# Lock-Free Fire Dispatch Sytem

## SENG490 – Directed Study

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Fall 2022

# INTRODUCTION

- 4th year Software Engineering student
- Previous Dr. Chester student
- Worked on fire dispatch system during co-op work term

# Agenda

01 FIRE & EMERGENCY DISPATCH

02 LOCK-FREE PROGRAMMING

03 PROGRAM IMPLEMENTATION

04 LESSONS LEARNED

# 01

# FIRE & EMERGENCY DISPATCH

# WHAT IS A DISPATCH SYSTEM?

- Interface between 911 call centre and fire station
- Human operator required to assign trucks to emergency situations
- Dispatch system notifies station

# MANUAL DISPATCHING

### 911 OPERATOR RECEIVES INFO

Caller provides event location & requirements

### INFO IS PASSED TO DISPATCHER

Fire, police, EMS are dispatched seperately

### DISPATCHER ASSIGNS CREWS TO EVENT

Crews are notified through radios/pagers connected to dispatch system

# DISPATCH SYSTEM REQUIREMENTS

## PERFORMANCE

Events are happening in real-time

## FAULT-TOLERANT

System failure may have lethal consequences

## EXTERNAL COMMUNICATION

Messages need to be sent to radios & pagers

## RESPONSIVENESS

Multiple operators may use system concurrently

# DISPATCH SIMULATOR

- Available vehicles & stations remain constant
- Timestamped event data provided at runtime
- Completely automated dispatching
- Results outputted to log

# WHY USE MULTITHREADING?

## INCREASED PERFORMANCE

Multiple events can be dispatched concurrently

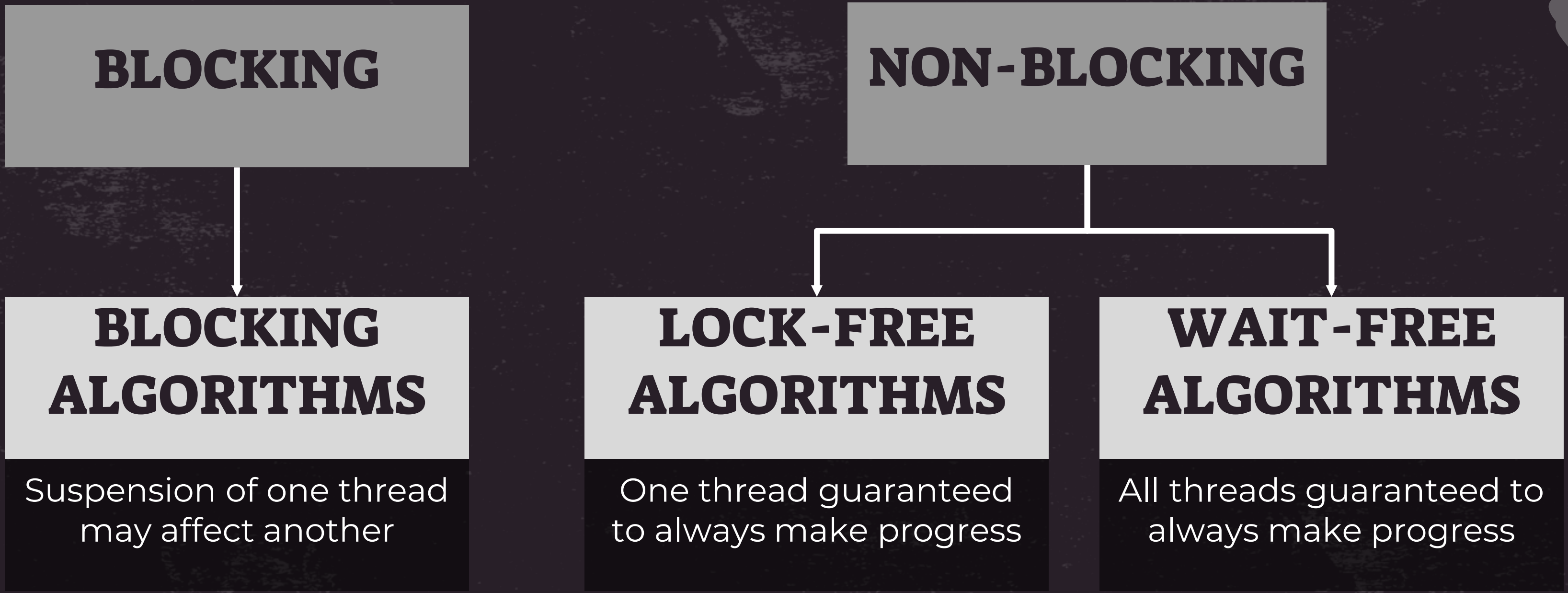
## IMPROVED RELIABILITY

Individual thread failure will not cause system failure

# 02

# LOCK-FREE PROGRAMMING

# MULTITHREADED PROGRAMMING



BLOCKING

NON-BLOCKING

BLOCKING ALGORITHMS

Suspension of one thread may affect another

LOCK-FREE ALGORITHMS

One thread guaranteed to always make progress

WAIT-FREE ALGORITHMS

All threads guaranteed to always make progress

# LOCK-FREE PROGRAMMING TOOLS

**Compare and Swap/Exchange (CAS)**

Atomic compare & swap if equal operation

- `std::atomic::compare_exchange_[weak/strong]`

```
atomic function CAS(int* modified, int old, int new):
    if *modified ≠ old
        return false
    *modified ← new
    return true
```

# CAS LOOP

## CODE EXAMPLE

CAS function usage:

1. Read data into local variable
2. Modify local variable
3. Compare local with stored and swap if equal

```
void increment(int* p):
    repeat:
        value := *p
    until CAS(p, value, value + 1)
```

# LIMITATIONS OF CAS

## DATA SIZE LIMITS

CAS operates on single- or double-word data

## A-B-A PROBLEM

Data is reallocated in address of previously deallocated data

# LINEARIZABLE HISTORY

- Manner of organizing multithreaded interactions with shared data
- Each interaction occurs at a discrete instant
- All interactions ordered sequentially

# POINT OF LINEARIZATION

- Interaction with shared data occurs at single point
- Location in code may differ based on branching
- Requirement for proving correctness of lock-free algorithms

# TREIBER STACK

## LOCK-FREE EXAMPLE

```
class stack <node*> top


void stack.push(node* n):
    repeat:
        o := top
        n->next := o
    until CAS(&top, o, n)
```

```
node* stack.pop():
    repeat:
        o := top
        if o = null: return null
        n := o->next
    until CAS(&top, o, n)
    return o
```

# 03

# PROGRAM IMPLEMENTATION

# PROGRAM ARCHITECTURE

## OBJECT-ORIENTED DESIGN

Vehicles, events, fire stations, etc. are individual classes

## EVENT QUEUE

Events moved from pending queue to active queue at start time

## GLOBAL BIT ARRAY

One bit per vehicle represents its availability

# EVENTS

- Events occur at a discrete time
- Each event has different vehicular and crew requirements
- Travel from station to event is considered for vehicles

# VEHICLE STATUS ENUM

- Status options:
  - Available
  - Responding
  - Returning
- Vehicle can be dispatched to event while in Available or Returning

# GLOBAL BIT ARRAY

- 64-bit variable to accommodate single-word CAS
- Bit N represents availability of Vehicle N
- Modification of bit array is program’s linearization point

# GLOBAL BIT LIST MODIFICATION

## RETURNS MODIFIED COPY OF globalBitArray

```
uint64_t BitArray::modifyBitArray(int vehicleID, bool writeTrue)
{
    uint64_t position = 1 << vehicleID;
    uint64_t copyGlobalBitArray  = globalBitArray;
    if( writeTrue )
    {
        // Write 1 to vehicle position in array
        copyGlobalBitArray |= position;
    }
    else
    {
        // Write 0 to vehicle position in array
        copyGlobalBitArray &= ~position;
    }
    return copyGlobalBitArray;
}
```

# OBTAINING MODIFIED BIT LIST

## modifiedBitArray IS INITIALIZED AS COPY OF globalBitArray

```
for (const auto & vehicle : vehicleList)
{
    if ( vehicle->getCurVehicleStatus() == VehicleStatus::Available
    || vehicle->getCurVehicleStatus() == VehicleStatus::Returning )
    {
         modifiedBitArray.setGlobalBitArray(
         modifiedBitArray.modifyBitArray(vehicle->getVehicleID(), true) );
    }
    else
    {
        return false;
    }
}
```

# ATOMIC MODIFICATION

## USING CAS

```
uint64_t expected = unmodifiedBitArray.getGlobalBitArray();
uint64_t desired = modifiedBitArray.getGlobalBitArray();
if( bitArray->globalBitArray.compare_exchange_weak(expected, desired) )
{
    for (const auto & vehicle : vehicleList)
    {
        vehicle->setCurVehicleStatus(VehicleStatus::Responding);
    }
    return true;
}
return false;
```

# 04

# LESSONS LEARNED

# DISCOVERING THE LIMITATIONS OF CAS

- Original plan was to modify statuses directly
- No atomic means of modifying disjoint memory locations exists
- CAS imposed limit on number of vehicles

# C++ SMART POINTERS

- Global vector of `unique_ptrs` for each of:
  - Vehicles
  - Fire Stations
  - Events
- Copies of each vector are made using raw pointers to the `unique_ptr` addresses
- Mitigates A-B-A problem
- Initial design did not use smart pointers, refactoring was complex

# THANKS!

## Do you have any questions?

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Project repository:
github.com/ethan-mcnamara/lock-free-programming