IT21325: A Hardware Wonk's Guide to Specifying the Best 3D and BIM Workstations, 2016 Edition

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Class summary

Working with today's leading Building Information Modeling (BIM) and 3D visualization tools presents a special challenge to your IT infrastructure. Wrestling with the computational demands of the Revit software platform, as well as BIM-related applications such as 3ds Max, Navisworks, Rhino, Lumion, and others, means that one needs the right knowledge to make sound investments in workstation hardware. This class gets inside the mind of a certified (or certifiable) hardware geek to understand the variables to consider when purchasing hardware to support the demands of these BIM and 3D applications.

Fully updated for 2016, this class will give you the scoop on the latest advancements in workstation processors, motherboards, memory, and graphics cards. This year we will pay special attention to the latest advancements in graphics technologies to meet the demands of high-end rendering, animation, and visualization across a wide variety of platforms

Key learning objectives

1. Understand the hardware demands of today's BIM and 3D applications.
2. Know where the current state of the art is in hardware components, and identify today's "sweet spots" in processors, memory, storage, and graphics.
3. Specify workstations for different classes of BIM and 3D usage profiles
4. Understand how to shop for complete systems and individual components

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.

Stuff we'll Talk About: Components In Depth

Central Processing Units (CPUs)

Graphics Processing Units (GPUs)

System Memory (RAM)

Mass Storage

Stuff We'll Talk About: Buying Guides

QUOTE ITEMS

Manufacturer	Description	Part Number	Qty	Price
System 1				
CUSTOM SKU	Mobile Precision 7510 Account Code: End User: 210-AFXM Mobile Precision 7510 XCTO BASE 338-BJUC Intel Xeon E3-1545M v5 (Quad Core Xeon 2.90GHz, 3.80GHz Turbo, 8MB 45W, w/Iris Pro Graphics P580) 329-BDFP E3-1545M, Smart Card Only, with Type-C, Assembly Base, Mobile Precision 7510 389-BHJY Intel XEON Processor Label 619-AHKN Win 10 Pro 64 English, French, Spanish 340-AJFC Kickstart Product Registration 422-0008 Dell Data Protection System Tools Digital Delivery/DT 525-BBCL SupportAssist 640-BBES Dell Precision Optimizer 640-BBLW Dell(TM) Digital Delivery Cirrus Client 640-BBPN System Driver for 7510 658-BBMQ Enable Low Power Mode 658-BBMR Dell Client System Update (Updates latest Dell Recommended BIOS, Drivers, Firmware and Apps),OptiPlex 658-BBNH Waves Maxx Audio 658-BCUV Dell Developed Recovery Environment 634-BEZQ Microsoft Office Home and Business 2016 490-BCPK Nvidia Quadro M2000M w/4GB GDDR5 490-BCQJ Heatsink with fan, MPWS 7510 387-BBDO No Energy Star 319-BBDS Bezel For Full HD Non Touch with Camera +MIC 320-BBQV Back Cover For Full HD Non Touch 391-BCFF 15.6" UltraSharp FHD IPS (1920x1080) Wide View Anti-Glare LED-backlit with Premium Panel Guarantee (72% color gamut) 370-ACDZ 64GB (4x16G) 2133MHz DDR4 Memory, MPWS 400-AJBI 1TB M.2 PCIe Solid State Drive, MPWS 401-AAGM No Additional Hard Drive 817-BBBN NO RAID 555-BCMT Intel Dual Band Wireless 8260 (802.11ac) W/ Bluetooth 555-BCNN Intel Wireless 8260A Driver 556-BBDZ No Mobile Broadband 580-ACLI Internal Dual Pointing Keyboard (US-English) 580-ADWY Keyboard Lattice 451-BBPP 6-cell (72Wh) Lithium Ion Polymer Battery with ExpressCharge 450-AATJ 180W AC Adapter 450-AAUO US Power Cord 346-BBRE Palmrest With NFC/ Smartcard Reader/ Fingerprint Reader 631-AAQR No Out-of-Band Systems Management, Mobile Precision 7510 340-AGIK Safety/Environment and Regulatory Guide (English/French/Dutch) 634-BENZ No DDP|ESS Software 954-3465 No DDPE Encryption Software 580-AABG No Keyboard Selected 570-AADK No Mouse 461-AABV No Accessories 620-AAYW Windows 10 Pro OS Recovery 64bit - DVD 340-ATPB Placemat,W10,BCC 332-1286 US Order	Dell-3000002525310.1	1	2854.03

Obligatory Disclaimer Slide

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. Which is unfortunate.

However, if you **do** want to send me things (free) to "evaluate" and/or pay me $$$ to say nice things about you and your product, *I likely will*.

Survey Questions

How many of you…

Have the Building Design Suite Premium? Ultimate? Collections?

Are using Revit? 3ds Max? Navisworks? Showcase? Lumion? Rhino? V-Ray?

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
imgflip.com

I. Industry Pressures and Key Trends

AEC Industry Pressures and Trends

AEC Industry Pressures and Trends

- Industry using advanced BIM tools at a record rate
- BIM usage by Designers > General and Sub Contractors > 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

Most hardware performance increases are getting smaller each year

2016 = CPU process at 14nm – **very** difficult to get down to 10nm and below
2016 = GPU at 16nm (Nvidia Pascal) and 14nm (AMD Polaris), down from 28nm

Rise of GPU Accelerated Computing (GPGPU)

High demand for photorealism – easily within reach of mere mortals
The rise of gaming engines for ArchViz (Unreal Engine 4, Unity, Stingray, Lumion)

Virtualization & Virtual Desktop Infrastructure

Multiple operating systems / users / servers on one machine

The Cloud →Amazon EC2

High demand for photorealism – easily within reach of mere mortals
Waste of money to try to compete with the cloud

The Impending End of Moore's Law

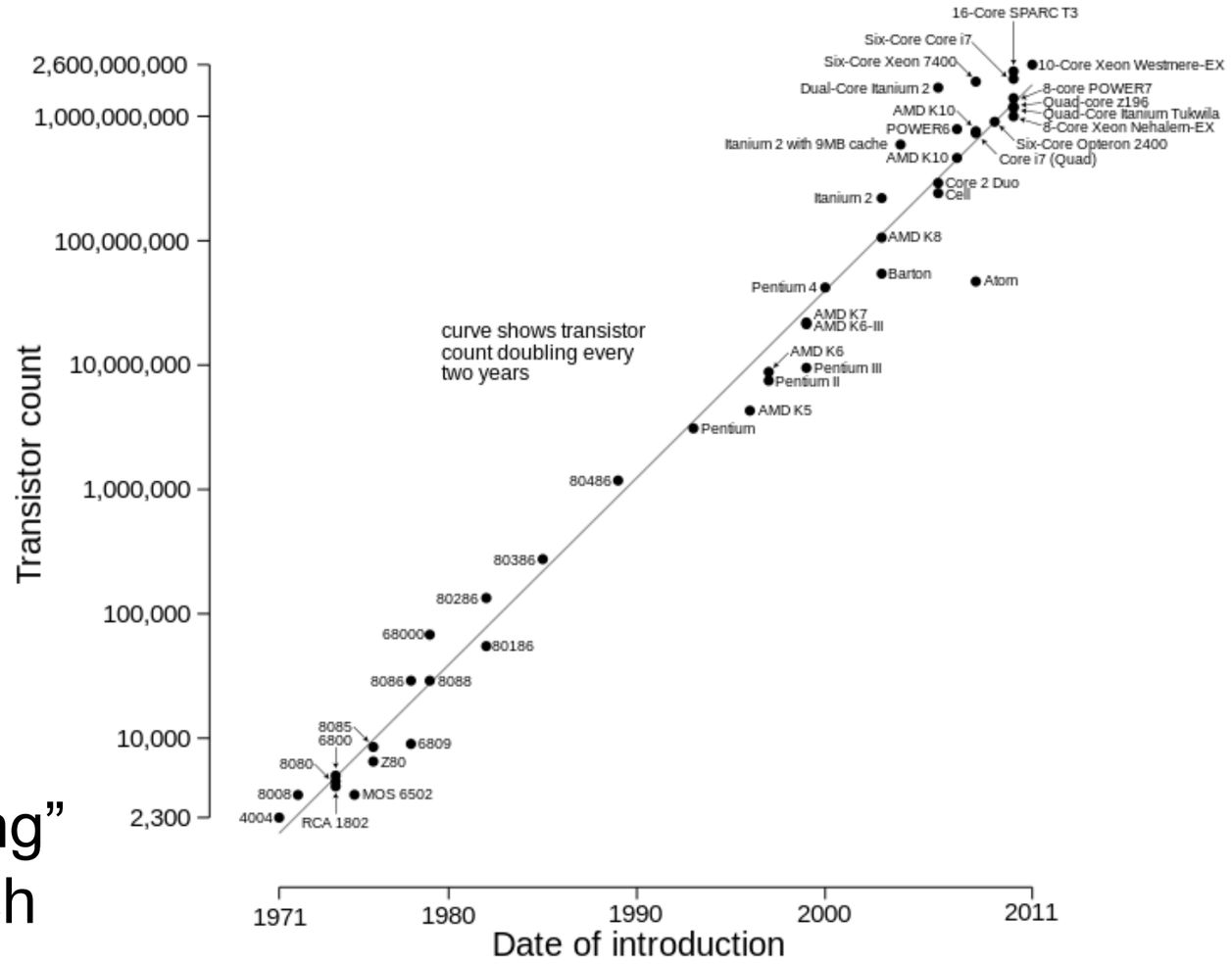
Moore's Law: The number of transistors on a chip doubles every 18-24 months.

Works by shrinking the size of the transistor "switch" to fit more on a chip

Exponential function, heading to 0nm

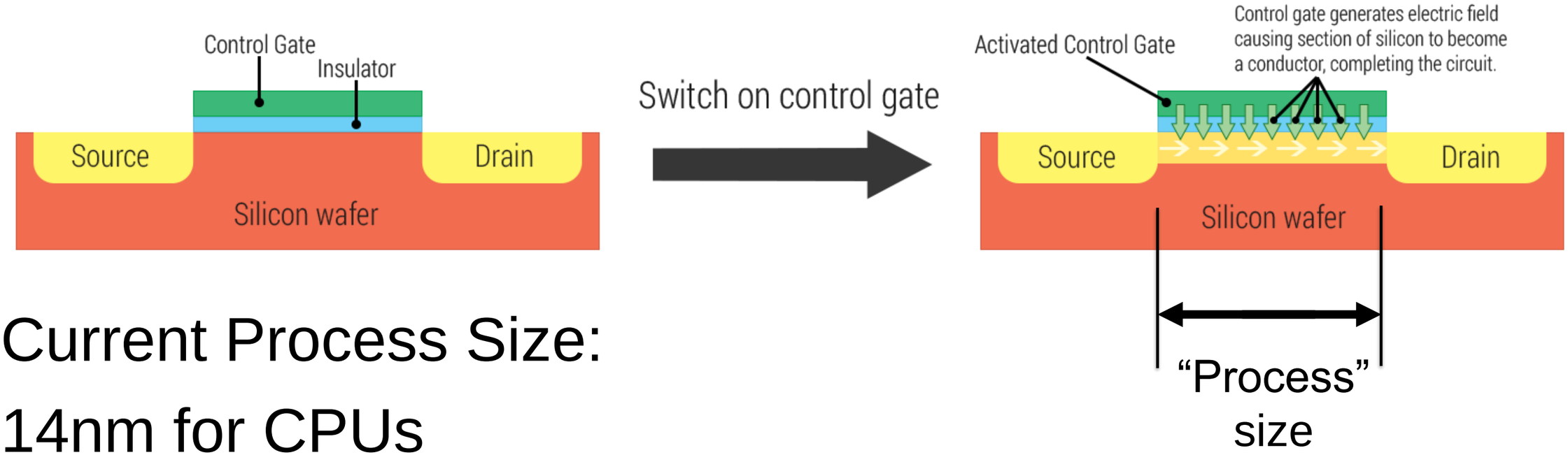
Problems:

- Running out of atoms in smaller processes (10nm, 7nm, etc.)
- Need to counteract "Quantum Tunneling" effects where electrons cross the switch



CPU Transistor and Process Size

How Transistors Work



Current Process Size:

14nm for CPUs

14/16nm for GPUs

Moore’s Law

1971 = 2,300 transistors @ 10um = 10,000nm

2016 = Over 1.3 billion transistors @ 14nm

Equal to shrinking a 5’-6” person to 3/32” high

Souce: https://uu.diva-portal.org/smash/get/diva2:548319/FULLTEXT01.pdf

Semiconductor manufacturing processes

10 µm – 1971
6 µm – 1974
3 µm – 1977
1.5 µm – 1982
1 µm – 1985
800 nm – 1989
600 nm – 1994
350 nm – 1995
250 nm – 1997
180 nm – 1999
130 nm – 2001
90 nm – 2004
65 nm – 2006
45 nm – 2008
32 nm – 2010
22 nm – 2012
14 nm – 2014
10 nm – 2017
7 nm – ~2019
5 nm – ~2021

Hardware Industry Pressures and Trends

Parallel Processing – Some Important Terms

Multiprogramming / Multitasking

- Multiple programs in memory; One program executes at a time.
- Goal is to keep the CPU busy as much as possible (e.g., preempt I/O tasks)
- Multiprogramming (older OS) – each program hijacks the CPU until it finishes
- Multitasking - Tasks broken down into threads which only take a quantum of CPU time
- Problems:
  - Fragmentation as programs enter / leave main memory
  - Protect each memory area allocated to each program
  - Program doesn't fit in main memory → pagination / virtual memory (slow)
  - Illusion of parallelism as CPU is reassigned to other tasks

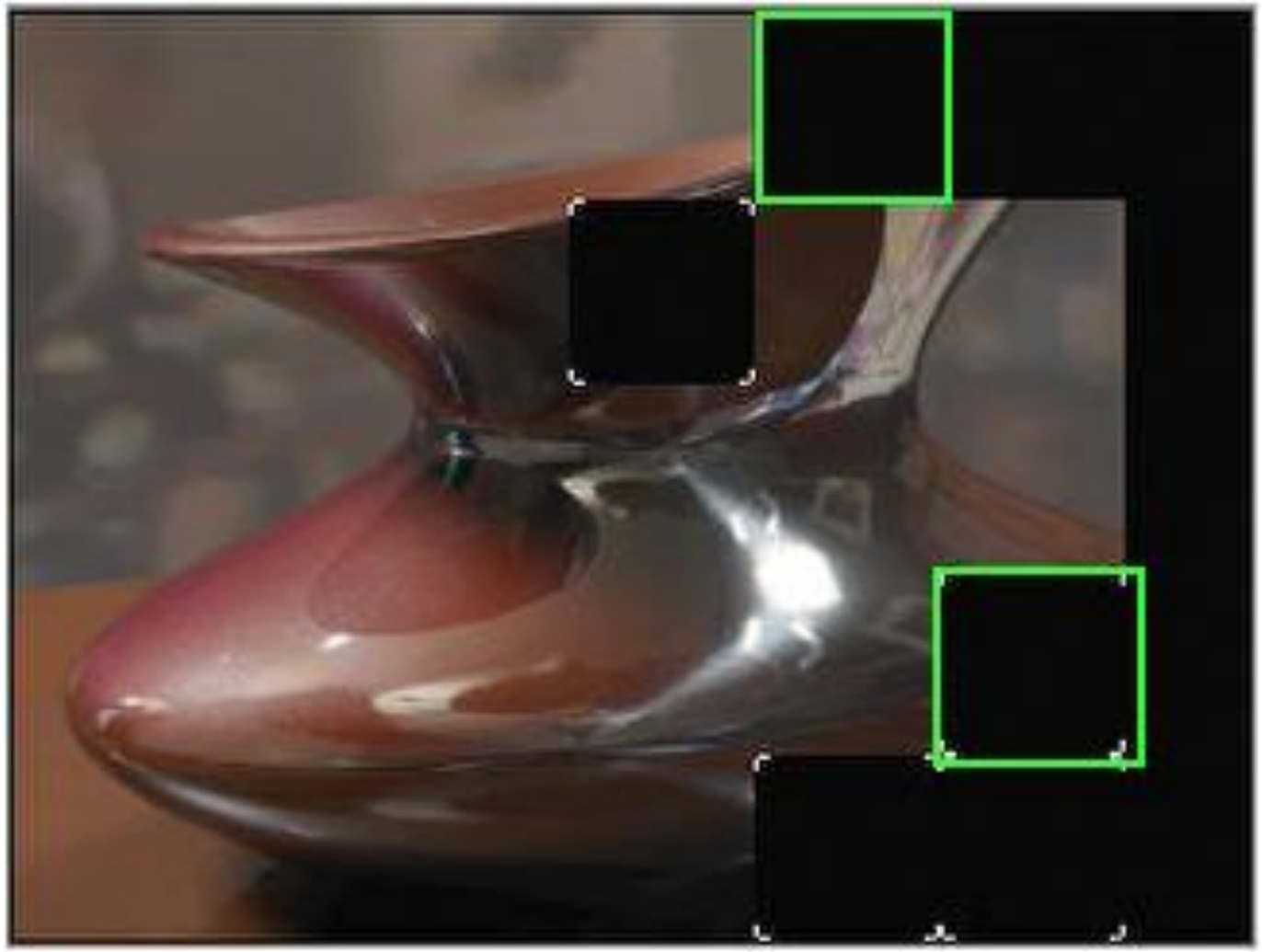
Multiprocessing – Uses hardware to execute >1 threads on >1 CPUs at the same time

Multithreading – Single process has >1 threads running concurrently within the context of that process. Threads are not sequential and can run in parallel in a multi-CPU system

Parallelism in mental ray Bucket Rendering

Each CPU core gets a “bucket” to render

Each bucket is processed at the same time and independently of the others



Gaming Engines for High End Visualization

Unreal Engine 4

Gaming Engines for High End Visualization

Stingray

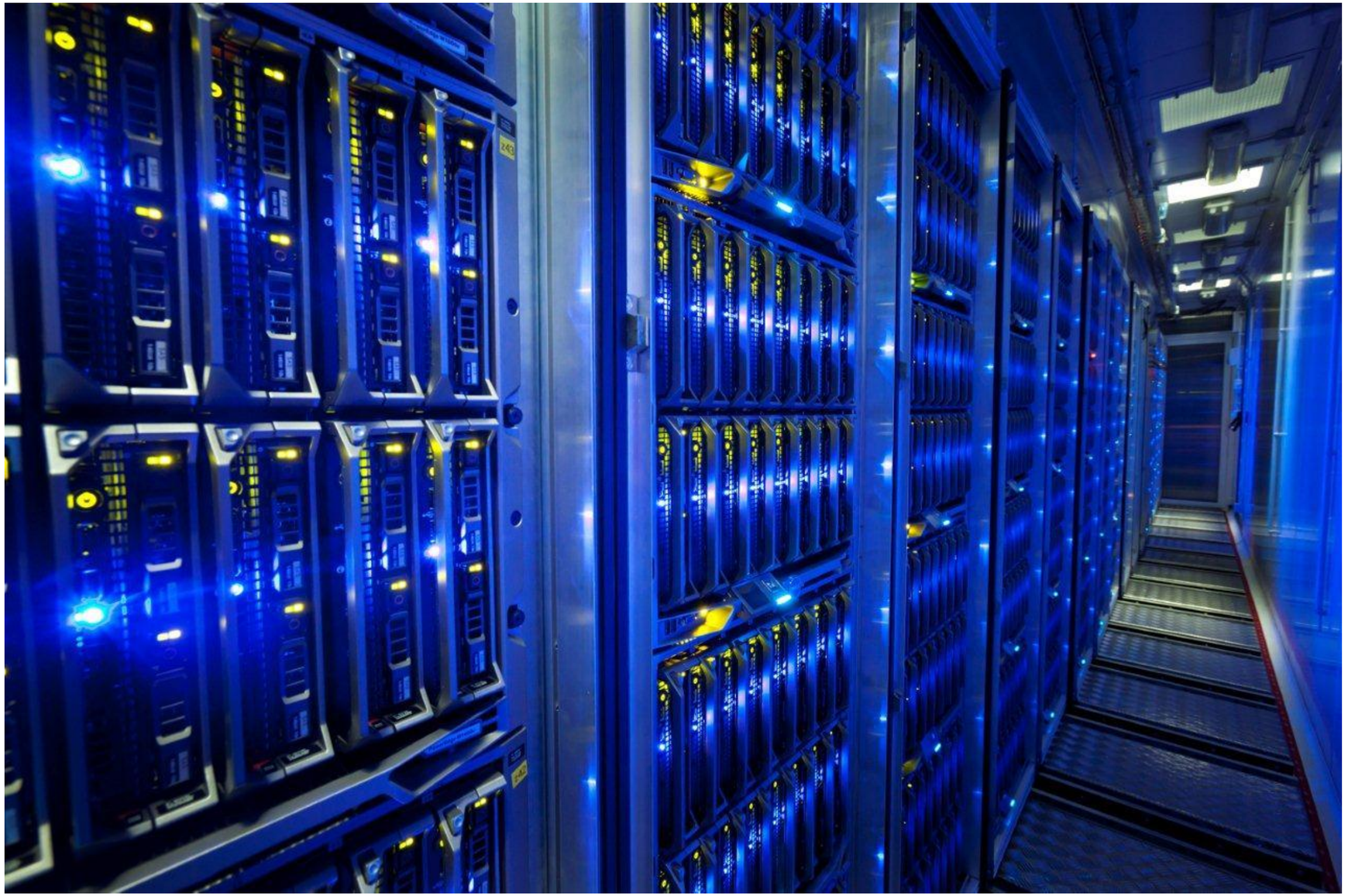
and

LIVE

Gaming Engines for High End Visualization

Lumion

The Cloud & Affect on Hardware Decisions



Pricing Compression

Each year = New hardware

New CPUs, graphics cards (GPUs), storage options

Push out the old / repurpose for new life

New stuff is typically more powerful but equal / lower in price

Commodity pricing:

- 1TB HD is $70, 4TB is $140. Why get the smaller drive?

II. Application Demands on Hardware

Building Design Suite Application Demands

	CPU Speed / Multithreading	Amount of System Ram	Graphics Card Capabilities	Graphics Card Memory Size	Hard Drive Speed
Revit	**10 / 9**	**10 / 7**	**7**	**5**	**10**
3ds Max Design	**10 / 10**	**9 / 7**	**7 / 5 / 10 (Nitrous / mr / iRay)**	**6 / 10 (mr / iRay)**	**10**
Navisworks Simulate Navisworks Manage	**7 / 7**	**7 / 6**	**7**	**5**	**7**
AutoCAD (2D & 3D)	**6 / 6**	**5 / 5**	**5**	**5**	**6**
AutoCAD Architecture AutoCAD MEP	**8 / 8**	**7 / 5**	**7**	**7**	**8**
ReCap	**10 / 10**	**9 / 5**	**9**	**7**	**10**

Note: A score of 7 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)

DBMS Applications stress hardware differently

Typically prefer 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 2017 Model Performance Technical Note

Parametric Change Engine scales well with CPU capabilities

Database behavior favors CPUs with large L1/L2/L3 caches – Look for L3 = 3MB+

Revit is Somewhat Multithreaded (and getting better):

Vector printing / vector export (e.g. to DWG/DXF)

Autodesk Raytracer rendering engine (100% CPU bound)

Wall join representation in plan and section views

Loading elements into memory reduces view open times

Computation of silhouette edges when navigating perspective 3D views

File open and save

DWF Export (individual sheets use multiple processes)

Point cloud data display

Color fills and calculation of structural connection geometry are processed in the background

Revit Views and Graphics Cards

Views are live reports of the project database:

- Users typically open many views at a time (consumes more main memory)
- Views always remain in sync with the underlying model 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, hard / ambient shadows, transparency, underlays
- Wireframe: Very fast but not often used (good for temporary speedups)
- Hidden Line: Most common mode for 2D views
- Shaded: Very effective but slower; Consistent Colors slightly faster (no shading)
- Realistic: Applies textures but not lighting. Would be nice to use 100% in 3D
- Ray Trace: Iterative rendering without long wait (based on iRay technology)

Revit Shadows

Hard Shadows

Usually computed on the graphics card, depending on the GPU model

Ambient Shadows

Also called Ambient Occlusion

Computes the distance between points and edges of nearby surfaces; darkens areas within a certain radius

Developed by Industrial Light & Magic for the movie “Pearl Harbor”

Often computed on the GPU per DirectX 9.0

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

Local and Server Storage System Considerations

- Long application load times
- Very large single files → 100MB+ to 1GB
- Local storage requirements for Worksharing local files – Need to clean up

Network Considerations

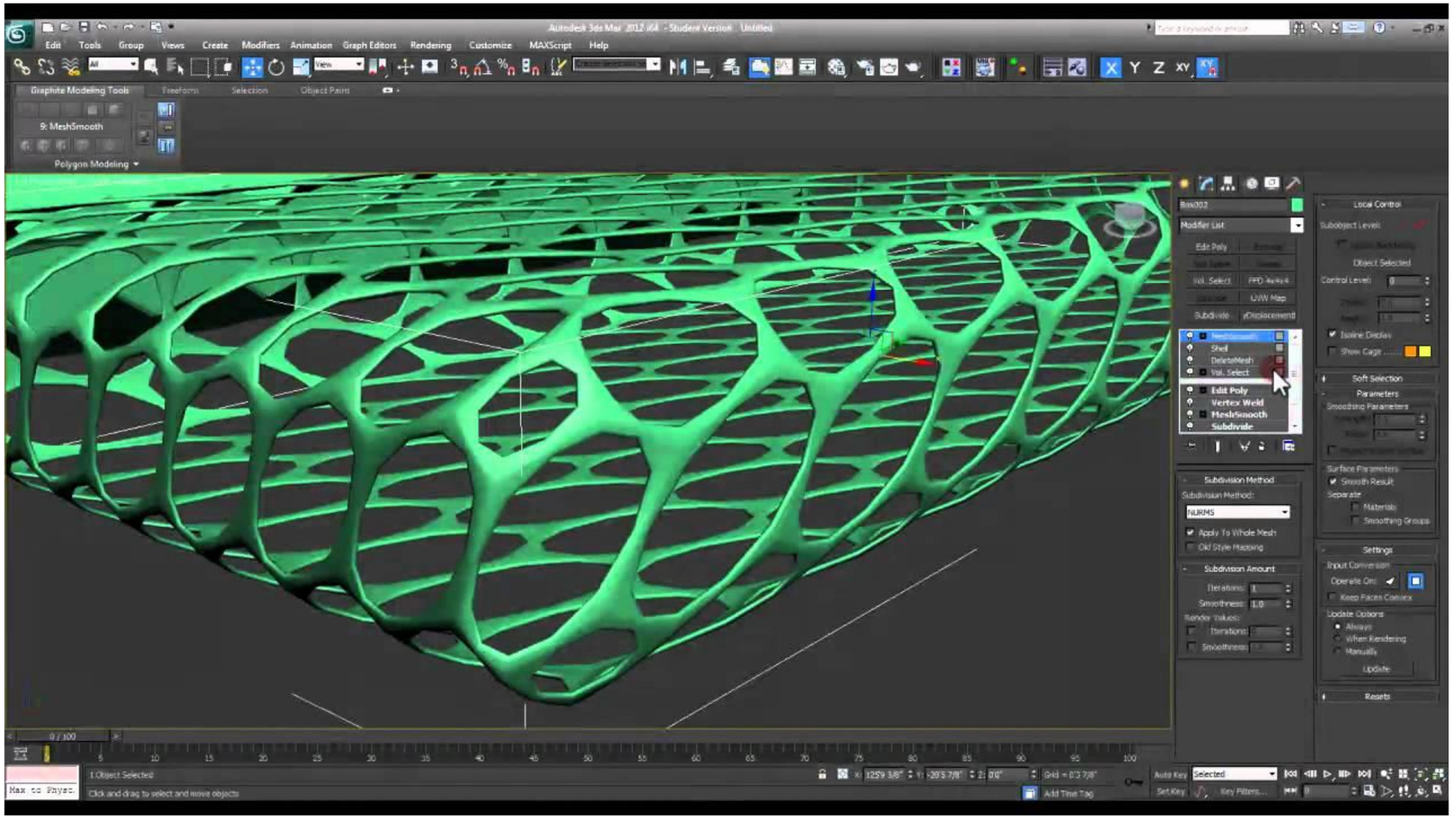
- Copying down new local files daily
- Saving / Synchronizing to Central (SWC) operations
- Working with remote offices demands fast WAN connectivity (Revit Server)

Application Demands – 3ds Max Design

Polygon Handling

Fast interaction with millions of vertices, edges, faces, and elements on screen

Rasterizing vector data many times a second (FPS) → GPU intensive operation in viewport navigation



Application Demands – 3ds Max Design

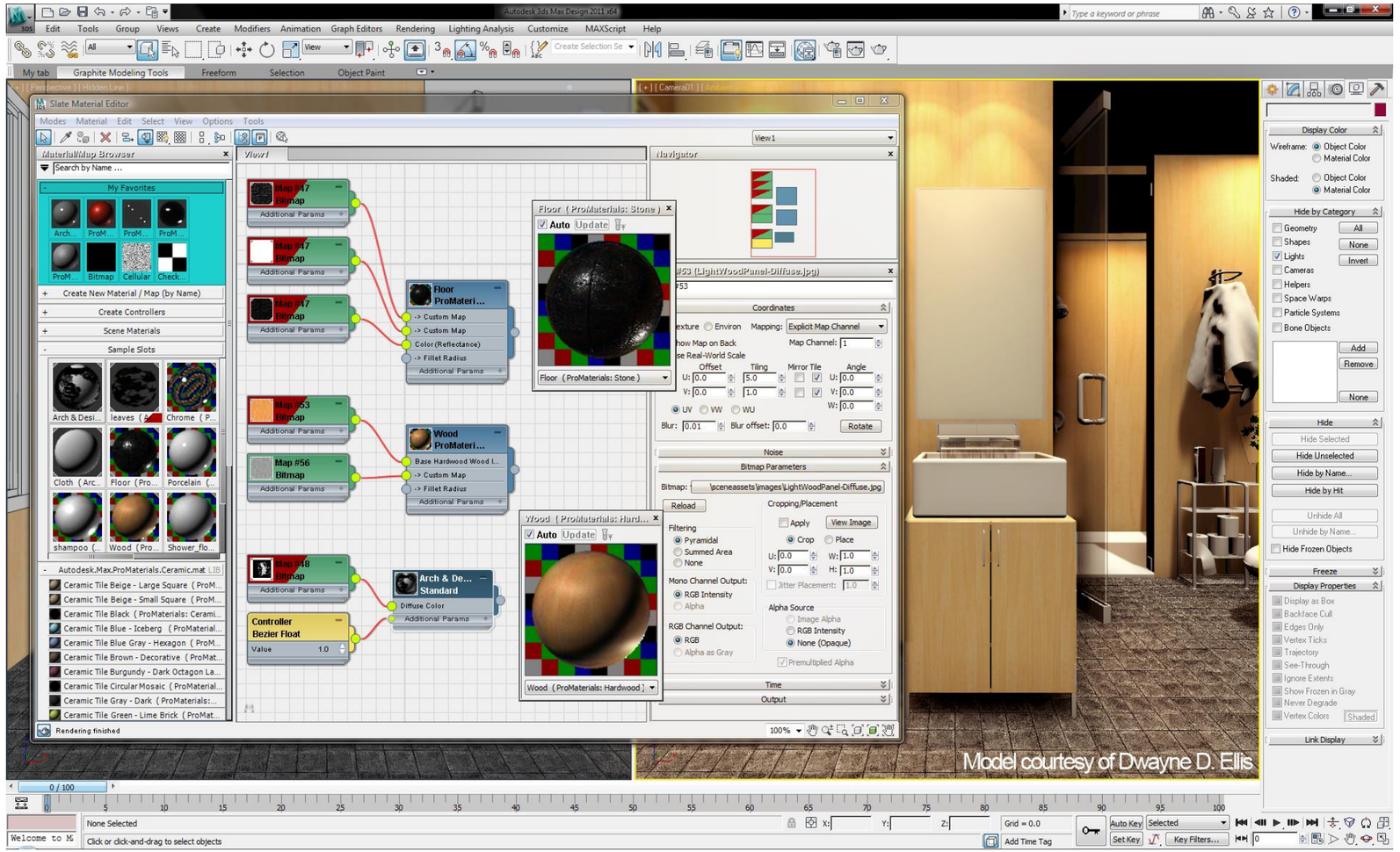
Material Handling

Process physical properties and reactions to incoming light energy across map channels

Diffuse, roughness, reflection, IOR, bump, translucency, displacement, contrast ….

UVW mapping

Procedural Materials

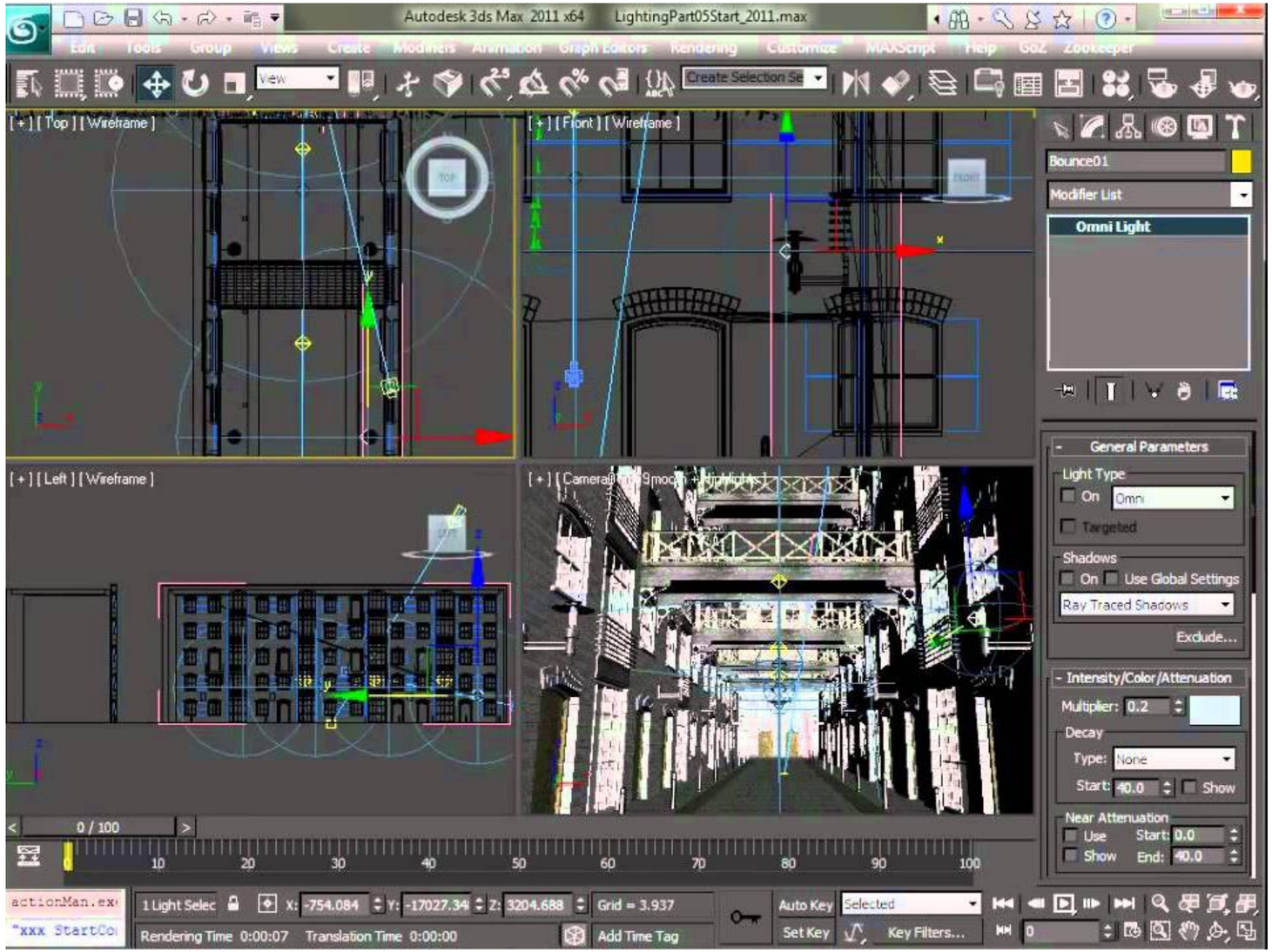


Application Demands – 3ds Max Design

Lighting

Processing physical (.IES photometric data) and non-physical lighting

Calculate direct and indirect illumination, shadows, and reflections



Application Demands – 3ds Max Design

Rendering

Combining polygons, materials, lighting, and environment together to produce photorealism

Ray tracing with ART, mr, Arnold, Iray engines

Post-rendering effects

Application Demands – 3ds Max Design

Processor:

Rendering with ART, Arnold, mental ray rendering engines 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 (GPU) for viewport speed, CPU for rendering

Includes Cloud Rendering

Application Demands – Autodesk ReCap

Process scan files = billions of points

Crop, measure, annotate scans

Process raw scans 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 2016

CPUs:

Skylake at 14nm Core i7-6700K = New desktop king

~~Broadwell (14nm die shrink of Haswell)~~ ***was largely a no-show in 2014/2015***

Broadwell E “High End Desktop” CPU – 6/8 Cores, **very fast in multithreaded apps**

Broadwell E based Xeons – 6/8/10…18 slow (2.x GHz) cores

Integrated Graphics Processors (IGPs) are better but still stink

Graphics: NVIDIA “Pascal” architecture improves greatly

Smaller 16nm Process from 28nm

1st Generation Pascal: GP104 GPU (GTX Titan X, GTX 1080, GTX 1070) - High end

RAM:

DDR4 is the new standard (Skylake / Broadwell E / Xeon)

Storage:

512GB SSDs now the new baseline standard, replaces 250GB

III Platforms, Processors, and Chipsets

Choosing the Right Platform

CPU determines the Platform; Platform determines the chipset / motherboard

Desktop Platform : i7-6700K → LGA1151 Socket w/Z170 Chipset & 4 DIMMs ($100 - $225)

HEDT Platform : I7-6800K → LGA2011-3 Socket w/X99 Chipset & 8 DIMMs ($280 - $400)

Workstation Platform : E3-12xx Xeon → FCLGA1151 Socket w/C230 chipset

E5-16xx Xeon → FCLGA2011-3 Socket w/C612 chipset

Note: No Xeon-based consumer parts readily available (reserved for system integrators)

Feature Sets in Quality Motherboards:

Full PCIe 3.0 slots = multi-GPU support, especially in Broadwell E i7-69xx

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 overclocks

For the kiddies: Bling, heat pipes, day-glo PCI slots, etc.

PCIe 3.0 Slots for Multi-GPU Configurations

- Example: **ASUS x99-Deluxe** motherboard for the Broadwell E platform
- Broadwell CPUs have either 28 or 40 PCIe 3.0 lanes depending on model
- Motherboard has five x16 slots and one x4 sized slot

PCIe 3.0 Expansion Capabilities:

40-Lane CPU: 5 x PCIe 3.0/2.0 x16 →
x16, x16/x16, x16/x16/x8, x8/x8/x16/x8, x8/x8/x8/x8/x8

28-Lane CPU: 3 x PCIe 3.0/2.0 x16 → x16, x16/x8, x8/x8/x8

Notes: The 5th PCIe x16 slot shares bandwidth with M.2 x4.
Triple PCIe 3.0/2.0 configuration is default set at x8/x8/x8

Multi Core meets Main Street

Intel's strategy:

Desktop = 4 cores

High end Desktop (HEDT) = 6 – 10 cores

Workstation = Up to 18 cores

Hyper-Threading doubles logical CPUs - 8 / 12 / 16 / 36 threads

Push for highest performance with the lowest power consumption

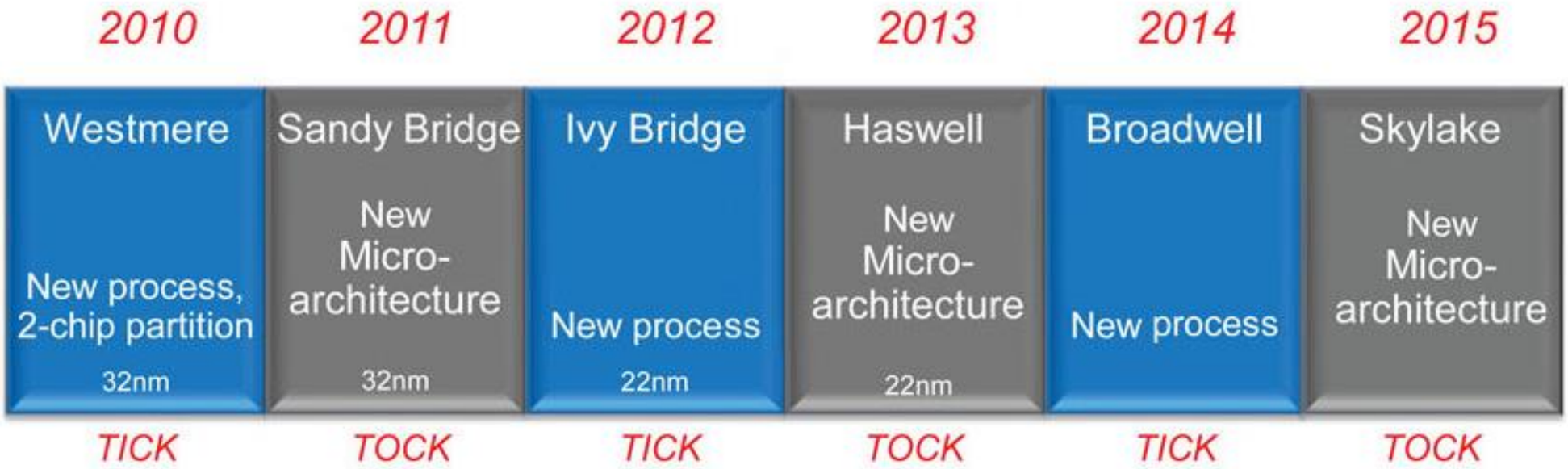
AMD's strategy:

Current performance ~= Intel Core i3 & i5 level performance

Cannot touch Core i7

2017: New 'Zen" targets HEDT performance levels

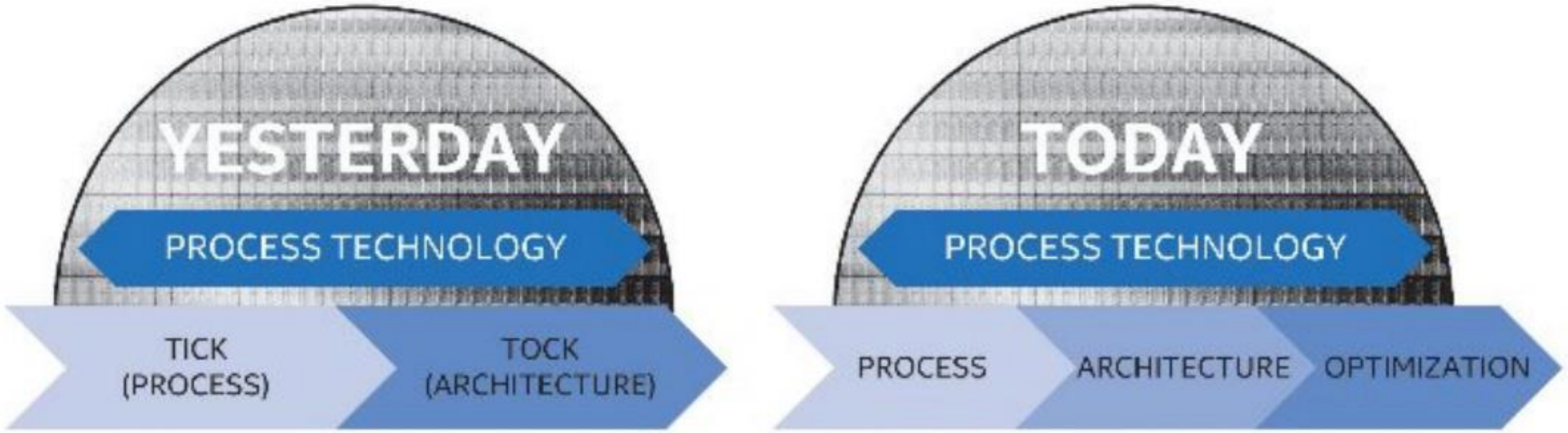
Intel's "Tick-Tock" Development Model (Pre-2016)



Ticks:
Microarchitectures die shrink (45nm > 32nm > 22nm >14nm …)

Tocks:
New Microarchitectures based on smaller process

Today: “Tick-Tock-Optimize”



Tick: Microarchitectures die shrink (45nm > 32nm > 22nm >14nm …)

Tock: New Microarchitectures based on smaller process

Optimize: Tweak out existing tock with slight improvements

What Makes a Good CPU for AEC?

Compare CPU specifications at ark.intel.com

Things to look for:

- Number of cores / Number of threads (HyperThreading)
- Core Clock Speed – Guaranteed rate regardless of load
- Turbo Boost Clock Speed – Maximum speed in STA
- L3 Cache Size – 8MB minimum → 25MB+
- Maximum RAM (platform dependent)
- Inclusion of IGP / version (varies within platform)

ark.intel.com

Compare Intel® Products

Update URL | Export Results

Highlight rows with differences

	Intel® Core™ i7-6700K Processor (8M Cache, up to 4.20 GHz)	Intel® Core™ i7-6700 Processor (8M Cache, up to 4.00 GHz)	Intel® Core™ i7-6785R Processor (8M Cache, up to 3.90 GHz)	Intel® Core™ i7-6700T Processor (8M Cache, up to 3.60 GHz)
Product Name				
Code Name	Skylake	Skylake	Skylake	Skylake
Essentials				
Processor Number	i7-6700K	i7-6700	i7-6785R	i7-6700T
Status	Launched	Launched	Launched	Launched
Launch Date	Q3'15	Q3'15	Q2'16	Q3'15
Lithography	14 nm	14 nm	14 nm	14 nm
Recommended Customer Price	$339.00 - $350.00	$303.00 - $312.00	N/A	$303.00
Included Items		Thermal Solution - E97379		Thermal Solution - E98290
Performance				
# of Cores	4	4	4	4
# of Threads	8	8	8	8
Processor Base Frequency	4.00 GHz	3.40 GHz	3.30 GHz	2.80 GHz
Max Turbo Frequency	4.20 GHz	4.00 GHz	3.90 GHz	3.60 GHz
Cache	8 MB SmartCache	8 MB SmartCache	8 MB	8 MB SmartCache
Bus Speed	8 GT/s DMI3	8 GT/s DMI3	8 GT/s DMI3	8 GT/s DMI3
# of QPI Links	0			
TDP	91 W	65 W	65 W	35 W

Turbo Boost 2.0 Explained

- Intel technology that allows CPU cores to “overclock” themselves depending on CPU workload
- Provided as a series of numbers for multi-core CPUs, format = a/b/c/d
- Each number is a multiplier of 100MHz that indicates the turbo Speed depending on # active cores
- Example: i7-6700 Skylake CPU has a base frequency of 3.4GHz (3400 MHz) and a max Turbo frequency of 4.0GHz. Its Turbo bins are **3/4/5/6**, which breaks down as:

Number of cores active	No. of Turbo bin steps	Turbo Boost Calculation	Max frequency
4	3	3400 + (3 × 100) = 3400 + 300 = 3700	3.7 GHz
3	4	3400 + (4 × 100) = 3400 + 400 = 3800	3.8 GHz
2	5	3400 + (5 × 100) = 3400 + 500 = 3900	3.9 GHz
1	6	3400 + (6 × 100) = 3400 + 600 = 4000	4.0 GHz

Hyper-Threading Explained

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

Mainstream Desktop:
Intel's 6th Gen 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 6th gen HD 530 Graphics; Win 10 / DirectX 12
- **Errata: TSX was disabled by Intel on all Haswell CPUs ☹**
- TSX Instructions enabled: Potentially faster multithreaded code

Intel’s Skylake Core i7 Processor Lineup – Core i7-6700K

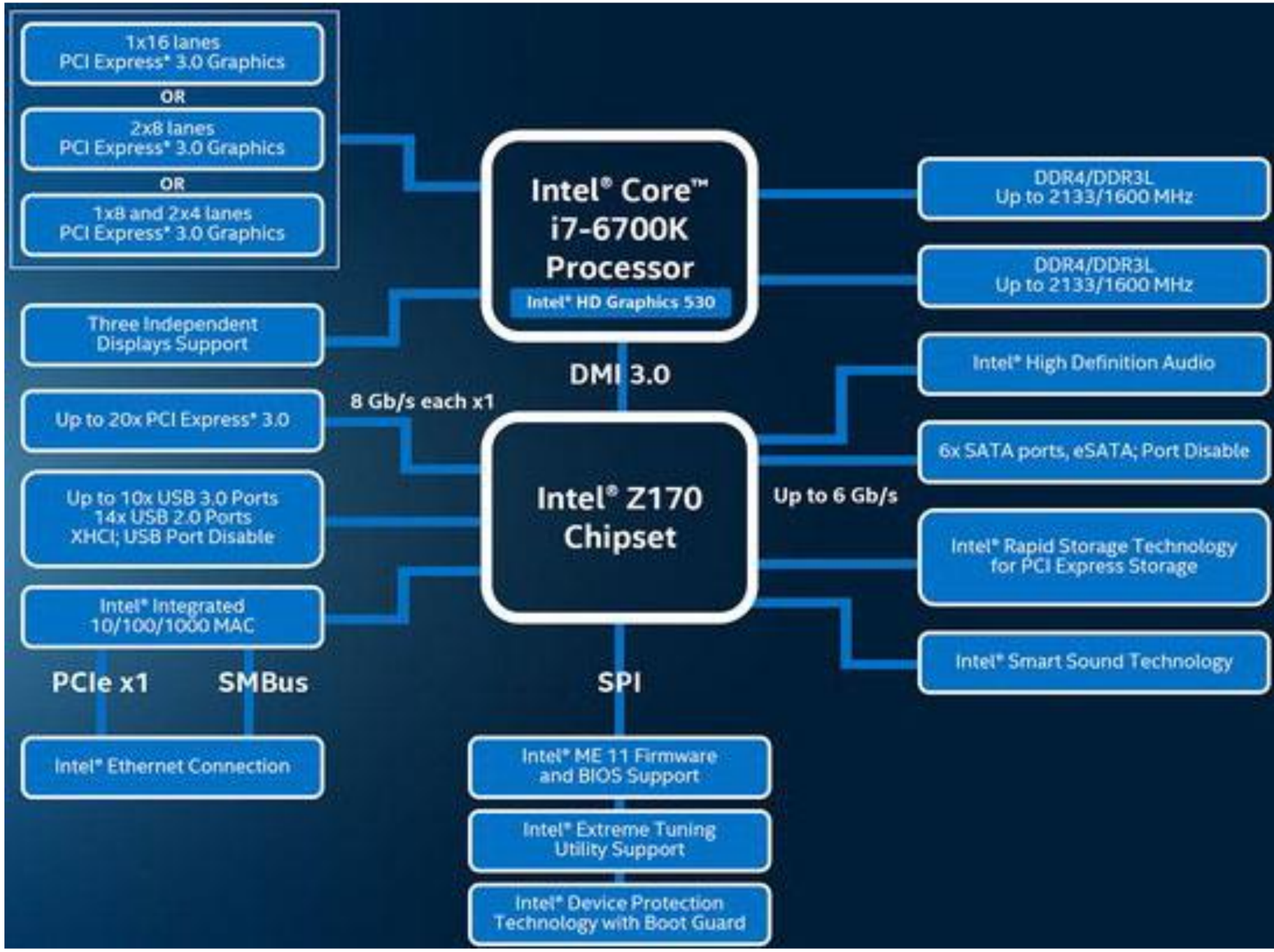
	Core i7-6700K
# of Cores / Threads	4 / 8
Base Clock Speed	4 GHz
Max Turbo Frequency	4.2 GHz
Cache	8 MB
Max TDP	91 W
System Integrator Pricing	$339.00
Max Memory Size	64 GB
Supported Memory Types	DDR4-1866/2133, DDR3L-1333/1600 @ 1.35V
# of Memory Channels	2
Max Memory Bandwidth	34.1 GB/s
Processor Graphics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

Intel Z170 Chipset for Skylake i7-5700K

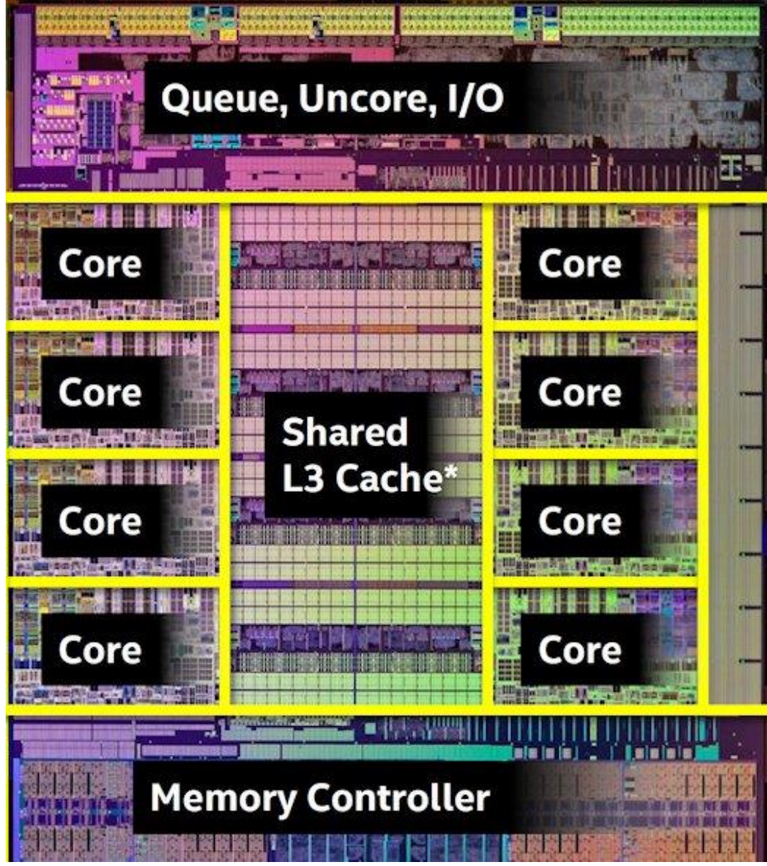
Up to 3 independent displays from CPU IGP

16 PCIe lanes from CPU for graphics in a 1x16 / 2x8 / 1x8 + 2x4 configuration

20 PCIe lanes from Z170 chipset for integrated peripherals (M.2, SATA, audio, NIC)



High End Desktop: Broadwell E



"High End Desktop" version of the Xeon E5 series

No integrated graphics processor (IGP)

True 6-, 8-, and 10-core designs
(12 / 16 / 20 threads total with HyperThreading

Uses DDR4 DIMMs / quad-channel memory controller
(RAM installed in 4s)

More expensive platform than Skylake desktop

Much faster than desktop 4–core i7-6700K in multithreading tasks

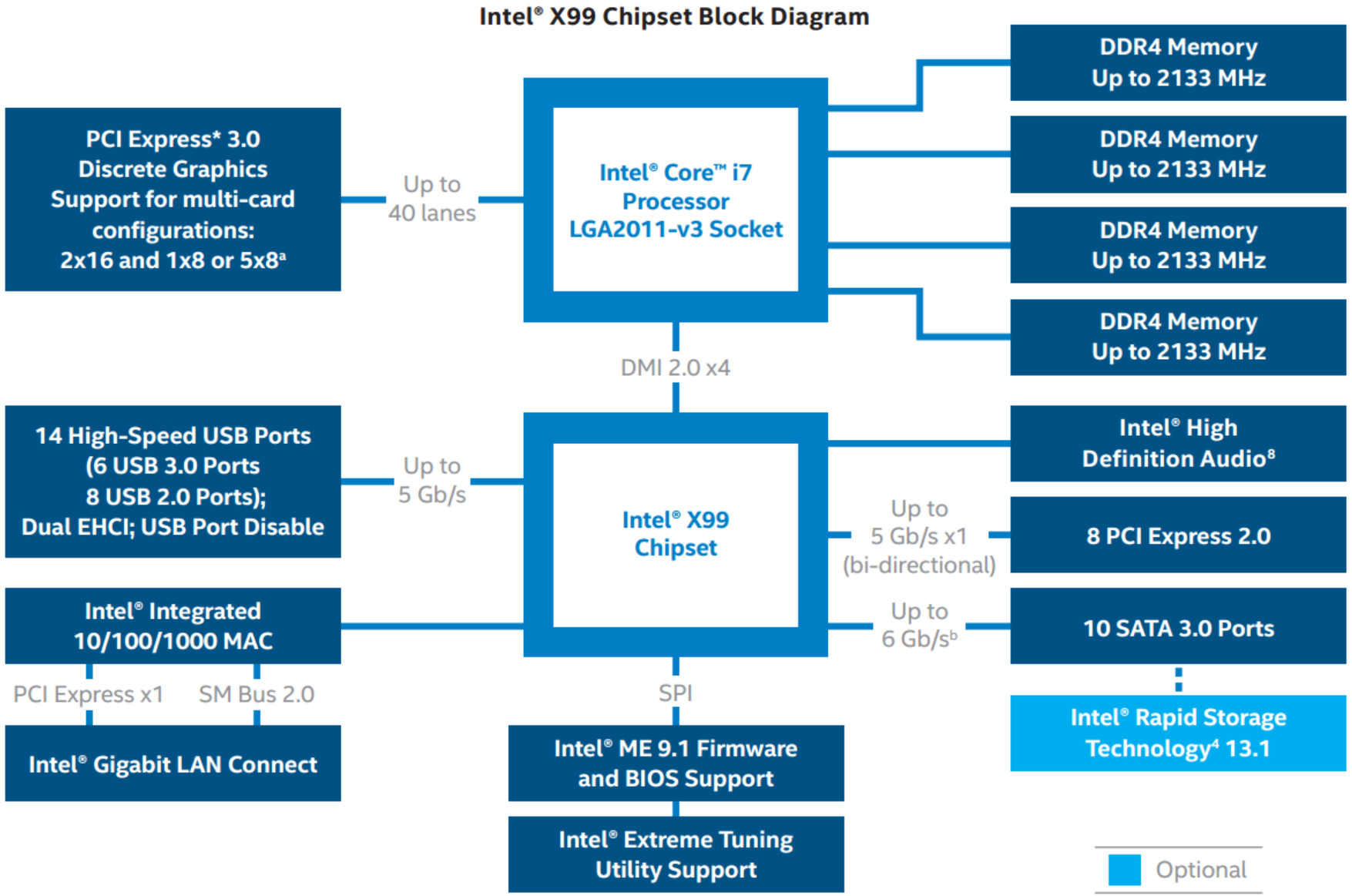
HEDT - Broadwell E Lineup

Intel Broadwell E Processor Lineup				
Processor Name	**Core i7-6800K**	**Core i7-6850K**	**Core i7-6900K**	**Core i7-6950X**
Cache	15 MB		20 MB	25 MB
Pricing	Box : $441.00 Tray: $434.00	Box : $628.00 Tray : $617.00	Box : $1109.00 Tray: $1089.00	Box : $1743.00 Tray: $1723.00
# of Cores	6		8	10
# of Threads	12		16	20
Base Frequency	3.4 GHz	3.6 GHz	3.2 GHz	3.0 GHz
Max Turbo Frequency	3.6 GHz	3.8 GHz	3.7 GHz	3.5 GHz
TDP	140 W			
Max Memory Size	128 GB			
Memory Types	DDR4-2400/2133			
# of Memory Channels	4			
ECC Memory Supported	No			
PCI Express 3.0 Lanes	28	40	40	40

Intel X99 Chipset for Broadwell E

[a] 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.

[b] All SATA ports capable of 6 Gb/s.



Xeon Processors

Designed for servers and “serious” workstations

3 Series to choose from:

- **E3-12xx v5** : Single CPU, **Skylake** based, 4 cores w/HT
- **E5-16xx v4** : Single CPU, **Broadwell E** based, 4, 6, 8 cores w/HT
- **E5-26xx v4** : Dual CPU capable, **Broadwell E** based, 4, 6, 8 … 18 cores

No Integrated Graphics Processor (IGP)

Many different models, clock speeds from 2.0GHz – 3.8GHz

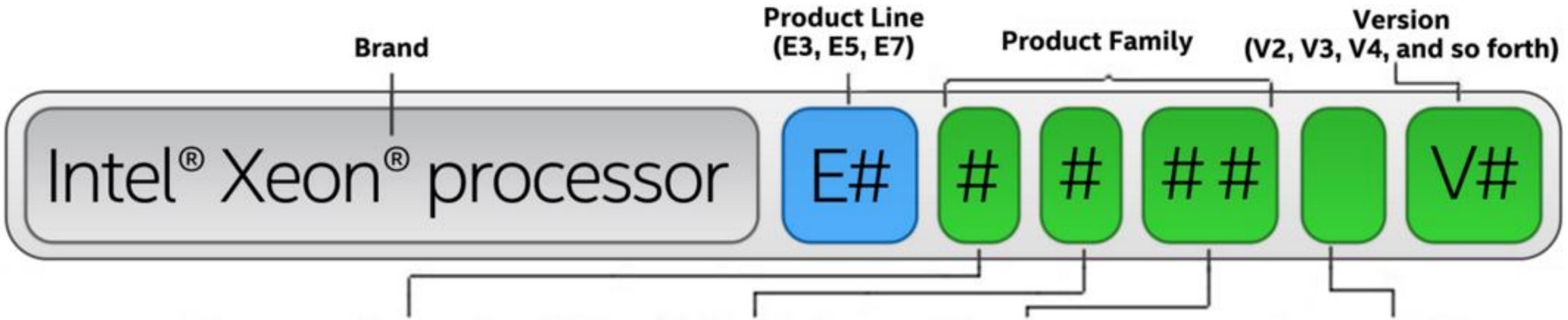
Support for ECC Memory (slower, more $$)

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

More L3 Cache (20MB – 45MB)

DDR4 RAM - Dual-channel RAM in E3 / Quad-channel in E5

Xeon Processors - Branding



Alpha Suffix	Description
L	Low power

[1] Socket type refers to socket capability—socket changes over time

Xeon E3-12xx v5 – Entry Level Workstation

Processor Name	Launch Date	Cores / Threads	Base Frequency	Max Turbo Frequency	L3 Cache	TDP	Bus Type	Price
E3-1230 v5	Q4'15	4 / 8	3.4 GHz	3.8 GHz	8 MB	80 W	DMI	$250.00
E3-1240 v5	Q4'15	4 / 8	3.5 GHz	3.9 GHz	8 MB	80 W	DMI	$282.00
E3-1270 v5	Q4'15	4 / 8	3.6 GHz	4 GHz	8 MB	80 W	DMI	$339.00
E3-1280 v5	Q4'15	4 / 8	3.7 GHz	4 GHz	8 MB	80 W	DMI	$612.00

Note: Compare the E3-1270 v5 @3.6GHz <= $339 => Skylake i7-6700K @ 4GHz

Xeon E5-16xx v4 Series – Mainstream Workstation

Processor Name	Launch Date	Cores / Threads	Processor Base Frequency	Max Turbo Frequency	L3 Cache	TDP	Price
E5-1620 v4	Q3'14	4 / 8	3.5 GHz	3.6 GHz	10 MB	140 W	$294
E5-1630 v4	Q3'14	4 / 8	3.7 GHz	3.8 GHz	10 MB	140 W	$406
E5-1650 v4	Q3'14	6 / 12	3.5 GHz	3.8 GHz	15 MB	140 W	$617
E5-1660 v4	Q3'14	8 / 16	3.2 GHz	3.8 GHz	20 MB	140 W	$1113
E5-1680 v4	Q3'14	8 / 16	3.4 GHz	4.0 GHz	20 MB	140 W	$1723

Note: E5-1650 v4 is **almost identical** to Broadwell E i7-6850K (6 cores, 15MB, 3.5 GHz)
E5-1660 v4 is **almost identical** to Broadwell E i7-6900K (8 cores, 20MB, 3.2 GHz)

Xeon E5-26xx v4 Series – Dual CPU Workstation

Processor Name	Launch Date	Cores / Threads	Processor Base Frequency	Max Turbo Frequency	L3 Cache	TDP	Price
E5-2637 v4	Q3'14	4 / 8	3.5 GHz	3.7 GHz	15 MB	135 W	$996
E5-2643 v4	Q3'14	6 / 12	3.4 GHz	3.7 GHz	20 MB	135 W	$1,552
E5-2667 v4	Q3'14	8 / 16	3.2 GHz	3.6 GHz	25 MB	135 W	$2,057

Note the CRAZY price jump from identical E5-16xx models:

E5-1650 v4 = 6 cores, 15MB, 3.5 GHz → **$617**

E5-2643 v4 = 6 cores, 20MB, 3.4 GHz → **$1,552**

IV System Memory

System Memory

DDR4 RAM is now less expensive and plentiful

Best bet: Purchase any new machine with 32GB. 64GB+ for Viz Wiz

Do not overpay for RAM upgrades from Dell / HP / XYZ-Corp.

16GB sticks still the best all-around buy today (2x16GB / 4x16GB / 8x16GB)

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

Physically different from DDR3

Higher densities up to 128GB DIMMs

Faster clock rates than DDR3

Lower voltages than DDR3 = Higher performance per Watt

Slow to get to market – Ultimately the CPU has to lead
(Skylake, Broadwell E, Xeon)

Not much faster than DDR3 (Applications are not memory-bound)

V Mass Storage

Solid State Drives (SSDs)

MUST HAVE FOR ALL MACHINES

Easiest way to improve performance

Prices falling to ~$0.70 GB; => $170 for 500GB SATA

Sweet spot = 500GB – 1TB

Performance is pretty consistent between SATA units

Research individual units carefully, read reviews

Expected lifespan: 2.5 PB of writes (50GB / day / 100+ years)

Say Hello to your New Little Friend

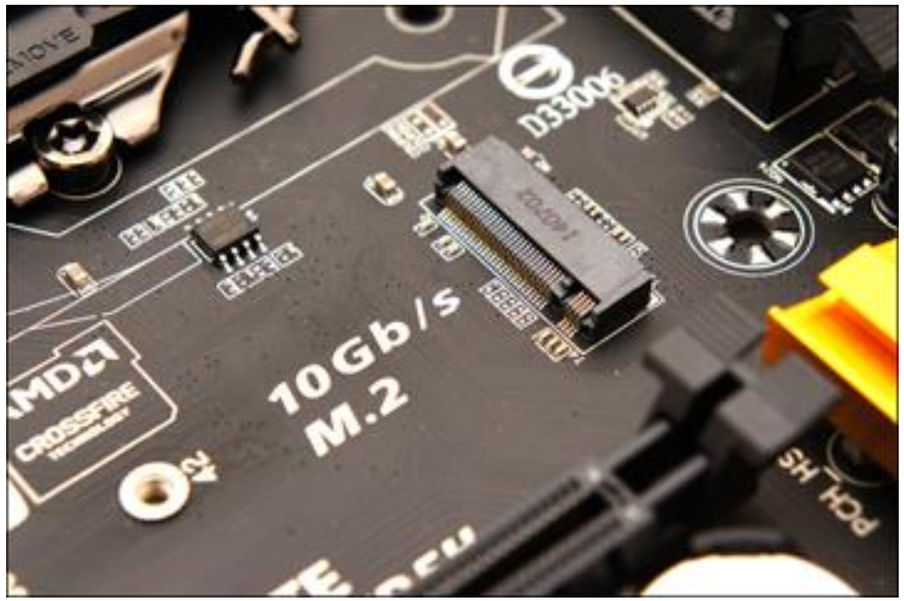
New 80mm M.2 form factor SSD

Small slot connector on motherboard

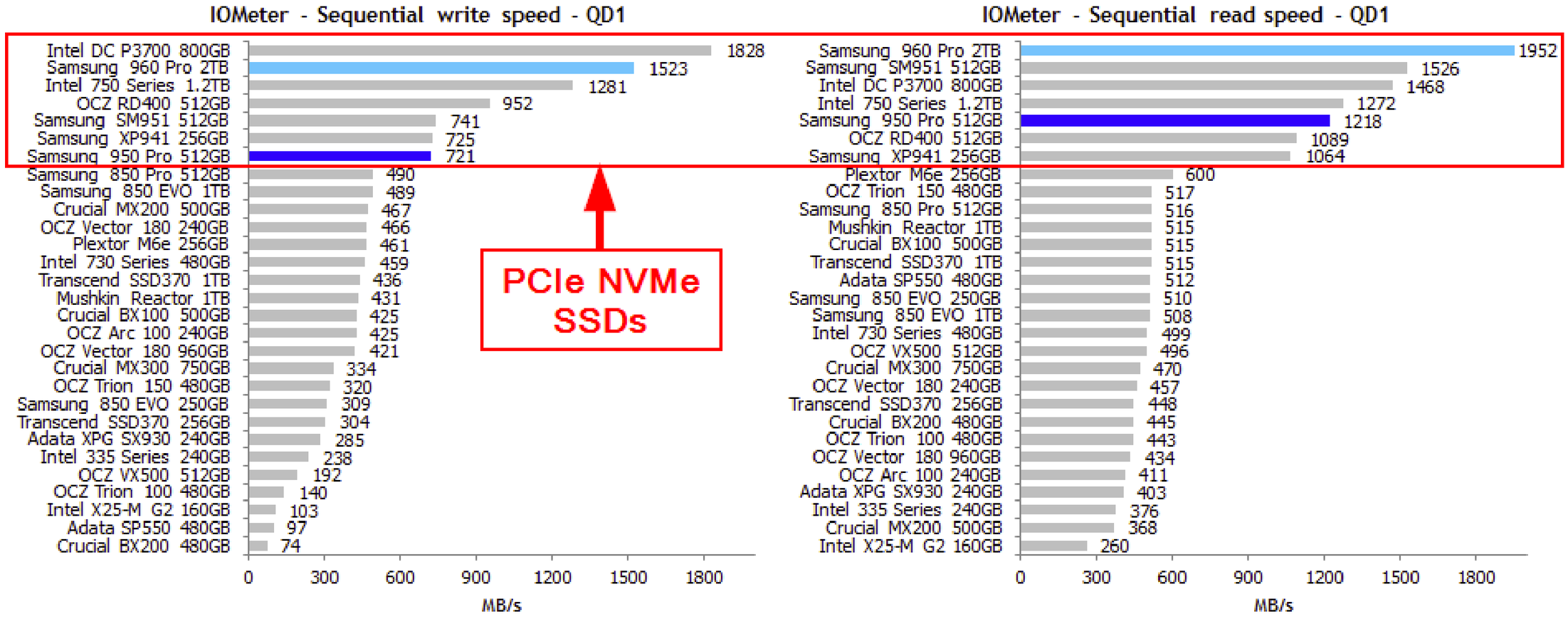
PCIe x4 interface replaces SATA

NVMe protocol replaces AHCI, optimized for solid state

Much faster than SATA



High-End SSD benchmarks



Benchmarks clearly show PCIe NVMe SSDs outperforming SATA

M.2 format is coming on strong, with more motherboard support

VI Graphics


HENDRICK'S
SMALL BATCH
HANDCRAFTED
HENDRICK'S
DISTILLED and BOTTLED IN SCOTLAND
DISTILLÉ et MIS EN BOUTEILLE EN ÉCOSSE
GIN
IMPORTED / IMPORTÉ
750mL
44%alc./vol.
EST. 1886

Graphics in Autodesk Applications

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

GPUs vs. CPUs

Fundamentally, CPUs and GPUs process tasks differently

CPUs have few cores that run very fast (4.0 GHz)

GPUs have massive numbers (2,000 - 3,000) of small, highly efficient cores

Designed to execute many concurrent threads more slowly

High-end GPUs are becoming specialized for compute-intensive, highly parallel general computation (GPGPU)

Graphics Explained: Direct3D / DirectX

Direct3D is the 3D API portion of DirectX, which is a whole set of APIs that covers handling multimedia on the Windows platform

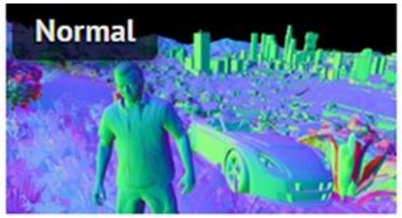
Direct3D was originally used for developing games for Windows and Xbox, has migrating to most CAD/CAM engineering applications

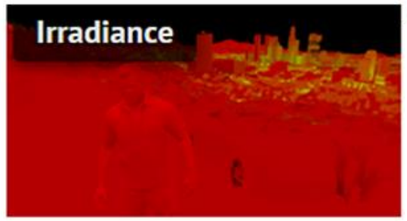
Replaced OpenGL as the graphics API of choice for all Autodesk apps

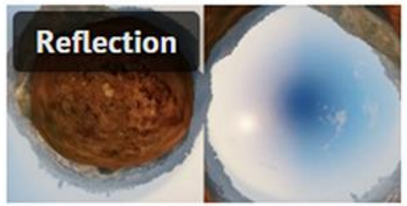
DirectX version is “somewhat” Windows version specific:

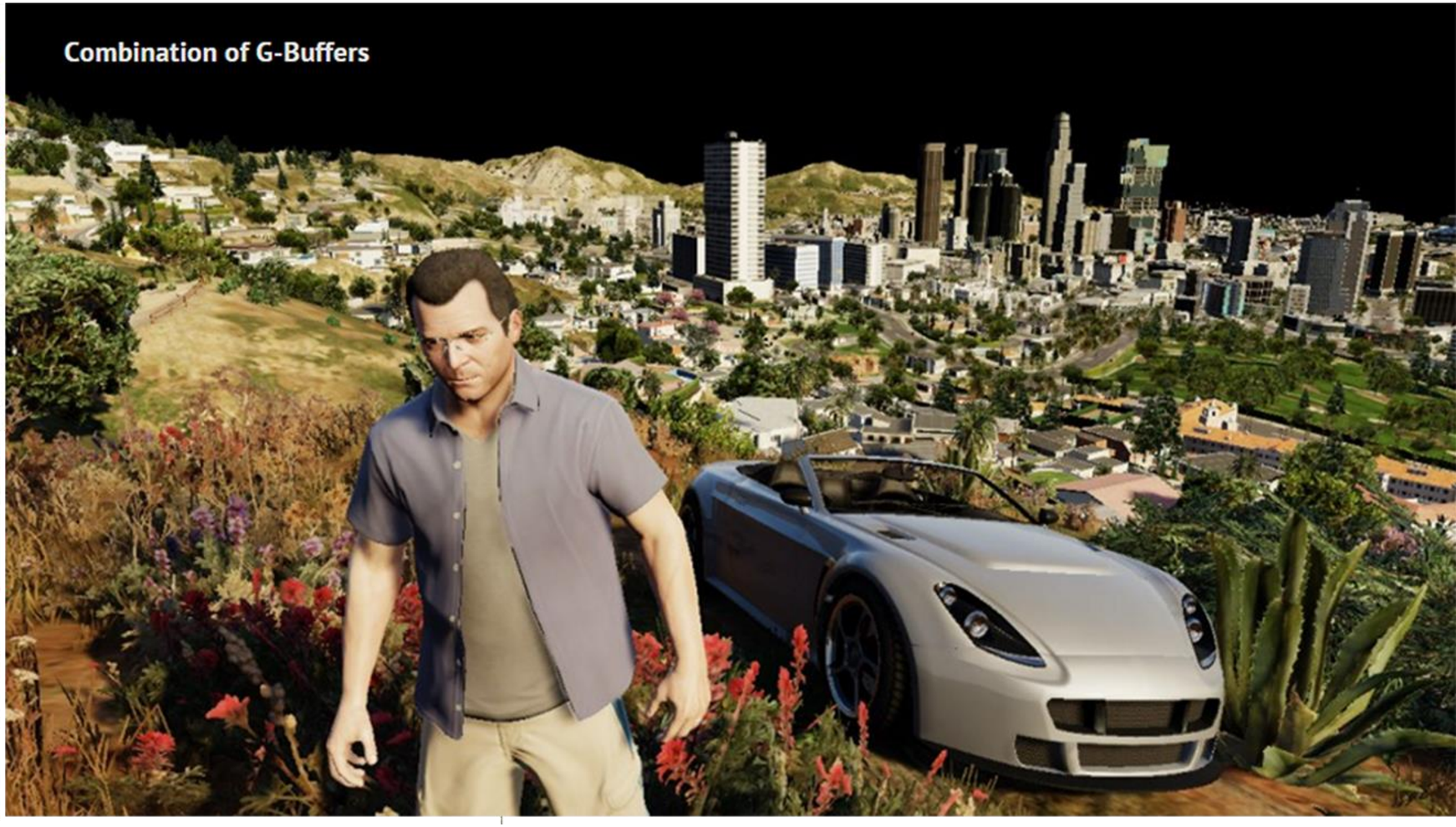
- DirectX 9 = Windows XP (XP will not run later DX versions)
- DirectX 10 = Windows Vista (can also run DX 11)
- DirectX 11 = Windows 7
- DirectX 11.1 = Windows 8, 8.1
- DirectX 12 = Windows 10 only. ***No other OS will run DirectX 12***.

Gaming and Shaders









Gaming and Shaders

GPUs operate using small programs called “Shaders”

Each shader takes in pixels or 3D geometry (vertex, edge, face)

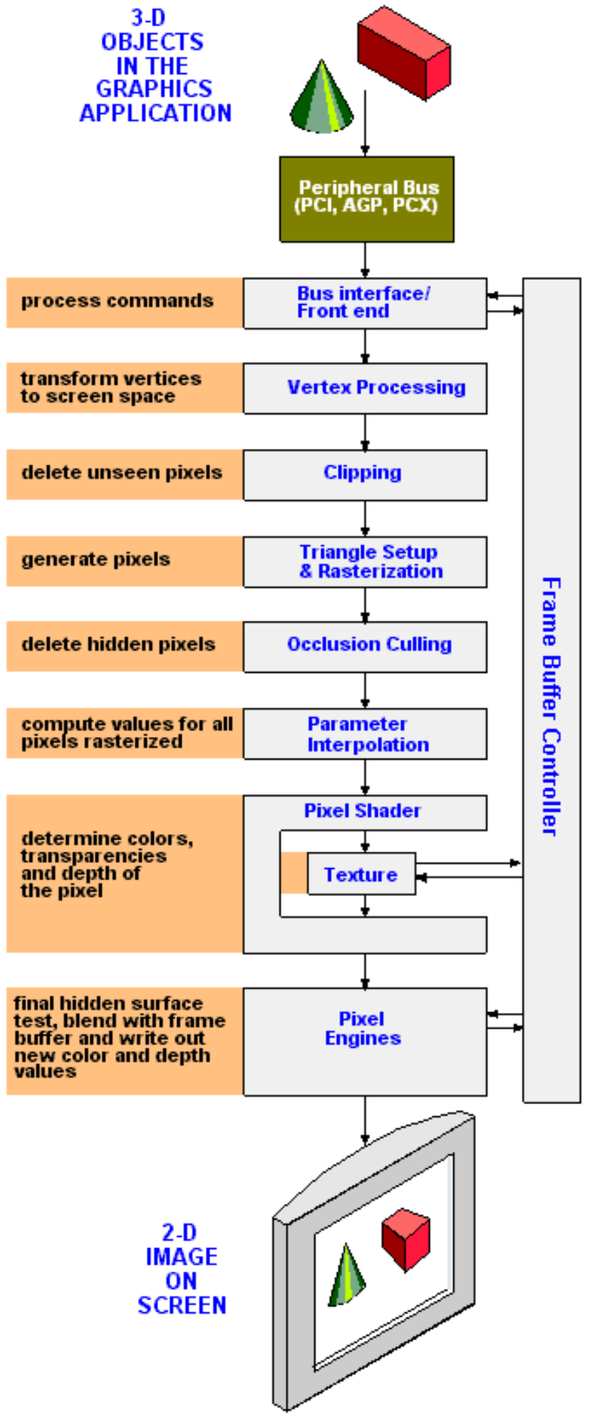
Does something to it

Returns the result for further shader processing

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

Shader Model is updated with each DirectX / Windows release

Windows 10 = Shader Model 5.0



Graphics in AEC Applications

In general: Any decent $250+ card will work in 90% of all cases

Exception: Iray GPU rendering requires specific features / mfr

AEC applications use DirectX 9 as a minimum

Will use features in DX11 → Any modern card will be fine.

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

** To a point

Rendering Engines in Autodesk Applications

Autodesk Raytracer (ART)

- Developed by Autodesk
- Replaces mental ray (developed by Nvidia, licensed by Autodesk)
- Fast, photorealistic, physically based renderer
- Included in 3ds Max, Revit, Inventor, Fusion 360
- Very simple - few dials / knobs / variables to deal with
- Implements image-based lighting, IES and photometric lights
- Uses “Physical Materials,” an advanced physically-based material design
- Supported by Backburner network rendering in 3ds Max
- 100% CPU-only; does not leverage graphics card at all

ART Rendering Engine in Autodesk 3ds Max

Rendering Engines in Autodesk Applications

Arnold

- Developed by Solid Angle SL headquartered in Madrid, Spain
- Purchased by Autodesk in 2015
- Strategy to remove licensing fees for 3rd party renderers (e.g. mental ray)
- Fast, photorealistic, physically based renderer
- Built into 3ds Max 2017, available as a free plugin for Maya
- Used in many movies – Pacific Rim, Guardians of the Galaxy, etc.
- Implements image-based lighting, IES and photometric lights, and more
- Supported by Backburner network rendering in 3ds Max
- 100% CPU-only; does not leverage graphics card at all

Arnold Rendering Engine in Autodesk 3ds Max

Rendering Engines in Autodesk Applications

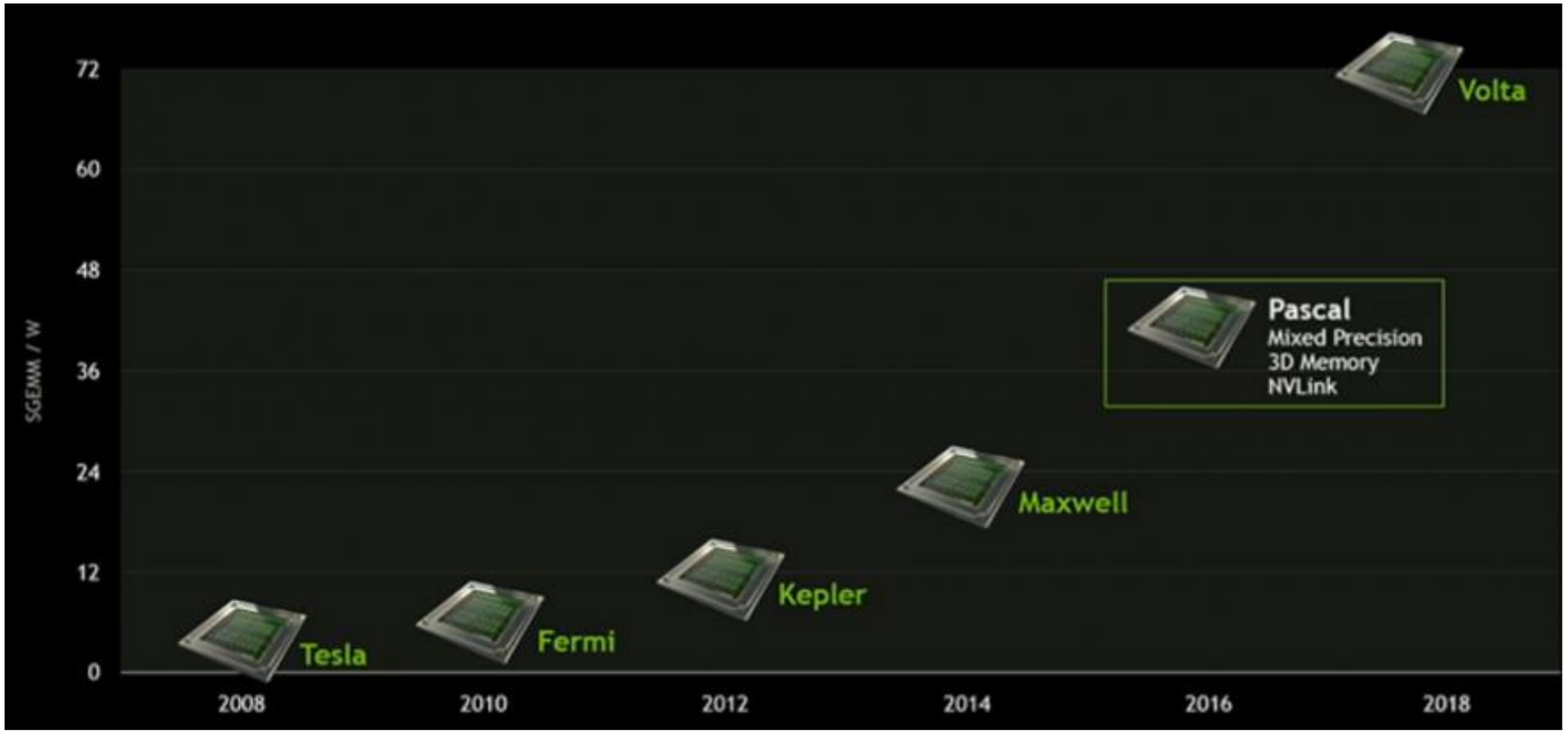
iRay™

- 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 Roadmap 2016 - 2018

Pascal: New architecture massively increases performance with Unified Memory, Nvlink, and smaller 16nm Process technology node



NVIDIA's Pascal Architecture

Design focus = Move to new 16nm FinFET process from 28nm HKMG

Extend and improve 2015's Maxwell architecture

Optimizes Streaming Multiprocessor (SM) units containing 128 CUDA cores

GPUs Up to 3,072 CUDA cores housed in 24 SM units

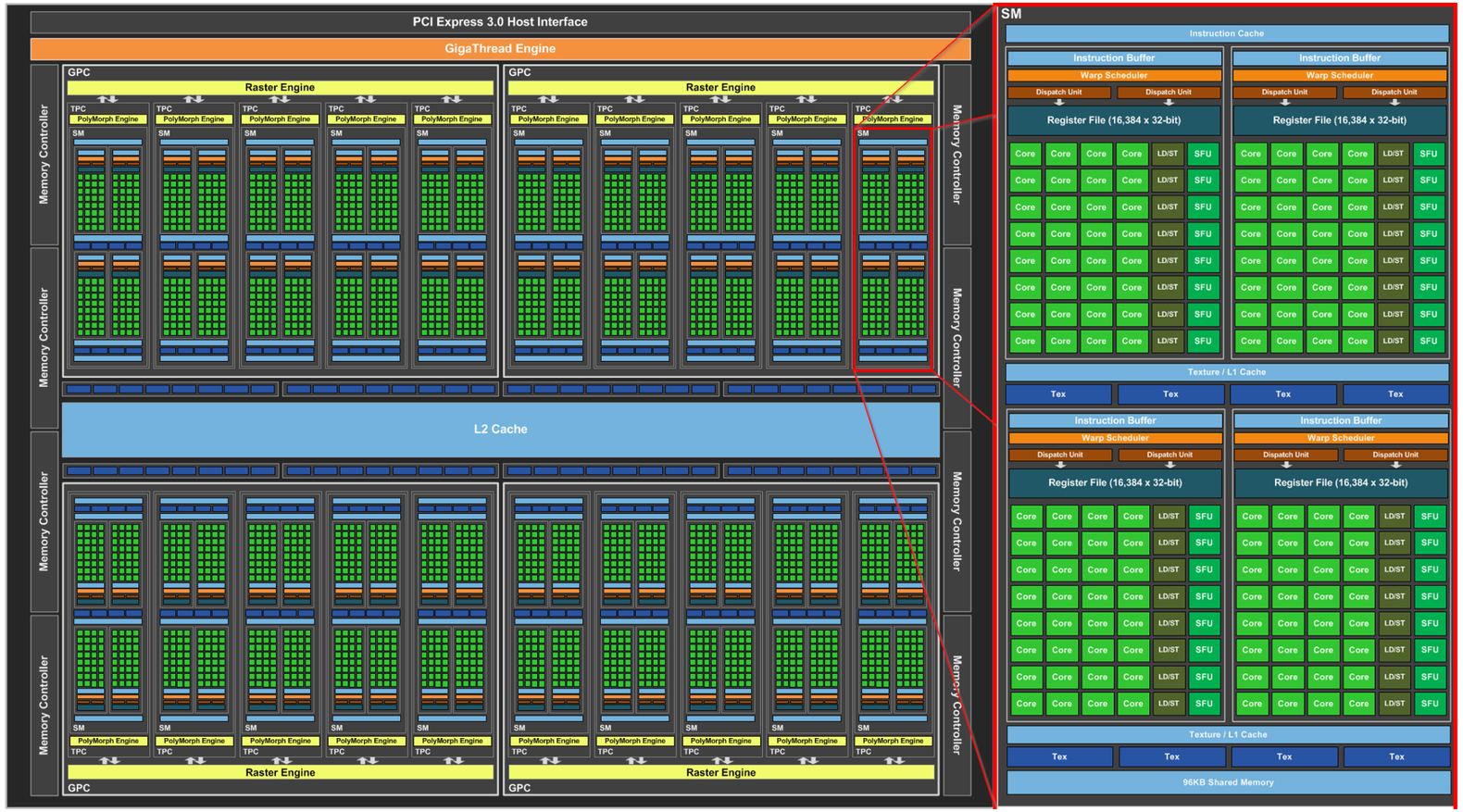
Today's GPUs:

- **GP100** in Tesla P100 = High Performance Computing (HPC)
- **GP102** in GTX Titan X = High end consumer (3,584 cores)
- **GP104** in GTX 1080 / GTX 1070 = Medium end (2,560 / 1920 cores)
- **GP106** in GTX 1060 (1,280 cores)
- **GP107** in GTX 1050 / 1050TI (640 / 768 cores)

G(raphics) **P**(ascal) **1**(st generation) **0 0..7** (Performance indicator high-low)

NVIDIA Pascal Architecture Up Close

GP104 GPU block diagram



4 Graphics Processing Clusters (GPC)

1GPC =
5 Streaming Multiprocessors (SM) =
20 Pascal SMs total

Each SM has:
- 128 CUDA cores (2,560 total)
- 256KB register file capacity
- 96KB shared memory unit
- 8 texture units (160 total)

NVIDIA GeForce GTX “Gaming” Class Cards

GeForce GTX TITAN X → GP102, 3,584 CUDA cores, 12GB, $1,200

GeForce GTX 1080 → GP104, 2560 CUDA cores, 12GB, $649

GeForce GTX 1070 → GP104, 1920 CUDA cores, 8GB, $429

GeForce GTX 1060 → GP106, 1280 CUDA cores, 6GB, $249

GeForce GTX 1050 Ti → GP107, 768 CUDA cores, 4GB, $140 (14nm process)

GeForce GTX 1050 → GP107, 640 CUDA cores, 2GB, $140 (14nm process)

GeForce GTX Features:

Designed for *aggressively strong performance in games.*

Higher core clock rates = run hotter than Quadro cards (this is OK with smaller process)

Drivers are ***not*** certified by Autodesk and cards are not sanctioned by Autodesk

Almost anyone can build a GTX card based on an Nvidia reference design

Manufacturer is responsible for quality control & warranty

NVIDIA Quadro workstation class cards

Quadro P6000 → GP102, 3840 CUDA cores, 24GB, $??

Quadro P5000 → GP104, 2560 CUDA cores, 12GB, $??

Quadro M6000 → GM200 (Maxwell), 3072 CUDA cores, 12GB, $5,999

Quadro M5000 → GM204 (Maxwell), 2048 CUDA cores, 8GB, $1,999

Quadro Features:

Designed for *solid* performance in Autodesk professional apps = **Stable**

Lower core clock rates = Can run 24/7/365 in data centers, 4U rackmount boxes

Drivers and cards are certified by Autodesk

Better manufacturing process = more quality control & NVIDIA warranty

Gaming vs. Workstation Cards for AEC

Gaming Cards – Nvidia GeForce GTX

All 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 Titan X, GTX 1080, GTX 1070

Cheap! If it doesn't work, sell it on eBay or CL

You can burn through five GTX 1080s before you touch the cost of a P6000.

Workstation Cards - Nvidia Quadro

Typically more stable drivers, certified by Autodesk

Note: This is no ***guarantee*** of stability in Autodesk applications

Possibly smoother viewport performance in all visual style modes (varies)

Unlocked firmware features like hardware anti-aliasing, Z-buffering, etc.

Insanely expensive for the performance

NVIDIA Pascal Graphics Card Lineup

	GTX Titan X	GTX 1080	GTX 1070	GTX 1060	Quadro P6000	Quadro P5000
GPU	GP102	GP104	GP104	GP106	GP102GL	GP104GL
CUDA Cores	3584	2560	1920	1280	3840	2560
SMs Enabled / Total	28/30	20/20	15/20	10/10	30/30	20/20
Core Clock (MHz)	1417	1607	1506	1506	1417	1607
Pixel Rate (GPixels/s)	136	102.8	96.4	72.3	136	102.8
Texture Rate (GT/s)	317.4	257.1	180.7	120.5	340	257.1
Single Precision (GFlops)	10157	8228	5783	3855	10883	8228
Memory Config	12GB GDDR5X	8GB GDDR5X	8GB GDDR5	6GB GDDR5	24GB GDDR5X	126GB GDDR5X
Memory Bus Width	384-bit	256-bit	256-bit	192-bit	384-bit	256-bit
Memory Bandwidth (GB/s)	480	320	256	192	480	320
TDP	250W	180W	150W	120W	250W	180W
DirectX/OpenGL/SM	12.0/4.5/5.1	12.0/4.5/5.1	12.0/4.5/5.1	12.0/4.5/5.1	12.0/4.5/5.1	12.0/4.5/5.1
Power Connectors	1x 6-pin + 1x 8-pin	1x 6-pin + 1x 8-pin	1x 6-pin + 1x 8-pin	1x 6-pin + 1x 8-pin	1x 6-pin + 1x 8-pin	1x 6-pin + 1x 8-pin
Outputs	1x DVI-D	1x DVI-I	1x DVI-I	1x DVI-I	1x DVI-D	1x DVI-D
	1x HDMI	1x HDMI	1x HDMI	1x HDMI	0x HDMI	0x HDMI
	3x DisplayPort	3x DisplayPort	3x DisplayPort	3x DisplayPort	4x DisplayPort	4x DisplayPort
Newegg Price (Nov. 2016)	$1,124.09	$649.00	$429.00	$249.00	?	?
Performance Ratio	100%	85%	72%	54%	100% +/-	85% +/-

Relative GPU Performance

Takeaways:

Pascal cards (in red) beat every other GPU architecture including AMD

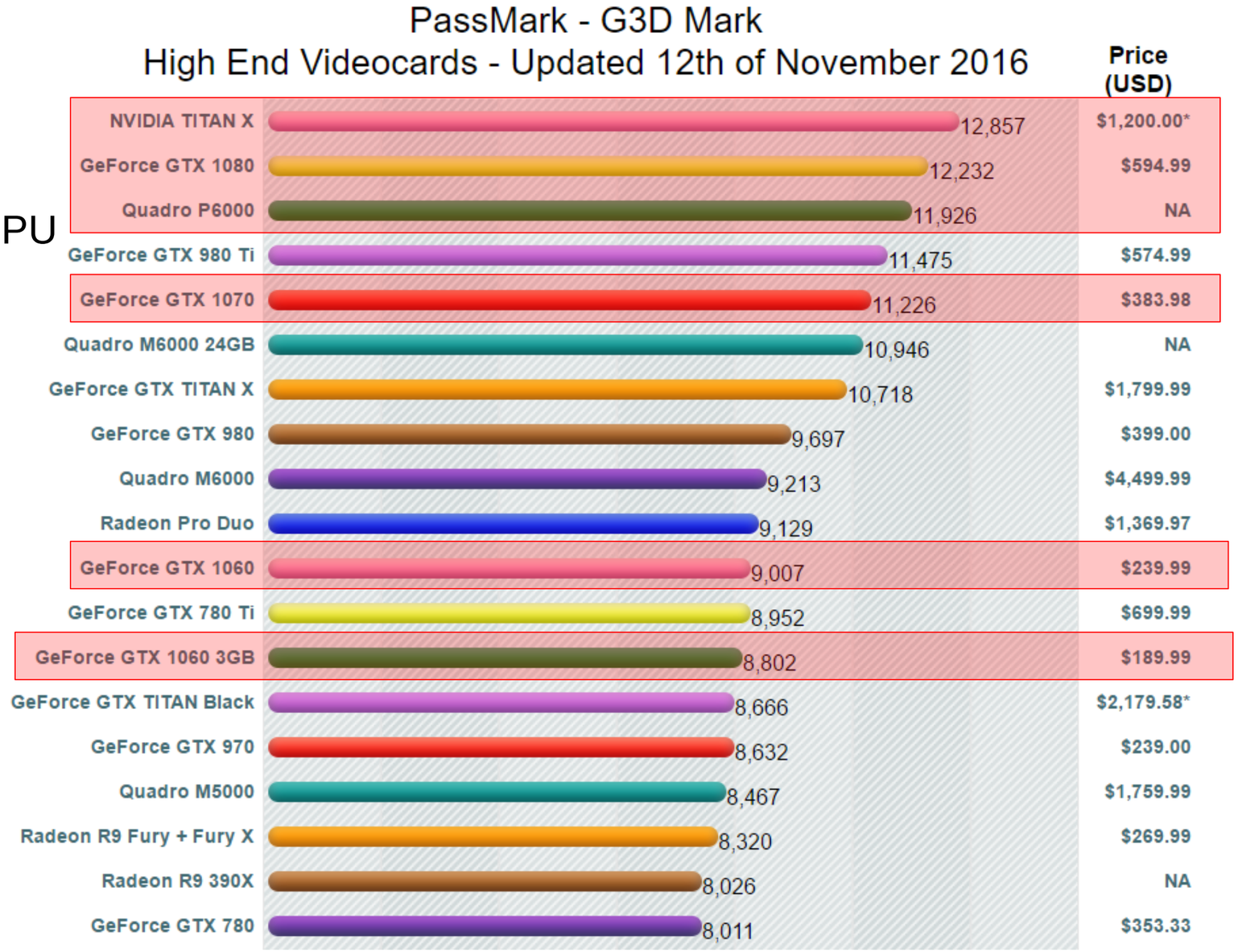
Titan X (GP102) beats out all others

GTX 1080 beats out the Quadro P6000

GTX 1070 is faster than last year's GTX 980 (top end gaming card)

GTX 980 Ti still a great card

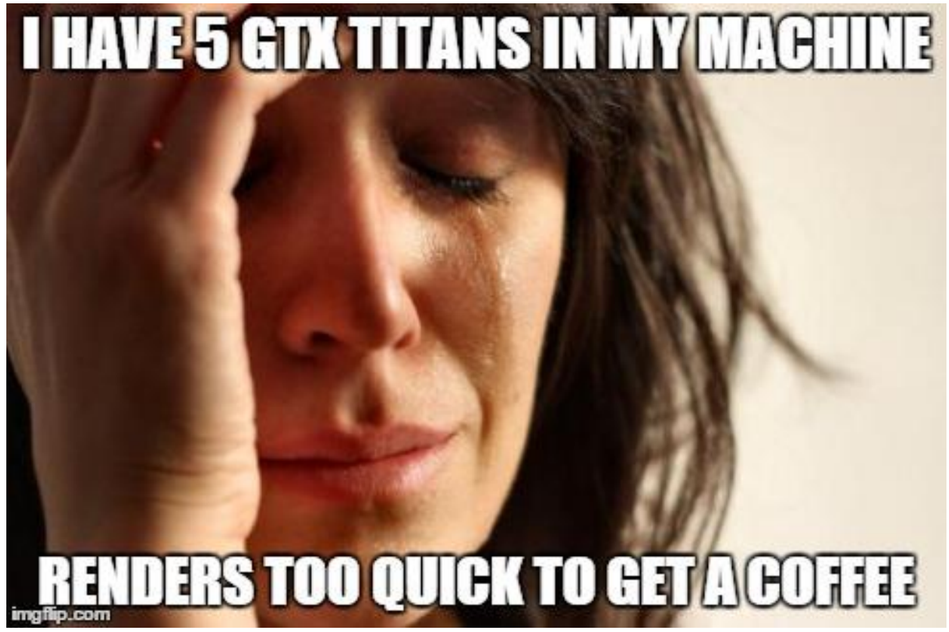
Quadro M6000/M5000 do very poorly

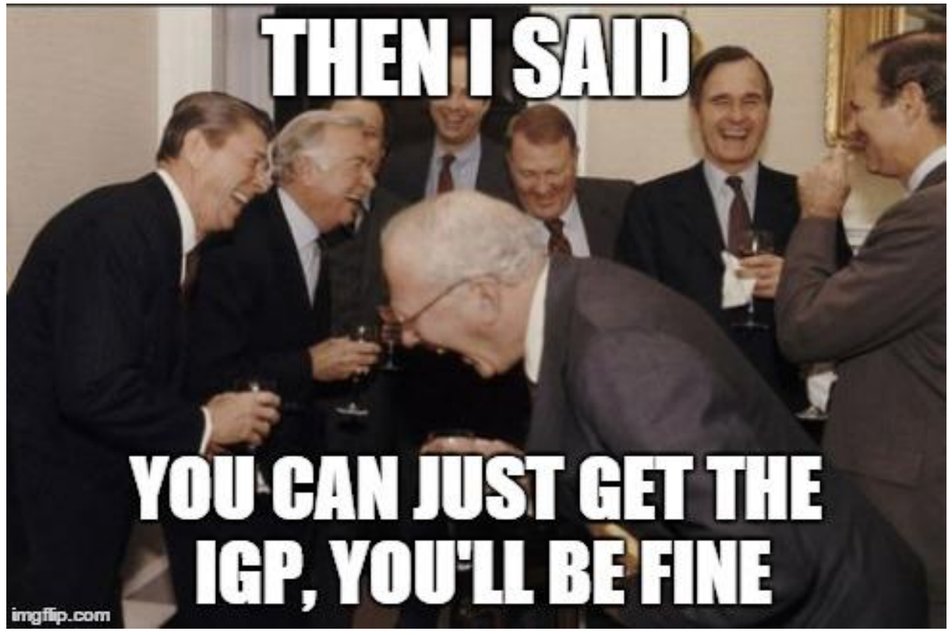


Best Buy Today: GTX 1070

- **GP104 GPU - Latest technology, almost full implementation**
- **1920 CUDA cores @ $429 = 4.47 Cores/$**
- **1506 MHz Core Clock**
- **1x DVI, 1x HDMI, 3x DisplayPort**
- **Compare to**
  GTX 1080 @ $629 = 3.94 Cores/$
  GTX Titan X @ $1,124 = 3.19 Cores/$


YOU NEED TO SPEND AT LEAST $1,200 ON A DECENT GRAPHICS CARD
BUT I RENDERED THIS IN 10 MINUTES ON A $400 CARD!
imgflip.com


I HAVE 5 GTX TITANS IN MY MACHINE
RENDERS TOO QUICK TO GET A COFFEE
imgflip.com


THEN I SAID
YOU CAN JUST GET THE IGP, YOU'LL BE FINE
imgflip.com

What about AMD?

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 AEC 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

7th Generation Kaby Lake Mobile CPUs

7th Generation Kaby Lake is primarily for Ultrabook / ultra low power machines
Includes 128MB eDRAM L4 cache for better performance

Processor Name	Cores / Threads	Base Frequency	Max Turbo Frequency	L3 Cache	TDP	IGP	Bulk Price
i7-7500U	2 / 4	2.7 GHz	3.5 GHz	4 MB	15 W	HD Graphics 620	$393.00
i7-7Y75	2 / 4	1.3 GHz	3.6 GHz	4 MB	4.5 W	HD Graphics 615	$393.00

6th Generation Skylake Mobile CPUs

6th Generation Skylake is primarily found in mainstream / high powered full size laptops
Q1’16 models include 128MB eDRAM L4 cache

Processor Name	Launch Date	Cores / Threads	Base Frequency	Max Turbo Frequency	L3 Cache	eDRAM	TDP	IGP	Bulk Price
i7-6700HQ	Q3’15	4 / 8	2.6 GHz	3.5 GHz	6 MB	-	45 W	HD Graphics 530	$378.00
I7-6770HQ	Q1’16	4 / 8	2.6 GHz	3.5 GHz	6 MB	128 MB	45 W	HD Graphics 580	$434.00
i7-6820HK	Q3’15	4 / 8	2.7 GHz	3.6 GHz	8 MB	-	45 W	HD Graphics 530	$378.00
i7-6820HQ	Q3’15	4 / 8	2.7 GHz	3.6 GHz	8 MB	-	45 W	HD Graphics 530	$378.00
i7-6870HQ	Q1’16	4 / 8	2.7 GHz	3.6 GHz	8 MB	128 MB	45 W	HD Graphics 580	$434.00
I7-6970HQ	Q1’16	4 / 8	2.8 GHz	3.7 GHz	8 MB	128 MB	45 W	HD Graphics 580	$623.00
i7-6920HQ	Q3’15	4 / 8	2.9 GHz	3.8 GHz	8 MB	-	45 W	HD Graphics 530	$568.00

Mobile Xeon CPUs

Mobile E3-15xx Xeons based on Skylake microarchitecture, found in mobile workstations
Newer models include 128MB of eDRAM L4 cache for better performance

Processor Name	Launch Date	Cores / Threads	Base Frequency	Max Turbo Frequency	L3 Cache	eDRAM	TDP	IGP	Bulk Price
E3-1505M	Q3'15	4 / 8	2.8 GHz	3.7 GHz	8 MB	-	45 W	HD Graphics P530	$434.00
E3-1535M	Q3'15	4 / 8	2.9 GHz	3.8 GHz	6 MB	-	45 W	HD Graphics P530	$434.00
E3-1515M	Q1'16	4 / 8	2.8 GHz	3.7 GHz	8 MB	128 MB	45 W	HD Iris Pro Graphics P580	$378.00
E3-1545M	Q1'16	4 / 8	2.9 GHz	3.8 GHz	8 MB	128 MB	45 W	HD Iris Pro Graphics P580	$378.00
E3-1575M	Q1'16	4 / 8	3.0 GHz	3.9 GHz	8 MB	128 MB	45 W	HD Iris Pro Graphics P580	$434.00

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 64GB w/4 DIMM slots

Storage: 500GB SSD minimum as C:\. Option: 1TB 7200RPM HD as D:\

Video: Ensure it has strong graphics, e.g. GTX 960M, Quadro M1000M/M2000M

Ports: Which ones, how many, where are they?

Keyboard: Backlit? Separate numeric pad? Multimedia keys?

Communications: 802.11n, WiGIG, Bluetooth

Docking Station – Get one if possible

Buying a Mobile Workstation - Thin is In

Dell Precision 15 5510

Apple Macbook Pro 13” & 15”

VIII Peripherals

Monitors, Keyboards, Mice

Monitors:

IPS panels in 24” 27” 30” (e.g. Dell U2410, U2717D, 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:

Look for Cherry MX switches for a solid mechanical feel

Colors – Red, brown, blue = varying feel, weights, etc.

Options: Wireless, multimedia keys, programmable F keys, 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

Buy It!

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

Purchasing Strategies – Hybrid Builds

- Most top tier vendors charge way too much for upgrades
- Example: Dell charges $250 for a 16GB upgrade
- You can get 16GB from Newegg for $78
- Solution: Purchase a base machine with minimum specifications and purchase upgrades from online vendors
- Newegg, Crucial.com, Amazon all have good reputations for handling returns and RMAs
- Purchase as much from one online store to minimize shipping costs

The Grunt Workstation: Dell T3620 Precision Workstation, Mini Tower		
Component	**Item**	**Price**
Processor	Intel Xeon E3-1270 v5 Quad-Core @ 3.6GHz	$2,013.34
Memory	32GB (2x16GB) DDR4 2133 Non-ECC	
Graphics	Nvidia Quadro NVS 315, 1GB	
Disk	M.2 512GB PCIe NVMe Class 40 Solid State Drive	
Power supply	365W Up to 92% Efficient Power Supply	
Keyboard	Dell KB216 Wired Keyboard Black	
Mouse	None (see below)	
Resource Disk	Windows 10 OS Recovery and Resource DVDs	
OS	Windows 10 Professional, 64-bit	
Warranty	3 Year Hardware Service with Onsite/In-Home Service after Remote Diagnosis	
Dell Subtotal		**$2,013.34**
Additional items purchased separately from Newegg.com		
Video Card	EVGA GeForce GTX 1070 w/8GB	$399.99
Monitors	Dell UltraSharp U2717D 27-inch Widescreen Flat Panel	$429.99
	Dell UltraSharp U2717D 27-inch Widescreen Flat Panel	$429.99
Mouse	Logitech MX Master Mouse	$69.99
Newegg Subtotal		**$1,329.96**
System Total		**$3,343.30**

The Grunt: Newegg		
Component	**Item**	**Price**
Case	Fractal Design Define R4 Black Silent Mid-Tower Computer Case	$109.99
Processor	Intel Core i7-6700K Skylake 4.0GHz LGA 1151 Processor	$339.99
Motherboard	ASUS Z170-P LGA 1151 motherboard	$109.99
Memory	Corsair Vengeance LPX 32GB (2 x 16GB) 288-Pin DDR4 SDRAM DDR4 2133	$167.99
Graphics	EVGA GeForce GTX 1070 w/8GB	$399.99
Storage	Samsung 960 Pro M.2 512GB Solid State Drive	$329.99
Power supply	Corsair AX Series AX 860 860W 80+ Platinum PSU	$169.99
Mouse	Logitech MX Master Mouse	$69.99
Keyboard	Logitech G610 Orion Red Mechanical Gaming Keyboard	$99.99
Monitors	Dell UltraSharp U2717D 27-inch Widescreen Flat Panel	$429.99
	Dell UltraSharp U2717D 27-inch Widescreen Flat Panel	$429.99
OS	Windows 10 Professional, 64-bit, OEM	$139.99
System Total		**$2,797.88**

The BIM Champ 6-Core Xeon: Dell Precision Tower 5810		
Component	**Item**	**Price**
Processor	Intel Xeon E5-1650 v4 6-Core @ 3.6GHz	$3,506.39
Memory	32GB (4x8GB) DDR4 2400 RDIMM ECC	
Graphics	Nvidia Quadro M4000 8GB card	
Storage	512GB 2.5" SATA Class 20 Solid State Drive	
Keyboard	Dell KB-216 Wired USB Keyboard Black	
OS	Windows 8.1 Professional, 64-bit, w/DVD Recovery	
Warranty	3 Year ProSupport with Next Business Day Onsite Service	
Chassis Option	Dell Precision Tower 5810 825W TPM, BW	
Resource Disk	Windows 10 64-Bit OS Recovery and Resource DVDs	
Dell Subtotal		**$3,506.39**
Additional items purchased separately from Newegg.com		
Video Card	EVGA GeForce GTX 1070 w/8GB	$399.99
Monitors	Dell UltraSharp U2717D 27-inch Widescreen Flat Panel	$429.99
	Dell UltraSharp U2717D 27-inch Widescreen Flat Panel	$429.99
Mouse	Logitech MX Master Mouse	$69.99
Newegg Subtotal		**$1,329.96**
System Total		**$4,836.35**

The BIM Champ 6-Core Broadwell E: Newegg		
Component	**Item**	**Price**
Case	Fractal Design Define R4 Black Silent Mid-Tower Computer Case	$109.99
Processor	Intel Core i7-6850K Broadwell E 6-Core 3.6 GHz	$609.99
Processor Cooler	Corsair Hydro H100i GTX Extreme Performance Water/Liquid CPU Cooler	$104.99
Motherboard	ASUS X99-E LGA 2011-v3 Motherboard	$209.00
Memory	Corsair Vengeance LPX 32GB (2 x 16GB) 288-Pin DDR4 SDRAM DDR4 2133	$167.99
Graphics	EVGA GeForce GTX 1070 w/8GB	$399.99
Storage	Samsung 960 Pro M.2 512GB Solid State Drive	$329.99
Power supply	Corsair AX Series AX 860 860W 80+ Platinum PSU	$169.99
Mouse	Logitech MX Master Wireless Mouse	$69.99
Keyboard	Logitech G610 Orion Red Mechanical Gaming Keyboard	$99.99
OS	Windows 10 Professional, 64-bit, OEM	$139.99
Monitor	Dell UltraSharp U2717D 27-inch Widescreen Flat Panel	$429.99
	Dell UltraSharp U2717D 27-inch Widescreen Flat Panel	$429.99
System Total		**$3,271.88**

The Viz Wiz 8-Core Xeon: Dell Precision Tower 7810		
Component	**Item**	**Price**
Processor	Intel Xeon E5-1660 v4 8-Core @ 3.2GHz	$5,880.72
Memory	64GB (4x16GB) DDR4 2400 RDIMM ECC	
Graphics	Nvidia Quadro M4000 8GB card	
	Nvidia Quadro M4000 8GB card	
Storage	512GB 2.5" SATA Class 20 Solid State Drive	
Keyboard	Dell KB-216 Wired USB Keyboard Black	
OS	Windows 10 Professional, 64-bit, w/DVD Recovery	
Warranty	3 Year ProSupport with Next Business Day Onsite Service	
Chassis Option	Dell Precision Tower 7810 825W, v2, BW	
Resource Disk	Windows 10 64-Bit OS Recovery and Resource DVDs	
Dell Subtotal		**$5,880.72**
Additional items purchased separately from Newegg.com		
Monitors	Dell UltraSharp U2717D 27-inch Widescreen Flat Panel	$429.99
	Dell UltraSharp U2717D 27-inch Widescreen Flat Panel	$429.99
Mouse	Logitech MX Master Mouse	$69.99
Newegg Subtotal		**$929.97**
System Total		**$6,810.69**

The Viz Wiz 8-Core Broadwell E: Newegg Edition		
Component	Item	Price
Case	Corsair Obsidian 750D Black Aluminum / Steel ATX Full Tower Computer Case	$149.99
Processor	Intel Core i7-6900K Broadwell E 8-Core 3.2 GHz	1,099.99
Processor Cooler	Corsair Hydro H100i GTX Extreme Performance Water/Liquid CPU Cooler	$104.99
Motherboard	ASRock X99 OC Formula/3.1 Extended ATX Intel Motherboard	$299.99
Memory	CORSAIR Dominator Platinum 64GB (4 x 16B) 288-Pin DDR4 SDRAM DDR4 3333 (PC4 26600) Memory Model CMD64GX4M4B3333C16	$499.99
Graphics	EVGA GeForce GTX 1070 w/8GB	$399.99
	EVGA GeForce GTX 1070 w/8GB	$399.99
	EVGA GeForce GTX 1070 w/8GB	$399.99
Storage	Samsung 960 Pro M.2 512GB Solid State Drive	$329.99
Power supply	CORSAIR AXi series AX1200i 1200W ATX12V 80 PLUS PLATINUM Power Supply	$309.99
Mouse	Logitech MX Master Mouse	$69.99
Keyboard	Logitech G610 Orion Red Mechanical Gaming Keyboard	$99.99
OS	Windows 10 Professional, 64-bit, OEM	$139.99
Monitor	Dell UltraSharp U2717D 27-inch Widescreen Flat Panel	$429.99
	Dell UltraSharp U2717D 27-inch Widescreen Flat Panel	$429.99
System Total		**$5,164.85**

Thank You!

Please fill out your evaluation forms online after class!

Please see me if you need the answers