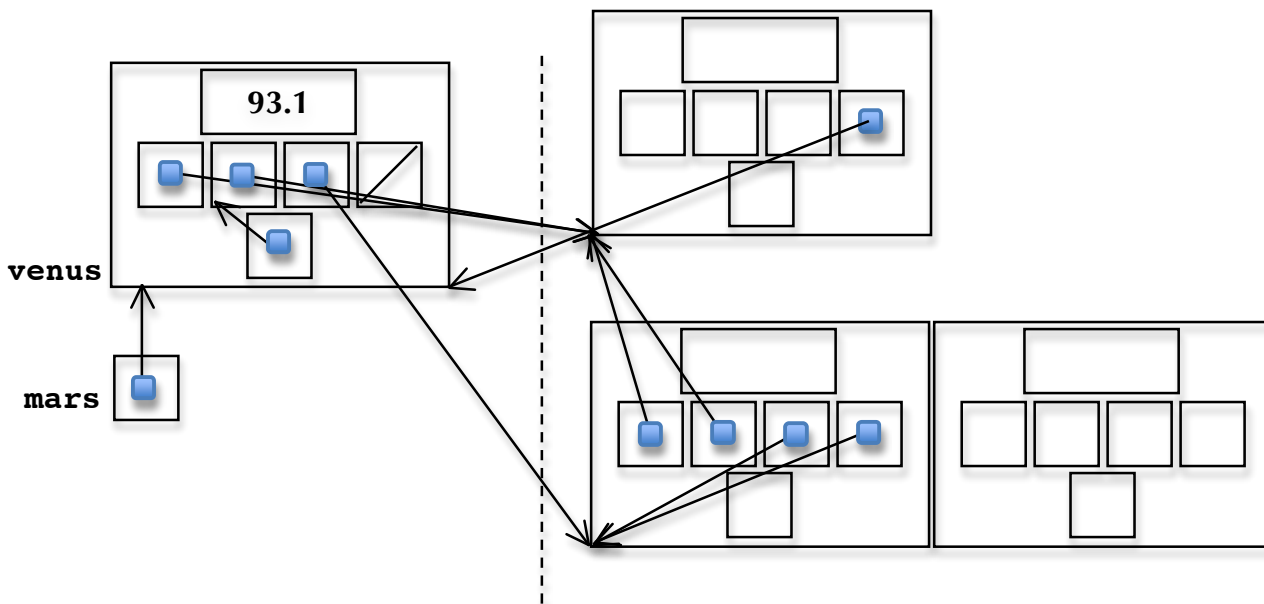


Section Solution

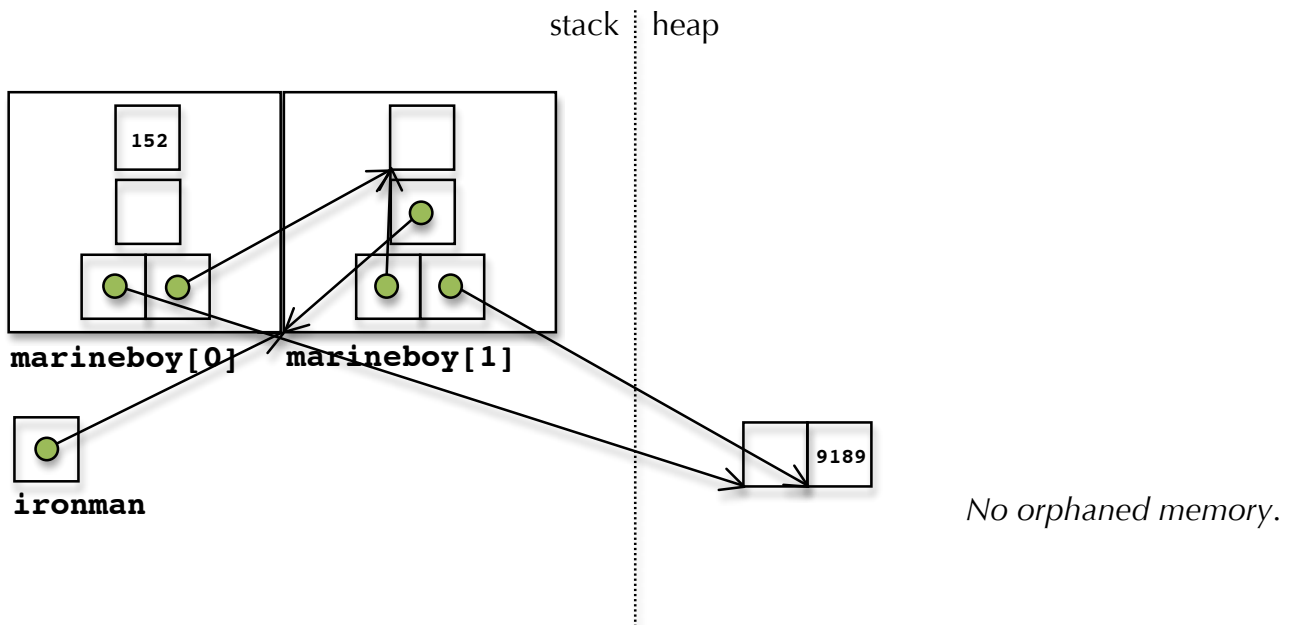
Discussion Problem 1 Solution: Planetarium Memory Trace

A snapshot of memory at the point indicated in the problem statement is presented below. Memory drawn to the left of the dashed line is in the stack (which is where all local variables live), and memory drawn to the right of the dashed line is in the heap (which is where all dynamically allocated memory lives).

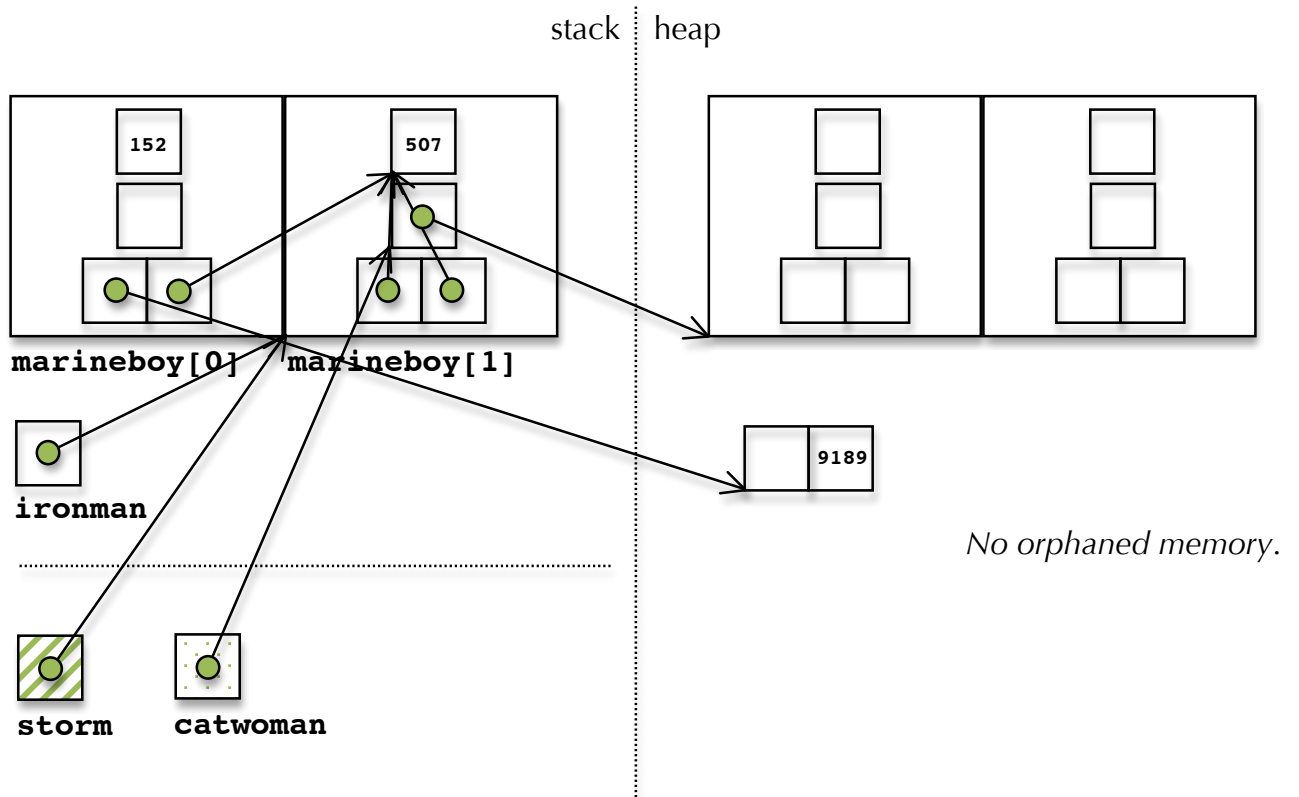


Discussion Problem 2 Solution: Superheroes Then and Now

State of memory just prior to the call to **barbarella**:



State of memory just before the call to **barbarella** exits:



Lab Problem 1 Solution: Bloom Filters and Sorted String Sets

Here's my **SortedStringSet** interface:

```
class SortedStringSet {
public:
    SortedStringSet(const Vector<int (*) (const std::string&, int)>& hashers);
    ~SortedStringSet();

    int size() const { return values.size(); }

    bool contains(const std::string& value) const;
    void add(const std::string& value);

private:
    Set<string> values;
    Vector<int (*) (const std::string&, int)> hashers;
    bool *footprints;
    int alloclength;
    int numfootprints;
    void createEmptyBloomFilter();
    void leaveFootprints(const std::string& value);
    void rehash();
};
```

Everything below the **Set<string> values** line is my own, and all of what's new helps to manage a Bloom filter. The two instance variables **footprints** and **alloclength** team up to manage the Bloom filter as a manually managed array of Boolean footprints that needs to be reallocated when we congest the filter with lots of **true** values.

The constructor and destructor are algorithmically straightforward. The primary reason I decompose the constructor to call the helper **createEmptyBloomFilter** method is that I need to execute the same exact code within the **add** method.

```
static const int kInitBloomFilterLength = 1001;
SortedStringSet::SortedStringSet(const Vector<int (*) (const string&, int)>& hashers)
    this->hashers = hashers;
    alloclength = kInitBloomFilterLength;
    createEmptyBloomFilter();
}

SortedStringSet::~~SortedStringSet() {
    delete[] footprints;
}

void SortedStringSet::createEmptyBloomFilter() {
    footprints = new bool[alloclength];
    for (int i = 0; i < alloclength; i++) {
        footprints[i] = false;
    }

    numfootprints = 0;
}
```

Note that `createEmptyBloomFilter` assumes that `alloclength` has been initialized to be the desired Bloom filter length before it's called. As is always the case, we need to manually zero out every entry in the footprints array, because C++ doesn't support default initialization like some other languages do. And because the Bloom filter is empty (e.g. there are no `true`s anywhere in the array), `numfootprints` is set to `0`.

The implementation of `contains` is potentially framed as a call to `contains` on the encapsulated `Set<string>`. But before we commit to the more expensive `Set<string>::contains` call, we examine the Bloom filter to see if the expected set of footprints have been left by the accumulation of all prior `add` calls. If they haven't been, we know there's no way the supplied `string` will be in the master `Set`. If they have been, then and only then is it sensible to examine the master `Set` to see if the referenced `string` is truly and officially present.

```
bool SortedStringSet::contains(const string& value) const {
    for (int i = 0; i < hashers.size(); i++) {
        int hash = (hashers.get(i))(value, alloclength); // get works, [] doesn't
        if (!footprints[hash]) {
            return false;
        }
    }

    return values.contains(value);
}
```

The implementation of `add` is more complicated, because we need to check to see if the Bloom filter is congested with a high fraction of footprints. Before we go on stamping down even more footprints, we need to check if there are more `true`s than `false`s. If so, we allocate a much larger filter, rehash all existing `strings` to leave new footprints, and dispose of the old filter. Whether or not we got a new filter, we need to leave some footprints on behalf of the supplied `string`, and then add it to the master `Set`.

```
static const double kSaturationFactor = 0.50;
void SortedStringSet::add(const string& value) {
    if (numfootprints > kSaturationFactor * alloclength) rehash();
    leaveFootprints(value);
    values.add(value);
}

void SortedStringSet::rehash() {
    delete footprints;
    alloclength *= hashers.size(); // heuristic: multiply by number of hashers
    createEmptyBloomFilter();
    foreach (string value in values) leaveFootprints(value);
}

void SortedStringSet::leaveFootprints(const string& value) {
    for (int i = 0; i < hashers.size(); i++) {
        int hash = hashers[i](value, alloclength);
        if (!footprints[hash]) numfootprints++;
        footprints[hash] = true;
    }
}
```