1. Compiler Construction Course Overview:

The document outlines objectives and tasks related to a course on compiler construction, likely targeting students in computer science or software engineering. The key concepts revolve around lexical analysis, which is the first phase of a compiler.

2. Course Learning Objectives (CLOs):

These are high-level outcomes that students are expected to achieve after completing the module:

- Apply mathematical formalisms such as regular expressions, grammars, finite automata (FAs), and pushdown automata (PDAs).
- Understand the functioning of compiler phases, especially lexical analysis and parsing.
- Compare different techniques of implementing lexical analyzers and parsers.
- Work individually or in teams to design, test, and deliver compiler analysis phases.

3. Important Books:

- "Compiler: Principles, Techniques, and Tools" by Aho, Sethi, and Ullman, a classic reference on compiler design.
- "Engineering a Compiler" by Keith D. Cooper & Linda Torczon.

4. Building a Lexical Analyzer Using C++ and Flex (Lex):

The goal of the lab is to implement a lexical analyzer using C++ and Flex, which is a tool used to generate lexical analyzers based on a set of rules and definitions. Flex takes input as a specification file (with a .l extension) to generate a C file containing code for lexical analysis.

5. Lexical Analyzer Components:

The key components of a Lex program are:

- **Definition Section:** Contains definitions of regular expressions used to identify tokens.
- **Rules Section:** Contains the actions to perform when a specific pattern is matched.
- **User Subroutines Section:** Contains C/C++ code that runs once a rule matches.

6. Task Example:

The students are tasked with extending the lexical analyzer by defining more rules and generating tokens for a C++ recursion program.

7. Writing a Tokenizer in C++:

A tokenizer breaks an input string into meaningful units (tokens) such as keywords, identifiers, numbers, operators, and punctuation. The algorithm to achieve this involves:

1. Initializing an empty list of tokens.
2. Looping through the input string and categorizing characters into different token types (whitespace, identifiers, numbers, operators, punctuation).
3. Returning the list of tokens.

8. Functions and Standard C++ Libraries:

- **isspace function:** Checks whether a character is a whitespace (e.g., space, tab).
- **isalpha function:** Checks if a character is a letter.
- **isdigit function:** Checks if a character is a digit.

9. Why Pass Strings by Reference?

Passing strings by reference (i.e., const std::string&) instead of by value improves performance because it avoids copying the entire string. In lexical analysis, source code can be large, so passing large strings by value would be inefficient.

10. Lab Tasks:

Students are asked to:

- Create data structures (lists, enums) to store tokens, keywords, operators, and symbols.
- Write functions to check if a string is a keyword.
- Tokenize the input string.
- Print the tokens.

11. Time and Space Complexity:

The students are encouraged to think about the space and time complexity of the Tokenize function. These complexities depend on how efficiently data structures are used to store and retrieve tokens during lexical analysis.

12. Week 4 Lab Assessment:

The lab assessment covers:

- Understanding of compiler phases.
- C++ fundamentals.
- Object-Oriented Programming (OOP) concepts.
- The C++ Standard Template Library (STL).
- Template programming.
- Threading in C++.

Solutions to Potential Problems:

1. **Space Complexity of Tokenize Function:** The space complexity is determined by the size of the input string and the number of tokens generated. If there are n characters in the input and m tokens, the space complexity is approximately O(n + m).
2. **Writing a Tokenizer Algorithm:** Here's a simplified version of a C++ tokenizer algorithm based on the description:

cpp

Copy code

```cpp
#include <iostream>

#include <cctype>

#include <string>

#include <vector>


enum TokenType { KEYWORD, IDENTIFIER, NUMBER, OPERATOR, PUNCTUATION, UNKNOWN };


struct Token {
```

```cpp
    TokenType type;
    std::string value;
};

bool isKeyword(const std::string &word) {
    // Simple example: Add your language's keywords here
    std::vector<std::string> keywords = {"if", "else", "for", "while"};
    return std::find(keywords.begin(), keywords.end(), word) != keywords.end();
}

std::vector<Token> tokenize(const std::string &input) {
    std::vector<Token> tokens;
    std::string token;
    for (size_t i = 0; i < input.size(); i++) {
        if (isspace(input[i])) {
            continue;
        } else if (isalpha(input[i])) {
            token.clear();
            while (isalpha(input[i]) || isdigit(input[i])) {
                token += input[i++];
            }
            i--; // Move back to the correct position
            if (isKeyword(token)) {
                tokens.push_back({KEYWORD, token});
            } else {
                tokens.push_back({IDENTIFIER, token});
```

```
      }
    } else if (isdigit(input[i])) {
      token.clear();
      while (isdigit(input[i])) {
        token += input[i++];
      }
      i--;
      tokens.push_back({NUMBER, token});
    } else if (ispunct(input[i])) {
      tokens.push_back({PUNCTUATION, std::string(1, input[i])});
    } else {
      tokens.push_back({UNKNOWN, std::string(1, input[i])});
    }
  }
  return tokens;
}

void printTokens(const std::vector<Token> &tokens) {
  for (const auto &token : tokens) {
    std::cout << "Token: " << token.value << ", Type: " << token.type << std::endl;
  }
}

int main() {
  std::string code = "if (x == 10) { y = 20; }";
  std::vector<Token> tokens = tokenize(code);
```

```
  printTokens(tokens);

  return 0;

}
```

3. **Time Complexity of Tokenize Function:** The time complexity is approximately O(n), where n is the length of the input string. This is because each character in the input is processed once.

If you need further explanation or assistance with specific tasks or problems, feel free to ask!

4o

You said:

explain the code please

ChatGPT said:

ChatGPT

Here's a step-by-step explanation of the C++ tokenizer code provided earlier:

Overview

The code is designed to implement a basic **lexical analyzer** or **tokenizer**. The task of this tokenizer is to break down an input string (typically source code) into smaller components called **tokens**. Each token could be a keyword, identifier, number, operator, or punctuation mark.

The code works by reading each character of the input string and grouping characters into meaningful units (tokens). It uses standard C++ libraries and functions like isspace, isalpha, and isdigit to classify characters.

1. Token Enum Type

cpp

Copy code

```cpp
enum TokenType { KEYWORD, IDENTIFIER, NUMBER, OPERATOR, PUNCTUATION, UNKNOWN };
```

This defines an **enumeration** (enum) for different types of tokens. Each token in the input string will belong to one of these categories:

- KEYWORD: Tokens that match specific language keywords (e.g., if, else, for).
- IDENTIFIER: Tokens that represent variable names, function names, etc.
- NUMBER: Tokens that represent numeric values.
- OPERATOR: Tokens that represent operators (e.g., +, -, *, ==).
- PUNCTUATION: Tokens that represent punctuation marks (e.g., {, }, ;).
- UNKNOWN: Tokens that do not fall into any of the categories.

2. Token Struct

cpp

Copy code

```
struct Token {
   TokenType type;
   std::string value;
};
```

This defines a **struct** to represent a token. Each token has two parts:

- type: This will store the type of the token (from the TokenType enum).
- value: This stores the actual string (value) of the token.

3. Function: isKeyword

cpp

Copy code

```
bool isKeyword(const std::string &word) {
   std::vector<std::string> keywords = {"if", "else", "for", "while"};
   return std::find(keywords.begin(), keywords.end(), word) != keywords.end();
}
```

This function checks if a string is a **keyword**. Here's how it works:

- A list of keywords (keywords) is defined as a vector of strings.
- The std::find function is used to search for the word in this list.

- If the word is found, the function returns true, meaning it's a keyword; otherwise, it returns false.

4. Function: tokenize

cpp

Copy code

```
std::vector<Token> tokenize(const std::string &input) {
```

This function processes the input string to produce a list of tokens. It returns a vector of Token objects.

Step-by-Step Explanation:

1. **Create an empty list of tokens:**

cpp

Copy code

```
std::vector<Token> tokens;

std::string token;
```

2. **Loop through each character in the input string:**

cpp

Copy code

```
for (size_t i = 0; i < input.size(); i++) {
```

A for loop is used to iterate through the input string character by character.

3. **Skip whitespaces:**

cpp

Copy code

```
if (isspace(input[i])) {

  continue;

}
```

If the current character is a whitespace (spaces, tabs, etc.), the loop moves to the next character using continue.

4. **Identify identifiers and keywords:**

cpp

Copy code

```
else if (isalpha(input[i])) {
  token.clear();
  while (isalpha(input[i]) || isdigit(input[i])) {
    token += input[i++];
  }
  i--;
  if (isKeyword(token)) {
    tokens.push_back({KEYWORD, token});
  } else {
    tokens.push_back({IDENTIFIER, token});
  }
}
```

- If the current character is an alphabetic letter (isalpha), the tokenizer starts collecting characters to form a token.
- It continues adding characters to the token as long as they are alphabetic or numeric (isalnum), which allows for identifiers like var1.
- After forming a token, it checks whether the token is a keyword using the isKeyword function.
- If the token is a keyword, it's added to the tokens list as a KEYWORD token. Otherwise, it's added as an IDENTIFIER token.

5. **Identify numbers:**

cpp

Copy code

```
else if (isdigit(input[i])) {
```

```cpp
  token.clear();
  while (isdigit(input[i])) {
    token += input[i++];
  }
  i--;
  tokens.push_back({NUMBER, token});
}
```

- If the current character is a digit (isdigit), the tokenizer starts collecting digits to form a number token.
- After collecting the entire number, it is stored in the tokens list as a NUMBER token.

6. **Identify punctuation:**

cpp

Copy code

```cpp
else if (ispunct(input[i])) {
  tokens.push_back({PUNCTUATION, std::string(1, input[i])});
}
```

- If the current character is a punctuation mark (ispunct), it is directly added to the tokens list as a PUNCTUATION token.

7. **Handle unknown characters:**

cpp

Copy code

```cpp
else {
  tokens.push_back({UNKNOWN, std::string(1, input[i])});
}
```

- Any character that doesn't match the above criteria (whitespace, letter, digit, or punctuation) is classified as UNKNOWN.

8. **Return the list of tokens:**

cpp

Copy code

```
return tokens;
```

5. Function: printTokens

cpp

Copy code

```
void printTokens(const std::vector<Token> &tokens) {
  for (const auto &token : tokens) {
    std::cout << "Token: " << token.value << ", Type: " << token.type << std::endl;
  }
}
```

This function takes the list of tokens and prints each token's value and type:

- It loops through the vector of tokens and prints the value and type of each token.
- token.type is an integer, so it will print the numeric equivalent of the TokenType enum.

6. main Function

cpp

Copy code

```
int main() {
  std::string code = "if (x == 10) { y = 20; }";
  std::vector<Token> tokens = tokenize(code);
  printTokens(tokens);
  return 0;
}
```

- A simple test string (code) is provided as an input to the tokenizer. This string represents a small snippet of code: "if (x == 10) { y = 20; }".

- The tokenize function processes the string and returns a list of tokens.
- The printTokens function prints the tokens along with their types.

Sample Output:

For the input "if (x == 10) { y = 20; }", the output might look something like:

yaml

Copy code

Token: if, Type: 0

Token: (, Type: 4

Token: x, Type: 1

Token: ==, Type: 1

Token: 10, Type: 2

Token:), Type: 4

Token: {, Type: 4

Token: y, Type: 1

Token: =, Type: 1

Token: 20, Type: 2

Token: ;, Type: 4

Token: }, Type: 4

Here, the Token values are printed alongside their corresponding Type (as integers).

Summary

This tokenizer breaks down an input string (such as source code) into a list of tokens like keywords, identifiers, numbers, operators, and punctuation. The tokenization process is essential for the **lexical analysis** phase of a compiler, where the source code is scanned to produce meaningful tokens that the later stages of the compiler can process.

4o

You said:

please explain this code too

ChatGPT said:

ChatGPT

Let's break down the code in the image step by step:

1. Header Section

flex

Copy code

```
%{
#include <stdio.h>
%}
```

- **%{ and %}**: These are delimiters for **C code**. Anything inside these delimiters will be copied directly into the generated C file.
- **#include <stdio.h>**: This includes the standard I/O library (stdio.h), which provides functions like printf used later in the code.

2. Flex Rules Section

flex

Copy code

```
%%
if|else|printf        { printf("%s is a keyword\n", yytext); }
[0-9]+              { printf("%s is a number\n", yytext); }
[a-zA-Z]+            { printf("%s is a word\n", yytext); }
[ \t\n]+             ;  // Skip whitespace (spaces, tabs, newlines)
.                   { printf("Unknown character: %s\n", yytext); }
%%
```

This section defines **rules** for the **lexical analyzer**. The rules tell Flex (a lexical analyzer generator) what to do when it encounters certain patterns in the input.

Explanation of Each Rule:

1. **Keywords:**

flex

Copy code

if|else|printf { printf("%s is a keyword\n", yytext); }

- This rule matches the strings if, else, and printf.
- If any of these keywords are encountered, it will print: <keyword> is a keyword, where <keyword> is the matched text (yytext is a built-in Flex variable that holds the matched token).

2. **Numbers:**

flex

Copy code

[0-9]+ { printf("%s is a number\n", yytext); }

- This rule matches sequences of one or more digits ([0-9]+).
- If a number is encountered, it prints: <number> is a number.

3. **Words (Identifiers):**

flex

Copy code

[a-zA-Z]+ { printf("%s is a word\n", yytext); }

- This rule matches sequences of one or more alphabetic characters ([a-zA-Z]+).
- If a word (identifier) is encountered, it prints: <word> is a word.

4. **Whitespace:**

flex

Copy code

[\t\n]+ ;

- This rule matches spaces ( ), tabs (\t), or newlines (\n), and skips them. No action is taken for these characters.

5. **Unknown Characters:**

flex

Copy code

```
. { printf("Unknown character: %s\n", yytext); }
```

  - This rule matches any single character (the . is a wildcard).
  - If an unrecognized character (like punctuation) is encountered, it prints: Unknown character: <character>.

3. Main Function

flex

Copy code

```
int main() {
  printf("\nEnter the string here:\n");
  yylex();  // Call the lexical analyzer to start scanning input
  return 0;
}
```

- The **main function** prints a message asking the user to input a string.
- It then calls the yylex() function, which is automatically generated by Flex. This function scans the input based on the rules defined above and processes each token.
- Finally, it returns 0, indicating successful execution.

4. yywrap Function

flex

Copy code

```
int yywrap() {
  return 1;
}
```

- This function is used by Flex to signal the end of input. Returning 1 tells Flex that there is no more input to process.

- The yywrap() function is often defined like this to handle EOF (End of File) situations in Flex programs.

Summary

This Flex program is a simple lexical analyzer that:

- Recognizes the keywords if, else, and printf as "keywords".
- Recognizes numbers (sequences of digits) and labels them as "numbers".
- Recognizes words (sequences of letters) and labels them as "words".
- Ignores whitespace (spaces, tabs, newlines).
- Flags any unknown characters and prints a message for them.

Example Output

For the input:

bash

Copy code

if x == 10 else printf a $ b

The output might be:

less

Copy code

if is a keyword

x is a word

Unknown character: =

Unknown character: =

10 is a number

else is a keyword

printf is a keyword

a is a word

Unknown character: $

b is a word

4o

You said:

• Phasis of Compiler with short understanding

ChatGPT said:

ChatGPT

Phases of a Compiler: A Brief Overview

A **compiler** is a program that translates high-level source code (e.g., C, Java) into machine code (or an intermediate code). The process of compilation involves several distinct **phases**, each responsible for a specific task. Below are the phases of a typical compiler with a short understanding of each:

---

1. Lexical Analysis (Scanner)

- **Purpose**: Breaks the source code into small units called **tokens** (e.g., keywords, identifiers, numbers).
- **Output**: Tokens, which are the smallest meaningful elements.
- **Example**: From int a = 5;, it generates tokens like int, a, =, 5, ;.

---

2. Syntax Analysis (Parser)

- **Purpose**: Checks the structure of the code based on grammatical rules (i.e., verifies that the tokens form valid expressions according to the language syntax).
- **Output**: A **parse tree** or **syntax tree**, representing the syntactic structure of the source code.
- **Example**: For the expression a = 5;, it ensures the code follows assignment grammar rules.

---

3. Semantic Analysis

- **Purpose**: Ensures the meaning of the program is valid (e.g., type checking, scope resolution).
- **Output**: An **annotated syntax tree** with semantic information.
- **Example**: It checks if a is declared before use or if operations (e.g., adding an integer and a string) make sense.

---

4. Intermediate Code Generation

- **Purpose**: Translates the syntax tree into an **intermediate code** that is not machine-specific but still lower-level than source code.
- **Output**: Intermediate code (like three-address code, abstract syntax tree).
- **Example**: For a = b + c;, it might generate something like t1 = b + c followed by a = t1.

---

5. Optimization

- **Purpose**: Improves the intermediate code by making it more efficient (e.g., reducing instruction count, eliminating redundant calculations).
- **Output**: Optimized intermediate code.
- **Example**: It might remove unnecessary code or simplify expressions like x = x + 0.

---

6. Code Generation

- **Purpose**: Converts the intermediate code into **machine code** (target code) that can run on a specific architecture (e.g., x86, ARM).
- **Output**: Machine code (binary code) or assembly code.
- **Example**: For the statement a = b + c, it generates the actual instructions that manipulate registers and memory.

---

7. Code Linking and Assembly

- **Purpose**: Links different code modules and external libraries into a complete program. Translates the assembly code into **machine language** (binary executable).

- **Output**: Final executable machine code.
- **Example**: It connects the code with system libraries and prepares it for execution by the processor.

---

8. Error Handling

- **Purpose**: Detects and reports errors (lexical, syntactic, semantic) during various compilation stages. Ensures the user is informed about mistakes in the code.
- **Output**: Error messages or diagnostic reports.
- **Example**: It reports errors like undeclared variables or missing semicolons.

Summary of the Compilation Phases:

1. **Lexical Analysis**: Tokenization of the source code.
2. **Syntax Analysis**: Structural validation via a syntax tree.
3. **Semantic Analysis**: Type checking and meaning validation.
4. **Intermediate Code Generation**: Platform-independent low-level code.
5. **Optimization**: Code improvement for efficiency.
6. **Code Generation**: Machine-specific code generation.
7. **Code Linking and Assembly**: Producing the final executable.
8. **Error Handling**: Detecting and reporting errors in the program.

Each phase plays a crucial role in converting source code into an efficient and executable form!

4o

You said:

STL

ChatGPT said:

ChatGPT

Standard Template Library (STL) in C++

The **Standard Template Library (STL)** is a powerful set of C++ template classes that provide common data structures and algorithms. It allows developers to reuse well-tested, efficient data structures and algorithms, saving time and reducing complexity in code.

Key Components of STL:

STL is primarily divided into three components:

1. **Containers**
2. **Iterators**
3. **Algorithms**

---

1. Containers

Containers are objects that store collections of data. STL provides a variety of container classes that implement common data structures.

Types of Containers:

- **Sequence Containers**: Store elements in a linear order.
  - **Vector**: A dynamic array, where the size can grow dynamically.
  - **List**: A doubly-linked list.
  - **Deque**: A double-ended queue allowing insertion/removal from both ends.
- **Associative Containers**: Provide efficient data retrieval based on keys.
  - **Set**: Stores unique elements in a sorted order.
  - **Map**: Stores key-value pairs where each key is unique and sorted.
  - **Multiset**: Similar to set, but allows duplicate elements.
  - **Multimap**: Similar to map, but allows duplicate keys.
- **Container Adapters**: Provide restricted interfaces to sequence containers.
  - **Stack**: Implements a Last In, First Out (LIFO) structure.
  - **Queue**: Implements a First In, First Out (FIFO) structure.
  - **Priority Queue**: Implements a heap where the highest-priority element is at the top.

Example:

cpp

Copy code

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

int main() {
   vector<int> vec = {1, 2, 3, 4, 5};
   for (int i : vec) {
      cout << i << " ";  // Output: 1 2 3 4 5
   }
   return 0;
}
```

---

2. Iterators

Iterators are objects that act as pointers to the elements of containers. They are used to traverse through the elements of a container and can be used with STL algorithms.

Types of Iterators:

- **Input Iterator**: Reads elements in a sequence (e.g., cin).
- **Output Iterator**: Writes elements in a sequence (e.g., cout).
- **Forward Iterator**: Moves forward in a sequence (e.g., used in singly linked lists).
- **Bidirectional Iterator**: Moves both forward and backward (e.g., used in doubly linked lists).
- **Random Access Iterator**: Provides direct access to any element in a sequence (e.g., vector, deque).

Example:

cpp

Copy code

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

int main() {
  vector<int> vec = {1, 2, 3, 4, 5};
  vector<int>::iterator it;

  for (it = vec.begin(); it != vec.end(); ++it) {
    cout << *it << " ";  // Output: 1 2 3 4 5
  }
  return 0;
}
```

Here, vec.begin() returns an iterator pointing to the first element, and vec.end() returns an iterator pointing one past the last element.

---

3. Algorithms

STL provides a rich set of algorithms that work on containers and iterators, making it easy to perform various operations like sorting, searching, modifying, etc.

Common Algorithms:

- **Searching**: find(), binary_search()
- **Sorting**: sort(), partial_sort()
- **Modifying**: copy(), swap(), replace()
- **Removing**: remove(), remove_if()
- **Mathematical**: accumulate(), count(), min(), max()

Example:

cpp

Copy code

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

int main() {
  vector<int> vec = {5, 2, 1, 4, 3};

  // Sorting the vector
  sort(vec.begin(), vec.end());

  // Displaying the sorted vector
  for (int i : vec) {
    cout << i << " ";  // Output: 1 2 3 4 5
  }
  return 0;
}
```

Here, the sort() algorithm is used to sort the elements in ascending order.

Key Advantages of STL:

1. **Efficiency**: STL algorithms and containers are highly optimized.
2. **Reusability**: You can use well-tested and robust components, reducing the need to implement common data structures and algorithms from scratch.

3. **Flexibility**: Since STL is based on templates, it supports generic programming, allowing containers and algorithms to be used with different types.
4. **Interoperability**: Algorithms work seamlessly with containers using iterators, making the code more modular.

Summary of STL Components:

- **Containers**: Store collections of data (e.g., vector, map, set).
- **Iterators**: Provide a way to traverse containers (e.g., vector<int>::iterator).
- **Algorithms**: Operate on containers (e.g., sort(), find()).

STL is a core part of C++ programming and provides tools that allow developers to write efficient, reusable, and modular code.

4o

You said:

Template Programming

ChatGPT said:

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Template Programming in C++

Template Programming is one of the most powerful features in C++. It allows writing generic and reusable code by using **templates**. Templates enable you to define functions, classes, and data structures that work with any data type, making your code more flexible and type-independent.

Key Concepts in Template Programming:

1. **Function Templates**: Allows creating generic functions that can operate on any data type.
2. **Class Templates**: Allows creating generic classes or data structures that can work with any data type.
3. **Template Specialization**: Allows customizing the behavior of templates for specific types.

---

1. Function Templates

A **function template** is a blueprint for creating functions that can work with different data types. Instead of writing multiple overloaded functions for each data type, you write a single function template that works for all types.

Syntax:

cpp

Copy code

```cpp
template <typename T>

T functionName(T a, T b) {

   // function body

}
```

- T is a **placeholder** for the data type, which gets replaced when the function is called with actual data types.

Example: Function Template for Addition

cpp

Copy code

```cpp
#include <iostream>

using namespace std;


template <typename T>

T add(T a, T b) {

   return a + b;

}


int main() {

   cout << add(3, 4) << endl;       // Works for integers, Output: 7
```

```
    cout << add(2.5, 3.1) << endl;    // Works for floats, Output: 5.6

    return 0;

}
```

Here, T is a generic type that can be an int, float, or any other type that supports the + operator.

---

2. Class Templates

A **class template** allows creating a generic class that can store or work with any data type. Similar to function templates, class templates provide flexibility and reusability by using a type parameter.

Syntax:

cpp

Copy code

```
template <typename T>

class ClassName {

public:

    T data;

    ClassName(T val) : data(val) {}

    void display() {

        cout << data;

    }

};
```

Example: Class Template for a Simple Data Holder

cpp

Copy code

```
#include <iostream>

using namespace std;
```

```
template <typename T>
class DataHolder {
public:
  T data;
  DataHolder(T val) : data(val) {}
  void display() {
    cout << "Data: " << data << endl;
  }
};

int main() {
  DataHolder<int> intHolder(100);
  DataHolder<float> floatHolder(123.45);

  intHolder.display();   // Output: Data: 100
  floatHolder.display(); // Output: Data: 123.45
  return 0;
}
```

Here, DataHolder is a template class that works for both int and float types. The T in the class is replaced with int or float when the object is created.

---

3. Template Specialization

Sometimes, you may need to **specialize** a template for a specific data type to customize its behavior. **Template specialization** allows you to create a specialized version of the template that is different from the generic version.

Syntax:

cpp

Copy code

```
template <>
class ClassName<specializedType> {
    // Specialized class implementation
};
```

Example: Specializing a Template for char*

cpp

Copy code

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

template <typename T>
class DataHolder {
public:
    T data;
    DataHolder(T val) : data(val) {}
    void display() {
        cout << "Data: " << data << endl;
    }
};

// Specialization for char*
template <>
class DataHolder<char*> {
public:
```

```
    char* data;
    DataHolder(char* val) : data(val) {}
    void display() {
        cout << "String: " << data << endl;
    }
};

int main() {
    DataHolder<int> intHolder(100);
    DataHolder<char*> stringHolder("Hello, Templates!");

    intHolder.display();      // Output: Data: 100
    stringHolder.display();   // Output: String: Hello, Templates!

    return 0;
}
```

In this example, the generic DataHolder class is specialized for char*, so it displays a string differently than it would for an int or other types.

---

4. Multiple Template Parameters

You can use more than one template parameter if needed.

Example: Multiple Parameters in a Template

cpp

Copy code

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

```
template <typename T1, typename T2>

class Pair {

public:

   T1 first;

   T2 second;

   Pair(T1 a, T2 b) : first(a), second(b) {}


   void display() {

       cout << "First: " << first << ", Second: " << second << endl;

   }

};


int main() {

   Pair<int, float> myPair(5, 6.7);

   myPair.display();  // Output: First: 5, Second: 6.7

   return 0;

}
```

In this example, the Pair class has two template parameters, allowing you to create a pair of different types, such as int and float.

---

5. Variadic Templates (Advanced)

A **variadic template** allows a function or class to accept any number of template parameters. It is useful when you don't know in advance how many types or arguments will be passed.

Example: Variadic Function Template

cpp

Copy code

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

template <typename T>
void print(T t) {
   cout << t << endl;
}

template <typename T, typename... Args>
void print(T t, Args... args) {
   cout << t << " ";
   print(args...);  // Recursive call
}

int main() {
   print(1, 2.5, "Hello", 'A'); // Output: 1 2.5 Hello A
   return 0;
}
```

Here, print is a variadic function template that accepts multiple arguments of different types and prints them.

---

6. Template Metaprogramming (Advanced)

Template metaprogramming (TMP) is a technique that uses templates to perform computations at compile time. TMP allows developers to write highly optimized code but is quite complex and usually reserved for very specific tasks like optimizing algorithms, type traits, or generating code during compilation.

Advantages of Template Programming:

1. **Code Reusability**: You can write a generic function or class once and use it with any data type.
2. **Type Safety**: Templates provide compile-time type checking, preventing type-related errors.
3. **Efficiency**: Since template code is instantiated at compile time, there is no performance penalty at runtime.
4. **Flexibility**: Templates allow creating functions and classes that work with different types, improving flexibility and reducing code duplication.

Summary:

- **Function Templates**: Create generic functions.
- **Class Templates**: Create generic classes or data structures.
- **Template Specialization**: Customize behavior for specific data types.
- **Variadic Templates**: Handle an arbitrary number of template arguments.
- **Template Metaprogramming**: Perform compile-time computations.

Template programming in C++ is a powerful tool that enhances code flexibility, reusability, and efficiency by allowing you to create type-independent implementations.

4o

You said:

• Threading in C++

ChatGPT said:

ChatGPT

Threading in C++

Threading in C++ allows you to run multiple threads concurrently within a program. It's a fundamental part of modern programming, enabling you to perform multiple tasks simultaneously and make the best use of CPU resources. Threads in C++ are part of the

C++11 standard and beyond, which introduced the <thread> library to handle multithreading.

Why Use Threads?

- **Concurrency**: Allows different parts of a program to run simultaneously, improving efficiency.
- **Responsiveness**: Helps in maintaining the responsiveness of an application, such as in GUIs, where one thread handles the interface while another does background work.
- **Resource Utilization**: Threads allow programs to fully utilize multiple CPU cores.

Basics of Threading in C++

C++ provides the <thread> library, which includes classes and functions to work with threads.

Example of a Simple Thread:

cpp

Copy code

```cpp
#include <iostream>

#include <thread>

using namespace std;


void hello() {

  cout << "Hello from thread!" << endl;

}


int main() {

  // Create a thread and execute the 'hello' function

  thread t(hello);
```

```
    // Wait for the thread to finish execution
    t.join();

    return 0;
}
```

Explanation:

- **std::thread t(hello);**: Creates a new thread that runs the hello function.
- **t.join();**: This ensures that the main thread waits for the t thread to finish before continuing.

---

1. Creating Threads

Threads can be created by:

- Passing a **function** to the thread constructor.
- Using a **lambda expression**.
- Passing a **callable object** (an instance of a class with an overloaded operator()).

Example with Lambda:

cpp

Copy code

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

int main() {
    thread t([](){
        cout << "Thread using Lambda" << endl;
```

```
    });

    t.join();  // Wait for the thread to finish
    return 0;
}
```

Example with Callable Object:

cpp

Copy code

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

class Callable {
public:
    void operator()() {
        cout << "Thread using Callable Object" << endl;
    }
};

int main() {
    Callable obj;
    thread t(obj);  // Pass the callable object to the thread

    t.join();
    return 0;
}
```

2. Joining and Detaching Threads

- **join()**: The join function is used to wait for a thread to complete its execution before proceeding. It ensures that the current thread does not terminate until the other thread has finished.
    - If you don't call join(), and the main thread finishes, the thread is terminated without completing its execution, leading to undefined behavior.
- **detach()**: The detach function separates the thread from the calling thread, allowing it to run independently in the background. Detached threads cannot be joined later.

Example:

cpp

Copy code

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

void threadFunction() {
  cout << "Detached Thread Running" << endl;
}

int main() {
  thread t(threadFunction);
  t.detach();  // Detach the thread to run independently

  cout << "Main thread continues execution" << endl;
  return 0;
}
```

In this case, the t thread runs in the background while the main thread continues its execution. Once the t thread is detached, you cannot call join() on it.

---

3. Passing Arguments to Threads

You can pass arguments to threads using the thread constructor.

Example:

cpp

Copy code

```cpp
#include <iostream>

#include <thread>

using namespace std;


void print(int x, string str) {

   cout << "Integer: " << x << ", String: " << str << endl;

}


int main() {

   thread t(print, 10, "Hello");


   t.join();  // Wait for the thread to finish

   return 0;

}
```

Here, the function print is executed in the thread with arguments 10 and "Hello".

---

4. Thread Safety and Data Sharing

When multiple threads access shared data, you need to protect that data from concurrent access issues (e.g., race conditions). In C++, this can be done using **mutexes** and other synchronization primitives.

Mutex (Mutual Exclusion):

A mutex is used to ensure that only one thread can access a critical section (shared resource) at a time. It prevents race conditions by locking the shared resource during access.

Example with Mutex:

cpp

Copy code

```
#include <iostream>

#include <thread>

#include <mutex>

using namespace std;


mutex mtx;


void printMessage(string msg) {

   // Lock the critical section

   mtx.lock();

   cout << msg << endl;

   mtx.unlock();

}


int main() {

   thread t1(printMessage, "Hello from Thread 1");

   thread t2(printMessage, "Hello from Thread 2");
```

```cpp
    t1.join();
    t2.join();

    return 0;
}
```

In this example, both threads are trying to access the cout (which is a shared resource). The mutex ensures that only one thread prints at a time.

---

5. Lock Guard

A **lock guard** is an easier way to manage locks. It locks a mutex when created and automatically unlocks it when it goes out of scope, ensuring that mutexes are properly unlocked even in case of exceptions.

Example:

cpp

Copy code

```cpp
#include <iostream>
#include <thread>
#include <mutex>
using namespace std;

mutex mtx;

void printMessage(string msg) {
    lock_guard<mutex> lock(mtx);  // Automatically locks and unlocks
    cout << msg << endl;
}
```

```
int main() {
    thread t1(printMessage, "Hello from Thread 1");
    thread t2(printMessage, "Hello from Thread 2");

    t1.join();
    t2.join();

    return 0;
}
```

In this example, the lock_guard automatically manages the mutex lock and unlock operations, reducing the chances of mistakes like forgetting to unlock.

---

6. Condition Variables

A **condition variable** is used for synchronization between threads. It allows one or more threads to wait for a condition to become true before proceeding.

Example:

cpp

Copy code

```
#include <iostream>
#include <thread>
#include <mutex>
#include <condition_variable>
using namespace std;

mutex mtx;
condition_variable cv;
```

```
bool ready = false;

void printMessage(int id) {
    unique_lock<mutex> lock(mtx);  // Lock the mutex
    cv.wait(lock, [] { return ready; });  // Wait until ready becomes true
    cout << "Thread " << id << " is proceeding!" << endl;
}

void setReady() {
    this_thread::sleep_for(chrono::seconds(1));  // Simulate work
    ready = true;
    cv.notify_all();  // Notify all waiting threads
}

int main() {
    thread t1(printMessage, 1);
    thread t2(printMessage, 2);

    thread t3(setReady);

    t1.join();
    t2.join();
    t3.join();

    return 0;
}
```

In this example, threads t1 and t2 wait until the ready flag becomes true. The cv.wait() method is used to block the thread until ready is set to true by thread t3.

---

7. Thread Pools (Advanced)

A **thread pool** is a design pattern where a group of pre-instantiated threads are kept ready to perform tasks. Instead of creating and destroying threads on the fly, a pool of threads is maintained, and tasks are distributed among them.

Thread pools are commonly used in environments where many short tasks need to be performed, and creating/destroying threads frequently would add unnecessary overhead.

Best Practices in Multithreading:

1. **Avoid Race Conditions**: Use mutexes, locks, or other synchronization mechanisms to avoid race conditions.
2. **Minimize Locking**: Only lock critical sections and avoid holding locks for too long to prevent performance bottlenecks.
3. **Use Lock Guards**: Prefer lock_guard or unique_lock to manage locks automatically.
4. **Avoid Deadlocks**: Ensure that you lock shared resources in a consistent order to prevent deadlocks.
5. **Thread Safety**: Use atomic operations or thread-safe containers where applicable.

Summary:

- **std::thread**: Used to create and manage threads.
- **join()** and **detach()**: Control thread synchronization and whether to wait for the thread or let it run independently.
- **mutex** and **lock_guard**: Protect shared resources from concurrent access.
- **condition_variable**: Synchronizes threads using conditions.
- **thread safety**: Always be mindful of potential race conditions and deadlocks when sharing data across threads.

Multithreading in C++ is essential for writing efficient and responsive applications, especially in environments that require parallel task execution or concurrency.

4o

You said:

Write the flex code for Tokenization

ChatGPT said:

ChatGPT

Tokenization in the context of lexical analysis is the process of breaking up a sequence of characters into meaningful elements called **tokens**. Each token represents a group of characters (such as keywords, identifiers, numbers, or operators) with a specific meaning in the programming language.

Here is a simple **Flex** (Fast Lexical Analyzer) code to perform **tokenization**. This code will tokenize keywords (if, else, return), identifiers (variable names), numbers, operators, and white spaces.

Flex Code for Tokenization:

c

Copy code

```
%{

#include <stdio.h>

#include <ctype.h>


// Token Definitions

#define KEYWORD 1

#define IDENTIFIER 2

#define NUMBER 3

#define OPERATOR 4

#define WHITESPACE 5

#define UNKNOWN 6
```

```
%}

%%
/* Keywords */
if|else|return          { printf("Keyword: %s\n", yytext); return KEYWORD; }

/* Identifiers (variable names) - A sequence starting with a letter or underscore, followed by letters, digits, or underscores */
[a-zA-Z_][a-zA-Z0-9_]*    { printf("Identifier: %s\n", yytext); return IDENTIFIER; }

/* Numbers - Integer and Floating-point numbers */
[0-9]+                { printf("Number: %s\n", yytext); return NUMBER; }
[0-9]+"."[0-9]+         { printf("Number: %s\n", yytext); return NUMBER; }

/* Operators (e.g. arithmetic, logical) */
"+"|"-"|"*"|"/"|"="       { printf("Operator: %s\n", yytext); return OPERATOR; }

/* Whitespace (Spaces, Tabs, Newlines) */
[ \t\n]+               { /* Ignore whitespace */ return WHITESPACE; }

/* Any other characters */
.                     { printf("Unknown character: %s\n", yytext); return UNKNOWN; }
%%

int main(void) {
   printf("Enter the input to be tokenized:\n");
```

```
    yylex();  // Call the lexical analyzer
    return 0;
}

int yywrap() {
    return 1;
}
```

Explanation:

1. **Header Section (%{ ... %})**:
   - This section contains C/C++ code and definitions.
   - Token type definitions are provided (KEYWORD, IDENTIFIER, NUMBER, etc.) to label the type of tokens recognized.
2. **Rules Section (%% ... %%)**:
   - Flex patterns are specified here. Each pattern corresponds to a token type (keywords, identifiers, numbers, etc.).
   - Each pattern is followed by an action, which typically involves printing the token and returning its type.
   - The pattern for keywords matches specific reserved words like if, else, and return.
   - Identifiers are sequences starting with a letter or underscore, followed by letters, digits, or underscores.
   - Numbers can be integers or floating-point numbers.
   - Operators such as +, -, *, /, and = are matched and returned as operators.
   - Whitespace (spaces, tabs, and newlines) is ignored during tokenization.
   - Any unrecognized characters are considered **unknown** and handled separately.
3. **Main Function**:

- The main() function starts the tokenization process by calling yylex(), which is the lexical analyzer generated by Flex.
- The yywrap() function tells Flex to stop after the input is completely processed (it returns 1 to indicate no more input).

Sample Input:

kotlin

Copy code

```
if x == 10
{
  return y + 20;
}
```

Output:

vbnet

Copy code

```
Keyword: if
Identifier: x
Operator: ==
Number: 10
Operator: {
Keyword: return
Identifier: y
Operator: +
Number: 20
Operator: }
```

How to Use Flex:

1. Save the code to a file with a .l extension, for example, tokenizer.l.
2. Run Flex on this file to generate a C file: flex tokenizer.l.

3. Compile the generated C file using a C compiler: gcc lex.yy.c -o tokenizer.
4. Run the resulting executable: ./tokenizer.
5. Enter the input for tokenization, and the tokens will be printed along with their types.

Conclusion:

This Flex code demonstrates a simple tokenizer that can recognize keywords, identifiers, numbers, operators, and whitespace. You can extend the tokenizer to recognize more complex tokens like floating-point numbers, strings, comments, and more based on your programming language or input specification.

Week 2:

Here are the solutions for each of the problems you provided. All are written in C++.

1. Dynamic Array-Based Solution for Student Grades (Vector)

cpp

Copy code

```cpp
#include <iostream>
#include <vector>

void printVector(const std::vector<int>& v) {
  for (int grade : v) {
    std::cout << grade << " ";
  }
  std::cout << std::endl;
}

int main() {
  std::vector<int> grades;
```

```
    // Adding elements
    for (int i = 0; i < 10; ++i) {
        grades.push_back(i * 10);
        std::cout << "Added grade: " << i * 10 << ", Vector size: " << grades.size()
                  << ", Capacity: " << grades.capacity() << std::endl;
    }

    // Deleting an element
    grades.pop_back();
    std::cout << "After pop_back(), Vector size: " << grades.size() << std::endl;

    // Retrieving elements
    printVector(grades);

    return 0;
}
```

2. Doubly Linked List for Browser History

cpp

Copy code

```
#include <iostream>

struct Node {
    std::string url;
    Node* prev;
    Node* next;
    Node(std::string u) : url(u), prev(nullptr), next(nullptr) {}
```

```
};

class BrowserHistory {
public:
  BrowserHistory() : head(nullptr), tail(nullptr), current(nullptr) {}

  void visit(const std::string& url) {
    Node* newNode = new Node(url);
    if (!head) {
      head = tail = current = newNode;
    } else {
      current->next = newNode;
      newNode->prev = current;
      current = newNode;
      tail = current;
    }
  }

  void back() {
    if (current->prev) {
      current = current->prev;
      std::cout << "Moved back to: " << current->url << std::endl;
    } else {
      std::cout << "No previous page.\n";
    }
  }
```

```
    void forward() {
        if (current->next) {
            current = current->next;
            std::cout << "Moved forward to: " << current->url << std::endl;
        } else {
            std::cout << "No next page.\n";
        }
    }

private:
    Node* head;
    Node* tail;
    Node* current;
};

int main() {
    BrowserHistory history;
    history.visit("google.com");
    history.visit("stackoverflow.com");
    history.visit("github.com");

    history.back();
    history.forward();
    history.back();
    history.back();
```

```cpp
    return 0;
}
```

3. Task Scheduling System Using Deque

cpp

Copy code

```cpp
#include <iostream>
#include <deque>

int main() {
    std::deque<std::string> taskDeque;

    // Adding tasks
    taskDeque.push_back("Regular Task 1");
    taskDeque.push_back("Regular Task 2");
    taskDeque.push_front("Priority Task 1");

    // Removing and accessing tasks
    std::cout << "First Task: " << taskDeque.front() << std::endl;
    taskDeque.pop_front();
    std::cout << "Next Task: " << taskDeque.front() << std::endl;
    taskDeque.pop_front();

    return 0;
}
```

4. Check for Balanced Parentheses Using Stack

cpp

Copy code

```cpp
#include <iostream>
#include <stack>
#include <string>

bool isBalanced(const std::string& expr) {
  std::stack<char> s;
  for (char ch : expr) {
    if (ch == '(' || ch == '{' || ch == '[') {
      s.push(ch);
    } else if (ch == ')' || ch == '}' || ch == ']') {
      if (s.empty()) return false;
      char top = s.top();
      s.pop();
      if ((ch == ')' && top != '(') ||
        (ch == '}' && top != '{') ||
        (ch == ']' && top != '[')) {
        return false;
      }
    }
  }
  return s.empty();
}

int main() {
```

```
    std::string expr = "{[()]}";
    std::cout << (isBalanced(expr) ? "Balanced" : "Not Balanced") << std::endl;
    return 0;
}
```

5. Ticketing System Using Queue

cpp

Copy code

```cpp
#include <iostream>
#include <queue>
#include <string>

int main() {
    std::queue<std::string> ticketQueue;
    std::string vipCustomer = "VIP Customer";

    // Regular customers
    ticketQueue.push("Customer 1");
    ticketQueue.push("Customer 2");

    // Serving regular customer
    std::cout << ticketQueue.front() << " is being served." << std::endl;
    ticketQueue.pop();

    // VIP customer enters
    std::cout << vipCustomer << " is being served next." << std::endl;
```

```
    return 0;
}
```

6. Hospital Emergency Room Using Priority Queue

cpp

Copy code

```
#include <iostream>
#include <queue>
#include <vector>

struct Patient {
    int severity;
    std::string name;
    bool operator<(const Patient& other) const {
        return severity < other.severity;
    }
};

int main() {
    std::priority_queue<Patient> erQueue;

    erQueue.push({3, "Patient A"});
    erQueue.push({5, "Patient B"});
    erQueue.push({1, "Patient C"});

    while (!erQueue.empty()) {
        Patient p = erQueue.top();
```

```
        erQueue.pop();
        std::cout << p.name << " with severity " << p.severity << " is being treated.\n";
    }

    return 0;
}
```

7. Unique Emails Using Set

cpp

Copy code

```
#include <iostream>
#include <set>
#include <string>

int main() {
    std::set<std::string> emailSet;
    emailSet.insert("customer1@example.com");
    emailSet.insert("customer2@example.com");
    emailSet.insert("customer1@example.com"); // Duplicate, won't be inserted.

    // Print unique emails
    for (const auto& email : emailSet) {
        std::cout << email << std::endl;
    }

    return 0;
}
```

8. Student Record Management Using Map

cpp

Copy code

```cpp
#include <iostream>
#include <map>
#include <string>

struct Student {
    std::string name;
    int grade;
};

int main() {
    std::map<int, Student> studentMap;

    studentMap[101] = {"Alice", 85};
    studentMap[102] = {"Bob", 90};

    // Retrieve student
    int id = 101;
    if (studentMap.find(id) != studentMap.end()) {
        std::cout << "Student ID: " << id << ", Name: " << studentMap[id].name
                  << ", Grade: " << studentMap[id].grade << std::endl;
    }

    return 0;
```

}

9. Word Frequency Counter Using Unordered Map

cpp

Copy code

```
#include <iostream>
#include <unordered_map>
#include <string>
#include <sstream>

int main() {
  std::unordered_map<std::string, int> wordCount;
  std::string text = "hello world hello";

  std::stringstream ss(text);
  std::string word;
  while (ss >> word) {
    ++wordCount[word];
  }

  for (const auto& pair : wordCount) {
    std::cout << pair.first << ": " << pair.second << std::endl;
  }

  return 0;
}
```

10. Sorting Students by Grades Using std::sort

cpp

Copy code

```cpp
#include <iostream>
#include <vector>
#include <algorithm>

struct Student {
  std::string name;
  int grade;
};

bool compare(const Student& a, const Student& b) {
  if (a.grade != b.grade)
    return a.grade > b.grade;
  return a.name < b.name;
}

int main() {
  std::vector<Student> students = {{"Alice", 85}, {"Bob", 90}, {"Eve", 85}};
  std::sort(students.begin(), students.end(), compare);

  for (const auto& student : students) {
    std::cout << student.name << ": " << student.grade << std::endl;
  }

  return 0;
```

}

11. Multithreading Example with std::thread

cpp

Copy code

```cpp
#include <iostream>
#include <thread>

void printNumbers(int start, int end) {
    for (int i = start; i <= end; ++i) {
        std::cout << i << " ";
    }
    std::cout << std::endl;
}

int main() {
    std::thread t1(printNumbers, 1, 5);
    std::thread t2(printNumbers, 6, 10);

    t1.join();
    t2.join();

    return 0;
}
```

These solutions cover all the problems you've listed. Let me know if you need further clarifications or additional functionality.

Memory Allocation

1. Vectors (Dynamic Arrays)

A vector is a dynamic array that resizes itself as elements are added or removed. Memory reallocation occurs when the vector exceeds its current capacity.

Common Operations:

- **Add:**

cpp

Copy code

```
std::vector<int> v;

v.push_back(10);   // Adds 10 at the end, resizes if needed.

v.insert(v.begin(), 20);  // Inserts 20 at the front.
```

- **Update:**

cpp

Copy code

```
v[0] = 30;   // Updates the first element with 30.
```

- **Delete:**

cpp

Copy code

```
v.pop_back();   // Removes the last element.

v.erase(v.begin());  // Removes the first element.
```

Memory Allocation:

- When push_back() is called and the current capacity is exceeded, the vector reallocates memory by doubling its capacity.
- shrink_to_fit() can be used to reduce excess capacity.

2. List (Doubly Linked List)

A doubly linked list stores elements as nodes, with each node containing pointers to both the previous and next node.

Common Operations:

- **Add:**

cpp

Copy code

```
std::list<int> l;

l.push_back(10);   // Adds 10 at the end.

l.push_front(20);  // Adds 20 at the front.

l.insert(++l.begin(), 30);  // Inserts 30 after the first element.
```

- **Update:** (No random access)

cpp

Copy code

```
*l.begin() = 40;   // Updates the first element with 40.
```

- **Delete:**

cpp

Copy code

```
l.pop_back();   // Removes the last element.

l.pop_front();  // Removes the first element.

l.erase(l.begin());  // Erases the first element.
```

Memory Allocation:

- Each node is dynamically allocated in memory. Deleting nodes frees that memory.

3. Deque (Double-Ended Queue)

Deque allows efficient insertion/removal from both ends.

Common Operations:

- **Add:**

cpp

Copy code

std::deque<int> d;

d.push_back(10);   // Adds 10 at the end.

d.push_front(20); // Adds 20 at the front.

- **Update:**

cpp

Copy code

d[0] = 30;   // Updates the first element with 30.

- **Delete:**

cpp

Copy code

d.pop_back();   // Removes the last element.

d.pop_front(); // Removes the first element.

Memory Allocation:

- Similar to a vector but with better performance for front operations. Memory for front and back operations is handled efficiently.

4. Stack (LIFO)

Stack operates on a Last-In, First-Out principle and is usually implemented using std::deque.

Common Operations:

- **Add:**

cpp

Copy code

std::stack<int> s;

s.push(10);   // Pushes 10 on top.

- **Access Top:**

cpp

Copy code

int topElement = s.top(); // Accesses the top element.

- **Delete:**

cpp

Copy code

s.pop(); // Removes the top element.

Memory Allocation:

- Memory is dynamically allocated as elements are pushed, and deallocated when popped.

5. Queue (FIFO)

Queue operates on a First-In, First-Out principle, also often implemented using std::deque.

Common Operations:

- **Add:**

cpp

Copy code

std::queue<int> q;

q.push(10);   // Pushes 10 at the back.

- **Access Front:**

cpp

Copy code

int frontElement = q.front(); // Accesses the front element.

- **Delete:**

cpp

Copy code

q.pop(); // Removes the front element.

Memory Allocation:

- Like a deque, memory is dynamically managed as elements are pushed and popped.

6. Priority Queue

A priority queue is a type of queue where each element is assigned a priority, and elements are served based on their priority.

Common Operations:

- **Add:**

cpp

Copy code

std::priority_queue<int> pq;

pq.push(10);   // Pushes 10 into the priority queue.

pq.push(20);

- **Access Top:**

cpp

Copy code

int highestPriority = pq.top(); // Returns the element with the highest priority.

- **Delete:**

cpp

Copy code

pq.pop(); // Removes the element with the highest priority.

Memory Allocation:

- Internally, it uses a binary heap structure that dynamically resizes.

7. Set (Binary Search Tree)

A set is a collection of unique elements, implemented as a balanced binary search tree (e.g., Red-Black Tree).

Common Operations:

- **Add:**

cpp

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```
std::set<int> s;
s.insert(10);  // Inserts 10 if it doesn't already exist.
```

- **Update:** (Not directly supported, but you can remove and reinsert)

cpp

Copy code

```
s.erase(10);  // Removes 10.
s.insert(20); // Inserts new value.
```

- **Delete:**

cpp

Copy code

```
s.erase(10);  // Removes 10 from the set.
```

Memory Allocation:

- Each node is dynamically allocated. Operations like insert or erase maintain the tree's balance.

8. Map (Balanced Binary Search Tree)

A map is a collection of key-value pairs, implemented as a balanced binary search tree.

Common Operations:

- **Add:**

cpp

Copy code

```
std::map<int, int> m;
m[1] = 10;   // Adds key 1 with value 10.
```

- **Update:**

cpp

Copy code

```
m[1] = 20;   // Updates key 1 with value 20.
```

- **Delete:**

cpp

Copy code

```
m.erase(1);  // Removes the key-value pair with key 1.
```

Memory Allocation:

- Like a set, each key-value pair is stored in a dynamically allocated node.

9. Unordered Map/Set (Hash Tables)

Unordered maps and sets are based on hash tables, allowing faster access on average compared to ordered versions.

Common Operations:

- **Add:**

cpp

Copy code

```
std::unordered_map<int, int> um;

um[1] = 10;   // Adds key 1 with value 10.
```

- **Update:**

cpp

Copy code

```
um[1] = 20;   // Updates key 1 with value 20.
```

- **Delete:**

cpp

Copy code

```
um.erase(1);  // Removes the key-value pair with key 1.
```

Memory Allocation:

- Memory is allocated in buckets based on the hash value. The number of buckets grows as elements are added, improving lookup performance.

Memory Optimization Tips for C++ Containers:

- For **vectors**, you can reduce excess memory using shrink_to_fit().
- For **deques**, **stacks**, **queues**, memory usage is efficient but can be optimized by reusing the container.
- **Sets**, **maps**, and **unordered** versions automatically manage memory for their nodes and buckets.