Blue Waters Petascale Semester Curriculum v1.0

Unit 9: Optimization

Lesson 3: Cache Memory Efficiency

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Program Efficiency Enhancement by Effective Caching

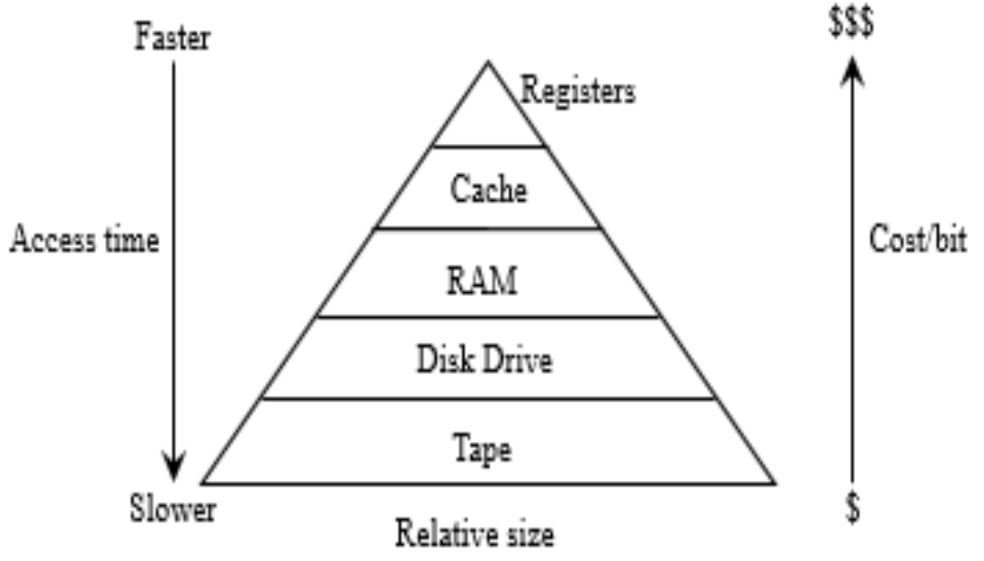
OVERVIEW OF THE **C** PROGRAMMING AND WRITING A BASH SCRIPT

Cache Memory

- An important part of the memory hierarchy in any computer system
- Physically located between the registers, which is part of the processor and random access memory (RAM)
- It is much larger than the number of registers and much smaller than the size of RAM
- Utilizes different technology compared to RAM
  - Faster
  - Uses more power
  - Costs more

Memory Hierarchy

- Gives the illusion of a large (RAM size), fast (cache speed) memory
- Compromise between cost, access time and size

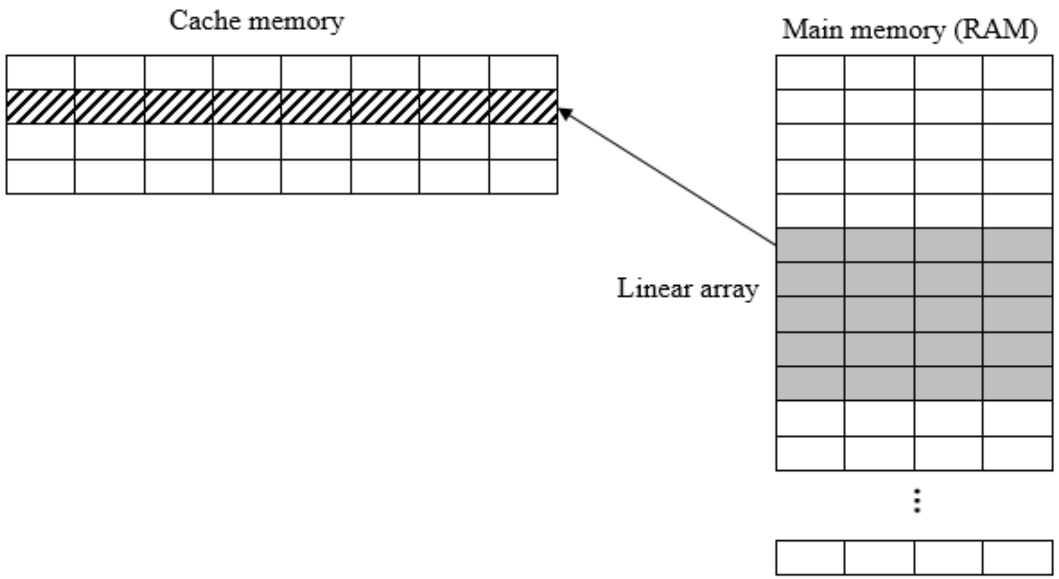


Cache Principles

- Principles of Locality
- Spatially
  - Likely nearby memory words will be accessed
  - More than one word is brought into the cache during a memory request
    - Cache line typically holds 64 bytes
- Temporally
  - Likely a memory word will be used again
  - Keep as much in the cache as possible (function of cache size)
  - Replace the least frequently used words when necessary

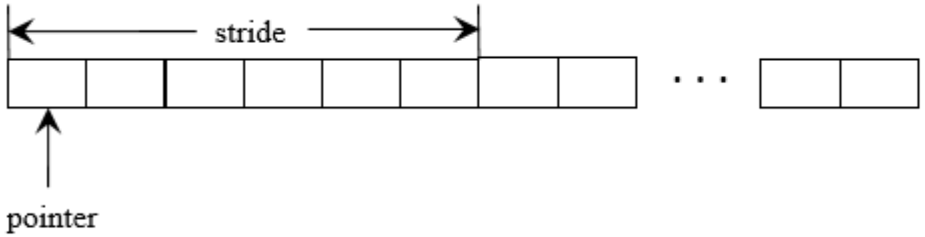
Efficient Memory Accesses

- Sequentially access each word in a linear array
  - First access word is not in the cache and RAM must be accessed (slow)
  - Some number of the next words are in cache (fast)
    - One slow access, n – 1 fast accesses



Program Overview

- The program name is **memStrideT**
- Allocates a linear array of some specified data type
- Initializes a pointer to the first element
- Iterates through all elements
  - It skips a specified number of elements called the **stride**
  - Makes multiple loops to ensure all elements are accesses
  - A value is written into each element to avoid compiler optimizations
- The time to access all array elements is output



C Language Primer

- The main function is a function that can be passed argumets
  - int main(int argc, char* argv[])
    - The argc argument means "argument count"
      - The number of arguments on the command line
    - The argv argument means "argument vector"
      - It is an array of pointers to characters (C string) representing the arguments value
    - If an argument is a number it needs to be converted from a **C** string into a decimal value, see the function strtol (string to long)

C Language Primer

- Dynamic memory allocation/deallocation
  - Use the **C** function named ***malloc***
  - It returns a pointer to a character, the first byte in the newly allocated memory block
  - The block is guaranteed to be contiguous memory locations
  - Use the **C** function ***free*** to give dynamic memory back to the Operating System
- Use the **C** function ***printf*** to output values

BASH Primer

- Linux shell can be programmed using a BASH script
- The first line in the ASCII script contains the complete pathname of the file (program) that should execute the file contents
  - **#!/bin/bash**
- Commands the would be typed can be put in the shell script
  - **make memStriderT**
- Shell scripts can define and use variables
  - **OUTFILE=memStrideDouble**
  - It is important there not be spaces

BASH Primer

- Shell scripts can contain conditional statements
- The following means remove the file if it exists in the same directory as the shell script

```
if [ -f $OUTFILE.csv ]; then
        rm -f $OUTFILE.csv
fi
```

- The value in a variable is accessed by preceding the variable name with a $ as in $OUTFILE above

BASH Primer

- Shell scripts can contain looping constructs

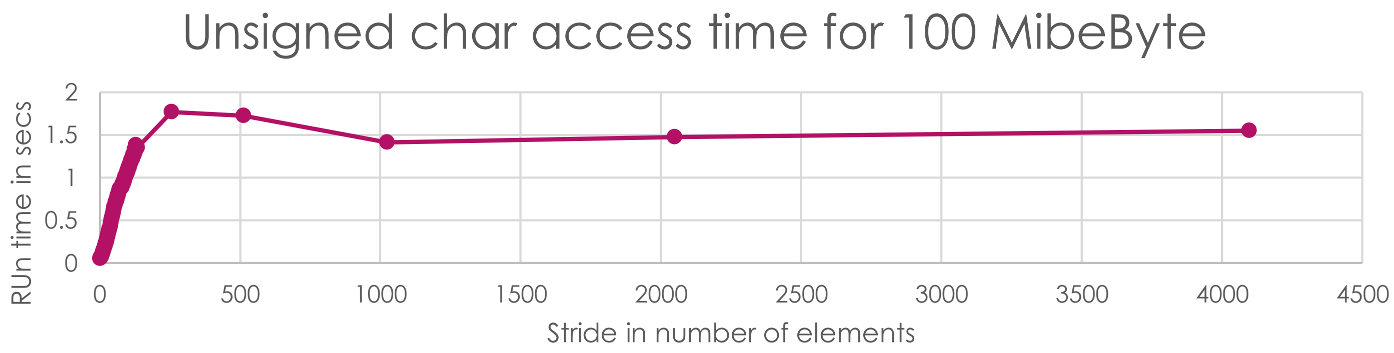
```
while [ $COUNTER -le 133 ]; do
        ./memStrideT 100 $COUNTER >> $OUTFILE.csv
        echo $COUNTER       #Progress Visualization
        let COUNTER=COUNTER+1
done
```

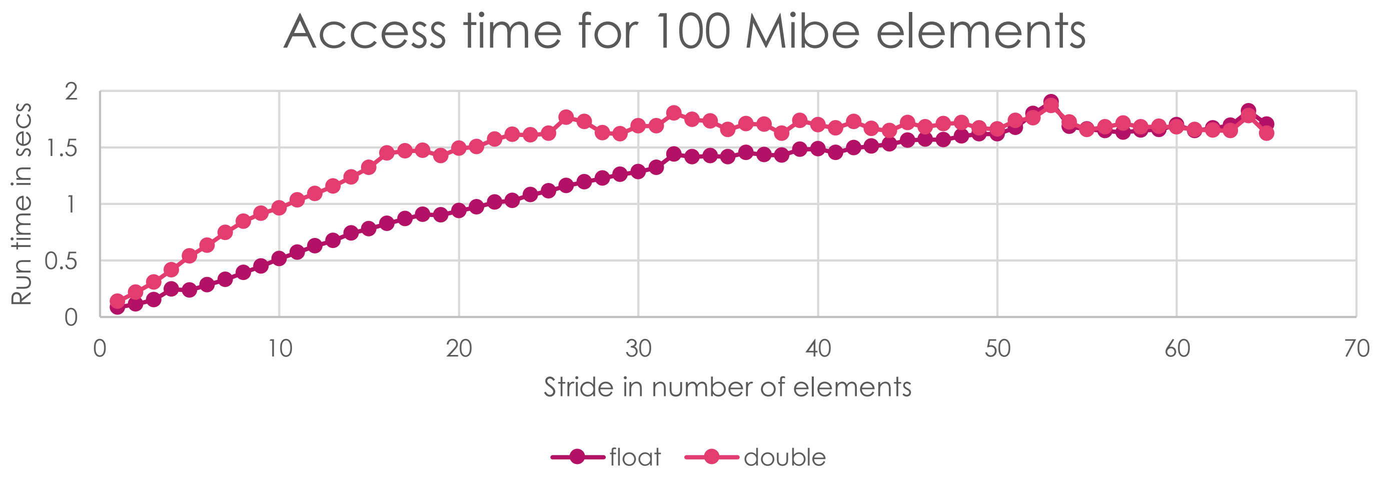
- This loop executes the program **memStrideT** with different values for the second argument, the number of elements to skip when accessing the linear array
- Program output is also appended to the output file during each iteration

Program Results

- The shell script takes approximately fifteen minutes to execute on a laptop with an i7 processor and 16 GB RAM
  - Surprisingly, the shell script takes even longer to execute on a massively parallel computer such as Blue Waters
- The program was executed with unsigned character, single- and double-precision floating-point elements
- In all cases, it appears the cache becomes inefficient when the stride is greater than 128 bytes
- To maximize cache efficiency it is best to access elements sequentially

Program Results


Unsigned char access time for 100 MibeByte
RUn time in secs
Stride in number of elements


Access time for 100 Mibe elements
Run time in secs
Stride in number of elements
float
double