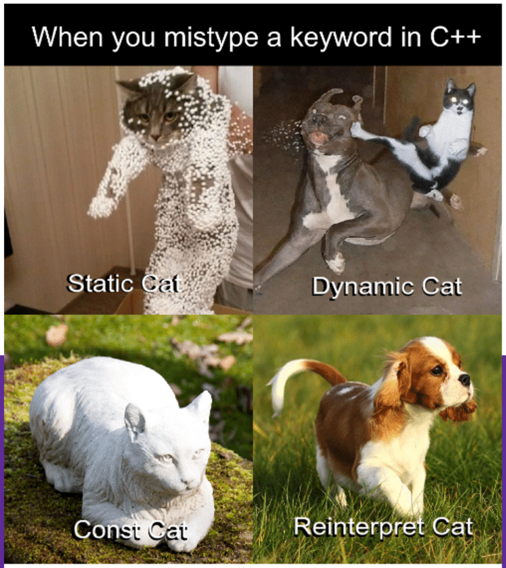
CSE 333
Section 7

HW3, C++, and Inheritance



Ever have a moment like this when programming?

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Logistics

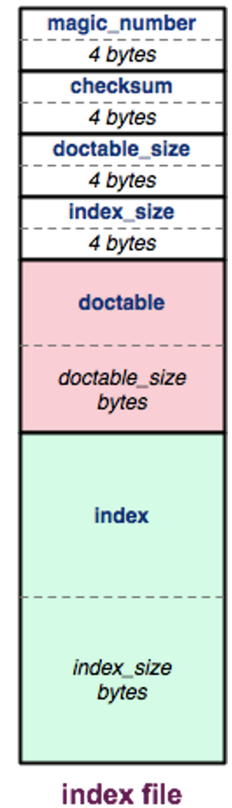
- **Veteran's Day** on **Friday** (11/11)
  - No Lecture! Will still hold Office Hours (zoom only).
- **Exercise 14**
  - Due **Monday** (11/14) @ 10:00am
- **HW3**
  - Due next **Thursday** (11/17) @ 11:00pm

HW 3 Overview

Index File

Crawling the whole file tree takes a long time!

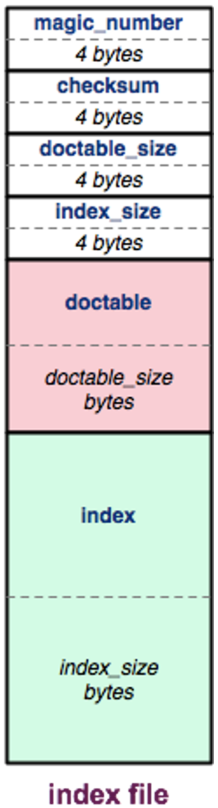
To save time we'll write the completed `DocTable` and `MemIndex` into a file!



Byte Ordering and Endianness

- Network (Disk) Byte Order (Big Endian)
  - The most significant byte is stored in the highest address
- Host byte order
  - Might be big or little endian, depending on the hardware
- To convert between orderings, we can use
  - `uint32_t htonl (uint32_t hostlong);   // host to network`
  - `uint32_t ntohl (uint32_t netlong);    // network to host`
- Pro-tip:
  The structs in HW3 have `toDiskFormat()` and `toHostFormat()` functions that will convert endianness for you.

Index File Components

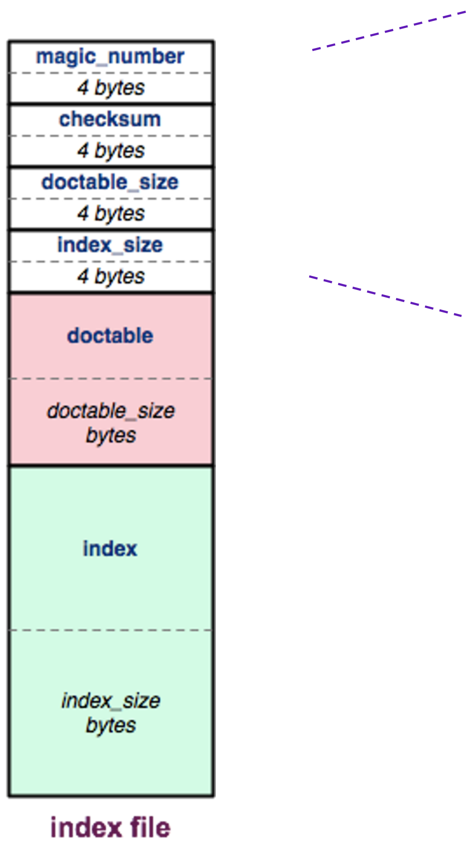


Header (metadata)

DocTable

MemIndex

Index File Header



- magic_number: `0xCAFEF00D`
- checksum: mathematical signature
- doctable_size: in bytes
- index_size: in bytes

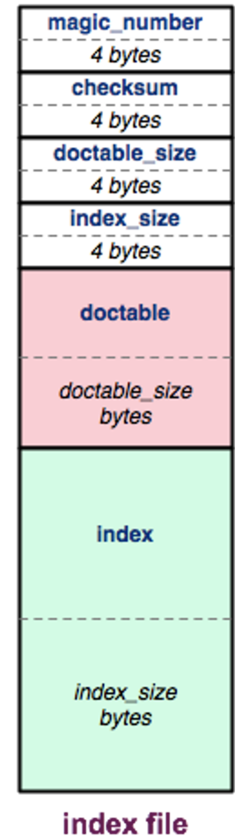
Index File Header - HEX

1. Find a hex editor/viewer of your choice
   - `xxd <indexfile>`
   - `hexdump -vC <indexfile>`
   - Pipe the output into a file or into `less` to view

```
0000000: cafe f00d 1c42 4620 0000 205b 0000 075d  .....BF .. [...]
0000010: 0000 0400 0000 0000 0000 2014 0000 0001  .......... .....
0000020: 0000 2014 0000 0001 0000 2031 0000 0001  .. ....... 1....
0000030: 0000 204e 0000 0000 0000 206b 0000 0000  .. N...... k....
0000040: 0000 206b 0000 0000 0000 206b 0000 0000  .. k...... k....
0000050: 0000 206b 0000 0000 0000 206b 0000 0000  .. k...... k....
```

The header:

Magic word Checksum Doctable size Index size



Hex View

- emacs – “M-x hexl-mode”

```
File Edit Options Buffers Tools Hexl Help
87654321  0011 2233 4455 6677 8899 aabb ccdd eeff  0123456789abcdef
00000000: cafe f00d ff48 a0a1 0000 006a 0000 024e  .....H.....j...N
00000010: 0000 0001 0000 0002 0000 001c 0000 0024  ...............$
00000020: 0000 0054 0000 0000 0000 0002 0026 2e2f  ...T.........&./
00000030: 7465 7374 5f74 7265 652f 7469 6e79 2f68  test_tree/tiny/h
00000040: 6f6d 652d 6f6e 2d74 6865 2d72 616e 6765  ome-on-the-range
00000050: 2e74 7874 0000 0000 0000 0001 001c 2e2f  .txt.........../
```

- vim – “:%!xxd”

```
00000000: cafe f00d ff48 a0a1 0000 006a 0000 024e  .....H.....j...N
00000010: 0000 0001 0000 0002 0000 001c 0000 0024  ...............$
00000020: 0000 0054 0000 0000 0000 0002 0026 2e2f  ...T.........&./
00000030: 7465 7374 5f74 7265 652f 7469 6e79 2f68  test_tree/tiny/h
00000040: 6f6d 652d 6f6e 2d74 6865 2d72 616e 6765  ome-on-the-range
00000050: 2e74 7874 0000 0000 0000 0001 001c 2e2f  .txt.........../
```

Hex View

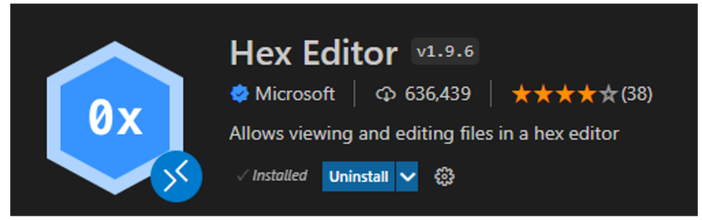
- emacs – “M-x hexl-mode”

```
File Edit Options Buffers Tools Hexl Help
87654321  0011 2233 4455 6677 8899 aabb ccdd eeff  0123456789abcdef
00000000: cafe f00d ff48 a0a1 0000 006a 0000 024e  .....H.....j...N
00000010: 0000 0001 0000 0002 0000 001c 0000 0024  ...............$
00000020: 0000 0054 0000 0000 0000 0002 0026 2e2f  ...T.........&./
00000030: 7465 7374 5f74 7265 652f 7469 6e79 2f68  test_tree/tiny/h
00000040: 6f6d 652d 6f6e 2d74 6865 2d72 616e 6765  ome-on-the-range
00000050: 2e74 7874 0000 0000 0000 0001 001c 2e2f  .txt.........../
```

- vim – “:%!xxd”

```
00000000: cafe f00d ff48 a0a1 0000 006a 0000 024e  .....H.....j...N
00000010: 0000 0001 0000 0002 0000 001c 0000 0024  ...............$
00000020: 0000 0054 0000 0000 0000 0002 0026 2e2f  ...T.........&./
00000030: 7465 7374 5f74 7265 652f 7469 6e79 2f68  test_tree/tiny/h
00000040: 6f6d 652d 6f6e 2d74 6865 2d72 616e 6765  ome-on-the-range
00000050: 2e74 7874 0000 0000 0000 0001 001c 2e2f  .txt.........../
```

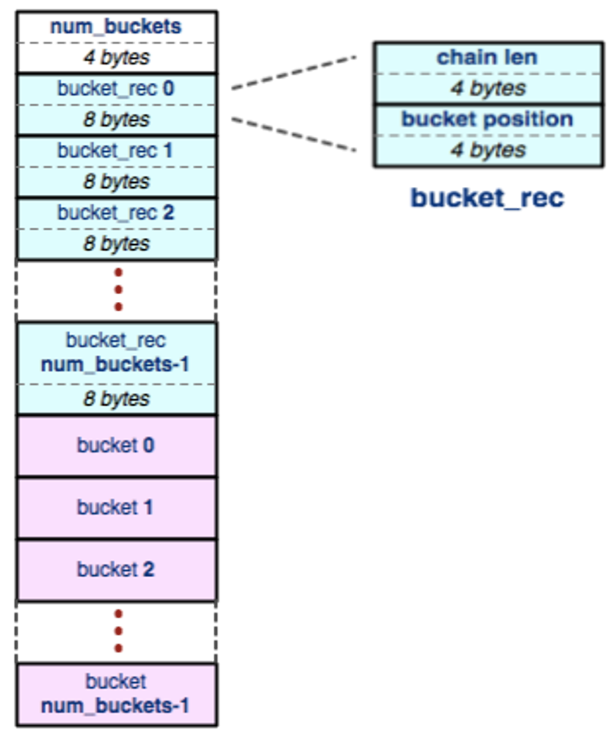
For those working in VSCode…



HashTable

- HashTable can have varying amount of buckets, so start with `num_buckets`.

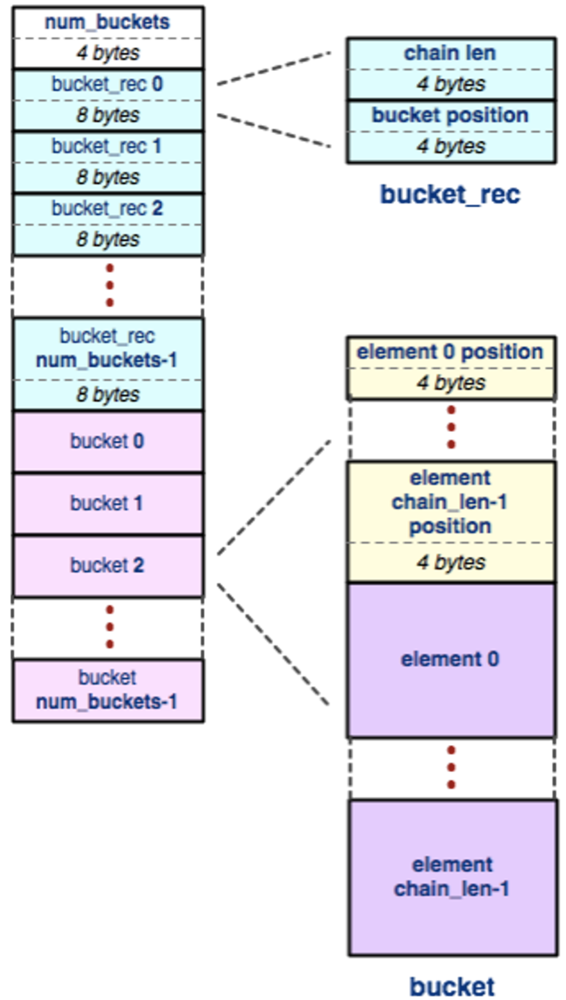
- Buckets can be of varying lengths. To know the offset, we store some bucket records.



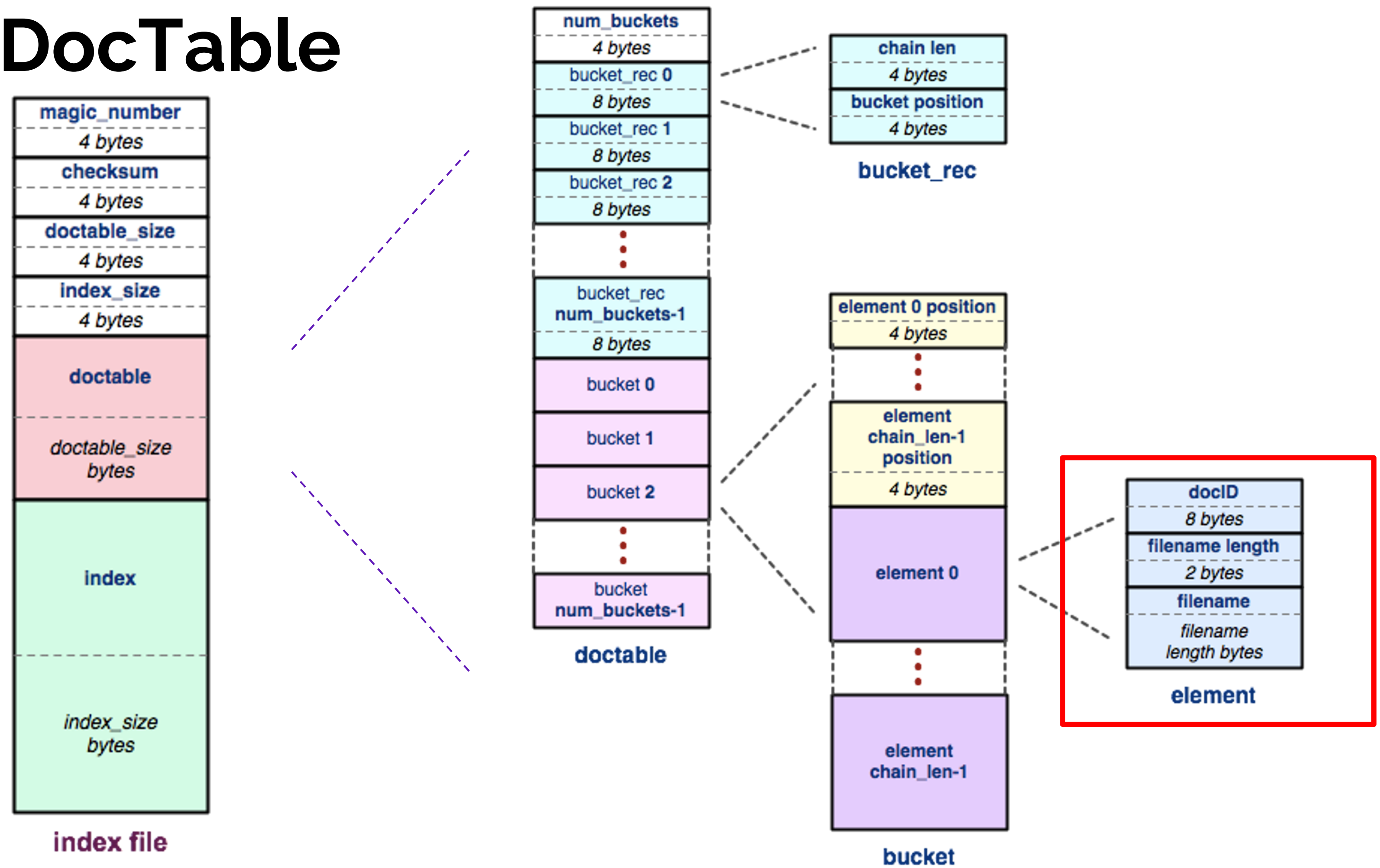
Buckets

- A bucket is a list that contains elements in the table. Offset to a bucket is found in a bucket record.

- Elements can be of various sizes, so we need to store element positions to know where each element is.

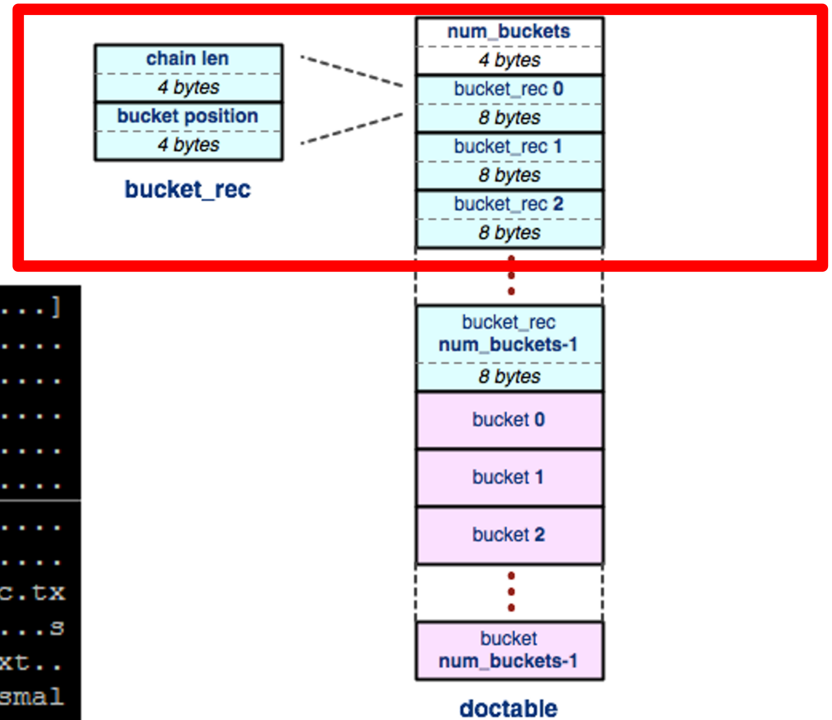


DocTable



magic_number
4 bytes
checksum
4 bytes
doctable_size
4 bytes
index_size
4 bytes
doctable
doctable_size bytes
index
index_size bytes
index file
num_buckets
4 bytes
bucket_rec 0
8 bytes
bucket_rec 1
8 bytes
bucket_rec 2
8 bytes
bucket_rec num_buckets-1
8 bytes
bucket 0
bucket 1
bucket 2
bucket num_buckets-1
doctable
chain len
4 bytes
bucket position
4 bytes
bucket_rec
element 0 position
4 bytes
element chain_len-1 position
4 bytes
element 0
element chain_len-1
bucket
docID
8 bytes
filename length
2 bytes
filename
filename length bytes
element

DocTable (Hex)



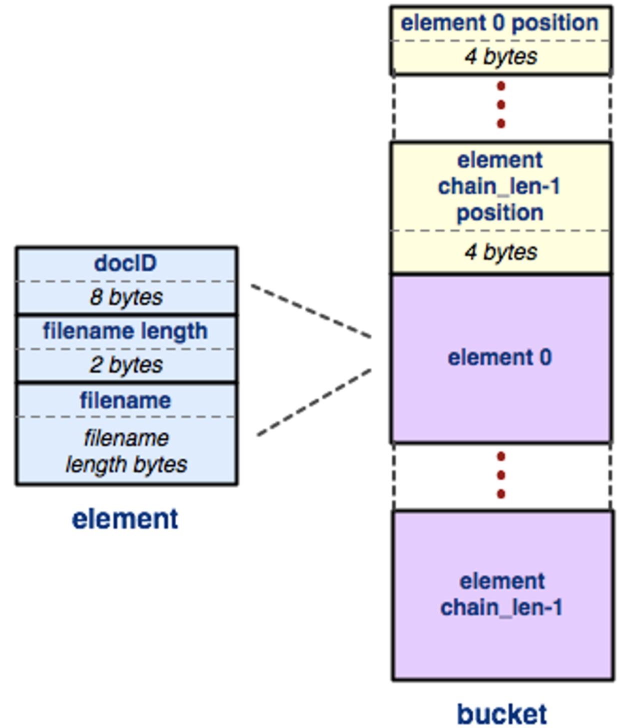

```
0000000: cafe f00d 1c42 4620 0000 205b 0000 075d  .....BF .. [...]
0000010: 0000 0400 0000 0000 0000 2014 0000 0001  .......... .....
0000020: 0000 2014 0000 0001 0000 2031 0000 0001  .. ....... 1....
0000030: 0000 204e 0000 0000 0000 206b 0000 0000  .. N...... k....
0000040: 0000 206b 0000 0000 0000 206b 0000 0000  .. k...... k....
0000050: 0000 206b 0000 0000 0000 206b 0000 0000  .. k...... k....
0002000: 0000 206b 0000 0000 0000 206b 0000 0000  .. k...... k....
0002010: 0000 206b 0000 2018 0000 0000 0000 0001  .. k.. .........
0002020: 000f 736d 616c 6c5f 6469 722f 632e 7478  ..small_dir/c.tx
0002030: 7400 0020 3500 0000 0000 0000 0200 0f73  t.. 5..........s
0002040: 6d61 6c6c 5f64 6972 2f62 2e74 7874 0000  mall_dir/b.txt..
0002050: 2052 0000 0000 0000 0003 000f 736d 616c   R.........smal
0002060: 6c5f 6469 722f 612e 7478 7400 0000 8000  l_dir/a.txt.....
0002070: 0000 0000 0024 6f00 0000 0000 0024 6f00  .....$o......$o.
```

The header

Num buckets (Chain len Bucket offset)*

DocTable

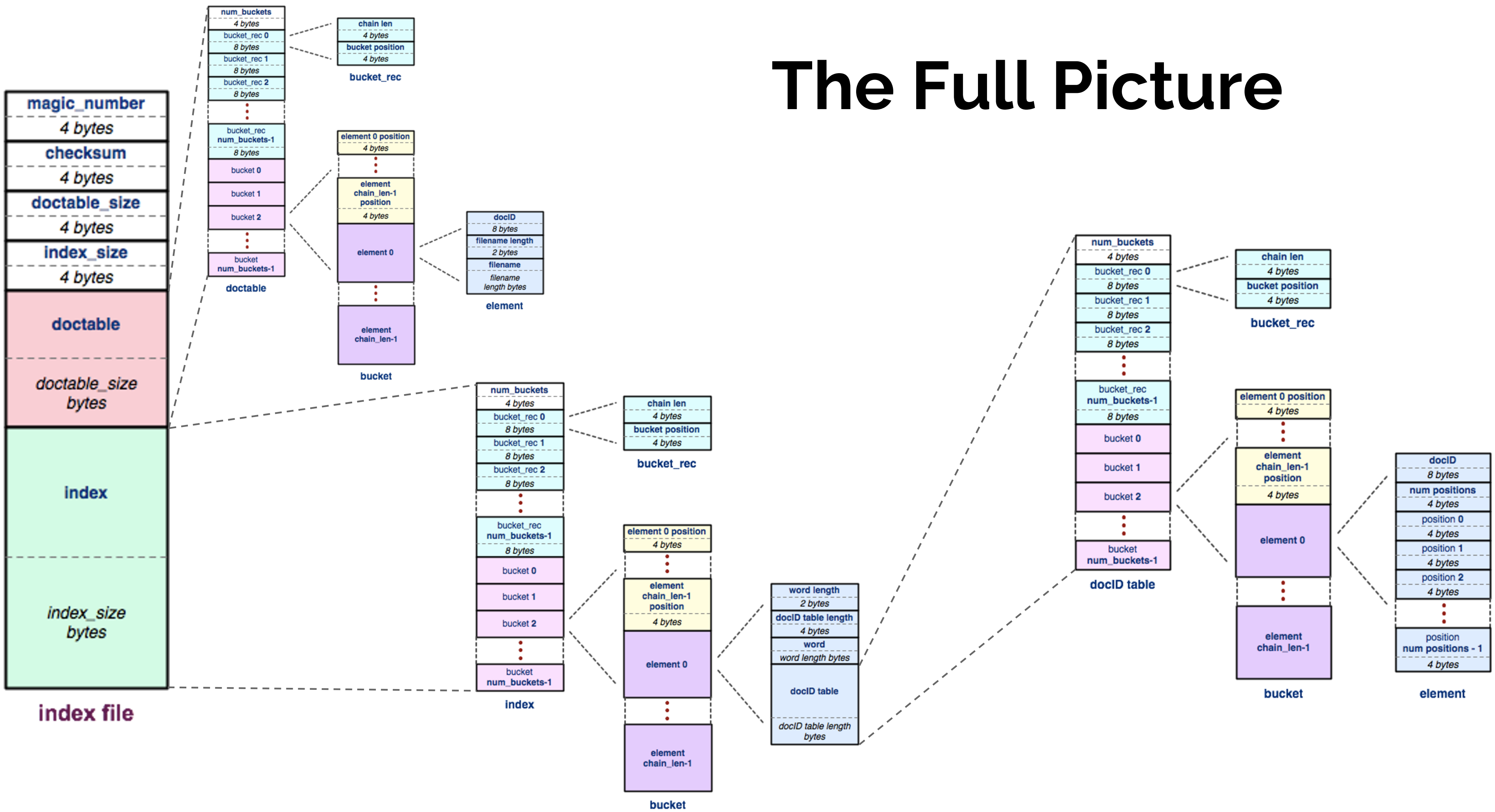
```
0002000: 0000 206b 0000 0000 0000 206b 0000 0000  .. k...... k....
0002010: 0000 206b 0000 2018 0000 0000 0000 0001  .. k.. .........
0002020: 000f 736d 616c 6c5f 6469 722f 632e 7478  ..small_dir/c.tx
0002030: 7400 0020 3500 0000 0000 0000 0200 0f73  t.. 5..........s
0002040: 6d61 6c6c 5f64 6972 2f62 2e74 7874 0000  mall_dir/b.txt..
```



The buckets: where n is equal to the number of elements

((Element offset)^n (DocID Filename len Filename)^n)*

The Full Picture



HW Tips

- When Writing, you should (almost) always:
  1. `.toDiskFormat()`
  2. `fseek()`
  3. `fwrite()`
- When Reading, you should (almost) always:
  1. `fseek()`
  2. `fread()`
  3. `.toHostFormat()`
- The most common bugs in the HW involve forgetting to change byte ordering, or forgetting to `fseek()`.

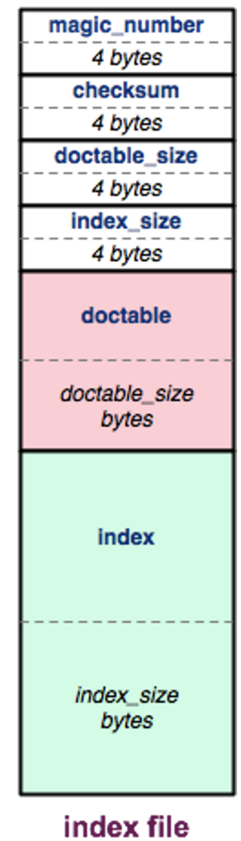
HW Tips: Index Checker (hw3fsck)

- Hw3fsck checks fields inside the file for reasonableness. Prints out a helpful message if it spots some kind of problem.

- More rigorous check on your index file you've produced
  - Run `./hw3fsck index_filename`

- Run after finishing WriteIndex.cc

- Can be found in hw3/hw3fsck directory (and compiled version in solution_binaries also)



Hex View Exercise

- Take a look at https://courses.cs.washington.edu/courses/cse333/22au/sections/sec07.idx
  - Download the file, then look into it using your viewer of choice.
- Try to figure out:
  - How many documents are in this index?
  - Which words are in each document?

Hex View Exercise

- Take a look at https://courses.cs.washington.edu/courses/cse333/22au/sections/sec07.idx
  - Download the file, then look into it using your viewer of choice.
- Try to figure out:
  - How many documents are in this index?
  - Which words are in each document?

Answer: This index file was built off of test_tree/tiny so 2 documents, and 9 words.

Smart Pointers!

Review: Smart Pointers

- **`std::shared_ptr`** (Documentation) – Uses reference counting to determine when to delete a managed raw pointer
  - **`std::weak_ptr`** (Documentation) – Used in conjunction with `shared_ptr` but does **not** contribute to reference count

- **`std::unique_ptr`** (Documentation) – Uniquely manages a raw pointer
  - Used when you want to declare unique ownership of a pointer
  - Disabled `cctor` and `op=`

Using Smart Pointers

- Treat a smart pointer like a **normal (raw) pointer**, except now you **won't** have to use **`delete`** to deallocate memory!
    - You can use `*`, `->`, `[]` as you would with a raw pointer!

- **Initialize** a smart pointer by passing in a pointer to **heap memory**:

```
unique_ptr<int[]> u_ptr(new int[3]);
```

    - For **`shared_ptr`** and **`weak_ptr`**, you can use cctor and op= to get a copy

```
shared_ptr<int[]> s_ptr(another_shared_ptr);
```

Using Smart Pointers cont.

- Want to transfer ownership from one `unique_ptr` to another ?

```
unique_ptr<T> V = std::move(unique_ptr<T> U);
```

- Want to convert your `weak_ptr` to a `shared_ptr`?

```
std::shared_ptr s = w.lock();
```

- Want to get the reference count of a `shared_ptr`?

```
int count = s.use_count();
```

Casting

Different Flavors of Casting

- static_cast<type_to>(expression);
  Casting between related types
- dynamic_cast<type_to>(expression);
  Casting pointers of similar types (only used with inheritance)
- const_cast<type_to>(expression);
  Adding or removing **const**-ness of a type
- reinterpret_cast<type_to>(expression);
  Casting between incompatible types of the **same size** (doesn’t do float conversion)

Tips with Casting

- Style: Use C++ style casting in C++
  - Tradeoff: Extra programming overhead, but provides **clarity** to your programs
  - Be **explicit as possible** with your casting! This means if you notice multiple operations in an implicit cast, you should explicitly write out each cast!

- Read documentation of casting on which casting to use
  - Documentation: https://www.cplusplus.com/articles/iG3hAqkS/
  - The purpose of C++ casting is to be less ambiguous with what casts you're using

Inheritance

Inheritance

- Motivation: Better modularize our code for similar classes!

- The public interface of a derived class inherits all **non-private** member variables and functions (**except** for `ctor`, `cctor`, `dtor`, `op=`) from its base class
  - *Similar to*: A subclass inherits from a superclass

- Aside: We will be only using **public, single** inheritance in CSE 333

Polymorphism: Dynamic Dispatch

- **Polymorphism** allows for you to access objects of related types (base and derived classes) – Allows interface usage instead of class implementation

- **Dynamic dispatch**: Implementation is determined *at* **runtime** via lookup
  - Allows you to call the **most-derived** version of the actual type of an object
  - Generally want to use this when you have a derived class

- `virtual` replaces the class's default **static dispatch** with **dynamic dispatch**
  - Static dispatch determines implementation at compile time
  - Meaning it does **not** use dynamic dispatch (just calls its function)

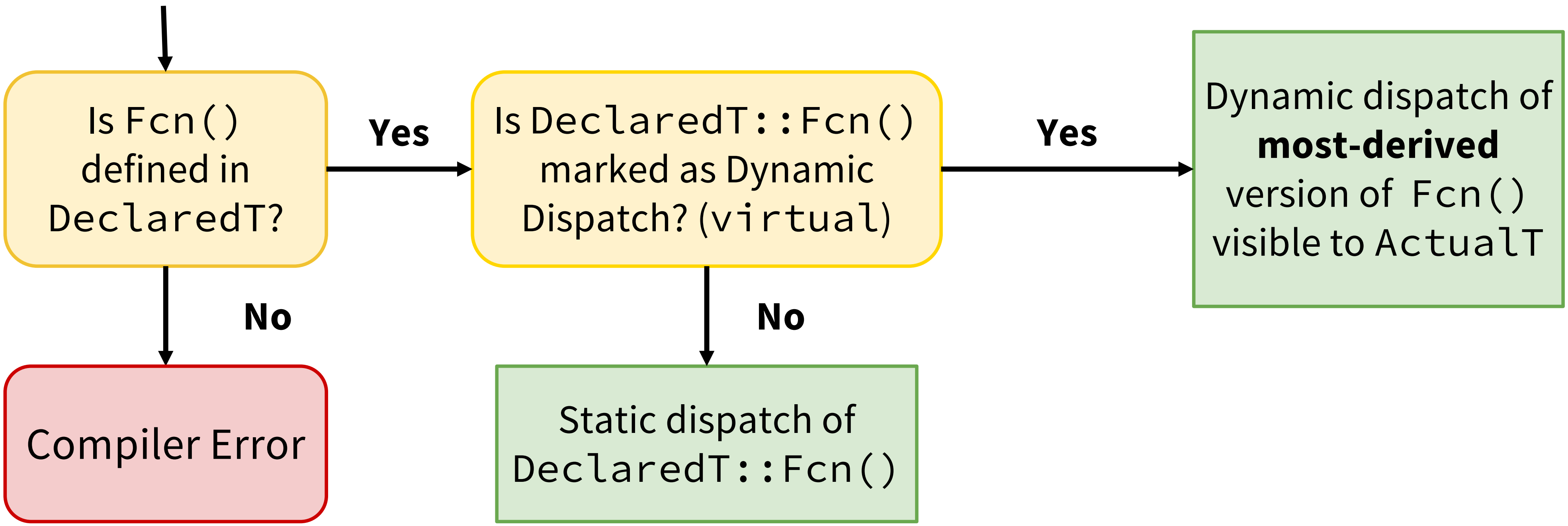
Dynamic Dispatch: Style Considerations

- Defining Dynamic Dispatch in your code base
  - Use `virtual` **only once** when first defined in the base class
    - (although in older code bases you may see it repeated on functions in subclasses)
  - All derived classes of a base class should use `override` to get the compiler to check that a function overrides a virtual function from a base class

- Use `virtual` for destructors of a base class – Guarantees all derived classes will use dynamic dispatch to ensure use of appropriate destructors

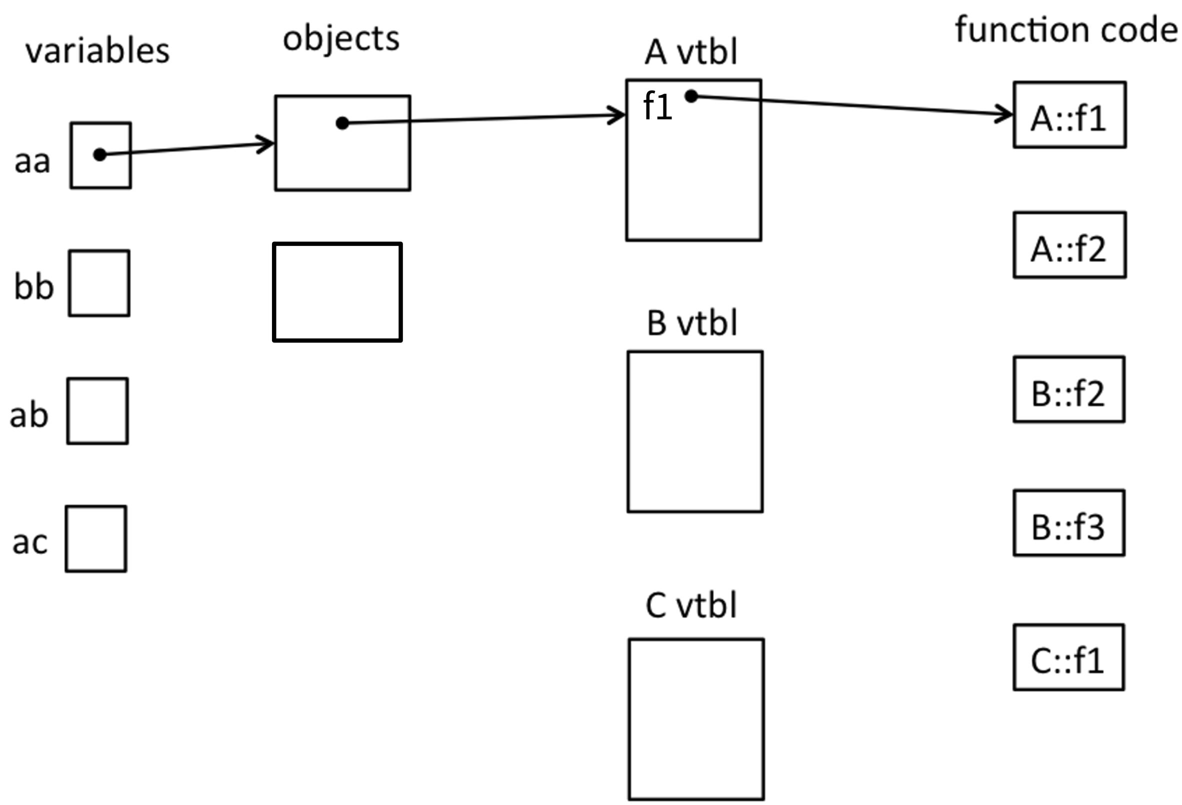
Dispatch Decision Tree

```
DeclaredT* ptr = new ActualT();
ptr->Fcn();  // which version is called?
```



Exercise 1

Exercise 1 (Drawing vtable diagram)



Exercise 1 Solution (pointers)

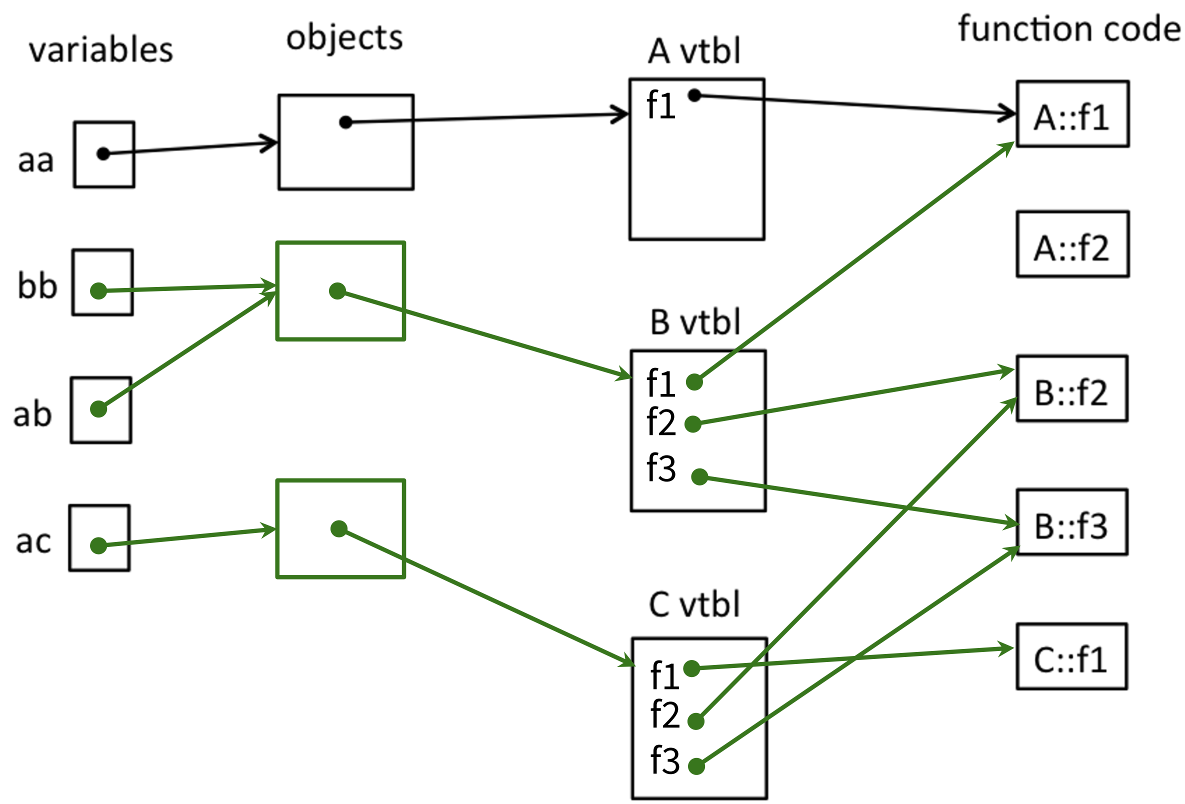
```
#include <iostream>
using namespace std;

class A {
 public:
  virtual void f1() { f2(); cout << "A::f1" << endl; }
  void f2() { cout << "A::f2" << endl; }
};

class B: public A {
 public:
  virtual void f3() { f1(); cout << "B::f3" << endl; }
  virtual void f2() { cout << "B::f2" << endl; }
};

class C: public B {
 public:
  void f1() { f2(); cout << "C::f1" << endl; }
};


int main() {
  A* aa = new A();
  B* bb = new B();
  A* ab = bb;
  A* ac = new C();
```



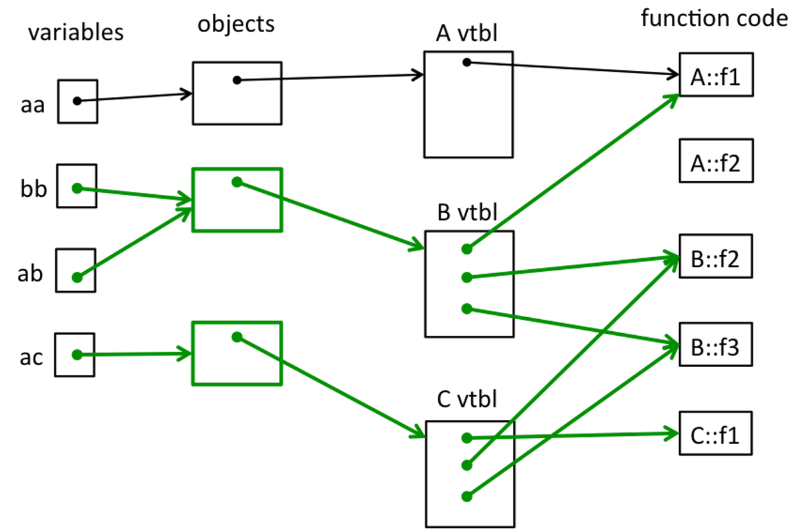
Exercise 1 Solution (output)

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

class A {
 public:
  virtual void f1() { f2(); cout << "A::f1" << endl;
}
  void f2() { cout << "A::f2" << endl; }
};

class B: public A {
 public:
  virtual void f3() { f1(); cout << "B::f3" << endl;
}
  virtual void f2() { cout << "B::f2" << endl; }
};

class C: public B {
 public:
  void f1() { f2(); cout << "C::f1" << endl; }
};
```

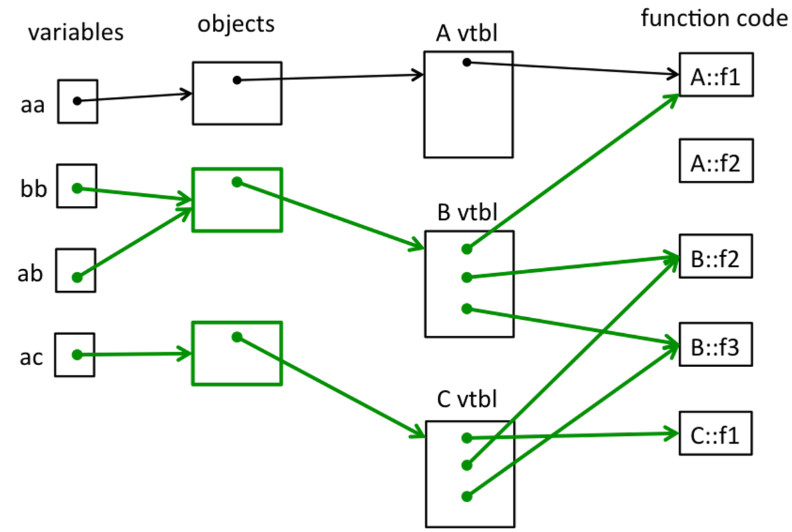



```
A* aa = new A();

aa->f1();
```

A	B	C	D
B::f2 A::f1	A::f2 C::f1	A::f2 A::f1	B::f2 C::f1

Exercise 1 Solution (output)




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

class A {
 public:
  virtual void f1() { f2(); cout << "A::f1" << endl;
}
  void f2() { cout << "A::f2" << endl; }
};

class B: public A {
 public:
  virtual void f3() { f1(); cout << "B::f3" << endl;
}
  virtual void f2() { cout << "B::f2" << endl; }
};

class C: public B {
 public:
  void f1() { f2(); cout << "C::f1" << endl; }
};
```

```
B* bb = new B();

bb->f1();
```

A	B	C	D
B::f2 A::f1	A::f2 C::f1	A::f2 A::f1	B::f2 C::f1

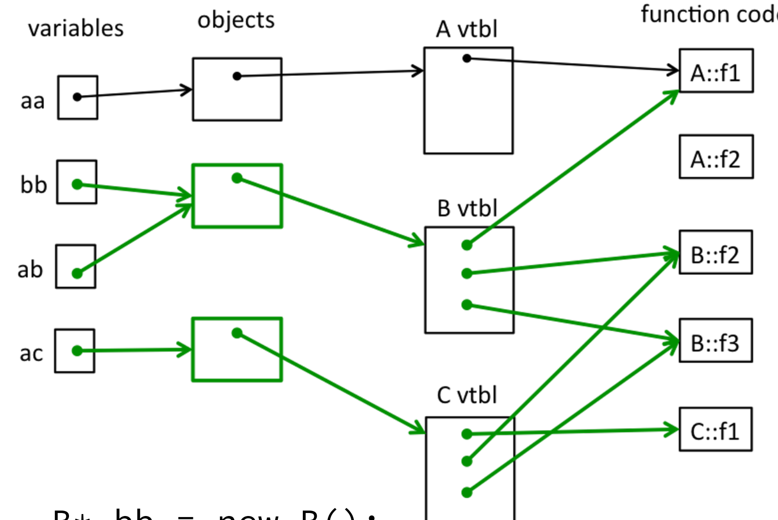
Exercise 1 Solution (output)

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

class A {
 public:
  virtual void f1() { f2(); cout << "A::f1" << endl;
}
  void f2() { cout << "A::f2" << endl; }
};

class B: public A {
 public:
  virtual void f3() { f1(); cout << "B::f3" << endl;
}
  virtual void f2() { cout << "B::f2" << endl; }
};

class C: public B {
 public:
  void f1() { f2(); cout << "C::f1" << endl; }
};
```




```
B* bb = new B();
A* ab = bb;

bb->f2();
cout << "----" << endl;
ab->f2();
```

A	B	C	D
B::f2 ---- B::f2	A::f2 ---- B::f2	B::f2 ---- A::f2	A::f2 ---- A::f2

Exercise 1 Extension

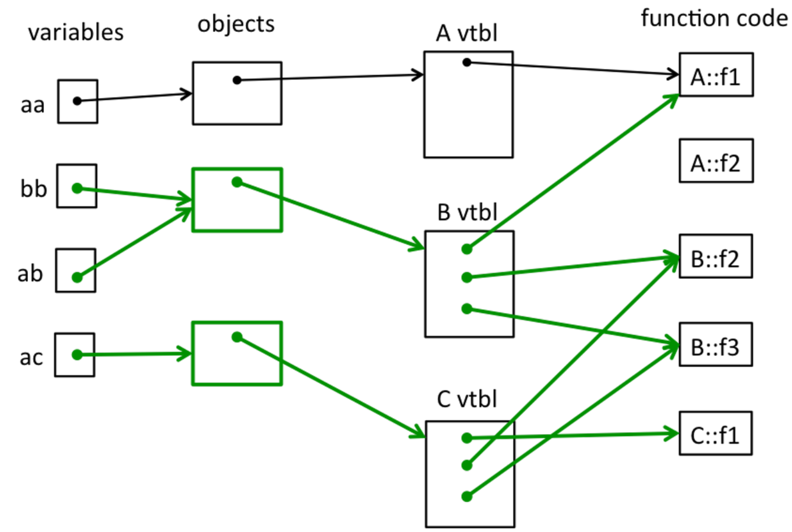
Exercise 2 Solution (output)

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

class A {
 public:
  virtual void f1() { f2(); cout << "A::f1" << endl;
}
  void f2() { cout << "A::f2" << endl; }
};

class B: public A {
 public:
  virtual void f3() { f1(); cout << "B::f3" << endl;
}
  virtual void f2() { cout << "B::f2" << endl; }
};

class C: public B {
 public:
  void f1() { f2(); cout << "C::f1" << endl; }
};
```




```
B* bb = new B();

bb->f3();
```

A	B	C	D
B::f2 A::f1 B::f3	A::f2 A::f1 B::f3	A::f2 C::f1 B::f3	B::f2 C::f1 B::f3

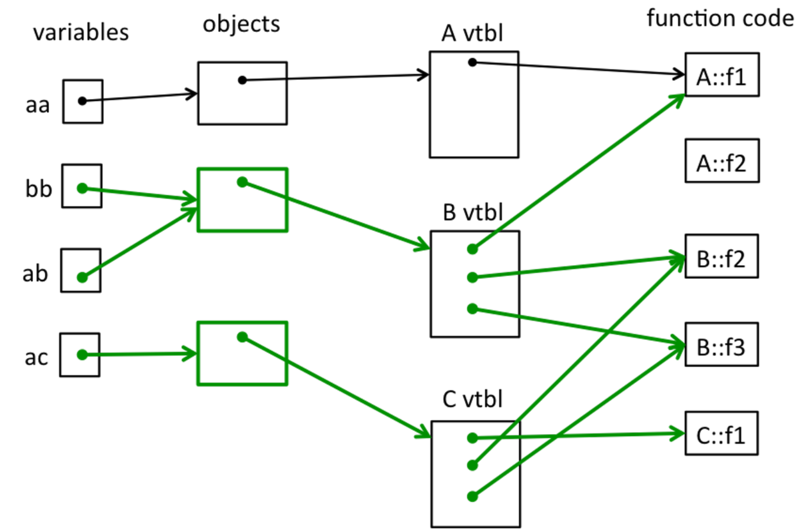
Exercise 2 Solution (output)

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

class A {
 public:
  virtual void f1() { f2(); cout << "A::f1" << endl;
}
  void f2() { cout << "A::f2" << endl; }
};

class B: public A {
 public:
  virtual void f3() { f1(); cout << "B::f3" << endl;
}
  virtual void f2() { cout << "B::f2" << endl; }
};

class C: public B {
 public:
  void f1() { f2(); cout << "C::f1" << endl; }
};
```




```
A* ac = new C();

ac->f1();
```

A	B	C	D
B::f2 A::f1	A::f2 C::f1	A::f2 A::f1	B::f2 C::f1

Bonus Exercise!

Bonus

Change the following code to use smart pointers.

```
#include <memory>
using std::shared_ptr;

struct IntNode {
  IntNode(int* val, IntNode* node): value(val), next(node) {}

  ~IntNode() { delete val; }

  int* value;
  IntNode* next;
};
```

Bonus

```
#include <memory>
using std::shared_ptr;

struct IntNode {
  IntNode(int* val, IntNode* node) :
   value(shared_ptr<int>(val)), next(shared_ptr<IntNode>(node)) {}

  ~IntNode() { delete value; }

  shared_ptr<int> value;
  shared_ptr<IntNode> next;
};
```

Bonus

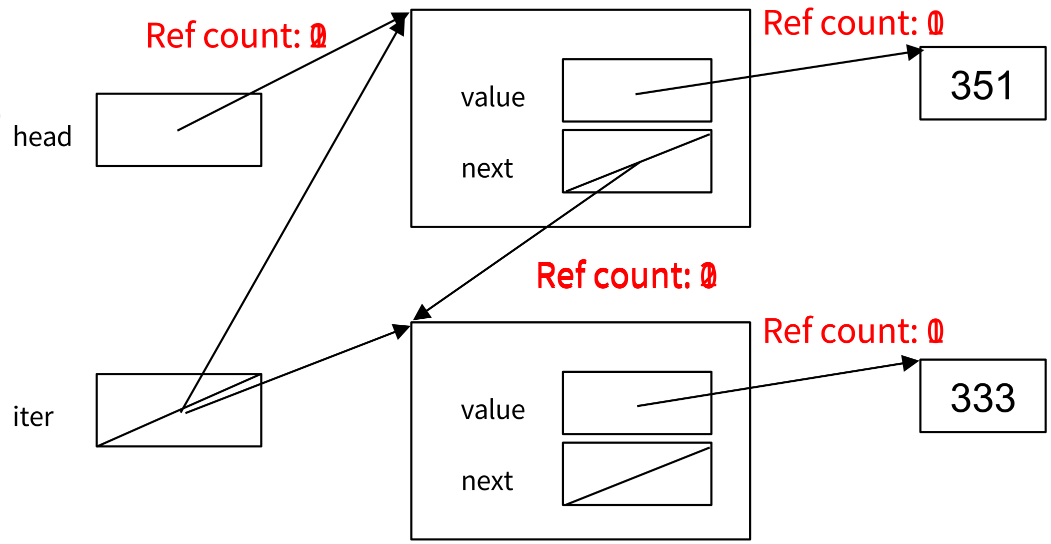
```
#include <memory>
using std::shared_ptr;

struct IntNode {
  IntNode(int* val, IntNode* node) :
   value(shared_ptr<int>(val)), next(shared_ptr<IntNode>(node)) {}

  ~IntNode() { delete value; }

  shared_ptr<int> value;
  shared_ptr<IntNode> next;
};
```

Bonus : Client Code




```
#include <iostream>

using std::cout;
using std::endl;

int main() {
  shared_ptr<IntNode> head(new IntNode(new int(351), nullptr));
  head->next = shared_ptr<IntNode>(new IntNode(new int(333), nullptr));
  shared_ptr<IntNode> iter = head;
  while (iter != nullptr) {
    cout << *(iter->value) << endl;
    iter = iter->next;
  }
}
```

Bonus: Client Code

Nothing left on the heap!

```
#include <iostream>

using std::cout;
using std::endl;

int main() {
  shared_ptr<IntNode> head(new IntNode(new int(351), nullptr));
  head->next = shared_ptr<IntNode>(new IntNode(new int(333), nullptr));
  shared_ptr<IntNode> iter = head;
  while (iter != nullptr) {
    cout << *(iter->value) << endl;
    iter = iter->next;
  }
}
```