COMP350: Algorithms & Optimisation

3: Optimising for CPU & Memory

Learning outcomes

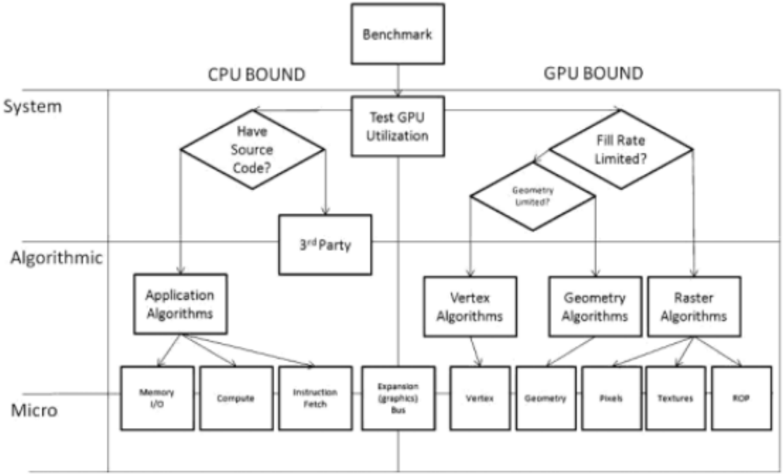
By the end of today’s session, you will be able to:

- **Understand** the memory hierarchy in modern PC/Consoles/Mobile
- **Implement** optimisations of Data Structures for memory access
- **Describe** CPU Optimisation

Introduction

- When we start the optimisation process in games, we want to check if we are CPU or GPU bound
- Once this is identified then we can start looking at different ways of optimising our code
  - System Level
  - Algorithm
  - Micro
- In this session we are going to assume our application is CPU bound

Optimisation Flow



Algorithms

Standard Template Library

- STL is a collection of containers and algorithms to support the creation of more reusable systems
- Containers:
  - Vector: Drop in replacement for a C/C++ array, elements are stored **contiguously**
  - List: Supports constant time insertion and removal of elements
  - Map: Search, removal and insertion have logarithmic complexity
- Algorithm:
  - Find: Find an element in a container
  - Transform: Apply a function to an element
  - Swap: Swaps the values of two objects
  - Reverse: Reverse the elements in a container

Common Container Errors

- Picking the wrong container!
  - If you are adding/removing elements from the middle of collection then use a list
  - Require random access, use a vector over a list
  - If you want to retrieve an element quickly, consider using a **map** or a **set**
  - Sorted vectors can give same performance as associative containers for retrieval
  - `http://john-ahlgren.blogspot.co.uk/2013/10/stl-container-performance.html`

Common Container Errors

- Resizing of vector
  - Resizing of vector requires a memory allocation
  - If you know the amount of data you are managing, you should use the **reserve** function to allocate the memory in advance

Algorithms

- Before you write something you should consider checking out the algorithms contained in the **algorithms** library
- These contain all sorts of useful functions for searching, sorting, counting, manipulating
- These are usually optimised for the compiler, so use these rather than write your own
- You can also customise how these algorithms function by providing predicate functions

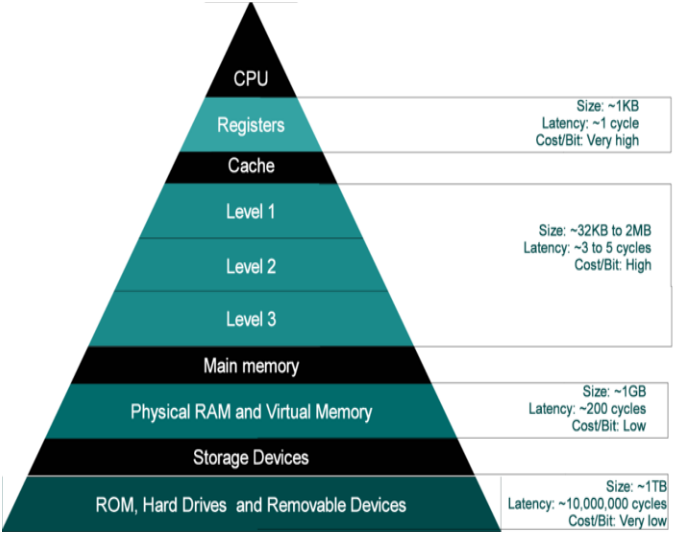
What about Unity or Unreal?

- Both Unity/C# & Unreal have containers
- List in C# & TArray in Unreal is equivalent to std::vector
- Dictionary in C# & TMap in Unreal is equivalent to std::map
- The containers in those engines should perform exactly like the C++ equivalents
- **BUT!** check the docs as these engines/languages have additional container types

Coffee Break

Memory & CPU

Memory Hierarchy



Registers

- Registers are the only memory directly on the CPU
- These tend to act as quick scratch pad for current calculations
- Everything that the CPU operate on will get shifted into registers
- Only issue it is slow to transfer data from RAM to registers
- This is where the Cache comes in!

Caches

- The cache acts as intermediate between the CPU and all off-board memory
- There is usually different levels of cache, with different capabilities dependent on CPU e.g
- Intel i-7 4770(Haswell)
  - L1 Data cache = 32KB with 4 cycles for simple access
  - L1 instruction cache = 32KB
  - L2 cache = 256KB with 12 cycles
  - L3 cache = 8MB with 26 cycles
- NB Ram typically takes 26 cycles + 57 nanoseconds to access

Memory Optimisation

- Reduce Memory footprint
- Write algorithms which reduce memory traversal
- Increase cache hits
- Increase temporal coherence
- Utilise Pre-fetching
- Avoid patterns which break caching

Reduce Memory Footprint

- Consider use smaller data types
- This will mean that your data structures will be more cache friendly
- You can perhaps collapse several booleans into one integer and use bit flags

Memory Alignment

- The CPU will read memory aligned data much faster than non-aligned
- Any *N*-byte data is memory aligned if its starting address is evenly divisible by *N*
- e.g. A 32 bit integer is memory aligned if the starting address is 0x04000000, not 0x04000002
- Make sure your structs or class has data types order highest to lowest

Avoiding Cache Misses

- The compiler and linker dictate how your code is laid out in memory
- However the linker/compiler follows some simple rules
- If you know these, then you can leverage them

Compiler & Linker rules

- The machine code for a single function is contiguous in memory
- Functions are laid out in memory in the order they appear in the cpp file
- Function in the cpp are always contigous

Applying Compiler & Linker rules

- Keep high performance code as small as possible
- Avoid calling functions from a performance critical section of code
- If you do have to call a function, place it as close as possible (never in another translation unit)
- Use inline functions. Inlining a small function can lead to a performance boost. But this can lead to bloated code if over used (and lead to cache misses)

Branch Prediction

- CPUs will try to predict what branch to take (if loop)
- If the guess is wrong then we executed instructions that shouldn’t have been called
- This causes a stall, as the pipeline is flushed and the first instruction of the branch is then called
- To solve this issue, you should attempt to reduce or remove all branches (see loop unrolling &)

Exercise

Research two of following areas

- Please start of your research journal!
  1. Loop unrolling
  2. Avoiding loops
  3. Memory alignment
  4. Array of Structures vs Structure of Arrays
  5. Memory Pools
  6. Statically allocated memory
  7. STL Algorithms & Containers

Further Reading

- Intel Optimisation Manual - `https://software.intel.com/sites/default/files/managed/9e/bc/64-ia-32-architectures-optimization-manual.pdf`
- Effective STL - `http://voyager.falmouth.ac.uk/vwebv/holdingsInfo?bibId=666539`
- Game Coding Complete 4th Ed Chapter 3 - `http://voyager.falmouth.ac.uk/vwebv/holdingsInfo?bibId=755157`
- Game Engine Architecture 2nd Ed Chapter 3 - `http://voyager.falmouth.ac.uk/vwebv/holdingsInfo?bibId=1084476`