CPSC 3300

Homework 1

Due 3:30PM, Jan. 25 on Canvas

(totally 100 points)

1. Moore’s law ((a) through (f): 10 points each)

Read the following three articles. (You may use other published sources to answer the questions; please cite those sources if you do.)

[2.1] "Exponential Growth," Wikipedia: The Free Encyclopedia, accessed Aug. 22, 2015. [Online] en.wikipedia.org/wiki/Exponential\_growth

[2.2] “moore’s law,” Wikipedia: The free Encyclopedia. [Online] https://en.wikipedia.org/wiki/Moore%27s\_law

[2.3] Chris Mack, "The Multiple Lives of Moore’s Law”. [Online] www.quora.com/ http://spectrum.ieee.org/semiconductors/processors/the-multiple-lives-of-moores-law (10 points each of the following subquestions)

1. Define exponential growth.

**Exponential growth** is exhibited when the [growth rate](https://en.wikipedia.org/wiki/Rate_(mathematics)#Of_change) of the value of a mathematical function is [proportional](https://en.wikipedia.org/wiki/Proportionality_(mathematics)) to the function's current value, resulting in its growth with time being an [exponential function](https://en.wikipedia.org/wiki/Exponential_function), i.e., a function in which the time value is the exponent

1. What did the original Moore’s Law observe and project?

**Moore's law** is the observation that the number of [transistors](https://en.wikipedia.org/wiki/Transistor) in a dense [integrated circuit](https://en.wikipedia.org/wiki/Integrated_circuit) doubles approximately every two years

Moore’s paper described a [doubling every year](https://en.wikipedia.org/wiki/Exponential_growth) in the number of components per integrated circuit, and projected this rate of growth would continue for at least another decade

(c) In your opinion, why has Moore’s prediction been accurate over the years? (any reasonable answer)

(d) What is Dennard Scaling and why is it important in processor technology evolvement.

Dennard scaling, also known as MOSFET scaling, is a scaling law based on a 1974 paper co-authored by Robert H. Dennard, after whom it is named. Originally formulated for MOSFETs, it states, roughly, that as transistors get smaller their power density stays constant, so that the power use stays in proportion with area: both voltage and current scale (downward) with length.

Dennard scaling relates to Moore's law and claims that the performance per watt of computing is growing exponentially at roughly the same rate. Historically, the transistor power reduction afforded by Dennard scaling allowed manufacturers to drastically raise clock frequencies from one generation to the next without significantly increasing overall circuit power consumption.

(e) According to Dr. Mack, scaling down or miniaturization marked the Moore’s Law 2.0 era. Scaling down reduces the size of transistors. List the feature sizes over the years to today.

This is an extensive list. Years that mark the advent of new available feature sizes among all processors would be sufficient.

| **Processor** | **Transistor count** | **Date of introduction** | **Designer** | [Process](https://en.wikipedia.org/wiki/Semiconductor_device_fabrication) | **Area** |
| --- | --- | --- | --- | --- | --- |
| [TMS 1000](https://en.wikipedia.org/wiki/Texas_Instruments_TMS1000) | 8,000 | 1974[[3]](https://en.wikipedia.org/wiki/Transistor_count#cite_note-3) | [Texas Instruments](https://en.wikipedia.org/wiki/Texas_Instruments) | 8,000 nm | 0.122 x 0.143 inches |
| [Intel 4004](https://en.wikipedia.org/wiki/Intel_4004) | 2,300 | 1971 | [Intel](https://en.wikipedia.org/wiki/Intel) | 10,000 nm | 12 mm² |
| [Intel 8008](https://en.wikipedia.org/wiki/Intel_8008) | 3,500 | 1972 | Intel | 10,000 nm | 14 mm² |
| [MOS Technology 6502](https://en.wikipedia.org/wiki/MOS_Technology_6502) | 3,510[[4]](https://en.wikipedia.org/wiki/Transistor_count#cite_note-4) | 1975 | [MOS Technology](https://en.wikipedia.org/wiki/MOS_Technology) | 8,000 nm | 21 mm² |
| [Motorola 6800](https://en.wikipedia.org/wiki/Motorola_6800) | 4,100 | 1974 | [Motorola](https://en.wikipedia.org/wiki/Motorola) | 6,000 nm | 16 mm² |
| [Intel 8080](https://en.wikipedia.org/wiki/Intel_8080) | 4,500 | 1974 | Intel | 6,000 nm | 20 mm² |
| [RCA 1802](https://en.wikipedia.org/wiki/RCA_1802) | 5,000 | 1974 | [RCA](https://en.wikipedia.org/wiki/RCA) | 5,000 nm | 27 mm² |
| [Intel 8085](https://en.wikipedia.org/wiki/Intel_8085) | 6,500 | 1976 | Intel | 3,000 nm | 20 mm² |
| [Zilog Z80](https://en.wikipedia.org/wiki/Zilog_Z80) | 8,500 | 1976 | [Zilog](https://en.wikipedia.org/wiki/Zilog) | 4,000 nm | 18 mm² |
| [Motorola 6809](https://en.wikipedia.org/wiki/Motorola_6809) | 9,000 | 1978 | Motorola | 5,000 nm | 21 mm² |
| [Intel 8086](https://en.wikipedia.org/wiki/Intel_8086) | 29,000 | 1978 | Intel | 3,000 nm | 33 mm² |
| [Intel 8088](https://en.wikipedia.org/wiki/Intel_8088) | 29,000 | 1979 | Intel | 3,000 nm | 33 mm² |
| [WDC 65C02](https://en.wikipedia.org/wiki/WDC_65C02) | 11,500[[5]](https://en.wikipedia.org/wiki/Transistor_count#cite_note-Christiansen-5) | 1981 | WDC | 3,000 nm | 6 mm² |
| [Intel 80186](https://en.wikipedia.org/wiki/Intel_80186) | 55,000 | 1982 | Intel | 3,000 nm | 60 mm² |
| [Motorola 68000](https://en.wikipedia.org/wiki/Motorola_68000) | 68,000 | 1979 | Motorola | 3,500 nm | 44 mm² |
| [Intel 80286](https://en.wikipedia.org/wiki/Intel_80286) | 134,000 | 1982 | Intel | 1,500 nm | 49 mm² |
| [WDC 65C816](https://en.wikipedia.org/wiki/WDC_65C816) | 22,000[[6]](https://en.wikipedia.org/wiki/Transistor_count#cite_note-6) | 1983 | [WDC](https://en.wikipedia.org/wiki/Western_Design_Center) | 3000nm[[7]](https://en.wikipedia.org/wiki/Transistor_count#cite_note-7) | 9 mm² |
| [Motorola 68020](https://en.wikipedia.org/wiki/Motorola_68020) | 190,000[[8]](https://en.wikipedia.org/wiki/Transistor_count#cite_note-DeMone-8) | 1984 | Motorola | 2,000 nm | 85 mm² |
| [Intel 80386](https://en.wikipedia.org/wiki/Intel_80386) | 275,000 | 1985 | Intel | 1,500 nm | 104 mm² |
| [ARM 1](https://en.wikipedia.org/wiki/ARM_architecture) | 25,000[[8]](https://en.wikipedia.org/wiki/Transistor_count#cite_note-DeMone-8) | 1985 | [Acorn](https://en.wikipedia.org/wiki/Acorn_Computers) | 3,000 nm | 50 mm² |
| Novix NC4016 | 16,000[[9]](https://en.wikipedia.org/wiki/Transistor_count#cite_note-9) | 1985[[10]](https://en.wikipedia.org/wiki/Transistor_count#cite_note-10) | [Harris Corporation](https://en.wikipedia.org/wiki/Harris_Corporation) | 3,000 nm[[11]](https://en.wikipedia.org/wiki/Transistor_count#cite_note-11) |  |
| [ARM 2](https://en.wikipedia.org/wiki/ARM_architecture) | 30,000[[8]](https://en.wikipedia.org/wiki/Transistor_count#cite_note-DeMone-8) | 1986 | Acorn | 2,000 nm | 30 mm² |
| 68030 | 273,000 | 1987 | Motorola | 800 nm | 102 mm² |
| [TI Explorer](https://en.wikipedia.org/wiki/TI_Explorer)'s 32-bit [Lisp](https://en.wikipedia.org/wiki/Lisp_(programming_language)) [machine](https://en.wikipedia.org/wiki/Lisp_machine) chip | 553,000[[12]](https://en.wikipedia.org/wiki/Transistor_count#cite_note-MegaChip-12) | 1987 | Texas Instruments | 2,000 nm[[13]](https://en.wikipedia.org/wiki/Transistor_count#cite_note-13) |  |
| DEC WRL MultiTitan | 180,000[[14]](https://en.wikipedia.org/wiki/Transistor_count#cite_note-14) | 1988 | DEC WRL | 1,500 nm | 61 mm² |
| [Intel i960](https://en.wikipedia.org/wiki/Intel_i960) | 250,000[[15]](https://en.wikipedia.org/wiki/Transistor_count#cite_note-15) | 1988 | Intel | 600 nm |  |
| [Intel 80486](https://en.wikipedia.org/wiki/Intel_80486) | 1,180,235 | 1989 | Intel | 1000 nm | 173 mm² |
| [ARM 3](https://en.wikipedia.org/wiki/ARM_architecture) | 300,000 | 1989 | Acorn |  |  |
| [68040](https://en.wikipedia.org/wiki/Motorola_68060) | 1,200,000 | 1990 | Motorola | 650 nm | 152 mm² |
| [R4000](https://en.wikipedia.org/wiki/R4000) | 1,350,000 | 1991 | [MIPS](https://en.wikipedia.org/wiki/MIPS_Technologies) | 1,000 nm | 213 mm² |
| [ARM 6](https://en.wikipedia.org/wiki/ARM_architecture) | 35,000 | 1991 | [ARM](https://en.wikipedia.org/wiki/ARM_Holdings) |  |  |
| [Pentium](https://en.wikipedia.org/wiki/Intel_P5) | 3,100,000 | 1993 | Intel | 800 nm | 294 mm² |
| [ARM700](https://en.wikipedia.org/wiki/ARM_architecture) | 578,977[[16]](https://en.wikipedia.org/wiki/Transistor_count#cite_note-16) | 1994 | ARM |  |  |
| [68060](https://en.wikipedia.org/wiki/Motorola_68060) | 2,500,000 | 1994 | Motorola | 600nm | 218 mm² |
| [SA-110](https://en.wikipedia.org/wiki/ARM_architecture) | 2,500,000[[8]](https://en.wikipedia.org/wiki/Transistor_count#cite_note-DeMone-8) | 1995 | Acorn/DEC/Apple | 350 nm | 50 mm² |
| [ARM 9TDMI](https://en.wikipedia.org/wiki/ARM_architecture) | 111,000[[8]](https://en.wikipedia.org/wiki/Transistor_count#cite_note-DeMone-8) | 1999 | Acorn | 350 nm | 4.8 mm² |
| [Pentium Pro](https://en.wikipedia.org/wiki/Pentium_Pro) | 5,500,000[[17]](https://en.wikipedia.org/wiki/Transistor_count#cite_note-17) | 1995 | Intel | 500 nm | 307 mm² |
| [AMD K5](https://en.wikipedia.org/wiki/AMD_K5) | 4,300,000 | 1996 | [AMD](https://en.wikipedia.org/wiki/AMD) | 500 nm | 251 mm² |
| [Pentium II](https://en.wikipedia.org/wiki/Pentium_II) Klamath | 7,500,000 | 1997 | Intel | 350 nm | 195 mm² |
| [Pentium II](https://en.wikipedia.org/wiki/Pentium_II) Deschutes | 7,500,000 | 1998 | Intel | 250 nm | 113 mm² |
| [AMD K6](https://en.wikipedia.org/wiki/AMD_K6) | 8,800,000 | 1997 | AMD | 350 nm | 162 mm² |
| [Pentium III](https://en.wikipedia.org/wiki/Pentium_III) Katmai | 9,500,000 | 1999 | Intel | 250 nm | 128 mm² |
| [Pentium III](https://en.wikipedia.org/wiki/Pentium_III) Coppermine | 21,000,000 | 2000 | Intel | 180 nm | 80 mm² |
| [Pentium II](https://en.wikipedia.org/wiki/Pentium_II) Mobile Dixon | 27,400,000 | 1999 | Intel | 180 nm | 180 mm² |
| [Pentium III](https://en.wikipedia.org/wiki/Pentium_III) Tualatin | 45,000,000 | 2001 | Intel | 130 nm | 81 mm² |
| [AMD K6-III](https://en.wikipedia.org/wiki/AMD_K6-III) | 21,300,000 | 1999 | AMD | 250 nm | 118 mm² |
| [AMD K7](https://en.wikipedia.org/wiki/AMD_K7) | 22,000,000 | 1999 | AMD | 250 nm | 184 mm² |
| [Pentium 4](https://en.wikipedia.org/wiki/Pentium_4) Willamette | 42,000,000 | 2000 | Intel | 180 nm | 217 mm² |
| [Pentium 4](https://en.wikipedia.org/wiki/Pentium_4) Northwood | 55,000,000 | 2002 | Intel | 130 nm | 145 mm² |
| [Pentium 4](https://en.wikipedia.org/wiki/Pentium_4) Prescott | 112,000,000 | 2004 | Intel | 90 nm | 110 mm² |
| [Pentium 4](https://en.wikipedia.org/wiki/Pentium_4) Prescott-2M | 169,000,000 | 2005 | Intel | 90 nm | 143 mm² |
| [Pentium 4](https://en.wikipedia.org/wiki/Pentium_4) Cedar Mill | 184,000,000 | 2006 | Intel | 65 nm | 90 mm² |
| [Pentium D](https://en.wikipedia.org/wiki/Pentium_D) Smithfield | 228,000,000 | 2005 | Intel | 90 nm | 206 mm² |
| [Pentium D](https://en.wikipedia.org/wiki/Pentium_D) Presler | 362,000,000 | 2006 | Intel | 65 nm | 162 mm² |
| [Atom](https://en.wikipedia.org/wiki/Intel_Atom) | 47,000,000 | 2008 | Intel | 45 nm | 24 mm² |
| [Barton](https://en.wikipedia.org/wiki/Athlon#Barton_and_Thorton) | 54,300,000 | 2003 | AMD | 130 nm | 101 mm² |
| [AMD K8](https://en.wikipedia.org/wiki/AMD_K8) | 105,900,000 | 2003 | AMD | 130 nm | 193 mm² |
| [Itanium 2](https://en.wikipedia.org/wiki/Itanium_2) McKinley | 220,000,000 | 2002 | Intel | 180 nm | 421 mm² |
| [Cell](https://en.wikipedia.org/wiki/Cell_(microprocessor)) | 241,000,000 | 2006 | [Sony](https://en.wikipedia.org/wiki/Sony)/[IBM](https://en.wikipedia.org/wiki/IBM)/[Toshiba](https://en.wikipedia.org/wiki/Toshiba) | 90 nm | 221 mm² |
| [Core 2 Duo](https://en.wikipedia.org/wiki/Core_2_Duo) Conroe | 291,000,000 | 2006 | Intel | 65 nm | 143 mm² |
| [Core 2 Duo](https://en.wikipedia.org/wiki/Core_2_Duo) Allendale | 169,000,000 | 2007 | Intel | 65 nm | 111 mm² |
| [Itanium 2](https://en.wikipedia.org/wiki/Itanium_2) Madison 6M | 410,000,000 | 2003 | Intel | 130 nm | 374 mm² |
| [AMD K10](https://en.wikipedia.org/wiki/AMD_K10) quad-core 2M L3 | 463,000,000[[18]](https://en.wikipedia.org/wiki/Transistor_count#cite_note-tomshardware.com-18) | 2007 | AMD | 65 nm | 283 mm² |
| [ARM Cortex-A9](https://en.wikipedia.org/wiki/ARM_architecture) | 26,000,000[[19]](https://en.wikipedia.org/wiki/Transistor_count#cite_note-19) | 2007 | ARM | 45 nm | 31 mm² |
| [Core 2 Duo](https://en.wikipedia.org/wiki/Core_2_Duo) Wolfdale 3M | 230,000,000 | 2008 | Intel | 45 nm | 83 mm² |
| [Itanium 2](https://en.wikipedia.org/wiki/Itanium_2) with 9 [MB](https://en.wikipedia.org/wiki/Mebibyte) cache | 592,000,000 | 2004 | Intel | 130 nm | 432 mm² |
| [Core 2 Duo](https://en.wikipedia.org/wiki/Core_2_Duo) Wolfdale | 411,000,000 | 2007 | Intel | 45 nm | 107 mm² |
| [Core i7](https://en.wikipedia.org/wiki/Core_i7) (Quad) | 731,000,000 | 2008 | Intel | 45 nm | 263 mm² |
| [AMD K10](https://en.wikipedia.org/wiki/AMD_K10) quad-core 6M L3 | 758,000,000[[18]](https://en.wikipedia.org/wiki/Transistor_count#cite_note-tomshardware.com-18) | 2008 | AMD | 45 nm | 258 mm² |
| [POWER6](https://en.wikipedia.org/wiki/POWER6) | 789,000,000 | 2007 | IBM | 65 nm | 341 mm² |
| Six-core [Opteron](https://en.wikipedia.org/wiki/Opteron) 2400 | 904,000,000 | 2009 | AMD | 45 nm | 346 mm² |
| 16-core [SPARC T3](https://en.wikipedia.org/wiki/SPARC_T3) | 1,000,000,000[[20]](https://en.wikipedia.org/wiki/Transistor_count#cite_note-20) | 2010 | [Sun](https://en.wikipedia.org/wiki/Sun_Microsystems)/[Oracle](https://en.wikipedia.org/wiki/Oracle_Corporation) | 40 nm | 377 mm² |
| [Apple A7](https://en.wikipedia.org/wiki/Apple_A7) (dual-core [ARM64](https://en.wikipedia.org/wiki/ARM64) "mobile SoC") | 1,000,000,000 | 2013 | Apple | 28 nm | 102 mm² |
| Quad-core + [GPU](https://en.wikipedia.org/wiki/Graphics_processing_unit) [Core i7](https://en.wikipedia.org/wiki/Sandy_Bridge_(microarchitecture)) | 1,160,000,000 | 2011 | Intel | 32 nm | 216 mm² |
| Six-core [Core i7](https://en.wikipedia.org/wiki/Gulftown_(microprocessor)) (Gulftown) | 1,170,000,000 | 2010 | Intel | 32 nm | 240 mm² |
| 8-core [POWER7](https://en.wikipedia.org/wiki/POWER7) 32M L3 | 1,200,000,000 | 2010 | IBM | 45 nm | 567 mm² |
| 8-core [AMD Bulldozer](https://en.wikipedia.org/wiki/AMD_Bulldozer) | 1,200,000,000[[21]](https://en.wikipedia.org/wiki/Transistor_count#cite_note-anandtech.com-21) | 2012 | AMD | 32 nm | 315 mm² |
| Quad-core + GPU [AMD Trinity](https://en.wikipedia.org/wiki/AMD_Trinity) | 1,303,000,000 | 2012 | AMD | 32 nm | 246 mm² |
| Quad-core [z196](https://en.wikipedia.org/wiki/IBM_z196)[[22]](https://en.wikipedia.org/wiki/Transistor_count#cite_note-22) | 1,400,000,000 | 2010 | IBM | 45 nm | 512 mm² |
| Quad-core + GPU [Core i7 Ivy Bridge](https://en.wikipedia.org/wiki/Ivy_Bridge_(microarchitecture)) | 1,400,000,000 | 2012 | Intel | 22 nm | 160 mm² |
| Quad-core + GPU [Core i7 Haswell](https://en.wikipedia.org/wiki/Haswell_(microarchitecture)) | 1,400,000,000[[23]](https://en.wikipedia.org/wiki/Transistor_count#cite_note-anandtech-23) | 2014 | Intel | 22 nm | 177 mm² |
| Dual-core [Itanium 2](https://en.wikipedia.org/wiki/Itanium_2) | 1,700,000,000[[24]](https://en.wikipedia.org/wiki/Transistor_count#cite_note-24) | 2006 | Intel | 90 nm | 596 mm² |
| Quad-core + GPU GT2 [Core i7 Skylake K](https://en.wikipedia.org/wiki/Skylake_(microarchitecture)) | 1,750,000,000 | 2015 | Intel | 14 nm | 122 mm² |
| Six-core [Core i7 Ivy Bridge E](https://en.wikipedia.org/wiki/Ivy_Bridge_(microarchitecture)) | 1,860,000,000 | 2013 | Intel | 22 nm | 256 mm² |
| Dual-core + GPU Iris [Core i7 Broadwell-U](https://en.wikipedia.org/wiki/Broadwell_(microarchitecture)) | 1,900,000,000[[25]](https://en.wikipedia.org/wiki/Transistor_count#cite_note-techreport-25) | 2015 | Intel | 14 nm | 133 mm² |
| Six-core [Xeon](https://en.wikipedia.org/wiki/Xeon) 7400 | 1,900,000,000 | 2008 | Intel | 45 nm | 503 mm² |
| Quad-core Itanium [Tukwila](https://en.wikipedia.org/wiki/Tukwila_(processor)) | 2,000,000,000[[26]](https://en.wikipedia.org/wiki/Transistor_count#cite_note-26) | 2010 | Intel | 65 nm | 699 mm² |
| [Apple A8](https://en.wikipedia.org/wiki/Apple_A8) (dual-core ARM64 "mobile SoC") | 2,000,000,000 | 2014 | Apple | 20 nm | 89 mm² |
| 8-core [POWER7+](https://en.wikipedia.org/wiki/POWER7#POWER7.2B) 80 MB L3 cache | 2,100,000,000 | 2012 | IBM | 32 nm | 567 mm² |
| Six-core [Core i7](https://en.wikipedia.org/wiki/Sandy_Bridge-E_(microprocessor))/8-core Xeon E5 (Sandy Bridge-E/EP) | 2,270,000,000[[27]](https://en.wikipedia.org/wiki/Transistor_count#cite_note-27) | 2011 | Intel | 32 nm | 434 mm² |
| 8-core [Xeon](https://en.wikipedia.org/wiki/Xeon) [Nehalem-EX](https://en.wikipedia.org/wiki/Beckton_(microprocessor)) | 2,300,000,000[[28]](https://en.wikipedia.org/wiki/Transistor_count#cite_note-28) | 2010 | Intel | 45 nm | 684 mm² |
| 8-core [Core i7 Haswell-E](https://en.wikipedia.org/wiki/Haswell_(microarchitecture)) | 2,600,000,000[[29]](https://en.wikipedia.org/wiki/Transistor_count#cite_note-29) | 2014 | Intel | 22 nm | 355 mm² |
| 10-core [Xeon](https://en.wikipedia.org/wiki/Xeon) [Westmere-EX](https://en.wikipedia.org/wiki/Westmere-EX) | 2,600,000,000 | 2011 | Intel | 32 nm | 512 mm² |
| Six-core [zEC12](https://en.wikipedia.org/wiki/IBM_zEC12_(microprocessor)) | 2,750,000,000 | 2012 | IBM | 32 nm | 597 mm² |
| [Apple A8X](https://en.wikipedia.org/wiki/Apple_A8X) (tri-core ARM64 "mobile SoC") | 3,000,000,000[[30]](https://en.wikipedia.org/wiki/Transistor_count#cite_note-30) | 2014 | Apple | 20 nm | 128 mm² |
| [Qualcomm Snapdragon 835](https://en.wikipedia.org/wiki/Qualcomm_Snapdragon) (octa-core ARM64 "mobile SoC") | 3,000,000,000[[31]](https://en.wikipedia.org/wiki/Transistor_count#cite_note-31)[[32]](https://en.wikipedia.org/wiki/Transistor_count#cite_note-32) | 2016 | [Qualcomm](https://en.wikipedia.org/wiki/Qualcomm) | 10 nm |  |
| 8-core Itanium [Poulson](https://en.wikipedia.org/wiki/Poulson_(processor)) | 3,100,000,000 | 2012 | Intel | 32 nm | 544 mm² |
| 10-core [Core i7 Broadwell-E](https://en.wikipedia.org/wiki/Broadwell_(microarchitecture)#.22Broadwell-E.22_.2814_nm.29) | 3,200,000,000[[33]](https://en.wikipedia.org/wiki/Transistor_count#cite_note-33) | 2016 | Intel | 14 nm | 246 mm²[[34]](https://en.wikipedia.org/wiki/Transistor_count#cite_note-34) |
| [Apple A10](https://en.wikipedia.org/wiki/Apple_A10) (quad-core ARM64 "mobile SoC") | 3,300,000,000 | 2016 | Apple | 16 nm | 125 mm² |
| [IBM z13](https://en.wikipedia.org/wiki/IBM_z13_(microprocessor)) | 3,990,000,000 | 2015 | IBM | 22 nm | 678 mm² |
| 12-core [POWER8](https://en.wikipedia.org/wiki/POWER8) | 4,200,000,000 | 2013 | IBM | 22 nm | 650 mm² |
| 15-core Xeon Ivy Bridge-EX | 4,310,000,000[[35]](https://en.wikipedia.org/wiki/Transistor_count#cite_note-35) | 2014 | Intel | 22 nm | 541 mm² |
| 8-core [Ryzen](https://en.wikipedia.org/wiki/Zen_(microarchitecture)) | 4,800,000,000[[36]](https://en.wikipedia.org/wiki/Transistor_count#cite_note-Anand_zen_announcement-36) | 2017 | AMD | 14 nm | 192 mm² |
| 61-core [Xeon Phi](https://en.wikipedia.org/wiki/Xeon_Phi) | 5,000,000,000[[37]](https://en.wikipedia.org/wiki/Transistor_count#cite_note-37) | 2012 | Intel | 22 nm | 720 mm² |
| [Xbox One](https://en.wikipedia.org/wiki/Xbox_One) main SoC | 5,000,000,000 | 2013 | [Microsoft](https://en.wikipedia.org/wiki/Microsoft)/AMD | 28 nm | 363 mm² |
| 18-core [Xeon Haswell-E5](https://en.wikipedia.org/wiki/Haswell_(microarchitecture)) | 5,560,000,000[[38]](https://en.wikipedia.org/wiki/Transistor_count#cite_note-pcper-38) | 2014 | Intel | 22 nm | 661 mm² |
| [Xbox One X (Project Scorpio)](https://en.wikipedia.org/wiki/Xbox_One) main SoC | 7,000,000,000[[39]](https://en.wikipedia.org/wiki/Transistor_count#cite_note-:0-39) | 2017 | Microsoft/AMD | 16 nm | 360 mm²[[39]](https://en.wikipedia.org/wiki/Transistor_count#cite_note-:0-39) |
| [IBM z13 Storage Controller](https://en.wikipedia.org/wiki/IBM_z13_(microprocessor)#Storage_Controller) | 7,100,000,000 | 2015 | IBM | 22 nm | 678 mm² |
| 22-core [Xeon Broadwell-E5](https://en.wikipedia.org/wiki/Broadwell_(microarchitecture)) | 7,200,000,000[[40]](https://en.wikipedia.org/wiki/Transistor_count#cite_note-40) | 2016 | Intel | 14 nm | 456 mm² |
| 32-core [SPARC](https://en.wikipedia.org/wiki/SPARC) M7 | 10,000,000,000[[41]](https://en.wikipedia.org/wiki/Transistor_count#cite_note-41) | 2015 | Oracle | 20 nm |  |
| 32-core AMD Epyc | 19,200,000,000 | 2017 | AMD | 14 nm | 4 x 192 mm2 |

(f) In your opinion, why are people discussing whether Moore’s law is dead or not. (any reasonable answer)

2. Use perf and time tool to profile program execution. Run all experiments on one of the school linux machines. download the whetstone http://www.netlib.org/benchmark/whetstone.c benchmark to your home directory. compile whetstone. You may need to explicitly specify the math lib folder and link to it, e.g., gcc -o whetstone whetstone.c -lm #link the math with -lm

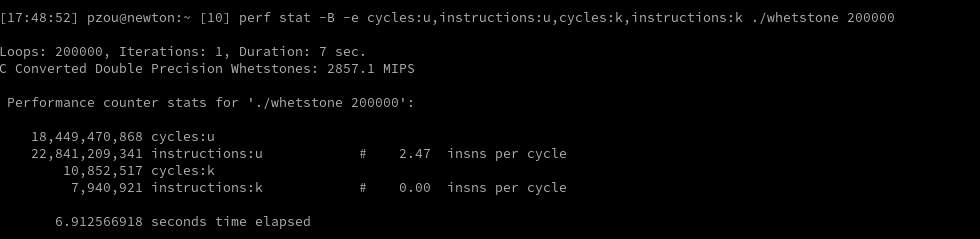
(20 points each of the following subquestions)

1) use perf to profile the execution of whetstone. For information about perf usage, type command

perf

you will see the commands that perf supports. You are encouraged to find online articles on perf and read them.

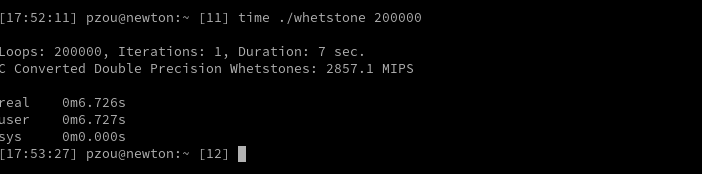
In this assignment, use perf to find out the number of instructions and cycles of whetstone that loops 200,000 times, and separate each count into user space and kernel space. Paste the screen shot of each output in your submission document. (-5 points if only displaying overall counts as opposed to user and kernel counts, -5 points if displaying counts for only instructions or only cycles as opposed to displaying both counts)



2) Use utility time to profile the execution of whetstone that loops 200,000 times

time ./whetstone 200000

Explain the timing output and the definitions. If the timings from perf and time are different, explain the cause.



There is no significant different between the timing from perf and time. The slight difference could be caused by the tools overhead.

* **Real** is wall clock time - time from start to finish of the call. This is all elapsed time including time slices used by other processes and time the process spends blocked (for example if it is waiting for I/O to complete).
* **User** is the amount of CPU time spent in user-mode code (outside the kernel) within the process. This is only actual CPU time used in executing the process. Other processes and time the process spends blocked do not count towards this figure.
* **Sys** is the amount of CPU time spent in the kernel within the process. This means executing CPU time spent in system calls within the kernel, as opposed to library code, which is still running in user-space. Like 'user', this is only CPU time used by the process. See below for a brief description of kernel mode (also known as 'supervisor' mode) and the system call mechanism.

Here the output sys is 0.000 but that does not mean the it spends no time in system calls within the kernel, only because it is very small, the time tool rounds it to 0.000.