Container Classes

The Bag Class with Dynamic Memory

A Dynamic Bag

Previously we made a bag that could hold a fixed number of items...

- lame, huh?

Now, we're going to make it dynamic

- the bag should transparently resize itself if it isn't large enough to support a given operation
- it is, in effect, a magic bag of holding!

The users of our bag will rejoice!

- how they use the class won't change...
- but it will be able to hold as many items as they need it to

Updated Specification

Updated Specification

Type definitions and member constants:

```
// data type of items in the bag
typedef _________ value_type;

// value_type must be a built-in type, or support:
//  - instantiation via a default constructor
//  - assignment operator   (x = y)
//  - equality operator     (x == y)
//  - non-equality operator (x != y)
```

Updated Specification

Type definitions and member constants:

```
// data type of variables that track a bag's size
typedef ________ size_type;
```

Updated Specification

Type definitions and member constants: `// CHANGED!`

```
// the default number of items a bag can hold
// used by the default constructor
static const size_type DEFAULT_CAPACITY = ___;
```

Updated Specification

Constructors: // CHANGED!

```
// creates an empty bag with the given capacity
bag(size_type initial_capacity = DEFAULT_CAPACITY);

// postcondition:
//   the bag is empty with the given initial capacity
//   the insert function will work efficiently (without
//     allocating new memory) until this capacity is
//     reached
```

Updated Specification

Modification member functions:

```
// removes all copies of @target from the bag
// returns the number of elements removed
size_type erase(const value_type& target);

// postcondition:
//   all copies of target have been removed from the bag
//   return value is the number of elements removed
```

Updated Specification

Modification member functions:

```
// removes a single copy of @target from the bag
// returns true if a value was removed; false otherwise
bool erase_one(const value_type& target);

// postcondition:
//   if @target was in the bag, then one copy is removed
//   otherwise, the bag remains unchanged
//   return value is true if a value was removed,
//     or false otherwise
```

Updated Specification

Modification member functions:

```
// inserts a new copy of @entry into the bag
void insert(const value_type& entry);

// postcondition:
//   a new copy of @entry has been added to the bag
```

Updated Specification

Modification member functions: // NEW!

```
// allocates a new data array of the requested size
void reserve(size_type new_size);

// postcondition:
//   The bag's current capacity is changed to new_size
//     (but not less than the number of items already in
//     the bag).
//   The insert function will work efficiently (without
//     allocating new memory) until the new capacity is
//     reached
```

Updated Specification

Modification member functions:

```
// inserts a copy of each item in @addend into the bag
void operator +=(const bag& addend);

// postcondition:
//   each item in addend has been added to the bag
```

Updated Specification

Constant member functions:

```
// returns the total number of items in the bag
size_type size() const;


// postcondition:
//   return value is the number of items in the bag
```

Updated Specification

Constant member functions:

```
// returns the total number of occurrences of @target
size_type count(const value_type& target) const;

// postcondition:
//   return value is the number of times @target occurs
//     in the bag
```

Updated Specification

Non-member functions:

```
// returns a new bag that is the union of @b1 and @b2
bag operator +(const bag& b1, const bag& b2);

// postcondition:
//   the bag returned is the union of b1 and b2
```

Updated Specification

Value semantics:

```
// bag objects may be:
//   assigned using operator =
//   copied via the copy constructor
```

Updated Specification

Dynamic memory usage: `// NEW!`

```
// If there is insufficient dynamic memory, then the
// following functions throw bad_alloc:
//   constructors
//   reserve
//   insert
//   operator +=
//   operator +
```

Updated Specification

Not much changed, did it?

- the specification is for the <u>users</u> of the class; the main change they see is that the bag is no longer limited to a fixed size

The updated specification did hint at a few implementation details...

- which functions use dynamic memory were listed
- two methods (the constructor and `reserve`) directly deal with the underlying capacity of the dynamically allocated array

Ideally, how a class is implemented should be completely transparent

- however, the added details still address how the class should be used
- good programmers will want to be able to handle errors appropriately and to use the class efficiently

Updated Implementation

Updated Implementation

Starting the header file:

```
// bag.h header file
// specification documentation
#pragma once
#include <cstdlib>

namespace CS262 {
    class bag {
        // bag class declaration
    };
}
```

Updated Implementation

Starting the implementation file:

```
// bag.cpp implementation file
// INVARIANT (coming soon)
#include "bag.h"
#include <algorithm>
#include <cassert>
using namespace std;

namespace CS262 {
    // member implementations
}
```

Updated Implementation

Type definitions and member constants:

```
class bag {
    public:
        typedef int value_type;
        typedef std::size_t size_type;
        static const size_type DEFAULT_CAPACITY = 30;

    private:
        value_type* data;
        size_type capacity;
        size_type used;
};
```

Updated Implementation

Here's the updated private section:

```
private:
    value_type* data;    // pointer to dynamic array
    size_type capacity; // current capacity of array
    size_type used;      // number of items in array
```

Compare that with the static version's data members:

```
private:
    value_type data[CAPACITY];
    size_type used;
```

Updated Implementation

Here's the updated private section:

```
private:
    value_type* data;   // pointer to dynamic array
    size_type capacity; // current capacity of array
    size_type used;     // number of items in array
```

Our implementation still uses an array...

- unlike before (when the array was static), we're now using a dynamically allocated array; this will allow us to resize the bag whenever needed by allocating a new array
- accordingly, we need to keep track of the current size of the array; this is stored in the member variable `capacity`
- again, the number of elements in the bag will be tracked by the `used` member variable

Updated Implementation

Document invariant in implementation file:

```
// bag.cpp implementation file
// INVARIANT for bag class:
// 1. the number of items in the bag is stored in the
//    member variable used
// 2. The actual items of the bag are stored in a
//    partially filled array. The array is a dynamic
//    array, pointed to by the member variable data
// 3. the size of the dynamic array is in the member
//    variable capacity
```

Updated Implementation

The constructor prototype:

```
// creates an empty bag with the given capacity
bag(size_type initial_capacity = DEFAULT_CAPACITY);
```

The user can now (optionally) set the initial capacity of the bag:

```
bag b1;        // a bag with the default capacity
bag b2(1000); // a bag with a capacity of 1000
```

Try writing this function

Updated Implementation

The constructor implementation:

```
// creates an empty bag with the given capacity
bag::bag(size_type initial_capacity) {
    data = new value_type[initial_capacity];
    capacity = initial_capacity;
    used = 0;
}
```

Updated Implementation

Another constructor implementation (using an initialization list):

```
// creates an empty bag with the given capacity
bag::bag(size_type initial_capacity) :
    capacity(initial_capacity), used(0)
{
    data = new value_type[initial_capacity];
}
```

Updated Implementation

The reserve function prototype:

```
// allocates a new data array of the requested size
void reserve(size_type new_size);
```

The user can request a resize via the reserve method

- it should dynamically allocate a new array of the requested size
- if the new capacity is the same as the current capacity, it doesn't need to do anything
- likewise, if the requested capacity is less than the current capacity, it cannot result in a loss of data (cannot be smaller than used)

Try writing this function

Updated Implementation

The reserve function implementation:

```
void bag::reserve(size_type new_size) {
    if (new_size == capacity) return;
    if (new_size < used) new_size = used;

    value_type* new_array = new value_type[new_size];
    copy(data, data + used, new_array);

    delete [] data;
    data = new_array;
    capacity = new_size;
}
```

Updated Implementation

The erase function prototype:

```
// removes all copies of @target from the bag
size_type erase(const value_type& target);
```

Does the implementation of this function need to change?

- Nope!

Updated Implementation

The erase function implementation (no change):

```
// removes all copies of @target from the bag
bag::size_type bag::erase(const value_type& target) {
    size_type i = 0, num_erased = 0;
    while (i < used) {
        if (data[i] == target) {
            data[i] = data[--used];
            num_erased++;
        } else i++;
    }
    return num_erased;
}
```

Updated Implementation

The erase_one function prototype:

```
// removes a single copy of @target from the bag
bool erase_one(const value_type& target);
```

Does the implementation of this function need to change?

- Nope!

Updated Implementation

The erase_one function implementation (no change):

```
// removes a single copy of @target from the bag
bool bag::erase_one(const value_type& target) {
    size_type i = 0;

    while (i < used && data[i] != target) i++;

    if (i == used) return false;

    data[i] = data[--used];
    return true;
}
```

Updated Implementation

The insert function prototype:

```
// inserts a new copy of @entry into the bag
void insert(const value_type& entry);
```

Does the implementation of this function need to change?

- Yes!
- insert must now allocate additional space, if necessary
- this should replace the assertion from the earlier implementation

Try writing this function

Updated Implementation

The insert function implementation (updated):

```
// inserts a new copy of @entry into the bag
void bag::insert(const value_type& entry) {
    // increase the bag's capacity, if necessary
    if (used == capacity) {
        reserve(2 * used);
    }

    data[used++] = entry;
}
```

Updated Implementation

The operator += function prototype:

```
// inserts a copy of each item in @b into the bag
void operator +=(const bag& b);
```

Does the implementation of this function need to change?

- Yes!
- must now allocate additional space, if necessary
- this should replace the assertion from the earlier implementation

Try writing this function

Updated Implementation

The operator += function implementation (updated):

```
// inserts a copy of each item in @b into the bag
void operator +=(const bag& b) {
    // increase the bag's capacity, if necessary
    if (used + b.used > capacity) {
        reserve(used + b.used);
    }

    // copies all items in b.data to the end of data
    copy(b.data, b.data + b.used, data + used);
    used += b.used;
}
```

Updated Implementation

The size function:

```
// returns the total number of items in the bag
size_type size() const { return used; }
```

Does the implementation of this function need to change?

- Yes! It's much too simple... Rabble rabble rabble!!!

Updated Implementation

The count function prototype:

```
// returns the total number of occurrences of @target
size_type count(const value_type& target) const;
```

Does the implementation of this function need to change?

- Nope!

Updated Implementation

The count function implementation (no change):

```
// returns the total number of occurrences of @t
bag::size_type bag::count(const value_type& t) const {
    size_type answer = 0;

    for (size_type i = 0; i < used; i++)
        if (data[i] == t)
            answer++;

    return answer;
}
```

Updated Implementation

The operator + function prototype:

```
// returns a new bag that is the union of @b1 and @b2
bag operator +(const bag& b1, const bag& b2);
```

Does the implementation of this function need to change?

- Yes!
- it must create a bag big enough to hold the items from both bags
- this can be done using the constructor's optional initial_capacity argument

Try writing this function

Updated Implementation

The operator + function implementation (updated):

```
// returns a new bag that is the union of @b1 and @b2
bag operator +(const bag& b1, const bag& b2) {
    bag union(b1.size() + b2.size());

    union += b1;
    union += b2;

    return union;
}
```

Updated Implementation

The bag class now uses dynamic memory...

- this means the automatic implementations of the copy constructor, assignment operator, and destructor are no longer sufficient

Why weren't these part of our specification?

- we specified copying as okay as part of the value semantics of our class, and copying and assignment are always done exactly the same way...
- users never explicitly call the destructor

Updated Implementation

The copy constructor prototype:

```
// creates a new bag as a copy of @source
bag(const bag& source);
```

The copy constructor must:

- allocate a new array of the same size as that in the source bag
- copy all the items from the source array to the new array
- update `used` and `capacity`

Try writing this function

Updated Implementation

The copy constructor implementation:

```
// creates a new bag as a copy of @source
bag::bag(const bag& source) {
    data = new value_type[source.capacity];

    used = source.used;
    capacity = source.capacity;

    copy(source.data, source.data + used, data);
}
```

Updated Implementation

The assignment operator prototype:

```
// assigns this bag as a copy of @source
bag& operator =(const bag& source);
```

The assignment operator must:

- check for self-assignment
- allocate a new array of the same size as that in the source bag, if necessary
- copy all the items from the source array to the calling object bag
- update `used` and `capacity`
- ideally, it should also return the calling object by reference (for assignment chaining)

Try writing this function

Updated Implementation

The assignment operator implementation:

```
bag& bag::operator =(const bag& source) {
    if (this == &source) return *this;

    if (capacity != source.capacity) {
        delete [] data;
        data = new value_type[source.capacity];
        capacity = source.capacity;
    }

    used = source.used;
    copy(source.data, source.data + used, data);
    return *this;
}
```

Updated Implementation

The destructor prototype:

```
// frees the memory used by this bag
~bag();
```

The destructor must:

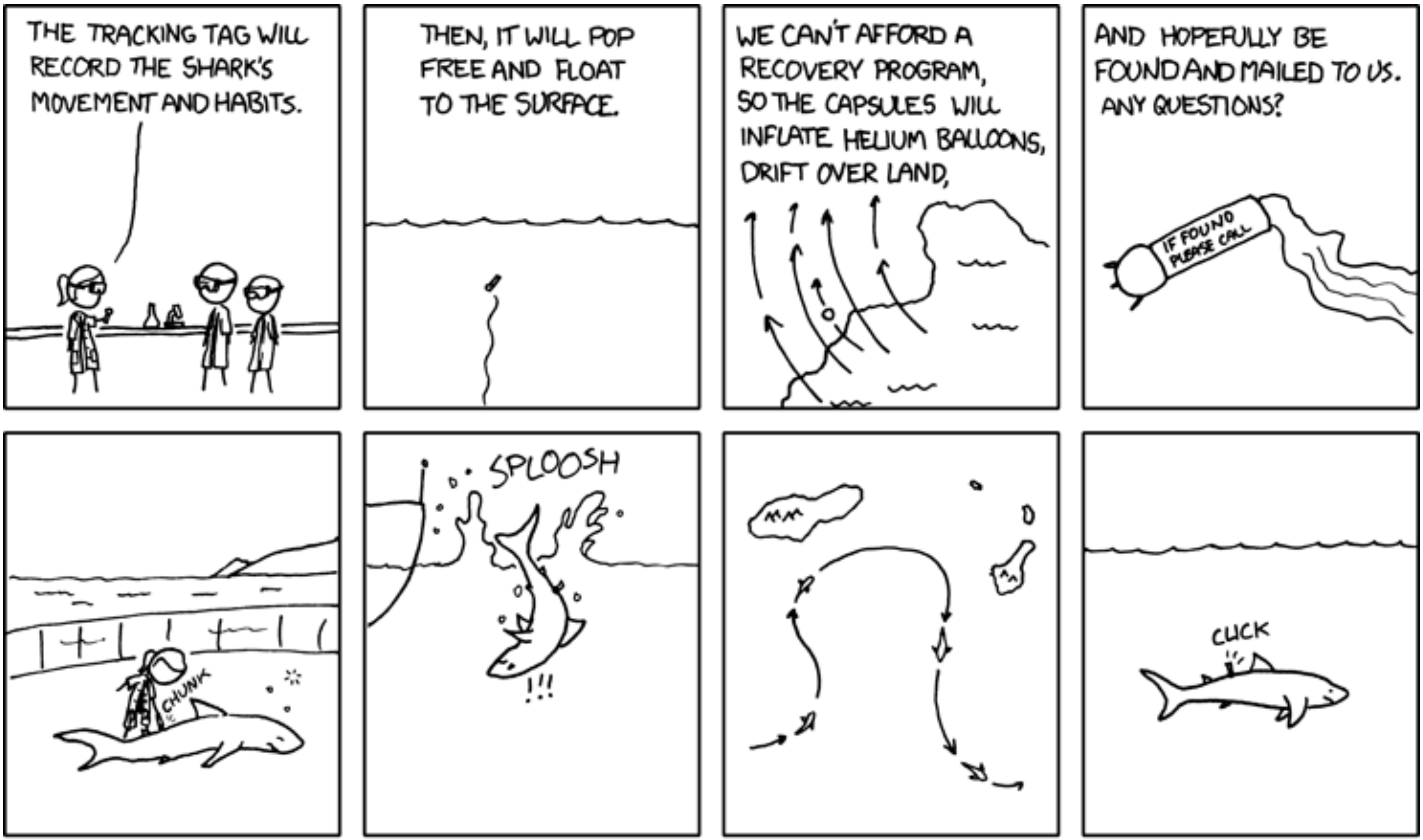
- deallocate any dynamically allocated memory used by the bag

Try writing this function

Updated Implementation

The destructor implementation:

```
// frees the memory used by this bag
bag::~bag() {
    delete [] data;
}
```


THE TRACKING TAG WILL RECORD THE SHARK'S MOVEMENT AND HABITS.
THEN, IT WILL POP FREE AND FLOAT TO THE SURFACE.
WE CAN'T AFFORD A RECOVERY PROGRAM, SO THE CAPSULES WILL INFLATE HELIUM BALLOONS, DRIFT OVER LAND,
AND HOPEFULLY BE FOUND AND MAILED TO US. ANY QUESTIONS?
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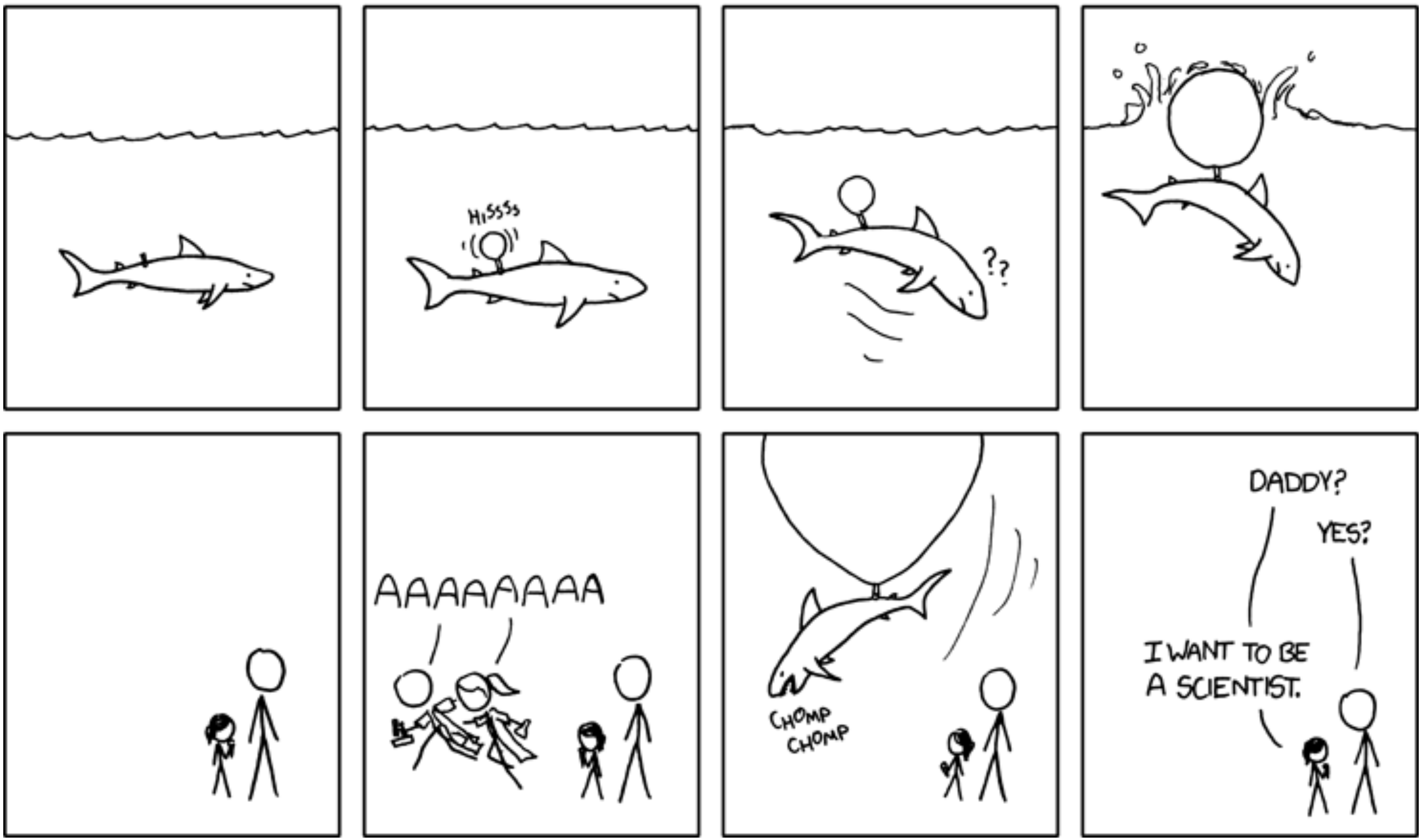
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