

Intel Processor Architectures

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Overview

- Analysis of Haswell and Ivy Bridge processor architecture by Intel
- Intel Core i5
 - Ivy Bridge – 3570k
 - Haswell – 4670k
- Intel Core i7
 - Ivy Bridge – 3770K
 - Haswell – 4770k

Overview

- Threading
- Intel's TICK-TOCK Model
- Instruction Sets
- Cache Performance
- Power Consumption
- Overall Performance
- Price/performance ratio
- Branch prediction

Threads

- Thread in processing is another way of virtualizing programs running concurrently.
- Can be thought of as the software version of running multiple CPUs
- A thread is a path of execution through a program.

Single-Thread Vs. Multi-Thread

- Single threaded programs have one path of execution.
- Multi-threaded programs have two or more paths of executions
- Single threaded programs can perform only one task at a time, and have to finish each task in sequence before they can start another.

Some background

- **Core i3**

- Two cores, hyper-threaded
- Acts like 4 cores

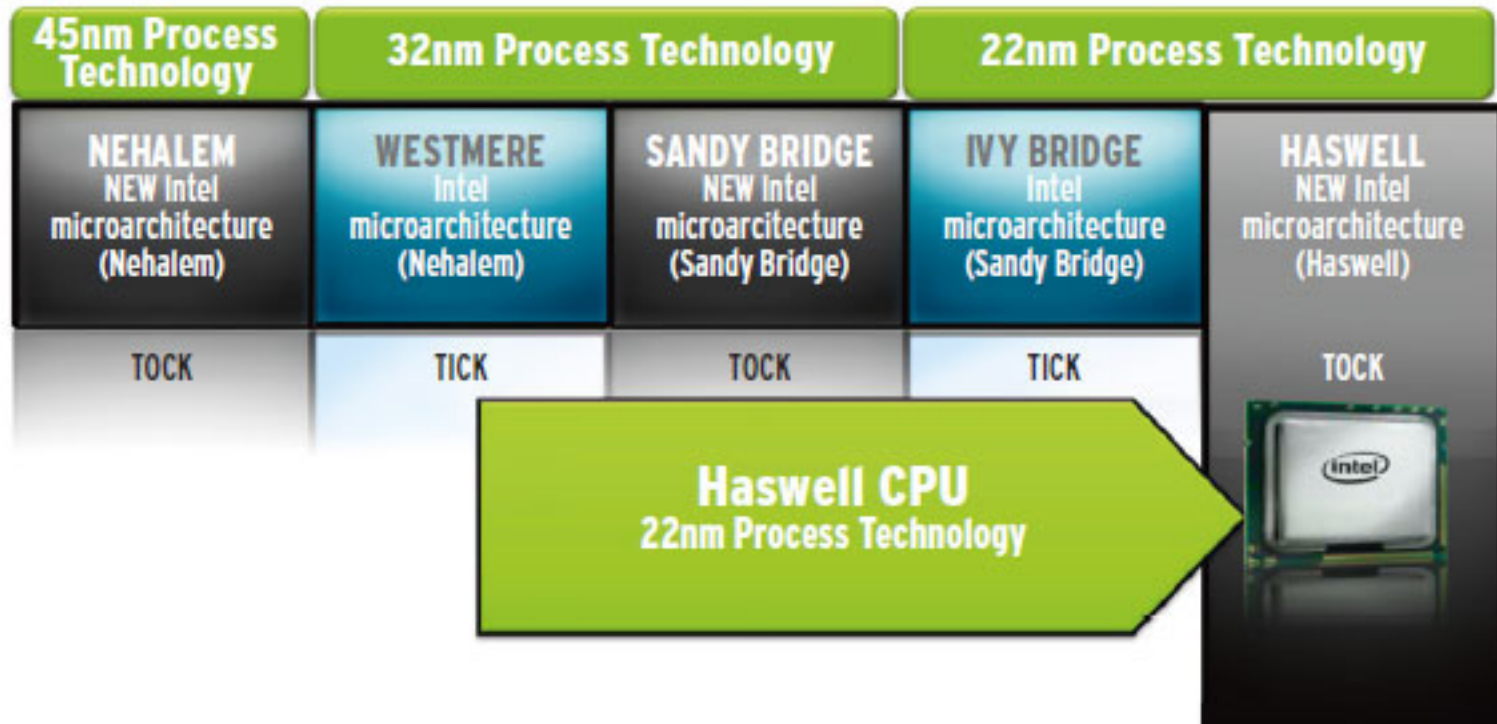
- **Core i5**

- Four cores
- Turbo-boost feature

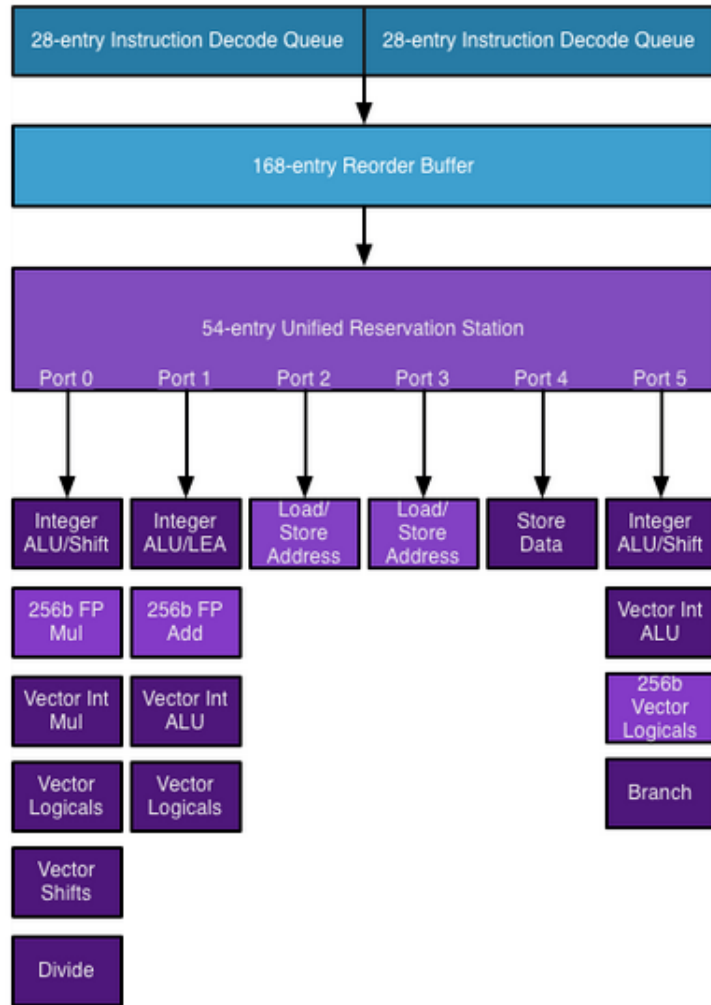
- **Core i7**

- Four cores, hyper-threaded
- Acts like 8 cores
- Turbo-boost feature

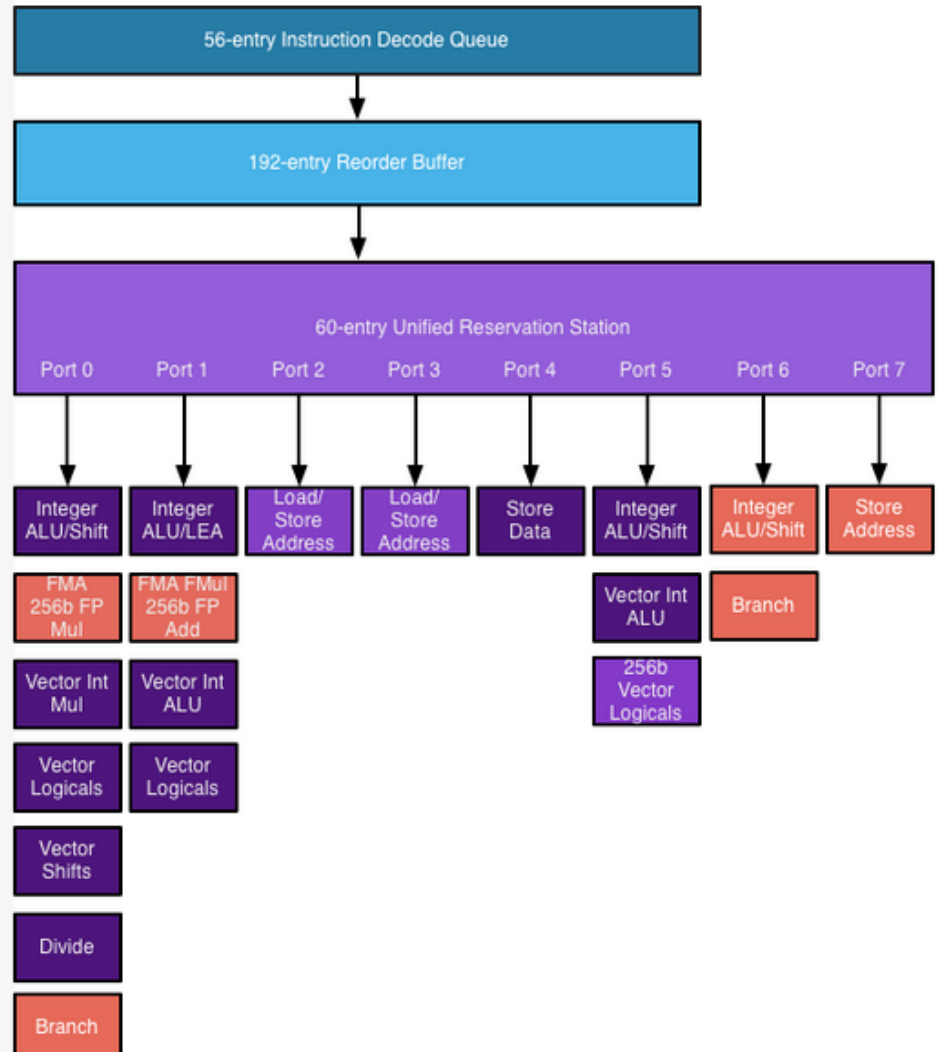
TICK/TOCK DEVELOPMENT MODEL



HASWELL BUILDS UPON INNOVATIONS IN THE 2ND- AND 3RD-GENERATION INTEL CORE i3/i5/i7 PROCESSORS (SANDY BRIDGE AND IVY BRIDGE)

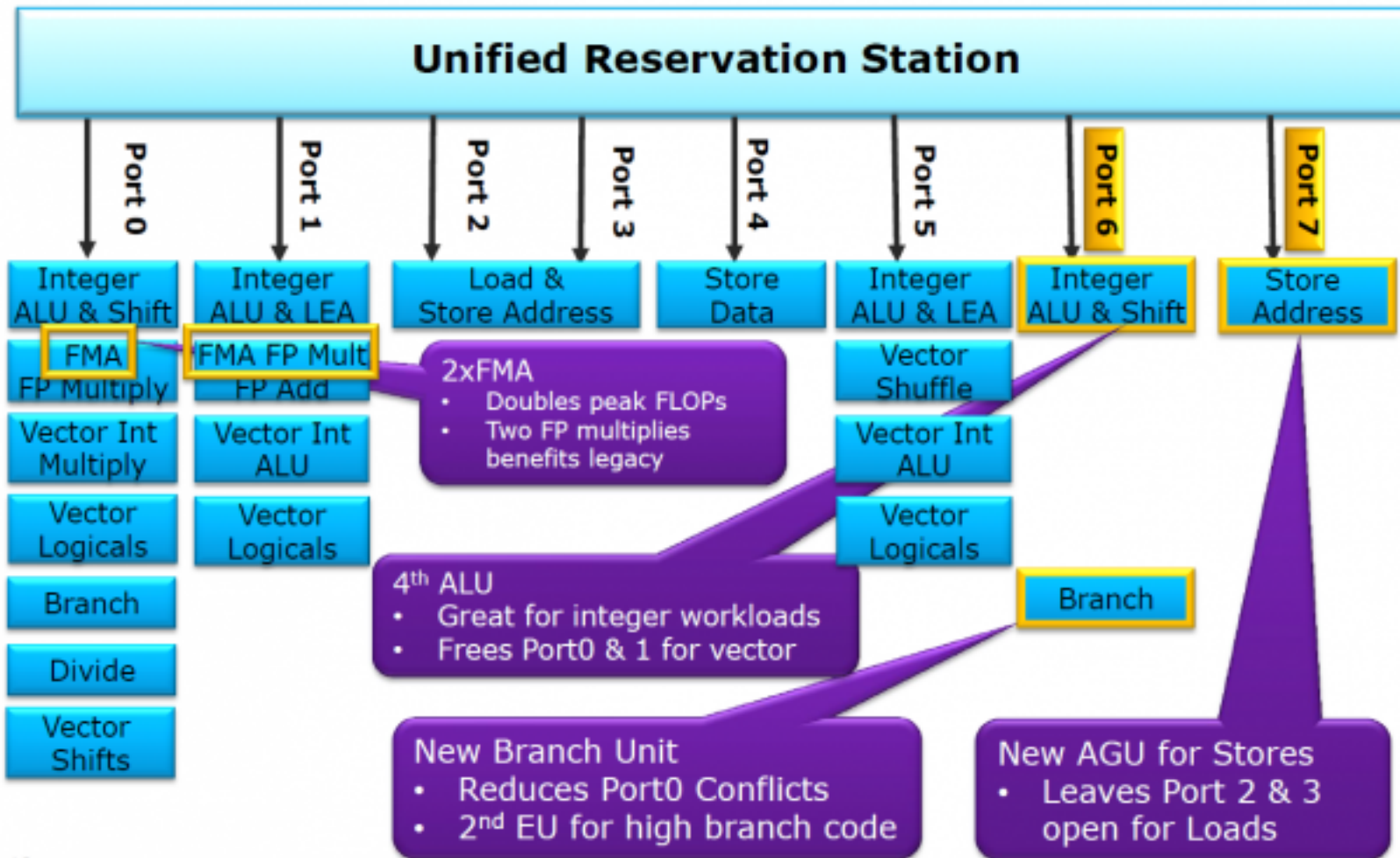


Ivy Bridge



Haswell

Haswell Execution Units



Haswell's Compute Instructions

- Haswell includes the AVX2 instructions.
 - AVX2: Advanced Vector Extension 2
 - FMA3: Fused Multiply-Add Extension 3
 - - (allows numbers to be multiplied and added in one operation)
- These extensions are not extensively supported by applications yet.

Example

- AVX came with 12 new instructions some of which are suitable for 3 variables

Example:

AVX: $C = A + B$

Before AVX: **$A = A + B$ and $C = A$**

- AVX2 takes this a step further. The integer execution units now can work with 256-bit numbers.

FMA

- AMD introduced FMA instructions with the Bulldozer core, which can work with four variables. i.e. $D = A \times B + C$.
- Intel went with FMA3, with a maximum of three variables. i.e. $C = A \times B + C$. Intel's simpler version can still improve performance quite a bit for AVX2-compiled software.

Intel AVX2 Instruction Set

- Includes
 - 256 bit Integer vectors
 - FMA: Fused Multiply-Add
- Benefits
 - High performance computing
 - Audio & Video
 - Games
- New Integer Instructions
 - Indexing and Hashing
 - Cryptography
 - Endian Conversion

Haswell - TSX

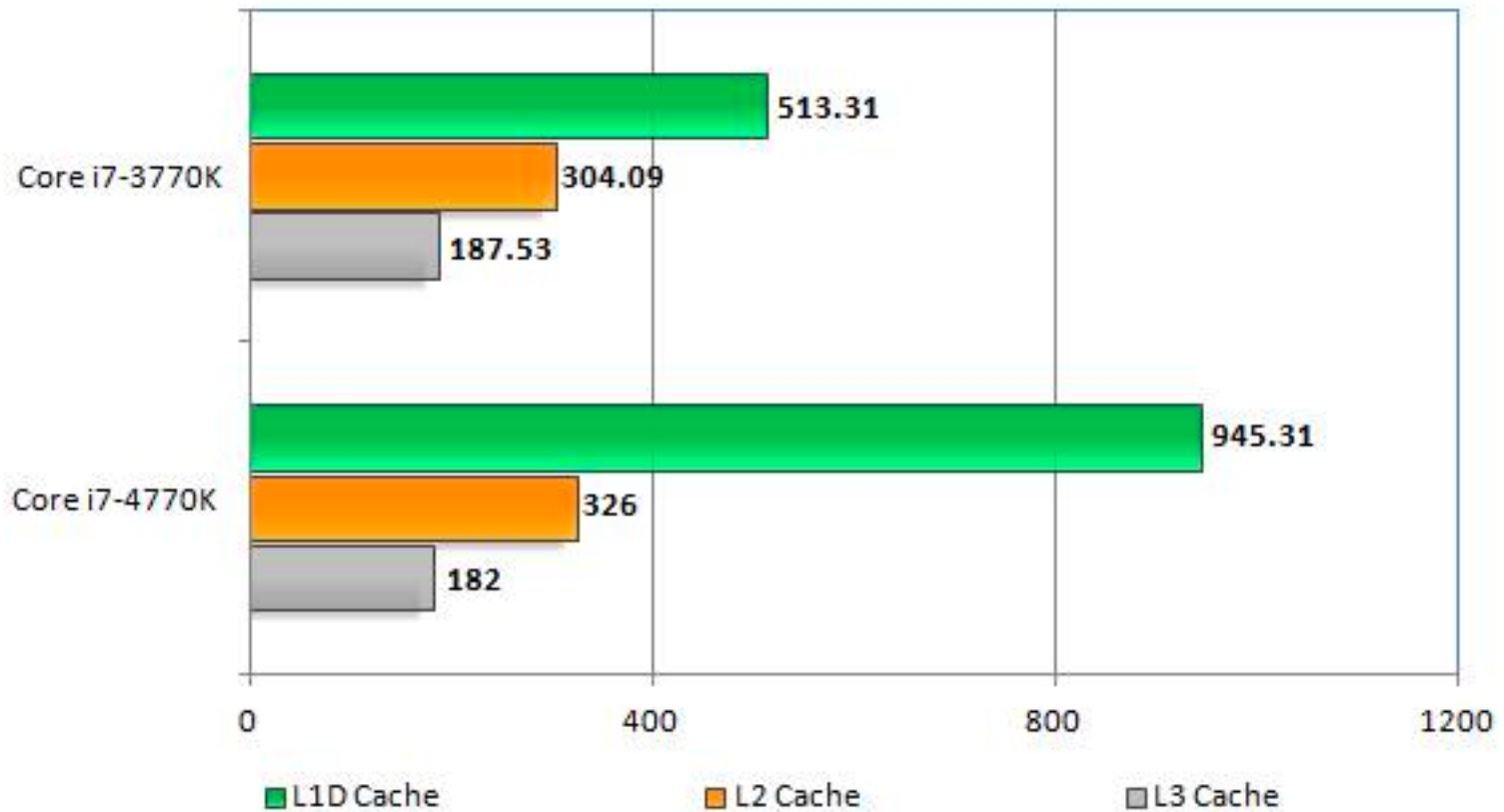
- Performance-boost for software is the new Transactional Synchronization Extensions (TSX)
- Improves the way multiple threads of the same program handle data in the memory
- Multi-threaded software should scale better to multiple cores as a result.

Difference in Cache

Metric	Ivy Bridge	Haswell
L1 Load Bandwidth	32 Bytes/cycle	32 Bytes/cycle
Store Bandwidth	16 Bytes/cycle	32 Bytes/cycle
L2 Bandwidth to L1	32 Bytes/cycle	64 Bytes/cycle
L2 Unified TLB	4K: 512, 4-way	4K+2M shared: 1024, 8-way

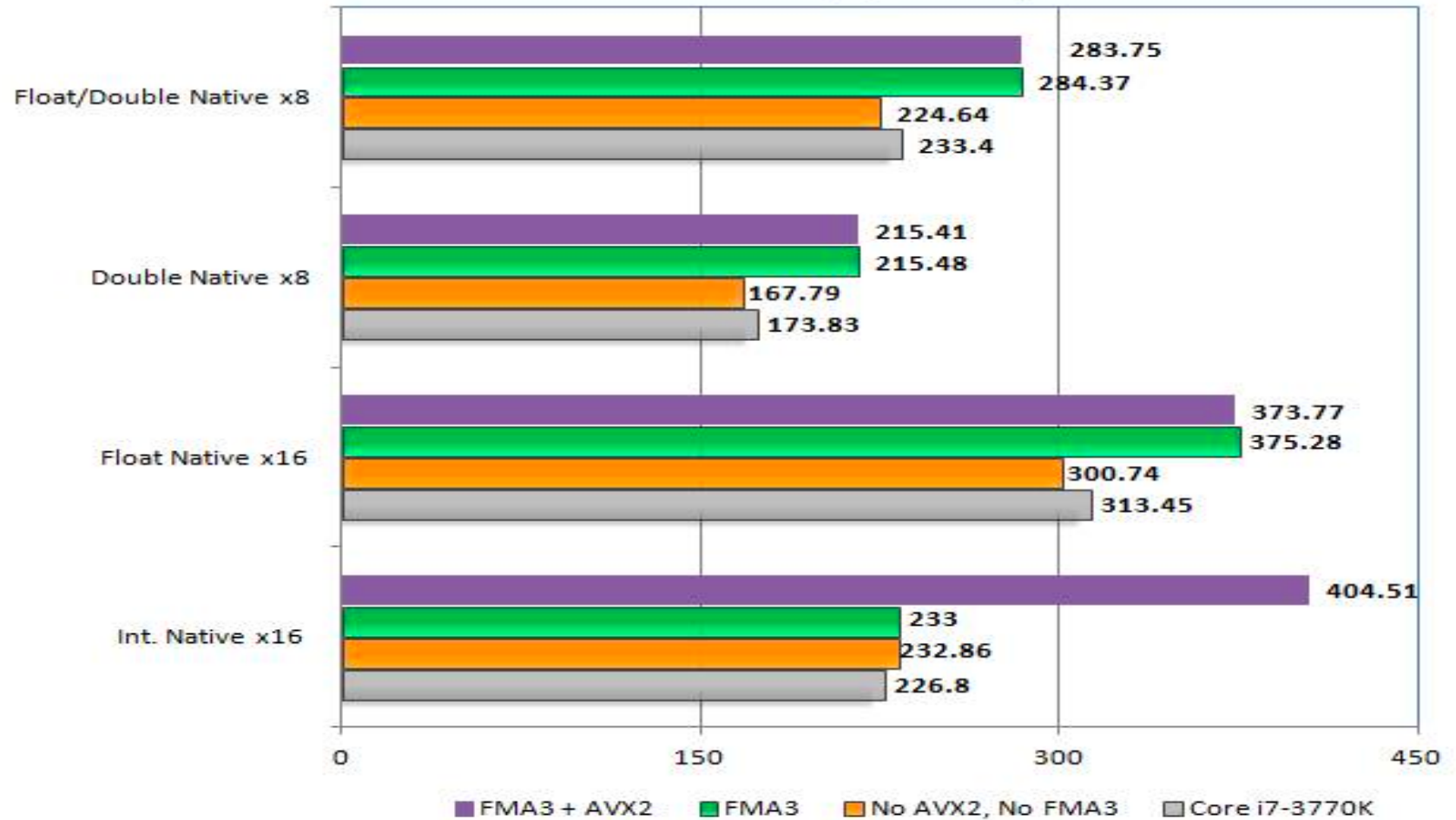
SiSoft Sandra 2013: Cache Bandwidth

In GB/s (Higher is Better)



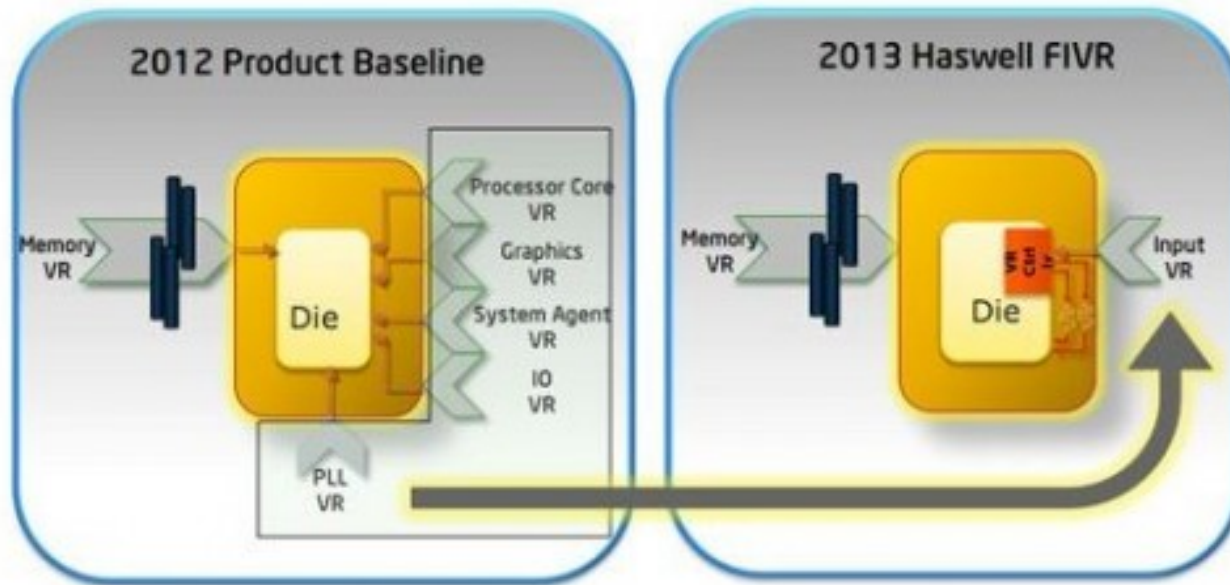
SiSoft Sandra 2013 AVX/AVX2 Multimedia Performance

In MPixels (Higher is Better)



Fully Integrated Voltage Regulator (FIVR)

FIVR Simplifies Platform Power Delivery Design



Idle Power

Total System Power Consumption in Watts - Lower is Better

Intel Core i5-4670K (3.4GHz)

32.8

Intel Core i7-4770K (3.5GHz)

34.4

Intel Core i7-3770K (3.5GHz)

45.9

Haswell has a lower power consumption than Ivy Bridge in idle state.

Branch Prediction

	IVY BRIDGE	HASWELL
Misprediction penalty	15 clock cycles or more for branches inside the μ op cache and slightly more for branches in the level-1 code cache	It was measured to 15 - 20 clock cycles. Varies a lot
Pattern recognition for conditional jumps	Nested loops and loops with branches inside are not predicted particularly well	Loops are successfully predicted up to a count of 32 or a little more. Nested loops and branches inside loops are predicted reasonably well

Branch Prediction

	IVY BRIDGE	HASWELL
Pattern recognition for indirect jumps and calls	Indirect jumps and indirect calls (but not returns) are predicted using the same two-level predictor as branch instructions	Indirect jumps and indirect calls are predicted well
Prediction of function returns	The return stack buffer has 16 entries for near returns	The return stack buffer has 16 entries for near returns

Summary – Ivy Bridge

PROS

- Needs less power,
- Insignificantly cheaper
- Slightly better price / performance ratio

CONS

- Performs a bit worse in all types of programs
- Lacks some instructions

Summary - Haswell

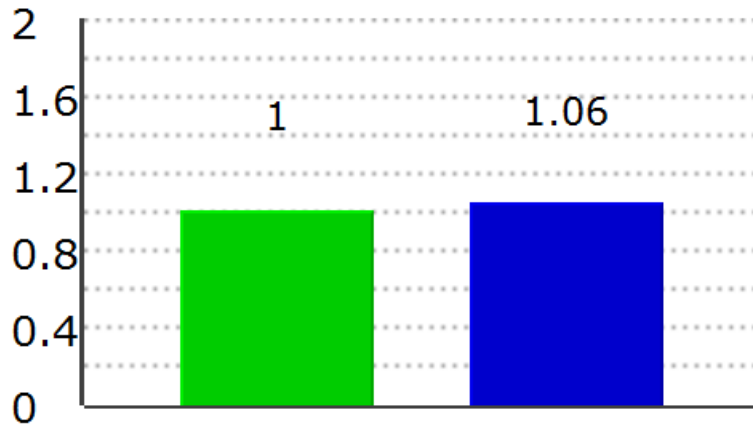
PROS

- Insignificantly faster in all kinds of tasks
- Features AVX2 / FMA3 instructions

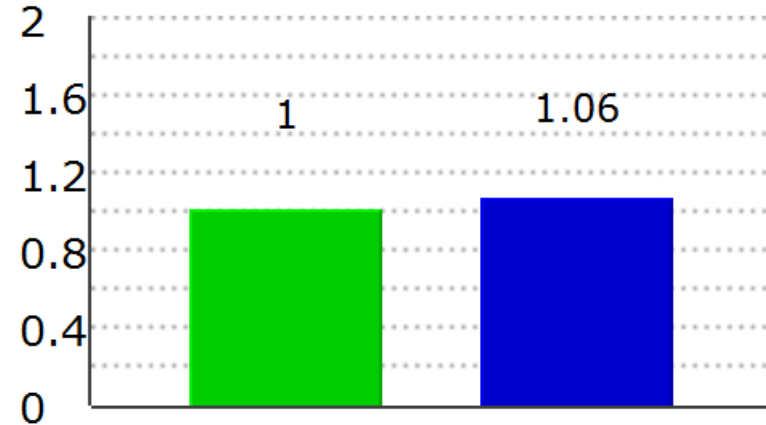
CONS

- Requires slightly more power
- Priced a bit higher
- Insignificantly worse price / performance ratio


Single Thread Performance




Multi-Thread Performance

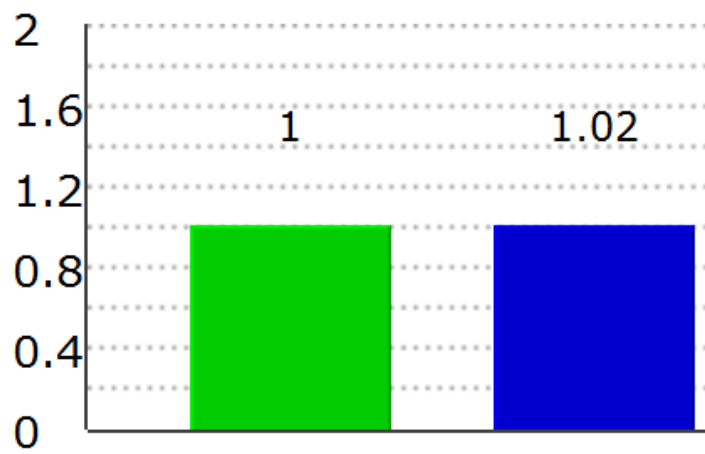


Higher is better

 - Intel Core i5-3570K

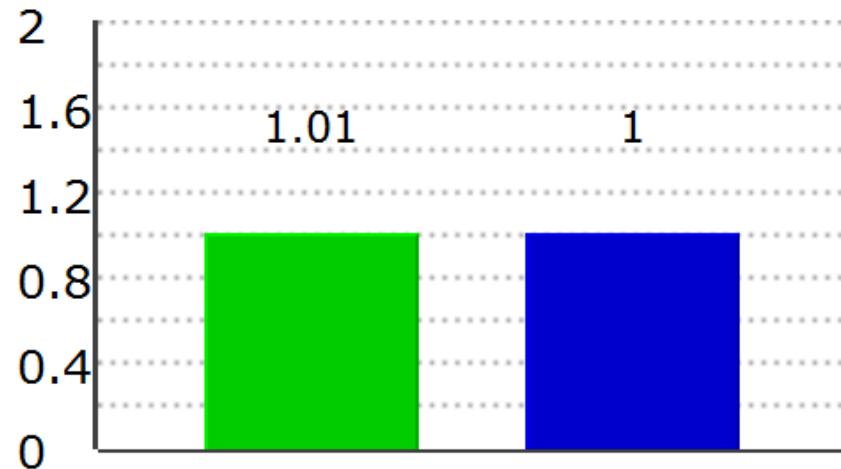
 - Intel Core i5-4670K

Memory –Intensive Application





Higher is better

Discrete Graphics Performance

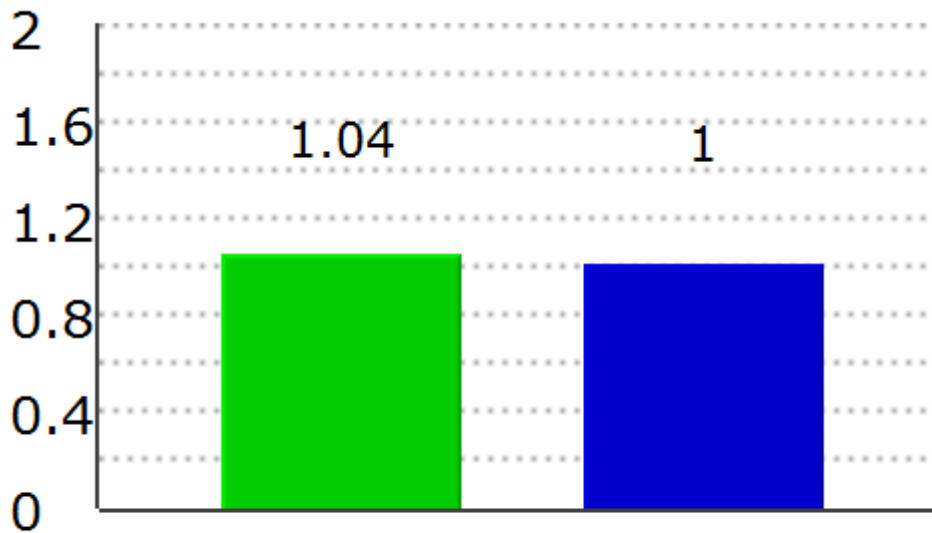


Higher is better


 - Intel Core i5-3570K


 - Intel Core i5-4670K

Price/Performance ratio



Higher is better

 - Intel Core i5-3570K

 - Intel Core i5-4670K



Questions?

References:

- **The Haswell paradox: The best CPU in the world... unless you're a PC enthusiast**

<http://www.extremetech.com/computing/157337-the-haswell-paradox-the-best-cpu-in-the-world-unless-youre-a-pc-enthusiast>

- **Fourth generation Intel Core preview: all about Haswell**

<http://us.hardware.info/reviews/4308/4/fourth-generation-intel-core-preview-all-about-haswell-avx2>

- **CPU World- Intel Core i5-3570K vs i5-4670K**

http://www.cpu-world.com/Compare/579/Intel_Core_i5_i5-3570K_vs_Intel_Core_i5_i5-4670K.html

- **Intel Core i7 4960X (Ivy Bridge) E review**

<http://www.anandtech.com/show/7255/intel-core-i7-4960x-ivy-bridge-e-review/2>