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Designing a 4K Production Workflow for an Educational Institution

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The purpose of this thesis is to analyze the requirements needed to facilitate 4K video production within Helsinki Metropolia University of Applied Sciences and design a feasible workflow, which gains full advantage of the available resources. By the purchase of the Blackmagic Design Production Camera 4K, students of Metropolia are now able to produce professional 4K video. Due to the sheer amount of data 4K video inherits, specialized workflows and data handling are required.

Before the actual 4K video acquisition, every component of the data flow model had to be tested and analyzed. Recording formats had to be evaluated based on image quality and resulting file size. Transport buses and connections needed to provide high enough bandwidths to support the heavy load of 4K video data. The most crucial and important component was the storage volume. 4K video processing requires a lot of fast storage to ensure fluent playback and editing. After the objective analysis of the individual components, several workflows were designed and tested based on the highest quality 4K footage in order to simulate maximum system stress. Workflows were designed to produce professional video quality, including color correction. Most importantly the concept of offline editing with proxy files, which enables 4K production on less powerful machines, was analyzed.

This thesis suggests that 4K video production at Metropolia is possible, yet at the current stage of development limited in its extent. A workflow based on proxy files allows multiple students to utilize the editing work stations already available at Metropolia's Media Lab. However, the computational power and data handling capabilities of the Mac Pro work station are still needed for many operations with 4K.

This thesis serves students as a guide for 4K video production. Furthermore, the institution can utilize the results of the data and component analysis to improve the facilities in future development, thus enabling multiple students to work with extensive 4K productions.

Keywords	4K, UHD, Video Production, Workflow, Video Codecs, Offline Editing, Proxy Files, Color Grading, RAW, Image Quality, Recording Formats, Video Compression, Thunderbolt, Data Storage

Contents

Terms and Abbreviations

4K	High resolution picture format with 3840 x 2160 pixels per frame
BMPC4K	Blackmagic Production Camera 4K
CC	Adobe CC stands for software offered by the Adobe Creative Cloud
CES	Consumer Electronics Show
DI	Digital Intermediate
FPS	Frames Per Second
GUI	Graphical User Interface
HDSLR	Digital single-lens reflex camera capable of recording HD video
HD	High Definition
ITU	International Telecommunication Union
LUT	Look Up Table
Mb/s	Mega bit per second
MB/s	Mega byte per second
MSRP	Manufacturer's suggested retail price
MST	Multi-Stream Transport
NLE	Non Linear Editing Program
OSD	On-Screen Display
PAL	Phase Alternating Line color encoding system, European standard
SDI	Serial Digital Interface
SMPTE	Society of Motion Picture & Television Engineers
SSD	Solid State Drive
SSD	Solid State Drive
UAS	University of Applied Sciences
UHDTV	Ultra High Definition Television
UHD	Ultra High Definition
USB	Universal Series Bus
VFX	Visual Effects
VOD	Video on Demand

1 Introduction

In recent years, the rapid advance in audiovisual technologies has flooded the industry and consumer markets. Highly performing and dedicated video systems are now offered to customers at affordable rates. The broad audience in cinemas and theaters expects to be immersed into a virtual visual environment, and growing numbers of people wish for a similar experience in their homes.

4K Ultra High Definition (UHD) systems are inevitably on the way to replace Standard and even High Definition (HD) technologies. In order to provide the industry with skilled engineers, educational institutions within the Information and Media Technology departments need to start preparing their students and upgrading their facilities towards Ultra High Definition capable systems.

The Media Department of the Helsinki Metropolia University of Applied Sciences (UAS) in Leppävaara has implemented stable and proven workflows for High Definition video productions; however, the current work stations available for students are not capable of processing the large amounts of data lying in the nature of 4K UHD. This thesis analyzes the components needed to establish a feasible 4K production workflow at the Media Department of the Helsinki Metropolia University of Applied Sciences. Furthermore, this thesis should serve as a guideline and learning resource for students interested in producing in 4K.

In order to stay in a reasonable scope, this thesis focuses on post production issues and data handling of 4K material. General production or cinematographic considerations are very much dependent on individual projects and applications and are not dealt with in this thesis.

2 Theoretical Background

2.1 Definition of 4K and Ultra HD

The terms generally used for 4K and Ultra HD technology comprise many different aspects including picture and recording format as well as content delivery. For instance, nowadays camera systems allow capturing digital video in 4K resolution, which can be displayed natively in full size on a 4K UHD television set or monitor, as well as in a theater, which utilizes 4K digital projection.

In 2009, the Society of Motion Picture & Television Engineers (SMPTE) stated the image parameter values for UHDTV1 (3840 × 2160) and UHDTV2 (7680 × 4320) in their standard ST 2036-1 [1]. In addition to that, the International Telecommunication Union (ITU) published the recommendation ITU-R BT.2020 for Ultra High Definition Television (UHDTV) in 2012, which is also referred to as Rec. 2020. The paper specifies the parameters for UHD technology as in Table 1. [2]

Table 1. Proposed UHDTV Spatial Characteristics. Data gathered from Recommendation ITU-R BT.2020 (2012) [3]

Parameter	Values	
Picture Aspect Ratio	16:9	
Pixel Count Horizontal x Vertical	7680 × 4320	3840 × 2160
Sampling lattice	Orthogonal	
Pixel Aspect Ratio	1:1	
Pixel addressing	Pixel ordering in each row is from left to right, and rows are ordered from top to bottom.	

The terms 8K and 4K refer to the pixel counts of 7680 × 4320 and 3840 × 2160 respectively and can be summarized under the image format name “Ultra HD”, “UHD” or sometimes also “Quad HD”. Furthermore, in some publications 4K might be expressed as 2160p, utilizing the vertical pixel count and indication for progressive scan mode, which used to be the convention for HDTV 1080p (1920 × 1080).

Figure 1 shows a visual representation of HD and Ultra HD resolutions according to their pixel counts. Already from this point it is possible to estimate the technical challenges in picture reproduction and data handling, regarding that 4K is exactly four times the resolution of Full HD.

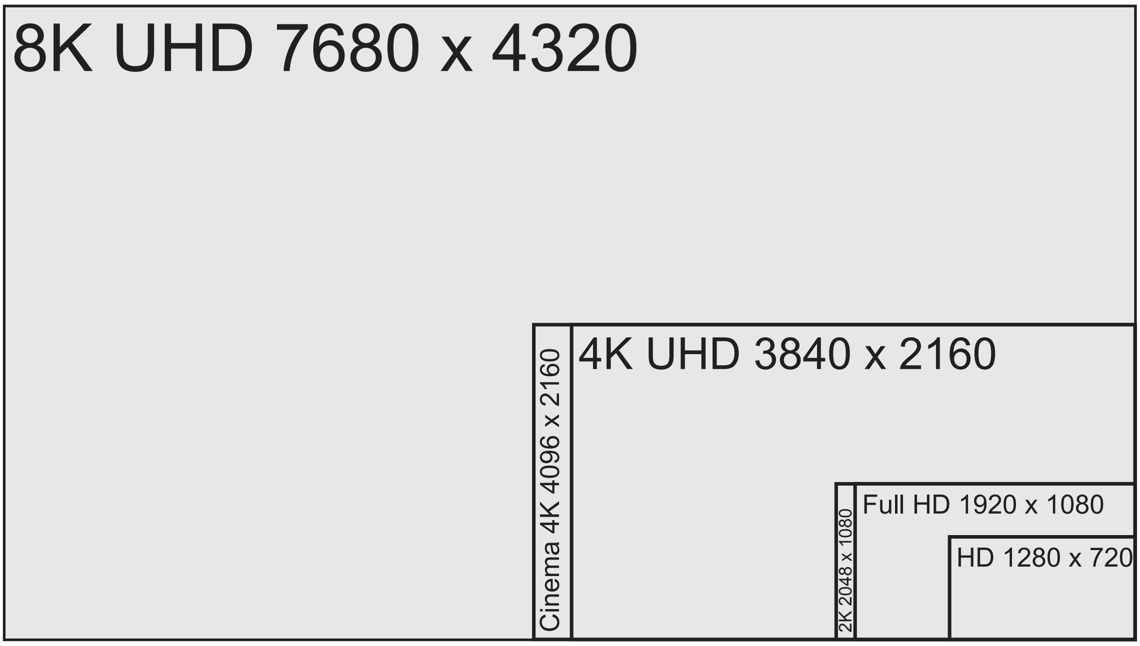

Figure 1. Visual Representation of Common Frame Sizes

Numerous papers and scientific surveys try to argue about the reasons behind the development towards 4K. Later in this text, the limits of human visual acuity in regards of viewing distance and screen size will be discussed in more detail. First, the initial starting point of 4K technology should be discussed.

2.2 The Digital Intermediate and Digital Cinema

Cinematographers, editors and Visual Effects (VFX) artists adopted to digitized workflows, because they saw the great potential and flexibility digital footage inherited over traditional film. The Digital Intermediate (DI) refers to a scanned and digitized version of the original 35 mm film footage. In order to maintain the picture quality of 35mm film, the scans needed to be made in very high resolution, such as 2K, 4K even 6K or higher.

For instance, *Spider-Man 2* (2004) was the first movie to be scanned and finished in 4K. This process of creating a DI can also be seen as a starting point towards a fully digitized 4K and UHD workflow, although the final output was mostly still 2K. [4,52-53;6,92]

The fact that many film companies are already scanning or producing content in Ultra High Resolution as their master reel is a strong argument against recent voices opposing to the new technology. Critics claim that there is no, or too little, UHD content to be shown on UHDTVs. Thus UHDTVs are obsolete for the consumer. Yet there is already plenty of content and there will be even more when looking at the constant and rapid development towards feasible and affordable workflows even for independent and low budget productions.

Digital Cinema tries to achieve similar image quality to 35mm film in terms of resolution, noise, sensitivity, contrast ratio, dynamic range and color gamut [7,2]. Technology has yet a rather long way to go in order to achieve that goal; however, it is clear that resolution alone will not be enough, which is why 4K is only the starting point of a digital cinema revolution and the next step towards a greater visual experience of video in the 21st century.

2.3 Timeline of Commercial 4K Development

In 2001 IBM announced the T220 monitor, which packed over 9 Million pixels on a 22.2-inch Screen. It was targeted for applications in medicine, automotive design and other fields of industry which would require a very high amount of detail in a picture. The starting prize point at that point was $22,000. [8]

Figure 2. The DALSA Origin[R]. Copied from Broadcast Newsroom [10]

At the 2003 National Association of Broadcasters (NAB) Show in Las Vegas, the DALSA Origin[R] (cf. Figure 2) was released as the first commercially available camera to capture 4K content, although there were barely any possibilities to deliver 4K at that time. However, cinematographers would benefit of the immense amount of detail captured digitally, even when down-sampling to 2K for screening. This meant a great step forward in the world of digital cinematography. [9]

Japan’s national broadcasting organization Nippon Hoso Kyokai (NHK, Tokyo, Japan) started experimenting with 8K or so called “Super Hi-Vision” technology already in 1995, which was targeted at 4000 scanning lines and a 22.2 channel surround sound system. The first prototype was presented to the public in 2002. Nine years later, in 2011 the first Super Hi-Vision display was showcased at the NHK Science and Technology Research Laboratories’ Open House exhibition. [11]

The current state of technology pushes the limits of feasible production workflows and delivery solutions for 4K; thus, 8K is of no relevant significance for the broad public at this moment. Furthermore, higher resolution alone does not guarantee better image quality. Improving temporal resolution by utilizing higher frame rates and reducing motion blur yields much higher results in improved overall image quality and is independent from viewing distance. Taking the IEEE journal’s recommendation of higher frame rates into the account of a future 4K production workflow, a work station should have enough computational capabilities to handle 4K footage not only at the recently and generally commonly used 24, 25 or 30 frames per second (fps), but also at 60 fps or higher. [12]

2.4 Industry Adaption towards 4K

Annual exhibitions of the industry leaders in audiovisual technologies give a great insight into trends and development within the current market. Visitors of the 2013 Consumer Electronics Show (CES) were amongst the first ones to be amazed by 4K Ultra High Definition Television (UHDTV) systems provided by almost all important companies in the display industry. Despite facing a number of challenges, such as the limited 4K content available, storage solutions and the extremely high acquisition price of those TVs at that time, it was obvious that this trend would not diminish similarly to 3D displays. [13]

However, even the most sophisticated 4K home cinema systems are not much worth for the consumer if there is no real 4K content to be presented on them. Manufacturers of digital video systems followed quickly and tried to enable 4K video capturing in their devices at any cost. As already mentioned in “2.3 Timeline of Commercial 4K Development” on page 4 of this thesis, the DALSA Origin^R was already able to capture 4K video, but missed out in commercial success. Possible reasons include the rather early stage of technology for digital post production as well as drawbacks in data storage and handling.

A highly mentionable competitor in the 4K market and one of the major early adopters to the technology is the Red Digital Cinema Camera company. With the release of the Red One camera in August 2007, Red set the bar very high in terms of ultra high resolution video capturing. The Red One camera was able to record 4.5K RAW video at a maximum frame rate of 29.97 fps. The modular nature of the Red camera systems still makes this model a popular choice for digital cinematography in terms of firmware and sensor upgrading options. [6,236-238]

2013 was the year for 4K. The major industry leaders and manufacturers presented their latest 4K equipment at the 2013 NAB exhibition. 4K was now affordable and production workflows were feasible. Slowly, all the components necessary for a full 4K production were available and tied together. Interface and computing speeds are high enough, external recorders enable high quality 4K even in so called 4K-ready cameras. Also, storage is cheaper and faster than ever. Table 2 gives a quick overview of some of the most relevant products related to 4K technology, which were presented at NAB 2013.

Table 2. 4K Technology presented at NAB 2013. Data gathered from Engadget.com (2013) [14]

Manufacturer	Type	Name/Description	MSRP (2013)
Blackmagic Design	Camera	Production Camera 4K	$3,995
Intel	Interface Cable	Second Generation Thunderbolt enabling 20 Gbps in both directions	Varies
Red	Sensor	Dragon Sensor Update for 5K and 6K	$8,500 to $9,500
Sony	Camera	4K DSLR-Type Camera Prototype	Not Available
Sony	Media Player	FMP-X1 4K Media Player	$699
Sony	Monitor	“A” Series OLED 4K Reference Monitors	Not Available
Sony	TV	Bravia XBR-55X900A 55” 4K	$5,000
Sony	TV	Bravia XBR-65X900A 65” 4K	$7,000
Vision Research	Hi-Speed Camera	Phantom Flex 4K	$99,000 to $159,900

Looking at Table 2 already gives insight for the reasoning behind the purchase of the Blackmagic Production Camera 4K for the Leppävaara Campus of Helsinki Metropolia UAS, from here on referred as Metropolia. Especially in regards of the recent price drop down to $2,995, the Blackmagic Production Camera 4K is a very affordable camera, which allows the media department of Metropolia to enter the realm of 4K. Furthermore, the camera utilizes an EF lens mount, which means students can take advantage of the vast selection of Canon EF lenses already available from the media department.

The line between consumer, prosumer and professional camera systems is getting very thin these days, but just because a camera can shoot in 4K, does not guarantee instant professional cinematic footage. Dynamic range, sensor characteristics and especially recording codecs make a great difference in the final quality of the footage. One has to discern between video and cinema cameras, whereas the latter are settled at a much higher price range and designed for dedicated cinema productions.

As discussed in an email interview with Vesa Mäntyharju, the sales manager of Mediatrade Oy (cf. Appendix 1), external recorders, such as the Atomos Shogun 4K and the Convergent Design Odyssey 7Q+, are able to enhance the capabilities of prosumer systems and allow 4K-ready cameras to record in RAW or high quality ProRes, bringing them closer to professional cinema quality. Whereas the acquisition price of an entry level 4K-capable camera might be very little compared to a high-end movie production camera, such as the ARRI Alexa or Amira, consumers and low budget film makers often underestimate the additional costs of external recorders, fast storage and capable editing systems for 4K.

Although the Blackmagic Production Camera 4K is able to record 4K internally, without the need of an extra recorder, there are only very few Solid State Drives (SSDs) which are fast enough to write the enormous amount of data pulled from the sensor in real time. These drives, such as the SanDisk Extreme Pro, retail around $285.00 for 480GB, but given the data rate of RAW 4K, one of them is full after approximately 35 minutes. This means that investing into two of them makes sense. In order to give an overview over the approximate costs for a general 4K work station, the current 4K hardware configuration of Metropolia is summed up in Table 3.

Table 3. Prize overview for Metropolia's 4K production station. Data gathered from B & H Foto & Electronics Corp (2015) [15]

Category	Name	#	Prize in $ (2015)
Acquisition	Blackmagic Production Camera 4K	1	2,995.00
Storage Media	SanDisk Extreme Pro SSD	2	285.00
Editing Monitors	ASUS PB287Q 4K UHD Monitor	2	599.99
Data Transport	Blackmagic MultiDock	1	595.00
Work Station	Mac Pro 3.5 GHz 6-core	1	3,999.00
Data Interface	Thunderbolt 2.0 Cable	1	39.00
Total			**$9,397.98**

As Table 3 illustrates, $10,000 are quickly spent for a 4K configuration, without even mentioning lenses, filters, external audio recording, racks, tripods or long time storage solutions. This however is only a fraction of the cost in comparison to high-end professional cinema systems; for instance the Arri Alexa Starter Kit retails around $80,110.00 [16]. Thus, Metropolia's 4K setup can be considered as a low cost solution for producing high quality video for digital cinema and television.

2.5 4K Distribution

As 4K acquisition and production, as well as 4K TV sets, projectors and monitors become more affordable, distribution is still the bottleneck of the industry. Whilst broadcasters have made the switch to Full HD not so long ago, distributing 4K seems a hard goal to reach at the moment. Physical media reaches its limits with 4K content and is generally not the most popular choice amongst consumers anymore, whereas Video on Demand (VOD) and online streaming is on a rise. This is clearly demonstrated by Netflix, YouTube, Amazon and Vimeo, with Netflix and YouTube being the most popular pioneers in 4K streaming. The architecture of the World Wide Web is constantly improving, expanding and offering bandwidths high enough to carry efficiently coded 4K content. [17,18]

When delivering 4K on any recent playback device, a highly efficient codec is needed to gain full advantage of the higher resolution, without sacrificing too much bandwidth or image quality. High Efficiency Video Coding (HEVC) also called H.265 tries to achieve exactly that and is the newest generation of video codecs. By implementing H.265, the new Blu-ray disk format is ready to support 4K; however, a market entry is not expected before the end of 2015 [19].

Whilst the development towards 4K has been mostly commercially driven, scientific reasoning behind ultra high resolution technology often falls short and manufacturers will do just about anything to label their products with 4K in order to lure consumers into investing into the technology. In the following paragraphs the benefits of UHD in terms of visual acuity will be evaluated and the field of applications suitable for implementing 4K will be analyzed.

2.6 Human Eye Sight and Reasoning behind 4K

The industry presented 4K displays, then started to produce digital 4K content (neglecting the digital intermediate) and is now slowly moving towards feasible solutions for 4K delivery. While it sounds great that 4K delivers four times the resolution of HD, it is important to ask, what it actually means in terms of visual image quality as perceived by the audience.

Doubters of the technology often claim that there is little or no perceived visual difference between HD and 4K regarding common viewing distances and screen sizes. Yet, the following analysis shows that there is a clear advantage of higher resolutions.

Based on the Snellen chart, a person with normal visual acuity has 20/20 vision. This means that this person is able to resolve detail accurately 20 feet away from the Snellen chart. Whereas a person with 20/40 vision for instance, would need to be twice as close to the chart to resolve the same detail as a person with 20/20 vision. However, there is a big percentage of people who have far better vision than 20/20. Additionally, the viewing angle plays an important role when trying to achieve an immersive and elaborated viewing experience. The central angle of the human eye is approximately 40-60 degrees. Anything beyond falls within the peripheral angle. The optimum viewing angle together with the angular resolution or visual acuity depicts the minimum distance a person can be away from a screen of a certain size, without being able to resolve individual pixels. [5]

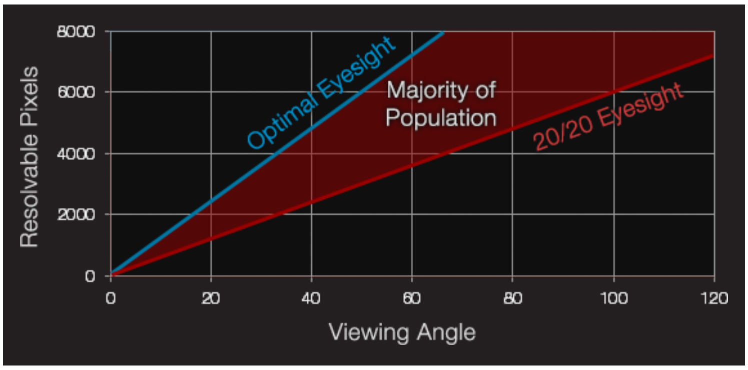

Figure 3. Resolvable Pixels by Viewing Angle and Eyesight. Copied from Red.com (2013) [5]

Figure 3 illustrates that within the optimum viewing angle, the amount of resolvable pixels is over 4000 for the majority of the population. Applying this concept for theatrical applications, Figure 4 shows that the closer the audience sits towards a large screen, the more pixels they can resolve. It suggests that HD or 2K is not enough for providing the audience with an immersive and high quality image.

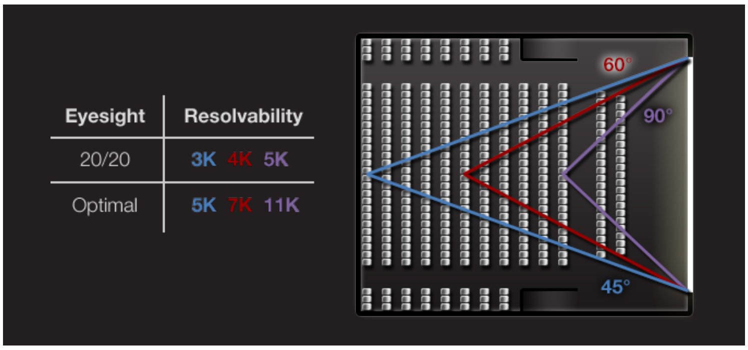

Figure 4. Pixel Resolvability in Cinema Theater Environment. Copied from Red.com (2013) [5]

Yet, true 4K image quality depends on every aspect and component of the production process; including, the image acquisition format and frame rate, the lens, focusing techniques and post production. Image quality can not entirely be achieved by simply increasing the pixel count. [5.]

2.7 Comparison to Current HD or HDSLR Workflow

Media Engineers at Leppävaara Metropolia UAS have access to a fair range of video cameras, such as the Panasonic AG-HPX171E, Panasonic AG-HVX200E or Sony HVR-Z1E camcorder type cameras, as well as the Canon EOS 5D Mark II/III and 7D digital single-lens reflex cameras capable of HD video capturing (HDSLR). Whilst these cameras perform well for most of the recent audiovisual applications at Metropolia, they will be obsolete in the near future of digital video, film and television. Reasons are obvious restrictions in capturing higher resolution, at higher frame rates and in higher quality codecs. Table 4 lists the available capturing formats for the cameras mentioned above. The table is reduced to HD relevant, non-interlaced formats encoded for Phase Alternating Line (PAL) systems.

Table 4. Current Maximum Quality Video Recording Capabilities at Metropolia. Data gathered from Stump (2014) [6,368]

Manu-facturer	Model	Stor-age	Max. Res.	Rec. Format	Com-pression	Sam-pling	Data Rate
Canon	EOS 5DMII	CF	1080p25fps	AVC	H.264	4:2:0	40+ Mb/s VBR
Canon	EOS 5DMIII	CF + SD	1080p25fps	AVC	H.264	4:2:0	40+ Mb/s VBR
Canon	EOS 7D	CF	1080p25fps	AVC	H.264	4:2:0	40+ Mb/s VBR
Panaso-nic	AG-HPX171E	P2	720p50p	DVC-PRO HD	DV/DVC-PRO 50	4:2:2	100 Mb/s
Panaso-nic	AG-HVX200E	P2	720p50p	DVC-PRO HD	DV/DVC-PRO 50	4:2:2	100 Mb/s
Sony	HVR-Z1E	PHD-VM-63DM	720p50p	HDV	MPEG-2	4:2:0	21 Mb/s

It is very important to mention the target applications for these camera systems when comparing the specifications listed above. The camcorders from Panasonic and Sony are optimized for broadcasting, thus equipped with interlaced video options as well as variable frame rates and other functionality priorly important for live and broadcast productions. The Canon DSLRs specialize in digital still photography and are very limited in their video capabilities.

Within the courses and workshops for audiovisual engineering, students have not had to face difficulties such as an offline editing workflow based on proxies, or hardware restrictions when editing HD material. The current work station configuration at the Media Lab allows seamless and easy handling of compressed HD data. The following table lists the specifications of an example work station in the Media Lab of Metropolia Leppävaara UAS next to the color grading and 4K dedicated work station.

Table 5. Work Stations at Metropolia

Type	Media Lab Dell	Mac Pro
Processor	Intel(R) Xeon(R) CPU E5-1620 v2 @ 3.70GHz	Intel XEON E5 6-core @ 3.50GHz
Memory (RAM)	16 GB	16 GB
System Architecture	64-bit	64-bit
Graphics Card	NVIDIA Quadro K2000	2 x AMD FirePro D500 with 3 GB of GDDR5 VRAM each
Storage	WD5000HHTZ 500GB Hard Drive	256 GB PCIe-based Flash Storage
Connectors	4 x USB 3.0 and 4 x USB 2.0	6 x Thunderbolt 2 and 4 x USB 3.0

While the Media Lab configuration is not necessarily the absolute top of the line, it is definitely powerful enough for most HD video applications within the current Metropolia curriculum for Media Engineers. However, regarding 4K data handling, the most concerning part within this setup is the installed hard drive and the lack of available fiber network storage at the time of writing this thesis. In order to prove the need for a dedicated 4K workflow, the system requirements will be analyzed and graphed more precisely in the next sections.

3 Technical Considerations

In order not to be restricted or *bottlenecked* when dealing with large amounts of video data, the bandwidth and computational capability for each part of the entire system from acquisition to delivery has to be considered. It is easy to get confused by marketing slogans and misinterpretation of numbers, for instance describing the performance of a hard drive.

As a concrete use case scenario, a Media Engineer at Metropolia has gathered an external hard drive full of Full HD video footage. He or she wants to edit the material within Adobe Premiere Pro CC at the Media Lab. Due to the size of the project, he or she wants to keep the material on an external hard drive and work straight from the drive. This is considered to be an online workflow. However, although the hard drive is advertised with read and write speeds up to 200 MB/s, he or she notices a heavy lag during the editing phase. Quickly the fault is found by analyzing how the data is sent back and forth via an Universal Serial Bus (USB) 2.0 connection, which maxes out at approximately 35 MB/s.

Generally the data flow for a 4K production is the same as in any other video production. Yet, the sheer amount of data requires a lot more attention. Acquisition, storage, transport and output are the key elements in this chain. In the following, the different options for recording 4K in the camera, the advantages of flash based storage, as well as the performance of the Mac Pro compared to the Media Lab work station will be explained. Furthermore, differences between USB 3.0, Thunderbolt and Display Port interfaces will be evaluated. Also, what solutions can be found to make editing 4K footage possible within a restricted, or less powerful system?

In order to meet the requirements needed for fluent 4K editing, fast storage and high bandwidth interfaces are absolutely indispensable. As listed in Table 3, the setup of Figure 5 rounds up to approximately $10,000. However, if the work station is not as powerful as the 2013 Mac Pro model Metropolia is utilizing for the 4K editing station, there are ways to bypass that bottleneck and still be able to produce 4K output. However, every component according to the model in Figure 5 has to be analyzed.

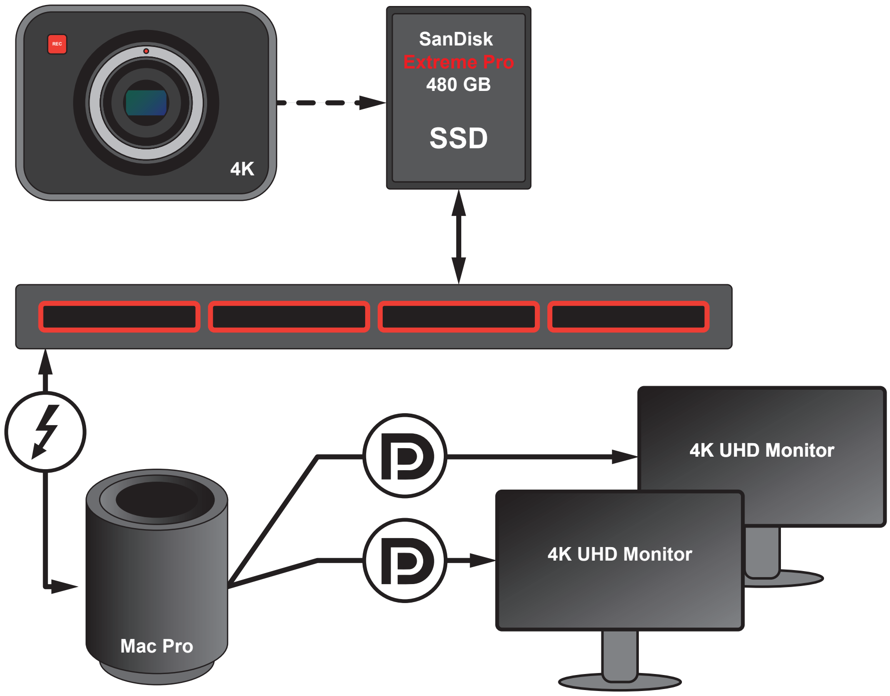

Figure 5. 4K Production Data Flow Model

The first step in dealing with 4K is recording in 4K. The Blackmagic Production Camera 4K (BMPC4K) offers several options for capturing 4K video.

3.1 4K Recording Formats of the Blackmagic Production Camera

The biggest advantage of dedicated video cameras over HDSLRs is the ability to record in a wide range of high quality codecs. In the case of the BMPC4K, these include various members of the Apple ProRes family as well as visually lossless CinemaDNG RAW. Which recording codec to choose highly depends on the application and the desired final output of the project. It is also important to consider customer demands in any given project. However, it is best practice to record footage at the highest quality possible to ensure quality integrity over the entire post production process up to delivery. High quality footage allows more freedom and flexibility in editing decisions, visual effects and final color grading.

On the other hand, if data storage is limited, and delivery is only meant for the Web or streaming, recording in lower resolution and at lower bit rate codecs might be the preferred option.

Table 6 lists the options offered to record 4K with the BMPC4K. In the following sections, the key elements: compression, bit depth and sampling will be explained.

Table 6. Recording Options for the BMPC4K. Data gathered from Apple and Blackmagic Design [20,21]

Dimensions	**Format**	**Bit Depth**	**Sampling**	**Data Rate @25p**	
				Mb/s	**GB/hr**
4000 × 2160	CinemaDNG	12 bit	4:4:4	1600	720
3840 × 2160	ProRes 422 HQ	8 bit	4:2:2	737	332
3840 × 2160	ProRes 422	8 bit	4:2:2	492	221
3840 × 2160	ProRes LT	8 bit	4:2:2	342	154
3840 × 2160	ProRes Proxy	8 bit	4:2:2	151	68
1920 × 1080	ProRes 422 HQ	8 bit	4:2:2	184	83
1920 × 1080	ProRes 422	8 bit	4:2:2	122	55
1920 × 1080	ProRes LT	8 bit	4:2:2	85	38
1920 × 1080	ProRes Proxy	8 bit	4:2:2	38	17

The desired frame rate can be chosen independently, thus it does not depend on codec or resolution. The user can set it to 23.98, 24, 25, 29.97 or 30 fps. The data rates mentioned in the table above are already impressive, but in order to demonstrate the advantage of compression, the file size of uncompressed 4K video is calculated below.

Amount of pixels per frame:	*3840 × 2160 = <u>8,294,400</u>*
25 frames per second:	*8,294,400 × 25 = <u>207,360,000</u>*
12 bit per pixel:	*207,360,000 × 12 = 2,488,320,000 ≈ <u>2488 Mb/s</u>*
Conversion to bytes:	*2488 Mb/s ÷ 8 = <u>311 MB/s</u>*
Data storage per hour:	*311 MB/s × 3.6 ≈ 1120 GB/h ≈ <u>1.12 TB/h</u>*

Looking at the calculation above, it becomes obvious why compression is absolutely inevitable for high quality video. Although compression always means losing some image data, sophisticated codecs and sampling methods allow decreasing bandwidth, without sacrificing too much image quality. In order to compress video and reduce bandwidth, intelligent codecs take advantage of the characteristics of human vision in terms of color and detail perception. The main concepts of bit depth, codecs and chroma sampling will be evaluated in the following chapters.

3.1.1 Compression

Compression is a complex topic in video technology and many people get confused by the concept. Generally, compression is needed to reduce the amount of bits used for storing data. The process of compressing and decompressing data is lossless by definition, however, by exploiting the characteristics of a video frame sequence, such as repetition and spatial correlations of color and motion, a codec can highly compress video, thus reduce file size. This is called lossy compression. Due to their highly accurate image reproduction, high quality and high bandwidth codecs, such as ProRes 422 HQ or CinemaDNG, are often referred to as *perceptually* or *visually lossless*, yet there is no official standard guaranteeing validity of this term. [22,147-153]

Analyzing compression ratios allows comparing the performance of codecs. The compression ratio can be easily calculated by the following equation:

Original Data Rate ⁄ Compressed Data Rate = Compression Ratio

Taking the bit rate of *2488 Mb/s* from the calculation of uncompressed UHD video and dividing that by the equivalent ProRes 422 HQ UHD bit rate results in a compression ratio of approximately 3.4:1. This compression ratio is highly conservative in image data compared to a ratio of 20:1 – 50:1 for AVCHD. Other common compression types or algorithms are HDCAM, MPEG2, MPEG4, JPEG 2000, RedCode and CineForm. Certain compression types are dedicated to certain stages of production. Requirements for file size and image quality differ a lot from acquisition to delivery. Intermediate or *mezzanine* compression ensures quality integrity over many generations of re- and encoding. Utilizing intra-frame coding enables smooth editing in Non Linear Editing programs (NLE). Where as when compressing for delivery, where file size is a critical aspect, a codec like H.264 can achieve a lot smaller file sizes by utilizing interframe coding. [22,151-152]

It is beyond the scope of this thesis to discuss compression methods and codecs in detail. However, the next paragraphs will focus on the relevant information related to compressing and encoding 4K and ultra high resolution video. As shown in Table 6 and the data size calculation, compression is key for handling 4K video data.

The initial drive towards 4K was the desire for higher image quality. Achieving higher resolution and a higher pixel density for TV sets, monitors and projectors was only the first and very little step towards fully gaining advantage of the amount of pixels 4K offers. Image quality is highly dependent on bit rate and frame rate. The more movement between frames, the higher bit rate is required in order to truly represent that image information in the final output. Higher bit rates ultimately mean bigger file sizes.

4K requires high bit rates and next generation codecs to fully gain its potential and not to waste image data. The next paragraphs will evaluate these topics more.

3.1.2 Bit Depth

Bits are used to describe data. One bit can hold two values; for instance, an 8-bit system holds $2^8 = 256$ values. Therefore, the more bits, the more detailed information can be described. Applying this principle to image data, tones and colors can be represented more accurately by utilizing a higher bit depth to a point where the limits of human vision are reached.

In the case of the BMPC4K, the ability to shoot in 12-bit RAW CinemaDNG is truly a great feature for professional video acquisition. Having that much data available yields in great flexibility during post production, especially concerning color correction. Furthermore, a higher bit depth results in a higher dynamic range, which allows easy correction of overexposed footage.

3.1.3 Chroma Sampling

Human vision is more sensitive to changes in luminance (brightness) than to changes in chrominance or chroma (color). Computer graphics usually utilize the RGB color model, whereas digital video uses the $Y'C_bC_r$ model. In this model, the Y' component contains the *luma* or grayscale information, alongside the *chroma* or color-difference information represented by the C_b and C_r components. By averaging and encoding fewer samples of the chroma components, the data rate can be reduced with little visual difference or loss of image quality. This is called *Chroma Subsampling*. The three most popular sampling methods are *4:4:4*, *4:2:2* and *4:2:0*, whereas for *4:4:4* there is no subsampling and all the color information is preserved.

4:2:2 is a professional format which averages the chroma values in such a way that for each luma sample, there is a C_b/C_r chroma sample pair. The BMPC4K is able to record in a variety of ProRes 422 formats, as well as RAW CinemaDNG (*4:4:4*). Most consumer cameras utilize the *4:2:0* format, such as AVC (e.g. Canon EOS 5D/7D) and HDV. For *4:2:0*, there is just one C_b/C_r chroma sample pair for every four luma samples. [20]

As the ultimate goal for 4K and UHD is improving overall image quality, it is important to preserve as much image information as possible. Thus, high quality formats, such as RAW CinemaDNG or Apple ProRes 4444 XQ and Apple ProRes 4444 should be the major choice for recording 4K video in future, despite the higher data rates.

3.2 Storage and Data Transfer Solutions

Due to the high data rate of 12-bit RAW CinemaDNG and 4K ProRes 422 HQ video, Blackmagic Design highly recommends to use only certified SSDs in the Blackmagic Production Camera 4K. The reason being that many manufacturers claim much higher write speeds of their SSDs than they can actually perform for video data. Video data contains a lot of random noise and motion, which can not be compressed efficiently, thus decreasing actual write speeds.

Table 7. Recommended SSDs. Data gathered from Blackmagic Design [23]

Manufacturer	Model	Capacity	Note
Digistor	DIG-PVD1000	1 TB	Pre-formatted exFat
Samsung	MZ-7KE256BW	256 GB	Spacer required
Samsung	MZ-7KE512BW	512 GB	Spacer required
Samsung	MZ-1T0BW	1 TB	Spacer required
SanDisk	SDSSDXPS-240G-G25	240 GB	Needs formatting
SanDisk	SDSSDXPS-480G-G25	480 GB	Needs formatting
SanDisk	SDSSDXPS-960G-G25	960 GB	Needs formatting

Table 7 lists the certified and recommended SSDs, tested by Blackmagic Design. Although SSDs are certainly not the cheapest solution for storage, they are however versatile regarding the entire production process. By utilizing an SSD docking station, such as the Blackmagic Design MultiDock, students are able to work directly from that SSD without the need to transfer data to the internal drive of the work station.

To ensure seamless high speed data transfer between the SSD and the work station, it is very important to utilize a capable transport interface. As the Mac Pro is the primary work station for 4K at the moment, utilizing the high bandwidth Thunderbolt 2 (2 x 10 Gb/s) connection was an obvious choice. However, USB 3.0, as found on the Media Lab work stations, is a fair competitor by offering 5 Gb/s, which almost covers the PC internal eSATA 6 Gb/s bus. As for now, there are no docking stations or suitable direct transfer options available for the Media Lab work stations at Metropolia, which makes the Mac Pro the first element in the 4K post production process.

As mentioned above, at any given step within the production process, high enough bandwidths to cover the data rates of 4K video data have to be ensured. The requirements will be graphed and summarized in the next paragraph. Furthermore, the capabilities of the work stations at the Media Lab compared to the Mac Pro, which is dedicated for 4K and higher computational demands, will be evaluated.

It is important to notice that without a dedicated server or RAID storage system, 4K video productions at Metropolia are limited in scale and size at this stage of development. The Mac Pro work station offers only 256 GB of internal PCIe-based flash storage, which translates to less than 20 minutes of 4K RAW CinemaDNG footage. This is why working straight from the 480 GB SSDs might be the only option for some projects at the moment. The same principle applies for the 500 GB internal HDDs at the Media Lab. The following test results will demonstrate, why this is not necessarily ideal.

3.3 Comparing Hardware Performance

Before testing the actual production workflow and the subjective performance of the work stations, experiments and measurements needed to be conducted to ensure an objective evaluation.

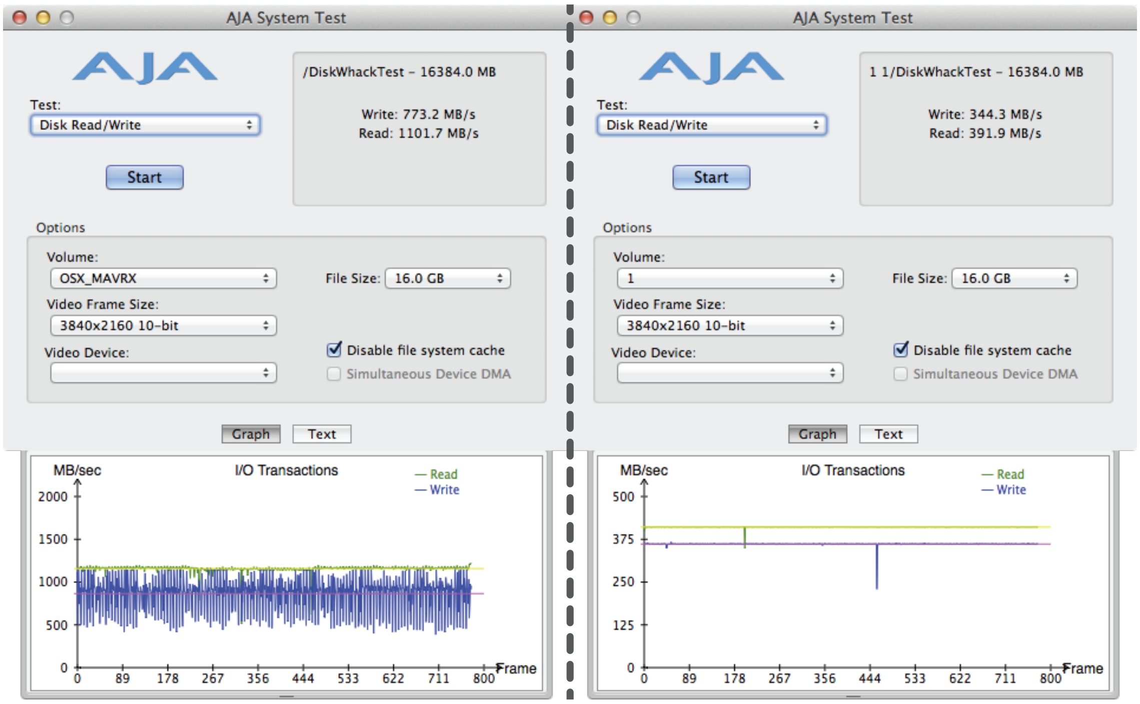

Figure 6. Mac Pro Disk Speed Test. Screenshot [24]

Figure 6 shows two tests conducted on the Mac Pro with the AJA System Test application. This application allows testing the performance of a selected drive depending on an arbitrary video file. For this test, the available 3840 × 2160 10-bit preset, with a file size of 16 GB, was chosen to stress the system at maximum. On the left side, the graph shows the performance of the internal PCIe-based flash storage of the Mac Pro. With an average write speed of 773.2 MB/s and read speed of 1101.7 MB/s, this system is very powerful and should have no problem dealing with 4K. Although alternating quite a lot, the write speed of the disk barely drops beneath 500 MB/s.

On the right hand side, the test shows the performance results of one of the SSDs connected to the Mac Pro via the Thunderbolt MultiDock. The high bandwidth of the Thunderbolt connection ensures that there is no bottleneck during transfer; however, the test shows that the approximate 500 MB/s read and write speed advertised by SanDisk can not be reached. As seen above, the SSD achieves only 344.3 MB/s in write and 391.9 MB/s read speed. Yet, this is to be considered a very good result in general.

Due to the limitations of the AJA System Test application on Windows operating systems, a different application had to be chosen to test the performance of the HDD built in the Media Lab work stations.

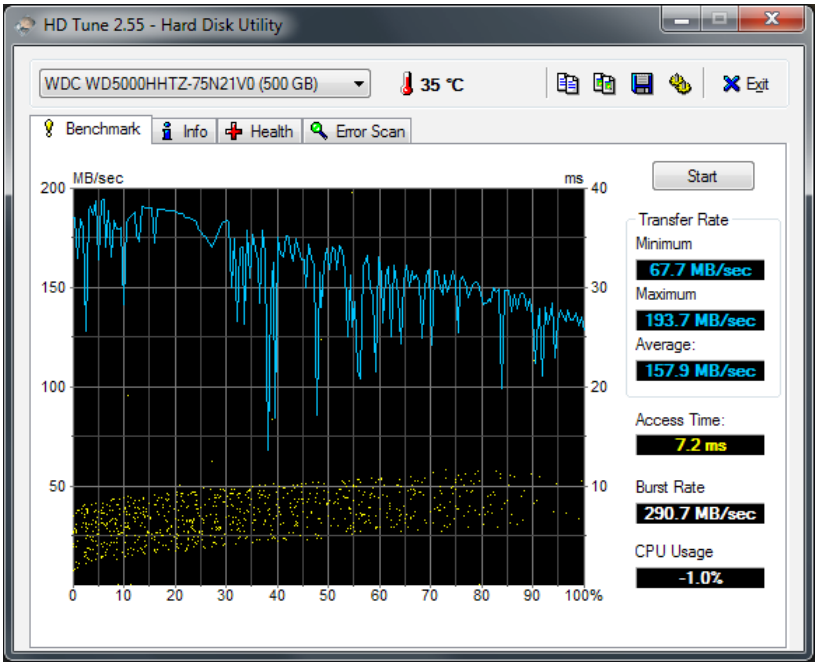

Figure 7. Media Lab Disk Speed Test. Screenshot [25]

This particular hard drive is advertised to reach approximately 200 MB/s read and write speed. The test according to Figure 7 shows that at maximum performance, it almost reaches this level, however the average rate is only 157.9 MB/s. Taking the 4K video data rates into account and comparing the average read and write speeds of the Mac Pro, the SSDs and the HDD, it becomes obvious that the works stations in the Media Lab will reach their limit when dealing with high bit rate 4K video.

It is very important to note that the bandwidth needed for 4K video processing increases dramatically when editing multicam shots and applying visual effects, where multiple video streams have to be rendered, accessed and computed at the same time, which is why one cannot rely on the maximum data rates advertised by hard drive manufacturers and simply compare it to the bandwidth required by a single stream of 4K video. Furthermore, a production company or educational institution in this field should consider future proofing their work stations.

As mentioned earlier in this thesis, 4K development strongly tends towards higher frame rates, which means that the data rates might double in near future. Thus, it is important to ensure enough headroom in the bandwidths of the systems. In order to give an approximate overview of possible bottlenecks of a system, the ideal performance cases are listed in Figure 8 alongside the data rate of 4K video in different formats at 25 fps.

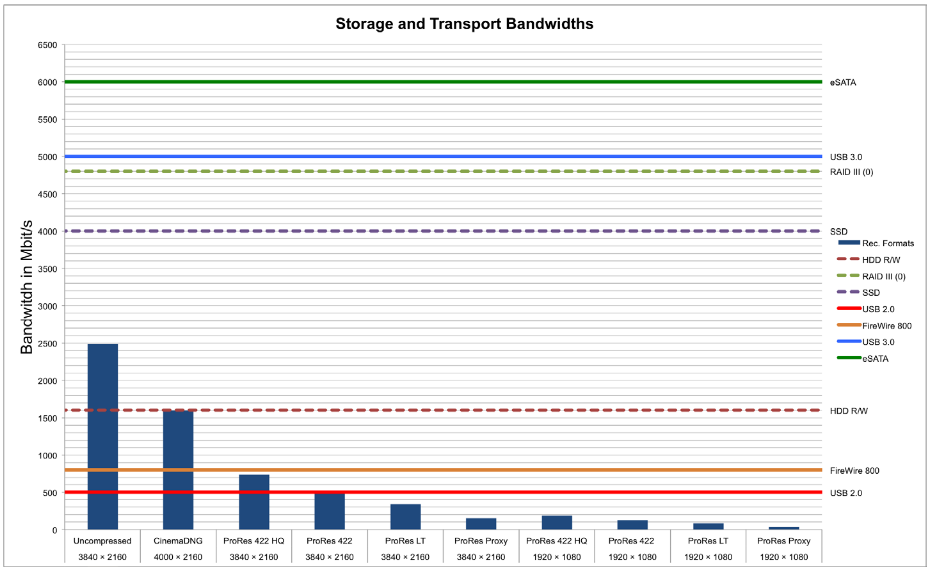

Figure 8. Storage and Transport Bandwidths

Figure 8 does not list Thunderbolt in order to emphasize components which might be bottlenecks within the data flow. The diagram illustrates clearly the bottleneck HDDs and USB 2.0 transport cause for high bit rate 4K video. Furthermore, the SSDs might reach their limits when dealing with multiple streams and considering their actual, instead of their ideal performance.

3.4 4K Output Monitoring

The final stage of the 4K data flow is the output on a screen. Whereas the footage will still look great downscaled on a smaller screen, it is desirable to edit and preview the footage in its actual size. Therefore, Metropolia has purchased two 4K UHD capable monitors, which are available at the 4K work station. As there were unknown and unforeseen technical problems at the time of writing this thesis, it was not possible to test the monitors properly.

However, there are generally a few things to be considered when connecting one or more 4K monitors to the Mac Pro. According to Apple, the Mac Pro supports up to three 4K displays. The three components which might cause trouble are the buses and connectors the displays are connected to, the cables and finally the firmware installed on the monitors. When connecting multiple displays, it has to be ensured not to connect more than two of them to the same bus as illustrated in Figure 9.

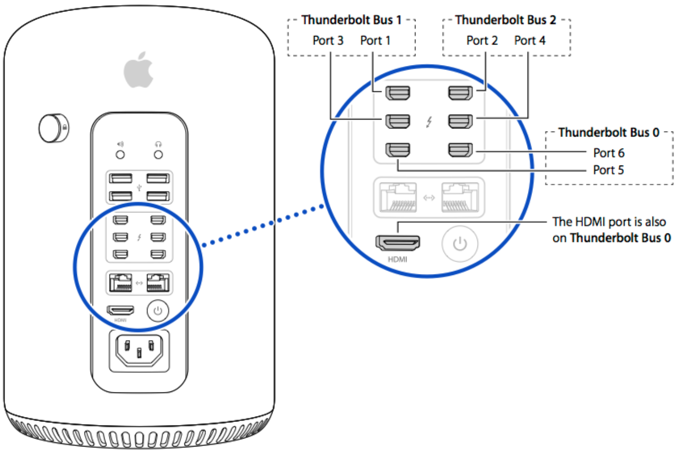

Figure 9. Buses and Connections of the Mac Pro. Copied from Apple [26]

Furthermore, the HDMI port installed on the Mac Pro only supports HDMI version 1.4, which supports 4K only at a refresh rate of 30 Hz. This results in a very lagging performance of the monitor. The Thunderbolt 2 connection inherits and supports DisplayPort and PCIe. DisplayPort version 1.2 enables Multi-Stream Transport (MST) and 4K at 60 Hz. However, MST has to be configured manually on the On-Screen Display (OSD) menu of the Asus 4K monitors. Due to possible misconfiguration or faulty firmware, it has not been possible to configure the setup correctly yet. [27]

4 Test Production with the Blackmagic Production Camera 4K

4.1 Camera Set-Up

The Blackmagic Production Camera 4K is a dedicated and heavy featured camera, which needs to be handled with care and understanding in order to gain full potential of its capabilities. Due to its size, weight, format, battery life and lack of special features, such as internal Neutral Density (ND) filters, the BMPC4K is not a *point and shoot* or *run and gun* camera. A production needs to be carefully planned and the camera needs to be set up accordingly. When producing with this camera, a full understanding of which setting to choose from the offered recording formats, color spaces and ISO performances is inevitable. These settings will be explained in the following paragraphs so that students can take this thesis as a guide, alongside the provided manual in Appendix 2.

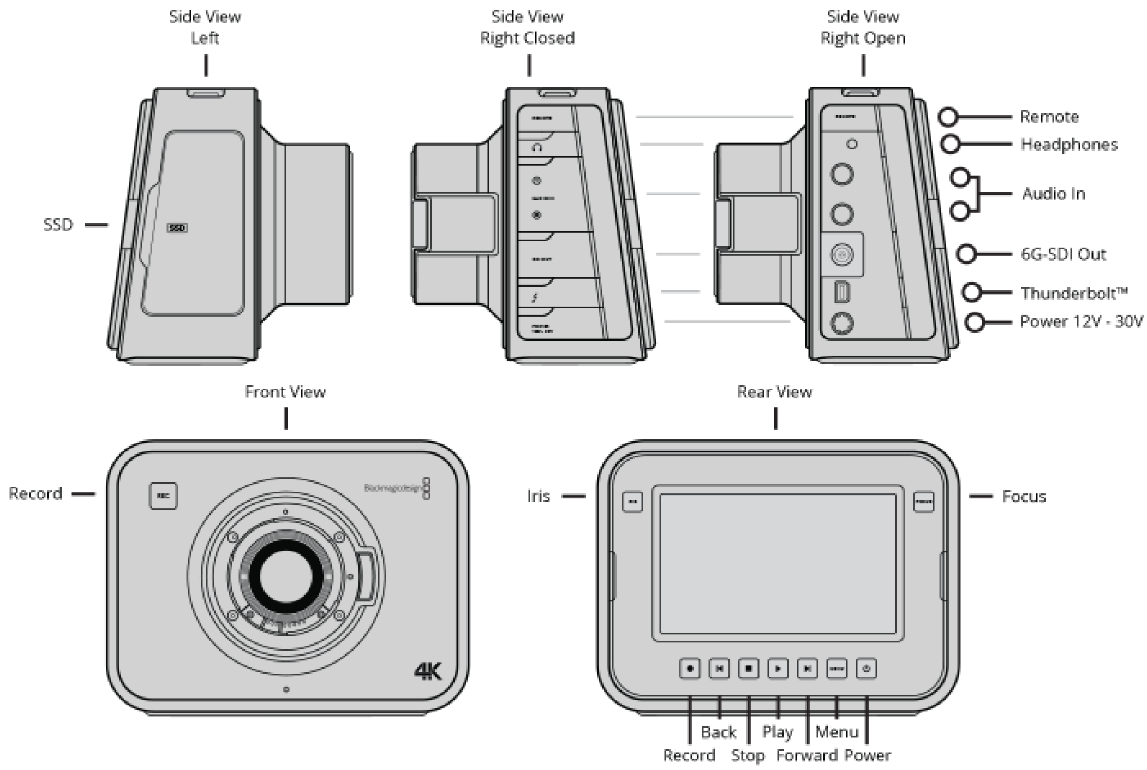

Figure 10. Controls and Connectors of the BMPC4K. Copied from Blackmagic Design [28]

Figure 10 shows the controls and connectors on the Blackmagic Production Camera 4K.

4.1.1 Camera Settings

By pressing the *Menu* button on the camera and choosing *Settings* from the main touch screen menu, four tabs as shown in Figure 11 allow configuring the camera precisely.

Figure 11. Touch Screen Menu of the BMPC4K. Copied from Blackmagic Design [29]

Settings such as *Date* and *Time* are self explanatory, but *ISO*, *White Balance* and *Shutter Angle* need to be explained in more detail. Coming from HDSLR or camcorder productions, it might seem odd to have only three settings for the ISO performance, which are 200ASA, 400ASA (native) and 800ASA. Due to sensor characteristics, the BMPC4K does not perform particularly well in low light. To ensure rich image quality and prevent noise, the ISO should be set to be 200 or 400 and enough artificial lighting has to be provided if necessary (for instance indoor shooting).

Shooting in CinemaDNG RAW allows great flexibility in post production, especially in terms of color correction. However, when shooting in any other format, such as ProRes 422 HQ, it is advisable to choose an appropriate white balance value according to the light conditions of the shooting. It is natively set on 5600K which is the optimum daylight temperature.

One of the great advantages of the BMPC4K over HDSLR type cameras is the implementation of a *global* instead of a *rolling* shutter. Systems implementing a rolling shutter are sensitive to many problems due to the nature of its mechanism. Digital video cameras do not have an actual mechanical shutter as a film camera would have; however, there are differences in how data is read from a sensor. As illustrated in Figure 12, a rolling shutter means that data is read from the sensor line by line. This, for instance, may result in distorted instead of straight lines while panning the camera. Also, the common 50 Hz rolling shutter curtain effect when filming under artificial light is a huge problem for rolling shutter systems.

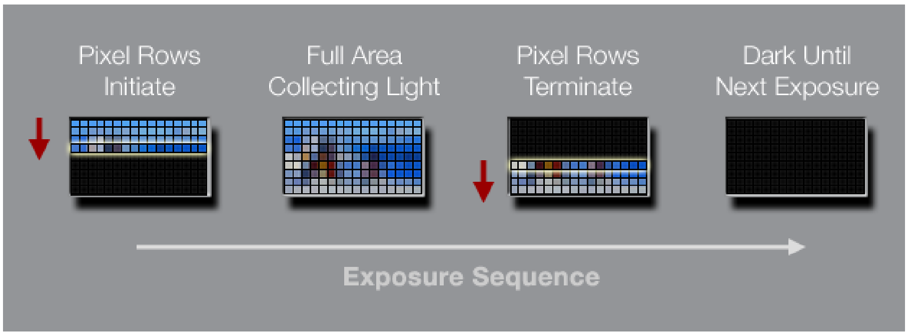

Figure 12. Rolling Shutter Data Reading Sequence. Copied from Red.com [30]

The advantage of a global shutter system is that the data is read from the sensor entirely at once, which results in either a full representation of the image (I) or no information (0). This allows a true and undistorted representation of motion and prevents rolling shutter curtains. The BMPC4K allows choosing the shutter angle. Defining the shutter angle determines the relation between shutter speed and frame rate, which results in either less or more motion blur. Motion blur is mostly desired for a cinematic look known from traditional film.

The audience expects fast moving objects to blur naturally on screen. Sometimes however, as for an example in TV sport coverage, this is not desired. By default the shutter angle in the BMPC4K is set to be 180 degrees, which relates to a traditional cinematic shutter speed of 1/48 seconds at 24 fps. A greater angle means slower shutter speeds, where as smaller angles mean faster shutter speeds accordingly. Thus, under low light conditions, choosing the shutter angle to be 360 degrees allows more light to be captured.

4.1.2 Audio

Audio recording options are presented on the second tab of the settings menu. Two 1/4 inch TRS Phone audio connectors are found on the left side of the camera, which allow microphone or line level audio as an input. Furthermore, a 3.5 mm stereo headphones jack allows monitoring. Within the menu, the levels of the two channels can be set individually or linked together.

Audio monitoring is only visible in the live view; thus, adjusting the channel input level correctly might be time consuming. Based on experience, using a dedicated external audio recorder and synchronizing audio in post production is strongly recommended. The audio captured by the built in microphone of the BMPC4K should only be considered to be used as a reference track for syncing with external audio.

4.1.3 Recording

Table 6 on page 16 already listed the available recording formats of the BMPC4K. Important to note for students who plan to record in 4K is to make sure that the recording format states a *4K* prefix (e.g. 4K ProRes HQ); otherwise, the camera will record in HD (e.g. ProRes HQ). The most important setting within the *Recording* tab is the Dynamic Range selection. Either *Film* or *Video* can be chosen(when shooting in CinemaDNG only *Film* can be selected).

When shooting in the *Film* dynamic range, the image is captured utilizing a log curve to preserve as much image data as possible and offer up to 12 steps of dynamic range. A logarithmic scale ensures a constant relation between exposure (stops) and the image signal. The output is generally a flat and desaturated looking picture, which needs to be encoded and interpreted by color correction software in order to reproduce the actual color of the image on a screen.

In post production this is usually done by applying a three dimensional Look Up Table (LUT), which interprets or rather translates image data from one color format into another. This is a quick and easy way to produce so-called *dailies* for editors who want a more realistic version of the video to work with instead of a flat looking log picture. However, if there is not much time for color grading within the production schedule, recording in *Video* mode might be the preferred approach.

Recording in the *Video* mode will result in video captured according to the Rec. 709 standard and will produce a brighter and more contrast output image. This yields in less flexibility for color correction in post production, but accelerates the editing process by skipping the need for producing dailies. Figure 13 illustrates the difference between a log and Rec. 709 encoded image.

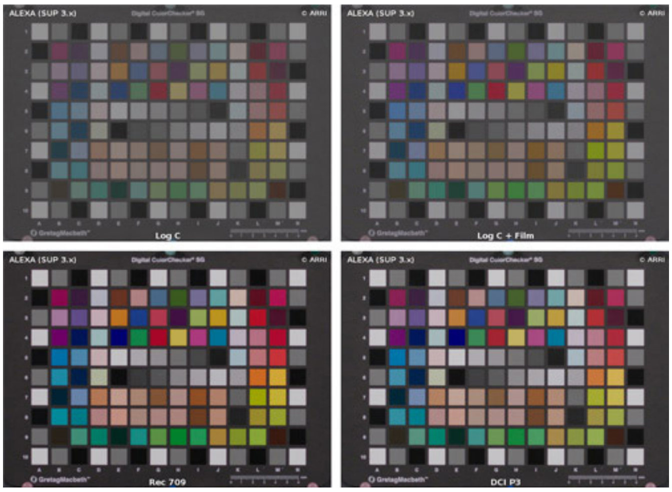

Figure 13. Color charts according to recording format: top left represents a typical log curve; bottom left Rec. 709. Copied from Arri.com [31]

In order to gain full potential of the camera's capabilities, the test videos were mostly shot in 4K RAW CinemaDNG and *Film* mode, which is why a color correction step had to be included into the workflow.

4.1.4 Display

Within the *Display* tab, the user can decide between previewing the scene in *Film* or *Video* mode on the LCD display. This setting is independent from what the user has set within the *Recording* menu; thus, care has to be taken when recording video. In short, It is not always "what you see, is what you get". This applies also to the display brightness setting, which might fool the eye of the cinematographer behind the camera. It is advisable to use the provided histogram to judge tone levels and exposure. Furthermore, the BMPC4K provides a *Zebra* overlay option to indicate overexposed highlights in the image.

The BMPC4K allows outputting 4K video straight via the Serial Digital Interface (SDI) into an external recording unit or a live production switch. This feature, alongside the low acquisition price makes this camera a mentionable contender in the field of 4K multi-camera live productions. In the *Display* menu, the user can configure the SDI output to be 4K or HD and include status and guideline overlays.

Going back to the main menu, the user is able to enter Metadata, enable focus peaking and can choose to display meters and frame guides in the live view. Furthermore, if an SSD is inserted, the user can format it straight from the main menu. More detailed information on the camera operation will be given in the attached student guide to a 4K production workflow.

4.2 Post Production

The most crucial part in a 4K video production is how to handle, edit and post process the large amounts of data coming from the camera. Educational institutions as well as small scale production companies are often not able to afford multiple high-end work stations and server systems needed to process, store and transport large amounts of high quality 4K footage.

However, smart workflows and technical know-how allows bypassing bottlenecks and enabling multiple students the possibility to work with 4K. In the following paragraphs the different workflows and approaches to edit and deliver high quality 4K video will be explained. To test heavy load stress on the editing work stations, footage shot on the BMPC4K in CinemaDNG RAW and 4K ProRes 422 HQ was utilized.

4.2.1 General Workflow Considerations

In modern production workflows, a Media Engineer might often encounter the terms *offline* and *online* workflow. It is important to understand that these do not have anything to do with the Internet. As mentioned earlier, video footage is often converted into different formats depending on the current application or stage of production. A master file should be kept at the highest possible quality, whereas intermediate or mezzanine formats allow for fluent editing on less powerful machines. Working offline means that an editor utilizes a smaller or lighter version of the original footage, which is called a proxy file. When the editing is done, the proxy files get replaced by the original footage to offer full quality in the delivery stage and final render.

Most of the media students at Metropolia may not be familiar with offline editing. Due to relatively powerful work stations in the Media Lab and the scale of the projects, HD footage has not been necessary to transcode to proxy files. Students have been able to work online with the original video material. Introducing high quality codecs and 4K material, offline workflows are necessary to enable students working with 4K on existing work stations at the Media Lab.

The reason for including a color grading step into the workflow was the ability to shoot in log dynamic range instead of Rec. 709, as well as the future availability of a dedicated color grading facility on campus. Furthermore, I believe that nowadays, color grading is an important skill for a future audiovisual Media Engineer, who seeks a profession in film and television.

By purchasing the Blackmagic Design Production Camera 4K, the university also received a full version copy of the excellent color grading software DaVinci Resolve. Resolve offers truly professional node based color grading functionality. In short, adding a node to a color correction resembles the process of working with layers in Adobe Photoshop. This makes color correction very flexible, intuitive and non-destructive. It is out of the scope of this thesis to cover the entire color correction process and explain DaVinci Resolve in detail; however, the following sections will focus on the information relevant for 4K video.

As licensing for multiple students may become an issue in future development of the color grading facility, a workflow based entirely on the software provided by the Adobe Creative Cloud (CC) was considered. The Adobe Creative Cloud is properly licensed for every student at Metropolia. Furthermore, working entirely within the Adobe software also inherits advantages such as *Dynamic Links* and a familiar Graphical User Interface (GUI). In order to replace DaVinci Resolve, Adobe Speed Grade was utilized to do the color grade.

4.2.2 Workflow I Mac Pro Online Adobe CC

As mentioned earlier, the workflows presented here are based on CinemaDNG footage to demonstrate maximum system stress. However, due to the native support of this file format within the newest version of Adobe CC, it does not make a difference in the procedure of the workflow. The CinemaDNG file format may be confusing at first, because instead of a single video clip for a shot, CinemaDNG saves every frame as an individual RAW picture. The picture sequence of one shot is then saved in a folder, which represents the clip. Technically, this allows the .dng images to be edited and batch processed in highly dedicated image software, such as Adobe Photoshop. Yet, native support and dedicated functions in DaVinci Resolve and Adobe Speed Grade make these options more or less obsolete.

The first step within this Adobe CC online workflow is to import the CinemaDNG sequences correctly into Premiere CC. Instead of importing the individual frames or the folders in which they are contained, it is necessary to navigate to the folder within the *Media Browser*. By clicking on the folder and revealing its content, Premiere CC recognizes the CinemaDNG sequence and shows a clip, instead of individual frames. The clip has to be dragged and dropped into the project window. Although the file ending is still .dng, the clip name contains information, which frames are inherited in the particular clip.

After importing the rest of the clips into the project folder, an individual clip can be previewed in the monitor window and the desired part selected for editing. By dragging and dropping the video onto the timeline, Premiere CC automatically sets the resolution and frame rate according to the source material. In this case, as the clips were unaltered

RAW CinemaDNG, the timeline resolution was set to 4000 × 2160 pixels. As the final output was desired to be UHD in 16:9 ratio, the timeline resolution had to be changed to 3840 × 2160 pixels. This results in a slight letterbox, which can be corrected by cropping and enlarging the video slightly via the effect control panel.

With 4K footage, an editor has great flexibility in re-framing, zooming or stabilizing the image due to the sheer amount of detail captured. This is relevant when the final output is supposed to be anything smaller than 4K. Figure 14 demonstrates how an editor could easily turn a medium wide shot from 4K source media into a close up without loosing any image quality.

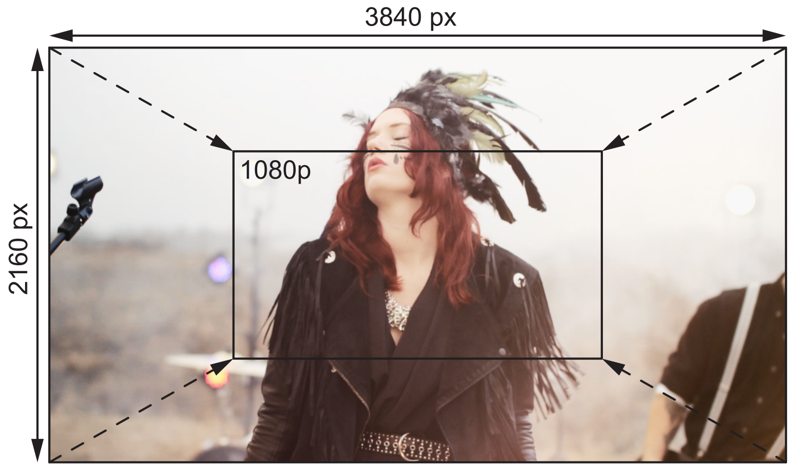

Figure 14. Re-framing possibilities with 4K footage

If the editor does not desire to crop or re-frame, the video will be downscaled. Downscaling means resizing a large video frame into a smaller one. When monitoring the edit in an NLE, the video is usually downscaled to fit within the preview window of the GUI. Premiere Pro CC as well as DaVinci Resolve allow specifying in which resolution and frame rate the video is monitored. Having two 4K UHD monitors available for full size editing is a great advantage of Metropolia's 4K work station. This allows pixel accurate corrections, masking, framing and other precise visual effect operations in 4K. Furthermore, utilizing the computational power of the Mac Pro together with the resolution and detail RAW 4K footage offers, stabilizing shaky footage with the Premiere Pro CC built-in *Warp Stabilizer* yielded in great results without sacrificing long render times.

Although Premiere Pro CC supports the CinemaDNG format, it was not possible to set up the project to display the RAW footage in its original log color space. It appeared that Premiere Pro CC automatically translated the footage into Rec. 709. However, this affects only the visual appearance. All the data of the RAW footage is still available and preserved for color correction. According to a forum discussion on this topic, the Adobe staff confirms this statement. [32]

After finalizing the edit, the next step of this particular online workflow was color correction. Via the Premiere Pro CC file menu, the option *Direct Link to Adobe Speed Grade* had to be chosen and changes had to be confirmed. Adobe Speed Grade offers a similar interface to DaVinci Resolve's color correction suite. Shots are displayed individually on a timeline with a centered preview window and the color correction tools beneath it. Within the *SpeedLooks Camera Patches* tab, presets are available for quick interpretation of footage coming from a selection of popular cameras, such as Blackmagic Design and Arri.

The primary controls for correcting shadows, mid-tones and highlights are most likely to be the same in any color correction software; however, the main difference of Adobe Speed Grade and DaVinci Resolve is the how multiple corrections are added and applied to a selected clip. Being familiar with the Adobe software family, it is easy to understand that corrections are applied as layers. The user can add primary or secondary look layers, re-arrange their order and toggle them individually on or off. On the other hand, as mentioned earlier, DaVinci Resolve's color correction suite is node-based, thus it offers greater flexibility for complex operations.

To finalize this online workflow, the Adobe Speed Grade corrections were saved and linked back to Premiere Pro CC. Due to the computational intensity of the operations, color correction via Speed Grade is only possible with a *direct* instead of a *dynamic* link, which means that changes will not be visible instantly in Premiere Pro and the user has to select the *Link Back to Premiere* option. The final editing step was applying titles and transitions to the graded footage and exporting the project via the Adobe Media Encoder.

Delivery and output for 4K will be covered in more detail later. For now, the YouTube 4K H.264 preset was chosen for rendering. This yields a good compromise of image quality, file size and rendering time. Furthermore, YouTube is one of the few commercially free available channels to publish 4K video.

4.2.3 Workflow II Mac Pro Round-Trip

A workflow based on proxy files is necessary to gain full advantage of the resources available at Metropolia. Combining the computational power of the Mac Pro, together with the available Media Lab work stations and utilizing dedicated software for each production step yields best results. Therefore, this particular workflow started on the Mac Pro by creating a new project within DaVinci Resolve. Within a professional production environment Resolve allows creating multiple users and workspaces, as well as collaborative network editing. However, it is sufficient for the purposes of Metropolia that students work with the already available *Admin* account.

By default, the project timeline within Resolve is set to HD resolution, yet the final goal was to produce 4K, regardless of the intermediate proxy files. Therefore, when creating a new project within Resolve, the timeline resolution had to be set up according to one of the available 4K resolution presets, such as 4K UHD. The project settings can be accessed via *File* > *Project Settings* > *Master Project Settings*. Within this panel, it was necessary to set up the frame rate, pixel aspect ratio and color space according to the footage and desired preferences. Furthermore, it is possible to select in which resolution the video should be monitored and played back within the application, to suit computational capabilities and monitoring facilities. When shooting in RAW CinemaDNG, the most important step is to set up Resolve in a way that the files are interpreted correctly by the software. Therefore, the student should choose the appropriate settings within the *Camera Raw* panel of the project settings. In this instance, the format was chosen to be CinemaDNG, the decoder to be based on the *Project* and the color space and gamma to be *BMD Film.* This results in the true representation of the footage shot in RAW CinemaDNG utilizing *Film* dynamic range.

Navigation within Resolve is similar to Premiere Pro. The *Media* panel shows the library and a monitoring window. Since the recording SSDs were already connected to the Blackmagic Design MultiDock station, it was possible to navigate through their contents.

Selecting and right-clicking the desired shots allowed to import them into the *Media Pool*. In the *Edit* panel, the shots which were added to the Media Pool in the previous step had to be selected and right clicked in order to *Create* [a] *timeline from* [the] *selected clips* or they had to be added to a previously created timeline. It is important to note that no actual editing was performed at this point. Instead, proxy clips had to be created to edit the video within Premiere Pro, which is a much more dedicated program for editing. However, continuing the workflow within Resolve, it was necessary to apply a light color correction to the individual clips within the *Color* panel. Furthermore, the *Blackmagic Production Camera 4K to Rec. 709* LUT was applied to translate the flat looking footage into a more appealing and more edit friendly version.

The following step was the most important at this stage of the workflow. Within the *Deliver* page of Resolve, proxy clips of the footage had to be created. As mentioned above, proxy files are smaller and lighter files used for editing and later replaced by the original footage. Therefore, the export resolution was set to be HD instead of 4K and the format to be Apple ProRes 422 LT. It is very important to maintain the original file name as well as export the timeline as individual clips. In order to keep a clear file structure, an output folder on the desired storage volume called *Proxies* was created.

Table 8. Render Settings for Proxies in Resolve

Category	**Option**	**Setting**
Presets	Easy-Setup	None
Video	Render Timeline as	Individual source clips
	Video Format	QuickTime
	Codec	Apple ProRes 422 LT
	Resolution	HD 1920x1080
Audio	Export Audio	Unchecked
File	Save as	Use Source Filename
	Custom Name	None
	Render to	Volume/Proxies

Table 8 summarizes the settings chosen to export the proxy files from the original 4K RAW CinemaDNG files within Resolve. The job was added to the render queue and the render initialized.

The Mac Pro is powerful enough to complete this task in real time. With the lighter proxy files, it can be decided whether to continue the edit on the Mac Pro or on one of the Media Lab work stations. Having multiple machines available at the Media Lab suggests the latter option, thus enabling more students to work simultaneously.

Editing the proxy files in Premiere Pro is identical to the online HD workflows already known to Media Engineering students. Students can simply import the files from the *Proxies* folder and edit the footage natively. However, at this point, no transitions, titles or other effects should be added. This particular workflow continues with a color grading and a final editing step. In order to bring the edited and locked timeline back to Resolve for the color grade, an XML file from Premiere Pro had to exported via *File > Export > Final Cut Pro XML*. The XML file contains all information of the edit, including cuts, tracks, media and file structures. Many cross-software applications utilize XML files to exchange timeline based media, thus enabling software independent collaboration.

In order to bring back the edit to the Mac Pro and into Resolve for the final color grade, it is important to import the XML to the Resolve project via *File > Import AAF, EDL, XML...*. The prompt menu offers options for importing the XML. In order to link back to the original 4K footage, it is important to uncheck the *Automatically import source clips into media pool* option, which would otherwise create a timeline with the proxy files. Furthermore, the option *Automatically set project settings* and *Use sizing information* has to be deselected. By confirming the action, Resolve will build the timeline based on the XML information and utilizing the original 4K RAW CinemaDNG footage. Possible reasons for an unsuccessful import might be renamed files or altered folder structures.

After finalizing the color grade within Resolve, the project should be brought back to Premiere for adding final transitions and titles, thus completing the workflow round-trip. On the *Deliver* page within Resolve, the easy setup preset *Final Cut Pro XML Round-Trip* should be chosen to export individual clips at a desired resolution and in a desired format together with a XML file. This time it is necessary to select a high bit rate codec, such as Apple ProRes 422 HQ and set the resolution to 4K UHD. The files should be rendered to a new folder called *FromResolve.*

Back in Premiere Pro, importing the XML will also import the clips and provide a timeline. However, in some cases the timeline might not match the desired output and has to be adjusted manually. Titles and transitions were added and the project exported via the Adobe Media Encoder. This final step in Premiere is preferably done on the Mac Pro, due to higher computational capabilities, which result in shorter rendering times. Again, the YouTube 4K export preset was chosen.

4.2.4 Workflow III Media Lab

For the last part of this workflow series, it was tested how the machines at the Media Lab would handle 4K. However, as there is currently no SSD docking station available for USB 3.0 at Metropolia, the video data had to be transferred onto a HDD via the Blackmagic MultiDock on the Mac Pro. Both options, either working directly from the external drive or copying the data first onto the internal HDD of the work station, were tested. As both transport buses, USB 3.0 and the internal eSATA, have high enough bandwidths to carry the data, the limiting factor is the read and write performance of the HDDs. Editing the full sized RAW CinemaDNG footage in Premiere Pro from the external HDD results in slow and lagging playback, as well as a high percentage of dropped frames. Reducing the monitoring resolution has little effect. Working straight from the internal HDD results in a slightly better performance.

Interestingly, the machines handle the higher bit rate CinemaDNG format better than Apple ProRes 422 HQ. This might be due to software related encoding and decoding processes. Although the machines at the Media Lab might not be as powerful as the 4K dedicated Mac Pro, they still perform very well in terms of trans-coding and rendering. However, a big drawback when working on the machines in the Media Lab is the lack of dedicated displays for either color grading or 4K monitoring.

In order to be able to work smoothly on the machines in the Media Lab, a proxy file based workflow as explained in the previous chapter is highly recommended. Furthermore, this allows gaining full advantage of the available monitors in the 4K lab, as well as the computational capabilities of the Mac Pro.

4.3 Delivery

At the time writing this thesis, 4K and UHD are still very young technologies. There are yet many open questions and problems to be solved before 4K will arrive at the homes of the public. One of the biggest issues is how the web and broadcasters will deliver 4K to computers, mobile phones and TV sets, without maxing out the network bandwidths or sacrificing image quality. The industry is asking for better and more intelligent compression, instead of higher compression, which would inevitably result in a loss of image quality.

The biggest contenders in the market of new age delivery codecs are the successor of H.264, H.265 (HEVC) and Google's VP9. As they are very much alike from a technical perspective, the biggest difference between the two is that VP9 is royalty free and open source, whereas HEVC has to be licensed. For mobile platforms, Apple already implemented HEVC within their FaceTime video conferencing application on the newest iPhone 6 models and could possibly support other applications with the new codec in future. Android 5.0 supports HEVC and VP9, but seems to target HEVC more. For smart TVs, the major trend goes towards HEVC support over VP9. However, YouTube has big influence and utilizes VP9 for its entire library. Furthermore, concerning computers, major browsers such as Chrome, Firefox and Opera already support VP9, but not HEVC. DivX and VLC offer browser plug-ins to support HEVC, yet they do not play a major role in the industry. [33]

At this stage of development, neither Adobe Media Encoder nor DaVinci Resolve supports encoding HEVC or VP9 natively. Thus, these delivery codecs are not yet applicable for workflows within Metropolia. In future, more platforms, devices and applications will support both HEVC and VP9, which will open up possibilities for delivering 4K anywhere. For now, students have to sacrifice image quality and file size when delivering H.264 encoded 4K.

5 Discussion and Evaluation

The initial question of this thesis was whether it is possible to establish a feasible 4K production workflow at Metropolia University of Applied Sciences. Utilizing the resources available, three workflows were designed and tested as described in the previous section. In order to make it easier for students to follow the instructions on how to deal with 4K, an additional instructional manual was written, which can be found in Appendix 2. Each of the workflows has strengths as well as limitations. An online workflow on the Mac Pro is the least complicated and the fastest, whereas a proxy based offline workflow allows multiple students to utilize the facilities at the Media Lab and still produce 4K video. The work stations at the Media Lab are not ready yet for standalone 4K production, but could be extended in future development.

5.1 Benefits of the Implemented System

Referring again to Table 3 on page 8, the hardware configuration for the main 4K Lab sums up to approximately $10,000, which, regarding the professional potential of this system, is fairly cheap. As the camera itself has standard measures and compatible mounts, students can utilize the hardware resources already available at Metropolia. These include tripods, EF-mount lenses, racks and other accessories. The task of an engineer is to find solutions and utilize resources in the most efficient way. By implementing the proxy based online Workflow II, students gain full advantage of every aspect of the available resources and facilities at Metropolia.

Future proofing is an important concept for any educational institution or small scale video production with a tight financial budget. By making the switch towards 4K, Metropolia keeps up to date with recent trends in the industry and provides students with the necessary skills required in professional digital cinema and television productions. The Mac Pro dedicated for the 4K Lab is powerful enough to support development towards 4K at higher frame rates and higher bit rate codecs, for instance Apple ProRes 4444 XQ. Furthermore, Blackmagic Design is known for constant development and updates of their firmware, which might unleash some more features of the BMPC4K.

One of the biggest advantages of the 4K hardware system implemented at Metropolia is the portability and flexibility. All the components, including the camera and the work station, are independent from a specific facility, thus could be moved anywhere, anytime. This is particularly interesting in the case that Metropolia wants to facilitate a 4K live production studio setup. The low price of the cameras as well as the production units manufactured by Blackmagic Design could soon enable experiments with live 4K at Metropolia.

5.2 Drawbacks and Needed Improvements

Regarding on-location video production with the BMPC4K, the biggest drawback is the battery life of the camera. Recording in RAW CinemaDNG is the most battery consuming and computational intense operation of the BMPC4K. Additionally, in bright daylight, the touch screen display needs to be at full brightness in order to allow correct monitoring, focus peaking and making setting adjustments. This, however, drains the internal battery even more and might result in less than 30 minutes of actual recording time. In order to preserve battery life, it is advisable to make sacrifices in terms the chosen recording codec, display brightness and stand-by time. An optimal solution for this issue might be an external battery pack, mounted on a rack together with the camera. Furthermore, to counter the display problematic, an additional electronic view finder would allow more precise focusing.

Yet the most crucial improvements are needed for 4K post production at Metropolia. As analyzed in the chapters above, fast storage and plenty of it is crucial for facilitating 4K. In order to enable multiple students the possibility to record, edit and store 4K video, a high speed server system connecting the work stations of Metropolia would be the ideal solution. The designed workflows are primarily targeted to low budget and small scale enterprises or institutions. Hence, they might not be ideal and have plenty of room for improvements, as long as financial budgets allow it.

The primary issue for Metropolia should be the implementation of a feasible data storage and exchange system. The calculations above show that 4K requires massive amounts of data. Multiplied by the amounts of students and the future development towards even higher resolutions and frame rates, ultra high resolution video production at Metropolia will reach its limits very soon, regarding the currently available and suitable facilities.

A temporary solution might be striped RAID sets, which are easily built, cost effective and fast enough to allow 4K video processing. The data storage manufacturer LaCie offers a top of the line 10TB 5-Disk RAID starting at 1479.00 €. While this is certainly not the cheapest option, it is definitely a very fast and reliable one. However, it utilizes Thunderbolt 2, which is currently only supported by the Mac Pro at Metropolia. [34]

A dedicated server system inherits more advantages than just plenty of fast storage. A server could be set up in a way to automatically create proxy files, thus enabling instant and uninterrupted 4K workflows at the machines in the Media Lab. This would eliminate the need for manual transcoding and transferring data to intermediate storage volumes. Furthermore, a fiber network could connect every office on campus, hence, data could be accessed from anywhere and production could be separated into logical units. For instance, editing could be done within the Media Lab and color correction in a dedicated and professionally equipped facility with correct lighting and calibrated monitors without the need of manually transferring data.

At this moment of development, there are no solutions for long time storage of 4K video at Metropolia, which means that student projects in 4K are limited in size and life time. A dedicated server system would allow long time storage and the realization of bigger 4K productions.

5.3 Expandability of the System

As the industry switches towards 4K, capable video cameras, storage and hardware will become more affordable. By investing in a 4K dedicated hardware configuration, Metropolia is future proofing its research facilities. Furthermore, it can easily be improved and expanded, whereas HD video production has already reached its peak.

By implementing technologies such as fiber networks, flash based storage, RAID systems, Thunderbolt 2 transport and professional UHD video acquisition, Metropolia might already be able to prepare for 8K, higher frame rates and sophisticated 3D visual effects.

Not only educational institutions like Metropolia, also small scale production companies benefit from switching towards 4K. 4K is a sales argument for customers who require high end video quality. Smart workflows allow 4K productions to be facilitated even within limited resources. Thus, as hardware becomes more affordable and companies start monetizing their 4K productions, workflows and facilities can be upgraded and optimized easily to support bigger and more demanding projects.

6 Conclusions

Finding feasible solutions to problems is the passion of every engineer. The technology industry is always rushing forward and institutions need to keep up accordingly. 4K and Ultra HD offer great possibilities and opportunities in bringing image quality and viewing experience to the next level. Yet, in order to gain full advantage of the technology, a video engineer has to understand every stage of the production process and realize possible problems or bottlenecks. At this point of development, there is simply no way of retaining high image quality at full resolution, and keeping file sizes and data rates small enough at the same time.

In order to facilitate 4K production within the premises of Metropolia or small scale video production companies accordingly, workflows were analyzed and specifically tailored to the available resources and desired outputs. As the media department of Metropolia has been dedicated to HD workflows until now, 4K needed special attention and the purchase of additional hardware to support the necessary requirements. This thesis tries to analyze every stage of 4K video production at Metropolia. This includes camera set up, recording formats, post production workflows and delivery methods. Furthermore this thesis should serve students as a guide to understand 4K technology and realize their own 4K projects.

The workflows which were designed try to take best advantage of the currently available resources at Metropolia. Yet, in future development, dedicated server storage and a fiber network connection are needed to allow multiple students to work on extensive 4K productions. 4K has already arrived in the industry; thus, engineers who have experience with the technology are needed. By implementing 4K in the engineering curriculum, Metropolia stays up to date with the industry and can educate students with the skills and tools needed for professional video productions.

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Appendixes

Appendix 1. Email Correspondence with Vesa Mäntyharju

Request from David Jakob:

Hi Vesa,

Apparently my first email to you got lost on the way or never sent, so I will state my request again in this message. My name is David Jakob and I am a graduating Media Engineering student at Metropolia University of Applied Sciences. I suppose you have been in contact with Jonna Eriksson, who has made great effort in upgrading our audio-visual facilities at the Leppävaara campus of Metropolia, including the purchase of the Blackmagic Production Camera 4K.

I am currently working on my Bachelor thesis in which I am trying to design a feasible 4K production workflow for our institution. In order to justify the need for 4K facilities at our university, I would like to conduct a small Interview with you as a representative of Mediatrade Oy and ask some questions related to the industry trends towards 4K.

A few other possible questions:

1. *What kind of customers demand 4K technology?*
2. *What alternatives are there to Blackmagic Designs affordable systems?*
3. *Where do you think the industry is heading?*
4. *Are broadcasters switching to 4K?*

I would very much appreciate your opinions on those questions and hope we can agree on a short interview. Please let me know what you think.

Best Regards,

David Jakob

Response from Vesa Mäntyharju:

Hi David,

Sorry for my late response, I had a vacation on last week and now I am quite busy so I try to answer to your questions by email…
I hope you understand my English ;)

1. *What kind of customers demand 4K technology?*

4K cameras are typically sold for the (cinematography equipment) rental companies, for small production houses and for freelancer.

But also for forerunners and technology freaks. Also, those who want to save 4K material in advance and use it (4K material) in afterwards (when a broadcast technology is workable). It is typical that the video material stored in the 4K format, but the 4K content down converted to HD. For example, you can download 4K material to the YouTube, so a threshold has been lowered:

https://www.4kdownload.com/howto/howto-download-youtube-video

For many customers, it comes as a nasty surprise how hard and expensive it is to manage and edit 4K material. You should buy a faster computer, a lot of (fast) hard disk space and a good quality 4K Monitor / Television etc.

2. *What alternatives are there to Blackmagic Designs affordable systems?*

The most popular 4K cameras are Sony A7s (compatible DSLR), Sony FS-7, Blackmagic Design Production 4K Camera, Blackmagic Design URSA, Panasonic GH4 (compatible DSLR) and Canon EOS C500 camera. The best cameras for 4K cinematography is ARRI Alexa and Amira and RED cameras (like: Epic, Dragon, One, Scarlett).

It is popular to use an external 4K recorder because many of the 4K cameras do not have an internal 4K recorder and the cameras internal recording is often too compressed and low-level for editing process. Mediatrade is selling example Atomos Shogun 4K and Odyssey 7Q + -4K recorders that can record uncompressed 4K RAW or good-quality ProRes format. The RAW material is better for post-production, example for color correction.

http://www.atomos.com/shogun/
https://convergent-design.com/products/plus.html

For heavier video formats (like: uncompressed Cinema DNG, RAW, Apple ProRes HQ 4K) you will need a good quality storage media (with a sufficient speed). Only a few kind of the storage media is good enough. Therefore, the market has today a faster SSD drives like SanDisk Extreme Pro -series and SanDisk & Lexar CFast 2.0 cards (based on CF cards) etc. At the moment, you can internally record 4K material with example Blackmagic Design Production Camera 4K, URSA and ARRI Amira. ARRI Amira and BMD URSA is recording 4K material to the new type of CFast 2.0 cards.

http://www.sandisk.com/products/memory-cards/cfastpro/

3. *Where do you think the industry is heading?*

In the future, cameras internal processing power are going better and even the smallest kind of 4K cameras can record (internally) a good quality (even uncompressed) 4K footage. The computers evolved (faster & better) and in the future you can easily edit 4K footage with a cheaper computers, even with laptops. Also, 4K monitors and TV's prices are falling. In the IBC exhibition "Future Zone" in Amsterdam has already been presented 8K, 12K and even 16K cameras and monitors, so the "K values" are rising. Japanese public broadcaster NHK will broadcast the 2020 Olympic Games in Tokyo with 8K (Super Hi-Vision) technology.

Super Hi-Vision display have 33 million pixels. When a 4K resolution is four times more than the current 1080p HD quality, the 8K format resolution is up to 16 times more than the HD quality.

4. *Are broadcasters switching to 4K?*

Many Broadcasters in Finland are just moving to the HD technology, so the technology (4K or above) goes above and the Broadcasters will follow in the far future. The rest of the world has already been testing 4K broadcast technology with Internet as well as with the antenna and satellite. The 4K content over the Internet is expected to become more common than the other kind of transfer methods.

Example Netflix has started broadcasting a 4K material to their customers. Netflix 4K streaming requires a monitor/TV, which is compatible with a Netflix Ultra HD playback. You must also have an internet connection with a speed of at least 25 Mbit/s.

http://www.techradar.com/news/television/4k-tv-broadcasts-are-on-the-way-but-there-are-problems-ahead-1259434

Best regards, Vesa

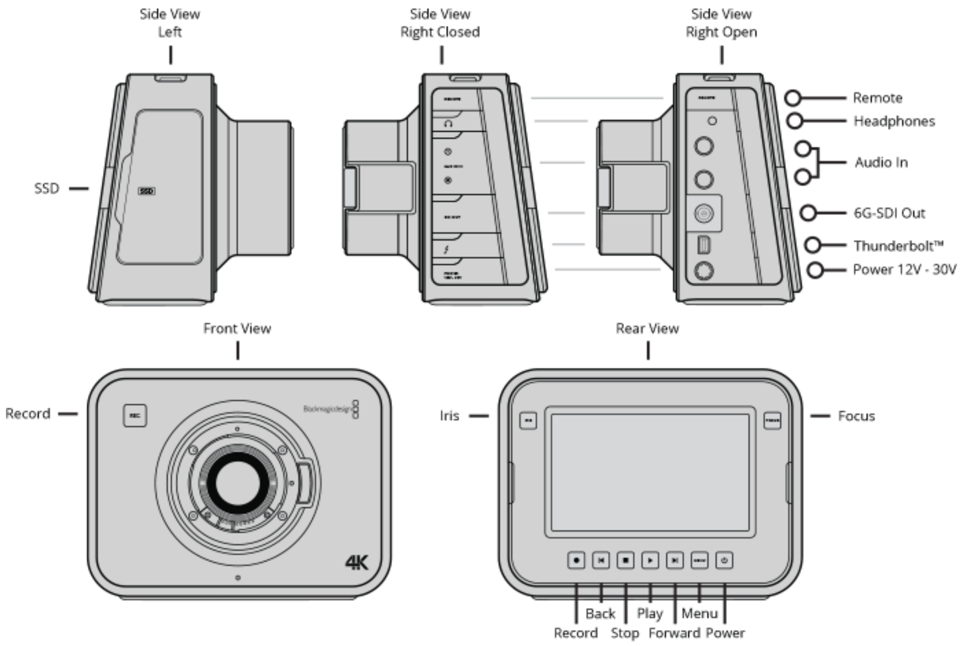
Vesa Mäntyharju
Sales Manager

Appendix 2. 4K Production Workflow Manual

The Blackmagic Production Camera 4K is capable of creating high quality ultra high resolution video. However, it needs careful planning and a precise setup in order to deliver great results. The following chapters should serve you as rough guideline on how to operate the camera, as well as how to post process 4K video material within the premises of Metropolia. In addition to this, I highly recommend the manual provided by Blackmagic Design, which can be found online here: Blackmagic Camera Manual [35].

I Camera Set Up and Operation

Compared to other professional film or video cameras, the Blackmagic Production Camera 4K is relatively simple to operate. The touch screen menu allows easy configuration and control over the functions. Depending on your project, utilize a suitable **EF-mount** lens from Metropolia's stock. Due to the poor low light performance of the camera, I recommend a fast lens with a wide aperture, such as f/2.8, f/1.8 or even f/1.4 when shooting in a poorly lit or low light environment. The sensor of the BMPC4K is approximately the same size as an APS-C sensor, which means that you can utilize lenses made for crop frame cameras without having to worry about vignetting.



The graphic above illustrates the main controls and functions of the camera. Metropolia provides two suitable 480 GB SSDs for your 4K project. If, for any reason, the SSDs are not recognized by the camera, make sure they are formatted correctly. The format should be **HFS+** or **exFAT**. The camera also allows internal formatting via the touch screen menu.

Before shooting with the camera, make sure that you go through every menu item and select the appropriate settings according to your project. In order to record the highest quality 4K video, choose the recording format to be **4K ProRes HQ** or **CinemaDNG**. Choosing the recording format highly depends on the requirements of your project. CinemaDNG will provide you with high quality RAW video data, yet consumes the most storage and battery. Often 4K ProRes 422 HQ will still result in excellent image quality but allows you to record more video for longer.

1. Press the power button to start up the camera
2. Press the menu button to access the dashboard, where all the relevant settings can be found. The dashboard contains the following menu items: Metadata, Settings, Format Disk, Focus Peaking, Meters, Frame Guides

Within the **Metadata** tab you can input relevant information and keywords to your current project, which might make archiving and structured post production easier. However, for smaller projects, this is not absolutely necessary. As mentioned earlier, the **Format Disk** button allows to clear and format the inserted SSD. The bottom row of the dashboard are all on/off buttons, where you can enable or disable focus peaking zebra overlays, audio and light meters and frame guide overlays.

The most important item in the dashboard is the **Settings** button, which brings up the camera set up menu. Here you can precisely configure: **Camera**, **Audio**, **Recording** and **Display** Settings. Withing the **Camera** menu tab, the three most important settings are **ISO**, **White Balance** and **Shutter Angle**. The following table should help you decide the appropriate settings for your project.

Item	Settings	Usage
ISO	200ASA	Bright Light Environment
	400ASA	Native/Standard ISO
	800ASA	Careful! Occurring noise patterns
White Balance	2500 – 4800K	Artificial Light/Tungsten/Sunrise/Sunset
	5000 – 5600K	Outdoors. Clear sunny day.
	6000 – 8000K	Various outdoor light conditions.
Shutter Angle	180°	Traditional and standard setting.
	360°	Low light conditions. Undesired motion blur might occur.
	172.8°	Prevent 50Hz flicker.
	Other	Increase or reduce the amount of light on the sensor. Be aware of motion blur or the lack of it.

The next menu item is **Audio**. As for most cameras, the internal microphone should only be used as a reference microphone. Record audio either with an external recorder and a dedicated microphone, or utilize the two inputs the BMPC4K offers. The BMPC4K takes two 1/4 inch TRS Phone audio connectors. If you want to use an XLR-microphone, you need an adapter. The audio menu lets you adjust input and monitoring levels and select the audio channels.

Most important is the third menu item, which lets you configure the **Recording** settings. The following table summarizes the options and explains their applications.

Item	Settings	Usage
Recording Format	RAW CinemaDNG	Records 4000 x 2160 12-bit RAW. Highest Possible Quality.
	4K ProRes 422 HQ	Records 8-bit 3840 x 2160. Longer recording, less battery consumption than RAW.
	4K ProRes 422	Still good quality, but only recommend in emergencies, if storage is not enough. Usually these are only used for proxy files.
	4K ProRes 422 LT	
	4K ProRes 422 Proxy	
	ProRes 422 HQ	Recording formats without the 4K prefix record in 1920 x 1080 HD!
	ProRes 422	
	ProRes 422 LT	
	ProRes 422 Proxy	
Dynamic Range	Film	Records in a flat log color space. Optimal preservation of colors and light. Recommended for workflows with color correction.
	Video	Records in Rec. 709 color space. Recommended for work-flows without extensive color correction.

Item	Settings	Usage
Frame Rate	23.98 fps	Use 24 fps for a cinematic style with adequate motion blur. Higher frame rates mean higher data rates, thus less recording time and more data.
	24 fps	
	25 fps	
	29.97 fps	
	30 fps	
Time Lapse Interval	Several	The camera can be configured to record time lapses with several presets available.

Within the **Display** menu tab, you can select in which color space or dynamic range you want to monitor the video. This might be helpful when shooting in RAW CinemaDNG, which natively records in a log color space, but you would like to preview the final image. Furthermore you can adjust display brightness, the opacity of the zebra overlays as well as the SDI/HDMI overlays when outputting the video to an external recorder or monitor.

Now that the camera is set up correctly, you can start shooting in 4K.

3. Press the **Menu** button twice to exit the menu.
4. Focus your shot either manually or use the autofocus feature by pressing the **Focus** button once. Pressing the **Focus** button twice will allow **Focus Peaking**.
5. Double tap the screen to zoom into the image and adjust your focus precisely if needed.
6. Press the **Iris** button to automatically set the exposure. Alternatively you can set the exposure manually by pressing the forward and backward buttons, which will close or open the iris accordingly.
7. Finally press **Record** to start recording, press it again to stop.

II Post Production

Based on the extent of your 4K project, you have several options for post processing 4K. Yet, in anyway the workflow starts at the Mac Pro and the Blackmagic MultiDock SSD docking station. You have the option of utilizing DaVinci Resolve as a color correction suite or work entirely within the Adobe Creative Cloud by utilizing Premiere Pro and Speed Grade.

When working entirely from the Mac Pro, the editing process is equivalent to the known HD workflow. The MultiDock connected via Thunderbolt enables editing straight from the SSD. Thus, an import of the media to the local PCIe storage is not required. However, it is recommended when the project requires intense speeds. But be aware that there is very limited space available on the Mac Pro.

Option 1: Mac Pro Online Adobe Workflow

Adobe Premiere Pro supports CinemaDNG and ProRes natively, thus no initial transcoding is required.

1. Insert the SSD(s) into the Blackmagic MultiDock.
2. Open Premiere Pro and create a new project.
3. Navigate to the storage volume within the Media Browser.
4. If you shot in RAW CinemaDNG, each clip is contained in a separate folder containing every single .dng frame.
5. Navigate to that folder within the Media Browser, and right-click to import the pre-composed .dng image sequence clip.
6. Repeat the same step for multiple clips.
7. Drag and Drop the clips onto a timeline. Premiere will automatically define the timeline settings.
8. As RAW CinemaDNG is 4000 x 2160 pixels, adjust the timeline setting to be 3840 x 2160 px, which results in a slight letterbox but follows the common 16:9 wide screen ratio.
9. To correct the letterbox, change the size of the clip via the clip effect panel and *Motion > Scale*.
10. Be aware that Premiere automatically translates log color space into Rec. 709 for video monitoring. Still all the image data is preserved. In order to color correct your footage, send the project to Adobe Speed Grade or utilize the color correction tools within Adobe Premiere's effect toolbox. For moving the project to Adobe Speed Grade, choose *File > Direct Link to Adobe Speed Grade.*
11. Finalize your color correction and click the Premiere icon in order to *Link Back to Premiere*
12. Add titles and transitions and prepare to export your project via *File > Export > Media*

13. Queue the project to bring it to the Adobe Media Encoder. As YouTube is the main platform for delivering and broadcasting 4K at the moment, choose the available Youtube 4K H.264 preset from the export preset list.
14. Do not change any of the settings in order to maintain best image quality. Otherwise, YouTube will re-compress your entire video, which mostly results in loss of image quality.

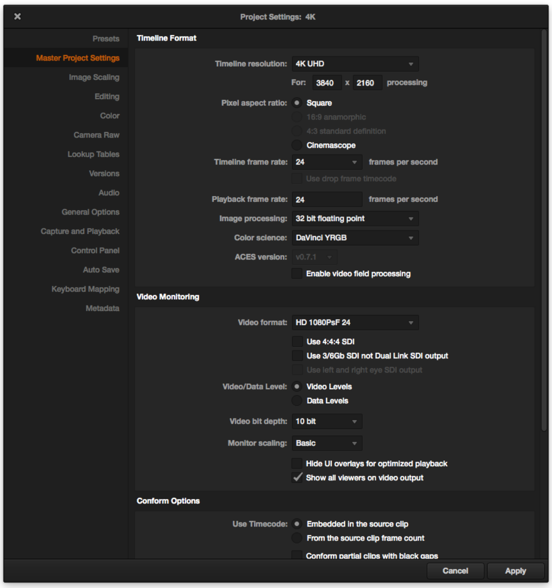
Option 2: Round Trip Workflow

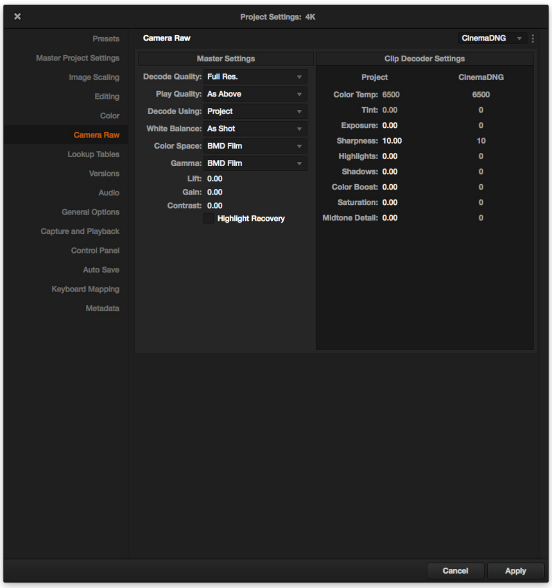
The following round trip workflow gains advantage of the color correction possibilities of DaVinci Resolve as well as the performance improvement when editing proxy instead of full sized video clips. Furthermore, this allows editing the footage on the Media Lab work stations or on your personal computer.

1. Insert the SSDs into the Blackmagic MultiDock
2. Open DaVinci Resolve and log in to the Admin account
3. Create a new project
4. Set up the project settings precisely via *File* > *Project Settings* > *Master Project Settings*. If you experience dropped frames or slow video monitoring, change the settings under the Video Monitoring tab to a lower resolution if necessary.

Setting up your project correctly in DaVinci Resolve is important to maintain best image quality for color correction and post processing. Always set your timeline to be the resolution of your final or desired output, which in this case should be 3840 x 2160 UHD. When shooting in RAW CinemaDNG, set up Resolve according to the dynamic range setting you chose when shooting with the BMPC4K. Access the Camera RAW setup via *File* > *Project Settings* > *Camera Raw.* An incorrect setup will result in undesired interpretation of color spaces.

Compare the settings presented in the following screen shots with your own project settings.





5. Confirm your settings by clicking apply.
6. Resolve is separated in four logical sections: **Media**, **Edit**, **Color** and **Deliver**. Locate the footage in the media browser and right click to add individual clips to the media pool.
7. Go to the **Edit** section. Select the desired clips and right click to choose *Create timeline from selected clips.*
8. Go to the **Color** section. Apply a light color correction and/or a LUT to translate the *Blackmagic Production Camera 4K Film to Rec. 709* (in case you shot in Film dynamic range), which makes the footage more appealing for editing decisions. To apply a LUT, right click on the clip and select a 3D LUT from the list. Alternatively you can add another node and apply the LUT there to gain more control over the appearance.
9. Go to the **Deliver** page and make sure you have all the clips of your timeline selected. Set an In- and Out-point on the displayed timeline if necessary.
10. The idea is now to create **smaller** and **lighter** versions of the 4K clips in order to edit them smoothly in a NLE of your choice, such as Premiere Pro. Once rendered, you can work with your edit on the machines in the Media Lab the same way you are used to when working with HD material. After that, you will come back to Resolve by creating an **XML** file of your locked edit and finalize the color correction. Therefore, choose a light format and a low resolution, for example ProRes 422 LT and 1080p/720p. Export as **individual clips** and **keep the same file name.** The file name has to remain the same in order to link back to the original footage later.
11. Create a new folder on a storage volume called **Proxies**, add the job and start the

render.

12. Open Premiere Pro, import the rendered proxy clips as usual and perform your edit. Due to the small file format, this can be done at the work stations in the Media Lab.
13. Do not add any transitions or effects within Premiere Pro yet. Finalize your edit and choose *File > Export > Final Cut Pro XML.* This will create an **XML** file containing all the editing information. Save the XML at a logical location, for instance a folder called *FromPremiere*.
14. Go back to your initial project in DaVinci Resolve. Import the XML via *File > Import AAF, EDL, XML.* **Uncheck** *Automatically import source clips into media pool* and *Use sizing information.* This ensures that Resolve links back correctly to your original full sized footage which should be located in the media pool.
15. Finalize your color correction, but do not make any changes in the edit. To add transitions and effects, we will utilize Premiere Pro once more.
16. Go to the **Deliver** page. Make sure all your clips are selected. Choose the **Roundtrip XML** preset, which will create individual clips alongside an XML file. Make sure you select a high quality format such as ProRes 422 HQ in the full size resolution (4K UHD). Export this to a folder called *FromResolve* to maintain a logical file structure. You can work straight on the SSDs mounted in MultiDock.
17. Open **Premiere** on the **Mac Pro** and import the **XML** file. This will result in the creation of a timeline, which sometimes has an incorrect resolution. Adjust the timeline resolution manually via the project settings panel.
18. Add transitions and titles.
19. Export your project via the Adobe Media Encoder. Choose custom settings for local playback at high quality or choose the YouTube 4K preset to optimize your video for YouTube distribution.

General Advice:

When working with proxy and XML files, it is very important to maintain file names and folder structures. Re-naming files or altering folder structures may result in corrupt data and extensive re-linking procedures, which might not always be successful. Workflows have to be tailored to specific projects. Thus, not everything mentioned in the workflows above might apply to your situation. However, it should give you a general idea of how to professionally handle high quality 4K video.