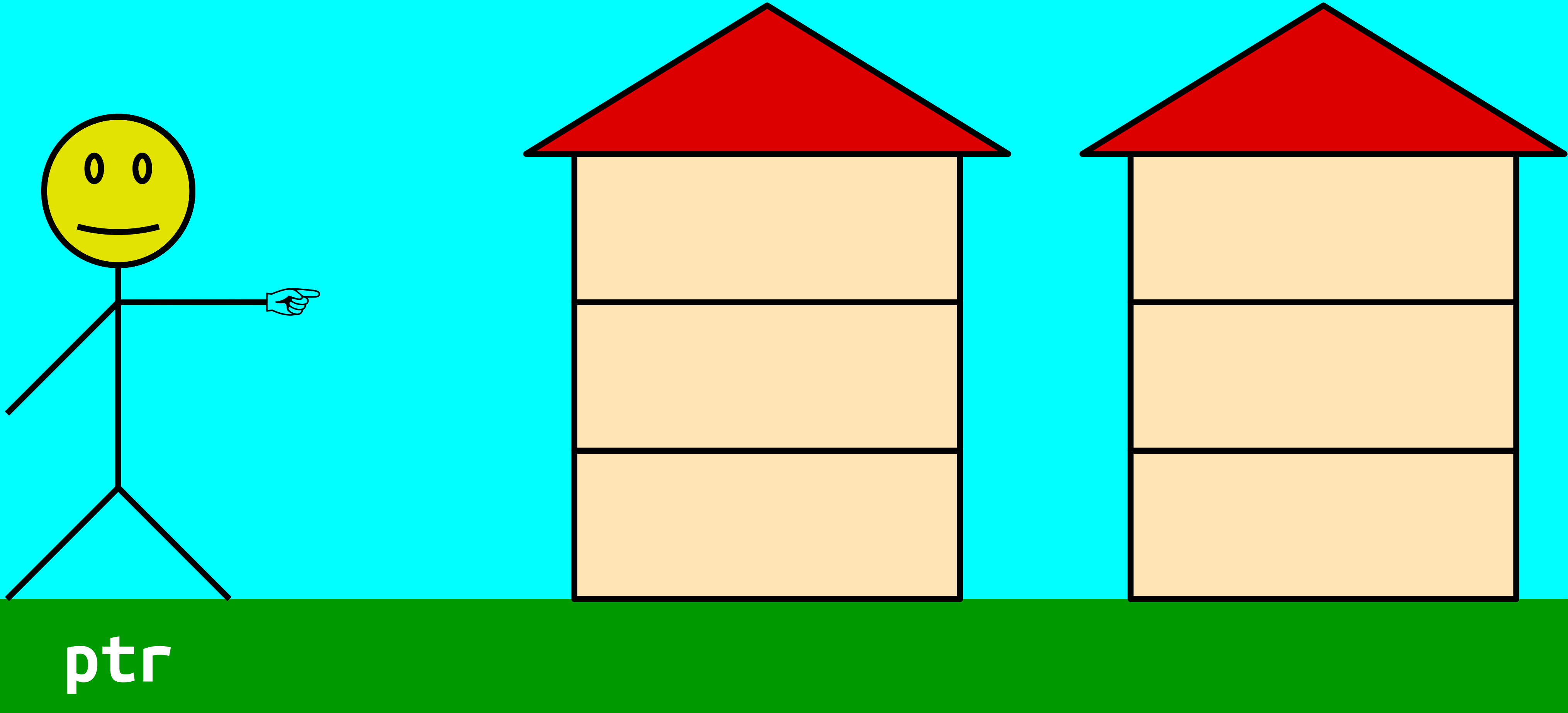

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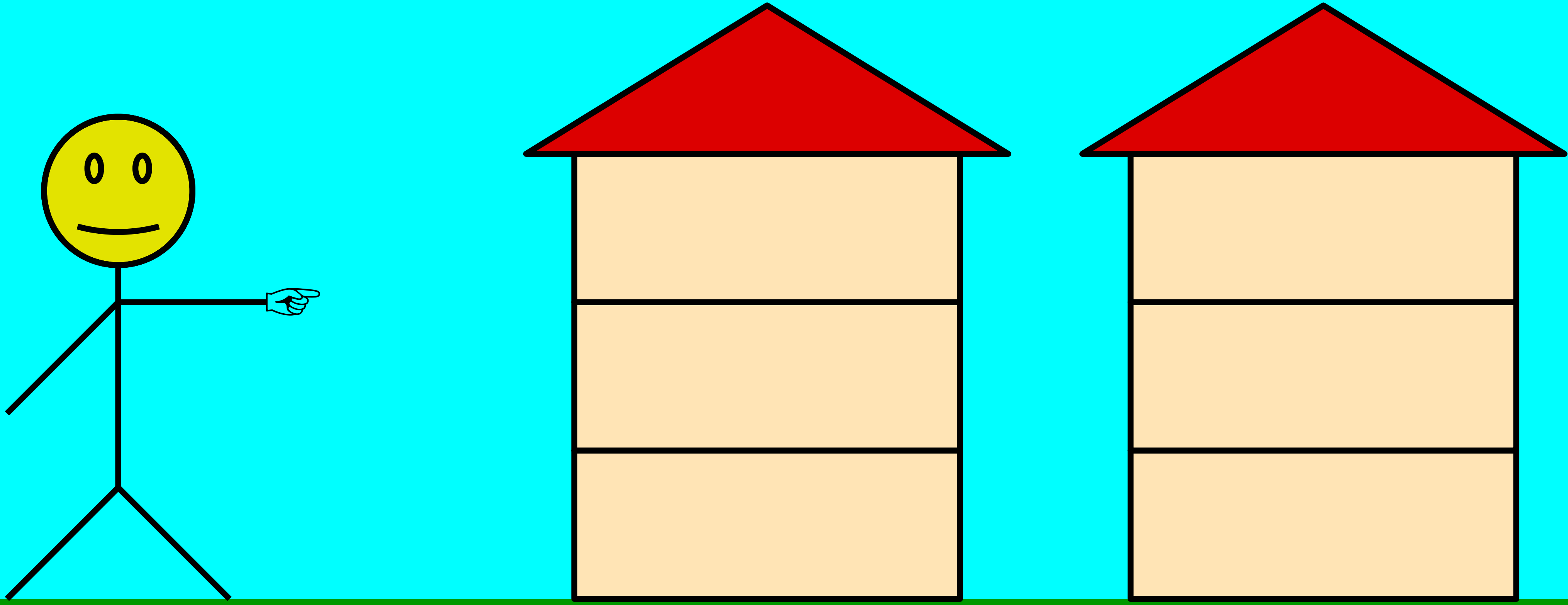

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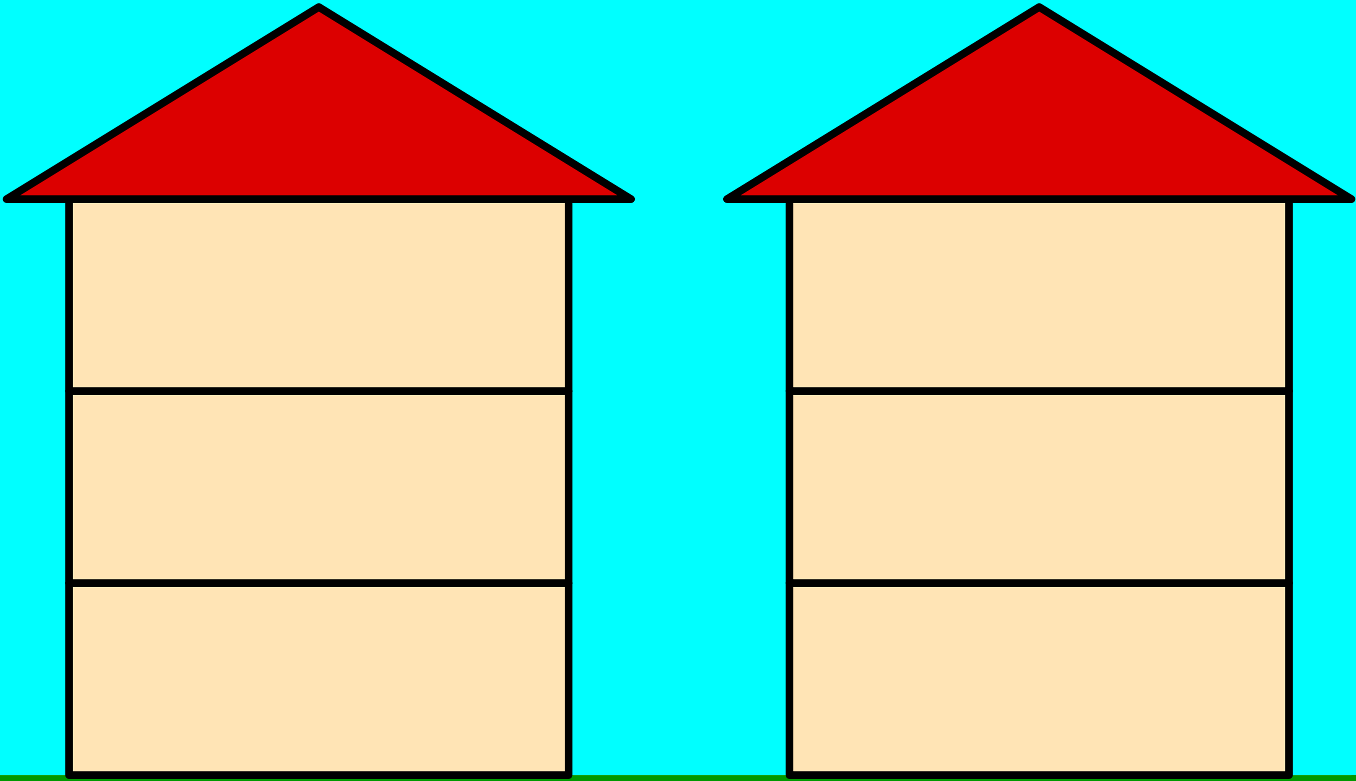

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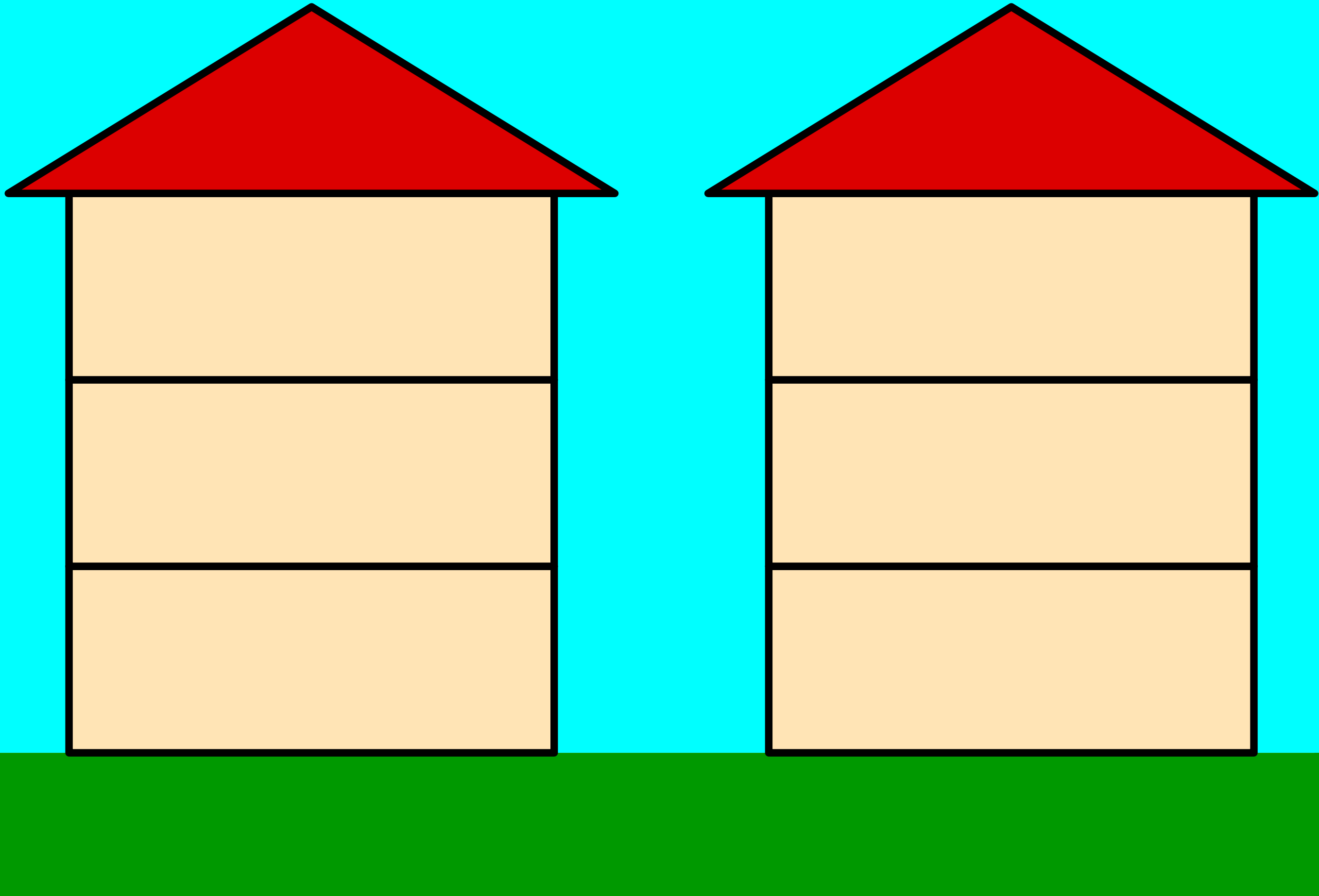

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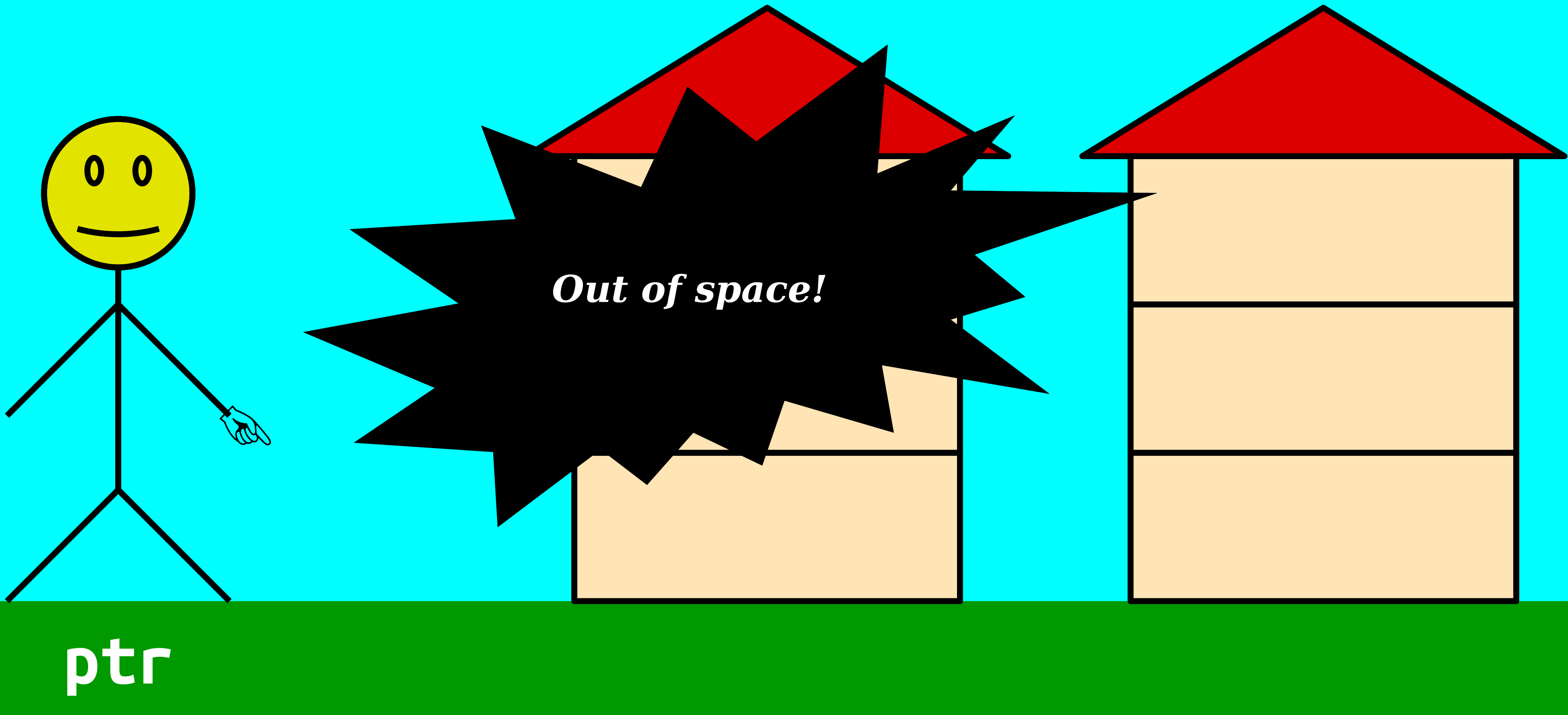
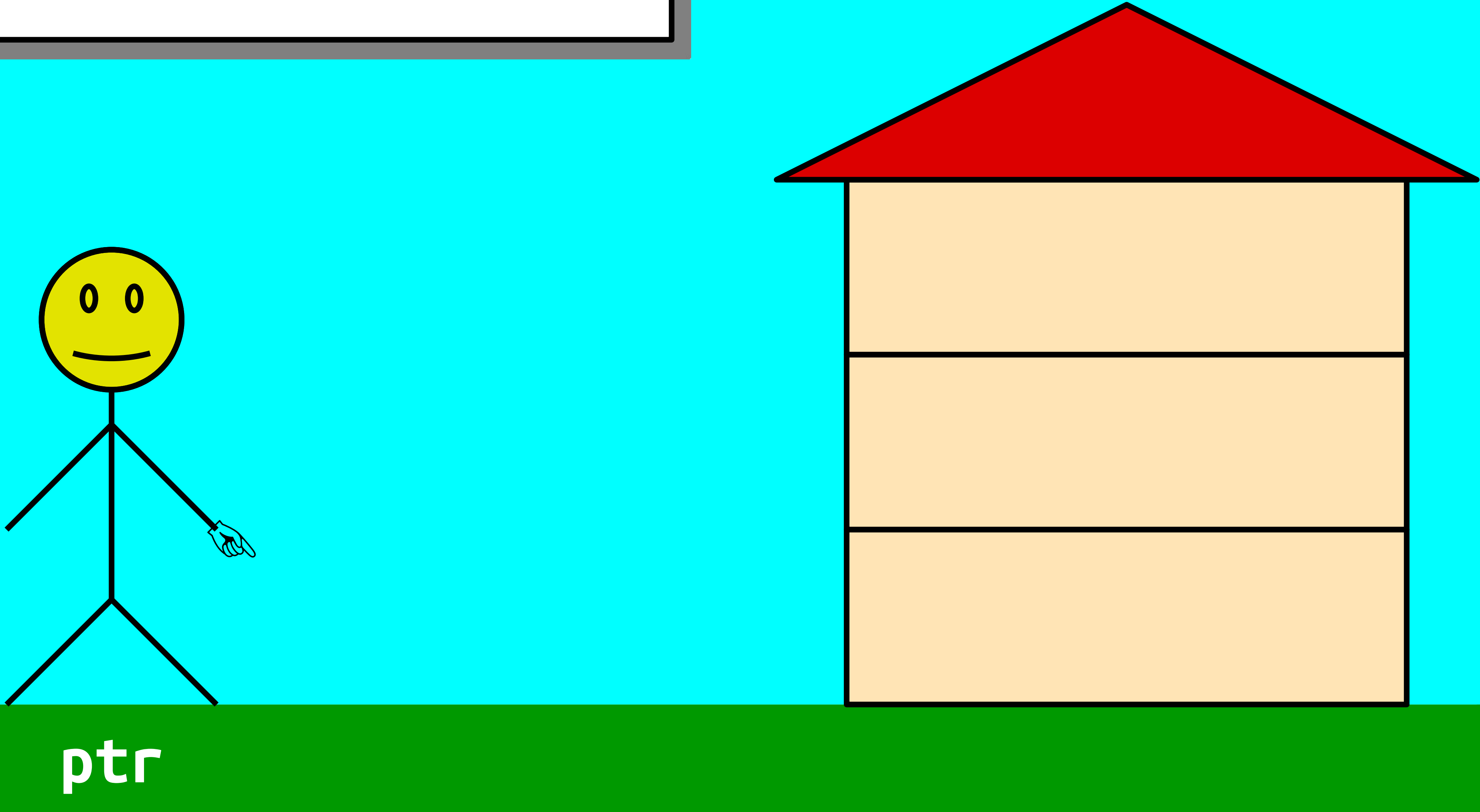


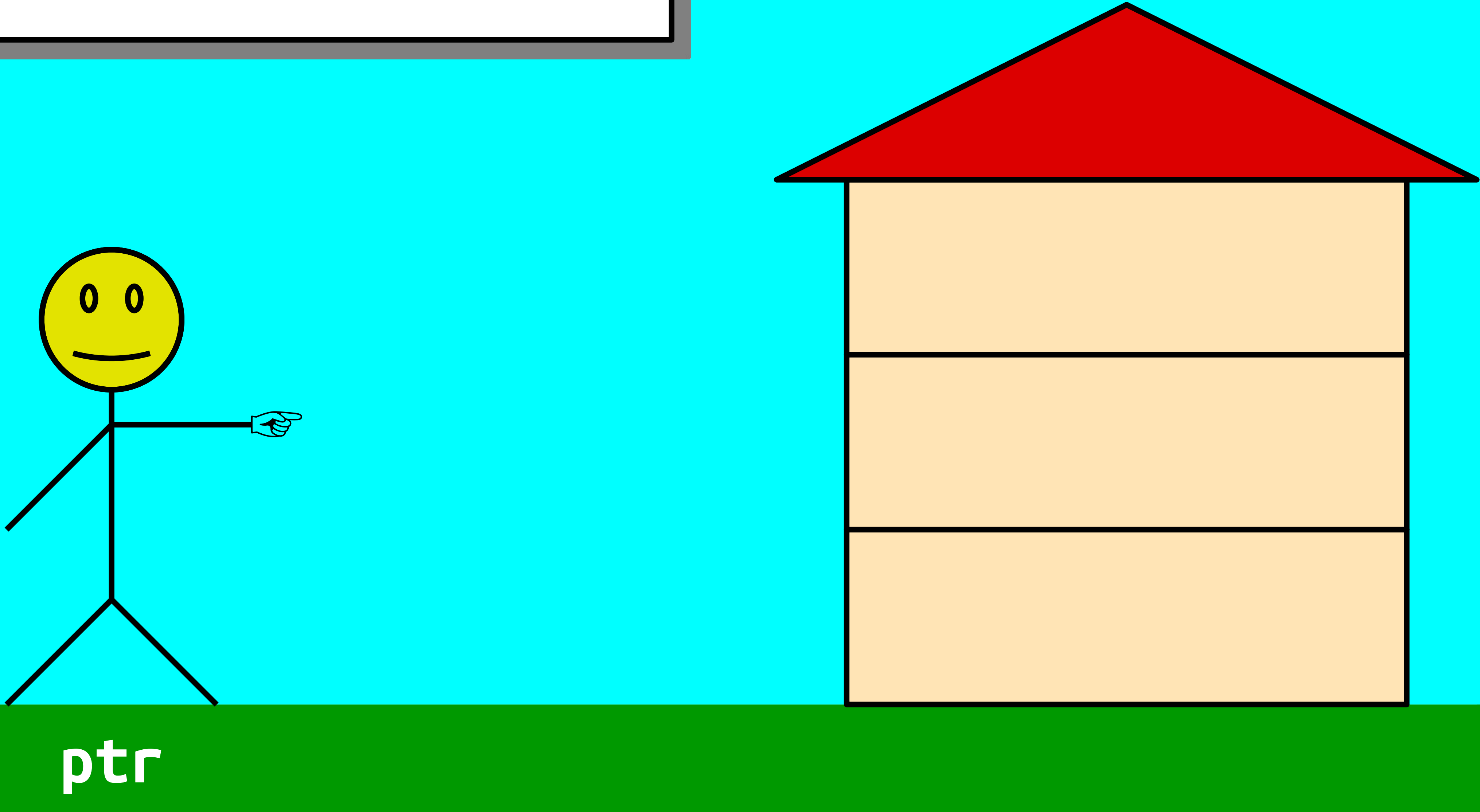
Cleaning Up

- When declaring local variables or parameters, C++ will automatically handle memory allocation and deallocation for you.
- When using `new[]`, you are responsible for deallocating the memory you allocate.
- If you don't, you get a ***memory leak***. Your program will never be able to use that memory again.
  - Too many leaks can cause a program to slow down and eventually crash as memory becomes more and more scarce!
- (Realistically, that previous example wouldn’t allocate enough memory to crash the program. You need to leak a bunch of memory before that will happen.)

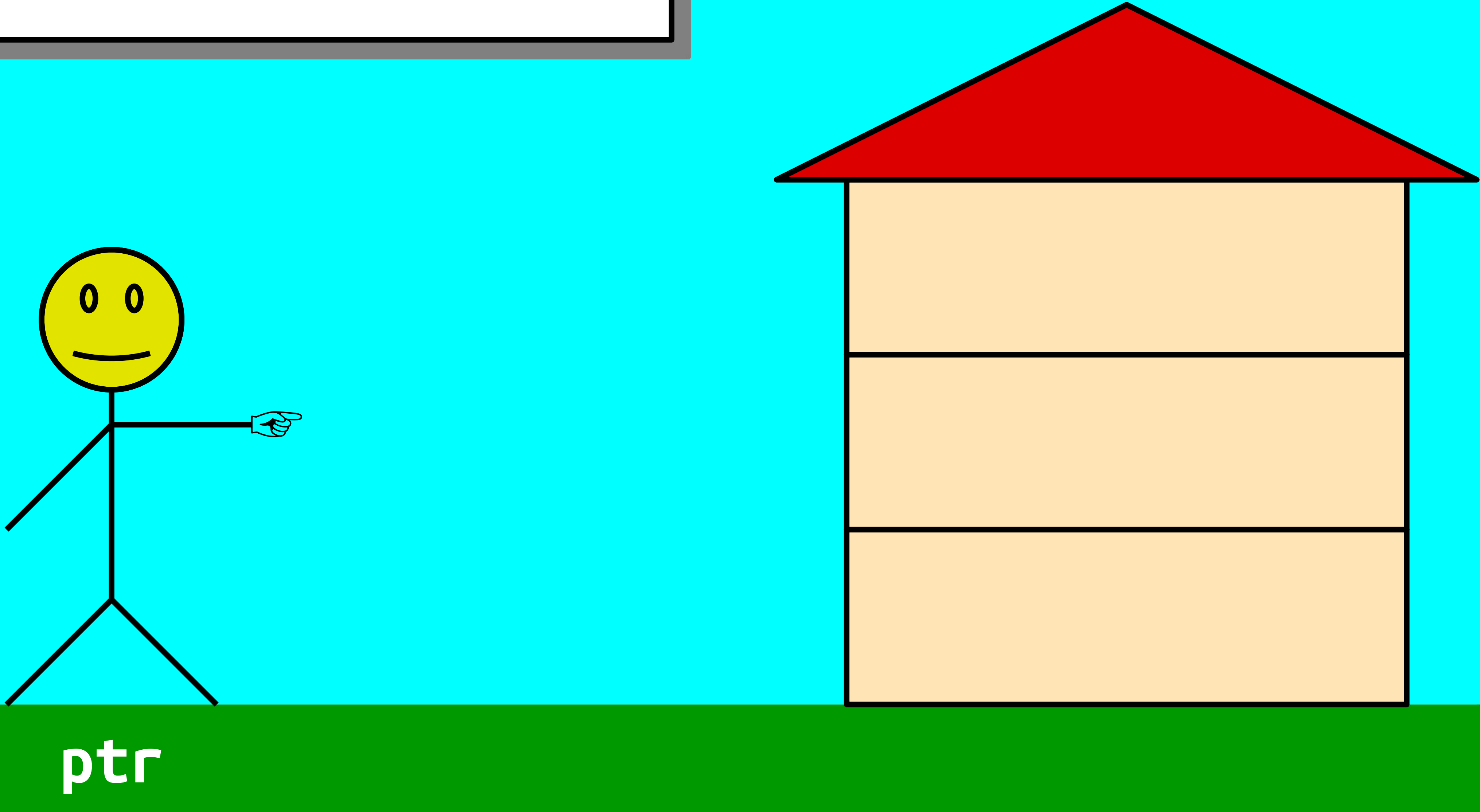
```
string* ptr = new string[3];
```



```
string* ptr = new string[3];
```



```
string* ptr = new string[3];
ptr[0] = "Coffee Shop";
ptr[1] = "Office Space";
ptr[2] = "Residential";
```



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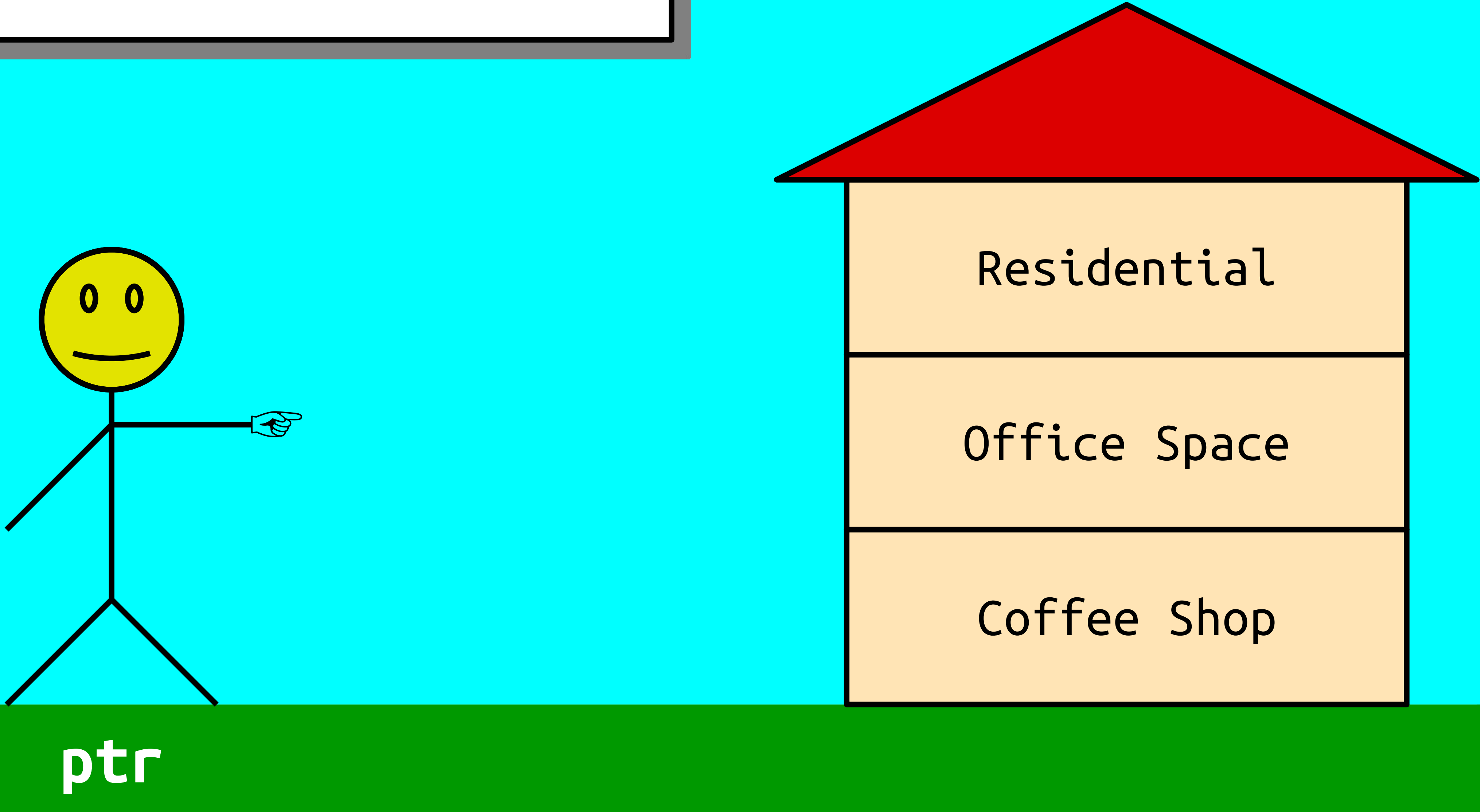
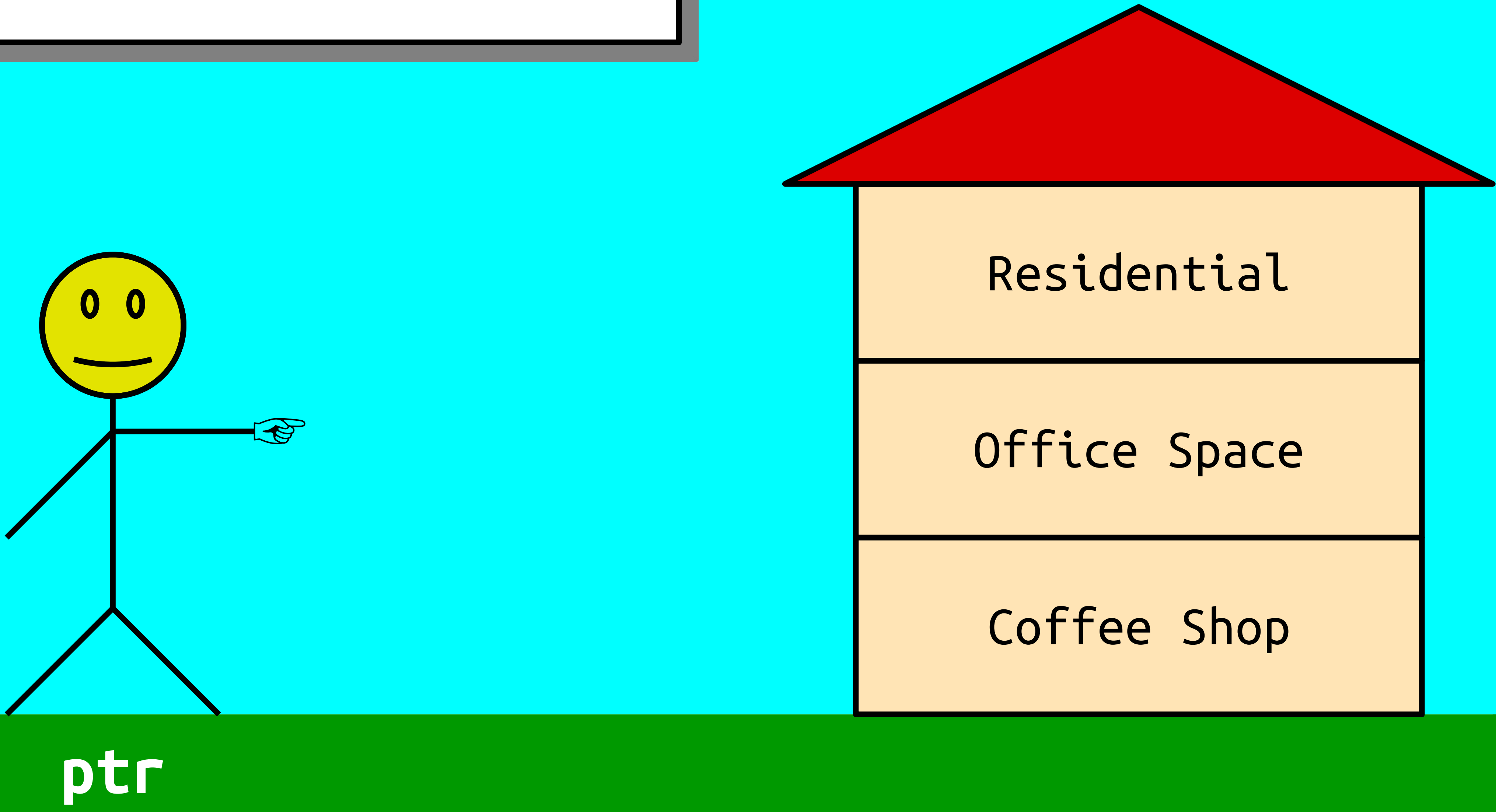


```
string* ptr = new string[3];
ptr[0] = "Coffee Shop";
ptr[1] = "Office Space";
ptr[2] = "Residential";

delete[] ptr;
```



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ptr[0] = "Coffee Shop";
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delete[] ptr;
```

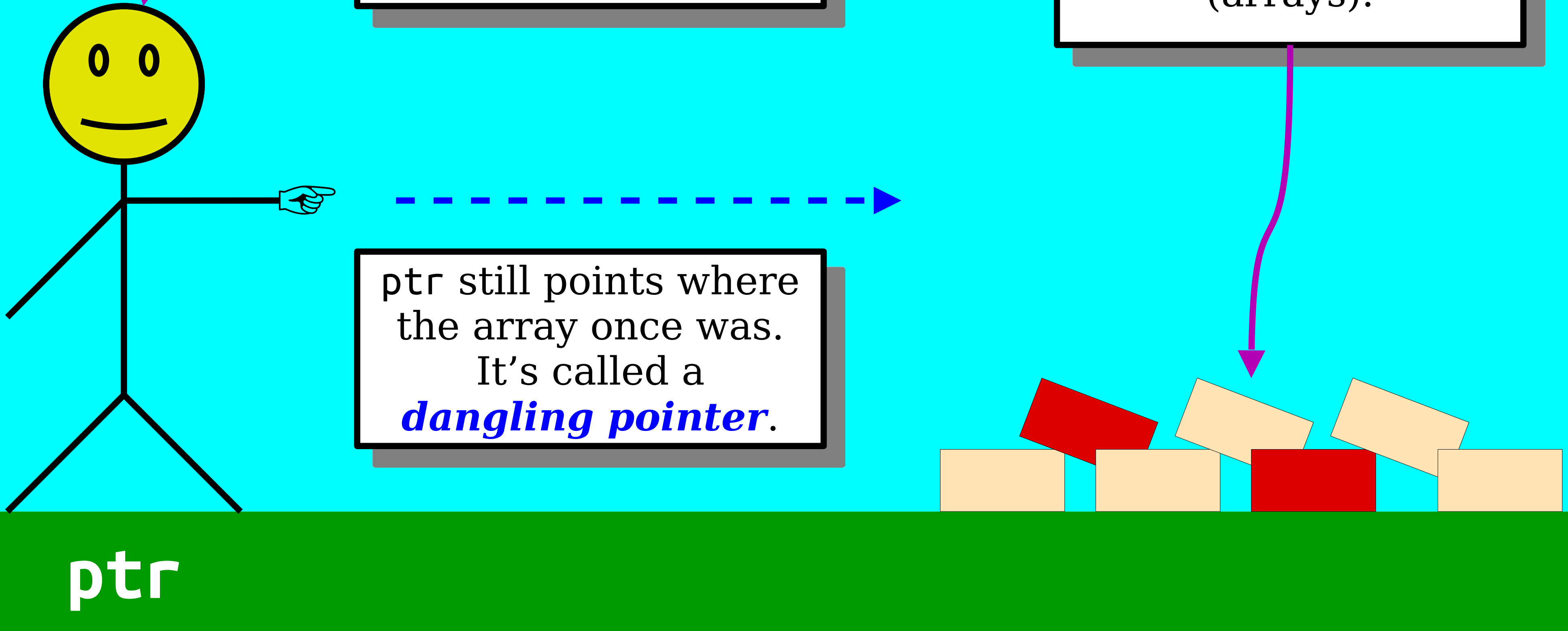
```
string* ptr = new string[3];
ptr[0] = "Coffee Shop";
ptr[1] = "Office Space";
ptr[2] = "Residential";

delete[] ptr;
```

The variable `ptr` is still here. It will stick around until the function returns.

We've freed up space for future buildings (arrays).

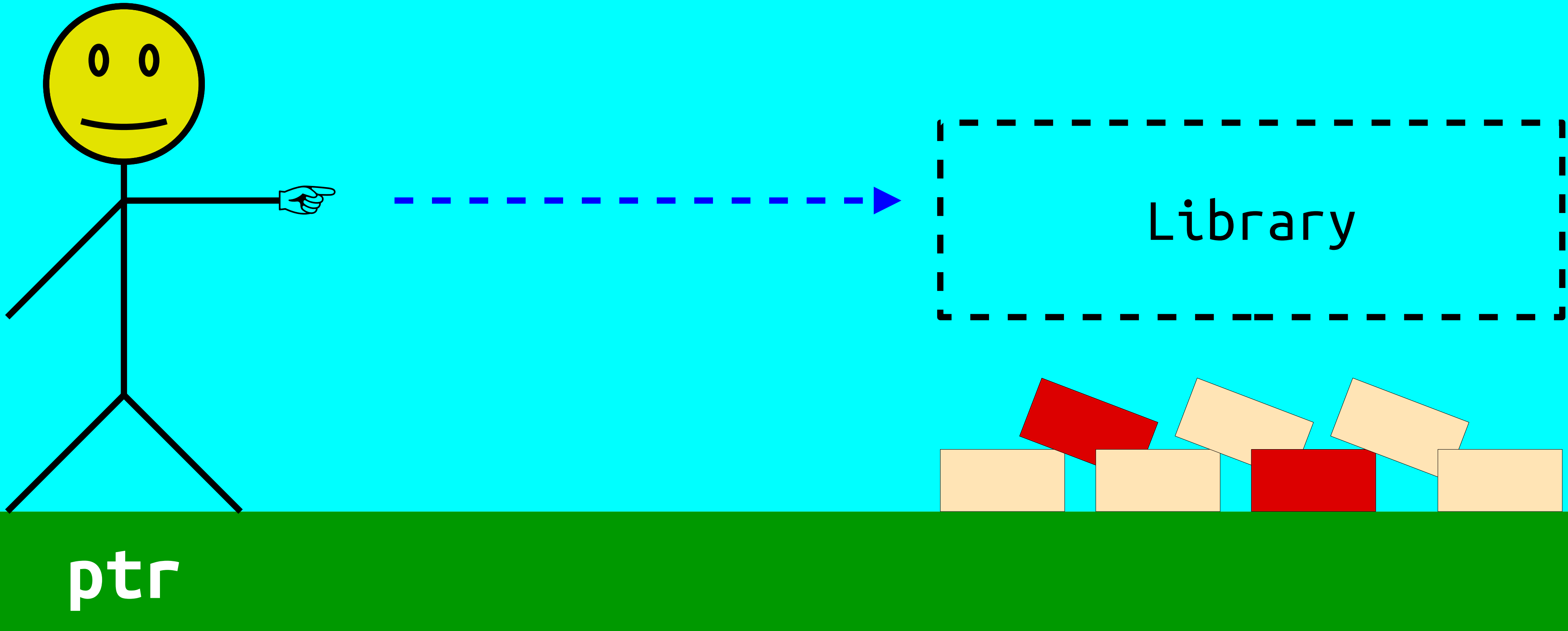
`ptr` still points where the array once was. It's called a ***dangling pointer***.



```
string* ptr = new string[3];
ptr[0] = "Coffee Shop";
ptr[1] = "Office Space";
ptr[2] = "Residential";

delete[] ptr;
ptr[1] = "Library"; // Uh…
```

C++ has no safety checks for reading/writing deallocated memory. It might crash your program, it might do nothing, or might corrupt data.



To Summarize

- Pointers point. Arrays hold things. ***There are two partners in the dance***.
- You can create arrays of a fixed size at runtime by using `new[]`.
- C++ arrays don't know their lengths and have no bounds-checking. With great power comes great responsibility.
- You are responsible for freeing any memory you explicitly allocate by calling `delete[]`.
- Once you've deleted the memory pointed at by a pointer, you have a dangling pointer and shouldn't read or write from it.

Implementing `Stack`

Implementing `Stack`

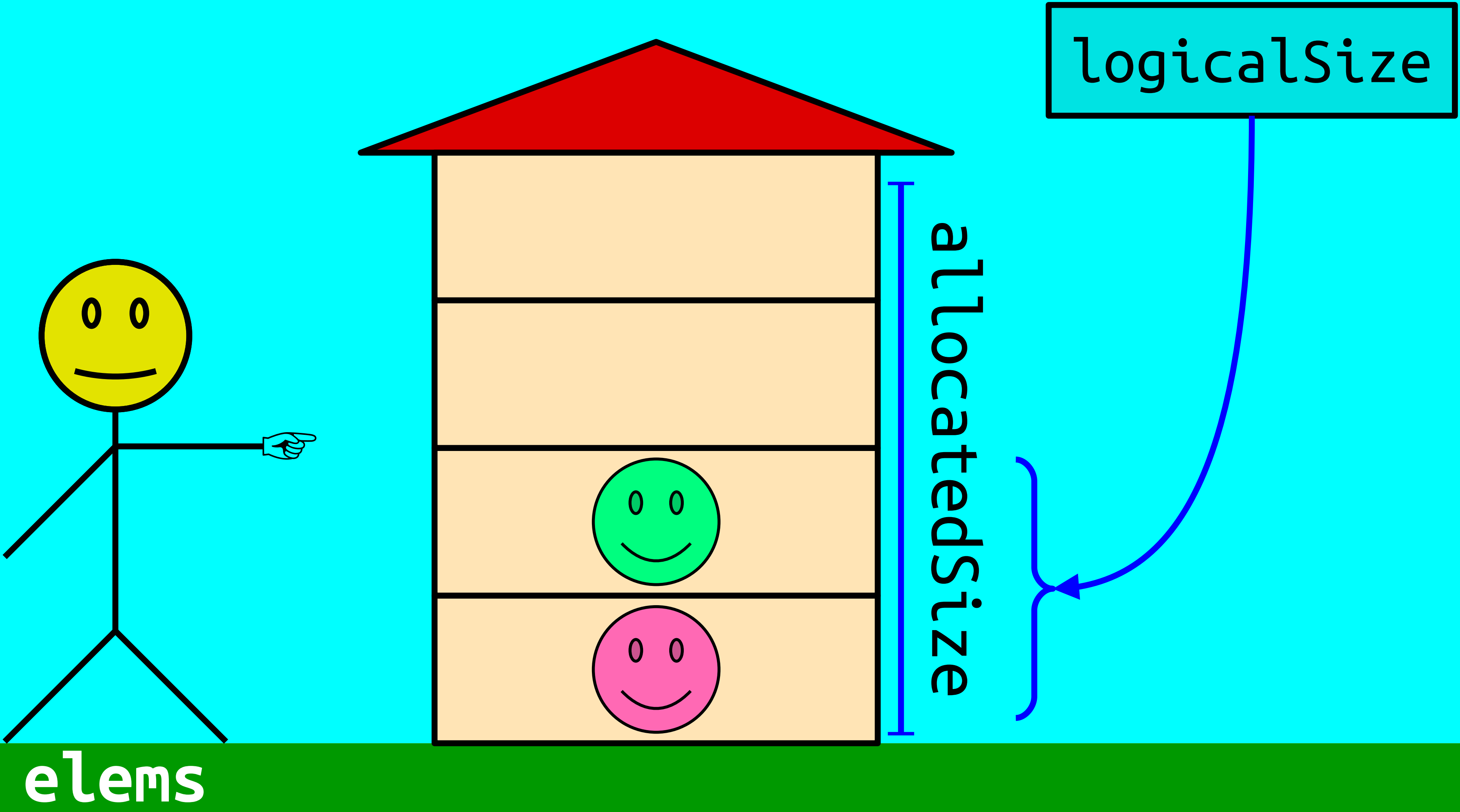
- Last time, we saw how to implement `RandomBag` in terms of `Vector`.
- We could also implement `Stack` in terms of `Vector`.
- What if we wanted to implement the `Stack` without relying on any other collections?
- Let's build the stack directly!

You Gotta Start Somewhere

- Our initial implementation of the stack will be a *bounded* stack with a maximum capacity.
- We’ll allocate a fixed amount of storage space for the elements, then write them into the array as they’re pushed.
- If we run out of space, we’ll report an error.
- Next time, we’ll update this code so that we can have a stack without any fixed maximum capacity.

What We Have

```
private:
    int* elems;
    int  allocatedSize;
    int  logicalSize;
```



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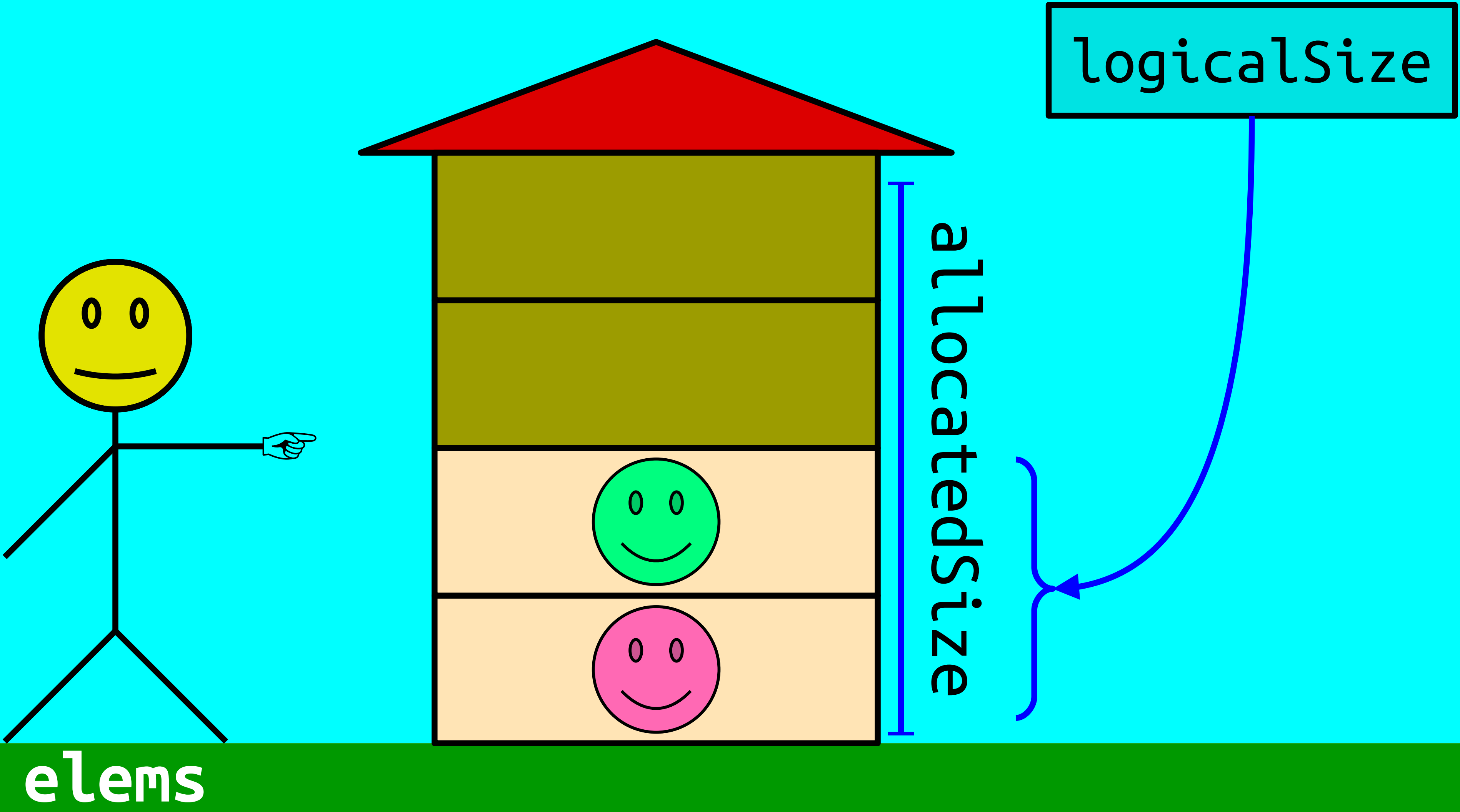

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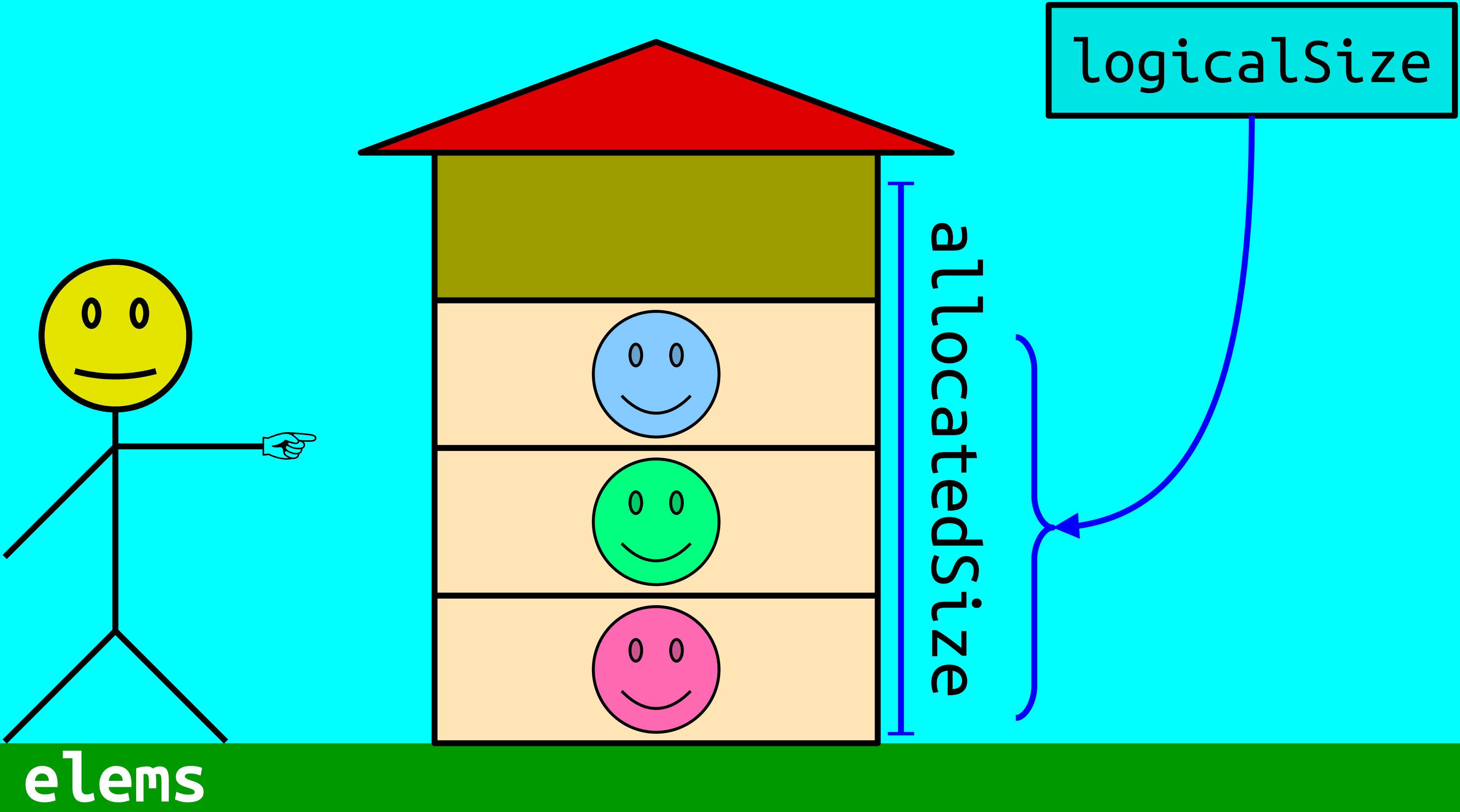

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private:
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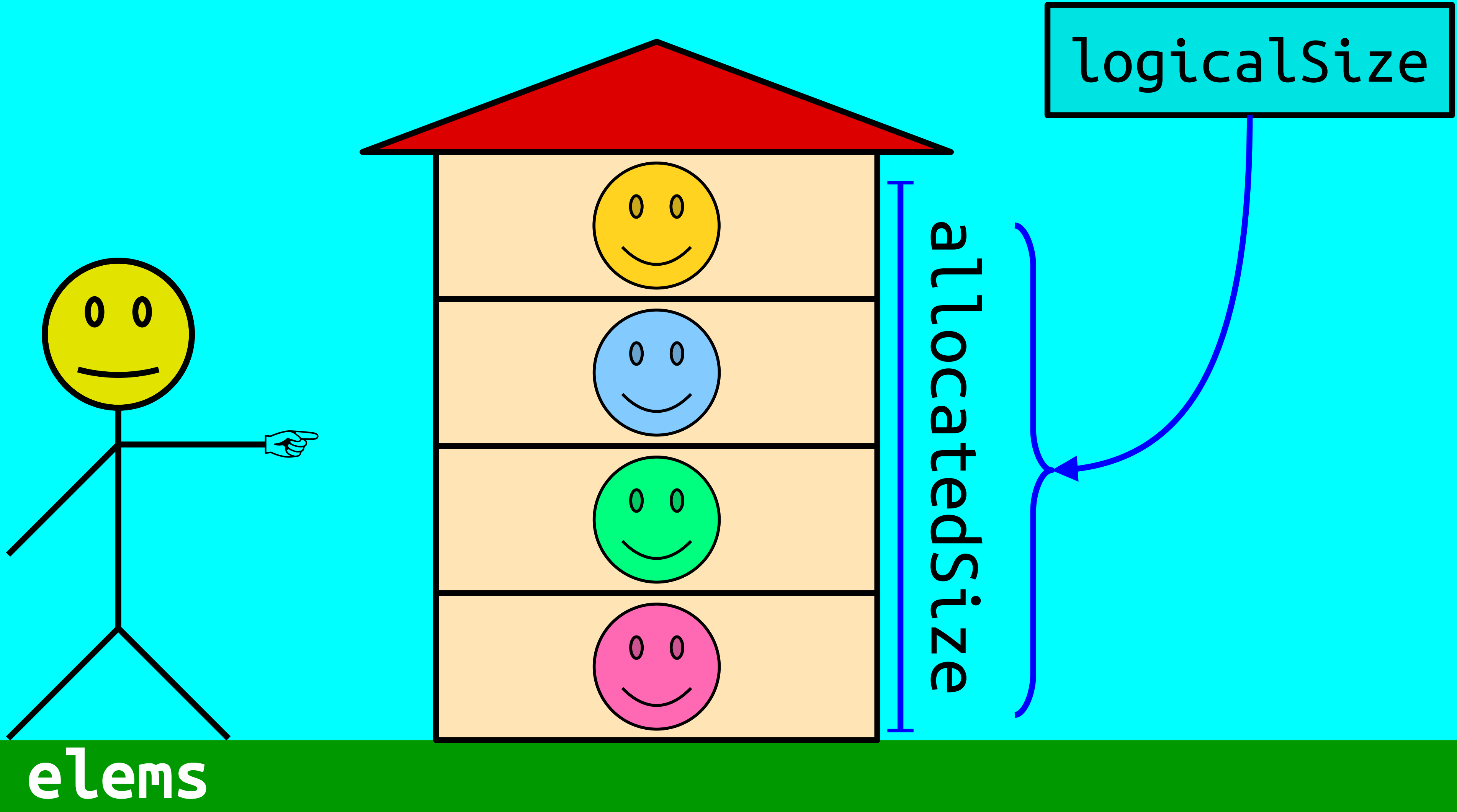

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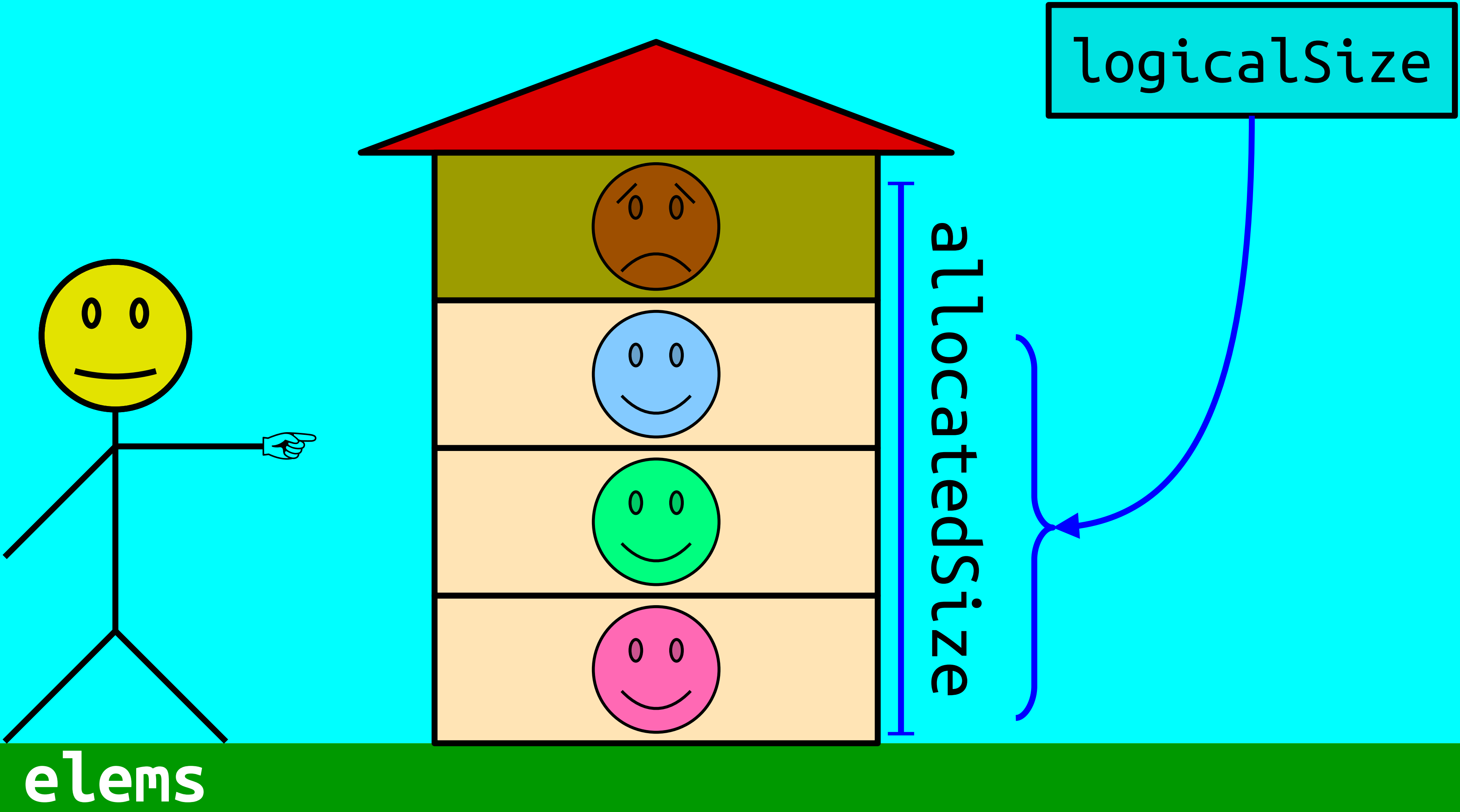

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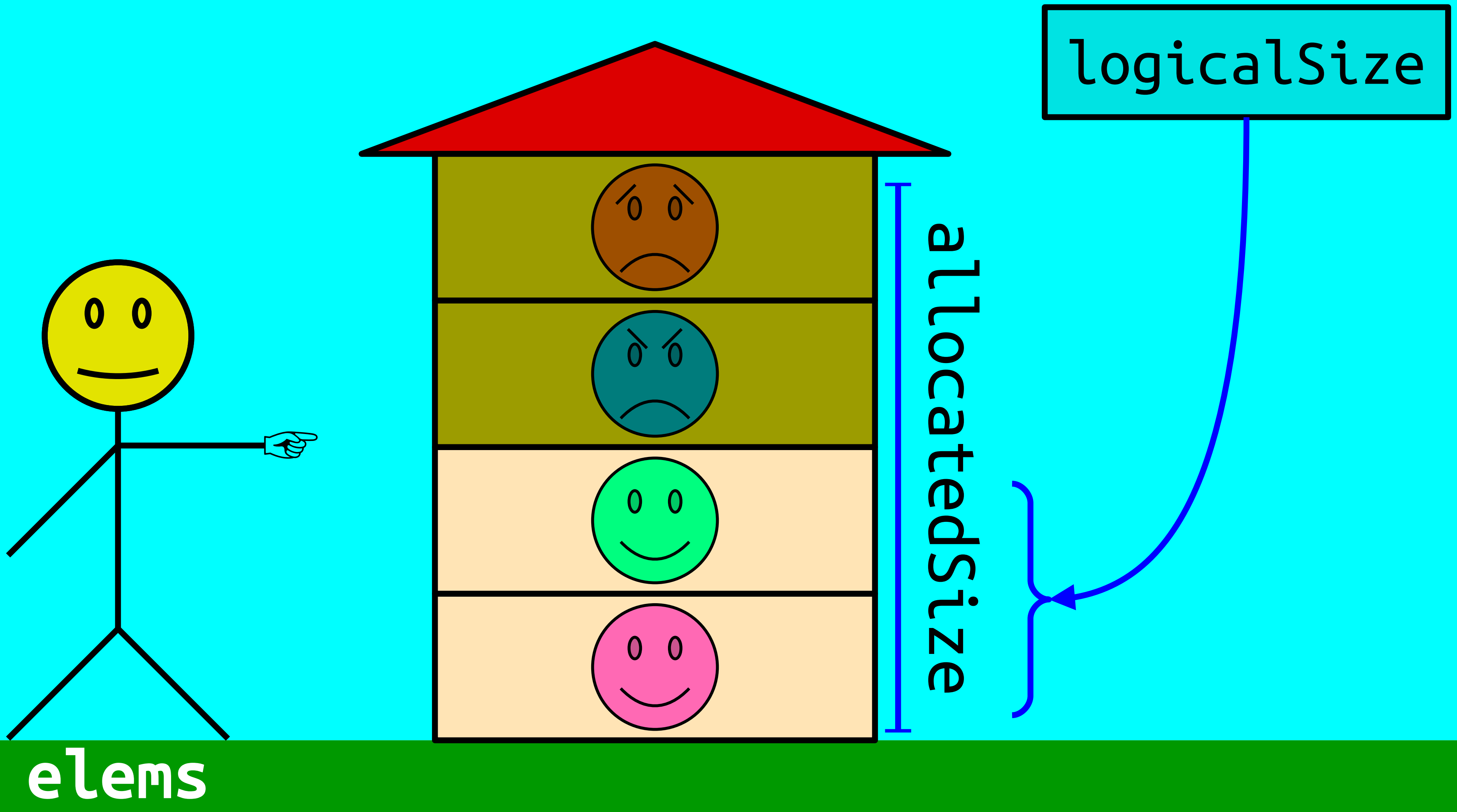

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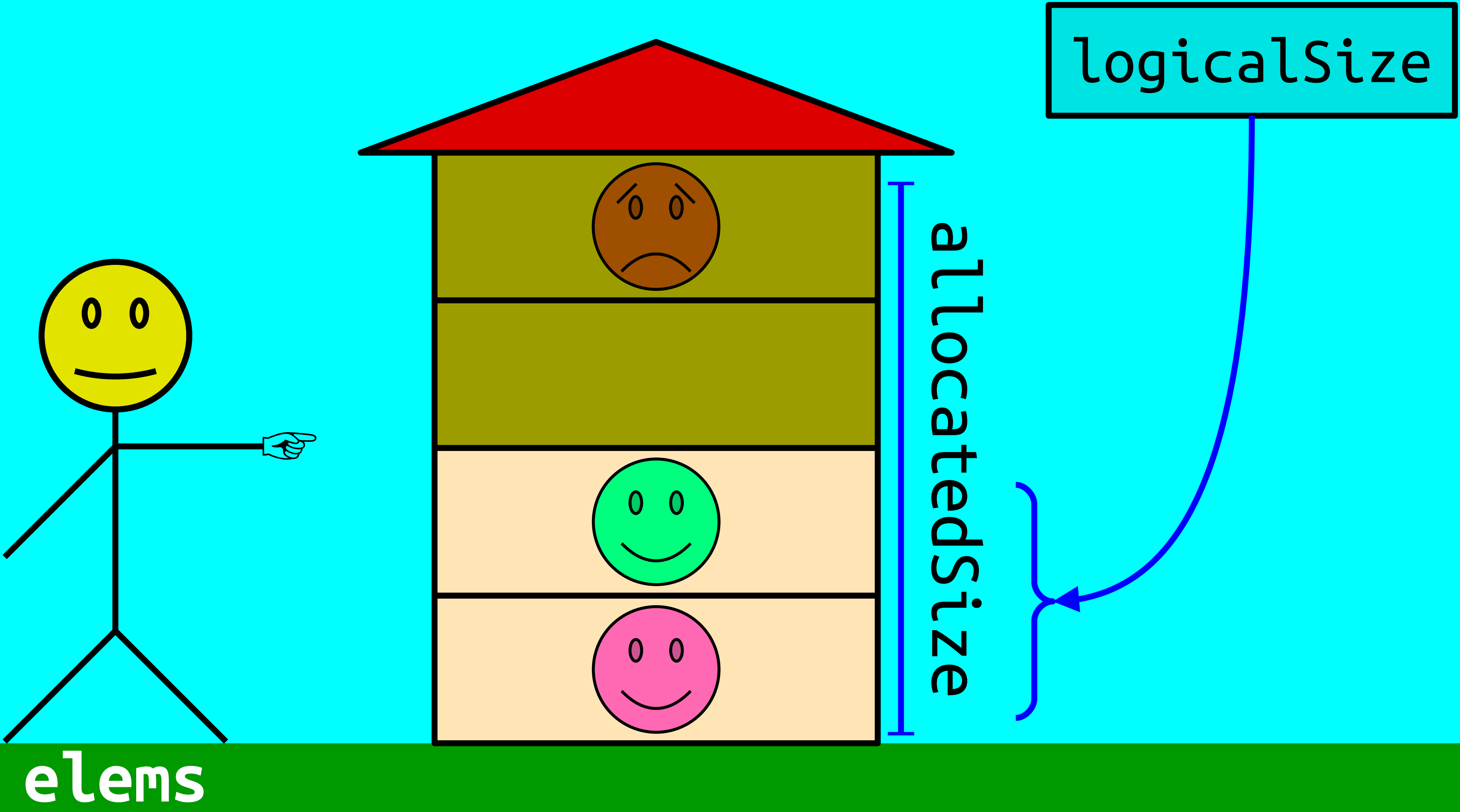
```



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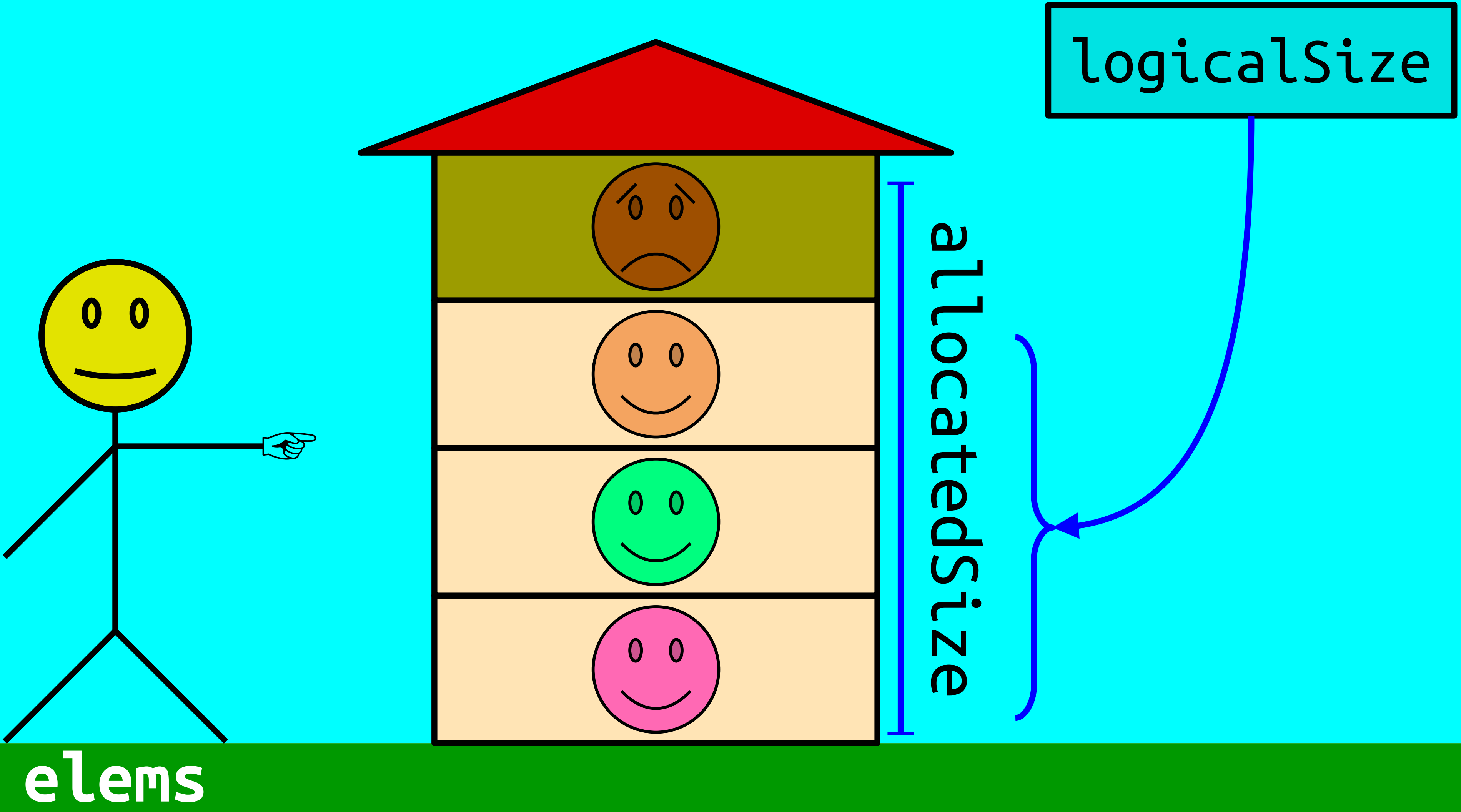

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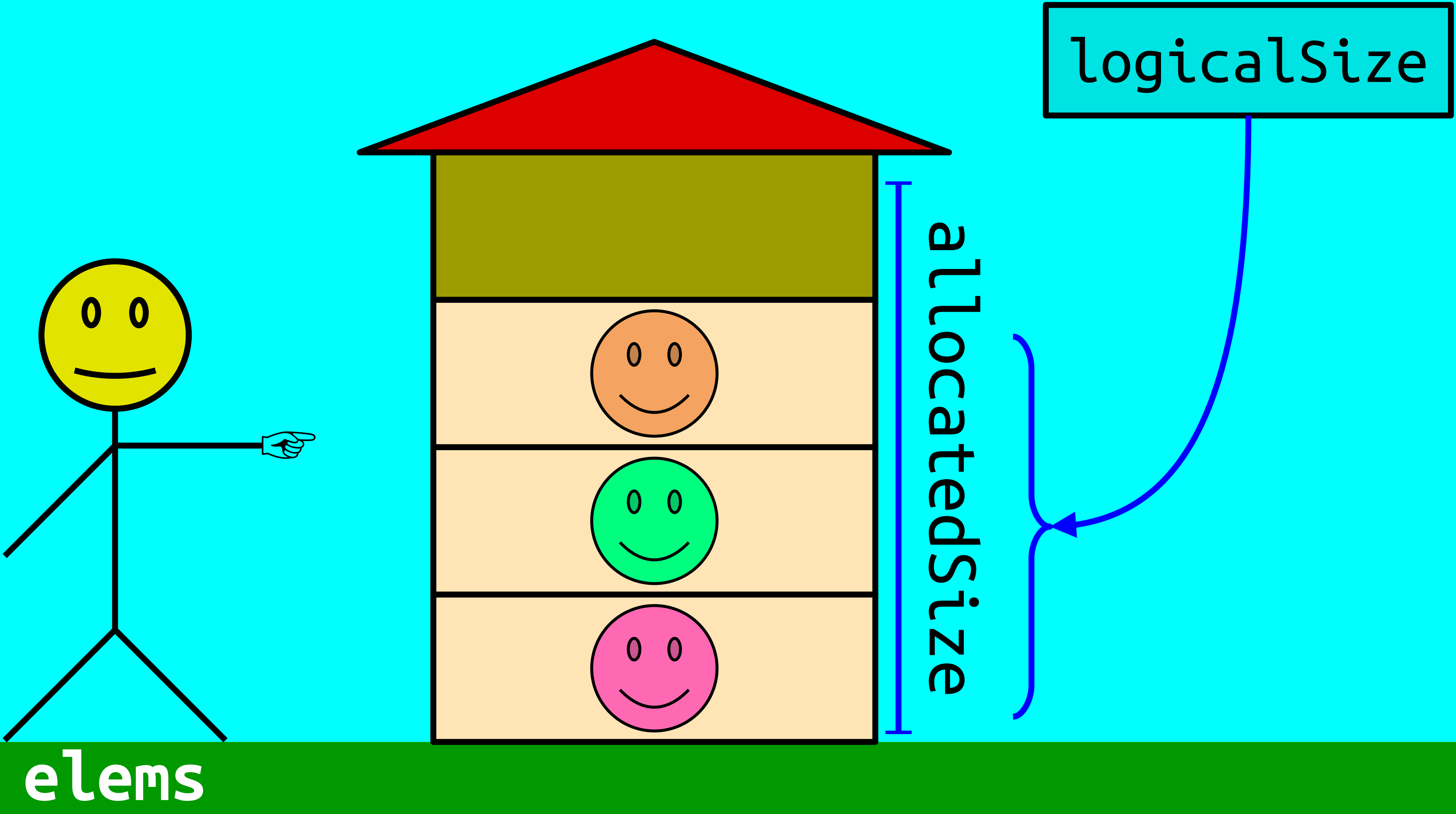

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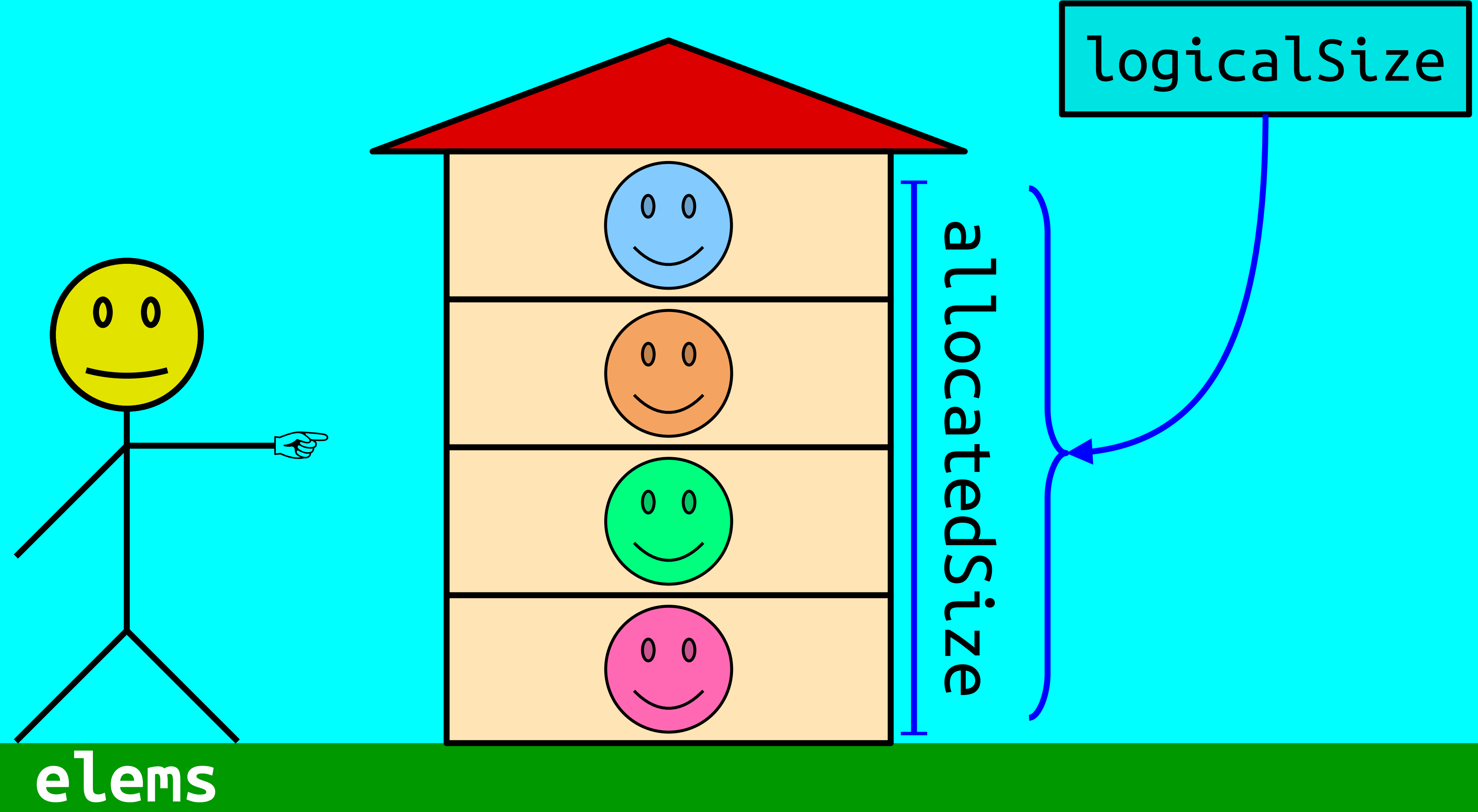

Before We Start: A Problem

Cradle to Grave

```
int main() {
    OurStack stack;

    /* The stack lives a rich, happy,
     * fulfilling life, the kind we
     * all aspire to.
     */

    return 0;
}
```

Cradle to Grave

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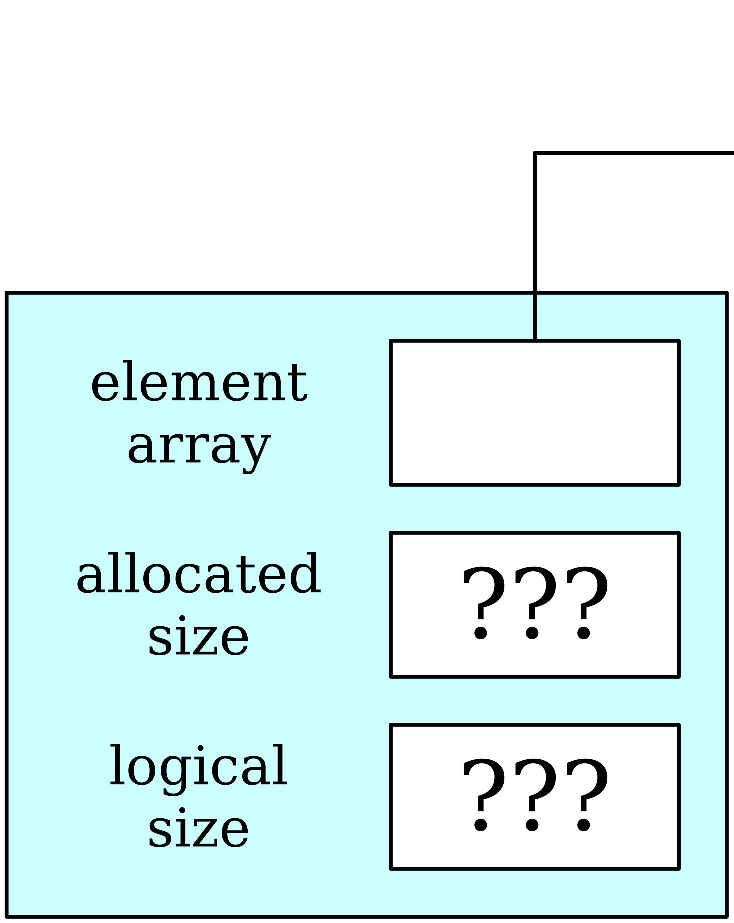
Cradle to Grave



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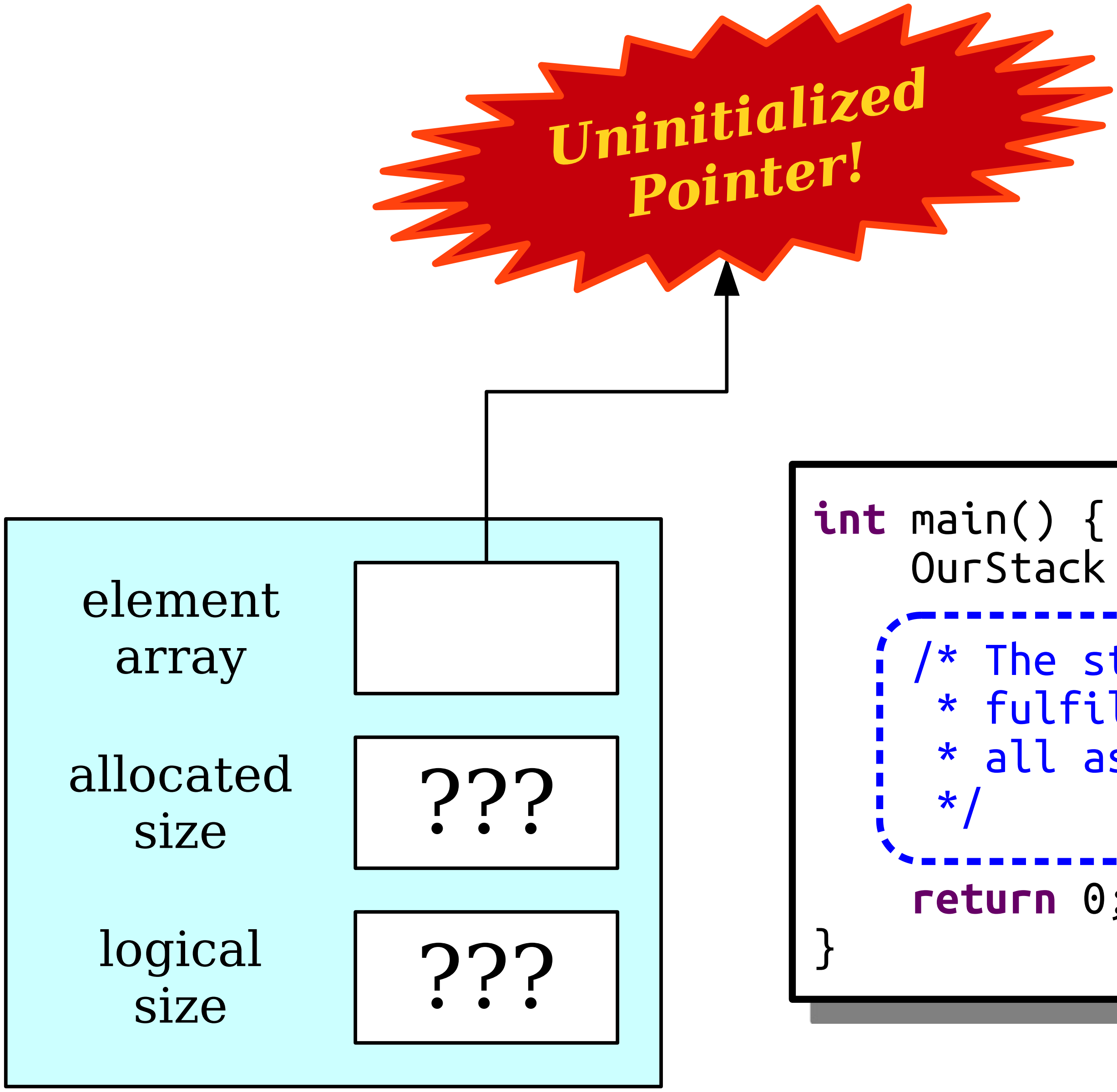
Cradle to Grave



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    OurStack stack;

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    return 0;
}
```

Constructors

- A ***constructor*** is a special member function used to set up the class before it is used.
- The constructor is automatically called when the object is created.
- The constructor for a class named ***ClassName*** has signature

  ClassName(***args***);

```
class OurStack {
public:


    void push(int value);
    int  peek() const;
    int  pop();

    int  size() const;
    bool isEmpty() const;

private:
    int* elems;
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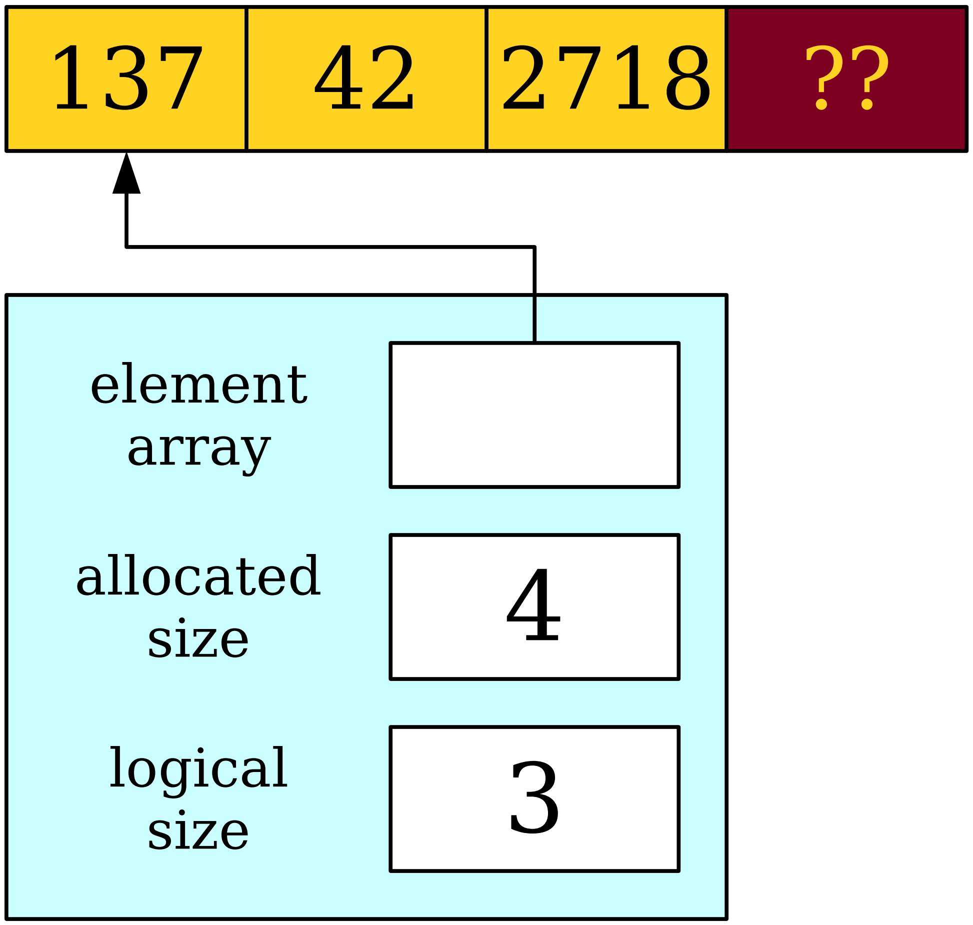
Implementing our Operations



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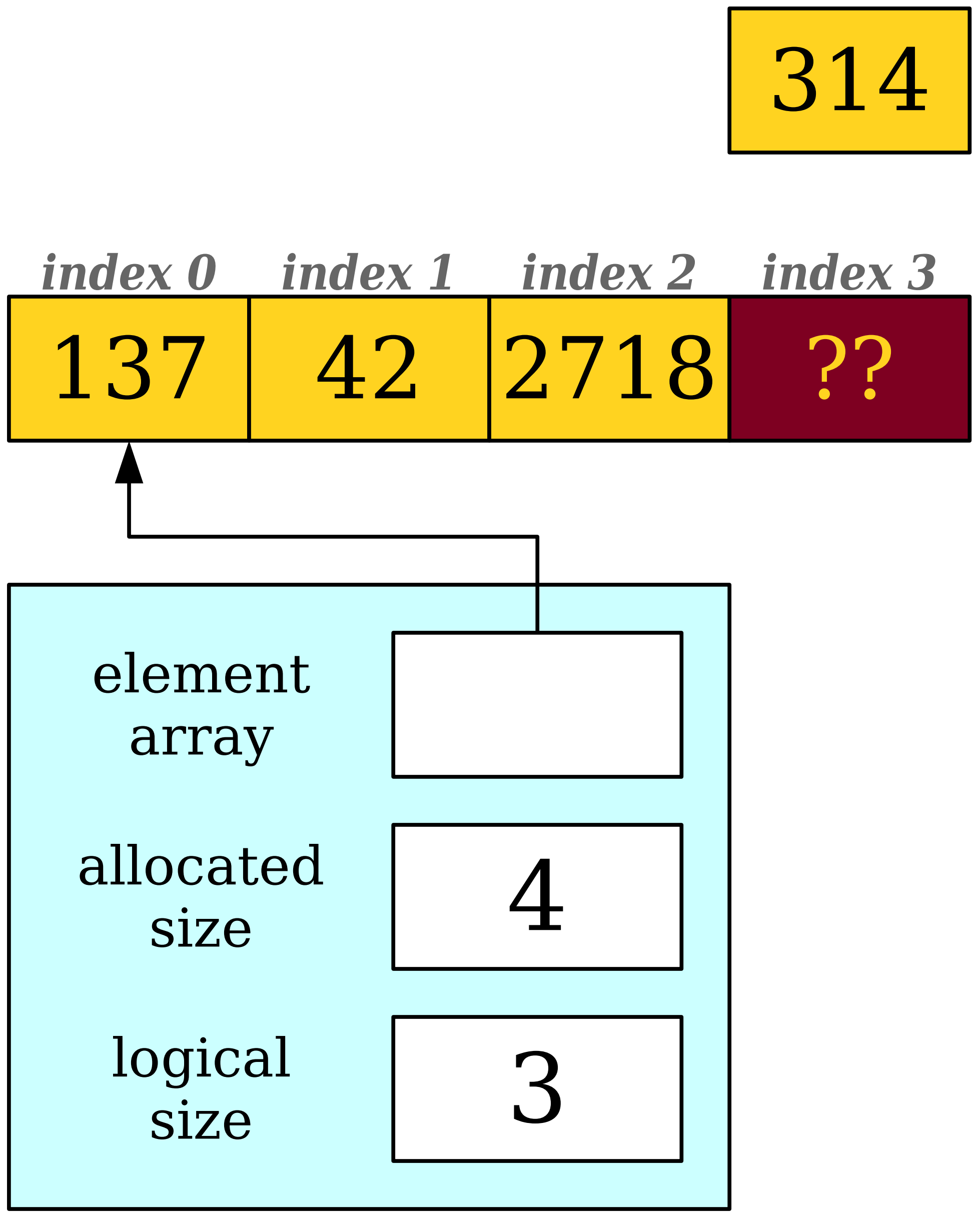

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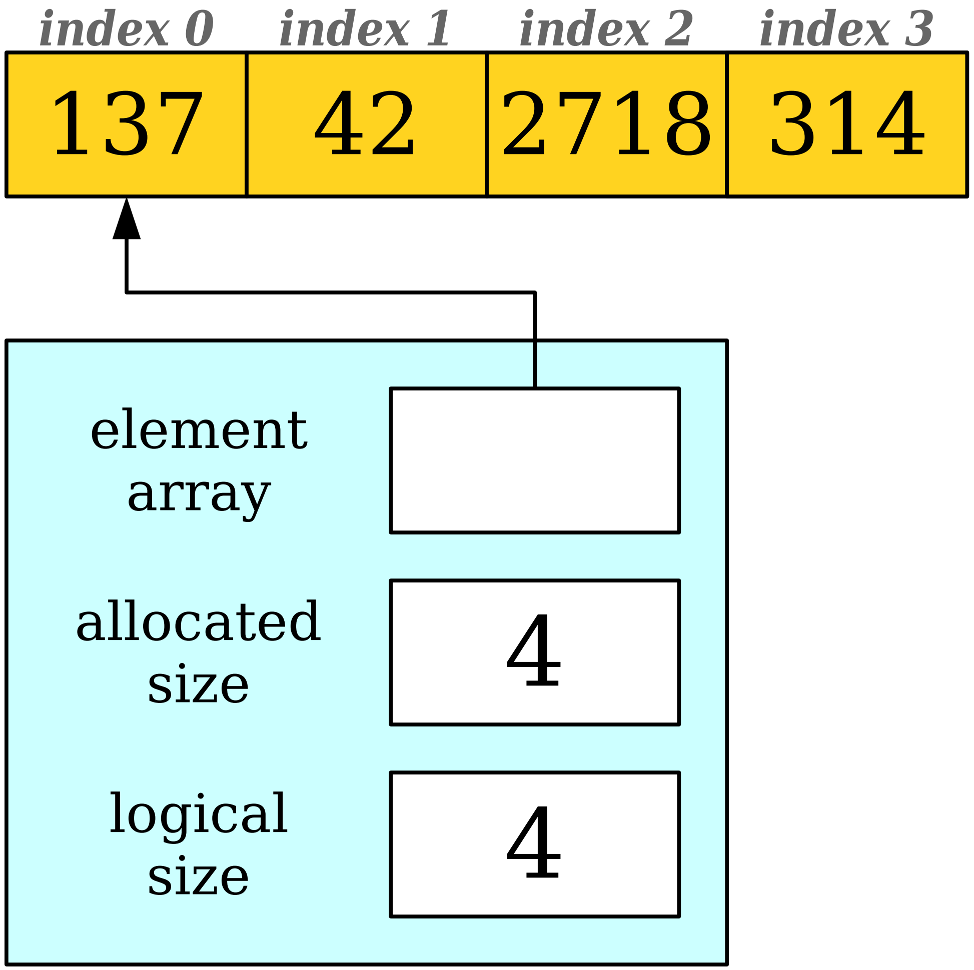

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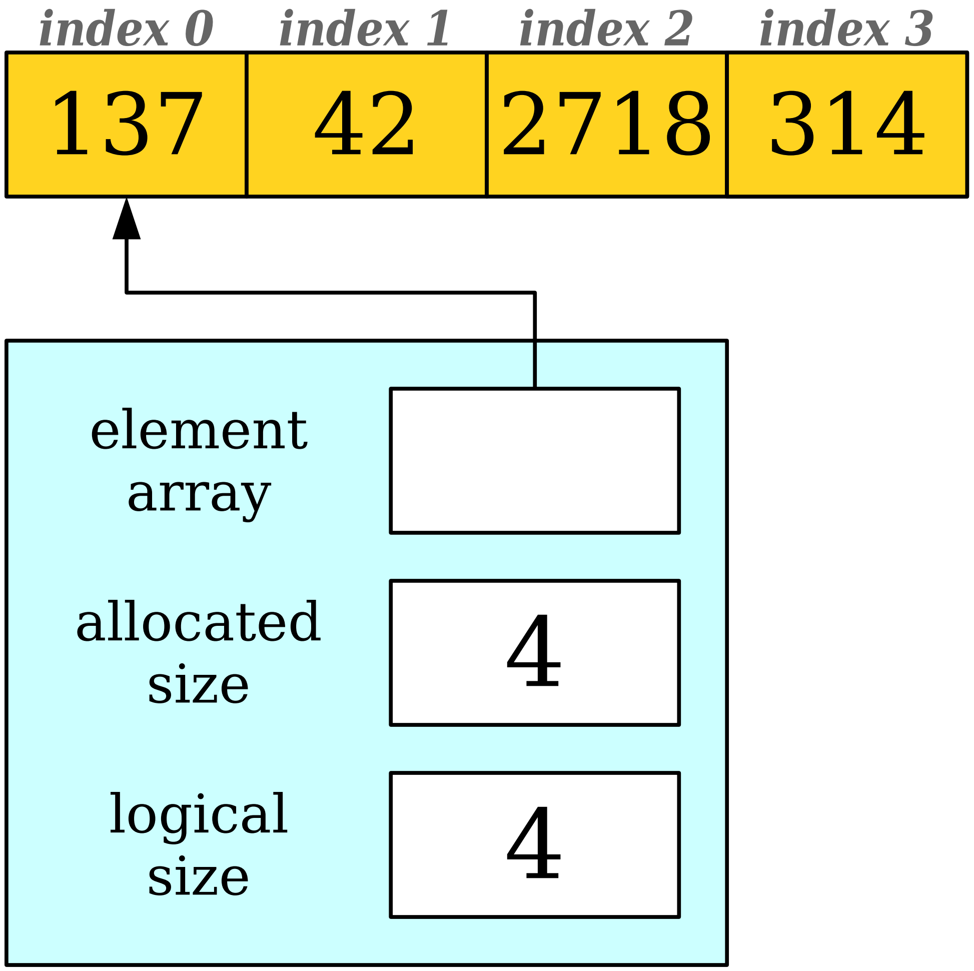

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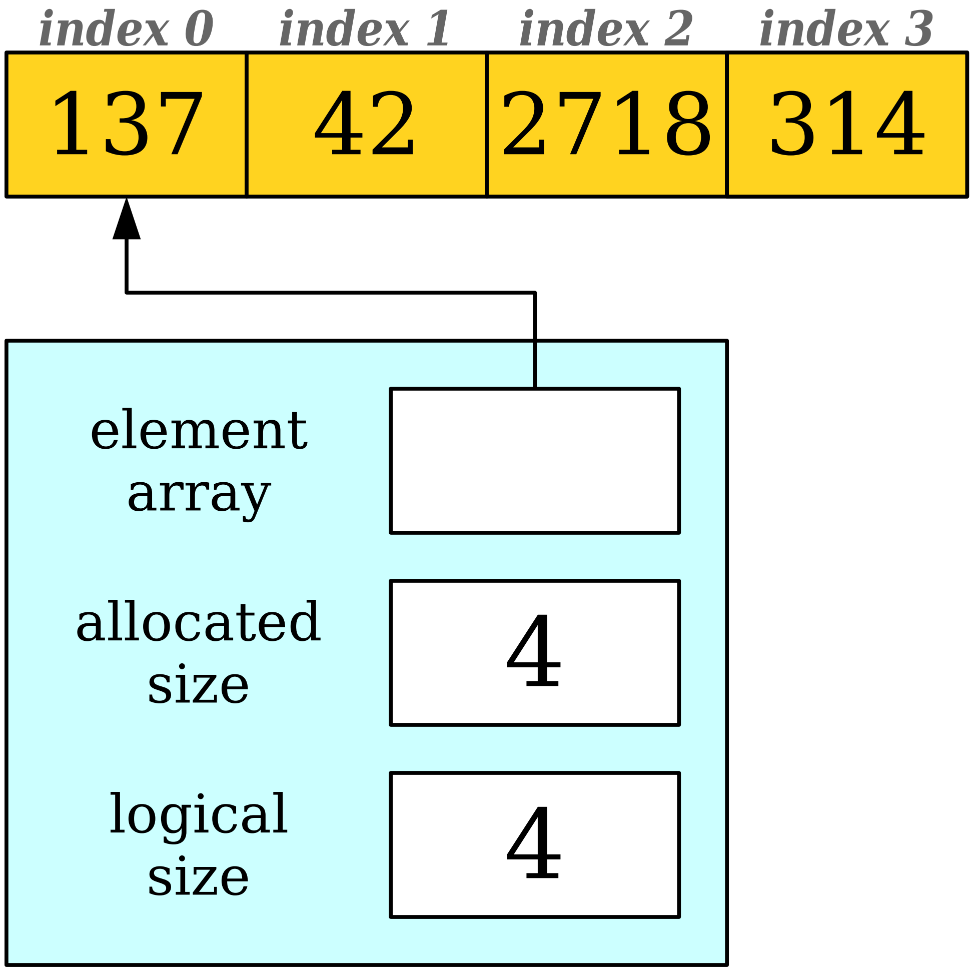

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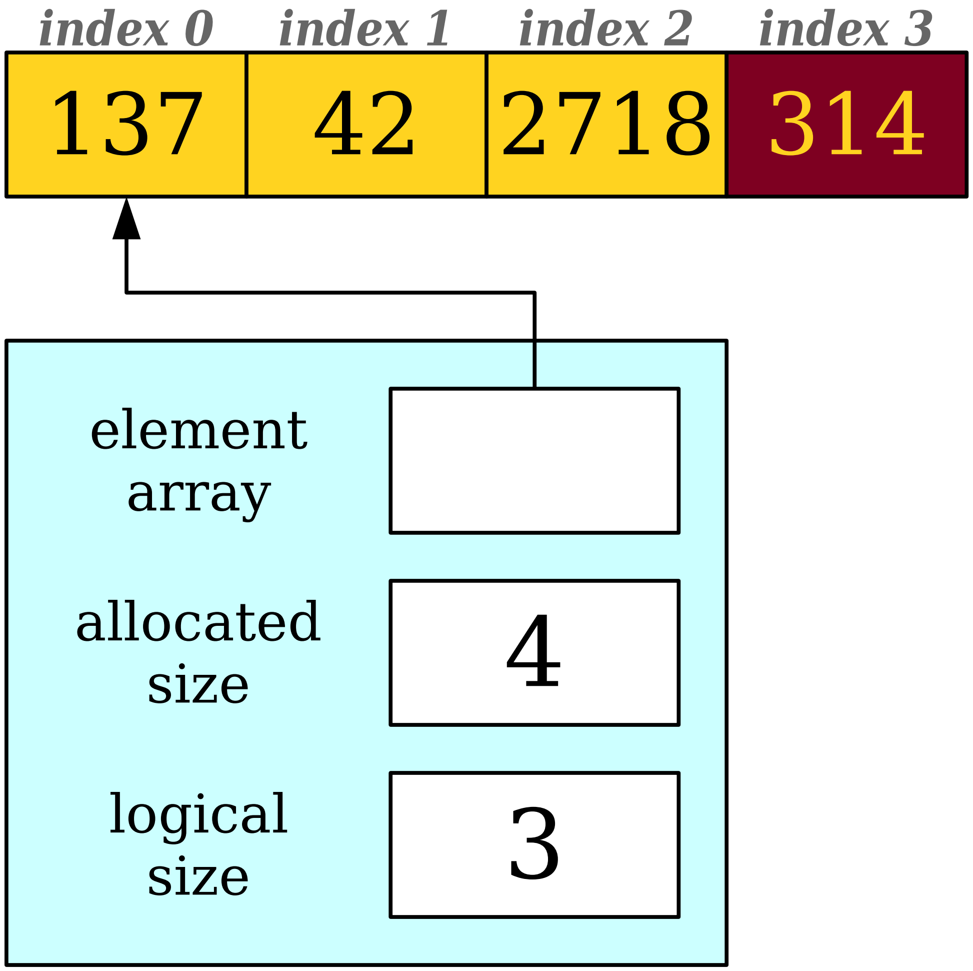

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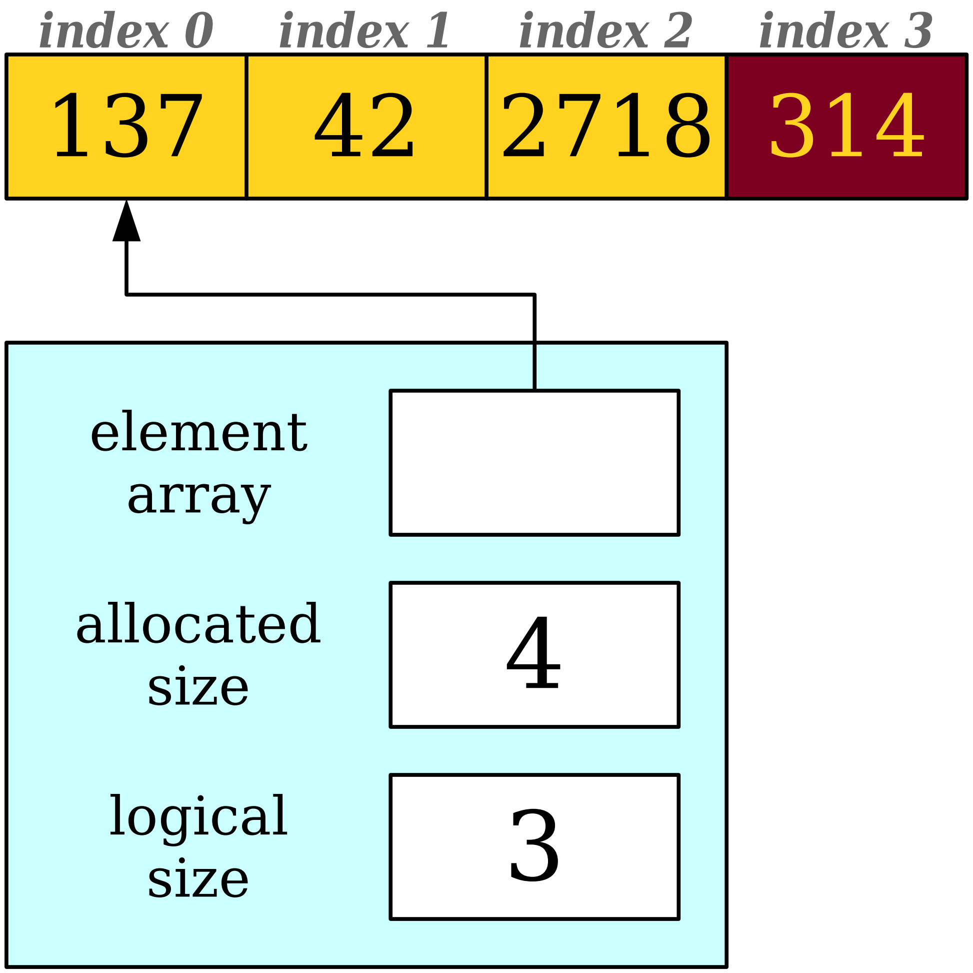

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private:
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    int  logicalSize;
};
```

So… we’re done?

Cradle to Grave, Take II

```
int main() {
    OurStack stack;

    /* The stack lives a rich, happy,
     * fulfilling life, the kind we
     * all aspire to.
     */

    return 0;
}
```

Cradle to Grave, Take II

```
int main() {
    OurStack stack;

    /* The stack lives a rich, happy,
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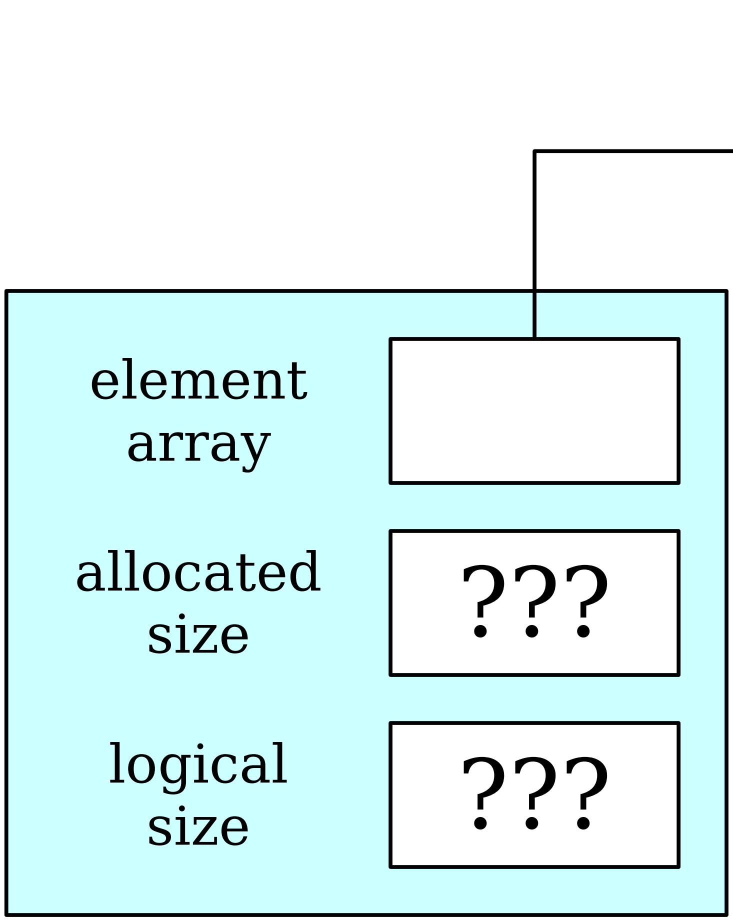
Cradle to Grave, Take II



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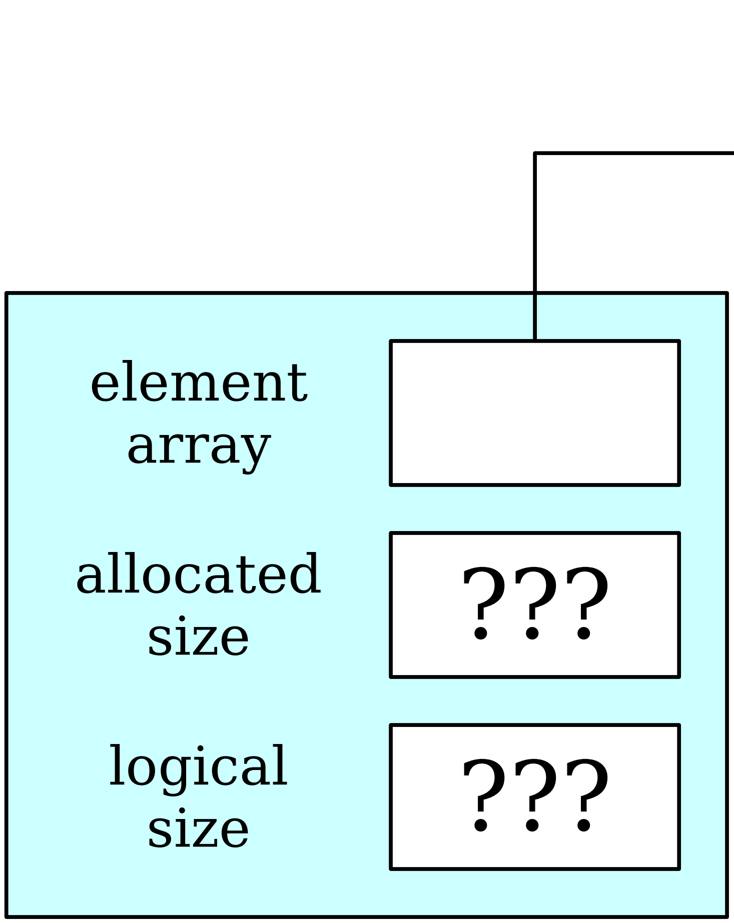
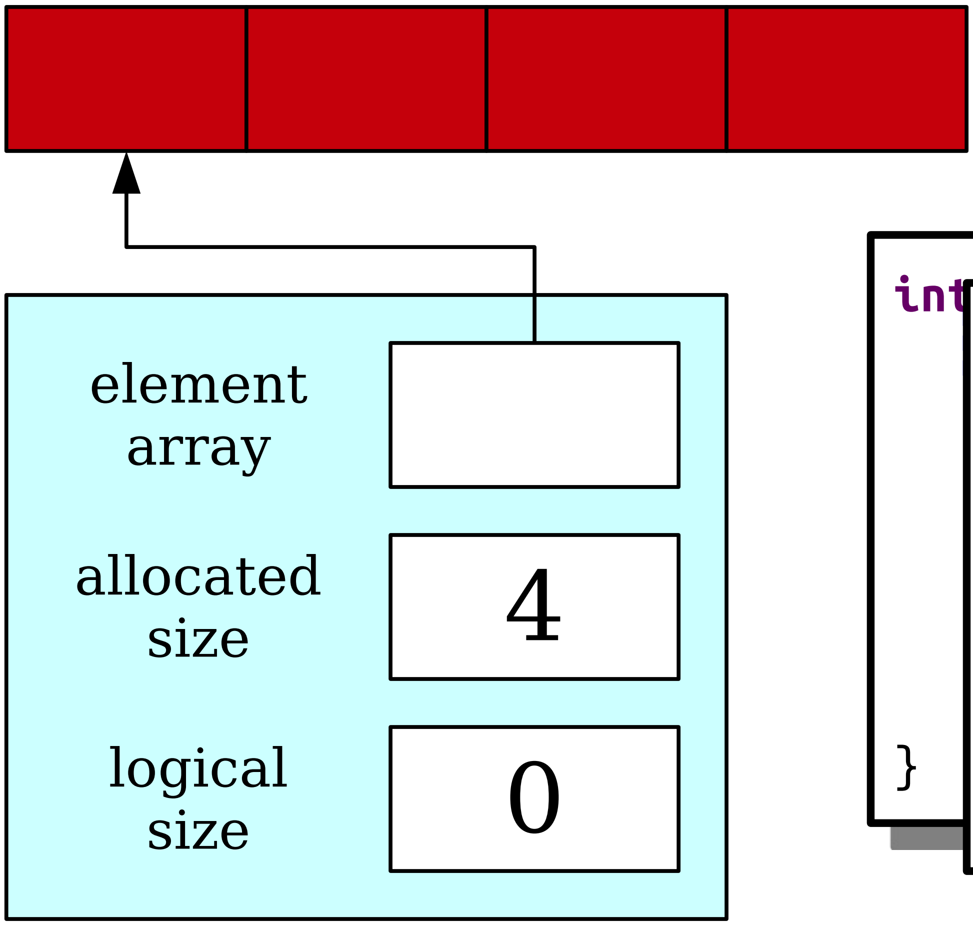
Cradle to Grave, Take II



```
int
}
```

```
OurStack::OurStack() {
    logicalSize = 0;
    allocatedSize = kInitialSize;
    elems = new int[allocatedSize];
}
```

Cradle to Grave, Take II



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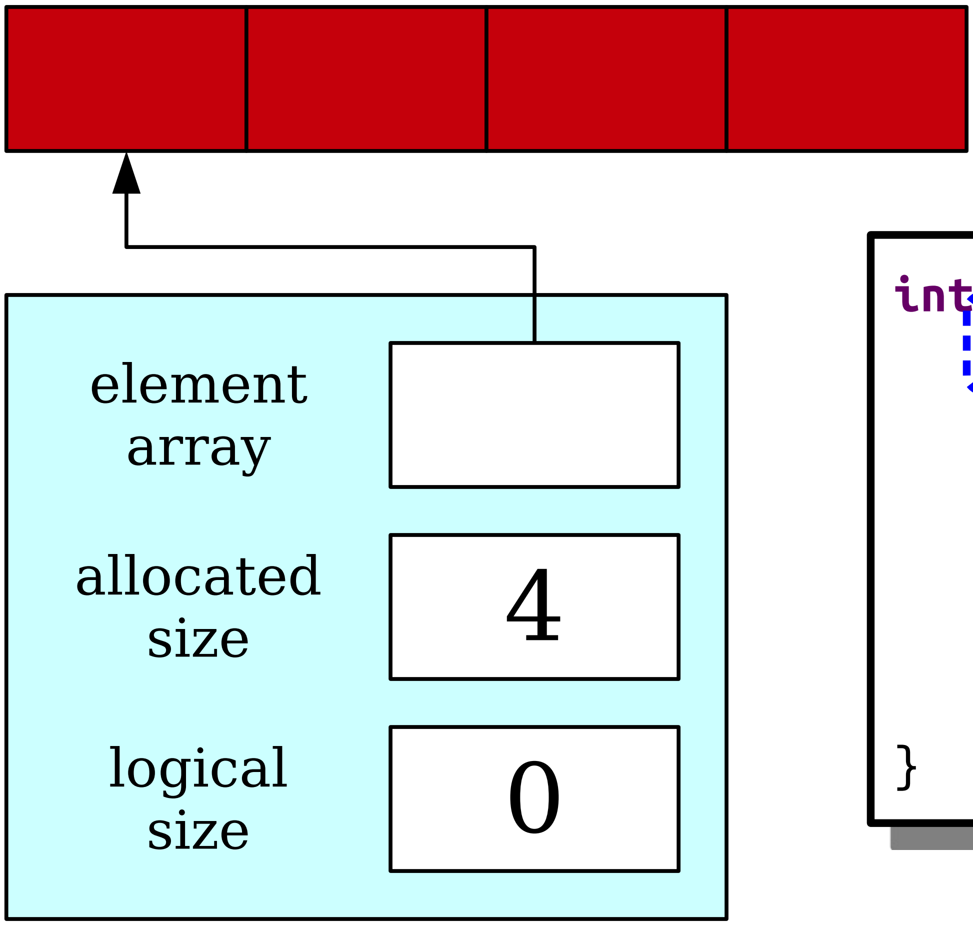

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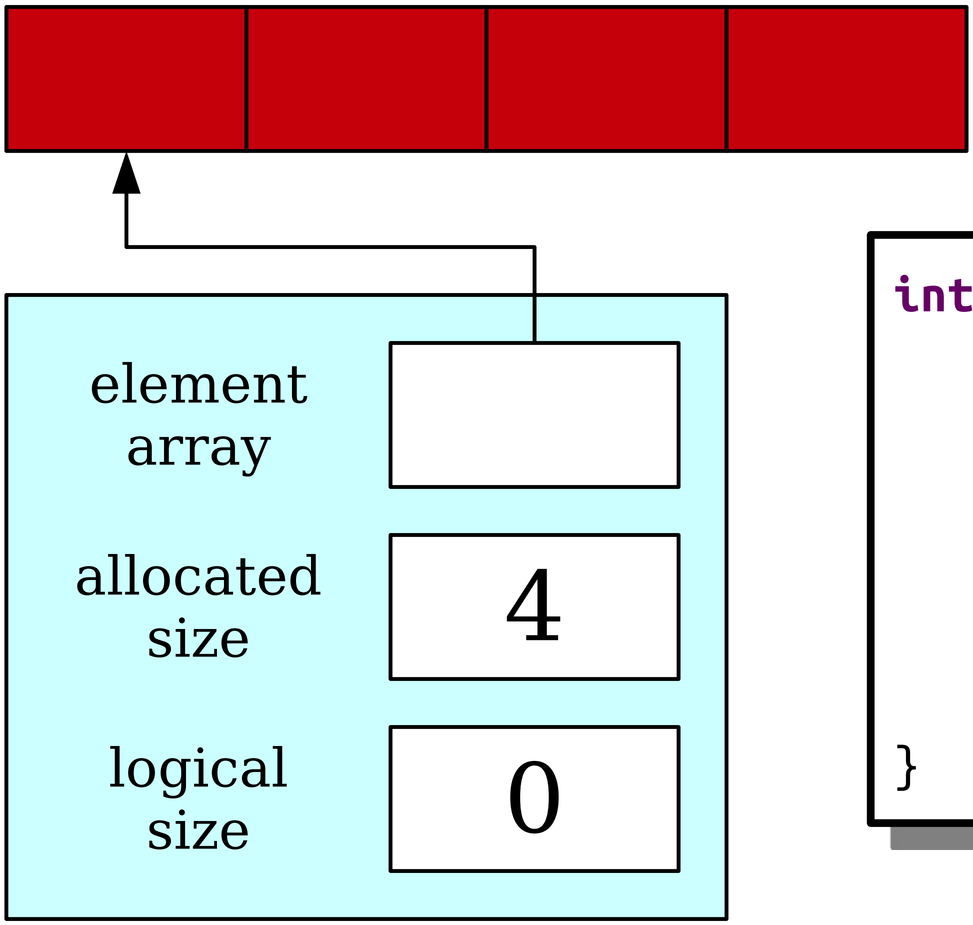

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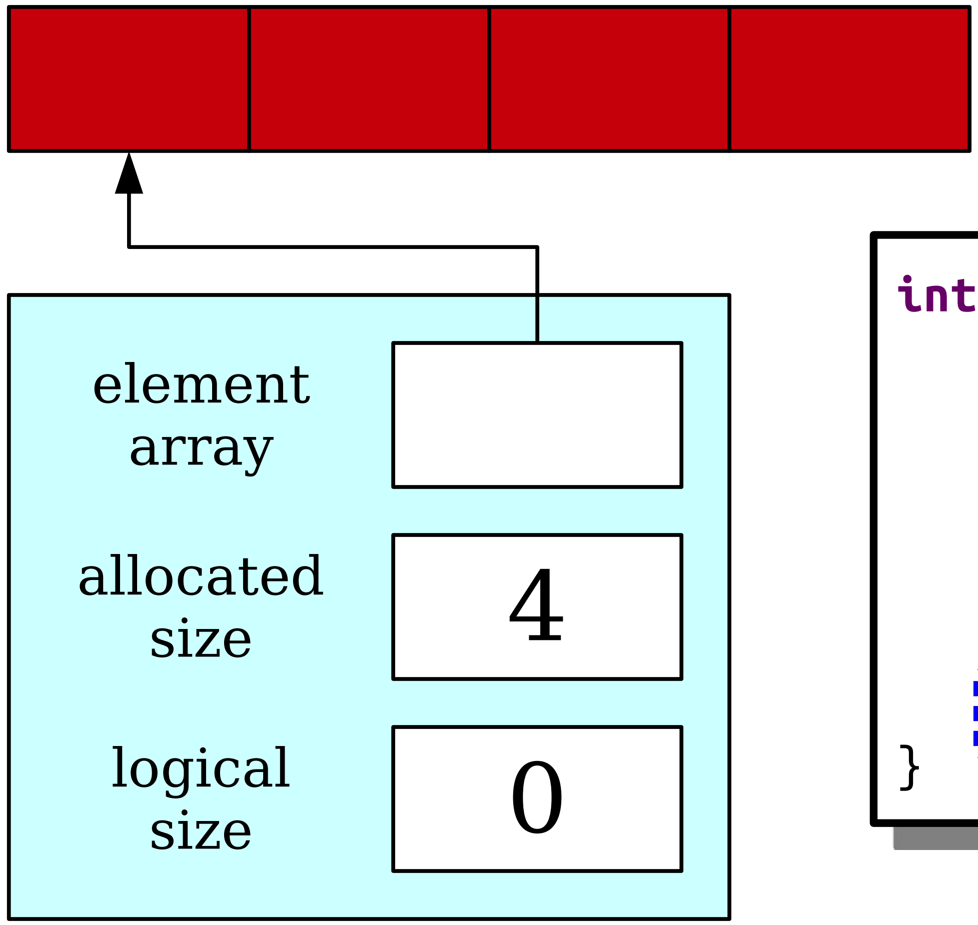

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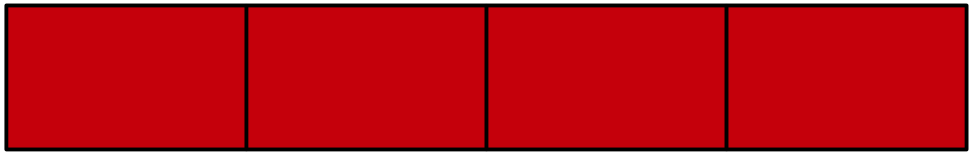

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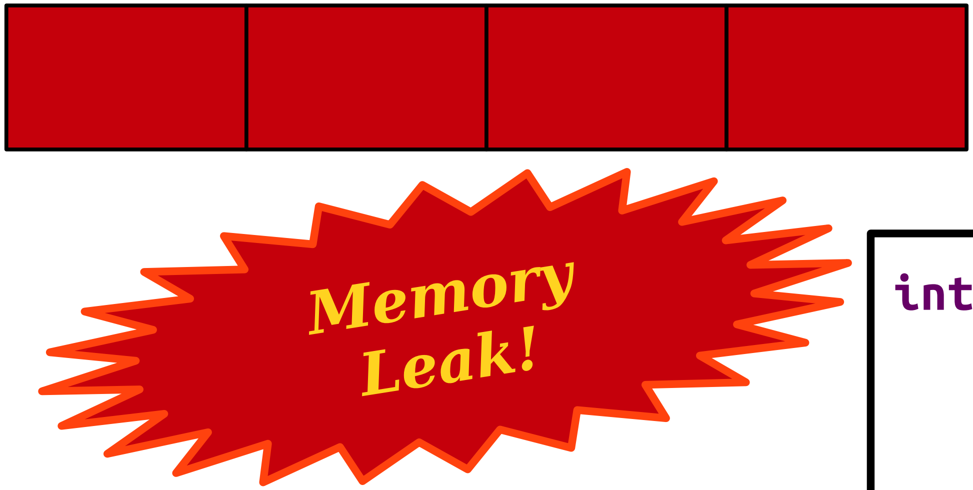
Cradle to Grave, Take II



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```

Destructors

- A ***destructor*** is a special member function responsible for cleaning up an object's memory.
- It’s automatically called whenever an object’s lifetime ends (for example, if it’s a local variable that goes out of scope.)
- The destructor for a class named ***ClassName*** has signature

  `~`***ClassName***`();`

```
class OurStack {
public:
    OurStack();


    void push(int value);
    int  peek() const;
    int  pop();

    int  size() const;
    bool isEmpty() const;

private:
    int* elems;
    int  allocatedSize;
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  ~***ClassName***();

```
class OurStack {
public:
    OurStack();
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    int  peek() const;
    int  pop();

    int  size() const;
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Cradle to Grave, Take III

```
int main() {
    OurStack stack;

    /* The stack lives a rich, happy,
     * fulfilling life, the kind we
     * all aspire to.
     */

    return 0;
}
```

Cradle to Grave, Take III

```
int main() {
    OurStack stack;

    /* The stack lives a rich, happy,
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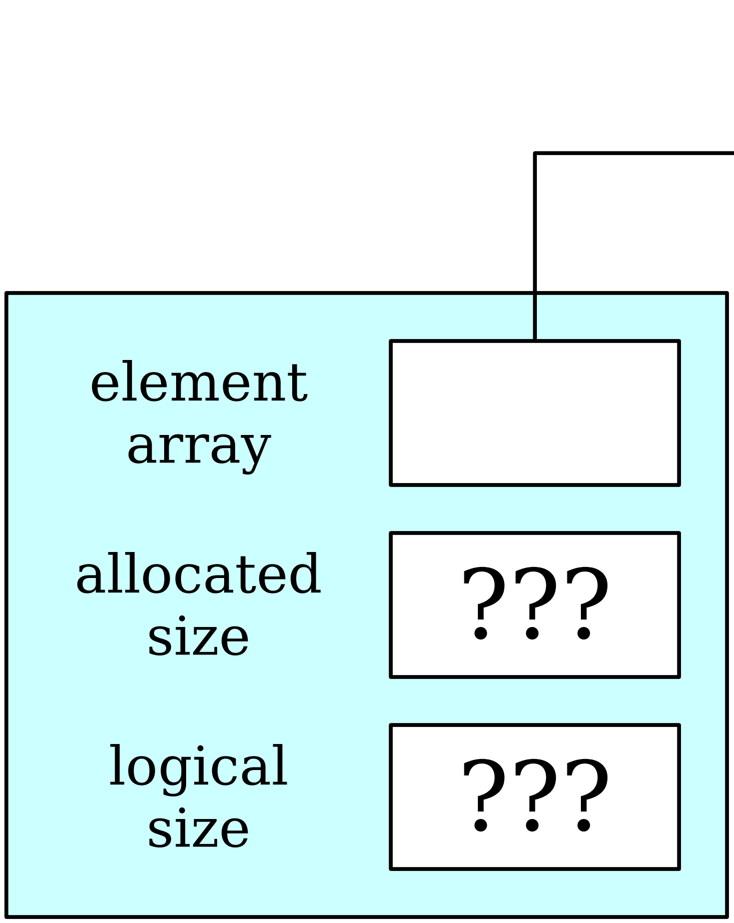
    return 0;
}
```

Cradle to Grave, Take III



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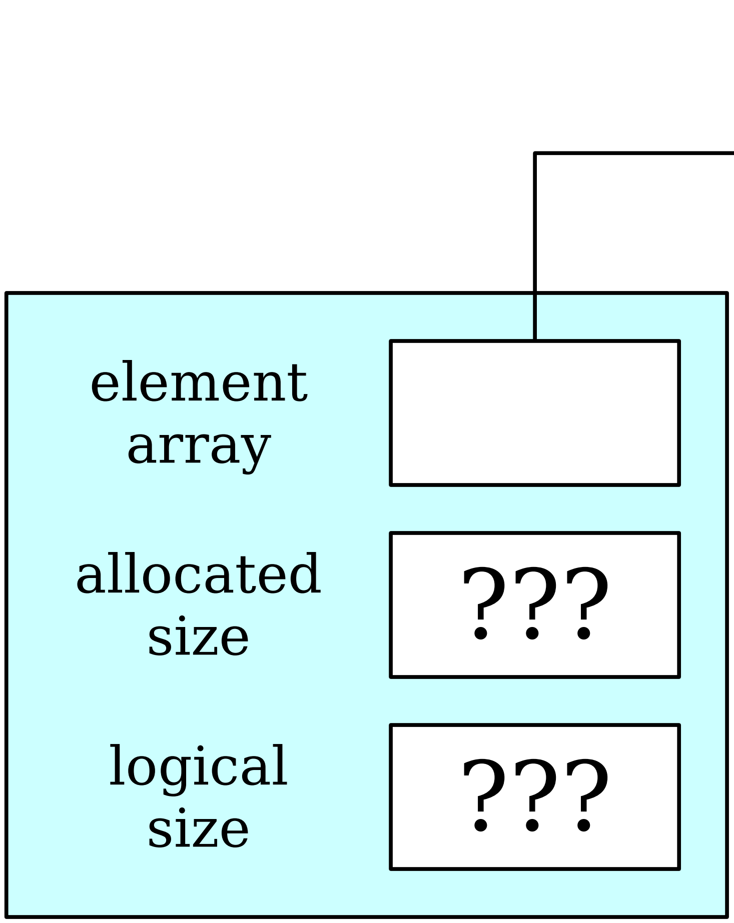
     */

    return 0;
}
```

Cradle to Grave, Take III

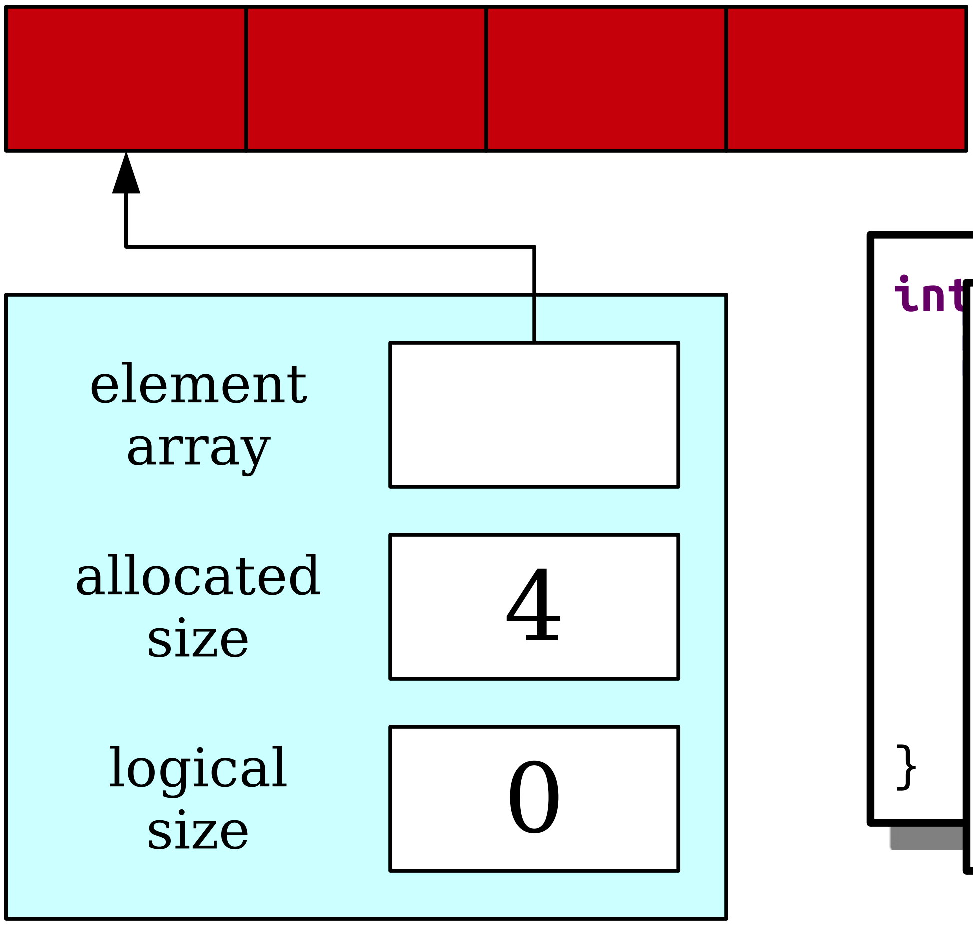


```
int
```

```
}
```

```
OurStack::OurStack() {
    logicalSize = 0;
    allocatedSize = kInitialSize;
    elems = new int[allocatedSize];
}
```

Cradle to Grave, Take III



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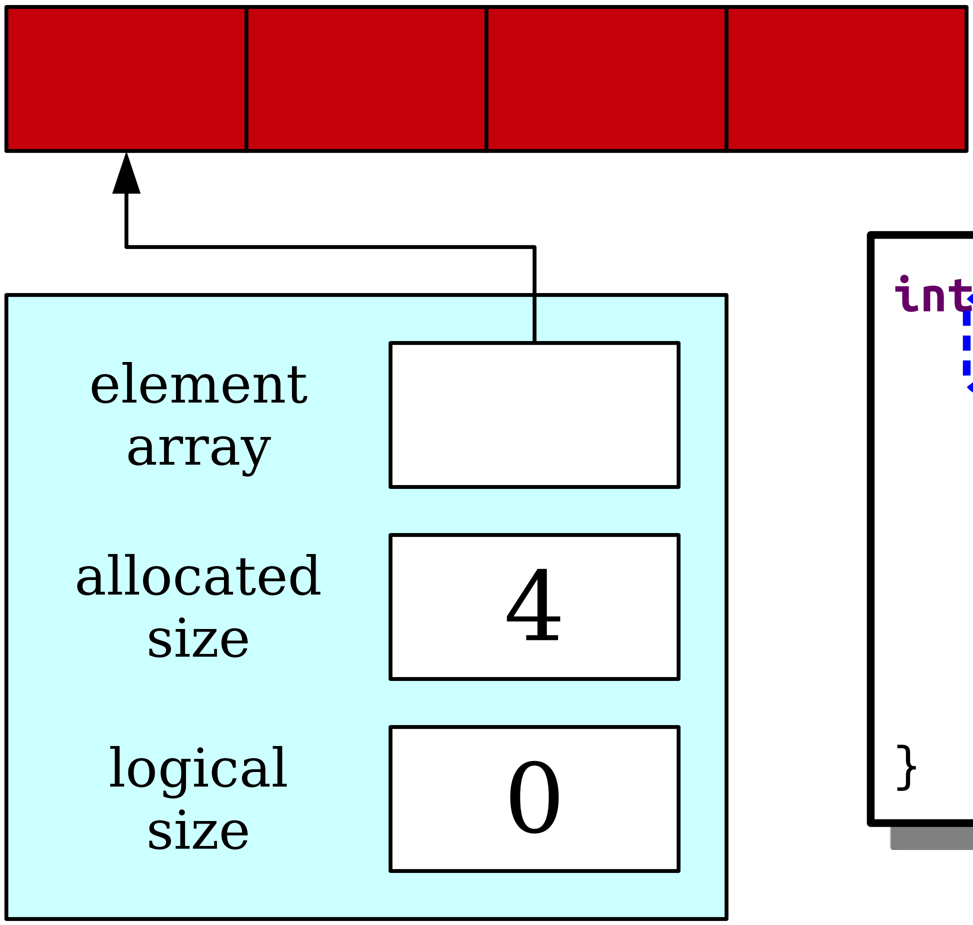
Cradle to Grave, Take III



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    return 0;
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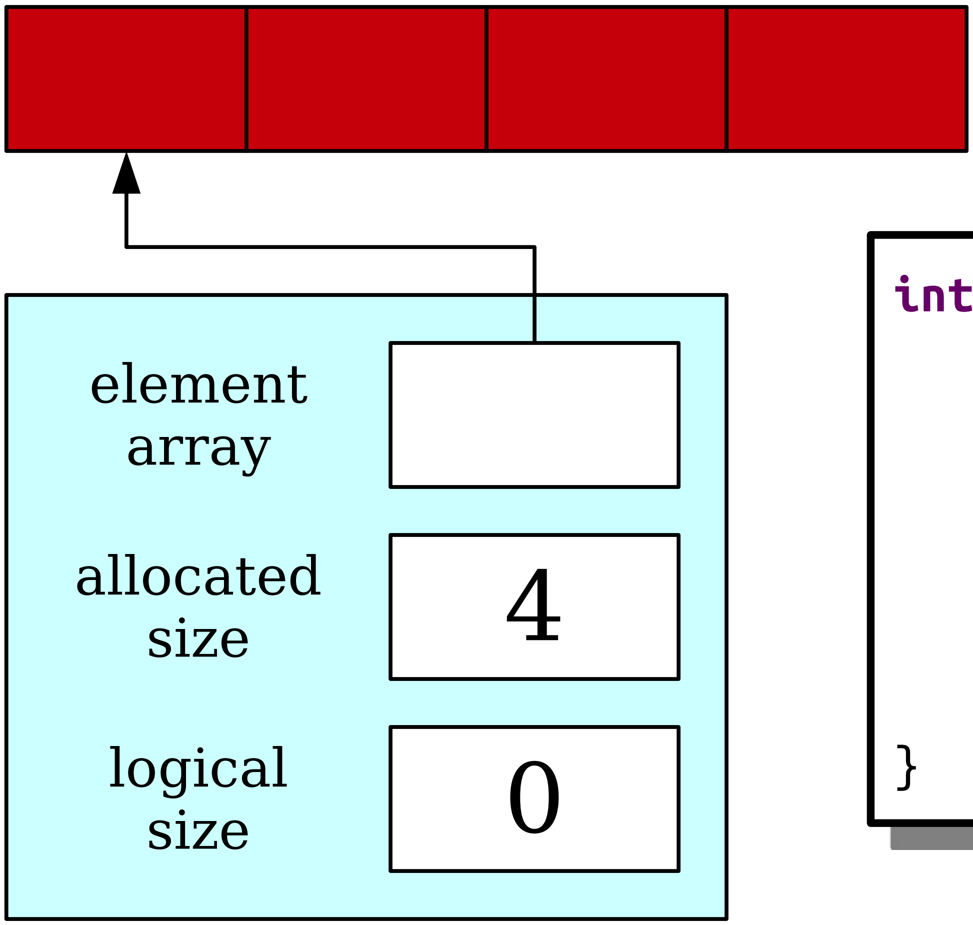
```

Cradle to Grave, Take III

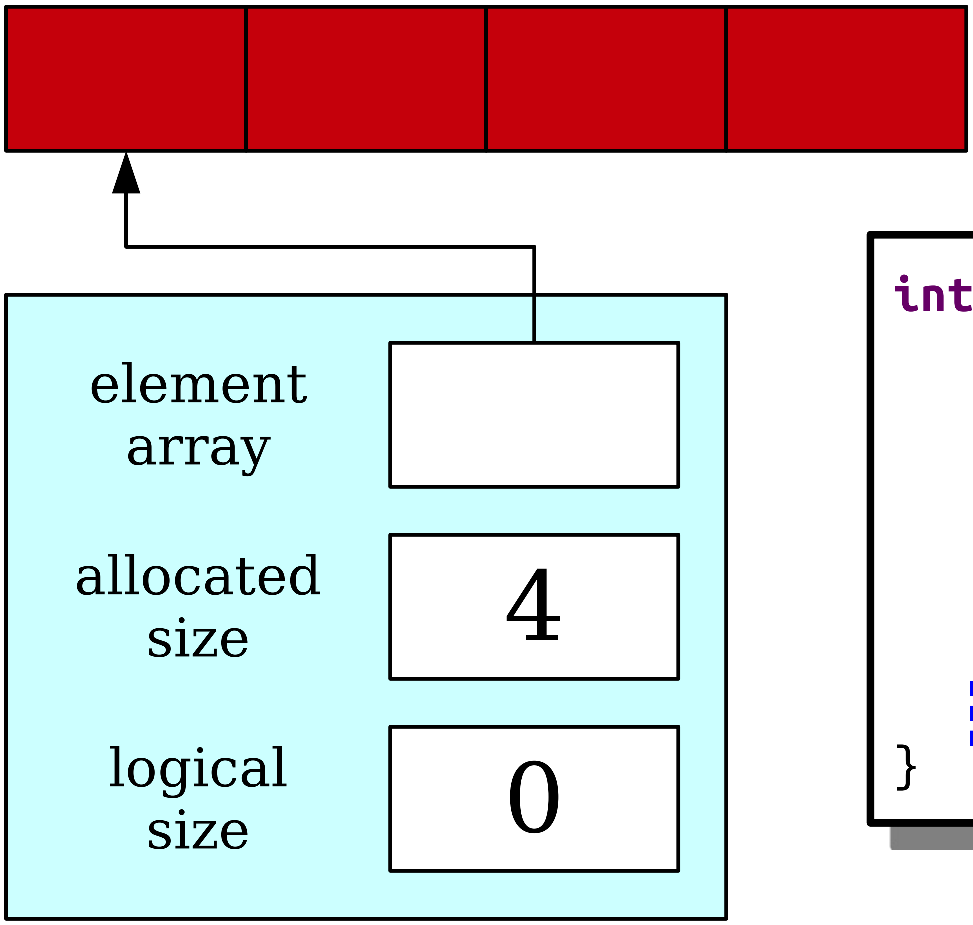


```
int main() {
    OurStack stack;

   /* The stack lives a rich, happy,
    * fulfilling life, the kind we
    * all aspire to.
    */

    return 0;
}
```

Cradle to Grave, Take III



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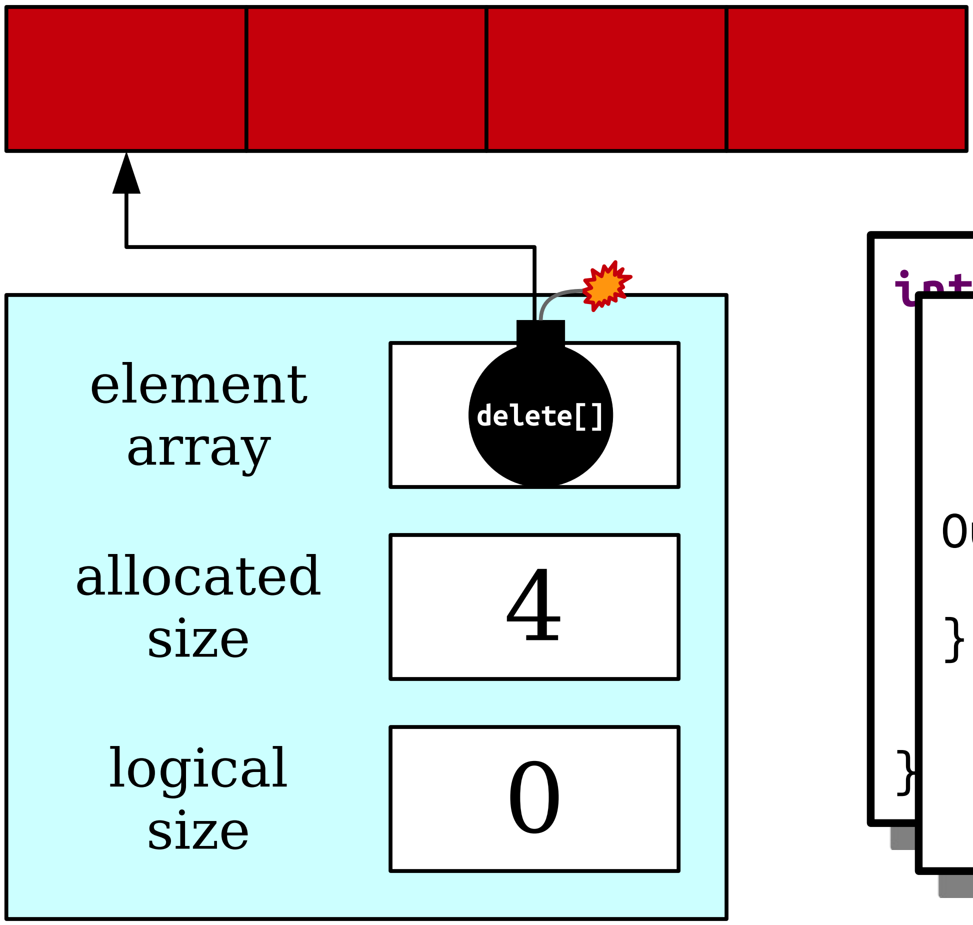
Cradle to Grave, Take III

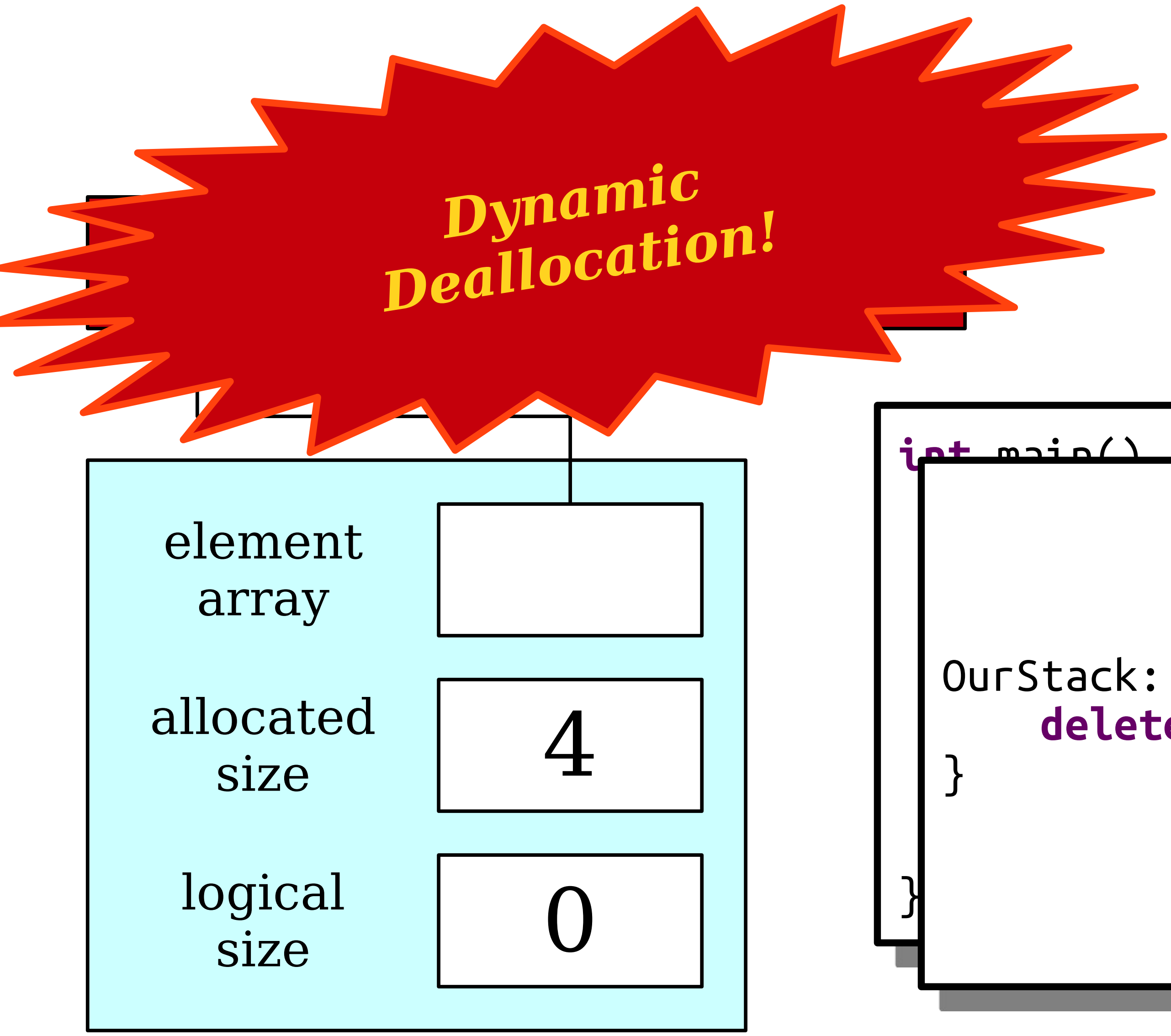


```
int main() {

}
```

```
OurStack::~OurStack() {
    delete[] elems;
}
```

Cradle to Grave, Take III



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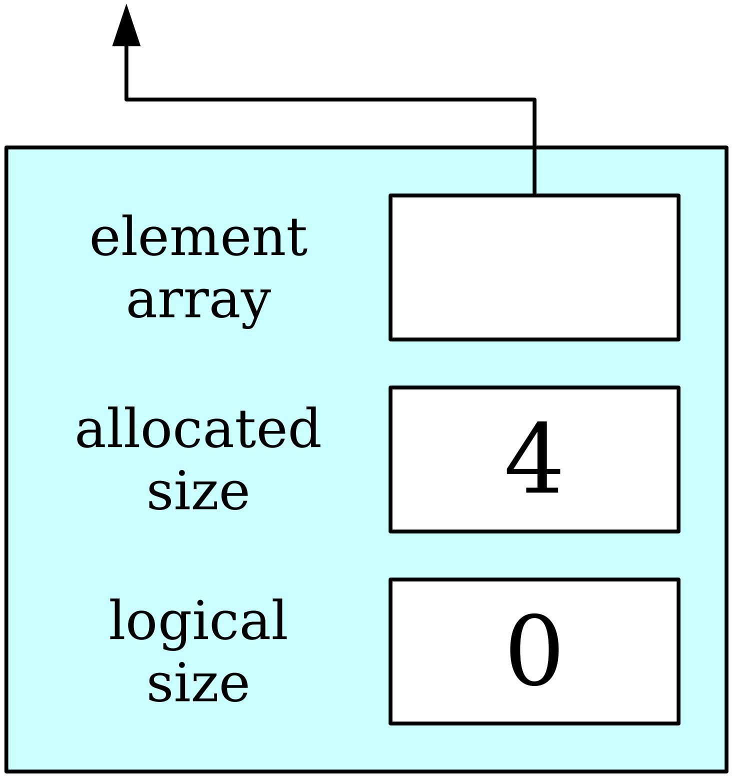
Cradle to Grave, Take III



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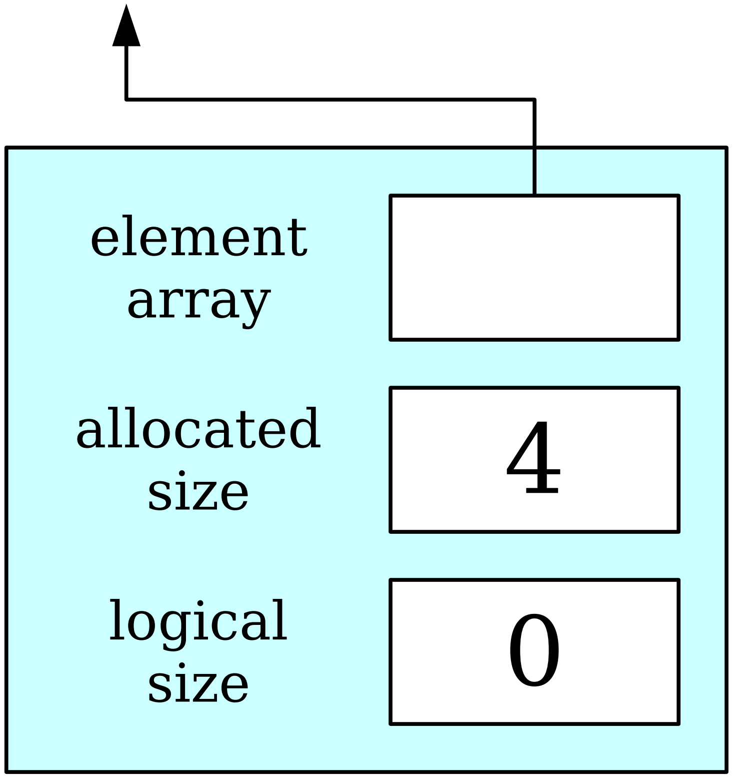
Cradle to Grave, Take III



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Cradle to Grave, Take III

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To Summarize

- You can create arrays of a fixed size at runtime by using `new[]`.
- You are responsible for freeing any memory you explicitly allocate by calling `delete[]`.
- Constructors are used to set up a class's internal state so that it's in a good place.
- Destructors are used to free resource that a class allocates.

Next Time

- ***Making Stack Grow!***
  - Different approaches to `Stack` growth.
  - Analysis of these approaches.
  - The reality: *everything is a tradeoff!*