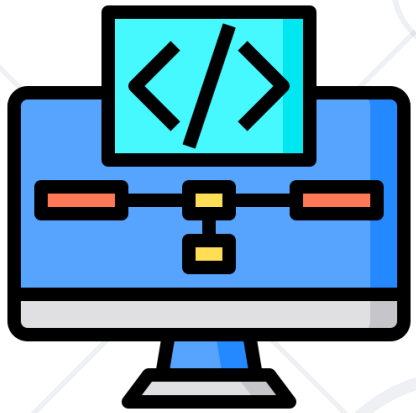
Rule of Three / Five / Zero



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Associating Resources with Object Lifetime

Resource Acquisition is Initialization

- The destructors of local objects are **invoked whenever their scope ends**
- This property is used to cleanup resources automatically, **allocate in a constructor, deallocate in the destructor**
- This way resource usage is tied to object lifetime (RAII)
  - Objects acquire their resources on initialization
  - Objects release their resources on destruction
  - Effect: no resource leaks if no object leaks

RAII in the STL

- Streams are **RAII**
  - Example: file streams open file on construction and close on destruction

```
void writeDataToFile(const std::string& data)
{
  std::ofstream fileStream("log.txt", std::ios::app);
  // acquire resources

  fileStream << data << std::endl;

  fileStream.close(); // manually close the stream
} // destroy stream object
  // even if the stream was not closed
  // the stream dtor would have closed it
```

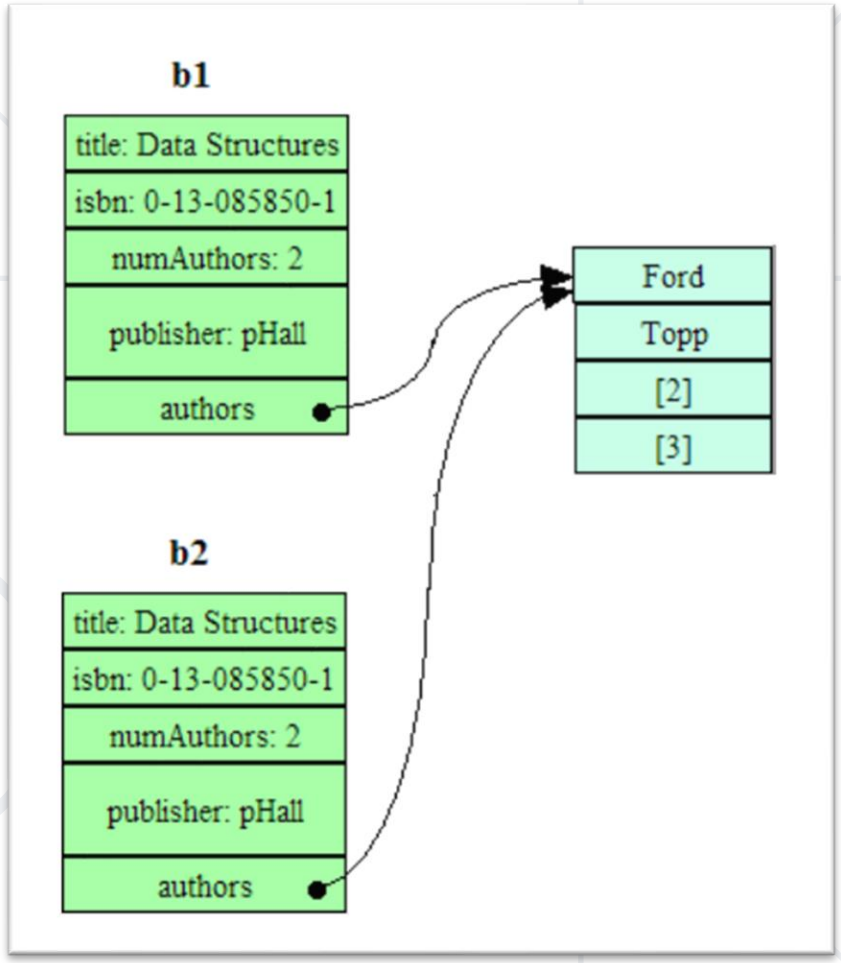
RAII in the STL

- All STL container classes are RAII
  - `vector<T>`, `list<T>`, `map<K, V>`, …
- `smart pointers`
  - `unique_ptr<T>` - only one **owner of the resource**
  - `shared_ptr<T>` - extends RAII **to multiple ownership**
    - Multiple objects own a resource
    - Release when a lifetime of last remaining owner ends

Rule of Three / The Big Three

Ownership and RAII

- The concept of **ownership**: the object responsible for cleaning up a resource owns that resource
- **copy-by-value semantics**: the so-called "**shallow copy**"



Destructors and Copies

- Constructor increases a static value, destructor decreases

```
void example()
{
  Lecturer a("Dandelion", 1),
  b("Geralt", 1.3),
  c("Yen", 4.2);

  vector<Lecturer> lecturers;
  lecturers.push_back(a);
  lecturers.push_back(b);
  lecturers.push_back(c);
}
```

```
class Lecturer
{
  static int Total;
...
public:
  Lecturer(...) ... { Total++; }
  ~Lecturer() { Total--; }
  ...
};

int Lecturer::Total= 0;
```

```
example(); cout << Lecturer::getTotal();
```

The Rule of Three

- Allows programmers to define **copy constructors** and **copy assignment** operators
- If a class **needs one of the following**:
  - **Copy Constructor**
  - **Copy Assignment operator=**
  - **Destructor**
- Then it probably needs ALL of them:

```
IntArray(const IntArray& other) { ... }

IntArray& operator=(const IntArray& other) { ... }

~IntArray() { ... }
```

Copy Construct / Assign

- General guidelines:
  - `new` can cause errors – make sure object state valid in that case
  - Free any **current object resources**
- Patterns:
  - Copy other object data into local variable, then set `this` fields
  - Extract a function to reuse code for copy construct and assign or use the **copy-and-swap idiom**

Copy-and-Swap Idiom

Copy-and-Swap Idiom

- Copy and swap idiom is used for simpler handling of dynamic resource (preventing `new` / `delete` / `delete[]` errors)
- Image a simple SmartArray implementation:

```
template <typename T>
class SmartArray
{
// …
private:
  size_t _size;
  T *_data;
};
```

Copy-and-Swap Idiom

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- The constructor / destructor are trivial:

```
SmartArray(size_t size) : _size(size), _data(_size ? new T[_size] { } : nullptr)
{

}
```

```
~SmartArray()
{
  if (_data)
  {
    delete[] _data;
  }
}
```

Copy-and-Swap Idiom

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- The copy constructor is also trivial:

```
SmartArray(const SmartArray &other)
  : _size(other._size), _data(_size ? new T[_size] { } : nullptr)
{
    std::copy(other._data, other._data + _size, _data);
}
```

Copy-and-Swap Idiom

- Here comes the interesting part:
  - We provide a friend public method swap that can efficiently swap two objects:

```
friend void swap(SmartArray &first, SmartArray &second)
{
  std::swap(first._size, second._size);
  std::swap(first._data, second._data);
}
```

  - Then the copy assignment operator is actually making a copy of the object:

```
SmartArray& operator=(SmartArray other)
{
  swap(*this, other);
  return *this;
}
```

Copy-and-Swap Idiom

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- This way a **new temporary object** is created, it is being populated by the copy constructor
- Then swapped with **the real object**
- The destructor of the previous object (previous this) takes care of deleting **dynamic allocated resources** (if any)

The Rule of Five

The Rule of Five

- If a class needs one of the following:
  - **Copy Constructor**
  - **Copy Assignment operator=**
  - **Destructor**
  - **Move Constructor**
  - **Move Assignment operator=**

Then it probably needs ALL of them:

```
IntArray(const IntArray& other) { ... }
IntArray& operator=(const IntArray& other) { ... }
IntArray(IntArray&& other) { ... }
IntArray& operator=(IntArray&& other) { ... }
~IntArray() { ... }
```

Rule of Five = Rule of Three

- **Rule of Five = Rule of Three**
- Move **construct** / **assign**
  - Custom implementation could also be provided for **Move Constructor** and **Move Assignment Operator**

```
SmartArray(SmartArray &&other) : _data(other._data), _size(other._size)
{
  other._size = 0;
  other._data = nullptr;
}
```

Rule of Five = Rule of Three

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```
SmartArray& operator=(SmartArray &&other)
{
  if (this != &other)
  {
    _data = other._data;
    _size = other._size;

    other._size = 0;
    other._data = nullptr;
  }
  return *this;
}
```

Copy and Swap Idiom for the Rule of Five

- In the implementation of **copy and swap for the Rule of Three** the copy assignment operator was implemented as such:

```
SmartArray& operator=(SmartArray other)
 {
  swap(*this, other);
  return *this;
}
```

Copy and Swap Idiom for the Rule of Five

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- If **move assignment operator** is added:

```
SmartArray& operator=(SmartArray &&other)
{
  //...
}
```

- The compiler will be ambiguous, which assignment operator you want to call
- This would mean that we have to **keep the current implementation** of the copy assignment operator, which now calls only assignment operator

The Rule of Four … and a half

The Rule of Four and a Half

- In order to enable the **Copy and Swap Idiom** for the **move** methods as well
- Given that the assignment operator takes its parameter **by non-const value**
- Only the **move constructor** should be implemented

```
// initialize using the default constructor first
SmartArray(SmartArray &&other) : SmartArray(0)
{
  swap(*this, other);
}
```

Single Responsibility

- If a class has one of **The Three / Five**, then:
  - It manages a **resource** (memory or something else)
  - It should manage a **single** resource
  - It should not do anything other than **manage the resource**
- Internal code deals **with constructors / destructors**
- Having such classes avoids implementing the **Rule of Three / Five ourselves**

Rule of Zero

Delegating Resource Management

Rule of Zero

- STL has **containers**, **smart pointers**, etc.
  - Wrap other resources with classes implementing Rule of 3 (or 5)
- All remaining classes use the above, so:
  - No need for **explicit destructor**
  - No need for **explicit copy-constructor**
  - No need for **explicit copy-assignment operator**
- If you can – **avoid resource management**

Rule of Zero for Array Class

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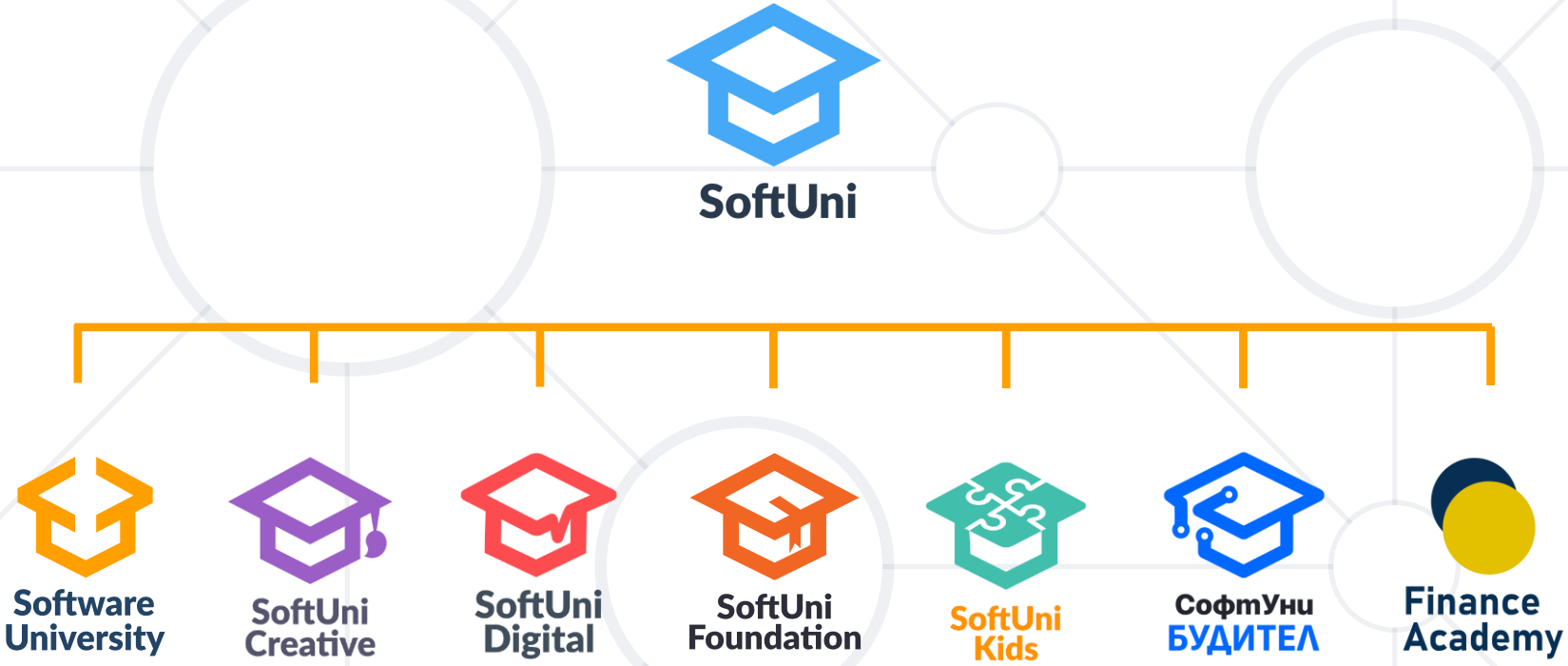
- Avoid memory management – `shared_ptr<int> data;`
- Tell `shared_ptr<T>` to release using array `delete[]`:
  - Second parameter accepts code to execute for deletion
  - `data(..., default_delete<int[]>)`
  - or `data(..., [](int* p) { delete[] p; })`
- No destructors, No copy construction, No copy assignment
- Or just use a `vector<T>`

Summary

- **RAII** – pattern of initializing memory in the constructor
- **Rule of Three** – implement or disable copy members
- **Rule of Zero** – delegate resource management to other classes

Questions?



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