Intel Core X-series (HED lines)

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Note

In this Chapter we use the designations processor line and processor series as synonyms.

We note that models of the X-Series carry different tags, like

- (EE) Extreme Edition
- X (Extreme)
- K (Unlocked)

Typically we intend to use the designations xxx E-Series and xxx-E processor models.

1. Introduction

1. Introduction

The X-Series processor models (E-lines) aim at high performance desktops for hardcore gamers and graphics enthusiasts.

They serve as HEDs (High End Desktops) termed also as HEDTs.

1. Introduction (2)

Hardcore gamer scenario [37]

1. Introduction -2

Key features of Intel's X-Series (E-lines/X-lines):

- They provide vs. mainstream desktops typically
  - more cores to utilize more parallelism available in their workloads
  - more PCIe lanes (either on the PCH or on the die) to allow to attach up to 4 discrete graphics cards)
  - more memory channels (to appropriately service more processing resources)
- they are unlocked, nevertheless
- they do not provide integrated graphics, as it is assumed that the installation is intended to provide high quality graphics by attaching multiple discrete graphics cards and
- they have a high power consumption of 130 to 165 W.

1. Introduction (4)

Subsequent generations of Intel's Core family

1. gen.		X-Series		2. gen.	3. gen.	4. gen.	5. gen.
Core 2 New Microarch. 65 nm	Penryn New Process 45 nm	Nehalem New Microarch. 45 nm	West-mere New Process 32 nm	Sandy Bridge New Microarch. 32 nm	Ivy Bridge New Process 22 nm	Haswell New Microarchi. 22 nm	Broad-well New Process 14 nm
TOCK	***TICK***	***TOCK***	***TICK***	***TOCK***	***TICK***	***TOCK***	***TICK***
(2006)	*(2007)*	*(2008)*	*(2010)*	*(2011)*	*(2012)*	*(2013)*	*(2014)*

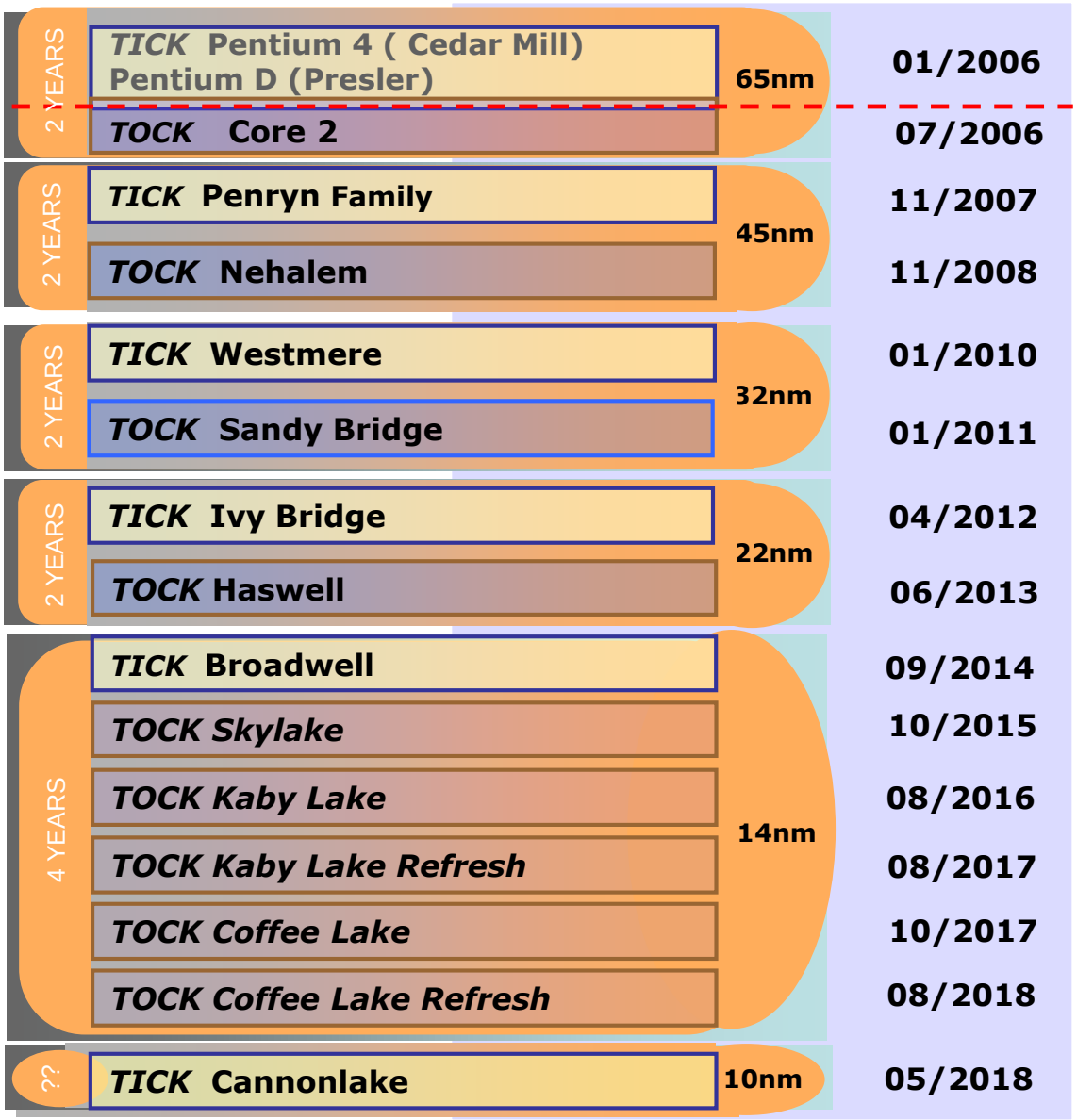
6. gen.	7. gen.	8. gen.[1]	9. gen.
Skylake New Microarch. 14 nm	Kaby Lake New Microarch. 14 nm	Kaby Lake R/G Coffee Lake Cannon Lake 14/10 nm	Coffee Lake R New Mocroarch. 14 nm
TOCK	***TOCK***	***TOCK***	***TOCK***
(2015)	*(2016)*	*(2017/18)*	*(2018)*

[1]Astonishingly, the 8th generation encompasses four processor lines, as follows:

- Kaby Lake Refresh
- Kaby Lake G with AMD Vega graphics
- Coffee Lake and
- 10 nm Cannon Lake designs [218].

R: Refresh

Key new features introduced in Intel's subsequent generations of the Core family -1

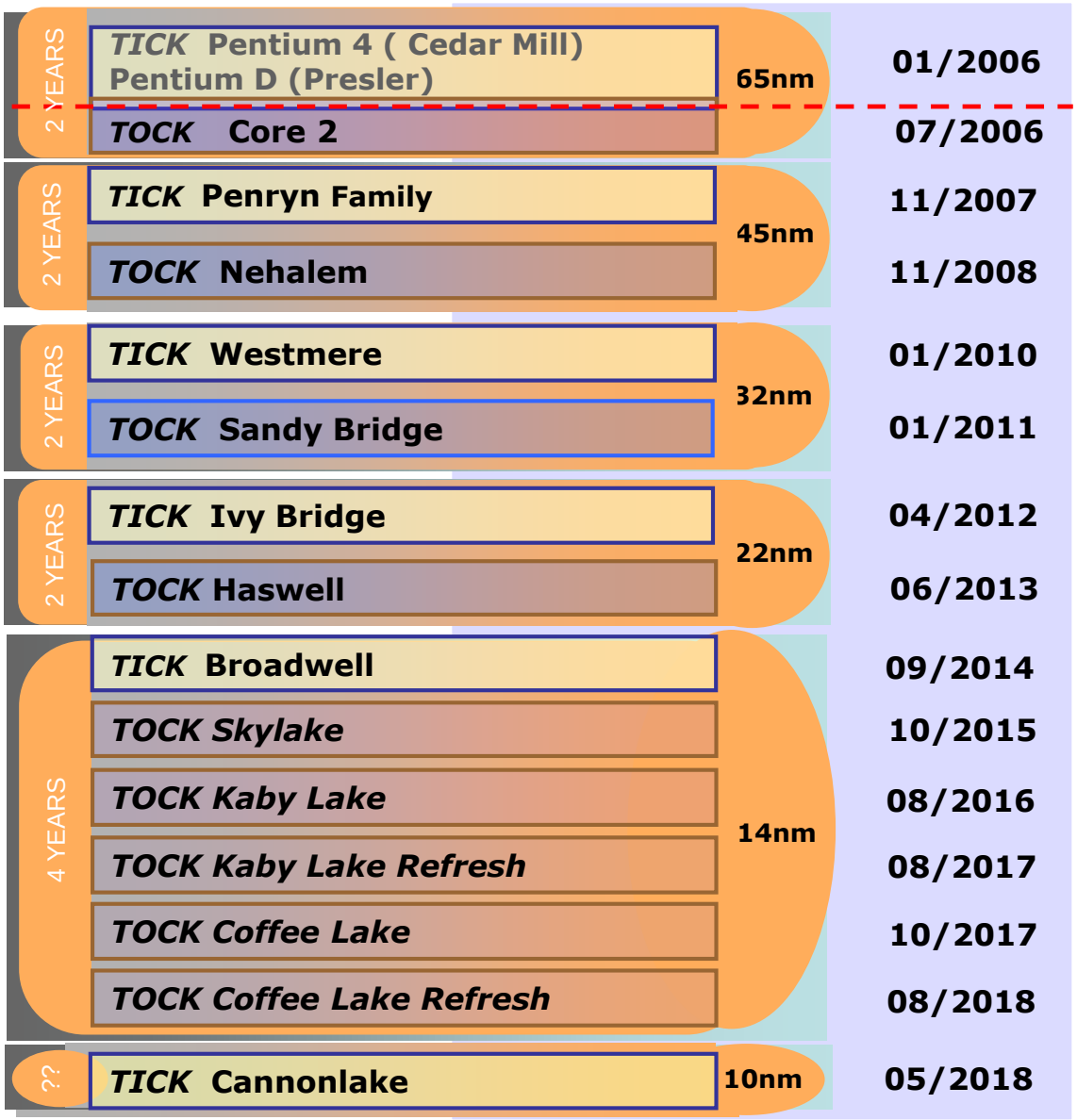


Key new features of the ISA and the microarchitecture

- New microarch.: 4-wide core, 128-bit SIMD FX/FP EUs, shared L2 , no HT
- New microarch.: 4 cores, integr. MC, QPI, private L2, (inclusive) L3, HT
- In package integrated GPU
- New microarch.: 256-bit (FP) AVX, ring bus, integrated GPU
- New microarch.: 256-bit (FX) AVX2, L4 cache (discrete eDRAM), TSX
- Shared Virtual Memory
- New microarch.: 5-wide core, ISP, Memory Side L4 cache, no FIVR
- Optane memory, in KBL G Series: in package integr. CPU, GPU, HBM2
- 6C, (PCHs of S-Series DTs support: USB G2, integr. conn., Optane 2)
- 8C
- AVX512

1. Introduction (6)

Key new features introduced in Intel's subsequent generations of the Core family -2



Key new features of the power management

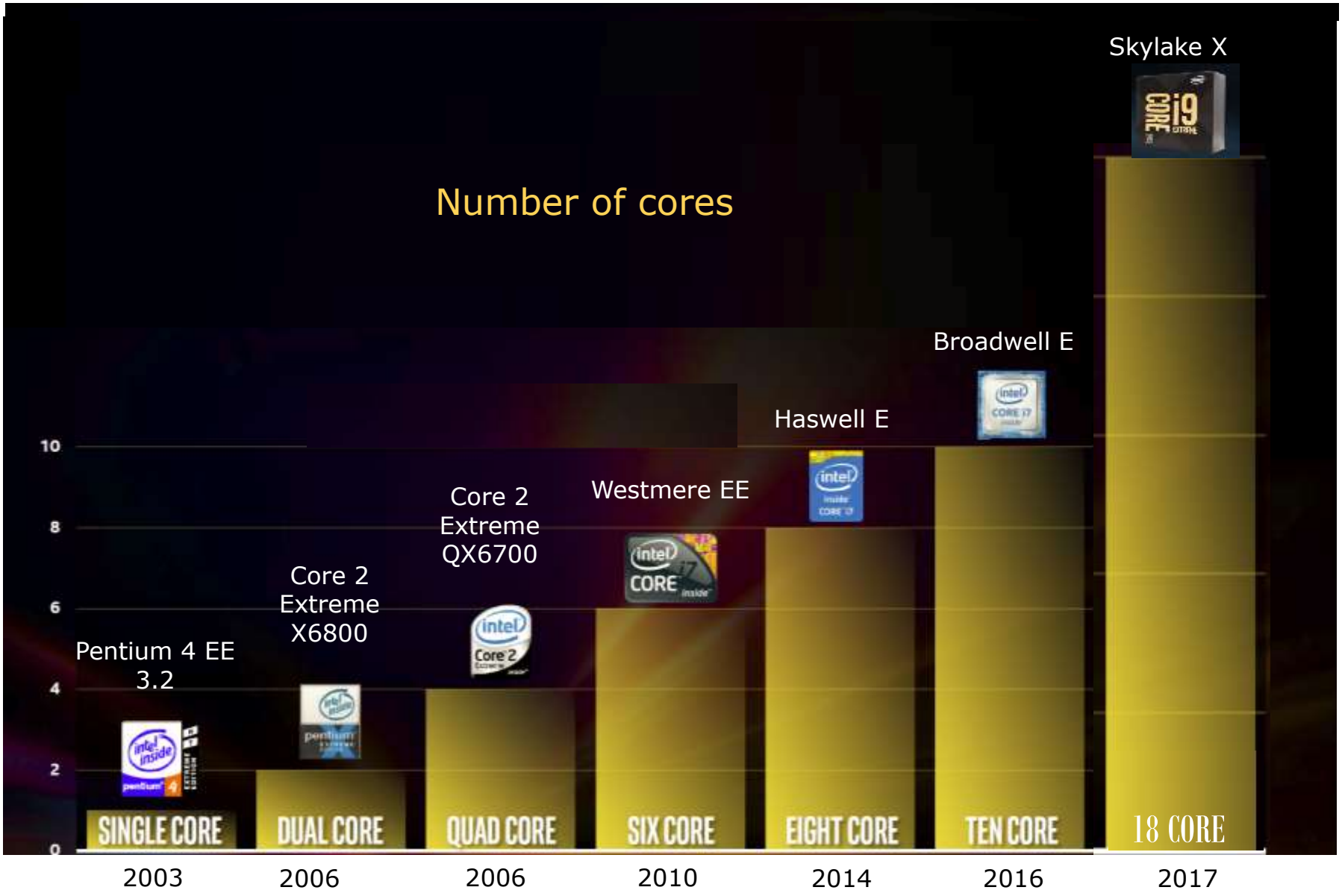
- Clock gating, PECI, Platform Thermal Control by 3. party controller
- EDAT
- Integrated Power Gates, PCU, Turbo Boost
- Turbo Boost 2.0
- FIVR
- 2. gen. FIVR
- Speed Shift Technology, Duty Cycle control, No FIVR except Skylake X
- Speed Shift Technology v2
- In H-Series: TVB (Thermal Velocity Boost)
- STIM

1. Introduction (7)

Intel's Core based X-Series (called differently, as EE-lines (Extreme Edition), E-lines X-lines, HED-lines or HEDT-lines)

Processors	Techn.	Date of intro.	Max. no. of cores	No. of mem. channels	Highest mem./ speed	PCIe lanes	PCH	Processor socket	TDP (Up to)
1. G. Nehalem EE	45 nm	11/2008	4C	3	DDR3-1067	36 PCIe 2.0 on the X58	X58 (Tylersburg)	LGA 1366	130 W
Westmere-EE	32 nm	3/2010	6C	3				LGA 1366	130 W
Sandy Bridge-E	32 nm	11/2011	6C	4	DDR3-1600	40 PCIe 2.0 on the die	X79 (Patsburg)	LGA 2011	150 W
Ivy Bridge-E	22 nm	9/2013	6C	4	DDR3-1866	40 PCIe 3.0 on the die		LGA 2011	130 W
Haswell-E	14 nm	8/2014	8C	4	DDR4-2133		X99 (Wellsburg)	LGA 2011-3	140 W
Broadwell-E	14 nm	5/2016	10C	4	DDR4-2400		X99 (Wellsburg)	LGA_2011-3	140 W
Skylake-X	14 nm	6/2017	18C	4	DDR4-2666	44 PCI-3.0 on the die	X299 (Basin Falls)	LGA-2066	165 W
Kaby Lake-X	14 nm	6/2017	4C	4	DDR4-2666	16 PCI-3.0 on the die	X299 (Basin Falls)	LGA-2066	112 W
Skylake-X Refresh	14 nm	10/2018	18C	4	DDR4-2666	44 PCI-3.0 on the die	X299 (Basin Falls)	LGA-2066	165 W

Evolution of the core counts in Intel's HED lines (Based on [29])



1. Introduction (9)

Overview of Intel's X-Series models up to the Broadwell-E line [Based on 19]

		Nehalem EE (130W)	Westmere EE (130W)	Sandy Bridge-E (130W)	Ivy Bridge-E (130W)	Haswell-E (140W)	Broadwell-E (140 W)
Four cores	<3.0 GHz						
	3.2 GHz	i7-965 EE					
	3.3 GHz	i7-975 EE					
	3.6 GHz			i7-3820			
	3.7 GHz				i7-4820K		
Six cores	3.2 GHz			i7-3930K			
	3.3 GHz		i7-980X	i7-3960X EE		i7-5820K	
	3.4 GHz				i7-4930K		i7_6800K
	3.5 GHz		i7-990X EE	i7-3970X EE (150W)		Ii7-5930K	
	3.6 GHz				i7-4960X EE		i7-6850K
Eight cores	3.0 GHz					i7-5960X EE	
	3.2 GHz						i7-/6900K
Ten cores	3.0 GHz						i7-6950X

Main features of the Nehalem EE and Westmere EE processor models [20]

Processor Number	i7-975 EE	i7-965 EE	i7-990X EE	i7-980X
Core type	Nehalem (Bloomfield)	Nehalem (Bloomfield)	Westmere (Gulftown)	Westmere (Gulftown)
Launch Date	Q2'09	Q4'08	Q1'11	Q1'10
Lithography	45 nm	45 nm	32 nm	32 nm
# of Cores	4	4	6	6
# of Threads	8	8	12	12
Processor Base Frequency	3.33 GHz	3.2 GHz	3.46 GHz	3.33 GHz
Max Turbo Frequency	3.6 GHz	3.46 GHz	3.73 GHz	3.6 GHz
Cache	8 MB	8 MB	12 MB	12 MB
System Bus	QPI	QPI	QPI	QPI
Bus Speed	6.4 GT/s	6.4 GT/s	6.4 GT/s	6.4 GT/s
# of QPI Links	1	1	1	1
ISA Extensions	SSE4.2	SSE4.2	SSE4.2	SSE4.2
VID Voltage Range	0.800V-1.375V	0.800V-1.375V	0.800V-1.375V	0.800V-1.375V
TDP	130 W	130 W	130 W	130 W
Recommended Price	: $1059	$990	$1059	$1059

Main features of Intel's Sandy Bridge-E and Ivy Bridge-E processor models [21]

Name	Cores/ Threads	Base Clock	Turbo Boost	Multi-plier	L2 cache	L3 cache	Memory channels	PCIe	TDP	Release Date	Price (US)
Sandy Bridge-E											
Core i7-3970X	6/12	3.50 GHz	4.00 GHz	Unlocked	256 KB /core private	2.5 MB/core[1] shared (inclusive)	4 channels up to DDR3-1600	40 (PCIe 2.0)	150 W	Q4 2012	$999
Core i7-3960X		3.20 GHz	3.90 GHz							11/2011	$990
Core i7-3930K		3.20 GHz	3.80 GHz								$555
Core i7-3820	4/8	3.60 GHz		Partially locked					130 W	2/2012	$305
Ivy Bridge-E											
Core i7-4960X	6/12	3.60 GHz	4.00 GHz	Unlocked	256 KB /core private	2.5 MB/core[1] shared (inclusive)	4 channels up to DDR3-1866	40 (PCIe 3.0)	130 W	Q3 2013	$999
Core i7-4930K		3.40 GHz	3.90 GHz								$583
Core i7-4820K	4/8	3.70 GHz									$323

1: Except i7-3930K and i7-4930K, they have only 2MB/core L3 cache

Main features of Intel's Haswell-E and Broadwell-E processor models [21]

Name	Cores/ Threads	Base clock	Turbo Boost	Multiplier	L2 cache	L3 cache	Memory channels	PCIe	TDP	Release Date	Price (US)
Haswell-E											
Core i7-5960X	8/16	3.0 GHz	3.5 GHz	Unlocked	256 KB /core private	2.5 MB/core shared (inclusive)	4 channels up to DDR4-2133	40 (PCIe 3.0)	140 W	08/2014	$999
Core i7-5930K	6/12	3.5 GHz	3.7 GHz								$550
Core i7-5820K		3.3 GHz	3.6 GHz								$396
Broadwell-E											
Core i7-6950X	10/20	3.00 GHz	3.50 GHz	Unlocked	256 kB/core (private)	2.5 MB/core shared (inclusive)	4 channels up to DDR3-2400	40 (PCIe 3.0)	140 W	5/2016	$1723
Core i7-6900	8/16	3.20 GHz	3.70 GHz								$1089
Core i7-6850K	6/12	3.60 GHz	3.80 GHz								$617
Core i7-6800K		3.40 GHz	3.60 GHz					28 (PCIe 3.0)			$434

Main features of Intel's Skylake-X and Kaby Lake-X processor models [38]

Name	Cores/ Threads	Base clock	Turbo 2.0	Turbo 3.0	L2 cache	L3 cache	Memory channels	PCIe	TDP	Release Date	Price (US)
Skylake-X											
Core i9-7980XE	18/36	2.6 GHz	4.2 GHz	4.4 GHz	1 MB/core (private)	1.375 MB/core shared (non-inclusive)	4 channels up to DDR4-2666	44 (PCIe 3.0)	165 W	9/2017	$1999
Core i9-7960X	16/32	2.8 GHz	4.2 GHz	4.4 GHz							$1699
Core i9-7940X	14/28	3.1 GHz	4.3 GHz	4.4 GHz							$1399
Core i9-7920X	12/24	3.0 GHz	4.3 GHz	4.4 GHz					140 W	8/2017	$1199
Core i9-7900X	10/20	3.2 GHz	4.3 GHz	4.5 GHz						6/2017	$999
Core i7-7820X	8/16	3.6 GHz	4.3 GHz	4.5 GHz				28 (PCIe 3.0)			$599
Core i7-7800X	6/12	3.4 GHz	4.0 GHz	n.a.							$389
Kaby Lake-X											
Core i7-7740X	4/8	4.3 GHz	4.5 GHz	Not available	256 kB/core (private)	2 MB/core (shared)	4 channels DDR4-2666	16 (PCIe 3.0)	112 W	6/2017	$339
Core i5-7640X	4/4	4.0 GHz	4.2 GHz			1.5 MB/core (shared)					$242

Main features of Intel's Skylake-X Refresh processor models [38]

Skylake-X Refresh											
Name	**Cores/ Threads**	**Base clock**	**Turbo 2.0**	**Turbo 3.0**	**L2 cache**	**L3 cache[1]**	**Memory channels**	**PCIe**	**TDP**	**Release Date**	**Price (US)**
Core i9-9980XE	18/36	3.0 GHz	4.4 GHz	4.5 GHz	1 MB/core (private)	1.375 MB/core	4 channels DDR4-2666	Up to 68 (PCIe 3.0)	165 W	10/2018	$1979
Core i9-9960X	16/32	3.1 GHz	4.4 GHz	4.5GHz		1.375 MB/core					$1684
Core i9-9940X	14/28	3.3 GHz	4.4 GHz	4.5 GHz		1.375 MB/core					$1387
Core i9-9920X	12/24	3.5 GHz	4.4 GHz	4.5 GHz		1.6 MB/core					$1189
Core i9-9900X	10/20	3.5 GHz	4.4 GHz	4.5 GHz		1.925 MB/core					$989
Core i9-9820X	10/20	3.3 GHz	4.1 GHz	4.2 GHz		1.65 MB/core					$889
Core i7-9800X	8/16	3.8 GHz	4.4 GHz	4.5 GHz		2.0625 MB/core					$589

[1]Shared (non-inclusive)

2. The Nehalem Extreme Edition Series

2. The Nehalem Extreme Edition line (1)

2. The Nehalem Extreme Edition Series

- It is part of the 1. gen. Nehalem line.
- Launched in 11/2008.

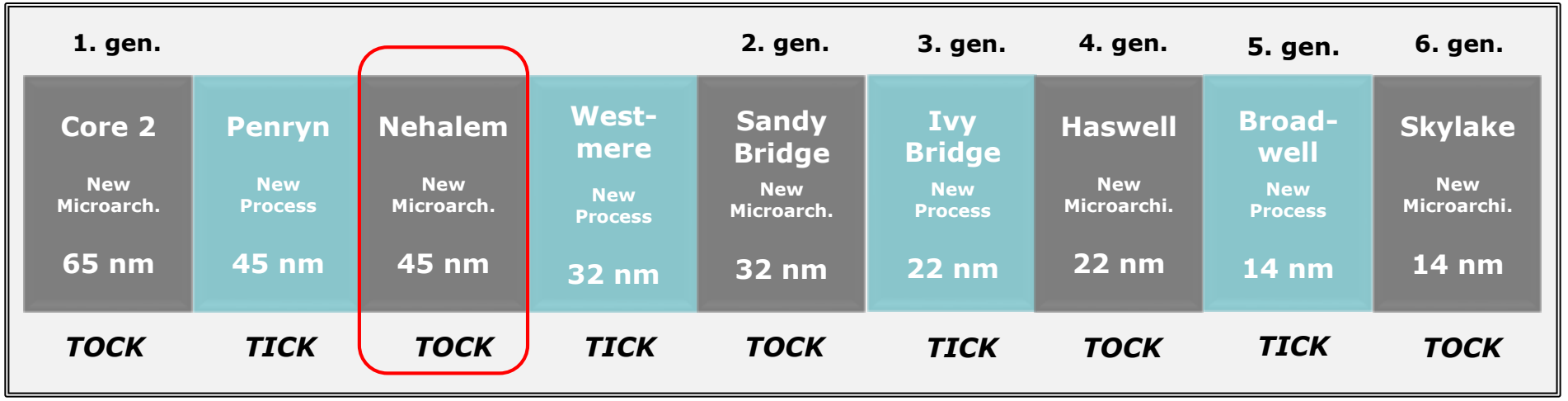


Figure 2.1: Intel's Tick-Tock development model (Based on [1])

2. The Nehalem Extreme Edition line (2)

Major innovations of the 1. generation Nehalem line [2]

- The major incentive in designing the microarchitecture of Nehalem is: to have native 4 cores.
- 4 cores need however twice as many bandwidth as dual core processors, such as the Core 2.
- Two memory channels used for dual core processors are more or less the limit attachable to the north bridge due to physical and electrical limitations.

Consequently, to provide enough bandwidth for 4 cores, a new memory design was necessary.

Major innovations of the 1. generation 4-core Nehalem line

- Integrated memory controller
- QuickPath Interconnect bus (QPI)
- New cache architecture
- Simultaneous Multithreading (SMT)
- SSE 4.2 ISA extension
- Enhanced power management
- Advanced virtualization
- New socket

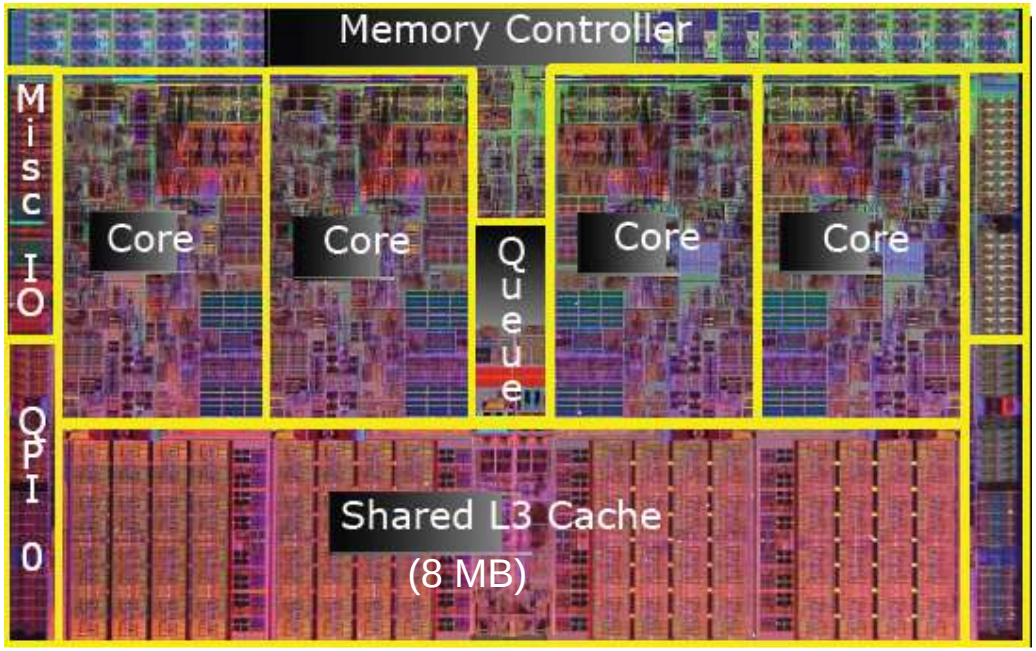


Figure 2.2: Die photo of the 1. gen. Nehalem desktop chip (designate Bloomfield)

2. The Nehalem Extreme Edition line (3)

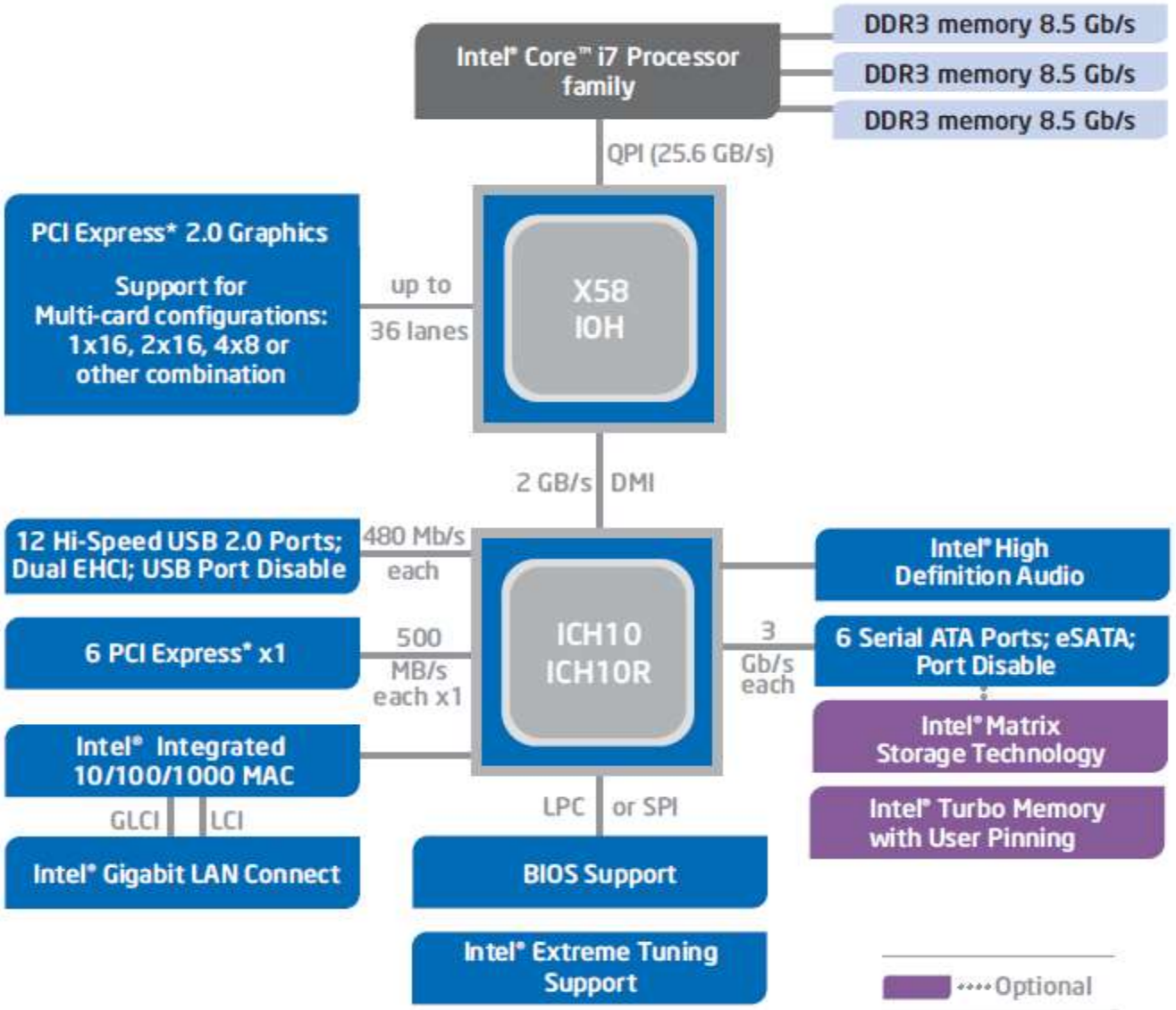
Main features of the Extreme Edition models of the Nehalem EE-Series [22]

	Cores	Clock	Cache	QPI	TDP	Pricing
i7-975 Extreme Edition	4	3.33GHz	8MB	3200MHz	150W	$1039
i7-965 Extreme Edition	4	3.20GHz	8MB	3200MHz	150W	$999
i7-950	4	3.06GHz	8MB	2400MHz	130W	$574
i7-940	4	2.93GHz	8MB	2400MHz	130W	$559
i7-920	4	2.66GHz	8MB	2400MHz	130W	$278

Note that Extreme Edition processors have a TDP of 150 W rather than 130 W as seen for the rest of the line and convert the additional TDP (20 W) to higher clock rate.

2. The Nehalem Extreme Edition line (4)

Typical system architecture of a Nehalem Extreme Edition processor [23]



2. The Nehalem Extreme Edition line (5)

Note that the system architecture is based on the X58 IOH that provides 36 PCIe 2.0 lanes to attach one or more discrete graphics cards, e.g. via 1x16, 2x16 or 4x8 lanes.

3. The Westmere-Extreme Edition Series

3. The Westmere Extreme Edition Series

- It is part of the Westmere family.
- Launched in 03/2010.

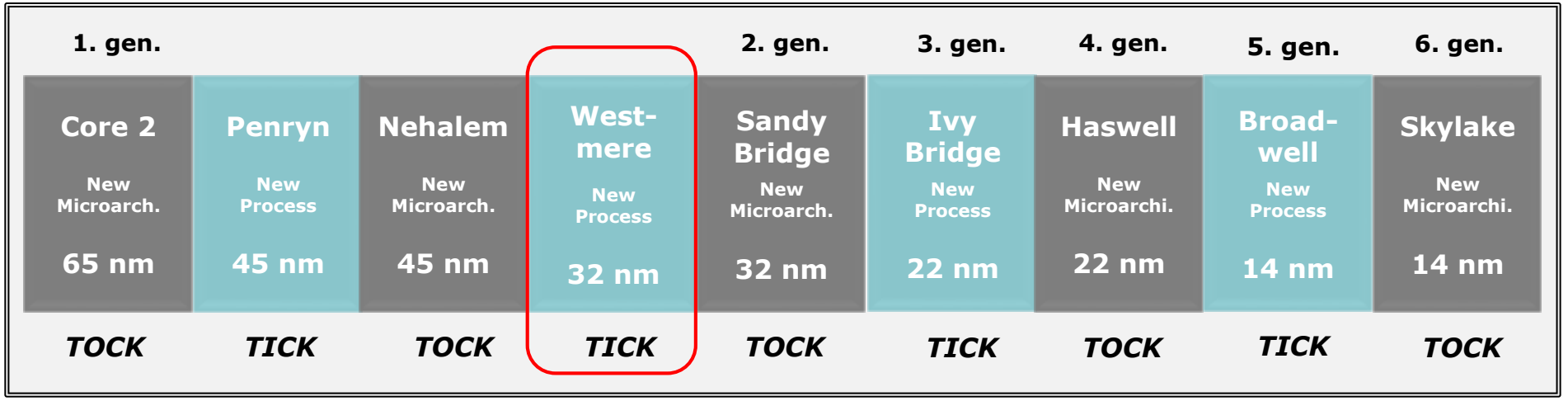
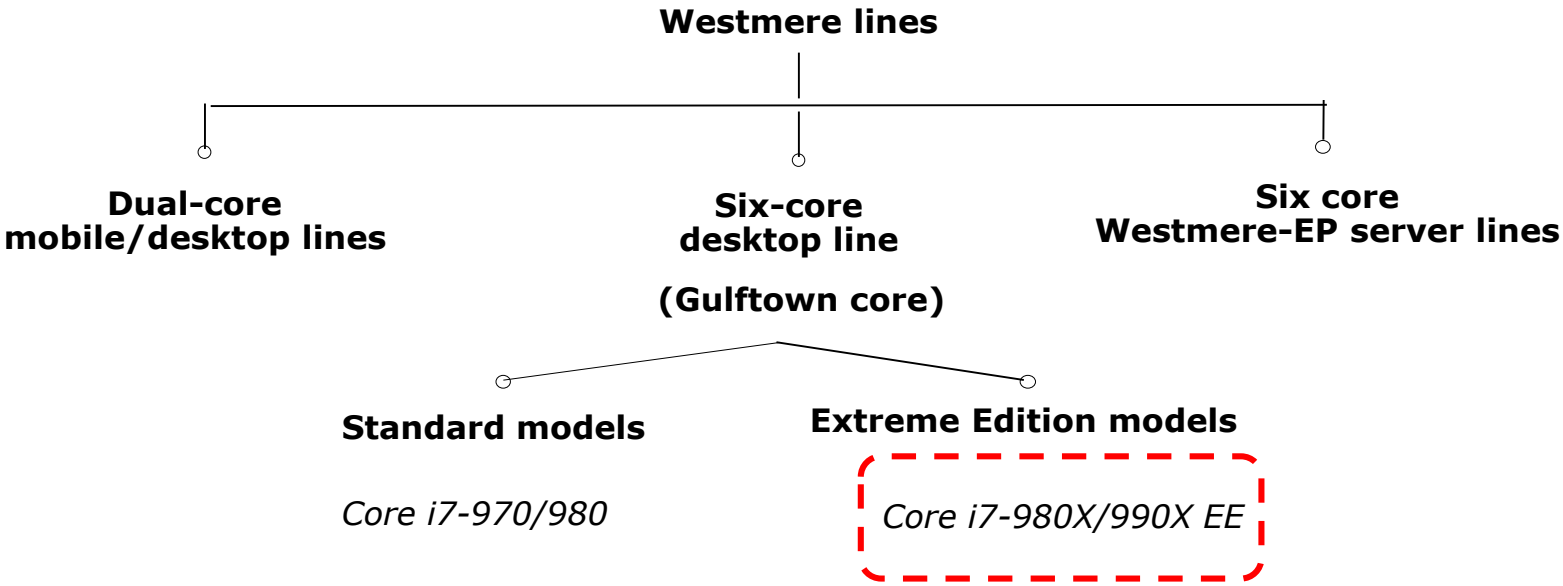


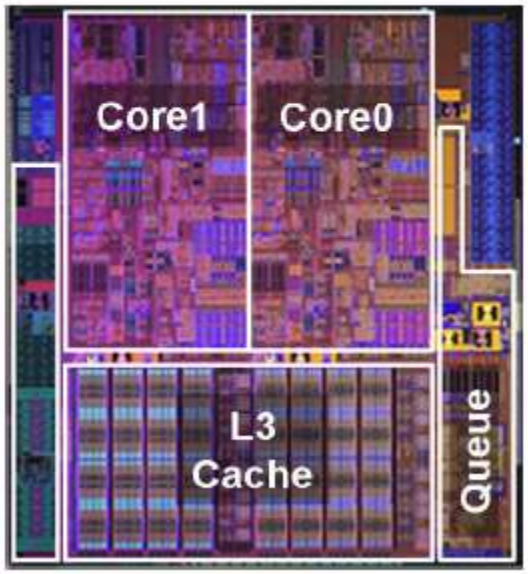
Figure 1.1: Intel's Tick-Tock development model (Based on [1])

3. The Westmere Extreme Edition line (2)



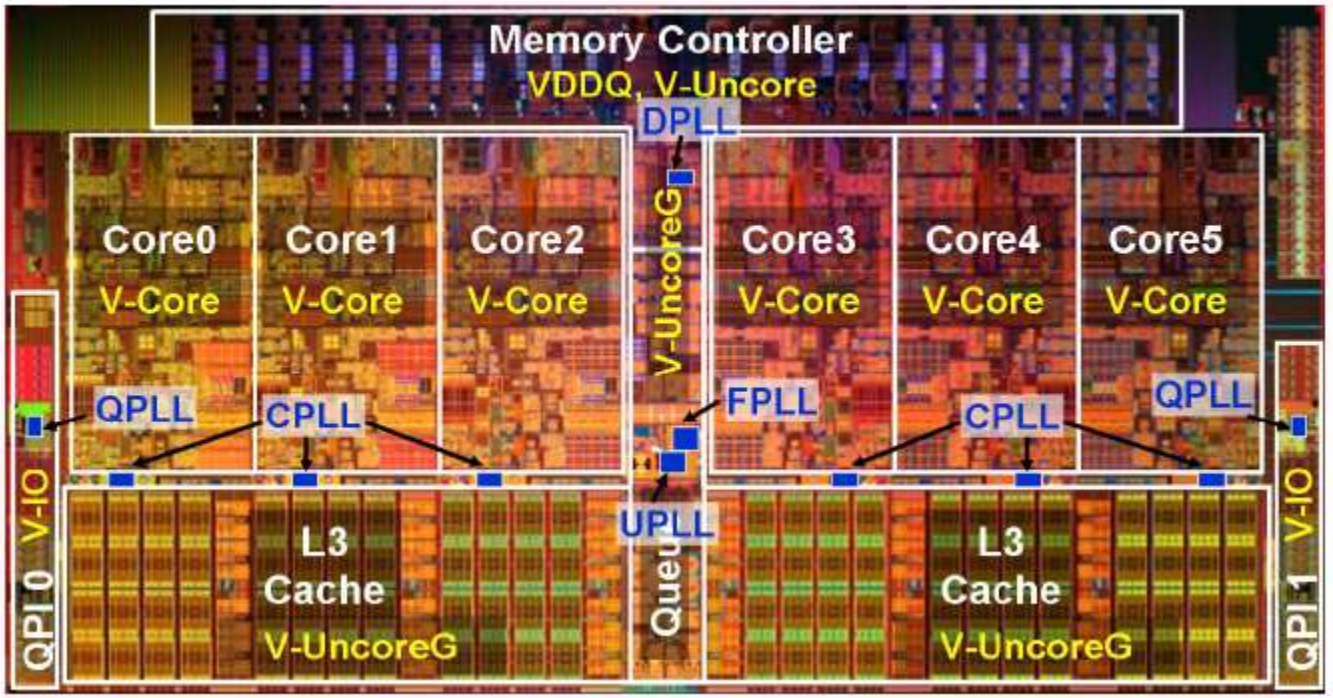
3. The Westmere Extreme Edition line (3)

Westmere 2-core and 6-core die plots [3]



2-core die plot

Arrandale (mobile)
Clarkdale (desktop)



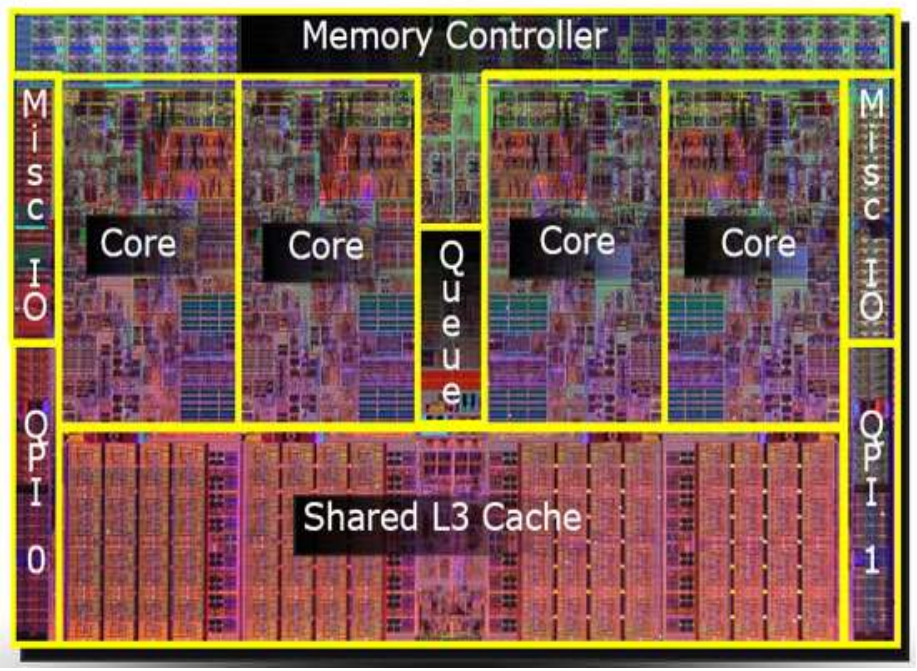
6-core die plot
248 mm2, 1.17 billion transistors)

Gulftown (desktop, Westmere-EP UP/DP server)

3. The Westmere Extreme Edition line (4)

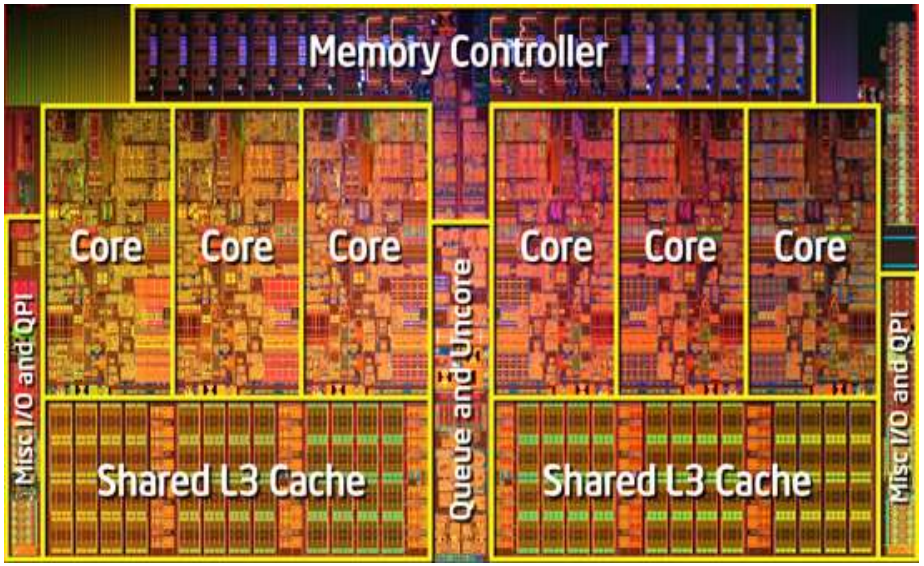
Comparing the die plots of Nehalem EE and Westmere EE processors [24]

Nehalem 45 nm



731 mtrs 263 mm^2

Gulftown 32 nm



1017 mtrs 240 mm^2

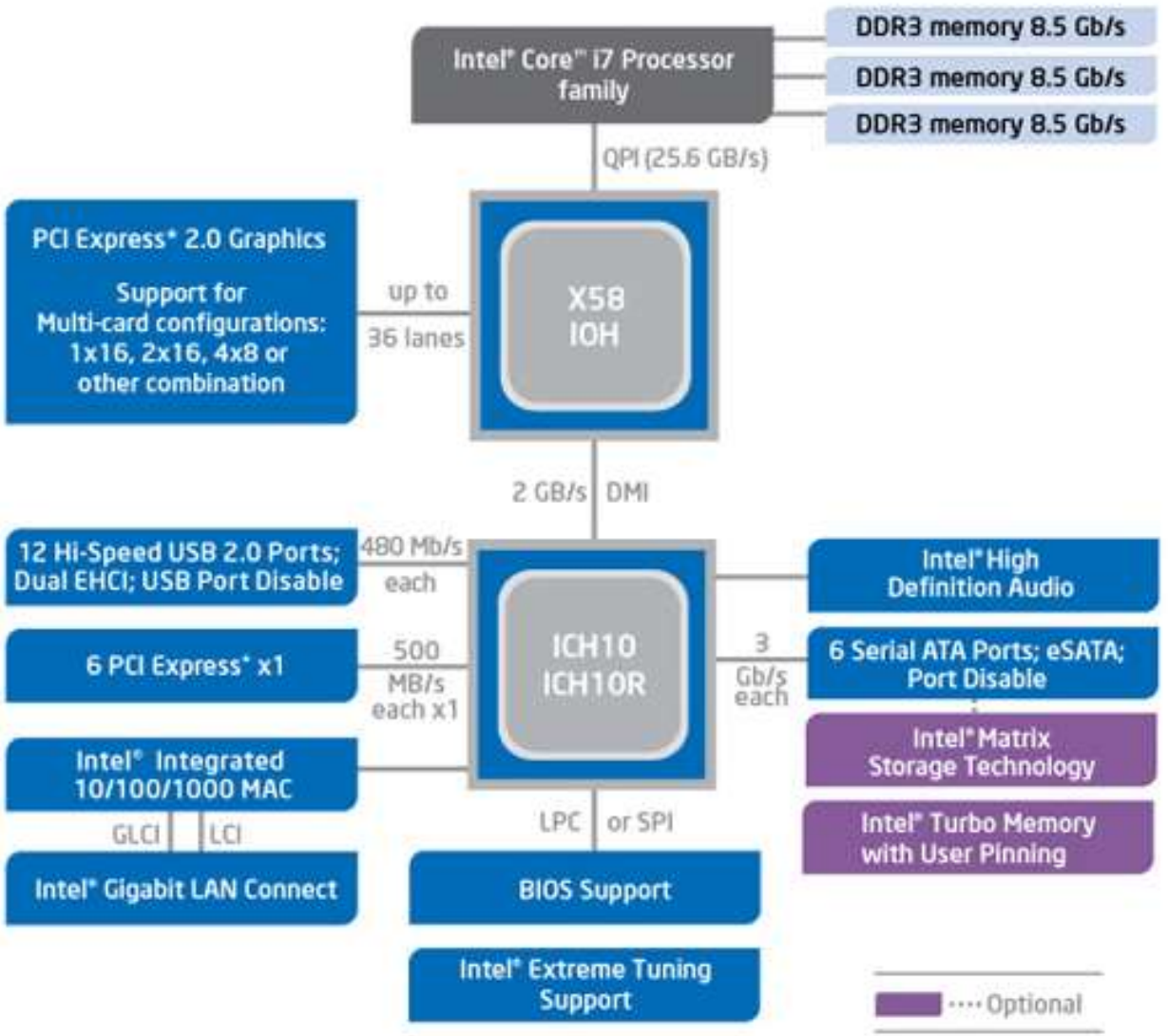
3. The Westmere Extreme Edition line (5)

Main features of the Nehalem EE and Westmere EE processors [20]

Processor Number	i7-975 EE	i7-965 EE	i7-990X EE	i7-980X
Core type	Nehalem (Bloomfield)	Nehalem (Bloomfield)	Westmere (Gulftown)	Westmere (Gulftown)
Launch Date	Q2'09	Q4'08	Q1'11	Q1'10
Lithography	45 nm	45 nm	32 nm	32 nm
# of Cores	4	4	6	6
# of Threads	8	8	12	12
Processor Base Frequency	3.33 GHz	3.2 GHz	3.46 GHz	3.33 GHz
Max Turbo Frequency	3.6 GHz	3.46 GHz	3.73 GHz	3.6 GHz
Cache	8 MB	8 MB	12 MB	12 MB
System Bus	QPI	QPI	QPI	QPI
Bus Speed	6.4 GT/s	6.4 GT/s	6.4 GT/s	6.4 GT/s
# of QPI Links	1	1	1	1
ISA Extensions	SSE4.2	SSE4.2	SSE4.2	SSE4.2
VID Voltage Range	0.800V-1.375V	0.800V-1.375V	0.800V-1.375V	0.800V-1.375V
TDP	130 W	130 W	130 W	130 W
Recommended Price	: $1059	$990	$1059	$1059

3. The Westmere Extreme Edition line (6)

Typical system architecture of a Westmere Extreme Edition processor [24]



4. The Sandy Bridge E-Series

- 4.1 Introduction
- 4.2 Differences to the original Sandy Bridge line
- 4.2.1 Overview
- 4.2.2 Up to 6 cores, no integrated graphics
- 4.2.3 2.5 MB/core vs. 2 MB/core L3 cache
- 4.2.4 4 memory channels
- 4.2.5 40 PCIe 2. gen. lanes to connect multiple graphics cards to the processor
- 4.2.6 LGA-2011 socket

4.1 Introduction

The Sandy Bridge E-Series belongs also to the 2. gen. Core processor family.

Introduced in 11/2011 as a "precursor" of the upcoming Sandy Bridge-EN/EP server lines with two cores of the 8 core Sandy Bridge-EN/EP lines disabled.

It targets HEDs (high performance desktops for enthusiast gamers).

It provides 40 configurable PCIe 3.0 lanes that allows to attach up to 4 graphics cards.

1. gen.				2. gen.	3. gen.	4. gen.	5. gen.	6. gen.
Core 2 New Microarch. 65 nm	Penryn New Process 45 nm	Nehalem New Microarch. 45 nm	West-mere New Process 32 nm	Sandy Bridge New Microarch. 32 nm	Ivy Bridge New Process 22 nm	Haswell New Microarchi. 22 nm	Broad-well New Process 14 nm	Skylake New Microarchi. 14 nm
TOCK	*TICK*	*TOCK*	*TICK*	*TOCK*	*TICK*	*TOCK*	*TICK*	*TOCK*

Figure: Intel's Tick-Tock development model (Based on [1])

4.1 Introduction (2)

Overview of the Sandy Bridge E-Series HED models

Core i7-3960X EE, 6C, HT, no vPro, 11/2011
Core i7-3930K, 6C, HT, no vPro, 11/2011
Core i7-3820, 4C, HT, no vPro, 02/2012

Data based on [5], [6]

4.1 Introduction (3)

Main features of the Sandy Bridge E-Series vs. the Sandy Bridge line [8]

Processor	Core Clock	Cores / Threads	L3 Cache	Max Turbo	Max Overclock Multiplier	TDP	Price
Intel Core i7 3960X	3.3GHz	6 / 12	15MB	3.9GHz	57x	130W	$990
Intel Core i7 3930K	3.2GHz	6 / 12	12MB	3.8GHz	57x	130W	$555
Intel Core i7 3820	3.6GHz	4 / 8	10MB	3.9GHz	43x	130W	TBD
Intel Core i7 2700K	3.5GHz	4 / 8	8MB	3.9GHz	57x	95W	$332
Intel Core i7 2600K	3.4GHz	4 / 8	8MB	3.8GHz	57x	95W	$317
Intel Core i7 2600	3.4GHz	4 / 8	8MB	3.8GHz	42x	95W	$294
Intel Core i5 2500K	3.3GHz	4 / 4	6MB	3.7GHz	57x	95W	$216
Intel Core i5 2500	3.3GHz	4 / 4	6MB	3.7GHz	41x	95W	$205

Again the extreme performance models have a higher TDP (130 W vs. 95 W) and convert the additional power to raise clock rate and have larger L3 caches.

4.2.1 Overview (1)

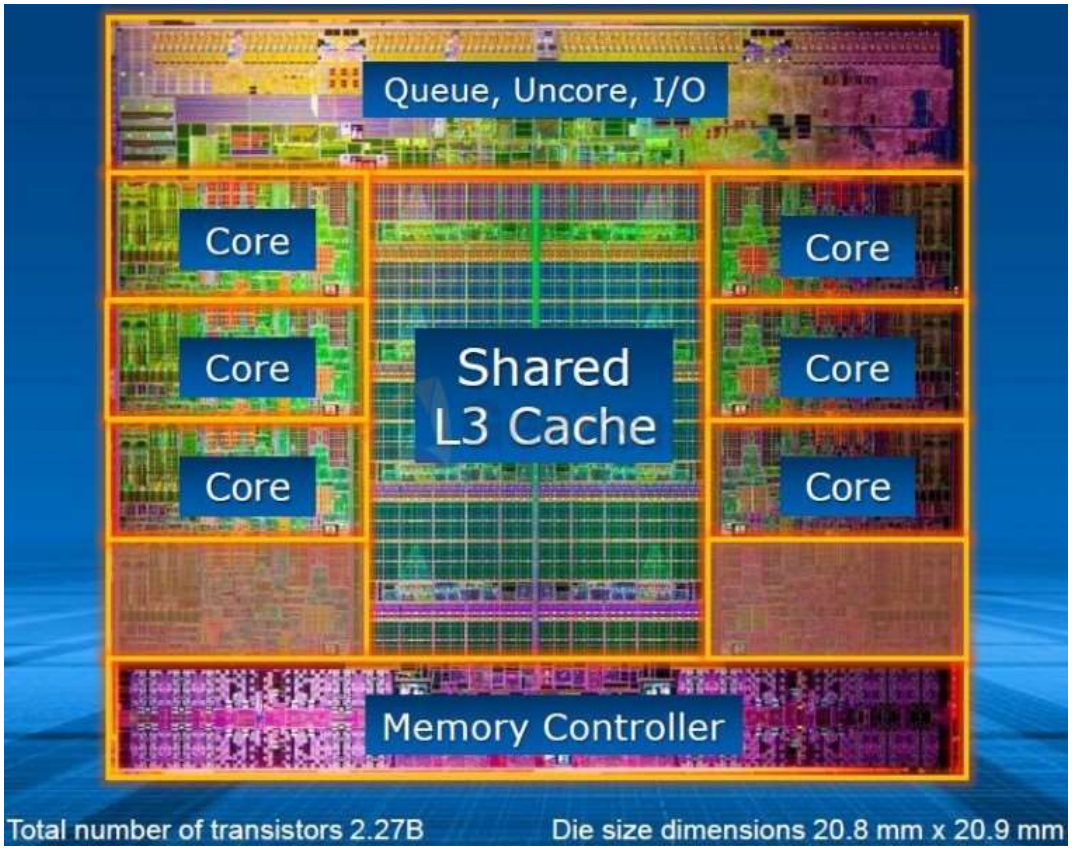
4.2 Differences to the original Sandy Bridge line

4.2.1 Overview

- Up to 6 cores, no integrated graphics (Section 4.2.2)
- 2.5 MB/core vs. 2 MB/core shared L3 cache available in the Sandy Bridge lines (Section 4.2.3)
- 4 DDR3 memory channels instead of 2 available in the Sandy Bridge lines (Section 4.2.4)
- 40 PCIe 2. gen. lanes for connecting multiple graphics cards to the processor instead of 16 available in the Sandy Bridge lines (Section 4.2.5)
- LGA-2011 socket instead of the LGA-1155 used in the original Sandy Bridge lines (Section 4.2.6)

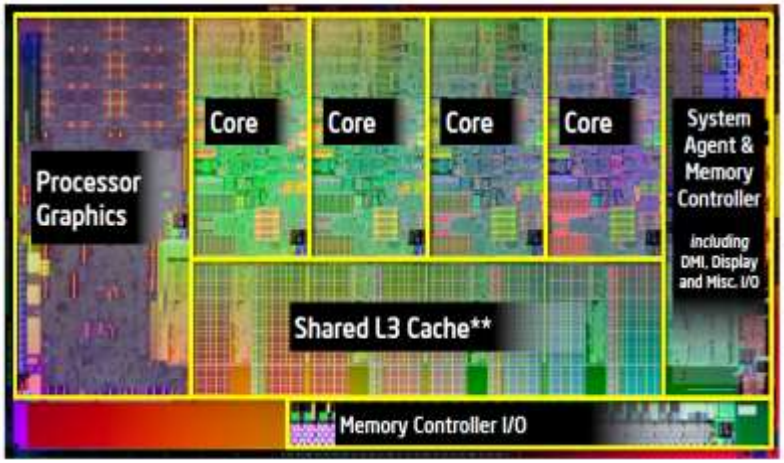
4.2.2 Up to 6 cores, no integrated graphics

- From the original 8-core Sandy Bridge-EN/EP server design 2 cores are disabled.
- As the Sandy Bridge-E targets HEDs with high end discrete graphics, there is no need for integrated graphics, This is the reason why the Sandy Bridge-E die does not include integrated graphics [7].



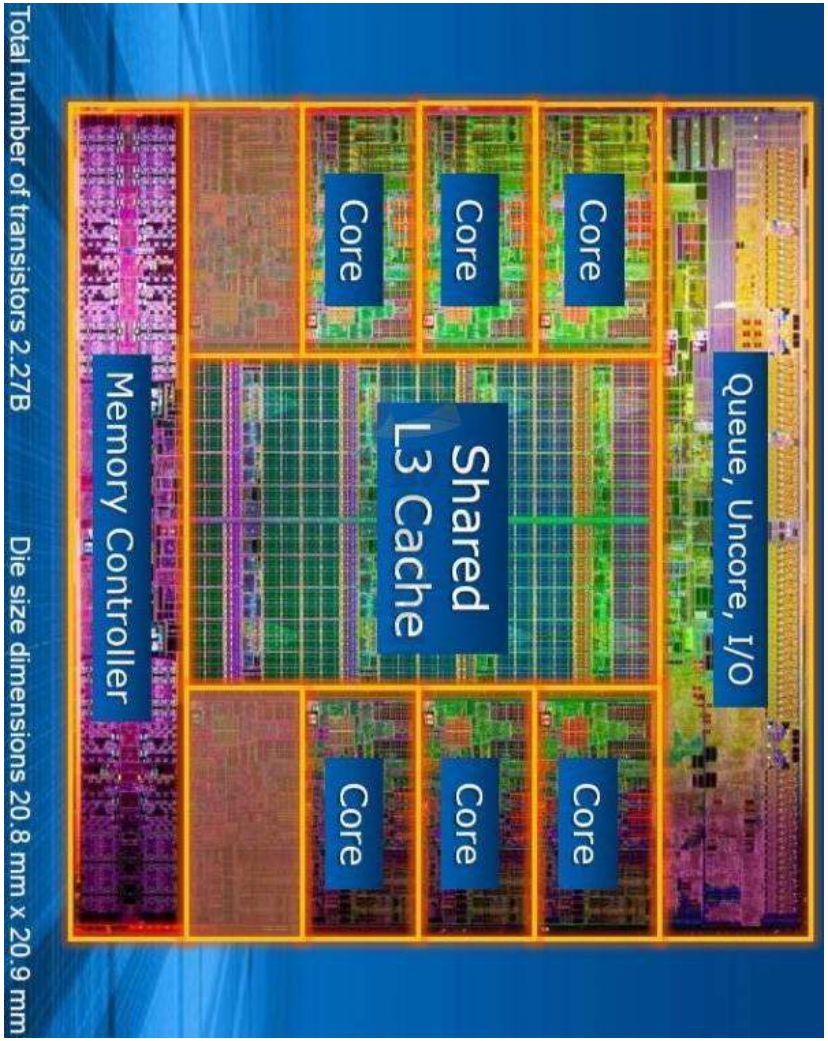
4.2.2 Up to 6 cores, no integrated graphics (2)

Sandy Bridge [4]



32 nm
216 mm^2 995 mtrs
8 MB L3

Sandy Bridge-E [7]



32 nm
435 mm^2 2.27 B trs
15 MB L3

4.2.2 Up to 6 cores, no integrated graphics (3)

Comparison of die parameters of recent DT processors [8]

Sandy Bridge-E has about 2x the die area of Sandy Bridge with 2.27 billion transistors, as the next Table indicates.

CPU Specification Comparison				
CPU	**Manufacturing Process**	**Cores**	**Transistor Count**	**Die Size**
AMD Bulldozer 8C	32nm	8	~2B	315mm^2
AMD Thuban 6C	45nm	6	904M	346mm^2
AMD Deneb 4C	45nm	4	758M	258mm^2
Intel Gulftown 6C	32nm	6	1.17B	240mm^2
Intel Sandy Bridge E (6C)	32nm	6	2.27B	435mm^2
Intel Nehalem/Bloomfield 4C	45nm	4	731M	263mm^2
Intel Sandy Bridge 4C	32nm	4	995M	216mm^2
Intel Lynnfield 4C	45nm	4	774M	296mm^2
Intel Clarkdale 2C	32nm	2	384M	81mm^2
Intel Sandy Bridge 2C (GT1)	32nm	2	504M	131mm^2
Intel Sandy Bridge 2C (GT2)	32nm	2	624M	149mm^2

4.2.3 2.5 MB/core vs. 2 MB/core shared L3 cache

It is revealed as part of the main features of the Sandy Bridge-E line [8]

Processor	Core Clock	Cores / Threads	L3 Cache	Max Turbo	Max Overclock Multiplier	TDP	Price
Intel Core i7 3960X	3.3GHz	6 / 12	15MB	3.9GHz	57x	130W	$990
Intel Core i7 3930K	3.2GHz	6 / 12	12MB	3.8GHz	57x	130W	$555
Intel Core i7 3820	3.6GHz	4 / 8	10MB	3.9GHz	43x	130W	TBD
Intel Core i7 2700K	3.5GHz	4 / 8	8MB	3.9GHz	57x	95W	$332
Intel Core i7 2600K	3.4GHz	4 / 8	8MB	3.8GHz	57x	95W	$317
Intel Core i7 2600	3.4GHz	4 / 8	8MB	3.8GHz	42x	95W	$294
Intel Core i5 2500K	3.3GHz	4 / 4	6MB	3.7GHz	57x	95W	$216
Intel Core i5 2500	3.3GHz	4 / 4	6MB	3.7GHz	41x	95W	$205

4.2.3 2.5 MB/core vs. 2 MB/core L3 cache (2)

Cache/memory latencies of the Sandy Bridge-E processors (in cycles) [8]

		L1	L2	L3	Main Memory
Bulldozer	AMD FX-8150 (3.6GHz)	4	21	65	195
	AMD Phenom II X4 975 BE (3.6GHz)	3	15	59	182
	AMD Phenom II X6 1100T (3.3GHz)	3	14	55	157
Sandy Bridge	Intel Core i5 2500K (3.3GHz)	4	11	25	148
Sandy Bridge-E	Intel Core i7 3960X (3.3GHz)	4	11	30	167

Note that larger per core L3 caches (2.5 MB/core instead of 2 MB/core) entails 5 cycles higher L3 cache access times.

4.2.4 4 memory channels

- There are 4 memory channels instead of 2 available in the Sandy Bridge line, inherited from the Sandy bridge-EN/EP server design.
- Support of a single DDR3-1600 DIMM per channel or 2 DDR3-1333 DIMMs per channel [9].

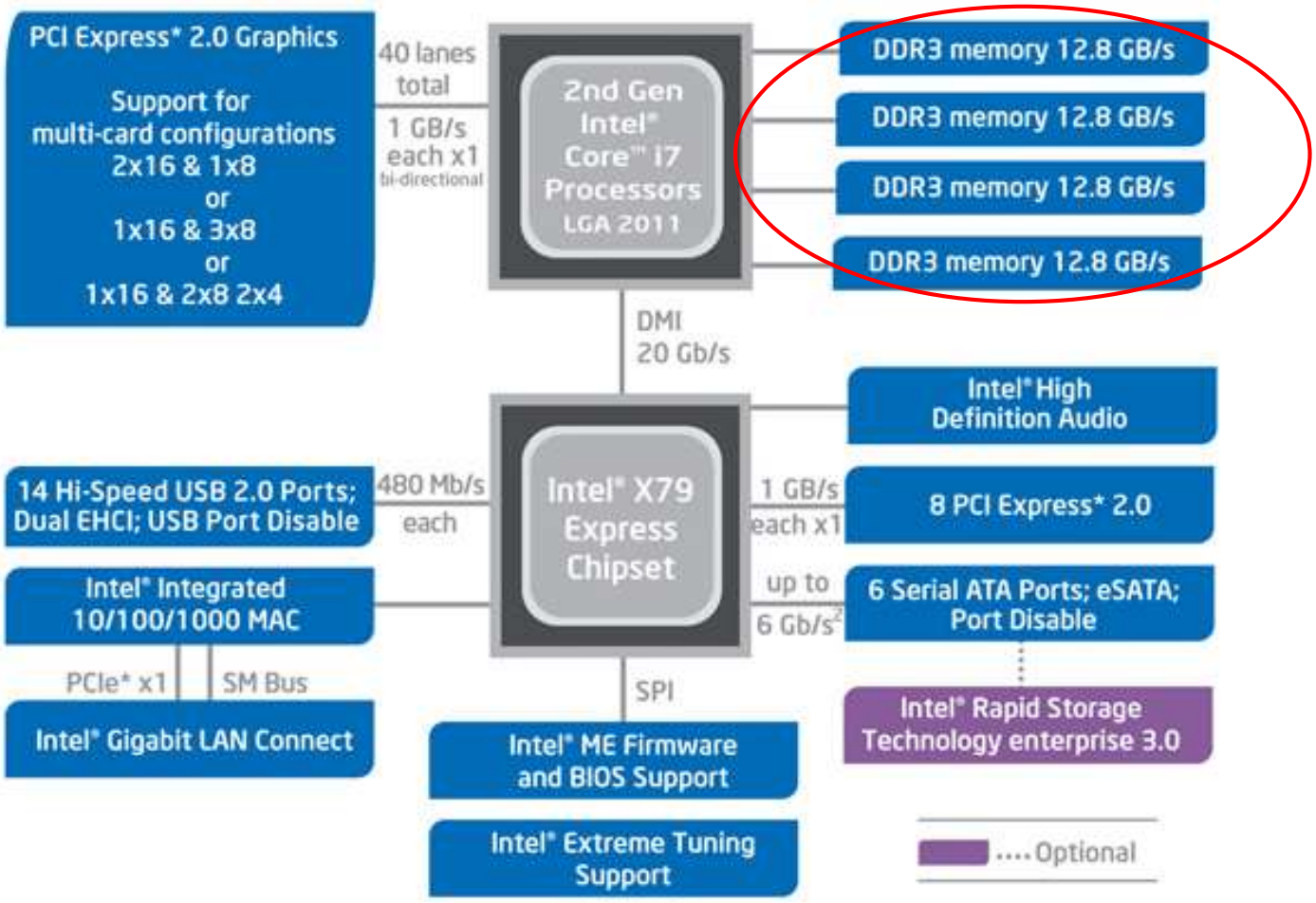


Figure: The Sandy Bridge-E platform with the X79 chipset [9]

4.2.4 4 memory channels (2)

Note

There are 4 memory channels provided to support up to 4 graphics cards.

4.2.5 40 PCIe 2. gen. lanes to connect multiple graphics cards to the processor

There is a vast increase in the number of PCIe 2. gen. lanes compared to 16 lanes provided by the original Sandy Bridge line [9].

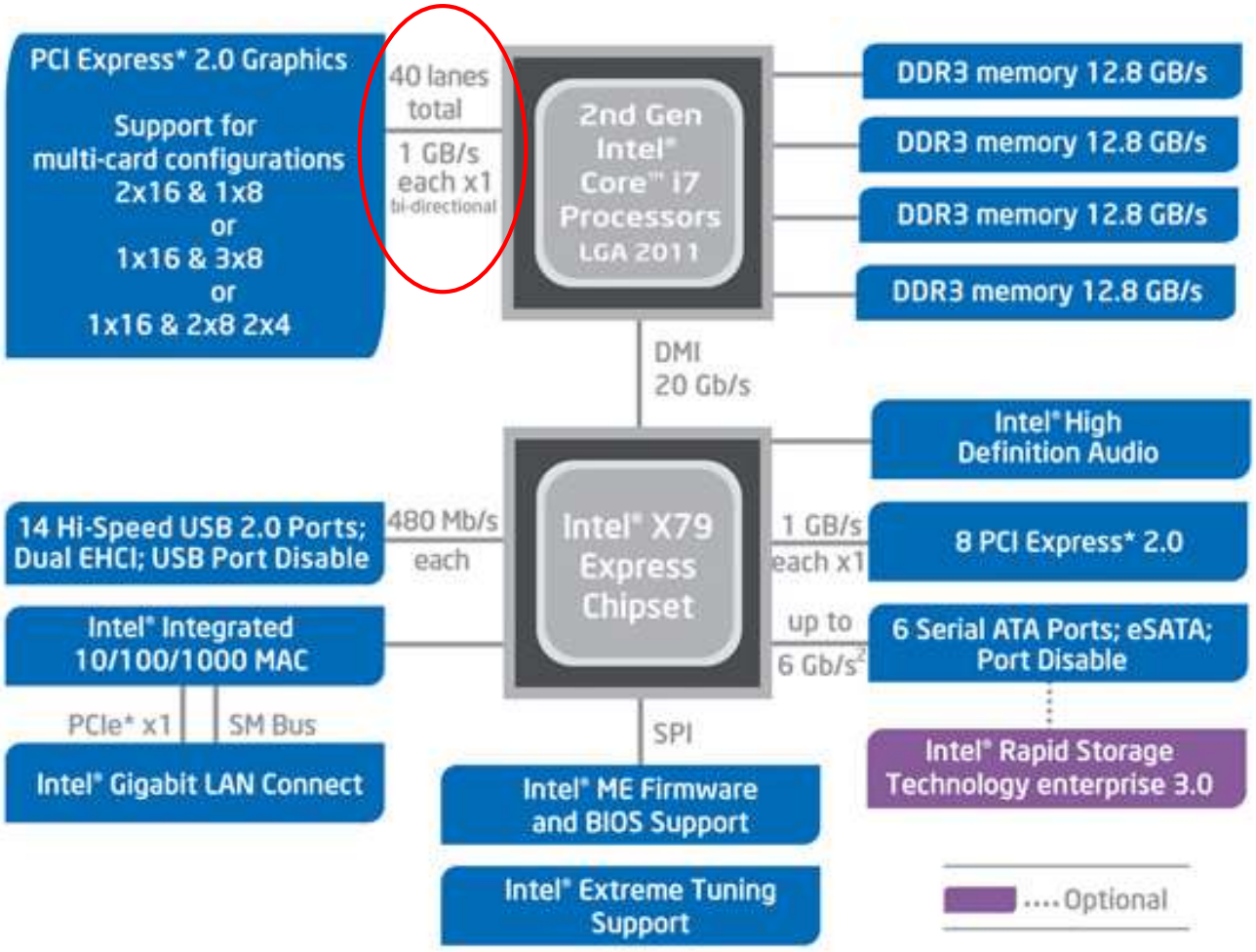
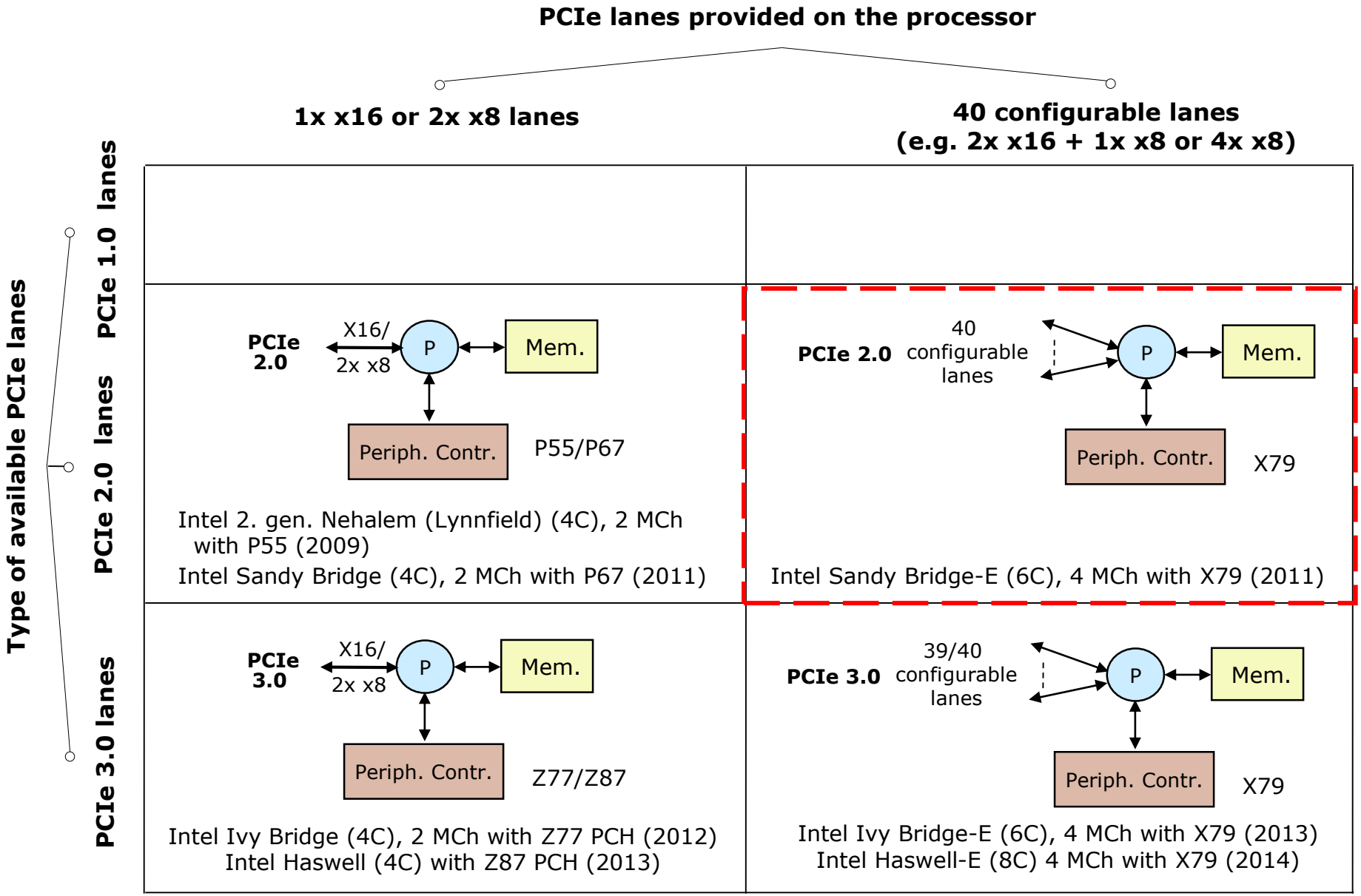


Figure: The Sandy Bridge-E platform with the X79 chipset [9]

4.2.5 40 PCIe 2. gen. lanes to connect multiple graphics cards (2)

Overview of providing PCIe lanes on Intel desktop processors



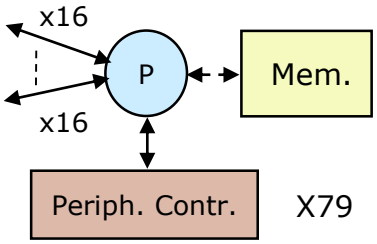
4.2.5 40 PCIe 2. gen. lanes to connect multiple graphics cards (3)

Lane configuration options - Sandy Bridge-E [11]

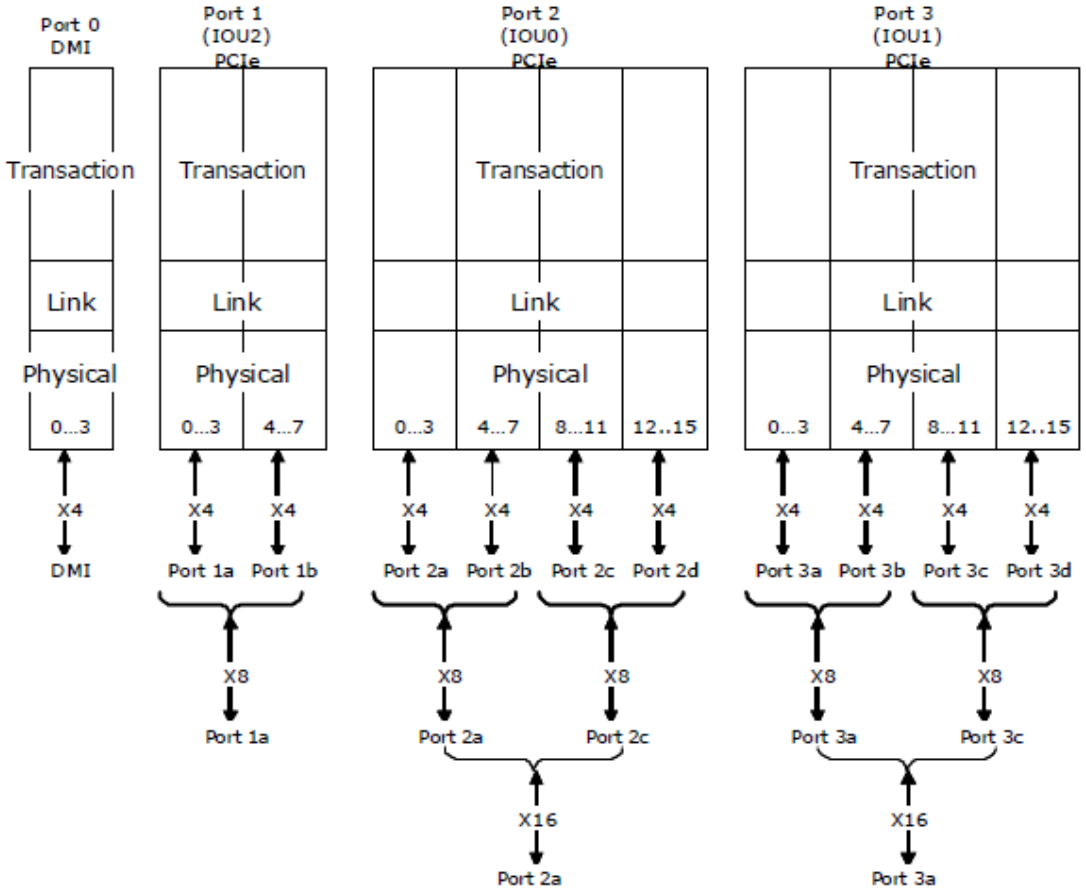
Intel Sandy Bridge EE (6C),
4 MCh with X79 (2011)

PCIe 3.0

40 configurable lanes



X79

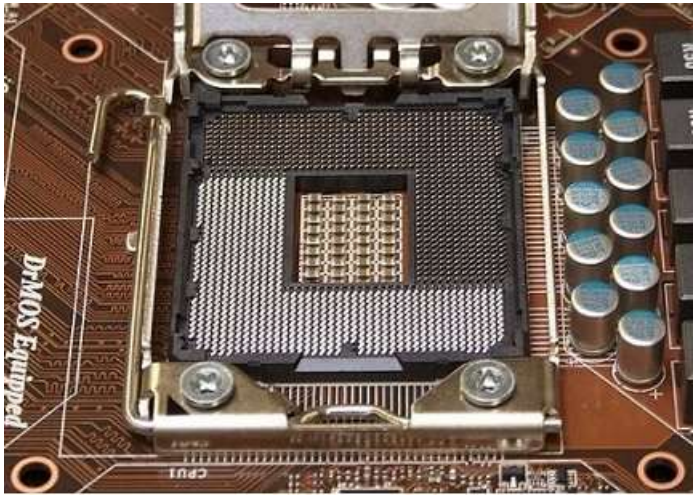


4.2.6 LGA-2011 socket

Due to the additional two memory channels connected to the processor die the Sandy Bridge-E processor needs more pins on its socket than the Sandy Bridge processor that has only two memory channels connected to its die and makes use of the LGA-1155 socket.

Intel's LGA sockets (Land Grid Array)

LGA 775 Pentium 4 Prescott until Nehalem	2 memory channels connected to the NB
LGA 1156 2. gen. Nehalem (Lynnfield)	2 memory channels connected to the processor die
LGA 1155 Sandy Bridge/Ivy Bridge	2 memory channels connected to the processor die
LGA 1366 1. gen. Nehalem (Bloomfield)	3 memory channels connected to the processor die
LGA 2011 Sandy Bridge-E/ivy Bridge-E	4 memory channels connected to the processor die

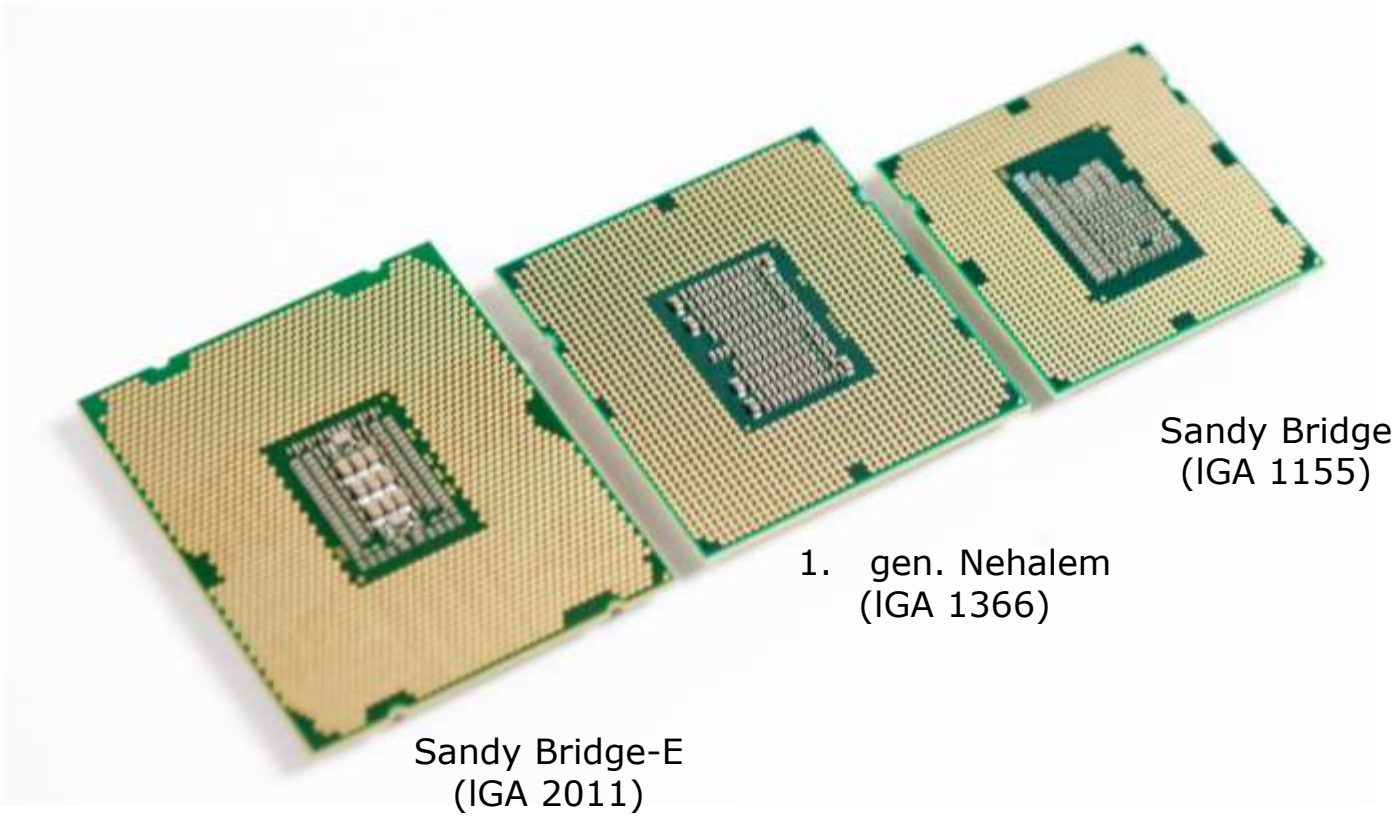


LGA 2011 [10]

LGA 1155 []

4.2.6 LGA-2011 socket (2)

Comparing related sockets [8]



4.2.6 LGA-2011 socket (3)

Example for a Sandy Bridge-E/X79 based 4-way SLI multi graphics card configuration

(ASUS's 4-Way SLI "Rampage IV Formula" motherboard with GTX 680 4-way ready graphics cards) [12]

5. The Ivy Bridge E-Series

- 5.1 Introduction
- 5.2 Differences to the previous Sandy Bridge-E line
- 5.3 Example for an Ivy Bridge-E based desktop platform with the X79 chipset
- 5.4 Performance increase achieved by the Ivy Bridge-E line vs. the Sandy Bridge-E line

5.1 Introduction

- The Ivy Bridge E-Series belongs also to the 3. gen. Core processor family.
- Introduced in 9/2013 one week before Intel's IDF Fall 2013.
- It targets high performance desktops for hardcore gamers and graphics enthusiasts.
- It provides 40 configurable PCIe 3.0 lanes that enables attaching up to 4 graphics cards.

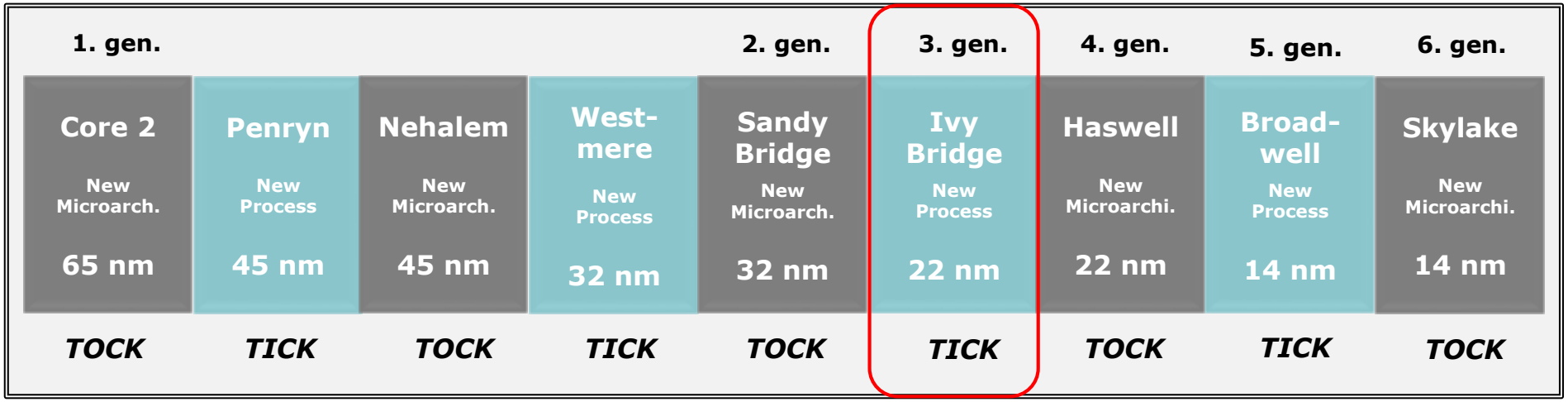


Figure: Intel's Tick-Tock development model (Based on [1])

5.1 Introduction (2)

Overview of the Ivy Bridge E-Series models

Core i7-4960X EE, 6C, HT, 9/2013
Core i7-4930K, 6C, HT, 9/2013
Core i7-4820, 4C, HT, 9/2013

Data based on [13]

5.2 Differences to the previous Sandy Bridge-E line (1)

Main features of Ivy Bridge-E models [13]

	Brand Name & Processor Number[1]	Base Clock Speed (GHz)	Turbo Frequency[2] (GHz)	Cores/ Threads	Cache	Memory Support	TDP	Socket (LGA)	Pricing (1k USD)
Ivy Bridge-E	NEW Intel® Core™ i7 4960X Unlocked	3.6	Up to 4.0	6/12	15 MB	4 channels DDR3 1866	130W	2011	$990
	NEW Intel® Core™ i7 4930K Unlocked	3.4	Up to 3.9	6/12	12 MB	4 channels DDR3 1866	130W	2011	$555
	NEW Intel® Core™ i7 4820K Unlocked	3.7	Up to 3.9	4/8	10 MB	4 channels DDR3 1866	130W	2011	$310
Haswell DT	Intel® Core™ i7-4770K Unlocked	3.5	Up to 3.9	4/8	8 MB	2 channels DDR3 1600	95W	1150	$317

5.2 Differences to the previous Sandy Bridge-E line (2)

5.2 Differences to the previous Sandy Bridge-E models [14]

The Ivy Bridge E-Series provides mainly the same features as the previous Sandy Bridge E-Series, such as

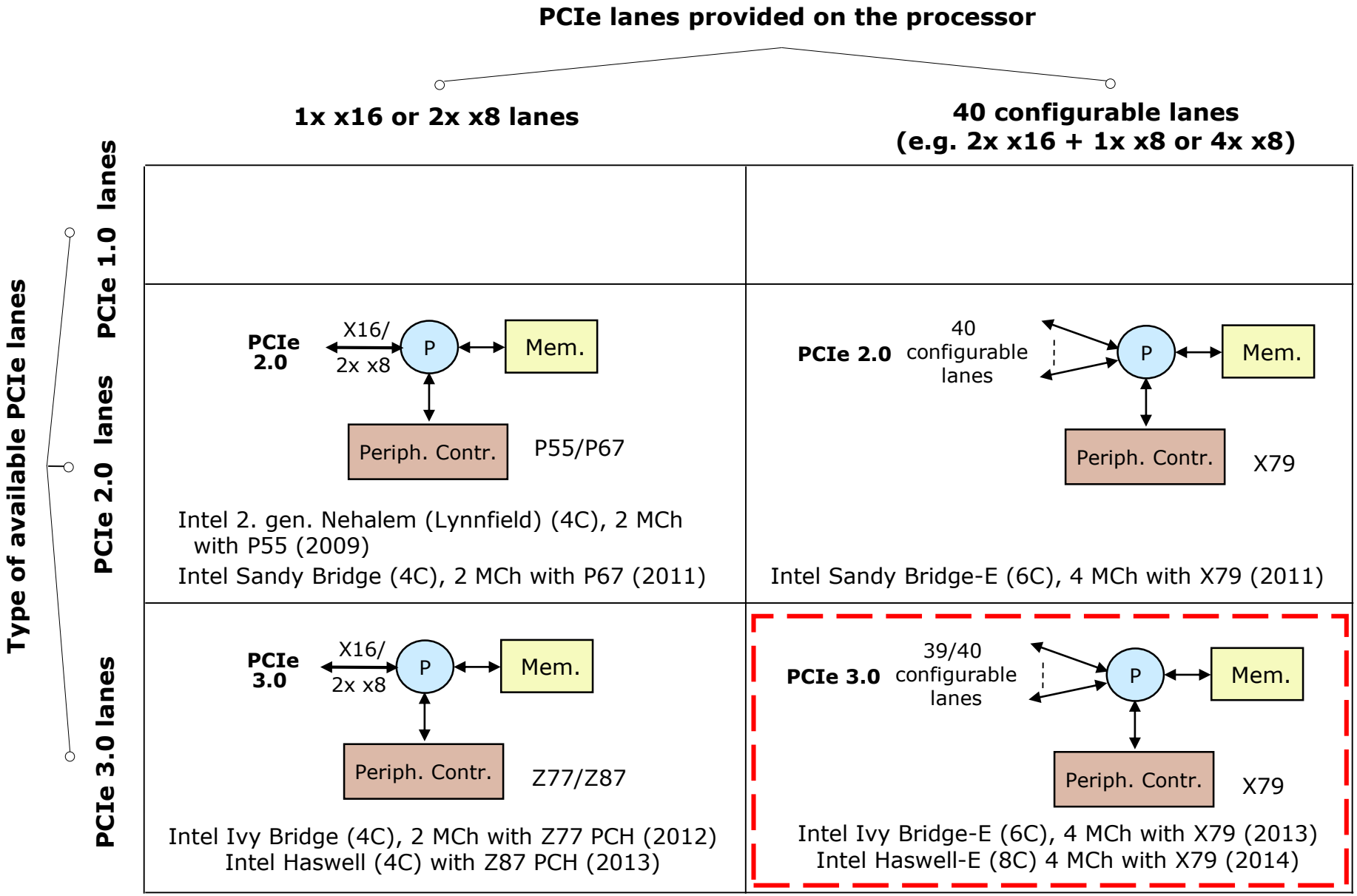
- Up to 6 cores, no integrated graphics
- 2.5 MB/core shared L3 cache
- LGA-2011 socket.

On the other hand it provides the following main enhancements vs. the previous Sandy Bridge-E lines:

- 4 parallel DDR3 memory channels with up to 1866 MT/s rather than up to 1600 MT/s,
- 39 or 40 PCIe 3. gen. lanes to connect up to 4 graphics cards to the processor rather than 40 PCIe 2. gen. lanes, as indicated in the next Figure.

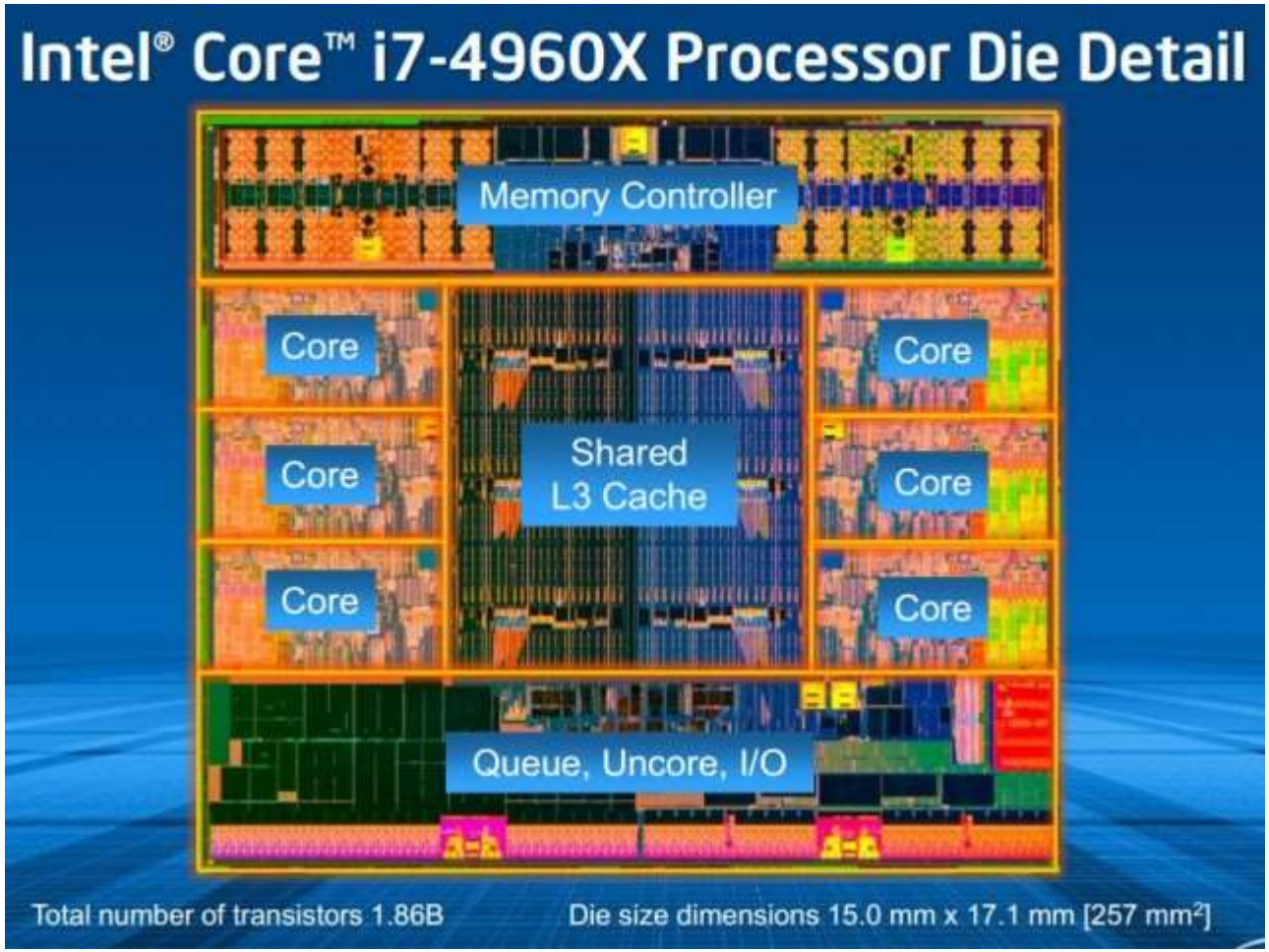
5.2 Differences to the previous Sandy Bridge-E line (3)

Overview of providing PCIe lanes on Intel desktop processors

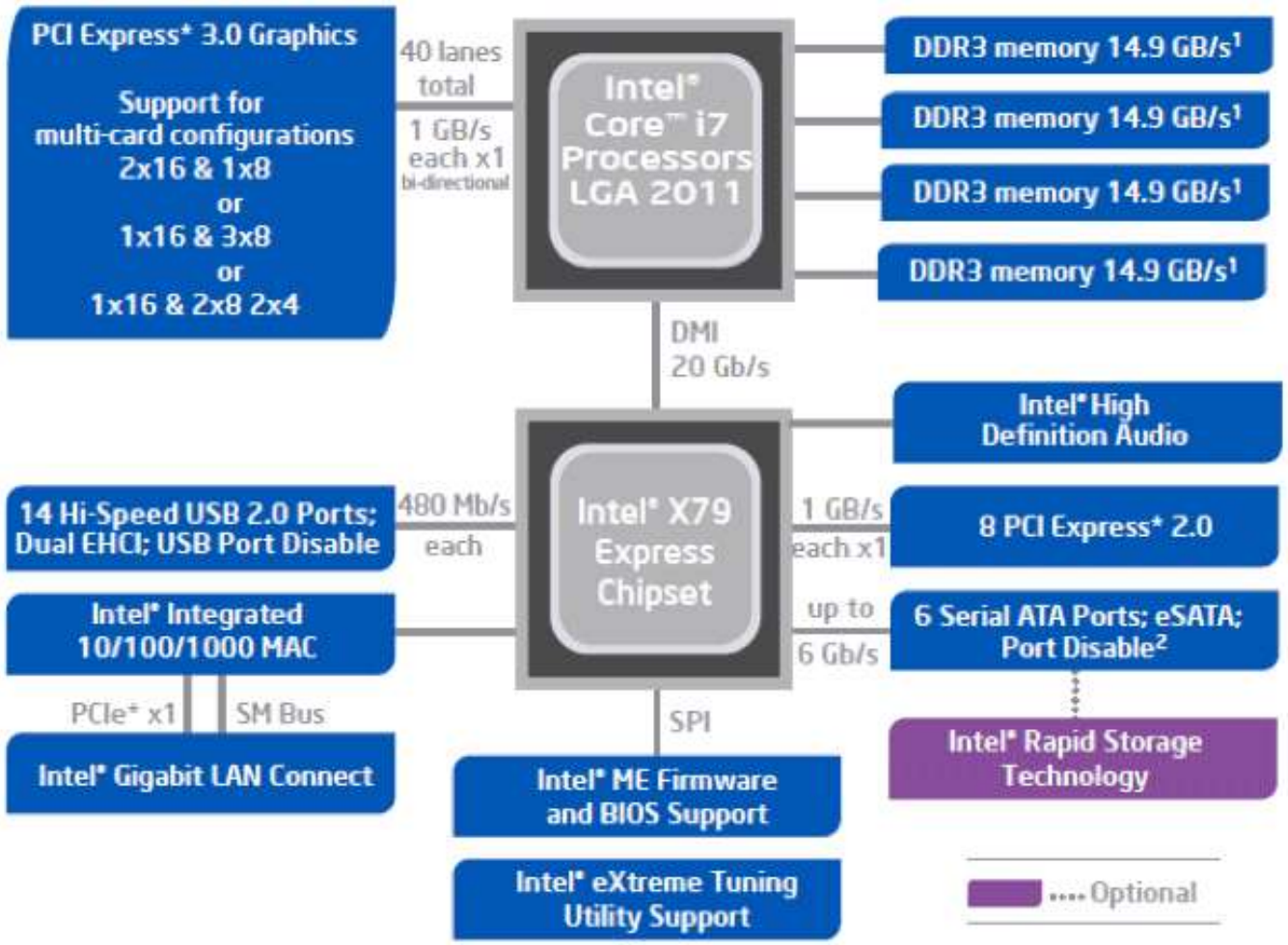


5.2 Differences to the previous Sandy Bridge-E line (4)

Die plot of an Ivy Bridge-E processor [15]

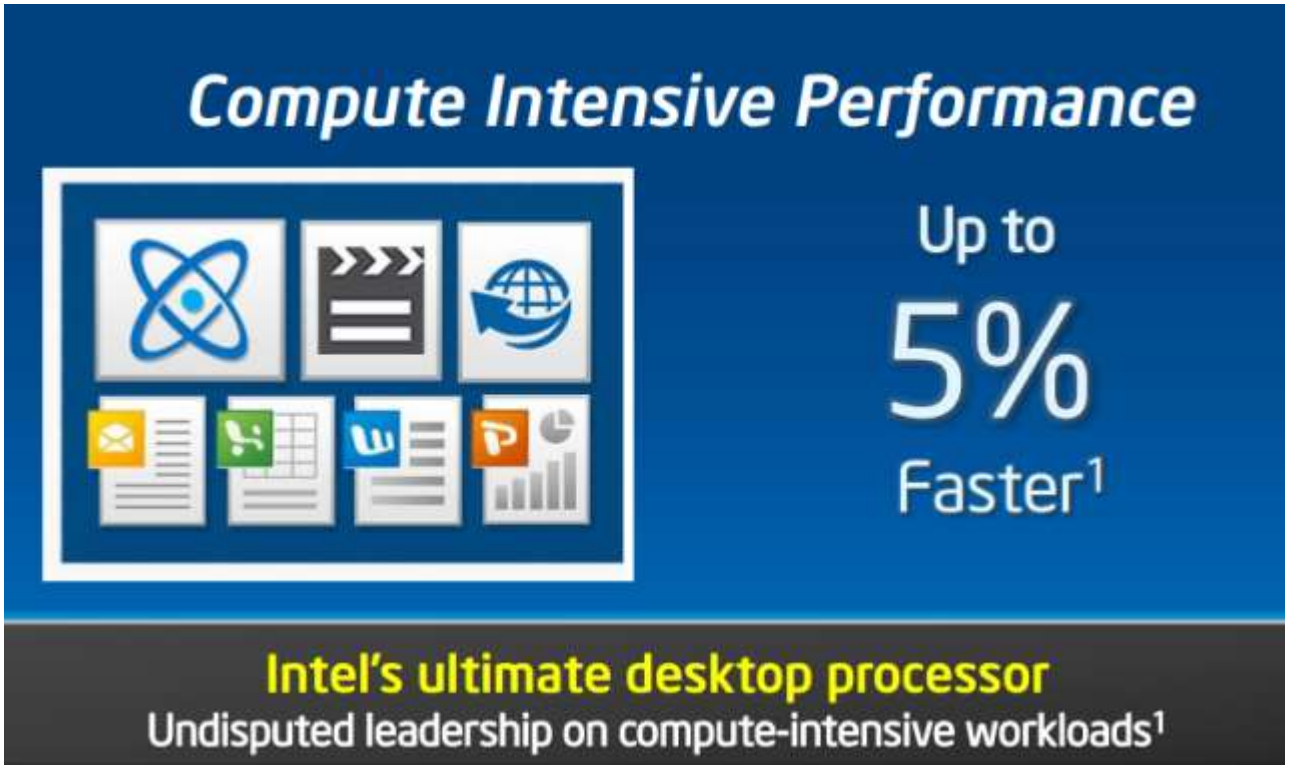


5.3 Example for an Ivy Bridge-E based HED platform with the X79 chipset [16]



[1] Theoretical maximum bandwidth
[2] All SATA ports capable of 3 Gb/s. 2 ports capable of 6 Gb/s.

5.4 Performance increase achieved by the Ivy Bridge E-Series vs. the previous Sandy Bridge E-Series [17]



6. The Haswell E-Series

- 6.1 Introduction
- 6.2 Differences to the Ivy Bridge E-Series
- 6.2.1 Overview
- 6.2.2 Integrated Voltage Regulator (IVR)
- 6.2.3 Haswell-E based system architecture
- 6.2.4 DDR4 memory
- 6.2.5 LGA 2011-3 socket

6.1 Introduction

- The Haswell-E line belongs to the 4. gen. Core processor family.
- Introduced in 08/2014.
- It targets HEDs (high performance desktops for hardcore gamers and graphics enthusiasts).
- It has up to 8 cores.
- It provides up to 40 configurable PCIe 3.0 lanes that enable attaching up to 4 graphics cards.

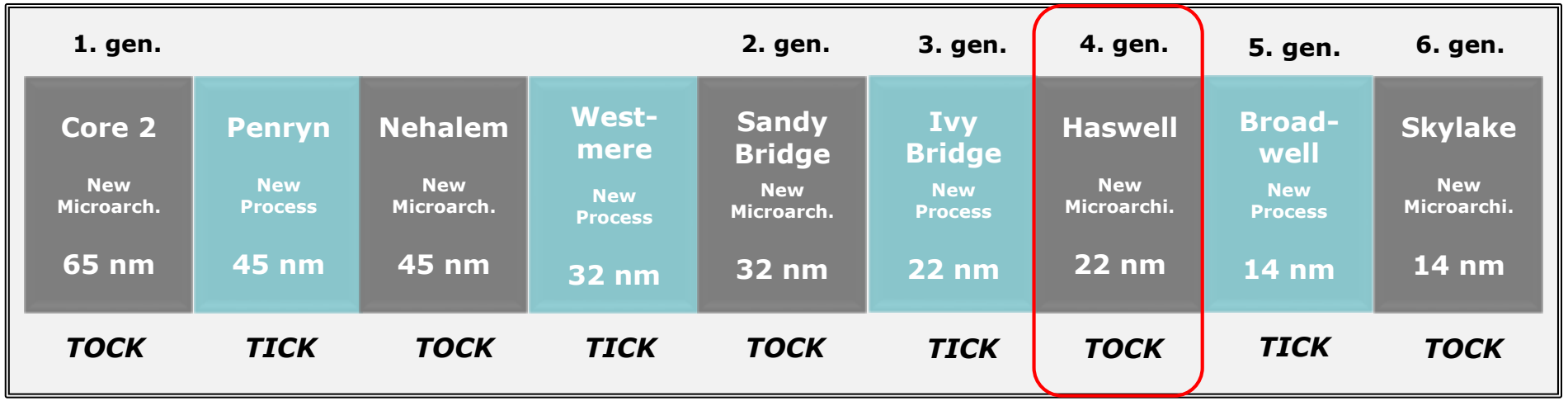
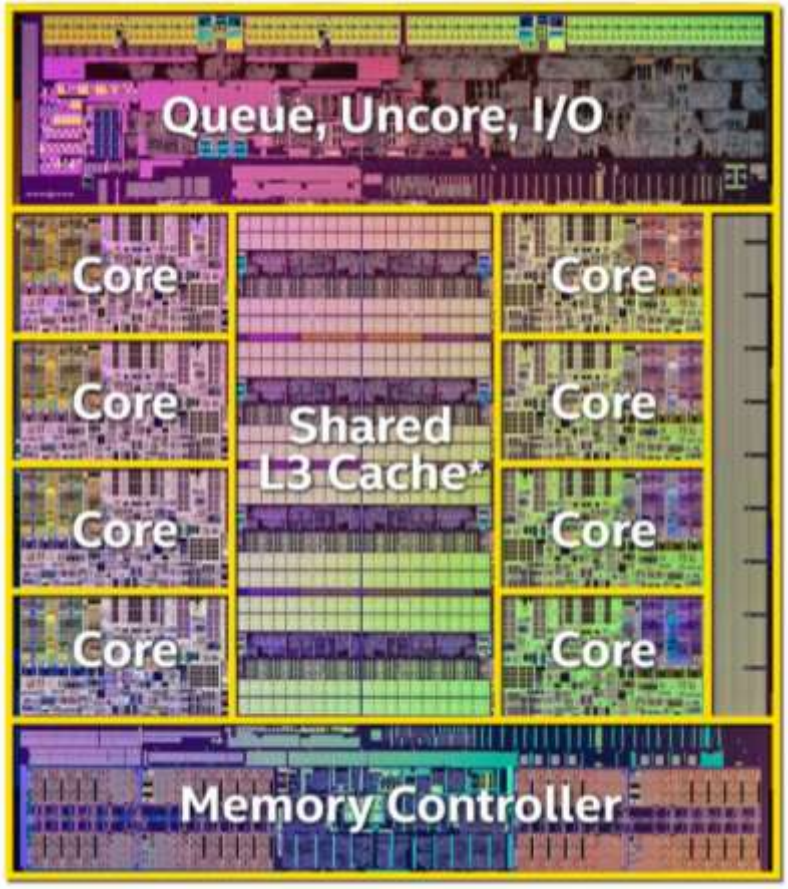


Figure: Intel's Tick-Tock development model (Based on [1])

Die plot of the 8-core Haswell-E i7-5960X [19]



Intel® Core™ i7-5960X Processor Extreme Edition
Transistor count: 2.6 Billion
Die size: 17.6mm x 20.2mm

For the six core models (the i7-5930K and the i7-5820K), one pair of cores is disabled; the pair which is disabled is not always the same, but is always one od the four left-to-right pair of the four rows.

6.1 Introduction (3)

Main features of available models of the Haswell E-Series [19]

Name	Cores/ Threads	Base clock	Turbo Boost	Multiplier	L2 cache	L3 cache	Memory channels	PCIe	TDP	Release Date	Price (US)
Core i7-5960X	8/16	3.0 GHz	3.5 GHz	Unlocked	256 KB /core private	2.5 MB/core shared (inclusive)	4 channels up to DDR4-2133	40 (PCIe 3.0)	140 W	08/2014	$999
Core i7-5930K	6/12	3.5 GHz	3.7 GHz								$550
Core i7-5820K		3.3 GHz	3.6 GHz								$396

6.2 Differences to the previous Ivy Bridge E-Series [18]

6.2.1 Overview

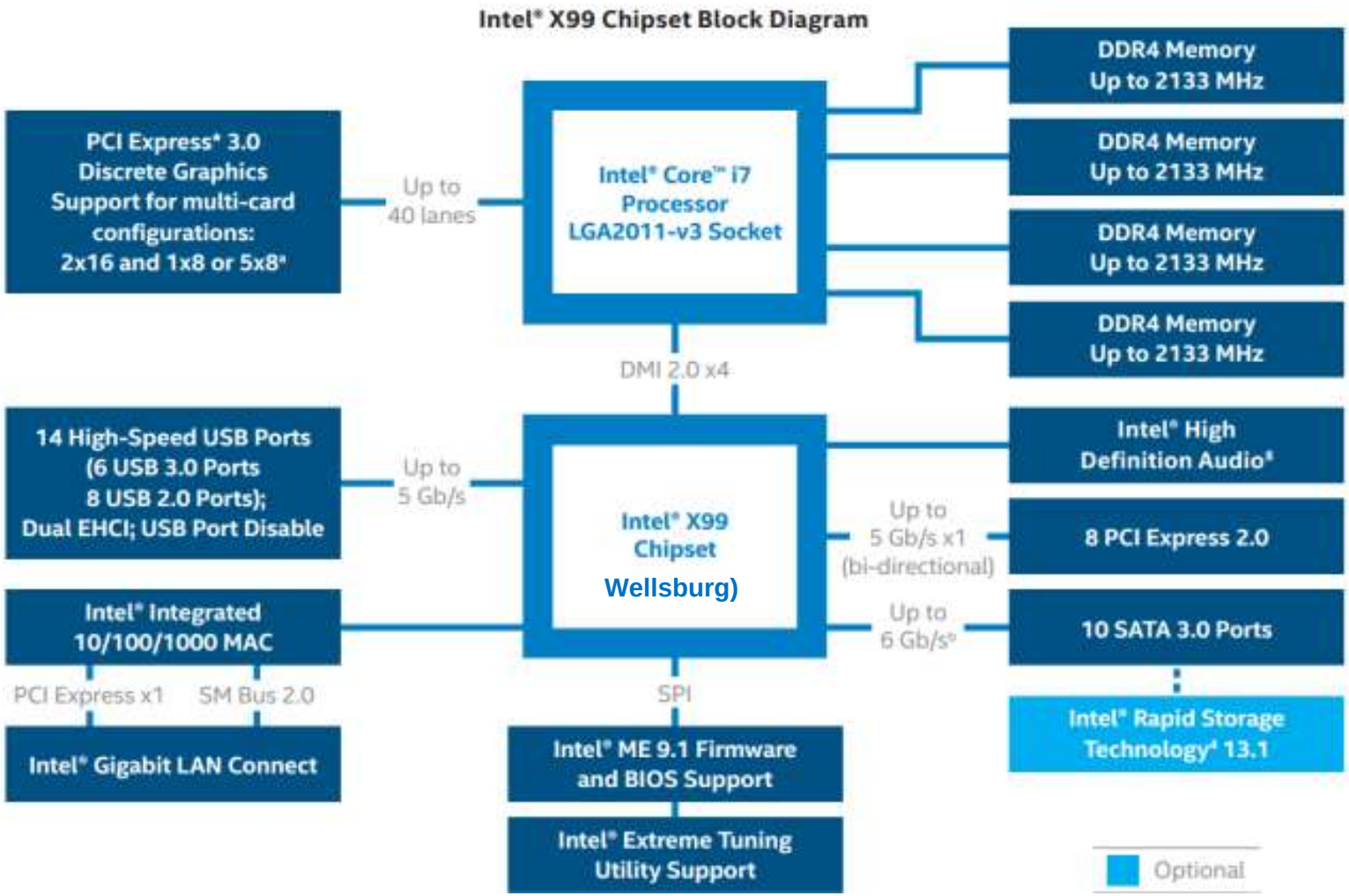
Feature	IVB-E	Haswell-E	Haswell
CPU Cores	6 and 4	**8** and 6	Up to 4
Shared Cache	Up to 15MB	**Up to 20 MB**	Up to 8 MB
PCIe Lanes off of processor	40	Up to 40	16
Discrete Gfx Configurations	2x16 / 4x8 of Gen 3 on processor	2x16 / 3x8 of Gen 3 on processor	1x16 / 2x8 of Gen 3
Integrated GPU	No	No	Yes
TDP	130 W	**130-140 W**	Up to 95 W
Socket	LGA 2011	**LGA 2011-3**	LGA 1155
Chipset Support	Patsburg	**Wellsburg**	Lynx Point
Technologies	SSE4, AVX, VT, AESNI	SSE4, AVX, VT, AESNI	SSE4, AVX, VT, AESNI
Memory	4 Channel DDR3 1866	**4 Channel DDR4 2133**	2 Channel DDR3 1600

6.2.2 Integrated Voltage Regulator (IVR) aka Fully Integrated Voltage Regulator (FIVR)

- FIVR was introduced in the Haswell basic architecture in 6/2013 and implemented in all categories, except of the high-end Haswell-X line.
- IVR allows to greatly simplify per-core voltage delivery for per-core P-state management, nevertheless, most Haswell lines do not make use of it.

  The only exception, worth mentioning is the Haswell-EP line (the Xeon e5-1600 v3 and E5-2600 v3 processors) that implements per-core P-state control.

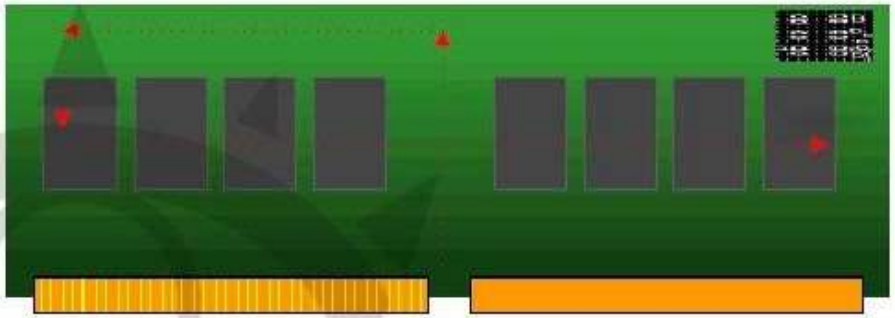
6.2.3 Haswell-E based system architecture [18]



6.2.4 DDR4 memory [18]

- **1.2V VDDQ**
  - Lower power
- **288 pin DIMM Connector**
  - Improved signal to ground ratio
  - 0.85 mm pin pitch
- **16 banks**
  - Performance
- **New power features**
  - Fine grain refresh control, Temp controlled refresh
- **Data bus signaling enhancement**
  - Per DRAM addressability, ODT improvements, VDDQ termination , External Vpp

Vpp : DRAM activating power supply (2.5V)



6.2.5 LGA 2011-3 socket [18]

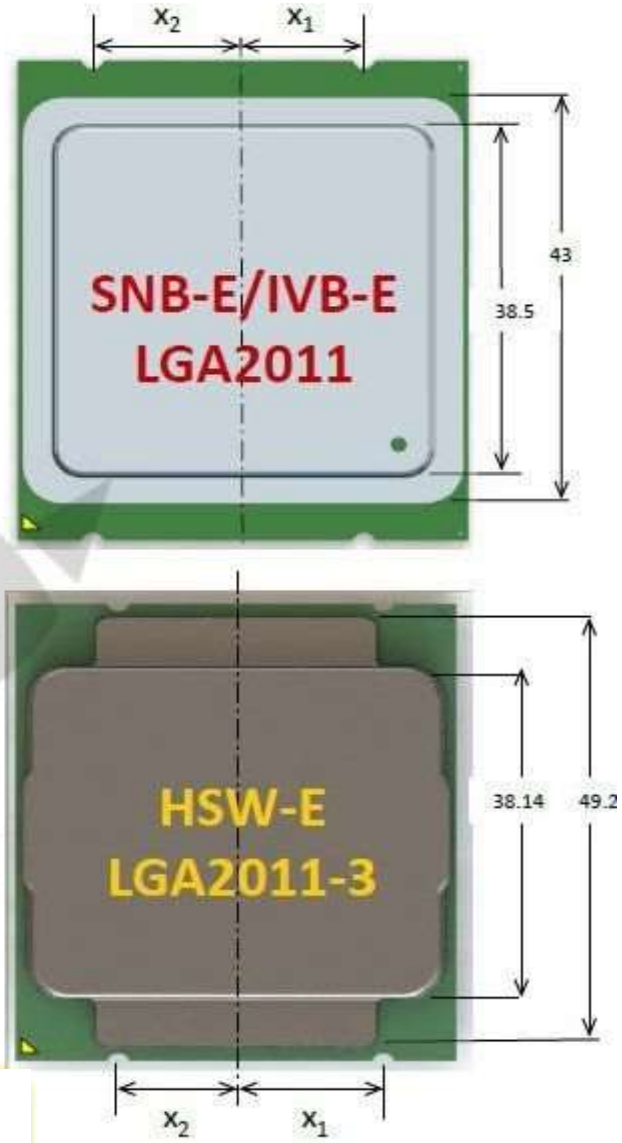
What's Same?

- **Same XY dimensions** as previous sockets (58.5 x 51.0 mm)
- **Same ball pattern pitch** (1.016 mm pitch (40 mil), hexagonal pitch)

What's Changing?

- **Keyed differently** than other R-derivative sockets
  - ILM key different (from LGA2011)
    - Ensures only LGA2011-3 ILMs are assembled with LGA2011-3 sockets
  - Processor keys relative to the y-axis have changed: left / right of center

Socket	x_1	x_2
LGA 2011-0	12	15
LGA 2011-3	14	13

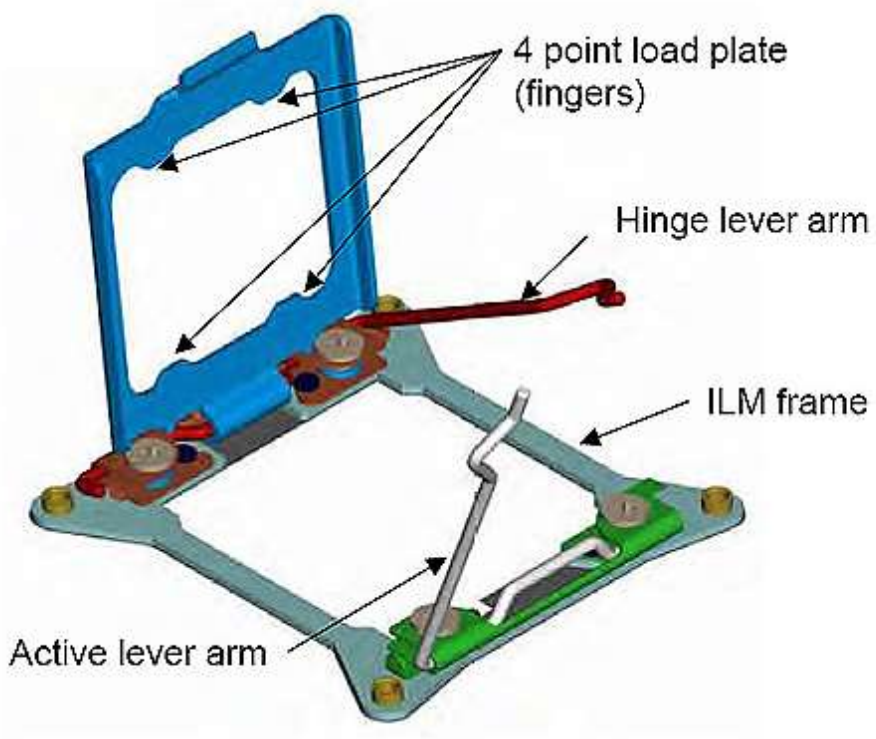


ILM: Independent Loading Mechanism

6.2.5 LGA 2011-3 socket (2)

Remark

The Independent Loading Mechanism (ILM) of Intel's LGA2011 socket [25]



7. The Brodwell E-Series

- 7.1 Introduction
- 7.2 Contrasting main feastures of Broadwell-E processor models with previous generations
- 7.3 Main features of Broadwell-E processor models
- 7.4 The Turbo Boost 3.0 Technology
- 7.5 Example: Broadwell-E based enthusiast's platform

7.1 Introduction

- The Broadwel E-Series belongs to the 5. gen. Core processor family.
- Introduced in 05/2016.
- It targets HEDs (high performance desktops for hardcore gamers and graphics enthusiasts).
- It has up to 10 cores.
- It provides up to 40 configurable PCIe 3.0 lanes that enables to attach up to 5 graphics cards[1].

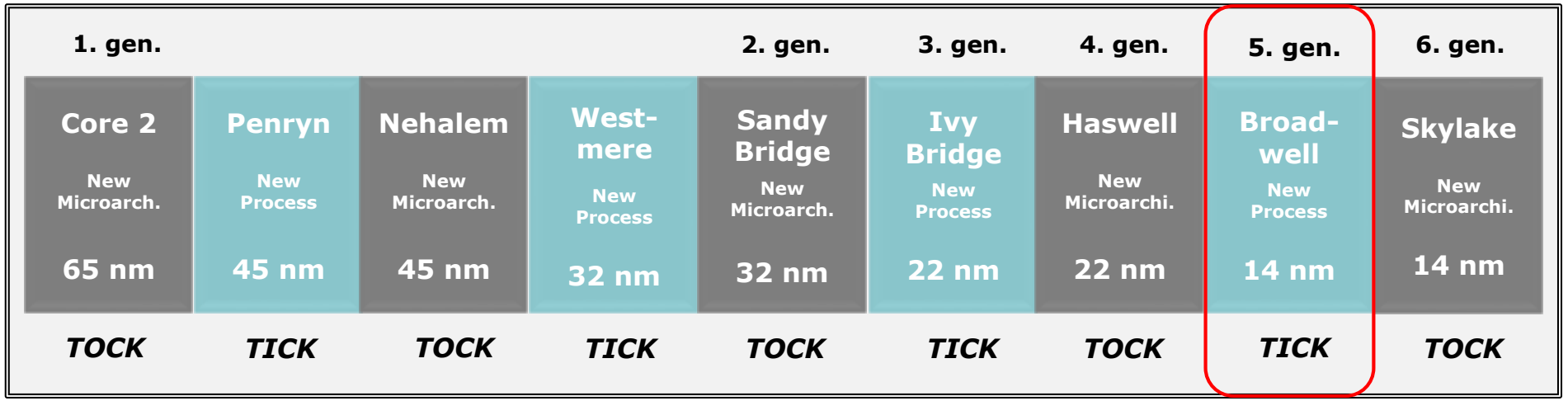
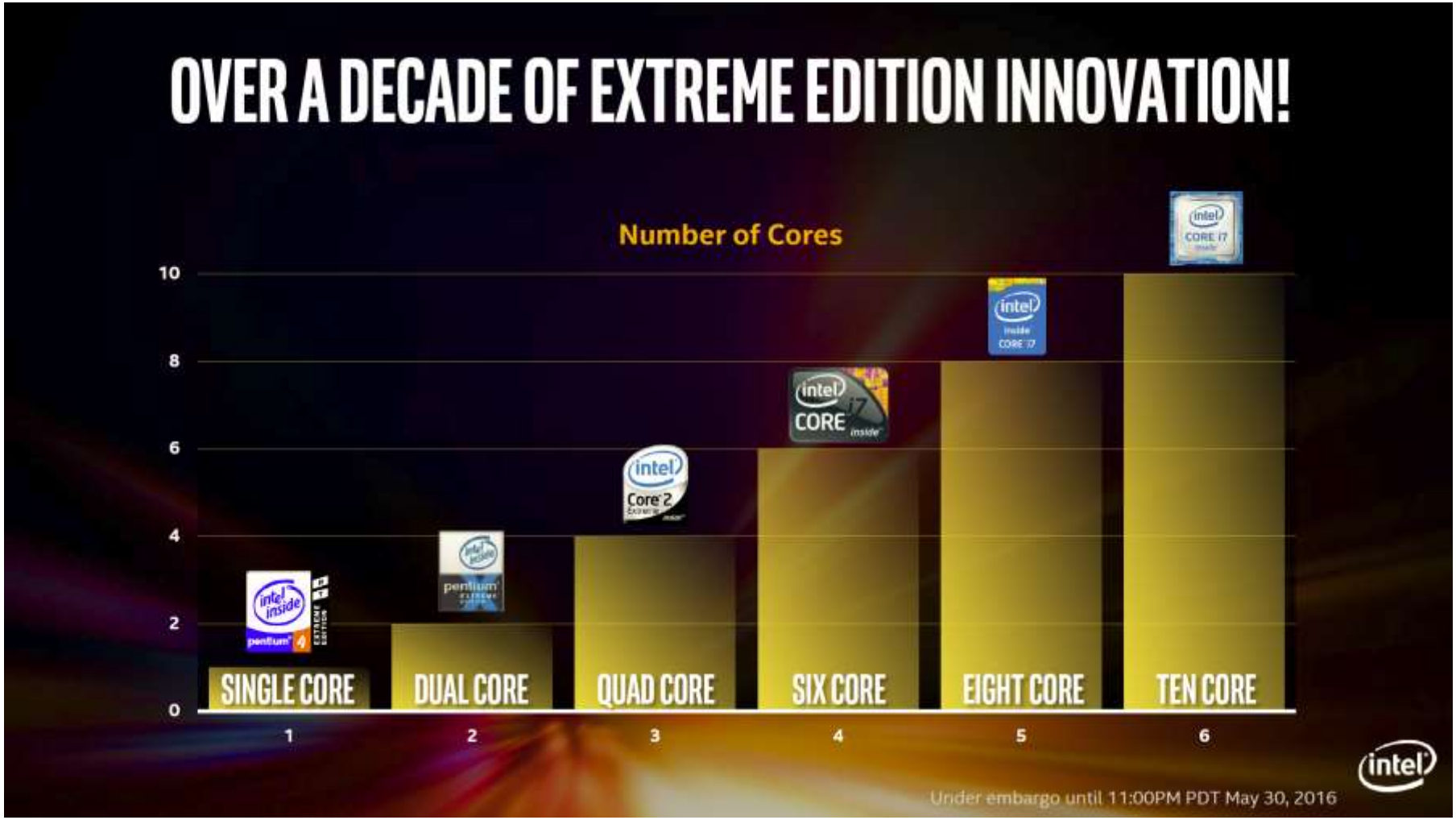


Figure: Intel's Tick-Tock development model (Based on [1])

[1]Requires addtional syytem clocks to be provided by third party components.

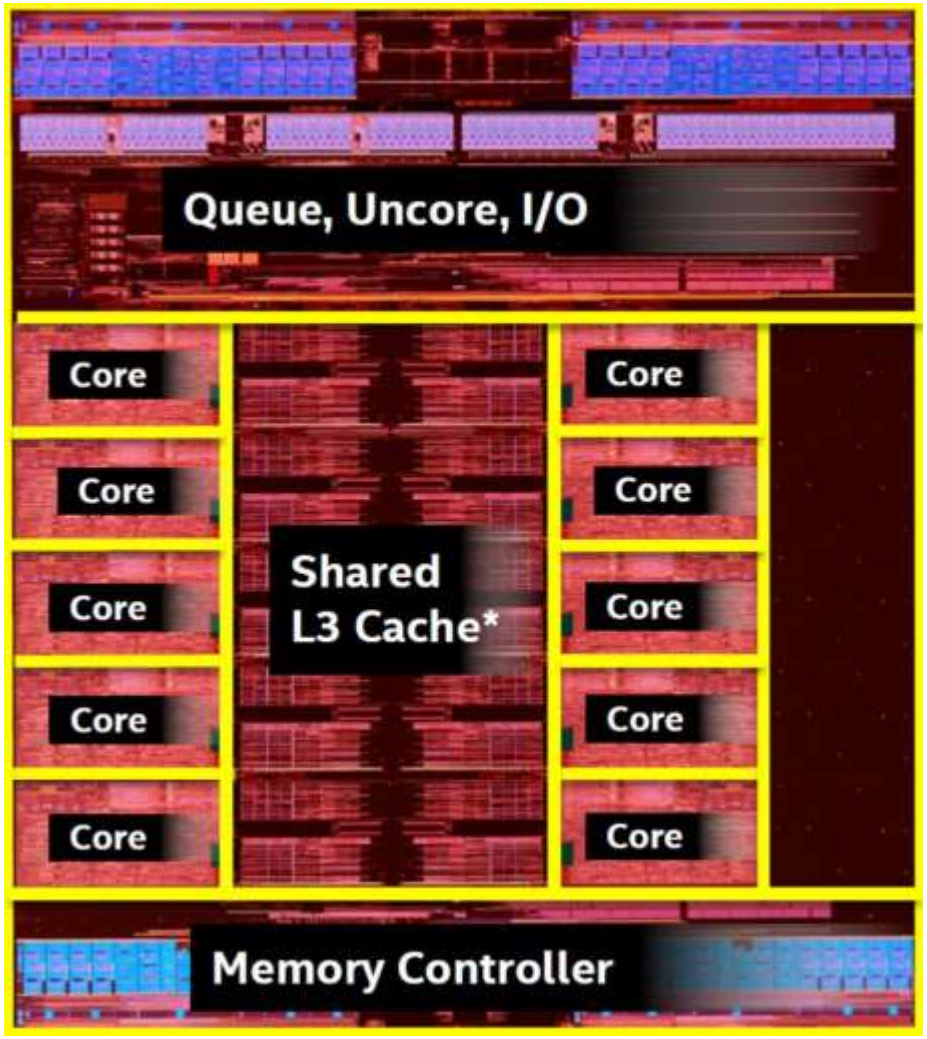
Evolution of the core count of HEDs up to the Broadwell E-Series [29]



Pentium 4 EE	Pentium EE	Nehalem-EE	Sandy Bridge-E Ivy Bridge-E	Haswell-E	Broadwell-E
(2004)	(2005)	(2008)	(2011/2013)	(2014)	(2016)

7.1 Introduction (3)

Die micrograph of the 10-core Broadwell-E 6950X model [26]



7.2 Contrasting main features of Broadwell-E processor models with previous generations [28]

Brand	Intel® Core™ i7 Processor / Intel® X99 Chipset		Intel® Core™ i7 Processor / Intel® X79 Chipset
Processor Family (Year)	BDW-E 2016	HSW-E 2014	IVB-E 2013
CPU Cores	**10**, 8 and 6	8 and 6	6 and 4
Intel® Turbo Boost Max Technology 3.0	**Yes**	No	No
Shared Cache	Up to **25MB**	Up to 20MB	Up to 15MB
PCIe* Lanes off of processor	Up to 40 (6800K has 28)	Up to 40 (5820K has 28)	40
Discrete GFX Configurations	2x16 / 5x8[1] of Gen 3 on processor	2x16 / 5x8[1] of Gen 3 on processor	2x16 / 4x8 of Gen 3 on processor
Memory	4 Channel DDR4 **2400**	4 Channel DDR4 2133	4 Channel DDR3 1866
TDP	140 W	140 W	130 W
Socket	LGA 2011-v3	LGA 2011-v3	LGA 2011
Unlocked	Yes	Yes	Yes

7.3 Main features of the Broadwell-E processor models [28]

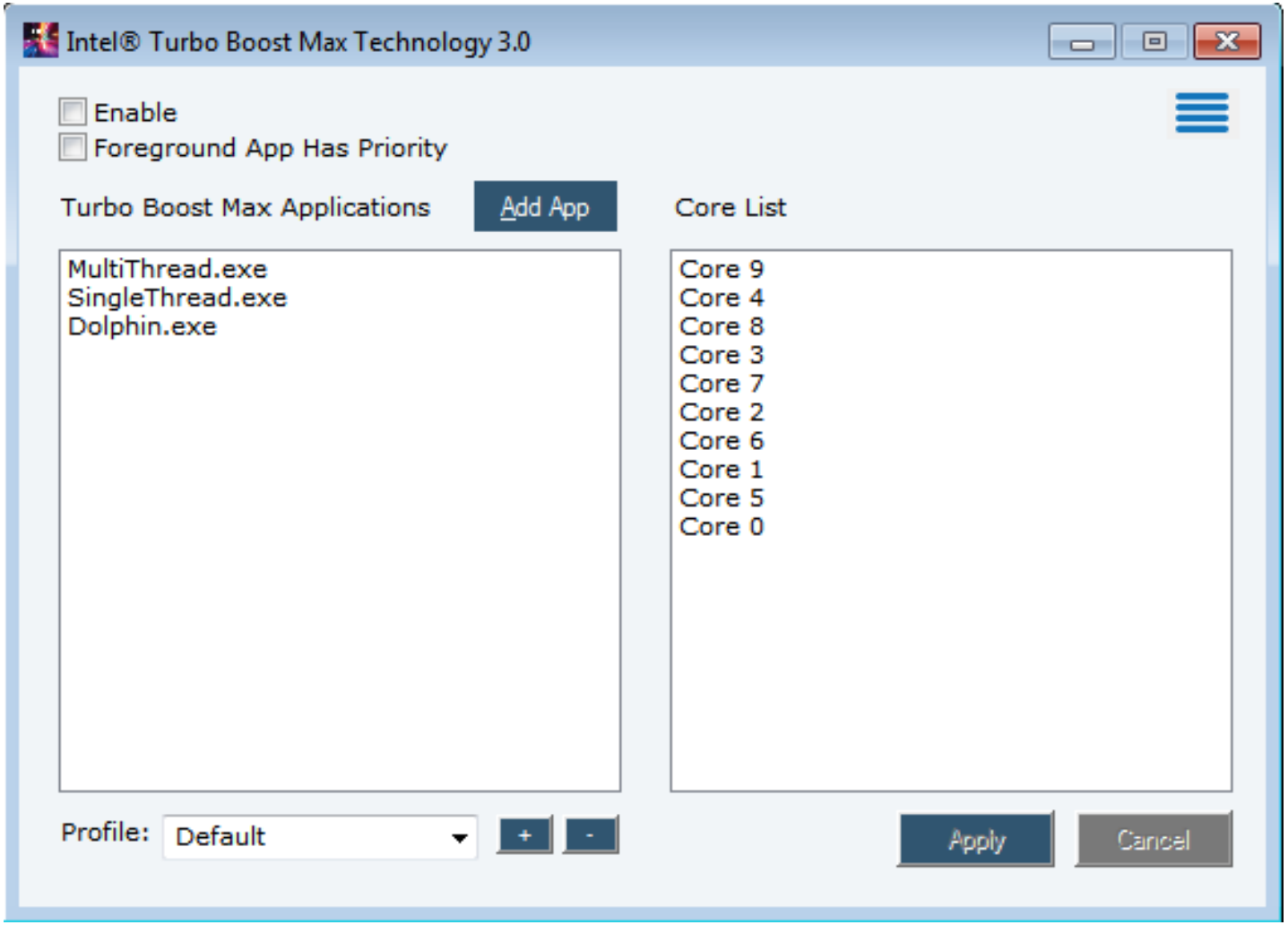
Intel® Core™ i7 Processor number	Base Clock Speed (GHz)	Intel® Turbo Boost Max Technology 3.0	Intel® Turbo Boost Technology 2.0 Frequency² (GHz)	Cores/ Threads	Cache	PCI Express* 3.0 Lanes	Memory Support	TDP	Socket (LGA)	Pricing (1K USD)
6950X NEW	3.0	Enabled	Up to 3.5	10/20	25MB	40	4 channels DDR4-2400	140W	2011-v3	$1723
6900K NEW	3.2	Enabled	Up to 3.7	8/16	20MB	40	4 channels DDR4-2400	140W	2011-v3	$1089
6850K NEW	3.6	Enabled	Up to 3.8	6/12	15MB	40	4 channels DDR4-2400	140W	2011-v3	$617
6800K NEW	3.4	Enabled	Up to 3.6	6/12	15MB	28	4 channels DDR4-2400	140W	2011-v3	$434
6700K	4.0	Not Supported	Up to 4.2	4/8	8MB	16	2 channels DDR4-2133 DDR3L-1600	91W	1150	$339
6600K	3.5	Not Supported	Up to 3.9	4/4	6MB	16	2 channels DDR4 2133 DDR3L-1600	91W	1150	$242

7.4 The Turbo Boost 3.0 (aka Turbo Boost Max 3.0) Technology [27] -1

- It is an enhancement to the Turbo Boost 2.0 technology introduced in the Sandy Bridge microarchitecture and used also in the Broadwell-E line.
- The Turbo Boost 2.0 technology raises the base frequency of all active cores in case of a light workload as far as the TDP allows it.
- By contrast the Turbo Boost 3.0 technology aims at increasing the performance of single threaded applications.
- To achieve this, during processor testing Intel determines the max. clock speeds of all cores and arrranges the cores into a list according to their max clock speed, as seen in the next Figure, where core 9 is the highest speed core.

7.4 The Turbo Boost 3.0 technology (2)

Example core speed list used in the Turbo Boost 3.0 mode [27]



7.4 The Turbo Boost 3.0 (aka Turbo Boost Max 3.0) Technology [27] -2

- The core list is written into the processor (presumable into an MSR).
  For single threaded workloads the fastest core (termed the favored core) will be activated.
- Turbo Boost 3 requires a special driver which should be distributed in X99 motherboard driver packages and later on also in the Windows 10.

Intel claims that using Turbo Boost 3.0 in Broadwell-E can boost the performance of single-threaded applications by about 15 % [294], as seen in the next Table.

7.4 The Turbo Boost 3.0 technology (4)

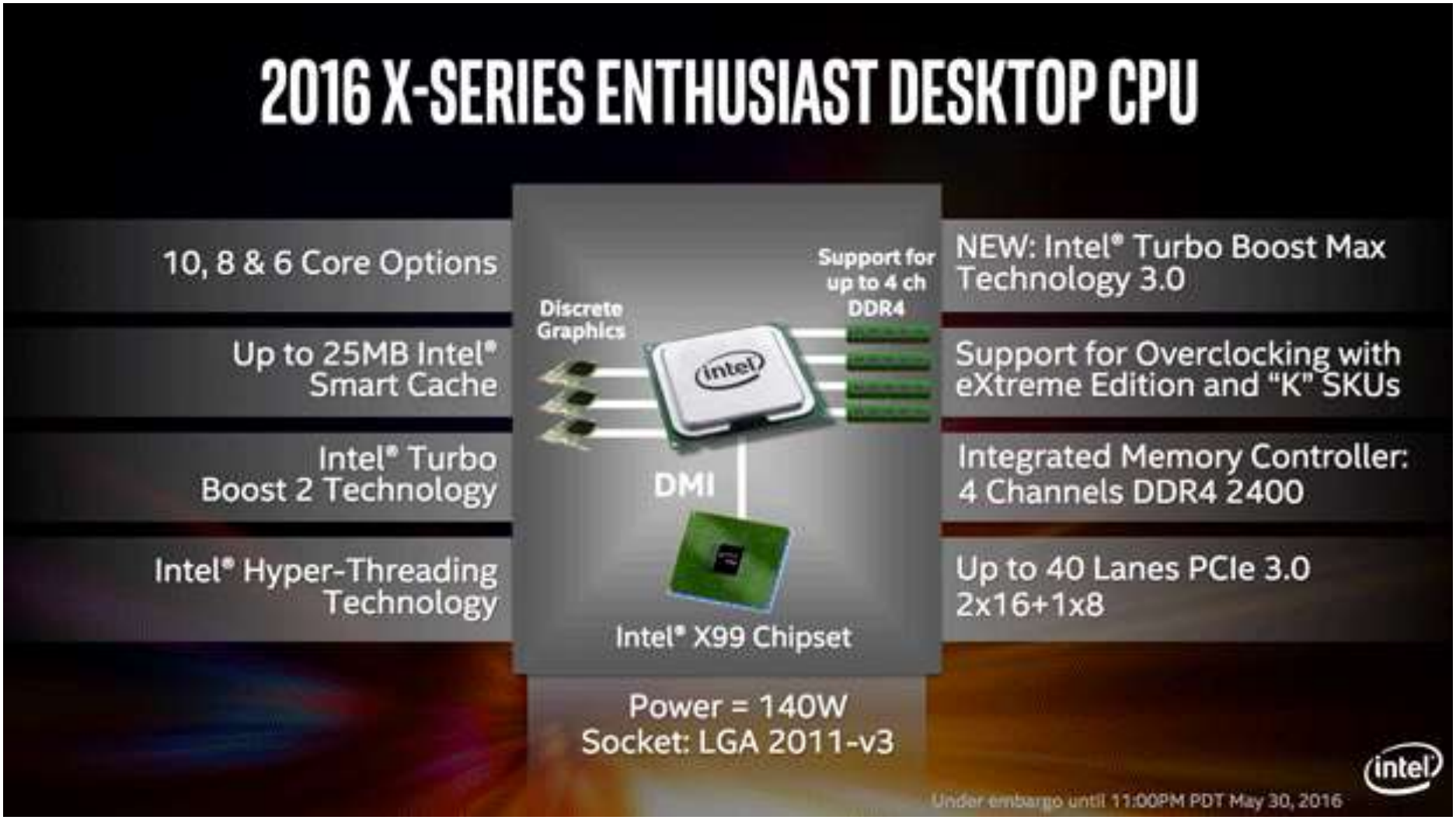
Turbo 2.0 and Turbo 3.0 clock frequencies of the Broadwell-E models [39]

	Cores/threads	Base clock GHz	Turbo 2.0 clock GHz	Turbo 3.0 clock Ghz
I7-6950X	10/20	3.0	3.5	4.0
I7-6900K	8/16	3.2	3.7	4.0
I7-6850K	6/12	3.6	3.8	4.0
I7-6800K	6/12	3.4	3.6	3.8

Remarks to the Turbo Boost Max 3.0 technology

- In practice, motherboard manufacturers often didn't support it or they do disable it in the BIOS by default.
- If users intend to make use of it they have to install the drivers and the BIOS as well.

7.5 Example: Broadwell-E based enthusiast's platform with the X99 chipset [40]



8. The Skylake X-Series

- 8.1 Introduction to the Basin Falls (X299 PCH-based) platform
- 8.2 Introduction to the Skylake X-Series
- 8.3 Key innovations of the Skylake X-Series
- 8.4 Performance assessment of the Skylake-X Series

8.1 Introduction to the Basin Falls (X299 PCH-based) platform

8.1 Introduction to the Basin Falls (X299 PCH-based) platform

- Announced in 5/2017 launched in 7/2017.
- It targets enthusiast gaming, VR, content creation and overlocking.
- At its introduction the platform is based on two Caby Lake-X and three Skylake-X processor models as well as the X299 PCH.
- The processors are manufactured on the 14 nm+ technology whereas the PCH on 22 nm.
- Above processor series include Intel's new powerful, scalable high-end desktop (HED) processor models that scale from 4 cores to 18 cores.
- These processors (as all E-Series processors) do not incorporate integrated graphics but are used along with discrete graphics cards.
- The new processors are launched to compete with AMD's Ryzen and ThreadRipper lines that incorporate 4 to 16 cores.

8.1 Introduction to the Basin Falls (X299 PCH-based) platform (2)

Overview of the processor models of the Kaby Lake X and Skylake X-Series

The Kaby Lake X-Series (2-chip designs, no integrated graphics, unlocked, LGA2066, Z299 chipset)

112 Watt X-Series

Core i7-7740X, 4C, HT, 6/2017
Core i5-7640X, 4C no HT, 6/2017

The Skylake X-Series (2-chip designs, no integrated graphics, unlocked, LGA2066, Z299 chipset)

140 Watt X-Series

Core i9-7920X, 12C, HT, 9/2017
Core i9-7900X, 10C, HT, 8/2017
Core i7-7820X, 8C, i7-7800X 6C, HT, 6/2017

165 Watt X-Series

Core i9-7980XE, 18C, i9-7960X, 16C, i9-7940X 14C, HT, 9/2017

8.1 Introduction to the Basin Falls (X299 PCH-based) platform (3)

Line-up of the Kaby Lake X and Skylake X-Series processors [38]

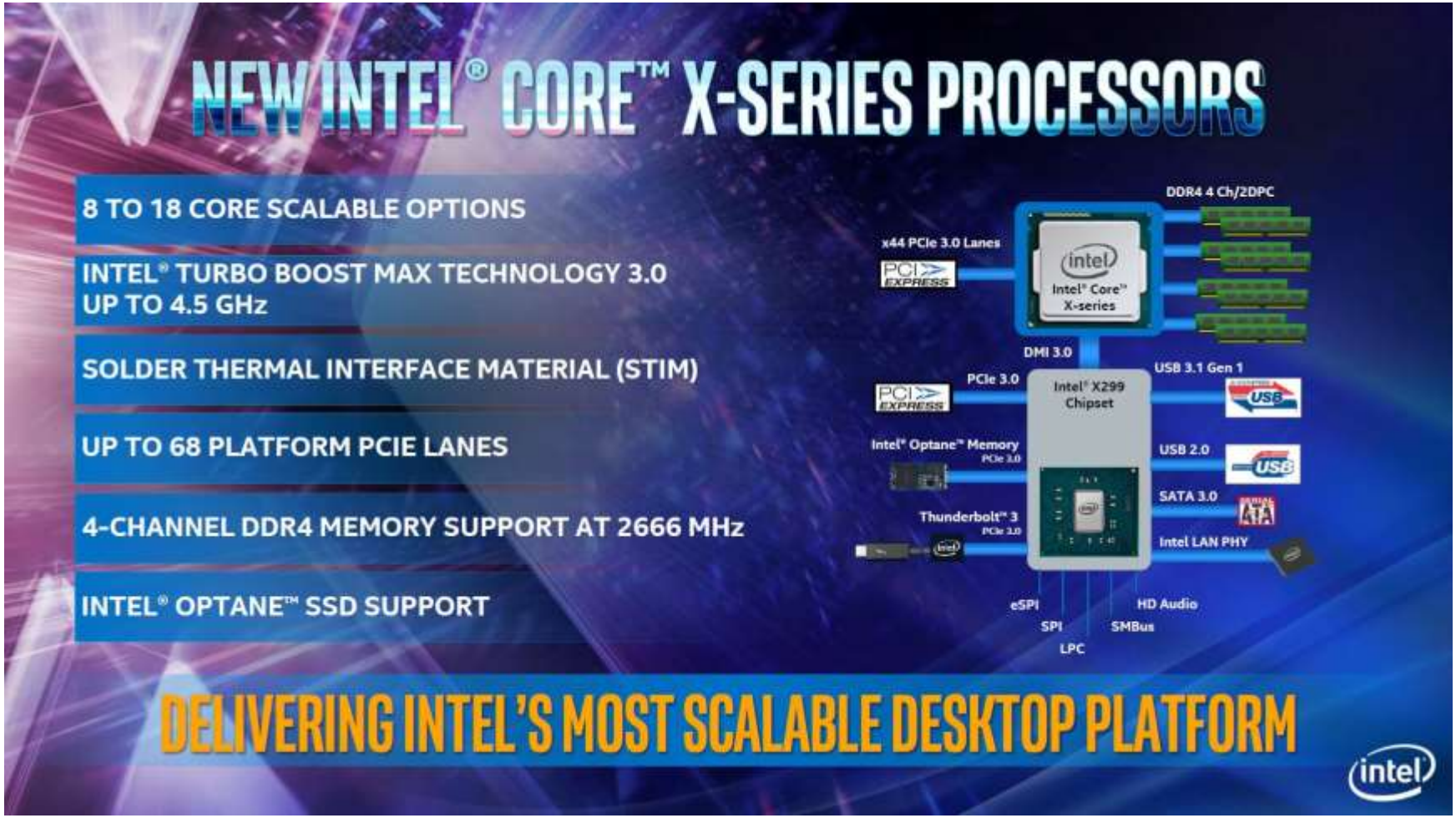
8.1 Introduction to the Basin Falls (X299 PCH-based) platform (4)

Platform comparison: Basin Falls vs. Broadwell-E and Haswell-W [38]

Brand	New Intel® Core™ X-series processor/ Intel® X299 chipset		Intel® Core™ X-series processor/ Intel® X99 chipset	Intel® Core™ X-series processor/ Intel® X99 chipset
Processor family (year)	SKL-X 2017	KBL-X 2017	BDW-E 2016	HSW-E 2014
CPU cores	18, 16, 14, 12, 10, 8, and 6	4	10, 8, and 6	8 and 6
Intel® Turbo Boost Max technology 3.0	Yes[1]	No	Yes	No
Shared cache	Up to 24.75 MB[2]	Up to 8 MB	Up to 25 MB	Up to 20 MB
PCIe lanes off of processor	Up to 44 (7800X & 7820X have 28)[3]	16	Up to 40 (6800K has 28)[3]	Up to 40 (6800K has 28)[3]
Discrete GFX configurations	2x16/4x8[4] of gen. 3 on processor	1x16/2x8 of gen. 3 on processor	2x16/4x8[4] of gen. 3 on processor	2x16/4x8[4] of gen. 3 on processor
Memory	Four-channel DDR4 2666[1]	Two-channel DDR4 2666	Four-channel DDR4 2400	Four-channel DDR4 2133
TDP	165W, 140W	112W	140W	140W
Socket	LGA 2066	LGA 2066	LGA 2011-v3	LGA 2011-v3
Unlocked	Yes	Yes	Yes	Yes

1. Not available on all SKUs.
2. See rebalancing cache hierarchy slide for details.
3. Motherboards must be Thunderbolt™ technology ready.
4. Requires additional system clocks to be provided by third-party components.

Key features of the Core X-Series (Basin Falls) processors [41]



8.1 Introduction to the Basin Falls (X299 PCH-based) platform (6)

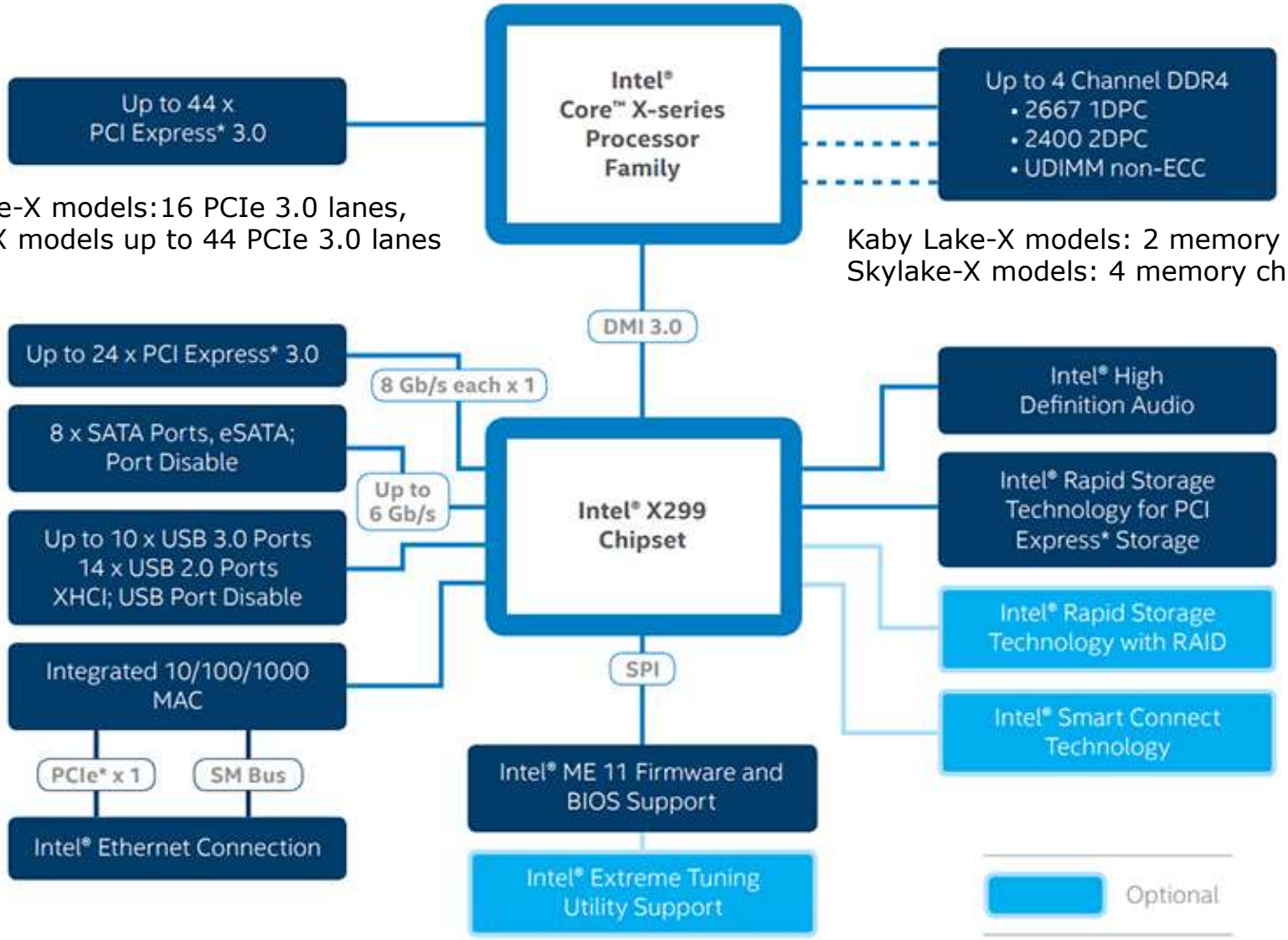
Main features of the Kaby Lake X and Skylake X processor models (Processors of the Basin Falls platform) [38]

Processor number[1]	Base clock speed (GHz)	Intel® Turbo Boost Technology 2.0 frequency[2] (GHz)	Intel® Turbo Boost Max Technology 3.0 Freqency[3] (GHz)	Cores/ threads	L3 cache	PCI express 3.0 lanes	Memory support	TDP	Socket (LGA)	RCP Pricing (1K USD)
i9-7980XE NEW	2.6	4.2	4.4	18/36	24.75 MB	44	Four channels DDR4-2666	165W	2066	$1,999
i9-7960X NEW	2.8	4.2	4.4	16/32	22 MB	44	Four channels DDR4-2666	165W	2066	$1,699
i9-7940X NEW	3.1	4.3	4.4	14/28	19.25 MB	44	Four channels DDR4-2666	165W	2066	$1,399
i9-7920X NEW	2.9	4.3	4.4	12/24	16.5 MB	44	Four channels DDR4-2666	140W	2066	$1,199
i9-7900X NEW	3.3	4.3	4.5	10/20	13.75 MB	44	Four channels DDR4-2666	140W	2066	$999
i7-7820X NEW	3.6	4.3	4.5	8/16	11 MB	28	Four channels DDR4-2666	140W	2066	$599
i7-7800X NEW	3.5	4.0	NA	6/12	8.25 MB	28	Four channels DDR4-2400	140W	2066	$389
i7-7740X NEW	4.3	4.5	NA	4/8	8 MB	16	Two channels DDR4-2666	112W	2066	$339
i5-7640X NEW	4.0	4.2	NA	4/4	6 MB	16	Two channels DDR4-2666	112W	2066	$242

1. Intel processor numbers are not a measure of performance. Processor numbers differentiate features within each processor family, not across different processor families. See intel.com/products/processor_number for details.
2. Refers to the maximum dual-core frequency that can be achieved with Intel® Turbo Boost Technology 2.0.
3. Refers to the maximum dual-core frequency that can be achieved with Intel® Turbo Boost Max Technology 3.0

8.1 Introduction to the Basin Falls (X299 PCH-based) platform (7)

The Basin Falls platform with the X299 chipset [30]



Kaby Lake-X models:16 PCIe 3.0 lanes,
Skylake-X models up to 44 PCIe 3.0 lanes

Kaby Lake-X models: 2 memory channels,
Skylake-X models: 4 memory channels

8.1 Introduction to the Basin Falls (X299 PCH-based) platform (8)

Main features of the X299 chipset of the Basin Falls platform [38]

INTEL® X299 CHIPSET

Redefines the enthusiast desktop experience

INCREASED SYSTEM RESPONSIVENESS

Intel® Optane™ memory ready[1]

Faster throughput times with DMI 3.0[2]

IMPROVED I/O CAPABILITIES

30 total high-speed I/O lanes with increased port flexibility:

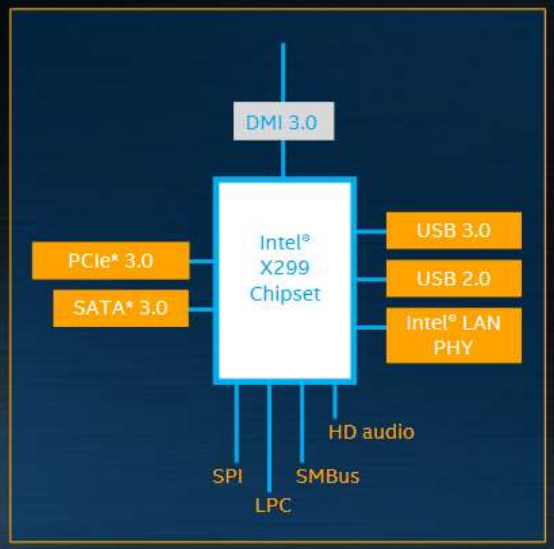
- Up to 24 PCIe 3.0 lanes
- Up to 8 SATA 3.0 ports
- Up to 10 USB 3.0 ports

Up to three Intel® Rapid Storage Technology PCIe 3.0 x4 storage support

Supports Intel® Ethernet Connection I219 (Jacksonville LAN PHY)

ULTIMATE SCALABILITY

New Socket R4 (LGA 2066) – compatible with all new Intel® Core™ X-series processors (4C–18C)



1. Compared to HDD alone.
2. Compared to Intel® X99 Chipset.

Software and workloads used in performance tests may have been optimized for performance only on Intel microprocessors. Performance tests, such as SYSmark and MobileMark, are measured using specific computer systems, components, software, operations and functions. Any change to any of those factors may cause the results to vary. You should consult other information and performance tests to assist you in fully evaluating your contemplated purchases, including the performance of that product when combined with other products. For more information, go to http://www.intel.com/performance.

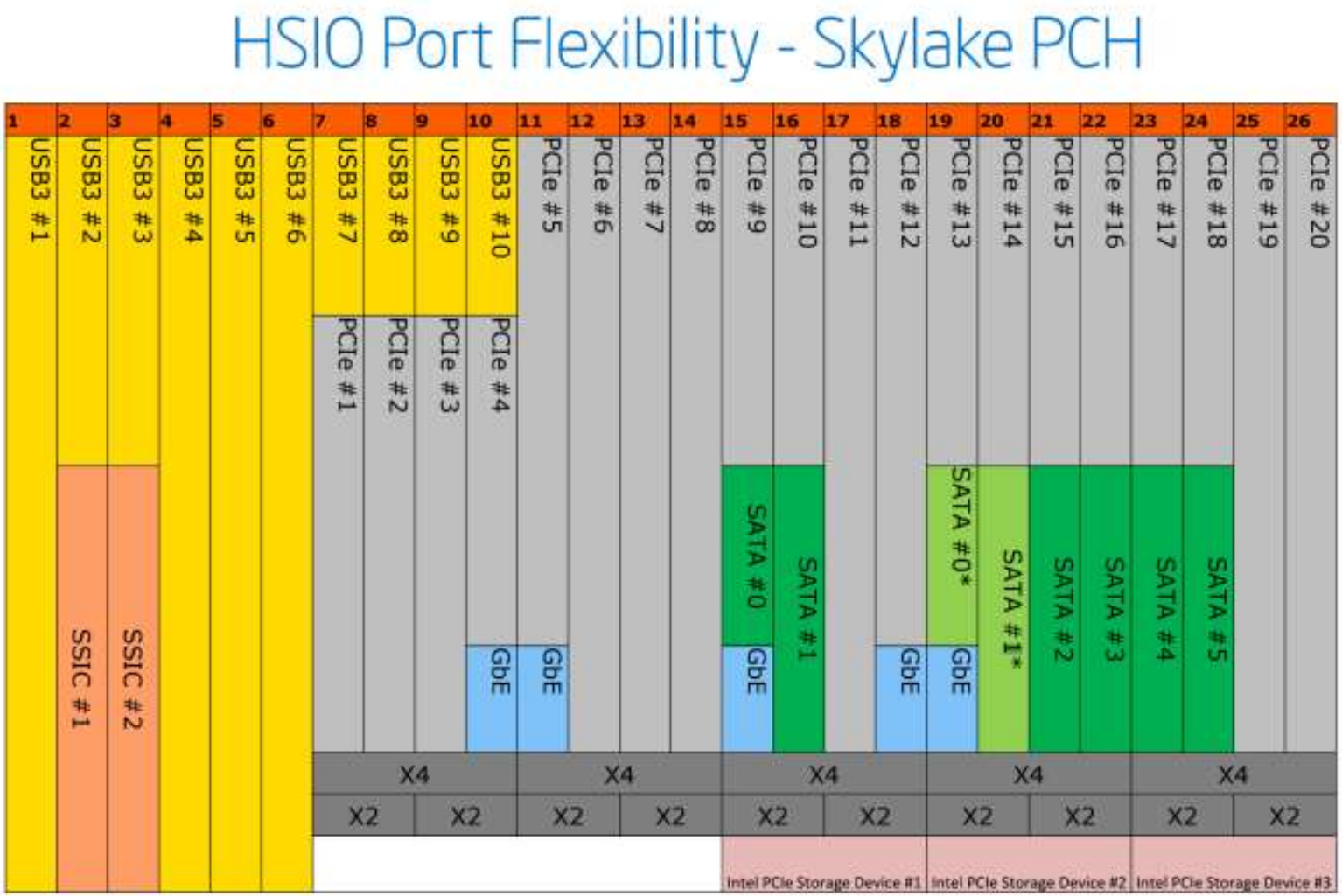
8.1 Introduction to the Basin Falls (X299 PCH-based) platform (9)

Remark

- In the Z299 PCH Intel makes use of the HSIO concept.
- HSIO (High-Speed I/O) lanes of the PCH are a lower level layer beneath the PCIe layer.
- It provides flexibility (in given limits) in implementing I/O-lanes, like USB lanes, PCIe lanes or SATA lanes to the OEMs.
- As indicated in the next Figure (for the Z170 PCH), HSIO lanes can be flexibly configured.

8.1 Introduction to the Basin Falls (X299 PCH-based) platform (10)

Port flexibility on the Z170 PCH lanes [42]



Suggested liquid cooling solution for the Core X-Series from Intel [38]

INTEL® LIQUID COOLING TS13X

HIGH-PERFORMANCE THERMAL SOLUTION FOR ENTHUSIASTS

Separate boxed SKU available from distribution and at retail

Fan speed	800–2,200 RPM (four-wire PWM)
Fan dimensions	120 mm x 120 mm x 25 mm
Fan CFM	73.84 CFM
Unit noise level	21 dBA @ 800 RPM 35 dBA @ 2,200 RPM
Radiator dimensions	150 mm x 118 mm x 37 mm
Pump Z height	31 mm
Total thermal solution weight	820 grams
Cooling liquid	Propylene glycol
Thermal interface material	Dow Corning* TC-1996

Compatible with socket 2011/1366/115X
Estimated retail pricing $85–$100

8.2 Introduction to the Skylake X-Series

8.2 Introduction to the Skylake X-Series -1

- Manufactured on 14 nm technology.
- Launched in three waves from 06/2017 to 09/2017 as follows:
  - the 6/8/10-core models in 06/2017
  - the 12-core model in 08/2017 and
  - the 14/16/18-core models in 09/2017.

8.2 Introduction to the Skylake X-Series (2)

Main features of the Skylake-X models [43]

Skylake-X Processors							
	7800X	7820X	7900X	7920X	7940X	7960X	7980XE
Silicon	LCC			HCC			
Cores / Threads	6/12	8/16	10/20	12/24	14/28	16/32	18/36
Base Clock / GHz	3.5	3.6	3.3	2.9	3.1	2.8	2.6
Turbo Boost 2.0/ GHz	4.0	4.3	4.3	4.3	4.3	4.2	4.2
TurboMax 3.0/ GHz (see Note)	N/A	4.5	4.5	4.4	4.4	4.4	4.4
L3	1.375 MB/core			1.375 MB/core			
PCIe Lanes	28		44	44			
Memory Channels	4			4			
Memory Freq DDR4	2400	2666		2666			
TDP	140W			140W	165W		
Launched	6/2017	6/2017	6/2017	8/2017	9/2017	9/2017	9/2017
Price	$389	$599	$999	$1199	$1399	$1699	$1999

8.2 Introduction to the Skylake X-Series (3)

Turbo 2.0 frequencies of Skylake-X processor models for different core loadings [43]

Intel LGA2066 Non-AVX Turbo Frequencies																				
AnandTech	Cores	LLC	TDP	Base	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Core i9 7980XE	18	24.75	165	2.60	4.2	4.2	4.0	4.0	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.5	3.5	3.5	3.5	3.4	3.4
Core i9 7960X	16	22.00	165	2.80	4.2	4.2	4.0	4.0	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.6	3.6	3.6	3.6		
Core i9 7940X	14	19.25	165	3.10	4.3	4.3	4.1	4.1	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	3.8	3.8				
Core i9 7920X	12	16.50	140	2.90	4.3	4.3	4.1	4.1	4.0	4.0	4.0	4.0	3.8	3.8	3.8	3.8						
Core i9 7900X	10	13.75	140	3.30	4.3	4.3	4.1	4.1	4.0	4.0	4.0	4.0	4.0	4.0								
Core i7 7820X	8	11.00	140	3.60	4.3	4.3	4.1	4.1	4.0	4.0	4.0	4.0										
Core i7 7800X	6	8.25	140	3.50	4.0	4.0	4.0	4.0	4.0	4.0												
Core i7 7740X	4	8.00	112	4.00	4.5	4.5	4.5	4.5														
Core i5 7640X	4	6.00	112	4.30	4.4	4.4	4.4	4.4														

Skylake-X

Kaby-X

8.2 Introduction to the Skylake X-Series (4)

Note -1

- With the Turbo Boost Max 3.0 (aka TurboMax 3.0 or Turbo Boost 3.0) technology max. speeds of all cores are measured while the processor is tested, and the cores are arranged into a list according to their speed, called the Core list, with the fastest core at the top.
- This list is stored in an MSR (Model Specific Register).

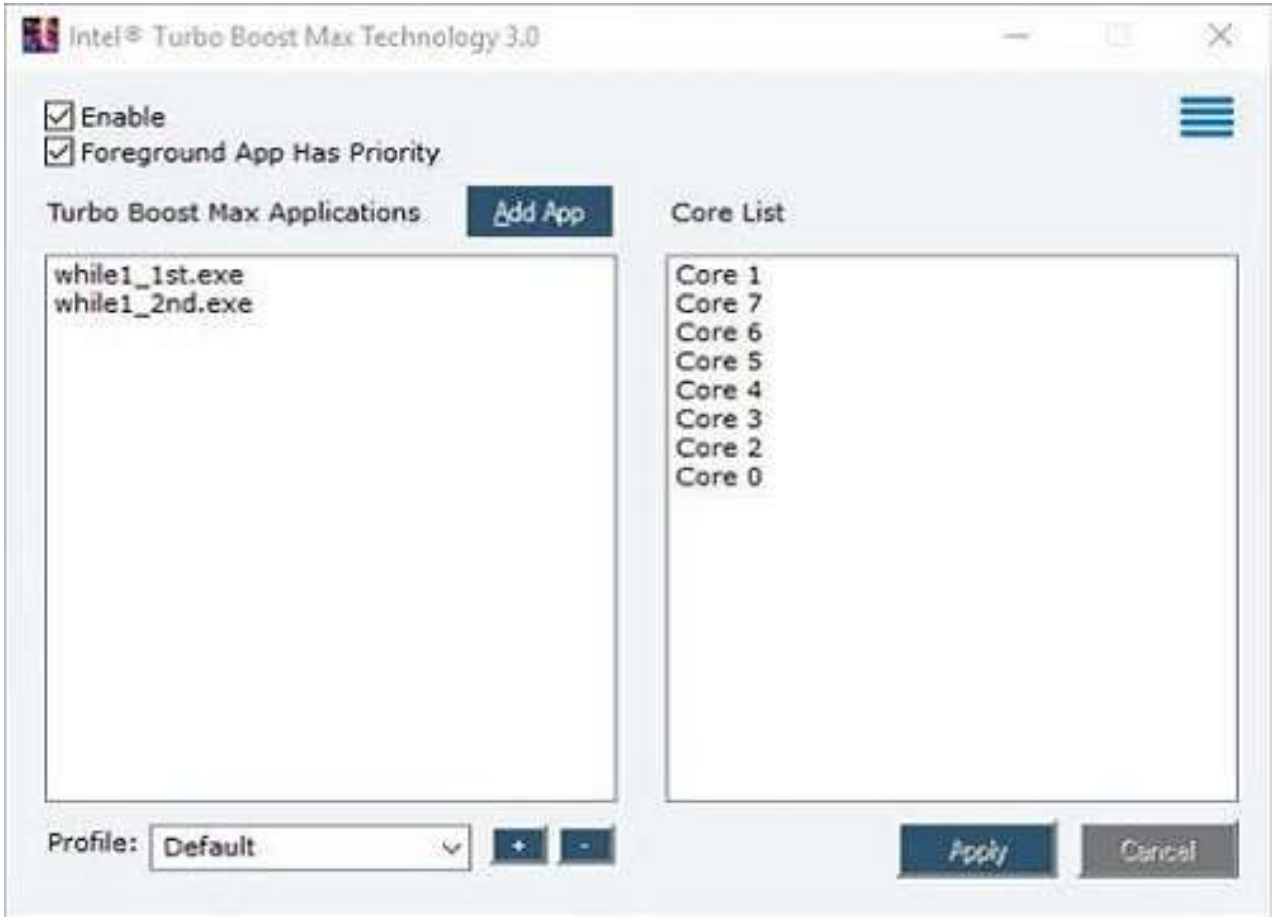


Table: Core list used in Intel's Turbo Boost Max Technology 3.0 [44]

8.2 Introduction to the Skylake X-Series (5)

Note -2

- The Turbo Boost Max 3.0 Technology speeds up the execution of single core applications by allocating the fastest core from the Core list to such workloads.
- Turbo Boost Max 3.0 was introduced in Broadwell-E models (2016) and in the Xeon E5-1600 v4 Series Broadwell-based server processors (2016) .
- There are however some requirements for utilizing the TurboMax 3.0 Technology including proper OS, BIOS and driver [44].
- The subsequent Skylake-X Series processors (e.g. i9-78xxX to i9-79xxXE) (2017) support further on this technology.
- Nevertheless, the following Skylake-X Refresh Series processors introduced an updated Turbo Boost Max Technology 3.0 that improves both single core and dual core performance by allocating the two fastest cores if two cores are needed.

8.2 Introduction to the Skylake X-Series (6)

Contrasting Intel's and AMD's competing HED models [43]

AMD vs Intel							
	TR 1900X	TR 1920X	TR 1950X	7920X	7940X	7960X	7980XE
Silicon	2 x Zeppelin			HCC			
Cores / Threads	8/16	12/24	16/32	12/24	14/28	16/32	18/36
Base Clock / GHz	3.8	3.5	3.4	2.9	3.1	2.8	2.6
Turbo Clock 2.0/ GHz	4.0	4.0	4.0	4.3	4.3	4.2	4.2
ITBM3.0	4.2	4.2	4.2	4.4	4.4	4.4	4.4
L2	512 KB/core			1 MB/core			
L3	32 MB	64 MB		1.375 MB/core			
PCIe Lanes	60			44			
Memory Channels	4			4			
Memory Freq DDR4	2666			2666			
TDP	180W			140W	165W		
Launched	8/2017	8/2017	8/2017	8/2017	9/2017	9/2017	9/2017
Price	$549	$799	$999	$1199	$1399	$1699	$1999

8.2 Introduction to the Skylake X-Series (7)

Note

- Benchmark results show that Intel's Skylake-X based models are superior over AMD's comparable 1. gen. ThreadRipper models indicated above [43].
- Nevertheless, AMD's subsequent, 2. gen. ThreadRipper models (TR2xxxx), launched between 8/2018 and 10/2018 regained superiority over Intel's related Skylake-X based models.
- In the next turn, however, in 10/2018 Intel launched their Core-X Refresh (i9-9xxxX/ i9-9990XE) Series processors that took back the leadership from AMD's 2. gen. ThreadRippers.

8.2 Introduction to the Skylake X-Series (8)

Derivation of the Skylake-X models -2 [43]

- The Skylake-S models are derived from the Skylake-SP server designs by disabling not needed parts of the design, e.g. UPI links, two memory controllers from the available 6 etc.
- The 6/8/10-core models are derived from the LCC (Low Core Count) and the 12/14/16-core models from the HCC (High Core Count) Skylake-SP dies, as indicated below.

Skylake-SP Die sizes			
	Arrangement	Dimensions (mm)	Die area (mm^2)
LCC Low Core Count)	3x4 (10-core)	22.0 x 14.0	308 mm2
HCC (High Core Count)	4x5 (18-core)	22.0 x 21.5	473 mm2
XCC Extreme Core Count)	5x6 (28-core)	21.5 x 31.5	677 mm2

Table: Skylake-SP die layouts [43]

8.2 Introduction to the Skylake X-Series (9)

For comparison: Skylake-SP's LLC and HCC die configurations [32]

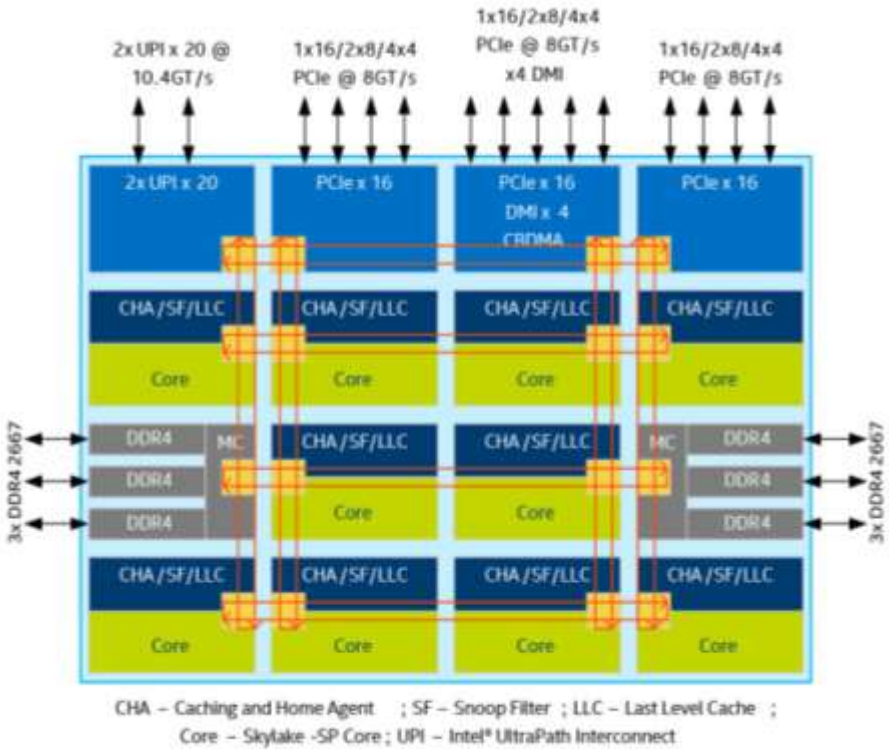


Figure: LCC die layout of Skylake-SP processors

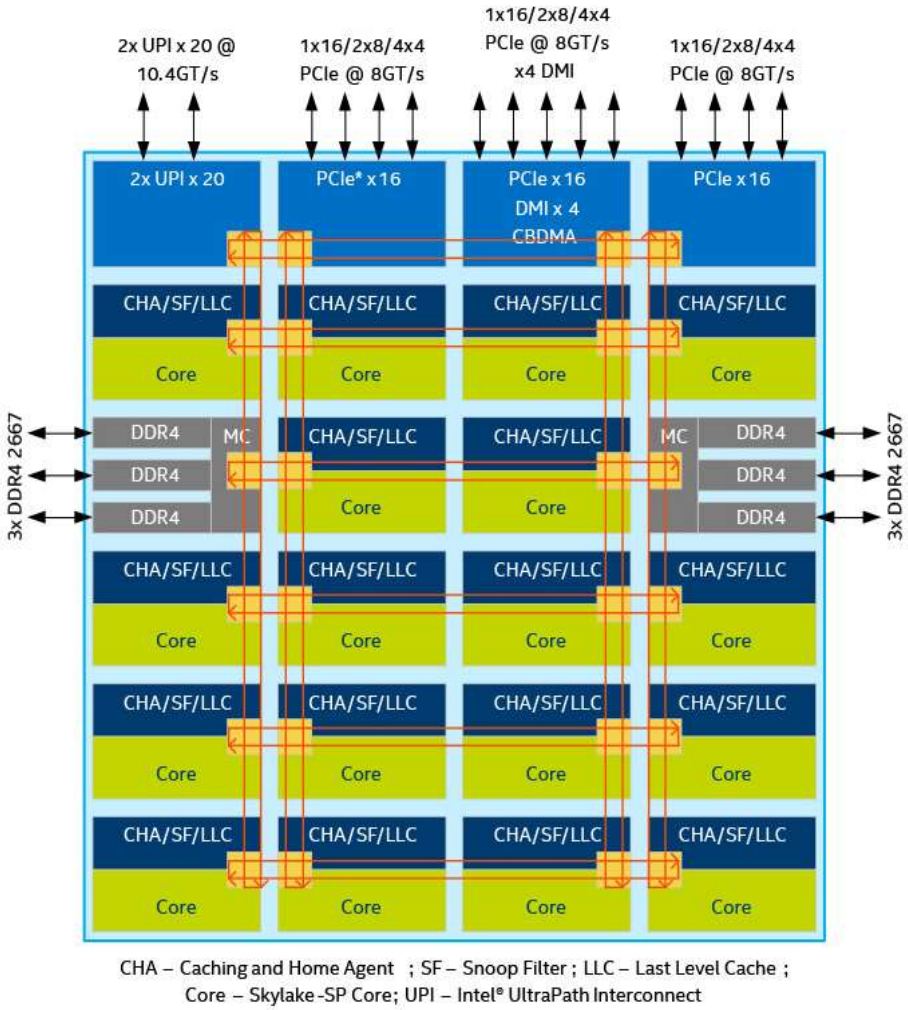


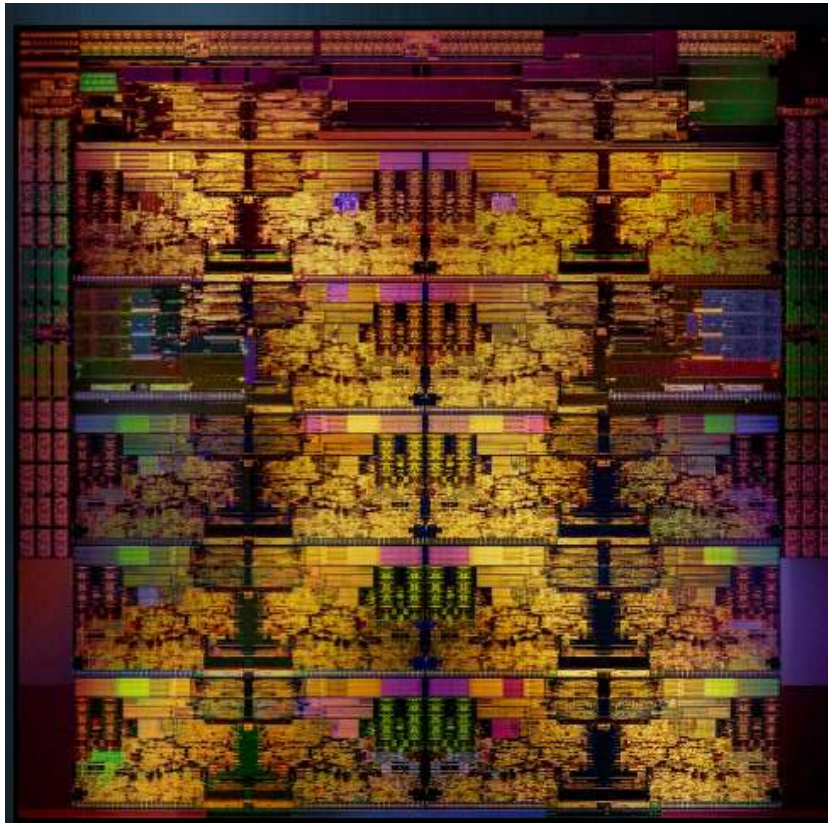
Figure: HCC die layout of Skylake-SP processors

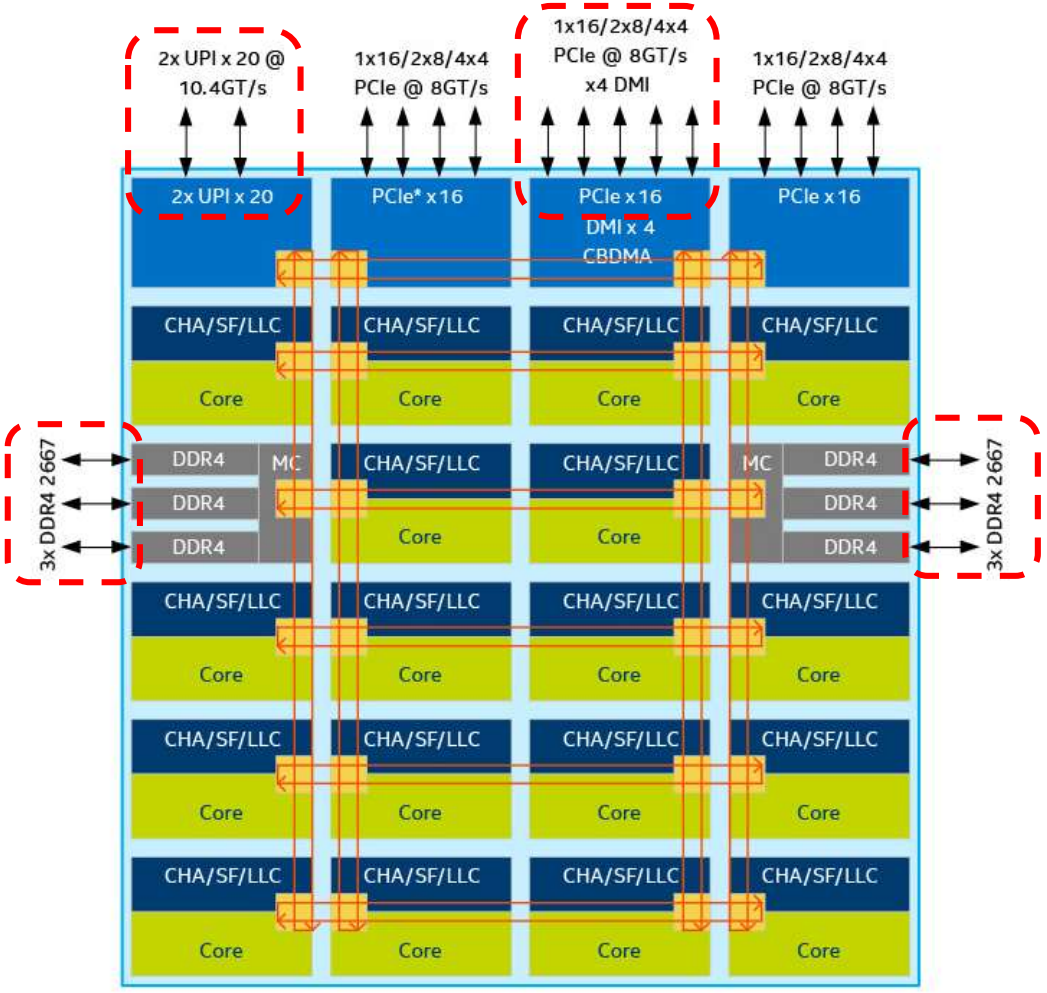
Note that the cores are interconnected via a 2D mesh (to be discussed later).

8.2 Introduction to the Skylake X-Series (10)

Example: Die micrograph of the i9-7980XE [a] and core configuration of the 18-core Skylake-SP (Xeon Gold 6150) [32] [38]

- No UPI links
- Only 44 PCI 3.0 lanes
- Only 4 Memory channels





CHA – Caching and Home Agent ; SF – Snoop Filter ; LLC – Last Level Cache ;
Core – Skylake-SP Core; UPI – Intel® UltraPath Interconnect

Main features of the Skylake-X models [38]

UNLOCKED INTEL® CORE™ X-SERIES PROCESSOR FAMILY

Processor number[1]	Base clock speed (GHz)	Intel® Turbo Boost Technology 2.0 frequency[2] (GHz)	Intel® Turbo Boost Max Technology 3.0 Freqency[3] (GHz)	Cores/ threads	L3 cache	PCI express 3.0 lanes	Memory support	TDP	Socket (LGA)	RCP Pricing (1K USD)
i9-7980XE NEW	2.6	4.2	4.4	18/36	24.75 MB	44	Four channels DDR4-2666	165W	2066	$1,999
i9-7960X NEW	2.8	4.2	4.4	16/32	22 MB	44	Four channels DDR4-2666	165W	2066	$1,699
i9-7940X NEW	3.1	4.3	4.4	14/28	19.25 MB	44	Four channels DDR4-2666	165W	2066	$1,399
i9-7920X NEW	2.9	4.3	4.4	12/24	16.5 MB	44	Four channels DDR4-2666	140W	2066	$1,199
i9-7900X NEW	3.3	4.3	4.5	10/20	13.75 MB	44	Four channels DDR4-2666	140W	2066	$999
i7-7820X NEW	3.6	4.3	4.5	8/16	11 MB	28	Four channels DDR4-2666	140W	2066	$599
i7-7800X NEW	3.5	4.0	NA	6/12	8.25 MB	28	Four channels DDR4-2400	140W	2066	$389
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i5-7640X NEW	4.0	4.2	NA	4/4	6 MB	16	Two channels DDR4-2666	112W	2066	$242

1. Intel processor numbers are not a measure of performance. Processor numbers differentiate features within each processor family, not across different processor families. See intel.com/products/processor_number for details.
2. Refers to the maximum dual-core frequency that can be achieved with Intel® Turbo Boost Technology 2.0.
3. Refers to the maximum dual-core frequency that can be achieved with Intel® Turbo Boost Max Technology 3.0

8.3 Key innovations of the Skylake X-Series discussed

- 8.3.1 AVX512
- 8.3.2 Re-architected L2/L3 cache hierarchy
- 8.3.3 Mesh architecture
- 8.3.4 Improved Turbo Boost Max technology 3.0

8.3 Key innovations of the Skylake X-Series processors discussed

8.3.1 AVX512 *(Section 8.3.1)*
8.3.2 Re-architected L2/L3 cache hierarchy *(Section 8.3.2)*
8.3.3 Mesh architecture *(Section 8.3.3)*
8.3.4 Improved Turbo Boost Max Technology 3.0 *(Section 8.3.4)*

*

8.3.1 AVX512

8.3.1 AVX512

Evolution of Intel's SIMD extensions

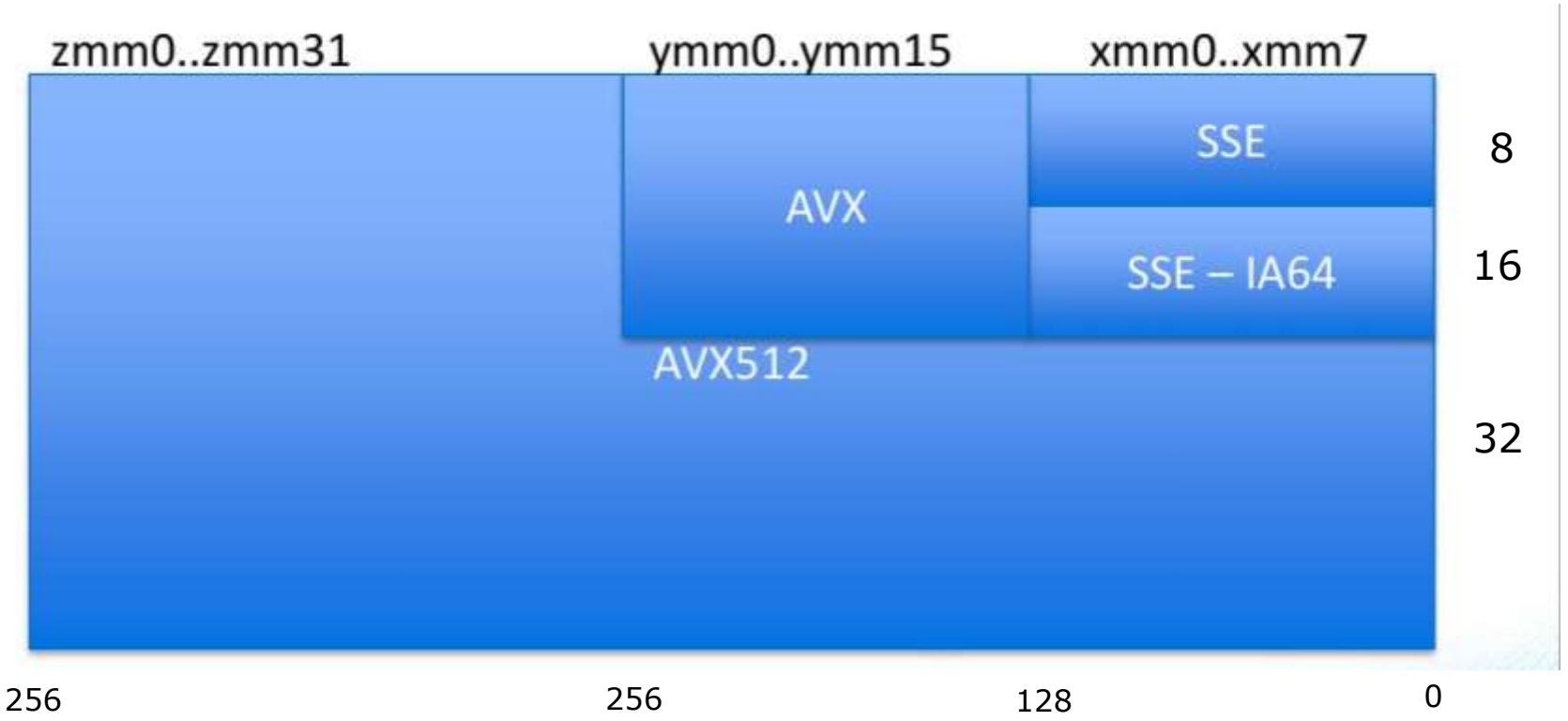
Designation	Intro.	Processor line	Technology	SIMD registers	SIMD Register set	Instruction set
MMX	1997	Pentium MMX	350 nm	MM [0:7][1]	8x64 bit	FX SIMD
SSE	1999	Pentium III	250 nm	XMM [0:7]	8x128 bit	FX/FP SIMD
SSE2	2000	Pentium 4	180 nm	XMM [0:15]	16x128 bit	FX/FP SIMD
AVX	2011	Sandy Bridge	32 nm	YMM [0:15]	16x256 bit	FP SIMD
AVX2	2013	Haswell	22 nm	YMM [0:15]	16x256 bit	FX/FP SIMD
AVX512	2017 2017 2018	Skylake-SP Core-X Cannonlake	14 nm	ZMM [0:31]	32x512 bit	FX/FP SIMD

[1]The MM registers are aliased with the mantissa part of the FP registers

*

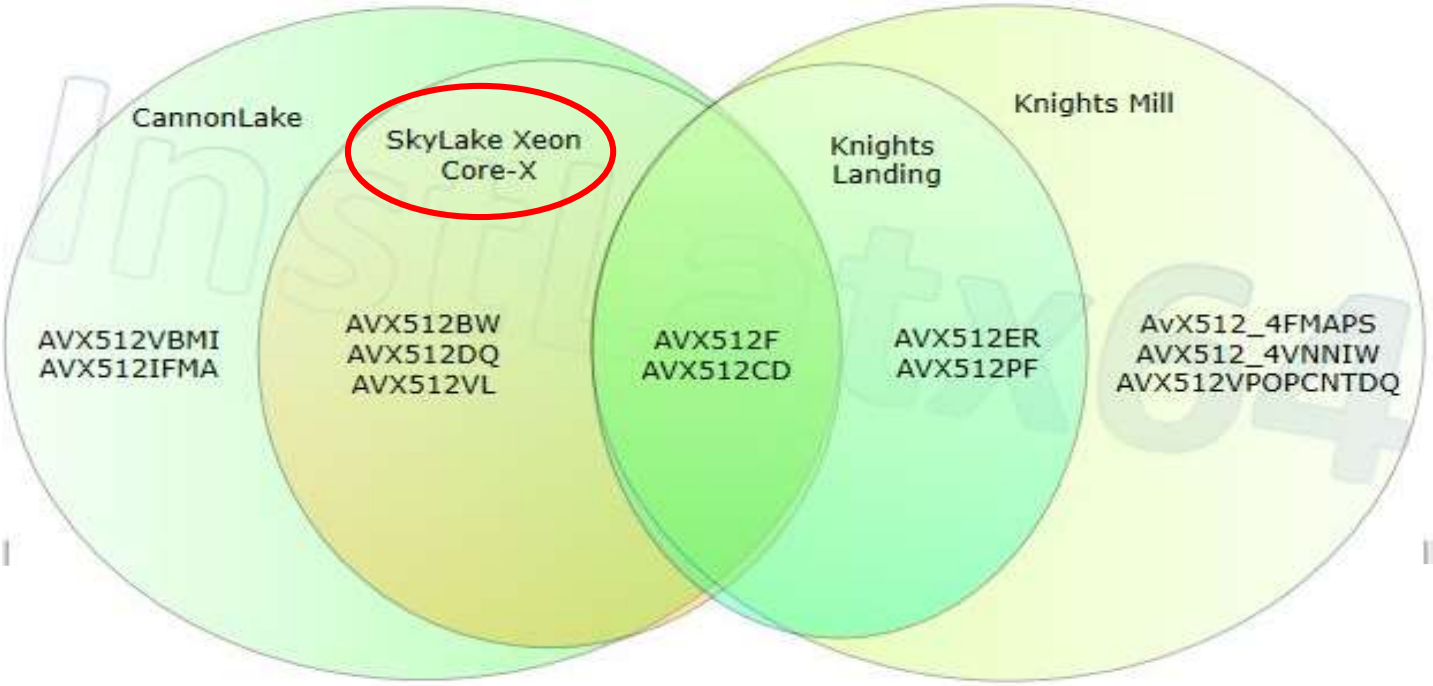
8.3.1 AVX512 (2)

Extension of the available SIMD register space [31]



8.3.1 AVX512 (3)

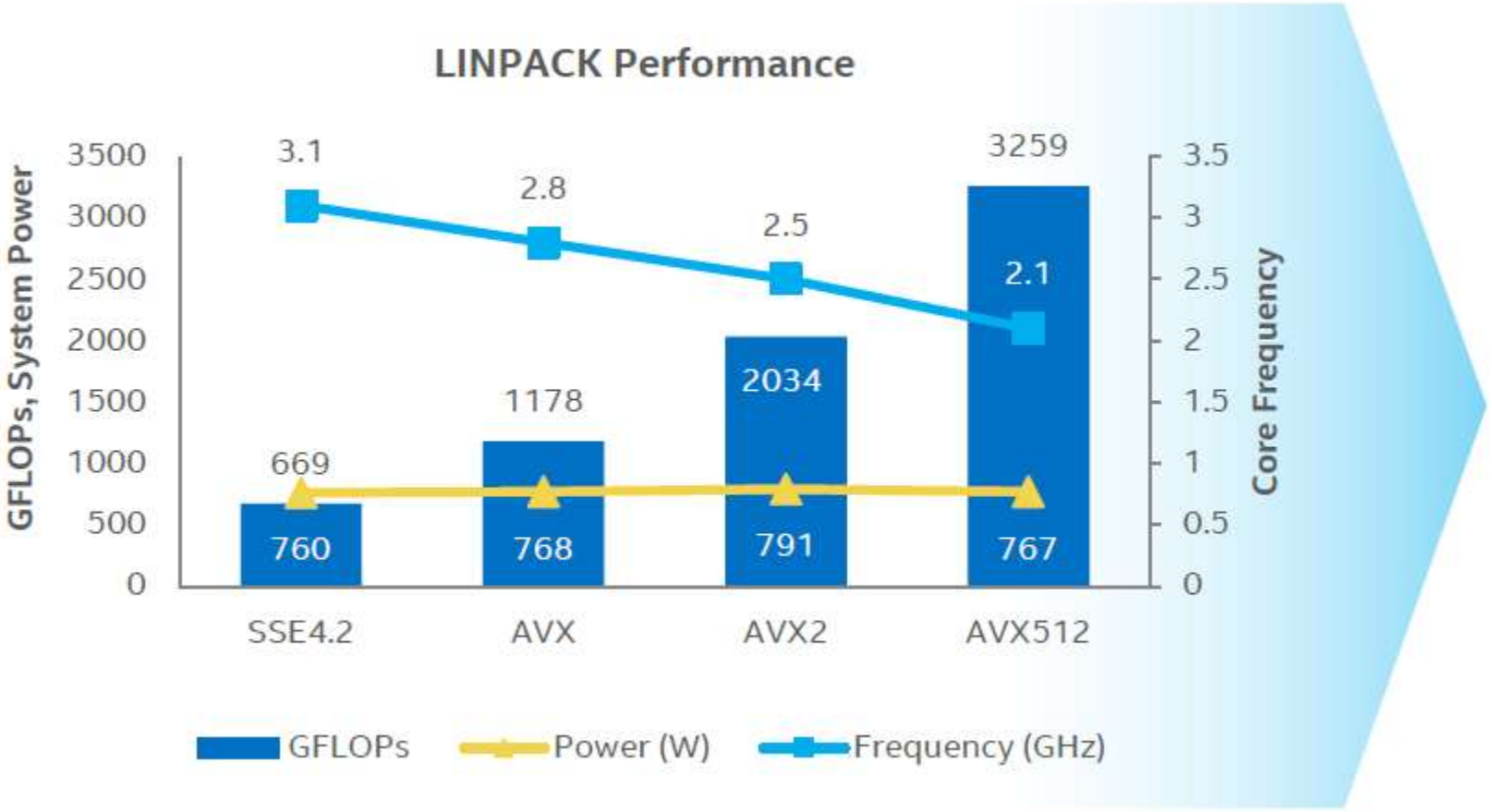
Different versions of the AVX512 instruction set [31] Source: Intel SDE 8.40 (2017-06-01)



AVX-512-F: Foundation instructions
AVX-512-CD: Conflict Detect (loop vectorization with possible conflicts)
AVX-512-BW: Support for 512-bit Word support
AVX-512-DQ: More instructions for double/quad math operations
AVX-512-VL: Foundation plus <512-bit vector length support
AVX-512-ER: Exponential and Reciprocal
AVX-512-IFMA: Integer Fused Multiply Add with 52-bit precision
AVX-512-PF: Prefetch Instructions
AVX-512-VBMI: Vector Byte Manipulation Instructions
AVX-512-4VNNIW: Vector Neural Network Instructions Word (variable precision)
AVX-512-4FMAPS: Fused Multiply Accumulation Packed Single precision

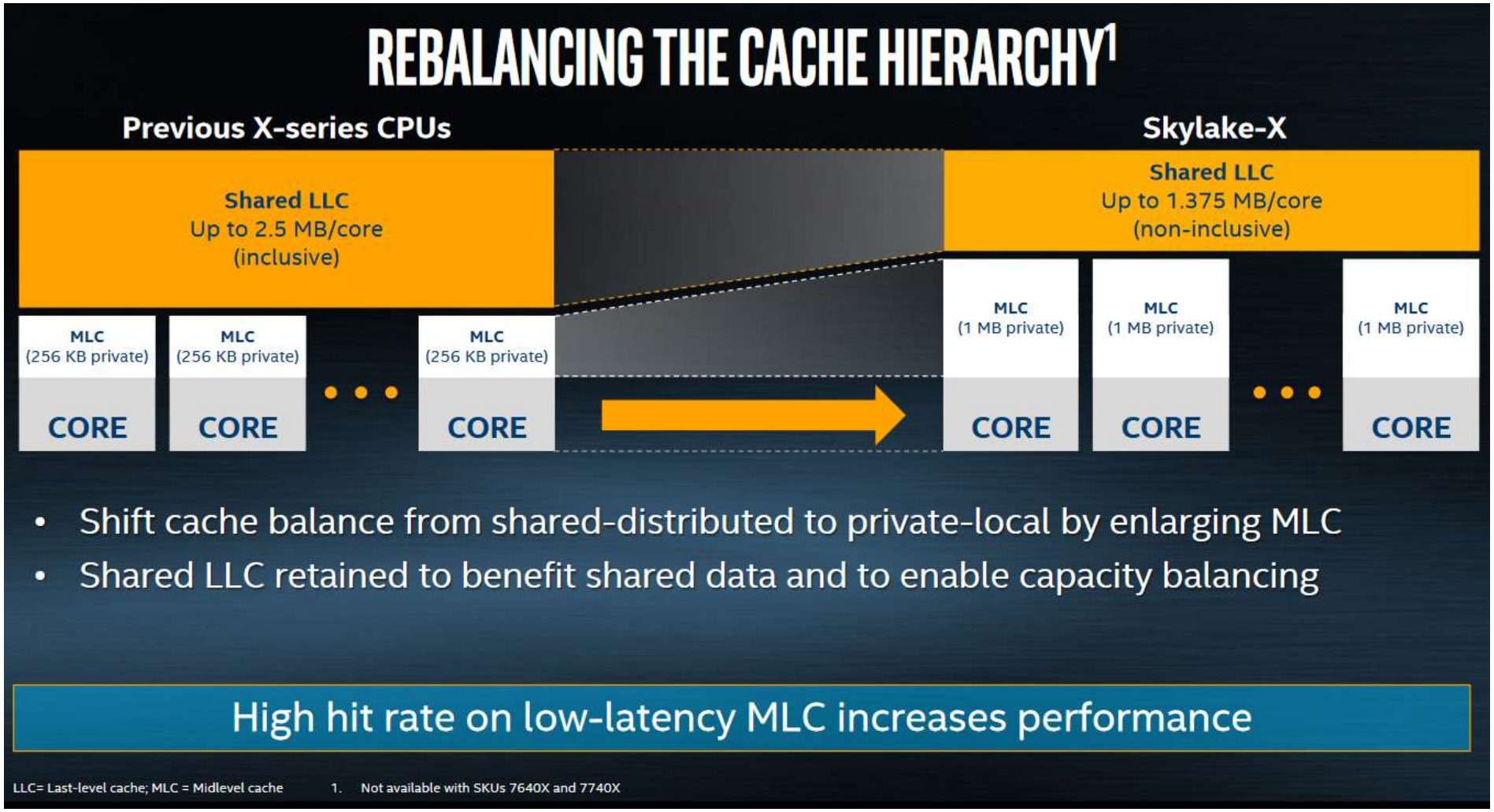
8.3.1 AVX512 (4)

Performance increase over SIMD generations [32]



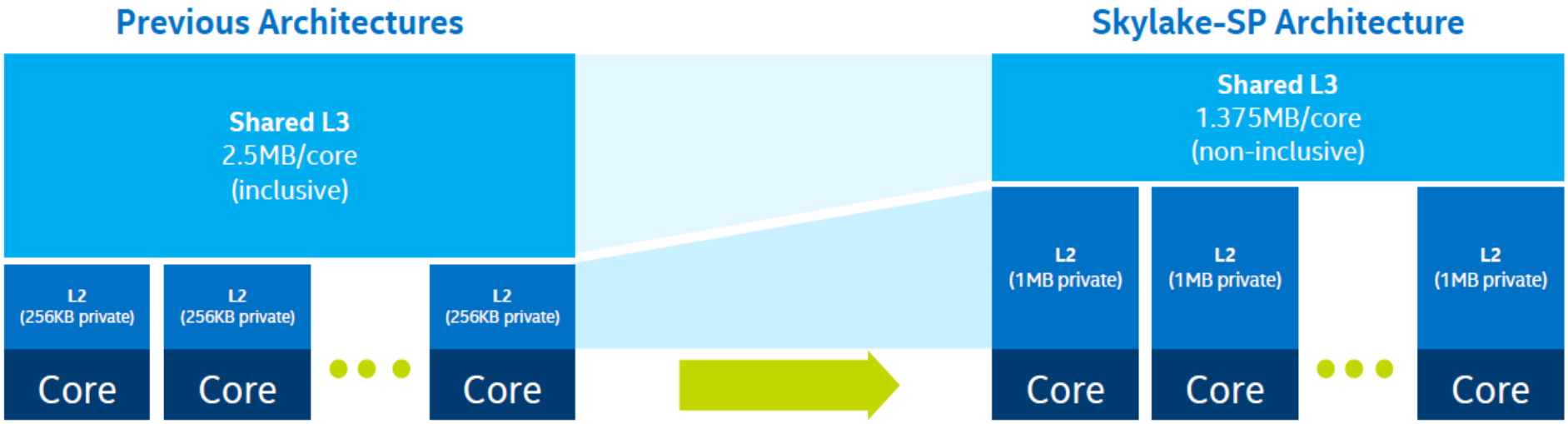
8.3.2 Re-architected L2/L3 cache hierarchy

8.3.2 Re-balancing the L2/L3 cache hierarchy [38]



8.3.2 Re-architected L2/L3 cache hierarchy (2)

Re-balancing the L2/L3 cache hierarchy [32]



- On-chip cache balance shifted from shared-distributed (prior architectures) to private-local (Skylake architecture):
  - Shared-distributed ➔ shared-distributed L3 is primary cache
  - Private-local ➔ private L2 becomes primary cache with shared L3 used as overflow cache
- Shared L3 changed from inclusive to non-inclusive:
  - Inclusive (prior architectures) ➔ L3 has copies of all lines in L2
  - Non-inclusive (Skylake architecture) ➔ lines in L2 ***may not*** exist in L3

*

8.3.2 Re-architected L2/L3 cache hierarchy (3)

Changing the L3 cache inclusion policy from inclusive to non-inclusive -1

Cache inclusion policies between subsequent levels of a cache hierarchy

Inclusive cache levels

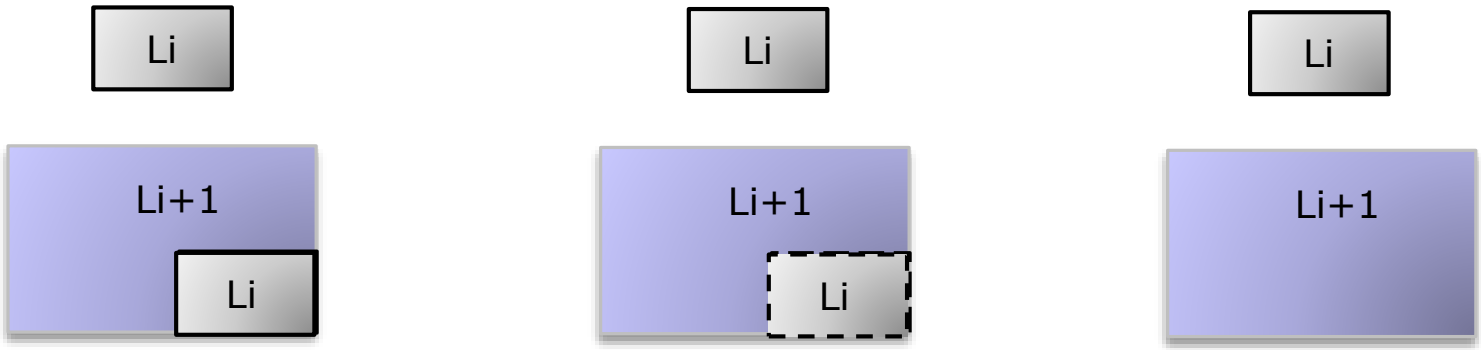
Non-inclusive cache levels (Victim cache)

Exclusive cache-levels

If the cache levels are inclusive, the higher cache level includes the content of the underneath cache level,
E.g. an inclusive L3 cache contains the content of the L2 cache

In non-inclusive cache levels the fact that a line is in level i does not imply that it is also in level i+1.

If the cache levels are exclusive, a data item (in fact a cache line) is contained either in the higher or in the lower level cache, but never in both.



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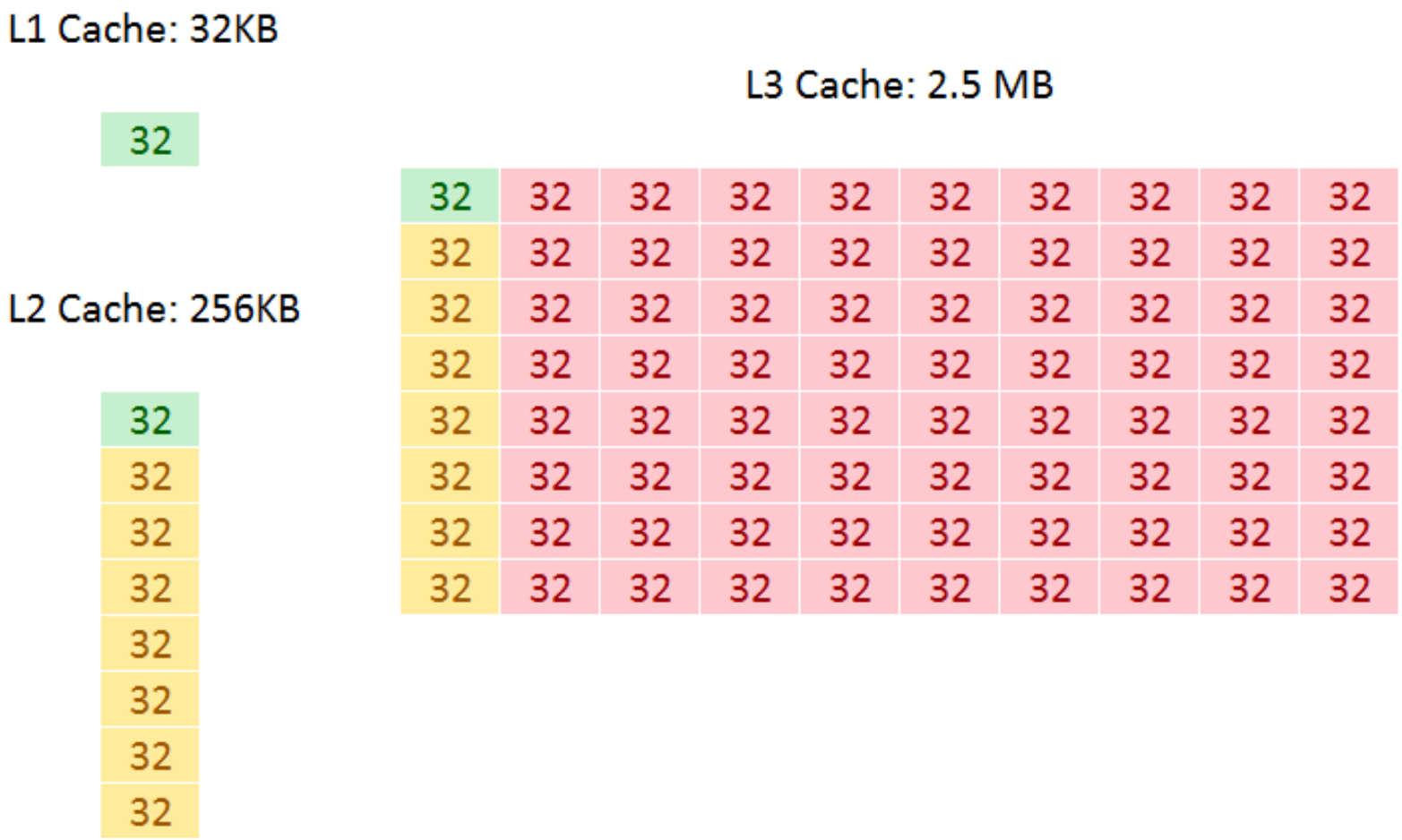
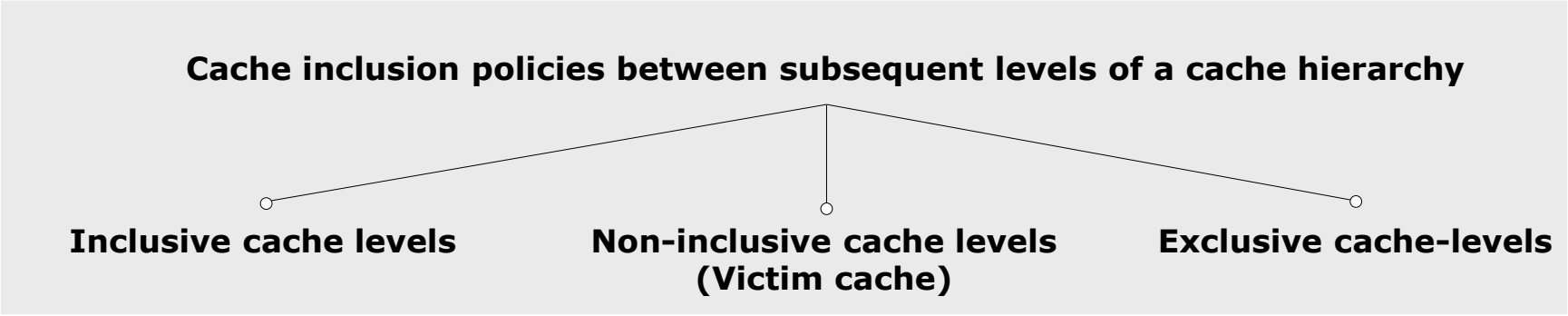
8.3.2 Re-architected L2/L3 cache hierarchy (4)

Example of an inclusive three-level cache-architecture [31]



8.3.2 Re-architected L2/L3 cache hierarchy (5)

Assessing and use of cache inclusion policies



Benefit

Inclusive cache levels reduce the snoop traffic, since in this case only the higher cache level needs to be snooped.

Non-inclusive cache levels seem to provide an efficient cache use.

Benefit of an exclusive cache levels is the efficient use of the cache space.

Drawback

Their drawback is the not efficient use of the cache space.

They need a more complex cache coherency protocol.

Their drawback is that they increase the snoop traffic since in this case both cache levels need to be snooped.

Examples

Intel's L3 caches in their Haswell to Skylake lines

Intel's L2 caches in their Pentium 4 and Core 2 based lines

Intel's L3 cache in their Skylake-SP line

AMD's L2 caches in their Athlon (K6) and Opteron based lines

*

8.3.2 Re-architected L2/L3 cache hierarchy (6)

Inclusion policies of cache hierarchies in Intel's Core 2 lines [33]

	L2 to L1	L3 to L2	L4 to L3
Core 2/ Penryn	Shared Non-inclusive		
Nehalem/ Westmere	Private Non-inclusive	Shared Inclusive	
Sandy Bridge/ Ivy Bridge	Private Non-inclusive	Shared Inclusive Sliced	
Haswell Broadwell	Private Non-inclusive?	Shared Inclusive Sliced	Shared Non-inclusive
Skylake/ Kaby Lake	Private Non-inclusive?	Shared Inclusive Sliced	Shared Non-inclusive
Skylake-SP Core-X	Private Non-inclusive	Shared Non-inclusive Sliced	??

All caches are write-back caches (WB) (except of the L1 Instruction cache).
L3 cache tags show which L1 and/or L2 caches hold the cache line

8.3.2 Re-architected L2/L3 cache hierarchy (7)

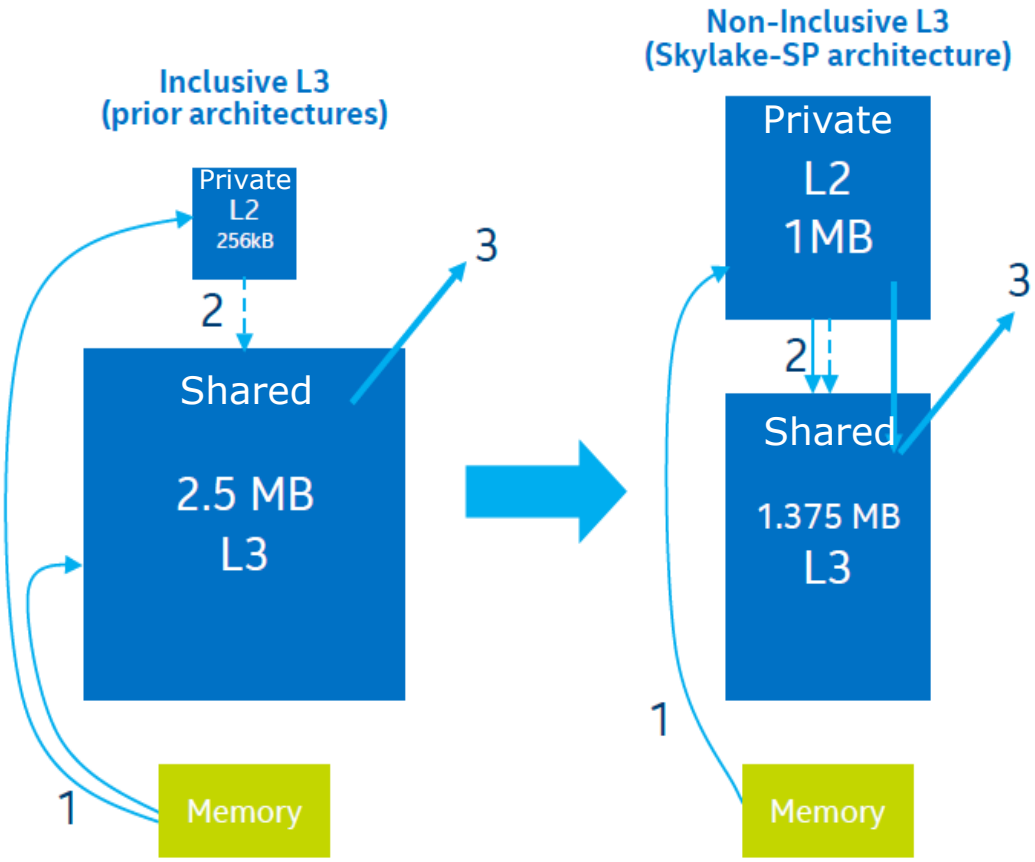
Changing the L3 cache inclusion policy from inclusive to non-inclusive -1

- In the previous Skylake generation the inclusive L3 cache amounts to up to 2.5 MB/core whereas the private L2 cache to 0.25 MB core and the L2 cache needs only about 10 % of the L3 cache space.
- By contrast, the Skylake-SP processor has an L3 cache of only 1.375 MB/core whereas the private L2 caches amount to 1 MB/core.
- Consequently, in the Skylake-SP processor the inclusive cache policy could not be used for the L3 cache, it had to be modified to the non-inclusive policy since then the L2 cache content is only partly included in the L3 cache.

*

8.3.2 Re-architected L2/L3 cache hierarchy (8)

Non-inclusive vs. inclusive L3 [32]



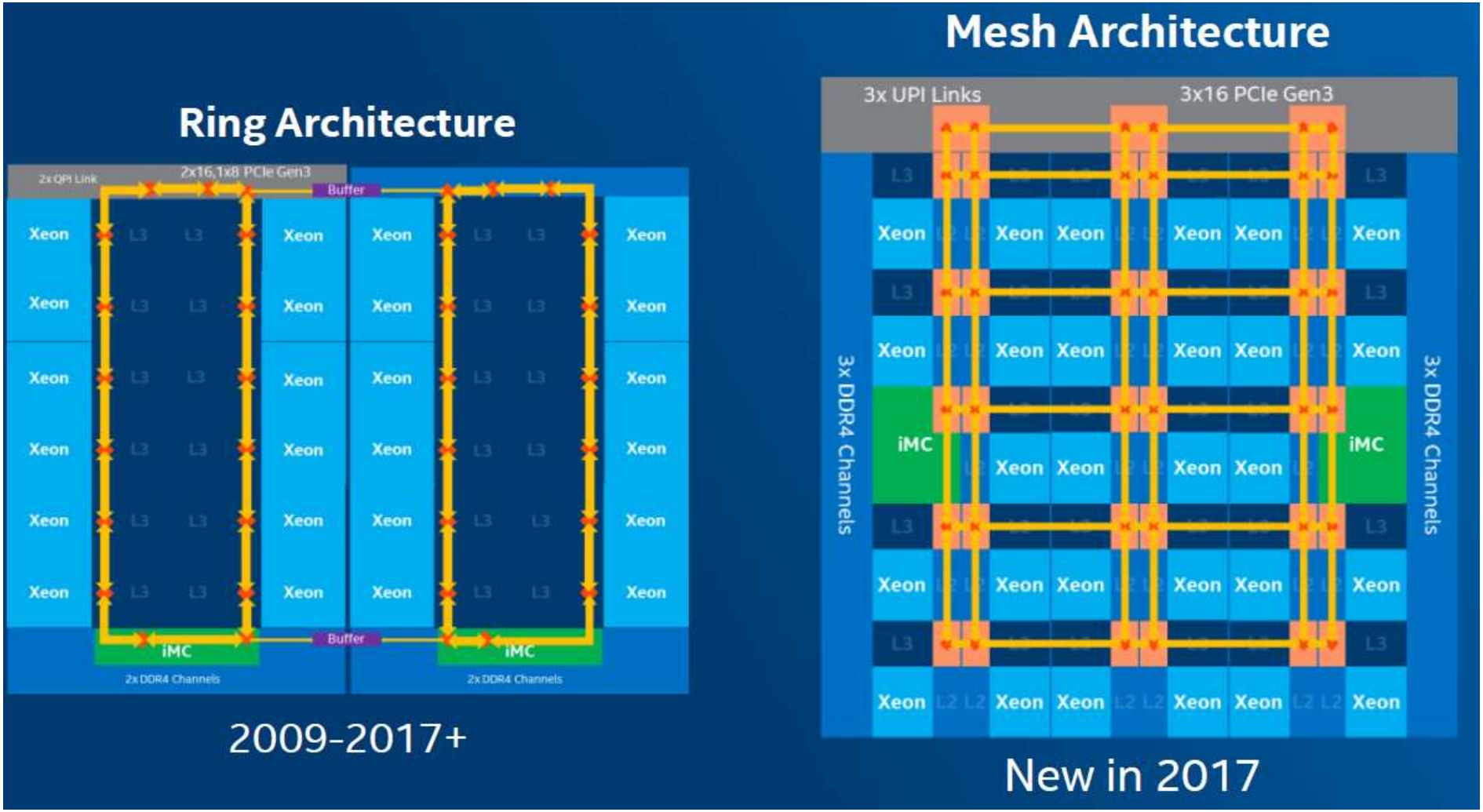
1. Memory reads fill directly to the L2, no longer to both the L2 and L3
2. When a L2 line needs to be removed, both modified and unmodified lines are written back
3. Data shared across cores are copied into the L3 for servicing future L2 misses

Cache hierarchy architected and optimized for data center use cases:

- Virtualized use cases get larger private L2 cache free from interference
- Multithreaded workloads can operate on larger data per thread (due to increased L2 size) and reduce uncore activity

8.3.3 Mesh architecture

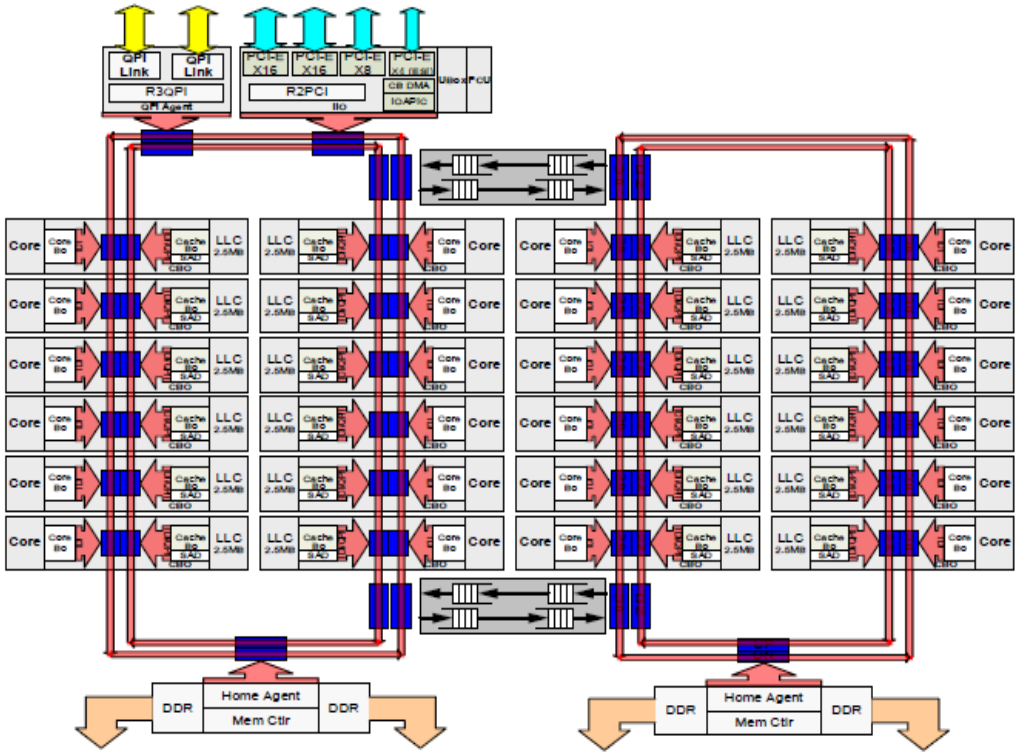
8.3.3 Mesh architecture [34]



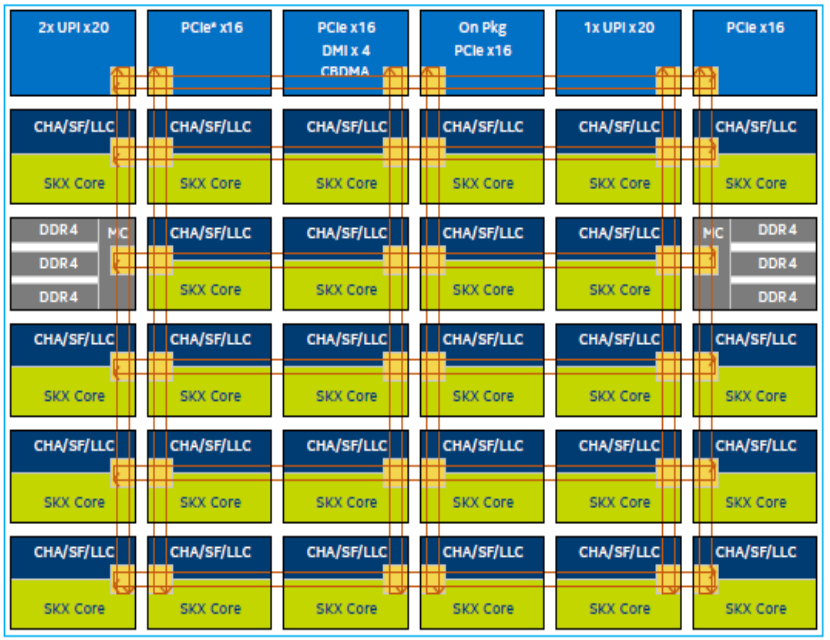
8.3.3 Mesh architecture (2)

Broadwell-EX's ring architecture vs. Skylake-SP's mesh architecture [32]

Broadwell EX 24-core die



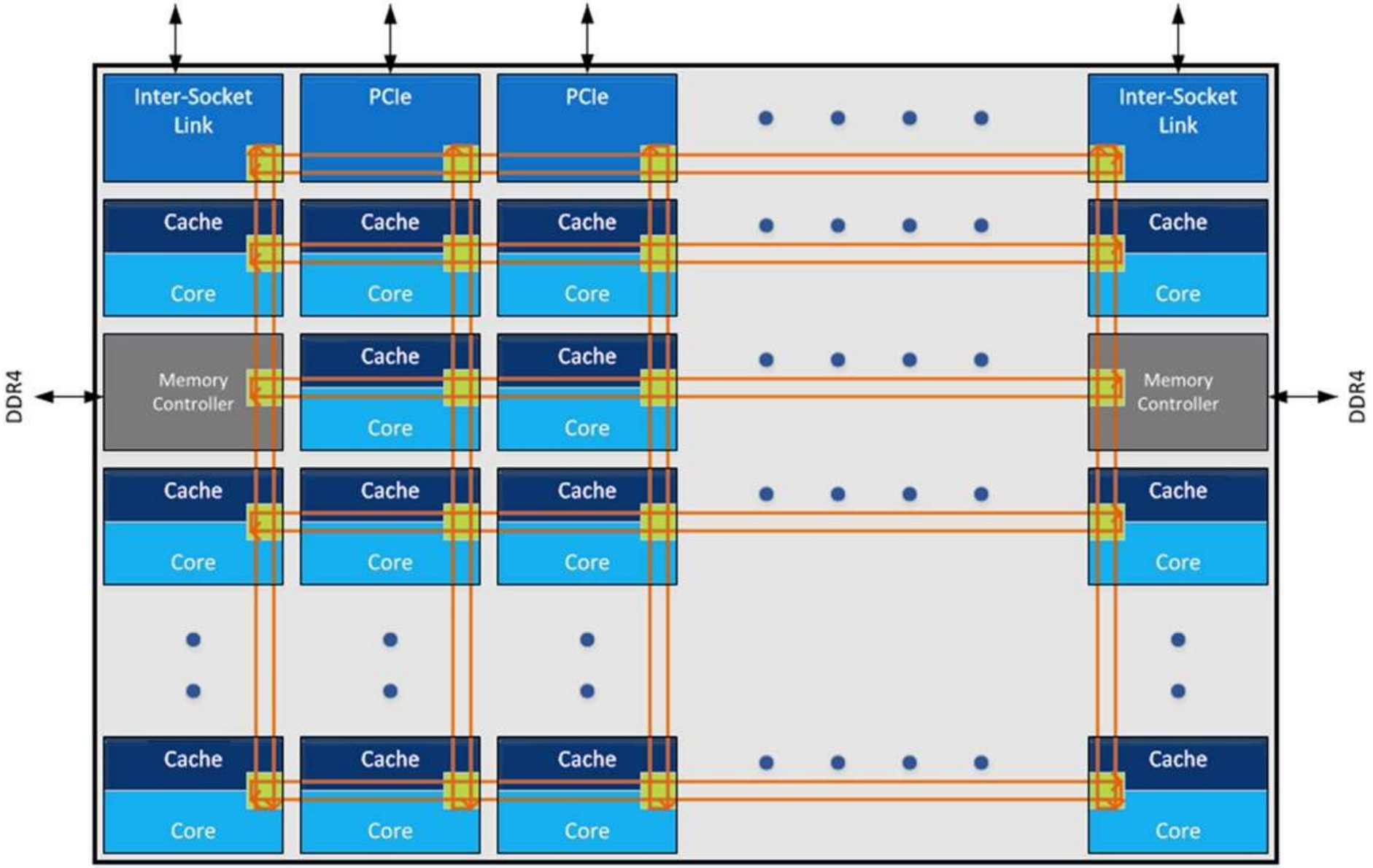
Skylake-SP 28-core die



CHA – Caching and Home Agent ; SF – Snoop Filter; LLC – Last Level Cache;
SKX Core – Skylake Server Core; UPI – Intel® UltraPath Interconnect

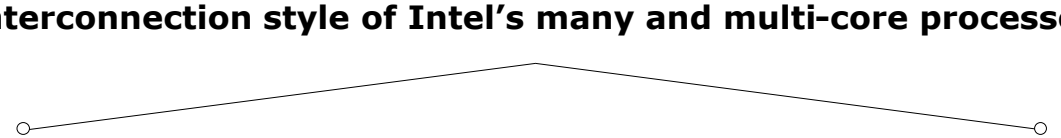
8.3.3 Mesh architecture (3)

Mesh architecture - more detailed [35]



8.3.3 Mesh architecture (4)

Interconnection style of Intel's many core and multi-core processors



Ring architecture

Sony/Toshiba/IBM Cell (2006): 8 cores

Larrabee (2009). 24-32 cores (cancelled)
Xeon Phi
Knights Ferry (2010): 32 cores
Knights Corner (2012): 57-61 cores

Nehalem-EX (Beckton) (2010) up to 8 cores
All **Sandy Bridge** lines (2011) up to 8 cores
All **Ivy Bridge** lines (from 2012 on) up to 15 cores
to
All **Broadwell** lines (from 2014 on) up to 24 cores
Skylake (2015) up to 4 cores

Mesh (2D grid) architecture

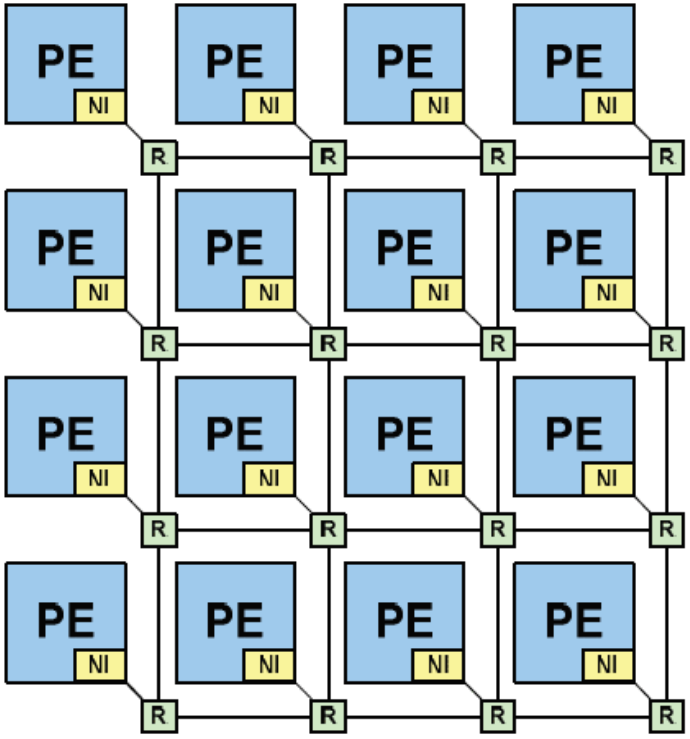
Tile processor (2007): 80 cores
SCC (2010): 48 cores

Xeon Phi
Knights Landing (2016): up to 72 cores

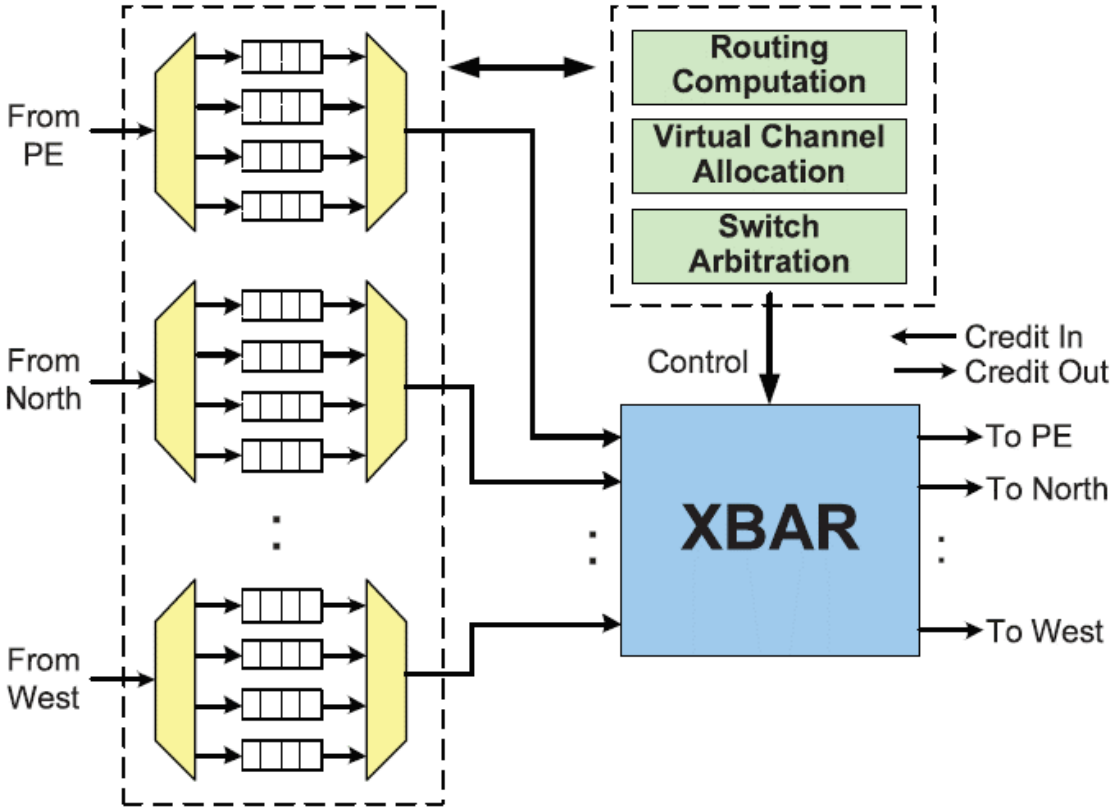
Skylake-X (HED) (2017) up to 18 cores
Skylake-SP (2017) up to 28 cores

8.3.3 Mesh architecture (5)

Principle of the implementation of a 4x4 2D mesh and the router [45]
(Only the North and West links are shown the South and East links are indicated)



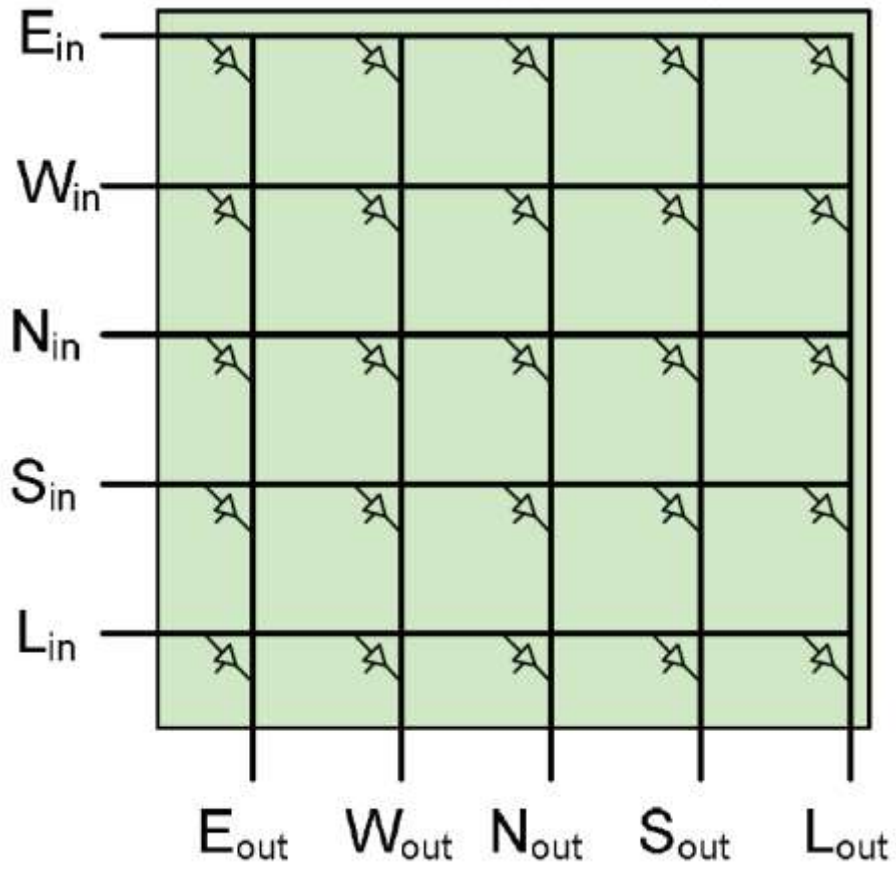
(a) 4x4 mesh topology
(PE: Local Processing Element,
NI: Network Interface, R: Router)



(b) Generic Router

8.3.3 Mesh architecture (6)

Principle of the implementation of a 5x5 crossbar [45]



8.3.3 Mesh architecture (7)

Benefits and the drawback of the mesh architecture

Benefit

- Lower latencies
- Lower latencies result in higher performance

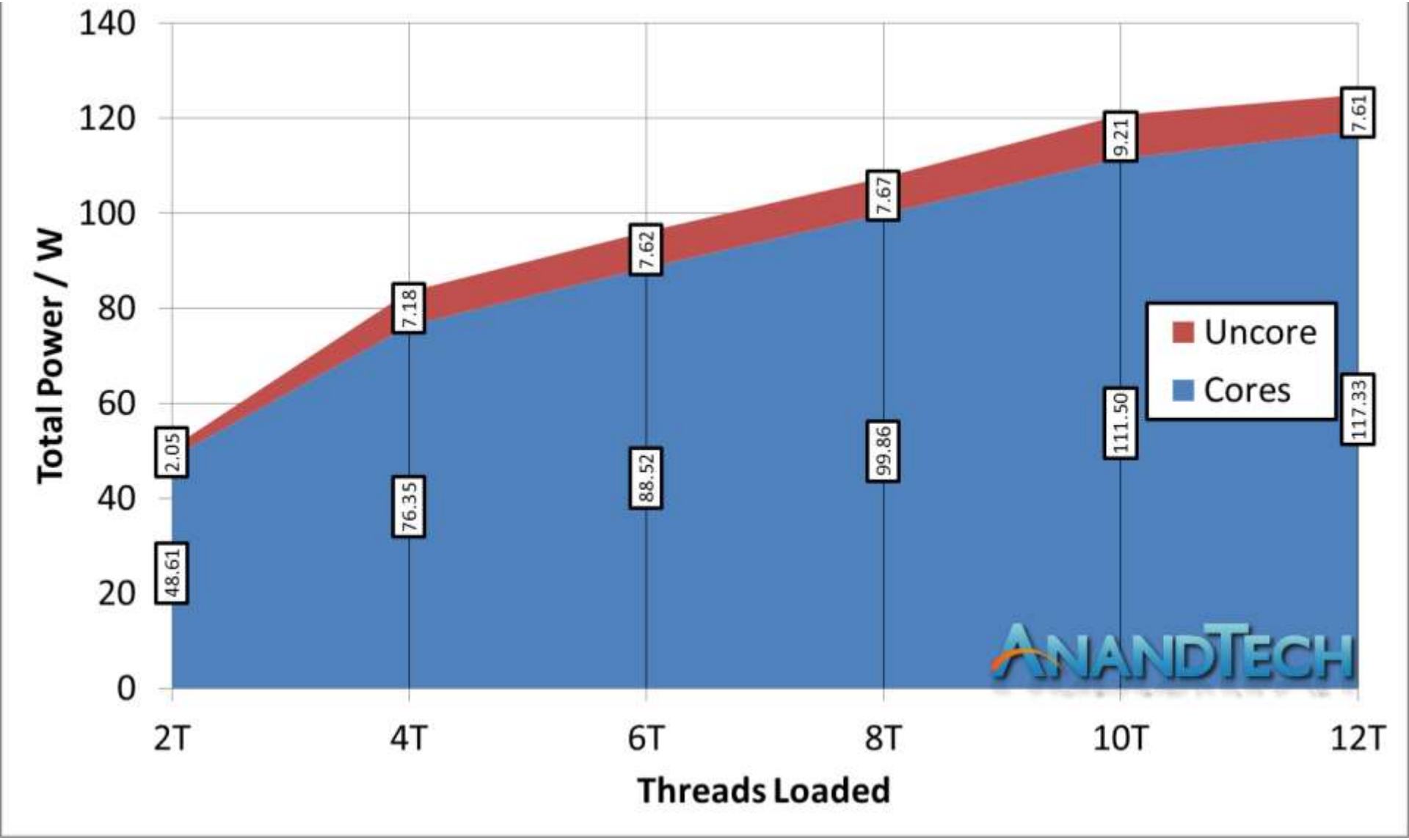
Drawback

- Higher power consumption, as shown in the next Figures.

*

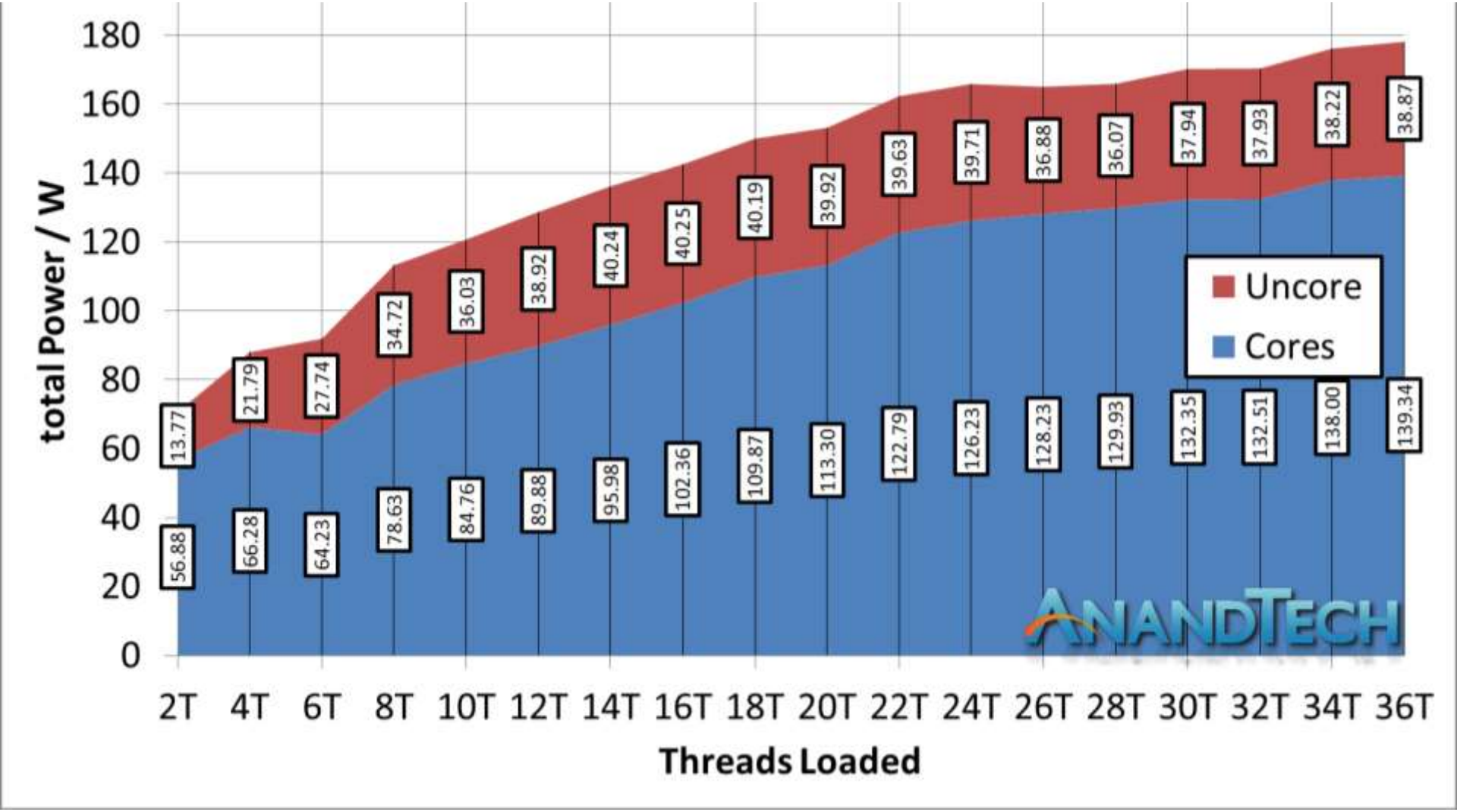
8.3.3 Mesh architecture (8)

Power distribution between the data ring and the cores in the 6-core i7-8700K (Coffee Lake) processor [46]



8.3.3 Mesh architecture (9)

Power distribution between the data mesh and the cores in the 6-core i9-7980XE (Skylake-SL-based Core-X processor [46]



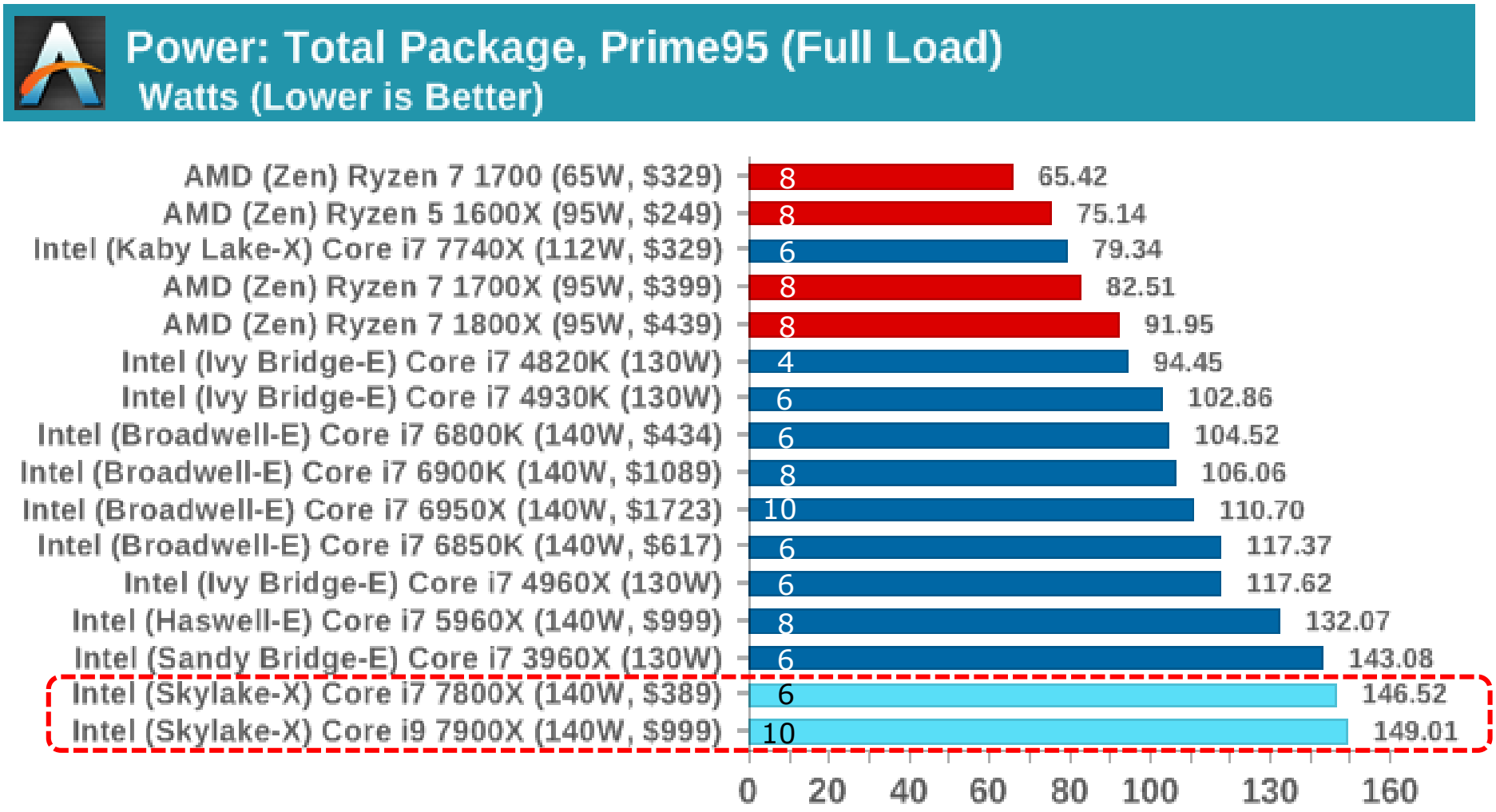
8.3.3 Mesh architecture (10)

Main features of the models of the Kaby Lake-X and Skylake-X Series [47]

Intel Basin Falls X299 Processors, Launched in July 2017					
	i5-7640X	i7-7740X	i7-7800X	i7-7820X	i9-7900X
	Kaby Lake-X	Kaby Lake-X	Skylake-X	Skylake-X	Skylake-X
Cores	4C/4T	4C/8T	6C/12T	8C/16T	10C/20T
Base Clock	4.0 GHz	4.3 GHz	3.5 GHz	3.6 GHz	3.3 GHz
Turbo Clock	4.2 GHz	4.5 GHz	4.0 GHz	4.3 GHz	4.3 GHz
TurboMax Clock	N/A	N/A	N/A	4.5 GHz	4.5 GHz
L2 Cache	256 KB per core		1 MB per core		
L3 Cache	6 MB	8 MB	8.25 MB	11 MB	13.75 MB
PCIe lanes	16		28		44
Mem. channels	2		4		
Memory freq.	DDR4-2666		DDR4-2400	DDR4-2666	
TDP	112 W		140 W		
Socket	LGA 2066		LGA 2066		
Price (1k)	$242	$339	$389	$599	$999

8.3.3 Mesh architecture (11)

Power consumption of Intel's HEDs and AMD's DTs [31]



Note that mesh-based Skylake-X processors have a large power consumption.

8.3.4 Improved Turbo Boost Max technology 3.0

8.3.4 Improved Turbo Boost max technology 3.0 -1 [38]

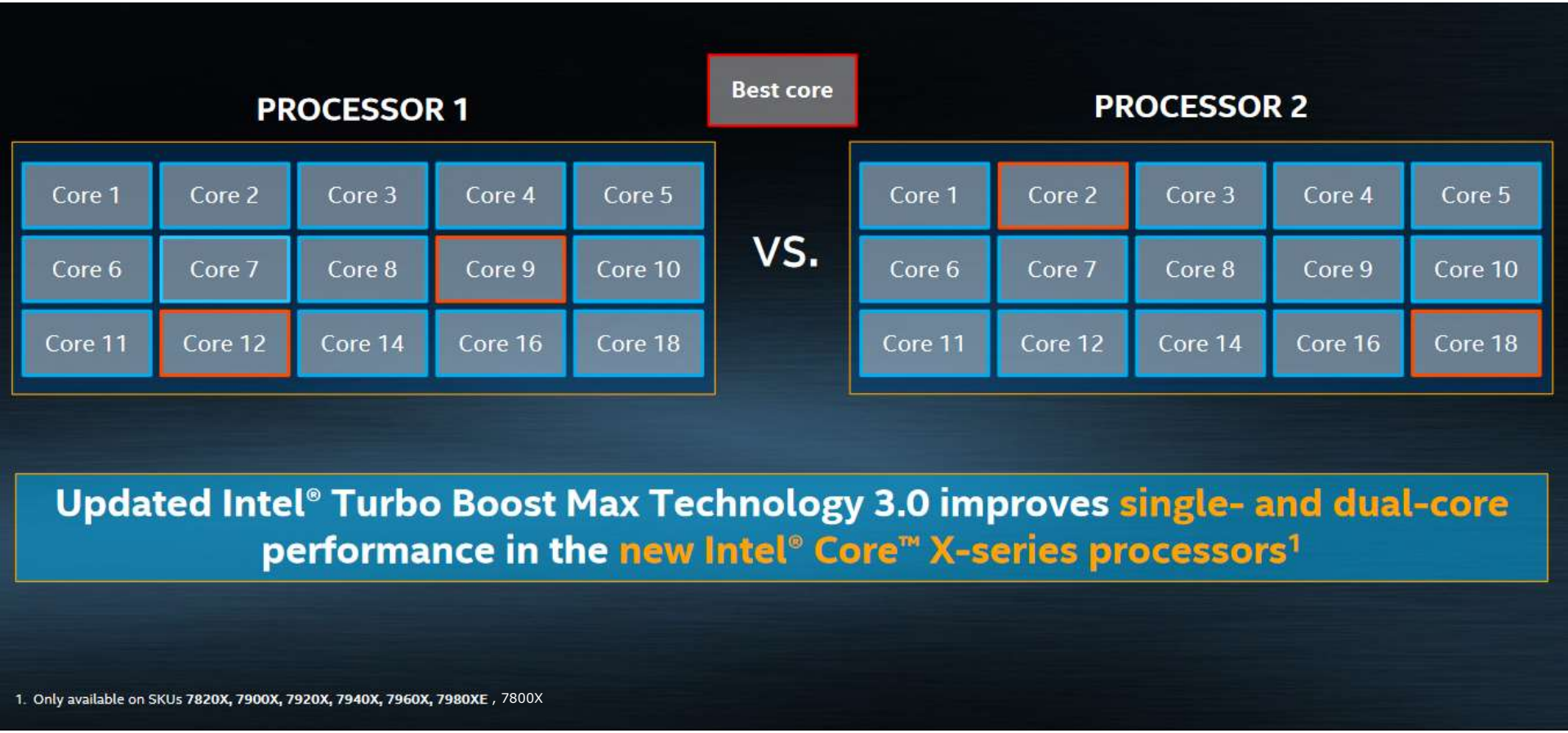
- The Turbo Boost max technology 3.0 was introduced in the Broadwell-E line.
- It aims at increasing the performance of single threaded applications.
- To achieve this, during processor testing Intel determines the max. clock speeds of all cores and arrranges the cores into a list according to their max clock speed.

  For single threaded workloads the fastest core (termed the favored core) will be activated.
- By contrast, the Improved Turbo Boost max technology 3.0 improves both single core and dual core performance by allocating the two fastest cores if two cores are needed, as indicated in the next Figure.

Its use requires an appropriate driver, OS version and BIOS.

8.3.4 Improved Turbo Boost Max technology 3.0 (2)

Improved Turbo Boost max technology 3.0 -2 [38]



Note that Improved Turbo Boost max technology 3.0 is supported only by the Skylake-X based models.

8.4 Performance assessment of the Skylake X-Series

8.4 Performance assessment of the Skylake X-Series (1)

Comparing the single threaded IPC values of Skylake-SP/-X and desktop Skylake-S processors[1] [31]

Intel SKL-SP vs SKL-S IPC Single Threaded Tests		
AnandTech.com		Gain over SKL-S
Web	Sunspider	1.8%
	Kraken	6.8%
System	PDF Opening	1.1%
	FCAT	1.4%
	Dolphin v5	5.7%
Rendering	Cinebench 15 ST	2.4%
Legacy	3DPM v1 ST	-4.1%
	Cinebench 11.5 ST	-1.4%
	Cinebench 10 ST	-1.6%
Overall	**9 Tests**	**1.3%**

[1]Actually, the comparison was made between the Skylake-S based Core i5-6600 and the Skylake-SP based Core i9-7900X while running both processors with only 4 cores, without hyperthreading, at 3 GHz on all cores with no Turbo active.

The benchmark scores show no notable differences betwwen the IPC values of the tested architectures.

8.4 Performance assessment of the Skylake X-Series (2)

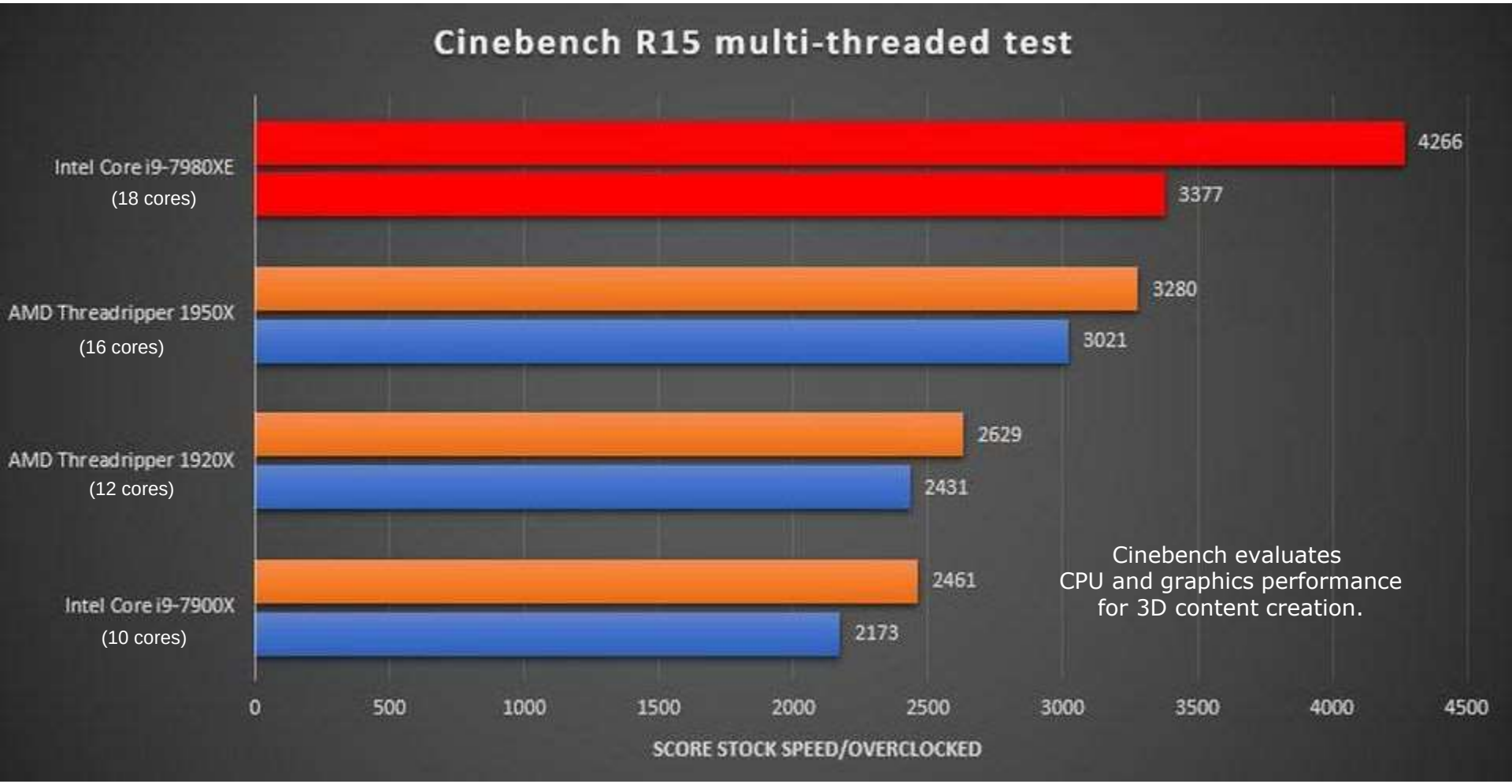
Comparing the multi-threaded IPC values of Skylake-SP/-X and desktop Skylake-S processors[1] [31]

AnandTech.com	Intel SKL-SP vs SKL-S IPC Multi Threaded Tests	Gain over SKL-S
Web	Octane	5.2%
	WebXPRT 15	-2.8%
System	3DPM v2.1	-0.3%
	DigiCortex v1.20	1.1%
Rendering	Corona 1.3	17.3%
	Blender 2.78	3.5%
	LuxMark CPU C++	-0.1%
	POV-Ray 3.7.1b4	1.3%
	Cinebench 15 MT	4.0%
Encode	7-Zip	1.4%
	HandBrake 264-LQ	-2.1%
	HandBrake 264-HQ	-8.0%
	HandBrake 265-4K	-1.2%
Legacy	3DPM v1 MT	1.4%
	x264 HD 3 Pass 1	0.9%
	x264 HD 3 Pass 2	1.4%
	Cinebench 11.5 MT	1.8%
	Cinebench 10 MT	5.2%
Overall	**18 Tests**	**1.7%**

Again, the benchmark scores show no notable differences between the IPC values of the tested architectures.

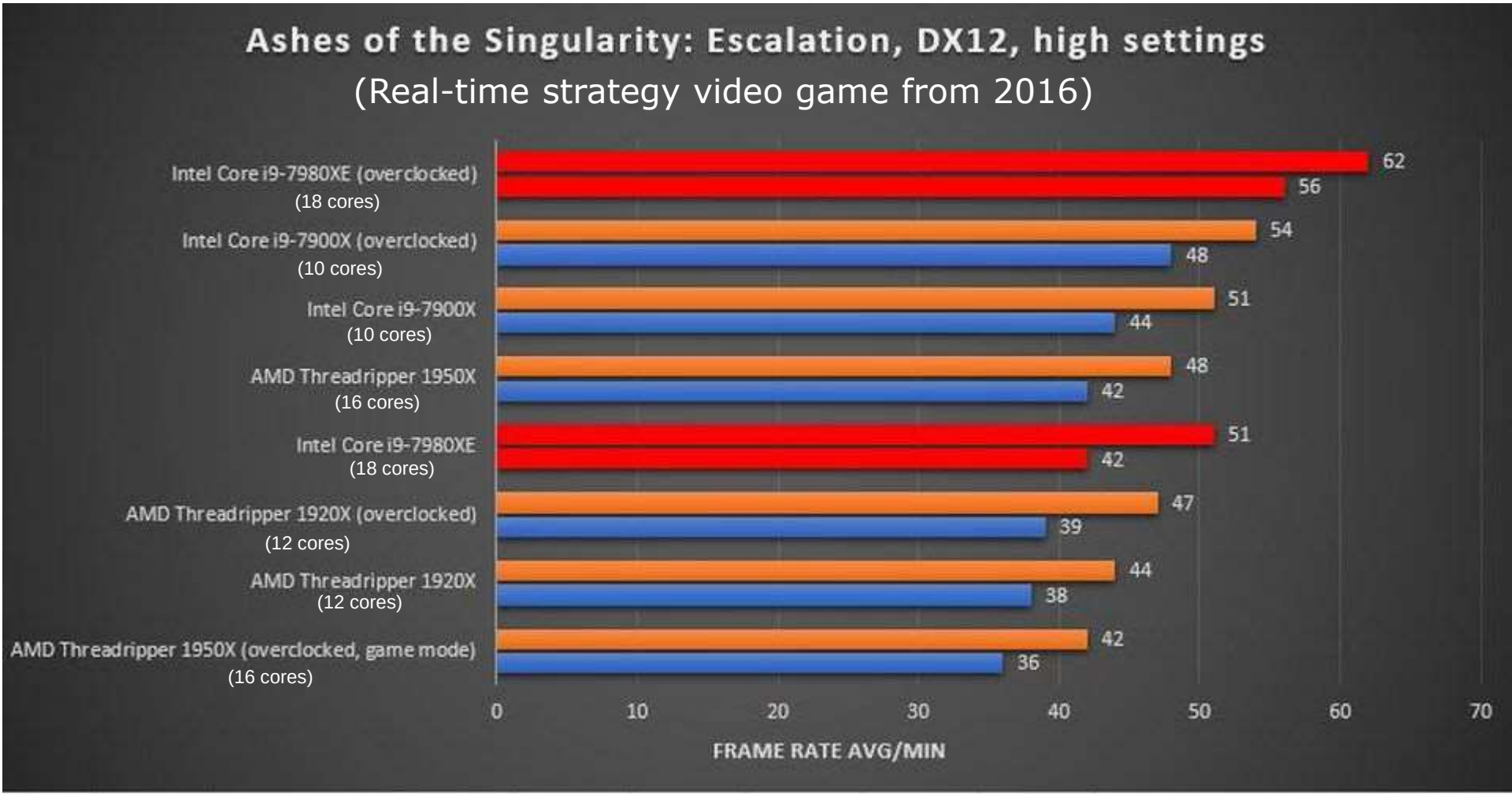
8.4 Performance assessment of the Skylake X-Series (3)

Benchmark results for the multi-threaded Cinebench R15 showing the superiority of Intel's 18-core Core i9-7980XE over AMD's 16-core ThreadRipper 1950X [48]



8.4 Performance assessment of the Skylake X-Series (4)

Benchmark results for gaming (Ashes of Singularity) showing the superiority of Intel's 18-core Core i9-7980XE over AMD's 16-core ThreadRipper 1950X [48]



8.4 Performance assessment of the Skylake X-Series (5)

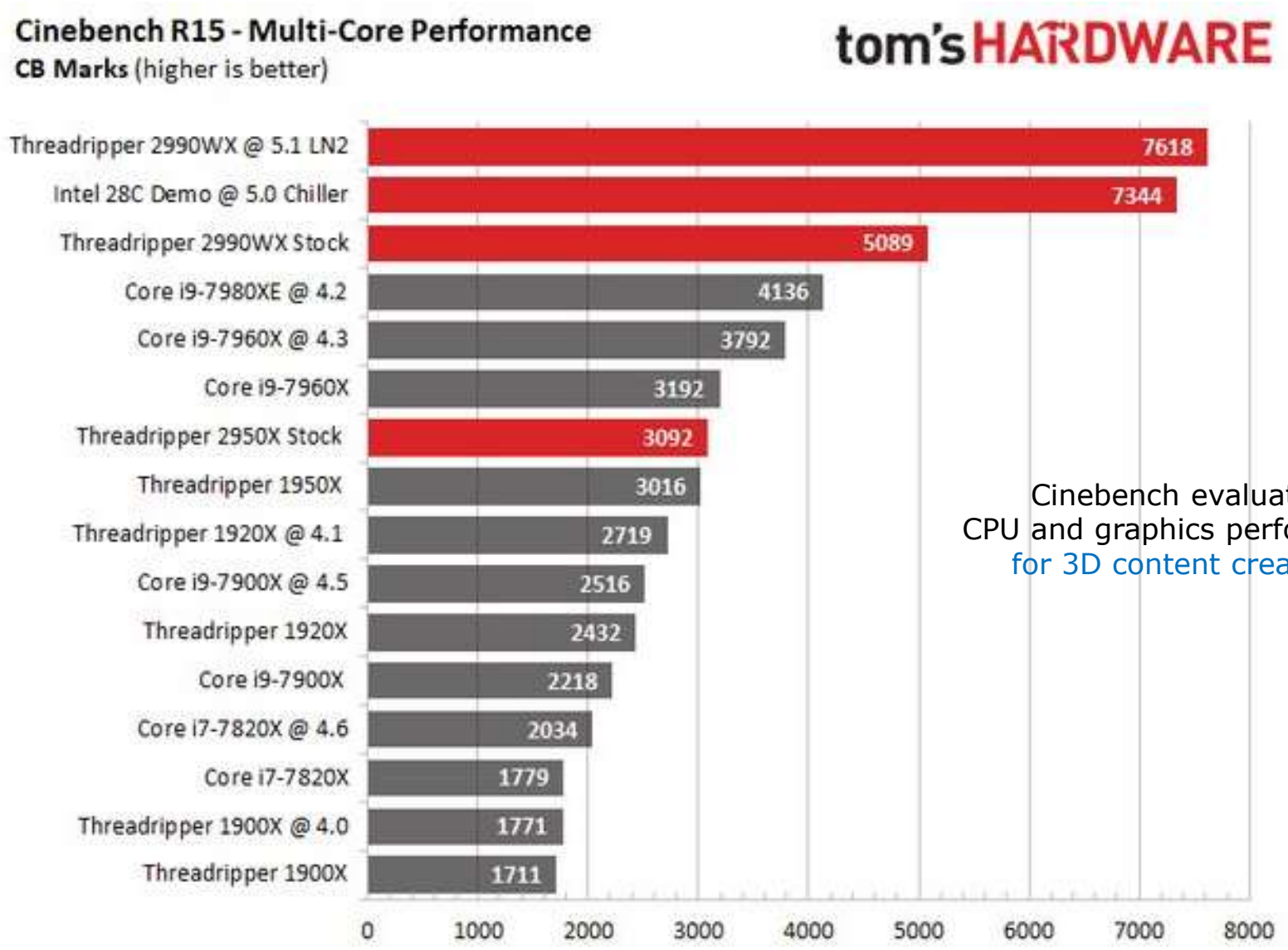
Performance assessment of Intel's Core i9-7980XE [49]

This model (and also the Skylake-X Series) has an impressive performance when compared with AMD's 1. generation ThreadRipper models or Intel's preceding Core i7-6950X, as indicated in the above Figures.

Nevertheless, this advantage vanished vs. AMD's 2. gen. ThreadRipper line, as the next Figure shows.

8.4 Performance assessment of the Skylake X-Series (6)

Benchmark results for the multi-threaded Cinebench R15 showing the superiority of AMD's 2. gen. 32-core ThreadRipper 2990WX over Intel's 18-core Core i9-7980XE [50]



Cinebench evaluates CPU and graphics performance for 3D content creation.

9. The Caby Lake X-Series

9. The Kaby Lake X-Series -1

1. gen.				2. gen.	3. gen.	4. gen.	5. gen.
Core 2 New Microarch. 65 nm	Penryn New Process 45 nm	Nehalem New Microarch. 45 nm	West-mere New Process 32 nm	Sandy Bridge New Microarch. 32 nm	Ivy Bridge New Process 22 nm	Haswell New Microarchi. 22 nm	Broad-well New Process 14 nm
TOCK	***TICK***	***TOCK***	***TICK***	***TOCK***	***TICK***	***TOCK***	***TICK***
(2006)	*(2007)*	*(2008)*	*(2010)*	*(2011)*	*(2012)*	*(2013)*	*(2014)*

6. gen.	7. gen.	8. gen.[1]	9. gen.
Skylake New Microarch. 14 nm	Kaby Lake New Microarch. 14 nm	Kaby Lake R/G Coffee Lake Cannon Lake 14/10 nm	Coffee Lake R New Mocroarch. 14 nm
TOCK	***TOCK***	***TOCK***	***TOCK***
(2015)	*(2016)*	*(2017/18)*	*(2018)*

[1]Astonishingly, the 8th generation encompasses four processor lines, as follows:

- Kaby Lake Refresh
- Kaby Lake G with AMD Vega graphics
- Coffee Lake and
- 10 nm Cannon Lake designs [218].

R: Refresh

9. The Caby Lake X-Series (2)

The Kaby Lake X-Series -2 [47]

- Announced in 5/2017 launched in 6/2017.
- Manufactured on the 14 nm+ technology.
- Intel introduced initially two 4-core models based on the Kaby Lake-S design while disabling the integrated graphics and using the spared power headroom to raise the core frequency.

  They are implemented as LCC dies (Low-Core-Count) (note that this die configuration includes up to 10 cores in the Kaby Lake-S line).
- They do not have any bundled cooler, but Intel is promoting its own TS13X liquid cooled loop for the Core-X Series.

9. The Caby Lake X-Series (3)

Main features of the models of the Kaby Lake X-Series [47]

Intel Basin Falls X299 Processors, Launched in June 2017					
	i5-7640X	i7-7740X	i7-7800X	i7-7820X	i9-7900X
	Kaby Lake-X	Kaby Lake-X	Skylake-X	Skylake-X	Skylake-X
Cores	4C/4T	4C/8T	6C/12T	8C/16T	10C/20T
Base Clock	4.0 GHz	4.3 GHz	3.5 GHz	3.6 GHz	3.3 GHz
Turbo Clock	4.2 GHz	4.5 GHz	4.0 GHz	4.3 GHz	4.3 GHz
TurboMax Clock	N/A	N/A	N/A	4.5 GHz	4.5 GHz
L2 Cache	256 KB per core		1 MB per core		
L3 Cache	6 MB	8 MB	8.25 MB	11 MB	13.75 MB
PCIe lanes	16		28		44
Mem. channels	2		4		
Memory freq.	DDR4-2666		DDR4-2400	DDR4-2666	
TDP	112 W		140 W		
Socket	LGA 2066		LGA 2066		
Price (1k)	$242	$339	$389	$599	$999

9. The Caby Lake X-Series (4)

Contrasting Kaby Lake-X models to related high performance Kaby Lake ones [51]

	Core i7		Core i5	
	Core i7-7740X	Core i7-7700K	Core i5-7640X	Core i5-7600K
	Kaby Lake-X	Kaby Lake	Kaby Lake-X	Kaby Lake
Socket	LGA2066	LGA1151	LGA2066	LGA1151
Cores/Threads	4/8	4/8	4/4	4/4
Base Frequency	4.3 GHz	4.2 GHz	4.0 GHz	3.8 GHz
Turbo Frequency	4.5 GHz	4.4 GHz	4.2 GHz	4.2 GHz
TDP	112 W	91 W	112 W	91 W
L2 Cache	256 KB/core			
L3 Cache	8 MB		6 MB	
DRAM Channels	2			
DRAM Support	DDR4-2666	DDR4-2400	DDR4-2666	DDR4-2400
Graphics	None	HD 620	None	HD 620
Price	$339		$242	
Launched	Soon	Jan 2017	Soon	Jan 2017

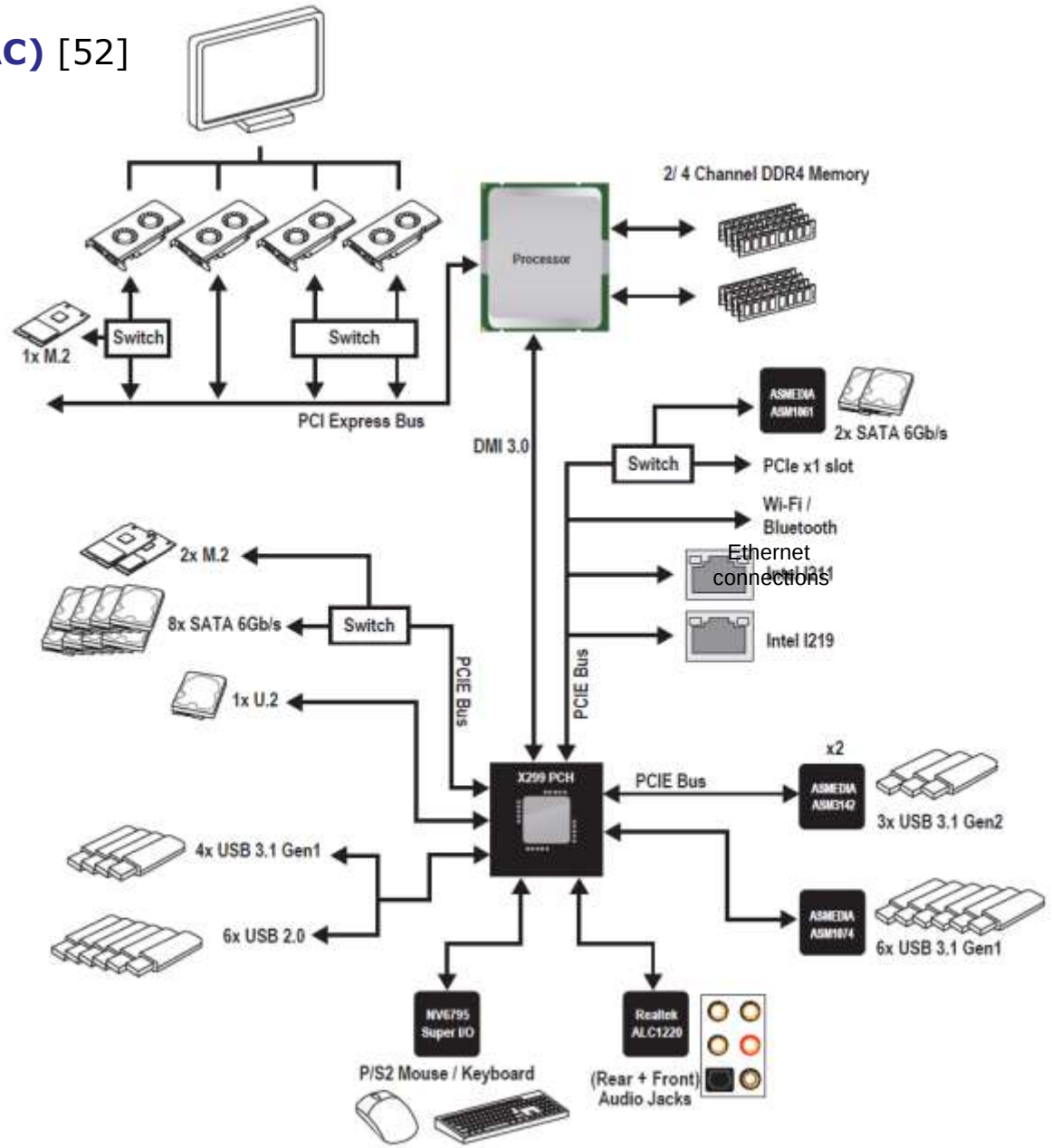
9. The Caby Lake X-Series (5)

Main differences of the Kaby Lake X-Series vs. the prior K-tagged Kaby Lake line

- Kaby Lake-X parts are essentially mainstream K-tagged Kaby Lake parts with disabled graphics and utilizing the resulting power headroom for higher clock frequencies.
- The differences are in more details as follow:
  - support for higher grade DDR4-2666 memory, over the DDR4-2400 on the prior platform
  - slightly (+100 or 200 MHz) higher base and Turbo frequencies but higher TD: 112W vs. 91 W
  - no integrated graphics and
  - use of the LGA2066 socket instead of the LGA1151 socket,

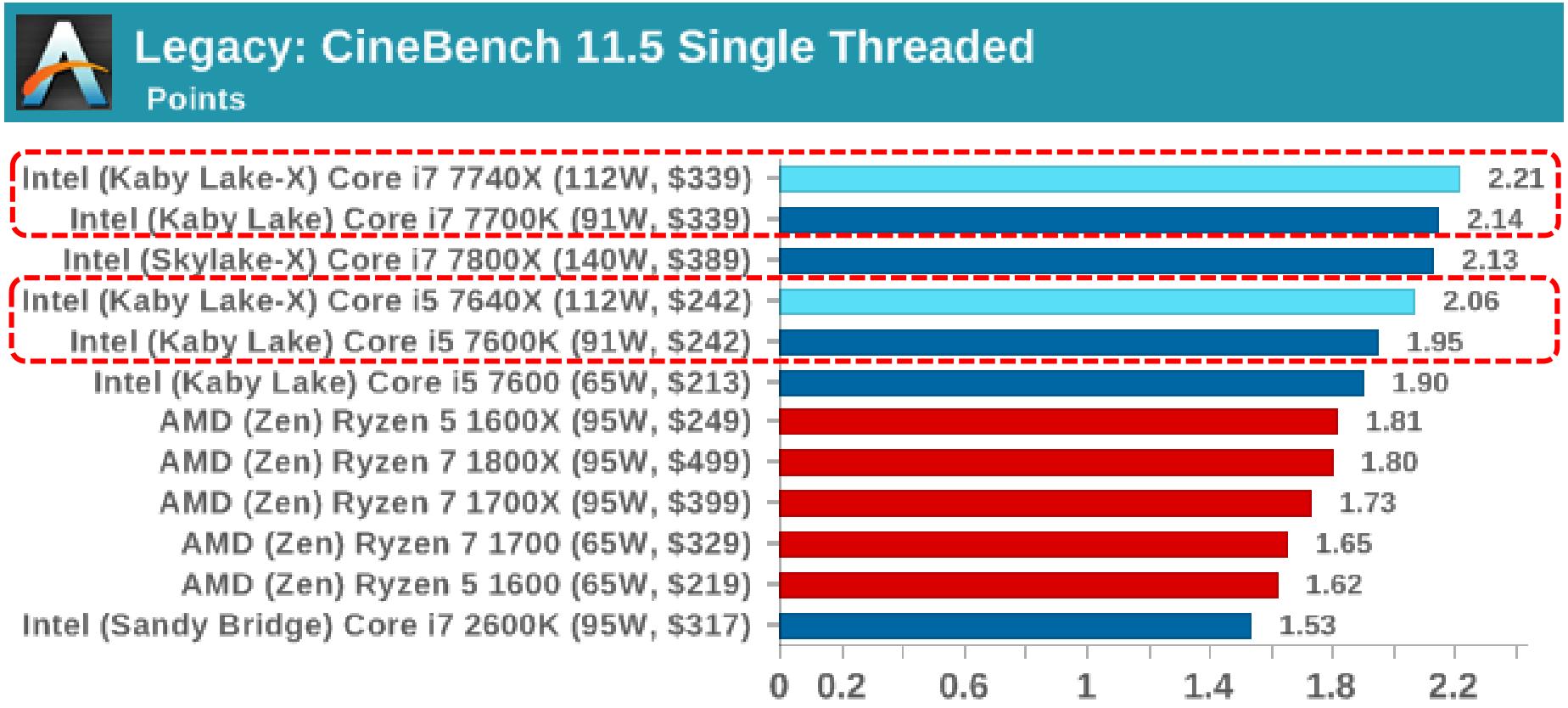
as seen in the above Table.

Example Kaby Lake-X platform (MSI's X299 XPower Gaming AC) [52]

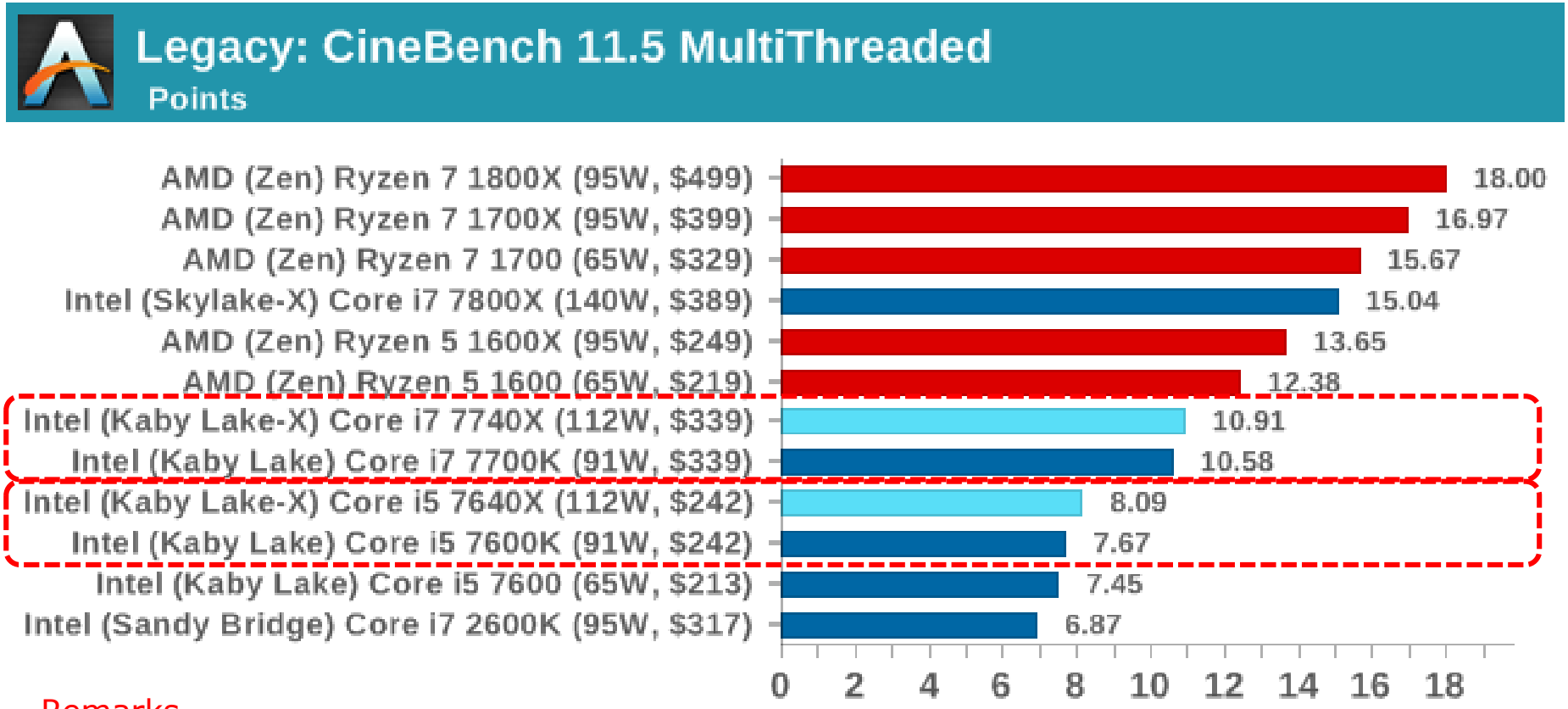


Chipset Diagram of MSI's X299 XPower Gaming AC, their high-end MB

Comparing CineBench ST benchmark results for related Kaby Lake-X and Kaby Lake models [47]



Comparing CineBench MT benchmark results for related Kaby Lake-X and Kaby Lake models [47]



Remarks

- AMD's Ryzen 7 processors shown above have 8 cores whereas Ryzen 5 processors only 6.
- By contrast, Intel's Kaby Lake-X processors include as few as 4 cores.
- This gives an explanation for the benchmark results shown.

Comparing CineBench benchmark results for related Kaby Lake-X and Kaby Lake models [47]

Above benchmark results show that the Kaby Lake-X models have only about 5 % more performance than the prior Kaby Lake ones whereas they consume more power (112 W vs. 91 W and do not provide integrated graphics.

In addition, it can be noted that AMD's related Ryzen models have lower single thread but higher multi-threaded performance (due to theirs higher core count (8 vs. 4)).

Remark on the CineBench benchmark

- It is a real-world cross-platform test suite that evaluates CPU and graphics performance for 3D content creation.
- It is based on MAXON's award-winning animation software Cinema 4D.

10. The Skylake X Refresh Series

10. The Skylake X Refresh Series

Introduced in 10/2018 as an update of the Skylake-X Series.

Manufactured on the 14 nm++ technology.

Main goal of the line is to provide a competitor versus AMDs 2. gen. TreadRipper line.

10. The Skylake X Refresh Series (2)

Main features of the Skylake X Refresh models [41]

PROCESSOR NUMBER	BASE CLOCK SPEED (GHZ)	INTEL® TURBO BOOST TECHNOLOGY 2.0 FREQUENCY (GHZ)[17]	INTEL® TURBO BOOST MAX TECHNOLOGY 3.0 FREQUENCY (GHZ)[18]	CORES/ THREADS	TDP	Intel® Smart Cache	UNLOCKED[4]	PLATFORM PCIE 3.0 LANES	MEMORY SUPPORT	INTEL® OPTANE™ MEMORY SUPPORT[6]	RCP PRICING (USD 1K)
Intel® Core™ i9-9980XE X-series	3.0	4.4	4.5	18/36	165W	24.75 MB	✓	Up to 68	Four channels DDR4-2666	✓	$1,979
Intel® Core™ i9-9960X X-series	3.1	4.4	4.5	16/32	165W	22 MB	✓	Up to 68	Four channels DDR4-2666	✓	$1,684
Intel® Core™ i9-9940X X-series	3.3	4.4	4.5	14/28	165W	19.25 MB	✓	Up to 68	Four channels DDR4-2666	✓	$1,387
Intel® Core™ i9-9920X X-series	3.5	4.4	4.5	12/24	165W	19.25 MB	✓	Up to 68	Four channels DDR4-2666	✓	$1,189
Intel® Core™ i9-9900X X-series	3.5	4.4	4.5	10/20	165W	19.25 MB	✓	Up to 68	Four channels DDR4-2666	✓	$989
Intel® Core™ i9-9820X X-series	3.3	4.1	4.2	10/20	165W	16.5 MB	✓	Up to 68	Four channels DDR4-2666	✓	$889
Intel® Core™ i7-9800X X-series	3.8	4.4	4.5	8/16	165W	16.5 MB	✓	Up to 68	Four channels DDR4-2666	✓	$589

tel® processor numbers are not a measure of performance. Processor numbers differentiate features within each processor family, not across different processor families.
ll processors are lead-free (per EU RoHS directive July 2006) and halogen free (residual amounts of halogens are below November 2007 proposed IPC/JEDEC J-STD-709 standards)
ll processors support Intel® Virtualization Technology (Intel® VT-x)
Other names and brands may be claimed as the property of others.

he new desktop processors include protections for the security vulnerabilities commonly referred to as "Spectre," "Meltdown" and "L1TF." These protections include a combination of the hardware design changes e announced earlier this year as well as software and microcode updates.

Speculative side channel variant Spectre V2 (Branch Target Injection) = Microcode + Software
Speculative side channel variant Meltdown V3 (Rogue Data Cache Load) = Microcode
Speculative side channel variant Meltdown V3a (Rogue System Register Read) = Microcode
Speculative side channel variant V4 (Speculative Store Bypass) = Microcode + Software
Speculative side channel variant L1 Terminal Fault = Microcode + Software

intel

10. The Skylake X Refresh Series (3)

Contrasting main features of Intel's Skylake-X and Skylake-X Refresh models [53]

Intel Basin Falls Skylake-X Refresh								
AnandTech		Cores	TDP	Freq	L3 (MB)	L3 Per Core	DRAM DDR4	PCIe
i9-9980XE	**$1979**	18 / 36	165 W	**3.0 / 4.5**	24.75	1.375	2666	44
i9-9960X	**$1684**	16 / 32	165 W	**3.1 / 4.5**	22.00	1.375	2666	44
i9-9940X	**$1387**	14 / 28	165 W	**3.3 / 4.5**	19.25	1.375	2666	44
i9-9920X	**$1189**	12 / 24	**165 W**	**3.5 / 4.5**	**19.25**	**1.604**	2666	44
i9-9900X	**$989**	10 / 20	**165 W**	**3.5 / 4.5**	**19.25**	**1.925**	2666	44
i9-9820X	**$889**	**10 / 20**	**165 W**	**3.3 / 4.2**	**16.50**	**1.650**	2666	44
i7-9800X	**$589**	**8 / 16**	**165 W**	**3.8 / 4.5**	**16.50**	**2.031**	2666	**44**
Skylake-X								
i9-7980XE	**$1999**	18 / 36	165 W	2.5 / 4.4	24.75	1.375	2666	44
i9-7960X	**$1699**	16 / 32	165 W	2.8 / 4.4	22.00	1.375	2666	44
i9-7940X	**$1399**	14 / 28	165 W	3.1 / 4.4	19.25	1.375	2666	44
i9-7920X	**$1199**	12 / 24	140 W	2.9 / 4.4	16.50	1.375	2666	44
i9-7900X	**$999**	10 / 20	140 W	3.3 / 4.5	13.75	1.375	2666	44
i7-7820X	**$599**	8 / 16	140 W	3.6 / 4.5	11.00	1.375	2666	28
i7-7800X	**$389**	6 / 12	140 W	3.5 / 4.0	8.25	1.375	2400	28

10. The Skylake X Refresh Series (4)

Main improvements of the Skylake X Refresh Series over the Skylake X-Series

A comparison of the related data reveals the following improvements (see above Table):

- partly significantly higher clock rates, e.g. +500 MHz for the i9-990XE vs. the i9-7980XE,
- slightly higher Turbo 2.0 and Turbo 3.0 frequencies (mostly +100 or +200 MHz) (not indicated in the Table comparing both series))
- higher TDP values for lower core (8-12 core) models (165 W vs. 140 W),
- larger per-core L3 sizes for lower core (8-12 core) models (1.604 to 2.031 MHz vs. 1.375 MHz),
- more PCIe 3.0 lanes for the 8-core model (44 lanes vs. 28 lanes).

10. The Skylake X Refresh Series (5)

Sources of frequency improvements of the Skylake X Refresh line vs the Skylake X-Series [54]

There are two main sources to be mentioned:

a) improved manufacturing technology (14 nm++ instead of 14 nm+) and

b) using Solder Thermal Interface Material (STIM) between the CPU die and the integrated head spreader,

as detailed next.

10. The Skylake X Refresh Series (6)

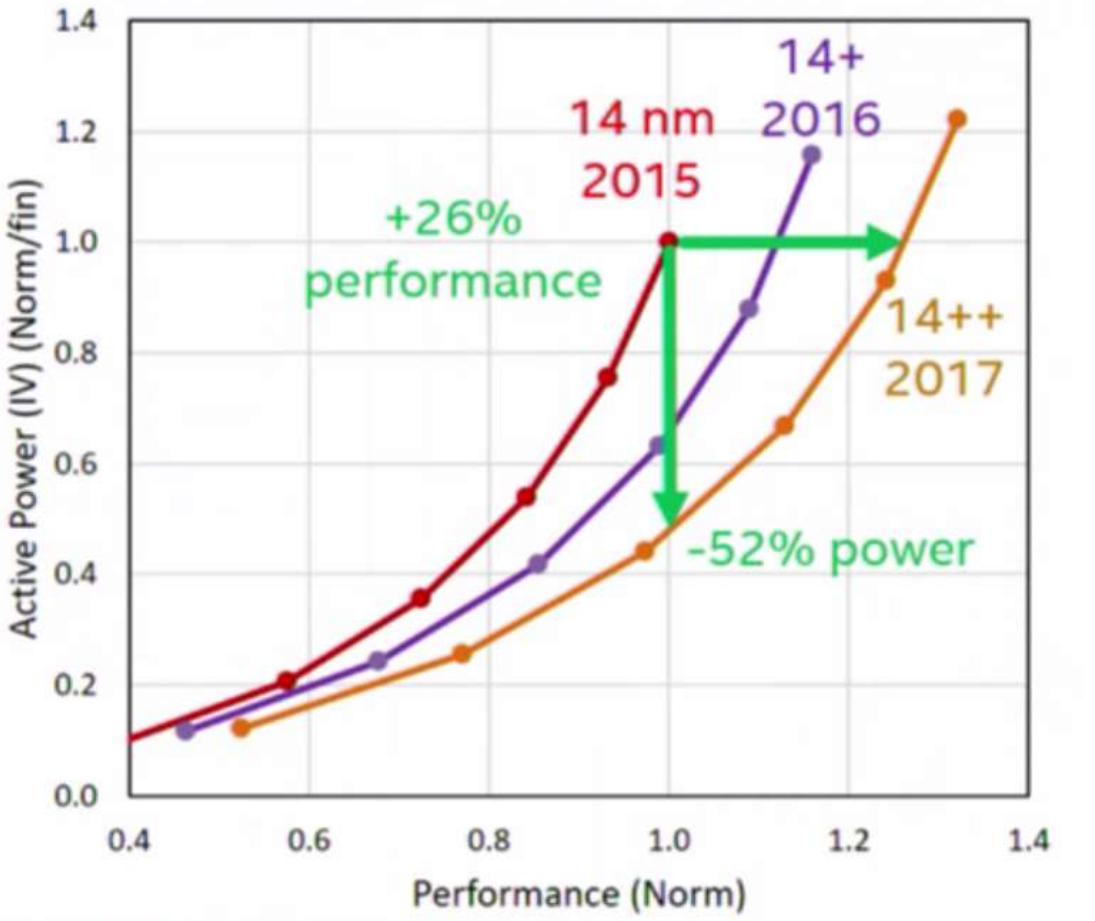
a) Improved manufacturing technology (14 nm++ instead of 14 nm+)

Manufacturing technology of Intel's Core processors (generations 2 to 9) [54]

Generation	Microarchitecture	Process node	Release year
2.	Sandy Bridge	32 nm	2011
3rd	Ivy Bridge	22nm	2012
4th	Haswell	22nm	2013
5th	Broadwell	14nm	2014
6th	Skylake	14nm	2015
7th	Kaby Lake	14nm+	2016
8th	Kaby Lake-R Coffee Lake-S Kaby Lake-G Kaby Lake-X Skylake-X Coffee Lake-U/H Whiskey Lake-U Amber Lake-Y Cannon Lake-U	14nm+ 14nm++ 14nm+ 14nm+ 14nm+ 14nm++ 14nm++ 14nm+ 10nm	2017 2017-2018 2018 2017 20017 2018 2018 2018 2017*
9th	Skylake-X Refresh Coffee Lake Refresh	14 nm++ 14nm**	2018 2018
Unknown	Ice Lake (Consumer)	10nm?	2019?
	Cascade Lake (Server) Cooper Lake (Server) Ice Lake (Server)	14nm** 14nm** 10nm	2018 2019 2020

Improvements of the power/performance curve with updated 14 nm technology [55] **-1**

- Skylake-X was manufactured on the 14 nm+ node whereas Skylake-X Refresh processors on the 14 nm++ node.
- This results in the following improvements:



10. The Skylake X Refresh Series (8)

Improvements of the power/performance curve with updated 14 nm technologies [55] **-2**

The power/performance curves of the 14 nm+ and 14 nm++ technologies indicate the following improvements over the 14 nm and 14 nm+ technologies: (assuming the highest performance model):

	Power consumption reduction for the same performance vs. the 14 nm technology (approximately)
14 nm+	35 %
14 nm++	52 %

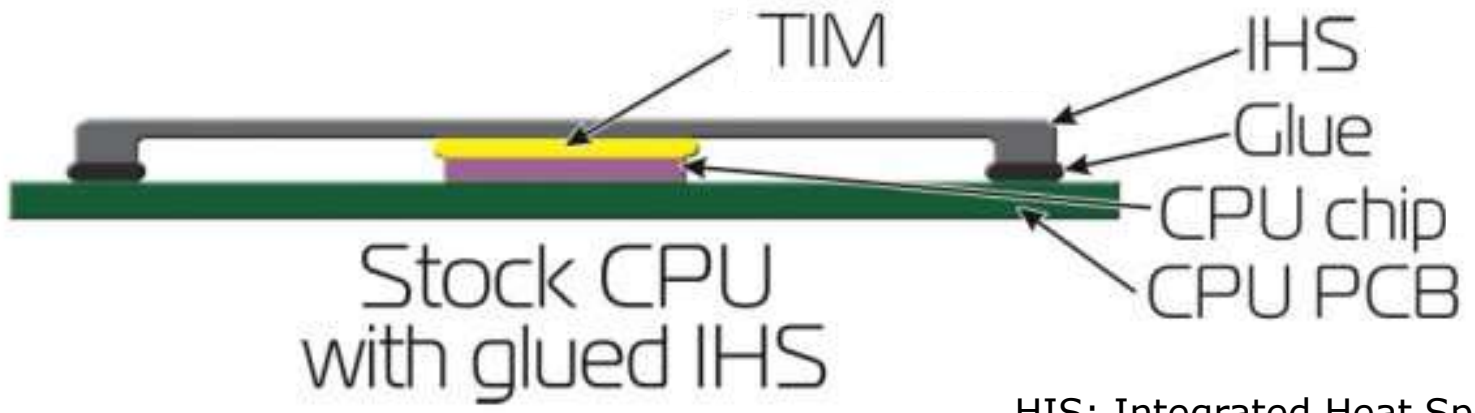
	Performance increase for the same power consumption vs. the 14 nm technology (approximately)
14 nm+	16 %
14 nm++	26 %

	Power consumption reduction for the same performance vs. the 14 nm+ technology (approximately)
14 nm++	17 %

	Performance increase for the same power consumption vs. the 14+ nm technology (approximately)
14 nm++	10 %

b) using Solder Thermal Interface Material (STIM) between the CPU die and the integrated head spreader,

- In a processor package there is a layer between the CPU die and the headspreader, often implemented as an Integrated head Spreader (HIS).
- This layer is made up of a Thermal Interface Material (TIM) (see Figure).
- The task of the TIM is to transfer the heat away from the processor die to the headspreader and eventually to the processor cooler.



HIS: Integrated Heat Spreader
TIM: Thermal Interface Material

Figure: The Thermal Interface Material (TIM) between the IHS (Integrated heat Spreader and the processor die [56]

- The Thermal Interface may be implemented either as a layer of cheap thermal paste or as a more costly indium-tin soldering.

10. The Skylake X Refresh Series (10)

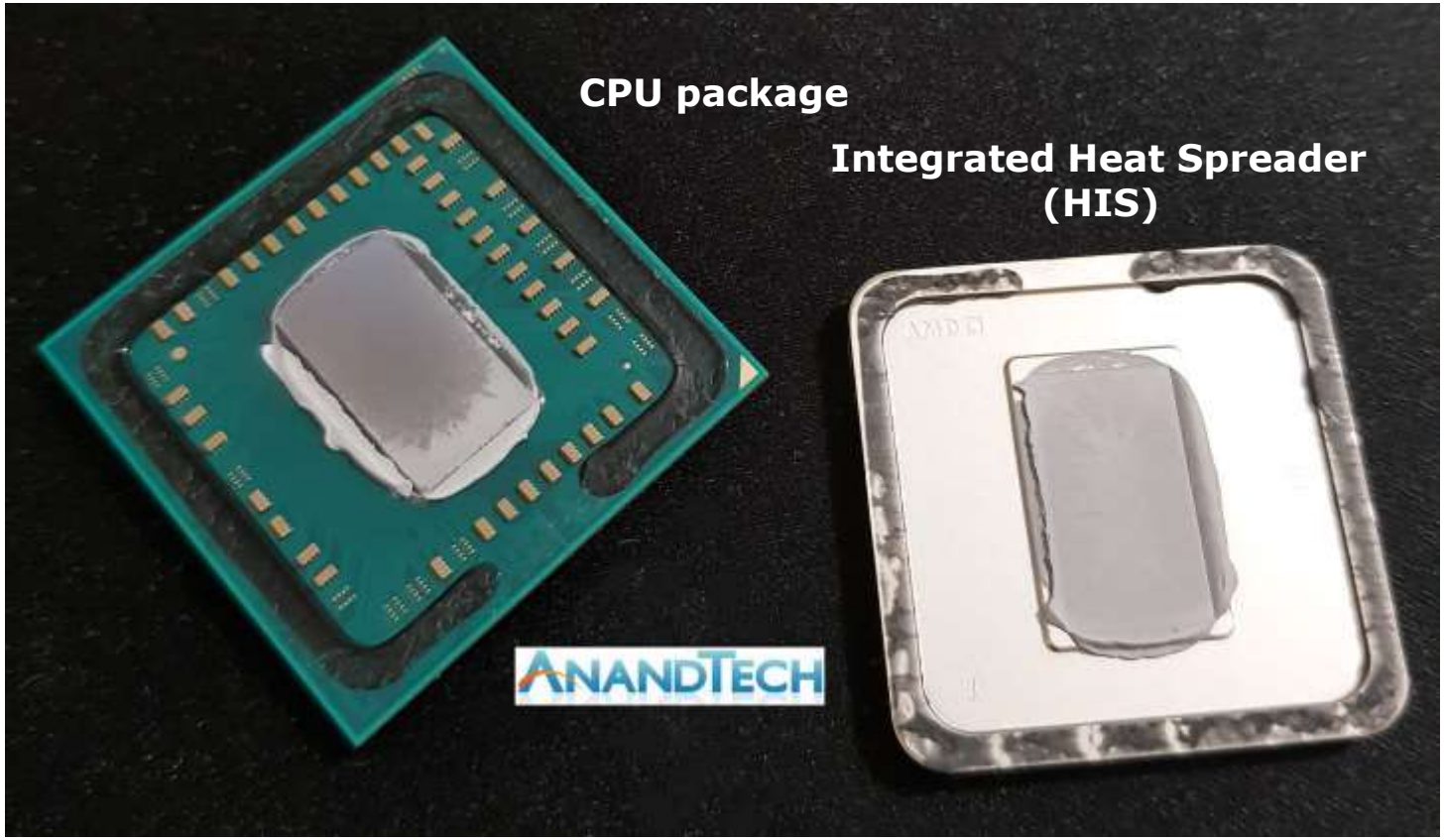
Benefits and drawbacks of the main implementation options of TIM

Type of TIM	Benefit	Drawback
Paste	• Lower cost • Longevity	• Worse heat conductivity
Soldered (Bonded)	• Better heat conductivity This results in larger power headroom and better overclocking capability	• Higher cost • Shorter lifecycle

Note that more costly soldered (bonded) interfaces provide a better heat conductivity and thus result in a larger power headroom that may be converted into higher clock frequency.

On the other hand, a soldered (bonded) thermal interface has a shorter lifecycle since the soldered implementation results in higher thermal tensions during usage (in thermal cycles) than the pasted one.

Pasted (glued) CPU package and integrated heat Spreader (HIS) after separation [56]



The Figure shows the gray colored glue that holds the IHS to the CPU package.

10. The Skylake X Refresh Series (12)

Use of a pasted or soldered (bonded) heat conducting layer between the CPU die and the integrated heat spreader in Intel's and AMD's processor sockets [36]

Thermal Interface							
Intel		Celeron	Pentium	Core i3	Core i5	Core i7/i9	HEDT
Sandy Bridge	**LGA1155**	Paste	Paste	Paste	Bonded	Bonded	Bonded
Ivy Bridge	**LGA1155**	Paste	Paste	Paste	Paste	Paste	Bonded
Haswell / DK	**LGA1150**	Paste	Paste	Paste	Paste	Paste	Bonded
Broadwell	**LGA1150**	Paste	Paste	Paste	Paste	Paste	Bonded
Skylake	**LGA1151**	Paste	Paste	Paste	Paste	Paste	Paste
Kaby Lake	**LGA1151**	Paste	Paste	Paste	Paste	Paste	-
Coffee Lake	**1151 v2**	Paste	Paste	Paste	Paste	Paste	-
CFL-R	**1151 v2**	?	?	?	K models: Bonded		-
AMD							
Zambezi	**AM3+**	Bonded		**Carrizo**	**AM4**	Bonded	
Vishera	**AM3+**	Bonded		**Bristol R**	**AM4**	Bonded	
Llano	**FM1**	Paste		**Summit R**	**AM4**	Bonded	
Trinity	**FM2**	Paste		**Raven R**	**AM4**	Paste	
Richland	**FM2**	Paste		**Pinnacle**	**AM4**	Bonded	
Kaveri	**FM2+**	Paste / Bonded*		**TR**	**TR4**	Bonded	
Carrizo	**FM2+**	Paste		**TR2**	**TR4**	Bonded	
Kabini	**AM1**	Paste					

*Some Kaveri Refresh models were bonded

Use of STIM (Solder Thermal Interface Material) in Intel's 9th generation Coffee Lake Refresh S line [36]

All three models introduced in the Coffee lake Refresh S Series make use of STIM that is Solder-based Thermal interface Material to improve heat conductivity between the CPU die and the integrated heat spreader (HIS), as indicated below.

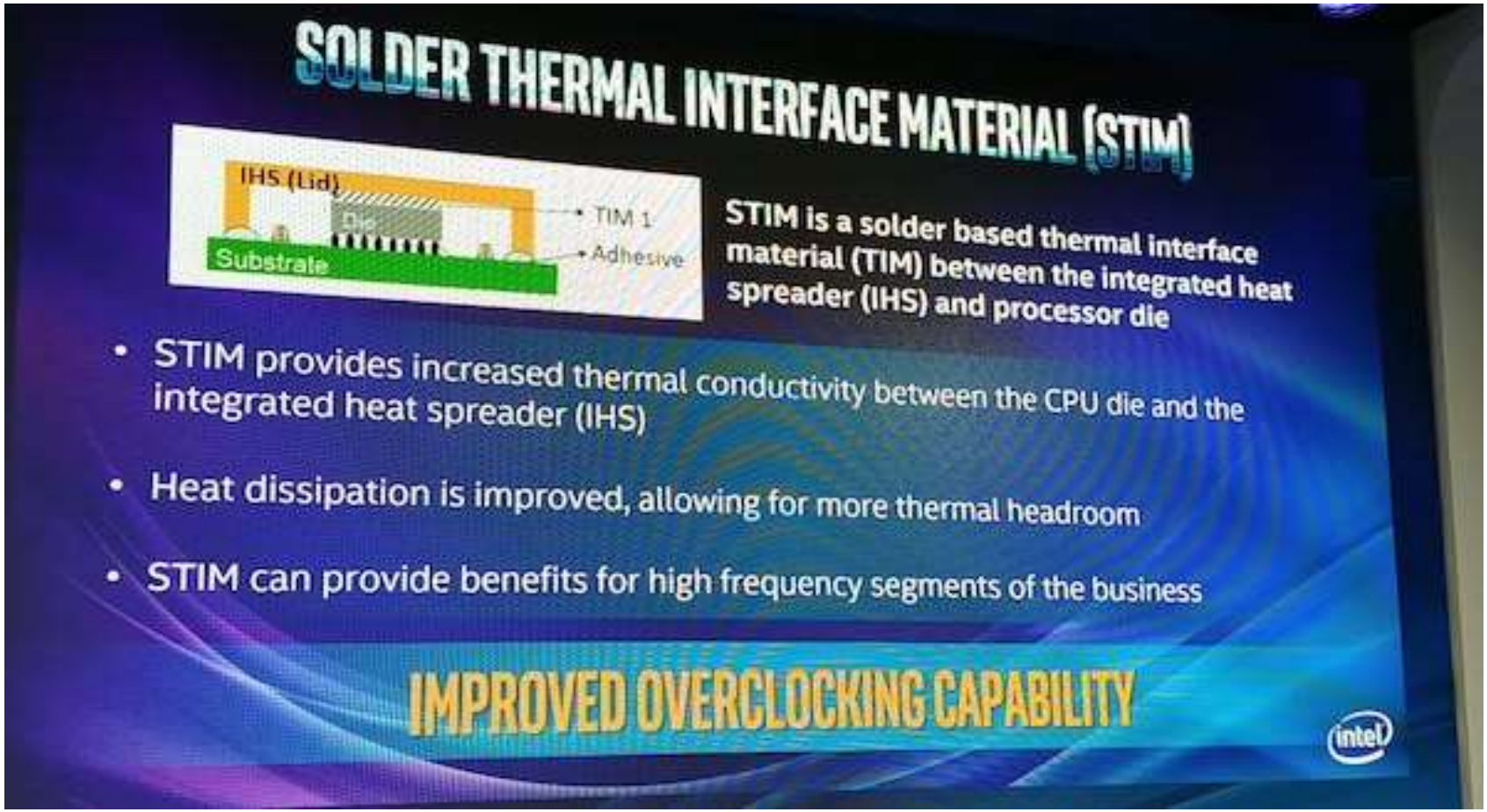


Figure: Introduction of STIM in the Coffee Lake Refresh S series to improve heat conductivity [36]

10. The Skylake X Refresh Series (14)

Comparing main features of Intel's Skylake X Refresh and AMD's 2. gen. ThreadRipper processor models [55]

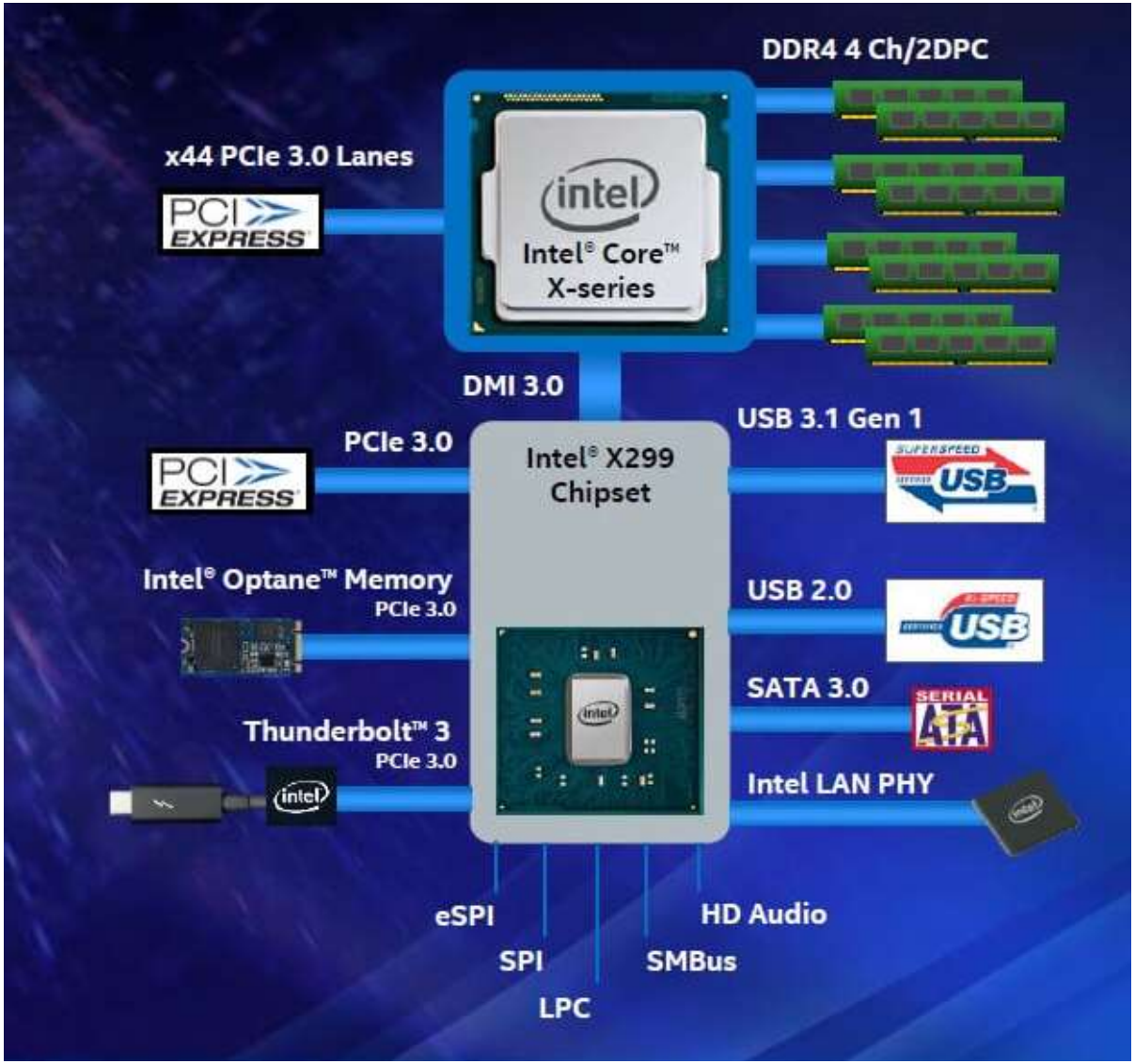
Model	Price	Cores	TDP	Freq	L3 (MB)	L3 Per Core	DRAM DDR4	PCIe
Intel								
i9-9980XE	$1979	18 / 36	165 W	3.0 / 4.5	24.75	1.375	2666	44
i9-7980XE	$1999	18 / 36	165 W	2.5 / 4,4	24.75	1.375	2666	44
AMD								
TR 2990WX	$1799	32 / 64	250 W	3.0 / 4.2	64.00	2.000	2933	60
TR 2970WX	$1299	24 / 48	250 W	3.0 / 4.2	64.00	2.000	2933	60
TR 2950X	$899	16 / 32	180 W	3.5 / 4.4	32.00	2.000	2933	60

Addressing Spectre and Meltdown by Intel [36]

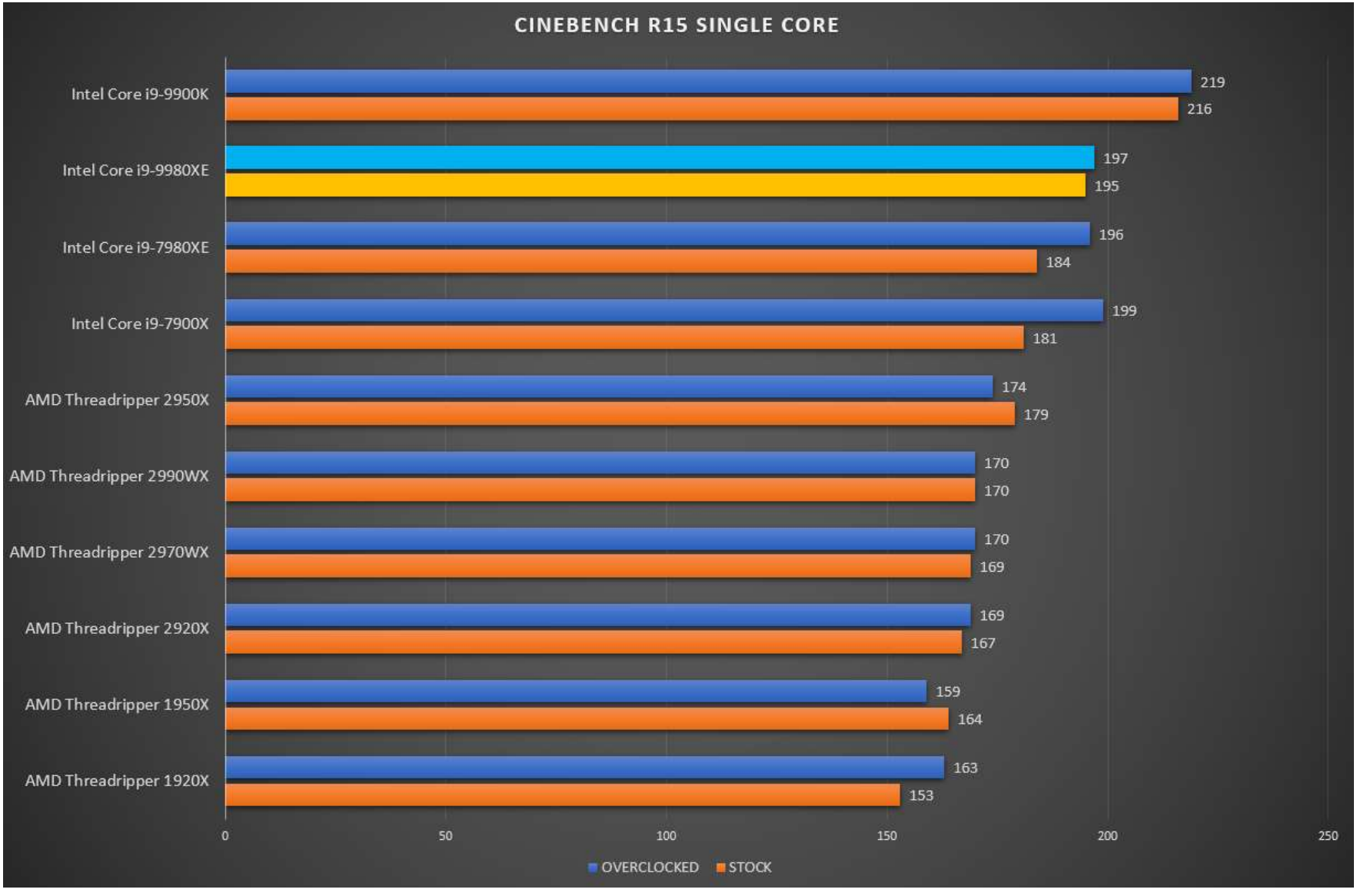
Addressing Spectre and Meltdown by Intel							
AnandTech			SKX-R 3175X	CFL-R	Cascade Lake	Whiskey Lake	Amber Lake
Spectre	Variant 1	Bounds Check Bypass	OS/VMM	OS/VMM	OS/VMM	OS/VMM	OS/VMM
Spectre	Variant 2	Branch Target Injection	Firmware + OS	Firmware + OS	Hardware + OS	Firmware + OS	Firmware + OS
Meltdown	Variant 3	Rogue Data Cache Load	Firmware	**Hardware**	Hardware	Hardware	Firmware
Meltdown	Variant 3a	Rogue System Register Read	Firmware	Firmware	Firmware	Firmware	Firmware
	Variant 4	Speculative Store Bypass	Firmware + OS	Firmware + OS	Firmware + OS	Firmware + OS	Firmware + OS
	Variant 5	L1 Terminal Fault	Firmware	**Hardware**	Hardware	Hardware	Firmware

CFL-R: Coffee Lake Refresh SKX-R: Skylake-X Refresh

Intel's Core X-Series Refresh (Basin Falls Refresh) platform [41]

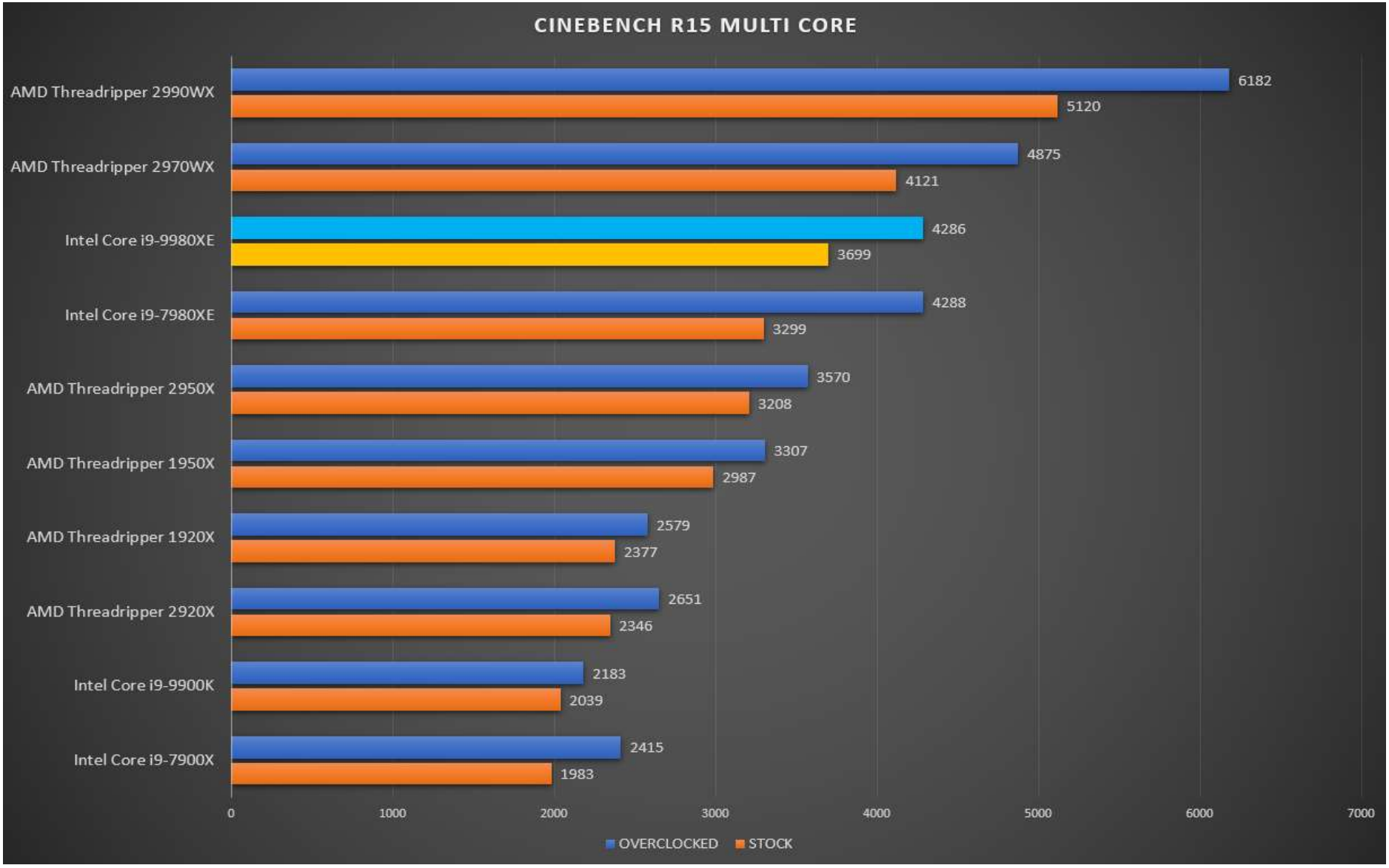


Contrasting Intel's i9-7980XE and i9-9980XE CineBench R15 single core benchmark result with those of AMD's Threadripper models [49]



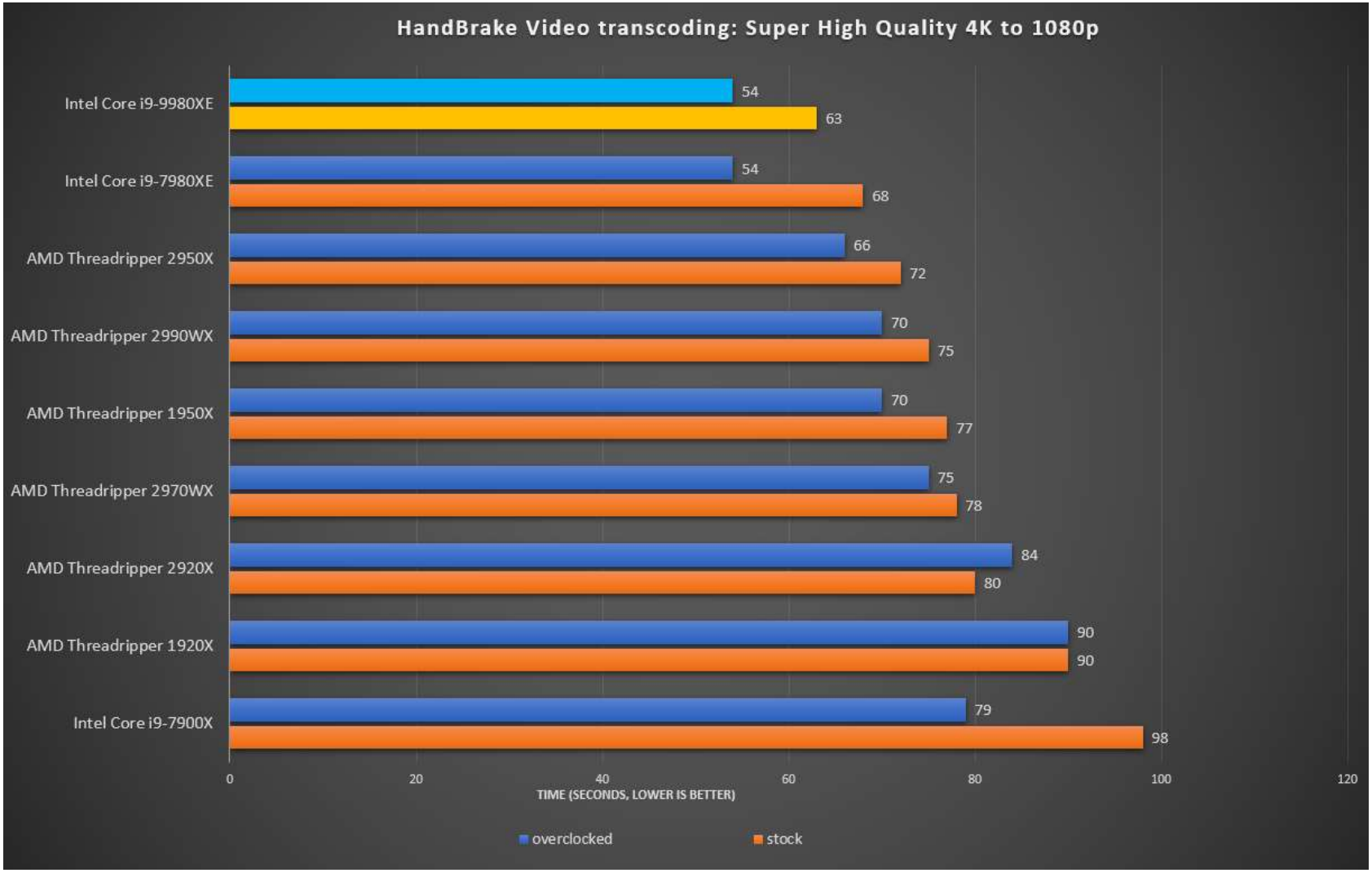
10. The Skylake X Refresh Series (18)

Contrasting Intel's i9-7980XE and i9-9980XE CineBench R15 single core benchmark result with those of AMD's Threadripper models [49]



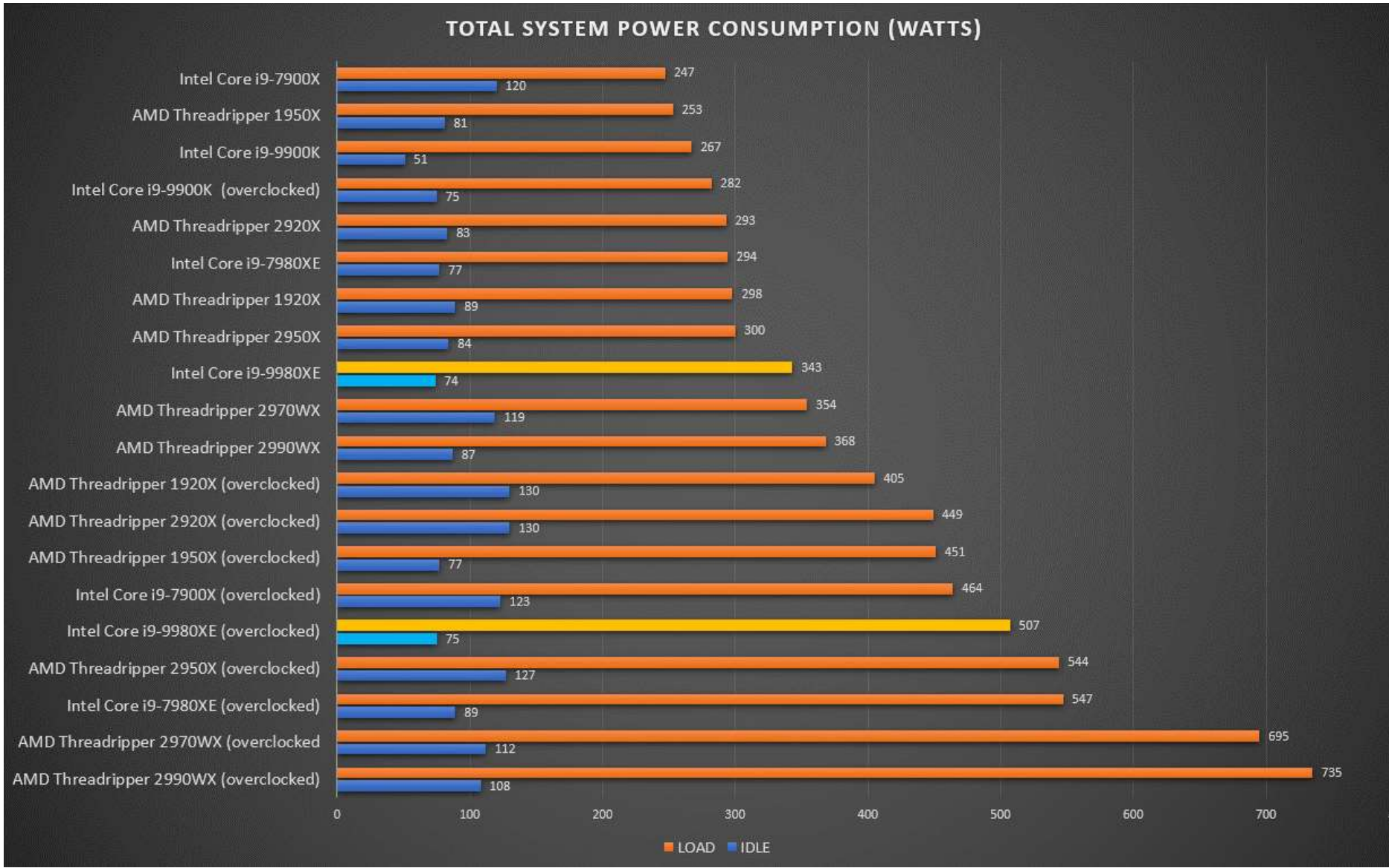
10. The Skylake X Refresh Series (19)

Contrasting Intel's i9-9980XE HandBrake (Video encoding) benchmark result with those of AMD's Threadripper models [49]



10. The Skylake X Refresh Series (20)

Total system power consumption (Watts) of Intel's i9-7980XE and i9-9980XE and AMD's ThreadRipper models [49]



Performance assessment of Intel's Skylake X-Series Refresh models [49]

As long as Intel's Skylake-X models were superior vs. AMD's 1. gen. ThreadRipper models, AMD's 2.gen. ThreadRipper models are simply far better value for content creation (2950X) and 3D modeling tasks (WX-Series), as seen in the above Figures.

Nevertheless, for converting videos from one format to another by e.g. HandBrake (see preceding Figure), or for 4K video export by Adobe Premier Pro, Intel's 18-core Skylake X-Series Refresh i9-9980XE outperforms AMD's 2. gen. ThreadRipper models.

10. The Skylake X Refresh Series (22)

Remarks

For heavily threaded workloads Intel announced in 10/2018 a workstation oriented 28-core processor, the Xeon 3175X, as seen below.

It is based on the Xeon Skylake-SP 8180 server processor and needs the LGA 3647 socket.

The Xeon 3175W is unlocked, it is clocked at 3.1 GHz base and 4.3 GHz boost and has a TDP of 255W,

Figure: Intel's Xeon 3175X workstation platform [41]

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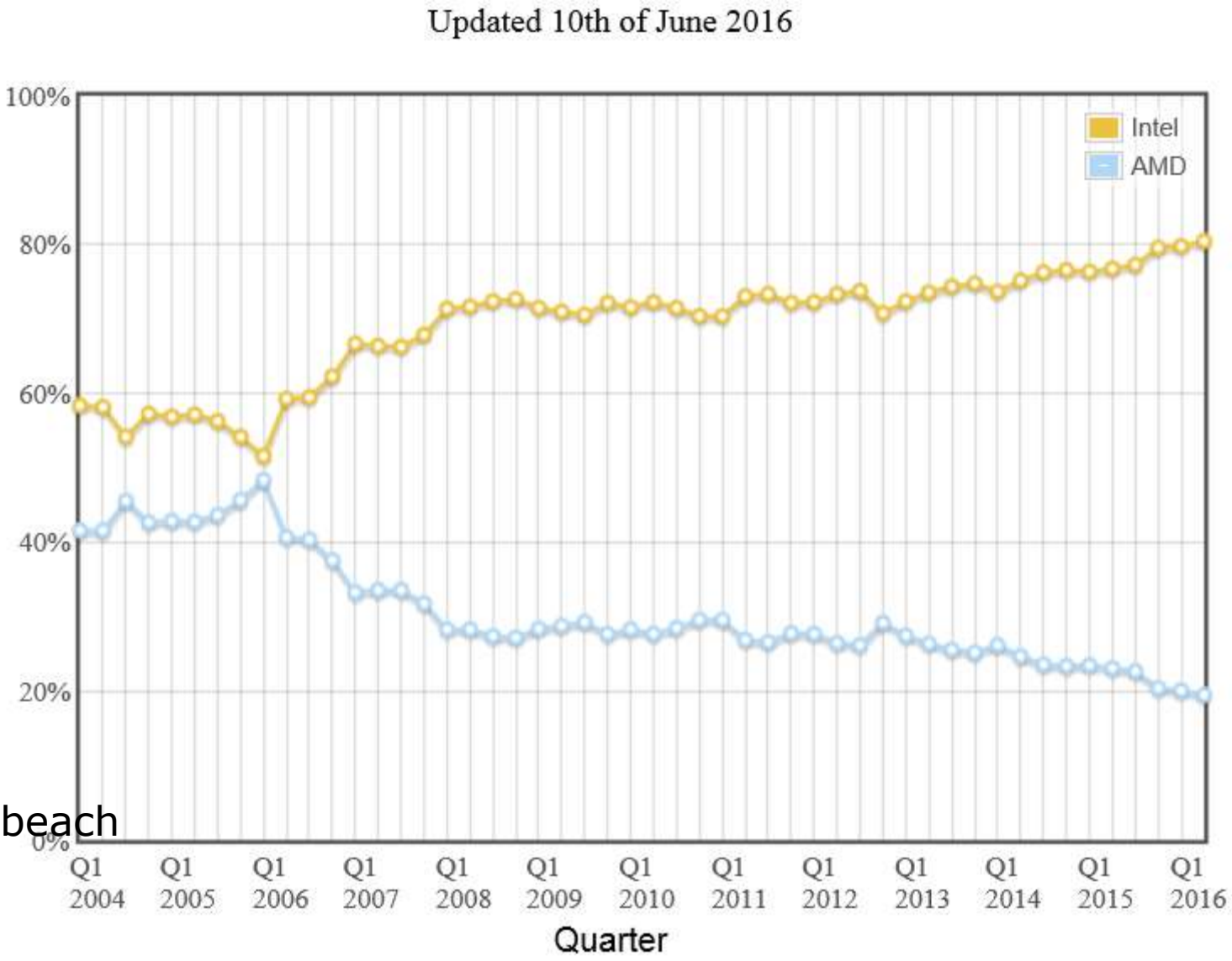
PC market share AMD vs Intel (PCs in use rather than PCs purchased)



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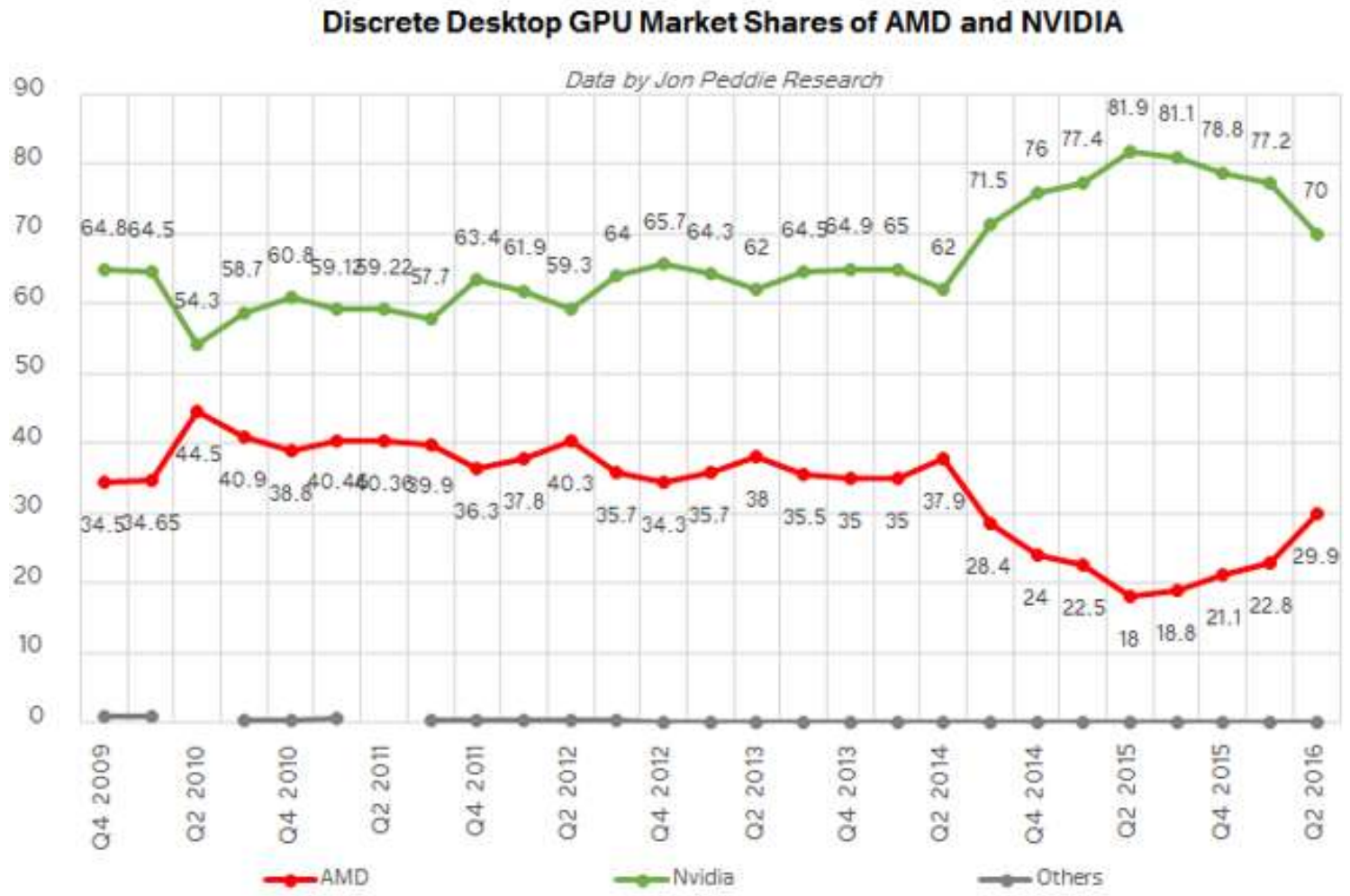

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