Report - Assignment 1

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Problem Statement:

To understand the effect of Cache.

System Setup:

All tests were done on **Intel(R) Core(TM) i3-5005U CPU @ 2.00GHz** processor.

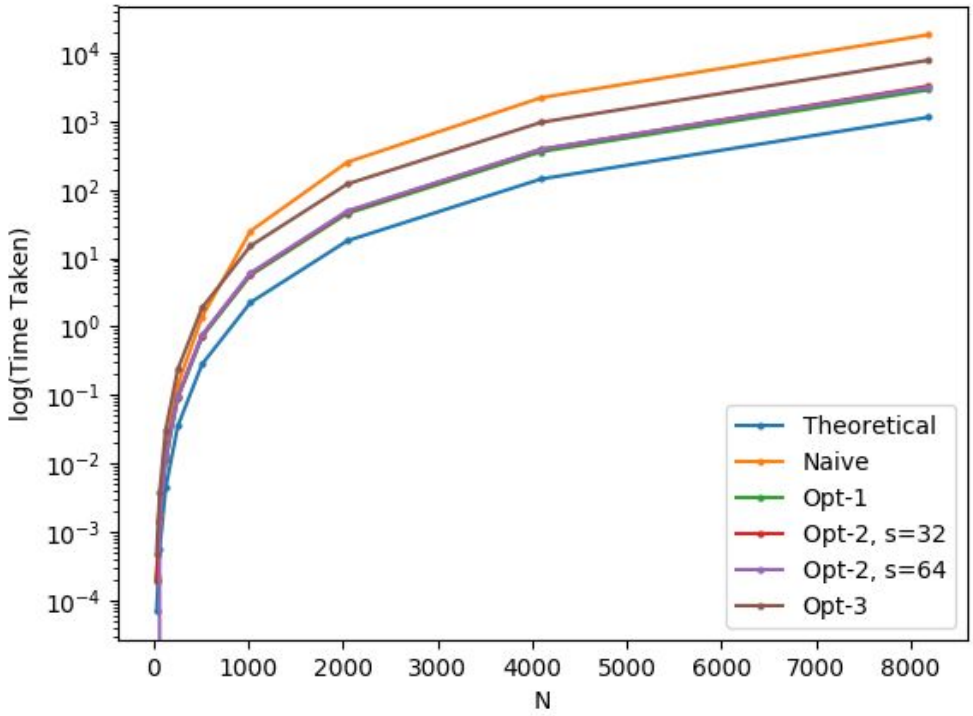
- **Clock Speed:**
  CPU max MHz: 1900.00
  CPU min MHz: 500.00
- **Memory Size:** 8076584 kB = 7887 MB
- **Cache Sizes:**
  L1d cache: 32K
  L1i cache: 32K
  L2 cache: 256K
  L3 cache: 3072K
- **Theoretical Estimations for different values of 'N':**
  Assumptions: Multiplication requires 3 clock cycles and Addition requires 1 clock cycle. We are assuming both the matrices are of sizes NxN.
  Now for matrix multiplication, we have for each element N multiplications and N-1 additions. And we do this for all N^2 elements, hence theoretically we will be requiring $N^2(3N_{\text{(for multiplication)}} + (N-1)_{\text{(for addition)}}) = N^2(4N-1)$ clock cycles. Hence theoretical time required is **$(4N^3 - N^2)$/(Clock Speed).**
  I am taking maximum clock speed of my pc, hence 1900 MHz.
  - N=32:
    $(4*32^3 - 32^2)/(1.9 \times 10^9) = 68.449 \times 10^{-6}$ s.
  - N=64:
    $(4*64^3 - 64^2)/(1.9 \times 10^9) = 0.000549726$ s.
    SImilarly,
  - N=128: 0.00440643 s.
  - N=256: 0.035286 s.
  - N=512: 0.282426 s.
  - N=1024: 2.25996 s.
  - N=2048: 18.0819 s.
  - N=4096: 144.664 s.
  - N=8192: 1157.35 s.

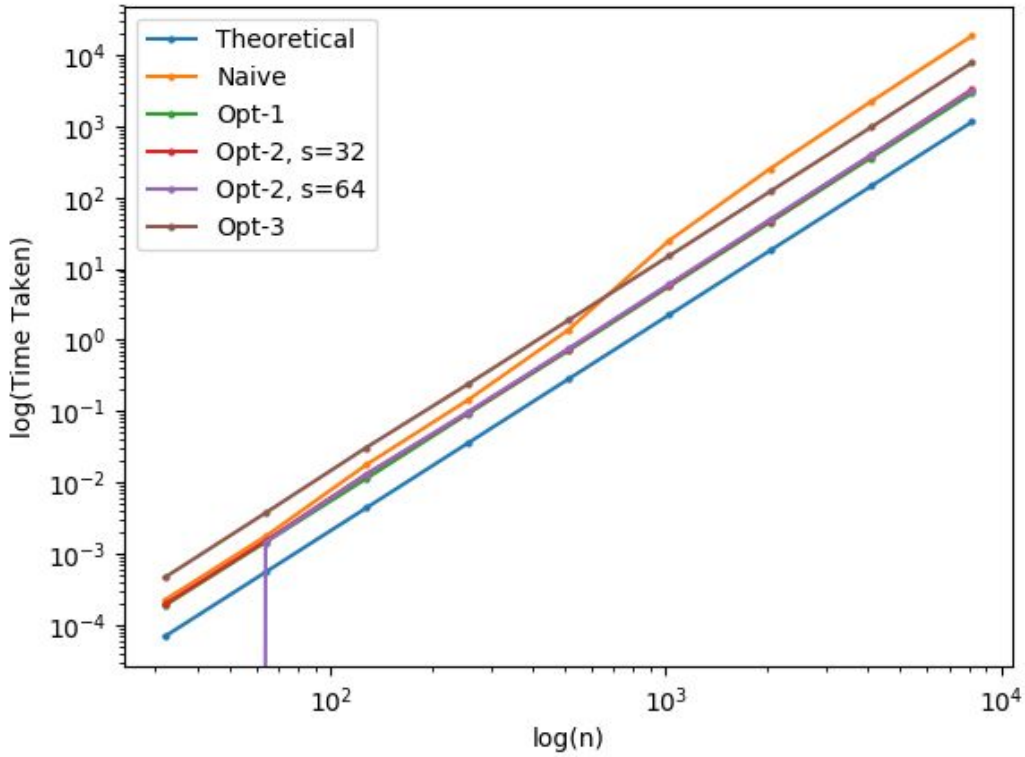
- **Theoretical estimation of ‘s’ for optimization 2:**
  s^2 = O(Memory Size)
  Therefore **s = O(** $\sqrt{M}$ **)**
  Now, cache memory size is 32kB = 32 x 1024 Bytes.
  Assuming 1 integer takes 4 bytes,
  The max. number of integers that can fit in L1d cache = sqrt(32*1024/4) = **90.5**.
  Keeping s power of 2 for good division of matrices, s = 64 is used for testing.

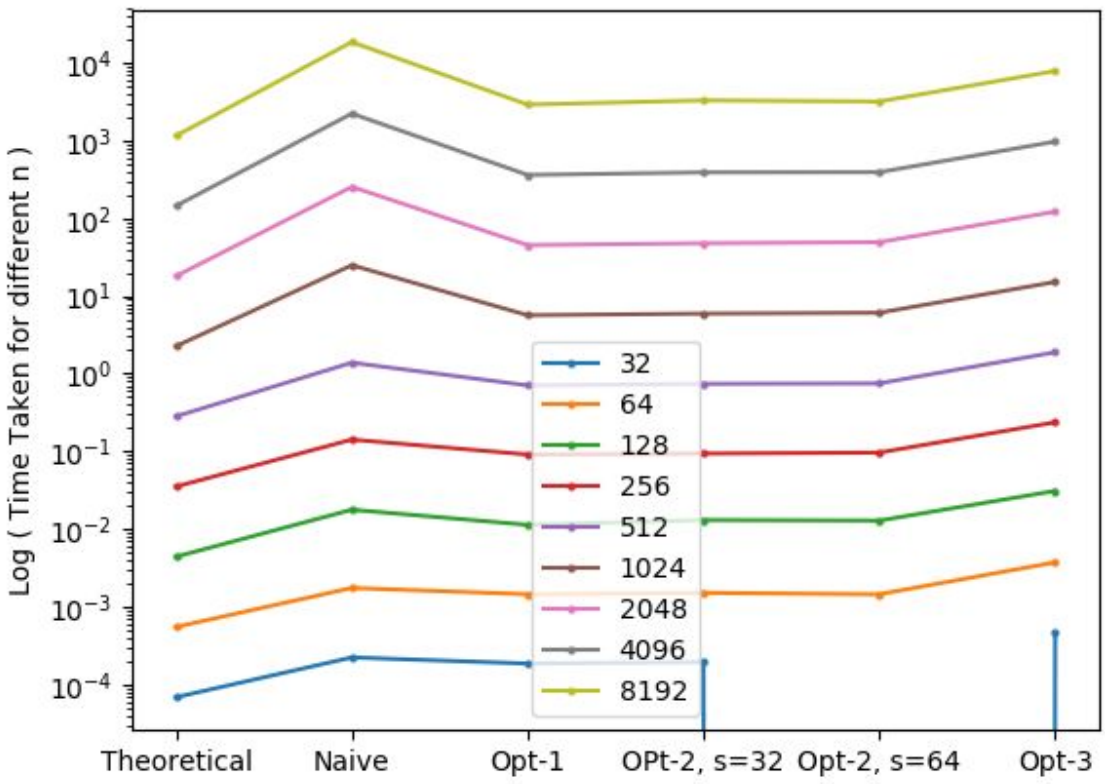
Values Observed:

I have taken 2 values of ‘s’ for optimisation 2, **s=32** and **s=64**.
Also during the tests it was insured **no** other application was running.

N	**Theoretical (in sec)**	**Naive (in sec)**	**Opt-1 (in sec)**	**Opt-2 (s = 32) (in sec)**	**Opt-2 (s = 64) (in sec)**	**Opt-3 (in sec)**
32	6.84463e-05	0.000223	0.000186	0.000194	0.00000	0.000461
64	0.000549726	0.001749	0.001451	0.001511	0.001451	0.003732
128	0.00440643	0.017780	0.011352	0.013084	0.012878	0.031031
256	0.035286	0.142042	0.091328	0.093948	0.096684	0.237299
512	0.282426	1.388570	0.708196	0.742125	0.751683	1.891817
1024	2.25996	24.969940	5.667843	5.950698	6.097923	15.196035
2048	18.0819	254.911866	45.265446	47.896635	49.376596	122.090300
4096	144.664	2233.643528	362.500027	391.200087	393.352007	973.819655
8192	1157.35	18600.95048	2914.189976	3304.406717	3192.598471	7894.428863


log(Time Taken)
N
Theoretical
Naive
Opt-1
Opt-2, s=32
Opt-2, s=64
Opt-3


log(Time Taken)
log(n)
Theoretical
Naive
Opt-1
Opt-2, s=32
Opt-2, s=64
Opt-3



Optimisations:

Initially, I tried to optimise my code by removing repetitive multiplications from my code and tried to convert into additions as much as possible. I saw a significant decrease in time by doing these optimisations. For n=1024, the time required was reduced from 10 seconds to 6 seconds for optimisation 2. Similarly, the time required reduced a bit for optimisation 1 too.