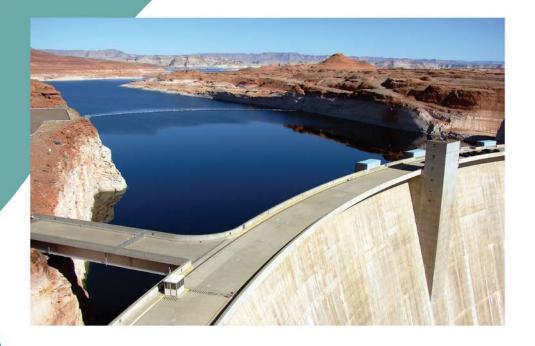
# Large-Scale C++ Volume I

Process and Architecture

John Lakos





# Large-Scale C++

# Large-Scale C++ Volume I: Process and Architecture

# **Table of Contents**

Cover

Half Title

Series Page

Title Page

Copyright Page

Dedication

Contents

**Preface** 

Acknowledgments

Chapter 0: Motivation

- 0.1 The Goal: Faster, Better, Cheaper!
- 0.2 Application vs. Library Software
- 0.3 Collaborative vs. Reusable Software
- 0.4 Hierarchically Reusable Software
- 0.5 Malleable vs. Stable Software
- 0.6 The Key Role of Physical Design
- 0.7 Physically Uniform Software: The Component
- 0.8 Quantifying Hierarchical Reuse: An Analogy
- 0.9 Software Capital
- 0.10 Growing the Investment
- 0.11 The Need for Vigilance



#### 0.12 Summary

#### Chapter 1: Compilers, Linkers, and Components

- 1.1 Knowledge Is Power: The Devil Is in the Details
  - 1.1.1 Hello World!
  - 1.1.2 Creating C++ Programs
  - 1.1.3 The Role of Header Files
- 1.2 Compiling and Linking C++
  - 1.2.1 The Build Process: Using Compilers and Linkers
  - 1.2.2 Classical Atomicity of Object (.o) Files
  - 1.2.3 Sections and Weak Symbols in .o Files
  - 1.2.4 Library Archives
  - 1.2.5 The Singleton Registry Example
  - 1.2.6 Library Dependencies
  - 1.2.7 Link Order and Build-Time Behavior
  - 1.2.8 Link Order and Runtime Behavior
  - 1.2.9 Shared (Dynamically Linked) Libraries
- 1.3 Declarations, Definitions, and Linkage
  - 1.3.1 Declaration vs. Definition
  - 1.3.2 (Logical) Linkage vs. (Physical) Linking
  - 1.3.3 The Need for Understanding Linking Tools
  - 1.3.4 Alternate Definition of Physical Linkage: Bindage
  - 1.3.5 More on How Linkers Work
  - 1.3.6 A Tour of Entities Requiring Program-Wide Unique Addresses
  - 1.3.7 Constructs Where the Callers Compiler Needs the Definitions Source Code
  - 1.3.8 Not All Declarations Require a Definition to Be Useful
  - 1.3.9 The Clients Compiler Typically Needs to See Class Definitions
  - 1.3.10 Other Entities Where Users Compilers Must See the Definition
  - 1.3.11 Enumerations Have External Linkage, but So What?!



- 1.3.12 Inline Functions Are a Somewhat Special Case
- 1.3.13 Function and Class Templates
- 1.3.14 Function Templates and Explicit Specializations
- 1.3.15 Class Templates and Their Partial Specializations
- 1.3.16 extern Templates
- 1.3.17 Understanding the ODR (and Bindage) in Terms of Tools
- 1.3.18 Namespaces
- 1.3.19 Explanation of the Default Linkage of const Entities
- 1.3.20 Summary of Declarations, Definitions, Linkage, and Bindage
- 1.4 Header Files
- 1.5 Include Directives and Include Guards
  - 1.5.1 Include Directives
  - 1.5.2 Internal Include Guards
  - 1.5.3 (Deprecated) External Include Guards
- 1.6 From .h /.cpp Pairs to Components
  - 1.6.1 Component Property 1
  - 1.6.2 Component Property 2
  - 1.6.3 Component Property 3
- 1.7 Notation and Terminology
  - 1.7.1 Overview
  - 1.7.2 The Is-A Logical Relationship
  - 1.7.3 The Uses-In-The-Interface Logical Relationship
  - 1.7.4 The Uses-In-The-Implementation Logical Relationship
  - 1.7.5 The Uses-In-Name-Only Logical Relationship and the Protocol Class
  - 1.7.6 In-Structure-Only (ISO) Collaborative Logical Relationships
  - 1.7.7 How Constrained Templates and Interface Inheritance Are Similar
  - 1.7.8 How Constrained Templates and Interface Inheritance Differ
    - 1.7.8.1 Constrained Templates, but Not Interface Inheritance
    - 1.7.8.2 Interface Inheritance, but Not Constrained Templates



- 1.7.9 All Three Inheriting Relationships Add Unique Value
- 1.7.10 Documenting Type Constraints for Templates
- 1.7.11 Summary of Notation and Terminology
- 1.8 The Depends-On Relation
- 1.9 Implied Dependency
- 1.10 Level Numbers
- 1.11 Extracting Actual Dependencies
  - 1.11.1 Component Property 4
- 1.12 Summary

#### Chapter 2: Packaging and Design Rules

- 2.1 The Big Picture
- 2.2 Physical Aggregation
  - 2.2.1 General Definition of Physical Aggregate
  - 2.2.2 Small End of Physical-Aggregation Spectrum
  - 2.2.3 Large End of Physical-Aggregation Spectrum
  - 2.2.4 Conceptual Atomicity of Aggregates
  - 2.2.5 Generalized Definition of Dependencies for Aggregates
  - 2.2.6 Architectural Significance
  - 2.2.7 Architectural Significance for General UORs
  - 2.2.8 Parts of a UOR That Are Architecturally Significant
  - 2.2.9 What Parts of a UOR Are Not Architecturally Significant?
  - 2.2.10 A Component Is Naturally Architecturally Significant
  - 2.2.11 Does a Component Really Have to Be a .h /.cpp Pair?
  - 2.2.12 When, If Ever, Is a .h /.cpp Pair Not Good Enough?
  - 2.2.13 Partitioning a .cpp File Is an Organizational-Only Change
  - 2.2.14 Entity Manifest and Allowed Dependencies
  - 2.2.15 Need for Expressing Envelope of Allowed Dependencies
  - 2.2.16 Need for Balance in Physical Hierarchy



- 2.2.17 Not Just Hierarchy, but Also Balance
- 2.2.18 Having More Than Three Levels of Physical Aggregation Is Too Many
- 2.2.19 Three Levels Are Enough Even for Larger Systems
- 2.2.20 UORs Always Have Two or Three Levels of Physical Aggregation
- 2.2.21 Three Balanced Levels of Aggregation Are Sufficient. Trust Me!
- 2.2.22 There Should Be Nothing Architecturally Significant Larger Than a UOR
- 2.2.23 Architecturally Significant Names Must Be Unique
- 2.2.24 No Cyclic Physical Dependencies!
- 2.2.25 Section Summary
- 2.3 Logical/Physical Coherence
- 2.4 Logical and Physical Name Cohesion
  - 2.4.1 History of Addressing Namespace Pollution
  - 2.4.2 Unique Naming Is Required; Cohesive Naming Is Good for Humans
  - 2.4.3 Absurd Extreme of Neither Cohesive nor Mnemonic Naming
  - 2.4.4 Things to Make Cohesive
  - 2.4.5 Past/Current Definition of Package
  - 2.4.6 The Point of Use Should Be Sufficient to Identify Location
  - 2.4.7 Proprietary Software Requires an Enterprise Namespace
  - 2.4.8 Logical Constructs Should Be Nominally Anchored to Their Component
  - 2.4.9 Only Classes, structs, and Free Operators at Package-Namespace Scope
  - 2.4.10 Package Prefixes Are Not Just Style
  - 2.4.11 Package Prefixes Are How We Name Package Groups
  - 2.4.12 using Directives and Declarations Are Generally a BAD IDEA
  - 2.4.13 Section Summary
- 2.5 Component Source-Code Organization
- 2.6 Component Design Rules
- 2.7 Component-Private Classes and Subordinate Components
  - 2.7.1 Component-Private Classes
  - 2.7.2 There Are Several Competing Implementation Alternatives



- 2.7.3 Conventional Use of Underscore
- 2.7.4 Classic Example of Using Component-Private Classes
- 2.7.5 Subordinate Components
- 2.7.6 Section Summary

#### 2.8 The Package

- 2.8.1 Using Packages to Factor Subsystems
- 2.8.2 Cycles Among Packages Are BAD
- 2.8.3 Placement, Scope, and Scale Are an Important First Consideration
- 2.8.4 The Inestimable Communicative Value of (Unique) Package Prefixes
- 2.8.5 Section Summary

#### 2.9 The Package Group

- 2.9.1 The Third Level of Physical Aggregation
- 2.9.2 Organizing Package Groups During Deployment
- 2.9.3 How Do We Use Package Groups in Practice?
- 2.9.4 Decentralized (Autonomous) Package Creation
- 2.9.5 Section Summary

#### 2.10 Naming Packages and Package Groups

- 2.10.1 Intuitively Descriptive Package Names Are Overrated
- 2.10.2 Package-Group Names
- 2.10.3 Package Names
- 2.10.4 Section Summary
- 2.11 Subpackages
- 2.12 Legacy, Open-Source, and Third-Party Software
- 2.13 Applications
- 2.14 The Hierarchical Testability Requirement
  - 2.14.1 Leveraging Our Methodology for Fine-Grained Unit Testing
  - 2.14.2 Plan for This Section (Plus Plug for Volume II and Especially Volume III)
  - 2.14.3 Testing Hierarchically Needs to Be Possible
  - 2.14.4 Relative Import of Local Component Dependencies with Respect to



#### Testing

- 2.14.5 Allowed Test-Driver Dependencies Across Packages
- 2.14.6 Minimize Test-Driver Dependencies on the External Environment
- 2.14.7 Insist on a Uniform (Standalone) Test-Driver Invocation Interface
- 2.14.8 Section Summary

#### 2.15 From Development to Deployment

- 2.15.1 The Flexible Deployment of Software Should Not Be Compromised
- 2.15.2 Having Unique .h and .o Names Are Key
- 2.15.3 Software Organization Will Vary During Development
- 2.15.4 Enterprise-Wide Unique Names Facilitate Refactoring
- 2.15.5 Software Organization May Vary During Just the Build Process
- 2.15.6 Flexibility in Deployment Is Needed Even Under Normal Circumstances
- 2.15.7 Flexibility Is Also Important to Make Custom Deployments Possible
- 2.15.8 Flexibility in Stylistic Rendering Within Header Files
- 2.15.9 How Libraries Are Deployed Is Never Architecturally Significant
- 2.15.10 Partitioning Deployed Software for Engineering Reasons
- 2.15.11 Partitioning Deployed Software for Business Reasons
- 2.15.12 Section Summary

#### 2.16 Metadata

- 2.16.1 Metadata Is By Decree
- 2.16.2 Types of Metadata
  - 2.16.2.1 Dependency Metadata
  - 2.16.2.2 Build Requirements Metadata
  - 2.16.2.3 Membership Metadata
  - 2.16.2.4 Enterprise-Specific Policy Metadata
- 2.16.3 Metadata Rendering
- 2.16.4 Metadata Summary
- 2.17 Summary

Chapter 3: Physical Design and Factoring



#### 3.1 Thinking Physically

- 3.1.1 Pure Classical (Logical) Software Design Is Naive
- 3.1.2 Components Serve as Our Fine-Grained Modules
- 3.1.3 The Software Design Space Has Direction
  - 3.1.3.1 Example of Relative Physical Position: Abstract Interfaces
- 3.1.4 Software Has Absolute Location
  - 3.1.4.1 Asking the Right Questions Helps Us Determine Optimal Location
  - 3.1.4.2 See What Exists to Avoid Reinventing the Wheel
  - 3.1.4.3 Good Citizenship: Identifying Proper Physical Location
- 3.1.5 The Criteria for Colocation Should Be Substantial, Not Superficial
- 3.1.6 Discovery of Nonprimitive Functionality Absent Regularity Is Problematic
- 3.1.7 Package Scope Is an Important Design Consideration
  - 3.1.7.1 Package Charter Must Be Delineated in Package-Level Documentation
  - 3.1.7.2 Package Prefixes Are at Best Mnemonic Tags, Not Descriptive Names
  - 3.1.7.3 Package Prefixes Force Us to Consider Design More Globally Early
  - 3.1.7.4 Package Prefixes Force Us to Consider Package Dependencies from the Start
  - 3.1.7.5 Even Opaque Package Prefixes Grow to Take On Important Meaning
  - 3.1.7.6 Effective (e.g., Associative) Use of Package Names Within Groups
- 3.1.8 Limitations Due to Prohibition on Cyclic Physical Dependencies
- 3.1.9 Constraints on Friendship Intentionally Preclude Some Logical Designs
- 3.1.10 Introducing an Example That Justifiably Requires Wrapping
  - 3.1.10.1 Wrapping Just the Time Series and Its Iterator in a Single Component
  - 3.1.10.2 Private Access Within a Single Component Is an Implementation Detail
  - 3.1.10.3 An Iterator Helps to Realize the Open-Closed Principle
  - 3.1.10.4 Private Access Within a Wrapper Component Is Typically Essential
  - 3.1.10.5 Since This Is Just a Single-Component Wrapper, We Have Several Options
  - 3.1.10.6 Multicomponent Wrappers, Not Having Private Access, Are Problematic
  - 3.1.10.7 Example Why Multicomponent Wrappers Typically Need Special Access
  - 3.1.10.8 Wrapping Interoperating Components Separately Generally Doesnt Work
  - 3.1.10.9 What Should We Do When Faced with a Multicomponent Wrapper?
- 3.1.11 Section Summary
- 3.2 Avoiding Poor Physical Modularity



- 3.2.1 There Are Many Poor Modularization Criteria; Syntax Is One of Them
- 3.2.2 Factoring Out Generally Useful Software into Libraries Is Critical
- 3.2.3 Failing to Maintain Application/Library Modularity Due to Pressure
- 3.2.4 Continuous Demotion of Reusable Components Is Essential
  - 3.2.4.1 Otherwise, in Time, Our Software Might Devolve into a Big Ball of Mud!
- 3.2.5 Physical Dependency Is Not an Implementation Detail to an App Developer
- 3.2.6 Iterators Can Help Reduce What Would Otherwise Be Primitive Functionality
- 3.2.7 Not Just Minimal, Primitive: The Utility struct
- 3.2.8 Concluding Example: An Encapsulating Polygon Interface
  - 3.2.8.1 What Other UDTs Are Used in the Interface?
  - 3.2.8.2 What Invariants Should our::Polygon Impose?
  - 3.2.8.3 What Are the Important Use Cases?
  - 3.2.8.4 What Are the Specific Requirements?
  - 3.2.8.5 Which Required Behaviors Are Primitive and Which Arent?
  - 3.2.8.6 Weighing the Implementation Alternatives
  - 3.2.8.7 Achieving Two Out of Three Aint Bad
  - 3.2.8.8 Primitiveness vs. Flexibility of Implementation
  - 3.2.8.9 Flexibility of Implementation Extends Primitive Functionality
  - 3.2.8.10 Primitiveness Is Not a Draconian Requirement
  - 3.2.8.11 What About Familiar Functionality Such as Perimeter and Area?
  - 3.2.8.12 Providing Iterator Support for Generic Algorithms
  - 3.2.8.13 Focus on Generally Useful Primitive Functionality
  - 3.2.8.14 Suppress Any Urge to Colocate Nonprimitive Functionality
  - 3.2.8.15 Supporting Unusual Functionality
- 3.2.9 Semantics vs. Syntax as Modularization Criteria
  - 3.2.9.1 Poor Use of uas a Package Suffix
  - 3.2.9.2 Good Use of util as a Component Suffix
- 3.2.10 Section Summary
- 3.3 Grouping Things Physically That Belong Together Logically
  - 3.3.1 Four Explicit Criteria for Class Colocation



3.3.1.1 First Reason: Friendship 3.3.1.2 Second Reason: Cyclic Dependency 3.3.1.3 Third Reason: Single Solution 3.3.1.4 Fourth Reason: Flea on an Elephant 3.3.2 Colocation Beyond Components 3.3.3 When to Make Helper Classes Private to a Component 3.3.4 Colocation of Template Specializations 3.3.5 Use of Subordinate Components 3.3.6 Colocate Tight Mutual Collaboration within a Single UOR 3.3.7 Day-Count Example 3.3.8 Final Example: Single-Threaded Reference-Counted Functors 3.3.8.1 Brief Review of Event-Driven Programming 3.3.8.2 Aggregating Components into Packages 3.3.8.3 The Final Result 3.3.9 Section Summary 3.4 Avoiding Cyclic Link-Time Dependencies 3.5 Levelization Techniques 3.5.1 Classic Levelization 3.5.2 Escalation 3.5.3 Demotion 3.5.4 Opaque Pointers 3.5.4.1 Manager/Employee Example 3.5.4.2 Event/EventQueue Example 3.5.4.3 Graph/Node/Edge Example 3.5.5 Dumb Data 3.5.6 Redundancy 3.5.7 Callbacks 3.5.7.1 Data Callbacks 3.5.7.2 Function Callbacks



3.5.7.3 Functor Callbacks 3.5.7.4 Protocol Callbacks

- 3.5.7.5 Concept Callbacks
- 3.5.8 Manager Class
- 3.5.9 Factoring
- 3.5.10 Escalating Encapsulation
  - 3.5.10.1 A More General Solution to Our Graph Subsystem
  - 3.5.10.2 Encapsulating the Use of Implementation Components
  - 3.5.10.3 Single-Component Wrapper
  - 3.5.10.4 Overhead Due to Wrapping
  - 3.5.10.5 Realizing Multicomponent Wrappers
  - 3.5.10.6 Applying This New, Heretical Technique to Our Graph Example
  - 3.5.10.7 Why Use This Magic reinterpret\_cast Technique?
  - 3.5.10.8 Wrapping a Package-Sized System
  - 3.5.10.9 Benefits of This Multicomponent-Wrapper Technique
  - 3.5.10.10 Misuse of This Escalating-Encapsulation Technique
  - 3.5.10.11 Simulating a Highly Restricted Form of Package-Wide Friendship
- 3.5.11 Section Summary
- 3.6 Avoiding Excessive Link-Time Dependencies
  - 3.6.1 An Initially Well-Factored Date Class That Degrades Over Time
  - 3.6.2 Adding Business-Day Functionality to a Date Class (BAD IDEA)
  - 3.6.3 Providing a Physically Monolithic Platform Adapter (BAD IDEA)
  - 3.6.4 Section Summary
- 3.7 Lateral vs. Layered Architectures
  - 3.7.1 Yet Another Analogy to the Construction Industry
  - 3.7.2 (Classical) Layered Architectures
  - 3.7.3 Improving Purely Compositional Designs
  - 3.7.4 Minimizing Cumulative Component Dependency (CCD)
    - 3.7.4.1 Cumulative Component Dependency (CCD) Defined
    - 3.7.4.2 Cumulative Component Dependency: A Concrete Example
  - 3.7.5 Inheritance-Based Lateral Architectures
  - 3.7.6 Testing Lateral vs. Layered Architectures
  - 3.7.7 Section Summary



#### 3.8 Avoiding Inappropriate Link-Time Dependencies

- 3.8.1 Inappropriate Physical Dependencies
- 3.8.2 Betting on a Single Technology (BAD IDEA)
- 3.8.3 Section Summary

#### 3.9 Ensuring Physical Interoperability

- 3.9.1 Impeding Hierarchical Reuse Is a BAD IDEA
- 3.9.2 Domain-Specific Use of Conditional Compilation Is a BAD IDEA
- 3.9.3 Application-Specific Dependencies in Library Components Is a BAD IDEA
- 3.9.4 Constraining Side-by-Side Reuse Is a BAD IDEA
- 3.9.5 Guarding Against Deliberate Misuse Is Not a Goal
- 3.9.6 Usurping Global Resources from a Library Component Is a BAD IDEA
- 3.9.7 Hiding Header Files to Achieve Logical Encapsulation Is a BAD IDEA
- 3.9.8 Depending on Nonportable Software in Reusable Libraries Is a BAD IDEA
- 3.9.9 Hiding Potentially Reusable Software Is a BAD IDEA
- 3.9.10 Section Summary

#### 3.10 Avoiding Unnecessary Compile-Time Dependencies

- 3.10.1 Encapsulation Does Not Preclude Compile-Time Coupling
- 3.10.2 Shared Enumerations and Compile-Time Coupling
- 3.10.3 Compile-Time Coupling in C++ Is Far More Pervasive Than in C
- 3.10.4 Avoiding Unnecessary Compile-Time Coupling
- 3.10.5 Real-World Example of Benefits of Avoiding Compile-Time Coupling
- 3.10.6 Section Summary

#### 3.11 Architectural Insulation Techniques

- 3.11.1 Formal Definitions of Encapsulation vs. Insulation
- 3.11.2 Illustrating Encapsulation vs. Insulation in Terms of Components
- 3.11.3 Total vs. Partial Insulation
- 3.11.4 Architecturally Significant Total-Insulation Techniques
- 3.11.5 The Pure Abstract Interface (Protocol) Class
  - 3.11.5.1 Extracting a Protocol



3.11.5.2 Equivalent Bridge Pattern
3.11.5.3 Effectiveness of Protocols as Insulators
3.11.5.4 Implementation-Specific Interfaces
3.11.5.5 Static Link-Time Dependencies
3.11.5.6 Runtime Overhead for Total Insulation
3.11.6 The Fully Insulating Concrete Wrapper Component
3.11.6.1 Poor Candidates for Insulating Wrappers
3.11.7 The Procedural Interface
3.11.7.1 What Is a Procedural Interface?
3.11.7.2 When Is a Procedural Interface Indicated?
3.11.7.3 Essential Properties and Architecture of a Procedural Interface
3.11.7.4 Physical Separation of PI Functions from Underlying C++ Components
3.11.7.5 Mutual Independence of PI Functions
3.11.7.6 Absence of Physical Dependencies Within the PI Layer
3.11.7.7 Absence of Supplemental Functionality in the PI Layer
3.11.7.8 1-1 Mapping from PI Components to Lower-Level Components (Using the z $\_$ Prefix)
3.11.7.9 Example: Simple (Concrete) Value Type
3.11.7.10 Regularity/Predictability of PI Names
3.11.7.11 PI Functions Callable from C++ as Well as C
3.11.7.12 Actual Underlying C++ Types Exposed Opaquely for C++ Clients
3.11.7.13 Summary of Essential Properties of the PI Layer
3.11.7.14 Procedural Interfaces and Return-by-Value
3.11.7.15 Procedural Interfaces and Inheritance
3.11.7.16 Procedural Interfaces and Templates
3.11.7.17 Mitigating Procedural-Interface Costs
3.11.7.18 Procedural Interfaces and Exceptions
3.11.8 Insulation and DLLs
3.11.9 Service-Oriented Architectures
3.11.10 Section Summary



3.12 Designing with Components

3.12.1 The Requirements as Originally Stated3.12.2 The Actual (Extrapolated) Requirements

- 3.12.3 Representing a Date Value in Terms of a C++ Type
- 3.12.4 Determining What Date V alue Today Is
- 3.12.5 Determining If a Date Value Is a Business Day
  - 3.12.5.1 Calendar Requirements
  - 3.12.5.2 Multiple Locale Lookups
  - 3.12.5.3 Calendar Cache
  - 3.12.5.4 Application-Level Use of Calendar Library
- 3.12.6 Parsing and Formatting Functionality
- 3.12.7 Transmitting and Persisting Values
- 3.12.8 Day-Count Conventions
- 3.12.9 Date Math
  - 3.12.9.1 Auxiliary Date-Math Types
- 3.12.10 Date and Calendar Utilities
- 3.12.11 Fleshing Out a Fully Factored Implementation
  - 3.12.11.1 Implementing a Hierarchically Reusable Date Class
  - 3.12.11.2 Representing Value in the Date Class
  - 3.12.11.3 Implementing a Hierarchically Reusable Calendar Class
  - 3.12.11.4 Implementing a Hierarchically Reusable PackedCalendar Class
  - 3.12.11.5 Distribution Across Existing Aggregates
- 3.12.12 Section Summary
- 3.13 Summary

#### Conclusion

Appendix: Quick Reference

Bibliography

Index

