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Key learning objectives

At the end of this class, you should be able to:

- Understand where the industry is in today’s high-end PC workstations
- Know where the current state of the art is, and identify today’s “sweet spots” in processors, memory, storage, and graphics.
- Optimize your hardware selections for BIM modeling, visualization, and construction coordination
- Answer the question, "Should I build or should I buy?"
Session outline

I. Industry Pressures and Key Trends
II. Application Demands on Hardware
III. Processors and Chipsets
IV. System Memory and Motherboards
V. Storage
VI. Graphics
VII. Mobile Computing
VIII. Peripherals
IX. Build or Buy?
X. System Builds
“Wow, this computer is way too fast for me.”
- No one. Ever.
I do not officially endorse nor am I sponsored by any of the companies or products that I talk about in class.

No one sends me things to review or pays me to say nice things about them. Sadly.

However, if you do want to send me things to “evaluate” and/or pay me $$$ to say nice things about you and your product, I will.
Survey Questions

How many of you…

- Have the Building Design Suite Premium? Ultimate?
- Create renderings and animations in any of these applications?
- Are running hardware more than two-three years old?
- Probably need new hardware, but aren’t sure of what to get?
I SHOULD BUY A NEW SYSTEM
I. Industry Pressures and Key Trends
Industry Pressures

MODEL

ALL THS THINGS
AEC Industry Pressures and Trends

- Industry using advanced BIM tools at a record rate
- Designers > General Contractors > Subcontractors > Owners
- New hardware capabilities allow for heavier problem solving
- Parallel problem solving in one PC → BIM, modeling, rendering
- Distributed computing → cloud analysis, cloud rendering
- Video games → people expect high end results
- Run >1 large application at a time (3ds Max/ Photoshop/Revit)
- More background Windows services (AV, etc.)
- More multithreaded applications or portions of applications
Hardware Industry Pressures and Trends

Hardware performance increases are getting smaller each year
Down to a 14nm process – VERY difficult to go further down to 10nm and below
GPU process is currently stalled at 28nm; 20m process is being skipped over

Parallel processing
Multiprocessing and Multithreading
Separate processes to many CPUs
One process = many threads to different CPUs

GPU Accelerated Computing (GPGPU)
Demand for photorealism
The rise of gaming engines for archviz

Virtualization ➔ Servers and workstations
The Cloud ➔ Amazon EC2
Moore’s Law: The number of transistors on a chip doubles every 24 months.

Works by shrinking the size of the transistor “switch”

Exponential function heading to 0nm

“Running out of atoms” in newer process sizes

Problems of heat dissipation not keeping up with shrinking process

The Impending End of Moore’s Law
Moore’s Law

1971 = 2,300 transistors @ 10um = 10,000nm
2014 = Over 1.3 billion transistors @ 14nm
Equal to shrinking a 5’-6” person to 3/32” high

The Cloud

What is it?
What does it do?
How does it work?
How much does it cost?
Affect on hardware purchasing considerations today?
How will it affect hardware configurations in the future?
Each year = new hardware iterations
New CPUs, graphics cards, storage options
Push out the old / repurpose for new life
New stuff is typically equal or even lower in price
Commodity pricing: 1TB HD is $60, 4TB is $125. Why get the smaller drive?
II. Application Demands on Hardware
## Building Design Suite Application Demands

<table>
<thead>
<tr>
<th>Application</th>
<th>CPU Speed / Multithreading</th>
<th>System Ram - Amount / Speed</th>
<th>Graphics Card GPU Capabilities</th>
<th>Graphics Card Memory Size</th>
<th>Hard Drive Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Revit</td>
<td>10 / 9</td>
<td>10 / 7</td>
<td>7</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>3ds Max Design</td>
<td>10 / 10</td>
<td>9 / 7</td>
<td>7 / 5 /10 (Nitrous / mr / iRay)</td>
<td>6 / 10 (mr / iRay)</td>
<td>10</td>
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<tr>
<td>Navisworks Simulate</td>
<td>7 / 7</td>
<td>7 / 6</td>
<td>7</td>
<td>5</td>
<td>7</td>
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<tr>
<td>Navisworks Manage</td>
<td>7 / 7</td>
<td>7 / 6</td>
<td>7</td>
<td>5</td>
<td>7</td>
</tr>
<tr>
<td>Showcase</td>
<td>9 / 8</td>
<td>7 / 6</td>
<td>9</td>
<td>5</td>
<td>9</td>
</tr>
<tr>
<td>AutoCAD (2D &amp; 3D)</td>
<td>6 / 6</td>
<td>5 / 5</td>
<td>5</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>AutoCAD Architecture</td>
<td>8 / 8</td>
<td>7 / 5</td>
<td>8</td>
<td>7</td>
<td>8</td>
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<tr>
<td>AutoCAD MEP</td>
<td>8 / 8</td>
<td>7 / 5</td>
<td>8</td>
<td>7</td>
<td>8</td>
</tr>
<tr>
<td>ReCap</td>
<td>10 / 10</td>
<td>9 / 5</td>
<td>8</td>
<td>7</td>
<td>10</td>
</tr>
</tbody>
</table>

Note: Any score of 6 or below can be handled by almost any machine you buy today.
Application Demands – Revit

Revit stresses every major subsystem in a workstation:
- CPU, RAM, Video Card, Mass Storage, Networking
  Revit is a desktop-based Database Management System

DBMS Applications stress hardware differently
- Typically like large CPU L1, L2, L3 caches
- Typically consume a lot of system memory

Revit is a Parametric Change Engine
- Changes propagate through the model
- No computational shortcuts to be had
Revit Stresses the CPU:

Revit is all about creating and maintaining relationships:

Between Hosted and Hosting Geometry
Cleanup of Wall Joins
Maintaining Constraints (Dimensional, Alignment, Equality)
Between Solids and Voids
Parametric families / nested families / linked parameters / formulas
Host and Linked Models – Copy / Monitor, Coordination Review

Maintaining these relationships is computationally expensive

Typically require the fastest CPU(s) available
Multithreading abilities in wall joins, rendering engine, family regeneration
Revit Specific CPU Considerations:

Review Autodesk’s *Revit 2015 Model Performance Technical Note*

- Parametric Change Engine scales well with CPU capabilities
- Database behavior favors CPUs with large L1/L2/L3 caches

Revit is *somewhat* multithreaded (and getting better):

- Rendering and hidden-line removal
- File open and save
- Wall join cleanup
- Vector & raster printing
- Family regeneration in views (since 2012)
- Perspective silhouette generation and navigation in perspective 3D views
- Progressive display (new in 2016)
Revit Stresses the Graphics Card

Views are live reports of the project database:
- Always remain in sync with the underlying data
- Regenerations are very common and often jarring to the user
- View properties are modified quite often
- Layered approach of Object Styles > V/G Overrides > Filters

Each view has its own display properties
- Visual styles, eye candy, shadows, transparency, overlay
- Wireframe: Very fast but not often used
- Hidden Line: Most common
- Shaded: Very effective but slower; Consistent Colors slightly faster (no shading)
- Realistic: Getting better. Would be nice to be able to use 100% of the time
- Ray Trace: Iterative rendering without long wait (based on iRay technology)
Revit Stresses RAM, Storage, Network

RAM Considerations
Typically consumes 20x the model size on disk in memory
100MB model = 2GB of RAM required; Small models = 650MB of RAM

Storage System Considerations
Long application load times
Very large single files → 100MB+ to 1GB
Uses local files for Workshared Projects

Network Considerations
Copying down new Local Files daily
Saving / Synchronizing to Central
Working with remote offices demands fast WAN connectivity (Revit Server)
Polygons - Interacting with millions of vertices, edges, faces, and elements on screen at any time;

Materials - Physical properties, bitmaps, reaction to incoming light energy, surface mapping on polygonal surfaces, and procedural mappings

Lighting - Physical and non-physical lighting models, calculating direct and indirect illumination, shadows and reflections;

**Rendering** - Combining polygons, materials, lighting, and environment together to produce photorealistic imagery; ray tracing with Global Illumination and Final Gather under the mental ray rendering engine; post-rendering effects
Application Demands – 3ds Max Design

**Processor:**
Rendering with the mental ray rendering engine is *wholly* CPU bound

**System Memory:**
Modeling with modifiers
Rendering requires lots of RAM

**Video card:**
Demands high speed wireframe, hidden line rendering in the viewport
Anti-aliasing (no jaggies) require more GPU oomph
Nitrous viewport technology adds eye candy with real time shadows, materials
Moving towards Real Time viewports, minimizing need for renderings
iRay rendering engine supports GPU-based rendering *on NVIDIA graphics only*
Application Demands - Navisworks

Much lighter on system resources than either Revit or 3ds Max

Import CAD/Revit models → NWC = lightweight “cache” geometry files

Handles large “supermodels” with ease (e.g., entire city models)

Clash Detective and TimeLiner relatively lightweight and very fast

Any machine built for Revit / 3ds Max will handle Navisworks

Uses DirectX for viewport rendering

Newer Autodesk rendering engine (multithreaded)

Cloud Rendering
Application Demands - Showcase

“Gaming” engine applied to AEC visualization and design review
Uses DirectX for all viewport operations
Stresses the video card more than anything else
Hardware applied lighting and shading, real time ray tracing
Typically considered slow compared to other applications
Application Demands – Autodesk ReCap

Process Point Clouds = billions of points
Crop, measure, annotate point clouds
Process raw clouds into .RCS files and .RCP projects
RCS/RCP can be linked into Revit, Navisworks, AutoCAD

Hardware Stresses in this order:

- Video card (billions of points to display, orbit)
- CPU (especially in point indexing)
- Hard disk (massive 20GB+ files)
Hardware Trends in 2015

CPUs:
Skylake at 14nm Core i7-6700K = New desktop king
Broadwell (14nm die shrink of Haswell) was a no-show in 2014/2015
Haswell-E “High End Desktop” CPU – 6/8 Cores, very fast
Haswell-E based Xeons – 4/6/8/10…18 cores
Integrated Graphics Processors (IGPs) are better but still stink

Graphics: NVIDIA “Maxwell” architecture improves slightly
Maxwell 1: GM107 GPU (GTX 750, GTX 750 Ti) – Low end → Dead to us
Maxwell 2: GM204 GPU (GTX 980 / GTX 970/ Quadro M5000) – Medium end
Maxwell 2+: GM200 GPU (GTX 980 Ti, GTX Titan X, Quadro M6000) - High end

RAM:
DDR4 is the new standard (Skylake / Haswell-E / Xeon)

Storage:
480GB SSDs now the new baseline standard, replaces 250GB from 2014
III Processors
Multi Core meets Main Street

Every CPU today is of a multicore design

Intel strategy:
4-core desktop, 6 - 8 core “HEDT,” Xeon up to 18 cores
Hyper-Threading doubles logical CPUs - 8 / 12 / 16 / 36 threads
Push for highest performance with the lowest power consumption

AMD strategy:
Targets Intel Core i3 & i5 level performance; cannot touch Core i7
No HT available → 4 / 6 / 8 actual physical cores on single CPUs
Higher clock rates 3.5GHz -> 4.0 GHz stock
Cache misses, aka the “Price check at the supermarket” problem:
Modern CPU pipeline wants to always execute threads per clock cycle
Uses L1, L2, L3 on-die memory caches to re-read data
A “cache miss” means having to go back to slow main memory for data
Thread execution stops until it gets back
Many cache misses can stifle CPU performance

Hyper-threading:
The OS can schedule another thread to jump in line with a cache miss
Keeps the pipeline stuffed with executions per each clock cycle
Side effect: The OS sees 2x as many cores; quad cores now look like 8
Intel Skylake Microarchitecture

Features:

- About 14% better performance over Haswell with less power
- Full support for new DDR4 memory standard
- Supports USB 3.1 Type C port and Thunderbolt 3
- Supports WiGig wireless docking and 4K wireless video
- Integrated 5th gen HD 530 Graphics; Win 10 / DirectX 12
- TSX Instructions enabled: Potentially faster multithreaded code

Errata: TSX is disabled by Intel on all Haswell CPUs 😞
## Intel’s Skylake Core i7 Processor Lineup - 2015

<table>
<thead>
<tr>
<th>Feature</th>
<th>Core i7-6700K</th>
</tr>
</thead>
<tbody>
<tr>
<td># of Cores / Threads</td>
<td>4 / 8</td>
</tr>
<tr>
<td>Base Clock Speed</td>
<td>4 GHz</td>
</tr>
<tr>
<td>Max Turbo Frequency</td>
<td>4.2 GHz</td>
</tr>
<tr>
<td>Cache</td>
<td>8 MB</td>
</tr>
<tr>
<td>Max TDP</td>
<td>91 W</td>
</tr>
<tr>
<td>System Integrator Pricing</td>
<td>$339.00</td>
</tr>
<tr>
<td>Max Memory Size</td>
<td>64 GB</td>
</tr>
<tr>
<td>Supported Memory Types</td>
<td>DDR4-1866/2133, DDR3L-1333/1600 @ 1.35V</td>
</tr>
<tr>
<td># of Memory Channels</td>
<td>2</td>
</tr>
<tr>
<td>Max Memory Bandwidth</td>
<td>34.1 GB/s</td>
</tr>
<tr>
<td>Processor Graphics</td>
<td>Intel® HD Graphics 530</td>
</tr>
<tr>
<td># of Displays Supported</td>
<td>3</td>
</tr>
<tr>
<td>PCI Express Revision</td>
<td>3.0</td>
</tr>
<tr>
<td>PCI Express Configurations</td>
<td>Up to 1x16, 2x8, 1x8+2x4</td>
</tr>
<tr>
<td>PCI Express Lanes</td>
<td>16</td>
</tr>
<tr>
<td>Intel® TSX-NI</td>
<td>Yes</td>
</tr>
</tbody>
</table>
Intel Z170 Chipset for Skylake i7-5700K
Haswell-E

“High End Desktop” computing platform
Sits between desktop Skylake and Xeon server
No integrated graphics processor (IGP)
True 6- and 8-core designs (12 / 16 threads total)
Uses DDR4 DIMMs / quad-channel memory controller (RAM installed in 4s)
More expensive platform than Skylake desktop
Much faster than i7-6700K in multithreading tasks
### Intel Haswell-E Processor Lineup

<table>
<thead>
<tr>
<th>Processor Name</th>
<th>Core™ i7-5820K</th>
<th>Core™ i7-5930K</th>
<th>Core™ i7-5960X</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cache</td>
<td>15 MB</td>
<td>15 MB</td>
<td>20 MB</td>
</tr>
<tr>
<td>Pricing</td>
<td>Box: $396.00</td>
<td>Box: $594.00</td>
<td>Box: $1059.00</td>
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<tr>
<td></td>
<td>Tray: $389.00</td>
<td>Tray: $583.00</td>
<td>Tray: $999.00</td>
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<tr>
<td># of Cores</td>
<td>6</td>
<td>6</td>
<td>8</td>
</tr>
<tr>
<td># of Threads</td>
<td>12</td>
<td>12</td>
<td>16</td>
</tr>
<tr>
<td>Base Frequency</td>
<td>3.3 GHz</td>
<td>3.5 GHz</td>
<td>3 GHz*</td>
</tr>
<tr>
<td>Max Turbo Frequency</td>
<td>3.6 GHz</td>
<td>3.7 GHz</td>
<td>3.5 GHz</td>
</tr>
<tr>
<td>TDP</td>
<td>140 W</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Max Memory Size</td>
<td>64 GB</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Memory Types</td>
<td>DDR4-1333/1600/2133</td>
<td></td>
<td></td>
</tr>
<tr>
<td># of Memory Channels</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Max Memory Bandwidth</td>
<td>68 GB/s</td>
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</tr>
<tr>
<td>ECC Memory Supported</td>
<td>No</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PCI Express 3.0 Lanes</td>
<td>28</td>
<td>40</td>
<td>40</td>
</tr>
</tbody>
</table>

Note: The i7-5960X is very overclockable to 4.5Ghz without much issue
Intel X99 Chipset for Haswell-E

- 3 slots available but need additional logic onboard to support more slots. 5x8 configuration requires additional system clocks to be provided by third party components.
- All SATA ports capable of 6 Gb/s.

PCI Express® 3.0
Discrete Graphics
Support for multi-card configurations: 2x16 and 1x8 or 5x8

14 High-Speed USB Ports
(6 USB 3.0 Ports
8 USB 2.0 Ports);
Dual EHCI; USB Port Disable

Intel® Integrated
10/100/1000 MAC

Intel Express x1
SM Bus 2.0

Intel Gigabit LAN Connect

Intel® Core™ i7
Processor
LGA2011-v3 Socket

DDR4 Memory
Up to 2133 MHz

DDR4 Memory
Up to 2133 MHz

DDR4 Memory
Up to 2133 MHz

Intel® High Definition Audio®

8 PCI Express 2.0

10 SATA 3.0 Ports

Intel® Rapid Storage
Technology® 13.1

Optional

Up to 40 lanes

Up to 5 Gb/s

Up to 5 Gb/s x1
(bi-directional)

Up to 6 Gb/s
Xeon Processors

Designed for servers and “serious” workstations

3 Series to choose from:

E3-12xx v5 : Single CPU configuration, Skylake based, 4 cores w/HT
E5-16xx v3 : Single CPU configuration, Haswell-E based, 4, 6, 8 cores w/HT
E5-26xx v3 : Dual CPU configuration, Haswell-E based, 4, 6, 8 … 18 cores

Built on Skylake (v5) and Haswell (v3) microarchitectures - no IGP

Many different models, clock speeds 2.0GHz – 3.8GHz

Support for ECC Memory (slower, more $$)

Dual-CPU configurations in high-end E5-26xx models

More L3 Cache (20MB – 45MB)

Dual-channel RAM in E3 / Quad-channel RAM in E5 Series (DDR4 only)
Xeon Processors - Branding

Intel® Xeon® processor

Wayness, maximum number of CPUs in a node (1, 2, 4, 8)

Socket Type\(^1\) (2, 4, 6, 8)

Processor SKU (10, 20, 30, and so forth)

Low power SKUs (after 4 digit number set)

\(^1\) Socket type refers to socket capability—socket changes over time

Alpha Suffix | Description
-------------|-------------
L | Low power
<table>
<thead>
<tr>
<th>Processor Name</th>
<th>Launch Date</th>
<th>Cores / Threads</th>
<th>Base Frequency</th>
<th>Max Turbo Frequency</th>
<th>L3 Cache</th>
<th>TDP</th>
<th>Bus Type</th>
<th>Price</th>
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</thead>
<tbody>
<tr>
<td>E3-1230 v5</td>
<td>Q4’15</td>
<td>4 / 8</td>
<td>3.4 GHz</td>
<td>3.8 GHz</td>
<td>8 MB</td>
<td>80 W</td>
<td>DMI</td>
<td>$250.00</td>
</tr>
<tr>
<td>E3-1240 v5</td>
<td>Q4’15</td>
<td>4 / 8</td>
<td>3.5 GHz</td>
<td>3.9 GHz</td>
<td>8 MB</td>
<td>80 W</td>
<td>DMI</td>
<td>$282.00</td>
</tr>
<tr>
<td>E3-1270 v5</td>
<td>Q4’15</td>
<td>4 / 8</td>
<td>3.6 GHz</td>
<td>4 GHz</td>
<td>8 MB</td>
<td>80 W</td>
<td>DMI</td>
<td>$339.00</td>
</tr>
<tr>
<td>E3-1280 v5</td>
<td>Q4’15</td>
<td>4 / 8</td>
<td>3.7 GHz</td>
<td>4 GHz</td>
<td>8 MB</td>
<td>80 W</td>
<td>DMI</td>
<td>$612.00</td>
</tr>
</tbody>
</table>

Note: The E3-1270 v5 @3.6GHz <= $339 => Skylake i7-6700K @ 4GHz
## Xeon E5-16xx Series – Mainstream Workstation

<table>
<thead>
<tr>
<th>Processor Name</th>
<th>Launch Date</th>
<th>Cores / Threads</th>
<th>Processor Base Frequency</th>
<th>Max Turbo Frequency</th>
<th>L3 Cache</th>
<th>TDP</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>E5-1620 v3</td>
<td>Q3'14</td>
<td>4 / 8</td>
<td>3.5 GHz</td>
<td>3.6 GHz</td>
<td>10 MB</td>
<td>140 W</td>
<td>$294</td>
</tr>
<tr>
<td>E5-1630 v3</td>
<td>Q3'14</td>
<td>4 / 8</td>
<td>3.7 GHz</td>
<td>3.8 GHz</td>
<td>10 MB</td>
<td>140 W</td>
<td>$372</td>
</tr>
<tr>
<td>E5-1650 v3</td>
<td>Q3'14</td>
<td>6 / 12</td>
<td>3.5 GHz</td>
<td>3.8 GHz</td>
<td>15 MB</td>
<td>140 W</td>
<td>$583</td>
</tr>
<tr>
<td>E5-1680 v3</td>
<td>Q3'14</td>
<td>8 / 16</td>
<td>3.2 GHz</td>
<td>3.8 GHz</td>
<td>20 MB</td>
<td>140 W</td>
<td>$1723</td>
</tr>
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</table>

Note: Xeon E5-1650 v3 is almost identical to Haswell-E i7-5930X; E5-1680 v3 is very close to Haswell-E i7-5960X
## Xeon E5-26xx Series – Dual CPU Workstation

<table>
<thead>
<tr>
<th>Processor Name</th>
<th>Launch Date</th>
<th>Cores / Threads</th>
<th>Processor Base Frequency</th>
<th>Max Turbo Frequency</th>
<th>L3 Cache</th>
<th>TDP</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>E5-2637 v3</td>
<td>Q3'14</td>
<td>4 / 8</td>
<td>3.5 GHz</td>
<td>3.7 GHz</td>
<td>15 MB</td>
<td>135 W</td>
<td>$996</td>
</tr>
<tr>
<td>E5-2643 v3</td>
<td>Q3'14</td>
<td>6 / 12</td>
<td>3.4 GHz</td>
<td>3.7 GHz</td>
<td>20 MB</td>
<td>135 W</td>
<td>$1,552</td>
</tr>
<tr>
<td>E5-2667 v3</td>
<td>Q3'14</td>
<td>8 / 16</td>
<td>3.2 GHz</td>
<td>3.6 GHz</td>
<td>20 MB</td>
<td>135 W</td>
<td>$2,057</td>
</tr>
</tbody>
</table>
IV System Memory and Motherboards
Choosing the Right Motherboard for DIY Builds

CPU choice determines platform; platform may determine CPU:
- i7-6700K → LGA1151 Platform w/Z170 Chipset & 4 DIMMs ($100 - $225)
- i7-5930K → LGA2011-3 Platform w/X99 Chipset & 8 DIMMs ($280 - $400)

Feature Sets:
- Full PCIe 3.0 slots = multi-GPU support, especially in Haswell-E i7-59xx
- Plenty of USB 3.0 headers for front panel ports; USB 3.1 Type C (universal)
- m.2 slot for new SSD form factors
- Wi-Fi onboard, 2 Gigabit ports, HDMI / DisplayPort, 8-channel audio
- UEFI replaces older BIOS = more low level features (e.g., 2TB+ boot disk)
- Easy overclocking: fine voltage control, easy reset from bad overcloks
- For the kiddies: Bling, heat pipes, day-glo PCI slots, etc.
System Memory

DDR4 RAM is getting much less expensive and is plentiful
Best bet: Purchase machine with 16GB or 32GB. 64GB for Viz Wizards
Do not overpay for RAM upgrades from Dell / HP / XYZ-Corp.
8GB sticks still the best all-around buy today (2x8GB / 3x8GB / 4x8GB)
Ensure your RAM configuration matches the CPU memory controller
Buy all RAM at one time from one place
Tip: Check the numbers on the chips if you have system instability
Different binnings may not be fully compatible with each other
DDR4 Memory

New standard for high performance computing
Higher densities; 128GB DIMMs just announced
Faster clock rates than DDR3
Lower voltages than DDR3 = Higher performance per Watt
Slow to get moving – lots of players, lots of changes
Ultimately the CPU has to lead (Skylake, Haswell-E, Xeon)
Not much faster than DDR3 (systems are not memory-bound)
V Storage
Storage Considerations

BDS Stresses:
- Long program load times
- Revit 300MB+ central models / Creating new Local Files daily

Mechanical Disk Solutions:
- Hard disks: 7,200, 10,000 and 15,000 RPM (Good / Fast / Cheap for storage)
- RAID 0 may provides solid benefits (YMMV).
  Note need for backups with RAID 0!

OR: Use multiple separate HDs
- Windows will multithread I/O between HDs on different channels / SATA ports
- Store page file on 2nd HD; move it before adding any additional data to drive
- Set page file size so min = max
Solid State Drives (SSDs)

MUST HAVE FOR ALL MACHINES (easy upgrade)

Prices falling; $0.70 GB; ~ $180 for 250GB
Sweet spot = 250GB – 480 GB

Use for the OS and Apps (store add’l data on mech. HD)

Performance is now pretty consistent between units
Research individual units carefully, read reviews
Expected lifespan: 1-1.5 PB of writes (50GB / day / 80 years)
Say hello to your new little friend

- New M.4 form factor SSD (gumstick)
- PCIe x4 interface replaces SATA
- NVMe protocol replaces AHCI, optimized for solid state
- More bandwidth than SATA
- Benchmarks clearly show PCIe SSDs outperforming SATA
- m.4 format is coming on strong, but may have heat issues
### Solid State Drive Benchmarks

#### TR DriveBench 2.0 - Mean service time - Read

<table>
<thead>
<tr>
<th>SSD Model</th>
<th>Service Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intel 520 Series 240GB</td>
<td>0.50</td>
</tr>
<tr>
<td>Intel 335 Series 240GB</td>
<td>0.51</td>
</tr>
<tr>
<td>Corsair Force Series GT 240GB</td>
<td>0.51</td>
</tr>
<tr>
<td>OCZ Vector 150 240GB</td>
<td>0.52</td>
</tr>
<tr>
<td>Sandisk Extreme II 240GB</td>
<td>0.52</td>
</tr>
<tr>
<td>OCZ Vector 256GB</td>
<td>0.54</td>
</tr>
<tr>
<td>Corsair Neutron 240GB</td>
<td>0.56</td>
</tr>
<tr>
<td>Seagate 600 SSD 240GB</td>
<td>0.56</td>
</tr>
<tr>
<td>OCZ Vertex 450 256GB</td>
<td>0.57</td>
</tr>
<tr>
<td>Corsair Neutron GTX 240GB</td>
<td>0.58</td>
</tr>
<tr>
<td>Samsung 840 Pro 256GB</td>
<td>0.59</td>
</tr>
<tr>
<td>Samsung 830 Series 256GB</td>
<td>0.60</td>
</tr>
<tr>
<td>Samsung 840 EVO 500GB</td>
<td>0.64</td>
</tr>
<tr>
<td>Samsung 840 Series 250GB</td>
<td>0.69</td>
</tr>
<tr>
<td>Crucial M500 480GB</td>
<td>0.71</td>
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<tr>
<td>Crucial M4 256GB</td>
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<tr>
<td>Crucial M500 240GB</td>
<td>0.84</td>
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<tr>
<td>Samsung 840 EVO 250GB</td>
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<tr>
<td>OCZ Agility 4 256GB</td>
<td>1.35</td>
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<tr>
<td>WD Caviar Black 1TB</td>
<td>5.48</td>
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#### TR DriveBench 2.0 - Mean service time - Write

<table>
<thead>
<tr>
<th>SSD Model</th>
<th>Service Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>OCZ Vector 150 240GB</td>
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</tr>
<tr>
<td>SanDisk Extreme II 240GB</td>
<td>0.39</td>
</tr>
<tr>
<td>OCZ Vector 256GB</td>
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<td>OCZ Vertex 450 256GB</td>
<td>0.42</td>
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<tr>
<td>Samsung 830 Series 256GB</td>
<td>0.44</td>
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<td>Corsair Neutron GTX 240GB</td>
<td>0.47</td>
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<td>Seagate 600 SSD 240GB</td>
<td>0.48</td>
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<tr>
<td>Corsair Neutron 240GB</td>
<td>0.56</td>
</tr>
<tr>
<td>Intel 335 Series 240GB</td>
<td>0.62</td>
</tr>
<tr>
<td>Corsair Force Series GT 240GB</td>
<td>0.64</td>
</tr>
<tr>
<td>Intel 520 Series 240GB</td>
<td>0.64</td>
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<tr>
<td>Samsung 840 Pro 256GB</td>
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<tr>
<td>OCZ Agility 4 256GB</td>
<td>0.84</td>
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<tr>
<td>Samsung 840 EVO 500GB</td>
<td>0.93</td>
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<tr>
<td>Crucial M500 480GB</td>
<td>0.93</td>
</tr>
<tr>
<td>Samsung 840 Series 250GB</td>
<td>1.06</td>
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<tr>
<td>Samsung 840 EVO 250GB</td>
<td>1.57</td>
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<tr>
<td>Crucial M4 256GB</td>
<td>1.80</td>
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<tr>
<td>WD Caviar Black 1TB</td>
<td>1.83</td>
</tr>
<tr>
<td>Crucial M500 240GB</td>
<td>2.90</td>
</tr>
</tbody>
</table>

Milliseconds (Lower is better)
VI Graphics
Graphics in Autodesk Applications

BUT INTEL SAYS THEIR IGPS ARE GREAT FOR BIM!

READ THE REVIEWS!

YEAH, IF YOU COULD JUST RENDER THIS RIGHT AWAY

THAT'D BE GREAT
What Graphics Cards Actually Do

Take 3D vector geometry from the CPU and converts it into pixels by a process through the graphics pipeline:

- Reads vertex data from CPU / memory
- Applies per-vertex lighting and shading
- Discards unseen geometry
- Projection Transformation (Perspective)
- Viewport Transformation
- Scan Conversion and Rasterization
- Output to monitor
- Repeat 60x / sec
What Graphics Cards Actually Do

Fundamentally, CPUs and GPUs process tasks differently. The GPU represents the future of parallel processing. Specialized for compute-intensive, highly parallel computation. Today GPUs have massive numbers of small highly efficient cores designed to execute many concurrent threads more slowly.
Direct3D is the 3D API portion of DirectX, which is a whole set of APIs that covers handling multimedia on the Windows platform.

Direct3D was originally used for developing games for Windows and Xbox, now migrating to CAD/CAM engineering applications.

Replaced OpenGL as the graphics API of choice for all Autodesk apps.

DirectX version is “somewhat” Windows version specific:
- DirectX 9 = Windows XP (XP will not run later DX versions)
- DirectX 10 = Windows Vista (can also run DX 11)
- DirectX 11 = Windows 7
- DirectX 11.1 = Windows 8, 8.1
- DirectX 12 = Windows 10 only. No other OS will run DirectX 12.
Graphics Explained: Shaders

Graphics Processing Units (GPUs) are now **Programmable**, not Fixed Function.

Shaders are small programs that act on one aspect of the pipeline and make complex effects happen in real time.

Shader Model: Collection of standard Vertex Shaders, Tessellation Shaders, Geometry Shaders, etc.

Updated with each DirectX release (i.e., Windows release)
Graphics in the Building Design Suite

In general: Any decent $200+ card will work in 90% of all cases

BDS uses DirectX 9 and features in DX11, meaning any modern card will be fine.

For 3D visualization work look for faster cards, $400 on up **

Look at specific cards to address specific issues, e.g. Rendering

** To a point
mental ray™

Developed by NVIDIA; licensed to Autodesk
Autodesk gets SDK, writes the front end
Included in 3ds Max Design and Revit
Fully featured, photorealistic realistic renderer
Supports Global Illumination, Final Gather, Caustics, etc.
Very complex – many dials / knobs / variables to understand
Supported by Backburner network rendering in 3ds Max / Design
Supports Distributed Bucket Rendering (DBR)
Almost 100% CPU bound; does not leverage graphics card***
Rendering Engines in Autodesk Applications

iRay™

Developed by NVIDIA specifically for NVIDIA GPUs and CUDA technology
Physically based ray tracing renderer - Excellent photorealistic results
Simplified interface – “Pushbutton” renders possible
Requires physically correct lighting and materials
Iterative renderer: Start rendering and stop when it looks good enough
Time based: Set the time for each rendering beforehand
Supported by Backburner (render farm)
Does not support Distributed Bucket Rendering (DBR)
Can use NVIDIA graphics cards and/or CPU for rendering
GPU on average 12x speed of fastest CPU for rendering
Note: Scene must entirely fit into GPU onboard memory for it to render **
3ds Max’s iRay – A Game Changer
NVIDIA’s Maxwell Architecture

Design focus = maximize performance per Watt (PPW)
2x PPW over 2012-2013 Kepler architecture (GTX 6xx / 7xx series)
Realigned internal Streaming Multiprocessor (SMM) unit
Up to 3,072 CUDA cores housed in 24 SMM units
Today’s GPUs:
- GM204 in GTX 970 / GTX 980 = Medium end (1,664 / 2,048 cores)
- GM200 in GTX 980 Ti, GTX Titan X, Quadro M6000 (2,816-3,072+ cores)
GM200 GPU block diagram

6 Graphics Processing Clusters (GPC)
Each with 4 SMM Units (24 total)

Each SMM Unit =
128 single-precision CUDA cores
(3072 total CUDA cores)

1.4x more performance / core
compared to a Kepler CUDA core

2x the performance per watt

Last year:
GM204 = 4 GPC / 16 SMM Units
@ 128 CUDA cores = 2,048 CUDA cores
## NVIDIA GPU Comparison Chart

<table>
<thead>
<tr>
<th></th>
<th>GTX 970</th>
<th>GTX 980</th>
<th>GTX 980 Ti</th>
<th>GTX Titan X</th>
<th>Quadro M5000</th>
<th>Quadro K6000</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>GPU Code Name</strong></td>
<td>GM204</td>
<td>GM204</td>
<td>GM200</td>
<td>GM200</td>
<td>GM204</td>
<td>GM200</td>
</tr>
<tr>
<td><strong>SMM Units</strong></td>
<td>13</td>
<td>16</td>
<td>22</td>
<td>24</td>
<td>16</td>
<td>24</td>
</tr>
<tr>
<td><strong>CUDA Cores</strong></td>
<td>1664</td>
<td>2048</td>
<td>2816</td>
<td>3072</td>
<td>2048</td>
<td>3072</td>
</tr>
<tr>
<td><strong>Core Clock (MHz)</strong></td>
<td>1050</td>
<td>1127</td>
<td>1000</td>
<td>1000</td>
<td>1050</td>
<td>988</td>
</tr>
<tr>
<td><strong>Pixel Rate (GPixels/s)</strong></td>
<td>58.8</td>
<td>72.1</td>
<td>96</td>
<td>96</td>
<td>67.2</td>
<td>94.8</td>
</tr>
<tr>
<td><strong>Texture Rate (GT/s)</strong></td>
<td>109</td>
<td>144</td>
<td>176</td>
<td>192</td>
<td>134</td>
<td>190</td>
</tr>
<tr>
<td><strong>Floating Point (GFlops)</strong></td>
<td>3494</td>
<td>4616</td>
<td>5632</td>
<td>6144</td>
<td>4301</td>
<td>6070</td>
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<tr>
<td><strong>Onboard RAM</strong></td>
<td>4GB</td>
<td>4GB</td>
<td>6GB</td>
<td>12GB</td>
<td>8GB</td>
<td>12GB</td>
</tr>
<tr>
<td><strong>Memory Bus Width</strong></td>
<td>256-bit</td>
<td>256-bit</td>
<td>384-bit</td>
<td>384-bit</td>
<td>256-bit</td>
<td>384-bit</td>
</tr>
<tr>
<td><strong>Memory Bandwidth (GB/s)</strong></td>
<td>224</td>
<td>224</td>
<td>337</td>
<td>337</td>
<td>212</td>
<td>317</td>
</tr>
<tr>
<td><strong>TDP</strong></td>
<td>148W</td>
<td>165W</td>
<td>250W</td>
<td>250W</td>
<td>150W</td>
<td>250W</td>
</tr>
<tr>
<td><strong>DX / OGL / SM</strong></td>
<td>12.0/4.5/5.0</td>
<td>12.0/4.5/5.0</td>
<td>12.0/4.5/5.0</td>
<td>12.0/4.5/5.0</td>
<td>12.0/4.5/5.0</td>
<td>12.0/4.5/5.0</td>
</tr>
<tr>
<td><strong>Power Connectors</strong></td>
<td>2x 6-pin</td>
<td>2x 6-pin</td>
<td>1x 6-pin + 1x 8-pin</td>
<td>1x 6-pin + 1x 8-pin</td>
<td>2x 6-pin</td>
<td>1x8-pin</td>
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<tr>
<td><strong>Outputs</strong></td>
<td>1x DVI</td>
<td>1x DVI</td>
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<td>1x DVI-I</td>
<td>1x DVI-I</td>
</tr>
<tr>
<td></td>
<td>1x HDMI</td>
<td>1x HDMI</td>
<td>1x HDMI</td>
<td>1x HDMI</td>
<td>0x HDMI</td>
<td>0x HDMI</td>
</tr>
<tr>
<td></td>
<td>3x DisplayPort</td>
<td>3x DisplayPort</td>
<td>3x DisplayPort</td>
<td>3x DisplayPort</td>
<td>4x DisplayPort</td>
<td>4x DisplayPort</td>
</tr>
<tr>
<td><strong>Newegg Price</strong> (Nov. 2015)</td>
<td>$349.00</td>
<td>$510.00</td>
<td>$660.00</td>
<td>$999.00</td>
<td>$1,999.00</td>
<td>$4,999.00</td>
</tr>
</tbody>
</table>
Relative GPU Performance

Takeaway:

GTX 980 Ti rivals GTX Titan X for about 60% of the cost ($660 vs $999)

Quadro M6000 at $6,000 equals the GTX Titan X at $1,000
NVIDIA Roadmap 2015 - 2018

Pascal - Massively increases performance with 3D memory, Nvlink
Smaller <20nm Process technology node
Best Buy Today: GTX 980 Ti

- GM200 GPU - Latest technology, full implementation
- 2,816 CUDA cores
- 1,000 MHz Core Clock
- 1x DVI, 1x HDMI, 3x DisplayPort
- $660
NVIDIA Quadro workstation class cards

Quadro K2200 → GM107 (Maxwell 1\textsuperscript{st} gen), 640 CUDA cores, 4GB, $429
Quadro M4000 → GM204 (Maxwell), 1,664 CUDA cores, 8GB, $889
Quadro M5000 → GM204 (Maxwell), 2,048 CUDA cores, 8GB, $1,999
Quadro M6000 → GM200 (Maxwell), 3,072 CUDA cores, 12GB, $5,999

Quadro Features:
Designed for \textit{solid} performance in Autodesk professional apps = Stable
Drivers certified by Autodesk
Better manufacturing process = more quality control & NVIDIA warranty
Perform \textit{horribly} next to much cheaper GTX cards
Gaming vs. Workstation Cards for BDS

Gaming Cards
Autodesk apps built for DirectX 9 as a minimum standard, not OpenGL
Render performance in iRay = CUDA core dependent
Go for >2000 CUDA cores on GPU = GTX 780 Ti, GTX 980, Titan Black
Cheap! If it doesn’t work, sell it on eBay or CL

Workstation cards
Typically more stable drivers (certified by Autodesk)
Possibly smoother viewport performance in all visual style modes (varies)
Unlocked firmware features like hardware anti-aliasing, Z-buffering, etc.
Informal Lumion Benchmark
GPU Benchmarks - iRay 2015 Photoreal

GPU Benchmarks - iRay Photoreal

Source: http://www.migenius.com/products/nvidia-iray/iray-benchmarks
YOU NEED TO SPEND AT LEAST $1,200 ON A DECENT GRAPHICS CARD

I HAVE 5 GTX TITANS IN MY MACHINE

BUT I RENDERED THIS IN 10 MINUTES ON A $400 CARD!

RENDERS TOO QUICK TO GET A COFFEE

THEN I SAID

YOU CAN JUST GET THE IGP, YOU'LL BE FINE
What about AMD / ATI?

Radeon HD are VERY good gaming cards
On par with GTX 770 in games

Expect ATI gaming cards to perform the same as NVIDIA GeForce cards at similar price points in BDS applications

As always, watch for issues typical with gaming cards, e.g., tearing in Inventor, wonky dialog boxes in Navisworks, etc.

Caveat: iRay / Vray RT rendering must use NVIDIA hardware
VII Mobile Computing
# 6th Generation Skylake Mobile CPUs

<table>
<thead>
<tr>
<th>Processor Name</th>
<th>Cores / Threads</th>
<th>Base Frequency</th>
<th>Max Turbo Frequency</th>
<th>L3 Cache</th>
<th>TDP</th>
<th>IGP</th>
<th>Bulk Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>i7-6700HQ</td>
<td>4 / 8</td>
<td>2.6 GHz</td>
<td>3.5 GHz</td>
<td>8 MB</td>
<td>45 W</td>
<td>HD Graphics 530</td>
<td>Tray: $378.00</td>
</tr>
<tr>
<td>i7-6820HQ</td>
<td>4 / 8</td>
<td>2.7 GHz</td>
<td>3.6 GHz</td>
<td>8 MB</td>
<td>45 W</td>
<td>HD Graphics 530</td>
<td>Tray: $378.00</td>
</tr>
<tr>
<td>i7-6920HQ</td>
<td>4 / 8</td>
<td>2.9 GHz</td>
<td>3.8 GHz</td>
<td>8 MB</td>
<td>45 W</td>
<td>HD Graphics 530</td>
<td>Tray: $568.00</td>
</tr>
<tr>
<td>i7-6820HK</td>
<td>4 / 8</td>
<td>2.7 GHz</td>
<td>3.6 GHz</td>
<td>8 MB</td>
<td>45 W</td>
<td>HD Graphics 530</td>
<td>Tray: $378.00</td>
</tr>
</tbody>
</table>
Buying a Mobile Workstation

Decide on screen size / portability needs first: 15” or 17”? Weight?

Screen resolution: 1900x1080+ is **working minimum** for Revit / 3ds Max

Installable RAM: Look for support for 32GB (4 DIMM slots)

Storage: 480GB SSD as C:\, 1TB HD as D:\ (Replace the optical drive)

Video: Ensure it has strong graphics, e.g. Quadro K1100M and K2100M

Case aesthetics: Where are the ports?

Keyboard – Backlit? Separate numeric pad? Multimedia keys?

Opt for better connectivity options – 802.11n WiGIG, Bluetooth

Docking Station – Get one if available
VIII  Peripherals
Monitors, Keyboards, Mice

Monitors:
- IPS panels in 24” 27” 30” (e.g. Dell U2410, U2713HM, U3011)
- Look for HDMI and DisplayPorts. DVI ports are on the way out.
- Extras: USB ports, card readers (nice but optional)

Mice:
- Wireless
- Programmable buttons
- Ergonomic

Keyboards:
- Cherry MX switches (varying feel, weights, etc.)
- Wireless, multimedia keys, programmable F keys, solid feel, backlighting
IX Build or Buy?
Build It!

Often done for SOHO operations
Looking for specific parts not available from a vendor
Hoping to save money
Enjoy a challenge
Corporate IT standards on workstation components
Corporate relationships with vendors
Often get preferred pricing
Warranties and level of technical support

Note: Limitations on high-end workstation configurability
X  System Builds

I DON'T ALWAYS NEED TO BUY NEW WORKSTATIONS

BUT WHEN I DO, I LISTEN TO MATT
The Grunt Workstation: Dell Precision T3620

<table>
<thead>
<tr>
<th>Component</th>
<th>Item</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Processor</td>
<td>Intel Xeon E3-1270 v5 Quad-Core @ 3.6GHz</td>
<td>$2,249.26</td>
</tr>
<tr>
<td>Memory</td>
<td>32GB (4x8GB) DDR4 2133 Non-ECC</td>
<td></td>
</tr>
<tr>
<td>Graphics</td>
<td>NVIDIA Quadro NVS 315, 1GB</td>
<td></td>
</tr>
<tr>
<td>Storage</td>
<td>512GB 2.5” SATA High Performance Solid State Drive (model unknown)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1TB 3.5” SATA 7200 RPM Hard Drive (model unknown)</td>
<td></td>
</tr>
<tr>
<td>Power supply</td>
<td>365W Up to 92% Efficient Power Supply</td>
<td></td>
</tr>
<tr>
<td>Keyboard</td>
<td>Dell KB216 Wired Keyboard Black</td>
<td></td>
</tr>
<tr>
<td>OS</td>
<td>Windows 10 Professional, 64-bit</td>
<td></td>
</tr>
<tr>
<td>Warranty</td>
<td>3 Year Hardware Service with Onsite/In-Home Service after Remote Diagnosis</td>
<td></td>
</tr>
<tr>
<td>Mouse</td>
<td>None (see below)</td>
<td></td>
</tr>
<tr>
<td>Resource Disk</td>
<td>Windows 10 OS Recovery and Resource DVDs</td>
<td>$549.99</td>
</tr>
<tr>
<td>Monitor</td>
<td>Dell UltraSharp U2715H 27-inch Widescreen Flat Panel</td>
<td>$549.99</td>
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<tr>
<td></td>
<td>Dell UltraSharp U2715H 27-inch Widescreen Flat Panel</td>
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<tr>
<td>Dell Subtotal</td>
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<td>Additional items purchased separately from Newegg.com</td>
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<tr>
<td>Video Card</td>
<td>EVGA GeForce GTX 980 Ti w/6GB</td>
<td>$649.99</td>
</tr>
<tr>
<td>Mouse</td>
<td>Logitech MX Master Mouse</td>
<td>$99.99</td>
</tr>
<tr>
<td>Newegg Subtotal</td>
<td></td>
<td>$749.98</td>
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<tr>
<td><strong>System Total</strong></td>
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<td><strong>$4,099.22</strong></td>
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</table>
## The Grunt Workstation: Newegg

<table>
<thead>
<tr>
<th>Component</th>
<th>Item</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case</td>
<td>Fractal Design Define R4 Black Pearl Mid-Tower Computer Case</td>
<td>$99.99</td>
</tr>
<tr>
<td>Processor</td>
<td>Intel Core i7-6700K Skylake 4.0GHz</td>
<td>$399.99</td>
</tr>
<tr>
<td>Motherboard</td>
<td>ASUS #Z170-PRO LGA 1151 motherboard</td>
<td>$184.99</td>
</tr>
<tr>
<td>Memory</td>
<td>Crucial 32GB (4 x 8GB) 288-Pin DDR4 SDRAM DDR4 2133 (PC4 17000)</td>
<td>$169.99</td>
</tr>
<tr>
<td>Graphics</td>
<td>EVGA GeForce GTX 980 Ti w/6GB</td>
<td>$649.99</td>
</tr>
<tr>
<td>Storage</td>
<td>Samsung 850 Pro 512GB 2.5&quot; Solid State Drive</td>
<td>$219.99</td>
</tr>
<tr>
<td></td>
<td>Western Digital Black 1TB 3.5&quot; 7200 RPM 6GB/s Hard Drive</td>
<td>$69.99</td>
</tr>
<tr>
<td>Power supply</td>
<td>Corsair AX Series AX 860 860W 80+ Platinum PSU</td>
<td>$164.99</td>
</tr>
<tr>
<td>Mouse</td>
<td>Logitech MX Master Mouse</td>
<td>$99.99</td>
</tr>
<tr>
<td>Keyboard</td>
<td>Corsair Vengeance K70 RGB Keyboard Cherry MX Red switches</td>
<td>$161.89</td>
</tr>
<tr>
<td>OS</td>
<td>Windows 10 Professional, 64-bit, OEM</td>
<td>$139.99</td>
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<tr>
<td>Monitor</td>
<td>Dell UltraSharp U2715H 27-inch Widescreen Flat Panel</td>
<td>$597.51</td>
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<td>Dell UltraSharp U2715H 27-inch Widescreen Flat Panel</td>
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<tr>
<td><strong>System Total</strong></td>
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<td><strong>$3,556.81</strong></td>
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## The BIM Champ 6-Core Haswell-E : Dell Precision 5810

<table>
<thead>
<tr>
<th>Component</th>
<th>Item</th>
<th>Price</th>
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<tbody>
<tr>
<td>Processor</td>
<td>Intel Xeon E5-1650 v3 6-Core @ 3.5GHz</td>
<td>$3,643.50</td>
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<tr>
<td>Memory</td>
<td>32GB (4x8GB) DDR4 2133 ECC</td>
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<tr>
<td>Graphics</td>
<td>NVIDIA Quadro M4000 8GB card</td>
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<tr>
<td>Storage</td>
<td>512GB 2.5&quot; SATA High Performance Solid State Drive (model unknown)</td>
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<td></td>
<td>8x Slimline DVD-ROM</td>
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<tr>
<td>Keyboard</td>
<td>Dell KB212-B QuietKey USB Keyboard Black</td>
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</tr>
<tr>
<td>OS</td>
<td>Windows 8.1 Professional, 64-bit, w/DVD Recovery</td>
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<tr>
<td>Warranty</td>
<td>3 Year Hardware Service with Onsite/In-Home Service after Remote Diagnosis</td>
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<tr>
<td>Mouse</td>
<td>None (see below)</td>
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</tr>
<tr>
<td>Resource Disk</td>
<td>Windows 8.1 OS Recovery and Resource DVDs</td>
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<tr>
<td>Monitor</td>
<td>Dell UltraSharp U2715H 27-inch Widescreen Flat Panel</td>
<td>$549.99</td>
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<td></td>
<td>Dell UltraSharp U2715H 27-inch Widescreen Flat Panel</td>
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<td>Dell Subtotal</td>
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Additional items purchased separately from Newegg.com

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<thead>
<tr>
<th>Mouse</th>
<th>Logitech MX Master Mouse</th>
<th>$99.99</th>
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**System Total** | **$4,843.47**
# The BIM Champ 6-Core Haswell-E: Newegg

<table>
<thead>
<tr>
<th>Component</th>
<th>Item</th>
<th>Price</th>
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<tbody>
<tr>
<td>Case</td>
<td>Fractal Design Define R4 Black Pearl Mid-Tower Computer Case</td>
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<tr>
<td>Processor</td>
<td>Intel Core i7-5930K Haswell-E 6-Core 3.5 GHz</td>
<td>$459.99</td>
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<tr>
<td>Processor Cooler</td>
<td>Corsair Hydro H100i GTX Extreme Performance Water/Liquid CPU Cooler</td>
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<tr>
<td>Motherboard</td>
<td>MSI X99A Raider LGA 2011-v3 Motherboard</td>
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<tr>
<td>Memory</td>
<td>Crucial 32GB (4 x 8GB) 288-Pin DDR4 SDRAM DDR4 2133 (PC4 17000) Desktop Memory Model CT4K8G4DFD8213</td>
<td>$169.99</td>
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<tr>
<td>Graphics</td>
<td>EVGA GeForce GTX 980 Ti w/6GB</td>
<td>$649.99</td>
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<tr>
<td>Storage</td>
<td>Samsung 850 Pro 512GB 2.5&quot; Solid State Drive</td>
<td>$219.99</td>
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<td></td>
<td>Samsung 18X DVD-ROM 48X Model SH-118CB/BEBE</td>
<td>$19.99</td>
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<td>Power supply</td>
<td>Corsair AX Series AX 860 860W 80+ Platinum PSU</td>
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<tr>
<td>Mouse</td>
<td>Logitech MX Master Mouse</td>
<td>$99.99</td>
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<tr>
<td>Keyboard</td>
<td>Corsair Vengeance K70 RGB Keyboard Cherry MX Red switches</td>
<td>$161.89</td>
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<tr>
<td>OS</td>
<td>Windows 10 Professional, 64-bit, OEM</td>
<td>$139.99</td>
</tr>
<tr>
<td>Monitor</td>
<td>Dell UltraSharp U2715H 27-inch Widescreen Flat Panel</td>
<td>$597.51</td>
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<td></td>
<td>Dell UltraSharp U2715H 27-inch Widescreen Flat Panel</td>
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<td><strong>System Total</strong></td>
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**The Viz Wiz 8-Core Haswell-E: Newegg**

<table>
<thead>
<tr>
<th>Component</th>
<th>Item</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case</td>
<td>Corsair Obsidian 750D Black Aluminum / Steel ATX Full Tower Computer Case</td>
<td>$124.99</td>
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<tr>
<td>Processor</td>
<td>Intel Core i7-5960X Haswell-E 8-Core 3.0 GHz</td>
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<tr>
<td>Processor Cooler</td>
<td>Corsair Hydro H100i GTX Extreme Performance Water/Liquid CPU Cooler</td>
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<td>Motherboard</td>
<td>ASRock X99 OC Formula/3.1 Extended ATX Intel Motherboard</td>
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<td>Memory</td>
<td>CORSAIR Dominator Platinum 64GB (8 x 8GB) 288-Pin DDR4 SDRAM DDR4 2400 (PC4 19200) C14 Memory Kit Model CMD64GX4M8A2400C14</td>
<td>$609.99</td>
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<tr>
<td>Graphics</td>
<td>EVGA GeForce GTX 980 Ti w/6GB</td>
<td>$649.99</td>
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<tr>
<td>Storage</td>
<td>Samsung SM951 M.2 512GB PCIe 3.0 SSD MZHPV512HDGL-00000 - OEM</td>
<td>$338.50</td>
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<td>Power supply</td>
<td>CORSAIR AXi series AX1200i 1200W ATX12V 80 PLUS PLATINUM Certified Full Modular Active PFC Power Supply</td>
<td>$299.99</td>
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<tr>
<td>Mouse</td>
<td>Logitech MX Master Mouse</td>
<td>$99.99</td>
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<tr>
<td>Keyboard</td>
<td>Corsair Vengeance K70 RGB Keyboard Cherry MX Red switches</td>
<td>$161.99</td>
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<td>Dell UltraSharp U2715H 27-inch Widescreen Flat Panel</td>
<td>$597.51</td>
</tr>
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**System Total** $6,480.29
Thank You!

Please fill out your evaluation forms online after class!

Please see me if you need the answers