SWEG2102 Fall 2026

Fundamentals of Programming II

Lecture 10

File Management (Part II)

Handling Binary Files

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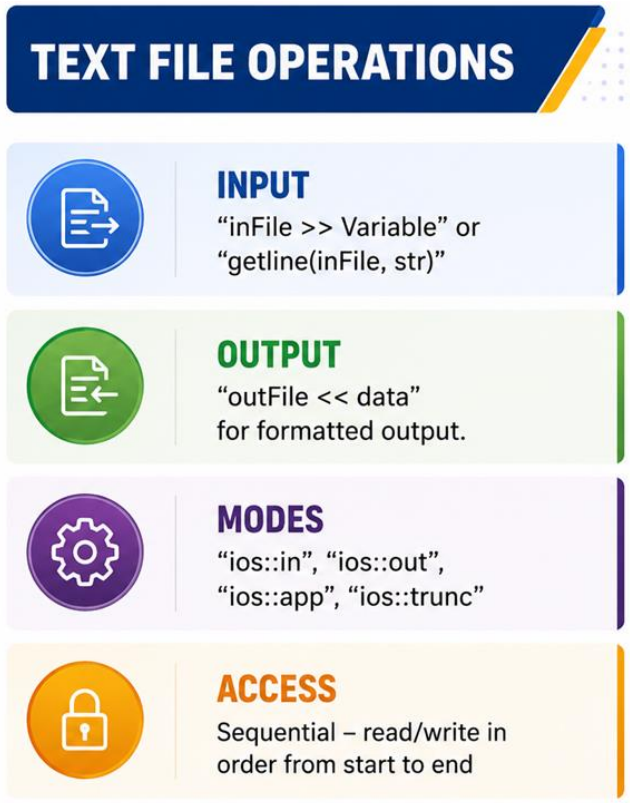
C++ **Standard ISO/IEC 14882**
Programming Language

Recap

Topics covered in previous sessions:

👉 Handling Text Files

- Introduction to File Management
- Types of Files & File Operations
- File Streams in C++
- Opening & Closing Files
- Writing to and Reading from Text Files
- File Operation Error Handling
- Practical Integrated Example



Outline

Topics Covered

01 Binary File Concepts & Representation

02 Advantages & Limitations of Binary Files

03 Opening, Writing and Reading Binary Files

04 **Serialization Concepts & Applications**

05 Random Access Files & File Pointers

06 Integrated Practical Example

07 Common Errors & Best Practices

Learning Objectives

By the end of this lecture, you will be able to:

- Explain **binary file** concepts and distinguish them from text files.
- Describe the advantages, limitations, and common applications of binary files.
- Apply C++ **file stream** classes to open, close, read from, and write to binary files.
- Explain **serialization** and apply them to store and retrieve structured data.
- Apply random access operations using: seekg(), seekp(), tellg() & tellp()
- Develop small C++ programs that integrate binary file handling concepts.
- Identify common binary file operation errors and apply best practices.

Binary File Concepts

What is a Binary File?

Definition box:

A binary file is a file stores data as raw bytes – exactly as it exists in memory.

Unlike text files, binary are not human-readable and do not use character encoding

👉 Key Characteristics ?

- **Byte-level storage:** Data stored as raw bytes (value 0-255)
- **Exact representation:** Mirror the memory layout precisely
- **Non-text format:** Cannot be opened or read with Notepad
- **Platform-Specific:** May have endianness difference across system.

Text Vs. Binary Representation

👉 Text Representation

- Character stored as ASCII codes
- ‘1’ = 0x31, ‘2’ = 0x32, ‘3’ = 0x33, ‘4’ = 0x34, ‘5’ = 0x35
- **Total size: 5bytes**
- **Human-readable**

👉 Binary Representation

- Integer stored as 4-byte binary value
- ‘0x00 0x00 0x30 0x39’ = 12345 in memory
- **Total size: 4 bytes**
- Efficient ✅ | Not human-readable ❌

Binary Files Advantages and Disadvantages

👉 Advantages

- ✓ **Smaller File Size** — 30–50% smaller than text files for numeric data
- ✓ **Faster I/O** — No text parsing or conversion needed
- ✓ **Exact Numeric Storage** — Preserves floating-point precision
- ✓ **Efficient for Large Datasets** — Ideal for structured data

👉 Disadvantages

- ✗ **Not Human-Readable** — Cannot view with standard text editors
- ✗ **Platform-Dependent** — May not transfer between OS/architectures
- ✗ **Structure-Sensitive** — Any struct change breaks compatibility
- ✗ **Harder to Debug** — Requires hex editors or specialized tools

Opening
Binary Files

Opening Binary Files in C++

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

int main() {
// Method 1: Using open()
ofstream outFile;
outFile.open("data.bin", ios::out | ios::binary);
if (!outFile.is_open()) return 1;

// Method 2: Constructor (shorter)
ifstream inFile("input.bin", ios::in | ios::binary);
if (!inFile) return 1;
outFile.close();
inFile.close();
return 0;
}
```

key Concepts

- “ios::binary” —Required flag; prevents text transiation (newline conversion)
- **Method 1 (open())** — Create stream object first, then call open()
- **Method 2 (Constructor)** — Pass filename and mode directly in constructor
- **Error checking** — Always verify with is_open() or operator!
- **Close files** — Explicitly call close() to flush buffers

Combining Binary File Modes

Mode Combination	Description	Use Case
ios::in | ios::binary	Read-only binary	Config files, data input
ios::out | ios::binary	Write-only binary (creates/truncates)	Data output, reports
ios::app | ios::binary	Append to end in binary	Log files, adding records
ios::in | ios::out | ios::binary	Read and write binary	Databases, in-place updates
ios::ate | ios::binary	Open at end, allows seeking	File size operations

```
// Most common for update operations:
fstream file("data.bin", ios::in | ios::out |
ios::binary);
if (!file) { cerr << "Failed to open file" << endl; }
```

Binary
I/O Operations

Writing Structures to Binary Data

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

int main() {

ofstream out("data.bin", ios::binary);
if (!out) { cerr << "Error opening file\n"; return 1; }

// Writing an integer (4 bytes)
int value = 42;
out.write(reinterpret_cast<const char*>(&value), sizeof(value));

// Writing a double (8 bytes)
double pi = 3.14159;
out.write((char*)&pi, sizeof(pi));

out.close();
return 0;

}
```

Function Signature & Key Points:

- ‘s’ — Pointer to the data, cast to constchar*
- ‘n’ — Number of bytes to write; use sizeof()
- ‘reinterpret_cast<const char*> ‘— Preferred C++ cast
- (char*) — C-style cast alternative (also acceptable)
- Returns — Reference to the stream (for chaining)
- Always check file opened successfully before writing

Writing Structures to Binary Data

```cpp
#include <iostream>
#include <fstream>
#include <cstring>
using namespace std;

struct Student
{
  char name[32]; // Fixed-size: NEVER use std::string
  double gpa;
  int age;
};

int main()
{
  Student s;
  strcpy(s.name, "Ada Lovelace");
  s.gpa = 3.9;
  s.age = 20;
  ofstream out("students.bin", ios::binary);
  if (!out)
  {
    cerr << "Error\n";
    return 1;
  }
  // Write entire struct in one call
  out.write(reinterpret_cast<const char *>(&s), sizeof(s));
  out.close();

  return 0;
}
```

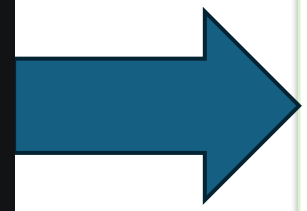
Critical Rules:

1. Use fixed-size struct members (char arrays, int, double, bool)‘n’ — Number of bytes to write; use sizeof()
2. Never use std::string — it contains internal pointers.
3. Open file with ios::binary flag
4. Cast struct address: reinterpret_cast(&s)
5. Size with: sizeof(Student) — writes the entire struct at once

Example Program: Save Student Record

C++ Example

```cpp
#include <iostream>
#include <fstream>
#include <cstring>
using namespace std;

struct Student {
  char name[32];
  int id;
  double gpa;
  bool enrolled;
};

int main() {
  Student s;
  strcpy(s.name, "Grace Hopper");
  s.id = 1001;
  s.gpa = 3.8;
  s.enrolled = true;

  ofstream out("students.bin", ios::binary);
  if (!out.is_open()) {
    cerr << "Error: Cannot open file" << endl;
    return 1;
  }

  out.write(reinterpret_cast<const char*>(&s), sizeof(s));
  out.close();
  cout << "Student saved successfully!" << endl;
  return 0;
}
```



Step-by-step breakdown

1. **Define struct** with fixed-size fields (char[], int, double, bool)
2. **Populate** the struct with data using strcpy for char array
3. **Open file** in binary mode with ios::binary
4. **Check** is_open() before proceeding
5. **Write** entire struct using sizeof(Student) bytes
6. **Close** the file to flush and release resources

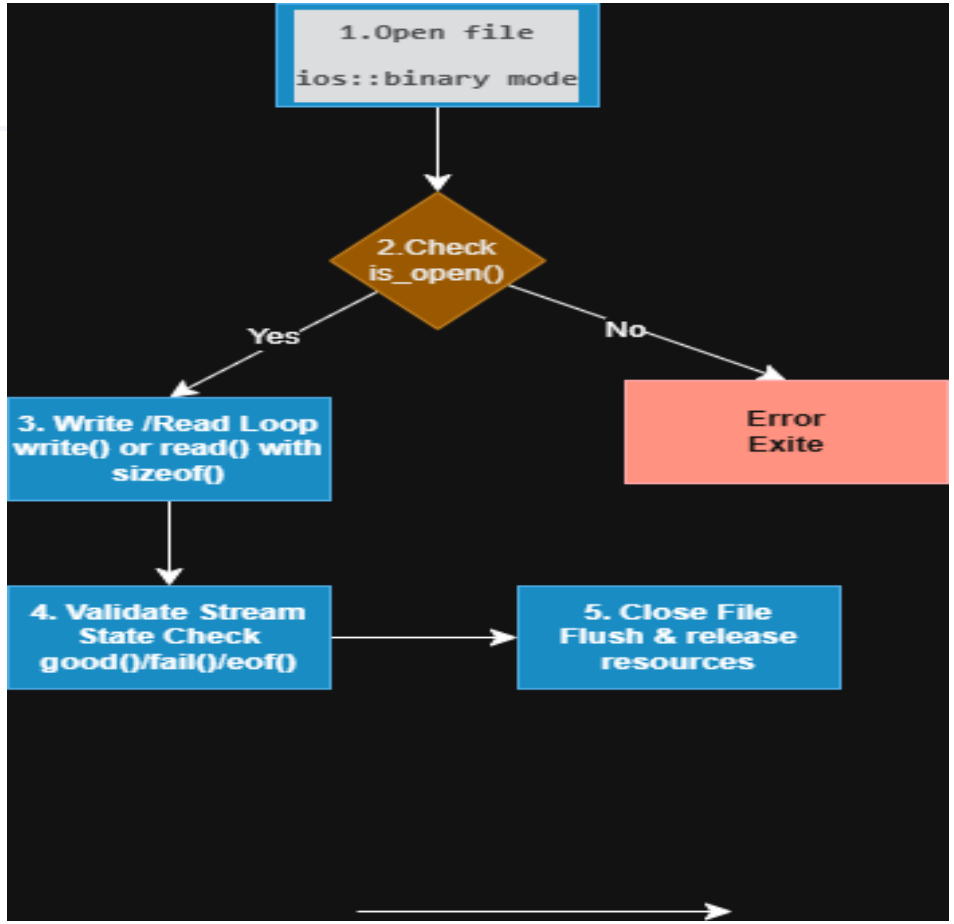
Reading Binary Data

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

struct Student {
  char name[32];
  double gpa;
};

int main() {
  ifstream in("data.bin", ios::binary);
  if (!in) { cerr << "Error\n"; return 1; }

  // Reading a single integer
  int x{};
  in.read(reinterpret_cast<char*>(&x), sizeof(x));
  cout << "Integer: " << x << endl;

  // Reading a struct
  Student s{};
  in.read(reinterpret_cast<char*>(&s), sizeof(s));
  cout << "Name: " << s.name << ", GPA: " << s.gpa << endl;

  // Reading multiple records with a loop
  Student record{};
  while (in.read(reinterpret_cast<char*>(&record), sizeof(record))) {
  cout << record.name << endl;
  }
  return 0;
}
```

key Concepts

- Reads **n bytes** from file into buffer s
- Cast pointer to char* for any data type
- **Loop pattern**: while(in.read(...)) reads all records
- **gcount()** — Returns bytes actually read (use for partial reads)
- Always initialize variables before reading: int x{};

Cont’d



Source: https://claude.ai/

- **Error path:** If is_open() fails → display error → exit
- **Read failure:** Check stream state → clear flags if needed
- **Key operations:** Use reinterpret_cast for type safety
- **Common mistakes:** Missing ios::binary , wrong sizeof() , unchecked stream state

Quick Pause and Checkout

1. Which line correctly writes double d to a binary file?

   A. out << d

   B. out.write((char*)&d, sizeof(d));

   C. write(d);

   D. out << to_string(d);

Answer: B

2. Why must you use a fixed-size char[] instead of std::string in a struct for binary serialization?

   A. std::string is too slow

   B. std::string uses dynamic memory (internal pointers)

   C. std::string is not supported in C++

   D. Char arrays hold more data

Answer: B

Serialization Concepts

</> What is Serialization?

Serialization is converting an object (in memory) into bytes for storage or transmission.

Deserialization reconstructs the object from bytes.

Data Flow:

Object in Memory → **Serialize** → **Byte Stream** → **Deserialize** → **Object Restored**

Real-World Applications:

🎮 **Game Saves**	Store player state, inventory, level progress
⚙ **Config Files**	User preferences and settings efficiently
🗄 **Databases**	Fixed-size records, random access
🌐 **Network Protocols**	Binary message transmission

</> Serialization: Limitations & Example

Critical limitations when serializing to binary files:

❌ **Dynamic Memory**	Never use std::string or std::vector — they contain pointers, not data
❌ **Pointer Serialization**	Never write raw pointers — addresses change between program runs
❌ **Versioning**	Changing struct fields breaks existing files — use version field
❌ **Platform Dependencies**	Endianness and padding vary — test on all target platforms

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

struct Product {
  int id;
  char name[50];
  double price;
  int qty;
};
int main() {
  Product p{1001, "USB-C Cable", 9.99, 120};
  // Serialize (write)
  ofstream out("products.dat", ios::binary);
  out.write((char*)&p, sizeof(p));
  out.close();
  // Deserialize (read back)
  Product q{};
  ifstream in("products.dat", ios::binary);
  in.read((char*)&q, sizeof(q));
  in.close();
}
```

Random Access

</> Sequential vs Random Access

Sequential Access 🐌

- Read from start until target
- Must read every record in order
- Time: O(n)
- Best for: Small files, full scans

Random Access ⚡

- Calculate byte offset → seek
- Jump directly to position
- Time: O(1)
- Best for: Large files, databases

Key formula: byte_offset = record_index × sizeof(RecordType)

Example:

Finding record #500 in file with 72-byte records:

```
Offset = 500 × 72 = 36,000 bytes  →  seekg(36000, ios::beg)  →  read()
[O(1) instant access]
```

</> File Pointers: Get & Put Positions

Get Pointer (Read Position):

- seekg(pos) — Move to absolute byte
- seekg(offset, origin) — Relative move
- tellg() — Query current position

Put Pointer (Write Position):

- seekp(pos) — Move to absolute byte
- seekp(offset, origin) — Relative move
- tellp() — Query current position

Seek Origins (for relative moves):

`ios::beg`	From beginning of file (absolute)
`ios::cur`	From current position (relative)
`ios::end`	From end of file (use negative offset)

Example code:

```
1  file.seekg(100, ios::beg);  // Byte 100
2  streampos pos = file.tellg();      // Query position
3  file.seekp(0, ios::end);   // Move to end
```

Random Access: Jump to Record #5

```cpp
#include <fstream>
using namespace std;

struct Product {
        int id;
        char name[50];
 };

int main() {
      ifstream f("products.bin", ios::binary);
      Product rec{};
      int idx = 5;
     f.seekg(idx * sizeof(Product), ios::beg);
     f.read((char*)&rec, sizeof(rec));
     cout << rec.name << endl;
 }
```

Step-by-Step:

1. *Open file in binary mode*
2. *Calculate offset: idx × sizeof()*
3. *seekg() to that byte position*
4. *read() pulls the struct*
5. *Check stream state*
6. *Display or process data*

</> Updating Specific Records

```
fstream file("products.dat",
             ios::in | ios::out | ios::binary);
Product p{};
int idx = 2;

// 1. Seek & READ
 file.seekg(idx * sizeof(Product), ios::beg);
 file.read((char*)&p, sizeof(p));

// 2. MODIFY field
 p.price = 29.99;

// 3. Seek BACK & WRITE
 file.seekp(idx * sizeof(Product), ios::beg);
 file.write((char*)&p, sizeof(p));
```

The Read-Modify-Write Pattern:

1. Calculate offset
2. seekg() to record
3. read() into memory
4. Modify fields
5. seekp() same position
6. write() back to file

⚠ **IMPORTANT**: After read(), the pointer advances by sizeof(Record) bytes.

➢ You MUST **seekp()** back to the same position before writing, or you'll corrupt the next record.

</> Deleting Records (Logical Deletion)

```
struct Product {
  int id;
  char name[50];
  double price;
  bool deleted = false;  // Flag
};

void markDeleted(fstream& f, int idx) {
  Product p{};
 f.seekg(idx * sizeof(Product), ios::beg);
 f.read((char*)&p, sizeof(p));
 p.deleted = true;
 f.seekp(idx * sizeof(Product), ios::beg);
 f.write((char*)&p, sizeof(p));
}
```

Why Logical Deletion?

- Physical delete = rebuild file (expensive)
- Logical delete = flip flag (instant)
- Preserves record positions
- Skip marked records on display

Best Practice:

- ➢ Use logical deletion for frequent updates.
- ➢ Periodically compact the file during off-peak maintenance by copying all non-deleted records to a new file.
- ➢ This is how production databases handle 'soft deletes'.

Practical Examples

Inventory System Design

Product struct (fixed-size, ~72 bytes):

```
struct Product {
        int id;
        char name[50];
        double price;
        int quantity;
        bool deleted = false;
};
```

System Features:

- ➕ Add products (append)
- 📋 List all (display non-deleted)
- ✏️ Update price (seek & write)
- 🗑️ Mark deleted (logical flag)

Data Flow:

User Input → **Product Struct** → **Binary Write** → **.dat File**

</> Inventory System — Implementation (Part 1)

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

 struct Product { int id; char name[50]; double price; int qty; bool deleted; };

 streamoff offsetOf(size_t idx) {
  return idx * sizeof(Product);
   }

void addProduct(const string& file, Product& p) {
ofstream out(file, ios::app | ios::binary);
  out.write((char*)&p, sizeof(p));
  }

void listAll(const string& file) {
ifstream in(file, ios::binary);
Product p{};
 while (in.read((char*)&p, sizeof(p)))
if (!p.deleted) cout << p.id << " | " << p.name << endl;
  }
```

Cont’d

Inventory System — Implementation (Part 2)

```
    void updatePrice(fstream& file, int idx, double price) {
    Product p{};
    file.seekg(offsetOf(idx), ios::beg);
    file.read((char*)&p, sizeof(p));
    p.price = price;
     file.seekp(offsetOf(idx), ios::beg);
     file.write((char*)&p, sizeof(p));
      }

    void markDeleted(fstream& file, int idx) {
     Product p{};
     file.seekg(offsetOf(idx), ios::beg);
     file.read((char*)&p, sizeof(p));
     p.deleted = true;
     file.seekp(offsetOf(idx), ios::beg);
      file.write((char*)&p, sizeof(p));
     }

    int main() {
       Product p1{1001, "USB Cable", 9.99, 120, false};
     addProduct("products.dat", p1);
      listAll("products.dat");
      return 0;
     }
```

Common Errors & Best Practices

Common Binary File Handling Errors

1. Forgetting ios::binary	Always use: ios::out | ios::binary or ios::in | ios::binary
2. Using std::string in structs	Replace with: char name[50] fixed-size arrays
3. Wrong sizeof() / offset math	Validate: offset = index × sizeof(Record); test small files
4. Ignoring stream state	Always: if (!file) { error; return 1; }
5. Writing pointers to file	Serialize data not pointers: write((char*)&data, sizeof(data))
6. Platform dependencies	Document struct version; test on all target platforms

</> Best Practices

Best Practices ✅

- Use fixed-size POD structs
- Centralize sizeof/offset logic
- Validate ALL I/O operations
- Document struct layout
- Use logical deletion
- Test with small files first

Key Takeaways 📌

1. Binary mirrors memory layout
2. ios::binary is MANDATORY
3. Serialize fixed-size only
4. offset = idx × sizeof()
5. seekg for read, seekp for write
6. Check stream state always

End-of-Lecture Practice:

1. Write a program storing 5 Employee structs; read back employee #3
2. Add updateSalary() using random access to modify a record
3. Implement logical deletion + compact() to remove deleted records

References

Text Books

- **C++ How to Program** [10th edition], Deitel, P. & Deitel, H., Global Edition, Global Edition (2017).
- **Problem Solving With C++** [10th edition], Walter Savitch, University of California, San Diego, 2018.

Reference Books

- **Object-Oriented Programming in C++ (4th Edition)** by Robert Lafore, Sams Publishing, 2022.
- **Principles of Object-Oriented Programming**, by Stephen W. & Dung N., OpenStax CNX, 2022.

Online Resources

- https://www.geeksforgeeks.org/cpp/c-plus-plus/
- https://www.w3schools.com/cpp/default.asp
- https://programiz.pro/resources/cpp
- https://www.hackerrank.com/domains/cpp
- https://cplusplus.com/doc/tutorial/

Study Tip: *Don't just read the code! Retype the examples from these slides and resources into your IDE, modify and compile them to see what happens.*

Thank You!

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