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
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

Unified Reservation Station

- Port 0: Integer ALU & Shift, FMA, FP Multiply, Vector Int Multiply, Vector Logicals, Branch, Divide, Vector Shifts
- Port 1: Integer ALU & LEA, FMA FP Multiply, FP Add, Vector Int ALU, Vector Logicals
- Port 2: Load & Store Address
- Port 3: Store Data
- Port 4: Integer ALU & LEA
- Port 5: Integer ALU & Shift
- Port 6: Integer ALU & Shift
- Port 7: Store Address

- 2xFMA
  - Doubles peak FLOPs
  - Two FP multiplies benefits legacy

4th ALU
- Great for integer workloads
- Frees Port0 & 1 for vector

New Branch Unit
- Reduces Port0 Conflicts
- 2nd EU for high branch code

New AGU for Stores
- Leaves Port 2 & 3 open for Loads
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

<table>
<thead>
<tr>
<th>Metric</th>
<th>Ivy Bridge</th>
<th>Haswell</th>
</tr>
</thead>
<tbody>
<tr>
<td>L1 Load Bandwidth</td>
<td>32 Bytes/cycle</td>
<td>32 Bytes/cycle</td>
</tr>
<tr>
<td>Store Bandwidth</td>
<td>16 Bytes/cycle</td>
<td>32 Bytes/cycle</td>
</tr>
<tr>
<td>L2 Bandwidth to L1</td>
<td>32 Bytes/cycle</td>
<td>64 Bytes/cycle</td>
</tr>
<tr>
<td>L2 Unified TLB</td>
<td>4K: 512, 4-way</td>
<td>4K+2M shared: 1024, 8-way</td>
</tr>
</tbody>
</table>
SiSoft Sandra 2013: Cache Bandwidth
In GB/s (Higher is Better)

Core i7-3770K
- L1D Cache: 304.09
- L2 Cache: 187.53
- L3 Cache: 513.31

Core i7-4770K
- L1D Cache: 326
- L2 Cache: 182
- L3 Cache: 945.31
Fully Integrated Voltage Regulator (FIVR)

FIVR Simplifies Platform Power Delivery Design

2012 Product Baseline

2013 Haswell FIVR
Haswell has a lower power consumption than Ivy Bridge in idle state.
## Branch Prediction

<table>
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<tr>
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<th>HASWELL</th>
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<tr>
<td>Misprediction penalty</td>
<td>15 clock cycles or more for branches inside the $\mu$ op cache and slightly more for branches in the level-1 code cache</td>
<td>It was measured to 15 - 20 clock cycles. Varies a lot</td>
</tr>
<tr>
<td>Pattern recognition for conditional jumps</td>
<td>Nested loops and loops with branches inside are not predicted particularly well</td>
<td>Loops are successfully predicted up to a count of 32 or a little more. Nested loops and branches inside loops are predicted reasonably well</td>
</tr>
</tbody>
</table>
## Branch Prediction

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<td>Pattern recognition for indirect jumps and calls</td>
<td>Indirect jumps and indirect calls (but not returns) are predicted using the same two-level predictor as branch instructions</td>
<td>Indirect jumps and indirect calls are predicted well</td>
</tr>
<tr>
<td>Prediction of function returns</td>
<td>The return stack buffer has 16 entries for near returns</td>
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</tr>
</tbody>
</table>
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

- Intel Core i5-3570K
- Intel Core i5-4670K

Higher is better
Memory-Intensive Application

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

- Fourth generation Intel Core preview: all about Haswell

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