Scaling through more cores

From single to multi core

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Scaling with single core until 2005

Moore's law	–	Transistors are doubled every 12 to 24 month
Smaller structures	–	New manufacturing technologies
Higher frequencies	–	Smaller structures need less power

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Problems and barriers: Problems

Higher frequencies	–	Needed for more computing power
Higher voltage	–	Needed for higher frequencies
Heat production	–	High frequencies and high voltage result in higher power consumption and dissipation (waste heat)

Problems and barriers: Barriers

Power consumption	–	Frequency and voltage directly influence the consumption: $P = a * C * V^2 * f$
Hot spots	–	Smaller structures result in smaller hot spots, that are more difficult to cool
Critical Point 2004	–	Pentium 4 with ~4 Ghz (air cooled) marked the line for the next years

Note: P = power(Watts), V = voltage(Volts), f = frequency(cycles/sec), C = capacitance(Farads), a = Coulombs/Volt

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Solution through more cores

Since 2006	–	Intel accepted the end of single cores and introduced the first Dual Cores with 1.5 to 2.33 Ghz
More Cores and HT	–	Intel combined more cores on one DIE with smaller structures and a customized architecture and later additionally the cheaper Hyper Threading
Heat production	–	Lower work load per core reduces the power consumption and heat production in total

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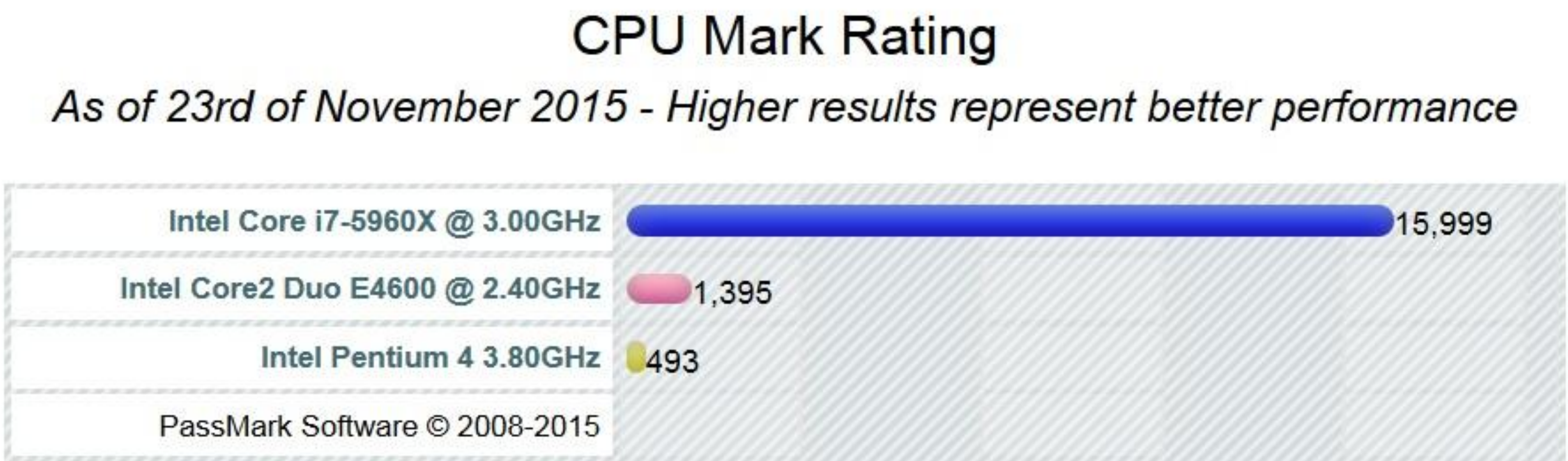
6. Conclusion

Current standard

Consumer PC	–	2 to 8 cores with a total of 16 threads
Handheld	–	2 to 8 cores
HPC in the Top 500	–	From thousands up to 3.12 million cores

Current standard



Graphic 1, s. Attachment

First multi cores	–	In comparison to Pentium 4 the Core2 Duo processor is ~2.8 times faster
Multi cores today	–	In comparison to Pentium 4 one of the newest processors with 8 cores and 16 threads is ~32.5 times faster

Current standard

	Intel Pentium 4 3.80GHz	Intel Core2 Duo E4600 @ 2.40GHz	Intel Core i7-5960X @ 3.00GHz
Socket Type	NA[2]	LGA775	LGA2011-v3
CPU Class	Desktop	Desktop	Desktop
Clockspeed	3.8 GHz	2.4 GHz	3.0 GHz
Turbo Speed	Not Supported	Not Supported	Up to 3.5 GHz
# of Physical Cores	1 (2 logical cores per physical)	2	8 (2 logical cores per physical)
Max TDP	65W	65W	140W
First Seen on Chart	Q4 2008	Q4 2008	Q2 2014
# of Samples	52	406	371
Single Thread Rating	824[3]	888	1993
CPU Mark	**493**	**1395**	**15999**

[1] - *Last seen price from our affiliates* ***NewEgg.com*** *&* ***Amazon.com****.*

[2] - *Information not available. Do you know?* ***Notify Us****.*

[3] - *Single thread rating may be higher than the overall rating, thread performance is just one* ***component*** *of the CPU Mark.*

Graphic 2, s. Attachment

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Multi core usage

Consumer/Handheld	–	Only a few programs that use more than 2 cores, especially games or graphic programs
HPC usage	–	Programs are limited by hardware – open potential!
Parallelization	–	The hardware power needs a optimized parallelization to achieve its full potential
Potential limited	–	Amdahl’s law shows the limits

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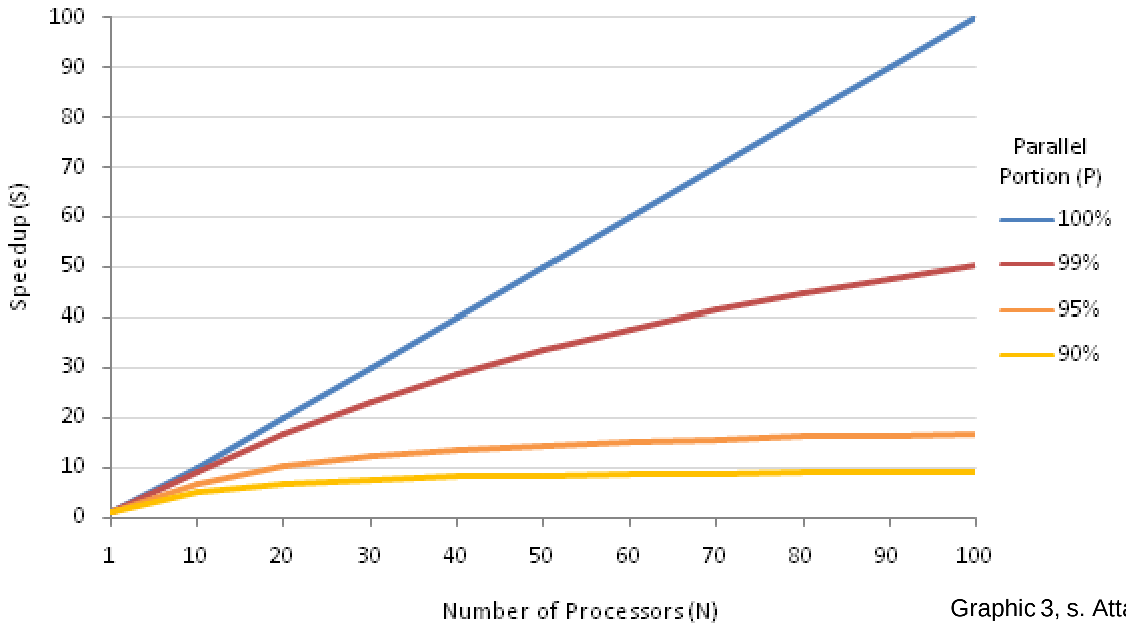
Amdahl's law

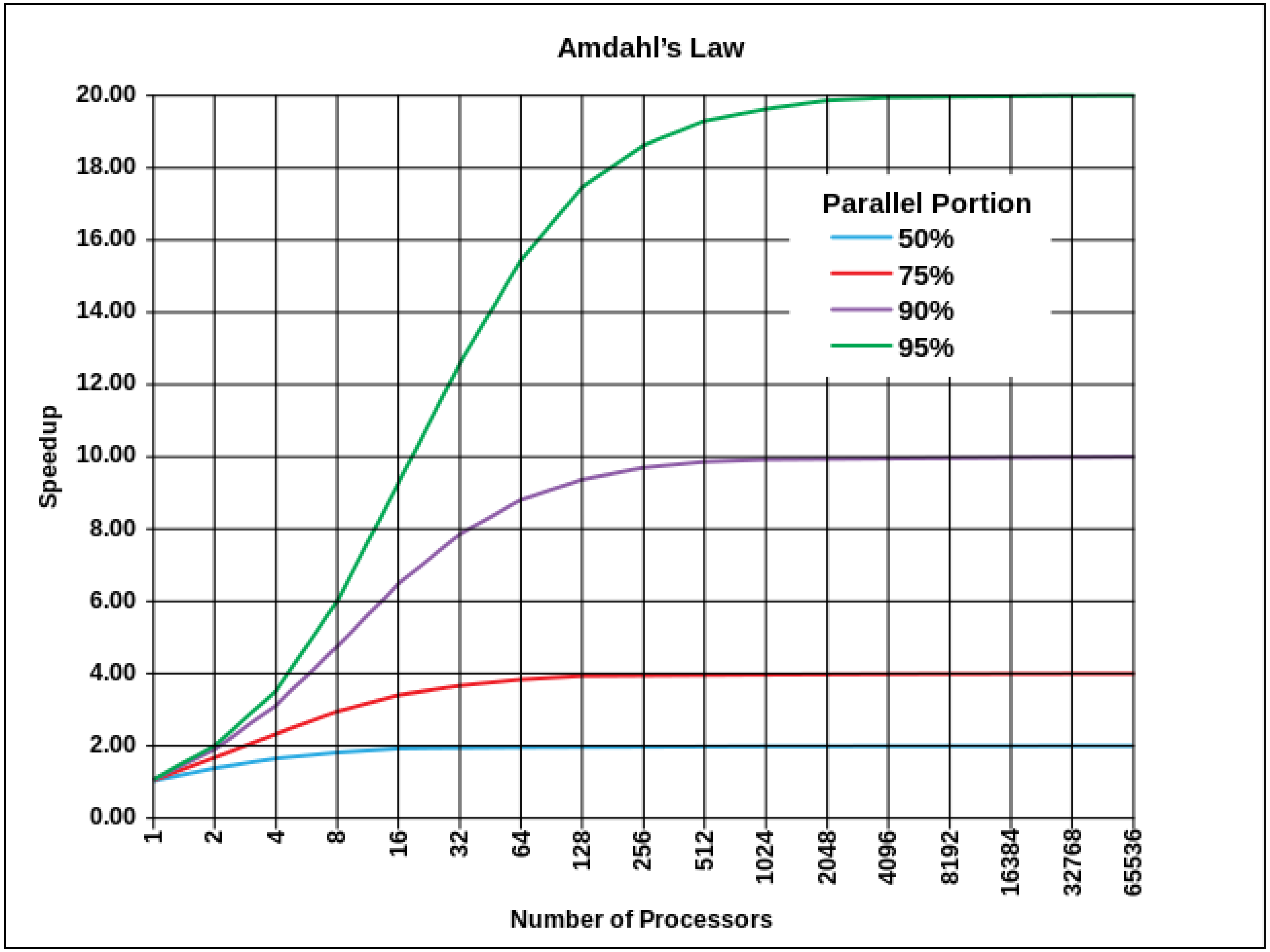


Graphic 3, s. Attachment

Amdahl's law $$\eta_S = \frac{T}{t_S + t_{O(n_P)} + \frac{t_P}{n_P}} \leq \frac{T}{T - t_P}$$

Note: *ns* = speedup, T = running time(RT), ts = serial RT, tp = parallel RT, np = cores, to(np) = synchron time

Amdahl's law



Graphic 4, s. Attachment

Amdahl’s law

Parallelization	–	Not every problem can be solved parallel if it is not possible to split it up and compute the problems separately
Time problem	–	A program running time can never be reduced below its serial components runtime
Tianhe-2	–	With 3.12 Million cores the computing power with >33 PFLOPS has a huge potential, but nearly no program can use it at once

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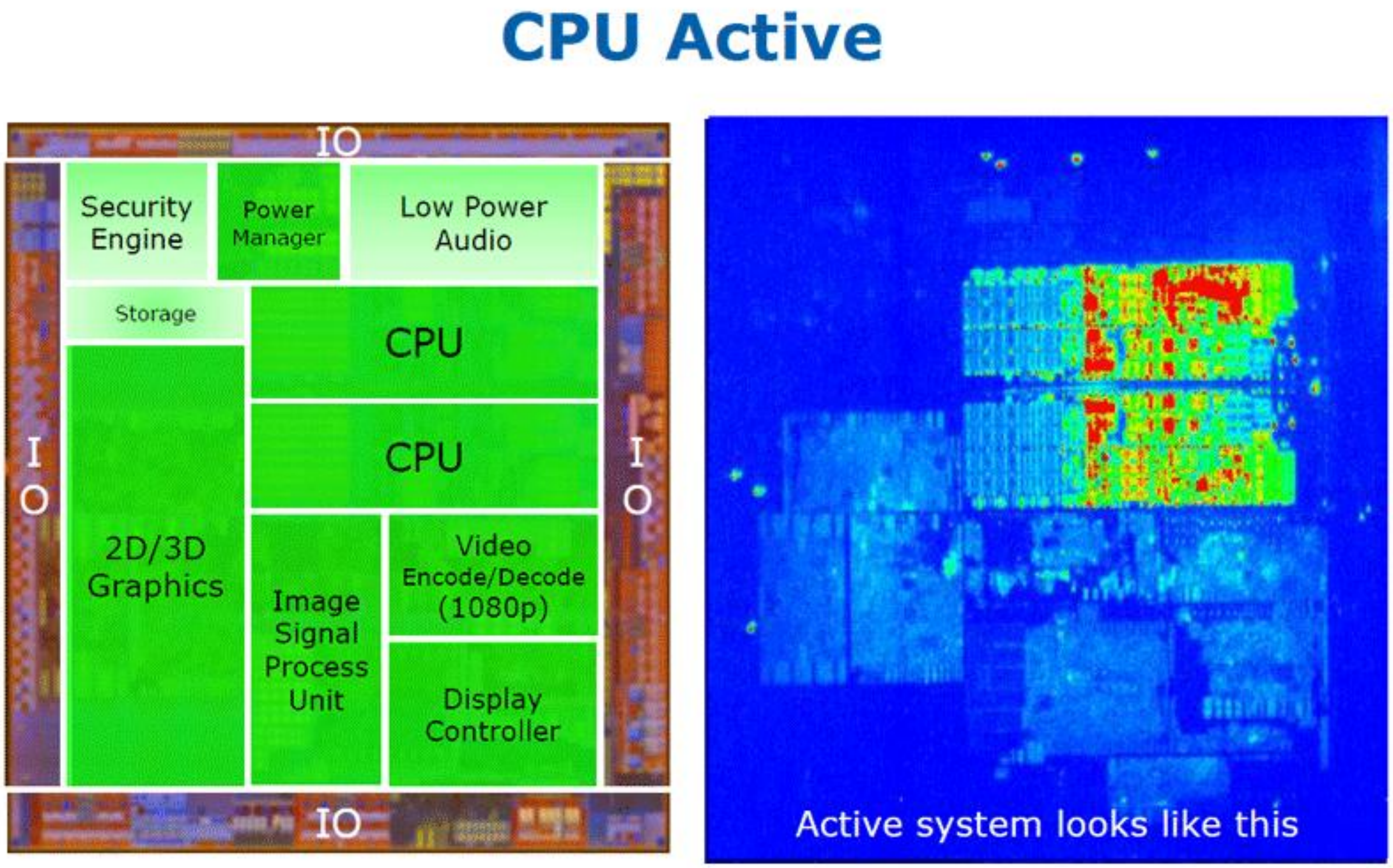
Hot spots

Small structures	–	Hot spots get more intense the smaller the structures get
High frequencies	–	Also multi cores have the weakness when one core clocks higher, that one small point gets hot
Hot Spot cooling	–	High temperatures in small areas are still hard to cool and the different cooling methods limit the possible waste heat

Hot spots



Graphic 5, s. Attachment

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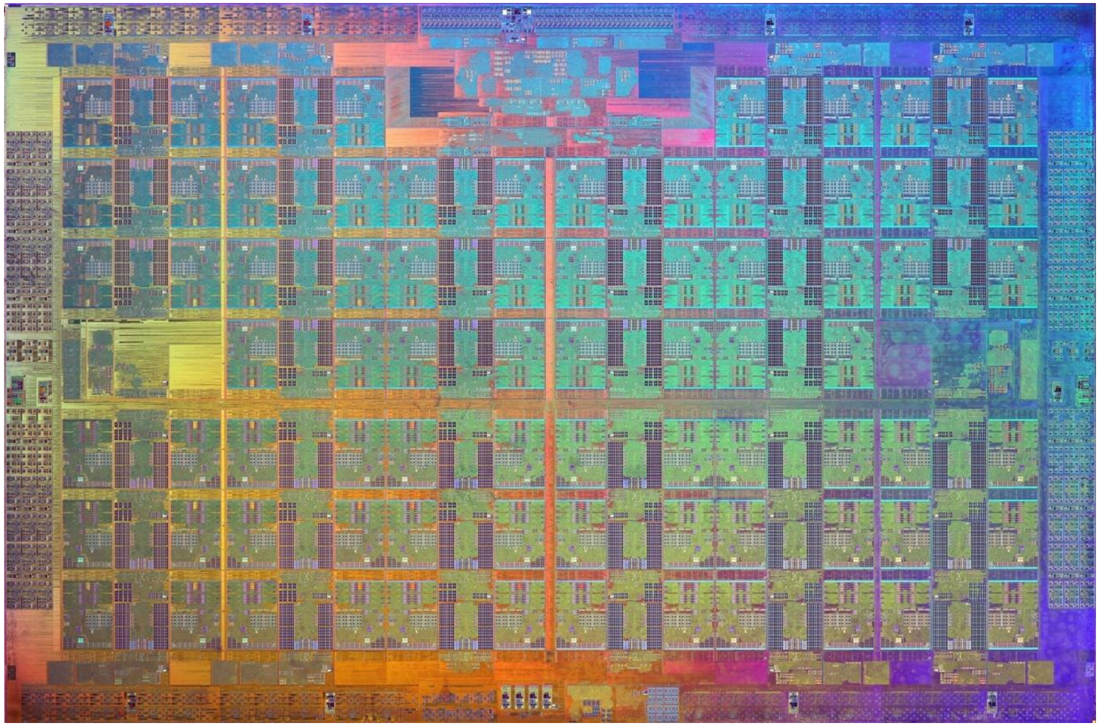
DIE size

Limited space on DIE	–	Space needed for the CPU, cache, register and today often the GPU
Smaller structures	–	More space for more technology but smaller hot spots
Knights Landing	–	Even with very low frequencies the heat generation will explode with too many cores (Up to 72(76) cores with a TDP of 200W)

DIE size: Intel Xeon PHI – Knights Landing



Graphic 6, s. Attachment

DIE size – 700 mm² produced with 14 nm Lithography

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Fabrication and approaches for new technologies

New architectures	–	Reprogrammable simple CPU parts for daily tasks to use the main CPU part on DIE for one special task
New cooling materials	–	Directly distributed between the components like a viscous mass to spread the heat

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New materials for higher frequencies

Semiconductor materials – Possible successor of silicon could be indium, germanium and gallium arsenide

Reduced voltage – This alternative materials can run at 0.5V while silicon needs a voltage around 1.1V

Higher frequencies – Reduced voltage requirement leads to higher frequencies to use the full potential

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Conclusion

Problems and barriers	–	Power consumption always exists and needs permanent optimization through new technologies
Parallelization	–	Developer have to learn to program and optimize their software for parallelization
New pathes	–	Specialized Hardware with its own software and code is a possible way for more speed

Sources

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