DESIGN AND ANALYSIS OF ALGORITHMS LAB

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BATCH: A

BRANCH: CSE DS

EXPT. NO.: 1A

AIM: To implement the various functions e.g., linear, non-linear, quadratic, exponential etc.

CODE:

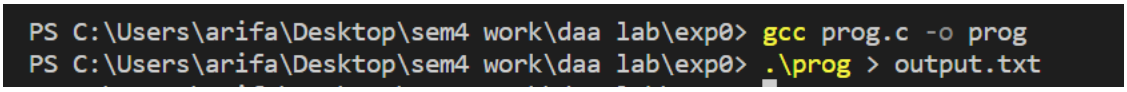
```c
#include <stdio.h>
#include <math.h>

static double log_2;

// (3/2)^n
double f1(int n)
{
    return pow(1.5, n);
}

// n^3
int f2(int n)
{
    return pow(n, 3);
}

// 2^n
unsigned long long f3(int n)
{
    return pow(2, n);
}

// (log2 n)
double f4(double n)
{
    return (log(n) / log_2);
}

// (log2 n)^2
double f5(int n)
{
    return pow(f4(n), 2);
}
```

```
// log2 (n!)
double f6(int n)
{
    if (n == 0)
        return 0;
    double ans = 0;
    for (int i = 1; i <= n; i++)
    {
        ans += log(i);
    }
    ans /= log_2;
    return ans;
}

// ln(ln(n))
double f7(int n)
{
    return log(log(n));
}

// nlog(n)
double f8(int n)
{
    return n * f4(n);
}

// (log2 (n))^(log2 (n))
double f9(int n)
{
    double a = f4(n);
    return pow(a, a);
}

// n^(log2(log2(n)))
double f10(int n)
{
    return pow(2.0, f4(f4(n)));
}

// n!
unsigned long long f11(int n)
{
    if (n == 0 || n == 1)
        return 1;
    return n * f11(n - 1);
}
```

```c
int main()
{
    log_2 = log(2);
    printf("n  |(3/2)^n                    |n^3      |2^n
     |log2(n)   |(log2(n))^2|(log2(n!))  |ln(ln(n))  |nlog2(n)
|(log2(n))^(log2(n))|n^(log2(log2(n)))|n!                   |\n");
    for (int i = 0; i < 181; i++)
    {
        printf("-");
    }
    printf("\n");
    for (int i = 0; i <= 100; i++)
    {
        printf("%3d", i);
        printf(" | %23.3f", f1(i));
        printf(" | %7d", f2(i));
        printf(" | %19llu", f3(i));
        printf(" | %8.3f", f4(i));
        printf(" | %9.3f", f5(i));
        printf(" | %10.3f", f6(i));
        printf(" | %9.3f", f7(i));
        printf(" | %7.3f", f8(i));
        printf(" | %17.3f", f9(i));
        printf(" | %15.3f", f10(i));
        printf(" | ");
        if (i <= 20)
            printf("%19llu |", f11(i));
        printf("\n");
        for (int i = 0; i < 181; i++)
        {
            printf("-");
        }
        printf("\n");
    }
}
```

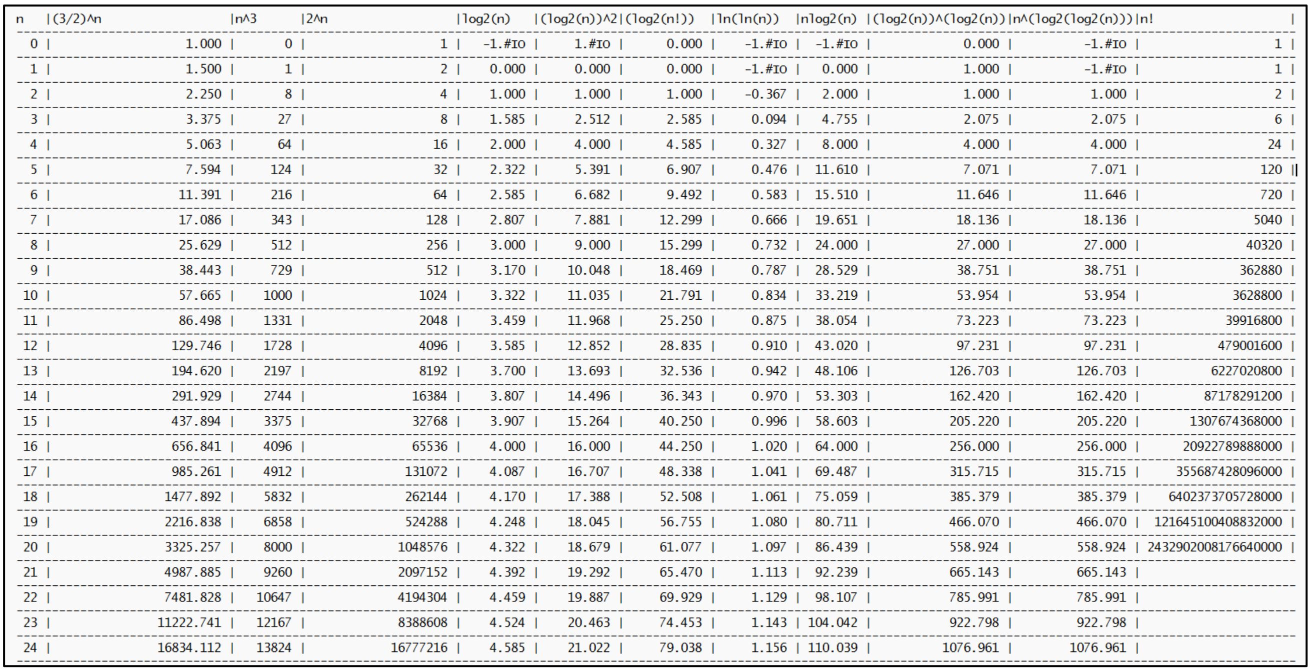
EXECUTION AND OUTPUT:

As the output was too large to display with correct formatting on terminal, it was redirected to a text file.



```
PS C:\Users\arifa\Desktop\sem4 work\daa lab\exp0> gcc prog.c -o prog
PS C:\Users\arifa\Desktop\sem4 work\daa lab\exp0> .\prog > output.txt
```

output.txt file:



```
n   |(3/2)^n        |n^3    |2^n              |log2(n)|(log2(n))^2|(log2(n!))|ln(ln(n))|nlog2(n)|(log2(n))^(log2(n))|n^(log2(log2(n)))|n!                   |
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  0 |         1.000 |      0 |                1 | -1.#IO |  1.#IO |   0.000 | -1.#IO |  -1.#IO |     0.000 |    -1.#IO |                   1 |
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  1 |         1.500 |      1 |                2 |  0.000 |  0.000 |   0.000 | -1.#IO |   0.000 |     1.000 |    -1.#IO |                   1 |
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  2 |         2.250 |      8 |                4 |  1.000 |  1.000 |   1.000 | -0.367 |   2.000 |     1.000 |     1.000 |                   2 |
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  3 |         3.375 |     27 |                8 |  1.585 |  2.512 |   2.585 |  0.094 |   4.755 |     2.075 |     2.075 |                   6 |
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  4 |         5.063 |     64 |               16 |  2.000 |  4.000 |   4.585 |  0.327 |   8.000 |     4.000 |     4.000 |                  24 |
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  5 |         7.594 |    124 |               32 |  2.322 |  5.391 |   6.907 |  0.476 |  11.610 |     7.071 |     7.071 |                 120 |
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  6 |        11.391 |    216 |               64 |  2.585 |  6.682 |   9.492 |  0.583 |  15.510 |    11.646 |    11.646 |                 720 |
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  7 |        17.086 |    343 |              128 |  2.807 |  7.881 |  12.299 |  0.666 |  19.651 |    18.136 |    18.136 |                5040 |
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  8 |        25.629 |    512 |              256 |  3.000 |  9.000 |  15.299 |  0.732 |  24.000 |    27.000 |    27.000 |               40320 |
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  9 |        38.443 |    729 |              512 |  3.170 | 10.048 |  18.469 |  0.787 |  28.529 |    38.751 |    38.751 |              362880 |
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 10 |        57.665 |   1000 |             1024 |  3.322 | 11.035 |  21.791 |  0.834 |  33.219 |    53.954 |    53.954 |             3628800 |
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 11 |        86.498 |   1331 |             2048 |  3.459 | 11.968 |  25.250 |  0.875 |  38.054 |    73.223 |    73.223 |            39916800 |
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 12 |       129.746 |   1728 |             4096 |  3.585 | 12.852 |  28.835 |  0.910 |  43.020 |    97.231 |    97.231 |           479001600 |
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 13 |       194.620 |   2197 |             8192 |  3.700 | 13.693 |  32.536 |  0.942 |  48.106 |   126.703 |   126.703 |          6227020800 |
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 14 |       291.929 |   2744 |            16384 |  3.807 | 14.496 |  36.343 |  0.970 |  53.303 |   162.420 |   162.420 |         87178291200 |
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 15 |       437.894 |   3375 |            32768 |  3.907 | 15.264 |  40.250 |  0.996 |  58.603 |   205.220 |   205.220 |       1307674368000 |
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 16 |       656.841 |   4096 |            65536 |  4.000 | 16.000 |  44.250 |  1.020 |  64.000 |   256.000 |   256.000 |      20922789888000 |
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 17 |       985.261 |   4912 |           131072 |  4.087 | 16.707 |  48.338 |  1.041 |  69.487 |   315.715 |   315.715 |     355687428096000 |
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 18 |      1477.892 |   5832 |           262144 |  4.170 | 17.388 |  52.508 |  1.061 |  75.059 |   385.379 |   385.379 |    6402373705728000 |
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 19 |      2216.838 |   6858 |           524288 |  4.248 | 18.045 |  56.755 |  1.080 |  80.711 |   466.070 |   466.070 |  121645100408832000 |
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 20 |      3325.257 |   8000 |          1048576 |  4.322 | 18.679 |  61.077 |  1.097 |  86.439 |   558.924 |   558.924 | 2432902008176640000 |
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 21 |      4987.885 |   9260 |          2097152 |  4.392 | 19.292 |  65.470 |  1.113 |  92.239 |   665.143 |   665.143 |
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 22 |      7481.828 |  10647 |          4194304 |  4.459 | 19.887 |  69.929 |  1.129 |  98.107 |   785.991 |   785.991 |
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 23 |     11222.741 |  12167 |          8388608 |  4.524 | 20.463 |  74.453 |  1.143 | 104.042 |   922.798 |   922.798 |
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 24 |     16834.112 |  13824 |         16777216 |  4.585 | 21.022 |  79.038 |  1.156 | 110.039 |  1076.961 |  1076.961 |
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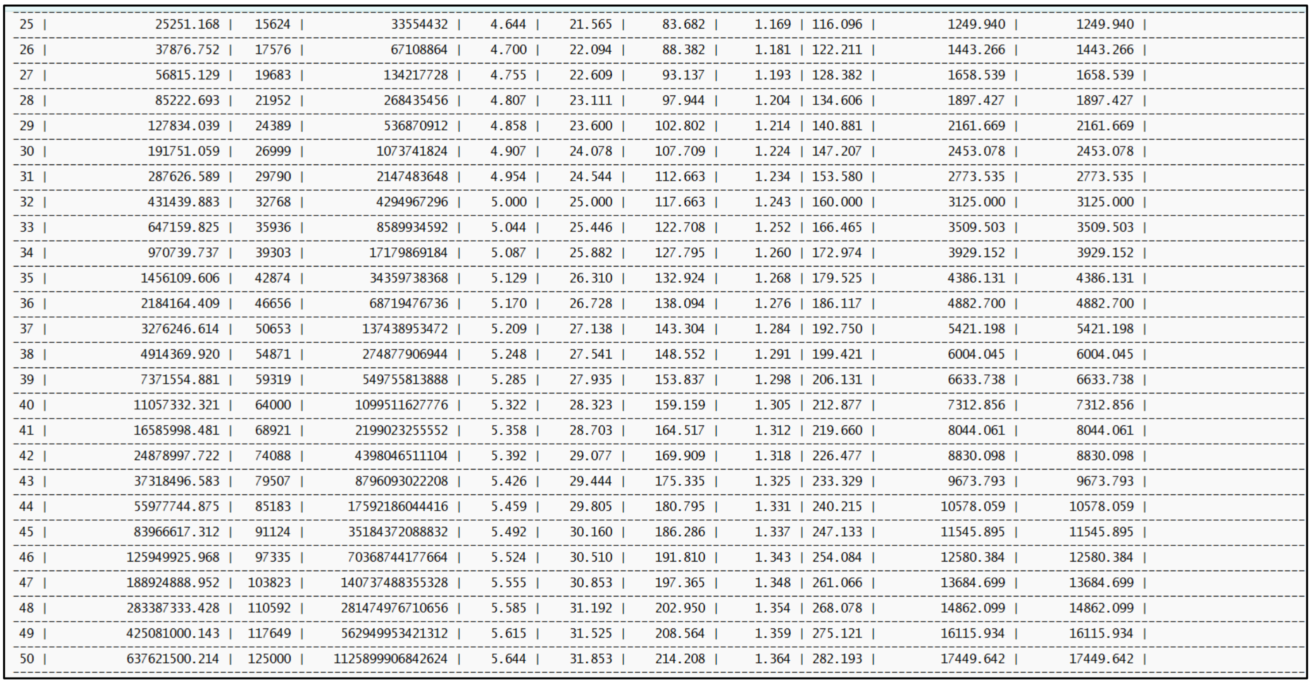

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 25 |     25251.168 |  15624 |         33554432 |  4.644 | 21.565 |  83.682 |  1.169 | 116.096 |  1249.940 |  1249.940 |
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 26 |     37876.752 |  17576 |         67108864 |  4.700 | 22.094 |  88.382 |  1.181 | 122.211 |  1443.266 |  1443.266 |
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 27 |     56815.129 |  19683 |        134217728 |  4.755 | 22.609 |  93.137 |  1.193 | 128.382 |  1658.539 |  1658.539 |
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 28 |     85222.693 |  21952 |        268435456 |  4.807 | 23.111 |  97.944 |  1.204 | 134.606 |  1897.427 |  1897.427 |
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 29 |    127834.039 |  24389 |        536870912 |  4.858 | 23.600 | 102.802 |  1.214 | 140.881 |  2161.669 |  2161.669 |
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 30 |    191751.059 |  26999 |       1073741824 |  4.907 | 24.078 | 107.709 |  1.224 | 147.207 |  2453.078 |  2453.078 |
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 31 |    287626.589 |  29790 |       2147483648 |  4.954 | 24.544 | 112.663 |  1.234 | 153.580 |  2773.535 |  2773.535 |
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 32 |    431439.883 |  32768 |       4294967296 |  5.000 | 25.000 | 117.663 |  1.243 | 160.000 |  3125.000 |  3125.000 |
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 33 |    647159.825 |  35936 |       8589934592 |  5.044 | 25.446 | 122.708 |  1.252 | 166.465 |  3509.503 |  3509.503 |
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 34 |    970739.737 |  39303 |      17179869184 |  5.087 | 25.882 | 127.795 |  1.260 | 172.974 |  3929.152 |  3929.152 |
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 35 |   1456109.606 |  42874 |      34359738368 |  5.129 | 26.310 | 132.924 |  1.268 | 179.525 |  4386.131 |  4386.131 |
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 36 |   2184164.409 |  46656 |      68719476736 |  5.170 | 26.728 | 138.094 |  1.276 | 186.117 |  4882.700 |  4882.700 |
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 37 |   3276246.614 |  50653 |     137438953472 |  5.209 | 27.138 | 143.304 |  1.284 | 192.750 |  5421.198 |  5421.198 |
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 38 |   4914369.920 |  54871 |     274877906944 |  5.248 | 27.541 | 148.552 |  1.291 | 199.421 |  6004.045 |  6004.045 |
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 39 |   7371554.881 |  59319 |     549755813888 |  5.285 | 27.935 | 153.837 |  1.298 | 206.131 |  6633.738 |  6633.738 |
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 40 |  11057332.321 |  64000 |    1099511627776 |  5.322 | 28.323 | 159.159 |  1.305 | 212.877 |  7312.856 |  7312.856 |
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 41 |  16585998.481 |  68921 |    2199023255552 |  5.358 | 28.703 | 164.517 |  1.312 | 219.660 |  8044.061 |  8044.061 |
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 42 |  24878997.722 |  74088 |    4398046511104 |  5.392 | 29.077 | 169.909 |  1.318 | 226.477 |  8830.098 |  8830.098 |
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 43 |  37318496.583 |  79507 |    8796093022208 |  5.426 | 29.444 | 175.335 |  1.325 | 233.329 |  9673.793 |  9673.793 |
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 44 |  55977744.875 |  85183 |   17592186044416 |  5.459 | 29.805 | 180.795 |  1.331 | 240.215 | 10578.059 | 10578.059 |
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 45 |  83966617.312 |  91124 |   35184372088832 |  5.492 | 30.160 | 186.286 |  1.337 | 247.133 | 11545.895 | 11545.895 |
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 46 | 125949925.968 |  97335 |   70368744177664 |  5.524 | 30.510 | 191.810 |  1.343 | 254.084 | 12580.384 | 12580.384 |
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 47 | 188924888.952 | 103823 |  140737488355328 |  5.555 | 30.853 | 197.365 |  1.348 | 261.066 | 13684.699 | 13684.699 |
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 48 | 283387333.428 | 110592 |  281474976710656 |  5.585 | 31.192 | 202.950 |  1.354 | 268.078 | 14862.099 | 14862.099 |
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 49 | 425081000.143 | 117649 |  562949953421312 |  5.615 | 31.525 | 208.564 |  1.359 | 275.121 | 16115.934 | 16115.934 |
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 50 | 637621500.214 | 125000 | 1125899906842624 |  5.644 | 31.853 | 214.208 |  1.364 | 282.193 | 17449.642 | 17449.642 |
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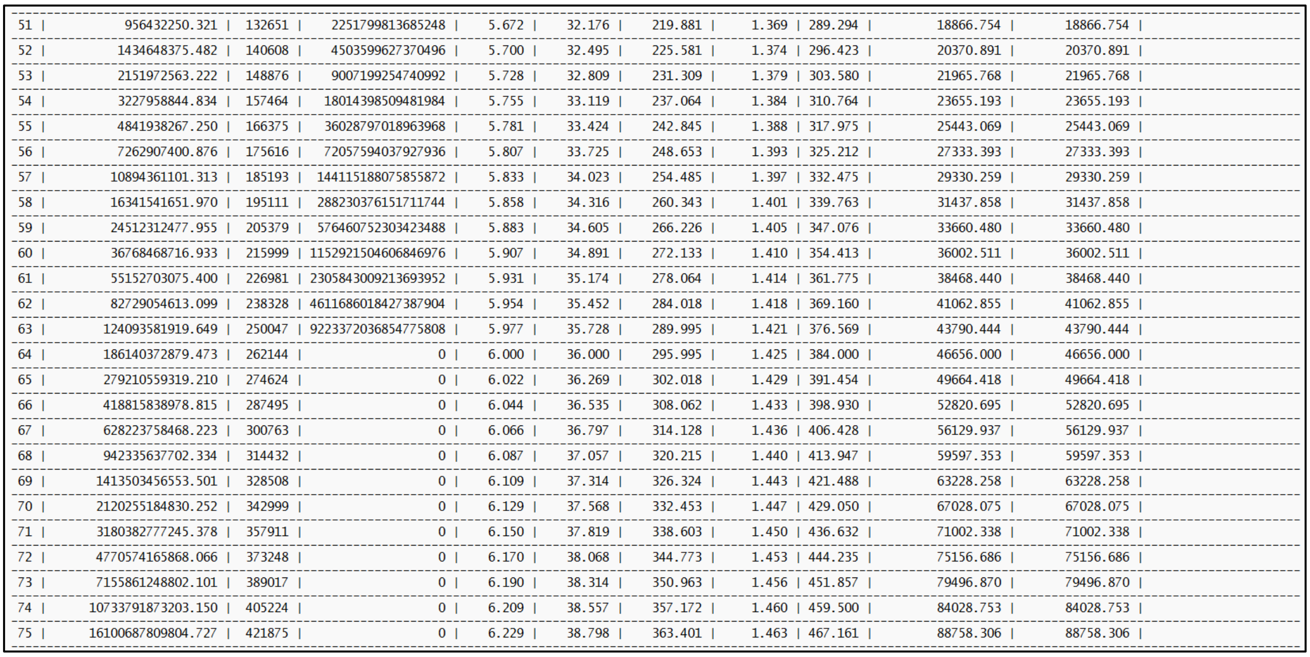

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 51 |        956432250.321 | 132651 |    2251799813685248 |    5.672 |   32.176 |  219.881 |    1.369 | 289.294 |      18866.754 |      18866.754 |
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 52 |       1434648375.482 | 140608 |    4503599627370496 |    5.700 |   32.495 |  225.581 |    1.374 | 296.423 |      20370.891 |      20370.891 |
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 53 |       2151972563.222 | 148876 |    9007199254740992 |    5.728 |   32.809 |  231.309 |    1.379 | 303.580 |      21965.768 |      21965.768 |
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 54 |       3227958844.834 | 157464 |   18014398509481984 |    5.755 |   33.119 |  237.064 |    1.384 | 310.764 |      23655.193 |      23655.193 |
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 55 |       4841938267.250 | 166375 |   36028797018963968 |    5.781 |   33.424 |  242.845 |    1.388 | 317.975 |      25443.069 |      25443.069 |
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 56 |       7262907400.876 | 175616 |   72057594037927936 |    5.807 |   33.725 |  248.653 |    1.393 | 325.212 |      27333.393 |      27333.393 |
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 57 |      10894361101.313 | 185193 |  144115188075855872 |    5.833 |   34.023 |  254.485 |    1.397 | 332.475 |      29330.259 |      29330.259 |
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 58 |      16341541651.970 | 195111 |  288230376151711744 |    5.858 |   34.316 |  260.343 |    1.401 | 339.763 |      31437.858 |      31437.858 |
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 59 |      24512312477.955 | 205379 |  576460752303423488 |    5.883 |   34.605 |  266.226 |    1.405 | 347.076 |      33660.480 |      33660.480 |
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 60 |      36768468716.933 | 215999 | 1152921504606846976 |    5.907 |   34.891 |  272.133 |    1.410 | 354.413 |      36002.511 |      36002.511 |
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 61 |      55152703075.400 | 226981 | 2305843009213693952 |    5.931 |   35.174 |  278.064 |    1.414 | 361.775 |      38468.440 |      38468.440 |
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 62 |      82729054613.099 | 238328 | 4611686018427387904 |    5.954 |   35.452 |  284.018 |    1.418 | 369.160 |      41062.855 |      41062.855 |
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 63 |     124093581919.649 | 250047 | 9223372036854775808 |    5.977 |   35.728 |  289.995 |    1.421 | 376.569 |      43790.444 |      43790.444 |
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 64 |     186140372879.473 | 262144 |                   0 |    6.000 |   36.000 |  295.995 |    1.425 | 384.000 |      46656.000 |      46656.000 |
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 65 |     279210559319.210 | 274624 |                   0 |    6.022 |   36.269 |  302.018 |    1.429 | 391.454 |      49664.418 |      49664.418 |
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 66 |     418815838978.815 | 287495 |                   0 |    6.044 |   36.535 |  308.062 |    1.433 | 398.930 |      52820.695 |      52820.695 |
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 67 |     628223758468.223 | 300763 |                   0 |    6.066 |   36.797 |  314.128 |    1.436 | 406.428 |      56129.937 |      56129.937 |
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 68 |     942335637702.334 | 314432 |                   0 |    6.087 |   37.057 |  320.215 |    1.440 | 413.947 |      59597.353 |      59597.353 |
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 69 |    1413503456553.501 | 328508 |                   0 |    6.109 |   37.314 |  326.324 |    1.443 | 421.488 |      63228.258 |      63228.258 |
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 70 |    2120255184830.252 | 342999 |                   0 |    6.129 |   37.568 |  332.453 |    1.447 | 429.050 |      67028.075 |      67028.075 |
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 71 |    3180382777245.378 | 357911 |                   0 |    6.150 |   37.819 |  338.603 |    1.450 | 436.632 |      71002.338 |      71002.338 |
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 72 |    4770574165868.066 | 373248 |                   0 |    6.170 |   38.068 |  344.773 |    1.453 | 444.235 |      75156.686 |      75156.686 |
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 73 |    7155861248802.101 | 389017 |                   0 |    6.190 |   38.314 |  350.963 |    1.456 | 451.857 |      79496.870 |      79496.870 |
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 74 |   10733791873203.150 | 405224 |                   0 |    6.209 |   38.557 |  357.172 |    1.460 | 459.500 |      84028.753 |      84028.753 |
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 75 |   16100687809804.727 | 421875 |                   0 |    6.229 |   38.798 |  363.401 |    1.463 | 467.161 |      88758.306 |      88758.306 |
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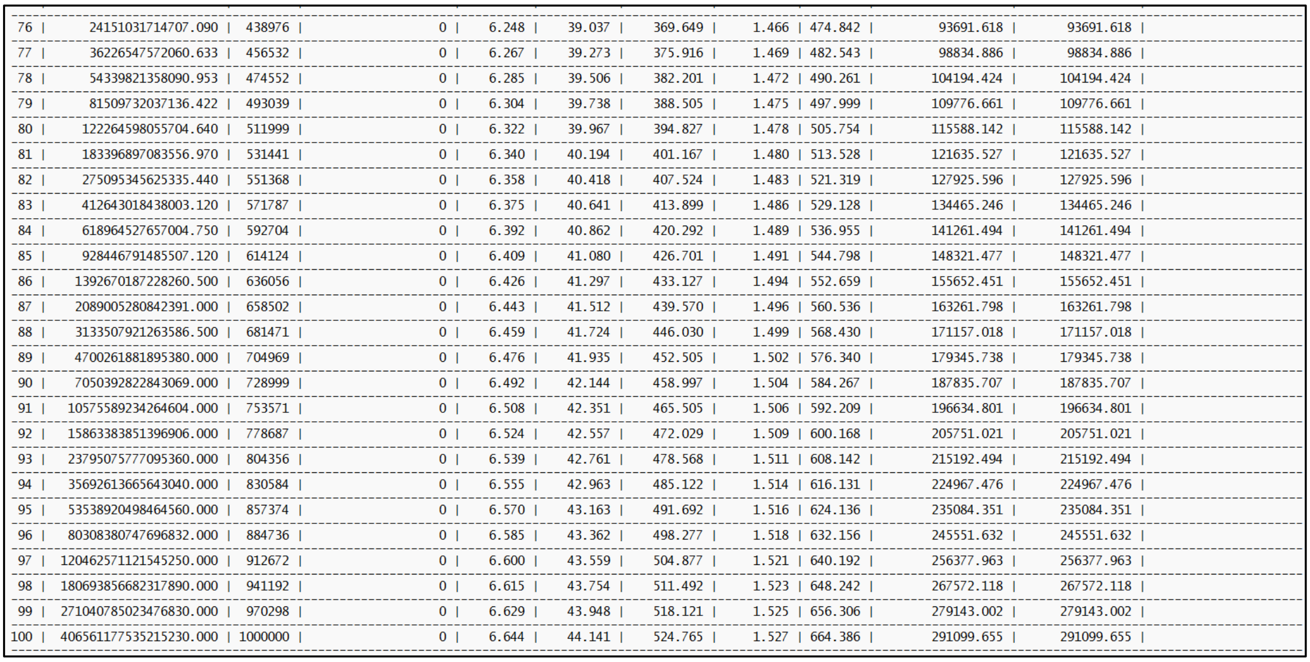

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 76 |   24151031714707.090 | 438976 |                   0 |    6.248 |   39.037 |  369.649 |    1.466 | 474.842 |      93691.618 |      93691.618 |
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 77 |   36226547572060.633 | 456532 |                   0 |    6.267 |   39.273 |  375.916 |    1.469 | 482.543 |      98834.886 |      98834.886 |
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 78 |   54339821358090.953 | 474552 |                   0 |    6.285 |   39.506 |  382.201 |    1.472 | 490.261 |     104194.424 |     104194.424 |
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 79 |   81509732037136.422 | 493039 |                   0 |    6.304 |   39.738 |  388.505 |    1.475 | 497.999 |     109776.661 |     109776.661 |
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 80 |  122264598055704.640 | 511999 |                   0 |    6.322 |   39.967 |  394.827 |    1.478 | 505.754 |     115588.142 |     115588.142 |
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 81 |  183396897083556.970 | 531441 |                   0 |    6.340 |   40.194 |  401.167 |    1.480 | 513.528 |     121635.527 |     121635.527 |
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 82 |  275095345625335.440 | 551368 |                   0 |    6.358 |   40.418 |  407.524 |    1.483 | 521.319 |     127925.596 |     127925.596 |
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 83 |  412643018438003.120 | 571787 |                   0 |    6.375 |   40.641 |  413.899 |    1.486 | 529.128 |     134465.246 |     134465.246 |
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 84 |  618964527657004.750 | 592704 |                   0 |    6.392 |   40.862 |  420.292 |    1.489 | 536.955 |     141261.494 |     141261.494 |
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 85 |  928446791485507.120 | 614124 |                   0 |    6.409 |   41.080 |  426.701 |    1.491 | 544.798 |     148321.477 |     148321.477 |
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 86 | 1392670187228260.500 | 636056 |                   0 |    6.426 |   41.297 |  433.127 |    1.494 | 552.659 |     155652.451 |     155652.451 |
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 87 | 2089005280842391.000 | 658502 |                   0 |    6.443 |   41.512 |  439.570 |    1.496 | 560.536 |     163261.798 |     163261.798 |
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 88 | 3133507921263586.500 | 681471 |                   0 |    6.459 |   41.724 |  446.030 |    1.499 | 568.430 |     171157.018 |     171157.018 |
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 89 | 4700261881895380.000 | 704969 |                   0 |    6.476 |   41.935 |  452.505 |    1.502 | 576.340 |     179345.738 |     179345.738 |
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 90 | 7050392822843069.000 | 728999 |                   0 |    6.492 |   42.144 |  458.997 |    1.504 | 584.267 |     187835.707 |     187835.707 |
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 91 | 10575589234264604.000 | 753571 |                  0 |    6.508 |   42.351 |  465.505 |    1.506 | 592.209 |     196634.801 |     196634.801 |
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 92 | 15863383851396906.000 | 778687 |                  0 |    6.524 |   42.557 |  472.029 |    1.509 | 600.168 |     205751.021 |     205751.021 |
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 93 | 23795075777095360.000 | 804356 |                  0 |    6.539 |   42.761 |  478.568 |    1.511 | 608.142 |     215192.494 |     215192.494 |
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 94 | 35692613665643040.000 | 830584 |                  0 |    6.555 |   42.963 |  485.122 |    1.514 | 616.131 |     224967.476 |     224967.476 |
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 95 | 53538920498464560.000 | 857374 |                  0 |    6.570 |   43.163 |  491.692 |    1.516 | 624.136 |     235084.351 |     235084.351 |
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 96 | 80308380747696832.000 | 884736 |                  0 |    6.585 |   43.362 |  498.277 |    1.518 | 632.156 |     245551.632 |     245551.632 |
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 97 | 120462571121545250.000 | 912672 |                 0 |    6.600 |   43.559 |  504.877 |    1.521 | 640.192 |     256377.963 |     256377.963 |
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 98 | 180693856682317890.000 | 941192 |                 0 |    6.615 |   43.754 |  511.492 |    1.523 | 648.242 |     267572.118 |     267572.118 |
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 99 | 271040785023476830.000 | 970298 |                 0 |    6.629 |   43.948 |  518.121 |    1.525 | 656.306 |     279143.002 |     279143.002 |
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100 | 406561177535215230.000 | 1000000 |                0 |    6.644 |   44.141 |  524.765 |    1.527 | 664.386 |     291099.655 |     291099.655 |
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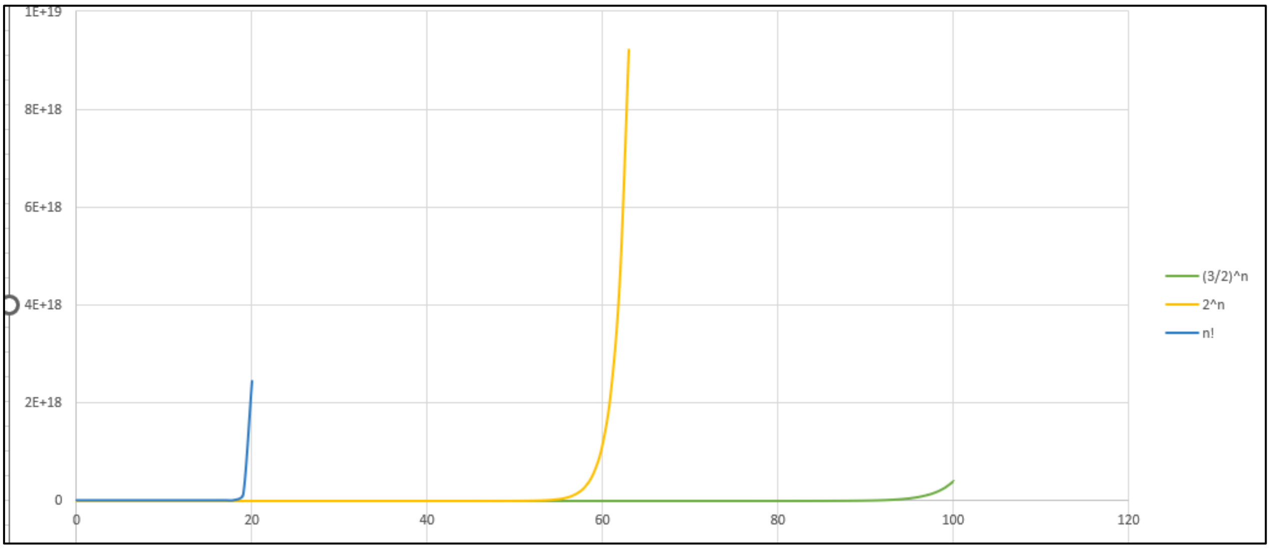
For n>=64, 2^n cannot be calculated on a 64-bit machine, as the largest unsigned integer that can be represent on a 64-bit architecture is $2^{64} – 1$ (18446744073709551615). Hence the output of 2^n for n>=64 was 0.

PLOTTING AND ANALYSING GRAPHS:

In the following discussion, n is a non-negative integer.

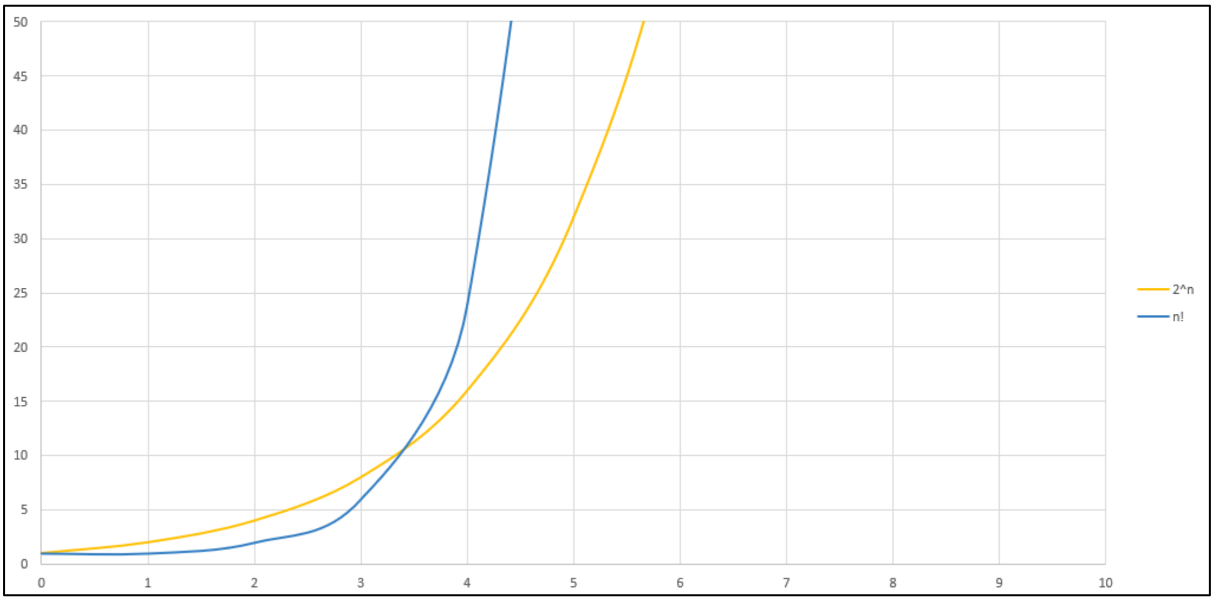
Comparing factorial and exponential functions:

Fastest growing functions were found to be n!, 2^n, 1.5^n respectively.



Largest unsigned integer that can be represented on a 64-bit machine is $2^{63}-1$ (9.223372e+18). Hence value of n! can only be calculated for n<=20, as 21! (5.1090942e+19) exceeds this upper bound. Similarly, value of 2^n can only be calculated for n<=63 on a 64-bit machine.

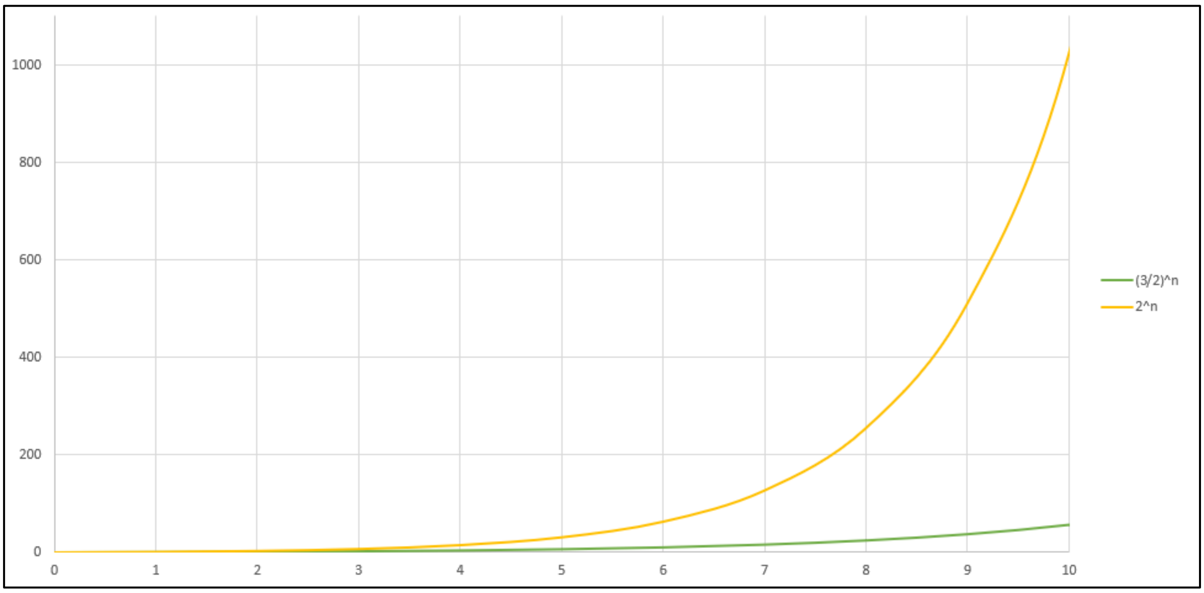
However, n! reaches surpasses this upper bound (at n=21) much faster than 2^n (at n=64).



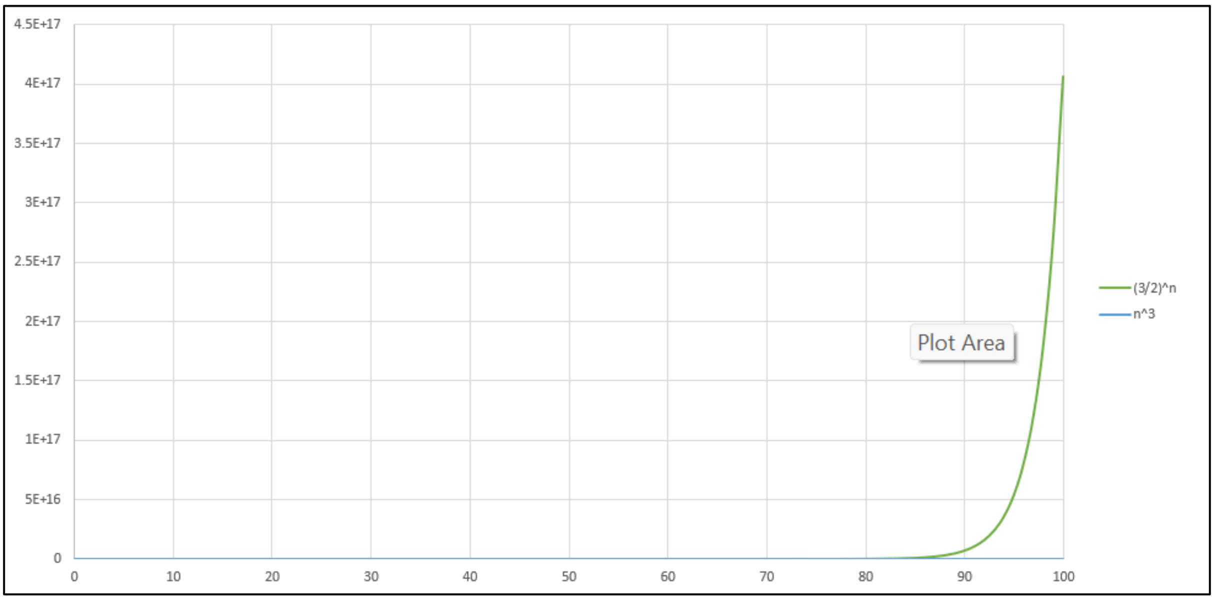
Value of n! is greater than that of 2^n for all n>=4.

In general, factorial function grows much faster than exponential functions with a constant base.

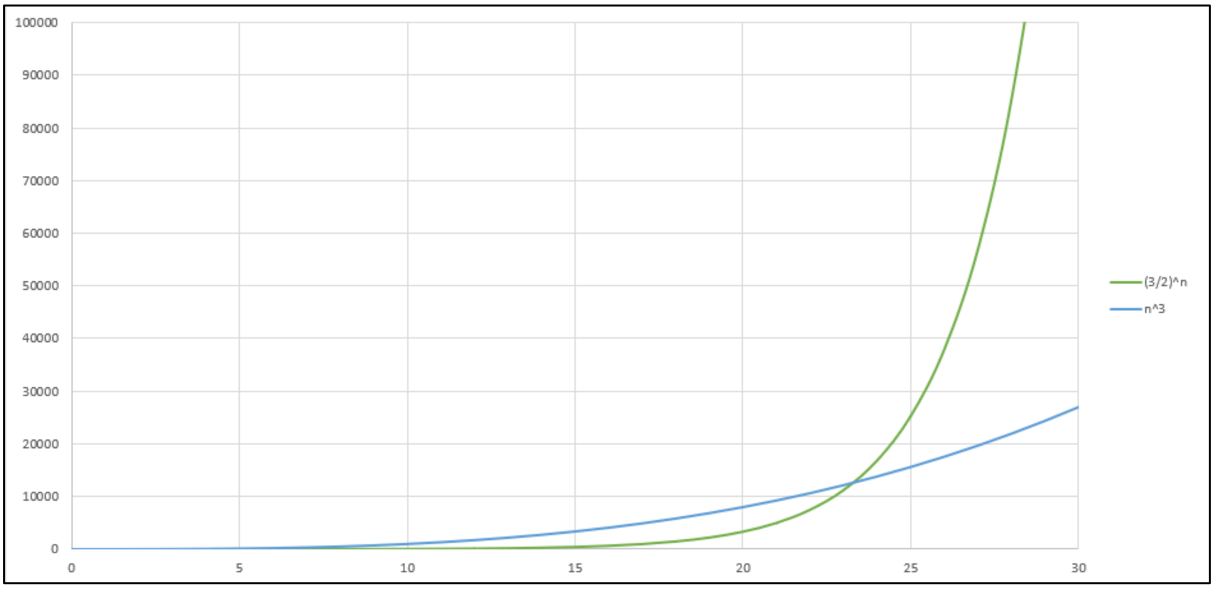
Even though both 1.5^n and 2^n are exponential functions with constant bases with a difference of only 0.5, their growth rates are vastly different. Even for n=10, 2^n value has a greater order of magnitude than 1.5^n.



Comparing exponential and polynomial functions:



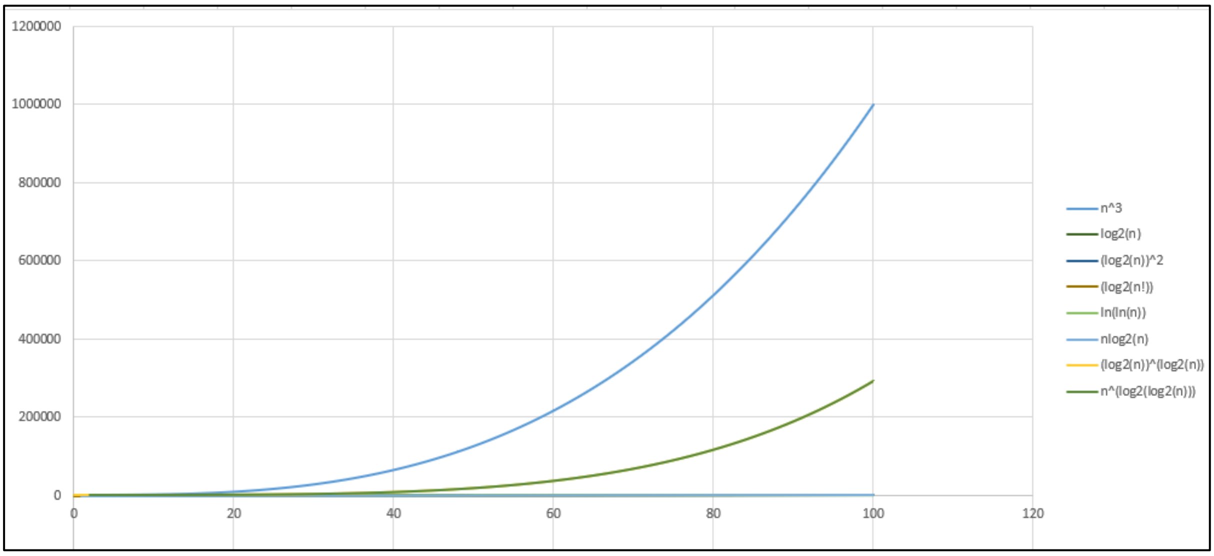
For large values of n, 1.5^n grows much faster than n^3.



However, for n<=23, n^3 is larger than and grows faster than 1.5^n.

In general, exponential functions grow faster than polynomial functions for large values of n.

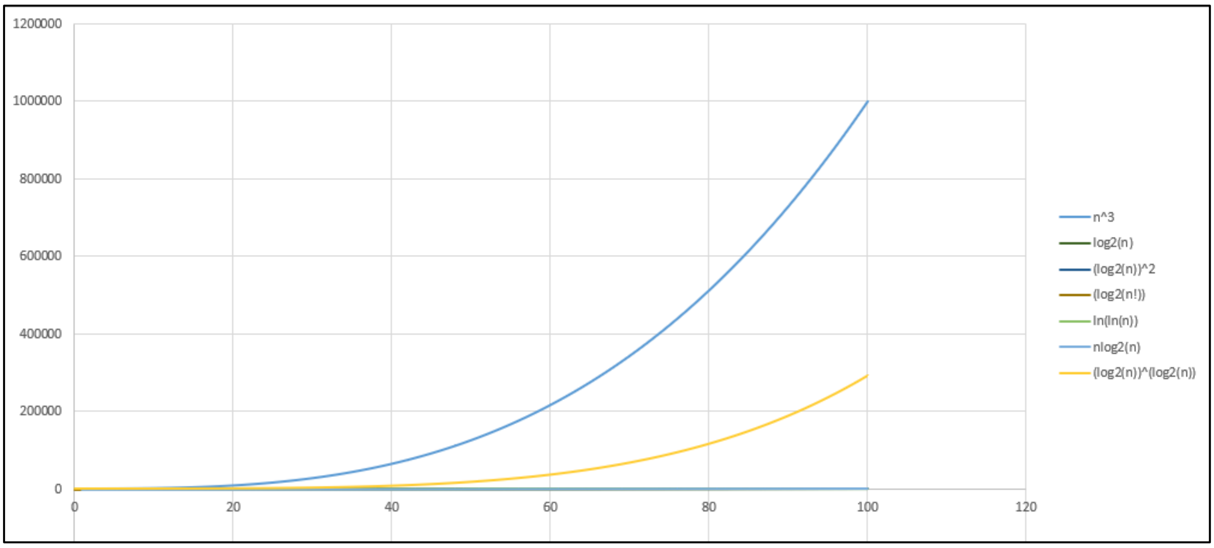
Comparing polynomial and various logarithmic functions:



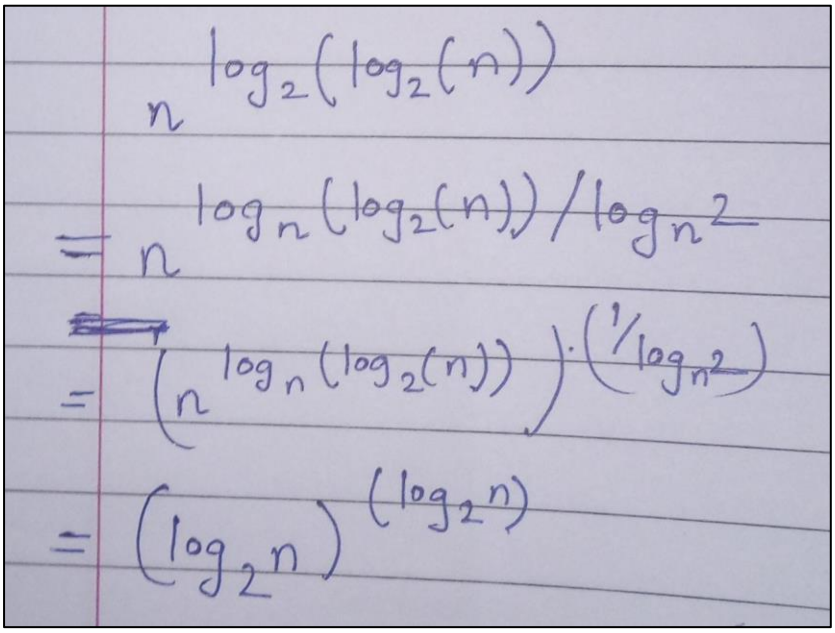
n^3 grows faster than all logarithmic functions on this list.

In general, polynomial functions grow faster than logarithmic functions for large values of n.

Among all logarithmic functions, $\log(n)^{(\log(n))}$ and $n^{\log(\log(n))}$ have the highest rate of growth. These two functions are in fact equivalent. Graph of $\log(n)^{(\log(n))}$ is hidden behind $n^{\log(\log(n))}$.



A small mathematical proof of these two functions being equivalent:

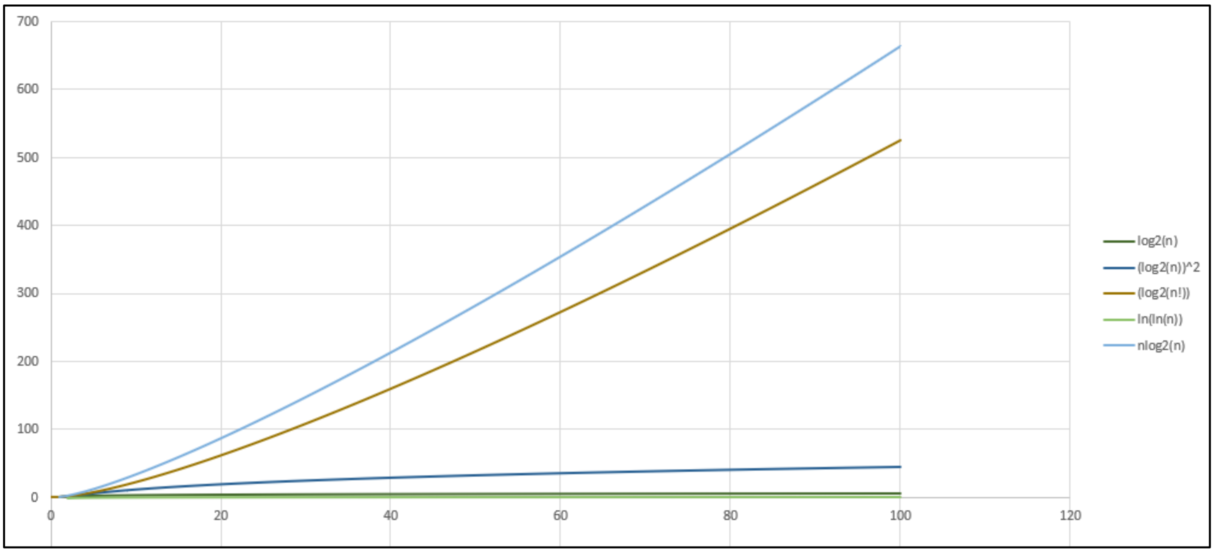


$$n^{\log_2(\log_2(n))}$$

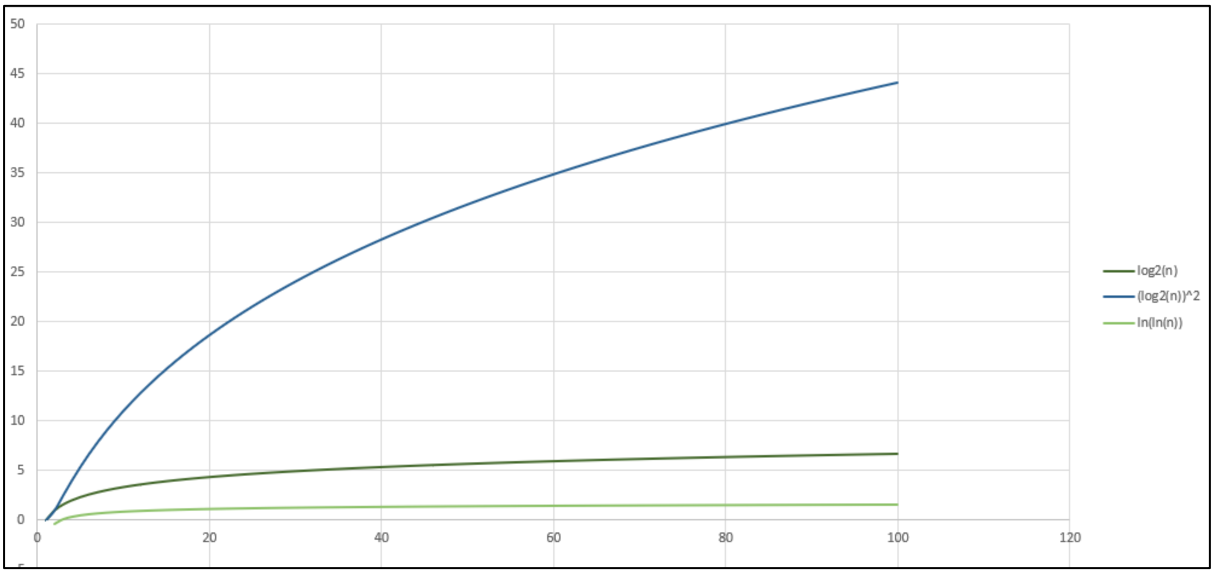
$$= n^{\log_n(\log_2(n))/\log_n 2}$$

$$= \left(n^{\log_n(\log_2(n))}\right)^{\cdot(1/\log_n 2)}$$

$$= (\log_2 n)^{(\log_2 n)}$$



n*log(n), having a linear as well as a logarithmic part, grows faster than pure logarithmic functions. Among all pure logarithmic functions, log(n!) grows the fastest as n! has an extremely high growth rate.



$(\log(n))^2$ being the square of log(n), grows faster than log(n). ln(ln(n)) is a double logarithmic function, and hence is the slowest growing function on this list.

CONCLUSION:

Final list of all functions in increasing order of their growth rates:

1. ln(ln(n))
2. log2(n)
3. (log2(n))^2
4. log(n!)
5. n*log2(n)
6. n$^{\log2(\log2(n))}$ OR log2(n)$^{\log2(n)}$
7. n^3
8. (3/2)^n
9. 2^n
10. n!