Get off my thread: Techniques for moving work to background threads

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September 2020

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- **Why do we need to** move work off the current thread?
- **How do we** move work off the current thread?
- Final Guidelines and Questions

Why do we need to move work off the current thread?

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Many environments have a dedicated thread for processing events:

- GUIs
- Client-Server applications

Performing extensive processing on the event thread prevents other events from being handled.

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Delaying response to external events can have undesirable consequences:

- Microsoft Windows will grey-out the entire application window if it doesn't respond to events
- Web browsers will time out if the web server doesn't respond within a reasonable time
- Other network applications will assume an operation failed if no response is received within a reasonable time

Why do we need to move work off the current thread?

We don't just need to move the **work**, we need to prevent **blocking** on our event-handling threads.

```
void event_handler(){
  auto handle=spawn_background_task();
  handle.wait(); // no benefit
}
```

Aside: Non-Blocking vs Lock-free

In lots of cases, short-term blocking (e.g. with short-lived `std::mutex` locks) is OK.

$\Rightarrow$ for those cases, **Non-Blocking** means **Not waiting for a lengthy task to run**.

Aside: Non-Blocking vs Lock-free

In lots of cases, short-term blocking (e.g. with short-lived `std::mutex` locks) is OK.

$\Rightarrow$ for those cases, **Non-Blocking** means **Not waiting for a lengthy task to run**.

In other cases, **Non-Blocking** means **Obstruction Free — If you suspend all but one thread at any point, that one thread will complete its task**.

$\Rightarrow$ for those cases, you need **Lock-free** allocators, message queues, etc.

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- Spawn a new thread for each event handler
- Pass data to a dedicated background thread
- Submit tasks to a generic thread pool
- Submit tasks to a special purpose executor

Spawning new threads

There are lots of ways to spawn new threads:

- `std::thread`
- `std::jthread`
- `std::async(std::launch::async,...)`
- Platform-specific APIs

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They all have the same problem: **detaching** the thread leaves it running, but **joining** the thread means you have to keep the handle around.

Managing thread handles

`std::thread` and `std::jthread` are similar:

```
std::vector<std::jthread> pending_threads;

void handle_event(Event details){
  auto handle=std::jthread(
    [=]{process_event(details);});
  pending_threads.push_back(
    std::move(handle));
}
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}
```

There is no reasonable way to test if any of the entries in `pending_threads` can be joined.

Managing thread handles II

`std::async` is a bit better: we can check the `std::future` to see if it is **ready**.

```
std::vector<std::future<void>> pending_threads;

void handle_event(Event details){
  auto handle=std::async(
    std::launch::async,
    [=]{process_event(details);});
  pending_threads.push_back(
    std::move(handle));
}
```

Managing thread handles III

Can remove completed tasks by periodically checking:

```
void check_for_done_threads(){
  for(auto it=pending_threads.begin();
    it!=pending_threads.end();){
    if(it->wait_for(0s)==
      std::future_status_ready)
      it=pending_threads.erase(it);
    else ++it;
  }
}
```

Managing thread handles III

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```

This is nasty: if you have a lot of events, you spawn a lot of threads, so the list will get large.

Guideline

Spawning a new thread for every task is a **bad idea**.

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7. (eventually) The dedicated thread is destroyed

Dedicated threads: downsides

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- The thread is long-lived and consumes resources
- The handling of the event is disconnected from the event
- No parallel processing: it's a single thread!

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- The events are handled in the same order as they arrive at the initial event handler
- The dedicated thread only communicates with the outside world via messages, so is easy to design and test
- Cancelling all outstanding tasks is easy: just shut down the thread

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3. The event handler reposts the event as a **task** to the thread pool
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2. The event handler receives an event
3. The event handler reposts the event as a **task** to the thread pool
4. The event handler returns ready to receive a new event
5. (sometime later) A thread from the pool runs the **task**
6. The thread then waits for a new **task**
7. (eventually) The thread pool is destroyed

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- The threads can be shared with the rest of the application

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- Tasks may be delayed due to tasks submitted from elsewhere in the application

Thread pools: downsides

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- The tasks are run in an arbitrary order as they are picked up by the pool
- The handling of the event is disconnected from the event
- The tasks may be run concurrently, so their interactions need to be verified
- Tasks may be delayed due to tasks submitted from elsewhere in the application
- Cancelling all the tasks from one source without affecting others is harder

Addressing thread pool downsides

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We can impose an ordering with **continuations**.

If task B is a **continuation** of task A, it cannot run concurrently.

Continuations

```
thread_pool pool;
std::optional<task_handle> last_task;

void handle_event(Event details){
  auto func=[=]{process_event(details);};

  if(last_task){
    last_task=last_task->then(func);
  } else {
    last_task=pool.submit(func);
  }
}
```

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Continuations: downsides

Downsides of using continuations like this:

- No concurrency: lengthy tasks delay subsequent event processing
- Still no fix for other problems: cancellation, disconnect from event and handling, etc.

Cancellation

Cancellation

Later events may require you to cancel tasks submitted to handle earlier events.

This is particularly the case for long-running tasks.

We need to avoid **dangling tasks** where the task outlives the desire for it to do anything.

Cancellation: Stop tokens

Pass a `std::stop_token` to each task that may need to be cancelled.

Keep the corresponding `std::stop_source` in the event handler.

Call `source.request_stop()` when the tasks need to be stopped.

Cancellation: Waiting for cancelled tasks

Cancelled tasks may continue running for a short time.

$\Rightarrow$ You need to ensure they are stopped before cleaning up the data

The simplest solution is a count of remaining tasks

Cancellation: Counting outstanding tasks

```
std::atomic<unsigned> pending_tasks;
std::stop_source source;

void handle_event(Event details){
  ++pending_tasks;
  pool.submit(
    [=,&pending_tasks,
    stopper=source.get_token()]{
      process_event(details,stopper);
      if(!--pending_tasks)
        pending_tasks.notify_all();
    });
}
```

Cancellation: Counting outstanding tasks

Cancel the tasks in some event handler:

```
void cancel_tasks(){
  source.request_stop();
}
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Cancel the tasks in some event handler:

```
void cancel_tasks(){
  source.request_stop();
}
```

Then wait for them when cleaning up (**not in an event handler!**):

```
void wait_for_tasks(){
  while(auto count=pending_tasks.load()){
    pending_tasks.wait(count);
  }
}
```

Progress Updates

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- Progress updates in a GUI
- Updating other UI information
- Initiating IO on an IO loop

Progress Updates

Typically you need to trigger an event on the event thread.

- Custom Windows messages
- Using `eventfd` to create a file handle for events
- Similar mechanism for other platforms

Progress Updates

Background thread:

```
void foo(unsigned progress){
  post_progress_event(progress);
}
```

Event loop:

```
void handle_progress(ProgressEvent ev){
  update_ui(ev.progress);
}
```

Coroutines

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... but they can provide simpler-looking code

Coroutines: example

```
void handle_event(Event details){
  schedule_on(thread_pool,process(details));
}

task<void> process(Event details){
  co_await step_1(details)
  co_await schedule_on_gui_thread(
    update_progress(1));
  co_await step_2(details)
  co_await schedule_on_gui_thread(
    update_progress(2));
  // ...
}
```

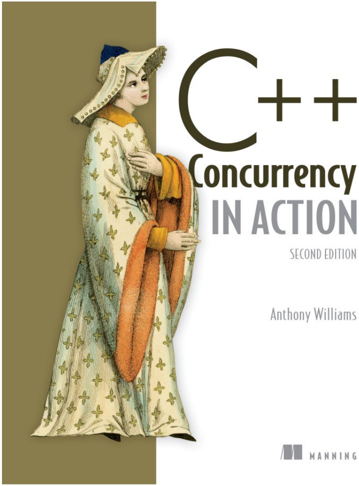
Guidelines

Guidelines

- Do not run time consuming tasks on threads that must be **responsive**
- Use a dedicated thread for long running tasks
- Use a thread pool for other tasks
- Use `std::stop_token` or similar for cancellation
- Ensure tasks are finished before destroying data they reference
- Check whether you need **lock-free** code or just short-lived locks

Questions?

My Book



C++ Concurrency in Action
Second Edition

Covers C++17 and the Concurrency TS

cplusplusconcurrencyinaction.com

Just::Thread Pro

`just::thread` Pro provides an actor framework, a concurrent hash map, a concurrent queue, synchronized values and a complete implementation of the C++ Concurrency TS, including a lock-free implementation of `atomic_shared_ptr` and RCU.

`http://stdthread.co.uk`