Digital Media Research

Master Document

DGM 2341

Prof. Micheal Harper

By: Dylan Smith

Table of Contents

The Goal in Mind

Going into these research papers was a daunting task, it was a lot of information to look up and tedious experimentation too. But it was all important to gain a futher understanding of how important it is to understand file formats, technology, and other related things in our Digital Media industry. This also was a practice to learn how to communicate via design and document my journey/process. One of the things I learned is how important it is for a developer to understand what is talked about in this documentation and I hope who I show this to in the future will feel the same way.

Section One: Audio Formats

Audio files don’t get the appreciation they deserve. Our world runs on technology, audio files is one of those key technologies.

So, it is important to understand how digital audio works, which mediums are out there for you to experience digital audio, and the standards. This documentation will go over that with you and help give you a snapshot of what digital audio is like.

First, you’ll be introduced to differnce between lossy, lossless, and uncompressed audio files. Second, delving into quality and tech specs of each codec. Third, intoduce you to popular streaming services. Finally, popular development software.

Digital audio is an important pillar of technology. We wouldn’t have modern communication if we didn’t have digital audio, we wouldn’t have entertainment if we didn’t have digital audio. So, It is important to understand the technology and its capabilites.

Introduction

Fig. 1. Roberto Sorin, *CD*, 9 April 2021

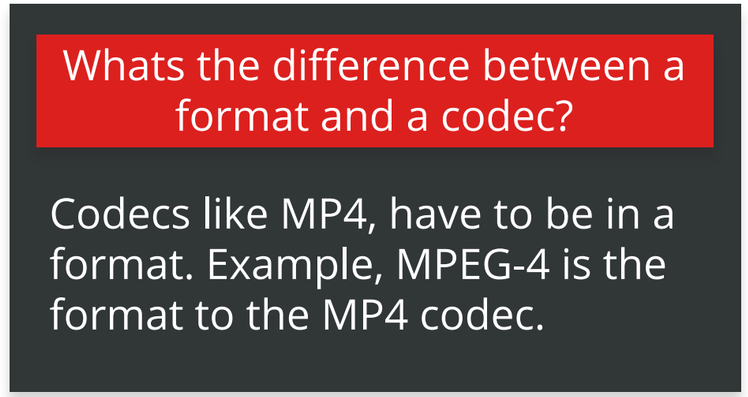


Fig 2. format vs. codec

Digital audio requires a file format to work properly. File formats or codecs will come in many forms. Depending on which codec you utalize, will effect the quality of audio. How would you define the quality of the audio? Well, that can be a topic of debate, "there's no single universal standard for hi-res audio" (Burns and Roberts). Meaning that this can be a pretty hard thing to talk about. So, that is when you resort to what the file formats are and the capabilities of each.

One of the most common file formats is MP3, and it's probably the most commonly known file format. Odds are if you ask someone what MP3 is, they'll say something along the lines of it being an audio file. The letters M and P in MP3 stand for MPEG, and that is an acronym as well! It means Moving Picture Experts Group, and there are 4 version of MPEG formats. This means there is a lot of file formats that work with audio. It is important to gain an understanding of what each file is and the tech behind each file format, which enables you to enjoy the best type of audio format when listening to music or enable you to have an impact on the industry you are in that requires you to know this stuff.

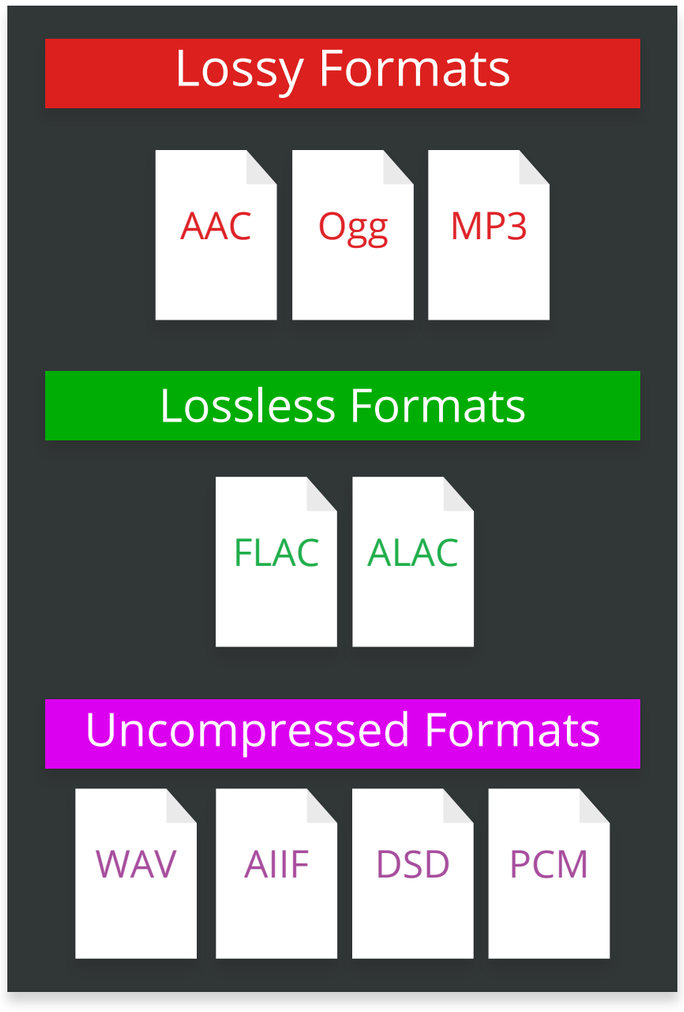


Fig 3. Codec and format example

The Audio Formats:

Audio files come in three main types: Lossy, Lossless, and Uncompressed. The idea of compressing a file is to manipulate the file to make it smaller in size. This allows you to maintain space because an uncompressed audio file can be a massive file. They're also called audio codecs and they're used to compress data for transmission, and used to decompress the data on the listening end (Berry and Boutillete). When you transmit an audio file across a medium, most of the time you'll have to compress it. Depending on that audio codec used on the file, you'll be able to listen to a decompressed audio file that may be missing data, or an audio file that has not lost any data.

Lossy files are the files that will lose data and may not sound the best when uncompressed and listened to. When you compress a file down, you're losing data and that data in a better term here is "quality." When you lose data, sound may not be as crisp and clear, and you may hear the static noise of compressed audio data. So, with understanding what a lossy file is, what would be a better audio format in terms of audio quality?

Lossless file formats, these file formats are simply put lossless file types. Meaning you don't lose data when you bounce an uncompressed file type to a lossless file such as Apple Lossless Audio Codec--or ALAC. This is a file type that's only compatible on Apple devices, a similar alternative is FLAC (Berry and Boutillette). It is a lossless audio codec that allows you to listen to an audio file that didn't lose data due to compression. However, these file types can be larger than lossy format and that can cause your device to have less available storage (Berry and Boutillette). Finally, uncompressed audio formats are RAW file types. Meaning, that the file size is the original file size from its creator, and this can be a massive file size--depending on how big the project is. Even though they are bigger file sizes, these file types will have better audio quality since it is not losing data like lossy files.

Audio Formats

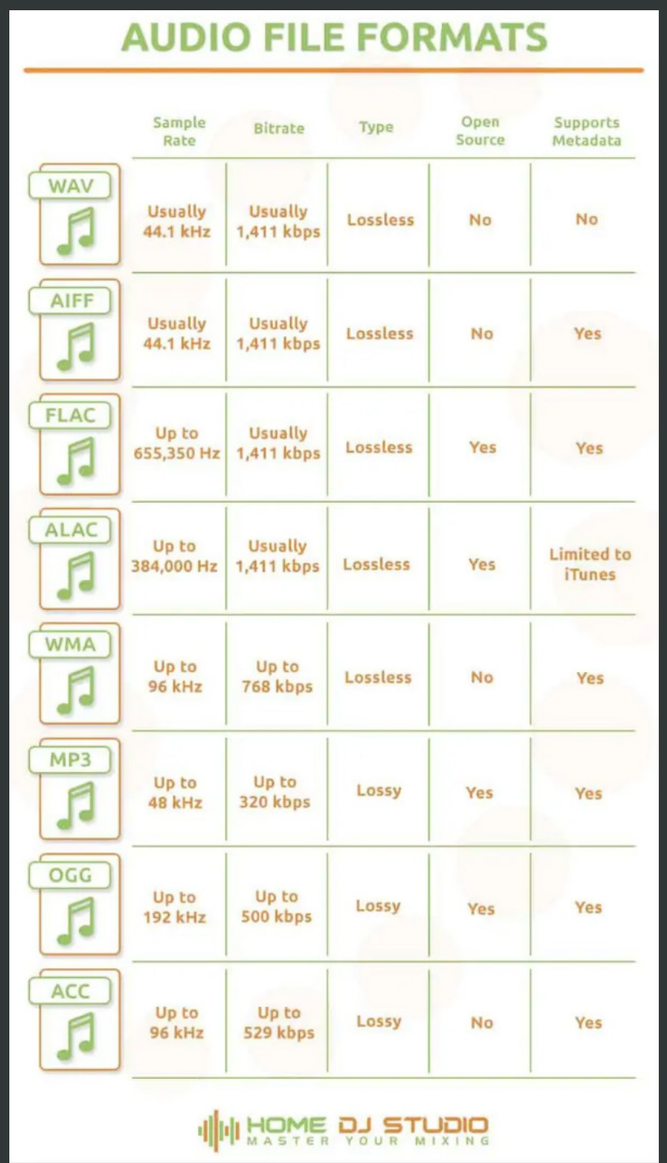


Figure 4 - Audio Bitrate File Size, Robert Calabrese, 3 Aug. 2021

Now, this is where you start to delve down into the rabbit hole. First, let me give you a bit of a reference point on audio quality. Audio quality is not only dependent on the file format but also on the producer. But let's say you're listening to an album by a great producer, maybe you're listening to that album off of a CD. The quality of CDs that contained music was great. This is important because Apple's ALAC codec has a minimum bitrate of 44.1 kHz at 16 bit which is what they define as CD quality (*About lossless audio*). This should give you a good reference point for getting an idea of what "good" audio quality is.

File formats typically have different bitrates and those differences set the file formats and codecs apart. Here is an example, the highest quality MP3 file has a bit rate of 320 kbps at 16 bit. But if you compared it to other audio files, such as WAV at 44.1 kHz at 16 bit and listened to them both you'll hear a subtle change in the quality or a drastic change (Calabrese). Keep in mind that a person's hearing may differ from another person. See figure 4 to see a great visual of the differences between some audio files. Keep in mind, higher quality is a higher bitrate, but the downside is higher file size.

The difference between audio files has led to a group of people know as Audiophiles, which is a person whose hobby is to collect and listen to the highest quality in audio. They may spend thousands of dollars in audio equipment, just to listen to a Beatles album. If you ask an Audiophile what the best quality is, they may direct you to a website/application or tell you which audio format is the best. They'll recommend you high-fidelity audio, which is a loss-less file format or possibly the actual uncompressed audio file. Both will offer a far different experience in your audio listening experience than any lossy files, like MP3 files.

When you start to delve into higher quality audio files, such as FLAC, MQA, and WAV, you start to get to experience loss-less audio and that brings you closer to the real experience of listening to it, like you were in the recording studio.

FLAC is an acronym: Free Lossless Audio Codec. This codec is hi-res and takes approx. half of what a WAV file would take (Scarrott). Some may prefer this format over others for hi-res music albums, but FLAC is not supported for Apple Music—Apple's alternative is known as ALAC (Scarrott). MQA file types are another option for higher quality music and its acronym stands for: Master Quality Authenticated. A popular music streaming company, Tidal, uses this audio codec for its capabilities to have lossless compression and it can efficiently stream to devices (Scarrott). The last file I want to briefly talk about is WAV, which stands for: Waveform Audio File Format. This audio codec is something that you may have used when you were playing the music off of a CD. This file format is the standard for all CDs and its good sound quality as well. But there is a catch, WAV is an uncompressed audio format and will typically result in huge file size if it is a hi-res quality CD (Scarrott).

That's not all of the different file types out there, there is a lot to look at still. But for that, look at figure 5 on the next page, this diagram I created will help show you what each audio file is capable of.

Figure 5 - The audio files and its relations

Acronym	Full Name	Bitrate	Associated extension(s)	Standard Body Responsible for Maintenance
.MP3	MPEG-1 Audio Layer III	96 - 320 Kbps at 16 bit	N/A	MPEG: Moving Picture Experts Group
.MP4	MPEG-4 Part	256 Kbps at 16-24 bit	.MP4, .M4A, .M4P, .M4B, .M4R, .M4V	MPEG: Moving Picture Experts Group
.WAV	Waveform Audio File Format	1411 Kbps at 24 bit	.wave	Microsoft and IBM
.AIFF	Audio Interchange File Format	1411 Kbps at 24 bit	.aif, .aifc	Apple
.AAC	Advanced Audio Coding	Up to 256 Kbps at 24 bit	MPEG Container: .m4a, .mp4 Apple Container: .m4a, .m4b, .m4p, .m4r, .m4v	Apple
.OGG	n/a	Up to 320 Kbps at 24 bit	.ogv, .oga, .ogx, .ogm, .spx, .opus	Xiph. Org Foundation
.ALAC	Apple Lossless Audio Codec	up to 192 kHz at 24 bit	.m4a	Apple and macOS forge
.MQA	Master Quality Authenticated	up to 192 kHz at 24 bit	.m4a	MQA Ltd
.FLAC	Free Lossless Audio Codec	1411 Kbps at 24 bit		Xiph. Org Foundation

Info from: Calbrese, Harper (In class lecture), Apple, Tidal, Spotify, Soundcloud, Lee, Costello, Harris, MQA, and Wikipedia

Audio Playback Applications

Moving onto the types of audio applications out there. Depending on who you are, you'll need a specific audio application for your prefrences. You could just use whatever music streaming/downloading application there is available. That could be a mistake, because you may be missing out on a great experience else where. Each company offers slightly different services and some are bit more open about their services then others as well.

First, let us talk about playing back audio, platforms such as Apple Music and Spotify have to consider which audio codecs they're using and whichever they choose to push out will affect how your audio sounds to you. So, you gotta ask yourself, what do you want? Let's say you want the best possible sound quality you can get, which means you'll have to pay more for that added benefit of crisper audio quality.

For example, Apple Music uses a file previously mentioned, ALAC or Apple Lossless Audio Codec. This codec allows apple to output audio files in a range of 44.1 kHz at 16 bit (CD Quality) to 192 kHz at 24-bit (*About lossless audio*). Having this power gives a pretty good audio file to an Apple Music user. If you're a big Apple product user and have any version of its Airpods you'll get pretty great sounding audio, if listened to with one of these devices. Sadly though, when you look more into it, Apple says that their headphone devices only run on a AAC Bluetooth audio codec to stream it to your audio device and in turn converting that ALAC into an AAC file which is lossless (*About lossless Audio*). To sum up that point, you're still getting great audio quality and is much better than MP3 but it is not a lossless audio file at that point. So, if you want true lossless audio you have to look into what devices you're listening with is capable of, which is an easy search depending on your devices

Here is a summary of some of the most popular audio playback applications and a bit of a more in-depth summary of one of my favorite music applications, Soundcloud.

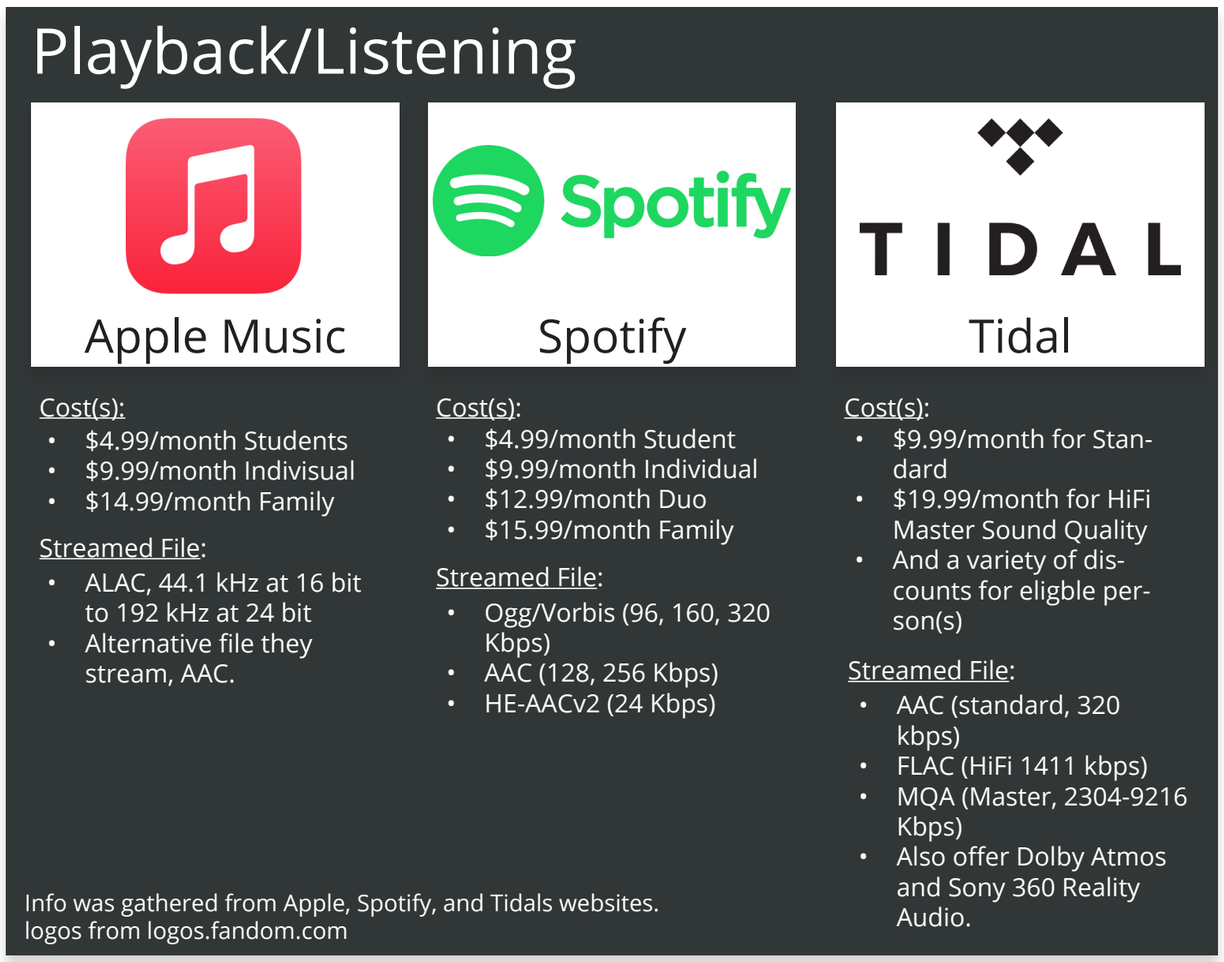


Fig 6. Music Streaming Services at a glance

Soundclound

This music platform is commonplace for those who create their music and post it too. It's a great place to get started on creating music, and many who started here ended up being successful artists. That isn't the only perk though about this platform, it's the freedom you get with the audio files you can upload, however, there are some limits.

SoundCloud's platform is compatible with these formats: FLAC, ALAC, WAV, AIFF, OGG, MP2, MP3, AAC, AMR, and WMA.

Some of those we didn't even talk about. But to keep it easy for now, let's focus on the lossless formats they accept to be uploaded to their system: FLAC, ALAC, WAV, and AIFF (*Uploading requirements*). Once a creator uploads their project, Soundcloud will take the file and will transcode that file into something more optimal for music streaming, AAC (*Uploading requirements*).

This file format was developed to be a successor to MP3 and the acronym stands for Advanced Audio Coding. This format is a lossy format, and you might be saying now "Wait! Isn't that bad?" It's not a bad thing actually, yes it's still losing data due to compression, but it's still a good-sounding audio format (Costello). The bitrate for this format can be 128, 192, or 256 Kbps (Costello). This could be considered a limit because there are other platforms like Tidal that offer Hi-Res audio which is 44.1 kHz at 24 Bit. Another limiting factor is that your total audio file size can't exceed 4GB, meaning when you're uploading a file you have to be careful and manage your project accordingly (*Uploading requirements*).

This platform is a favorite because it's a site for creativity and great music. Sadly, you're not getting the best audio because you're not getting Hi-res quality streaming. But that was the solution Soundcloud is going with, it's a free platform, so streaming hi-res may be too costly.

Audio Development Applications

As a quick introduction to applications that can help you develop and output audio, let me first say there is a lot of solutions out there. So with that said I'll only delve into three applications. You can use any development tool you want, each has its capabilities and many audio producers will use multiple audio applications. But the key thing to keep in mind is which audio file you're outputting your work to. Here is a more in-depth summary of Logic Pro because it's one of the most popular applications for the development.

Logic Pro X

Logic Pro is Apple's premium audio development application. This allows you to argue that this application is a favorite amongst audio developers in the industry.

The application comes in a free version and a paid version that is $199.99 only on Mac products (Lendino). You'll need a Mac device with macOS 11 or later as well to run Logic Pro (*Logic Pro*). The product is also on iOS devices! This version of Logic Pro is called Logic Remote. Logic Remote is available only on iOS 14.0 or later iOS versions and is compatible with the iPhone, iPod touch, and IPad (*Logic Pro*). However, the important features that are a part of this DAW are only present on iPad devices.

NOTE: I'm going through and updated citations, and have noticed Apple has updated their minium requirements for Logic Pro on systems, so it seems that is an ever changing variable because each new release of logic pro will not perform as well on older hardware.

- Audio file and I/O resolution up to 192 kHz at 24 bit
- Max project length 6 hours at 96 kHz and 13 hours at 44.1 kHz.
- Massive sound library and plug-ins
- Surround capable, available configurations: Quadraphonic, LCRS, 5.1, 6.1, 7.1 (SDDS or 3/4.1)
- Can play AIIF, WAV, CAF, SDII, ALAC, MP3, AAC
- Recordble files are AIIF, CAF, and WAV
- Bounce files to AIIF, WAV, CAF, MP3, and M4A (ALAC, AAC)
- You can also burn to CD or DVD-A
- and so much more, check out more here: https://www.apple.com/logic-pro/specs/

Logic Pro is a capable tool and having the ability to work with many different codecs gives you the capability to create the highest quality you can make as an audio producer. Once you're done with your project on Logic Pro you get to save it to a proper file format and then you can upload it to anywhere you want that supports playback of your audio file. Such as Soundcloud or Apple Music, those two music streaming services accept the majority, if not all, of the files that you can produce with Logic Pro X.

Fig 7. Music Developing Apps at a glanceAug. 2021

Conclusion

This was an introduction to audio formats and some respected software/applications in the audio industry. The goal was to prime you for the next section which is a bit more of an in-depth dive into audio formats and the listening experiences behind them. So, what did you learn in this section? You now know the most common audio file formats that are being used and the specs behind them, the associated file extensions, and the tools/software being used. With this information, you should be ready to learn more about these files and the experiences you get when you listen to them. The question will be if you can perceive the quality differences between files.

Section Two: Audio Listening

The Value of Music can be appreciated in many ways. It just depends on what you want to listen to usually and not to mention people hear things differently as well. But some will argue that to truly appreciate music is to listen to audio that is in a higher quality file than the common MP3 or AAC files.

In this documentation, I'll attempt to describe to you the different experiences that occur with file types and streaming services. I'll be taking the approach of controlling my environment variables and utilizing devices that offer different capabilities of audio playback.

Section summaries:

Part 1: Downloaded Listening Experiences

I'll be downloading music to my devices, in a variety of available file types provided to me and some that I own already.

My process is documented with the devices I'll be using and the specs that each device has, the file type of the song I'm listening to, my controlled environment variables, and I'll listen to the audio files from the lowest quality to highest quality based off of the file type. Following this process, I should hopefully describe to you if there is a difference between audio files.

Part 2: Streaming Service Experiences

Following the process established in part 1, now I'll be exclusivley streaming the same music and some extras of my choosing. They question is if consumers are actually listening to quality music or if the advertising from the music streaming services are not worth the money. The new variable to consider in this section is bitrates as well, since there is data streaming now instead of listening to a downloaded file.

I'll primarly be listening to Apple Music, Tidal, Qobuz, and Spotify. All of which offers some form of higher quality audio files to be streamed/downloaded from their platform.

Fig 1. Marvel Studios. Loki Varients, July 2021.

If you have watched Loki, you may find this analogy humorous and may help you understand the idea of what audio formats are.

The audio format is a lot like a variant. You can have the same song, but in a different, format, and those different formats have their pros and cons, but we love them all.

Downloaded Listening Experiences

In this section, I'll try to describe in words my own listening experience of downloaded music—with the different available audio formats. The range of bit depths and sample rate for these audio codecs is 16-Bit at 44.1 kHz to 24-Bit at 96 kHz.

The audio files I'll listen to in order will be MP3, AAC, FLAC, AIFF, and HiRES as well. I will also use my vocabulary to the best of my abilities to describe the audio listening experience in each and hopefully provide a picture of the sound I'm listening to. All based on my hearing, this may differ for others.

Live Reactions

For each file type, I listen to with my headphones (see fig 2), I'll do journal-like entries of my first and live reactions to the songs as I progress in different file types. The tone is informal and just an unfiltered reaction to the song. I have had listened to some songs before, so I'll mention that in my reactions.

Note that my experiences will most likely differ from everyone else, people hear differently and may have different devices that could alter the audio slightly or drastically. In short, these sections are my best attempt to provide a relatable way to describe the audio quality differences I hear.

My Listening Enviorment

To conduct a proper experiment, I had to control my environment as much as possible. Meaning, each file type was played back at the same volume, same audio device(s), and no external distractions. This will give me the ability to decisively say I can perceive any differences, and the opportunity to describe those differences as well.

Listening Device(s)

I have two "proper" sets of audio listening devices. The primary one I'll be using for this experience is my PC headset, however, I'll also compare that to my Air Pods Pro to see if the Bluetooth factor influences the audio listening experience.

My primary headset is the Corsair Virtuoso SE HiFi Gaming Headset. Any PC gear that is branded with the word "gaming" is potentially gimmicky. But this headset is a $210 headset and has the potential of listening to audio with 96 kHz at 24-Bit (Virtuoso RGB). Which is perfect for this listening experiment. But, for this headset, it needs to be connected via its USB cable and have the necessary drivers as well installed—via Corsairs, iCUE software (Virtuoso RGB). It is also good to mention it has the capability for 7.1 Surround Sound—but is only manageable via the iCUE software.

My secondary device is the Air Pods Pro from Apple. These are Apple's high-end wireless earbuds that are priced at $250. These earbuds have active noise canceling, an adaptive EQ, the ability for a high dynamic range, and also the perk of spatial audio via Apple's head-tracking technology (AirPods Pro). However, the earbuds run off of Bluetooth 5.0 technology (AirPods Pro). This means that the bandwidth available for these wireless earbuds is up to 2 Mbps—other benefits of this tech that is noticeably present in the Air Pod Pros are extended wireless range and energy efficiency (Jones). Even though that bandwidth is an upgrade to any previous Bluetooth versions, it could affect the audio quality when played back. But the question is will I notice the difference if there is any.

Another device I'll mention is my car's sound system.

Fig 2. Corsair Virutoso SE

Fig 3. Apple Air Pod Pros

The End Of The Innocence

by Don Henley (1989)

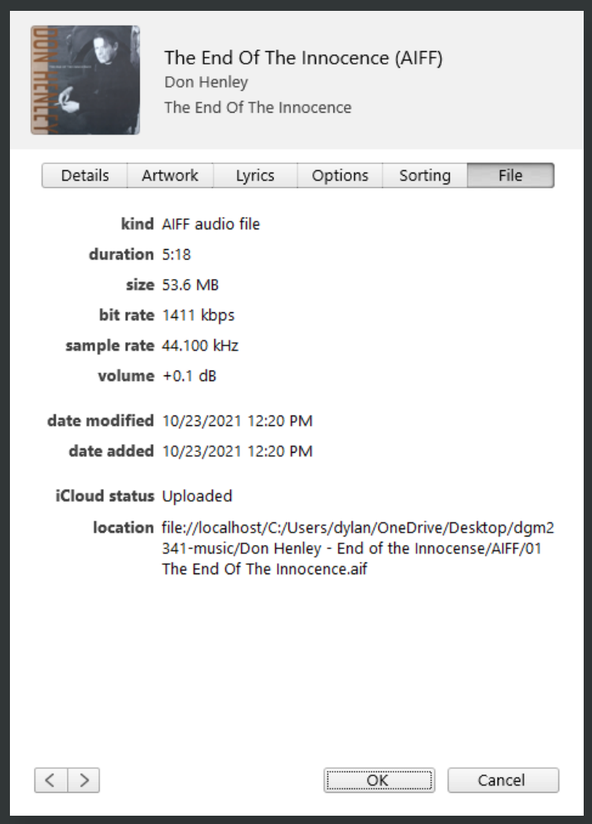


Fig 4. AIFF Audio File Example, iTunes player.

Album Art from Itunes

Live reactions

This is a classic song, but I've noticed instantly that his singing voice has this "short/static" sound at certain points (especially when he sings words that have the letter S in it)—almost like artifacts.

However, it's completely listenable and seems pretty standard. This is the first song I've listened to for this experiment though. Each component of the song is present it seems, and I can appreciate the primary instrumentation being used.

I mentioned that I have noticed this "short/static" artifact on his lyrics that end/start with S, this seems to be less prevalent in this AAC audio file.

The instrumentation sounds about the same on top of that—as compared to the MP3 audio file. I guess there is more of a dynamic range because I'm not noticing those weird audio artifacts, but it's so minuscule that I'm comfortable in saying I don't notice a huge difference between the two audio files at all.

I will note that I thought the saxophone sounded clearer to the ear but, after playing both parts back in the AAC and the MP3, I believe there isn't much of a difference at all.

Already noticeably soulful and present in the ears, even at the same volume as played with the AAC and MP3 files.

The weird-sounding "S" artifacts are not present, and his lyrics are much clearer. I can hear the raspiness of his voice with a wall of sound behind him. Simply put this is a massive difference compared to the MP3 and AAC. I can appreciate the instrumentation much more in this audio file. Giving the song more value if we compare it to the other audio versions of the same song.

As a note, even the saxophone in this audio file is more alive and the solos with it are captivating rather than just prevalent. It gives me more appreciation for the composer, which is Bruce Hornsby based on the FLAC audio files information.

Just like the FLAC file, his lyrics that end/start with S are much clearer and don't have the weird artifact present in MP3 and AAC versions. It sounds identical to the FLAC audio version, meaning both are far superior to the MP3 and AAC versions.

I'm able to distinguish more instrumentation and listen to each strum of a guitar and push of a key on a piano. I realized too there is an instrument that I'm assuming is the cymbal of a drum—I didn't notice that in other audio files. The saxophone solo is just as captivating as it is in the FLAC, it has its presence that is fully appreciated in the entire composition of the song.

Air Pods Pros Listen Experience

After listening to the song now on my iPhone and my Air Pods Pro connected to them. Excluding the FLAC version of the song because it is playing off of an iPhone. Each song file version was downloaded to my phone and played back via the Bluetooth connection of my Air Pods Pro. In short, the listening experience for each of them was similar. I can't tell a difference between the three files that were available on my phone (MP3, AIFF, and HiRes version as well).

I can only infer that the device I'm using is overall just giving me a different experience. I'm simulating the environment variables for what I did with my other listening device to the best of my capabilities. I think in conclusion, I couldn't tell a difference with my Air Pods Pro for this Don Henley song.

HiRes

This is by far the best. The audio file specs are the max range of my primary listening equipment. But I'm able to listen to the full capability of the audio file. If I had to describe this version in short, it would be a pure wall of sound. It is a completely different audio experience, and I can't go back to listening to lower-quality music. Every instrument is not being drowned out and is contributing to the overall wall of sound. His voice is being perfectly transmitted to my ears as well, no weird sounding artifacts at all. I'm completely emersed in this song right now—that is thanks to the listening equipment I have that should be noted here.

File Size Comparrison(s):

Each song will along with living reactions to the file types, will have a file size comparison chart. After reading each file type reaction, look at the charts to see where they defer, this is another way to see that there is a difference between audio files and you should be able to notice them.

Note that similiar bit depths are common and sample rates, but they are different file types that handle compression differently and the file size(s) increase as the file quality goes up too.

File size comparrison — **Song Duration: 5:18**

File Type	File Size	Sample rate	Bit Depth	Compression
MP3	7.3 MB	44.1 kHz	16 Bit	Lossy
AAC	10.1 MB	44.1 kHz	16 Bit	Lossy
FLAC	53.7 MB	44.1 kHz	16 Bit	Lossless
AIFF	53.5 MB	44.1 kHz	16 Bit	Lossless
HiRes	174 MB	96 kHz	24 Bit	Lossless

On The Turning Away

by Pink Floyd (1987)

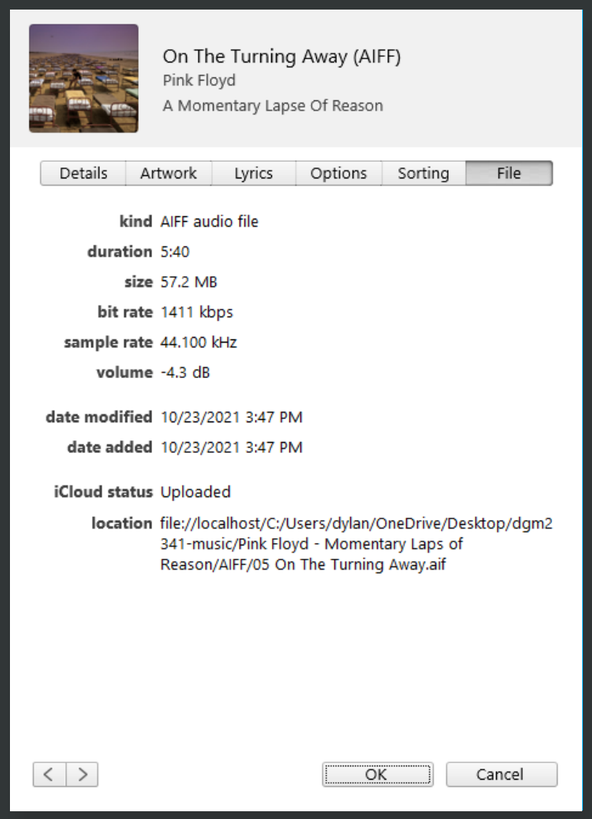


Fig 5. AIFF Audio File Example, iTunes player.

Album Art from Itunes

Live reactions

The first impression is that it sounds good so far, almost as I would remember listening to this song. But based on the last comparison of the Don Henley song, I'm expecting a progression as we go up in audio quality with each file.

It is completely listenable and sounds pretty good, but one thing I've noticed is that lower-quality audio files tend to have a lower preset of volume/decibel level and this song has a lot of instrumentation that should be loud and powerful—it should be a wall of sound. But, in the MP3 it just doesn't provide that. The one thing to reference in the song is the guitar solo that starts approx. 3 minutes and 40 seconds into the song, it sounds pretty strong.

First impression and after going back and forth between the two formats—MP3 and AAC. I've determined the difference is almost non-existent.

To my ears, I can't tell any difference. I want to say it's livelier to my ears, but I'm pretty skeptical to say that. I think the perceptible quality is hard for me to distinguish between the two.

For example, the guitar solo is a heavy part of the song and is meant to have your attention on the power of the guitar. But it sounded the same to me as it did in the MP3 format. I'm expecting the next format FLAC will provide a much different experience though.

As I expected, FLAC was a better experience than AAC and MP3. The wall of sound that I've mentioned previously is prevalent here. More immersive and not as flat sounding, meaning I can listen to each instrument and hear more of what each of those is doing to contribute to the song.

Also, using the guitar solo is more alive and present in this file version. You can almost close your eyes and picture a guitarist doing this solo on stage. That's the best way I can describe it in words. I think immersion is the best term to describe my listening experience with this file, I was more immersed.

I for sure will say the wall of sound is a bit different than the FLAC file version of the song. But other than that, I don't think there is much of a difference. It just seems about the same.

This is shocking because I was expecting to be at least some difference. Which cuts this description of the AIFF file version listening experience. That is based on my hearing, I'll note that may differ with others.

Air Pods Pros Listen Experience

For this song, I thought the AIFF file version sounded the best, as you should. But that was not the case for the Don Henley song, even with a HiRES version of the song. However, the AIFF for this Pink Floyd song on the Air Pods Pro sounded livelier and the guitar solo was more dominating rather than in the other formats. Admittedly, that is subjective and my opinion. In conclusion, the other formats sounded great but the AIFF for sure had its notable differences and I think that this was just dependent on the song being played here.

File size comparrison — Song Duration: 5:40

File Type	File Size	Sample rate	Bit Depth	Compression
MP3	7.8 MB	44.1 kHz	16 Bit	Lossy
AAC	11.2 MB	44.1 kHz	16 Bit	Lossy
FLAC	57.3 MB	44.1 kHz	16 Bit	Lossless
AIFF	57.1 MB	44.1 kHz	16 Bit	Lossless

Clocks

by Coldplay (2002)

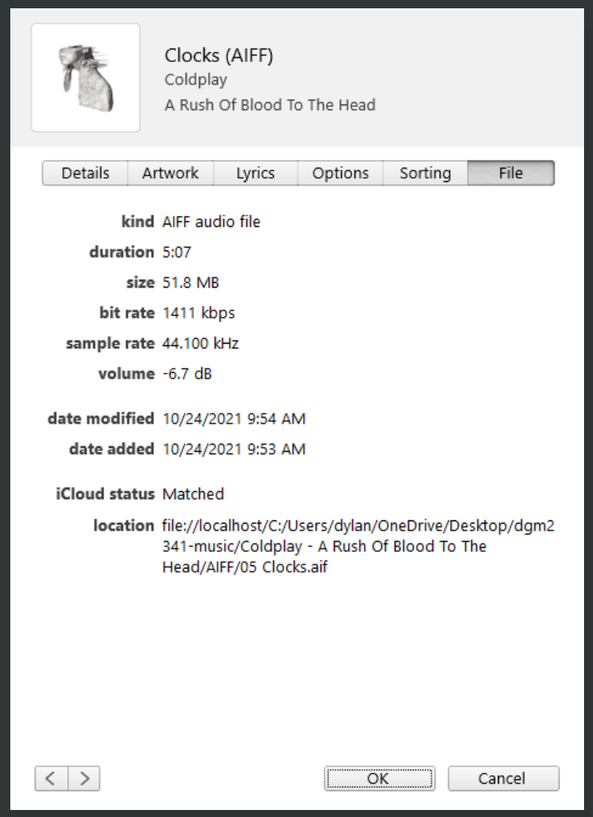


Fig 6. AIFF Audio File Example, iTunes player.

Album Art from Itunes

Live reactions

I'm pretty sure this is the same version of the song I've listened to my whole life with this song. It sounds exactly as I remember it would be.

So, I'm expecting a quality change that the other songs went through as we progress through the files. I really can't point out any flaws with this version of the song, but if I had to guess it is when the cymbals of the drum are hitting, I bet that those sounds more clear, louder, and unique than it is in the MP3 file version of the song.

After further investigation, while I'm listening to this song, this is the song version I've been listening to recently. Because this is my already existing default file for this song.

With that said, I don't have much else to mention about the song. It just sounds good to me and nostalgic. Moving forward though I'm expecting the sound quality to be different, because I'm certain the AAC file version of this song is one I've owned and listened to for a while, and it's ex-actly as I remember.

The first impression is this is a way different experience than what I remember the song is. Chris Martin's voice sounds about as it would on a SiriusXM radio show. Meaning his voice is more powerful and prevalent it seems.

The wall of sound I've mentioned before is here again and not in the AAC or MP3 versions. Keep in mind, same environment variables as established earlier. In conclusion, there is more immersion with this song, and when I close my eyes those piano keys striking each time are intense.

It was pretty much the same experience as the FLAC version was. Each instrumentation is unique, and I can appreciate it more than MP3.

Also, Chris Martin's voice sounds about the same as it would on FLAC. Meaning the range of his vocals—and the instruments—can be heard at different levels and intensity without any audio artifacts—the dynamic range is another term for what I'm trying to describe. The dynamic range of the file is far superior to MP3 or AAC.

Air Pods Pros Listen Experience

It seems my phone is only able to download two file versions of the song. MP3 and AIFF, and I'm missing the AAC version of the song. Starting with the MP3 version of the song, it sounded perfect almost. It just sounds like what I'm used to hearing the song as, but I will note the piano keys are less lively—the piano keys sounded better on my PC headset. The AIFF file though was playing off of the ALAC settings for apple music—44.1 kHz at 16-bit.

It was noticeably more immersive, especially with the noise-canceling enabled. As a reference, the piano keys had more energy to them it seemed, the notes were more powerful. It was for a sure overall better experience than the MP3, but I'll admit I wouldn't have even noticed a difference if I wasn't learning about different audio files and their respective qualities.

File size comparrison — Song Duration: 5:07

File Type	File Size	Sample rate	Bit Depth	Compression
MP3	7.04 MB	44.1 kHz	16 Bit	Lossy
AAC	10.4 MB	44.1 kHz	16 Bit	Lossy
FLAC	51.8 MB	44.1 kHz	16 Bit	Lossless
AIFF	57.1 MB	44.1 kHz	16 Bit	Lossless

Sowing the Seeds of Love

by Tears for Fears (1989)

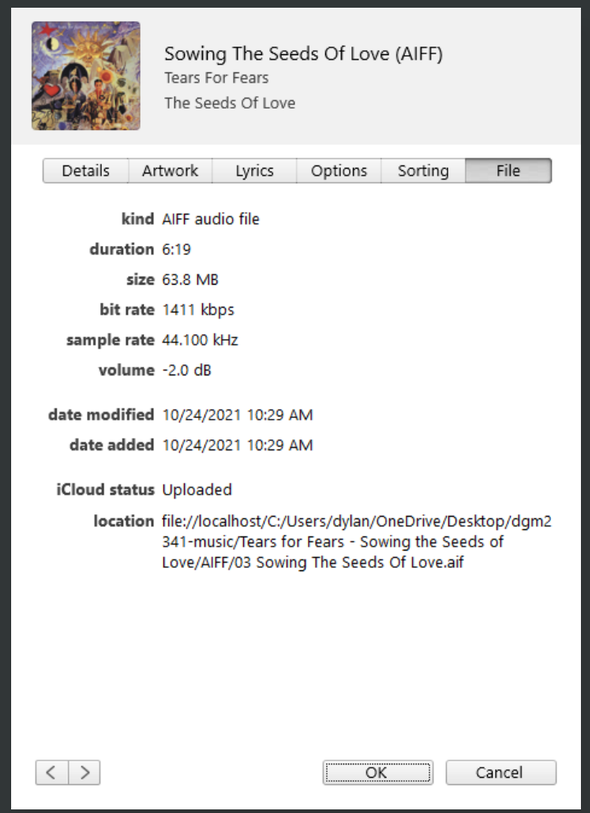


Fig 7. AIFF Audio File Example, iTunes player.

Album Art from Itunes

Live reactions

I grew up with Tears of Fears music and this is one of the ones I knew growing up. The first impression is that it sounds just as I remember it would be. The MP3 file music isn't bad, and it sounds pretty good for what it is.

The first impression is that it sounds pretty similar to what the MP3 sound file did. I think that the difference between MP3 and AAC is out of my hearing capabilities. Because there is a difference, it's just so hard to perceive what I feel.

Everything part of the song, vocals, instrumentation, highs, and lows, all are similar or the same as they sounded on the MP3. But I'm hypothesizing that the FLAC will offer some type of difference.

Same thing as before with other songs. The higher the quality you go in the audio file, I'm noticing the liveliness and intensity increase. I'm keeping all my environment variables the same, so I can hear a difference between the files.

Around 2 minutes and 14 seconds, the trumpet instrumentation is so strong, and I feel that wasn't there in the other audio file versions of the song.

Sounds pretty similar to the FLAC experience. It feels quieter though, I've just double-checked my volume mixer and audio levels in my iTunes app and Windows Media Player (for the FLAC file). Everything is about the same as possible, so I should pick out differences. I think I would venture to say I prefer the FLAC version of this song. But this version of the song is on a different level of music power than on the MP3 versions as well.

I think it's mainly due to the bass, after playing the other versions back, I've noticed the bass seems more intense on the higher quality audio files.

Air Pods Pros Listen Experience

I didn't notice any differences between all the audio file versions of the song. It sounded almost the same and I found myself forcing myself trying to find a difference that I think wasn't there. I mention this because I didn't want to be skeptical with anything and wanted to say a difference I'm sure is there. I don't think I could've done that with this song.

File size comparrison — **Song Duration: 6:19**

File Type	File Size	Sample rate	Bit Depth	Compression
MP3	8.67 MB	44.1 kHz	16 Bit	Lossy
AAC	11.8 MB	44.1 kHz	16 Bit	Lossy
FLAC	64.0 MB	44.1 kHz	16 Bit	Lossless
AIFF	63.7 MB	44.1 kHz	16 Bit	Lossless

Everybody Wants To Rule the World

by Tears for Fears (1985)

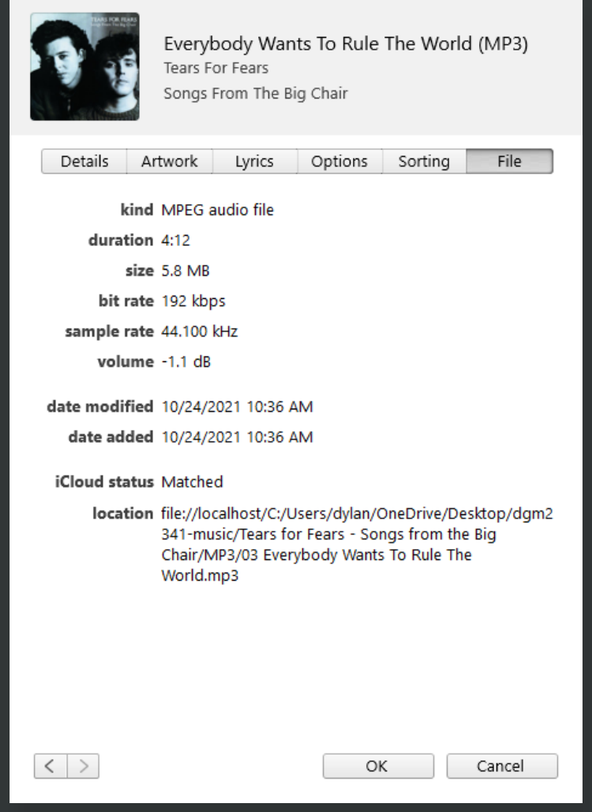


Fig 8. MP3 Audio File Example, iTunes player.

Album Art from Itunes

Live Reactions

I've grown up with this song as well. I'm pretty sure this file version isn't the one I remem-ber though.

But I feel like this one is off of what I have in my audio library already. It seems more con-stricted than the song should be.

This is odd because I've said that there isn't much difference between the audio files. However, the vocals sound great, but the guitar solo seems too lackluster and I know with the higher audio quality the guitar can sound purer.

It sounds just like the MP3 file to me. So, am I experiencing some type of placebo effect now?

In my head, it was going to sound much better, but after the first part of the song thus far, it sounds just as it did in the MP3 file. Vocals, guitar solo, bass, and more are all about on the same intensity, making it hard to perceive a difference.

As I expected it would be, the intensity is present in this version. The bass is heavy and more prevalent. I can't stress that enough, the bass seems more alive and guiding the song.

I'm biased with a strong bass in the song—doesn't have to be overpowering at all. The audio is just on a different level than the MP3 and AAC, which is allowing the bass to be free and sound more real. The guitar solo and even the iconic high tone strum of the guitar are more alive to me in this version.

Sounds just as it did in the FLAC file. At this point, I'm seeing the trend of the higher quality audio versions and it's pushing the equipment I have to its max potential.

So, I feel that the FLAC and AIFF experiences are so good and yet so similar that it's hard to tell a difference. Just as I can't tell a difference with the MP3 and AAC file versions. If I had to make one thing of note—even though it's prevalent in the FLAC file—the bass is strong and present here. More than I think it is in the lower quality audio files.

Air Pods Pros Listen Experience

After completion of the final song with my Air Pod Pros, I'm left dis-pleased. But not in the way that the audio files sounded horrible on my Air Pod Pros--In fact the music sounded amazing!

The issue was that I was expecting to be a massive difference between each song file, but I actually couldn't say that I can hear a difference, even between the AAC and FLAC transition! Everything sounded the same to me and it was overall shocking revelation at the end of this experiement.

File size comparrison **Song Duration: 4:11**

File Type	File Size	Sample rate	Bit Depth	Compression
MP3	5.75 MB	44.1 kHz	16 Bit	Lossy
AAC	7.87 MB	44.1 kHz	16 Bit	Lossy
FLAC	42.4 MB	44.1 kHz	16 Bit	Lossless
AIFF	42.3 MB	44.1 kHz	16 Bit	Lossless

Car Listening Experience

Additionally, I decided to test out my car's speaker system. My car is the Honda Accord Touring 2021 model, I mention this because I'm having trouble figuring out the audio system in the car. But, according to Honda, the sound system is a "powerful 450-watt, 10-speaker premium audio system" and you may note that those are some pretty strong marketing words (*Accord Sedan Specs Features*).

Once I started to listen to the songs in the car, I noticed it a completely different since there are way more distractions and background noise because I'm in a car. So, noting that new variable in the experience, I'm confident in saying that each audio file for the song sounded the same to me. Keep in mind the quote I cited about what Honda says is in my car. I feel that my Corsair headphones are the ideal listening device I own because it helps me give my full attention to the song.

Why is higher resolution audio files better?

In short, yes, the higher the resolution the better the audio quality will be. This is due to the possible dynamic range with different bit-depth levels. The dynamic range is the possible range an audio file can record audio levels at, without the risk of any artifacts or distortions from the highs and lows in the audio track (*Bit Depth*).

Also, it is good to remind ourselves that that lossless and lossy file formats are drastically different. Lossless file formats--FLAC and ALAC--can keep sound quality as true as possible from the process of compressing and decompressing the audio format (Berry and Boutillette). While Lossy is the opposite--MP3 and AAC--and they lose data (audio quality) from compression (Berry and Boutillette). This is a major distinguishing factor between audio files.

Using my listening experiment as an example, each time I listened to the MP3/AAC file, things seemed quieter and in hindsight and some distortions at the audio level, I was playing all the music files. Then once I got to the higher quality files like FLAC, the song's highs and lows sounded crisper and I can say that because I noticed more bass in some of the songs (E.g. Sowing the Seeds of Love, Tears For Fears).

It is hard to describe in words, again that is why I opted to do those live reactions to try to capture my thoughts. In general, for all the songs I listened to that was provided and songs from my library (See Fig 9 for audio files I played back from a lossy format to apples ALAC--if available ALAC was available) the higher quality audio files--FLAC and AIFF--sounded so much better than the lower quality files. Thanks to my Corsair Virtuoso SE headphones, sadly my Apple Air Pod Pros and my car sound system did not noticeable justice to higher quality audio files. In conclusion, the higher resolutions are better but you won't notice differences if your devices don't fully support what the audio files are capable of (E.g Bit depth and sample rate).

What is Sound Quality?

Sound quality is the over all resolution that is being played back. For example, more pixels in an image would produce a more detailed image right and this would also result in bigger file size. The same concept exists in the audio file realm of digital media. But instead of pixels, sample rate and bit depth are what helps determine the overall quality of the audio file--the higher the sample rate and bit depth the louder the audio file will be (Berry and Rodocker). There are more factors such as bitrate, but that is more for data transfer factors--which is important for streaming services (Berry and Rodocker).

Well, after completion of this listening experiment I've learned that the sound file does matter if you care about quality. If you are just casually listening to a song, then AAC or MP3 files are great. But, I can't go back to these file types, and that's due to now being exposed to what higher sound quality is. Even though there is a downside of having to use more space in your storage for higher quality audio files, but it is a reasonable price to pay in my opinion.

Downloaded Listening Experiment Conclusion

After my first experience with testing my hearing perceptibility, I believe I've started to grasp why it's important to listen to different audio file formats. I think the experience you get from listening to these types of audio files gets you closer to the music. I say this based upon this immersive feeling I was getting as I listened to higher-quality audio files.

I was able to pick out some more bits that I don't think I noticed before, such as some bass strumming, ambient noise, and more. But it was always subtle little things that made that experience much more than you would get just listening to a standard file like MP3 or AAC. Things felt more lively and it was more fun to listen to in general as well. This was also my first time listening to high-quality audio files I think because I had a genuine reaction to each file type I listened to, that is why I wanted to take the approach of unfiltered reactions to capture that brief moment if possible.

In short, IF I was utilizing the proper listening equipment and listening to the higher quality audio files, I did notice a difference. Everything was more lively and immersive, and that is due to the listening equipment I have that enables the audio playback to be at a higher resolution format like AIFF.

Fig 9. Other music I tested

Hybrid Theory, Linkin Park

This is a child hood favorite, I was able to stream and download this album with the ALAC and I originally owned the MP3 version. After listening to the ALAC version of the album and using the proper audio equipment, I can confidently say I noticed a difference it was mainly more loud and it felt more engaging than the MP3 version.

Sgt. Pepper's Lonely Hearts Club Band, The Beatles

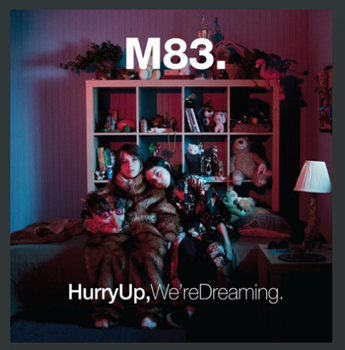
I mainly listened to "Lucy In The Sky With Diamonds" because that is a go-to favorite of mine from the Beatles so I was curious if I would notice a difference. One thing I noticed was the high pitch of the guitar in the song ringed more in my ears but was more clear. Is it a massive difference from MP3? Not really, but I did notice a slight difference with how the playback of the song handled the high notes.

Pressure Machine, The Killers

This is a favorite band of mine and when I saw they released a new album and was offered with spatial and lossless audio with Apple Music, I had to test it out. I used all my devices (headphones, Air Pods, and car sound system). In short, it sounded best on my Apple Air Pod Pros, and the second-best was my head-phones. The car was had no noticeable difference between switching from streamable audio files. This contradicts what I experienced with the provided music for the experiment, maybe it was more optimized for the Air Pod devices.

Hurry Up, We're Dreaming, M83

I mainly listened to "Midnight City" from this album, after switching my set-tings to download/stream the highest quality audio file, and following the ex-periment pattern that I described before. I did notice the overall loudness dif-ference between each file, but I rather describe the loudness as more engag-ing--meaning I was more engaged in listening and enjoying the music. But, it sounded the same between both my headphones and my Air Pod Pros.



Album art is from iTunes

Investigation of Streaming Services

Ever since the point in history where Steve Jobs introduced iTunes on January 9th, 2001. The world of digital music services has evolved to a point where services can offer a higher degree of digital audio experiences.

"Apple has done what Apple does best -- make complex applications easy, and make them even more powerful in the process."
--Steve Jobs

I think that many modern streaming services have taken that quote and built their platform to mimic that idea Steve Jobs is talking about. Platforms such as Spotify, Tidal, Qobuz, and Apple's modern iteration of iTunes is Apple Music has focused on the new modern platform and serves up high-quality audio files and experiences.

I mention that quote from the Macworld Expo of January 9th, 2001 for a specific reason. I think that iTunes set the bar--or the blueprint--for digital platforms to help facilitate music consumption. I used Zune's desktop application growing up--it has been discontinued in 2015 (*Zune service retirement*). But, iTunes has endured and evolved since its conception. Due to that, my hypothesis for this part two of the digital audio listening experiment is that most other modern streaming services will mimic iTunes/Apple Music in terms of aesthetics. But, may differ in how content is discovered or navigated, or have certain exclusivities that others don't have.

The Investigation Process:

To determine the difference between the common music streaming platforms. I'll be doing the following: listen to a provided playlist (same songs from part one of this documentation) and some other chosen songs from my library. Listening environment variables and audio listening devices are the same as well, I'll be using the Corsair Virtuoso SE, Air Pod Pros, and my car sound system--see **Fig 2-3**.

Essentially the same process, except NO downloaded music, it is only streamed. This will help answer the question of if streaming music platforms can serve up higher resolution audio files, the factor that can limit the potential of a streaming service is bitrate (see **Fig 11**). I'll additionally documentate any information gathered on that as well.

What to consider with Streaming Services

Now a days, you can pick many types of streaming services, and each offers specific perks. Such as exclusive artists/songs, pricing solutions, and technology that could benefit the overall consumer experience. Part two of this documentation will focus mainly on the tech and how it's being served up.

When choosing a streaming service, you should be careful with how you spend your money. Because the platform could be offering something that may not be worth the cost for it. For instance, in **Fig 11** you can see what Tidal offers with their streaming service. Streaming quality has been a common concern for consumers, and services have taken that concern and built a market around it. Tidal offers up streamed audio files from AAC (normal/standard quality) to MQA (Master quality)--specifically, they can serve up AAC, FLAC, and MQA (*Clearly the best sound*). That is just an example of what one of these streaming services can offer.

So with that said, when picking a streaming service, you must consider what your service of choice can offer you. Many people have been going towards platforms that offer audio formats that mimic the original recording as much as possible. I'll explore this later as I spotlight each streaming service.

Common Streamed Audio Files

Just as another refresher, here are the common file types that these services will offer to be streamed. Which is a major selling point for platforms that are trying to appeal to the Audiophile demographic, because certain file types offer Master quality/HiRes quality that is about as close as you can get to real-life studio performance.

Lossy

These file formats are formats the compress data down to a more manageable/desired file size, at a cost of lost data that is not recoverable (Berry and Boutillette). Files that do this are MP3, AAC, and Ogg Vorbis which are some files that served up with these streaming services. The downside of these formats is that they sacrifice the overall sound quality is presented to you since it's losing data due to compression (Berry and Boutillette). But, this helps with streaming because the bitrate is more manageable with the common household or mobile device. For example, MP3 bitrate ranges from 96-320 Kbps (Berry and Boutillette). Nowadays, that is a managed data stream to deal with, but because it is a lossy file, you are sacrificing quality/data for this benefit

Lossless/Uncompressed

These file formats are the opposite of lossy files, data is preserved and that also means quality is preserved as well (Berry and Boutillette). But, quality comes at a cost as well! File sizes are typically much larger and this, in turn, increases the needed available bandwidth to comply with the file's streamable bitrates. File examples are ALAC, FLAC, AIFF, WAV, and MQA.

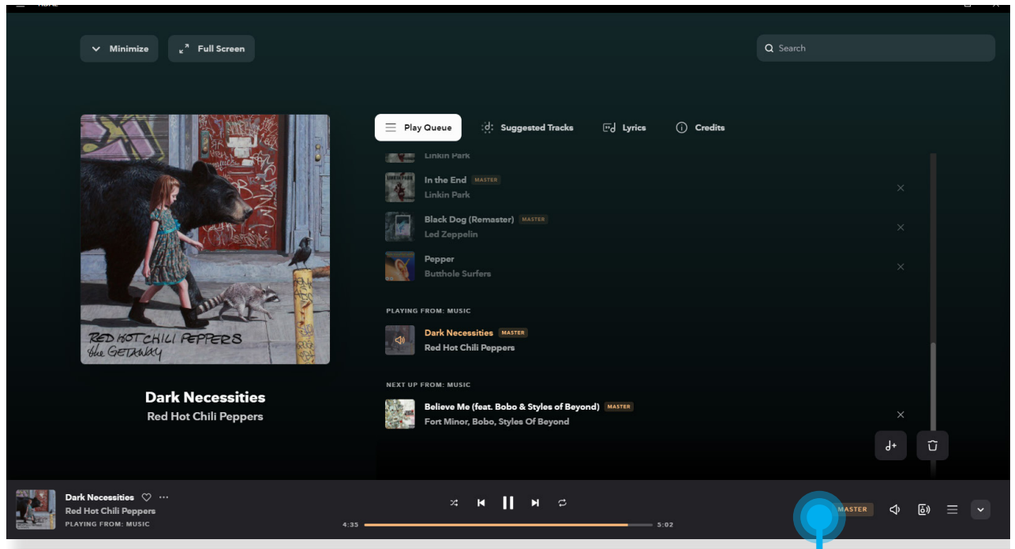


Fig 10. Tidal Desktop Application

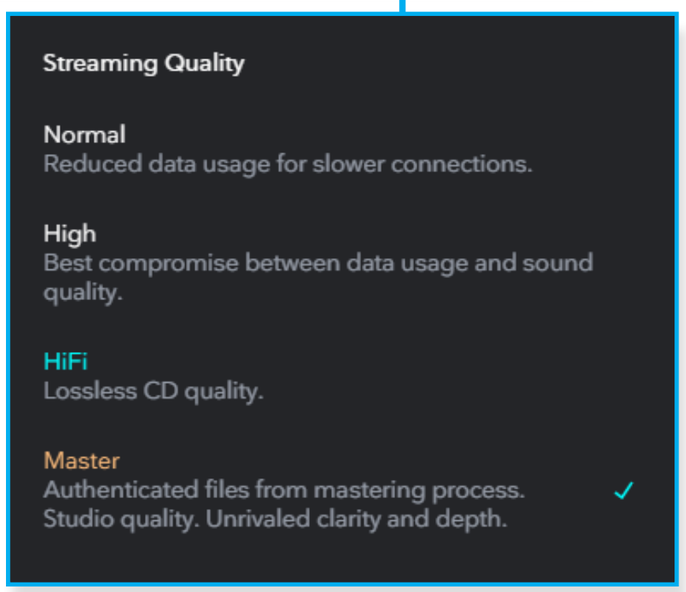


Fig 11. Tidal Desktop Application File Quality Picker Open

What is bandwidth?

Bandwidth is often talked about alongside internet speeds. Yes, a better internet speed would help with download/upload rates. But bandwidth is the concept of the max amount of data able to be communicated over some time (Bandwidth). It is calculated by megabits per second or Mbps.

Streaming Quality

Platforms, such as Tidal--**Fig 10**--ofer different streaming quality settings. In the desktop application, you can click on the bottom right where it would say a quality type to be streamed. Of course, this is subject to your subscription to Tidal.

Tidal advertises three streaming quality/file types on their site, while there are four available options in the application for your streaming preference. With that said Tidal offers AAC (Standard, 320 Kbps bitrate), FLAC (HiFi, 1411 Kbps bitrate), and MQA (Master/High-Res Quality, 2304-9216 Kbps) which is Tidals main selling point in their streaming platform (*Clearly the best sound*).

Other platforms offer this as well, but Tidal is a perfect example of having the freedom of what streaming quality you want to listen to. This is giving the consumer the ability to listen to what they want to, and if they have the proper audio devices to listen to the Master quality music they can! Keep in mind, the streaming service doesn't matter--if you only want the HiFi and upper streaming qualities--if you don't have the proper audio equipment.

Fig 12. The Music Playlist

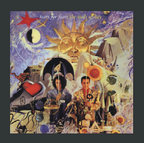
Here is the music I'll listen to for part two of this documentation. It is mostly the same music that is listened to in part one, but now I'm only streaming the music--not downloading.

"The End Of The Innocence"
by Don Henley

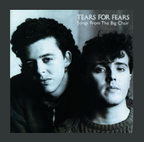
"On the Turning Away"
by Pink Floyd

"Babylon Sisters"
by Steely Dan

"Clocks"
by Coldplay



"Sowing the Seeds of Love"
by Tears for Fears



"Everybody wants to rule the world"
by Tears for Fears

I additionally listened to some music that I chose from my music library, and tested them all on all of the music platforms, at different streaming qualities if available.

- "Feel Good Inc", Gorrillaz - 2006
- "Don't Forget Me", Red Hot Chili Peppers - 2002
- "Where Is My Mind?", Pixies - 1988
- "Points of Authority", Linkin Park - 2002
- "Black Dog", Led Zeppelin - 1971
- "Pepper", Butthole Surfers - 1996
- "Dark Necessities", Red Hot Chili Peppers - 2016
- "Believe Me", Fort Minor - 2005

Album art from iTunes

Apple Music

Ever since my Zune broke in 2011, I started to use iTunes as my primary solution to download and consume music. Then it became my primary choice for streaming music as well, albeit it is my primary choice because I'm on a great family plan package. I mention this because I recognize I may be biased on my descriptions of iTunes/Apple Music.

Apple Music is evolved recently with the introduction of new technology Apple has developed, such as the Apple Air Pod Pros and the Apple Air Pods Max as well. Then Apple Music had the addition of Spatial Audio that had the added perk of Dolby Atmos and on top of Apple's lossless codec (ALAC), the music listening experience is truly awesome!

What does Apple Music Offer?

Apple Music has begun to offer higher quality audio for those who use Apple music. They offer lossless audio files, Dolby Atmos, and since June 2021 Apple Music has combined those two technologies with Spatial Audio (*Apple Music announces*). This is massive to me because as of late, immersion has been the topic in my mind. Spatial audio is truly a fun thing to play around with and since I'm subscribed to Apple Music, I can listen to any artist who specifically mixes their music to have that immersion factor, because of the support of Dolby Atmos (*Apple Music announces*).

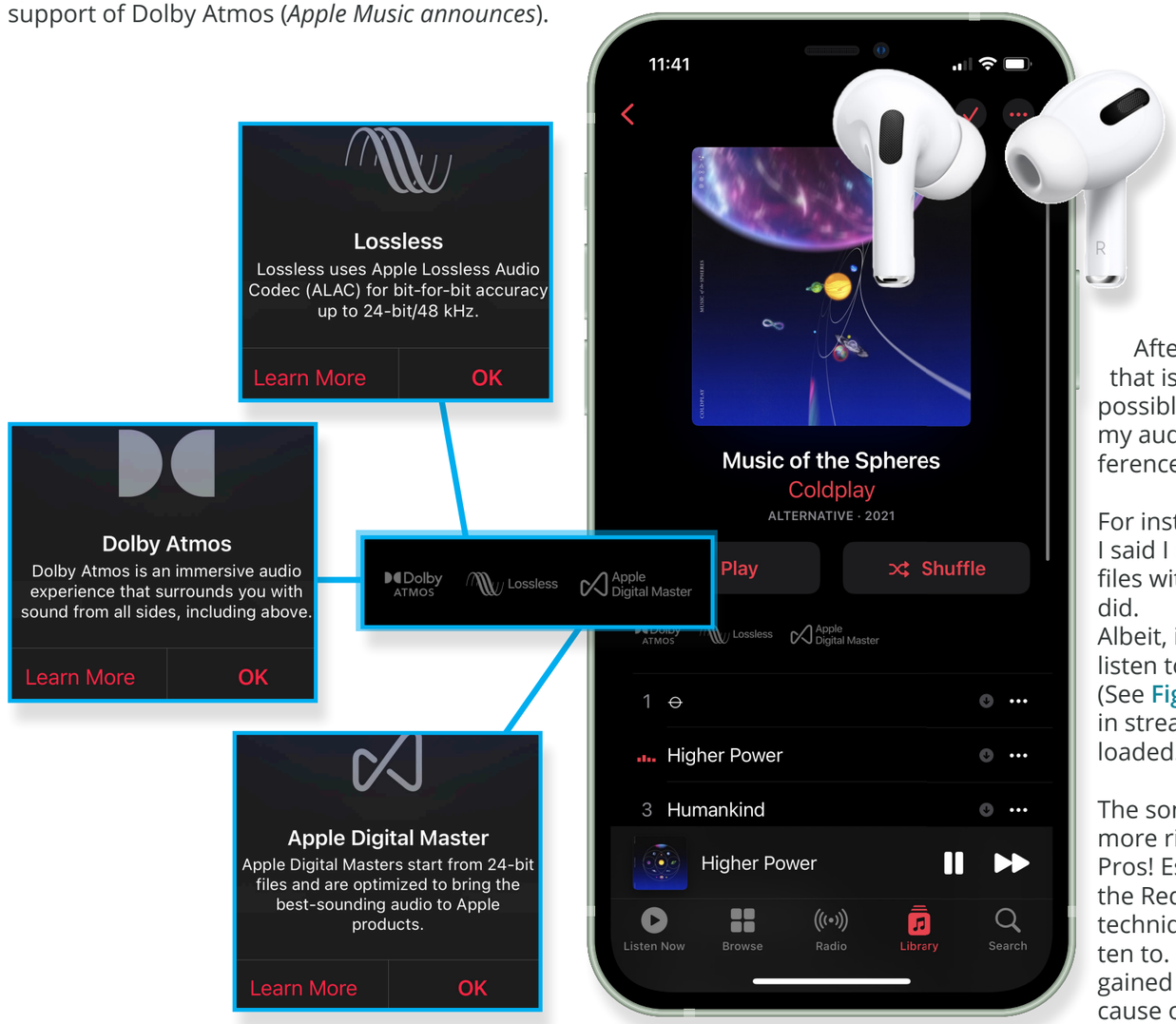


Fig 13. Apple Music iOS, Audio Tech.

Apple offers these audio streaming capabilites. But, you must have the proper bandwidth and peripherals, such as Air Pod Pros Max or other listening devices.

How to Change Audio Quality

I found changing my audio streaming quality distasteful, I was surprised by how Apple has you navigate to where you can change the setting to stream the music.

If you're on your phone, you have to navigate to your phone's Settings app > Music > then Audio Quality (See Fig 14). That setting isn't natively available on your iOS Music App, which is why I never actually even enabled the setting till now! I thought it was automatically playing the best audio for me, but it wasn't.

The same process follows in the iTunes desktop app as well, but it is also an annoying process to get to that point. Once your iTunes app is open go to Edit > Preferences > then Playback. Look towards the bottom of the window and you can see what sample rate you want to stream and bits per sample as well.

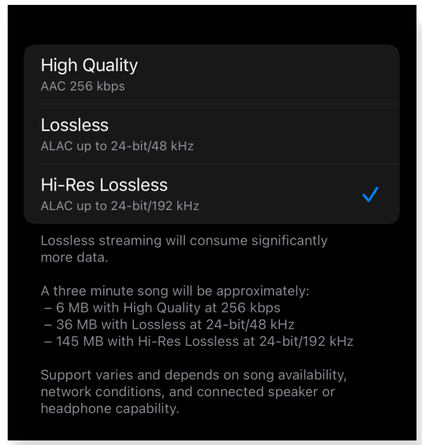


Fig 14. Streaming Quality Settings Screen Shot

Stream Quality Differences?

After spending more time listening to music that is set to be streamed to me in the highest possible setting--Hi-Res LossLess. Listened with my audio devices in Fig 2 and 3. I did notice a difference in quality in specific albums/songs.

For instance, in part one of this documentation, I said I didn't notice a difference between audio files with my Air Pod Pros, but this time around I did.
Albeit, it was with more songs that I chose to listen to. Sadly, the songs that are provided to me (See Fig 12) did not have a noticeable difference in streaming them instead of having them downloaded.

The songs I did notice a difference though, felt more rich and immersive, even in my Air Pod Pros! Especially in the song "Dark Necessities", by the Red Hot Chili Peppers. The Flea's slap bass techniques were so much more pleasing to listen to. I always knew Flea was a legend, but I've gained more of an appreciation for his art because of the streaming quality that the song was played back at--ALAC 24-bit and 48 kHz.

Spotify

As I offered full transparency of my pre-existing experience with iTunes/Apple Music, I'll do the same for Spotify. I haven't had any prior experience with this service, nor have I ever cared to. I was always under the impression, admittedly not giving the application a chance at all, that Spotify was just bad. I was heavily invested in iTunes/Apple Music, I feel that is the main driving force and rationale I formulated for my reasoning. With that out of the way, I think Spotify isn't a bad platform at all and if I wasn't invested in the Apple counterpart already, I would see myself using this service.

What does Spotify Offer?

Spotify says they offer up a few solutions for their streaming service, and this varies on your plan as well. They offer Ogg/Vorbis (96, 160, 320 kbps), AAC (128, 256 kbps), and HE-AACv2 (24 kbps) which is essentially their range file types they can stream (*Audio file formats for Spotify*). That is on the file types Spotify says they'll stream to you, but those files require certain bandwidths to stream at the file's full capabilities.

Music Qualities

If you're in a web browser, using Spotify's service, you'll be limited to a couple of very specific streaming qualities. The first is Spotify Free (AAC, 128 kbps) and the second is Spotify Premium (AAC 256 kbps), this limitation though is only present in the Web Browser (*Audio Quality*).

Using the Desktop, tablet, and mobile applications allows you the ability to listen to a bit more possible streaming qualities. Giving you the freedom to pick how you use your bandwidth. In **Fig 15**, you can see that you can pick and choose your streaming quality. But, it doesn't offer much transparency on what each setting is streaming to you.

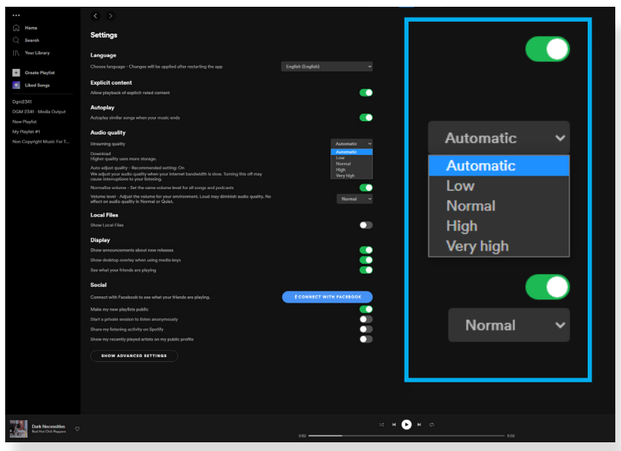


Fig 15. Spotify Desktop audio play solutions

Spotify Streaming Qualites - Desktop, Tablet, and Mobile application

Automatic: This setting adapts based on your network connection. In other words, it adapts to what your bandwidth is--which can be dynamic.	**Low:** Streams 24 kbps to the client, which limits the overall sound quality of the audio file you're listening to.	**Normal:** Streams 96 kbps to the client, which is getting to a more of a standard sound quality.
High: Streams 160 kbps to the client, which is above normal. Info from Spotify	**Very High:** Streams 320 kbps to the client. This is only for Spotify Premium though, you'll have to pay for this stream quality.	

Stream Quality Differences?

In short, there were very few songs where I could pick out a difference between songs. Some songs sounded better on Apple Music than Spotify, for instance, "Believe Me" by Fort Minor, sounded much better on Apple Music. But, there could've been some issues with my bandwidth and caused it to sound bad. But, just as Apple Music, I had my stream quality settings set on max. For overall user experience, it's fun and interactive, especially with the music videos that play in the background. But, they aren't very clear on what you're getting with these stream quality presets at all.

Tidal

Tidal's mission is to be a global platform for consumers to listen to their favorite artist's music at the highest possible sound quality while being streamed. They emphasize their ability to deliver high-quality music to a consumer because it is a lossless, high-fidelity file quality that is being streamed to you (*What is Tidal?*). Because of that, it has become a music streaming platform that has disrupted the market.

What does Tidal Offer?

Tidal offers a variety of streamable audio files and support for audio listening devices. Companies have teamed up with Tidal to ensure that the best possible sound quality is being played on the device for the consumer (*Clearly the best sound*). These companies are Bluesound, Cambridge Audio, Denon, Kef, and McIntosh (*Clearly the best sound*). But, those partnerships don't matter if the file that is being streamed from Tidals service isn't a high-fidelity file!

The files they stream to consumers are AAC (Standard - 320 Kbps), FLAC (HiFi - 1411 Kbps), and MQA (Master/HighRes Quality - from 2304 to 9216 Kbps)--there is another tech such as Dolby Atmos and 360 Reality Audio offered up as well (*Clearly the best sound*). You can see this in **Fig 11**.

Fig 17. Tidal iOS, Master File Playing

What is MQA?

Master Quality Authenticated (MQA) is a file format that is designed to be the highest possible quality--which is a 24 bit and 96 kHz sound file (*Clearly the best sound*). The story behind MQA has some controversy too. However, that boiled down is just controversy about how MQA is a licensed format and you have to pay to use that for your work. Which could understandably leave a bad taste in some people's mouths. But in reality, MQA is a high-quality file that offers more than it hurts I'd argue.

MQA was designed to offer master quality audio but also be streamed seamlessly across the internet, it is a lossless audio format that is also able to be a small file size too (*What is MQA Audio?*).

Stream Quality Differences?

Yes, I could pick up a difference in quality cycling between stream quality presets. But, only on a few specific songs, I listened to in this experiment. For instance, in **Fig 17**, the song "Don't Forget Me" by the Red Hot Chili Peppers had some notable differences as I picked between stream qualities. Albeit, minor differences that I wouldn't have noticed if I wasn't doing this research at all. In short, the song had more dynamic range and heavier tones that made me resonate with the song. It is a reason why I'll be keeping my Tidal subscription.

Qobuz

This platform was founded in 2008 and its goal is to provide high-fidelity music to Audiophiles (*Why Qobuz Is Unique*). They emphasize their streamable audio quality, and they claim they were the first platform to offer 24-Bit Hi-Res streaming for consumers (*Why Qobuz Is Unique*).

Fun back story, Qobuz's name and logo are inspired by an ancient instrument 'Kobyz', and come from the Central Asia area (*Why Qobuz Is Unique*). This is a platform by Audiophiles for Audiophiles

What does Qobuz Offer?

Qobuz offers a range of streamable sound qualities, essentially the same as all other streaming services. They offer MP3 (320 Kbps), CD Quality (16 Bit - 44.1 kHz), and Hi-Res Audio (24 Bit - 192 kHz) which is the main driving force for their platform (*Because your music*). They signify music in their catalog with a symbol that you may have seen around, see Fig 19. Just as what you see in other streaming services, they signify in somewhat you're listening to a high-fidelity file type.

You can go to Qobuz's Audio Quality page on their website, and you'll see a glossary of terms and other important information they think their consumers should know about--see Fig 18. Even though this is just on their website, and not right on their application. The fact that they have this page proves the passion that is being driven here to enable people across the world to have access to high-fidelity music.

So, why do I mention this? Well, that is because there wasn't anything else that I noticed with other streaming platforms that gave me the feeling they care about their product. Just because they offer a page to help educate their users on some important concepts.

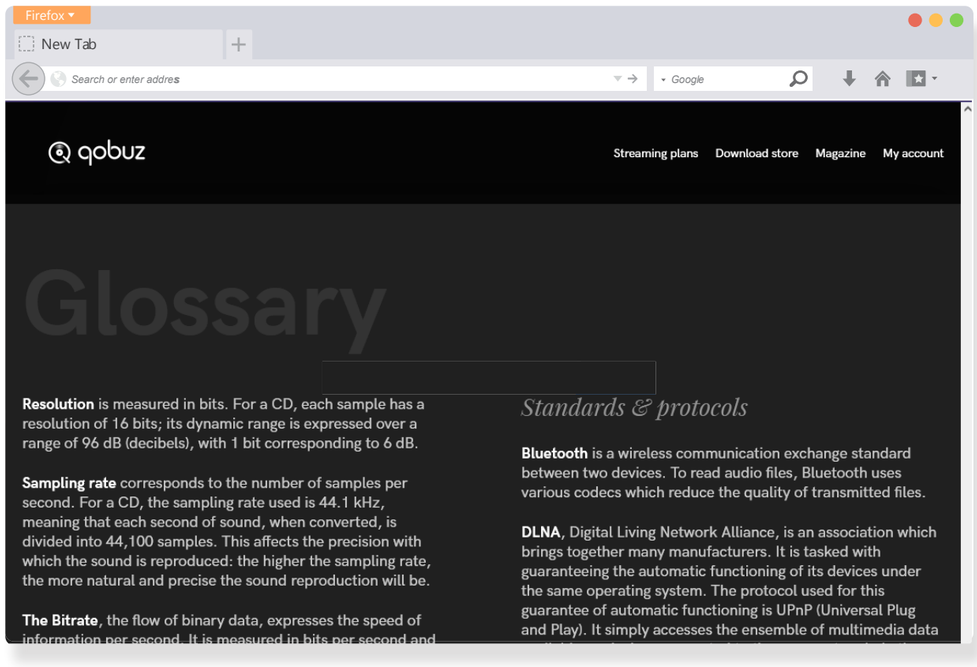


Fig 18. Qobuz Screen Shot of Website, qobuz.com/us-en/audio-quality

Stream Quality Differences?

Just as Tidal, I didn't personally notice any differences in the provided music. But, when I started to look at my Music in the different streamable qualities Qobuz offers, I did notice differences in the same music I noticed were sounding different from the other services. These songs from Red Hot Chili Peppers, Gorrilaz, and Fort Minor felt more interactive. In summary, yes there were notable differences but it was the same experience essentially like the other services I tested out.

Fig 19. Hi-Res Symbol seen on Qobuz

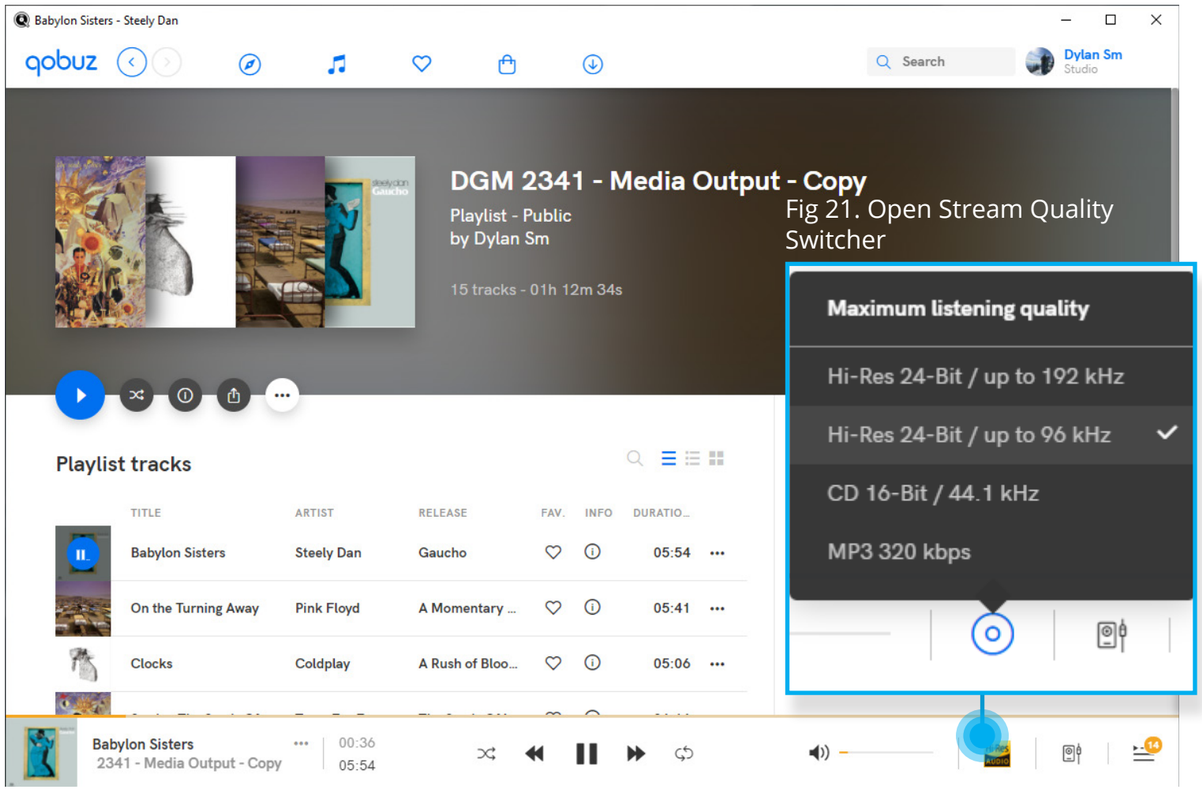


Fig 21. Open Stream Quality Switcher

Fig 20. Qobuz Desktop Application Stream Quality Switcher

Above you can see how Qobuz handles stream quality switching. The process is essentially the same across the other platforms, so is the desired outcome. But what differs here is the use of symbology to establish what you're listening to.

Conclusion

To sum up the overall experiment. As I was listening to the provided music--downloaded and streamed--I did my best to pick out if there was any quality differences or experience difference. While part one offered me some issues with picking out the difference on some things. Part two offered more evidence to me that there is a difference in quality between files and streams.

However, those differences were only notable in songs that I picked from my library. This isn't the outcome I was searching for, I wanted to be able to notice more differences. But I couldn't and I think that is because my hearing is different to others--because I had peers say they noticed a difference in stream quality. Although, for the songs that I did note a difference in quality as I cycled through file types and stream qualities, I was able to gain the information I need to say this experiment was successful.

That information was yes there are differences, you need specific equipment to listen for those quality differences, and the knowledge of different file types is important to know so you can utilize that equipment.

Section Three: Image Formats

Image formats come in many different types, just like audio files or video files, each file will have its pros and cons. It is important to understand those differences to inform yourself of which would be the best file format to use. As a developer, understanding those differences allows you to communicate that to any designers or clients and the knowledge of how to optimize your projects. As a designer, understanding the difference informs on what each file is capable of, how the overall design will be impacted with your choice of format, and you'll be able to make sure you're picking the optimal files for developers to implement into the project.

Files such as JPEG, PNG, and GIF are amongst the most commonly known image formats out there. The reason being, each is typically pretty great for websites, if they're compressed enough for load times. Each has its differences and use cases. For example, JPEG is a lossy file format that allows you to display raster images to the web and you have an option of different compression choices. If you go into Adobe Photoshop and work with a JPEG image, you have an option to compress the image quality in a range from low-high--higher the quality more detail in the image is preserved (*File formats*). The other formats like PNG, GIF, and many more have their qualities as well. PNG is a lossless format and offers support for designs that have transparent elements (*Image file type and format guide*). GIF is also a lossless compression and offers better quality sharp edges and curves--fewer artifacts along edges of designs when scaled up (*Image File Formats - JPEG, GIF, PNG*).

With that quick summary of arguably some of the most common image formats, here is the deep dive into the technology.

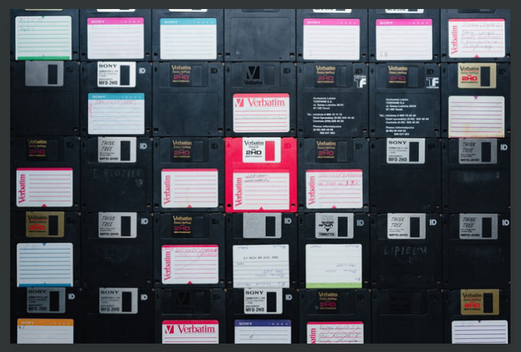


Figure 1. Migaj, *A flat lay of few old school diskettes,* 1 Apr. 2021.

Image file formats is a lot to take in all at once. You have to take the time to look at each file format and understand how to properly employ it. Sometimes you'll have to worry more about the exact details of each format. Todo that you'll have to have a fundemantal understanding of each file format.

In this documentation, I'll walk you through some important concepts to understand, the basics of each file, when and where to deploy them, how to work with them, and why you should work with them.

As a designer or developer, it is absolutely key to understand the tech you're working with to optimize the expereince for a user. That is a goal that anyone in this industry should have. There should be no excuse for the lack of effort into building a website and trying to load an image on there that'll take minutes to load.

Here is a snapshot of Image File Formats.

Introduction

Comparison: Raster vs. Vector

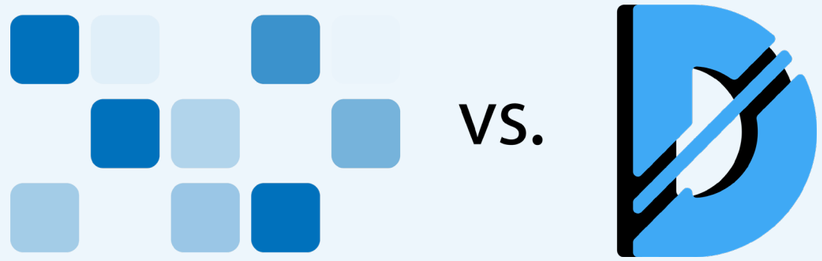


Figure 2: Raster vs. Vector

Raster images are made up of pixels and are dependent on the resolution of the image, so an image is set to be only one size (Lundquist). Meaning this, if you scale that raster image up, you may start to see artifacts in the image because the computer is trying to fill the voids that result by scaling up a raster image. That is because a raster image file itself is set to be one thing only—the resolution as it is—which leads to the problem of distortion of your image when you scale it up (*Sebastian*). In other words, raster image files have a defined set of instructions for that image and when a device tries to display it, it'll go by those instructions to display it (*Sebastian*). Does that mean all raster images are bad? No, these images can look amazing! Especially when we use it for photography because there are raster image codecs that are still of great quality.

The difference with vector images is that they are fully scalable. Meaning if you scale a vector graphic, you'll be able to see the quality as it is. If you scale a regular raster image, eventually you'll start to see a mess of pixelation, because your computer is trying to fill in the gaps. The reason why for this is that vectors are fundamentally different as compared to raster (*Sebastian*). Vector files such as SVG, "defines lines and shapes and their positions relative to each other" (*Sebastian*). Simply put, a vector file is a math-based formula, which allows it to scale properly. Another massive plus is that vector files are a lot smaller than their counterpart, raster images.

Can you see quality?

If you're someone who doesn't work with images and file formats daily, you may not be able to look at an image and notice imperfections in that image due to compression. On the other hand, if you're someone who works with these things daily, you could look at an image and get an idea of what format is being used. Each format has its differences and some have signs of lost data, resulting in an image that has less overall quality.

For example, you can take an image that is a RAW format and then take another image that is converted to another format like JPEG. The difference will be night and day for anyone who is analyzing the image. JPEG is a format that compresses data down, it is a lossy format as well, resulting in a loss of data and quality of the image. Even though it is one of the most common image formats out there (*Overview of JPEG 1*). It is not the best due to it being lossy compression and JPEG only supports 256 colors as well (*Image file type and format guide*). Even though the quality of the image is down, the benefits are smaller file sizes which are beneficial for websites and you can also compress JPEG at different qualities as well offering you the ability to have wiggle room (Lundquist).

When you start to get into different image file formats like TIFF, you get to deal with higher quality images because TIFF is an uncompressed file format--but does offer compression sup-port as well (*Image file type and format guide*). TIFF offers a greater range in color mode(s) as compared to JPEG and a higher amount of pixels that can be contained in the image as well. TIFF can contain much more data since it is uncompressed and because of that, you'll be able to look at an image that is a TIFF file and see details you would NOT get any lossy compression formats.

See figure 3, as an example of the same image but compressed at two different qualities. As previously mentioned JPEG is a lossy compression codec. I'm choosing JPEG here because it is one of the most common image formats for the web, and it allows you to compress the quality at different levels--enabling you to have control of how much data/image quality is lost (*Optimizing images for the JPEG format*). It may be hard to tell the difference, so I recommend trying out this experiment yourself and with whatever formats you want as well.

In conclusion of this topic, the concept of perceptible quality is the ability to perceive the differences of quality between things, in this case, images and specifically the image file formats being used. The ability to perceive the dif-ferences may take a trained eye at the end of the day. So, when you're working with imagery over the web you may have difficulty noticing the differences. Because there are so many different types of devices and screens in the world that can display imagery differently, for example, an image could look different on an Apple device than it would on a Samsung. To get around the issue of users on these devices noticing bad quality, web developers/designers employ responsive web design--especially with image files. You can code different images that vary in quality and sizes to display images, mini-mizing the ability to perceive imperfections in the quality of content on screen.

Figure 3. McGowan, *Colorful Image, 23 Feb. 2020*

Popular Image Editing Software

As an introduction to image editing software out there. I want to state I selected some that are some of the most commonly used. There are many solutions out there to choose from, but for simplicity, I'll be covering: Adobe Photoshop, Adobe Lightroom, and GIMP. However, for photoshop I'll talk more about it since it's a powerful photo editor and it's one of the most commonly used in the industry. With that said, here are some good choices for applications that allow you to edit images, manage, export/import image types, and much more.

Adobe Photoshop

Photoshop is a very common photo editing tool amongst all levels of photographers or any digital media designers. The power it can give to a person is mind-boggling, but it is an industry tool and professionals use this. Meaning it has a lot of features to learn about. You can edit layers, colors, paint, and so much more (*Lightroom vs. Photoshop*). However, we are here primarily for the image formats you can work with this editing software.

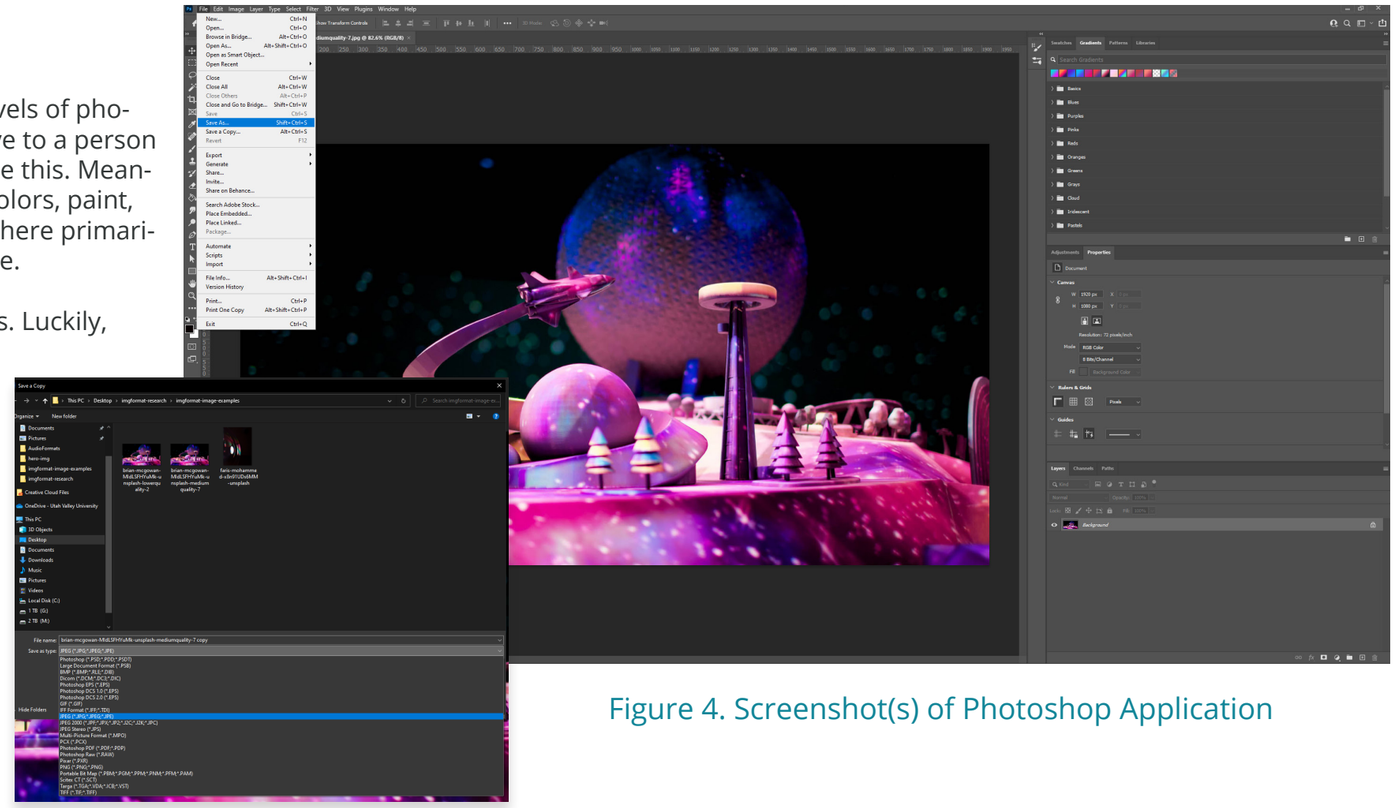


Figure 4. Screenshot(s) of Photoshop Application

File formats are superheroes, each has a power and a weakness. Luckily, Photoshop can work with an absurd number of file formats. See Figure 4, which is a screenshot of the graphic file format that Photoshop can support. Well, you might be saying now that isn't absurd at all, it's just a lot of graphic file formats. Not only does Photoshop support graphic file formats, but it also offers these as well Video file formats (import/export) and 3D file formats (*Supported image formats*).

As you can see, Photoshop offers a great deal of compatibility for different file formats. The cool thing though to do with photoshop is to take a RAW file such as BMP, and then work on all the details you want! The reason is that the RAW file is a complete original data set, which is an image (*Image File Formats - JPEG, GIF, PNG*). You can touch up an image or go crazy and make something that is a masterpiece, and if you make a mistake you can go back to a reference point of the file without risk of causing damage to the file (Harper). However, RAW files are massive files, which isn't ideal for storage space. So, that's when you get to export that RAW image to another extension that can downsize that file to a size you would as the creator. This makes it one of the best photo editing tools for professionals, some say it is "The world's best image editing software" (Muchmore).

Adobe Light Room

This application is popular amongst photographers because it offers great tools for output and printing options for the photographer (Muchmore). You can say it's a sibling to Photoshop since it's under the Adobe umbrella of digital media applications, but there are some key differences here. The main difference is the goal of the creator. Lightroom is great for creators that have a bunch of photos that need to be managed and processes (*Lightroom vs. Photoshop*). Adobe designed the application to enable professional photographers to have a streamlined workflow of image management and touch-ups to photos (Adobe).

Perks of Adobe Light Room:

- Organization: When you're a professional photographer, you need to be able to manage your photos properly. Adobe Lightroom provides that with the ability to manage and catalog your photos, which is beneficial for a wedding photoshoot for example.
- Editing: Lightroom can edit images by tweaking: light, color, aspect ratios, and more to add a final touch to your photo.
- Supported File formats: Camera raw formats, DNG, HEIF/HEIC, TIFF, JPEG, PSD, PSB, CMYK files, PNG, and some Video file formats.
- Limits: doesn't support adobe illustrator files and file dimensions greater than 512 megapixels.

Information was gathered from Adobe.

GIMP

GIMP is similar to Photoshop, in that it manipulates images. The key difference between the two applications is that GIMP is free to use (*About GIMP*). The name of the tool itself is an acronym and it means GNU Image Manipulation Program (*About GIMP*). It is an alternative for photoshop and could be the perfect place to start with editing photos because it is free. It does photo/image editing, paint, batch processing, image rendering, and the one that is key to this paper is its ability to be an image format converter (*About GIMP*).

The perks of GIMP:

- Supported File Formats: BMP, GIF, JPEG, PNG, PCX, PDF, PNG, PS, PSD, SVG, TIFF, TGA, XPM
- Supported Platforms: GNU/Linux, Windows (7 or older), macOS(10.6 or older)

Information was gathered from *Downloads,* GIMP.

Some more image editing applications: Adobe Photoshop Elements, DxO PhotoLab, Corel Paintshop Pro, Adobe Photoshop Express (Muchmore).

Image File Formats

Image file formats come in many different flavors; each has its use case. In this next section, you'll be able to see a snapshot into each format and see the core differences in each of them as well. This should help inform someone on which format to use, but as a web developer, the ones to look at the most maybe JPEG, GIF, PNG, and SVG file formats. The rest could result in a poor experience for the user because the bigger the file or the higher the quality of the image will result in longer lead times. If you have the applications that I previously mentioned--or a similar one that allows you to work with multiple files--I recommend messing around with the file formats and see how each one is objectively different.

Raster Image Types:

Joint Photographic Experts Group:

JPEG 1 (standard: ISO/IEC 10918) was developed in 1992 and is one of the most common image formats (*Overview of JPEG 1*). It is a lossy compression type, which means your quality goes down as you compress the file more (Nichols). JPEG image files are commonly used on the web to display imagery since it's compressed so well, it helps with load times for users. However, since it's a raster image, you must keep track of your resolution and the file size as well to help optimize your use of JPEG files (Nichols).

The tech behind JPEG:

- Standard Body for Maintenance: JPEG
- MIME type: image/jpeg
- Compression type: Lossy
- File extension(s): .jpg, .jpeg, .jpe, .jif, .jfif
- Color Mode(s): True Color (8 bit RGB; 256 Colors)
- Compatible Browsers: Firefox, Chrome, Edge, Safari, Internet Explorer, and Opera
- Max image dimensions: 65,535 x 65,535 pixels

Graphics Interchange Format

GIF format is a great solution—as a raster file type—for graphics that have sharp edges and curves, such as Logos (*Image File Formats - JPEG, GIF, PNG*). Yes, it is a raster image type, so you may be thinking that might not be good for objects that have edges and curves because that could cause artifacts to pop up due to compression. Well, GIF is a raster image format with lossless compression! It gives you the ability to work with graphics that have edges and curves, it results in a cleaner image (*Image File Formats - JPEG, GIF, PNG*). But it's limited to 256 colors and that results in images—or animated GIFs—to look grainy at times (*Image File Formats - JPEG, GIF, PNG*). In short, it has a use case for digital design but there are alternatives like PNG.

The tech behind GIF:

- Standard Body for Maintenance: CompuServe
- MIME type: image/gif
- Compression type: Lossless (LZW)
- File extension(s): .gif
- Color Mode(s): Indexed Color (8-bit; the concept is that the 8 bit serves as an index for an array of 24-bit colors; 256 Colors)
- Compatible Browsers: Firefox, Chrome, Edge, Safari, Internet Explorer, and Opera
- Max image dimensions: 65,536 x 65,536 pixels

PNG

Portable Network Graphics

PNG is a favorite solution because it offers greater flexibility with design due to PNG's ability to support transparency or alpha channels (*Image file type and format guide*). Since it is also a lossless compression type as well, you have to keep in mind file sizes and how that'll impact your website/application. But it still can compress graphics down without artifacts so it isn't a massive file size as compared to maybe what a TIFF file size would be.

The tech behind PNG:

- Standard Body for Maintenance: W3C
- MIME type: image/png
- Compression type: Lossless (an alternative to GIF)
- File extension(s): .png
- Color Mode(s): Greyscale (up to 16 bit), True Color (up to 16 bit), indexed color (up to 8 bit), greyscale & alpha channel (up to 16 bit), and true-color with alpha channel (up to 16 bit); 256 Colors.
- Compatible Browsers: Chrome, Edge, Firefox, IE, Opera, Safari (some features vary on each browser)
- Max image dimensions: 2,147,483,647 × 2,147,483,647 pixels

TIFF

Tagged Image File Format

As a raster graphic file format, TIFF is a pretty massive file size for a format. Due to it being an uncompressed format, results in massive file sizes. But this allows for a high quality of images—making it popular amongst photographers (Nichols). You can also work with this in Photoshop and this file format can define layers and has a resistance to file corruption (Harper). With that said, this file format should be avoided for websites because it may take forever to load, and each second that passes loading a website is a lost user.

The tech behind TIFF:

- Standard Body for Maintenance: Adobe—Originally was developed by Aldus Corp. then was acquired by Adobe and now is maintained by Adobe (File format).
- MIME type: image/tiff
- Compression type: Lossless (an alternative to GIF)
- File extension(s): .tif, .tiff
- Color Mode(s): Bilevel, Greyscale (up to 8 bit), True Color (8 bit), indexed color (up to 8 bit), greyscale with alpha (up to 8 bit), true-color with alpha (8 bit).
- Compatible Browsers: No browsers have integrated support according to MDN Web Docs, it's typically a download format.
- Max image dimensions: 4,294,967,295 × 4,294,967,295 pixels (theoretical)

BMP

Bitmap Image

BMP files can end up being massive files. This means that this file isn't the best for websites typically since load times will be a considerable amount of time. It is an uncompressed raster image most commonly (*Image file type and format guide*). When used for content on web applications, do your best to optimize the experience for the user because you'll most likely have load time(s) to deal with.

The tech behind BMP:

- Standard Body for Maintenance: Microsoft
- MIME type: image/bmp
- Compression type: Uncompressed
- File extension(s): .bmp
- Color Mode(s): Greyscale (up to 16 bit), True Color (up to 16 bit), indexed color (up to 8 bit), greyscale & alpha channel (up to 16 bit), and true-color with alpha channel (up to 16 bit); 256 Colors.
- Compatible Browsers: Chrome, Edge, Firefox, IE, Opera, Safari
- Max image dimensions: between 32,767 x 32,767 and 2,147,483,647 x 2,147,483,647 pixels

PSD

Photoshop Document

This is the default file for Adobe Photoshop and is maintained by them too. When you create a document that is the file extension for the document—PSD. Like TIFF, PSD can manipulate layers (*Supported image formats*). It has a range of 16-bit up to 32-bit channels, leaving you the ability to work with a high range of quality of the image (*Supported image formats*). You're also able to export PSD to many file times, lossy or lossless compression, give you the ability to output your work to the world.

We went into more of a deep dive earlier in this documentation. See Figure 5 for the files that a PSD file can be bounced to.

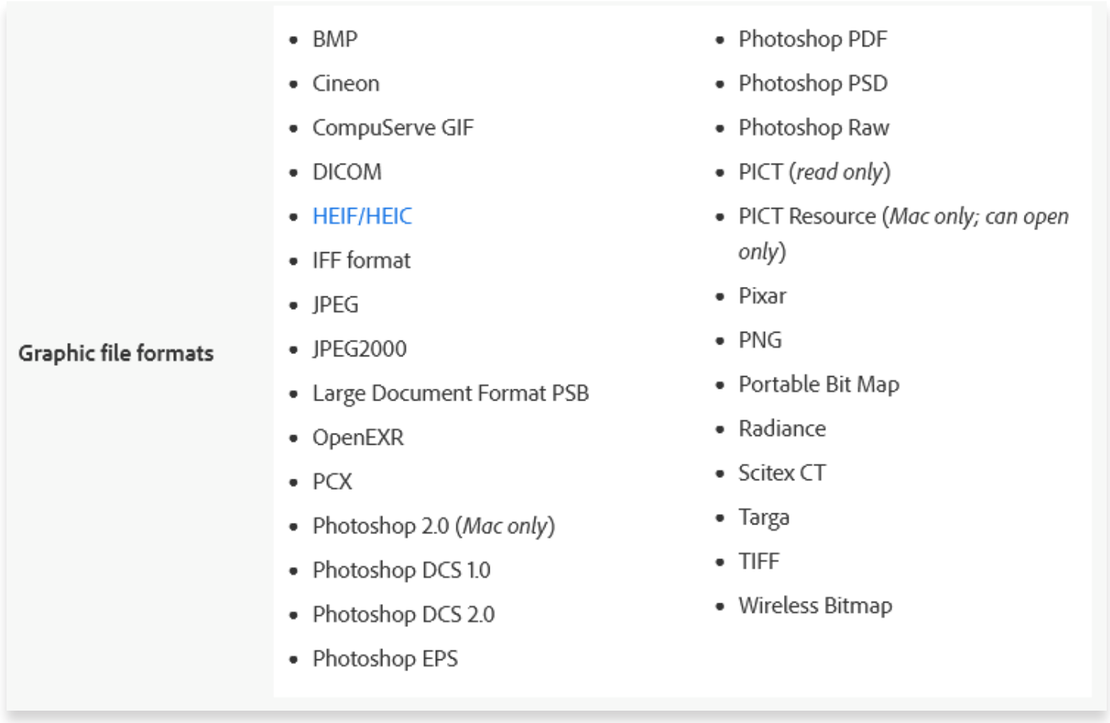


Figure 5. Adobe, *Screenshot of Supported Image Formats for Adobe Photoshop,* 19 Aug. 2021.

RAW

RAW image files

RAW files are typically what is from the camera that took the image. This file is referred to as "Digital Negatives" and this ends up being a massive file (*Image File Formats - JPEG, GIF, PNG*). The benefit of having your image files be RAW is that if you're a professional photographer, you have a file that allows you to have complete control over the image and edit how you want. When you take a picture in a camera this process happens: you tell the camera to take a picture, the sensors in the camera take in light and convert it into raw data, and then can be converted into a compressed format or kept as a raw file with no processing/compression done to it yet (*When to use raw vs. JPEG*). If you want more quality color, and exposure corrections then you should take your pictures as RAW files. RAW files offer these perks because it's completely uncompressed and about as pure as an image can get digitally. See Figure 6, for a comparison of a processed image and raw image.

Another great perk is that RAW files are non-destructive, and if you mess up the file by accident you can go back to the reference point of the file where it wasn't messed up (Harper). You can also take a RAW file and convert it into a lossy, lossless compression format as well. In short, working with RAW files offers flexibility that wouldn't be present if you were taking photographs in a file format that isn't a RAW image file.

Figure 6. Adobe, *Image of Red Mountains landscape with the right side of the photo showing more contrast and color,* Accessed 27 Sep. 2021.

Info for Raster Image Section is taken from Lundquist, Adobe, Techquickie, Hubspot, MDN Web Docs, Nichols, File format, and JPEG.

Vector Image Types:

PDF

Portable Document Format

PDFs* are under the vector category because you can retain vector graphics in one, allowing you to have the perk of vector graphics for your design. You should use this when you are trying to display a document via the web or print (Lundquist).

**PDFs are typically considered vector, but depending on how you created your PDF originally, it can be raster or vector. It also depends on whether you, as the creator, flatten all layers, which will determine the type of image: raster or vector (Vector, Raster, JPG, EPS, PNG - Whats The Difference?).*

See Figure 7, Here is a screenshot of this very pdf document you're reading. There is In this document raster images are being used and one vector graphic that was exported from Adobe Illustrator. So what do you think this PDF would be considered as, Raster or Vector?

Figure 7. Screen Shot of this PDF Document--super meta.

EPS

Encapsulated PostScript

EPS is typically used for vectors, but it does have the capability to have raster images in them and is commonly used for single designs that are for bigger overall designs (Lundquist). Some good use cases for this are for logos since it is a vector you have no worries about scaling issues, but you should not use it for anything to do with photography, even though it can handle raster it something you should avoid since its better as a vector file format (Lundquist).

The tech behind EPS:

- Standard Body for Maintenance: Adobe
- Internet Media Type: application/postscript
- Compression type: Lossless
- File extension(s): .eps, .epi, .epsf, .epsi

Ai

Adobe Illustrator

Adobe developed Illustrator as a proprietary vector image format, which is mainly a vector-based file (Lundquist). It is a powerful application that designers can use to develop scalable illustrations. You can also export AI files to PDF/EPS/SVG and raster file types as well for websites and other editing (Lundquist). You should be using this file and application whenever you're designing a vector graphic, creating content for websites, logo work, and anything else that would be best suited for a vector graphic (Lundquist).

In Figure 8, I created a logo for my branding. It is saved as an AI file and is using lines and shapes, so that is a vector graphic in the figure. I then exported it into an SVG file, which is present in Figure 2.

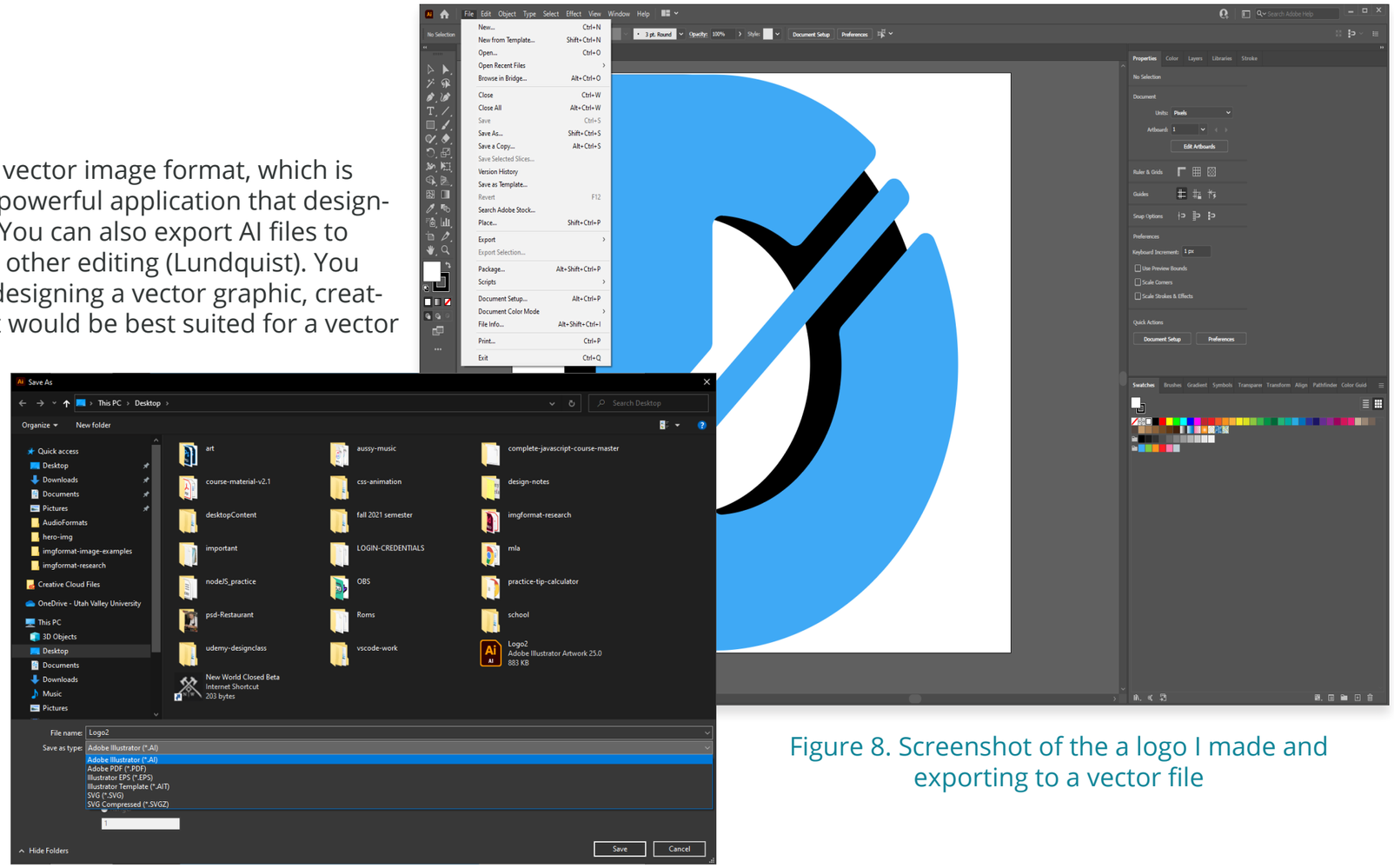


Figure 8. Screenshot of the a logo I made and exporting to a vector file

SVG

Scalable Vector Graphics

SVG's are scalable graphics that is an optimal solution for Websites as compared to other image times because SVG takes up much less space and is quick to load. It is also a popular choice for interface elements in web design (*Image file type and format guide*). For the most part, you should use an SVG when you can and should, it is an optimal choice for load times.

The tech behind BMP:

- Standard Body for Maintenance: W3C
- MIME type: image/svg+xml
- Compression type: Lossless
- File extension(s): .svg
- Color Mode(s): Color for SVG are specified via CSS syntax
- Compatible Browsers: Browser supports vary.
- Max image dimensions: Unlimited

Info for Vector section was grabbed from Lundquist, Adobe, Library of Congress, and MDN Web Docs.

Heard of a Lottiefiles?

You may have heard of this file type. But I'll be honest, I haven't ever heard of this file type before. I think the reason being is because it is a fairly new file type. The whole idea of Lottiefiles summed up is that this is the best way to display content on web pages, because of the optimal file sizes and creativity options (Lottiefiles). Here is a special snapshot into something that I think deserves some special attention.

Lottie

This file format is probably one of the coolest ideas and inventions that I've ever heard of for a while. Let me explain.

Lottiefiles was born out of a time when designers created anima-tions and exported them at low-quality formats— compressed file formats—and gave them to developers to remake them in code (*What is a Lottie?*). That may seem to be a rough process, it was. You can do that, but there is a need to know how to remake those animations in code and the time to match it to the designer's animation. See Figure 10, for the perks of Lottie, and here is a quick store of what Lottie is now and where it came from.

The origin story...

In 2015, Hernan Torrisi, came up with the idea of exporting animations via Adobe After Effects (After Effects), and then he would start rendering that animation at runtime (*What is a Lottie?*). He accomplished this by creating a plugin for After Effects, that plugin would help export a created animation to JSON (Javascript Object Notation) and he called it Bodymovin (*What is a Lottie?*). His original idea is what eventually spawned what Lottiefiles is today. He opened up the door to have animations run smoothly and offering a bet-ter solution for adding animations to a website.

Lottiefiles now...

Today, there is a whole community of people who love Lottie anima-tions. On the Lottiefiles website, you can have access to paid and free animations made by de-signers and available for the world. You can even pay for designers via the Lottefiles website to develop a JSON-based animation for you as well (Lottiefiles). Another option available is the use of After Effects. If you have a designer or if you know how to make animations in After Effects, you can export the animation in a ".lottie" file format (*What is a Lottie?*). This offers freedom with creativity and is accessible for all kinds of developers and de-signers in the industry who want to use animations.

The creation of Lottie...

Airbnb, yes the business that is known for Vacation Rentals for tour-ists, helped usher a new era of animations--Lottiefiles is independent of Airbnb, it was just created by people who worked for Airbnb (*What is a Lottie?*). Based upon the work of Hernan Torrisi, four Airbnb em-ployees believed in the potential of what JSON animations have to offer for the world. These developers were: Brandon Withrow (Engineer), Gabriel Peal (Engineer), Leland Richardson (Engineer), and Sa-lih Abdul-Karim the lead animator of the project (*What is a Lottie?*). These four all believed in the power of this new way of implementing animations, and they came up with the name "Lottie."

Figure 10. Why you should use Lottie

Multi-platform Capable

Lottie is compatable with iOS, Android, Websites, and React Native.

Highquality

Lottie is capable of SVG like quali-ty vector elements and high qual-ity raster elements as well.

Small File Sizes

Lottie files are incredibly small as compared to img formats that are capable of animations or animatons exported from After effects. File sizes can be below 50 kb small (Skane). That is incredi-bly small compared to other solu-tions out there.

Resolution Independent

Similar to SVG files, Lottie is com-pletely scalable and able to do so at runtime as well.

Implementation

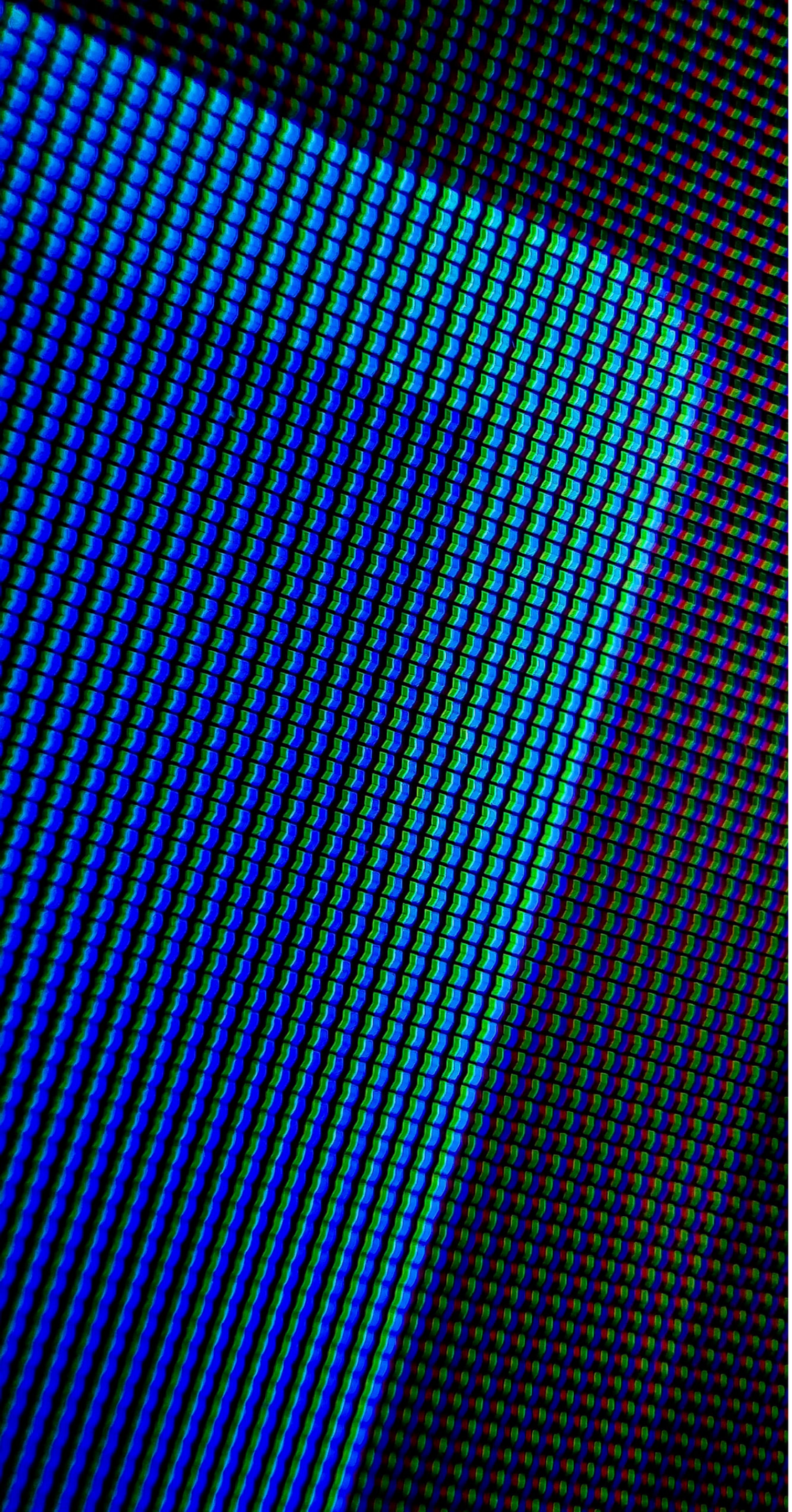
As a developer, you can actively target components in a Lottie file. Meaning you are able to edit elements of the Lottie animations and add interactivity.

Info was grabbed from Lottiefiles and Skane.

Conlusion

This section was all about getting you prepped for the next section. Image formats are pretty complex and many people misunderstand them, I'm still learning about them myself. But this section should've got you up to speed for the next section that will go into great detail about the ramifications of each format when being used.

So, what did we learn? You now understand the most commonly used image formats out there, raster vs. vec-tor, the awesome Lottie files, and the specifics of each file format. You should now be ready for the next section, but if there is any confusion about a format or a specific thing about a format, refer back to this section.



Section Four: Image Export Evaluation

Author's Note:

Through out this documenation you'll see a progressive change in each format I discuss. JPEG will be a primer in how the process and outcome of each method (E.g. Save As, Export As, and Save for Web) is done. In order to avoid being repetitive the rest of the image formats and their documentation will be cut down. Instead they will include a image comparison section, file size chart, necessary screen shots, and a brief description of each format.

JPEG Image Compression

As a developer, file size is of great importance to me--as it should be for everyone else, designers and developers. Because, in our industry, a lot of our work is working with file types, and those files will affect the experience our users will have.

The ideal situation to have on the website for example is to have the fastest load times possible! Because each second that passes, a second for the user to decide they can't be bothered for waiting to load your web page. It is a serious thing to consider and plan in our line of work. Of course, websites that are filled to the brim with graphics or images are a different story. But that's why I said the ideal situation is to shoot for the fastest load times possible, there are times you'll have to increase your file size limit on a given page. In short, aim for the most optimized experience possible for your users, and here is how with JPEG compression.

Refresher, what is JPEG?

Joint Photographic Experts Group (JPEG), is one of the world's most common image file formats. The acronym is the organization that standardized the format, and has been going strong since the late 1980s (*JPEG files*). File type extensions such as JPG, JPE, JIF, JFIF, JFI, and its actual acronym JPEG are all essentially the same because they're all part of the same family for example (Adobe). The perks of JPEG are that it can support 24-bit color depth and is a Lossy file type--JPEG selects data to throw it out and decrease the overall file size (*JPEG files*). This is commonly used for photography, and not vector graphics or lines are of some kind because it doesn't support transparency and the compression artifacts can cause jagged edges running along sharp lines or curves--PNG and SVG would be better for that as a side note.

As a quick example. Fig 1, is a picture I took of my dog. I wanted to use this image as an example of JPEG compression.

Dogs are covered in fine hairs, their noses are textures too. Which are some key things to consider when compressing a JPEG image.

Observe the differences between each from the full view and the magnified view. Is A or B better?

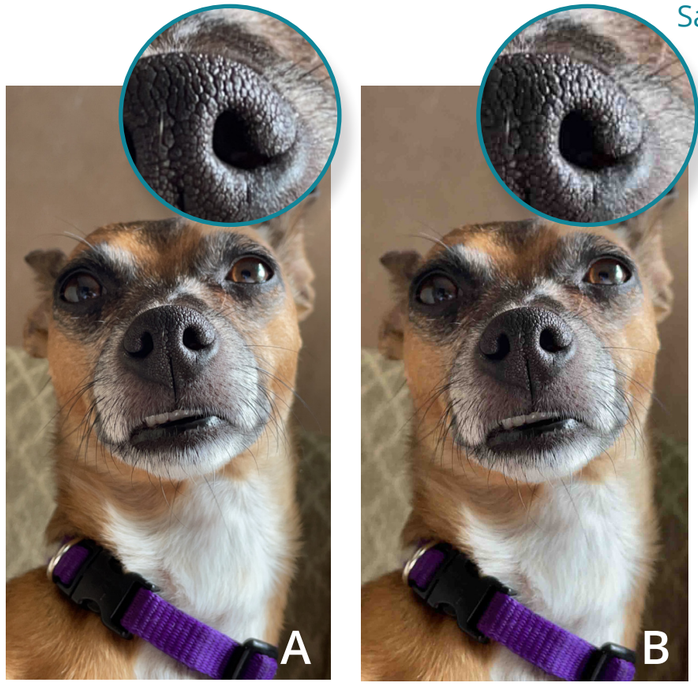


Fig 1. Portait of my Doggo, comparison of JPEG save as compression.

Compression Workflow

My main digital media applications are Adobe based, so in this documentation, I'll be using Adobe Photoshop (v23.0.1). I mention the version because it is possible in the future the process to export media from Photoshop could change. The export processes I'll be exploring are **Save As**, **Export As**, and **Save for Web**. Each serves the same function, to export media to the desired file type and compression quality as well. But each differs in how the workflow is to accomplish a task and the final product will differ in quality and file size as well.

This leads to the question of which is best and why?

Save As

This method of exporting a document from Adobe/saving a file is one I think is most commonly used amongst the general community that uses Photoshop. I say this because I did the same learning photoshop and just learned about the capabilities of the other methods of exporting a file recently. What is the process of Save As? See **Fig 6 - 7** for screenshots of how this process occurs. This will be our reference point to start with.

Export As

This method of exporting documents from Photoshop differs from **Save As**, mainly the difference is the Dialogue Box that pops up. Export As has a different way to compress images down, the main difference is the provided set quality presets and this led to a difference in file size(s) between export methods. You are also able to view your images in different preview modes, to give you a visual of how the quality goes down as you compress the image more if you like how it looks. See **Fig 10** for the Export As process.

Save for Web

This method is a legacy way to export files. I haven't seen anyone use this, unlike **Save As** and **Export As**. But the Dialogue Box for this method is more akin to the Export As Dialogue Box (See **Fig 17 - 18**). But, how you save the file's quality--how much compression you want--is different from the other methods that have been mentioned. Because of that, the resulting file sizes are different as well.

File Naming Structure

As a developer, I've already been introduced to the importance of concise file naming and organization. So this was a perfect opportunity to practice that skill to perform this experiment. In **Fig 3**, you can see the structure I set in place. The file **imgFormatTesting > jpeg > img-01** will be open as an example of what each folder contains. This allowed me to easily navigate and organize the images I have compressed and tested--also helped organize the images for this documentation.

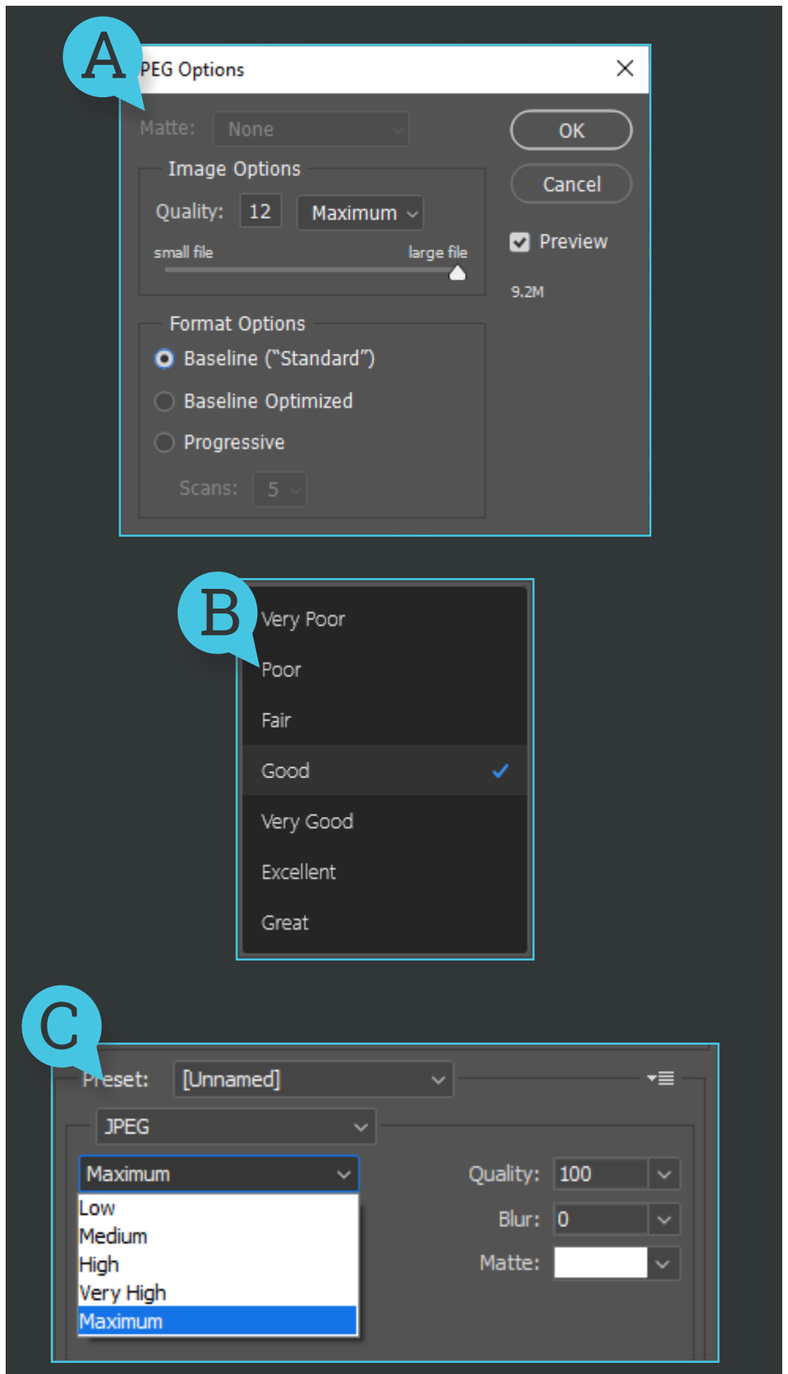
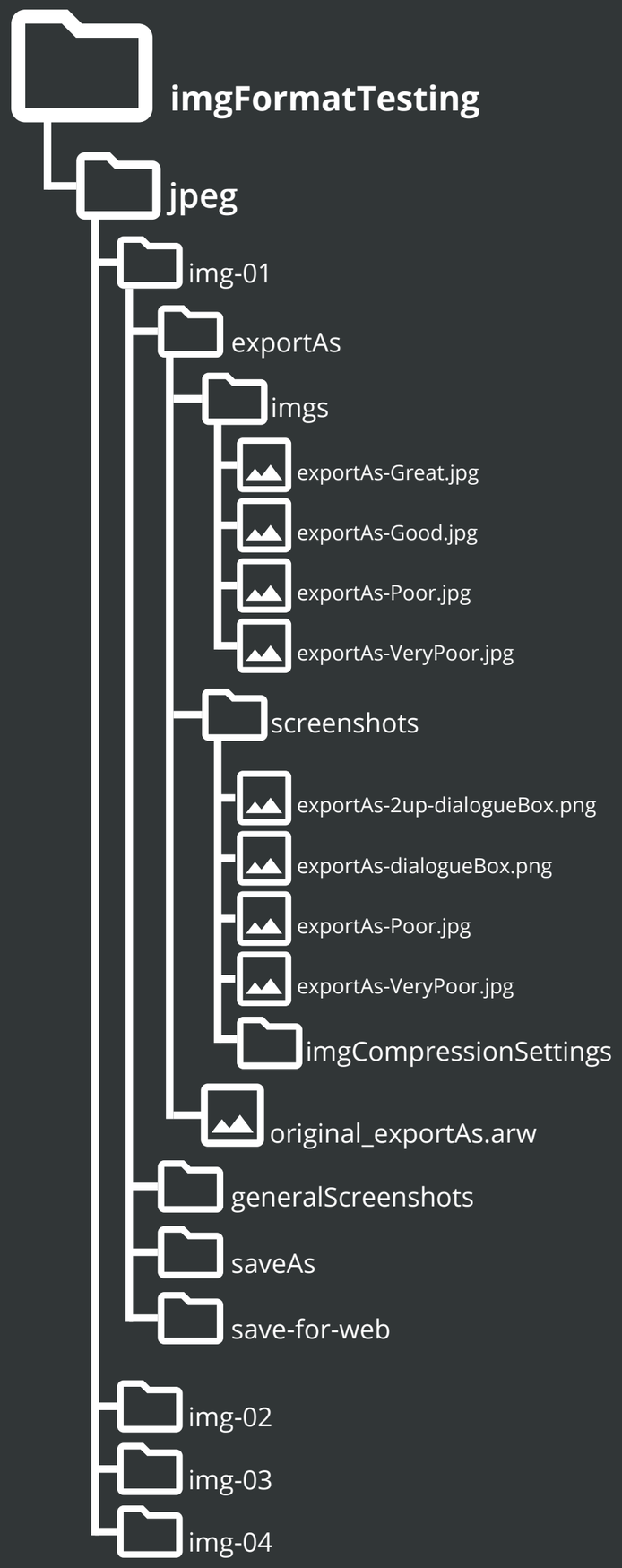


Fig 2. Screen shots of each method's file quality picker. Save As (A), Export As (B), and Save for Web (C).

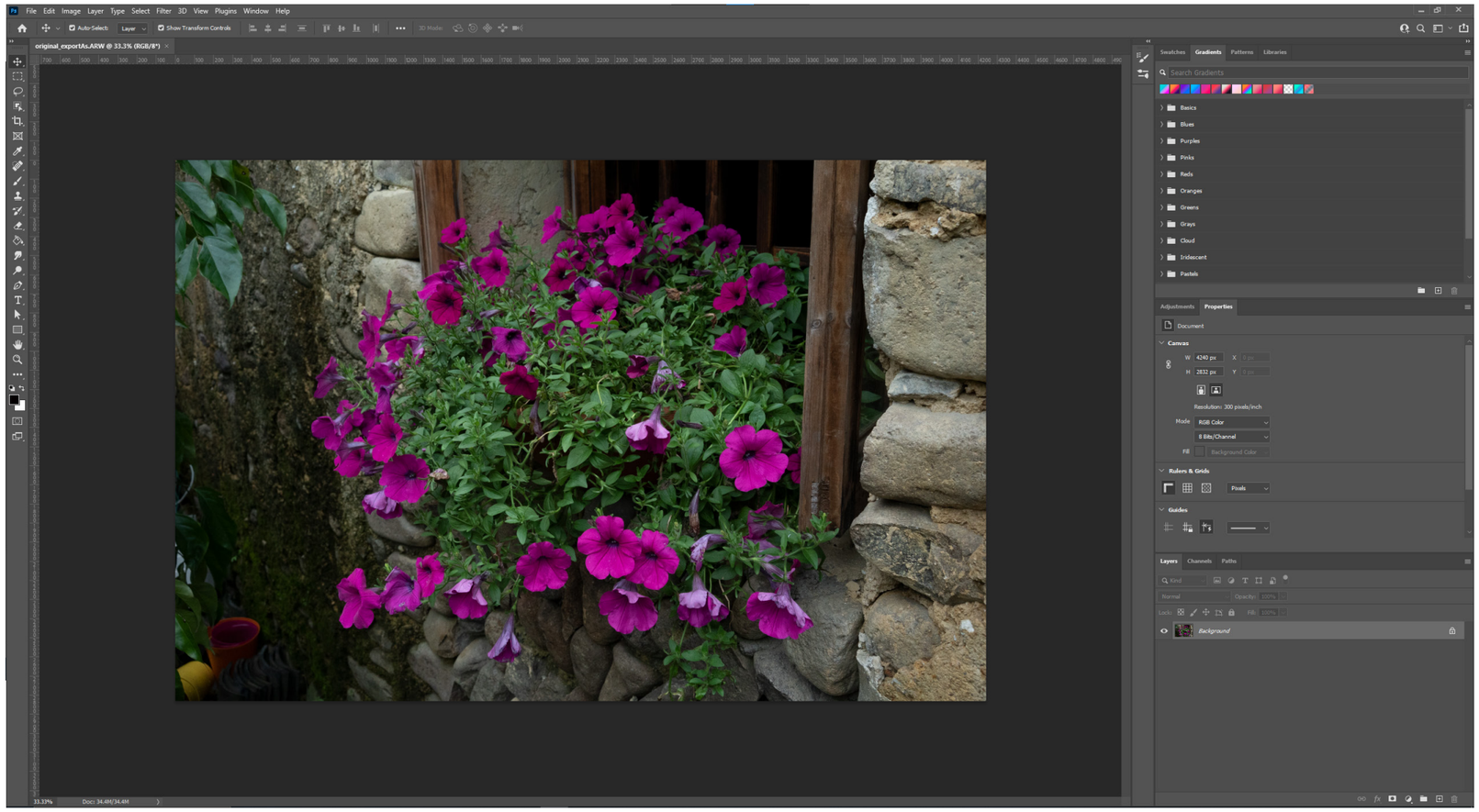
To see how each method is completed See **Fig 4** and read the steps process following that. I'll show you the workflow for each method and the implications for each as well.

Fig 3. File Structure and Naming



Each file type that will tested, such as PNG, JPEG-2000, and GIF files, will be following the exact same file structure.

Fig 4. Adobe Photoshop (v23.0.1)



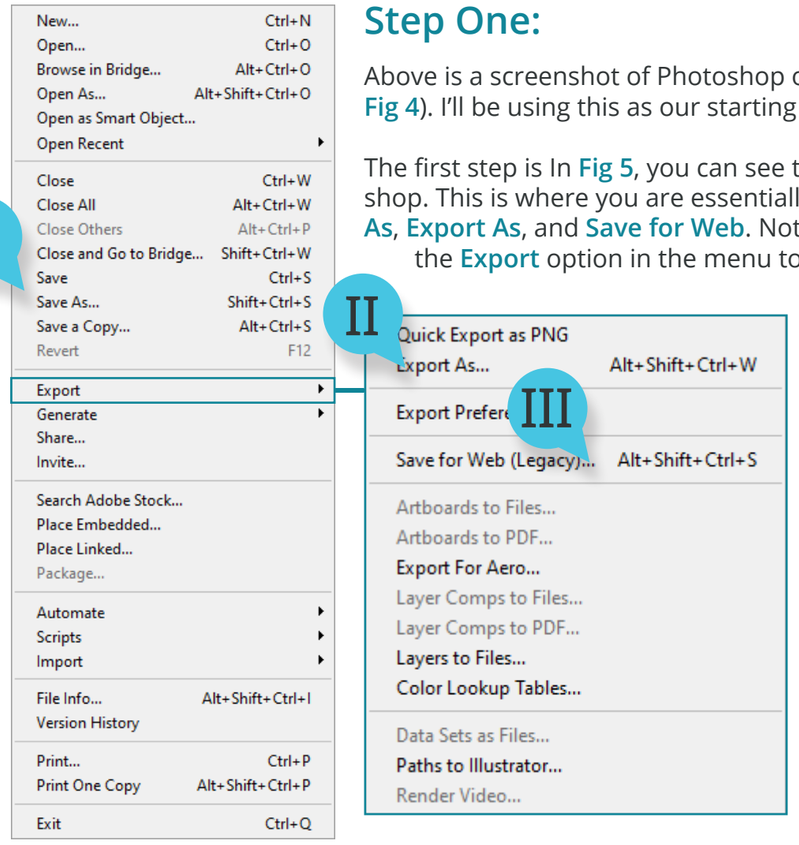


Fig 5. File menu open, and Export sub-menu open

Step One:

Above is a screenshot of Photoshop open on my desktop, with the **original_exportAs.arw** file open (See **Fig 4**). I'll be using this as our starting point to visualize all exporting methods.

The first step is In **Fig 5**, you can see the menu you see when you click on **File** on the top left of Photoshop. This is where you are essentially managing your file in any way you need. But we are here for **Save As**, **Export As**, and **Save for Web**. Note that to find **Export As** and **Save for Web** you have to hover over the **Export** option in the menu to display a sub-menu for more export options.

Step Two:

I Here you can see where Save As is located under the File menu. Go to the **Save As Section** to see the rest of the Save As process.

II Here is where you start the Export As method. To see the rest of the process go to the **Export As Section.**

III Here is where you start the Save for Web method, it is under the same Export sub-menu as Export As because both methods are similar. Got to **Save for Web Section** to see the rest of the Save for Web process.

Save As Section

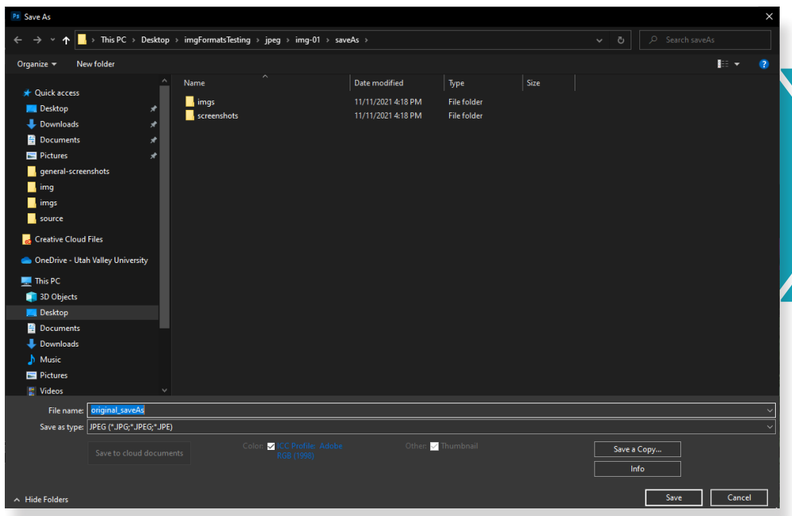


Fig 6. Windows File Explorer

Once you've clicked on File > Save As in Photoshop, your default OS File Explorer will open.

You then name your file and choose a file type to save as and the file location--for example, save the file as JPEG. Then a Dialogue Box will open up, and you'll choose the quality your file will be saved at--the quality scale is zero to twelve. Higher the quality fewer data will be discarded and the Lower the quality more data will be discarded--this affects file size.

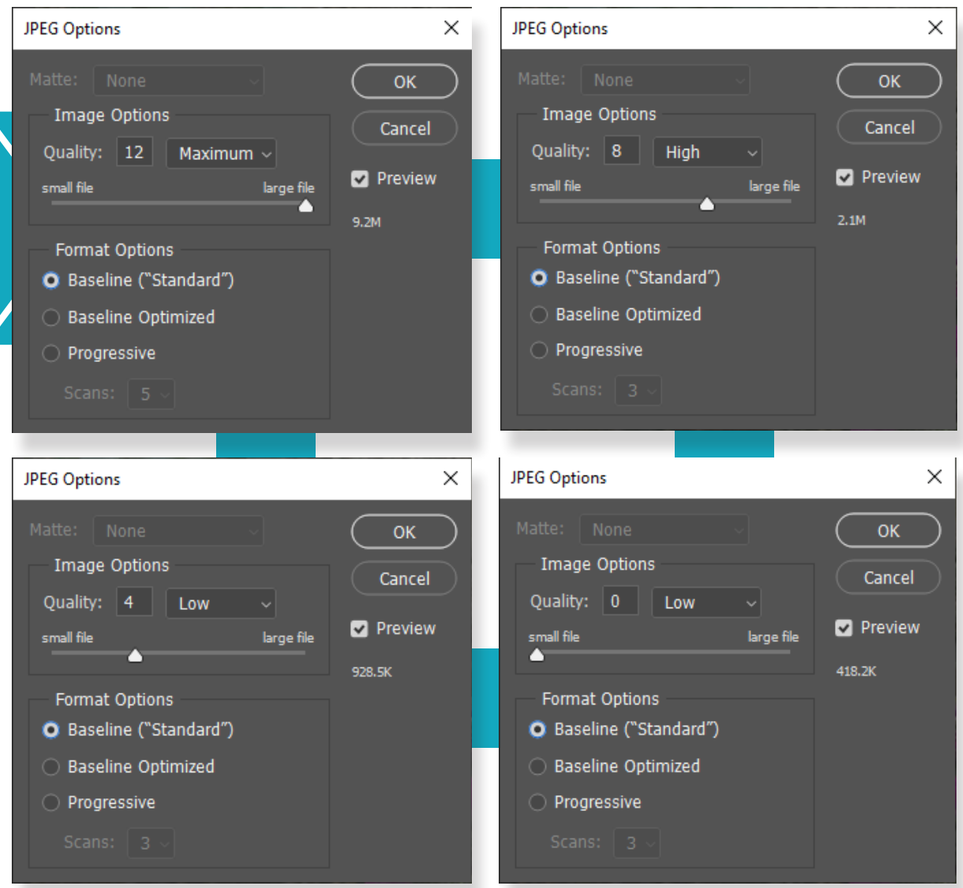


Fig 7. Save As JPEG Compression Dialogue Box(s)

Then a Dialogue Box will open up, and you'll choose the quality your file will be saved at--the quality scale is zero to twelve. Higher the quality fewer data will be discarded and the Lower the quality more data will be discarded--this affects file size.

In Fig 7, I'm showing you each one I encountered because it demonstrates how you pick your compression settings. Notice how you can preview the file size as well.

imgFormatTesting > jpeg > img-01

Fig 8. Save As Compression, from left to right decreasing in quality.

Fig 9. Save As File size and Quality Chart

imgFormatTesting > jpeg > img-01

File Name	Compression	Size
saveAs-12.jpg	12 (Max Quality)	9.18 MB
saveAs-8.jpg	8 (High Quality)	2.09 MB
saveAs-4.jpg	4 (Low.Quality)	914 KB
saveAs-0.jpg	0 (Low Quality)	404 KB

Above is a chart of how each Save As instance on the same image differed based upon different compression qualities. Compare this to Fig 8, which is the actual image(s) and is tagged with the numbers 12, 8, 4, and 0--this corresponds with the file size and quality chart.

Export As Section

Once you've clicked on **File > Export > Export As** in Photoshop will open its dialogue box before the default OS file explorer.

This method differs a great amount as compared to the **Save As** method. The main reasons are the new dialogue box that is presented to us, which allows us to have control of the file type we are exporting, the compression quality, preview of the image, file size, and more (See **Fig 10**).

Fig 10. Export As Dialogue Box

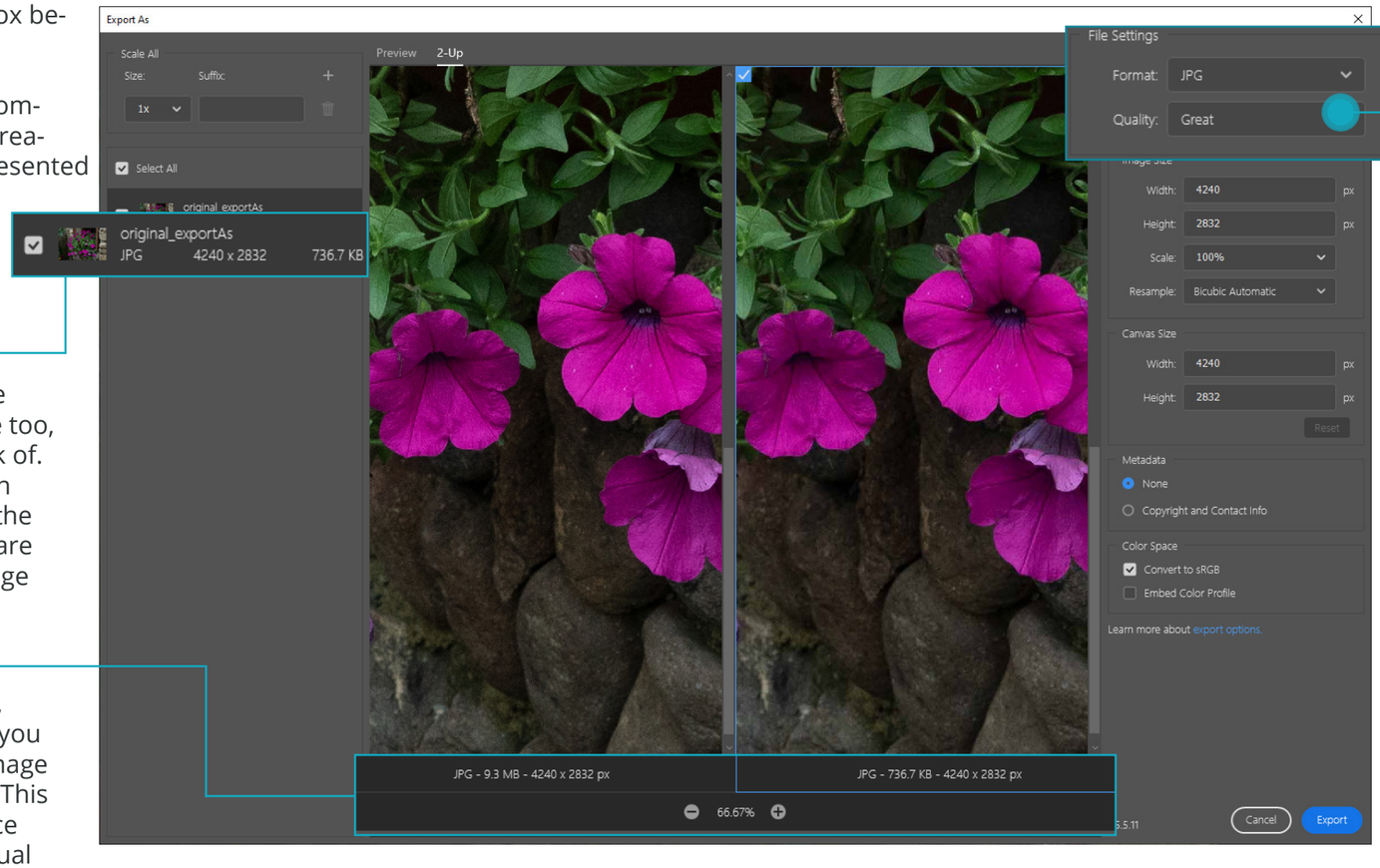


Fig 11. Export As File Size

In this dialogue box, you can view the file type you're working with and the file size too, which is an important thing to keep track of. Because the whole point of com-pression is to save file space, and since you have the 2-Up previewer too you can easily compare the visual quality as well while you manage the file size.

Fig 13. Another File Size Viewer

Since this is in the 2-Up previewer mode, meaning you can see the original image you were working with then the simulated image with your desired compression settings. This helps provide a visual in quality, and since you can also see the file size with the visual example, it enables you to pick the optimal compression set-tings for your needs.

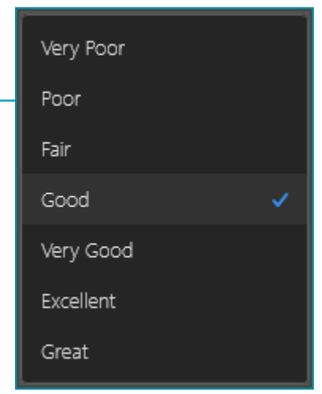


Fig 12. Quality Presets

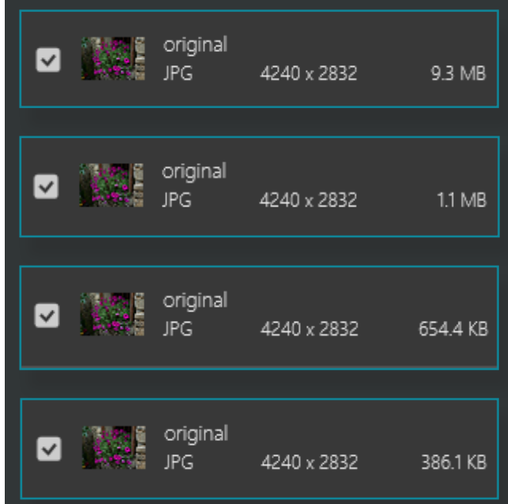
Unlike Save As and Save for Web, Export As has preset the compression settings when you're exporting your JPEG image.

This differs from the others because you kinda have to guess what is best! Also, doesn't "Excellent" seem would be better than "Great"? Well, it just doesn't make sense at all!

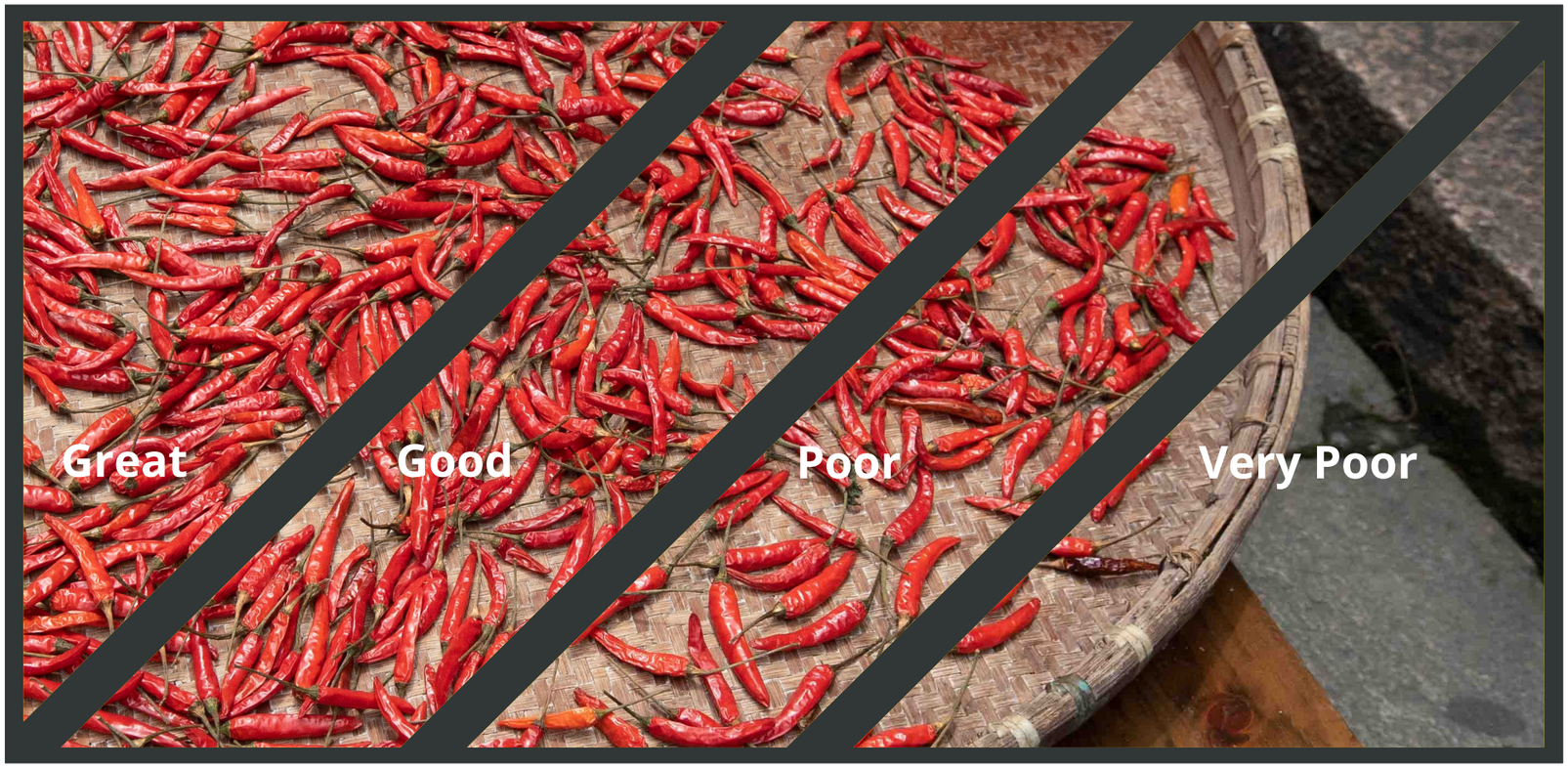
With that said, you can still gauge the file size and visual quality with the tools in the dialogue box. But, you don't have the precision in the quality you might feel you have with the other two methods.

Fig 14. Export As File size and Quality Chart

imgFormatTesting > jpeg > img-01



Compare this to Fig 12 and see where each preset is on the scale of quality for this method. Then go back to Fig 7 and Fig 19 to compare them to the other method's compression qualities and file size(s).



imgFormatTesting > jpeg > img-02

Fig 15. Export As Compression, from left to right decreasing in quality.

Save for Web Section

Once you've clicked on **File > Export > Save for Web**. Just like **Export As**, you'll be introduced to another dialogue box that is visually more complex than the Export As version. As seen in **Fig 17**.

This is a legacy version of exporting media from Photoshop, as seen in **Fig 5**. Visually it seems more complex, but it saves the same purpose essentially. **EXCEPT**, the resulting files you run through this method as JPEG, the file sizes will differ just the other two methods does too. But the quality picker seems more precise since it does offer you the ability to pick between a range of zero to a hundred.

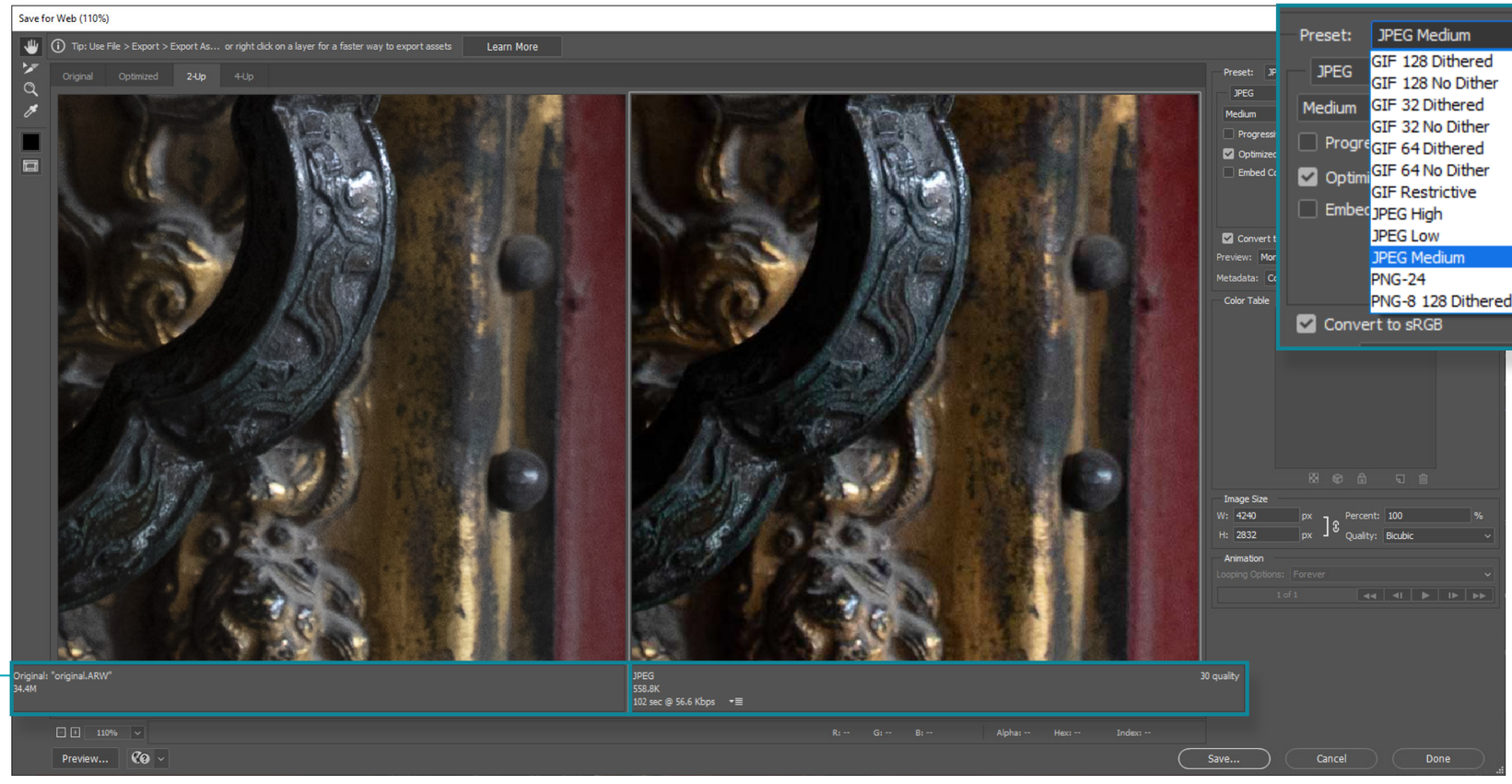


Fig 17. Save for Web Dialogue Box

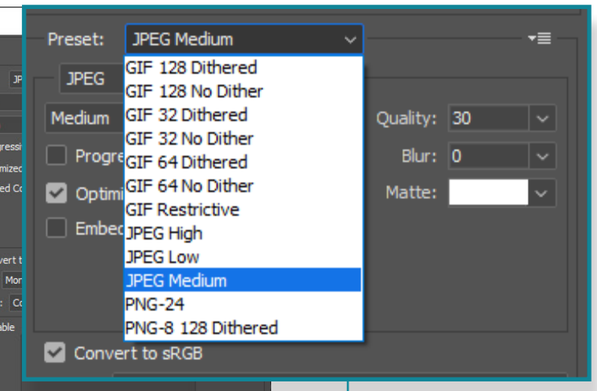


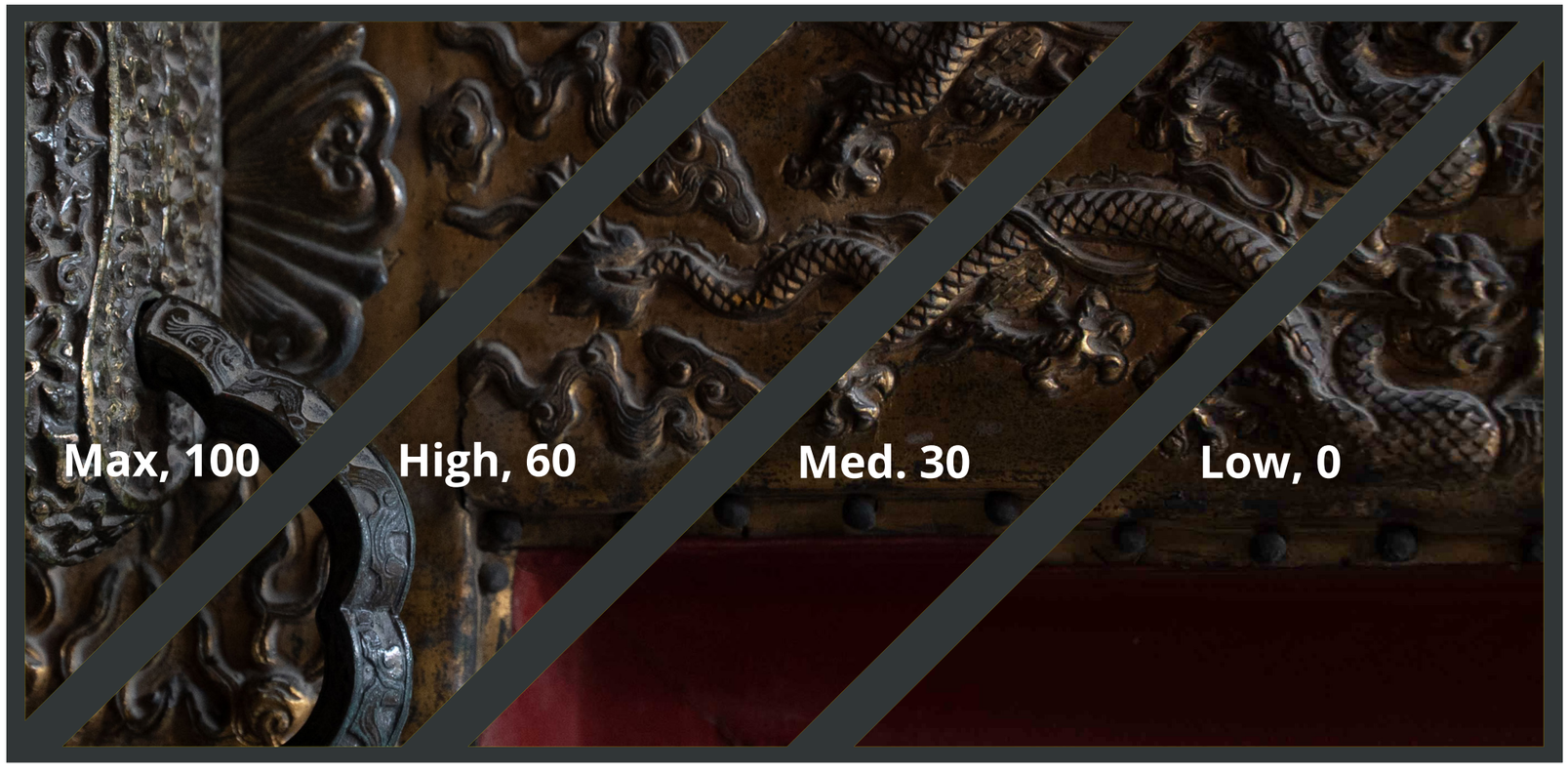
Fig 18. Quality Presets

Fig 19. Quality Slider

As you can see, this quality preset picker has much more options rather than its counterparts. It also offers you a quality picker that gives you an option of a slider or input a number between zero and hundred for compression quality (See **Fig 19**).

Fig 16. File Size Preview

Same Export As, you can preview the file size that your image would be after your finish the exporting process.



imgFormatTesting > jpeg > img-03

Fig 20. Save for Web Compression, from left to right decreasing in quality.

Fig 21. Save for Web File size and Quality Chart

imgFormatTesting > jpeg > img-03

File Name	Compression	Size
Savefor-Web-Maximum_100.jpg	Low Compression	9.18 MB
Savefor-Web-High_60.jpg	Mid. Compression	2.09 MB
Savefor-Web-Medium_30.jpg	High Compression	914 KB
Savefor-Web-Low_0.jpg	Max Compression	404 KB

JPEG Compression Testing Conlusion

In conclusion, this documentation was just me testing things out, and that is the best form of evidence. So after completing the **Save As**, **Export As**, and **Save for As** processes. I was able to have not only visual graphics to look at to determine the visual quality based upon what compression I used, but I had actual numbers to look at as evidence--See **Fig 22**.

There you can see each method that was done and the resulting outcome of the image. The key is the file size that results from each method, the size varies! That is due to some issues with how they let you decide your compression quality--what I mean is each method is not one-to-one and differs. It is fair to note that the image does affect the amount of data in the file as well, so there is a chance that these test results can be different if I used different images. But with what I tested, based upon textures colors, shadows, and brightness, I learned that each method you use is in face different.

Adobe defines compression as a technique used to reduce the overall file size and compressed images are used for web pages because it helps with overall performance (*Compression*). It is important to understand that you can't have a website with relatively massive file sizes. You must shoot to have the most optimized site, and compression is helpful with that. As you can see in **Fig 22** again, if I wanted to use these images on a site I can make an informed decision because I have the data that describes the file in terms of file size and visual quality.

Later in this documentation, I'll show a graph of the other images I tested. For now, **Fig 22** is the first Image I tested, and the out some is essentially the same as you progress between each different image. So, this should be sufficient for a snapshot of the difference between **Save As**, **Export As**, and **Save for Web**.

Fig 22. Final Comparison

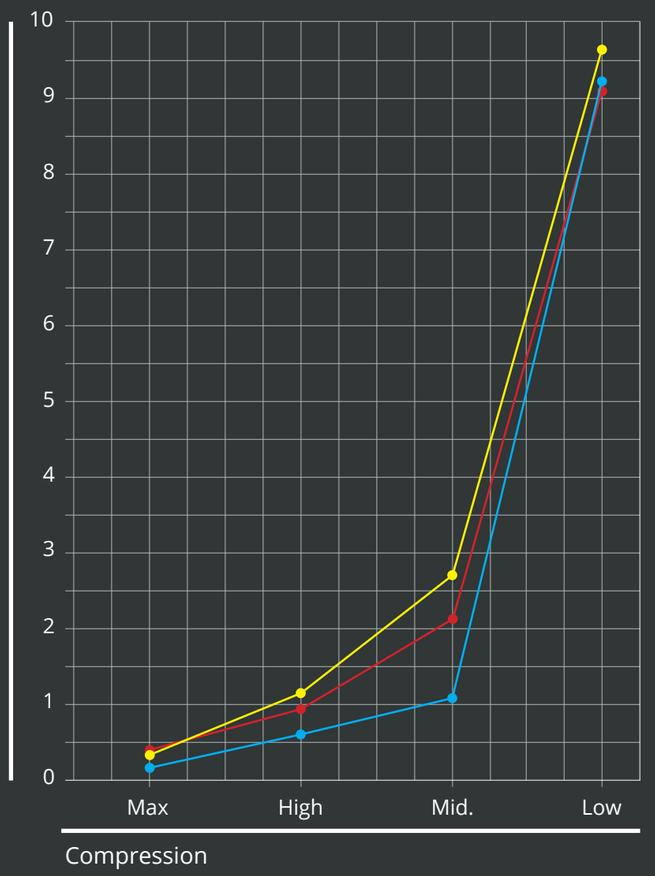
imgFormatTesting > jpeg > img-01

File Name	Method	Compression Quality	File Size
saveAs-12.jpg	Save As	Max Quality (12), min. Compression	9.18 MB
saveAs-8.jpg		High Quality (8), some Compression	2.09 MB
saveAs-4.jpg		Mid. Quality (4), mid. Compression	914 KB
saveAs-0.jpg		Low Quality (0), Max Compression	404 KB
exportAs-Great.jpg	Export As	Max Quality, min. Compression	9.29 MB
exportAs-Good.jpg		High Quality, Mid. Compression	1.10 MB
exportAs-Poor.jpg		Mid Quality, High. Compression	654 KB
exportAs-VeryPoor.jpg		Low Quality, Max. Compression	386 KB
SaveforWeb-Maximum_100.jpg	Save for Web	Max Quality (12), min. Compression	9.66 MB
Savefor-Web-High_60.jpg		Max Quality (12), min. Compression	2.77 MB
SaveforWeb-Medium_30.jpg		Max Quality (12), min. Compression	1.24 MB
SaveforWeb-Low_0.jpg		Max Quality (12), min. Compression	452 KB

The graph to the right demonstrates the outcomes of the specfic image after being processed through each method.

Pay attention to the Max and the Low compression settings. These are the extremes--maximum possible compression on the left and least possible compression on the right.

Each method is not the same at all, and this graph is the perfect example. So, why does this matter? It matters because this knowledge enables you to optimize your images correctly, without risking potential file savings and quality preservation.



Ranking in overall filesize, kind of...

Comparing the chart to the graph, this one image alone that has gone through this test should give you an idea of what each method is capable of, it is hard to rank them because each image is not the same. Also, the majority of people will use Save As or Export As. So, in the end, it is really up to you which method you take.

JPEG-2000 Image Compression

What is JPEG-2000

We now know what JPEG stands for--Joint Photographic Experts Group--but what is JPEG-2000? This format was developed to be an upgrade to its predecessor JPEG, essentially the format was supposed to be the “next-generation JPEG” and was developed to be overall better than JPEG (*JPEG 2000 files*).

So, if you’re not my Professor reading this right now, why have you have not heard of this format? I’m assuming that you may have not seen or used this format before. Because I never heard of this format before either! It isn’t a common format because the format has never become a mainstream format to use (Adobe). There are reasons as to why this happened. But first, I want to note that this format came out around the year 2000--hence, JPEG-2000--so keep in mind the era of technology that was in during this period. One of the reasons is due to how JPEG-2000 wasn’t able to work with older hardware--in other words, not backward-compatible--and this cut out many potential instances of using this format (*JPEG 2000 files*). Another reason is the fact that to process a JPEG-2000 image requires memory, and at the time many computers didn’t have enough memory to process a JPEG-2000 image (*JPEG 2000 files*). This led to the eventual fate of this format, not being popular and not seeing much attention.

Compression Workflow

So, JPEG-2000 is an interesting format, a black-sheep of all the formats I’ll be talking about in this documentation. This is due to it not being a popular format. But, the compression workflow with this format on Adobe Photoshop is what I’m saying is an odd thing I want to highlight.

First, the format can only be exported from the **Save As** method. You cannot use the other two methods at all, so this makes the workflow pretty straightforward.

So, to use this format you’ll do the following in Photoshop: navigate to **File > Save As** and then choose the format JPEG-2000 from the file explorer window that pops up. Then a JPEG-2000 exclusive dialogue box will pop up. See **Fig 23**, for a visual of this workflow.

I. Here you can see where Save As is located under the File menu. Go to the **Save As Section** to see the rest of the Save As process.

II. Click here to drop down the file format selector, and search for JPEG-2000.

III. This is the open view of the file format selector, here is where you will find the elusive JPEG-2000. After clicking on this and click Save. A new dialogue box will open up, see **Fig 25**.

Fig 23. JPEG-2000 first steps

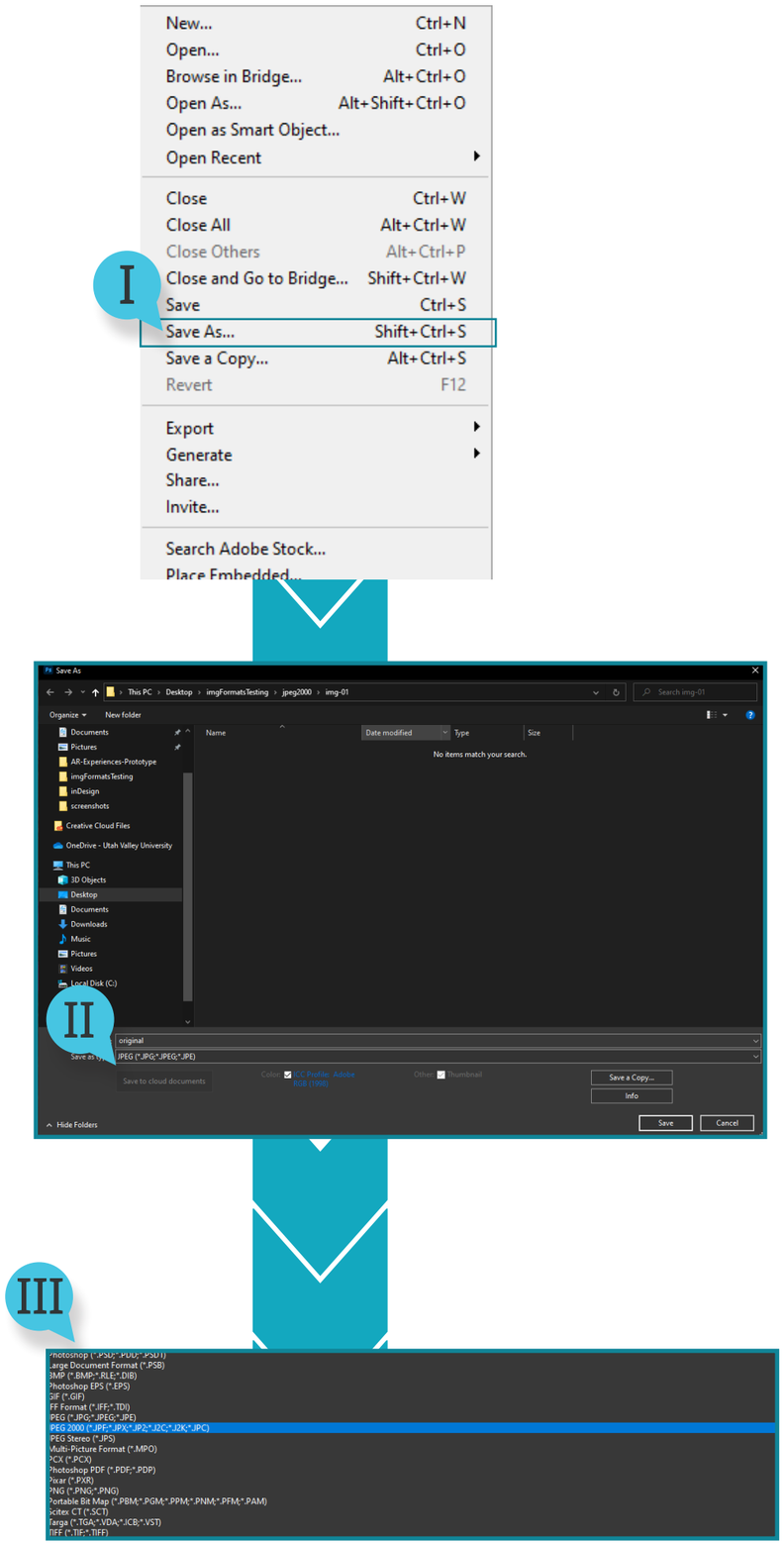


Fig 24. File Structure and Naming

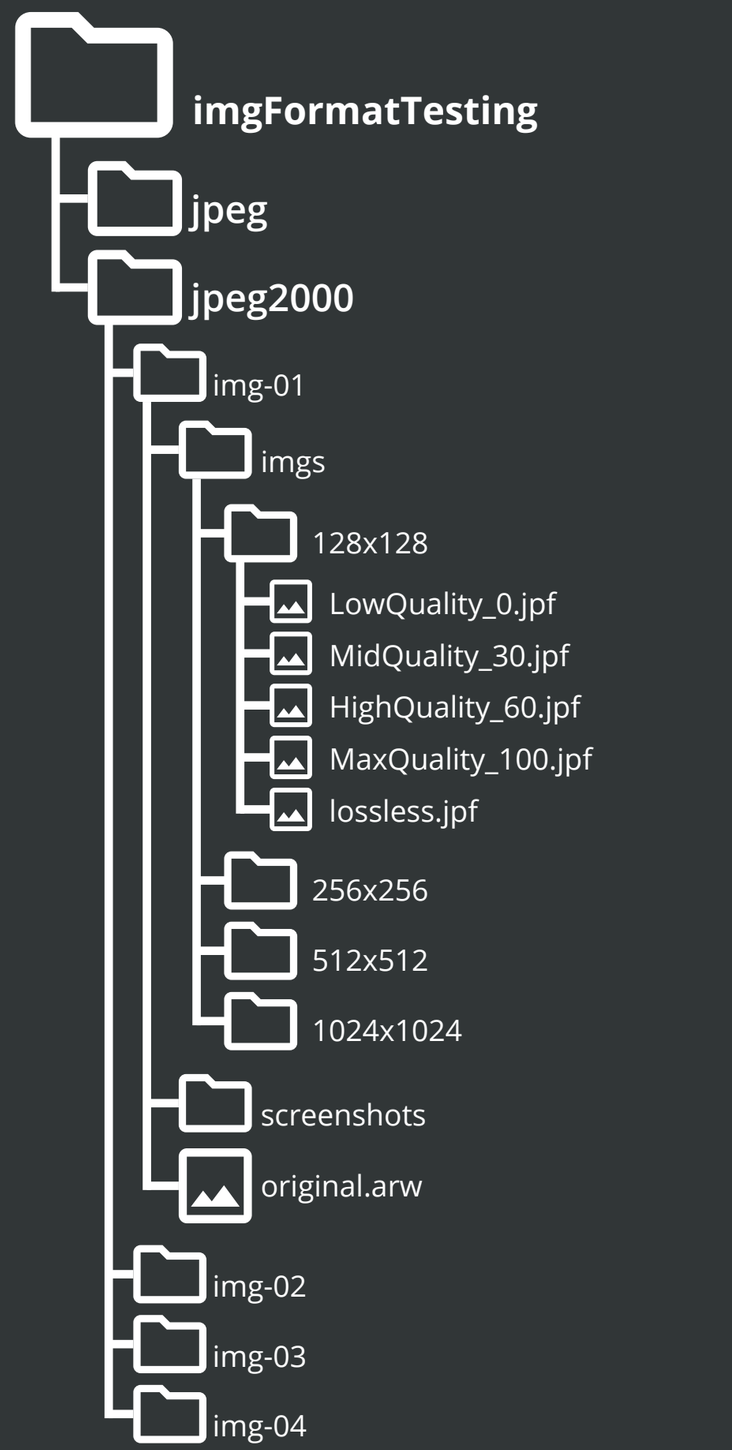
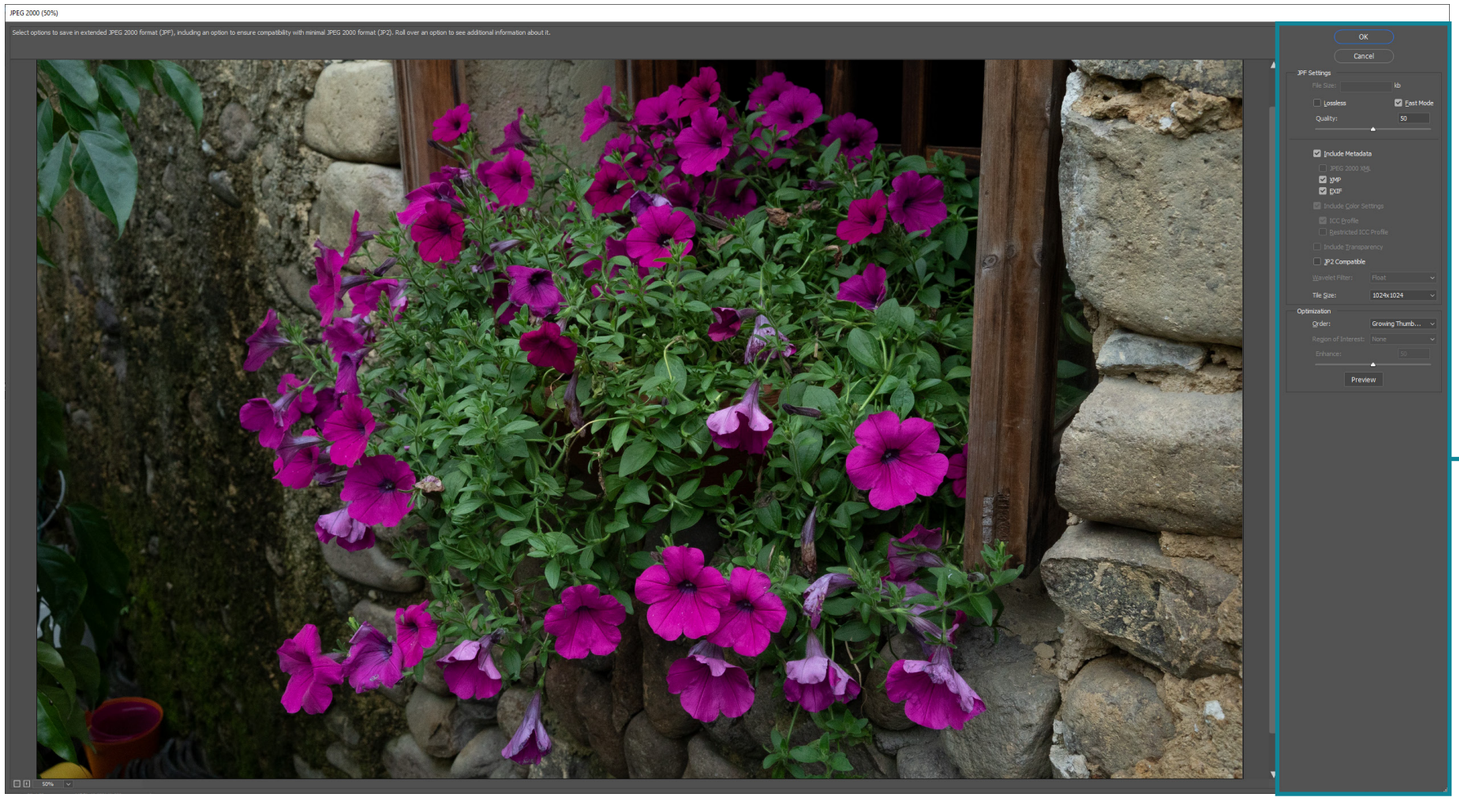
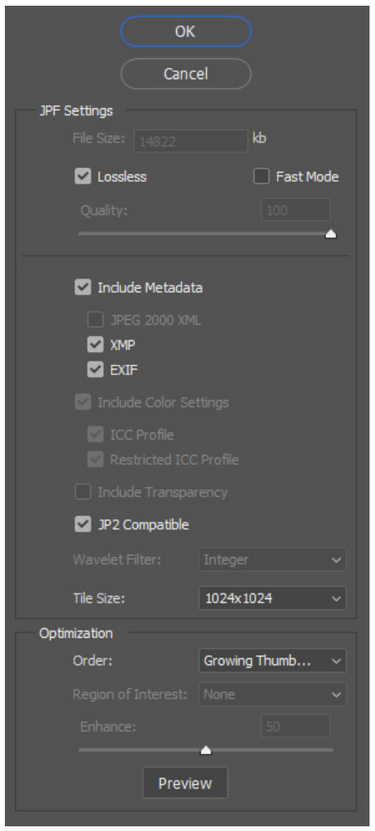


Fig 25. JPEG-2000 Dialouge Box.

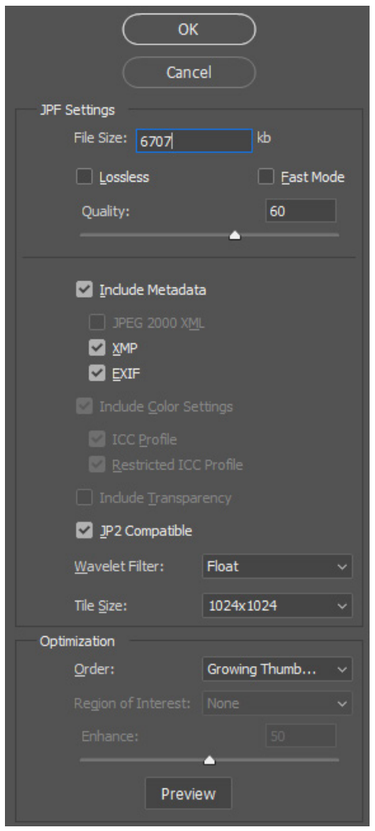
imgFormatTesting > jpeg2000 > img-01 > orignal.arw



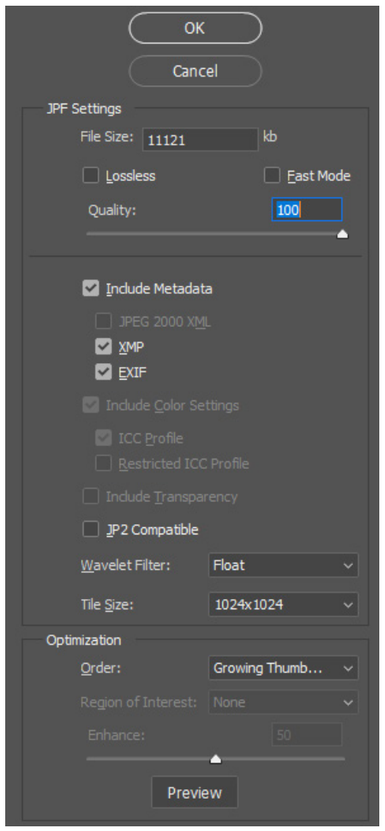
In Fig 25, you can see this interesting dialogue box that is exclusive to the JPEG-2000 file format in Adobe Photoshop. You get your preview of the image you're working with, in this instance, it is img-01. arw file I've been working with previously with just JPEG compression. Compare this to all the other dialogue boxes thus far, it's confusing that there isn't one set dialogue box. In this instance, we can only use this dialogue box with the Save As method.



Lossless Preset

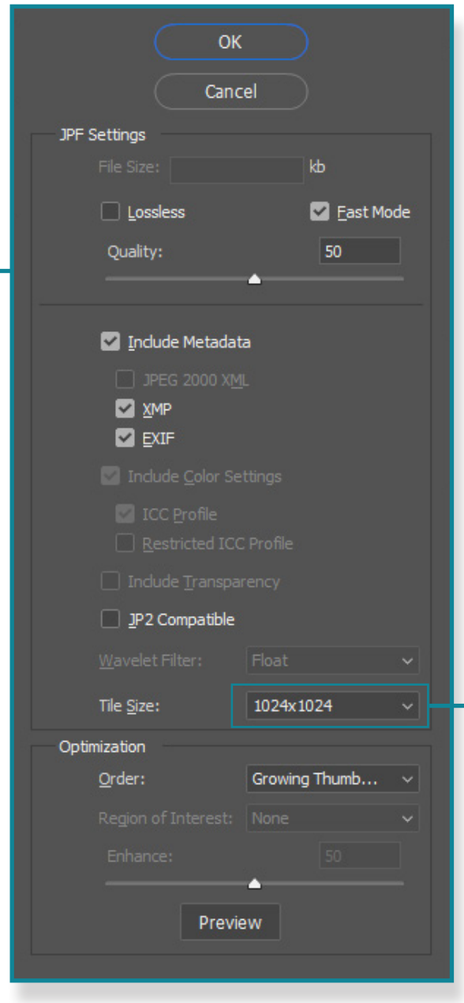


Lossy Preset 60 Quality



Lossy Preset 100 Quality

Fig 26. JPEG-2000 Options



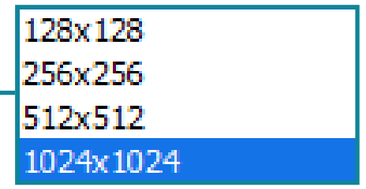


Fig 27. Tile Size(s)

In Fig 26, you see a zoomed-in view of the options we get with this format. To keep it simple and keep continuity throughout this portion of the image testing, I'll only be adjusting these settings: Lossless/Lossy, Fast Mode, Quality, Tile-Size, and I did enable JP2 compatible on all formats.

In Fig 27, you see the tile size options. This is how the JPEG-2000 compresses and image down, in tiles that are at a set size. In Fig 28, you can see how these tiles look compared to the uncompressed file, it is a perfect visualization of how this compression works.

Note that this is just an example image of some preset settings.

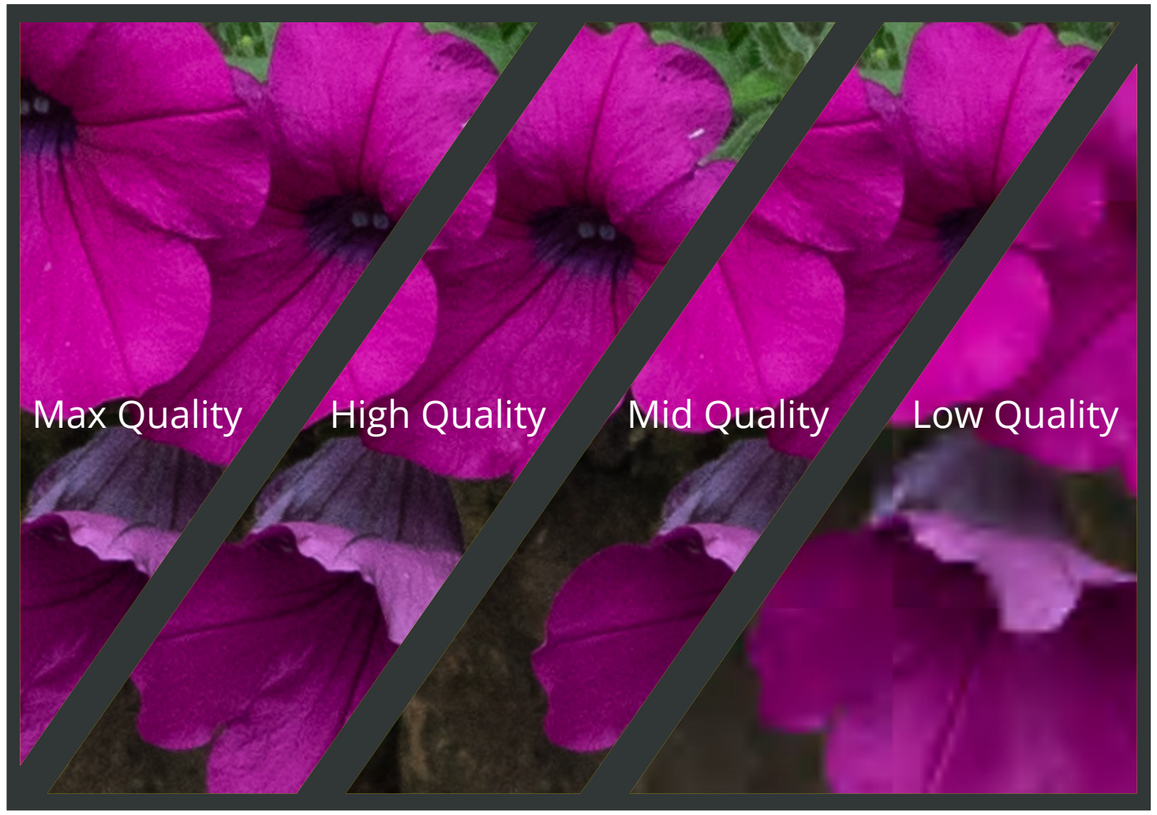


Fig 28. imgFormatTesting > jpeg2000 > img-01 > imgs > 256x256

Here we can see an example of what it looks like as we compress a JPEG-2000 image down with the tile preset of 256x256, note that depending on the tile preset this image will look different and this is only just an example to see what the tiles are.

JPEG-2000 Compression Testing Conlusion

To close the section for JPEG-2000. Yes, this section was comparably smaller and quicker than the JPEG section, that is due to how simple the JPEG-2000 process is. Again, that is due to it only being available through the Save As method.

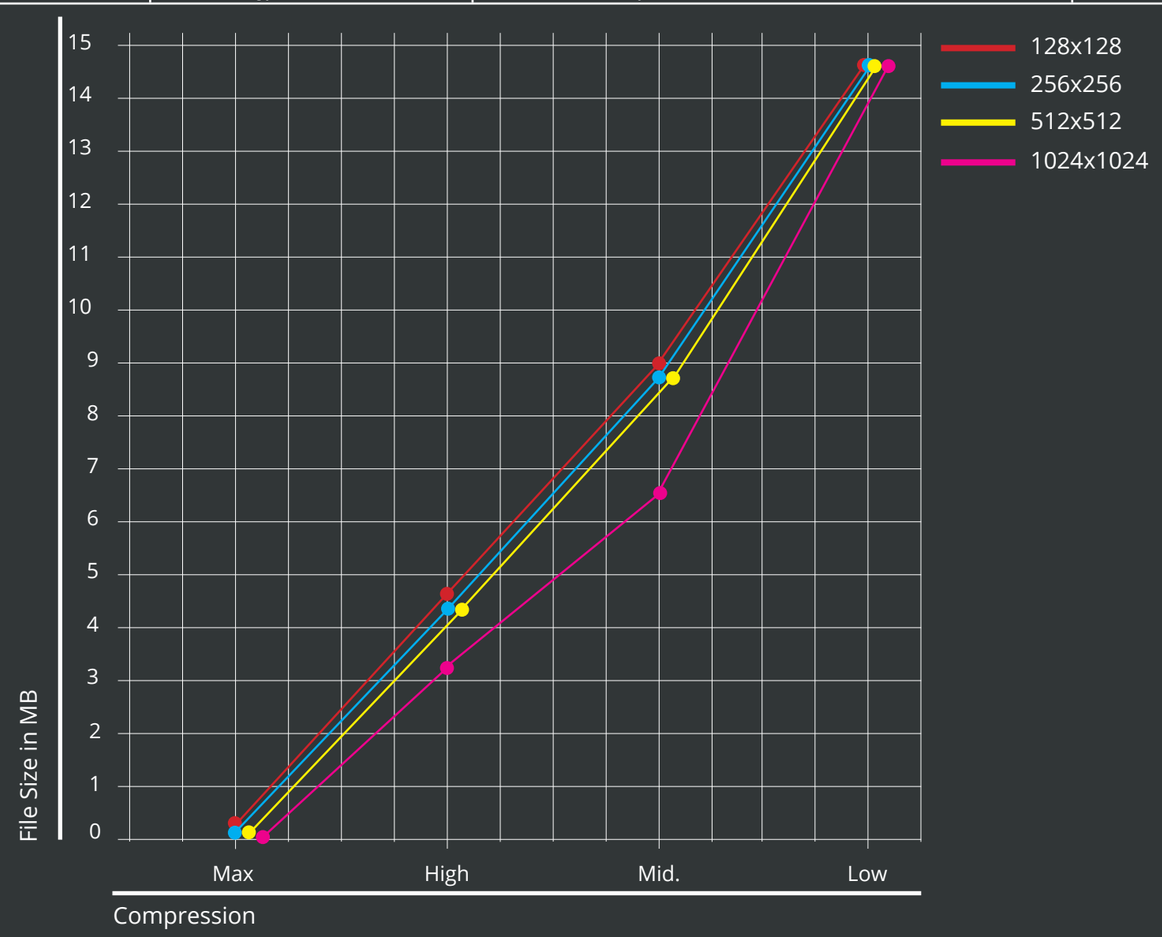
The options you have are what is described in **Fig 26**, and there are some similar options/tools such as the quality picker with a slider. It is pretty similar to what JPEG offers, but now you can do some more modern options--such as Lossless JPEG-2000 files. This makes this file truly awe-some! Except, you probably will never use this file on a project such as a website! That is because this format isn't supported on most browsers, excluding Safari and Safari iOS (*JPEG 2000 image format*). Remember that I mentioned this image format wasn't mainstream? Well, it seems the popularity of this format has never changed up until recently with Safari, and it's the year 2021!

This format is just over two decades old and it offers great file size and image quality options! I will hope for the day to be able to display this image type on multiple browsers when I'm a full-fledged developer. Until then, this format is pretty underrated and hopefully, support will change. But is there even a need for that? Because if JPEG offers similar results, for that compare **Fig 29** and **Fig 22** to see what the differences are like--especially observe the file size differences. I'd argue that the difference is probably not big enough to prompt a change to use JPEG-2000 over its predecessor.

In conclusion, this format is great and has potential to be used in a professional environment for big projects if there was support for it. But there is no support as of yet, and that could be due to its predecessor being more commonly known and used or the results offer no big enough differ-ence to prompt the switch to widely support JPEG-2000 across all browsers.

Fig 29. JPEG-2000 File Comparison

Tile Size	File Name	Compression Quality and Type	File Size
128x128	LowQuality_0.jpf	Lowest Quality (0), Max Lossy Compression.	289 KB
	MidQuality_30.jpf	Mid. Quality (30), High Lossy Compression.	4.64 MB
	HighQuality_60.jpf	High Quality (60), Mid Lossy Compression.	9.00 MB
	MaxQuality_100.jpf	Max Quality (100), No/Low Lossy Compression.	14.7 MB
	lossless.jpf	Lossless Compression.	14.7 MB
256x256	LowQuality_0.jpf	Lowest Quality (0), Max Lossy Compression.	216 KB
	MidQuality_30.jpf	Mid. Quality (30), High Lossy Compression.	4.46 MB
	HighQuality_60.jpf	High Quality (60), Mid Lossy Compression.	8.79 MB
	MaxQuality_100.jpf	Max Quality (100), No/Low Lossy Compression.	14.5 MB
	lossless.jpf	Lossless Compression.	14.5 MB
512x512	LowQuality_0.jpf	Lowest Quality (0), Max Lossy Compression.	196 KB
	MidQuality_30.jpf	Mid. Quality (30), High Lossy Compression.	4.41 MB
	HighQuality_60.jpf	High Quality (60), Mid Lossy Compression.	8.74 MB
	MaxQuality_100.jpf	Max Quality (100), No/Low Lossy Compression.	14.4 MB
	lossless.jpf	Lossless Compression.	14.4 MB
1024x1024	LowQuality_0.jpf	Lowest Quality (0), Max Lossy Compression.	154 KB
	MidQuality_30.jpf	Mid. Quality (30), High Lossy Compression.	3.30 MB
	HighQuality_60.jpf	High Quality (60), Mid Lossy Compression.	6.55 MB
	MaxQuality_100.jpf	Max Quality (100), No/Low Lossy Compression.	14.4 MB
	lossless.jpf	Lossless Compression.	14.4 MB



PNG Image Compression

What is PNG

Portable Network Graphics (*PNG files*) is another raster image format that we can use to output our media, specifically for media that involve any logos, alpha channels, and other graphics (Adobe). For instance, a PNG would be a great option for your logomark in a header/nav position--I want to note SVG files are my personal favorite for this example scenario, but I won't talk about them in this documentation.

It has been around for over 20 years, it was launched in 1995 and was originally called PING and the end goal from the creator(s) of this format was to be overall better than GIF (*PNG files*). It was meant to be efficient, offer lossless capabilities, and have a greater range of colors (*PNG files*). Since PNG can store more colors, is broadly used/supported format across browsers, and is capable of lossless compression (Adobe). Which makes it an easy decision to use this over GIF nowadays, in my opinion.

However, PNG's can be greater in file size(s) than the other formats (E.g. JPEG) and shouldn't be used for anything but Web-based applications, also can cause slower load times for users on a websites (*PNG files*). As a developer, this is important to me because I can ensure a client's project will be optimized much as possible with this knowledge.

Compression Workflow

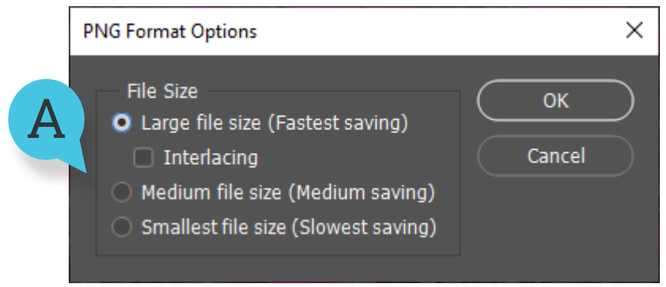
So, PNG is more normal as compared to JPEG-2000 output workflow and can be exported from all the methods: **Save As**, **Export As**, and **Save for Web**. I will show only the dialogue boxes because at this point it is repetitive in how you reach these dialogue box (E.g. opening the File sub-menu and navigating to each method).

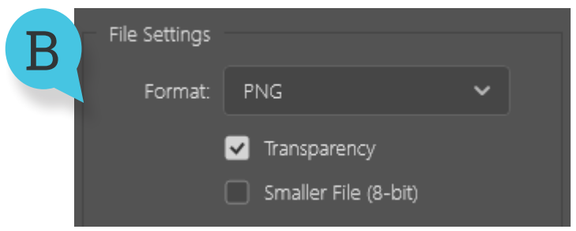
A — This is the Save As dialogue box for PNG. You are introduced to a few options. Depending on what you want in a generic sense, this is a perfect option to quickly save a file as a PNG.

B — Here is a snapshot of a specific section of the Export As dialogue box that pops up. I cropped out the options that weren't relevant, but you can also edit the image and canvas size, along with adding some metadata and color space options. I focused on this specific section because these are the only options I edited for this documentation.

C — This is the Save for Web dialogue box for PNG. A lot more confusing and cluttered with options to pick from. But it does give you'll a great look into the color table and what is being saved. Note that I only edited some options under the PNG-8 or PNG-24 presets.

Fig 30. PNG Dialouge Boxes





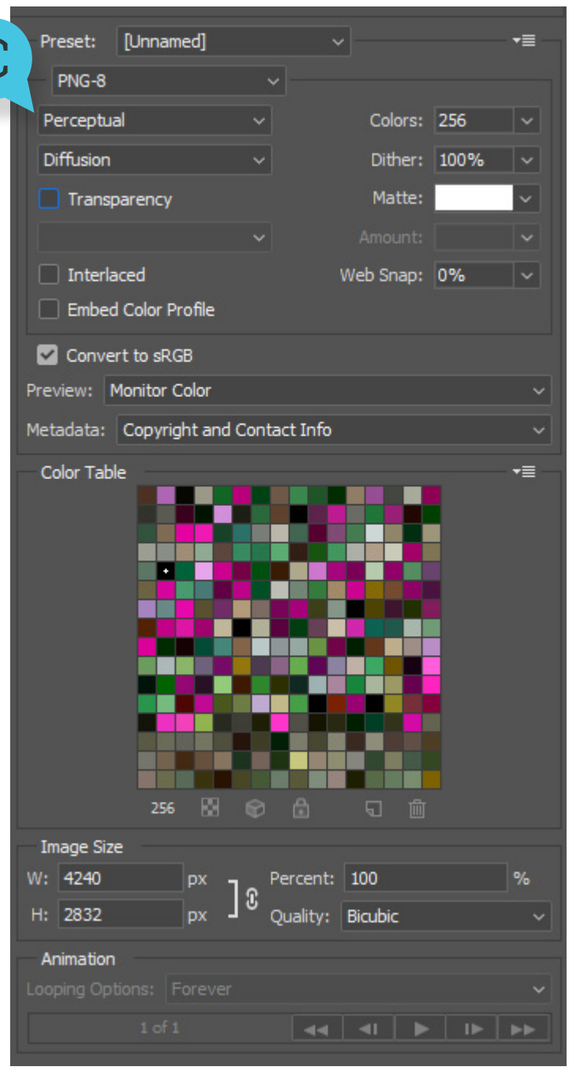


Fig 31. PNG file structure

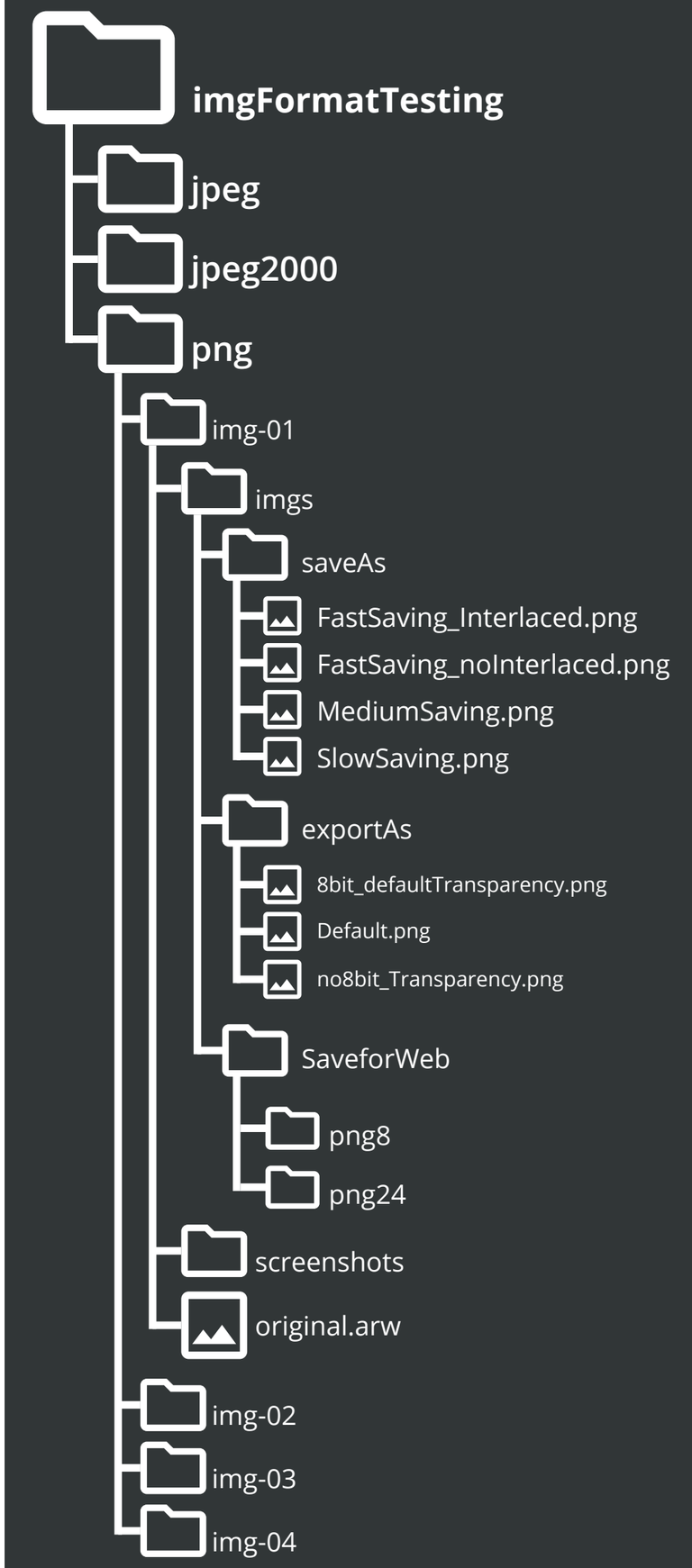


Fig 32. PNG Compression - Save As and Export As

imgFormatTesting > png > img-01

Method	File Name	Compression Quality and Type	File Size
Save As	SlowSaving.png	Low Quality, Max Compression	18.8 MB
	MediumSaving.png	Mid. Quality, Mid/High Compression	18.8 MB
	FastSaving_noInterlaced.png	High Quality, no Interlacing, Mid. Compression.	19.6 MB
	FastSaving_Interlaced.png	Max Quality (100), No/Low Lossy Compression.	22.0 MB
Export As	8bit_defaultTransparency.png	Low Quality, High Compression	8.95 MB
	Default.png	High Quality, No Transparency.	20.6 MB
	no8bit_Transparency.png	High Quality, With Transparency.	20.6 MB

In Fig 32, you can see the two methods: Save As and Export As. I'm choosing to have these compared on their own based on how complex Save for Web is and that will be in its chart. The difference between these two methods in Fig 32. is kind of odd. I got the same file sizes with certain options, such as the Transparency option and the default preset in the Export As method. You get the same file size, and the same for Save As with its Slow and Medium saving options. Resulting in a pretty lackluster graph, but take note of the file sizes as compared to other image formats.

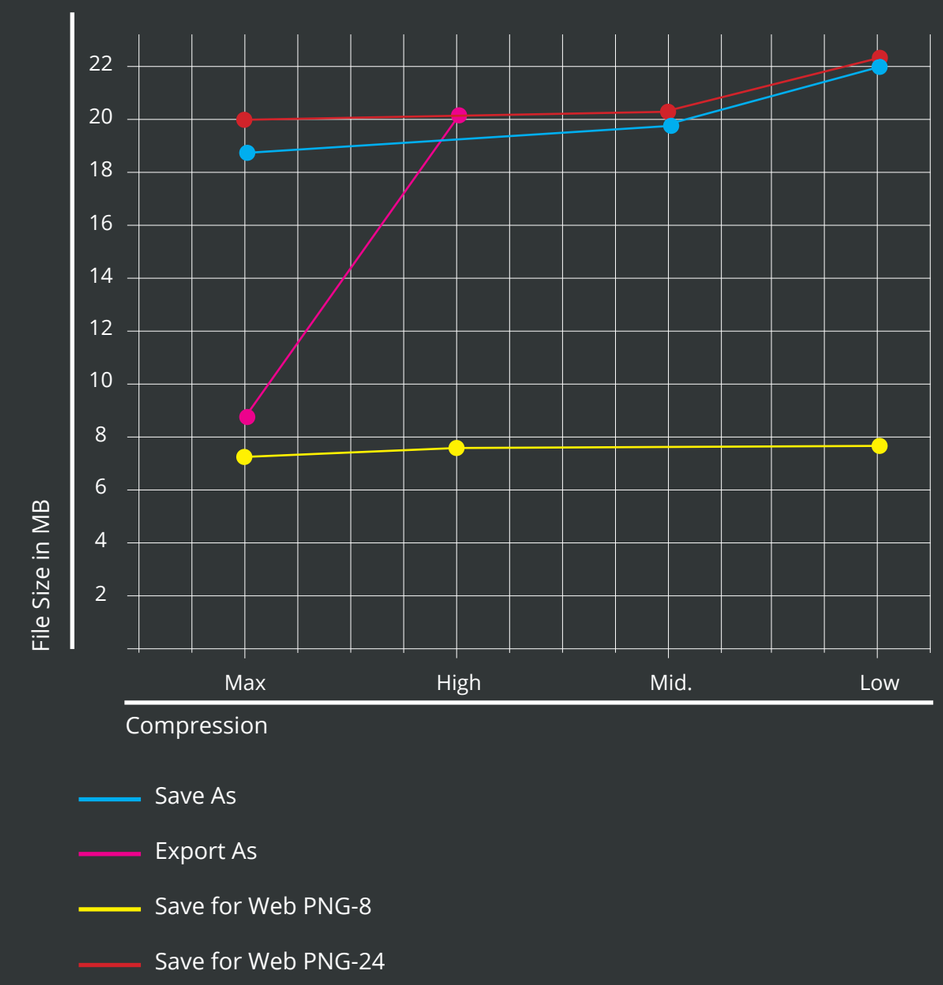
Fig 33. PNG Compression - Save for Web

imgFormatTesting > png > img-01

Bit	File Name	Compression Quality and Type	File Size
8-Bit	Transparency.png	Low Quality, Max Compression	7.24 MB
	DefaultPreset.png	Low Quality, Max Compression	7.24 Mb
	EmbededColorProfile.png	Low Quality, High Compression	7.25 MB
	Interlaced.png	Low Quality, Lower Compression	7.59 MB
24-Bit	Transparency.png	Low Quality, Max Compression	20.1 MB
	DefaultPreset.png	Low Quality, Max Compression	20.1 MB
	EmbededColorProfile.png	Mid. Quality, High Compression	20.12 MB
	Interlaced.png	High. Quality, Low Compression	22.2 MB

In Fig 33, you can see how Save for Web can be pretty complex. Because now you can have more control of which options you get to manipulate for 8-bit and 24-bit PNG files--see Fig 30.C for an image of the dialogue box options. Notice how that each file size is a minimal difference at the end of the day, and how different 8-bit is compared to 24-bit! That bit-depth difference is an exponential leap of file size(s)! Albeit, even the differences between each 24-bit file are also pretty slim.

Fig 34. PNG Compression Graph



PNG Compression Testing Conlusion

PNG is a great option for certain use cases. We are limited to using this format because it results in a larger file size--unless you're using the PNG-8 preset under the Save for Web PNG Dialogue Box. You should only use this if you're trying to display a logo on a webpage, graphics with lines and curves and if you're okay with using a larger file-sized format on your webpage as well.

Look at **Fig 35**. it is an example of the PNG-8 images I created, notice the overall quality that has degraded. That is because there are a lot fewer colors being used here, making it seem pixelated. Albeit, this is an image from a camera and isn't the perfect image to use as a PNG, but it still demonstrates what it does to an image. Each method I used for PNG-8 offered a different outcome and led to a pretty crazy-looking graph in **Fig 34**. Because each exporting method is different, this leads to a wide range of results of images after compression.

In conclusion, if you're going to use PNG for a project, I recommend only using the methods **Save As** and **Export As**. Because the **Save for Web** method is dated and the amount of options is overwhelming. Also, the resulted outcome of the file sizes for each method--excluding PNG-8--was pretty similar. So, since **Save As** and **Export As** are miles simpler to process an image and essentially the same type of file sizes as **Save for Web** PNG-28, I recommend sticking to those options when you've find yourself needing to produce a PNG image.

Fig 35. imgFormatTesting > png > img-01 > SaveforWeb > png8

Ordered from left to right, Biggest to Smallest File Size

GIF Image Compression

What is GIF

Graphical Interchange Format (GIF) was invented by Steve Wilhite in the late 1980s and was intended to produce images that would loop automatically (Lepard). Since this format is old, relative to some other formats, it has many limitations in our modern media era. But, still has its use cases just like the other formats. Typically, you'll see them with internet memes due to their simplistic nature for social media.

GIF is only capable of 256 colors--8 bit--and will result in massive color/detail loss when you compress an ARW image to a GIF file for example (*About the GIF format*). Essentially, you are greeted with a posterized effect on your image. Its alternative is PNG-8.

Compression Workflow

GIFs compression workflow works with the three methods: Save As, Export As, and Save for Web. Again each process is different and offers different solutions as well. See below for more details for each dialogue box from the methods.

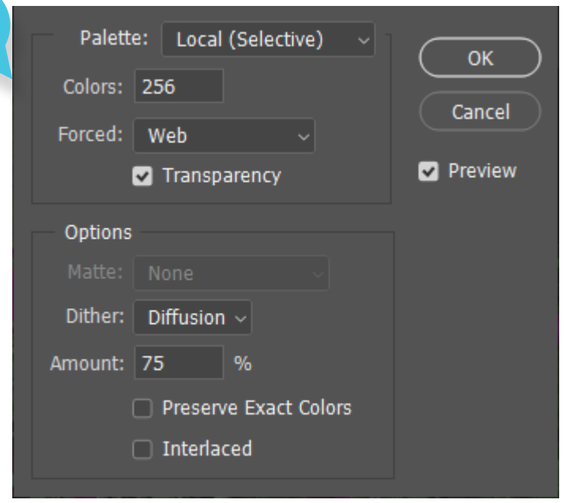
A This is the dialogue box that pops up after the default file explorer on your computer when you choose the Save As method. Observe what is available in this dialogue box. I only manipulated the Dither Amount under the Options section.

B This is a cutout portion of the Export As dialogue box, see Fig 10 for a refresher of what the overall dialogue box looks like. As you can see when you select GIF under the Export As a method, you don't get to choose any options that are proprietary for the GIF format. Instead, we are greeted with just Image Size and Canvas Size options, by far the simplest dialogue box for an image format.

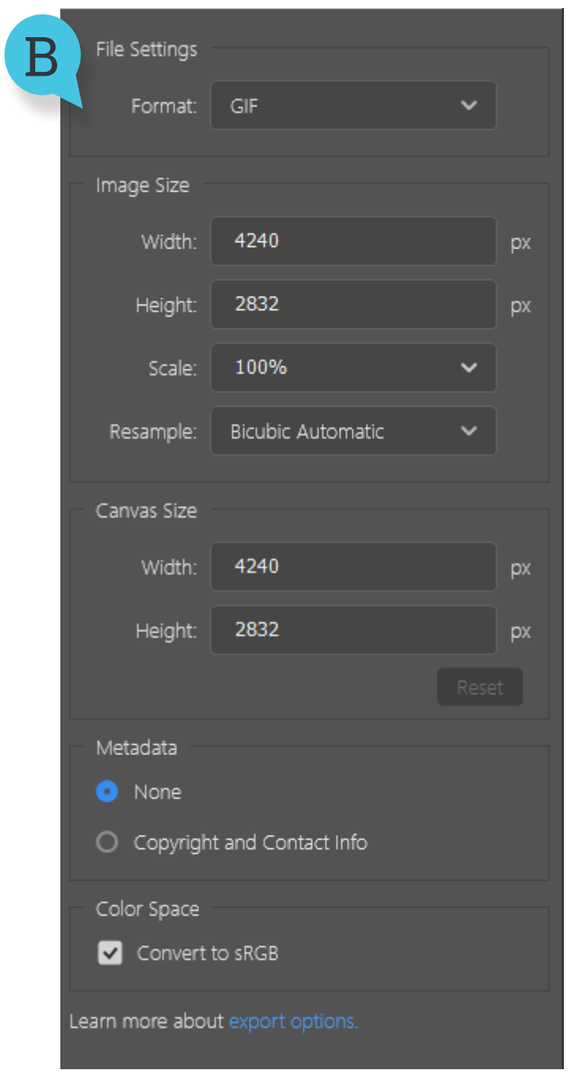
C This is the Save for Web dialogue box for GIF. It is pretty similar to the PNG dialogue box for PNG--see Fig 30.C for reference. It is essentially the same as the PNG dialogue box. But, since we are working with GIFs now, we get more presets that range in compression settings. These are the primary settings I manipulated for the GIF portion of this documentation.

Fig 36. GIF Dialouge Boxes

A



B



C

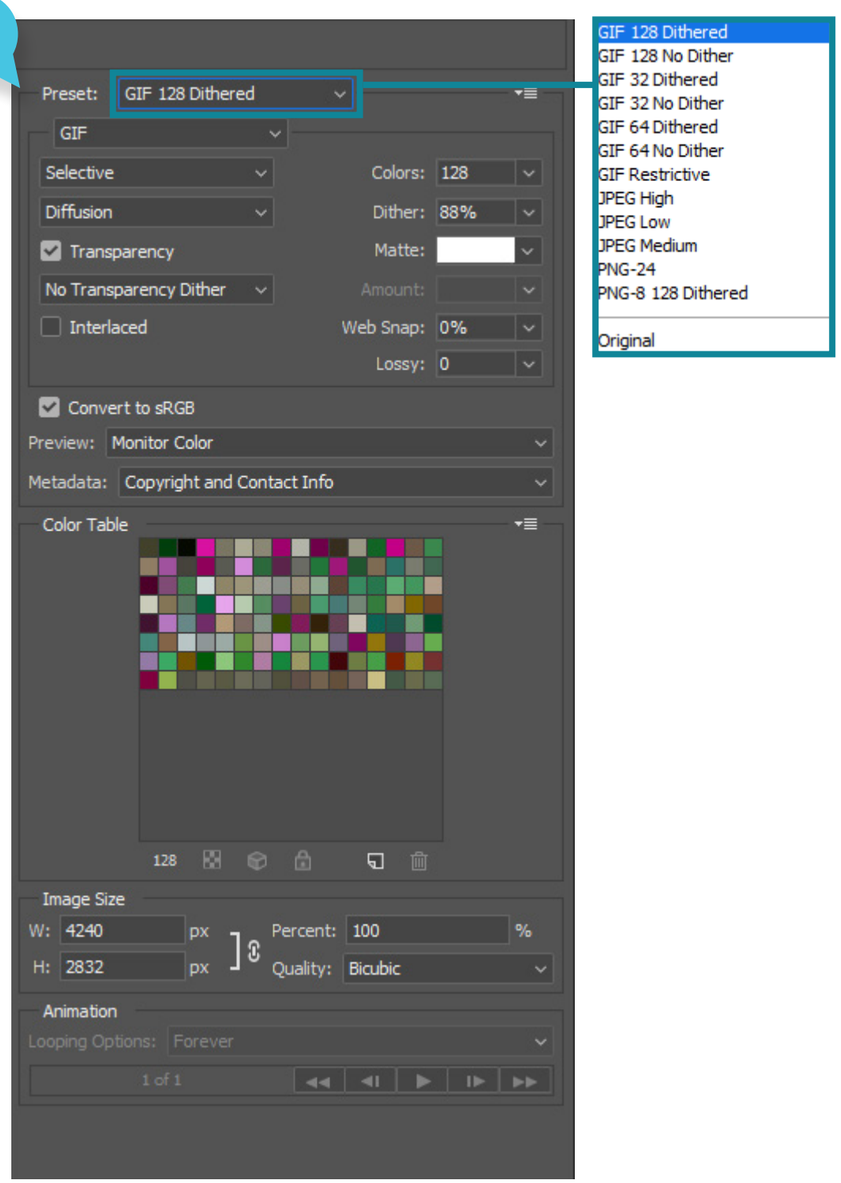


Fig 37. GIF File Structure

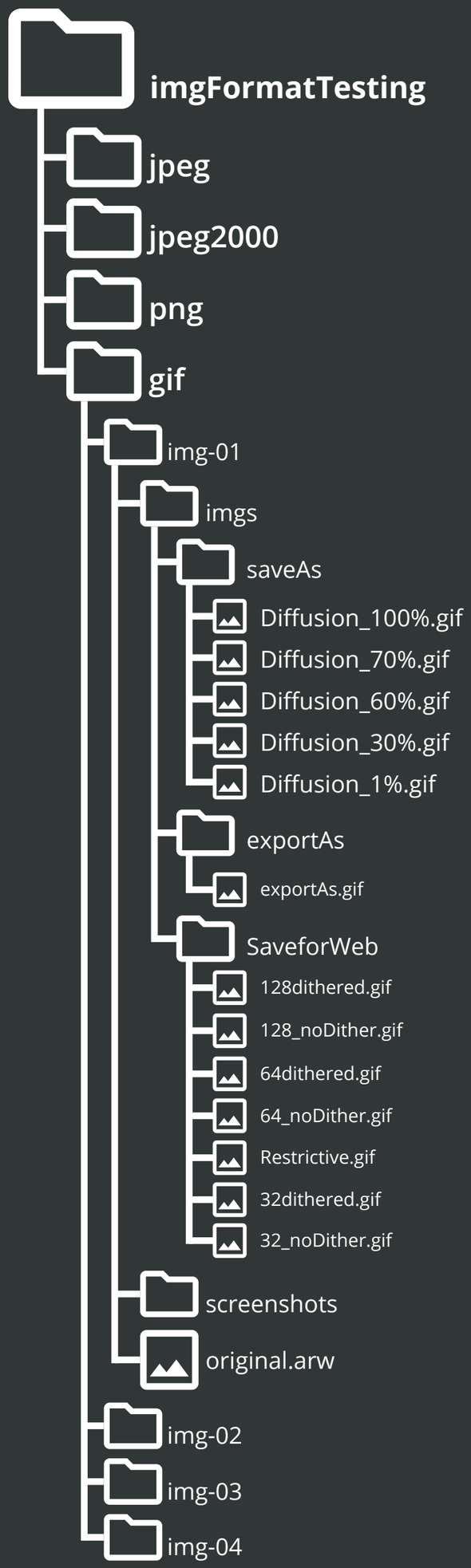
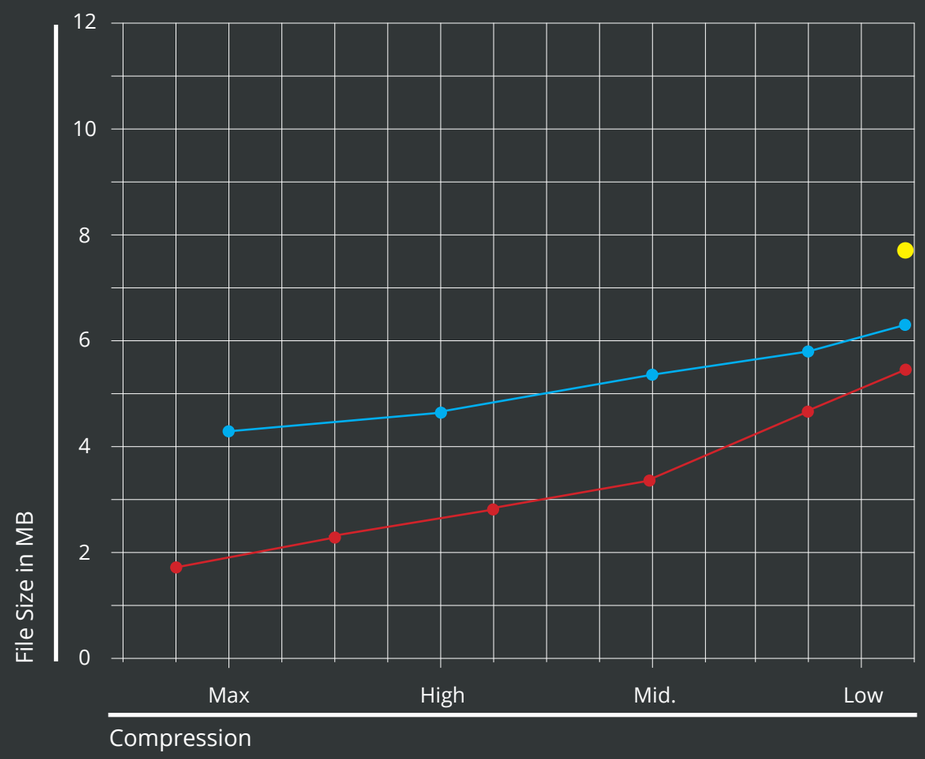


Fig 38. GIF Compression

imgFormatTesting > gif > img-01

Method	File Name	Compression Quality and Type	File Size
Save As	Diffusion_1%.gif	Lowest Quality, Max Compression.	4.44 MB
	Diffusion_30%.gif	Low Quality, High Compression.	4.77 MB
	Diffusion_60%.gif	Mid. Quality, Mid. Compression.	5.32 MB
	Diffusion_70%.gif	High Quality, Low Compression.	5.61 MB
	Diffusion_100%.gif	Max Quality, Lowest Compression.	6.25 MB
Export As	exportAs.gif	Default Quality and Type	7.62 MB
Save for Web	32_noDither.gif	Lowest Quality, Max Compression.	1.90 MB
	32dithered.gif	Low Quality, High Compression.	2.35 MB
	Restrictive.gif	Low Quality, High Compression.	2.72 MB
	64_noDither.gif	Mid. Quality, Mid. Compression.	3.12 MB
	64dithered.gif	Mid. Quality, Mid. Compression.	3.51 MB
	128_noDither.gif	High Quality, Low Compression.	4.79 MB
	128dithered.gif	Max Quality, Lowest Compression.	5.21 MB

Fig 39. GIF Compression Graph



Note: When making this graph I was introduced to the challenge of where to plot my points for the Save for Web portion. So, this graph was subject to my opinion of where each point should be on the graph.

GIF Compression Testing Conlusion

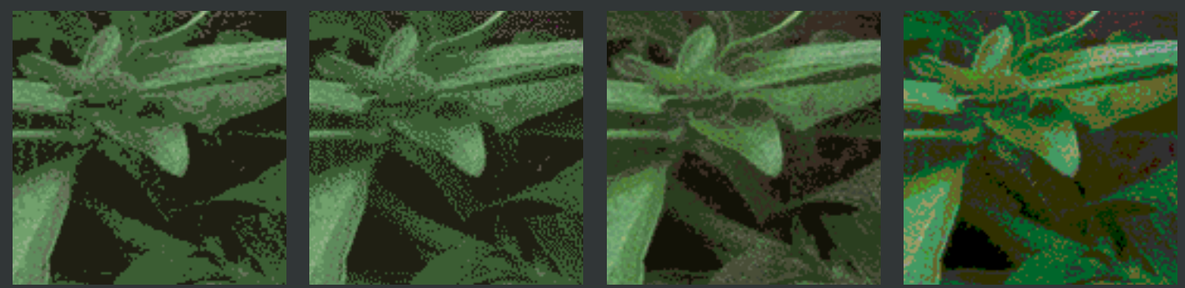
To conclude the GIF section, I want you to look at Figs 37-39. The outcomes are pretty interesting, especially if you compare the file sizes to the image examples--note that I'm only displaying the Save for Web examples. Those file sizes are relatively big and sadly the quality doesn't excel either as compared to other image formats. Remember, this is due to the bit-depth of GIF and our limit to 256 colors.

Is it worth it nowadays to use this format? Just like every other format, there is a use case for GIF. But, you're probably better off using PNG or JPEG, because you get more quality out of an image and reasonable file sizes. Even PNG has much larger file sizes because there is more color, the quality trade-off for file size is reasonable. So, when would you use this format then? Well, these are great for internet memes of course! But also, they are commonly used with Discord users to communicate in a fun way with friends. A lot of messaging platforms offer options for animated images to be sent to others. From a developer standpoint, I would use GIFs on my web projects for fun small animated graphics to add character, but I would have to keep in mind how big the image resolution and file size is to properly display it to a user.

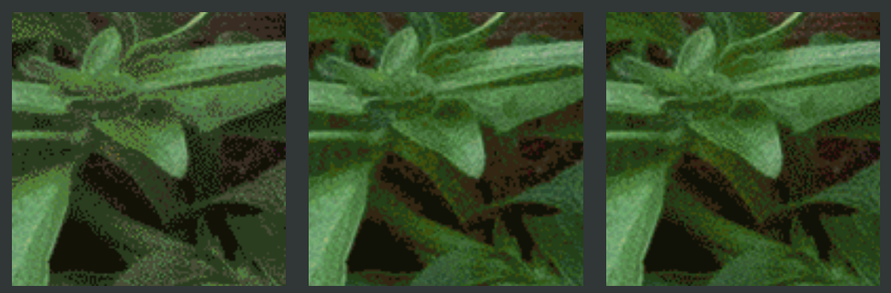
In conclusion, GIFs are an old format that you would never use for logos, camera images, and things like that. Nowadays, quality is expected and a low-quality image like GIF wouldn't be ideal and would probably have an absurd file size relative to the image quality of the file.

Fig 39. GIF Save for Web examples. Zoomed in.

imgFormatTesting > gif > img-01 > SaveforWeb



32_noDither.gif | 32dithered.gif | 64_noDither.gif | Restrictive.gif



64dithered.gif | 128_noDither.gif | 128dithered.gif

Final Evaluation

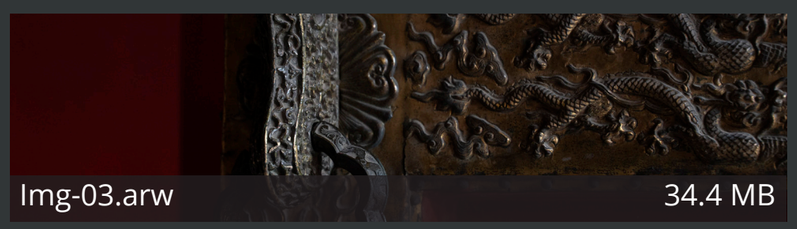
Evaluation Purpose

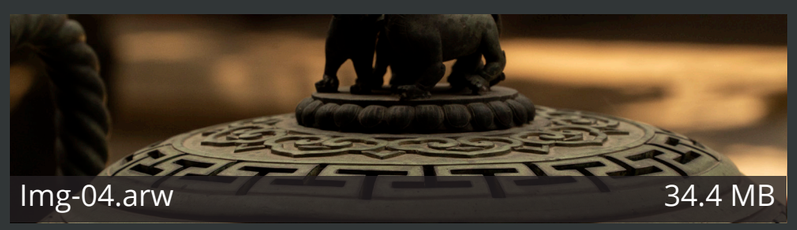
Before this section, I introduced you to how each process is carried out, the dialogue boxes, and the respected compression options in each. I even showed a quick image example as well. However, in this section will be a targeted visual of the implications of each image format and compression results.

Using the four selected images I've used throughout this whole process, I'll put together a gallery in a sense. This will help show the difference between image formats, at different zoomed-in views. I'll help point out any artifacts in all different formats as well. Then at the end of the gallery for an image (E.g. IMG-01.arw), I'll throw together a plot graph, instead of a line graph I've done in prior sections. The graph will help describe the corresponding filesizes to each format for one single image.

Below are the images that you've seen before. The title for each image (E.g. img-01) will be the title section for each image, and again each section will compare multiple versions of the same image just in different formats.

NOTE: I have well over 5 GB of images from this entire testing process. Which would make this section long If I displayed these images in tiles. So, to keep it simplistic, I'll display each image and each file format. But, I'll display one method for each image like the Save As a method, since each image format can be used with the Save As method--especially only JPEG 2000.





Img-01 Evaluation

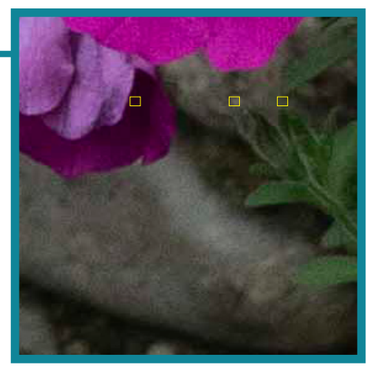
Fig 41. img-01.arw results from JPEG Save As

img-01 — 34.4 MB — 4240x2832

Image Name — Orignal File Size — Image Resolution

Zoomed-in blocks like these will be the focus areas to visualize what is going on with each image format and its respected compression technique. Here you can look closely and see each colored pixel in this zoomed-up view. Each pixel is the detail that we perceive.

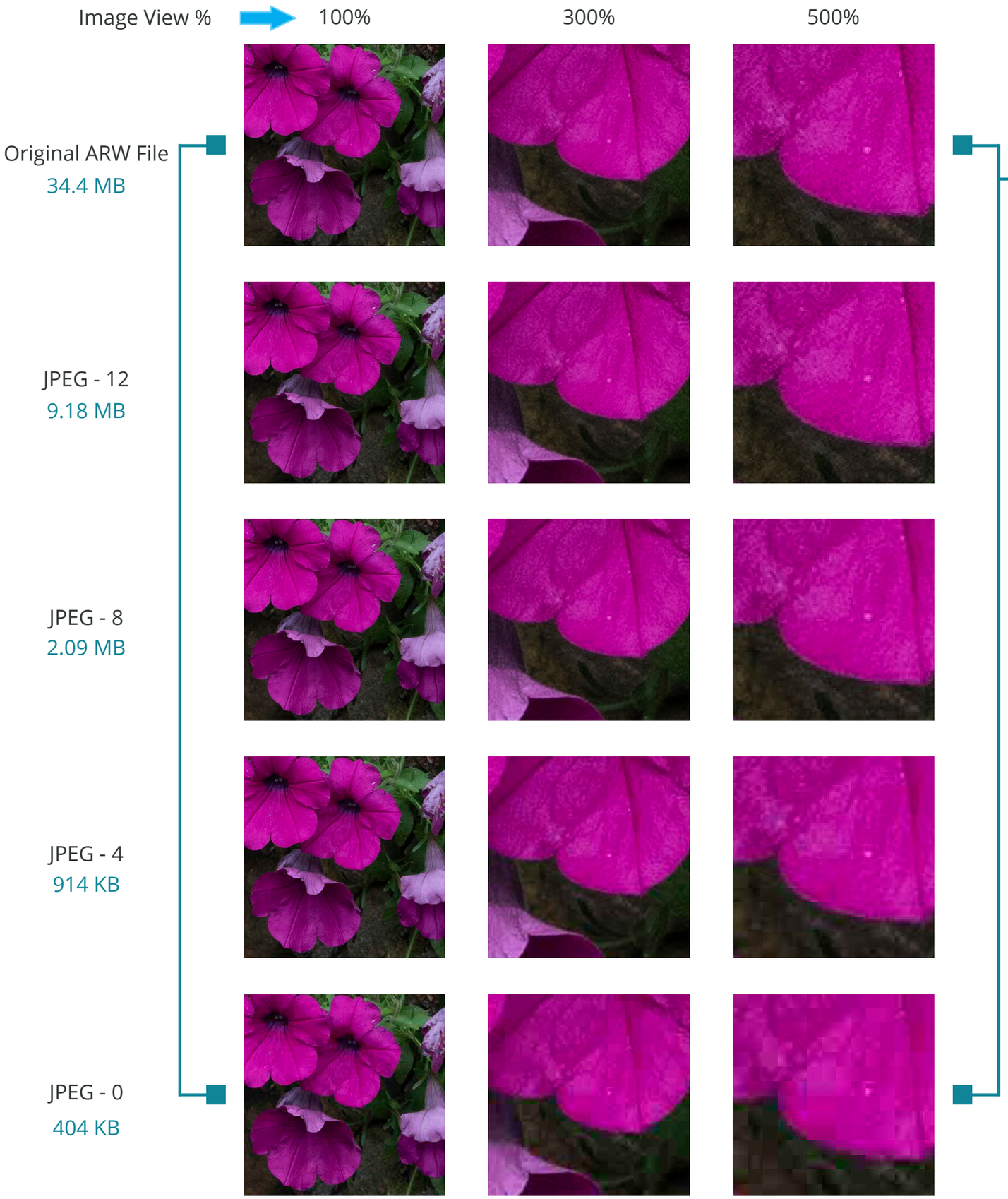
See Fig 41 for a comparison of image types just with this one block. I'll choose sections based upon color and texture that I think will be skewed with each image type and its compression intensities.



Here is another potential spot to zoom in and analyze

These will be present in JPEG compression at various degrees, you'll notice them more in JPEG-2000 because you can modify the tile sizes you're working with--refer back to Fig 28.

Fig 41. img-01.arw results from JPEG Save As



This will be the structure of how I'll demonstrate the visual difference along with the file size to correlate it later with a final chart to compare all image formats that I tested on img-01.arw.

This way will help you not only quantify perceptible quality but also help inform you on a sweet spot of file compression.

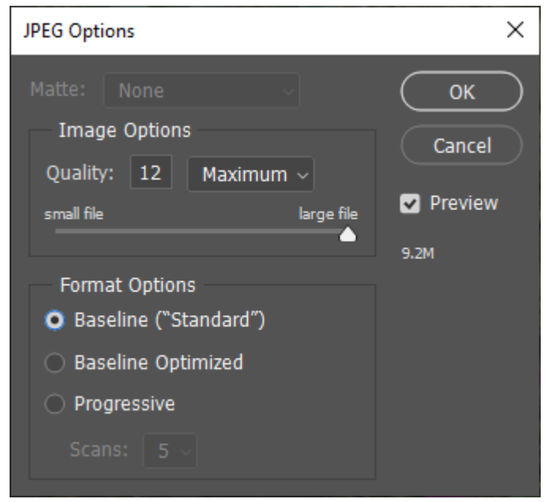


Fig 42. Save As Dialouge Box

Each tile evaluation will have an example image of the dialogue box that was used in the process.

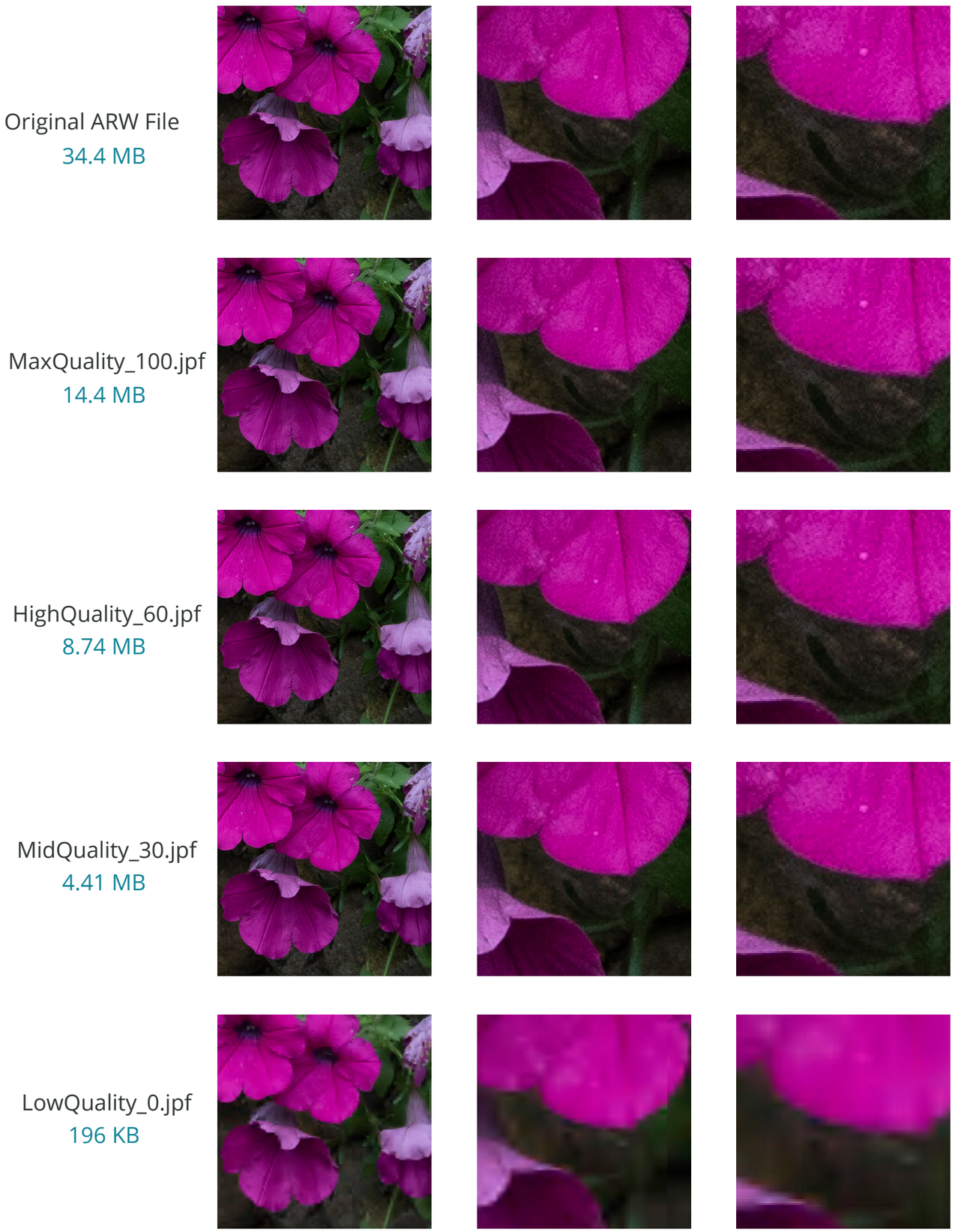
Visual Analysis

JPEG is a pretty standard image format and given what was described in the JPEG image compression section. We can now see a more in-depth visual here in **Fig 41**. The top image is our original file--all the other images I tested, their original ARW file was approx. 34.4 MB uncompressed in PhotoShop--and this file is partnered with two more zoomed-in tiles.

I want you to observe how each pixel is accumulated into essentially a blob of whatever color the compression algorithm deemed to be placed there. I use the word blob because it's kind of a blob of pixelation and distortion to an extent as you compress the image down even more. This is due to how the compression compares pixels and results in fewer data--or fewer color details.

I chose to only display img-01 out of the other three because it is a similar general outcome. Albeit there are different colors, shadows, textures, and so much more that could be present in an image. Meaning images are not the same, they all differ slightly. So I acknowledge images will differ still, but I feel that img-01 alone should demonstrate what each format is visually doing to an image to give a sense of what happens in any image.

Fig 43. img-01.arw results from JPEG-2000 512x512 Tiles



Original Resolution: 4240x2832

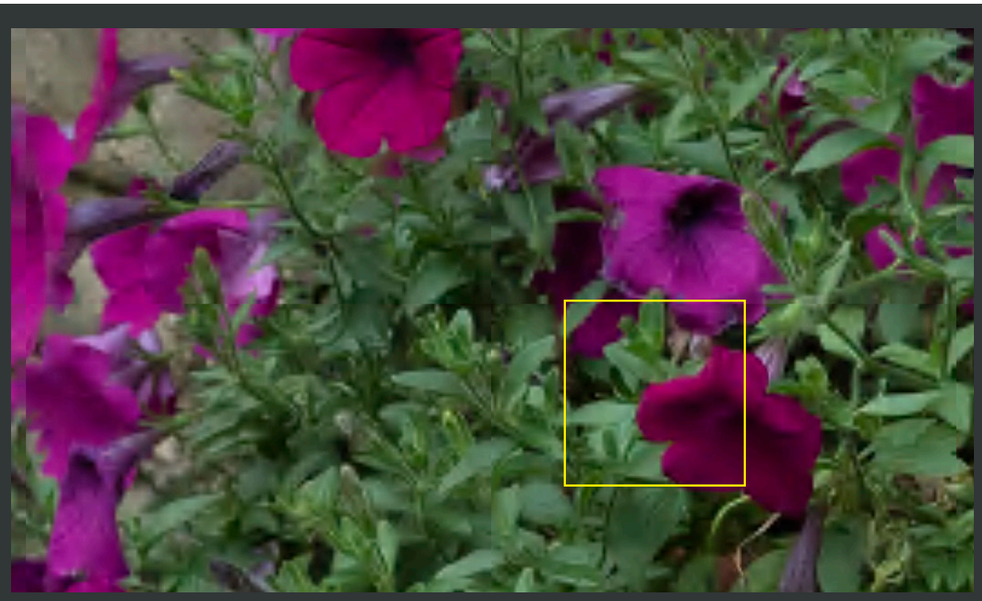


Fig 44. imgFormatTesting > jpeg2000 > img-01 > imgs > 512x512 > lossy > LowQuality_0.jpf1

This is a blown-up view of the bottom image in Fig 43. It is a bit easier to see the tiles this way that are present from JPEG-2000 compression. Granted it is not as intense as what you would see with 128x128 tiles. But you can still see the subtle lines that are left on the screen from each tile--like artifacts. Yellow outline is one Tile.

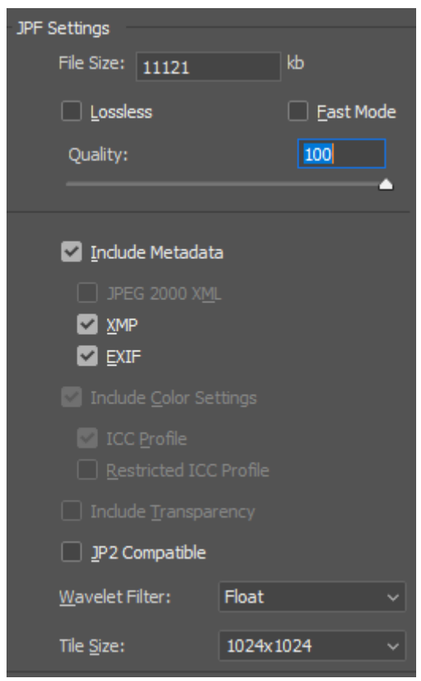


Fig 45. JPEG-2000 dialouge box.

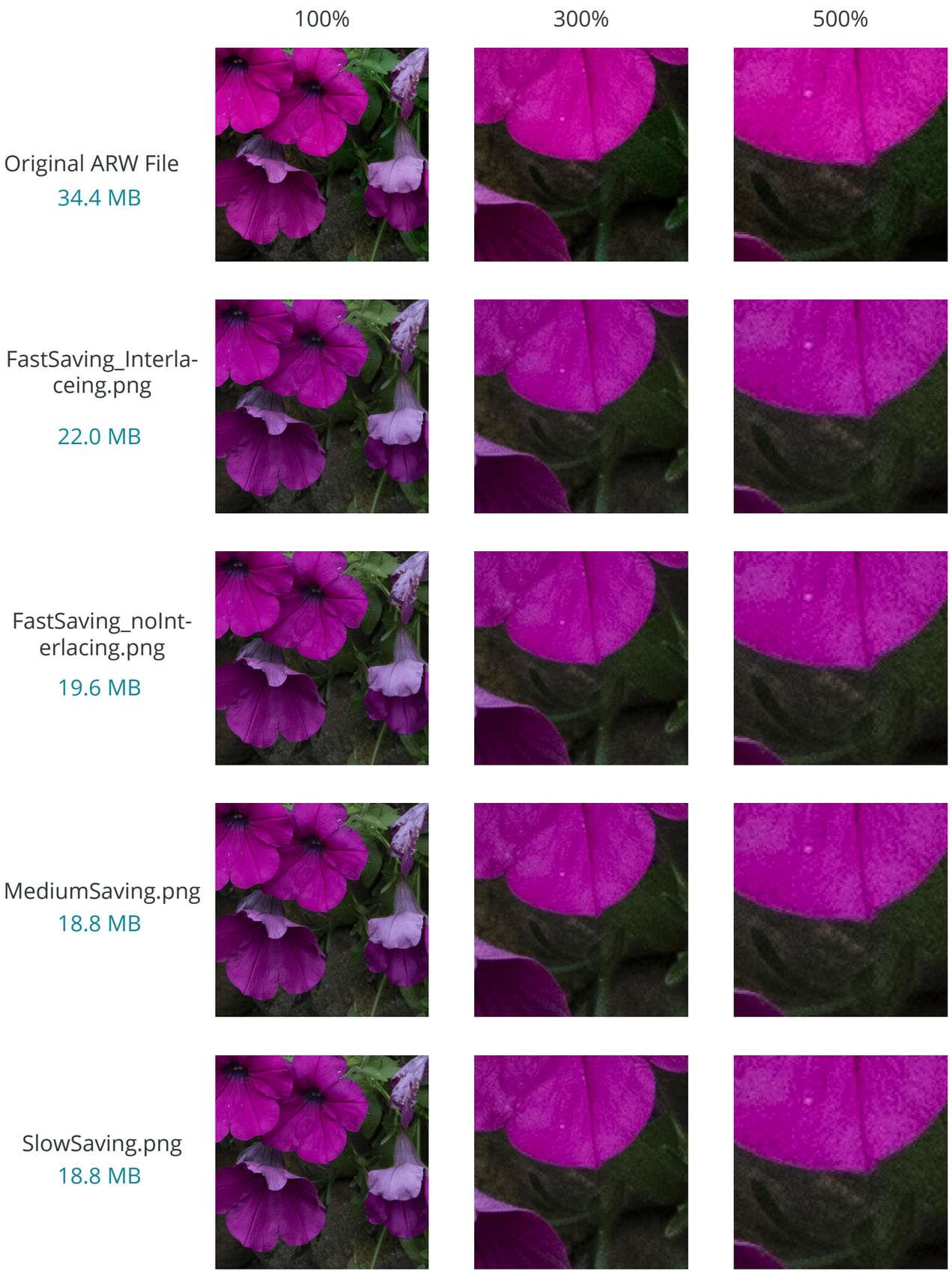
Visual Analysis

Unlike JPEG, JPEG-2000 does work with tiles that are set in a range of sizes--mentioned in **Fig 44.** It is also capable of lossless compression, which enables it to be an awesome JPEG solution--albeit the format was not ever widely supported (*JPEG 2000 files*). **Fig 43** is a demonstration of this compression with 512x512 tiles.

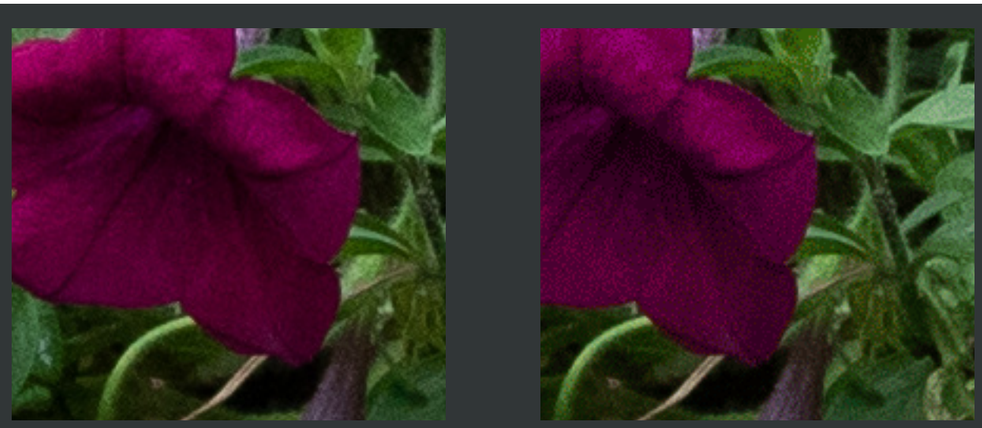
You should be able to see how the pixels and details are lost with this compression. But this time it is with bigger tiles and results in these subtle line artifacts when you compress with JPEG-2000. Some formats also don't retain the true original color, JPEG and JPEG-2000 do this fairly well--unlike PNG, which will be seen next.

The lowest possible quality with JPEG-2000 offers a lot more "softness" to the image rather than its lowest-quality version in the JPEG format. Does it look bad? Well, yeah it's pretty bad. But, if you need a really small raster image for a project, you could use this to get a very small file size rather than what JPEG could do! But, again this format is not supported.

Fig 46. img-01.arw results from PNG Save As



Original Resolution: 4240x2832



20.1 MB | 16 million+ Colors

7.24 MB | 256 Colors

Fig 48. PNG Save for Web PNG-24 vs. PNG-8

For Fig(s) 46-47, you are seeing the results of PNG via the Save As method. Here though, you can observe two of many possible results with the Save for Web method. This method allows you to save a PNG file as a 24-bit or an 8-bit file. If you choose 8-bit, it takes you a lot closer to what GIFs offer.

Also, refer back to Fig 39. for an example of PNG-8 with various Dithering settings. Here you are seeing two bit-depths with 100% dithering and default presets.

Visual Analysis

For some odd reason, PNG just isn't a fan of preserving color. As you can see starting from the original file--again at the top of Fig 46--and going down to the lowest quality file via the Save As a method, results in the overall color being less vibrant. Another word to describe this anomaly is that the color seems less alive when compared to the original file.

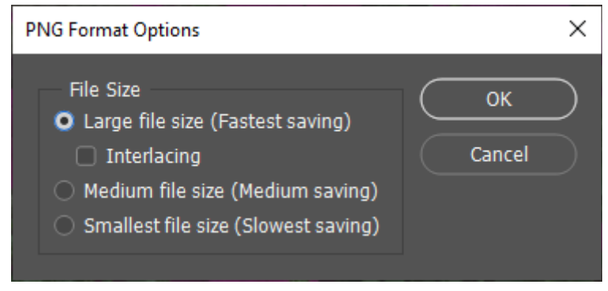


Fig 47. PNG Save As dialouge box.

But, you will notice that there are no tiles of any kind in this compression process, unlike JPEG-2000. Take note as the file size compresses down, it is not a drastic change at all. Even the MediumSaving.png and SlowSaving.png file is the same file size! I did double-check that I didn't accidentally process the same image twice, and got the same outcome twice. That was not the case, I got the same file size with two different compression settings. So, at least for this image, there was no difference between the two distinct compression/quality presets.

As a final note, the file size and the visual consequences of using this file just aren't worth it in my opinion. Unless you are working with a graphic that is like a Logo, for example, you shouldn't use this because of how the color is tossed aside in an image like this that has vibrant hues.

Fig 47. img-01.arw results from GIF Save As

Original Resolution: 4240x2832

Fig 49. imgFormatTesting > gif > img-01 > imgs > SaveforWeb > 32_noDither.gif

This specific image is from the Save for Web method and is the lowest possible preset for GIF via this method. You can see zoomed-in pictures back in Fig 39. This is important to see compared to the Save As method because even though it is the same image format, because of the presets this image and the images in Fig 47 look drastically different. Almost a posterize type effect just from compression.

Visual Analysis

Now, we all know GIFs and how they have impacted the internet culture. But, now you should see how they utterly destroy an image and I love it! It reminds me of horrible posterized images, especially when you use the dither settings via the Save for Web method--see Fig 49.

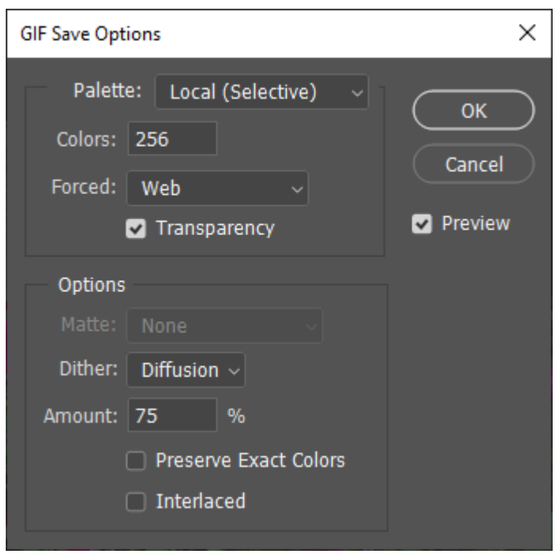


Fig 48. GIF dialouge box. Save As

But, I want to note how horrible the image looks, and yet the file size is about as big as a generic single static web page! This is an old format, so I got to cut it some slack, but as a developer and designer, I see no use case for a GIF. Except for super small graphics like emojis, the Discord chatting service accomplishes this perfectly. Also, since we're working with GIF we only get 256 possible colors and that is something we take for granted because we are fortunate enough to have devices that display millions of colors.

In short, with this visual in Fig 47, you can see the consequences you have with this compression on an image and should only be used in very specific situations I feel like in our modern era of digital media. One such use case is sending fun consumable media via chat, which is already a thing.

Img-01 Evaluation Chart

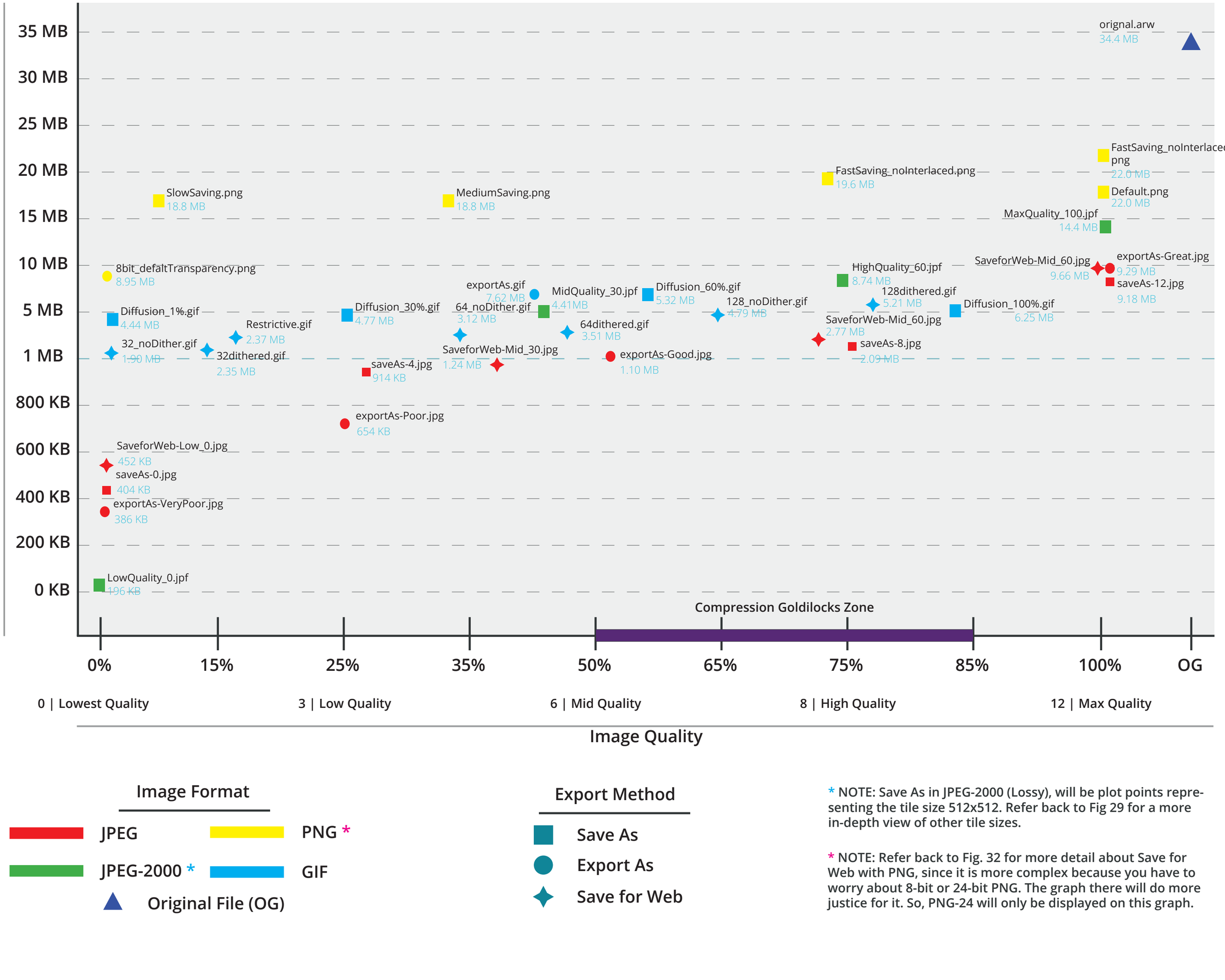


Image Format

- JPEG
- PNG *
- JPEG-2000 *
- GIF
- Original File (OG)

Export Method

- Save As
- Export As
- Save for Web

* NOTE: Save As in JPEG-2000 (Lossy), will be plot points representing the tile size 512x512. Refer back to Fig 29 for a more in-depth view of other tile sizes.

* NOTE: Refer back to Fig. 32 for more detail about Save for Web with PNG, since it is more complex because you have to worry about 8-bit or 24-bit PNG. The graph there will do more justice for it. So, PNG-24 will only be displayed on this graph.

Img-02 Evaluation Chart

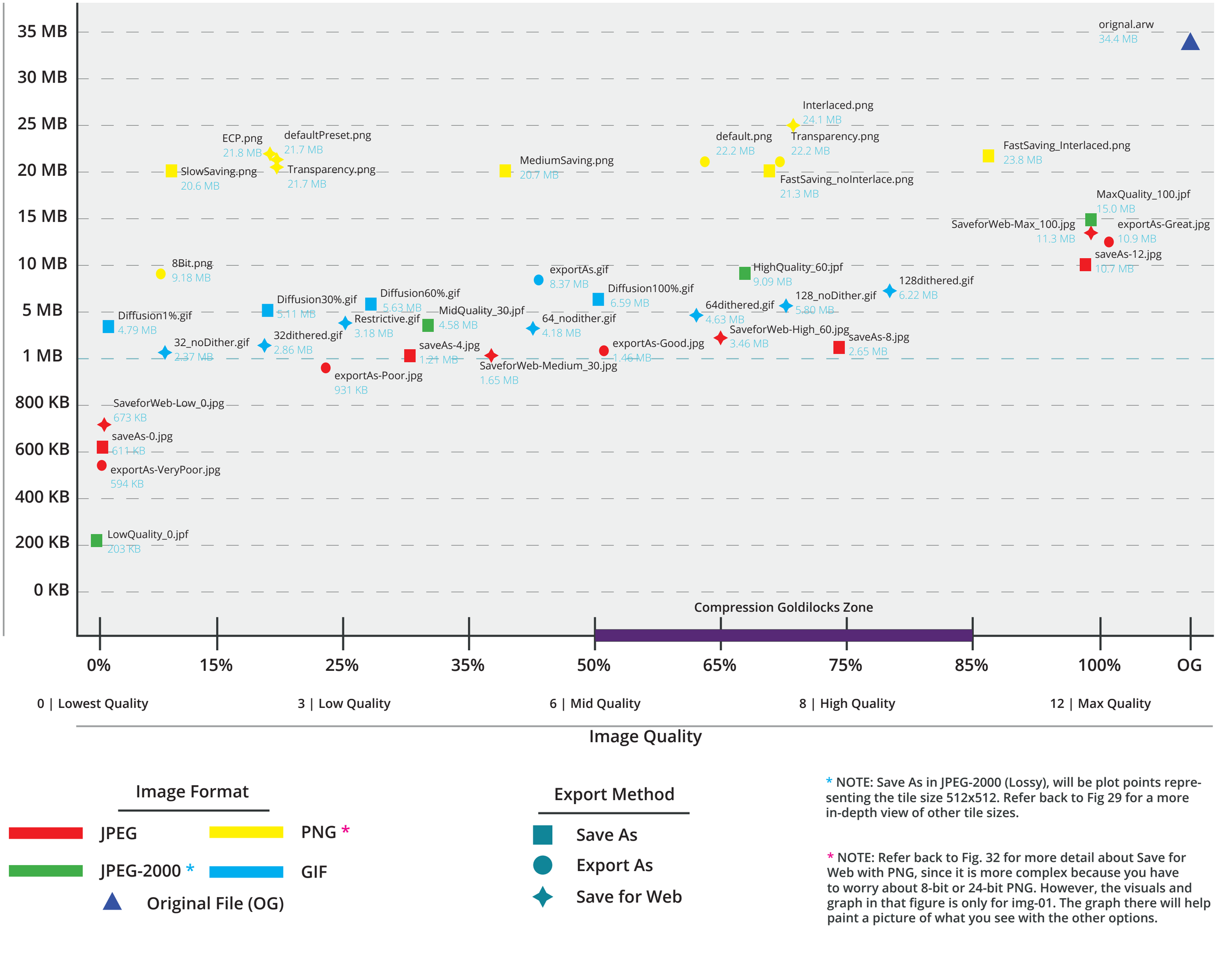


Image Format

- JPEG
- PNG *
- JPEG-2000 *
- GIF
- Original File (OG)

Export Method

- Save As
- Export As
- Save for Web

* NOTE: Save As in JPEG-2000 (Lossy), will be plot points representing the tile size 512x512. Refer back to Fig 29 for a more in-depth view of other tile sizes.

* NOTE: Refer back to Fig. 32 for more detail about Save for Web with PNG, since it is more complex because you have to worry about 8-bit or 24-bit PNG. However, the visuals and graph in that figure is only for img-01. The graph there will help paint a picture of what you see with the other options.

Img-03 Evaluation Chart

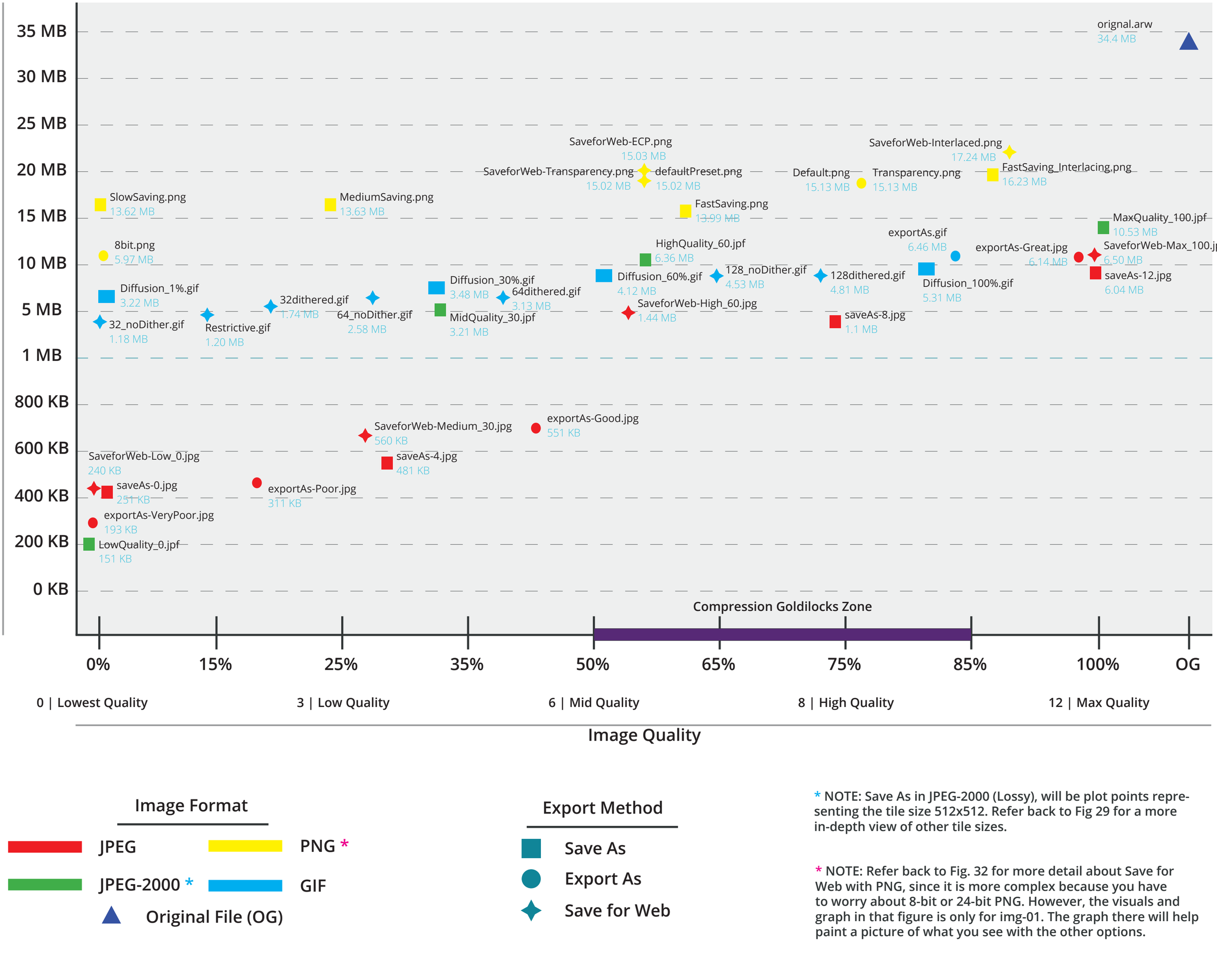


Image Format

- JPEG
- PNG *
- JPEG-2000 *
- GIF
- Original File (OG)

Export Method

- Save As
- Export As
- Save for Web

* NOTE: Save As in JPEG-2000 (Lossy), will be plot points representing the tile size 512x512. Refer back to Fig 29 for a more in-depth view of other tile sizes.

* NOTE: Refer back to Fig. 32 for more detail about Save for Web with PNG, since it is more complex because you have to worry about 8-bit or 24-bit PNG. However, the visuals and graph in that figure is only for img-01. The graph there will help paint a picture of what you see with the other options.

Img-04 Evaluation Chart

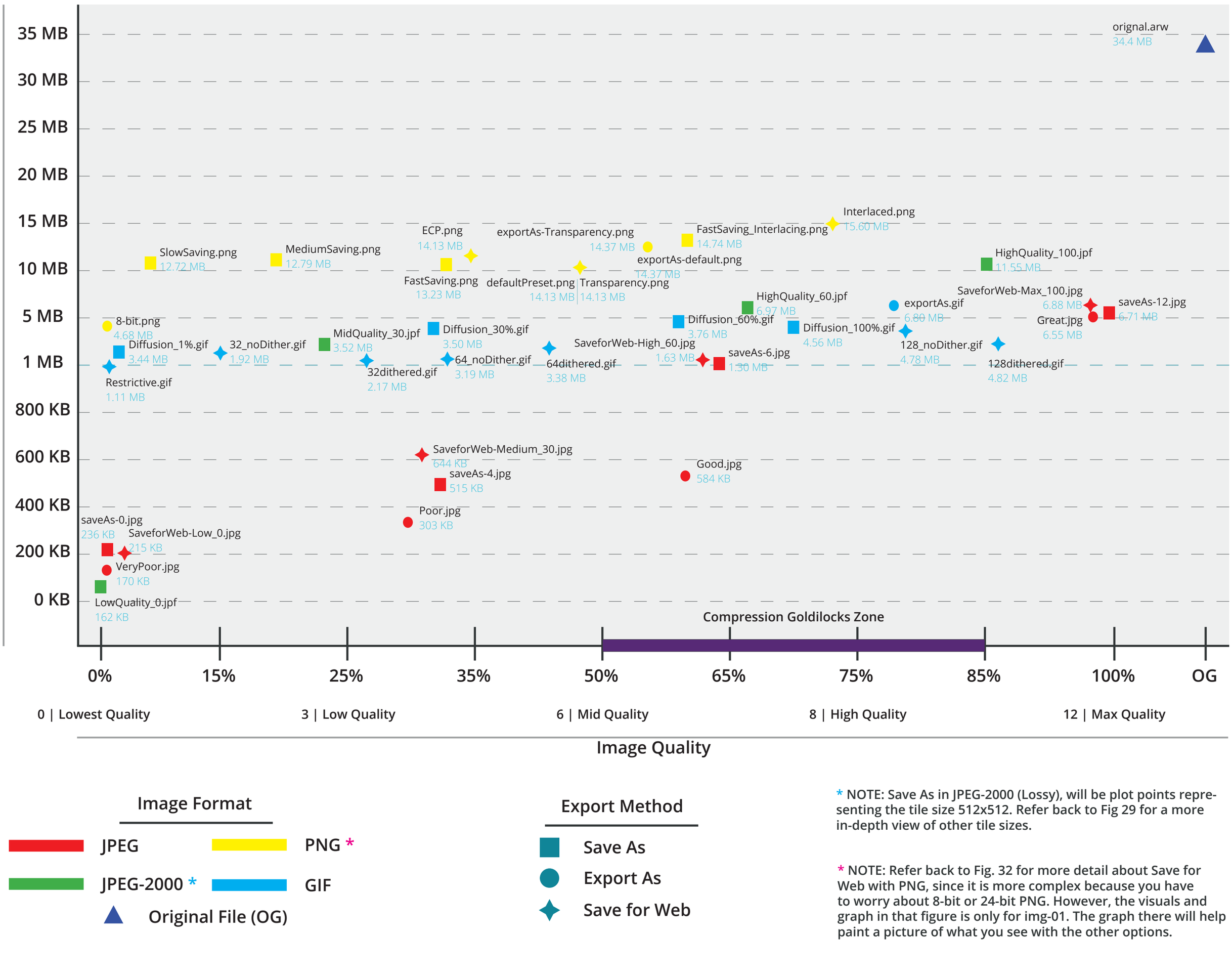


Image Format

- JPEG
- PNG *
- JPEG-2000 *
- GIF
- Original File (OG)

Export Method

- Save As
- Export As
- Save for Web

* NOTE: Save As in JPEG-2000 (Lossy), will be plot points representing the tile size 512x512. Refer back to Fig 29 for a more in-depth view of other tile sizes.

* NOTE: Refer back to Fig. 32 for more detail about Save for Web with PNG, since it is more complex because you have to worry about 8-bit or 24-bit PNG. However, the visuals and graph in that figure is only for img-01. The graph there will help paint a picture of what you see with the other options.

Image Compression Conclusion

I opted to only display img-01 for the visual comparisons just to help save space. So, I provided a graph that--albeit not the most accurate--demonstrates the differences between images. The qualities are fairly subjective, and I'm open to debate about where to place items. But, I placed them based on their specific format and methods quality settings. Across all images, they had this goldilocks zone of compression you would want to shoot for--when you're compressing an image. Managing space is a huge issue in the digital media industry, especially for Web Developers. So, having these evaluation charts for images 0-4 gives us a perspective of what options we can use for a good-looking image to use.

I do want to note, that even though different formats share the same local space (in terms of file size) on the charts, does not mean they look the same or good at all! GIF looks pretty bad--refer back to Fig 39--and yet they have pretty massive file sizes, albeit it was with these already existing big images that have a lot of data within them. In short, look at each of those graphs and understand that file size doesn't entirely correlate to image quality.

To end this long confusing documentation of image compression practices, I won't mention that the number one thing I learned from this entire process is that you won't learn by not doing it, you have to find an image and mess around with compression options! Find what works best and burn that in your mind. Because now I can look at an image--a raw image to be specific--I can tell someone which would be the best format and a good compression setting for that. As a developer, I've empowered myself to do this by testing all kinds of compression settings.

Section Five: Technology Assessment

This section is meant to be a fun examination of technology, it will seem to be as a refresher possibly at this point in the entire document. However, but this section is placed here because it helps lead you into the section about video file formats. So, after a long section about Image Compression, take a break and have fun reading this section. You'll learn/re-learn some key concepts and terms that you have to know if you'll be working in this industry.

Aliasing & Anti-Aliasing

When you're playing a video game or looking at an image in general, and if you look along the edges of objects in the image/game, you may see some weird jagged-like artifacts. This is called aliasing and occurs when the resolution is too low (*Aliasing & anti-aliasing*). These are known as "jaggies" and is due to the device you're using, it is especially prevalent with older/lower-end tier pc components (Cabading). Before that, you have to know some key components of a computer. See Figure 1 for an example.

What are the primary components of a consumer pc? It is the CPU, Motherboard, GPU, RAM, Storage, Coolers, and PSU. All of these work together to form a computer, see Figure 9 showing the location of these components in a desktop PC.

One of the major components that deal with on-screen graphics is the Graphics Processing Unit. In short, the graphics card is designed to carry most—if not all—of the weight of the graphic-induced load on the PC. It works in tandem with the CPU—along with every other component in the PC. That tandem work flow is called GPU acceleration, which the GPU supporting the CPU in playback of media at a giher quality than with out GPU accerlation (*GPU accelerated rendering*).

Therefore, when seen, the jagged artifacts are due to the computer having some problems in fully rendering the graphic element because the element (whatever it is) is composed of lines and curves (Cabading). Because the resolution of the element that is being displayed is composed of so many pixels and if there isn't a high enough resolution being displayed, the aliasing artifacts will appear (Cabading). This is due to how each pixel is aligned-vertical and horizontal (Cabading).

Figure 1. Adobe, *Letter A with and without anti-aliasing,* 22 Aug. 2016

Different types of anti-aliasing

Spatial anti-aliasing

this is the process of taking a low-resolution image and improving the color accuracy that is akin to what you would get in a high-resolution image, these new colors then blend the pixels of a low-resolution image and the jaggies are minimized (Cabading).

Post-process anti-aliasing

This is anti-aliasing that is being actively rendered, pixels are blurred after the GPU decides where polygon edges are, then compares colors between each pixel and blurs the pixels porportionally to their contrast (Cabading). This process also helps with minimizing the required amount of processing power to achive anti-aliasing as compared to spatial anti-aliasing (Cabading).

Anti-Aliasing Methods

Spatial Anti-Aliasing solutions

SSAA:

Supersampling anti-aliasing is a very effective solution for spatial aliasing and also know as full-scene anti-aliasing (Cabading). This offers great photorealistic adjustments for images, but doesn't work well with vertical and horizontal lines--it softens these lines too much (Cabading).

MSAA:

Multisample anti-aliasing is when the GPU smooths out polygon shapes on the screen, but does not smooth out any textures--which is important to know for games.

CSAA and EQAA:

Coverage Sampling Anti-Aliasing and Enhanced Quality Anti-Aliasing, these two were developed by GPU manufactures for their graphic cards, NVIDIA (CSAA) and AMD (EQAA) (Cabading). These are grouped together because they essentially function the same. They target polygons in images and picks out sections that are most likely to have jaggies present, then supersample those targeted pixels in the region.

Post-Proccess Anti-Aliasing solutions

MLAA and FXAA:

AMD and NVIDIA both developed a post-process anti-aliasing tech. AMD developed MLAA (Morphological anti-aliasing) and Nvidea developed FXAA (fast approximate anti-aliasing) and both work similarly (Cabading).

Both function as described for the definition of post-process anti-aliasing (Cabading).

TXAA:

Temporal anti-aliasing is akin to film motion because its function is to mimic smooth motion and that is popular among video games (Cabading).

It helps produce a sharper image by supersampling and induces smooth motion blur at the same time--this process requires more computing power than MLAA and FXAA (Cabading).

SMAA:

Enhanced subpixel morphological anti-aliasing was developed by a student, Jorge Jimenez, he designed it to combine spatial and post-processing anti-aliasing techniques (Cabading).

It takes each pixel and smooths them using the blurring method that both MLAA and FXAA employ while supersampling the image for sharpness (Cabading).

This process requires less computing power than MLAA/FXAA (Cabading).

Lossy vs Lossless

Whats the difference?

Media file types—images, video, and audio—all have compression options. Compression is the process of reducing a file size down to the desired size (*Compression*). Which helps deliver content across the internet. So, what's lossy and lossless compression?

Lossy is compression that takes data from the media file and deletes it to reduce a file size down (*Lossy vs Lossless Compression*). This does reduce the file size a great amount but at a cost. Think that the data that is being lost is essentially quality (image quality, video quality, and audio quality) being lost as a result of lossy compression. The missing data due to compression will appear as artifacts in the image such as blurs, or pixilation.

Lossless compression is the opposite of lossy. Compression is still taking place so the file size is reducing a great amount. But the difference is that lossless deletes all un-needed data and uses algorithms to do so (*Lossless compression*). Which allows for this compression process to be reversed to its original uncompressed state as well.

See figure 2 for example.

Note: These images are JPEG formats and are saved from orignal size and compressed down to lowest quality image. The orignal size is a stand-in for an uncompressed format, since the orignal is the highest quality version of this image.

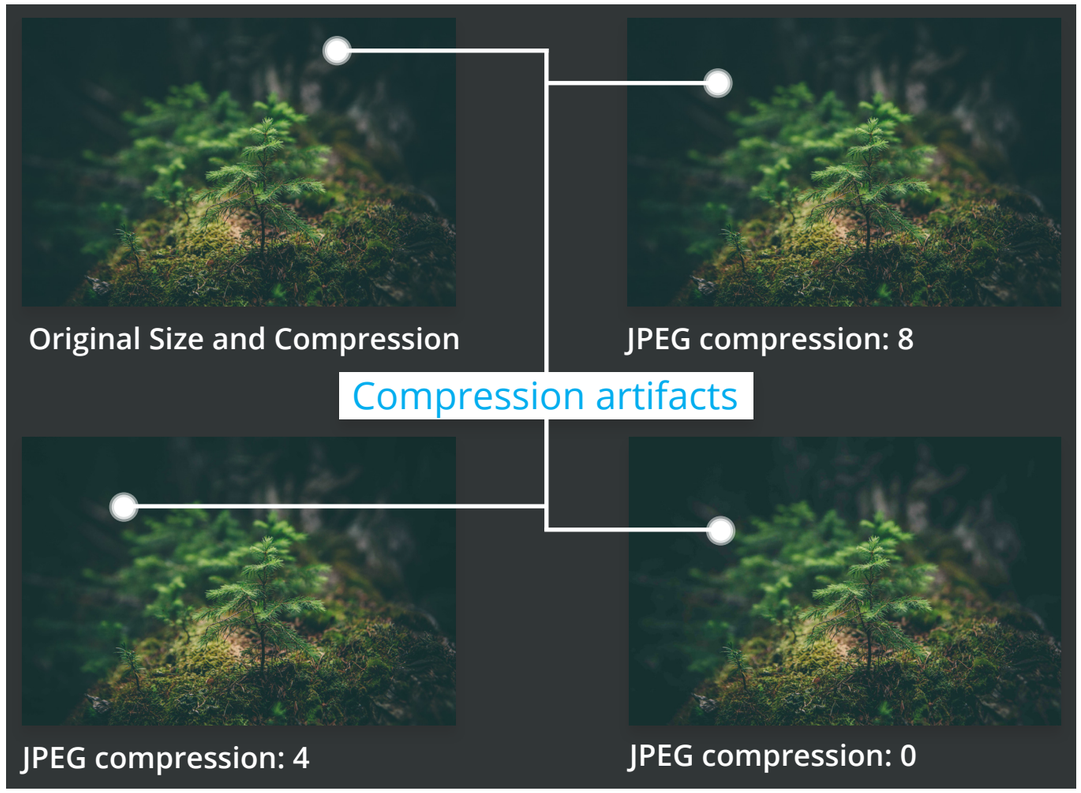


Figure 2. Smith, *Conifer sapling,* 20 Jan. 2015

Raster vs Vector

There are two different types of graphics, Raster and Vector. Each is a different way a graphic is structured.

A Raster (bitmap) is an image composed of a grid of pixels. While Vector images are composed of different lines, shapes, and curves that are algorithmically positioned in space—relative to each other—to render a scalable image (*Raster & Vector*).

The best time to use a vector graphic is when you need a completely scalable graphic—icons for example. While raster images are best for images that you would take off of a camera because all the detail is captured at that specific resolution you took the image at (Sebastian). The problem when you see raster images is when you're trying to scale a raster image that is different from its original size.

See figure 3 for an example of this in action.

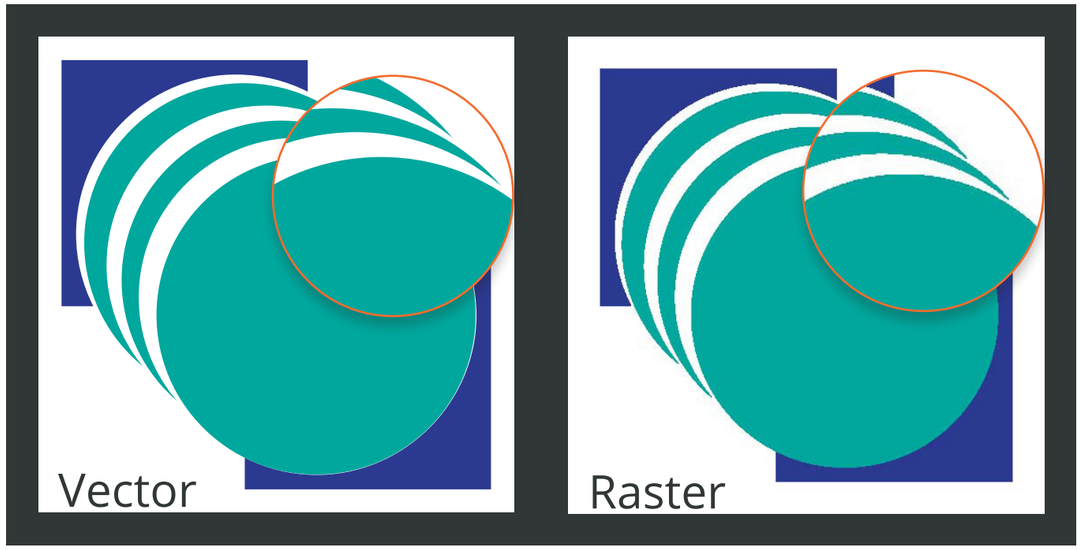


Figure 3. Vector vs Raster

Storage

What is storage and its bytes?

Before I explain this, I want to note that memory and storage are different components in a PC. The RAM is the memory and storage (HDD/SSD) is your storage device. Each device uses similar terminology because they both use the term Byte. To know the difference, remember this, RAM provides memory—that isn't permanent—to the CPU, and HDD/SSDs provide permanent storage for the computer (Akanksha_Rai). But both use the units of measurement for Bytes, it is key to not confuse these two components.

In storage units and ram units, they are always advertised for their rated storable/RAM capacity. This unit is called a Byte, which is composed of 8 Bits which is a set of ones and zeros, which states an on or off position—also known as binary/machine code (Akanksha_Rai).

Just like the Metric system, Bytes can get cataloged in a different name because there are so many Bytes. For example, what are 1000 meters? It is 1 Km. The same process is in measuring bytes. See figure 4 for a graph of these different unit sizes.

The higher the capacity—unit of measurement—allows you more possible storage/memory. However, the higher the storage capacity the more expensive it is. So, PCs typically won't need more than TB, unlike massive data centers that may require well over a Petabyte.

Byte Sizes, smallest to largest:

Name	Equal To	Size in Bytes
Bit	1 Bit	1/8
Byte	8 Bits	1
Kilo Byte	1024 Bytes	1024
Mega Byte	1024 KB	1,048,576
Giga Byte	1024 MB	1.07×10^{9}
Tera Byte	1024 GB	1.09×10^{12}
Peta Byte	1024 TB	1.12×10^{15}
Exa Byte	1024 PB	1.15×10^{18}
Zetta Byte	1024 XB	1.18×10^{21}
Yotta Byte	1024 YB	1.208×10^{24}

Figure 4. *Info from Akanksha_Rai,* Size in bytes is in scientific notation

Resolutions

If you're going to be using any device, and want to have a stellar display so you can consume whatever form of media there is. Either you're on a TV watching a movie or on your computer watching youtube. The TV and your monitor for your computer are screens. Screens have resolutions and they come in many different forms.

Resolution refers to the number of pixels—horizontally and vertically (Russell). For screens, the resolution could make big difference, however, the screens take another factor that improves the clarity of the screen, pixels per inch or PPI (Russell). How you calculate PPI is by taking the horizontal amount of pixels divided by the width of a screen in inches (*Pixel density*).

Figure 5. Ilenda. *Red Dulashock Gamepad,* 22 June 2020

For example, my current primary monitor for my PC is an ASUS MG278Q, its specs are 27 inches diagonally (23.5 inches wide and 13.25 inches high) and a 2560x1440 resolution.

PPI = 2560 px / 23.5 inch

PPI = 109 PPI (exact is 108.9 PPI)

2560x1440 Resolution

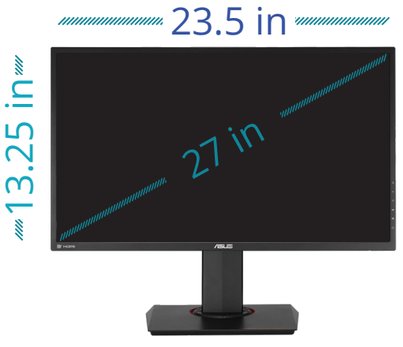


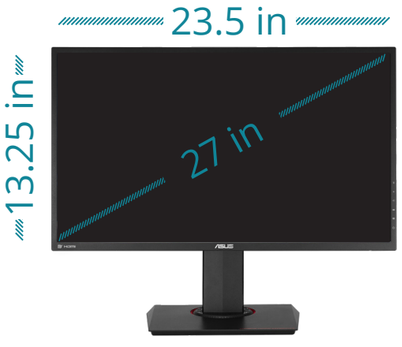
Figure 6. ASUS. *MG278Q Monitor,* Accessed 7 Oct. 2021

While my secondary monitor is a smaller version of my primary. It's an ASUS VG278Q same physical dimensions but has a different resolutionresolution of 1920x1080. This is where PPI differences will be seen.

PPI = 1920 px / 23.5 inch

PPI = 82 PPI (exact is 81.7 PPI)

1920x1080 Resolution



Using my monitors as a reference, what do you think has more detail and quality retained?

My primary monitor—2560x1440 with a 109 PPI. This is why that is my primary monitor, all creative projects, gaming, and anything dependent upon resolution is better with my primary monitor. More detail is captured per inch as compared to my secondary.

So now, let's compare a bigger version of my main monitor is. The ASUS TUF Gaming VG32AQL1A monitor, 32.5 inches big (remember that is diagonal) and has a resolution of 2560x1440 px, but the physical horizontal (h) and vertical (v) dimensions of the screen is 698.112x392.688 mm—27.48 h x 15.46 v (*TUF Gaming*). This is where it gets interesting, compare this to my primary monitor.

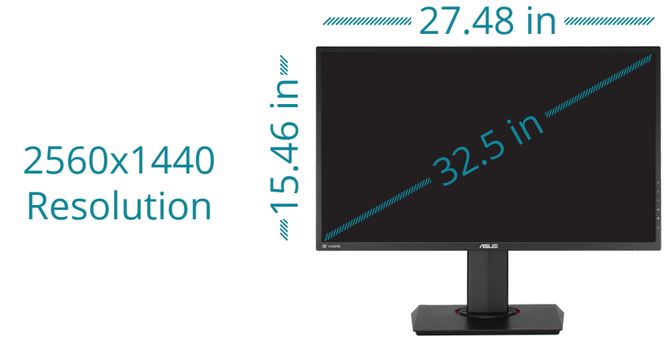
See Figure 7, for an example of standerd screen resolutions. Use the information you just saw here, resolutions matter and so do the physical dimensions.

So, what has more quality per inch that is displayed on the screen? Well, if we are going by the formula to calculate PPI. The version that is bigger and is supposedly better because it has a better screen, right? Yes, you can argue the difference isn't that much and you could be right. It may be hard to differentiate between the two and say which is better, I don't have the TUF gaming monitor to test that. But I'll leave you with this, if you calculate the percentage, the TUF monitor is capable of 85% of the quality per inch as compared to my screen—(93.15 / 109) * 100 = 85.45%.

Note: All math done is done by me based of the formula for finding PPI. I checked the physical demensions by measuring them in real world and compared it to its tech specs. Then double checked it by doing the pythagorean theorem. Overkill? Yes.

PPI = 2560 px / 27.48 inch

PPI = 93.15 PPI



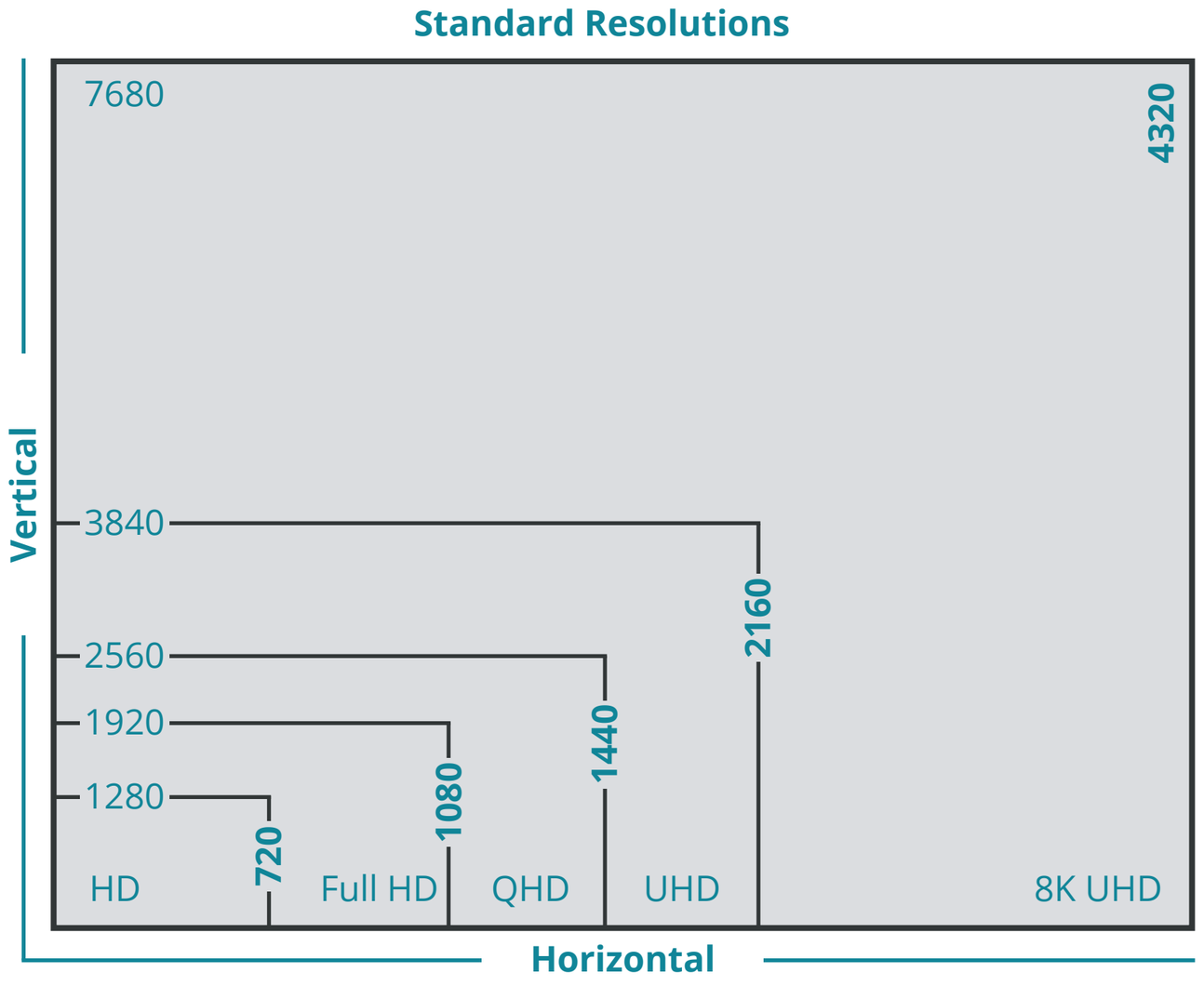


Figure 7. Screen resolutions info grabbed from Morrison

Bit Depth

Media files like images, video, audio all have something called bit-depth. Depending on what that bit-depth is for a file, will determine the overall quality of the file.

So, for media files that deal with color, such as images and videos, the bit depth can determine "how much color information is available for each pixel" (*Bit depth and preferences*). While for audio files, bit-depth can determine the overall quality or resolution of which the sound is captured and stored as data into a file—higher the bit-depth means more details are recorded (Harris).

Do NOT confuse bit-rate and bit-depth, two are very distinct things. Bit-rate is meant to measure how much data is transmitted per second when audio is being played back (Harris).

Visual Bit Depth

For images and videos, color-depth is another term used to describe bit-depth but for now, I'll be just calling it bit-depth. So, bit-depth can be at a multitude of different levels such as 8-bit, 10-bit, 12-bit (Datavideo). First, what are 8, 10, and 12-bit depth? In an 8-bit RGB system, there are going to be 256 possible colors (Datavideo). To make sense of this, consider this as more data is stored and resulting in a higher quality image with color! So, as you continue up to 10 and 12-bit depths that the possible number of colors only just goes up. See figure 8 for a visualization of this.

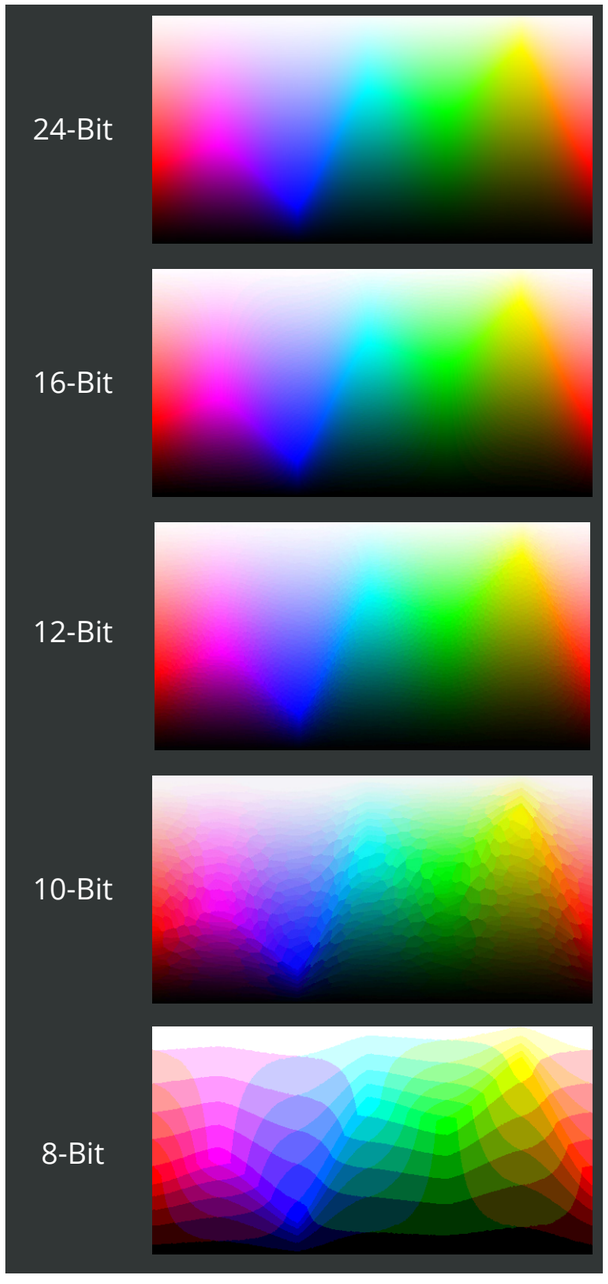


Figure 8. Cambridge in Colour, *Bit Depth Visualization,* Accessed 8 Oct. 2021

Audio Bit Depth

For audio bit-depths, as I mentioned the bit-depth is the measurement for how much data/audio is captured. Higher the bit-depth means the audio quality will sound more crisp and more details are captured (Harris). Having the correct bit-depth for your audio file can help reduce background noise, so higher bit-depths will reduce the prevalence of any background noise (Harris).

How is bit-depth calculated?

Bit-depth is based upon the binary base number system, which is base 2. So, the formula to calculate the amount of colors availible is by doing 2 to the power of X--which is the bit-depth like 8-bit: Bit-depth = 2^x (Cambridge in Colour)

Bit-depth	Formula	Colors
1-bit	2^1	2
8-bit	2^8	256
10-bit	2^{10}	1024
12-bit	2^{12}	4096
24-bit	2^{24}	16,777,216

Motherboard: The motherboard, simply put, is the component of the PC that connects all others together. It allows for devices to communicate together andand workd in tandem.

This is the board that is hooked to PC case, and everything else hooks to it

Storage: This is permant storage. All games, images, files, etc. will be stored here for you to access anytime.

Not in the image. Storage can be house in a number of places. Mine is on the backside of the case. But on solution to store in the front is at this point.

GPU: Graphics proccessing unit. This component carries most of the load to render graphics/images, which helps CPU take care of other task--this process is called GPU Acceleration (Dobbin).

PSU: The Power Supply Unit. This is tyically housed in the bottom-back side of desktop computers.

Note: do not tinker with these. These are highly dangerous components when opened up or tampered with

CPU: Central Processing Unit, this is the brain of you computer essentially (Dobbin). Machine code, binary--1s and 0s--is processed in this component.

Housed/seeded onto the motherboard behind the my cooler

Cooler: Computers can heat up from use and components need cooling to function properly. Coolers are fans that induce air flow and/or liquid cooling with fans on a radiator.

CPU's will always have a cooler connected directly to it. Corsair housing is the cooler over mthe CPU

RAM: Random Access Memory. How RAM works is as a device with short-term memory loss. Meaning, any data that doesn't need to be saved permantly will be kept here till it isn't needed (Intel).

Figure 9. Image of my home build PC and components.

Section Six: Video Formats

Video codecs are housed within containers—such as QuickTime/MOV, AV1, MP4, WMV, WebM, and more. So this means that when you see these containers/file extensions, you will see the container containing the video codec (Strieb). Those containers are good and all, but what are the video codecs helping power these containers?

Well, you have AV1, H.263, H.264, H.265, and you'll see some more later in this document. We'll cover the most popular ones. Each one has its qualities and uses cases. But typically, you'll see these contained and paired with an audio file, giving you an illusion of the single file. But it is actually built by a codec to provide content for viewing.

Until we talk about those, first, you got to understand some key terms that would be beneficial for you to know. Such as Video Streaming, Bandwidth, and Progressive Download.

Key Concepts

Progressive Download

If you're going to be using video on the web, you have to know what some terms are. One of the terms is progressive download. Everyone has seen this in action and many take it for granted. Progressive Download summed up, is the process of delivering a playback solution for users of your website/application. It employs an HTTP protocol to send a request (from you) to a server then as a response, the server starts an immediate playback solution, while the video is being downloaded still (*progressive download*). See figure 2 as an example of this in action. The video is stored temporarily and can be used again with less wait time if you watch the video again in the same session (*progressive download*).

What is Video Streaming?

I'm willing to state that most people in our world have used or seen video streaming. Video Streaming is the technology that allows us to watch online videos over our internet (*Media streaming*). Companies such as Youtube, Netflix, HBO, and many more offer video streaming. It works by sending broken down data packets that contain media files across the internet to a user's device that is requesting that data (*Media streaming*). There is a lot of layers of technology that allow this to happen, and one main issue to hurdle is Bandwidth. Depending on the network of the source of the streaming service and your own network, it could limit the amount of data that can be communicated across the network (*Media streaming*). Meaning, if you're trying to watch a video that has a video codec that gives it the possibility to watch a 4k video, and if your network doesn't meet the required bandwidth to stream it, you may watch a lower quality version of the file as a result.

Logos from Logopedia.

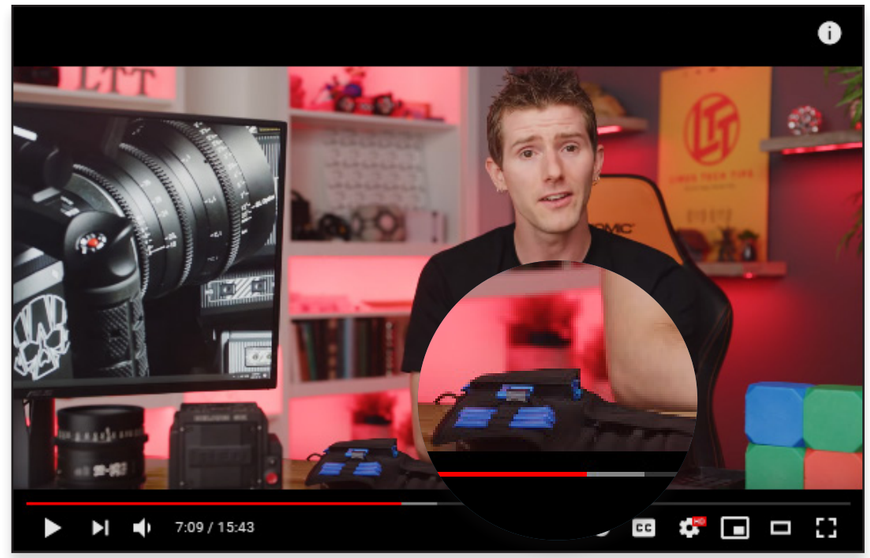


Figure 2 - Screenshot off of Youtube, Channel is Linus Tech Tips, *Progressive Download Example*

What is Mbps?

Mbps is a measurement standing for Megabits per Second. Which describes upload and download speeds (Pensworth). You will probably hear about this with your Internet Service Providers since they advertise their internet speeds (upload/download speeds). So, why do this matter to you and your consumption of online media? Because, modern technology and our lives are dependent on fast upload and download speeds, which enables us to consume content and an accelerated rate. Especially with video file formats, because video files can be pretty intensive to manage. As you look at the container/codecs sections, look at the possible bit rates for each.

Bandwidth: is your download/upload rates, essentially the fastest possible speed of download rates (Pensworth)

Resolutions	Dimensions	Also Know As	Devices
720P	1280x720	HD, High Defintion	TVs
1080P	1920x1080	Full HD, HD, FHD	TVs, Monitors, projectors
WUXGA	1920x1200	Wide Screen Ultra Extended Graphics Array	Monitors, projectors
4K	3840x2160	4k, Ultra HD, UHD	TVs, Monitors, Projectors
8K	7680x4320	8K UHD	TVs

Figure 3 - Graph of possible resolutions, info from Morrison.

4K/UHD/QHD

There is an issue with advertising, surprising right? When you shop for products you have to be careful with how branding works. Such as resolutions, companies tend to hype the resolution up and say it's Ultra HD! Well, take that with a grain of salt and peer into what 4k, 8k, and UHD are.

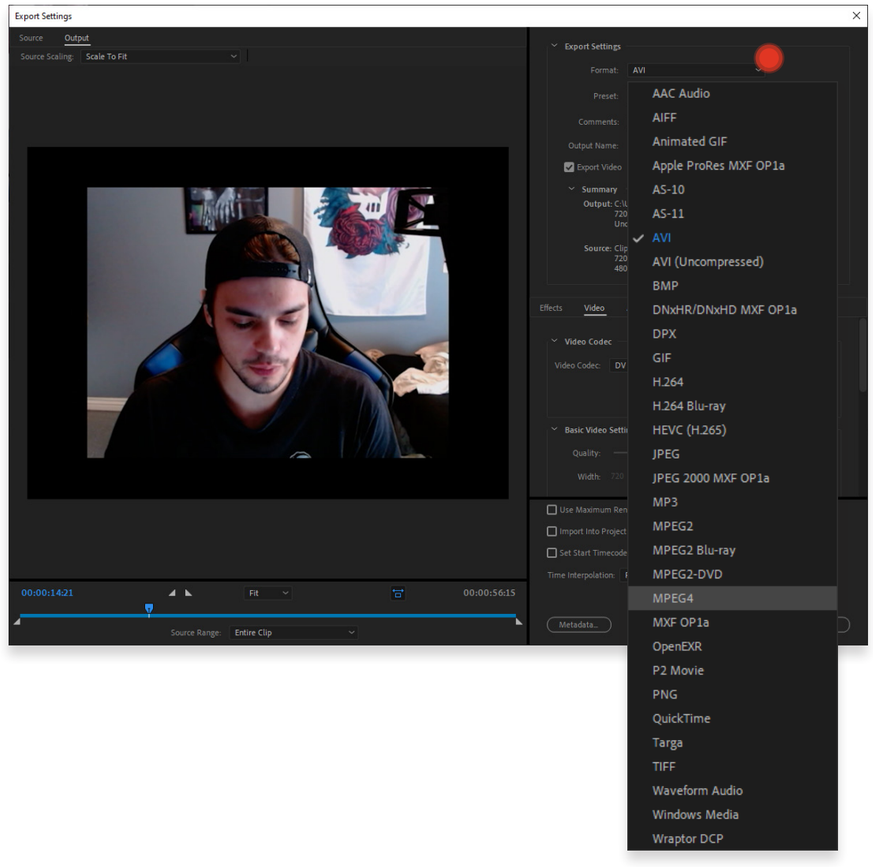
So, what is resolution? Resolution is the width x height pixels on a screen (Hernandez). See figure 3, it is a matrix of different resolutions and what they are.

Applications

Adobe Premiere Pro

Adobe Premiere Pro is probably the most popular video editing software out there. As you read my previous documents on image and audio file formats, you notice how Adobe is in the top 3 at least. Most of Adobe's flagship applications will be some of the top tools in the industry.

With that said, why would Premier Pro be the top choice for people who want to work with video? It is because this tool offers the ability to import/export audio files (especially across adobe applications), edit the video to your creative extent, mix audio, and much more (*Welcome to the Premiere Pro User Guide*). It offers you tools to create something pretty cool and many other video editing software has those perks as well but since Premiere Pro is Adobe, you have access to many other Adobe applications to help with your project (*Choosing the right video format*). You also have access to dynamic and organized editing interface, tools for organizing, stabilization tools, support for high-quality video formats, edit VR 360-degree content, and Premiere Pro can export high quality codecs such as H.265 or HEVC (Muchmore).



Premiere Pro Details

- Edit: Sequences, Video, Audio, and more advanced editing practices
- Video Graphics and custom transitions
- Compositing: able to work with alpha channels, masking and tracking, and blending modes
- Color Correction capabilities
- Works accorss the Adobe umbrella applications
- Additional Info:
    - macOS or Windows operation systems required
    - Offers support for VR/AR editing and equipment

Info was grabbed from Adobe

Apple Final Cut Pro

Probably the next most commonly used video editing software is Apple Final Cut Pro. I used this in High School that was for a Video Editing Class and TV broadcasting. Albeit it was really basic to work with these applications, but It was my introduction to applications like this. With that said, it is also a direct competitor to Premiere Pro since File Cut Pro is considered a professional tool as well.

Final Cut Pro is targeted at a broad spectrum of video editors—beginner to professional (Muchmore). Anyone can use this and edit a project, but just like Premiere Pro, you can also edit a project in a professional setting. This application is for Mac only though, limiting the user-base for this software. This is probably why many use Adobe's Premiere Pro because it is cross-platform—Mac and Windows (*Choosing the right video format*).

Final Cut Pro Details

- Edit: Sequences, Video, Audio, Trimming, Effects, and more.
- Color Correction
- Supported Formats: HEVC, HEIF, H.264 and a many audio files to wrap into a container
- Lmited to Mac Users only.

Info was grabbed from Apple

Apple iMovie

iMovie is the alternative to Final Cut Pro. What I mean is it is the free video editing software that Apple offers as a product. With that said, you can assume that iMovie won't be as complex as its counterpart. It is a great stepping stone for those who want to learn video editing at a basic level and still work with credited editing software. Albeit it is limited to Mac users only since it can only run on macOS and iOS (*iMovie*). But you can still work with 4k video, export your work, import existing video and edit it, and edit audio as well (*About incompatible media in iMovie*).

iMovie details

- Edit: Video, Audio, Trim, Effects
- Supported Formats: Apple Animation Codec, Apple Intermediate Codec, Apple ProRes, AVCHD, DV, H.264, HDV, HEVC, iFrame, Motion JPEG, MPEG SD
- Supported Containers: 3GP, AV1, M4V, QuickTime, MP4

Info was grabbed from Apple

Logos from Logopedia.

Containers and Codecs

What are Video Codecs/Containers?

Video files will come in many different flavors and this can be overwhelming at first. So, here are some of the most common video formats that you should know about. Some common ones are MP4, QuickTime, AVCHD, AV1, WebM (*Choosing the right video format*).

The difference between a media container and a video codec can be a complicated topic but the gist of what the difference is is as follows. Containers are made up of audio/video codecs and held within a container such as MPEG-4, while video codecs are your images captured in a video format such as H.265 (*Media container formats*). In short, a digital file format that holds audio/video and supports any compression methods, and isn't restricted to one specific codec—can use a multitude of codecs in the container (*multiemedia container*). See the Container section for a more of a look into some common containers and contained codecs in the Codecs Section.

Some things to consider about file contents

When you're creating a video and wanting to export it to share it with the world, you'll have to consider some important factors. If you don't keep track of what these factors are it will limit what codec you can use because some don't do as well as some others with certain elements of video (*Media container formats*). Some are bad with shapes and edges, colors, dark shadows, and many more elements on screen that could affect how your video will look when exported as a codec. Also, each of these factors—depending on the intensity of each—can increase the file size as a consequence (*Web video codec guide*).

Possible Effects on file Quality

- Color Depth/Bit Depth
- Frame Rate(s)
- Captured Motion
- Noise
- and Resolutions

Info was grabbed from MDN Contributors

Container vs. Wrapper

What's the difference between containers and a wrappers? These are common names and are often confused as well. Wrappers are unique in that they add on to a file with out changing the codec in anyway. For example, Audible uses a file extension called M4B and it helps with organizing these audio book files--nothing else it is just wrapping that file (Harper). While containers actually manipulate the file/codecs into a new state, such as recompression with adding a container onto a new file (Harper). Or even with video, using video streaming as an example, you are capturing video at a set container but if you need it to be more optimal for streaming you'll have to take that existing container and recontain it into a new format that is optimal for streaming (Harper).

Containers

Moving Pictures Experts Group (1 & 2)

These formats are used mainly used for physical media such as DVDs and commonly contained MP3 audio codecs (*Web video codec guide*). Both files are very similiar, that is why they are grouped together. MPEG-1 Part 2 visual was released 1992 and then MPEG-2 came in 1996 (*Media container formats*).

The tech behind MPEG:

- Standard Body for Maintenance: MPEG
- MIME type: audio/mpeg and video/mpeg
- Compression type: Lossy
- File extension(s): .mpg, .mpeg, .m2v, .mp3
- Contained Codec(s): MPEG-1 Part 2 Visual and MPEG-2 Part 2 Visual

Moving Picture Experts Group - 4

MP4 is arguably one of the most commonly known media file formats, even those who don't work in the industry, at some point someone has mention MP4—similar to how many know about MP3. It was a very popular container to be used and it supports many codecs, audio and visual (*Media container formats*). It is a very accessible video format, meaning that many modern devices—if not all—can run this video format and the codecs within it (Basu). Use cases for this format are pretty open because it is so common it makes it one of the most supported formats on devices. Meaning, you can create something and export it as MP4 and it will run on any device. But, the issue is that MP4 offers lower resolutions as compared to other higher quality formats such as MOV (*Choosing the right video format*).

The tech behind MP4:

- Standard Body Responsible for Maintenance: Moving Picture Experts Group
- MIME type(s): audio/mp4 and video/mp4
- Extension(s): .mp4, .m4a, .m4p, .m4b, m4r, and .m4v
- Contained Codec(s): H.264, AV1, H.263, MPEG-4 Part 2 Visual, VP9. (Audio codecs: AAC, FLAC, MP3, Opus)

Third Generation Partnership

This file format was designed to help with transmitting media files across cellular networks, albeit it was originally for 3G mobile devices (*Media container formats*). Since it was designed for the constraints of the 3G mobile devices, it makes it not as appealing to use for modern devices. The reason being is because technology in terms of bandwidth, data-caps, and anything limiting for mobile device users—using a Cellular network, not Wifi (*Media container formats*). Even though it has fallen out of use due to the evolution of technology, it is still employed in mobile networks that are limited in the capabilities of their networks (*Media container formats*). The best use case for this format will be when you know you'll have users that have these cellular limitations, you can accommodate for that by utilizing 3GP as a developer.

The tech behind 3GP:

- Standard Body Responsible For Maintenance: Third Generation Partnership Project
- MIME type(s): audio/3gpp, audio/3gpp2, audio/3gp2, video/3gpp, video/3gpp2, video/3gp2
- Extension(s): .3gp
- Contained Video Codec(s): AVC, H.263, MPEG-4 Part 2 (MP4V-es), VP8
- Contained Audio Codec(s): AMR-NB, AMR-WB, AMR-WB+, AAC-LC, HE-AAC v1, HE-AAC v2, MP3

QuickTime; Apple QuickTime Movie

QuickTime is a lot to talk about, but in short this file format was developed by Apple to playback movies (*Media container formats*). At some point, Apple allowed Windows devices to run QuickTime formats. But in 2016, Windows devices are not able to run QuickTime formats, thus leaving Apple devices only able to run this file (*Media container formatss*). Quicktime ends up being a very capable file format. For instance, Quicktime supports AAC and H.265, which could end up being a media file in massive size but high quality (*Media container formats*). In short, Quicktime is a great source of professional and high-quality work. Nowadays, however, even Apple defers to using just MP4 formats for videos rather than their own in-house developed media container (*Media container formats*).

The tech behind QuickTime:

- Standard Body Responsible for Maintenance: Apple
- MIME Type(s): video/quicktime
- Extension(s): .mov
- Contained Video Codec(s): AVC, Cinepak, Component Video, DV, H.261, H.263, MPEG-2, MPEG-4 Part 2 Visual, Motion JPEG, Sorenson Video 2 and Sorenson Video 3
- Contained Audio Codec(s): AAC, ALaw 2:1, ALAC, HE-AAC, MP3, and many more.

Ogg

As mentioned in my Audio formats guide, Ogg is used for Spotify music streaming service. However, Ogg is a container, and these containers contain media files such as audio and video. It supports only a few Video codecs and that is because Ogg never really got the "support needed to make it a good first choice for a media container" (*Media container formats*). So that is why you won't see it as commonly—unlike MP4. As just mentioned, Ogg doesn't have the best support on browsers. So, what would be the best use case? Maybe when you are tackling the issue of browser compatibility. For instance, older browsers may not support modern formats like WebM but could run Ogg instead. Such as Firefox 3.5 and 3.6, each version supports Ogg but not WebM (*Media container formats*).

The tech behind MP4:

- Standard Body Responsible for Maintenance: Xiph.org Foundation
- MIME type(s): audio/ogg and video/ogg
- Extensions: .ogg
- Contained Video Codec(s): Theora, VP8, VP9
- Contained Audio Codec(s): FLAC, Opus, Vorbis
-

Web Media

This is probably the best solution for videos on web pages. The reason being is that these formats can easily be embedded into a website, also this format offers small file sizes with quick load times (*Choosing the right video format*). According to Wikipedia about WebM, it was developed and passed to companies a multitude of times. But as of right now, it is maintained by Google (*WebM*). The concept of this container was to be a modern solution for websites while being an open-source solution (*Media container formats*). Meaning you can use this without paying for licensing fees, unlike some other containers and codecs.

The tech behind WebM:

- Standard Body Responsible for Maintenance: Google
- MIME Type(s): audio/webm and video/webm
- Extension(s): .webm
- Contained Video Codec(s): .av1, .vp8, .vp9
- Contained Audio Codec(s): Opus and Vorbis
-

Info in bullet points is grabbed from Wikipedia Contributors, MDN Contributors, and Adobe.

Video Codecs

AoMedia Video 1

AV1

Originally this video format was not free, but now it is available for anyone who wants to use this codec, no costs (*Web video codec guide*). One of the main reasons to use this codec is because it offers a wide range of color bit-depths, allowing for creators to have the ability to have a professional-looking video with a strong base of colors present on the screen (*Web video codec guide*). While that is good, sadly AV1 still has no support for Safari and Internet Explorer browsers, thus probably creating issues for your project.

The tech behind AV1:

- Standard Body Resonislbe for Maintenance: Alliance for Open Media
- Extension(s): .AV1
- Compatabile Container(s): MP4 and WebM
- Compression: Lossy
- HDR Support: Yes
- Supported Frame Size(s): up to 65,535 x 65,535 pixels
- Supported Bit Rates: Varies on how intense your video is, but can be up to 800 Mbps.
- Licensing: Royalty-free, open standard license.

H.263 Video

H.263

This codec is a predecessor to H.264 and H.265. With that said, you can assume that H.263 would be less quality as compared to is future iterations. You'd be right, H.263 was designed for low-bandwidth usage situations and was directly focused on video-conferencing (*Web video codec guide*). With that said, this is known as a "legacy media format" and you should refrain from using it since there are more modern formats available (*Web video codec guide*). You should look into using H.264 or newer formats.

The tech behind H.263:

- Standard Body for Maintenance: ITU
- Extension(s): h.263
- Compatible Container(s): 3GP, MP4, Quicktime
- Compression: Lossy
- HDR Support: No
- Supported Frame Size(s): up to 1408 x 1152 px
- Supported Bit rate: Unrestricted. However, usually seen below 64 Kbps
- Licensing: Proprietary; Commercial use requires a license.

Advanced Video Coding (AVC)

H.264

The origins of AVC are actually from MPEG-4, even though the name isn't saying anything related to MPEG, it is derived from MPEG-4 specifications. In short, this format is a higher quality video format that is available for use in all sorts of media, a common one that many know is Blue-Ray discs (*Web video codec guide*). The capabilities of this format are because it supports HDR and a wide range of color profiles with a max bit-depth of 14! Also, it offers great compression with some decent video quality and this format compresses images akin to how JPEG compressed images (Strieb). Thus making this a commonly used file format, except it is a proprietary codec and requires a license (*Web video codec guide*). As a comparisTo utilize this format, you'll have to pay for a license to encode your video files (*Web video codec guide*).

The tech behind H.264:

- Standard Body for Maintenance: Motion Pictures Expert Group and ITU
- Extension(s): .avc and h.264
- Compatabile Container(s): 3GP and MP4
- Compression: Lossy
- HDR Support: Yes
- Supported Frame Size(s): 8,192 x 4,320 px
- Supported Bit Rate(s): Varies by how intense your video is.
- Licensing: Proprietary; Commercial use requires a license.

High-Efficiency Video Encoding (HEVC)

H.265

High-Efficiency Video Encoding is the modern codec that can deal with very high resolutions—up to 8k video (*Web video codec guide*). Even though you can use this for lower-quality videos, this is a premier solution for encoding high-resolution videos.

The tech behind H.265:

- Standard Body for Maintenace: ITU and Motions Pictures Expert Group
- Extension(s): .hevc
- Compatible Container(s): MP4
- Compression: Lossy
- HDR Support: Yes
- Supported Frame Size(s): up to 8,192 x 4,320 px
- Supported Bit rate: up to 800,000 kbps (800 gb/s)
- Licensing: Proprietary; Commercial use requires a license.

MP4V-ES

MPEG-4 Video Elemental Stream

MPEG-4 Video Elemental Stream is tied to MPEG-4 Part 2 Visual standard, but it is primarily used for RTP (Real-time Transfer Protocol)—simply put, video streaming (*Web video codec guide*). Sadly though, this file format is considered "obsolete" and that's due to browser compatibility issues (*Web video codec guide*). So as a developer, this should be avoided and a better alternative may be H.264.

The tech behind MP4V-ES:

- Standard Body for Maintenace: Motion Pictures Experts Group
- Extension(s): .mp4v (NOT .mp4)
- Compatible Container(s): MP4, 3GP
- Compression: Lossy
- HDR Support: No
- Supported Frame Size(s): up to 4,096 x 4,096 px
- Supported Bit Rate: up to 1 Gbps
- Licensing: Proprietary; Commercial use requires a license.

MPEG-2

MPEG-2 Part 2 Visual

The file format is an iteration upon its predecessor MPEG-1 Part 2 Visual—also known as H.262 if you go by the ITU specification (*Web video codec guide*). This format is kinda unique, it has four specific levels of qualities and those qualities will be best suited for what the dimensions of your video are (*Web video codec guide*). In short, the higher the resolution and targeted frame rate you are wanting, the higher the level you need for MPEG-2. Those levels are: Low Level (LL; max frame size: 352x288 px), Main Level (ML; max frame size: 720x576 px), H-14 (High 1440; max frame size: 1440x1152 px), and HL (High Level; max frame size: 1920x1152). Sadly, there isn't a big reason to use this file format since—just like MPEG-1 Part 2 Visual—this format isn't supported on most browsers, only Safari (*Web video codec guide*).

The tech behind MPEG-2:

- Standard Body for Maintenace: Motion Pictures Experts Group and ITU
- Extension(s): .mpg, .mpeg, .m2v
- Compatible Container(s): MPEG, MPET-TS, MP4, and QuickTime
- Compression: Lossy
- HDR Support: No
- Supported Bit Rate(s): Up to 100 Mbps
- Supported Frame Size(s): up to 1920x1152 px
- Licensing: Proprietary; however all patents expired and are free use now

MPEG-1

MPEG-1 Part 2 Visual

Being created in the early 1990s, this is a very outdated video format and thus leading to some issues (*Web video codec guide*). Such as, MPEG-1 is only supported by Safari Web Browsers and nothing else—making it a fairly unused file format (*Web video codec guide*). In short, avoid using this format on websites due to not being functionally capable of most browsers.

The tech behind MPEG-1:

- Standard Body for Maintenace: Motion Pictures Experts Group
- Extension(s): .mpg, .mpeg, .mp1, .mp2, .mp3, .m1v, .m1a, .m2a, .mpa, .mpv
- Compatible Container(s): MPEG
- Compression: Lossy
- HDR Support: No
- Supported Bit rate(s): up to 1.5 Mbps
- Supported Frame Size(s): 4,095 x 4,095 px
- Licensing: Proprietary; but since patents have expired it is free-use now.

Theora

Theora

You'll recognize the OGG file format, this is where it might get a little confusing. The file extension is .ogv and .ogg, but the main component that handles video in the OGG container is Theora. The codec is a competitor to MPEG-4 Part 2 Visual (which is a newer generation of MPEG-1/2 Part 2 Visual formats) and AVC (*Web video codec guide*). It was developed to be an open-source video codec and does not induce heavy CPU loads (*Web video codec guide*).

The tech behind Theora:

- Standard Body for Maintenace: Xiph.org
- Extension(s): .ogv, .ogg
- Compatible Container(s): OGG
- Compression: Lossy
- HDR Support: No
- Supported bit Rate(s): up to 2 Gbps
- Supported Frame Size(s): 1,048,560 x 1,048,560 px
- Licensing: Open Source
-

VP8

Video Processor 8

Google purchased this codec type from On2 Technologies and then was released as an open-source video format (*Web video codec guide*). This video format can work with alpha channels if supported by the browser that is being used to see this video format—with that said there is a great range of support for this format (*Web video codec guide*). This is a pretty great solution to use this format anywhere, just keep in mind file sizes and how you're content will be viewed on-screen.

The tech behind VP8:

- Standard Body for Maintenace: Google
- Extension(s): .vp8
- Compatible Container(s): WebM, Ogg, 3GP
- Compression: Lossy
- HDR Support: No
- Supported Bit Rate(s): No limit, unless limits are enforced.
- Supported Frame Size(s): up to 16,384 x 16,384 px.
- Licensing: Open Source

VP9

Video Processor 9

As the iteration from VP8, this codec was aimed to be faster at encoding/decoding than its predecessor and other codec competitors like AVC (*Web video codec guide*). Google wanted to take the work further and make a modern format that can compete with even HEVC codec (*Web video codec guide*). It is supported on most browsers—except Safari and Internet Explorer—and is a primary choice to be used in WebM containers (*Web video codec guide*). It is a great solution to have to get high-quality video out there, but since it isn't supported for all browsers, the alternative should be is earlier version VP8.

The tech behind VP9:

- Standard Body for Maintenance: Google
- Extension(s): .vp9
- Compatible Container(s): WebM, MP4, OGG
- Compression: Lossy
- HDR Support: Yes (HDR10+)
- Supported Bit Rate(s): No limit, unless limits are enforced.
- Supported Frame Size(s): up to 65,536 x 65,536 px
- Licensing: Open source
-

Info in bullet points was grabbed from Wikipedia and MDN Contributors.

Conclusion

This section was also an introduction to video formats, just like the image formats section. You should now know the most commonly used video formats--containers and the codecs--and should know about some of the techs behind each format. It's pretty similar to how the image formats work with compression and quality, but instead, you're dealing with a lot of images or frames within one second. meaning that you'll have to compress each image down and that requires a lot of power from a PC to successfully compress a high-quality video format. So it is similar to how image formats work, but it is just that times 24.

If you get that joke, I'm sorry.

Section Seven: Video Streaming

Introduction

The purpose of this documentation is to evaluate select video streaming service(s) that are commonly used. The at home movie watching experience isn't exactly what you would be getting in cinemas. So many, who don't invest into the high-end sound and video systems, would end up using a streaming service like that to have ease of access to movies/shows.

With that said, these services market them selves to have exclusivities and certain features that will give you--or mimic--that movie going experience. From the luxary of your home and not a crowded theater. So, hopefully with what I find from researching these services and also watching some of the movies on the service to see if they are providing a stellar movie watching experience.

Chosen Services

I've choses these three services based upon me already owning them, their popularity, their catalog, and the assumption that these would be the services that should be giving a stellar moving experience for their users.

Alternate Services : VRV, Youtube, Amazon Prime, Hulu...

Research Purposes

The goals are to discover how popular each service is, based upon subsriber count. Find out what devices and platforms are supported, so that a user cant have access to their desired streaming service. Talk about the possible streamed resolutions and video file formats that are being used if available. Talk about qualities in differences--minamal screen shots with this because streaming services have safe guards in place to prevent any form of piracy, so any screen shots of movies in a streaming service app belongs to that company and is only used for educational purposes.

Also, I should mention that certain equipment is required to stream high quality videos, such as good Internet Service Providers (ISP) that have a wide enough bandwidth to stream bigger files.

My Setup

I've introduced my setup in my Tech Assessment Documentation. But here will be another quick run down of what I have available to me. Watching a movie from home is a whole different "ballgame" when compared to a traditional cinema experience. Which leads to some people trying to get equipment that can essentially replicate the cinema experience--if you have a lot of money. For me, I did invest into above average monitors, and I do have a great PC that will playback anything essentially. Albeit, I'm severly limited when compared to others, I don't own any TVs or home entertainment systems. But, I feel what I got can help get the point accross of what an average person could possible achieve.

Audio Devices

Apple Air Pods

These are capable of high-end audio, with dynamic range and noise canceling. This should be a fairly great experience when you're watching a movie.

Corsair Virutoso SE RGB

These are my primary headset, which is capable of 96 kHz audio, but only when wired. Meaning, my only way to even try to get an immersive audio experience with movies is via these and wired in.

Screens

ASUS MG278Q

My primary screen of any kind is what you see above. It is an ASUS monitor that is capable of higher resolution video, 2560x1440p to be exact. Sadly, this is the best screen I own currently that is capable of higher resolution playback. So, I'll primarily use this to test for crisp-looking video via these streaming services.

ISP

My internet service provider is Xfinity, and they advertise that I get bandwidth up to 200 Mbps. However, with a recent internet speed test, I got 233 Mbps to download speeds and 4 Mbps upload speeds. In short, i should have the ability to stream high definition video at least.

Streaming Compatability

Each service is available through many mediums so that these services have a wider range of the market. But, this also enables people who don't have the best devices to modern standards--and modern standards change yearly in the technology world.

So, here are the icons I'll display for each service to signify that it works with that specific medium.

Smart TVs

TVs have started to become essentially massive tablets smacked onto your wall. The reason being is that tablets are a smart device that has many capabilities, TVs now have caught up to that. I was never really fortunate to own a good TV, but each time I've seen or used one is awesome. These devices will have apps that are for streaming services, just like your tablet.

PCs

Streaming services will have an in-browser solution to stream videos, albeit it may limit your potential video quality. Also, you can most likely download an app from your PC's App Store as an alternative, which will most likely give you better potential video quality. For example, in Fig 1 is a screenshot of my Windows Netflix app.

Game Consoles

Many game consoles have apps that allow you to watch your favorite streaming service. This ability to use apps on your console goes back to when Xbox 360 and Playstation 3 were released.

Blue-Ray Players

Some of these players can have an app of some kind for a streaming service. It is similar to how you would use an app on your Smart TV.

Smart Devices (Phones/Tablets)

It is a standard to have access to apps on your smart devices, and you'll most likely be able to find an app for your desired streaming service. Android and iOS devices both have app stores that will have your streaming service app available.

214 million subs as of 2021 (Serman and Subin)

Netflix has probably become the world's most popular movie streaming service. They have grown massively in the past 15 years, from my point of view. When I was younger, all we did was rent these movies from the dropbox thing they have set up at select locations. Even though they still offer physical DVD rentals, they are now a world leader in streaming movies to people. So what do they offer?

Netflix streaming Resolution

Netflix is capable of streaming up to 4k UHD but requires internet speeds that have a capable bandwidth and a plan that supports this feature (*Internet connection speed recomendation*). If you're excluding the necessary visual devices to consume 4k, that's your only limitation. The internet speeds and if you're paying for the plan that enables you, and of course if the video you want to watch has a UHD available file to be streamed. But you can edit your stream quality in select presets: Low, Medium, High, and Auto (*How to control how much data Netflix uses*).

To watch UHD you'll need to have at least 25 Mbps bandwidth--bandwidth is dependent on your ISP and the plan you pay for (*Internet connection speed recomendation*).

Codec

It was hard to find what Netflix is serving up, but it seems the default is H.264 with the added recent codec they are using, which is AV1 (Peters). Netflix is most likely opting to use this format for a multitude of reasons.

The cool stuff about AV1 is that it is a newer generation format that is supposed to be double the efficiency of H.264, capable of high-quality data transfer via the internet, royalty-free, and finally able to deliver an above-average watching experience for users that may have some type of constraint on their bandwidth (*AV1 & Media Codecs*). This is a game-changer because of how AV1 is being accepted by Netflix, Disney+, and even Prime Video (Sung).

Cool little back story, this format was manifested by big hitters in the tech. industry. The following companies worked together to create this open-source format: Mozilla, Cisco, Google, Amazon, Netflix, AMD, Intel, Nvidia, and ARM (*AV1 & Media Codecs*). These companies came together to create AV1, specifically, they created AOMedia, and then eventually the new AV1 codec came to be (*AV1 & Media Codecs*). From what I can find, there is no specific wrapper that is detailed Netflix exclusively uses.

Netflix supported device(s)

Netflix is supported on a multitude of devices, based on what they say on their website (*Connect to Netflix*). Devices range from older to the news device on the market, cementing the ability for many kinds of users to have access to Netflix. Here is what one of their help pages say about supported devices.

Streaming media players: AppleTV, Chromecast, Portal, fireTv, Nvidia Shield, and Roku

Smart TVs: fireTv, Hisense TVs, LG TVs, Panasonic TVs, Philips TVs, Roku TVs, Samsung TVs, Sanyo TVs, Sony TVs, and Vizio TVs.

Game Consoles: Xbox 360, Xbox One, Xbox Series X | S, PSVita, PS3, PS4, and PS5.

Blue-ray players: Funai, LG, Magnavox, Panasonic, Philips, Samsung, Shapr, Sony, and Toshiba players.

Smartphones/Tablets: Android devices, Apple devices, and Windows Phone.

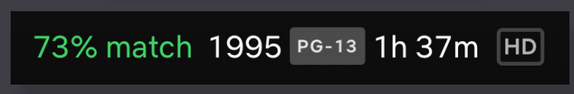
Windows OS App and is compatible/optimized for browser watching rather than an App. Also of note that many set-top boxes support quick access to Netflix, they treat it akin to how Channel works on your TV (*Connect to Netflix*). Sometimes, remotes even have quick ease of access button to Netflix.

Netflix Accross Devices:

Fig 1. Netflix Windows App Screenshot

Screenshot of Netflix's solution to how they display what you're getting for your movie. They provide a synopsis and important info on what quality of video you're getting.

Fig 2. Netflix iOS App Screenshot



Just like on the desktop app, and I'd assume across all other devices, it will state what your movie will be played back as. So you can notice how the mobile app is missing the 5.1 surround sound.

Fig 3. Netflix Desktop App, Red Notice.

Here is a screenshot of a movie I watched recently, and I remembered that this scene is fairly dark and I just knew there would be artifacts left over. The tile in the center I have popped out is a zoomed-in view of the section between Hollywood sweet-heart Ryan Reynolds and the Rock in this scene. In the tile, you can see these artifacts that I'm receiving from my stream. I have the capabilities of 4k streaming--on a good day--but yet there were still these artifacts present. You can even see them without this zoomed-in view on the sides.

118 million subs as of 2021 (Sherman and Subin).

Disney has hit the scene hard with their streaming service, albeit it has less of a catalog than other services or stuff in the catalog I care about in all honestly. With that said, I've only watched Disney+ for a few things: Marvel, Docu-series, and Star Wars. Yet, it is a massive platform that does enable you to use Hulu and ESPN if you get the plan for it, but In all honesty, I will only use it for the shows I mentioned, mainly Marvel

Disney+ streaming Resolution

With this platform, you can consume video in multiple resolutions. You can stream UHD, HDR10, Dolby Vision, and even IMAX enhanced (*Video quality on Disney+*). Keep in mind, these resolutions don't matter if you don't have the devices and ability to watch a movie in this resolution.

You are unable to choose your video playback resolution though. Disney has opted to automatically adapt your stream quality to whatever bandwidth you have available through your ISP (*Video quality on Disney+*).

Codec

I'm unable to find a specific video codec they're using or wrapper. When you look this up, you don't get a direct answer. If I had to assume what they were serving up, it could be H.264-265 or even AV1. I would argue this depends on the available bandwidth with your ISP. As previously mentioned, Disney+ will adapt your video quality--or appropriate video file--so that you won't have issues with playback, excluding the fact the resolution will go down.

Note: this was all speculation because I couldn't find a page I felt comfortable enough with trusting and citing. I was mainly trying to paint a picture of what could be going on based on common practice in the industry.

Disney supported device(s)

Just like any other streaming service, Disney+ offers the ability to use its service on a multitude of devices. This was grabbed from Disney help pages about supported devices (*Disney+ supported devices*). It is notably smaller than what Netflix offered and that could be because it is a newer service as compared to Netflix I think, or what is documented on their page isn't the full picture.

Streaming media players: Amazon TV, Apple TV, Chromecast, Roku, Xfinity Flex, and X1 TV Box.

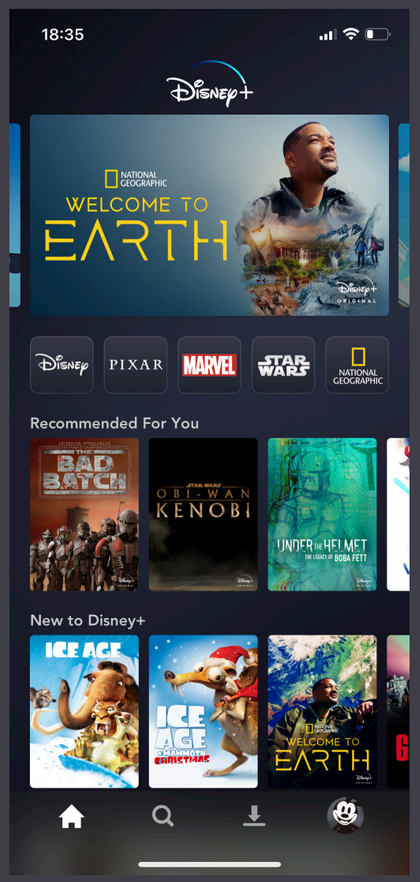
Smart TVs: Android TVs, Hisense TVs, LG WebOS TVs, Panasonic TVs, Samsung Tizen TVs, and Vizio SmartCast TVs.

Game Consoles: Xbox consoles and Playstation Consoles.

Smartphones/Tablets: Apple, Andriod, Amazon Fire, windows 10/11 devices too.

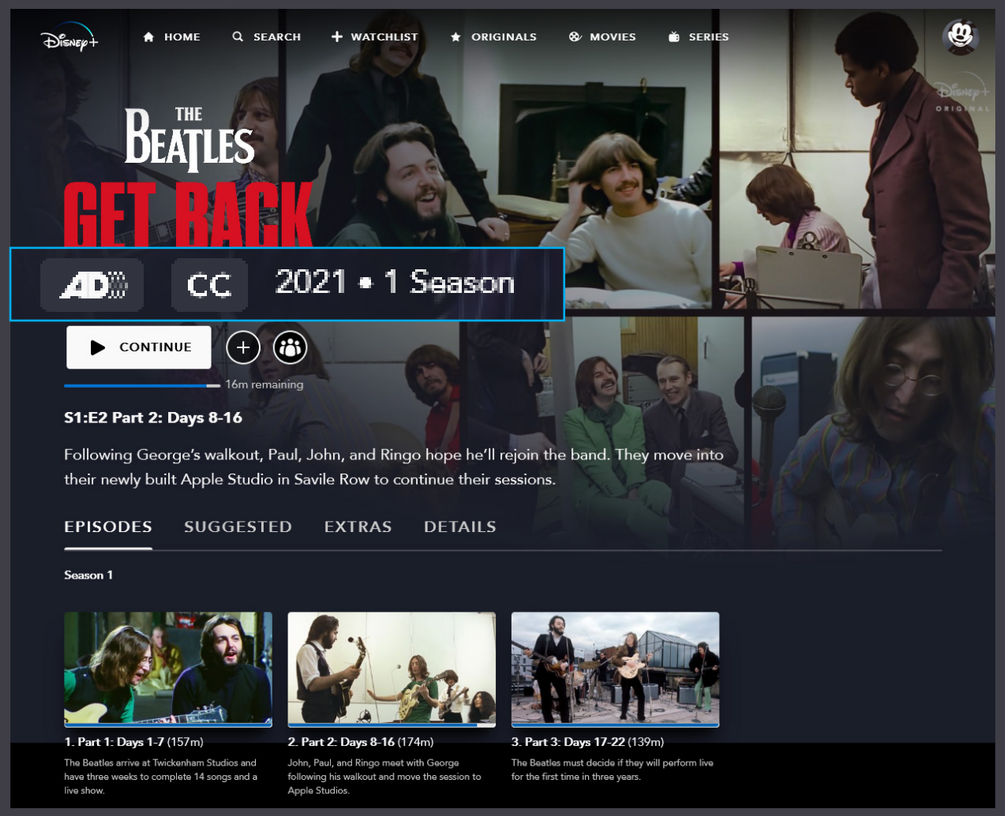
Disney+ Accross Devices:

Fig 4. Disney+ iOS App



This is a screenshot, of the Disney+ iOS app home screen. I wanted to share this because this is a pretty unique inventory in it that they have some pretty big-budget productions. Also, UX-wise, this app is pretty fun to use because I'm able to navigate easily to what I want to watch without any thought. Unlike some other apps.

Fig 5. Disney+ Browser Screen Shot



This is a screenshot of the view when you have selected a movie/show you want to watch in Disney+, specifically this is from in a Browser. I picked this as a screenshot to share because the Beatles are amazing and it also isn't in HD at all. But yet, when you watch the docu-series it is a crisp clean, albeit restored, film. It looks amazing, and yet it doesn't have the HD badge on it at all.

I can't screenshot specific scenes in Disney+ due to how they set up their piracy protection. So, that is the best description I could give.

69 million subs as of 2021 (Sherman and Subin).

HBO has had a plethora of apps and streaming solutions. I swear, I've owned at least two different HBO apps on my phone that essentially served the same purpose. With the oddities aside, HBOmax does offer a great catalog.

This is a recent thing, I missed it sadly, but HBOmax was streaming Dune (2021) at the same time it was released in Cinema. So, there are some cool exclusive events and shows that HBOmax offers to their users. Although it was a special event and probably doesn't happen often, the other services don't offer this special event to my knowledge.

HBOmax streaming Resolution

Similar to the other two streaming services I talked about. HBOmax doesn't necessarily let you adjust what resolution your video stream is at, but they do update the stream quality automatically based upon what your internet speeds are like at the time (*Can I manually adjust the video quality?*). Essentially, if you have the proper bandwidth you can stream your video at a higher resolution.

The resolutions HBOmax offers are HD up to 4k HDR (*Can I manually adjust the video quality?*). However, to attain that 4K HDR you'll need the proper screen that plays Dolby Vision and/or HDR10, a streaming device capable of high-resolutions, and the proper internet bandwidth--at least 25 Mbps (Watch HBO Max in 4K HDR).

Codec

Similar to Disney+, I can't find a reliable source about what Codec they use. So, I'll be basing what I'm about to say on an educated guess and what I learned when researching the resolutions that HBOmax offers.

HBOmax has the capabilities to stream videos from HD to 4k, and even 4k HDR10 (*Watch HBO Max in 4K HDR*). So, I would have the assumption they are streaming formats from H.264 to H.265 and other optimized formats that are good for streaming. So, maybe AV1 like how Netflix streams some videos. For downloads on HBOmax, you can download a video that ranges in quality and thus file size. They state you can download the highest quality files that are a bigger file size to the smallest file size with a fast download (*Download shows and movies*). However, on smartphones/tablets you can't download a video resolution bigger than 1080p--or HD (*Download shows and movies*).

For some odd reason, they have this information as an enigma and describe the video quality/formats how I just described. I assume that is to simplify the jargon behind this tech to allow anyone to understand what they are getting from a file or their streaming service.

HBOmax supported device(s)

HBOmax, akin to Disney+, oddly displays their compatible devices. They classify game consoles as TV, in other words, game consoles are nested in an array named TV (*Which devices work with HBO Max?*). Here is a list of compatible devices grabbed from their help pages on their site.

Streaming media players: Amazon Fire TV, Android TV, Apple TV, Roku, Xfinity X1, and Xfinity Flex.

Smart TVs: LG Smart TVs, Samsung TVs, and Vizio Smart TVs.

Game Consoles: Xbox Series X | S and Xbox One.

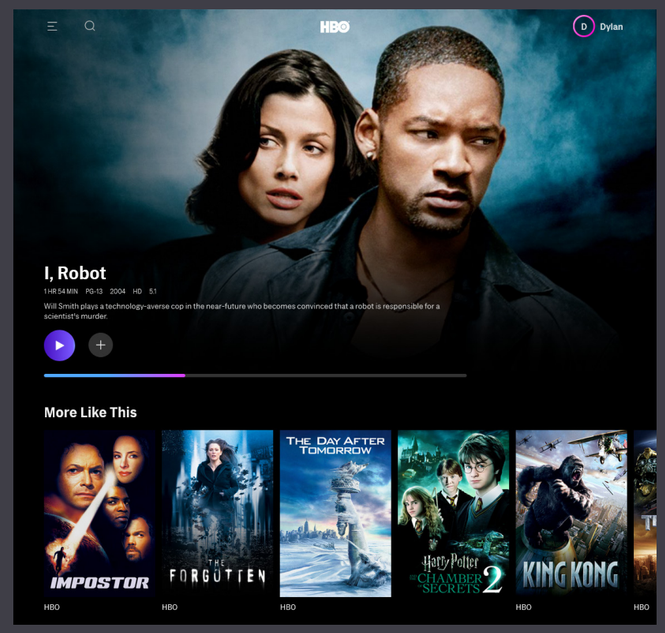
Smartphones/Tablets: Apple devices (iOS 12.2 and later), Android (Android OS 5 and later), and Amazon Fire Tablets.

HBOmax Accross Devices:

Fig 6. HBOmax iOS App

I wanted to share a screenshot as a comparison to the other two apps as well. Notice that they all share the badges--such as HD and 5.1.

Fig 7. HBOmax In Browser



This screenshot is of the browser HBOmax app. Essentially the same as what you would get on Mobile and Tablet as well.

Fig 8. HBOmax Desktop App Screenshot of I, Robot

On this screen, it is a screenshot of a scene in the movie I, Robot. I screenshotted this for educational purposes. So that I can demonstrate what the streaming quality and compression do. In the tile above the screenshot, it is a zoomed-in view of the specific region. I was getting HD when I was watching this for this assignment. But yet, when you look closely you see a lot of artifacts and pixelation. Albeit, I didn't notice this issue till I looked closer at the screenshot I was able to get.

Conclusion

To sum up my experience throughout researching these three streaming services. It was pretty hard to find the info I want, that I felt was accurate. Then when I did find info, directly from the streaming service, it wasn't technical. Meaning that they used language that would help anyone--someone that may not know a lot about file formats/codecs and other associated technology--and this makes sense. You want to be able to market the plan with enough of a description that anyone can get an idea of what they are getting in terms of stream quality.

Do I think how they word things is good? No, not at all. Because I was more curious about the exact files and tech they were using. I even hopped on a chat line with Disney+ just to try to find out what they were using and they couldn't tell me anything really--I got nowhere essentially. I wish a streaming service would at least go into more detail on their help/FAQ pages on their sites, for those who are curious like me. Because of all of that, I had to perform some educated guesses on what each service would be using. However, I did find some info on the internet about each service user, I opted not to use that because how can they find that info when the file format info isn't present on the streaming service(s) site?

In short, I learned that It is key to mainly just have a good ISP that provides at least the minimum recommended bandwidth for streaming in 4k, a device to use the streaming services app, and a screen capable of displaying high-resolution films.

Dylan Smith

Motion Pictures
The Illusion of Motion Pictures

Fig. 1. Kodak, *Motion heritage photo theatrereel fullres*, Accessed *7 Sept. 2021*

Have you ever thought about what a motion picture is? They are an illusion, let me explain why. Imagine a stack of sticky notes and on each note, there is an illustration of a ball. On the first sticky note, the ball is hovering above the ground, but on the next sticky note that ball is slightly down towards the ground. This trend continues until that ball has hit the ground. Then, the ball would bounce off the ground and go back up in the air. Each sticky note is a single captured image at an instance of time, and if you run your finger along with the sticky notes so that each note would flip up, you would see the illusion of a motion picture. When cinema theaters started to show motion pictures, they incorporated tech that took sound and color to intensify that illusion. It is the cinema's job to provide this illusion, to trick the consumer or immerse them into a movie experience and technological innovation cemented that idea even further.

Fig. 2. Encyclopædia Britannica, *Kinetograph, 1888*

Cinematographers use this illusion of fast-moving still images to make motion pictures. A film is simply many still images taken at an instance of time and stitched together, and if you cycle through the images fast enough, you'll get a motion picture—also known as the Seventh Art. The technology that started all of this and brought the Seventh Art to our world was the Kinetograph. This device was created in 1888, by William Kennedy Laurie Dickson, he was a lab assistant that worked for Thomas Edison, who invented the Phonograph in 1877 (Cook et al.). As the story goes, Edison had wanted to add a component to the Phonograph, that would thus become a motion picture camera. Edison asked Dickson to develop that component and eleven years after the Phonograph was invented, the Kinetograph was introduced to the world (Cook et al.).

With the invention of the Seventh Art, thanks to Dickson, we get to be able to enjoy the magic of movies… or is it movie magic? But that's what it is, it's amazing that something like that was invented and all the iterations that followed truly became something magical. Which intensified the illusion of motion pictures. Now think how motion pictures have impacted our world! Anywhere from entertainment, education, commercialism, scientific research, and Gifs online! Great movie directors like Alfred Hitchcock to the Russo Brothers wouldn't have been able to provide amazing cinema experiences if we didn't have the invention of the Kinetograph. With all that said, there are some drawbacks to what the Kinetograph had to offer. Those drawbacks are key components in the modern cinema experience, such as lacking sound and color. New technology had to fill that gap, and it did.

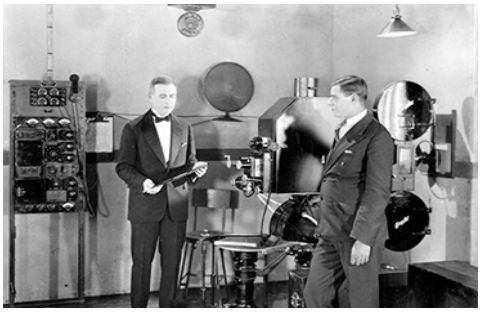


Fig. 3. OpenMind BBVA, *Demonstration of Vitaphone,* Accessed 8 Sept. 2021

By the year 1916, any motion picture was black and white. Within that same year, the Technicolor was invented (Bernardo). This new technology allowed filmmakers to film in color, which could intensify that illusion even further. At first, the invention by Daniel Comstock and Burton Wescott had some difficulties in the theater, the projection on screen just had issues that didn't solidify the color component in the cinema experience (Bernardo). Until the inventors of Technicolor iterated their technology to a point where it revolutionized the entire movie industry.

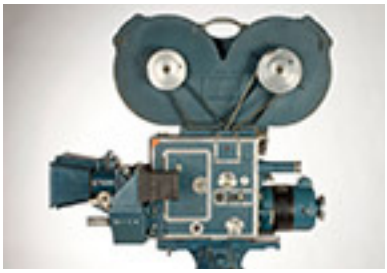


Fig. 4. George Eastman Museum, *Technicolor,* 2015

In comes the Technicolor three-strip, introduced in 1932, this new iteration utilized three-strips of film to produce a color film. The process was as follows; light enters the camera lens then is split into two paths via a beam-splitting prism. Then one of the film strips records green tones onto black-and-white film and the remaining two film strips are stacked on top of each other and exposed to black-and-white film again. During this process, the top strip of film is sensitive to blue light and the other is sensitive to any red light (Eastman Museum). The three colors: red, green, and blue are what is combined and exposed to black-and-white film. Color is arguably an important component in motion pictures, but some movies are designed to be watched in black and white. Whichever method you choose, you're not getting the full experience if there isn't sound with the film and the introduction of sound to cinema resulted in a modern cinema experience.

Sound in cinema wasn't present until 1927. Everything was silent films, such as Charlie Chaplin films. But in 1927, Alan Crosland introduced a film called The Jazz Singer. This was the first film to be produced and played back with sound (Bernardo). The technology that brought sound to the cinema was the Vitaphone. Analogous to vinyl, which playback classical music, the Vitaphone utilized discs that had sound engraved on it (Bernardo). Having the ability to have sound paired with a film helped that illusion becoming something more relatable, tapping into one of our five senses. Now having the ability to watch a motion picture with color and sound introduced us to the modern era of cinema.

Fig. 5. HistoryLink.org, *The Jazz Singer,* 1927

We wouldn't have our modern cinema-going experience if we didn't have these inventions. Every step of the evolution of motion pictures was to enhance the experience you feel in the movie theater, providing that illusion that is at the heart of motion pictures. Having color film, sound, and great artists have had an impact on each person's life. Anything from watching movies in school to your date to the new big movie. Your reality wouldn't be the same without it.

Fig. 6. Derks24, *Empty Movie Theater,* 13 July. 2017

So, what is the next big thing for motion pictures and the experience behind that? Well, you could leave this reality and put on a virtual reality headset and enjoy a movie-going experience in that! From all the inventions that have sculpted our modern era of motion pictures, a step towards virtual reality might be the next big thing for motion pictures. Let me explain. If you have a VR headset, you can ask some friends that have VR headsets as well to watch a movie in a virtual movie theater. Your friends could be a house away or even across the world. The fact is you can sit down in your chair, put on your headset, and watch your favorite movie with some friends. You're simulating that cinema experience with those who are far away. There are apps you can install on your VR headsets like Bigscreen, which makes a virtual movie theater for you and your friends! Pick a movie and sit back and be immersed in everything that made cinema up to this point.

Remember when I said motion pictures are an illusion? That statement is truer than it ever was before. From the Kinetograph to modern devices such as VR headsets, the idea of illusion still stands. Each device I've mentioned has had an impact on making that illusion work. The key thing to create an illusion is tapping into our natural senses, such as our vision and hearing. Movie theaters accomplished this with the innovation of the technology that stimulated those senses. Now, you may be able to add motion to the list of senses thanks to VR headsets. Who knows what the future may hold, but I'm sure that the great illusion of the Seventh Art will hold true as the technology matures even more.

Fig. 7. Darshan Shankar, *The Bigscreen "Cinema" has a 110-foot screen & realistic real-time lighting,* 2017

Work Cited

"About lossless audio in Apple Music." *Apple*, 22 July. 2021 https://support.apple.com/en-us/HT212183.

"Accord Sedan Specs Features." *Honda,* Accessed 5 Nov. 2021, https://automobiles.honda.com/accord-sedan/specs-feature-modals/450-watt-premium-audio-system.

"An image format for the Web." *Google,* 16 Aug. 2021, https://developers.google.com/speed/webp.

"About incompatible media in iMovie for macOS." *Apple,* 7 Oct. 2019, https://support.apple.com/en-us/HT209029.

"About GIMP." *GIMP,* Accessed 25 Sep. 2021, https://www.gimp.org/about/introduction.html.

"Adobe Lightroom User Guide." *Adobe,* 6 Sep. 2021, https://helpx.adobe.com/lightroom-cc/user-guide.html.

"Advanced Audio Coding." *Wikipedia*, *The Free Encyclopedia,* Accessed 23 Sep. 2021, https://en.wikipedia.org/wiki/Advanced_Audio_Coding.

"AirPods Pro." *Apple,* Accessed 5 Nov. 2021, https://www.apple.com/airpods-pro/specs/.

"Apple Introduces iTunes—World's Best and Easiest To Use Jukebox Software." *Apple,* 9 Jan. 2001, https://www.apple.com/newsroom/2001/01/09Apple-Introduces-iTunes-Worlds-Best-and-Easiest-To-Use-Jukebox-Software/.

"Apple Music announces Spatial Audio with Dolby Atmos; will bring Lossless Audio to entire catalog." *Apple*, 17 May 2021, https://www.apple.com/newsroom/2021/05/apple-music-announces-spatial-audio-and-lossless-audio/.

"Apple Lossless Audio Codec." *Apple,* Accessed 23 Sep. 2021, https://macosforge.github.io/alac/.

"Aliasing & anti-aliasing." *Adobe,* 22 Aug. 2016, https://helpx.adobe.com/photoshop/key-concepts/aliasing-anti-aliasing.html.

"About the GIF format." *Adobe,* 27 Apr. 2021, https://helpx.adobe.com/photoshop-elements/using/optimizing-images-gif-or-png.html.

Akanksha_Rai. "Understanding file sizes | Bytes, KB, MB, GB, TB, PB, EB, ZB, YB." *GeeksforGeeks,* 15 Apr. 2021, https://www.geeksforgeeks.org/understanding-file-sizes-bytes-kb-mb-gb-tb-pb-eb-zb-yb/.

"Audio Quality." *Spotify,* 12 Aug. 2021, https://support.spotify.com/us/article/audio-quality/.

"Audio file formats for Spotify." *Spotify,* Accessed 7 Nov. 2021, https://artists.spotify.com/help/article/audio-file-formats.

"Audio Interchange File Format." *Wikipedia, The Free Encyclopedia,* Accessed 23 Sep. 2021, https://en.wikipedia.org/wiki/Audio_Interchange_File_Format.

"AV1 & Media Codecs." *Mozilla,* Accessed 7 Dec. 2021, https://research.mozilla.org/av1-media-codecs/.

"Bandwidth." *Verizon,* Accessed 6 Nov. 2021, https://www.verizon.com/info/definitions/bandwidth.

Basu, Sreejata. "Top 5 Video Formats in 2021: A Detailed Guide." *Muvi,* 23 July 2021, https://www.muvi.com/blogs/top-5-video-formats-in-2021.html.

"Because your music is worth it." *Qobuz,* Accessed 6 Nov. 2021, https://www.qobuz.com/us-en/audio-quality.

Berry, Gus and Rodocker, Peter. "Understanding audio bitrates." *Adobe,* Accessed 7 Nov. 2021, https://www.adobe.com/creativecloud/video/discover/audio-bitrate.html.

Berry, Gus and Boutillete Lo. "The best audio format types for audiophiles." *Adobe*, Accessed 20 Sep. 2021, https://www.adobe.com/creativecloud/video/discover/best-audio-format.html.

Burns, Verity and Roberts, Becky. "High-resolution audio: everything you need to know." *What Hi-Fi?*, 9 Feb. 2021, https://www.whathifi.com/us/advice/high-resolution-audio-everything-you-need-to-know.

"Bit Depth | iZotope Pro Audio Essentials." *Youtube,* uploaded by iZotope, Inc., 25 Apr. 2016, https://www.youtube.com/watch?v=ubCMl3Jq6e4.

"Bit Depth Tutorial." *Cambridge in Colour,* Accessed 8 Oct. 2021, https://www.cambridgeincolour.com/tutorials/bit-depth.htm.

"Bit Depth Visualization." *Cambridge in Colour,* Accessed 8 Oct. 2021, https://cdn.cambridgeincolour.com/images/tutorials/bitdepth_08bpp_580.png.

"Bit depth and preferences." *Adobe,* 5 Sep. 2021, https://helpx.adobe.com/photoshop/using/bit-depth.html.

Cabading, Zach. "Anti-Aliasing: Everything You Need to Know." *HP*, 28 Aug. 2019, https://www.hp.com/us-en/shop/tech-takes/what-is-anti-aliasing.

Calabrese, Robert. “Ultimate Guide To Audio Bitrate & Audio Formats.” *Home DJ Studio*, 3 Aug. 2021, https://homedjstudio.com/audio-bitrates-formats/.

“Choosing the right video format.” *Adobe,* Accessed 27 Sep. 2021, https://www.adobe.com/creativecloud/video/discover/best-video-format.html.

Costello, Sam. “What Makes an MP3 Different From an AAC?” *Lifewire Tech For Humans*, 13 Mar. 2021, https://www.lifewire.com/mp3-vs-aac-iphone-file-types-1999464.

“Clearly the best sound.” *Tidal*, Accessed 7 Nov. 2021, https://tidal.com/sound-quality.

“Compression.” *BBC*, Accessed 3 Oct. 2021, https://www.bbc.co.uk/bitesize/guides/zqyrq6f/revision/4.

“Compression.” *Adobe*, 15 Nov. 2021, https://helpx.adobe.com/photoshop/key-concepts/compression.html.

“Can I manually adjust the video quality?” *Warner Media,* HBO Max, Accessed 8 Dec. 2021, https://help.hbomax.com/us/Answer/Detail/000001238.

“Connect to Netflix using your favorite devices.” *Netflix*, Accessed 8 Dec. 2021, https://devices.netflix.com/en/.

Datavideo. “What are 8-bit, 10-bit, 12-bit, 4:4:4, 4:2:2 and 4:2:0.” *Datavideo,* 7 Jan. 2020, https://www.datavideo.com/eu/article/412/what-are-8-bit-10-bit-12-bit-4-4-4-4-2-2-and-4-2-0.

”Does MP4 provide lossless compression?” *Adobe,* Accessed 30 Sep. 2021, https://www.adobe.com/creativecloud/video/hub/features/does-mp4-provide-lossless-compression.html.

Dobbin, Jolene. “GPU vs CPU: What Matters Most for PC Gaming?” *HP*, 24 Feb. 2019, https://www.hp.com/us-en/shop/tech-takes/gpu-vs-cpu-for-pc-gaming.

“Discover.” *Qobuz,* Accessed 7 Nov. 2021, https://www.qobuz.com/us-en/discover.

“Disney+ supported devices.” *Disney*, Accessed 8 Dec. 2021, https://help.disneyplus.com/csp?id=csp_article_content&sys_kb_id=20177cfedbaaf05cdbc9c28d1396195f.

“Downloads.” *GIMP*, Accessed 25 Sep. 2021, https://www.gimp.org/downloads/.

“Download shows and movies.” *Warner Media*, HBO Max, Accessed 8 Dec. 2021, https://help.hbomax.com/us/Answer/Detail/000001242.

Ellis, Matt. “What is WebP? Pros and cons of this next-gen image format.” *99designs,* Feb. 2021, https://99designs.com/blog/tips/webp-image-format/.

"Episode 5 'Journey Into Mystery." *Marvel*, Accessed 4 Nov. 2021, https://terrigen-cdn-dev.marvel.com/content/prod/2x/VGM1045_104_comp_v014_20210609_r709.1101_R.jpg.

"Feature Overview." *GIMP,* Accessed 25 Sep. 2021, https://www.gimp.org/features/.

"File formats." *Adobe,* 19 Aug. 2021, https://helpx.adobe.com/photoshop/using/file-formats.html.

"Final Cut Pro." *Apple,* Accessed 27 Sep. 2021, https://www.apple.com/final-cut-pro/specs/.

"FLAC." *Wikipedia, The Free Encyclopedia,* Accessed 23 Sep. 2021, https://en.wikipedia.org/wiki/FLAC.

"Garage Band for Mac." *Apple,* Accessed 19 Sep. 2021, https://www.apple.com/mac/garageband/.

"GarageBand User Guide." *Apple*, Accessed 19 Sept. 2021, https://support.apple.com/guide/garageband/import-audio-and-midi-files-gbndd01649ed/mac.

"GPU accelerated rendering." *Adobe,* 25 July 2021, https://helpx.adobe.com/premiere-elements/using/gpu-acceleration.html.

Harper, Michael. "Image Formats." Output for Interactive Media, 23 Sep. 2021, Utah Valley University. Lecture.

Harper, Michael. "Part 5 Technology Assessment." DGM 2341, 5 Oct. 2021, Utah Valley University, Orem, Lecture.

Harris, Mark. "ALAC Audio Format: Is It Better To Use Than AAC?" *Lifewire Tech For Humans*, 10 May 2021, https://www.lifewire.com/what-is-alac-audio-format-2438531.

Harris, Mark. "What is Bit Depth?" *Lifewire,* 11 Sep. 2020, https://www.lifewire.com/what-is-bit-depth-2438536.

Harper, Michael. "Part 5 Technology Assessment." DGM 2341, 5 Oct. 2021, Utah Valley University, Orem, Lecture.

Hernandez, Alex. "Making Sense of Device Resolution & Pixel Density." *Prototypr.io,* Medium, 11 June 2018, https://blog.prototypr.io/making-sense-of-device-resolution-pixel-density-40922aeb8a6.

”High Efficiency Video Coding.” *Wikipedia, The Free Encyclopedia,* 11 Sep. 2021, https://en.wikipedia.org/w/index.php?title=High_Efficiency_Video_Coding&oldid=1043765176.

“How to stream Netflix in HD.” *Netflix*, Accessed 8 Dec. 2021, https://help.netflix.com/en/node/13844.

“How to control how much data Netflix uses.” *Netflix,* Accessed 8 Dec. 2021, https://help.netflix.com/en/node/87.

Ilenda, Michal. “Red Dulashock Gamepad.” *Unsplash*, 22 June 2020, https://unsplash.com/photos/6Y4n49g7k9c.

“Image file type and format guide.” *Mozilla,* MDN Web Docs, 6 Sep. 2021, https://developer.mozilla.org/en-US/docs/Web/Media/Formats/Image_types.

“Image File Formats – JPEG, GIF, PNG.” *Youtube,* uploaded by TechQuickie, 16 May 2017, https://www.youtube.com/watch?v=ww12lImOJ38.

“Image of Red Mountains landscape with the right side of the photo show more contrast and color.” *Adobe,* Accessed 27 Sep. 2021, https://helpx.adobe.com/content/dam/help/en/lightroom-cc/how-to/raw-vs-jpeg/jcr_content/main-pars/image_1051440177/raw-vs-jpeg-step1_900x506.jpg.

“iMovie User Guide.” *Apple*, Accessed 27 Sep. 2021, https://support.apple.com/guide/imovie/welcome/mac.

“iMovie.” *Apple,* Accessed 29 Sep. 2021, https://www.apple.com/imovie/.

“Internet connection speed recommendations.” *Netflix,* Accessed 8 Dec. 2021, https://help.netflix.com/en/node/306.

Jones, Sarah. ”5 Ways Bluetooth 5 Makes Wireless Audio Better.” *Harman*, 18 May 2020, https://pro.harman.com/insights/harman-pro/5-ways-bluetooth-5-makes-wireless-audio-better/.

“JPEG files.” *Adobe*, Accessed 15 Nov. 2021, https://www.adobe.com/creativecloud/file-types/image/raster/jpeg-file.html.

“JPEG 2000 files.” *Adobe*, Accessed 1 Dec. 2021, https://www.adobe.com/creativecloud/file-types/image/raster/jpeg-2000-file.html.

”JPEG 200 image format.” *Can I Use.* Accessed 1 Dec. 2021, https://caniuse.com/jpeg2000.

“Letter A with and without anti-aliasing.” *Adobe*, 22 Aug. 2016, https://helpx.adobe.com/content/dam/help/en/photoshop/ps-key-concepts/aliasing.png.

Lepard, Chase. ”What are GIFs and How to Effectively Use Them on Social Media.” *Wix*. 16 Nov. 2017, https://www.wix.com/blog/2017/11/gifs-in-social-media/.

Lee, Joel. “The 10 Most Common Audio Formats: Which One Should You Use?” *make use of*, 2 Dec. 2019, https://www.makeuseof.com/tag/audio-file-format-right-needs/.

Lendino, Jamie. “The Best Audio Editing Software for 2021.” *PCMag*, 29 Dec. 2020, https://www.pcmag.com/picks/the-best-audio-editing-software.

Lendino, Jamie. “Apple GarageBand (for Mac) Review.” *PCMag*, 26 Sep. 2019, https://www.pcmag.com/reviews/apple-garageband-for-mac.

Lendino, Jamie. “Apple Logic Pro X (for Mac) Review.” *PCMag*, 8 June 2020, https://www.pcmag.com/reviews/apple-logic-pro-x-for-mac.

Lendino, Jamie. “Avid Pro Tools Review.” *PCMag*, 31 Oct. 2019, https://www.pcmag.com/reviews/avid-pro-tools.

Library of Congress. “Encapsulated PostScript (EPS) File Format, Version 3.x.” *Library of Congress*, 10 Aug. 2021, https://www.loc.gov/preservation/digital/formats/fdd/fdd000246.shtml.

“Lightroom vs. Photoshop: When to use each image editing program.” *Adobe,* Accessed 25 Sep. 2021, https://www.adobe.com/creativecloud/photography/discover/lightroom-vs-photoshop.html.

“Lottiefiles Logo.” *Lottiefiles*, Accessed 28 Sep. 2021, https://static3.lottiefiles.com/images/v3/lf-intergrations-logo.svg.

“Logic Pro.” *Apple*, 8 June 2020, https://www.apple.com/logic-pro/specs/.

“Logic Pro User Guide.” *Apple,* Accessed 22 Sep. 2021, https://support.apple.com/guide/logicpro/import-compressed-audio-files-lgcp4f68cbe3/mac.

Lovell, Daniel. “QuickTime and File Support Improvements in Pro Tools 2021.6.” *Avid*, 24 June 2021, https://www.avid.com/resource-center/quicktime-and-file-support-improvements-in-pro-tools-2021-6.

“Lossy vs Lossless Compression.” *KeyCDN,* 21 Nov. 2018, https://www.keycdn.com/support/lossy-vs-lossless.

“Lossy compression.” *MDN Web Docs*, 13 Jan. 2021, https://developer.mozilla.org/en-US/docs/Glossary/lossy_compression.

“Lossless compression.” *MDN Web Docs,* 20 Sep. 2021, https://developer.mozilla.org/en-US/docs/Glossary/Lossless_compression.

Lundquist, Samual. “Image file formats: when to use each file type.” *99designs,* 2019, https://99designs.com/blog/tips/image-file-types/.

“MG278Q Monitor.” *ASUS,* Accessed 7 Oct. 2021, https://dlcdnwebimgs.asus.com/gain/c4c365e3-e006-4157-bc30-ea4ecf588cb3/w692.

Martindale, Jon and George, Anita. “The best free photo-editing software for 2021.” *Digitaltrends,* 13 Apr. 2021, https://www.digitaltrends.com/computing/best-free-photo-editing-software/.

McGowan, Brian. “Colorful Image.” *Unsplash*, 23 Feb. 2020, https://unsplash.com/photos/MIdLSFHYuMk.

“Media streaming is now part of our lives, but how does video streaming work?” *CDNetworks,* 24 May 2021, https://www.cdnetworks.com/media-delivery-blog/what-is-video-streaming-and-how-does-it-work/.

“Media type and format guide: image, audio, and video content.” *MDN Web Docs,* 23 Feb. 2021, https://developer.mozilla.org/en-US/docs/Web/Media/Formats.

“Media container formats (file types).” *MDN Web Docs*, 28 June 2021, https://developer.mozilla.org/en-US/docs/Web/Media/Formats/Containers.

Morrison, Nicole and Byrne, Jenn. “RAW vs. JPEG: Which format should you shoot in?” *Adobe,* Accessed 26 Sep. 2021, https://www.adobe.com/creativecloud/photography/discover/raw-vs-jpeg.html.

Morrison, Geoffrey. “4K vs. 8K vs. 1080p: TV resolutions explained.” *CNET,* 12 July 2021, https://www.cnet.com/tech/home-entertainment/4k-1080p-2k-uhd-8k-tv-resolutions-explained/.

Muchmore, Michael. “The Best Photo Editing Software for 2021.” *PC Mag,* 18 Aug. 2021, https://www.pcmag.com/picks/the-best-photo-editing-software.

Muchmore, Michael. “Adobe Premiere Pro Review.” *PC Mag*, 14 Apr. 2021, https://www.pcmag.com/reviews/adobe-premiere-pro-cc.

Muchmore, Michael. “Apple Final Cut Pro Review.” *PC Mag,* 8 Apr. 2021, https://www.pcmag.com/reviews/apple-final-cut-pro.

”multimedia container.” *PC Mag,* Accessed 29 Sep. 2021, https://www.pcmag.com/encyclopedia/term/multimedia-container.

“MPEG-1.” *Wikipedia, The Free Encyclopedia,* 29 Sep. 2021, https://en.wikipedia.org/wiki/MPEG-1.

"MPEG-2." *Wikipedia, The Free Encyclopedia,* 11 Jul. 2021, https://en.wikipedia.org/wiki/MPEG-2#Filename_extensions.

"MPEG-4 Part 14." *Wikipedia, The Free Encyclopedia*, 3 Sep. 2021, Accessed 21 Sep. 2021, https://en.wikipedia.org/wiki/MPEG-4_Part_14.

Migaj, S. "A flat lay of few old school diskettes." *Unsplash,* 1 Apr. 2021, https://unsplash.com/photos/ocUAiaMTCM0.

Nichols, Jessie-Lee. "10 Types of Image File Extensions and When to Use Them." *HubSpot*, 27 Apr. 2021, https://blog.hubspot.com/insiders/different-types-of-image-files.

"Optimizing images for the JPEG format." *Adobe*, 27 Apr. 2021, https://helpx.adobe.com/photoshop-elements/using/optimizing-images-jpeg-format.html.

"Ogg." *Wikipedia, The Free Encyclopedia,* Accessed 22 Sep. 2021, https://en.wikipedia.org/wiki/Ogg.

"Overview of JPEG 1." *JPEG*, Accessed 25 Sep. 2021, https://jpeg.org/jpeg/index.html.

"Overview of JPEG 2000." *JPEG,* Accessed 25 Sep. 2021, https://jpeg.org/jpeg2000/index.html.

Parrish, Kevin. "How Much Speed Do I Need to Stream Music?" *HighSpeedInternet.com,* 14 July 2021, https://www.highspeedinternet.com/resources/how-much-speed-do-i-need-for-pandora-and-spotify.

"PNG files." *Adobe,* Accessed 30 Nov. 2021, https://www.adobe.com/creativecloud/file-types/image/raster/png-file.html.

Peters, Jay. "You can see Netflix's new AV1 streaming tech on select TVs and the PS4 Pro." *The Verge*, 10 Nov. 2021, https://www.theverge.com/2021/11/10/22775150/netflix-av1-codec-tv-streaming-ps4-pro.

Pensworth, Luke. "What is Mbps?" *DailyWireless,* 7 Mar. 2020, https://dailywireless.org/internet/what-is-mbps/.

"Plans and Pricing." *Netflix,* Accessed 10 Dec. 2021, https://help.netflix.com/en/node/24926.

"Pixel density." *Wikipedia, The Free Encyclopedia,* 24 Sep. 2021, https://en.wikipedia.org/wiki/Pixel_density.

"progressive download." *PC Mag,* Accessed 1 Oct. 2021, https://www.pcmag.com/encyclopedia/term/progressive-download.

"Raster & Vector." *Adobe,* 19 Dec. 2016, https://helpx.adobe.com/photoshop-elements/key-concepts/raster-vector.html.

Russell, Wendy. “What Is ‘Resolution’ for Displays or Images?” *Lifewire,* 7 Dec. 2019, https://www.lifewire.com/what-is-resolution-2767449.

Scarrott, Becky. “MP3, AAC, WAV, FLAC: all the audio file formats explained.” *What Hi-Fi?*, 30 Apr. 2021, https://www.whathifi.com/advice/mp3-aac-wav-flac-all-the-audio-file-formats-explained.

Sorin, Roberto. “CD DVD.” *Unsplash,* 9 Apr. 2021, https://unsplash.com/photos/7qn9wis0Wns.

Sebastian, Linus. “How Do Vector Graphics Work?” *Youtube,* uploaded by TechQuickie, 18 Oct. 2016, https://www.youtube.com/watch?v=W2xknX3k6FY&t=291s.

Skane, Rebecca. “Hottie Lottie: Bloat-free Animations for WordPress.” *Media Template,* 30 Mar. 2021, https://mediatemple.net/blog/web-development-tech/hottie-lottie-bloat-free-animations-for-wordpress/

Sherman, Alex and Subin, Samantha. ”Disney makes the trend clear: Growth is slowing for streaming services.” *CNBC,* 10 Nov. 2021, https://www.cnbc.com/2021/11/10/disney-netflix-and-other-streaming-services-subs-arpu-q3-2021.html.

Smith, Matthew. “Conifer sapling.” *Unsplash,* 20 Jan. 2015, https://unsplash.com/photos/Rfflri94rs8.

Strieb, James. “Video File Formats – MP4, MOV, MKV.” *Youtube,* uploaded by TechQuickie, 28 Sep. 2018, https://www.youtube.com/watch?v=hvgxn8v--8Q.

“Supported image formats.” *Adobe,* 26 Apr. 2021, https://helpx.adobe.com/lightroom-classic/help/supported-file-formats.html.

Sung, Dan. “What is AV1? The 8k video codec coming soon to streaming services.” *What HiFi?,* 3 Mar. 2021, https://www.whathifi.com/us/advice/what-is-av1-the-8k-video-codec-coming-to-a-streaming-service-near-you.

“TIFF.” *FileFormat,* Accessed 25 Sep. 2021, https://docs.fileformat.com/image/tiff/.

“TUF Gaming VG32AQL1A.” *ASUS*, Accessed 4 Oct. 2021, https://www.asus.com/Displays-Desktops/Monitors/TUF-Gaming/TUF-Gaming-VG32AQL1A/techspec/.

”Uploading requirements.” *Soundcloud*, Accessed 21 Sep. 2021, https://help.soundcloud.com/hc/en-us/articles/115003452847-Uploading-requirements.

“Vector, Raster, JPG, EPS, PNG – What’s The Difference?” *MODassic*, Accessed 25 Sep. 2021, https://modassicmarketing.com/insights/articles/understanding-image-file-types.

"Virtuoso RGB Wireless SE High-Fidelity Gaming Headset—Gunmetal." *Corsair*, Accessed 5 Nov. 2021, https://www.corsair.com/us/en/Categories/Products/Gaming-Headsets/Wireless-Headsets/VIRTUOSO-RGB-WIRELESS-High-Fidelity-Gaming-Headset/p/CA-9011180-NA.

"Video Quality on Disney+." *Disney*, Accessed 8 Dec. 2021, https://help.disneyplus.com/csp?id=csp_article_content&sys_kb_id=8b26fe26dbf7f4d4db5ed404ca961988.

"WAV." *Wikipedia, The Free Encyclopedia,* Accessed 23 Sep. 2021, https://en.wikipedia.org/wiki/WAV.

"Watch HBO Max in 4K HDR." *Warner Media,* HBO Max, Accessed 12 Dec. 2021, https://help.hbomax.com/us/Answer/Detail/000001167.

"Web video codec guide." *MDN Web Docs,* 20 Jul. 2021, https://developer.mozilla.org/en-US/docs/Web/Media/Formats/Video_codecs.

"WebP." *Wikipedia, The Free Encyclopedia,* Accessed 25 Sep. 2021, https://en.wikipedia.org/wiki/WebP.

"Welcome to the Premiere Pro User Guide." *Adobe*, 22 Aug. 2021, https://helpx.adobe.com/premiere-pro/user-guide.html.

"What is PDF?" *Adobe,* Accessed 26 Sep. 2021, https://www.adobe.com/acrobat/about-adobe-pdf.html.

"What is a Lottie?" *Lottiefiles,* Accessed 28 Sep. 2021, https://lottiefiles.com/what-is-lottie.

"What's new in PhotoShop." *Adobe*, 13 Sep. 2021, https://helpx.adobe.com/photoshop/using/whats-new.html?promoid=2SLRC6G5&mv=other.

"What Is MQA Audio?" *MQA*, 20 July 2021, https://www.mqa.co.uk/newsroom/faqs/what-is-mqa.

"What is Tidal?" *Tidal*, Accessed 6 Nov. 2021, https://tidal.com/about.

"What Is Computer RAM?" *Intel,* Accessed 6 Oct. 2021, https://www.intel.com/content/www/us/en/tech-tips-and-tricks/computer-ram.html.

"When to use raw vs. JPEG." *Adobe,* Accessed 27 Sep. 2021, https://helpx.adobe.com/lightroom-cc/how-to/raw-vs-jpeg.html.

"Which devices work with HBO Max?" *Warner Media,* HBO Max, Accessed 8 Dec. 2021, https://help.hbomax.com/US/Answer/Detail/000001243.

"Why Qobuz Is Unique." *Qobuz,* Accessed 6 Nov. 2021, https://www.qobuz.com/us-en/about.

"Zune service retirement." *Microsoft,* Accessed 6 Nov. 2021, https://support.xbox.com/en-US/help/games-apps/apps-help/zune-retirement.