Interview Review Chart

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1 Parallelism

1.1 Concepts

Concurrency When two or more tasks can start/run/complete in overlapping time periods. This does not necessarily mean they'll be running in overlapping time periods. Examples include:
RTOS

Parallelism When tasks run at the same time (e.g. on a multi-core CPU)

Multithreading When multiple tasks are running on a CPU. This can be implemented truly parallel where each task has access to separate HW/core. However, more common in desktop applications is SMT.

SMT (Simultaneous Multithreading) Multiple threads share 1 core. The thread instructions are pipelines s.t. they run mostly in-parallel, and when one is waiting for I/O the other can run uninhibited, however since only one thread can access a dedicated HW block at any given time they are not truly parallel.

1.2 Implementation

- Concurrency and Multithreading
  - Basic concepts of threads and processes
  - Thread synchronization mechanisms (mutexes, semaphores, locks)
  - Race conditions:
    1. Multiple threads accessing a shared resource
    2. At least one thread writes to the resource
    3. Lack of proper synchronization
  - deadlocks

```
std::mutex m1, m2;
// Must have 2 locks where they are locked in different orders
    in different locations/threads
thread1: m1.lock(); m2.lock(); m1.unlock(); m2.unlock();
thread2: m2.lock(); m1.lock(); m2.unlock(); m1.unlock();
```

  - Atomic operations

```
std::atomic<T> var; // where T is a primitive type
var = val;
var.load(val);
var.store(val);
var.wait(); // waits until the value changes
```

```
T current = var.exchange(val); // writes val to var and gets previous/current value of var
// Compare-and-swap. Atomically compares object.value with that of expected. If bitwise-equal then replaces former with desired. Otherwise loads actual value into expected (via load operation)
bool res = var.compare_exchange_strong(expected, desired); // preferred when don't expect high contention and cost of retrying is significant. Simpler, but slower.
bool res = var.compare_exchange_weak(expected, desired);  // preferred if you're anyways retrying in a loop or cost of retrying is low. More efficient, but more complex.
```

```
// Weak usage
std::atomic<int> value{0};
int expected = 0;
int desired = 1;
while(!value.compare_exchange_weak(expected, desired)){
  ; // handle spurrious failures
}

// Strong usage
if(value.compare_exchange_strong(expected, desired)){
  // op successful
}
else
{
  // op failed
}
```

- Thread-Safe Data Structures:
  - Concurrent collections
  - Concurrent collections (e.g., ConcurrentQueue, ConcurrentBag)
  - Lock-free data structures
  - Understanding the differences between thread-safe and non-thread-safe collections
- Design Patterns for Concurrency:
  - Producer-Consumer pattern
  - Readers-Writer pattern
  - Thread pool pattern
- Language-Specific Concurrency Features for C++:
  - std::thread
  - <atomic>
- Callback Mechanisms:
  - Function pointers

```
#include <stdio.h>

// Define a struct with function pointers for arithmetic operations
typedef struct {
    int (*add)(int, int);
} ArithmeticOperations;

```

```c
// Define the functions for arithmetic operations
int add(int a, int b) { return a + b; }

int main() {
    // Initialize the struct with function pointers
    ArithmeticOperations ops;
    ops.add = add;
    // Use the function pointers to perform operations
    int x = 10, y = 5;
    printf("Add: %d + %d = %d\n", x, y, ops.add(x, y));
    return 0;
}
```

  - Delegates (in languages that support them)
  - Lambda expressions

- Performance Considerations:
  - Understanding the overhead of different synchronization mechanisms
    Generally best practice to measure performance in single-threaded vs multithreaded/parallel environments. Since there is overhead with creating/cleaning up threads/processes it can make your program run slower in smaller data sets.
  - Balancing thread safety with performance

- Testing Multithreaded Code:
  - Techniques for writing unit tests for concurrent code
  - Tools for detecting race conditions and deadlocks
    * **Helgrind:** Part of Valgrind suite. Checks for race conditions, but slow.
    * **ThreadSanitizer:** Compiler flag in llvm/clang. Faster than Helgrind.
    * **RacerD:** Meta's C++-specific concurrent static analyzer. Good for larget code-bases.
    * **Clang Static Analyzer:** Detects some simple conditions.

- Distributed Systems Concepts:
  While not directly related to this problem, understanding concepts like eventual consistency and distributed locking can be beneficial

- Algorithms for Concurrent Operations:
  - Compare-And-Swap (CAS) operations
  - Lock-free algorithms

- Memory Models:
  - Understanding memory barriers and volatile variables
  - Cache coherence issues in multi-core systems

    Cache Coherence The process of ensuring that data is stored in multiple caches within a multiprocessor system is consistent and synchronized.

    This ensures that all processors have a *consistent* view of shared memory. Cache coherence protocols manage the flow of data between caches, updating cache lines and tracking the status of shared data. This can be complicated because it requires balancing perforamnce and coherence overhead. The 2 main types of protocols are Directory-based and Snoop-based.

Directory-based The sharing status of a block of physical memory is kept in just one location (the directory). The direcotry can also be distributed to improve scalability. Communication is established using point-to-point requests through the interconnection network.

Snoop-based Every cache that has a copy of the data from a block of physical memory also has a copy of the sharing status of the block, but no centralized state is kept. Caches are all accessible via some broadcast medium (a bus or switch), and all cache controllers monitor or *snoop* on the medium to determine whether or not they have a copy of a block that is requested on a bus or switch access. Requires broadcast, csince caching information is at processors. This is useful for small-scale machines.

Point of Coherency (PoC) Point at which all agents in a system which can access memory are guaranteed to see the same data.

Migration Data is migrated to the local cache levels.

Replication The same data is replicated across all caches.

Assume Snoop-based protocol. There are 2 ways to maintaint coherence:

1. **Write Invalidate Protocol**: Ensure that a processor has exclusive access to a data item before it writes that item. This is most common protocol.
2. **Write Broadcast/Update**: All cached copies are updated simultaneously. This requires more bandwidth. When multiple updates happen to the same location, unnecessary updates are done. However, this is a lower latency between write/read.

- Practice Problems:
  - Implement a thread-safe singleton

```cpp
#include <iostream>
#include <mutex>

class Singleton {
 public:
    // Delete copy constructor and assignment operator to prevent creation of additional instances through copying
    Singleton(const Singleton&) = delete;
    Singleton& operator=(const Singleton&) = delete;

    // Static method to get the instance of the singleton
    static Singleton& getInstance() {
        static Singleton instance;  // Static Local variables are guaranteed to be thread-safe in C++11 and later
        return instance;
    }

    void showMessage() { std::cout << "Singleton instance accessed!" << std::endl; }

 private:
    // Private constructor to prevent instantiation
    Singleton() { std::cout << "Singleton instance created!" << std::endl; }
};

int main() {
    // Access the singleton instance
    Singleton& singleton = Singleton::getInstance();
    singleton.showMessage();
```

```
27
28      return 0;
29  }
```

- Create a simple producer-consumer queue

```
1   #include <chrono>
2   #include <condition_variable>
3   #include <iostream>
4   #include <mutex>
5   #include <queue>
6   #include <thread>
7
8   class ThreadSafeQueue {
9    public:
10      void enqueue(int item) {
11          std::lock_guard<std::mutex> lock(mutex_);
12          queue_.push(item);
13          cond_var_.notify_one();
14      }
15
16      int dequeue() {
17          std::unique_lock<std::mutex> lock(mutex_);
18          cond_var_.wait(lock, [this] { return !queue_.empty();
                });
19          int item = queue_.front();
20          queue_.pop();
21          return item;
22      }
23
24   private:
25      std::queue<int> queue_;
26      std::mutex mutex_;
27      std::condition_variable cond_var_;
28  };
29
30  void producer(ThreadSafeQueue& queue, int numItems) {
31      for (int i = 0; i < numItems; ++i) {
32          std::this_thread::sleep_for(std::chrono::milliseconds
                (100));  // Simulate work
33          queue.enqueue(i);
34          std::cout << "Produced: " << i << std::endl;
35      }
36  }
37
38  void consumer(ThreadSafeQueue& queue, int numItems) {
39      for (int i = 0; i < numItems; ++i) {
40          int item = queue.dequeue();
41          std::cout << "Consumed: " << item << std::endl;
42      }
43  }
44
45  int main() {
46      ThreadSafeQueue queue;
47      const int numItems = 10;
48
49      std::thread producerThread(producer, std::ref(queue),
            numItems);
50      std::thread consumerThread(consumer, std::ref(queue),
            numItems);
51
52      producerThread.join();
53      consumerThread.join();
54
```

```
    return 0;
}
```

- Implement a basic thread pool

```
#include <execution>  // Required for std::execution::seq
#include <iostream>
#include <numeric>
#include <random>
#include <thread>
#include <vector>

void accumulateRandomNumbers(int threadID) {
    static std::mutex m;
    std::random_device rd;
    std::mt19937 gen(rd());
    std::uniform_real_distribution<double> dis(0.0, 1.0);

    std::vector<double> numbers(1024 * 1024);
    for (auto& num : numbers) {
        num = dis(gen);
    }

    double sum = std::reduce(std::execution::seq, numbers.
       begin(), numbers.end());
    std::lock_guard<std::mutex> lock(m);
    std::cout << "Thread " << threadID << " accumulated sum: "
        << sum << std::endl;
}

int main() {
    const int numThreads = std::thread::hardware_concurrency()
       ;  // Number of threads in the pool
    std::vector<std::thread> threadPool;

    // Create and launch threads
    for (int i = 0; i < numThreads; ++i) {
        threadPool.emplace_back(accumulateRandomNumbers, i);
    }

    // Join threads to the main thread
    for (auto& thread : threadPool) {
        thread.join();
    }

    return 0;
}
```

- Solve classic concurrency problems like the dining philosophers problem

```
#include <chrono>
#include <condition_variable>
#include <iostream>
#include <mutex>
#include <thread>
#include <vector>

class DiningPhilosophers {
 public:
    DiningPhilosophers(int numPhilosophers)
        : numPhilosophers_(numPhilosophers), states_(
           numPhilosophers, State::THINKING) {}

```

```
13      void philosopher(int id) {
14          while (true) {
15              think(id);
16              pickUpForks(id);
17              eat(id);
18              putDownForks(id);
19          }
20      }
21
22  private:
23      enum class State { THINKING, HUNGRY, EATING };
24
25      void think(int id) {
26          std::cout << "Philosopher " << id << " is thinking."
                << std::endl;
27          std::this_thread::sleep_for(std::chrono::milliseconds
                (1000));
28      }
29
30      void eat(int id) {
31          std::cout << "Philosopher " << id << " is eating." <<
                std::endl;
32          std::this_thread::sleep_for(std::chrono::milliseconds
                (1000));
33      }
34
35      void pickUpForks(int id) {
36          std::unique_lock<std::mutex> lock(mutex_);
37          states_[id] = State::HUNGRY;
38          cond_var_.wait(lock, [this, id] { return canEat(id);
                });
39          states_[id] = State::EATING;
40      }
41
42      void putDownForks(int id) {
43          std::unique_lock<std::mutex> lock(mutex_);
44          states_[id] = State::THINKING;
45          cond_var_.notify_all();
46      }
47
48      bool canEat(int id) {
49          int left = (id + numPhilosophers_ - 1) %
                numPhilosophers_;
50          int right = (id + 1) % numPhilosophers_;
51          return states_[id] == State::HUNGRY && states_[left]
                != State::EATING && states_[right] != State::EATING
                ;
52      }
53
54      int numPhilosophers_;
55      std::vector<State> states_;
56      std::mutex mutex_;
57      std::condition_variable cond_var_;
58  };
59
60  int main() {
61      const int numPhilosophers = 5;
62      DiningPhilosophers diningPhilosophers(numPhilosophers);
63      std::vector<std::thread> threads;
64
65      for (int i = 0; i < numPhilosophers; ++i) {
66          threads.emplace_back(&DiningPhilosophers::philosopher,
                &diningPhilosophers, i);
```

```
    }

    for (auto& thread : threads) {
        thread.join();
    }

    return 0;
}
```

Write a few test cases in addition to the solution Remember, for interviews, it's not just about knowing the solutions, but also being able to explain your reasoning, discuss trade-offs, and analyze the performance and correctness of your solutions. Lastly, be prepared to write code on a whiteboard or in a simple text editor. Practice implementing these concepts without relying on an IDE's features.

2 Operating Systems

2.1 Caches

TLB The TLB is a small, fast, and fast-access memory that is used to translate virtual memory addresses into physical memory addresses. a.k.a. Translation Lookaside Buffer.

2.2 Basic Concepts

- **TLB: Translate Lookaside Buffer**
- **Processes and Threads**
  - Process creation and termination
  - Thread lifecycle and management
- **Memory Management**
  - Virtual memory
  - Paging and segmentation
- **File Systems**
  - File system structure
  - File operations and permissions

3 C

3.1 Preprocessor

```
# // stringizes the macro parameter
#define stringify(x) #x
#define foo 1
stringify(foo) // --> evaluates to "foo", NOT "1"
```

```
## // concatenates the macro parameter
#define COMMAND(NAME)  {#NAME, NAME ## _command}
struct command commands[] = {
  COMMAND(quit), // equivalent to {quit_command}
  COMMAND(help), // equivalent to {help_command}
}
```

- predefined macros
  - __FILE__
  - __LINE__
  - __DATE__
  - __TIME__
  - __STDC_VERSION__
  - __cplusplus
- item2
- item3
- item4

3.2 Peripherals

- **I2C**
  SDA is data, SCL is clock. PURs typically in the 1-4.7k range. Too weak = slow comm and errors. Clocks are usually 100k-1MHz. Addr can be 7 or 10 bit. This is rate-limiter for number of slaves, though line impedance would increase for each slave. Here are some use usage examples:

  1. Master sends START and slave Addr
  2. Master sends data to slave
  3. Master terminates with a STOP

  1. Master sends START and slave Addr
  2. Master sends data to slave
  3. Master sends repeatedSTART and either sends more data to slave or receives data from slave.
  4. Master sends STOP

- **SPI**
  Serial Peripheral Interface (SPI) is a synchronous serial communication protocol used for short-distance communication, primarily in embedded systems. It uses a master-slave architecture with a single master and multiple slaves. Communication is full-duplex, and it requires four wires: MOSI, MISO, SCLK, and SS.

- **UART**
  Universal Asynchronous Receiver-Transmitter (UART) is a hardware communication protocol that uses asynchronous serial communication with configurable speed. It is commonly used for communication between microcontrollers and peripherals. UART requires only two wires: TX (transmit) and RX (receive).

- **USB**
  Universal Serial Bus (USB) is an industry-standard for short-distance digital data communications. It supports plug-and-play installation and hot swapping. USB is used for connecting peripherals such as keyboards, mice, printers, and external storage devices to computers.

- **HDMI**
  High-Definition Multimedia Interface (HDMI) is a proprietary audio/video interface for transmitting uncompressed video data and compressed or uncompressed digital audio data from an HDMI-compliant source device to a compatible display device. It is commonly used for connecting devices like TVs, monitors, and projectors.

4 C++

4.1 <algorithm>

- **batchOperations**
  - for_each, ranges::for_each, for_each_n, ranges::for_each_n

```cpp
std::vector<int> numbers = {1, 2, 3, 4, 5};

// Use std::for_each to print each element
std::for_each(numbers.begin(), numbers.end(), [](int n) { std::cout << n << " "; });

// Use std::for_each_n to print the first 3 elements
std::for_each_n(numbers.begin(), 3, [](int n) { std::cout << n << " "; });

// Use std::ranges::for_each to print each element
std::ranges::for_each(numbers, [](int n) { std::cout << n << " "; });

// Use std::ranges::for_each_n to print the first 3 elements
std::ranges::for_each_n(numbers.begin(), 3, [](int n) { std::cout << n << " "; });
```

- **Search Operations**
  - all_of, any_of, none_of

```cpp
std::vector<int> numbers = {1, 2, 3, 4, 5};
// Use std::all_of to check if all elements are positive
bool allPositive = std::all_of(numbers.begin(), numbers.end(), [](int n) { return n > 0; });
// Use std::any_of to check if any element is greater than 4
bool anyGreaterThanFour = std::any_of(numbers.begin(), numbers.end(), [](int n) { return n > 4; });
// Use std::none_of to check if no elements are negative
bool noneNegative = std::none_of(numbers.begin(), numbers.end(), [](int n) { return n < 0; });
```

  - ranges::contains, ranges::contains_subrange

```cpp
std::vector<int> numbers = {1, 2, 3, 4, 5, 6, 7, 8, 9, 10};

// Check if the range contains the value 5
bool containsFive = std::ranges::contains(numbers, 5);
// Check if the range contains the value 11
bool containsEleven = std::ranges::contains(numbers, 11);
// Define a subrange to check
std::vector<int> subrange = {4, 5, 6};
// Check if the range contains the subrange
bool containsSubrange = std::ranges::contains_subrange(numbers, subrange);
// Define another subrange to check
std::vector<int> nonExistentSubrange = {7, 8, 11};
// Check if the range contains the non-existent subrange
bool containsNonExistentSubrange = std::ranges::contains_subrange(numbers, nonExistentSubrange);
```

- find, find_if, find_if_not, ranges::find, ranges::find_if, ranges::find_if_not

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

int main() {
    std::vector<int> numbers = {1, 2, 3, 4, 5, 6, 7, 8, 9, 10};

    // Use std::find to find the first occurrence of 5
    auto it = std::find(numbers.begin(), numbers.end(), 5);

    // find the first even number
    it = std::find_if(numbers.begin(), numbers.end(), [](int n) { return n % 2 == 0; });
    // find the first odd number
    it = std::find_if_not(numbers.begin(), numbers.end(), [](int n) { return n % 2 == 0; });
    // find the first occurrence of 5
    auto range_it = std::ranges::find(numbers, 5);
    // find the first even number
    range_it = std::ranges::find_if(numbers, [](int n) { return n % 2 == 0; });
    // find the first odd number
    range_it = std::ranges::find_if_not(numbers, [](int n) { return n % 2 == 0; });
}
```

- find_last, find_last_if, find_last_if_not, find_end, ranges::find_end

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

std::vector<int> numbers = {1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 5, 6, 7};

// find the last occurrence of 5
auto lastFive = std::ranges::find_last(numbers, 5);
// find the last even number
auto lastEven = std::ranges::find_last_if(numbers, [](int n) { return n % 2 == 0; });
// find the last odd number
auto lastOdd = std::ranges::find_last_if_not(numbers, [](int n) { return n % 2 == 0; });

// Define a subrange to find
std::vector<int> subrange = {5, 6, 7};

// find the last occurrence of the subrange
auto lastSubrange = std::find_end(numbers.begin(), numbers.end(), subrange.begin(), subrange.end());

// find the last occurrence of the subrange
auto lastSubrangeRange = std::ranges::find_end(numbers, subrange);
```

- find_end, ranges::find_end, find_first_of, ranges::find_first_of
- adjacent_find, ranges::adjacent_find

- count, count_if, ranges::count, ranges::count_if
- mismatch, ranges::mismatch, equal, ranges::equal
- search, search_n, ranges::search, ranges::search_n
- ranges::starts_with, ranges::ends_with

- **Fold Operations**
  - ranges::fold_left, ranges::_fold_left_first, ranges::fold_left_with_iter, ranges::fold_left_first_with_iter
  - ranges::fold_right, ranges::fold_right_last

- **Copy Operations**
  - copy, copy_if, ranges::copy, ranges::copy_if
  - copy_n, ranges::copy_n
  - copy_backwards, ranges::copy_backwards
  - move, ranges::move
  - move_backward, ranges::move_backward

- **Swap Operations**
  - swap
  - swap_ranges
  - ranges::swap_ranges
  - iter_swap

- **Transform Operations**
  - transform, ranges::transform

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

int main() {
    // Original vector
    std::vector<int> l1 = {1, 2, 3, 4, 5};
    std::vector<int> l2 = std::vector<int>(l1.size(), 0);
    std::vector<int> l3 = std::vector<int>(l1.size(), 0);

    // simple transform (1 input, 1 output)
    std::transform(l1.begin(), l1.end(), l2.begin(), [](int a)
        { return a * 10; });

    // transform (2 inputs, 1 output)
    int multiplier = 2;
    std::transform(std::execution::par_unseq, l1.begin(), l1.
       end(), l2.begin(), l3.begin(),
                   [multiplier](int a, int b) { return (
                      multiplier * a) + b; });

    return 0;
}
```

  - replace, replace_if, ranges::replace, ranges::replace_if

```cpp
std::vector<int> numbers = {1, 2, 3, 4, 5, 6, 7, 8, 9, 10};

// Using std::replace to replace all occurrences of 5 with 50
std::replace(numbers.begin(), numbers.end(), 5, 50);
// Result: numbers = {1, 2, 3, 4, 50, 6, 7, 8, 9, 10}

// Using std::replace_if to replace all even numbers with 0
std::replace_if(numbers.begin(), numbers.end(), [](int n) {
    return n % 2 == 0; }, 0);
// Result: numbers = {1, 0, 3, 0, 0, 0, 7, 0, 9, 0}

// Reset the numbers vector for ranges example
numbers = {1, 2, 3, 4, 5, 6, 7, 8, 9, 10};

// Using std::ranges::replace to replace all occurrences of 5
    with 50
std::ranges::replace(numbers, 5, 50);
// Result: numbers = {1, 2, 3, 4, 50, 6, 7, 8, 9, 10}

// Using std::ranges::replace_if to replace all even numbers
    with 0
std::ranges::replace_if(numbers, [](int n) { return n % 2 ==
    0; }, 0);
// Result: numbers = {1, 0, 3, 0, 0, 0, 7, 0, 9, 0}
```

- replace_copy, ranges::replace_copy, replace_copy_if, ranges::replace_copy_if

```cpp
std::vector<int> numbers = {1, 2, 3, 4, 5, 6, 7, 8, 9, 10};
std::vector<int> result(numbers.size());

// Using std::replace_copy to copy elements and replace 5 with
     50
std::replace_copy(numbers.begin(), numbers.end(), result.begin
    (), 5, 50);
// Result: result = {1, 2, 3, 4, 50, 6, 7, 8, 9, 10}

// Using std::replace_copy_if to copy elements and replace
    even numbers with 0
std::replace_copy_if(numbers.begin(), numbers.end(), result.
    begin(), [](int n) { return n % 2 == 0; }, 0);
// Result: result = {1, 0, 3, 0, 5, 0, 7, 0, 9, 0}

// Using std::ranges::replace_copy to copy elements and
    replace 5 with 50
std::ranges::replace_copy(numbers, result.begin(), 5, 50);
// Result: result = {1, 2, 3, 4, 50, 6, 7, 8, 9, 10}

// Using std::ranges::replace_copy_if to copy elements and
    replace even numbers with 0
std::ranges::replace_copy_if(numbers, result.begin(), [](int n
    ) { return n % 2 == 0; }, 0);
// Result: result = {1, 0, 3, 0, 5, 0, 7, 0, 9, 0}
```

- **Generation Operations**
  - fill, fill_n, ranges::fill, ranges::fill_n
  - generate, generate_n, ranges::generate, ranges::generate_n
- **Removing Operations**
  - remove, remove_if, ranges::remove, ranges::remove_if
  - remove_copy, remove_copy_if, ranges::remove_copy, ranges::remove_copy_if

  - unique, unique_copy, ranges::unique, ranges::unique_copy

- **Order-Changing Operations**
  - reverse, ranges::reverse, reverse_copy, ranges::reverse_copy
  - rotate, rotate_copy, ranges::rotate, ranges::rotate_copy
  - shift_left, shift_right, ranges::shift_left, ranges::shift_right
  - shuffle, random_shuffle, ranges::shuffle

- **Sampling Operations**
  - sample, ranges::sample

- **Random Number Generation**
  - ranges::generate_random

- **Partitioning Operations**
  - is_partitioned, ranges::is_partitioned
  - partition, ranges::partition
  - partition_copy, ranges::partition_copy
  - stable_partition, ranges::stable_partition
  - partition_point, ranges::partition_point

- **Sorting Operations**
  - sort, ranges::sort
  - stable_sort, ranges::stable_sort
  - partial_sort, ranges::partial_sort
  - partial_sort_copy, ranges::partial_sort_copy
  - is_sorted, ranges::is_sorted
  - is_sorted_until, ranges::is_sorted_until
  - nth_element, ranges::nth_element

- **Binary Search Operations (on partitioned ranges)**
  - lower_bound, ranges::lower_bound, upper_bound, ranges::upper_bound
  - equal_range, ranges::equal_range
  - binary_search, ranges::binary_search

- **Set Operation (on sorted ranges)**
  - includes, ranges::includes
  - set_union, ranges::set_union
  - set_intersection, ranges::set_intersection
  - set_difference, ranges::set_difference
  - set_symmetric_difference, ranges::set_symmetric_difference

- **Merge Operations (on sorted ranges)**
  - merge, ranges::merge, inplace_merge, ranges::inplace_merge

```cpp
std::vector<int> vec1 = {1, 3, 5, 7};
std::vector<int> vec2 = {2, 4, 6, 8};
std::vector<int> merged(vec1.size() + vec2.size());

// Using std::merge to merge two sorted ranges into a new range
std::merge(vec1.begin(), vec1.end(), vec2.begin(), vec2.end(), merged.begin());
// Result: merged = {1, 2, 3, 4, 5, 6, 7, 8}

// Using std::ranges::merge to merge two sorted ranges into a new range
std::vector<int> mergedRanges(vec1.size() + vec2.size());
std::ranges::merge(vec1, vec2, mergedRanges.begin());
// Result: mergedRanges = {1, 2, 3, 4, 5, 6, 7, 8}

// Using std::inplace_merge to merge two consecutive sorted ranges within a single range
std::vector<int> inplaceVec = {1, 3, 5, 7, 2, 4, 6, 8};
std::inplace_merge(inplaceVec.begin(), inplaceVec.begin() + 4, inplaceVec.end());
// Result: inplaceVec = {1, 2, 3, 4, 5, 6, 7, 8}

// Using std::ranges::inplace_merge to merge two consecutive sorted ranges within a single range
std::vector<int> inplaceVecRanges = {1, 3, 5, 7, 2, 4, 6, 8};
std::ranges::inplace_merge(inplaceVecRanges, inplaceVecRanges.begin() + 4);
// Result: inplaceVecRanges = {1, 2, 3, 4, 5, 6, 7, 8}
```

- **Heap Operations**
  - push_heap, ranges::push_heap, pop_heap, ranges::pop_heap

```cpp
std::vector<int> heap = {3, 1, 4, 1, 5, 9, 2, 6};

// Convert the vector into a heap
std::make_heap(heap.begin(), heap.end());
// Result: heap = {9, 6, 4, 1, 5, 3, 2, 1}

// Using std::push_heap to add a new element and maintain heap property
heap.push_back(7);
std::push_heap(heap.begin(), heap.end());
// Result: heap = {9, 7, 4, 6, 5, 3, 2, 1, 1}

// Using std::pop_heap to remove the largest element and maintain heap property
std::pop_heap(heap.begin(), heap.end());
heap.pop_back();
// Result: heap = {7, 6, 4, 1, 5, 3, 2, 1}

// Using std::ranges::push_heap to add a new element and maintain heap property
heap.push_back(8);
std::ranges::push_heap(heap);
// Result: heap = {8, 7, 4, 6, 5, 3, 2, 1, 1}

// Using std::ranges::pop_heap to remove the largest element and maintain heap property
std::ranges::pop_heap(heap);
heap.pop_back();
// Result: heap = {7, 6, 4, 1, 5, 3, 2, 1}
```

– make_heap, ranges::make_heap, sort_heap, ranges::sort_heap

```cpp
std::vector<int> numbers = {3, 1, 4, 1, 5, 9, 2, 6};

// Using std::make_heap to create a max-heap from the numbers vector
std::make_heap(numbers.begin(), numbers.end());
// Result: numbers = {9, 6, 4, 1, 5, 1, 2, 3}

// Using std::sort_heap to sort the heap
std::sort_heap(numbers.begin(), numbers.end());
// Result: numbers = {1, 1, 2, 3, 4, 5, 6, 9}

// Reset the numbers vector for ranges example
numbers = {3, 1, 4, 1, 5, 9, 2, 6};

// Using std::ranges::make_heap to create a max-heap from the numbers vector
std::ranges::make_heap(numbers);
// Result: numbers = {9, 6, 4, 1, 5, 1, 2, 3}

// Using std::ranges::sort_heap to sort the heap
std::ranges::sort_heap(numbers);
// Result: numbers = {1, 1, 2, 3, 4, 5, 6, 9}
```

– is_heap, ranges::is_heap, is_heap_until, ranges::is_heap_until

```cpp
std::vector<int> numbers = {9, 6, 4, 1, 5, 1, 2, 3};

// Using std::is_heap to check if the numbers vector is a heap
bool isHeap = std::is_heap(numbers.begin(), numbers.end());
// Result: isHeap = true

// Using std::is_heap_until to find the first position where the heap property is violated
auto heapEnd = std::is_heap_until(numbers.begin(), numbers.end());
// Result: heapEnd points to numbers.end(), indicating the entire range is a heap

// Using std::ranges::is_heap to check if the numbers vector is a heap
bool isHeapRanges = std::ranges::is_heap(numbers);
// Result: isHeapRanges = true

// Using std::ranges::is_heap_until to find the first position where the heap property is violated
auto heapEndRanges = std::ranges::is_heap_until(numbers);
// Result: heapEndRanges points to numbers.end(), indicating the entire range is a heap

// Modify the vector to violate the heap property
numbers = {9, 6, 4, 10, 5, 1, 2, 3};

// Re-check using std::is_heap
isHeap = std::is_heap(numbers.begin(), numbers.end());
// Result: isHeap = false

// Re-check using std::is_heap_until
heapEnd = std::is_heap_until(numbers.begin(), numbers.end());
// Result: heapEnd points to numbers.begin() + 3, where the value 10 violates the heap property

// Re-check using std::ranges::is_heap
```

```
isHeapRanges = std::ranges::is_heap(numbers);
// Result: isHeapRanges = false

// Re-check using std::ranges::is_heap_until
heapEndRanges = std::ranges::is_heap_until(numbers);
// Result: heapEndRanges points to numbers.begin() + 3, where
    the value 10 violates the heap property
```

- **Min/Max Operations**

  - max, min, ranges::max, ranges::min

```
int a = 10;
int b = 20;

// Using std::max to find the maximum of two values
int maxVal = std::max(a, b);
// Result: maxVal = 20

// Using std::min to find the minimum of two values
int minVal = std::min(a, b);
// Result: minVal = 10

std::vector<int> numbers = {3, 1, 4, 1, 5, 9, 2, 6, 5, 3, 5};

// Using std::ranges::max to find the maximum value in a range
int maxInRange = std::ranges::max(numbers);
// Result: maxInRange = 9

// Using std::ranges::min to find the minimum value in a range
int minInRange = std::ranges::min(numbers);
// Result: minInRange = 1
```

  - max_element, min_element, ranges::max_element, ranges::min_element

```
std::vector<int> numbers = {3, 1, 4, 1, 5, 9, 2, 6, 5, 3, 5};

// Using std::max_element to find the maximum element in a
    range
auto maxElement = std::max_element(numbers.begin(), numbers.
    end());
// Result: *maxElement = 9

// Using std::min_element to find the minimum element in a
    range
auto minElement = std::min_element(numbers.begin(), numbers.
    end());
// Result: *minElement = 1

// Using std::ranges::max_element to find the maximum element
    in a range
auto maxElementRanges = std::ranges::max_element(numbers);
// Result: *maxElementRanges = 9

// Using std::ranges::min_element to find the minimum element
    in a range
auto minElementRanges = std::ranges::min_element(numbers);
// Result: *minElementRanges = 1
```

  - minmax, ranges::minmax, minmax_element, ranges::minmax_element

```
int a = 10;
int b = 20;

```

```cpp
// Using std::minmax to find the minimum and maximum of two values
auto minmaxPair = std::minmax(a, b);
// Result: minmaxPair.first = 10, minmaxPair.second = 20

std::vector<int> numbers = {3, 1, 4, 1, 5, 9, 2, 6, 5, 3, 5};

// Using std::minmax_element to find the minimum and maximum elements in a range
auto minmaxElements = std::minmax_element(numbers.begin(), numbers.end());
// Result: *minmaxElements.first = 1, *minmaxElements.second = 9

// Using std::ranges::minmax to find the minimum and maximum in a range
auto minmaxRange = std::ranges::minmax(numbers);
// Result: minmaxRange.min = 1, minmaxRange.max = 9

// Using std::ranges::minmax_element to find the minimum and maximum elements in a range
auto minmaxRangeElements = std::ranges::minmax_element(numbers);
// Result: *minmaxRangeElements.min = 1, *minmaxRangeElements.max = 9
//
// TODO (ksolomon): make sure usage is correct. why does minmax return a pair, whereas ranges::minmax return a tuple?
//
```

- clamp, ranges::clamp

```cpp
int value = 15;
int lowerBound = 10;
int upperBound = 20;

// Using std::clamp to constrain the value within the range [lowerBound, upperBound]
int clampedValue = std::clamp(value, lowerBound, upperBound);
// Result: clampedValue = 15

// Using std::clamp to constrain a value below the lower bound
int belowLower = 5;
int clampedBelow = std::clamp(belowLower, lowerBound, upperBound);
// Result: clampedBelow = 10

// Using std::clamp to constrain a value above the upper bound
int aboveUpper = 25;
int clampedAbove = std::clamp(aboveUpper, lowerBound, upperBound);
// Result: clampedAbove = 20

// Using std::ranges::clamp to constrain the value within the range [lowerBound, upperBound]
int clampedValueRanges = std::ranges::clamp(value, lowerBound, upperBound);
// Result: clampedValueRanges = 15

// Using std::ranges::clamp to constrain a value below the lower bound
int clampedBelowRanges = std::ranges::clamp(belowLower, lowerBound, upperBound);
```

```
// Result: clampedBelowRanges = 10

// Using std::ranges::clamp to constrain a value above the upper bound
int clampedAboveRanges = std::ranges::clamp(aboveUpper, lowerBound, upperBound);
// Result: clampedAboveRanges = 20
```

- **Lexicographical Operations**
  - lexicographical_compare, ranges::lexicographical_compare
  - lexicographical_compare_three_way
- **Permutation Operations**
  - next_permutation, ranges::next_permutation, previous_permutation, ranges::previous_permutation, is_permutation, ranges::is_permutation

```
std::vector<int> numbers = {1, 2, 3};
std::vector<int> otherNumbers = {3, 2, 1};

// Using std::next_permutation to get the next lexicographical permutation
std::next_permutation(numbers.begin(), numbers.end());
// Result: {1, 3, 2}

// Using std::ranges::next_permutation to get the next lexicographical permutation
std::ranges::next_permutation(numbers);
// Result: {2, 1, 3}

// Using std::previous_permutation to get the previous lexicographical permutation
std::previous_permutation(numbers.begin(), numbers.end());
// Result: {1, 3, 2}

// Using std::ranges::previous_permutation to get the previous lexicographical permutation
std::ranges::previous_permutation(numbers);
// Result: {1, 2, 3}

// Using std::is_permutation to check if two sequences are permutations of each other
bool isPermutation = std::is_permutation(numbers.begin(), numbers.end(), otherNumbers.begin());
// Result: true

// Using std::ranges::is_permutation to check if two sequences are permutations of each other
bool isPermutationRanges = std::ranges::is_permutation(numbers, otherNumbers);
// Result: true
```

- **Numeric Operations**
  - iota, ranges::iota

```
// Using std::iota to fill a vector with sequential values
std::vector<int> numbers(10);
std::iota(numbers.begin(), numbers.end(), 1);  // Fills with values starting from 1

// Using std::ranges::iota to fill another vector with sequential values
```

```
std::vector<int> moreNumbers(10);
std::ranges::iota(moreNumbers, 11);  // Fills with values starting from 11
```

- accumulate, reduce, transform_reduce

```
std::vector<int> numbers = {1, 2, 3, 4, 5};

// Using std::accumulate to sum the elements
int sum = std::accumulate(numbers.begin(), numbers.end(), 0);

// Using std::reduce to sum the elements (C++17)
int sumReduce = std::reduce(std::execution::seq, numbers.begin(), numbers.end(), 0);

// Using std::transform_reduce to compute the sum of squares
int sumOfSquares = std::transform_reduce(numbers.begin(), numbers.end(), 0, std::plus<>(), [](int n) { return n * n; });
```

- inner_product

```
std::vector<int> vector1 = {1, 2, 3};
std::vector<int> vector2 = {4, 5, 6};

// Using std::inner_product to compute the inner product of vector1 and vector2
int result = std::inner_product(vector1.begin(), vector1.end(), vector2.begin(), 0);
// result = 32
```

- adjacent_difference

```
std::vector<int> numbers = {1, 2, 3, 4, 5};
std::vector<int> partialSums(numbers.size());

// Using std::partial_sum to compute the partial sums of the numbers vector
std::partial_sum(numbers.begin(), numbers.end(), partialSums.begin());
// partialSums: [1, 3, 6, 10, 15]
```

- partial_sum

```
std::vector<int> numbers = {1, 2, 3, 4, 5};
std::vector<int> partialSums(numbers.size());

// Using std::partial_sum to compute the partial sums of the numbers vector
std::partial_sum(numbers.begin(), numbers.end(), partialSums.begin());
// partialSums = [1,3,6,10,15]
```

- exclusive_scan, inclusive_scan, transform_exclusive_scan, transform_inclusive_sc

```
std::vector<int> numbers = {1, 2, 3, 4, 5};
std::vector<int> exclusiveScanResult(numbers.size());
std::vector<int> inclusiveScanResult(numbers.size());
std::vector<int> transformExclusiveScanResult(numbers.size());
std::vector<int> transformInclusiveScanResult(numbers.size());

// Using std::exclusive_scan to compute exclusive prefix sums
std::exclusive_scan(numbers.begin(), numbers.end(), exclusiveScanResult.begin(), 0);
```

```
// Result: {0, 1, 3, 6, 10}

// Using std::inclusive_scan to compute inclusive prefix sums
std::inclusive_scan(numbers.begin(), numbers.end(),
    inclusiveScanResult.begin());
// Result: {1, 3, 6, 10, 15}

// Using std::transform_exclusive_scan to compute exclusive
    prefix sums of squares
std::transform_exclusive_scan(numbers.begin(), numbers.end(),
    transformExclusiveScanResult.begin(), 0, std::plus<>(),
                                  [](int n) { return n * n; });
// Result: {0, 1, 5, 14, 30}

// Using std::transform_inclusive_scan to compute inclusive
    prefix sums of squares
std::transform_inclusive_scan(numbers.begin(), numbers.end(),
    transformInclusiveScanResult.begin(), std::plus<>(),
                                  [](int n) { return n * n; });
// Result: {1, 5, 14, 30, 55}
```

- **Uninitialized Memory Operations**

4.2 Classes

- **Class Definition**
  - Syntax and structure
  - Access specifiers: public, private, protected
- **Inheritance**
  - Single and multiple inheritance
  - Virtual inheritance
- **Polymorphism**
  - Function overloading
  - Operator overloading
  - Virtual functions and abstract classes

4.3 Containers

- Sequence
  - **array**

```
std::array<int, 3> arr; // uninitialized (whatever was in
    memory before)
std::array<int, 3> arr = {}; // initialized as 0s
std::array<int, 3> arr1 = {1, 2, 3};
std::array<int, 3> arr2{1, 2, 4};
arr1.fill(0); // fills array with 0s
arr1.swap(arr2); // swaps contents of arr1 and arr2
```

  - **vector**

```
std::vector<int> v;
v.capacity(); // size of currently allocated memory
v.shrink_to_fit(); // releases unused memory
v.reserve(100); // pre-allocates 100 elements
v.clear(); // erases all elements
```

```
v.erase(v.begin()); // erases first element
v.push_back(1); // adds 1 to the end
v.rbegin(); // reverses iterator
std::erase_if(v, [](int x) { return x > 10; }); // removes all
    elements > 10
std::vector<Pair<int,int>> classV;
classV.emplace_back(10,1); // create Pair object and push to
   back
```

  - **inplace_vector**
  - **deque**

- Associative
  - **Set**
  - **Map**
  - **Multiset**
  - **Multimap**

- Unordered Associative
  - **unordered_set**
  - **unordered_map**
  - **unordered_multiset**
  - **unordered_multimap**

- Adaptors
  - **stack**
  - **queue**
  - **priority_queue**
  - **flat_set**
  - **flat_map**
  - **flat_multiset**
  - **flat_multimap**

4.4 Modern C++

- C++11
  - **Alias Templates**

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

// Alias template for a vector of a specific type
template <typename T>
using Vector = std::vector<T>;

// Alias template for a map with string keys and a specific
   value type
template <typename V>
using StringMap = std::map<std::string, V>;

int main() {
    // Using the alias template for a vector of integers
    Vector<int> intVector = {1, 2, 3, 4, 5};
```

```
    std::cout << "Vector of integers: ";
    for (const auto& elem : intVector) {
        std::cout << elem << " ";
    }
    std::cout << std::endl;

    // Using the alias template for a map with string keys and integer values
    StringMap<int> ageMap = {{"Alice", 30}, {"Bob", 25}, {"Charlie", 35}};
    std::cout << "Map of ages: ";
    for (const auto& pair : ageMap) {
        std::cout << pair.first << ": " << pair.second << " ";
    }
    std::cout << std::endl;

    return 0;
}
```

- **atomic**
  Well-defined behavior in the event of RMW race contition. Accesses to atomics may establish inter-thread synchronization and order non-atomic accesses.

```
atomic_bool b; // same as std::atomic<bool> b;
```

- **auto**
- **constexpr**
- **final**

  * Specifies that a class cannot be inherited from.
  * When used in a virtual function, specifies that the function cannot be overridden by a derived class.
  * final is also a legal variable/function name. Only has special meaning in member function declaration or class head.

```
struct Base
{
    virtual void foo();
};
struct A : Base
{
    void foo() final; // Base::foo is overridden and A::foo is the final override
    void bar() final; // Error: bar cannot be final as it is non-virtual
};

struct B final : A // struct B is final
{
    void foo() override; // Error: foo cannot be overridden as it is final in A
};

struct C : B {}; // Error: B is final
```

- **initializer list**

```
/*
 * In this program:
 *  Vector Initialization: A `std::vector` is initialized
    using an initializer list, which provides a concise way to
```

```cpp
 * initialize containers with a list of values. Class Constructor: The `MyClass` constructor takes an
 * `std::initializer_list<int>` as a parameter, allowing objects of `MyClass` to be initialized with a list of integers.
 *  Function Parameter: The `printList` function takes an `std::initializer_list<std::string>` as a parameter,
 * demonstrating how initializer lists can be used to pass a variable number of arguments to a function. This program
 * demonstrates the flexibility and convenience of using initializer lists in various contexts in C++.
 */

#include <initializer_list>
#include <iostream>
#include <vector>

class MyClass {
 public:
    MyClass(std::initializer_list<int> list) {
        for (auto elem : list) {
            data_.push_back(elem);
        }
    }

    void print() const {
        for (auto elem : data_) {
            std::cout << elem << " ";
        }
        std::cout << std::endl;
    }

 private:
    std::vector<int> data_;
};

void printList(std::initializer_list<std::string> list) {
    for (const auto& elem : list) {
        std::cout << elem << " ";
    }
    std::cout << std::endl;
}

int main() {
    // Initializing a vector using an initializer list
    std::vector<int> vec = {1, 2, 3, 4, 5};
    std::cout << "Vector elements: ";
    for (int v : vec) {
        std::cout << v << " ";
    }
    std::cout << std::endl;

    // Using initializer list in a class constructor
    MyClass myObject = {10, 20, 30, 40, 50};
    std::cout << "MyClass elements: ";
    myObject.print();

    // Passing an initializer list to a function
    std::cout << "String list: ";
    printList({"Hello", "World", "from", "initializer", "list"});

    return 0;
```

```
}
```

- **iota**

```
void iota(ForwardIterator begin, ForwardIterator end, T v); // fills range [first-last] with sequentially increasing values starting at v in begin
```

- **lambdas**

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

int main() {
    // Basic lambda with no capture
    auto greet = []() { std::cout << "Hello, World!" << std::endl; };
    greet();

    // Lambda with capture by value
    int a = 10;
    auto captureByValue = [a]() { std::cout << "Captured by value: " << a << std::endl; };
    captureByValue();

    // Lambda with capture by reference
    int b = 20;
    auto captureByReference = [&b]() {
        b += 10;
        std::cout << "Captured by reference: " << b << std::endl;
    };
    captureByReference();
    std::cout << "Modified b: " << b << std::endl;

    // Lambda with explicit return type
    auto add = [](int x, int y) -> int { return x + y; };
    std::cout << "Sum: " << add(3, 4) << std::endl;

    // Generic lambda
    auto multiply = [](auto x, auto y) { return x * y; };
    std::cout << "Product: " << multiply(3, 4.5) << std::endl;

    // Lambda with STL algorithms
    std::vector<int> numbers = {1, 2, 3, 4, 5};
    std::for_each(numbers.begin(), numbers.end(), [](int n) { std::cout << n << " "; });
    std::cout << std::endl;

    // C++23: Deducing 'this' in lambdas
    struct Counter {
        int count = 0;
        auto increment() {
            return [this]() {
                ++count;
                std::cout << "Count: " << count << std::endl;
            };
        }
    };

    Counter counter;
    auto inc = counter.increment();
```

```
    inc();
    inc();

    return 0;
}
```

capture comma-separated list of variables which are captured/modified by the lambda. Captures cannot have same name as input parameters.

Capture list

* & = capture all used variables by reference
* = = capture all used variables by copy
* varName = by-copy
* varName... = by-copy pack-expansion
* varName initializer = by-copy w/ initializer
* &varName = by-reference
* &varName... = by-reference pack-expansion
* &varName initializer = by-reference w/ initializer
* this = by-reference capture of current object
* *this = by-copy capture of current object
* ... = by-copy capture of all objects w/ pack expansion
* &... initializer = by-reference w/ initializer and pack expansion

```
// If the capture-default is &, subsequent simple captures must not begin with &.
[&] {};           // OK: by-reference capture default
[&, i] {};        // OK: by-reference capture, except i is captured by copy
[&, &i] {};       // Error: by-reference capture when by-reference is the default
[&, this] {};     // OK, equivalent to [&]
[&, this, i] {}; // OK, equivalent to [&, i]
```

```
// If the capture-default is =, subsequent simple captures must begin with & or be *this(since C++17) or this(since C++20).
[=] {};          // OK: by-copy capture default
[=, &i] {};      // OK: by-copy capture, except i is captured by reference
[=, *this] {}; // until C++17: Error: invalid syntax
               // since C++17: OK: captures the enclosing S2 by copy
[=, this] {};  // until C++20: Error: this when = is the default
                  // since C++20: OK, same as [=]
```

- **mutex**
- **override**
- **random**

```
#include <stdlib>
int rand(); // returns integer in [0, RAND_MAX]
```

```
#include <random>
// default_random_engine
// philox4x64 -> philox_engine
// random_device = non-deterministic generator based on hardware entropy
```

```
std::random_device rd;
rd.entropy(); // estimate of random number device entropy.
   Deterministic entropy = 0.
std::uniform_real_distribution<double> dist(0.0, 1.0);
```

Distribution list

  * uniform
    - int
    - real (double)
  * bernoulli
    - bernoulli
    - binomial
    - negative binomial
    - geometric
  * Poisson
    - poisson
    - exponential
    - gamma
    - weibull
    - extreme_value
  * Normal
    - normal
    - lognormal
    - chi_squared
    - cauchy
    - fisher_f
    - student_t
  * Sampling
    - discrete
    - piecewise_constant
    - piecewise_linear
    - item4

- **range-based for**
- **thread**
- **trailing return type** auto main() --> int {return 0;}

- C++14
  - **Variable Templates**
  - **Generic Lambdas**

- C++17
  - **tuple**

```
#include <iostream>
#include <string>
#include <tuple>

int main() {
    // Create a tuple with different types
    std::tuple<int, std::string, double> person = std::
       make_tuple(25, "Alice", 68.5);

    // Access elements of the tuple using std::get
    int age = std::get<0>(person);
```

```
    std::string name = std::get<1>(person);
    double weight = std::get<2>(person);

    // Modify elements of the tuple
    std::get<0>(person) = 30;
    std::get<2>(person) = 70.0;
    // Use std::tie to unpack tuple into variables
    int newAge;
    std::string newName;
    double newWeight;
    std::tie(newAge, newName, newWeight) = person;

    std::cout << "Unpacked Name: " << newName << ", Unpacked
        Age: " << newAge << ", Unpacked Weight: " << newWeight
            << std::endl;

    // Use std::ignore to unpack only specific elements
    std::tie(std::ignore, newName, std::ignore) = person;
    std::cout << "Unpacked Name with ignore: " << newName <<
        std::endl;

    return 0;
}
```

- **execution policies**

  seq used to disambiguate parallel algorithm overloading and require that a parallel algorithm's execution must be sequential. This is used by default when no execution policy is specified.

  par Indicates that a parallel algorithm MAY be parallelized. Synchronization techniques (e.g. mutexes) may be used.

  par_unseq A parallel algoithm MAY be parallelized, vectorized, and moved between threads. Vectorization MUST not use any vectorization-unsafe operations (e.g. mutexes and std::atomic)

  unseq An algorithm's execution MAY be vectorized. Synchronization techniques MUST NOT be used. Since C++20 (the rest of the policies were introduced in C++17).

- C++20
  - **Modules**
  - **Coroutines**
  - **Ranges**

    Extension/Generalization of algorithms and iterator libraries to make them less error-prone. Ranges are an abstraction of the following:

    * [begin, end) iterator pair : ranges::sort()
    * begin + [0, size) : views::counted()
    * [begin, predicate) : views::take_while() (conditionally-terminated sequences
    * [begin, ..) : unbounded (e.g. views::iota())

    std::views // shorthand for std::ranges::views TODO: do more usage/investigation on these
  - **Midpoint**

    Can be used on any arithmetic type, excluding bool. Can be used on objects as long as they are not incomplete types. Returns half the sum of the two inputs, no overflow occurs (this is the main reason to use STL rather than custom implementation). Inputs must point to elements in same object, else behavior is undefined. In case of decimal in average, rounds down.

- **using enum**
- **constinit**
- **string formatting**
- **template concepts**
- **coroutines**
- **modules**

- C++23
  - **print/println**

```cpp
#include <print>
std::print("{0} {2}{1}!", "Hello", 23, "C++"););
std::println(); // adds newline to std::print();
```

  - **byteswap**

```cpp
#include <bit>
std::byteswap(T n) noexcept; // T can be any integer value
```

  - **flat_map/flat_set**

4.5 Concepts

- **Types**
- **RAII**

  RAII Resource Acquisition Is Initialization
- **item3**
- **item4**