Effective Moore's Laws in High Performance Computing Based on Gordon Bell Prize Winners

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Abstract: Moore's law is surprisingly accurate in predicting the overall development speed of integrated circuits. But in high performance computing, the development speed is more than the prediction. In this report, I am going to introduce two effective Moore's Laws for peak performance and price/performance in high performance computing.

1 Moore' Law

Gordon Moore made his famous observation, the so called "Moore's Law" in 1965[1]. In his original paper, Moore predicted that the number of transistors per integrated circuit would double every year and the speed would double every 18 months. He forecast that this trend would continue through 1975. Actually after nearly forty years, this prediction is still surprisingly accurate. People have extended Moore's Law to many fields to predict the development trend, such as Internet bandwidth.

Although Moore's Law is accurate for the overall development, people see faster development in high performance computing. We want an effective Moore's Law for the high performance computing. In this report, we use the performance of Gordon Bell Prize winners as the reprehensive of each year's development in high performance computing to summarize the effective laws. We also compare the effective law based on top500 list.

2 Gordon Bell Prize[2]

The Gordon Bell Prizes are awarded each year since 1983 to recognize outstanding achievement in high-performance computing. The $5000 prize money is donated by Gordon Bell, pioneer in high-performance and parallel computing who is also the principle investigator of successful VAX series. Prizes are awarded in three categories:

1. ***Peak Performance:*** The prize in the peak performance category is given to the entry demonstrating the highest performance achieved in terms of operations per second on a genuine application program.
2. ***Price/Performance:*** The prize in the price/performance category is given to the entry demonstrating the best price-performance ratio as measured in megaflop/s per dollar on a genuine application.
3. ***Special:*** The prize in the special category may be given to an entry whose performance is short of that of the Peak Performance prize, which nevertheless utilizes innovative techniques to produce new levels of performance on a real application. Such techniques may be, for instance, in mathematical algorithms, data structures, or implementations.

Depending on the entries received, in some years no prize may be awarded in a given category. Because of the interest of this report, I only choose the winners in the first two categories.

3 Effective Law for Achievable Peak Performance

A purpose of the award is to track the progress over time of parallel computing in applications. Since the peak performance requires real application instead of a benchmark of some kernels, it would a more reasonable criteria to pick the most powerful machine of each year. So we choose Gordon Bell Prize as the representitive of development in high performance computing. Figure 1 shows the peak performance reported as the winning performance each year. Based on these data, we summarize the first effective Moore's Law as :

The achievable processing power of high performance computers increases 1.6 times every year or the processing power doubles every 15 months.

On the other hand, the top 500 list[1] uses LINPACK to rank the machines . We might wonder how good these two standards be consistent over the years. From Table 1 in Appendix A, we can see it is not always true that peak performance achieved on the most powerful machine in top500 list. ASCI White has been No.1 in top500 list for two years. It seems there is still no real application can achieve one-third of its Linpack score(7226GFlops).

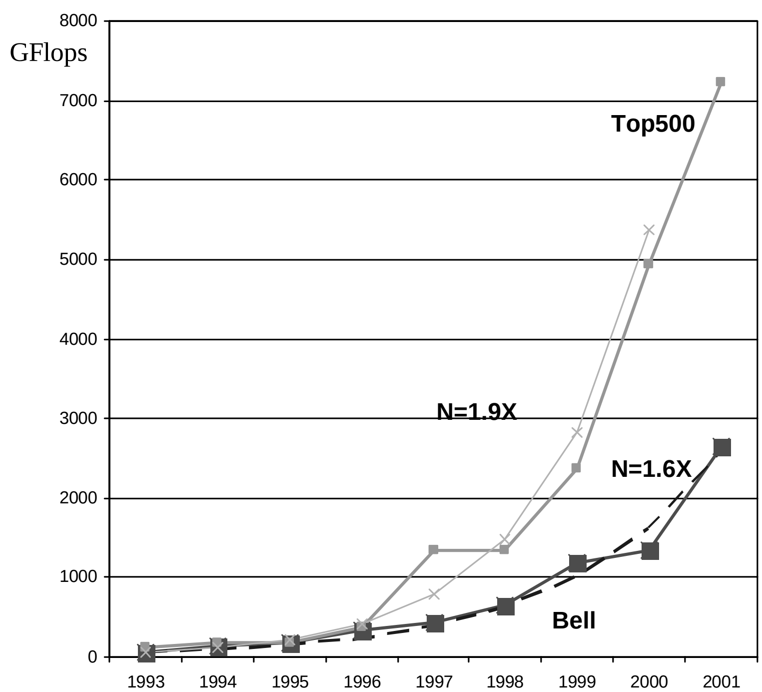

Figure 1 Comparison of Peak Performance between Bell Prize Winners and Top Machine in Top500 List

Figure1 shows the Rmax of the top machine in Top500 list increases by 1.9 times over the previous year. With this speed, the gap between these two peaks will increase in the future, which can be explained by the fact that the most powerful machines consists

[1] There are two lists each year, here we only use the November's lists

thousands processors and it is difficult to a real application to use them efficiently. I also doubt the Bell Prize winner will kept this speed in the future on general purpose computers. Since people rely on increasing the number of processors to achieve better peroformance and the interconnection becomes more and more critical, it will be more difficult to efficiently use those MPP machines.

3. Effective Law for Price/Performance

It's very interesting that Gordon Bell prize includes a category for the best price/performance achieved in a year. From Figure 2, one can see how significantly the price for one 1MFlops drops. If we just compare the absolute number, the price for 1MFlops dropped from $2000 in 1989 to 92 cents in 2000.

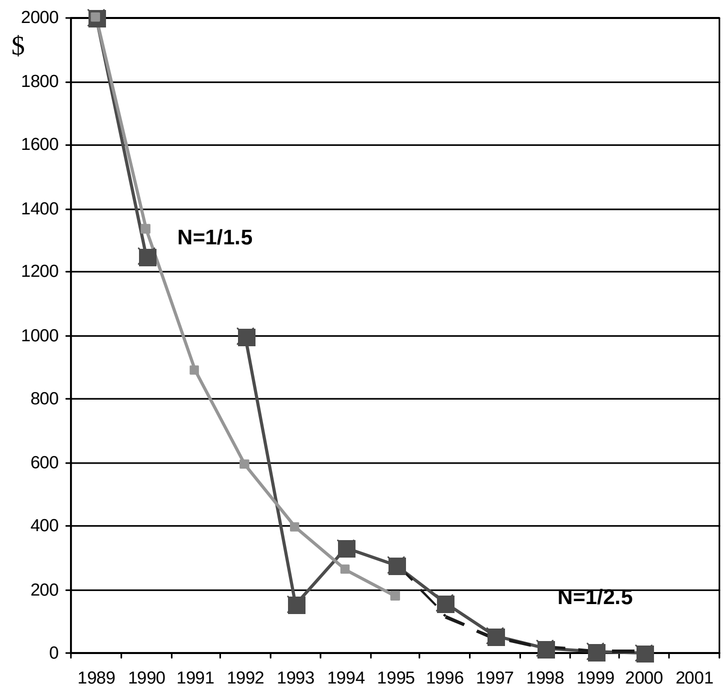

Figure 2 Price for one MFlops

Based on these data, we can come up with a law to summarize the trend of price/performance:

The price for processing power drops 2.5 times every year or the price for processing power halves every 10 months

I believe this speed should continue, or be more significant because of price for powerful commodity processors drops quickly and users will pay less for software because of open source software. Appendix A gives the list of winners in Best price/performance category.

4. Conclusion

In this report, we summarize two effective Moore's laws to predict the achievable peak performance and price for high performance computers: The achievable performance doubles every 15 months and the price halves every 10 months. I believe the trend for price will continue in the future, while the achievable performance may not keep up with this speed, especially on general purpose supercomputers.

Reference:

[1] Cramming More Components onto Integrated Circuits, Gordon Moore, Electronics April 1965
[2] http://www.sc2000.org/bell/
[3] top500 list archive http://www.top500.org/Main/Archive.php3
[4] SC2001 Proceedings
[5] Multi-teraflops Spin Dynamics Studies of the Magnetic Structure of FeMn/Co Interfaces, A. Canning, B.Ujfalussy. et.al 2001 Supercomputing Proceedings.

Appendix A: Winners of Peak Performance

Year	Machine	Application	Performance	Position in Top500
1988	Cray-YMP	Static Finite Element Analysis	1GFlops	N/A
1989	CM-2	Seismic Data Processing	6GFlops	N/A
1990*	CM-2	Seismic Data Processing	14GFlops	N/A
1992	Intel TouchStone Delta	Simulation of nBody	5GFlops	N/A
1993	CM-5/1024PE	Modeling a Shock Front	60GFlops	1
1994	Intel Paragon/1904PE	Structural Mechanics Modeling	140GFlops	1
1995	Fujistu Numerical Wind Tunnel/128PE	Quantum Chromo dynamics Simulation	179GFlops	1
1996	Numerical Wind Tunnel/166PE	Fluid Dynamics	111GFlops	2
1996*	Grape-4/1269PE	Simulation of nBody	333GFlops	
1997	ASCI Red/4096PE	Simulation of nBody	430GFlops	1
1998	Cray T3E/1024PE	Non-collinear magnetic arrangements	657GFlops	2
1999	Blue Pacific	Simulation of Fluid Turbulence	1.18TFlops peak 1.04TFlops sustained	2
2000**	Grape-6	Simulation of Molecular Dynamics	1.34TFlops	N/A
2001[2]	IBM 16way SP/3328PE	Simulation of magnetic structure	2.64TFlops	3

* Honorable mention, not Bell Prize winner
**Tie with another special purpose machine.

[2] I don't have the official 2001 Peak Performance winner. I was told by Allan Snavely that NERSC won this year's Bell Prize. The data is based on NERSC's paper[5]

Appendix B: Winners of Best Price/Performance

1989 500MF for 1M$ on CM-2
1990 800MF for 1M$ on Intel iPSC/860
1992 1GF for 1M$ on a distributed heterogeneous machines
1993 6.5GF for 1M$ on a custom-built machine called SNAP
1994 3GF for 1M$ on a cluster of eight HP workstations
1995 3.6GF for 1M$ on 20HP workstations
1996 6.4GF for 1M$ on an SGI power challenge with 6 MIPSR8000 processors
1997 10.8GF for 1M$ on 28 DEC Alpha machines
18GF for 1M$ on cluster of 16 PentiumPro 200MHz
1998 79.7G for 1M$ custom system with 2048PE TI chips(32bit Fops)
64.9GF for 1M$ on 70PE DEC
1999 144GF for 1M$ on custom built Grape 5 32 processor
2000 92Cents/MFlops on a custom built PIII cluster