Over-Clocked: Building & Testing Extreme Machines for Legal Technologists

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INTRODUCTION

Legal Technology professionals are often assigned projects with an "ASAP" deadline, and in those circumstances, speed and efficiency matter. Shaving time off of projects sometimes means the difference between making, or missing, a deadline. Considering that most tasks assigned to Legal Technologists involve waiting on computers to process, transfer, or handle data in some way, it's logical to assume that faster computers would mean less waiting, and consequently, faster results.

So it makes sense to compare the performance of high-end hardware to the standard equipment that firms typically assign their end users – even if only to satisfy a curiosity: how much faster is it? Many firms already spec up the hardware for Legal Technologists, but many others do not, opting instead to issue the same model of computer to all staff. This paper will explore the process of speccing, building, and testing an over-clocked computer against a typical, "standard-issue" computer that most firms assign to users. This paper isn't a comprehensive guide to building computers, nor is it a scientific comparison of hardware. Its purpose is to serve as a basic guide for choosing hardware and custom-building a computer, as well as to answer the question that Legal Technologists have often posed: "How much faster is that faster computer?"

Part 1 will explore the process of building an over-clocked computer – from research to Windows installation, driver / program installation, and over-clocking. Part 2 will compare a typical, firm-assigned desktop to this build. An unlocked CPU (Intel i7-6700K) was chosen for the test build, so its processor will be incrementally over-clocked for testing. It's important to understand that this is not an "apples-to-apples" comparison – different operating systems and hardware technologies between the "standard build" and "custom build" make it practically impossible to attribute performance differences to any particular piece(s) of hardware. These tests are simply rough comparisons of "latest and greatest" v. "standard issue." How much better is the best, and is it really worth it?

THE COMPUTERS

STANDARD, FIRM-ISSUED COMPUTER ("STANDARD BUILD")

Model:	Dell Optiplex 9010
Operating System:	Windows 7 Professional 64-bit
CPU:	Intel i7-3770 3.4GHz LGA 1155
Memory:	SK Hynix DDR3 1600 8GB (4GB x 2) (HMT351U6CFR8C-PB)
Graphics card:	AMD Radeon HD 7470 [Dell]
Hard drive – OS:	Samsung 850 Pro 128GB (MZ-7KE128BW)
Hard drive – data:	WD Black Performance Hard Drive 500GB (WD5000LPLX)

OVER-CLOCKED, CUSTOM BUILD ("CUSTOM BUILD")

Operating System:	Windows 10 Professional 64-bit
Motherboard:	Asrock Z170 OC Formula LGA 1151*

CPU:	Intel i7-6700K 4.0GHz LGA 1151
CPU cooler:	Corsair H100i*
Memory:	G.SKILL Ripjaws V Series DDR4 2400 16GB (8GB x 2) (FA-2400C15D-16GVR)
Graphics card:	Galaxy GeForce GTX 670 GC 4GB (67NQH6DN6KXZ)*
Hard drive – OS:	Samsung 960 EVO M.2 250GB (MZ-V6E250BW)
Hard drive – data:	Samsung 750 EVO 500GB (MZ-750500BW)
PSU:	Corsair HX750 80 PLUS GOLD
Case:	Corsair 600Q Black*

**Best opportunities for cost-savings: weigh features, performance needs, and price.*

PART 1: PUTTING IT ALL TOGETHER

There are many excellent guides for building computers on the Internet, like these:

How to Build A PC (Tom's Hardware):
http://www.tomshardware.com/reviews/build-your-own-pc,2601.html

Beginner's Guide: How to Build a Computer (JayzTwoCents):
https://www.youtube.com/watch?v=k1Q8ksRI1Eo

A Beginner's Guide to Building a PC from Scratch (Digital Trends):
http://www.digitaltrends.com/computing/how-to-build-a-computer/

But building a computer is the easiest part of the process. Doing research and deciding which parts to choose for your build are the hardest – there are many different choices for every component, and some parts are incompatible with others. Always do diligent research to ensure an "uneventful" build. Expect to spend a lot more time reading about, searching for, and pricing out the hardware than building. If you want to shortcut the research process altogether and go with tested components, then Google "completed build [CPU MODEL]" to find a suitable parts list.

HARDWARE RESEARCH

1. Research / select a CPU.
    a. There are many sites on the Internet with CPU reviews and testing. If you have a specific use in mind, search "best CPU for…," and find some help.
        i. If you are interested in Intel CPUs, start here: http://www.intel.com/content/www/us/en/products/processors/core.html.
        ii. If you are interested in AMD CPUs, start here: http://www.amd.com/en/products/desktops.
    b. Navigate to the product page for your selected CPU, and identify which motherboards are compatible – choose from this list. This build uses an Intel CPU (i7-6700K): http://processormatch.intel.com/.
        i. For best results, follow the manufacturer's recommendations.
2. Research / select a motherboard.
    a. Choice of motherboard comes down to cost v. features (chipset, number / type of ports, quality, etc.). There are many choices, and like CPUs, there are many Internet resources

comparing different boards and chipsets. Take your time, and do the reading. Motherboards with a "Z" prefix allow over-clocking.

   b. Once you've selected a motherboard, visit the manufacturer's site and identify which memory (RAM) and hard drives (if using PCIe / M.2 SSDs) are compatible. Most board manufacturers publish memory and storage support lists – this build uses the Asrock Z170 OC Formula: http://www.asrock.com/mb/Intel/Z170%20OC%20Formula/.
      i. For best results, follow the manufacturer's recommendations.
      ii. Note that almost every 2.5" SSDs and 3.5" HDDs will work with almost every motherboard. Be more selective and follow the manufacturer's recommendations when choosing a newer hard drive technology (like PCIe / M.2).

3. Research / select RAM.
   a. Note that more RAM is not always better, but too little RAM may be bad. 16GB is a good start for just about anything. Consider using more if building a machine for digital imaging / video applications.
   b. Some motherboards support over-clocked RAM. Faster RAM is beneficial in many use case scenarios, but it can also be pricey. Balance your RAM selection on speed requirements, size (GB), and price. Be sure to select RAM based on the motherboard manufacturer's recommendation.
4. Research / select a CPU cooler.
   a. Over-clocked CPUs require high-performance cooling. Like every other component, there are many options, but keep in mind that CPU cooler selection may affect your computer case and / or memory (RAM) selection: some coolers can only be mounted without modification(s) in larger cases, and some extend over the RAM slots. It's a good idea to research motherboard / RAM / CPU cooler combinations on the Internet to determine if a particular cooler will cause a problem with a particular brand / model of RAM.
   b. There are two types of CPU coolers: air and water cooled. Air coolers are good for most computers with mild over-clocks (up to 4.2-4.4GHz), but you'll need a water cooler to manage temperatures on mid-to-high over-clocks (4.4GHZ and up). In general, air coolers are less expensive than water coolers.
5. Research / select a case.
   a. Match the motherboard size and CPU cooler with a case. This build uses an ATX motherboard and a Corsair H100i CPU cooler – here are some good resources for determining case compatibility with this cooler:
      i. *Case Compatibility Thread* (Mattyd893): http://www.overclock.net/t/1144409/h80-h80i-h90-h100-h100i-h110-case-compatibility-thread-page-1-for-full-listings
      ii. *Corsair Hydro Series CPU Cooler Decoder Ring and Case Compatibility Chart* (Corsair): http://www.corsair.com/en-us/blog/2015/april/corsair-hydro-series-cpu-cooler-decoder-ring-and-case-compatibility-chart

   b. Consider airflow, noise levels (some cases are quieter than others), features, and size when selecting a case. This build uses a Corsair 600Q: http://www.corsair.com/en-us/carbide-series-quiet-600q-inverse-atx-full-tower-case.
6. Research / select a power supply.
   a. Be sure to select a power supply with enough punch to power your build. There are several excellent resources online, like these:
      i. *Cooler Master Power Supply Calculator* (Cooler Master): http://www.coolermaster.com/power-supply-calculator/
      ii. *Power Supply Calculator*: http://powersupplycalculator.net/
   b. Select a high-end power supply if your build will be over-clocked – they have better components and last longer. Power supplies of different wattages come in grades: 80 Plus, 80 Plus Bronze, 80 Plus Silver, 80 Plus Gold, 80 Plus Platinum, and 80 Plus Titanium. It's best to use Gold-, Platinum-, or Titanium-rated power supplies when over-clocking, and it's best to have more wattage than needed. Use the online power supply calculators to find a good match.
7. Research / select hard drives.
   a. In order of increasing performance: HDD < SSD < PCIe / M.2.
      i. Note that only certain motherboards support PCIe / M.2 drives. If you want to use these ultra-high-performance drives, be sure to select a motherboard that supports them.
   b. Always use SSD for the "C" drive and active data drives. HDDs are best for high volume, archival storage. M.2 drives are incredibly fast, but they are only compatible with a limited set of motherboards at present.
8. Research / select a graphics card.
   a. Or not. Many CPUs have graphics capabilities built-in, but expect a dip in performance if using the CPU for graphics.
   b. Premium graphics cards should be considered when using programs that utilize graphics card architectures and processing power, like image / video editing, animation suites, password cracking programs, etc. If the build is intended for processing power alone, any graphics card will do. Check the internet for reviews, testing, and editorials before purchasing. The price range on graphics cards is from cheap and effective to very expensive and "wow!"

THE BUILD

There's a lot of debate on the best strategy for building a computer, and there are two general approaches. Some assemble hardware outside of the case and test it prior to bolting it down. This is a reasonable approach, and it makes a lot of sense, but others install everything in the case before testing. Defective hardware happens, so there's always a chance that something will have to be unassembled / uninstalled at some point. This build was assembled directly into the case. Changing out hardware can be tedious, but it's generally not a big deal, and it doesn't happen that often.

PREPARE THE CASE

Unpack the case, gather up all the parts, and read the manual. Be sure to use the screws that came with your case – these are designed for, and matched with, it (one exception: mount the power supply using the screws that came with it).

INSTALL THE MOTHERBOARD

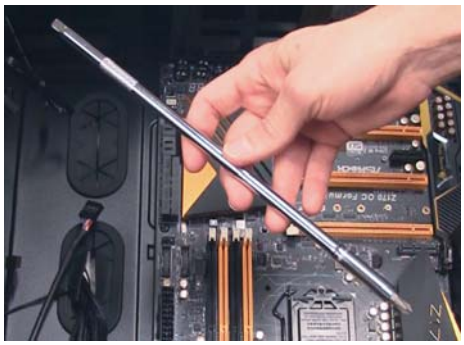
Read the manual.

Check to ensure that all required motherboard posts are installed in the case. Some cases ship with the posts pre-installed for ATX boards, and others provide them un-installed. It's a best practice to confirm that all posts are equally snug before installing the motherboard.

Install the motherboard backplate. Take time to install it in the correct orientation.

Install the motherboard – *carefully*. Line up the motherboard to the backplate, and carefully lower it onto the posts. Avoid scratching the upper or lower surfaces – take your time.

Tighten down the motherboard screws gently, but firmly – do not overtighten. It may be useful to use a handle-less screw driver to prevent over-zealous seating, like this:



Handle-less screw driver limits torque.

INSTALL THE CPU

Remove the CPU socket cover from the motherboard (refer to the motherboard manual for more information).

Take care not to touch the pins on the underside of the CPU. Remove it from its packaging with two fingers, and install it in the motherboard socket. CPUs cannot be installed in the wrong orientation – match the arrow on the CPU to the arrow on the socket, and match the socket guides to the slots on the CPU (refer to the motherboard manual for more information).

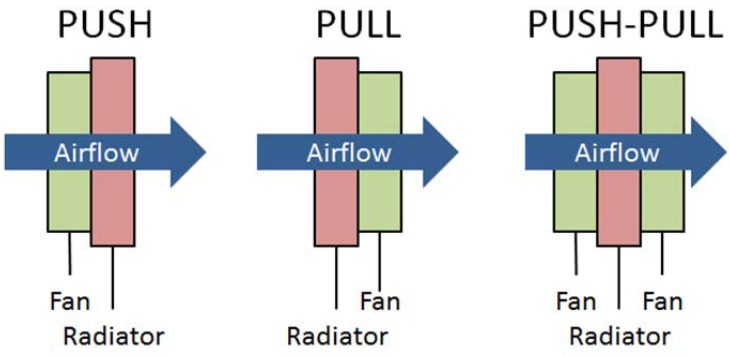
Fasten down the CPU bracket. There are often strange cracking and straining noises when securing the CPU – this is normal. Some require a lot of force. Take care to align and lower the fastening bracket according to the instructions in the motherboard manual.

INSTALL THE CPU COOLER

Unpack the CPU cooler, and prepare it for installation. Depending on the model, this may take some time. For best results, follow the manual exactly. Air-cooled CPU coolers are generally smaller and easier to install, but the hassle of configuring and mounting liquid coolers is more than made up in cooling performance.

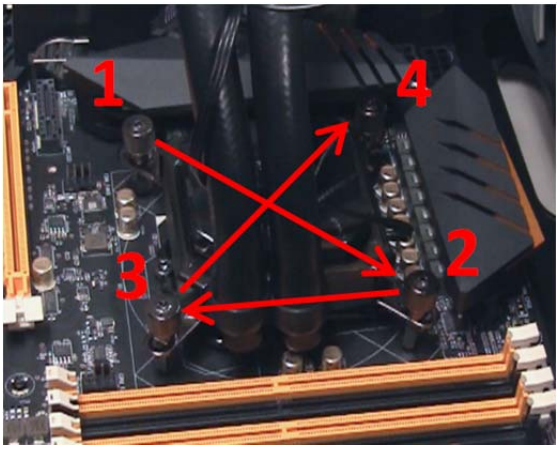
This build uses a Corsair H100i, so it is necessary to consider overall case cooling strategy before installation. There are many airflow strategies for cooler radiators, ranging from two to four fans in "push," "pull," and "push-pull" configurations. More on this here:

Testing: How much do fan configs matter? Push vs Pull vs Push/Pull (JayzTwoCents): https://www.youtube.com/watch?v=IJmE13sG9PI)



It is generally best to expel warm air from the case, so most builders vent air out of the case through the radiator. This build uses fans in a "push" configuration – exhausting air through the radiator and out the bottom of the case (more on case cooling strategies later).

Install the CPU cooler on the CPU. Always read the manual, and take time to ensure proper seating. Tighten down the cooler on the CPU in a diagonal pattern in small increments, like this:



Diagonal pattern encourages proper seating.

It is tedious to reseat an improperly installed CPU cooler, but it happens. Refer to this guide on thermal paste application when reseating:

Thermal Paste Application Methods – Which one is best? – The Workshop (LinusTechTips): https://www.youtube.com/watch?v=r2MEAnZ3swQ

INSTALL THE RAM

Refer to the motherboard manual, and install the RAM gently, but firmly. Fully seat each stick and secure with the retention clip(s). If using only two sticks, be sure to consult the manual and install into the correct slots.

INSTALL THE POWER SUPPLY

Unpack the power supply, gather up all the parts and cables, and read the manual. Secure the power supply to the case using the screws that came with it. If you selected a modular power supply, use only the cables you need to power all of your hardware – this will keep your build clean.

INSTALL THE "C" DRIVE

Install the hard drive in the case. If using a PCIe / M.2 SSD drive, refer to the motherboard manual for proper installation. Use a SATA3 port when using a 2.5" SSD – it's the fastest connection for that type of drive (use the port with ID: SATA0). Always use an SSD for the operating system.

Many argue it's a best practice to install additional drives after the operating system has been loaded. This simply eliminates the possibility that Windows will be installed on the wrong drive.

After Windows has been loaded, install the other hard drives. Use SATA3 ports for all drives, or when the board has a limited number, prioritize SATA3 ports for the fastest drives.

INSTALL THE GRAPHICS CARD

If installing a graphics card, use the top PCIe slot (closest to the CPU) for best performance. Ensure the graphics card lock engages on the PCIe slot upon insertion, and secure the device to the case with the provided thumb screws.

CONNECT ALL THE CABLES

Refer to the motherboard, case, power supply, graphics card, CPU cooler, and other manuals to ensure all cables and power connections are properly connected. It is best to keep cables organized and zip-tied to improve airflow in the case. Expect to spend some time working out the best routes for cables.

Be sure to gently, but firmly, seat power supply connectors to the motherboard, graphics card, and other peripherals.

Ensure that the CPU cooler is connected to the "CPU Fan" connector on the motherboard.

CASE COOLING STRATEGY

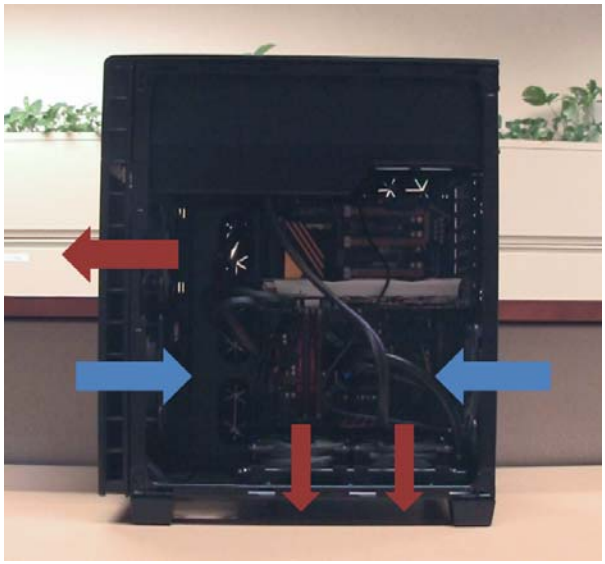
There are two considerations when deciding on case and component cooling strategy: airflow and dust control. An excellent discussion is here:

Case Flow and Pressure Demonstration – How to balance airflow (JayzTwoCents):
https://www.youtube.com/watch?v=a12aDCxrcts

The higher the air flow, the cooler your case and components will be. Use high-flow fans on the case, and use high static pressure fans on the CPU heat sink / radiator. If your case or CPU cooler comes with fans, use those, otherwise, purchase the correct fan for the correct application. Study your case and determine if additional fans are required.

Dust control is achieved by having a greater air inflow than outflow. This creates positive pressure on the inside of the case (more air is entering than leaving), and most dust will settle outside of the case as a result. Positive pressure strategies mean longer intervals between "deep" cleanings but require more frequent cleanings of fan intakes and vents. Keep fan intakes and vents clean to ensure consistent airflow.

Adjust or install case fans as necessary to achieve maximum airflow and positive pressure. Airflow direction is indicated on many fans with an arrow – if no indicators are present, check online (search "[MODEL #] airflow direction") to determine airflow direction.



Overall airflow strategy for custom build.

HARDWARE CHECK

Once all the plugs and pieces are connected, power up the computer and boot into the BIOS ("DELETE" key for most motherboards). Here's an excellent, but lengthy, post-build guide:

First 5 Things to Do with a New PC Build (Paul's Hardware)
https://www.youtube.com/watch?v=LbpqkiaO7q4&t=892s.

On first boot, this build proved problematic, as CPU temperatures in the BIOS registered in the mid-80sC. Out of an abundance of caution, the CPU cooler was reseated. Second boot yielded CPU temps in the mid-70sC, which is better, but still not acceptable. A quick search online showed several users with

the same issue – most pointed to the BIOS as the problem. This particular motherboard shipped with BIOS v.1.50, and the motherboard support page showed the current BIOS as v.7.40. After updating the BIOS (refer to the motherboard manual for more information), the third boot yielded CPU temps in the low 30sC, which is acceptable.

Check that all installed components are registered in the BIOS, load “default settings,” and then restart.

INSTALLING SOFTWARE & DRIVERS

Windows 10 is much easier to install than previous operating systems. Boot to the Windows installation drive and install. Note that M.2 drives may require manual partitioning – this can be done in the Windows setup process when selecting the installation drive (click "New" and set partition to maximum size). You may get an error that the M.2 drive can't be partitioned if you don't do this.

After installing Windows, it’s time to install drivers and software. Many argue it isn’t necessary to install motherboard drivers unless there are alerts in Device Manager (exclamation points or question marks). But others argue it is best practice to install the drivers provided by the motherboard manufacturer even if there are no obvious issues with the drivers installed by Windows. There’s also debate on many online forums about the installation order / need for motherboard drivers, and that discussion is well outside the scope of this project. Programs and drivers were installed on this build as follows:

1. Windows 10 Pro 64-bit
2. HWiNFO64
    (a) Double-check temperatures on CPU, motherboard, graphics card, etc. before continuing.
3. Run Windows Update
4. Hardware drivers (download and install)
    (a) Motherboard
        (i) INF (chipset)
        (ii) SATA3
        (iii) Intel Rapid Storage Technology
        (iv) LAN (device drivers only)
        (v) IME
    (b) Graphics card
        (i) NVIDIA
5. Install Malwarebytes (anti-malware)
6. Install Asrock Formula Drive (for simple over-clocking)
7. Install Office 2010
8. Run Windows Update
9. Install NovaBench (benchmark software)
    (a) Install .NET Framework 3.5
    (b) Run Windows Update
10. Install MSI Afterburner (for graphics card fan control and other)
11. Install FTK Imager
12. Install 7-Zip

INSTALL & CONFIGURE DATA DRIVES

After loading drivers and programs, install additional hard drives and configure in Disk Management. As before, use the fastest connections available.

APPLY XMP SETTINGS TO RAM

Default settings on motherboards clock all DDR4 memory at 2133MHz. If faster memory was selected for your build – in this case, 2400MHz – it's necessary to configure it in the BIOS to run at rated speeds and timings. Called XMP Profiles, these settings make RAM tuning easy. More information is here:

XMP Memory Profiles as Fast As Possible (Techquickie):
https://www.youtube.com/watch?v=vc8G5_sW8lk

Set your RAM to "XMP Profile 1" in the BIOS. The Z170 OC Formula motherboard used in this build has a physical switch that auto-loads the XMP settings – in such a case, simply toggle it on.

OVER-CLOCK THE CPU

It is important to note that over-clocking can destroy your CPU slowly, or very quickly, if you don't properly manage voltage and temperature. Over-clocking means running the CPU at a higher frequency than stock, and that generally requires more energy in the form of increased voltage (Vcore). Simply put, the extra voltage keeps the CPU stable at higher frequencies, but it also increases operating temperature. Over-clocking is an exercise of balance between higher speeds and cooling capacity, and every CPU has a unique "sweet spot" – a nice balance between higher clocks and higher temperatures. Some CPUs run a lot cooler or require much lower voltage than others at different frequencies – many call this the "silicon lottery." Some win, and some don't, and the losers have to settle for a lower over-clock. CPU cooler selection can play a very large role in determining over-clock scenarios for any particular processor. Water coolers are required for high over-clocks (generally, 4.4-4.6GHz and above).

For almost every CPU on the market, 70C is a generally accepted target for full power stress tests. 1.34-1.35V is a generally accepted target for maximum Vcore on the i7-6700K for long-term use – other CPUs will vary, depending on their architecture.

Do the research and find recommended strategies (including optimal voltages and temperatures) for over-clocking and stress testing your CPU – monitor temperature and voltages closely using HWiNFO64 or a similar program. There are a lot of resources on the Internet covering BIOS and software over-clocking. Spend some time researching and reading about your CPU / motherboard combination to determine the best approach (search "overclock [CPU MODEL] [MOTHERBOARD MODEL]").

The Z170 OC Formula motherboard used in this build provides software for simple over-clocking (Formula Drive). Over-clocks were set in Formula Drive and tested at 4.4GHz and 4.6GHz: voltages / temperatures were 1.34V / 62C and 1.35V / 71C, respectively. Note that "auto over-clocking" features in the BIOS and some software packages tend to over-volt the CPU, leading to much higher temperatures. It is necessary to closely monitor and test different over-clocking strategies – if opting for mid-to-higher over-clocks, expect to spend some time tweaking the various settings. If simply using

"quick-and-dirty" auto-over-clocking, it's OK to settle for a lower frequency if it means extending the life of your hardware.

PART 2: BENCHMARKS & TESTING

One of the best ways to test PC performance is with benchmarks. Benchmarks are standardized tests against which computers can be compared. There are many benchmarks on the Internet that test everything from memory to CPUs to graphics cards, etc. – basically all types of hardware. Some are free, and some have a price. Benchmark scores allow direct comparison of different computers, hardware, and hardware configurations, but it's important to note that benchmarks provide only a theoretical basis for comparison. While benchmarks offer valuable insight into differences in hardware performance, "real world" results may vary non-linearly with benchmark scores.

Comparing a Dell Optiplex 9010 running Windows 7 (the standard build) with an over-clocked, premium build running Windows 10 (the custom build) isn't going to be a scientific affair. Hardware / hardware technology differences in both computers make direct comparison and analysis practically impossible. The purpose of such a comparison is simply to determine the difference in performance – on benchmarks and common Legal Technology tasks – between a standard, firm-issued computer and a high-end build. Is it worth it to spec up computers for Legal Technologists, or not?

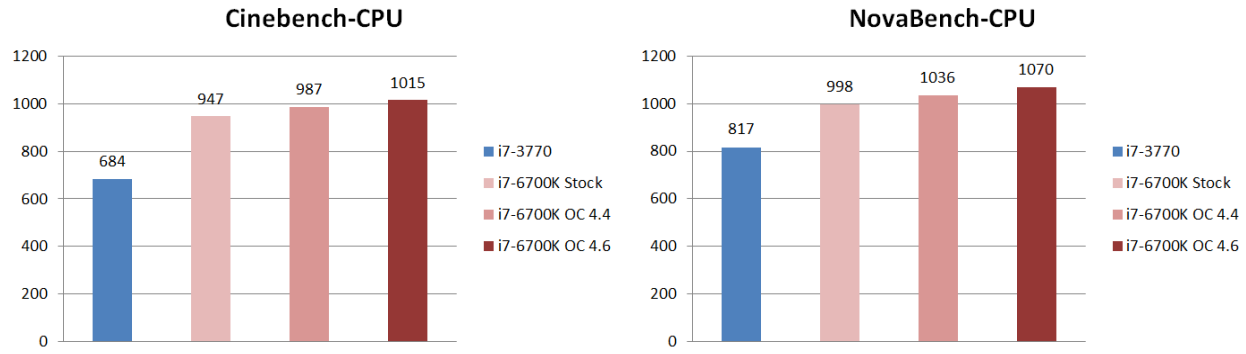
The data and graphs below show test results for the standard build (i7-3770) and the custom build (i7-6700K). Power Settings on both computers were set to "High Performance" (default) and rebooted between tests. Each test was repeated three times, and all scoring was recorded as an average. The custom build (i7-6700K) was tested at 4.0GHz (with 4.2GHz Turbo) (default settings), OC (over-clock) 4.4GHz, and OC 4.6GHz.

CPU

Two CPU benchmarks were compared: Cinebench and NovaBench. The custom build (i7-6700K) scored significantly better than the standard build (i7-3770), and that was expected. At OC 4.4 and OC 4.6, the custom build (i7-6700K) produced scores among the highest recorded for 4-core CPUs on both tests.

BENCHMARK	i7-3770	i7-6700K Stock	i7-6700K OC 4.4	i7-6700K OC 4.6
Cinebench-CPU	684	947 **(+38.4%)**	987 **(+44.3%)**	1015 **(+48.4%)**
NovaBench-CPU	817	998 **(+22.2%)**	1036 **(+26.8%)**	1070 **(+30.1%)**

Benchmark results for the standard (i7-3770) and custom (i7-6700K) builds. Higher is better.



Published Cinebench scores for various processors:
http://cbscores.com/

Published NovaBench scores for various processors:
https://novabench.com/parts/cpu.

When considered by itself, the i7-6700K realizes only modest gains with over-clocking, but the difference between stock and OC 4.6 is still a respectable +7%.

BENCHMARK	i7-6700K Stock	i7-6700K OC 4.4	i7-6700K OC 4.6
Cinebench-CPU	947	987 **(+4.2%)**	1015 **(+7.2%)**
NovaBench-CPU	998	1036 **(+3.8%)**	1070 **(+7.2%)**

Benchmark results for the custom (i7-6700K) build. Higher is better.

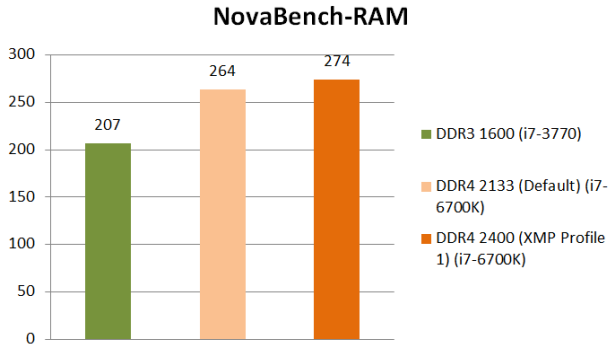
RAM

It's worth pointing out the difference in memory speed between the standard and custom builds. DDR3 memory, used in the standard build, ranges in speed from 800-2133MHz. DDR4 memory, used in the custom build, ranges from 2133MHz and up (currently peaked out at 4000MHz+). In general, faster memory improves overall performance, but like CPUs, a consequence of faster RAM is higher temperatures. Many extreme memory kits include heat sinks and even fans to control temperatures and prevent overheating.

Comparing RAM in the standard and custom builds is basically an apples-to-oranges comparison, but it is interesting to see the difference in performance. Not surprisingly, the DDR4 RAM in the custom build significantly outperforms the DDR3 RAM in the standard build. Note also the modest score improvement between the DDR4 RAM clocked at 2133MHz (default) and 2400MHz (XMP Profile 1).

RAM	NovaBench-RAM
DDR3 1600 (i7-3770)	207
DDR4 2133 (Default) (i7-6700K)	264 **(+27.5%)**
DDR4 2400 (XMP Profile 1) (i7-6700K)	274 **(+32.4%)**

Benchmark results for DDR3 and DDR4 RAM. Higher is better.



RAM	NovaBench-RAM
DDR4 2133 (Default) (i7-6700K)	264
DDR4 2400 (XMP Profile 1) (i7-6700K)	274 **(+3.8%)**

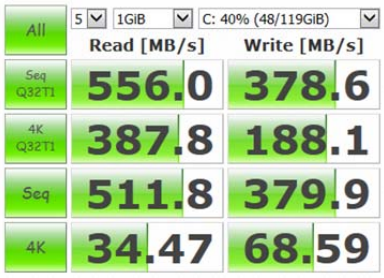
Benchmark results for DDR4 RAM. Higher is better.

"C" DRIVE

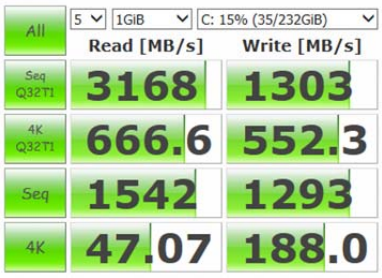
Another big difference between the standard and custom builds is the SSD technology employed. The Samsung 850 Pro is one of the best 2.5" SSDs ever made, but it benchmarks remarkably lower than the newer Samsung 960 EVO M.2 drive. It's complicated, but the performance difference is due to the technology connecting the drives to the motherboard: the 850 Pro uses SATA3 (rated to 6Gb/s), and the 960 EVO M.2 uses PCIe (rated to 32Gb/s). As expected, the 960 EVO M.2 dramatically outperforms the 850 Pro in practically every category, but it's important to note that "real world" performance differences aren't always as dramatic as benchmark scores would indicate. That said, Windows boot times, program responsiveness, file transfers to and from the C:\ drive, and other routine operations are virtually instantaneous – it just "feels" faster in every way.

Also worth noting is that M.2 SSDs run very hot compared to 2.5" SSDs – there are many lamentations on the Internet about these drives throttling themselves down to prevent thermal damage under heavy use. Some newer M.2 SSDs are being manufactured with heat sinks to manage temperatures as a result.

Samsung 850 Pro 128GB (i7-3770)



Samsung 960 EVO M.2 250GB (i7-6700K)



CrystalDiskMark results. Higher is better.

"REAL WORLD" TESTING & RESULTS

In addition to benchmarking, the standard and custom builds were also tested with "real world" tasks that are common to Legal Technologists. Descriptions of the tests follow:

Extract contents of ZIP file using Windows

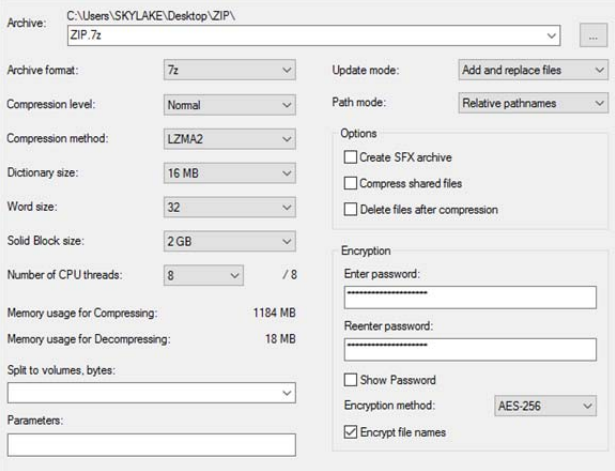
- Zip file on Desktop; extracted to Desktop (uncompressed size: 4.02GB, 500 files, 10 folders)

Extract contents of RAR file using 7-Zip

- RAR file on Desktop; extracted to Desktop (uncompressed size: 3.54GB, 25690 files, 17 folders)

Create encrypted 7-Zip archive

- Files saved on Desktop; archive created on Desktop (uncompressed size: 7.57GB, 26190 files, 29 folders)
- Archive settings:



Export files from forensic image using FTK Imager

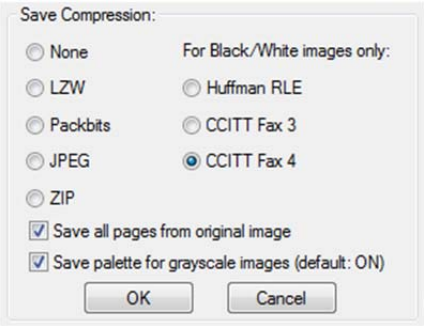
- Forensic image saved on data hard drive and loaded in FTK Imager (image size: 18.7GB); files exported to C:\ (size: 23.5GB, 12647 files, 240 folders)

Filter emails by keyword using PinPoint Labs One Click Collect

- Filter settings: de-duplicate, keyword filter
- Two PST files saved to Desktop; search results exported to data hard drive
    - PST1 (size: 15.8GB, 30601 emails)
    - PST2 (size: 7.07GB, 17624 emails)

Convert PDFs to TIF using IrfanView

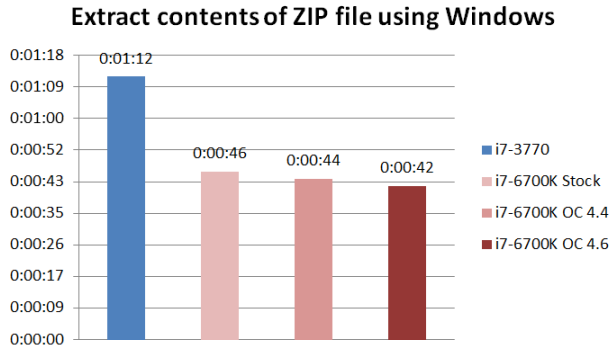
- PDFs saved to Desktop and batch converted to TIF; converted images saved to data hard drive (size: 3.0GB, 4000 files)
- Compression settings:

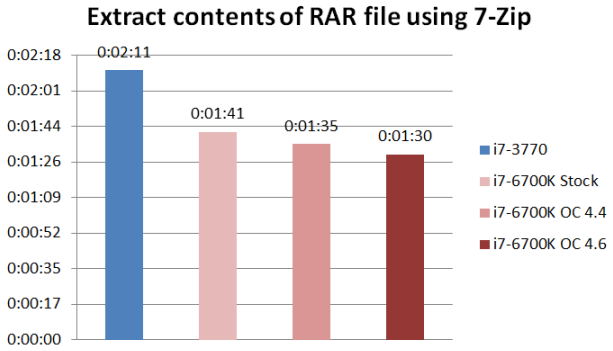


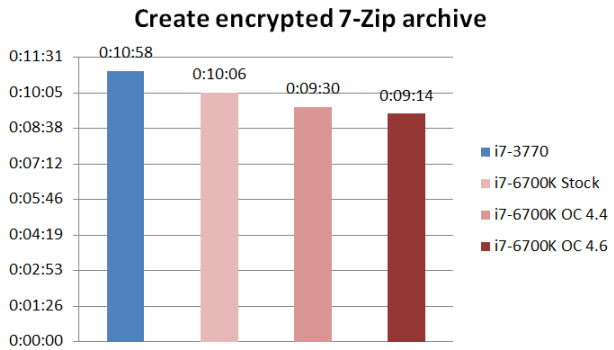
Once again, the custom build (i7-6700K) performs noticeably better in all tests as compared to the standard build (i7-3770), with the most significant time savings realized in longer tasks. It's easy to see how benchmarking scores aren't always representative of "real world" applications, though in some tests, the differences in performance are almost identical. There are many factors, but most significant is the manner in which different programs utilize the CPU and memory (RAM).

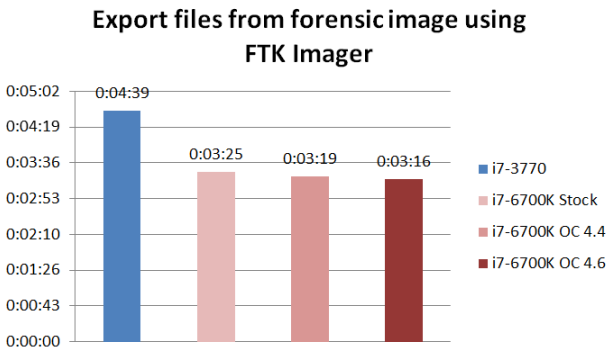
TEST	i7-3770	i7-6700K Stock	i7-6700K OC 4.4	i7-6700K OC 4.6
Extract contents of ZIP file using Windows	00:01:12	00:00:46 **(-36.1%)**	00:00:44 **(-38.9%)**	00:00:42 **(-41.7%)**
Extract contents of RAR file using 7-Zip	00:02:11	00:01:41 **(-22.9%)**	00:01:35 **(-27.5%)**	00:01:30 **(-31.3%)**
Create encrypted 7-Zip archive	00:10:58	00:10:06 **(-7.9%)**	00:09:30 **(-13.4%)**	00:09:14 **(-15.8%)**
Export files from forensic image using FTK Imager	00:04:39	00:03:25 **(-26.5%)**	00:03:19 **(-28.7%)**	00:03:16 **(-29.7%)**
Filter emails by keyword using PinPoint Labs One Click Collect	01:58:54	01:41:23 **(-14.7%)**	01:36:59 **(-18.4%)**	01:32:57 **(-21.8%)**
Convert PDFs to TIF using IrfanView	01:02:09	00:50:41 **(-18.4%)**	00:49:03 **(-21.1%)**	00:46:40 **(-24.9%)**

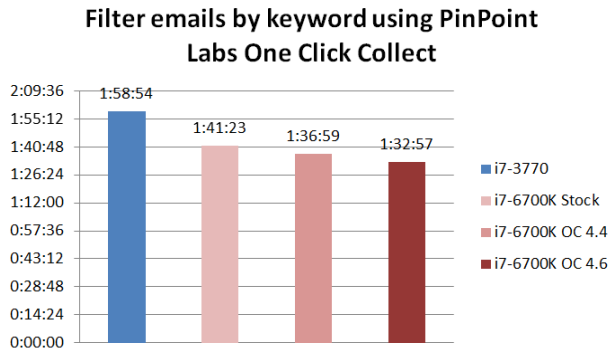
Test results for the standard (i7-3770) and custom (i7-6700K) builds. Results in HH:MM:SS. Lower is better.

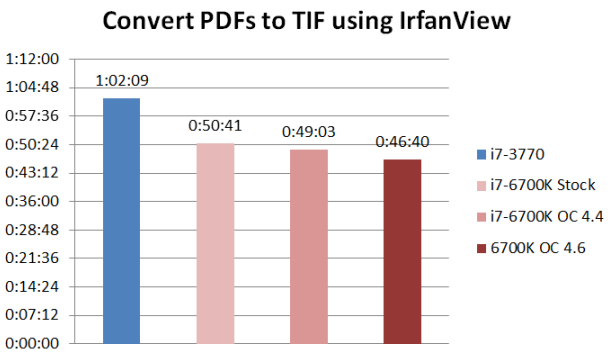












When viewed in isolation, the i7-6700K sees modest gains in performance with over-clocking – small, but almost linear improvements. But since over-clocking is an exercise of diminishing returns, at some point, the effort required to manage and cool the CPU overrides any additional performance gains.

TEST	i7-6700K Stock	i7-6700K OC 4.4	i7-6700K OC 4.6
Extract contents of ZIP file using Windows	00:00:46	00:00:44 **(-4.3%)**	00:00:42 **(-8.7%)**
Extract contents of RAR file using 7-Zip	00:01:41	00:01:35 **(-5.9%)**	00:01:30 **(-10.9%)**
Create encrypted 7-Zip archive	00:10:06	00:09:30 **(-5.9.%)**	00:09:14 **(-8.6%)**
Export files from forensic image using FTK Imager	00:03:25	00:03:19 **(-2.9%)**	00:03:16 **(-4.4%)**
Filter emails by keyword using PinPoint Labs One Click Collect	01:41:23	01:36:59 **(-4.3%)**	01:32:57 **(-8.3%)**
Convert PDFs to TIF using IrfanView	00:50:41	00:49:03 **(-3.2%)**	00:46:40 **(-7.9%)**

Test results for the custom (i7-6700K) build. Results in HH:MM:SS. Lower is better.

CONCLUSION

Building a custom PC is as easy as it's ever been – there are countless resources, guides, testing data, and editorials on the Internet. We explored the basic process of building a high-end, over-clocked computer in Part 1, and in Part 2, we compared that build to a typical, standard, firm-issued machine. As expected, the custom build showed significant performance improvements – it was better specced in every way. But how or when a premium, custom computer will benefit your practice is more difficult to answer: it depends on how you use it.

Realizing large statistical differences in benchmark scores is very different from realizing actual time savings in "real world" tasks. Benchmark scores and task times of the standard build were consistently worse than the custom build by double-digit percentages. But time differentials in performing common tasks weren't always impressive. Performance improvements on shorter tasks were measured in seconds, while longer tasks realized a much greater time savings – 15-25 minutes on some tests. When comparing the i7-6700K at various frequencies, improvements were steady, but much less dramatic. Best time savings between i7-6700K stock tuning and OC 4.6 fell in the 4-8 minute range on the longest tasks.

Altogether, the performance of the custom i7-6700K build was phenomenal, especially at OC 4.6. Over-clocking was basically "test-it-set-it-forget-it," and there were no stability issues during any testing. In terms of time, the standard build (i7-3770) had respectable numbers, completing most tasks within a minute or so of the custom build (i7-6700K), even at the highest over-clocks. But for longer tasks, the custom build proved its pedigree, besting the standard build by 15+ minutes or more.

There's a lot to be said for the "feel" of the custom build – everything is faster: booting, programs, file transfers, etc. Is it fast enough to warrant the time to build it? Would 1, 2, 5, 15, or even 25 minute time savings on routine tasks make a difference? Probably not on any given day, unless there's a tight deadline, but it's likely the time savings over the course of a year would be considerable. Is it worth the

time and money to over-clock? Probably – it isn't difficult to spec out a custom build at a comparable price to the standard build in this paper. Mild over-clocks are easy and stable, and if you're using an unlocked CPU, why not do some research and turn it up a bit?

No matter how you spin it, faster CPUs, faster memory, and faster hard drives make everything happen faster – especially over months and years of use. And if cumulative time savings and increased efficiencies aren't enough, speccing up your Legal Technologists' computers – or better, letting them build their own – will yield remarkable and priceless results: a sense of accomplishment and a really big grin.